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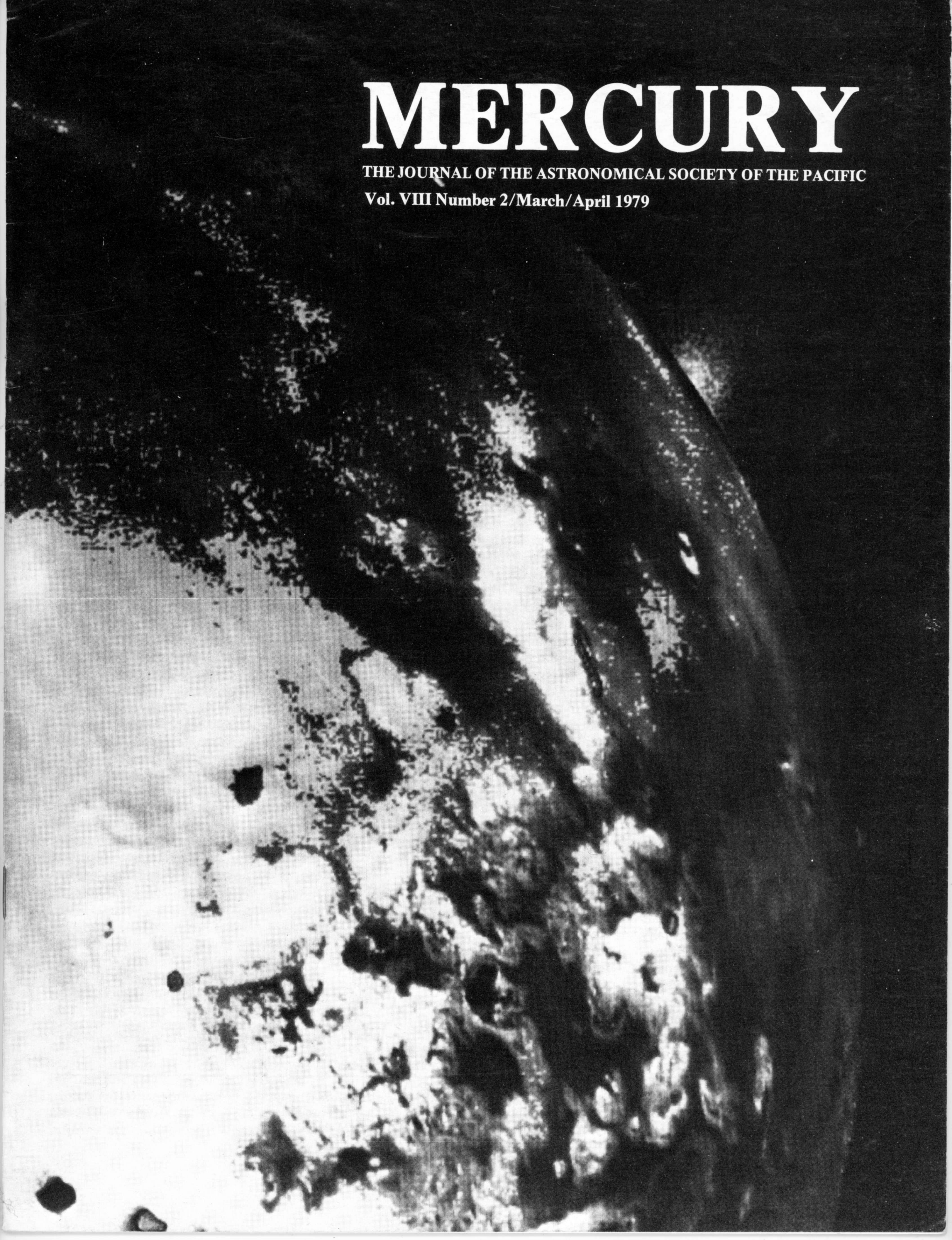

Eavesdropping on the Earth

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Editor's Note:
Many an introductory astronomy text includes a general statement to the effect that we are revealing our presence to the universe at large by means of the radio wave transmissions which "leak" from our planet. In fact, several writers have speculated that we may be quarantined by any advanced interstellar species until the quality of our television programming improves.

But how well *could* the Earth be detected by an observer at interstellar distances? To find out, Dr. Sullivan and his students have carefully analyzed the "radio signature" of the Earth. Their study has important implications for anyone interested in the prospects for interstellar contact.

