Mr. Grote Reber:

Could you write down informally a couple of paragraphs summarizing what you said to me about possible radio-observations from space vehicles (please enlarge these ideas if you wish)?

O.S.

To be used on a proposal for funds

RADIO ASTRONOMY FROM SPACE VEHICLES

Grote Reber

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The atmosphere of the earth is very nearly transparent to electromagnetic waves throughout the wavelength range from one centimeter to ten meters. Below one centimeter the path attenuation increases to nearly total extinction at one millimeter wavelength. This attenuation is due to molecular absorption in the dense part of the atmosphere near the surface of the earth. It may be greatly reduced by raising the observer to a few kilometers altitude. A few tens of kilometers altitude will remove this attenuation for all practical purposes. The equipment used for measurements at wavelengths less than one centimeter is relatively light and compact. The weights will rarely exceed a hundred kilograms or the volume a cubic meter. The only celestial object likely to be observed with present techniques is the sun. By considerable technical improvement the moon and a few bright thermal sources will probably be added to the list during the next ten years.

At wavelengths longer than ten meters the path attenuation is a complex phenomenon. In part it is due to absorption, but to a much larger extent to more or less coherent backward scattering from the electrons in the ionosphere. The region of maximum electron density is known as the F layer. Its altitude under normal circumstances varies from two hundred to four hundred kilometers; and is a function of the latitude and longitude of the observer, and the time of day, season of year and part of the solar activity cycle. The manner in which the electron density varies with altitude below the level of maximum density is known fairly well from ionospheric soundings using radio techniques. These fail at levels above the maximum electron density because no echoes are returned. The manner in which the electron density varies with altitude above the level of maximum density is substantially unknown. Very simple theory predicts an inverse exponential function. However, such indirect evidence as is available tends to indicate much more material is present than simple theory predicts. The distribution of this material apparently is a function of latitude, p rhaps longitude and probably time of day, year and part of the solar activity cycle.

Under very auspicious circumstances of place and time [1] such as Tasmania near solar activity minimum the ionosphere is substantially transparent at wavelengths up to three hundred meters during several hours before sunrise. By this choice, it is possible to conduct high grade radio astronomical observations from the surface of the earth at these wavelengths. Elaborate and complex antennas kilometers in size may be used to advantage successfully. The ease and satisfaction with which terrestrial equipment may be constructed, tested and operated mitigates against the usefulness of space vehicles in this wavelength range.

By using an artifice [2, 3] associated with the extraordinary longitudinal mode of wave propagation in the ionosphere, radio astronomical observations of a limited nature may be conducted at the surface of the earth up to wavelengths of about one kilometer. However, the results leave much to be desired and the interpretation of the data is complex and rather uncertain. The field of usefulness of space vehicles in radio astronomy is primarily for observations at wavelengths longer than one kilometer and secondarily in the wavelength range from one kilometer down to one tenth kilometer.

Neglecting the above artifice, the ionosphere will be substantially transparent to all waves shorter than the critical wavelength. At this wavelength the refractive index drops to zero and total reflection takes place. The critical wavelength is $(1110/N)^{\frac{1}{2}}$ kilometers, where N is electrons per cubic centimeter. If celestial radio waves of one kilometer length are to be detected, how high must the observer be before the electron density drops to 1110 electrons per cubic centimeter? The answer to this question is unknown. However, observations at 578 meters wavelength during 1957 demonstrated that the electron density frequently exceeded 3320 per cc at a height of 3000 km above the earth's surface. The electron density always was much in excess of 250 per cc at 8000 km above the surface. The epoc was near solar activity maximum. Similar observations during 1955 indicated a much lower electron density at 3000 km. On this rather meager evidence, it is apparent that the limiting feature of radio astronomical observation at kilometer waves is not the earth's atmosphere, but instead the density of the solar corona in the neighborhood of the earth. Apparently space vehicles which orbit a few hundred kilometers above the surface of the earth have no advantage over terrestrial observations. It seems as though a desirable vehicle would have a very elliptical orbit which went far out, perhaps beyond the moon. The data could be collected at apogee and read out near perigee. Presumably this orbit would remain fixed in space. From time to time the moon would pass by. Any change in the intensity of cosmic static observed when the moon is present could be inferred as due to remnants of a tenuous lunar atmosphere. To make radio astronomical observations at wavelengths markedly longer than one kilometer will probably require choosing a time and place such that the solar corona has v ery low electron density. Solar activity minimum out near Mars would probably be auspicious.

