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SCIENTIFIC BASIS OF OBSERVATIONS FROM SPACE

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Applications of Orbiting Platforms and Space Probes in Radio Astronomy

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ABSTRACT

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There is considerable information to be gained by orbiting platforms and space probes in radio astronomy. This report deals with one example of an area in radio astronomy which would be extremely benefited by observations from space -- the knowledge concerning the planet Jupiter. The limitations of ground-based astronomical studies are discussed, and the many advantages of extra-ionospheric observation are emphasized.

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INTRODUCTION

On January 26, 1966, a space science seminar was held at George C. Marshall Space Flight Center, Huntsville, Alabama. Dr. Alexander G. Smith, professor of physics and astronomy and Assistant Dean of the Graduate School at the University of Florida, was the speaker. Dr. Smith spoke on "Scientific Basis of Observations from Space," and specifically on applications of orbiting platforms and space probes in radio astronomy.

Dr. Smith is currently the principal investigator in Government grants and contracts in radio astronomy with the U. S. Army Research Office, the Office of Naval Research, the National Science Foundation, and the National Aeronautics and Space Administration.

The following is an edited version of the transcribed speech given by Dr. Smith. The Appendix which follows is the transcription of part of the question and answer session which followed the presentation.

APPLICATIONS OF ORBITING PLATFORMS AND SPACE PROBES IN RADIO ASTRONOMY

Man's view of the heavens has been an extremely limited one from the surface of the Earth, as Figure 1 indicates. The Earth's atmosphere is opaque to much of the enormous spectrum of waves and particles that swarm through space. Until very recent times man's entire view of the exterior universe has been limited to the very narrow optical window shown in the figure. However, within the past two decades there have been two important breakthroughs that have enormously enlarged man's view. One of these is the capability of lifting instruments above the straining effect of the atmosphere; the other was the discovery of an entirely new window in the electromagnetic spectrum in the radio frequency region, which is relatively broader than the optical window.

The Earth's atmosphere imposes several limitations on ground-based radio astronomy. There is a cutoff at the short wavelength end which is due to molecular absorption in the atmosphere, and a cutoff at the long wavelength end which is due to the opacity of the Earth's ionosphere. This limitation not only takes the form of opacity in regions that the ground-based radio astronomer would like to study, but because of the inhomogeneities of the atmosphere and the ionosphere, scintillation and refraction are introduced, interfering with the precision of the observation, both in measurement of intensity and in accuracy of position measurements. Therefore it would be most advantageous to the radio astronomer to base his instruments outside the atmosphere, either on board a space vehicle or on a lunar base.

My presentation today deals largely with the particular problem that illustrates the desirability of radio astronomical observations from space: that of the study of the radio frequencies spectrum of the planet Jupiter, which has been a foremost object of interest to astronomers for the past 10 years. This particular problem will illustrate the desirability of pushing back this long wavelength boundary by going beyond the Earth's atmosphere.

The powerful signals from Jupiter are in what we call the decametric region of the spectrum (wavelengths of approximately 10 meters). The discovery of these signals was made accidentally in 1955, by two radio astronomers at the Carnegie Institute in Washington who were involved in testing a new radio telescope; their records were, they thought, being ruined by some kind of strong interference. This was in fact radio noise of an unusually high level, coming from the planet Jupiter -- the first instance of the reception of radio waves from another planet. Figure 2 shows an example of this noise. Time is progressing in the direction indicated, and each one of the intervals is 15 minutes. There is a constant background of noise due to synchrotron emission from the electrons in our own Galaxy, and any other signals received are superimposed on this background signal. At about 0045 these strong impulses from the planet Jupiter begin, and they continue, varying by the particular noise.

Our station in Florida and two in Chile have monitored this noise for about 10 years. Analysis of the enormous backlog of records from these stations shows interesting data, as shown in Figure 3. As the frequency increases, the probability of receiving the radiation falls rapidly; i.e., as the wavelength increases, the probability of receiving radiation increases down to around 5 to 10 megacycles, which is imposed by the ionosphere on ground-based observations. Similarly, analysis of the intensity of the radiation, as shown in Figure 4, shows that the preceding figure indicated the probability of receiving it. Figure 5 shows the intensity of the radiation. Advancement to higher frequencies follows rapid fall of the intensity, or, conversely, advancement to longer wavelengths approaching the ionospheric limit in this vicinity seems to follow rise of intensity. Whether it actually flattens off here is questionable, since the ionosphere is an unknown parameter in the range, as far as possible attenuation is concerned. So if both the fraction of time the radiation is received and its intensity decrease as frequencies increase, the average flux, which is in essence the product of these two, falls off with enormous rapidity as higher frequencies are approached; in fact, the slope of this part of the curve is something like frequency to the -8th power. As wavelengths lengthen toward the ionospheric cutoff, this energy seems to increase. Its behavior in this vicinity is again uncertain because of possible ionospheric attenuations in that region.

The area under such a curve can indicate the total power being received. This is in the characteristic flux units of radio astronomy, that which is incident on the surface of the earth on each square meter in a band with one cycle per second wide. Therefore, by integrating overall frequencies under curve, one can derive the total power under the curve, and applying the inverse square law, calculate the total power radiated by Jupiter at the planet. Under this curve (Figure 5) the area back at Jupiter is approximately 25 million kilowatts. It is also evident from the shape of the curve that the major portion of this power resides at very low frequency, and the amount of energy which might be in the extreme low frequency tail beyond the ionospheric cutoff poses an interesting problem. Probably the major portion of the energy in the Jovian spectrum would lie at frequencies too low to be received with any reliability, at least from ground-based radio telescopes. (See Figure 6.) Instruments above the ionosphere would push such a curve down to the vicinity of zero megacycles and easily measure this very interesting low-frequency tail. To make any speculations about energy sources for the radiation, one should know how much energy is necessary to evaluate this curve completely down to the end of the low frequency tail.

