SEARCHING FOR INTERSTELLAR COMMUNICATIONS

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NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation ; (2) origin of life ; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known ; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

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To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We shall assume that long ago they established a channel of communication that would one day become known to us, and that they look forward patiently to the answering signals from the Sun which would make known to them that a new society has entered the community of intelligence. What sort of a channel would it be ?

The Optimum Channel

Interstellar communication across the galactic plasma without dispersion in direction and flight-time is practical, so far as we know, only with electromagnetic waves.

Since the object of those who operate the source is to find a newly evolved society, we may presume that the channel used will be one that places a minimum burden of frequency and angular discrimination on the detector. Moreover, the channel must not be highly attenuated in space or in the Earth's atmosphere. Radio frequencies below ~1 Mc./s., and all frequencies higher than molecular absorption lines near 30,000 Mc./s., up to cosmic-ray gamma energies, are suspect of absorption in planetary atmospheres. The band-widths which seem physically possible in the near-visible or gamma-ray domains demand either very great power at the source or very complicated techniques. The wide radio-band from, say, 1 Mc. to 10^4 Mc./s., remains as the rational choice.

In the radio region, the source must compete with two backgrounds: (1) the emission of its own local star (we assume that the detector's angular resolution is unable to separate source from star since the source is likely to lie within a second of arc of its nearby star); (2) the galactic emission along the line of sight.

Let us examine the frequency dependence of these backgrounds. A star similar to the quiet Sun would emit a power which produces at a distance R (in metres) a flux of:

$$10^{-15} f^2/R^2 \quad \text{W.m.}^{-2}(\text{c./s.})^{-1}$$

If this flux is detected by a mirror of diameter l_d, the received power is the above flux multiplied by l_d^2.

The more or less isotropic part of the galactic background yields a received power equal to:

$$\left(\frac{10^{-12.5}}{f}\right)\left(\frac{\lambda}{l_d}\right)^2 (l_d)^2 \quad \text{W.(c./s.)}^{-1}$$

where the first factor arises from the spectrum of the galactic continuum, the second from the angular resolution, and the third from the area of the detector. Thus a minimum in spurious background is defined by equating these two terms. The minimum lies at:

$$f_{\text{min.}} \approx 10^4 \left(\frac{R}{l_d}\right)^{0.4} \text{c./s.}$$

With $R \approx 10$ light years $= 10^{17}$ m. and $l_d = 10^2$ m., $f_{\text{min.}} \approx 10^{10}$ c./s.
The source is likely to emit in the region of this broad minimum.

At what frequency shall we look? A long spectrum search for a weak signal of unknown frequency is difficult. But, just in the most favoured radio region there lies a unique, objective standard of frequency, which must be known to every observer in the universe: the outstanding radio emission line at 1,420 Mc./s. (λ = 21 cm.) of neutral hydrogen. It is reasonable to expect that sensitive receivers for this frequency will be made at an early stage of the development of radio-astronomy. That would be the expectation of the operators of the assumed source, and the present state of terrestrial instruments indeed justifies the expectation. Therefore we think it most promising to search in the neighbourhood of 1,420 Mc./s.

Power Demands of the Source

The galactic background around the 21-cm. line amounts to:

$$\frac{dW_b}{dS\,d\Omega\,df} \approx 10^{-21.5} \quad \text{W.m.}^{-2}\,\text{ster.}^{-1}\,(\text{c./s.})^{-1}$$

for about two-thirds of the directions in the sky. In the directions near the plane of the galaxy there is a background up to forty times higher. It is thus economical to examine first those nearby stars which are in directions far from the galactic plane.

If at the source a mirror is used l_s metres in diameter, then the power required for it to generate in our detector a signal as large as the galactic background is:

$$\frac{dW_s}{df} = \frac{dW_b}{dS\,d\Omega\,df}\left(\frac{\lambda}{l_s}\right)^2\left(\frac{\lambda}{l_d}\right)^2 R^2 = 10^{-24.5}\,R^2/l_s^2 l_d^2 \quad \text{W.(c./s.)}^{-1}$$

For source and receiver with mirrors like those at Jodrell Bank (l = 80 m.), and for a distance $R \simeq 10$ light years, the power at the source required is $10^{2.2}$ W.(c./s.)$^{-1}$, which would tax our present technical possibilities. However, if the size of the two mirrors is that of the telescope already planned by the U.S. Naval Research Laboratory (l = 200 m.), the power needed is a factor of 40 lower, which would fall within even our limited capabilities.

