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SYMPOSIUM: PLANETARY RADIO ASTRONOMY

AN ACCOUNT OF THE DISCOVERY OF JUPITER AS A RADIO SOURCE

BY K. L. FRANKLIN

Vannevar Bush has said that there is no more thrilling experience for a man than to be able to state that he has learned something no other person in the world has ever known before him. This experience is not rare in the life of a successful research scientist, as witness the papers published in our journals and to be presented to this meeting in the next few days. Often, such an experience comes gradually and almost without one's awareness; but occasionally a discovery is made with dramatic swiftness which leaves the participants in a state of excitement. I have been lucky enough to be included in such an event, and I have been asked to recount this anecdote as an introduction to this symposium.

When I arrived at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington as a Research Fellow, on September 1, 1954, I was introduced to the world's largest (and least conspicuous, as Bernard Burke remarked) radio telescope. This Mills Cross, described in the literature, had been constructed during June and was being operated by Burke. Dr. M. A. Tuve, Director of D.T.M., suggested that I work with Dr. Burke on the 22.2 Mc Sky Survey for which the Mills Cross was built. I had to learn many things that I still find mysterious, and it was interesting to participate in the development of some of the tools of radio astronomy.

The receiver and auxiliary equipment were constantly being improved during the first few months of 1955. In order to discern the results of each improvement, we left the pencil beam (about $2^{\circ}\!.5$ wide to half-power points) directed to the declination of the Crab Nebula, the strong radio source in Taurus, and compared records obtained before and after each modification. We decided to scan the region near the Crab Nebula in order to build up a two-dimensional picture of this part of the sky. Arbitrarily, we directed the beam southward by about 1° at three- or four-week intervals.

The records themselves showed the characteristic hump as the Crab Nebula passed through the pencil beam. This was followed by a smaller hump, lasting the same 15^{m}, attributed to IC443. At times the records exhibited a feature characteristic of interference, occurring some time later than the passage of the two known sources. This intermittent feature was curious, and I recall saying once that we would have to investigate the origin of that interference some day. We joked that it was probably due to the faulty ignition of some farm hand returning from a date.

We decided to present the material we had to the Princeton meetings of the A.A.S. in April 1955. Accordingly, Burke assembled all the records of the Taurus region for the first three months of 1955 in preparation for the reductions. He temporarily laid aside those with interference on them, and concentrated on the two-thirds remaining. Burke noticed a gentle rise and fall that was usually present some time after IC443 had crossed the meridian. To investigate this feature more fully, he examined the records containing interference, finding that the interference usually occurred at the time the rise-and-fall was supposed to be present. He was then startled to find that the interference always occurred at almost the same sidereal time. A strange rural romance this was turning out to be! As spring drew nearer, our swain was returning home earlier and earlier, each evening.

Since the source of the "interference" was clearly attached to the sky, we immediately went to an atlas to find anything that might be obvious. A peculiar galactic cluster and an interesting planetary nebula were candidates, but they were ruled out when we noticed that this strange source was not always at the same right ascension. It appeared to drift westward, slightly, over the three-month interval, so that in March the two interesting objects were not in the beam at the time of the recorded event.

The late Howard Tatel, a man of many parts, was present in the laboratory, working on some of his seismic records. He and Dr. Tuve were the principal investigators at D.T.M. of the distribution of hydrogen in the galaxy. At the suggestion of Dr. Richard Roberts of D.T.M., Tatel had looked at Jupiter a few nights before with the *H*-line equipment, and found nothing. Having this in mind, he somewhat facetiously suggested to Burke and me that our source might be Jupiter. We were amused at the preposterous nature of this remark, and for an argument against it I looked up Jupiter's position in the American Ephemeris and Nautical Almanac. I was surprised to find that Jupiter was just about in the right place, and so was Uranus. Here was something which needed clearing up. Unfortunately, we had no more time that afternoon to work on it, because we had to go out to the Mills Cross and work until evening. As twilight came and went, we were delighted by a fine, clear sky. Burke asked me what one exceptionally bright object was, almost on the meridian. We had a good laugh when I told him it was Jupiter.

The next morning, I plotted the right ascensions as a function of the date for the points of beginning and ending of each recorded event, and drew a smooth curve through the points locating each phenomenon. I then placed the right ascensions of the two interesting galactic objects on the plot, and followed this with the positions of Uranus throughout the observing interval. The objects of fixed right ascension were represented by horizontal straight lines, and Uranus exhibited the slow westward change due to its retrograde motion at the time. The galactic objects nearly fit within the region of the plot bounded by the two similar curves representing the limits of the recorded events, but these objects could not represent the change of right ascension with date. Uranus, while apparently within the beam early in January, did not drift westward nearly as rapidly as the events required. At this point in the growth of the diagram, I began to plot the right ascensions of Jupiter. As I plotted each point, Burke, who was watching over my left shoulder, would utter a gasp of amazement. Each point appeared right between the boundary lines representing the beginning and end of each event! The meaning was exquisitely clear: these events were recorded only when the planet Jupiter was in the confines of the narrow principal beam of the Mills Cross. Not only did this source have the same direction in space as Jupiter, but it also exhibited the same change of direction as Jupiter did during its retrograde loop of 1955. No other object could satisfy the data: the source of the intermittent radiation was definitely associated with Jupiter!

