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Translating Popular Astronomy and Astrophysics. A chapter from Astrophysics: A Very Short Introduction

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INTRODUCTION

This thesis aims at providing a translation from English into Italian of the third chapter of James J. Binney's book *Astrophysics: A Very Short Introduction*, published on March 24, 2016 by Oxford University Press. *Very Short Introductions* are books concerning a great variety of topics and areas of study, written by experts for a wide public made up of both specialists and laypeople. The chosen chapter of this popular science book, entitled *Stars*, focuses specifically on the study of stars and their life-cycles from birth to death, discussing the application of the main principles of physics which are necessary to explain the origin and evolution of celestial objects and phenomena.

The choice of this subject combines a deep interest in scientific and technical translation, and in scientific popularisation, which is nowadays paramount to help the public of non-experts understand scientific knowledge and phenomena, as well as to develop a 'scientific culture' among people, that is to say a vivid curiosity about the mechanisms governing the Universe and the latest scientific and technical advances. As world citizens and inhabitants of the Universe, human beings should be familiar with domains such as astronomy and astrophysics, among others.

Before achieving the core of this work, the final translation, some theoretical concepts, such as special languages, controlled natural languages, scientific popularisation and specialised translation, will be introduced, discussing their main features so to better outline the source text. More specifically, Chapter 1 starts with a description of the main features of languages for specific purposes (LSPs), considering both the horizontal and vertical dimensions, as well as the diachronic, diatopic, diastratic and diamesic variations. The language of science, which is the special language shared by astronomy and astrophysics, will be examined in the second section of the chapter, along with a general presentation of these two domains involved. They were once clearly distinct from each other, but today some scientists consider them synonyms for practical purposes, since they both use physics and chemistry to study and explain the cosmos. Since one of the main features of the language of science is standardisation, the last section will provide a view towards controlled natural languages (CNLs) and controlled vocabularies, both interrelated with the concept of special language. Particular attention will be given to the ASD Simplified Technical English (ASD-STE100), a CNL that was developed in the aerospace field, which contains a number of mandatory rules to be followed in order to ensure clarity and disambiguation when writing scientific and technical documentation. On the other hand, among controlled vocabularies, two examples of thesauri will be presented: the NASA Thesaurus and the Unified Astronomical Thesaurus.

The first section of Chapter 2 will focus on the importance of communicating science, and, of course, astronomy and astrophysics (functioning as ‘science catcher’), in today’s hyper-technological society. Communication starts at school, since school education plays a crucial role in whether or not future adults will understand science- and technology-related issues that may develop, and continues thanks to mass media. The main features of scientific popularisation will be discussed as well, including information on the target audience and function, its relationship with the scientific discourse, the various degrees of popularisation, the origins and history of the genre and the main reason for popularising science. Particular attention will be dedicated to concepts like open science, citizen science, science democratisation, which are essential to develop a positive attitude towards science. The second section will provide a view towards technical and scientific translation, while the third towards the translation of popular science texts, outlining the main analogies and differences between English and Italian texts of the same genre.

Lastly, Chapter 3 is also divided into three sections. After presenting an analysis of the source text with some information about the author and the Oxford’s *Very Short Introductions* book series (section 3.1.) and the final translation (section 3.2.), the last section of this thesis will be focused on the translation process. A detailed commentary on the lexical, semantic and syntactic difficulties encountered and the main translation strategies adopted to face them will be provided. All the most challenging parts will be listed, along with the translation choices, which will be always justified and explained. Of course, the translation method will be based on the theory described in the two previous chapters, and on a reference corpus of English and Italian parallel texts dealing with the same subject matter. Online dictionaries, such as Merriam-Webster and Oxford Learner’s Dictionary, will be used as well.

CHAPTER 1: AN INTRODUCTION TO SPECIAL LANGUAGES AND TO ASTRONOMY AND ASTROPHYSICS

1.1. Special discourse: definition and main features

As Gualdo and Telve (2011: 11) state, special languages (LSPs) permeate daily life by constantly importing neologisms and technical scientific knowledge into general language. In doing so, mass media and the web play a key role.

LSPs are referred to by several denominations, both in English, e.g. 'special languages', 'languages for special purposes', 'languages for specific purposes', and in Italian: Cortelazzo (1994: 15), Scarpa (2008: 1-2), Gualdo and Telve (2011: 20-21) list all the existing numerous terms designating the same concept, i.e. 'lingua speciale', 'linguaggio speciale', 'linguaggio settoriale', 'linguaggio specialistico', 'sottocodice', 'linguaggio tecnico-scientifico', 'tecnoletto', 'microlingua', 'lingua per scopi speciali', and so on. According to Cortelazzo (1994: 21-22), LSPs cannot be considered 'jargons' by nature, but only when experts aim at stressing their belonging to a specialised sector or at making their discourse understandable only to their peers. Indeed, jargons connote opaqueness to non-experts and also denote informal usage within LSPs.

Scholars have tried to define special languages in different ways, even though a univocal description of their main features has been provided. Before analysing them in detail, it is necessary to clarify the important distinction between general language (or LGP) and special language (ISO 1087: 2019):

> general language
>
> natural language characterised by the use of linguistic means of expression independent of any specific domain.
>
> special language
>
> natural language used in communication between experts in a domain and characterized by the use of specific linguistic means of expression.
>
> Note 1 to entry: The specific linguistic means of expression always include domain-specific terminology and phraseology and also can cover stylistic or syntactic features.

Special languages are therefore varieties of the natural language, i.e. the language used in a community of people, characterised by a set of rules which are mainly deduced from usage (ISO 1087: 2019). Cortelazzo (1994: 16) defines them as functional varieties – recently adding that it is possible to speak of 'diaphasic varieties' – of a natural language, used by specific groups of people who are experts in a certain specialised field in order to communicate knowledge, and to meet and satisfy their communication needs, which are primarily referential, i.e. objective. Widdowson (1998: 4) introduces the concept of 'discourse community':

> A discourse community is a group of people – usually a group of professionals – who share a set of public goals, patterns of conceptualization and conventions of behaviour. In the furtherance of their goals, these like-minded people communicate among themselves on topic relevant to their aims by using specific discourse procedures and practices, text genres and lexis.

Of course, a LSP can also be used in a number of diverse contexts, e.g. when communication takes place between experts and laypeople or between experts in more informal situations or when information is conveyed through mass media, causing its 'simplification' (Gualdo and Telve 2011: 19).

LSPs also differ from general language since they are made up of 'terms' instead of 'words'. A term can be defined as a "designation that represents a general concept by linguistic means" (ISO 1087: 2019). This means that special languages are characterised by arbitrariness of the sign, i.e. a biunivocal relationship between signifier (any material thing that signifies) and signified (the concept that a signifier refers to), and, as a consequence, by more precision. Furthermore, typical phenomena of general language, such as polysemy and synonymy, are substantially reduced in LSPs. This aspect is particularly noticeable in the case of the so-called special languages 'in the narrow sense'.

Scarpa (2008: 2), Gualdo and Telve (2011: 20) report the noteworthy distinction between LSPs 'in the narrow sense' and 'in the broad sense' proposed by Berruto in 1974: the former comprise highly specialised languages with a distinctive nomenclature (e.g. the language of physics or chemistry); the latter are not characterised by a distinctive lexis, so they often borrow terms from other special languages (e.g. the language of sport or advertising).

As LSPs are related to the notion of linguistic variation, all the scholars mentioned above agree about the existence of a variety of specialised languages linked by common characteristics and explained by Cortelazzo's (1994: 3-4) proposal of structuring special languages in two dimensions: the horizontal dimension and the vertical dimension.

The horizontal dimension aims at identifying disciplinary sectors and subsectors focusing on the content. In this context, it is useful to consider the distinction between 'hard sciences' (i.e. physical or natural sciences) and 'soft sciences' (i.e. human or social sciences). Dardano draws up a list arranging sciences into a hierarchy from hard to soft: mathematics, physics, engineering, chemistry, biology, medicine, sociology, law, psychology, anthropology, historical and philological studies, philosophy (Gualdo and Telve 2011: 33, referring to Dardano 1994).

On the other hand, the vertical dimension distinguishes the different levels at which a LSP can be used, depending on the extra-linguistic context, i.e. the communicative situation and the textual type, together with the recipient, the subject matter and the purpose (Sobrero 1993: 240). It thus corresponds to the diaphasic variation that is based on the socio-pragmatic aspect of communication. This implies that different registers will be used depending on the whole communicative situation, e.g. exchanges between experts or between experts and laypeople, didactics, scientific popularisation, and the like. As Musacchio (1995: 19) affirms, the recognition of a vertical dimension implies the existence of a sociolinguistic dimension of special languages, that is to say they have a variable degree of technicality which depends on how far their lexicon deviates from the general language.

The concept of 'degree of technicality', introduced by Arntz (2001: 195), can be explained as "a specific descriptive dimension in language for special purposes (LSP) research and may therefore be highly relevant to the theoretical description and empirical investigation of STT" (i.e. scientific and technical translation, Krüger 2016: 98), and should be taken into account in conjunction with the subject-matter competence of the participants in specialised discourse. Krüger (2016: 98-99) recognises three modes of communication: expert-to-expert (that is a symmetrical communication, since the people involved in the communicative situation are all competent in that specific topic), expert-to-semi-expert and expert-to-layperson (that are asymmetrical, due to the imbalance between the subject-matter competence of the two parties involved). The degree of technicality is determined based on two parameters: the complexity of the topic of the text (i.e. how frequently technical terms, diagrams, tables are used) and the specialisation of the text in a given domain (i.e. to which domain the terminology used in the text belongs). Of course, “the frequency of basic terms usually decreases with an increasing degree of specialisation of a text” (Krüger 2016: 100, referring to Arntz 2001: 195-196).

By considering all these aspects, Arntz developed a ranking scale consisting of eleven degrees of technicality of scientific and technical texts, linked to specific genres, intended recipients and specialised knowledge requirements (See Appendix 1: Table 1. Degrees of technicality/difficulty of scientific and technical texts according to Arntz). If these degrees are linked to the three communicative configurations discussed previously, it can be assumed that “the potential audience of didactic-instructive texts such as textbooks, operating instructions, etc. is much more heterogeneous and may hence exhibit different levels of knowledge that will have to be reflected in the degree of technicality of the respective texts” and “some genres (such as patents) can be assigned a rather fixed degree of technicality, while other genres may show a stronger variation in this regard, making it more difficult to assign them a fixed place in Arntz’s scale” (Krüger 2016: 101). The first degree of technicality/difficulty, to which encyclopaedias and popular science texts belong and whose intended recipients are ideally laypersons with a general interest in science, is the focus of the present work and will therefore be discussed more in detail in Chapter 2.

Gualdo and Telve (2011: 22-30) point out the importance of considering additional variation parameters, which are often interrelated, in order to understand how specialised communication works: the diachronic, the diatopic, the diamesic, and the diastratic variations. First of all, the diachronic dimension considers the evolution of a language over time. Although the study of LSPs is typically synchronic, considering the predominance of the contemporary perspective, the diachronic dimension may help understand how LSPs’ terminology and syntax develop over time, being the result of their relationship with Latin, that used to be the language of scientific communication before English (Gualdo and Telve 2011: 46-51).

The diatopic dimension considers all (eventual) regional variants or variants relating to different linguistic areas within LSPs. Each region has indeed its own phonetic and intonational elements, precise language choices and grammatical constructs. Spatial variation mostly affects lexis, in fact it is essential to understand the presence of foreign terms, Greek- and Latin-based terms, slang, regionalisms in special languages. An important phenomenon is called 'geosynonymy' (Gualdo and Telve 2011: 55-56), which are distinct synonyms based on the geographical areas within a territory, often arising out of a need for expressiveness. They are also used in formal and highly specialised contexts, e.g. slang communication between experts, as well as popularisation, or become part of the technical lexicon for commercial and descriptive reasons. Nowadays, European and international institutions (such as ISO) try to standardise special languages with codes and norms to express the objects of their research in a univocal and unambiguous way.

The diamesic dimension takes the channels used for disseminating communication into account. In the last two decades, a third element has been added to the distinction between the written and the oral channel (i.e. the face-to-face conversation between two interlocutors), namely the transmitted channel, explainable as writing intended to be read at a distance in space and time and conveyed by information technologies (e.g. someone reading what they say on the news). Studies on channel-dependent variations date back to the early 1970s with Halliday, Gregory and Carroll (1978), who speak of 'modes', and have gradually intensified with the growing socio-cultural role assumed by TV and digital communication. Therefore, the concepts of mono- and multi-modality have been introduced, meaning that media may transmit both verbal and non-verbal codes: textual messages, images, sounds, etc. Nowadays, communicative situations in which oral, written and various forms of broadcasting coexist and are used in turn depending on needs and context are thus very common.

Finally, the diastratic variation, based on the speaker's social and cultural level, and social group, is to be considered since LSPs are often used to satisfy not only the referential communicative needs of the speakers, but also those needs linked to a group identity construction. In this case, language may be perceived as a factor of social belonging. Although some scholars tend to consider the diastratic dimension less in the context of specialised communication, it is acknowledged as part of the vertical dimension (Gualdo and Telve 2011: 138).

As already mentioned, the boundary between LGP and LSP is not clearly drawn. Widdowson (1979) hypothesised that a LSP is “a variety of ‘scientific discourse’, that is, the ‘universal’ language of science, whose ‘deep structure’ is common to all LSP users and can be actualised using the ‘surface structures’ of the various natural languages (Balboni 1986: 3). Scholars have tried to define the main features of LSPs, considering that “LGP and LSP have a number of elements in common on several linguistic levels, such as morphology, syntax, discourse and lexis” (Di Prisco 2018). Gotti (2011: 47) adds that the process of terminological creation follows the same rules employed by general language, even though special languages are far more productive.

Cortelazzo’s (1994: 8) definition provides an explication of the lexical and morphosyntactic features common to all special languages:

> La lingua speciale è costituita a livello lessicale da una serie di corrispondenze aggiuntive rispetto a quelle generali e comuni della lingua e a quello morfosintattico da un insieme di selezioni, ricorrenti con regolarità, all'interno dell'inventario di forme disponibili nella lingua.

The author (Cortelazzo 1994: 9) maintains that lexicon represents the distinctive feature of a special language, since it allows to distinguish it from other LSPs and, naturally, from the general language. Although LSPs vocabulary also comprises nontechnical words, “there is a strong influx of neologisms, new words formed on the basis of Greek or Latin roots, with Greek, Latin or English affixes” (Balboni 1986: 4).

Many authors, including Sobrero (1993: 243), Musacchio (1995: 21), Gotti (2011: 20), Gualdo and Telve (2011: 78) rely on the list of eleven features proposed by Hoffman in 1984: exactitude, simplicity and clarity; objectivity; abstractness; generalisation; density of information; brevity or laconism; emotional neutrality; unambiguousness; impersonality; logical consistency; use of defined technical terms, symbols and features. However, according to Sobrero, the coexistence of all these elements within a LSP is not required, since many of these are almost equivalent, although precision and emotional neutrality are essential for the specialised communication. Therefore, it is a matter of fact that scientific language is precise, because it consists of sets of terms (terminologies), made up of completely new words and words taken from everyday language which have been resemantised, i.e. they have acquired one or more additional meaning(s), in order to identify objects and concepts unfamiliar to the general language.

From a lexical point of view, there are two phenomena related to the so-called 'semantic shift', i.e. the change in the meaning of a word (which, in case of specialisation, consequently becomes a term):

> I. specialization, in which the meaning of a word narrows over the years (LGP to LSP); for example, mouse which has developed a specialized meaning in computing; and
>
> II. generalization, in which the meaning and reference of a word widen over the years (LSP to LGP); for example, the originally specialized term neurotic is now used to designate any excessively anxious person (Di Prisco 2018, referring to McArthur 1992).

As mentioned above, LSPs terminologies are based on the biunivocal relationship between signifier and signified, so that a "term cannot be suitably substituted by a synonym but only by its definition or a paraphrase" (Gotti 2011: 25). This feature, called 'monoreferentiality', is a distinctive trait of special languages, and produces a high level of lexical repetition due to the avoidance of synonymous terms and indirect reference.

Moreover, it has been highlighted that communication needs in certain specialised domains are mainly referential, so that there is a need to express contents and information without emotive connotations. This 'lack of emotion' (Gotti 2011: 26-27) is characterised by a neutral, sometimes artificial tone, in particular when the aim of the text is to inform the reader about a certain topic.

Another characteristic of LSPs is 'transparency', which is mainly realised through derivational or compositional neoformations (Gualdo and Telve 2011: 92-100), particularly employed by hard sciences, which are based on taxonomy (i.e. hierarchical classification of concepts), such as botany and chemistry. Derivational neoformations involve adding conventional prefixes or suffixes to a root or base word to create a new word with a slightly different meaning, while compositional neoformations imply the combination of two or more existing words to create a new one.

Symbols, abbreviations and acronyms are particularly employed in LSPs to achieve 'conciseness', i.e. the need for concepts to be expressed in the shortest possible form (Gotti 2011: 31), as well as to avoid connotative nuances and ambiguity. As

Cortelazzo (1994: 14) points out, they often gain autonomy compared to the phrases they abbreviate and behave as lexical units. Furthermore, many of them are recognised at the international level by entering (almost) every language's vocabulary.

On the other hand, there are special languages that violate the principle of conciseness. Legal language, in particular, tends to employ two interchangeable terms for the same concept (named binomial expressions or doublets), increasing the degree of 'redundancy', especially when one of the two terms adds no new semantic content to the sentence. The reason for this tendency lies in 'conservativism', i.e. a strong compliance to tradition (Gotti 2011: 32-39).

Similes and metaphors are other useful devices in scientific communication. They consist of a technical concept that is paired with a concept from the interlocutor's cultural background. These rhetorical figures possess a great evocative power and the ability to condense arguments, providing a rapid information transfer of the information. Moreover, they respond to the need for terminological transparency and language economy (conciseness), and create visual and real references by evoking an emotional response in the reader. This aspect may increase, of course, the degree of persuasiveness (Gotti 2011: 42, referring to Kuhn 1962). Nevertheless, these tools may convey a lower degree of precision, being more difficult to decode for the recipient, and violate the feature of emotional neutrality. Gualdo and Telve (2011: 83, referring to Temmerman's classification) recognise three types of metaphors: the lexical metaphor, which involves a single pair of terms; the conceptual metaphor, which involves a set of words belonging to the same conceptual frame or category; the domain metaphor, that involves more than one category and makes use of resembling words belonging to the general language.

In relation to LSPs' morphosyntactic features, Cortelazzo speaks of 'ricorrenze' in his definition, meaning that certain characteristics occur more frequently in specialised discourse than in general language. This means that special languages tend to use only a small part of the grammar of a natural language or, more precisely, there are preferred tenses and modes that are not used in the same way as in common language, e.g. the third person singular or plural in the simple present tense appears very frequently in specialised texts with a communicative purpose, because it conveys objectivity and allows nominalisation, i.e. the substitution of a noun for a verb (Balboni 1986: 4; Cortelazzo

1994: 30; Gualdo and Telve 2011: 119). Sometimes, authors of a specialised text may decide to use the first person pronoun to express personal opinion and convince their recipients. As Gotti (2011: 51) points out:

> […] specialized texts […] do not follow rules restricted to specialized languages but normally implement rules found also in general language.

Specialised discourse is in general characterised by lexical density, conciseness, and compactness. There is a number of devices that LSPs employ to make the sentence structure appear lighter: the omission of phrasal elements (e.g. articles, auxiliaries and prepositions), which "can easily be deduced by the decoder" (Gotti 2011: 52); the avoidance of relative clauses through the use of elliptical forms; premodification which produces long noun compounds; the preference for generic polyvalent verbs, especially *to be* in English (essere, avvenire, comportare, consistere, dipendere, esistere, rappresentare, riferirsi in Italian, Cortelazzo 1994: 17), whose function is merely copulative.

Specialised texts tend to be highly formal, impersonal and cohesive, due to the occurrence of nominalisation and depersonalisation, which "requires the abuse of -ing forms in English, of impersonal verbs in romance languages, etc." (Balboni 1986: 4). According to Cortelazzo (1994: 26), one of the main syntactic features of specialised discourse is 'de-agentivisation', which is linked to the orientation towards abstract and time-independent objects, events, processes and actions rather than towards the agent. For this reason, passive verbs are considerably used due to the possibility to omit the agent of the action, since it is the same for all the operations described or there is no specific actor behind the action (Gotti 2011: 74), so that the focus is entirely shifted on the action itself.

As regards textual features, Balboni (1986: 4) describes technical and scientific texts as:

> "monotonously" paratactic, coordination rather than subordination being the general stylistic rule; moreover, LSP text structure is based on "conceptual paragraphs" and the rules of its rhetoric are strict and codified.

Cortelazzo points out that specialised texts tend to be coherent and cohesive by making the logical-semantic concatenation within sentences more explicit than in other text types. According to Gualdo and Telve (2011: 125), they are characterised by a linear thematic sequence, that is to say the criteria of logical coherence and grammatical cohesion must be considered when moving from one information to another. The 'theme' of the communication (i.e. the item of information known to the addressee, which often corresponds to the subject of the sentence) generally occurs on the left, initially, and the 'rheme' (i.e. the new information to be added) on the right (Gualdo and Telve 2011: 121-122; Gotti 2011: 84-85).

Cohesion can be realised through anaphoric reference, that is to say through the use of items, such as personal pronouns, to indicate something that has been already mentioned in the text in order to avoid repetition, or cataphora, when the aim is to indicate something to be introduced later. Of course, linking words also play an important role in this respect, in fact there is a general tendency in LSP texts to connect statements in a more explicit way than in other texts types to ensure clarity of exposition and completeness. Connectors and conjunctions are widely employed to describe a relationship between two statements, respectively two separate sentences or two elements within a sentence, such as clauses or nouns. These devices "have a pragmatic function, which clarifies the purpose of the sentence that follows" (Gotti 2011: 83-84). On the other hand, certain LSPs like legal language prefer to resort to lexical repetition in order to avoid ambiguity as much as possible (Gotti 2011: 79-80).

According to Sobrero (1993), Van Dijk (1997) and Giovanardi (2006), specialised texts follow most of the time a codified textual organisation framework, consisting of four main sections: introduction, problem, solution, conclusion. In addition to these, there are some required sections (e.g. notes and references) and optional sections (e.g. illustrations, graphs, appendix). Due to these conventions and to textual standardisation, a number of textual genres have therefore appeared in all disciplinary fields, many of them having an argumentative purpose.

1.2. The language of science: a view towards astronomy and astrophysics

As indicated by the title, the text which is at the core of the present work focuses on two scientific domains: astronomy and astrophysics. It is thus necessary to provide a definition of the two disciplines involved, especially because many non-experts may not know the differences between them. According to the Oxford University physics dictionary (2019):

> Astronomy is the study of the universe beyond the earth's atmosphere. The main branches are astrometry, celestial mechanics, and astrophysics.
>
> Astrophysics is the branch of astronomy concerned with the physical processes associated with the celestial bodies and the intervening regions of space. It deals principally with the energy of stellar systems and the relation between this energy and the evolution of the system.

It has been ascertained that astronomy and astrophysics are not synonymous terms referring to the same concept. If astronomy may be considered as a sort of superordinate concept (i.e. broader concept, generic concept or comprehensive concept, ISO 1087: 2019), aiming to ascertain positions, luminosities and motions in space of celestial objects, astrophysics is rather one of its branches "which concentrates on the physical processes associated with the entities that comprise the universe" (Mangum 2020, cited in National Radio Astronomy Observatory 2023). Since space science use physics, as well as chemistry, to seek to understand the mechanisms governing the Universe, the lines between these disciplines can blur to the point that some scientists consider them synonyms for practical purposes. Cosmology can also be considered an additional 'sibling science' (Balter 2022) or 'cousin' (Nakra 2023) of astronomy and astrophysics, because it also studies the Universe but on a larger scale, focusing on its origin, evolution, and ultimate fate. "Cosmology differs from astronomy in that the former is concerned with the Universe as a whole while the latter deals with individual celestial objects" (Nakra 2023).

Referring to Dardano's distinction between hard and soft sciences, these fields of knowledge can be categorised as hard sciences, as they are types of natural sciences, i.e. "any of the sciences (such as physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformations or with objectively measurable phenomena" (Merriam-Webster Dictionary 2023). The distinctive feature of hard sciences is naturally the pure application of the experimental scientific method, pioneered by Galileo Galilei and predicated on evidence-based research. Sant (2019) indicates the steps of the scientific method:

1. Observation and description of natural phenomenon.
2. Formulation of a testable hypothesis to explain the phenomenon.

3. Use the hypothesis to predict other phenomenon or results.
4. Perform an experiment or experiments to ensure that results predicted based on hypothesis are achieved in the experiments.

They thus rely on quantifiable data and mathematical models, and on a high degree of accuracy of information, objectivity, cumulativeness, replicability, straightforward predictions (Fanelli 2010).

While astronomy is one of the oldest natural sciences (according to the European Space Agency 2019, its origins date back to 1,000 B.C., when ancient Assyro-Babylonians systematically observed and recorded periodical motions of celestial bodies), astrophysics can be said to begin in 1687 when Sir Isaac Newton first proposed a comprehensive and complete, single theory of gravity, describing one of the first fundamental forces of the Universe that acted on all matter and helped to explain the movement and behaviour of objects in space (Balter 2022). Research in the astronomy field continued in Ancient Greece (Ptolemy's geocentric system is considered as one of the main contribution of the time), then in Asia and in the Islamic world during Middle Ages, up to Renaissance when Copernicus published his theory of a heliocentric system (confuting Ptolemy's theory), "identifying the Sun as the centre of the Universe, with the Earth and the other planets bound to move around it" (ESA 2019), and Tycho Brahe made great strides in observational astronomy by compiling an accurate catalogue with the positions of about 1000 stars.

The first true breakthrough in humankind's exploration of the universe arrived with the invention of the telescope in the 17th century in the Netherlands. However, it was the discovery of spectroscopy, i.e. "a discipline analyzing the ability of matter to split light into different wavelengths depending on its chemical composition" (Carter and Pultarova 2023), and photography in the late 19th century that generated a revolution in people's understanding of the cosmos. The following statement by Center for History of Physics (2023) synthetises the birth of astrophysics:

> For the first time, scientists could investigate what the universe was made of. This was a major turning point in the development of cosmology, as astronomers were able to record and document not only where the stars were but what they were as well.

Indeed, thanks to spectroscopy, astronomers began to study the chemical composition of celestial objects, in addition to their position in the Universe. Of course, first analysis concerned near heavenly objects, such as the Moon and the Sun, but later the more distant ones, including stars and even galaxies, were also been investigated.

In the early 20th century, NASA and other institutes of astronomy and astrophysics built new more sophisticated telescopes (e.g. the Orbiting Astronomical Observatory 2, nicknamed Stargazer, and the Hubble Space Telescope) with which astronomers began to analyse the cosmos more accurately, until they understood that "the universe was expanding probably from the time of a giant explosion that had created it in the most distant past. The Big Bang theory was born" (Carter and Pultarova 2023). In addition, technological progress allowed spaceflight and the birth of space telescopes. These powerful, fine-tuned telescopes, such as the Event Horizon Telescope that "released the first-ever image of the black hole at the heart of the M87 galaxy" (Nakra 2023) in 2019 and NASA's James Webb Space Telescope launched in 2021, have increased astronomers and astrophysicists' endeavour in discovering the nature of the Universe and many of its secrets. "Yet, the more astronomers see, the more questions are arising and the answers to the grand questions of the nature of the universe and our place in it remain elusive" (Carter and Pultarova 2023).

From a linguistic perspective, it can be said that these two scientific disciplines share the same language: the language of science. Since its dawn, the language of science has been aimed at disseminating knowledge and explaining natural phenomena, so much so that its birth was due to the necessity to find new words for the enormous amount of new concepts, inventions, findings. Its origin and development have been widely investigated and, as Gualdo and Telve (2011: 59) point out, cultural, political and economic hegemony has always played a crucial role in the specialised communication. Indeed, in the classical world Greek and Latin were acknowledged as scientific linguae francae (i.e. "any of various languages used as common or commercial tongues among peoples of diverse speech", Merriam-Webster Dictionary 2023), while in the Middle Ages Arabic contributed in the development of the language of biology, mathematics and astronomy, so much so it left traces in many European languages by mean of adapted borrowings. The Age of Enlightenment, which developed mainly in France thanks to the publication of the *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers*, made French become the international scientific language. Nowadays, scientists have identified English as the scientific lingua franca, as it is particularly suitable to talk about science both for historical, economic and cultural reasons, because it is one of the most widely spoken languages all over the world, and for linguistic reasons, because of its tendency to conciseness and morphological simplicity.

Obviously, the language of science can be classified as a LSP, as it shares the same main linguistic features. In addition, Gualdo and Telve (2011: 251), Ahmad (2012: 48) and Klímová (2013: 53) affirm that the internal organisation in the majority of scientific texts, especially research articles, follows a logical macrostructure, as it is based on distinct constituents (or sections), i.e. Introduction, Method, Result and Discussion – to which Swales (1990) also adds Conclusion. Indeed, Fabbro (1999: 324) affirms that LSPs, just as general language, are characterised by a conventional style.

Generally speaking, scientific language is said to be clear, concise, precise, accurate, objective, as it gives priority to the subject matter and conveys technical concepts and verifiable research findings in a manner that is easily understood by other scientists and researchers. Cortelazzo (1994: 11) adds that scientific language is much more regulated as general language. Ahmad (2012: 47) describes it as follows:

> The scientific language is accurate, precise and detached from individual impulse. It aims to inform about an important issue and what particular approach is taken up to investigate that issue. It is an objective interpretation of facts and findings. It contains such components and findings that need external and experimental evidence to consolidate their validity. […]

By making a comparison between scientific texts and literary texts, the author (Ahmad 2012: 47-52) points out that the former do not deviate from conventional norms of grammar (e.g. they generally follow the usual syntactic order), and resort more frequently to nominalisation and to passive forms of the verb, especially in the Method section so to describe experimental procedures. Furthermore, scientific texts are often characterised by the presence of rhetorical devices, e.g. metaphors, questions (named 'interrogative gambit') and hedges (which are very useful to gain reader acceptance of claims, since it "can be applied to increase conceptual fuzziness when information such as exact reference or precise numerical is unobtainable or unnecessary in view of the needs of the readers", Ahmad 2012: 52).

Focusing particularly on the language of astrophysics, it developed (and keeps developing) in parallel with the advancement of knowledge in the field of astronomy and particle physics over centuries. It constitutes the result of contributions from scientists (e.g. Copernicus, Kepler, Newton, Galilei), observations of celestial phenomena, and advancements in theoretical understanding, space exploration and modern cosmology. More recently, the formulation of the Big Bang theory and the discovery of cosmic microwave background radiation brought new terms and concepts into the language of astrophysics, e.g. *inflation*, *dark matter*, and *dark energy*. As Cortelazzo (1994: 23-29) points out, Galilei provided a valuable contribution to the development of the language of physics and brought clarity and syntactic linearity to the scientific prose.

From a semantic point of view, Galilei coined new terms through semantic redetermination, i.e. he resemantised words belonging to ordinary vocabulary (e.g. *forza*, *massa, resistenza, energia, potenza, densità*). Gualdo and Telve (2011: 90-91) also speak of lexical transfert (or transdisciplinary borrowing) when one specialised field borrows a term belonging to another specialised field, giving it another meaning. For instance, the Italian language of astrophysics has incorporated the word *collasso* from the language of medicine into its own vocabulary, meaning "rapida contrazione delle stelle dovuta al prevalere delle forze di gravità su quelle di pressione" (Gualdo and Telve 2011: 91).

Furthermore, the study conducted by Tarone et al. (1998) is particularly relevant from a morphosyntactic perspective, since it examines the use, frequency and function of active and passive verb forms specifically in astrophysics papers. Firstly, the researchers does not share the same macrostructure of the typical scientific research article "for a very simple reason: the subject matter does not lend itself to experimentation" (Tarone et al. 1998: 115). Therefore, papers written in the field of astrophysics describe logical arguments instead of experiments:

> Journal papers in astrophysics consist of logical arguments which cite observations and draw conclusions which are based on logic, citation of established procedure, and proposals for new choices and procedures, all involving the use of mathematical equations.

It has been observed that active verbs occur much more frequently than the passive, especially in the first person plural *we*. The authors (Tarone et al 1998: 127) thus indicate four rhetorical functions of the passive and active voices:

> Generalization I: Writers of astrophysics journal papers tend to use the first person plural active WE form to indicate points in the logical development of the argument where they have made a unique procedural choice; the passive seems to be used when the authors are simply following established or standard procedure, as in using accepted equations or describing what logically follows from their earlier procedural choice.
>
> Generalization IIA: When these authors contrast their own research with other contemporary research they use the first person plural active for their own work, and the passive for the work being contrasted.
>
> Generalization IIB: When these authors cite other contemporary work which is not in contrast to their own, they generally use the active form of the verb.
>
> Generalization III: When these authors refer to their own proposed future work, they use the passive.
>
> Generalization IV: The use of active as opposed to passive forms of the verb seems to be conditioned by discoursal functions of focus - as when the author chooses to postpose or to front certain sentence elements for emphasis - or by the excessive length of those elements.

To sum up, it can be noticed that, on one hand, the active form is much more used from the authors of astrophysics papers when they describe a proposed procedure, often resulting from their own research, or when they cite the work of other scientists which is not in contrast with their own. On the other hand, writers employ the passive form when they adopt established or standard procedure, sometimes in contrast with their own research, and when they aim at proposing future studies and research on that specific area. The fourth generalisation is noticed by the authors in the astrophysics papers analysed only with regards to lengthy equations, which are often placed at the end of the sentence so that they do not "interfere with the reader's processing of the basic grammar of the sentence" (Tarone et al. 1998: 126). For this reason, they conclude by saying that this last generalisation can be applied also to general English.

1.3. An attempt of linguistic standardisation: the ASD Simplified Technical English (ASD-STE100)

As explained in the previous sections of this chapter, LSPs are highly standardised and codified, not only in their semantic and morphosyntactic features, but also as regards to their textual organisation. During the last decades, research has increased on the area of text simplification through the introduction of controlled natural languages (CNLs), or simply controlled languages. As for LSPs, scholars have proposed a number of definitions for CNLs, since "CNL approaches emerged in different environments (industry, academia, and government), in different disciplines (computer science, philosophy, linguistics, and engineering), and over many decades (from the 1930s until today)" and "[…] they also exhibit a very wide variety: Some are inherently ambiguous, others are as precise as formal logic; virtually everything can be expressed in some, only very little in others; some look perfectly natural, others look more like programming languages; some are defined by just a handful of grammar rules, others are so complex that no complete grammar exists" (Kuhn 2014: 121-122). However, although these differences, according to Kuhn (2014: 121) and Wyner et al. (2010: 282), it is possible to identify some interrelations and common attributes among CNLs, i.e. controlled, processable, simplified, technical, structured, and basic.

As Kuhn (2014: 124) points out, there is an interrelation between CNLs and LSPs (he speaks of 'sublanguages', referring to Kittredge's definition), since they both are based on a natural language, i.e. their base language, but are more restrictive with respect to lexicon, syntax, and semantics. "The crucial difference between the two terms is that sublanguages emerge naturally, whereas CNLs are explicitly and consciously defined" (Kuhn 2014: 124). Indeed, a controlled language may also be referred to as an 'engineered language', a 'constructed language', an 'artificial language' or a 'planned language' (just as Esperanto or programming languages), because it preserves the main properties of a natural language but has been consciously defined to meet a special purpose, e.g. to facilitate communication among humans (translation or writing of technical documentation, especially for non-native speakers of the respective natural language) or human to machine communication (interfaces with databases or automated inference engines, information extraction, etc.). According to Fuchs and Schwitter's (1995) definition, controlled natural languages have to be interpreted by computers, which in turn can analyse the text more accurately and efficiently.

Wyner et al. (2010: 283-286) generally indicate generic, design and linguistic properties common to all CNLs, many of which have been considered fuzzy by Kuhn (2014). On one hand, the authors (Wyner et al. 2010: 283-286) point out that users, purposes, and domain of the CNL (i.e. the generic properties) determine the requirements which are the design properties that the CNL needs to meet, e.g. the degree to which the language is easy to describe, teach, learn, read, write, and understand; what are the formal properties of the CNL in terms of expressivity, tractability, and decidability; whether the language is formally or informally defined, and easily and systematically extensible; etc. The design properties, in turn, may determine the linguistic properties, among which the grammatical classes, the morphological word formation rules, and the types of subordinate clauses supported; whether the lexicon supports polysemy or only monosemy, and the language is mono- or multi-lingual; and whether interrogative and imperative forms, as well as metaphors and idioms, are allowed.

On the other hand, Kuhn (2014: 125-126) collects nine clear-cut properties which "describe the application environment of languages", in order to better categorise CNLs. The author starts from Schwitter's (2002) statement:

> Controlled natural languages can be roughly subdivided according to the problem they are supposed to solve.

