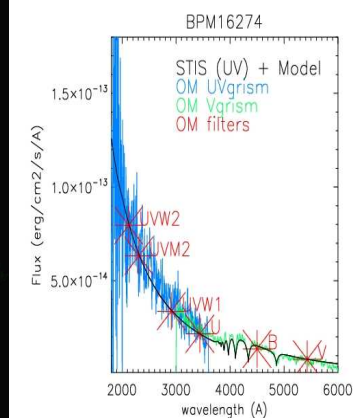
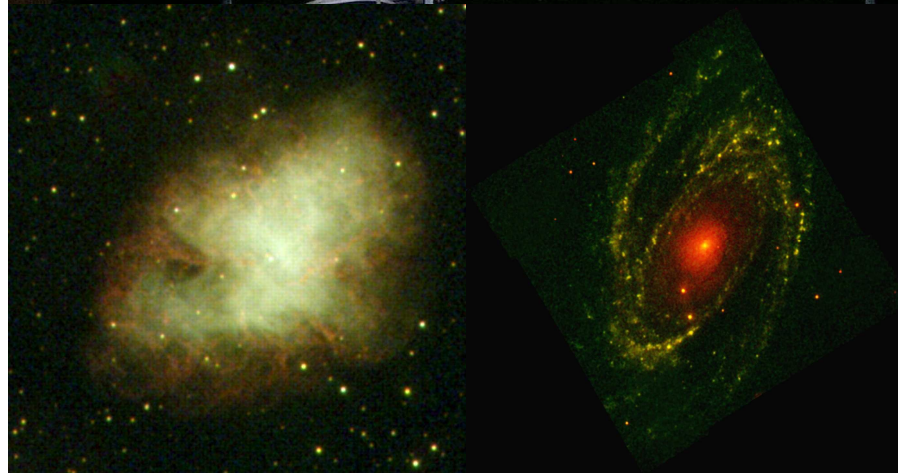
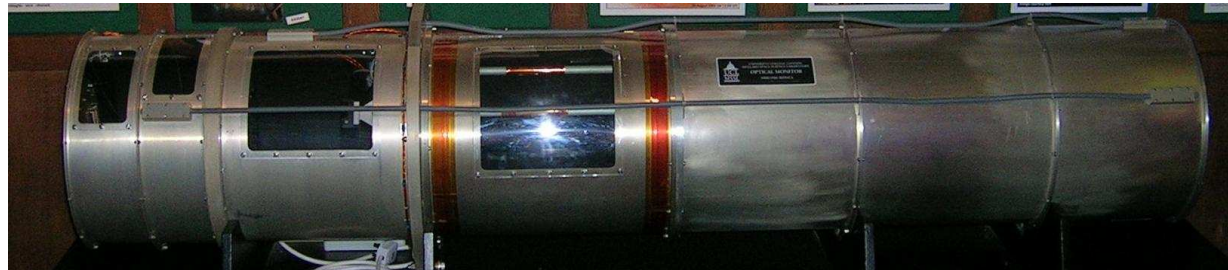


XMM-NEWTON



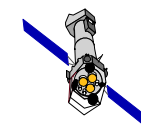
XMM-Newton Optical-UV Monitor: introduction and calibration status



OM instrument and calibration

Antonio Talavera

XMM-Newton Science Operation Centre, RSSD, ESA

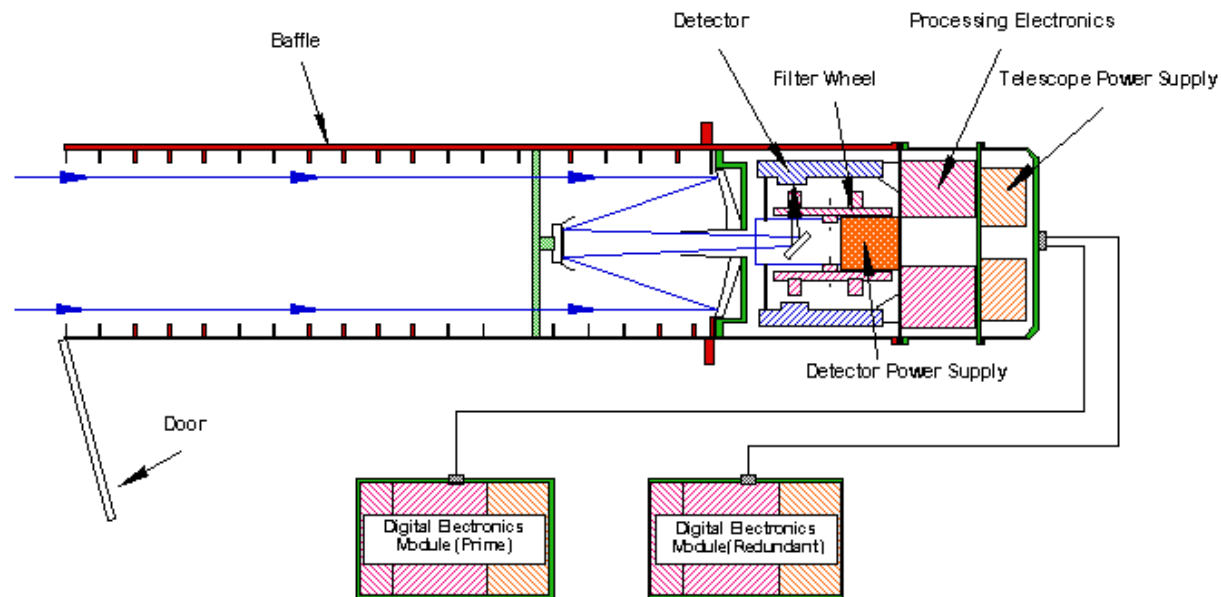


XMM-Newton

Antonio Talavera / XMM-SOC

OM: Instrument Description

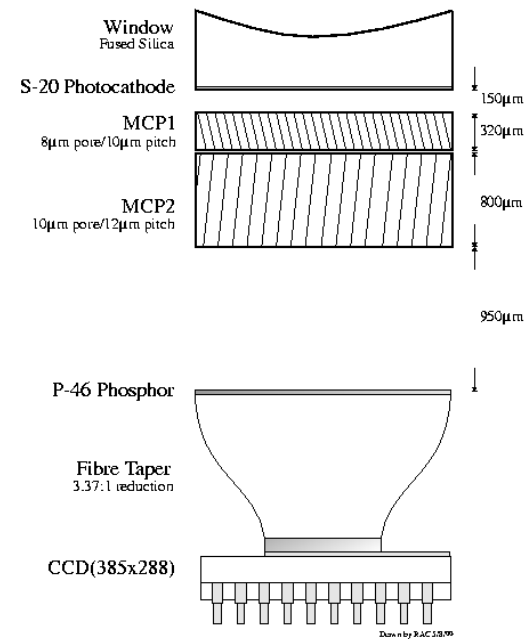
- 30 cm Ritchey-Chretien telescope
- Focal ratio of f/12.7 and focal length of 3.8 m
- Total coverage between 170 nm and 650 nm of a 17 arcmin square field of view
- Filter wheel with 11 apertures: one blanked off, six broad band filters (U, B, V, UVW1, UVM2 and UVW2), one white, one magnifier and two grisms (UV and optical)
- Detector: micro-channel plate intensified CCD (2048 x 2048 pixels final format)



