Scientific potential of 3.6 m DOT and ILMT in the field of Galactic Astrophysics

- Background of Indo-Belgian scientific Cooperation
- Capability of telescope based on site survey carried 2 decades ago; no NIR Info
- Scientific potential of 3.6 m DOT with emphasis on resolution and NIR
- Ongoing projects in Galactic Astrophysics
- Summary and Conclusions

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Indo-Belgian Collaboration in S&T Signed on Nov 3, 2006

AMOS; Santosh Joshi & Margarida Freire talks

Belgian Federal Office for Science Policy (BELSPO)

and Department of Science &Technology (DST)

- It covers wide range including; Physics and Astrophysics as one Key area;
- 3.6 meter new technology & 4-meter ILMT telescopes
- BELSPO contributed 2 M€ cash towards 3.6 m DOT in 2009
- Invited talk on May 14, 2012 during Annual meeting in Brussels
- Number of exchange visits & Joint Supervision of PhD scholars
- **Belgo-Indian Network for Astronomy and Astrophysics** (BINA) approved in 2016 and First BINA workshop was held in India

De cat et al. (2018) and Sagar (2018)

Purpose of an optical telescope

Collect more photons than the unaided eye – light gathering power;

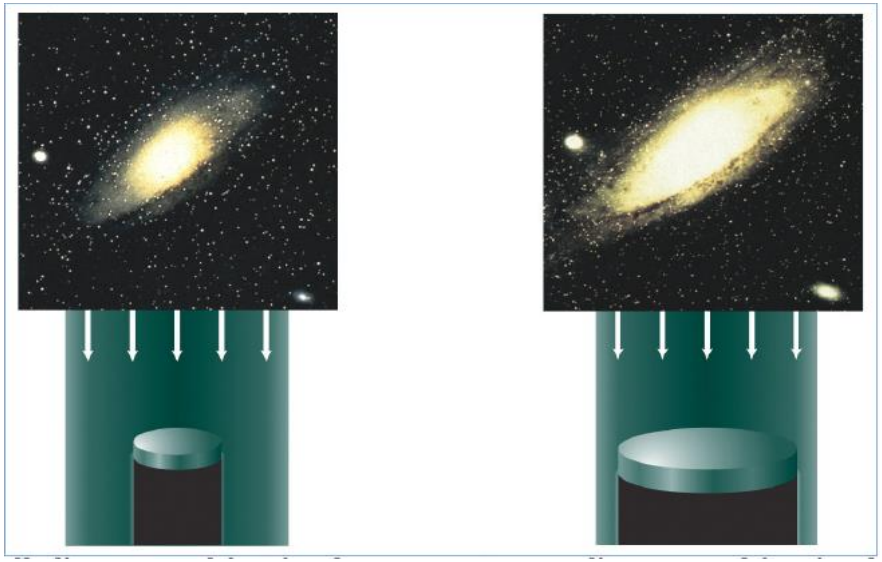
Talks by Hans & Gert emphasized importance of Back-end instruments on a telescope; Comparison between 1.2m vs E-ELT & VLT

Light gathering power (A) = $T(D/S)^2$
= 25×10^{4} * T for a 4 meter size Telescope

D – diameter of the telescope
S - diameter of the pupil of eye
T–Losses due to optics and detector

$S/N \propto \sqrt{(t*A)/(\varepsilon * B(\nu))}$

t --- integration time
$B(\nu)$ ---- sky brightness
ε-- angle formed by image

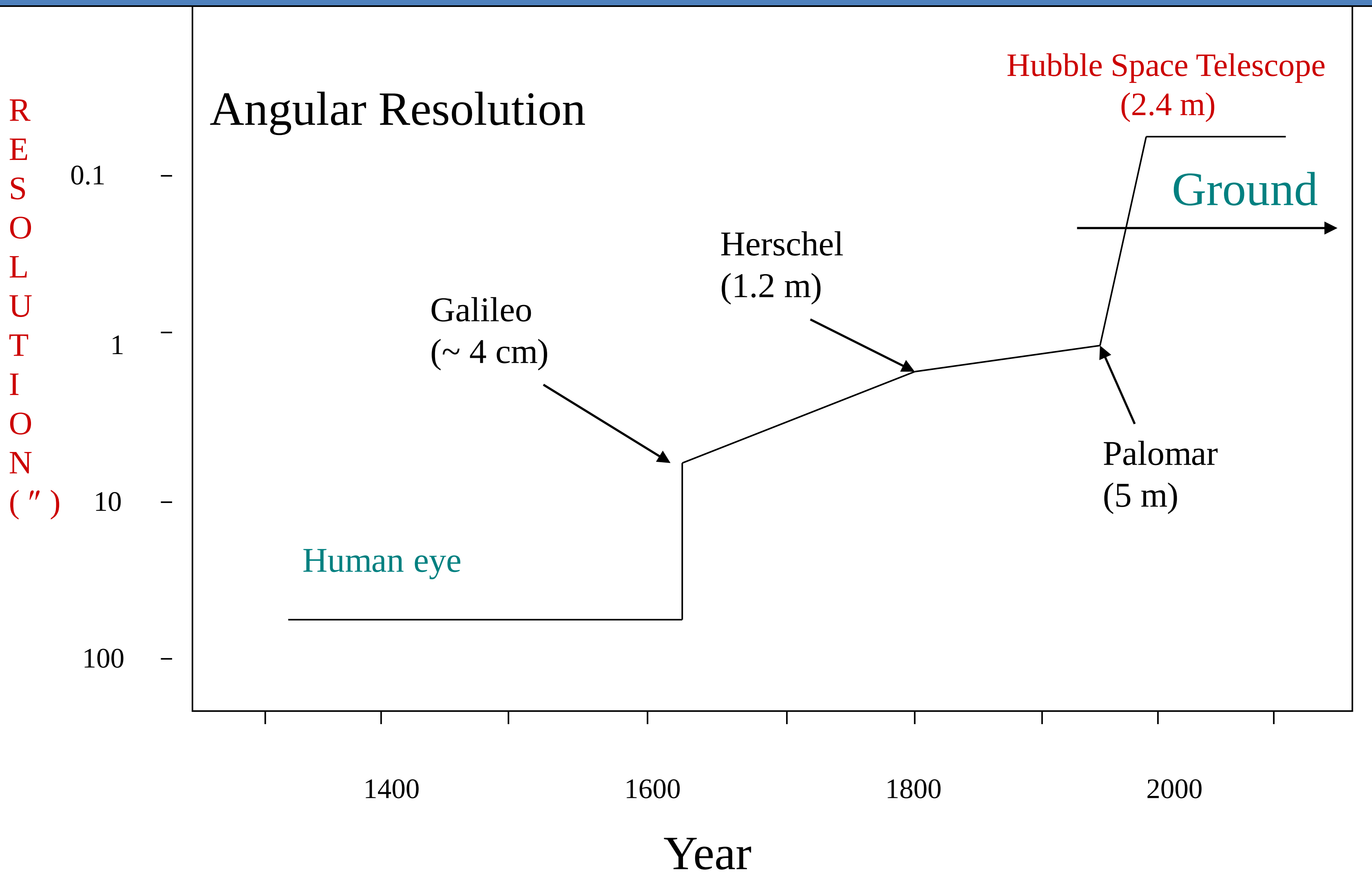


Site characterization becomes essential for the technical specification of the telescope e.g. surface accuracy of mirrors and λ range

Resolving Power (RP) = 1.22 λ / D = 14" / D (in cm) At 5500 Å; On Ground RP α λ/ r_0

while r_0 α $\lambda^{6/5}$ so FWHM α $\lambda^{1/5}$; Earth Atmosphere:- Seeing = 1 to 2";

Best values 0.3 to 0.5 " ; AO **(CT02 benefit to DOT)** and interferometry provides better RP



Background of the site search &Project (4 decades)

Stalin, Santosh & Yogesh participated;dedicated & sincere team work

- First time talked by UP CM Shri H N Bahuguna in 1976
- Preliminary site survey carried out during 1980-1990 with the grant provided by UP Govt (Sanwal et al. 2018) DPR & Execution (EFC like)
- In 1996, Modern techniques of seeing measurements, meteorological measurements, land transfer, infrastructure development etc started [Sagar R, Stalin C S, et al. (2000) Evaluation of Devasthal site for optical astronomical observations; AAS 144: 349-362; Sagar R (2007) A modern 3.6 meter new technology optical telescope as a major national initiative in astrophysics; National Academy Sciences Letters 30: 209–212; Sagar R et al. (2011) The new 130-cm optical telescope at Devasthal, Nainital; Current Science 101: 1020-1023; Sagar R et al. (2011) ASI Conf. Ser. 4: 173-180 & Sagar R et al. (2012) New optical telescope projects at Devasthal observatory. in Ground-based and Airborne Telescopes IV, Proc. of SPIE 8444 8444T1–12/doi: 10.1117/12.925634]
- **Contributions from IIA and TIFR (under leadership of Gopal)**

Kumar et al. (2018) The Devasthal site

Sagar et al. (2000) and Stalin et al. (2001) **Highlighted by A. Omar & J C Pandey talk**

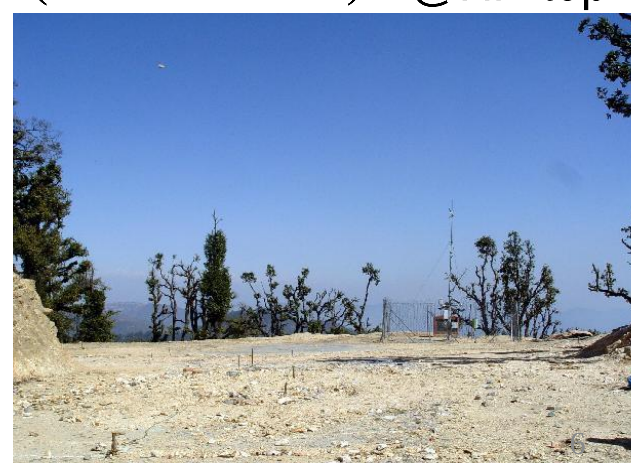
Seeing : 1."1(median); best 0."7; 40% of observing time < 1" in which a stretch of > 2 hr is for 55%; no temporal variation; No knowledge about NIR sky; Its use in Telescope specifications; AMOS reaction (S. N. Tandon)

Table 1: Key parameters of Devasthal site.

