

University of Groningen

The Impact of neutral hydrogen on the current evolution of early-type galaxies

Yildiz, Mustafa

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2017

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Yildiz, M. (2017). *The Impact of neutral hydrogen on the current evolution of early-type galaxies*. Rijksuniversiteit Groningen.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Summary

*“In generosity and helping others, be like a river;
In compassion and grace, be like sun;
In concealing others’ faults, be like night;
In anger and fury, be like dead;
In modesty and humility, be like earth
In tolerance, be like a sea;
Either seem as you are or be as you seem.”*

— M.J. Rumi (ca.1207-ca.1273)

Human beings are always inclined to classify things in their lives. This is very fundamental and natural such as thumb sucking. Sometimes, people classify things without a purpose. However, thanks to science and scientific view-point, we do also classify things with some purposes such as developing our knowledge and understanding the Universe and the life in it.

Until the 17th century, the only tool for astronomers had been visible light coming from the space. Sources of the observed light were almost identical and, therefore, classifying these sources was important to understand the working mechanism of the universe. In the 17th century, astronomers identified a new class of objects different than stars by using telescopes: the so called nebulae. This was a name for any diffuse astronomical object at the beginning marking their difference from the point-like stars. During the 18th century, astronomers like Charles Messier, William Herschel observed and catalogued thousands of nebulae. In those times, it was believed that these objects were inside our galaxy, the Milky way, and what we now call spiral galaxies were in general referred to as “spiral nebulae” (e.g., the Andromeda Nebula) before the true nature of galaxies was confirmed in the early 20th century by Vesto Slipher, Edwin Hubble and others.

In 1936, Hubble published a classification scheme known as the tuning-fork diagram in the Realm of the Nebulae (see Fig. 1). In this tuning-fork diagram, galaxies are divided into two observational groups as spiral and elliptical galaxies. Hubble added one hypothetical class in this diagram: lenticular

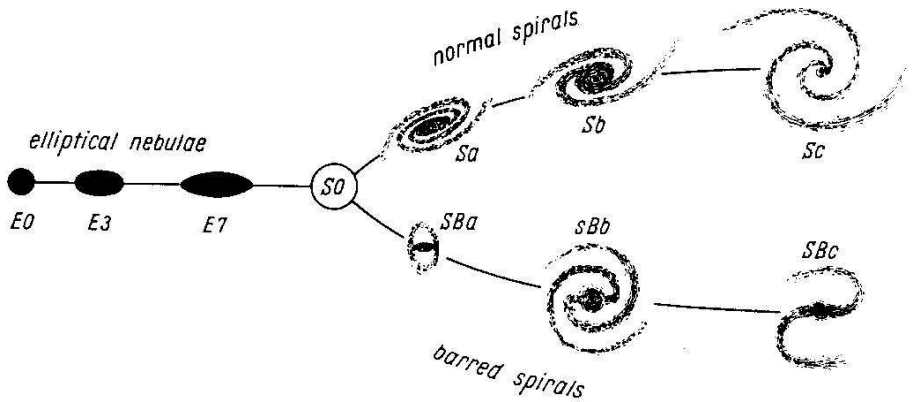


Figure Summary .1 – Hubble’s original tuning-fork diagram as published in 1936 in his *Realm of the Nebulae* (Hubble, 1936).

galaxies (labelled as S0 in Fig. 1). Today, spiral galaxies are labelled as late-type galaxies, while the family of early-type galaxies contain both ellipticals and lenticulars. These galaxies are gravitationally bound systems of stars, gas, dust, and dark matter. Galaxies contain billions of stars like our sun, and the size of galaxies is enormous. Therefore, the distance between stars within a galaxy is also vast. A simple example can help to understand these sizes: The diameter of the Milky Way is about six billion times larger than the distance between the Sun and Earth (we live 1 astronomy unit away from the Sun, which corresponds approximately 150 million km).

Although the space between stars in a galaxy looks empty at first glance, astronomers have discovered that it is actually full of matter such as gas, molecules, and dust, which together form the interstellar medium (ISM). The ISM interfuses smoothly into surrounding intergalactic space. Matter in the ISM exists in multiple phases (ionic, atomic, or molecular), and different temperatures and densities. The dominant part of the ISM is gas (~ 99 percent), and the remaining part is dust (1 percent). Of the gas in the ISM, by mass, about 70 percent is hydrogen, 28 percent is helium, and the rest of it is heavier elements. Astronomers use the word “metals” as a general term for all these elements except hydrogen and helium. The gas in the ISM is extremely sparse by terrestrial standards. The density in compact regions of the ISM, where molecules can form, is ten thousand times lower (1 million molecules per cm^3) than the density of the air at sea level, while in diffuse regions of the ISM this can be much lower, as low as 1 atom per cm^3 !

