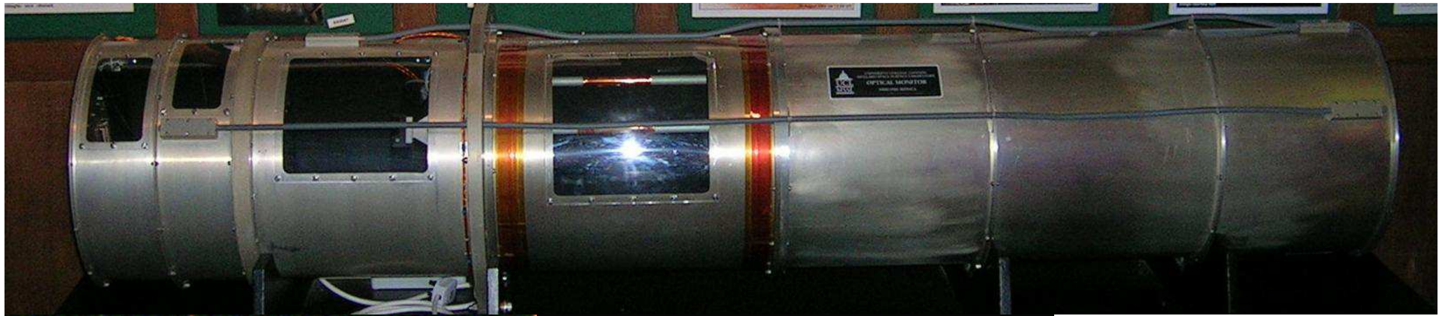
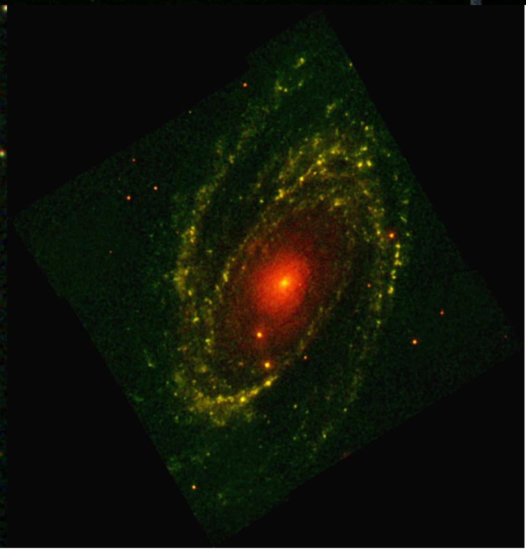
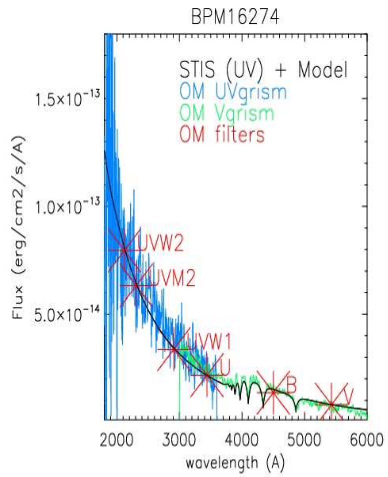
XMM-Newton Optical-UV Monitor: introduction and calibration status







OM instrument and calibration

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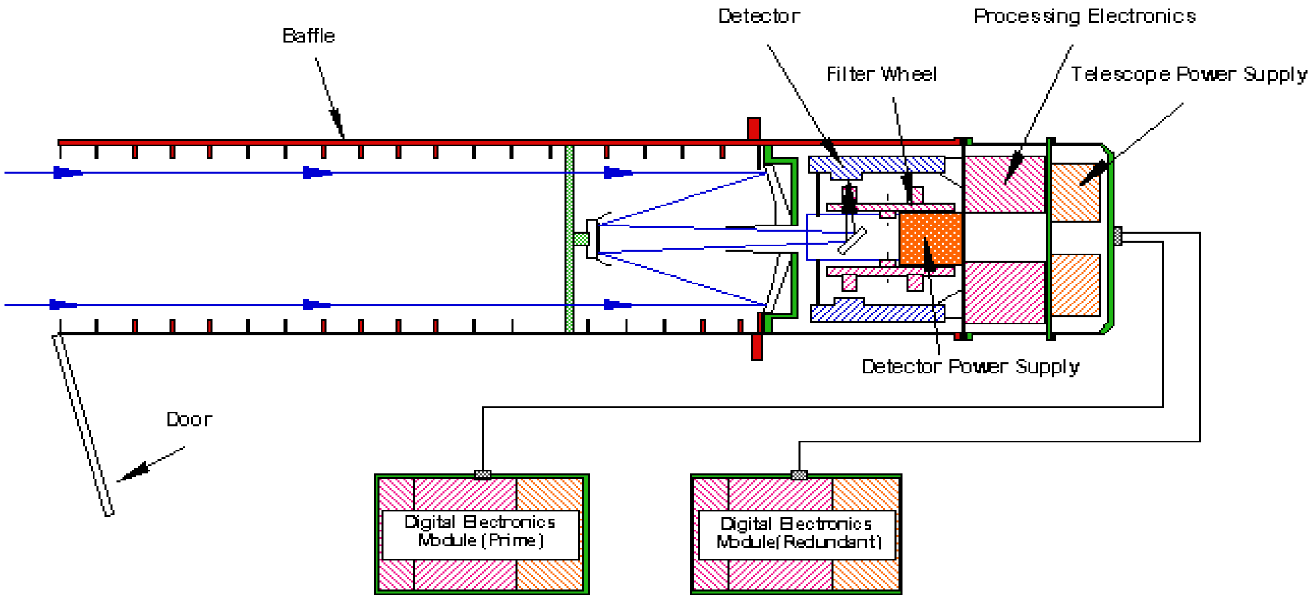
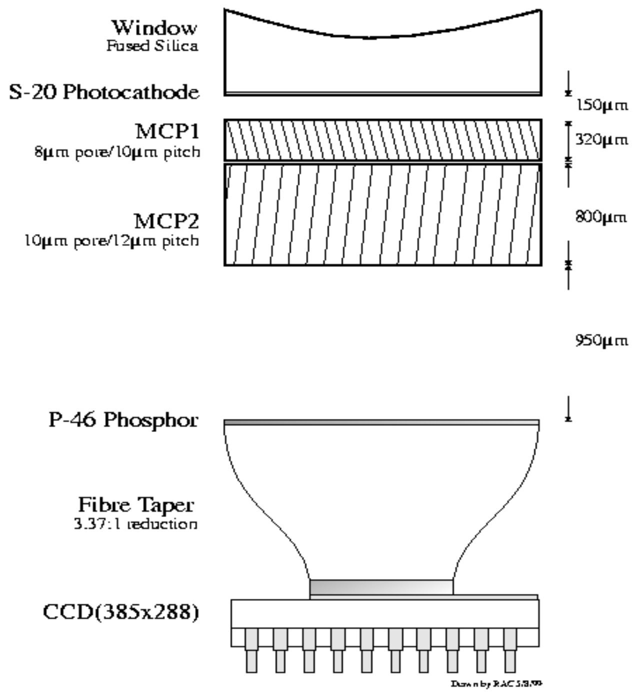
OM: Instrument Description

