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THE INTELLIGENT OBSERVATORY

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Abstract

The Intelligent Observatory (IO) is the vision of the South African Astronomical Observatory (SAAO) to enhance scientific support for the South African and global astronomical communities. By optimizing services, the IO initiative aims to create a seamless collaboration among diverse local and hosted astronomical facilities situated on the Sutherland Plateau. Achieving this vision necessitates strategic technological enhancements, such as upgrading telescopes for remote observations and automation, alongside a comprehensive redesign of the existing Sutherland operations model. The primary research driver is time-domain and transient science.

INTRODUCTION

The South African Astronomical Observatory (SAAO) provides ground-based optical and IR observational facilities for astronomers across South Africa and internationally, conducts world-class astronomical research, and communicates the excitement of astronomy to the people of South Africa. The administrative headquarters, are based in Cape Town including the electronics and high precision mechanical and optical laboratories, whereas the telescopes are located on a barren plateau outside the Karoo town of Sutherland, approximately 350 kms from Cape Town (Fig. 1).

The Telescopes

The SAAO is the premier facility for optical astronomy on the African continent, and owns and operates several optical and infrared telescopes which include the Southern African Large Telescope (SALT), Lesedi (1.0 m), the 1.0 m and 1.9 m telescopes. Other facilities, such as the Infra-Red Survey Facility are co-owned and operated with other international partners. The remaining ~20 facilities the SAAO hosts on behalf of other international institutes for which the SAAO is either permitted a percentage of time access or data access.

Each of these facilities have their own modes of operation primarily depending on the science driver and/or ownership. SALT issues 2 calls per year for applications from the partner institutes. The amount of time applied for and eventually awarded is tailored to meet the scientific goal of the application. The telescope uses a queue-based mechanism for executing the observing program, with dedicated SALT astronomers and operators performing the observations.

Applications to the SAAO 1.9 m, 1.0 m and the IRSF are made 3 times per year and the PI is expected to perform their own observations. Time is allocated in 1 week blocks as a result of the practicalities of travelling and accommodating in Sutherland. Applications are open to the entire national and international community and time is awarded primarily on scientific merit. The hosted facilities are all generally operated for specific science goals and consequently their mode of operation is mostly robotic and queue scheduled

IO RATIONALE

The main science driver for the IO is time-domain and transient astronomy. The time over which astronomical objects can vary ranges from milliseconds to years depending of the characteristics of the objects. Synoptic monitoring of objects that are changing slowly are observed over time-scales of days and years, while the variability of close binary stars takes place on timescales of tens of minutes to hours, examples are cataclysmic variables and X-ray binaries. Then there are rapidly varying objects, such as pulsars and accretion instabilities in flows and discs that require high time resolution observations of sub-seconds. Many transients are found through e.g. all-sky surveys or high-energy events are discovered with X-ray, gamma-ray, and radio telescopes. More recently events are being discovered with gravitational wave and neutrino detectors. Such a range of objects and their corresponding phenomena result in a variety of emissions across the entire electromagnetic and multi-messenger spectrum.

It is through observing these timely events that we get the opportunity to improve our knowledge and understanding of these objects, their underlying physics and make new discoveries along the way. Observations will have to be tailored to the type of object and the nature of the optical/IR emissions. With ~25 different facilities operating on the Sutherland plateau with even more instruments ranging from wide-field imagers and spectrographs to specialised modes of high cadence observations or polarimetry, the SAAO is uniquely equipped to explore all transient and time domain phenomena - provided that all the facilities can be intelligently managed and operated with this vision in mind.

THE IO VISION

The vision for the SAAO is to have all the SAAO facilities (telescopes and instruments) integrated into the IO. The operational model for the IO will add additional functionality to the operations of the observatory. For exam-

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ple, in addition to the traditional call for proposals schedule, the IO will allow astronomers to submit observation proposals anytime. Observers will also be able to define whether they want their observation to be placed in a queue for automated observation, operated manually from the Cape Town control room, operated manually from a remote desktop anywhere in the world or by actually operating the facility manually on-site. In addition, the schedule of the observation programme, will be agile enough to run the most effective and efficient rolling observation programme queue system, where it is reactive to allow the queue to be updated continuously in real-time and even allow resources (telescopes or instruments) to be reallocated during a night's observing in the event of receiving an alert of a high priority target of opportunity (TOO). In this respect the IO will permit programmatic submission of observation requests thereby enabling rapid follow-up of automated alerts emanating from e.g. gravitational wave and/or gamma burst events.

