UVIT and its Capabilities

S N Tandon, IUCAA

Advanced Astrosat Data Analysis Workshop
Astrosat Science Support Cell (IUCAA)
June 21-30, 2021

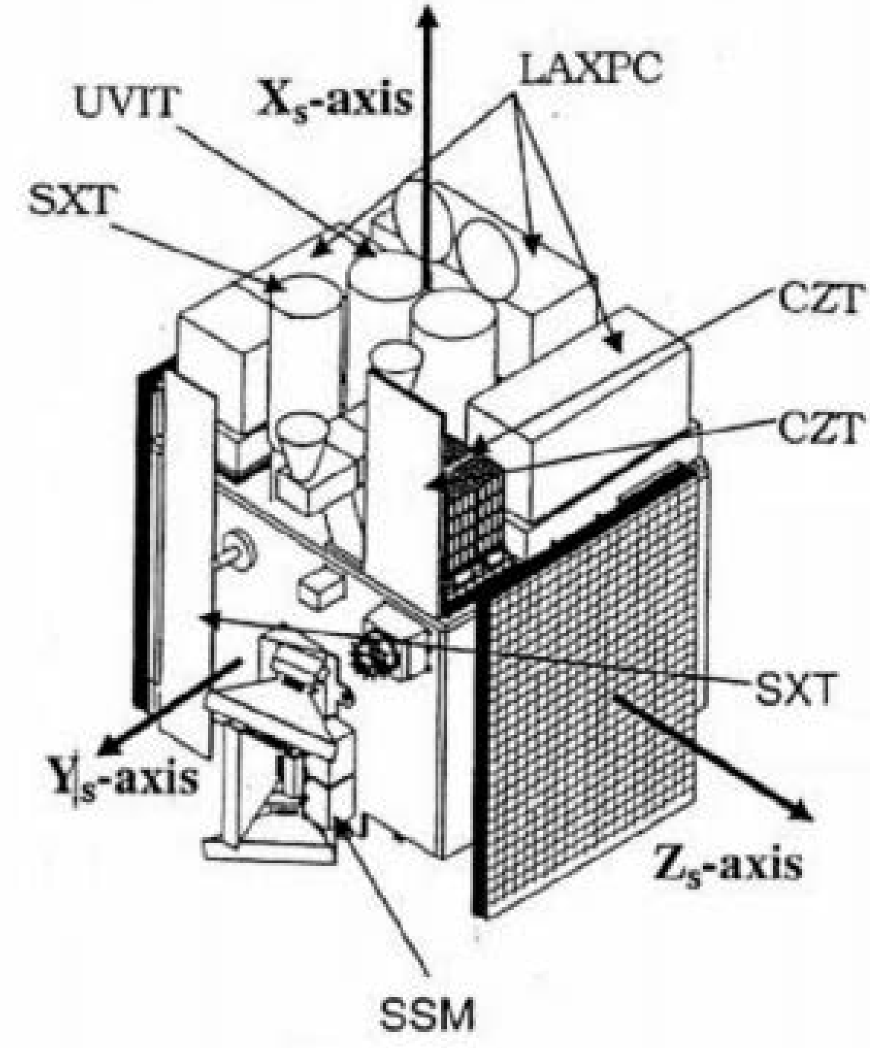
Plan of the talk

- About Astrosat
- Design and Specifications of UVIT
- Observing with UVIT
- Capabilities of UVIT
- Illustrative results

About ASTROSAT

- ASTROSAT is an Indian satellite for multi wavelength astronomy with emphasis on High Energy Astronomy
- For simultaneous observations there are four co-aligned telescopes: 3 for X-rays and one for ultraviolet, and one X-ray Scanning Sky Monitor
- The three X-ray telescopes cover a range from 1 – 100 keV , and the ultraviolet telescope (UVIT) covers a wavelength range 1250 A to 3000 A
- The project started in 2004 and launch was on September 28, 2015

Configuration of ASTROSAT



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ASTROSAT-SPACECRAFT

- Altitude :   650 km
- Inclination to Equator: 8 deg.
- Mass : 1500 kg. (780 kg. Payloads)
- Power generated : 1900 watts
- PSLV launch from India
- Launch September 28, 2015
- Operational life of minimum 5 years
- Pointing <3’, and drift < 0.5”/s

Current Status of ASTROSAT

- Targets awarded time in "A02 to A10" cycles: CZT – 9, LAXPC-264, SXT-183, and UVIT-880
- Targets observed till June 15, 21 : "2215" ?
- Papers published: "132" till March 2021, including instrumentation and pre-prints
- Instruments' status:

  CZT and SXT: Fully Operational

  LAXPC and UVIT: Partly Operational
- UVIT Status: Of the two UV channels, NUV failed in 2018 and now only FUV channel is operational

  All the quality parameters for FUV are unchanged

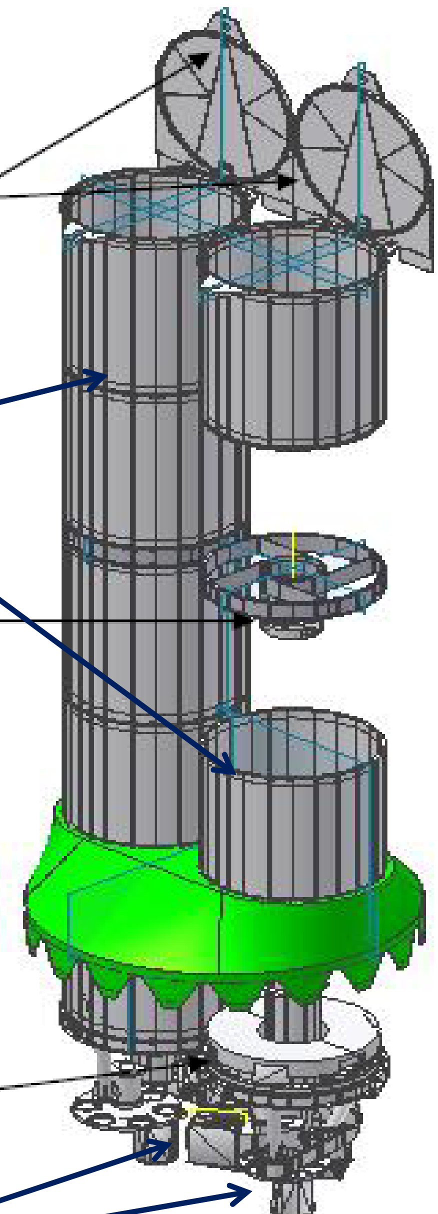
Collaboratoring Institutes for UVIT

- Indian Institute of Astrophysics
- Inter University Centre for Astronomy & Astrophysics
- Tata Institute of Fundamental Research
- Many Centres of ISRO
- Canadian Space Agency

Configuration of UVIT

- Two telescope of ~ 38 cm aperture
- Simultaneous imaging of the field in 3 bands: Far UV, Near UV, and Visible
- Why Visible?
- Mass ~ 200 kg

UVIT- Configuration



दृढ़ता

तापमान की स्थिरता

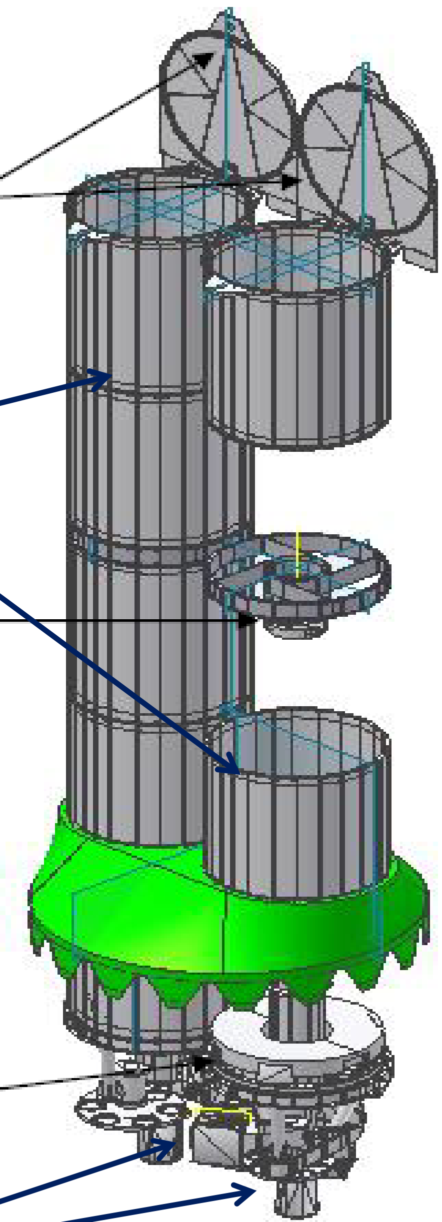
FUNCTIONAL SPECs of UVIT

- SPECTRAL CHANNELS : FUV NUV VIS
  130-180 200-300 320-550 nm
- FIELD OF VIEW : ~ 28’
- Aperture of Telescopes : 375 mm
- SELECTABLE FILTERS : for Part of the Band
- SPECTROSCOPY (Slitless) : ~ 100 res. in FUV/NUV
- TEMPORAL RESOLUTION : ~ 5 ms
- OBSERVING MODE : STARE
- SENSITIVITY IN FUV : mag. 20 in 1000 s
- PHOTOMETRIC ACC. : < 10%
- SPATIAL RESOLUTION : FWHM <1.5”

Design of UVIT

See the next few slides

UVIT- Configuration



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तापमान की स्थिरता

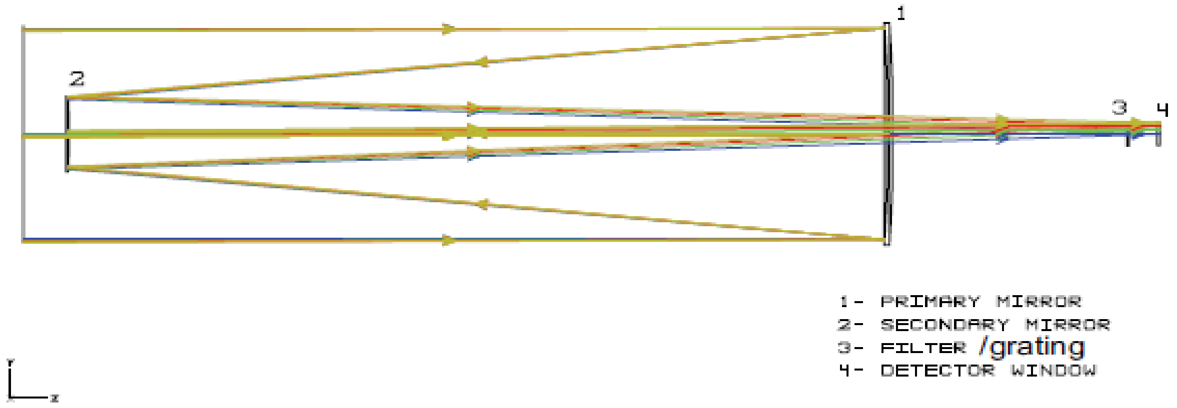
Focussing Optics

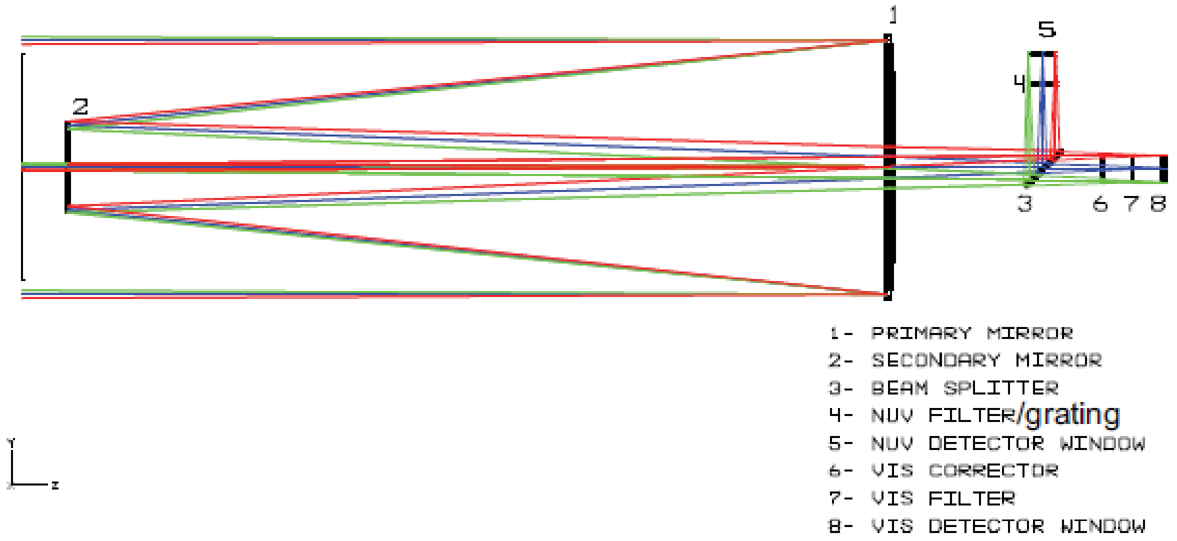
- Pair of co-aligned Cassegrain Telescopes, each of ~ 375 aperture with f/12 beam

Useful field	~ 30' dia
Plate Scale	~ 0.075 mm/arcsec
Telescope 1	for FUV
Telescope 2	for NUV & VIS

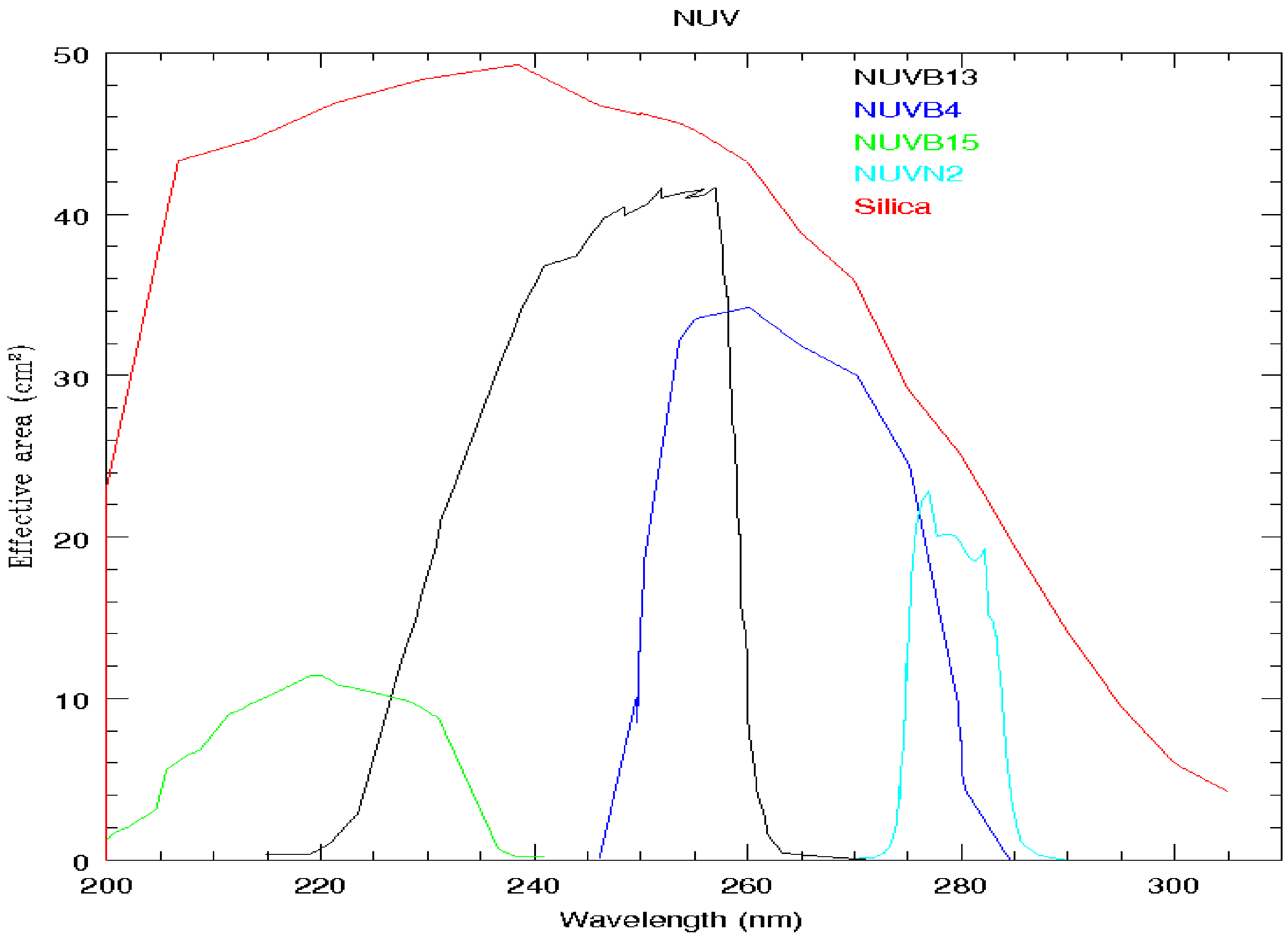
- Structure made of Invar
- No focus adjustment in orbit

Optics of UVIT



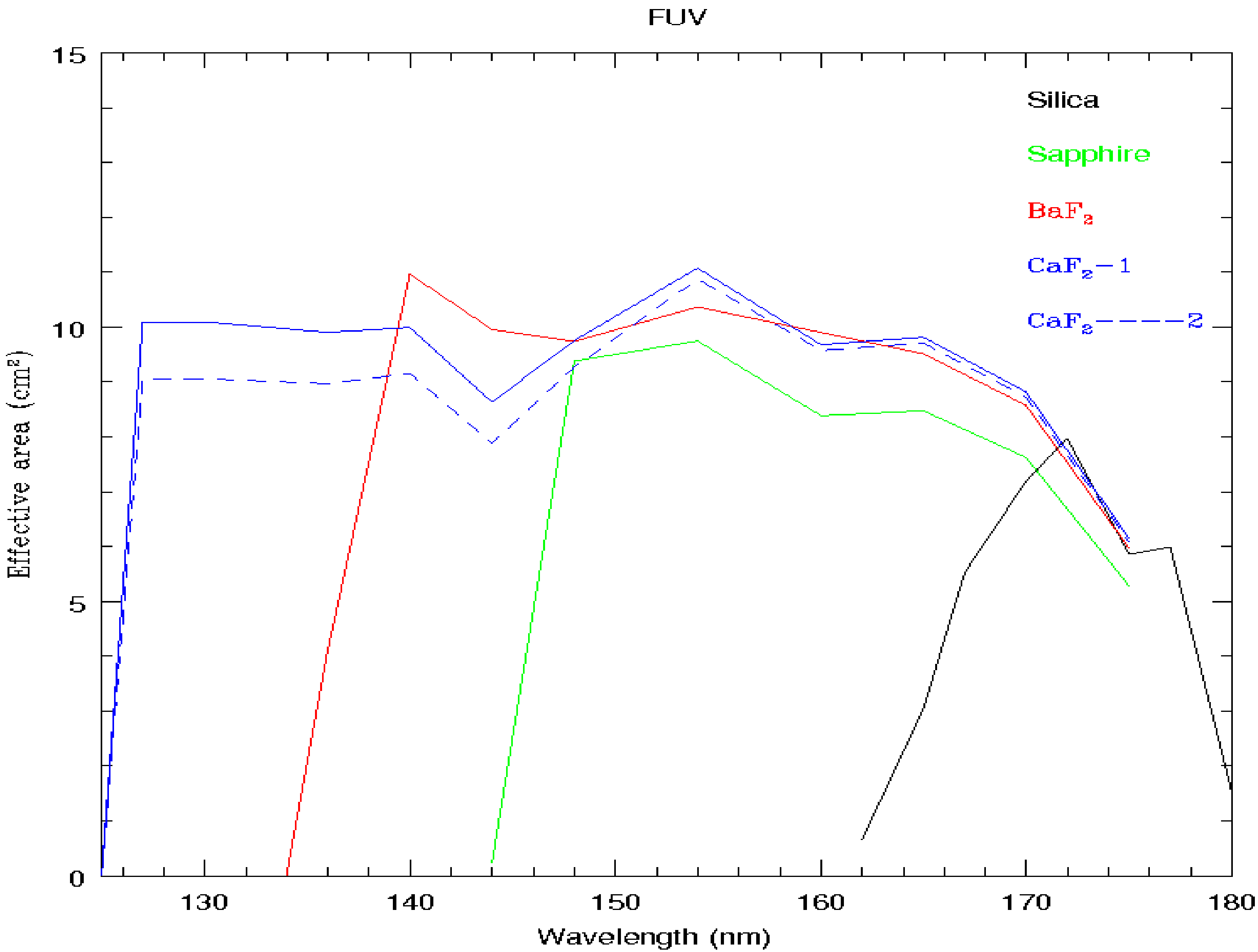


NUV Filters



NUV
NUVB13
NUVB4
NUVB15
NUVN2
Silica
Effective area (cm²)
Wavelength (nm)
0
10
20
30
40
50
200
220
240
260
280
300

FUV Filters (Uncoated)



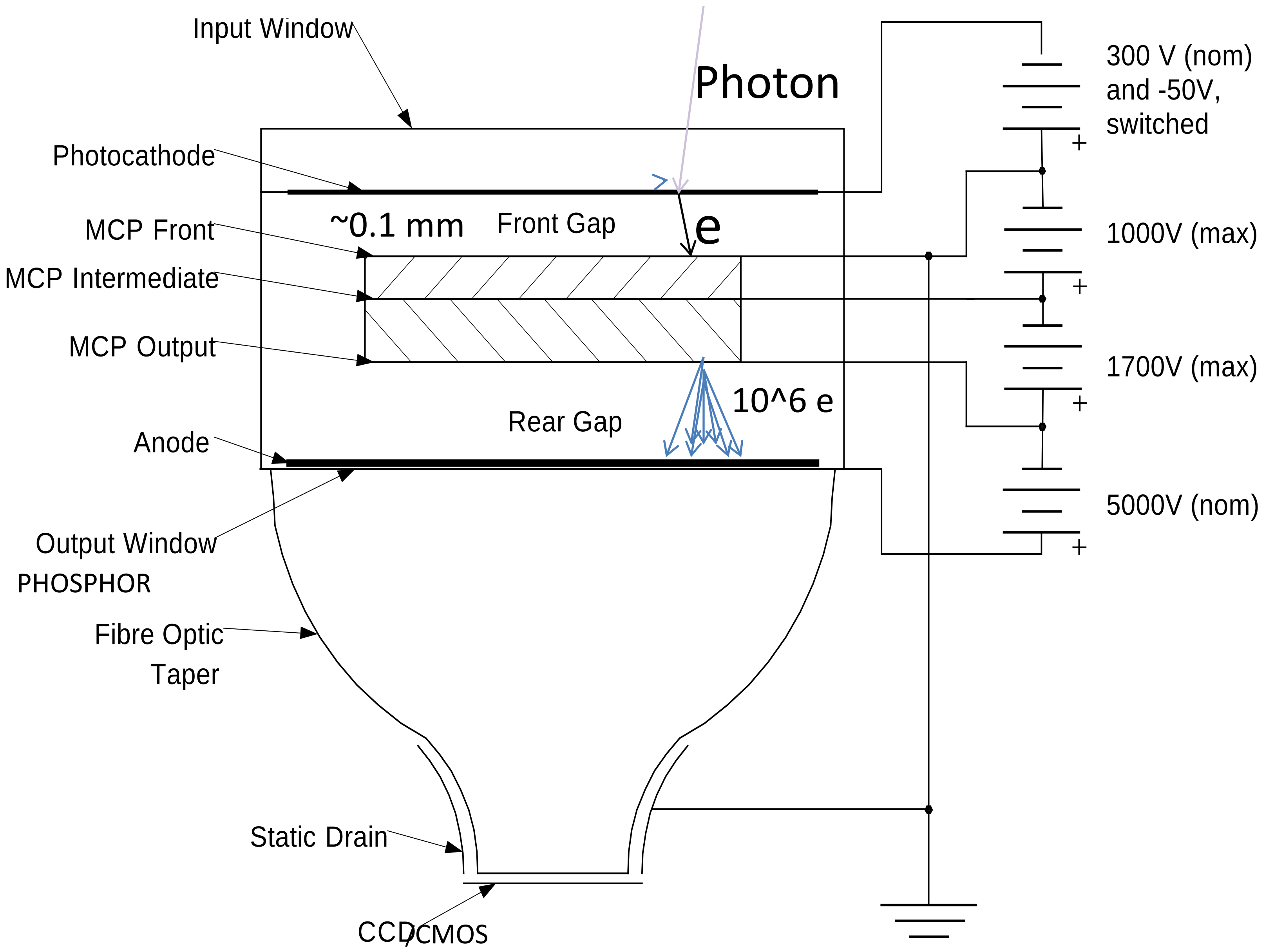
Detectors

- *Pointing of the S/C drifts by >> 1"*
- *Track the drift on ~ 1 S time-scale*
- Combine << 1 S exposures by Shift and Add
- Faintest sources could give < 0.001 e/s