The nine properties may be combined and synthetised as follows:

1. the goal is comprehensibility and improvement in communication among humans;
2. the goal is manual, computer-aided, semi-automatic, or automatic translation;
3. the goal is formal representation (including automatic execution);
4. the language is intended to be written;
5. the language is intended to be spoken;
6. the language is designed for a specific narrow domain;
7. the language originated from academia;
8. the language originated from industry;
9. the language originated from a government or a UN agency.

In addition, Kuhn (2014: 125-126) proposes a scheme consisting of four dimensions, i.e. Precision, Expressiveness, Naturalness, and Simplicity (PENS), so to better classify CNLs basing on their inherent language properties. The scheme is based on the general criterion "CNLs are more formal than natural languages but more natural than formal ones" (Kuhn 2014: 127). Precision consists in the degree to which the meaning of a text in a certain language can be directly retrieved from its mere textual form (i.e. the sequence of language symbols), without need for additional contextual information. This means that the more a language is characterised by fixed semantics and syntax, the more it is precise, unambiguous and clear. Expressiveness in measured by the range of propositions that a certain language is able to express. Of course, more expressive languages are able to express anything that can be communicated between two individuals. Naturalness takes the parameters of readability and understandability into account, so to measure how much the structure of the language in question is close to that of its base natural language. Lastly, simplicity is measured by the number of pages written in natural language, which are necessary to describe the language at issue in an exact and comprehensive manner (of course, only one single page is sufficient to accurately describe very simple languages).

Studies have confirmed that the use of CNLs has many advantages concerning text comprehension, machine-assisted translation and post-editing, and understandability of logic formalisms. Since machine translation engines are trained with these languages, they perform better when dealing with specialised texts written in a controlled natural language, so that "the time needed for post-editing is reduced on average by 20%" (Kuhn 2014: 125, referring to Temnikova 2010, 2012). Indeed, as expressed in the last updated issue of the ASD-STE100 specification (2021):

> If the vocabulary, meanings of words, and the types of sentence constructions in a text are controlled, the variation between texts will be minimal. Thus, it is easier for translators or translation machines to translate text written in STE into the target language.

One of the best known CNL is ASD Simplified Technical English (ASD-STE100), often abbreviated to Simplified Technical English (STE) or just Simplified English. Following Kuhn's PENS Classification Scheme, STE can be said to be "considerably more precise than full English, [even though] it does not allow for reliable automatic interpretation. Full expressiveness and full naturalness of unconstrained English are retained, but also its complexity" (Kuhn 2014: 136). This means that, this CNL is definitely less ambiguous, vague, and context-dependent than natural languages, and as expressive, complex and natural (with regard to semantics and style) as natural languages. Moreover, STE originated from the aerospace industry for the specific narrow domain of aviation, it has always been intended to be written, and it aims at improving both human comprehensibility and translation of technical documentation, which must be written "in a clear, simple, and unambiguous manner that readers throughout the world will find easy to understand" (Specification ASD-STE100, Issue 8, 2021). Since most of these documents concern safety and maintenance, it is of paramount importance that all readers, especially those who are not proficient in English, fully understand their content.

ASD-STE is an international specification developed in the early 1980s, based on the English language and consisting of a set of sixty writing rules about grammar and style, as well as a controlled dictionary where aerospace terms are listed. In addition to these, Rule 1.5 "You can use words that you can include in technical name category" allows the use of company- or project-specific (user-defined) technical names and verbs by always regulating "the way to express the content" (Specification ASD-STE100, Issue 8, 2021). The specification rule lists all the terms belonging to the twenty categories permitted, including vehicles, tools, materials, systems, and the like.

As regards to writing rules, they specifically concern lexicon, syntax, and semantics. For each rule, the specification provides useful examples. For instance:

- Rule 1.2 "Use approved words from the dictionary only as the part of speech given" is related to the semantic level of the CNL, since it indicates the approved part of speech for each term, e.g. 'test' can be used only as noun, but not as verb.
- Rule 2.1 "Write noun clusters of no more than three words" concerns the syntactic level of the language, as it provides information on how to regulate noun clusters, in particular those made up of several nouns and adjectives. Very dense noun clusters may appear ambiguous and unclear to readers and, therefore, have to be rephrased, e.g. 'runway light connection resistance calibration' is rephrased as 'calibration of the resistance of the runway light connection'.
- Rule 1.3 "Use approved words only with their approved meanings" is about semantics. Given that monoreferentiality is one of the main features of STE, each word has only one meaning. As other CNLs, STE avoids both polysemy and synonymy in order to avoid ambiguity as much as possible, e.g. the verbs 'follow' and 'obey' cannot be used interchangeably, because the approved meaning of the former is "come after, go after". As a consequence, the sentence "Follow the safety instructions" is classified as non-STE, because the appropriate verb to use in this context is 'obey'.

STE has been internationally acknowledged in the aerospace and aviation industry as one of the best practice standards for writing technical documentation (Ingalls and Cipolletti 2011: 8). Indeed, it has been a requirement of the ATA (Air Transport Association of America) Specification named *S1000D, "International Specification for Technical Publications Utilizing a Common Source Database (CSDB)"*, as "ATA has joined with the AeroSpace and Defence Industries Association of Europe (ASD) and the Aerospace Industries Association (AlA) to form this much-enhanced and expanded international specification" (Ingalls and Cipolletti 2011: 11). However, Simplified Technical English is nowadays widely used also outside the aviation industry, including companies in the defence, machinery, electronics, semiconductor, medical equipment, IT, renewable energies, logistics, and hi-tech industries. As written in the Specification ASD-STE100, Issue 8, 2021:

> Today, the success of STE is such that other industries use it beyond its original intended purpose of aerospace maintenance documentation. Interest in STE has also increased dramatically in the areas of language services, professional translation and interpreting, and in the academic world.

Furthermore, as Kuhn (2014: 124) states, the concept of 'controlled vocabularies' is also related to CNLs. The European Union defines them as "standardized and organized arrangements of words and phrases presented as alphabetical lists of terms or as thesauri and taxonomies with a hierarchical structure of broader and narrower terms" (EU Vocabularies, available on Publications Office of the European Union 2023). Differently from natural language vocabularies, controlled vocabulary schemes mandate the use of predefined terms that have been preselected by their creators. Moreover, while CNLs have to deal not only with terms, but also with morphosyntactic issues, controlled vocabularies only consist of domain-specific collections of terms whose aim is to facilitate content organisation and retrieval through browsing or searching. Of course, as CNLs, controlled vocabularies are a very useful tool for specialised translators since "[u]sers frequently need to locate information in more than one system or database" (ANSI/NISO 2005: 3), so that interoperability is one of the main purpose of controlled vocabularies: a good data management allows an efficient data and knowledge retrieval, integration and reuse (Wilkinson et al. 2016: 7).

In addition, vocabulary control is essential to achieve consistency in indexing, i.e. "uniformity in term format and in the assignment of terms" (ANSI/NISO 2005: 11), basing on four guiding principles, which highlight the affinity with CNLs: eliminating ambiguity; controlling synonyms; establishing relationships among terms where appropriate; testing and validation of terms (ANSI/NISO 2005: 12). Indeed, the need for controlled vocabularies arises to ensure a biunivocal relationship between a term and its related concept and to cope with homographs (i.e. words having the same spelling but representing different concepts), which are characteristic of natural language and cause of ambiguity.

In particular, thesauri are more complex controlled vocabularies which are structured hierarchically and contain a large number of terms and their relationships. ANSI/NISO (2005: 9) defines a thesaurus as:

> A controlled vocabulary arranged in a known order and structured so that the various relationships among terms are displayed clearly and identified by standardized relationship indicators. Relationship indicators should be employed reciprocally.

As explained (ANSI/NISO 2005: 46-66), hierarchical relationships are based on degrees of superordination and subordination of concepts, respectively designated by broader (or parent) terms and narrower (or child) terms. It is possible for each term to select the expanded view to see the full term detail. Therefore, differently from the simple lists, thesauri include "explicit devices for controlling synonyms, arranging hierarchies, and creating associative relationships" (ANSI/NISO 2005: 17). Associative relationships are symmetrical relationships between terms that are semantically or conceptually (though not hierarchically) associated to one another, so that they are referred to as related terms.

Since these tools are very useful "to support semantic enrichment of the literature" (Accomazzi et al. 2014: 462), a significant number of thesauri have been created for the most diverse fields of knowledge. One example is the NASA Thesaurus, which "contains the authorized subject terms by which the documents in the NASA Aeronautics and Space Database are indexed and retrieved" (NASA Thesaurus 2012: 5) in the STI[1] Repository.

[1] The acronym stands for 'scientific and technical information'. The STI Repository is also known as the NASA Technical Reports Server (NTRS), which provides access to NASA metadata records, full-text online documents (e.g. papers, journal articles, patents), images, movies, and technical videos (NASA STI Repository 2023).

Terms are listed alphabetically together with their definition, hierarchical interrelationships, and USE references (i.e. the recommended terms to use). Of course, the NASA Thesaurus has been created for a specific narrow domain, namely aerospace engineering, but its scope also includes supporting areas of engineering and physics, the natural space sciences (astronomy, astrophysics, and planetary science), Earth sciences, and the biological sciences (NASA Scientific and Technical Information Program 2023).

Another example is the Unified Astronomy Thesaurus (UAT), created by a working group composed of the Institute of Physics (IOP), the American Institute of Physics (AIP), the SAO/NASA Astrophysics Data System (ADS), the CfA Wolbach Library, and the IVOA Semantics and the American Astronomical Society (AAS) with the aim of "merging and reconciling existing and emerging vocabularies and thesaurus" (Accomazzi et al. 2014: 462) in astronomy and astrophysics by collecting all astronomical concepts and terms and their interrelationships. The main strength of this open, interoperable, freely-available thesaurus is definitely the community support. Indeed, the possibility to suggest additions, refinements, revisions and modifications, as the UAT has been built using open standards and formats, contributes to its reuse and constant update and revision (Accomazzi et al. 2014: 462-464).

Moreover, progress in text mining has implemented semantic enrichment of the literature, in order to reduce time-consuming manual work of experts and to cope with new theories and findings, and, consequently, new concepts which require a designation. As Frey and Accomazzi (2018: 5) observe:

> Early tests have indicated that the UAT could be used in conjunction with text mining techniques to automatically extract a set of concepts discussed in a paper with reasonable accuracy.

CHAPTER 2: COMMUNICATING AND TRANSLATING POPULAR SCIENCE

2.1. Scientific popularisation: the importance of communicating astronomy and astrophysics

The concepts of ‘open science’ and ‘scientific popularisation’ are central in today’s hyper-technological and -populated society, where the internet allows the dissemination of scientific knowledge and data through full access to the large amount of scientific articles which are published every day. As Hawking (2019: 143) points out, world population, electricity consumption and the number of scientific publications are indicators of the exponential (at this stage uncontrolled) scientific and technological development of humankind. Of course, scientific progress and overpopulation have generated a number of challenges and problems of various kinds that humans have to face, namely climate change, global warming, resource scarcity, poverty, pandemic and epidemic diseases, marine pollution.

Therefore, it is of paramount importance that laypeople become more interested in and aware of science, and that governments and institutions make “efforts to stimulate public interest in science” (Madsen and West 2003), considering that, on one hand, people nowadays seem to be more interested in scientific and technical advances, but, on the other hand, a decreasing number of young people decide to study and seek careers within science (Madsen and West 2003; L’Astorina and Valente 2011: 211). According to Madsen and West (2003):

> […] there is also a strong motivation for public science communication which is embedded in a genuine conviction that science presents a unique opportunity for humankind to obtain a better understanding of the natural world. As a consequence, it may also serve to improve living conditions for all of humanity on this planet of limited resources. In fact, it may even be the only plausible way forward in an age that is beginning to sense the effects of heavy ecological impacts by rapidly growing numbers of energy-hungry citizens.

The scientific community itself stresses the importance of developing a “positive attitude towards science” (Anjos, Russo and Carvalho 2021: 13) and a “scientific culture” (Hawking 2019: 189) among people, in particular among non-experts, who might fund research, become new scientists or even be part of the so-called ‘citizen science’, i.e. scientific research conducted in cooperation with the public of non-experts, amateurs who choose to contribute to scientific research and progress by collecting, analysing and categorising data (Meschia 2016). Of course, citizen science is based on the principles of open science, open access, open data and open research, and it is therefore crucial to lay the foundations for a knowledge democracy (Gioè 2016), i.e. a democratic society based on science, in which "both dominant and non-dominant actors have equal access and ability to put this knowledge forward in the process of solving societal problems" (Bunders et al. 2010: 125). Furthermore, since 2014 citizen science has been acknowledged at European level with the establishment of the European Citizen Science Association (ECSA), which considers science as "a collective human enterprise that encompasses a wide range of activities" (European Citizen Science Association 2023), naturally based on evidence. The association proposes a number of projects to realise its main goals, namely "to increase the democratisation of science, encourage the growth of citizen science in Europe, and support the participation of the general public in research processes – across the natural sciences, social sciences, humanities, and the arts" (European Citizen Science Association 2023). One example is Zooniverse, a citizen science projects internet portal which has a community of more than 480.000 volunteers and, as far as astronomy is concerned, in 2007 it launched Galaxy Zoo, an international astronomical project where members help classify galaxies by looking at telescope images provided by astronomers and cosmologists (Zooniverse 2023). It is one of the most valuable examples of citizen science, as it also benefits from the collaboration of prestigious universities such as Oxford, Yale and John Opkins (Meschia 2016).

According to Pietro Greco (2009), the principles at the basis of science communication and dissemination, naturally revised in a more modern key and adapted to the changing society, date back to the 17^{th} century, when Galileo Galilei published his *Sidereus Nuncius* (1610). Although written in Latin and thus understandable by only a small segment of the population of the time, namely educated people and aristocrats, it is considered the first published scientific work based on observations made through a telescope, so the first attempt to communicate new discoveries to as many people as possible. The author (Greco 2009) explains that modern science, based on observation, interpretation and communication, originates from the scientist's desire to share knowledge as world heritage, and to explain scientific facts thoroughly, using a simple, referential style (described as *aridus*). Galilei pioneered the modern scientific prose by proposing precise textual specifics based on the principles of coherence and cohesion, as well as a specific textual organisation (called *dispositio*).

By analysing Galilei's intention more deeply, Greco (2009) points out that science communication has become so important, and continues to be so important, since it gives the possibility to scientists to obtain public consensus and support, necessary to do research. As Anjos, Russo and Carvalho (2021: 7-8) state and confirm through their study on the perceptions and practices of the astronomy communication community, the public may influence science policies, especially science funding, in fact:

> Science policies and the role of governments and scientific organizations were highlighted as crucial aspects of the science-society relationship. Policies were prized either by potentially promoting equal access amongst several groups (considering gender, ethnicity, race, disabilities), by promoting proximity and free access to science, or by levering the economy through investments on science infrastructures.

The more innovative a research is, the more scientists necessitate approval from the general public by communicating their methodology, observations and findings. Scientists have always needed, at first, the endorsement of the most influential political decision-makers, institutions and stakeholders in order for their research to be funded. Then, they have always aimed at involving the whole of society, including non-experts. Indeed, in order to involve as many laypeople as possible, Galilei decided to start writing in Italian, and in 1632 he published the *Dialogue Concerning the Two Chief World Systems*, in which he compares the Copernican system with the Ptolemaic system. In so doing, he introduced the dialogic form, which is still one of the main features of today's popular science texts, increasing the capability to capture the attention of a wider target group of people on specific themes.

As Greco (2009) observes, unlike in the 17^{th} century, when most people were illiterate and unable to understand more complex and technical information, today the need for knowledge is strongly felt by all, in particular because everyone can access to knowledge and be informed thanks to media and the internet. Moreover, science communication is not to be conceived as a result of the scientific revolution, but rather the opposite: a new interpretation of communication and the breaking down of the 'paradigm of secrecy' brought to the birth of modern science and the scientific method. By quoting the theoretical physicist John Ziman, Greco acknowledges that "science is a social activity which tends to reach a «rational consensus of opinion» in the widest field possible. […] There is no science without communicating science. In fact the communication system is the scientific community's fundamental social institution. An institution whose features are characterized by total transparency and accessibility" (Greco 2012).

"Communicating everything to everyone" has become a central motto since 1660, when the Royal Society of London, the first scientific academy of the United Kingdom, was founded. Scientific academies began to appear throughout Europe, e.g. the French *Académie des sciences* in 1666, promoting open access to knowledge through their journals, i.e. domain-specific periodical publications containing the most advanced findings of scientific research at the time. Journals, which also exist today, are based on "peer review, with ex ante critical analysis on the colleagues' part who are experts on the authors" (Greco 2012), which guarantees accuracy, quality and transparency. Although, on one hand, during that period specialised knowledge circulated only among experts, who could access scientific data to evaluate their reliability by repeating experiments and confirm or correct the results previously obtained, on the other hand, it is thanks to academies that scientific publications have been growing at an even faster pace. Furthermore, this has brought to the growth and internationalisation of the scientific community, the specialisation of scientific knowledge (i.e. the distinction among different domains has become more pronounced), and, of course, the development of LSPs.

Nowadays, it is even possible to talk about "communicating everything to everyone in real time", because of the enormous progress in information and communications technology that have been made, even though, as Greco (2012) argues, "the request by private companies who now finance a large part of research throughout the world – but also many countries, for security reasons – to keep secrets rather than communicate the research results" may be a dramatical obstacle to total transparency in science communication. However, open access allows scientists and researchers to directly communicate with the public of non-experts, who are generally more informed and can express their opinions, doubts, ideas and feedbacks, so much so that communication is now viewed as an interaction, a two-way process. The scientific community is therefore required to change the way it communicates with its recipients by adapting communication to their interests, capabilities and educational/specialisation levels. Scientists cannot simply explain *what* they have discovered, but they are also required to specify *how* they have reached that conclusion or final result, in order to assure everyone that confidence in science is based on evidence.

According to Anjos, Russo and Carvalho (2021: 2), much more attention should be dedicated to research on science communication, as there is a gap between the practice of science communication and the academic research on the field, also among practitioners themselves (Anjos, Russo and Carvalho 2021: 3, referring to Gerber et al. 2022). Science communication practitioners belong to different professional groups, in fact they are not only scientists, who want to share their knowledge and work with the public, but also science educators, press officers, science journalists, bloggers. As the authors (Anjos, Russo and Carvalho 2021: 15) observe:

> As most practitioners have formal training in science, there is a need for additional training on science communication, as well as for widening collaborations and partnerships with other science communication stakeholders, such as journalists and scholars.

Training on science communication may be of the utmost importance, considering that many scientists "report not participating in outreach because they feel unprepared to effectively interact with the public" (Varner 2004: 333, referring to Royal Society 2006; Jensen et al. 2008; Besley and Nisbet 2011), since "it is difficult to learn about effective outreach from the literature" and "scant infrastructure currently exists for scientists to receive formal training in public communication" (Varner 2004: 333). There is a number of possibilities to increase the interconnection between research on and practice in science communication, e.g. projects involving storytelling for engaging with the public, citizen science initiatives, science cafes, scientists' participation in scientific processes through social media platforms. Although the relationship between science and media is not always positive and based on trust and collaboration (in fact, "[…] interviewees affirm that there is a barrier between the media and the scientific community, a mutual misunderstanding and mistrust", Anjos et al. 2021: 10), since most scientists are convinced that media reinforces people's stereotypes and misconceptions about science, it is crucial that practitioners actively use media in order to foster public participation and trust in science, being media "the main channel of information for the public to obtain scientific knowledge" (Madsen and West 2003).

According to several scholars, such as Madsen and West (2003), Gualdo and Telve (2011: 184), Varner (2004: 333), Anjos et al. (2021: 8), these initiatives based on effective interaction between the scientific community and the public are fundamental to abandon the traditional transmission model of communication and information deficit model, that conceive communication as a one-way, linear process in which the public of non-experts is merely seen as a homogeneous group of passive information receivers "inadequately informed about science" (Varner 2004: 334, referring to Royal Society 2006; Davies 2008; Jensen et al. 2008; Besley and Nisbet 2011). On the other hand, initiatives based on the principle of open science are intended to build a knowledge-society, where each citizen may develop a "scientific mind" and a "critical thinking" (Anjos et al. 2021: 8), and may "create meaning and contribute to knowledge production in various ways" (Varner 2004: 335, referring to Berkowitz et al. 2005) by actively interact with experts, not only during public conferences, presentations, demonstrations, laboratories, etc., but also during online debates via social media, web sites and podcasts.

Furthermore, the scientific community should strive to engage diverse publics in dialogue and other outreach activities, including overlooked publics, e.g. urban or at-risk young people, incarcerated people, legislators and public officials, given that the lay public is not an homogeneous one (Varner 2004: 338). It has largely been demonstrated that interacting with the public also enhances scientists' communication skills (Varner 2004: 338, referring to Pearson et al. 1997; Davies 2008; Laursen et al. 2012).

Given that great scientists like Stephen Hawking (2019: 183-190) are of the view that the future of new generations will depend more and more on science and technology in order to confront both existing and new difficulties, the engagement of young people (maybe also of "new Einsteins") is a noteworthy aspect, and education plays a crucial role in that. As Cortelazzo (1994: 96) argues, school is the first place where people get acquainted with scientific concepts and terminology, so much so that its function is decisive for the speaker's overcoming of the language barriers that limit the dissemination of scientific knowledge in society. To prove his point of view, Hawking adds (2019: 182-183) that the human mind needs a "spark of enquiry and wonder", which is often ignited by a brilliant teacher able to spread love for science and inspire his/her students by encouraging them to cultivate their capabilities, in order to face those difficulties with long-term projects, e.g. ocean clean, cure of diseases, smart and cautious use of AI technology, and the like. School should commit itself to combat stereotypes, such as "science is difficult" or "[it is] only for special people" (Anjos et al 2021: 7), also the gender-related ones, e.g. "the school system encourages males more than females to study sciences" and "males have greater technological competence" (Armeni 2006: 38).

According to the Organisation for Economic Cooperation and Development (OECD 2009), "the education system - in particular through the textbooks and classroom instruction - participates in the formation of future citizens not only promoting knowledge but also attitudes and values". Therefore, the education system is partly responsible for the setting up of a scientific culture within the young generations, and a positive relationship between science and society, and science and institutions as well. Indeed, as L'Astorina and Valente (2011: 211) point out, "the process of acquiring a scientific culture must begin very soon, starting with the younger generations". In 2000, the European Commission launched the Lisbon Program, with the aim of investing more in human capital and training opportunities, in order to turn Europe into "the most important knowledge-based economy" (L'Astorina and Valente 2011: 211). The authors (L'Astorina and Valente 2011: 212, referring to Murcia, De Haan, Huck 2008) analyse two European reports and argue that what emerges from these reports is a widespread lack of interest of young people in science, often caused by obsolete teaching methods which do not consider students' involvement, participation and motivation. Moreover, the content of science taught is usually perceived by students themselves as "abstract and far from the daily life".

In order to face this problem, the research group "Science Communication and Education" of the Italian National Research Council (CNR) developed the inquiry-based learning (IBSE) methodology within the Project "Perception and Awareness of Science" (PAS) (L'Astorina and Valente 2011: 212). This methodology is beneficial for both students and teachers, since, on one hand, it allows a direct contact between students and experts, and reserves more space to students' questions, comments and proposals. In addition, IBSE methodologies "stimulate rational and critical thinking in students, develop skills that enable them to investigate, select the sources of documentation, analyze a scientific problem, form personal opinions, seek solutions" (L'Astorina and Valente 2011: 213, referring to Murcia 2009; De Haan 2008) and, of course, it encourages students to always express their points of view, also improving their social skills, e.g. problem solving and cooperation. On the other hand, teachers understand their active role on students' education, learn how to adopt innovative and engaging teaching activities for their students (such as visiting scientific laboratories, reproduce historical experiments at school, use computer simulations/virtual labs, etc.), act as tutors by stimulating questions about a specific topic, and support students during the debate with experts (L'Astorina and Valente 2011: 214-216).

It is possible to agree that IBSE methodologies are really efficient, since they are based on participatory methods, which allow everyone to express their voices, and make students aware of an 'in progress (not static) science' and of the importance of developing an 'information culture', that is young people should learn to retrieve pertinent information by comparing and evaluating sources, in order to identify the most reliable ones. As L'Astorina and Valente (2011: 217-218) conclude:

> [Students] feel great pleasure when they discover they also have a sort of knowledge (even if "tacit"), and they can trace the deepest "motivation" that link them to issues which they apparently do not seem to have any relationship with (climate change, water crisis, GMO, etc.). Students seem to appreciate very much the direct contact with experts and think communication be not only a transmission of facts but also a sharing of theories, knowledge and approaches. […] Students also ask to find a connection between what they study, discuss and debate at school and what they experience in their everyday life. […] A link perhaps still too implicit and undervalued, which can become evident within an effective practice of public communication by all subjects of science communication: museums, schools, scientific institutions, etc.

Focusing on the teaching of astronomy, Madsen and West (2003) present the validity of the case-study approach proposed by Shapin, which is at the basis of a number of educational programmes, e.g. Astronomy-OnLine, Sea & Space, Hands On Universe. This approach can illustrate many aspects of science and include laboratory work, increasing pupils' interest in and understanding of science. In the Declaration on the teaching of Astronomy in European Schools (1994), the European Association for Astronomy Education (EAAE) has listed the main points expressing the minimum all people should know about astronomy:

> By the age of 14, students should have acquired
> - knowledge and understanding of the Sun, the Moon, the Earth and their principal relations (the seasons and their effects, the movements in sky and space, the nature of these bodies, etc.) - a first view of the Solar System.
> In addition, they should have
> - acquired a basic understanding of what the stars are, and

- performed simple observations of the day- and night-sky.

Of course, EAAE encourages the participation of students and young people also in extra-curricular activities, optional courses, Astronomical Olympiads, summer schools, astronomy camps, or exchange of experience by network, which are of paramount importance for increasing the interest in astronomy and allow cooperation in this field on a European level.

As highlighted by several authors, among others Armeni (2006: 27), Gualdo and Telve (2011: 190-191), Anjos et al. (2018: 202), astronomy and astrophysics occupy an important place in media activities related to public science communication, even though medicine and the environmental science are at the first position, because they are directly implicated in human health (Armeni 2006: 25, referring to European Commission 2005). According to Madsen and West (2003), astronomy "functions as a general science 'catcher', especially for young people", as it can "trigger interest in STEM (Science, Technology, Engineering and Mathematics) subjects" (Anjos et al. 2018: 202). Anjos et al. (2021: 7) point out that "the public is emotionally connected to astronomy". People are indeed fascinated by this pluridisciplinary visual science, since it offers amazing space images and spectra representing the Universe and can help people find an answer to the big questions, which Stephen Hawking (2019) collects in his last book *Brief Answers to the Big Questions*, namely "Is there a God? How did it all begin? What is inside a black hole? Can we predict the future? Is time travel possible? Will we survive on Earth? Is there other intelligent life in the universe? Should we colonise space? Will artificial intelligence outsmart us? How do we shape the future?".

Communication in these fields is also deeply important, since, as reported by Anjos et al. (2018: 202), "according to recent data from IAU (International Astronomical Union), women represent 17% of the membership of professional astronomers and people from developing countries are far from participating fully in astronomy research". The authors (Anjos et al. 2018: 203, referring to Stocklmayer 2001; Couper 2005; Cope and Kalantzis 2009) delineate seven recommendations for astronomy communicators:

1. keep the language as straightforward as possible;
2. think about the possibility of alternative conceptions;
3. concentrate on finding good introductory "hooks," if possible using the "human factor";

4. give audience a role in your practice (making them have an experience);
5. use different modes of meaning (such as visual, tactile, digital, linguistic, etc.);
6. be creative and inclusive;
7. keep it at the right level for your audience.

By considering the reason why communicating science in today's society is so important, it is possible to introduce the related concept of scientific popularisation and, of course, outline its main features. Popularisation is generally defined as "a process of communicating scientific knowledge" which can take different forms, e.g. the media, museums, science festivals, science blogs, and science cafés, and involve a number of actors who play the role of addresser, including scientists, science communicators, educators, journalists, and policymakers (Vrabec and Pieš 2023: 207, referring to Jurdant 2016; Poliakoff and Webb 2007). Garzone (2006: 84) points out that the aim of practitioners of this genre is "to make scientific and technological knowledge accessible to their selected audience, without distortion and without unnecessary simplification". Indeed, Olohan (2016: 203) specifies that "popular science genres can be regarded as scientific genres in their own right, rather than simplified versions of professional science" or its "vulgarization" (Olohan 2016: 174), since popularised articles are often not only addressed to laypeople, but also to a more educated readership that includes professional scientists. It can be assumed that there are different degrees of popularisation, considering that sometimes popular discourse aims to entertain the audience rather than merely inform it, and a stark distinction between professional scientific discourse and popular science discourse is not always appropriate (Olohan 2016: 174). Popularisation is thus meant to communicate scientific and technological information in a way that may also be understood both in content and form by a wide audience of educated, and interested, laypeople with different degrees in expertise (Manfredi 2019: 75).

As in science journalism, one of the main objectives in scientific popularisation is to inform and update the public, even though popularisation may also aim at "increasing knowledge and understanding of science, influencing attitudes or behaviour, ensuring that a diversity of perspectives on science is considered when seeking solutions to societal problems" (Science Media Centre Spain 2022). In so doing, science journalists play a crucial role, because they can influence public perceptions and, consequently, decisions about public policies, but, on the other hand, they have the duty to report information and findings in an accurate and transparent way.

According to Garzone (2006: 82-83), newspaper articles, the daily press and the TV news are some of the most powerful and "democratic" forms of popular science, since they make specialised information accessible to as many people as possible. In so doing, practitioners have a great responsibility, i.e. they have to choose which facts, notions or discoveries in the field of science and technology are worthy of being communicated to the audience on the basis of their impact on everyday life and their relevance and consonance to the readers' existing beliefs and attitudes. Moreover, it has been demonstrated that "bad news is certainly more newsworthy than good news", since people tend to pay more attention to news concerning risk, disasters and negative scenarios in general (Garzone 2006: 84-85).

As Vrabec and Pieš (2023: 207, referring to Wynne 1992; Irwin and Michael 2003) explain, there are different – often conflicting – opinions on popularisation of science:

> Some scholars argue that popularization can lead to the oversimplification and distortion of scientific information, which may result in misunderstandings and misconceptions. Others argue that popularization can be a useful tool in enhancing public engagement with science and promoting informed decision-making.

On one hand, science offers one approach to form an opinion on science-related issues since "scientific knowledge provides a network of propositions that help predict reality (under certain conditions, x will cause y)" (Scharrer et al. 2017: 1003), so that popularised articles, which are characterised by information simplification (Scharrer et al. 2017: 1014, referring to Singer 1990; Brechman et al. 2009), is of paramount importance to support laypeople in their decision-making. However, as Scharrer et al. (2017: 1004-1008) observe, oversimplification may lead to the so-called 'easiness effect of science popularization', i.e. the lay audience may have the impression of having already obtained a fairly complete picture of the issue at hand, overestimating the extent of the knowledge they have acquired through reading the simplified information provided and underrating the role played by experts.

Moreover, Vrabec and Pieš (2023: 208) present another issue, that of fake scientific information, which is nowadays becoming popular and increasingly troublesome due to people's extensive use of social media platforms. In fact, a lot of people consider these platforms a useful means to stay informed about specialised content and have the opportunity to better understand scientific and technical topics. The problem is that information is often spread in social networks by individuals (mainly influencers and content creators) "who have not completed a university degree, are not authors of scientific studies and research, and are not familiar with the process and criteria of scientific inquiry" (Vrabec and Pieš 2023: 209), so much so that they cannot be considered reliable sources of specialised information, as they are mere science enthusiasts rather than specialists. Indeed, open access and open data allow everyone, regardless of their education and reputation or acquired knowledge in the field, "to create and disseminate various types of manipulated media content in unlimited quantities" (Vrabec and Pieš 2023: 209). Facts are therefore often disseminated in a superficial way and without providing the recipients with evidence, context and background of scientific research (i.e. trustworthy references, such as scholarly publications and scientific papers).

Considering that many recipients lack adequate scientific literacy necessary to recognise pseudoscience from real science, this is a critical issue the scientific community has to face. As Anjos et al. (2021: 7) argue, "for astronomy communicators, the confusion between astronomy and astrology is a much-referenced example". Although the main social media platforms, such as Facebook and Instagram, cooperate with fact-checking organisations certified by the International Fact-Checking Network (IFCN), which use algorithms and machine learning systems to check online specialised content accurately in order to safeguard users from disinformation and fake news (Meta 2023), it is impossible to identify all false information and phony accounts, given the volume of postings and newly generated accounts that occur every day (Vrabec and Pieš 2023: 212).

In addition to a good scientific and media literacy (i.e. the ability to select reliable information and make more informed decisions, basing on facts, research, and knowledge, instead of opinions or rumours, Vrabec and Pieš 2023: 214), one of the main solutions to help the lay public not to fall into the trap of pseudoscience, disinformation, misinformation (i.e. a false information which is created respectively to harm someone or unintentionally) and malinformation (that Staats 2023 has defined as "the intentional publication of private information for personal or corporate interest and the intentional alteration of the context, date, or time of the actual content"), is "avoiding the more speculative aspects of science in order to avoid confusion and misleading the public" (Vrabec and Pieš 2023: 209, referring to Cornelis 1998), among others the simplification of complex information and of specialised technical terms. Indeed, "scientific information in the online space can take the form not only of text, but also of images, video or sound" (Vrabec and Pieš 2023: 208), which are generally more appealing to recipients, especially in the case of space science. Differently from scientific instruction texts, whose main purpose is to train "readers in the use of the specialized language" (Garzone 2006: 86), so that they may familiarise themselves with the insiders' communicative practices, as well as with the concepts and terminology of a given domain, popular science publications show rather a tendency to use general language. More precisely, as Cortelazzo (1994: 21) affirms, texts belonging to this genre use a LSP which seems to lose some of its features, becoming very similar to everyday language.

Generally speaking, popular science texts are characterised by a lower lexical density and a greater syntactic complexity than specialised texts. By investigating further, from a lexical point of view, popularisers may decide either to avoid technical terms by replacing them with simpler words known to the lay public, phrases (named 'periphrases') written in LGP and common lexicon's equivalent expressions (having the same denotative value, Cortelazzo 1994: 36) or to include technical terms in the text by explaining them through metaphors, similes, notes and paraphrases. Explanatory paraphrase is one of the most commonly used tools by scientists, who naturally tend to adopt specialised terminology more than journalists, as it consists in a simplified – often informal – reformulation of the technical term through a definition written either in LGP or LSP. However, when the definition is provided in LGP, popularisers may run the risk of oversimplification or imprecision, while when it is provided in LSP laypeople may still find the discourse difficult to understand.

Gualdo and Telve (2011: 241, referring to Giovanardi 2006) point out that, when dealing with technical terms represented by acronyms, it is necessary to expand the acronyms, so to ensure maximum transparency and greater comprehensibility. Furthermore, as Cortelazzo (1994: 34-35) argues, with reference to the popularisation of medical information, scientific terminology is often accompanied by colloquial formulae and lexical – sometimes even slang – items belonging to everyday language in order not to tire the non-expert reader.

Popular science texts differ from specialised texts also from a morphosyntactic and textual point of view. As explained in the previous chapter of the present work, the latter resort to some devices, such as nominalisation, de-agentivisation and the passive voice of the verb, while popularisation opts for a less rigid and organised, "more prolix and redundant" and "more expositive than argumentative" (Garzone 2006: 89) structure, characterised by a shorter sentence length, which guarantees the recipients' correct information understandability. As Gualdo and Telve (2011: 251-253) note, the presence of the passive without an agent in popular science texts is less noticeable, as well as in astrophysics texts where the active voice is prevalent. This happens because sometimes articles published in scientific popularisation magazines, e.g. *Scientific American*/*Le Scienze*, summarise field research without citing the references the authors have considered when presenting their work in the scientific publication. Moreover, one of the main distinctive feature (probably the most important one) of popular science discourse is its dialogical form, which, together with rhetorical questions, attitude markers, implicit dialogue forms (e.g. *let's suppose, let's imagine*), the question-answer pattern, and, therefore, a more informal, colloquial register, is useful to establish a deeper contact with recipients and to promote news with a more captivating and persuasive tone. According to Koroleva (2017: 61), the dialogic character of popular science discourse increases the degree of its expressiveness which, in turn, positively affects the audience's efficiency in perceiving some new information and keeping it in mind. In texts of this kind, quotations from experts' interviews are often reported through direct, indirect or integrated speech, in order to lend more authority to the text, promote the dialogue between the scientific community and the lay public (Garzone 2006: 97-100; Gualdo and Telve 2011: 191), and "limit the writer's responsibility" (Garzone: 2006: 100) when reporting someone else's statement (i.e. it is a form of hedging). Furthermore, Ahmad (2012: 51) explains that the interrogative gambit "is a typical device used in scientific journals to popularize facts and findings", which "enables the writer to catch the readers' quick response and to make up their minds for the follow up".