Antonio Talavera / XMM-SOC

OM: Instrument Description

- Detector: micro-channel plate intensified CCD with 384 x 288 physical pixels (Active area 256x256). **Amplification: 10^5**
- Photon events centroided to 1/8 physical pixel (2048 x 2048): **0.5"**
- "Shift and Add" mechanism to compensate S/C drift or jitter
- Fast event timing: **500 ms** in fast mode



Schematic Structure of Detector Head

OM: some examples

Optical and UV



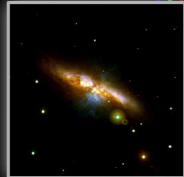
V+B
(540nm, 434 nm)



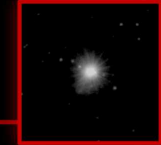
U+UVW1
(348nm, 294nm)



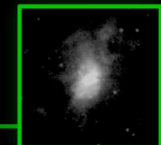
UVM2+UVW2
(234nm, 218nm)



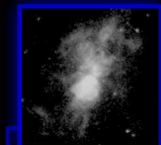
X-Ray



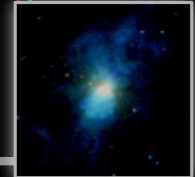
1.2-7.0keV



0.7-1.2keV



0.3-0.7keV

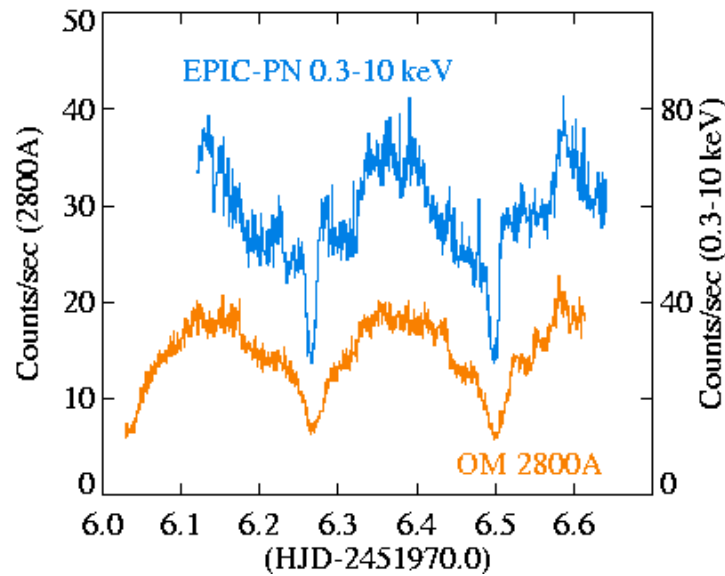


M E S S I E R 8 2

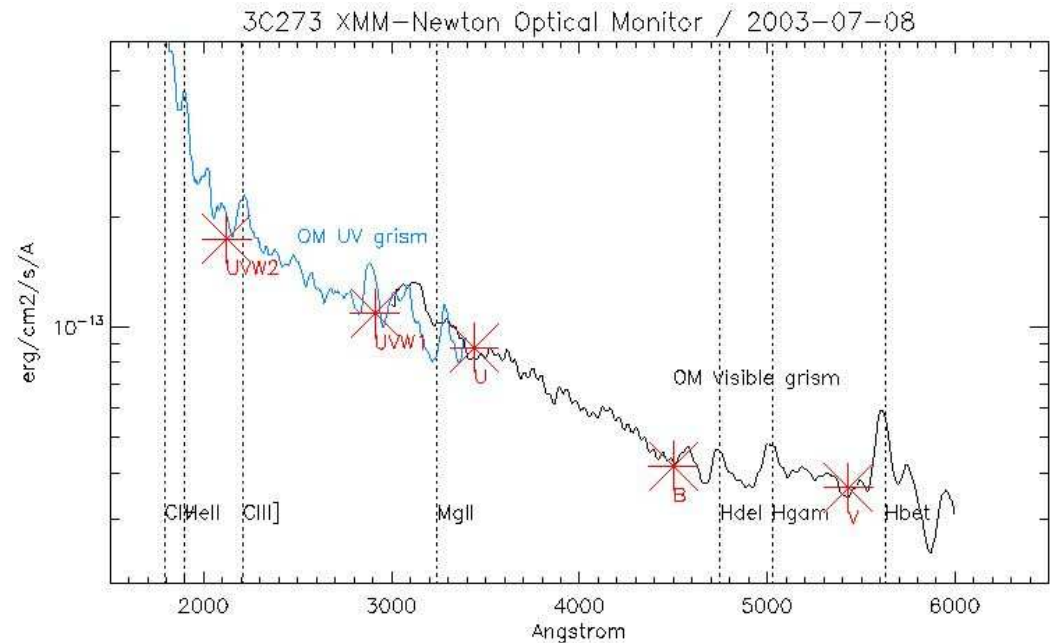
To celebrate the International Year of Astronomy, and as part of the 100 Hours of Astronomy cornerstone project, the European Space Agency is releasing this magnificent image of the starburst galaxy Messier 82 (M82) obtained with the XMM-Newton observatory. The image shows bright knots in the plane of the galaxy, indicating a region of intense star formation, and emerging plumes of supergalactic winds glowing in X-rays.