"Nobody passes us in the deep
quiet of the dark sky;
Nobody sees us floating out here
among the stars . . . .
No one receiving the radio
signals today . . . ."
— Brian Eno —

Most estimates of the possibility of communication with extraterrestrial civilizations in our galaxy depend on the assumptions that planetary systems about stars are common and that many of these are suitable for the development of intelligent life. Yet mankind's current knowledge of the astronomical and physical processes involved in the formation of stars and their planetary systems is not sufficient for us to know whether or not our Earth and its cousins represent a truly rare phenomenon. In fact, the solar system in which we participate is the only one known definitely to exist in the universe! Why don't we have more of the needed information? A good way to answer this question is to turn the tables and examine various ways an extraterrestrial astronomer might find evidence of our own solar system.

Much of his difficulty would stem from our system's insignificance on a cosmic scale. While the Earth-Sun distance of 150,000,000 kilometers (or one *astronomical unit*) may seem large, that to the *nearest* star is over 200,000 times larger. Furthermore, planets are small and contain little mass; Jupiter is one thousandth the mass of the Sun and yet more massive than all the other planets combined. Planets also are not very bright — the "full Earth" is about one billion times (or 23 magnitudes) fainter than the Sun and would not be visible beyond 20 light-years to an extraterrestrial astronomer using even a 5-meter telescope (such as the one on Mt. Palomar)[1]. It is because their observable effects are so minute that we cannot expect planets like those we know to be detectable over great distances.

Two Unusual Cases

There are two exceptions to this last statement known to us, both of which probably represent extreme cases. The first of these is Barnard's Star, a binary system in which an unseen companion can be deduced to have a mass of only about twice that of Jupiter and to orbit at a distance of about 5 astronomical units. An object with so small a mass must surely be planet-like, but we can only detect it by indirect means and then only by virtue of Barnard's Star's low mass (one-seventh that of the Sun) and its proximity to us (six light-years, the closest system beyond Alpha Centauri). If these deductions are correct (and there is much disagreement among astronomers), then we are either quite fortunate to have such a case so close for study or else planetary companions are common occurrences. We should add that there are a handful of other cases among the nearer stars in which observations apparently yield masses for unseen companions on the order of 10 Jupiters. For these and other reassons, astronomers currently favor theories in which planetary systems are not uncommon, forming rather routinely from the debris of gas and dust remaining after the birth of a star. However, we cannot be certain that these theories are correct.

The second extreme situation renders at least one known planet much more easily detectable than it would otherwise be. This is the phenomenon of life on Earth, life which has recently reached such a stage as to announce our planet's presence over interstellar distances to any being possessing astronomical knowledge and technology comparable to our own. And it turns out that much more than just the simple presence of our Earth could be deduced by possible inhabitants of other, distant planetary systems. Within the signals which leak into space from

1. In practice, the situation would be even worse due to the tremendous glare of the nearby Sun.

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Earth, there is detailed information about both the source planet and the "disturbance" at its surface which sent the signal on its way.

"Leaking" Radiation

Let us examine the various sources of energy that not only escape the Earth, but also completely leave the solar system and enter the interstellar environment. All such leakage has to date been electromagnetic in nature, meaning "light" of various wavelengths such as radio, infrared, and visible. (The Pioneer 10 spacecraft, which will become the first man-made material object to leave the solar system, is passing Saturn this year. When it passes Pluto its speed will be only 1/30,000th of the speed of light and it will be quite a while before it reaches another star.

Detailed consideration of all parts of the electromagnetic spectrum reveals that it is *radio* waves which are by far the most important "leakage" from the Earth[2]. For instance, nothing that Man does with visible light, not even exploding a hydrogen bomb, compares in the least with the Sun's output. But at wavelengths from 1 centimeter to 30 kilometers our society has organized a host of activities on Earth which give our planet an unnatural "radio signature": television and radio broadcasting, radars used for weather, navigational and military purposes, "shortwave" communications ("hams", Citizens Band, taxis, police), satellite communications, etc., etc.

We now want to put ourselves in the "shoes" of an extraterrestrial radio astronomer on a planet revolving about a star far from our Sun. Which of these radio services would be "best" for our "eavesdropper" to tune in on? Which is detectable to the greatest distances? Which potentially carries the most information of use to the eavesdropper? To answer these questions one must study many factors including the power of each service's transmitters, the frequencies and bandwidths involved, types of antennas used, and the fraction of time spent transmitting.[3,4] One example of these factors is the general trade-off between the information content (TV picture, spoken words, Morse code) of a transmitted signal and the range (distance) to which it can be detected. This can be understood by noting that one gets more range by concentrating transmitted power at the fewest number of frequencies possible. But the information content of a signal is contained in the arrangement of its power among a number of neighboring frequencies and increases as we spread the power over a greater bandwidth.

