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Status of Boyden observatory and equipment for optical counterpart studies of high energy sources

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The status of the Boyden observatory and equipment will be evaluated for use in optical counterpart studies of high energy sources. Optical systems include the 1.5 m Boyden telescope which has recently received system and equipment upgrades to the photometer, specifically a new sCMOS camera system. Additionally a state of the art spectro-polarimeter has been commissioned and is in final testing and initial observing phases. Besides the 1.5 m telescope, there is also robotic telescope systems, e.g. Watcher and BOOTES-6. Watcher, was primarily for follow-up of gamma ray bursts, but has also been used for optical counterpart and survey studies, and target-of-opportunity events. BOOTES-6, or Burst Observer and Optical Transient Exploring System, is a new telescope system that allows for much faster target acquisition for Gamma-ray bursts events, but is also available for optical studies of transient phenomena or optical counterpart studies. With these optical systems, various multi-wavelength studies and collaborative efforts are envisioned for the Observatory

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1. Introduction

The Boyden Observatory (GPS: -29.0382 S, 26.4036 E), E to NE of Bloemfontein, South Africa is host to various telescopes, from the 13 inch Clark refractor dating to 1889 to the newest autonomous telescope system BOOTES-6. The use of these telescopes varies from museum exhibits to educational outreach, training and scientific observations. (For more on the history of the observatory refer to [1]). The most prominent telescopes used for research are the Boyden 1.5 m, the BOOTES-6 system [2] and the Watcher Robotic telescope [3]. The following sections will discuss these systems and their uses, especially regarding ability to support or drive optical counterpart studies of high energy sources.

2. Boyden 1.5 m telescope

The telescope's history dates back to 1889. The telescope has undergone various changes in configuration during this time, including the mount, optics and attached instruments. Currently it is configured on an English equatorial mount with Cassegrain optics which has an effective focus of 2382 cm. It has 2 instrument configurations or "packs" available, an Apogee U55 CCD[1], with a peak quantum efficiency (QE) of 90% or a FLI Kepler KL4040 sCMOS[2](peak QE 74%) [4] photometer system with Johnson-Cousins UBVR$_C$I$_C$ filters, or a newly commissioned spectro-polarimeter with a selection of gratings, wave plates and a microLine FLI CCD [5]. Auto-guiding capabilities are also available.

Part of the recent system upgrades to accommodate the new spectro-polarimeter and new sCMOS based photometer, was the development of a new graphical user interface (GUI) based on python. This new GUI, application programming interface (API) and software links with the various components. The GUI for the spectro-polarimeter can be seen in Figures 1&2.

The new systems were tested during various observations for effectiveness, stability and usability. The produced output, i.e. image data was also checked for quality and scientific usability. An example of preliminary produced data from the spectrometer can be seen in Figure 3, with a reference spectrum from an arc lamp (top) and a preliminary spectrometer measurement of the star HIP2612 (bottom). The grating used during the tests gave an effective spectral range of 3800-5465 Å. Unfortunately polarimetric data was at the time of publication not yet available, as that part of the system was still in commissioning phase.

In addition to testing the spectro-polarimeter for acquisition of spectra from stellar sources, the new sCMOS camera on the photometer was also tested with multiple runs on cataclysmic variable (CV) sources and Blazars. A good test was several observations on AR Scorpii. It is the first CV star discovered to exhibit pulsar-like behavior. The rotating white dwarf in AR Scorpii has a strong magnetic field that emits beams of radiation. These beams of radiation cause the entire system to brighten and dim periodically. Refer to [6–8] for more on the pulsar-like behavior of AR Scorpii in various wavelengths. The optical observations resulted in the detection of the known beat period that is a strong signature of the source.

