Design and Status of the MPE Fast Timing Photo-Polarimeter OPTIMA

G. Kanbach[1] , H. Steinle[1] , S. Kellner[1], C. Straubmeier[2]

[1] MPE, Garching [2] U. Köln

further information: gok@mpe.mpg.de or http://www.mpe.mpg.de/OPTIMA

MAX-PLANCK-GESELLSCHAFT

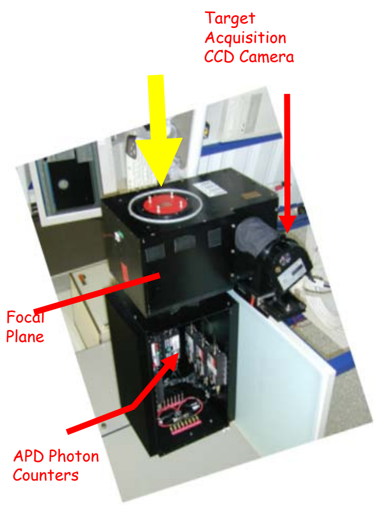
DESIGN:

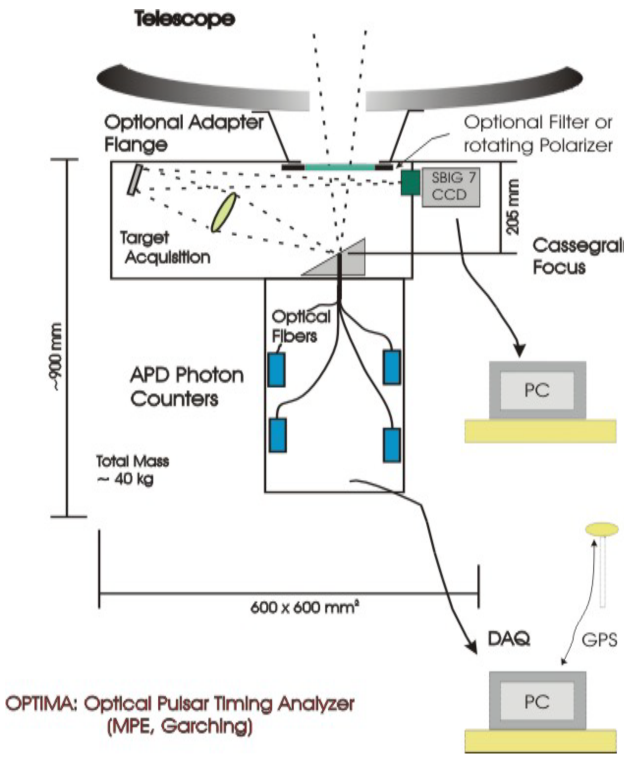
The high-speed photometer, OPTIMA („ Optical Pulsar Timing Analyzer “) has been designed as a sensitive, portable detector to observe optical pulsars and other highly variable sources. The detector contains eight fiber fed avalanche photodiode (APD) photon counters, a GPS timing receiver, a CCD camera for target acquisition and a stand-alone PC control unit. The target array of fibers is configured as a hexagonal bundle. A separate fiber is located at a distance of ~1‘ as a night sky background monitor. Single photons are recorded in all channels with absolute timing accuracy of ~2 µs. The quantum efficiency of the APDs reaches a maximum ~ 60% at 750 nm and is above 20% in the range 450-950 nm. Compared to similar photometers based on PMTs, OPTIMA has a ~6 times higher sensitivity due to its large bandwidth and high Q.E.

Recently a rotating polarization filter and a prism spectrograph, allowing the simultaneous recording of photons in 4 colour bands, have been added to the system as optional equipment.

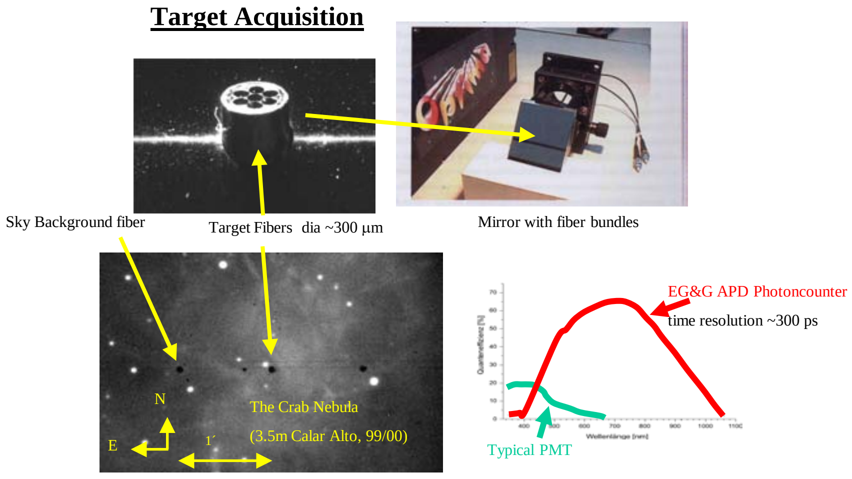
Since January 1999 OPTIMA has been used on different telescopes to measure detailed lightcurves and polarization of the Crab Pulsar, search for optical emission from the Geminga pulsar, and to perform timing measurements on cataclysmic variables and X-ray transients. Optical measurements on a black hole candidate were obtained simultaneously with RXTE X-ray observations.

