A Brazilian Robotic Telescope

White paper for the Comissão Especial de Astronomia

Antônio Kanaan (Coord.)
Antônio Mário Magalhães
Bruno Castilho
Cláudia Mendes de Oliveira
Cláudia Vilega Rodrigues
Francisco J. Jablonski
Jorge Carvano
Raymundo Baptista

Janeiro/2010

1 Introduction

This white-paper puts forward a discussion on the need of a Brazilian medium-size robotic telescope at a good observing site.

A medium size (2-3 m) robotic telescope comes as a natural extension of Brazil's present access to the Gemini Observatories (2.5% of two 8-m telescopes, rising to 5% in the near future) and the SOAR telescope (34% in a 4-m telescope). A robotic telescope at a premier observing site and with a quasi exclusive Brazilian access will enhance our existing capabilities and open up opportunities for new science. In particular, it will allow long-term projects to be initiated, what is normally discouraged at SOAR and impossible at Gemini, given the small share of observing time available. This ability to pursue long-term studies is fundamental for the Brazilian astronomical community which presently amounts to at least two hundred active users.

The project has three technological branches: the telescope, instrumentation and software. Medium size telescopes may be considered almost off-the-shelf items nowadays, but unfortunately beyond present Brazilian industrial capabilities. Instrument design and construction – either for imagery or spectroscopy – may be done by Brazilian research institutions in collaboration with local industry. We expect to develop the high level software for this telescope entirely in Brazil.

2 Science

A robotic telescope is ideal for repetitive observing strategies such as monitoring of variable sources, surveys, synoptic observations and quick pointing of targets of opportunity. We outline below some scientific cases in which a robotic telescope can improve the Brazilian astronomical production, in number and quality.

2.1 Pulsating stars

Pulsating white dwarfs have periods around 10 minutes and amplitudes of a few millimagnitudes. The oscillations occur simultaneously in many modes, what puts strong constraints on the theoretical models of their internal structure. These many modes can be difficult to detect owing to their low amplitude, but also because they are very closely spaced in frequency. In order to resolve all pulsation modes, and therefore extract useful information from these observations, continuous data are needed for around two weeks extent at a sampling rate of 10 seconds. The Brazilian community has had a leading role in the Whole Earth Telescope (WET), a loosely assembled group who has made important contributions in the area of white dwarfs seismology. Most of what has been said here about pulsating white dwarfs applies to δ Scuti stars, rapidly oscillating Ap stars, Cepheids, Be stars, stars which are studied by several Brazilian astronomers.

2.2 Interacting binaries

They include many classes of objects such as cataclysmic variables, X-ray binaries, and symbiotic systems. Their common denominator is transfer of matter between the components, with the build-up of accretion disks and/or columns. Variability in these binaries occurs on a wide range of timescales, from second to several months and even years. The ability to accumulate long time-series probing the short-time scale variability is key to address the physics of accretion, whereas the capability to follow the brightness changes along dwarf nova outbursts and nova eruptions is fundamental to the understanding of the underlying physics. Accretion structures are present in other astrophysical contexts such as active galactic nuclei and young stellar objects, and binaries provide the best environment for their detailed study; what is learned in the interacting binaries context can be applied to understand the related objects.

2.3 Planet searches

Over a thousand microlensing events (MLE) are presently detected in the direction of dense stellar fields by experiments such as OGLE, MACHO and MOA. A by-product of these surveys are the anomalies in the classical amplification pattern due to the presence of extra masses close to the main lensing mass. Several exoplanets have been discovered by this method that has the advantage to be sensitive to both earth-like and giant planets, either at small as well as at large distances from the parent star. Observing anomalies in MLE is not very time consuming, as they have time-scales of hours. Observations in the Target of Opportunity category, in collaboration with consortia like PLANET or MOA, can be very effective in terms of scientific revenues.