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)
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	2 m (average over year, 80% during Monsoon)
Snowfall	2 ft (average; during Jan and Feb only)
Clear nights	208 (spectroscopic); 175 (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 : $k_U = 0.40 \pm 0.01$; $k_B = 0.22 \pm 0.01$ $k_V = 0.12 \pm 0.01$; $k_R = 0.06 \pm 0.01$
Sky Brightness	~ 22.3 mag/airmass^2 at V and R bands
Relative humidity	≤ 60% during spectrocopic nights Much higher during June to September

Mohan et al. (2000)

- Modern DIMM 80 nights (1998-99)
- Mirror 2 m above ground
- Microthermal measurements indicated 0.2 to 0.3" seeing at 13 to 18 m above ground (Pant et al. 2000) @Hill-top



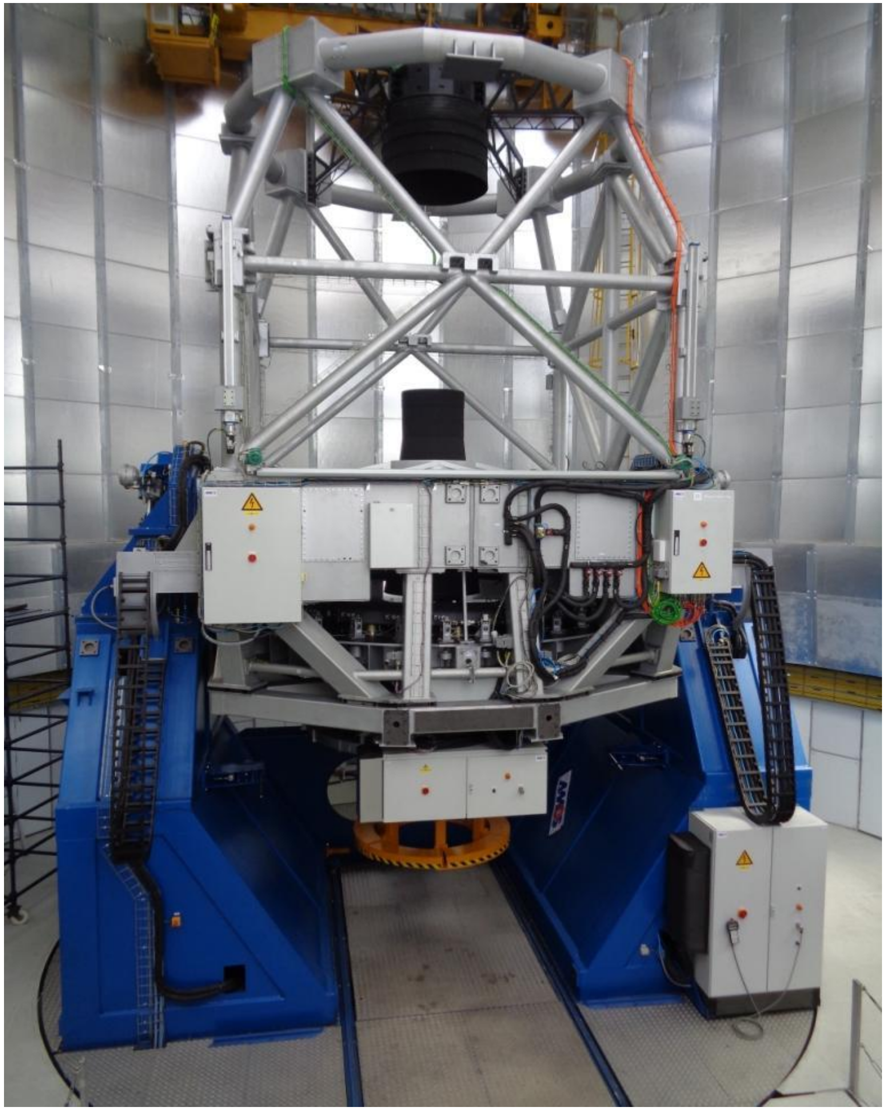
3.6 meter DOT

Kumar et al. (2018) **installation, infrastructure development, Telescope building, Mirror aluminum coating plant and first light performance Results;** **low thermal mass not degrading seeing**

Omar et al. (2017) Advantage and performance

Talks by A Ramaprakash; A Omar & J C Pandey

Performance of existing and upcoming back end Instruments; **Adaptive optics??**



Observing with 3.6 DOT

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

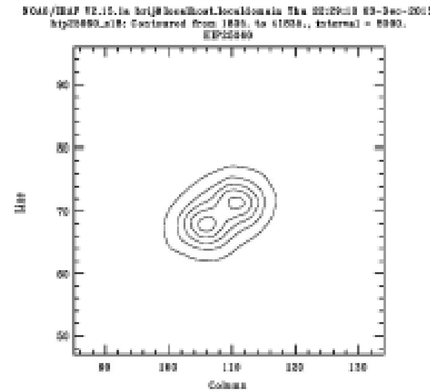
- Prospects of science with ILMT after first light (**Surdej et al. 2018**)
- Technical activation done on 30 March 2016 from Brussels
- Online User manual provide information
- **Belgium 7%; ARIES 33% and others 60%**
- **Time allocation committee exists for both India and Belgium**
- Cycle 2017B (October 2017 to January 2018)
- Cycle 2018A (February 2018 to June 2018) and
- 4KX4K CCD imager and TIFR NIR imaging camera (TIRCAM2)
- Observing proposals were invited and times were allocated

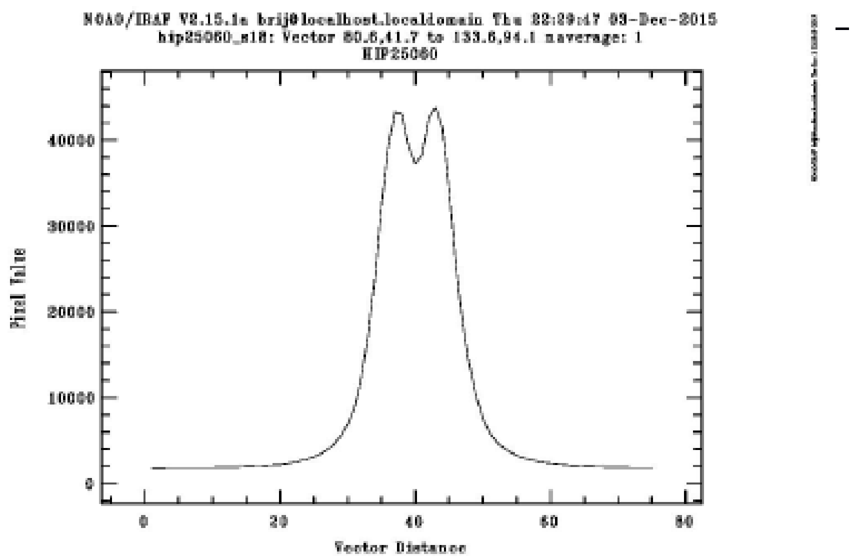
Proposals in the field of Galactic Astronomy

1. Star formation and stellar evolution:- Star forming regions; star clusters, pre-main sequence, Blue straggler stars (BSSs) in galactic and globular clusters; Binary and multiple stars; Lithium rich K giant

2. Exo-planet research and Variable stars (J C Pandey & A Omar Talks)

HIP 25060 – double star (with known separation ~ 0.37 arcsec)





4Kx4K CCD Imager mounted on 3.6 m DOT

Pandey et al. (2018) & User manual; Earlier talks

Specifications/ Parameters	Values
CCD Chip	15 μm/pixel, 4096x4096 pixels, back-illuminated, 16-bit A-D
Full-well capacity	250k – 265k electrons, MPP/non-MPP/CAB modes
Gain	1,2,3,5,10 e^-/ADU (selectable)
Read-out Noise (@Speed)	7-9 e^- (@1 MHz) or 4-6 e^- (@500 KHz) or 2-3 e^- (@100 KHz)
Linearity/CTE	10% to 90% of the full well / 0.999999
Binning	2x2, 3x3 or 4x4 (selectable)
Dark Current	0.0005 e^-/s at -120°C
Dewar/cooling	Liquid Nitrogen cooled, -121.3°C

