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LETTER

*Letter to the Editor*

# A follow-up optical investigation of the binary pulsar PSR J1811−1736

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**Abstract.** PSR J1811−1736 ($P$ = 104 ms) is a binary pulsar in a highly eccentric orbit ($P_{\rm orb}$= 18.8 d) around an unidentified companion. Here, an optical follow-up investigation of the pulsar field, performed using photographic plates from the UK-SERC Equatorial red survey, is reported. No object is detected at the pulsar position down to $R \sim 22$. At the pulsar distance of 6 kpc, this implies, for a likely value of $A_R$ ($\approx 5$), an absolute magnitude $M_R \geq 3$ for the companion star. Although the present upper limit is deep enough to rule out a red giant, it still leaves open the possibility of a main sequence star or a red dwarf companion. Deeper optical observations are thus required to investigate the presence of white dwarf or a neutron star.

**Key words:** stars: pulsars: individual: PSR J1811−1736 – stars: binaries: general

## 1. Introduction

The pulsar PSR J1811−1736 has been detected @ 1374 MHz (Lyne et al. 2000) during an observation of the galactic plane carried on as part of the Parkes Multibeam pulsar radio survey (see Lyne et al. 2000 for a description of the project). The pulsar has a period P=104 milliseconds and is characterized by an asymmetric pulse profile with a sharp rise to the maximum followed by a quasi-exponential decay. The timing parameters of the pulsar give a spin-down age of $\sim 9 \times 10^8$ years and a magnetic field of $1.4 \times 10^{10}$ G i.e. PSR J1811−1736 lies below the spin-up line in the $B - P$ diagram and thus it probably underwent an accretion phase in the past. A periodic modulation of the pulse is observed, consistent with an highly eccentric ($e \approx 0.8$) orbital motion of the pulsar with a period of 18.8 days. The complete timing solution of the pulsar, also accounting for general relativistic effects on the advance rate of the periastron $\dot{\omega}$, allowed to constrain the total mass of the system to $\approx 2.6 \pm 0.9 M_{\odot}$. In particular, as suggested by Lyne et al., the small value of $\dot{\omega}$ would imply that the pulsar companion be a second neutron star rather than a giant or a main sequence star. Of course, no definitive conclusion on the nature of the companion star can be drawn without optical observations. Indeed, in their paper Lyne et al. report the result of a preliminary optical investigation, quoting an upper limit of $V = 16$ on the flux of the unseen companion. However, in their analysis they did not take in consideration the large interstellar extinction towards the pulsar, which inevitably affected their conclusions on the nature of the companion star.

Here, a report is given of a quick follow-up optical investigation of the pulsar field using deeper data obtained from an R-band digitized photographic plate survey.

## 2. Optical observations

The optical investigation of the binary pulsar PSR J1811−1736 was performed using as a reference a IIIaF photographic plate ($\lambda = 6500$ Å, $\Delta\lambda \approx 1200$ Å) of the region obtained with the UK Schmidt Telescope during the SERC-Equatorial Red Survey. This survey has been used as one of the inputs for the generation of the *Guide Star Catalog II* (see McLean et al. 1997 for a description of the project). The plate (#ER611) was scanned at the Space Telescope Science Institute through a microdensitometer Gamma machine at $15\,\mu$ resolution, which corresponds to a pixel size of 1 arcsec. A dedicated pipeline was run on the digitized scan as part of the routine GSC-II plate processing program, resulting in object detection and morphological classification. The astrometric calibration of the extracted objects has been automatically performed using a set of Tycho/Hipparcos reference stars matched in the plate and is accurate to $\approx 0\farcs6$ r.m.s. both in right ascension and declination. The conversion from photographic densities to R-band magnitudes has been obtained using reference stars extracted from the *Guide Star Photometric Catalogue 2* (Postman et al. 1997), yielding a final photometric accuracy of 0.1 magnitudes.

