The Spectral States of Cygnus X-1

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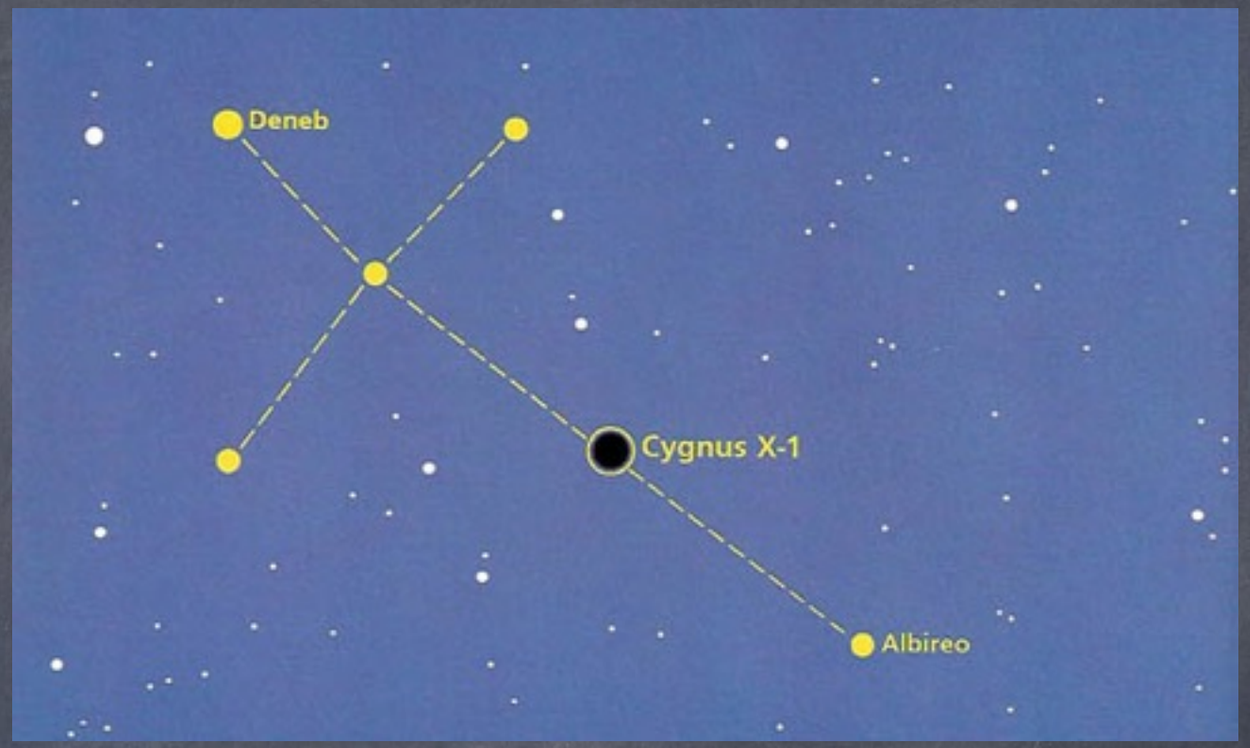
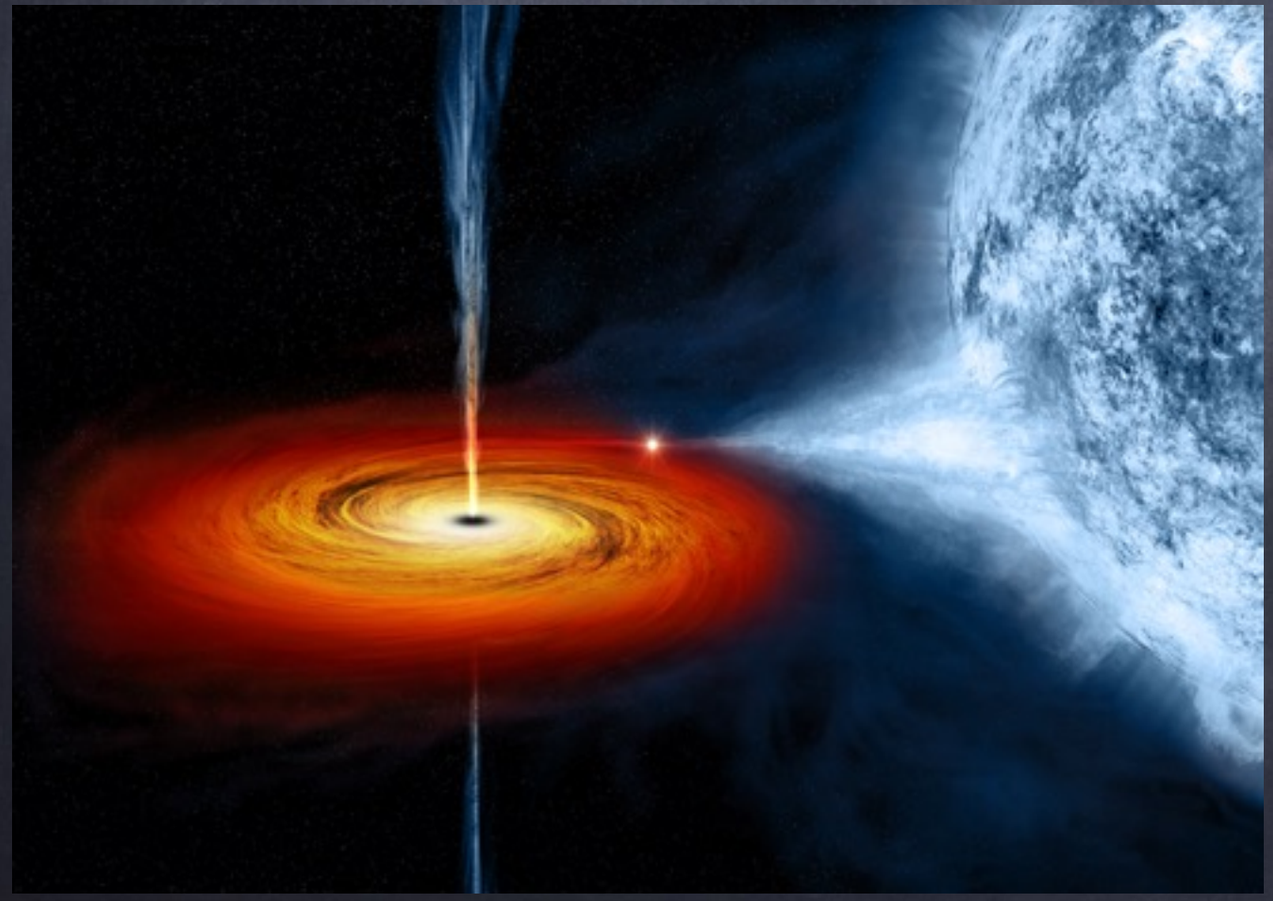
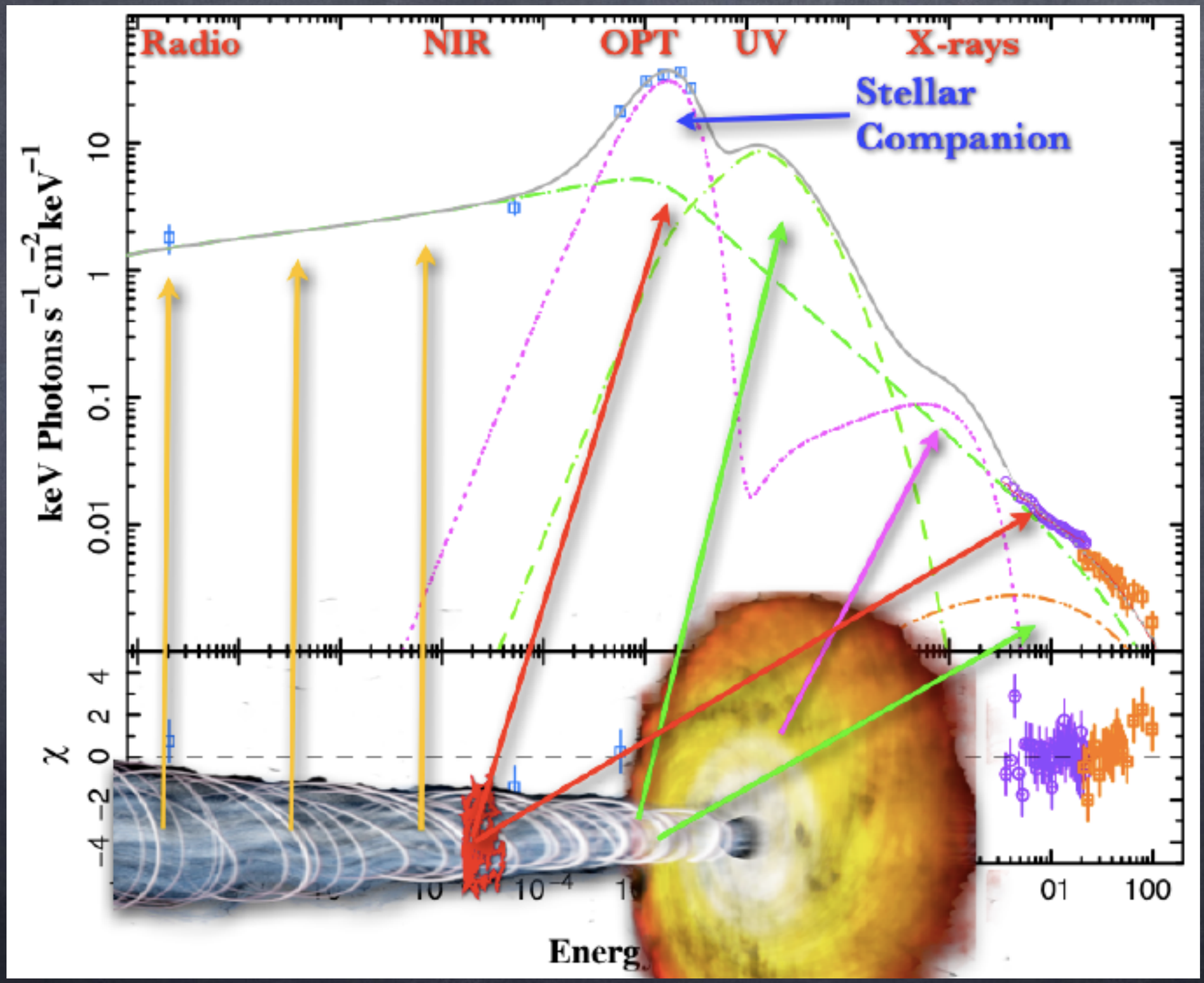
The Spectral States of Cygnus X-1

- microquasar
- O9.7Iab companion star
- m_V=8.95
- ~ 15 of the $M_{BH}=21 \pm 8\ M_\odot$
- ~ 5.6 d rotation