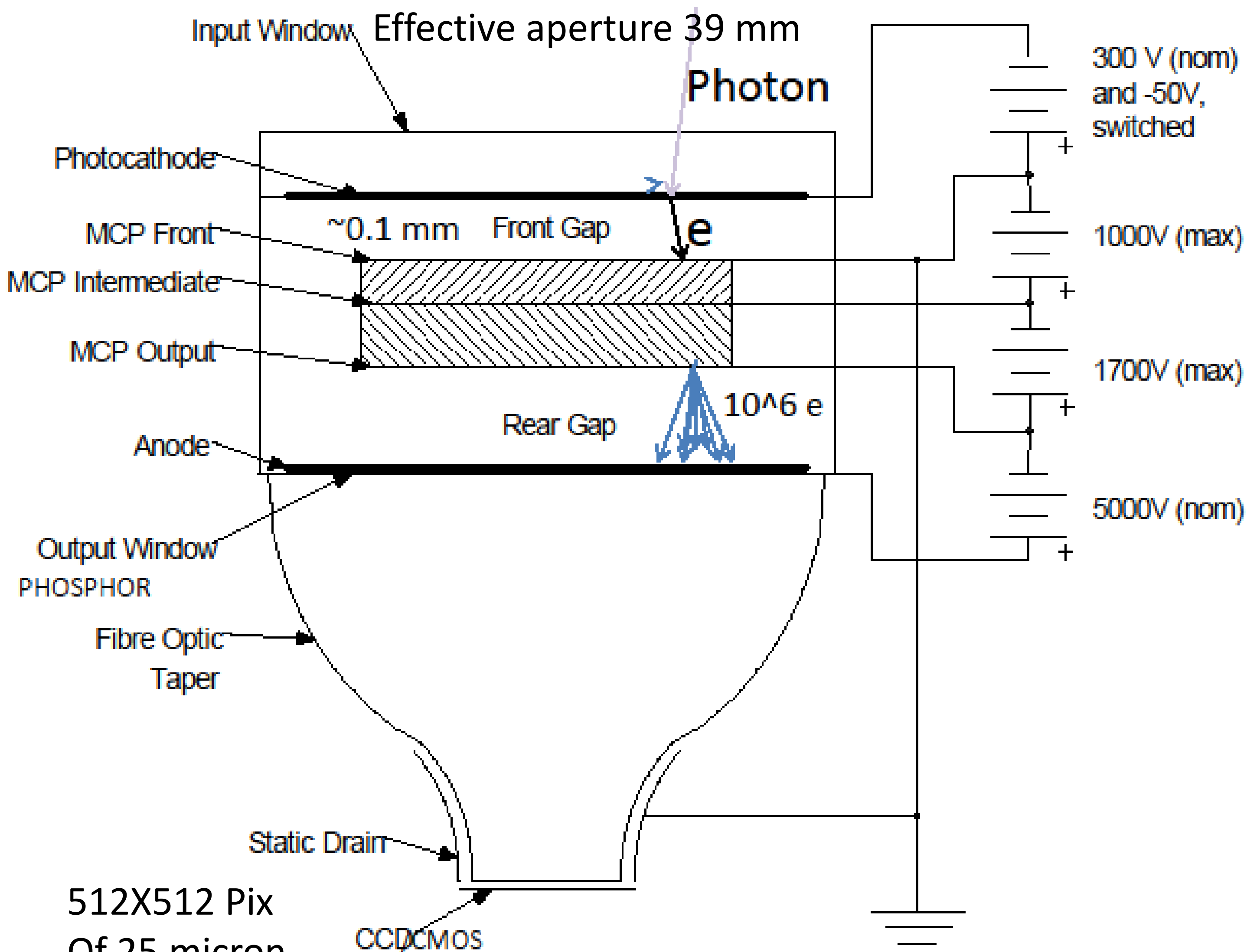
Thus the read noise should be << 1 electron and Photon Counting detectors are needed

Dark current too should be << 1/s per PSF, solar blind detectors with high work-function are convenient as these do not require cooling and red-leak is not an issue.

UV PHOTON COUNTING DETECTOR

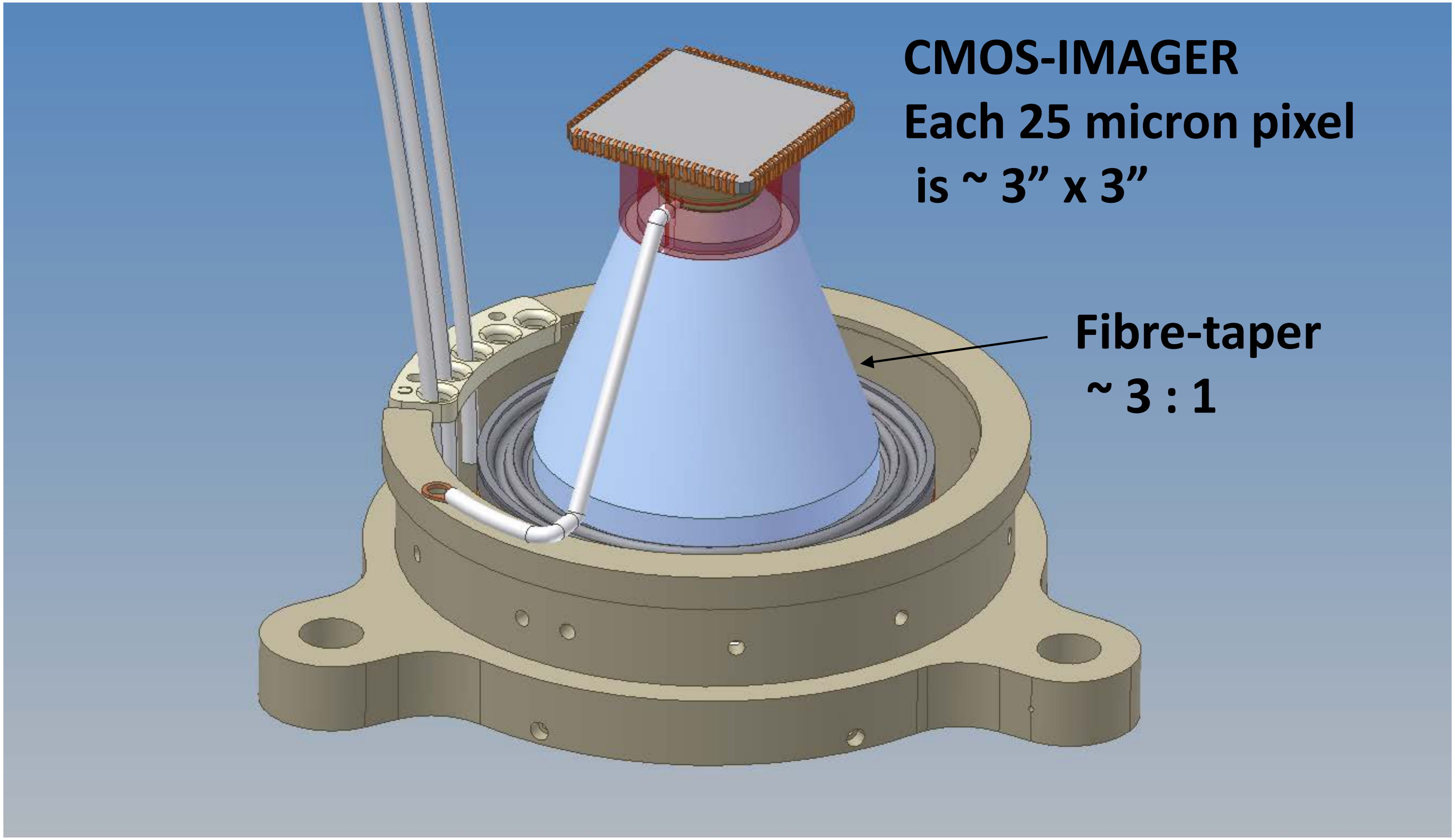


UV PHOTON COUNTING DETECTOR



512X512 Pix
Of 25 micron

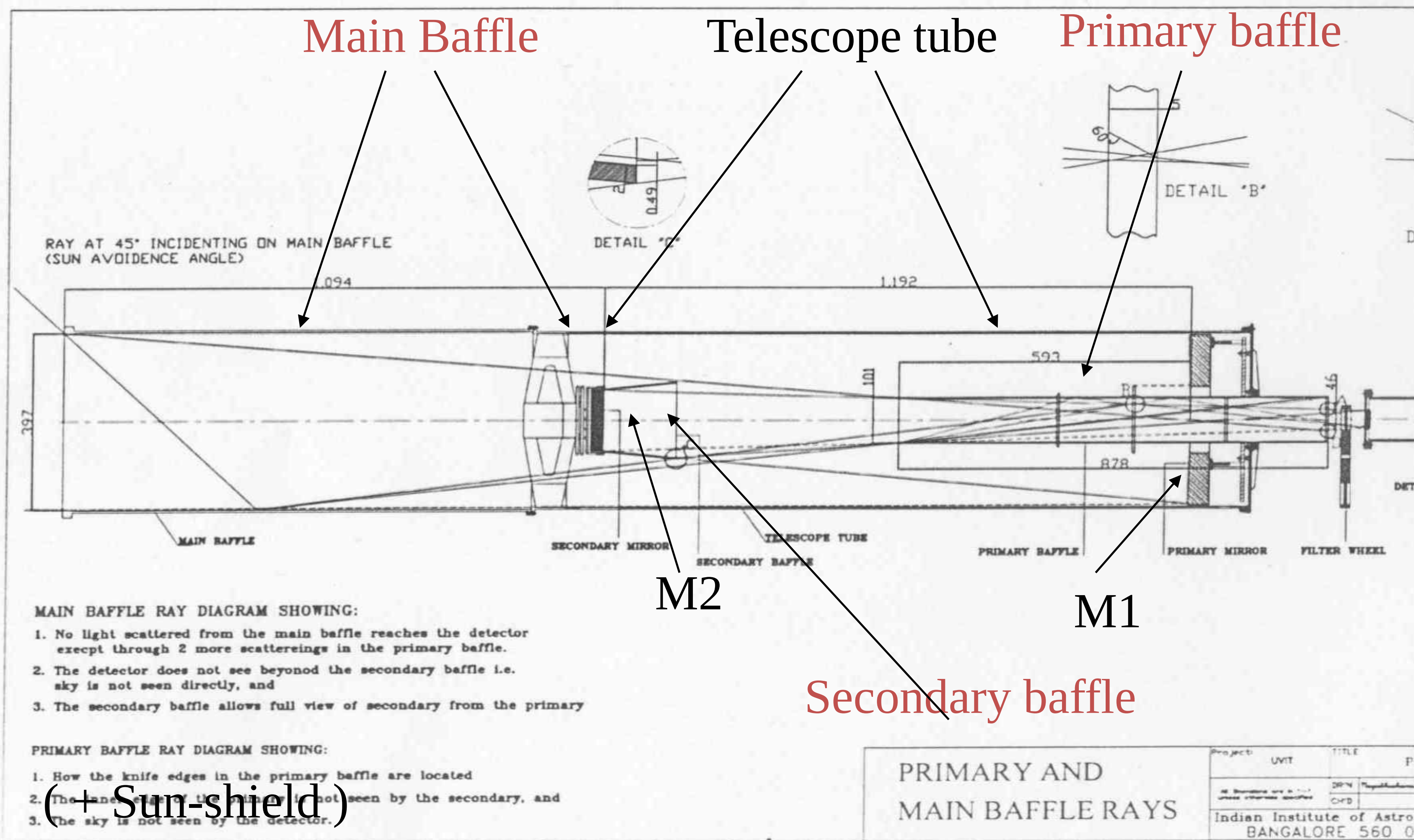
DETECTOR MODULE



Scattered Light from out of the Field

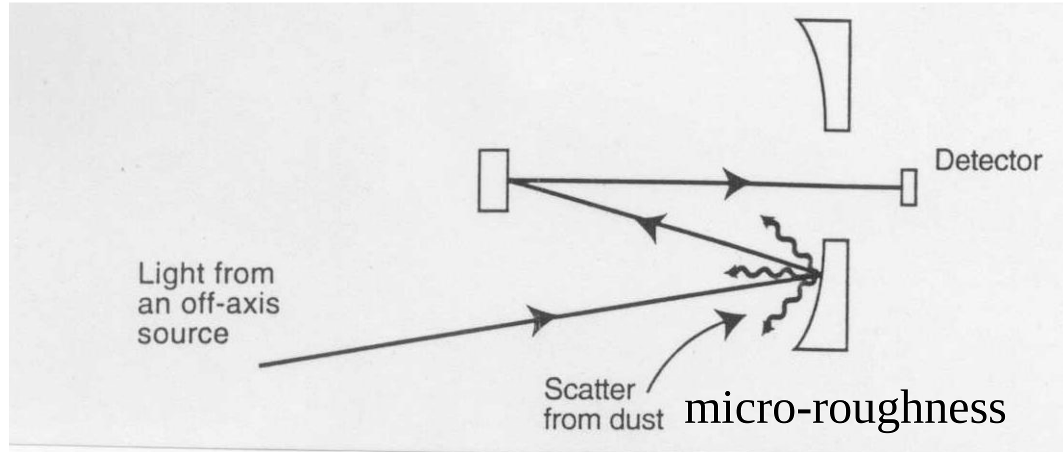
- All direct light from out of the field is avoided
- After one scatter: Only for angles < 10 deg
- Scattering from optical surfaces are minimised by minimising micro-roughness
- All the structural surfaces are black-painted
- In the absence of any overlaying material this scattered light can be attenuated by very large factors

Baffle system for UVIT

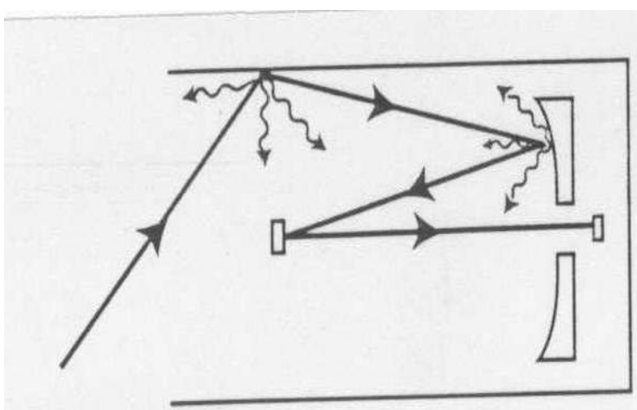


Scattering processes :

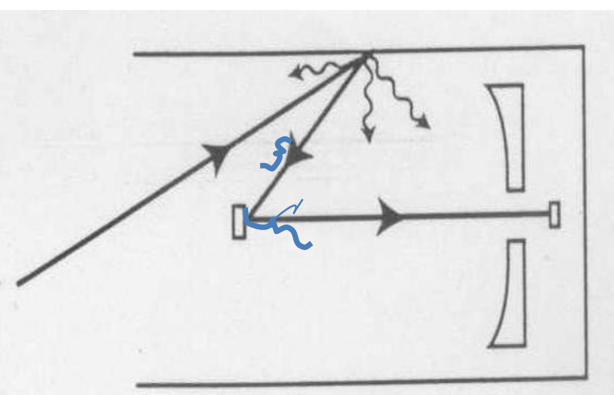
Scattering from mirrors
due to : micro-roughness



Various scattering paths via baffle :



large angle scattering

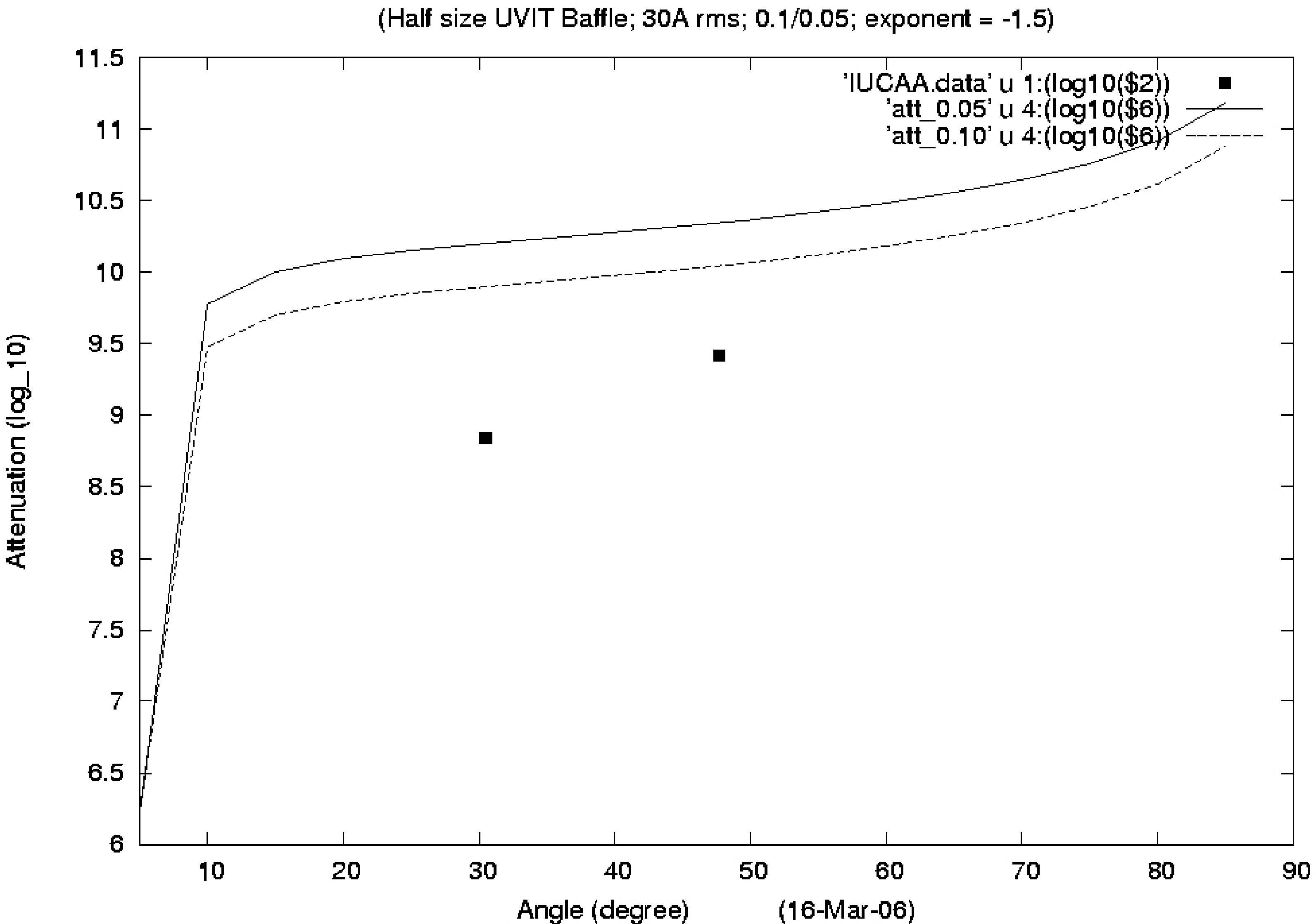


small angle scattering

Comparing measured 'attenuation factor' with calculations :

Calculation; micro-roughness : 30 A; reflectivity : 5% & 10%;

Measred: Half size model with 2 mirrors of micro-roughness 30 A



2.6x10^9

7.0x10^8

Contamination Control

- This was an important global issue to be controlled in all the parts contained within structure of the telescope, and for all locations of testing and assembly, storage, and transport, and launch and in-orbit
- For Far UV even a monomolecular layer of organics can reduce transmission a lot
- Invisible devil, took years to convince people that it was real devil and not imagination

What did it involve

- Minimise use of plastics , and test any plastic to be used
- Avoid exposure to ultraviolet on gound and in the orbit
- Isolate the telescopes with a door from the rest of ASTROSAT for the first 2 months in the orbit.

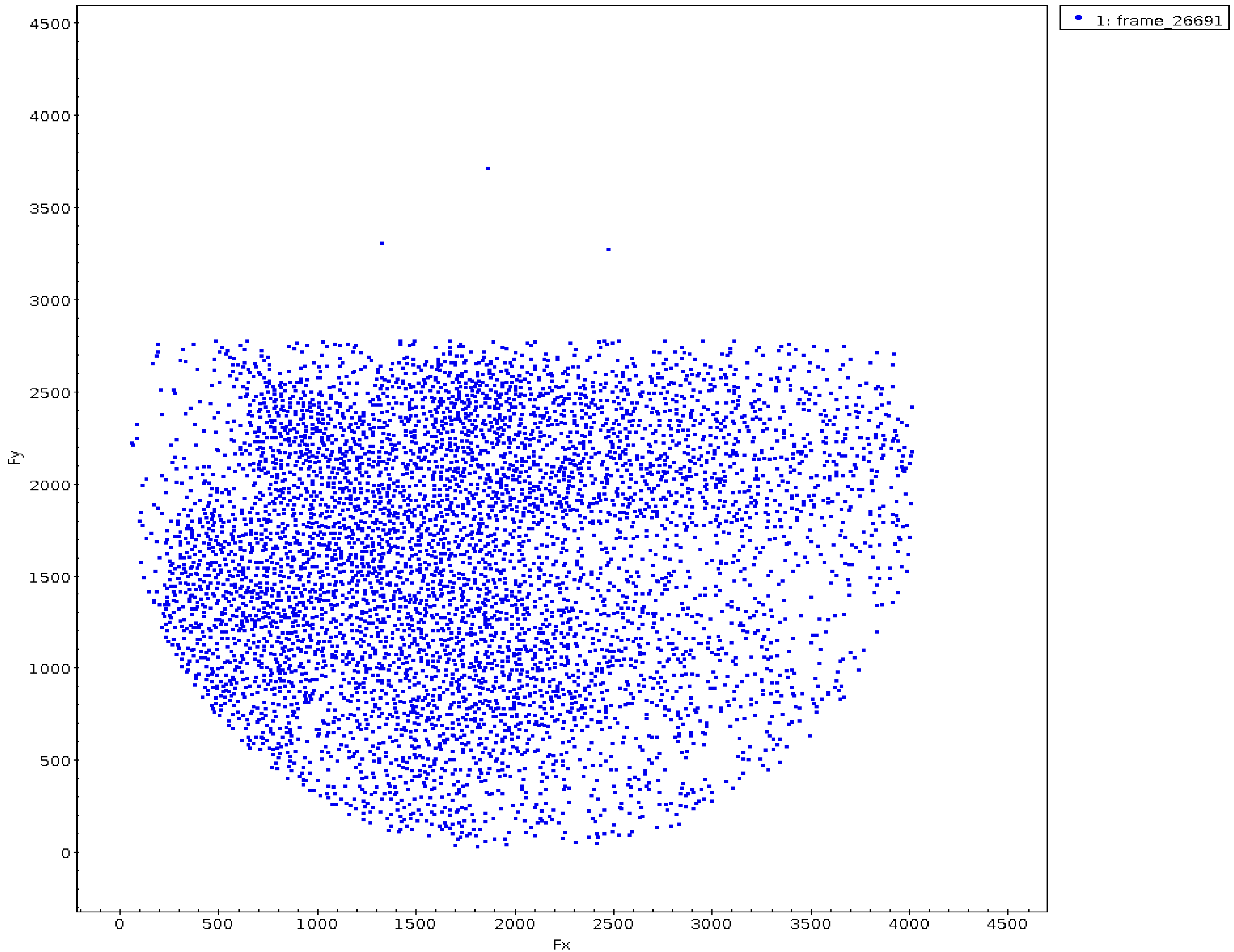
What did it involve

- A special clean laboratory was constructed at IIA between 2003 and 2008 for all testing and assembly activities
- A lot of preparations were done at the different centres of ISRO too for this control
- ***All the hard work at IIA and ISRO paid, and any contamination reduced the efficiency on ground by < ~20% for Far UV, and in 4 yrs of orbit by < 3%***
- If an ant had entered the telescope cavity?

Comments on Observations

- **Safety factors**: Bright Object Detected
- **Fast drift** in the beginning : due to drift of Gyros and sudden correction by Star Tracker --- in effect the PSF might have invisible tail and loss of exposure time
- **Frames with Cosmic Ray Showers**: increase the background (~ 150 events/s), but the frames can be discarded statistically.

