AD-FOSC observation planning and proposal preparation document

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Purpose of this document is to enable proposers to plan and propose observations on the 3.6-m Devasthal Optical Telescope (DOT) using ARIES-Devasthal Faint Object Spectrograph & Camera (ADFOSC). Technical observing manuals are prepared separately and provided at the time of observations.

1. Overview:

A low-resolution slit spectrograph-cum-imager, assembled in ARIES through in-house research and development activities, is available for scientific use on the 3.6-m DOT. The operation, usage modalities, and data reduction procedure of this spectrograph are similar to other Faint Object Spectrograph & Camera (FOSC) instruments, working on several moderate aperture telescopes. This spectrograph is here called as ARIES-Devasthal FOSC or AD-FOSC. The AD-FOSC is mounted on the axial port of the 3.6-m DOT. The spectrograph uses an in-house developed 4Kx4K Charge Coupled Device (CCD) camera cooled to -120 C using closed-cycle cryo-cooling system. A spectral calibration unit is also functional in the instrument. A technical summary of AD-FOSC is available in Omar, A., Kumar T.S., Krishnareddy, B., Pant J., Mahto, M., 2019, current science, vol. 116, pp. 1472-1478.

All publications using the AD-FOSC data should cite this paper.

https://www.currentscience.ac.in/Volumes/116/09/1472.pdf

2. Observation modes and procedures:

AD-FOSC has capabilities to carry out wide field of view (13.6' x 13.6') imaging and low dispersion spectroscopy (R < 2000) using standard filters and grisms and a prism. The optical elements such as filters, grisms, slits are selected via 4 motorized and remote-controlled wheels, namely, slit wheel (hosting air slits), narrow-band wheel (hosting narrow-band filters), broad-band wheel (hosting broad-band filters), and grism wheel (hosting grisms). Therefore, mode change between imaging and spectroscopy is possible instantly.

The following observing modes are presently released for scientific uses-

(i) Imaging (broadband/narrowband)
(ii) Slit or slit-less spectroscopy

A brief description with observing setup of imaging and spectroscopy modes is provided below:

I. Imaging:

It is possible to carry out both broad-band and narrow-band imaging using the AD-FOSC.

Broad-band imaging:

Filters available: SDSS ugriz, BG-39, RG-610 - providing FoV of 13.6' x 13.6'.

The broad-band filters are placed in the collimated beam near the pupil plane. To use this mode, the following set-up is recommended:

- Select clear slot in the narrowband (NB) wheel, slit wheel (SW), and grism wheel (GW).
- Place appropriate broad-band filter in the optical beam through broad-band (BB) wheel.

Narrow-band imaging:

Filters available: Center wavelengths 491.6, 660.9, 674.3, 683.3 nm with FWHM ~10 nm, providing FoV of ~11' diameter.

The narrow-band filters are placed in the f/9 beam of the 3.6-m DOT. To use this mode, the following set-up is recommended:

- Select clear slot in the slit wheel (SW), broad-band (BB) wheel and grism wheel (GW).
- Place appropriate narrow-band filter in the beam through narrowband (NB) wheel.

II. Slit-spectroscopy:

The spectroscopy is carried out using three common grisms and one prism, providing different spectral resolutions. A spectral calibration unit with spectral lamps (Ne and Hg-Ar) and continuum sources (LED, Tungsten) can be used for calibration purposes.

The following dispersive elements are presently available:

(i) 100 groves/mm grism providing a resolution of 0.7 nm/15 micron
(ii) 300 groves/mm providing a resolution of 0.23 nm/15 micron.
(iii) 420 groves/mm providing a resolution of 0.16 nm/15 micron.
(iv) 600 groves/mm providing a resolution of 0.10 nm/15 micron.

Users can choose to carry out spectroscopy in slit-mode or slit-less mode. Slits having width 60, 120, 180, 240, 500 micron (approximately) or equivalent ~0.4”, 0.8”, 1.2”, and 1.6”, 3.2" slits are available. Each slit is ~75 mm (8-arcmin) long. Table 1 and 2 lists dispersions/resolutions and free spectral ranges achievable with different grisms in the AD-FOSC.

To use this mode, the following set-up is recommended:

- Select clear slot in the narrowband (NB) wheel.
- Select either clear slot or appropriate broad-band filter (e.g., order-sorting filter) in the BB-wheel.
- Select appropriate slit using slit-wheel (SW)
- Select desired dispersing element through GW wheel.

Table 1: Characteristics of the grisms

Grism	Undeviated wavelength(nm)	Dispersion (nm)/pixel	Resolution @0.6" seeing	Resolution @1" seeing
100 gr/mm	~350	~0.7	350@500 nm	200@500nm
770R-300 gr/mm	580	0.2288	845 @580nm	515 @580nm
676R-420 gr/mm	556	0.1598	1160 @556nm	707 @556 nm
132R-600 gr/mm	488	0.1032	1576 @488nm	961 @488nm

Table 2: Free-spectral range and order overlapping analysis

Grism (Newport catalogue no)	Wavelength range (nm) on CCD chip	First order (free spectral range – no order overlap)	Contaminations in first order-//Second order
100 gr/mm	350-1080[c]	350-700nm	700-1080 nm// 350-540 nm
770R-300 gr/mm	350-1080[c]	350-700nm	700-1080 nm// 350-540 nm
676R-420 gr/mm	350-895[c]	350-700nm	700-895 nm// 350-452 nm
132R-600 gr/mm	350-710[c]	350-700nm	700-710 nm// 350-355nm

*c => cutoff wavelength (Wavelength beyond this range will be falling out of the CCD chip) ; Analysis holds good for slit in the center and perpendicular to CCD. It is assumed that flux is insignificant below 350 nm.

Use of order-sorting filter through BB-wheel:

Gratings (used in Grism) form spectrum in multiple orders. The gratings are blazed to transfer most of the light in the positive first order near the middle of the visible waveband, however, some light is also transferred to higher orders. The deviation angle for first order 700 nm wavelength and that for second order near 350 nm matches (and so for other wavelengths above 700 nm) and hence light from the first and second orders overlap beyond 700 nm (considering atmospheric cutoff is at 350 nm). Therefore, the first order spectrum falling on the CCD beyond ~700 nm will be contaminated by second order spectrum of light at wavelengths >350 nm. Fig. 2a explains this phenomenon by use of the SDSS-g filter in the spectrum obtained from AD-FOSC.

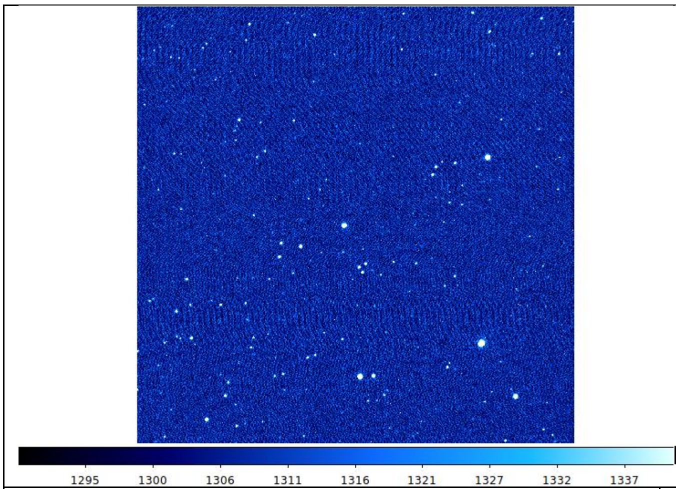
To overcome this problem, two broad-band filters BG-39 and RG-610 are provided in AD-FOSC. The recommendation for their usage is the following:

- BG-39 filter may be used if pure (non-overlapping) first order and pure second order spectrum between 350-700 nm is desired. Due to blaze conditions in the gratings, second order spectrum near 350 nm has higher efficiency compared to the corresponding first order spectrum. Hence, users desiring work in blue bands (<400 nm) may consider using BG-39 filter.

