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New optical telescopes at Devasthal Observatory : 1.3-m installed and 3.6-m upcoming

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Abstract. The Devasthal Observatory, located at about 2420 m height above sea level in the central Himalayas, operates a 1.3-m optical telescope, commissioned in the year 2010 and building another 3.6-m optical telescope to be ready by 2013. Both of these are general purpose telescopes, providing spectral and seeing-limited imaging capabilities at optical and near infrared wavebands. The current status of these telescopes alongwith the planned backend instrumentation are described.

Keywords : Telescope – optical:instrumentation

1. Introduction

The Devasthal (Longitude : 79°41′04′′E, Latitude :29°21′40′′N) is located at an altitude of about 2420 m, in the central Himalayas. It is about 50 km east by road from the city of Nainital. An extensive site survey in the Kumaon region of the central Himalayas revealed that Devasthal is a potential site for astronomical observations at optical and near infrared wavebands (Pant, Stalin & Sagar 1999; Sagar et al. 2000; Stalin et al. 2001). It is well connected by road with the Manora Peak (Longitude:79°27′26′′E; Latitude: 29°21′39′′N; Altitude :1920 m) located in the vicinity of Nainital (Sinvhal et al. 1972; Sagar 1999). Both the sites Manora Peak and Devasthal are located in the Devabhumi of Uttarakhand, Nainital and they are operated by the Aryabhatta Research Institute of Observational Sciences (acronym ARIES), an autonomous research institute under the Department of Science and Technology (DST), Government of India (Sagar 2006). The Devasthal has well developed infrastructure and excellent communications with Manora Peak, making the logistics and operations of observational facilities at both places easy.

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Figure 1. The 1.3-m Optical Telescope at Devasthal.

Small and moderate size (up to 4-m class) optical telescopes at good astronomical site have several advantages over very large (10-m class) and giant (30-m class) ones, e.g. in efficiency, availability, survey work, serendipitous and time-critical observations (Sagar 2000). A new modern 1.3-m optical telescope has therefore been commissioned in 2010 at Devasthal and another new technology 3.6-m optical telescope is being built. Both these telescopes are intended to significantly increase the access to moderate size optical telescopes to the Indian astronomical community. The technical details of the telescope along with the planned back-end instruments are presented below in this contribution.

2. The 1.3-m optical telescope

In October 2010, a new modern 1.3-m optical telescope (hereafter 1.3-m DFOT[1]) has been installed successfully at Devasthal (Sagar et al. 2011). A picture of the telescope is given in Fig. 1. The telescope design of the 2-mirror Ritchey-Chrietein optics along with a single element corrector is optimized (Melsheimer & MacFarlane 2000) to deliver a fast beam (f/4) and a naturally flat-field of 66 arcmin diameter at the axial Cassegrain focus. It is therefore suitable for wide-area survey of a large number of point as well as extended sources. Without autoguider the tracking accuracy of the telescope is better than 0.5 arcsec in an exposure of 300 s up to a zenith distance of 40

[1]Devasthal Fast Optical Telescope

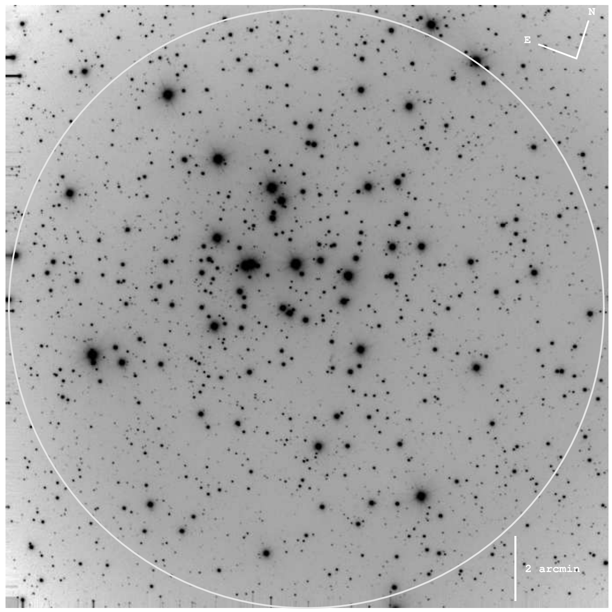

Figure 2. The R-band image of the star cluster M 36 taken on 30th November 2010 from 1.3m DFOT at Devasthal-Nainital. The image is a 45 co-added frames of 10s each, covers about 18′ on a side and the FWHM seeing is about 2′′. The unvignetted field of view is shown in circle.