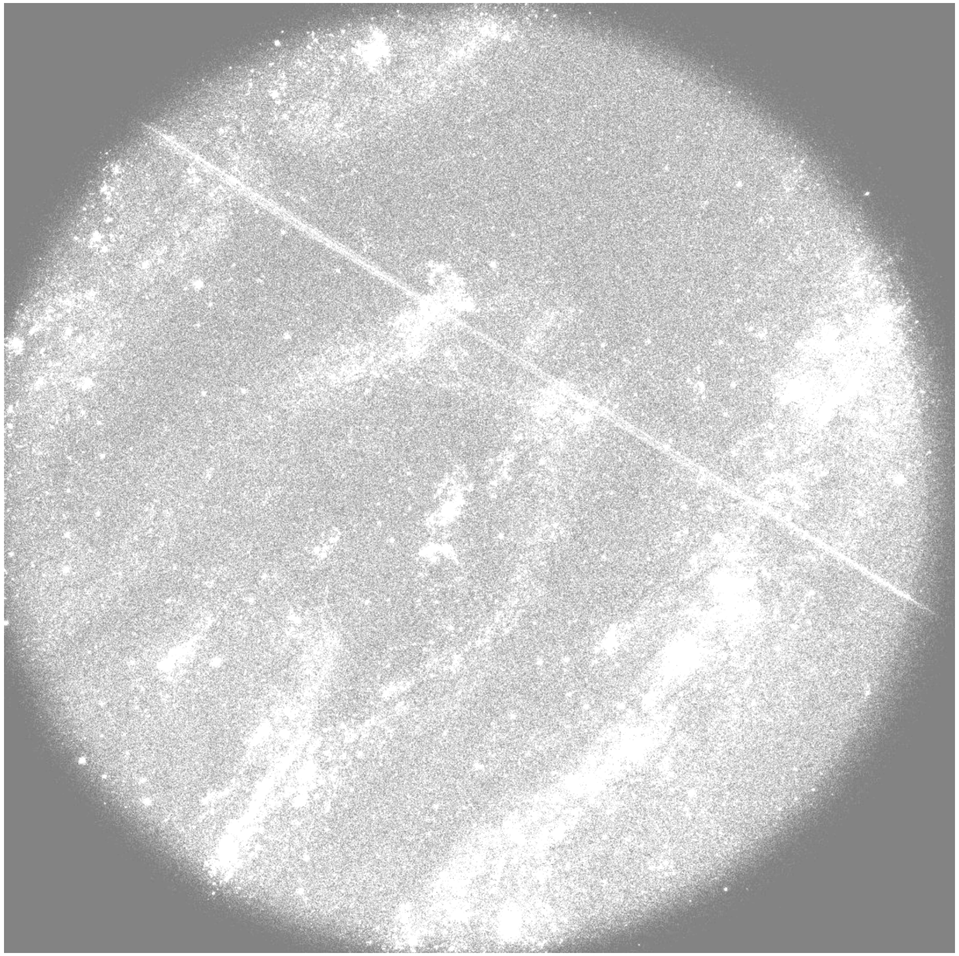
Cosmic Ray Shower



Comments on …

- As there is no active transmitting optics, there are no ghosts
- In some cases a **bright streak** is seen for NUV when a very bright object is present close to edge of the field

Streak in M31 Image



Comments on …

- **Saturation**: If > 1 photon is detected in a frame within ~ 10”X10” (3X3 pixels of Star250) area, these are detected as as single event
- Thus a correction is required for any point sources which give > 0.1 c/frame
- For bright sources ,it is best to observe with partial frames to get a higher rate of frames/second

Comments on …

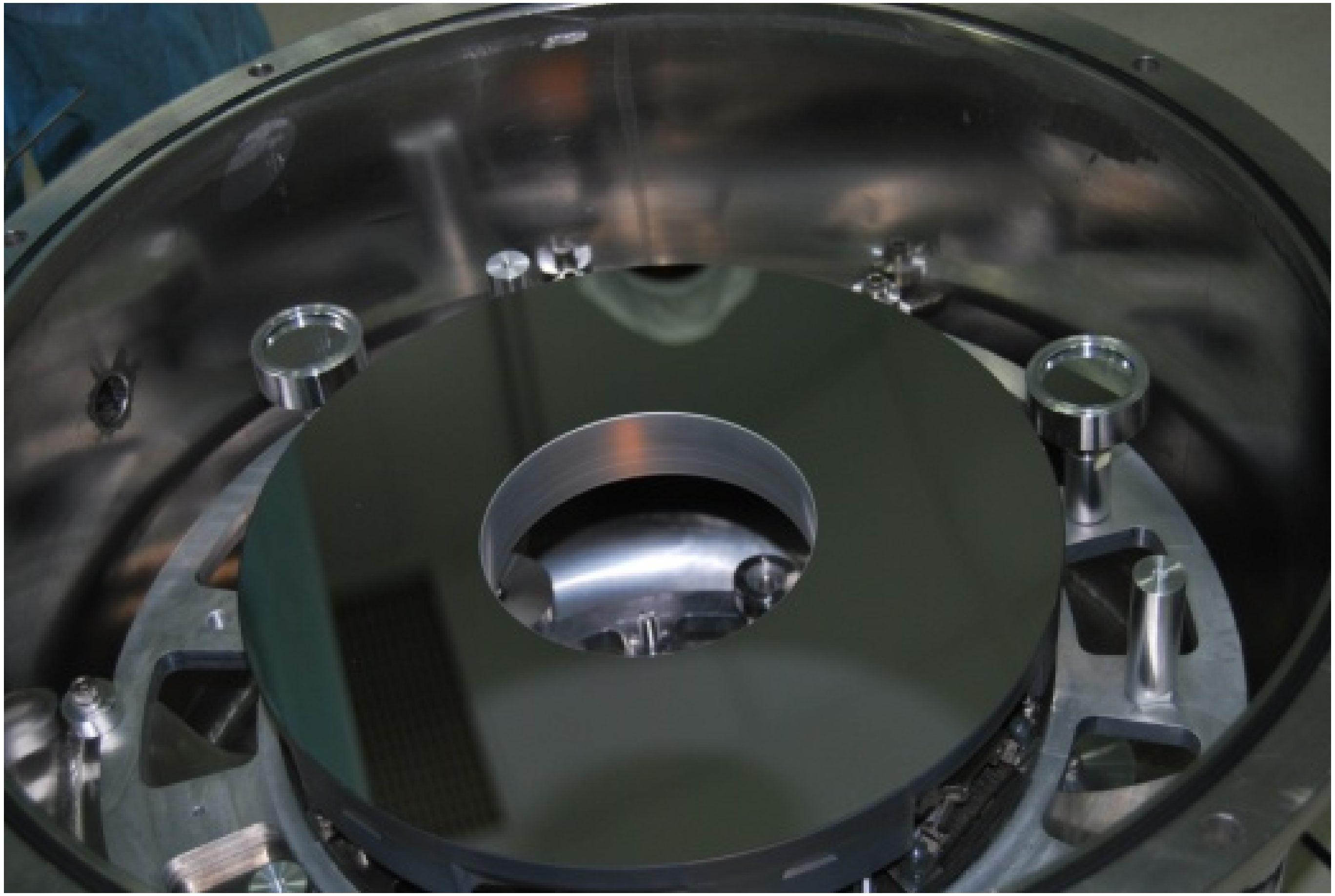
- Filter for VIS band: the filter should be selected such that the signal for the brightest star is within the desired limit (4800 events/s), and yet signals for the stars are not attenuated too much else tracking suffers.
- Follow the recommendation of the technical committee for the final settings.

MGKM Clean Laboratory, IIA

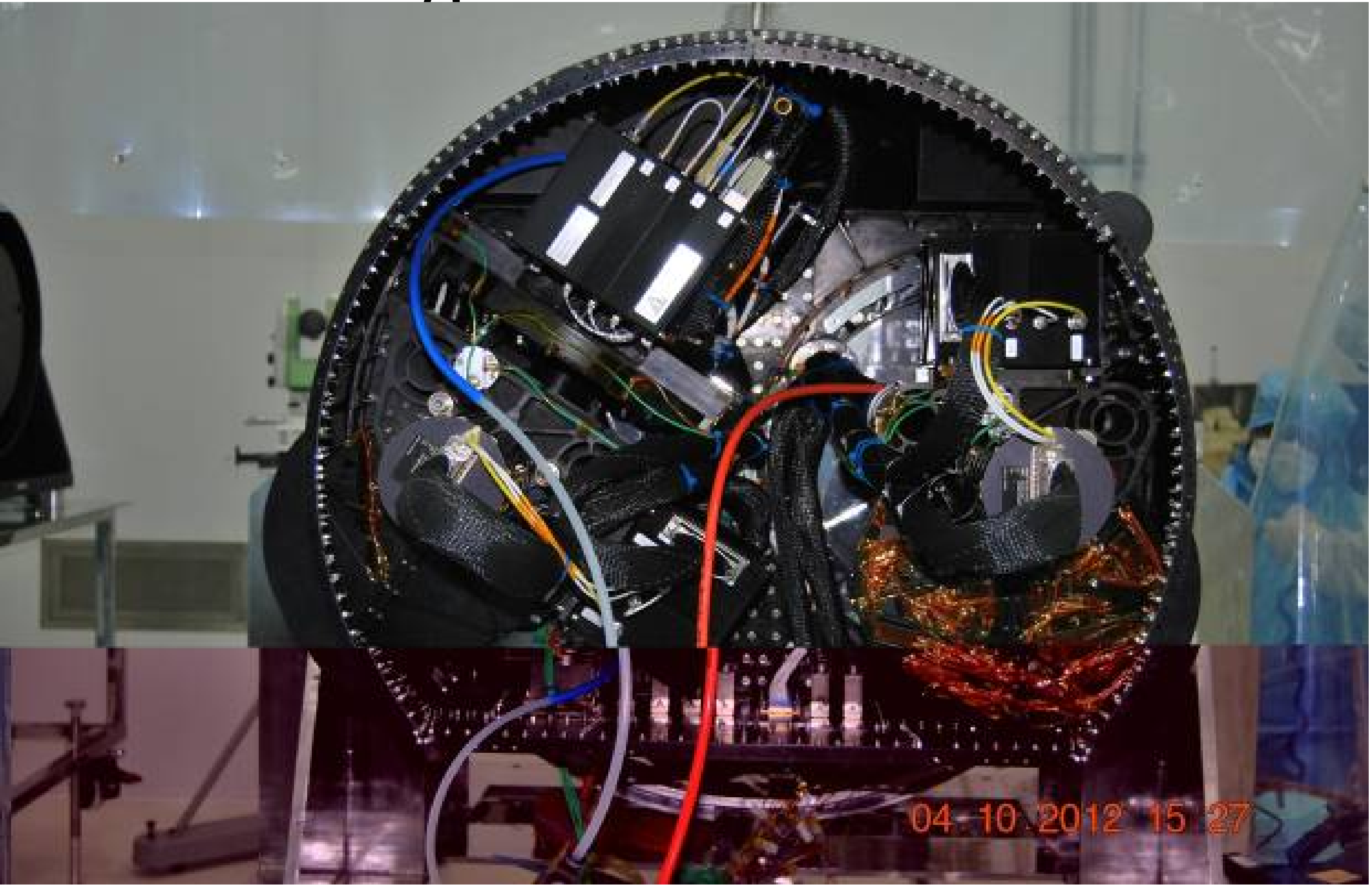
Testing Materials

Testing Materials

Coupan in centre of PM



Purging of Focal Plane
Nitrogen for Motor Lubrication



Working in Class 1000 clean-room

Capabilities of UVIT

- Basic features
- Imaging, and Slitless Spectroscopy (res. ~ 100)

PSF FWHM < 1.5”

Low Dark Current 10-50 c/s in the field

Low Distortion over the field < 0.4” rms

Long term stability of effective areas

Thus good for Deep Imaging with long exposures and imaging of crowded fields

An early Image (NGC 2336) all frames added directly

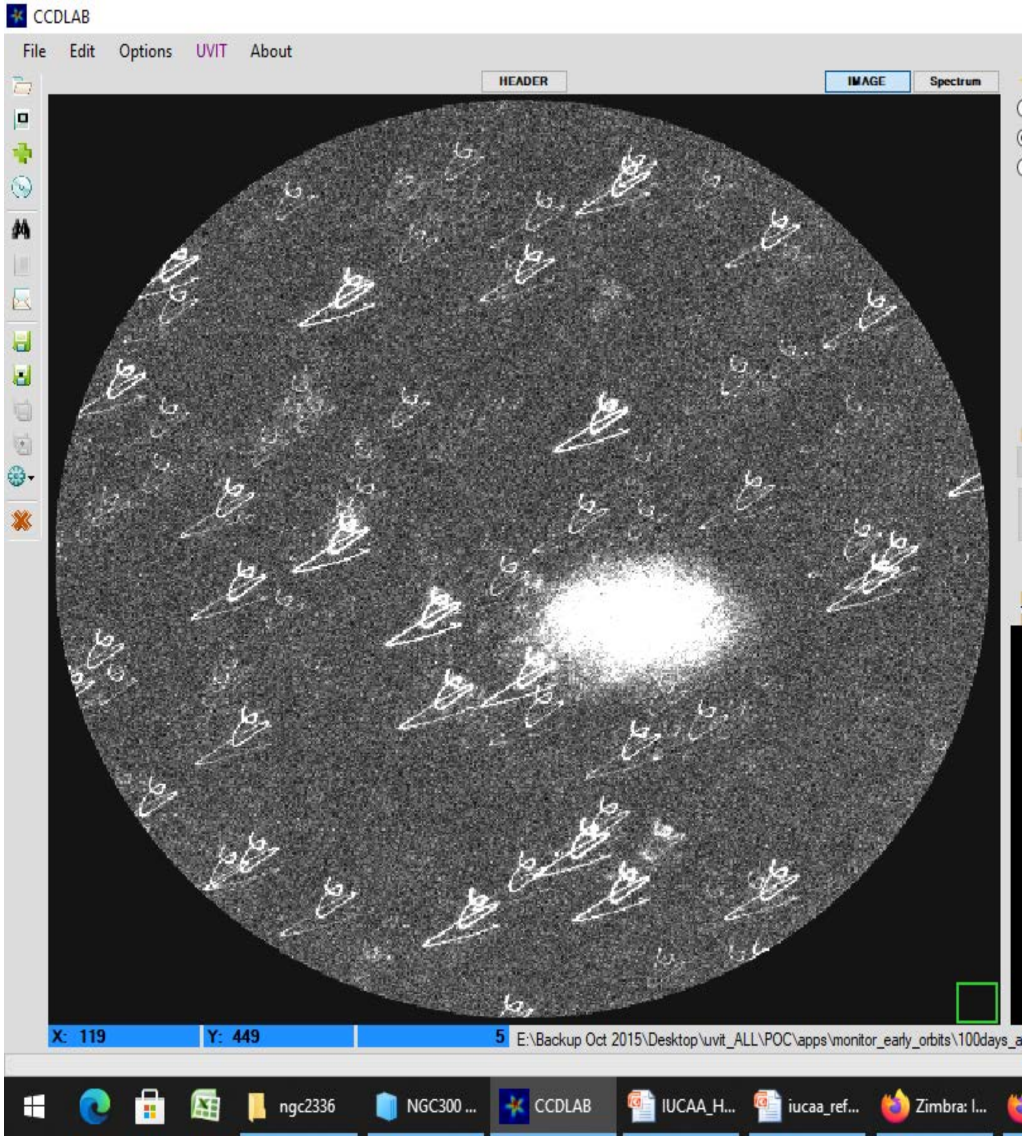
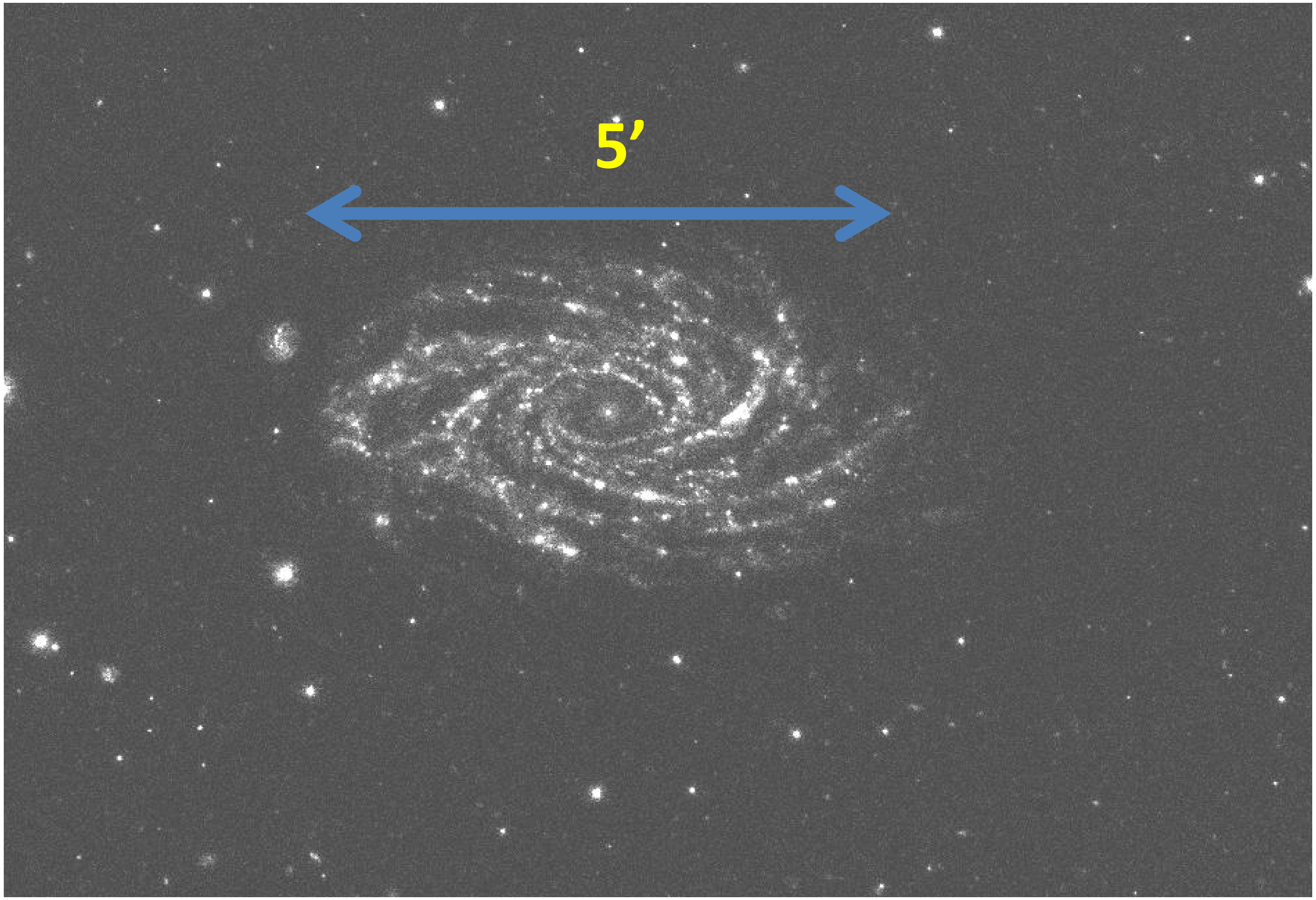


Image (NGC2336) with shift and add



Performance parameters

- Targets observed so far > 800
- Image Quality

Spatial Resolution < 1.5” FWHM

Zero Point AB mag for FUV-Caf2 18.1

stable to < 3% over 4 years

Distortion in final images < 0.4” rms

Flat-field variation in the field < 5% rms

Except for NUV B15 filter

Small Instrumental dark/noise

Some Illustrative Results

1 Good Spatial Resolution FWHM ~ 1.5”

2 Low instrumental dark/noise: allows very long exposures for high sensitivity

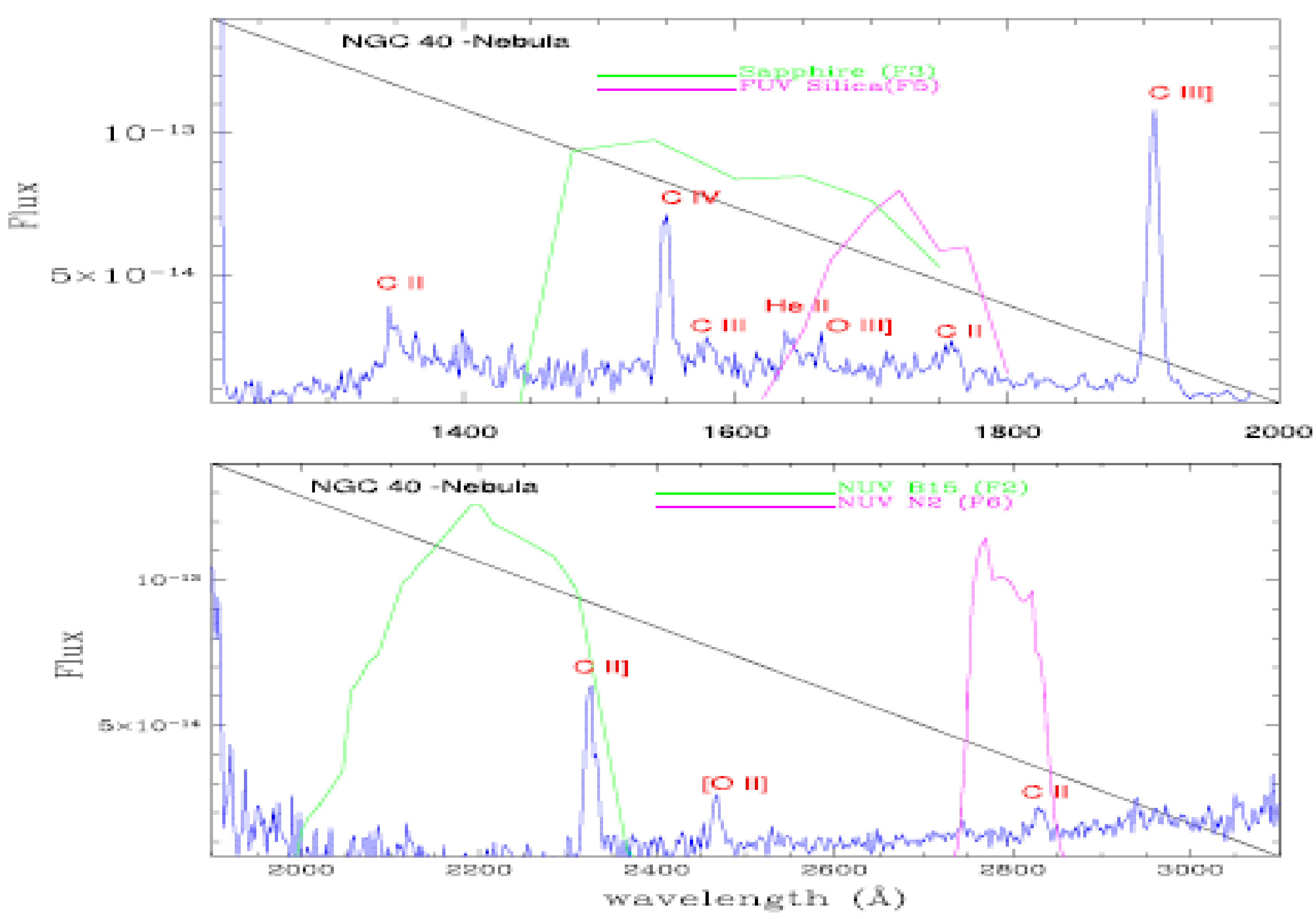
3 Good linearity of scale (0.4” on the full field) to match sources in crowded fields

4 Differential between filters to estimate bright emission lines

5 Spectral information : Slitless spectroscopy

6 Temporal correlation X-ray and UV

NGC 40 Spectrum (N K Rao et al)
(Emision lines in FUV and NUV filters)

