The *Swift* UV Optical Telescope

The calibration of the grisms

-- a talk by Paul Kuin

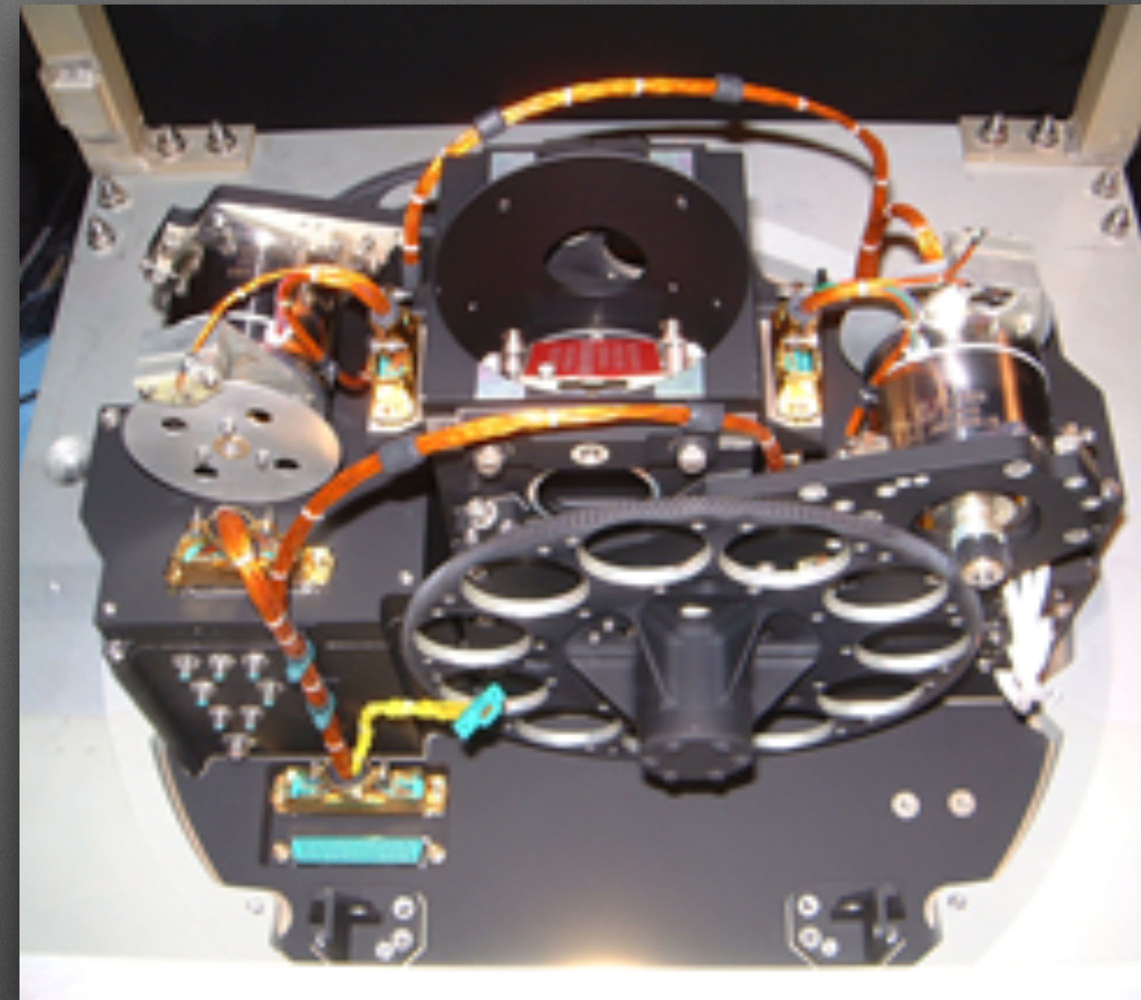
The main contributors to the calibration are

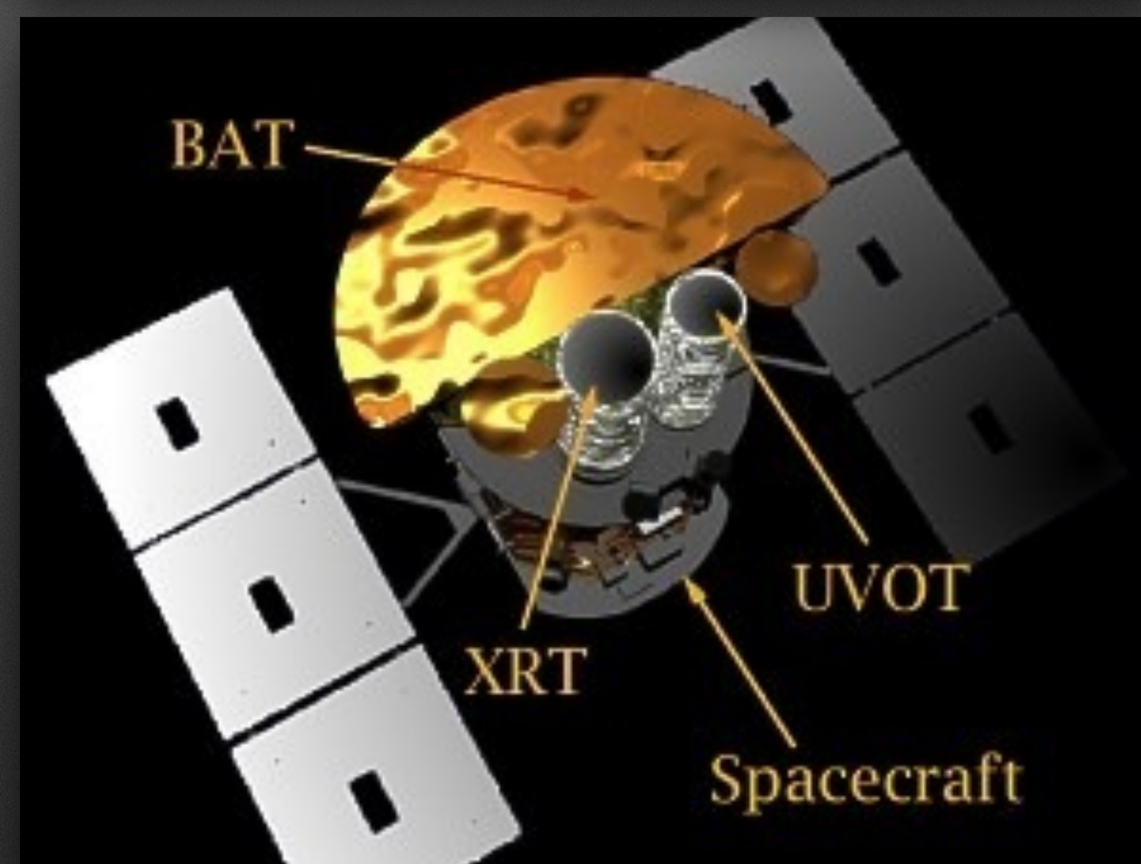
Wayne Landsman, Alice Breeveld, Mat Page, Cynthia James, Herve Lamoureux,

and various contributions to the instrument and calibration also from

M. Mehdipour, Martin Still, Vladimir Yershov, Peter Brown, Mary Carter, Tom Kennedy,
Sally Hunsberger, Frank Marshall, Keith Mason, Pete Roming, Mike Siegel, Samantha Oates, Phil Smith, +?

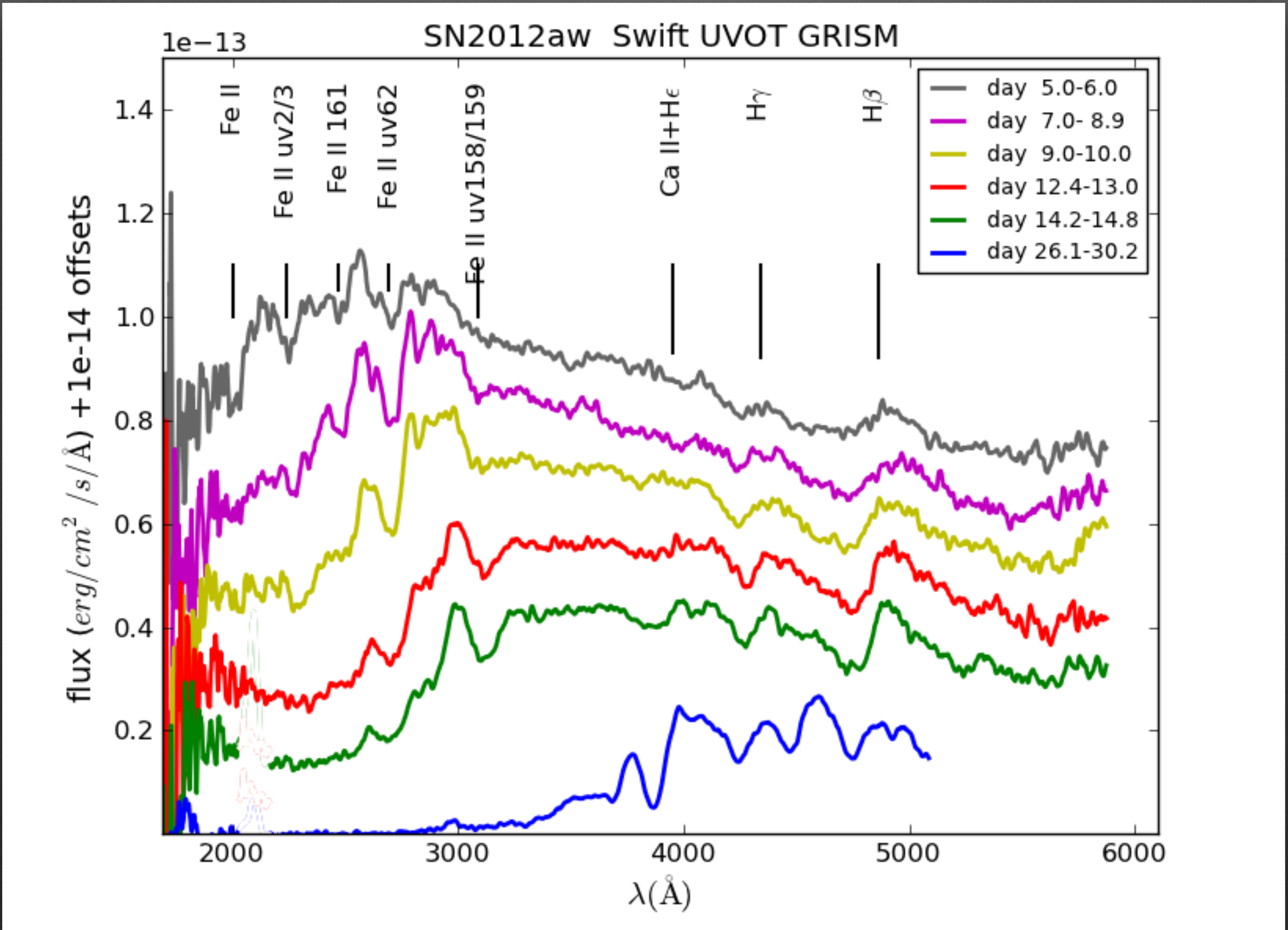

M51




BAT
UVOT
XRT
Spacecraft

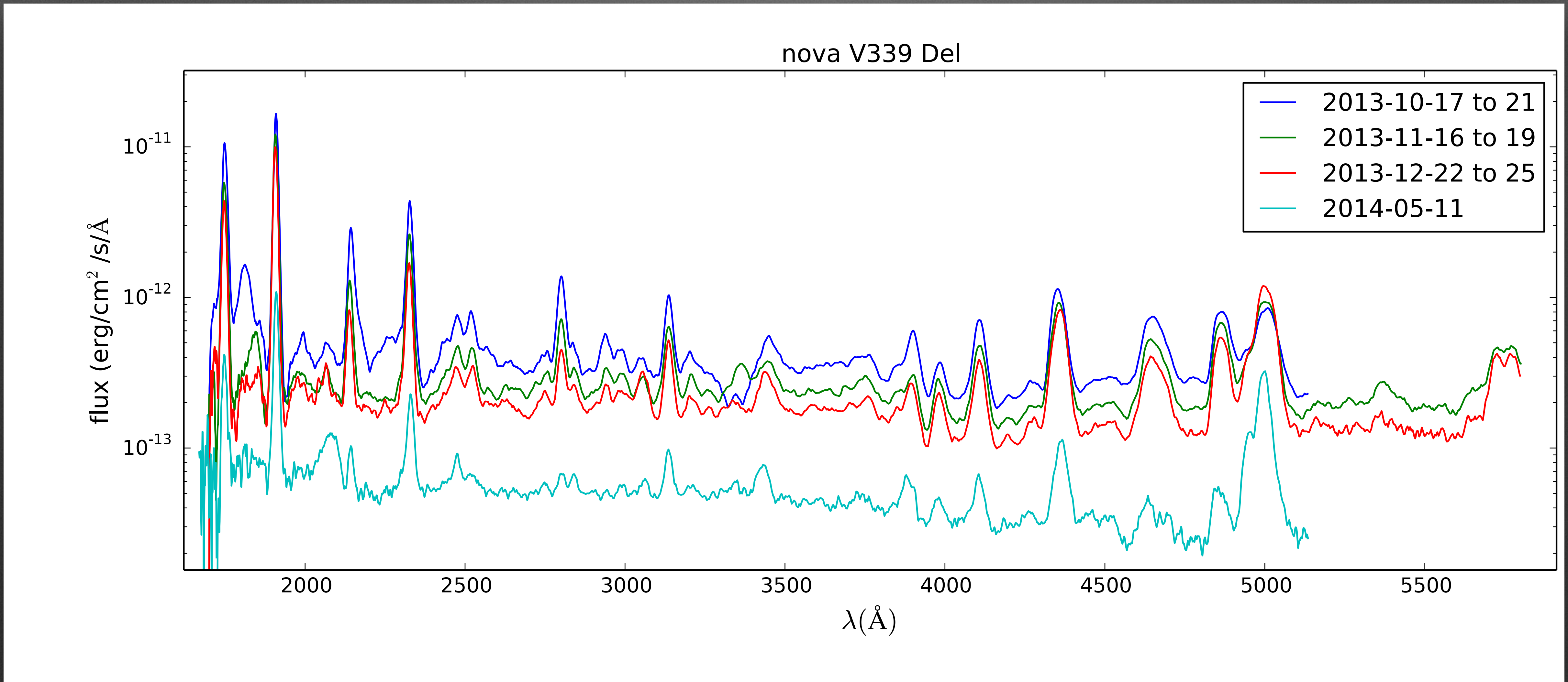
A talk in three

- Showcase spectra of various astronomical sources
- The instrument
- Calibration of the grisms