OM: some examples

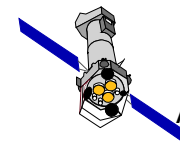
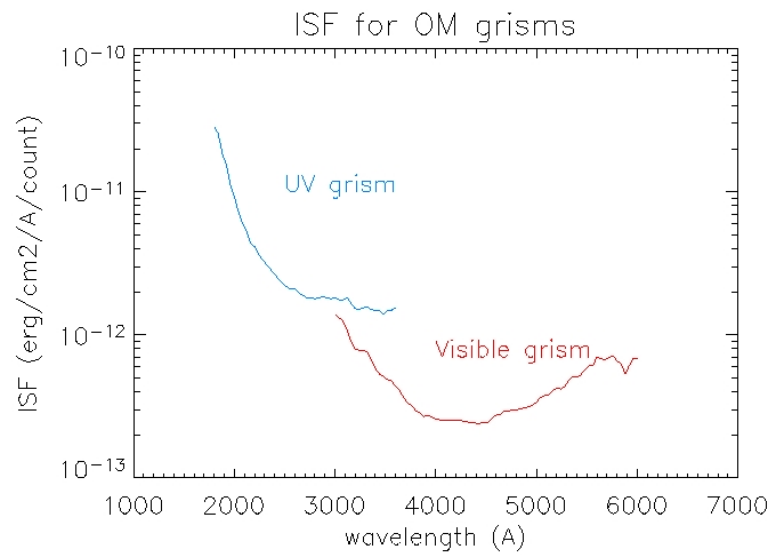
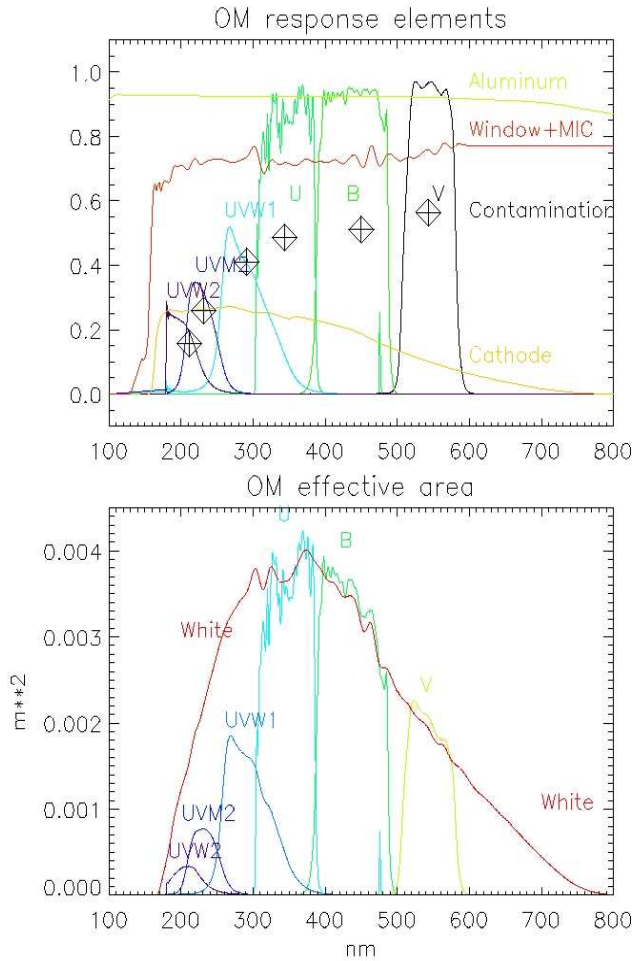


UV & X-ray light curves of X1822-371



Spectral energy distribution of 3C273 with grisms and filters

OM: filters & gratings



OM: operational configuration with filters

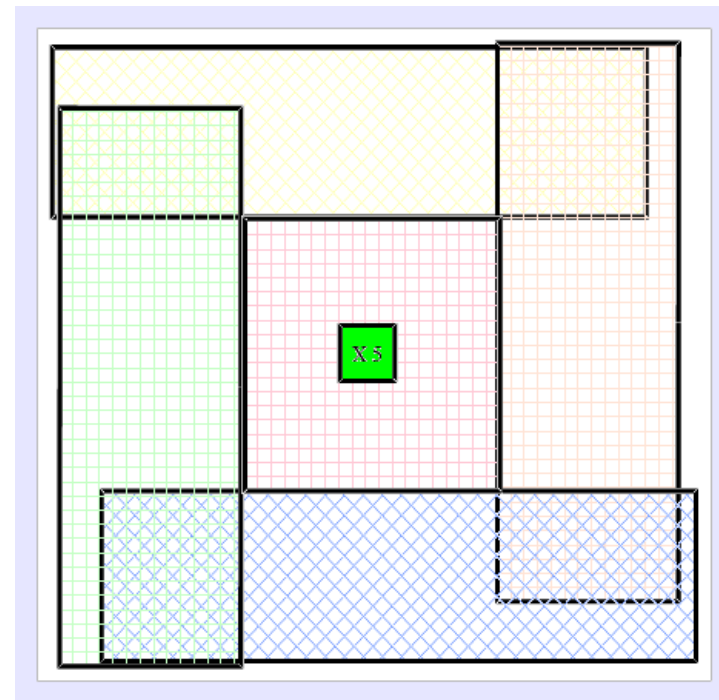
Two basic modes:

- Imaging
- Fast mode (< 512 pix)
- Default image
- Default image + fast mode
- User defined windows (up to 5 windows, 2 in fast mode)
- Full-Frame Low-Resolution
1024 x 1024 1" pixels
- Full-Frame High-resolution
2048 x 2048 0.5" pixels
- Engineering modes
(Eng 0, 1, 3, 4, 5, 6)

