



“Pi of the Sky” telescopes in Spain and Chile

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Abstract. “Pi of the Sky” is a system of robotic telescopes designed for observations of short timescale astrophysical phenomena, like prompt optical emission of GRBs. The apparatus is designed to monitor a large fraction of the sky with 12-13 mag range and time resolution of the order of 1-10 seconds. In October 2010 the first unit of the new “Pi of the Sky” detector system was successfully installed in the INTA El Arenosillo Test Centre in Spain. We have also moved our prototype detector from Las Campanas Observatory to San Pedro de Atacama Observatory in March 2011. Status and performance of both detectors are presented.

Keywords : Gamma Ray Burst (GRB) – prompt optical emission – optical transients – novae stars – variable stars – robotic telescopes

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1. Introduction

“Pi of the Sky” is a robotic telescope designed for observations of short timescales astrophysical phenomena, especially for prompt optical counterparts of Gamma Ray Bursts (GRBs). Other scientific goals include searching for novae and supernovae and monitoring of interesting objects such as blazars, AGNs or variable stars. Apparatus design allows to monitor a large fraction of the sky with range 12-13 mag and time resolution 1 – 10s. “Pi of the Sky” project involves scientists, engineers and students from leading Polish academic and research units: National Centre for Nuclear Research (former Soltan Institute for Nuclear Studies), Center for Theoretical Physics (Polish Academy of Science), Institute of Experimental Physics (Faculty of Physics, University of Warsaw), Warsaw University of Technology, Space Research Center (Polish Academy of Science).

The standard approach to optical observations of GRBs is to react to satellite alerts distributed by The Gamma Ray Burst Coordinates Network (GCN) and move the telescope to the target as fast as possible. However, this approach does not allow to observe optical emission from the source exactly at the moment or before of the GRB explosion, which is crucial to understand the nature of GRBs. “Pi of the Sky” apply innovative solution, which assumes a continuous observation of a large part of the sky to increase a probability of catching a GRB. A dedicated detector has been designed to search and observe prompt optical counterparts of GRBs during or even before the gamma-ray emission. To manage this goal, it is also necessary to develop an advanced and fully automatic software for real-time data analysis and identification of optical transients.

2. The prototype

Before building the full detector system, validity of the assumed observational strategy and the analysis methods were tested with the prototype. After first tests performed in Poland in 2003, the prototype with two custom-designed CCD cameras using the Fairchild 442A CCD chip of 2048×2048 pixels, was installed in Las Campanas Observatory (LCO) in Chile in June 2004. Starting May 2006 the cameras are armed with Canon telephoto lenses with the focal length $f = 85\text{-cm}$, $f/d = 1.2$ covering $20^\circ \times 20^\circ$ field of view (see Fig. 1). The pixel size of the CCD is $15 \times 15 \mu\text{m}^2$ which corresponds to 36 arcsec on the sky. The CCD is cooled with two-stage Peltier module up to 40 degrees below the ambient temperature. Both cameras observe the same field of view with a time resolution of 10 seconds. The limiting magnitude for a single frame is about 12 mag and rises up to 13.5 mag for a frame stacked from 20 exposures. Until May 2009 all observations were made in white light with no filter, except for IR-cut one, minimizing the sky background. From May 2009 we have Bessel-Johnson R-band filter installed on one of the cameras in order to facilitate absolute calibration of measurements. The prototype has been working at Las Campanas Observatory (LCO) in Chile till the end of 2009. In 2008, it automatically recognized and observed the

prompt optical emission from the famous “naked-eye” GRB 080319B (Racusin et al. 2008). This spectacular observations confirm the efficiency of the developed flash recognition algorithms and usefulness of the observational strategy.

In March 2011 the prototype was moved from LCO and installed in San Pedro de Atacama Observatory (see Fig. 2). New location is placed approximately 740 km north of previous location and about 2,400 meters above sea level. Thanks to closer distance to equator the observed part of the sky is bigger than that in LCO. The new site was selected because of good and stable weather conditions, sky is clear for more than 80% of the nights (in 2010 there were 309 observing nights, see Fig. 3). The SPdA hosts several robotic telescopes, up to 50-cm, used for various researches as exoplanet search, transit observations or comets, and a variety of “tourist” telescopes. The observatory is coordinated by Alain Maury’s, who provides support for these telescopes, general maintenance as well as the weather station providing a real-time information about weather conditions.

