User's Manual

3.6m Devasthal Optical Telescope

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Contents

List of Figures **4**

List of Tables **5**

1 About the manual **6**

2 Overview of the facility **7**

2.1 Devasthal site characterisation . . . 7

2.2 Update on night sky condition at Devasthal . . . 9

3 About the telescope **11**

3.1 Guider of telescope . . . 12

3.2 As-built performance of telescope . . . 13

3.3 Current status of telescope . . . 14

3.4 Update on Instruments . . . 16

3.4.1 IMAGER . . . 16

3.4.2 ADFOSC . . . 16

3.4.3 TIRCAM2 . . . 19

3.4.4 TANSPEC . . . 19

4 Observing with the telescope **22**

5 Checklist for facility operation **23**

5.1 Emergency calls and assistance . . . 24

Bibliograbhy **24**

List of Figures

2.1 A panoramic view of ARIES Devasthal Observatory, Nainital. The larger white dome houses 3.6m Optical Telescope whereas the Roll-off roof houses a 1.3m wide-field optical telescope. 7
2.2 The components of 3.6m DOT Facility at Devasthal. 8

3.1 The fish-eye view of 3.6m telescope inside the rotating dome structure - courtesy Anna 11
3.2 ARISS (Adapter rotator instrument interface structure) : a- main instrument envelope, b. side-port instrument envelope, c- rotator bearing, e- pick-off mirror, f- adaptor bearing, g-turn table, h- optical bench with guider camera and wavefront sensor. 13
3.3 The iso-intensity contour images of close-separation binary stars observed with 3.6m telescope. 15
3.4 Top: The picture of IMAGER instrument mounted on the main-port of the telescope. Bottom-left:A 30s R-band image of a $6'.5 \times 6'.5$ field centered at SLSN 2020ank taken on 16th March 2020 using IMAGER with pixel binning of 2×2. Bottom Right: Image profile of a stellar source of the same field. The PSF FWHM is 3.25 pixel ($0''.62$). 17
3.5 A view of the ADFOSC mounted on the main-port of telescope. Bottom-right:A 30s r-band image of a $13'.6 \times 13'.6$ field centered at SN 2020ue taken on 27th May 2020 using ADFOSC with pixel binning of 2×2. Bottom Left: Image profile of a stellar source of the same field. The PSF FWHM is 2.3 pixel ($0''.92$). 18
3.6 Top: TIRCAM2 instrument mounted with the side-port1 of the telescope. Bottom-left: The stellar image of a source observed with TIRCAM2 in the night of 16th Oct 2017. Bottom-right: The radial profile of the source is measured to be $0''.45$ FWHM. 20
3.7 Top: TANSPEC instrument mounted with the main-port of the telescope. Bottom-left: The $1' \times 1'$FOV J-band image centered on a galaxy with integrated exposure of 10 min observed with TANSPEC in the night of 15th February 2020. Bottom-right: The radial profile of the stellar source in the image is measured to be $0''.5$ FWHM. 21

List of Tables

2.1 Characteristic parameters of the Devasthal site measured during 1996-2001 9
2.2 Number of clear nights month-wise at Devasthal 10

3.1 Key as-designed parameters of telescope laid down in 2007 12
3.2 Key as-built characteristics of telescope measured in 2016 14

Chapter 1

About the manual

This document contains general description and operations of the 3.6 meter Devasthal Optical Telescope and its back-end instrumentation. The detailed technical description about the telescope and the available instruments can be found in the cited documentation. The materials in this manual and the subsequent updates are available at:

http://www.aries.res.in/dot

Chapter 2

Overview of the facility

The 3.6m Devasthal Optical Telescope (DOT) facility is located at Devasthal in the Nainital District of Uttarakhand, India. The Devasthal site is operated by the Aryabhatta Research Institute of Observational Sciences [1, acronym ARIES]. The site also hosts a 1.3m aperture, f/4 RC optical telescope since 2010 [2] and there is a plan to set up another 4-m aperture liquid mirror telescope [3]. A long distance view of ARIES Devasthal Observatory is shown in Figure 2.1.

Figure 2.1: A panoramic view of ARIES Devasthal Observatory, Nainital. The larger white dome houses 3.6m Optical Telescope whereas the Roll-off roof houses a 1.3m wide-field optical telescope.

The 3.6m DOT facility consists of a 3.6m diameter optical telescope, a suite of back-end instruments, a rotating dome and an auxiliary building with a aluminising plant, a control room and a data center. A pictorial presentation of the facility is shown in Figure 2.2. The research account of the 3.6m DOT project is described in [4, and references therein]. The facility became operational from March 2016.

2.1 Devasthal site characterisation

The Devasthal site is located at an altitude of about 2450 m in the foothills of central Himalayan region. The site is situated about 50 km east of Nainital city by road. An extensive site characterisation was performed during 1999-2000. The seeing measurements at Devasthal were carried out

