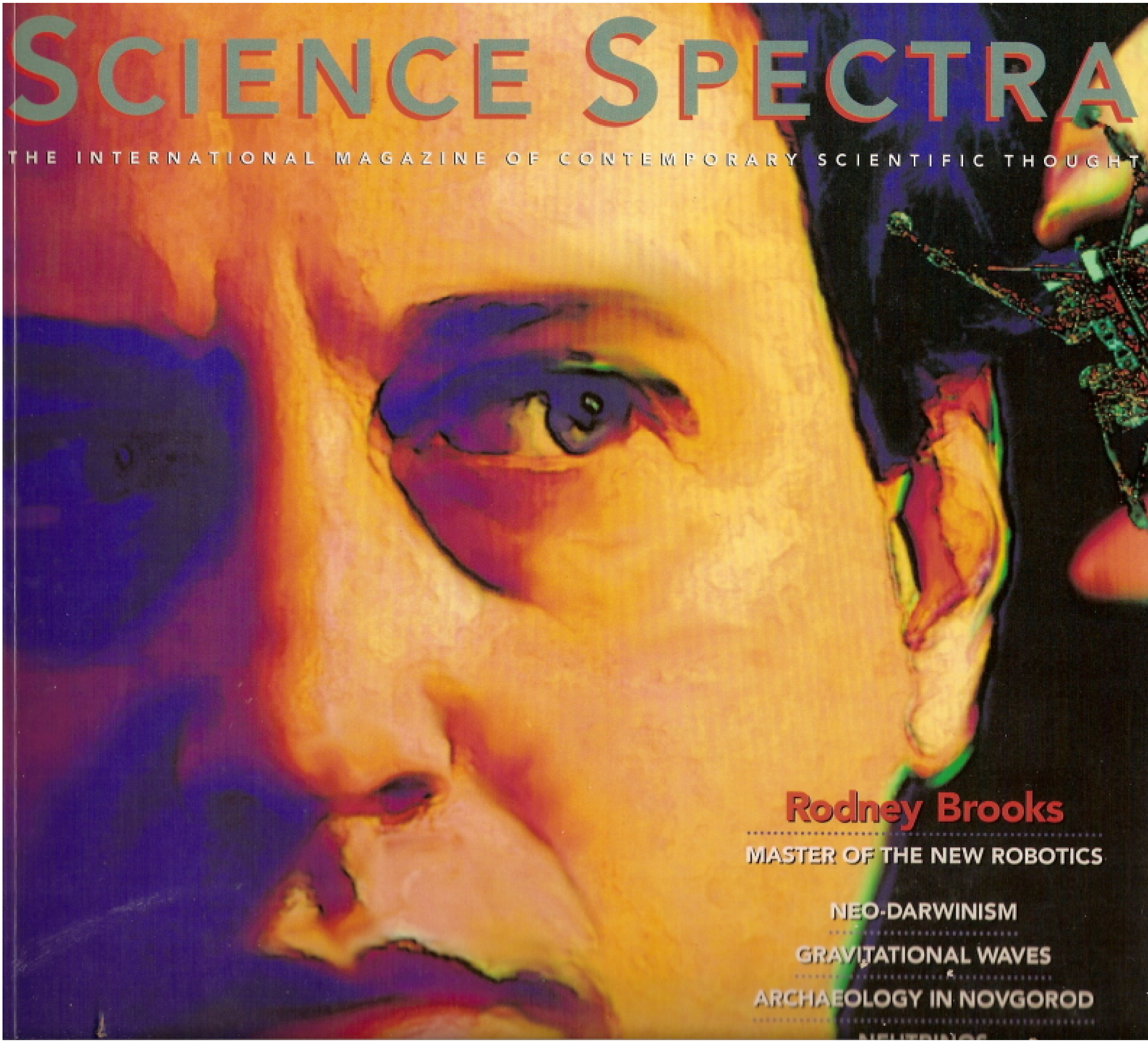
SCIENCE SPECTRA
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