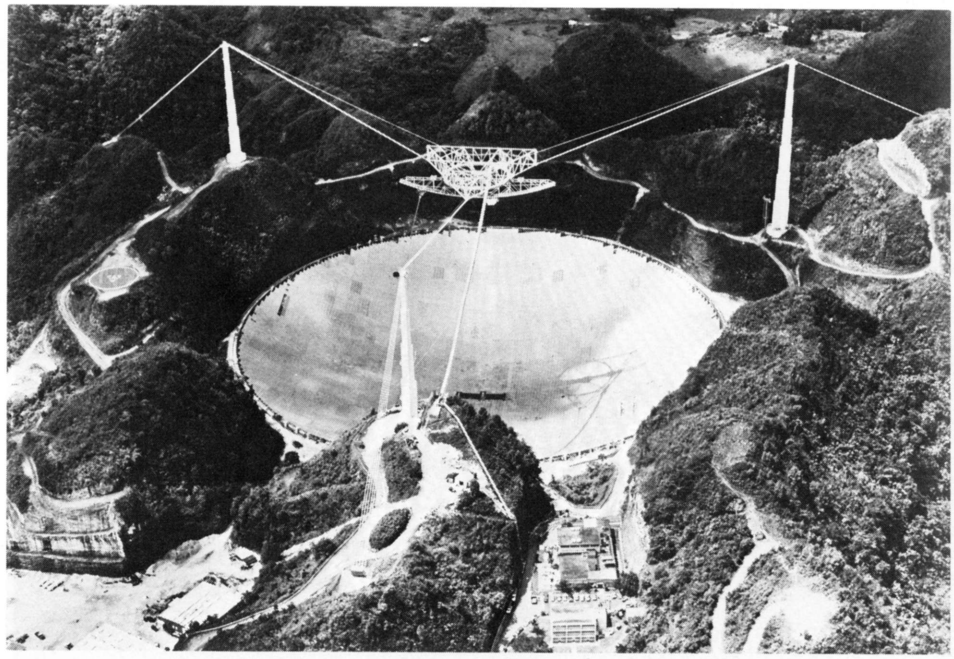

Figure 1. Aerial view of the 1000-foot radio telescope at Arecibo, Puerto Rico (Photograph courtesy of Cornell University)

Three other important criteria in the evaluation of each radio service are: (a) that the signal should be exactly the same from day to day, (b) that the amount of sky "illuminated" by the transmitting antennas should be large, and (c) that the number of transmitters on Earth should be large. Regarding (b), remember that the radio waves from even a stationary antenna can sweep out a large portion of the sky as a result of the Earth's rotation. Furthermore, each antenna has a characteristic "beam" into which the transmitter power is directed. If an antenna, say a parabolic reflector or "dish", is designed so that the power is concentrated into a relatively small region of the sky, the range of detection for the signal increases, but at the expense of excluding many potential listeners.

Acquisition and Information Signals

Keeping the above factors in mind, an examination of all the radio services on Earth reveals two categories of strong signals escaping the Earth that might be of interest to an extraterrestrial observer.

An *acquisition signal* merely announces our presence over a large region of space by its very existence, but is not generally useful for careful study because it fails to meet one or more of the criteria given above. An *information signal,* however, satisfies all three criteria. At the present time on Earth some of the most important acquisition signals originate from a half-dozen or so U.S. military radars (and their presumed Soviet counterparts). These Ballistic Missile Early Warning System (BMEWS) radars sweep out a large fraction of the local horizon with extraordinarily powerful transmitters. The result is that this "radio service" provides by far the most

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2. This was first pointed out in 1963 by the Soviet astrophysicist I. S. Shklovski. See the first entry under references.

3. For a more technical discussion of these factors, interested readers are referred to W. T. Sullivan III, S. Brown, and C. Wetherill, "Eavesdropping: The Radio Signature of the Earth" in *Science,* Vol. 199, p. 377 (27 Jan 1978) and the letters in *Science,* Vol. 202, p. 374 ff (27 Oct 1978).

4. The bandwidth of a signal is the range of frequencies over which it is sent. Readers not familiar with this terminology should think of a band of frequencies as a band of possible "channels" for broadcasting. A broad frequency band would have a lot of channels. — Ed.