By way of conclusion, popular science texts can be considered as a sort of 'translation', as they involve a form of rewriting, reformulation and recontextualization of scientific knowledge. As Calsamiglia and van Dijk (2004: 386) affirm:

> Finally it is interesting to observe that the recontextualization of scientific knowledge in popularization discourse and its transformation into everyday, commonsense knowledge, combines precise knowledge with fuzzy or approximate knowledge, which, however, will form the basis for further ‘learning’: either in future news and popularization discourse or motivating more systematic approaches through other media.

Popular science will be analysed in more detail in the last section of this chapter, where special attention will be given to its translation. Before that, it is necessary to introduce specialised translation, outlining its main characteristics, some of which are also common to the translation of popular science texts.

2.2. Specialised translation: scientific and technical translation

Scarpa (2008: 75) defines specialised translation as the mediated interlinguistic communication of documents written in LSP from one language into one or more target language(s), whose aim is to convey technical and scientific information internationally. Although English is considered, as previously explained, the “hegemonic language of science” (Wright 2011: 257), so much so that almost all specialised documents are written in the same source language (SL) and the international scientific community has adopted it as its working language, the majority of translations requested by the global translation market are of a specialised nature (namely technical, economic, legal, medical, administrative and scientific texts), while literary and editorial translation accounts for less than 1%.

First of all, Scarpa (2008: 83-85) outlines the difference between literary translation and specialised translation. Although there is a ‘continuum’ between the two genres, as they both offer more or less the same variety of procedures to the translator, she explains that they require a different approach due to their characteristics and purposes. Indeed, differently from literary texts that are ‘open’ because they allow more than one interpretation and it is almost impossible for the translator to convey their whole meaning into the target language(s) (TL), scientific and technical texts are rather ‘closed’, that is to say they require a more rational, ‘domesticating’ (or ‘localising’), reader-centred approach because they allow only one correct interpretation: any variation may indeed only concern the form of the text, as the content must be entirely conveyed in a way that is comprehensible to the readers of the target text (TT) by adapting the source text (ST) to the target language and culture conventions.

This means that specialised translators have a great product liability (Scarpa 2008: 84-85), i.e. they are responsible for rendering information in an accurate and transparent way, avoiding errors of any kind and always considering intertextual norms and conventions. Furthermore, Scarpa (2008: 87), affirms that the specialised translator's choices have a great impact on the TL, since it is not uncommon that new terms designating technical innovations and new scientific concepts enter the vocabulary of everyday language. Moreover, since in recent years it has been acknowledged that special languages have become less 'aseptic' and impersonal, allowing much more creativity to writers of specialised texts, it may happen, just as in literary texts, that some elements (e.g. puns and idiomatic expressions) in a specialised text are strongly bound to the source culture, and, as a consequence, reaching a high degree of functional equivalence between the ST and the TT may be an issue that the translator, being also a cultural mediator between the ST addresser and the TT addressee (Halliday 1992), has to face by trying to bridge the distance between the two cultures involved. According to House (1977), it is thus fundamental to "aim at equivalence of pragmatic meaning, if necessary at the expense of semantic equivalence". With the introduction of the Skopostheorie at a later time (Reiss and Vermeer 1991 [1984]; Vermeer 1996), the communicative purpose (called *skopos*) of the TT acquires importance over the ST itself (which, in turn, in some cases is merely considered a source of information to be translated into the TL, Scarpa 2008: 91), meaning that the translation is seen as "a text functioning in a target-culture for target-culture addressees" (Vermeer 1996).

Scarpa (2008: 94) concludes that it is possible to consider a ST and its translation (TT) equivalent if the level of semantic, functional and sociocultural correspondence between the two is maximum. Since the TT can be compared to a "guided creation of meaning" (Halliday 1992), i.e. a reformulation of the ST content, meaning and socio-communicative value, the two texts are to be considered of equal importance and necessarily related to one another. Of course, the communicative function of the translation, as well as how it will be employed, are essential parameters to consider when dealing with specialised translation. For this reason, the translator should always ask for a detailed "translation brief" (Chesterman and Wagner 2002; Scarpa 2008: 143; Olohan 2016: 18-21; See appendix 2: Table 1.1 Translation parameters for a translation project specification), made up of all the guidelines to be followed during the translation project on the basis of the client's needs and preferences regarding style, terminology, layout, etc. In fact, it must always be considered that, on one hand, instruction may deviate from the prototypical translation and involve either a reduction of the content of the ST or a different communicative purpose (Scarpa 2008: 123-125), and, on the other hand, translation does not correspond to the act of a single individual, i.e. the translator. As Wright (2011: 252-253) explains, there are defined roles in the translation work order, namely the author of the text, the client who requests the translation, the project manager (PM) who coordinates the project, the translator service provider (TSP) that can be an individual or a company supplying the translation, the editor (also known as proof-reader) who revises the translation, and the end user (or consumer).

Therefore, the specialised translator should consider and evaluate the specific communicative situation, in which the translation is embedded, in addition, of course, to the source document, in order to create a first macro-strategy. As first step, the translator should outline both the extratextual and intratextual factors, which are respectively those concerning the communicative situation and the semantic and syntactic structure of the ST, necessary to fix the purpose of the TT (Scarpa 2008: 113-114). Moreover, as Krüger (2016: 97-98) states, "the *degree of technicality* of the texts to be translated [may be regarded] as a potential factor influencing the frequency and distribution of explicitation in (scientific and technical) translation", as it is, in conjunction with the cognitive content and the purpose of the ST, an important element which help translators identify the specific text type in which the ST in question can be collocated. As Scarpa (2008: 11-12) points out, the classification of text types, which form the basic style of writing and "reflect the *intention* of the author as a sender of a speech act (Sager et al. 1980) or the *function* of the text itself (Bühler 1965; Reiss and Vermeer 1984/1991; Nord 1997)" (Wright 2011: 248), may help translators distinguish texts on the basis of the pragmatic function of the discourse. Some examples of text types' classification are those provided by Hatim and Mason (1990) – i.e. descriptive, narrative, expository and argumentative – or by Wright (2011: 248) – i.e. informative/factual/referential, expressive/evaluative, appellative/persuasive and phatic.

The classification model proposed by Taylor (2006) (Scarpa 2008: 119-120, 132), which is specific to specialised translation, identifies four text macrotypes by considering the degree of creativity that characterises the ST and is, consequently, required by the translator to be reproduced into the TT by producing a new text. It can be recognised that the more a text is characterised by a high degree of technicality and a standardised language (a LSP or a CNL), the lower its degree of creativity and uniqueness (or intertextuality), which are measured on the basis of the presence of “culture-bound terms”. Taking this aspect into account, Taylor proposes three translation approaches – foreignising, localising (either partially or heavily) and standardising – to be chosen in relation to the specific macrotype. When the ST presents a high degree of creativity with frequent culture-bound terms (e.g. popular science magazines’ articles), the foreignising approach is the most suitable, since the translator is required to accomplish pragmalinguistic, stylistic and rhetorical choices during the translation process, so to produce a new text by keeping the differences between the source and target languages and cultures. As already stated, the most typical approach required for the translation of some specialised texts, including academic specialised journals’ articles, advertising brochures, business letters (characterised by a medium level of cultural references, as well as by frequent standardised linguistic structures), is the localising one, which consists in adapting the ST content to the target culture. At the opposite end, when the ST presents almost only standardised linguistic structures, and no culture-bound elements (e.g. technical instruction manuals and guidelines), it is recommended to use the standardising approach, consisting in the increasing use of translation technology, i.e. “computer software and other tools to support the translation process” (Digital.gov 2023), namely computer-aided technology (assisted translation) and machine (mostly automated) translation tools, which allow to transpose the standardised lexical and syntactic structures of the ST into the corresponding ones of the TT.

According to Gualdo and Telve (2011: 66-67), the combination of assisted translation, based on the use of translation memories, glossaries and term banks, and translation based on corpora allow the specialised translator to work more efficiently thanks to the great number of linguistic data s/he can collect. A corpus can be defined as “an electronic collection of texts, compiled according to some organizing principles” (Olohan 2016: 27), and its analysis makes it possible to gather and fix grammatical, syntactic and semantic rules (i.e. collocations).

Therefore, as Scarpa (2008: 121-122) and Olohan (2016: 49) suggest, it is advisable that specialised translators make reference to some models to use for their translations, either that of previous translations or comparable target language texts. The latter are called parallel texts and consist in documents written in the TL, which are very similar to the ST both for genre and content. As Olohan (2016: 49) states, reference corpus are widely used by professional translators, as they are "very useful resources for terminological and phraseological research in preparation for translation". When there is no model in the target culture to use as a reference for translations, the translator has the possibility to produce a "translation-specific document type" (Sager 1998), which may be integrated into the target culture for future translation of documents of that type, as well as for original documents drafted in that specific domain, or keep their status as translation.

Scarpa (2008: 126-130, referring to Rossini Favretti and Bondi Paganelli 1988; Nord 1992) adds that, when the translator has to deal with the translation of specialised texts, a two-phases careful reading of the ST is required before starting the translation process (albeit not always possible due to the rigid time constraints frequently imposed on translators). At first, a 'global reading' is necessary to understand the meaning, purpose and text type of the text in question, while an 'intensive reading' aims to identify its most problematic parts and, therefore, to find efficient strategies to solve those problems. Problems can concern the pragmatic-cultural sphere (e.g. variation in the communicative situation between the ST and the TT, differences in conventions and norms between the SL and the TL, etc.) or the linguistic sphere (both from a lexical and morphosyntactic perspective, such as false friends, polysemy, different word order, complex noun phrases, etc.).

In specialised translation, in particular scientific translation, cognitive problems, which are a particular type of linguistic problems, are also very common (especially among novice translators). They are linked to a misinterpretation of the ST's conceptual content, as well as to difficulties related to the SL at the discourse level, e.g. words belonging to the everyday lexicon that acquire a different meaning in a specialised context, including 'grammatical metaphors' (i.e. nominalisation). Gualdo and Telve (2011: 87) stress that attention should be paid when transferring metaphors from one language and culture to another, since an inaccurate translation and the use of calques and loan words (which are very frequent in the IT domain, Scarpa 2008: 191) can lead to serious misunderstandings. Schäffner (2004: 1253) recognises that metaphors and their translatability can constitute a challenging translation problem. Although "[i]n equivalence-based approaches, the underlying assumption is that a metaphor, once identified, should ideally be transferred intact from SL to TL", intact transfer is not always possible due to cultural differences between the two languages involved and to the fact that most metaphors are culture-specific, so much so that "the image that is attached to the metaphor is unknown in the TL" (Schäffner 2004: 1256).

Scholars have suggested a number of metaphor translation possibilities (Schäffner 2004: 1256-1257). For instance, van den Broeck (1981) proposes three approaches, namely the translation 'sensu stricto' (i.e. transfer of both SL image and SL image into TL), the substitution (i.e. replacement of SL image by a different TL image with more or less the same tenor/sense), and the paraphrase (i.e. rendering a SL metaphor by a non-metaphorical expression in the TL). On the other hand, Newmark (1981) lists seven procedures (in order of preference), considering, however, that sometimes the use of a compromise solution may lead to a loss of the intended emotive effect:

1. Reproducing the same image in the TL.
2. Replacing the image in the SL with a standard TL image which does not clash with the TL culture.
3. Translating metaphor by simile, retaining the image.
4. Translating metaphor (or simile) by simile plus sense (or occasionally a metaphor plus sense).
5. Converting metaphor to sense.
6. Deletion, if the metaphor is redundant.
7. Using the same metaphor combined with sense, in order to enforce the image.

Schäffner (2004: 1264) concludes by saying that "if a metaphor activates different associations in the two cultures, one should avoid a literal translation and opt either for a corresponding TL-metaphor or for a paraphrase. If, however, the culture-specificity of the ST is to be stressed, then it would be better to reproduce the SL-metaphor and add an explanation, either in a footnote or by means of annotations".

Literal translation and paraphrase are also the two main methods that translators can use to translate specialised texts. As stated above, translators may intervene on the form of certain parts of the ST in order to reproduce them in the TT in a more comprehensible way, thus improving the final version of the translation, which must 'function' in the target culture (Scarpa 2008: 145). Literal translation, also known as word-for-word translation, consists in keeping the same constituents of the ST while adapting its syntactic and lexical structures to the grammatical and stylistic norms of the TL, producing a TT that is as close to the ST as possible. This approach is generally seen as the simplest one, and sometimes it is even understated, even though it is widely used in technical and scientific texts characterised by standardised terminology and lexical and syntactic structures, as well as for writing a first ST-oriented draft, which will be then adapted to the target culture (Scarpa 2008: 146-147). On the other hand, paraphrase is a freer method, consisting in a reformulation of the ST, or, more precisely, in a rewriting of the ST in the TL. Therefore, the ST has to be partly modified in order to reach a functional balance between the two texts. Scarpa (Scarpa 2008: 148-152) identifies various types of paraphrase: transposition, modulation, adaptation, explicitation, expansion, reduction, elimination.

Transposition is the syntactic paraphrase, consisting in expressing the meaning of the ST through different syntactic structures, e.g. by changing a verb into a noun or viceversa, or a paratactic structure into a hypotactic structure, by rendering a single word or a phrase in the TT though a sentence, by changing the constituents' order within the sentence, or the diathesis, the tense and/or the form of the verb, etc.

Modulation is the semantic paraphrase, consisting in a change of perspective, necessary to express the meaning of the ST. This may concern the logical derivation, e.g. the procedure is replaced by the tool used, the tool by the result, the effect by the cause; the antonymic translation, i.e. "a translation mode whereby an affirmative (positive) element in the ST is translated by a negative element in the TT and, vice versa, a negative element in the ST is translated using an affirmative element in the TT, without changing the meaning of the original sentence" (Maskaliūnienė 2016: 21); the substitution of a dynamic structure with a static one, or of a concrete term with an abstract one.

Adaptation is rather used to solve a pragmatic or cultural problem, and includes the descriptive equivalence and the functional equivalence. The latter implies a change in the cognitive content of the ST by replacing culture-specific terms and expressions with some sounding more familiar to the target audience. This strategy also includes the temporal collocation of events, which consists in taking into account, for example, the technological advances of the reference country that will make use of the translation.

Explicitation has been defined by Vinay and Darbelnet (1995) as a "stylistic translation technique which consists of making explicit in the target language what remains implicit in the source language because it is apparent from either the context or the situation", and by Krüger (2016: 96-97) as a translation technique by which information (which is not verbalised but deemed to be implicit in the source text (ST) or contextually inferable based on the source text) is moved to the textual surface of the target text (TT). This can be realised through the substitution of a pronoun with the name it refers to, the addition of linkers and connectors expressing the logical-semantic links between different sentences, the explanation of culture-bound information. After a deep evaluation of the context, the translator may choose to resort to expansion, reduction or elimination of some constituents of the ST, e.g. when a text segment is not relevant to the cultural context of the TL or is not of interest to the translation recipients.

Furthermore, by comparing English STs and their respective Italian translations, Scarpa (2008: 195-199) notices that Italian specialised translators tend to intervene in particular on the register, as Italian scientific and technical texts seem to be more formal, abstract and referential than English ones. Italian texts appear, consequently, more objective, and show a tendency to simplification, implying the elimination of redundant information and emotionally-charged expressions. On the other hand, they tend to have a more complex hypotactic structure, due to the wide use of explicitation and expansion, as well as of nominalisation and passive and impersonal forms, while English thematic structure appears more linear and compact (Scarpa 2008: 165). As both Musacchio (2007: 108-109) and Scarpa (2008: 156-160) explain, while in English texts the repetition of the same term is often considered necessary to make the text clearer and transparent, Italian translators prefer to resort to lexical variation for stylistic reasons. From a textual point of view, Musacchio (2007: 102) also notices that Italian translations tend to keep the same paragraphs as in the ST. From a lexical point of view, Scarpa (2008: 188-191) points out that it is of paramount importance for the translator to have a deep knowledge of the terminology and phraseology of the domain to which the ST belongs, in order not to make mistakes related to false friends, calques, loan words. Indeed, by referring to Montgomery (2010), Manfredi (2019: 85) explains that "a growing number of translators also have a scientific training" and "many of them tend to become specialized in specific subject fields of science".

Analysing scientific and technical translation in more detail, they have been defined as subtypes of specialised translation and have always been studied in relation to a specific language for special purposes (Manfredi 2019: 84), even though, as Wright (2011: 243) affirms, "it is nonetheless difficult to draw clear boundaries between the concepts", to the point that it is possible to consider them as a continuum, referred to as 'Sci-Tech', which includes a wide range of subdomains, "each one with its own set of sub-topics and text classes". By reporting the definitions of science and technology provided by *Oxford Learner's Dictionaries*, Olohan (2016: 6) explains that the two "designate different, though related knowledge domains", since technology is described as "scientific knowledge used in practical ways in industry, for example in designing new machines" (Oxford Learner's Dictionaries 2023), so it has often been seen merely as a discipline emerging from pure science, which is instead considered "the means by which knowledge is obtained" (of course, through the scientific method, consisting, as already discussed, in 'observation' and 'experiment'). However, some scholars, such as Forman (2010), have questioned the primacy of science at the expense of technology, claiming that:

> [T]his relationship has been reversed in the postmodern era […], from around the late 1970s or early 1980s, we have become more interested in ends than means, and technology has become the 'principal model for all our social and cultural activities'. […] resourcefulness, risk-taking and utilitarian entrepreneurship are now more highly valued in society than scientific means and methods.

The main differences between scientific and technical translation concern both purpose and style. The former works on pure science texts whose approach is mostly theorical, while the focus of the latter is on technological texts, which are generally drafted by technical writers/communicators and aim at helping the user do something (e.g. instructions for use), so the translator is required to use a more concrete, simple, concise and unambiguous language. On the other hand, scientific translation presents information in a more interesting and impressive way, also using rhetorical strategies and a rich vocabulary, since its purpose is not only to convey information and explain scientific phenomena, but also to engage the audience by entertaining it (if one thinks of scientific dissemination).

Of course, this does not mean that creativity is absent in technical translation, since a promotional function may be required in some contexts to ensure successful communication, e.g. through the use of visuals, such as images, symbols, videos (Olohan 2016: 54-55), as well as to make texts "authoritative enough to convince the user of their reliability and usefulness", e.g. "by congratulating the user on their choice or purchase of that particular product" (Olohan 2016: 58). However, the main responsibility of technical translators remains the thorough transmission of information, which should be used correctly and effectively. Indeed, the presence of warnings and additional information to make procedures better understandable and express safety caution is very common in texts of this type (Olohan 2016: 62-63).

Furthermore, as Olohan (2016: 77) argues, "instructions may require cultural adaptation, not only in relation to cultural references, but also with regard to degree of explicitness and level of detail of stepwise instructions". For this reason, technical translators are regarded as 'transcultural technical communicators', as they make texts written by technical writers suitable for the TL audience. Both figures accomplish a translation process, with the difference that the technical writer "gathers information from a variety of sources including documents that were produced by and for experts such as programmers and engineers", and rebuild, reinterpret, remodel and restructure this information so that it can be understood and used by the target user, while "the translator needs to transform information from a form which was produced by and for speakers of the source language into a form which can be understood by the target audience. This is achieved by editing, rearranging, adding and even removing information" (Byrne 2010: 17-18). One example may concern the way the translator adapts sentences describing actions to the target conventions: English texts usually use the imperative form of the verb, while in Italian texts it is more common to find the infinitive form. In addition, technical data, e.g. measurements, certifications, rules, as well as abbreviations and acronyms, are often culture-specific, so their adaptation to the TL conventions and standards is essential to guarantee the user's complete comprehension.

According to Fabbro (1999: 322-324), both the scientific translator and the technical translator have to fully understand the ST and to produce a TT that adequately communicates the ST's content. This requires the possession of both linguistic and extralinguistic knowledge, that is to say the translator should have linguistic and textual competence and writing skills in both working languages, together with intercultural, technological and terminological research/information mining competence (Olohan 2016: 14-15, referring to the European Commission Directorate-General for Translation 2019). Terminological research is of paramount importance, considering that, while specialised documents are always innovative, glossaries and other terminological resources are not always upgraded, so much so that the translator has to use also extra-linguistic resources, such as encyclopaedias, technical manuals, monographs and specialised textbooks, in order to find the more appropriate translation solution on the basis of the context (Scarpa 2008: 306-311). Scarpa (2008: 253-254) adds that, of course, translators should have the ability to recognise problems and to justify their choices, i.e. a metacognitive competence. Moreover, specialised translators should have a deep knowledge of the specific subject-matter's terminology and style of writing. For instance, Fabbro (1999: 328) cites the so-called mandatory forms, whose translation is often problematic, since the translator has to adapt the degree of obligation to the target culture's conventions and to the specific context. In fact, the verb *shall* can be translated into Italian either as *dovere* or using the present tense, rather than the future form of the verb.

Furthermore, while technical terminology is more concrete, and focuses on functions and objectives, scientific terminology is more formal and abstract, since it shows the tendency to focus on taxonomies. In fact, the research article, that is one of the most typical scientific texts, as changes in its form and content reflect changes in how scientific research is done, has become "more abstract, more densely packed with information, more focused in their argumentation, and more centred on the research than the researcher" (Olohan 2016: 149). In addition, corpus-based analyses have shown a wide tendency in scientific texts to use academic terms (e.g. nouns such as *study, process,* *research, model, result*, and verbs such as *include, indicate, support, represent*). In fact, there are word lists that learners can use to acquire LSPs (Olohan 2016: 145) and to understand "academic preferences among synonyms" (Olohan 2016: 146). Word clusters (e.g. *had no effect on*) and lexical bundles, i.e. "strings of words which follow each other more frequently than expected by chance" (Hyland and Tse 2007), such as *on the other hand, in the case of, as well as, it was found that, it should be noted*, etc., are also very common in specialised discourse (Olohan 2016: 148).

To sum up, when translating scientific research articles, the translator has to understand both the science and the genre-related conventions. Moreover, the specialised translator should naturally take into account the progress of knowledge and the consequent changes in terminological, phraseological and stylistic norms and conventions.

2.3. Popular science discourse in translation

As argued at the end of the first section of this chapter, according to Calsamiglia and van Dijk (2004: 386), scientific popularisation implies a form of rewriting, reformulation and recontextualization of scientific knowledge, thus, as Gotti (2012: 148) and Manfredi (2019: 64-65) affirm, it can be conceived as a form of 'intralingual translation' in the sense meant by Jakobson (1959), i.e. the special language underlying scientific discourse is rendered into everyday language to be addressed to the general audience. Moreover, the output of rewriting is "a text that is not completely equivalent to its original and that requires recontextualisation to make it suitable for the lay public […] through additions, deletions, substitutions, rearrangements, and elaborations" (Musacchio and Zorzi 2019: 483). In so doing, as Gotti (2012: 145-146) adds, it is essential to make reference to everyday life experiences and situations, which the recipient can consider as concrete examples useful for making comparisons. The mediator should resort to discursive strategies which aim at expressing specialised knowledge in a more approximate way by using devices such as metaphors and similes, as well as at addressing information to the recipient by using second-person pronouns and multimodality (Gotti 2012: 147-151).

As Manfredi (2019: 77-79) points out, making reference to Myers (1990), popular science language differs from pure science language in the type of narrative used, i.e. respectively narrative of nature and narrative of science. Narrative of nature, on which popular science language is based, is characterised by a different text organisation established by editors, by the presence of adverbs conveying time, analogies, simple sentences, repetitions, direct quotes, questions, second-person pronouns, frame information with explanations, and by a scanty use of specialised terms and hedges. Referring particularly to online journalism, the author (Manfredi 2019: 80-81) cites Boyle (2006), who gives some advice to web science writers: it is necessary to be direct, "to 'chunkify' the story into readable 'chunks', or modules (to improve readability), and 'accessorize', with clickable boxes, sidebars and hyperlinks", which offer external references and do not weigh down the text with long explanations.

Science writers are often considered "*mere interpreters or translators* rather than 'real' writers" (Manfredi 2019: 68, quoting Ferris 2006), even though this perspective is too reductionist and has thus been questioned. Popularisation is not a mere simplification of specialised concepts, as claimed by the dominant view, but rather a particular form of communication and of 'science journalism' (Manfredi 2019: 63-68). As Garzone (2006: 83) points out, in today's society there are many political issues linked to the scientific and technological sphere, which are reported in the media to the vast public (and, in so doing, translation naturally plays a central role), that, in turn, is required to express its own opinion. For this reason, it is important that science journalists, in addition to explaining scientific facts, so to inform the public of non-experts, explain the social implications of those facts by 'selling' science (Gotti 2012: 152; Manfredi 2019: 17-19). Musacchio and Zorzi (2019: 482) indeed argue in this regard:

> […] when science brings up contentious issues, especially concerning ethics, politics and public health, other communicative purposes, closer to argumentation and persuasion, come into play along with information and entertainment. Scientific controversies, especially when their impact is perceived as relevant at the public level, emphasise the increasing awareness on the part of society at large – including public institutions, private companies, scientists themselves, and citizens – of the importance for scientists to communicate research activities and results outside specialised contexts.

Unsurprisingly, the first scientific disseminators were "scientists who travelled around to popularize their work" (Manfredi 2019: 62, quoting Nelkin 1987) in the first half of the nineteenth century, because they needed to gain notoriety due to the proliferation of specialisation and professionalisation. However, it was in the late twentieth century that scientific dissemination became popular in the media, as "newspapers, magazines and television increasingly devoted space to it" (Manfredi 2019: 63, quoting Lewenstein 1987). Manfredi (2019: 63) also cites a study (reported by Rodriguez and Dahlstrom 2018) presenting television as the medium which is mainly used by the general public to acquire scientific and technical information, while those possessing a higher level of expertise tend to prefer specialised magazines.

Therefore, as already mentioned and argued by Olohan (2016: 174-175), there are various degrees of popularisation, which comprise, as exemplified by the author, articles in popular science magazines, scientific funding proposals requiring accessible versions or summaries of applicants' research proposals, television documentaries on scientific themes, popular science news websites, science museums interactive exhibitions for children, citizen science initiatives. Manfredi (2019: 75) stresses the fact that popular science discourse is so diversified because the audience is diversified, too, and inevitably "interacts with other public discourses, whether economic, cultural or political" (Olohan 2016: 175).

For this reason, it is necessary to frame and reframe science news stories, always considering the different social and cultural contexts and agendas. In translation adjustments are of paramount importance "to situate this discourse within the different legal and ethical frameworks of the target cultures" (Olohan 2016: 198). Scientists, journalists, editors and translators are all required to consider the recipients' sense of wonder, curiosity and interest to create a "good story" (Musacchio 2017). As Musacchio (2017) affirms:

> The writer of popular science, and the translator of the same, has to ensure that the facts and narration are in tandem: facts should not overwhelm the narrative, and the narrative should not skirt around (awkward) facts. The translator has the additional responsibility of remaining faithful to the narrative and to navigate across cultural and ethical norms.

Unlike the general view, which considers popular science translation as "a special type of scientific translation, rather than as a journalistic activity", Manfredi (2019: 82-85) presents it as a form of 'interlingual translation' that has not yet been investigated in depth. In this respect, Musacchio and Zorzi (2019: 483-484, referring to Katan 2013) speak of ‘intercultural mediation’ (IT), a process “which considers the impact of cultural distance”, and is thus undertaken by press officers, journalists and translators (Olohan 2016: 177). IT includes some translation strategies, namely ‘transediting’ (i.e. “a combination of translating and editing” involving the shift from one language to another, Musacchio 2017) and ‘transcreation’, i.e. “a practice going beyond translation to recast the source text in a new language while preserving the intended content” (Musacchio 2017, quoting Pedersen 2014). Musacchio (2017) reports Stetting (1989)’s classification of the three forms of transediting:

> Cleaning-up transediting is used to make the text conform to the target language standards for the genre/text type. Situational transediting is meant to render the text maximally effective in its new context of use. Cultural transediting adapts the text to the conventions of the target language culture.

Science editors are also highly involved in the process of producing scientific writing, since their main role is to adapt what they receive from scientists and/or science writers to the readers’ degree of expertise and the standard required for publication, “setting the structure, the language and the tone” (Manfredi 2019: 73). The team of editors and subeditors (which comprises different figures, basing on the various roles and tasks accomplished) firstly examines the proposal (or draft) submitted by the science writer by offering several feedbacks and proposing adjustments. Then, a prescription containing all suggestions and improvements is sent to the science writer. Finally, when the article is considered ready to be published, the team of editors and subeditors has the task of creating the so-called ‘display type’, i.e. “headlines, captions and all peritextual elements that attract the reader’s attention into a story” (Manfredi 2019: 74, referring to DiChristina 2006), as well as of checking grammar, style, layout, and so on.

All authors mentioned above focus on written media, namely scientific news articles, which are important for translation. These deal with a wide range of topics and specialised domains, can be produced by scientific research organisations or institutions and published not only in the press, e.g. in local and national newspapers and news magazines, but also online on dedicated websites (Olohan 2016: 176-177; Manfredi 2019: 59). Popular science magazines, which “have the scope to publish feature articles, themed dossiers and other long-form writing, as well as short news reports” (Olohan 2016: 192), also issue international editions (e.g. *Scientific American/Le Scienze*) and online digital versions, to which it is possible to subscribe just as for the print version. Furthermore, Manfredi (2019: 75-76) reports Russell (2006)'s distinction between 'broadsheet' (or 'quality') newspapers, which are generally addressed to a "university-educated, typically middle-class readership", consumer magazines, which are addressed to a larger, also non-specialised audience, and more specialised science magazines, dedicated to laypeople deeply interested in the topic.

Popular science articles are mostly organised in the same way as other forms of news reporting, with headlines and standfirsts among their main typical features. The headline is basically the title of the news article, while the standfirst is defined as "a short piece of text in a newspaper article below the headline (= title) that gives the most important facts and ideas that are contained in the article that follows" by Cambridge Dictionary (2023). By analysing and comparing some popular science articles, Olohan (2016: 179) points out that the standfirst often aims at emphasising the newness of the research "but also frames the finding more positively in terms of the payoffs for the reader", i.e. the positive news. This means that the focus is generally on the utility and application of science and technology, "on the payoff rather than the methods or details of the research" (which the writer can choose to report or not later in the article) (Olohan 2016: 182), and this is particularly noticeable in standfirsts (Olohan 2016: 184). Moreover, hedging is much more present in standfirsts than in headlines, which, in turn, usually are shorter, may have an elliptical format (i.e. verbs and articles are omitted), convey snappiness by using active and imperative verbs to address the reader explicitly (Olohan 2016: 183-184) and, according to Hyland (2010), usually foreground the main claim.

As Musacchio (2017) states, headlines and standfirsts might include figurative language, puns and allusions, which often are based on cultural references, and, consequently, in these cases the most appropriate translation strategy is transcreation. Other elements representing cultural specificity, e.g. place names, institutions, proper names, measurements and currency, have to be dealt with always considering the target readership's knowledge, familiarity and conventions: sometimes, in particular when they are known internationally, they are reproduced without change in the TT, while on other occasions they are translated into the TL. The science writer or the translator can choose to add an explanation or the acronym at his/her discretion, sometimes even omitting information deemed unnecessary for the target reader (Olohan 2016: 194-197). Moreover, Manfredi (2019: 136) makes reference to the astronomy writer M. Lemonick (2006), who stresses the necessity for popular astronomy writing and translation to find a compromise between accuracy and readability, and to limit the number of omissions of facts and concepts. According to Lemonick (2006), the major challenge is indeed "to fascinate a reader who does not necessarily share the same passion for the universe".

There are cases in which the story is accompanied by images, which are generally added by subeditors for several reasons and purposes, e.g. to catch the reader's attention, as supportive device useful to provide further explanation or exemplification, as framing device to reinforce the message of the text and influence the reader's interpretation accordingly (Olohan 2016: 186). Furthermore, specialist terminology is less common in popular science texts than in pure science texts, albeit sometimes necessary (in particular in the case of texts addressed to non-experts readers possessing specialist knowledge). Unfamiliar concepts are thus explained accurately, also resorting to cohesive devices, such as repetition (Olohan 2016: 191, referring to Hyland 2010).

Since "[r]eference to experts' statements and opinion is key in science communication" (Musacchio and Zorzi 2019: 492), in Hyland (2010)'s view, quotations are one of the main features of popular science writing. According to Olohan (2016: 180-181, 185, 188), quoting scientists' and experts' voices is necessary to convey credibility, authority and objectivity, although, by making reference to the study of Sleurs et al. (2003), she recognises that sometimes quotations used in press releases are constructed by the press officer and approved by the person quoted; for this reason, they are referred to as 'pseudo-quotations'. Moreover, Olohan's analysis demonstrates that in some cases quotation marks are used within the texts for the same purposes for which quotations from experts are used, i.e. "to lend the text an impression of objectivity and credibility" (2016: 190).

As Olohan (2016: 180) explains (referring to Sleurs et al. 2003; Strobbe and Jacobs 2005), headlines, standfirsts, quotations and other textual resources are all considered 'preformulating devices', i.e. "devices used in press releases that are designed to facilitate reuse of the press release by journalists". In the case of international editions of popular science magazines, Olohan (2016: 189), Musacchio (2017) and Manfredi (2019: 115) have shown in their analyses that the STs and their translations are very similar as regards both information content and text structure and organisation, also from a graphical point of view, as all visual and peritextual elements are faithfully reproduced in the TT. However, according to Manfredi (2019: 158), whose analysis concerned a corpus of English popular science texts and their translations into Italian, Italian texts seem to be "more in line with scientific writing" because of the "cautious attitude" they convey, as well as their extensive use of nominalisation and more elaborated and explicative structures. The author (Manfredi 2019: 271-278) concludes by saying that in texts of this genre the intervention on the part of translators and editors is evident, in particular in the case of consumer magazines, also considering that Italian popular science texts tend to be much more didactic and informative than their English counterparts. Manfredi's analysis confirms that the most relevant shifts in the translation process were grammatical, rather than lexical and terminological (2019: 275). In fact, "[t]he denotational lexis of the subject matter was almost exclusively rendered with direct equivalents into the TL and sometimes it became even more specialized in the TT", so much so that "experiential, logical, interpersonal and textual meanings were the core issues of the translation", i.e. the main differences concerned the way in which the message was conveyed, and reality and interpersonal relations represented (Manfredi 2019: 272).

In addition to promoting research on popular science writing, Olohan (2016: 199-201) agrees with Myers (2003) by arguing that additional research should be made on other genres, too, such as lecture demonstrations, TV documentaries and museum exhibits, since, as already claimed, visuals are an essential element in scientific dissemination and relevant for its translation. For instance, many scientific documentary films are broadcasted internationally in languages other than the SL, which is usually English. These often rely on voice-over, a technique that allows to keep the original visual and auditory content while the original script is translated and revoiced by a dubbing artist or actor, while, in the case of intralingual versions, this is done by a more recognisable actor. Other genres that are frequently translated are research centre websites, which generally offer a multilingual version, and popular science books, which are often written by well-known scientists and researchers and have the function of communicating specialised knowledge in an entertaining way. Finally, Olohan (2016: 201) refers to some translation activities involving popular science where "scientific popularisation and volunteer translation meet", i.e. which are "generally not undertaken as professional, paid activities, but rather by translation volunteers, who may or may not be trained translators". Examples are TED initiatives and its TED Talks, that are largely disseminated online, and citizen science initiatives, such as the portal Zooniverse.

CHAPTER 3: ANALYSIS AND TRANSLATION OF CHAPTER 3 OF *ASTROPHYSICS: A VERY SHORT INTRODUCTION*

3.1. Analysis of the source text

Before moving on to the translation from English into Italian of the third chapter of *Astrophysics: A Very Short Introduction*, it is necessary to provide a brief introduction and an analysis of the ST, as well as some information about the author. The book was written on March 24, 2016 by the British astrophysicist James J. Binney, professor of physics at the University of Oxford. In addition to a number of prestigious prizes and honours (e.g. the Maxwell Prize of the Institute of Physics in 1986), in 2013 he was awarded with the Institut d'Astrophysique de Paris (IDP) medal "for his inspiring contribution to theoretical Galactic and extragalactic astrophysics" (Institut d'Astrophysique de Paris 2023). Moreover, he is a Fellow of the Royal Society (FRS), the Institute of Physics (FInstP), the Royal Astronomical Society and Merton College of Oxford (National Academy of Sciences 2023). As he claims on the website of the University of Oxford, his research interests focus on the structure, dynamics and formation of galaxies (University of Oxford – Department of Physics 2023). Professor Binney wrote a series of reference papers, articles, reviews and textbooks on the field of astrophysics, including the two bestsellers *Galactic Dynamics* and *Galactic Astronomy*, which is "amongst the top-selling astronomy textbooks", although he "had also made important contributions in domains outside astrophysics", e.g. physics of quantum mechanics by publishing a book together with David Skinner in 2008 (Institut d'Astrophysique de Paris 2023).

Furthermore, by publishing *Astrophysics: A Very Short Introduction*, he demonstrated a keen interest in scientific popularisation. The book was published by Oxford University Press (OUP) and belongs to the *Very Short Introductions* series, which began in 1995 and consists of more than 700 popular science books concerning a great variety of topics and areas of study (e.g. music, religion, psychology, history, business, politics, art, life sciences, law, etc.). The books are meant to be concise and original, but at the same time engaging, introductory guides, written in English by experts for a wide public made up of both specialists and laypeople and translated into more than forty different languages (Oxford Academic 2023). OUP (2023) describes the purpose of the book series as follows:

> These pocket-sized books are the perfect way to get ahead in a new subject quickly. Our expert authors combine facts, analysis, perspective, new ideas, and enthusiasm to make interesting and challenging topics highly readable.

