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Editors: J. C. Tello, A. Riva, D. Hiriart & A. J. Castro-Tirado

PI OF THE SKY CONTRIBUTIONS TO THE GLORIA PROJECT

L. Obara,[1,2] A. Cwiek,[3] M. Cwiok,[1] A. Majcher,[3] L. Mankiewicz,[4] M. Zaremba,[1] A. F. Żarnecki[1]

RESUMEN

"Pi of the Sky" es un sistema de telescopios robóticos de campo amplio, que buscan fenómenos astrofísicos de escala temporal corta, especialmente la emisión óptica temprana de GRBs. En julio de 2013 el último sistema de detectores de "Pi of the Sky", con 16 cámaras CCD, fue comisionado e integrado a la red de ciencia ciudadana GLORIA (GLobal Robotic-telescope Intelligent Array). Está disponible para que los usuarios de GLORIA realicen observaciones programadas. Datos selectos de archivo del telescopio prototipo de "Pi of the Sky" en Chile fueron usados también para implementar un experimento off-line para GLORIA. Gracias al gran campo de visión del telescopio la muestra seleccionada de entorno a 500 imágenes permite el análisis de variabilidad de objetos brillantes de un tipo distinto. El procesamiento de imágenes está basado en la infraestructura LUIZA, que fue implementado para GLORIA para el análisis eficiente y flexible, basado en la experiencia de experimentos de física de altas energías.

ABSTRACT

"Pi of the Sky" is a system of wide field-of-view robotic telescopes, which search for short timescale astrophysical phenomena, especially for prompt optical GRB emission. In July 2013 the final "Pi of the Sky" detector system, with 16 CCD cameras on 4 mounts, was comissioned and integrated into the citizen-science network GLORIA (GLobal Robotic-telescope Intelligent Array). It is available to GLORIA users for scheduled observations. Selected archive data from the "Pi of the Sky" prototype telescope in Chile was also used to implement off-line demonstrator experiment for GLORIA. Thanks to the wide field of view of the telescope the selected sample of about 500 images allows for variability analysis of bright objects of different kind. Image processing is based on the LUIZA framework, which was implemented for GLORIA for efficient and flexible data analysis, based on the experience from high energy physics experiments.

Key Words: techniques: image processing — stars: variables — telescopes

1. GLORIA

GLORIA (GLobal Robotic-telescope Intelligent Array) is an innovative citizen-science network of robotic observatories, which will give free access to the professional telescopes for a virtual community via the Internet. Contribution to GLORIA is given by 13 partners with 17 robotic telescopes scattered in 7 countries all over the world. This will allow for continuous observations of celestial objects from different locations.

GLORIA allows users to run experiments in the network. These experiments can be divided into two general types:

- on-line experiments, for making observations with robotic telescopes. Experiments can involve teleoperation of the telescope (interactive mode) or doing scheduled sky observations in the network (batch mode).
- off-line experiments, for analyzing of the collected data on basic level (for education or outreach) or doing more advanced image analysis (research level).

GLORIA project provides free standards and tools for doing research in astronomy, both by observing with robotic telescopes and by analyzing data that other users have acquired with GLORIA and/or from other free access databases, such as the European Virtual Observatory. To present network capabilities and performance of the developed tools demonstrator experiments were created. To participate in such an experiment one only needs to create a user account via the project's website, and then, after signing in, user can choose between different on-line and off-line experiments.

2. PI OF THE SKY PROJECT

The main goal of the Pi of the Sky project is a search for short timescale astrophysical phenomena,

[1]Faculty of Physics, University of Warsaw, Hoża 69, 00-681 Warsaw, Poland.
[2]Send correspondence to: Lukasz.Obara@fuw.edu.pl
[3]National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland.
[4]Center for Theoretical Physics, Al. Lotnikow 32/46, 02-668 Warsaw, Poland.