In addition to limiting studies of the spectrum at low frequencies, the ionosphere unquestionably introduces certain scintillation effects. At ground level we observe pulse structure of this type (See Figure 7.) in the Jovian noise storm. The records shown in Figure 8 are taken at much higher speed than those of the preceding record; each one of these divisions is one second. Radiation is most often observable in the form of burst pulses which are typically on the order of a second or a few tenths of a second in length. Very short bursts, such as those of this record, are more rare. The vertical slashes and oscillographic studies indicate that these are as short as milliseconds. Still more rare are long, slow pulses, lasting sometimes tens of seconds.

A major consideration here is the amount of this pulse structure which actually originates at the planet, and the amount attributable to the Earth's ionosphere. This problem of long debate could be settled clearly by observations from above the ionosphere. High-speed records offer reasonably positive evidence that there is a strong ionospheric influence, as shown in Figure 9. Again the divisions are one second; these are Brush records made simultaneously at the two stations -- about 7000 kilometers apart. There is very little burst-to-burst agreement with the record. When one is at its maximum, the other is at its minimum. One seems to have a changing out-of-phase or in-phase fading; nevertheless persuasive evidence points to strong ionospheric influence. When beat frequency receivers are used for the structure of the burst in the frequency domain, at about a 3-megacycle bandwidth, a variety of burst forms appears on a spectrum analyzer. This is the background cosmic radio noise from the Galaxy. This is rather a narrow, wider band Jupiter burst.

Sometimes a very curious comblike structure is observed, such as the one on the figure. This is Faraday rotation twisting of the electric magnetic field as it comes down through the Earth's ionosphere through the magneto-ionic medium. This twisting causes a rotation of the polarization plane of the radiowaves so that our antennas are linearly polarized, and as the wave twists because of the variations in the ionosphere, in one moment the wave is lined up parallel to the antenna; another moment it is twisted until it is at right angles to that antenna and does not cause excitation. This effect is frequency-sensitive at any instant, so that certain frequencies are rotated more than others. Some will be lined up with the antenna, and some will be at right angles to the antenna; therefore, as frequency progresses there is maximum where that frequency happens to be lined up to the antenna, minimum when that frequency is at right angles to the antenna. Then the comblike Faraday rotation pattern appears -- again evidence that there is a strong ionospheric influence on the radiation.

A number of observations have been made with the X-66 Beacon Satellite of its 20-megacycle signal, and simultaneously of the 20-megacycle signal from Jupiter. These were compared to show whether the scintillation structure of the satellite signals were the same as the pulse structure or whether it showed any correlation with the pulse structure from the planet. The result is shown in Figure 10, in which one index describes the duration of the Jupiter pulses and one the duration of the satellite signal scintillation. There is a complete scatter for the X-66 signal. There is very slight correlation between the structure imposed on the satellite signals by the ionosphere and the form of the Jupiter pulses, indicating contradictory evidence. On the figure is some evidence that shows very strongly an ionospheric influence on the radiation that is quite important in forming the pulses.

Yet many studies are made concerning diurnal and seasonal effects comparing the Jupiter radiation for satellite signals which indicate or suggest that the ionosphere is not the agent which forms the burst structure of the Jupiter pulses, so that probability of argument and doubt rises as to the real origin of the Jovian pulse structure. Again, a very obvious and direct way to settle this controversy is to make measurements from above the ionosphere. The timing of decrement signals, bursts, noise storms, etc., from Jupiter appears at first to be rather sporadic, but statistical studies of their occurrence indicate that they are far from random. Figure 11 illustrates this fact.

The assumption that there is a system of longitudes encircling the planet Jupiter evolves a Jovian system of longitude to describe locations on Jupiter. Such a longitude system must be arbitrary. To set up this system one may postulate arbitrarily that zero of longitude is at the center of visible disc at some given instant and that from there the longitude rotates at some arbitrary speed. Then the visual or photographic observers can locate objects, spots, streaks, etc., with respect to this arbitrary longitude system. Radio observers can report radio events using, to describe the events, the arbitrary longitude which was at the center of the disc at the instant the observation was made. If the radio events are reported in this fashion, their distribution is shown to be far from random. Any particular frequency, e.g., at 22 megacycles per second, when the arbitrary longitude of around 240 degrees is near the center of the disc, will produce a very high probability -- possibly 50% -- of receiving signals. Otherwise, when the longitude is in the vicinity of zero degrees of the center of the disc, there is almost zero chance of receiving a radio signal. Thus the appearance of the radiation is strongly correlated with the face of the planet that happens to be turned toward the Earth.

This structure changes somewhat with frequency. There is threefold symmetry which is quite characteristic of the structure at the higher frequencies, but as lower frequencies are approached this seems to smear out. Ground-based data at 5 megacycles might have transposed to a twofold symmetry. It is rather tempting theoretically to connect radiation with a dipolar magnetic field to the planet. But many a theorist has stubbed his toe in trying to explain decametric radiation in this fashion.

Proper selection of the rotation period of the arbitrary longitude system will indicate any features being tracked at the same longitude all the time -- i.e., the longitude system will be rotating at the same speed as these features. Improper selection will cause the features to drift with respect to the longitude system. The system used more often by visual and optical observers is called "System II," which in effect is an average rotational period of the great red spot, the feature that has been longest observed on Jupiter. Plotting radio events in that longitude system causes the situation indicated in Figure 12. For the radio features, the main peaks, A, B, and C, drift about a hundred degrees a year in this longitude system, indicating that the speed of rotation is much slower from the direction of the drift than the actual rate of rotation of the radio features. They are not rotating, then, at the mean rate of most of the optical features. As a result another longitude system called "System III" is recommended -- one which represents a better rotational period for the radio features.