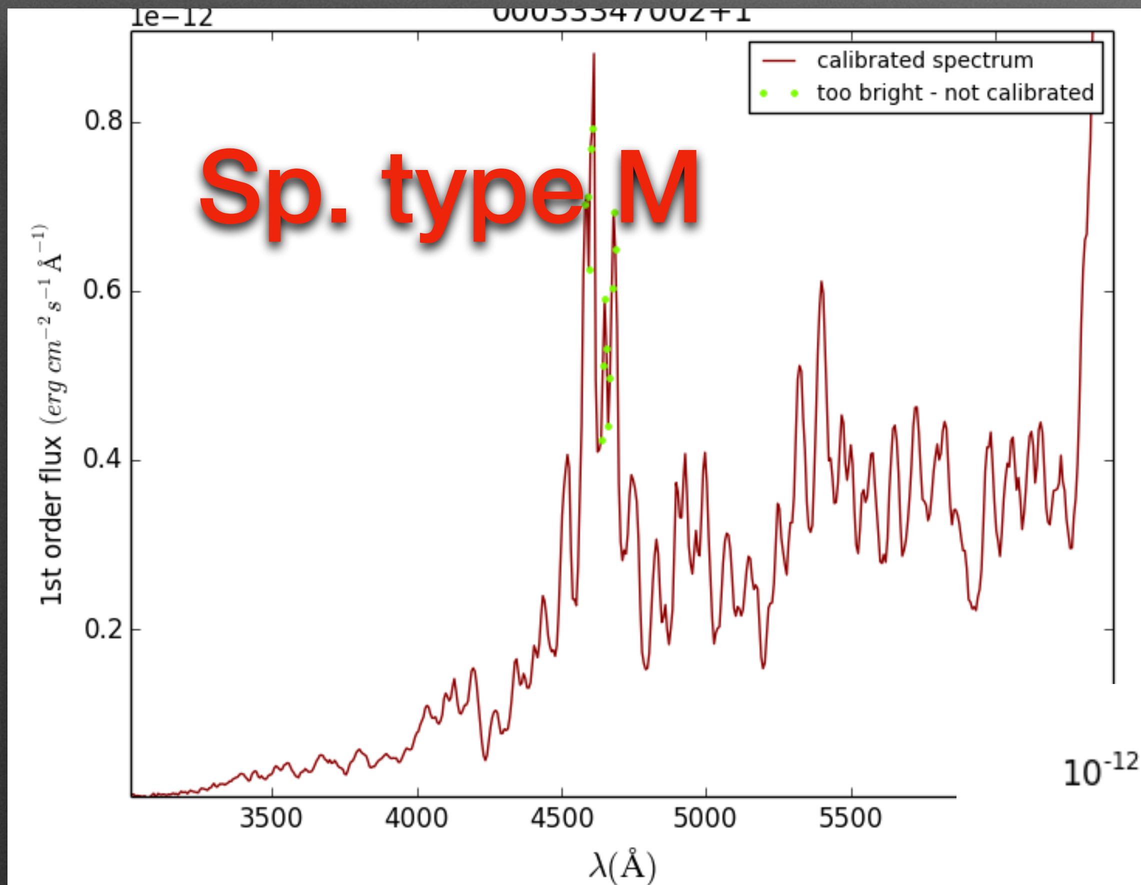
Supernovae

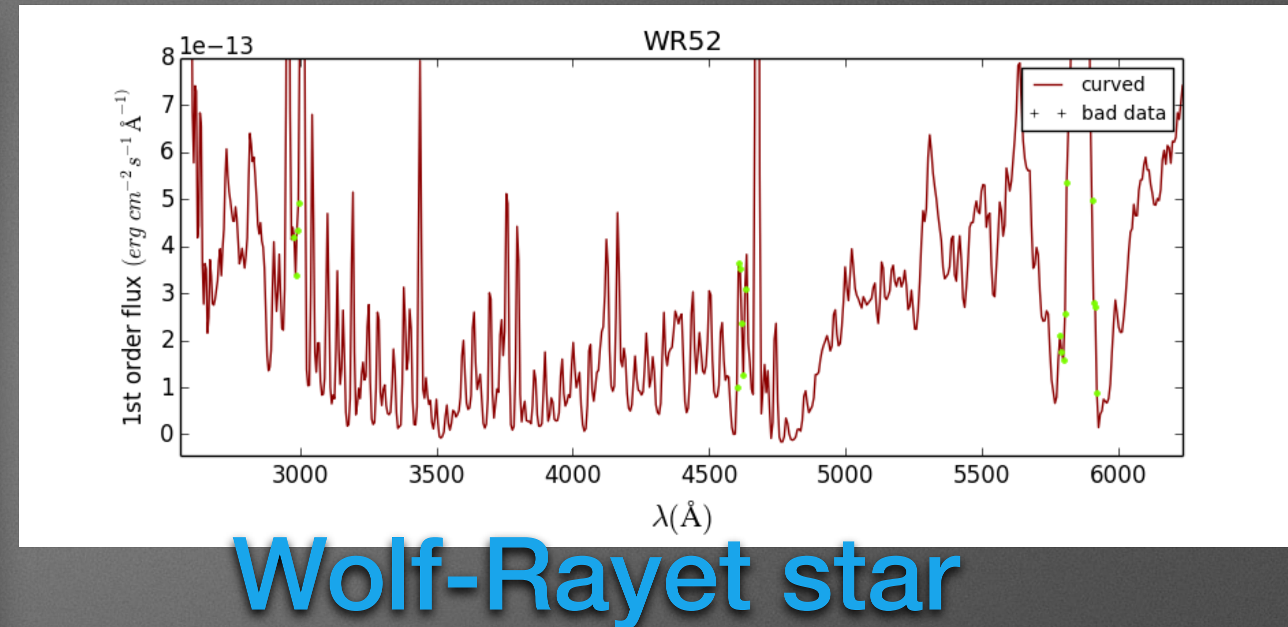
to date: 29 SN Ia, and 20 core-collapse SNe (II, IIP, Ib, IIn, IIL). Typically around maximum, with multiple visits using uv grism

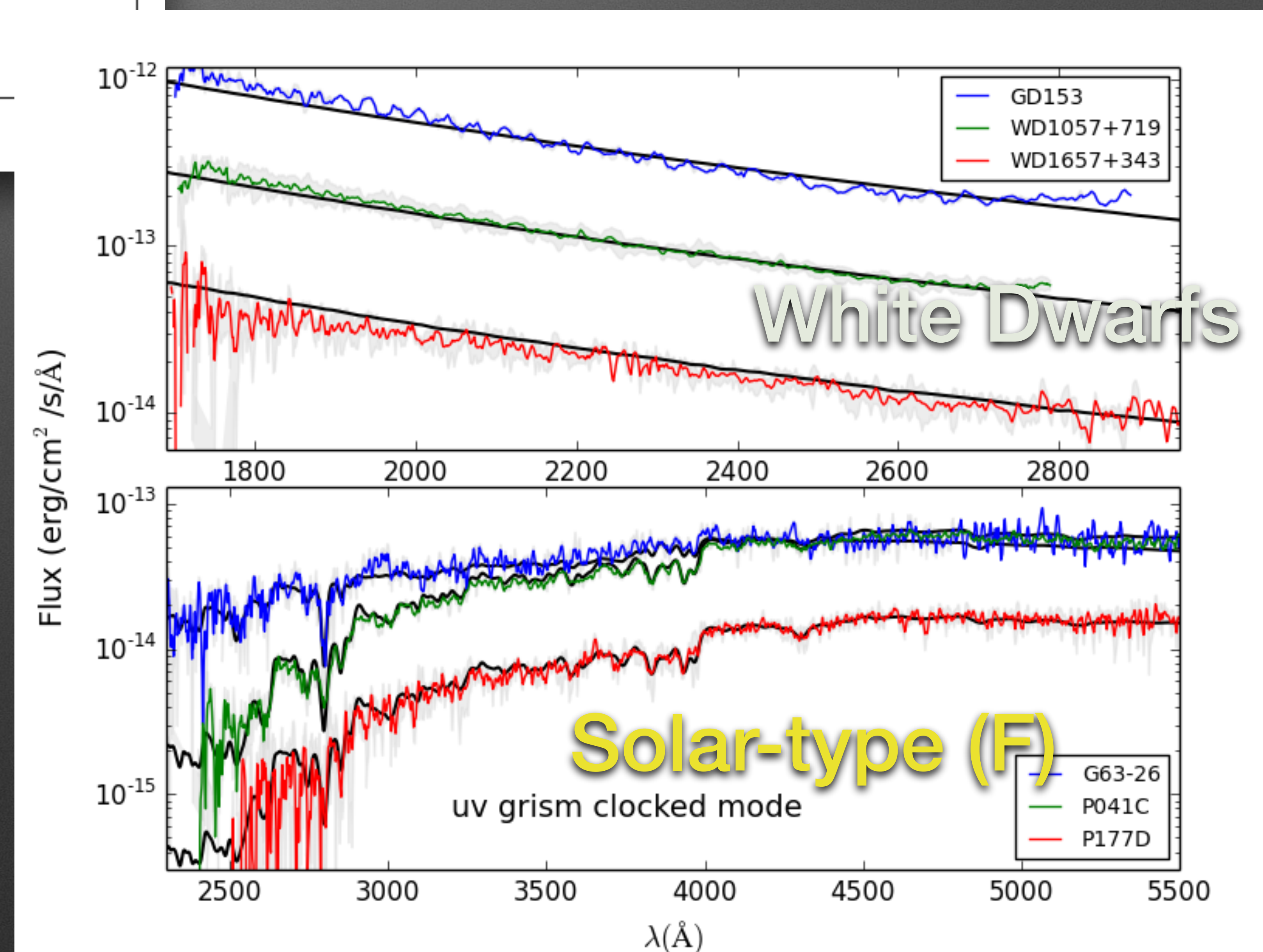


Novae

RS Oph 2006, GK Per (nova per 1901, outburst 2006),
KT Eri 2009, U Sco 2009, T Pyx 2011,
V339 Del 2013, V745 Sco 2014, V1280 Sco 2013,
V1369 Cen 2014, V5666 Sgr 2014

