Measurement of the optical Polarization of the Crab pulsar with OPTIMA

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• Description of the MPE-OPTIMA (" Optical Pulsar Timing Analyzer ") high-speed photo-polarimeter
• Measurements on the Crab pulsar in January 2002 at Calar Alto
• Verification of the polarimeter and data analysis
• Results
The OPTIMA photometer

Target Acquisition CCD Camera

Focal Plane

APD Photon Counters

single photon counting and timing:
APDs: high Q.E. ~60% (450-950 nm) -> ~6 times more sensitive than PMT system
Timing with GPS: ~ 2 µs

Options:
Linear Polarization using a rotating filter, 4 colour-band prism spectrometer
Target Acquisition

Mirror with fiber bundles

Sky Background fiber

Target Fibers dia ~300 mm
(maximum signal/noise ratio)

The Crab Nebula
(3.5m Calar Alto, 99/00)
The OPTIMA Rotating Polarization Filter

1. Rotating polarisation filter unit
2. & 3. Hall sensor switch (reference)
4. Polaroid filter
5. Motor driven roller bearing (typical rotation frq.: 3 Hz)

Advantage: total field of view is analysed for polarisation simultaneously -> essential for Crab nebula!

Disadvantage: only 50% transmission
Assignment of polarization angle to individual recorded photons

Regular pulses from the Hall sensor switch of the RPF

Single photon event

Recorded Photon arrival times

360°

φ
polarization filter position angle
Verification of Polarimeter: Morning Sky Polarization

Rayleigh scattered sunlight (dawn or dusk) is highly polarized (~50%)
The E-vector in the zenith is orthogonal to the azimuth of the Sun.
For this exposure: Sun azimuth 111° (E of N), E-Vector: 21° (E of N)

Filter Rotation Angle 0° corresponds to E-vector 339° (E of N)
i.e. 42° filter rotation angle corresponds to E-vector 21° (E of N)

Dawn Sky Background 11-01-2002 06-38-10
Resolution = 3°
OPTIMA at the Calar Alto 3.5m Telescope (Jan. 2002)
Crab Observations

Jan 9.-13., 2002 Calar Alto 3.5 m telescope

white light: ~ 6 hours
polarization: ~ 3 hours
colour filters: ~ 3 hours

High statistics single pulse studies
Time resolved Polarimetry
3 colour filter photometry (red, green, blue)
Simultaneous optical – radio observations
(Collaboration with Copernicus University, Torun)
The small scale polarization of the Crab Nebula (Schmidt & Angel, 1979)

close to pulsar:
degree of polarization: 8-13%
position angle ~ 140°
Nebula Polarization (OPTIMA)

Close to pulsar:
degree: 8-13%
angle ~ 140°
(Schmidt & Angel, 79)
Crab single rotation and summed lightcurve

Crab Pulsar, OPTIMA, Calar Alto 3.5m, Jan 10, 2002 20:08:01 UT + t(s), no Filter

Crab single rotation variability studies
(→ next talk by Aga Wozna)
Crab Polarization (OPTIMA)

Measure lightcurves for different positions of the rotating polarisation filter at $[\phi_0, \phi_0+90^\circ]$ and $[\phi_0+45^\circ, \phi_0+135^\circ]$.

Calculate Stokes-Parameters:
$Q = I(0^\circ) - I(90^\circ)$,
$U = I(45^\circ) - I(135^\circ)$

angle of polarization: $\Theta = \frac{1}{2} \cdot \arctan \frac{U}{Q}$

degree of polarization: $V = \sqrt{Q^2 + U^2} / I$

Stokesparameters Q,U (normalized to first peak = 100)
Polarisation Properties of PSR 0531+21

Smith et al. 1988

Our results
Polarization for Synchrotron emission for relativistic particles with small pitch angles (Epstein, 1973)

Chen et al., 1996:
Degree of polarization vs. time (=l.o.s. angle) for an outer gap model

Not quite what we find!
The polarization angle:
Magnetic field Geometry in the Emission regions

Romani et al., 1995: outer gap model
Two pole emission model (Smith et al., 1988):
Explanation for the symmetric structure of the Stokes diagram

\[ \Delta t = 2r_l \tan \phi \sin \theta = 2 \tan \phi \sin \theta / \omega \]
Open Questions

what is this feature on therising flank of peak 1?

is there a similar feature on the rising flank of peak 2?

what is this overshoot at peak 1?

there is a sharp change of slope of the angular swing at peak 1