Ultraviolet Imaging Telescopes on the ISRO Astrosat observatory

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NRC Canada

ASTROSAT observatory

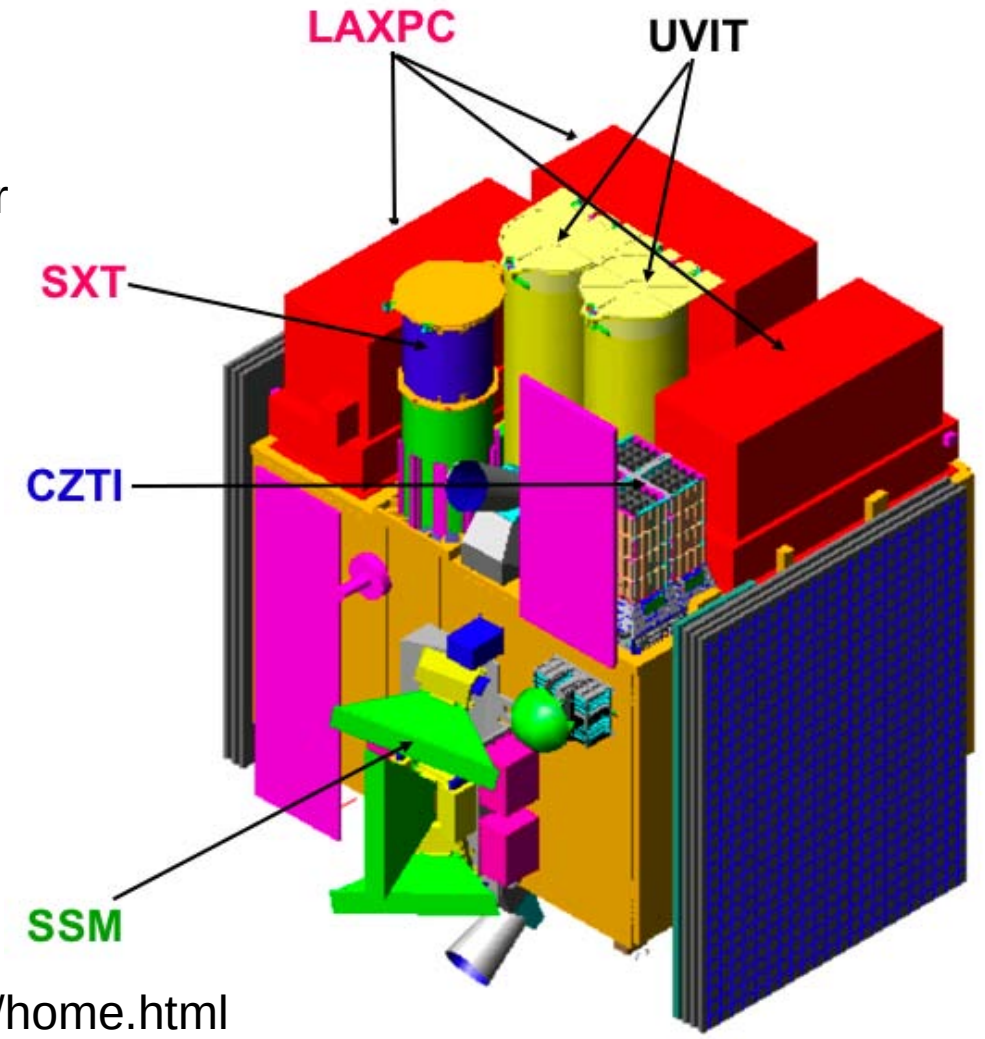
Large Area X-ray Proportional Counter

Ultra-Violet Imaging Telescopes

Soft X-ray Telescope

Cadmium Zinc Telluride Imager

Scanning Sky Monitor

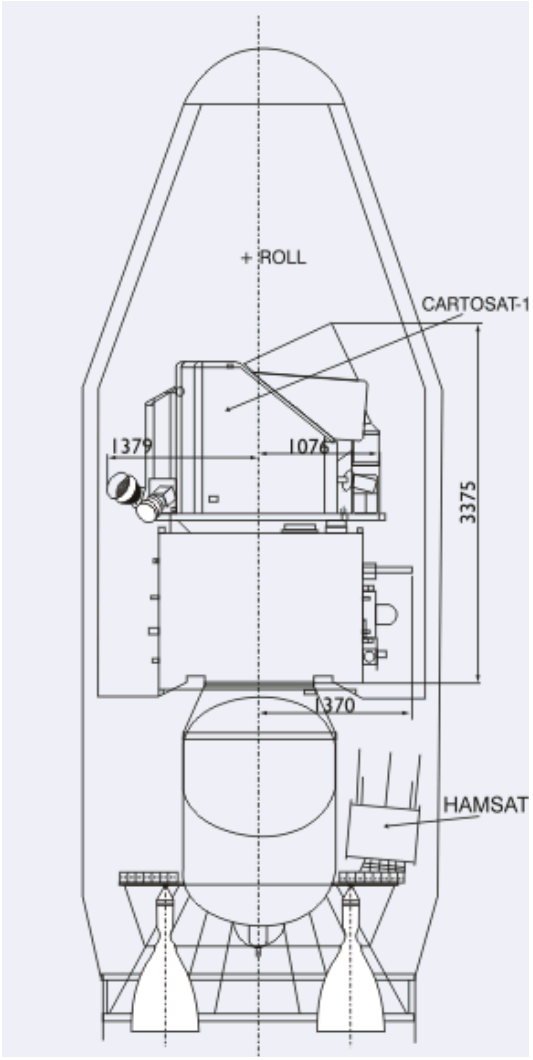


Launch 2014, >5 year life

http://meghnad.iucaa.ernet.in/~astrosat/home.html

PSLV launch vehicle

PSLV at Umblical Tower



Instrument summary

	UVIT / OPT	SXT	LAXPC	CZTI	SSM
Optics	Twin Ritchey Chretian 2 mirror system.	Conical foil (~Wolter-I) mirrors	Collimator	2 - D coded mask	1- D coded mask
Bandwidth	1300-3200 Ang	0.3 - 8 keV	3 - 100 keV	10 - 100 keV	2 - 10 keV
Geometric Area (cm^2)	1250	250	10800	1000	180
Effective Area (cm^2)	60 (depends on filter)	125@0.5 keV 200@1-2 keV 25@6 keV	6000@5-30 keV	1000 (E>10 keV)	~40 @ 2 keV 90 @ 5 keV (Xe gas)
Field of View	0.50^0 dia	0.35^0 (FWHM)	$1^0 \times 1^0$	$17^0 \times 17^0$	$6^0 \times 90^0$
Energy Resolution	<1000 A (depends on choice of filters)	2%@6keV	9%@22 keV	5% at 10 keV	19% @ 6 keV
Angular Resolution	1.8 arcsec	3 - 4 arcmin (HPD)	~(1-5) arcmin (in scan mode only)	8 arcmin	~10 arcmin
Time resolution	10 ms	2.6s, 0.3s,1ms	10 microsec	1 ms	1 ms

Primary Science Objectives of ASTROSAT

8. Understand high energy processes in binary systems
9. Search for black hole sources in the Galaxy.
10. Measure magnetic fields of neutron stars.
11. Study high energy processes in extragalactic systems.
12. Detect new transient X-ray sources.
13. Limited high-angular resolution sky survey in UV (130-300 nm).

These primary science objectives are being met with 5 science payloads.

6. Three identical Large Area Xenon-filled Proportional Counters (LAXPC)
7. Cadmium-Zinc-Telluride Imager (CZTI)
8. A Soft X-ray Imaging Telescope (SXT)
9. A Scanning Sky Monitor (SSM)
10. A Ultra Violet Imaging Telescope (UVIT)

UVIT capability

Two 40cm telescopes: 3 simultaneous wavelengths

FUV 130-180nm

NUV 180-300nm + Opt 300-650nm (guiding)

Photon-counting or integrate mode

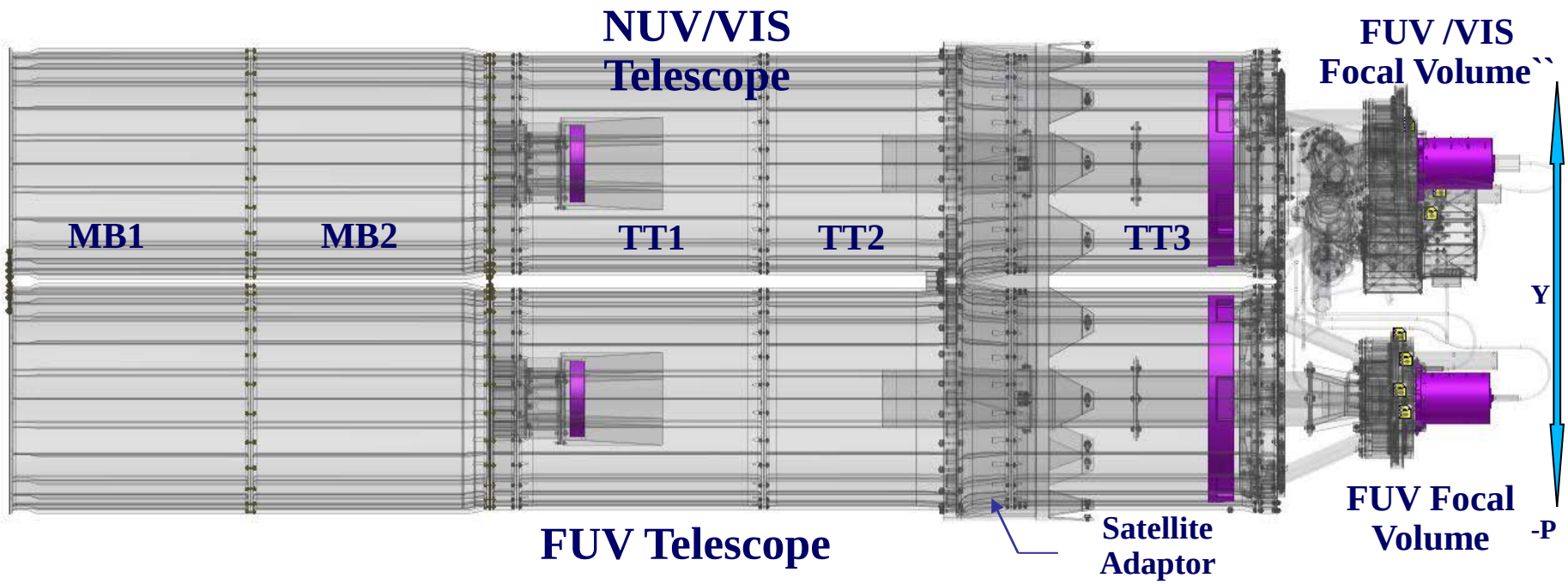
FOV 0.5 degrees, images 4096 pixels, 29Hz read