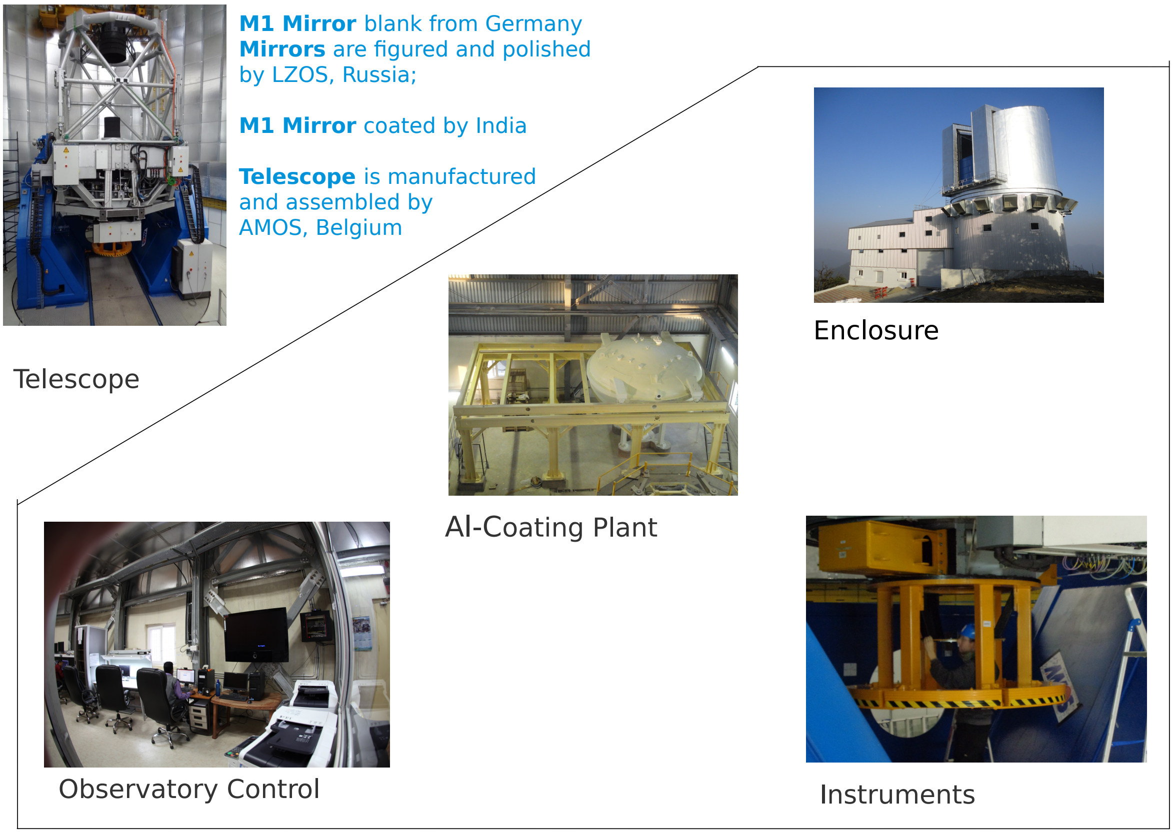

Figure 2.2: The components of 3.6m DOT Facility at Devasthal.

over 80 nights during 1998-1999 with a Differential Image Motion Monitor (DIMM) using a 38-cm telescope with the location of mirror about 2 m above the ground. This set-up yielded a median seeing of $1''.1$; the 10 percentile values between $0''.7$ to $0''.8$ (mean = $0.''75$) while for 35% of the time the seeing was better than $1''$. A summary of key site parameters obtained during 1998-2001 are given in Table 2.1. A detailed information on technical atmospheric characteristics of the site can be found in [5, and reference therein].

The inference of a true median seeing for a site depends on many factors, for example, statistics, instrument used and data reduction procedures. The DIMM seeing measurements at Devasthal are made with a 10 ms exposure time, using a hole separation of 24 cm and a pixel separation of 60. It is observed that a finite, say 10 ms exposure is likely to under estimate the seeing by 10 percent. This shall degrade the median seeing estimate to about $1''.2$ FWHM (Full Width at Half Maximum). Furthermore, the above median seeing ($1''.1$) estimate are performed at 2 m above ground level and it is observed that the contribution of air slab from 12 to 18m above ground will reduce to a seeing of $0''22$ [6]. In addition, the free air seeing gets further degraded by the local air turbulence due to dome design and this may contribute from a few percent to tens of percent.

The primary mirror of 3.6m DOT is placed at about 14m above the ground and hence the contribution of free air seeing to the images recorded by the telescope are expected to be few tenths of an arcsec.

Table 2.1: Characteristic parameters of the Devasthal site measured during 1996-2001

Parameters	**Value**
Location	Alt: 2424 ± 4 m; Long:79°41′04″E; Lat:29°21′40″N
Seeing (Ground level)	1″.1 (median); 0″.75 (median of 10 percentile values)
Estimated Seeing	0″.86 for 6-12m and 0″.22 for 12-18m slabs above ground level
Wind	< 3 m/s for 75% of time
Air temperature	21.5 deg C to −4.5 deg C (variation during year) ≤ 2 deg C (variation during night)
Rain	2m (average over year, 80% during June-September)
Snowfall	60 cm (average; during January and February only)
Clear nights	208 spectroscopic nights of which 175 are photometric
Sky Transparency (mag/airmass)	Average : $k_U = 0.49 \pm 0.09$; $k_B = 0.32 \pm 0.06$ $k_V = 0.21 \pm 0.05$; $k_R = 0.13 \pm 0.04$; $k_I = 0.08 \pm 0.04$ Best : $k_U = 0.40 \pm 0.01$; $k_B = 0.22 \pm 0.01$ $k_V = 0.12 \pm 0.01$; $k_R = 0.06 \pm 0.01$
Relative humidity	≤ 60% during spectrocopic nights; much higher during July to September

2.2 Update on night sky condition at Devasthal

At present, the Devasthal site does not host any dedicated ground level seeing monitor and hence it is not possible to get instant measured value of seeing during the night. Also, we do not have any nightly record of seeing at Devasthal site since 2001 till now. It is, however, noted that an occasional measurement of FWHM of point sources using 1.3m (in operation since 2010) and 3.6m telescope (in operation since 2016) indicate that the ground level seeing values recorded about two decades earlier holds good.

The number of clear nights at Devasthal is an important parameter for users. Though we do not have any all sky camera which maps the cloud coverage at Devasthal every night but we do maintain online/offline records on the night sky for the 1.3m and 3.6m telescope at site. Based on our records and experience particularly during past two years from Oct 2018 to May 2020, we tabulate below the number of clear nights which can be expected every month at Devasthal.

Table 2.2: Number of clear nights month-wise at Devasthal

Months	**Clear Nights (Avg.)***	**Remarks**
Oct	20	Post-monsoon period, slightly humid
Nov Dec	25 25	Best months with maximum number clear nights
Jan Feb	20 20	Nights lost are mostly affected by snowfall; 3 to 4 events per year, 2 per month. The event lasts for 4 days max, but, some nights are lost due to blockage of road, etc. and inability to access telescope.
Mar Apr May	15 15 15	severely affected by western disturbance which brings rain and clouds. The atmospheric transparency becomes poor mainly due to aerosol loading and this results in less number of photometric nights for this period.

*Note: (a) More than 90% of the nights during June to September are cloudy.
(b) The average number of partly clear nights per month is about 20% of the clear nights .

Chapter 3

About the telescope

The telescope has two mirror Ritchey-Chretien optical configuration with three Cassegrain ports for instruments - viz an axial main-port, and two side-ports. A field corrector is also provided to achieve desired optical performance at optical wavelengths over the field of view of 30 arcmin. The meniscus primary mirror is active and it is supported by pneumatic actuators. The azimuth axes system is equipped with hydrostatic bearings. The key as-designed performance requirements laid down in 2007 for the telescope is given in Table 3.1.

The picture of as-built telescope is shown in Figure 3.1 whereas the coverpage of this document shows the actual view of telescope dome building at Devasthal.