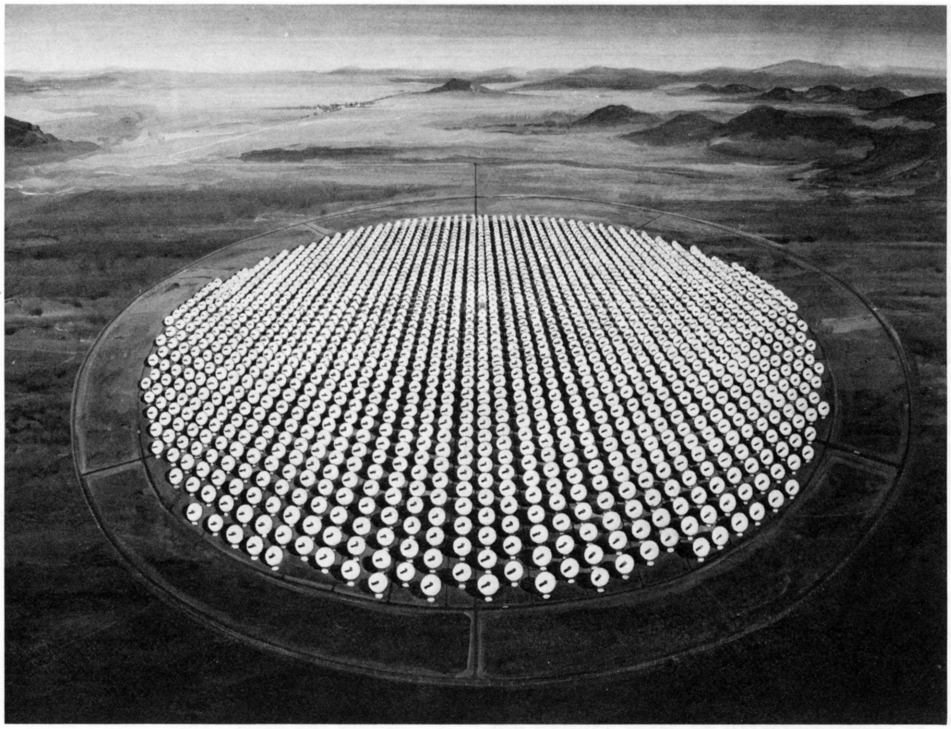

Figure 2. Artist's conception of an array of radio telescopes proposed by the Project Cyclops study sponsored in 1971 by Stanford University and NASA (Photo courtesy of NASA-Ames Research Center)

intense signals which leak from our planet to a large fraction of the sky.

While BMEWS radars pass criterion (b) above, they fail (c) and partially fail (a) because there are so few of these radars and they often change their frequency of operation to avoid being jammed. Nevertheless, if an external observer used equipment comparable to the most sensitive radio telescope on Earth (the 305-meter diameter dish at Arecibo, Puerto Rico; see Figure 1), we calculate that a BMEWS-type radar could be detected as far away as 30 light-years. This distance includes only about 200 stars, but of course it is possible that our eavesdropper possesses a much more sensitive radio telescope than we. If he had something like the largest one ever proposed for Earth, namely the array of 1000 100-meter dishes called for by Project Cyclops (See Figure 2 and Reference 4), he could detect a BMEWS-type radar at a distance of 500 light-years. In this case at least 1,000,000 stars are possible candidates for such an eavesdropper's location. But note that radio waves travel at the finite speed of one light-year per year and thus it will take until the 25th century, or 500 years from now, before all of these stars have had a chance to be bathed in the radiation of our defense system radars![5]

After picking up a BMEWS (or other) acquisition signal, the observer needs at least 100 times more sensitivity in his equipment to reach the rich lode of *information signals* emanating from Earth. It turns out that television broadcast antennas (or "stations") are the most intense sources of such signals. All other services either have their transmitter power spread over too broad a frequency band (for instance, FM broadcasting and most radars) or they do not transmit continuously (ham radio operators) or from the same location on Earth each day (taxis, aircraft). Many signals, such as medium-wave AM broadcasting and almost all shortwave communications, never even penetrate the reflective layer of charged particles, called the *ionosphere,* which surrounds the Earth. We thus concentrate on TV broadcasting — all other services which leak from Earth are less intense and merely add to the background "noise" which a distant observer would measure in the direction of our Sun as seen in his sky.

