HST proper motion confirms the optical detection of PSR B1929+10

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Abstract. We have measured the proper motion of the candidate optical counterpart of the old, nearby pulsar PSR B1929+10, using a set of HST/STIS images collected in 2001, 7.2 years after the epoch of the original FOC detection (Pavlov et al. 1996). The yearly displacement, \( \mu = 107.3 \pm 1 \ \text{mas yr}^{-1} \) along a position angle of \( 64.6^\circ \pm 0.6^\circ \), is fully consistent with the most recent VLBA radio measurement. This result provides a robust confirmation of the identification of PSR B1929+10 in the optical band.

1. Introduction

PSR B1929+10 is an old (\( \tau \sim 3 \times 10^6 \) y) radio pulsar (P=227 ms), one of the closest (330 pc) to the solar system, as recently assessed by Brisken et al.(2002) on the basis of VLBA radio parallax measurements. It has been observed also as an X-ray pulsar with ROSAT (Yancopoulos et al. 1994) and later with ASCA (Wang & Halpern, 1997). However, the actual nature of the X-ray emission (either thermal or magnetospheric, or a mixture of the two) has remained elusive as a consequence of the poor statistics in the data. The ROSAT/PSPC image showed also the presence of a diffuse nebula, elongated in the direction opposite to the pulsar’s proper motion (Wang et al. 1993).

A candidate optical counterpart for PSR B1929+10 was proposed by Pavlov et al.(1996), who detected with the HST/FOC a faint source (U\( \sim \)25.7) very close (0.4) to the radio position. At variance with middle-aged (\( \tau \sim \) a few \( 10^5 \) y) pulsars such as PSR B0656+14, PSR B1055-52 and Geminga, characterized by optical fluxes somewhat compatible with the extrapolations of their X-ray
spectra, the flux of the PSR 1929+10 candidate counterpart deviates by about 3 orders of magnitude from the expected values. Indeed, the general picture of the pulsars’ optical emission is far from clear. The data available for young \( (\tau \sim 10^3 \, \text{yr}) \) to middle-aged pulsars suggest, as a general trend, a decreasing importance of non-thermal processes as a function of the characteristic age. Very little is known about old pulsars. A firm identification of the optical counterpart of PSR B1929+10 could thus provide new, important clues to understand the long-term evolution of the optical emission from pulsars.

To secure the identification of PSR B1929+10 optical counterpart we have chosen the same strategy successfully used by Mignani et al. (2000) in the case of PSR B0656+14: the study of the candidate counterpart proper motion. The detection of an yearly displacement in agreement with the radio one, recently reassessed with high accuracy by Brisken et al. (2002) with VLBA \( (\mu = 104.1 \, \text{mas} \, \text{yr}^{-1} \) along a position angle of 65.6° \) would be a robust proof of the optical identification of the pulsar.

Here we report on our successful proper motion determination: using a set of HST/STIS images collected in 2001, we have measured the angular displacement of the candidate counterpart since the epoch (1994) of the original HST/FOC detection.

2. HST observations

The field of PSR B1929+10 was imaged with the STIS instrument onboard HST during five different visits on August 28th 2001, September 11th, 15th, 21st 2001, October 20th 2001. For each visit the integration time was 2400 s, split in two exposures of 1200 s each. The exposures were performed through the F25QTZ filter \( (\lambda = 2364 \, \text{Å}, \Delta \lambda \sim 842 \, \text{FWHM}) \) to extend the multicolor information offered by the FOC data of Pavlov et al. (1996), taken at at \( \sim 3400 \, \text{Å} \). The NUV-MAMA detector \( (24''7 \times 24''7 \, \text{field of view}, 0''024 \, \text{pixel size}) \) was used in TIME-TAG mode to obtain time-resolved images with a resolution of 125 \( \mu \text{s} \) and to search for pulsations at the radio period. The timing results will be presented elsewhere (Mignani et al., in preparation).

As a first step, the STIS time-integrated images were calibrated using the standard pipeline and corrected for the CCD geometric distortion. The two exposures taken during each of the five visits were then coadded accounting for the telescope jitter. The pulsar optical counterpart was clearly detected in all of the five images at the expected flux level. The original FOC images were retrieved from the STScI archive and recalibrated on-the-fly using the best reference files. The observations were performed using two different focal lengths configurations and through three different filters; the pulsar optical counterpart was detected only through the F130LP and F342W filters (Pavlov et al. 1996).

To measure the candidate counterpart proper motion we followed the relative astrometry approach applied in several previous works (see e.g. De Luca et al. 2000; Mignani et al. 2000). The strategy relies on an accurate superposition of the images taken at different epochs. The registration of the frames is performed by computing a general coordinate transformation using as reference a grid of coordinates of common sources identified in the two images. Once
the images have been aligned in a common reference frame, the epoch-to-epoch
displacement of the target can be measured by computing the difference in its
relative coordinates.