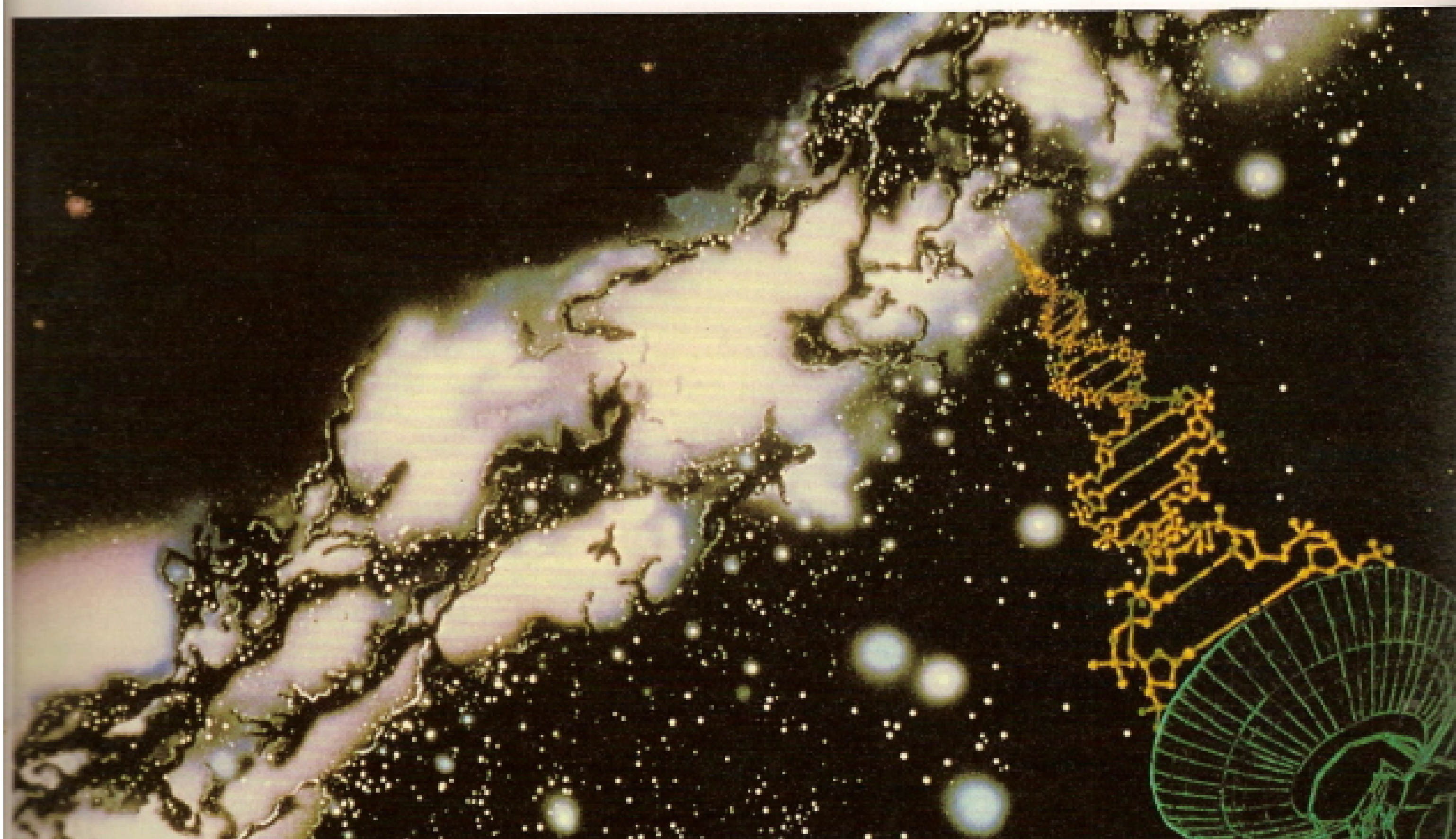
THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

