Max-Planck-Institute for extraterrestrial Physics

Optical Polarization of The Crab Pulsar with ~10 μs Time Resolution

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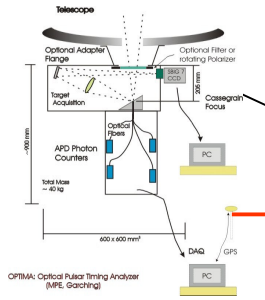
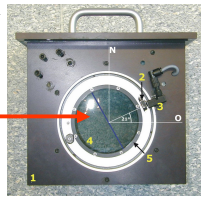
The Crab nebula and pulsar have been observed for about 25 hours with the high-speed photo-polarimeter OPTIMA in November 2003 at the 2.5m Nordic Optical Telescope (NOT), La Palma, Canary Islands, Spain. The detector sensitivity (white light) extends from about 450nm to 950nm. The incoming light was filtered to a range of 450-750nm to stay within the range of efficiency of a rotating polaroid filter, which modulated the radiation over the entire field of view. The Crab pulsar is imaged onto a hexagonal bundle of optical fibers which are coupled to single photon APD (Avalanche Photodiode) counters. The spacing and size of the fibers corresponds to 2.''35 on the sky, leading to almost complete containment of the pulsar in the central fiber under good seeing conditions. GPS based time tagging of single photons with 4μs resolution, together with the instantaneous determination of the position angle of the 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 very high statistical accuracy. On time scales of a few tens of μseconds significant constrains can be placed on to optical polarisation of the main emission peaks. We compare the phase resolved optical polarization to the phase structure at radio wavelengths and we find a surprising correspondence which requires more elaborate theoretical models than those available in the literature (e.g. [7],[1],[2],[6]).

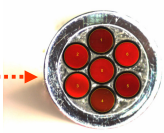
OPTIMA at the NOT

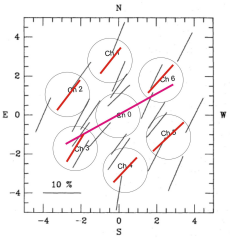


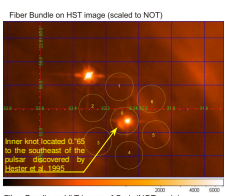
Schematic of the OPTIMA instrument and Rotating Polaroid Filter

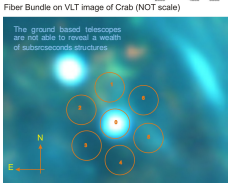


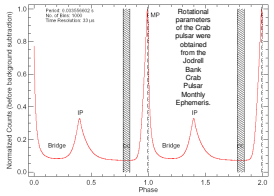
Fiber pick-up and projection on the inner part of the Crab nebula; Nebular polarization compared to the result of Smith et al, 1988