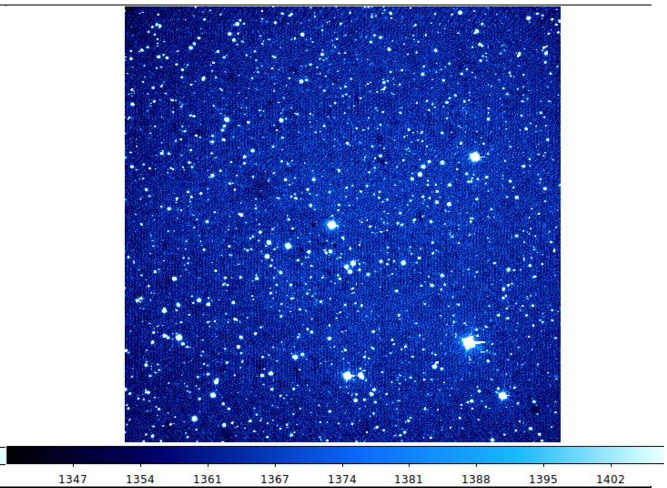
- RG-610 filter may be used if pure (non-overlapping) spectrum in first order at wavelengths above 700 nm is desired.

Sample images and full technical specifications:

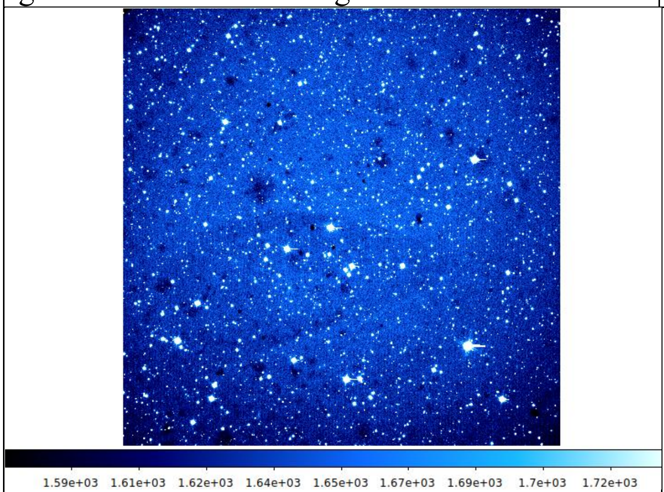
Fig. 1 shows sample images in broad-band filters. Fig. 2b shows a spectrum over the full working wavelength range of ADFOSC (350 – 1080) using 300 gr/mm grism without any filter. Some other spectrums are shown in Appendix. Fig.3 shows a typical image taken in the narrow-band filter. Table 3 lists all the important technical specifications of the AD-FOSC.



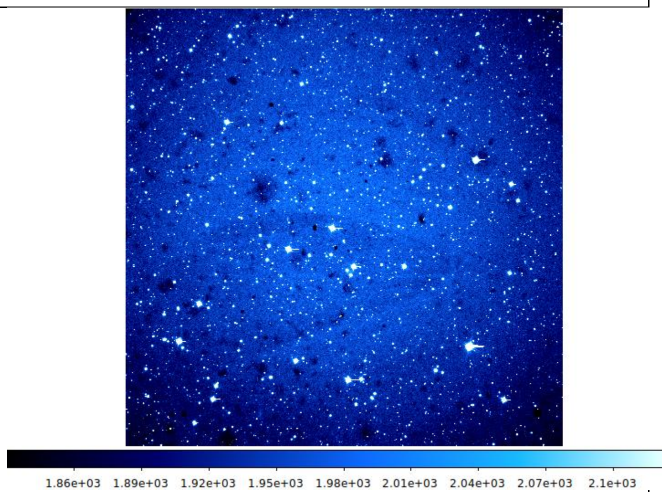
60-sec u-band image of a field (13.6x13.6') at galactic latitude = 3.5 deg.



30-sec g-band image of the same field.



30-sec i-band image of the same field.



30-sec z-band image of the same field.

Fig. 1: SDSS band images (without flat-fielding corrections) of a field taken from AD-FOSC. The FoV is 13.6' x 13.6'. Presently, ugriz filters are available.

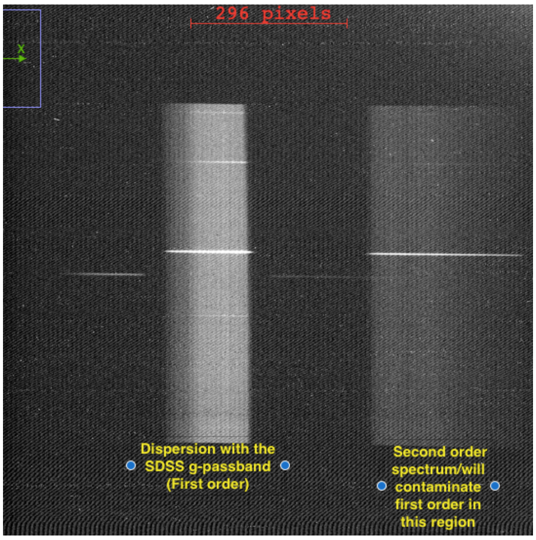


Fig. 2a: Spectrum through grism-300gr/mm limited by SDSS-g filter/ shows second order contamination region in first order space.

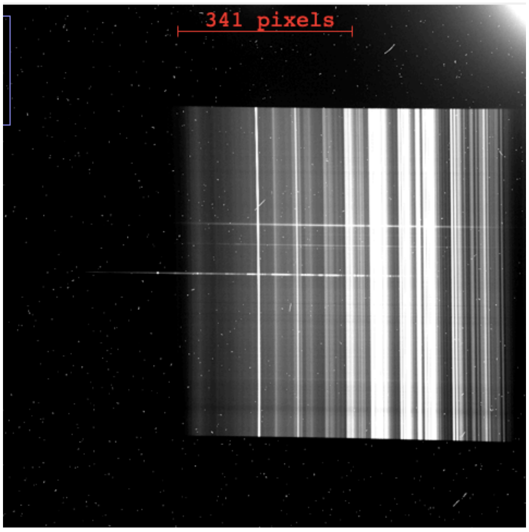


Fig 2b: Full spectrum (normal mode) through grism-300gr/mm without any filter. Slit is vertical and bright sky-lines can be easily seen.