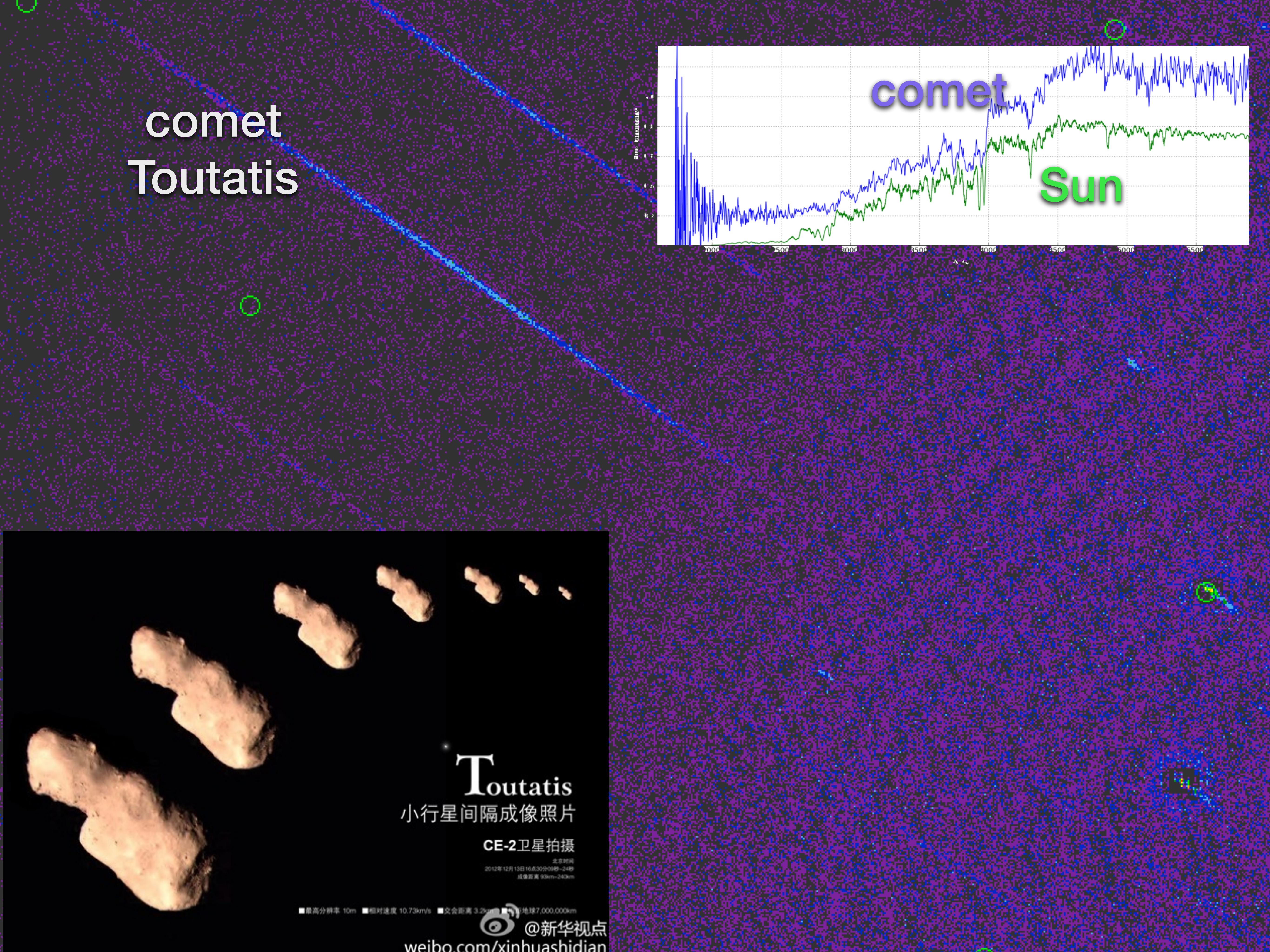






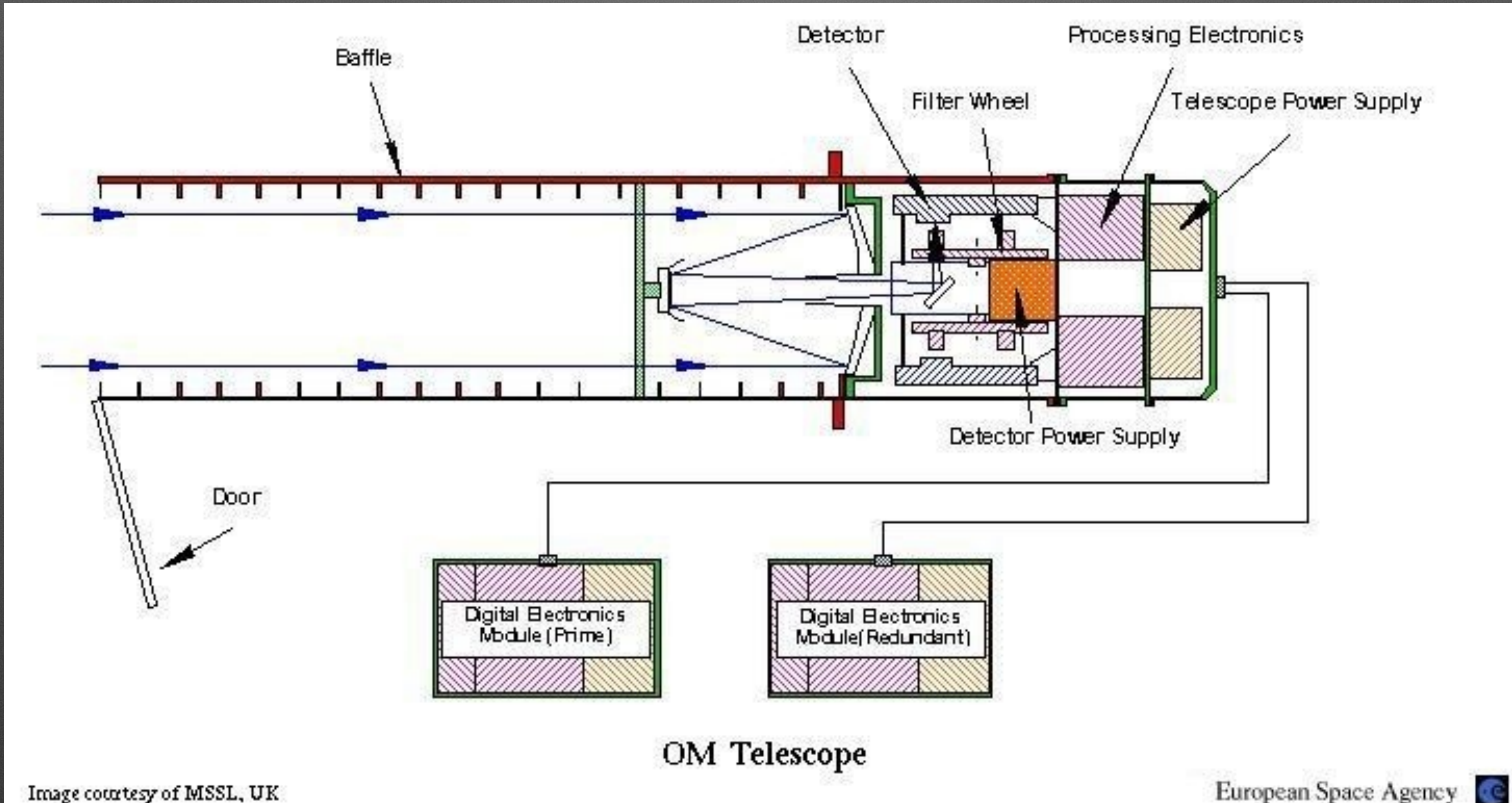
** stars **

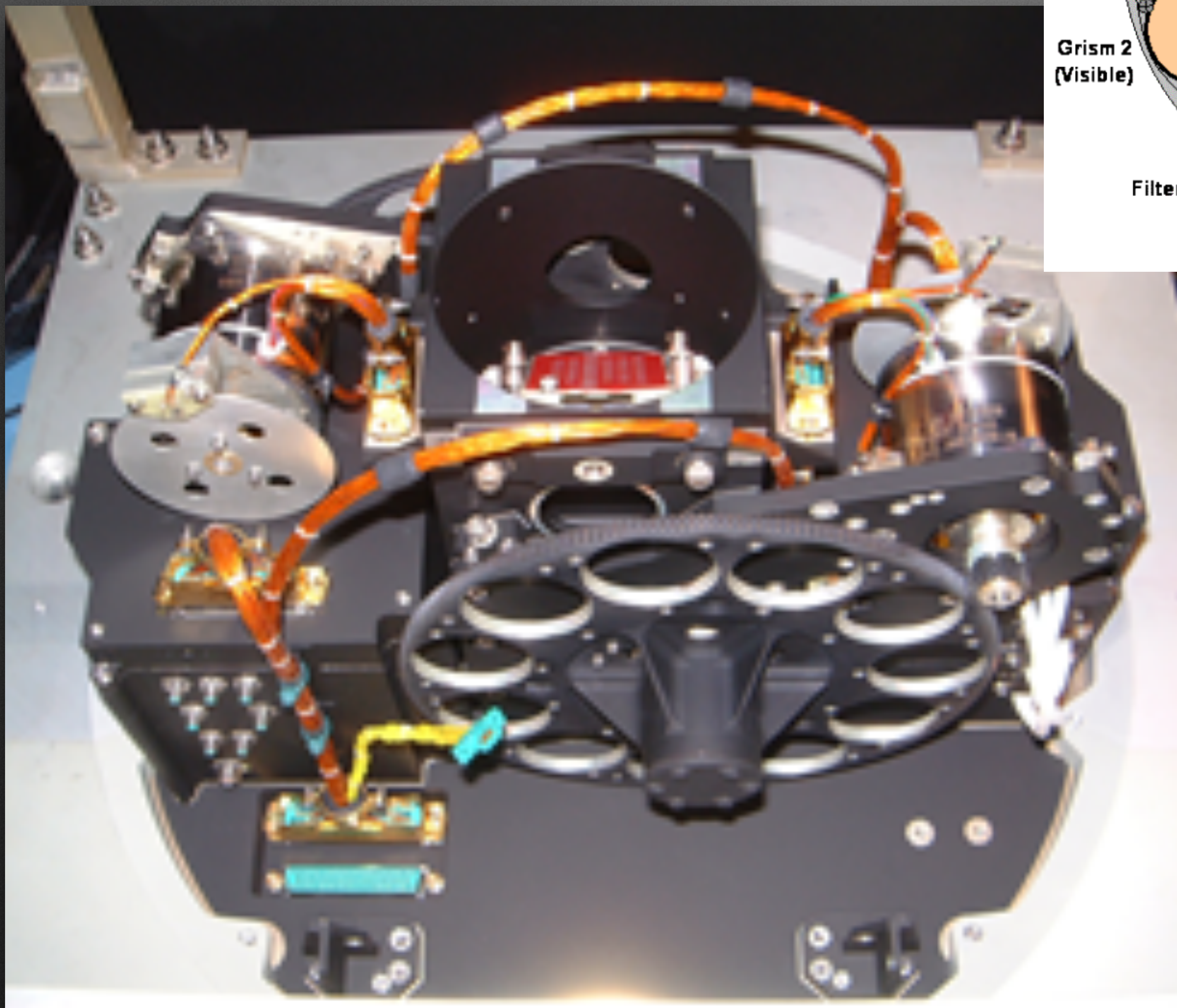
Solar-type stars (spectral type F)
Wolf-Rayet Stars
cool M-type
etc.

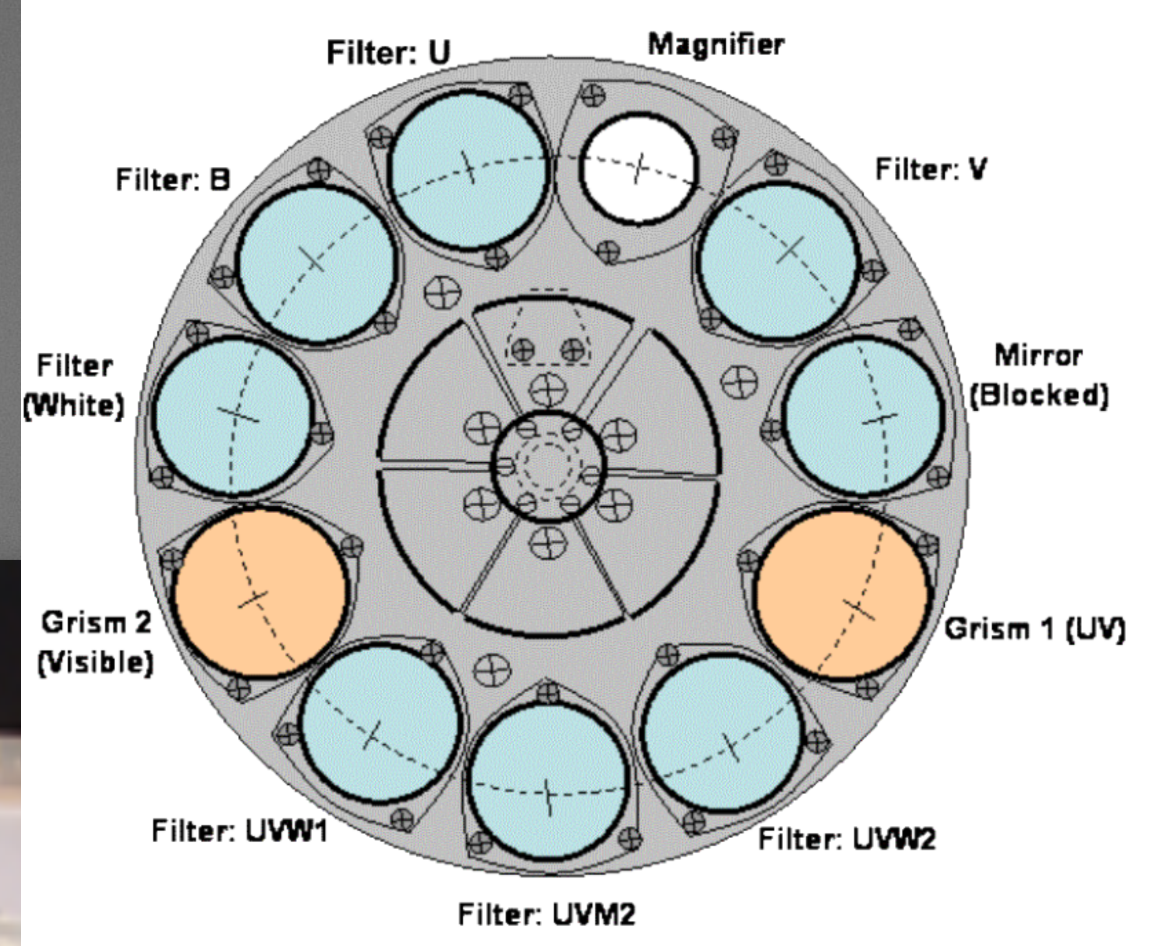

comet
Toutatis
comet
Sun
Toutatis
小行星间隔成像照片
CE-2卫星拍摄
■最高分辨率 10m
■相对速度 10.73km/s
@新华视点
weibo.com/xinhuashidian

UVOT Instrument

- Telescope
- filter wheel
- detector: image intensifier
- electronics / operational software


Baffle
Detector
Processing Electronics
Filter Wheel
Telescope Power Supply
Detector Power Supply
Door
Digital Electronics Module (Prime)
Digital Electronics Module(Redundant)
OM Telescope
Image courtesy of MSSL, UK
European Space Agency




Filter: U
Magnifier
Filter: B
Filter: V
Filter
(White)
Mirror
(Blocked)
Grism 2
(Visible)
Grism 1 (UV)
Filter: UVW1
Filter: UVW2
Filter: UVM2

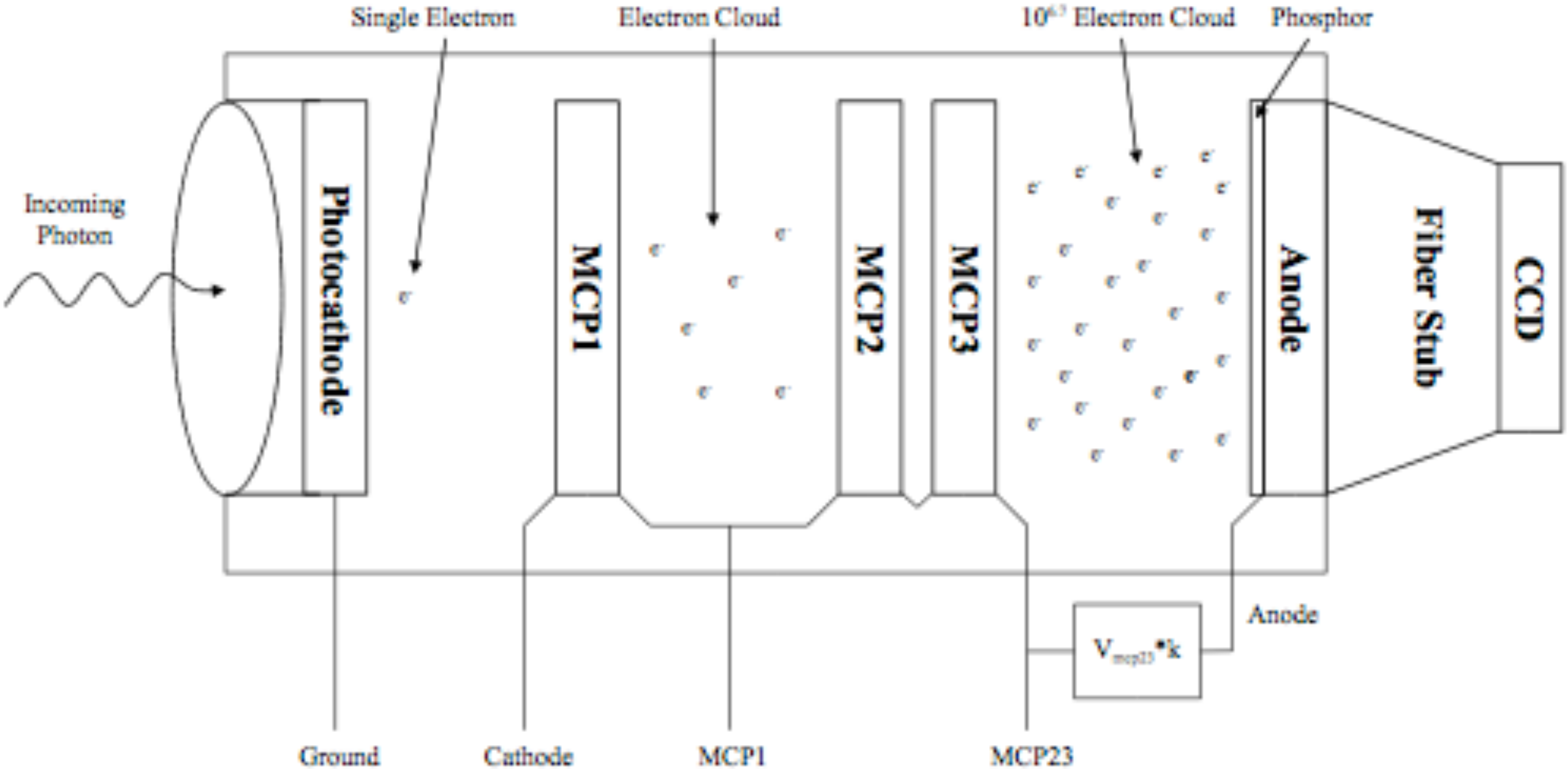
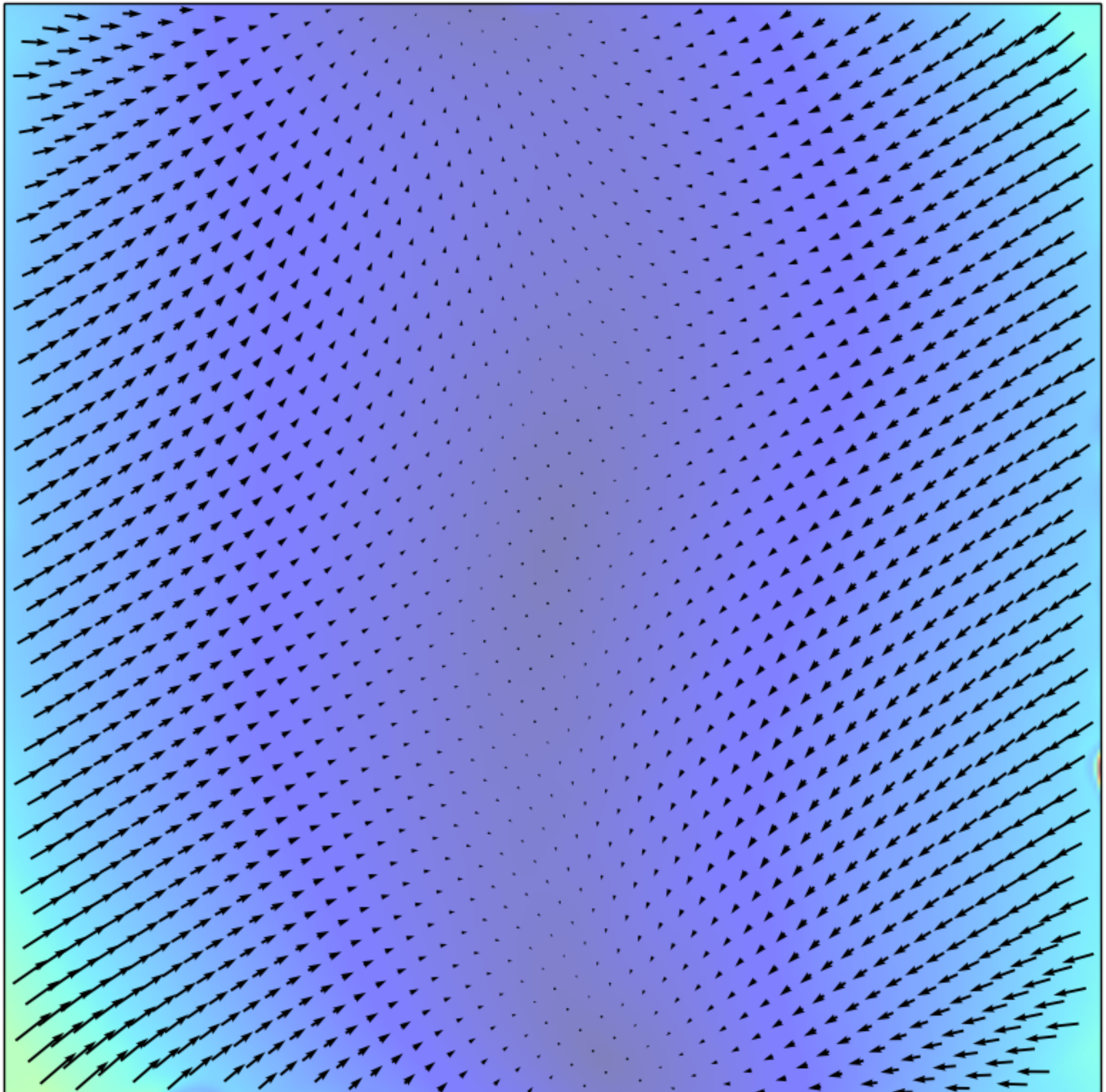