Figure 3.1: The fish-eye view of 3.6m telescope inside the rotating dome structure - courtesy Anna

Table 3.1: Key as-designed parameters of telescope laid down in 2007

Parameters	**Value**
Focal ratios	Primary : F/2; Effective : F/9; Plate Scale : $6''.366$ /mm
Science Field of View	10 arcmin on side ports, 30 arcmin on axial main port, (35 arcmin for the AGU)
Operational waveband	350 nm to 5000 nm
Optical image quality	- Encircled Energy 50% < 0.3 arcsec, - Encircled Energy 80% < 0.45 arcsec, - Encircled Energy 90% < 0.6 arcsec, For the waveband 350 nm to 1500 nm; without corrector for 10 arcmin FOV.
Mounting	Alt-azimuth
Sky coverage	15 to $87^\circ.5$ in elevation
Pointing accuracy	$< 2''$RMS
Tracking accuracy	$< 0''.1$ RMS for 1 minute in open loop, $< 0''.1$ arcsec RMS for 1 hour in close loop, $< 0''.5$ arcsec Peak for 15 minutes in open loop.
Instruments	1 axial main-port instrument: - mass: 2000 kg - allocated room: 1.8 m X 3 m (Height X Diameter) - instrument flange: 40 cm before the focus. 2 side-port instruments: - mass: 250 kg per instrument - allocated room: 0.5 m X 0.5 m X 0.7 m (H X W X L) - instrument flanges: 10 cm before the focus.

3.1 Guider of telescope

The acquisition and guiding unit (AGU) of the telescope measures wavefront errors and the tracking errors in operation. A pick-off mirror can be aligned on a guide star located at the edge of the FOV (30-35 arcmin annulus). The guide star light beam is then directed towards an optical bench equipped with a wavefront sensor and a guider camera, see Figure 3.2. The pick-off mirror is positioned on the guide star using the movements of adapter and the turntable. The centroid of star on guide camera (400-700nm sensitivity) is used to correct the tracking errors while the wavefront sensor camera (uv and red region) measures the wavefront errors which is used to modify the force distribution of M1 axial actuators. Focus and coma are corrected using hexapod mechanism of M2. The main instrument and two side ports are fixed to a structure (called ARISS) including a rotator that de-rotates the image of sky. The Side-port fold mirror (SPFM) is also located in this structure. The AGU, rotator, SPFM are nested at the reare of M1, just above the instrument.

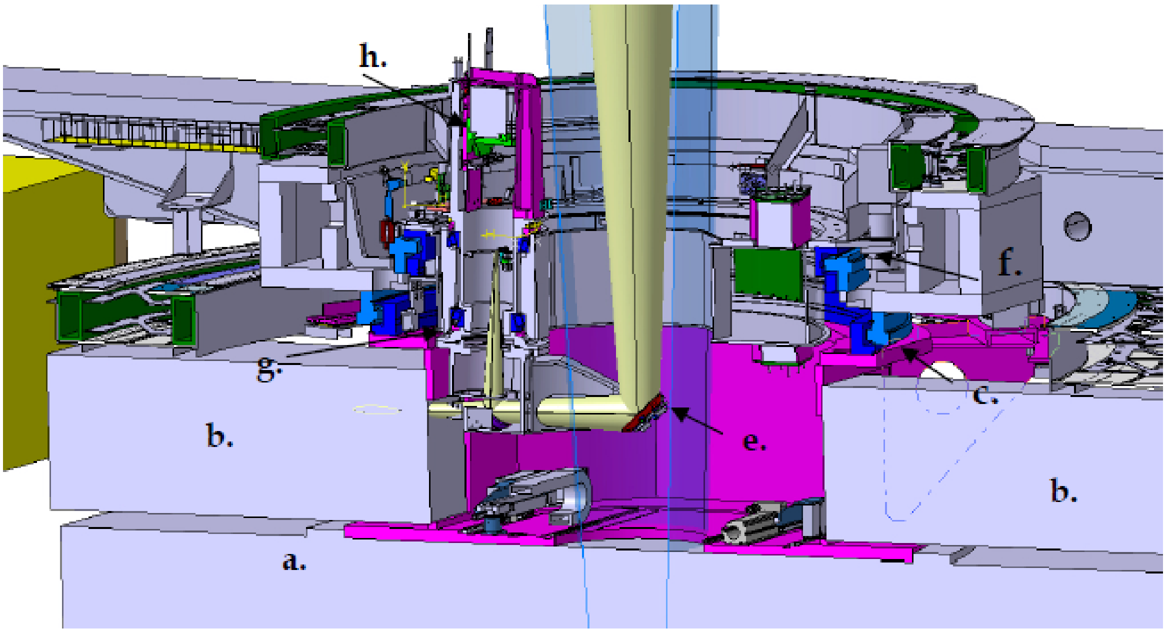

Figure 3.2: ARISS (Adapter rotator instrument interface structure) : a- main instrument envelope, b. side-port instrument envelope, c- rotator bearing, e- pick-off mirror, f- adaptor bearing, g-turn table, h- optical bench with guider camera and wavefront sensor.

3.2 As-built performance of telescope

A set of four system level tests viz. pointing accuracy, tracking accuracy, optical quality and guider sensitivity were carried out during performance verification of telescope at Devasthal site in late 2015 and early 2016. A technical committee chaired by Prof. S. N. Tandon made assessment of the tests performed. The first aluminization of M1 was performed at site in February 2015. The mean reflectivity in the spectral range from 400 nm to 1000 nm is found to be 86% The M2 has a protective Aluminium coating and it has a mean reflectivity of 87% in the visible region. The synchronization scheme of telescope with that of dome was developed in-house at ARIES and the dome has been tested to track the position of telescope automatically.

A set of four instruments were used for the purpose of tests, viz. Test-Camera and Test-Wave Front Sensor (WFS) which were used at Cassegrain ports of the telescope; the AGU-Camera and the AGU-WFS which are part of telescope. A comprehensive set of data were collected, analysed and the test procedures and results were put in form of a professional technical report. The as-built system level performance of telescope is listed in Table 3.2. Further details on on-site performance can be found in [7]

The images of a few binary stars with known separation were observed on different nights during November-December 2015 using test-camera (9 micron, 1024 pixel). Stars up to 0.4 arcsec angular separation were resolved in the best seeing conditions, see Figure 3.3. This is consistent with the image quality of optics of 0.17± 0.03 arcsec (FWHM) , corresponding to as-measured mean E80 of 0.26±0.04 arcsec.