BY GUILLERMO A. LEMARCHAND

NEXT YEAR, THE WORLD'S MOST AMBITIOUS SEARCH YET FOR SIGNS OF INTELLIGENT LIFE BEYOND EARTH BEGINS. BUT WHAT ARE THE ASSUMPTIONS BEHIND SUCH A DARING AND PERHAPS HUBRISTIC VENTURE? DR GUILLERMO A. LEMARCHAND OF THE UNIVERSITY OF BUENOS AIRES, ARGENTINA, OUTLINES THE CASE.

If there is a thread that links ancient Greek philosophers and modern space scientists, it is the uncertainty about the plurality of inhabited worlds in the cosmos. Vast and old beyond human understanding, the universe leaves us pondering the ultimate significance, if any, of our tiny but exquisite life-bearing planet. With our present understanding of the laws of nature and modern technical capability, we are for the first time in history in a position to test the possibility that extraterrestrial civilisations exist. This is the search for extraterrestrial intelligence, or SETI which, in the deepest sense, is also a search for ourselves.

SETI proponents like to think of life as a natural byproduct of physical processes on Earth-like worlds. Our galaxy has hundreds of billions of stars, in a universe with billions of galaxies, and so life *should* be common in this cosmic realm. Or so the theory goes. There should be many habitable planets, each sheltering its brood of living creatures, with some of these developing intelligence and a technological civilisation with an interest in communicating with other sentient creatures. Using electromagnetic waves, it should be possible to establish contact across interstellar distances, and extraterrestrial communication should have an electromagnetic signature that humans can recognise.



The search for extraterrestrial intelligence is speculative, but like all questions in science, it should be pursued with rigour. But it also is, in a sense, a search for ourselves and humanity's place in the universe.

In recent years, evidence has arisen in favour of some of these views. Astronomical observations increasingly suggest that planetary systems are common. Almost half the Sun-type stars in the neighbourhood of our Sun – such as Beta Pictoris, Formalhaut, HD 4796 and Vega – have accretion disks of dust, which appear to be indicative of planetary formation.

Only planets supporting and recycling liquid water within their atmospheres are expected to support life. This helps us to define circumstellar habitable zones, or orbital bands around a star within which planets like Earth could develop. The zone's inner boundary is the point at which a runaway greenhouse effect occurs, as on Venus; and the outer boundary is where carbon dioxide condenses out of an atmosphere and can no longer warm a planet, as on Mars. Using mathematical models for the distribution of planets that might form in these zones, astronomers theorise that up to two Earth-like planets may be found within each planetary system with a main sequence star, orbiting at a distance where liquid water is possible.

We now know that the time required for life to emerge is very short. When Earth formed some 4.6 billion years ago, it was a lifeless, inhospitable place. Only one billion years later, the planet was teeming with organisms resembling today's cyanobacteria. The question is, once life appears, will intelligence follow? Ernst Mayr of the Museum of Comparative Zoology at Harvard University in the U.S. affirms that only one out of some 50 billion species that have arisen on Earth was potentially capable of generating something that might have approached civilisation. Among these potential 20 civilisations, only one advanced to the point of developing interstellar communication technology. This is not usually discussed in detail by SETI proponents, who prefer to subscribe to what was once called the "Assumption of Mediocrity" view: "what happened on Earth", goes the theory, "is the average among all the habitable worlds in the universe". Under this assumption, we may expect a logical progression from life to sentience: presence of planets with suitable environments → emergence of life → emergence of intelligence → emergence of interstellar communication technology. Such faith is probably mistaken, but it is still a hypothesis that needs to be tested. SETI programmes, either under way or soon to start up, offer our present best chance to do this.