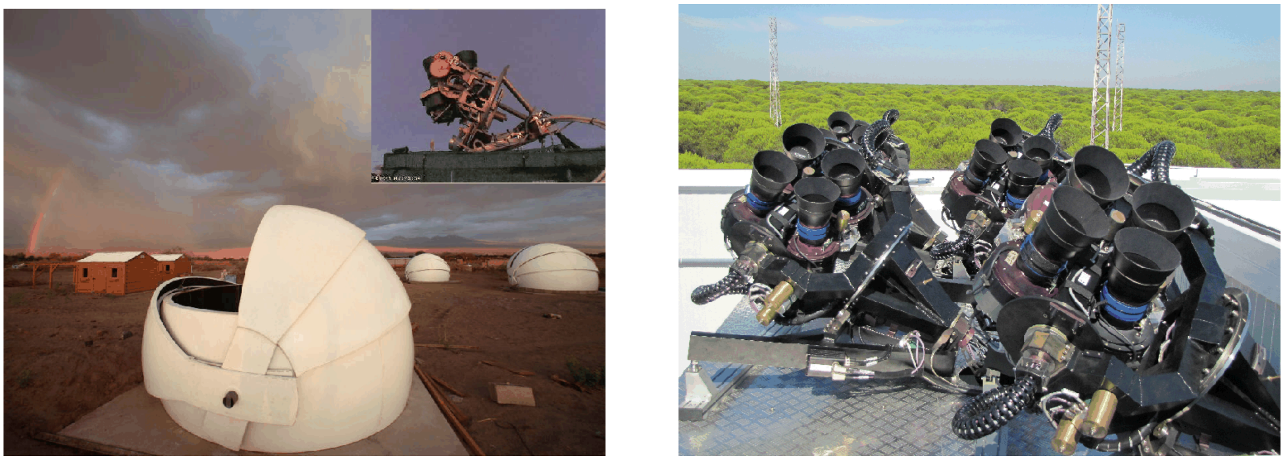

Fig. 1. Observatories of the Pi of the Sky project: prototype telescope at San Pedro de Atacama in Chile (left) and the final system or 4 telescopes (16 CCD cameras) in INTA, Spain (right).

especially for prompt optical GRB emission, with a system of wide field-of-view robotic telescopes currently installed in two observatories (Cwiek et al. 2013). The prototype device was installed in 2004 in Las Campanas Observatory (LCO), Chile, and moved to San Pedro de Atacama in 2011, see Fig. 1 (left). It consists of 2 CCD cameras on single mount. First detector unit of the final system was installed in October 2010 at INTA, El Arenosillo nearHuleva, Spain. An additional 3 units were installed in July 2013, see Fig. 1 (right). In all cases we use custom designed cameras with 2000x2000 pixel matrix and Canon lenses (f = 85 mm, f/d = 1.2). All cameras in Spain and one camera in Chile have only standard UV and infrared cut filters installed, whereas the second camera in Chile has an R Johnson-Bessel filter.

The detector and system design have been optimized for effective search for fast optical transients (eg. coming from GRBs). 16 cameras of the final system allow for constant monitoring of a large part of the sky (2 srad, corresponding to the SWIFT satellite FOV) with high temporal resolution. All collected data are analyzed in real-time by multi-level selection algorithm. This allows autonomous recognition and position determination for optical flashes of cosmic origin.

Pi of the Sky telescope is controlled by a custom designed software suite consisting of many programs. There are independent control programs for telescope mount and cameras. Fast image analysis and automatic transient detection in real time is run in parallel. Performance of all tasks is controlled by the dedicated shell supporting also script execution. The system was designed and optimized for autonomous operation without human supervision.

3. SCHEDULED OBSERVATIONS

Taking into account the design and operation mode of the Pi of the Sky system, it is not possible to allow GLORIA users to take control of the telescope in interactive mode. To allow doing scheduled observations for GLORIA we implemented a dedicated option allowing to execute external observation script at given time. For Pi of the Sky telescope in Spain, the time slot currently reserved for GLORIA observations is between 1 and 2 UT.

