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INTERSTELLAR INITIATIVES

1/25/91

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ABSTRACT

This paper defines the scope of the Space Congress session on "Interstellar Initiatives". It identifies and briefly discusses the following main areas of interest:

- interstellar medium
- interstellar probes
- interstellar communication
- interstellar travel (manned)
- other scientific questions

BACKGROUND

The limits of space exploration are moving outwards with time; from sounding rockets, to Earth orbit, to the Moon, to the nearer planets, and to the outer planets. With the first steps, as far as the Moon, unmanned probes have been followed by manned spacecraft. We expect both unmanned and manned spaceflight to continue outwards for the foreseeable future.

SCOPE

This session of the Space Congress, Interstellar Initiatives, is intended to cover the next step of space exploration beyond the Solar System. Astronomy has to date been almost our only source of information on some questions related to interstellar initiatives. However, in this session we are addressing the physical exploration of interstellar space.

The scope of the topic (Figure 1) includes speculative areas of science and technology like sending people to the stars, but also more conservative goals which are of more immediate interest such as research on the interstellar medium. Little physical exploration of interstellar space has yet been done, although we do have a few probes out beyond the orbit of Pluto. The next few decades will see increasing activity. In consequence, this is a good time to consider how we should proceed.

GOAL

The goal of the session is to identify and explore interesting questions relating to:

- the interstellar medium
- interstellar probes
- interstellar communication
- interstellar travel
- other scientific questions

WHAT IS INTERSTELLAR SPACE?

Interstellar space is the space between the stars which is far enough away from any physical body that local effects of those bodies can be neglected. Obviously, this distance depends on the effects being studied, but interstellar space is generally taken to begin beyond the heliosphere, where the interplanetary magnetic field and the solar wind no longer dominate over the effects of the interstellar medium. The boundary is thought to be 50 to 100 AU¹ from the Sun.

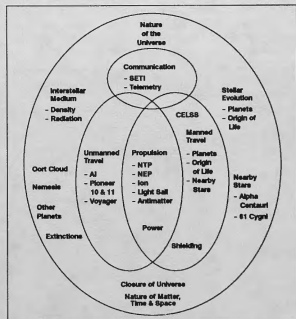


Figure 1. Scope of Interstellar Initiatives

¹One AU is the mean distance from the Earth to the Sun, 93 million miles.

Pluto has a mean orbit of about 39 AU. Thus interstellar space begins well beyond Pluto, and there may be other solar planets beyond Pluto. Predictions of additional planets have been made by analyzing the orbits of the known planets and comets. Percival Lowell estimated that a large planet was needed to account for the perturbations, but any planet beyond Pluto must be of small mass and low brightness. Tombaugh, the discoverer of Pluto, searched 70% of the sky down to 17th magnitude and did not discover another planet.

The Sun's gravitational field extends out beyond Pluto. A cloud of comets, the Oort Cloud, is thought to orbit the Sun at distances of from 30,000 to 100,000 AU. We can only see the comets whose orbits are perturbed enough for them to enter the inner Solar System, when they get closer to the Sun and volatile gases boil off and become visible by reflected sunlight.

The next objects out beyond the Oort cloud are the stars. There has been speculation that the Sun is a distant binary, and that it's companion star (Nemesis) perturbs the comets in the Oort cloud at intervals of about a hundred million years. The resulting impact of comets on the Earth could account for the major extinctions of life on Earth, such as at the end of the Mesozoic period when the dinosaurs became extinct. To date, no such star has been found.

The nearest star known is Alpha Centauri, a triple star. Alpha Centauri A is slightly larger than the Sun with the same G0 spectral class. B is smaller and cooler, with a separation ranging from 11 to 35 AU (one to three billion miles). Proxima is a red dwarf, widely separated from the other two. Alpha Centauri is about 260,000 AU from the Sun (4.3 light years). Some of the stars close to the Earth are shown in Figure 2. Most of them are smaller and cooler than the sun.