Figure 13 shows the great red spot and the opaque clouds covering Jupiter. It is never possible to observe its surface; therefore the speed of the rotations of the solid part of the planet is unknown. Measurement of the speed is one of the applications of the radio observations, although the System II represents a kind of mean or compromise speed for the optical features. Cloud features are all moving at different rates; even a given feature such as the great red spot exhibits a variable period of rotation over the years, and so observation of the optical features is not conclusive for determination of rotational period. The radio observations seem to offer for the first time a real chance to determine this period. All popular theories of the radio wave origin seem to connect the waves with the magnetic field of the planet, and an analogy with the Earth would indicate that the magnetic field originates in the core of the planet. Therefore the magnetic field should be rotating at the speed of the solid portion. Timing the rotational period of the radio sources, then, could indicate the period of rotation of the planet itself, and for this reason has aroused much interest.

Figure 14 shows what has happened. It is surprising to see the radio radiation back in 1950, actually after it was discovered. Examination of old records showed that Jupiter radiation had been recorded many years earlier, but had not been recognized. Selection of a particular radio frequency rotation period, System III, indicates that for almost a decade, from 1950-51 to 1960, the main radio feature -- the principal peak A -- seems to remain fairly constant in longitude. Then in 1960 it seems to have begun drifting and according to our measurements was continuing to drift at the rate of about 11 degrees per year since that time to our most recent observations. At about the same time the great red spot had also started drifting at approximately the same slope, and there was speculation as to whether there were some connection between the two events. Today the answer is probably no, because several years later the great red spot reversed its direction of drift but the radio sources continued as they were previously.

A very challenging problem of interpretation would be to decide what has happened to cause this change in the radio-frequency rotation period, particularly if it is associated with the core of the planet. Was there actually a change in the rotational period of the core of the planet? Strangely enough some geophysicists seem to believe that there may be, for example, a torsional oscillation between the core and mantel of the planet. Possibly one would expect this to be, over a period of decades, attributed to oscillatory motion. One scientific theory denotes the great red spot as a Taylor column, a kind of hydrodynamic vortex. A Taylor column is created by a rotating fluid and an obstacle at the bottom moving with respect to the fluid. This theory holds that the atmosphere of Jupiter is slipping over the surface of the planet at differential rotation, and that some kind of obstacle on the surface is setting up such a vortex. The great red spot at the top of the atmosphere is the visible manifestation of this Taylor column.

There is a good deal of laboratory work to substantiate existence of the mechanisms of these Taylor columns. It is a well known fact that the period of the great red spot shows quite wide variations during intervals of the order of decades. This same theory proposes to explain that there is such a torsional oscillation of the planet between the mantel and the core and exchange of angular momentum, thus accounting for the red spot drift.

One of the events which surprised Jupiter astronomers about a year ago was the discovery of the Io effect. An Australian statistician showed that the period of emission of the times of emission of the strong decametric signals from Jupiter were strongly correlated with the location of Io, the innermost of the large Jupiter satellites and the first of the Galilean satellites. Figure 15 shows our own observations analyzed in this fashion. We found an extremely striking effect at all the frequencies at which we performed the analysis. There is a very strong probability of getting emission from Jupiter when the satellite Io is in one of two different positions. Shown on the figure is a scale of positions around Jupiter where zero degrees means that the satellite is behind the planet as we see it, and 180 degrees means that the satellite is right in front of the planet in the center of the disc. Likewise, 90 degrees would mean that the satellite would be off to one side; 270 degrees, the other side. There is a striking maximum in the probability of getting radiation from Jupiter when the satellite is at 90 degrees off on one side of the planet or about 240 degrees approaching the furthest angular separation on the other side of the planet. One suspects a tidal influence as an explanation of these peaks, and since Io is the innermost of the major satellites, it is the major tide-raising force on Jupiter; it might be due to ionospheric or magnetospheric tides.

One list made of the current theories concerning the reasons for these very powerful outbursts of radio noise from Jupiter ran to 17 theories -- approximately the number of people working in the field. The earliest theories centered around the possibility of thunderstorm activity where these signals are. This theory seemed to be excluded by the spectrum and the temporal variations. It has been theorized that the radiation might be due to plasma oscillations in Jupiter's ionosphere or magnetosphere. One Russion theorist strongly espoused this. The suggestion was that these plasma oscillations were excited by volcanic explosions on the surface of the planet, sending shock waves out through the ionosphere. Another theory proposed that the radiation is due to the emission from trapped electrons in Jupiter's very powerful radiation belts; particles are dumped from the radiation belt down into Jupiter's lower atmosphere, and that as they strike the atmosphere, they give rise to these radio waves by the process known as Cherenkov radiation. This theory recently seems to have been rejected because it required that the center of Jupiter's magnetic field or its magnetic dipole to be 0.7 of the way to the surface of the planet, a possibility which contradicts some very precise and recent microwave observations. Another possibility is that the radiation is due to a cyclotron process. This theory seems most plausible. Recent thermal work seems to indicate that Jupiter is probably a hot planet, since it is emitting more heat than it is receiving from the Sun -- 2 to 4 times as much. The corresponding figure for the Earth is an outward flow 1/30,000 as much as the inward flow from the Sun. The only possible explanation for the Jupiter figure would be the internal heat of the planet.

Current speculation is that Jupiter is an incipient star, and because of its small size, it has not become self-luminous. This indicates still another source of energy for driving mechanisms to generate the radiowaves.

This review summarizes the major points in the radio astronomy of Jupiter and indicates a number of areas in which observations are badly needed at lower frequencies than those which can be obtained from the ground. The high-energy, low-frequency part of the spectrum may be visualized from above the ionosphere. By this method one can determine the influence the ionosphere has on the signals, and whether the time structure that we observe in the signals is really planetary, Jovian in origin, or simply imposed by the ionosphere.

The development of an orbital radiometer is under way at the present time. There is a prototype model, which was developed under contract with NASA for the University of Florida, of an orbital radiometer, to make measurements at $\frac{1}{2}$, 1, 2, and 4 megacycles, and the present hope is to fly this radiometer on one of the late OGO's or perhaps on one of the Apollo experiments, to get measurements of this important low-frequency region of the spectrum.