OPTIMA at the Calar Alto 3.5m Telescope



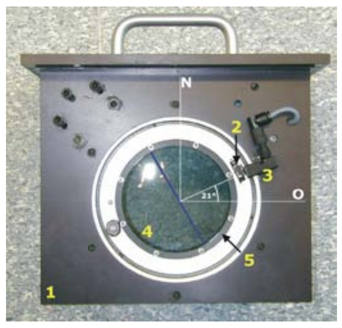


Target Acquisition



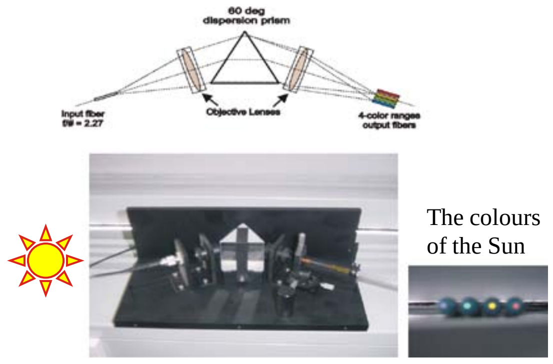
Rotating Polarization Filter

The filter (4) is mounted on a roller bearing (5) and driven by a motor. A signal is generated by the Hall sensor (2,3) at the angular reference position



4-colour prism spectrograph

Light from the input target fiber is dispersed into 4 colour bands and fed to separate detectors, allowing simultaneous photon counting. The sample shows sunlight transmitted through the spectrograph



The colours of the Sun

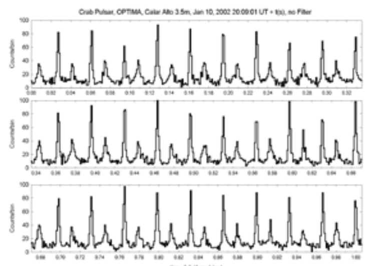
SELECTED RESULTS:

Cosmic high-energy sources, like pulsars, stellar and galactic black-holes, neutron star or white dwarf binaries, and gamma ray bursts are characterized by extremely fast temporal variations of their emissions throughout the spectrum. Optical radiation from these high-energy sources is often closely tied to the non-thermal particle populations that generate the X- and γ-ray photons (e.g. synchro-cyclotron emission vs. inverse Compton and curvature radiation). Optical photons therefore carry unique spectral, timing and polarisation information about their origin and are readily measured from various telescopes on the ground.

The primary verification target, the Crab pulsar, was observed at the 3.5m telecope of the German-Spanish observatory on Calar Alto, Spain in January 2000, when OPTIMA was only equipped with two detector channels, and later in January 2002 with all detectors and the polarization filter in place.

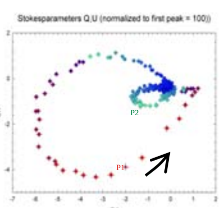
Observations in July 2000, September 2001 and May 2002 were carried out at the 1.3m telescope at Skinakas Observatory, Crete, Greece. The targets during these campaigns were compact binary systems and some observations were carried out simultaneous with observations at X-ray energies using the Rossi X-Ray Timing Explorer (RXTE).

Timing the Crab Pulsar

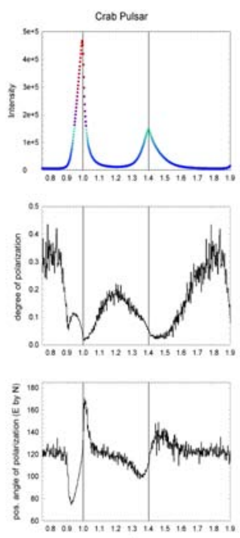


Single optical pulses from the Crab pulsar recorded with OPTIMA at the CAHA 3.5m telescope (white light).

Polarization of PSR B0531+21 (Crab)



Stokes-Parameters Q and U of optical light from the Crab pulsar (normalized to the peak 1 intensity = 100). The color coding corresponds to the lightcurve below and the peaks are marked by a triangle. The pulsar rotational phase increases counter-clockwise



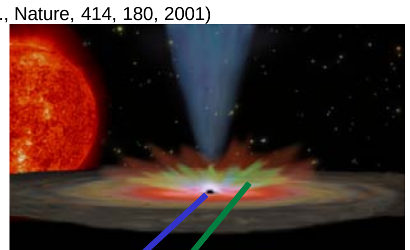
Lightcurve, degree of polarization and the position angle of the E-vector on the sky for the Crab pulsar. This result agrees well with a previous measurement by Smith et al., 1988 but shows details with much better definition and statistics. The interpretation of these data in terms of polarized synchro-tron emission from the outer magnetosphere has just been started.