2.4 Gamma Ray Bursts (GRBs)

The rapid pointing response of a robotic telescope makes it a very valuable tool for observing optical afterglows (OA) of GRBs. About 80% of all GRBs show optical/near-infrared afterglows but the number of well observed time-evolved spectra is still small. Robotic telescopes are the main contributors to the presently available OA data. As much as for the GRBs themselves, OAs are rather poorly understood — still they may provide important clues about the nature of the main engine. Clearly, a larger sample of OAs is needed for further progress. In particular, very basic predictions can be tested if the response time of the optical observations after the GRB is less than 100 seconds, what can be achieved with a robotic telescope as the one we are proposing, and which is far beyond the capabilities of LSST or PanSTARRS.

2.5 Supernovae Ia - SNIa

Thirty thousand Type Ia SNe per year at $z < 0.3$ are expected to be detected by LSST. LSST will not, however, be able to produce light curves detailed enough to add any new information to their behavior. A 3-m telescope should be able to follow up half of these objects in sufficient detail to improve our understanding of their intrinsic differences and therefore minimize the scatter in their inferred absolute magnitudes caused by systematic errors.

2.6 Solar System Objects

The minor bodies in the Solar System exist in three large stable reservoirs – the Main Asteroid Belt, the Kuiper Belt and the Oort Cloud, as well as in scattered, unstable populations: the Near-Earth Asteroids (NEAs), the Centaurs, and short and long period comets. A small subset of the NEA population has non-negligible probability of collision with the Earth, and is considered as Potentially Hazardous Asteroids (PHAs). For each population we need a better determination of: 1) their number and orbital distribution; 2) physical parameters; 3) compositions. The main difficulty in pursuing these goals is exactly in the amount of available telescope time in total number of hours as well as the availability in specific times. A robotic telescope with a good scheduler should be able to optimize its time and make these observations possible. Polarimetric capability is important, as it allows the determination of albedo. Useful constraints on the composition can be placed using the spectral energy distribution in the visible, either from low-dispersion spectra or successive flux-calibrated photometry in a suitable set of filters.

2.7 Polarimetric studies

The polarization of the incoming photons can be produced in asymetric geometries and/or by non-thermal emission processes and is an important tool for many astrophysical studies.

The much improved sampling of starlight polarization across the sky will contribute in different areas. It will allow for a much better modeling of the foreground galactic polarization at the far-IR & sub-mm wavelengths. This correction is crucial for analyzing the observed Cosmic Microwave Background (CMB) polarization. Observations of the magnetic field structure in different phases of the Interstellar Medium (ISM) will provide understanding the connection of the field from the diffuse ISM down to the embedded dense cores and an unprecedented knowledge of the Galactic magnetic field structure, down to the Local Bubble.

Temporal polarization observations of AGN should provide characteristic sizes of the dominant scattering regions, essential to understanding of the structure of broad-line type 1 AGN, and magnetic field properties of the non-thermal emitting regions.

Statistics and time evolution of explosive phenomena, as GRB, will provide insight into the explosion mechanism, its asymmetry, how such asymmetry evolve with time and its relation to photometric signatures.

Polarimetry of the highly non-spherical circumstellar environments of both YSOs and evolved objects will provide a means to study angularly resolved and unresolved envelopes.

3 The telescope overview

The telescope concept should be guided by the following principles, some of which conflicting:

- simplicity - the whole telescope system must be designed to keep maintenance events as rare as possible to minimize costs and maximize uptime;

- efficiency - the telescope must be planned to take most advantage of its primary mirror to be on the leading edge of other telescopes of the same class;
- uniqueness - this telescope should be able to do things other telescopes are unable to. This would give the telescope an advantage in the area allowing for important results to be reached by us before the competition gets there.
- flexibility - we plan to accommodate several research projects to widen the scope of this telescope.

Items 1,2 and 3 are in a way contradictory to item 4 and in the good balance between 1,2,3 and 4 lies the recipe of this telescope's success.