3. New detector unit in Spain

Single detector unit of the final “Pi of the Sky” system consists of the custom-designed open fork equatorial mount capable of carrying four CCD cameras. In October 2010, the first unit of the “Pi of the Sky” detector system was successfully installed in the Instituto Nacional de Técnica Aeroespacial (INTA) El Arenosillo test centre in Mazagón near Huelva, Spain, at the coast of the Atlantic Ocean, see Fig. 4. Cameras (Kasprowicz et al. 2009) used with this telescope are the improved version of cameras developed for the prototype system operational in Chile. One of the most important improvements is the Ethernet interface and a custom mudp protocol for fast data transmission.



Figure 1. “Pi of the Sky” prototype at Las Campanas Observatory in Chile: 2004 mount design (left) and picture of the mount with Canon lenses used from May 2006 (right).



Figure 2. “Pi of the Sky” prototype at San Pedro de Atacama Observatory.

The mount design enables two operation modes, thanks to the dedicated mechanism for deflecting the cameras (see Fig. 5):

- Common-target (DEEP), when all cameras point to the same object, increasing the precision of the measurement (and allowing multi-wavelength observations if different filters are used), and
- Side-by-side (WIDE), with cameras covering adjacent fields, giving combined field of view of $40^\circ \times 40^\circ$.

With harmonic drives, encoders and control solutions based on Ethernet and industrial CAN standard new design of the telescope mount provides much better pointing accuracy and shorter reaction time than the prototype. Every part of the sky available in about 25 seconds and the pointing as well as the tracking precision is of the order of the pixel size.

First data collected with the detector unit at INTA show that the photometry quality is very similar (in good weather conditions) to that in Chile. Shown in Fig. 6 is the

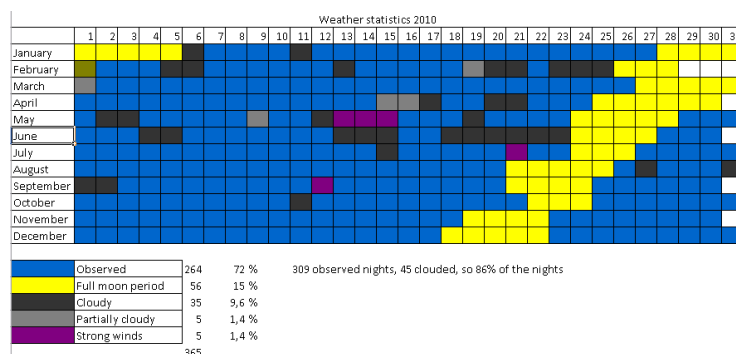


Figure 3. Diagram showing weather conditions at San Pedro de Atacama in 2010.



Figure 4. Detector unit of the final “Pi of the Sky” system: mount design (left) and the picture of the first detector unit installed in the INTA El Arenosillo test centre near Huelva, Spain, (right).



Figure 5. Two observation modes of the final “Pi of the Sky” detector: WIDE (left) and DEEP (right).

estimated precision of the star magnitude determination as the function of the star V magnitude for the prototype in LCO and the new detector.

4. The ultimate system

The full “Pi of the Sky” system will consist of 6 detector units (24 cameras) in two sites (12 cameras on 3 equatorial mounts in each). The first unit already installed near Huelva will be soon complemented by additional two units. We are then planning to install the second site near Malaga, at the distance of about 240 km. Pairs of cameras will work in coincidence and observe the same field of view. Thanks to this configuration, the system will be capable to identify and remove the reflections from the satellites by the parallax and eliminate cosmic rays by analyzing the coincidence on both cameras. This will significantly improve purity of event sample selected by our real-time flash recognition algorithms. Data collected so far revealed that the most common background sources are flashes due to cosmic rays and flashes due to the Sun light reflection from satellites.

The whole system will be capable of continuous observations of about 1.5 steradians of the sky, which roughly corresponds to the field of view of the BAT instrument on board of the Swift satellite. The final system will therefore allow to eliminate time delay due to re-pointing the telescope to the coordinates from GCN and the dead time due to decision process and signal propagation from the satellite to the GCN and from the GCN to a ground-based telescopes.

“Pi of the Sky” is fully automated robotic system. Although remote supervision via Internet is possible, no human action is required except for serious problems. Flexible observation strategy definition system includes following center of SWIFT FoV, evening and morning all sky scan, scheduled observations of the interesting objects from the predefined list. Reaction to alerts from GCN is also fully automatic, repointing the detector if the GRB position is outside FoV. On-line flash recognition algorithms (Sokolowski et al. 2010) process the data once collected and recognize flashes. Candidate events are then a subject to human verification. Full data reduction pipeline follows.

