Fabra-ROA Baker-Nunn camera at Observatori Astronòmic del Montsec: an instrument update for space debris observation

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1. ABSTRACT

A series of Baker-Nunn Cameras (BNC) were manufactured by Smithsonian Institution during the 60s as optical tracking systems for artificial satellites. They were designed to perform optimal optical and mechanical specifications. One of these BNCs was installed at the Real Instituto y Observatorio de la Armada (ROA).

An extensive refurbishment project has been conducted over this camera, turning it into a CCD remote and robotic facility. It has been installed at the Observatori Astronòmic del Montsec (OAdM), in the Catalan Pre-Pyrenees.

As a result, this BNC offers an optimal combination of instrumental specifications for observing space debris, namely: a huge FOV (4.4ºx4.4º), limiting magnitude (V~20) with 30s integration time, capabilities of tracking at arbitrary RA and DEC rates, and opening and closing CCD shutter at will during the exposure. All this performance, together with their remote and robotic natures, allows the refurbished Baker-Nunn camera to revisit an observational program very similar to which was conceived.

2. ORIGINS AND REFURBISHMENT PROJECT

This Baker-Nunn camera was commissioned at ROA (San Fernando) in the 60s by the Smithsonian Institution, with the aim of monitoring artificial satellites. It was optically designed by Perkin-Elmer as a f/1 0.5m photographic wide field (5ºx30º) telescope with a spot size smaller than 20µm throughout the field and mechanically manufactured by Baller & Chivens. During the 80s, the Baker-Nunn cameras were superseded by new technologies (laser, radar and CCD) and it was donated to ROA, where it has been maintained inactive but in excellent state of conservation.

Three other Baker-Nunn cameras have been already refurbished into equatorial, optically refigured and CCD-based facilities: APT at Siding Springs [1], Phoenix at AMOS [2] and NESS-T at RAO [3]. Thanks to these previous experiences we could optimize the *know-how* of this complex refurbishment process and speed-up the learning curve. Later to our initiative, another BNC at ARIES (India) has been started to refurbish [4].
The looking of the BNC before and after such project can be seen in Figs. 1.1 and 1.2.

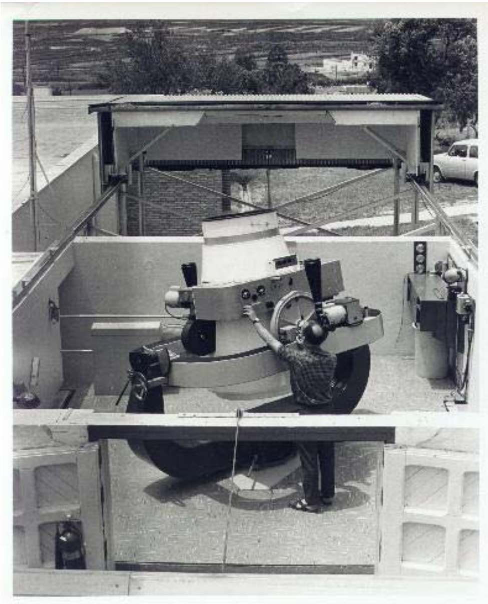

Fig.1.1. Pre-refurbished Fabra-ROA Baker-Nunn.