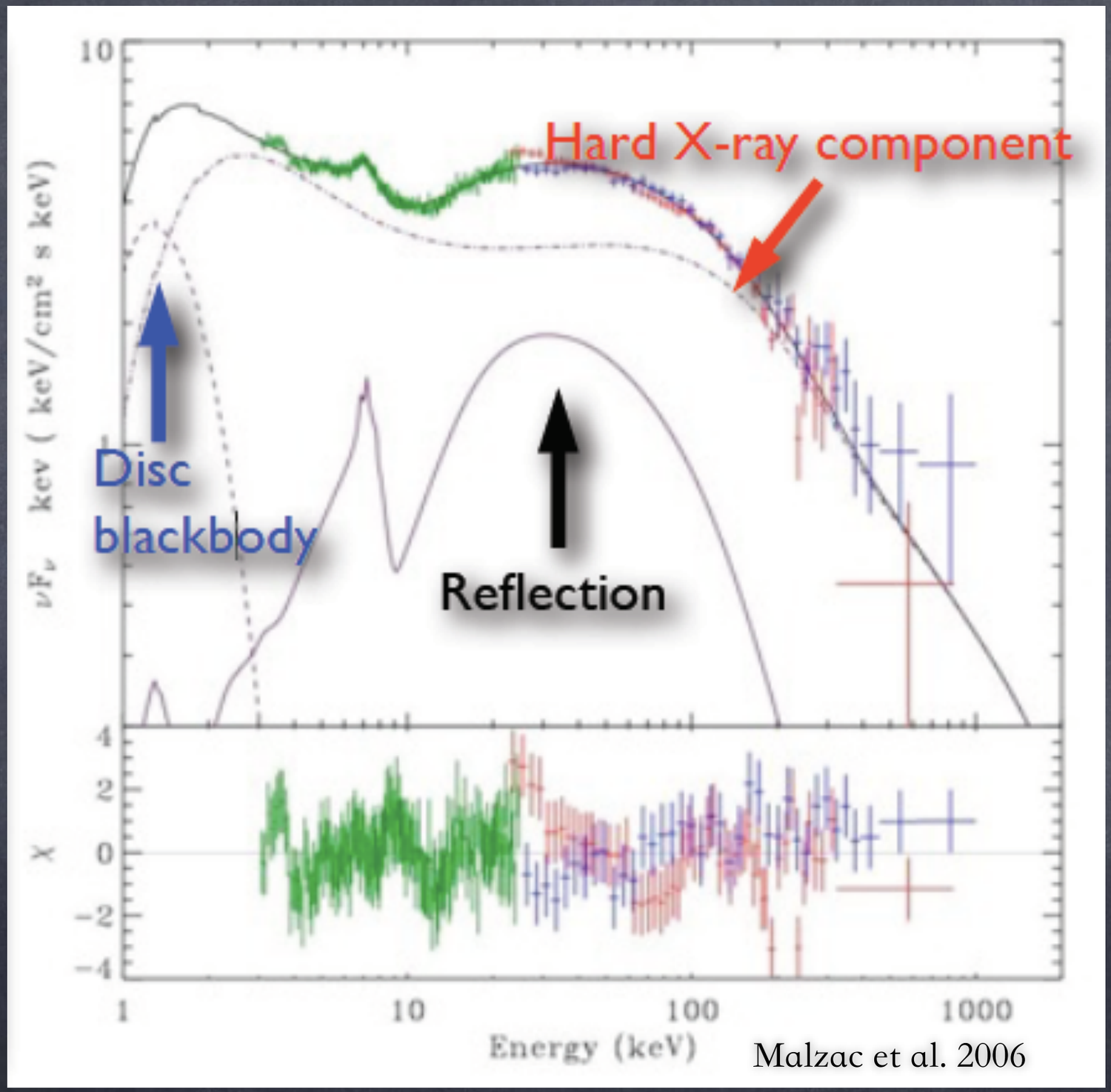




SED of Cyg X-1


Radio
NIR
OPT
UV
X-rays
Stellar
Companion
keV Photons s^{-1} cm^{-2} keV^{-1}
10
1
0.1
0.01
χ
4
2
0
−2
−4
10^{-4}
01
100
Energ

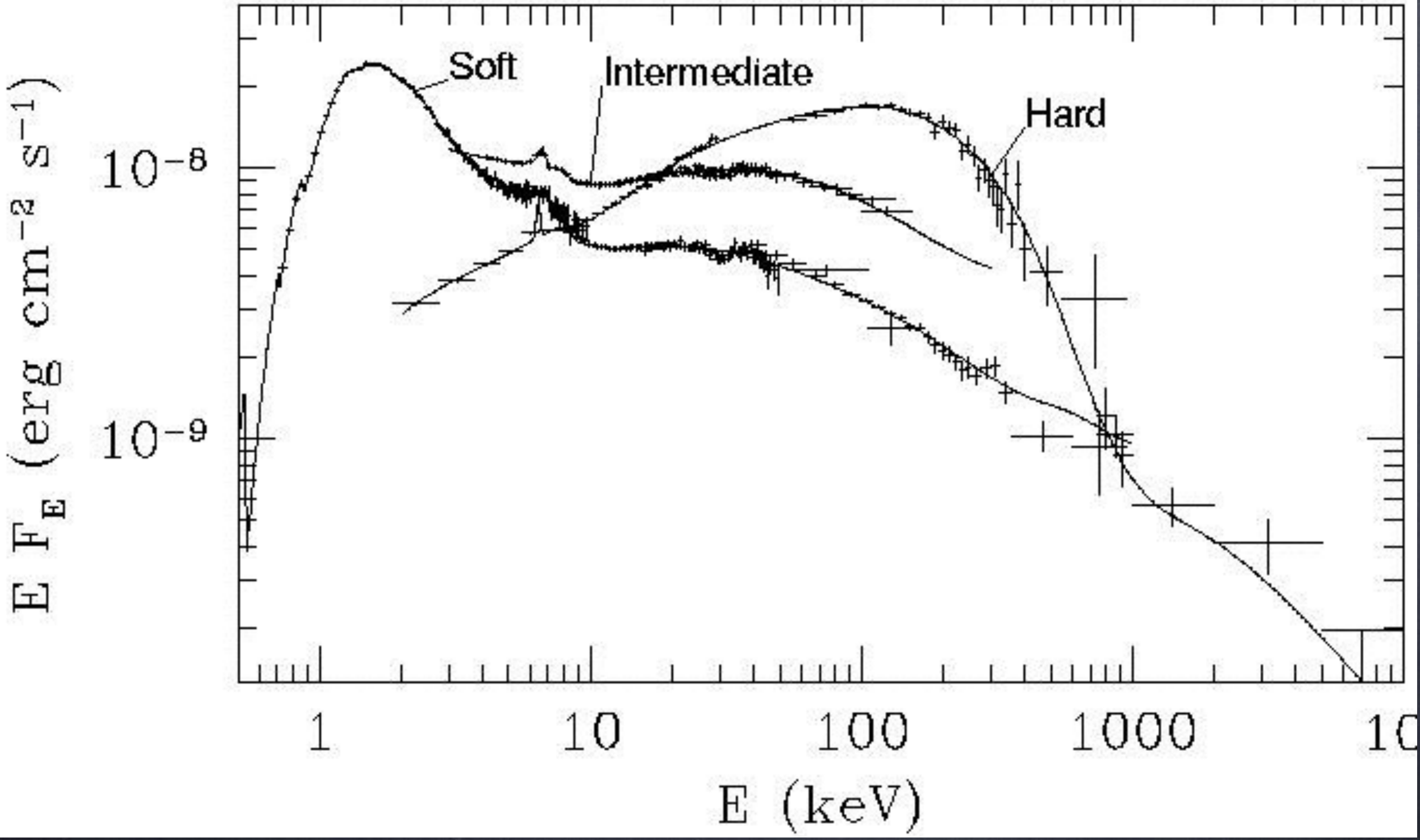
The Spectral States of Cygnus X-1



Malzac et al. 2006

variety of xspec models

The Spectral States of Cygnus X-1

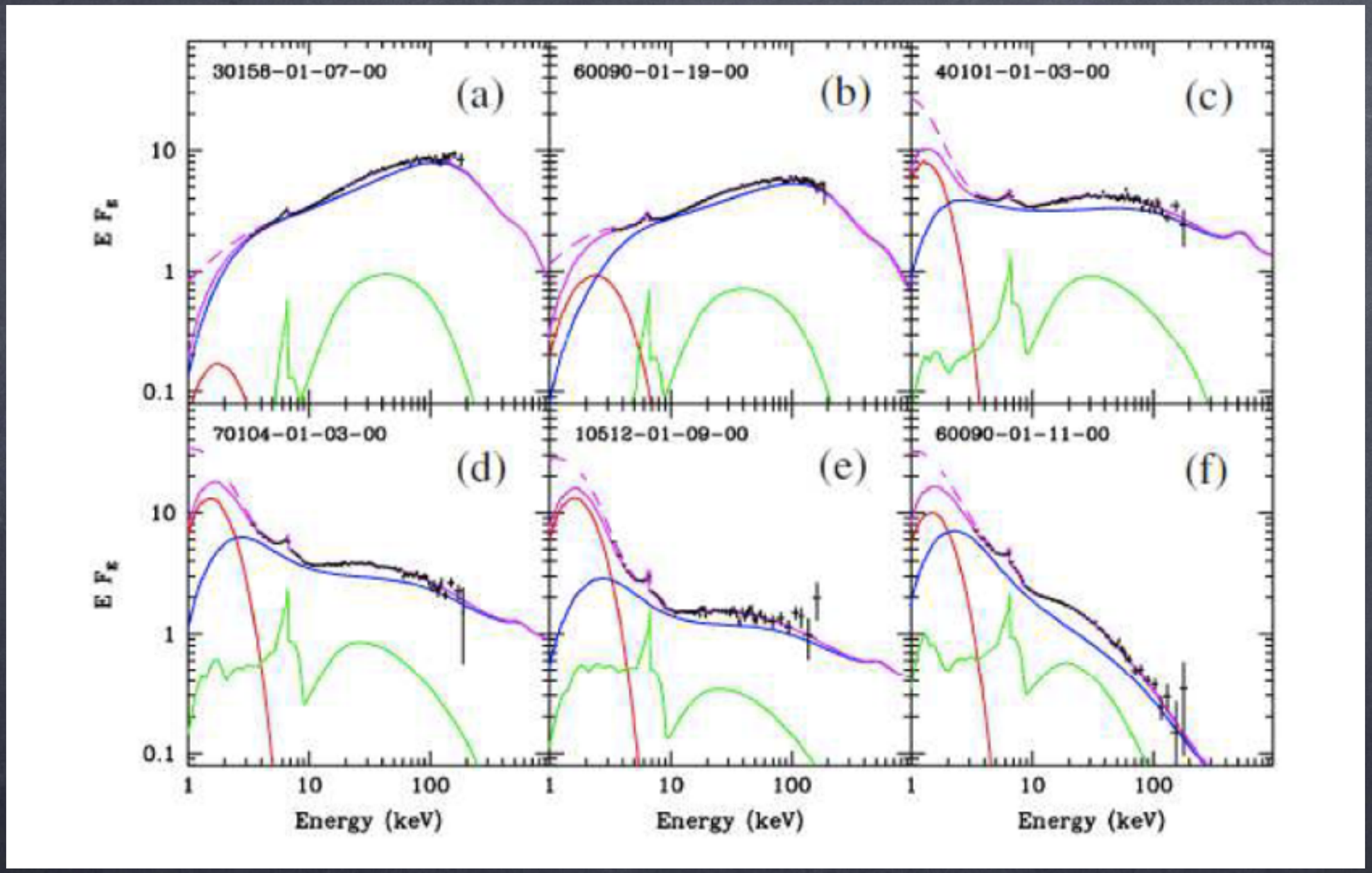


The Spectral States of Cygnus X-1

states

- **hard**, non-thermal power-law with an exponential cut-off >150 keV, strong radio emission
- IM, X-ray spectrum softens and radio flaring is observed
- **soft**, an accretion disk spectrum, weak X-ray variability, and radio emission from the jet is non-detectable

The Spectral States of Cygnus X-1



The six characteristic spectra of Cyg X-1, from (a) very hard to (f) very soft, fitted by the hybrid Comptonization model (Gierlinski1, Zdziarski2 , Done, arxiv: 1011.584

The Spectral States of Cygnus X-1

Standard picture: truncated disc model

LOW HARD STATE

cold disc truncated at ~ 100-1000 Rg
+ hot inner accretion flow

⇒ Thermal comptonisation
in the hot (10^9 K) plasma

(Shapiro, Ligthman & Eardley 1976; Rees et al. 1982; Narayan & Yi 1994, Abramowicz et al. 1995, Esin et al. 1997, Yuan & Zdziarski 2004, Petrucci et al. 2010...)

