An observational view of black hole X-ray binaries with *INTEGRAL*

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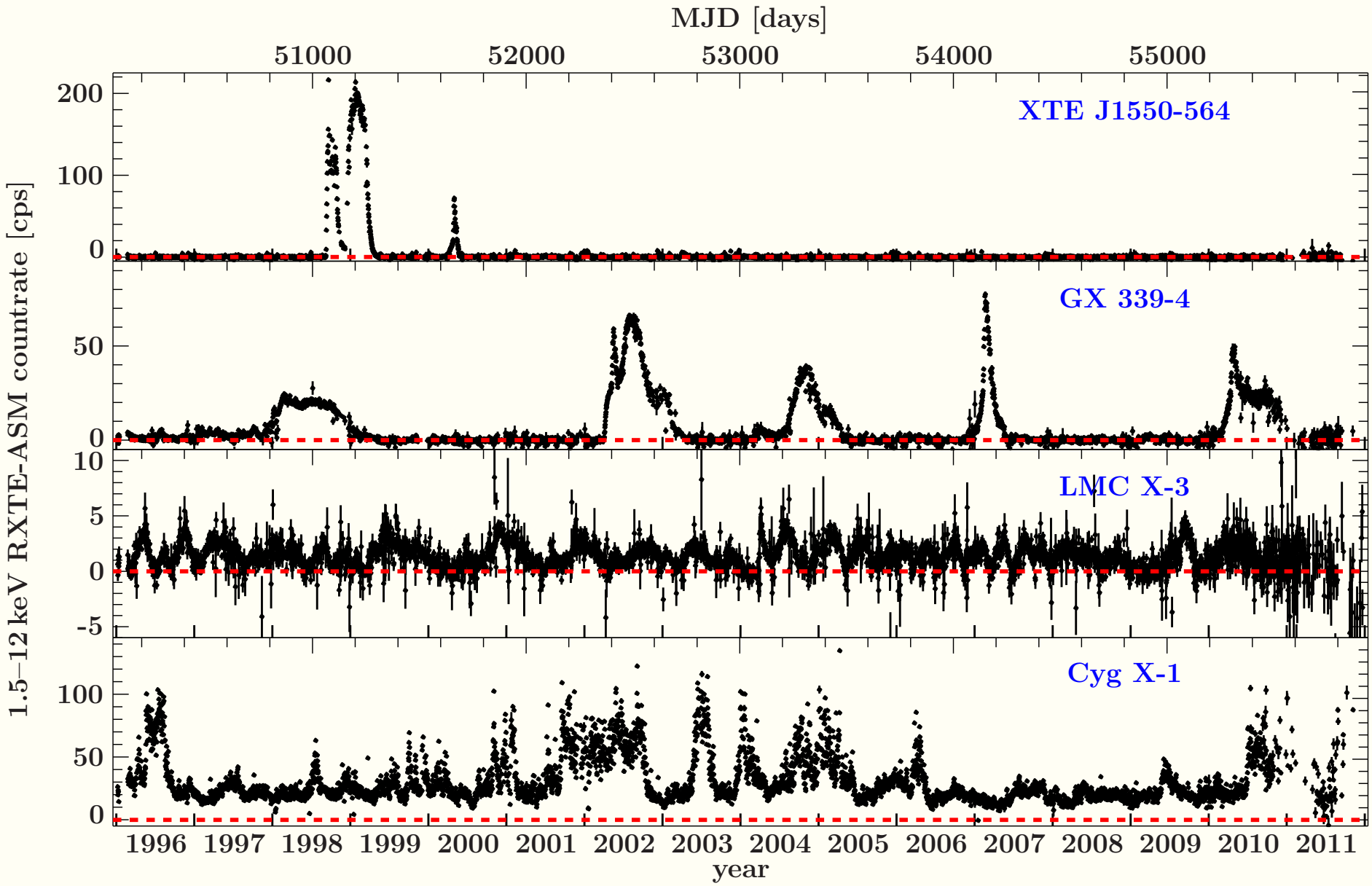
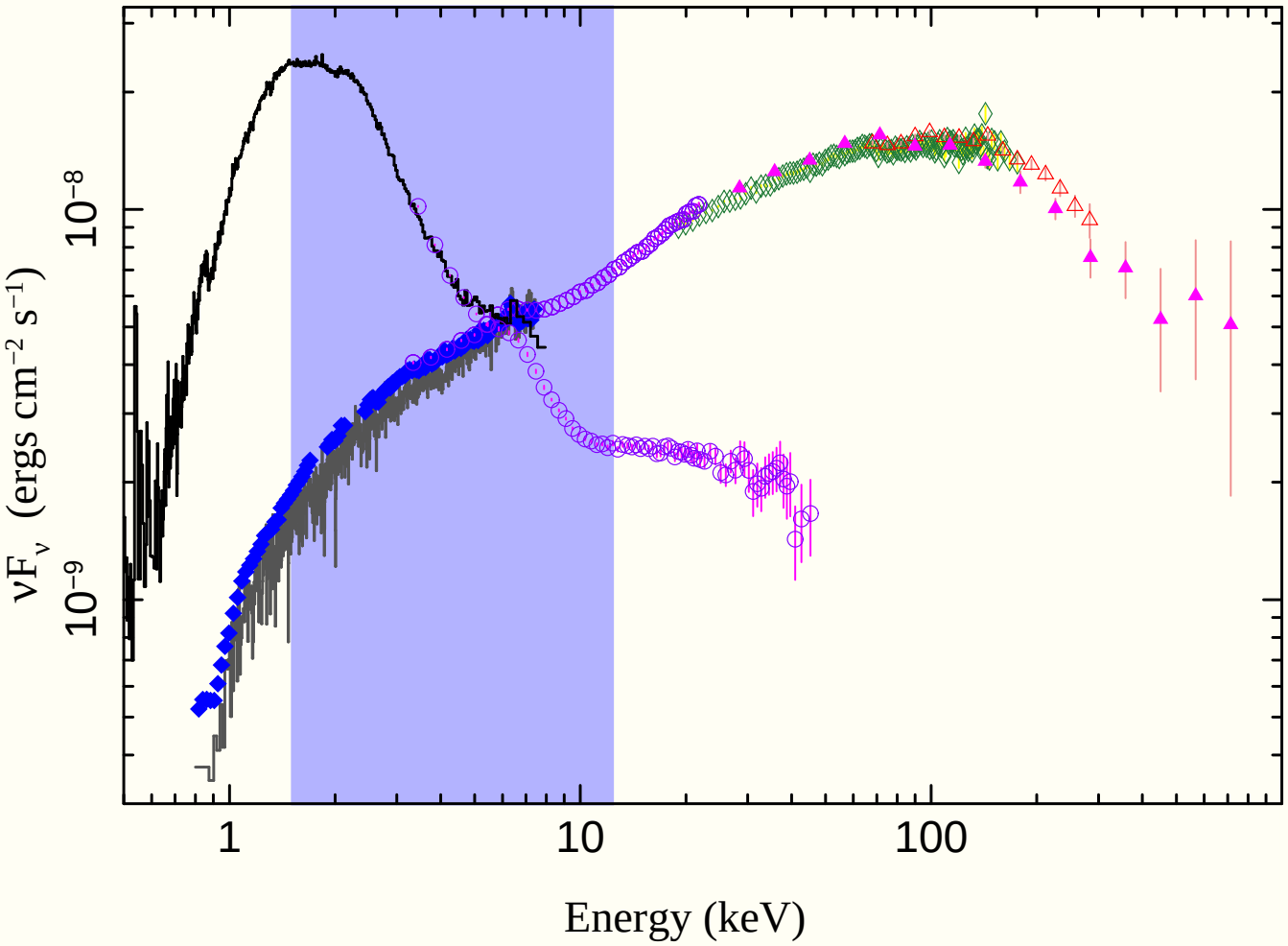
Black hole X-ray binary activity