Filters	Central wavelength/ Band-width (Å)
Bessel U	3663 / 650
Bessel B	4361 / 890
Bessel V	5448 / 840
Bessel R	6407 / 1580
Bessel I	7980 / 1540
SDSS u	3596 / 570
SDSS g	4639 / 1280
SDSS r	6122 / 1150
SDSS i	7439 / 1230
SDSS z	8896 / 1070

Broad band Imaging capabilities; Numbers are for 1.1 arc sec seeing; Improvement in better seeing conditions

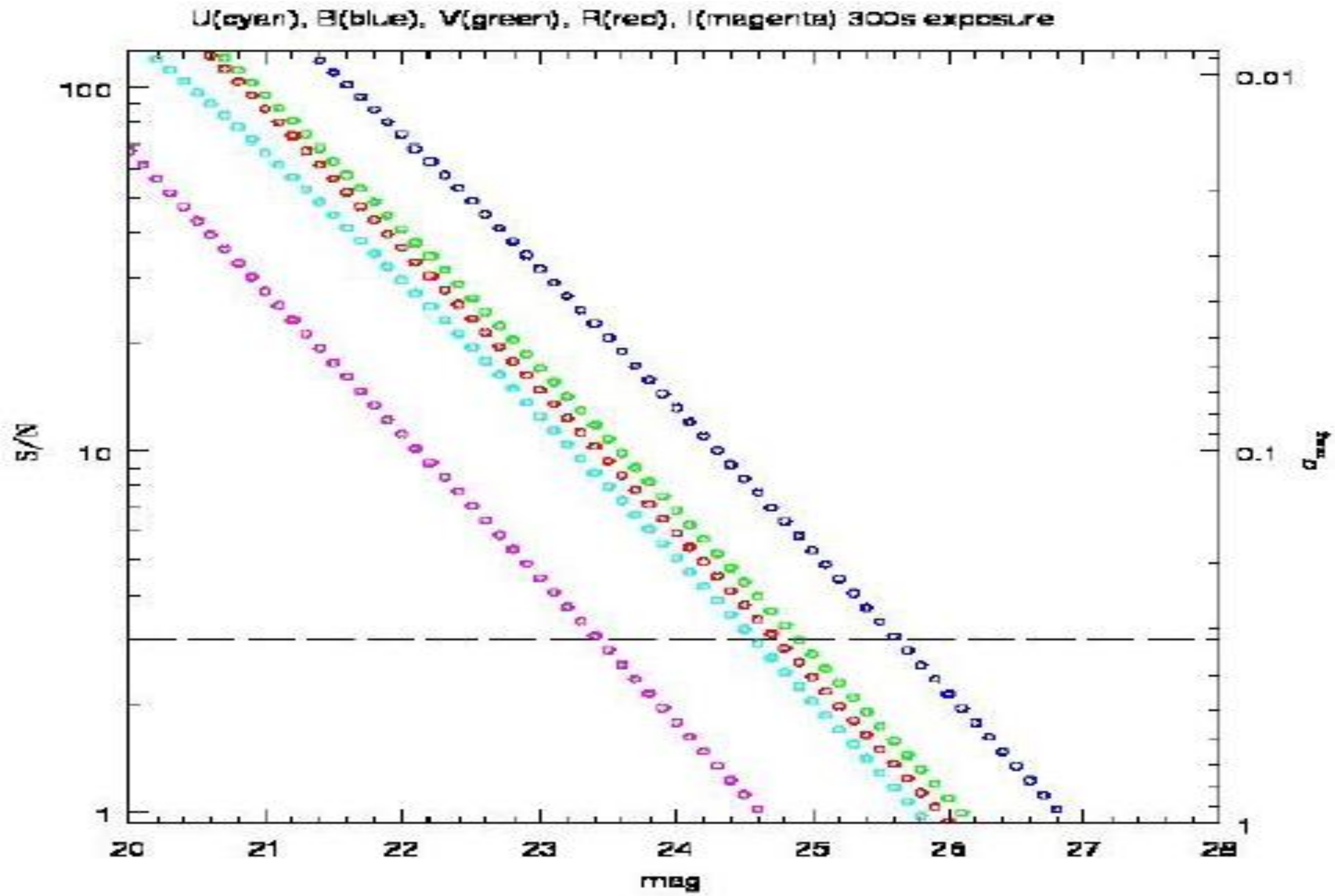


Figure 1: Simulated throughput in terms of S/N for the combined set-up of the 4Kx4K CCD Camera and the 3.6m DOT for a given exposure time of 300 sec in set of Bessel UBVRI filters for reference.

TIFR Near Infrared Imaging Camera-II (TIRCAM2)

Baug et al. (2018); Ojha et al. (2018) & User manual

The TIRCAM2 is a closed cycle cooled (35 K while Operating) imager. Wavelength range from 1 to 3.7 µm.
512X512 InSb based Aladdin III Quadrant focal plane array
Equiped with standard filters J, H, Kcont, K, Br, polycyclic aromatic hydrocarbon (PAH) and narrow-band L (nbL) for imaging. The main highlight is the camera's capability of observing in the nbL (3.59 µm) band enabling mapping of PAH emission at 3.3 µm.

Table 1. TIRCAM2 filter characteristics.

Filter name	λ_{cen} (μm)	$\Delta\lambda$ (μm)
J	1.20	0.36
H	1.65	0.30
Br-γ	2.16	0.03
K-cont	2.17	0.03
K	2.19	0.40
PAH	3.28	0.06
nbL	3.59	0.07

Fig. 1. The TIRCAM2 mounted at the axial port of the 3.6 m DOT.

Performance during 11-23 May 2017; FWHM > Seeing
Expect better numbers during Oct-Dec; FWHM α $\lambda^{-0.2}$

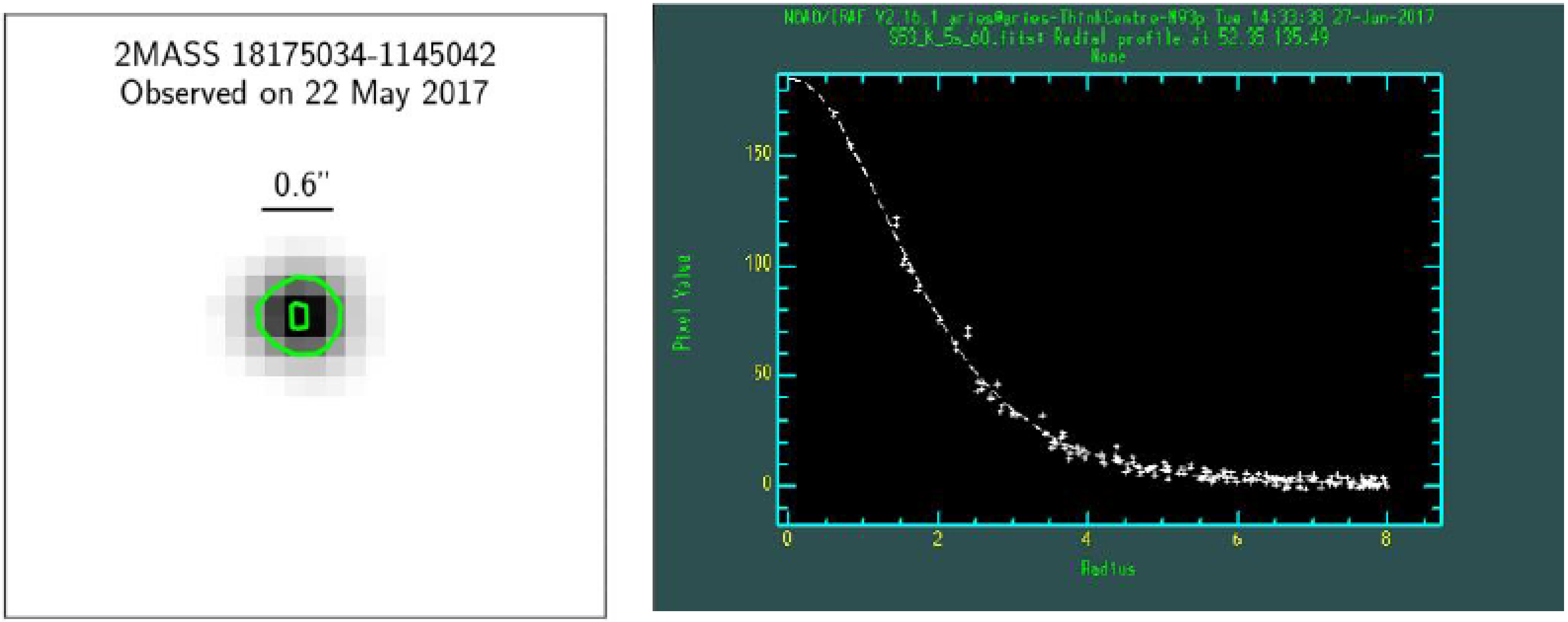


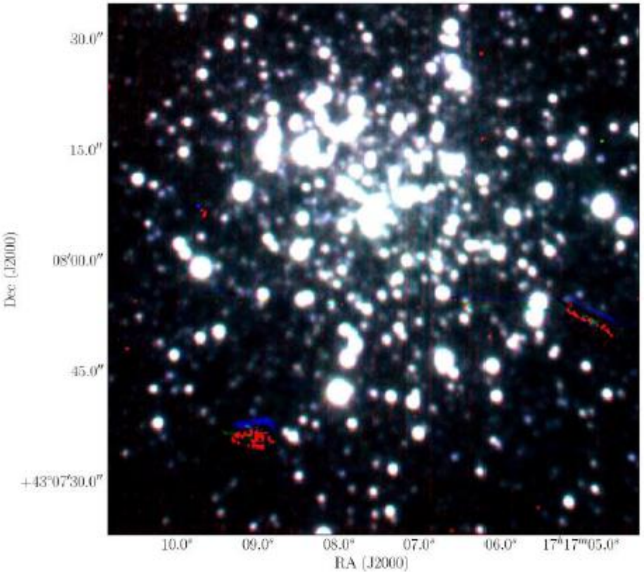
Figure 3: Left panel shows cut-out of a stellar image observed with TIRCAM2 in K-band on 22 May 2017 towards the Serpens OB2 association. Typical seeing on this night was ~0.6 arcsec. The outer green contour shows the stellar FWHM of the image. The right panel shows the radial profile of the image shown in the left panel.