Table 3.2: Key as-built characteristics of telescope measured in 2016

Parameters	**Value**
Pointing Accuracy	Specs: less than 2 arcsec RMS Results: 1.1, 1.3 and 1.2 arcsec for side-port1, side-port2 and main-port respectively.
Tracking Accuracy Open-Loop (without guider):	Specs: < 0.1 arcsec RMS for 1-min Results : 0.06, 0.08, 0.08, 0.08, 0.09, 0.09, 0.10, 0.12, 0.12, 0.14 arcsec. Mean : 0.08±0.03 arcsec Specs: < 0.5 arcsec PEAK for 15-min Results : 0.16, 0.22, 0.24, 0.24, 0.25, 0.32, 0.34, 0.35, 0.36, 0.42 arcsec. *Values which are marginally above specs are affected by seeing and local weather disturbance.*
Tracking Accuracy Close-Loop (with guider):	Specs : < 0.11 arcsec RMS for 1-hr Results : 0.07, 0.07, 0.08, 0.09, 0.09, 0.09, 0.10, 0.10, 0.10, 0.11, 0.13, 0.13 arcsec. Mean : .09±0.02 arcsec
Optical Image Quality	Specs: E50 < 0.3 arcsec diameter;E80 < 0.45 arcsec diameter E90 < 0.6 arcsec diameter Results: E50 values are 0.19, 0.13, 0.13, 0.12, 0.18, 0.14 arcsec diameter; E80 values are 0.37, 0.27, 0.23, 0.25, 0.33, 0.23 arcsec diameter (0.26±0.04); E90 values are 0.49, 0.36, 0.31, 0.32, 0.42, 0.30 arcsec diameter.
AGU Guider Sensitivity	Specs: V mag of about 13 mag Results: 12.85 mag star tested successfully

3.3 Current status of telescope

The 3.6m DOT was commissioned in March 2016 and the first call for proposals (Early Science) were announced for the observing period from 2nd April 2017 to 31st May 2017 (2017-C1). The telescope worked very well during this first Cycle. The calls for next two cycles - October 2017 to January 2018 (2017-C2) and February-May 2018 (2018-C1)) were also announced but these were put on hold due to some operational restrictions as the telescope developed major technical issues, which included failure of azimuth motor and ungluing of mirror pads.

Over the past one year, the telescope has gone through major repair activities. The replacement of azimuth motor as well as gluing of pads have been successfully achieved during the last quarter of 2019. Since January 2020, the telescope has been used to carry out test observations with instruments. The health of the telescope has been closely monitored by the technical team during the past six months and it worked well. The telescope is producing sub-arcsec images in best

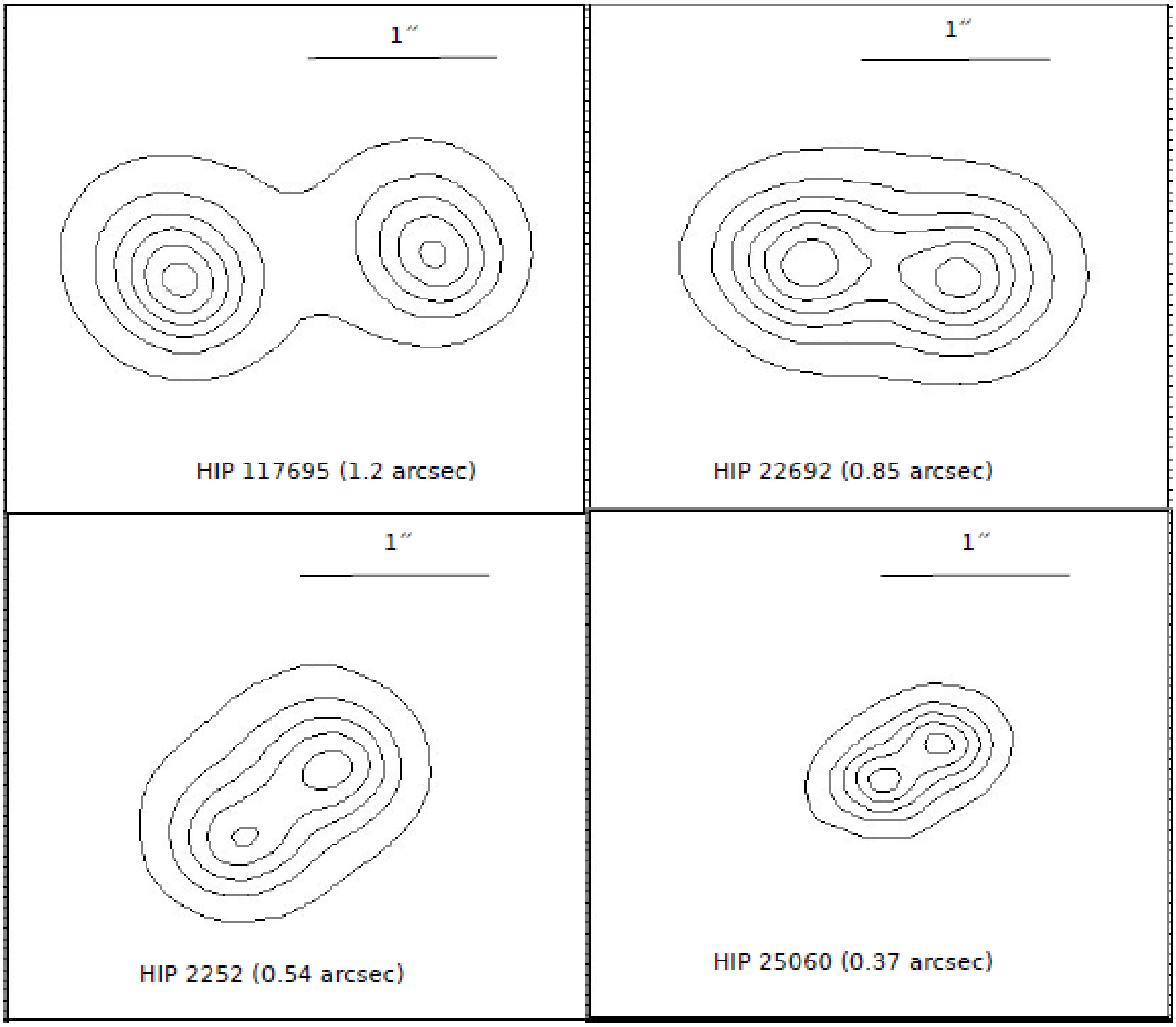

Figure 3.3: The iso-intensity contour images of close-separation binary stars observed with 3.6m telescope.

observing conditions as before.