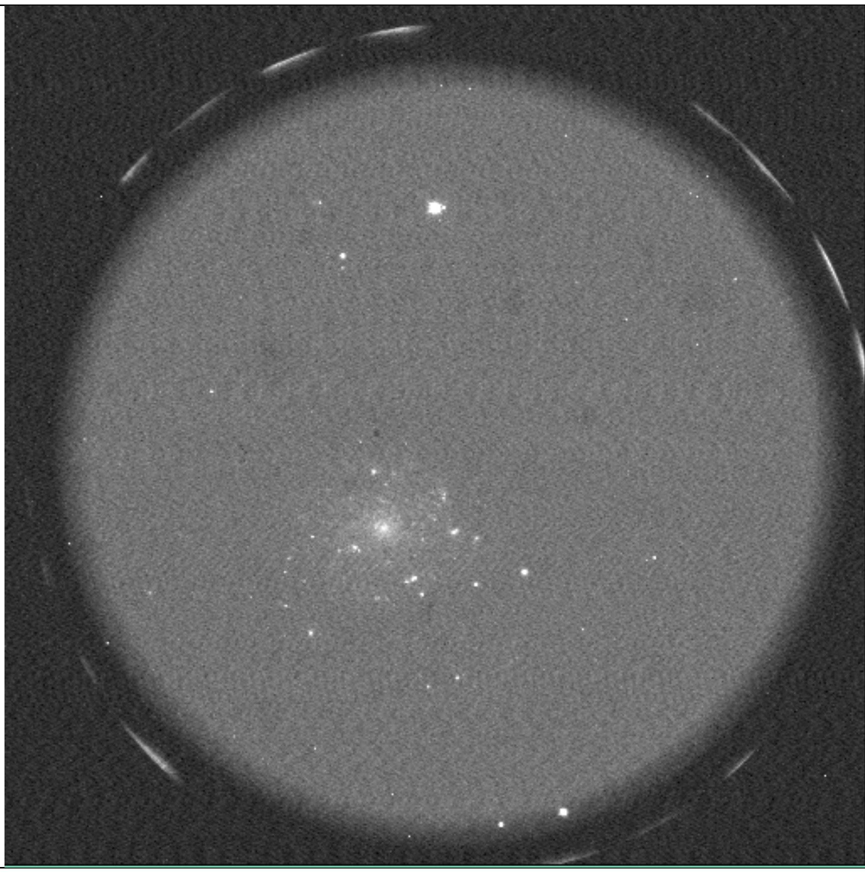


Fig. 3: Typical image taken in narrow-band filter. The available FoV is limited to 11' diameter.

Table 3: Main specification and characteristics of the instrument

Parameter	Value	Comments
Input F/#	F/9	Telescope native beam
Output F/#	F/4.3	
Useful image field of view	62.4 x 62.4 mm	On CCD plane
Intermediate pupil diameter	44.1 mm	
Object field of view	128 x 128 mm	13.6 x 13.6' max on sky
Transmission <500 -900 nm>	85.6%	Computed value based on witness samples and OHARA® Guaranteed values (for main optics)
Transmission <380-500 nm>	86.5%	- do -
Transmission <350-380 nm>	82.9%	- do -
Transmission @ 350 nm	71%	- do -
Image quality @365-436 nm	82 - 89 %	EE in % within 30 micron diameter within 19' FoV (as measured)
Image quality @546 nm	82 – 89 %	- do -
Image quality @780 nm	86 – 91 %	- do -
Image quality @900 nm	87 – 91%	- do -
Total WFE in collimation	2.1 wave-rms	@ 633 nm
Slots in slit wheel	5 (100x100 mm) + 1 clear (Ø192 mm)	
Slots in broad-band filter wheel	5 + 5 = 10	
Broad band filter size	Ø80 mm and Ø90 mm	One slot free/clear. FoV 13.6'x13.6'
Slots in narrow-band filter wheel	5 (Ø120 mm) + 1 clear (Ø192 mm)	clear FoV 11' diameter
Slots in grism wheel	10 (50x50 mm)	One slot free/clear.
Broadband Filters	SDSS ugriz	
Narrow-band filters passband	491.6, 660.9, 674.3, 683.3 nm	FWHM = 10.2 nm
Order sorting (blocking) filters	BG-39, RG-610	
Grism dispersion	0.7, 0.23 nm, 0.16 nm, 0.10 nm per pixel	Pixel = 15 micron
Slits	~0.4", 0.8", 1.2", and 1.6", 3.2" width	

Slit length	8 arcmin	
CCD camera **FoV = 13.6'x13.6' max**	4096 x 4096 pixel 15 micron pixel 1.6 e-/ADU 8 e- rms @0.16 MHz 16-bit ADU Dark 3 e-/hr/pixel Q.E. = 84% @400 nm Q.E. = 90% @650 nm Q.E. = 60% @900 nm	E2V 231-84 Grade-0, back illuminated NIMO, 350 ke-well capacity, multi-layer astro-BB coating Sensor cooled to -120 C using closed-cycle cryocooler.
Sensitivity Imaging (Best)	i=25 AB mag in ~1 hr	3-sigma (see note)
Sensitivity spectroscopy (Best)	g=19 AB mag in ~10 min	5-sigma with 0.16 nm/pixel grism
Calibration	Hg-Ar, Ne, Tungsten, LED	Lamps
Range of Zenith distance	Zenith to 70 degree	

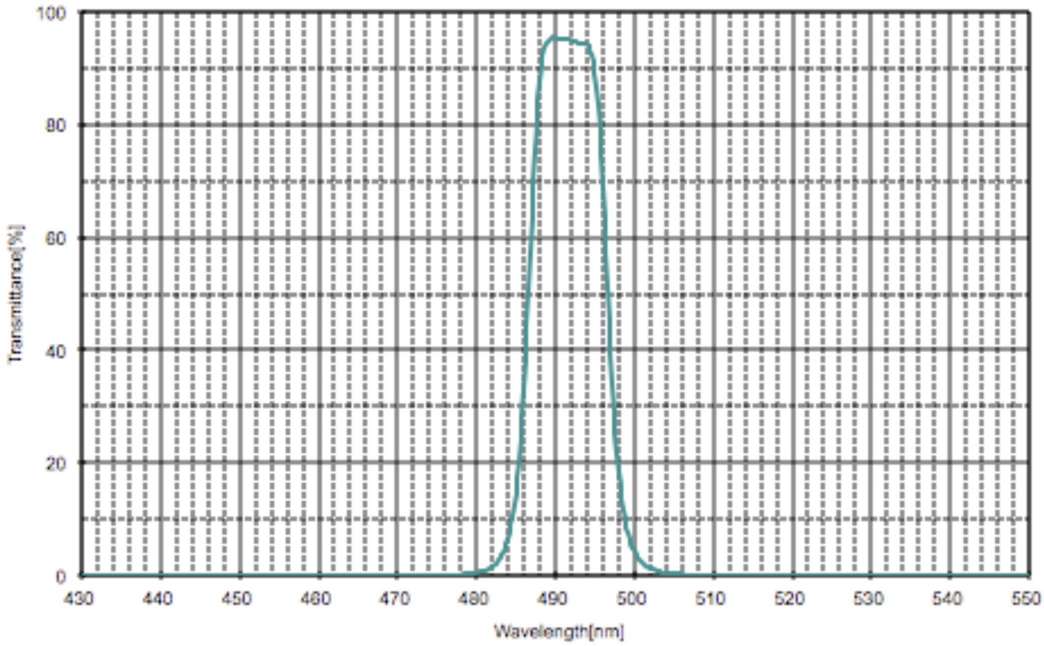
Note: The best sensitivity is achieved with fresh-coated mirror, cleaned AD-FOSC optics, and in the best observing conditions. The sensitivity will generally be lower in typical observing and instrument conditions. As data is collected over the period and analysed, a sensitivity calculator will be provided for each cycle in future.

