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New initiatives in optical astronomy at ARIES

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Abstract. The Institute is establishing a 3.6-m new technology modern optical telescope at Devasthal. This telescope will have instruments providing high resolution spectral and seeing-limited imaging capabilities at visible and near-infrared bands. In addition to optical studies of a wide variety of astronomical topics, it will be used for follow-up studies of sources identified in the radio region by GMRT and UV/X-ray by ASTROSAT. A few other facilities with very specific goals are also being established. These are 1.3-m optical telescope to monitor optically variable sources, a 0.5-m wide field (25 square degrees) Baker-Nunn Schmidt telescope to produce a digital map of the Northern sky at optical bands, and a 4-m liquid mirror telescope for deep sky survey of transient sources. These optical facilities with specialized back-end instruments are expected to become operational within the next few years. All the telescopes, except the 0.5-m Schmidt, will be located at Devasthal, Nainital in the central Himalayas.

Keywords : Telescope – optical:instrumentation

1. Introduction

Aryabhatta Research Institute of Observational Sciences (acronym ARIES), an autonomous research institute under the Department of Science and Technology (DST), Government of India, has taken the initiative to establish a 1.3-m and a 3.6-m new technology optical telescope at Devasthal, Nainital. Major national research institutions participating in the 3.6-m telescope project are Indian

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Institute of Astrophysics (IIA), Bangalore and Tata Institute of Fundamental Research (TIFR), Mumbai. Russia and Belgium are also participating in the project under their respective bi-lateral programs of cooperation in science and technology with India.

Two other survey telescopes with very specific goals are also planned to be set up within the next one year. The first one is a 0.5-m wide field (25 square degrees) Schmidt telescope at Manora Peak, designed and being built in-house by converting a 79/51-cm f/1 Baker-Nunn satellite tracking camera into a Schmidt telescope, and the second one is a 4-m Liquid Mirror Telescope, to be set-up at Devasthal with active participation from Belgium and Canada.

As these telescopes are being installed at a good observing site (Devasthal) in India, it has an added advantage of crucial geographical location for a number of time-critical observations of cosmic events. The next section describes Devasthal as an astronomical site while the quantitative importance of locating the above optical telescopes at Devasthal and the expected observational sensitivities along with the prime science drivers are given in Section 3.

2. Devasthal site

An extensive site characterization conducted during 1980 - 2001 in the central part of the Himalayan Range, identified Devasthal (Lat:$29^\circ 21' 40''$N, Lon:$79^\circ 41' 04''$E, Alt: 2420 m above msl) as a potential site for optical observations(Pant et al. 1999, Sagar et al. 2000, Stalin et al. 2001). Seeing measurements close to ground level were successfully carried out on 80 nights using a modern differential image motion monitor. They are spread over a period of two years mainly during summer and winter months of 1998-99. This yielded a median ground level seeing estimate of about 1.1 arcsec; the 10 percentile values lie between 0.7 to 0.8 arcsec (mean = 0.75 arcsec) while for 35 percent of the time the seeing was better than 1 arcsec. These coupled with the number of yearly spectroscopic nights ($\sim$ 210), darkness of the per square arcsec sky (V $\sim$ 21.8 mag) and other atmopsheric parameters for Devasthal make this site comparable to international standards (Stalin et al. 2001, Sagar et al. 2000).

Devasthal site is located about 50 km by road east of Nainital having a direct line-of sight distance ($\sim$ 22 km) from the present location of ARIES at Manora Peak. The transfer of 4.48 hectares of land from the State Government and the environmental clearance from the Ministry of Environment and Forests, Govt. of India, for setting up the proposed optical observing facilities has been granted to ARIES. Construction of a 6 m wide and 3 km long metalled road connecting the state highway from Jadapani to Devasthal site has been completed. The site has already been connected with Manora Peak by a high speed 2.4 GHz microwave link having a bandwidth of 1.8 Mbps. This link enables the transfer of computer data, INTERNET data, and telephone voice data for communications between the two places. A high tension, 11 kVA dedicated electrical transmission line has been installed and energised by the Uttarakhand Power Corporation and it currently feeds two substations with load capacities 65 kW and 150 kW. The requirement of water is met by a bore well connected to the water table about 110 feet below the ground level. Other infrastructural requirements are being developed.