- Typical seeing during May 2017 nights was **< 1.0 arcsec** in the NIR bands.
- Best seeing achieved during these nights was ~**0.6 arcsec** in K-band.

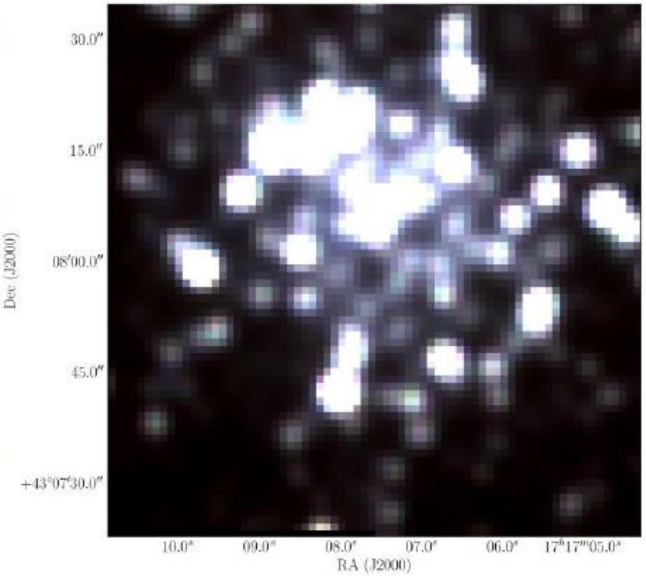
M 92 Galactic Globular Cluster

Science Calibration results

3.6 Telescope

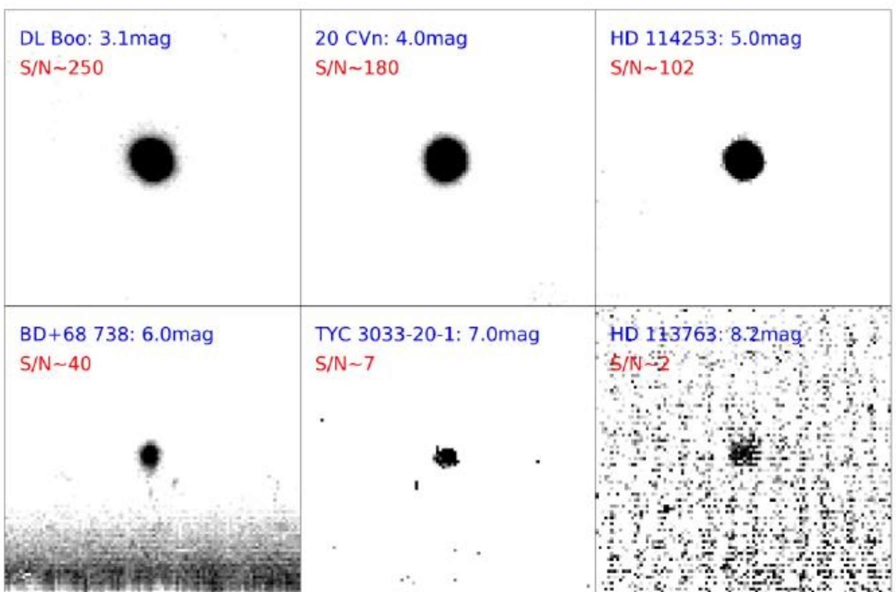


2 MASS



Ojha et al.
(2018) BSRSL
Vol 87, 58

Baug et al.
(2018) JAstIns
Vol 7 p1850003



nbL Band (3.59±0.07 μm)
Images (100X100 pixels)

Typical Sky brightness at Devasthal (May 2017):

The typical values of sky brightness values obtained in good night conditions (during May 2017) are the following:

- J-band : **16.4 mag / arcsec^2**
- H-band : **14.0 mag / arcsec^2**
- K-band: **12.2 mag / arcsec^2**

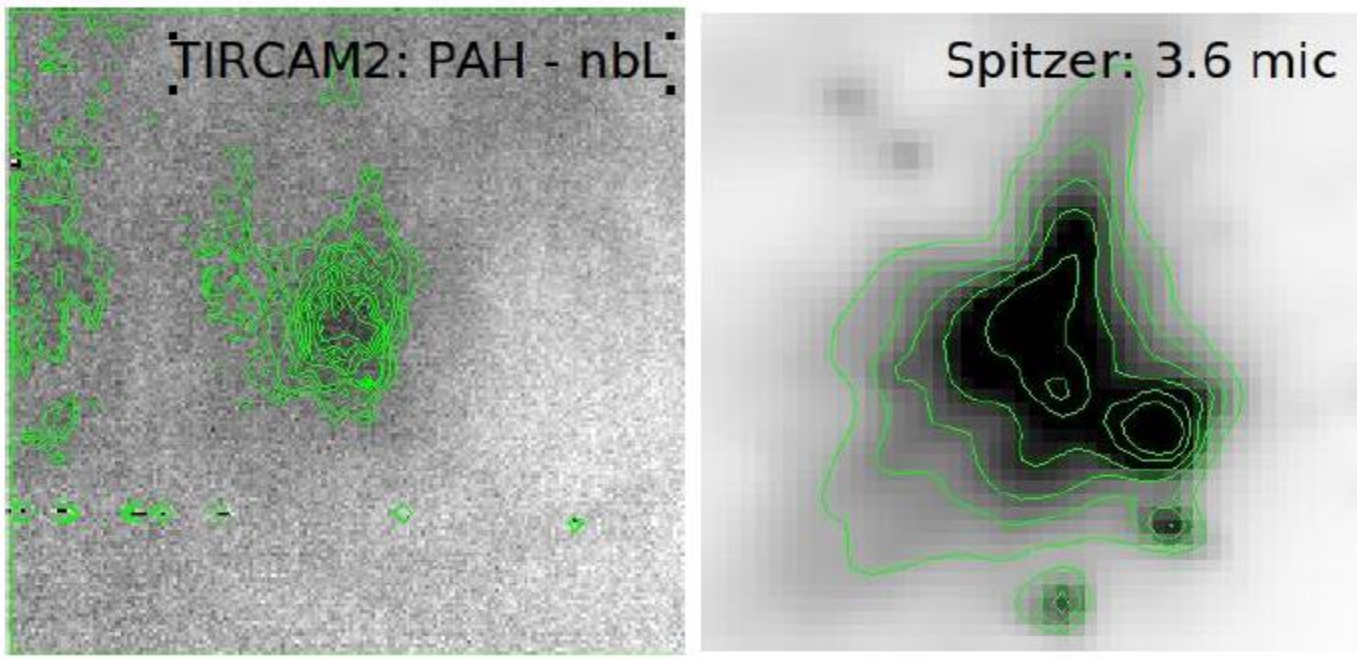
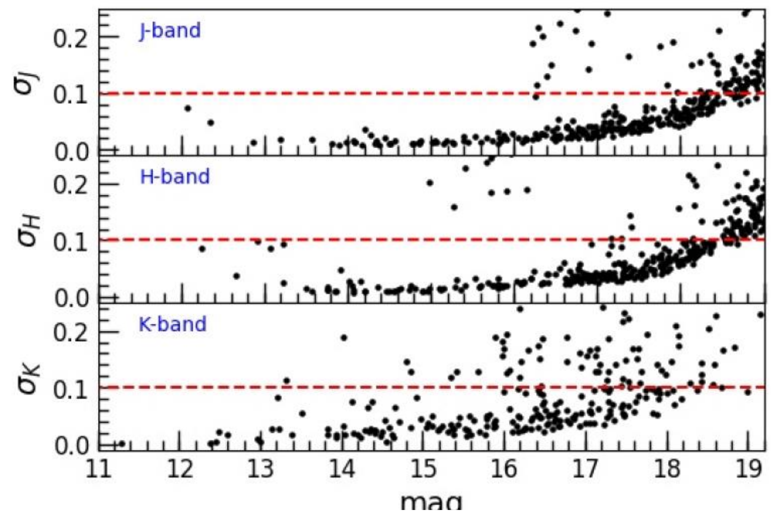