The primary (M1) mirror of telescope looses its reflectivity with time and it has to be coated regularly at least once every alternate year. The 1st M1 coating took place in February 2015 and subsequently, it was coated in March 2017 (2nd time), and in August 2019 (3rd). The measurement of freshly coated M1 mirror using a reflectometer gives a typical reflectivity value between 85-88% at visible wavelengths [8]. A monthly in-situ cleaning of M1 mirror with dry CO2 is also performed to maintain the reflectivity. The last measurements of reflectivities in early 2020 suggests that the reflectivity lies in the range 75 to 85%.

Telescope has three cassegrain ports for mounting instruments viz. axial main-port, side-port1 and side-port2. It is possible to switch the ports within a minute using a fold mirror. In principle, a set of three instruments can be mounted with the telescope and used near simultaneously. The side-port2 is free at the moment. The 3.6m DOT currently offers four instruments for carrying out high resolution imaging and low resolution spectroscopic observations of celestial sources. One instrument is permanently mounted on the side-port1 of the telescope and it is always available for observations, whereas other instruments are mounted one at a time on the axial-port. The guider of the telescope is under maintenance and hence the instruments using the guider of the telescope may not offer single exposures exceeding 5 to 10 minutes depending upon the position of the telescope.

3.4 Update on Instruments

The telescope currently offers four instruments and for the sake of completeness of this manual a brief description is given below. For latest update on the back-end instruments, please visit http://www.aries.res.in/dot/.

3.4.1 IMAGER

IMAGER is an optical imaging instrument covering wavelengths ranging from 400 to 900nm [9]. It employs a 4096 × 4096 CCD camera with a pixel scale of about $0\farcs1$ arcsec on the telescope and it covers a field of view of $6\farcm5 \times 6\farcm5$. The available filters are Bessel U,B,V,R,I and SDSS u,g,r,i,z. Imaging observations show that the instrument has the capability to observe sources up to 24.0 mag, 25.2 mag and 24.6 mag with 10% photometric accuracy in B, g, r band respectively, with corresponding effective exposures of 1200s, 3600s, and 4320s. It can only be mounted on the axial main-port of the telescope. Stellar images with FWHM of ~ $0\farcs6$ in R-band were recorded in March 2020 in best conditions (see Figure 3.4).

3.4.2 ADFOSC

ADFOSC is a low resolution slit-spectrograph and camera having sensitivity in the wavelength range 350 nm to 1050 nm[10]. It uses a 4096 × 4096 deep-depletion fringe-suppressed E2V CCD camera with a pixel (px) scale of ~0.2 arcsec and it covers a field of view of $13\farcm6 \times 13\farcm6$. The available filters are broad-band SDSS u,g,r,i,z and narrow-band (10.2 nm width) with central wavelengths at 491.6, 660.9, 674.3, and 683.3 nm. The spectral dispersions provided by different grisms are in the range of 0.1 to 0.7 nm/px and an $8'$long slit with different available widths ($0\farcs4$ - $3\farcs2$) can be used. Imaging observations show that the instrument has the capability to detect sources up to 24.5 mag AB (i-band) with 10% photometric accuracy in r-band in effective exposure of ∼2 hours in dark nights. Spectroscopic observations with the instrument show that a spectroscopic trace of g=19 mag source at 5σ level can be detected in 10 minutes of exposure at ~0.2 nm/px dispersion. Hg-Ar, Ne, and continuum lamps are available for spectral calibration. The CCD camera is in development mode and presently it shows some departures from linearity at low-light and bright-light conditions, which needs to be corrected using an IRAF script. It can only be mounted on the axial-port of the telescope. Stellar images with FWHM of $0\farcs9$ arcsec in r-band were recorded in May 2020 in best sky conditions (see, Figure 3.5)