Planning observations, calibration data and analysis procedure

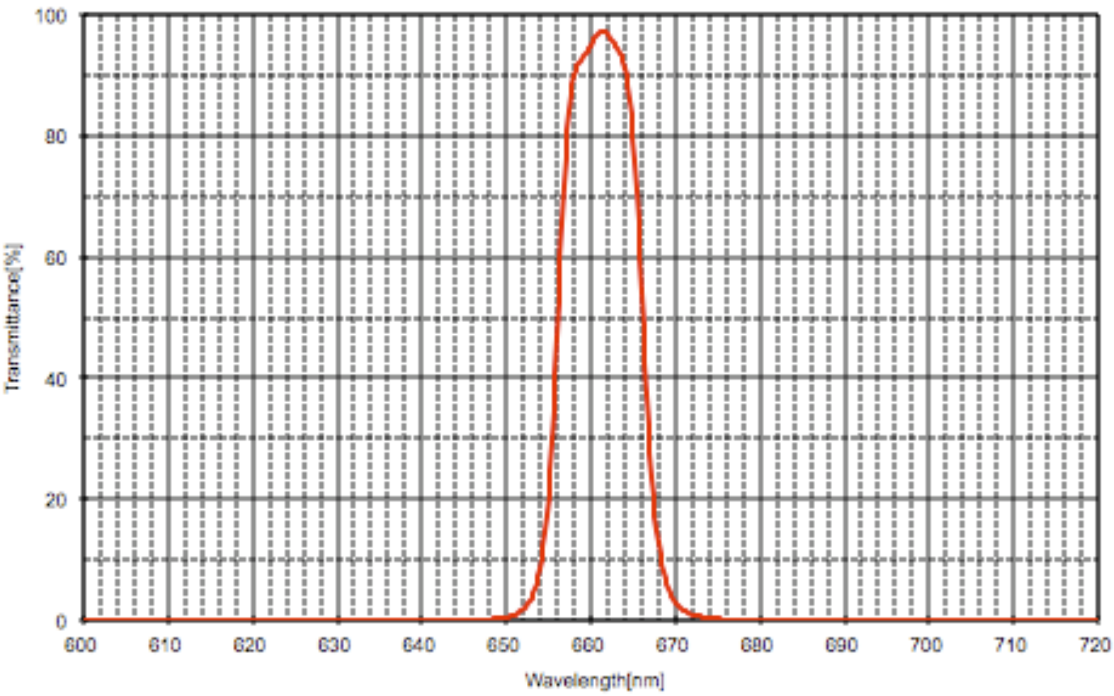
The science observations typically consist of taking multiple science frames and some calibration frames. The observation time should be divided into multiple frames of 5-10 min of exposures. 5-10 min of observations of bright sources (<15 mag) in the field may cause saturation trails, which may affect proper background subtraction and photometry. To avoid saturation in the CCD pixels, exposures time may need to be shortened. ADFOSC users are advised to check bright sources in the field and design best strategy for the observations. Sufficient numbers of CCD bias frames and flat-field frames (night sky blank fields or twilight sky) are required for calibration. Flat-fielding corrections are very sensitive to stray light (scattered light) reaching to detector in different light conditions in the sky and therefore special attention is required to obtain best flat fielding in the science frames. For spectroscopy, spectral calibration frames using the lamps provided in the ADFOSC calibration unit can be taken.

The analyses of ADFOSC data can be carried out following the standard procedures as implemented in open source (no cost to users) software packages such as IRAF (Image Reduction and Analysis Facility) distributed by NOAO (see e.g., http://ast.noao.edu/data/software). The AD-FOSC CCD images are saved in .FITS (Flexible Image Transport System) format and any suitable FITS viewing and analyzing software e.g., DS9; https://sites.google.com/cfa.harvard.edu/saoimageds9) can be used.

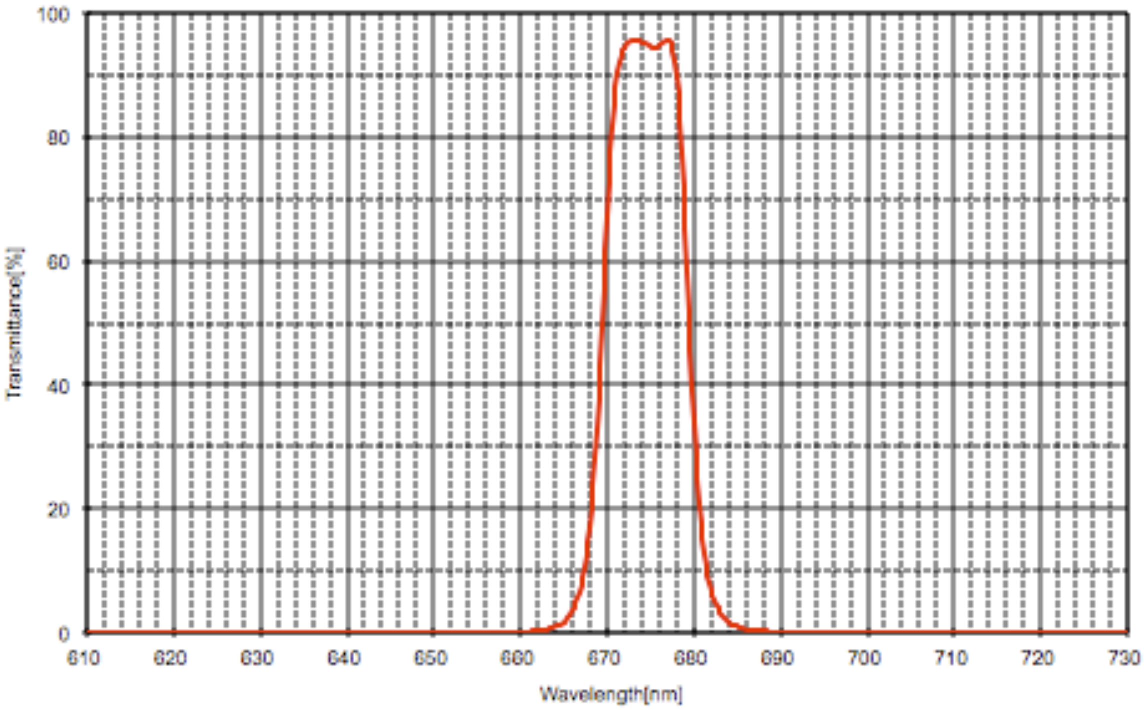
Filter transmission curves (Narrowband)



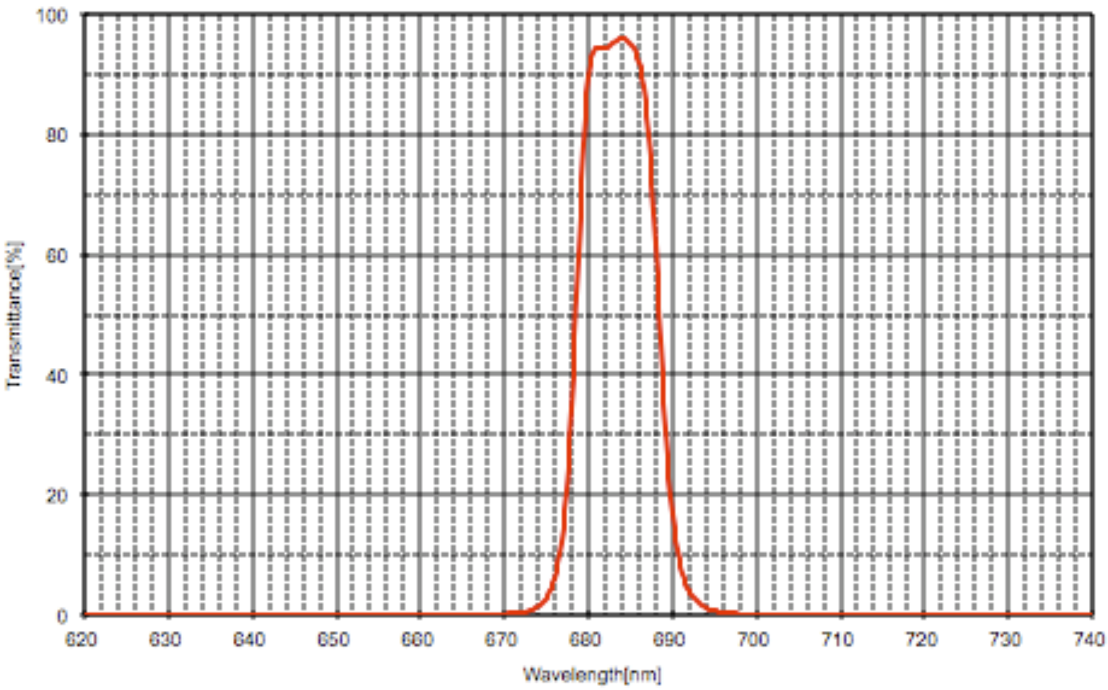
The H-beta filter [FWHM=10.2 nm, center=491.6 nm, Peak T=95.5%]