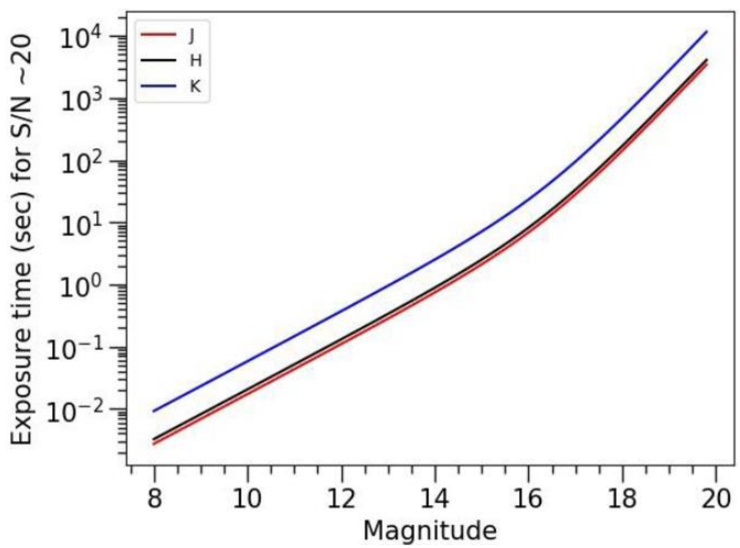
Figure 12: The left panel shows the continuum-subtracted PAH band image of 30 x 30 arcsec^2 area towards the Sh2-61 region. Contours are overlaid for clarity. *Spitzer* 3.6 μm image for the same area is also presented for comparison in the right panel.

Science Calibration results

- J-band : **19.0 mag** (S/N ~ 10); for a total exposure time of **550s**
- H-band : **18.8 mag** (S/N ~ 10); for a total exposure time of **550s**
- K-band: **18.0 mag** (S/N ~ 10); for a total exposure time of **1000s**
- L-band: **8.2 mag** (detection limit); for a total exposure time of **20s**

10 σ limiting mag





Performance is as good as with any other 4 m class Telescopes located in Chile or elsewhere

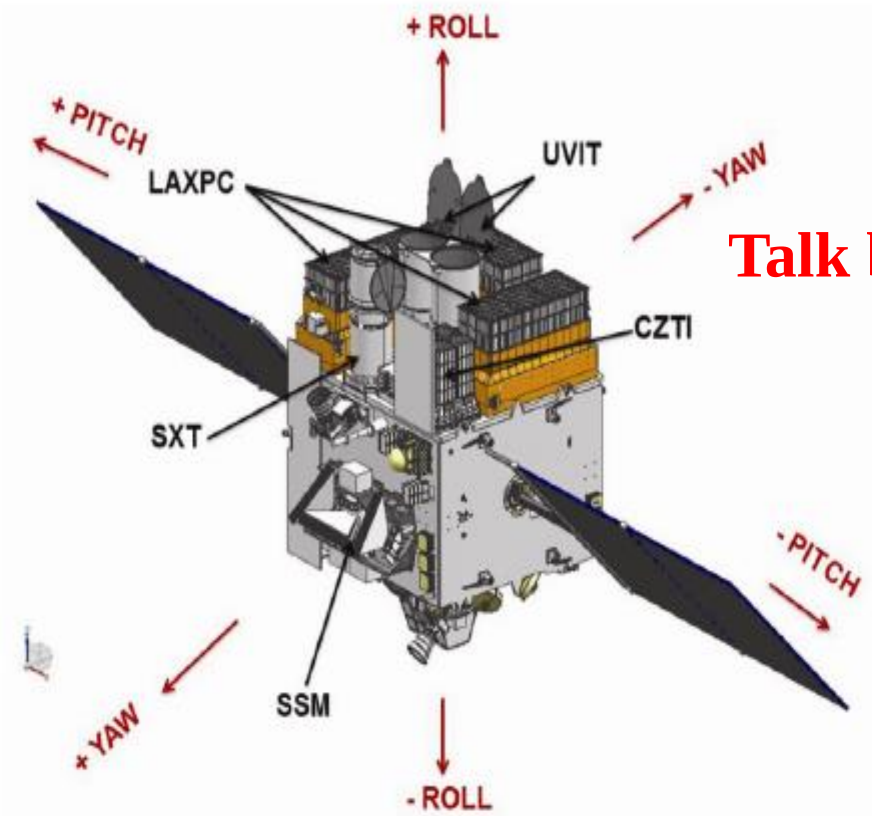
From angular resolution Point of view very good

(Both optical and NIR Images indicate sub arc sec seeing for a good fraction of observing time)

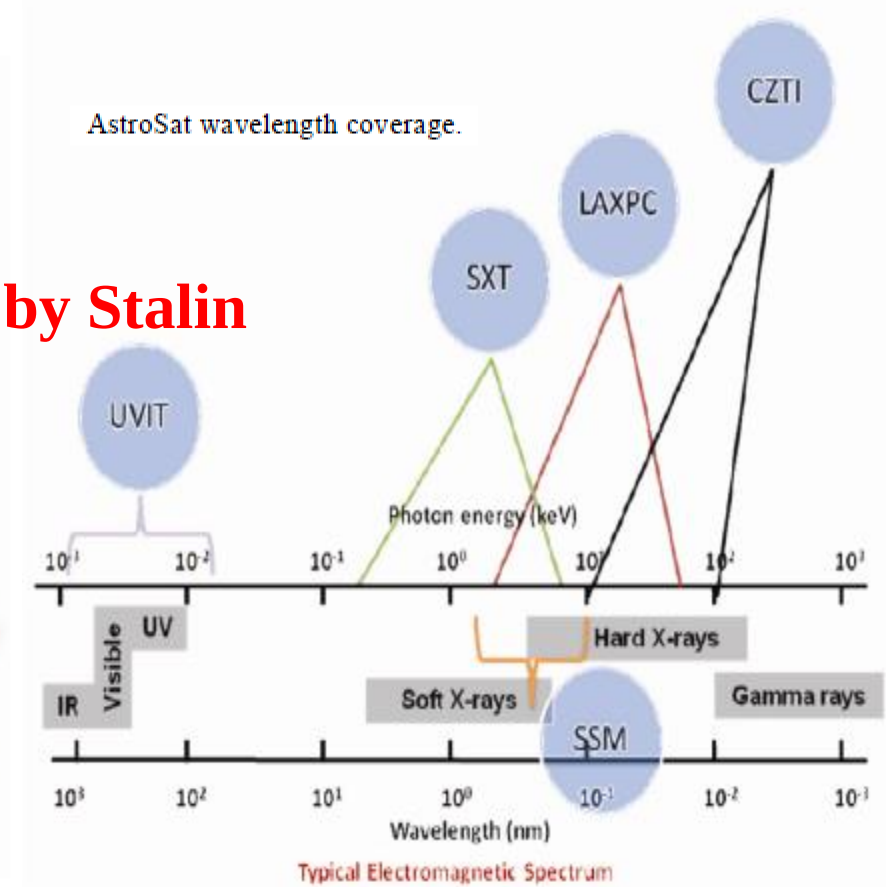
NIR upto 5 μm

After successful launch of Chandrayaan-1 and Mars Orbiter Mission, First Indian Multi-wavelength Astronomical Satellite (AstroSat) – Optical, UV & X-Ray Space Observatory was launched successfully on 28 September 2015. Out of 5 years of Mission life time, ~3 years of successful operation and performance is completed. **Talk by Girish**

Space craft axes definition; Pointing accuracy ~ 3 arc min; Alt drift ~ 1.1 arc sec/sec; Jitter < 0.3 arc sec.   UVIT, SXT, LAXPC & CZTI are co-aligned to view same sky



Talk by Stalin



Advantage of UVIT over GALEX

Table 1: Properties of all the filters are shown. First column gives the name, second column gives the material or code, third column gives the average wavelength, and the last column gives the bandwidth.

Adopted name	Filter	Wavelength (A°)	Bandwidth(A°)
FUV:			
F148W	CaF2-1	1480.8	500
F148Wa	CaF2-2	1485.4	500
F154W	BaF2	1540.8	380
F172M	Silica	1716.5	125
F169M	Sapphire	1607.7	290
NUV:			
N242W	Silica-1	2418.2	785
N242Wa	Silica2	2418.2	785
N245M	NUVB13	2447.1	280
N263M	NUVB4	2632.2	275
N219M	NUVB15	2195.5	270
N279N	NUVN2	2792.3	90
VIS:			
V347M	VIS1	3466.2	400
V391M	VIS2	3909.4	400
V461W	VIS3	4614.0	1300
V420W	BK7	4200.3	2200
V435ND	ND1	4353.6	2200