Subwindows for reads to 600Hz

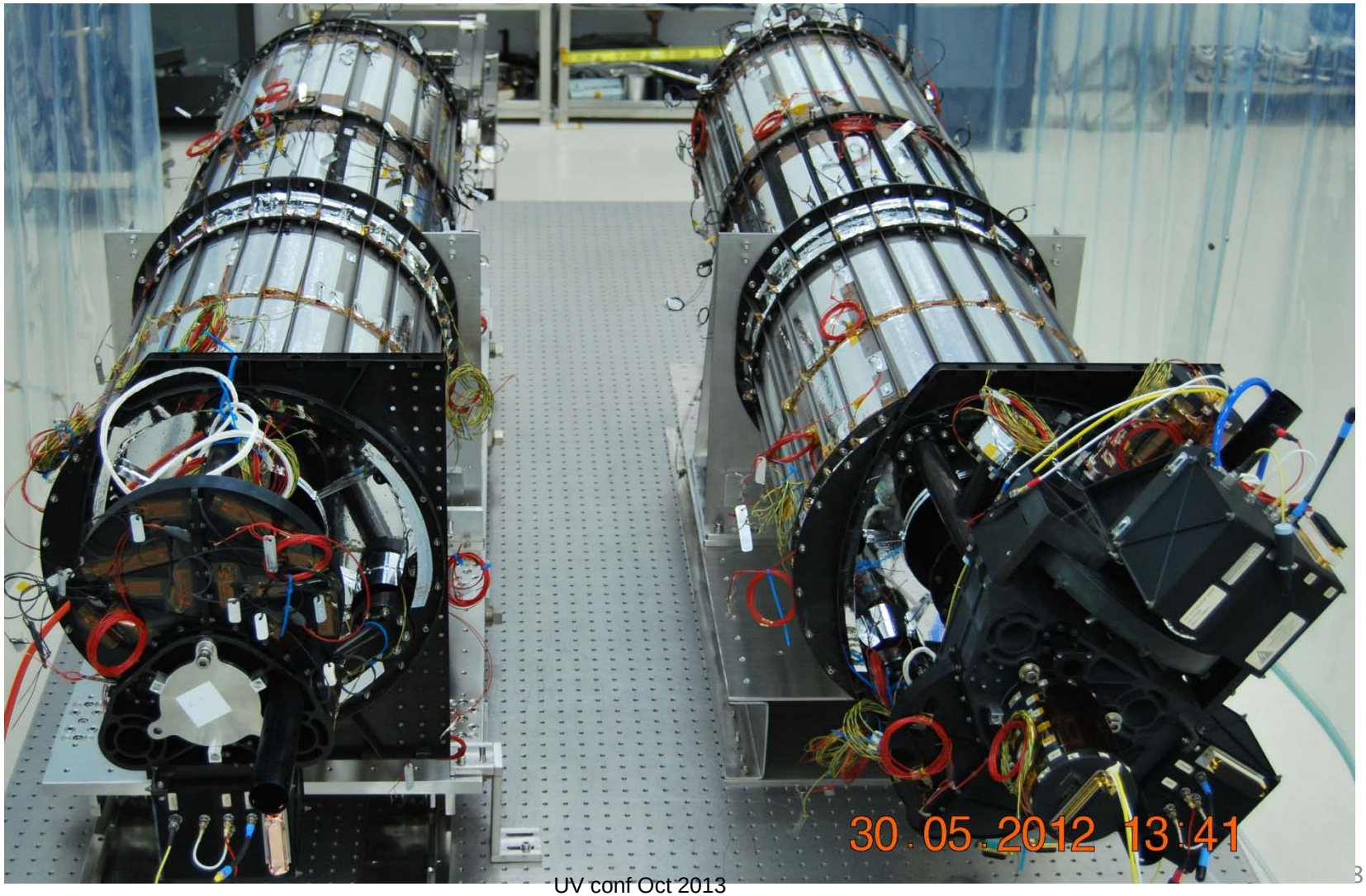
Resolution ~1”, depending on filter

Filters in all channels, objective gratings in UV

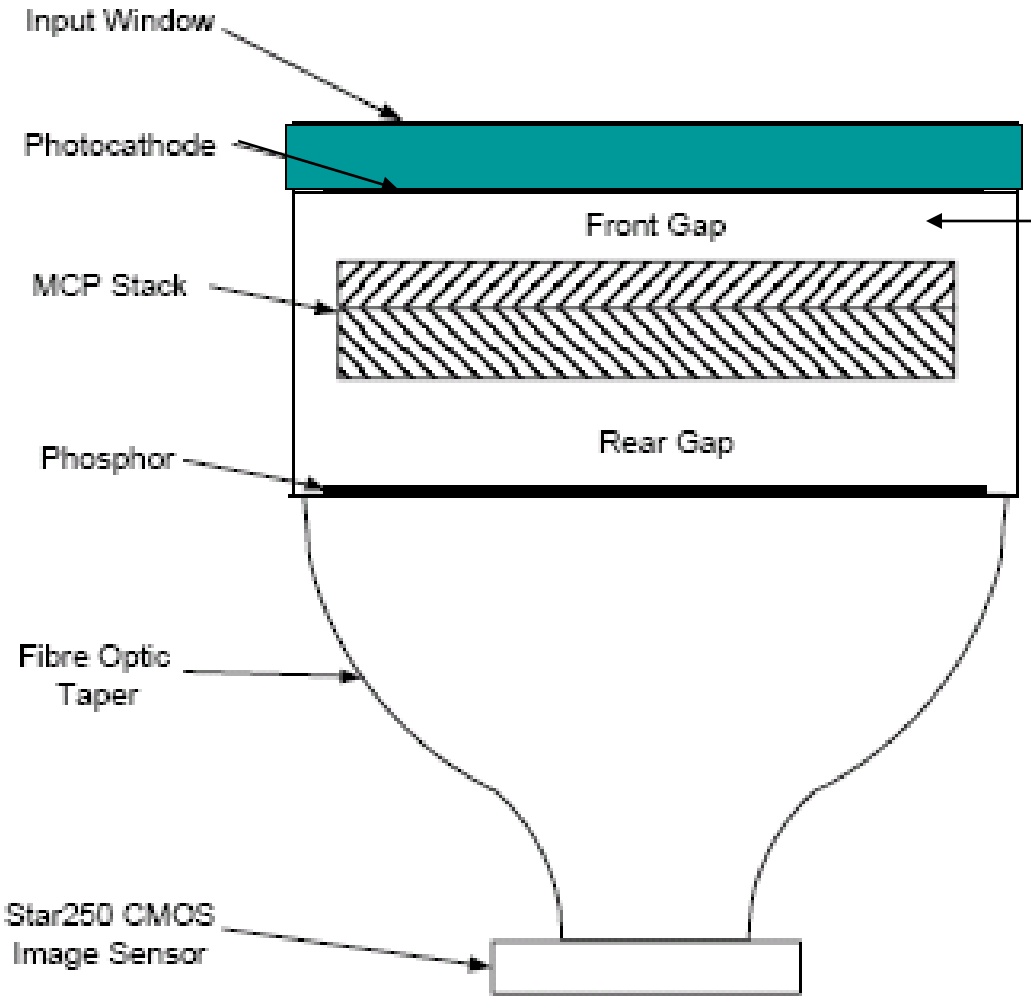
Exposure calculator for all modes, target types


NUV/VIS
Telescope
FUV /VIS
Focal Volume``
MB1
MB2
TT1
TT2
TT3
Y
FUV Telescope
Satellite
Adaptor
FUV Focal
Volume
-P