degree. The pointing accuracy of the telescope is better than 10 arcsec RMS for any point in the sky. Further technical details on the as-designed specifications as well as as-built performance of the telescope system are given elsewhere (Sagar et al. 2010, Omar et al. in preparation). The main scientific objective is to monitor optical and near infrared (350-2500 nm) flux variability in the astronomical sources such as transient events (Gamma-ray bursts, supernovae), episodic events (active galactic nuclei and X-ray binaries), stellar variables (pulsating, eclipsing and irregular), transiting extrasolar planets - and to carry out photometric and imaging surveys of extended astronomical sources, e.g. HII regions, star clusters, and galaxies. Further details on the scientific objectives can be found elsewhere (Sagar 2006).

During commissioning phase, the telescope was equipped with a 13.5 micron pixel, 2kx2k Andor camera[2] which covers a square area of about 18 arcmin sky on a side. A set of Johnson-Cousins *B*, *V*, *R* and H_α filters, circular in size and providing unvignetted field of 18 arcmin diameter on CCD were available. In order to calibrate the telescope and camera system, the star cluster M 36 ($\alpha_{\rm J2000}$ = $05^{\rm h}36^{\rm m}12^{\rm s}$, $\delta_{\rm J2000}$ =

[2]The CCD can be read out with 31, 62, 500 and 1000 kHz speed, with the corresponding system RMS noise of 2.5, 4.1, 6.5, 7 e^- and gain of 0.7, 1.4, 2, 2 e^-/ADU. The camera could thermoelectric cool down to -80 degC. The CCD chip has QE of 90% between 500-700 nm and falls off to 50% at 400 and 900 nm.

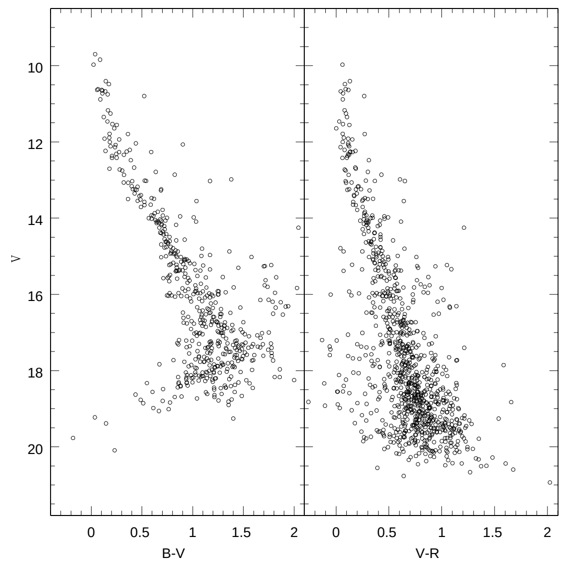

Figure 3. The color-magnitude diagram of the star cluster M 36 observed in *BVR* on 30th November 2010 from 1.3m DFOT at Devasthal, Nainital.

-09°47′43′′) was observed on 30th November 2010 in broad-band *B*, *V* and *R* filters. The camera was operated at 1 MHz speed, in accumulate mode and 11 exposures of 50s (5 accumulations of 10s each) were obtained in each filter. During the observations, the FWHM seeing was around 2′′ and the airmass varied between 1 to 2. Fig. 2 shows an R-band frame of M 36. The photometric data reductions of the CCD images were done using standard procedure (e.g. see Yadav et al. 2008, and references therein). For near-zenith observations, in about 2′′ FWHM PSF, we could reach a signal-to-noise ratio of 5 for 20 mag in *B* and 21 mag in *V* and *R* in five summed images of 10s each. The instrumental magnitudes were calibrated using the Landolt (2009) equatorial fields SA98 and SA95 of standard stars observed on the same night. The 1σ error in calibration was 0.021 mag in *B* and 0.015 mag in both *V* and *R* filters. The atmospheric extinctions in *B*, *V*, and *R* are estimated as 0.16 ± 0.01, 0.11 ± 0.01 and 0.05 ± 0.02 mag/airmass respectively. The calibrated color magnitude diagram in *BVR* is shown in Fig. 3 and a well defined zero-age main-sequence of the young (∼ 16 Myr) star cluster M 36 can be clearly seen. Further details of the calibration and science verification results of the commissioning data will be presented elsewhere (Kumar et al. in preparation).