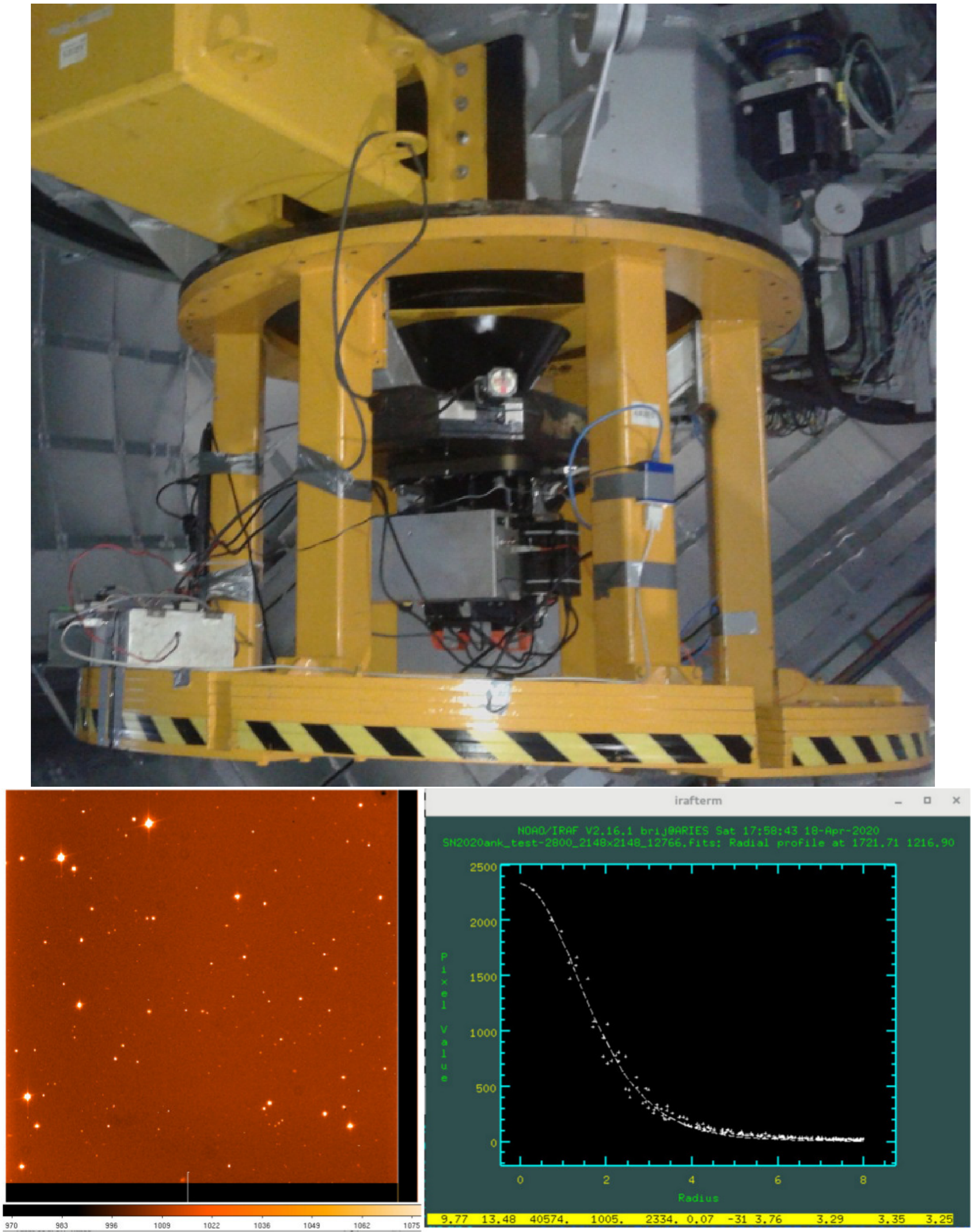

Figure 3.4: Top: The picture of IMAGER instrument mounted on the main-port of the telescope. Bottom-left:A 30s R-band image of a $6\farcm5 \times 6\farcm5$ field centered at SLSN 2020ank taken on 16th March 2020 using IMAGER with pixel binning of 2×2. Bottom Right: Image profile of a stellar source of the same field. The PSF FWHM is 3.25 pixel ($0\farcs62$).

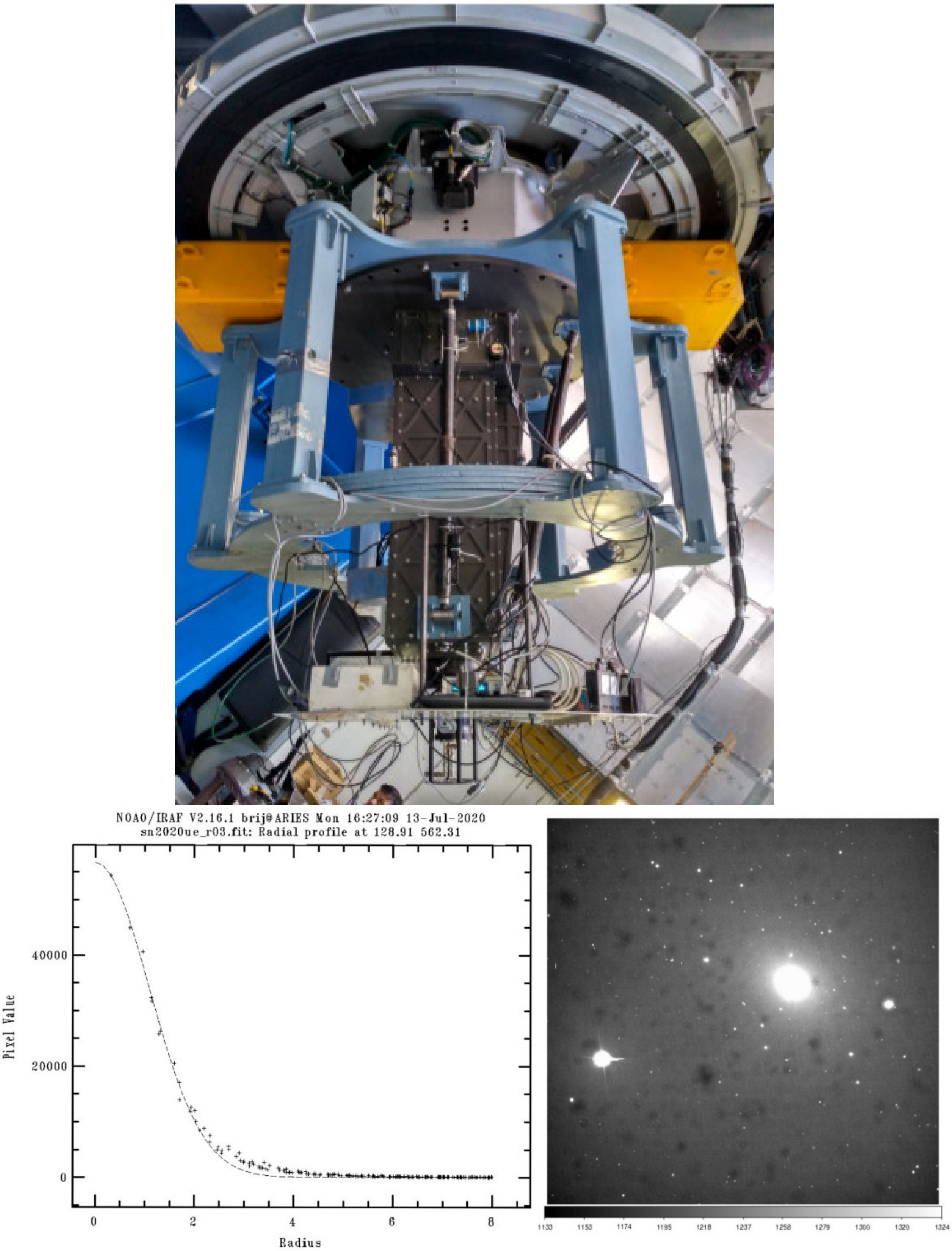

Figure 3.5: A view of the ADFOSC mounted on the main-port of telescope. Bottom-right:A 30s r-band image of a 13′.6 × 13′.6 field centered at SN 2020ue taken on 27th May 2020 using ADFOSC with pixel binning of 2 × 2. Bottom Left: Image profile of a stellar source of the same field. The PSF FWHM is 2.3 pixel (0′′.92).

3.4.3 TIRCAM2

TIRCAM2 can provide near infrared imaging observations in the wavelength range from 1 to 3.7 μm [11]. It employs an InSb array with a pixel scale of $0\overset{''}{.}17$ and it covers a field of view of $86\overset{''}{.}5 \times 86\overset{''}{.}5$ arcsec. It has broad-band J,H,K and narrow-band BrG, K-cont, PAH and nbL filters. Deep imaging observations show that the instrument has the capability to observe sources up to 19.0 mag, 18.8 mag and 18.0 mag with 10% photometric accuracy in J, H, K band respectively, with corresponding effective exposures of 550s, 550s and 1000s. It is permanently mounted on the side-port1 of the telescope. Stellar images with FWHM of $0\overset{''}{.}45$ arcsec in K-band were recorded in best conditions (see Figure 3.6).

