

New optical polarization measurements of the Crab pulsar

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ABSTRACT

The Crab nebula and pulsar have been observed for about 3 hours with the high-speed photo-polarimeter OPTIMA in January 2002 at the Calar Alto 3.5m telescope. The instrumental sensitivity (white light) extends from about 450nm to 950nm. The Crab was imaged onto a hexagonal bundle of optical fibers which are coupled to single photon APD counters. The spacing and size of the fibers corresponds to about 2 arcsec, leading to almost complete containment of the pulsar in the central fiber. GPS based time tagging of single photons, together with the instantaneous determination of the position angle of a rotating polaroid filter, allows to measure the phase dependent linear polarization of the pulsar and the surrounding nebula simultaneously. The Crab pulsar and its net optical polarization are determined at all phases of rotation with high statistical accuracy. We also separated the so-called off-pulse phase emission, with an intensity of about 1.2% compared to the first peak (assumed to be present at all phases), from the pulsed emission and show the 'net' polarization of the pulsed structures. Recent theoretical results indicate that the measured optical polarization of Crab is similar to expectations from a two-pole caustic emission model.

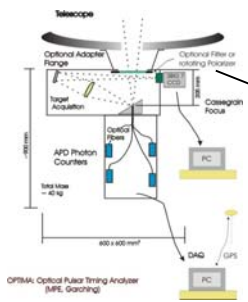
INSTRUMENT and OBSERVATIONS

The Photometer [1,2]:



OPTIMA at the Calar Alto 3.5m Telescope

Crab observations:
2002 Jan 10-11: 3 hrs polarization
09-13: ~10 hrs photometry



The Polarimeter [3]:

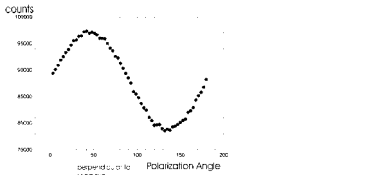
Requirements for measurements in the Crab nebula:

- Determine quasi simultaneously the state of linear polarization of the target (pulsar) and the surrounding nebula, including the sky-background
- accurately time tag the photons and the position angle of the polarizing filter

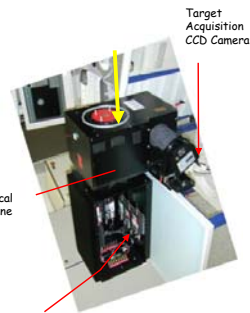
The incoming beam is modulated with a rotating polaroid filter which modulates the incoming radiation effectively for wavelengths shorter than 850nm



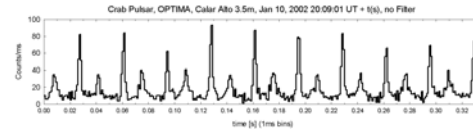
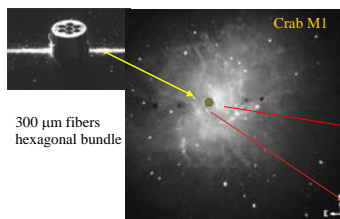
Verification of polarimeter: modulation of Raleigh scattered light of the morning sky



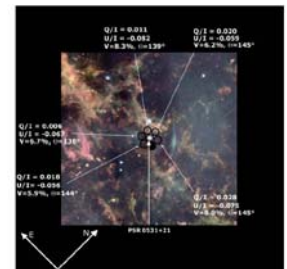
Target Acquisition



APD Photon Counters:
QE ~ 60% at 750 nm and > 20% at 450-950 nm

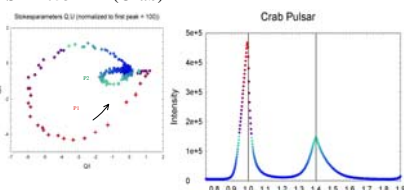


Polarization of the nebula next to the Crab pulsar

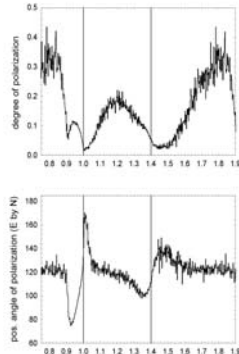


Polarization of total emission of PSR B0531+21 (Crab)

Stokes-Parameters Q and U of optical light from the Crab pulsar (normalized to the peak I intensity = 100). The color coding corresponds to the light-curve and the peaks are marked by a triangle. The pulsar rotational phase increases counter-clockwise



Lightcurve, degree of polarization and position angle of the E-vector on the sky for the Crab pulsar. This result agrees well with a previous measurement by Smith et al., 1988 [5] but shows details with much better definition and statistics.

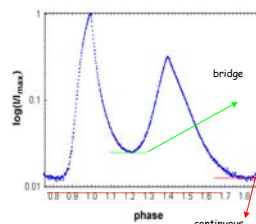


Conclusions:

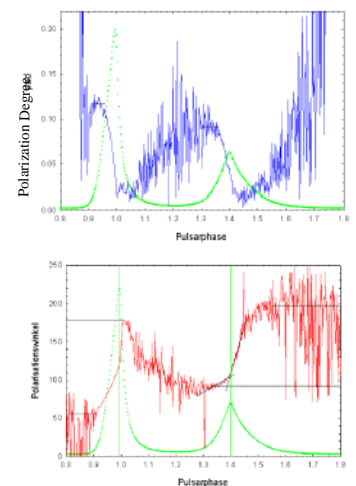
- The optical emission from the Crab pulsar is highly polarized, especially in the bridge and off-pulse phases
- The degree and angle of linear polarization show well defined structures:
 - at the peaks of the lightcurve the degree of polarization is minimal
 - there is a well defined bump in polarization on the rising flank of the main pulse (possibly also for the 2nd peak)
 - the polarization angle swings through a large angle in both peaks: after subtraction of an assumed constantly polarized continuous emission (intensity 1-1.5% of main pulse) the angles swing for 125° (main pulse) and 92° (second peak)
- The polarization signatures observed for the Crab show a high degree of similarity with theoretical estimates recently published by Dyks, Harding and Rudak [4] in the framework of the Two pole caustic model of magnetospheric emission

Separation of "Pulsed component" and "Continuous component":

Assume that a continuous component is present at all phase angles and has constant polarization. The polarization of the "pulsed component" is then calculated by subtracting the respective Stokes parameters I,Q,U for linear polarization



Polarization: pulsed component only



References:

- [1] Straubmeier, C., Kanbach, G., and Schrey, F., *Exp.Astron.*, **11**, 157, 2001
- [2] Kanbach, G., Kellner, S., Schrey, F., Steinle, H., Straubmeier, C., *SPIE Conf. Proceed.*, 4841, 82, 2003
- [3] Kellner, S., Diploma Thesis, Techn. Univ. München, 2002 available at www.mpg.de/gamma/instruments/optima/www/optima-papers.html (in German)
- [4] Dyks, J., Harding, A.K., Rudak, B., *Ap.J.*, 2004, in press
- [5] Smith et al., *MNRAS*, **233**, 305, 1988