CURRENT STATUS

The Telescopes

We first focussed on SAAO's three work-horse telescopes, spanning 10-75 years of age, each undergoing hardware and software upgrades to enable complete remote observations. These upgrades include control upgrades to not only the telescopes but also the dome structures and the scientific instruments. Notably, all operations can now be conducted without any physical presence inside the domes.

The upgrades involved enhancing various devices, including implementing PLC (Programmable Logic Controller) and software-based controls for building power management. Additionally, APIs were developed for the telescope control systems, enabling control through user-friendly web GUIs. To ensure the telescopes' safety, a weather service was integrated for automatic shutdowns, and audio-video systems were set up for remote monitoring purposes.

A significant milestone was achieved with the 1.0 Lesedi telescope, which has been transformed into a fully autonomous system. This transformation required the development of multiple in-house software algorithms to replace the human control processes. These algorithms automate tasks such as preparing the telescope and dome for night-time operations, accurately acquiring targets, adjusting and fine-tuning focus, configuring instruments, and acquiring data. The telescope is now capable of conducting spectroscopy and photometric imaging. A scripting system was devised to execute sequences of night-time observations, defined using JSON file formats. All software code utilizes C, CPP and Python in a Linux operating systems.

At highest user level interface, we adapted the open-source Observatory Control System (OCS) software from the Las Cumbres Observatory [1]. This adaptation provided a user-friendly web interface for telescope users to manage their observation requests and subsequent data. One of the key functions of the OCS backend is to create nightly priority observing queues. Our scripting system continuously polls the OCS, updating every minute to maintain an accurate live observing queue and executes observations accordingly.

Moreover, it's crucial to highlight that the OCS can receive observation requests programmatically. Leveraging this functionality, we have created scripts that monitor alert streams from facilities such as the Swift and Fermi gamma ray observatories and the NASA Atlas network. These scripts automatically submit observation requests into the OCS for rapid optical follow-up using Lesedi.

THE SCIENCE

As mentioned above, the main science driver behind the vision of the IO is time-domain and transient astronomy. With the full automation of the Lesedi telescope this vision is being realised. Here we give three examples where the automation of Lesedi has enabled the exploration of different time-domains in astronomy.

Capturing the DART Mission

DART (Double Asteroid Redirection Test, NASA) was the first-ever mission dedicated to investigating and demonstrating one method of asteroid deflection by changing an asteroid's motion in space through kinetic impact [2]. Knowing the exact time of the impact on 26th September 2022, we were able to schedule the Lesedi telescope to point and track the asteroid in an attempt to capture any evidence of the resulting impact. Figure 2 shows a single frame of an image sequence that clearly showed an expanding plume of material as a result of the impact.

High-Cadence Observations of a New White Dwarf Pulsar

Figure 3 shows ~6 hours of continuous ~3s cadence photometric observations of J191213.72-441045.1, which harbours a white dwarf in a 4.03 h orbit with an M dwarf and exhibits pulsed emission with a period of 5.30 min. These observations formed part of a multi-wavelength campaign from which this discovery establishes binary white dwarf pulsars as a class and provides support for proposed formation models for white dwarf pulsars. See [3, 4] for the detailed observations and analysis.

Figure 4 demonstrates the longer time-scale capabilities of scheduling snap-shot observations over a period of several months. The light-curve has quite clearly captured the photometric variability as a result of a micro-lensing event. In this case the light from a background star has been amplified as an un-seen binary system passes in front of our line-of-sight to the background star. The light-amplification is as a result of gravitational lensing by the intervening binary system. By modelling the variation in the light-curve it is possible to determine the constituents of the intervening binary system

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FUTURE PROSPECTS

With Lesedi now fully automated the next step will be to automate the much older 1.0 m and 1.9 m telescopes. Although older they have already received hardware and software upgrades to enable remote operations. Therefore, the path to at least a hybrid mode of full-automation and remote operations is entirely possible. In addition, as of October 2023, we have designed, manufactured and installed an instrument selector port for the 1.9 m telescope. This will permit 2 instruments to be co-mounted on the telescope at the same time and thereby enabling the ability to switch between either instrument multiple times during the course of a night. Previously an instrument change would require a few hours of work for a team of 3-4 technicians and was therefore restricted to a few times per year.

With the addition of a second and then a third telescope to the core IO it will be possible to offer even more options in not only terms of time-domain but also a more versatile suite of instruments covering imaging, spectroscopy and polarimetry.

Figure 1: The ~25 telescopes located on the Sutherland plateau.