The basic assumption of SETI researchers is that the physical laws governing the universe are the same everywhere. We think this is true, but it could be false. If the same physical laws apply across the cosmos, we will be able to communicate by referring to those things we have in common with extraterrestrials – physics, mathematics, and so on. However, Nicholas Rescher, Professor of Philosophy at the University of Pittsburgh, believes that it may not be as easy as all that. He contends that extraterrestrials are extremely unlikely to have any type of science that would be recognisable to us, despite sharing the same 'universal' laws. They will be very different organisms, with different needs, senses, and behaviour; they will inhabit environments strikingly different from our own, environments in which neither science nor technology may be needed for survival. Several successful species have flourished on Earth without developing intelligence, so sentience may not be a necessary adaptation, and should not be automatically expected to develop elsewhere. The science of an alien civilisation would reflect the way they perceive nature. It might therefore be impossible for us to fathom their view of the universe or their approach to science.

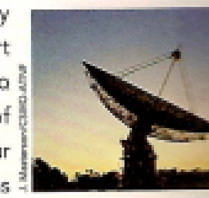
However, artificial intelligence pioneer Marvin Minsky, of Boston's Massachusetts Institute of Technology, disagrees,. He argues that intelligent extraterrestrials "will think like us, in spite of different origins". This is based on the idea that all intelligent problem-solvers are subject to the same ultimate constraints – limitations of space, time and resources. In order for life to evolve successful strategies for dealing with such constraints, they must be able to represent the situations they face, and they must have processes for manipulating those representations. He proposes two basic principles for every "intelligence":

Economics: every intelligence must develop symbol-systems for representing objects, causes and goals, and for formulating and remembering the procedures it develops for achieving those goals.

Sparseness: every evolving intelligence will eventually encounter certain very special ideas – e.g. arithmetic, casual reasoning and economics – because these particular ideas are very much simpler than other ideas with similar uses.

According to Minsky, extraterrestrials will therefore have evolved thought processes and communication strategies that will mirror our own, to a degree that will enable us to comprehend them. SETI proponents largely agree with Minsky, choosing also to believe that there is some "convergence" in the interpretations of the physical laws in all galactic civilisations.

Assuming the universality of natural laws, the next problem for SETI proponents are the distances. These are so large that, limited by the speed of light and our short lifespans, we cannot go out into the universe to seek evidence of extraterrestrial civilisations. But our understanding of the universe has not been greatly hampered by this: we have gleaned a wealth of knowledge through analysis and deduction of incoming 'information carriers'. Modern astrophysics is founded on what we have learned via electromagnetic radiation (radio, infrared, optical, ultraviolet, X-rays, and gamma rays), cosmic rays (electrons and atomic nuclei), and neutrinos. There is another possible carrier, gravitational waves, but they are extremely difficult to detect (see article on page 14) and far too difficult to generate in order to be used for interstellar communication.



The 64-metre Parke telescope in Australi

It is, of course, impossible for all of these carriers to be continuously monitored on Earth. Each observation technique acts as an information filter, and only a fraction of the incoming radiation can be gathered. Using our criteria of "sparseness" and of "economics", we should therefore select those information carriers that require a minimum amount of energy to exceed the natural background; those that travel at, or close to, the speed of light; that are not deflected by galactic or stellar fields; can be easily generated, detected and beamed; and will not be absorbed by the interstellar medium or by planetary atmospheres and ionospheres. Only photons meet all of these criteria; electromagnetic waves of some frequency are therefore the only truly suitable signal carriers for extraterrestrial signals.

NASA/JPL

Left: The "Sounds of Earth" record and the American flag being prepared for the Voyager 2 space probe in 1977.
Right: Aboard both Voyager craft which are now headed out of the solar system, the gold-plated copper records carry images of life on Earth, music and greetings in 60 languages. They are designed to last a billion years.

The production of such radiation is directly related to the physical conditions prevailing at the emission site. Information carried by electromagnetic waves (photons) is also affected by the conditions along its path. The trajectories followed depend on the local curvature of the universe, and thus on the local distribution of matter and its gravitational effects; extinction affecting different wavelengths unequally; neutral hydrogen absorbing all radiation below the Lyman limit (912 Angstroms); and absorption and scattering by interstellar dust, which is more severe at short wavelengths. Interstellar plasma absorbs radio wavelengths of a kilometre and above, while the scintillations caused by them become a very important effect for the case of extraterrestrial radio transmissions, because of the large temporal variability in the signal amplitude. The inverse Compton effect lifts low-energy photons to high energies in collisions with relativistic electrons, while gamma and X-ray photons lose energy by the direct Compton effect. The radiation reaching the observer thus bears the imprint of both the source and the accidents of its passage though space.