For integration of the Pi of the Sky telescope with the GLORIA scheduler a dedicated server was prepared. The server is implemented on the virtual machine running Scientific Linux SLC release 6.5. The interface is base on Python library BaseHTTPServer, allowing both the GLORIA Scheduler and the telescope system to connect with the server via simple HTTP call. The core functionality of the interface is implemented using PostgreSQL database. In particular it is used to store all configuration parameters, including telescope location and capabilities, time window dedicated to scheduled GLORIA observations and constraints imposed on the observing plans.

The procedure for doing scheduled observations is the following:

- observation target is defined by giving its position on the Sky,
- observation plan is defined by specifying the exposure parameters for a given target (exposure time, number of frames, possible constraints on the observation conditions),

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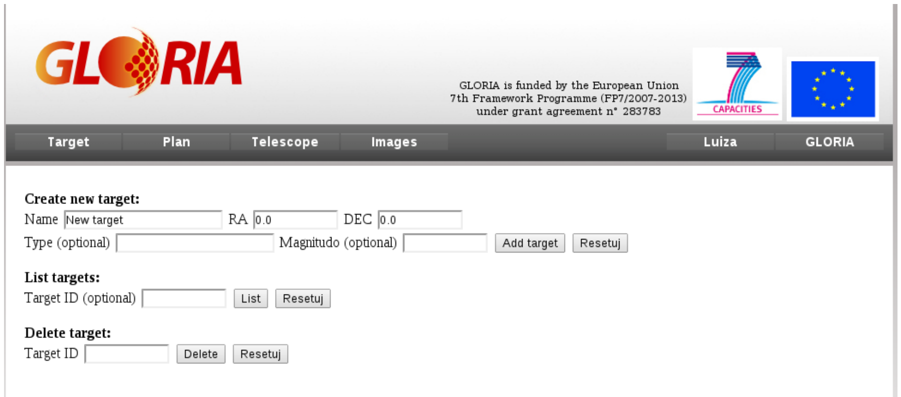

Fig. 2. Web interface to the Pi of the Sky server implemented for scheduling target observations for GLORIA. Target definition page is shown as an example.

- observation plan is checked for observability and accepted or rejected
- if confirmed, observation plan is used to generate observation script which is then downloaded and executed by the Pi of the Sky telescope,
- resulting images are uploaded to the server and accessible through the same interface.

The procedure is automatic and involves only GLORIA scheduler, the interface (plus database) and the telescope server. However, a dedicated web interface has also been designed, which allows developers (or advanced users) to communicate directly with the interface, see Fig. 2. The interface implements most of calls defined in the interface specification. Some calls are not implemented for security reasons (e.g. setting telescope parameters).

4. LUIZA FRAMEWORK

One of the challenges we have to face in designing environment for GLORIA off-line experiments is dealing with huge amounts of data and large variety of analysis tasks. We need an analysis framework which would be both very efficient and very flexible. High Energy Physics experiments deal with enormous amounts of data and complicated analysis tasks since many years. LUIZA (Zarnecki et al. 2013), an analysis framework for GLORIA, has been created based on the concept of Marlin (Gaede 2006), program developed for efficient data reconstruction and analysis in the future International Linear Collider (ILC) experiments.

LUIZA is a framework for implementation of various image reduction and analysis tools. It is based on the following assumptions:

- each data (image) analysis can be divided into small, well defined steps, implemented as so called processors,
- each step has to have well defined input and output data structure,
- by defining universal data structures we make sure that different processors can be connected in a single analysis chain,
- processor configuration and their parameters can be set by user at run time in a simple steering file.

LUIZA framework implements all basic data structures required for image analysis. Two basic data formats are:

- **GloriaFitsImage** - class for storing FITS images, which uses fitsio library for reading and storing images, and basic methods for image manipulation implemented,
- **GloriaFitsTable** - flexible class for storing other data (integers, floats, strings, vectors of int/float),

They are also used to implement other classes, dedicated to defining object lists on the CCD image (**GloriaObjectList** class) or catalogs of objects (**GloriaSkyCatalog** class). Dedicated **GloriaDataContainer** class is used to store "collections" of images and tables, each collection having a unique name.