Object	Distance (LY)	Comments
Alpha Centauri	4.3	Triple Star: G2, K5, M5
Barnards Star	6	M5
Wolf 359	7.7	M8
Sirius	8.7	Binary: A1, White Dwarf
UV Ceti	9	Binary: M5, M6
Ross 154	9.6	M4
Ross 248	10.4	M6
Epsilon Eridani	10.9	K2
L789-6	10.9	M7
Ross 128	11	M5
61 Cygni	11.2	Binary: K5, K7, Massive Planet
Epsilon Indi	11.4	K5
Procyon	11.6	Binary: F5, White Dwarf

Figure 2. Stars Close to the Earth

Interstellar space is not completely empty - the existence of interstellar gas was discovered by Hartmann in 1904. The interstellar medium has an average density of one hydrogen atom per cubic centimeter (about a tenth of the density of the solar wind near the Earth). There is about one dust grain per 10,000 cubic meters. The interstellar medium has an optical density of about 2 magnitudes (a factor of eight loss of illumination) per kiloparsec. These are average figures. The actual figures vary from place to place, as can be seen by looking at the night sky. A variety of nebulae are visible, resulting from variations in density and composition of the interstellar medium: reflection nebulae, ionized hydrogen (HII), planetary nebulae, supernova remnants, and dark nebulae.

In addition to clouds of hydrogen, molecular clouds are widespread; more than 60 types of molecule and radical have been detected. Some theories ascribe importance to this material in the origin of life.

10% of the mass of the galaxy is thought to be interstellar medium. Although it is extremely tenuous, there is a lot of it. There is a constant cycle of condensation of the medium into stars, and subsequent disruption of the stars as supernova. Over a scale of kiloparsecs, the structure of the interstellar medium is dominated by the merging of expanding supernova remnants.

ISSUES

Interstellar Medium. There are a number of questions about the interstellar medium that cannot readily be answered from within the Solar System. For example, the extent of the heliosphere is not known with any accuracy. The Voyager spacecraft are expected to identify the location of the magnetopause and collect data about the interstellar medium beyond.

We can infer some properties of interstellar space from Earth based and near-Earth astronomical observations. However, other properties will only be locally observable. Some of these may be related to the properties of space away from the gravitational effects of large masses. Space-time near the Earth is curved by the presence of the Earth itself - a curvature we detect as gravity. There may be other effects both predicted and unpredicted.

Existing/Planned/Possible Probes. Four probes are on trajectories which will take them outside the Solar System; Voyagers 1 and 2, and Pioneers 10 and 11. Perturbations of their trajectories would give an indication of any transplutonian planets.

Pioneer 10 was launched from the Cape in 1972, and flew by Jupiter in 73. Pioneer 11 was about a year behind it. Both are on trajectories which will eventually take them out of the Solar System. They each carried a plaque intended to communicate something of the human race to anyone who finds them.

Voyagers 1 and 2 were launched in 1977. They visited several of the outer planets, returning incredible pictures of the planets and their moons, and are now on a trajectory that will take them out of the Solar System. Each carried a 12 inch copper audio disk of sounds of Earth.

There is no question that we can send unmanned probes out of the Solar System, as we have already done so. However, none of these probes is intended to visit another star. It is interesting to consider what sort of mission we would choose for an unmanned probe.

The most likely target would be the nearest star - Alpha Centauri. Besides being the closest star, it is an interesting target in its own right, a close binary orbited by a third companion at a greater distance. Thus we would get information about three types of stars in one mission: one close to the sun in physical characteristics, one smaller and redder, and a red dwarf. Probably, the three stars of Alpha Centauri formed about the same time as the Sun, but evidence either way would be interesting.

Many characteristics of stars can be deduced from astronomical measurements. However, other attributes such as the characteristics of the various layers of the star - chromosphere, photosphere, etc, cannot be deduced from observations currently possible at this distance. Undoubtedly, observing three other suns at close range will advance our knowledge of stars in general, and also our understanding of the Sun.

Would the three stars have planets? Close binaries could disrupt planets, or even prevent them forming. From the observed orbits of the three stars, it appears that each could have some planets. The closest two are separated by about the distance of the orbit of Saturn, and thus would not be expected to prevent planets forming close to each other. Conceivably, planets could orbit the A B pair. Certainly planets could orbit Proxima. Observations of any planets and their moons would increase tremendously our knowledge of planetary science, restricted as it currently is to the 9 planets in the Solar System and their moons.

Alpha A could well have an Earth-like planet, in which case it would be extremely informative to know if life had evolved, and if so, what form it took. The other two stars, with lower intrinsic luminosity, would have a narrower zone of temperatures which we could tolerate. Even in this range, we would expect major differences in adaptation due to the different conditions on such planets. However, life, being a phenomenon of local negative entropy, could be more widespread than the conditions necessary for carbon-water life. In any case, the presence or absence of life would be perhaps the most critical information we could hope to acquire.