TV Broadcasting Signals and Antennas

In order to understand why television is so valuable to the eavesdropper as an

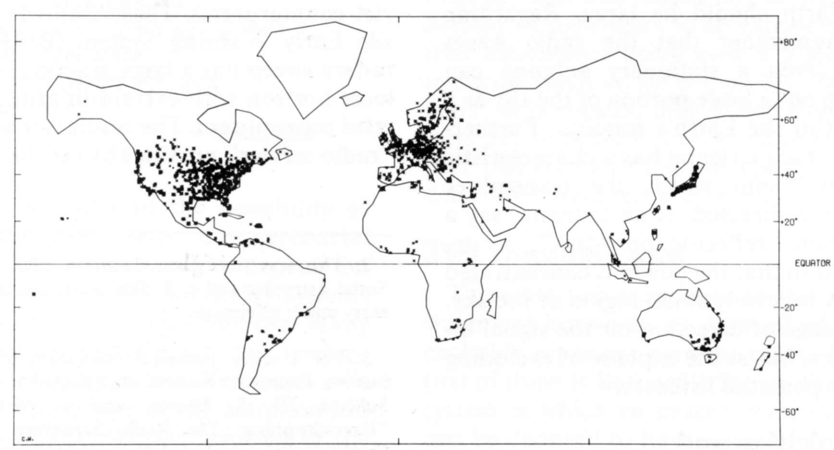

Figure 3. Map of the Earth showing the 2200 most powerful television transmitters, possessing about 97% of the world's total TV power. Note the absence of stations in the southern hemisphere and the marked concentrations in North America, Europe, Japan, and Australia. Full information for stations in the Soviet Union and China was not available, but estimates indicate that there is negligible television power in these countries. 896 transmitters in the United States are included.

5. There is actually another powerful transmitter on Earth: the U.S. Naval Space Surveillance System at Archer City, Texas. An Arecibo-type antenna could pick up its signal some 30 light-years away and a Cyclops array up to 500 light-years. It has been on the air since 1976.

information signal, it will be helpful to discuss some of the characteristics of TV broadcasting signals. Perhaps the most important facts are that there are a large number of very powerful TV stations on Earth (see Figure 3), and that about one-half of a station's broadcast power resides in an extremely narrow band of frequencies, only about 0.1 Hertz (or 0.1 cycle per second) wide, called the *video carrier signal*. The other half of the power contains the picture information and is spread out in a complex manner over a far larger frequency range of about 5 Megahertz (5 million Hertz). Nowhere in this broader region is the power per Hertz even a thousandth that at the video carrier frequency. It would therefore be much more difficult for the eavesdropper to receive full program material than to simply detect the presence of the carrier signal. (Given the quality of most TV programs, we find this fact very reassuring!) An observer near Barnard's Star, at a distance of 6 light-years from Earth, is thus about to receive television signals originating from the 1973 World Series, but he probably cannot find out that Oakland won! In the discussion below, we assume that only the video carrier signals of stations, *not* program material, are detected.

The combination of reasonably high power and small bandwidth means that the most powerful TV carrier signals can be detected at distances as large as one-tenth of those discussed for the BMEWS radars. The narrow-band nature of the signal also enables the observer to measure extremely accurate *Doppler shifts* in the frequency of the carrier signal.[6] This, in turn, would allow him to determine the relative speed with which each station is moving, to an accuracy of about 0.0001 km/sec (0.4 km/hr). Each station's signal thus contains information concerning the myriad motions in which its broadcast antenna participates while anchored to the Earth (see Figure 4). Note that stations on a common channel will not fall precisely on top of each other's frequency because the combined effects of engineering sloppiness, deliberate frequency offsets, and Doppler motions all shift a station's video carrier frequency by much more that its width. This means that our hypothetical observer could not obtain a more powerful signal by trying simultaneously to receive all the Channel 5's, for example, but must be content to observe each station separately.

The beam patterns into which TV broadcast antennas radiate are important to consider in such an analysis. It turns out that these antennas (whose purpose, after all, is to broadcast to Earth and not to the stars) confine the transmitter power to within a few degrees of the horizon, but distribute it about equally in all compass directions. Those radio waves directed above the horizon completely escape the Earth's atmosphere, and even about half of those below the horizon manage to escape by bouncing off the ground. (Only a negligible portion ever reaches any TV set!) Since most of the power is broadcast near the horizon, only when a star is rising or setting (i.e. is on the horizon), as seen from a given antenna location, will it be illuminated with radio power. This is illustrated in Figure 4.

After his initial discovery of these radio waves from the direction of our Sun, our eavesdropper would undoubtedly first ask, "Is this some kind of strange natural radio emission, or has some form of civilization produced it?" It would seem that the narrowband nature