Figure 6. UVOT Detector assembly.

raw->det distortion



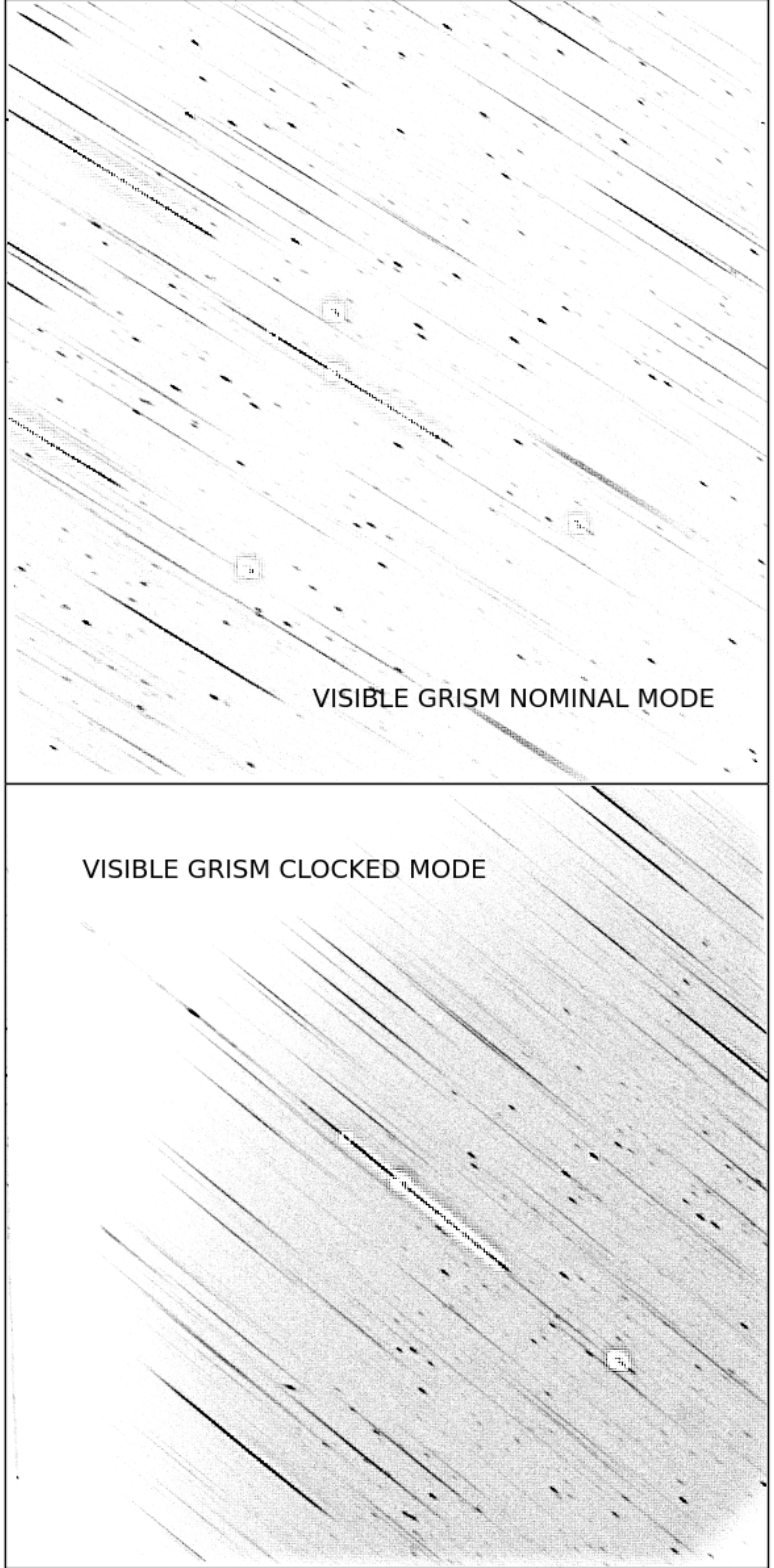
Overview of the grism images

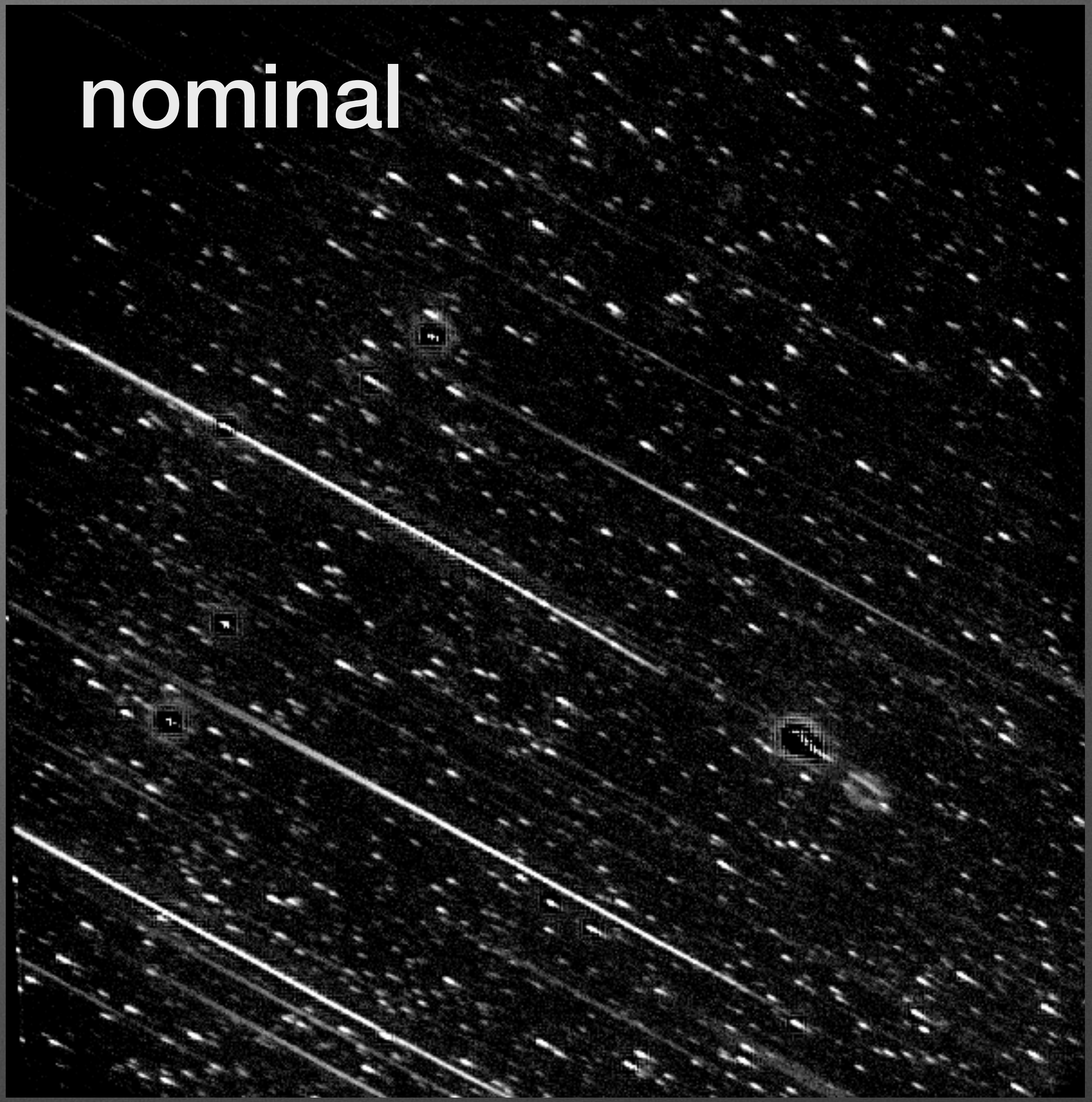
The spectra of the visible grism are straight and orders fall along the same line.

Two modes:
nominal means the grism centre is aligned with the optical axis.

clocked means the filterwheel rotates further to obscure part of the grism - its centre is not aligned with the optical axis.

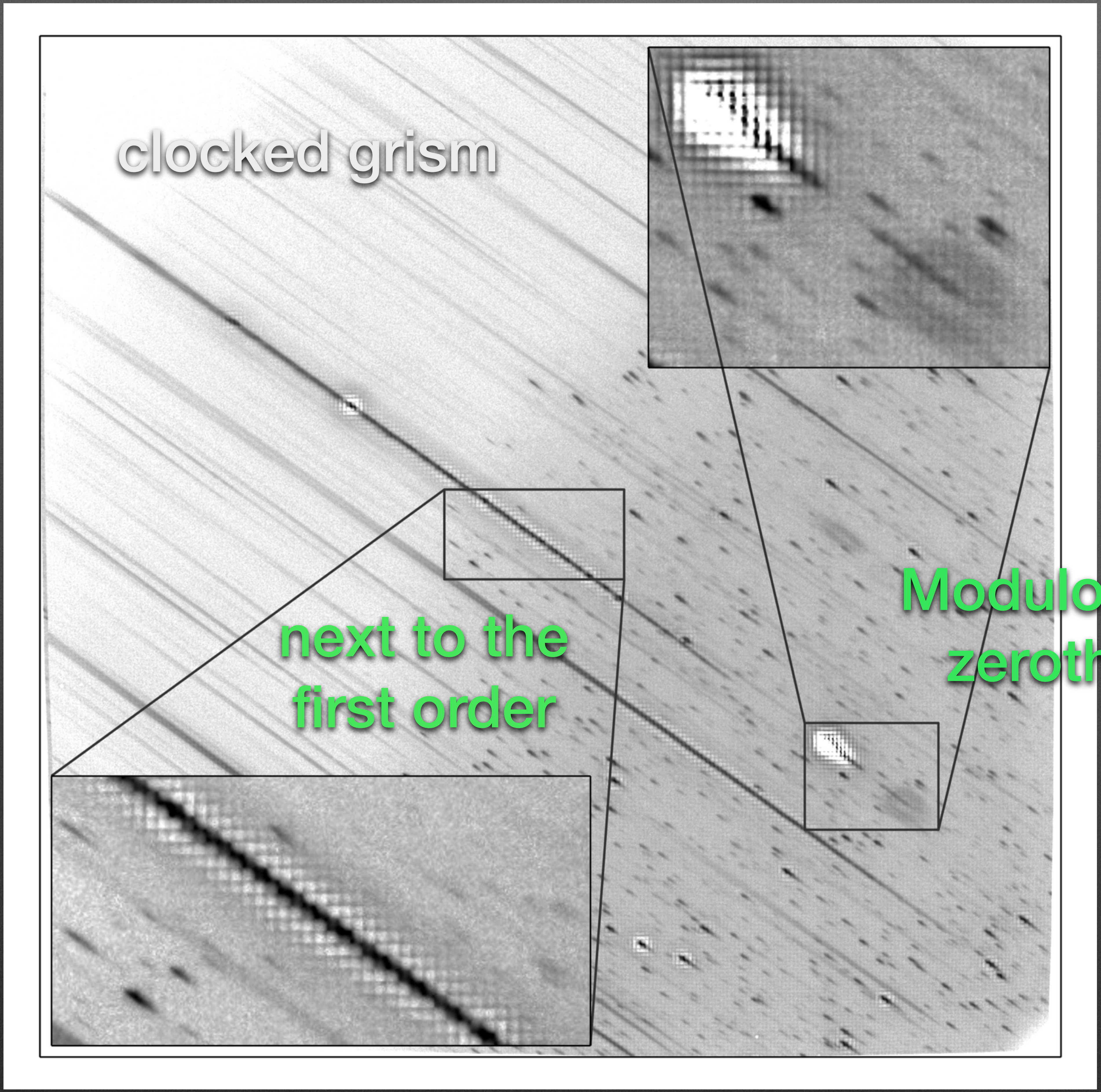
Nominal and clocked spectra angle is different.





uv grism

- *curved orders*
- *higher spectral resolution (~3Å/pixel)*
- *not blazed -> lots of power in zeroth and 2nd orders*



overview:
mod8 in
Bright sources

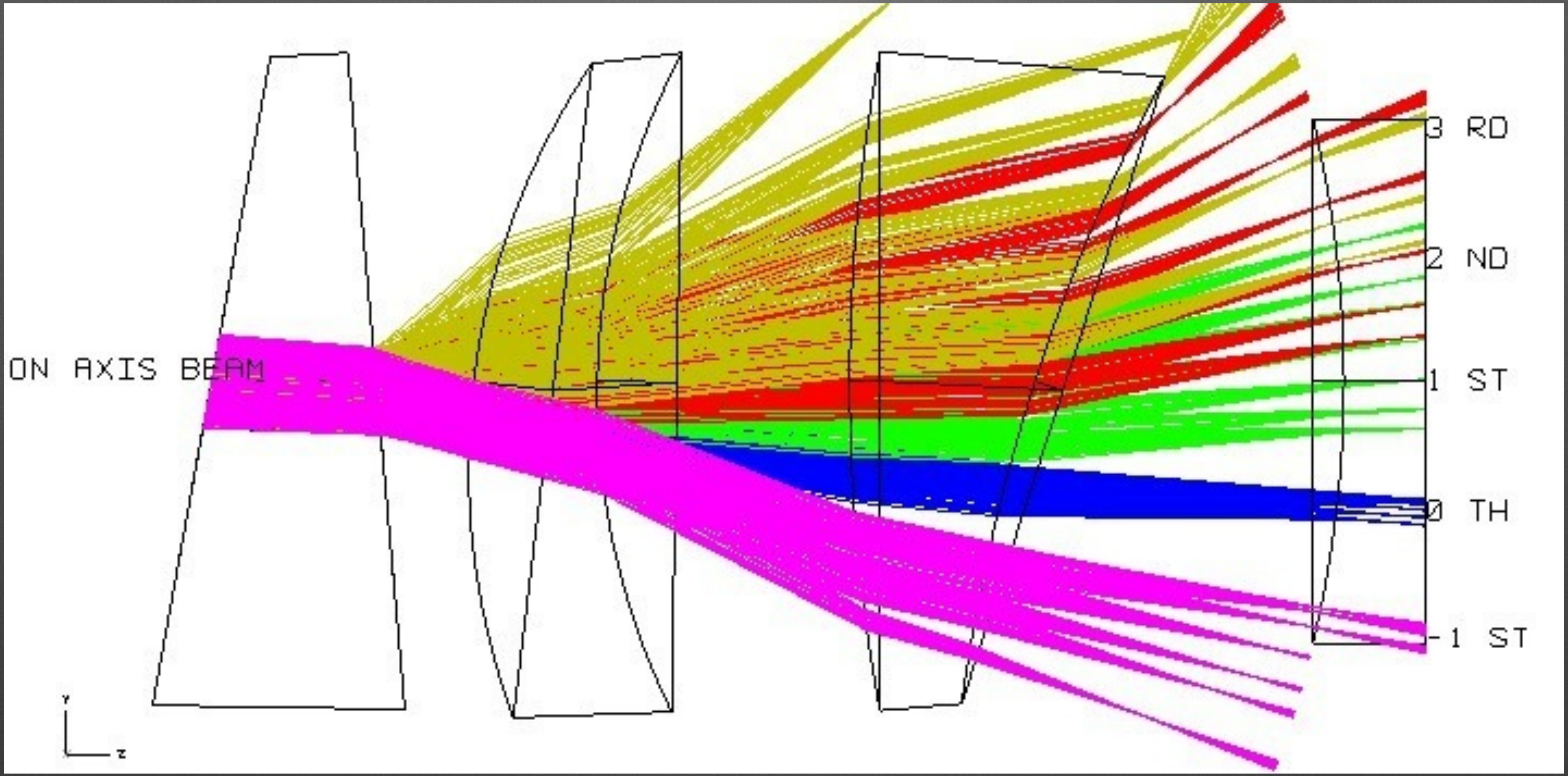
Grism calibration

- selection of sky calibration sources
- anchor point to match a spectrum to the sky position
- using the optical model to predict variation over detector
- wavelength calibration
- coincidence loss calibration
- effective area calibration