In order to know the detection limits of low-amplitude flux variations in brighter (∼ 10 mag) celestial sources set by scintillation in the Earth's atmosphere, we also carried out photometric observations of a known transiting extrasolar planet WASP-12 ($\alpha_{\rm J2000}$ = $06^{\rm h}30^{\rm m}32^{\rm s}$, $\delta_{\rm J2000}$ = 29°40′40′′, V = 11.7 mag). We used 16 micron

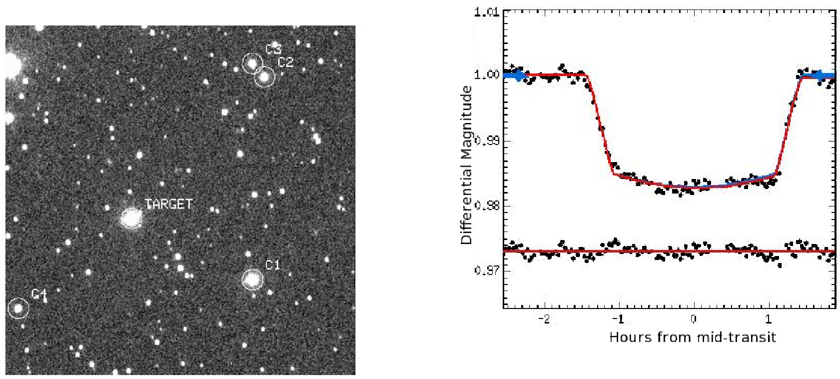

Figure 4. The R-band image (left) and differential light curve (right) of the transiting extrasolar planet WASP12 ($V \sim 11.7$ mag star) observed on 5^{th} February 2011 with the 1.3-m DFOT at Devasthal, Nainital. The image is exposed for 5s and it covers about $6'$ on a side. The target and the four comparison stars are encircled. Each single data point in the light curve represents flux from twenty coadded frames. The model is overplotted and a typical error in each data point is of the order of 1 mmag.

pixel, 512x512 Andor camera[3] and operated it in the conventional 1 MHz readout mode with RMS noise of 6.1 $e^-$and a gain of 1.4 e^-/ADU. On 5^{th} February 2011, we recorded a set of 3300 CCD frames of 5s each in Cousins R-band during a continuous observations for 4.5 hours. The observations were made without auto guider[4]. The data reduction was done in usual manner as described in (Joshi et al. 2009, and references therein) and the differential light curve was generated using ensemble photometry by employing four comparison stars (see Fig 4). The differential light curve had a typical photometric accuracy of 3 mmag. To improve the signal-to-noise ratio, we co-added 20 frames of 5s each and it resulted in a photometric accuracy of better than 1 mmag. The co-added differential light curve of the WASP-12 transiting system along with the model fit is shown in the upper panel of Fig 4. A flux variation of $\sim$17 mmag is clearly seen in the transit light curve. In the lower panel, residuals of the model fit indicates a photometric precision of 1 mmag for a 11.7 mag star. As a comparison, a similar observations using 1.04-m Sampurnanad telescope at Manora Peak, we get an accuracy of about 3 to 4 mmag. Hence the 1.3-m DFOT at Devasthal would be suitable for the scintillation limited science programs requiring a detection of few mmag on a time scale of hrs (e.g. exoplanet search and AGN variability).