The chosen one provides an authoritative introduction to astrophysics, presented by the author in the abstract available on the website of Oxford Academic (2023):

> Astrophysics is the physics of the stars and, more widely, the Universe. It explores the structure and evolution of planetary systems, stars, galaxies, interstellar gas, and the cosmos as a whole. The field has expanded rapidly in the past century, with vast quantities of data gathered by telescopes exploiting the full electromagnetic spectrum, combined with the rapid advance of computing power, allowing increasingly effective mathematical modelling. *Astrophysics: A Very Short Introduction* illustrates how the application of fundamental principles of physics—the consideration of energy and mass, and momentum—along with relativity and quantum mechanics, has provided insights into phenomena ranging from supernovae and accretion discs to pulsars and spiral galaxies.

Science writer Andrew May reviewed it in Popular Science online magazine (2023) as "an enjoyably easy read, and a long way from being a stodgy textbook". Like the other books belonging to the series, it is under 200 pages long (precisely 176), has both a paper and a digital version, and provides a table of contents, presenting the organisation of the text. More specifically, the book is divided into eight chapters, each one providing a thorough explanation of a particular phenomenon and divided into subchapters:

1. Big ideas
2. Gas between the stars
3. Stars
4. Accretion
5. Planetary Systems
6. Relativistic astrophysics
7. Galaxies
8. The big picture

In addition, there is a List of illustrations (numbered consecutively and with source reference) and an Index with the technical terms used (with page reference), along with Further reading, i.e. a series of books recommended by the author to delve deeper into each of the topics treated in chapters 2 to 7.

By briefly outlining the content of each chapter of the book, ‘Big ideas’ introduces Newton’s physical laws, which laid the foundations of astrophysics and are valid in every part of the Universe and at all time to explain the origin and evolution of celestial objects and phenomena. These gave rise to three important conserved quantities: momentum, angular momentum, and energy (Oxford Academic 2023). ‘Gas between the stars’ “describes interstellar absorption and the reddening of stars—when dust grains in the gas [mostly hydrogen and helium] absorb blue and ultraviolet light, but let red light from the Sun pass through” (Oxford Academic 2023). As its name suggests, chapter 3 focuses on stars’ lifecycles from birth, i.e. their formation caused by a cloud of interstellar gas suffering a runaway of its central density, to death, i.e. when the star burns all the helium in its core and explodes giving rise to other celestial bodies, e.g. black holes, neutron stars, etc (Oxford Academic 2023). “‘Accretion’ describes accretion discs including basic disc dynamics, accretion onto stellar-mass objects, and quasars, and goes on to consider jets, which carry material away from the accreting object extremely supersonically” (Oxford Academic 2023). ‘Planetary systems’ explains how planetary systems (also the extra-solar) formed “by the collision of asteroids to form bigger and bigger asteroids”, and evolved (Oxford Academic 2023). ‘Relativistic astrophysics’ outlines Einstein’s relativity theory “and lists some situations where this theory is needed: radio galaxies, micro-quasars, gamma rays, cosmic rays, neutron stars, x-ray sources, the solar system, and the universe. It goes on to explain muon lifetimes, rest-mass energy, plasma jets, shocks and particle acceleration, and synchrotron radiation” (Oxford Academic 2023). Chapter 7 focuses on galaxies, consisting of “a huge number of point masses—stars and dark matter—that move freely in the gravitational field that they jointly generate”, whose nature is largely determined by its luminosity and environment (Oxford Academic 2023). Lastly, ‘The big picture’ illustrates the main discoveries about the Universe, namely its geometry and dynamics, that were made possible thanks to general relativity, together with the main challenge concerning its secrets. In fact, as the author argues, “we are far from understanding how the various processes played out” and “we have much, much more to learn” (Oxford Academic 2023).

By focusing specifically on 'Stars', the chapter for which a translation into Italian will be provided in this thesis, it is divided into fourteen subsections, namely 'Star formation', 'Nuclear fusion', 'Key stellar masses', 'Life after the main sequence, 'The surfaces of stars', 'Stellar coronae', 'Exploding stars', 'Core-collapse supernovae', 'Deflagration supernovae', 'Testing the theory', 'Globular star clusters', 'Solar neutrinos', 'Stellar seismology', and 'Binary stars'. Furthermore, there are nine figures that accompany the text, including space pictures and diagrams, which are used in this case as supportive device, useful to provide further explanation or exemplification of concepts and procedures to the reader.

From a lexical point of view, the author makes use of terms belonging to the domains of astronomy, physics, cosmology and chemistry, which in some cases are marked through italics (which is also used as emphasis marker, e.g. "The sudden release of energy by all this burning *does* produce enough pressure to overwhelm gravity and the star flies apart, leaving no gravitationally bound object where it was") and are explained through parenthesis (e.g. "The restructuring of the envelope into a bloated convective mass enlarges the star's photosphere, the sphere that emits most of the star's light") or cataphoric reference (e.g. "Stars with initial mass smaller than 0.08 $M_\odot$ only get hot enough to burn deuterium to helium. Deuterium is an isotope of hydrogen in which the nucleus consists of a proton bound to a neutron rather than a lone proton"). Another strategy employed by the author is to first provide the explanation and then enclose the specialised term in brackets, as in the following example: "To this day our most important probes of the universe are telescopes that gather either visible photons or photons with only slightly longer wavelengths (infrared photons)".

Moreover, concepts that are more difficult to understand for the lay audience are generally explained through examples of everyday life (e.g. "The energy scale of nuclear reactions is a million times larger than that of the chemical reactions that power our bodies and our cars", "Moreover, the luminosity of the star, and therefore radiation pressure grows as the quantity of gas that is blanketing the intensely hot core diminishes—the star's loft insulation is disappearing") or approximation (e.g. "To a first approximation, a star is a black body and emits black-body radiation at the temperature of its photosphere").

However, there are cases in which the author does not provide an explanation of the specialised information, as happens in the following examples for the technical terms ‘quiescent’, ‘heavy water’, ‘half life’ and ‘function of time’: “In stars more massive that ~ 2 M⊙ the ignition is quiescent, but in less massive stars the helium ignites explosively and we speak of the *helium flash*”, “From the mid-1980s two huge neutrino detectors were built that use either water (H2O) or heavy water (D2O) as the detector”, “A significant part of the dispersed material of the star consists of a highly radioactive isotope of nickel (^{56}Ni) which has a half life of 6.1days”, “This theft causes both stars to deviate from the evolutionary path we have described for single stars because mass is a key determinant of stellar evolution, and now each star’s mass has become a function of time”.

Furthermore, Binney uses several devices, such as figurative language, i.e. similes (e.g. “We detect about a billion stars individually, as tiny unresolved points of light”, “Stars like bells have natural frequencies at which they can oscillate”, “These are a little like ocean waves […]”) and metaphors (e.g. “So the release of energy by nuclear reactions in the core of a cloud is a game changer”, “This theft causes both stars to deviate from the evolutionary path we have described for single stars […]”), as well as second person pronouns (e.g. “When you heat a piece of metal strongly, it first glows dull red, then becomes yellow and white, and if you could raise its temperature even further it would glow blue”) to address readers more directly, and first person plural pronouns (e.g. we discuss, we shall see, we speak of, we saw above) to better involve his public. Lexical repetition also occurs very frequently in order to avoid ambiguity as much as possible (e.g. “[…] its central temperature rises, and this rise in temperature soon proves fatal for the star—it suddenly blazes up into fireball and becomes a supernova” or “Similarly, as gravity compresses the gas of a collapsing cloud, work is done on the gas and the gas will warm if it cannot radiate the newly acquired energy”).

Although the wide use of specialised terms, the register can be considered at times informal, due to the presence of contractions (e.g. “[…] neutrinos produced by the fusion of protons don’t have enough energy to transmute Cl into Ar; the more energetic neutrinos Davis hoped to detect came from other reactions whose rates are very temperature sensitive, and don’t produce much of the Sun’s energy”), colloquialisms (e.g. “[…] the atoms whizz about faster and faster and the violence of their collisions steadily increases.

Electrons are knocked clean out of atoms so more and more nuclei become bare" or "Massive stars are spendthrifts: the bigger the inheritance of fuel they have at birth, the sooner they are bankrupt by virtue of having consumed that fuel"), rhetorical questions (e.g. "So what heats the corona? Outer space?"), attitude markers (e.g. "Then, astonishingly, it starts to rise […]", "[…] this is a stupendously big atomic nucleus that's seriously neutron-rich", "Remarkably, general relativity predicts that pressure is itself a source of gravity, […]"), implicit dialogue forms (e.g. "Now let's take a look at how stars work"). All these tools are useful to make the text much more expressive, so to engage the audience more effectively.

Syntactically speaking, the text presents mainly a paratactic, expositive structure, characterised by a shorter sentence length, which can help readers correctly understand scientific facts and information. Furthermore, active and passive verbs seem to recur with the same frequency: the former appear especially in sentences characterised by the presence of first person plural, while the latter when procedures are described. The active voice is used by Binney both to address the reader explicitly (e.g. "[…] we shall see, however, that small star clusters are not stable and tend to evolve into a binary and a series of single stars") and to refer to the community of astronomers and astrophysicists as a whole, naturally including himself (e.g. "We think most of the star's mass is ejected into interstellar space leaving only a black hole as marker of the star's existence"). When the passive voice is used, the agent is almost always specified to convey information more thoroughly, as it can be noticed in the following sentence: "After the density has increased by an enormous factor, of an order of a million million (1012), photons emitted by atoms and molecules start to have trouble escaping from the cloud because they are scattered by molecules and dust grains after going only a small distance through the dense mass of gas and dust".

3.2. Final translation

Chapter 3

Capitolo 3

Stars

To this day our most important probes of the universe are telescopes that gather either visible photons or photons with only slightly longer wavelengths (infrared photons). At these wavelengths the night sky is entirely dominated by stars. We detect about a billion stars individually, as tiny unresolved points of light, and a billion billion more as contributors to the light coming from galaxies so distant that we cannot distinguish individual stars in the great agglomerations of stars that galaxies are.

Le stelle

Ad oggi i principali strumenti che ci permettono di sondare l'Universo sono telescopi che raccolgono sia i fotoni visibili sia quelli che possiedono lunghezze d'onda solo leggermente superiori (fotoni infrarossi). A queste lunghezze d'onda il cielo notturno è interamente dominato dalle stelle. Riusciamo a rilevare circa un miliardo di stelle individualmente, simili a minuscoli punti di luce perpetui, e un altro miliardo di miliardi di stelle che contribuiscono alla luce proveniente da grandi agglomerati, chiamati galassie, che sono talmente distanti da non permetterci di distinguere le singole che li costituiscono.

So most of what we know about the Universe has been gleaned from a study of stars, and one of the major achievements of 20th-century science was to understand how stars work, and to understand their life-cycles from birth to death.

Gran parte di ciò che sappiamo sull'Universo è dovuta allo studio delle stelle ed una delle maggiori conquiste della scienza del XX secolo è stata quella di comprendere il loro funzionamento e i loro cicli di vita dalla nascita alla morte.

Star formation

Stars form when a cloud of interstellar gas suffers a runaway of its central density as discussed at the end of Chapter 2. After the density has increased by an enormous

La formazione delle stelle

Le stelle si formano quando una nube di gas interstellare subisce un aumento incontrollato della sua densità centrale, come spiegato alla fine del Capitolo 2. A factor, of an order of a million million (1012), photons emitted by atoms and molecules start to have trouble escaping from the cloud because they are scattered by molecules and dust grains after going only a small distance through the dense mass of gas and dust. When you pump up your bicycle tyres, the pump becomes warm from the work you do compressing air inside it.

seguito dell'aumento di densità di un fattore enorme, dell'ordine di un milione di milioni (1012), i fotoni emessi dagli atomi e dalle molecole iniziano ad avere difficoltà ad uscire dalla nube poiché, dopo aver percorso solo una breve distanza all'interno di questa densa massa di gas e polvere, vengono dispersi da molecole e grani di polvere. Quando gonfiate i pneumatici della vostra bicicletta, la pompa si riscalda a causa del lavoro di compressione dell'aria al suo interno.

Similarly, as gravity compresses the gas of a collapsing cloud, work is done on the gas and the gas will warm if it cannot radiate the newly acquired energy. Once photons find it difficult to escape from the cloud, the work done by compression cannot be radiated in a timely manner and the temperature begins to rise. However, even as the temperature and pressure rise at the centre of the cloud, the crushing force of gravity increases too as more and more gas falls onto the core of the cloud. The consequence is a prolonged period of rising central temperature and density. If a cloud is sufficiently massive, the temperature and density are eventually sufficient to ignite *nuclear burning*, energy release by transmuting hydrogen to helium, and then helium nuclei into

Allo stesso modo, la compressione del gas di una nube in collasso gravitazionale produce lavoro e il gas si riscalda nel momento in cui non riesce ad irradiare l'energia appena acquisita. Quando i fotoni hanno difficoltà a uscire dalla nube, l'energia generata dal lavoro non può essere irradiata tempestivamente e la temperatura comincia ad aumentare. Tuttavia, anche se la temperatura e la pressione aumentano al centro della nube, aumenta anche l'azione comprimente della forza di gravità, poiché sempre più gas cade sul nucleo della nube. Ne consegue un prolungato periodo di aumento della temperatura e della densità centrali. Se una nube è sufficientemente massiccia, riesce prima o poi, attraverso la sua temperatura e la sua densità, ad heavier nuclei such as carbon, silicon and iron. We discuss nuclear burning below.

innescare la *fusione nucleare*, con emissione di energia mediante la trasmutazione dell'idrogeno in elio e, successivamente, dei nuclei di elio in nuclei di elementi più pesanti come carbonio, silicio e ferro. Spieghiamo ora come avviene la fusione nucleare.

When an interstellar cloud suffers a runaway increase in its density, it does not form one star but a whole group of stars. We do not understand completely this process of fragmentation, but it is an important empirical fact. Within the deforming interstellar cloud several regions of runaway density arise, each capable of seeding a star. The rates at which these seeds accumulate mass varies greatly, with the result that a few give rise to massive stars and many give rise to low-mass stars. The most massive stars have masses $\sim 80M_\odot$, and the masses of stars extend down to below the mass $\sim 0.01M_\odot$ at which a star is too faint to detect at any point in its life.

Quando una nube interstellare subisce un aumento incontrollato della sua densità, non forma una sola stella, ma un intero gruppo di stelle. Non comprendiamo completamente questo processo di frammentazione, tuttavia è un importante fatto empirico. All'interno della nube interstellare in fase di deformazione, si formano diverse regioni di densità crescente, ognuna delle quali in grado di originare una stella. La velocità con cui questi 'semi' accumulano massa varia notevolmente, con il risultato che alcuni danno origine a stelle massive e molti altri a stelle di piccola massa. Le stelle più massive hanno masse di $\sim 80M_\odot$ (masse solari). Le masse delle stelle possono estendersi fino a valori inferiori a $\sim 0{,}01M_\odot$, non permettendo la rilevazione della stella in alcun momento della sua vita, a causa della sua scarsa luminosità.

Since the original cloud was a heaving, swirling mass of gas, the seeds move with respect to one another. One aspect of this motion is that one seed will get in the way

Il fatto che la nube originaria fosse una massa di gas densa e turbolenta porta i semi a muoversi l'uno rispetto all'altro. Un aspetto di questo moto è che un seme si of gas falling onto another seed, so augmenting its own growth and suppressing that of its neighbour. Another aspect of the relative motion is that seeds often go into orbit one around another to form a binary star.

Elsewhere whole groups of seeds go into orbit around each other to form a gravitationally bound cluster of stars. In Chapter 7, 'Slow drift', we shall see, however, that small star clusters are not stable and tend to evolve into a binary and a series of single stars.

As the seeds accumulate mass and begin to resemble stars, their nuclear energy output becomes more and more significant for gas in the lower density parts of the original cloud. The more massive stars start to radiate ultraviolet photons, which heat low-density gas as we saw on page 13. In Chapter 4 we shall see that young stars are surrounded by bodies of orbiting gas called accretion discs, and that these discs eject jets of gas along their spin axes. These jets slam into and heat diffuse gas in the neighbourhood. The upshot of all this activity by young stars is that quite soon after the density in a cloud runs away at specific locations, most of the cloud's gas is heated up and driven away.

frapporrà al gas che cade su un altro seme, aumentando così la propria crescita e sopprimendo quella del seme vicino. Un altro aspetto del moto relativo è che spesso i semi entrano in orbita uno attorno all'altro, formando una stella binaria.

In altri casi, interi gruppi di semi entrano in orbita uno attorno all'altro per formare un ammasso di stelle legato gravitazionalmente. Nella sezione intitolata 'Lenta deriva' del Capitolo 7, vedremo, tuttavia, che i piccoli ammassi stellari non sono stabili e tendono a evolvere in una stella binaria e una serie di stelle singole.

Man mano che i semi accumulano massa e cominciano a somigliare a delle stelle, la loro produzione di energia nucleare diventa sempre più significativa per il gas nelle parti a bassa densità della nube originaria. Le stelle più massive iniziano ad irradiare fotoni ultravioletti, che riscaldano il gas a bassa densità, come abbiamo visto a pagina 13. Nel Capitolo 4, vedremo che le stelle giovani sono circondate da formazioni di materiale gassoso in orbita, ovvero i dischi di accrescimento, i quali emettono getti di gas lungo i loro assi di rotazione. Questi getti colpiscono il gas diffuso nelle vicinanze e lo riscaldano. Il risultato di tutta questa attività svolta dalle stelle

Consequently, from a cloud containing, say, 10 4 M⊙ of gas, only ∼ 100 M⊙ of stars will form. This low *efficiency of star formation* enables galaxies like our own to go on forming stars at a fairly steady rate throughout the age of the Universe because it implies a low rate of conversion of interstellar gas into stars.

giovani è che non appena la densità in una nube aumenta in alcuni suoi specifici punti, la maggior parte del gas al suo interno viene riscaldato e spinto via. Di conseguenza, da una nube contenente, ad esempio, 10^4 M⊙ di gas, si formeranno solo ∼ 100 M⊙ di stelle. Questa bassa *efficienza nella formazione stellare* consente a galassie come la nostra di continuare a formare stelle a un ritmo abbastanza costante durante tutta la vita dell'Universo, poiché implica un basso tasso di conversione del gas interstellare in stelle.

Nuclear fusion

Atoms consist of a tiny positively charged nucleus surrounded by one or more electrons that move on orbits that take them − 10 −10 m from the nucleus. Nearly all the atom’s mass is contained in the nucleus, which is only ∼ 10 −15 m across. When two atoms collide, the orbits of the electrons deform so the distribution of negative charge surrounding each nucleus changes, and the nuclei experience electrostatic forces that deflect them from their original straight-line trajectories. The upshot is that even a head-on collision of two atoms is unlikely to lead to a collision of the nuclei themselves because their velocities will be reversed by electrostatic forces before the nuclei have a chance to

La fusione nucleare

Gli atomi sono costituiti da un minuscolo nucleo con carica positiva circondato da uno o più elettroni che si muovono su orbite che li portano a una distanza di circa 10^{-10} m dal nucleo. Quasi tutta la massa dell'atomo è contenuta nel nucleo, il cui diametro misura soli ∼ 10^{-15} m. Quando due atomi si scontrano, le orbite degli elettroni si deformano, variando la distribuzione della carica negativa attorno a ciascun nucleo. Di conseguenza, i nuclei subiscono forze elettrostatiche che li deviano dalla loro traiettoria rettilinea originale. Il risultato è che anche una collisione frontale tra due atomi difficilmente porterà alla collisione dei loro nuclei, poiché le loro velocità saranno come into contact. In a sense an atom's electrons provide a sophisticated anti-shock packaging for the nucleus that carefully protects the nucleus in all but the most extreme collisions.

invertite dalle forze elettrostatiche prima che i nuclei abbiano la possibilità di entrare in contatto. In un certo senso, gli elettroni di un atomo forniscono al nucleo un sofisticato imballaggio antiurto, che lo protegge attentamente in tutte le collisioni, eccetto quelle più estreme.

As the temperature rises at the centre of a forming star, the atoms whizz about faster and faster and the violence of their collisions steadily increases. Electrons are knocked clean out of atoms so more and more nuclei become bare. Still colliding nuclei are unlikely to come into physical contact because, as positively charged bodies, they repel one another electrostatically. But eventually the collisions are so violent that some colliding nuclei actually touch. At this point nuclear reactions start to take place.

Quando la temperatura al centro di una stella che si sta formando aumenta, gli atomi sfrecciano sempre più velocemente e la violenza delle loro collisioni aumenta con costanza. Gli elettroni vengono letteralmente spazzati via dagli atomi, quindi sempre più nuclei ne vengono privati. Nonostante ciò, i nuclei che si scontrano difficilmente entrano in contatto fisico perché, essendo corpi carichi positivamente, si respingono elettrostaticamente. Tuttavia, ad un certo punto, le collisioni diventano così violente che alcuni nuclei in collisione arrivano a toccarsi ed iniziano a verificarsi le reazioni nucleari.

The energy scale of nuclear reactions is a million times larger than that of the chemical reactions that power our bodies and our cars. So the release of energy by nuclear reactions in the core of a cloud is a game changer. The density is soon stabilized at the value at which nuclear reactions release energy at just the rate at which heat diffuses outwards through the

La scala di energia delle reazioni nucleari è un milione di volte più grande di quella delle reazioni chimiche che alimentano i nostri corpi e le nostre automobili. Pertanto, il rilascio di energia nel nucleo di una nube da parte delle reazioni nucleari segna un punto di svolta. La densità si stabilizza rapidamente al valore in cui le reazioni nucleari rilasciano now massive overlying envelope of gas; if the rate of energy release is slightly lower than the rate of outward leakage, the central pressure falls, the core collapses, the temperature and density rise, and so does the rate of nuclear reactions. Conversely, if nuclear reactions are releasing energy faster than it can diffuse outwards, the central pressure rises, the core expands, the temperature falls and so does the nuclear reaction rate. Thus nuclear energy release makes a star an inherently stable mechanism.

energia alla stessa velocità con cui il calore si diffonde verso l'esterno attraverso l'ormai imponente involucro di gas sovrastante; se il tasso di rilascio di energia è leggermente inferiore al tasso di perdita verso l'esterno, la pressione centrale diminuisce, il nucleo collassa, la temperatura e la densità aumentano, così come il tasso di reazioni nucleari. Al contrario, se le reazioni nucleari rilasciano energia più rapidamente di quanto essa possa diffondersi verso l'esterno, la pressione centrale aumenta, il nucleo si espande, la temperatura diminuisce e così anche il tasso di reazioni nucleari. Il rilascio di energia nucleare rende quindi una stella un meccanismo intrinsecamente stabile.

Key stellar masses

A star more massive than 0.08 $M_\odot$ now settles to the business of nuclear burning. Stars more massive than 0.08 $M_\odot$ but less massive than $\sim 0.5 M_\odot$ burn hydrogen to helium but cannot ignite helium. Stars with initial masses in the range $0.5 - 8 M_\odot$ burn hydrogen and then helium, but cannot ignite carbon. Stars initially more massive than 8 $M_\odot$ but less massive than $\sim 50 M_\odot$ burn carbon to silicon and then silicon to iron. Iron nuclei are the most tightly bound so no energy can be obtained by transmuting iron into any

La massa delle stelle

Una stella con massa superiore a 0,08 $M_\odot$ raggiunge una temperatura tale da innescare reazioni di fusione nucleare. Le stelle con massa maggiore di 0,08 $M_\odot$ ma inferiore a $\sim$ 0,5 $M_\odot$ bruciano l'idrogeno trasformandolo in elio ma non possono innescare la sua fusione. Le stelle con masse iniziali comprese tra 0,5 e 8 $M_\odot$ bruciano l'idrogeno e, successivamente, l'elio, ma non possono innescare la fusione del carbonio. Le stelle con massa iniziale maggiore di 8 $M_\odot$ ma inferiore a $\sim$ 50 $M_\odot$ bruciano il carbonio other element—iron nuclei constitute nuclear ash.

trasformandolo in silicio, la cui successiva fusione conduce alla produzione di ferro. I nuclei di ferro sono quelli più strettamente legati, quindi non è possibile ottenere energia trasmutando il ferro in qualsiasi altro elemento: i nuclei di ferro costituiscono la cenere nucleare.

Stars more massive than 50 M⊙ become unstable and explode before they have reached the stage of silicon burning. We know they become unstable, but are not certain what the final outcomes of these instabilities are. We think most of the star's mass is ejected into interstellar space leaving only a black hole as marker of the star's existence.

Le stelle con massa superiore a 50 M⊙ diventano instabili ed esplodono prima di raggiungere la fase di fusione del silicio. Sappiamo che diventano instabili, ma non sappiamo con certezza quali siano i risultati finali di tali instabilità. Riteniamo che la maggior parte della massa della stella venga espulsa nello spazio interstellare, lasciando solo un buco nero come segno dell'esistenza della stella.

Stars with initial mass smaller than 0.08 M⊙ only get hot enough to burn deuterium to helium. Deuterium is an isotope of hydrogen in which the nucleus consists of a proton bound to a neutron rather than a lone proton. Deuterium like hydrogen was created in the Big Bang and is destroyed in stars. It is ~ 10 −5 times less abundant than ordinary hydrogen, so it does not take long for a star to exhaust this fuel. An object that is only burning deuterium is called a brown dwarf. When the deuterium is consumed the object will cool to become an almost undetectable black dwarf.

Le stelle con massa iniziale inferiore a 0,08 M⊙ raggiungono una temperatura appena sufficiente per permettere di innescare la fusione del deuterio in elio. Il deuterio è un isotopo dell'idrogeno in cui il nucleo è composto da un protone legato a un neutrone, piuttosto che solo da un protone. Il deuterio, proprio come l'idrogeno, si è formato nel Big Bang e viene distrutto nelle stelle. La sua quantità è di circa 10^{-5} volte inferiore rispetto all'idrogeno ordinario, quindi una stella riesce ad esaurire questo combustibile in un lasso di tempo molto breve. Un oggetto celeste che brucia solo deuterio è chiamato nana bruna. Quando il deuterio sarà esaurito, l'oggetto si raffredderà diventando una nana nera quasi impossibile da rilevare.

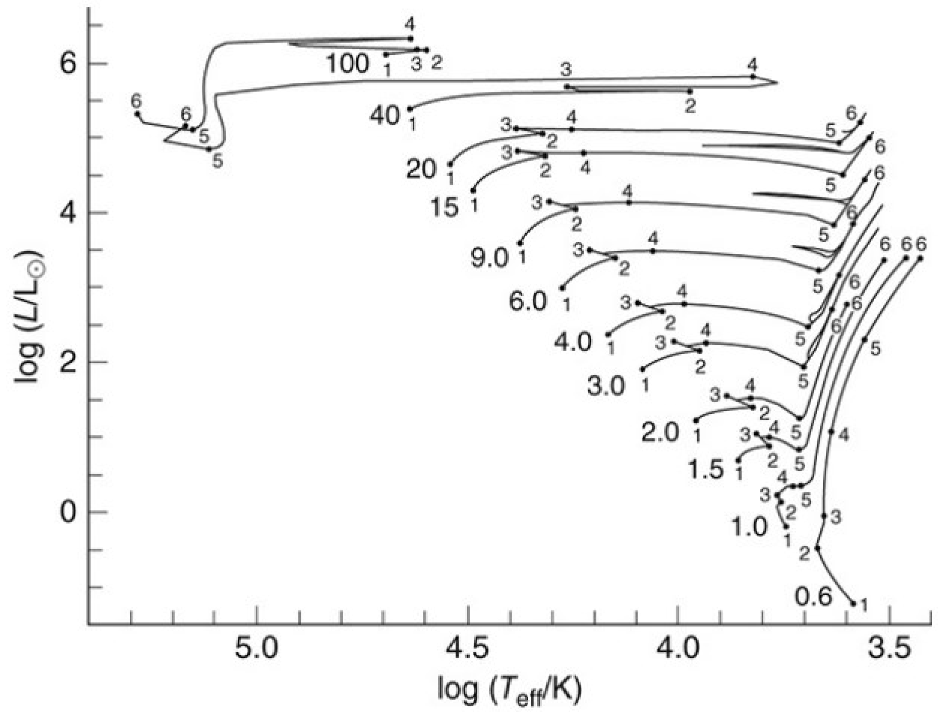
The main phase in the life of a star more massive than $0.08 M_{\odot}$ is the burning of hydrogen in its core. Since three quarters of the original interstellar cloud comprised hydrogen, in this stage there is lots of fuel to burn, and, as a bonus, more energy per nucleon (a neutron or proton) is released when hydrogen is burnt than when any other nuclear fuel is burnt. The Sun has been burning hydrogen in its core for 4.6 Gyr and it is only half way through the process. For reasons that will become apparent when star clusters are discussed in Chapter 3, ‘Testing the theory’, we call a star that’s burning the hydrogen in its core a *main-sequence star* (Figure 3).

La fase principale della vita di una stella con massa superiore a 0,08 $M_{\odot}$ è la fusione dell'idrogeno nel suo nucleo. Poiché tre quarti della nube interstellare originaria erano costituiti da idrogeno, in questa fase c'è molto combustibile da bruciare e, come bonus, viene rilasciata più energia per nucleone (un neutrone o un protone) quando viene bruciato l'idrogeno rispetto a qualsiasi altro combustibile nucleare. Il Sole sta bruciando idrogeno nel suo nucleo da 4,6 miliardi di anni ed è solo a metà del processo. Per ragioni che diventeranno più chiare quando parleremo di ammassi stellari nella sezione ‘Test della teoria’ del presente capitolo, chiamiamo una stella che sta bruciando l'idrogeno nel suo nucleo una *stella di sequenza principale* (Figura 3).

The more massive a star is, the more quickly it depletes its stock of core hydrogen and the shorter its main-sequence lifetime. Massive stars are spendthrifts: the bigger the inheritance of fuel they have at birth, the sooner they are bankrupt by virtue of having consumed that fuel. Figure 3 quantifies this fact by showing the luminosities of stars of

Più una stella è massiva, più rapidamente esaurisce le sue scorte di idrogeno all’interno del suo nucleo e più breve è la sua permanenza nella sequenza principale. Le stelle massive sono spendaccione: maggiore è l'eredità di combustibile che hanno alla nascita, prima lo esauriscono consumandolo tutto. La figura 3 quantifica questo fatto mostrando la luminosità di different masses as functions of surface temperature. During its main-sequence phase a star moves between the dot at the left end of its curve in this diagram and the point on the curve marked ‘2’. The big numeral gives the star’s mass in solar masses. The vertical scale is logarithmic so there is a factor of a million in luminosity between the mainsequence points of stars with masses 0.6M? and 20 M⨀. Consequently, while a star of mass 0.6 M⨀ will remain on the main sequence for 78Gyr, nearly six times the age of the universe, a 20 M⨀ star will be on the main sequence for just 8.5Myr.

stelle di massa differente in funzione della temperatura superficiale. Durante la fase di sequenza principale, una stella si sposta tra il punto situato all'estremità sinistra della sua curva in questo diagramma e il punto sulla curva contrassegnato con ‘2’. Il numero grande indica la massa della stella calcolata in masse solari. La scala verticale è logaritmica, quindi c'è un fattore di un milione nella luminosità tra i punti di sequenza principale di stelle di massa 0,6M? e 20 M⨀. Di conseguenza, mentre una stella di massa 0,6 M⨀ permarrà nella sequenza principale per 78 miliardi di anni, quasi sei volte l'età dell'Universo, una stella di 20 M⨀ permarrà in questa fase di stabilità per soli 8,5 milioni di anni.



3. Luminosity plotted vertically in units of the luminosity of the sun as a function of surface temperature in degrees K for stars of various initial masses. The large number at the left end of each curves give the mass of a star in units of the solar mass M⨀. While on the main sequence a star sits near the dot at the left end of its curve. It moves away from this dot when it has converted most of its core hydrogen to helium.

Figure 3 quantifies another key fact: the surface temperature of a main-sequence

3. Luminosità rappresentata verticalmente in unità della luminosità del Sole in funzione della temperatura superficiale in gradi K per stelle di varie masse iniziali. Il numero grande all'estremità sinistra di ciascuna curva indica la massa di una stella in unità di massa solare M⨀. Quando è nella sequenza principale, una stella si trova vicino al punto all'estremità sinistra della sua curva. Si allontana da questo punto quando ha convertito la maggior parte dell'idrogeno del suo nucleo in elio.

La Figura 3 quantifica un ulteriore dato fondamentale: la temperatura superficiale star increases with its mass. So massive stars are luminous, hot, and have short lives, while low-mass stars are faint, cool, and have long lives. When you heat a piece of metal strongly, it first glows dull red, then becomes yellow and white, and if you could raise its temperature even further it would glow blue. Hence hot stars are blue while cool stars are red. Figure 3 shows that all blue stars are massive, and we have seen that massive stars have short lives. So blue stars are always young.

di una stella di sequenza principale aumenta con la sua massa. Pertanto, le stelle massive sono luminose e calde ed hanno una vita breve, mentre le stelle di piccola massa sono poco luminose e fredde ed hanno una vita lunga. Se riscaldate un pezzo di metallo a temperatura elevata, prima questo comincia a brillare di un rosso opaco, poi diventa giallo e bianco e, se la sua temperatura venisse ulteriormente aumentata, brillerebbe di blu. Per questo motivo le stelle calde sono blu, mentre quelle fredde sono rosse. La figura 3 mostra che tutte le stelle blu sono massive, e abbiamo visto che le stelle massive hanno una vita breve. Quindi le stelle blu sono sempre giovani.

The link between the colours and temperatures of stars reflects an important piece of physics. A *black body* absorbs any photon that hits it and emits a characteristic spectrum of radiation that depends only on the body's temperature and not on what the body is made of. Radiation with this spectrum is called *black-body radiation*. To a first approximation, a star is a black body and emits black-body radiation at the temperature of its photosphere.

Il nesso tra i colori e le temperature delle stelle riflette un importante concetto della fisica. Un *corpo nero* assorbe qualsiasi fotone che lo colpisce ed emette uno spettro caratteristico di radiazioni che dipende solo dalla temperatura del corpo e non dalla sua composizione. La radiazione con questo spettro è chiamata *radiazione di corpo nero*. In prima approssimazione, una stella è un corpo nero ed emette radiazione di corpo nero alla temperatura della sua fotosfera.

Life after the main sequence

Once the hydrogen in a star's core has been consumed, hydrogen burning occurs in a spherical shell around the helium core and the core grows more massive, contracts and becomes hotter. In Figure 3 the star moves rather rapidly from point 2 to point 6 on its track, and we see that during this manoeuvre the luminosity increases, while the surface temperature falls. The rise in luminosity is most dramatic for low-mass stars, which have low main-sequence luminosities, and the decline in surface temperature is most pronounced for massive stars, which have high main-sequence temperatures. In fact, stars that have reached point 6 on their tracks all have rather similar temperatures, 2,000 K.

La fase post-sequenza principale

Dopo che la stella ha consumato l'idrogeno nel nucleo, l'idrogeno comincia a fondere in uno strato sferico che circonda il nucleo di elio. Di conseguenza, il nucleo si contrae e diventa più caldo e massiccio. Nella Figura 3 vediamo che la stella si sposta piuttosto rapidamente dal punto 2 al punto 6 della sua traiettoria e che, durante questa manovra, la luminosità aumenta, mentre la temperatura superficiale diminuisce. L'aumento della luminosità è più evidente nel caso di stelle di piccola massa, che hanno una bassa luminosità nella sequenza principale, mentre la diminuzione della temperatura superficiale è più pronunciata per le stelle massive, che hanno alte temperature nella sequenza principale. Di fatto, le stelle che hanno raggiunto il punto 6 della loro traiettoria hanno tutte temperature piuttosto simili, pari a 2.000 K.

The reason the surface temperature drops as the luminosity rises, is that the increased flux of nuclear energy flowing from the hydrogen-burning shell puffs the star's enveloping gas into a bloated heaving body of gas in which energy is less transported by outward diffusion of photons that by convection. Convection is the process by which radiators heat rooms:

Il motivo per cui la temperatura superficiale cala all'aumentare della luminosità è che il maggior flusso di energia nucleare prodotta dal guscio che brucia l'idrogeno fa sì che il gas che avvolge la stella si espanda in una densa e grande massa di gas, in cui l'energia viene trasportata più per convezione, meno attraverso la diffusione dei fotoni verso hot air that has been in contact with the radiator rises, and is replaced by cooler air that falls down surfaces such as window glass and external walls that are unusually cool. The restructuring of the envelope into a bloated convective mass enlarges the star's photosphere, the sphere that emits most of the star's light. The swollen photosphere can radiate even the increased luminosity at a lower temperature than before. Since main-sequence stars are smaller than they will become once they have depleted their core hydrogen, they are called *dwarf stars*, and they will evolve into *red giant stars*.

l'esterno. La convezione è il processo con cui i termosifoni riscaldano le stanze: l'aria calda che è stata a contatto con il termosifone sale e viene sostituita da aria più fredda che scende lungo superfici particolarmente fredde, come i vetri delle finestre e le pareti esterne. La riorganizzazione dell'involucro in una massa convettiva più rigonfia ingrandisce a sua volta la fotosfera della stella, la sfera che emette la maggior parte della sua luce. La fotosfera allargata riesce ad irradiare anche la maggiore luminosità a una temperatura inferiore rispetto a prima. Dato che le stelle di sequenza principale, che non hanno ancora esaurito l'idrogeno all'interno del proprio nucleo, sono più piccole, vengono chiamate *stelle nane*. Quando avranno esaurito queste scorte di idrogeno, si evolveranno in *stelle giganti rosse*.