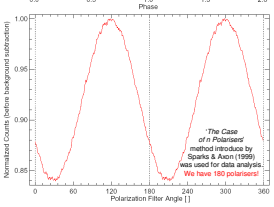




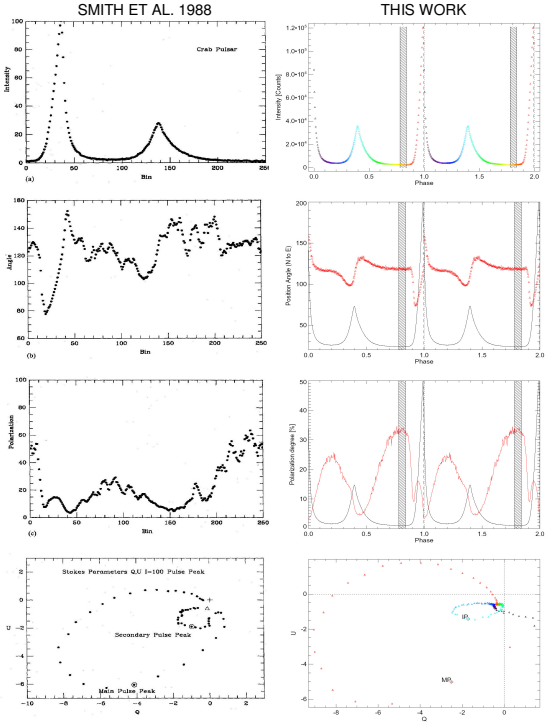




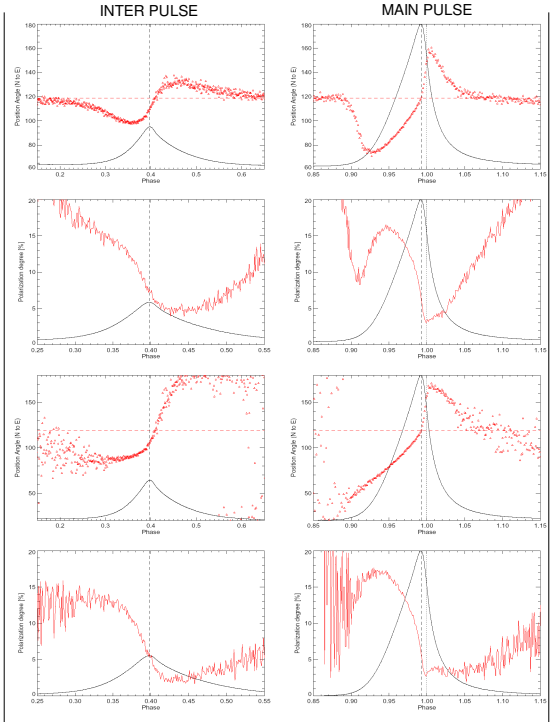




SMITH ET AL. 1988 | THIS WORK | INTER PULSE | MAIN PULSE

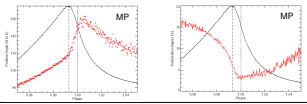


Comparison of the results obtained by Smith et al. 1988 (left) and this work (right). From top to bottom; the intensity, position angle, polarisation degree, and the Stokes parameters Q, U plotted as a vector diagram as a function of the pulsar phase. There are 250 bins per cycle in both cases, the only difference is that for clarity we show two periods. As a DC component Smith et al. took 50 out of 250 bins, whereas we took only 7% of the rotational period.



Polarisation characteristics, θ and *p* for both Crab pulsar peaks; left and right column is for the IP and MP, respectively. First two rows show the polarisation characteristics of the Crab peaks before DC (phase range: 0.78-0.84, θ=118.9°, *p*=33%) subtraction, whereas the succeeding two rows after this subtraction. Black dashed lines indicates the optical maximum phases of the peaks, black dotted line indicates the radio phase. Red dashed horizontal line shows the θ_{DC}=118.9°. For clarity the light curve of the Crab pulsar is over plotted (black solid-line).

θ and *p* zoomed around the phase range 0.95-1.05



The optical emission from the Crab pulsar is highly polarised, especially in the bridge and the 'off-pulse' phases. The θ and *p* of linear polarisation as a function of rotation phase show well determined properties:

a) the polarisation characteristics of the MP and IP components are very similar,

b) the polarisation degree is minimal at the phases of maximum radio intensity; therefore, it is NOT aligned with the optical peaks,

c) there is a well defined bump in polarisation degree on the rising flank of MP,

d) there is an indication of such a bump also for IP (especially after the DC subtraction),

e) the polarisation angle swings through a large angle in both peaks: after subtraction of an assumed constant polarisation component, the angle swing is 130° and 100° for MP and IP, respectively.

Theoretical models, like the two-pole caustic model [1] or the striped pulsar wind model [6] are able to reproduce (qualitatively, at least) some of these properties, e.g. (a) and (e). However, full explanation of the properties (a) to (e) will require more detailed models to be developed. Detailed presentation and discussion of these results will be given elsewhere (Słowikowska, PhD Dissertation 2006).

References

[1] Dyks et al., ApJ 606, 1125, 2004
[2] Dyks et al., IAU Symposium 218, 373, 2004
[3] Hester et al., ApJ 448, 1995
[4] Kanbach et al., SPIE 4841, 2003
[5] Kanbach et al., AIP Conf. Proc. 801, 306, 2005
[6] Pétri & Kirk, ApJ 627, 37, 2005
[7] Romani & Yadigaroglu, ApJ 438, 314, 1995
[8] Smith et al., MNRAS 233, 305, 1988
[9] Sparks & Axon, PASP 111, 1298, 1999

Acknowledges

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