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FRAM: SHOWERS, COMETS, GRBS AND POPULAR SCIENCE

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RESUMEN

El telescopio FRAM, operado por el Instituto de Física de la Academia de Ciencias de la República Checa está ubicado en el Observatorio Pierre Auger de Argentina. Su objetivo principal es proveer calibración atmosférica al medir el contenido de aerosol y las características de la atmósfera sobre el Observatorio. Ya que este programa toma solo una pequeña porción del tiempo de observación disponible, el telescopio también hace seguimiento a una variedad de objetivos astronómicos, como GRBs, cometas, asteroides y estrellas variables. Dentro del proyecto GLORIA hemos desarrollado un programa de divulgación extenso, incluyendo frecuentes apariciones de nuestros resultados en los medios para el público en general.

ABSTRACT

The FRAM telescope operated by the Institute of Physics of the Academy of Sciences of the Czech Republic is located at the Pierre Auger Observatory in Argentina. Its primary goal is to provide the atmospheric calibration by measuring the aerosol content and characteristics in the atmosphere above the Observatory. As this program takes only a small fraction of the available observing time, the telescope also follows a variety of astronomical targets, such as GRBs, comets, asteroids and variable stars. Within the GLORIA project we have developed an extensive outreach program, including frequent appearances of our results in general public media.

Key Words: astroparticle physics — atmospheric effects — techniques: miscellaneous

1. INTRODUCTION

The FRAM robotic telescope (short for the F/(Ph)otometric Robotic Atmospheric Monitor) is a part of the atmospheric monitoring system of the Pierre Auger Observatory, the largest astroparticle observatory in the world (the Observatory, its subject of study and need for atmospheric monitoring are described in more detail in Ebr et al. (2014)), located near Malargüe, in the Mendoza province of Argentina (69 ° W, 35 ° S, 1400 m a.s.l.). The telescope is housed in a small dome, only several meters from one of the four buildings that host the large optical fluorescence telescopes of the Observatory, on a small hill called Los Leones, about 20 kilometers east from the town, which is the only source of light pollution in an otherwise deserted grassy plain of the Argentinean pampa. As the location of the Observatory was selected with optical observations in mind, it is not surprising that it is a very good astronomical site, with average annual cloud cover of $\sim 35\%$. The FRAM telescope has been installed in 2005 and entered routine operation in 2006. However in 2009 the bulk of the hardware was changed and additional hardware improvements have been done since then. In this paper, we refer to the current (as of November 2013) state of the telescope, unless otherwise noted (this older setup, as well as the role of FRAM in the Observatory, are described in Prouza et al. (2010)). FRAM was designed primarily to provide measurements of atmospheric extinction in different wavelengths using stellar photometry while being ready to react to GRB triggers. In time its activities expanded into a wide range of astronomical and outreach applications.

2. HARDWARE, SOFTWARE AND OPERATION

The FRAM setup (Figs. 1 and 2) consists of two instruments: a small astronomical telescope and a telephoto lens, both equipped with a CCD camera, both mounted on a single Paramount GT-1100M equatorial mount, which is capable of tracking a 60 second exposure on the equator with the 2-meter effective focal length of the main telescope without guiding (120 second exposures were possible before issues caused by worm-gear degradation in the dusty pampa environment appeared) and has an absolute homing sensor which ensures that the mount can be operated fully remotely, even in the case of a power failure that would otherwise cause the system to forget its pointing direction.

The main telescope is a 12-inch, f/10 Meade Schmidt-Cassegrain equiped with a 0.66× focal reducer and a micro-focuser by Optec. The light from

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Fig. 1. The FRAM telescope.

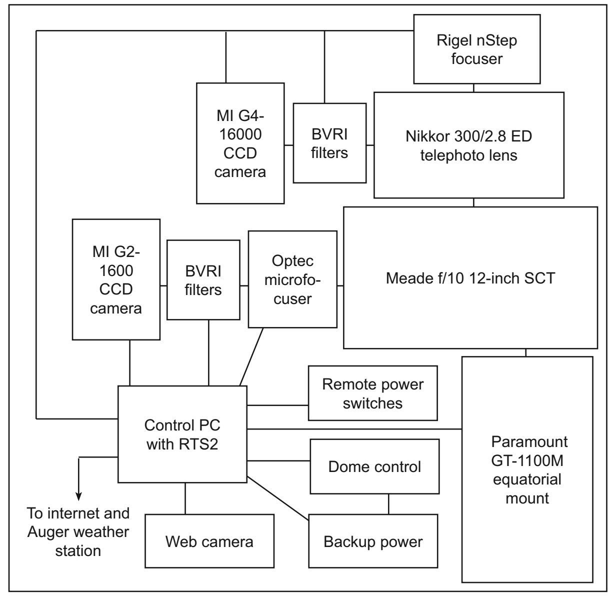

Fig. 2. Scheme of the individual components of the FRAM setup and their mutual relations.