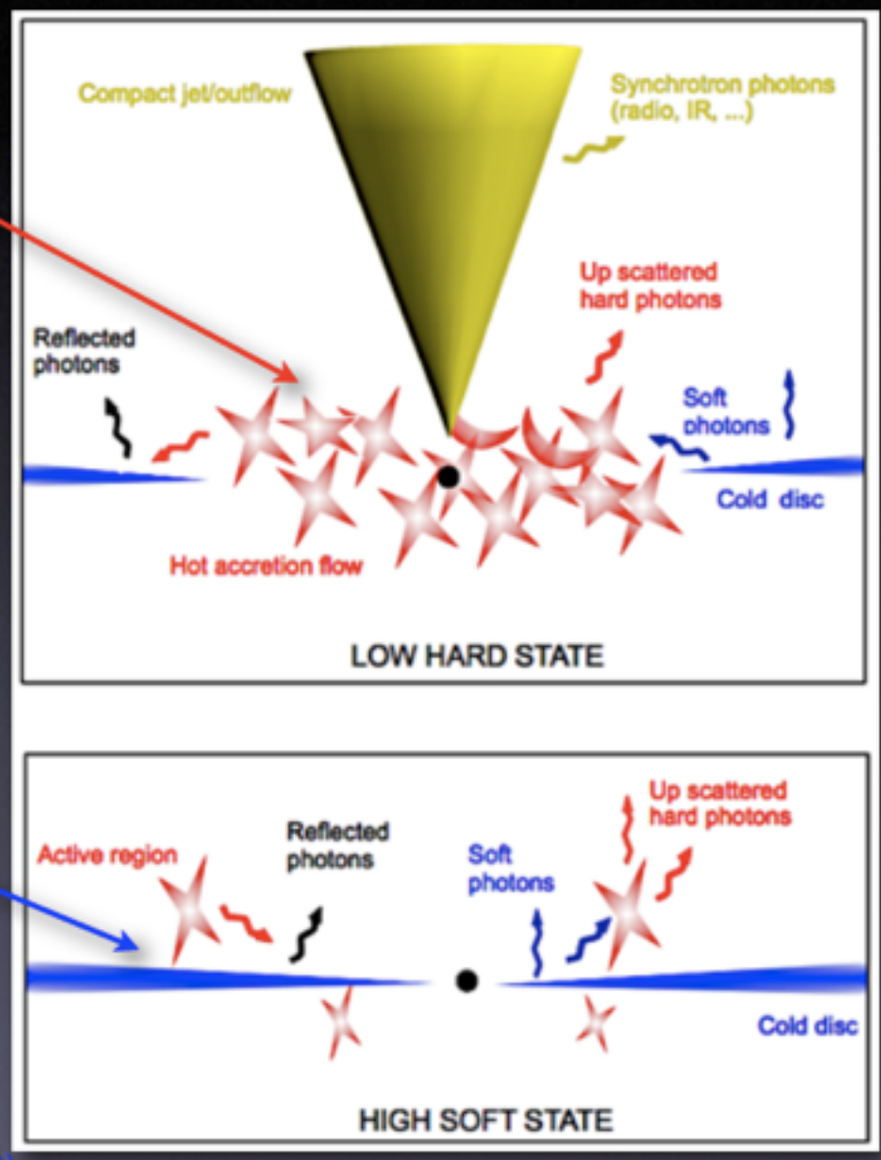
HIGH SOFT STATE

cold geometrically thin disc
down to the last stable orbit
+ weak non-thermal corona

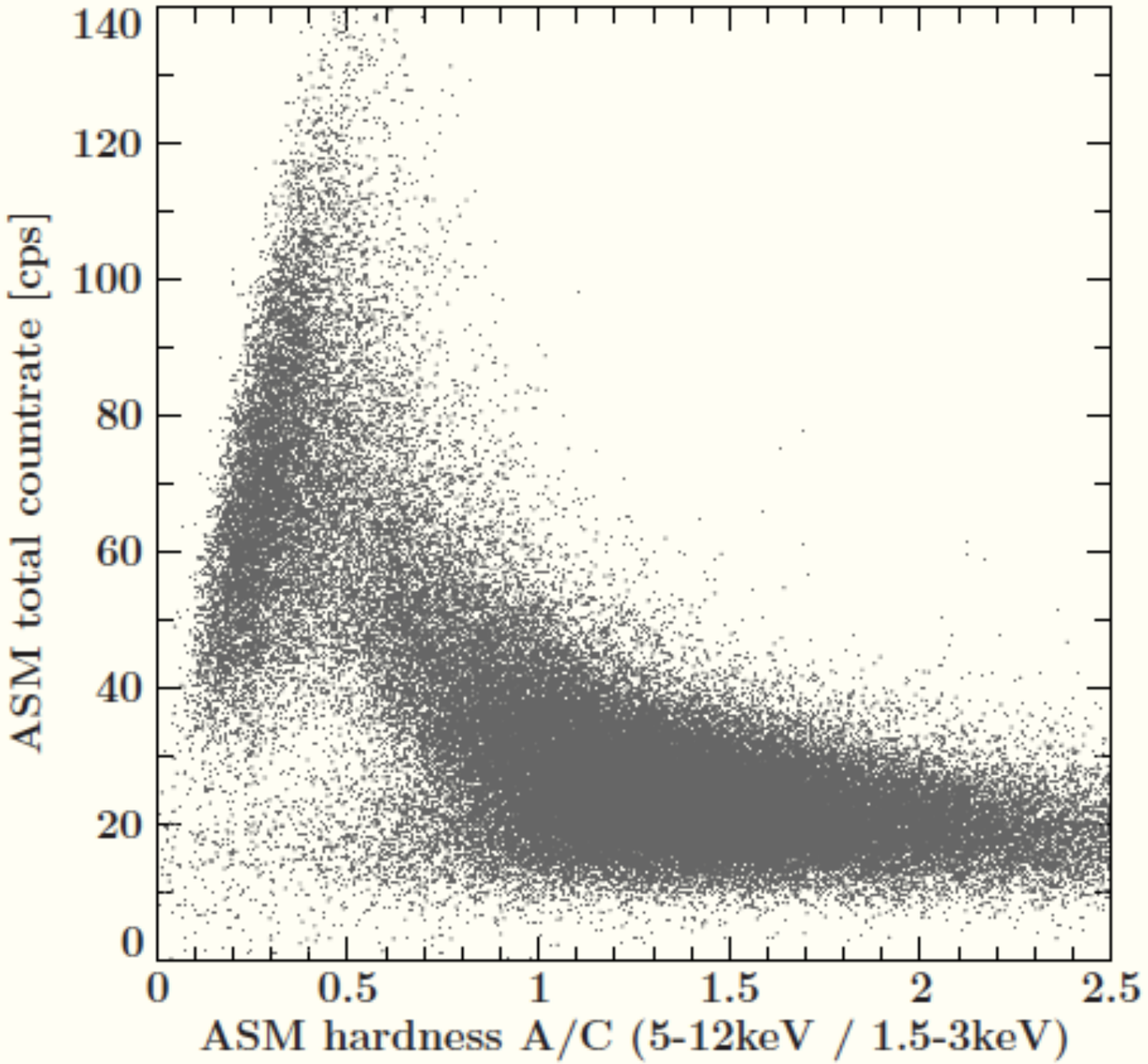
⇒ dominant thermal disc emission

+ non-thermal comptonisation

(Shakura & Sunyaev 1973, Galeev et al. 1979, Coppi 1999)



Hardness definition



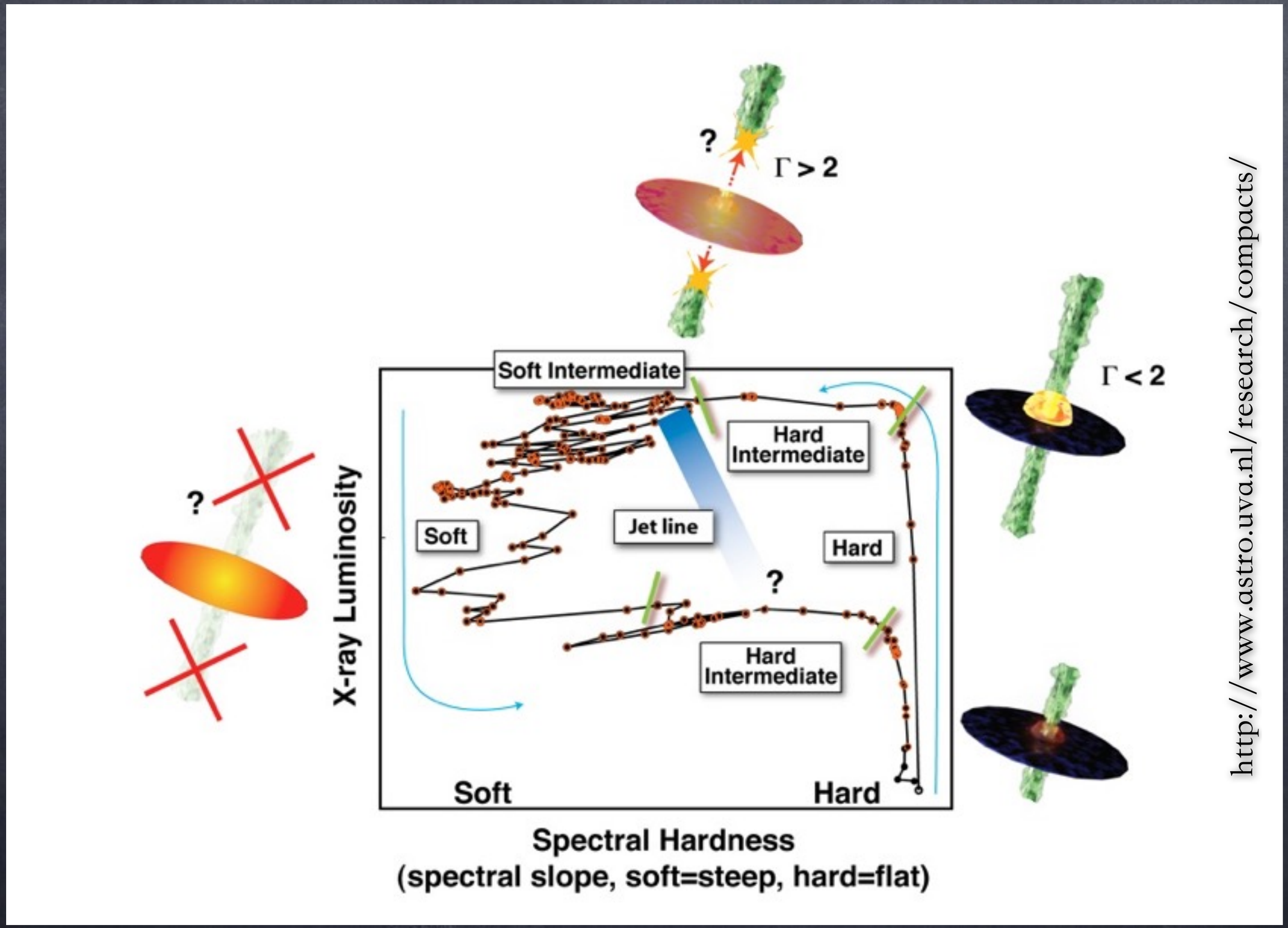
X-ray hardness ≙
X-ray colour:

$$\text{Hardness} = \frac{\text{hard countrate}}{\text{soft countrate}}$$

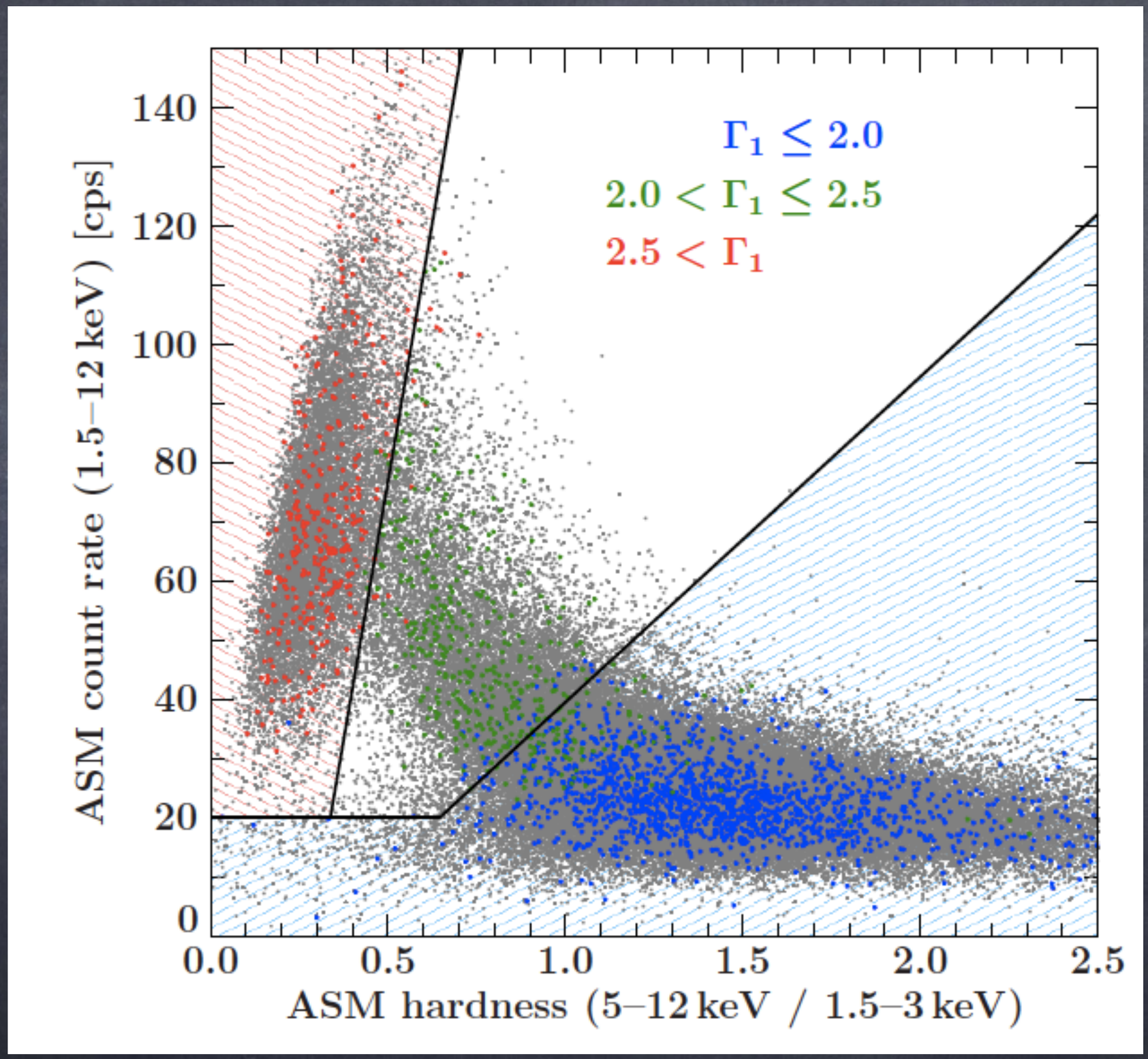
hardness intensity diagramm (HID)
=
hardness vs. total countrate

Grinberg V., 2012

Hardness diagrams

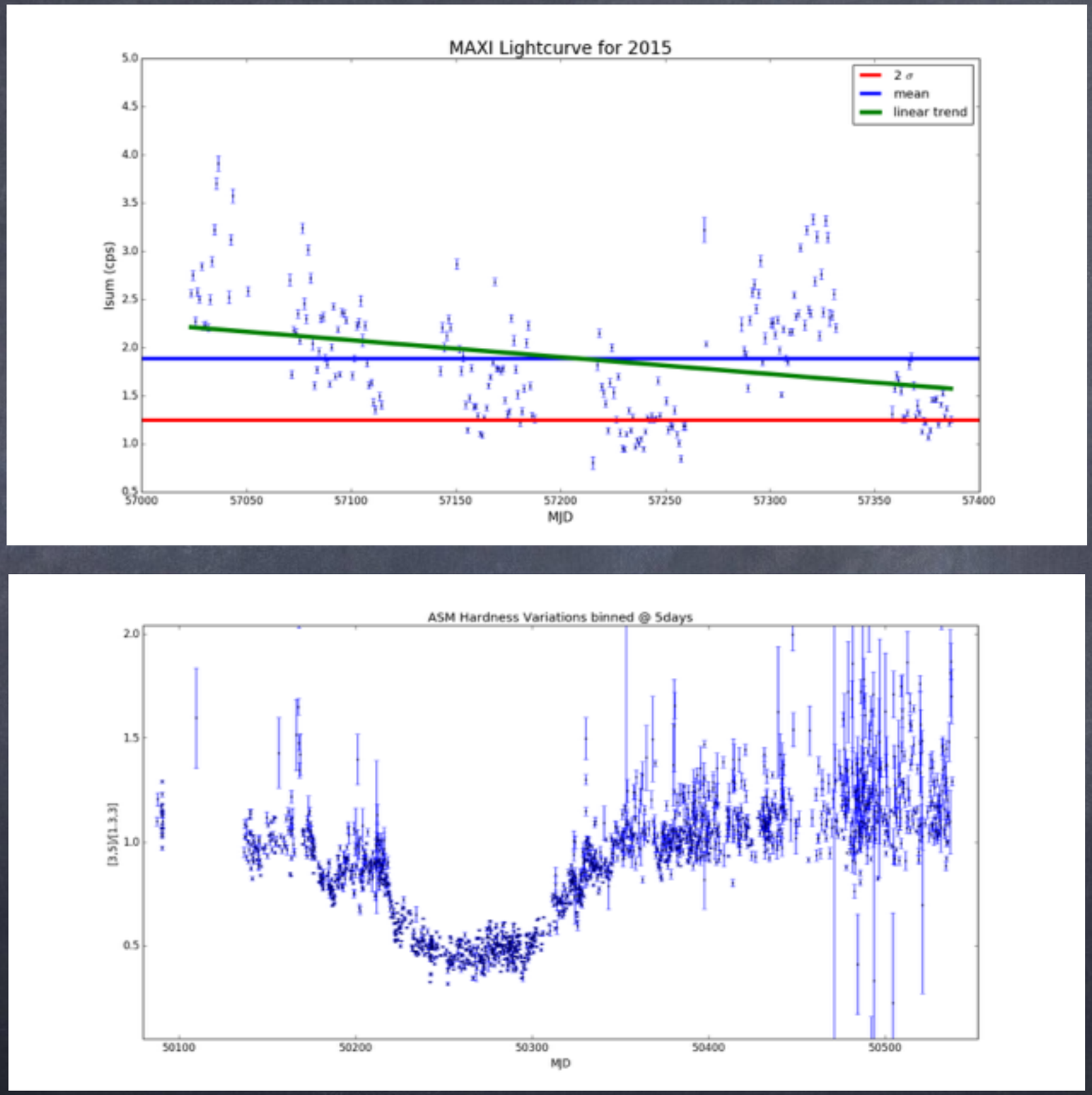


Hardness studies



Grinberg et al. 2013A&A...554A..88G

Hardness studies



2-10 keV

2-12 keV

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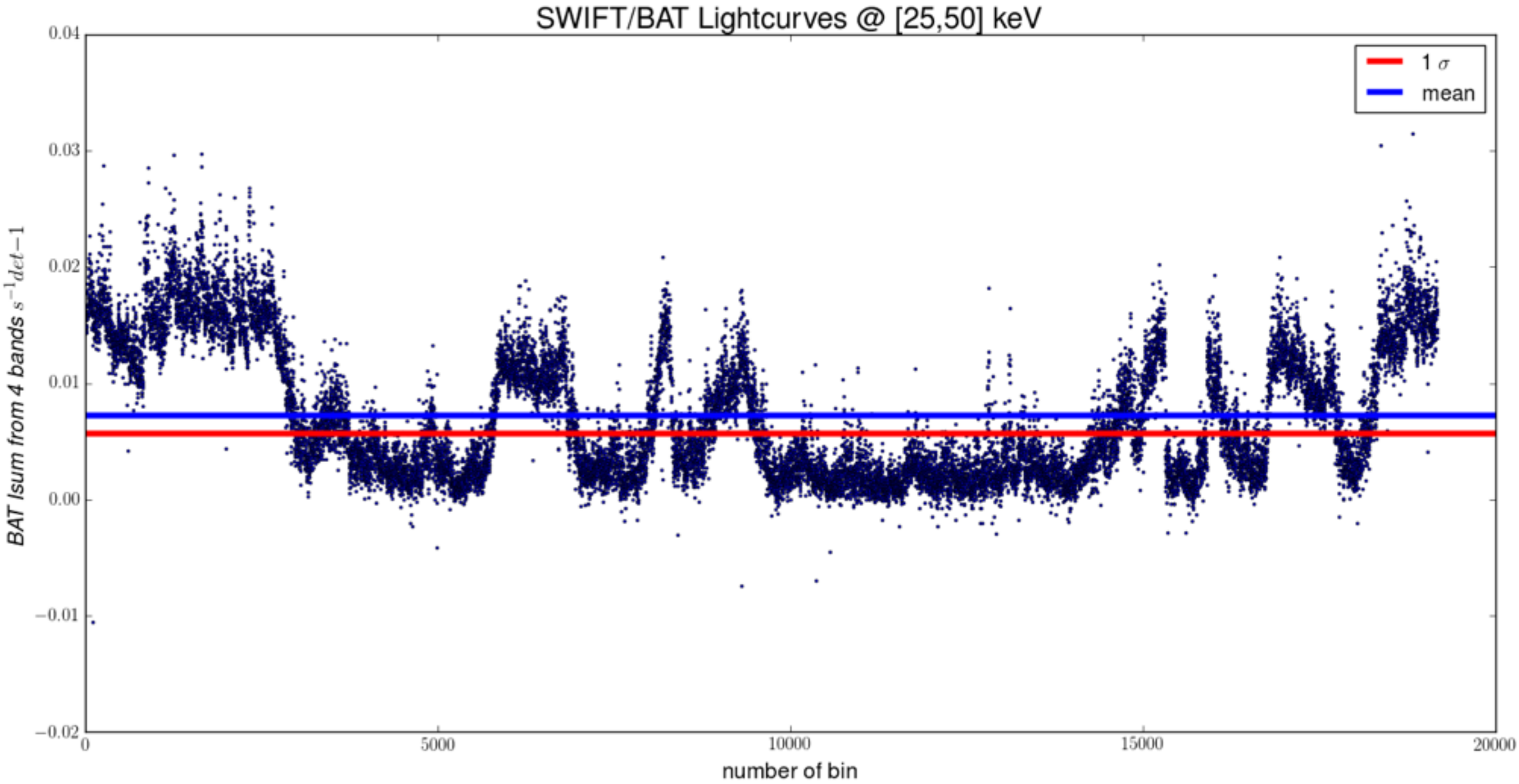


INTEGRAL

INTEGRAL

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL) of the European Space Agency was successfully launched on October 17, 2002. It was lifted off from Baikonur in Kazakhstan on a Russian Proton launcher and is now on a 72-hour elliptical orbit, ranging from 9,000 km up to 155,000 km from Earth. INTEGRAL is the successor of the ESA gamma-ray observatory Cos-B and the NASA gamma-ray Observatory CGRO. It will produce a complete map of the sky in the soft gamma-ray waveband and it is capable of performing high spectral and spatial observations in gamma rays. The observatory is also equipped with X-ray and optical detectors to provide simultaneous observations in these wavebands.

Mission Characteristics

- Lifetime : October 2002 - (nominal 2 year mission, extented up to December 2008)
- Energy Range : 3 keV - 10 MeV and Optical V-band
- Special Features : High spectral and spatial resolution.
Simultaneous Gamma-ray, X-ray and Optical observations.
- Payload :

  - 2 Gamma-ray instruments
    - Spectrometer (SPI; 20 keV - 8 MeV)
      Coded aperature mask. FOV 16°, detector area. 500 cm^2 (Germanium array) spectral resolution (E/dE) 500 @ 1 MeV, spatial resolution 2°.
    - Imager (IBIS; 15 keV - 10 MeV)
      Coded aperature mask. FOV 9° X 9°, detector area. 2600 cm^2 (CdTe array) & 3100 cm^2 (CsI array), spatial resolution 12´.