Integrated UVIT Payload in 100Class



UVIT photon counting detector



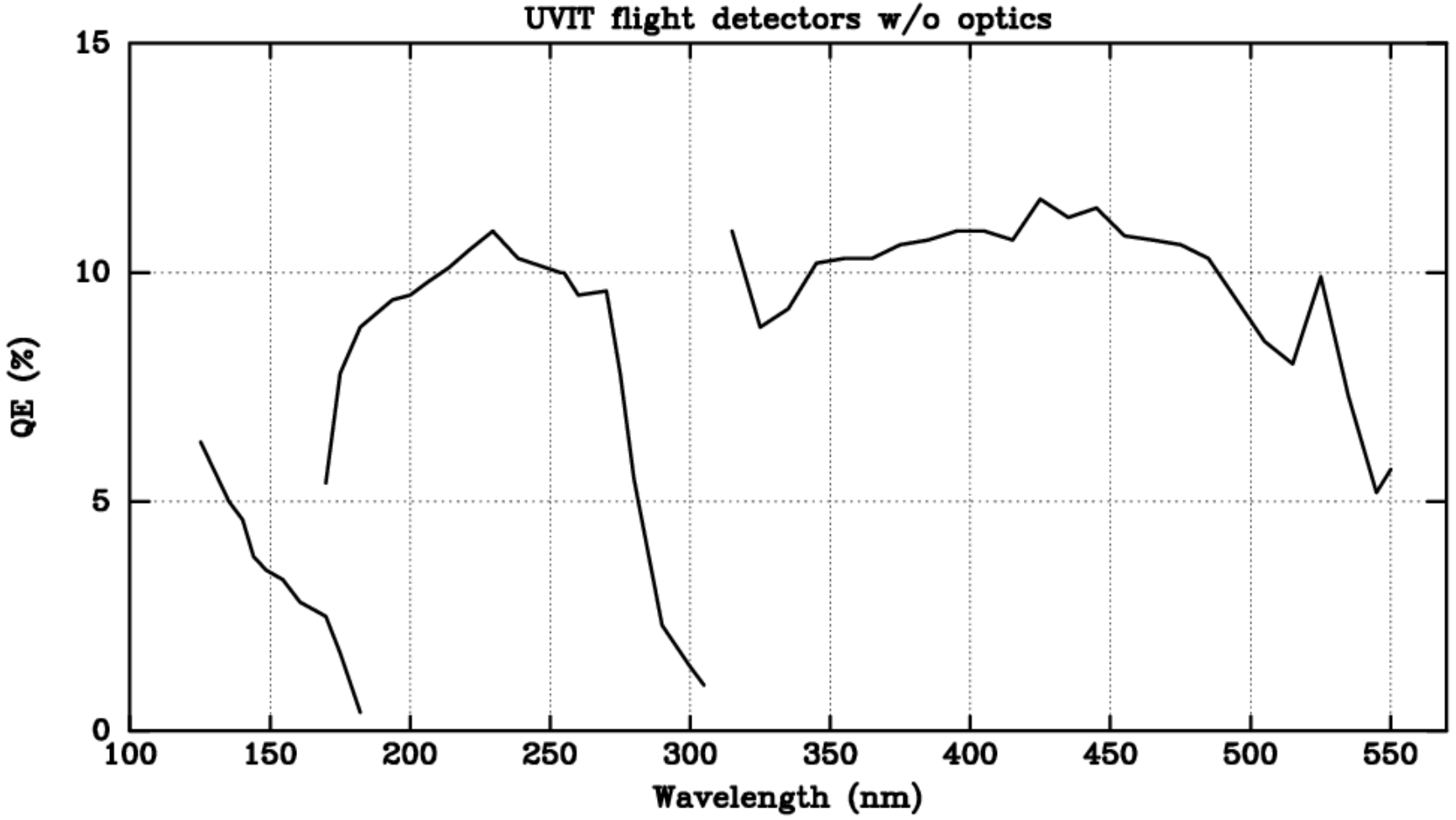
Resolution depends on

Front gap size
Window-MCP voltage
Wavelength (e-energy)

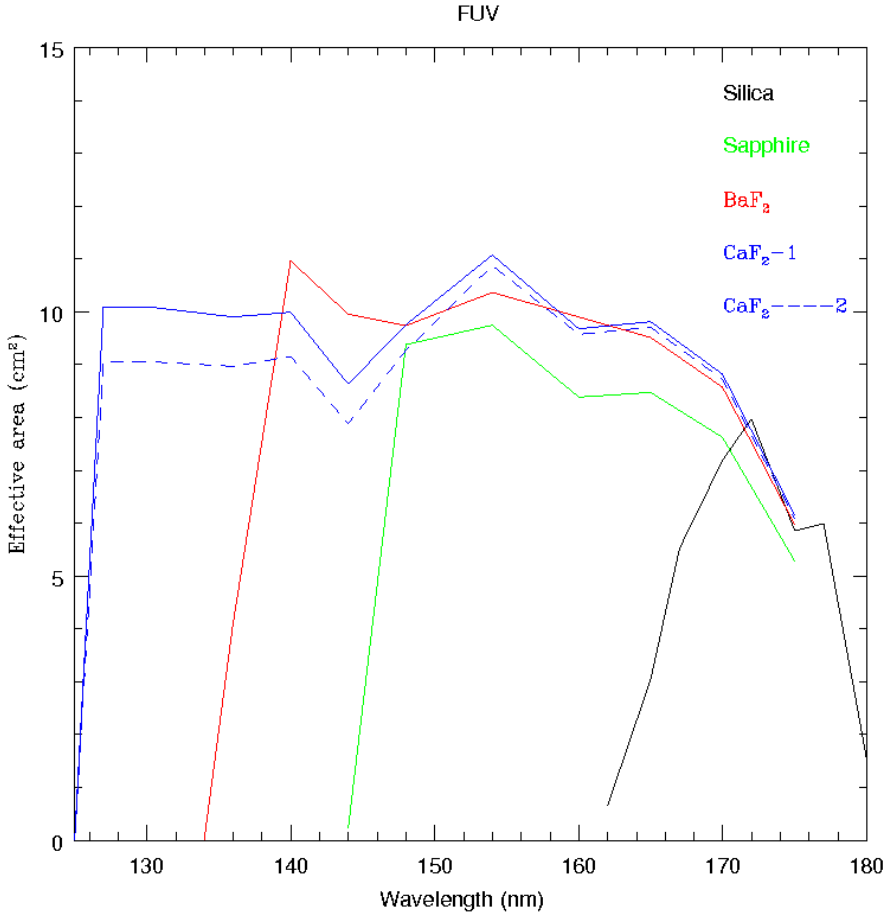
UVIT observation and data options

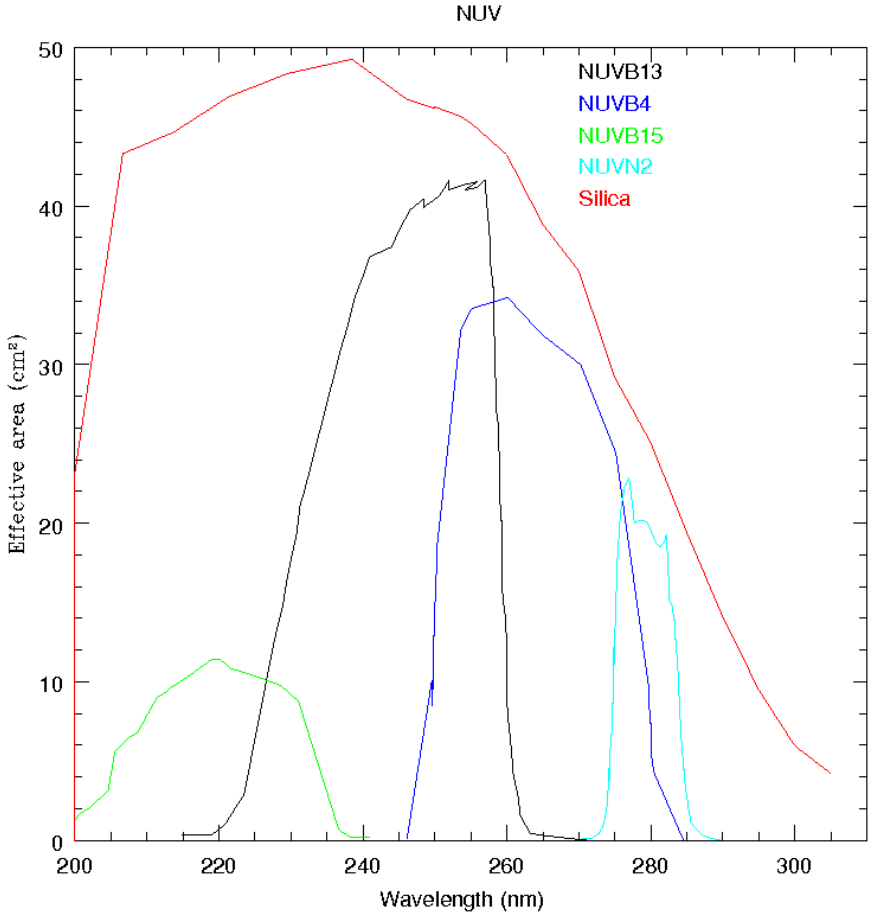
Full-field readouts at 29Hz, 1/5 field sub-images at 600Hz
3 centroiding algorithms, selection uploaded; also INT mode
Photon events downloaded with position, time, double-event threshold
Centroids to 1/8 of 512-pixel CMOS = 4096 pixels over 28arcmin
Systematic centroid corrections for CMOS pixels applied
Guide star centroid monitors boresight drift at ~2 Hz
Science images assembled on the ground – select, shift, add
Science images may reject or correct double events
Science images may reject centroids from CMOS pixel corners
Time sequences for selected objects/areas
Simultaneous operation of FUV, NUV, VIS channels
Filters in all channels, gratings in UV channels
Co-aligned X-ray telescopes operating simultaneously
Data from all instruments to observer