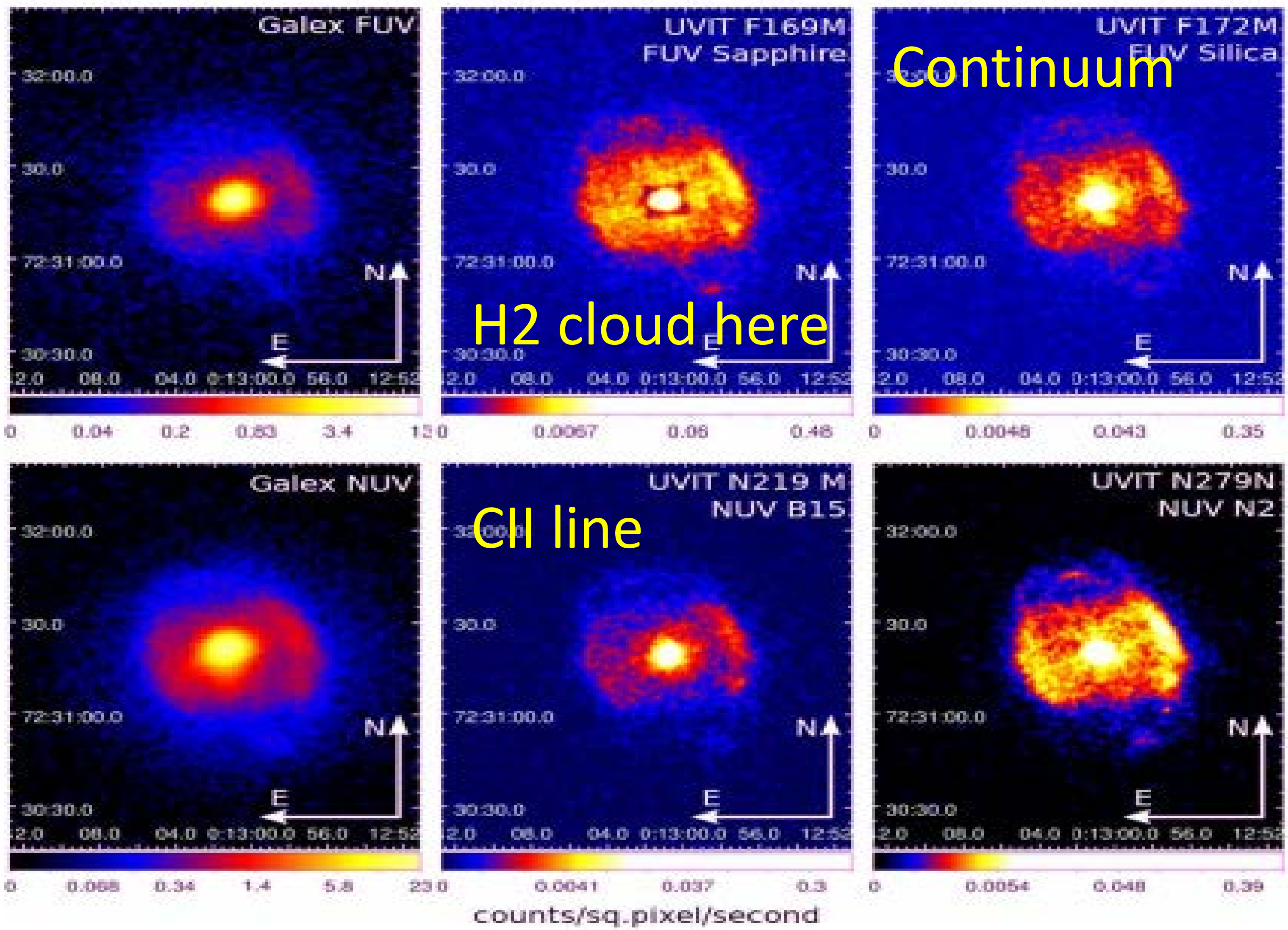


NGC 40 Spectrum (N K Rao et al)
(Emision lines in FUV and NUV filters)

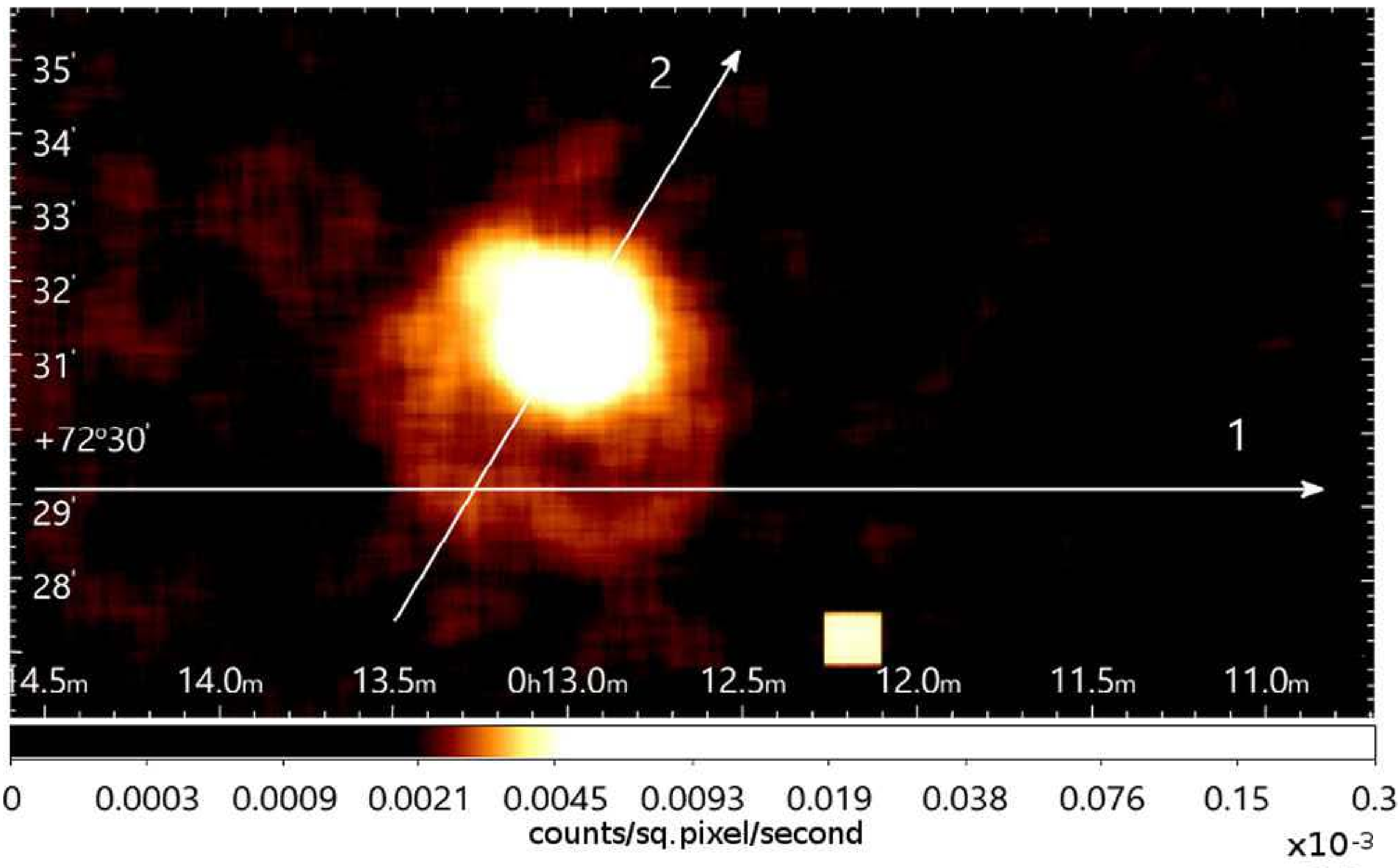
Fig. 1. IUE low-resolution nebular spectrum of NGC 40 (blue line) obtained at 6″ north and 13″ west of the central star. FUV and NUV are plotted at the top and bottom, respectively, with UVIT-filter effective areas (relative) shown. In the *top panel*, green denotes *F169M* FUV Sapphire and magenta denotes *F172M* FUV Silica, and in the *bottom panel*, green is *N219M* NUV B15 and magenta is *N279N* NUV N2.

8.27 x 11.69 in

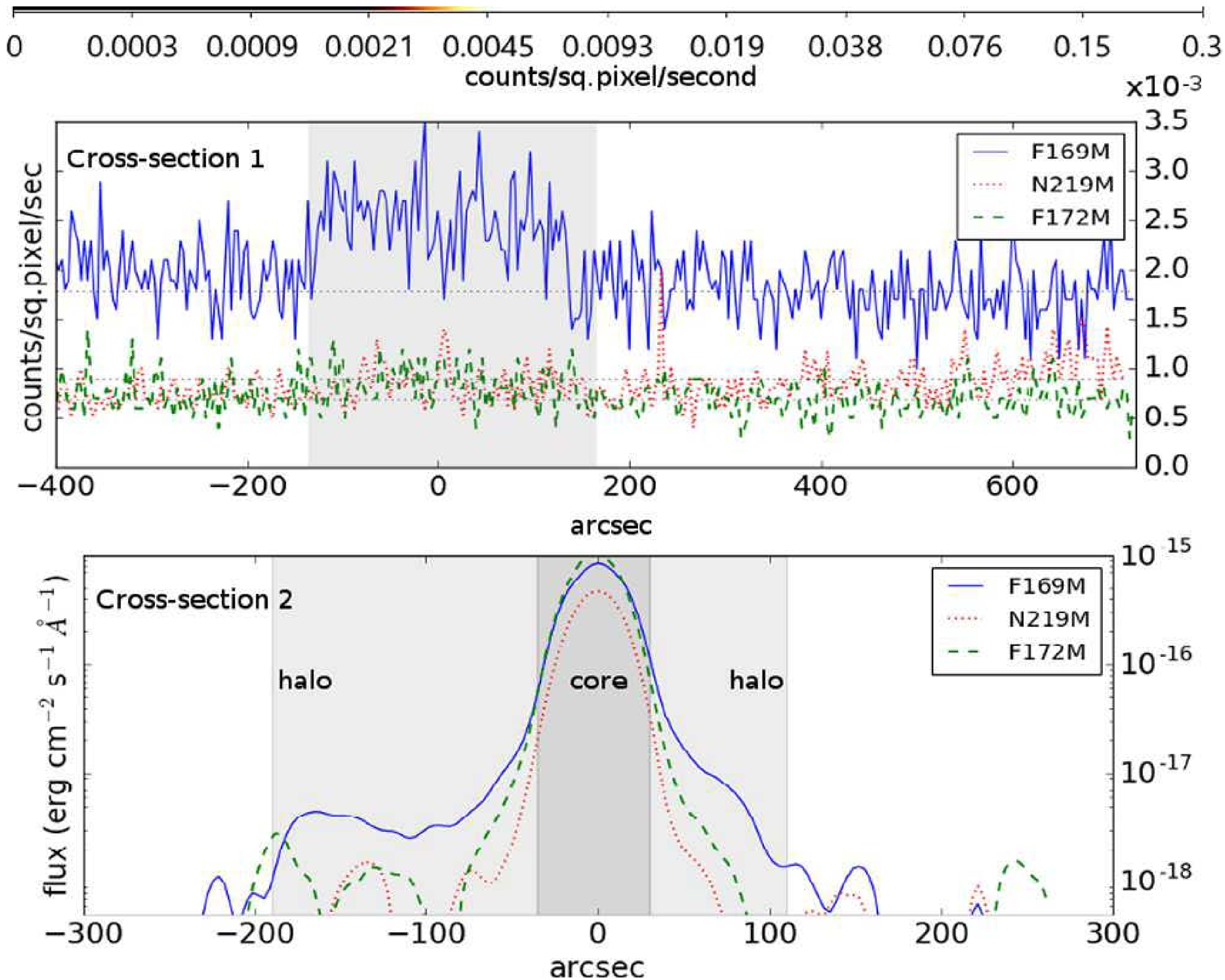
NGC 40 : H2 Cloud
Credit: N K Rao et al



NGC 40 (N K Rao et al)

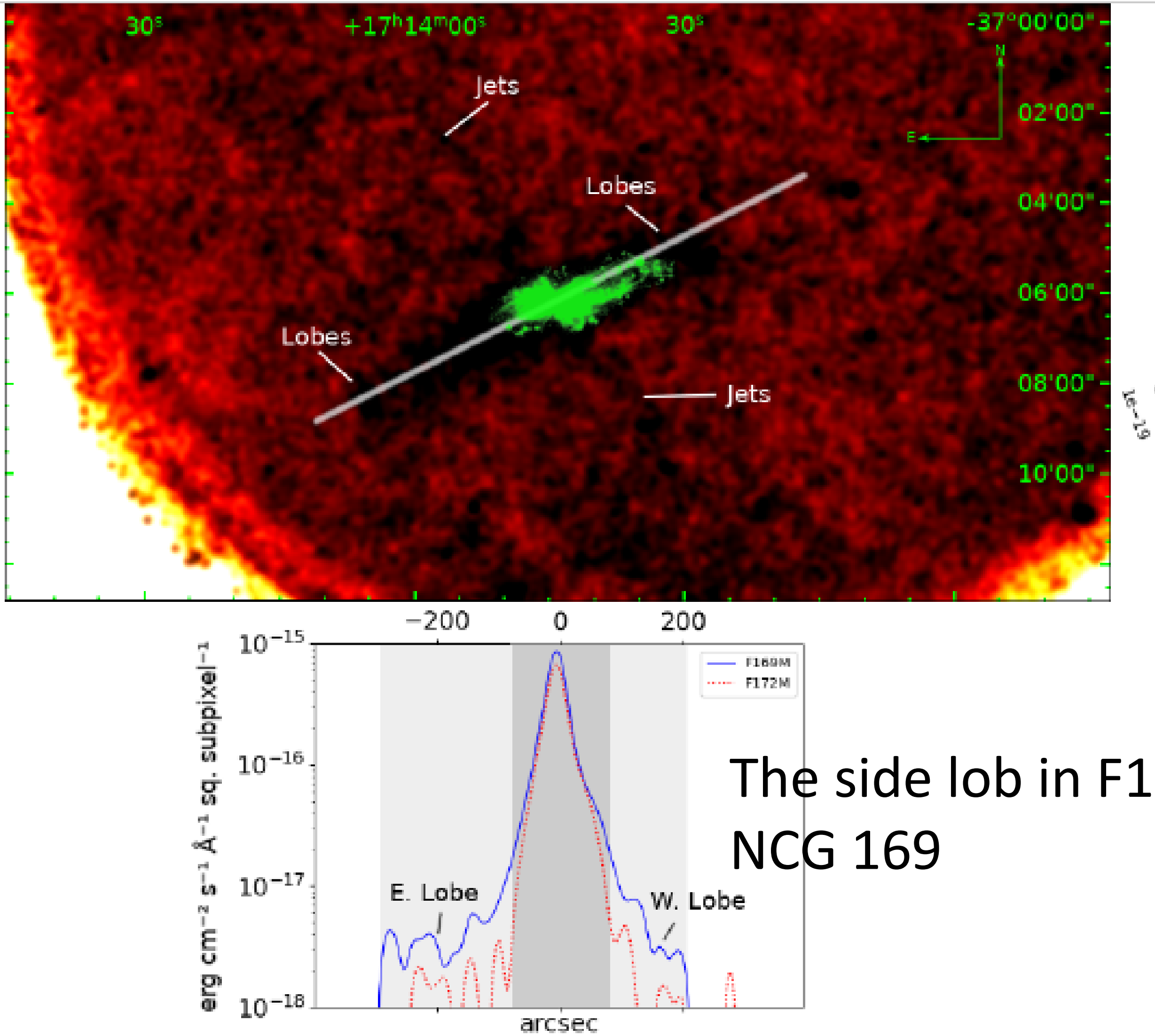


NGC 40 (N K Rao et al)



- Fig. 4. Cross-cuts in the images of the nebula in three filters; F169M
- (blue), F172M (green), and N219M (red) made along the white lines
- shown in the slightly smoothed F169M image of the nebula (top). Crosscuts
- of 8 pixel widths were obtained in all the images at the same
- locations (coordinates). The bottom cross-cut, which passes through the
- nebular core, is on a logarithmic scale and has been smoothed. We note
- the faint quasi-circular extended halo around the core of the nebula (on
- the south-east side). This region has been shown with a grey overlay
- in the plots. Despite having similar core fluxes in all three filters, only
- F169M shows the presence of the halo.

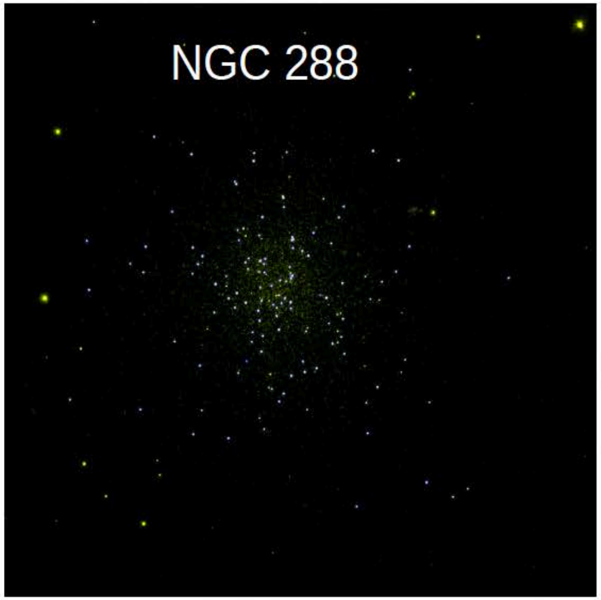
NGC 6302 (N K Rao et al)

