Second Workshop on Robotic Autonomous Observatories
ASI Conference Series, 2012, Vol. 7, pp 25 – 32
Edited by Sergey Guziy, Shashi B. Pandey, Juan C. Tello &
Alberto J. Castro-Tirado

BOVIS, the visible eye of Bootes-IR[*]

A. Riva[1], M. Jelínek[2], R. Cunniffe[2], S. Vítek[3], A. J. Castro-Tirado[2],
M. Riva[4] and F. M. Zerbi[4]

[1]*INAF - Osservatorio Astronomico di Torino, Strada Osservatorio, 20, I-10025,*
Pino Torinese (TO), Italy
[2]*IAA - Instituto de Astrofisica de Andalucia (CSIC), Camino Bajo de Huètor, 50,*
18008 Granada, Spain
[3]*Faculty of Electrical Engineering, Czech Technical University in Prague, Technická, 2,*
166 27, Praha, Czech Republic
[4]*INAF - Osservatorio Astronomico di Brera, Via E. Bianchi, 46, I-23807, Merate (LC), Italy*

Abstract. This paper describes the design of a visible camera (BOVIS - BOotes VISible camera) to be installed at the Nasmyth focus of the BOOTES-IR telescope, operating at OSN, Granada, Spain. BOVIS will be fed by the visible light produced by means of a dichroic that splits the light coming from the telescope into two channels. Visible channel ranges from 400 *nm* to 850 *nm*, while the existing infrared channel (covered by the BIRCAM camera) ranges from 900 *nm* to 2300 *nm*. The instrument is compared to the REM-ROSS2 facility (La Silla, Chile) currently in refurbishing phase. An adaptive optics option is also proposed as a possible technique to increase performance beyond the seeing limitations of the Sierra Nevada site.

Keywords : GRB – visible camera – robotic instrumentation

1. Introduction

One of the most significant issues in GRB science is the detection of the afterglow in the optical wavelength range. The first instrument devoted to such afterglow detection onboard of a robotic telescope was ROSS, installed on the Italian REM telescope at La Silla, Chile (Zerbi et al. 2003; Tosti et al. 2004; Zerbi et al. 2004). The REM-ROSS instrument provides simultaneous coverage of the visible and infrared band for GRB

---

[*] email: `riva@oato.inaf.it`

afterglow detection. The ROSS camera was recently re-designed and is currently in a commissioning phase as ROSS-2.

The BOOTES-IR telescope was born as a twin of REM for the northern hemisphere, installed at OSN (Observatorio de Sierra Nevada), Granada, Spain (Castro Tirado et al. 2006). Two years ago we discussed the first scientific light of the infrared camera, BIRCAM (Bootes Infrared CAMera), installed on BOOTES-IR (Riva et al. 2010). In this paper, we present the design of a visible instrument as an improvement of the BOOTES-IR experiment.

2. REM experiment

REM (Rapid Eye Mount) is an Italian robotic 60 *cm* telescope installed in June 2003 at the ESO site of La Silla. It is fully operational since 2005 and is equipped with two instruments: an infrared camera (REMIR) sensitive from 1 to 2.3 μm and a visible instrument (ROSS). It produces on average around 10 refereed papers per year and an average 15 GCN (Gamma-ray Burst Coordination Network) alerts per year. It serves a broad community that includes GRB science, Supernovae, AGNs and is expected to provide support/followup for the Gaia satellite mission.

2.1 ROSS and ROSS-2

ROSS (REM Optical Slitless Spectrograph) was the first generation instrument onboard REM, covering the visible band. It was equipped with a 1024x1024 CCD detector, with 13 μm pixel size and a Field Of View (FOV) of 10 *arcminutes* (Tosti et al. 2004).

ROSS was equipped with an Amici prism, capable of a low resolution optical spectroscopy, and the broadband V, R, I photometric filters mounted in a filter-wheel.

The ROSS-2 instrument discards the filter-wheel (Spanò et al. 2010) in favor of simultaneous (Sloan g', r', i' and z') imaging on different areas of a single (larger) CCD (see Figure 1 and Figure 2). The new CCD is 2048x2048 pixels, with a pixel size of 13.5 μm, and the resulting instrument has a plate scale of 0.58 *arcsec* per pixel, and a corresponding effective FOV of 10 *arcminutes*. In this design, the light comes from the collimator and is split into four beams via a succession of dichroic beamsplitter cubes with different coating substrates. The four beams are displaced in the same direction and are clustered by means of folding prisms such that each beam is focused on a separate quadrant of the single detector. This is detailed in Riva & Spanò (2008). The final result is an instrument with four separate 1024x1024 pixel scientific acquisitions gathered by a single detector and a single set of readout electronics. A mechanical sketch of the instrument is represented in Figure 3.