Raw QE measures

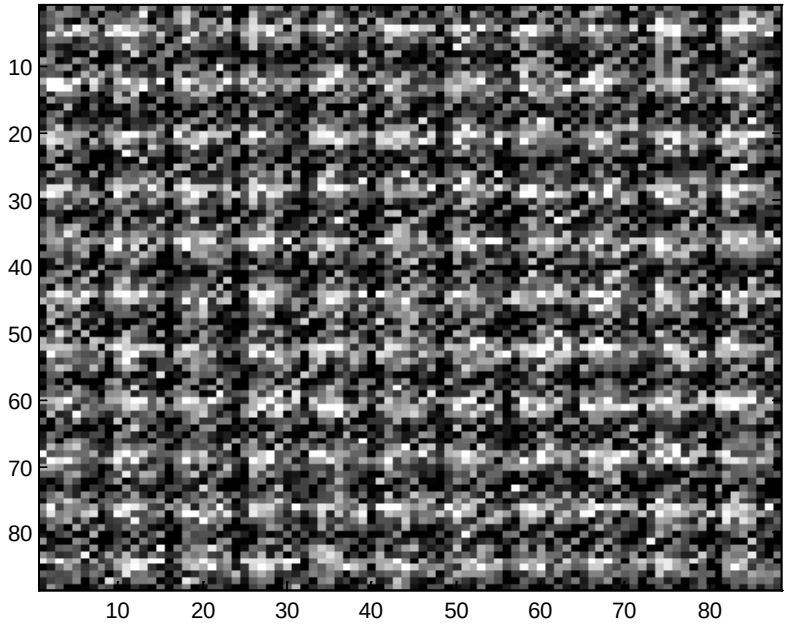


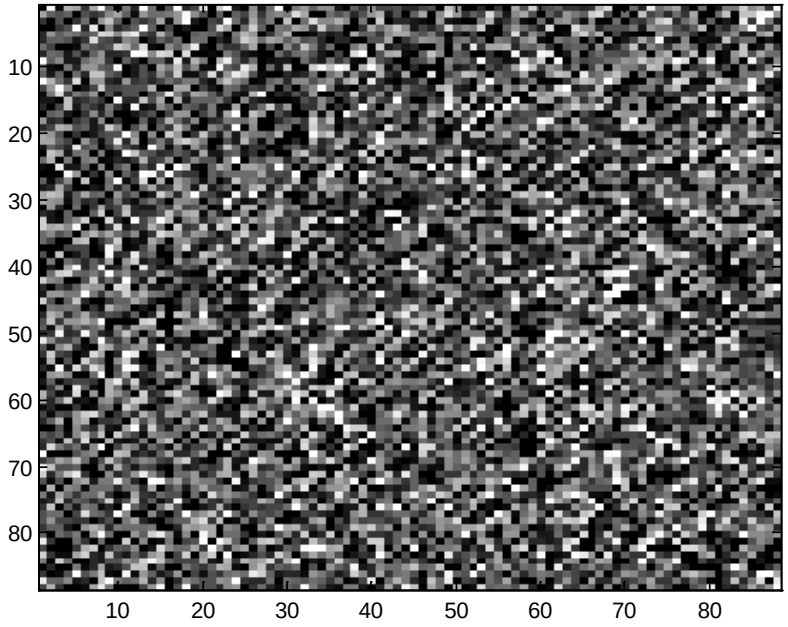
UV flight filters



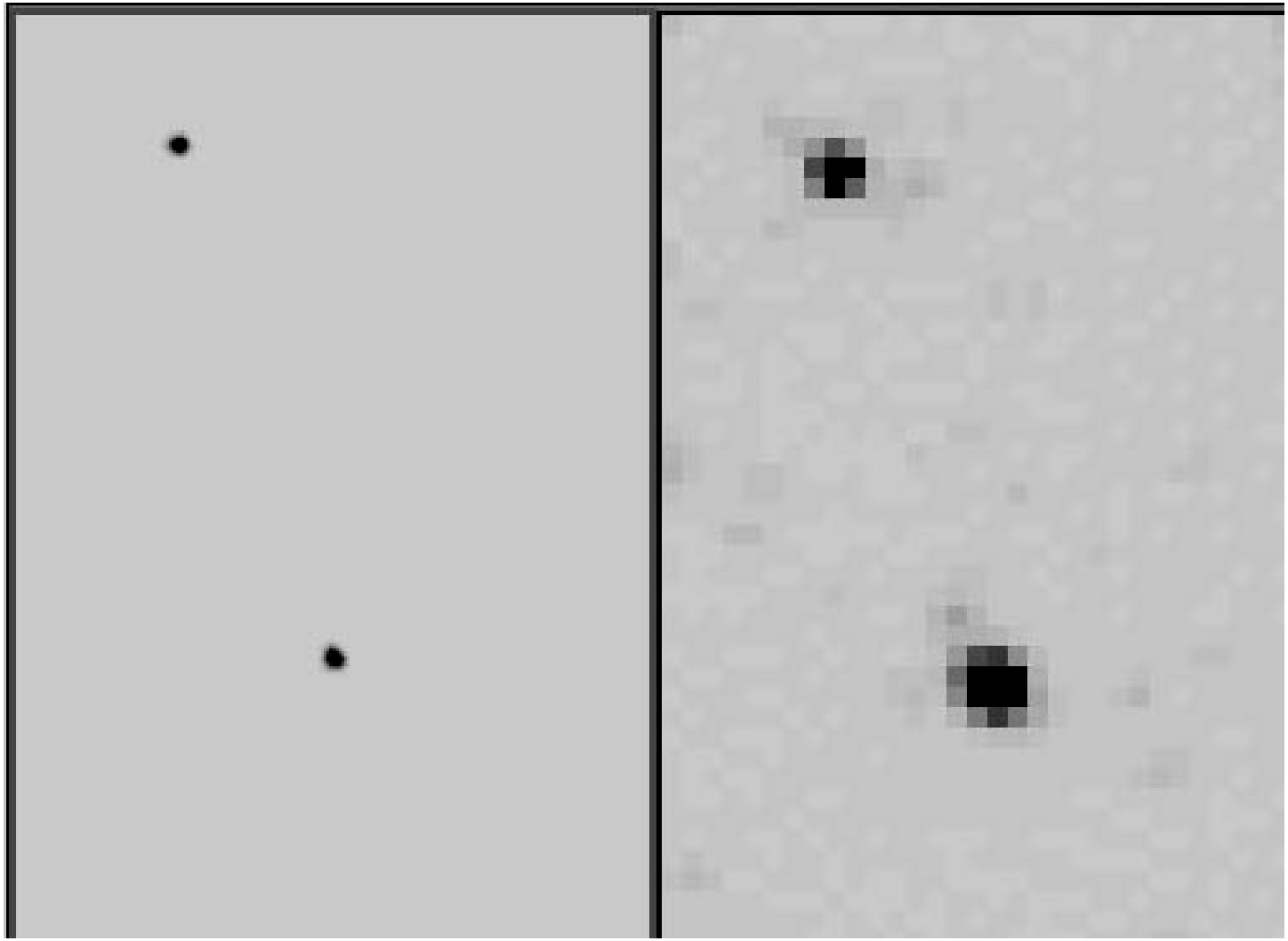


FUV 3S flat fields before and after centroid-correction

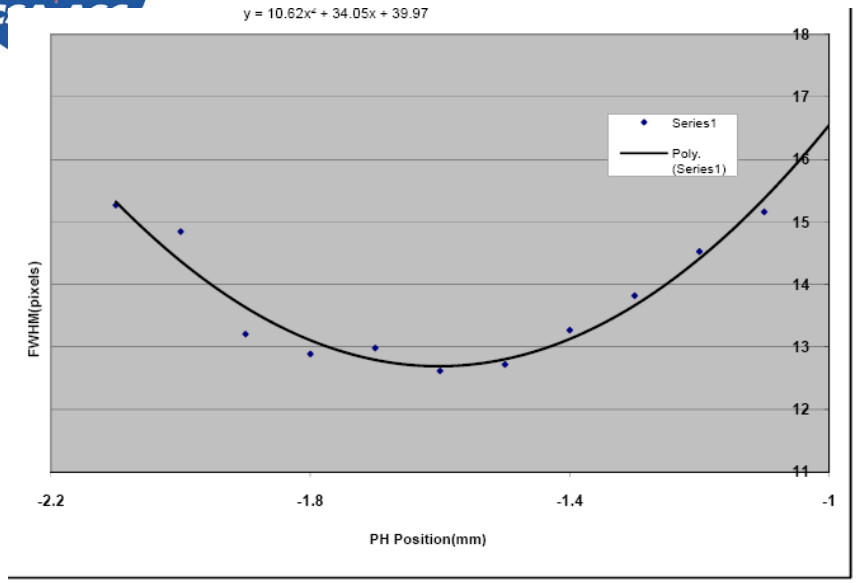




Centroid and integrate mode spot images



FUV focus details



FUV Detector

Field : ON Axis

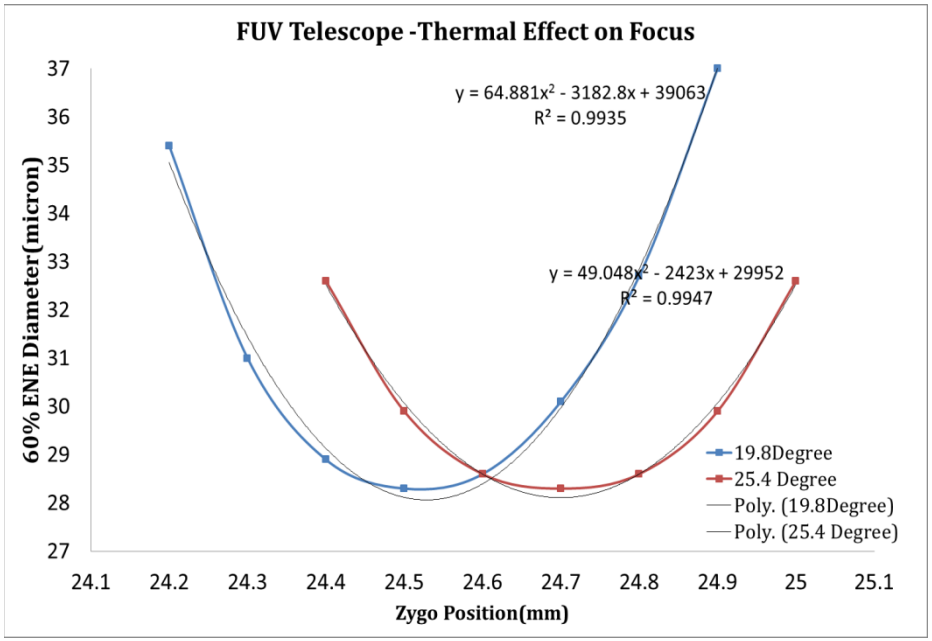
Resolution <1.3“ (1.8”)