At the point 6 in Figure 3 the helium in the star's core ignites. In stars more massive that ~ 2 M⊙ the ignition is quiescent, but in less massive stars the helium ignites explosively and we speak of the *helium flash*. The energy released in the flash causes the star's envelope to pulse violently and a significant portion of the envelope is ejected back to interstellar space. In stars more massive than 2 M⊙

Al punto 6 mostrato nella Figura 3 avviene l'accensione dell'elio nel nucleo della stella. Nelle stelle di massa superiore a ~ 2 M⊙ questa avviene in modo quiescente, più graduale, ma nelle stelle meno massicce l'elio brucia generando un'esplosione, chiamata *flash dell'elio*. L'energia rilasciata nel flash fa sì che l'involucro della stella pulsi violentemente, causando l'espulsione the regulatory mechanism described on page 25 functions properly and helium burning starts quietly. The onset of core helium burning causes the luminosity to drop slightly and the star to become slightly bluer.

nello spazio interstellare di una buona parte dell'involucro. Nelle stelle con massa superiore a 2 M⨀ il meccanismo di regolazione descritto a pagina 25 funziona correttamente e dà avvio ad un periodo di tranquilla combustione dell'elio nel nucleo, che rende la stella leggermente più blu e meno luminosa.

The period of a star's life during which it quietly burns its core helium is the second most extensive period after that of the main sequence. Stars with initial masses up to 2.5 M⨀ all spend ~ 130 Myr in this phase. At higher masses the duration of this period decreases rapidly with mass, and for a 20 M⨀ star it is a mere 0.6 Myr.

Inoltre, questo periodo corrisponde alla fase più lunga dopo quella di sequenza principale. Le stelle con masse iniziali fino a 2,5 M⨀ trascorrono tutte ~ 130 milioni di anni in questa fase. In caso di masse superiori, la durata di tale fase diminuisce rapidamente in relazione alla massa, tant'è che per una stella di 20 M⨀ è di soli 0,6 milioni di anni.

Once the core helium has been burnt, helium burning shifts to a shell around the carbon core, beyond which hydrogen burning continues is an outer shell, and the star's luminosity rises rapidly. The star's envelope swells and instabilities frequently cause significant parts of it to be ejected into interstellar space. During this period these stars blow away most of their original mass in an increasingly powerful wind. As the gas flows outwards it cools and elements that form solids with high melting points condense into dust grains, so these stars have much in

Una volta che l'elio contenuto nel nucleo è stato bruciato, la fusione dell'elio si sposta in un guscio attorno al nucleo di carbonio, oltre il quale la fusione dell'idrogeno continua in un guscio esterno e la luminosità della stella aumenta rapidamente. L'involucro della stella si gonfia e le instabilità causano frequentemente l'espulsione di diverse sue parti nello spazio interstellare. Durante questo periodo, la maggior parte della massa originaria di queste stelle viene spazzata via da un vento sempre più intenso. Poco alla volta, il gas fluisce common with a Victorian factory chimney.

verso l'esterno raffreddandosi e i materiali che formano solidi ad alto punto di fusione si condensano in grani di polvere. Ecco perché queste stelle non sono poi così tanto diverse dalle ciminiere delle fabbriche vittoriane.

The rate of blow-off becomes a runaway process because as the star grows less massive, the power of gravity to hold gas in against radiation pressure in the envelope diminishes. Moreover, the luminosity of the star, and therefore radiation pressure grows as the quantity of gas that is blanketing the intensely hot core diminishes—the star's loft insulation is disappearing. Eventually the bottom of the envelope, where helium burning was taking place, lifts right off and the envelope becomes an expanding shell of gas around the star that is powerfully illuminated by the now naked core. The shell is ionized by photons from the core and glows brightly—the object is now a *planetary nebula* (Figure 4).

Il tasso di espulsione diventa un processo incontrollato perché, man mano che la stella diventa meno massiva, diminuisce la capacità della gravità di trattenere il gas contro la pressione delle radiazioni nell'involucro. Inoltre, la luminosità della stella e, di conseguenza, la pressione delle radiazioni, aumentano man mano che diminuisce la quantità di gas che ricopre il nucleo intensamente caldo: l'isolamento dell'involucro della stella sta scomparendo. Alla fine, la parte inferiore dell'involucro, dove stava avvenendo la fusione dell'elio, si solleva e l'involucro si trasforma in un guscio di gas in espansione che circonda la stella, illuminato intensamente dal nucleo ormai spoglio. Il guscio viene ionizzato dai fotoni provenienti dal nucleo e si illumina in maniera intensa: l'oggetto è ora una *nebulosa planetaria* (Figura 4).

In the core nuclear reactions have ceased, so it gradually cools. It has become one of the white dwarf stars whose physics Chandrasekhar correctly outlined on the voyage from Bombay (page 7).

Essendo cessate le reazioni nucleari al suo interno, il nucleo comincia a raffreddarsi gradualmente, diventando una delle stelle nane bianche la cui fisica è stata correttamente delineata da Chandrasekhar durante il suo viaggio da Bombay (pagina 7).

Stars initially more massive than 8 M⊙ ignite carbon, burn it to silicon and then ignite that and burn it to iron. Since iron cannot be burnt, they are now obliged to replace heat that leaks out of their cores by contracting and thus releasing gravitational energy. Unfortunately, when a self-gravitating body contracts, its central temperature rises, and this rise in temperature soon proves fatal for the star—it suddenly blazes up into fireball and becomes a supernova.

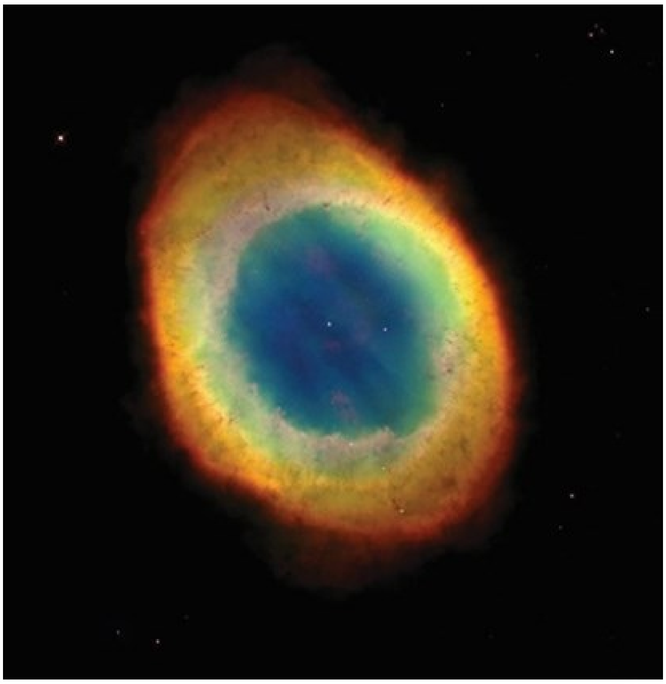
Le stelle con massa iniziale superiore a 8 M⊙ innescano la fusione del carbonio convertendolo in silicio, per poi innescare la fusione del silicio e trasformarlo in ferro. Siccome il ferro non può essere bruciato, sono costrette a compensare il calore che fuoriesce dai loro nuclei contraendosi e rilasciando così energia gravitazionale. Purtroppo, quando un corpo autogravitante si contrae, la sua temperatura centrale aumenta, e questo aumento di temperatura si rivela subito fatale per la stella, che improvvisamente esplode in una supernova.

The surfaces of stars

The density of gas in a star decreases continuously from the centre outwards, at first gradually but with increasing speed, although the density never falls precisely to zero. As the density falls, the distance a typical photon can travel before it’s scattered or absorbed by an atom increases. At a certain radius this distance quite suddenly becomes comparable to the distance over which the density halves, and many photons can escape from that radius to infinity. The observed properties of the star are largely determined by the physical conditions in the spherical shell of this radius, the *photosphere* (Figure 5).

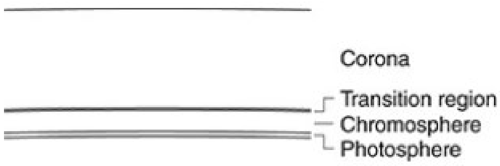
La superficie delle stelle

La densità del gas in una stella diminuisce continuamente dal centro verso l'esterno, dapprima gradualmente ma con velocità crescente, anche se la densità non scende mai esattamente a zero. Man mano che la densità diminuisce, aumenta la distanza che un tipico fotone può percorrere prima di essere disperso o assorbito da un atomo. A un certo raggio, questa distanza diventa improvvisamente paragonabile alla distanza su cui la densità si dimezza, e molti fotoni possono sfuggire a quel raggio all'infinito. Le proprietà osservate della stella sono in gran parte determinate dalle condizioni fisiche del guscio sferico di questo raggio, ovvero la *fotosfera* (Figura 5).



4. The planetary nebula Messier 57. Photons of different frequencies escape from the star from radii that increase with the photon's propensity to be scattered by free electrons. Some photons have an unusually high propensity to scatter because they resonate with an oscillation of a common atom or molecule, and these remain trapped to the largest radii.

4. La nebulosa planetaria Messier 57. I fotoni di diversa frequenza fuoriescono dalla stella da raggi che aumentano in base alla propensione del fotone ad essere disperso da elettroni liberi. Alcuni fotoni possiedono una straordinaria tendenza alla dispersione, poiché vibrano con oscillazioni simili a quelle di un comune atomo o molecola, e finiscono per rimanere intrappolati nei raggi più grandi.



5. The outer layers of the Sun. Sunlight comes from the photosphere. The temperature of the solar plasma reaches a minimum in the lower part of the chromosphere. In the transition region the temperature leaps from ~ 10,000 K to over a million degrees. The blisteringly hot corona extends very far out and is readily observed during a total solar ellipse.

Hence the brightness of the star varies with wavelength and the star's spectrum contains spectral lines. The shape of these lines conveys information about radial gradients in density and temperature around the photosphere. Consequently, astronomers make huge efforts to obtain high-quality spectra for large numbers of stars. The precision with which the mass, radius, temperature and chemical composition of a star can be inferred from its spectrum is often limited by our ability to compute to the necessary accuracy the spectrum of light emitted by a star of particular mass, radius, *etc*.

5. Gli strati esterni del Sole. La luce solare proviene dalla fotosfera. La temperatura del plasma solare raggiunge il suo minimo nella parte inferiore della cromosfera. Nella zona di transizione la temperatura balza da ~ 10,000 K ad oltre un milione di gradi. La corona rovente si estende a grandi distanze ed è facilmente visibile durante un'eclisse totale di Sole.

La luminosità della stella varia, quindi, in base alla lunghezza d'onda ed al suo spettro. Quest'ultimo contiene delle righe spettrali, la cui forma fornisce informazioni sui gradienti di densità e di temperatura radiali attorno alla fotosfera. Ciò comporta enormi sforzi da parte degli astronomi al fine di ottenere spettri di alta qualità per un gran numero di stelle. La precisione con cui è possibile dedurre la massa, il raggio, la temperatura e la composizione chimica di una stella dal suo spettro è spesso limitata dalla nostra capacità di calcolare con la dovuta accuratezza lo spettro della luce emessa da una stella di particolare massa, raggio, *ecc*.

Stellar coronae

The temperature of material in the Sun falls steadily all the way from the centre to the top of the photosphere—the visible

La corona delle stelle

La temperatura dei materiali che compongono il Sole si abbassa con costanza dal centro fino alla sommità della surface—where it is about 4,500 K. Then, astonishingly, it starts to rise, at first slowly and then extremely rapidly— in the *transition region*, which is only 100km thick, the temperature surges from ~ 10,000 K to over 1,000,000 K (Figure 5). Since heat always flows from hotter to cooler material, the corona must be heating the Sun, not the other way round. So what heats the corona? Outer space?

fotosfera, la sua superficie visibile, dove raggiunge i 4.500 K circa. Poi, sorprendentemente, comincia ad aumentare, prima lentamente e poi con estrema rapidità: nella regione di transizione, che ha uno spessore di soli 100 km, la temperatura passa da ~ 10.000 K a oltre 1.000.000 K (Figura 5). Poiché il calore fluisce sempre dal materiale più caldo a quello più freddo, è la corona a riscaldare il Sole e non il contrario. Quindi viene spontaneo domandarsi: cosa riscalda la corona? Lo spazio cosmico?

Convection carries much of the heat generated in the Sun's core on the last stage of its journey to the surface. Blobs of hot gas rise from 210,000 km below the photosphere, come to rest in the photosphere and there cool by radiating into space. Finally, they fall back to be reheated below the surface. Although convection is mainly an up-and-down process, in the photosphere gas does move horizontally before falling. So convection drives an unsteady circulation of gas.

La convezione trasporta gran parte del calore generato all'interno del nucleo del Sole durante l'ultima tappa del suo viaggio verso la superficie. Sacche di gas caldo risalgono da 210.000 km al di sotto della fotosfera, dove si fermano e si raffreddano irradiandosi nello spazio. Infine, cadono nuovamente per essere riscaldati al di sotto della superficie. Sebbene la convezione preveda principalmente movimenti verticali, di salita e discesa, nella fotosfera il gas si muove orizzontalmente prima di cadere. Quindi la convezione determina una circolazione instabile del gas.

The highly ionized gas in the Sun is a near perfect conductor of electricity because the many free electrons move easily in response to the tiniest electric field.

Il gas altamente ionizzato contenuto nel Sole è un conduttore di elettricità quasi perfetto, perché i numerosi elettroni liberi si muovono facilmente in risposta al più

Magnetic field lines freeze into and are swept along by such a conducting fluid, and the Sun's gas is magnetized. So the chaotic stirring of the Sun's surface by convection is constantly stretching and tangling the field lines that are embedded in the gas.

piccolo campo elettrico. Le linee di campo magnetico si congelano in questo fluido conduttore, da cui vengono trasportate, e, di conseguenza, il gas del Sole viene magnetizzato. Quindi il caotico rimescolamento della superficie del Sole dovuta alla convezione estende ed intreccia continuamente le linee di campo che sono incorporate nel gas.

Magnetic field lines are analogous to elastic bands: there is a tension along the field line, and if a field line is stretched by the flow, the field grows stronger and its tension increases. In this case the fluid does work on the field; conversely, if the field line contracts, the field works on the fluid.

Le linee di campo magnetico sono simili agli elastici: lungo queste vi è una tensione, per cui se una linea di campo viene allungata dal flusso, il campo si rafforza e la sua tensione aumenta. In questo caso, il fluido compie lavoro sul campo; viceversa, se la linea di campo si contrae, il campo compie lavoro sul fluido.

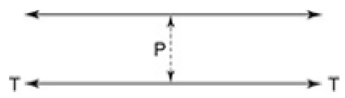
Adjacent field lines that are running in the same direction repel each other (Figure 6). If the field happens to be running parallel to the surface, this pressure pushes the field lines that are nearer the surface up and away from the field lines that run deeper down.

Linee di campo allineate nella stessa direzione si respingono (Figura 6). Se il campo è parallelo alla superficie, questa pressione spinge verso l'alto le linee di campo più vicine alla superficie, allontanandole da quelle più profonde.

Gas cannot move across field lines, but it can flow down them, and once a field line has started to bow upwards, gas runs down the field line away from the crest of the bow. This flow diminishes the weight that is bearing on bowed field lines, so they rise up some more, encouraging more gas

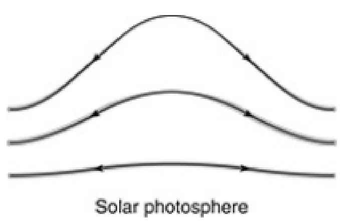
Il gas non può attraversare le linee di campo, ma può fluire lungo di esse. Quando una linea di campo inizia ad incurvarsi verso l'alto, il gas scorre lungo di essa allontanandosi dalla cresta della curva. Questo flusso riduce il peso che grava sulle linee di campo incurvate, che to drain away from the peak, and soon a big loop of magnetic field is sticking out of the Sun's surface (Figure 7). Meanwhile, the dense gas in which the two ends of the loop is embedded flows over the Sun's surface in response to both convection and the systematic rotation of the Sun, and the field lines that make up the loop often become tangled in the sense that field lines that are moving in quite different directions are dragged close to one another. At this point the field *reconnects* somewhere in the corona as sketched in Figure 8.

quindi si alzano ancora un po', facilitando il deflusso di altro gas dal picco, e presto un grande anello (loop) di campo magnetico fuoriesce dalla superficie del Sole (Figura 7). Nel frattempo, il gas denso in cui si trovano le due estremità dell'anello fluisce sulla superficie del Sole in risposta sia alla convezione sia alla rotazione sistematica del Sole. Le linee di campo che compongono l'anello spesso si aggrovigliano: ciò avviene perché linee di campo che si muovono in direzioni molto diverse vengono trascinate l'una vicino all'altra. A questo punto, il campo *si riconnette* da qualche parte nella corona, come illustrato nella Figura 8.



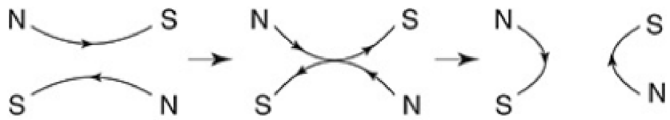
6. Each magnetic field line is under tension and repels similarly directed field lines.

6. Ciascuna linea di campo magnetico è sotto tensione e respinge linee di campo orientate nella stessa direzione.



7. Plasma draining away from the crests of three upward bowing field lines.

7. Plasma che fluisce dalle creste di tre linee di campo che si incurvano verso l'alto.



8. When magnetic field lines that are moving in opposite directions are brought together, their oppositely directed sections cancel out, releasing magnetic energy, and the field settles to a different, 'reconnected' pattern.

8. Quando le linee del campo magnetico che si muovono in direzioni opposte si riuniscono, le loro sezioni dirette in senso opposto si annullano, rilasciando energia magnetica, e il campo si assesta su un modello differente, detto 'ricollegato'.

When field lines reconnect, energy stored in the magnetic field is used to accelerate particles. Most of these energetic particles collide with nearby electrons and ions and lose their extra energy by heating nearby gas. So in the vicinity of a reconnection event the gas becomes extremely hot. Thus the searing heat of the corona is maintained by a constant flow of magnetic energy from the turbulent layer that is bounded by the photosphere through the 2,000km thick chromosphere, a region of low-density gas that envelops the photosphere (Figure 5).

Quando le linee di campo si riconnettono, viene utilizzata l'energia immagazzinata nel campo magnetico per accelerare le particelle. La maggior parte di queste particelle energetiche si scontra con gli elettroni e gli ioni vicini e perde la propria energia extra riscaldando il gas circostante. Quindi, in prossimità di un evento di riconnessione, il gas diventa estremamente caldo. In più, il calore ardente della corona è mantenuto da un flusso costante di energia magnetica proveniente dallo strato turbolento, delimitato dalla fotosfera tramite la cromosfera, una regione di gas a bassa densità spessa 2.000 km che la avvolge (Figura 5).

Much of the gas in the corona is too hot to be confined by the Sun's gravitational field, so it flows away from the Sun as the *solar wind*. About 60,000km from the Earth the wind is deflect around us by the Earth's magnetic field. Electrons that have been accelerated to extreme energies in reconnection events above the photosphere, escape into the wind without losing much of their energy, and some of these particles become trapped in the Earth's magnetic field. These particles make up the *van Allen* radiation belts. They race at close to the speed of light from one magnetic pole to the other, exciting air molecules to glow as they approach the surface of the Earth near the north pole—this is the origin of the northern lights.

Gran parte del gas della corona è troppo caldo per essere confinato dal campo gravitazionale del Sole, quindi fluisce lontano dal Sole come *vento solare*. A circa 60.000 km dalla Terra, questo vento viene deviato dal campo magnetico terrestre. Gli elettroni che sono stati accelerati a energie estremamente alte durante gli eventi di riconnessione sopra la fotosfera si uniscono al vento solare, senza perdere gran parte della loro energia, e alcune di queste particelle rimangono intrappolate nel campo magnetico terrestre. Queste particelle, che costituiscono le fasce di radiazione di *Van Allen*, si muovono quasi alla velocità della luce da un polo magnetico all'altro, portando le molecole dell'aria a brillare mentre si avvicinano alla superficie terrestre, precisamente in prossimità del polo nord: questo è ciò che origina l'aurora boreale.

Exploding stars

Very occasionally a single star will become for a week or two as luminous as a whole galaxy of 100 billion stars. Such an event is called a supernova. In a galaxy like ours we expect a *supernova* to occur roughly every fifty years, although the last Galactic supernova to be observed was

L'esplosione delle stelle

In rare occasioni, una singola stella diventa – per una o due settimane – tanto luminosa quanto un'intera galassia costituita da 100 miliardi di stelle: questo fenomeno prende il nome di supernova. In una galassia come la nostra ci aspettiamo che una *supernova* si verifichi that found by Johannes Kepler in 1604—remnants have been found of supernovae that exploded in about 1680 and 1868, but the events themselves passed unnoticed. In February 1987 a supernova, *SN1987a*, was observed in the Large Magellanic Cloud, a small galaxy that is currently passing very close to our Galaxy and will eventually be eaten by it. This event provided by far the best opportunity to observe a supernova that mankind has so far enjoyed.

indicativamente ogni cinquant'anni, anche se l'ultima supernova galattica ad essere osservata è stata quella che venne rilevata da Johannes Kepler nel 1604. Sono stati rinvenuti solo i resti di supernove esplose intorno al 1680 ed al 1868, ma gli eventi in sé sono passati inosservati. Nel febbraio 1987, è stata osservata una supernova, denominata *SN1987a*, nella Grande Nube di Magellano, una piccola galassia che attualmente sta passando molto vicino alla nostra Galassia e che finirà per essere divorata da essa. Questo evento ha fornito senza ombra di dubbio la migliore opportunità di osservare una supernova di cui l'umanità abbia goduto fino ad ora.

Supernovae are key cosmological tools because they can be observed out to vast distances. Consequently, major observational resources have in recent years been devoted to detecting and measuring large numbers of supernovae.

Le supernove sono strumenti cosmologici di fondamentale importanza, poiché possono essere osservate ad immense distanze. Di conseguenza, negli ultimi anni sono state impiegate le migliori risorse osservative con l'obiettivo di individuare e misurare un gran numero di supernove.

It turns out that two completely different mechanisms can generate a supernova.

È emerso che una supernova può avere origine da due meccanismi completamente diversi.

Core-collapse supernovae

In the incredibly dense cores of stars that have burnt carbon to silicon, much of the pressure that resists gravity is provided by

Le supernove da collasso del nucleo

Nei nuclei incredibilmente densi delle stelle che hanno fuso il carbonio in silicio, gran parte della pressione che resiste alla the electrons, which are obliged by the Heisenberg and Pauli principles (page 7) to whizz about much faster than they would do at the same temperature but a lower density. As a consequence they have so much kinetic energy that it can be energetically advantageous for them to become trapped inside a nucleus, lowering its charge and thus transforming it into the nucleus of the element before it in the periodic table. Each such capture reduces the number of electrons that contribute to the pressure opposing gravity.

gravità è fornita dagli elettroni, che, secondo i principi di Heisenberg e di Pauli (pagina 7), sono costretti a muoversi molto più velocemente di quanto farebbero alla stessa temperatura ma a densità inferiore. Di conseguenza, possiedono così tanta energia cinetica che il fatto di rimanere intrappolati all'interno di un nucleo può costituire per loro un vantaggio da un punto di vista energetico, poiché abbassano la sua carica e lo trasformano nel nucleo dell'elemento che lo precede nella tavola periodica. Ogni cattura di questo tipo riduce il numero di elettroni che contribuiscono alla pressione che contrasta la forza di gravità.

As the core contracts, its temperature rises and the average energy of the photons in the ambient black-body radiation (page 28) rises. Eventually, this radiation contains a significant number of photons that are energetic enough to blast an atomic nucleus to pieces (*photo-dissociate* it). The gas of photons in the core makes a significant contribution to the pressure that resists gravity and each photo-dissociation reduces the pressure by withdrawing energy from the photon gas.

Quando il nucleo si contrae, aumentano sia la sua temperatura sia l’energia media dei fotoni presenti nella radiazione del corpo nero dell’ambiente circostante (pagina 28). Alla fine, tale radiazione contiene un numero considerevole di fotoni abbastanza energetici da causare la frammentazione di un nucleo atomico (facendolo *fotodissociare*). Il gas di fotoni nel nucleo contribuisce in modo significativo alla pressione che resiste alla gravità ed ogni fotodissociazione riduce la pressione sottraendo energia al gas di fotoni.

Hence the star is on a slippery slope: contraction drives up the temperature,

La stella si trova quindi su una sorta di pendio scivoloso: la contrazione fa which leads to more electrons being captured and more photo-dissociation of nuclei, which inevitably lead to further contraction. Within a few milliseconds the core is in free fall and cataclysm is inevitable.

As the central density rises, the atomic nuclei, so patiently assembled through the life of the star, are blasted apart. Most of the fragments end up as neutrons. Now the neutrons start to play the role that was earlier played by the electrons: they make a major contribution to the pressure by moving much faster than they would at the same temperature and a lower density because they have to conform to the Heisenberg and Pauli principles. Consequently, at some point the pressure within the core rises steeply with density and the core abruptly stops contracting, or 'bounces.

Most of the star's mass lies outside this pressure-supported core and is falling inwards very fast. The inevitable result is a shock (Chapter 6, 'Shocks and particle acceleration') in which the inward falling material is brought to rest and violently heated.

aumentare la temperatura, cosa che porta alla cattura di un numero maggiore di elettroni ed alla fotodissociazione dei nuclei, il che inevitabilmente porta ad un'ulteriore contrazione. In pochi millisecondi, il nucleo è in caduta libera e la catastrofe diventa inevitabile.

Man mano che la densità centrale aumenta, i nuclei atomici, così pazientemente prodotti durante la vita della stella, vengono disintegrati. La maggior parte dei frammenti si trasforma in neutroni, i quali iniziano ora a svolgere il ruolo precedentemente ricoperto dagli elettroni: contribuiscono in modo determinante alla pressione muovendosi molto più rapidamente di quanto farebbero alla stessa temperatura ma a una densità inferiore, sempre per conformarsi ai principi di Heisenberg e di Pauli. Di conseguenza, ad un certo punto la pressione all'interno del nucleo aumenta vertiginosamente insieme alla densità ed il nucleo cessa improvvisamente di contrarsi o, come si suol dire, 'rimbalza'.

Gran parte della massa della stella si trova al di fuori di questo suo nucleo supportato dalla pressione ed è in rapida caduta verso l'interno. L'inevitabile risultato è un urto (Capitolo 6, sezione 'Urti e accelerazione di particelle'), in cui il materiale in caduta verso l'interno viene portato a riposo e violentemente riscaldato.

The temperature and density are now so high that collisions within the plasma of electrons, neutrons and protons generate neutrinos in abundance. Because neutrinos have incredibly small cross sections for colliding with anything (page 6), they move significant distances between collisions even in the stupendously dense centre of the star. As a consequence the core become enormously luminous by radiating neutrinos rather than photons—it radiates photons too, but they are slow to diffuse outwards, so the neutrinos carry off energy much faster. So at this stage an enormous flux of neutrinos is flowing out through the envelope of the star, most of which is still falling onto the almost point-like core. A small fraction of the neutrinos collide with infalling nuclei, transferring energy and momentum to them. These transfers can be sufficient to reverse the inward motion of much of the envelope and blast it outwards in a great ball of fire.

La temperatura e la densità attuali sono così elevate che le collisioni all'interno del plasma di elettroni, neutroni e protoni generano abbondanza di neutrini. Poiché i neutrini hanno sezioni d'urto incredibilmente piccole di collisioni con qualsiasi cosa (pagina 6), si spostano per lunghe distanze tra una collisione e l'altra, perfino nel centro della stella che possiede una densità elevatissima. Di conseguenza, il nucleo diventa luminosissimo poiché irradia neutrini piuttosto che fotoni; irradia anche fotoni, ma questi impiegano molto tempo a diffondersi verso l'esterno, al contrario dei neutrini che trasportano energia molto più rapidamente. In questa fase, un'enorme quantità di neutrini fuoriesce dall'involucro della stella, la maggior parte dei quali ancora continuano a cadere sul nucleo, ormai quasi puntiforme. Una piccola parte dei neutrini collide con i nuclei in caduta, trasferendo loro energia e momento. Questi trasferimenti possono essere sufficienti a invertire il moto verso l'interno di gran parte dell'involucro e a farlo esplodere verso l'esterno in una grande palla infuocata.

Before the material of the envelope disperses into interstellar space, it is

Prima che il materiale dell'involucro si disperda nello spazio interstellare, è exposed to an intense flux of neutrons boiled off the neutron-rich core. Nearly all the neutrons are absorbed by atomic nuclei in the envelope, converting them into heavier nuclei. Usually the nucleus formed by the absorption of a neutron is highly radioactive and quickly decays to another nucleus, often by the emission of an electron and always with the emission of a photon. Hence radioactive decay becomes a significant source of heat within the dispersing envelope. Some nuclei absorb several neutrons one after the other, and undergo several radioactive decays. All elements that lie beyond iron in the periodic table were formed in this way—thus the nuclei of bromine, silver, gold, iodine, lead, and uranium were all created in supernova explosions.

esposto a un intenso flusso di neutroni emessi dal nucleo, che è per l'appunto ricco di neutroni. Quasi tutti i neutroni vengono assorbiti nell'involucro dai nuclei atomici e vengono convertiti in nuclei più pesanti. Di solito, il nucleo formato dall'assorbimento di un neutrone è altamente radioattivo e si decompone rapidamente in un altro nucleo, emettendo spesso un elettrone e sempre un fotone. Pertanto, il decadimento radioattivo diventa una fonte significativa di calore all'interno dell'involucro disperdente. Alcuni nuclei assorbono diversi neutroni uno dopo l'altro e subiscono una serie di decadimenti radioattivi. Tutti gli elementi che si trovano oltre il ferro nella tavola periodica si sono formati in questo modo: i nuclei di bromo, argento, oro, iodio, piombo e uranio sono stati tutti creati a seguito di esplosioni di supernove.

As the fireball expands, its photosphere swells, so its optical luminosity rises. In the case of SN1987a the optical luminosity peaked three months after the core imploded—we know when the latter happened because the blast of neutrinos as the core bounced was detected. (To date SN1987a is the only supernova from which we have detected neutrinos.) Spectra taken at this stage show the material of the envelope to be fleeing the

Quando la palla infuocata si espande, la sua fotosfera si gonfia e, di conseguenza, la sua luminosità ottica aumenta. Nel caso di SN1987a, la luminosità ottica ha raggiunto il suo picco tre mesi dopo l'implosione del nucleo: sappiamo che ciò è avvenuto perché è stata rilevata l'esplosione di neutrini durante il rimbalzo del nucleo (SN1987a è l'unica supernova di cui finora abbiamo osservato i neutrini). Gli spettri presi in questa fase mostrano core at a few thousand kilometres per second. At this speed each solar mass of ejected material has 2 × 10 43J of kinetic energy, so the ~ 5 M⊙ of ejected material contains ~ 10 44 J of energy. This is just ~ 1 per cent of the gravitational energy released by the collapse of the core. This is a characteristic feature of supernovae: the spectacular explosion we detect and the profound impact that the event has on the interstellar medium are both powered by a tiny fraction of the energy that is actually released: 99 per cent of the energy is carried off by neutrinos that will never interact with anything, ever.

che il materiale dell'involucro si allontana dal nucleo a una velocità di alcuni migliaia di chilometri al secondo. A questa velocità, ogni massa solare di materiale espulso possiede un’energia cinetica di 2 × 10^{43}J, quindi i ~ 5 M⊙ di materiale espulso contengono ~ 10^{44} J di energia. Si tratta di appena ~ l'1% dell'energia gravitazionale rilasciata dal collasso del nucleo. Questa è una peculiarità delle supernove: la spettacolare esplosione che osserviamo e il profondo impatto che l'evento ha sul mezzo interstellare sono entrambi alimentati da una minuscola frazione dell'energia che viene effettivamente rilasciata, dato che il 99% dell'energia viene portata via dai neutrini, che non interagiscono mai con nulla.

Eventually the expanding envelope becomes so diffuse that optical photons cannot be trapped for long within most of it. Hence its optical luminosity fades over a few weeks. As it expands and becomes more diffuse, dynamical interaction with the gas that was in the volume around the star becomes more important. In fact the gas density in this region is likely to be anomalously high, because before the star imploded as a supernova it was blowing off mass quite fast as a wind. The blast wave from the exploding star ploughs into the wind and shock heats it. Significant

Ad un certo punto, l’espansione dell’involucro diventa tale che i fotoni ottici non possono essere intrappolati a lungo nella maggior parte di esso. Di conseguenza, la sua luminosità ottica si affievolisce nell'arco di poche settimane. Espandendosi sempre di più, la sua interazione dinamica con il gas che si trovava nel volume intorno alla stella diventa più importante. In effetti, è probabile che la densità del gas in questa regione sia anomala (troppo alta), perché prima che la stella esplodesse in supernova stava soffiando via massa emission at radio wavelengths can arise at this stage.

abbastanza velocemente, proprio come un vento. L'onda d'urto provocata dall’esplosione della stella si propaga verso il vento e lo riscalda. In questa fase può verificarsi una significativa emissione a lunghezze d'onda radio.

Meanwhile, back in the core, much has been happening. We have seen that the collapsing core became very neutron-rich, and pressure generated by the neutrons caused the core to bounce and generate a burst of neutrinos that ejected much of the envelope. After the bounce, material continues to fall onto the stabilized core and a neutron star takes shape: this is a stupendously big atomic nucleus that’s seriously neutron-rich. Within it neutrons dash around at mildly relativistic speeds, creating the pressure that resists gravity in just the same way that electrons resist gravity inside a white dwarf. The mass of this neutron star grows as material continues to fall onto it. As its mass grows, its radius shrinks (white dwarfs behave the same way), its gravitational field grows yet stronger, and the neutrons move ever faster to resist gravity. Remarkably, general relativity predicts that pressure is itself a source of gravity, so the harder the pressure resists gravity, the stronger gravity becomes. If the mass of the neutron star increases beyond a critical

Nel frattempo, nel nucleo, sono successe molte cose. Abbiamo visto che il nucleo in collasso è diventato estremamente ricco di neutroni e che la pressione generata dai neutroni ha causato un rimbalzo del nucleo, generando un'esplosione di neutrini che ha espulso gran parte dell'involucro stellare. Dopo il rimbalzo, il materiale continua a cadere sul nucleo stabilizzato e si forma una stella di neutroni: si tratta di un nucleo atomico straordinariamente grande ed estremamente ricco di neutroni. Al suo interno, i neutroni si muovono a velocità leggermente relativistiche, creando una pressione che resiste alla gravità proprio come resistono alla gravità gli elettroni all'interno di una nana bianca. La massa di questa stella di neutroni cresce man mano che il materiale continua a cadere su di essa e, con l’aumento della sua massa, il suo raggio si riduce (le nane bianche si comportano allo stesso modo), il suo campo gravitazionale diventa ancora più potente e i neutroni si muovono sempre più velocemente per resistere alla gravità.

value, Mcrit , gravity overwhelms the pressure generated by the neutrons and the object collapses into a black hole.

È sorprendente che la teoria della relatività generale preveda che la pressione sia essa stessa una fonte di gravità, quindi più la pressione resiste alla gravità, più la forza gravità aumenta. Se la massa della stella di neutroni aumenta oltre un valore critico, indicato come Mcrit, la gravità annulla la pressione generata dai neutroni e l'oggetto collassa in un buco nero.