Calibration sources

- Known spectra, HST flux calibrated sources, accuracy 2-3%
- typically white dwarfs, solar type spectra (F)
- Use WR stars with many emission lines for wavelenght calibration

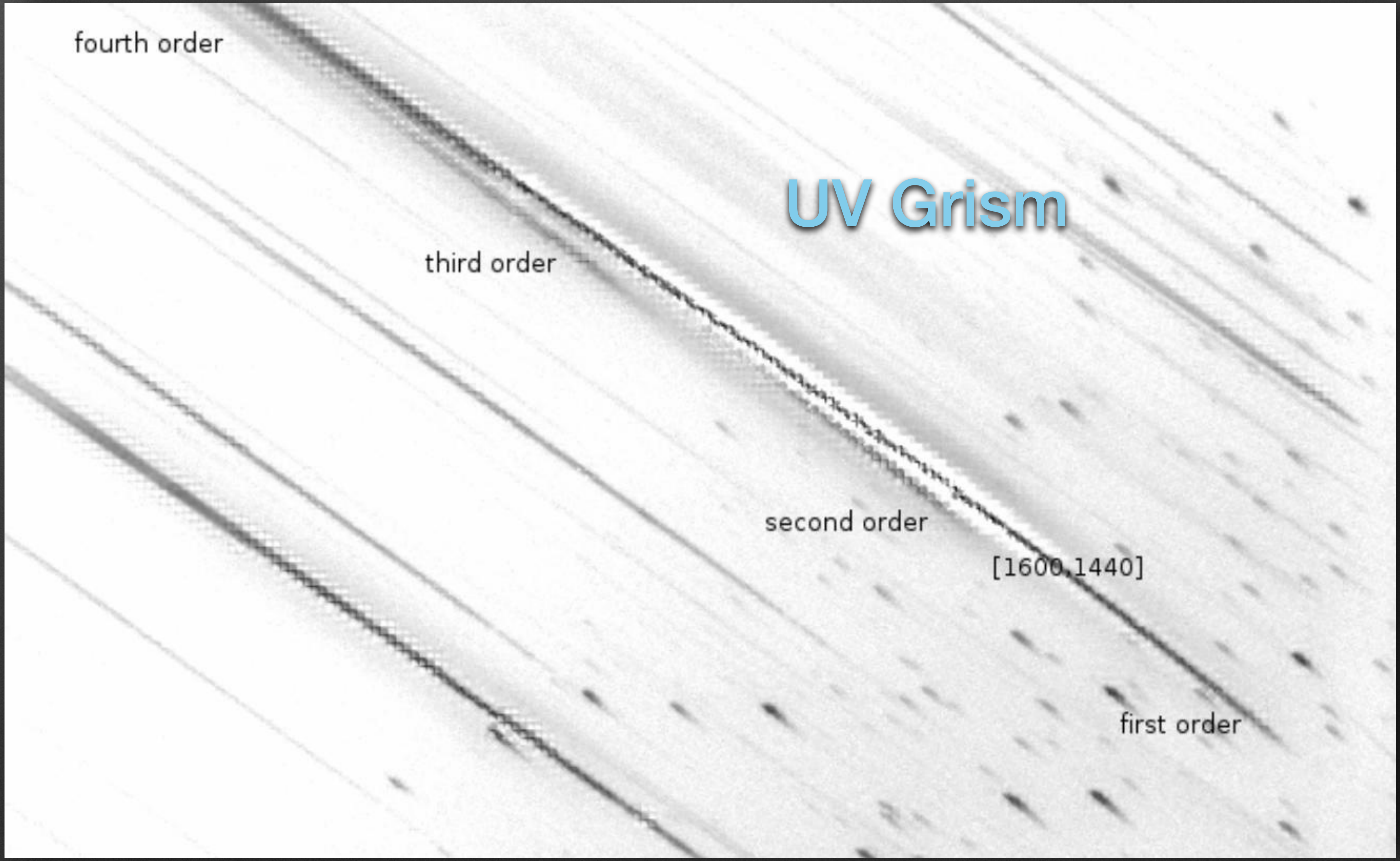
name/ID	sp. type	J2000 RA	position DEC	used for	reference spectrum, notes
WR1	WN4	00:43:28.4	+64:45:35.4	1	IUE, *
WR4	WC5+?	02:41:11.7	+56:43:49.7	1	IUE
WR52	WC4	13:18:28.0	-58:08:13.6	1	IUE,#
WR86	WC7(+B0III-I)	17:18:23.1	-34:24:30.6	1	IUE,#
WR121	WC9d	18:44:13.2	-03:47:57.8	2	IUE, $
WD0320-539	DA	03:22:14.8	-53:45:16.5	3,4,5	CALSPEC
WD1057+719	DA1	11:00:34.2	+71:38:03.9	3,4,5	CALSPEC
WD1657+343	DA1	16:58:51.1	+34:18:53.5	3,4,5	CALSPEC
GD153	DA1	12:57:02.3	+22:01:52.7	5l	CALSPEC
GSPC P177-D	F0V	15:59:13.6	+47:36:41.9	3,4,5	CALSPEC
GSPC P 41-C	F0V	14:51:58.0	+71:43:17.4	3,4,5	CALSPEC
BPM16274	DA	00:50:03.7	-52:08:15.6	4,5	ESO HST standards
GD108	sdB	10:00:47.3	-07:33:31.0	4,5	CALSPEC
GD50	DA2	03:48:50.2	-00:58:32.0	4,5	CALSPEC
LTT9491	DB3	23:19:35.4	-17:05:28.5	4,5	CALSPEC
WD1121+145	sdB	11:24:15.9	+14:13:49	3,4,5	CALSPEC
G63-26	sdF	13:24:30.6	+20:27:22.1	3,4,5	STIS-NGSLv2
AGK+81 266	DB2	09:21:19.2	+81:43:27.6	5	CALSPEC
BD+25 4655	DB0	15:51:59.9	+32:56:54.3	5	CALSPEC
BD+33 2642	B2 IVp	15:51:59.9	+32:56:54.3	5	CALSPEC



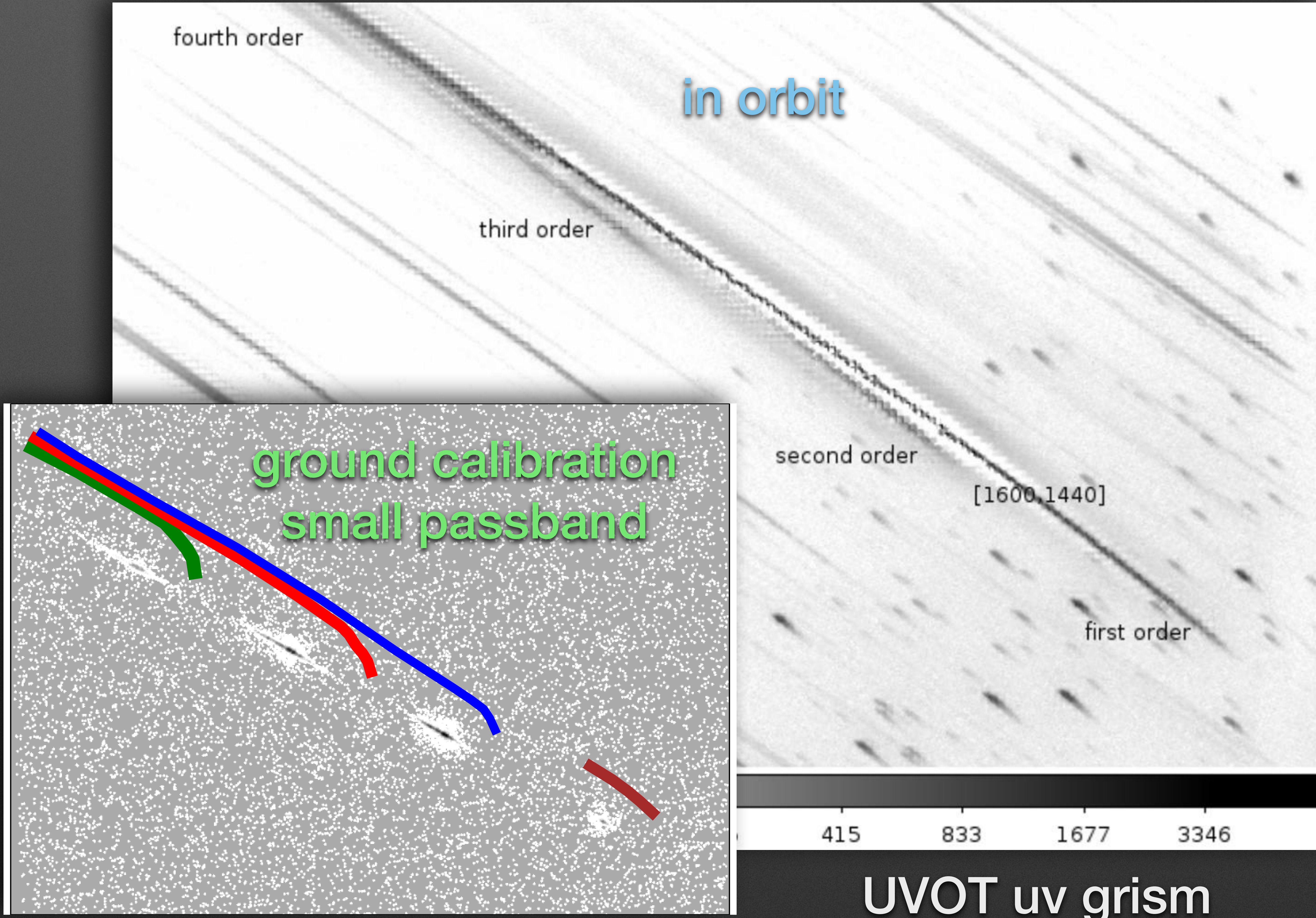
grism optical model (zemax)

- *includes telescope*
- *does not include fibre taper (MCP->CCD)*

Anchor: a reference point to the location in the sky



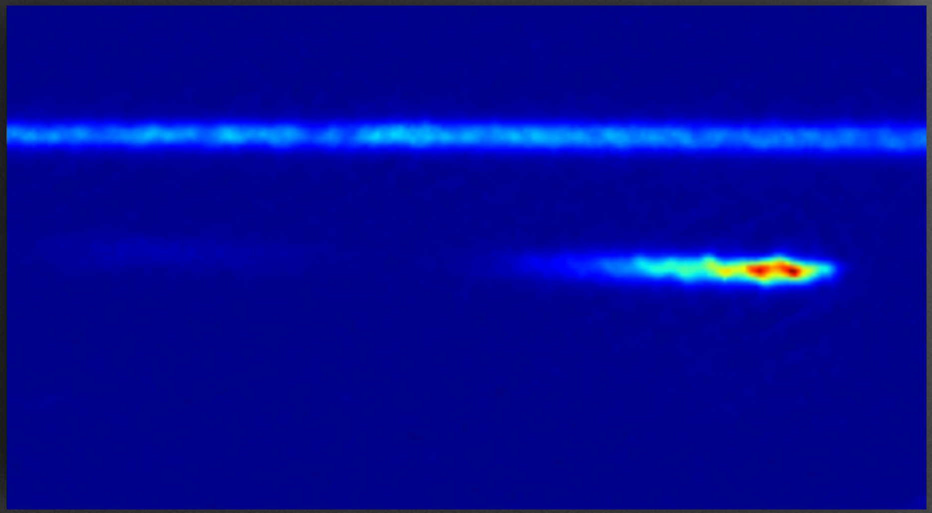
- *up to 5 spectral orders on the detector*: -1,0,1,2,3



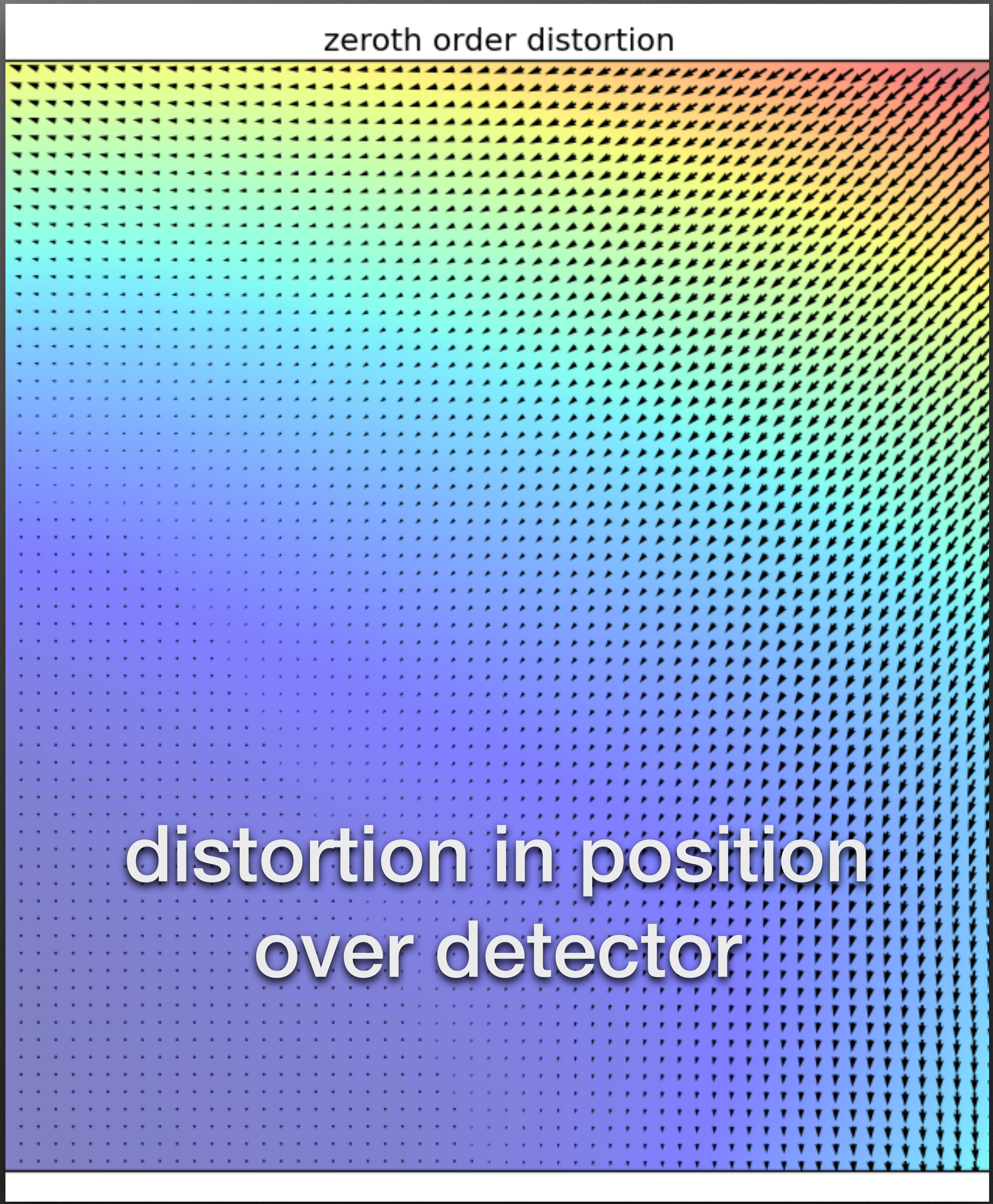
UVOT uv grism

choosing the anchor

- original choice (like XMM-OM): zeroth order peak
- 0th order is extended:



- 0th order suffers MOD-8
- 0th order positions on det image do no correspond linearly to sky positions



choosing the anchor...