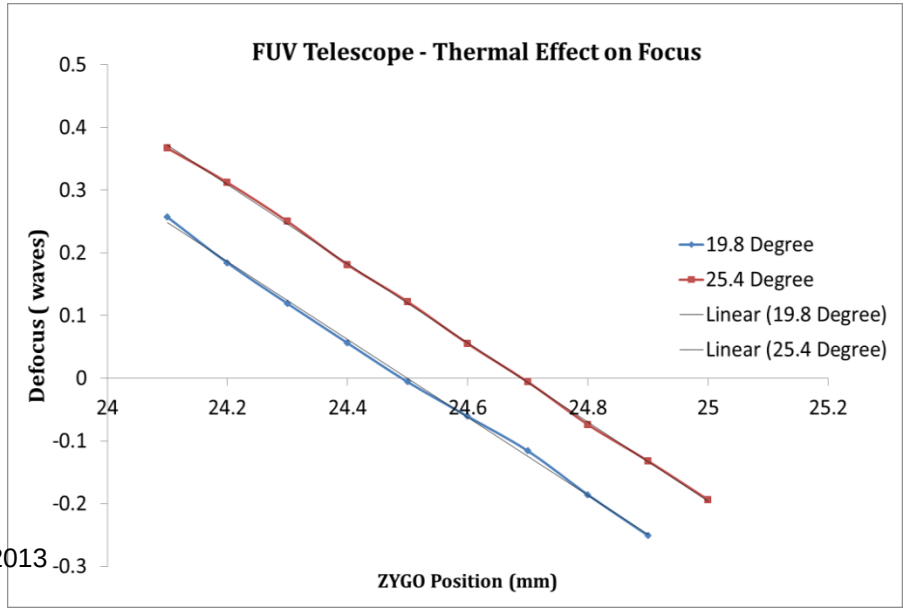
FUV FOCUS TEST RESULTS - Center of Field

Theodolite Angles:	Filter Name	Slot No	Wavelength (nm)	Position		PH Position	FWHM
				X	Y		
V: 90° 11' 26", Hz: 0° 02' 53"	Caf2	1	150	258.5565	256.5314	-1.61	12.29
V: 90° 11' 28", Hz: 0° 02' 44"	Baf2	2	160	261.4736	257.3692	-1.60	10.72
V: 90° 11' 28", Hz: 0° 02' 44"	Sapphire	3	160	262.3986	257.427	-1.59	10.27
V: 90° 11' 28", Hz: 0° 02' 44"	Silica	5	170	259.6639	257.1991	-1.60	11.62
V: 90° 11' 28", Hz: 0° 02' 44"	Caf2	7	150	260.3312	257.2692	-1.60	12.69

Thermal Effect on Focus-FUV TELESCOPE

Date 05/05/2012	Temperature 19.8Deg		Date 06/05/2012	Temperature 25.4Deg	
Zygo Position (mm)	Defocus (w)	60%ENE Dia (micron)	Zygo Position (mm)	Defocus (w)	60%ENE Dia Micron
24.1	0.257	41.2	24.1	0.367	48.3
24.2	0.184	35.4	24.2	0.312	43.9
24.3	0.119	31	24.3	0.25	38.8
24.4	0.056	28.9	24.4	0.181	32.6
24.5	-0.006	28.3	24.5	0.122	29.9
24.6	-0.061	28.6	24.6	0.055	28.6
24.7	-0.116	30.1	24.7	-0.006	28.3
24.8	-0.186	32.7	24.8	-0.074	28.6
24.9	-0.251	37	24.9	-0.132	29.9
25	-0.341	42.5	25	-0.194	32.6





Focus Shift < 189micron/5.6 Degree
~32 Micron/^{o}C

Focus change with temperature

FUV

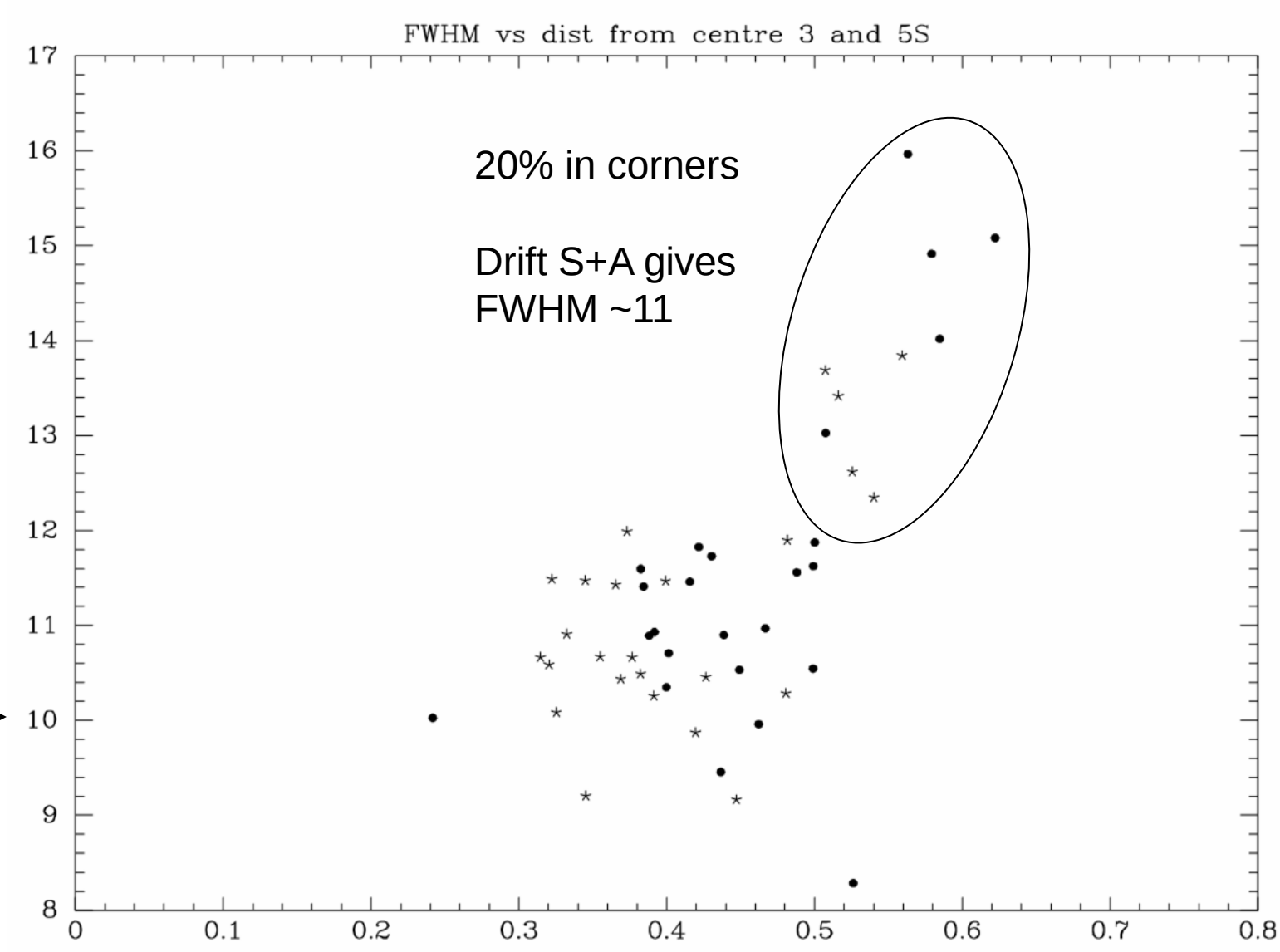
Filter Name	-1.76	-1.7	-1.64
	Focus @+2°C Thermal	Focus@ Nominal	Focus @-2°C Thermal
	Edge of the field		
Caf2 (1)	11.7	11.7	11.8
Caf2 (1)	12.7	12.5	12.5
Caf2 (1)	11.4	11.5	11.7
Caf2 (1)	12.6	12.6	12.6
	Center Field		
Caf2(1)	12.5	12.4	12.3
Baf2	11.0	10.8	10.7
Sapphire	10.7	10.5	10.4
Silica	11.9	11.7	11.6
Caf2(2)	13.0	12.8	12.7

NUV

Filter Name	-1.75	-1.7	-1.65
	Focus @+2°C Thermal	Focus@ Nominal	Focus @-2°C Thermal
	Edge of the field		
Silica (3.0)	8.5	8.9	9.5
Silica (3.0)	10.6	10.4	10.3
Silica (3.0)	11.5	11.7	12.0
Silica (3.0)	8.5	8.7	9.0
	Center Field		
Silica(3.0)	9.9	9.8	9.8
Silica (3.3)	8.7	8.5	8.4
NUV B13	10.0	9.7	9.5
NUV B4	12.3	12.0	11.8
NUV N2	8.8	8.6	8.5
NUV B15	12.0	12.0	12.1

