PUPIL RESEARCHER INITIATIVE

ET Phone Earth

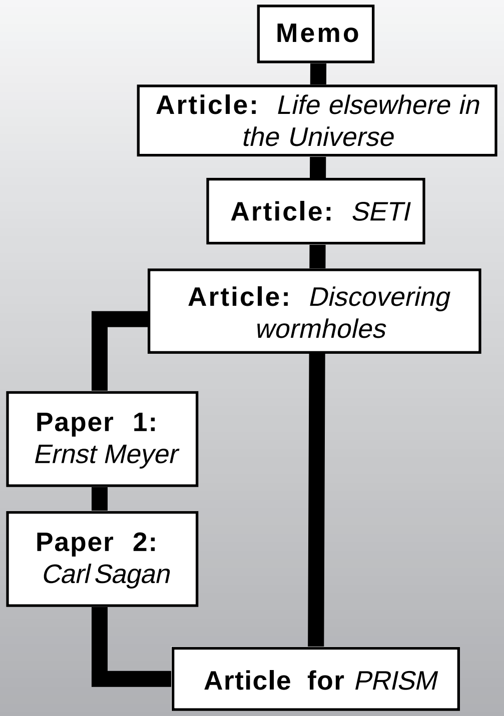
Pupil Research Brief

Teachers' Notes

Syllabus Coverage *Subject Knowledge and Understanding*

- ❑ our Sun is just one of many millions of stars in a group of stars called a galaxy
- ❑ the stars in a galaxy are often millions of times further away from each other than the planets in the Solar System
- ❑ the Universe as a whole is made up of at least a billion galaxies
- ❑ fossils are the 'remains' of plants or animals from many years ago which are found in rocks
- ❑ we know that all species of living things that exist today have evolved from simple life forms which first developed more than 3 billion years ago

Route through the Brief



Introduction

In this Brief pupils are placed in the position of a group of space scientists asked to write an article for *PRISM*, the PRI pupil journal, about the possibility of the existence of extraterrestrial life. They are asked to use a number of background articles and papers as a basis for their article and also to suggest activities that the readers of *PRISM* could carry out - possibly an investigation.

Experimental and investigative skills

- analysing and evaluating evidence and drawing conclusions (from secondary sources)

Note : if pupils plan and trial an investigation activity to go into the *PRISM* article for other pupils to do, then this could possibly cover all four skill areas of *Experimental and Investigative Science* (England, Wales, Northern Ireland GCSE syllabuses).

Prior knowledge

Before attempting this Brief, pupils should have done some work about the planets in the Solar System and the conditions prevailing on our planet that allowed life to evolve. Some idea of the distance between stars would be useful.

Teachers' Notes continued

Running the Brief

Pupil grouping

The Brief could be set as an individual assignment. However, there is a great deal to be gained from the pupils working in pairs and/or small groups, analysing and discussing arguments and evidence, forming their own views, and then preparing a balanced article for *PRISM*.

There are three short background articles and two longer papers, and so the reading tasks for an individual pupil would be demanding. Hence the benefits of sharing the tasks and reporting back, or making the analysis of the two longer papers an optional activity. The following pupil groupings are suggested:

Initial briefing	-	whole class; teacher introduces the topic to stimulate interest
Analysis of memo	-	groups of 3 - 6
Analysis of three background articles and/or two papers	-	tasks shared between individuals or pairs within the small groups
Feedback and discussion of background reading followed by planning of PRISM article	-	original groups of 3 - 6
Communication	-	compilation of *PRISM* article (individual or group) and whole class discussion of topic (optional)

Timing

The Brief should take approximately 3 hours of classroom time; alternatively some of the work could be set as homework.

Activities

The teacher should issue pupils with the **Study guide** which provides pupils with a summary of what they should produce as they work through the Brief. It can also act as a checklist for pupils to monitor their own progress.

The first three background articles cover :

1 the possibility of the existence of primitive life-forms on Mars
2 the possibility of travel between solar systems
3 the possibility of communicating with extraterrestrial life-forms

In the first article, the existence of bacterial life on Mars is considered. There is information about the tests carried out by the Viking probes in the 1970s and information about how knowledge of methods to test for the presence of bacteria has improved since then. The article includes some information about the possible discovery of microfossils of bacteria inside a meteorite that is thought to have come from Mars.

The second article on interstellar travel suggests three possibilities on how this could be achieved given the huge distances between stars:

- the Space Ark
- the Interstellar Photon Jet
- travelling through wormholes.

Each possibility presents problems, which are mentioned briefly.

The third article on communication with extraterrestrial life-forms sketches in the origins of SETI (Search for Extraterrestrial Intelligence) and includes an explanation of the Green Bank equation. There is information on what work is being carried out now, and some proposals for possible further developments in this area.

The Brief contains **two further, longer papers**, which could be used as optional exercises. The 2 papers are condensed and simplified from papers by two distinguished scientists, Ernst Mayr and Carl Sagan. The two papers argue against (Mayr) and in favour of SETI (Sagan), and they first appeared in consecutive editions of *Bioastronomy News*. Both contain provocative, contentious statements. Pupils are asked to identify some of these and offer counter-arguments to them as part of their preparation for writing the article for *PRISM*. The inclusion of this material is intended to show that opinions can differ sharply between distinguished scientists in the absence of conclusive proof, and that things are not always cut and dried in science.