Figure 16 is indicative of what might happen if we can obtain observations under very ideal conditions. About a year ago a new low-frequency station was set up in the Chilean Andes in an isolated spot near the town of Huanta. It is in a deep valley in the Andes which is very well shielded on all sides from terrestrial interference. The year's records from that station were compared with the 18-megacycle observations made at our Florida station. The probability of receiving Jovian radiation when the A peak is turned toward the Earth at the Huanta station leads to the most incredible value as far as most Jupiter observers are concerned: 80% of the time that the peak was turned toward the Earth, radiation was received. The corresponding probability from the Florida station was about half that. This comparison is indicative of the advantage one might expect to derive from making observations from beyond the atmosphere -- possibly 100% under truly ideal conditions. At the lower frequencies, 18 megacycles is a relatively easy frequency at which to work from an Earth station. At still lower frequencies this advantage would be even more marked.

Aside from this particular astronomical problem, there are others which could be benefited by space observation. In the figure showing the Jupiter noise storm, there was a background of radio noise due to synchrotron emission from electrons in our Galaxy. A study of that cosmic radio noise is of value because it gives information about the particle content of the Galaxy. In Figure 17 the intensity of the cosmic background radiation increases as frequency decreases, or as the wavelength increases, and it appears to be reaching some sort of maximum around the ionospheric cutoff. But because of the unknown influence of the ionosphere, one does not have much confidence in the data from this region. To date a few preliminary experiments in measuring from space have already been made although at the present time the results are rather discordant. If one looks at the spectra of the discrete sources, some of which are super nova remnants in our own Galaxy, and some of which are external galaxies of the same magnitude of our own Milky Way system, one finds in many cases that these spectra also increase steeply towards the lower frequencies, toward the ionospheric cutoff. There is some indication of a turnover or a leveling off. Again data in this region are not sufficiently reliable, and low-frequency data taken from a space station would be of enormous importance in establishing what happens in the low-frequency region of these curves. This would also give valuable information on particle fluxes, magnetic fields, etc.

From Figure 18, the Sun is the strongest radio source in the sky; its only rival is Jupiter. Strong Jupiter bursts get in the same range as strong bursts from the Sun. The spectrum of the Sun is quite complex, but it consists of many features. A steady thermal component thus decreases in intensity as wavelengths are increased. This scale, however, is turned around from the preceding ones. As longer wavelengths are approached, the intensity decreases. Other types of radio noise coming from the Sun and the great bursts seem to increase again as lower frequency is approached.

At the present time one does not know what happens to these in the extreme low-frequency domain beyond the ionospheric cutoff. An experiment was once conducted from an OGO in an attempt to find out, but because of equipment malfunctions no results were obtained.

This is another very important application of low-frequency space-based radio astronomy -- to chase the Solar spectrum into the long wavelength region.

My review has included only one aspect of space-based radio astronomy, that of pushing back the long wavelength of the radio astronomy window. Another possibility of course is to conduct very high-frequency short-wave experiments from space vehicles to push back the short wavelength end of that window. There is much valuable information to be obtained by orbiting platforms and space probes for radio-astronomy purposes.

APPENDIX

QUESTION AND ANSWER SESSION

QUESTION: I am intrigued by the last probability you have here, approaching 100%. Is there not evidence now that there is a sporadic radiation?

ANSWER: This kind of data could indicate that the radiation might be quasi-continuous in the direction in which the principal source is aimed. One analogy sometimes helps: you might think of Jupiter as similar to a rotating aircraft beacon sending out beams. And when one of these beams sweeps across the earth we receive the radio signals, just as when one of the lighthouse beams or aircraft beacons aims its beam toward you, you see the light. And it may well be that these beams are continuous; the only reason that they seem discontinuous is that we are listening under unfavorable ionospheric conditions or conditions of local interference. Certainly this data from Huanta would indicate there is something very close to that 80% of the time, a pretty high probability. It means that that beacon, during the period of these observations, was certainly turned on 80% of the time when it was aimed toward the Earth. And that certainly is approaching a continuous operation. My impression as an observer is that, as you go toward the lower frequencies slower than 18 megacycles for which this data applied, this quasi-continuousness of the signals is even more pronounced. We have a channel operating at 10 megacycles, which is really below the frequency we can operate in Gainesville. We tried 6 megacycles this year and it is almost hopeless, in spite of the fact that Jupiter is currently near the zenith. At 10 megacycles I have the impression that whenever the listening conditions are good enough I can hear Jupiter. The only reason I can't hear Jupiter at 10 megacycles is that the listening conditions are not good enough. And again this is a question that could be answered, should be answered by experiments in a more favorable environment, meaning above the ionosphere.

QUESTION: At what time of day, or how close to the Sun can you observe Jupiter?

ANSWER: As far as time of day is concerned, we have found that broadly speaking we have to work at night, because the level of interference is far lower, and largely because of the fact, of course, that the ionosphere is a creature of the Sun. It's created by solar radiation, and so therefore it is not surprising to find that it condenses during the daytime and is most troublesome to the radio astronomer - not only from preventing signals from getting in, but also in reflecting back terrestrial interference into its antennas. This is an even more serious problem at intermediate frequencies such as 15 or 20 megacycles. Because of the daytime noise, we ordinarily make our observations like the optical astronomers during the night time hours. Currently, for example, we are running watches from about 6 p.m. to about 6 a.m. As for the time of year, we observe Jupiter essentially the year around. We usually omit a week or two around conjunction, when the planet is almost in line with the Sun. If we have some important wiring to do or an antenna to take down, we do it during that period if we can. But one has to point out that although we observe the year around we get far more radiation, far more results, when Jupiter is near opposition, that is 180 degrees from the Sun. If you plot the amount of energy that you get as a function of Jupiter's distance from the Sun, you get a curve something like that. In other words, the farther Jupiter is from the Sun, the higher your probability is of receiving radiation. Certainly all of this, or much of this is an observational effect.

QUESTION: With our space vehicles we can send about 20,000 pounds of payload to Jupiter. I think we could, depending on orbital radius, still put about 2000 pounds into orbit around Jupiter and be able to send information back. What do you think would be the most attractive types of experiments? What would be the best vehicle?

