New Horizons in Time-Domain Astronomy
Proceedings IAU Symposium No. 285, 2011
R.E.M. Griffin, R.J. Hanisch & R. Seaman, eds.

doi:10.1017/S1743921312001135

Optical Polarimetry of the Crab Nebula

Paul Moran[1], Andy Shearer[1], and Roberto Mignani[2]

[1]Centre for Astronomy, NUI Galway, Newcastle, Galway, Ireland
email: p.moran4@nuigalway.ie

[2]Mullard Space Science Laboratory, Dorking, Surrey, RH5 6NT, UK

Abstract. Time-resolved polarisation measurements of pulsars provide an unique insight into the geometry of the emission regions. Hubble Space Telescope (HST) polarisation data of the Crab Nebula were obtained from the Multimission Archive at STScI (MAST). The data are composed of a series of observations of the Crab Nebula with the HST and ACS camera system taken in three different polarisation filters (0°, 60° and 120°) between 2003 August and 2005 December. Polarisation vector maps of the Nebula were produced with the polarimetry software IMPOL. The degree of polarisation (P.D.) and the position angle (P.A.) of the pulsar's integrated pulse beam were measured, and also that of the nearby Synchrotron Knot, yielding P.D. = 4.90 ± 0.33 %, P.A. = 106°.46 ± 1°.9 for the pulsar, and P.D. = 61.70 ± 0.72 %, P.A. = 126°.86 ± 0°.23 for the Synchrotron Knot. These results are consistent with those of obtained by others using INTEGRAL.

Keywords. Pulsar, Polarimetry, Crab Nebula

1. Introduction

The raw HST ACS polarisation science frames of the Crab Nebula (M1) were obtained from the Multimission Archive at STScI (MAST) (See Fig. 1). The data are composed of a series of observations of the Crab Nebula with the HST and ACS camera system taken in three different polarisation filters (0°, 60° and 120°) between 2003 August and 2005 December. The images had already been flat-fielded; they were then geometrically aligned, combined, and averaged with cosmic-ray removal using IRAF. For each set of observations the images taken in the 0°, 60° and 120° polarisers were combined to give a single Stokes intensity image. The intensity images were analysed by the IMPOL software which produces polarisation vector maps.

Determining the polarisation in a crowded field such as the Crab Nebula is complex. In order to determine the Crab pulsar's polarisation profile we need to know the level of background polarisation. The problem is compounded by possible variations in the Crab gamma-ray flux, such as flaring phenomena, in the the surrounding pulsar wind nebula. Our work is intended to map accurately the polarisation of the Cab Nebula, and to act as a guideline for future time-resolved polarisation measurements of the Crab pulsar using the Galway Astronomical Stokes Polarimeter (GASP). GASP is an ultra-high-speed, full Stokes, astronomical imaging polarimeter based on the Division of Amplitude Polarimeter (DOAP). It has been designed to resolve extremely rapid variations in objects such as optical pulsars and magnetic cataclysmic variables.

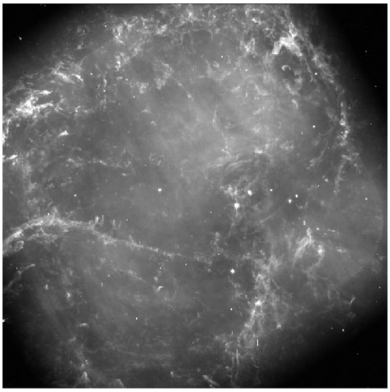

Figure 1. HST image of the Crab Nebula

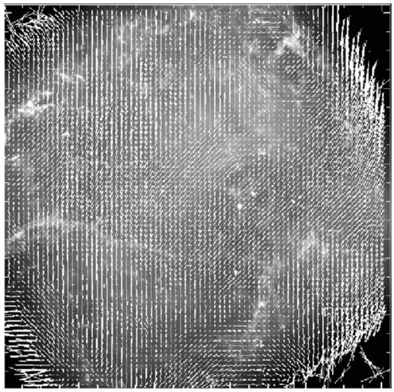

Figure 2. Polarisation Map of the Crab Nebula

Table 1. Overall Results for the Polarisation Degree and Position Angle.