The background articles and papers presented in the Brief could be supplemented by other material - articles from magazines and newspapers, books, CD Roms and information from the Internet, etc. - depending on the level of enthusiasm shown by the pupils. Pupils are asked to **suggest and try out** investigations or projects that the readers of *PRISM* could do (see memo). Possible small scale projects could include devising their own message to be sent out to nearby solar systems, some work on UFO's

Teachers' Notes continued

(these are not mentioned in the given material), and consideration of how the human body would react to long periods in zero-gravity conditions. Possible investigation suggestions could include designing a method to test for bacteria in soil samples obtained from another planet. for example, culturing microorganisms from soil samples using sealable agar plates, or detecting CO_2 emissions from a soil sample using bicarbonate indicator.

Using IT. Pupils could use word processing or desk top publishing packages to produce their article. Other IT applications, such as datalogging, use of spreadsheets, databases, multimedia and the Internet are all possibilities, depending on the activity or investigation which the pupils plan for *PRISM* readers.

Safety issues

PLEASE NOTE: Pupils will be planning and carrying out an investigation, details of which they will include in their article. It is therefore important that you prepare your own risk assessments for this practical work in the usual way. It is advisable for pupils to wear goggles and plastic gloves when handling chemicals.

Assessment issues for *Experimental and Investigative Science* (National Curriculum for England and Wales, Northern Ireland Curriculum)

Pupils' ability to analyse, evaluate and draw conclusions from expert opinions (provided in secondary sources) are encouraged by this Brief. However, since details of the investigation methods used by the authors are not made plain in the background papers, assessment opportunities are unlikely to arise. However, if pupils plan and carry out their suggested pupil investigation for the *PRISM* article, then assessment opportunities will be available, possibly for each of **Skill Areas P, O, A and E**.

Scottish syllabus coverage

Standard Grade Physics - *Space Physics*

Further pupil research opportunities

The subject of the search for extraterrestrial intelligence is very lively and topical, particularly since the discovery of planets orbiting other stars. Pupils can look out for any news that appears on television or in newspapers and magazines and incorporate any new issues or findings in their *PRISM* article or any possible follow-up article.

The topic would also be an excellent one for a class, year group or even school debate. This would be an ideal activity to hold during a school science fair or a ***set***/astronomy week event. It would also be a good basis for a longer term project since there is good coverage of the topic in science magazines, newspapers, on television and the Internet.

PUPIL
RESEARCHER
INITIATIVE

ET Phone Earth

Setting the Scene

You are a member of the Planetary Research Team and you have been asked to write an article for PRISM, the PRI journal, about the possibility of life existing in other parts of the Universe. A range of articles and papers on this topic are provided as useful background material for planning and writing the article.

Pupil Research Brief

Study Guide

Syllabus Targets *Science you will learn about in this Brief*

- ❒ our Sun is just one of many millions of stars in a group of stars called a galaxy
- ❒ the stars in a galaxy are often millions of times further away from each other than the planets in the Solar System
- ❒ the Universe as a whole is made up of at least a billion galaxies
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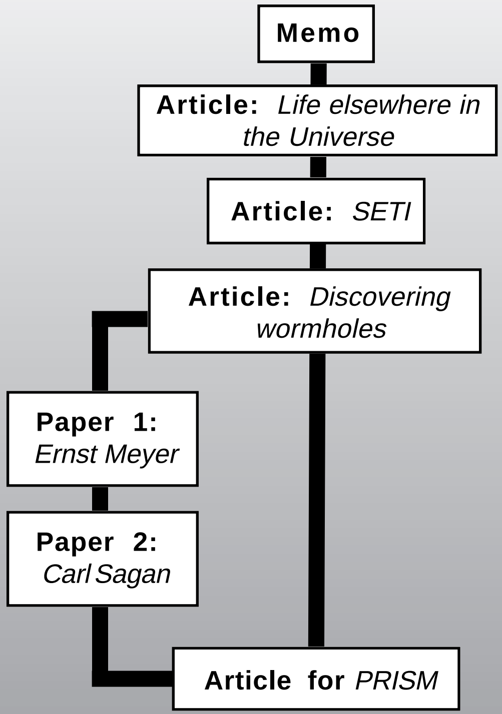


Outcome Checklist

You will produce a 7-800 word article for the pupil journal *PRISM*. The article will include a suggestion for an investigation for other pupils to carry out. You should make sure you produce the following items as you work through the Brief.

Background papers and articles

- ❏ summary notes on reading task(s)

Group discussion

- ❏ plan for *PRISM* article
- ❏ draft of *PRISM* article, including suggested pupil investigation

Department of Space Science

Memo

From: Frank Matthews, Team Leader

To: Planetary Research Team

Subject: Article for *PRISM*

Date:

The editors of *PRISM*, the journal of the Pupil Researcher Initiative, have asked us to write an article about the possibility of life existing in other parts of the Universe. Since this is related to our research, I thought that the team could have a go at putting the first draft together. The journal is aimed at school pupils aged 14 to 16 years, and is issued twice a year. Articles for *PRISM* are written by science and engineering researchers, as well as pupils writing about their own investigations.

Their letter asks for a 7-800 word article, including one or two graphics. They would like us to focus on three main points.

1 Is it possible that life-forms, no matter how primitive, might exist elsewhere in the Solar System?

2 Is it possible that intelligent life-forms exist elsewhere in the galaxy and that we could communicate with them?

3 Is it possible for us to travel to planets outside our Solar System or could intelligent beings from these planets travel to our Solar System?

They would also like us to include one idea for an investigation or project which school pupils could carry out. This could be based on any aspect of the article. We would have to run a trial of the investigation before we suggest it to *PRISM*.

