LUNAR REFLECTIONS OF TERRESTRIAL RADIO LEAKAGE

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ABSTRACT. Terrestrial radio leakage as reflected off the moon has been observed with the Arecibo antenna. We find that military radars and television transmitters are main contributors in the 150-500 MHz range, as predicted in the model of Sullivan et al. (1978). The earth indeed is revealing itself (eventually) to any interstellar eavesdropper with an Arecibo-like antenna at distances up to 30 light years, and with a Cyclops-like system up to fifteen times farther.

1. INTRODUCTION

When designing a strategy for the search for extraterrestrial intelligence (SETI) most persons have assumed that we should seek an intentional signal, a beacon set up by the other party to attract our attention. While this is of course a distinct possibility and it makes the search in some ways easier to define, it may not be correct. *A priori* it seems just as likely that we might learn of the existence of extraterrestrial intelligence not through their will, but rather through some sort of accidental leakage, a byproduct of their civilization. Examples might include infrared radiation from waste heat, navigational beacons used for interplanetary or interstellar travel, communications links, power transfer beams, or broadcasting beams. The ideal SETI strategy therefore should take both possibilities into account and the presently outlined NASA plans (given elsewhere in this volume) indeed do so.

In thinking about the potential for interstellar eavesdropping, Sullivan et al. (1978, 1981) considered the one technical civilization whose existence is without question, namely our own. They showed that for decades we have been leaking prodigious amounts of radio power

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which are in fact detectable at large distances for an eavesdropper with our present technical abilities. With an Arecibo-like antenna we can be detected at ~30 light years and with a Cyclops-like array (1000 100 meter dishes) at ~500 light years. (This is in contrast to the total of 3 minutes of purposeful signal (Arecibo staff, 1975) which we have transmitted.) Sullivan et al concluded that the most detectable forms of terrestrial leakage are (a) powerful military radar pulses, such as the U.S. Ballistic Missile Early Warning System (BMEWS), and (b) video carriers of television transmitters. On this basis a model of the leaking video carrier radiation was developed to calculate the flux densities and Doppler shifts any external observer could observe as a function of frequency and time.

The model comprised the locations, frequencies, antenna patterns, and schedules for the 2200 strongest television transmitters on earth. These parameters were based on the best engineering and industry data available, but one nevertheless should, whenever possible, check any model against the real world. Very little data exists relevant to the appearance of the radio earth from "outside"; see Herman (1978) for a summary and also Rush et al. (1980) and Skomal (1983). The task then was to make actual measurements of our civilization's radio signature as it appears from deep space. This at first appears to be a multi-million dollar space project, but there is a much simpler solution. Since decades of radar studies have revealed that the lunar surface acts as a reasonably efficient, rough (Lambert-like) scatterer (Evans, 1969), we chose to gain a deep space vantage without leaving earth by simply observing the moon, which acts as a handy mirror of our technical society.

2. THE EXPERIMENT

For three nights in December 1978 we used the 305 meter spherical reflector of Arecibo Observatory (which is operated by the National Astronomy and Ionosphere Center under contract to NSF) to observe the moon at a variety of frequencies. A log-periodic feed was connected to a frequency-agile transistor amplifier easily tunable over the range 70-500 MHz. The antenna HPBW was ~40' at 190 MHz, scaling linearly with wavelength, and thus included the entire moon for frequencies less than 250 MHz. Spectra were recorded using a 1008 channel autocorrelator with total bandwidths ranging from 10 MHz to 78 kHz. All spectra were Hanning smoothed. We typically observed the moon for an ON integration of 1 or 2 minutes and followed this with an OFF integration taken on a patch of blank sky ~3.7° east of the moon. Final spectra were then defined as (ON-OFF)/OFF.

The primary difficulty with this experiment was distinguishing between two types of terrestrial transmitter radiation: (1) that of local origin which was directly entering the feed, perched as it was high above the Puerto Rican karst topography, and (2) that which entered the feed after in turn bouncing off the moon and the reflector surface. This was the primary reason for the OFF runs. If any signal appeared at a particular frequency in the OFF run, then a signal of identical frequency in the ON run was taken to be local interference. In order further to combat local interference, we made our observations during the period 0000-0400 local time when most transmitters, in particular local television, were not in operation.