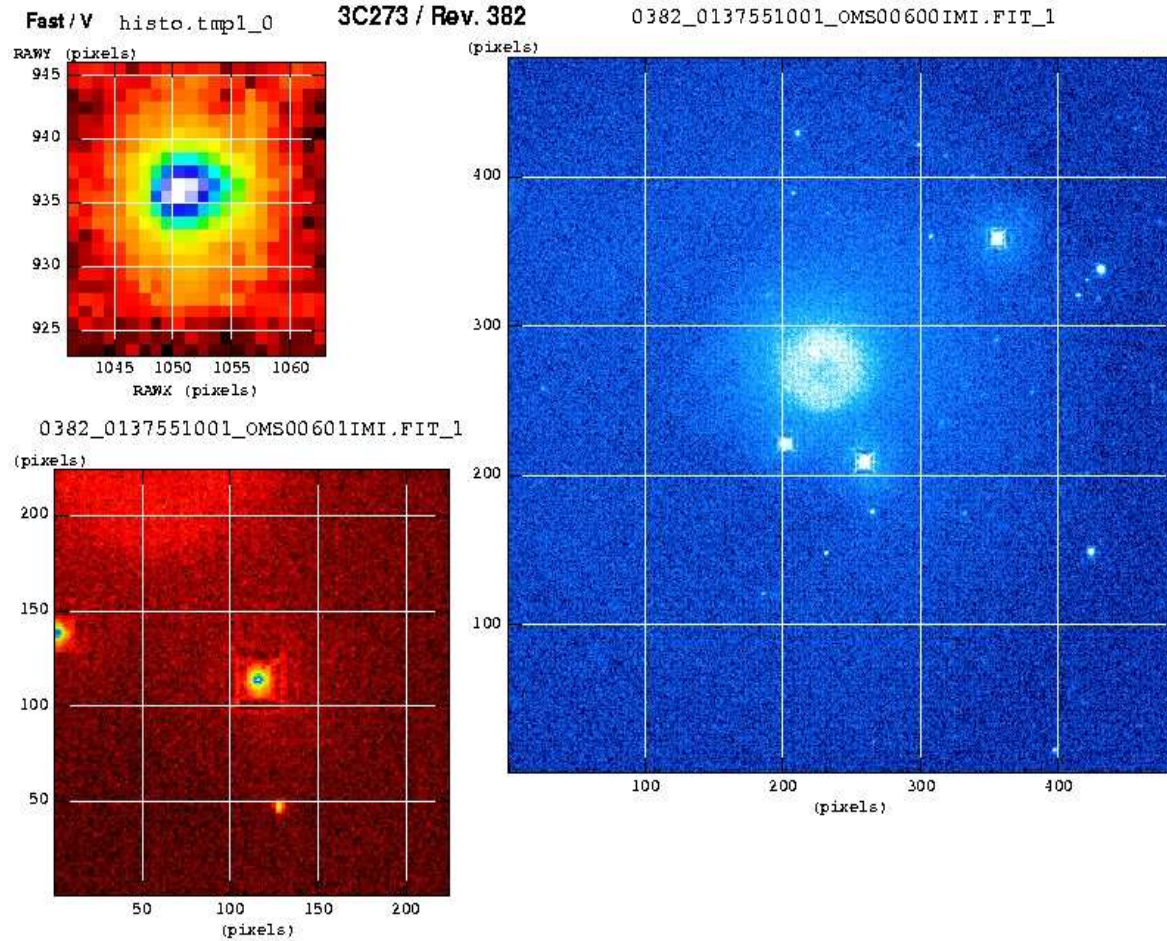
Total number of pixels is limited

Fast window: 22 x 23

Default configuration:

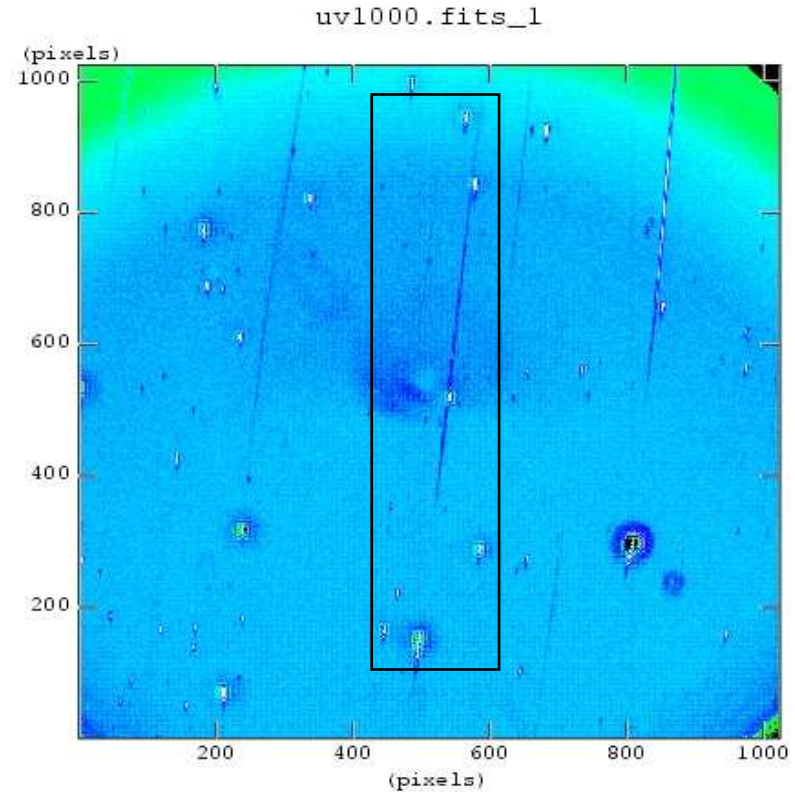
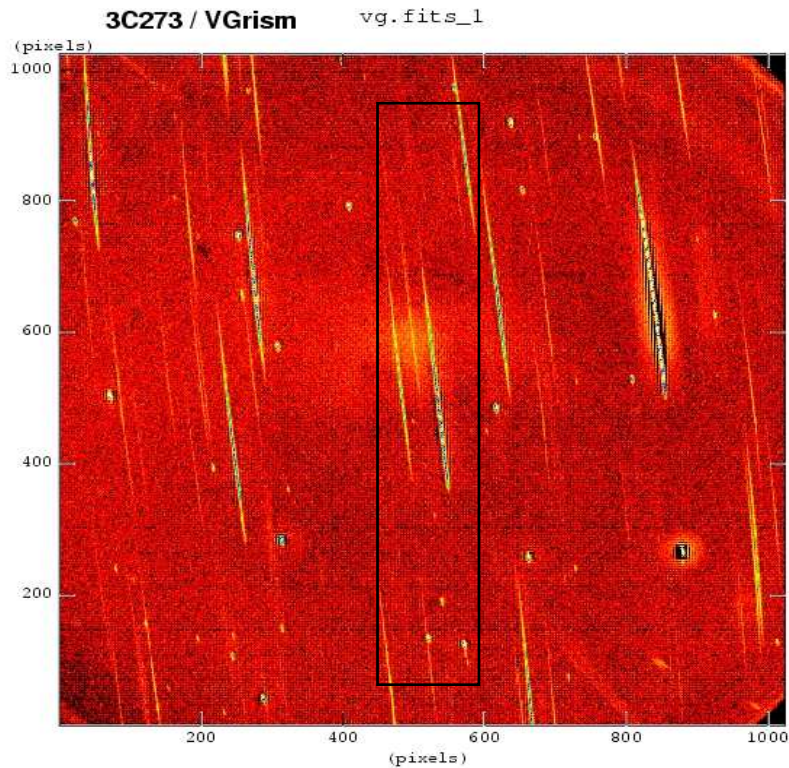