The universe observable with electromagnetic radiation can be characterised as multi-dimensional phase space. The space of configuration for the transmission and reception of interstellar electromagnetic signals includes a four-dimensional coordinates subspace (the spatial coordinates and transmission epoch of the extraterrestrial civilisation), and a seven-dimensional information subspace (the modulation type, transmitting frequency, information rate, frequency width of the signal, polarisation, code and semantics).

In 1961, SETI pioneer Sebastian von Hoerner classified the possible nature of the extraterrestrial signals into three general potential scenarios: local communication on the other planet; interstellar communication between extraterrestrial civilisations, or between the home planet and their extra-solar outposts; and a desire to attract the attention of undiscovered civilisations. Thus he named them as "local broadcast", "long-distance calls", and "contacting signals", or beacons. Most of the past 60 SETI radio projects have worked on the hypothesis that several civilisations are transmitting omnidirectional "beacon" signals, or that we are capable of eavesdropping on the local broadcasts of intelligent beings on nearby stars.

Considering the entire microwave region of the electromagnetic spectrum (300 MHz to 300 GHz) and avoiding the temporal synchronisation between transmission and reception and the cryptographic variables (polarisation, modulation, information rate, code and semantics), it is easy to show that this 'cosmic haystack' has roughly 3×10^{29} cells. This is assuming equal weight in each unit of each axis of our remaining space of configuration, and each cell would have a 0.1 Hz bandwidth, per the number of directions in the sky in which an Arecibo-type radio telescope would need to be pointed to conduct an all-sky survey, per a sensitivity between 10^{-20} and 10^{-30} [W m^{-2}]. The number of "cells" increases dramatically if we expand our search to other regions of the electromagnetic spectrum, or we decide to include the other variables. Until now, only a small fraction of the whole 'haystack' has been explored (approximately 10^{-15} to 10^{-16}).

The success of a radio search for extraterrestrial intelligence depends not only on the unknown abundance of civilisations in our galaxy, but also on their assumed transmission strategies. How can the extraterrestrials announce their presence to their galactic neighbours? The best transmission strategy should set all the variables of the space of configuration following the so-called "Principle of Anti-Cryptography". In this way, we suppose that the signal will be designed and operated in such a way as to maximise its probability of discovery, both by intentional searches and by accidental observations. Even if there are a large number of civilisations in mutual communication, the probability that we on Earth would be able to eavesdrop on narrow beam of extraterrestrial signals sent at a random is vanishingly small. Very advanced civilisations might be able to broadcast omnidirectionally over great distances and during long periods of time, but such civilisations may develop interests other than contacting emerging civilisations.

The real difficulty in detecting a signal is knowing where to point your radio telescope, when a transmission is being sent. Synchronisation is the most difficult element of the search strategy. It is possible to select and search "rationally" all the other elements – frequency, bandwidth, polarisation, direction – but you would have to be extremely lucky to capture an extraterrestrial signal while aiming your radio telescope at a region of the sky at the precise moment a message is passing through Earth. SETI researchers therefore pin their hopes on omnidirectional beacons: firstly, that they exist and secondly, that they will find them.

What kind of signal might one expect from a distant civilisation? If it is sent intentionally, it will most likely be narrow-band (approximately 1 Hz or less), ideally a single wavelength, and something with a high monochromatic. There are two main reasons for this: firstly, to distinguish between "natural" and artificial signals (most monochromatic natural sources are the cosmic masers with bandwidths of about 500 Hz); and secondly, such a signal travels furthest for a given transmitting power. Most of the existing SETI projects are only capable of distinguishing the presence of a monochromatic signal (continuous wave or pulsed) among a broad band of cosmic noise, but not the possible content of the hypothetical message coded in some unknown modulation form. This kind of strategy limits our search to the detection of "long distant calls" and "contact signals", since "local broadcasts", such as voice signals, require a wider band of wavelengths. Television is even wider: a standard satellite TV bandwidth signal is 27 MHz, or 27 million times more powerful than a sinusoidal 1 Hz beacon for the same detection.