[3]The CCD can be read out with 10, 5, 3, 1 MHz speed in Electron multiplying amplifier and with 3, 1 MHz speed in conventional Amplifier mode with the values of system readout noise from less than 1 to 49 e^-@10 MHz. A variable readout dependent gain to match the 16-bit digitization can be chosen. The camera could thermoelectric cool down to -80 degC. The CCD chip has a QE of 90% between 500-700nm and falls off to 35% at 375 and 950 nm

[4]Observations with auto guider reduces the flat-field calibration error and increases the photometric accuracy of the differential light curve.

Figure 5. The 3.6-m Optical Telescope at the AMOS (Advanced Mechanical and Optical System) factory, Belgium in June 2011.

3. The 3.6-m optical telescope

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 an instrument derotator interface. The telescope has two side ports and one main Cassegrain port. Further technical details can be found elsewhere (Sagar 2007; Flebus et al. 2008; Sagar et al. 2010). As of June 2011, the assembly and integration of the telescope with dummy mirrors have been completed at the AMOS (Advanced Mechanical and Optical System) factory, Belgium (Fig. 5) and the fine-tuning and testing of various telescope motions are in progress. Both the primary and secondary mirrors of the telescope are polished at the LZOS, Russia and the polishing accuracy (RMS wavefront error at 600nm) of 35 nm for primary and 30 nm for secondary has been achieved. The acceptance of the telescope at factory is likely to take place in March 2012.

The first generations focal plane instruments are a faint object spectrograph and camera, a high resolution fiber-fed optical spectrograph, an optical–near infrared spectrograph and imager, and a CCD optical imager (see Table 1).

The ADFOSC (ARIES Devasthal Fain Object Spectrograph) is a focal reducer instrument. The instrument shall work in imaging and spectroscopic mode. The instrument will have imaging capabilities with one pixel resolution of less than $0''.2$ arcsecond in the field of view ($\sim 14' \mathrm{X}\ 14'$) of the telescope, and low-medium spectroscopy with spectral resolution (250-4000) covering the wavelength range from 350 nm to 900 nm. A computer simulation indicate that we can image a 25 mag star in V band within an hour of exposure time. The Optical design of instrument has been completed as on June 2011 and the mechanical design is in progress.

A high resolution fiber-fed spectrograph capable of giving continuous spectral coverage (380 nm to 900 nm) in a single exposure is also proposed. The instrument shall be capable of measuring spectrum with signal-to-noise ratio of 100 per 20 km/s bin for an integration time of one hour for a star of $V \sim 16$ mag.

A general purpose optical–near infrared imaging camera with limited spectroscopic capability is proposed jointly by TIFR Mumbai and ARIES for observations in the near-infrared bands between 1000 to 2500 nm. 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 primary aim of this instrument would be to obtain broad and narrow band imaging of the fields as large as 6x6 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.

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.

Acknowledgments

This work is presented on behalf of a larger team associated with the 3.6-m on-going telescope project. The authors are thankful to the Devasthal Observatory staff for their assistance during observations taken with 1.3-m telescope. Useful scientific inputs from Drs. R.K.S. Yadav, S.B. Pandey, J.C. Pandey and G. Maheswar and technical help from Engineers J. Pant and S. Yadava are thankfully acknowledged.

Table 1. Technical specifications of the proposed 3.6m Instruments

Parameters	value
ARIES Devasthal Faint Object Spectrograph and camera:	
Spectral coverage	350-900 nm
Field-of-view	14x14 arcmin (imaging); 10x10 arcmin (spectroscopy)
Image quality	80% energy in 0.4 arcsec diameter
Resolving power	250-2000 @1 arcsec slit-width with single grisms
	4000 @1 arcsec slit-width with VHP Gratings
High-resolution fiber-fed optical spectrograph :	
Spectral coverage	380-900 mm
Resolving power	30000 and 60000 (fixed)
Radial velocity resolution	20 km/s
Optical-NIR meadium resolution spectrograph and imager:	
Spectral coverage	500 nm - 2500 nm
Resolving power	3000-4000
Field of view	7 arcmin
CCD Optical imager:	
Spectral coverage	300 nm - 900 nm
Field of view	6.5 x 6.5 arcmin
Spatial resolution	0.1 arcsec/pix

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