  - Joint European X-ray Monitor (JEM-X; 3- 35 keV)
    Coded aperature mask with 2 high pressure microstrip gas chambers.
    FOV 4.8°, detector area. each 500 cm^2, spatial resolution 3´.

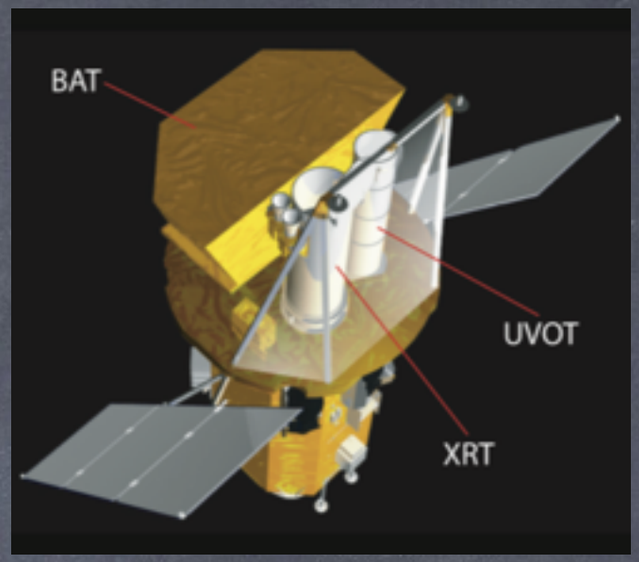
  - Optical Monitoring Camera (OMC; 500-850 nm). 50mm lens with CCD.
    FOV 5° X 5°.

[ESA INTEGRAL Home page] [INTEGRAL Science Data Center]
[INTEGRAL Guest Observer Facility]

INTEGRAL artist's view courtesy of ESA.

SWIFT

Burst Alert Telescope	
Aperture	Coded Mask
Detecting Area	5200 cm^2
Detector	CdZnTe
Detector Operation	Photon Counting
Field of View	2.0 sr (partially coded)
Detection Elements	256 modules of 128 elements
Detector Size	4mm x 4mm x 2mm
Telescope PSF	17 arcminutes
Location Accuracy	1 - 4 arcminutes
Energy Range	15 - 150 keV
Burst Detection Rate	>100 bursts/year



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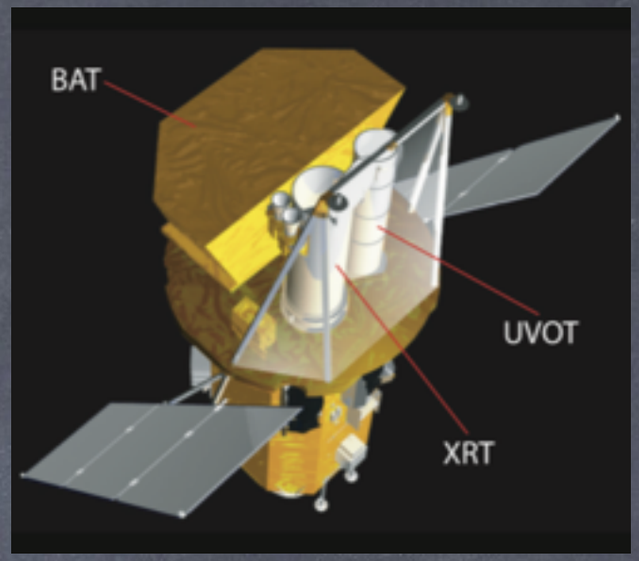
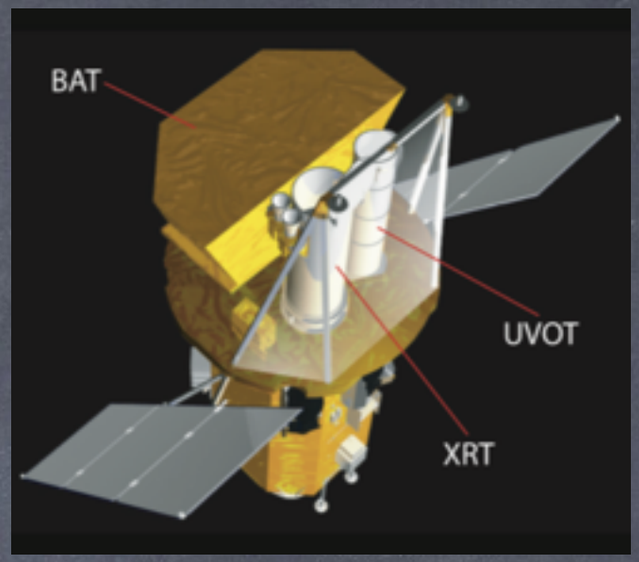


UltraViolet/Optical Telescope	
Telescope	Modified Ritchey-Chrétien
Aperture	30 cm diameter
F-number	12.7
Detector	Intensified CCD
Detector Operation	Photon Counting
Field of View	17 x 17 arcminutes
Detection Element	2048 x 2048 pixels
Telescope PSF	0.9 arcsec @ 350 nm
Location Accuracy	0.3 arcseconds
Wavelength Range	170 nm - 650 nm
Colors	6
Spectral Resolution (Grisms)	$\lambda/\Delta\lambda \sim 200$ @ 400 nm
Sensitivity	B = 24 in white light in 1000 sec
Pixel Scale	0.48 arcseconds
Bright Limit	$m_V = 7$ mag

SWIFT



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X-Ray Telescope	
Telescope	Wolter I
Detector	XMM EPIC CCD
Effective Area	135 cm^2 @ 1.5 keV
Detector Operation	Photon Counting, Integrated Imaging, & Rapid Timing
Field of View	23.6 x 23.6 arcminutes
Detection Element	600 x 600 pixels
Pixel Scale	2.36 arcsec/pixel
Telescope PSF	18 arcsec HPD @ 1.5 keV
Location Accuracy	3 - 5 arcseconds
Energy Range	0.2 - 10 keV
Sensitivity	2 x 10^{-14} ergs cm^{-2} s^{-1} in 10^4 sec

UltraViolet/Optical Telescope	
Telescope	Modified Ritchey-Chrétien
Aperture	30 cm diameter
F-number	12.7
Detector	Intensified CCD
Detector Operation	Photon Counting
Field of View	17 x 17 arcminutes
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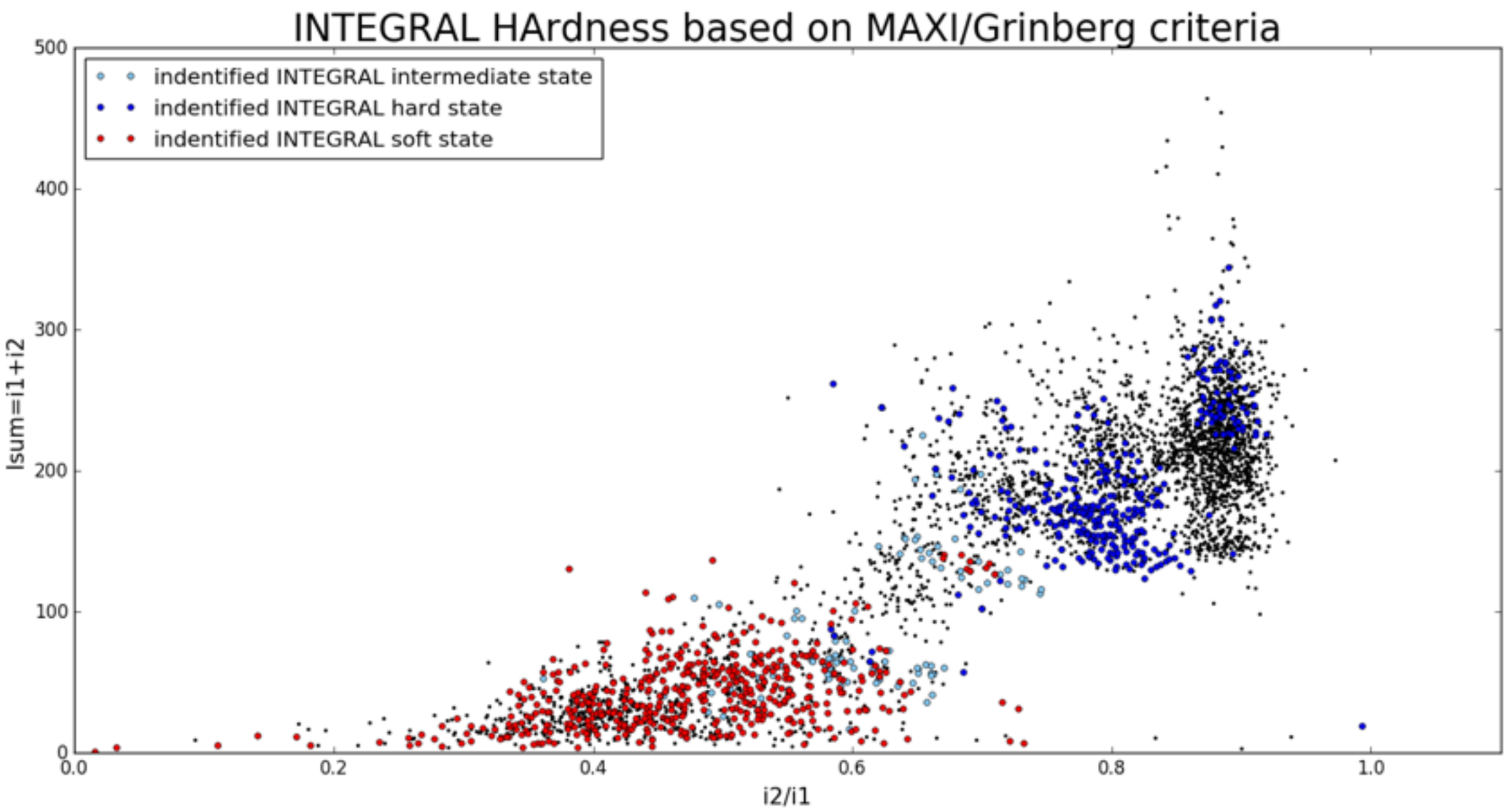