The FOC F130LP image, where the candidate counterpart was detected
with the highest S/N, was chosen as the reference for the superposition. We
decided to separately align each of the five STIS images on the reference one
to obtain five totally independent proper motion measurements. A complete
description of the image alignment procedure with a detailed discussion of the
error budget is reported in Mignani et al. (2002).

![Figure 1](image.png)

Figure 1. (left) Inner part of the STIS/NUV-MAMA field of view,
centered around the pulsar position. The five images have been stacked
to enhance the S/N. The pulsar optical counterpart is marked with two
ticks. As a reference, we have labelled star 1 from figure 2c of Pavlov
et al. (1996). The cross shows the relative coordinates of the pulsar
at the epoch of the FOC observations. The pulsar displacement over
the 7.2 years is evident. (right) X-ray map of the pulsar field from the
ROSAT/PSPC observation. The trail of diffuse emission extending
∼10 arcmin on the SW of the pulsar position is well aligned with the
revised optical/radio proper motion vector, marked by the arrow.

3. Results

After the registration of the different epoch images in a unique reference frame,
we could easily measure the candidate optical counterpart displacement over the
7.2 years. The five independent measurements yielded results fully consistent
within the errors. Using a simple \( \chi^2 \) fit we obtained the best proper motion
values: \( \mu_\alpha \cos(\delta) = +97 \pm 1 \text{ mas yr}^{-1} \) \( \mu_\delta = +46 \pm 1 \text{ mas yr}^{-1} \) corresponding
to a yearly displacement \( \mu = 107.35 \pm 1 \text{ mas yr}^{-1} \) along a position angle of
64.63° ± 0.55°. Within the errors, these results are fully compatible in both
magnitude and direction with the radio ones (Brisken et al. 2002): $\mu_\alpha \cos(\delta) = +94.82 \pm 0.26$ mas yr$^{-1}$ $\mu_\delta = +43.04 \pm 0.15$ mas yr$^{-1}$ at a position angle of 65.58° $\pm$ 0.09°. Our proper motion measurement thus provide a robust proof that the candidate proposed by Pavlov et al.(1996) is indeed the optical counterpart of PSR B1929+10.

4. Conclusions

We have studied the displacement of the candidate optical counterpart of PSR B1929+10 using a set of HST/STIS and FOC images collected 7.2 years apart. We have obtained a proper motion of $\mu_\alpha \cos(\delta) = +97 \pm 1$ mas yr$^{-1}$ and $\mu_\delta = +46 \pm 1$ mas yr$^{-1}$. This result agrees with the radio value determined by Brisken et al.(2002) and thus provides a secure confirmation of the pulsar identification at optical wavelengths.

A firm optical identification of an old pulsar such PSR B1929+10 adds an important piece of information to understand the evolution of the optical emission of pulsars. The FOC/STIS multicolour data available (see Mignani et al. 2002 for a description of the STIS images photometric analysis) are confined in a narrow band and give poor constraints on the shape of the optical spectrum; nevertheless, it is quite evident that in the case of PSR B1929+10 the optical emission seems to be non-thermal and unrelated to the X-ray emission, at odds with the behaviour of middle-aged pulsars. More data towards longer wavelengths are obviously required to better characterize the spectral shape.

Finally, we note that the revised radio/optical proper motion vector is almost perfectly aligned with the major axis of the elongated X-ray trail detected with ROSAT (Wang et al.1993). This evidence (see Fig.1, right panel) clearly supports the idea of a physical connection between the X-ray structure and the pulsar high-velocity ($\sim 170$ km s$^{-1}$ projected on the plane of the sky) motion through the interstellar medium (Becker et al., in preparation).

References

Brisken, W.F., Benson, J.M., Goss, W.M. and Thorsett, S.E., 2002, ApJ 571, 906 ASP Conference Series, Vol. 202, p. 202, Eds. M. Kramer, N. Wex, and N. Wielebinski
De Luca, A., Mignani, R.P. and Caraveo, P.A., 2000, A&A 354, 1011 X-ray Emissions, Eds. J. Danziger and P. Gorenstein (Dordrecht: Reidel), 471
Mignani, R., 1998, Neutron Stars and Pulsars : Thirty Years after the Discovery, Frontiers science series n. 24, p.335, Eds. N. Shibazaki et al.
Mignani, R.P., De Luca, A., Caraveo, P.A., 2000, ApJ 543, 318
Mignani, R.P., De Luca, A., Caraveo, P.A. and Becker, W., 2002, ApJL, accepted, astro-ph/0208491
Pavlov, G.G., Stringfellow, G.S. and Córdova, F.A., 1996, ApJ 467, 370
Yancopoulos, A., Hamilton, T.T. and Helfand, D.J., 1994, ApJ 429, 832
Wang, Q.D., Li, Z.-Y. and Begelman, M.C., 1993, Nature 364, 127
Wang, F.Y.-H., and Halpern, J.P., 1997, ApJ 482, L159