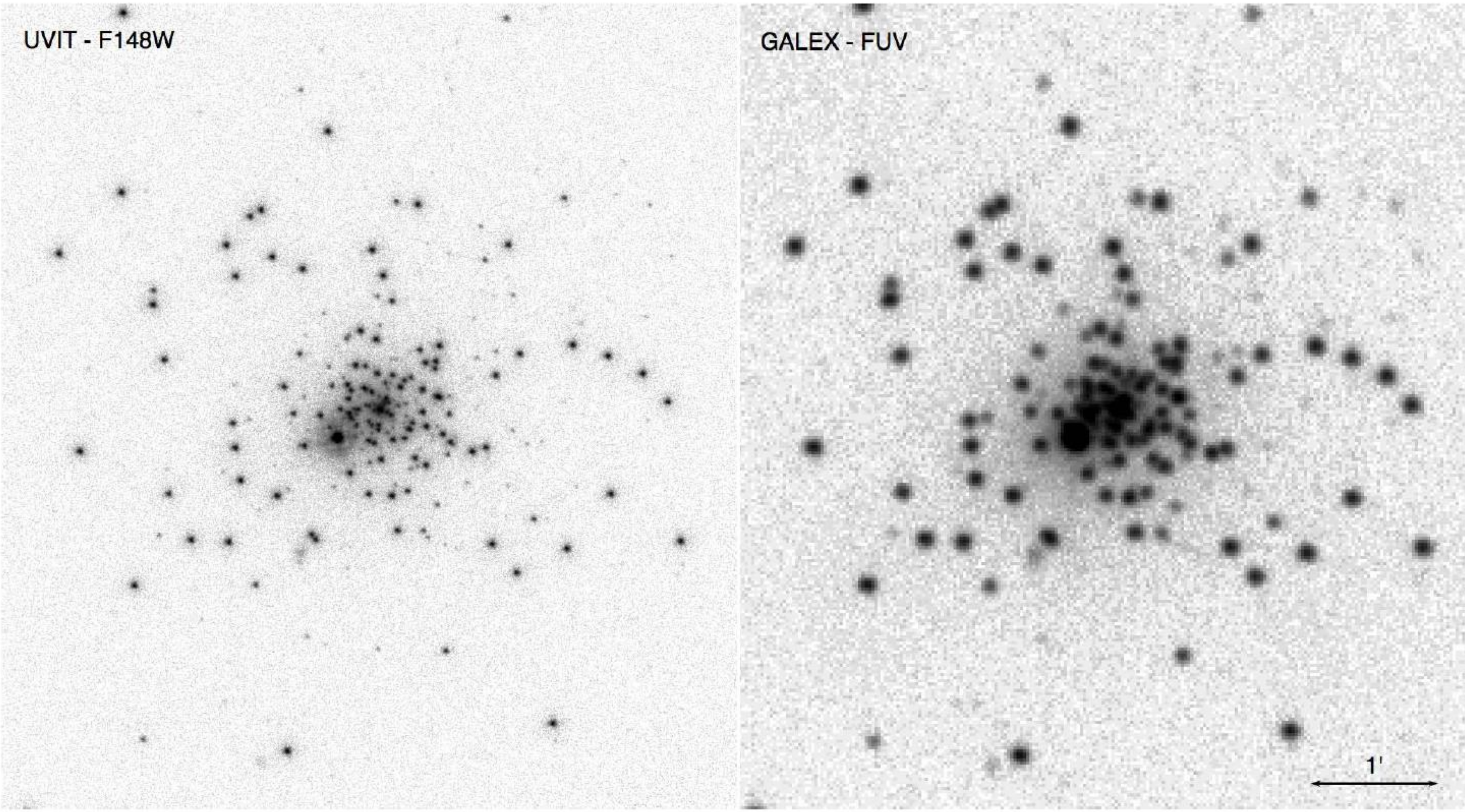
Tandon et al. (2017)

FUV has 5 filters
NUV has 6 filters
Visual has 5 filters

This unique capabilities can be used for precise determination of SEDs

Better angular resolution

NGC 1851 - FUV: UVIT vs GALEX



Subramaniam, Sahu, Postma et al. (2017)

What are Blue Straggler Stars (BSS)??

- **BSS** are located along an extrapolation of MS.
- Brighter and bluer than TO.
- Discovered by Sandage in 1953 but formation process is not yet well understood.

- Location suggest that BSS are more massive than cluster population. Confirmed by a few mass measurements made recently.

- GCs have no evidence of recent star formation. Mass Transfer (MT) processes between binary companions up to the complete coalescence and the merger of stars induced by direct collisions.

- Being more massive than average cluster stars, BSSs sink towards the cluster centre due to dynamical evolution.

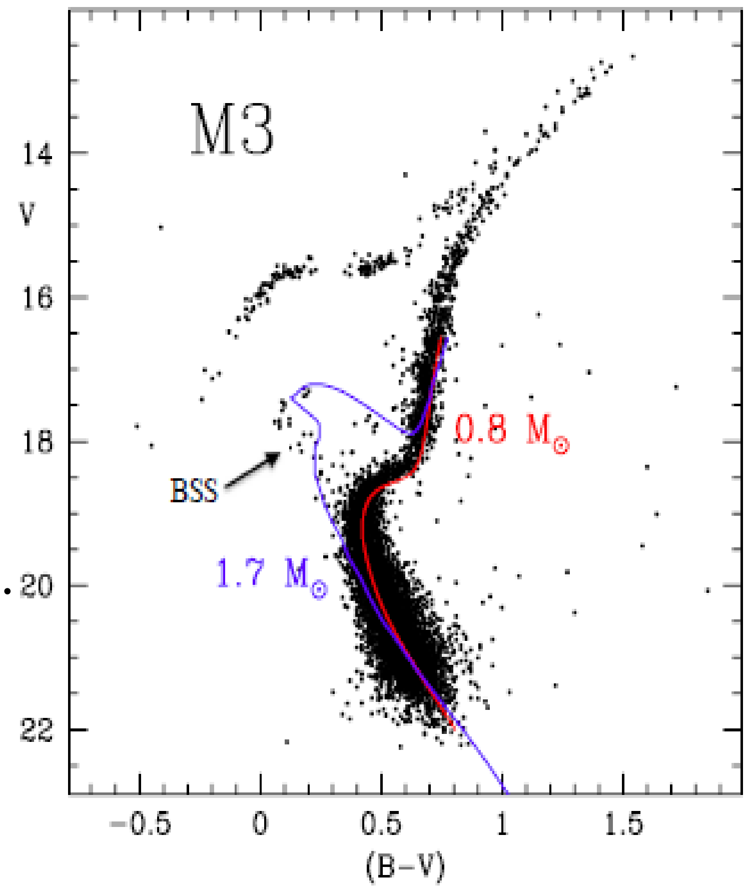
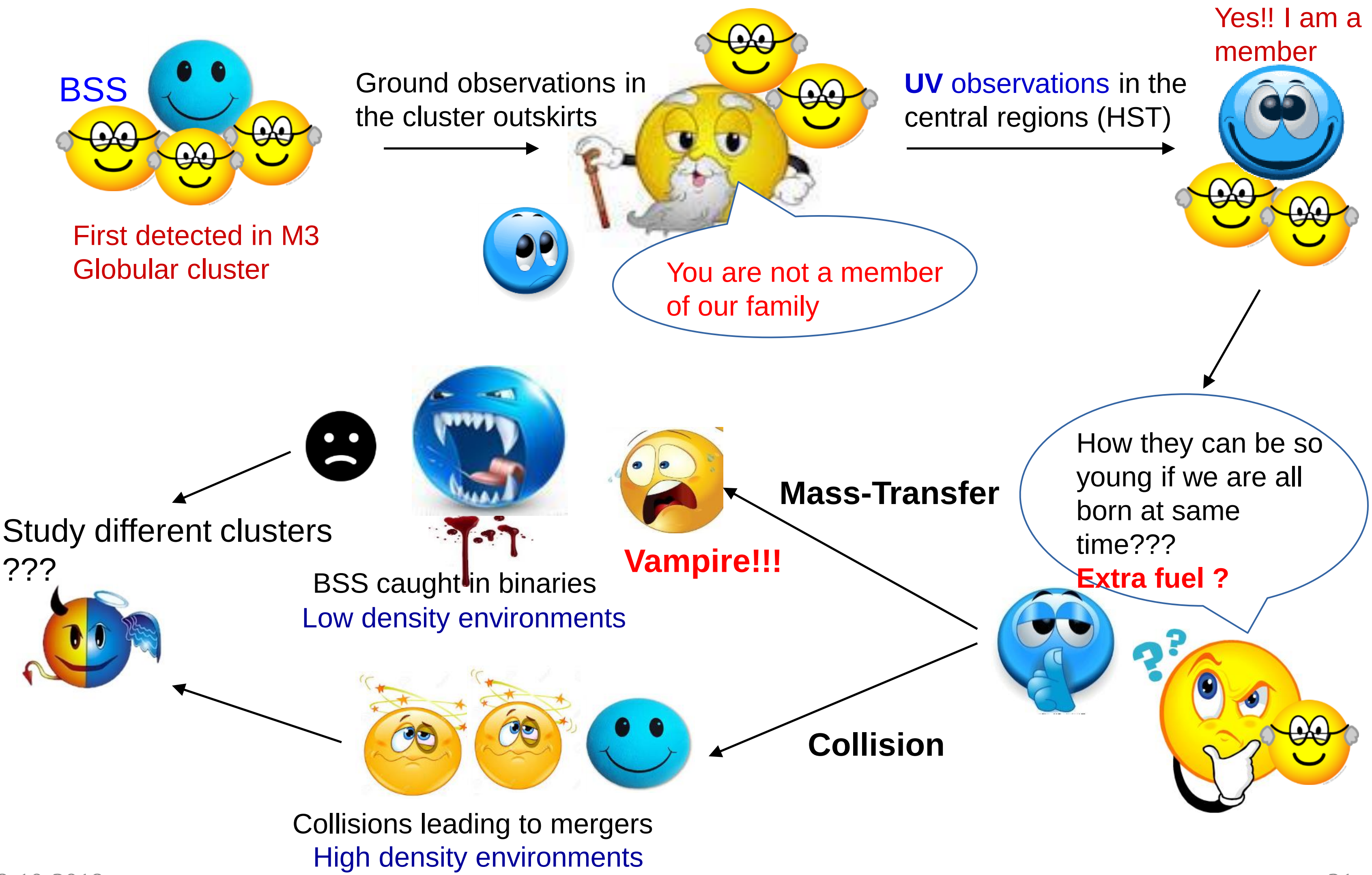


Fig. 5.1 Optical CMD of the globular cluster M3, with the location of BSSs indicated by the arrow. The theoretical track corresponding to 0.8 $M_\odot$ reproduces well the main evolutionary sequences of the cluster, while BSSs populate a region of the CMD where core hydrogen-burning stars of ~ 1.7 $M_\odot$ are expected. From [9].