I have included a few relevant background articles and papers which the team could use as a starting point. The deadline for the *PRISM* article is not far off, and so I would welcome a copy of your first draft early next week.

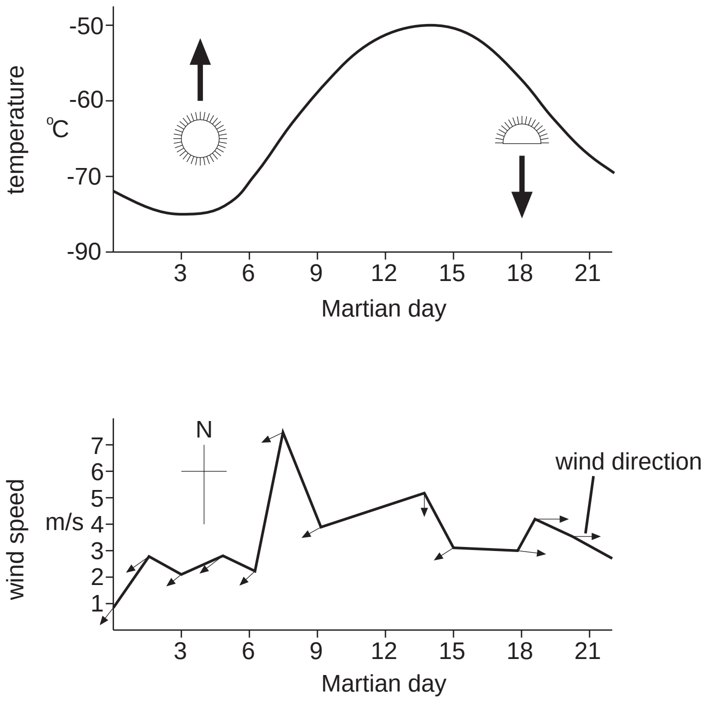
It might be a good idea if you share the background reading between individuals or pairs in the team, who can then make brief notes on their reading task. You can then pool the information as a group in preparation for writing the article.

Life elsewhere in the Solar System

All living organisms on Earth are carbon-based. This means that they are made from complex molecules consisting of chains of carbon atoms with mainly hydrogen, oxygen and nitrogen atoms attached. It has been suggested that life-forms with a completely different chemical structure such as silicon-based molecules could have evolved. We have never found such life-forms and have no way of devising tests to detect their presence. So we have to assume that any life-forms we can discover are ones that have the same basic chemical structure as those found on Earth.

Of the eight other planets in our Solar System the only one at all likely to contain some kind of life is Mars. Mars has the only surface temperature that is bearable by humans. It has a thin atmosphere that is 95% carbon dioxide with 2-3% nitrogen and traces of water vapour, oxygen and argon. The planet has polar ice-caps which are likely to be made of frozen water and carbon dioxide. The Mariner space probes of the 1970s sent back pictures of the surface of Mars. They showed that there are many extinct volcanoes, and the photographs also showed features that are strikingly like dried-up river beds. This could mean that water once flowed on Mars. It is likely that this water is now frozen and trapped beneath the Martian surface.

Figure 1. Temperature and wind speed on the Martian surface, as monitored by Viking 1

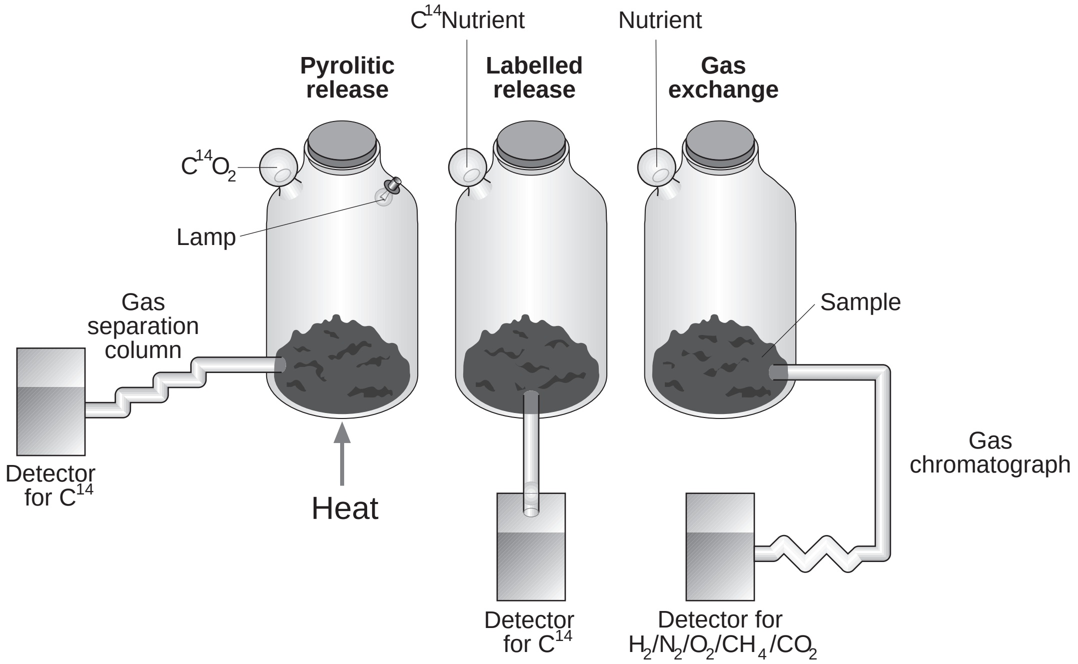


Two Viking space probes soft landed on the surface of Mars in 1976. The landers contained equipment that could scoop up Martian soil and carry out tests on it designed to detect signs of life. The tests did not find any clear evidence of the presence of life forms. Since 1976 great strides have been made in our understanding of primitive life-forms, and in particular of bacteria.