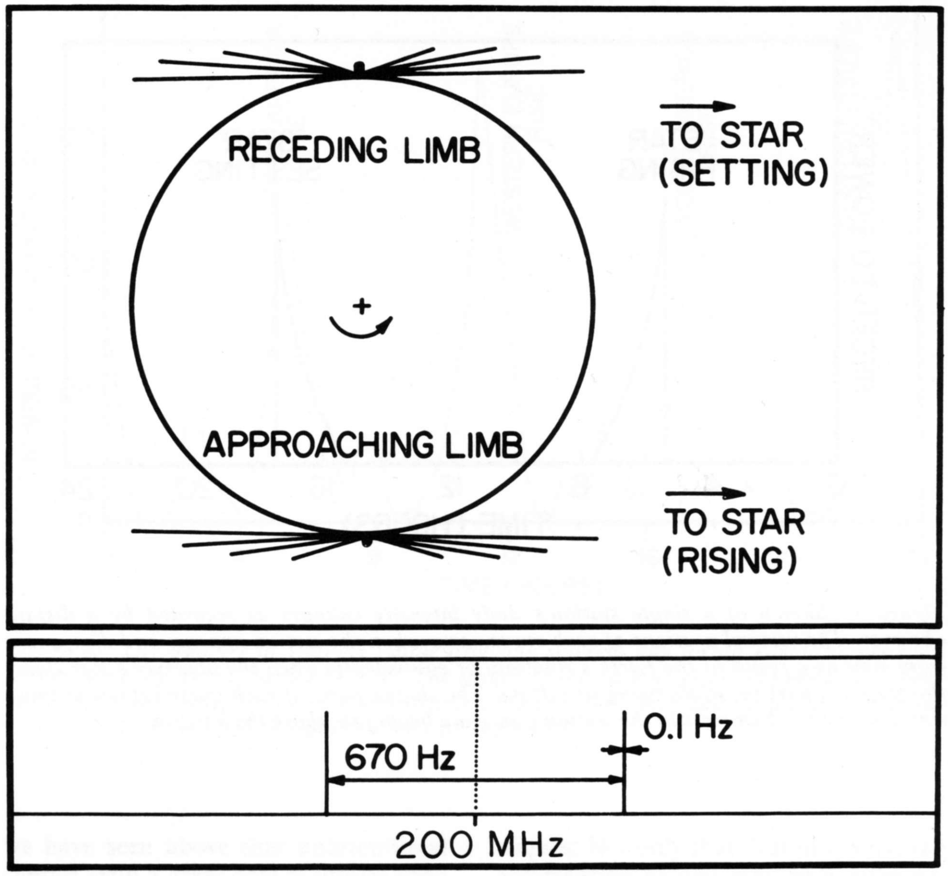

Figure 4. (Top) Sketch of two TV broadcasting antennas as seen from above the Earth's pole. (The sketch also applies to a single station as it would be seen at 12-hour intervals.) The length of a particular line of radiation indicates the relative amount of power "beamed" in that direction. As seen from a distant star located to the right, both stations are at maximum intensity, but one is just coming into view and the other is just disappearing. From the point of view of the stations, one sees this star rising and the other sees it setting.

(Bottom) Radio spectrum of the two stations' video carriers as measured at the distant star. Both stations are assumed to radiate from Earth with the same rest frequency (dotted line); the observed frequencies are different as a result of the Doppler effect arising from the Earth's rotation. The numbers given are for stations taken to radiate at 200 megahertz (approximately channel 11) on the equator, and are typical of those for most stations.

6. The Doppler effect causes the measured frequency (or wavelength) of a signal to change (shift) if the source of the signal is moving towards or away from the observer.

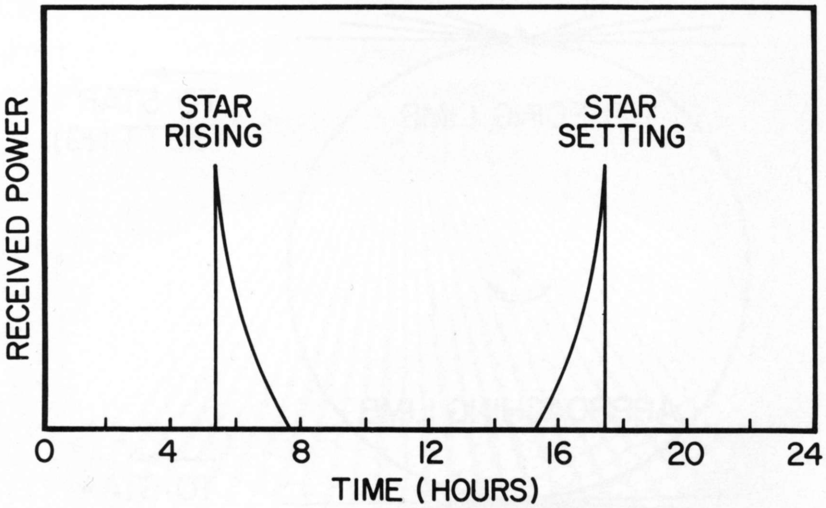

Figure 5. Sketch of a single station's daily intensity changes as recorded by a distant observer. The vertical portions of each curve occur when the station appears and disappears from view as a result of the Earth's rotation, or equivalently when the observer's star clears the station's horizon while rising or setting. The sloped parts of each curve represent those times when the observer is in the station's antenna beam just above the horizon.

of the signals would be one of the best clues that the signal is artificial in nature, as no astrophysical process (known to us) can channel comparable amounts of energy into such small frequency intervals. Other clues, such as polarization of the signals, also exist. And yet, who knows? Perhaps the theorists of another planet are clever enough to come up with a substance whose emission spectrum matches that of the observed radio waves! Clever theorists notwithstanding, for this discussion we assume that the signals from Earth will be recognized as artificial.