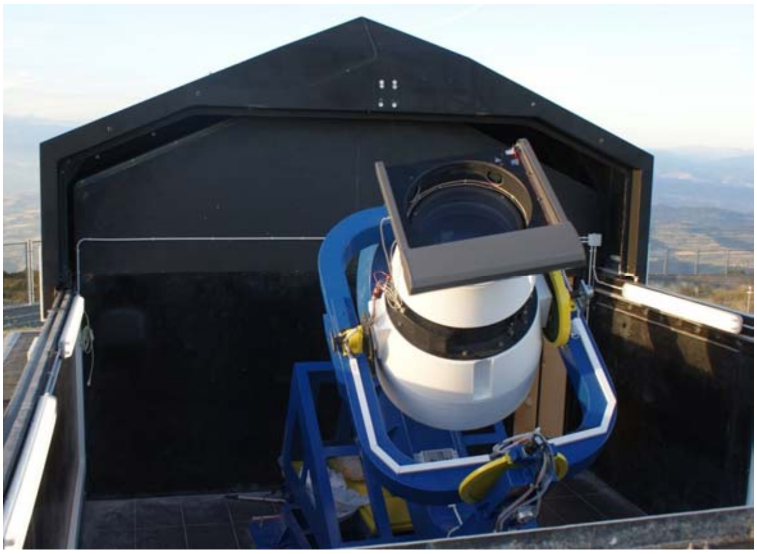

Fig.1.2. Post-refurbished Fabra-ROA Baker-Nunn at Observatori Astronòmic del Montsec.

The refurbishment process can be summarized in the following steps:

A) The original alt-azimuthal mount has been converted into equatorial type. The motion of RA and DEC axes are geared with digital servo drives and feeded-back with absolute position encoders.

B) A new spider vanes and focus system for the CCD was designed and machined by Moreno Pujal S.L. (Fig. 2). Such support is athermal and the focus accuracy was found to be ±10µm.

C) A 20µm spot size has been guaranteed throughout a flat FOV of 6.25º in diameter thanks to the design (Malcolm J. MacFarlane, PhD.) and manufacture of a CaF 64mm field flattener (Harold Johnson Optical Labs, Inc.) and a 180mm fused silica ellipsoidal meniscus (Tucson Optical Research Corporation, Inc.) lenses.

D) By the first-time a large-format chip commercial CCD was designed and manufactured with a field flattener lens inside the camera body by Finger Lakes Instrumentation, Inc. (Fig. 3). The flattener lens was placed as close as 0.65mm to the CCD chip. The camera also includes a new large aperture (90mm) shutter and glycol recirculation cooling.

E) A 12mx5mx4.5m reinforced glass-fiber enclosure was designed and constructed by GRPro, Inc (Fig. 4). This prototype is inspired in the one built for Super-WASP project [5]. It has turned to be very robust to weather conditions with no incidence to their mobile parts (sliding roof and south gabling wall).

F) An state-of-the-art observatory control software based on the INDI device communication protocol was designed and implemented by Elwood C. Downey [6]. It allows both remote and robotic control of every device in the observatory via Internet with the use of Java clients or schedulers (Figs.5, 6 and 7). Observing blocks are directly written in XML. Complex environmental conditions decisions are easily scriptable with Perl, bash or other languages.

G) Mirror realuminization (Fig. 8) and repolishing of outermost 50cm lens (Fig. 9) were performed by H.L.Clausing, Inc. and Harold Johnson Optical Labs, Inc., respectively.

The specifications achieved after the refurbishment process are shown in Table 1.

Table 1. Post-refurbished Fabra-ROA Baker-Nunn specifications.

Mount	
Type	Equatorial
Motion	
RA and DEC	Digital servo drives with arbitrary drift rate
Optics	
Design	Baker-Nunn design with field flattener and meniscus lenses
Aperture	0.5m
Focal ratio	f/0.96
Scale	3.9 arcsec / pixel
Mirror diameter	0.78m
Field of view	4.4º x 4.4º
Spot size	20µm
Filter	Schott GG475
Detector	
Sensor	Kodak KAF-16803
Format	4Kx4K, 9µm
QE	60% peak at 550nm
Camera	FLI PL16803 cooled with glycol (ΔT=65ºC)

Fig.2. Spider vanes and focus support.

