ON THE CRAB PROPER MOTION.

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ABSTRACT. Owing to the dramatic evolution of telescopes as well as optical detectors in the last 20 yrs, we are now able to measure anew the proper motion of the Crab pulsar, after the classical result of Wyckoff and Murray (1977) in a time span 40 times shorter. The proper motion is aligned with the axis of symmetry of the inner Crab nebula and, presumably, with the pulsar spin axis.

1. Introduction

Isolated Neutron Stars are fast moving objects (e.g. Caraveo, 1993, Lyne and Lorimer, 1993; Lorimer, 1998), and the Crab is no exception. The measure of the proper motion of Baade’s star (later recognized to be the optical counterpart of the Crab pulsar) was attempted several times (e.g. Trimble, 1968), yielding vastly different values. This prompted Minkowski (1970) to conclude that the proper motion of the star was not reliably measured. The situation changed few years later, when Wyckoff and Murray (1977) obtained a new value of the Crab proper motion which allowed to reconcile the pulsar birthplace with the center of the nebula, i.e. the filaments’ divergent point. The relative proper motion measured by Wyckoff and Murray amounts to a total yearly displacement of $15 \pm 3$ mas, corresponding to a transverse velocity of 123 km/s for a pulsar distance of 2 kpc.

Recently, Hester et al (1995) have drawn a convincing picture of the central part of the Crab Nebula ”symmetrical about the (presumed) rotation axis of the pulsar” by associating the ROSAT/HRI picture of the pulsar and its surroundings with HST/WFPC2 images of the remnant. However, they failed to note that the position angle of such an axis of symmetry is fully compatible with the position angle of the proper motion vector measured by Wyckoff and Murray (1977). Since the link between pulsars’ proper motions and their spin axes has been the subject of many inconclusive studies, we have sought an independent measurement of the pulsar proper motion.

2. The Method and the Data

In order to measure the tiny angular displacement of the Crab pulsar, we need high resolution images taken at different epochs, like the ones available in HST Public Archive. Browsing through the HST archive, one finds for the Crab about 60 entries, 30 of
which are images taken with the different instruments used throughout the mission: FOC, WFPC, STIS and NICMOS. Since the WFPC2 was the most commonly used, both as Wide Field and as Planetary Camera, we focussed on it, selecting images taken through the same filter. The 547M medium bandpass ($\lambda = 5454\,\text{Å}; \Delta\lambda = 486.6\,\text{Å}$) turned out to be the most popular, totalling 12 images, with the Crab pulsar positioned either in one of the three Wide Field Camera chips or, more often, in the Planetary Camera. The 547M data set has been retrieved and after cosmic ray cleaning, all images have been inspected to define a suitable set of reference stars. When doing astrometric studies the presence of good reference stars is very important: an outstanding image without at least 4 reference objects, is of no use for our purposes. While finding reference stars for the Wide Field images is not a problem, the smaller field of view of the Planetary Camera rarely contained enough reference objects. Indeed, only the PC observation shown in Figure 1 meets our requirements.

The need for reference stars limits the data-set to just three images, taken in March 94 (WFC-chip#2), August 95 (PC) and January 96 (WFC-chip#2). The images have been superimposed following the rotate-shift procedure outlined in Caraveo et al (1996). First, the frames have been corrected for the WFPC2 geometrical distortion (Holtzman et al, 1995) and the scale transformation from the PC (0”.045/px) to the WFC (0”.1/px) scale was applied. Next, the frames have been aligned in right ascension and declination according to their roll angles and the ”best” positions of the Crab pulsar, as well as of the

Fig. 1. 2000 sec PC image of the Crab Nebula taken in Aug 1995, through the F547M filter. North to the top, East to the left. The labels mark the stars used for relative astrometry. The arrow shows the Crab pulsar proper motion direction.
reference stars, have been computed by 2-D gaussian fitting of their profiles. Particular care was used for the pulsar itself in order to make sure that the object’s centroid is not affected by the emission knot observed \( \sim 0.7 \) arcsec to the SE. A positional accuracy ranging from 0.02 px to 0.03 px was achieved for the pulsar as well as for the reference stars. Finally, we used the common reference stars (1 to 4 in Fig. 1) to compute the linear shifts needed to overlay the different frames onto the march 94 image, which was used as a reference.

3. Results

With three images accurately superimposed we can compare the positions obtained for the Crab pulsars over 1.9 yrs. While the positions of the reference stars at the three different epochs are virtually unchanged, the pulsar is clearly affected by a proper motion to NW. A linear fit to the \( \alpha \) and \( \delta \) displacements (shown in Fig. 2a,b) yields the Crab proper motion relative to the reference stars. This turns out to be

\[
\mu_\alpha = -17 \pm 3 \text{ mas yr}^{-1}, \mu_\delta = 7 \pm 3 \text{ mas yr}^{-1}
\]

corresponding to an overall annual displacement \( \mu = 18 \pm 3 \text{ mas yr}^{-1} \) in the plane of the sky, with a position angle of 292° \( \pm 10^\circ \). This vector is also plotted in figure 1. Our result is to be compared with the value of

\[
\mu_\alpha = -13 \pm 2 \text{ mas yr}^{-1}, \mu_\delta = 7 \pm 3 \text{ mas yr}^{-1}
\]

obtained by Wyckoff and Murray (1977).

4. Conclusions

According to Hester et al (1995), the position angle of the axis of symmetry of the inner Crab Nebula is \( \sim 115^\circ \), or, rather, \( \sim 295^\circ \), to take into account an 180° offset. This
value is to be compared to our result $\sim 292^\circ$ or to that of Wyckoff and Murray ($\sim 298^\circ$). Although a chance coincidence probability at a few level cannot be totally dismissed, it is interesting to speculate on the implications of such an alignment. Since a neutron star acquires its proper motion at birth, there is no doubt that the pulsar motion has been present "ab initio". However, its energy content is far too small to account for the surrounding structures and their rapid evolution. Therefore the link, if any, between proper motion and axis of symmetry must go through some basic characteristics which was also present when the Crab pulsar was born.

Hester et al (1995) proposed a scenario associating the symmetrical appearance of the Nebula with the pulsar spin-axis. Under this hypothesis, the neutron star motion would turn out to be aligned with the spin axis, reflecting an asymmetry of the supernova explosion along the progenitor spin-axis. Proper motion spin-axis alignments have been discussed in the literature (see e.g. Tademaru, 1977) but no conclusive evidence was found. If the X-ray jets do indeed trace the pulsar spin axis, Crab would provide the first case of such an alignment.

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