To use LUIZA framework each user has to create a steering file (GUI is provided), in which an analysis chain can be defined by selecting processors and defining their order. The steering file allows also to define input-output streams and set other processor

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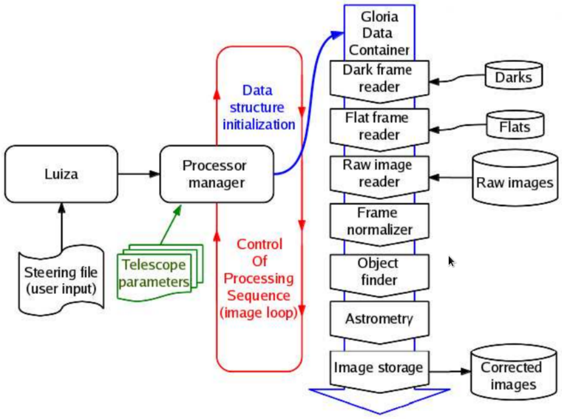

Fig. 3. Example scheme of image processing in LUIZA framework.

parameters. Each LUIZA processor gets a pointer to global GloriaDataContainer instance. Different tools allow user to create a new data collection by reading data from file, access and modify data stored in memory or save analysis results to output file. The whole analysis chain, typical for astronomical data analysis, has already been implemented in LUIZA, including frame stacking, image normalization (dark subtraction, flat correction), background calculation, photometry, astrometry, star catalog matching, frame calibration (based on a catalog or selected reference stars) and light curve reconstruction. An example scheme of image processing in LUIZA framework is shown in Fig. 3.

5. OFF-LINE DEMONSTRATOR EXPERIMENT

Using analysis tools implemented in LUIZA, data from Pi of the Sky was used to implement the research-level off-line demonstrator experiment for GLORIA, focusing on light curve reconstruction and classification of variable objects. The experiment is based on the pre-selected data from the telescope in Chile.

Pi of the Sky telescope takes sky images with 10 s exposure time. However, much better photometry accuracy is obtained from sums of 20 subsequent frames, corresponding to 200 s exposure time. Selected for the demonstrator experiments were stacked images taken from 2006 to 2009 in Las Campanas Observatory (LCO) as well as in 2012 and 2013 in San Pedro de Atacama (SPdA), Chile. After visual inspection an image pre-processing (see following section) about 500 images remained. Field of view of Pi of the Sky cameras is $20^\circ \times 20^\circ$. Selected frames correspond to 4 overlapping observation fields, and the central region of about $9^\circ \times 9^\circ$,

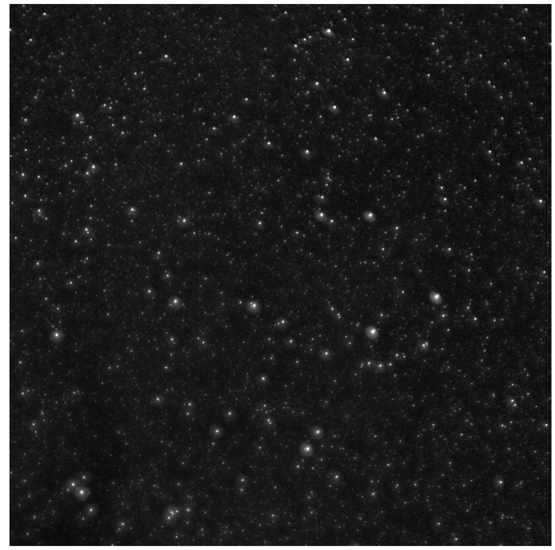

Fig. 4. Example image of the observation field selected for the demonstrator GLORIA experiment based on Pi of the Sky data.

visible on all frames was selected as the subject of the analysis, see Fig. 4.

The aim of the experiment is to allow user to reconstruct light curves of selected stars in real time. Light curve reconstruction is done with the LUIZA. Dedicated user interface was developed for easy star selection and result viewing. The interface is currently implemented on the dedicated LUIZA server running at University of Warsaw (accessible from the GLORIA user pages).