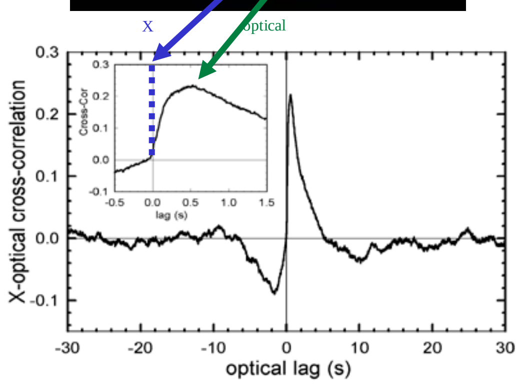
Correlated fast X-ray and optical variability in the black hole candidate XTE J1118+480

From January to August 2000 the bright X-ray transient XTE J1118+48 (=KV UMa) provided a unique opportunity for simultaneous X-ray and optical observations. KV UMa is a nearby binary system (~2 kpc) at high galactic latitude and contains a black hole with more than 6 solar masses. OPTIMA was used on the 1.3m telescope at Skinakas observatory for a simultaneous exposure of 2.5 hours with RXTE on July 4-7, 2000.

The X-ray / optical cross-correlation shows the optical emission rising suddenly following an increase in X-ray output. The optical response lags the X-rays by typically 500 ms with a very fast onset with a timescale of ~30 ms. The fast onset and the narrow autocorrelation of the optical light argues strongly against reprocessing of X-rays. It is proposed that the optical light is separately generated as cyclosynchrotron emission in a region about 20000 km from the black hole. The delay is then explained as a time of flight delay of disturbances in a relatively slow (~0.1 c) magnetically controlled outflow.

(Kanbach, et al., Nature, 414, 180, 2001)



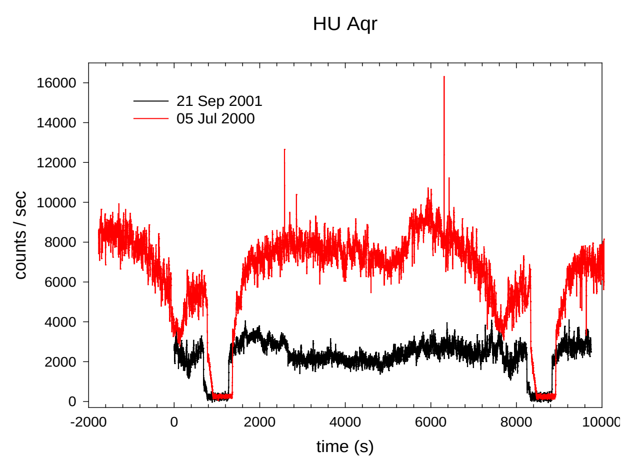


Sketch of an accreting black hole binary system. The black hole is surrounded by an accretion disk and emits a highly relativistic jet and the new hypothetical slow outflow. The optical response correlated to X-ray variations of XTE J118+48 shows time delayed emission and a not yet understood ‚pre-cognition‘ dip.

The Cataclysmic Variable HU Aquarii (AM Her type)

Several short period binary systems were measured with OPTIMA. As an example we present lightcurves for HU Aqr, which was observed repeatedly.

The AM Her type cataclysmic variable HU Aqr (RE 2107-05) is a close eclipsing binary system containing a highly magnetic white dwarf and a secondary star of type M4V. The orbital period is ~ 125 min. With a range of observed magnitudes from ~ 15 to 18 it is one of the brightest sources of this type. Short timing signatures were expected in this object, in particular at the eclipse entry and exit of the dwarf star. OPTIMA was used at the 1.3m telescope on Mt. Skinakas, Crete to monitor this source over several orbits. The figure shows two lightcurves with 1 sec resolution measured on July 5, 2000 and September 21, 2001. Two eclipses of the white dwarf are the dominant features of the lightcurves. Since the sky background in the vicinity of the source has been subtracted using data from the fibres around the target fibre the low countrate level in the eclipse is due to the secondary M4 star of magnitude ~19.



Optical lightcurves of HU Aqr measured in 2000 (red) and 2001 (black). HU Aqr was about 4 times brighter in 2000 (higher accretion state) and showed previously unknown very short (~sec timescale) optical outbursts (Kanbach et al., in preparation, 2002).

References:

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Spruit, H.C., and Kanbach, G., Correlated X-ray and optical variability in KV UMa, A&A , **391**, 225, 2002