Optical Monitor: default windows

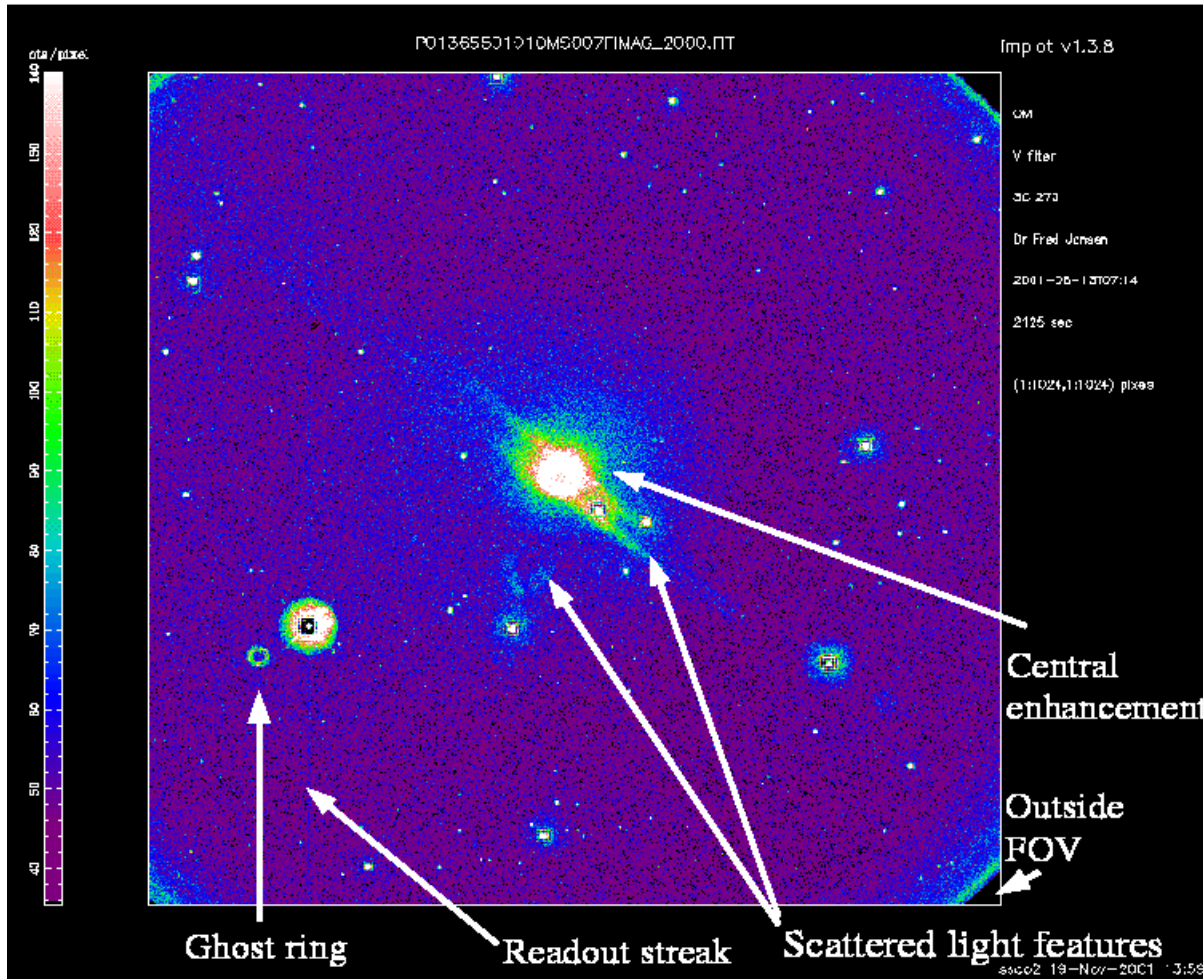


OM: operational configuration with gratings

- Single object spectroscopy:
target at the boresight
- Field spectroscopy:
all objects in the f.o.v.



Artifacts in OM images



- Straylight loops
- Central bright patch
- Ghost images
- Streaks

Optical Monitor calibration: what is it?

Instrumental corrections

- Astrometry: Geometric distortion, Boresight
- Photometry: Measuring the count rate of detected sources
 - aperture
 - PSF
 - coincidence losses and dead time
 - time sensitivity degradation
 - cosmetic (bad pixels)
 - *flat field (not applied in OM)*
- Spectroscopy: Measuring the count rate of the source as a function of wavelength
 - geometry: distortion, rotation
 - modulo_8
 - wavelength
 - flux

All corrections are included into OM data processing through corresponding SAS CCFs

Optical Monitor calibration: what is it?

PHOTOMETRY:

Magnitudes: the origin

- $m_1 - m_2 = -2.5 \log (F_1/F_2)$ **F2 = Reference = Standard star = Vega**
- $m_1 = -2.5 \log F_1 + \text{Zero_point}$ **Zero_point = $m_2 + 2.5 \log F_2$**
- $m \text{ (OM)} = -2.5 \log F(\text{OM}) + \text{Z_OM}$ **Z_OM = magnitude producing 1 count/s**

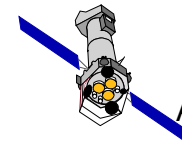
- Standard System: UBV (Johnson) \Leftrightarrow OM system (U, B & V filters)

Magnitudes & colors \Rightarrow Physical parameters, models,.....

Absolute Fluxes: modern photometry & spectrophotometry

- from magnitude to flux through Vega
- direct transformation: $F(\lambda) = K(\lambda) * \text{OM}(\lambda)$ **K(λ): from spectrophotometric standard stars**
K(λ) = instrumental response (= response matrix) \Rightarrow average K per filter

Absolute fluxes \Rightarrow Physical parameters, models,.....



XMM-Newton

Antonio Talavera / XMM-SOC

Optical Monitor calibration: what is it?

SPECTROSCOPY:

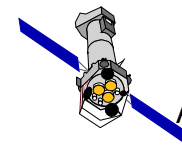
- dispersed light \Rightarrow wavelength scale
- spectral energy distribution \Rightarrow flux scale: **Inverse Sensitivity Function (ISF)**

$$\text{ISF}(\lambda) = F_{\text{std}}(\lambda) / \text{CR}_{\text{std}}(\lambda)$$

$$F_{\text{obs}}(\lambda) = \text{CRObs}(\lambda) \times \text{ISF}(\lambda)$$

ASTROMETRY:

- from detector X, Y to R.A. & Dec : S/C attitude, OM boresight, OM geometry
- refinement through x-correlation with catalogue (USNO)
- grisms: from zero order detector position to R.A. & Dec



OM photometry: zero points

Zero points for Zero epoch

The definition of the zero point (magnitude giving one count per second) can be given as:

$$\text{Zero_point} = m_{\text{vega}} + 2.5 \cdot \log_{10}(\text{count_rate}_{\text{vega}})$$

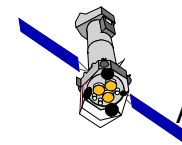
The count rate of Vega is obtained through simulations

Zero points for OM instrumental system (at zero epoch)

17.9502	19.2429	18.1979	17.2038	15.7724	14.8667
V	B	U	UVW1	UVM2	UVW2

(Zero points, corrected to Johnson UBV are:

17.9633 19.2661 18.2593)



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AB magnitude system for OM

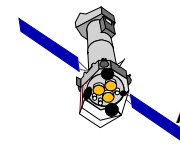
An input spectrum of 1 erg/s/cm²/hz gives a photon rate in each filter, n_phot.