In the last 35 years, most SETI projects have been developed in the microwave region of the electromagnetic spectrum, searching for interstellar monochromatic beacons. There are four operating SETI programs: Serendip, META, Project Phoenix and the Ohio State University program. The box at right shows the main characteristics, strategies and signals sought. So far, there has been no conclusive evidence of success.

WHO SPEAKS FOR EARTH?

Should we one day awake to find an extraterrestrial spaceship floating above the United Nations building, we would have little choice but to pay heed. But if extraterrestrial contact is made via radio, humanity would face a momentous decision: should we reply? During the past decade, several scholars have proposed that an international process be established for humanity to decide as a whole. John Billingham, of the privately-funded SETI Institute in the United States, recently prepared a draft of such a process for the U.N., which would require international coordination.

What can we learn from past experience? On November 16, 1974, the 305-metre Arecibo radio telescope in Puerto Rico transmitted a message directed at the globular cluster M13. The message described some characteristics of life on Earth. Because of the choice of frequency (2,380 MHz), duration of the message (169 seconds), and distance of the target (25,000 light years), the Arecibo message is unlikely to ever be detected by an alien civilisation. However, its transmission did provoke debate. U.S. diplomat Michael A. G. Michaud considered the exercise a political act: he said that such a monumentous decision should be made openly, in the full glare of publicity, "with the involvement of public authorities", and not be left to scientists alone. The other major objection was raised by Sir Martin Ryle, a Nobel laureate and then-Astronomer Royal of the United Kingdom. He wrote to leading astronomers, arguing that it was a hazardous folly to reveal our existence and location to the universe. For all we know, "any creatures out there are malevolent or hungry", he wrote, and once they knew of us, "they might came to attack or eat us". Ryle strongly recommended that no messages of this type be

ONGOING MAJOR SETI PROJECTS

META I and META II

"Mega-channel Extraterrestrial Assay"

OBSERVATORIES

The 26-metre antenna at Harvard University, Massachusetts, USA, (META I) and a 30-metre antenna at the Argentine Institute for Radio Astronomy, near Buenos Aires, Argentina (META II). Funded by The Planetary Society, an international organisation based in Pasadena, USA.

CAPABILITY

Monitors 8.4 million channels at once. Spectral Resolution: 0.05 Hz. Instantaneous Bandwidth: 0.4 MHz. Total Frequency Coverage: 1.2 MHz. Maximum Sensitivity: 7×10^{-24}, W m^{-2}. Sky Coverage (META I and II): 93 per cent. Type of Signals: carriers. RFI rejection: anti-chirp. META I will soon be upgraded, becoming BETA (Billion-channel Extraterrestrial Assay), and will use a revolutionary technique to avoid terrestrial frequency interference.

FINDINGS TO DATE

After five years of observations from the northern hemisphere, META I found 34 candidate signals, but the data are insufficient to determine their real origin. Interestingly, the observed signals appeared to cluster near the galactic plane, where the major density of stars is located. META II after three years of observations from the southern sky found 19 candidate signals with similar characteristics to those of META I. For two days a week, the observatories in Harvard and Buenos Aires observe the same region of the sky (declinations between -10 and -30°) simultaneously, with META I and META II fixed at the same frequency and reference frame.

OHIO STATE UNIVERSITY SETI PROGRAM

OBSERVATORY

Rectangular telescope, equivalent to a 53-metre parabolic radio telescope, in Columbus, Ohio, USA.

CAPABILITY

Monitors 3,000 channels. Spectral Resolution: 100 kHz. Instantaneous Bandwidth: 5 MHz. Total Frequency Coverage: 300 MHz. Maximum Sensitivity: 6×10^{-23}, W m^{-2}. Sky Coverage: 74 per cent. Type of Signals: carriers. RFI rejection: subtraction effect of the switched beams.