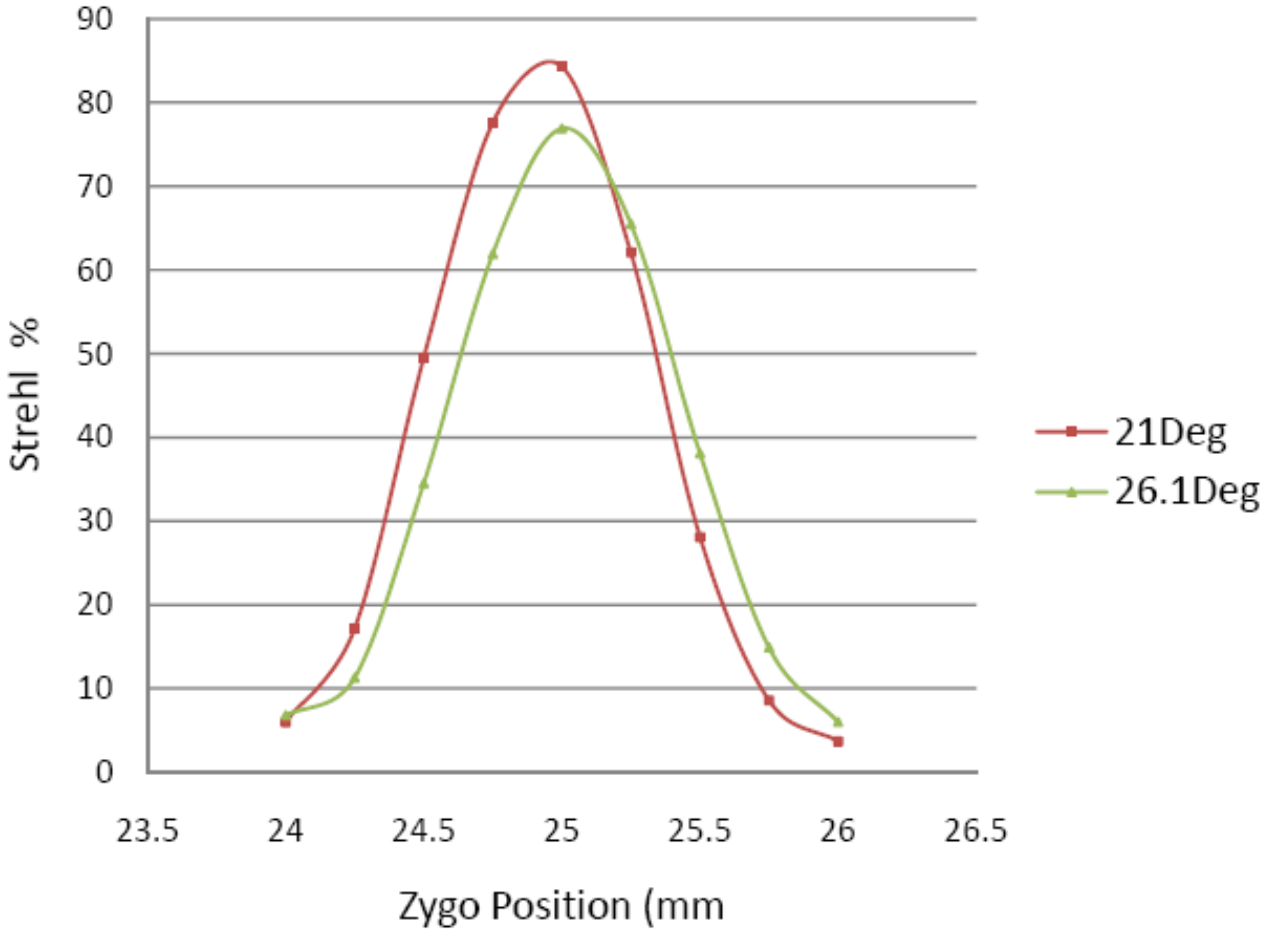
NUV (and VIS) flight resolution

Telescope and detectors combined



NUV/VIS Telescope Thermal Effect on Focus

Strhel @ 632.8nm



UVIT image quality

Channel	FUV	NUV	VIS
Best FWHM (")	1.1	0.9	0.9
Worst FWHM (")	1.2	1.2	1.1

These numbers are better than I had anticipated and are very good news. Spec was 1.8".
Values a little higher for some filters.
With these values, the gratings give R~100 and 200 for first and second order.

- FUV throughout down 5% over 18 months: launch soon!
- Cleanliness, purging, witness samples in plan to monitor this.
- Image quality robust to expected temp changes: heaters installed
- VIS images corrected with lens – match those of UV channels
- Shift and add tested with no FWHM degradation
- Readout pixel edge effects calibrated; drift will sample these

Extended image restoration

Image with all recorded events

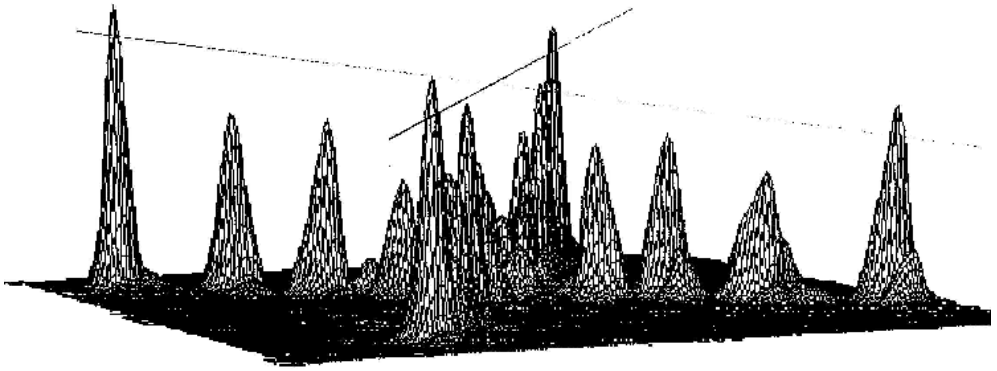


Image with single events only

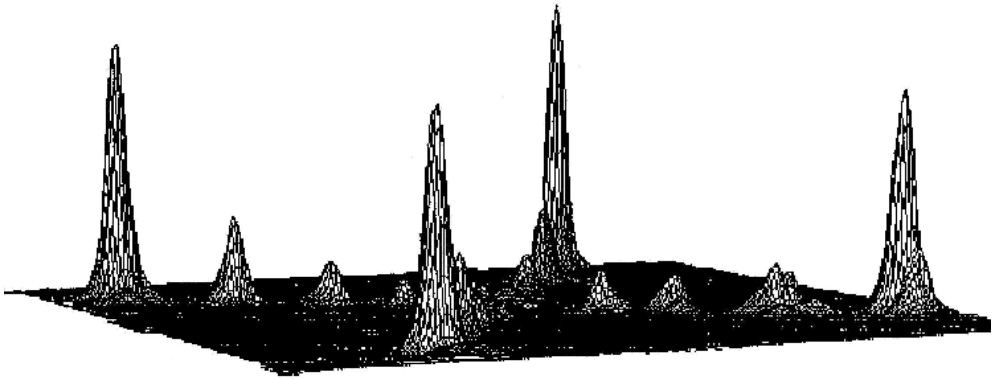
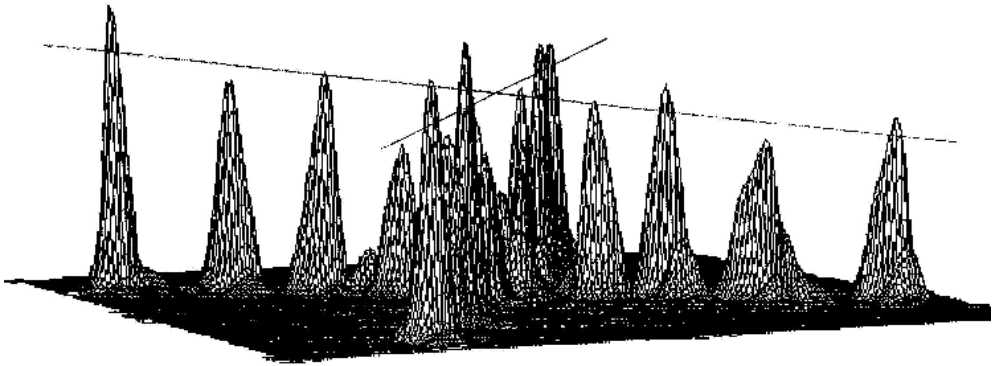
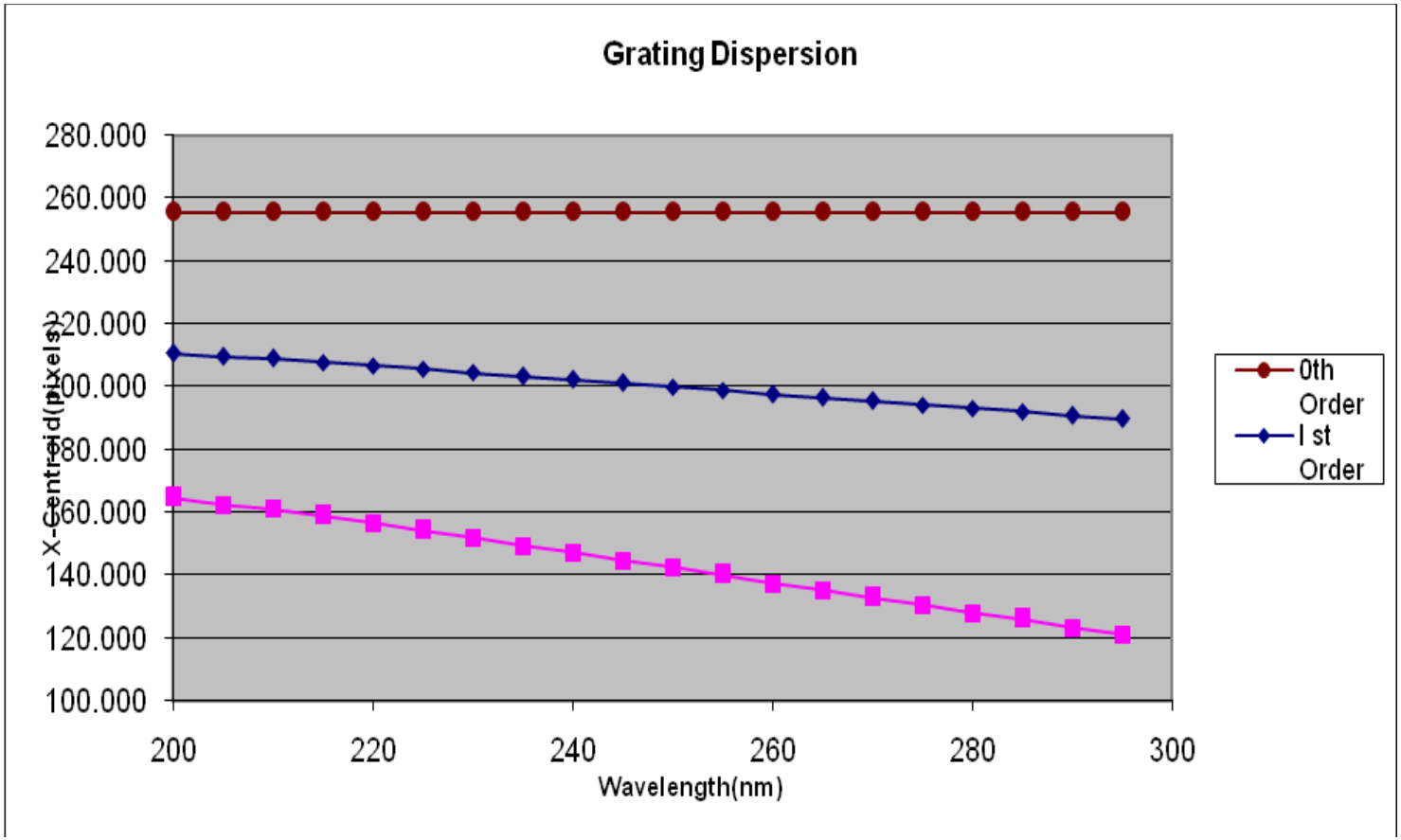