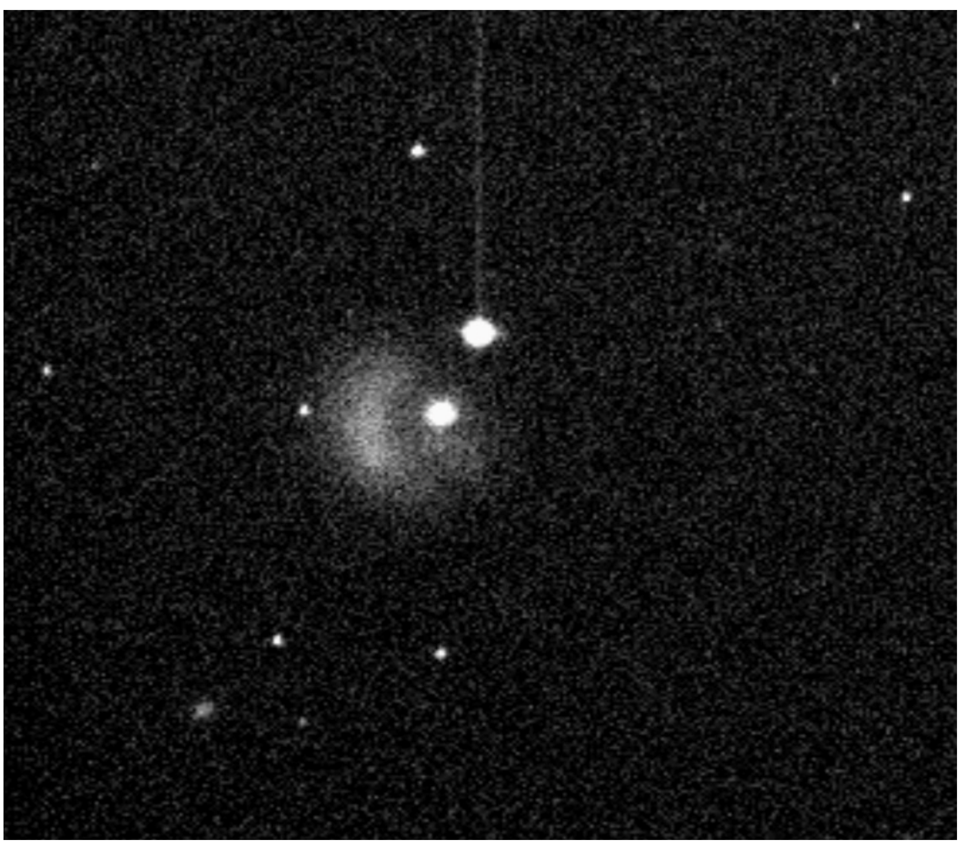

Figure 2: Single from captured from the image sequence taken with the Lesedi telescopes capturing the expanding plume of material from the DART mission.

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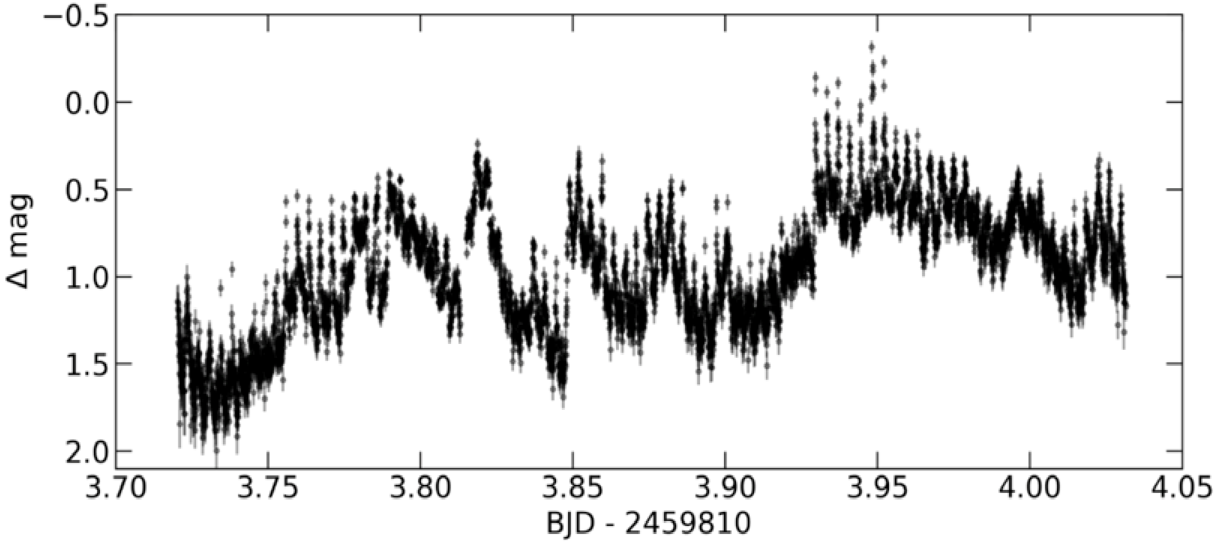

Figure 3: Light curve of J1912−4410 taken with the SAAO 1-m Lesedi telescope on 21 August 2022.