The H-alpha (1) filter [FWHM=10.2 nm, center=660.9 nm, Peak T=97.1%]

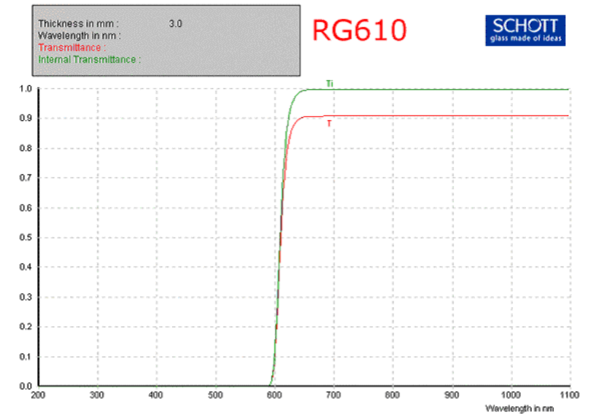


The H-alpha (2) filter [FWHM=10.2 nm, center=674.3 nm, Peak T=95.7%]

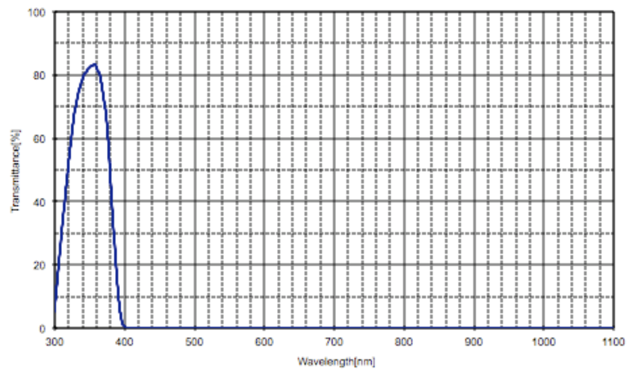


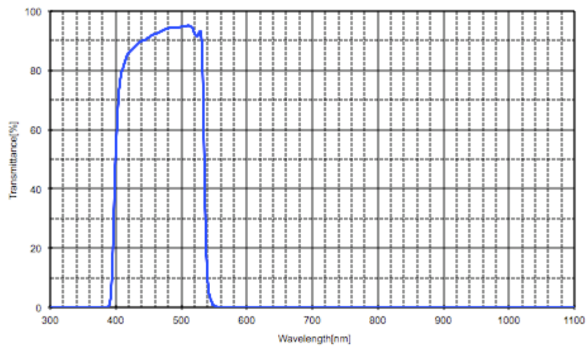
The H-alpha (3) filter [FWHM=10.2 nm, center=683.3 nm, Peak T=96.0%]

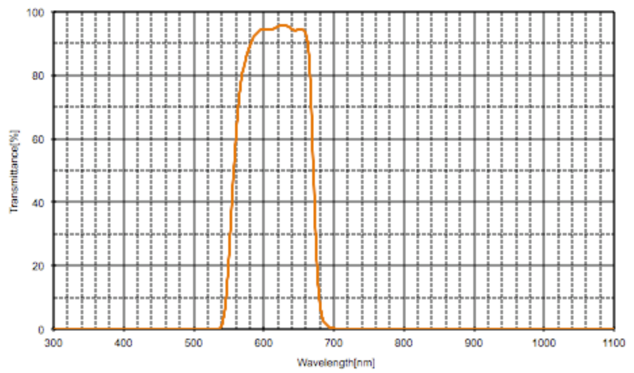
Filter transmission (Broad-band)

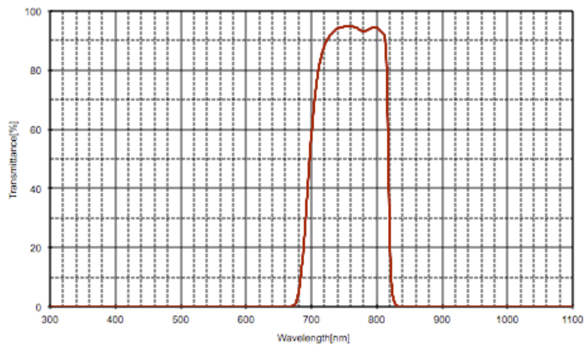


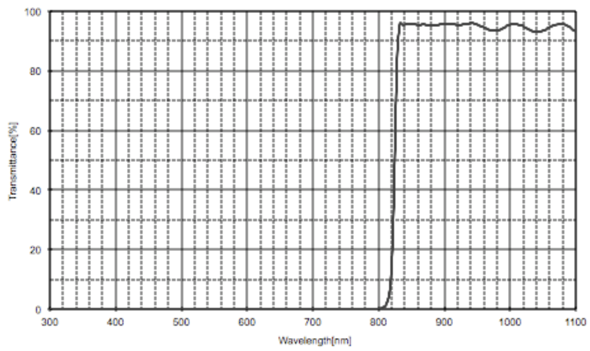
Transmission curves of the order-sorting filters, BG-39 and RG 610.









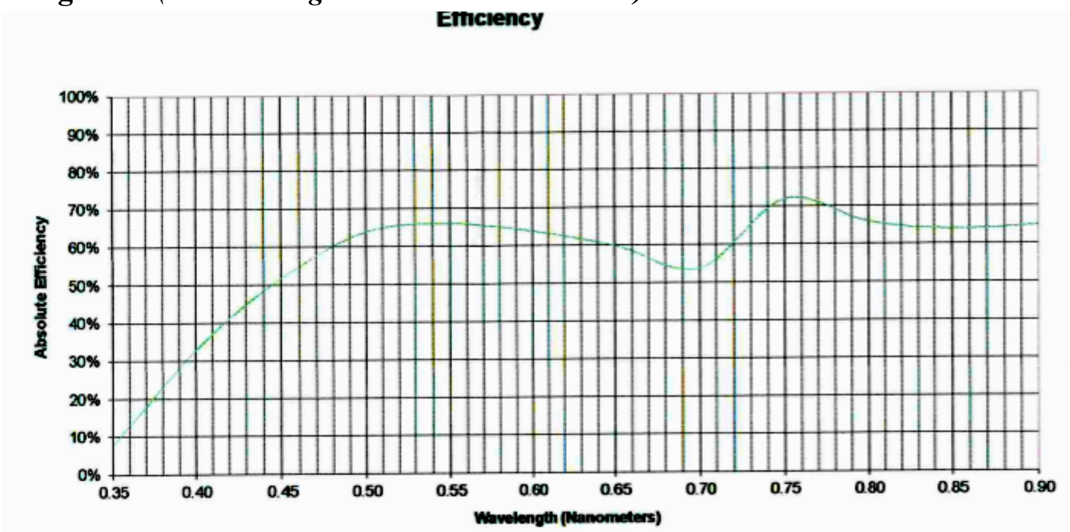


Filter transmission curves for SDSS u-g-r-i-z filters used in AD-FOSC.