It has been suggested that no life was found on Mars because of the thin atmosphere, the harsh temperatures and the lack of an ozone layer. Ozone protects Earth from ultraviolet rays. UV rays are harmful to certain microorganisms.

However, in 1996 scientists at NASA published a paper in the journal *Science* that presented the results of studies made on a meteorite that had come from Mars. The paper claimed that microscopic structures inside the meteorite showed evidence of having been caused by living things, perhaps similar to bacteria. The evidence has been strongly disputed, but if the findings are correct then it shows that primitive life forms have evolved elsewhere in the Universe. These Martian organisms would have been alive millions of years ago, but their decendants might still be alive on Mars today. So why did the Viking probe not detect them? In recent years new techniques have been devised by biologists for detecting the presence of bacteria and many new species of these organisms have been found thriving in extreme conditions: deeply embedded in ice in the Antarctic; in hydrothermal vents on the sea floor, where the temperature is 100 degrees Celsius; in hot springs where they digest sulphur; and in the Puerto Rico Trench 8000 metres beneath the ocean surface, where no sunlight ever penetrates. It is possible therefore that bacteria may exist on Mars beneath the surface, living in the permafrost. The Viking probes in 1976 only scraped up surface soil for testing. The next probes that land on Mars will have more advanced equipment for detecting signs of life than the Viking probes did in 1976. They will look for bacteria-like organisms beneath the surface.

Figure 2. One of the main tasks of the Viking probes of the 1970s was the search for life. Each landing craft had an automatic biology laboratory. Soil samples were collected by mechanical scoops and delivered to each of three containers, each one housing a different experiment.



1 **Pyrolitic release:** radioactively labelled CO_2 was added to a soil sample, and any uptake by photosynthesising organisms would produce a fall in the amount of labelled CO_2 detected in the gas extracted by the gas separation column.

2 **Labelled release:** nutrients containing radioactively labelled carbon were added to the soil. The soil was then analysed to see if the carbon turned up in any new compounds which might indicate metabolic activity in the soil.

3 **Gas exchange:** nutrients (which might stimulate metabolic activity in possible soil organisms) were added to the soil. Air from the container was then analysed to see if any gases were present which might indicate metabolic activity.

S.E.T.I

The Search for Extraterrestial Intelligence

Paul Lambert, Centre for Space Science

In the 1930s astronomers discovered that some objects in space gave out radio waves, and this led to special receivers being built to study them. These `radio-telescopes' have added tremendously to our knowledge of the Universe, and phenomena such as quasars (extremely bright and distant objects, much smaller than a galaxy but far brighter) and pulsars (very small, fast-spinning stars). Radio waves have been studied from greater distances than visible light waves, and almost all the information we have about the most distant regions of the Universe is derived from radio astronomy.

The largest radio-telescopes are incredibly sensitive. The radio telescope in Arecibo, Puerto Rico can pick up signals with a power of only $1x10^{-14}$ W (one hundredth of a millionth of a millionth of a watt). It occurred to astronomers that such telescopes could be capable of picking up weak signals, similar to our radio or television broadcasts, being emitted from distant planets inhabited by intelligent life-forms.

The first attempt to detect radio signals from extraterrestrial civilisations was made by an American astronomer called Frank Drake. He monitored radio emissions from two nearby stars, Tau Ceti and Epsilon Eridani, for two months, but did not discover anything recognisable as an artificial radio transmission. Interestingly, at the time the search was being made, alien creatures who may have been on planets orbiting these stars could have been monitoring radio signals from Earth for thirty years and television signals for fifteen years.

This lack of success did not deter scientists. In 1961 a conference was organised at Green Bank Observatory, West Virginia. The experts attending worked out the equation that theoretically allows you to estimate the number of technologically advanced civilisations in the Galaxy. We are on safest ground if we assume that life is most likely to evolve in solar systems like our own. The stars need to be G-type dwarf class stars like the Sun, and the planets where the conditions are right must be like Earth, i.e. not too hot or cold, not too large or small, with an atmosphere like our own and with large quantities of water. There are at least eight billion stars in the galaxy that resemble the Sun. The Green Bank equation is set out in Figure 1 below.

