Reports

Photoelectric and Spectroscopic Observations Related to a Possible Optical Counterpart for Pulsar CP 1919+21

Abstract. *Spectroscopic observations of the two stars near the pulsar CP 1919+21 are not sufficiently conclusive to permit an identification of either object with the source of the radio pulses. However, our most extensive series of photometric observations of a region of sky near the radio source position, which region includes the brighter of the two stars, suggests an approximately sinusoidal variation. It is significant that the period of the variation is double the period of the radio pulsations.*

Two spectrograms have been obtained of the faint "red" star that falls near the radio position error rectangle for CP 1919+21 (*1*). The better of these spectrograms shows what are undoubtedly the H and K lines and the MgI b-band in absorption. The G band may also be present. At approximately 4590 Å there is what appears to be a broad emission feature. We have no special reason to doubt the reality of this feature except that we have little experience with the appearance of spectra of faint red stars at low dispersion. It seems most likely that the interpretation of the emission feature is mistaken and that the object is a normal late-type star.

We have obtained three spectrograms of the "blue" star that appears within the radio position error rectangle. The two best spectrograms clearly show the H and K lines in absorption and a relatively strong and broad absorption line at the position of Hβ. There is little or no evidence of the presence of other members of the Balmer series.

Photoelectric observations have been conducted on 13 nights since 5 April 1968 in an effort to detect the presence of an optical counterpart for CP 1919+21. The observations were made with a refrigerated 1P21 photomultiplier and the Kitt Peak 50-inch (1.27-m) automated telescope. The photometric equipment was operated in a pulse-counting mode, with the pulses being stored in a 400-channel multiscaler (Radiation Instrument Development Laboratory).

The channels of the scaler were sequentially addressed by a pulse source serving as a clock and providing 400 channel-advance pulses during a time interval exactly equal to the radio period or an integral multiple thereof. Thus it was possible to accumulate photometric data from many successive cycles of the radio variation. The primary timing source was a General Radio frequency synthesizer which proved to have a stability of 1 part in 10^7 at constant temperature. It was possible to make corrections to the period to allow for the earth's orbital and diurnal motions and to preserve phase over long periods of time, even from night to night.

The purpose of the photometric program was not only to search for variation in the two stars near the position of the radio source but also to possibly detect variation in any other objects that might occur within the radio position error rectangle. The early results of the program were generally discouraging. The only indication of a positive result came at a time when it had been established that any variation in either of the two stars could be no more than a few percent of their average brightness.

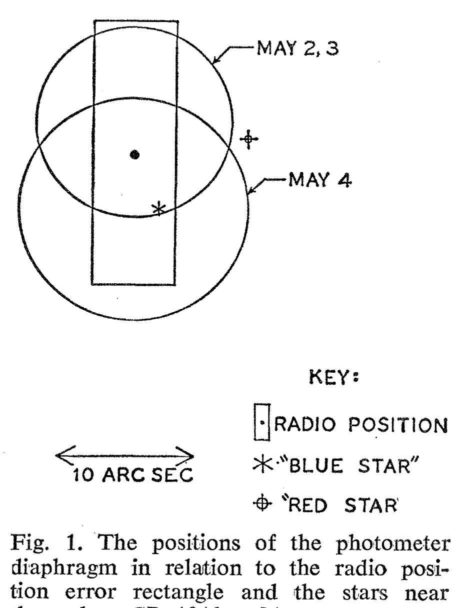

Fig. 1. The positions of the photometer diaphragm in relation to the radio position error rectangle and the stars near the pulsar CP 1919 + 21.

On three successive nights (2, 3, and 4 May) observations were made without a filter and with the photometer diaphragm positioned to investigate the region of the radio position without regard for the positions of the stars (Fig. 1). This was the first series of observations that used the radio source period as revised by Radhakrishnan, Komesaroff, and Cooke (*2*), and for which the phase of the addressing system was actually preserved for several days. It is the most extensive coherent series of observations that we have obtained thus far; the total observing time for the three nights was 8.7 hours.