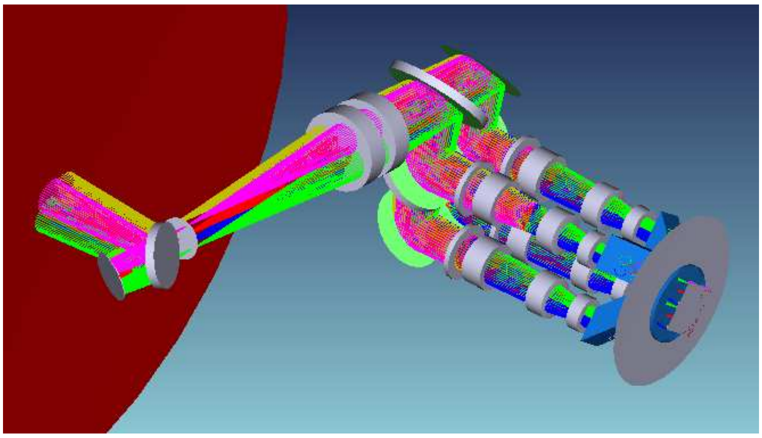

Figure 1. Optical layout of ROSS-2 with respect to the derotator flange in red (courtesy of Paolo Spanò).

3. BOOTES-IR

BOOTES-IR, the Burst Observer and Optical Transient Exploring System in the near-InfraRed is the extension of the BOOTES project towards near-IR, installed at Sierra Nevada (OSN) at 2986 *m* above sea level. It is designed as a twin of the REM experiment, with the same philosophy and some modifications. The BOOTES-IR experiment was first proposed in 2001. The enclosure was built in the Summer of 2003. The telescope was installed at the end of 2004 and first light was obtained in February 2005. In October 2006 the infrared camera BIRCAM produced its first scientific light (Riva et al. 2010). The telescope can point to a new target within ~10 seconds, and with the BOOTES-IR camera (BIRCAM) can image a GRB anywhere within the field (3 *arcminutes* of precision) identified by the SWIFT satellite (Gehrels et al. 2004). This combination allows the coverage of a GRB in near-IR within the first minute after its detection.

3.1 BIRCAM

BIRCAM is an infrared camera working in the 1-2.3 μm wavelength range. The camera is designed around a 1024 x 1024 pixel HgCdTe detector, and covers a 12 *arcminutes* FOV with a plate scale of 0.7 *arcsec* per pixel. The camera has a rotating tilted window placed before the camera entrance in order to displace the field of view in different zones of the detector, allowing software correction of the background sky without moving the telescope (though for extended sources, this is not enough, and dithering must be done with the telescope itself). The camera is liquid-nitrogen cooled, via an internal reservoir. Recent installation of a liquid-nitrogen plant for

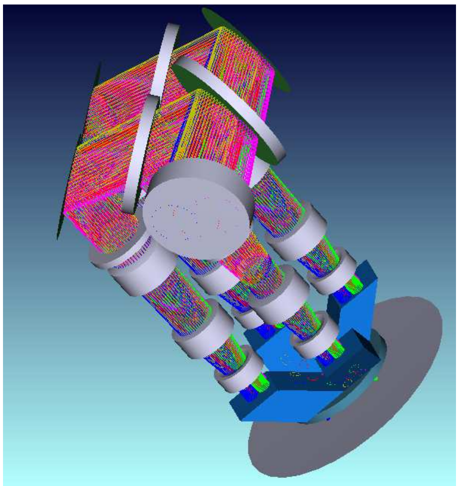

Figure 2. Detail of the optics used for the four simultaneous channels on the same detector for ROSS-2 (courtesy of Paolo Spanò).

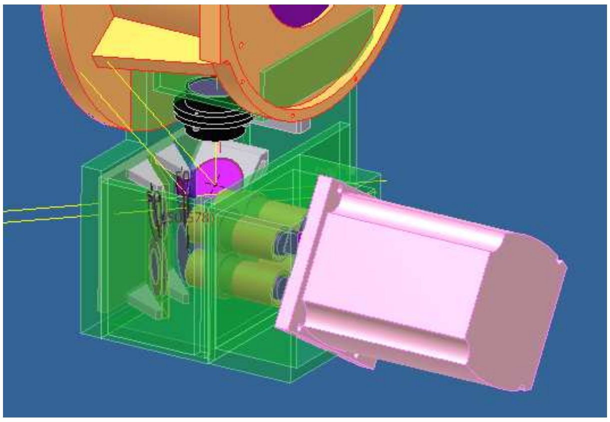

Figure 3. Mechanical layout of ROSS-2 with respect to the infrared flange in yellow (courtesy of Vincenzo De Caprio).

the telescope allows far greater autonomy for the instrument. An automatic refilling system has been designed and will be implemented after a refurbishment of the dome currently in progress.