X-ray states



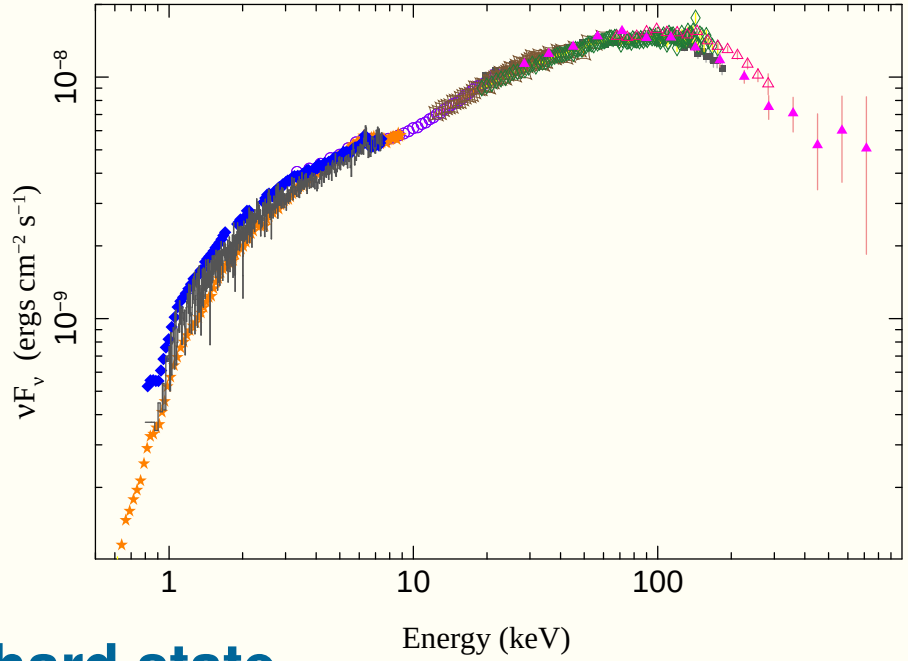
typical X-ray spectra of galactic black holes