The electromagnetic environment in which the space vehicle finds itself will be rather different from that at the surface of the earth. An observer of kilometer waves on the surface finds very strong terristrial atmospherics as well as varying amounts of man-made radiation. Using proper equipment these difficulties can be more or less overcome. Since the ionosphere is a two way shield, these disturbances will not leak out to regions above a few hundred kilometers. Consequently the space vehicle observations will not be encumbered by these difficulties. However, another kind of phenomenon will be encountered, probably in copious amounts. This is Cerenkov radiation produced in the region from a few hundred to several thousand kilometers. It is caused by low energy particles travelling through regions of very high refractive index. The phenomenon was observed strongly during 1957 at 578 and 2100 meters wavelength. During 1955 it was much less prevalent. Apparently this nuisance rises and falls with solar activity. On this count also, long wave radio astronomical observations will probably be most successful near solar activity minimum, even with the use of space vehicles.

The question arises why make radio astronomical measurement at kilometer waves? This is very far from the present popular waves in the decimeter to dekameter range. The long waves have been called the wings of the phenomenon. Such is quite untrue. The intensity per unit bandwidth continues to rise as the wavelength increases from the shortest observed near a few centimeters to the longest observed near two hundred meters. On this basis, the short waves are on the wings of the phenomenon, while the center of the phenomenon is probably on the order of kilometer waves. Certainly a much better understanding of the source of cosmic static would be available if intensity measures could be secured which showed an inverse intensity versus wavelength relation. Then it would be possible to state at what wavelength the center of the phenomenon occurred. There are other deeper matters relating to the self perpetuating or winding up of the universe which may also be elucidated.

In the case of space vehicles certain practical matters must be taken care of. Radio astronomy is only meaningful if the direction of arrival of the wavefront is known. Either the vehicle must be stabilized in a frame of reference oriented to the fixed stars or else its actual instantaneous orientation must be known and the data corrected accordingly. The former seems preferable. The matter of longwave antennas on a space vehicle is quite awkward. Antennas may be divided into two classes. The first is a loop or magnetic dipole. It may be relatively small, such as a meter square. The second is a longwire or electric dipole. This could be a trailing wire. The directivity pattern of both types is similar to a doughnut.

The pickup efficiency of both types is equal. In theory they extract energy from the wavefront over an area equal to a circle four tenths of a wavelength in diameter. In practice the electric dipole approaches this in performance. The magnetic dipole is much poorer because it has very large ratios of respectively reactance and loss resistance divided by radiation resistance. Acceptance patterns with greater directivity will require more elaborate antennas such as might be attached to a space station.

In summary, the most plausible measurements in radio astronomy would be from a space vehicle in a very elliptical orbit near solar activity minimum at wavelengths on the order of one, two, five and ten kilometers simultaneously. Even though the information secured from the sidereal universe might be quite small, probably significant data would be secured on the electron density of the solar corona. If the vehicle has a useful life of several years, interesting changes might be observed in the electron density of the corona.

Presently a satellite experiment is being undertaken by the group at University of Michigan. They intend to use four wavelengths in the range 23 to 110 meters. Their antennas will be four whips, each about two meters long. Probably it would be well to learn the outcome of this undertaking before anything more elaborate is embarked upon.

1. Cosmic Radio Frequency Radiation near One Megacycle, Grote Reber and G.R. Ellis, Journal of Geophysical Research. Vol. 61, No. 1, March 1956, p. 1-10.

2. Between the Atmospherics, Grote Reber, Journal of Geophysical Research, Vol. 63, No. 1, March 1958, p. 109-123.

3. Cosmic Static at Kilometer Waves, Grote Reber, Proceedings of DRB/NRC symposium at Ottawa, Canada, July 20-21, 1959. In the press.

25 Oct 54

$\mu = 0$ when $\frac{81N}{f^2} = 1$

N = electrons per cc

f = kilocycles

KC = 300/km

$1 = \frac{81\,N\,km^2}{300^2} = \frac{81N\,km^2}{90,000}$

$N = \frac{90000}{81\,km^2} = \frac{1110}{km^2}$ electrons/cc

when $\mu = 0$

or $km = (1110/N)^{1/2}$

at 145 KC = 2.07 km, N = 259/cc

at 520 KC = .578 km, N = 3320/cc