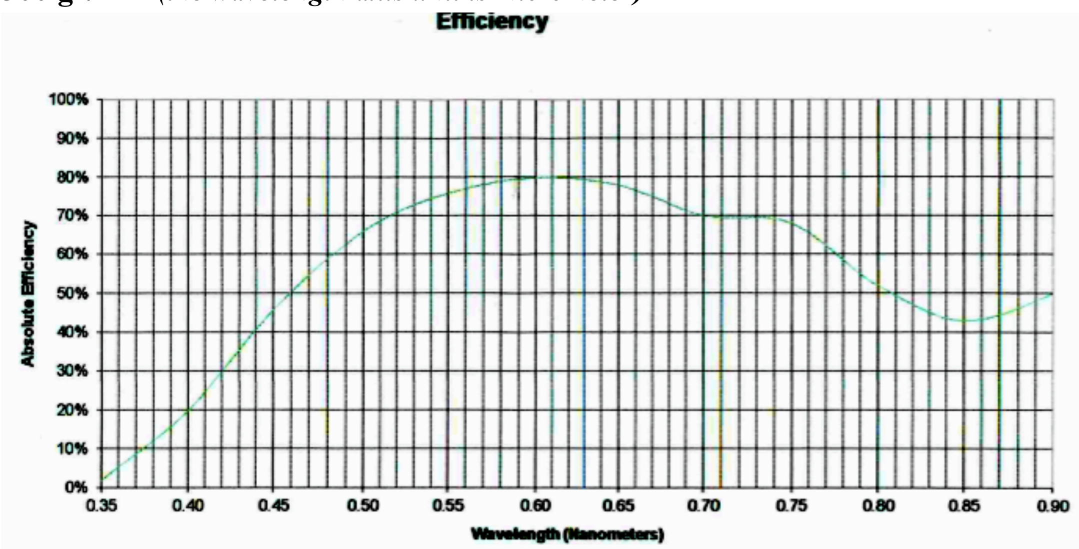
Efficiency curves for Richardson Grisms

420 gr/mm ***(the wavelength axis unit is micrometer)***

600 gr/mm ***(the wavelength axis unit is micrometer)***

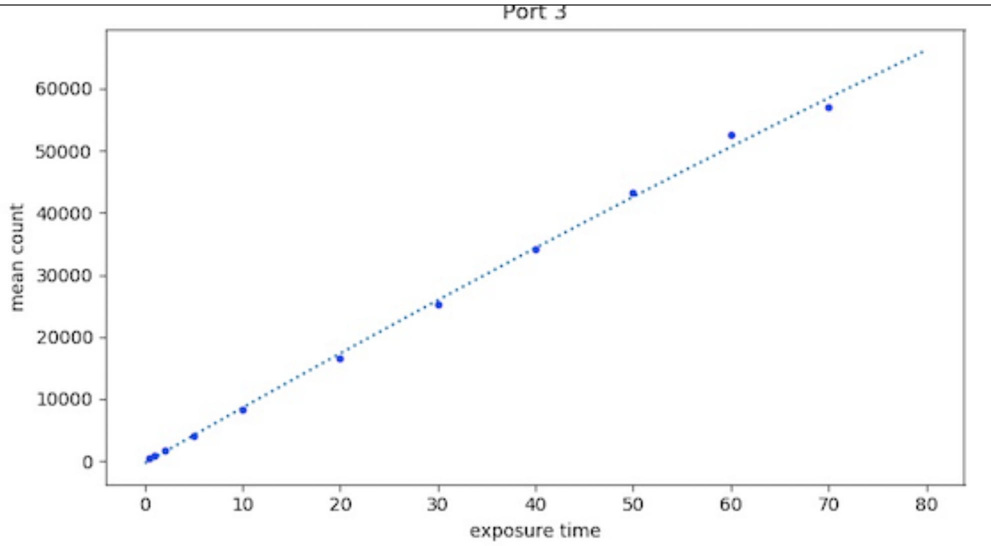


300 gr/mm ***(the wavelength axis unit is micrometer)***

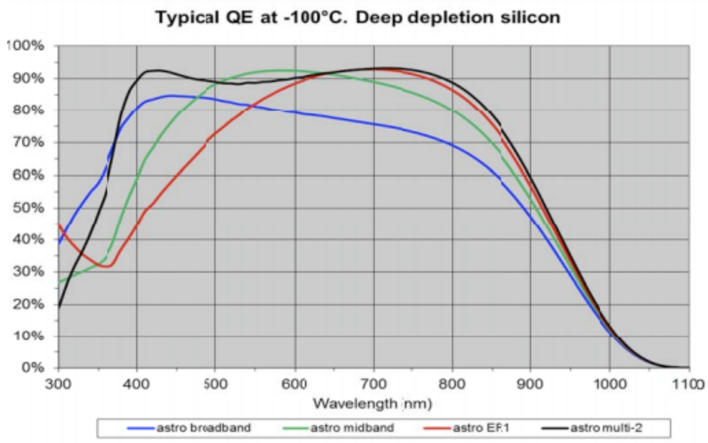


4Kx4K CCD camera

This is a closed-cycle cryo-cooled (@ –120^0 C) CCD camera using a grade-0, 4096 x 4096 (15 micron pixel) E2V® 231-84 sensor (deep-depletion, fringe suppression, AR coated, back-illuminated), the ARC® controller, Lakeshore® thermal control PID system, and Polycold/Cryotiger® cryo-cooling system. This CCD camera is developed and fully assembled in ARIES in technical collaboration from HIA, Victoria BC, Canada. The CCD camera can be operated using 'Owl' GUI and images in FITS format can be displayed in DS9 or any other FITS visualization software. Users can define exposure time and on-chip pixel binning. This camera is fitted with a Bonn® mechanical shutter to control light exposures on the CCD sensor. The shutter is interfaced with the Owl software. Single frame readout in single port takes about 100 seconds in full resolution mode. Typical read noise is 8e- rms and gain (e-/ADU) is close to 2 (estimated from mean background flux vs standard deviation curve). The dark current is ~3 e- per hour per pixel. The bias levels are stable from night to night. The native resolution provided by the CCD is 0.2" in the sky.



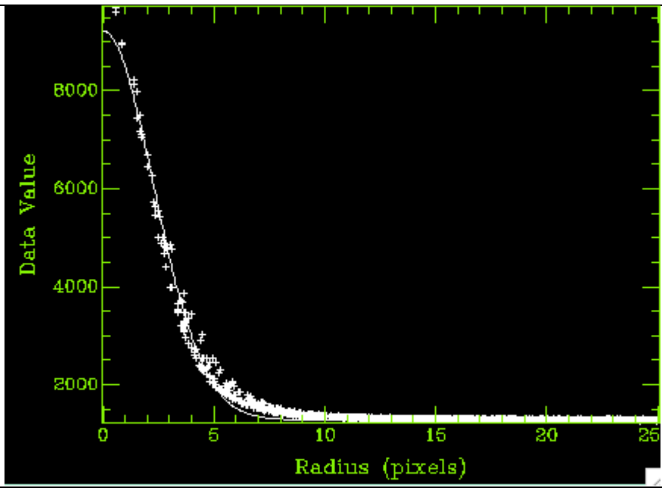
CCD signal linearity curve measured in the laboratory conditions. Presently, single port readout will be released. An IRAF script will be provided to users to make corrections for low-level non-linearity of the CCD response observed at low-light and bright-light conditions near saturation.



Quantum efficiency: ARIES 4Kx4K CCD camera uses E2V 231-84 version with astro multi-2 coating shown here by black curve.

Stellar profile analysis

Stellar profiles are found stable with elevations down to 30-deg. At lower elevations, broadband image quality may be affected by differential atmospheric refraction. Best FWHM are seen at ~1" in red bands and about 1.5" in the u-band. Table lists values of FWHM obtained in same night for all filters.