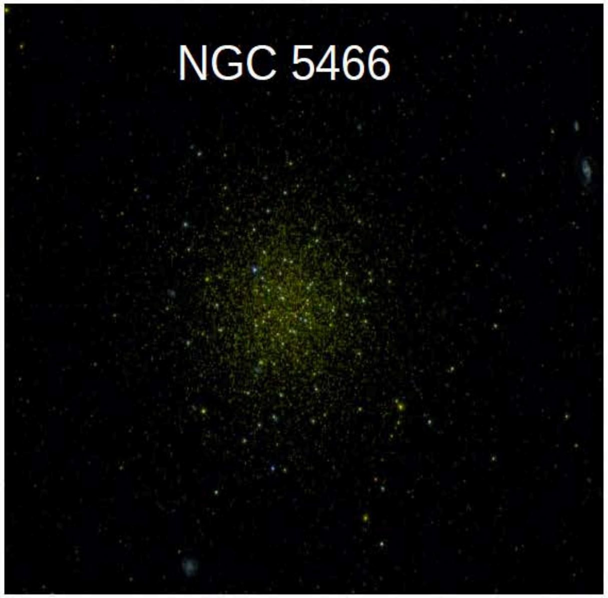


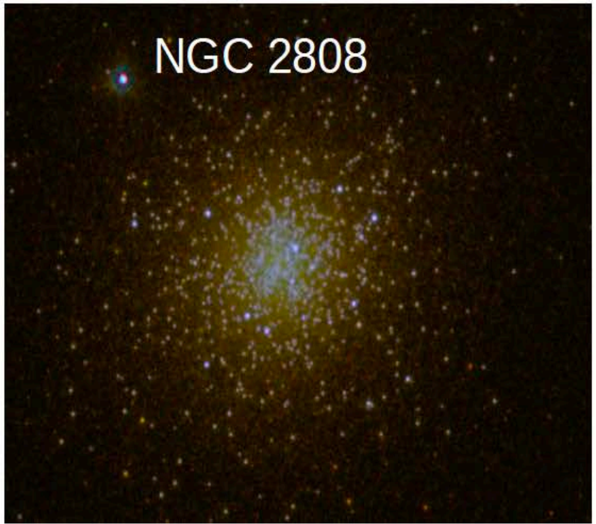
The side lob in F172 and in NCG 169

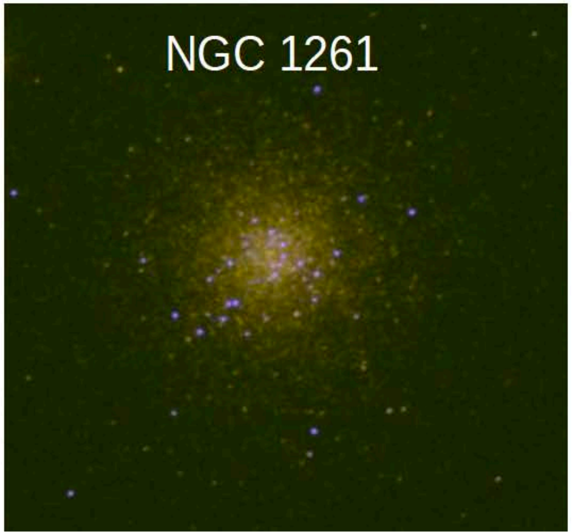
UVIT Images of GCs

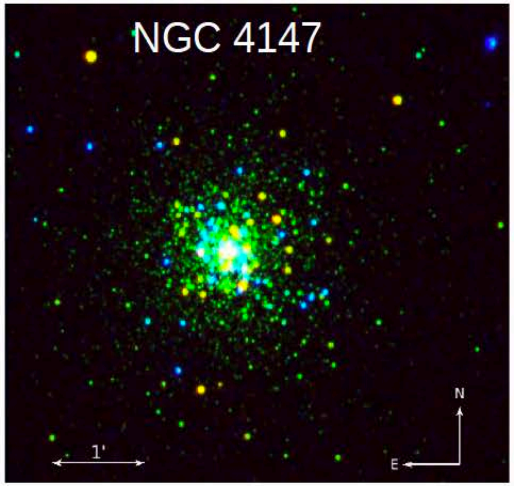
Credit: Annapurni



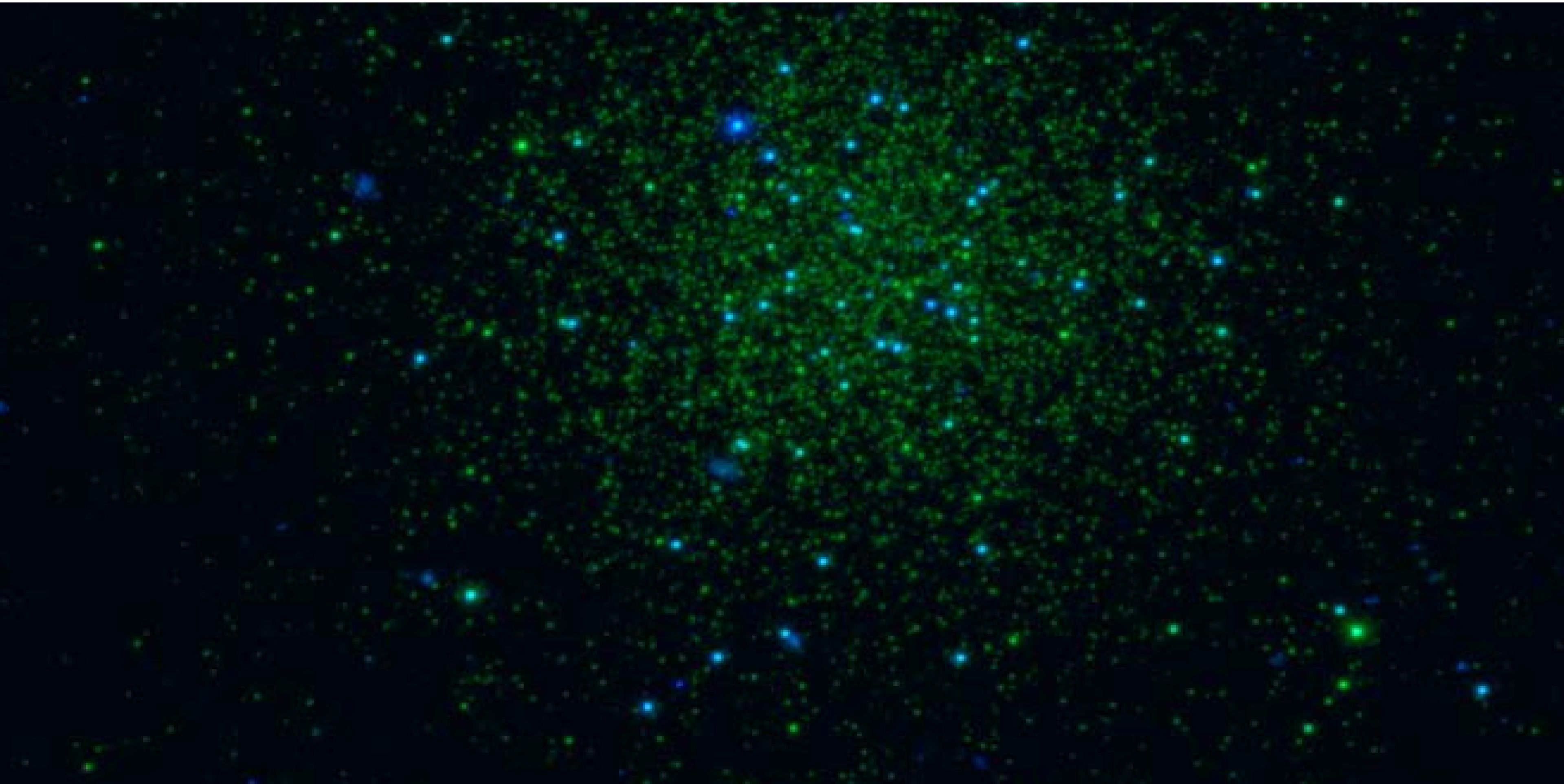




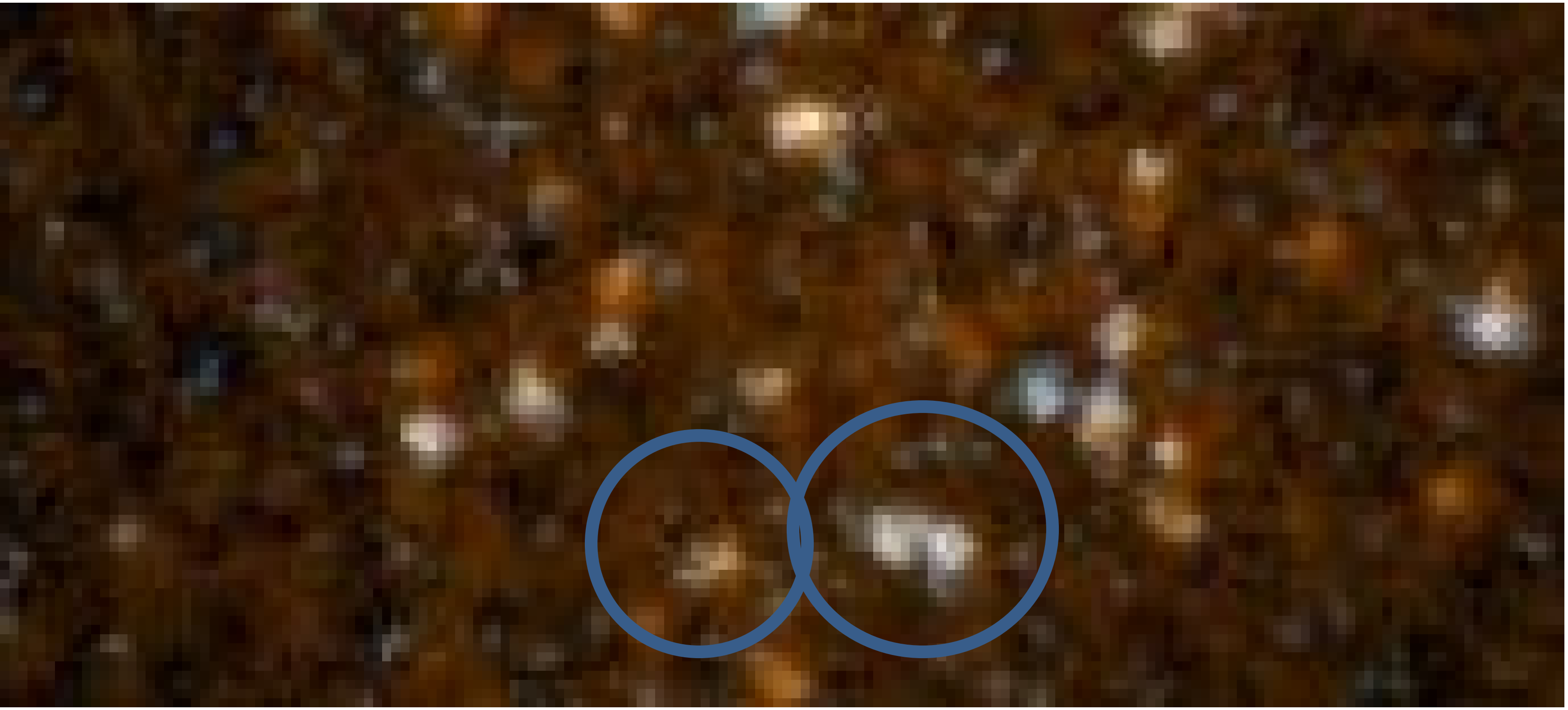




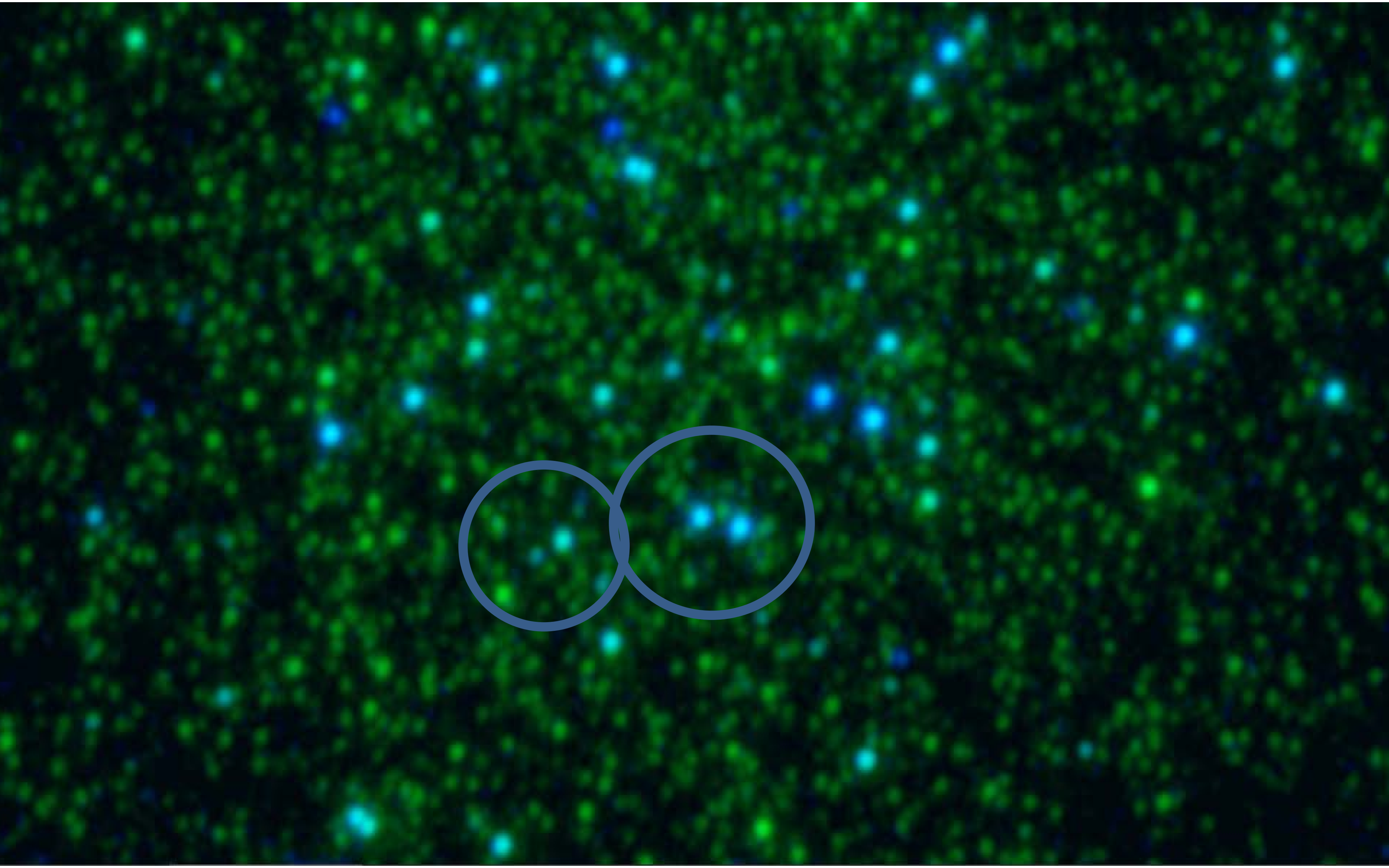
NGC 5466 with UVIT



NGC 5466 with Galex

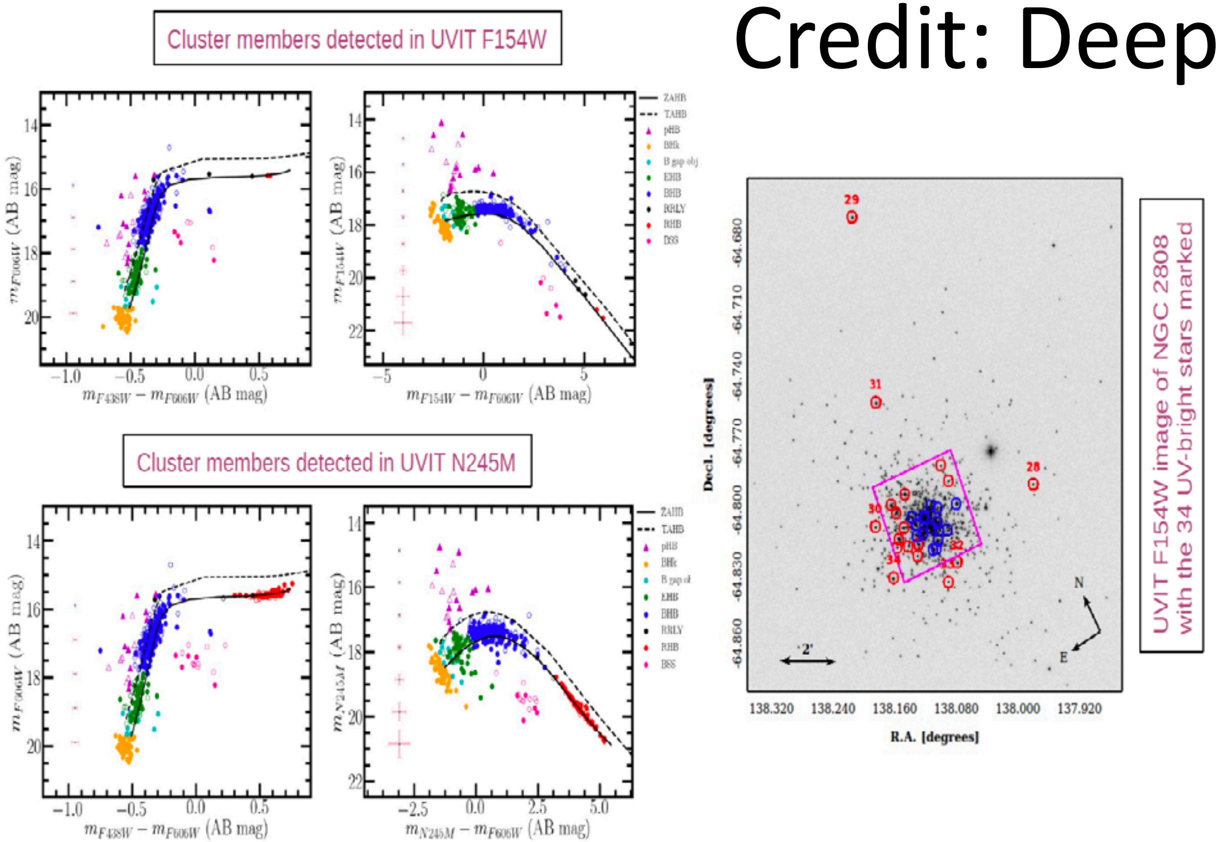


NGC 5466 with UVIT;Snehlata Sahu et al



Hot UV-bright stars in GC NGC 2808

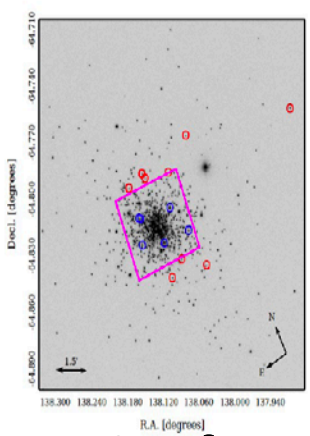
Credit: Deepthi et al



- 18 UV-bright member stars are detected using UVIT photometry. All these are 1 mag or more brighter than the ZAHB in FUV and have FUV - NUV < 0.6 mag.
- 16 additional UV-bright stars (located within 30" from cluster center) are identified using *HST* photometry. Total of 34 UV-bright stars are identified.

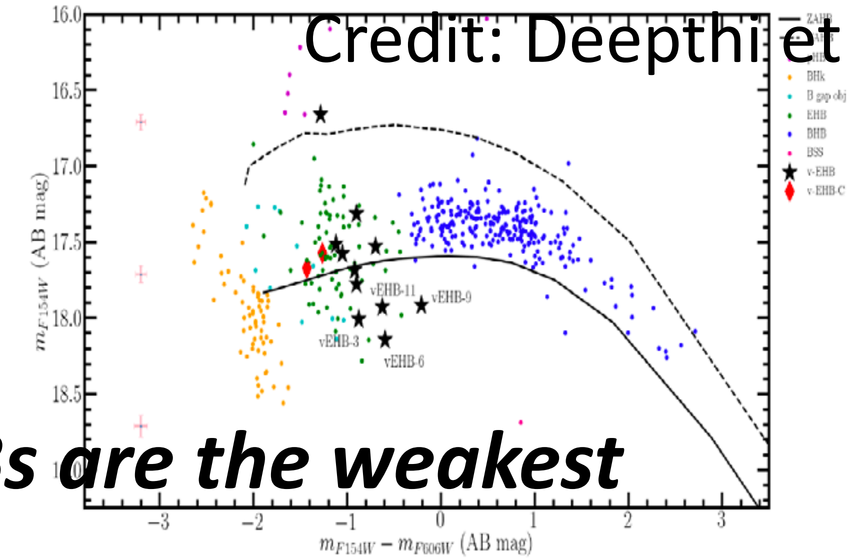
Deepthi et al. 2020, ApJ

UVIT photometry of variable EHB stars in NGC 2808



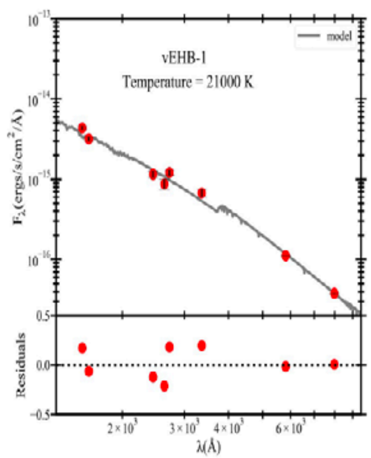
UVIT F154W image of NGC 2808 with the vEHB stars marked

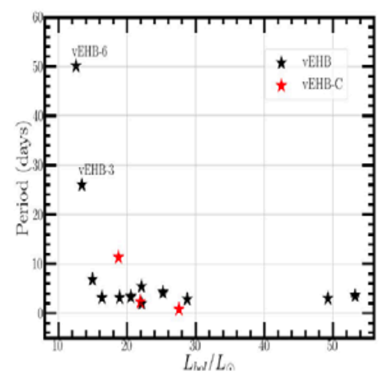
Credit: Deepthi et al



Longest period vEHBs are the weakest

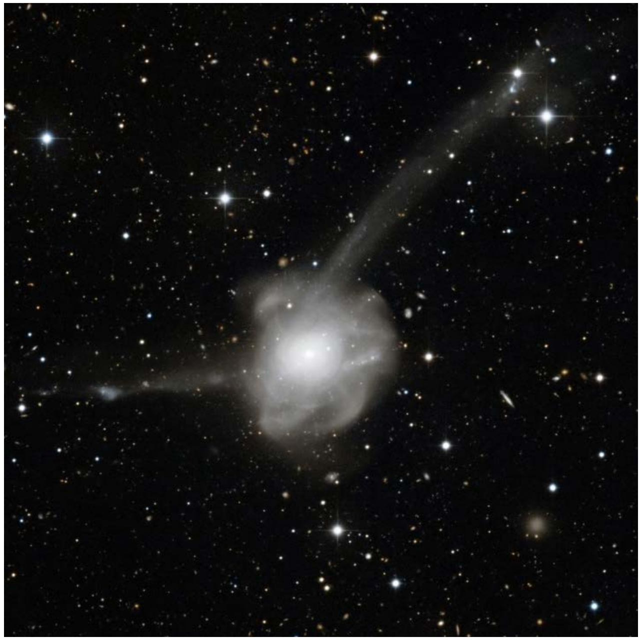
A comparison of FUV magnitudes of the already reported variable EHB stars (vEHBs) shows that the longest period vEHBs are the faintest, along with a tentative correlation between rotation period and UV magnitudeof spotted stars





Deepthi et al. 2020, JAA

NGC 7252: "Atoms-for-Peace"



Post-merger galaxy

Red shift ~ 0.0159

Distance ~ 68 Mpc

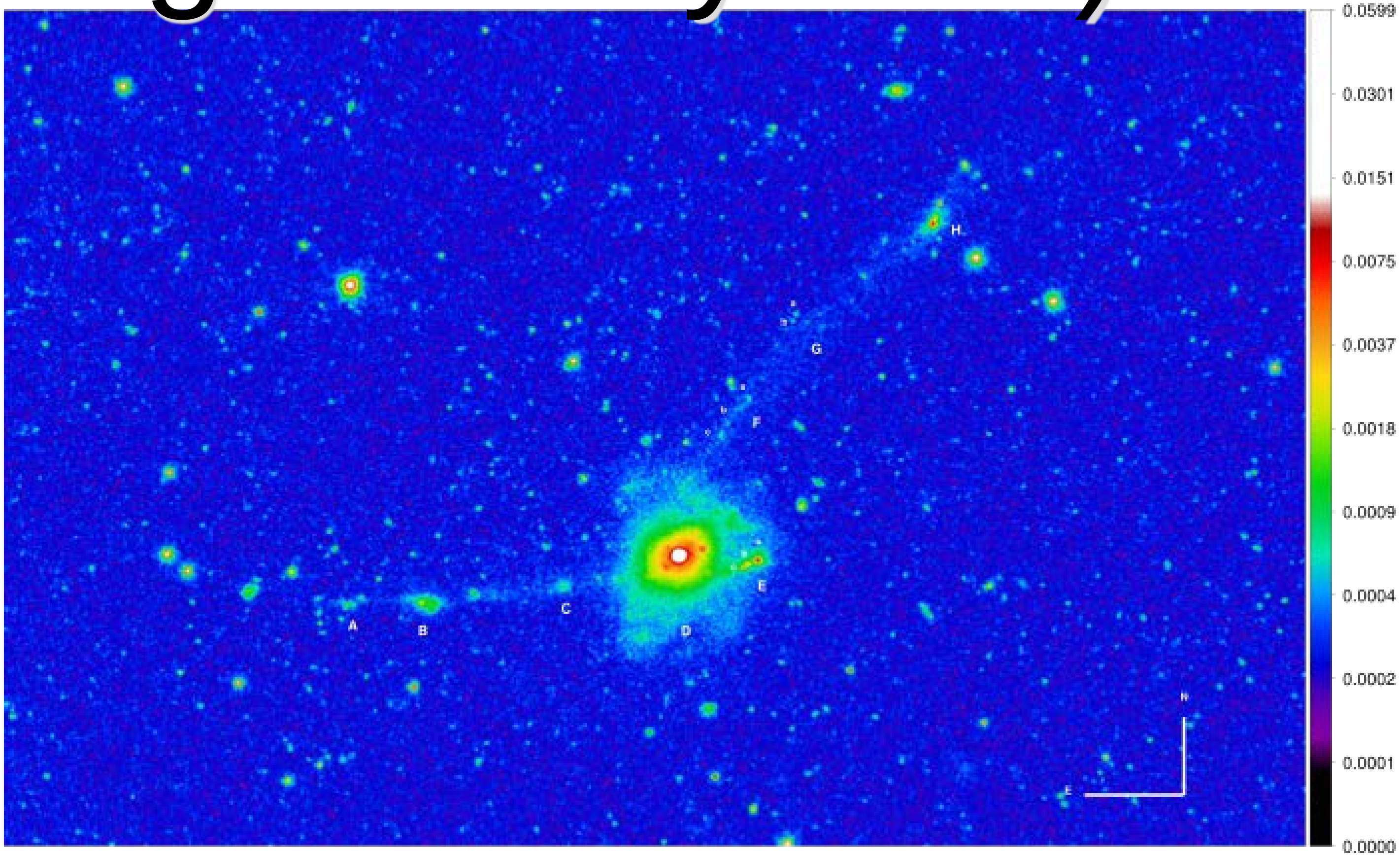
UVIT spatial resolution ~ 400 pc

UVIT integration time:

NUV Silica ~ 7915s
FUV Silica ~ 8138s

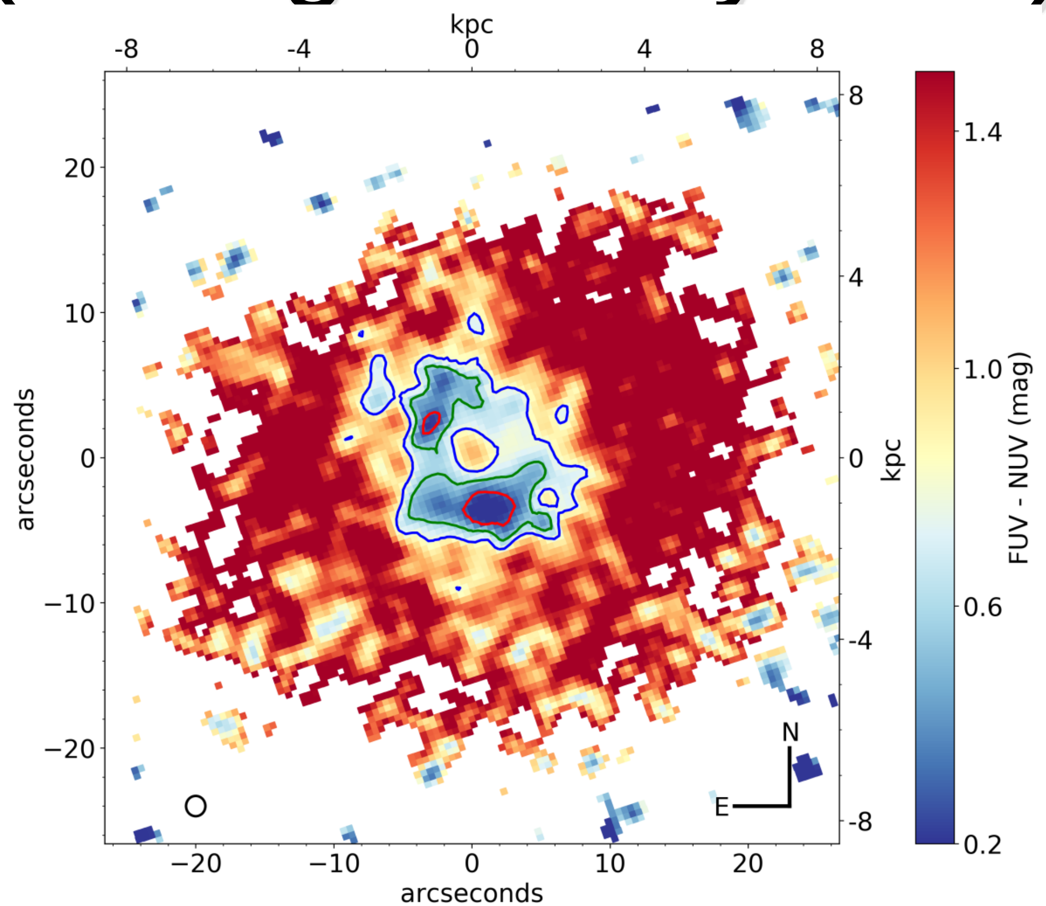
Aim: To study the spatial variation of star formation in the galaxy and the tidal tails.

NGC 7252: "Atoms-for-Peace" (George Koshy et al)



NUV image: Star forming regions in the tidal tail are of dwarf galaxy size

NGC 7252: “Atoms-for-Peace” galaxy (FUV-NUV colour map) (George Koshy et al)



The pixel colour map of NGC7252 reveals a blue circumnuclear ring of diameter ~ 10" (3.2 kpc) with bluer patches located over the ring.

