2.8 TIME VARIABILITY OF THE DISPERSION OF THE CRAB NEBULA PULSAR

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Abstract. The dispersion of the Crab nebula pulsar was measured as a function of time from 10 May 1969 to 24 July 1970. Transient events occurred in the middle of June each year which coincided with the occultation of the pulsar by the solar corona. In addition there were 2 or 3 distinct events which produced enhancements of several times 10^{16} electrons cm^{-2}; these were characterized by rise times of about 50 days and decay times several times longer. One event correlated with the fre-jump of the pulsar at the end of September 1969 and with the observation of optical activity in the quency nebula. A discussion is given of the interpretation of the variations in dispersion measure.

1. Experimental Results

The routine multi-frequency timing observations of the Crab Nebula pulsar which have been made at the Arecibo Observatory (Richards and Roberts, 1970) since May, 1969, have also been used to monitor the dispersion of the pulsar. Figure 1 is a plot of the dispersion as a function of time for the period between 10 May 1969 and 24 July 1970. The data are presented in terms of the dispersion constant in units of sec MHz^2 as it is this quantity which is most accessible experimentally. Conversion to dispersion measure in the more common units of e$^-$/cm^2 or e$^-$ pc/cm^3 involves both the use of physical constants whose values are imprecisely known and assumptions about the ionic constitution of the interstellar medium. In providing the auxilliary scale in Figure 1 we have used the conversion factor 7.43366×10^{14} e$^-$/cm^2/sec MHz^2 which assumes an interstellar medium of pure hydrogen and the physical constants in Allen (1964).

The most striking features in Figure 1 are the transient events occurring in the middle of June each year. These are the result of the occultation of the pulsar by the solar corona. The interpretation of these events, which is complicated by scattering from irregularities in the corona, has been considered elsewhere (Rankin, 1970; Counselman and Rankin, 1971) and will not be discussed here.

Apart from the coronal events, Figure 1 shows two or three distinct events which produce enhancements of several times 10^{16} e$^-$/cm^2. Each event is characterized by a rise time of the order of 50 days and a decay which is several times longer. The total dispersion increases with time. This might result from the summation of the separate

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events, or the events could be superposed on a quasi-linear increase resulting from some separate mechanism. These events are very much larger than the random errors which are indicated by the rms errors of the daily means shown in the figure. It should be noted, however, that the zero point of the dispersion scale may have a systematic error as large as ± 15 sec MHz^2 due to the failure to correctly separate the f^{-2} plasma group delay (plotted in Figure 1) from the f^{-4} delay associated with the interstellar multi-path broadening (Rankin *et al.*, 1970; Rankin and Roberts, 1970).

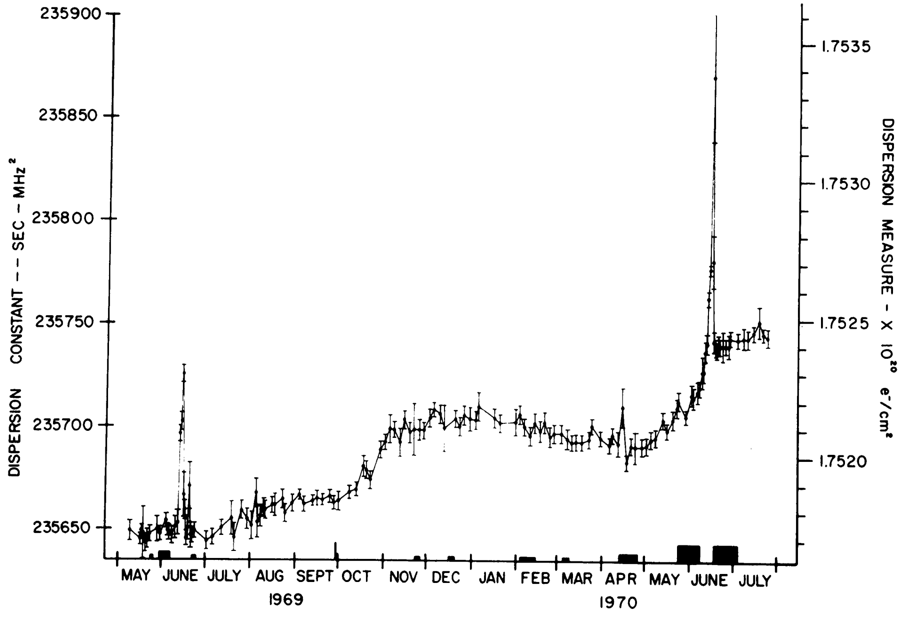

Fig. 1. Dispersion constant as a function of time for the period between May 10, 1969 and July 24, 1970. An auxiliary scale in dispersion measure is also provided (see text). The filled blocks along the abscissa denote times when the pulsar repetition frequency was irregular; the height and width of the blocks indicate the severity and duration of the irregularity, respectively.