Blue Stragglers (BSS)



- **UV Route to study BSS; Both Galactic Open and Globular clusters**

  (RS and A Subramaniam & her PhD students)
- Visible light ➔ old stellar populations are bright cool Giants like SGB & RGB
- UV light ➔ Narrow & Vertical Sequence ~ 3 mag
- Ideal for selecting BSSs even in the core of GCs

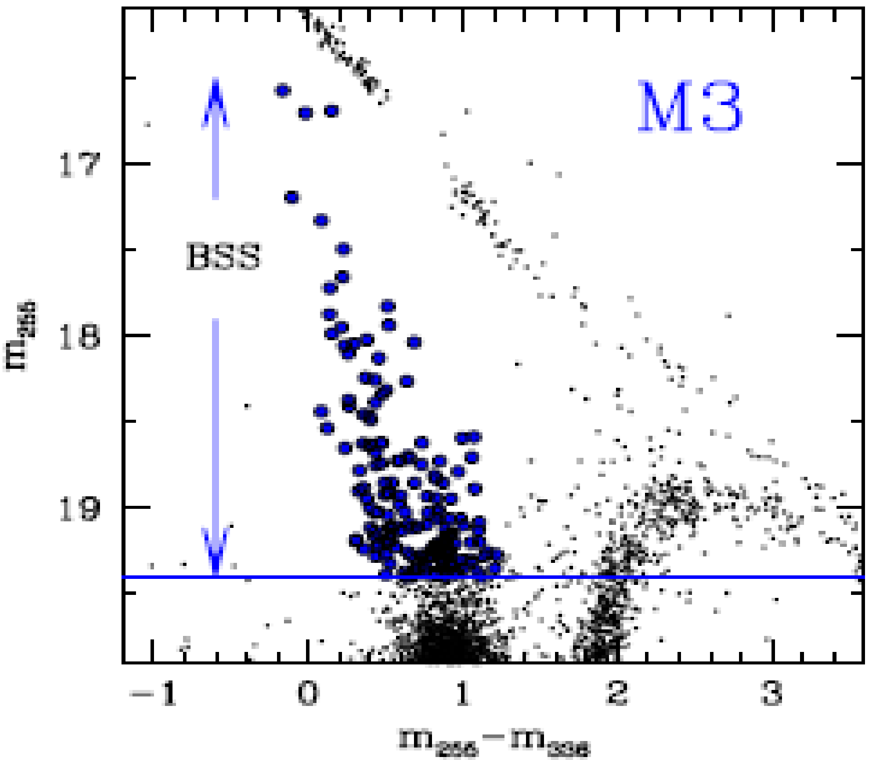


Fig. 5.4 BSS in the UV: the case of M3. The horizontal line at m_{255} = 19.4 is the assumed BSS limiting magnitude, corresponding to ~ 5σ above the turnoff level. From [24].

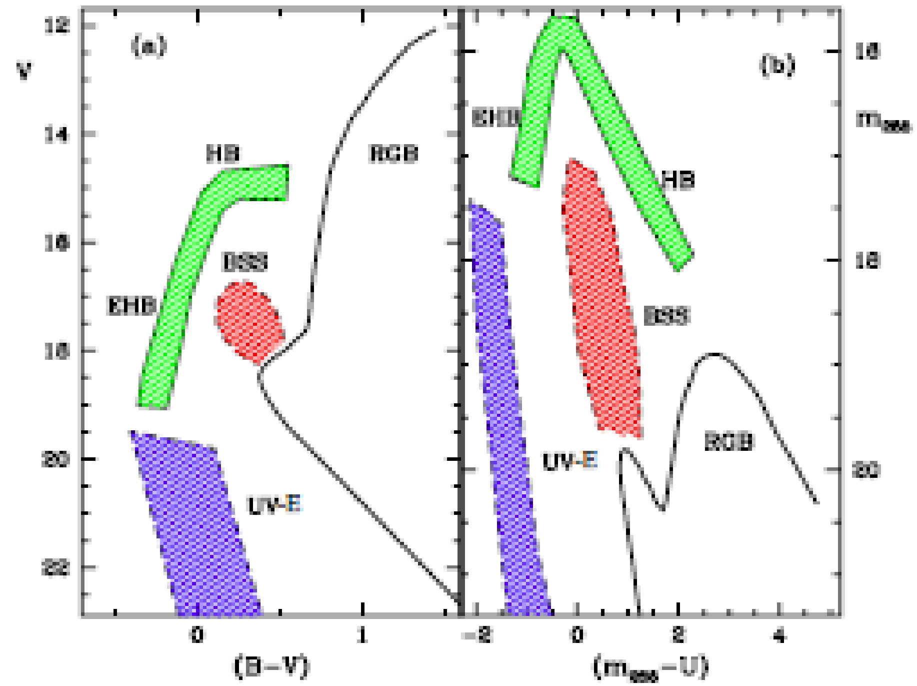
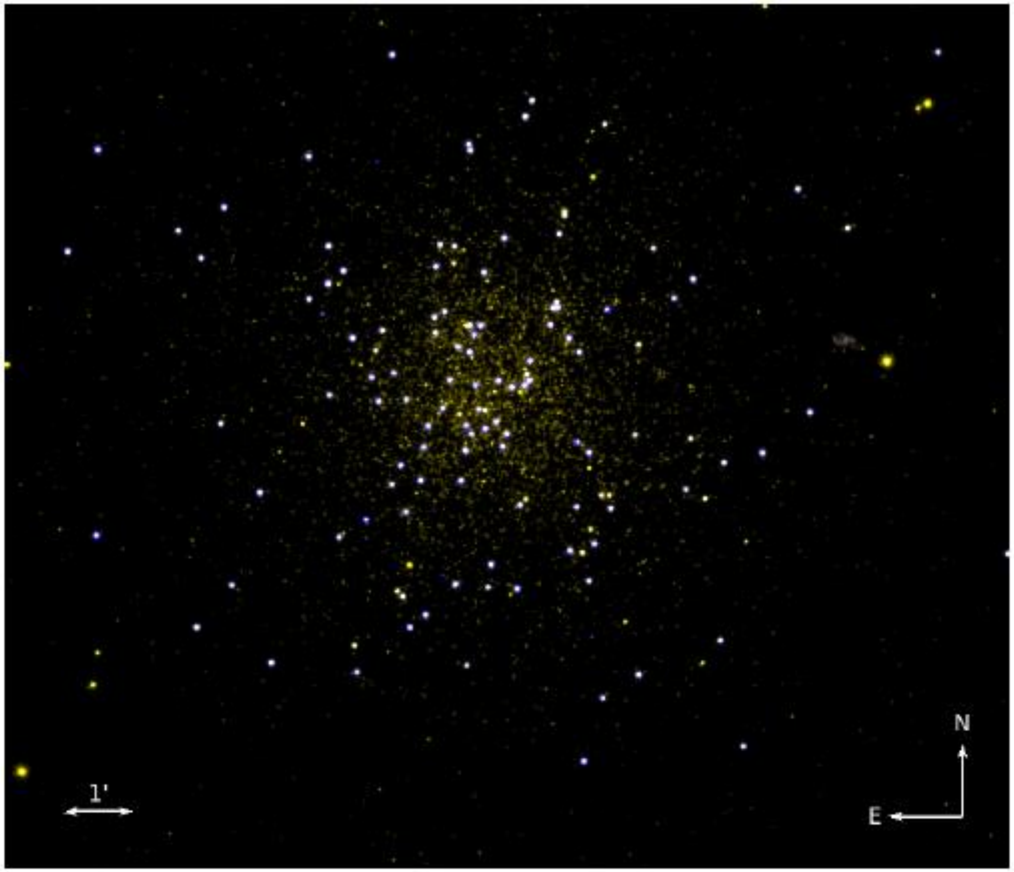


Fig. 5.3 Sketch of the stellar evolutionary sequences in the optical (left panel) and in the UV (right panel) CMDs. The loci of RGB, BSS, HB, extreme-HB stars (EHB) and stars with UV excess are marked.