- 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)



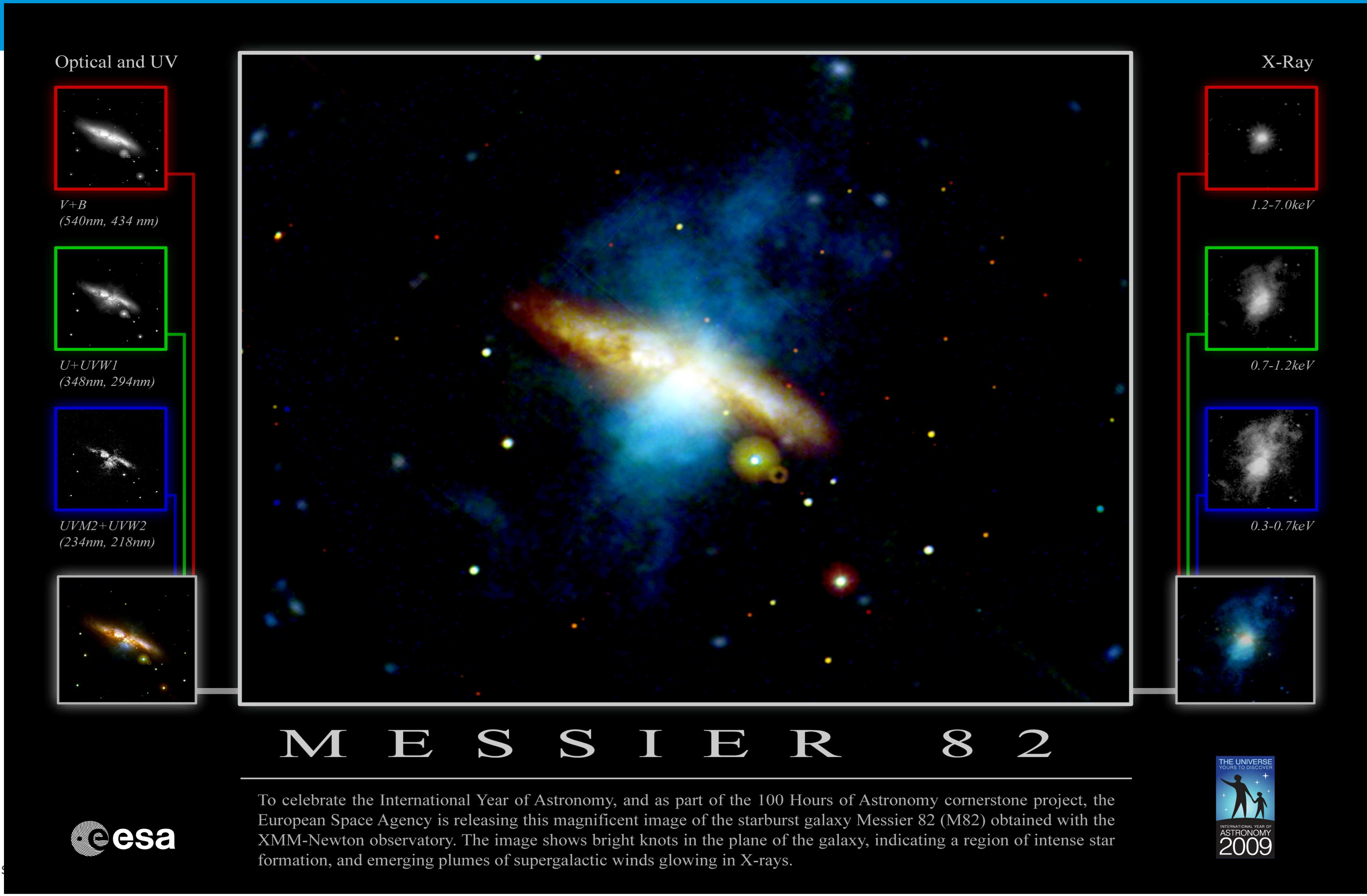
OM: Instrument Description

- 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

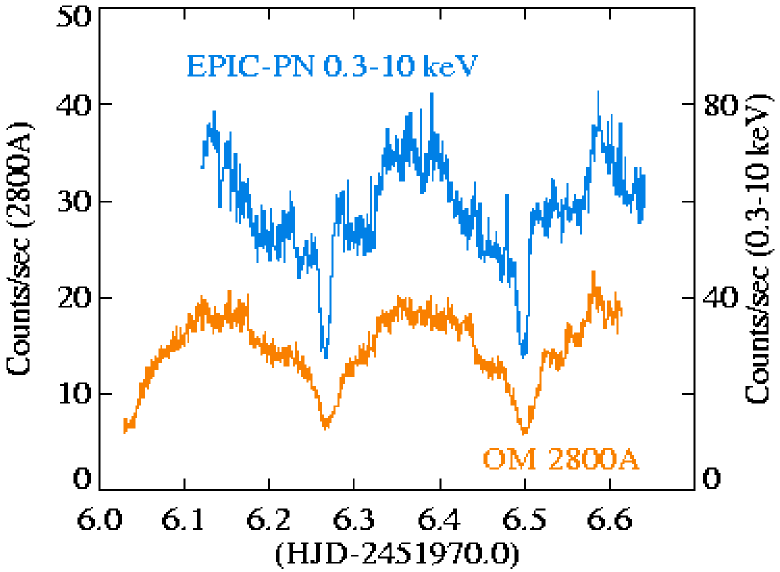


Schematic Structure of Detector Head

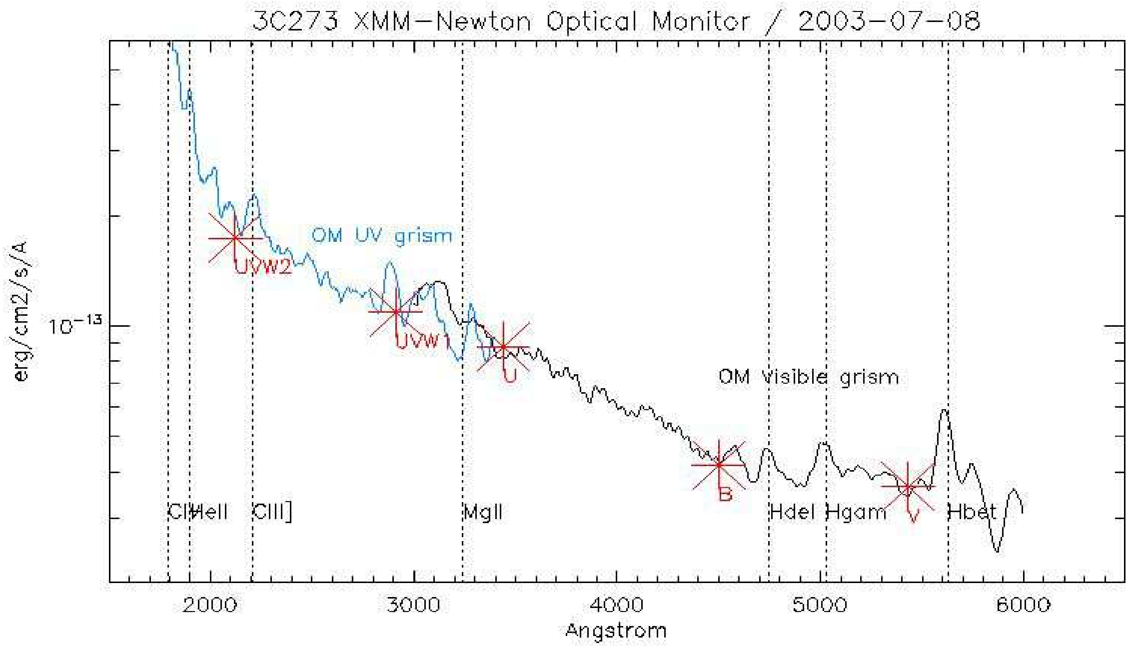
