Search for an Effect of Mass on Frequency during a Close Approach of Pulsar CP 0950 to the Sun

Abstract. *Observations of the pulse arrival times from the pulsar CP 0950 were made during August when the line of sight to the pulsar approached within 5 degrees of the sun in order to test a suggested mass-on-frequency effect. The observations do not show evidence for the predicted effect.*

Two experiments which suggest that the presence of a mass affects the frequency of a periodic event have been described (*1*). In the first experiment the 1420-Mhz absorption line in Taurus A appeared to be red-shifted when the line of sight to Taurus A approached the sun. In the second experiment, the frequency of a portable cesium clock was compared with the frequency of a similar clock transmitting from Cape Fear, North Carolina. An apparent decrease of the frequency of the received signals as a function of the distance between the two clocks was found. A third experiment, in which the highly constant pulse period of the pulsar CP 0950 was used has just been performed in an effort to confirm the suggested effect. The line of sight to CP 0950 approached the sun during the first part of August, coming to within 5 degrees at closest approach on 20 August. If the tentative relation between mass and frequency as stated in reference (*1*) is correct, the pulse period of CP 0950 should increase, and the pulse arrival times should be progressively delayed from the arrival times predicted on the basis of a constant period as the line of sight nears the sun.

Observations were conducted from 2 through 26 August; the 150-foot (45-m) antenna at Naval Research Laboratory, Sugar Grove, West Virginia, was used. The system accepted linearly polarized radiation at 404.8 and 445.8 Mhz with a predetection bandpass of approximately 1.5 Mhz and a postdetection bandpass of 10 khz. Timing was derived from a cesium standard which was calibrated both before and after the experiment at the Naval Observatory with the Naval Observatory master clock. The data were recorded on magnetic tape and subsequently analyzed with a 100-channel signal analyzer (Princeton Applied Research Waveform Eductor). A typical measurement consisted of averaging a train of approximately 1400 pulses with a 400-μsec time resolution per channel. An average pulse profile was fitted by eye to each individual average to obtain the pulse arrival time. The ratio of the peak pulse amplitude to root-mean-square noise ranged from 20 to 100.

Direct instrumental timing errors are believed to result in pulse arrival timing errors of less than 100 μsec. For example, timing errors due to variations in the cesium standard over the duration of the experiment were less than 10 μsec. Timing errors due to changes in the weighted center frequency of the predetection bandpass along with interstellar dispersion of the radiation were found to be less than 20 μsec by measurements of the predetection bandpass before and after each observing period and by measurements of the dispersion between the two observing frequencies. Timing errors in recording, distortion during magnetic tape replay, in the delay line, and in synthesis of the pulsar repetition frequency are all believed to be less than 100 μsec. Dispersion in the solar corona is expected to result in pulse delays of less than 100 μsec at 404.8 Mhz (*2*); the dispersion at 445.8 Mhz is 18 percent less than at 404.8 Mhz. Although an excess delay of about 500 μsec during the close approach is not excluded by the observations, there is no indication that the dispersion in the solar corona is significantly different from that predicted.

A second source of additional time delay in the received pulses is predicted from general relativity (*2*); this effect has a form similar to the coronal dispersion and is also less than 100 μsec. Whereas both the coronal dispersion and general relativity effects predict an additional measured delay when the source is close to the sun, these effects disappear after the end of the close approach period. The mass on frequency effect, in contrast, predicts an additional measured delay that accumulates and remains after the close approach; in addition, it is two orders of magnitude larger than the dispersion and relativity effects. Instrumental noise, man-made interference, and possible slight changes in average pulse shape are believed to be the main source of the apparent root-

