

The optical pulse profile of the Vela pulsar

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Summary. Optical observations of the Vela pulsar have resulted in an improved pulse profile. The results suggest that the two main pulse components are asymmetric and that there is significant pulsed emission at other phases of the profile.

Optical pulses from the Vela pulsar, PSR 0833–45, were first detected by Wallace *et al.* (1977) using a twin-photometer system on the Anglo-Australian telescope, near Coonabarabran, NSW. An improved pulse profile incorporating additional observations was given by Manchester *et al.* (1978). These observations were consistent with the optical pulses coming from ‘Star M’ (Lasker 1976); this association was confirmed in observations using the Image Photon Counting System (IPCS) in a two-dimensional mode (Peterson *et al.* 1978). The IPCS data showed that about half of the light from Star M was apparently unpulsed. This ‘unpulsed’ light may be a true steady background, either scattered pulsar light or light from another object, or it may be pulsed emission not recognized as such because of the relatively low signal-to-noise ratio. The observations reported here are an attempt to improve the signal-to-noise ratio of the optical profile and hence to differentiate between the different possible origins of the ‘unpulsed’ background.

The observations were made at the $f/15$ Cassegrain focus of the 3.9-m Anglo-Australian telescope on 1979 February 26–27 using the high-speed twin-photometer system with unfiltered S20 photomultipliers. Conditions were excellent for part of the session with seeing ≤ 1 arcsec; at other times seeing was 2–3 arcsec. An aperture diameter of 2.4 arcsec was used at times of good seeing and 3.5 arcsec at other times. The aperture was positioned using Star X as a reference and offsetting to Star M as described by Manchester *et al.* (1978). Uncertainty in the pointing was less than or about 0.5 arcsec, depending on the seeing. The total integration times obtained on the Vela pulsar was 6.71 hr.

Photon counts were recorded at 1 ms intervals on magnetic tape and were simultaneously integrated synchronously with the apparent pulsar period for on-line display. Off-line processing was the same as for previous observations (Manchester *et al.* 1978) with mean profiles representing an observation time of about 1 hr added with a weight proportional to

1P**

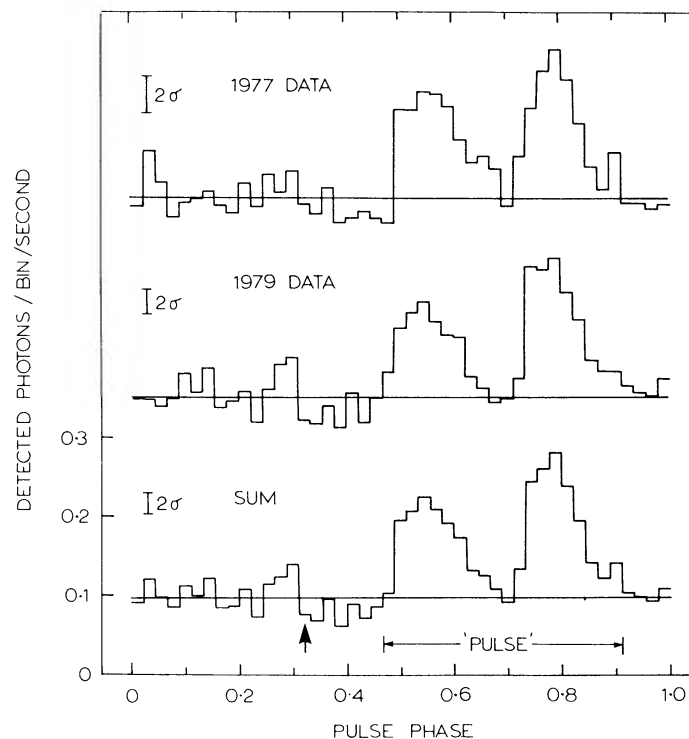


Figure 1. Optical pulse profiles for the Vela pulsar. The top profile is from Manchester *et al.* (1978), the middle one is from the present observations and the lower one is the sum, the two profiles being weighted to optimize the signal-to-noise ratio in the final profile. In each case the time resolution is 2 ms and 2σ error bars computed from photon statistics are shown. The arrow marks the phase of the radio pulse peak as emitted from the pulsar (Manchester *et al.* 1978). Zero phase is arbitrary.

the square of the signal-to-noise ratio. Pulsar period data required to phase the observations were obtained from radio observations at Tidbinbilla (*cf.* Manchester *et al.* 1976) which bracketed the optical observations.

The resultant pulse profile is shown in Fig. 1 together with the profile from the 1977 observations and the profile obtained by summing the 1977 and 1979 data. For the sum profile the ordinate is labelled with a true zero based on the *B* filter IPCS observations (Peterson *et al.* 1978). From an observation of 'Star K', which has a *B*-magnitude of 18.89 ± 0.03 (Manchester *et al.* 1978), a count rate of 0.1 detected photons/bin/second corresponds to a *B*-magnitude of 24.0 for an object with $B-V = 0.0$. The baselines as plotted were fitted to the profile excluding the region marked 'pulse'.

The results indicate that there is significant pulsed emission in the portion of the profile normally interpreted as baseline. The broad dip centred at phase 0.4 in Fig. 1 appears in both the 1977 and 1979 profiles and extends across several bins with a mean depth in each bin of about 2σ . Similarly, the peak near phase 0.3 in Fig. 1 appears in both the 1977 and 1979 profiles and has a mean amplitude of about 2σ in two or three bins. The χ^2 statistic for the 26 baseline bins is 47.7, which has a < 1 per cent probability of occurring by chance. We therefore conclude that there is significant modulation in the baseline as defined. There is also a suggestion in Fig. 1 that the two main pulse components are asymmetric in form with sharp leading edges and a more gradual decay on the trailing edge.

The presence of additional pulse components in the nominal baseline would be consistent with the model proposed by Manchester & Lyne (1977) in which the two main pulse components originate from a single magnetic pole on a neutron star. It is possible that a second double pulse originating from the other magnetic pole exists in the phase range

0.0–0.3 of Fig. 1. On the other hand, the asymmetry of the two main components perhaps lends support to a model in which these components originate in opposite poles. The asymmetric shapes are reminiscent of scattered profiles seen at radio frequencies. Electron densities sufficiently large to produce such scattering would preclude the transmission of radio pulses; this would not be a problem if the radio pulses originated outside the scattering region. Alternatively the scattering could be due to dust. The observed short characteristic delay (≤ 10 ms) implies that any scattering medium is either strongly forward scattering or very close to the pulse emission region.

More definite conclusions on these points requires a considerable improvement in signal-to-noise ratio of the optical profile. Polarization data would also be of great interest. Unfortunately the extremely low intensity of the pulsar light effectively precludes obtaining these data from ground-based observatories. The required improvement could be obtained by use of the proposed high-speed photometry system on the space telescope with a very small effective aperture.

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