ANSWER: I would like to see the usual sort of particle flux and energy density measurements, to show whether the theories about the radiation belts derived from the radio observations have been correct, and those of magnetic field measurements because there have been values of the magnetic field deduced both from the microwave observations from what you might call the thermal regime on the planet, and from the decametric observations. One can't live with the same magnetic field with both sets of radio observations. It would be nice to find out if this is really the proper value, or if the theories are astray.

Such an experiment would probably weigh a few pounds, and I think we can do better than that. Now 20,000 pounds would be available just for a "fly-by" experiment. But if you convert some of that 20,000 pounds into propellants and deboosts, you can set up a satellite around Jupiter that can provide data for a year or several years. In turn, if you put something down into the atmosphere it will give more information and it will also get direct data of the atmospheric composition. I don't know whether that is possible, to get it all the way to the ground and still get useful information back through the Jupiter atmosphere to that orbiter, and then relay it back to Earth. Or is that out of the question?

This is what one might term an occultation type of radio experiment; it would be of interest. One suspicion is that many of the radio effects that we observe - perhaps the shape of the histogram in which one saw the probability of receiving radio signals varying with longitude in the aspect of the planet - might be propagation effects. Maybe the radio waves only propagate away from Jupiter along certain ducts or certain paths, in Jupiter's ionosphere and magnetosphere. And if one could send up an occultation experiment or simply a radio beacon experiment in which radio beacon is sent into Jupiter's atmosphere in a known location, and measured the radio signal as it came back, position, intensity, polarization, etc., I would think that one could get a great deal of useful information. It would be in a sense somewhat analogous to the Martian flyby.

QUESTION: Dr. Smith, it would appear that there are two ways of making space flight useful in receiving Jupiter's decametric radiation. One would be to put antennas in an orbiter around earth, that can be aimed or directed very precisely toward Jupiter. You could, very conveniently, man these facilities, get there, return them to Earth, and recover data received. You can combine very sophisticated photography and rid yourself of all the troubles introduced by the Earth's atmosphere. But I think once you send a probe to Jupiter, it would be more attractive to use the physical presence of this thing so close to Jupiter that you could compute more data than you could possibly get from an orbit around the Earth. And I think that the idea of getting something into the Jupiter atmosphere ought to be of tremendous interest.

Now suppose we could build a capsule that we could decelerate with rockets in an orbit around Jupiter to the point that it will fall drastically down towards the planet. And it would be a long shape so that the residual velocity, let us say the parachute velocity, would be very low in which it would descend. Do you have any ideas as to whether there is a chance of getting radio signals or any kind of signals again? If not, there is still another possibility. You can allow a thing like this to fall down almost to the surface of Jupiter. It has a little built-in solid rocket and the break offs, and then some simple gadget like a radar altimeter, so that as it is approaching the solid surface or when it is getting too hot or too cold, you shoot the solid rocket that goes right back out of the atmosphere again. Then you dump your information that you stored on the tape recorder back to the Earth and have the orbiting object relay it back to us. When you have about 2000 pounds, you can accomplish many things. I think we should not stick to the kind of methods that you can also use for years from here. We should see what we really could do if this gadget were placed there.

ANSWER: I agree with you completely; that is why I didn't mention the first thing that one might expect a radio astronomer to measure and that is to make radio observations from around Jupiter. I think that we have pretty good signal-to-noise ratio from Earth-based observations, and I think they would be as I have indicated, far better perhaps from an orbital vehicle outside of the ionosphere. I don't really feel confident myself that one would greatly improve the radio observations by making them from close in. But I certainly agree with you that there are other kinds of information which would be extremely interesting. I would say that the radio signals will cut off regardless of what frequency is chosen. The radio signals will cut off at some depth; therefore, the second alternative that you suggested of somehow sensing a critical depth and firing a telemetry package back out to report what it had seen would be a very intriguing experiment. The reason I say that I strongly suspect you would lose radio contact at some depth is that people like Wendell de Marcus and Rupert Wildt, who are involved in the theory of planetary interiors, particularly the major planets, question whether there is such a thing as a sharp, hard surface on Jupiter. They think that there is a possibility that the gases might just get denser and denser until there is kind of a quasi-liquid or a quasi-slush such as we might have outside, and this thing might slowly sink into molasses, getting gooier and gooier. Eventually the molasses is going to become opaque to the radio waves.

I don't think this means that such experiments should not be conducted. For example, you could have several such probes that you would drop slowly into the atmosphere and shoot out again - you just fire that rocket that gets them out again with a timer. Begin with a modest time, go only into the uppermost layers of the atmosphere, and as it comes out, just set the timer a little longer for the next one. You get the density specifications of the atmosphere as you go, and after you have two or three such successful flights, you get a pretty good idea of what the makeup of the atmosphere is. You could probably build a mental model that tells you what to expect underneath if this trend continues. If it finally turns to molasses, there is a point at which you don't get it back.

I think that experiments of this type would be of enormous importance because they would give data on things which at the moment are just sheer speculation. For example, on the pressure depth profile of the atmosphere below the clouds, and on the temperature depth characteristics of the atmosphere, turbulence, one has no data at all. Of course the optical evidence suggests enormous turbulence. The high resolution photographs of the belts immediately suggest enormous turbulence, and velocity or period measurements of features in adjacent belts suggest relative slippage of these belts with respect to each other at speeds of hundreds of kilometers per hour.

QUESTION: I mean after all, we do have transistorized transmitters you can fire from a gun. You have electronic fuses on the aircraft.

ANSWER: I worked for several years on those. I think there is an experiment which would be very valuable to radio astronomy in the Jupiter neighborhood. It is to see the scintillation effects of the interplanetary plasma. Notice the comparison on the slide of the S66 signals and the Jupiter signals received at ground level. It does look as though the Earth's ionosphere is producing a great deal of scintillation as seen in the Jupiter signal. Now you go to an Earth orbit and get rid of any ionospheric scintillation. But still, if you look at any source off in the distance like Jupiter, you still have the interplanetary media; so if you can do radio astronomy from the neighborhood of Jupiter, then you have isolated another factor: you can see just what the solar winds, clouds of plasma, in interplanetary space are doing. You can do this not only from Jupiter but also in the direction of the Sun, but if it is clouds of plasma in space, with a heliocentric distribution, you would eliminate the possibility by going in the direction of the Sun because it would get denser. This would really be another factor to consider by radio astronomy in the neighborhood of Jupiter.