Even though the gas in the ISM is dispersed, the total amount of matter between the distant stars can be large enough to form new stars. Stars form in giant molecular clouds, the densest regions of the ISM, embedded in regions of cool gas, mostly made of hydrogen. During the formation process, stars deplete

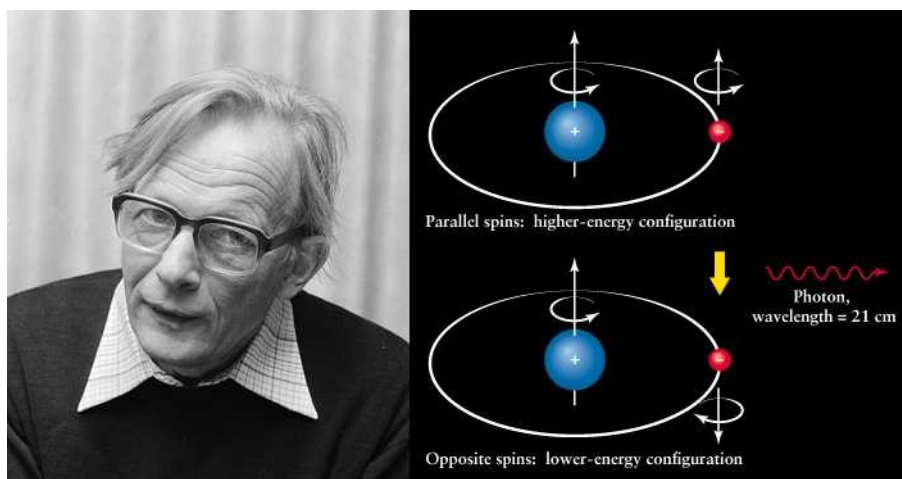


Figure Summary .2 – *Left:* Hendrik C. van de Hulst (19 November 1918 - 31 July 2000) was a Dutch astronomer. He predicted the existence of the 21 cm line emission of neutral hydrogen. *Right:* A schematic display for this emission line.

all the gas in their birth place, then, they regenerate the ISM (hydrogen and other heavy elements) due to the evolution. After a long time, the evolution of stars comes to an end: they die by ejecting all the matter in their atmosphere and energy through planetary nebulae and supernovae.

Hydrogen, the dominant component of the ISM and the most abundant element in the Universe, plays a crucial role in the life cycle of the stars and thus the evolution of galaxies.

In 1944, Hendrik van de Hulst, a Dutch astronomer, predicted that neutral hydrogen (HI) could produce radiation at a frequency of 1420.4058 MHz (21 cm) due to the structure of its atom (Fig. 2; the hydrogen atom in its simplest, low-energy state has two energy levels, which depend on whether the spin of the electron in the atom is aligned with the spin of the central proton). He also claimed that 21 cm line emission might be detectable in interstellar space. After the Second World War, scientists in U.S. and the Netherlands started searches to detect this emission line. Unfortunately, the Dutch team had lost their receiver because of a fire, and their work was delayed several months. In 1951, the observational discovery of the 21 cm line emission was carried out by Ewen and Purcell at Harvard University. Their discovery was confirmed by successful observations within a few weeks by Dutch astronomers Muller and Oort in the Netherlands, and by Christiansen and Hindman in Australia. The original horn antenna used by Ewen and Purcell is currently on display at the National Radio Astronomy Observatory, Greenbank, West Virginia. In the 1950's, the first maps of HI in the Milky Way showed spiral structures and, therefore, place our galaxy in the family of spiral galaxies.

After the discovery that HI can be observed at radio frequencies, astronomers started to observe galaxies to understand the effect of this element on galaxy evolution. These observations showed that the spiral galaxies (on the right-hand side of Fig. 1) like our own galaxy contain a large amount of HI, while early-type galaxies (on the left-hand side of Fig. 1) contain much less or no detectable HI at all.

Until recently, astronomers have believed that early-type galaxies are simple systems with little gas, dust and activity –*red and dead*. However, we now know that early-type galaxies are more complicated than that. Early-type galaxies show structural similarities with spiral galaxies. They harbour stellar discs which can extend beyond their optical body. They contain dust and gas in different phases and temperatures, from very hot ionized gas to cold atomic hydrogen gas. However, the efficiency of converting this gas reservoir into new young stars in early-type galaxies is lower than those in spiral galaxies.

Studying the relation between neutral hydrogen (HI), star formation and dust in early-type galaxies will contribute to solving the puzzle of current galaxy evolution and the evolution of the inter stellar medium. In this Ph.D. thesis, I have studied *red and dead* early-type galaxies, particularly, the effect of the HI gas on their current evolution, and shown that some early-type galaxies are not really red and dead! My doctoral thesis consists of three interrelated scientific chapters, and I will briefly discuss the results of these sections in the next three parts.