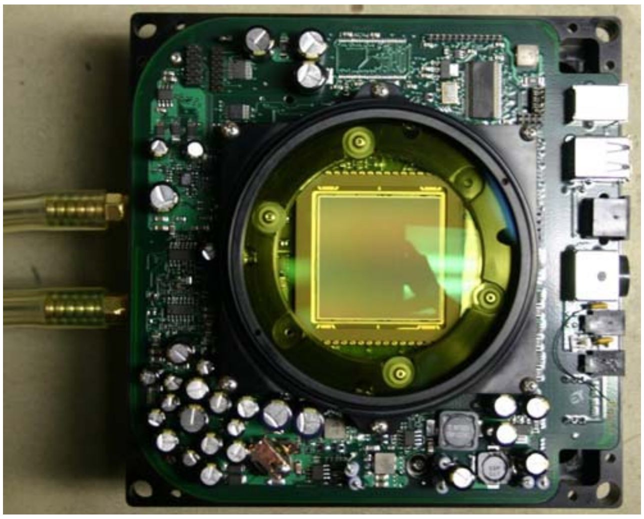

Fig.3. Finger Lakes Instrumentation, Inc. CCD with flattener lens and glycol cooling.

Fig. 4. Reinforced glass-fiber enclosure at Observatori Astronòmic del Montsec.

Fig.5. Main window of INDI-based control software in remote mode.

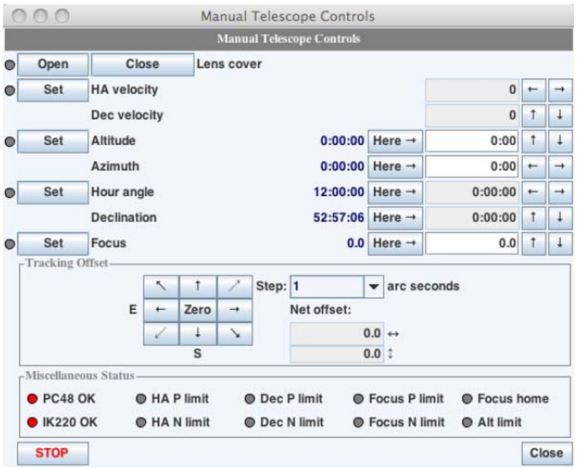

Fig.6. Manual telescope control in remote mode.

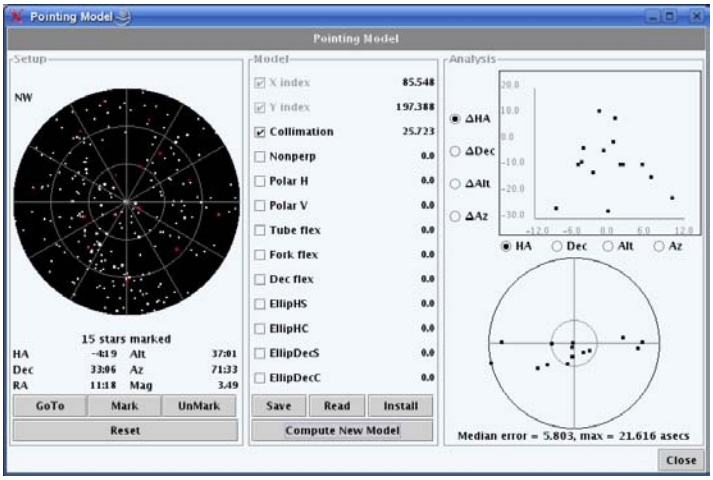

Fig.7. Pointing model with up to 13 coefficients.

Fig.8. Realuminizated mirror with SiO_2 coating.

Fig.9. Repolishing of outermost 50cm lens.

3. FIRST TECHNICAL LIGHT

On 23 Sep 2009, with unpolished lens, non-realuminizaed mirror, non collimated optics and the non-optimal light pollution conditions of the testing site at San Fernando Observatory, a series of images were taken. In spite of the four former drawbacks, the quality of the images was promising. These good expectations were confirmed in the first light at the definitive observing site (Observatori Astronòmic del Montsec), which was performed at the time of writing, after mirror realuminization, outermost lens repolising and preliminary collimation of the optical system. As seen in Fig. 10, the quality fully guarantees the scientific usefulness of the telescope.