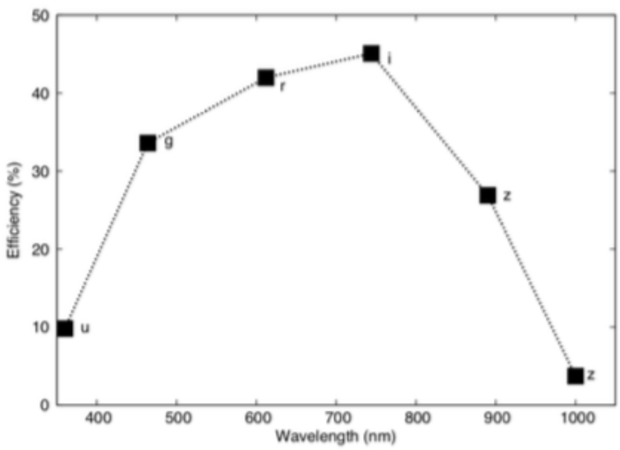


Radial profile of a star measured using AD-FOSC

Table 4: Typical stellar profile FWHM obtained with AD-FOSC in a night

SDSS Band	FWHM (pixel)	FWHM (arcsec)
u	7.4	1.48
g	6.0	1.20
r	5.6	1.12
i	5.4	1.08
z	5.4	1.08

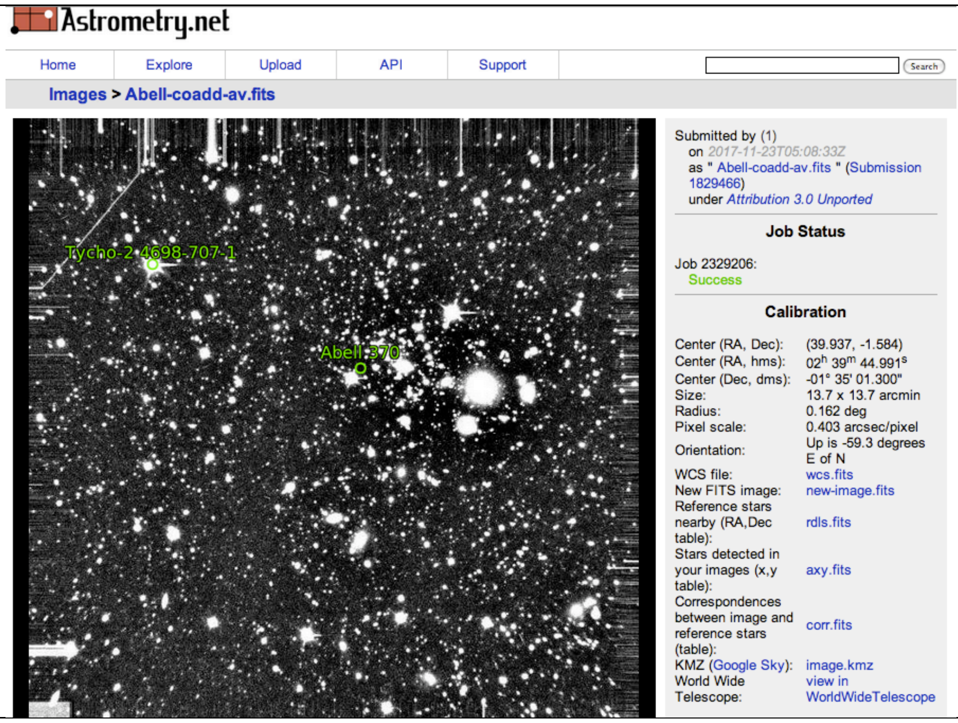
Peak efficiency (best) of AD-FOSC instrument including CCD camera, telescope, and atmospheric transmission at Devasthal



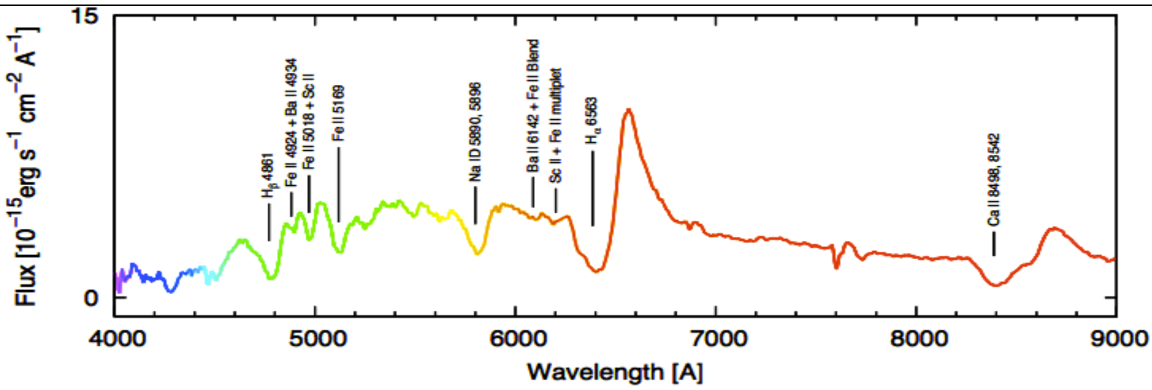
On-sky sensitivities (based on June 2020 observations)

Given some limitations (e.g., ADFOSC cleaning of lenses is due, DOT's auto-guider status unknown and telescope's M1 poor (unknown) reflectivity, we are presently detecting (>5-sigma) r=24.5 mag sources in deep imaging in about 2 hours of observations and detecting a visible spectroscopic trace (3-sigma) for r=21 mag sources in about 2 hours of observations. These sensitivities are expected to reach to close to the original values listed in Table 3 after a servicing and cleaning of the AD-FOSC planned in the monsoon period of 2020.

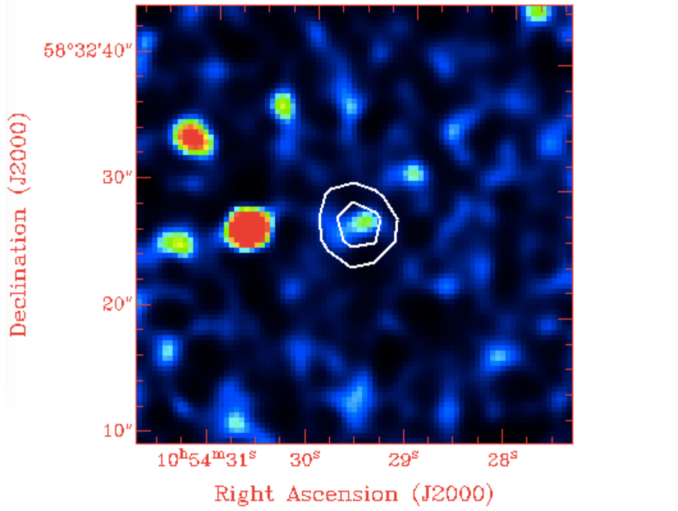
Best images from AD-FOSC



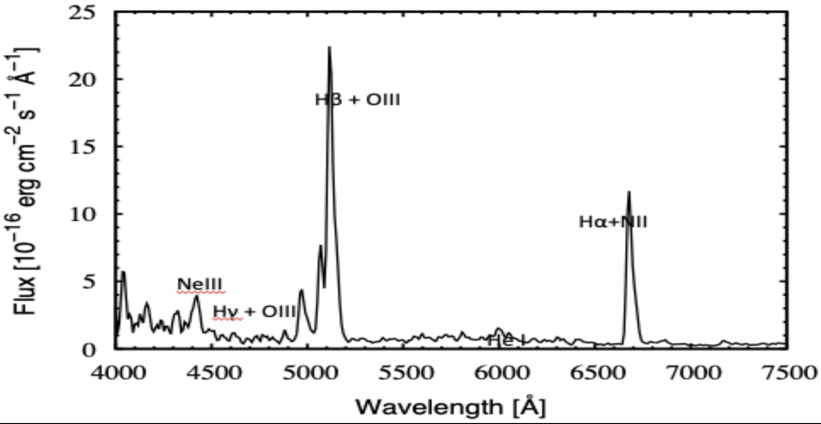
The final co-added (11 frames x 300 sec = 3300 sec) 13.6'x13.6' image of Abell 370 field along with solution obtained from Astrometry.net. The image detects i~25 mag sources at 3-sigma level.