3. EXPECTATIONS

One can only observe at Arecibo within 20^{o} of the zenith and so the moon was only available to us for a total of 5 hours on the three nights. Figure 1 shows the situation on earth from the man in the moon's point of view. The two lunar symbols indicate the range of sub-lunar points on one particular night of observation. The swath of

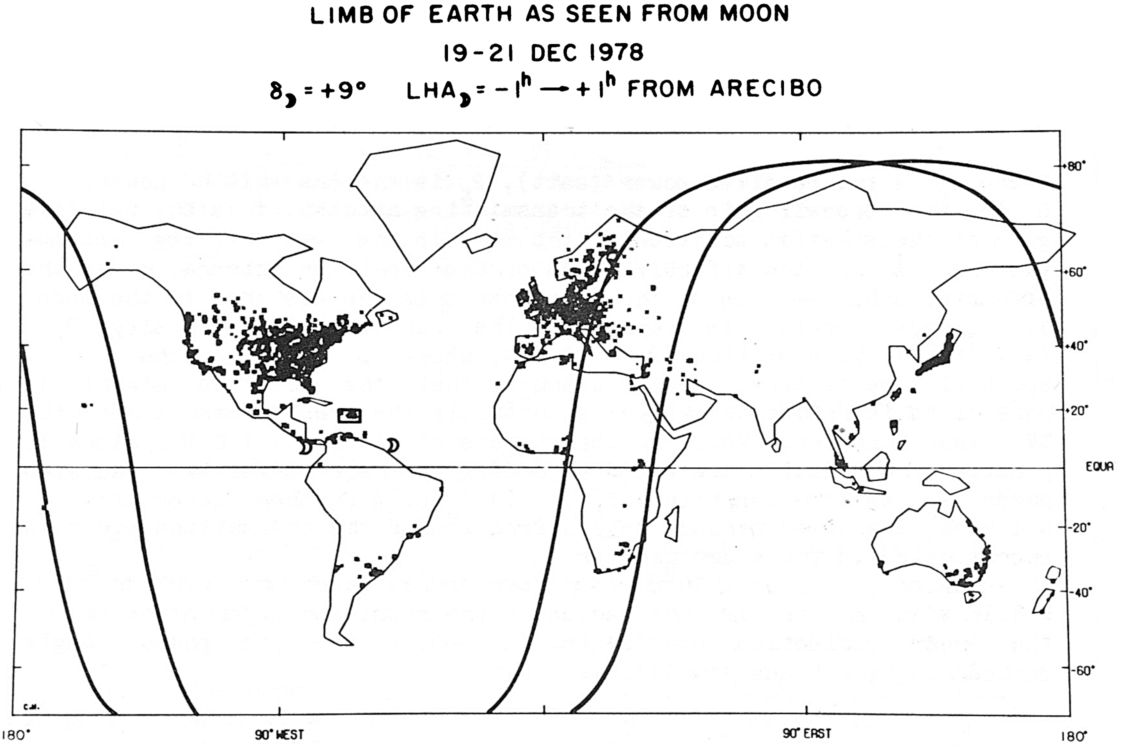

Figure 1. The observational situation. On the map are indicated the locations of the 2200 strongest television transmitters. The two lunar symbols to the south of Arecibo, Puerto Rico (boxed) indicate the extrema of the sub-lunar points for our two-hour observation period on 20 December 1978. The broad swath shows the range of the position of the terrestrial limb, as seen from the moon, during this same period. TV transmitters, which broadcast along their local horizon, will be most easily detected in this region.

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width $\sim 30^{\circ}$ shows the location of the limb of the earth as seen from the moon over a two hour period centered on transit at Arecibo. The terrestrial limb is of interest because television transmitting antennas have beam patterns which are (usually) roughly omnidirectional in azimuth, but highly confined to the horizon, where the eager viewers lie. The beamwidths in elevation angle are typically 4°, centered close to the horizon (see Sullivan *et al.* (1978) for further details and references about television antennas and signals). Thus it is the TV transmitters on the terrestrial limb, as seen from the moon, which we would expect to detect; as we monitor the moon, we should see the strongest signals originating from a continuously moving swath of $\sim 4^{\circ}$ in longitude. Note, however, that any antenna also radiates weakly in directions other than that of the main beam; if a receiver has sufficient sensitivity, TV transmitters might then be detectable even when well away from the limb.

What are the expected strengths for these "lunar" signals? We start with the radar equation

$$P_r/P_t = f\,G\,A\,\sigma/(4\pi d^2)^2$$

where P_r is the received power (watt), P_t is the transmitted power, G is the overall gain of the transmitting antenna, f is the relative gain at the specific position of the moon in the transmitting antenna pattern, A is the effective area of the receiving antenna, σ is the effective cross section of the moon, and d is the distance to the moon. To express results in terms of the received flux density S_r ($w\ m^{-2}Hz^{-1}$), we substitute $P_r = S_r\,B\,A$, where B (Hz) is the spectral resolution. This assumes that the detected signal is unresolved in frequency, which is certainly the present case since the TV video carriers which we observe are of width 0.1-1.0 Hz. Since in practice transmitters are rated according to their effective radiated power P_e, we also substitute $P_t = 1.64\,P_e/G$. A further factor of 0.4 must be applied because only a fraction of the transmitted power is concentrated in the video carrier.