The zero points in AB system are defined as:

$$\text{Zero_point} = - 48.60 - 2.5 * \log(1./n_phot)$$

Zero points in AB system for OM (at zero epoch)

17.9230	19.0809	19.1890	18.5662	17.4120	16.5719
V	B	U	UVW1	UVM2	UVW2



OM counts to flux conversion based in white dwarfs

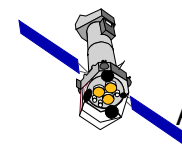
Count rate to flux conversion (from WD's)

uvw2	uvm2	uvw1	u	b	v
2120.	2310.	2910.	3440.	4500.	5430.
$5.71e-15, 2.20e-15, 4.76e-16, 1.94e-16, 1.29e-16, 2.49e-16$					

This gives erg/cm²/s/Å

the relative errors (stdev/mean) are :

0.054 0.0401 0.068 0.042 0.068 0.013



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OM counts to flux conversion from White Dwarfs versus Pickles and BPGS spectral libraries

Pickles library

Filter	A0V	B0V	F0V	G0V	K0V	M0V	Vega
V	2.50E-16	2.48E-16	2.52E-16	2.54E-16	2.56E-16	2.65E-16	2.50E-16
B	1.36E-16	1.16E-16	1.41E-16	1.53E-16	1.60E-16	1.81E-16	1.34E-16
U	1.71E-16	1.94E-16	1.80E-16	1.83E-16	1.88E-16	2.01E-16	1.70E-16
UVW1	4.96E-16	4.72E-16	4.96E-16	4.51E-16	3.88E-16	1.09E-16	4.86E-16
UVM2	2.20E-15	2.14E-15	2.10E-15	1.84E-15	1.66E-15	n.a.	2.19E-15
UVW2	6.06E-15	5.56E-15	7.15E-15	6.05E-15	5.76E-16	n.a.	5.88E-15

BPGS library

Filter	A0V	B0Ib	F0IV	G0V	K0V	M0V
V	2.48E-16	2.50E-16	2.50E-16	2.55E-16	2.56E-16	2.61E-16
B	1.29E-16	1.17E-16	1.38E-16	1.44E-16	1.55E-16	1.80E-16
U	1.66E-16	1.97E-16	1.77E-16	1.88E-16	1.85E-16	1.94E-16
UVW1	4.79E-16	4.76E-16	4.84E-16	5.02E-16	5.15E-16	3.14E-16
UVM2	2.15E-15	2.17E-15	2.18E-15	2.27E-15	2.02E-15	1.42E-15
UVW2	5.56E-15	5.25E-15	6.14E-15	6.50E-15	6.34E-15	2.46E-15

WD's

2.49E-16

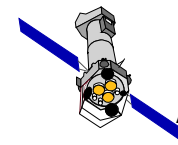
1.29E-16

1.94E-16

4.76E-16

2.20E-15

5.71E-15



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OM fluxes in AB system

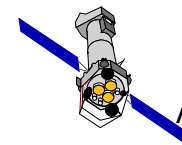
If n_{phot} is the number of photons produced by 1 erg input spectrum, then $1/n_{\text{phot}}$ is the rate to flux conversion factor (in frequency space).

Count rate to flux conversion in AB system (frequency)

uvw2	uvm2	uvw1	u	b	v
2120.	2310.	2910.	3440.	4500.	5430.
8.535e-27	3.937e-27	1.360e-27	7.663e-28	8.465e-28	2.459e-27

This gives erg/cm²/s/hz

Note that the effective frequency of a filter can be any within the filter range since the flux is constant. Even if we are in frequency space, we can characterise the filter by its effective wavelength.



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OM fluxes in AB system

We can then convert these factors to lambda space by multiplying by (c / λ^2) and we get:

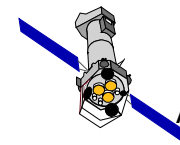
Count rate to flux conversion in AB system (λ)

uvw2	uvm2	uvw1	u	b	v
2120.	2310.	2910.	3440.	4500.	5430.
5.70e-15	2.21e-15	4.82e-16	1.94e-16	1.25e-16	2.50e-16

This gives $\text{erg/cm}^2/\text{s}/\text{\AA}$

Not surprisingly, if we compare these last factors with the ones derived directly from WD's fluxes, we have:

1.002	0.994	0.988	0.999	1.029	0.995
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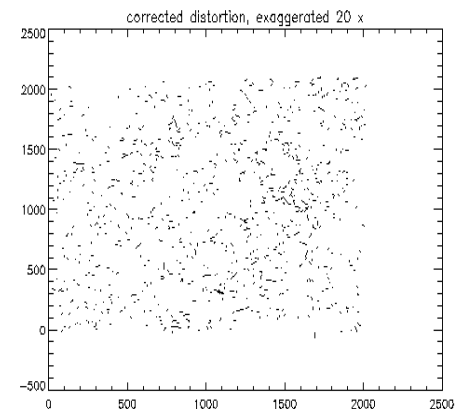
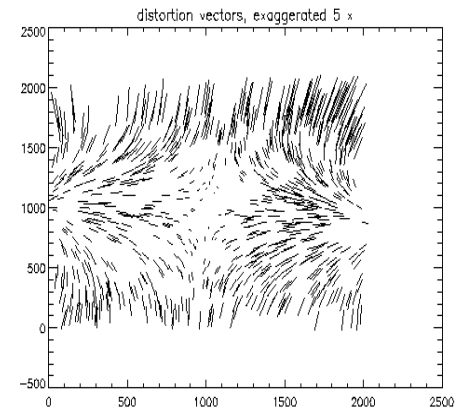


XMM-Newton

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OM Astrometry

- Geometric distortion
 - distortion map derived from OM image using more than 800 stars
 - it corrects positions to 0.7" rms error
- SAS provides RA & Dec for all sources detected in OM images - from X_Y, AHF (star tracker) & boresight information.
- Additional cross-correlation (in SAS) with USNO catalogue allows us to improve the coordinates:
 - Using the new boresight:
 - RMS offset from USNO < 1.5"



OM grisms calibration

Wavelength calibration:

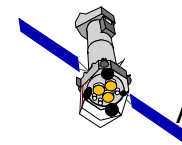
- F-type stars: HD 221996, HD 224317 (V & UV grisms, low & high resolution)
HD 13499, HD 13434 (V & UV grisms, low resolution, across FOV)
(Field stars at different positions in FOV (V & UV grisms))
- White dwarfs with Hydrogen lines (BPM 16274, GD50,...) (for V-grism)

Flux calibration:

- Spectrophotometric standard stars (WD):
GD 153, HZ 2

Grisms distortion:

- 3C273
- other science observations



XMM-Newton

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OM grisms calibration: wavelength

- The wavelength scale: **anchor point** → **zero order**

Measuring zero-order position: it can be predicted for User Def. observing windows, (with less accuracy for full frame images), and then refined by centroiding algorithm

- Wavelength range:

- Vis-grism: 3000 - 6000 Å
- UV-grism: 1800 - 3600 Å (second order contamination)

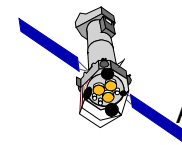
(the range could be extended, but not the flux calibration)

- Wavelength scales

UV: $\lambda \text{ (Å)} = 991.778 + 1.8656 X + 0.0007713 X^2$ (X : pixels from zero order)

Vis: $\lambda \text{ (Å)} = 200.898 + 5.626 X$

- internal error: < 7 Å (UV)
- global shift due to zero order position: about +/- 10 Å

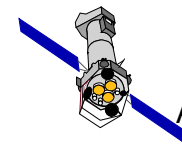


XMM-Newton

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OM grisms data calibration: wavelength

