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Letter to the Editor

Optical observations of PSR1706−44 with the test camera of the VLT-UT1*

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Abstract. We report on the optical observations of the γ-ray pulsar PSR1706−44 performed with the Test Camera of the VLT-UT1 during the telescope Science Verification programme. With a limiting magnitude of $V \sim 27.5$, these are the deepest optical observations ever performed for this pulsar, for which, however, no likely counterpart has been detected. The non-detection of PSR1706−44 sets an upper limit on its optical luminosity varying from $\simeq 2 \times 10^{28}$ to $\simeq 5 \times 10^{29}$ erg s^{-1}, depending on the exact amount of interstellar absorption.

Key words: stars: pulsars: individual: PSR1706-4 – instrumentation: detectors – telescopes

1. Introduction

PSR1706−44 is a young ($\simeq$ 17 000 yrs) pulsar (P=102 ms), discovered during a 20cm radio survey of the southern hemisphere (Johnston et al. 1992). The pulsar was originally associated with the supernova remnant G343.1−2.3 (McAdam, Osborne and Parkinson 1993) but pulsar scintillation measurements (Nicastro, Johnston and Koribalski 1996) indicate a transverse velocity at least 20 times smaller than required ($\geq$ 1 000 km s^{-1}). PSR1706−44 has been also detected as a γ-ray pulsar by the EGRET instrument aboard the Compton GRO (Thompson et al. 1992) and identified with a the COS-B source 2CG342−02 (Swanenburg et al. 1981). While the other bright EGRET pulsars are double-peaked (see e.g. Thompson 1998),the γ-ray light curve of PSR1706−44 is characterized by a single broad peak, offset in phase relative to the radio one. PSR1706−44 has been also detected in soft X-rays by the ROSAT/PSPC (Becker, Brazier and Trümper 1995), as a weak non-pulsating source with a 18% upper limit on the pulsed fraction. Pulsations were neither found in more recent ASCA, HRI (Finley et al. 1998) nor RXTE (Ray, Harding and Strickman 1998) data. From a general point of view, it is interesting to note that PSR1706−44 has many characteristics in common with the Vela Pulsar. Their spin periods ($P \simeq 100$ ms) as well as the age ($\tau \sim 10^4$ yrs) and the rotational energy loss ($\dot{E} \sim 10^{36}$ erg s^{-1}) are similar. Furthermore, their multiwavelength behaviour is comparable, with a similar spin-down power conversion efficiency both in soft X-rays and high-energy ($\geq$ 100 MeV) γ-rays. Assuming that these similarities hold also in the optical domain and scaling the magnitude of Vela ($V = 23.6$, d =500 pc) for the distance of PSR1706−44 (1.8 kpc, see Taylor & Cordes 1993), we get a rough magnitude of $V \sim 26$, to which a correction of at least one magnitude must be added to account for the higher interstellar absorption (Finley et al. 1998). However, we note that this estimate is very tentative since the Vela pulsar is still the only case of a $\sim 10^4$ yrs neutron star detected in the optical and we can not exclude *a priori* that PSR1706−44 be brighter.

In the optical, the field of PSR1706−44 has been observed by our group both in 1993 and 1995 with the ESO/NTT but no source was observed at the radio position (Johnston et al. 1995) down to a limiting magnitudes of $V \sim 24$ (Mignani 1998) and $R \sim 24.5$ (unpublished). The pulsar field was observed again by Chakrabarty & Kaspi (1998) who also performed the first optical timing experiment but no pulsation was detected resulting in an upper limit of $R \geq 18$.

New observations of PSR1706−44 have been performed last August as a test case for the Science Verification (SV) phase of the First Unit (UT1) of the ESO Very Large Telescope (Leibundgut, De Marchi and Renzini 1998), aimed to assess the scientific potentialities of the telescope.

The results of these observations are reported in Sect. 2 and the results briefly discussed in Sect. 3.

2. Observations

The field of PSR1706−44 has been observed on the night of Aug 17th, 1998 with the VLT-UT1 at the ESO observatory in Paranal.