Scientific Deductions

As shown in Figure 4, when a star is near the horizon and thus illuminated by a particular station, the station must be near the edge of the Earth as seen from the direction of the star. The result is that the Earth has a very "bright" edge, or *limb,* when observed with a receiver for television frequencies (40 to 800 megahertz). The great distance to our eavesdropper's radio telescope means that he is unable actually to discern the disk of the Earth. Nevertheless, the Doppler shift of each station, due to the rotation of our planet can tell him not only whether the station is on the approaching or receding side of the Earth, but also whether its latitude is near the fast-spinning equator or the more slowly moving polar regions. Furthermore, he could discover a station's longitude from the *times* of the twice-daily appearance of the carrier signal from each station (see Figure 5). Thus he could construct a map (just like Figure 3, but without the outlines of the continents) of all detected stations, each located to an accuracy of a few kilometers.

Because of the extremely nonuniform distribution of stations on the Earth, the total number of stations visible at any one time to an outsider will vary with a 24-hour period.[7] The situation as it would be measured from Barnard's Star (located near our celestial equator) is shown in Figure 6. The peaks correspond to the times when population centers with concentrations of television transmitters are on the Earth's limb. By combining data on these intensity variations and Doppler shifts in a straightforward fashion, any eavesdropper could deduce his position relative to our equator (we would say his *declination*), the radius of the Earth (6000 kilometers), and the rotational velocity at the equator (0.5 km/sec).

With this information in hand, the observer is likely to suspect that he is dealing with a planet-like body. His next step might be to study the Earth's annual motion about the Sun (at a rate of 30 km/sec), which causes very large Doppler shifts in the signals of all the individual stations. By tracking these shifts over a year or more, the Earth-Sun system can then be studied exactly as astronomers here study what they call *single-line spectroscopic binaries.* In such a system two bodies (usually two stars) are orbiting about each other, but only the Doppler shifts in the spectral lines of one member (usually the brighter of the two) can be measured. In the present case the "spectral lines" are the TV carrier signals and the "bright" member is the Earth, far outshining the Sun at the radio frequencies we are discussing. It can be shown that radio observations of the Earth, together with standard optical observations of the associated G2 dwarf star, which we call our Sun, would yield all the vital orbital data for the Earth: its orbital period, its eccentricity, the Sun-Earth distance, etc. The radio astronomer-eavesdropper would then be able to provide his colleagues in the Exobiology Department with a good estimate for the Earth's surface temperature, allowing them to place constraints on the possible forms of life responsible for the radio signals. It also turns out that from the information in Figure 5 the dimensions of the transmitting antennas (typically 15 to 20 meters) can be readily deduced, yielding clues to the size scales of terrestrial engineering.

There are also more subtle effects contained in the TV carrier signals that may or may not remain ambiguous to the observer. The effects of seasonal variations in vegetation, weather, and the ionosphere will leave their mark in each station's signal. Vegetation has an influence on the amount of power reflected from the surface, as does the choppiness of the sea for coastal stations. The weather and ionosphere affect the direction and intensity of the radiated power, either through winds flexing the antenna structure or through our upper atmosphere bending and absorbing the radio waves on their way out. These conditions will cause the observed power levels and times of station appearance to vary slightly and, at first, inexplicably from those predicted.

7. This represents the true rotation period of the Earth of 24 *sidereal* hours or one sidereal day, equal to 23 hours 56 minutes of solar time.

Detailed study may nevertheless allow a few basic conclusions — for example, the presence of an ionized gas around the planet might be deduced from the clue that the lowest frequency stations are much more affected than those at higher frequencies.

A second type of complexity results from such things as a station's daily sign-off hour and the specific frequency and antenna conventions which it follows. These generally vary from one country to another, but can be the same even for countries which are widely separated, but otherwise cooperative in trade, politics or technology. For example, frequency assignments and other conventions are very similar in Japan and the United States. *We* can interpret these diverse patterns with our detailed cultural and historical knowledge, whereas the extraterrestrial probably cannot — unless his social theory is advanced far beyond our own. The overall problem is not unlike that confronting an archaeologist trying to understand an ancient city with a knowledge of only its street plan. It can only be hoped that the many unsolved puzzles would not hinder the eavesdropper from understanding the simpler, more regular features of the Earth's radio spectrum.