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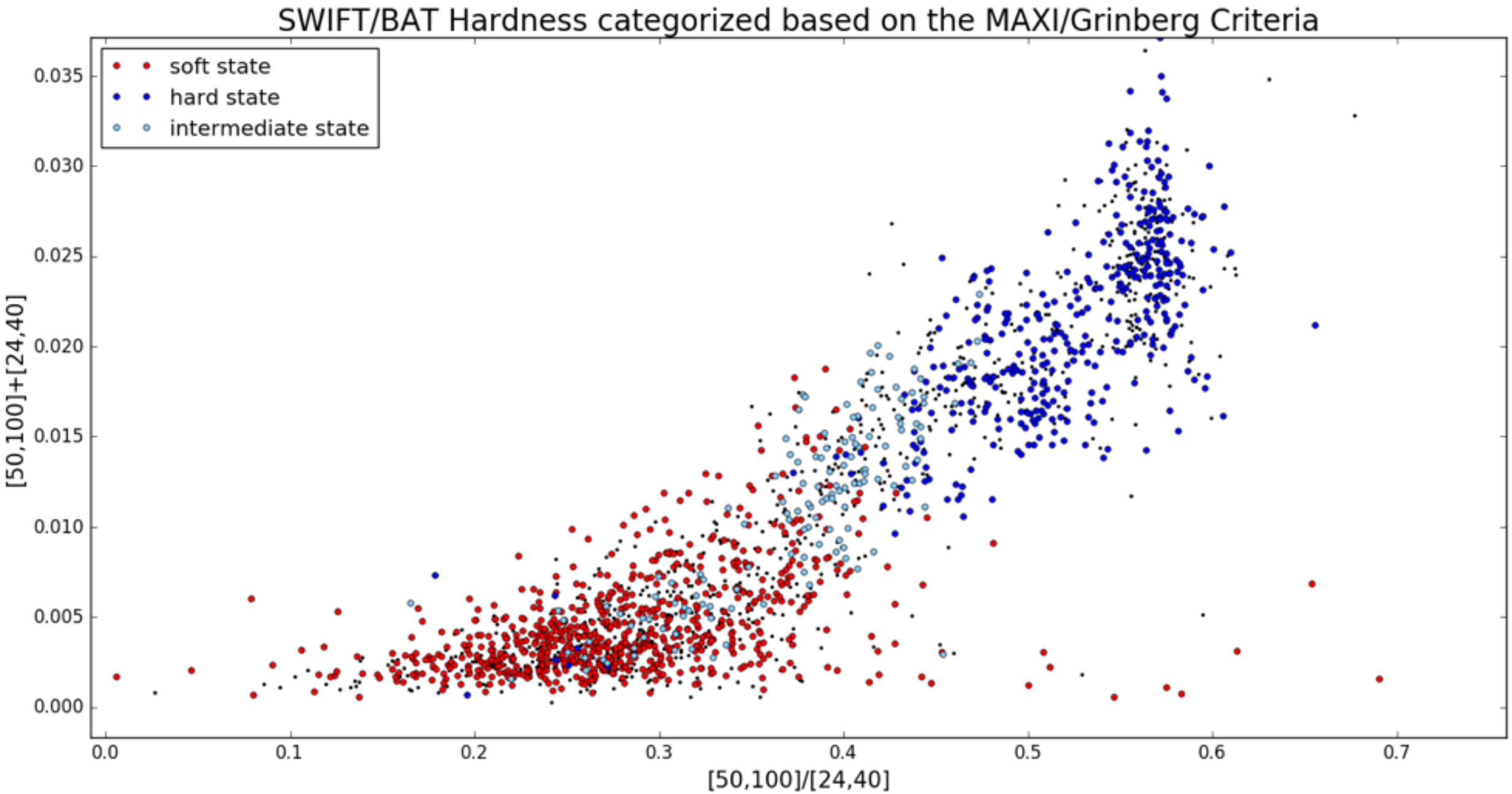

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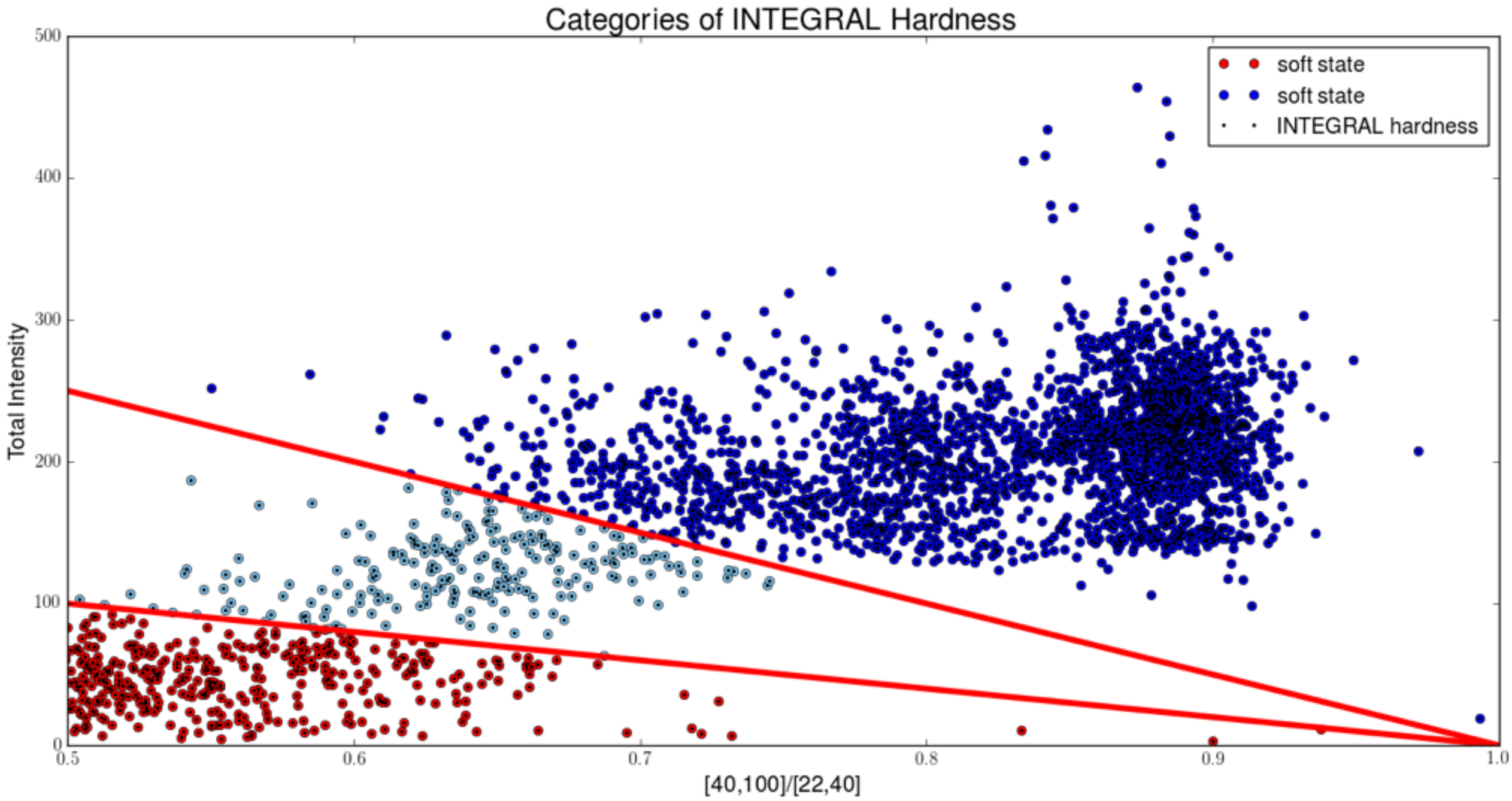
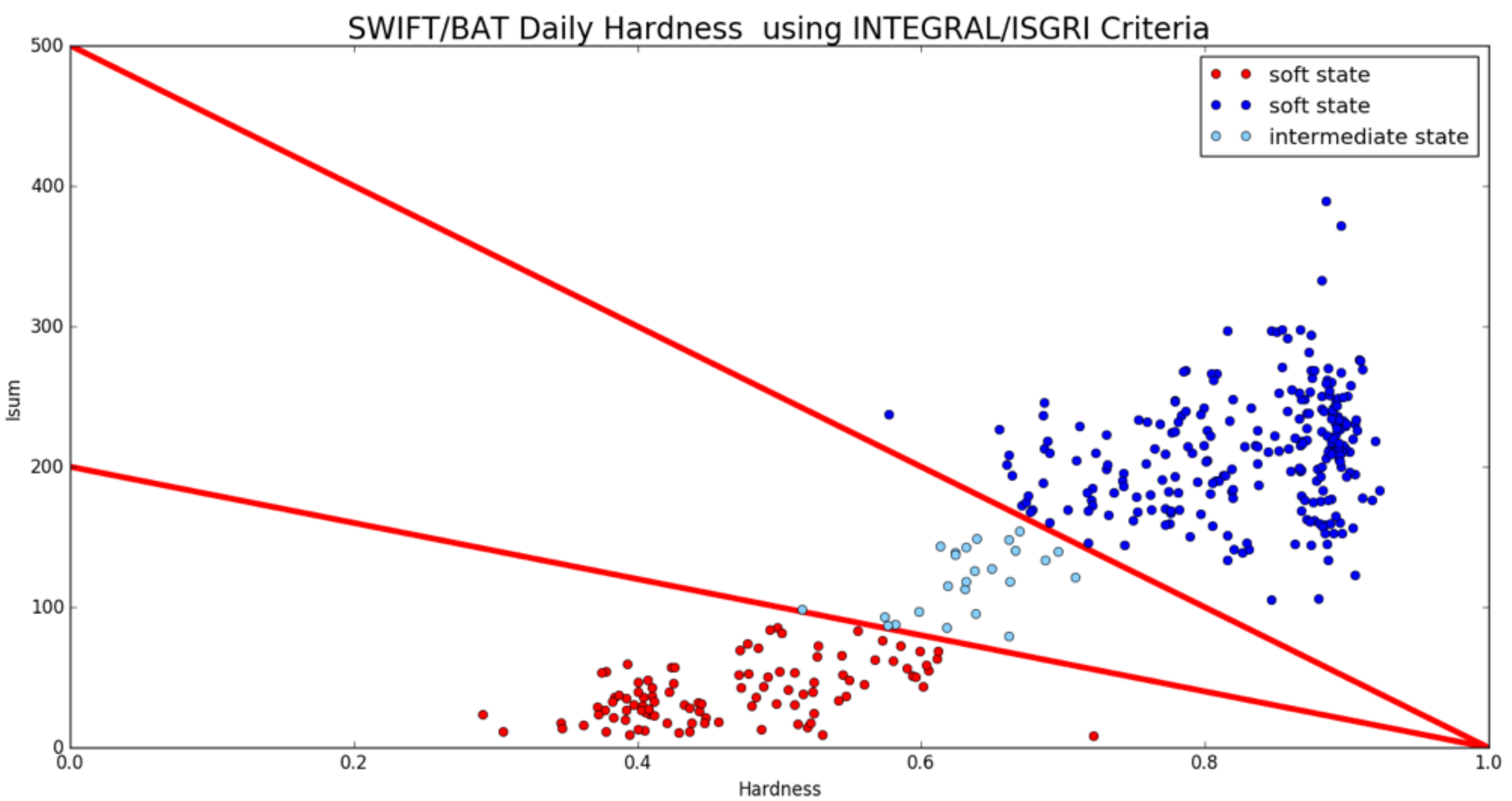
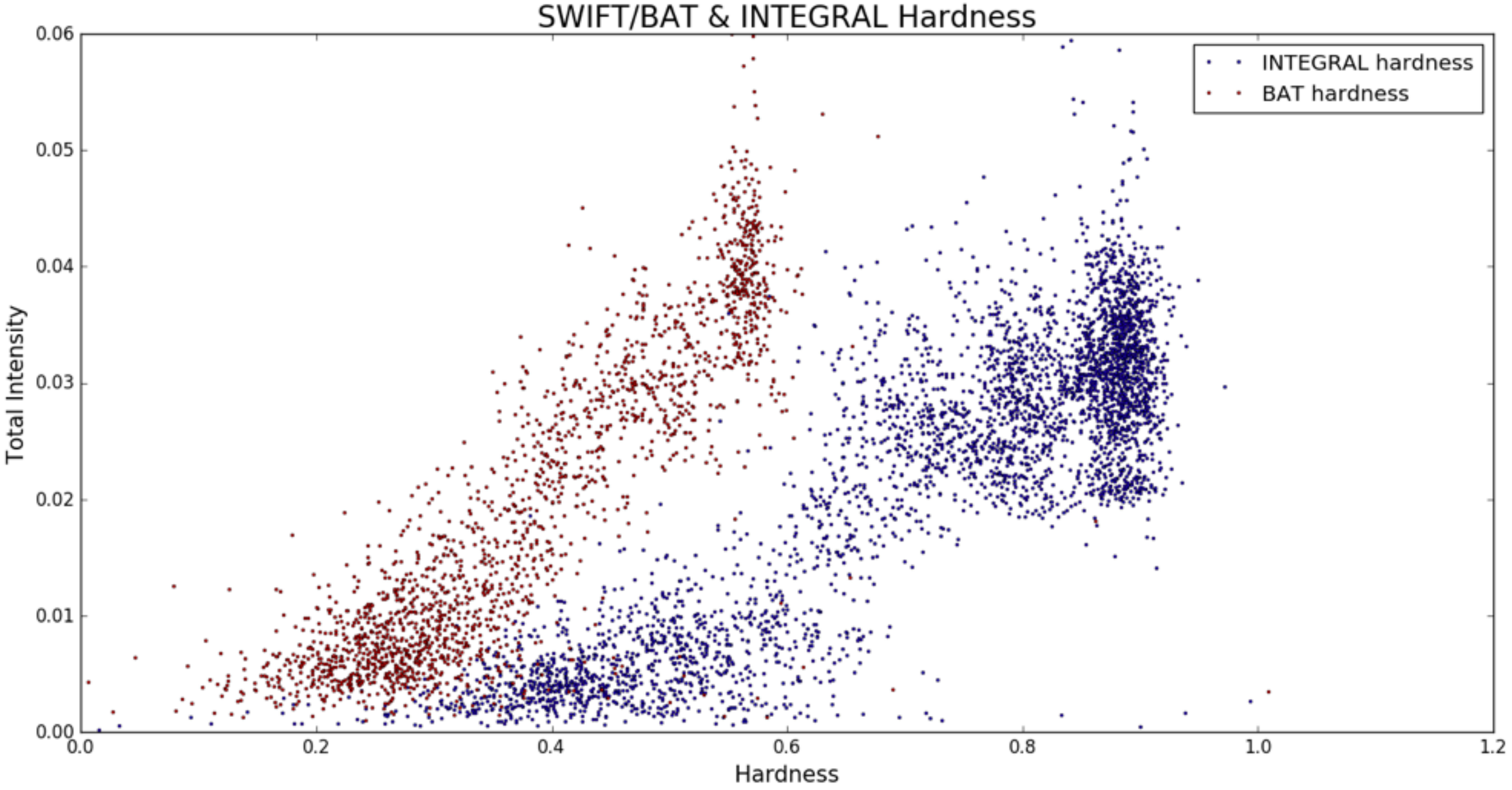