- Wavelength scale variations across f.o.v.:
 - HD 13499 offset observations and field stars in fflr science observations:
 - **Wavelength shift on right hand part of the image: up to 50 A**
- Resolution : **limited by mod_8**
 - UV grism: better than 15 A @ 2600 A (from NGC 40 observations)
 - V grism: worst than UV
 - **Mod_8 is stronger in V grism (because of higher response)**



OM grisms data calibration: flux

The Flux scale:

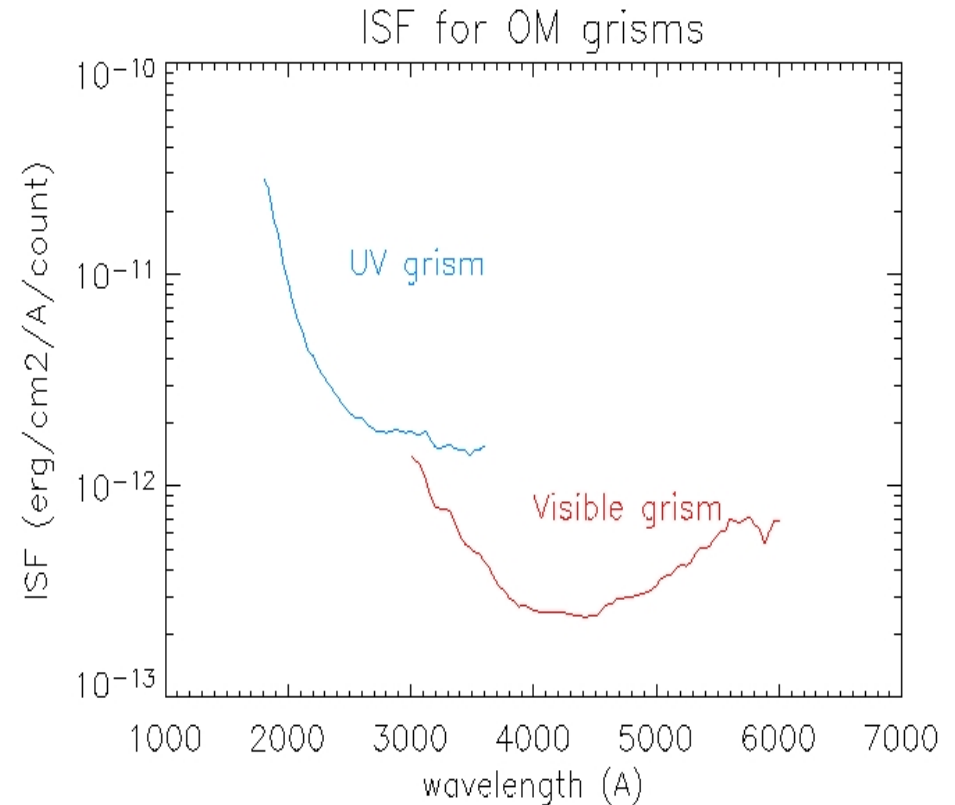
Inverse Sensitivity Function (ISF)

$$\text{ISF}(\lambda) = F_{\text{std}}(\lambda) / \text{CR}_{\text{std}}(\lambda)$$

$$F_{\text{obs}}(\lambda) = \text{CRObs}(\lambda) \times \text{ISF}(\lambda)$$

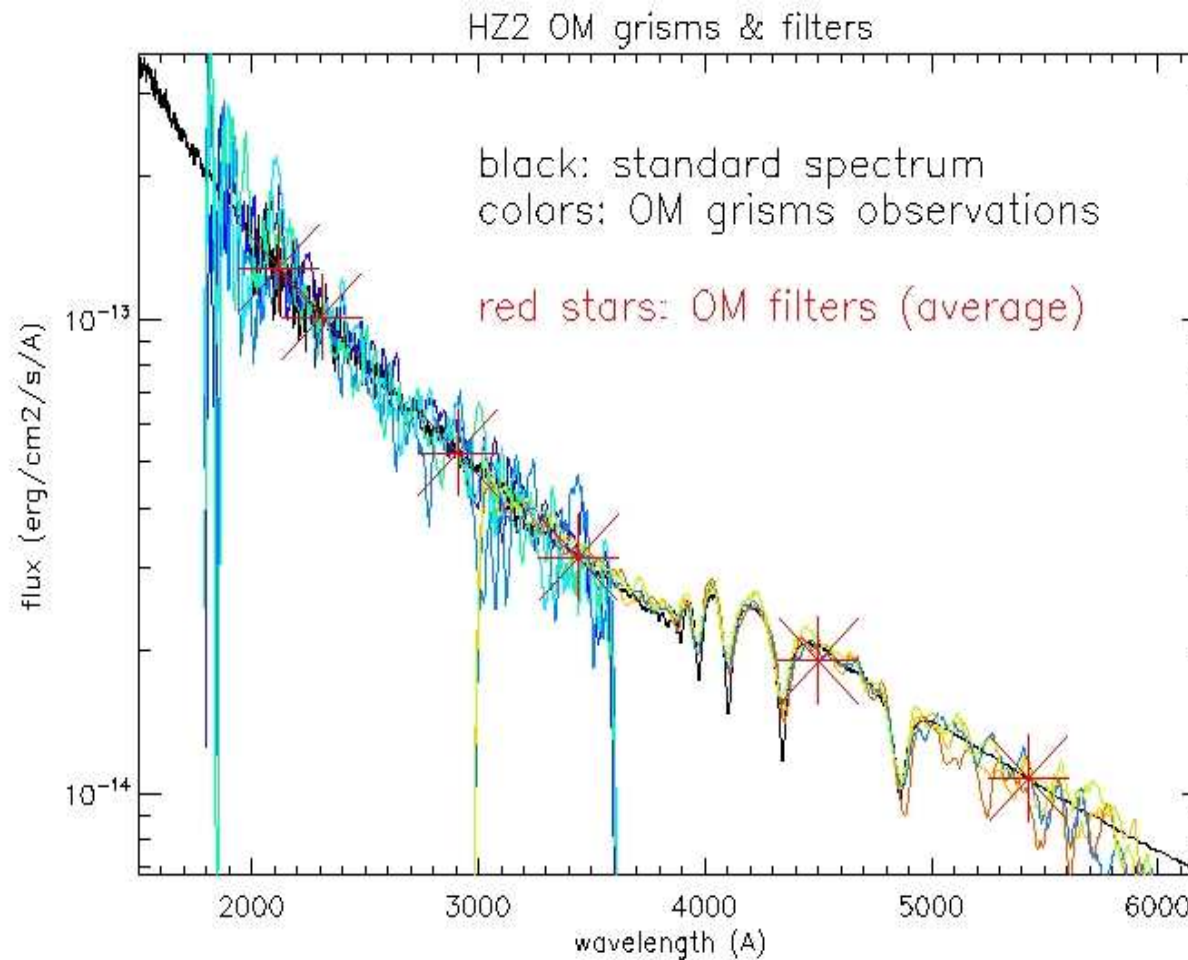
OM_GRISM CAL_0004.CCF

- Flux accuracy: **around 10%** (slightly worst at long wavelength end of V_grism)
- UV and V common range: **excellent agreement!!!**
- V, B, U, UVW1, UVM2, UVW2 versus Grisms: **excellent agreement!!!**
- Time sensitivity variation: **< 1% p.a.**