FINDINGS TO DATE

With several upgrades, this system has been in operation since 1973. It detected one promising candidate – the so-called "WOW signal" – but subsequent searches have been unable to detect it again.

PROJECT PHOENIX

OBSERVATORY

The 64-metre antenna at Parkes, Australia.

CAPABILITY

Monitors 15 million channels per module. Spectral Resolution: 1, 2, 4, 7, 14, 28 Hz. Instantaneous Bandwidth: 10 MHz. Total Frequency Coverage: 2000 MHz. Maximum Sensitivity: 3×10^{-25}, W m^{-2}. Sky Coverage: 0.02 per cent (target search mode only). Type of Signals: carriers, chirp signals and pulsed signals. RFI rejection: re-observation and confirmation by another observatory.

FINDINGS TO DATE

Initial observations take place in the first half of 1995. In total, approximately 200 Sun-like stars will be scrutinised during this first run.

PROJECT SERENDIP

"Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations"

OBSERVATORY

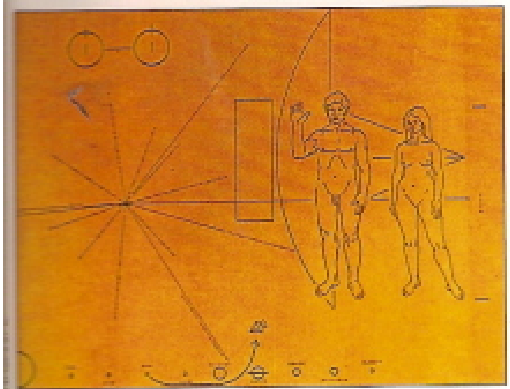
There is no dedicated search antenna; instead, the project uses the output of radio astronomy receivers that are being used for conventional astronomical observations. SERENDIP III made their observations from the 305-metre radio telescope at Arecibo, Puerto Rico.

CAPABILITY

Monitors 4.2 million radio channels at once. Spectral Resolution: 0.6 Hz. Instantaneous bandwidth: 2.4 MHz. Total Frequency Coverage: 12 MHz. Maximum Sensitivity: 9×10^{-25}, W^{-2}. Sky Coverage: 22 per cent. Type of Signals: carriers, chirp signals and slow chirp signals. RFI rejection: re-observation/d-base. System soon to be upgraded to SERENDIP IV, capable of monitoring 160 million channels at once.

FINDINGS TO DATE:

This program has found almost 400 candidate signals that are unusual enough to merit further investigation.



The first interstellar message sent to the stars, engraved on a 152 × 229 mm gold anodised plaque and attached to the pair of Pioneer space probes launched in 1971 and 1972.

sent again, and even asked the executive committee of the International Astronomical Union (IAU) to move a resolution condemning such transmissions. SETI pioneer Frank Drake later wrote to Ryle, saying that it was really too late: "The deed is done, and repeated daily with every television transmission, every military radar signal, every spacecraft command ... They're too far away to pose a threat. I think that hostile tribes bent on war, be they terrestrial or extraterrestrial, destroy themselves with their own weapons long before they have any notion of how to attempt interstellar travel. The more peaceful nations, who study science and have perhaps cracked the secret of immortality, are more likely to be benevolent, shy, and wary of contact for their own reasons." According to Drake, Ryle appeared satisfied with this rejoinder, and the IAU never did issue a prohibition against interstellar messages.

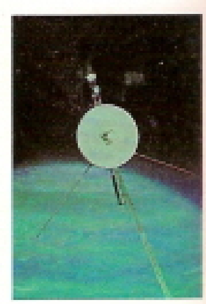
Ben R. Finney, a Professor of Anthropology at the University of Hawaii, has considered possible impact scenarios that extraterrestrial radio contact might have on human society. Finney defines potential responses as being either "paranoid" or "pronoid": either excessively fearful and distrustful or its antonym, coined by Finney. In the first case, the aliens are seen to pose a danger to humanity; in the second, interaction with 'benevolent' creatures is seen as wholly beneficial to humanity. This dichotomy of mind sets is a useful conceptual tool for the discussion of the possible consequences of interstellar contact.