[1]Charged Coupled Device

[2]Scientific Complementary Metal-oxide Semiconductor

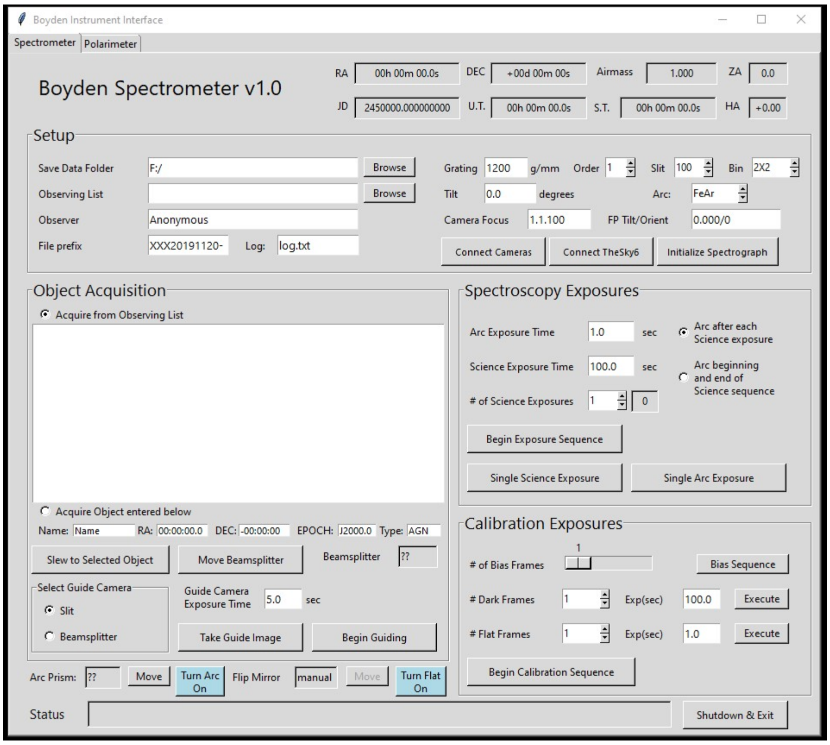

Figure 1: Python based user interface on the 1.5 m telescope system for the Spectrometer.

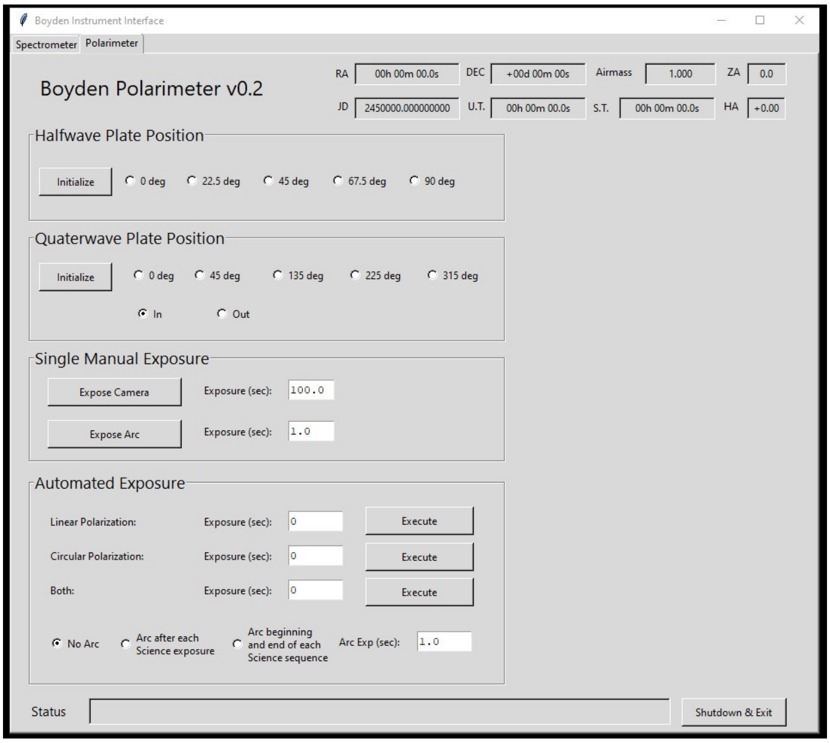

Figure 2: Python based user interface on the 1.5 m telescope system for the Polarimeter.

