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 unenlightened 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 stars other than 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 sciences 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 discrimin-
naion on the detector. Moreover, the channel must not be highly attenuated in space or in the Earth's atmosphere. Radio frequencies below \(\sim 1 \text{ MeV} \cdot \text{s}^{-1}\), and all frequencies higher than molecular absorption lines near 20,000 \(\text{MeV} \cdot \text{s}^{-1}\), up to cosmic-ray gamma-ray energies, are subject of absorption in planetary atmospheres. The bandwidths which seem physically possible in the near-infrared or gamma-ray domain demand either very great power at the source or very complex techniques. The wide radio-band from, say, 1 \(\text{MeV} \cdot \text{s}^{-1}\) to 100 \(\text{MeV} \cdot \text{s}^{-1}\), remains as the radio-signal choice.

In the radio region, the source must compete with two backgrounds: (1) the emission of its own local star two sources that the detector's angular resolution is unable to separate source from star since the source is likely to lie within a second 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 meters) a flux of: 

\[
\frac{dW}{dS} = \frac{10^{12} \text{W}}{\text{m}^2 \cdot \text{Hz}^{-1}} \left(\frac{\lambda}{10 \text{cm}}\right)^{\frac{1}{2}} \left(\frac{f}{10 \text{Hz}}\right)
\]

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 various background is defined by equating these two terms. The minimum lies at:

\[
f_{\text{min}} \approx 10^5 \frac{\lambda}{10 \text{cm}} \text{ Hz}
\]

With \(R=10\) light years \(10^{11} \text{ m}\), and \(R=10^7 \text{ m}\),

\[
f_{\text{min}} \approx 10^8 \text{ Hz}
\]

The source is likely to emit in the range of this broad minimum.

At what frequency shall we look? A long spectrum search for a weak signal of unknown frequency is difficult. But, within the broad bandwidth region there is a unique, objective standard of frequency, which may be known to every observer in the universe: the outstanding radio emission line at 1,420 \(\text{Mc} \cdot \text{s}^{-1}\) (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 satellite, and the present state of terrestrial instruments indeed justifies the expectation. Therefore we think it may prove promising to search in the neighborhood of 1,420 \(\text{Mc} \cdot \text{s}^{-1}\).

Power Demands of the Source

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

\[
dW = 10^{-16} \text{W} \text{m}^{-2} \text{Hz}^{-1} \text{ ster}^{-1} \left(\frac{\lambda}{10 \text{cm}}\right)\left(\frac{\lambda}{10 \text{cm}}\right)^{2}
\]

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 fifty times higher. It is thus reasonable to assume that these nearby stars which are in directions far from the galactic plane.

If the source is used, 4, a power required for it to generate in our detector a signal as strong as the galactic background is:

\[
dW_{\text{in}} = \frac{10^{12} \text{W}}{\text{m}^2 \cdot \text{Hz}^{-1}} \left(\frac{\lambda}{10 \text{cm}}\right)^{\frac{1}{2}} \left(\frac{f}{10 \text{Hz}}\right)^2 = 10^{16-4} \text{W} \text{m}^{-2} \text{Hz}^{-1} \text{ ster}^{-1}
\]

For sources and receivrs with mirrors like those at Jodrell Bank (450 m), and for a distance \(R=10\) light years, the power at the source required is \(10^{16-4} \text{W} \text{m}^{-2} \text{Hz}^{-1} \text{ ster}^{-1}\), 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 (650 m), the power required is a factor of 40 lower, which would fall within our limited capabilities.

We have assumed that the source is beaming towards all the sun-like stars in its galactic neighborhood. The support of, say, 100 different branches in the sky 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 the 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 non-moving atomic frequency by \(\pm \sim 300 \text{ kHz} \cdot \text{s}^{-1}\) (\(\pm 100 \text{ km} \cdot \text{sec}^{-1}\)). 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 frequency as observed from the direction of the Sun.

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

\[
\frac{\Delta f}{B} \approx \frac{1}{\sqrt{\Delta f}}
\]

where \(\Delta f\) is the bandwidth of the detector and \(\tau\) is the time constant of the post-detection recording equipment. On the other hand, the bandwidth accepted by the receiver is:

\[
B = \frac{\Delta W}{\Delta f} \Delta f, \quad \tau = \frac{\Delta f}{\Delta B}
\]

If we set \(\Delta f\) equal to some fixed value, then the bandwidth \(B\) required to examine the band \(F\) within which we postulate the signal to lie is given by:

\[
\tau = \frac{F}{\Delta B} \approx \frac{1}{\Delta B}
\]

independent of receiver bandwidth \(\Delta f\).

Of course, the smaller the bandwidth chosen, the weaker the signal which can be detected, provided \(\Delta f < \Delta f\). It looks reasonable for first effort to choose a bandwidth \(\Delta f\) normal in 21 cm, practice, but an integration time \(\tau\) 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, or grounds of bandwidth and of rotation. 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 of an artificial signal, one signal might contain, for example, a sequence of small prime numbers of pulses, or simple arithmetic series.

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 $\gamma$ Ceti, $\theta$ Eridani, $\epsilon$ Eridani, and $\epsilon$ Indi. All these happen to have southern declinations. Three others, a Centauri, 70 Ophiuchi and 61 Cygni, lie near the galactic plane and therefore stand against higher backgrounds. There are about 500 hundred stars of the appropriate luminosity among the stars of known spectral type within some 50 or light years. All main-sequence dwarfs between perhaps 60 and $K2$ with visual magnitudes less than about +6 are candidates.

The reader may seek to expand those speculations wholly to the domain of scieno-theology. 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.