OM: some examples



OM: some examples

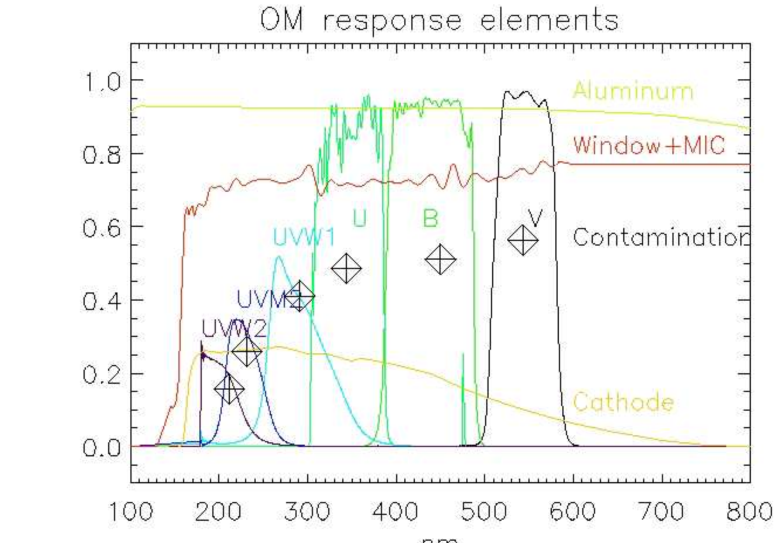


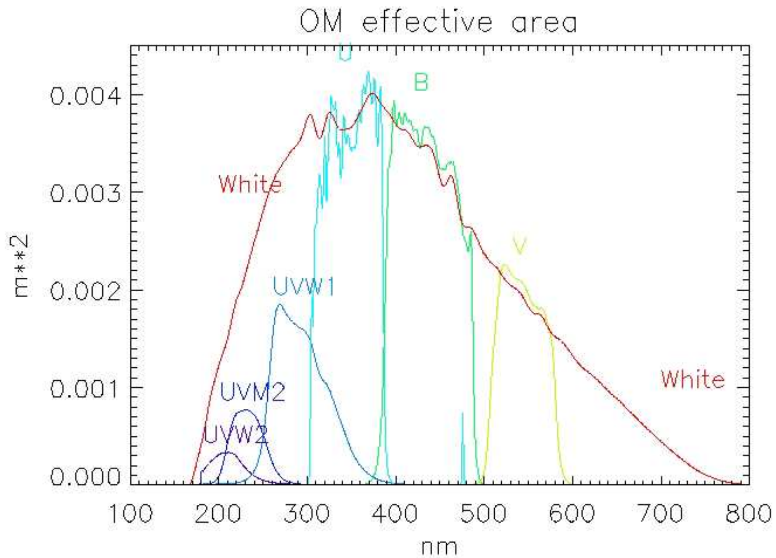
UV & X-ray light curves of X1822-371

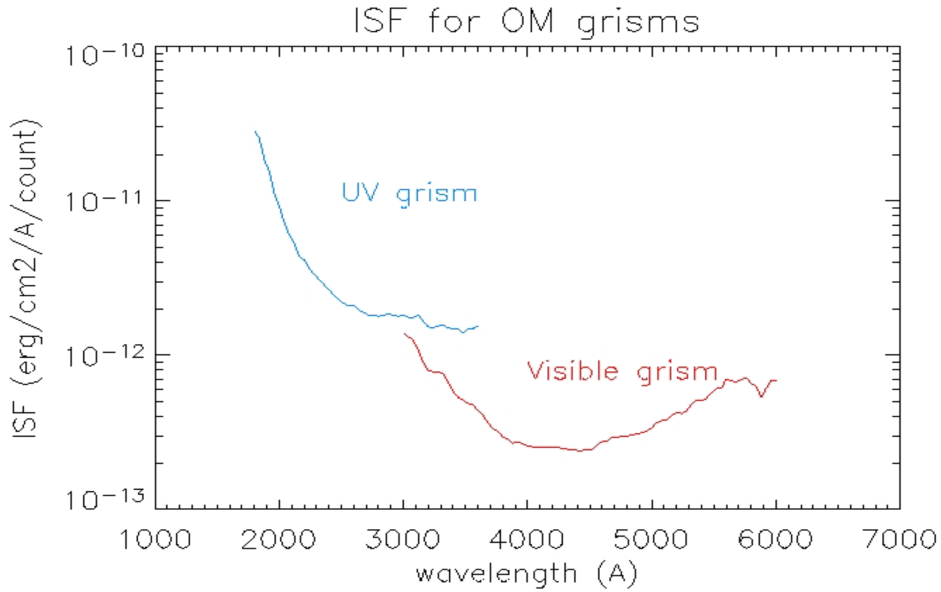


Spectral energy distribution of 3C273 with grisms and filters

OM: filters & grisms