We propose at this point to build a 3-m robotic telescope capable of spectroscopy, imagery and polarimetry. The 3-m diameter will place us in the forefront of robotic telescopes, being the largest robotic telescope on the planet. The flexibility to do spectroscopy in addition to imagery will increase the number of doable projects with this telescope. A robotic telescope with polarimetric capability will be unique among similar instruments and will open a niche not explored in present astronomical projects world-wide. So, the size, polarimetry, and spectroscopic ability will certainly provide us with the desired uniqueness and flexibility. How do we achieve simplicity and efficiency?

3.1 Instrumentation

The simplicity can be found with a proper instrumental design. As a baseline we are working with the idea of a CCD mosaic wide-field camera capable of high-speed photometry in at least one of its detectors. The high-speed photometry can be achieved either by using one frame transfer CCD at one of the camera's edges or by using an EMCCD or a scientific CMOS detector. To achieve low spectral resolution we are considering the possibility of using a few grisms in the filter wheel or designing a filter wheel with tens of intermediate width filters to provide some sort of low resolution spectroscopy. Polarization can be measured by the insertion of one analyzer and a retarder in the beam. The instrument should allow measurements of linear and circular polarization. The latter is particularly important in studies of variability of cataclysmic variables.

Instrumentation development is an activity with steady growth in our community. FOTRAP and CAMIV are very successful instruments developed in collaborations (INPE/LNA, IAG-USP/INPE). Both have been used for decades at OPD. The SOAR Integral Field Spectrograph (SIFS) though having initial difficulties has paved the way for larger instruments on 4-m class telescopes. It was the first modern instrument with decisive institutional commitment in its construction. STELES, the cross-dispersed echelle for SOAR, has benefited from the infrastructure investments made at LNA to build SIFS. The Brazilian Tunable Filter Imager (BTFi) is a user instrument for SOAR that incorporates innovative technologies such as the combination of Fabry-Perot tunable devices, volume phase holographic gratings and EMCCDs with reduced read-out noise.

Based on the current infrastructure available and the recent history of developments in Brazil, at least part of the instrumentation should be built in Brazil.

3.2 Software

It is the software behind a telescope that makes it robotic. The ability of different pieces of software to communicate and operate in a concerted way is the key to an efficient, easy to maintain and easy to upgrade system. We identify three major software groups in a robotic telescope: control, scheduling and data reduction. The success in making these three groups of software to work as a whole is the success of the telescope. Stable and reliable hardware are of course the basic condition for the stability and reliability of the software itself.

Control: The robotic telescope control system must be able to coordinate the operations of all components at the observatory. Each hardware component made for the observatory must have drivers that accept commands from the control system and be able to post the status of all its variables.

Scheduling: A good scheduling program is capable of choosing what are the best observations for each night, following a set of rules according to scientific priorities, observing conditions and the degree of completeness each project has already achieved. This scheduling program must be able to interact with the observatory control and the data reduction system to make informed decisions on what is best to observe next.

Data Reduction: A robotic telescope can easily lead us to a paradoxical situation: overabundance of data may lead to decrease of production of useful data due to the enormous amount of time spent in data reduction. To avoid this situation, we plan, from day one, to write a data reduction pipeline - and include realistic time and cost estimates - for each instrumental. This pipeline should be operational at the instrument first light. The pipeline will be integrated to the rest of the software system accessing the scheduler database to ask for calibration files, and creating its own database with final reduced data available to the observers who requested the data. These data will be stored in a repository compatible with the Virtual Observatory (VO) rules for use by the community.

3.3 Operations

Except for possible emergency maintenance, this telescope may be operated completely unmanned; no operators are needed, and no on-site technicians are necessary as there are no instrument changes. It is, however, necessary to plan for scheduled maintenance as well as for unpredicted problems. At this stage, we think the simplest and most effective way to operate this telescope, is to install it at a well established astronomical site to benefit from the already existing infrastructure. Operation will either be contracted or bartered for observing time with the host observatory.

4 Conclusion

We propose to build a Brazilian medium-size (2-3m) robotic telescope to be installed at a good observing site with competitive instrumentation that make it unique, efficient and flexible. It can be a driver for the pursue of excellence both in scientific and technological developments in Brazil.