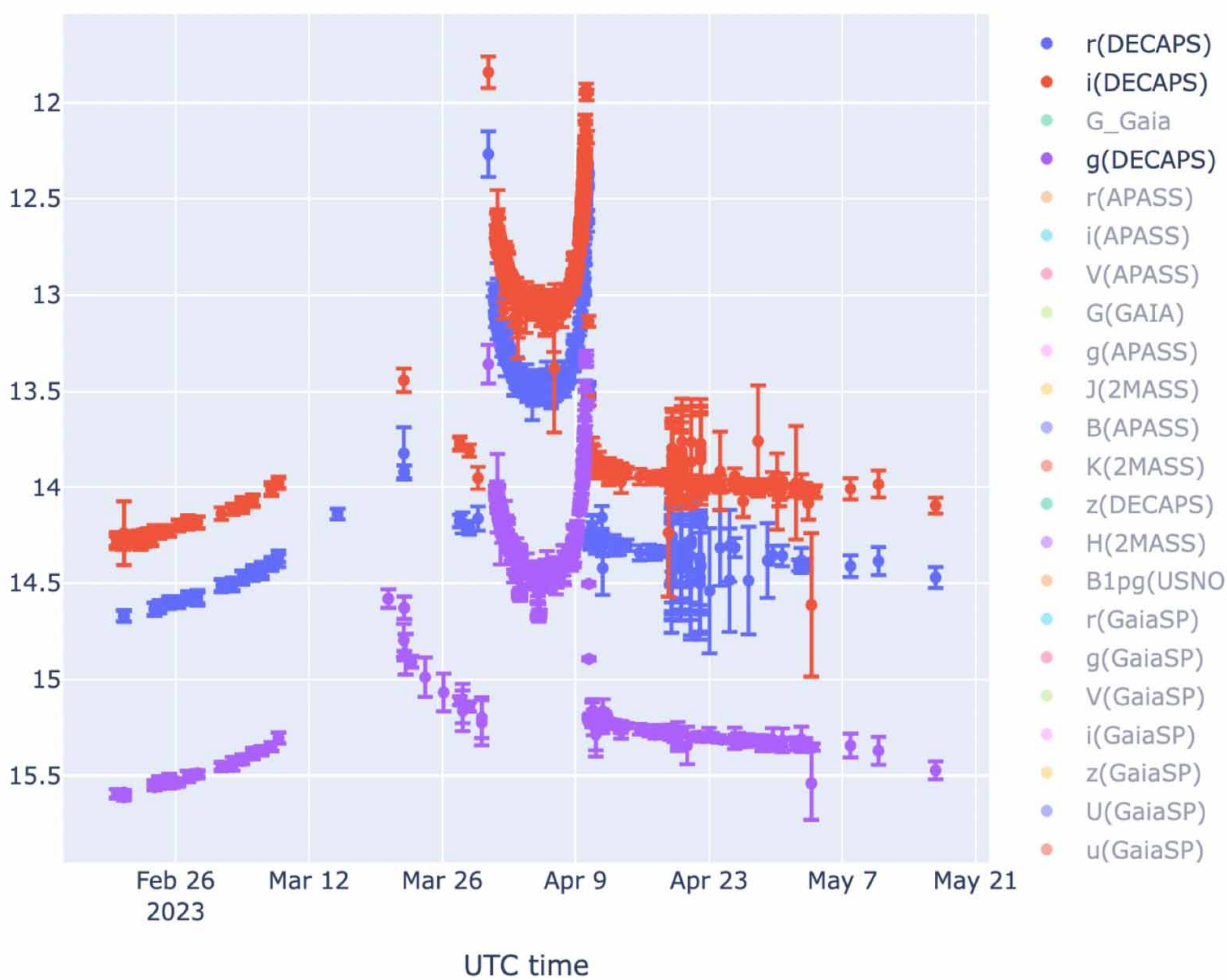

Figure 4: Multi-filtered snap-shot observations of a micro-lensing event spanning ~4 months.

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