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* Based on observations collected at the European Southern Observatory, Paranal, Chile (VLT-UT1 Science Verification Program)

Observation were performed in visitor mode by R. Gilmozzi and B. Leibungut of the SV team. The UT1 was equipped with a Test Camera, commissioned for the SV program, mounting a Tektronix 2048^2 CCD with a measured conversion factor of 2.5 e^-/ADU and a readout noise of 7.9 e^- r.m.s. The CCD pixel size is 27 μ which translates to 0.0455 arcsec at the telescope plate scale, corresponding to a nominal field of view of 93 $\times$ 93 arcsec (see http://www.eso.org/paranal/sv/ for further details). However, during the science verification all observations were taken with a 2×2 binning of the CCD, leading to an actual pixel size of 0.09 arcsec. A total of 6 exposures of 600 sec each has been obtained in a Johnson V filter. Seeing conditions varied from 0.5 to 0.6 arcsec between single exposures, with an average airmass of 1.06.

2.1. Data reduction

Data reduction has been performed in Garching by members of the ESO SV team. Particular care was used for the basic reduction steps since the CCD suffered for color dependent blemishes, with the largest one located practically at the center. Variations in the CCD sensitivity caused by dust grains were also noted by comparing flat field images taken in different nights. All these problems made flatfielding very tricky and requested a non-standard procedure. Data were thus flatfielded using flats obtained directly from the sky by median-combining several science exposures taken in different nights. The use of these *superflats* lead finally to a flatfielding accuracy for wide-band filters down to 1%, much higher than achievable either with dome or twilight flats. Bias frames were obtained nearly every day and show no noticeable structure or changes with time. Bias subtraction and flatfielding were performed using the IRAF *ccdred* package. Images were then corrected for the CCD dithering and combined using the IRAF tasks *imalign* and *imcombine*. Photometric calibrations have been performed by imaging the standard star PG1633+099 from a Landolt field. The zero-point was computed applying the IRAF photometry package *digiphot*, with a final accuracy of 0.03 magnitudes.

Astrometry on the image has been performed using as a reference the coordinates of a few field stars extracted from the USNO catalogue using the ESO Skycat tool. The pixel-to-sky coordinates transformation has been thus computed using the UK STARLINK software ASTROM (Wallace, 1990), leading to a final accuracy of $\simeq 0.5$ arcsec on our absolute astrometry after taking into consideration both the r.m.s. of the astrometric fit ($\simeq 0.3$ arcsec) and the average uncertainty on the USNO coordinates ($\simeq 0.25$ arcsec).

2.2. Results

The most recent radio position of PSR1706−44, also reported in Table 2 of the paper of Chakrabarty & Kaspi (1998), has been obtained by radio interferometry measurements and independently confirmed by pulsar radio timing. The revised pulsar radio position has thus been superimposed on the combined, one hour, V-band image of the field (Fig. 1). The star $(V = 17.4)$ close to the radio position is star 1 of Chakrabarty & Kaspi (1998).

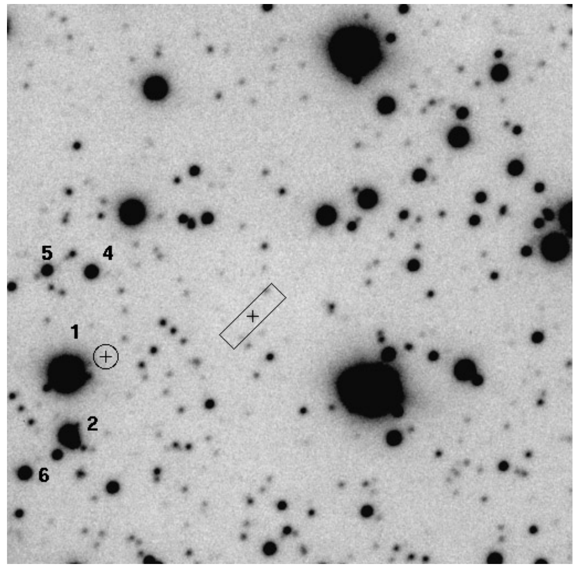

Fig. 1. V-band image of the field of PSR1706−44 taken with the Test Camera of the VLT-UT1 for a total exposure time of one hour. The frame is tilted of $\simeq 45^\circ$ clockwise wrt the North. The image size is 46×46 arcsec. The two crosses mark, from right to left, the pulsar radio position according to Johnston et al. (1995) – position #1 – and the one quothed by Chakrabarty & Kaspi (1998) – position #2. The overall uncertainty of our astrometry, resulting both from the errors on the absolute coordinates of our reference stars and on the r.m.s. of the astrometric fit is $\simeq$ 0.5 arcsec. The rectangle (1.6 $\times$ 6 arcsec in size) corresponds to the error region associated to position #1 while the size of the error circle around position #2 ($r \simeq 1.0$ arcsec) has been confidently exaggerated.