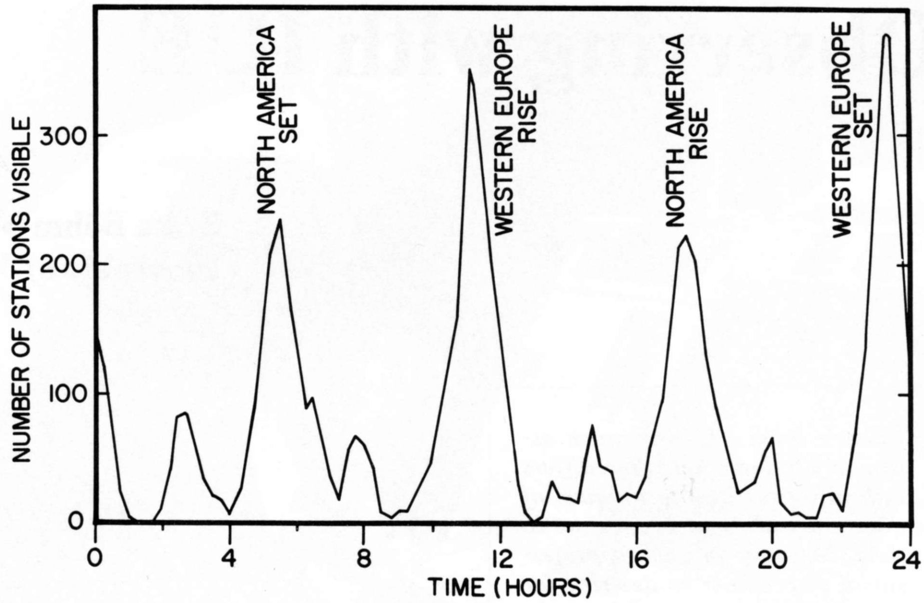

Figure 6. The number of stations visible over one sidereal day for an eavesdropper on a planet revolving about Barnard's Star. The origin of the various peaks is indicated; "rise" and "set" refer respectively to the appearance at the western limb and disappearance at the eastern limb of a particular region on the rotating Earth.

Should We Try to Eavesdrop?

The above discussion is of course relevant to the larger issue of our own attempts at contact with extraterrestrial civilizations (see the references below). We can make either of two basic assumptions about the first contact: (i) that it will arise through a purposeful attempt, perhaps through the use of an interstellar radio beacon, or (ii) that a civilization will be detected through no special efforts of its own. Most attention to date had been directed toward possibility (i), but in fact for the one civilization about which we do know something (our own), note that it has sent out virtually no purposeful signals, yet has been leaking radiation for several decades. How typical this situation will be in our own future or at any time for other galactic civilizations is impossible to say. For instance, cable television may replace the present system of broadcasting antennas, but new forms of radio leakage may just as well appear. It is true that the range of detection of any purposeful beacons is probably much larger than for leaking signals. But purposeful signals require decoding of any received message, while we have seen above that unintentional signals yield a great deal of information using only standard astronomical techniques. Not only that, but in a sense the information gained may be a more accurate reflection of the society's major concerns. At least this seems to be true for the case of our own civilization with its military and television leakage, although we might not wish to admit it.

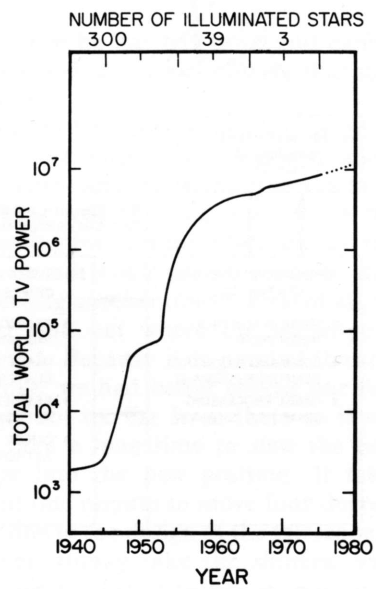

Figure 7. Estimated growth in the world's transmitted power (in watts) since TV broadcasting began. Only data for the United States were available, but world levels are not more than a factor of two greater. The current number of stars bathed by the expanding "power bubble" for the signals which left in a given year is indicated at the top of the diagram.

In summary then, we should keep both possibilities in mind when searching for extraterrestrial signals. We cannot know whether the most likely signals to be detected will place us in the role of intended recipient or of eavesdropper. ■

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