Image with double events restored

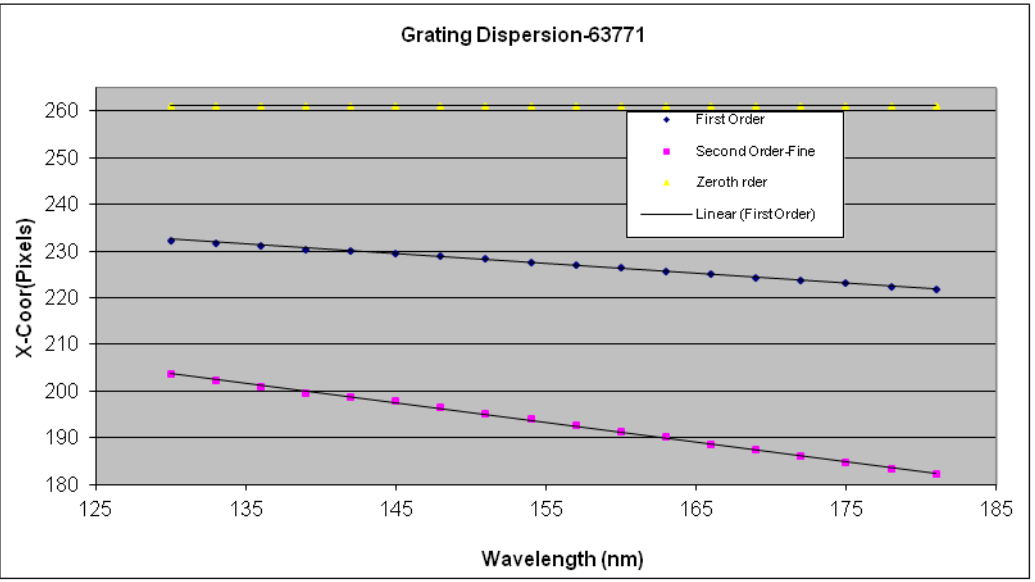


UVIT grating



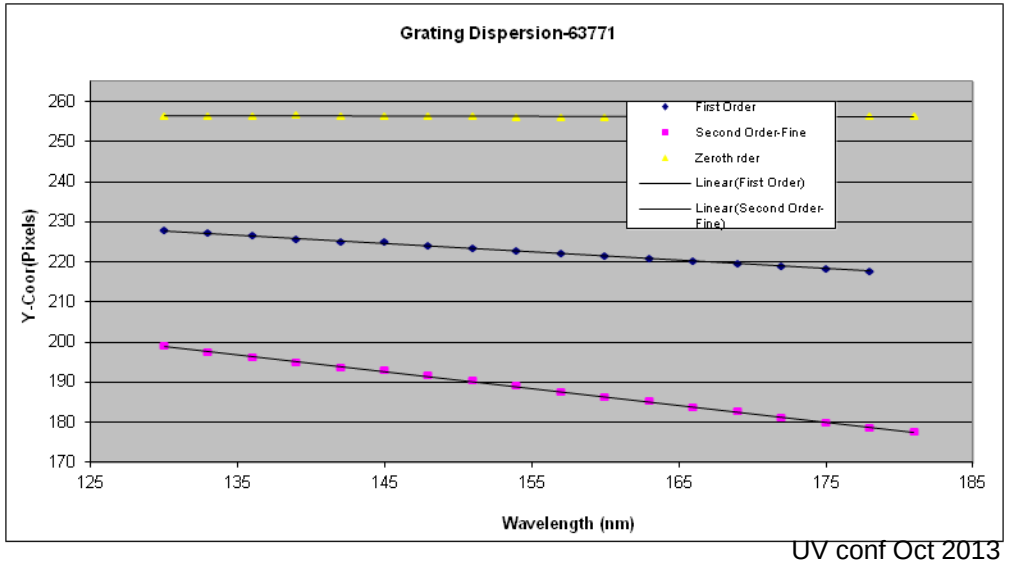
Position of the spots for different orders (0, 1, and 2) are shown for 200 -300 nm.

Grating Test results



Dispersion:

First Order: 4.8nm/Pixel &
Second Order: 2.38nm/Pixel



Dispersion:

First Order: 4.78nm/Pixel &
Second Order: 2.36nm/Pixel

http://oryx.ras.ucalgary.ca//cgi-bin/UVIT.cgi

UVIT Exposure Time Calculator

Source

Point Source

Help

Distance (kpc)

mv 0.5 Distance 0.5 kpc

Radius 7.4 Solar Radii

12.5 m

0 Red Shift

10 R (arcsec)

8 Re (arcsec)

1 n

- (•) Blackbody 50000 Temperature (K)
- ( ) Power Law f(nu)

  1 Alpha nu 1 Normalization (10^{-10} ergs cm^{-2} s^{-1} keV^{-1}) Normalized at 1 keV

  1 Alpha lambda 1 Normalization (10^{-13} ergs cm^{-2} s^{-1} Ang^{-1}) Normalized at 300nm
- ( ) Spectral Type O5V Stellar Properties
- ( ) AGN Linear (norm: V=12.5)
- ( ) Galaxy Bulge (norm: V=12.5)

S/N Warning AGNs & Galaxies

Extinction

- (•) 1 Visual Band Extinction, Av Rv = 3.1
- ( ) 1 Column Density (10^{21} cm^{-2}) Help
- ( ) Distance

Calculate

Source

Point Source

Help

Distance (kpc)

mv 0.5 Distance 0.5 kpc

Radius 7.4 Solar Radii

17 m

0.2 Red Shift

10 R (arcsec)

8 Re (arcsec)

1 n

- Blackbody 50000 Temperature (K)
- Power Law f(nu)
  - 1 Alpha nu 1 Normalization (10^{-10} ergs cm^{-2} s^{-1} keV^{-1}) Normalized at 1 keV
  - 1 Alpha lambda 1 Normalization (10^{-13} ergs cm^{-2} s^{-1} Ang^{-1}) Normalized at 300nm
- Spectral Type O5V Stellar Properties
- AGN Seyfert1 (norm: B=12.5)
- Galaxy Bulge (norm: V=12.5)

S/N Warning AGNs & Galaxies

Extinction

- .05 Visual Band Extinction, Av Rv = 3.1
- 1 Column Density (10^{21} cm^{-2}) Help
- Distance

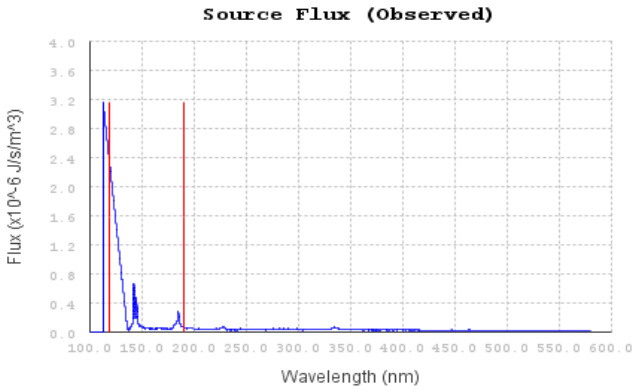
Calculate

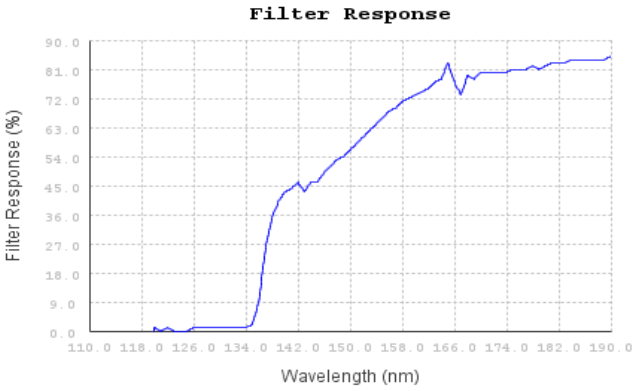
UVIT Filter

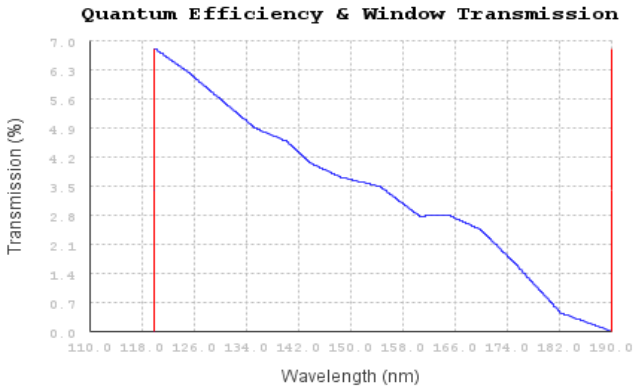
	Cts/frame (29.0Hz)	Time for S/N=10		Cts/frame (29.0Hz)	Time for S/N=10		Cts/frame (29.0Hz)	Time for S/N=10
BaF2 (120-210nm)	9.4e-02	3.4e+02	NUVN1 (184-201nm)	4.2e-03	1.2e+04	VIS1 (319-373nm)	3.1e-01	1.0e+02
Sapphire (120-210nm)	6.9e-02	4.7e+02	NUVB2 (190-240nm)	4.3e-02	7.6e+02	VIS2 (362-417nm)	2.8e-01	1.1e+02
CaF (120-210nm)	6.2e-01	5.0e+01	NUVB3 (220-257nm)	1.7e-01	1.8e+02	VIS3 (383-538nm)	8.5e-01	3.6e+01
MgF (124-210nm)	2.4e-01	1.3e+02	NUVB4 (245-285nm)	1.6e-01	2.0e+02	B (370-510nm)	2.9e-01	1.1e+02
Silica (120-210nm)	2.0e-02	1.8e+03	NUVN2 (270-290nm)	4.1e-02	8.0e+02	1%N.D. (265-560nm)	1.8e-02	2.0e+03