The precise value of Mcrit is controversial because it depends on how matter behaves at nuclear densities. Although we believe we know what equations we need to solve, those of *Quantum Chromodynamics (QCD)*, it is extremely hard to determine from first principles the required relationship between density and pressure. Moreover, we do not have good access to the relevant regime experimentally—the most massive nuclei on Earth contain only ~ 240 protons and neutrons and generate negligible gravitational fields. The experts are confident, however, that Mcrit lies between 1.4 M⊙ and 3 M⊙, so some corecollapse supernovae leave neutron stars, while others produce black holes. The supernova recorded by the Chinese in 1054 left a neutron star (the *Crab pulsar*) that has been extensively studied. Our understanding of SN1987a implies that it involved the formation of a neutron star,

Il valore preciso di Mcrit è oggetto di controversia perché dipende dal comportamento della materia alle densità nucleari. Anche se crediamo di conoscere le equazioni da risolvere, in questo caso quelle della Cromodinamica Quantistica (QCD), è estremamente difficile determinare la fondamentale relazione tra densità e pressione attraverso i principi di base. Inoltre, non abbiamo un buon accesso al regime rilevante dal punto di vista sperimentale: i nuclei più massicci sulla Terra contengono solo ~ 240 protoni e neutroni e generano campi gravitazionali trascurabili. Gli esperti sono comunque certi che Mcrit sia compreso tra 1,4 M⊙ e 3 M⊙, per cui alcune supernove da collasso del nucleo lasciano il posto a stelle di neutroni, altre a buchi neri. La supernova registrata dai cinesi nel 1054 ha lasciato una stella di neutroni (la cosiddetta *pulsar del Granchio* o *pulsar Crab*), che è stata ampiamente studiata. La but meticulous searches have failed to reveal a relic star of any kind.

Deflagration supernovae

We saw above that stars with initial masses smaller than $8M_\odot$ fail to ignite carbon and lose their envelopes, leaving a core of carbon and oxygen that gradually cools as a white dwarf star. If the star has no companion, that is the end of its story. The majority of stars do have a companion, however, and then the future can be much more exciting. If the companion was initially the less massive star, its evolution will occur on a longer timescale. Consequently, the companion will swell up and start blowing off mass at a significant rate after its companion has become a white dwarf. If the distance between the two stars is not too great, a significant part of the mass blown off by the companion will be captured by the white dwarf's gravitational field and form an accretion disc. Accretion discs of this type are studied by their X-ray emission (Chapter 4, 'Time-domain astronomy'). At the inner edge of the disc, gas transfers from the accretion disc to the white dwarf star, so the latter's mass increases.

nostra comprensione di SN1987a implica la formazione di una stella di neutroni, ma, nonostante siano state effettuate ricerche meticolose, non si è giunti alla rilevazione di reliquie stellari di alcun genere.

Le supernove da deflagrazione

Abbiamo visto che stelle con massa iniziale inferiore a $8M_\odot$ non riescono a fondere il carbonio e perdono il proprio involucro, lasciando un nucleo composto da carbonio e ossigeno che si raffredda gradualmente diventando una stella nana bianca. Se la stella non ha una compagna, è giunta alla fine della sua vita. Ma la maggior parte delle stelle possiede una compagna, e in questo caso il futuro è molto più emozionante. Se la compagna era inizialmente la stella meno massiva, la sua evoluzione avverrà su una scala temporale più lunga. Di conseguenza, la compagna si gonfierà e inizierà a soffiare via massa a un ritmo notevole dopo che la sua compagna sarà diventata una nana bianca. Se la distanza tra le due stelle non è troppo grande, una parte significativa della massa persa dalla compagna sarà catturata dal campo gravitazionale della nana bianca e formerà un disco di accrescimento. I dischi di accrescimento di questo tipo sono studiati attraverso le loro emissioni di raggi X (Capitolo 4, sezione 'Astronomia nel dominio del tempo'). Sul bordo interno del disco, il gas viene trasferito dal disco di accrescimento alla stella nana bianca, provocando un aumento della massa di quest'ultima.

As the mass increases, the star's radius decreases and its gravitational field becomes more intense. The Heisenberg and Pauli principles then decree that the most energetic particles speed up. Eventually some nuclei are moving fast enough to trigger the conversion of carbon into silicon. This conversion releases energy, which heats the star, so more nuclear reactions take place.

Aumentando la massa della stella, diminuisce il suo raggio mentre il suo campo gravitazione diventa più intenso. I principi di Heisenberg e di Pauli stabiliscono, quindi, che le particelle più energetiche si muovono più velocemente. Alcuni nuclei arrivano a muoversi abbastanza velocemente da innescare la fusione del carbonio in silicio. Questa trasformazione libera energia, che riscalda la stella, permettendo altre reazioni nucleari.

If the thermal motion of the nuclei were making a significant contribution to the pressure within the star, the star would respond to the heat input from nuclear reactions by expanding and cooling, both of which changes would slow the rate of nuclear reactions, and the system would be stable. But in a white dwarf the nuclei make an insignificant contribution to the pressure, which is dominated by the electrons. Consequently the density does not decrease as the nuclei are heated, and the rate of nuclear reactions spirals out of control. The technical term for the way the rate of nuclear reactions runs away is *deflagration*, a kind of slow explosion in

Se l'agitazione termica dei nuclei contribuisse in modo significativo alla pressione all'interno della stella, quest'ultima risponderebbe al calore generato dalle reazioni nucleari espandendosi e raffreddandosi, entrambi cambiamenti che rallenterebbero il tasso di reazioni nucleari rendendo il sistema stabile. Ma in una nana bianca i nuclei non contribuiscono in modo significativo alla pressione, la quale è dominata dagli elettroni. Di conseguenza, la densità non diminuisce quando i nuclei vengono riscaldati e diventa impossibile controllare il tasso di reazioni nucleari. Il termine tecnico per indicare tale condizione è which a front of enhanced temperature and reaction rate moves through the medium at a speed that is slower than the speed of sound.

deflagrazione, una forma di lenta esplosione il cui fronte, caratterizzato da un aumento della temperatura e della velocità di reazione, si muove attraverso il corpo al di sotto della velocità del suono.

Within a fraction of a second about a solar mass of carbon and oxygen has been burnt all the way to iron and nickel. The sudden release of energy by all this burning *does* produce enough pressure to overwhelm gravity and the star flies apart, leaving no gravitationally bound object where it was. A significant part of the dispersed material of the star consists of a highly radioactive isotope of nickel (^{56}Ni) which has a half life of 6.1days. Gamma rays produced by the decay of ^{56}Ni to iron heat the dispersing material and cause it to glow brightly. It is by this glow that we detect deflagration supernovae. They are generally called *type Ia SNe* from the empirical classification of their optical spectra.

In una frazione di secondo, circa una massa solare di carbonio e ossigeno viene bruciata fino a diventare ferro e nichel. L'improvviso rilascio di energia da parte di tutta questa combustione produce una pressione sufficiente a sopraffare la gravità, al punto che la stella arriva a disintegrarsi, senza lasciare dietro di sé alcun oggetto gravitazionalmente legato. Una parte significativa del materiale disperso è costituita da un isotopo altamente radioattivo del nichel (^{56}Ni), che ha un tempo di dimezzamento di 6,1 giorni. I raggi gamma prodotti dal decadimento del ^{56}Ni in ferro riscaldano il materiale disperso e lo portano a brillare intensamente. È da questo bagliore che rileviamo le supernove da deflagrazione, generalmente chiamate *SNe di tipo Ia* sulla base della classificazione empirica dei loro spettri ottici.

Type Ia SNe are important for astronomy in two different ways. First it proves possible to estimate the luminosity of a type Ia SN from the rate at which its brightness declines. Consequently, these objects can be used as *standard candles*:

Le SNe di tipo Ia sono importanti per l’astronomia per due diversi motivi. In primo luogo, è possibile stimare la loro luminosità dal tasso di diminuzione della sua luminosità. Pertanto, questi oggetti possono essere utilizzati come *candele* objects of known luminosity whose distances can be determined from their apparent brightnesses. Second type Ia SNe are major producers of iron since nearly all the original white dwarf is eventually converted to iron. Core-collapse supernovae, by contrast, produce a cocktail of heavy elements that is much richer in the *alpha elements*, which include carbon, silicon, magnesium, and calcium. Consequently, by measuring the abundance in a star of iron relative to the alpha elements, one can determine the relative importance of type Ia and core-collapse supernovae to the enrichment of the star's material. In Chapter 7, 'Chemical evolution', we shall see the value of this determination.

Testing the theory

The theory of stellar evolution requires as inputs a great deal of atomic and nuclear physics and involves both extensive numerical calculations and some assumptions about how turbulent fluids mix. Can we be sure that it is correct? We think it is fundamentally sound because it has now been possible to compare several aspects of what it predicts to the actual outcomes of observations.

standard, oggetti con luminosità fissa di cui è possibile determinare la distanza possono sulla base della loro luminosità apparente. Inoltre, le SNe di tipo Ia sono le principali produttrici di ferro, poiché l'originaria nana bianca da cui si generano viene alla fine quasi interamente convertita in ferro. Le supernove da collasso del nucleo, al contrario, producono una miscela di elementi pesanti molto più ricca di *elementi alfa*, tra cui carbonio, silicio, magnesio e calcio. Di conseguenza, misurando l'abbondanza di ferro rispetto agli elementi alfa in una stella, si può determinare l'importanza relativa delle supernove di tipo Ia e di quelle da collasso del nucleo nell'arricchimento del materiale stellare. Vedremo il valore di questa determinazione nella sezione 'Evoluzione chimica' del Capitolo 7.

Test della teoria

La teoria dell'evoluzione stellare richiede come input parecchia fisica atomica e nucleare e comporta sia complessi calcoli sia alcune ipotesi sulla miscelazione dei fluidi turbolenti. Possiamo essere certi della sua correttezza? Riteniamo che sia fondamentalmente solida perché è stato possibile confrontare diversi aspetti di ciò che essa prevede con gli effettivi risultati delle osservazioni.

Globular star clusters

Globular star clusters provided the classic tests of the theory in its formative years. Our Galaxy has about 150 star clusters that are very nearly spherical and quite compact—in a cluster such as NGC 7006 (Figure 9) several tens of thousand stars lie within ~ 10 pc of the cluster centre—for comparison, within 10 pc of the Sun there are fewer than a hundred such stars. The feature of a globular cluster that makes it an ideal test of the theory of stellar evolution is that, to an excellent approximation, its stars differ only in their masses: they have the same distance, age, and chemical composition. Moreover, the chemical composition of the stars can be estimated from the stars' spectra. For any conjectured age of the cluster and distance to it, the theory then predicts that the stars will lie on a curve called an *isochrone* in a *colour-magnitude* diagram, a plot such as Figure 10 in which the brightnesses of stars are plotted against their colour. For historical reasons, blue colours (implying hot surface temperatures) are plotted on the left of the diagram. The vertical brightness scale is always logarithmic, so changing the assumed distance to the cluster shifts the isochrone along which stars are predicted to lie up (for reduced distance) or down without distorting the

Gli ammassi stellari globulari

Gli ammassi stellari globulari sono stati i classici test per verificare la teoria durante gli anni della sua formazione. Nella nostra Galassia ci sono circa 150 ammassi stellari dalla forma quasi sferica e piuttosto compatti: in un ammasso come NGC 7006 (Figura 9) diverse decine di migliaia di stelle si trovano in un raggio di ~ 10 pc dal centro dell'ammasso; a titolo di confronto, in un raggio di 10 pc dal Sole ci sono meno di un centinaio di stelle di questo tipo. La caratteristica di un ammasso globulare che lo rende un test ideale per la teoria dell'evoluzione stellare è che, con un'ottima approssimazione, le sue stelle differiscono solo per le loro masse; di fatto, hanno la stessa distanza, età e composizione chimica. Inoltre, la composizione chimica delle stelle può essere stimata dai loro spettri. Per qualsiasi età stimata dell'ammasso e per qualsiasi distanza da esso, la teoria prevede che le stelle si trovino su una curva chiamata *isocrona* in un diagramma *colore-magnitudine*, simile a quello mostrato nella Figura 10 in cui la luminosità delle stelle è rappresentata rispetto al loro colore. Per ragioni storiche, i colori blu (che indicano alte temperature superficiali) vengono rappresentati a sinistra nel diagramma. La scala verticale isochrone’s shape in any way. Changing the assumed age changes the isochrone’s shape in computable ways. The age and distance are determined by finding the isochrone with the shape that best matches the observed distribution of stars and then finding the vertical position that produces the best match.

della luminosità è sempre logaritmica, quindi cambiando la presunta distanza dall'ammasso si sposta l’isocrona, lungo la quale si prevede che siano disposte le stelle, verso l’alto (per distanze ridotte) o verso il basso, senza distorcere in alcun modo la forma della curva. Cambiando l'età stimata, è possibile calcolare il modo in cui cambia la forma dell'isocrona. L'età e la distanza vengono determinate trovando l'isocrona la cui forma meglio riproduce la distribuzione delle stelle osservata, ovvero trovando la posizione verticale che permette di ottenere la migliore corrispondenza.

9. The globular cluster NGC 7006.

9. L’ammasso globulare NGC 7006.

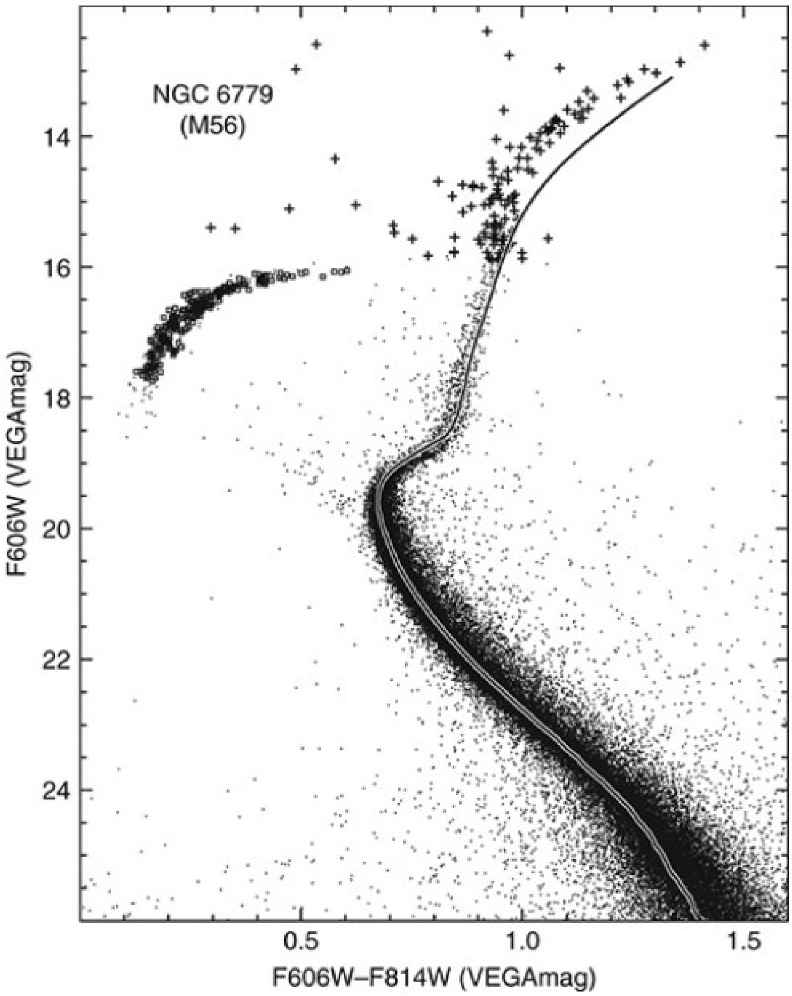
As Figure 10 illustrates, excellent matches between theory and observation can be

Come illustrato nella Figura 10, in questo modo è possibile ottenere eccellenti produced in this way. Nevertheless, slight discrepancies do arise, and astronomers continue to refine the data and assumptions that go into stellar modelling to diminish these discrepancies. The ability of the theory to match data for many clusters leaves little doubt of its fundamental soundness, however.

corrispondenze tra teoria e osservazione. Ciononostante, inevitabilmente si verificano lievi discrepanze, motivo per cui gli astronomi continuano a perfezionare i dati e le previsioni della modellazione stellare proprio con l'intento di ridurre tali discrepanze. Tuttavia, la capacità della teoria di corrispondere ai dati nel caso di molti ammassi lascia pochi dubbi sulla sua solidità.

A fascinating aspect of these fits is that our Galaxy's globular clusters prove to be extremely old—at one time the ages being derived were inconsistent with the age of the Universe. Since then refinements in our understanding of both the cosmic expansion and stellar evolution has yielded consistent ages. Clusters that have the lowest abundances of 'metals' (elements later in the periodic table than helium) tend to be the oldest, and even these have ages ~ 12 Gyr that are not larger than the age on the Universe, 13.8Gyr.

Un aspetto affascinante di queste corrispondenze è che gli ammassi globulari della nostra Galassia risultano essere estremamente vecchi. In un primo momento, le età ricavate erano incompatibili con l'età dell'Universo. Da allora, i nostri progressi nella comprensione dell'espansione cosmica e dell'evoluzione stellare hanno permesso di ottenere età compatibili. Gli ammassi con minore abbondanza di 'metalli' (elementi successivi all'elio nella tavola periodica) sono generalmente i più vecchi, con un'età di ~ 12 miliardi di anni che comunque non supera quella dell'Universo, che è di 13,8 miliardi di anni.



10. Brightness plotted against colour for stars in the globular cluster NGC 6779. Blue stars are on the left and bright stars at the top. The curves are theoretical isochrones (see text). The points from bottom right up to the sharp bend comprise the main sequence. Stars here are burning hydrogen in their cores.

10. Luminosità rappresentata rispetto al colore delle stelle dell'ammasso globulare NGC 6779. Le stelle blu si trovano a sinistra, quelle luminose nella parte superiore. Le curve sono isocrone teoriche (vedi testo). I punti che vanno dalla parte inferiore destra fino alla curva a gomito comprendono la sequenza principale. Le stelle che si trovano in questa zona bruciano l'idrogeno nei loro nuclei.

Solar neutrinos

Every time two protons fuse in the Sun to make deuterium that shortly afterwards produces helium, a neutrino is produced that escapes from the Sun. Consequently, the Sun radiates neutrinos in addition to photons. In the 1960s Ray Davis set out to detect neutrinos from the Sun, arguing that their detection would be an important test of the theory of stellar evolution since they come to us direct from the Sun's energy-generating core and thus probe an entirely different region from the photosphere, from which we receive photons.

Davis's experiment involved processing tons of dry-cleaning fluid (tetrachloromethane CCl_4) down a mine—only by working in a mine could he exclude cosmic rays, which would generate a tiresome background signal. The CCl_4 was a convenient store of ^{37}Cl nuclei, which could become argon (Ar) after being hit by a neutrino. The argon had to be extracted and its quantity measured. After years of hard work, Davis measured only a third of the expected flux of neutrinos from the Sun. The scientific community was not very excited by Davis's failure: some wondered whether

I neutrini solari

Ogni volta che all'interno del Sole avviene la fusione di due protoni con conseguente produzione di deuterio, che poco dopo viene convertito in elio, viene prodotto un neutrino che sfugge dal Sole. Ciò significa che il Sole emette neutrini, oltre che fotoni. Negli anni Sessanta, Ray Davis decise di rilevare i neutrini provenienti dal Sole. Egli sostenne che la loro rilevazione sarebbe stata un'importante prova della teoria dell'evoluzione stellare, poiché i neutrini giungono sulla Terra direttamente dal nucleo del Sole, che produce energia, sondando una regione completamente diversa dalla fotosfera, quella da cui i fotoni giungono a noi.

L'esperimento di Davis consisteva nel trattare tonnellate di fluido per il lavaggio a secco (tetraclorometano CCl_4) in una miniera. Di fatto, solo lavorando in una miniera egli avrebbe potuto escludere l'interferenza causata dai raggi cosmici, che avrebbero generato un fastidioso segnale di fondo. Il CCl_4 costituiva un comodo deposito di nuclei di ^{37}Cl, che dopo l'interazione con un neutrino si trasformano in argon (Ar), il quale doveva poi essere estratto e la sua quantità misurata. Dopo anni di duro lavoro, Davis rilevò solo un terzo del flusso previsto di neutrini solari. La comunità scientifica the experiment could detect Ar as efficiently as was claimed, others doubted the accuracy of the predicted neutrino flux.

non prese affatto bene l'insuccesso di Davis: alcuni si chiesero se l'esperimento fosse in grado di rilevare Ar con l'efficienza dichiarata, altri dubitarono dell'accuratezza del flusso di neutrini previsto.

These doubts were troubling because the experiment was sensitive to only a small minority of the neutrinos produced by the Sun: neutrinos produced by the fusion of protons don't have enough energy to transmute Cl into Ar; the more energetic neutrinos Davis hoped to detect came from other reactions whose rates are very temperature sensitive, and don't produce much of the Sun's energy. A small change in the rate at which heat is carried from the Sun's core could drastically lower the flux of these energetic neutrinos. So the experts re-examined their models of the Sun, but they were unable to reduce the flux of the higher energy neutrinos enough to be consistent with Davis's experiment.

Questi dubbi costituivano una fonte di preoccupazione, perché l'esperimento era sensibile solo a una piccola minoranza dei neutrini prodotti dal Sole: i neutrini prodotti dalla fusione dei protoni non hanno abbastanza energia per trasmutare il Cl in Ar; i neutrini più energetici che Davis sperava di rilevare provenivano da altre reazioni il cui tasso è molto sensibile alla temperatura e non contribuiscono in modo significativo alla produzione dell'energia solare. Una piccola variazione nella velocità di trasporto del calore dal nucleo del Sole potrebbe, di fatto, ridurre drasticamente il flusso di questi neutrini energetici. Gli esperti hanno quindi sottoposto ad ulteriore esame i loro modelli del Sole, ma non sono riusciti a ridurre il flusso dei neutrini più energetici in misura tale da essere coerenti con l'esperimento di Davis.

Another issue was that Davis's experiment was only sensitive to one type of neutrino: there are three kinds of neutrinos, associated with electrons, muons, and tau particles. Davies's

Un altro problema riguardava il fatto che l'esperimento di Davis fosse sensibile solamente ad un tipo di neutrino. Esistono, difatti, tre tipi di neutrini, associati a particelle di elettroni, muoni e tauoni, e experiment could detect only electron neutrinos. This should not have been a problem as the nuclear reactions were expect to produce electron neutrinos. But could somehow two thirds of the emitted neutrinos pass through Davis's lab as undetectable muon or tau neutrinos?

l'esperimento di Davis era in grado di rilevare solo i neutrini elettronici. Questo non avrebbe dovuto costituire un problema, dato che tipicamente i neutrini che si producono nelle reazioni nucleari sono di tipo elettronico. Ma è possibile che due terzi dei neutrini emessi abbiano attraversato il laboratorio di Davis come neutrini muonici o tau non rilevabili?

From the mid-1980s two huge neutrino detectors were built that use either water (H2O) or heavy water (D2O) as the detector. A major advantage of these detectors is sensitivity to all three types of neutrino. One of these detectors, the *Kamiokande II detector* in Japan, observed the burst of neutrinos from SN1987a, and the other, the *SNO detector* in Canada, showed that when all three neutrino types are counted, the flux of neutrinos from the Sun is consistent with the original model predictions. This result from the SNO detector confirmed the idea that as a neutrino makes its way out of the Sun, it morphs from an electron neutrino into the other kinds of neutrino, with the result that roughly equal numbers of the neutrinos of each kind reach the Earth. Thus the astrophysics of the Sun had been correct from the outset, and the problem with Davis's experiment lay with particle physics.

A partire dalla metà degli anni Ottanta, sono stati costruiti due enormi rivelatori di neutrini che utilizzano acqua (H_2O) o acqua pesante (D_2O) come bersaglio. Uno dei maggiori vantaggi di questi rivelatori è la sensibilità a tutti e tre i tipi di neutrini. Il primo, il giapponese *Kamiokande II*, ha osservato l'esplosione di neutrini emessi dalla SN1987a, mentre l'altro, il canadese *SNO*, ha dimostrato che quando vengono considerati tutti e tre i tipi di neutrini, il flusso di neutrini prodotti dal Sole concorda con quello calcolato nel modello originale. Il risultato ottenuto dal rivelatore SNO ha confermato l'idea che, quando un neutrino elettronico si allontana dal Sole, può trasformarsi in neutrino di un altro tipo, con il risultato che circa lo stesso numero di neutrini di ciascun tipo raggiunge la Terra. Pertanto, l'astrofisica del Sole era corretta fin dall'inizio e il problema dell'esperimento di Davis riguardava prettamente la fisica delle particelle.

The idea that neutrinos oscillate between the different types was first invoked to explain the outcome of solar-neutrino experiments, but later the process was studied in some detail using beams of neutrinos from nuclear reactors. It is a particularly important phenomenon because it implies that neutrinos have nonzero rest masses. Various experiments constrain the rest mass of the electron neutrino to a small value < 2eV but neutrino oscillations establish that neutrinos have non-zero rest masses.

L'idea che i neutrini oscillino, trasformandosi da un tipo all'altro, è stata presa in considerazione per la prima volta per spiegare i risultati degli esperimenti sui neutrini solari, ma successivamente il processo è stato studiato in dettaglio utilizzando fasci di neutrini generati da reattori nucleari. Si tratta di un fenomeno particolarmente importante perché implica che i neutrini abbiano masse a riposo non nulle. Diversi esperimenti vincolano la massa a riposo del neutrino elettronico a un valore molto piccolo, inferiore a 2 elettronvolt (< 2eV), ma le oscillazioni dei neutrini confermano che i neutrini hanno masse a riposo non nulle.

Stellar seismology

Stars like bells have natural frequencies at which they can oscillate. Each oscillation frequency is associated with a particular *mode* or type of oscillation. Bubbling associated with convection excites a star's modes of oscillation, and a great deal about the structure of a star can be learnt from measuring the spectrum of frequencies at which a star oscillates. Consequently, since about 1985 major observing programmes have monitored first the Sun and later nearby, relatively

L'astrosismologia

Le stelle possiedono frequenze naturali con cui oscillano, proprio come le campane, ed ogni frequenza di oscillazione è associata ad un particolare *modo* o tipo di oscillazione. Le bolle di convezione influiscono sul modo di oscillazione di una stella, tant'è che si può imparare molto sulla sua struttura misurando il suo spettro di frequenze di oscillazione. Per questo motivo, dal 1985 circa, hanno preso avvio importanti programmi di osservazione per monitorare prima il Sole e poi le stelle bright, stars to determine their oscillation spectra.

vicine e relativamente luminose, con l’obiettivo di determinarne i loro spettri di oscillazione.

A star’s modes are of two basic types. The easiest to appreciate are the *p-modes*. These are analogous to the modes of an organ pipe: a standing sound wave is set up that involves alternating compression and rarefaction of the air in the organ pipe or gas in the star. P-modes are of less interest astrophysically than the other type of mode, *g-modes*. These are a little like ocean waves: when a less dense fluid (air) sits on top of a denser fluid (water), waves in which the surface of the denser fluid oscillates above and below its equilibrium level can propagate over the interface between the two fluids. Waves on the surface of the ocean are associated with a discontinuity in fluid density, but within the body of the ocean there is often a continuous gradient in density associated with salinity: salty water is denser than fresh water so in equilibrium more saline water underlies less saline water, and waves that distort the contours of equal salinity move across the ocean.

Vi sono due tipi di oscillazione principali. I *modi P* rappresentano quelli più facili da apprezzare e sono molto simili ai modi di una canna d'organo: viene creata un'onda sonora stazionaria che alterna compressione e rarefazione dell'aria nel caso della canna d'organo o del gas nel caso della stella. I modi P sono meno interessanti dal punto di vista astrofisico rispetto all'altro tipo, i *modi G*. Questi assomigliano un po' alle onde oceaniche: quando un fluido meno denso (aria) si trova sopra un fluido con densità maggiore (acqua), le onde in cui la superficie del fluido più denso oscilla al di sopra e al di sotto del suo livello di equilibrio possono propagarsi lungo l'interfaccia tra i due fluidi. Le onde sulla superficie dell'oceano sono associate a una discontinuità nella densità del fluido, ma all'interno del corpo dell'oceano c'è spesso un gradiente continuo di densità associato alla salinità: l'acqua salata è più densa dell'acqua dolce, quindi in equilibrio l'acqua più salata tende ad andare sotto quella meno salata, e le onde che alterano le linee di uguale salinità si muovono attraverso l'oceano.

In a star, gas that has lower *entropy* underlies gas of higher entropy. Entropy is

In una stella, il gas che ha un'*entropia* minore si sposta al di sotto di un gas con a measure of the thermal disorder in a fluid; it is increased by conducting heat into the fluid and decreased by extracting heat from it. It is distinct from temperature in that when air is compressed in a bicycle pump or the cylinder of a diesel engine, the air’s temperature rises, but its entropy stays the same. Waves in which the surfaces of constant entropy oscillate up and down propagate around the star in the same way that waves in the surfaces of constant salinity propagate through the ocean. G-modes are standing waves of this type.

Oil companies prospect for oil by launching seismic waves with explosions and detecting the waves at remote sensors. A computer subsequently deduces the density and elastic properties of the rocks in the region from how the waves have travelled through the Earth from the source to the detectors. The pattern of frequencies of a star’s oscillation modes is similarly sensitive to the density and rotation velocity of gas at different levels within the star, so with appropriate software one can constrain the density and rotation velocity within the star. These values can be compared with the

un'entropia maggiore. L'entropia misura il grado di disordine termico di un fluido, che può aumentare quando il calore viene condotto nel fluido e diminuire quando, invece, il calore viene estratto da esso. Si distingue dalla temperatura in quanto, quando l'aria viene compressa in una pompa per bicicletta o nel cilindro di un motore diesel, la sua temperatura aumenta, mentre la sua entropia rimane invariata. Le onde in cui le superfici di entropia costante oscillano verso l'alto e verso il basso si propagano attorno alla stella nello stesso modo in cui le onde nelle superfici di salinità costante si propagano nell'oceano. I modi G sono onde stazionarie di questo tipo.

Le compagnie petrolifere cercano il petrolio generando onde sismiche da esplosioni e rilevandole attraverso sensori remoti. Successivamente, un computer deduce la densità e le proprietà elastiche delle rocce della regione, in base al modo in cui le onde si sono propagate attraverso la Terra dal punto di origine al rilevatore. L'andamento delle frequenze dei modi di oscillazione di una stella è altrettanto sensibile alla densità e alla velocità di rotazione del gas a diversi livelli all'interno della stella, pertanto è possibile vincolare la densità e la velocità di rotazione all'interno della stella predictions of theoretical models. The major uncertainty in the models is the star's age, which must in practice be estimated by matching models to the observational data, and the star's spectrum of normal modes most strongly constrains the age because as a star ages, its central concentration increases: the core contracts, growing hotter and denser, while the envelope expands. This evolution changes the pattern of oscillation frequencies.

servendosi di un software apposito. Questi valori possono essere confrontati con le previsioni dei modelli teorici, la cui incertezza maggiore è rappresentata dall'età della stella, che nella pratica deve essere stimata facendo corrispondere i modelli ai dati osservativi. Inoltre, lo spettro dei modi normali di oscillazione della stella vincola in modo molto forte l'età, poiché, quando una stella invecchia, la sua concentrazione centrale aumenta: il nucleo si contrae, diventando più caldo e denso, mentre l'involucro si espande. Questa evoluzione modifica l'andamento delle frequenze di oscillazione.

The seismology of the Sun has demonstrated that models of the Sun that are founded on a wide range of data from nuclear and atomic physics work very well but not perfectly. Small discrepancies between the predictions of the models and the seismographic findings probably arise from limitations of the atomic data, or the stellar models. But it's just possible that they point to completely new physics being involved in the transport of energy out of stars: 'dark-matter' particles (Chapter 7) could become trapped inside stars and on account of their low propensity to scatter off other particles contribute disproportionately to the outward transport of heat.

L'eliosismologia ha dimostrato che i modelli del Sole basati su un'ampia gamma di dati di fisica nucleare e atomica funzionano molto bene, ma non perfettamente. Le piccole discrepanze tra le previsioni dei modelli e i risultati sismografici derivano probabilmente da limitazioni dei dati atomici o dei modelli stellari. Tuttavia, è possibile che queste implichino il coinvolgimento di una fisica completamente nuova nel trasporto di energia fuori dalle stelle: le particelle di 'materia oscura' (Capitolo 7) potrebbero rimanere intrappolate all'interno delle stelle, a causa della loro bassa tendenza alla dispersione di altre particelle, contribuendo in modo sproporzionato al trasporto di calore verso l'esterno.

Binary stars

At least half of all stars are members of a binary system, and the existence of binary stars is a major issue for the theory of stellar evolution because when the more massive, faster evolving, star swells up as it becomes a red giant star, its companion is liable to grab gas from the swelling envelope. This theft causes both stars to deviate from the evolutionary path we have described for single stars because mass is a key determinant of stellar evolution, and now each star's mass has become a function of time.

Le stelle binarie

Almeno la metà di tutte le stelle è parte di un sistema binario, e l'esistenza di stelle binarie è una questione di rilievo per la teoria dell'evoluzione stellare, poiché, quando la stella più massiva e in rapida evoluzione si espande sino a diventare una gigante rossa, la sua compagna tende a sottrarre il gas dall'involucro in espansione. A causa di questo furto, entrambe le stelle si discostano dal percorso evolutivo che abbiamo descritto per le stelle singole, perché la massa è un parametro determinante nell'evoluzione stellare, mentre in questo caso la massa di ogni stella diventa una funzione del tempo.

As material falls onto the more compact, less massive star, energy is radiated (Chapter 4). Some of this radiation heats the outer layers of the more massive star, and they may become hot enough to escape from the binary altogether as a wind.

Quando il materiale viene trasferito alla stella più compatta e meno massiccia, viene irradiata energia (Capitolo 4). Una parte di tale radiazione riscalda gli strati esterni della stella più massiccia, che possono diventare abbastanza caldi da fuoriuscire completamente dalla binaria sotto forma di vento.

Both the transfer of mass from one star to the other and loss of gas in a wind will change the binary's orbit and can draw the two stars closer together. If the stars do move closer, the rate of transfer or ejection

Sia il trasferimento di massa da una stella all'altra sia la perdita di gas nel vento modificano l'orbita della binaria e possono avvicinare le due stelle. Se ciò accade, il tasso di trasferimento o di

of matter will accelerate, so these processes can run away and lead to the two stars merging. In fact the more massive star may envelop the less massive star in its swelling envelope even if the binary's orbit does not evolve up to that point.	espulsione di materia accelera, portando ad una situazione fuori controllo che potrebbe causare la fusione delle due stelle. In effetti, la stella più massiccia potrebbe avvolgere la sua compagna meno massiccia nel suo involucro in espansione, anche se l'orbita della binaria non si evolve fino a quel punto.
Once the less massive star is inside the more massive star, its orbital motion will be opposed by friction. The envelope will be heated and the less massive star will spiral inwards. After a time the system will have become a single star, but neither the star's core nor its envelope could have been produced by the evolution of a single star.	Una volta che la stella meno massiccia si trova all'interno di quella più massiccia, il suo moto orbitale viene contrastato dall'attrito. L'involucro si riscalda e la stella meno massiccia si muove a spirale verso l'interno. Dopo un certo tempo, il sistema si sarà evoluto come stella singola, senza però che né il nucleo né l'involucro della stella siano stati generati da questa evoluzione.
In short, close binary stars constitute a Pandora's box of complexities, and attempts to understand the contents of this box are an active area of research.	In breve, le stelle binarie strette costituiscono un vaso di Pandora di complessità e gli sforzi per comprenderne il contenuto rappresentano un'area di ricerca attiva.

3.3. Translation process: difficulties and strategies

After presenting the final translation, in this very last section the focus will be on the translation process, which will be accurately described considering both the difficulties encountered and the strategies adopted to face them. To begin with, some general considerations should be made, always keeping in mind the theory related to specialised translation and, more specifically, the translation of popular science texts discussed in Chapter 2.

As suggested by Musacchio (2007: 102), the ST organisation in paragraphs is faithfully reproduced in the Italian translation, along with other visual choices made by the author, including the use of bold font for titles and descriptions below figures, italics for terms to be highlighted within the text, inverted commas to refer to the titles of other chapters' subsections cited in the text, and other symbols related to formulae. Moreover, since the word 'universe' appears in the ST either capitalised or uncapitalised, the capital letter is always used in the TT for the sake of consistency.

Since this is a popular astrophysics book, whose aim is to also involve a public of non-experts, the first and second person pronouns used by Binney have also been kept in the translation. In fact, as already explained, they represent the author's desire to address his readership directly. Unlike Italian specialised texts, which are mainly characterised by emotional neutrality and impersonality, addressing the audience directly can constitute a strategy to make them understand the content of the text more effectively, notwithstanding the difficulty of the specialised subject matter. As the following example shows, the first personal pronoun plural 'we' is reproduced in the translation:

(1) We detect about a billion stars individually, as tiny unresolved points of light, and a billion billion more as contributors to the light coming from galaxies so distant that we cannot distinguish individual stars in the great agglomerations of stars that galaxies are.

Riusciamo a rilevare circa un miliardo di stelle individualmente, simili a minuscoli punti di luce perpetui, e un altro miliardo di miliardi di stelle che contribuiscono alla luce proveniente da grandi agglomerati, chiamati galassie, che sono talmente distanti da non permetterci di distinguere le singole stelle che li costituiscono.

As this sentence demonstrates, sometimes some changes are required to make the text stylistically compact and avoid unnecessary repetitions that would not sound good in the TT. In this case, the repetition of 'galaxies' could be avoided in the translation, by using a structure that allows to anticipate the explanation of the term, which occurs at the end of the sentence in the ST. Moreover, it is worth noting that the noun 'contributors' in the ST has been transposed into the TT with a verb, which is much more commonly used in Italian texts of this kind.