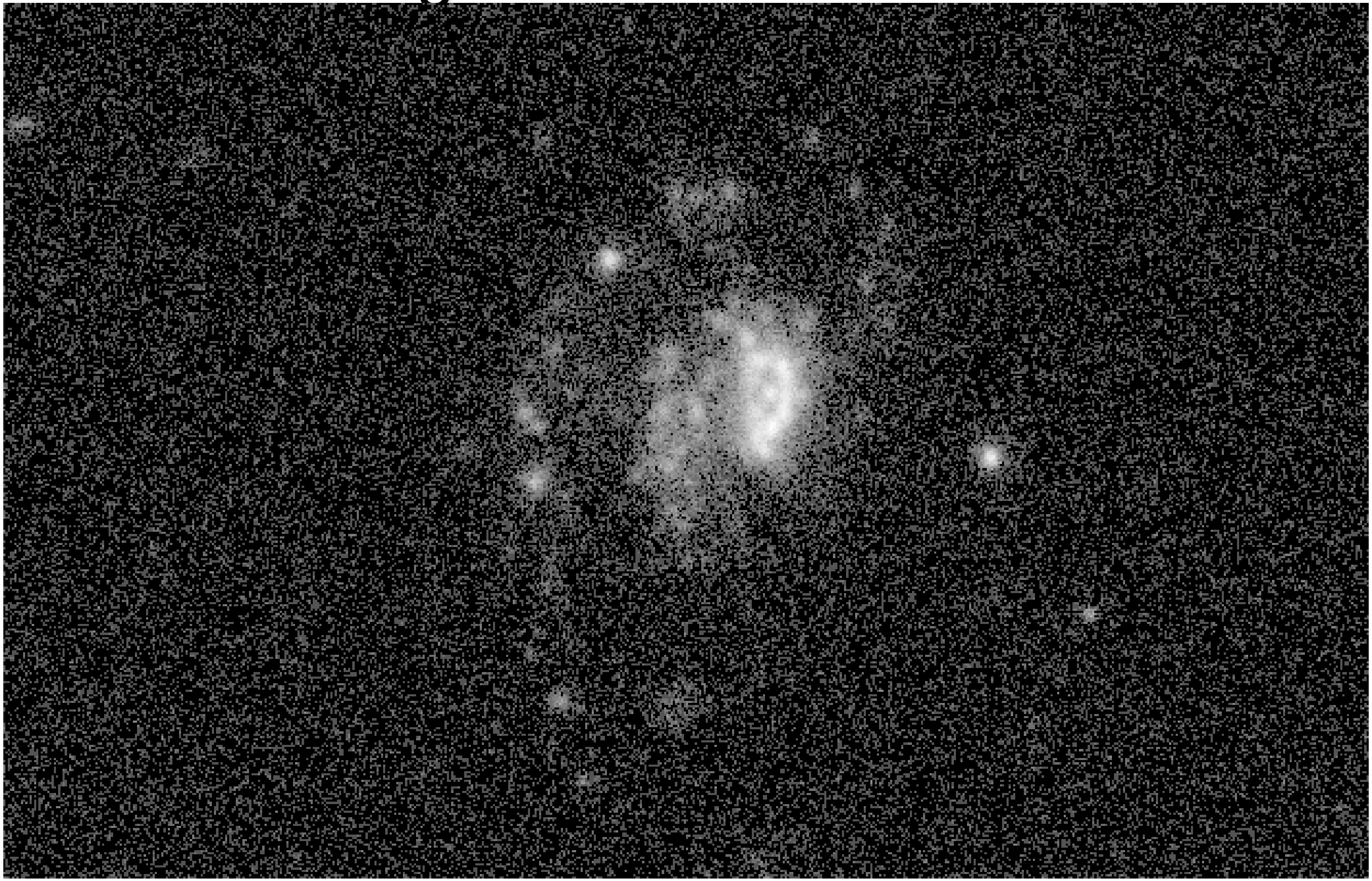
Based on a comparison to single stellar population models, we show that the ring is comprised of stellar populations with ages □ < 300 Myr, with embedded star-forming clumps of younger age (□ < 150Myr).

Age contours of 150 (red), 250 (green), 300 (blue) Myr.

George. K, et al, A&A 613, L

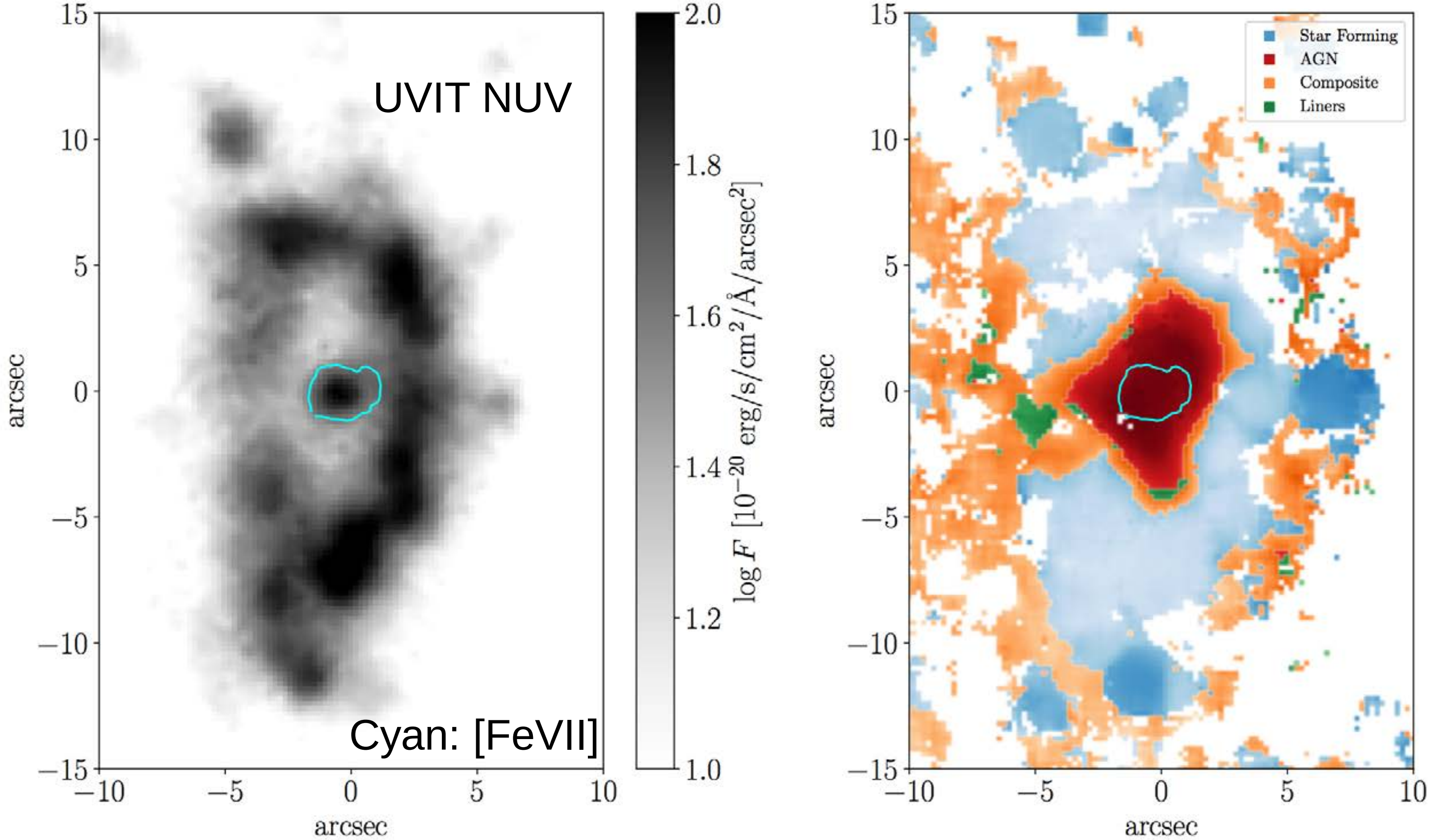
FUV UVIT image of Jellyfish galaxy JO201

Credit:George Koshi



UVIT FUV Exposure time ~ 15ks

JO201: AGN feedback



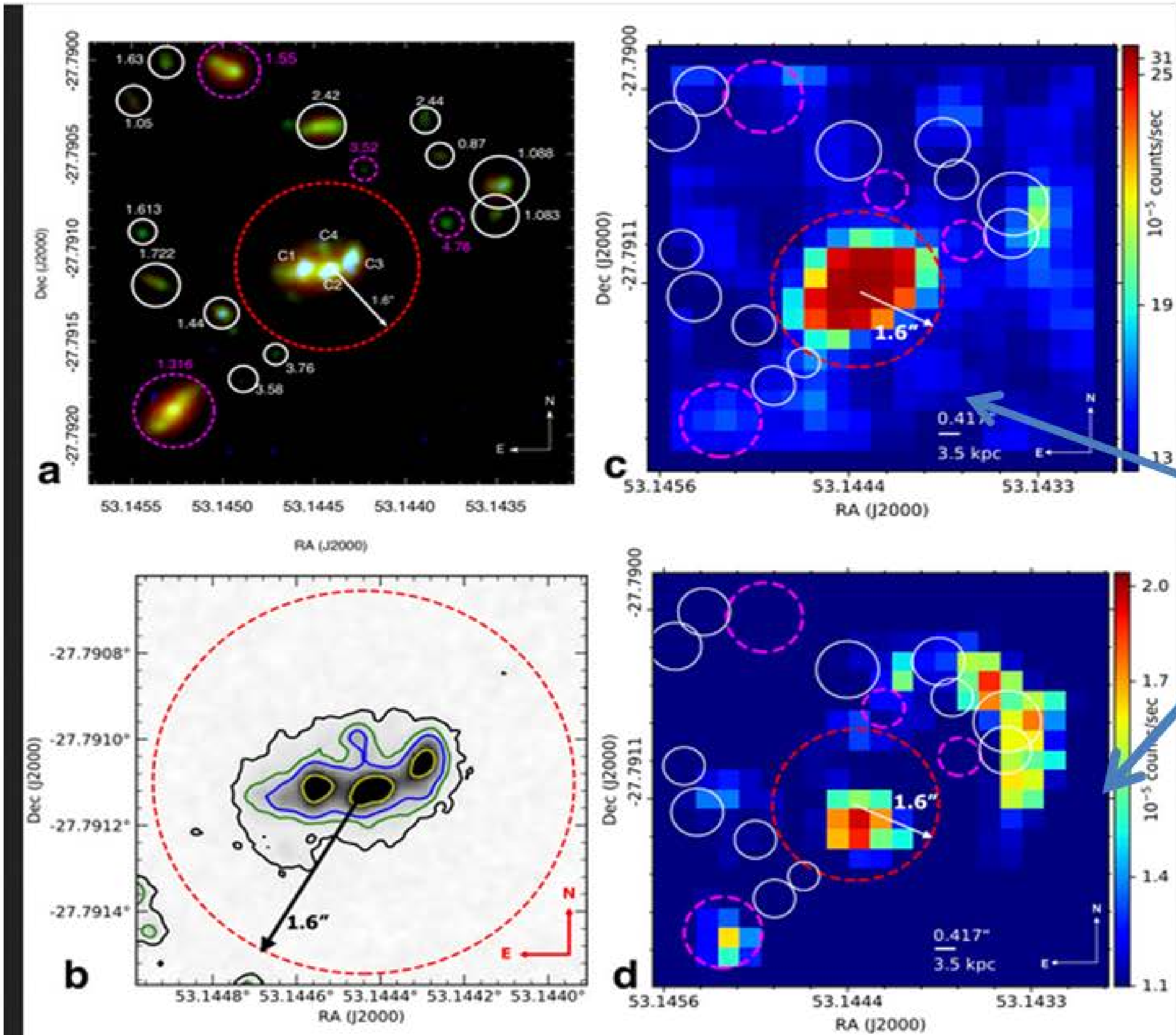
Evidence for star formation quenching due to feedback from an active galactic nucleus in a jellyfish galaxy undergoing strong ram pressure stripping.

George et al, MNRAS

mag 26.5 Galaxy at Z ~ 1.4 Emitting Ly-cont.

Kanak et al

Hubble Images



NUV

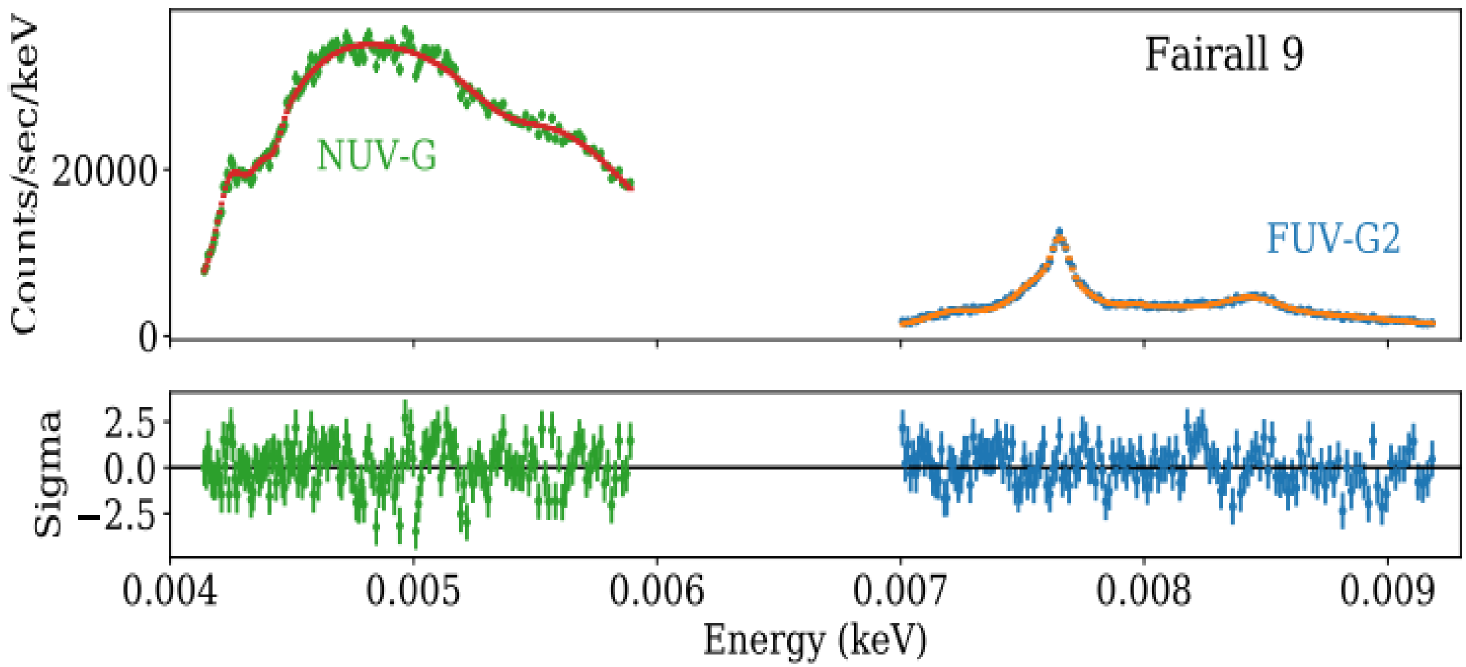
UVIT Images

FUV

Measuring black hole spin of Fairall 9 with AstroSat UV/X-ray spectroscopy

G. C. Dewangan,1 Shrabani Kumar,1 I. E. Papadakis,2, 3 K. P. Singh,4 and P. Tripathi1

UV spectrum



Fairall 9
NUV-G
FUV-G2
Counts/sec/keV
20000
0
Sigma
2.5
0.0
−2.5
0.004
0.005
0.006
0.007
0.008
0.009
Energy (keV)

Fitting UV-X-ray Spectra to Spin

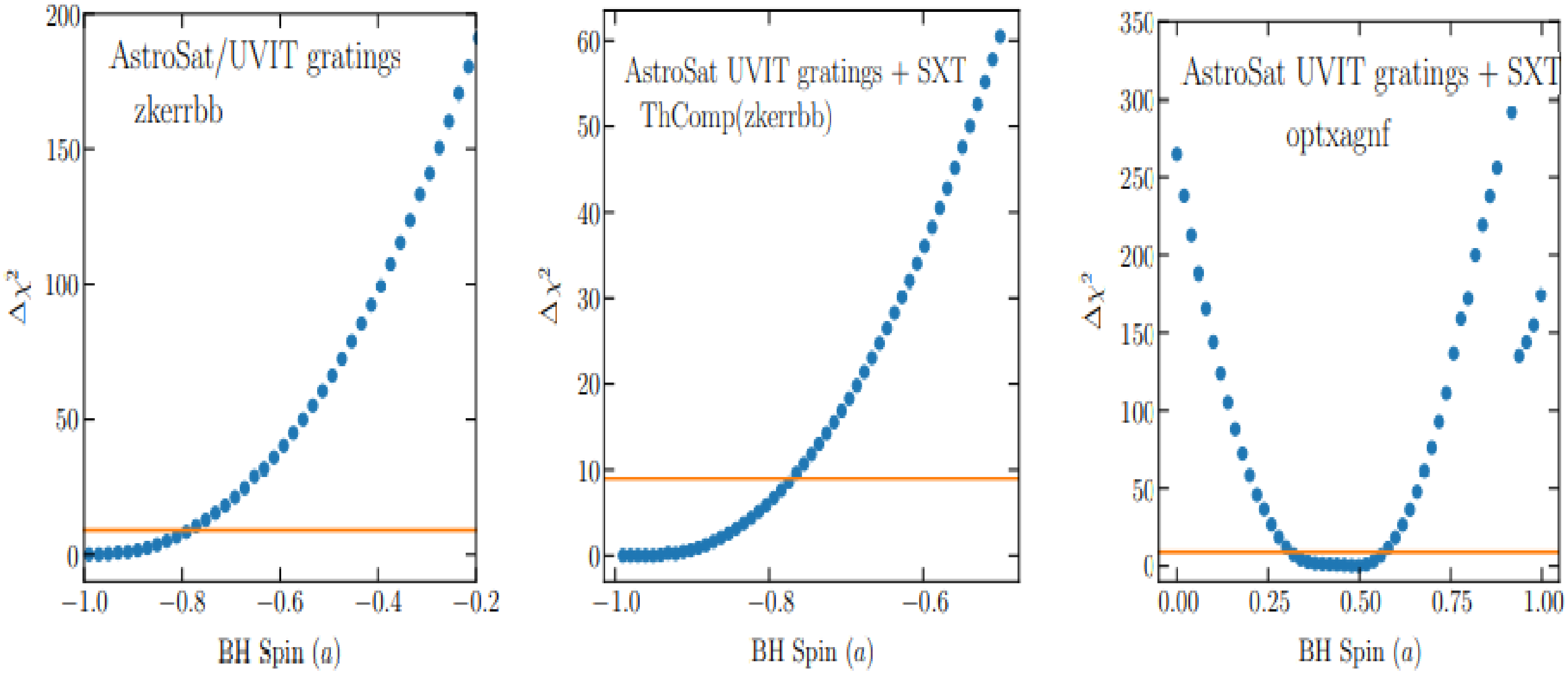
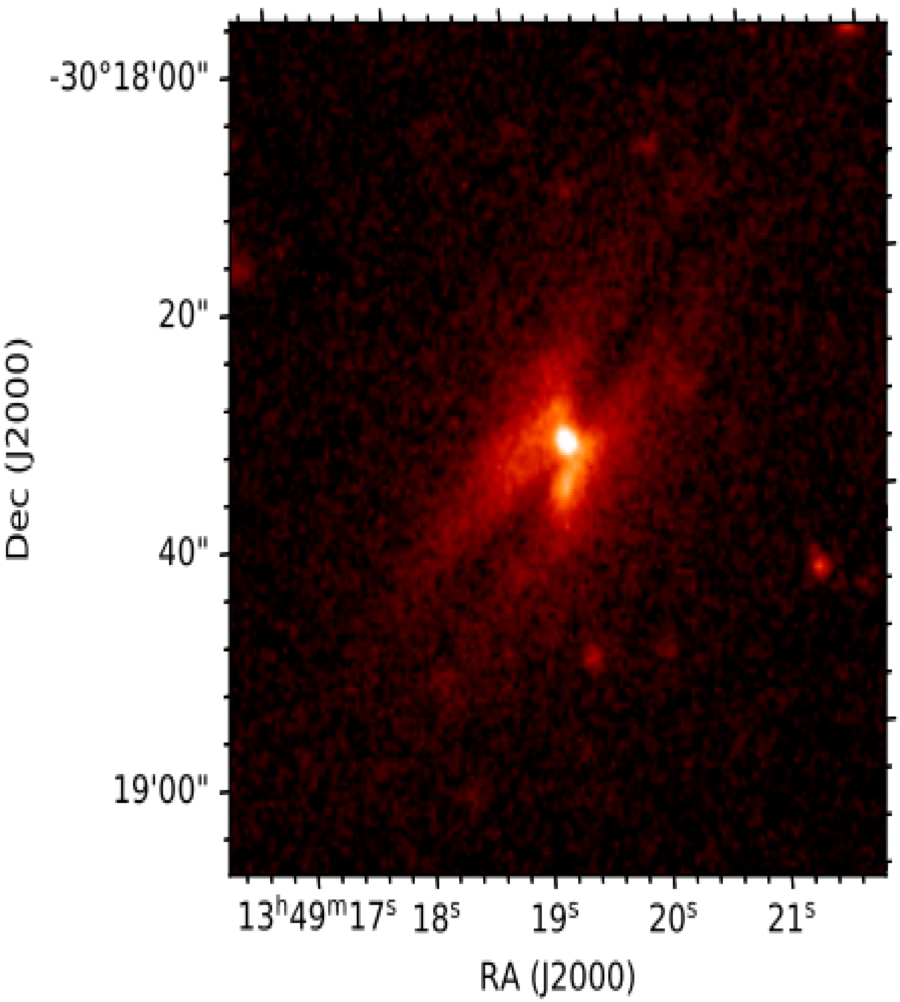
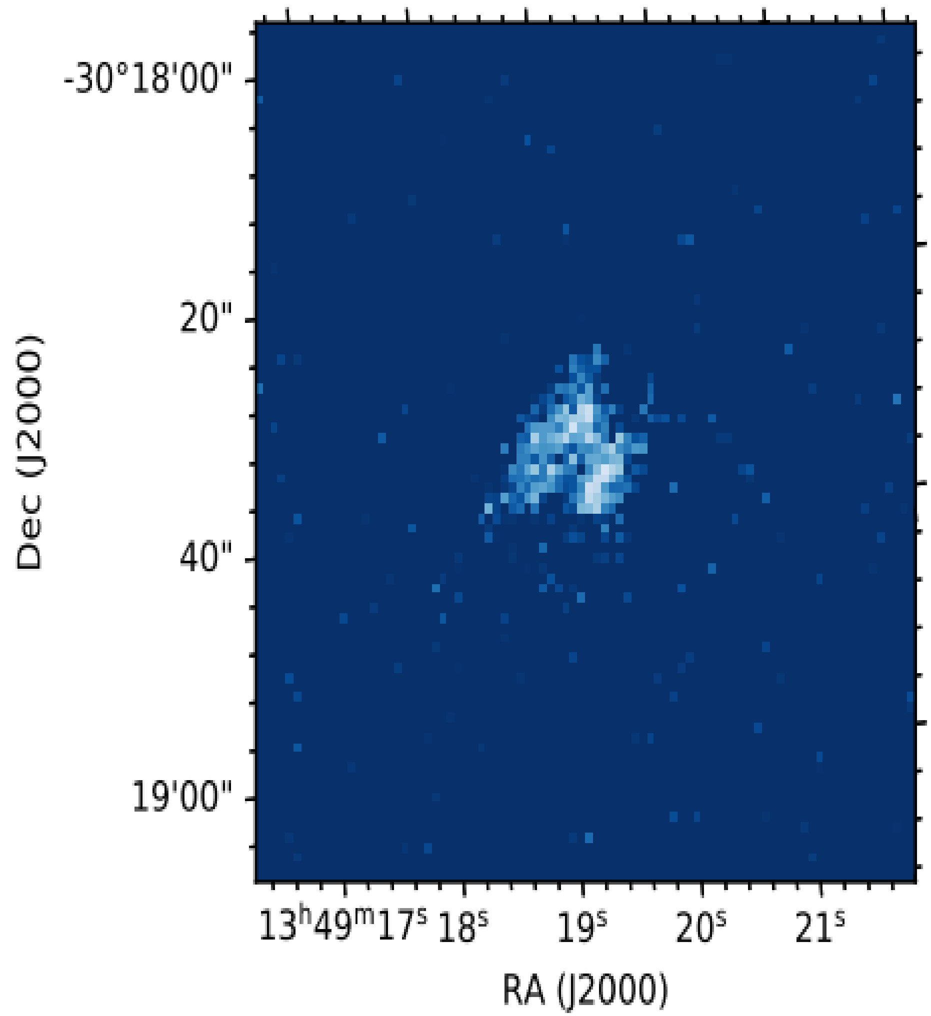


Figure 3. Constrains on the measurement of the black hole spin parameter (a). *Left:* 3σ upper-limt on a based on relativstic accretion disk model (zkerrbb) fit to the FUV-G2 and NUV-G grating spectra. *Middle:* 3σ upper-limit on a based on the thermal Comptonization of relavistic disk emission model fit to the *AstroSat* UV and X-ray spectral data simultaneously. *Right: sigma* range on a based on the `optxagnf` model fit to the UV and X-ray data.

- AstroSat/UVIT observations of IC 4329A: Constraints on the accretion disc inner radius Gulab C. Dewangan,1? P. Tripathi,1 I. E. Papadakis,2,3 and K. P. Singh4 .