	Polarisation Degree (%)	Position Angle(°)
Pulsar	4.90±0.33	106.46±1.90
Synchrotron Knot	61.70±0.72	126.86±0.23

2. Polarimetry

In order to determine the polarimetry, aperture photometry was first performed on the pulsar and its synchrotron knot in each image. The Stokes vectors were then calculated using the following formulæ:

$$I = \tfrac{2}{3}\,[r(0) + r(60) + r(120)]$$
$$Q = \tfrac{2}{3}[2r(0) - r(60) - r(120)]$$
$$U = \tfrac{2}{\sqrt{3}}\,[r(60) - r(120)],$$

where r(0), r(60) and r(120) are the calibrated count rates in the 0°, 60° and 120° polarised images, respectively.

2.1. *Computing the fractional polarisation (P.D.) of the target*

Included is a factor which corrects for cross-polarisation leakage in the polarising filters. This correction is useful for the POLUV filters; values of T_{par} and T_{perp} can be found in Figure 5.4 of the ACS Instrument Handbook. The instrumental polarisation of the WFC (∼ 2%) must be subtracted from it.

2.2. *Computing the position angle (P.A.) on the sky of the polarisation E-vector*

The parameter PAV3 is the roll angle of the HST spacecraft, and is called PA_V3 in the data headers. The parameter χ contains information about the camera geometry which is derived from the design specifications; for HRC, $\chi = -69^\circ.4$, and for the WFC $\chi = -38^\circ.2$.

$$\text{P.D.} = \frac{\sqrt{Q^2+U^2}}{I}\,\frac{T_{par}+T_{perp}}{T_{par}-T_{perp}}$$

$$\text{P.A.} = \tfrac{1}{2}\,tan^{-1}(\tfrac{U}{Q}) + \text{PAV3} + \chi$$

https://doi.org/10.1017/S1743921312001135 Published online by Cambridge University Press

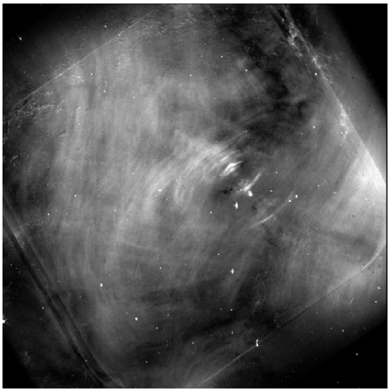

Figure 3. Polarised Flux Map of the Crab Nebula

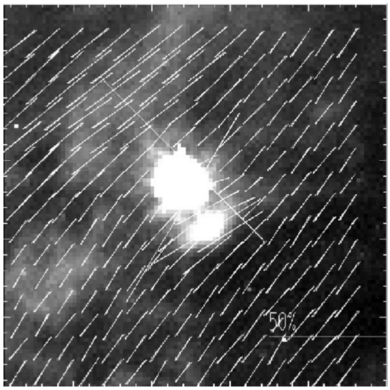

Figure 4. Polarisation Vector Map of region around pulsar and synchrotron knot

3. Discussion

The polarisation maps show the variation of the polarisation throughout the nebula and particularly in the vicinity of the pulsar itself. One can distinctly see the overall structure of the nebula, the degree of polarisation of the knots and the synchrotron emission (see Figs. 2, 3 & 4). The Crab Nebula was observed by AGILE in September 2010 to flare in the gamma-ray spectrum. This was the first ever discovery of such an event. The flare emission is synchrotron from a small region close to the pulsar and possibly the nearby knot. The April 2011 flare was roughly 30 times brighter than the average pulsar and nebula flux. These observations challenge emission models of the pulsar wind interaction, particle acceleration processes, as well as our understanding of the Crab system and pulsars themselves.

4. Conclusion

The results (listed in Table 1) are in good agreement with those of Słowikowska *et al.* (2009). These measurements will be used as a background measure of the pulsar and nebula contribution for future time-resolved polarisation measurements of the Crab pulsar. We plan to use GASP to measure both the linear and circular polarisation from the Crab on time-scales of <100 microseconds. In order to do this we have to subtract the polarisation of the background. Polarisation measurements give a unique insight into the geometry of the emission region see (McDonald *et al.* 2011), and enable us to determine the pulsar geometry, emission altitude, pulsar inclination, field inclination and pitch angle.

References

McDonald, J., *et al.* 2011, *MNRAS, arXiv:1106.5207M*
Słowikowska, A., *et al.* 2009, *MNRAS, arXiv:0901.4559v1* [astro-ph.SR]

https://doi.org/10.1017/S1743921312001135 Published online by Cambridge University Press