QUESTION: Yes, to dispense with the interplanetary media by essentially getting so close that there was no appreciable amount of it. That is an interesting point.

QUESTION: You could consider that Jupiter has a very strong Van Allen belt, couldn't you?

ANSWER: I would say the radio evidence indicates that it has quite a powerful radiation belt.

QUESTION: Would this Jupiter atmosphere probe be moving through that Van Allen belt?

ANSWER: It would be moving, yes, through the inner part of it.

QUESTION: You didn't say anything about radio astronomy from the lunar surface. Does this mean that we do not have to go up there? I understand that you want to get up out of the ionosphere and out of the magnetosphere.

ANSWER: Yes, if you wanted to go to very low frequencies then of course you would have to go to a region where the local plasma density is below the frequencies in which you are interested, which means that to go to very low frequencies you would have to go to quite high orbits. I think for example that a synchronous orbit would be well adapted to the sort of experiments that we have immediately in mind. I certainly didn't mean at all to downgrade lunar-based experiments particularly. I think in the low frequency regime, where in order to get reasonable resolving power you need enormous antenna arrays, there might be much to be said for a lunar base where you could fairly readily erect large antennas, particularly from the back side of the Moon. That has of course a tremendous appeal because it would screen you from terrestrial interference. If I had to choose my favorite site for low frequency radio astronomy, it would be the back side of the Moon, where one could put up large arrays and be screened by the bulk of the Moon from terrestrial interference.

QUESTION: Do you think that the surface of the Moon still has good possibilities compared to, say, a lunar orbit?

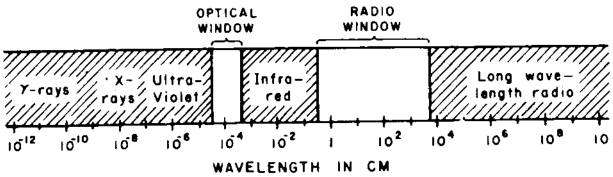
ANSWER: Aren't some of the optical inhibitions associated with flexure considerations? On the Moon you still have to worry about flexure and in space perhaps you don't, i.e., in a zero-g environment. It is probably more a question of the temperature variations - hot on one side, cold on the other, or even light scattering within the instrument.

QUESTION: Can radio positions be obtained using the horizon as a carving edge?

ANSWER· Yes. It has been pointed out that, unlike the case on the Earth where you have the refraction and the absorption problem in the atmosphere, you could actually use the horizon as a knife edge in the case of the Moon, i.e., occultation times.

QUESTION: Do you observe many bursts from a radio star? Or are these due to one single burst? Pulsating radio stars (i.e., whole galaxies) are diffiult to interpret.

ANSWER: I really don't think that it is due to one or more bursts. I think what is happening there is that one has out-of-phase scintillation. That is, that if you look at a steady source, as in Jupiter, the question is whether it is a steady source or whether the pulse structure generated somewhere along the way. In any event we always observe Jupiter as a pulse type source, but the radio stars or discrete sources are steady sources if they are observed under optimum conditions near the zenith and not at low altitude. If you observe the radio stars under unfavorable conditions, at somewhat lower frequencies and near the horizon, then they too scintillate. You get a twinkling, just like the twinkling of the optical stars, characteristically in an intermediate frequency range. These scintillations usually have a period on the order of 30 seconds; if you average them, you get the order of magnitude. Of course this scintillation appears as a fading. At one moment the signal is strong and 15 or 20 seconds later it has faded considerably in intensity, and then 15 or 20 seconds later it is strong again. It is an amplitude modulation. There is also a phase modulation if you are measuring phase. And I think that the effect we say on this slide is precisely analogous to that radio star scintillation - that we are simply seeing a gross amplitude modulation of the entire radiation envelope, whatever the details of the pulses may be. By the same mechanism this is responsible for the scintillation of the radio stars. The Brush records can run to 300 feet because that is the length of the roll; if you take these records and trace, you find on many occasions that you are getting this fading in and out of the signal with the mean period, about the right order of magnitude. And sometimes the fading in and out is in synchronism at the two stations; sometimes it is as we saw on these two particular slides, out of phase. In other words, there seemed to be an independent scintillation at the two stations which may or may not be in phase with each other. So I would interpret that particular effect to be the same sort of scintillation which is attributed to drifting of clouds of ions in the F-region in the ionosphere. I would attribute that effect to the same thing that causes the scintillation of the radio stars. And the mechanism that creates the pulses, whatever it is, wherever it is, is a different mechanism than that.



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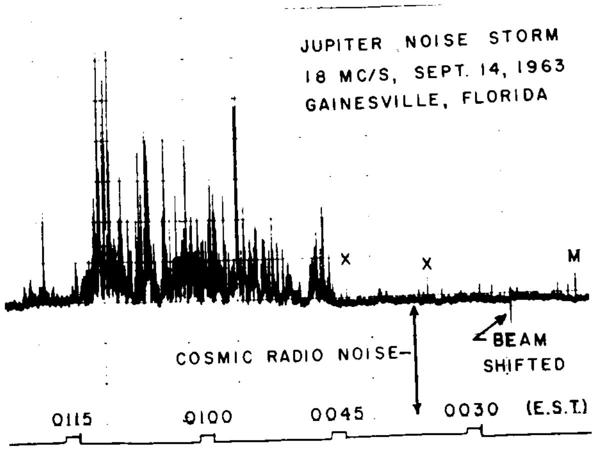