Syntactic paraphrase has been used in other cases, namely:

(2) To this day our most important **probes** of the universe are telescopes that gather either visible photons or photons with only slightly longer wavelengths (infrared photons).

Ad oggi i principali strumenti che **ci permettono** di sondare l'Universo sono telescopi che raccolgono sia i fotoni visibili sia quelli che possiedono lunghezze d'onda solo leggermente superiori (fotoni infrarossi).

(3) Because neutrinos have incredibly small cross sections for colliding with anything (page 6), they move significant distances between collisions even in the **stupendously dense** centre of the star.

Poiché i neutrini hanno sezioni d'urto incredibilmente piccole di collisioni con qualsiasi cosa (pagina 6), si spostano per lunghe distanze tra una collisione e l'altra, perfino nel centro della stella che possiede una **densità elevatissima**.

In example (2) the noun 'probes' has been changed into the verb 'ci permettono', while in example (3) the adjective 'stupendously dense' into the noun 'densità elevatissima'. Nominalisation occurs much more frequently – also as a tool to avoid repetition, as in example (6) – as shown in the following six examples:

(4) After the density **has increased** by an enormous factor, of an order of a million million (1012), photons emitted by atoms and molecules start to have trouble escaping from the cloud because they are scattered by molecules and dust grains after going only a small distance through the dense mass of gas and dust.

A seguito dell'**aumento** di densità di un fattore enorme, dell'ordine di un milione di milioni (1012), i fotoni emessi dagli atomi e dalle molecole iniziano ad avere difficoltà ad uscire dalla nube poiché, dopo aver percorso solo una breve distanza all'interno di questa densa massa di gas e polvere, vengono dispersi da molecole e grani di polvere.

(5) If a cloud is sufficiently massive, the temperature and density are eventually sufficient to ignite *nuclear burning*, energy release by **transmuting** hydrogen to helium, and then helium nuclei into heavier nuclei such as carbon, silicon and iron.

Se una nube è sufficientemente massiccia, riesce prima o poi, attraverso la sua temperatura e la sua densità, ad innescare la *fusione nucleare*, con emissione di energia mediante la **trasmutazione** dell'idrogeno in elio e, successivamente, dei nuclei di elio in nuclei di elementi più pesanti come carbonio, silicio e ferro.

(6) Stars initially more massive than 8 M⊙ but less massive than ~ 50M⊙ **burn** carbon to silicon and then silicon to iron.

Le stelle con massa iniziale maggiore di 8 M⊙ ma inferiore a ~ 50 M⊙ **bruciano** il carbonio trasformandolo in silicio, la cui successiva **fusione** conduce alla produzione di ferro.

(7) Eventually, this radiation contains a significant number of photons that are energetic enough to **blast** an atomic nucleus to pieces (*photo-dissociate* it).

Alla fine, tale radiazione contiene un numero considerevole di fotoni abbastanza energetici da causare la **frammentazione** di un nucleo atomico (facendolo *fotodissociare*).

(8) Every time two protons **fuse** in the Sun to make deuterium that shortly afterwards produces helium, a neutrino is produced that escapes from the Sun.

Ogni volta che all'interno del Sole avviene la **fusione** di due protoni con conseguente produzione di deuterio, che poco dopo viene convertito in elio, viene prodotto un neutrino che sfugge dal Sole.

(9) In the case of SN1987a the optical luminosity **peaked** three months after the core imploded—we know when the latter happened because the blast of neutrinos as the core bounced was detected. (To date SN1987a is the only supernova from which we have detected neutrinos.)

Nel caso di SN1987a, la luminosità ottica ha raggiunto il suo picco tre mesi dopo l'implosione del nucleo: sappiamo che ciò è avvenuto perché è stata rilevata l'esplosione di neutrini durante il rimbalzo del nucleo (SN1987a è l'unica supernova di cui finora abbiamo osservato i neutrini).

As already argued, the Italian language tends to use connectors, conjunctions, and anaphoric and cataphoric reference more than English, in order to make the text sound more formal, cohesive, smoother, and easier to read in general. Sentence (4) above also shows an example of anaphoric reference, since the phrase 'the dense mass of gas and dust' refers to the 'cloud' that had been previously mentioned, so that in the TT the demonstrative adjective 'questa' has been added to highlight the link between the two elements. Another example of this kind is the following, where the term 'detector' appears seven times and, in some cases, it has been rendered in the TT either omitting it or translating it as 'bersaglio' rather than 'rivelatore' (which appears only three times), since it was the most appropriate term basing on the specific context:

(10) From the mid-1980s two huge neutrino **detectors** were built that use either water (H2O) or heavy water (D2O) as the **detector**. A major advantage of these **detectors** is sensitivity to all three types of neutrino. One of these **detectors,** the *Kamiokande II* ***detector*** in Japan, observed the burst of neutrinos from SN1987a, and the other, the *SNO* ***detector*** in Canada, showed that when all three neutrino types are counted, the flux of neutrinos from the Sun is consistent with the original model predictions. This result from the SNO **detector** confirmed the idea that as a neutrino makes its way out of the Sun, it morphs from an electron neutrino into the other kinds of neutrino, with the result that roughly equal numbers of the neutrinos of each kind reach the Earth.

A partire dalla metà degli anni Ottanta, sono stati costruiti due enormi **rivelatori** di neutrini che utilizzano acqua (H_2O) o acqua pesante (D_2O) come **bersaglio**. Uno dei maggiori vantaggi di questi **rivelatori** è la sensibilità a tutti e tre i tipi di neutrini. Il **primo**, il giapponese *Kamiokande II*, ha osservato l'esplosione di neutrini emessi dalla SN1987a, mentre **l'altro**, il canadese *SNO*, ha dimostrato che quando vengono considerati tutti e tre i tipi di neutrini, il flusso di neutrini prodotti dal Sole concorda con quello calcolato nel modello originale. Il risultato ottenuto dal **rivelatore** SNO ha confermato l'idea che, quando un neutrino elettronico si allontana dal Sole, può trasformarsi in neutrino di un altro tipo, con il risultato che circa lo stesso numero di neutrini di ciascun tipo raggiunge la Terra.

In some cases, the translator has to add some elements to make the information clearer and more precise. For instance, the phrase 'heavier nuclei' in sentence (5) above should be rendered as 'nuclei di elementi più pesanti' to achieve maximum accuracy. In addition, the order of some constituents within this sentence has been changed in order not to translate ‘sufficient’ literally after ‘sufficiently’, making the discourse smoother. The same happens in the following examples:

(11) Nearly all the atom’s mass is contained in the nucleus, which is only ∼ 10 −15 m across.

Quasi tutta la massa dell'atomo è contenuta nel nucleo, il cui **diametro** misura soli $\sim 10^{-15}$ m.

(12) The temperature of material **in** the Sun falls steadily all the way from the centre to the top of the photosphere—the visible surface—where it is about 4,500 K.

La temperatura dei materiali **che compongono** il Sole si abbassa con costanza dal centro fino alla sommità della fotosfera, la sua superficie visibile, dove raggiunge i 4.500 K circa.

(13) Various experiments constrain the rest mass of the electron neutrino to **a small value < 2eV** but neutrino oscillations establish that neutrinos have non-zero rest masses.

Diversi esperimenti vincolano la massa a riposo del neutrino elettronico a **un valore molto piccolo, inferiore a 2 elettronvolt (< 2eV)**, ma le oscillazioni dei neutrini confermano che i neutrini hanno masse a riposo non nulle.

By searching for parallel texts on the internet, it is possible to notice that the measurement cited in example (11) refers to the diameter of the nucleus, so much so that it is worth specifying it in the translation, addressed to a lay audience. The ‘material in the Sun’ in example (12) has been translated as ‘materiali che compongono il Sole’ because it was considered more precise. Furthermore, the author often uses abbreviations, which may be unknown to an Italian public of non-experts, without specifying their meaning. Therefore, it was considered appropriate to adapt those elements to the target audience, as shown in the following examples:

(14) The Sun has been burning hydrogen in its core for 4.6 **Gyr** and it is only half way through the process.

Il Sole sta bruciando idrogeno nel suo nucleo da 4,6 **miliardi di anni** ed è solo a metà del processo.

(15) Consequently, while a star of mass 0.6 M⊙ will remain on the main sequence for 78**Gyr**, nearly six times the age of the universe, a 20 M⊙ star will be on the main sequence for just 8.5**Myr**.

Di conseguenza, mentre una stella di massa 0,6 M⊙ permarrà nella sequenza principale per 78 **miliardi di anni**, quasi sei volte l'età dell'Universo, una stella di 20 M⊙ permarrà in questa fase di stabilità per soli 8,5 **milioni di anni**.

Example (15) also introduces another strategy that aims at avoiding repetitions within the same sentence, i.e. the use of a synonym that replaces the specific term (‘main sequence’) with a more general one belonging to the TL (‘fase di stabilità’). The same strategy has been adopted in examples (16) and (17) as follows:

(16) The vertical brightness scale is always logarithmic, so changing the assumed distance to the cluster shifts the **isochrone** along which stars are predicted to lie up (for reduced distance) or down without distorting the **isochrone**'s shape in any way.

La scala verticale della luminosità è sempre logaritmica, quindi cambiando la presunta distanza dall'ammasso si sposta l'**isocrona**, lungo la quale si prevede che siano disposte le stelle, verso l'alto (per distanze ridotte) o verso il basso, senza distorcere in alcun modo la forma della **curva**.

(17) Consequently the density does not decrease as the nuclei are heated, and **the rate of nuclear reactions spirals out of control**. The technical term for the way **the rate of nuclear reactions runs away** is *deflagration*, a kind of slow explosion in which a front of enhanced temperature and reaction rate moves through the medium at a speed that is slower than the speed of sound.

Di conseguenza, la densità non diminuisce quando i nuclei vengono riscaldati e **diventa impossibile controllare il tasso di reazioni nucleari**. Il termine tecnico per indicare **tale condizione** è *deflagrazione*, una forma di lenta esplosione il cui fronte, caratterizzato da un aumento della temperatura e della velocità di reazione, si muove attraverso il corpo al di sotto della velocità del suono.

Sentence (18) below represents another way to reduce repetitions, since the verb 'to rise', that appears twice, has been conjugated in the plural form in the TT:

(18) As the core contracts, its temperature **rises** and the average energy of the photons in the ambient black-body radiation (page 28) **rises**.

Quando il nucleo si contrae, **aumentano** sia la sua temperatura sia l'energia media dei fotoni presenti nella radiazione del corpo nero dell'ambiente circostante (pagina 28).

Among the difficulties encountered during the translation process, it is worth mentioning the two sentences containing the emphatic 'do', which is used in English to give extra force to the main verb and is generally rendered as 'sì', 'proprio', 'eccome' and 'davvero' in Italian. In sentence (19) it has been omitted because the resulting Italian sentence would have sounded unnatural with one of the alternatives previously mentioned, while in sentence (20) it has been expressed through an adverb:

(19) The sudden release of energy by all this burning ***does*** **produce** enough pressure to overwhelm gravity and the star flies apart, leaving no gravitationally bound object where it was.

L'improvviso rilascio di energia da parte di tutta questa combustione **produce** una pressione sufficiente a sopraffare la gravità, al punto che la stella arriva a disintegrarsi, senza lasciare dietro di sé alcun oggetto gravitazionalmente legato.

(20) Nevertheless, slight discrepancies **do arise**, and astronomers continue to refine the data and assumptions that go into stellar modelling to diminish these discrepancies.

Ciononostante, **inevitabilmente si verificano** lievi discrepanze, motivo per cui gli astronomi continuano a perfezionare i dati e le previsioni della modellazione stellare proprio con l'intento di ridurre tali discrepanze.

Some of the main challenging translation problems have concerned syntax, as the sentences often needed to be completely reorganised to appear smoother and more comprehensible to an Italian lay audience, as in the following two examples:

(21) Since main-sequence stars are smaller than they will become once they have depleted their core hydrogen, they are called *dwarf stars*, and they will evolve into *red giant stars*.

Dato che le stelle di sequenza principale, che non hanno ancora esaurito l'idrogeno all'interno del proprio nucleo, sono più piccole, vengono chiamate *stelle nane*. Quando avranno esaurito queste scorte di idrogeno, si evolveranno in *stelle giganti rosse*.

(22) Hence the brightness of the star varies with wavelength and the star's spectrum contains spectral lines. The shape of these lines conveys information about radial gradients in density and temperature around the photosphere.

La luminosità della stella varia, quindi, in base alla lunghezza d'onda ed al suo spettro. Quest'ultimo contiene delle righe spettrali, la cui forma fornisce informazioni sui gradienti di densità e di temperatura radiali attorno alla fotosfera.

In certain cases, it was necessary to separate two clauses within the same sentence (examples 23, 24, 26, 27), or to join them (examples 25, 31, 32), change the constituents' order (example 26) or the diathesis (example 30), or create a relative clause (example 29), in order to make the text more cohesive:

(23) The most massive stars have masses $\sim 80M_\odot$, and the masses of stars extend down to below the mass $\sim 0.01M_\odot$ at which a star is too faint to detect at any point in its life.

Le stelle più massive hanno masse di $\sim 80M_\odot$. Le masse delle stelle possono estendersi fino a valori inferiori a $\sim 0{,}01M_\odot$, non permettendo la rilevazione della stella in alcun momento della sua vita, a causa della sua scarsa luminosità.

(24) When two atoms collide, the orbits of the electrons deform so the distribution of negative charge surrounding each nucleus changes, and the nuclei experience electrostatic forces that deflect them from their original straight-line trajectories.

Quando due atomi si scontrano, le orbite degli elettroni si deformano, variando la distribuzione della carica negativa attorno a ciascun nucleo. Di conseguenza, i nuclei subiscono forze elettrostatiche che li deviano dalla loro traiettoria rettilinea originale.

(25) But eventually the collisions are so violent that some colliding nuclei actually touch. At this point nuclear reactions start to take place.

Tuttavia, ad un certo punto, le collisioni diventano così violente che alcuni nuclei in collisione arrivano a toccarsi ed iniziano a verificarsi le reazioni nucleari.

(26) Once the hydrogen in a star's core has been consumed, hydrogen burning occurs in a spherical shell around the helium core and the core grows more massive, contracts and becomes hotter.

Dopo che la stella ha consumato l'idrogeno nel nucleo, l'idrogeno comincia a fondere in uno strato sferico che circonda il nucleo di elio. Di conseguenza, il nucleo si contrae e diventa più caldo e massiccio.

(27) Meanwhile, the dense gas in which the two ends of the loop is embedded flows over the Sun's surface in response to both convection and the systematic rotation of the Sun, and the field lines that make up the loop often become tangled in the sense that field lines that are moving in quite different directions are dragged close to one another.

Nel frattempo, il gas denso in cui si trovano le due estremità dell'anello fluisce sulla superficie del Sole in risposta sia alla convezione sia alla rotazione sistematica del Sole. Le linee di campo che compongono l'anello spesso si aggrovigliano: ciò avviene perché linee di campo che si muovono in direzioni molto diverse vengono trascinate l'una vicino all'altra.

(28) In the 1960s Ray Davis set out to detect neutrinos from the Sun, arguing that their detection would be an important test of the theory of stellar evolution since they come to us direct from the Sun's energy-generating core and thus probe an entirely different region from the photosphere, from which we receive photons.

Negli anni Sessanta, Ray Davis decise di rilevare i neutrini provenienti dal Sole. Egli sostenne che la loro rilevazione sarebbe stata un'importante prova della teoria dell'evoluzione stellare, poiché i neutrini giungono sulla Terra direttamente dal nucleo del Sole, che produce energia, sondando una regione completamente diversa dalla fotosfera, quella da cui i fotoni giungono a noi.

(29) Entropy is a measure of the thermal disorder in a fluid; it is increased by conducting heat into the fluid and decreased by extracting heat from it.

L'entropia misura il grado di disordine termico di un fluido, che può aumentare quando il calore viene condotto nel fluido e diminuire quando, invece, il calore viene estratto da esso.

(30) It turns out that two completely different mechanisms can generate a supernova.

È emerso che una supernova può avere origine da due meccanismi completamente diversi.

(31) It is by this glow that we detect deflagration supernovae. They are generally called *type Ia SNe* from the empirical classification of their optical spectra.

È da questo bagliore che rileviamo le supernove da deflagrazione, generalmente chiamate *SNe di tipo Ia* sulla base della classificazione empirica dei loro spettri ottici.

(32) Another issue was that Davis's experiment was only sensitive to one type of neutrino: there are three kinds of neutrinos, associated with electrons, muons, and tau particles. Davies's experiment could detect only electron neutrinos.

Un altro problema riguardava il fatto che l'esperimento di Davis fosse sensibile solamente ad un tipo di neutrino. Esistono, difatti, tre tipi di neutrini, associati a particelle di elettroni, muoni e tauoni, e l'esperimento di Davis era in grado di rilevare solo i neutrini elettronici.

For some specialised terms, several translation alternatives were possible in Italian, but of course those more frequently used in parallel texts have been chosen. In more detail, in sentence (33) the term 'time-domain astronomy' could be translated as ‘astronomia nel dominio del tempo’, ‘astronomia temporale’, ‘astronomia degli eventi transienti’; in example (34) ‘thermal motion’ has four translation alternatives in Italian, i.e. ‘moto termico’, ‘moto di agitazione termica’, ‘moto browniano’, and ‘agitazione termica’ that best gives the idea of a disordered motion; lastly, in example (35) ‘tau neutrinos’ can be rendered as ‘neutrini tauonici’, ‘neutrini tau’, ‘neutrini del tau’.

(33) Accretion discs of this type are studied by their X-ray emission (Chapter 4, ‘**Time-domain astronomy’**).

I dischi di accrescimento di questo tipo sono studiati attraverso le loro emissioni di raggi X (Capitolo 4, sezione ‘**Astronomia nel dominio del tempo’**).

(34) If the **thermal motion** of the nuclei were making a significant contribution to the pressure within the star, the star would respond to the heat input from nuclear reactions by expanding and cooling, both of which changes would slow the rate of nuclear reactions, and the system would be stable.

Se l’**agitazione termica** dei nuclei contribuisse in modo significativo alla pressione all'interno della stella, quest'ultima risponderebbe al calore generato dalle reazioni nucleari espandendosi e raffreddandosi, entrambi cambiamenti che rallenterebbero il tasso di reazioni nucleari rendendo il sistema stabile.

(35) But could somehow two thirds of the emitted neutrinos pass through Davis’s lab as undetectable muon or **tau neutrinos**?

Ma è possibile che due terzi dei neutrini emessi abbiano attraversato il laboratorio di Davis come **neutrini** muonici o **tau** non rilevabili?

The text is rich of phrasal verbs which were very difficult to translate into Italian, in fact it was often not possible to convey their full meaning, with all its nuances, as the following extract demonstrates:

(36) As the temperature rises at the centre of a forming star, the atoms **whizz about** faster and faster and the violence of their collisions steadily increases. Electrons **are knocked clean out** of atoms so more and more nuclei **become bare**.

Quando la temperatura al centro di una stella che si sta formando aumenta, gli atomi **sfrecciano** sempre più velocemente e la violenza delle loro collisioni aumenta con costanza. Gli elettroni vengono letteralmente **spazzati via** dagli atomi, quindi sempre più nuclei **ne vengono privati**.

Here the meaning of the verb ‘to whizz’, which in Oxford Learner’s Dictionary is explained as “to move very quickly, making a high, continuous sound”, has been rendered as ‘sfrecciare’ into the TL, although some of the nuances related to the sound conveyed by the English verb got unavoidably lost. Moreover, Oxford Learner’s Dictionary provides several explanation for the phrasal verb ‘to knock out’, and the most appropriate ones for this sentence are “(in boxing) to hit an opponent so that they cannot get up within a limited time and therefore lose the fight” and “to defeat somebody so that they cannot continue competing” (synonym: ‘to eliminate’). Since the verb acquires a metaphorical meaning in this context, reinforced by the use of ‘clean’, it has been translated as ‘spazzare via’ in Italian. Finally, the expression ‘to become bare’ refers to the nuclei that lose all their electrons, due to the action of the atoms.

It can be concluded that the major difficulties concerned the figurative language widely employed by the author. One example of this can be found at the very beginning of the chapter, where in ‘Star formation’ he speaks of ‘seeds’ to refer to the regions of runaway density that arise in an interstellar cloud, capable of ‘seeding’, i.e. forming a star. As it may be seen below, ‘seeds’ has been translated literally as ‘semi’ in the TT, but with the addition of the inverted commas:

(37) When an interstellar cloud suffers a runaway increase in its density, it does not form one star but a whole group of stars. We do not understand completely this process of fragmentation, but it is an important empirical fact. Within the deforming interstellar cloud several regions of runaway density arise, each capable of **seeding a star**. The rates at which these **seeds** accumulate mass varies greatly, with the result that a few give rise to massive stars and many give rise to low-mass stars.

Quando una nube interstellare subisce un aumento incontrollato della sua densità, non forma una sola stella, ma un intero gruppo di stelle. Non comprendiamo completamente questo processo di frammentazione, tuttavia è un importante fatto empirico. All'interno della nube interstellare in fase di deformazione, si formano diverse regioni di densità crescente, ognuna delle quali in grado di **originare una stella**. La velocità con cui questi **‘semi’** accumulano massa varia notevolmente, con il risultato che alcuni danno origine a stelle massive e molti altri a stelle di piccola massa.

Another metaphorical expression that was very difficult to translate into Italian was ‘to settle to business’, which has been interpreted as the temperature reached by some type of stars, which is hot enough to trigger nuclear fusion reactions:

(38) A star more massive than 0.08 $M_\odot$ now **settles to the business** of nuclear burning.

Una stella con massa superiore a 0,08 $M_\odot$ **raggiunge una temperatura tale da innescare** reazioni di fusione nucleare.

As already stressed, the author uses metaphors and similes to help his lay readership better understand a number of difficult astrophysics concepts, making the tone of the text much more colloquial and quite friendly, also offering useful examples of everyday life. Some examples are provided below, which have been naturally adapted to the target language and culture:

(39) The energy scale of nuclear reactions is a million times larger than that of the chemical reactions that **power our bodies and our cars**. So the release of energy by nuclear reactions in the core of a cloud is a **game changer**.

La scala di energia delle reazioni nucleari è un milione di volte più grande di quella delle reazioni chimiche che **alimentano i nostri corpi e le nostre automobili**. Pertanto, il rilascio di energia nel nucleo di una nube da parte delle reazioni nucleari **segna un punto di svolta**.

(40) Massive stars are **spendthrifts**: the bigger the **inheritance** of fuel they have at birth, the sooner they **are bankrupt** by virtue of having consumed that fuel.

Le stelle massive sono **spendaccione**: maggiore è l'**eredità** di combustibile che hanno alla nascita, prima **lo esauriscono** consumandolo tutto.

(41) Hence the star is on a **slippery slope**: contraction drives up the temperature, which leads to more electrons being captured and more photo-dissociation of nuclei, which inevitably lead to further contraction. Within a few milliseconds the core is in free fall and cataclysm is inevitable.

La stella si trova quindi su **una sorta di pendio scivoloso**: la contrazione fa aumentare la temperatura, cosa che porta alla cattura di un numero maggiore di elettroni ed alla fotodissociazione dei nuclei, il che inevitabilmente porta ad un'ulteriore contrazione. In pochi millisecondi, il nucleo è in caduta libera e la catastrofe diventa inevitabile.

(42) The reason the surface temperature drops as the luminosity rises, is that the increased flux of nuclear energy flowing from the hydrogen-burning shell **puffs** the star's enveloping gas **into a bloated heaving body of gas** in which energy is less transported by outward diffusion of photons that by convection.

Il motivo per cui la temperatura superficiale cala all'aumentare della luminosità è che il maggior flusso di energia nucleare prodotta dal guscio che brucia l'idrogeno fa sì che il gas che avvolge la stella **si espanda in una densa e grande massa di gas**, in cui l'energia viene trasportata più per convezione, meno attraverso la diffusione dei fotoni verso l'esterno.

(43) In fact the gas density in this region is likely to be anomalously high, because before the star imploded as a supernova it was **blowing off** mass quite fast **as a wind.** The **blast wave** from the exploding star ploughs into the wind and **shock** heats it.

In effetti, è probabile che la densità del gas in questa regione sia anomala (troppo alta), perché prima che la stella esplodesse in supernova stava **soffiando via** massa abbastanza velocemente, **proprio come un vento**. L'**onda d'urto** provocata dall'esplosione della stella si propaga verso il vento e lo riscalda.

Example (39) makes a comparison between the energy released by nuclear reactions and that powering human bodies and cars, describing the former as a 'game changer', in the sense that it is so massive "that completely changes the way a situation develops" (Oxford Learner's Dictionary 2023) – in a cloud's nucleus, in this case. This may be rendered into Italian either as 'segnare un punto di svolta' or 'cambiare le carte in tavola'. Example (40) basically explains, by means of an analogy, how massive stars tend to consume the fuel they have stored from their birth very quickly: the greater the amount of this fuel, the faster it is consumed, and the star is no longer capable of storing it. Moreover, the Italian expression ‘una sorta di’ has been added accompanying the translation of the onomatopoeic noun ‘slippery slope’ in sentence (41), in order to highlight the analogy. The translation of the verb ‘to puff into’ in sentence (42) was very challenging, as it means “to distend with or as if with air or gas” (Merriam-Webster 2023). Therefore, it literally means ‘gonfiare’ in Italian, but in this case it can be interpreted as the action of nuclear energy that enlarges the star’s enveloping gas generating a huge body full of gas. The adjectives ‘bloated’ and ‘heaving’ are quite similar, as the former means “full of liquid or gas and therefore bigger than normal, in a way that is unpleasant”, and the latter simply “full of somebody/something” (Oxford Learner’s Dictionary 2023). For this reason, it has been translated as ‘densa e grande massa di gas’ in the TT. Lastly, in example (43), the gas density is described as a wind that blows off mass, so a literal translation has been proposed; as regards the second sentence of the example, the word ‘shock’ has been omitted in the TT, because it would have been a repetition – as ‘blast wave’ means ‘onda d’urto’ and ‘shock’ means ‘urto’.

With respect to figurative language, significant are the last two examples below, since in (44) a process is described as a journey, while in (45) the death of a star is explained as ‘the end of its story’:

(44) Convection carries much of the heat generated in the Sun’s core on **the last stage of its journey** to the surface. Blobs of hot gas rise from 210,000 km below the photosphere, come to rest in the photosphere and there cool by radiating into space.

La convezione trasporta gran parte del calore generato all’interno del nucleo del Sole durante **l’ultima tappa del suo viaggio** verso la superficie. Sacche di gas caldo risalgono da 210.000 km al di sotto della fotosfera, dove si fermano e si raffreddano irradiandosi nello spazio.

(45) If the star has no companion, **that is the end of its story**. The majority of stars do have a companion, however, and then the future can be much more exciting.

Se la stella non ha una compagna, **è giunta alla fine della sua vita**. Ma la maggior parte delle stelle possiede una compagna, e in questo caso il futuro è molto più emozionante.

CONCLUSIONS

The purpose of this thesis was to provide a translation from English into Italian of *Chapter 3: Stars* of the popular science book *Astrophysics: A Very Short Introduction*, written by the astrophysicist James Binney and published on March 24, 2016 by Oxford University Press.

As the author explains in the book, "most of what we know about the Universe has been gleaned from a study of stars", therefore it is of paramount importance that also non-experts acquire a basic knowledge of the main principles of physics which are necessary to explain the origin and evolution of celestial objects and phenomena, so to understand the functioning of the Universe as a whole. For this reason, scientific popularisation is nowadays an essential tool to help the lay audience understand technical and scientific information, and to engage people by developing a scientific culture. In particular, domains like astronomy, astrophysics and cosmology function like 'science catcher' and make people feel like citizens of this planet. Furthermore, popular science translation should be investigated in depth, as it is inevitably related to a number of other types of public discourses, namely the economic, cultural or political discourses.

The thesis has been structured into three chapters, each one being divided into three subsections. First of all, it was necessary to introduce some theoretical concepts to better outline the source text. In the first section of Chapter 1, the main features of languages of special purposes (LSPs) have been discussed, considering both the horizontal and vertical dimensions, as well as the diachronic, diatopic, diastratic and diamesic variations.

The second section of the same chapter has been dedicated to the language of science, that is the special language shared by the two domains at the core of the present work, i.e. astronomy and astrophysics, which have also been presented outlining their analogies and differences. They were once clearly distinct from each other, but today the distinction has lost much of its meaning as physics is essential to study and explain the Universe.

Since the language of science is highly standardised, the last section provides a view towards controlled natural languages (CNLs), which are based on a natural language, just like LSPs. One example that has been provided is ASD Simplified Technical English (ASD-STE100), a CNL which was developed in the aerospace field and contains a number of mandatory rules to be followed in order to ensure clarity and disambiguation when writing scientific and technical documentation. As regards controlled vocabularies, also two examples of thesauri used in several space science domains have been presented – the NASA Thesaurus and the Unified Astronomical Thesaurus.

The first section of Chapter 2 focuses on the importance of communicating science, and, specifically for the purpose of this work, astronomy and astrophysics, in today's hyper-technological society. The main features of scientific popularisation have been discussed as well, including information on the target audience and function, the various degrees of popularisation, the origins and history of the genre, the main reason for popularising science, and the important role played by experts and teachers in educating new generations to develop a scientific culture. In particular, concepts like open science, citizen science, science democratisation are all essential to develop a positive attitude towards science. The second section has been dedicated to specialised translation, namely technical and scientific translation, also outlining the main skills that are required to the specialised translator. Lastly, the third section has focused on popular science translation, which has been defined as a form of 'interlingual translation', outlining the main analogies and differences between English and Italian texts of the same genre.

The final translation of *Chapter 3: Stars* has been provided in the last chapter of the thesis, accompanied with an insight into the whole text and the author, an analysis of the source text and a detailed commentary on the lexical, semantic and syntactic difficulties encountered during the translation process, along with the main translation strategies adopted to face them. As regards the translation method adopted, it was based on the use of some online dictionaries, such as Merriam-Webster and Oxford Learner's Dictionary, and a reference corpus of English and Italian parallel texts dealing with the same topics as the source text, which is about the study of stars and their life-cycles from birth to death.

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APPENDIX

APPENDIX 1

Table 1. Degrees of technicality/difficulty of scientific and technical texts according to Arntz

degree of technicality/ difficulty	genre(s)	intended recipients	required specialised knowledge
I	encyclopaedias, popular science texts	laypersons with a general interest in science and technology	little or no specialised knowledge
II	general works of reference in the fields of science and technology	persons with a specific interest in science and technology	general specialised knowledge at a basic level
III	works of reference in a scientific/technical subfield	persons with a specific interest in a scientific/ technical subfield	knowledge in a scientific/technical subfield
IV	introductory handbooks and introductory textbooks	persons interested in systematically presented/systematic basic knowledge	knowledge of scientific basics
V	practice-oriented works of reference in a scientific/technical subfield	persons interested in the practice of a scientific/ technical subfield	practical knowledge in a scientific/technical subfield
VI	advertising articles in learned journals, product information	potential users in a professional context	applied scientific/technical knowledge
VII	articles in learned journals	experts interested in very specific areas of a scientific/ technical subfield	thorough theoretical and applied knowledge in a scientific/technical subfield
VIII	installation manuals and assembly instructions	experts in a very specific area of a scientific/technical subfield working in an applied context	detailed applied knowledge in a specific area of a scientific/technical subfield
IX	academic textbooks	students, scientists working in a scientific/technical subfield	thorough theoretical knowledge in science and technology
X	research reports	scientists concerned with theoretical issues	complex and detailed theoretical knowledge in science/technology
XI	standards, patents, application reports	engineers responsible for system planning	very detailed theoretical and applied knowledge in science/ technology

APPENDIX 2

Table 1.1 Translation parameters for a translation project specification

Table 1.1 Translation parameters for a translation project specification

1. Source characteristics	1A. Source language 1B. Genre 1C. Audience(s) 1D. Communicative purpose(s)
2. Specialized language	2A. Subject field (e.g. chemical engineering) 2B. Terminology (here the client specifies if they want ST terms translated in a certain way, e.g. by providing a glossary of source terms)
3. Volume	(The amount of translation, usually measured in words)
4. Complexity	(Any factors that make the project difficult, e.g. special file formats, special use of graphics, particular linguistic difficulties of the ST)
5. Origin	(Any details about the ST authoring or provenance)
6. Target language information	6A. Target language 6B. Target terminology (as 2B above, but also encompassing any particular TL terms that the client wants to use, e.g. as specified in a bilingual glossary or termbase)
7. Target audience	
8. Target purpose	
9. Content correspondence	(How the target content is expected to match the source content, e.g. a complete or abridged translation, a full or summary translation, an overt or covert translation)
10. Register	(Level of formality of language)
11. File format	
12. Style	12A. Style guide (from client, if available) 12B. Style relevance (i.e. an indication of how relevant style is to the project)

13. Layout	
14. Typical production tasks	(Preparation, initial translation, self-checking, revision, review, final formatting, proofreading)
15. Additional tasks	(E.g. additional sample/spot checks for quality)
16. Technology	(What technologies will be used in the translation process?)
17. Reference materials	(E.g. documents, glossaries, translation memories – see Chapter 2)
18. Workplace requirements	(E.g. any restrictions on where the work is to be performed)
19. Permissions	19A. Identification of the copyright holder of the translation (this is usually the client once the translation has been delivered and paid for)
	19B. Recognition (i.e. will the translator or LSP's name appear on the document?)
	19C. Restrictions (i.e. are there any restrictions on use of translation memories developed for the project?)
20. Submissions	20A. Qualifications (e.g. does the LSP have to meet any requirements, such as accreditations or standards certifications?)
	20B. Deliverables (i.e. what is to be delivered, including the translation but perhaps also an updated translation memory, glossaries or style guide created by the translator or LSP)
	20C. Delivery (i.e. means by which the translation is to be delivered)
	20D. Deadline
21. Expectations	21A. Compensation (i.e. payment, how calculated, what rate, any discounts, how long after invoicing?)
	21B. Communication (e.g. procedures for asking and answering questions of client, contact person in LSP and client company)

Source: adapted from British Standards Institution 2012: 16–28

RIASSUNTO IN ITALIANO

Lo scopo del presente elaborato è quello di offrire una proposta di traduzione in lingua italiana del terzo capitolo, intitolato *Stars*, del libro *Astrophysics: A Very Short Introduction*, scritto nel 2016 da James J. Binney, astrofisico britannico e professore di fisica presso l'Università di Oxford. Si tratta di un libro di divulgazione scientifica, volto a fornire informazioni di carattere generale sull'astrofisica, definita come la fisica delle stelle e dell'Universo, che ci permette di comprendere la struttura e l'evoluzione di fenomeni e oggetti celesti, tra cui le stelle, i pianeti solari, le galassie, ecc. Il motivo di questa scelta risiede nell'interesse provato verso la traduzione tecnico-scientifica, approfondita durante gli studi universitari, e la divulgazione scientifica, la quale svolge un ruolo informativo di fondamentale importanza all'interno di una società sempre più evoluta, dove ognuno è chiamato a prendere posizione nei confronti delle nuove sfide che si presentano. In particolare, come affermano studiose come Olohan (2016) e Manfredi (2019), la traduzione dei testi divulgativi rappresenta un'area su cui andrebbe fatta molta più ricerca dato il legame del discorso divulgativo con altri tipi di discorso, tra cui quello pubblico, economico e sociale.

La prima sezione del Capitolo 1 si propone di delineare le caratteristiche principali delle cosiddette lingue speciali (in inglese languages for specific purposes o LSP), che sono alla base della traduzione tecnico-scientifica e della traduzione dei testi divulgativi e, come affermato da molti studiosi, fra cui Cortelazzo (1994), Gualdo e Telve (2011), importano nella lingua generale (in inglese languages for generic purposes o LGP) sempre nuovi termini, utilizzati per designare i concetti specializzati. Pertanto, le LSP possono essere considerate come varietà di una lingua naturale, ognuna delle quali caratterizzata da una serie di regole e da una particolare terminologia. Per Cortelazzo (1994) sarebbe più preciso parlare di varietà funzionali e diafasiche, in quanto le lingue speciali sono perlopiù utilizzate da una specifica comunità di parlanti, esperti nel settore, per soddisfare bisogni comunicativi principalmente di tipo referenziale e oggettivo. Ciò non toglie, però, che queste possano essere utilizzate in altre situazioni comunicative, ad esempio tra esperti e profani nella divulgazione o attraverso i mass media oppure tra specialisti ma in contesti più informali.