There would probably be other smaller bodies in orbit round the three stars. Asteroids should be commoner, as the gravitational effects should have prevented the formation of planets in the Saturn to Pluto range of distances from the primaries. Comets could be rarer, as the Oort Cloud, if one exists, would presumably be further away and already depleted. However, as a corollary there could have been much more comet impact activity in the history of the planets.

An interstellar probe to address these questions and transmit data back to Earth would be large and complex. Most significantly, it would have to be autonomous, with perhaps the capability to update its mission directives as data arrives back to the Earth and is assessed. (About ten years for mission directives to reach Alpha Centauri.) The necessary level of capability of autonomous action would far exceed that of any existing vehicle. In addition to the need for mission autonomy, the vehicle would need to be capable of intelligently configuring its systems to maximize the probability of mission success.

System survival over the long timeframes likely even with advanced propulsion systems will be a major challenge. We currently have few systems which run for long periods of time without maintenance. Probably the record is held by space probes, some of which are still active into the second decade. Clearly our technology would have to develop significantly to make even a hundred year mission feasible. Biological systems can survive for this type of duration, and we would almost certainly have to develop similar methods for system survival.

The vehicle would need a large power output to send a signal back to Earth. As much of the mission would be away from any star, a nuclear power system is most likely. Conceivably an RTG could be used, with solar power for the terminal phase when it is again near a star. It would need a capable propulsion system for maneuvering within the target system as well as to get to the target star. To provide these basic capabilities would require a large vehicle. Thus the instrument package is also likely to be large and complex.

The most likely mission would be to flyby each of the stars, and by any planets discovered. It would probably end with a close approach to one of the stars, and finally an orbit round the most interesting object, whether a planet or star. In addition to local observations, a vehicle 4 light years from the Earth could provide the capability for observations of parallax and interferometry.

The instruments on such a vehicle would undoubtedly include cameras, particularly telescopic cameras, if only so that we can see what the various objects look like. Spectrographs would be essential, for evaluating the atmospheres of any objects found. For example, the most likely indication of an active biosphere will be a thermodynamically unstable atmosphere: for example, the Earth's oxygen atmosphere was created and is sustained by photosynthesis. These two classes of instruments would address most if not all the topics identified above, and would most likely provide the core of the instrument package. Additional instruments would be added to characterize the interplanetary medium and, during transit, the interstellar medium.

Interstellar Communication. While it is unsure if people will ever be able to travel from star to star, interstellar communication is technically feasible today. We have radio telescopes and lasers powerful enough to send a signal that we have the technology to detect even at interstellar distances. All four of the probes which are on trajectories taking them

out of the Solar System carry a message to anyone intelligent enough to read them.

There are some significant issues with interstellar communication. The major one is whether anyone is out there. There are so many stars, and so many galaxies, that it seems impossible to anyone with a mechanistic view of the universe for life to be unique to the Earth. Simple formulae have been worked out (Figure 3) to estimate the probability of intelligent extraterrestrial races, but the answers depend on assumptions which we cannot substantiate at this time.

<p>Probability of life =</p> <ul style="list-style-type: none">Number of stars being consideredX probability of star having planetsX probability of planet being suitable for lifeX probability of life arising <p>Probability of contact =</p> <p>Probability of life</p> <ul style="list-style-type: none">X probability of intelligence arisingX probability of developing technologyX technological longevity÷ lifetime of star populationX probability of two civilizations seeking contact

Figure 3. Probabilities of Communication

To give an idea of the size of our galaxy, it is about 30 kiloparsecs (100,000 light years) across and 3 thick. The Sun is two thirds of the way from the center. There are about 10^{11} stars in the galaxy.

There are even more uncertainties when we begin to consider the probability of intelligent life at a level of technology which would permit communication. Technology may be a self limiting development, and technological societies may be short lived. Looking at a sample of one – our own society – technology creates difficult, possibly insuperable, problems due to pollution, ecological destruction and instability, and the difficulty of avoiding use of the increasingly potent weapons made possible by that technology.