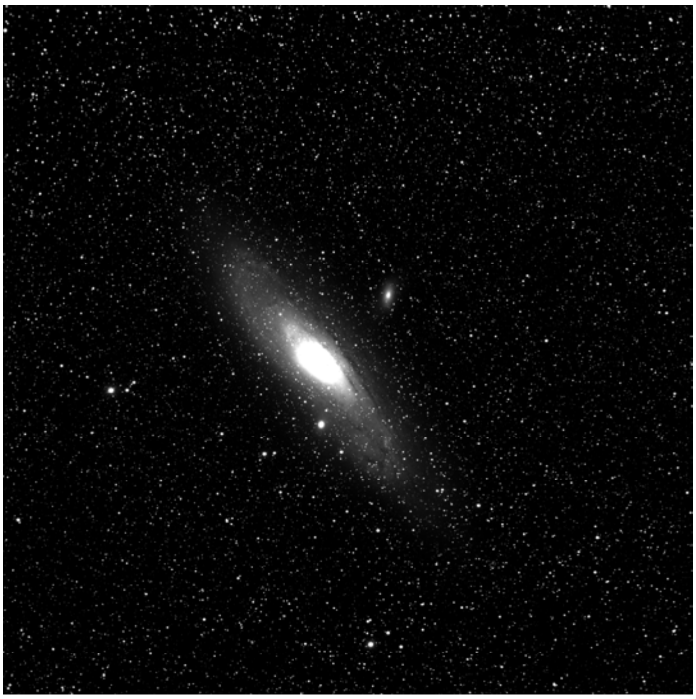

Fig. 10. First 4.4ºx4.4º technical image of M31 taken at Observatori Astronòmic del Montsec on 11 Sep 2010.

4. COMMISSIONING SCHEDULE AND SPACE DEBRIS OBSERVATIONAL PROGRAM

At the time of writing, the telescope is being commissioned at its definitive site at Observatori Astronòmic del Montsec. This implies that the post-refurbished Fabra-ROA Baker-Nunn camera will be mostly operational *in-situ* mode by the end of September 2010. The remote and robotic control has already been tested at San Fernando successfully, and will be fully operative by the end of 2010.

The following combination of instrumental specifications of the Fabra-ROA BNC provides unique efficiency to detect and track faint GTOs, GEOs and other space debris in a very short time:

1. Moderately deep limiting magnitude ($V\sim20$ mag) with 30s integration time.
2. Huge FOV (4.4º x 4.4º) free of optical aberrations.
3. Capability of tracking simultaneously in RA and DEC at arbitrary rates.
4. Capability of triggering several times the CCD shutter at will during an exposure.
5. A preliminary (with non-collimated and unpolished lens) astrometric accuracy of point-like objects of 0.25 arcsec.
6. Millimagnitude photometric accuracy is expected for point-like objects of $8<V<16$. This accuracy has already been achieved by the APT BNC at Siding Springs in the $8<V<14$ range with a less sensitive and coarse pixel CCD.

As other institutions (CNES, ESA, ISON, see e.g. [7]) the ROA have developed techniques for observing and reducing images with parked telescope, especially suited for the detection and characterization of objects in the Geostationary ring (PASAGE project [8]). With these techniques and the Fabra-ROA Baker-Nunn camera will allow us nearly immediately to monitor our visible "GEO Protected Region", in accordance with the recommendations of the IADC (Inter-Agency Space Debris Coordination Committee) and the UN Space Debris Mitigation Guidelines [9].

In addition, other scientific programs can benefit from the above Fabra-ROA BNC instrumental specificacions (discovery and monitoring of NEAs, NEOs, KBOs, TNOs, main belt asteroids, comets and search of extrasolar planets by transit).

And finally, we are aware that there are two instrumental aspects which will require our special attention:

1. Flatfield for huge FOVs and fast systems (f/1) are challenging.
2. Focal length stability with temperature with an f/1 system requires calibration or monitoring.

5. REFERENCES

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