Le lingue speciali differiscono dalla lingua generale principalmente perché costituite da termini piuttosto che da parole. La particolarità dei termini è che possono essere sostituiti esclusivamente dalla propria definizione, dunque ciò fa sì che le lingue speciali siano caratterizzate da arbitrarietà del segno, ovvero da un rapporto biunivoco tra significante (l'immagine acustica, una successione di suoni e lettere, la materialità di un segno che rinvia ad un contenuto) e significato (il concetto mentale associato al significante), e da una maggiore precisione, con conseguente riduzione di fenomeni linguistici come la polisemia e la sinonimia, che invece caratterizzano la lingua generale. Questo è evidente soprattutto nel caso delle lingue speciali 'in senso stretto' (ad esempio la lingua della fisica), che possiedono una propria nomenclatura distintiva, a differenza di quelle 'in senso lato' (tra cui il linguaggio pubblicitario) che prendono in prestito termini da altre lingue speciali, considerando la distinzione proposta da Berruto nel 1974.

Studiosi come Scarpa (2008), Gualdo e Telve (2011) concordano con la proposta di Cortelazzo (1994) di strutturare le lingue speciali in due dimensioni, quella orizzontale e quella verticale. La prima dimensione offre una distinzione basata sui settori e sottosettori di specialità, quindi di particolare rilievo è quella proposta, tra gli altri, da Dardano, che stila una lista gerarchica partendo dalle 'scienze dure' (le scienze fisiche e naturali) fino alle 'scienze molli' (le scienze umane e sociali): matematica, fisica, ingegneria, chimica, biologia, medicina, sociologia, diritto, psicologia, antropologia, storia, filologia e filosofia. La dimensione verticale, invece, corrisponde alla dimensione socio-pragmatica delle LSP e distingue i loro diversi livelli di utilizzo in base al contesto extra-linguistico, che, come indicato da Sobrero (1993) considera la situazione comunicativa, il tipo testuale, il destinatario, il settore e lo scopo comunicativo, nonché il loro 'grado di tecnicità', che misura sia quanto il lessico della lingua speciale si allontana dalla lingua generale sia la complessità del testo. Come spiegato da Krüger (2016), il concetto di grado di tecnicità, introdotto da Arntz nel 2001, considera tre modalità comunicative: la comunicazione simmetrica tra esperti e quella tra esperto e semi-esperto oppure tra esperto e profano, entrambe asimmetriche.

Essendo le LSP strettamente legate al concetto di variazione linguistica, è importante considerare anche altre tipologie di varietà. Di fatto, le lingue speciali sono influenzate anche da varietà diacroniche, diatopiche, diamesiche e diastratiche. Sebbene lo studio delle lingue speciali sia generalmente sincronico, la dimensione diacronica è importante per comprendere la loro evoluzione nel tempo, sia da un punto di vista lessicale che sintattico, e comprendere quanto il latino, in passato considerato la lingua della comunicazione scientifica, abbia svolto un ruolo centrale in questa evoluzione. La dimensione diatopica considera le varianti regionali e tutte quelle varianti sviluppatesi in diverse aree linguistiche all'interno di una lingua speciale, dotate di elementi fonetici e costrutti grammaticali distintivi, che nascono spesso da bisogni di espressività e vengono usate anche in contesti formali nelle comunicazioni tra esperti o nella divulgazione. La dimensione diamesica riguarda i canali di comunicazione utilizzati per trasmettere l'informazione, quindi canale scritto, orale e trasmesso (scritto per essere letto a distanza attraverso le tecnologie dell'informazione), oggigiorno spesso coesistenti in situazioni comunicative multimodali. Infine, la dimensione diastratica considera il livello sociale e culturale del parlante, nonché il suo gruppo di appartenenza; di fatto, spesso le lingue speciali sono un mezzo per soddisfare bisogni comunicativi volti alla costruzione di un'identità di gruppo, tant'è che tale dimensione viene considerata da Gualdo e Telve (2011) e molti altri studiosi come parte della dimensione verticale.

Le LSP condividono alcune caratteristiche con la lingua generale, come per esempio il processo di creazione terminologica che, secondo Gotti (2011) segue le stesse regole seguite dalla LGP (sebbene le LSP siano molto più produttive), ma presentano altrettante differenze. Come afferma Cortelazzo (1994), ciascuna lingua speciale è basata sul vocabolario di una lingua naturale, ma possiede anche un proprio lessico distintivo, mentre, da un punto di vista morfosintattico, si riconosce un uso più frequente di tempi e modi verbali specifici, come il passivo, che permette la depersonalizzazione e una maggiore enfasi sull'azione, anziché sull'agente. Sulla base delle undici proprietà proposte da Hoffman nel 1984, gli studiosi concordano sul fatto che le lingue speciali siano precise, impersonali, oggettive, semanticamente dense e compatte, neutre dal punto di vista emotivo. Esse presentano un alto grado di 'monoriferenzialità', che fa riferimento a quel rapporto biunivoco tra termine e concetto, e di 'trasparenza', realizzata in primis dalle scienze dure attraverso neoformazioni derivazionali e composizionali, rispettivamente mediante l'aggiunta di affissi (prefissi o suffissi) ad una radice oppure mediante la combinazione di due o più parole già esistenti. Inoltre, le LSP utilizzano ampiamente simboli, abbreviazioni e acronimi che conferiscono loro un maggior grado di concisione, evitando qualsiasi tipo di significato connotativo e ambiguità. Un'altra particolarità delle lingue speciali è la tendenza ad utilizzare il linguaggio figurato, quindi similitudini e metafore, per questioni di chiarezza espositiva e concisione e per un più rapido trasferimento delle informazioni, evocando riferimenti visivi e reali nel destinatario. Queste lingue sono caratterizzate da un alto grado di coesione e coerenza, realizzate mediante l'uso di connettivi, anafore e catafore (le quali rispettivamente indicano qualcosa che è già stato menzionato all'interno del testo oppure che verrà menzionato nella frase successiva). Di fatto, tendono ad utilizzare solo una piccola parte della grammatica della loro lingua base: si notano l'utilizzo di persone verbali che permettono la nominalizzazione ed una maggiore oggettività e di verbi polivalenti (come essere, avvenire, comportare, consistere, dipendere, esistere, rappresentare), l'omissione di elementi frasali (articoli, ausiliari, preposizioni) e di frasi relative attraverso forme ellittiche, la predominanza della paratassi e della coordinazione. La struttura e l'organizzazione testuale appaiono, pertanto, semplici, lineari e standardizzate, generalmente in paragrafi, come dimostrato da Sobrero (1993), van Dijk (1997) e Giovanardi (2006).

La seconda sezione si concentra in particolar modo sulla lingua della scienza e sulle due discipline alla base del testo di partenza, ovvero l'astronomia e l'astrofisica. Riportando le definizioni dell'Oxford University physics dictionary (2019), da un lato l'astronomia è descritta come lo studio dell'Universo oltre l'atmosfera terrestre, le cui branche principali sono l'astrometria, la meccanica celeste e l'astrofisica; dall'altro, l'astrofisica è definita come quel ramo dell'astronomia che si concentra sui processi fisici associati ai corpi celesti e alle regioni dello spazio. Sebbene ci siano differenze tra le due scienze, da queste definizioni si nota come esse siano strettamente correlate, al punto che spesso gli scienziati spesso le usano in maniera interscambiabile per praticità, poiché entrambe fanno uso della fisica e della chimica per comprendere e spiegare i fenomeni che interessano l'Universo. Anche la cosmologia è da considerarsi quale scienza affine, con la differenza che essa si occupa dell'origine, dell'evoluzione e del destino dell'Universo su scala più ampia rispetto alle altre due (Nakra 2023). Entrambe queste discipline sono classificate come scienze dure, soprattutto perché basate su dati quantificabili, modelli matematici e sull'applicazione del metodo scientifico sperimentale galileiano, basato a sua volta sull'osservazione di fenomeni naturali, la formulazione di ipotesi testabili, la previsione di risultati e la sperimentazione per confermare le ipotesi.

Da un punto di vista storico, l'astronomia rappresenta una delle scienze più antiche, le cui origini risalgono al 1000 a.C. con le osservazioni degli Assiro-Babilonesi, fino ad arrivare all'importante teoria eliocentrica copernicana ed ai primi telescopi olandesi del XVII secolo. Per quanto riguarda l'astrofisica, si sostiene che sia nata nel 1687 con la teoria della gravità di Sir Isaac Newton, ma il punto di svolta è stato segnato dalla scoperta della spettroscopia e della fotografia nel XIX secolo, che hanno rivoluzionato la comprensione dell'Universo. Nel XX secolo, importante è stato il lavoro svolto dalla NASA e da altri istituti ed osservatori, che hanno sviluppato strumenti più sofisticati, come il telescopio spaziale Hubble, i quali hanno contribuito alla scoperta dell'espansione dell'Universo e alla formulazione della teoria del Big Bang. Da un punto di vista linguistico, l'astronomia e l'astrofisica condividono la stessa lingua, ovvero la lingua della scienza, caratterizzata come qualsiasi altra lingua speciale da chiarezza, precisione, oggettività e dall'uso di strutture linguistiche-testuali più standardizzate rispetto a quelle della lingua generale (Cortelazzo 1994; Fabbro 1999; Gualdo e Telve 2011; Ahmad 2012; Klímová 2013), per esempio la nominalizzazione, il passivo ed espedienti retorici come metafore, domande e hedge (usati per mitigare determinate affermazioni). Se questa un tempo era rappresentata dal greco e dal latino, durante l'Età dei Lumi passa ad essere il francese, mentre oggi il primato è detenuto dalla lingua inglese, che costituisce di fatto la lingua scientifica internazionale.

La terminologia e il linguaggio dell'astronomia e dell'astrofisica si sono evoluti e continuano ad evolversi nel tempo, costantemente influenzati da importanti contributi scientifici e dalle più recenti scoperte, che rendono necessari neologismi che possano designare concetti nuovi. Un grande primo contributo è stato dato da Galilei, il quale ha coniato nuovi termini tramite rideterminazione semantica, ovvero dando un nuovo significato specializzato a parole già presenti nel vocabolario della lingua generale. La produttività lessicale è data anche dal transfert lessicale, attraverso cui un settore di specialità prende in prestito un termine appartenente ad un altro dominio, dandogli un altro significato. Da un punto di vista specificamente morfosintattico, rilevante è lo studio di Tarone et al. (1998) sui testi di astrofisica, che mostra come questi non condividano la stessa struttura del classico articolo di ricerca scientifica, poiché descrivono osservazioni ed argomentazioni logiche servendosi di equazioni matematiche, dati e procedure standard (piuttosto che esperimenti), ragion per cui l'utilizzo della forma attiva è maggiore di quella passiva.

Infine, la terza sezione del Capitolo 1 si focalizza sui linguaggi naturali controllati (in inglese controlled natural languages o CNL), che sono un classico esempio di tentativo di standardizzazione linguistica in ambito specializzato e peraltro, come affermato da Kuhn (2014), vi è una correlazione tra CNL e LSP. Di fatto, le CNL sono lingue standardizzate e semplificate, che, come le LSP, sono basate su una lingua naturale. Queste hanno cominciato ad emergere dagli anni Trenta per essere utilizzate nei più disparati contesti e settori specialistici, tra cui l'industria, l'accademia, il governo, e l'ingegneria, la filosofia, la linguistica, l'informatica. Nonostante le differenze che intercorrono tra le varie CNL (ovvero, alcune sono più precise e regolate, altre più ambigue e complesse, alcune appaiono più naturali, altre più simili a linguaggi di programmazione), in generale, secondo Wyner et al. (2010) e Kuhn (2014), è possibile riconoscere alcuni attributi che le accomunano, come il fatto che siano molto più controllate, processabili, semplificate, tecniche, strutturate e restrittive in termini di lessico, sintassi e semantica rispetto alle lingue naturali su cui sono basate. Questo perché, a differenza delle lingue speciali e naturali che emergono naturalmente, le CNL vengono letteralmente create – tanto da essere definite 'lingue artificiali' – per scopi specifici, quali migliorare sia la comunicazione tra esseri umani sia la comunicazione uomo-macchina (in attività quali l'estrazione delle informazioni, la traduzione assistita, il post-editing, la comprensione dei testi in formato digitale, ecc), e per essere processate da computer (Fuchs e Schwitter 1995).

Uno dei linguaggi controllati più conosciuto è l'ASD Simplified Technical English (ASD-STE100), che nasce in ambito aerospaziale negli anni Ottanta ed è oggi ampiamente utilizzato in diversi settori. Lo STE è basato sulla lingua inglese e conserva la sua espressività e naturalezza (Kuhn 2014), quindi, nonostante sia più preciso, appare comunque come una lingua complessa e 'naturale' da un punto di vista semantico e stilistico. La Specification ASD-STE100 contiene una serie di regole di scrittura da seguire per evitare qualsiasi tipo di ambiguità durante la stesura della documentazione tecnica, in modo che chiunque possa comprenderne il contenuto, ed un vocabolario controllato che elenca i termini predefiniti utilizzati per garantire la coerenza nell'indicizzazione dei documenti. Secondo l'Unione Europea, i vocabolari controllati sono insiemi di parole e frasi organizzati in liste di termini in ordine alfabetico oppure in thesauri e tassonomie, i quali seguono una struttura gerarchica che va dai termini più generici a quelli più specifici del dominio in questione. Il loro scopo è quello di facilitare l'organizzazione e il recupero dei contenuti, garantendo l'interoperabilità ed il riutilizzo dei dati, ragion per cui costituiscono anch'essi un ottimo strumento per il traduttore specializzato. Di fatto, per ciascun termine viene fornita una definizione e vengono messe in luce le relazioni gerarchiche ed i riferimenti USE (quando viene raccomandato l'utilizzo di quel dato termine). Alcuni esempi sono il NASA Thesaurus e lo Unified Astronomy Thesaurus (UAT), thesauri utilizzati in vari settori, soprattutto in quello delle scienze dello spazio quali astronomia e astrofisica, per organizzare e arricchire il linguaggio utilizzato nella letteratura scientifica. Tali strumenti vengono costantemente aggiornati grazie al lavoro della comunità scientifica, che contribuisce attivamente alla loro continua evoluzione e revisione, tenendoli sempre al passo con le ultime teorie e scoperte.

Il Capitolo 2 si concentra sulla comunicazione e sulla traduzione dei testi divulgativi. La prima sezione spiega l'importanza della comunicazione scientifica nella società moderna, ipertecnologica e densamente popolata. Come affermato da Hawking (2019), la crescita esponenziale delle pubblicazioni scientifiche, della popolazione globale e del consumo di elettricità sono da ritenersi come indicatori dello sviluppo scientifico e tecnologico dell'umanità, ormai pressoché incontrollato. Questo sviluppo ha generato e continua a generare diverse sfide, tra cui il cambiamento climatico, la scarsità di risorse, la povertà, le epidemie, l'inquinamento marino, a cui gli esseri umani sono chiamati a far fronte. Proprio per questo, diventa sempre più necessario che il pubblico, anche e soprattutto dei non esperti, acquisisca maggiore interesse e consapevolezza della scienza, e i governi e le istituzioni mondiali svolgono un ruolo fondamentale nel stimolare questo interesse pubblico. Secondo Madsen e West (2003), L'Astorina e Valente (2011), sebbene le persone oggi sembrino più interessate ai progressi scientifici, il numero di giovani che intraprendono carriere scientifiche sembra essere in diminuzione. È pertanto di fondamentale importanza che ognuno sviluppi una cultura scientifica, un'attitudine positiva nei confronti della scienza, e in questo la cosiddetta 'scienza aperta' e la divulgazione scientifica sono considerate cruciali. Alla base di una scienza più democratica, aperta ed accessibile a tutti, vi è il concetto di 'scienza dei cittadini' (in inglese citizen science), un modo per coinvolgere i non esperti nella ricerca scientifica attraverso una serie di attività e progetti in diversi campi del sapere.

Fin dai suoi albori, la comunità scientifica ha sempre cercato di coinvolgere il pubblico comunicando le proprie teorie e scoperte: basti pensare a Galileo Galilei, che è stato pioniere della divulgazione scientifica, oltre che della prosa scientifica e del metodo sperimentale, nel momento in cui ha scelto di condividere le sue osservazioni astronomiche con un pubblico più ampio, arrivando ad utilizzare la lingua italiana (invece del latino) nei suoi scritti. La comunicazione della scienza nasce dalla necessità degli scienziati di ottenere consenso, supporto pubblico e, ovviamente, finanziamenti per le ricerche, influenzando le politiche scientifiche. Con la nascita della prosa scientifica galileiana, si comprende l'importanza della forma dialogica nella comunicazione scientifica per coinvolgere un pubblico più ampio, utilizzando uno stile più semplice, diretto, referenziale. Se un tempo la conoscenza scientifica circolava perlopiù tra esperti che frequentavano le accademie scientifiche e leggevano le riviste (revisionate tra esperti), oggi, nell'era dell'informazione, la comunicazione scientifica è vista come parte essenziale della scienza moderna e diventa sempre più necessaria, in quanto ognuno ha la possibilità di accedere alle informazioni grazie a Internet e ai media. Di fatto, come osserva Greco (2009), oggi si parla di "comunicare tutto a tutti in tempo reale" grazie agli sviluppi nelle tecnologie dell'informazione ed alla trasparenza della scienza aperta, che rende la comunicazione un processo a due vie, un'interazione tra pubblico ed esperti, i quali sono chiamati ad adattare la comunicazione agli interessi, alle capacità ed alle conoscenze del loro pubblico, fornendo spiegazioni chiare non solo su *cosa* hanno scoperto, ma soprattutto su *come* sono giunti a quella conclusione, al fine di costruire un rapporto tra pubblico e scienza che sia basato sulla fiducia.

Secondo studiosi come Anjos, Russo e Carvahlo (2021), andrebbe fatta più ricerca sulla comunicazione scientifica, in quanto è stato rilevato un divario tra la pratica e la ricerca, nonché tra i diversi attori coinvolti, come scienziati, educatori scientifici, giornalisti scientifici e blogger. Di fatto, è stato notato come spesso gli scienziati evitano di occuparsi di divulgazione scientifica, perché si sentono impreparati a interagire con il pubblico o perché hanno preconcetti sia sul pubblico sia sui media che si occupano di diffondere le informazioni. In generale, si è notata una carenza di formazione in questo settore, proprio perché la letteratura scientifica spesso offre poche risorse per imparare a comunicare efficacemente con il pubblico. Vi sono però una serie di iniziative volte a colmare il divario tra la ricerca scientifica e la pratica della comunicazione scientifica, a coinvolgere il pubblico e a rendere possibile lo sviluppo di un pensiero critico riguardo argomenti scientifici, tra cui lo storytelling, la citizen science, i laboratori, la partecipazione attiva degli scienziati ai dibattiti scientifici su social media e podcast, sia per incrementare il dialogo sia per migliorare le competenze di comunicazione degli scienziati.

Anche l'istruzione svolge un ruolo fondamentale nel plasmare la cultura scientifica tra le giovani generazioni, combattendo stereotipi e promuovendo l'uguaglianza di genere in ambito scientifico. Per questo motivo, gli insegnanti devono essere in grado di coinvolgere e motivare gli studenti e fare in modo che sviluppino abilità, come problem solving e cooperazione, e pensiero critico e razionale, rendendo i programmi meno 'astratti' e proponendo attività volte ad incrementare l'interesse nei confronti della scienza, come visite a laboratori e a musei scientifici, dibattiti con esperti, esperimenti riprodotti in classe. L'Unione Europea riconosce anche l'importanza dell'insegnamento delle cosiddette materie STEM (scienze, tecnologia, ingegneria, matematica), tra cui rientrano ovviamente anche l'astronomia e l'astrofisica, incentivando la promozione di attività extra-curriculari, corsi opzionali e summer school. Secondo alcuni autori, tra cui Armeni (2006), Gualdo e Telve (2011), Anjos et al. (2018), queste due scienze pluridisciplinari sono in grado di affascinare il pubblico, soprattutto dei giovani, che spesso sviluppano un forte interesse nei loro confronti anche per cercare risposte alle grandi domande sull'Universo e sul futuro dell'umanità.

Facendo riferimento nello specifico alla divulgazione scientifica, molti studiosi l'hanno definita come un processo volto a comunicare il sapere scientifico ed hanno riconosciuto il fatto che tale processo possa assumere forme differenti (media, musei, festival della scienza, blog, ecc), al punto che, secondo Olohan (2016), è possibile parlare di diversi livelli di divulgazione. Garzone (2006) e Manfredi (2019) affermano che l'obiettivo primario della divulgazione è quello di rendere accessibili le informazioni tecnico-scientifiche ad un pubblico, che può essere costituito da non esperti, professionisti o entrambi, interessato nell'argomento ma con differenti livelli di competenza, senza ricorrere a semplificazioni eccessive o distorsioni. Di fatto, la divulgazione ed il giornalismo scientifico possiedono spesso più di uno scopo: intrattenere il pubblico, informarlo, influenzare le sue percezioni e decisioni su questioni pubbliche. Come sottolineano alcuni autori, come Vrabec e Pieš (2023), Scharrer et al. (2017), vi sono a volte dei rischi, per esempio quello di una esagerata semplificazione nella trasmissione dell'informazione oppure delle cosiddette 'fake news scientifiche', legate alle pseudoscienze, che stanno prendendo sempre più piede con la diffusione dei social media (anche se molte di queste piattaforme hanno cominciato a dotarsi di strumenti e algoritmi capaci di individuare le false informazioni). Un esempio che si potrebbe citare è quello della tendenza parecchio diffusa di confondere l'astronomia con l'astrologia (Anjos et al. 2021).

In generale, i testi di divulgazione scientifica tendono ad avere una densità lessicale più bassa e una maggiore complessità sintattica rispetto ai testi specializzati. Chi si occupa di divulgazione può scegliere di evitare l'utilizzo di termini tecnici, sostituendoli con parole più semplici conosciute al pubblico di non esperti o con perifrasi scritte in lingua generale, oppure di inserirli all'interno del testo accompagnandoli con una spiegazione attraverso metafore, similitudini, note e parafrasi (definizioni formulate in lingua speciale o generale, particolarmente utilizzate dagli scienziati), talvolta addirittura formule colloquiali e slang (Cortelazzo 1994). Gualdo e Telve (2011) sottolineano anche la necessità di espandere gli acronimi e sigle per garantire massime trasparenza e comprensibilità. Dal punto di vista morfosintattico e testuale, Garzone (2006) afferma che i testi divulgativi tendono ad avere una struttura più espositiva che argomentativa, spesso più prolissa e meno rigida ed organizzata di quella che caratterizza le pubblicazioni specialistiche. Mentre in queste ultime si nota una certa prevalenza della forma passiva, nei testi divulgativi, proprio come in quelli di astrofisica, si ricorre maggiormente alla voce attiva, poiché capita molto spesso che i divulgatori, per alleggerire il testo e renderlo più leggibile, non citano i riferimenti. Inoltre, un aspetto distintivo dei testi di divulgazione scientifica è la loro forma dialogica, che include l'uso di domande retoriche, marcatori di discorso, forme di dialogo implicito ed, in generale, un registro più informale e colloquiale, tutti elementi che aiutano a stabilire un contatto con il pubblico rendendo il testo più coinvolgente e persuasivo. Al fine di dare maggiore autorità al testo e promuovere il dialogo tra la comunità scientifica e il pubblico, spesso anche per limitare la responsabilità di chi scrive, questi testi citano interviste a esperti attraverso discorso diretto, indiretto o integrato (Garzone 2006; Gualdo e Telve 2011). In definitiva, come sostenuto da Calsamiglia e van Dijk (2004), i testi di divulgazione scientifica possono essere considerati come una forma di traduzione che riformula e ricontestualizza l'informazione scientifica, ricorrendo ad una lingua più simile a quella generale, per renderla accessibile ad un più vasto pubblico.

Nella seconda sezione viene introdotta, da un punto di vista teorico, la traduzione specializzata, definita da Scarpa (2008) come la comunicazione interlinguistica mediata di documenti redatti in lingue speciali, il cui obiettivo primario è il trasferimento di informazioni tecnico-scientifiche, ormai indispensabile per il funzionamento della società, a livello internazionale. I testi tecnico-scientifici sono, secondo Scarpa (2008), testi 'chiusi', poiché permettono solo una interpretazione e richiedono, pertanto, un approccio più razionale ed 'addomesticante': variazioni sono permesse perlopiù a livello della forma testuale, ma non del contenuto, che deve essere riprodotto nel testo d'arrivo in maniera completa e comprensibile ai lettori target, sempre considerando le convenzioni della lingua e della cultura d'arrivo. Spesso è complicato raggiungere un grado di equivalenza funzionale tra testo di partenza e d'arrivo, proprio perché le lingue speciali sono diventate meno 'asettiche' e più creative, ragion per cui il traduttore specializzato diventa, secondo Halliday (1992) e Scarpa (2008), un mediatore culturale, il cui obiettivo primario è quello di dar priorità sempre all'equivalenza pragmatica, piuttosto che semantica. Nella traduzione specializzata è necessario considerare parametri quali la funzione comunicativa del testo e della relativa traduzione, così come il modo in cui questa verrà utilizzata, perciò strumenti quali il cosiddetto 'translation brief', che elencano tutte le linee guida e le preferenze del committente che il traduttore deve seguire, diventano fondamentali. Il traduttore specializzato deve possedere conoscenza della terminologia specifica e delle convenzioni dei generi testuali e competenza linguistica ed informatica, essendo in grado di utilizzare strumenti utili come i corpora, i testi paralleli, le risorse terminologiche, i sistemi di traduzione automatica e assistita. Inoltre, al fine di costruire delle strategie traduttive efficienti, è necessario che consideri i fattori extra- ed intratestuali, che individui le maggiori difficoltà traduttive (tra cui metafore, espressioni idiomatiche, regionalismi, ecc). Tra le principali metodologie traduttive, Scarpa (2008) individua la traduzione letterale, o parola-per-parola, e la parafrasi. Nel primo caso, la traduzione apparirà molto simile al testo di partenza, poiché il traduttore manterrà gli stessi costituenti adattando le strutture lessicali e sintattiche alle norme stilistiche e grammaticali della lingua d'arrivo. Sebbene spesso venga sottostimato, questo approccio è molto utile per creare una prima bozza di traduzione, ma anche in caso di testi che presentano una terminologia e delle strutture standardizzate (soprattutto quei testi scritti in linguaggi naturali controllati). La parafrasi consiste in un approccio più libero, che prevede la riscrittura del testo di partenza in lingua d'arrivo, e può riguardare cambiamenti a livello della sintassi (trasposizione), della semantica (modulazione) o della pragmatica (adattamento); il traduttore può anche decidere di ricorrere ad esplicitazioni, per spiegare ciò che viene lasciato implicito nel testo di partenza, oppure a espansioni, riduzioni o eliminazioni, sempre valutando il contesto. Comparando testi di partenza inglesi con le relative traduzioni italiane, Musacchio (2007) e Scarpa (2008) hanno osservato che, dal punto di vista dell'organizzazione testuale, spesso c'è la tendenza a riprodurre la stessa suddivisione in paragrafi del testo di partenza. Tuttavia, i testi italiani presentano spesso una struttura più complessa (in cui prevalgono l'ipotassi, lo stile nominale, le forme passive ed impersonali), un registro più formale, astratto e referenziale, e per motivi stilistici tendono ad evitare le ripetizioni (che sono più comuni nei testi inglesi).

Spesso ci si riferisce alla traduzione specializzata con traduzione scientifica e traduzione tecnica, di fatto trattasi di due sottotipi della traduzione specializzata. Tuttavia, è difficile tracciare confini netti tra queste due tipologie, tanto che alcuni studiosi come Wright (2011) le considerano come un continuum denominato 'Sci-Tech', che comprende una vasta gamma di sottodomini. La traduzione scientifica riguarda testi di scienze pure con un approccio principalmente teorico ed una terminologia più astratta ed uno stile maggiormente formale, mentre la traduzione tecnica si concentra su testi tecnologici generalmente redatti da tecnici e mira ad aiutare l'utente a compiere azioni specifiche, richiedendo quindi un linguaggio ed una terminologia più concreti, semplici, concisi. Come sostenuto da Olohan (2016), la traduzione tecnica può richiedere adattamenti culturali, ragion per cui i traduttori di testi tecnici sono considerati ‘comunicatori tecnici transculturali’, in quanto rendono i testi redatti dai tecnici adatti al pubblico d’arrivo (ad esempio, come notato da Fabbro 1999, il traduttore deve adattare il grado di obbligo del modale *shall* alle convenzioni culturali della lingua d’arrivo). Per entrambe le tipologie di traduzione, il traduttore deve avere una profonda comprensione del contenuto del testo di origine e produrre una traduzione che trasmetta adeguatamente quel contenuto, considerando le convenzioni legate al genere, che spesso seguono l'evolversi della sapere tecnico-scientifico. Questo richiede competenze linguistiche e di ricerca terminologica, nonché la capacità di riconoscere problemi e giustificare le scelte (competenza metacomunicativa).

L’ultima sezione del secondo capitolo riprende il concetto di divulgazione scientifica, ma concentrandosi sulla sua traduzione. Dato che la divulgazione comporta la riscrittura, la riformulazione e la ricontestualizzazione del testo, con l’obiettivo di renderne il contenuto accessibile al vasto pubblico, Gotti (2012) e Manfredi (2019) definiscono questo processo come una forma di ‘traduzione intralinguistica’, poiché la lingua speciale in cui è stato redatto il testo di partenza viene ‘tradotta’ in una lingua più simile a quella generale, usata quotidianamente dai destinatari. Come affermato da Musacchio e Zorzi (2019), questa riscrittura implica anche una serie di aggiunte, omissioni, sostituzioni e rielaborazioni che rendano il testo adatto al pubblico di non esperti, tra cui esempi pratici ed analogie, molto utili da usare come termine di paragone per comprendere concetti specializzati più complessi. Dunque, la divulgazione scientifica, così come la sua traduzione, non sono mere semplificazioni di concetti specializzati, ma forme specifiche di giornalismo scientifico che tengono conto delle implicazioni sociali e politiche delle scoperte scientifiche, volte a creare una ‘buona storia’ che sappia stimolare la curiosità del pubblico di destinazione (Musacchio 2017). Difatti, si è notato come gli articoli di divulgazione abbiano una struttura molto simile a quelli giornalistici. Queste attività di traduzione, definite da Manfredi (2019), Musacchio e Zorzi (2019) come forme di ‘traduzione interlinguistica’ e di ‘mediazione interculturale’, coinvolgono diversi tipi di testi, tra cui articoli scientifici, documentari televisivi, libri e siti di divulgazione scientifica, iniziative di citizen science. La traduzione e la riscrittura in questo contesto richiedono l'adattamento ai contesti sociali e culturali della lingua e della cultura di arrivo, ragion per cui sono necessarie strategie di ‘transediting’ e ‘transcreation’. Al traduttore di testi di questo genere viene sempre richiesta una accurata valutazione del contesto e degli elementi presenti all'interno del testo, come nomi propri, acronimi, valute, unità di misura, che spesso possono necessitare di una spiegazione, oltre alla traduzione, per rendere il testo più familiare ai lettori target. Nei testi di divulgazione si è, infine, notato un uso maggiore di immagini e citazioni di esperti, elementi che catturano l'attenzione del lettore, gli forniscono maggiori delucidazioni ed aumentano la credibilità del testo. La traduzione di questo genere di testi può variare tra diverse lingue, ma nella maggior parte dei casi si cerca di mantenere la struttura e i contenuti tra lingue per preservare la coerenza e l'efficacia del messaggio scientifico: come nota Manfredi (2019), in genere vi è un alto grado di somiglianza da un punto di vista contenutistico, strutturale e grafico tra testo di partenza e di arrivo, con un intervento maggiore da parte del traduttore sulla grammatica e sul modo in cui il messaggio viene reso.

Il terzo capitolo è interamente dedicato al fulcro della tesi, ovvero la traduzione, presentata nella sezione centrale del capitolo, preceduta nella prima sezione da un'analisi del testo di partenza, in cui vengono fornite anche informazioni sull'autore, e seguita nella terza ed ultima sezione da un dettagliato commento sulle difficoltà incontrate durante il processo traduttivo e le strategie adottate per farvi fronte. *Astrophysics: A Very Short Introduction* è di uno dei 700 libri divulgativi appartenenti alla collana delle *Very Short Introductions*, pensata dalla Oxford University Press per far conoscere e comprendere le maggiori informazioni in diversi campi del sapere – che spaziano dalle scienze naturali alla filosofia, dall'economia alla politica – ad un vasto pubblico composto sia da esperti sia da profani. Come in ogni buon testo di divulgazione scientifica, gli esperti fanno in modo di rendere le spiegazioni dei concetti e dei termini tecnici – anche quelli più complessi – più coinvolgenti e semplici, accompagnandole ad esempi pratici e ad un tono più colloquiale, a tratti perfino amichevole. Il testo presenta otto capitoli divisi in sottosezioni, una lista di termini specialistici appartenenti ai domini della chimica, della fisica, dell'astronomia e della cosmologia (che, nella maggior parte dei casi, vengono spiegati nel testo attraverso parentesi, frasi relative, catafore, esempi, analogie), una serie di immagini (nel dettaglio, foto dello spazio e diagrammi che hanno lo scopo di fornire maggiori spiegazioni ed esemplificazioni al lettore, accompagnando il testo). Binney adotta uno stile informale con forme contratte, espressioni colloquiali, domande e figure retoriche e l'utilizzo dei pronomi personali di prima e seconda persona, al fine di dare più espressività al testo e quindi coinvolgere il lettore in modo più efficace. Inoltre, si ricorre spesso alla ripetizione lessicale, elemento su cui sono stati fatti maggiori interventi durante la traduzione, proprio perché la lingua italiana opta per la variazione lessicale piuttosto che per la ripetizione. La struttura sintattica del testo è principalmente paratattica ed espositiva, caratterizzata da frasi abbastanza brevi proprio per facilitare la comprensione dei fatti scientifici. Il testo utilizza la forma attiva e quella passiva in egual misura, con l'agente del passivo quasi sempre specificato per una maggiore chiarezza e trasparenza.

Per quanto riguarda la traduzione, sono state riprodotte l'organizzazione del testo in paragrafi e le altre scelte di tipo grafico dell'autore, tra cui l'uso del grassetto per i titoli e le descrizioni sotto le immagini, il corsivo per i termini da evidenziare all'interno del testo, le virgolette per riferirsi ai titoli delle sottosezioni di altri capitoli citati nel testo e altri simboli relativi alle formule. Inoltre, poiché la parola 'universe' compare nel testo di partenza sia con la lettera maiuscola che minuscola, nel testo d'arrivo è sempre stata utilizza la lettera maiuscola per motivi di coerenza. Sono stati mantenuti anche i pronomi di prima e seconda persona, che rappresentano la volontà dell'autore di riferirsi alla comunità scientifica e di rivolgersi direttamente al pubblico dei lettori. A differenza dei testi specialistici italiani, caratterizzati principalmente da neutralità emotiva e impersonalità, rivolgersi direttamente al pubblico può costituire una strategia per ottenere una migliore comprensione del contenuto del testo, nonostante la difficoltà dell'argomento. In più, come anticipato, sono stati effettuati dei cambiamenti a livello della struttura della frase, per evitare le ripetizioni lessicali che avrebbero reso il testo d'arrivo poco compatto stilisticamente parlando, ricorrendo, ad esempio, a trasposizioni, anticipazioni, nominalizzazioni, connettori, congiunzioni, anafore, catafore o all'utilizzo di sinonimi. Questi elementi sono largamente utilizzati in italiano proprio per rendere i testi più formali, coesi, fluidi e leggibili. In alcuni casi, è stato necessario aggiungere alcuni elementi per rendere le informazioni più chiare e precise, modificare l'ordine di alcuni costituenti all'interno della frase per rendere il discorso più scorrevole, e spiegare le abbreviazioni sconosciute adattandole al pubblico target. Tra le difficoltà incontrate, sono da segnalare i due periodi contenenti il 'do' enfatico, utilizzato in inglese per dare maggiore forza al verbo principale e che in italiano viene generalmente reso con 'sì', 'proprio', 'eccome' e 'davvero': in una frase è stato omesso perché la frase italiana risultante sarebbe apparsa innaturale utilizzando una delle alternative precedentemente citate, mentre nell'altra è stato espresso attraverso un avverbio adatto al contesto. Spesso i problemi di traduzione hanno riguardato la sintassi, poiché è stato ritenuto necessario riorganizzare completamente i periodi per far sì che apparissero più scorrevoli e comprensibili a un pubblico italiano non esperto. In base al contesto, è stato necessario separare o unire due frasi all'interno dello stesso periodo, cambiare l'ordine dei costituenti o la diatesi, oppure creare una frase relativa. Per alcuni termini specializzati vi erano più possibilità di traduzione in italiano, ma naturalmente sono state scelte le alternative più ricorrenti nei testi paralleli. Le maggiori difficoltà hanno riguardato il linguaggio figurato, ampiamente utilizzato dall'autore. Di fatto, il testo è ricco di phrasal verbs difficili da tradurre in italiano, infatti spesso non è stato possibile renderne il significato completo, con tutte le sue sfumature. Binney fa largo uso di espressioni metaforiche e idiomatiche, metafore e similitudini, spesso per aiutare il suo pubblico di lettori non esperti a comprendere meglio una serie di concetti astrofisici complessi, rendendo il tono del testo molto più colloquiale ed informale. Tutti questi elementi sono stati adattati alla lingua e alla cultura di arrivo durante il processo traduttivo.