Taking $d = 3.96 \times 10^{8}$m (for our runs) and $\sigma = 0.07\,\pi r^2 = 6.66 \times 10^{11} m^2$ (r is the radius of the moon; for information on the lunar reflection coefficient of ~ 0.07 and its phase angle dependence, see Evans (1969)), we derive

$$S_r\ (\mathrm{Jy}) = 11\,f\,P_e/B\ ,$$

where 1 Jy = $10^{-26} w\ m^{-2}Hz^{-1}$. It can readily be seen that the video carriers of TV transmitters, with P_e of typically 100-1000 kw, should be easily picked up off the moon, even with a modest-sized dish (let alone Arecibo!) and even if the f factor should be as small as 0.01-0.001. Typical levels should be 1-100 Jy for B = 1 kHz.

4. RESULTS

Figure 1 shows that our observing circumstances at Arecibo were not ideal since we did not have the bulk of the earth's TV transmitters, heavily concentrated in Europe and North America, in good position. But Hawaii and Russia proper were both on the limb, and signals at the expected transmitter frequencies indeed appeared. Their intensities yielded f values ranging from 0.1 to 0.7, i.e., the moon was at a sidelobe position in the transmitting beam corresponding to 10-70 per cent of the peak. Examples are shown in Figure 2. On the top

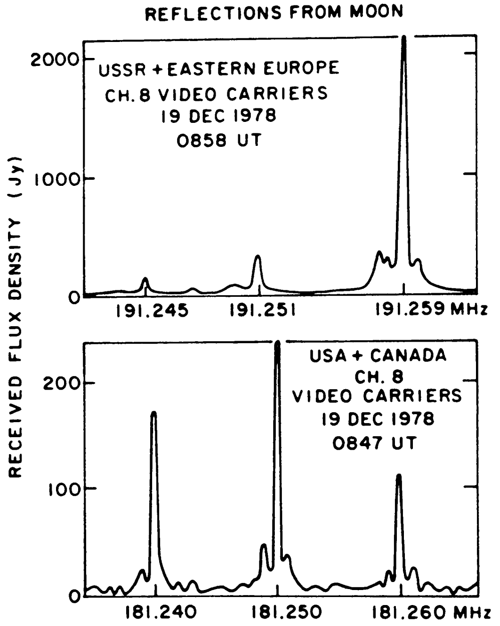

Figure 2. Video carriers of television transmitters observed after reflection off the moon. Resolution is 0.3 kHz.

we identify the signals as originating in the USSR and/or eastern Europe because international frequency allocations assign 191.25 MHz to the video carrier of Channel 8 in that region. On the bottom of Figure 2 are likewise seen the video carriers for Channel 8 on the USA/Canada convention. Signals appear at <u>three</u> distinct frequencies, spaced at intervals of 10 kHz (in the USA), because the frequencies of geographically adjacent stations of the same channel number are offset to minimize their mutual interference. Doppler shifts of the transmitted frequencies, arising from both earth rotation and the moon's orbit, are less than 1 kHz for the present cases and therefore of minimal significance with our spectral resolution. We unfortunately did not have time to investigate the interesting problem of the expected changing Doppler shift of any specific signal.

Perhaps the most surprising result of the experiment was the ease with which TV transmitters which were far from the terrestrial limb (as seen from the moon) could be detected. Referring to the bottom of Figure 2, there are in fact no Channel 8 transmitters in Hawaii; therefore, all of the radiation we see must be originating from North America and represent leakage from transmitting antennas at elevations of 30°-60°. The intensity of each feature in Figure 2 (bottom) can be accounted for by one or two typical stations with $P_e \sim 300$ kw and $f \sim 0.01$. Examination of measured patterns of TV broadcast antennas, kindly supplied by RCA and the BBC, in fact do indicate that at elevation angles from 15° to the zenith sidelobe levels vary irregularly over a typical range $f \sim 0.002$-0.010.