the telescope is collected by a Moravian Instruments CCD camera G2-1600 with the KAF-1603ME sensor that has 1536×1024 pixels covering an area of 13.8×9.2 mm^2 which translates to 23×15 arcmin of field of view. The camera has a maximum quantum efficiency of more than 80 % and an integrated filter wheel occupied by a set of photometric BVRI filters. This setup (called in short the narrow-field camera, NF) reaches 16–17 mag for a 60 second unfiltered exposure and over 20 mag with image stacking. Originally, the main telescope was equipped by a photoelectric photometer, but using a CCD camera has proven to be more efficient, because more stars can be measured at once and problems with pointing accuracy, seeing and calibration are alleviated. Apart from various astronomical measurements, the main purpose of the telescope is in "slow" global extinction measurements – it cannot cover a large area of the sky fast, but it reaches high level of precision for photometry in selected standard fields.

On top of the telescope, the wide-field camera (WF) is mounted. It consists of a photographic Nikkor 300/2.8 ED lens and a Moravian Instruments CCD camera G4-16000 with the KAF-16803 sensor. This huge CCD chip with quantum efficiency of 50 % at 550 nm boasts 4096×4096 pixels and its physical dimensions are 36.8×36.8 mm^2. The lens was specifically chosen because it is able to provide almost perfect stellar images over such a large area, resulting in a fully useful field of view of $7^\circ \times 7^\circ$ over which 14 magnitude stars are reachable in individual exposures. Additional equipment includes an external filter wheel with photometric BVRI filters an the nStep focuser from Rigel systems which drives the manual focusing ring of the camera using a stepping motor. The main purpose of the WF camera is the fast measurement of extinction over a large field of view in the Shoot-the-Shower program, but it is also invaluable for fast location of transient optical phenomena in a large field (such as during GRB follow-up observations).

All the equipment is housed in a custom-built dome (Fig. 3) which is opened and closed using a hydraulic pump controlled by the Schneider Zelio programmable microcomputer. The system communicates with the Auger weather station and closes automatically when rain or strong winds are detected or no weather data are available. In case of a power failure, or loss of communication with the main PC, the dome controller closes the dome immediately. As the dome can be closed in any telescope position, this allows for a completely safe operation without any human oversight – a necessary requirement, as FRAM is in a remote location with no staff directly on site and only limited manpower available for maintenance (during the day only) from the 20-km distant Malargüe. To this end, the dome is equipped by a web camera, UPS and remote power switches, so that most issues can be solved remotely.

The whole system is operated using the RTS2 software (Kubánek et al. 2004). This complex suite for robotic telescopes is being developed chiefly by

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Fig. 3. The FRAM dome opening.

Petr Kubánek since 1999 and is used at dozens of telescopes (even meter-sized) around the world, with FRAM serving as one of the testbeds for new features. The software allows the autonomous observation of targets from a predefined pool based on a merit function or follow one or more ordered queues of targets while always allowing for interruption by external triggers. On FRAM we use mainly the queue-based target selection because of the complex time relationship between extinction observations and astronomical measurements. The triggering function is enabled for the Shoot-the-Shower program and GRB follow-ups.

3. ATMOSPHERIC MONITORING

Besides the rapid monitoring (Shoot-the-Shower) program described in Ebr et al. (2014), FRAM also measures the Angstrom exponent of the power-law wavelength dependence of extinction, which is related to the size and amount of aerosol particles in the atmosphere. Considering the information provided by the other atmospheric monitoring devices of the Pierre Auger Observatory, the results of this measurement have a relatively small effect on the reconstruction of the parameters of the observed showers. However this information is necessary for the complex understanding of the atmospheric conditions at the site.

To extract the Angstrom exponent for a given night (assuming that the aerosol content of the atmosphere changes slowly), FRAM takes regular measurements of suitable stellar fields in BVRI filters several times per night. During this time, the stars pass through different altitudes and thus are observed at different airmasses. The Angstrom exponent is then determined from the fit of the zenith angle dependence of measured brightnesses in the different filters, effectively removing the dependence

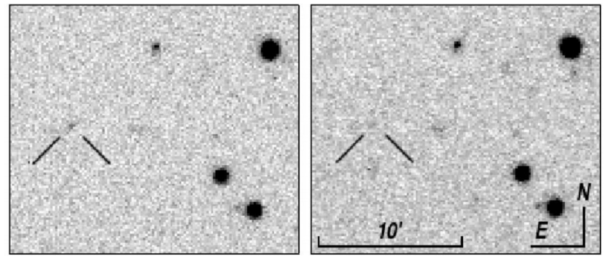

Fig. 4. Detection of an optical counterpart of GRB 060117 by FRAM (marked object) at different times (249 and 480 s) after the trigger.

on the absolute response of the system. Recently we have been working on establishing methods for absolute measurements of extinction from single images, which is so far promising, but not yet ready to use.