The observations for each of the three nights are plotted in Fig. 2. Because there was no indication of any variation with a time scale of the order of the radio pulse width, the data have been plotted for 20-channel groups. The error bars shown refer to the expectation of the standard deviation; estimates of the standard deviation derived from the internal agreement within each group, and those derived from the square root of the total count, are in exact agreement. The phase given refers to the scan period for the multiscaler, which was exactly double the period of the radio pulses. The points plotted in the right-hand third of the diagram are the same as those in the left-hand third.

There was a tendency on all three nights for the observations near 300° phase to be slightly lower than those near 120° phase. The significance of the effect on any one night seems marginal at best, but the occurrence of the effect on all three nights is difficult to dismiss as statistical chance. The result of adding the observations from the three nights is shown in Fig. 3. The range of the apparent variation is about 2000 counts of approximately three times the standard deviation for each 20-channel data point. However, the variation is nearly seven times the standard deviation for the data in each block of 100 channels, which represents a more appropriate precision estimate for evaluating the statistical reliability of the apparent sine-wave variation.

Although the variation appears to have a high statistical probability of being real, the effect is sufficiently small so that the possibility of an instrumental cause will be difficult to rule out. Observations to confirm or deny the existence of the variation must be made, preferably with other equipment and larger telescopes. Previous attempts to detect the optical variation have been reported (*3*); however, these attempts have been unsuccessful, and the upper limits quoted have been greater than the variation indicated by our data.

If we assume that the variation is real, then what is varying? In Fig. 1 it is seen that the "blue" star is in the diaphragm. If we assume that this star is responsible for the variation and that its photographic magnitude is approximately 18.5, the range of variation is 0.04 magnitude. On the other hand, if the variation is due to an unknown star in the photometer diaphragm, the average apparent magnitude of such a star would be 22, if it is assumed that the star varies from 50 percent to 150 percent of its average brightness. The magnitudes quoted here are based on the assumption that the average sky brightness is magnitude 22 per square second of arc. Unfortunately, no standard-star observations were made without filters.

The data obtained on 2, 3, and 4 May can also be used to place upper limits on the strength of any optical pulses similar in width to the radio pulses (*4*). Adopting three times the standard deviation as the minimum detectable signal, we can say that the "blue" star does not show pulses as large as 0.05 magnitude or 0.1 percent of the total light emitted by the star. If the source is an unknown object in the field of the diaphragm, such an object will have a peak magnitude fainter than 22 or an integrated magnitude fainter than 26, if it is assumed that 100 percent of its radiation is emitted within the pulses.

If the result quoted here is verified, the most significant aspect from the standpoint of theoretical models is the fact that the period of the light variation is double the period of the radio pulsation. Future observations must attempt to determine the object responsible for the variation, the wavelength dependence of the variation, other Fourier components present in the variation, and the phase relationship between the optical and the radio phenomena.

Note added in proof: New spectrograms of higher quality leave no doubt that the Balmer series is present; the lines are strong and about 15 Å wide. The spectral type appears to be near F0 or A7.