After short description of the experiment and basic information about the Pi of the Sky project, user goes to the star selection page. Three methods of star selection are available: from the sky image (by clicking with mouse), from the list (with 20 preselected objects, few of them variable) or by giving star coordinates. After the star is selected its coordinates are send to the LUIZA analysis server, which returns the reconstructed light curve after about 3-5 seconds. To verify if the selected star is a periodic variable user has to find a variability period for this star. This can be done by scanning different period values by hand (using arrows above the image, or trying to guess the value and enter it into the numeric frame) or by selecting the "Estimate" button (still experimental).

User can also make additional quality selection of light curve points based on the measurement uncertainty estimate calculated in LUIZA. As the absolute value of the optimal cut varies from star to star, we decided that user should rather decide how many

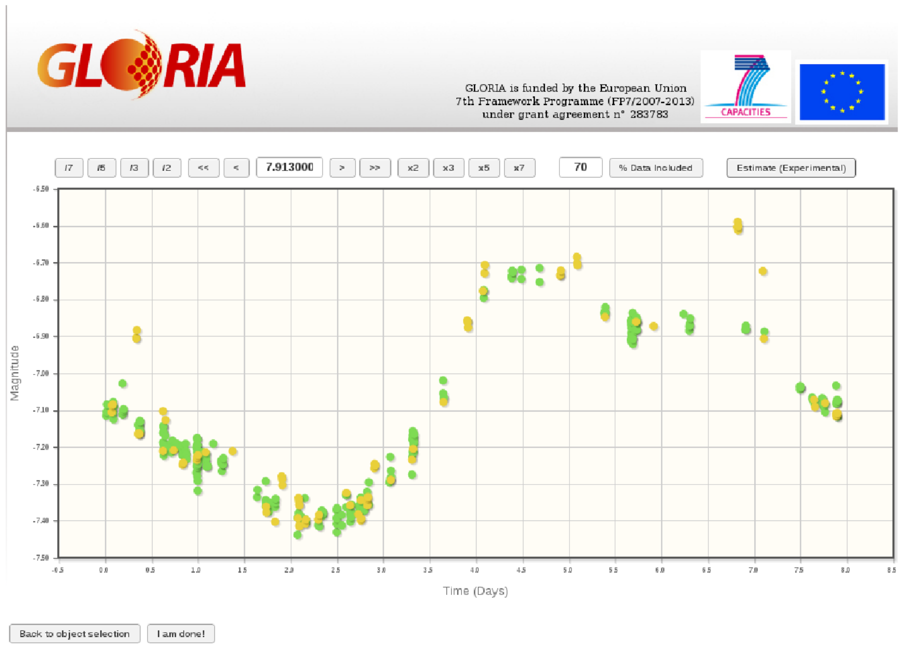

Fig. 5. Example lightcurve for W Gem cepheid star (period of 7,913 days), as obtained in the GLORIA demonstrator experiment based on Pi of the Sky data after selecting 70% of measurements with best quality. (green points 60% and orange next 10%)

data points should be presented, assuming that the most precise points are always selected first. The suggested choice is 80%, which means that 20% of points with the worst quality will be removed from the plot. To help user in deciding which points should be removed and which should be kept, a dedicated color code is used.

As an example, the phased light curves for W Gem cepheid star, obtained after selecting 70% of best measurements, is shown in Fig. 5.

6. CONCLUSIONS

The on-line and off-line demonstrator experiments in GLORIA network are already available to registered users. Pi of the Sky detector system in Spain, installed and commissioned in 2013, has been integrated into the network and is accessible for all interested amateurs and professionals for doing scheduled night sky observations. The prototype telescope in Chile is to become available to GLORIA users in March 2014.

The first research-level off-line demonstrator experiment has been developed based on the Pi of the Sky data collected in Las Campanas Observatory and San Pedro de Atacama Observatory (Chile). Archive data can be used to identify and classify variable stars. Users can also use LUIZA framework, developed by Pi of the Sky team for the GLORIA project, for more advanced analysis of their own images.

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