Even if there are technological societies out there, it may not be easy to make contact, due to technical, temporal, and logical barriers. The obvious medium of communication (obvious to us) is electromagnetic radiation such as radio or laser emissions. However, the universe is a noisy place. Electromagnetic radiation is generated by a wide range of astronomical objects. It would be a poor strategy to broadcast a wide angle broad band signal – the energy required to make such a signal detectable at stellar distances would be prohibitive. Narrow band, highly directional signals are much more appropriate, but then frequency and target selection become critical. The Search for Extraterrestrial Intelligence (SETI) program has formulated a

number of strategies to reduce this problem to one of manageable proportions, and is looking for contacts. The lack of results to date puts an upper bound on the abundance of intelligent technological life in the universe.

A further obstacle is time. How long are you willing to wait for a reply? If we detected a message from Alpha Centauri, and sent a message back at once, almost 9 years would have passed before the sender received a reply. To put this in perspective, United States government funding is on a year by year basis, and there is no guarantee anyone would be listening for a reply after 9 years if we were the ones sending out the message. SETI has been close to being shut down. There are more suns, and more opportunities, the further out we look, but the time lag gets worse.

Even discounting the lag time of at least 9 years, we might find ourselves unable to communicate. Different intelligences with different histories and ecologies will have different ideas of what is important. Meaningful communication for one species may be noise to another. We may discover we can't find anything to say to one another. Attempts have been made to identify universally important and recognizable messages to use to open communication, but we have so much trouble talking to one another on Earth, that the probability of success in communicating with extraterrestrial intelligences does not seem high.

Another aspect of the time constraint is the limited lifetime of species. Looking at the fossil record, a lifetime of a million years is about average for a terrestrial species (so we might be nearing the end of our species lifetime). Even more constraining, the human race has been capable of communicating with a similar species over interstellar distances for perhaps quarter of a century. (The Jodrel Bank radio telescope was completed in 1960.) If we are to establish two-way communications with another species, our lifetimes as technological species must overlap. As the age of the universe is of the order of 20 billion years, this is not a trivial restriction.

All technologies for communication which are currently respectable are based on electromagnetic radiation. Some more exotic options have been discussed, ranging from hypothetical but scientifically acceptable tachyons to wilder concepts such as telepathy. No evidence exists that these options are worth pursuing.

As a final note on the topic, some people feel it is unwise to send any messages out of the Solar System, possibly attracting attention we might regret. However, the option to hide from the universe may no longer be possible. While the power level is still small, we have been sending electromagnetic radiation from the Earth for decades. The wave front of these signals is past the nearest stars.

Interstellar Travel. Opinions on the feasibility of manned interstellar travel vary from inevitable to impossible, due to the enormous distances involved. Some of the milestone space missions and their maximum distances are shown in Figure 4. Even though a logarithmic scale is used, it is hard

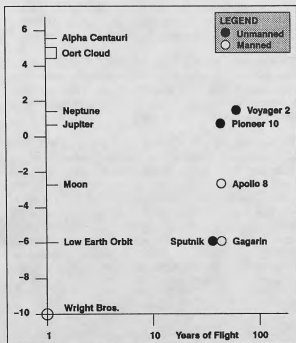


Figure 4. Scale of Interstellar Space and Our Explorations

to show on the same scale the objects of interest of this section and distances with which we are familiar.

As stated above, the nearest star is 4.3 LY from the Sun. A presently reasonable ΔV is 25 miles per second. At this energy, a trip to Alpha Centauri would take about 70,000 years. Even if we decreased the trip time to 1% of this, and we have no realistic idea how to do so, the trip would still take more time than we have had a technological society.

Certainly we cannot travel to another star with current technology or finances. However, technology has a history of transcending what was said to be impossible. To someone living in the early nineteenth century, heavier than air flight was impossible. To someone living in the early 20th century, supersonic flight was impossible. Both of these impossibilities are now routine. It would be foolish to dismiss out of hand the possibility of manned interstellar travel some time in the future.

Even if we never travel to another star, there is a high probability we will send people out of the Solar System. However, even that may be prevented by the high cost and high level of technology required, particularly if the swing away from technology which is seen in Western societies continues.

We can look at propulsion options & limits. Enough is known to say with some certainty that no system operational today can be developed to the point where manned interstellar travel becomes feasible. However, there are concepts which would make it possible, and most likely the technologies which make it possible will have no more relevance to

modern technology than does the phlogiston theory to Space Shuttle operations.