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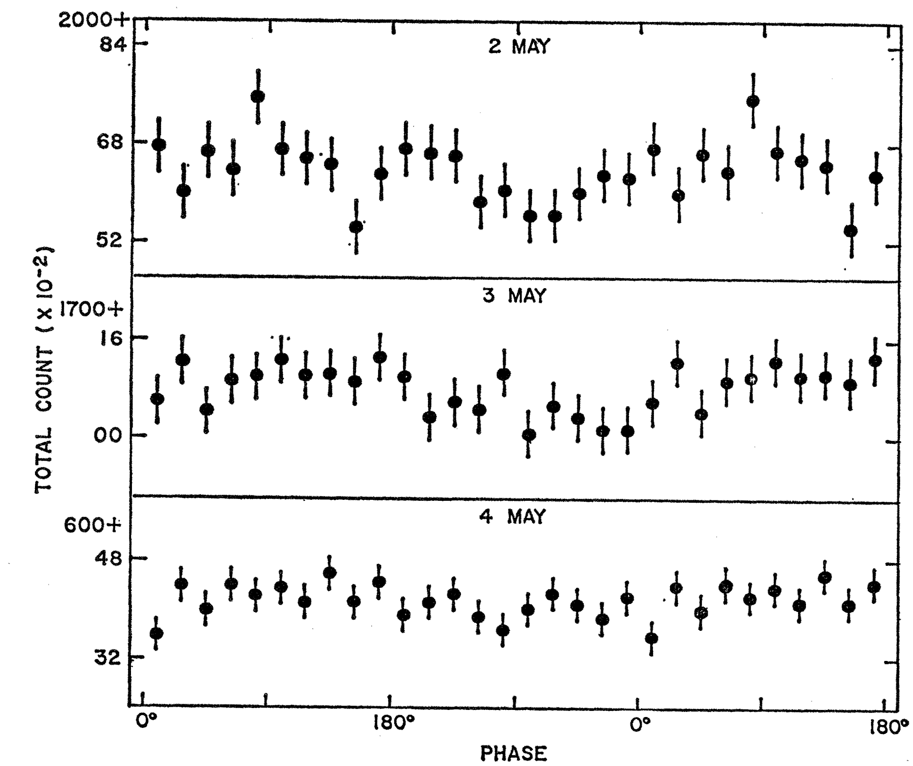

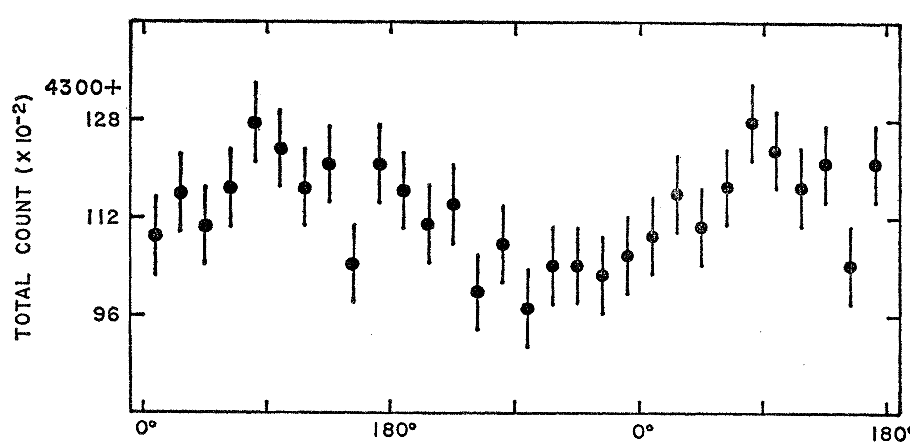

Fig. 2 (top). The photometric data on the CP 1919+21 region for three separate observations. The ordinate is the total photon event count in independent groups of 20 channels of the 400 channels of the scaler. The error bars are reliable estimates of the standard deviation. The phase refers to the period of addressing the 400 channels of the scaler, which is exactly double the interval between radio pulses. The data for the first 180° in phase are repeated on the right-hand side of the figure. Fig. 3 (bottom). The combined photometric data on the CP 1919+21 region for the three nights illustrated separately in Fig. 2. The presentation of the data is the same as in Fig. 2.

References and Notes

1. M. Ryle and J. A. Bailey, *Nature* **217**, 907 (1968).
2. V. Radhakrishnan, M. M. Komesaroff, D. J. Cooke, *ibid.* **218**, 229 (1968).
3. R. G. Bingham, *Int. Astronom. Union Circ. No. 2066* (1968); J. G. Duthrie, C. Sturch, E. M. Hafner, *Science* **160**, 415 (1968); C. Barbieri and G. Grueff, *Int. Astronom. Union Circ. No. 2070* (1968); C. Papaliolios, N. P. Carleton, P. Horowitz, W. Liller, *Science* **160**, 1104 (1968).
4. F. D. Drake, *Science* **160**, 416 (1968).

5. We thank Miss Katherine Moyd for computer programming used in the ephemeris calculations and data reduction. Contribution No. 326 from Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a NSF contract.

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