Figure 1. The Green Bank Equation

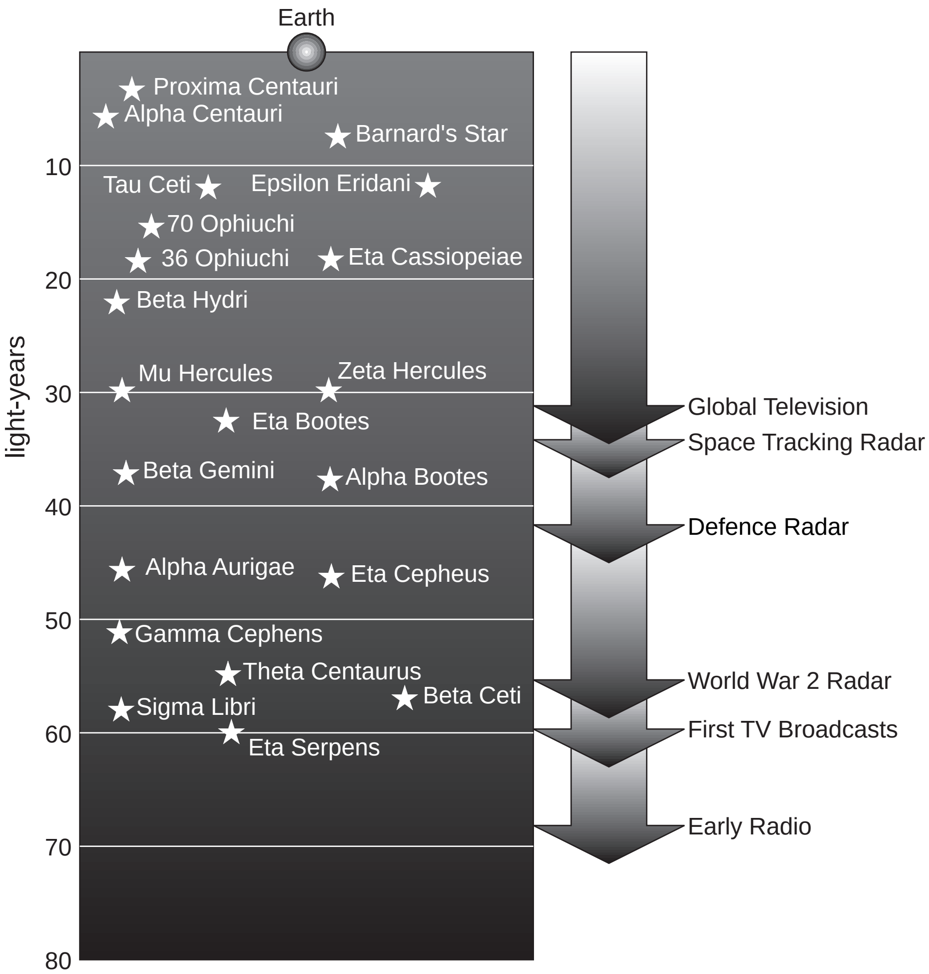
$$N = R\, f_p\, n_e\, f_e\, f_i\, f_c\, T$$

N is the number of advanced civilisations we might detect.
R is the number of stars in the Galaxy favourable to the development of life.
f_p is the fraction of these that have planets orbiting them.
n_e is the number or planets located the right distance from the star.
f_e is the fraction of these planets where life exists.
f_i is the fraction of these planets where intelligent life has evolved.
f_c is the fraction of the civilisations that try to contact others.
T is the time in years spent searching for interstellar communications.

Of course, no-one knew for sure at the time that other stars did have planetary systems, and it was only in 1995 that scientists found evidence for the existence of planets around Sun-like stars. Several such planets have been detected since. The Green Bank conference gave new impetus to the search for extraterrestrial intelligence, and various projects were initiated under the programme known as S.E.T.I. (the Search for Extraterrestrial Intelligence).

Astronomers around the world have monitored radio-signals from space in the hope of discovering `space messages'. In the United States scientists have built receivers capable of monitoring eight million channels at the same time, and a project called CYCLOPS was proposed. This called for 1500 radio antennae, each several metres in diameter, to be built to search for alien radio signals. The cost was estimated at $10 billion. The great radio telescope at Arecibo, Puerto Rico beamed an encoded message to a star cluster known as M13 in 1974. If the signal is received by intelligent life forms we can expect to receive a reply in 50 000 years time.

Figure 2. How far radio signals from the Earth would have travelled into space. The stars shown are similar to our Sun. Could life have evolved there?



Discovering wormholes

Jonathan Lorrie discusses how we might travel to distant stars in the distant future.

Interstellar travel

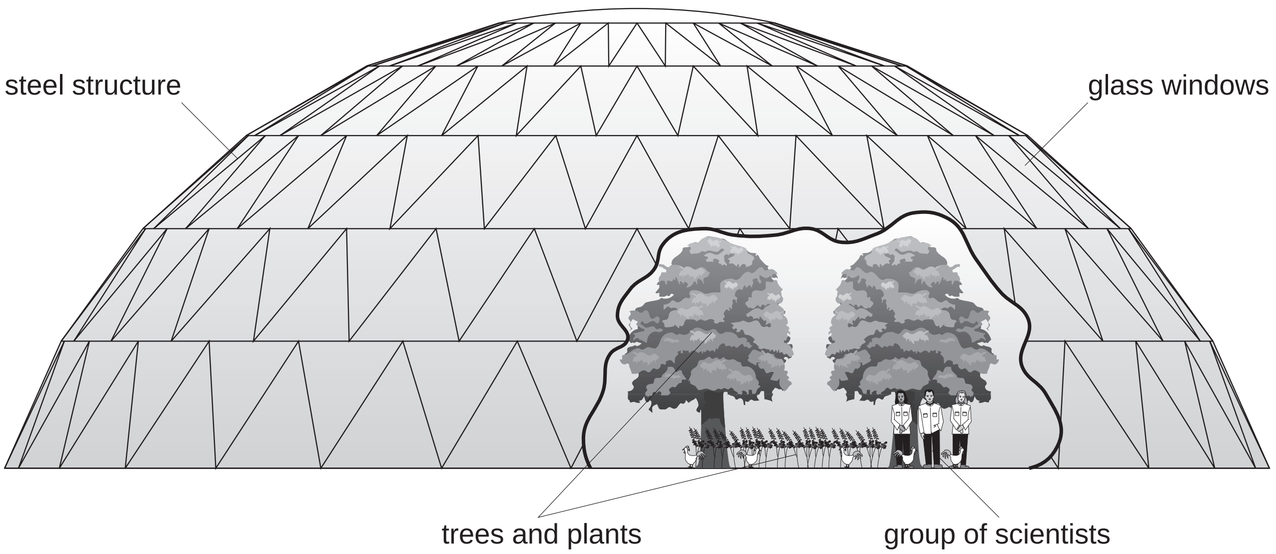
There have been reports of sightings of Unidentified Flying Objects (UFOs) throughout history. Some people claim that there is even a description of a UFO sighting in the Bible (Ezekiel, chapter 10). The modern intense interest in UFOs really dates from 1947 when a pilot called Kenneth Arnold reported seeing a formation of gleaming discs flying over the Rocky Mountains of Washington State, USA. He described them as "skipping like saucers across water", and the name `flying saucer' quickly captured public imagination. Since then there have been many thousands of sightings all over the world. Most of them can be explained away, but about 23% have not so far received satisfactory explanations.