3. Telescopes, back-end instruments and key science drivers

3.1 The 0.5-m Schmidt telescope

During the International Geophysical year (1957-58), a 79/51-cm f/1 Baker-Nunn satellite tracking camera was installed at the Institute by the Smithsonian Astrophysical Observatory, USA. It was the only center in India but actively networked as a part of the 12 centers established all over the globe. The first photograph of an artificial satellite was taken on 29th August 1958. The camera successfully photographed a total of over 45,700 satellite transits. After 1976, the camera is not in use due to the advent of modern observational techniques in the area. Following successful conversion of such cameras into wide field Schmidt-telescopes for carrying out astronomical survey work by Australian and Spanish groups, ARIES initiated this conversion in 2005.

The basic optical design of the 79/51-cm f/1 Baker-Nunn staellite tracking camera uses a three-element corrector to produce an extremely wide field of view across a curved plane at the prime focus for photographic imaging. Major jobs in converting the existing Baker-Nunn camera into a 0.5-m Schmidt telescope with CCD imaging capabilities are (i) modification of optical design from photographic curved to flat focal plane for CCD observations, (ii) changing the mounting system from alt-azimuthal to Equatorial English mount (iii) computer control of the telescope, and (iv) optical alignment and installation of a new customized CCD imaging system at the prime focus having plate scale of ~ 7 arcmin per mm.

The telescope will be installed at Manora Peak, Nainital, India and it can reach 20th magnitude with 10% photometric accuracy for an integration time of 1 min. Scientific programs like study of variable stars, Asteroids and Near-Earth-Objects, detection of extra-solar planets though transit method, transient objects like GRBs and supernovae, and imaging of large star clusters could be suitably accomplished with this wide-field imaging telescope. The

Dome construction is almost complete and the assembly, integration and verification are expected to be completed within a few months.

3.2 The 1.3-m optical telescope

The setting up of a new 1.3-m optical telescope facility at Devasthal is guided by the scientific objectives, which require optical observations of transient events, certain types of variable sources and new surveys requiring months or years of monitoring at short intervals (Sagar 2006). As the telescope will be equipped with INTERNET facility, it is suitable for monitoring time-critical phenomena like transient events (Gamma Ray Bursts and Supernova Explosions), pulsation and variability studies of both Galactic (rapidly oscillating Ap Stars, delta-Scuti Stars, white dwarfs and chromospherically active stars) and extra-galactic (active galactic nuclei and micro-lensing, supernova search) objects.

The key specifications of the 1.3-m telescope are listed in Table 1. F-ratios of the primary and the secondary mirrors were chosen in such a way that the resulting final F/4 Ritchey-Chrétien Cassegrain system provides a natural flat-field whereas other F-ratios will require a field corrector. Normally, the field corrector requires at least two elements and for a wide field requires three elements. The present F/4 system, because it has a natural flat field, only requires one element and results in a large (~ 1 deg) field of view free from any optical distortions.

The focal length of the primary mirror determines the size of the telescope tube and hence the size of the enclosure. By building a primary mirror of smaller f-ratio, there is a reduction in the size of the telescope tube, the telescope mount and the dome. Consequently, the reduction in overall size of the building results in considerable cost savings. A ratio of f/2.35 for the primary was therefore chosen. It means that the length of the telescope tube is around 3 m. Another important parameter is the thickness of the primary mirror, reduction in which would bring down the weight of the telescope. An aspect ratio of 8.7 has therefore been chosen for the primary mirror made of Corning TSG with almost zero temperature coefficient. The telescope has an equatorial fork type of mounting. The optical tube assembly is of open-truss design with sufficient baffling at the focal plane. The mechanical structure is made up of steel with invar spacers to provide an athermal focus and is rigid enough to support a load of the astronomical instruments up to 100 kg at the Cassegrain focus. A five-axis housing mechanism in the secondary provides computer controlled fine motions in translation and tip/tilt. This 5-axis mechanism allows collimation and focusing adjustments from the telescope control room. The full telescope control system shall be capable of operating the telescope and the enclosure automatically. At the same time it shall be capable of interfacing with a global position system clock to maintain the time standard; the weather

Table 1. Technical specifications of the 1.3m and 3.6m optical telescopes.