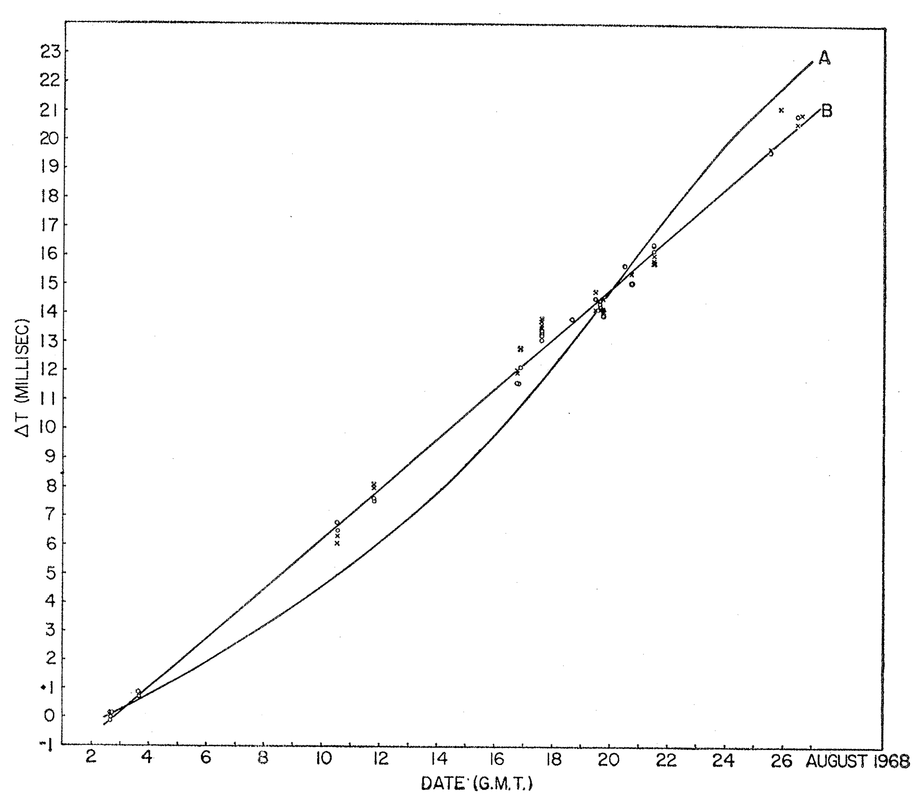

Fig. 1. Pulse arrival times from CP 0950; ΔT is the difference between the measured and predicted pulse arrival time based on a pulse period of 0.253 065 030 second U.T. The open circles are observations at 404.8 Mhz, and the crosses are measurements at 445.8 Mhz with an added delay of 13.2 msec to correct for interstellar dispersion. Curve A is the predicted differential arrival time, if one assumes the mass-on-frequency effect and a pulse period of 0.253 065 030 70 second U.T. Curve B is a least-squares straight line fit to the observations.

mean-square timing error of 400 μsec derived from the scatter of the data about curve B in Fig. 1.

The results of the observations are shown in Fig. 1, where the difference between the measured pulse arrival times and the predicted arrival times are plotted against the date of observation. The predicted arrival times are based on a pulse period of 0.253 065 030 second U.T. $\pm 1 \times 10^{-9}$ second U.T. (*3*), and all times are referred to the solar system barycenter (*4*). Corrections for the position of the observer included all rotational and orbital effects according to Newtonian physics; Jet Propulsion Laboratory ephemeris data DE–19 was used as a basic source. The open circles are observations at 404.8 Mhz, and the crosses are measurements at 445.8 Mhz with a delay of 13.2 msec added to correct for interstellar dispersion. The measured average delay between the two observing frequencies of 13.2 ± 0.2 msec is in agreement with that predicted from the measurements of other observers of 13.24 ± 0.18 msec (*5*). Curve A is the predicted differential arrival time based on a period of 0.253 065 030 70 second U.T. and on the mass-on-frequency effect suggested in (*1*) using a value for the constant K of 3×10^{-30} cm/g. Curve B is a least-squares straight line fit to the data. It is clear that the observations do not fit curve A and are not in accordance with the speculated relation between mass and frequency presented in reference (*1*). The present observations can only be reconciled with the experimental results of reference (*1*), if there is a fundamental difference between this experiment and the previous two experiments. In the Taurus A experiment, the shift of a spectral line was measured; in the cesium clock experiment, the accumulated phase difference of two monochromatic waves was measured; whereas in this experiment, the arrival time of a pulse envelope was measured. It is not clear whether these differences in experimental procedure involve any fundamental difference in the experiments.