- There was a problem with zeroth order anchor accuracy
- Remedy: use zeroth order distortion map and weak zeroth orders to locate anchor from sky position
- This method is better but sometimes fails depending on the kind and number of field stars present in the image

This one ?

keep looking

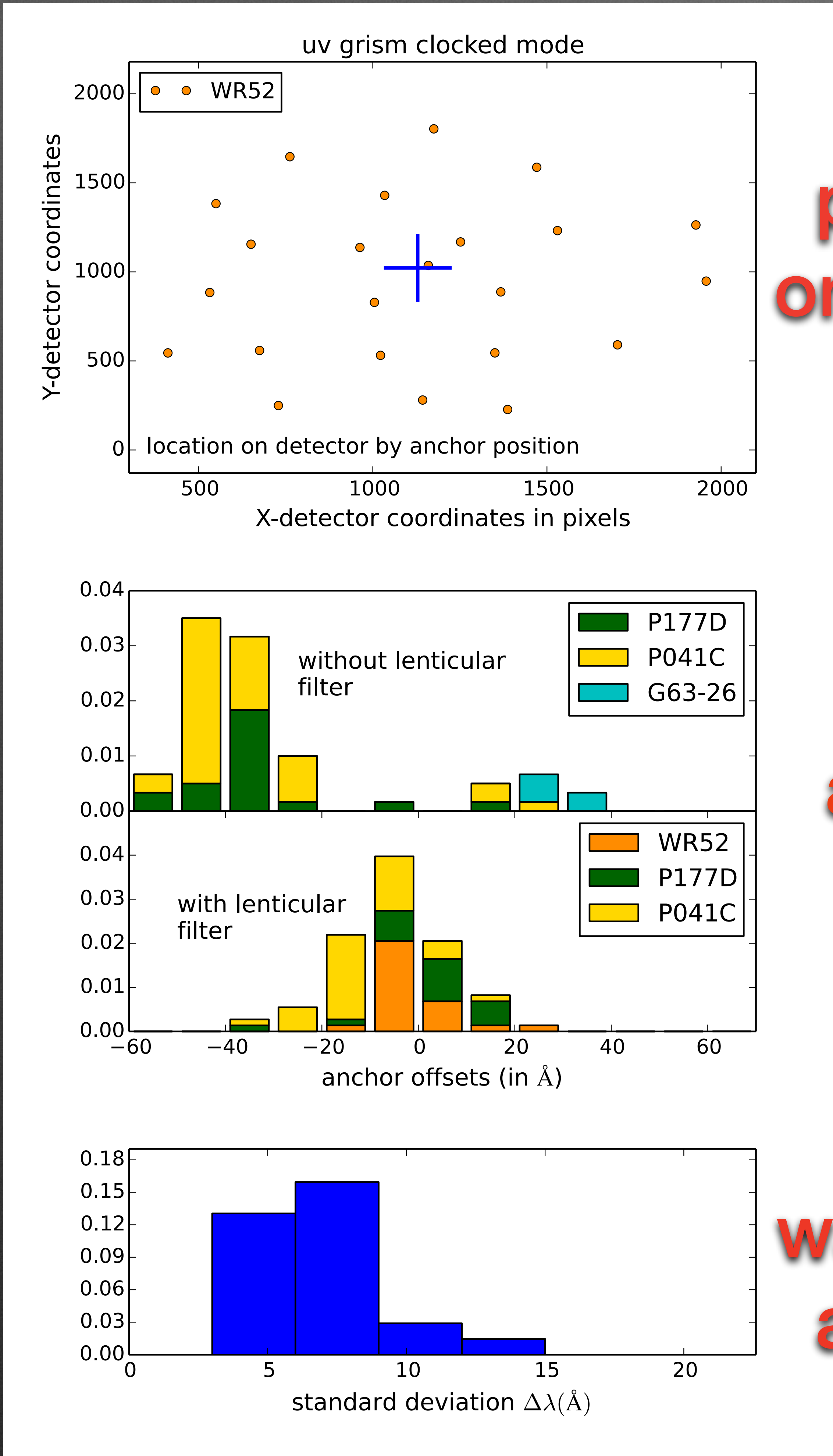
- An alternative: observe grism+lenticular filter in one go, back to back

- pick anchor at a fixed wavelength in the first order

- Use spectra with bright lines (WR stars) to find the anchor in the spectrum on the image

- Compare to location star on a lenticular filter image

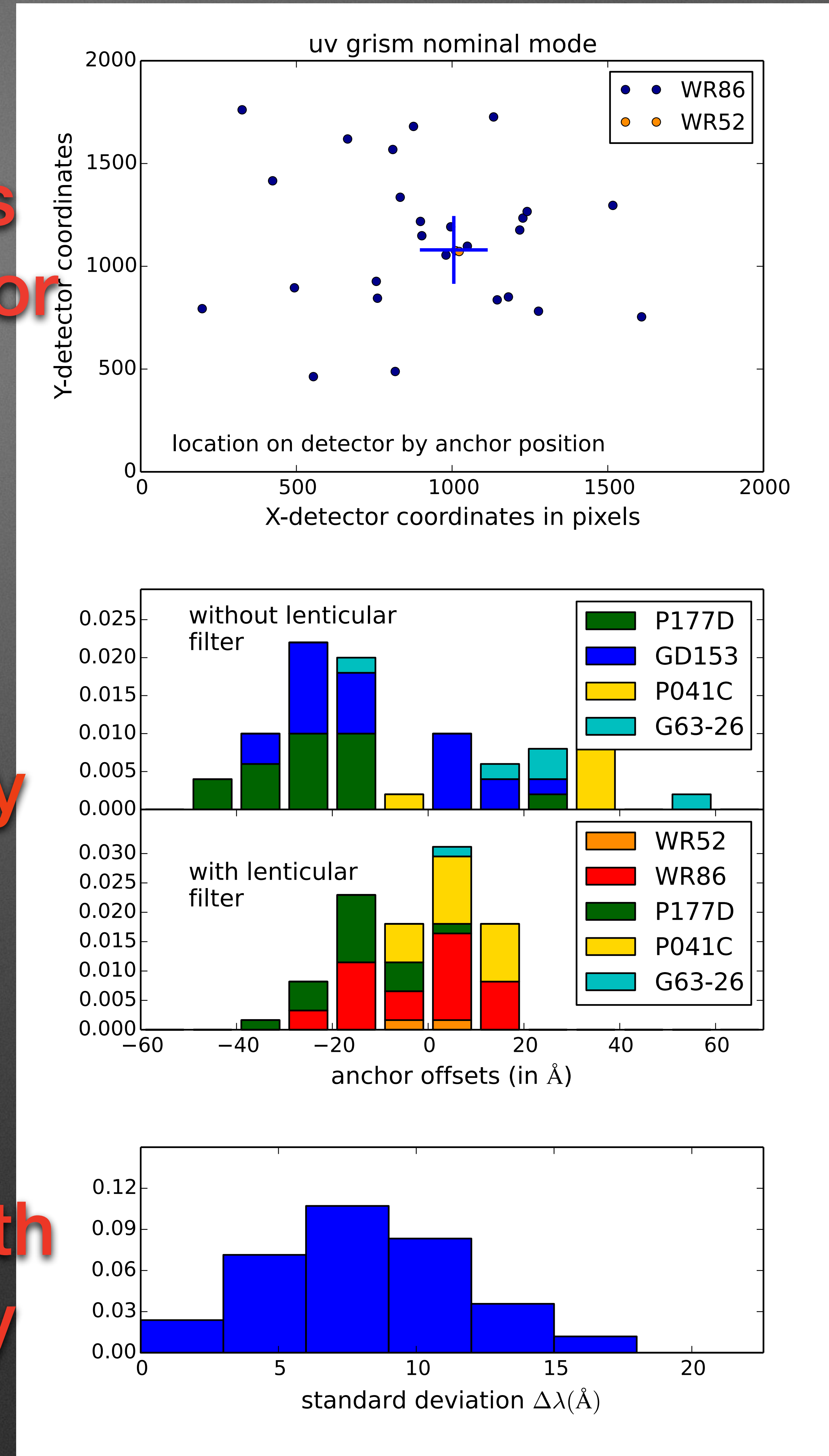
- Find map from position in lenticular filter image to anchor in grism image. Use optical model for variation over detector

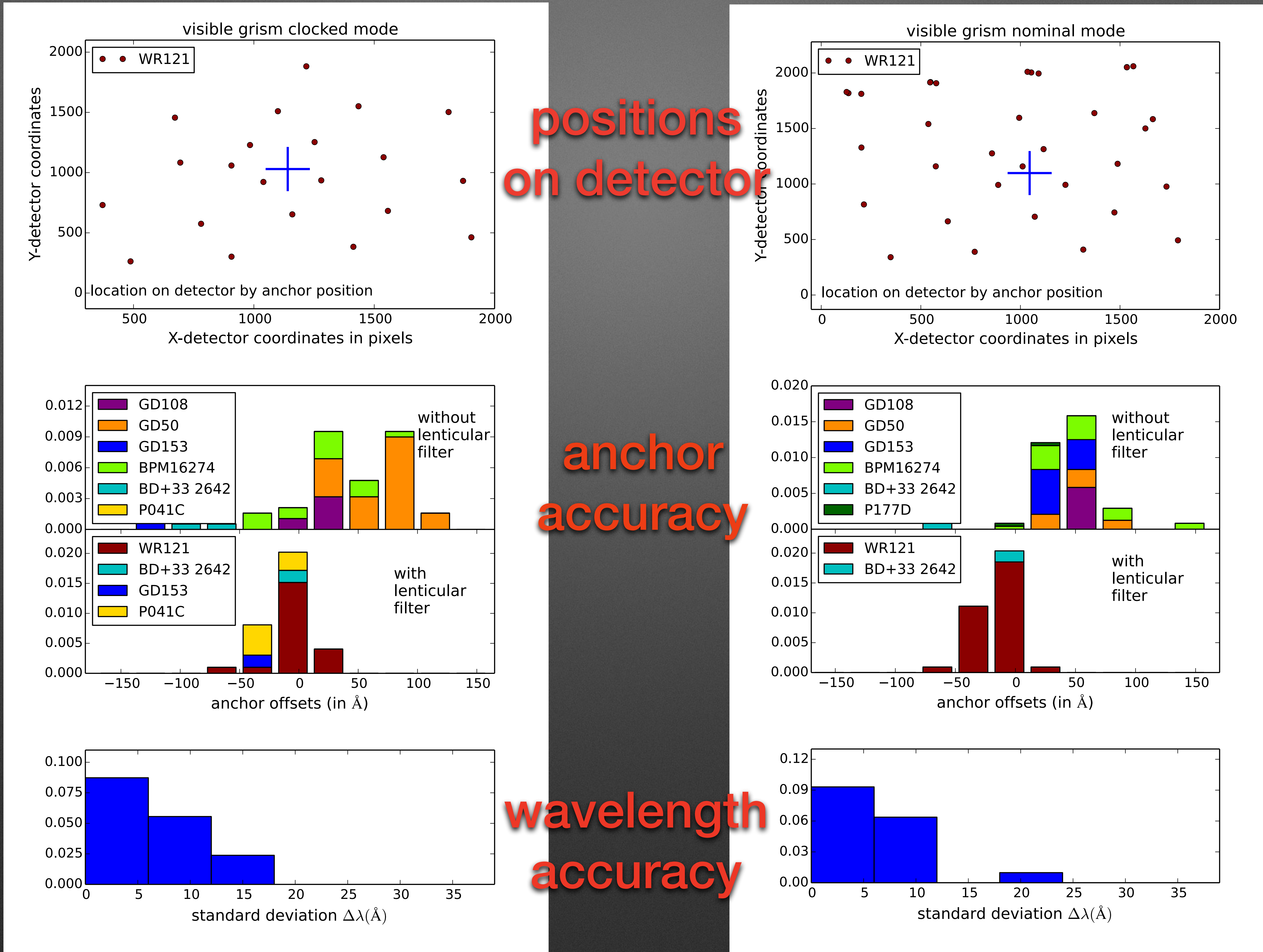


positions on detector

anchor accuracy

wavelength accuracy




visible grism clocked mode
WR121
location on detector by anchor position
Y-detector coordinates
X-detector coordinates in pixels
visible grism nominal mode
WR121
location on detector by anchor position
Y-detector coordinates
X-detector coordinates in pixels
positions
on detector
GD108
GD50
GD153
BPM16274
BD+33 2642
P041C
without
lenticular
filter
WR121
BD+33 2642
GD153
P041C
with
lenticular
filter
anchor offsets (in Å)
GD108
GD50
GD153
BPM16274
BD+33 2642
P177D
without
lenticular
filter
WR121
BD+33 2642
with
lenticular
filter
anchor offsets (in Å)
anchor
accuracy
standard deviation Δλ(Å)
standard deviation Δλ(Å)
wavelength
accuracy

resulting accuracy

Table 3. Default anchor positions and wavelength accuracy.