We have assumed that the source is beaming towards all the sun-like stars in its galactic neighbourhood. The support of, say, 100 different beams of the kind we have described does not seem an impossible burden on a society more advanced than our own. (Upon detecting one signal, even we would quickly establish many search beams.) We can then hope to see a beam toward us from any suitable star within some tens of light years.

Signal Location and Band-Width

In all directions outside the plane of the galaxy the 21-cm. emission line does not emerge from the general background. For stars in directions far from the galactic plane search should then be made around that wave-length. However, the unknown Doppler shifts which arise from the motion of unseen planets suggest that the observed emission might be shifted up or down from the natural co-moving atomic frequency by $\pm$ ~300 kc./s. ($\pm$100 km. s.$^{-1}$). Closer to the galactic plane, where the 21-cm. line is strong, the source frequency would presumably move off to the wing of the natural line background as observed from the direction of the Sun.

So far as the duration of the scanning is concerned, the receiver band-width appears to be unimportant. The usual radiometer relation for fluctuations in the background applies here, that is:

$$\frac{\Delta B}{B} \propto \sqrt{\frac{1}{\Delta f_d \tau}}$$

where Δf_d is the band-width of the detector and τ the time constant of the post-detection recording equipment. On the other hand, the background accepted by the receiver is:

$$B = \frac{dW_b}{df}\,\Delta f_d \text{ and } \tau \propto \frac{\Delta f_d}{(\Delta B)^2}$$

If we set ΔB equal to some fixed value, then the search time T required to examine the band F within which we postulated the signal to lie is given by:

$$T = \frac{F\tau}{\Delta f_d} \propto \frac{F}{(\Delta B)^2}$$

independent of receiver band-width Δf_d.

Of course, the smaller the band-width chosen, the weaker the signal which can be detected, provided $\Delta f_d \geqslant \Delta f_s$. It looks reasonable for a first effort to choose a band-width Δf_d normal in 21 cm. practice, but an integration time τ longer than usual. A few settings should cover the frequency range F using an integration time of minutes or hours.

Nature of the Signal and Possible Sources

No guesswork here is as good as finding the signal. We expect that the signal will be pulse-modulated with a speed not very fast or very slow compared to a second, on grounds of band-width and of rotations. A message is likely to continue for a time measured in years, since no answer can return in any event for some ten years. It will then repeat, from the beginning. Possibly it will contain different types of signals alternating throughout the years. For indisputable identification as an artificial signal, one signal might contain, for example, a sequence of small prime numbers of pulses, or simple arithmetical sums.

The first effort should be devoted to examining the closest likely stars. Among the stars within 15 light years, seven have luminosity and lifetime similar to those of our Sun. Four of these lie in the directions of low background. They are τ Ceti, o_2 Eridani, ϵ Eridani, and ϵ Indi. All these happen to have southern declinations. Three others, α Centauri, 70 Ophiucus and 61 Cygni, lie near the galactic plane and therefore stand against higher backgrounds. There are about a hundred stars of the appropriate luminosity among the stars of known spectral type within some fifty light years. All main-sequence dwarfs between perhaps $G0$ and $K2$ with visual magnitudes less than about $+6$ are candidates.

The reader may seek to consign these speculations wholly to the domain of science-fiction. We submit, rather, that the foregoing line of argument demonstrates that the presence of interstellar signals is entirely consistent with all we now know, and that if signals are present the means of detecting them is now at hand. Few will deny the profound importance, practical and philosophical, which the detection of interstellar communications would have. We therefore feel that a discriminating search for signals deserves a considerable effort. The probability of success is difficult to estimate; but if we never search, the chance of success is zero.