A synoptic series of spectra extending over 40 minutes is shown in Figure 3. It can be seen that a wealth of video carriers were detect-

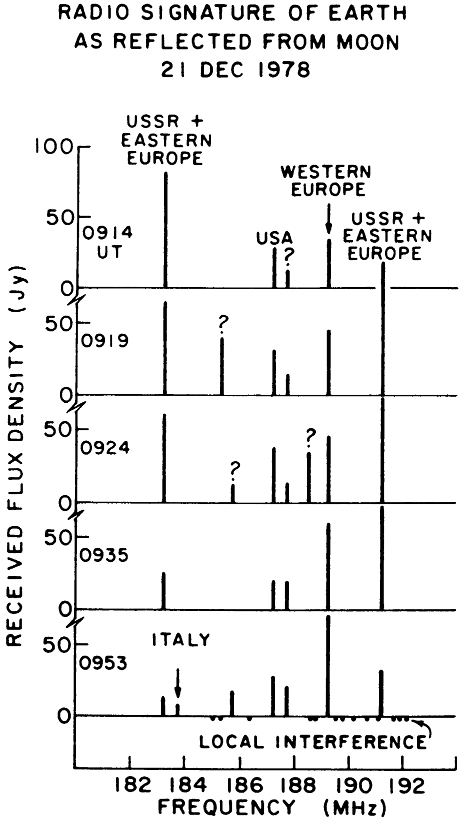

Figure 3. Synoptic series of spectra (20 kHz resolution) observed towards the moon in one of the VHF bands assigned to TV broadcasting. Probable identifications are based on international frequency allocations of video carriers.

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able, as well as a number of expected ones being blocked from view by local interference. Most signals could be identified with some confidence based solely on international frequency allocations, although a few mysteries remain. (The "triplets" no longer appear due to the coarser resolution.) As the limb of the earth moved from Russia towards western Europe, one indeed sees the expected fall in strength of the Soviet signals and increase in the western European ones. Once again, the U.S. signal must represent a transmitter sidelobe far above the horizon.

Besides the TV transmitters, one other signal of interest was definitely detected. The U.S. Navy operates a space surveillance radar in Archer City, Texas which consists of a 3 km north-south row of dipoles radiating 1 Mw into a beam of 1.5' by 120^{o} (Breetz, 1968). This system has $P_e = 1.4 \times 10^{10}$ w, all radiated into a bandwidth of ~0.1 Hz! (At the time of the 1978 study by Sullivan et al., we did not know of the existence of this radar, which in fact is detectable by any interstellar eavesdropper to somewhat greater distances than the BMEWS radars - ~30 lt-yr for an Arecibo technology.) With a spectral resolution of 300 Hz, we observed this signal at a level of 120 Jy at 216.98024 MHz, 240 ± 40 Hz above its nominal frequency. The frequency offset is largely due to Doppler shifts (as mentioned above). We were of course not at all observing the main lobe of this antenna, but in fact were ~20^{o} off-axis. Our observed intensity implies an effective value $f \sim 10^{-7}$, surprisingly low. But because the main beam and sidelobes are so narrow, in particular much smaller than the size of the moon, it is difficult to know what to expect.

In addition to the above observations less extensive, but similar moon-bounce data were taken at Arecibo in February 1977 and March 1980. Many non-local, lunar signals were detected over the range 290-445 MHz, with the highest concentration in the 405-425 MHz range. It was not possible to identify any of these, although they are undoubtedly all radars of one type or another (BMEWS in fact operates somewhere in the range 400-450 MHz). The range 1370-1400 MHz was also searched (with a 3' beam) for about one hour, but no lunar reflections were found.

5. CONCLUSIONS

The moon, like the earth, is remarkably bright at radio wavelengths. Although the present brief study is only a beginning, the basic model of the radio signature of the earth presented by Sullivan et al. (1978) has received some validation. It is indeed military radars and television transmitters by which we are making ourselves known to the vast reaches of interstellar space. Turning matters around, it may well be through inadvertent leakage that we will discover another technical civilization. It has been remarked that our "television leakage phase" will be short-lived and that therefore this type of eavesdropping analysis has no general validity. But we think this is wrong - there will always be inefficiencies in any engineering system. As an example, let us suppose that in fifty years all TV on earth is through cable and that peace on earth has eliminated the need for powerful missile-watching radars. If this can happen, then so can a system of solar power satellites, each collecting solar optical energy and transferring $\sim 10^{10}$ w to earth in a few-arcsecond microwave beam. Such a beam will not be perfect, however, and just the slightest backlobes will dwarf in range of detection anything heretofore considered. In fact a backlobe with $f \sim 0.001$ would be detectable to distances 100 times greater than the present radars. Other likely future sources include powerful navigational beacons set in place for interplanetary or interstellar travel. We conclude that successful detection of extraterrestrial intelligence is a priori just as likely to happen via leakage radiation as through a purposeful beacon.

We thank the always helpful Arecibo staff for assistance with the equipment and Tommy Thompson for supplying the lunar ephemerides. If any reader knows of other such lunar reflection studies or of other powerful sources of radio leakage from the earth, we would appreciate being informed.

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