Most scientists are highly sceptical about UFOs. Professor Stephen Hawking was asked if he thought that Earth had been visited by aliens and he said "I don't believe we have, I think that any such visit would be obvious and probably unpleasant. What would be the point of aliens revealing themselves only to a few cranks?".

Others point out the formidable problems of travelling the vast distances from one star to the next. One way of examining this issue is to imagine the situation in reverse: human beings want to visit a planet discovered orbiting a nearby star. The nearest star to the sun is Proxima Centauri, which is 4.3 light years away. Rockets powered by chemical fuels would take nearly 200 000 years to get there and the amount of fuel needed would be unimaginably huge.

So, there are really three alternatives open to us if we want to journey to other stars. These are:

1 the space ark
2 the interstellar photon rocket
3 discovering wormholes



The space ark

Because the distance from the Earth to the nearest star is so vast many scientists believe that we will never be able to travel to another star in less than several thousand years of journey time. The only way we could do so is to build a space version of Noah's Ark.

An experiment to see if people could live in a completely self-contained environment was carried out in America in the late 1980's. 'Biosphere 2' (see Figure 1) was a huge building filled with plants and some animals. Eight scientists were sealed inside for two years. The seals on the entrance were airtight. The idea was to produce an environment where everything was recycled and all food was grown inside to see if it was possible to use such a structure on a very long space journey. The experiment was only a partial success, but it may be possible to build something like this in the future. For a journey to a star the Space Ark would need to be the size of a city and be capable of carrying several thousands of people. The space vehicle would still need to carry huge nuclear reactors, and it would also need to provide energy for the people in the Ark. This place would be the home of these human beings and animals and all their descendants for hundreds of years until the ship reached the star. Some people have suggested that building such a structure would be one way of making sure human beings survive if we made our planet uninhabitable through pollution.

The interstellar photon rocket

Rockets using chemical fuels are hopelessly inadequate for long journeys in space. Much research has been carried out in the USA into the possibility of building an engine which replaced the gases emitted from the exhaust of a chemical rocket with a vast stream of photons - in other words, a beam of light. The thrust produced would be very low, but it could be maintained indefinitely, and over the years the acceleration would build up until it approached light speed.

Such a vehicle would have to be about 10km long with a crew of 300-500. The power supply would come from nuclear reactors. Such a vehicle is theoretically possible, but we are not even close to beginning to develop the technology needed to construct it and make it work.

Discovering wormholes

The scientist and science fiction writer Carl Sagan wanted to write a story in which interstellar travel was possible in a very short time. He consulted a physicist at the California Institute of Technology (Caltech) called Kip Thorne to see if such a thing was theoretically possible. Thorne eventually came up with something called an 'Einstein-Rasen bridge', better known as a wormhole. This is a passage associated with a black-hole, between two parts of the same Universe. The idea of the existence of wormholes is not absolutely impossible, according to the current ideas in physics, but they would have to be made out of something scientists call `exotic matter'. This is matter made up of very strange particles that have weird properties. Such exotic matter may exist, but we haven't found it yet. We also do not know what wormholes might look like. If wormholes do exist , travelling to stars would be relatively easy, and time-travel would be possible as well.

Paper 1

I've found these two papers about SETI. I think they include some controversial statements. You could summarise them and pick out the most provocative statements and come up with some counter arguments for them. I think this will help you with the PRISM article.

A critique of the search for extraterrestrial intelligence (SETI)

by Ernst Mayr, Emeritus professor of Zoology, Harvard University, USA.

How probable is it that life exists somewhere else in the Universe?

Even most sceptics of the SETI project will answer this question optimistically. Molecules that are necessary for the origin of life, such as amino acids and nucleic acids, have been identified in cosmic dust, together with other macromolecules, and so it would seem quite conceivable that life could originate elsewhere in the Universe.

Some of the modern scenarios of the origin of life start out with even simpler molecules - a beginning that makes an independent origin of life even more probable. Such an independent origin of life, however, would presumably result in living entities that are drastically different from life on Earth.

Where can one expect to find such life?

Obviously, only on planets. Even though we have up to now secure knowledge only of the nine planets of our Solar System, there is no reason to doubt that in all galaxies there must be millions if not billions of planets. The exact figure, for instance, for our own galaxy can only be guessed.

How many of these planets would have been suitable for the origin of life?