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**

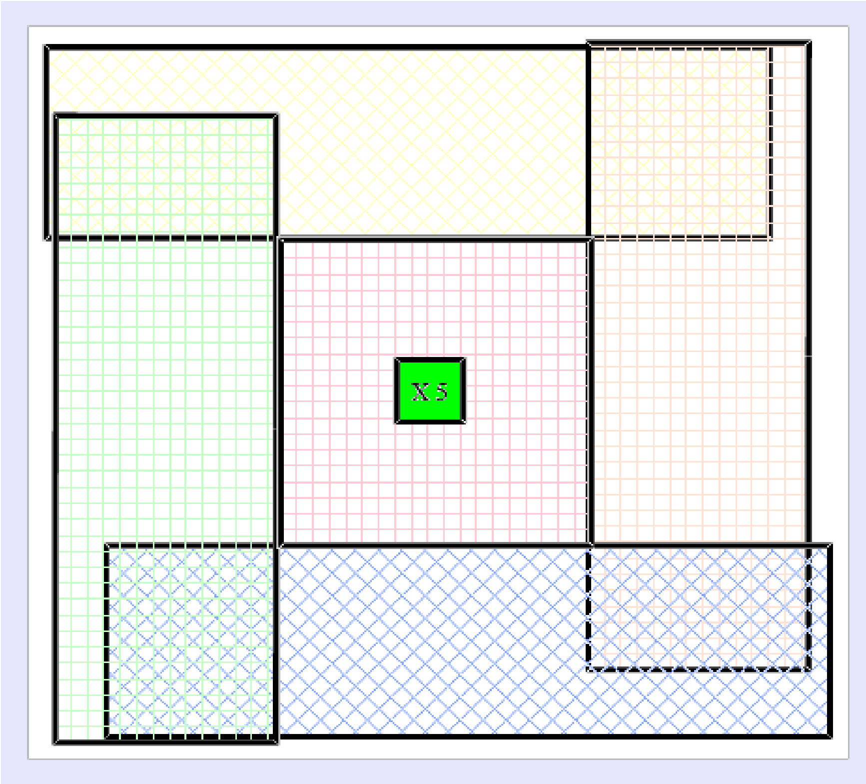
2048 x 2048 0.5" pixels

➢ **Engineering modes (Eng 0, 1, 3, 4, 5, 6)**

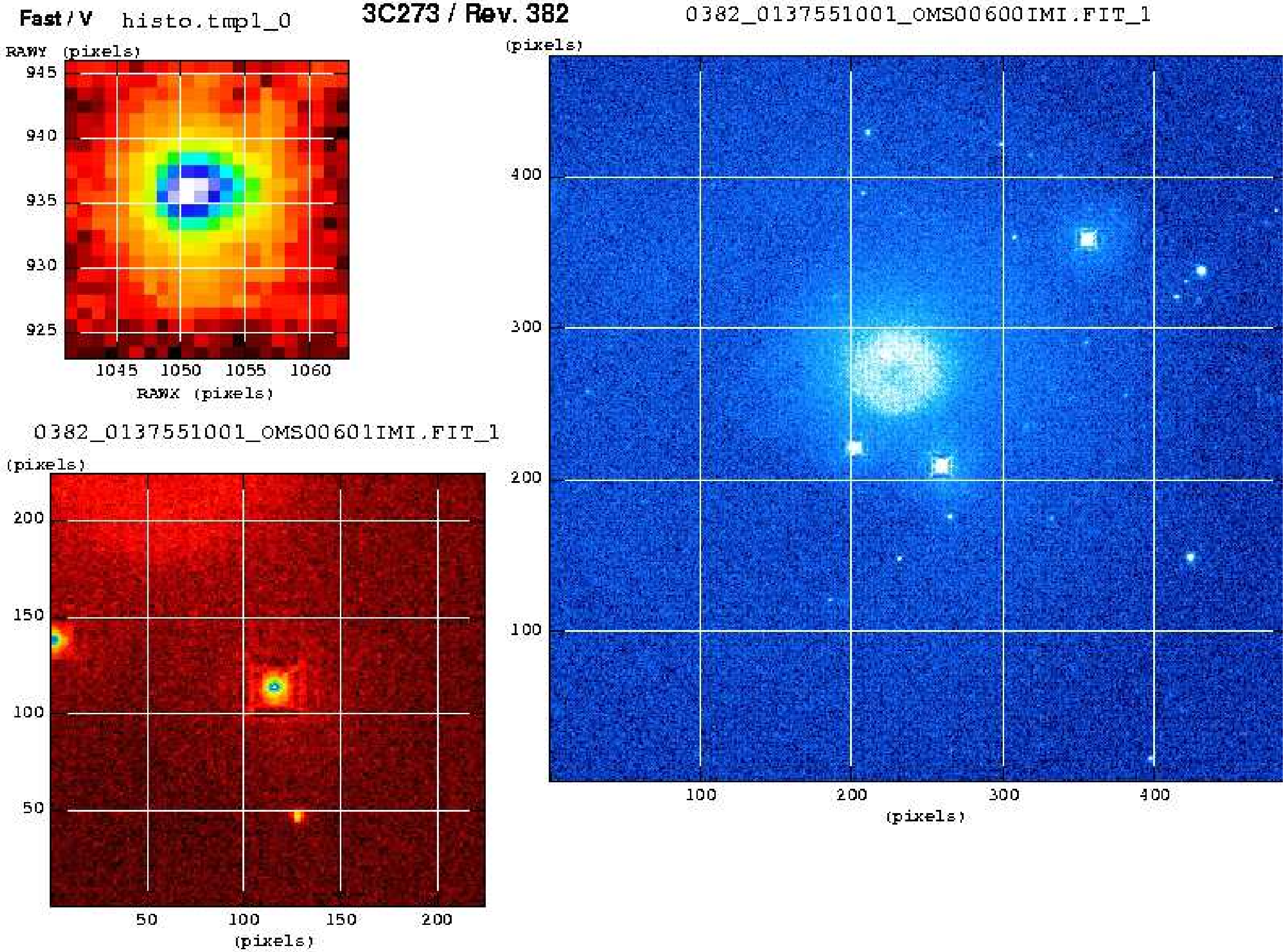
Total number of pixels is limited

Fast window: 22 x 23

Default configuration:

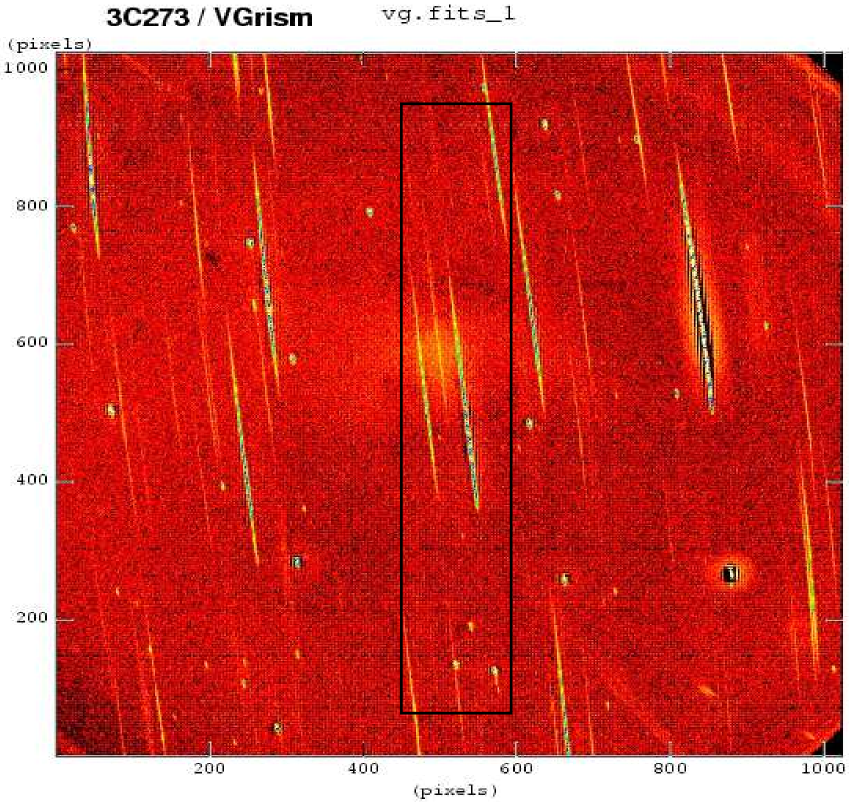


Optical Monitor: default windows

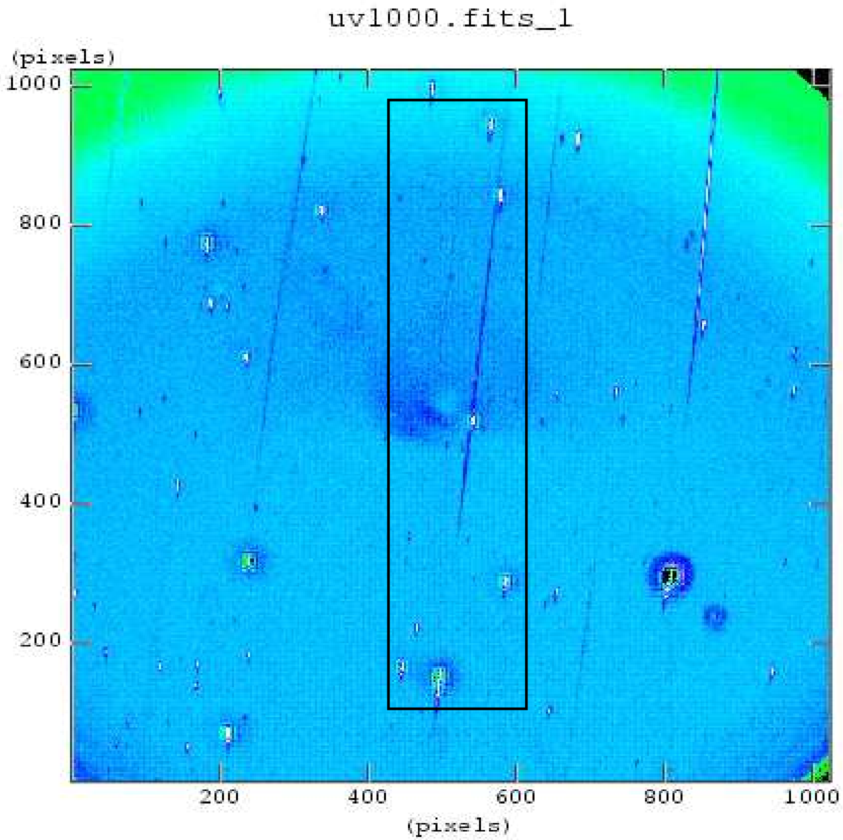


OM: operational configuration with grisms

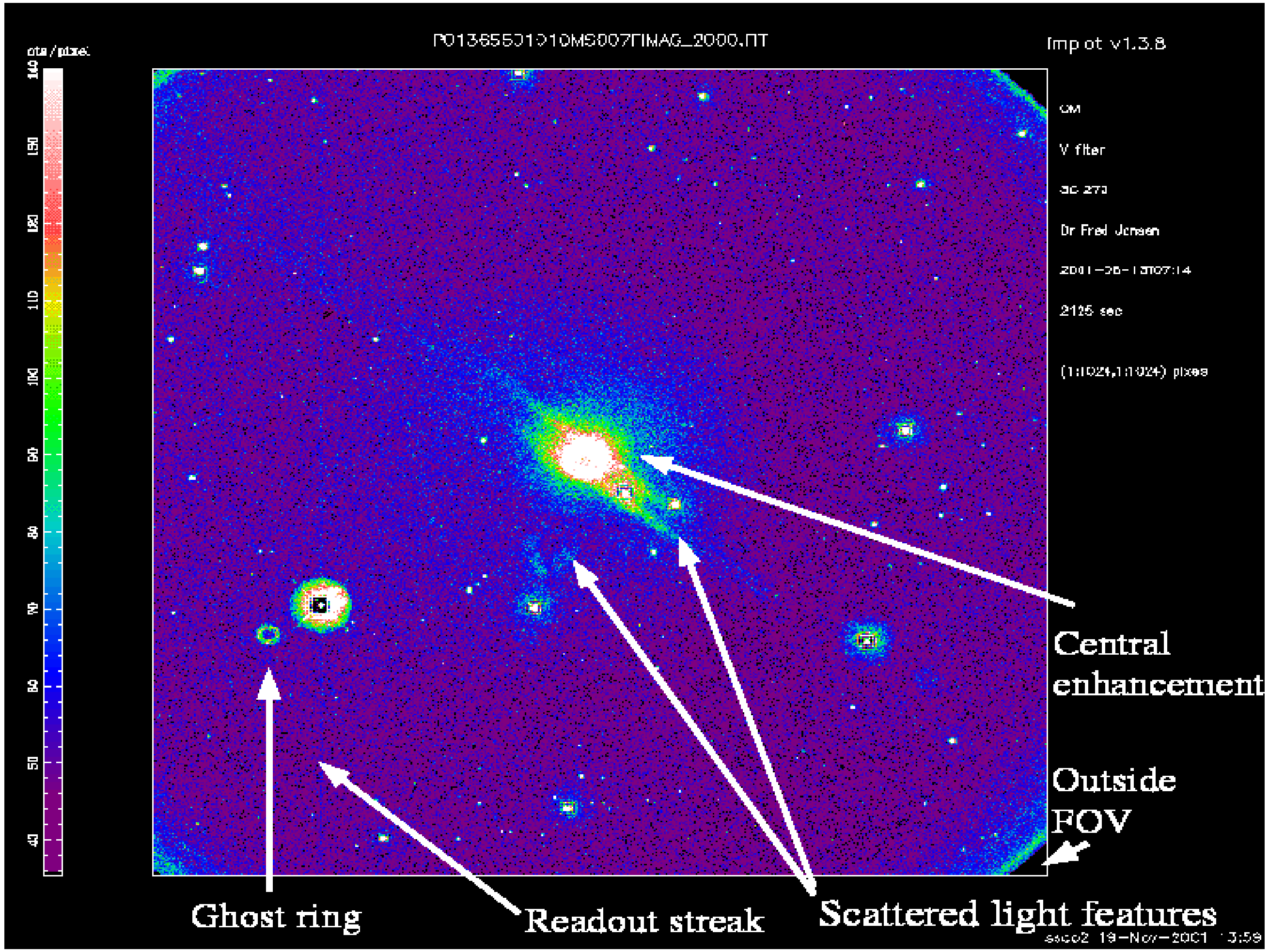
- **Single object spectroscopy:**
  target at the boresight



- **Field spectroscopy:**
  all objects in the f.o.v.