We note that the new radio coordinates of PSR1706−44 are markedly different ($\simeq 6$ and $\simeq 11$ arcsec in RA and Dec, respectively) from the old ones of Johnston et al. (1995), also superimposed in Fig. 1 for completeness. A blow-up of the two radio error boxes is shown in Fig. 2a and b. However, due to their much smaller error (~ 0.6 arcsec) and to the higher confidence on the new measure, we adopt the coordinates reported in the paper of Chakrabarty & Kaspi (1998) – hereafter referred as #2 – i.e. α_{2000}=17^{h}09^{m}42$^s\!\!.$73 and δ_{2000}= -44°29′07″.70. Star F ($m_V = 25.9$), visible at about two arcsec from the expected pulsar position (Fig. 2b), is probably too far to claim a convincing association. No other object is visible close to position #2 down to a limiting magnitude of $V \sim 27.5$.

3. Conclusions

We have presented the first deep search for a pulsar optical counterpart performed with a 8 metre class telescope. Although these observations with the UT1 of the VLT improve by more than two magnitudes our previous imaging with the NTT, no optical counterpart to PSR1706−44 has been detected down to a limit of $V \sim 27.5$. Only new observations with the VLT-UT1,

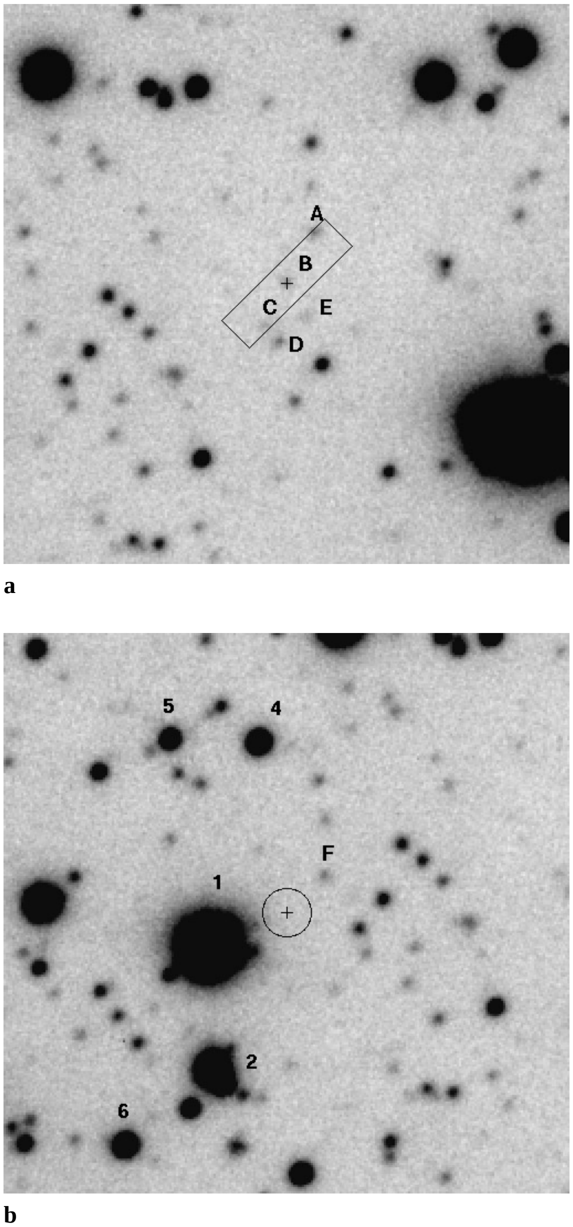

Fig. 2a and b. Enlargement of Fig. 1 around position #1 **a** and position #2 **b**. Five objects with magnitudes between 25.7 and 26.8 are seen close or inside the superseeded radio error box. No object is observed at position #2 except for a ~ 25.9 mag object (star F) located about 2 arcsec away.

equipped with FORS1 could give higher chances for an optical detection of the pulsar.