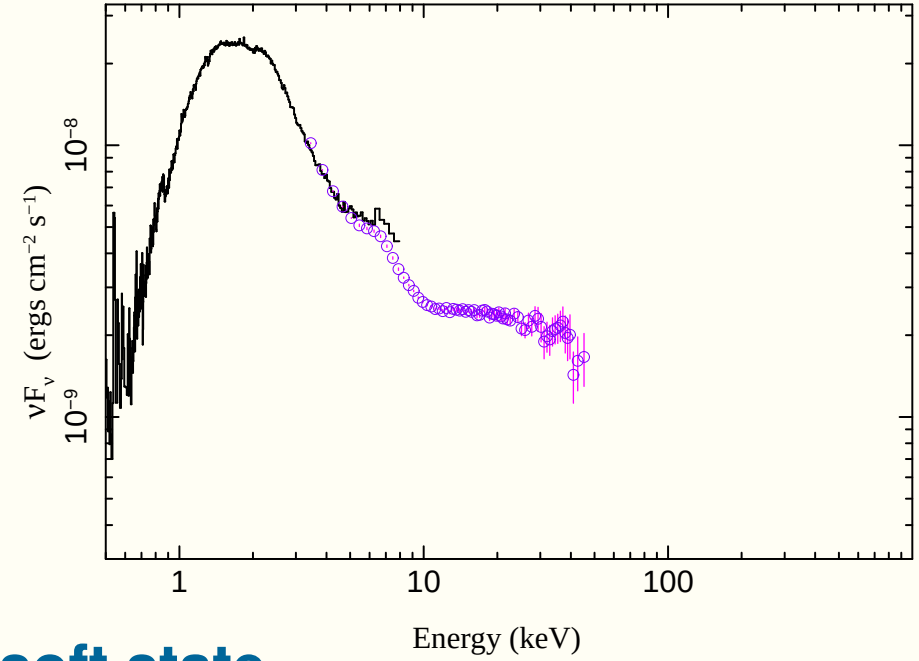
distinct radiation regimes ≙ states

Cygnus X-1; *Nowak et al., 2011*

Chandra • *Suzaku*-XIS • *Suzaku*-GSO • *RXTE*-PCA • *RXTE*-HEXTE • *INTEGRAL*

X-ray states





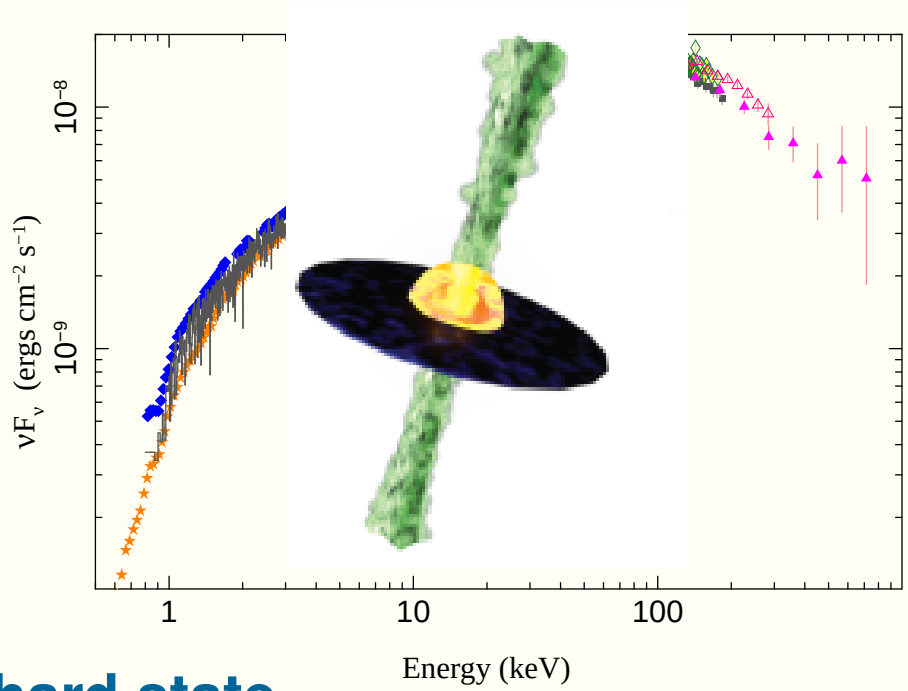
hard state

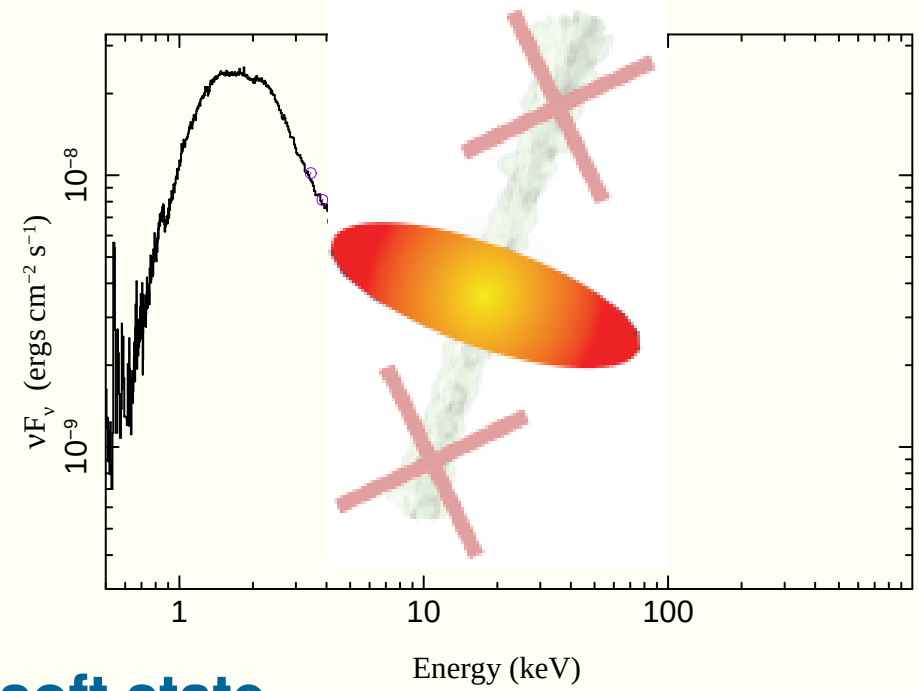
- weak disk component
- strong power law component with $\Gamma \approx 1.7$ and cut-off
- emission >10 keV dominates
- high variability (rms $\geqq 40\%$)
- radio emission

soft state

- strong disk component
- weak powerlaw, steep with $\Gamma \approx 2.5$–3
- thermal emission dominates
- low variability (rms $\leqq 5\%$)
- no radio emission