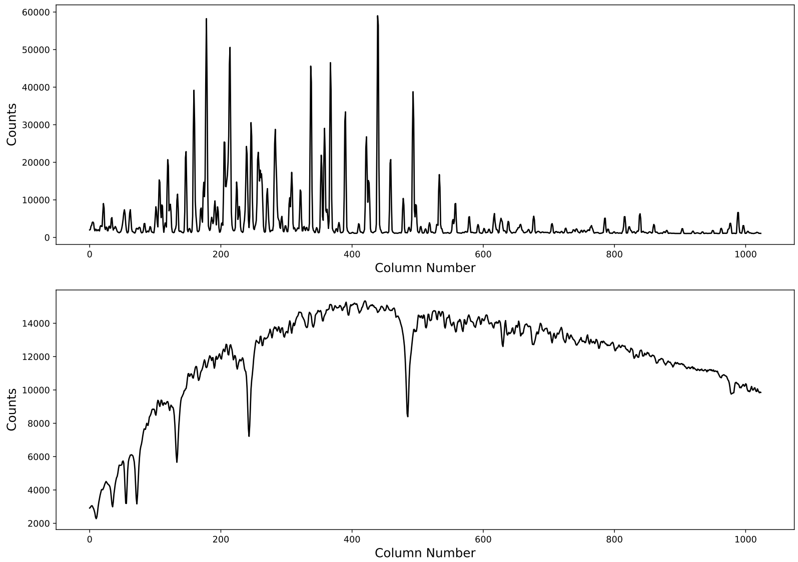

Figure 3: Examples of spectroscopic output from the newly (2023) commissioned Spectro-polarimeter. Top image is a reference spectrum from an arc-lamp (3500-5465 Å), while the bottom spectrum is a stellar spectrum of HIP2612. As the spectra is only for demonstration and not analysis, they have not been normalised to wavelength.

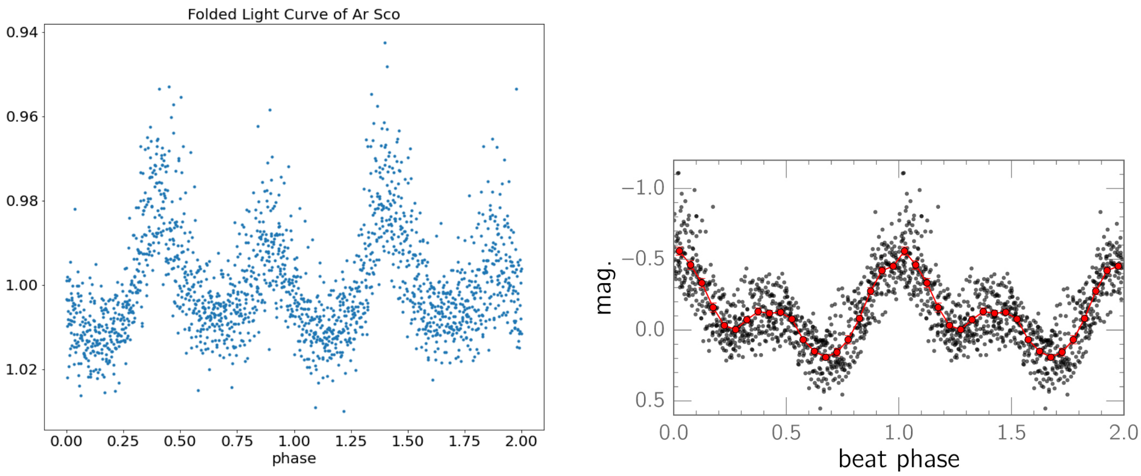

Figure 4: Beat period phase folded light-curve of AR Scorpii based on optical observations from the Boyden 1.5 m telescope (left) compared to optical observations made by [6] (right).