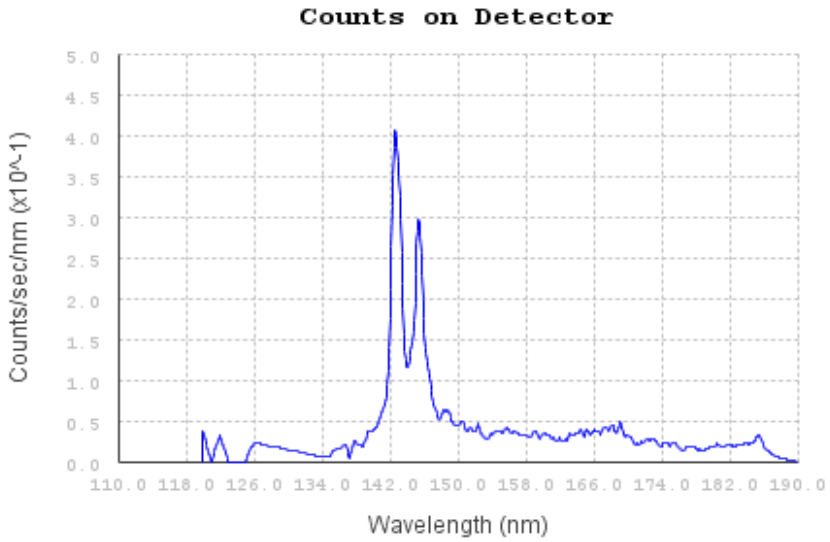
Warning Code

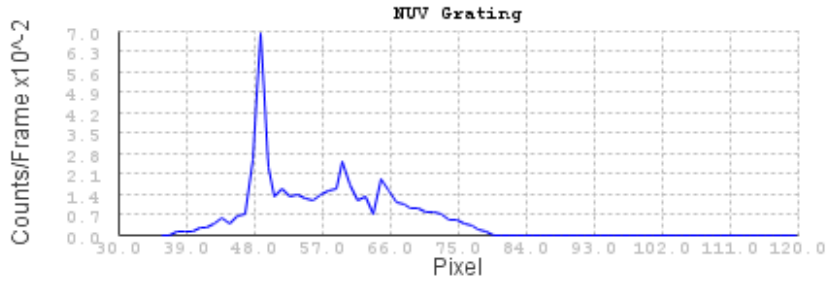
Plots

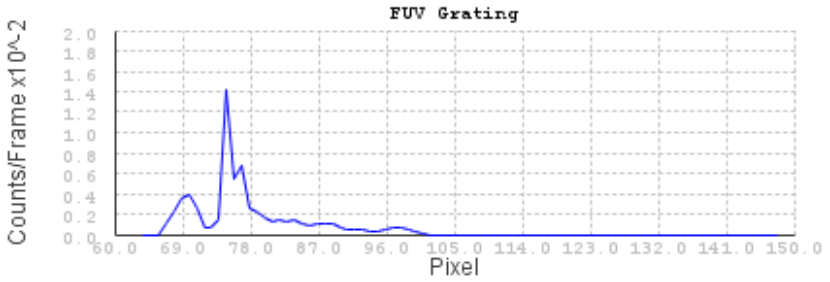


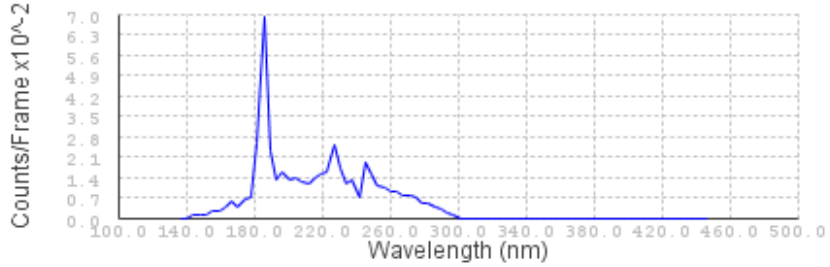


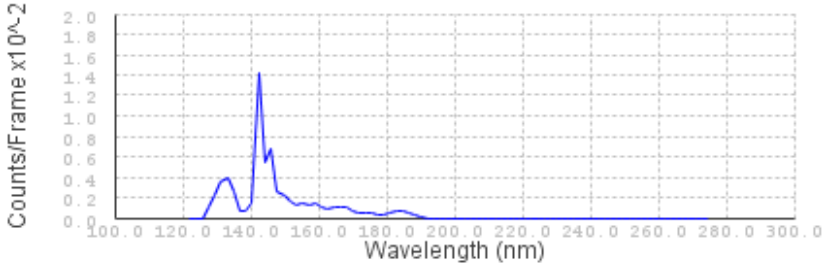



Counts on Detector
Counts/sec/nm (x10^-1)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
110.0 118.0 126.0 134.0 142.0 150.0 158.0 166.0 174.0 182.0 190.0
Wavelength (nm)


NUV Grating
Counts/Frame x10^-2
7.0
6.3
5.6
4.9
4.2
3.5
2.8
2.1
1.4
0.7
0.0
30.0 39.0 48.0 57.0 66.0 75.0 84.0 93.0 102.0 111.0 120.0
Pixel


FUV Grating
Counts/Frame x10^-2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
60.0 69.0 78.0 87.0 96.0 105.0 114.0 123.0 132.0 141.0 150.0
Pixel


Counts/Frame x10^-2
7.0
6.3
5.6
4.9
4.2
3.5
2.8
2.1
1.4
0.7
0.0
100.0 140.0 180.0 220.0 260.0 300.0 340.0 380.0 420.0 460.0 500.0
Wavelength (nm)


Counts/Frame x10^-2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
100.0 120.0 140.0 160.0 180.0 200.0 220.0 240.0 260.0 280.0 300.0
Wavelength (nm)

AGNs

Type	Spectral Coverage(nm)	Normalization	Comment
LINER	123.5 - 755.0	V = 12.5	Spectrum of M81
Seyfert 2	123.5 - 994.5	V = 12.5	Average of spectra
Seyfert 1	113.2 - 707.8	B = 12.5	Spectrum of NGC 5548
QSO	80.0 - 600.0	B = 12.5	Average of spectra
NGC-1068	100.0 - 1100.0	Composite	Model: lines + cont.

Galaxies

Type	Spectral Coverage(nm)	Normalization	Comment
Elliptical	123.5 - 993.5	V = 12.5	
Bulge	123.5 - 754.5	V = 12.5	
S0	123.5 - 994.0	V = 12.5	
Sa	123.5 - 994.0	V = 12.5	
Sb	123.5 - 994.0	V = 12.5	
Sc	123.5 - 766.0	V = 12.5	
Starburst1	123.5 - 994.5	V = 12.5	E(B-V)<0.1
Starburst2	123.5 - 994.5	V = 12.5	0.11
Starburst3	123.5 - 994.5	V = 12.5	0.25
Starburst4	123.5 - 994.5	V = 12.5	0.39
Starburst5	123.5 - 994.5	V = 12.5	0.51
Starburst6	123.5 - 994.5	V = 12.5	0.61

Type	T_{eff}	log_g	Kurucz model
O5V	44500	4.04	kp00_45000[g50]
O6V	41000	+3.99	kp00_40000[g45]
O8V	35800	+3.94	kp00_35000[g40]
B0V	30000	+3.94	kp00_30000[g40]
B3V	18700	+3.94	kp00_19000[g40]
B5V	15400	+4.04	kp00_15000[g40]
B8V	11900	+4.04	kp00_12000[g40]
A0V	9520	+4.14	kp00_9500[g40]
A5V	8200	+4.29	kp00_8250[g45]
F0V	7200	+4.34	kp00_7250[g45]
F5V	6440	+4.34	kp00_6500[g45]
G0V	6030	+4.39	kp00_6000[g45]
G5V	5770	+4.49	kp00_5750[g45]
K0V	5250	+4.49	kp00_5250[g45]
K5V	4350	+4.54	kp00_4250[g45]
M0V	3850	+4.59	kp00_3750[g45]
M2V	3580	+4.64	kp00_3500[g45]
M5V	3240	+4.94	kp00_3500[g50]
B0III	29000	+3.34	kp00_29000[g35]
B5III	15000	+3.49	kp00_15000[g35]
G0III	5850	+2.94	kp00_5750[g30]

etc

RED => Damage to the detector.

YELLOW => Beyond good photometric calibration for full field read rate.

UVIT special strengths

1. **Spatial resolution of ~1"**
   - Resolving stars in crowded fields – local galaxies and globular clusters
   - Structure of distant galaxies
   - Identification of AGN, X-ray sources, GRBs, SN
2. **Suite of filters**
   - Isolate emission line objects
   - Photo-redshifts of distant objects
   - Stellar population diagnosis, M star shells, asteroseismology, nebulae, T-Tau stars
3. **Gratings**
   - Identify/classify hot objects and AGN, Local group massive stars
   - Identify emission line objects
4. **Time resolution**
   - Pulsar timing, eclipse/occultation timing
   - Identify variables
5. **Simultaneous in 3 bands**
   - Variability with wavelength
   - Identify objects over wide wavelength
   - Combine photometry and variability
6. **Simultaneous with X-ray observations**
   - Multi-wavelength monitoring of AGN, X-ray sources, SNR
   - Serendipitous deep fields around X-ray targets
7. **Field of view.**
   - Cover galaxies, clusters, deep fields efficiently, cosmology surveys

Astrosat observing time

Instruments	*PV Phase (6 months)*[3]	*Guaranteed Time (next 6 months)*[4]	*First Year Regular observations*	*Second year Regular observations*	*Third year Regular observations*
X-ray Inst. Teams	67%	4 months	32.5%	20%	-
UVIT Teams	33%	2 months	17.5%	10%	-
Indian proposals	-	-	35%	45%	65%
International proposals	-	-	-	10%	20%
Canada	-	-	5%	5%	5%
LU Team[2]	-	-	3%	3%	3%
TOO	-	-	5%	5%	5%
Calibration time	-	-	2%	2%	2%