The filled blocks along the abscissa of Figure 1 denote times when the pulsar repetition frequency was irregular (Richards and Roberts, 1970). The height and width of the blocks indicate the severity and duration of the irregularity, respectively. The frequency jump at the end of September 1969 is well correlated with the onset of one of the events in Figure 1, and Scargle and Harlan's (1970) observation of activity in the nebula following this frequency jump makes this coincidence even more tantalizing. However, the other main increase in Figure 1 does not appear to be associated with any definite frequency jump in the pulsar.

2. Discussion

If the underlying increase in Figure 1 is produced in some other way, then the events could be caused by clouds of ionization drifting across the line of sight. An interstellar cloud with a transverse velocity of 10 km/sec, a scale size of 0.5 AU, and a peak density of 4000 e^-/cm^3 could produce the central event in Figure 1. A more likely explanation is a cloud within the nebula with a velocity $\sim$500 km/sec, a scale size $\sim$25 AU and a central density of 75 e^-/cm^3.

If the dispersion changes are associated with irregularities in the rotation of the pulsar, one might suppose that additional ionization is ejected from the star or its magnetosphere, or that an ionizing disturbance travels outward from the pulsar ionizing previously neutral material in the nebula. Two difficulties arise with the simple ejection model. Firstly, the timing observations suggest a sudden occurrence at the neutron star occupying a day or two, whereas the dispersion change begins slowly and continues to increase for of the order of 50 days. Secondly, on the basis of simple models, the observed dispersion changes would require electron densities in the vicinity of the neutron star which are so great as to be opaque to 111 MHz radiation (the lowest frequency at which the present observations were made). Both of the difficulties could be circumvented if, for example, a cloud of ionized gas were ejected at the time of the frequency jump, but in such a way that it did not affect the measured dispersion until it was a considerable distance from the star, and then only slowly attained its maximum effect. Pacini (1970) has discussed a model of this type.

Both of these problems are also avoided if one invokes an expanding ionizing front. This would produce a slow increase in dispersion beginning near the time of the frequency jump and since the ionization is nowhere highly concentrated the problem of high densities would not occur. Scargle and Harlan's report (1970) of changes in the optical appearance of the nebula, which they attribute to a travelling disturbance, provides some support for this type of mechanism. However, the occurrence of repeated increases in dispersion before the previous increase has appreciably decayed presents a problem. This would seem to require either that each disturbance only partially ionizes the neutral material, or else that the successive events produce their ionization at increasingly greater distances from the star.

If extra ionized gas is produced, as in the last two models, it is necessary to consider the decay of this ionization. At the densities one is likely to encounter, it would seem that recombination is completely negligible. Spreading of the ionization in directions perpendicular to the line of sight is a much more likely cause of a decrease in the dispersion measure.

Finally, the nature of the dispersion events may be illuminated by a further experiment. The dispersion provides a measure of $\int N\,\mathrm{d}s$, while Faraday rotation measures $\int N\mathbf{B}\cdot\mathbf{ds}$, where $\mathbf{B}$ is the magnetic flux density along the path. The magnetic field in the Crab Nebula is very much stronger than that in the intervening interstellar medium, about 10^{-3} G as compared to about 10^{-6} G. Close to the neutron star the field will be even greater. If the dispersion increases are caused by electrons within the Crab Nebula they should be accompanied by measurable increases in the Faraday rotation. For a mean longitudinal field of 10^{-3} G, the total measured change in dispersion would cause a change of the rotation measure of 16 rad/m^2.

This report is a brief summary of a paper in preparation (Rankin and Roberts, 1970),

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Discussion

F. C. Michel: Is this the same data on which the limit: $n_e < 0.25/cm^3$ was deduced. If so, the *rise* in DM, which is not well understood, could mask any secular decrease due to nebular expansion.

J. Rankin: The earlier limit on electron density from secular changes in the dispersion measure was deduced by H. D. Craft, Jr., from other less accurate data. Since we now see that there are large unexplained phenomena in the time variation of the dispersion measure, it is apparent that no information can be deduced on the electron density in the Crab Nebula.

J. Kristian: Would you expect to see the geometrical dilution factor on the same scale as the data that you have shown?

J. Rankin: My recollection is that the rate of decrease of dispersion due to geometrical effects (i.e. expansion) is comparable to the linear rate of increase of dispersion measure that might be deduced from the data presented. Thus such an effect should easily be observable.