Parameters	1.3m	3.6m
PRIMARY MIRROR :		
Optical Diameter	1313 mm	3600 mm
F-number	2.35	2
Surface	Concave hyperbolic	Concave hyperbolic
Conic constant	-1.637	-1.032959
Diameter-to-thickness ratio	8.7 (plano)	22 (meniscus)
Mirror material	Corning TSG	Schott Zerodur
Supports	36-point (passive)	69-point (active)
Polishing accuracy	λ/15 RMS WFE	40 nm RMS WFE
SECONDARY MIRROR :		
Optical Diameter	609 mm	900 mm
F-number	4.97	2.56
Surface	Convex hyperbolic	Convex hyperbolic
Conic Constant	-35.782	-2.795610
Diameter-to-thickness ratio	7 (plano)	10(plano)
Mirror material	Corning TSG	Astrositall
Mirror support	Hexapod	Hexapod
Polishing Accuracy	50 nm RMS WFE	32 nm RMS WFE
TELESCOPE SYSTEM :		
Effective Focal Ratio	F/4.02	F/9
Image Scale	40 arcsec / mm	6 arcsec / mm
Image Quality (EE80)	< 0.6 arcsec diameter	< 0.4 arcsec dia
Pointing Accuracy	10 arcsec RMS	Not exceeding 2 arcsec RMS
Tracking Accuracy	0.5 arcsec / 10 min	Not exceeding 0.1 arcsec
Enclosure	Roll-off Roof	Conventional Dome

monitoring system and safety systems along with a schedule manager which can accept commands, directly through INTERNET or LAN.

As first generation focal plane instruments, it is proposed to have a high performance 2k x 2k CCD camera, 512x512 frame transfer CCD and a low resolution Echelle spectrograph ($\lambda/\Delta\lambda \sim 5000$). The 2kx2k camera will cover a field of 18 x 18 arcmin and has QE $>$ 30% at 350 nm, 90% at 500 nm, 50% at 900 nm and $>$ 80% between 450 to 800 nm. Fig. 1 displays the expected photometric sensitivity of the 1.3 m telescope with this detector for Devasthal site. This indicates that for one hour exposure, the 5-sigma detection of a 24 magnitude star can be made. On the other hand the variability of stars up to 17 mag can be studied with a signal-to-noise ratio of 100. The spectrograph can provide a maximum spectral resolution up to 5000.

To avoid degradation due to dome seeing the telescope will be located at a height of 3 m above the ground level. It has a simple roll-off roof design for the enclosure. The ground floor will house equipment related to the telescope, UPS, batteries, computers and electronic systems. The roof is made of galvanized corrugated steel heavy sheets. The telescope building is constructed to withstand the climate at Devasthal. Special considerations are given to the seismic activities for the region, the heavy winds and the expected snowing at the site.

The telescope is under fabrication since March 2006 at DFM Engineering Inc, USA. Construction of all parts of the telescope, except secondary mirror, are completed. The telescope is, therefore, expected to be transported to the site within a few months. Installation and verification tests may take another few months.

3.3 The 4-m International Liquid Mirror Telescope (ILMT)

The mercury mirror of the ILMT will have a 4 meter diameter with a focal ratio of f/2. The ILMT is proposed to be installed at Devasthal as a joint collaboration between ARIES, Belgium and Canada. It will perform as a transit telescope. A CCD detector shall be positioned at the prime focus of the telescope. The mirror being parabolic in shape needs a corrector to get a flat focal surface of about 30 arcmin diameter. The rotation of the Earth induces the motion of the sky across the detector surface. The CCD detector works in a Time delay integration mode, i.e. it tracks the stars by electronically stepping the relevant charges at the same rate as the target moves across the detector, allowing the integration as long as the target remains inside the detector area. At the latitude of $29°30'$, a band of half a degree covers 156 square degrees, with 88 square degrees being covered at high galactic latitude ($b > 30°$) including the direction of the north galactic pole. The nightly integration times are rather short, typically 120s but it is possible to co-add data from selected nights in order to get sky images of longer integration times.