A 45-degree dichroic placed before the first IR-specific optical element reflects wavelengths shorter than 800nm, providing an opportunity (for which mechanical support was provided in the mounting flange) to add an optical camera, as done on REM. However, the current dichroic introduces a ghost into the IR image - a second copy of each star, containing approximately 10% of the corresponding light. This has slowed down the development of the optical arm but although the IR camera cannot achieve a perfect focus with the dichroic removed, it is still able to acquire astronomical images with a small impact on the image quality.

The investigation of the dichroic problem lead us to several possibilities that must be tested onboard the telescope, which will be tested after the current dome and mirror refurbishment. The most probable causes are an unpredicted bi-refringence effect due to a mechanical stress in the dichroic or the pollution due to the absence of an anti-reflection coating on the back side of the dichroic itself.

4. BOVIS

BOVIS (BOotes VISible camera) is designed for installation as the optical arm of BOOTES-IR telescope. We designed this instrument using the same philosophy as ROSS-2 for REM. The main driver of the design is to acquire simultaneous images of the same field in the visible band too.

The main difference with respect to the precursor is the wavelength of cut-off of the dichroic that feeds the infrared arm. In REM, the dichroic has a cut-off at 940 *nm*, while the BOOTES-IR one has the cut-off at 800 *nm*. This specification for the Spanish instrument was explicitly requested in order to have the possibility to includethe z' filter in the infrared channel (UKIRT z-filter: central wavelength 877 nm, FWHM 95 nm, cut-on 830 *nm*, cut-off 925 *nm*). The first effect of this is to reduce the number of channels from four to two (Spanò et al. 2010). This drastically reduces the complexity of the instrument. In the next subsections we detail the instrument's requirements and the proposed baseline solution.

4.1 Requirements

The primary design requirement for the visible arm is to match the FOV and plate-scale with those of BIRCAM, in order that both infrared and the visible channels will offer simultaneous images of the same sky portion.

The primary design restriction is the limited mechanical envelope available. The IR camera is mounted to the Nasmyth focus via a derotator. A shelf containing the IR camera electronics is mounted below the Nasmyth mount, with ~ 35cm clearance between the top of the electronic equipment and the IR camera's barrel. The optical instrument must de-rotate along with the IR camera, and therefore must fit within this envelope. Furthermore, the IR camera has protrusions on three out of four sides: pre-amplifier electronics, liquid-nitrogen refilling point, and the filter-wheel drive mechanism), leaving only one side free for an optical instrument.

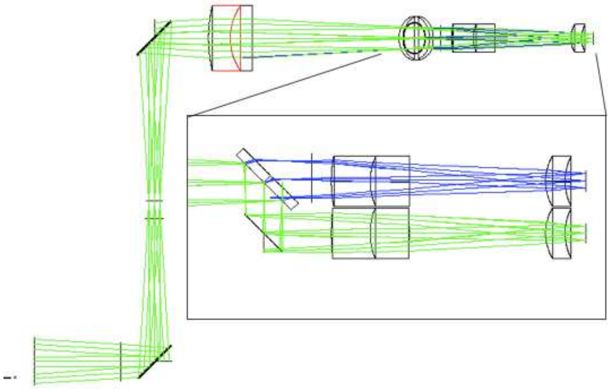

Figure 4. Optical layout of BOVIS. The figure shows how the light is bent from the dichroic to the visible camera, and a detail of the second dichroic that splits the light into the two channels.

4.2 Optics

Taking these constraints into account, we designed a compact camera with two channels and only one detector. By imaging both channels onto one half of the detector, we also have new options with regard to frame-transfer, and/or higher frame rates due to only reading out half the chip.

Figure 4 shows the layout of the designed optics. After the beamsplitter, represented by a fold mirror, the beam reaches its first focal plane, just outside the envelope of the interface between instrumentation and derotator (called "dadone"). After a thickness of 150 *mm*, another fold mirror bends the light back parallel to the infrared one. This displacement of the optical axis is designed in order to optimize the space occupied by the visible camera. The diverging beam encounters the collimator stage, composed by two lenses in optical glass F2 and BK7. Once the beam is collimated, a dichroic splits the light into two arms. This beam splitting is developed in the plane parallel to the lateral face of the infrared camera. This idea helps in the final compactness of the instrumentation onboard of the telescope. We call the two beams as "b+v" and "r+i". The "b+v" beam crosses the dichroic, while the "r+i" is reflected at 90 degrees.