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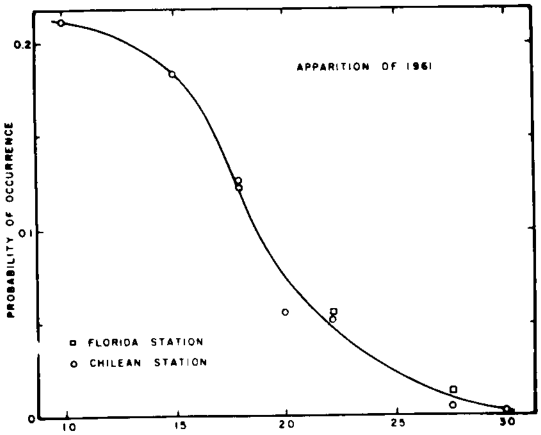

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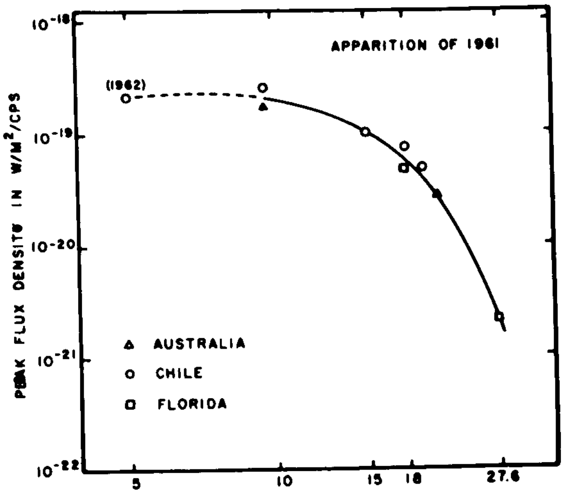

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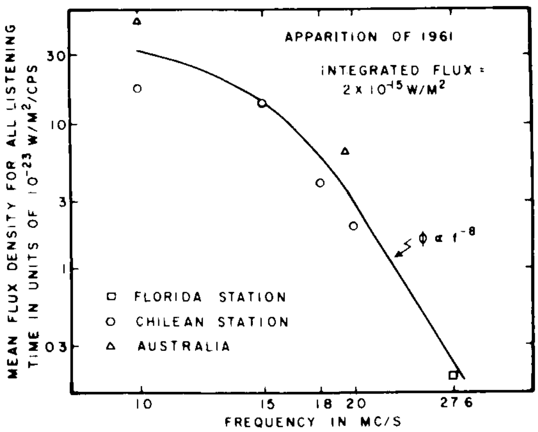

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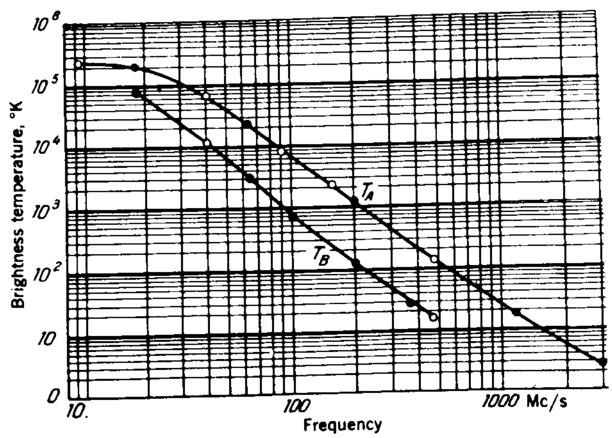

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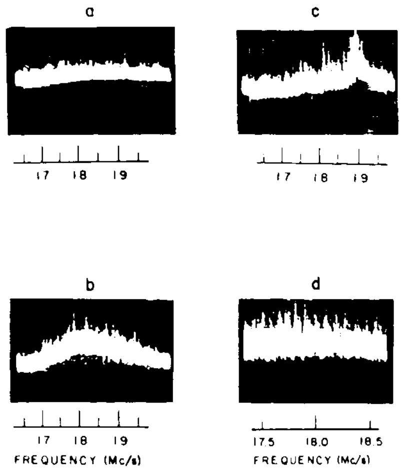

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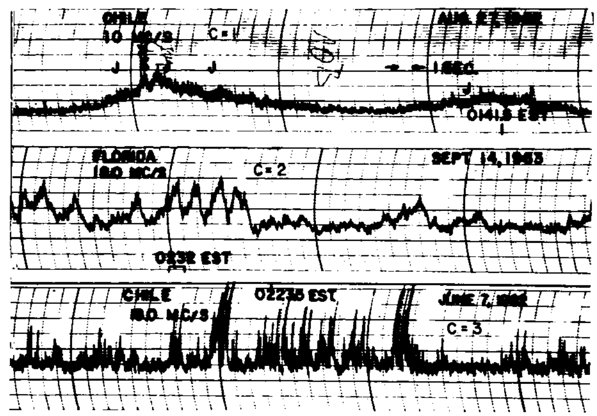

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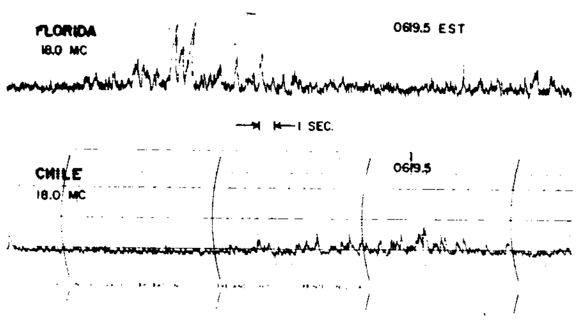

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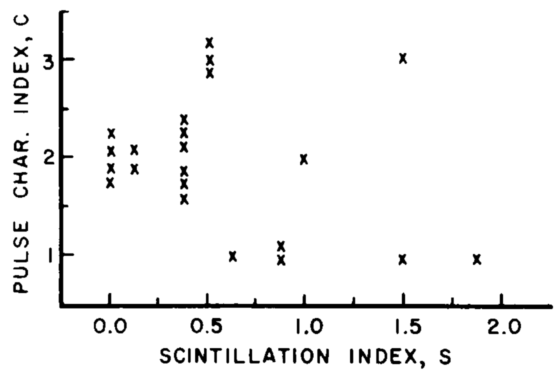