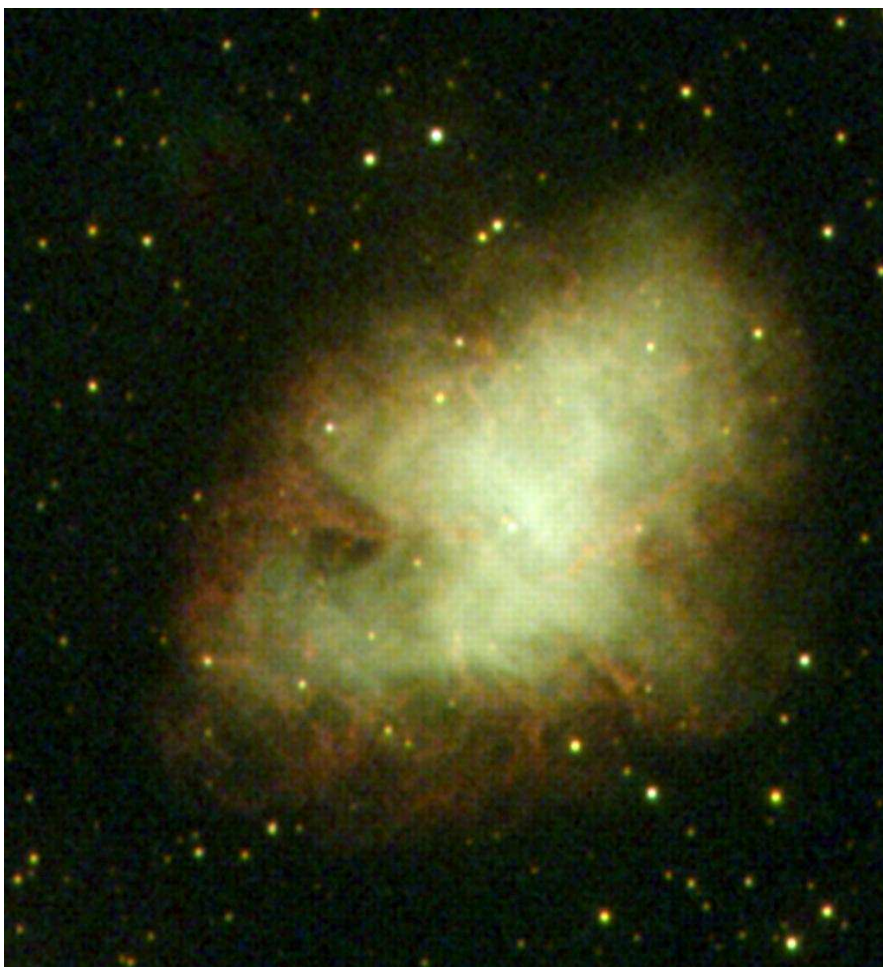


OM grisms data reduction with SAS

HZ 2



The Crab: OM(231, 291, 344 nm) versus composite X_opt_radio

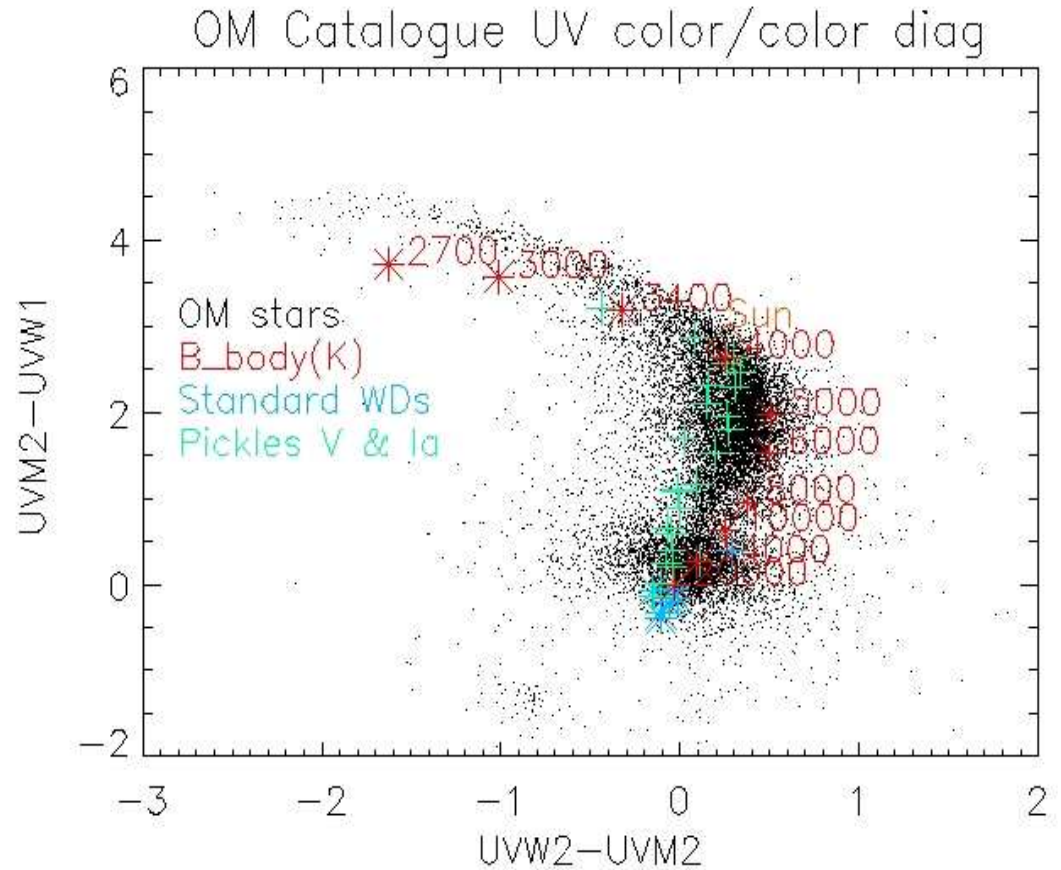


OM filter	Count rate	AB mag	AB Flux (erg/cm ² /s/Å)
UVW2	0.12	18.84	7.05e-16
UVM2	0.29	18.74	6.49e-16
UVW1	1.89	17.88	9.11e-16
U	5.18	17.40	1.00e-15



OM Catalogue

- Sources catalogue
(at least one UV measurement)
- Homogeneous processing
(XSA)
- Available through XSA
- 2417 observations
- 753,578 sources
- 21974 sources with all UV filters
- 1628 sources with all OM filters



OM Catalogue