X-ray states





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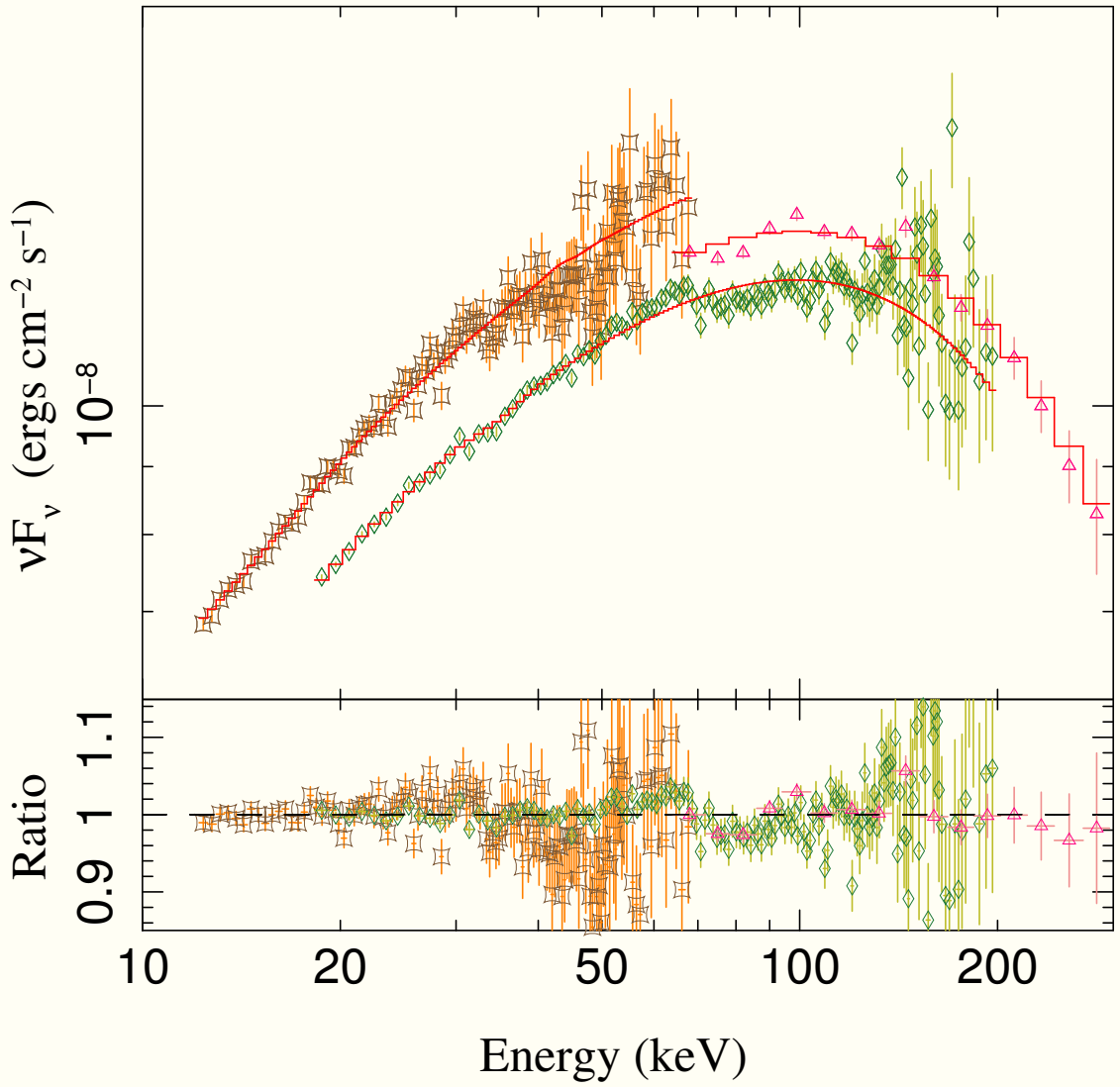
Hard state: observational consensus #1