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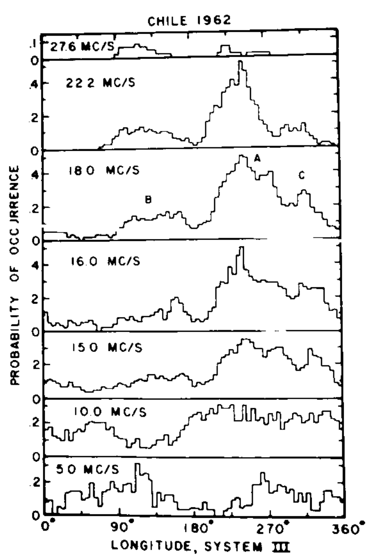

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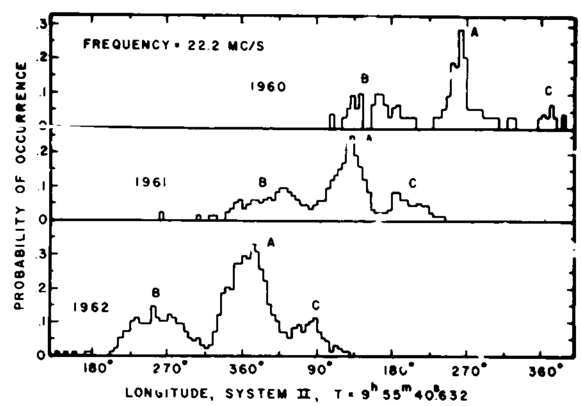

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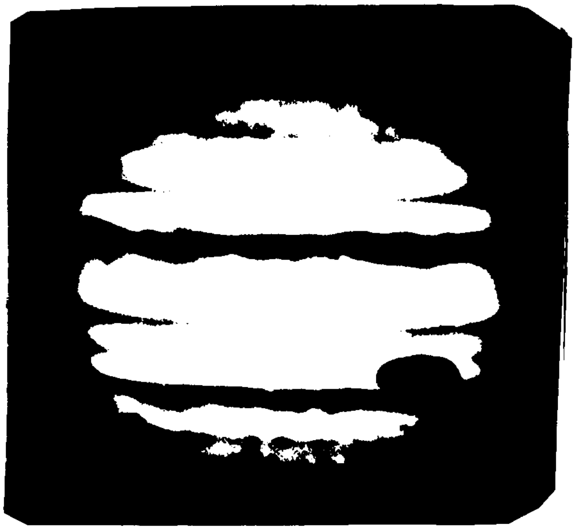

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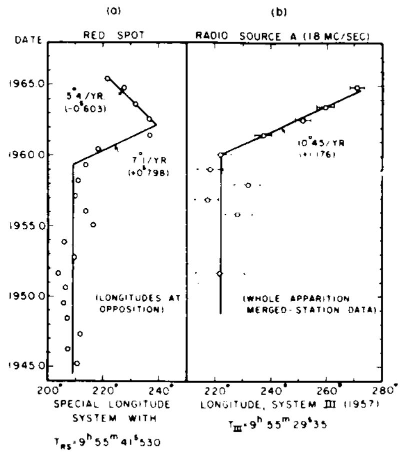

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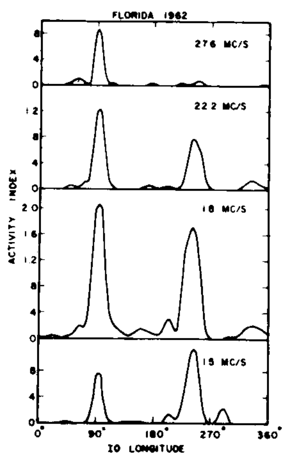

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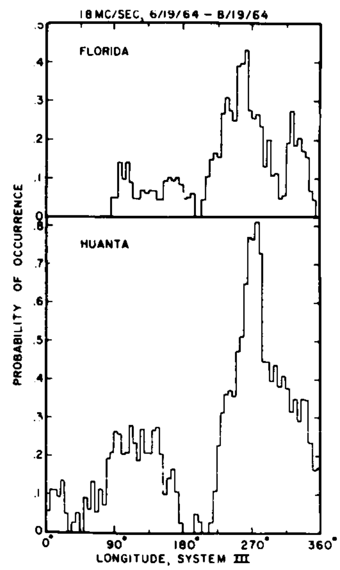

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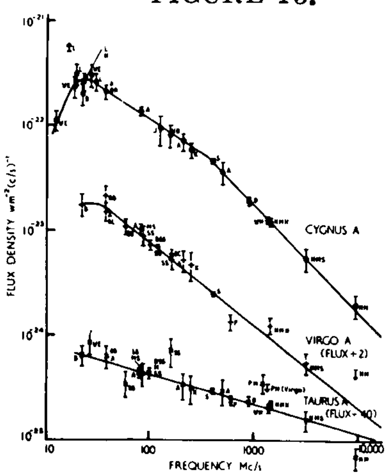

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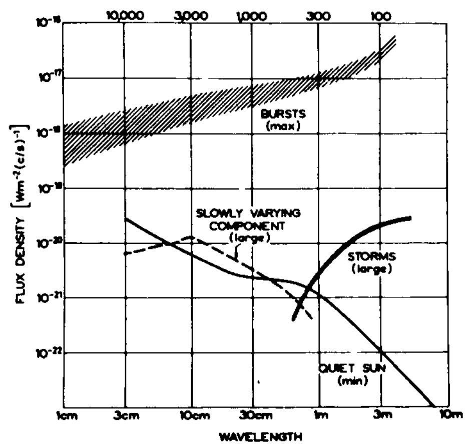

FIGURE 18.

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SCIENTIFIC BASIS OF OBSERVATIONS FROM SPACE

Applications of Orbiting Platforms and Space Probes in Radio Astronomy

by Dr. Alexander G. Smith

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Ernst Stuhlinger

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Director, Research Projects Laboratory

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