Artefacts in OM images



- **Straylight loops**
- **Central bright patch**
- **Gost images**
- **Streaks**

Optical Monitor calibration: what is it?

<u>Instrumental corrections</u>

- Astrometry: Geometric distortion, Boresight
- Photometry: Measuring the count rate of detected sources
  - aperture
  - PSF
  - coincidence losses and dead time
  - time dependent sensitivity degradation
  - cosmetic (bad pixels)
  - *flat field (not applied in OM)*

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

- Spectroscopy: Measuring the count rate of the source as a function of wavelength
  - geometry:distortion, rotation
  - modulo_8
  - wavelength
  - flux

Optical Monitor calibration: what is it?

PHOTOMETRY:

Magnitudes: the origin

- m1-m2 = -2.5 log (F1/F2) **F2 = Reference = Standard star = Vega**
- m1 = -2.5 log F1 + **Zero_point** **Zero_point = m2 + 2.5 log F2**
- m (OM) = -2.5 log F(OM) + **Z_OM** **Z_OM = magnitude producing 1 count**/s

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

Magnitudes & colors ⇒ Physical parameters, models,.....

Absolute Fluxes: modern photometry & spectrophotometry

- from magnitude to flux through Vega
- direct transformation: $F(\lambda) = K(\lambda) * OM(\lambda)$ $K(\lambda)$: from spectrophotometric standard stars

$K(\lambda)$ **= instrumental response *(= response matrix)* ⇒ average K per filter**

Absolute fluxes ⇒ Physical parameters, models,.....

Optical Monitor calibration: what is it?

SPECTROSCOPY:

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

$$ISF(\lambda) = Fstd\ (\lambda)\ /\ CRstd\ (\lambda)$$

$$Fobs(\lambda) = CRobs(\lambda) \times ISF\ (\lambda)$$

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:

Zero_point = m_vega+2.5*alog10(countrate_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)

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:

Zero_point = - 48.60 - 2.5 * log(1./n_phot)

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

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

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/A

 the relative errors (stdev/mean) are :