4. ASTRONOMICAL OBSERVATIONS

As both hardware and software of FRAM were designed with GRBs in mind, it is capable of a very fast follow-up observation of optical counterparts of GRBs. At least four such events were positively detected by FRAM: GRB 060117 was observed (Fig. 4) between 2 and 10 minutes after trigger and a counterpart with maximum brightness R=10.1 was detected (Jelínek et al. 2006); for GRB 060418 we took first exposures 51 seconds after the burst, but the detection was only possible after 5 minutes using 220 seconds of integrated exposure time, capturing the light curve peak at 14.2 mag. Both of these were captured using the oldest setup with no CCD camera on telescope, thus using only the WF camera on a 200/2.8 lens. With the newer setup, we observed GRB 120913B, starting at 24.4 seconds, obtaining a measurement of R = 16.3 on a sum of 8×10 second images obtained between 271 and 364 s after the burst. Finally, the data from GRB 130605A are still being processed, with possible positive detection; additionally more than 10 useful limits on other GRBs were obtained.

Thanks to the flexibility of the RTS2 system, the telescope can also make various planned observations in its "free time" (between observations for atmospheric monitoring). Regular FRAM targets are variable stars, particularly eclipsing binaries and Be stars. As we check every observed field for new variables, we have already discovered 14 of them, including CzeV500, the 500th Czech variable star discovery. Another important area of research on FRAM is astrometry of asteroids and comets and photometry of comets. Until October 2012, we have published observations in 75 circulars of the Minor Planet Center (station id I47). Furthermore, we

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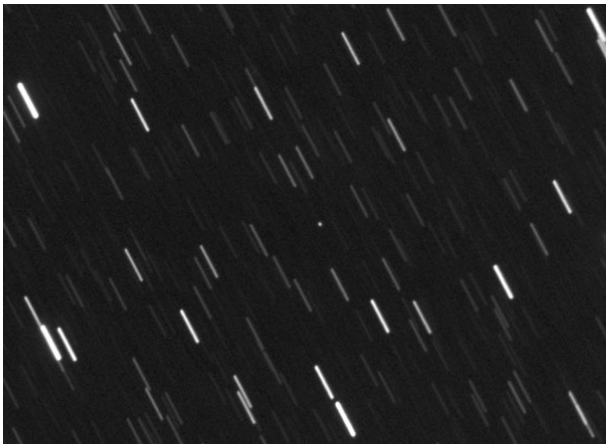

Fig. 5. Example of a near-Earth object imaged by FRAM: asteroid (99942) Apophis.

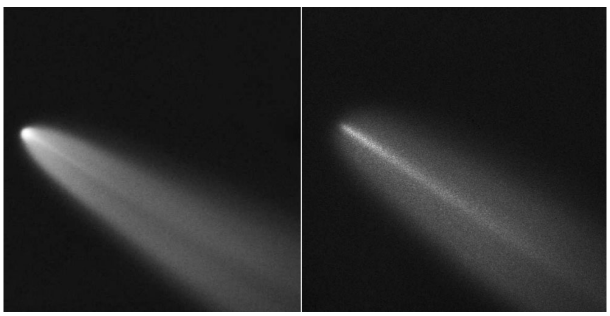

Fig. 6. Two of the post-perihelion images of comet C/2011 W3 (Lovejoy) taken by FRAM.

carry out follow-up observations of near-Earth objects (Fig. 5), BVRI photometry of selected comets (a program which is very underrepresented at the southern hemisphere), measurements of dust content in comets for the CARA (Cometary ARchive for Afrho) database and general observations of interesting objects, such as the recent recovery of comets 260P/McNaught and 296P/Garradd on their second perihelion passages or the observations of comet C/2011 W3 (Lovejoy) which constitute the first ever ground CCD photometry of a Kreuz family comet, including unique post-perihelion images (Fig. 6) that have been used in an article by leading experts in the field (Sekanina & Chodas 2012).

5. OUTREACH AND CITIZEN SCIENCE

Some of our observations of small solar system bodies have reached widespread recognition on news websites. For example our images of comet C/2011 L4 (Panstarrs) have reached the front-page of spaceweather.com, while those of the near-Earth passage of asteroid 2012 DA14 were featured at websites such as space.com, usatoday.com in the U.S. and many more in other countries such as Japan, Australia or Indonesia; our unique images of C/2011 W3 (Lovejoy) can be found accompanying dozens of articles.

The project has also its own web pages at gloria.fzu.cz with information about the telescope and frequent updates. FRAM and GLORIA are frequently presented in Czech media thanks to our collaboration with www.astro.cz (the main Czech portal about astronomy) and two different stations of Czech Radio. There, to stimulate interest among listeners, we created a “Get your object observed” campaign, where we sent a call for proposals from the general public. As a result, we imaged for example Pluto for a 7-year old astronomer and presented the image to the young scientist at Czech Radio during live broadcast.

We are also working on a system allowing the public to request observation on demand using the RTS2-BigBrother software that allows batch-mode observations through web front-end. The user can simply register at gloria.fzu.cz and fill in a form requesting a target to be observed. After an approval from an administrator, the target is queued for observation on FRAM and when the data are ready, the user receives an e-mail with instructions how to retrieve calibrated images.

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