However, useful information can be obtained also using the present results. According to the Pacini law (Pacini, 1971), the optical emission of young pulsars is expected to be purely magnetospheric and to decay on a timescale of few thousands years at a rate uniquely determined by the neutron star spin parameters and magnetic field. Although the reality of this, so called, secular decrease has never been convincingly proven (Nasuti et al. 1996) it always seemed circumstanciated by the case of the

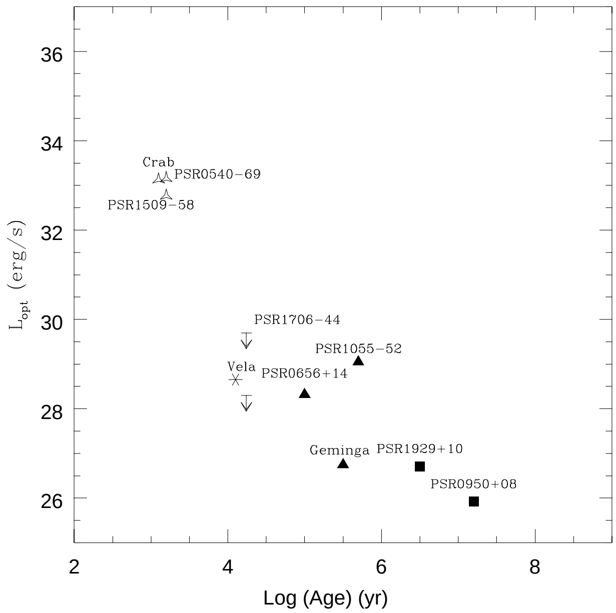

Fig. 3. The upper limit range for the optical luminosity of PSR1706−44 is plotted as a function of the spin-down age together with the actual values for the pulsars with an associated (proposed) optical counterpart (see Mignani 1998 and references therein). Young ($\sim 10^3$ yrs), middle-aged ($\sim 10^5$ yrs) and old ($\geq 10^6$ yrs) objects are indicated by open triangles,full triangles, and filled squares, respectively. Vela is marked by an asterisk.

Vela Pulsar, which, being only a factor 5 older than the Crab, is nearly 5 orders of magnitude weaker. However, the lack of observational data for other, similar, 10^4 yrs old neutron stars left the evolution of the optical luminosity of young pulsars an open point for a long time, especially in view of the markedly different behaviour of middle-aged objects such as PSR0656+14, Geminga and PSR1055−52 (Pavlov et al. 1997; Mignani et al. 1998; 1997). Our deep optical observations of PSR1706−44, comparable to the Vela pulsar in many respects (age, timing, high-energy emission), provide now a new piece of evidence to address this issue.

In fact, in spite of the null result of these observations, the magnitude upper limit, by far the lowest obtained so far from the ground for an isolated neutron star, can be used to put contraints on the optical luminosity of PSR1706−44 and thus to assess how this object fits into the panorama of the optically emitting neutron stars. Since the interstellar extinction expected from an hydrogen column density 10^{21} cm^{-2} $\leq N_H \leq 5 \times 10^{21}$ cm^{-2} (Finley et al. 1998) spans in the interval 0.6–3 magnitudes, the corresponding upper limit on the optical luminosity of PSR1706−44 can vary between $\simeq 2 \times 10^{28}$ and $\simeq 5 \times 10^{29}$ erg s^{-1}. These values, although just upper limits, compare favourably with the the general trend recognizable in Fig. 3, where we have plotted the optical luminosity of the nine pulsars known to have an optical counterpart (see e.g. Mignani 1998) as a function of their characteristic age. In particular, a turnover in the optical luminosity seems to occur for pulsars aging around 10^4 yrs. For older objects, the scenario appears more complicated by the onset of thermal emission from the neutron star surface which, as in the case of the middle-aged PSR0656+14 (Pavlov et al. 1997) and Geminga (Mignani et al. 1998), can significantly, if not completely, account for the overall optical luminosity.

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