Grism mode	anchor[1] default	anchor 2σ accuracy(Å) detector centre[2,3]	dispersion accuracy(Å) detector centre[2,3]	anchor 2σ accuracy(Å) full detector	dispersion accuracy(Å) full detector
anchor position determined using a mode combined with lenticular filter					
uv nominal	[1005.5,1079.7]	30	7,18,36	35	8,16,34
uv clocked	[1129.1,1022.3]	12	8,11,21	17	7,22,18
visible nominal	[1046.3,1098.3]	30	5,10,6	44	6,13,6
visible clocked	[1140.7,1029.6]	48	5,14,13	44	4,13,12
anchor position determined using astrometry from uvotgraspcorr					
uv nominal	[1005.5,1079.7]	53	46,15,22	53	51,17,25
uv clocked	[1129.1,1022.3]	47	8,11,21	47	7,12,18
visible nominal	[1046.3,1098.3]	88	3,10,8	88	5,13,7
visible clocked	[1140.7,1029.6]	118	9,16,14	118	8,16,12

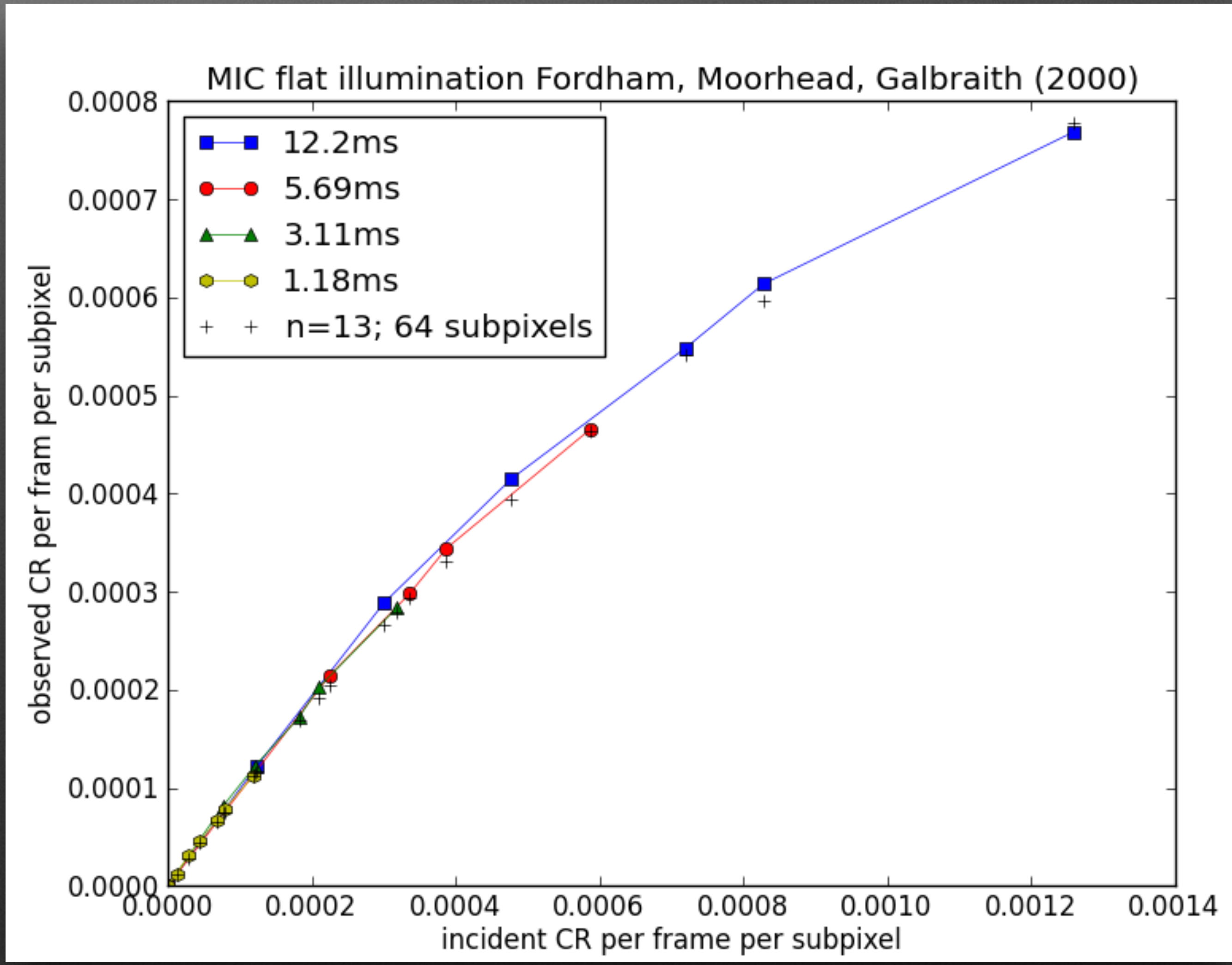
1 first order, in detector coordinates

2 The detector centre is defined by image pixels between 500 and 1500 in X and Y.

3 2σ errors for three ranges in the uv grism of $\lambda < 2000\AA, 2000 < \lambda < 4500\AA, 4500\AA < \lambda$, and in the visible grism of $\lambda < 3100\AA, 3100 < \lambda < 5500\AA, 5500\AA < \lambda$.

Coincidence loss

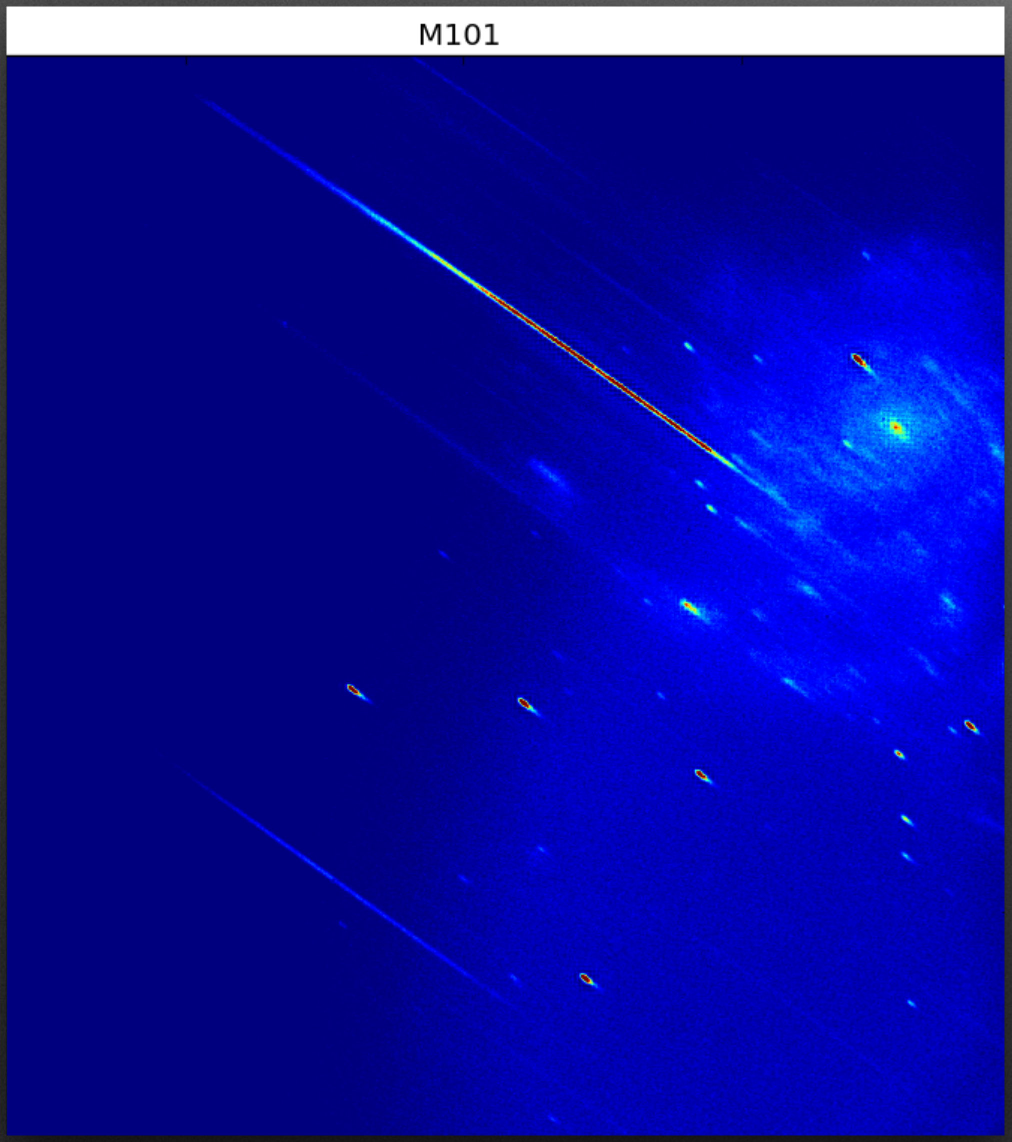
- lost counts when multiple photons incident during a frame
- long an outstanding issue for spectra
- well understood for point sources and flat illumination
- correction based on statistics of many readout detector frames
- first successful correction was ad-hoc
- recognition of different coincidence loss area key

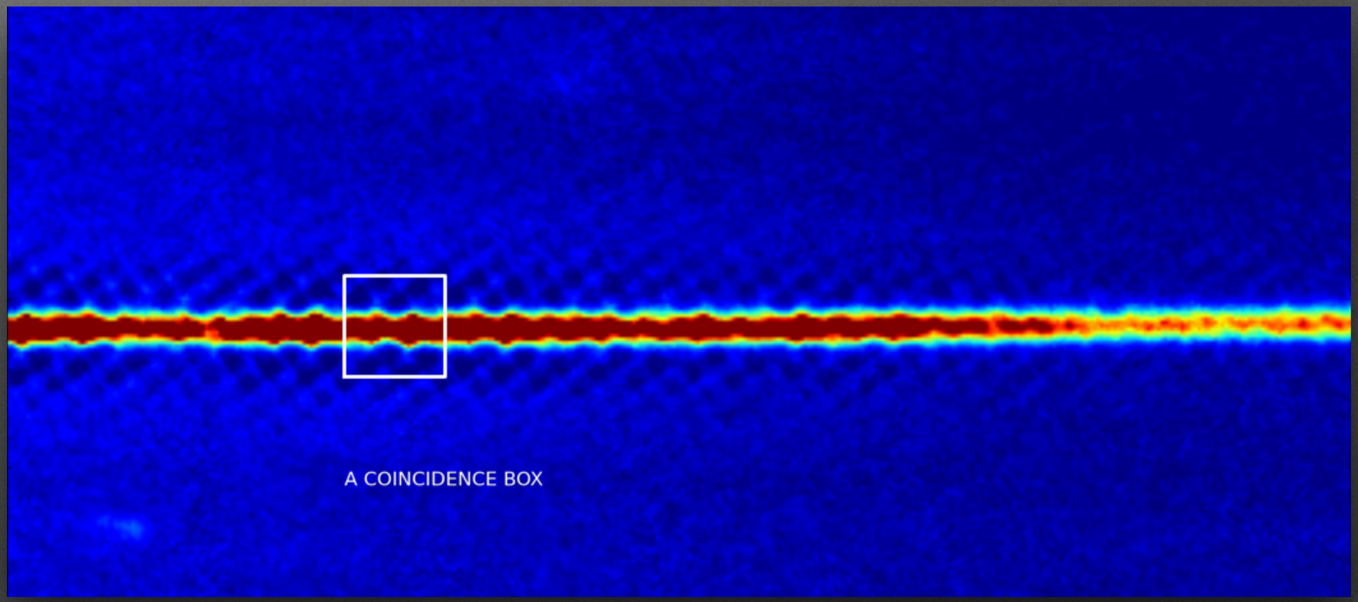


coincidence loss in the MIC detector

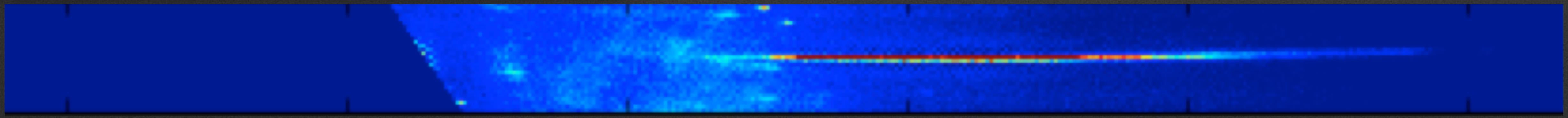
coincidence area in spectrum

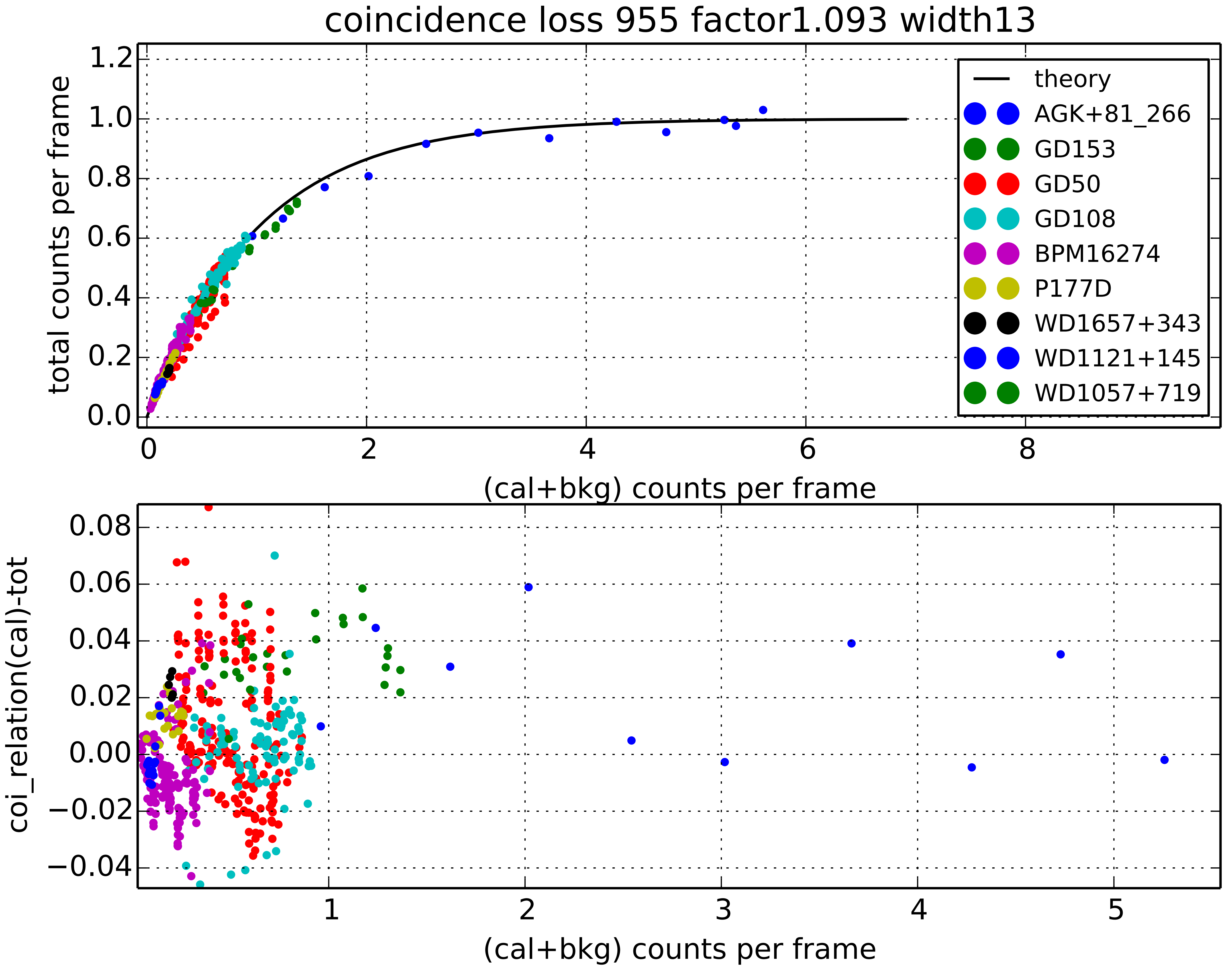
- box of length = 24/cos(angle spectrum) pixels