Such is the actual story of this very unexpected discovery. The events which followed are essentially anti-climatic, but it may prove amusing to recount one other personal part in the story of Radio Jupiter. After the announcement of the discovery was made at Princeton, the National Broadcasting Company requested that we make a tape recording of this noise which they could put on their first Monitor program. They supplied the recorder and we hooked it into the equipment. Only fifteen minutes each day were possible in which we could receive any radiation from Jupiter. On Easter Sunday, there was a fine event recorded on the paper tape, but the magnetic recorder was not operating until the next day. Each afternoon, I raced the twenty miles out to the field in order to be on hand when and if Jupiter should be active. Roughly three weeks later the next event occurred on a Friday afternoon. Until I played the tape for everyone at D.T.M. on Monday morning, I was the only one in the world who had heard Jupiter and who knew it.

Naturally, we wrote to our colleagues in other parts of the world. C. A. Shain, in Australia, immediately began observations which confirmed our identification, and he searched his old records for possible prediscovery observations. It turned out that he had actually received noise from Jupiter in 1950, but had attributed it to interference. Those prediscovery records have proved of great value as early-epoch data, and have been discussed in the literature.

Our identification of Jupiter as a radio source is not based directly on reasoning, but more on luck. (Professor Herbert Dingle once described this as the real scientific method, in a talk before the National Science Foundation.) We were led into it by the nature of our equipment: a very narrow pencil beam. Shain had a broad beam which was suited to his needs, but which enabled him to overlook the celestial source of "interference" appearing on his records. Another curious bit of chance shows up when we reviewed our arbitrary southward redirection of the pencil beam: we were inadvertently following Jupiter southward as well as if we had planned it! (Incidentally, we never did learn the cause of the rise and fall which started all this.)

A further favorable attribute of much of the radiation from Jupiter is its intensity. It can be very powerful, even more intense than Cassiopeia A, the strongest source in the sky at this frequency, around 20 Mc. Only the active sun is apparently stronger, at times. Thus, when Jupiter is acting well, it is not difficult to observe, as radio sources go. It is well, however, to recall that any radio source is very weak compared to the general amount of noise entering the antenna system, and even sometimes produced in the equipment itself. As a reminder to the prospective observer of extraterrestrial radio noise, I shall conclude by offering the following motto for radio astronomers (with apologies to Gertrude Stein): Signals in the grass, alas!

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RADIO FREQUENCY EMISSION FROM THE PLANET JUPITER

BY THOMAS D. CARR

Until 1955, the only source of observational information on the strange phenomena occurring in the atmosphere of Jupiter was the light from the tops of the Jovian clouds. However, the discovery by Burke and Franklin (1955) that Jupiter is sporadically emitting intense bursts of energy in the radio spectrum in the vicinity of 22 Mc provided a new means for gaining knowledge about the planet and its atmosphere. The cause of the radiation is not yet known; nevertheless, investigation of it by the several participating research groups has already yielded considerable information about the environment in which it originates.

Although the radio noise burst occurrences are unpredictable, statistical analysis of data recorded over a period of several months indicates an unmistakable correlation with the rotation of the planet. Immediately after learning of the discovery of Burke and Franklin, Shain (1956) in Australia re-examined a series of records he had made four years earlier at 18 Mc, and found on them many instances of Jupiter noise activity. These events had previously been mistaken for terrestrial interference. Shain demonstrated that there is a striking correlation of occurrence probability with the longitude of the central meridian of Jupiter's visible disc provided a rotational period is assumed which lies within about 30 seconds or so of that of System II ($9^h55^m40^s.6$). There was no correlation if the System I period ($9^h50^m30^s$) was assumed. His analysis showed that occurrences were largely limited to a band of central meridian longitudes less than 180° wide. This indicates, he pointed out, not only that the radio sources are concentrated within a certain area but also that the planet is surrounded by an ionosphere. Thus, escape is possible only for the cone of rays incident on the ionosphere at less than the critical angle.

The next logical step was to determine whether or not the principal noise source remains fixed at the same longitude from one year to the next. Unfortunately, terrestrial ionospheric effects have thus far limited reliable radio observations of Jupiter to the two or three months of the year during which meridian transit occurs between about 2 A.M. local time and sunrise. The rotational period established from the data obtained during a single apparition is usually relatively inaccurate. However, with data from three or more apparitions, one can determine with considerable accuracy whether or not the rotational period of the principal noise source was constant. Gallet (1957) of the National Bureau of Stand-