In the absence of the mass-on-frequency effect, curve B can be interpreted as resulting from a slight error in the adopted pulsar period or, alternatively, in the adopted pulsar position (*6*). An error in the adopted pulsar period would generate a linear slope with time in the residual arrival time plot. An error in the adopted pulsar position would lead to a sinusoidal error with a period of 1 year in the time corrections used to refer the observations to the solar system barycenter; because of the limited observing period in this experiment it was not possible to distinguish this effect from that of a period error. On the assumption of no error in the position of the pulsar, curve B indicates a period for CP 0950 of 0.253 065 032 54 second U.T. The error based only on the internal consistency of the data is $\pm 3 \times 10^{-11}$ second. A new and more precise position for CP 0950 than the one adopted has just become available (*7*). If we use this position of $9^h50^m30.76^s \pm 0.15^s$ right ascension and $+8°09'48'' \pm 5''$ declination epoch 1950.0, the data is best fit by a period of 0.253 065 032 0 second U.T. $\pm 4 \times 10^{-10}$ second U.T., where the error is completely determined by the positional uncertainty. Observations over a period of 1 year will allow a distinction between the effects of a period error and a position error, enabling a determination of both quantities.

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References and Notes

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Earth's Bow Shock: Elapsed-Time Observations by Two Closely Spaced Satellites

Abstract. *Coordinated observations of the earth's bow shock were made as Vela 3A and Explorer 33 passed within 6 earth radii of each other. Elapsed time measurements of shock motion give directly determined velocities in the range 1 to 10 kilometers per second and establish the existence of two regions, one of large amplitude magnetic "shock" oscillations and another of smaller, sunward, upstream oscillations. Each region is as thick as 1 earth radius, or more.*

The collisionless plasma shock that forms sunward of the earth as the super-Alfvénic solar wind streams from the sun toward the obstacle presented by the geomagnetic field (*1*) varies in momentary location and appearance, as witnessed by numerous satellite measurements (*2–4*) and emphasized by multiple shock crossings during individual satellite passes (*3–5*). Some experimenters have succeeded in estimating parameters characterizing the shock, such as velocity, range of movement, and thickness, by applying models of periodic shock motion to sequences of multiple crossings seen by single satellites (*4–6*). An obvious refinement of this approach is to compare measurements by two or more satellites near the shock at the same time. One such comparison has been made in which shock velocity was measured by using concurrent observations on opposite sides of the earth by two satellites separated from each other by 26 earth radii (R_E) (*7*), but no information was obtained on local shock structure. The first opportunity to secure simultaneous dual satellite observations of shock at relatively close spacing came during the flights of Explorer 33 and Vela 3A.

On 12 to 13 July 1966, during the inbound portion of its first orbit, Explorer 33 passed close to Vela 3A near the earth's shock below the ecliptic, in the dawn-to-noon quadrisphere. The two satellites spent 6 hours within 6 R_E of each other, coming as close as 5.2 R_E in straight-line distance. Concurrent observations by magnetometers aboard the two vehicles occurred as Explorer 33, entering the transition region inbound, was encountering the shock, while Vela 3A, exiting the transition region outbound, was also encountering the shock. Both satellites passed through or into the shock and its upstream magnetic oscillations several times, allowing mutual observation of a variety of shock-related phenomena, including apparent shock motion between the spacecraft, from which shock velocity and dimension can