3.4.4 TANSPEC

TANSPEC is a medium resolution spectrograph and camera having sensitivity in the wavelength range from 550 to 2540 nm [12]. It employs a 1024 × 1024 h1rg array with a pixel scale of $0\overset{''}{.}25$ and it covers a field of view of $1' \times 1'$. It offers broad-band r, i, Y, J, H, K and narrow-band H2 and BrG filters. The object of 18 mag in K has been successfully detected in 1-min exposure. It is possible to detect sources at J, H, K of 19.5, 18.9, 18.4 mag respectively at 10σ level in 10 minutes exposure. For spectroscopy, it employs an 2048 × 2048 h2rg array and it can be used in cross-dispersed (R~2750) as well as in prism mode (R~100-350). The slits available in these modes have widths between $0\overset{''}{.}5$ to $4\overset{''}{.}0$ arcsec. It is possible to take R ~ 2750 (~100-350) spectra of J=14.3 (17.3) mag source in 1 hour at 100σ level for stellar sources with FWHM of $1''$. Currently the instrument is available for imaging and low-resolution (R~100-350) prism mode spectroscopy. The availability of the high resolution mode is subject to the successful installation of a new grating. However, the availability will be intimated in due course on the webpage of 3.6m DOT. TANSPEC can only be mounted on the axial-port of the telescope. Stellar images with FWHM of $0\overset{''}{.}5$ in K-band were recorded in February 2020 in best conditions (see, Figure 3.7).

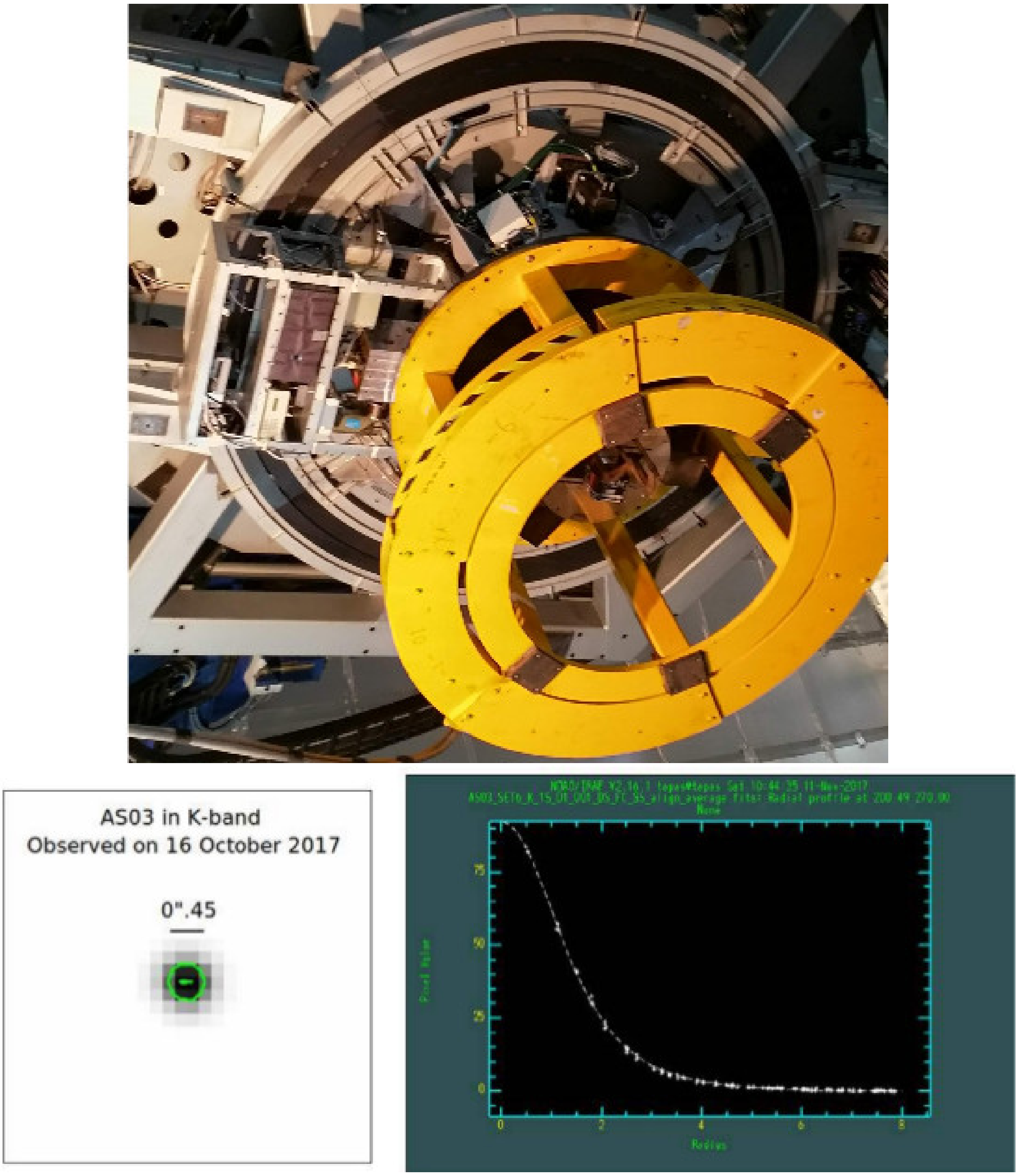

Figure 3.6: Top: TIRCAM2 instrument mounted with the side-port1 of the telescope. Bottom-left: The stellar image of a source observed with TIRCAM2 in the night of 16th Oct 2017. Bottom-right: The radial profile of the source is measured to be 0.″45 FWHM.