The expected limiting magnitudes are 24.5 at U, B and V bands, 23.5 at R and I bands and 22.3 at Gunn-z band. The expected database towards the Galactic Bulge direction includes 10 million stars, 30000 variables, 8000 binaries, 8000 LPVs/SRVs, 5000 spotted RSCVn, 1400 RR Lyrae, 250 δ-Scuti, 20 Cepheids, 50/yr microlenses and 5/yr Cataclysmic variables - providing valuable inputs for the studies of stars, galaxies and cosmology.

3.4 The 3.6-m Devasthal optical telescope (DOT)

The f/9 configuration of the telescope has an alt-azimuth mount. It has Cassegrain focus fitted with a 30 arcmin wide field three-lens corrector, auto-guiding unit and a derotator instrument interface. The telescope has two side ports and one main Cassegrain port (Fig. 1). Table 1 lists the technical specifications while Sagar (2007) provides details of the new technology 3.6-m DOT project. The telescope is expected to be installed at Devasthal in 2012.

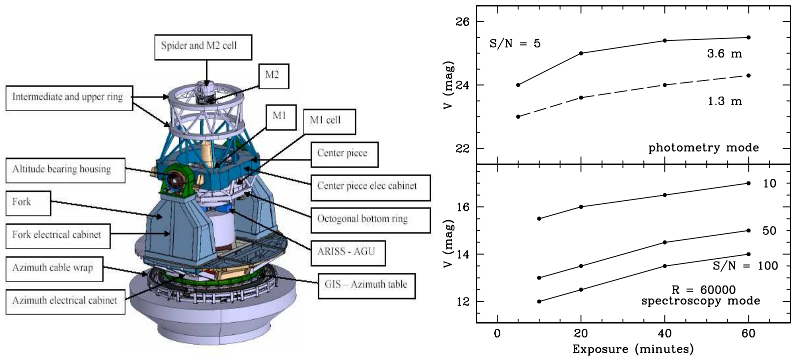

Figure 1. Left:Major sub-assemblies of the telescope with height ∼14 m and weight ∼120 ton; Right : The sensitivities of 3.6-m and 1.3-m optical telescopes

The first generation focal plane instruments are a Faint Object Specrograph and Camera (FOSC) and a near infrared spectrometer and imager (IRSPEC). The FOSC is a focal reducer instrument. The instrument shall work in imaging, polarimetric and spectroscopic mode. The instrument will have imaging capabilities with one pixel resolution of less than 0.3 arcsecond in the whole unvignetting field of view (10 X 10 arcmin) of the telescope, imaging/spectro polarimetry and low-medium spectroscopy with spectral resolution (250-5000) covering the wavelength range from 350 nm to 1000 nm . It is expected that we can image a 25 mag star in V band within an hour of exposure time (Fig. 1).

A general purpose near-infrared imaging camera with limited spectroscopic capability is proposed by TIFR Mumbai for observations in the near-infrared bands between 1 to 2.5 micron. It will use a 1024x1024 Hawaii HgCdTe detector array manufactured by Rockwell International USA and will have flexible optics and drive electronics that will permit a variety of observing configurations. The array will have a pixel size of 40 microns, read-noise of about 30 e/pixel, dark current of less than 0.2 e/sec/pixel and a gain of 10 e/adu. The primary aim of this instrument would be to obtain broad and narrow band imaging of the fields as large as 4x4 arcmin and also to use it as a long-slit spectrometer with moderate resolving power ($\lambda/\Delta\lambda \sim 400$) when attached to the telescope. The proposed IRSPEC when coupled with the 3.6 m telescope is expected to reach the 5σ detection of 22.5 mag in J, 21.5 mag in H and 21.0 mag in K with one hour integration.

A high resolution spectrograph capable of giving continuous spectral coverage (350 nm to 1000 nm) in a single exposure is also proposed. The instrument shall be capable of measuring spectrum with signal-to-noise ratio of 100 per 4 km/s bin for an integration time of one hour for a star of 14 magnitude at V band (Fig. 1).

The above mentioned focal plane instruments shall be used to carry out observations for the studies related to exo-planets, stellar variability and asteroseismology, interacting binary systems, variability in late type soft x-ray stars, formation and evolution of stars, studies of galaxies, dark matter in the galaxy, optical follow-up of the sources identified by GMRT and ASTROSAT and the highly energetic events - SNe and GRBs.

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