NUV (left) and FUV Images





Radial Fits to the Images (NUV: left, FUV: right)

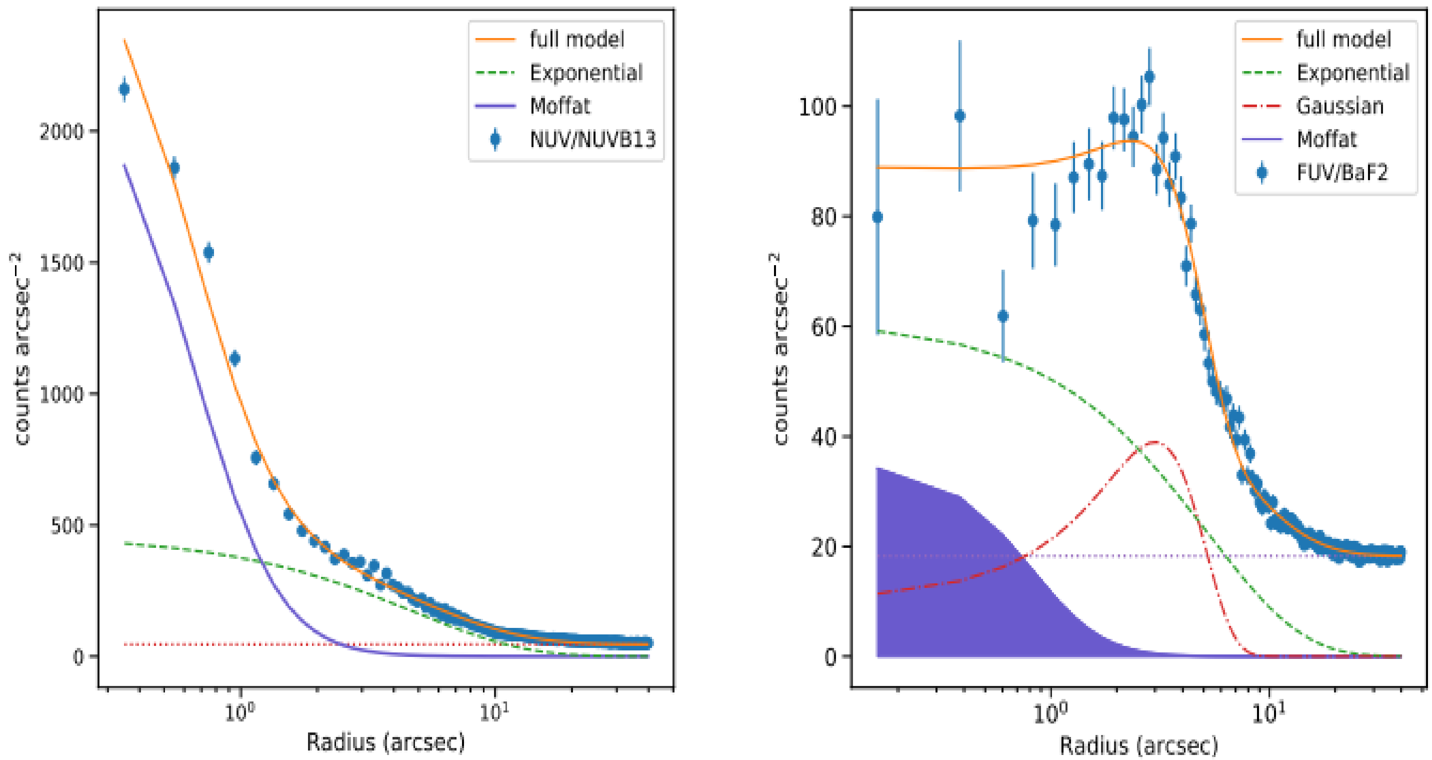


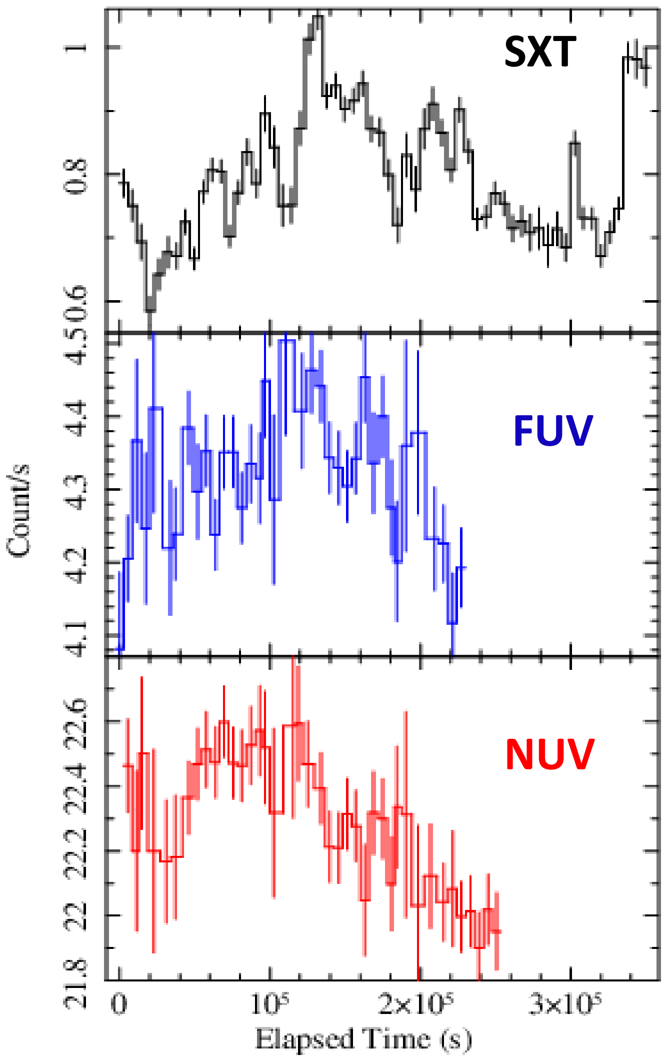
Figure 2. Radial profile of IC 4329A derived from the merged *AstroSat*/NUV (*left*) and FUV (*right*) images. The radial profiles are fitted with the instrument PSF for the AGN, and an exponential function for the galaxy emission plus a Gaussian function to account for the extra emission detected in the FUV band, probably due to the central star forming region. The AGN is not detected in the FUV band, and the shaded region in the right panel shows the 3σ upper limit on the AGN contribution. The deficit in the FUV emission in the central region is due to the the dust lane passing through the centre of the galaxy.

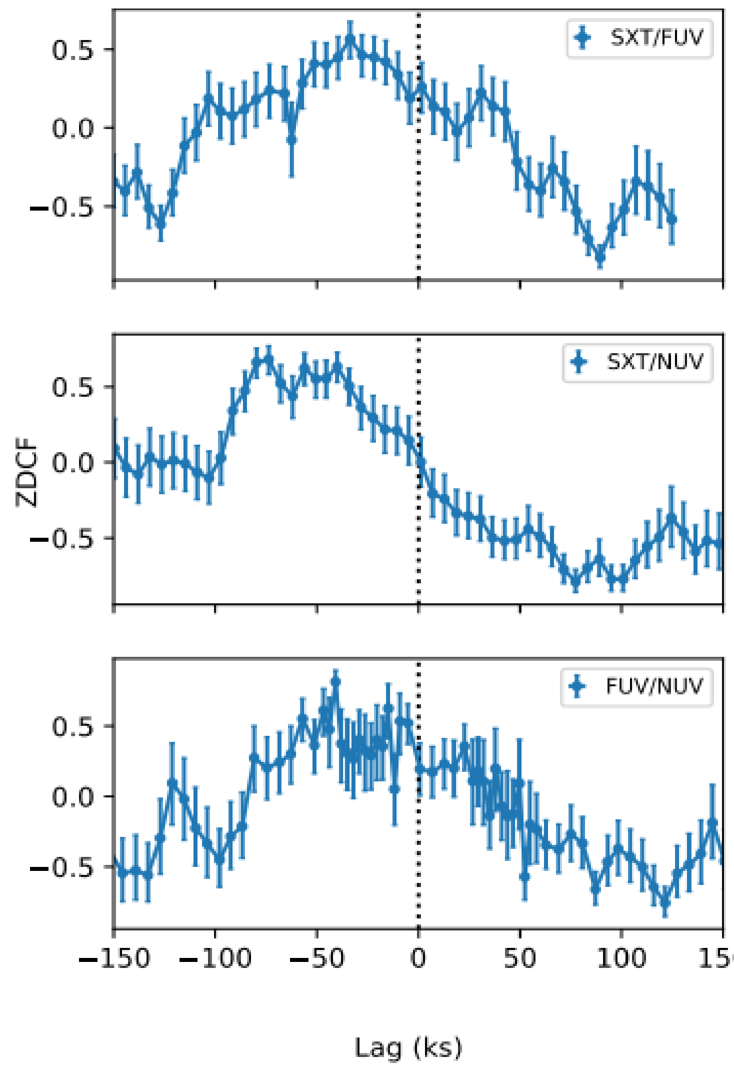
- The excellent spatial resolution of the UVIT data has allowed us to accurately separate the extended emission from the host galaxy and the AGN emission in the far- and near UV bands. We derive the intrinsic AGN flux after correcting for the Galactic and internal reddening, as well as for the contribution of emission lines from the broad and narrow-line regions. The intrinsic UV continuum emission shows a marked deficit compared to that expected from the 'standard' models of the accretion disc around an estimated black hole mass of 1-2 × 10^8 $M_\odot$ when the disc extends to the innermost stable circular orbit. We find that the intrinsic UV continuum is fully consistent with the standard disc models, but only if the disc emits from distances larger than ~80-150 gravitational radii.

UV/X-ray variability of AGN with AstroSat

NGC7469 (Dewangan et al)

$M_{BH} = (9 \pm 1) \times 10^6\ M_{\odot}$





FUV leading X-rays

NUV leading X-rays

NUV leading FUV

Observing with UVIT - more

- PC mode and saturation due to > 1 photon in a frame
- Bright object avoidance
- Sun, Moon, bright earth avoidance
- Selection of filter in VIS

Some Incidences

- During the vibrations tests of the Engineering model, the secondary mirror came loose

  This was possibly due to less than full tightening of a bolt – it happened!!

  The bolts were replaced by larger bolts
- A primary mirror was found to have an unexpected aberration when tested at IIA after being passed by LEOS.

Some …

This was a real surprise and had to be confirmed by multiple rounds of testing and many discussions between UVIT and Leos over several weeks.

Actually in such instrumentation any unexpected observation takes long to resolve because it is examined from all possible angles

Some …

- The VIS detector failed during the vibration test of the flight model -- in March 2013

  Could not find any design fault for the failure and It took 2 years to get this fixed
- A single point suspension of the flight model had a faulty bolt connection but was detected before it could lead to damage.

Making …

- Testing of each optical component

  Mirrors by LEOS and IIA

  Detectors by CSA & IIA, and ISRO

  Filters & Gratings by IIA

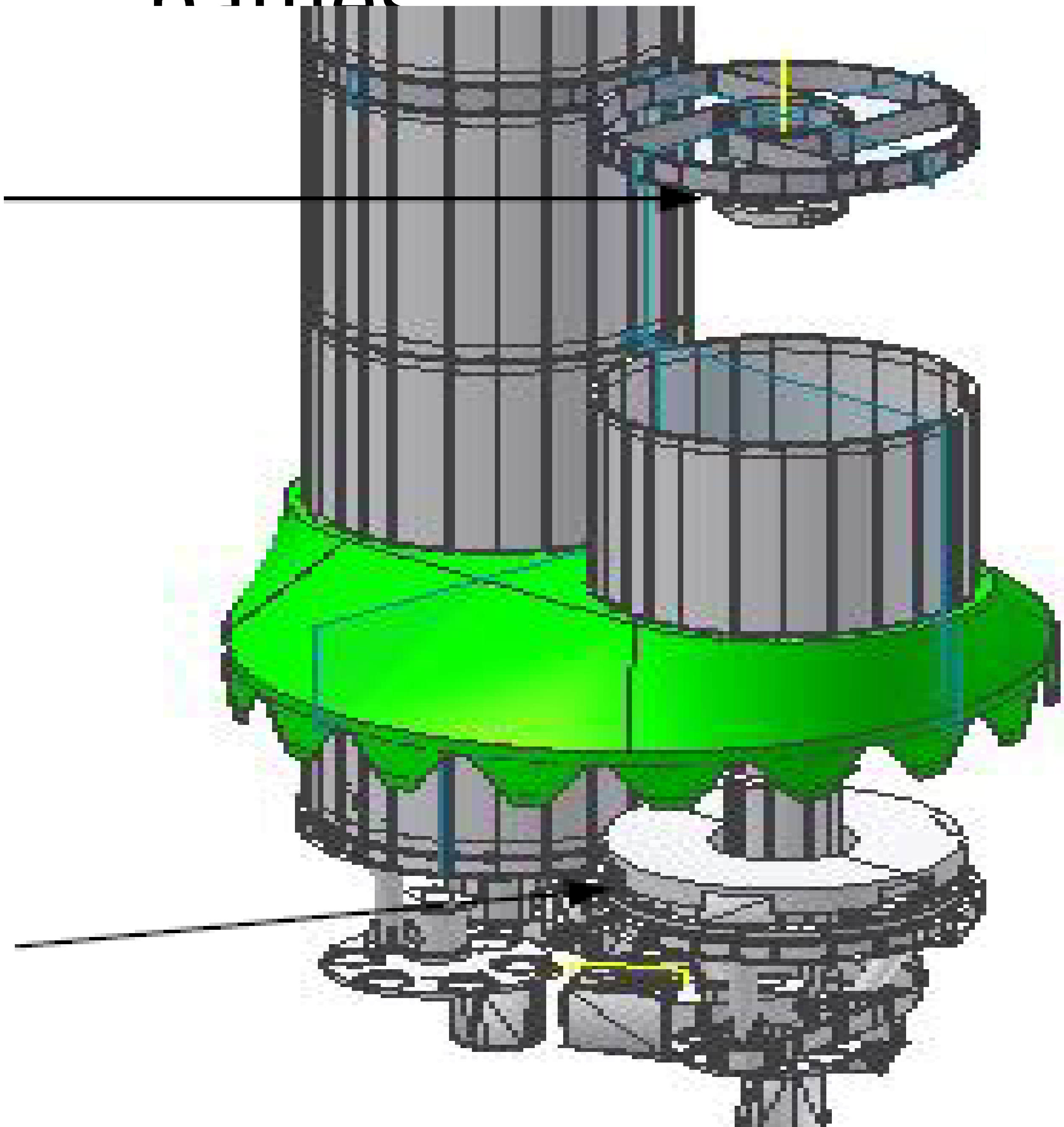
  Filter wheel motors-drivers delivered by ISRO
- Assembly & Testing of individual telescopes

  Testing the mirror assembly alone, next with the filters and the detectors: All in clean room of Class 1000 and tests of the full telescopes in vacuum chamber
- Assembly of full instrument at IIA

Making of UVIT-Time Line

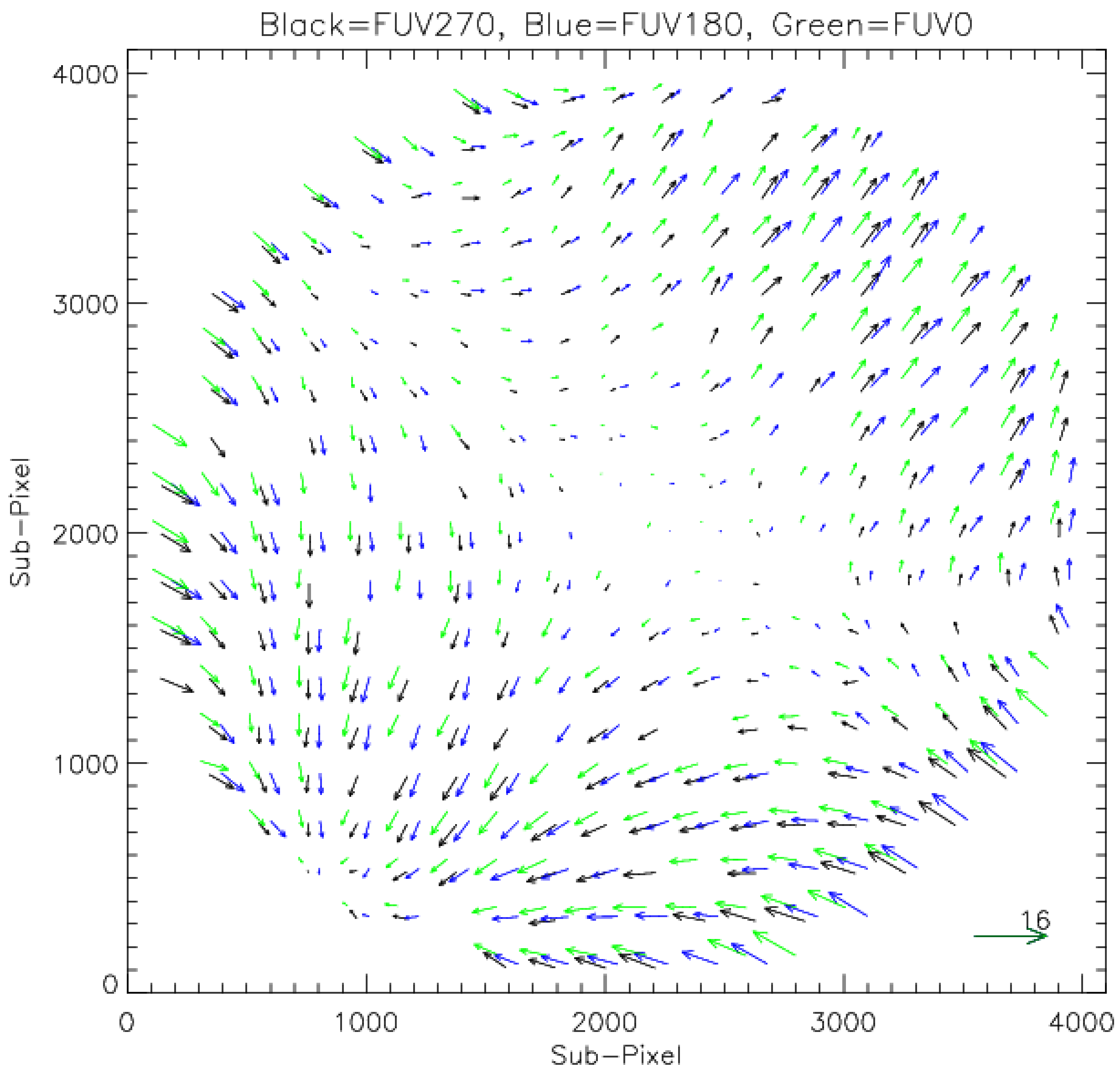
- 2002 Maximal configuration, with FarUV and Near UV bands approved
- 2003 Agreement between ISRO and CSA for development of the detectors
- 2004 Formal approval of ASTROSAT project
- 2015 September 28 launch of ASTROSAT
- Near UV detector of UVIT failed in 2018, and UVIT still making good images in Far UV