Hardness plots



Hardness plots



Xspec & FTOOLS

fv: Header of Ffile1001.pha[1] in /home/filothodoros/refit/

File Edit Tools Help

Search for: Find Case sensitive? No

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TFORM6  = '1I      '           / Format of column GROUPING
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EXTREL  = '10.4    '           / ISDC release number
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TELESCOP= 'INTEGRAL'           / Telescope or mission name
ORIGIN  = 'ISDC    '           / Origin of FITS file
INSTRUME= 'IBIS    '           / Instrument name
DETNAM  = 'ISGRI   '           / Name of the detector layer
ISDCLEVL= 'SPE     '           / ISDC level of data processing
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DATE    = '2016-04-21T14:07:37' / Creation or modification date
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OBTEND  = '0000023736494745190 4' / OBT of the end of the Science Window
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EXP_SRC =     1047.70275878906 / [s] Effective exposure time for the source
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DEC_OBJ =     35.2016754150391 / Source declination in degrees
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NAME    = 'Cyg X-1 '           / One commonly used name for the source
HDUCLASS= 'OGIP    '           / Format conforms mostly to OGIP standards
HDUCLAS1= 'SPECTRUM'           / Dataset contains a spectrum
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SWID    = '087700130010'       / Science Window identifier
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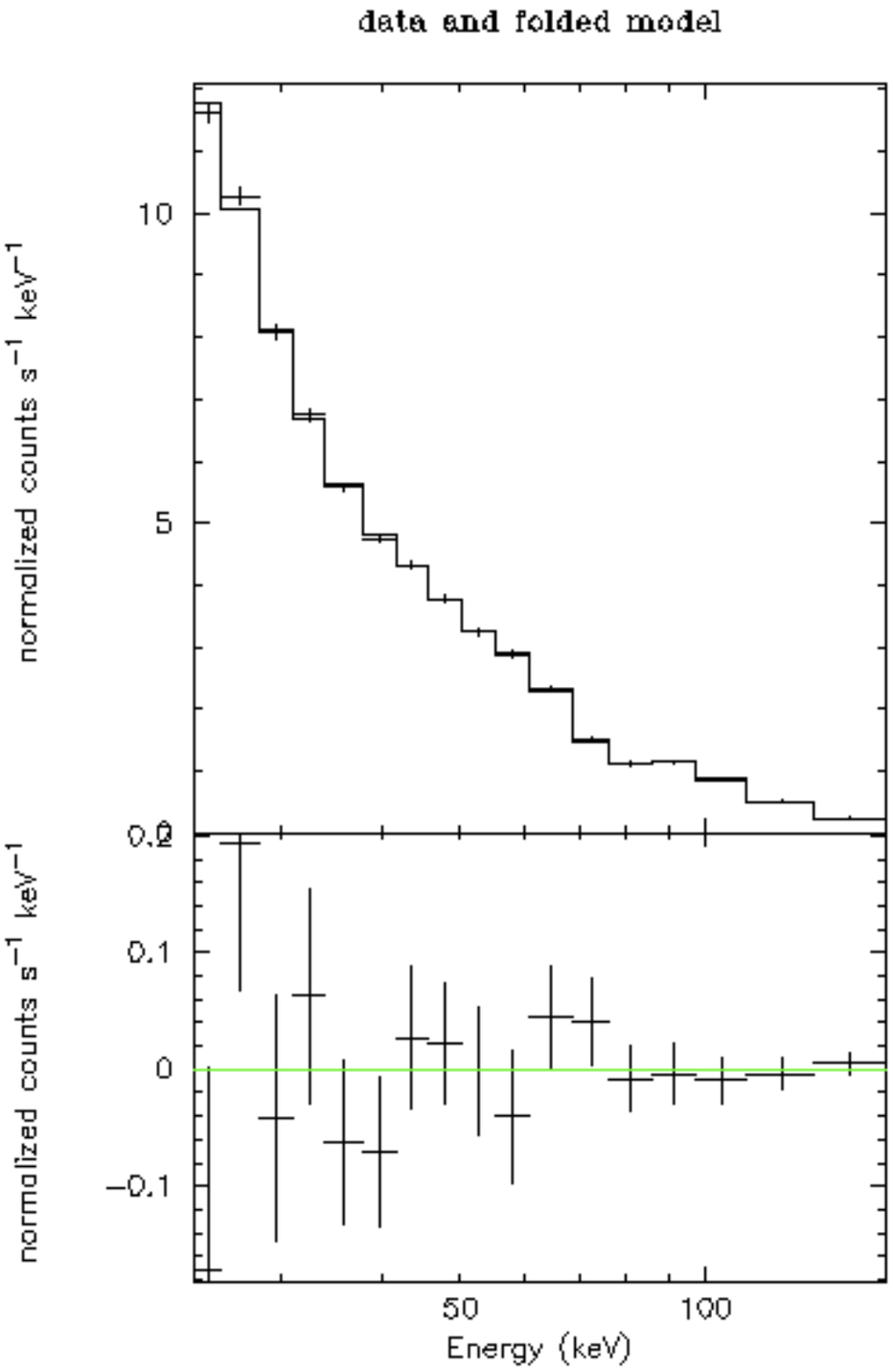
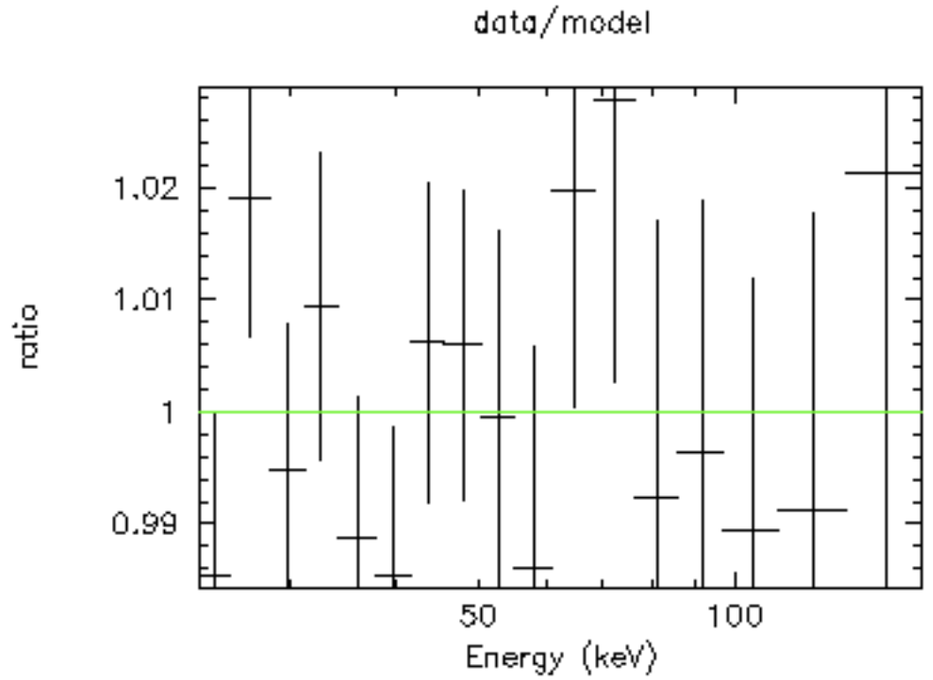
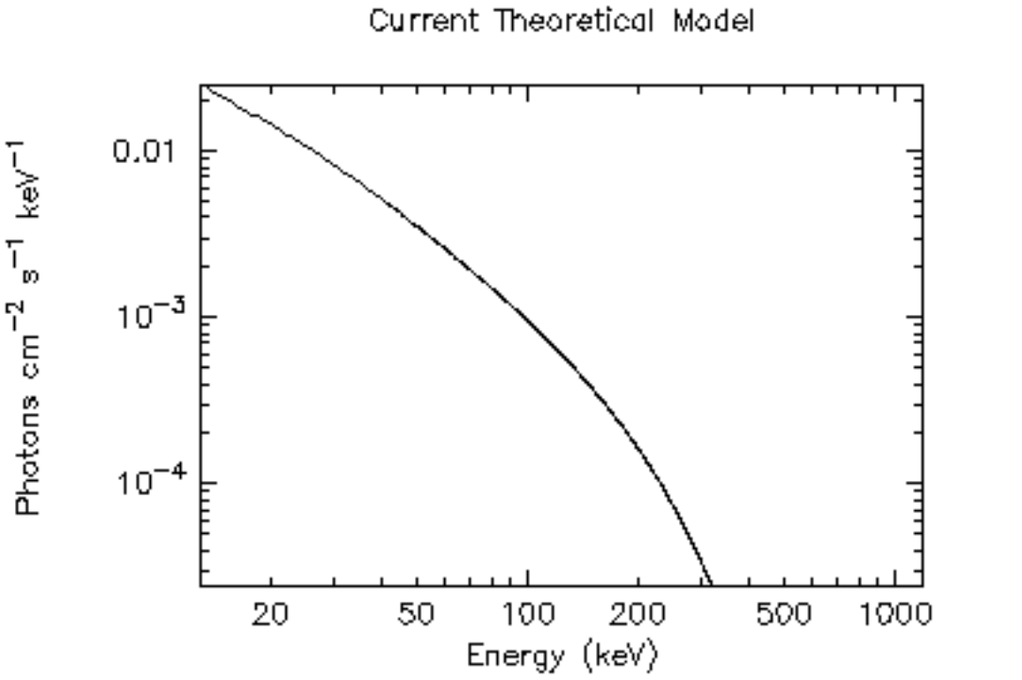
Xspec







filothodoros 14–Jul–2016 23:11

Xspec

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   3    2   reflect    Redshift              0.0          frozen
   4    2   reflect    abund                 1.00000      frozen
   5    2   reflect    Fe_abund              1.00000      frozen
   6    2   reflect    cosIncl               0.450000     frozen
   7    3   compTT     Redshift              0.0          frozen
   8    3   compTT     T0         keV        0.103718     +/-  977.823
   9    3   compTT     kT         keV        47.7707      +/-  6.29261
  10    3   compTT     taup                  1.42463      +/-  0.143526
  11    3   compTT     approx                1.00000      frozen
  12    3   compTT     norm                  9.77068E-02  +/-  459.457
------------------------------------------------------------------------


Fit statistic : Chi-Squared =           9.85 using 17 PHA bins.