This Ph.D. thesis

Part I- A pilot study

Some studies show that early-type galaxies can harbour very large gaseous discs rotating around their centre. As a pilot study, I selected one of the known early-type galaxies containing a large HI disc. To attain better resolution and see the details of how the hydrogen gas is distributed, this galaxy, NGC 4203, was observed for a much longer time (hundreds of hours) than previous observations by using the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands (also see the cover of this thesis). To understand whether this HI gas is feeding the star formation, we need to observe particularly young newly formed stars. Young stars emit mostly very energetic photons that can be observed at ultraviolet wavelengths from space. Therefore, the regions containing recently formed stars can be located. However, some of these energetic photons can be obscured by dust and re-emitted in infrared wavelengths. As a result, I have performed a detailed multi-wavelength study by using good quality ultra-violet (UV), infrared, optical, and HI data. I have investigated the relation between star formation and HI column density¹ in the outer regions of this galaxy. The

¹A column density is the number of e.g., atoms, per unit area.

details of this study are given in Chapter 2 of this Ph.D. thesis. The main results of this study are listed below.

- The HI disc consists of two distinct components: an inner star forming ring and an outer disc.
- The outer HI disc is 9 times more massive than the inner HI ring. However, its gas is spread over a much larger area than that of the inner ring and, therefore, the gas density is extremely low.
- The amount of star formation varies significantly across the HI disc and ring, even in regions that have the same density of HI. A possible cause for these large variations is that some of the gas is produced during the evolution of stars, while other gas is accreted from another galaxy or the environment surrounding the galaxy. The accreting gas has much lower metallicities causing different star formation efficiency.
- Despite the gigantic HI reservoir and some low-level star formation, the morphology of NGC 4203 is unlikely to change significantly in the foreseeable future since the stellar disc of the galaxy is growing at a very low rate.

Part II- Looking at the outer regions of Early-Type Galaxies

In chapter 3 of my Ph.D. thesis, I have enlarged the sample galaxies used to investigate the relation between HI and star formation. Unlike in the first study, I look at the colours of the outer regions of early-type galaxies as well. Colour of a galaxy might reveal information about the age of the stars in the galaxy. For example, if young stars are dominant in a galaxy, its colour seems blue, while if there are more old stars than young, its colour seems red. Many of the early-type galaxies do not contain detectable HI gas and, therefore, I use HI-poor early-type galaxies as a control sample. Since galaxies are hundreds of millions times larger than our solar system, some properties change throughout the galaxies. Therefore, I separate the outer regions into two parts: 1-3 and 3-10 effective radius². Our main results are given below.

- HI gas in the outer regions of early-type galaxies feed star formation with a low efficiency, but this efficiency is comparable to those found in the outskirts of spiral and dwarf galaxies
- Beyond the center, HI-rich early-type galaxies are bluer (in UV-optical colours) than HI-poor control early-type galaxies. In some extreme early-type galaxies the outer colour is comparable to that of spirals. This indicates that the most recent star formation has occurred at the location of the HI gas.

²The *effective radius* (R_{eff}) is a term that astronomers use to indicate the radius within which half of the total light of the system is emitted.

- The process of star formation in a low-column density region does not seem to depend on the host galaxy type.

Part III- Cold gas and dust: Hunting spiral-shape structures in early type galaxies

Dust grains can be identified as the chemical reaction sites in the inter stellar medium. For example, molecular hydrogen (H_2) can be formed on the surface of dust grains. Since stars form in the molecular clouds, dust in early-type galaxies is most likely related to recent star formation.

The presence of dust at a given position in a galaxy is detected by its effects upon starlight passing through them. Some of the main effects are following:

- Absorption of light coming from distant stars and scattering of starlight by dust. These absorption and scattering effects are together called extinction effect.
- Reddening of the starlight because the extinction is stronger for blue light than for red.

Since extinction due to the dust grains depends on the wavelength of the electromagnetic radiation, in chapter 4 of my Ph.D thesis, I make use of different colour bands (g and r) in optical wavelengths to find dust structures in the nearby early-type galaxies. I have also compared HI-rich and -poor early-type galaxies to understand whether the presence of HI is related to the presence of dust. Finally, I have classified the dust morphology in these dusty early-type galaxies. Below, I list the main results.

- All nearby HI-rich early-type galaxies show dust structures (mostly spiral-shaped structures), while a little more than half of the HI-poor galaxies show dust.
- Dust in HI-rich galaxies has a diameter about two times larger than that of HI-poor galaxies.
- The large dust structures tend to be in HI-rich galaxies, while the small size dust structures are generally found in the HI-poor early-type galaxies.

In summary, I have for the first time studied the effect of large HI reservoirs (hosting potential material for star formation) on the nearby early-type galaxies, which are normally considered passive (i.e., not forming new stars). I have found that:

- some of the large HI discs detected with radio telescopes do host a significant amount of star formation.
- if the metallicity of the gas is different, the star formation efficiency can dramatically change.

- in the outer regions of early-type galaxies with HI, this gas is converted into new stars with a similar efficiency as in the outer regions of spiral galaxies.
- since the relatively low amount of HI is distributed over a large area, this formation of new stars cannot significantly change the appearance of the host galaxy any time soon, unless, for example, these galaxies crashed into another gas-rich galaxy.
- the presence of HI distributed out to very large distances from the main stellar body of galaxies is also felt in their central regions. Indeed, galaxies with large amounts of HI at large radius are also characterised by a large amount of dust in their centre. This shows that gas at large radii can feed the inner region of galaxies, where new stars can then form.