baffles

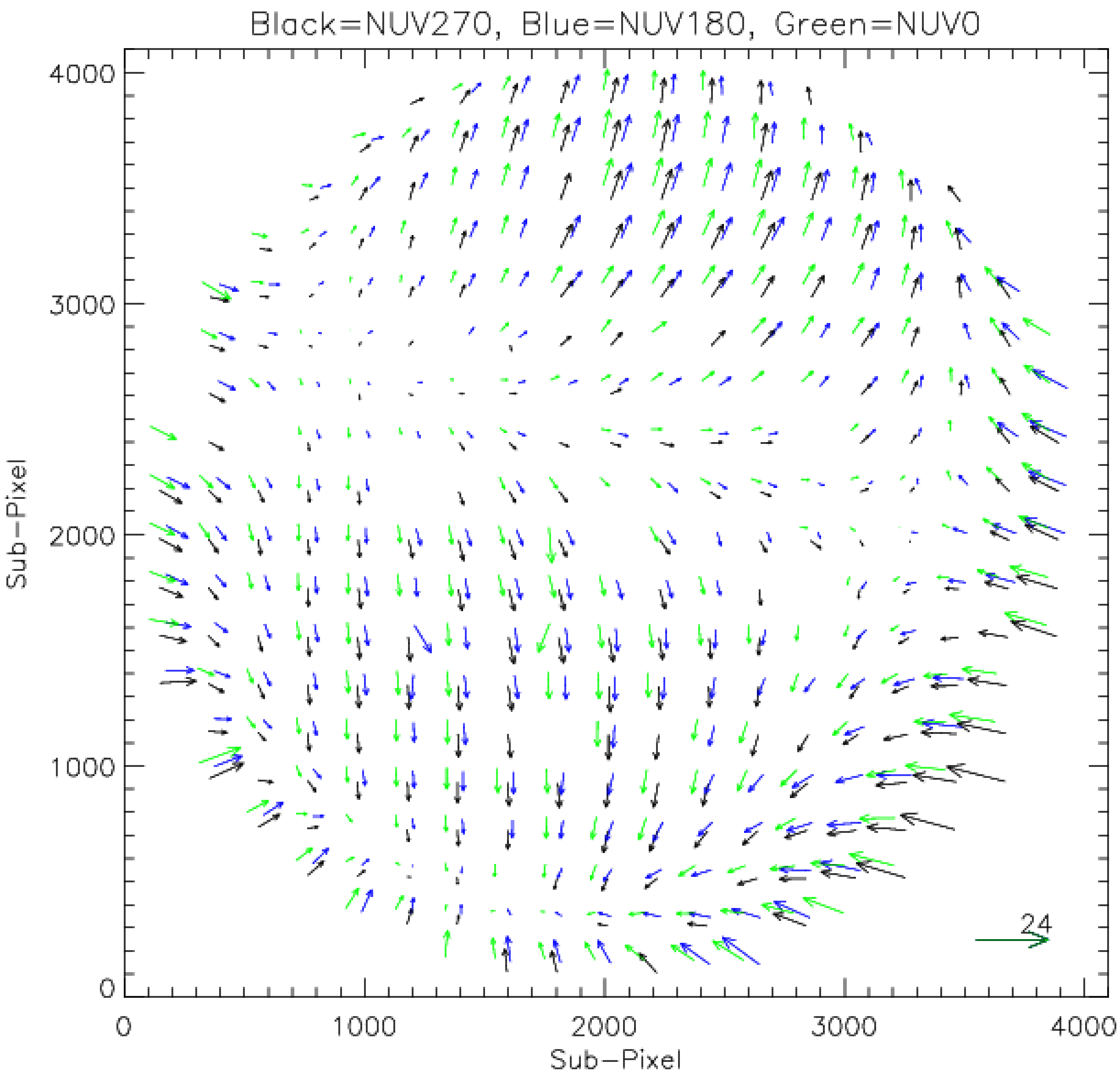


Uncorrected Distortion FUV Detector

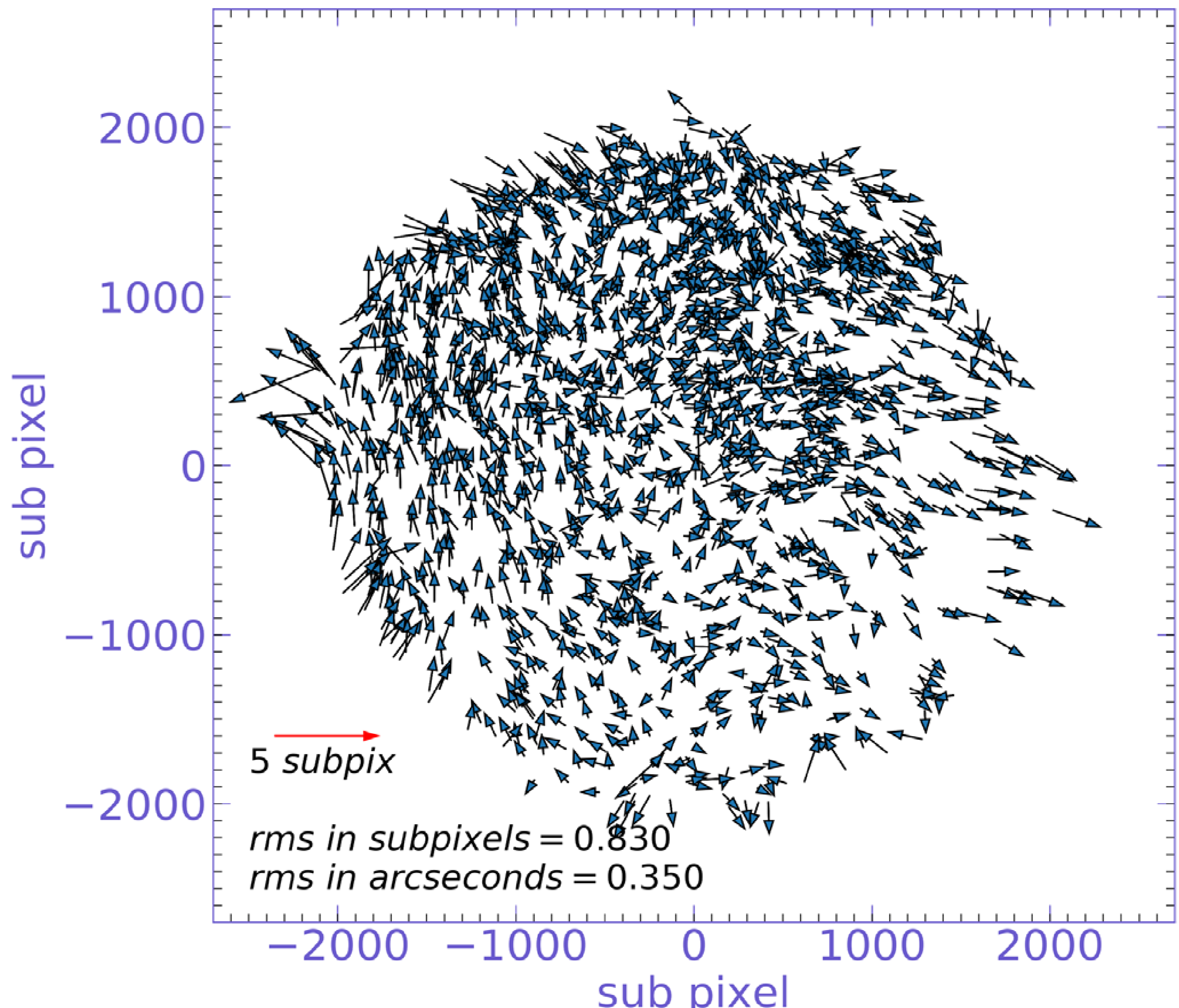
PHOSPHOR



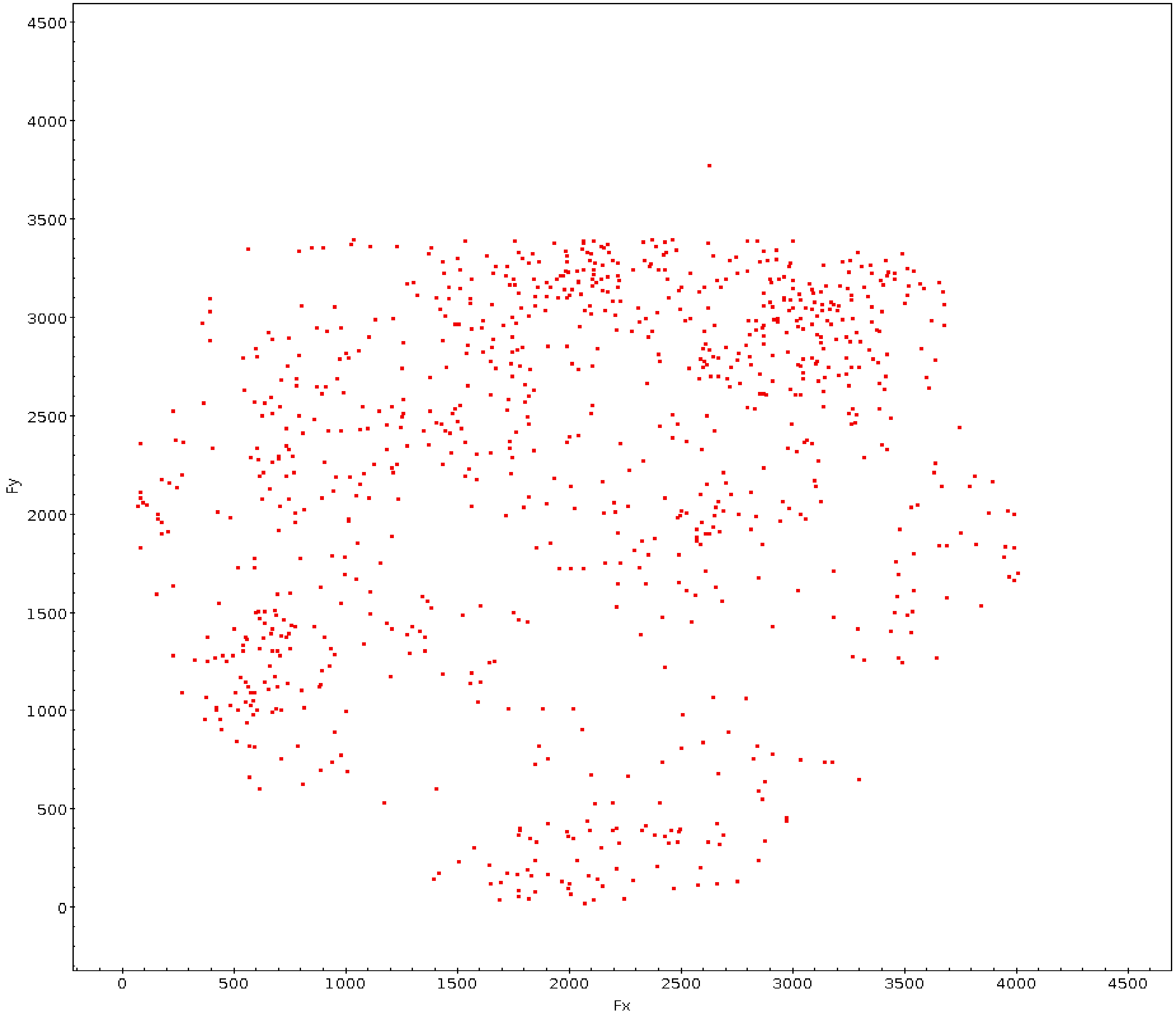
Uncorrected Distortion NUV Detector



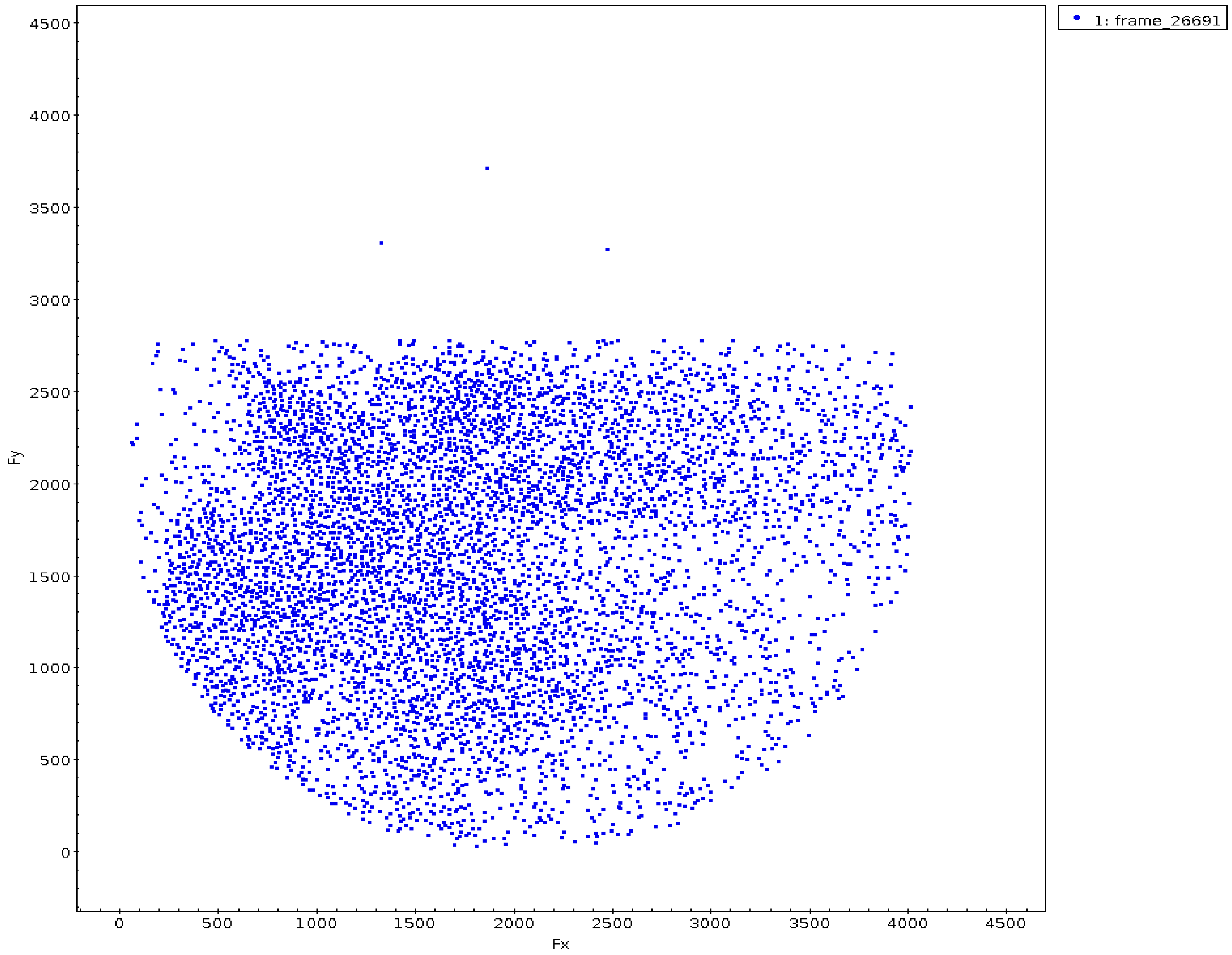
Relative positions FUV and NUV



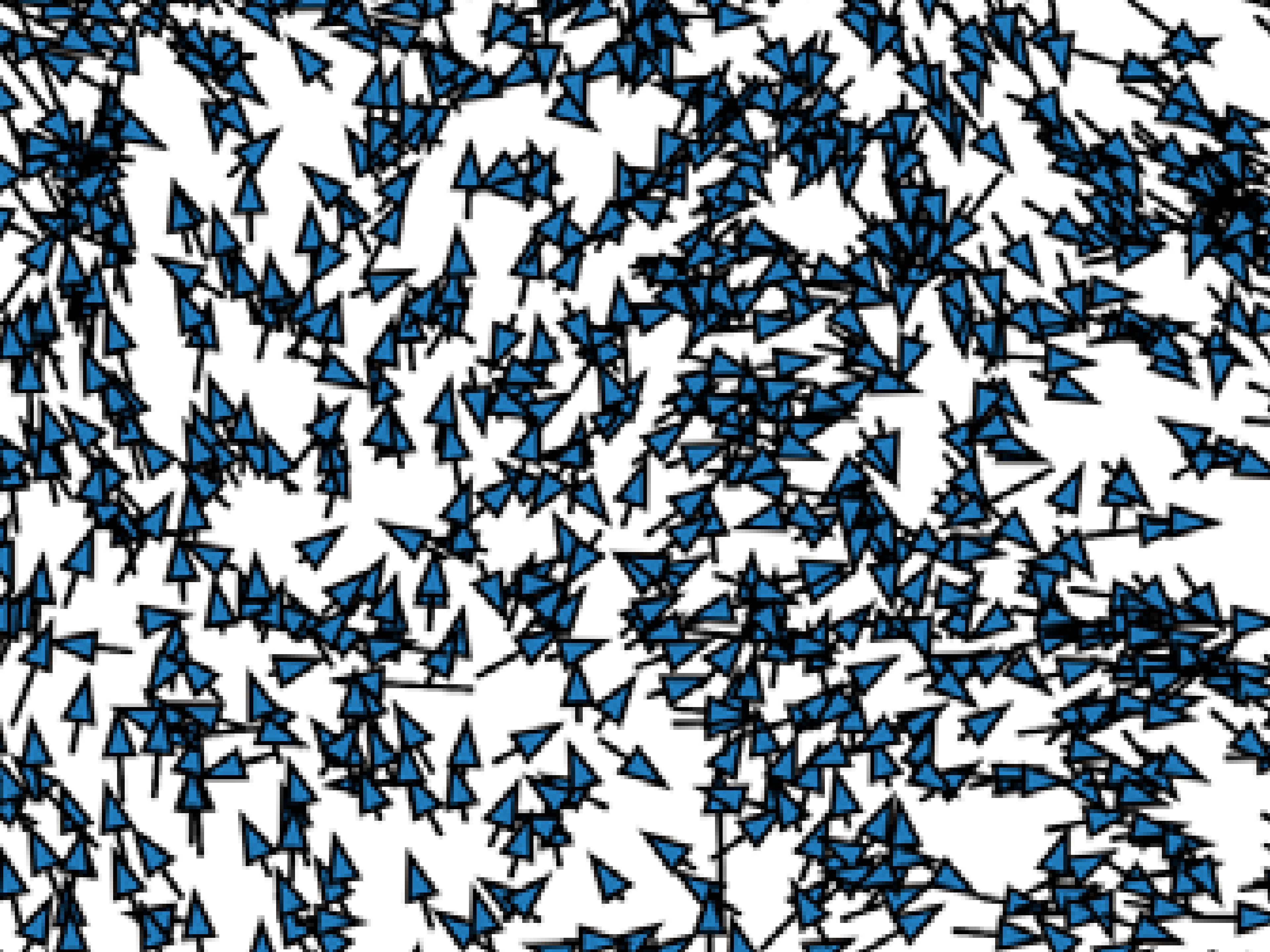
Cosmic Ray Shower



Cosmic Ray Shower

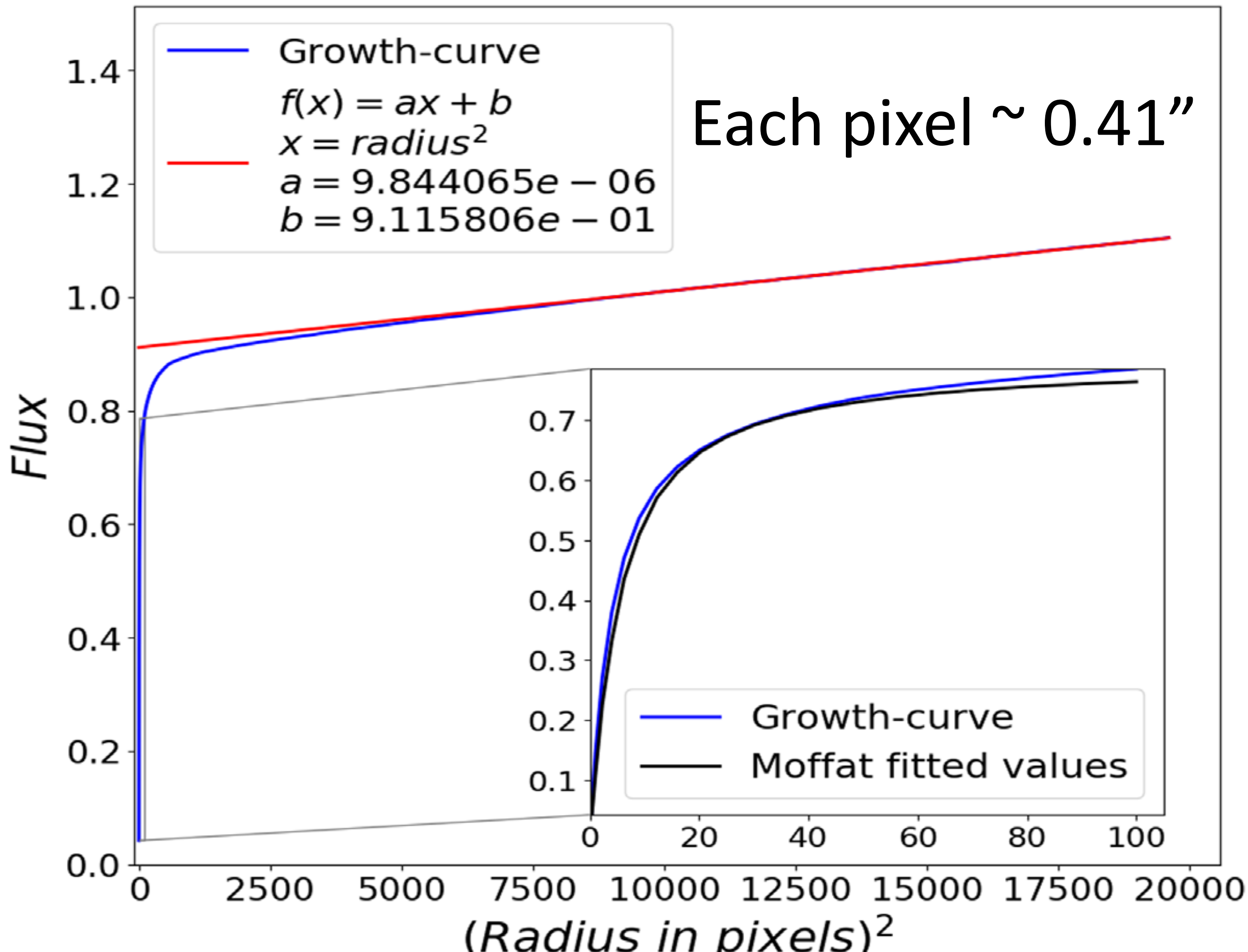


Relative differences in the positions of the stars in the UVIT images
of the SMC taken with FUV-F154W and NUV-N263M are shown as vectors,
where the tail of the vector corresponds to the position in the NUV field.
Positions and errors are shown in subpixels. For radii <1900 subpixels, any
source giving an error >2 subpixels is either a close double or is at a radius
>1900 subpixels in the FUV detector.

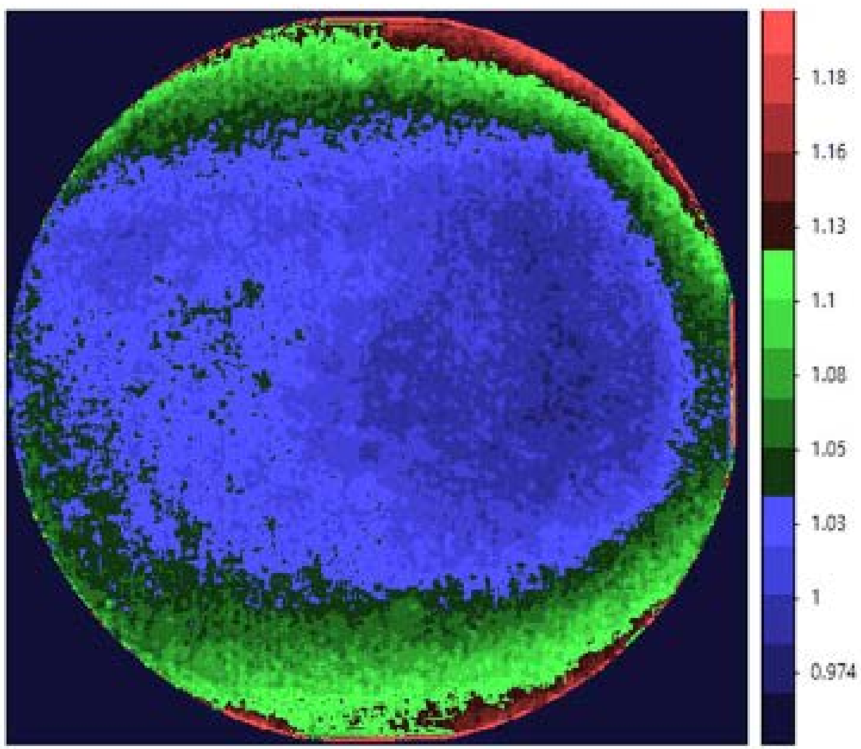


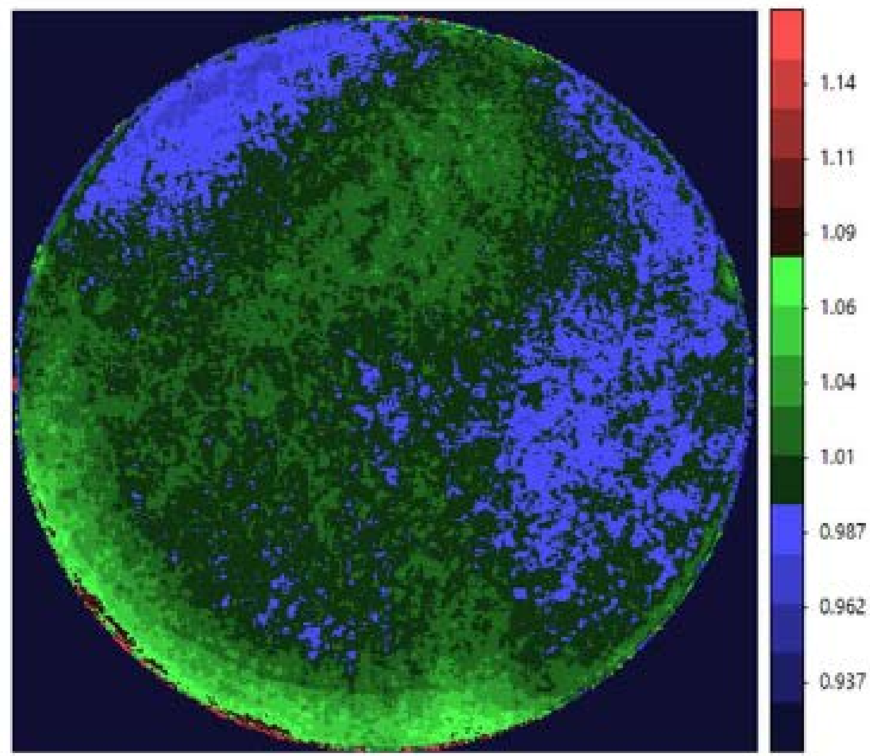
PSF obtained

Each pixel ~ 0.41”

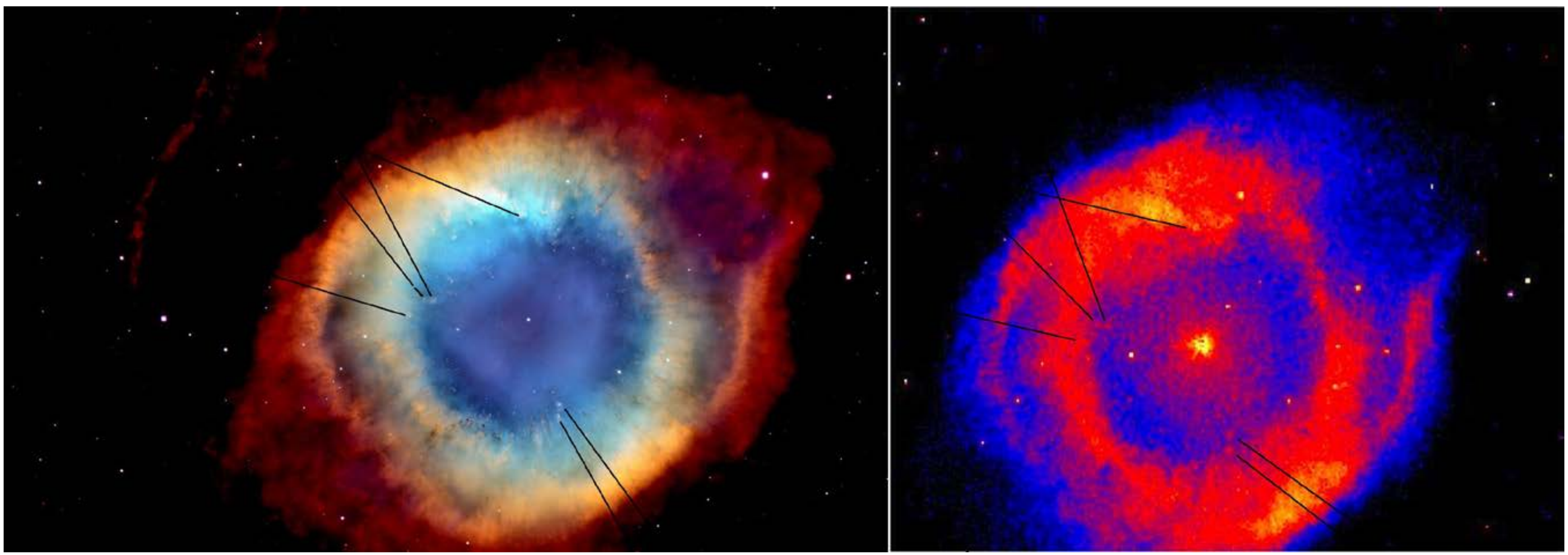


Typical flat field correction (Left: FUV; Right: NUV) rms variation < 5%





HST and UVIT (NUV) Images : Helic (NGC 7293); Credit : N K Rao



NGC 40: H2 Cloud and H-alpha Contours
Credit: N K Rao et al