There are evidently rather narrow constraints for the possibility of the origin and maintenance of life on a planet. There has to be a favourable average temperature; the seasonal variation should not be too extreme; the planet must have a suitable distance from its sun; it must have the appropriate mass so that its gravity can hold an atmosphere; this atmosphere must have the right chemical composition to support early life; it must have the necessary consistency to protect the new life against ultraviolet and other harmful radiations must be suitable for the origin and maintenance of life.

One of the nine planets of our Solar System had the right kind of mixture of these factors. This, surely, was a matter of chance. What fraction of planets in other solar systems will have an equally suitable combination of environmental factors? Would it be one in 10, or one in 100, or one in 1 000 000? Which figure you choose depends on your optimism. It is always difficult to extrapolate from a single instance. This figure, however, is of some importance when you are dealing with the limited number of planets that can be reached by any of the SETI projects.

What percentage of planets on which life has originated will produce intelligent life?

Life originated on Earth about 3.8 billion years ago, but high intelligence did not develop until about half a million years ago. If Earth had been temporarily cooled down or heated up too much during these 3.8 billion years, intelligence would have never originated.

For the first 2 billion years only very primitive bacteria, with no organised cell nucleus, existed on Earth. About 1.8 billion years ago the first cells with organised nuclei appeared. From these cells there eventually evolved fungi, plants and animals. None of the millions of fungi and plants produced intelligence.

Animals branched into 60 to 80 lineages (phyla). Only one of these led to genuine intelligence - the vertebrates. Among the vertebrates only the mammals led to high intelligence.

The evolution of the brain of human-like creatures, the hominids, began less than 3 million years ago, and the species *Homo sapiens* - modern human beings - appeared about 300 000 years ago. This highly condensed account of evolution demonstrates that the chances of life evolving into some kind of high intelligence are very improbable.

Why is high intelligence so rare?

Adaptations that are favourable to selection, such as eyes or bioluminescence, originate in evolution scores of times independently. High intelligence has originated only once, in human beings. I can think of only two possible reasons for this rarity. One is that high intelligence is not at all favoured by natural selection, contrary to what we would expect. In fact, all other kinds of living organisms, millions of species, get along fine without high intelligence.

The other possible reason for the rarity of intelligence is that it is extaordinarily difficult to acquire. Some grade of intelligence is found only among warm-blooded animals (bird and mammals), not surprisingly so because brains have extremely high energy requirements. But it is still a very big step from “some intelligence” to “high intelligence.”

The hominid lineage separated from the chimpanzee lineage about 5 million years ago, but the big brain of modern man was acquired less than 300 000 years ago. As one scientist has suggested (Stanley 1992), it required complete emancipation from tree-dwelling life to make the arms of mothers available to carry the helpless babies during the final stages of brain growth. Thus, a large brain, permitting high intelligence, developed in less than the last 6 percent of the life on the hominid line. It seems that it requires a complex combination of rare, favourable circumstances to produce high intelligence (Mayr 1994).

How much intelligence is necessary to produce a civilization?

As stated, rudiments of intelligence are found already among birds (ravens, parrots) and among non-hominid mammals (carnivores, porpoises, monkeys, apes and so forth), but none of these instances of intelligence has been sufficient to found a civilization.

Is every civilization able to send signals into space and to receive them?

The answer is by no means certain. Even on Earth many groups of animals are specialized for olfactory or other chemical stimuli and would not react to electronic signals. Neither plants nor fungi are able to receive electronic signals. Even if there were higher organisms on some planet, it would be rather improbable that they would have developed the same sense organs that we have.

How long is a civilization able to receive signals?

All civilizations have only a short duration. I will try to emphasize the importance of this point by telling a little fable. Let us assume that there were really intelligent beings on another planet in our galaxy. A billion years ago their astronomers discovered Earth and reached the conclusion that this planet might have the proper conditions to produce intelligence. To test this, they sent signals to Earth for a billion years without ever getting an answer. Finally, in the year 1800 (of our calendar) they decided they would send signals only for another 100 years. By the year 1900, no answer had been received, so they concluded that surely there was no intelligent life on Earth.

This shows that even if there were thousands of civilizations in the universe, the probability of a successful communication would be extremely slight because of the short duration of the "open window". One must not forget that the range of SETI systems is very limited, reaching only part of our galaxy. The fact that there are a near infinite number of additional galaxies on the universe is irrelevant as far as SETI projects are concerned.

Conclusions: an improbability of astronomic dimensions

What conclusions must we draw from these considerations? No less than six of the eight conditions to be met for SETI success are improbable. When one multiplies these six improbablities with each other, one reaches an improbability of astronomic dimensions.

Why are there nevertheless still proponents of SETI? When one looks at their qualifications, one finds that they are almost exclusively astronomers, physicists and engineers. They are simply unaware of the fact that the success of any SETI effort is not a matter of physical laws and engineering capabilities but essentially a matter of biological and sociological factors. These, quite obviously, have been entirely left out of the calculations of the possible success of any SETI project.

References

Ernst Mayr, "Lohnt sich die Suche nach extraterrestrischer Intelligenz (Is it worthwhile to search for extraterrestrial inteligence?)", Naturwissenschaftliche Rundschau, vol. 45, no. 7, 1992, pp. 264-266.

Ernst Mayr, "Does it pay to acquire high intelligence?" Perspectives in Biology and Medicine, 1994, pp. 150-154.