        0.054    0.0401    0.068     0.042     0.068      0.013
```

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	WD's
V	2.48E-16	2.50E-16	2.50E-16	2.55E-16	2.56E-16	2.61E-16	2.49E-16
B	1.29E-16	1.17E-16	1.38E-16	1.44E-16	1.55E-16	1.80E-16	1.29E-16
U	1.66E-16	1.97E-16	1.77E-16	1.88E-16	1.85E-16	1.94E-16	1.94E-16
UVW1	4.79E-16	4.76E-16	4.84E-16	5.02E-16	5.15E-16	3.14E-16	4.76E-16
UVM2	2.15E-15	2.17E-15	2.18E-15	2.27E-15	2.02E-15	1.42E-15	2.20E-15
UVW2	5.56E-15	5.25E-15	6.14E-15	6.50E-15	6.34E-15	2.46E-15	5.71E-15

OM fluxes in AB system

If n_phot is the number of photons produced by 1 erg input spectrum, then 1/n_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.

OM fluxes in AB system

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

Count rate to flux conversion in AB system (lambda)

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

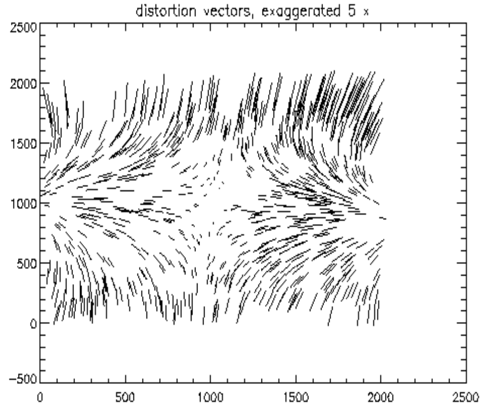
This gives erg/cm2/s/A

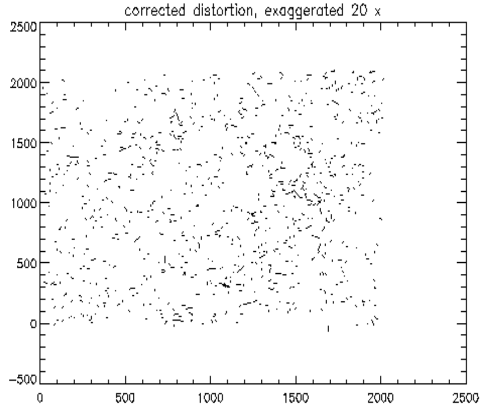
Not surprisingly, if we compare these last factors with the ones derived directly from WD's fluxes, we have:

1.002	0.994	0.988	0.999	1.029	0.995

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

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 A
  - UV-grism: 1800 - 3600 A (second order contamination)
    (the range could be extended, but not the flux calibration)
- Wavelength scales
  UV: lambda (A) = $991.778 + 1.8656\ X + 0.0007713\ X^2$ (X : pixels from zero order)
  Vis: lambda (A) = $200.898 + 5.626\ X$
  - internal error: < 7 A (UV)
  - global shift due to zero order position: about +/- 10 A

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:

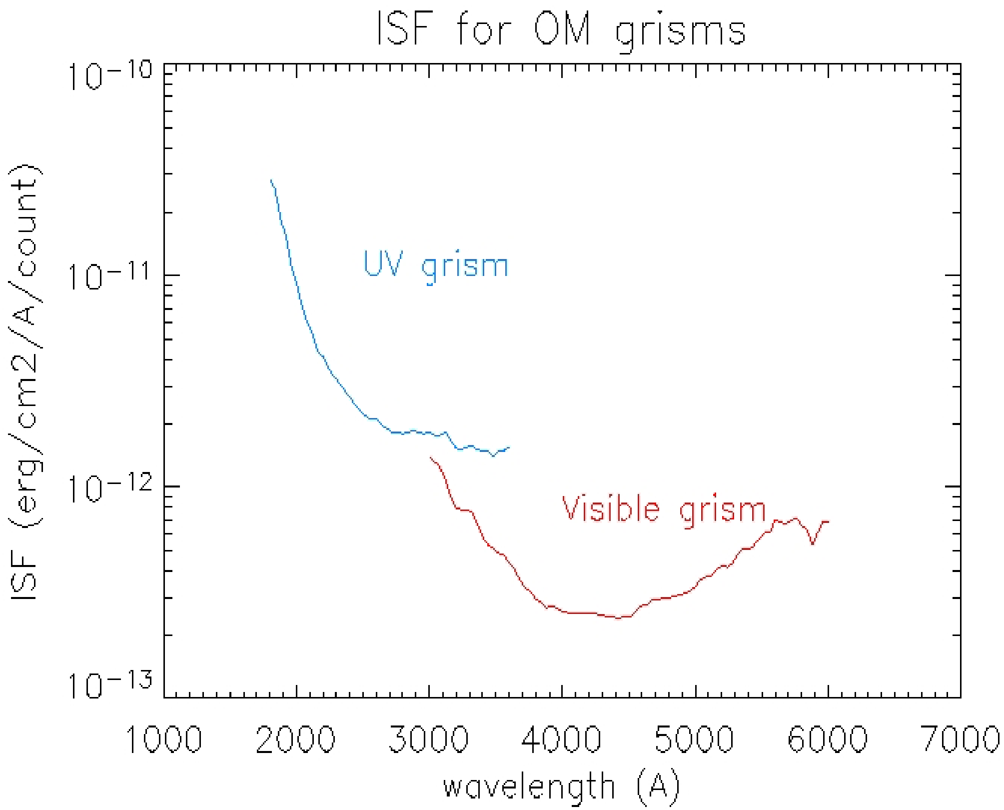
Inverse Sensitivity Function (ISF)

$ISF(\lambda) = Fstd(\lambda) / CRstd(\lambda)$

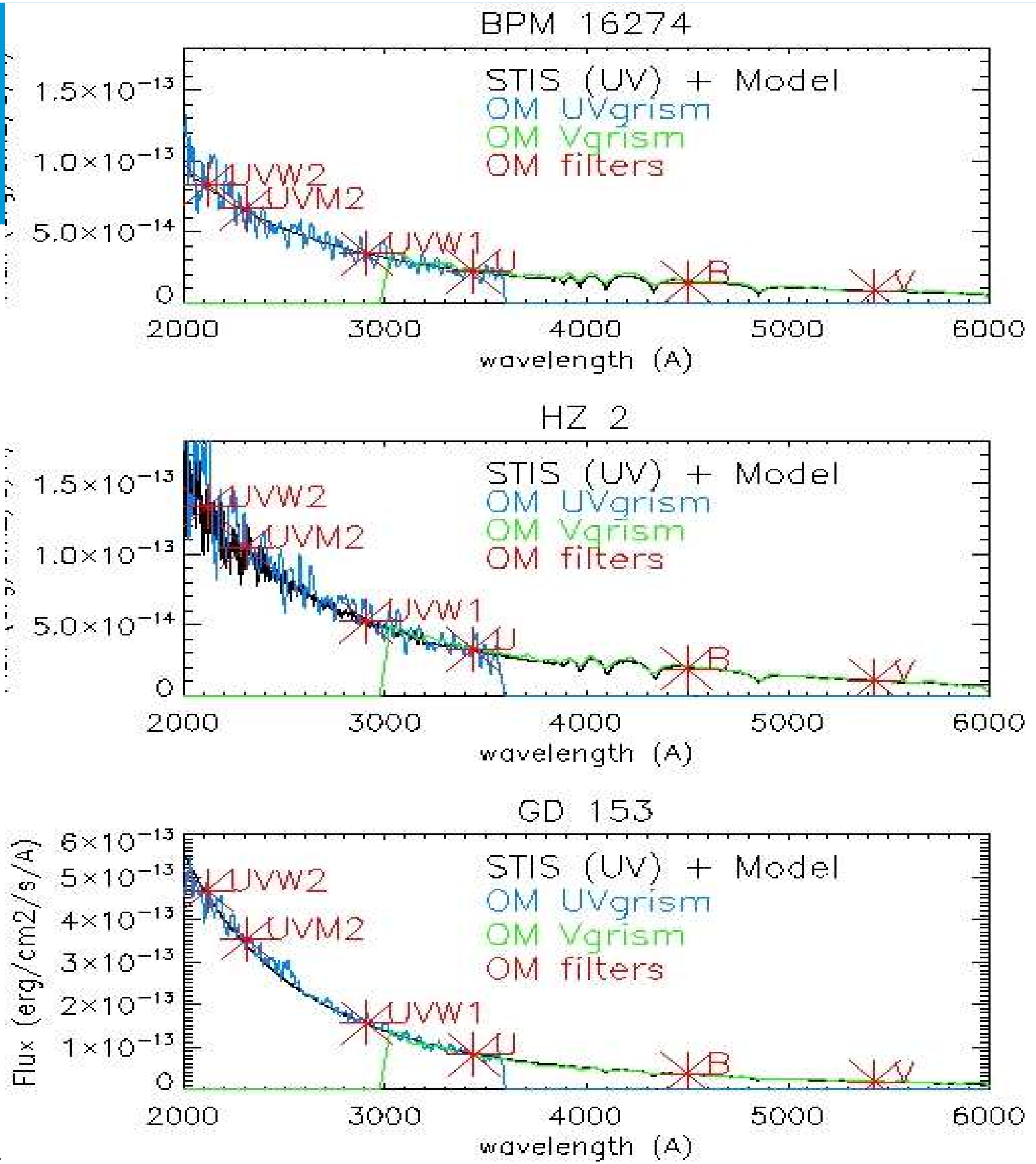
$Fobs(\lambda) = CRobs(\lambda) \times ISF(\lambda)$

OM_GRISMCAL_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.

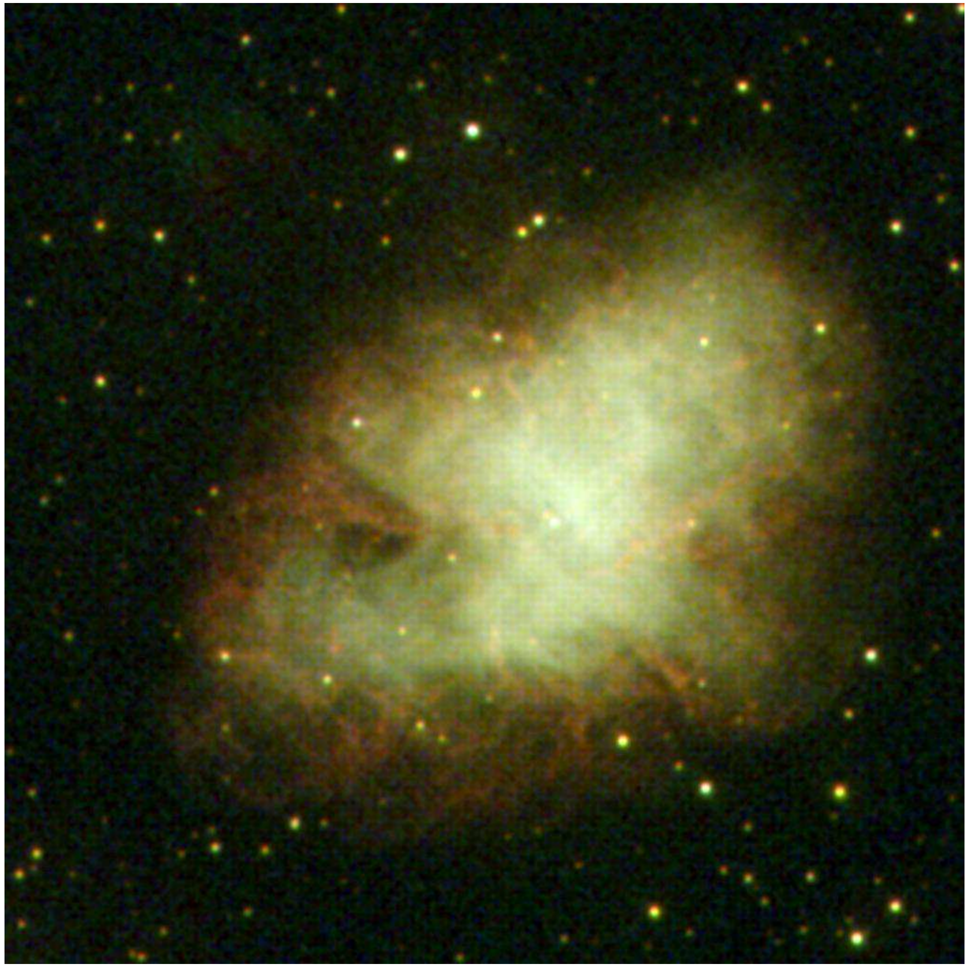


OM grisms & filters processed with SAS



Spectrophotometric Standard Stars observed With OM

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

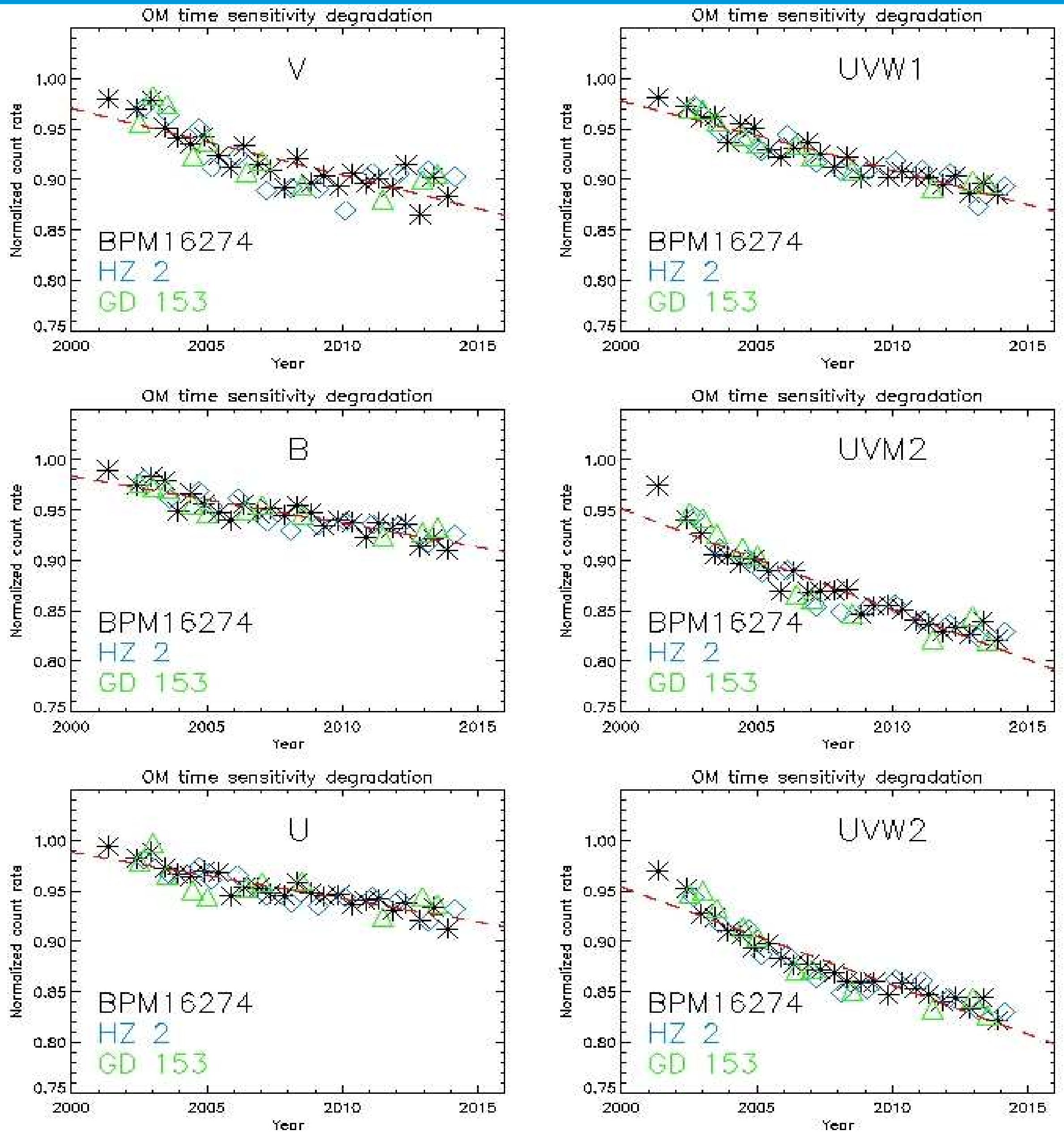


OM filter	Count rate	AB mag	AB Flux (erg/cm2/s/A)
UVW2	0.12	18.84	7.05e-16
UVM2	0.29	18.74	6.49e-16
UVW1	1.89	17.88	9.11e-16
U	5.18	17.40	1.00e-15

OM Calibration & SAS

- Continuous photometric monitoring: observations of standard WDs
  - Time sensitivity degradation: new correction
  - SAS repeatability & stability
- On-going:
  - *Visible Grism: extending calibration up to 7000 A (Halpha studies)*
  - *Grisms wavelength and sensitivity variation across the f.o.v.*
  - *Grisms time sensitivity degradation: determination & correction*

OM time sensitivity degradation



OM throughput

Filter	Current	Expected in 2025
UVW2	0.82	0.74
UVM2	0.81	0.73
UVW1	0.88	0.82
U	0.92	0.88
B	0.92	0.87
V	0.88	0.82

Repeatability & Stability of OM photometry: BPM 16274

Average count rate Revs. 261 – 2650 (26 observations):

uvw2	uvm2	uvw1	u	b	v	*white*	
14.7	30.5	73.2	113.1	108.1	32.9	*434.3*	
1.6	1.7	1.1	0.8	0.9	2.0	*1.8*	(stdev %)

Prediction from estimated effective area:

14.3	29.2	72.3	109.0	107.0	32.1	*481.0*	

(>> no time dependent sensitivity degradation correction for White filter)