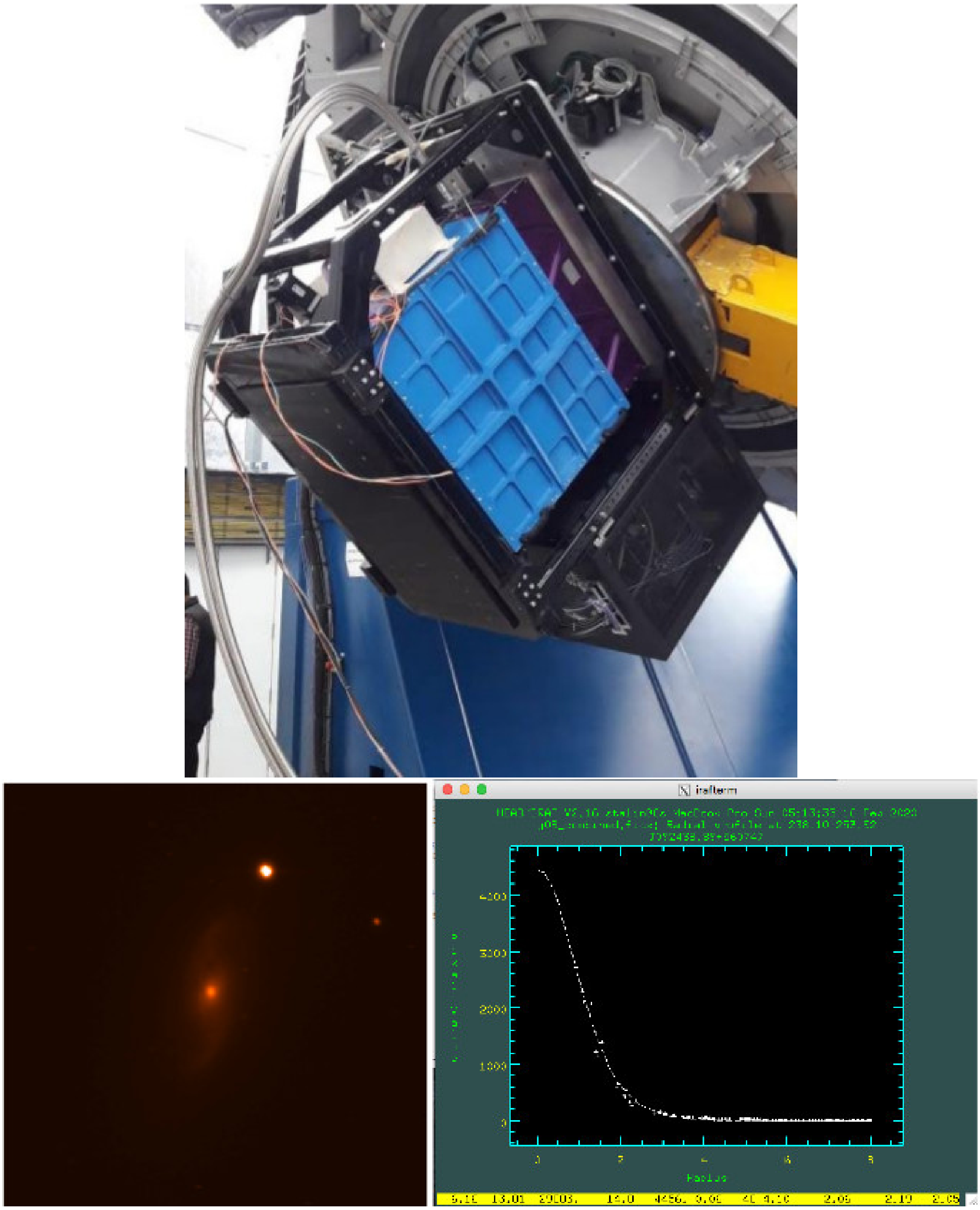

Figure 3.7: Top: TANSPEC instrument mounted with the main-port of the telescope. Bottom-left: The 1′× 1′FOV J-band image centered on a galaxy with integrated exposure of 10 min observed with TANSPEC in the night of 15th February 2020. Bottom-right: The radial profile of the stellar source in the image is measured to be 0.′′5 FWHM.

Chapter 4

Observing with the telescope

The observation time on telescope will be allotted by Time Allocation Committee through a call for proposals and an online proposal submission and evaluation system. The science observing policy document for 3.6m DOT can be obtained from https://www.aries.res.in/dot. The proposers will be free to select the instruments depending on the science objectives of the proposal. All the proposed instruments will be mounted and tested during day-time and this activity will be performed by the DOT technical team dedicated by ARIES to look into the operation and maintenance of 3.6m DOT facility.

The telescope, AGU, back-end instrument, and the dome works in tandem to achieve the goal of observations and data acquisition. Basically the proposer has to get acquainted with the operating procedure of telescope, instrument and the dome. Preparing the telescope for observations is done using Telescope control software PC and the active-optics-system PC. A quick start-up procedure is written to make telescope ready. The steps involve start-up, initialization, park and shutdown. It takes about twenty minutes to make the telescope ready. The dome is controlled by a dome control software and it is installed on a separate PC. The instrument operation and acquisition of celestial sources is achieved using Instrument control software. So, there are four different PCs (two for telescope, one each for dome and instrument) to control the observations.

During the cycle 2020-C2, the proposer is required to be present at site and coordinate the observations. In order to assist the proposer during night, there is a plan to provide an operation team with one scientific assistance, one electrician and one helper. Preceding the first night of observation, it is advisable that the proposer gets acquainted with the operation procedures of telescope, dome, and instrument by going through the respective manuals and also by interacting with the day-time DOT team.

It is mandatory for the proposer to fill the on-line activity log (summarising troubles faced if any) at the end of night observation so that the problem could be attended during day-time next day by the DOT technical team. The web-link for filling the activity log is :

https://www.aries.res.in/intranet/eadmin/nightlog_3p6/nightlog_3p6.php

Additionally, the proposer has to create science observation log in a pre-specified format and leave the original with the observatory.

All the operation procedures are available at http://aries.res.in/dot

Chapter 5

Checklist for facility operation

1. Dome-slit opening: (Time of start of operation:)
   (a) Checked that manual slit-lock from inside is open (Yes/No)
   (b) Checked that Mirror cover is closed (Yes/No)
   (c) Slit opened manually (Yes/No)
2. Observing floor:
   (a) Checked that telescope platform has no extra equipment (e.g., ladder, chair, tools etc.) yes/no
   (b) Checked that no obstruction between telescope floor and telescope moving platform is present (Yes/No)
   (c) Are fan doors opened (Yes/No)
3. Lights:
   (a) Checked that CCTV cameras on telescope floor are switched-off (yes/No)
   (b) Checked that all other lights are off in the building (yes/No)
   (c) Opened mirror cover before science observations (yes/No)
4. Closing observatory:
   (a) Telescope parked by TCS (yes/No)
   (b) Checked that mirror cover is closed (yes/no)
   (c) Slit was fully closed manually (yes/no)
   (d) Dome was parked in its position (slit facing East) (yes/no)
   (e) All fan doors closed manually (yes/no)
   (f) TCS and AOS PC shutdown (yes/no)
   (g) The main switch of telescope off manually (yes/no)
   (h) Science log/activity log filled (yes/No)

(Time of closing the observatory :)

5.1 Emergency calls and assistance

For any assistance, please contact :

1. Brijesh Kumar
   Astronomer-in-charge
   Mobile: 7351440011
   Email: brij@aries.res.in

2. Saurabh
   Assistant astronomer-in-charge
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3. Tarun Bangia
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4. T. S. Kumar
   Engineer in-charge (ELectronics, computer and related)
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