UVIT-HST-GAIA view of NGC 288: A census of hot stellar population and their properties from UV

Snehlata, Subramaniam et al. (2018) ArXiv:1810.01846



Radial variation of BSS and BSS up to a Radius of 10 arc min

Advantage of combining UVIT&HST

Bright BSSs are more centrally located

Mass (solar) ranges 0.86-1.25; Peak @1

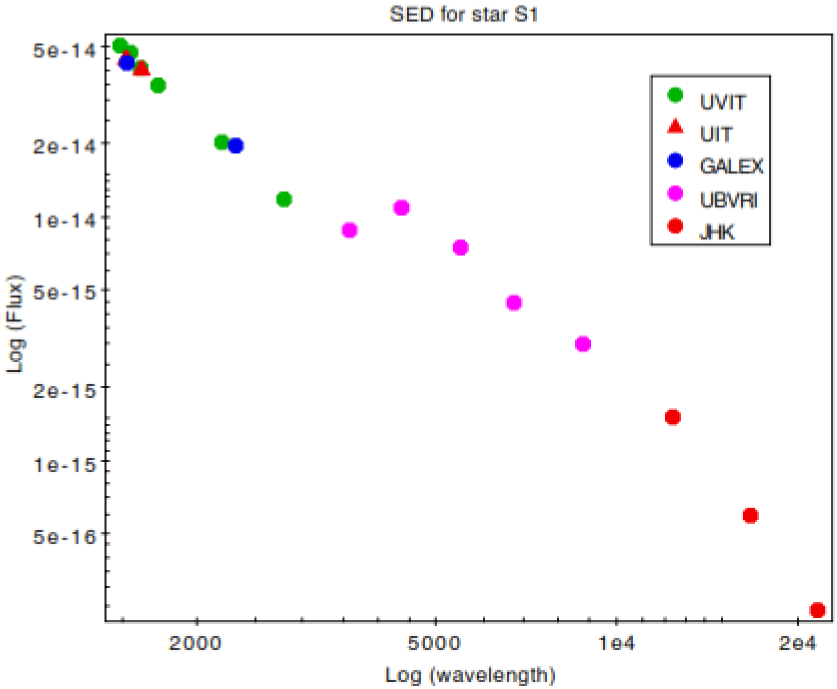
Age (Gyr) ranges 2-10; Peak@4

UVIT Images

Tandon et al. (2017) & Subramaniam et al. (2016)

BSS ➔ 6000±150 K; post—AGB/HB ➔ 17000±500 K; not Sub-dwarf
FUV bands show that flux is rising at least until 1481 A; First such BSS identified in an open star cluster; BSS formation via mass transfer

Advantage of more filters in UV



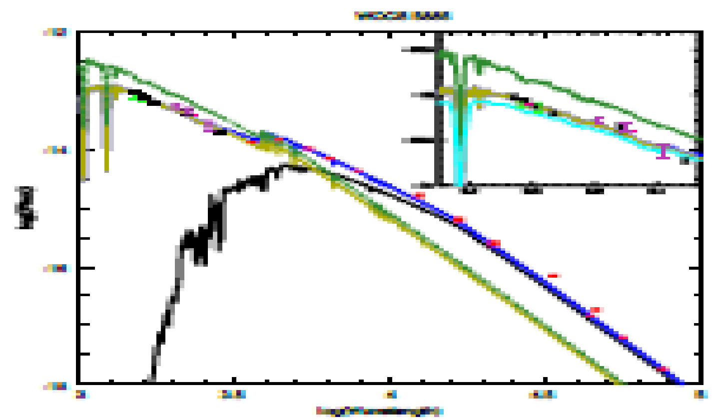
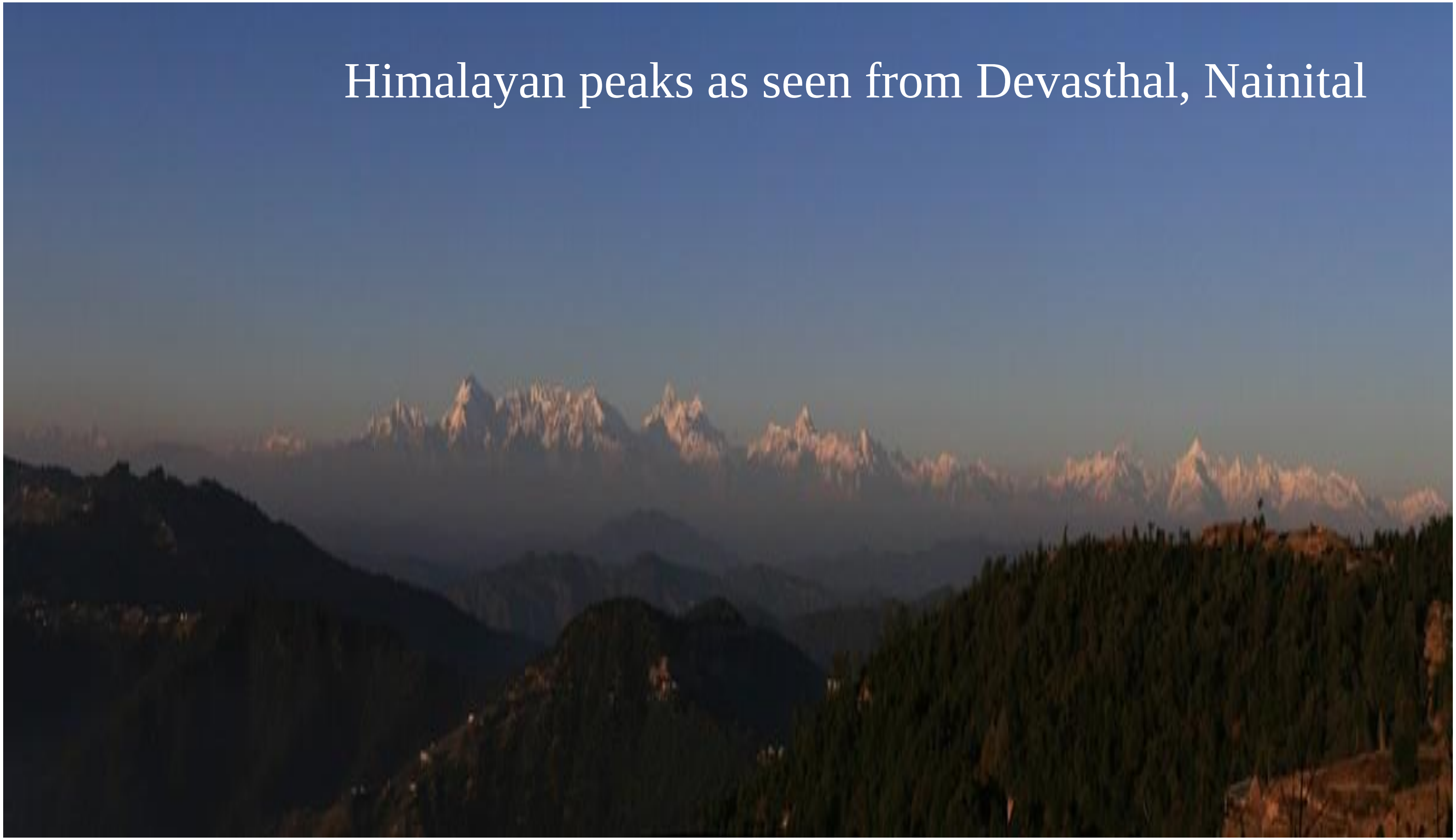


Figure 2. The extinction-corrected spectral energy distribution (SED) of WOCS-5885. The black (UVIT), magenta (GALEX) and green (UIT), pink (UVOT) points indicate the UV fluxes (shown in the inset as well); all other flux measurements are shown in red. Kurucz Model spectra (Log(g) = 5.0) for the separate components are shown in gold (17 000 K) and black (6 000 K), with the composite spectrum in blue. For comparison, we have shown a hotter spectrum of temperature (20 000 K) in dark green. We have also shown the helium rich model spectrum for a temperature of 18 000 K, log g = 4.0, H= 0.30, He =0.70, and CN = 0.00005 from Jeffery et al. (2001), in Cyan. Scaling factors of 4.45E-22 and 3.1E-23 have been used to combine the 6 000 K and 17 000 K spectra, respectively. The unit of wavelength is Å and flux is ergs cm^{-2} s^{-1} $Å^{-1}$. The data points which were not considered for the final reduced χ^2 value are, GALEX(NUV), U, W1, W2, I2, I3.

Summary and Conclusions

- Devasthal Optical Observatory:- Northern sky coverage and longitudinal advantage as it is located almost in the center of Spain in West and Australia in East for transient objects;
- 3.6 m DOT thin (1:23) well surfaced primary mirror with active optics technology is capable of providing sub arc sec images for a good fraction of observing time; Optical & NIR; FWHM α $\lambda^{-0.2}$
- **care taken in the construction of the telescope houses has paid a rich dividend as their thermal mass is so low that it has not degraded the natural atmospheric seeing at Devasthal measured about 2 decades ago. Best angular resolution is 0.4 arc sec; and**
- Excellent Near-IR sky performance; Survey type key science goals; follow-up observations of GMRT and ASTROSAT; Modern back end instruments including Adaptive optics and high resolution spectrograph coupled with excellent atmospheric conditions have immense potential to contribute to the global astronomy in coming years as has been shown by other similar telescopes



Thanks for patient hearing