Test statistic : Chi-Squared =           9.85 using 17 PHA bins.
 Reduced chi-squared =          0.821 for     12 degrees of freedom
 Null hypothesis probability =   6.291077e-01
XSPEC12>
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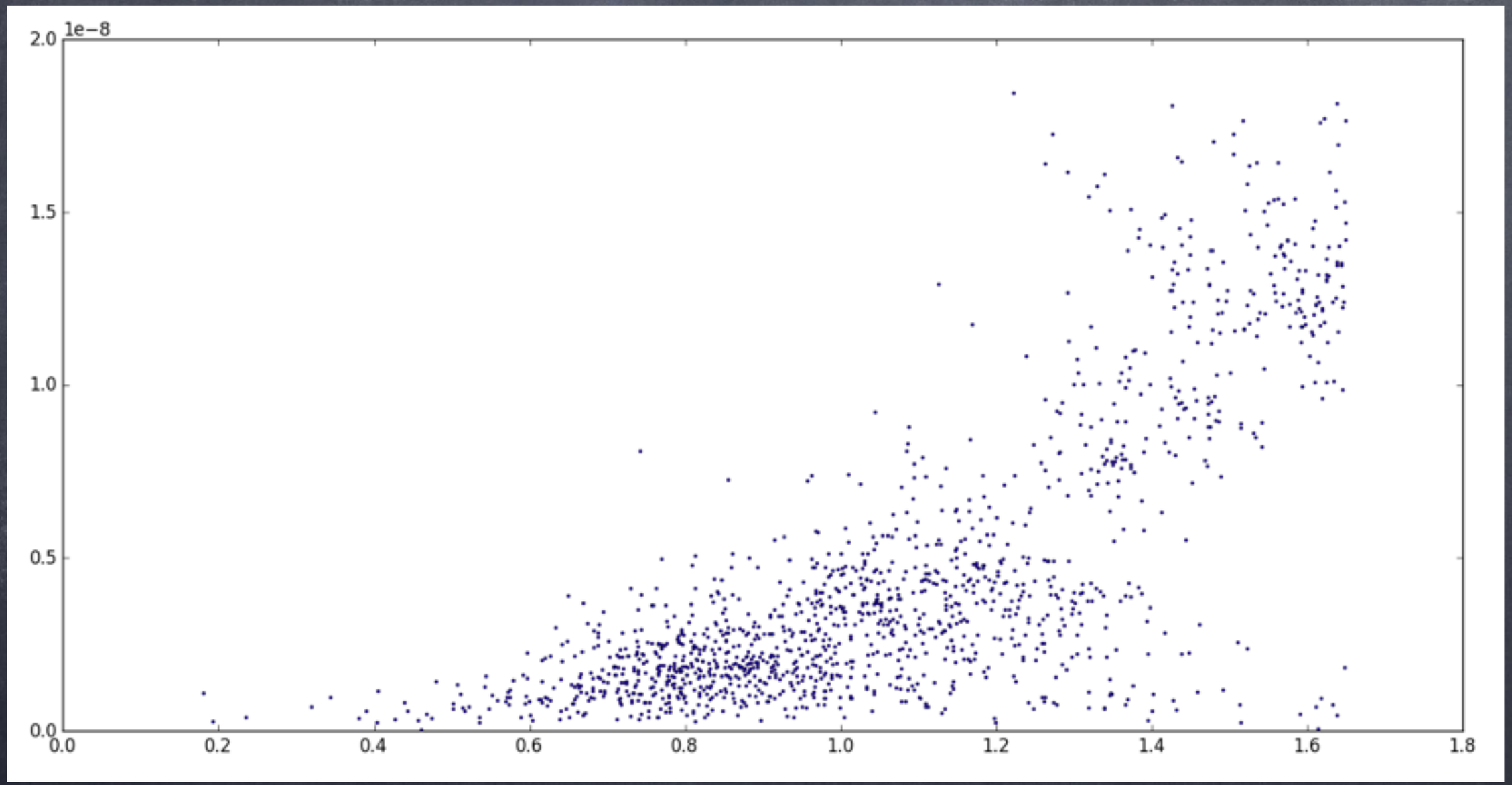
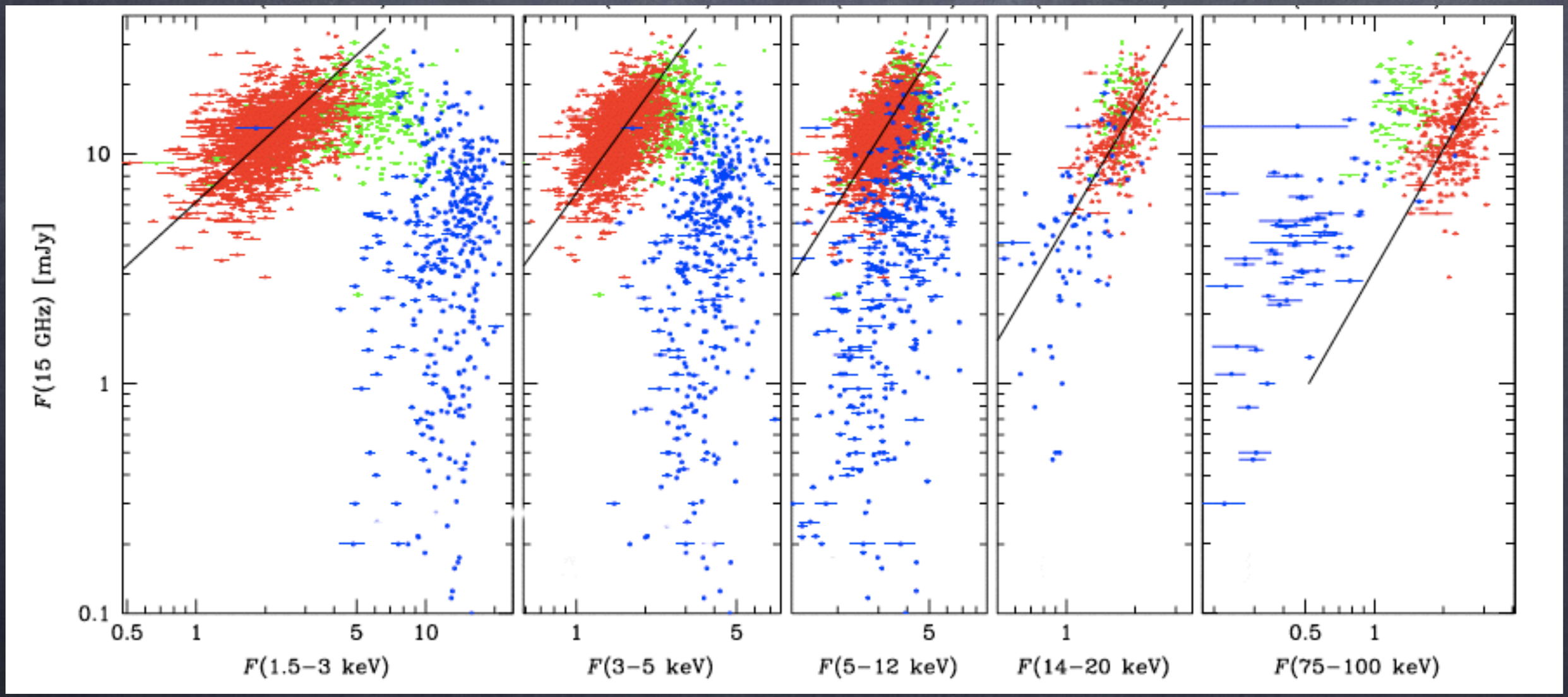
Theoretical hardness (work in progress)

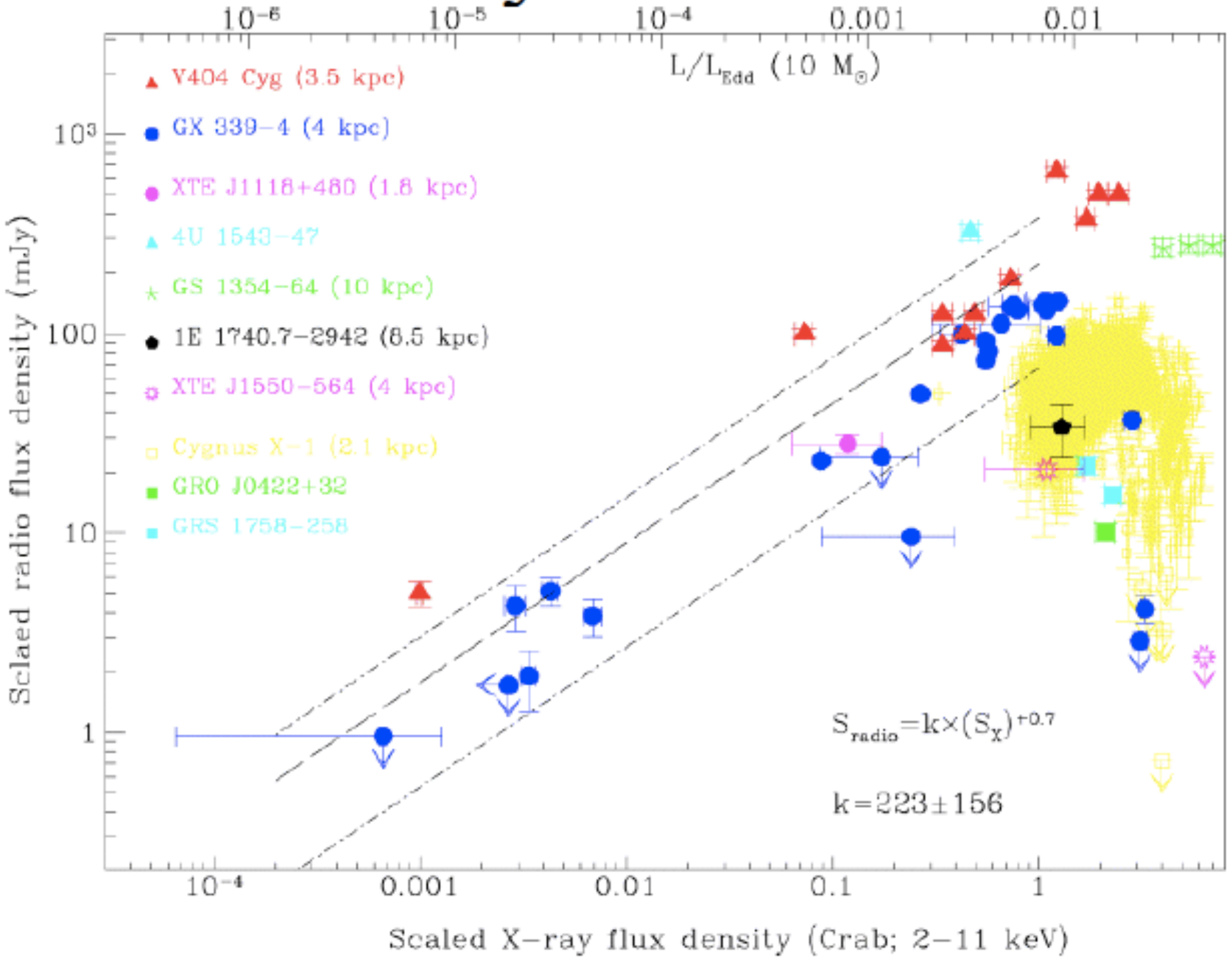


Radio/X-ray flux correlation



Zdziarski et al. 2011MNRAS.416.1324Z

Radio/X-ray Flux Correlation



$F_{radio} \propto F_X^{+0.7}$

Corbel et al. (2000,2003)

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Conclusions

- INTEGRAL/ISGRI seems to be a very good choice for defining the Cyg X-1 spectral states.
- The study of the physical meaning behind this classification is a work in progress and looks promising.

To do list:

- JEMX
- radio observations
- distinguish the intermediate and hard state using only ISGRI data
- model parameters dependent on the orbital and super orbital phase?