The energy requirements are huge for any interstellar trip which is within the scope of current physics. One idea which could overcome this problem is the possible availability of free space energy. The idea of free space energy, based on Steven Hawking's theories of the "evaporation" of black holes, is scientifically respectable, but the ability to exploit it is unproven.

A number of exotic ideas have been developed which could permit interstellar travel, many having at least a superficial respectability in theory. Distortions in spacetime such as black holes and wormholes are popular ideas. Conditions outside the (unknown) limits of relativity theory are also popular. In both cases, we just do not know enough to say they are impossible. However, at best they are unproven.

A concept which often appears in science fiction novels is multigenerational interstellar travel. Some of the problems of this ark concept have also been identified. For example, sociological and biological instability would be expected with a small isolated community over the hundreds of years involved. Reliability of the spacecraft would also be a challenge.

There are some interesting biological implications of the spread of mankind among the stars using a slow form of travel (Figure 5). The scenario of a small group of individuals establishing an isolated colony, growing rapidly in numbers, then coming up against an environmental limit is precisely the situation thought to be responsible for the formation of new species on Earth. If we colonized the stars in this fashion, the human race, currently one species, would fragment into many species. Hopefully, we would also become more tolerant of diversity.

OTHER SCIENTIFIC QUESTIONS

A number of other scientific questions can benefit by interstellar travel, even of the modest (but still expensive) variety in the Sun's vicinity.

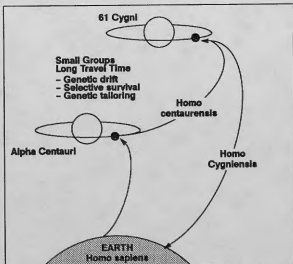


Figure 5. Biological Implications of Interstellar Travel

Long Baseline Observations. The scale we ascribe to the universe depends ultimately on measurements of parallax. Using the Earth's orbit as our baseline, we can get a parallax measurement for the distance of nearer stars, from which we extrapolate to the scale of the universe.

The distance to a star measured by parallax was first published in 1838 by Bessel, who measured the distance to 61 Cygni. Henderson, a year later, published the distance to Alpha Centauri. These measurements are difficult to make, and so are prone to inaccuracy. For example, Henderson's measurement of 200,000 AU was 23% in error. A later measurement by Struve of the distance to Vega was 50% of the current distance. Even today, a typical error is such that the inaccuracy on the distance to Alpha Centauri is 1% - which means that the error at 100 parsecs (326 LY) equals the measured distance.

Increasing the measurement baseline would enable us to increase the accuracy of the measurements. Going out to Pluto, with a maximum distance from the Sun of 39 AU (4.6 billion miles), would increase our accuracy by about 20 times (assuming a baseline from Earth to Pluto). Going out to Alpha Centauri, at 4.3 light years, would increase it by about 100,000 times.

Clean Observational Environment. We are surrounded by environmental noise. For centuries, this has been a recognized problem for ground-based astronomy, primarily because of the turbulence of the atmosphere. It is getting more acute as we become more industrialized. For example, the largest telescope in the world used to be the 200 inch on Mt. Palomar, California. The site was chosen because it was isolated, with no nearby sources of light. Now the observatory has problems because of the growth of Los Angeles, and the

consequent light pollution of the night sky. The site of a new telescope was recently selected in Chile. How long will they have before nearby industrial growth becomes a constraint?

The environment in near-Earth space is much cleaner, above the unsteady atmosphere with its limiting electromagnetic windows. Indeed the maligned but quite successful Hubble Space Telescope was put up because of the increased observational possibilities in space.

However, the Sun puts out large quantities of EM radiation and particles. An observational base on the Farside of the Moon, where it would be shielded from the Earth and for part of the month from the Sun, would go some way towards providing even better observational opportunities. However, some problems will exist even there. For example, neutrinos will pass through the Moon without appreciable absorption. Observations with even lower signal to noise ratios will be possible away from the Sun, in interstellar space. In this case, the background noise from the Sun will diminish with the square of the distance.

SUMMARY

In summary, interstellar space is interesting both to conventional scientists, and to others of a more speculative nature. As we are starting to send probes beyond the boundary of the Solar System, it is appropriate to discuss options for exploring this region, as an extension of the Space Exploration Initiative.