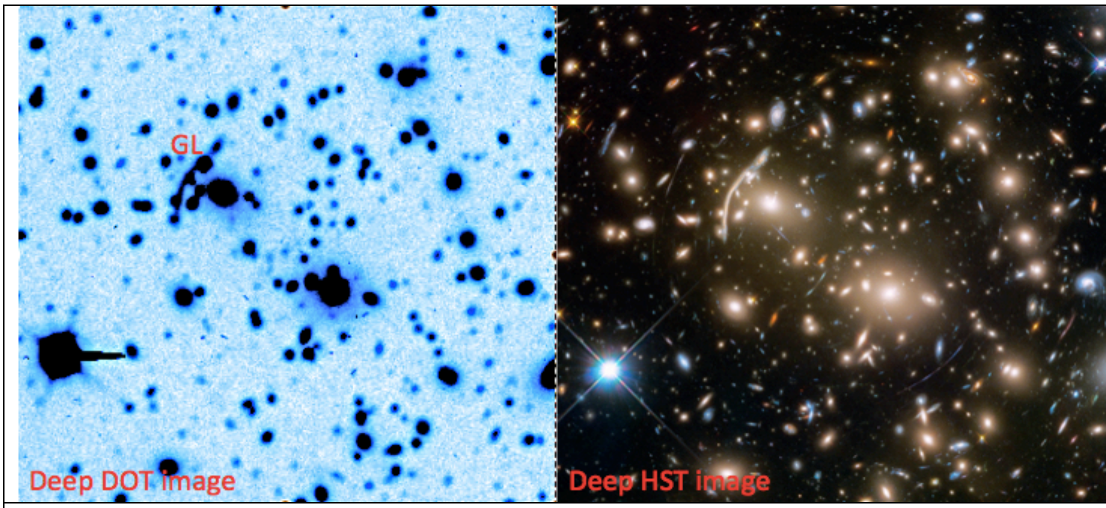
Calibrated spectrum of a supernovae at V=15 mag made using 300-sec of observations using the AD-FOSC.



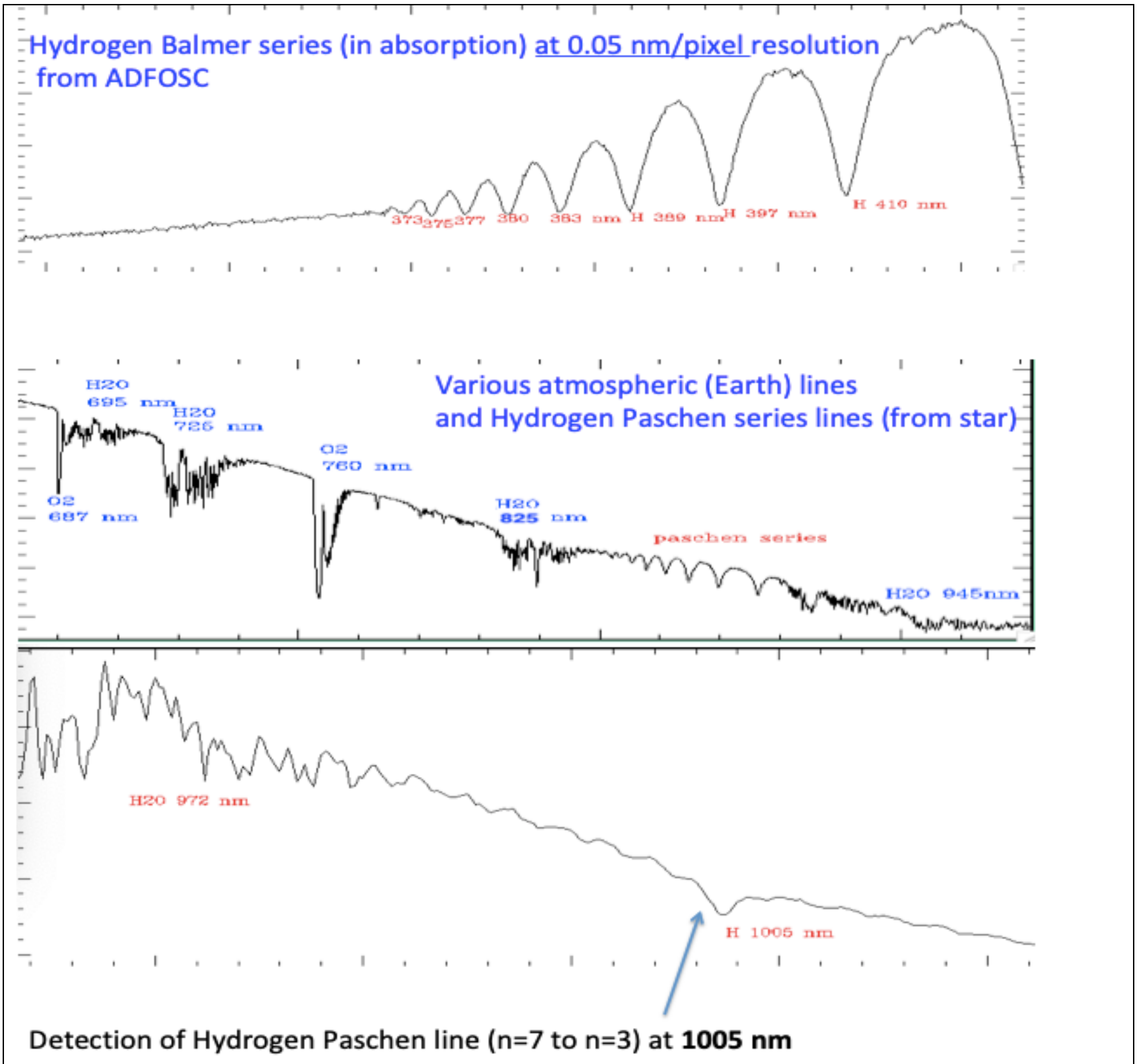
An i-band image showing detection at ~24.3 mag using 1-hr of AD-FOSC observations for a high-z candidate radio galaxy. Radio contours are shown for identifying the location of the galaxy. See details in https://www.ias.ac.in/article/fulltext/joaa/040/02/0009



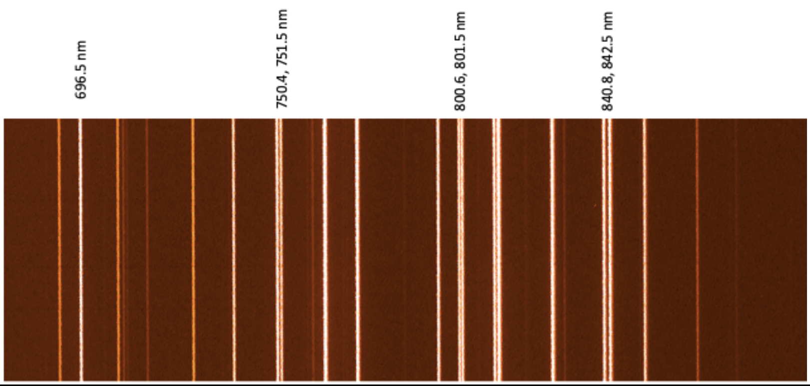
Calibrated spectrum of a dwarf galaxy of g=19 mag made using 600-sec of observations using AD-FOSC.



The best deep image obtained with AD-FOSC (3300-sec) in the i-band of core of Abell 370 cluster is compared with the deep HST image to highlight detections of very faint sources at i~25 mag. This portion of the image has sky-flatness at a level of 0.1% of the background.



Detections of various absorption lines against a bright star in a 10-sec of observation using the AD-FOSC. The top panel is extracted from the second order spectrum using the 600 gr/mm grism in the AD-FOSC.



A portion of the Ar lamp spectrum recorded using the AD-FOSC.