Much of science fiction literature in the past has followed the paranoid theme. Perhaps influenced by Darwinism, H.G. Wells postulated an invasion of Earth in *The War of the Worlds* in 1898. Wells cast the alien as a competitor, a natural enemy of mankind, and a genocidal invader, and this quickly became the stereotype. This mind set went on to dominate contemporary thinking on extraterrestrials: in the early 1960s, the Brookings Institution presented a report to NASA concluding that "the discovery of life on other worlds could cause the Earth's civilisation to collapse". The same ideas were also expressed by such distinguished scientists as Martin Ryle and George Wald, and in editorials of *The New York Times*. Medical anthropologist Melvin Konner later said that "evolution predicts the existence of selfishness, arrogance and violence on other planets even more surely than it predicts intelligence. He considered it to be both philosophically and scientifically naive to believe that advanced extraterrestrials might benevolently pass on their galactic wisdom. He argued that the likely result of contact could be the most cataclysmic disaster to ever befall our species. Konner believed that instead of spending a US$100 million on NASA's SETI project – which finally lost its funding last year – humanity should hide, at least for a few centuries, until it can protect itself from creatures that are likely to treat us as well as we have treated "rhesus monkeys, cows, dogs and dodos," he said.

Professor Michael Archer, a biologist at the University of New South Wales in Australia, has much the same position: "Any creature we contact will also have had to claw its way up the evolutionary ladder, and will be every bit as nasty as we are. It will likely be an extremely adaptable, extremely aggressive super-predator, and the galaxy may not be big enough for two such fierce rivals." He sees the gold-plated phonograph records affixed to each of the two Voyager space probes – filled with images of life on Earth and greetings in 60 languages – as giant 'dinner invitations' to the cosmos: "Come to Earth, we have lots of nice, exotic things to eat."

Finney's concept of the pronoid school of thought is reflected in the writings of William Newman and Carl Sagan, and in films like *ET – The Extra-Terrestrial*, still the biggest grossing film of all time. The pronoid school suggests that there may be universal impediments against cosmic imperialism, and perhaps a 'Codex Galactica' exists to educate younger societies on how to behave. Sagan and Newman further argue that advanced civilisations with long histories must have learned how to be benign and how to treat an adolescent society "delicately", or else they would not themselves have lasted. To answer the 'cannibalistic arguments' of the paranoid faction, Sagan suggests that it is implicit in the evolutionary process that extraterrestrial carnivores are unlikely to find the sequences of amino acids in human proteins especially tasty or nourishing. Considering the high energy cost of interstellar travel and the technological effort required, it would be much cheaper to "synthesise proteins in the amino acid sequences favoured by extraterrestrial gastronomers than to muster a luncheon expedition to Earth".

Encouraging the search for extraterrestrial intelligence and trying to imagine how aliens might reveal themselves, we have also learned about ourselves. We construct models that explain the origin of planetary systems, try to see which conditions were present on our planet for the emergence of life, develop hypotheses for evolution from simple biological systems to complexity and intelligence, speculate about the universality of the laws of nature, and learn to use those laws to establish contact with other hypothetical beings. In doing so, we define criteria to distinguish intelligent sources among the cacophony of natural noise. Finally we search deep within our souls and try to imagine the nature of a completely alien society and its concept of morality. Contact, after a search for extraterrestrial intelligence program, may be the most important event in the history of human civilisation. But the results of such enterprise – whether positive or negative – will have profound implications for our view of our universe, and of ourselves.



The study of neighbouring planets in our solar system has helped develop SETI scientists develop comparative planetology theories that underpin the search for extraterrestrial intelligence. Artist's impression of a Voyager flyby of Uranus.

Julian Baum/SPL