In case of hardware or software problems there is a build-in control and error recognition logic and automatic algorithms for recovery. System design is very modular, so each system element can be easily replaced by its backup, see Fig. 7. Changes of system configuration can be made remotely via Internet.

Independent slow control system for monitoring detector operation is also included. It allows for control of all important system performance parameters including power supply voltages, camera temperatures etc. Parameters are stored in a database and can be displayed via the web interface. In addition, slow control units are equipped with solid state memory cards for permanent storage of all measurements.

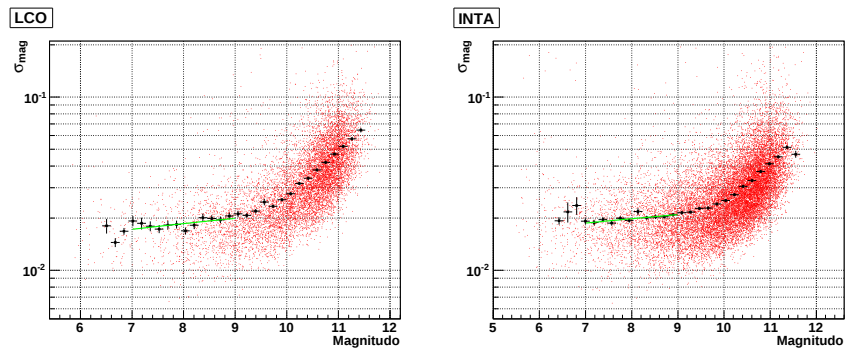


Figure 6. Precision of photometry for “Pi of the Sky” prototype in LCO (left) and new detector in INTA (right). Shown is the precision of the star magnitude determination as the function of the star V magnitude. Red dots correspond to single stars, black points to the average uncertainty in magnitude bins.

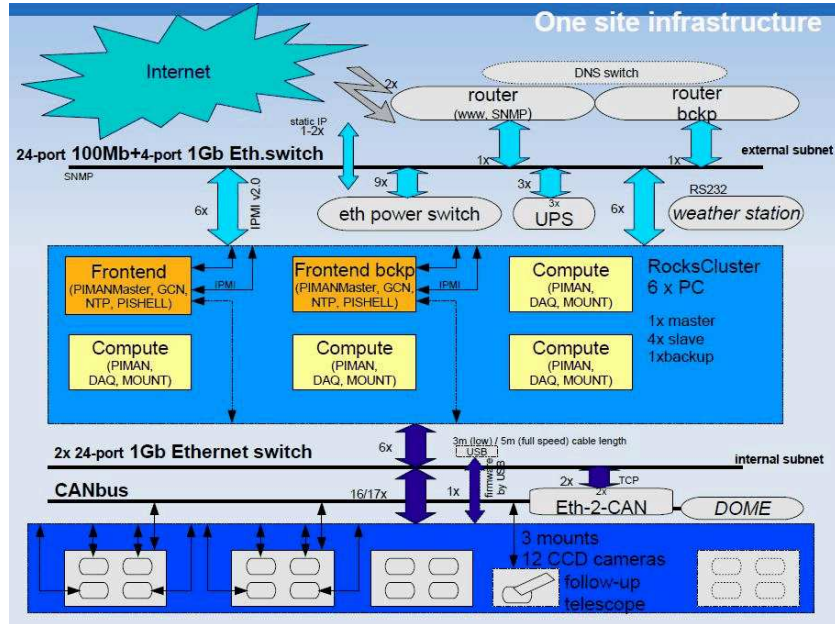


Figure 7. Schematic diagram of system architecture for one of the “Pi of the Sky” site.

This allows us to check the reason for system failure even in case of computer or communication problems.

5. Summary

Important developments took place in the “Pi of the Sky” project in the recent months. The prototype detector operational in the Las Campanas Observatory in 2004-2009 was successfully moved and installed in San Pedro de Atacama Observatory (SPdA) in March 2011. In October 2010 we manage to install the first unit of the final “Pi of the Sky” detector system in the INTA El Arenosillo Test Centre in Spain. Both “Pi of the Sky” instruments operate in the fully autonomous mode, practically without any human supervision and search for short timescales astrophysical phenomena. Installation of the subsequent detectors is expected in the coming months

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