S. Stanley, "An ecological theory for the origin of *Homo*", Paleobiology, vol. 18, 1992, pp. 237-257.

Paper 2

This is the second paper

In defense of the search for extraterrestrial intelligence: the abundance of life-bearing planets

by Carl Sagan, Cornell University, USA

We live in an age of remarkable exploration and discovery. Fully half of the nearby Sun-like stars are surrounded by discs of gas and dust similar to that from which our planets formed 4.6 billion years ago. A range of new Earth-based and space-borne techniques have enabled scientists to discover several planets around other stars. It is only a matter of time before a planet similar to Earth is found.

Once you have found another planet of Earth-like mass, however, it of course does not follow that it is an Earth-like world - consider Venus. But there are means by which, even from the vantage point of Earth, we can investigate this question. We can look for the spectral signature of enough water to be consistent with oceans. We can look for oxygen and ozone in the planet's atmosphere. We can seek molecules like methane.

The best current estimates suggest that Sun-like stars are likely to have one or two `blue worlds' orbiting them (`blue world' - planets with oceans). Given the number of stars that are similar to our sun, this means that there are vast numbers of planets distributed throughout the Milky Way.

Need intelligence evolve on an inhabited world?

We know from lunar cratering statistics, calibrated by returned Apollo samples, that Earth was under extreme bombardment by small and large objects from space until around 4 billion years ago. This pummeling was sufficiently severe to drive entire atmospheres and oceans into space. Earlier, the entire crust of Earth was a magma ocean. Clearly, this was no breeding ground for life.

Yet, shortly thereafter - 3.8 billion years ago - some early organisms arose (according to the fossil evidence). Presumably the origin of life had to have occurred some time before that. As soon as conditions were favourable, life began amazingly fast on our planet. It seems to me that the origin of life must be a highly probable circumstance; as soon as conditions permit, up it pops! Does a similar analysis apply to the evolution of intelligence? Here you have a planet burgeoning with life, profoundly changing the physical environment, generating an oxygen atmosphere 2 billion years ago, going through elegant diversification and yet not for almost 4 billion years does anything remotely resembling a technical civilization emerge.

In the early days of such debates writers argued that an enormous number of individually unlikely steps were required to produce something very like a human being, a `humanoid'; that the chances of such a precise repetition occuring on another planet were nil; and therefore that the chance of extraterrestrial intelligence was nil. But clearly when we're talking about extraterrestrial intelligence, we are not talking - despite *Star Trek*- of humans or humanoids. We are talking about the functional equivalent of humans - say, any creatures able to build and operate radio telescopes. They may live on the land or in the sea or air. They may have unimaginable chemistries, shapes, sizes, colours, appendages and opinions.

We are not requiring that they follow the particular route that led to the evolution of humans. There may be many evolutionary pathways, each unlikely, but the sum of the number of pathways to intelligence may nevertheless be quite substantial. Evolution is opportunistic and not foresighted. It does not `plan' to develop intelligent life a few billion years into the future. It responds to short-term contingencies. And yet, other things being equal, it is better to be smart than to be stupid, and an overall trend toward intelligence can be perceived in the fossil record. On some worlds, the selection pressure for intelligence may be higher, or on others, lower.

If we consider the statistics of one, our own case, and take a typical time from the origin of a planetary system to the development of a technical civilization to be 4.6 billion years, what follows? We would not expect civilizations on different worlds to evolve in lock step. Some would reach technical intelligence more quickly, some more slowly, and doubtless, some never. But the Milky Way is filled with second and third generation stars (that is, those with heavy elements) as old as 10 billion years.

So let's imagine two curves. The first is the probable time scale to the evolution of technical intelligence. It starts out very low; by a few billion years it may have a noticeable value; by 5 billion years, it's something like 50 percent, by 10 billion years, maybe it's approaching 100 percent. The second curve is the ages of Sun-like stars, some of which are very young - they're being born right now - some of which are as old as the Sun, some of which are 10 billion years old. If we convolve these two curves, we find there's a chance of technical civilizations on planets of stars of many different ages - not much in the very young ones, more and more for the older ones. The most likely case is that we will hear from a civilization considerably more advanced than ours. For each of those technical civilizations, there have been tens of billions or more other species. The number of unlikely events that had to occur to evolve the technical species is enormous, and perhaps there are members of each of those species who pride themselves on being uniquely intelligent in all the Universe.

Need civilizations develop the technology for SETI?

It is perfectly possible to imagine civilizations of poets or (perhaps) Bronze Age warriors who never stumble on James Clerk Maxwell's equations and the science needed to invent radio receivers. But they are removed by natural selection. The Earth is surrounded by asteroids and comets. Occasionally the planet is struck by one large enough to do substantial damage. There is ample evidence that one such event 65 million years ago extinguished the dinosaurs and most other species of life on Earth. There is every chance that a similarly devastating impact could occur again. It is clear we need elaborate means for detecting and tracking Near-Earth Objects, as well as the means for intercepting and destroying them. Any long-lived civilization, whether on Earth or on another planet, must come to grips with this hazard. Other solar systems than ours are just as likely to have asteroids and comets that could destroy life on planets.

Radar monitoring and radio telescopes are vital to the detection of Near-Earth Objects on a collision course with Earth. Any long-lived civilization will have to develop similar technology. In developing radar telescopes we have also developed the means to receive and send messages from and to alien intelligences. The belief that human beings are unique because we have intelligence is very old and very deep-seated. The notion that there may be other species in the Universe which are as intelligent as us or more intelligent is shocking to many people. But surely this is mere conceit?

We do not **know** that there **is** extraterrestrial intelligence, but let us use the technology we have developed to try and actually find out the answer.