- *averages over mod8 noise*
- *fine tuned to theory*





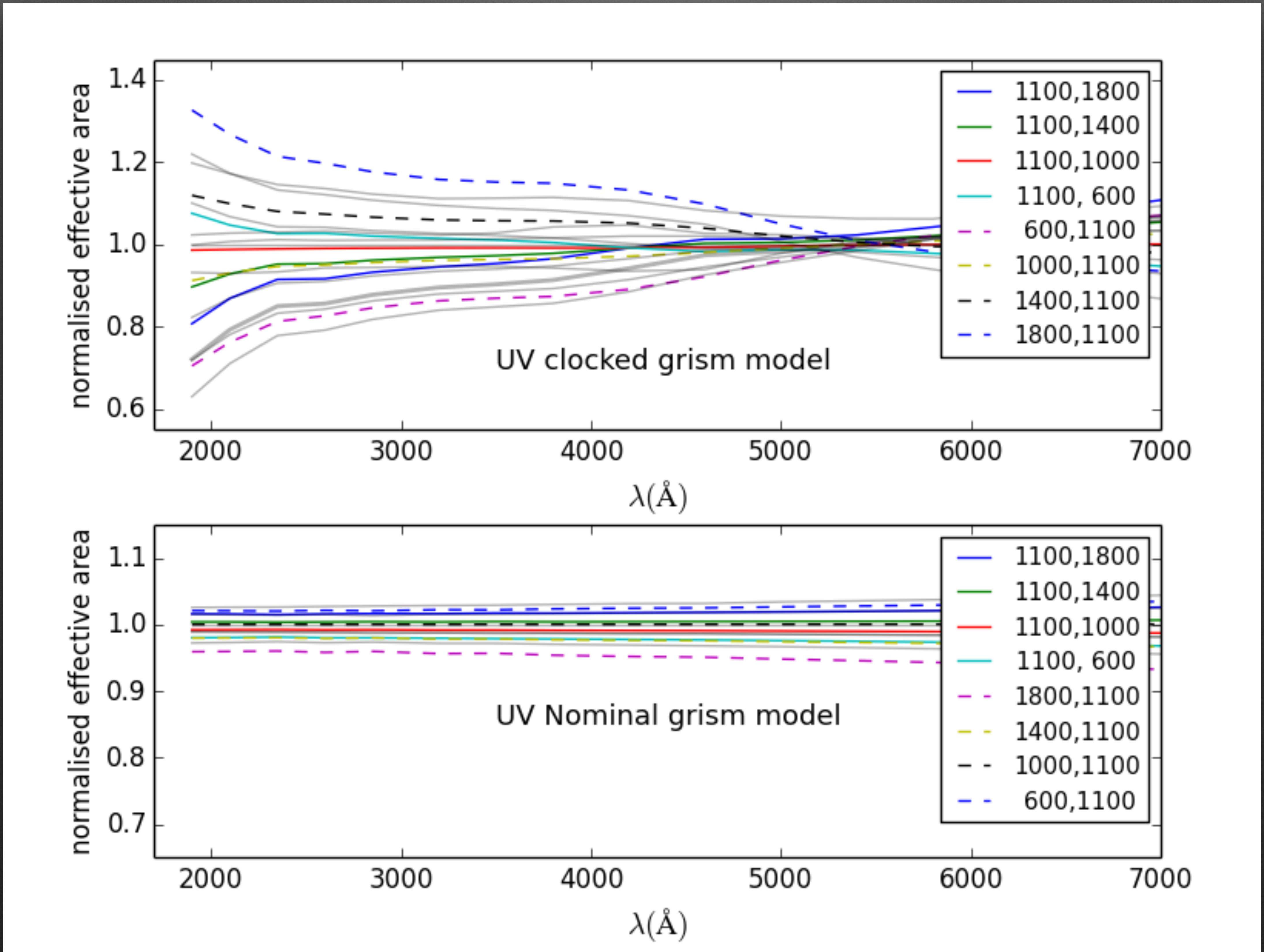
coincidence loss 955 factor1.093 width13
total counts per frame
(cal+bkg) counts per frame
theory
AGK+81_266
GD153
GD50
GD108
BPM16274
P177D
WD1657+343
WD1121+145
WD1057+719
coi_relation(cal)-tot
(cal+bkg) counts per frame

coincidence loss

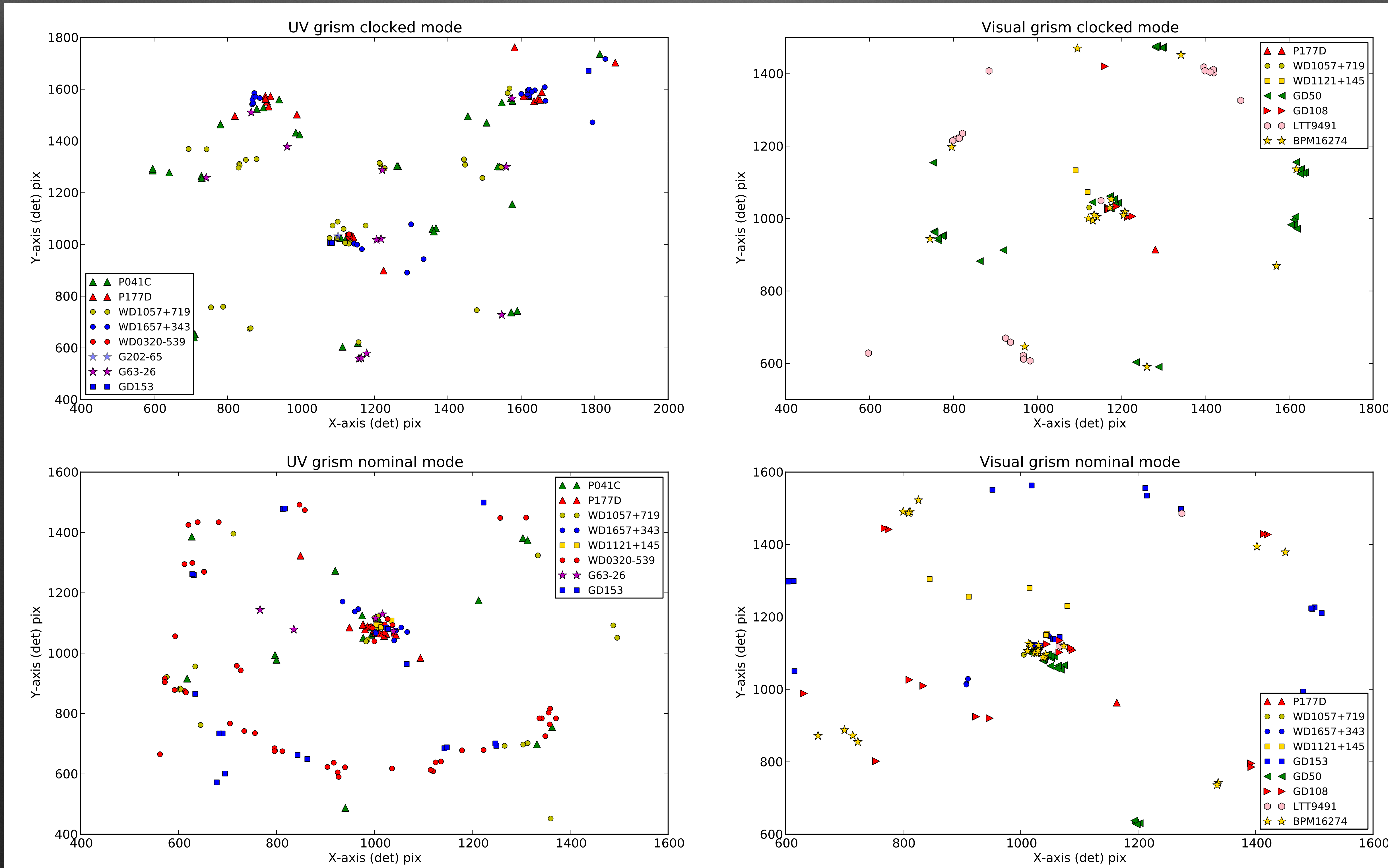
- well characterised now for spectra
- errors of coincidence loss *correction* are from 5 - 10%

effective area

- zemax model prediction
- not much variation over detector for nominal mode
- lots of variation over detector for clocked mode



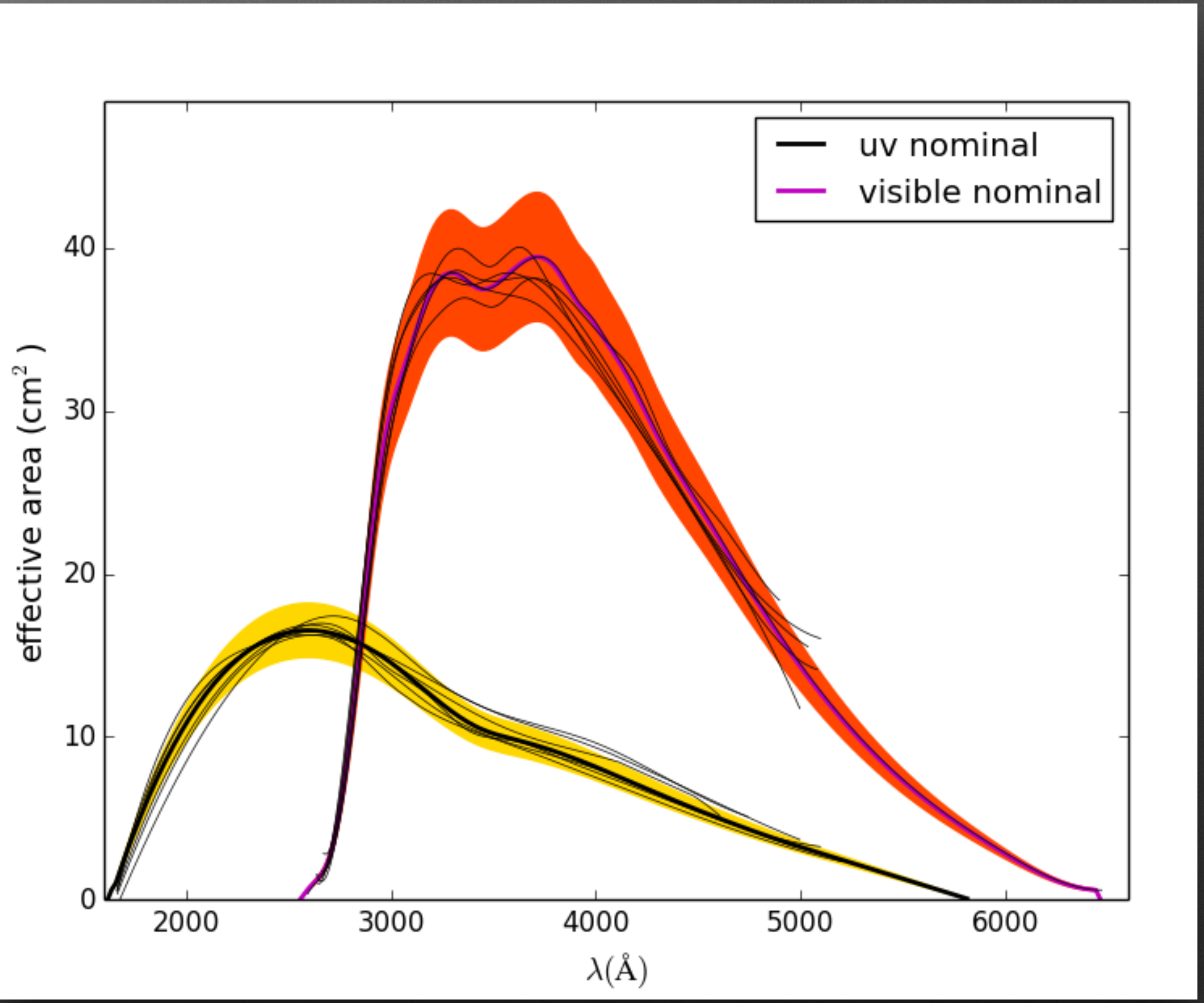
optical model: predicted sensitivity variation



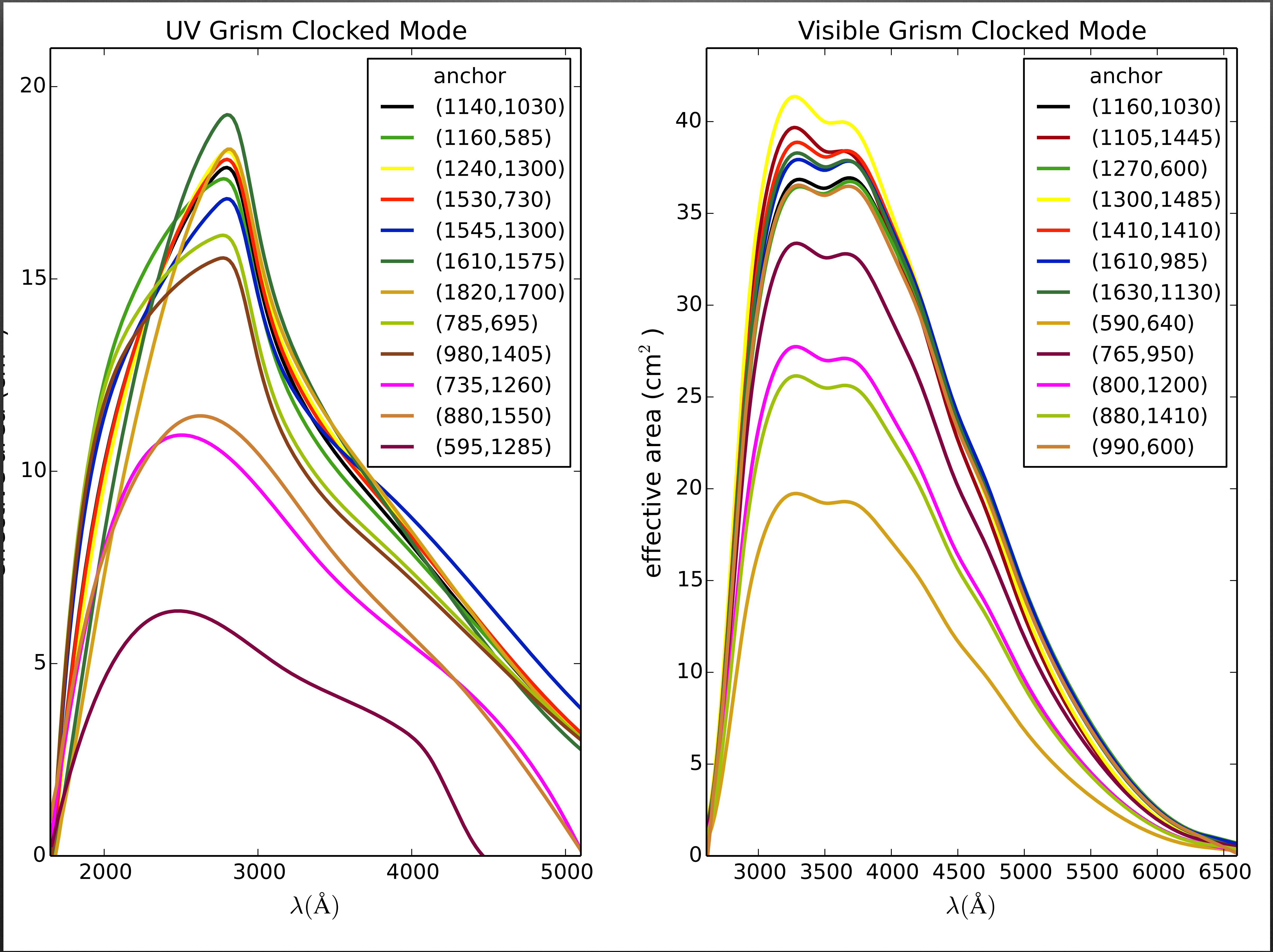
locations of uvot observed spectra for flux calibration by anchor position

nominal grisms

- effective area varies over detector by ~5%, within measurement errors



effective area clocked modes



flux calibration

- effective area accuracy varies from 5% (uv grism) to 15% (visible grism)
- flux depends on coincidence loss correction also, so typically the flux error is 5 to ~20%, depending on the size of the coincidence loss correction

other calibration issues

- for the zeroth order an equivalent photometric zeropoint has been derived
- the second order wavelengths have been derived using the brightest lines in WR spectra, and can be used to determine where bright spectral lines may contaminate the first order
- second order effective area is roughly known, but complicated by coincidence loss and overlap with first and third orders
- not discussed were the PSF variation, the width of the orders, and the grism software which are in the upcoming calibration paper