As can be seen in Figure 4 the phase folded light curve on the detected beat period using the Boyden 1.5 m observation data (left) is compatible with a similar phase folded light curve in optical found by [6] (right). The Boyden results is also compatible with phase folded light curves determined by [7, 8].

Figure 5: World map of BOOTES network telescopes.

3. BOOTES-6

The BOOTES-6 system is part of the Burst Observer and Optical Transient Exploring System network. BOOTES-6 is a collaborative effort between CSIC[3] (70%), Boyden (15%) and UCD[4] (15%). Commissioning was completed in 2023. It is the 0.6 m Dolores Pérez-Ramírez robotic telescope which has a mount slew speed > 100 deg/s with an Andor iXon high-QE electron multiplying CCD (EMCCD) camera (peak QE of 95%) and Sloan SDSS u'g'r'i' and UKIRT[5] ZY filters. The system also include a small dome developed in partnership with the UFS Department of Physics and support divisions, that hosts two all-sky cameras (MORAVIAN C4 CMOS sensors with 16mm f2.8 lenses), that sample the sky every second. The BOOTES global network consists of 6 telescopes relatively similar in design and configuration, besides two devoted to wide-field astronomy. This offers the opportunity for rolling or continuous observations. Refer to Figure 5 for a world map indicating the various locations of the 7 BOOTES systems. It offers ground support for space-borne experiments such as *INTEGRAL*, *Swift*, *Fermi* and the MAXI@Kibo-module on the *ISS* to name a few. More detail can be found in [9, 10].

The science done with the BOOTES network include:

- Gamma-ray Bursts (GRB) follow-up observations forms the main targets. The telescopes have the ability to slew to GCN/TAN[6] targets within 8-20 seconds.
- Flaring stars.

[3]Consejo Superior de Investigaciones Científicas
[4]University College Dublin
[5]United Kingdom Infrared Telescope
[6]GRB Coordinates Network/Transient Astronomy Network

- Search for accompanying optical emission in magnetars.
- Optical counterpart search for gravitational wave events.
- Follow-up observations of IceCube alerts of neutrino sources.

Since it became operational, BOOTES-6 has already completed various follow-up observations, including [11–13] to list a few.

4. Watcher Robotic telescope

Watcher is a fully robotic telescope designed primarily for rapid GRB follow-ups with typical response times of < 30 s since the GRB trigger. It is a 40 cm telescope with an Andor iXon EMCCD (peak QE of 95%), with Johnson BVRI, Sloan g'r'i' and narrowband Hα, OIII filters available [14]. It is configured for automatic follow-up of sources from the GCN, as well as semi-automatic follow-up from Gaia Alerts, Astronotes and ATels[7]. Science targets include:

- Gamma-ray bursts and electromagnetic counterparts of gravitational waves (20% total time, e.g. [15, 16])
- Blazars (40% total time, e.g. [17, 18])
- Supernovae (25% total time, e.g. [19, 20])
- Microlensing events (10% total time, e.g. [21])
- Other sources (5% total time, e.g. [22])

Watcher is currently being upgraded to better match and integrate with the BOOTES network and similar autonomous observatory systems, with the aim to do simultaneous observations alongside BOOTES-6. The upgrade has the goal to ease support and compatibility using modern and scalable tools such as `pyobs` [23]. Final testing and resume of normal observations will start in Spring 2024. These upgrades will allow Watcher to continue producing first class science for over two decades.

5. Conclusion

The preliminary results from testing of the new equipment (photometer and spectro-polarimeter) on the Boyden 1.5 m telescope indicates that a whole range of new observational projects will be possible, including photometric and spectroscopic optical counterpart studies of high-energy sources. There is a strong effort to also finalize the commissioning of the polarimeter and to start testing it on polarized sources and analyse the Stokes parameters and how they relate to the state of some of these multi-wavelength sources. The BOOTES-6 and Watcher systems allow for rapid autonomous follow-ups of GRB's and various other multi-wavelength sources, allowing for collaborative studies and better management of the available observing schedules of the various research resources available to the observatory.

[7]The Astronomer's Telegram

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