The pulsar position of Lyne et al., $\alpha_{2000}$=18$^h$11$^m$55$\fs$01(1) and $\delta_{2000}$= -17°36′36$\farcs$9(13), was thus superimposed on the plate according to the computed astrometry of the plate. A $3\farcm3 \times 3\farcm3$ section of the plate is shown in Fig. 1, with the pulsar position marked by a cross. As it is seen, no object is detected within a 15″radius from the pulsar position. This is well above the uncertainties of the present astrometry, conservatively estimated to be $1\farcs5$ in both coordinates, after adding in quadrature

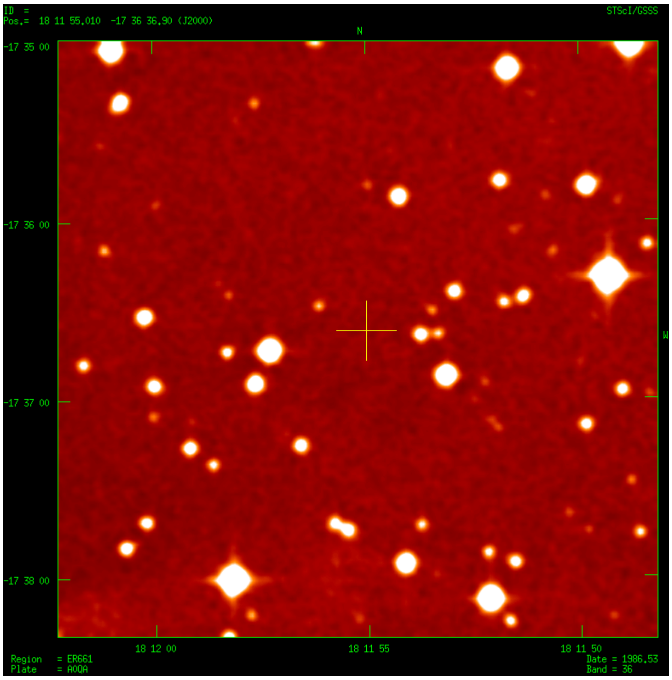


**Fig. 1.** $3\overset{\prime}{.}3 \times 3\overset{\prime}{.}3$ R-band image centered on the position of the binary pulsar PSR J1811−1736. North to the top, East to the left. The image has been obtained from the digitization of a IIIaF photographic plate from the UK SERC-Equatorial Red Survey. The computed pulsar position is marked by the cross (the length of each arm is 10 arcsec). The overall error of the astrometry, resulting from the combination of both the r.m.s. of the plate astrometric solution ($\approx 0\overset{\prime\prime}{.}6$) and the uncertainty on the pulsar radio coordinates, is $\approx 1\overset{\prime\prime}{.}5$ in each coordinate, i.e., smaller than two image pixels. No object is detected down to the plate limit of $R \approx 22$.

both the error on the pulsar coordinates and the accuracy of the plate astrometric solution ($\approx 0\overset{\prime\prime}{.}6$). The companion star must thus be fainter than the plate limit i.e. $R \approx 22$.

For the pulsar distance of $\sim 6$ kpc, computed from the Taylor and Cordes model (Taylor and Cordes 1993) for the measured DM (Lyne et al. 2000), the absolute magnitude of the companion star turns out to be $M_R \geq 8$, with an unknown amount of interstellar exctinction to be accounted for. Using e.g. the code of Hakkila et al. (1997), the average interstellar extinction toward the pulsar has been estimated to be $A_V \approx 6$. After correcting for the differential extinction factor between the $V$ and $R$ bands (e.g. Rieke & Lebofsky 1985), the value of $A_R$ finally turned out to be $\approx 5$. This implies an absolute magnitude $M_R \geq 3$ for the companion star.

If this were a star evolved from the main sequence, the present limit would allow us to exclude a red giant. On the other hand, for the allowed range of masses ($\sim 0.7M_{\odot} \leq m \leq \sim 2M_{\odot}$ for a minimum neutron star mass of $1.4M_{\odot}$), the companion could be either a very late F-type main sequence or a G or early K dwarfs (Allen 1973; Johnson 1966). Of course, the possibility that it is a white dwarf or a neutron star can not be discarded on the basis of the present data.

## 3. Conclusions

An optical follow-up investigation of the binary pulsar PSR J1811−1736 has been performed using a deep photographic plate. The companion star turns out to be undetected down to $R \sim 22$. At the pulsar distance of 6 kpc and for a reasonable value of the interstellar absorption ($A_R \approx 5$), the present upper limit implies an absolute magnitude $M_R \geq 3$ for the companion star. This means it could be a low-mass main sequence star, a white dwarf or a neutron star. Although these conclusions are basically the ones obtained by Lyne et al. (2000) based both on the estimated size of the orbit and on the small value of $\dot{\omega}$, they have now been circumstanciated by the results of significantly deep optical observations. Certainly, much deeper optical observation, possibly to be performed with either the HST or the VLT, are required to finally asses the nature of the companion. Were it finally identified to be a neutron star, PSR J1811−1736 would be one of the very few cases of a double neutron star system.

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