Since the idea is to reach the same focal plane, the two outgoing arms have different optical elements. The "b+v" arm is composed by three lenses, while "r+i" is composed by a fold mirror and three lenses. All optical specifications are summarized in table 1.

The two focused beams go onto the same detector, a 2048x2048 CCD using only two quadrants (for an equivalent 1024x2048). The final FOV matches that of the infrared camera, $12' \times 12'$ with $0.7''$ plate scale.

Table 1. In this table, values of the optical train are reported.

Name	Material	Thickness[a]	Radius 1[a]	Radius 2[a]	Diameter[a]
Fold mirror	Aluminum	/	$inf.$	/	45
First Collimator	F2	20	-136.022	-51.846	60
Second Collimator	BK7	20	-51.846	130.371	60
Dichroic	BK7	5	$inf.$	$inf.$	40
Second fold mirror	Aluminum	/	$inf.$	/	28
First Camera[b]	F2	20	-61.310	-30.191	26
Second Camera[b]	BK7	20	-31.191	-211.391	26
Third Camera[b]	BK7	20	-25.417	-28.210	26
First Camera[c]	F2	20	-100.521	-34.129	26
Second Camera[c]	BK7	20	-34.129	146.162	26
Third Camera[c]	BK7	20	-25.417	-28.210	26

Notes: (a) values are in [mm]; (b) referred to “b+v” arm; (c) referred to “r+i” arm.

The mechanical structure needed for holding the optical elements is very simple. The only requirement is mechanical stability once the system is aligned - there are no moving parts. The optical bench with all its parts is enclosed in a simple, light-tight aluminum box, which together with the low cost of the glass required (BK7 and F2) yields an inexpensive and effective scientific instrument..

5. Future developments: adaptive optics

One constraint of BOOTES-IR is the dimension of the primary mirror (0.6 *m*). A small diameter mirror necessarily has a high diffraction limit. In conjunction with the 1” median seeing of Sierra Nevada, it represents a limit for the optical and infrared observations.

We are considering a possible improvement of BOVIS by trying to reduce the PSF since we cannot increase the collecting area. We briefly studied the option of adaptive optics using lateral sky zones. Since the scientific requirement imposed by SWIFT is the dimension of a circular field (12’) we can take advantage from the corner portions of the sky. We localized a small portion of the sky in the first focal plane zone (the one just outside the “dadone”). In this area we extract some light to a wavefront sensing instrument. By improving the telescope, changing the M3 mirror into a fast tip-tilt mirror by means of piezoelectric actuators, we predict that we will be able to reduce the typical image size from 1” to 0.5” with relatively low efforts.

Such development will be studied in future work, but the BOVIS camera has been designed to take this possibility into account.

6. Conclusions

In this paper we presented the future evolution of the BOOTES-IR instrument. After the installation and commissioning of BIRCAM, a camera devoted to infrared observations, the instrument will host a visible camera BOVIS. Visible light is produced by means of a dichroic that separates the light before entering in the infrared camera. The development philosophy of BOVIS is similar to the ROSS-REM one, a single instrument with more than one simultaneous band observed by the same detector. A further improvement of the instrument will be the possible adaptive option through a modification of the tertiary flat mirror of the telescope.

Acknowledgements

We want to thank the three main communities involved in this study: the REM collaboration, the IAA GRB community and the Golem workgroup. Special thanks are due to Paolo Spanò and Vincenzo De Caprio, who developed the ROSS-2 instrument and provided very useful data and qualified support for the BOVIS design. IAA collaborators are also consistent and everyone gave a valid contribution to BOVIS and BOOTES-IR project as can be seen from author list of many of the cited papers. Last but not least the Golem group (namely based in INAF-OABr but spread in the world) offered the possibility of developing the BIRCAM camera and of studying BOVIS.

References

Castro Tirado A. J., Cunniffe R., de Ugarte Postigo A. et al., 2006, SPIE proceedings, 6267, 62670I
Gehrels N., Chincarini G., Giommi P. et al., 2004, ApJ, 611, 1005
Riva A., Conconi P., Castro-Tirado A. J. et al., 2010, Advances in Astronomy, 2010, 39
Riva A., Spanò P., 2008, SPIE proceedings, 7014, 165
Spanò P., de Caprio V., La Foresta M. et al., 2010, SPIE proceedings, 7735, 202
Tosti G., Bagaglia M., Campeggi C. et al., 2004, SPIE proceedings, 5492, 689
Zerbi F. M., Chincarini G., Ghisellini G. et al., 2003, SPIE proceedings, 4841, 737
Zerbi F. M., Chincarini G., Ghisellini G. et al., 2004, Advances in Space Research, 34, 2739