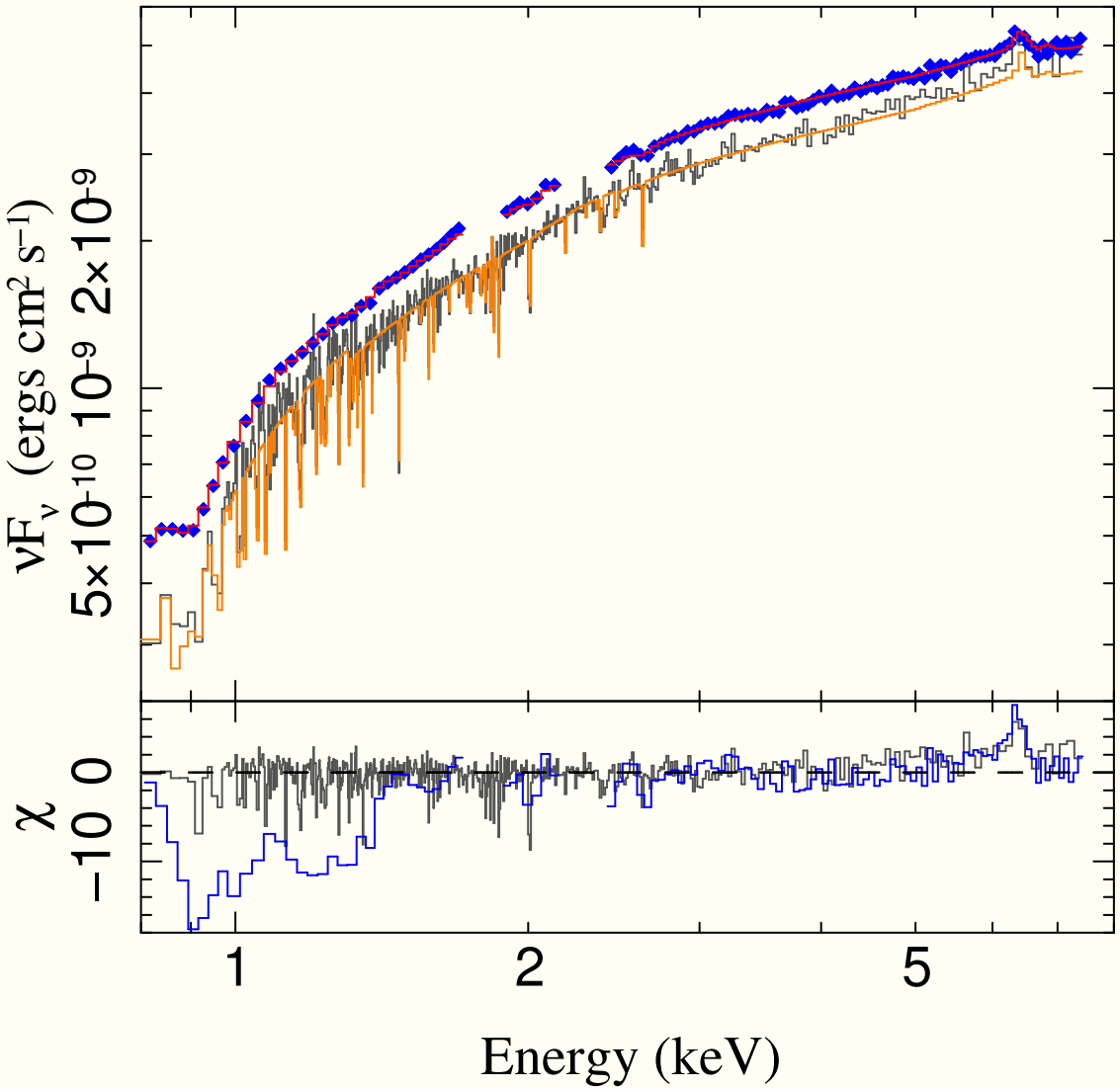


Cyg X-1; Nowak et al., 2011

the spectrum above 10 keV is an exponentially cutoff power-law:
$F_E \propto E^{-\Gamma} e^{-E/E_{\rm fold}}$

- $E_{\rm fold} \sim 50$–300 keV
- nonthermal "hard tails" at $\gtrsim 200$ keV in some sources

Hard state: observational consensus #2

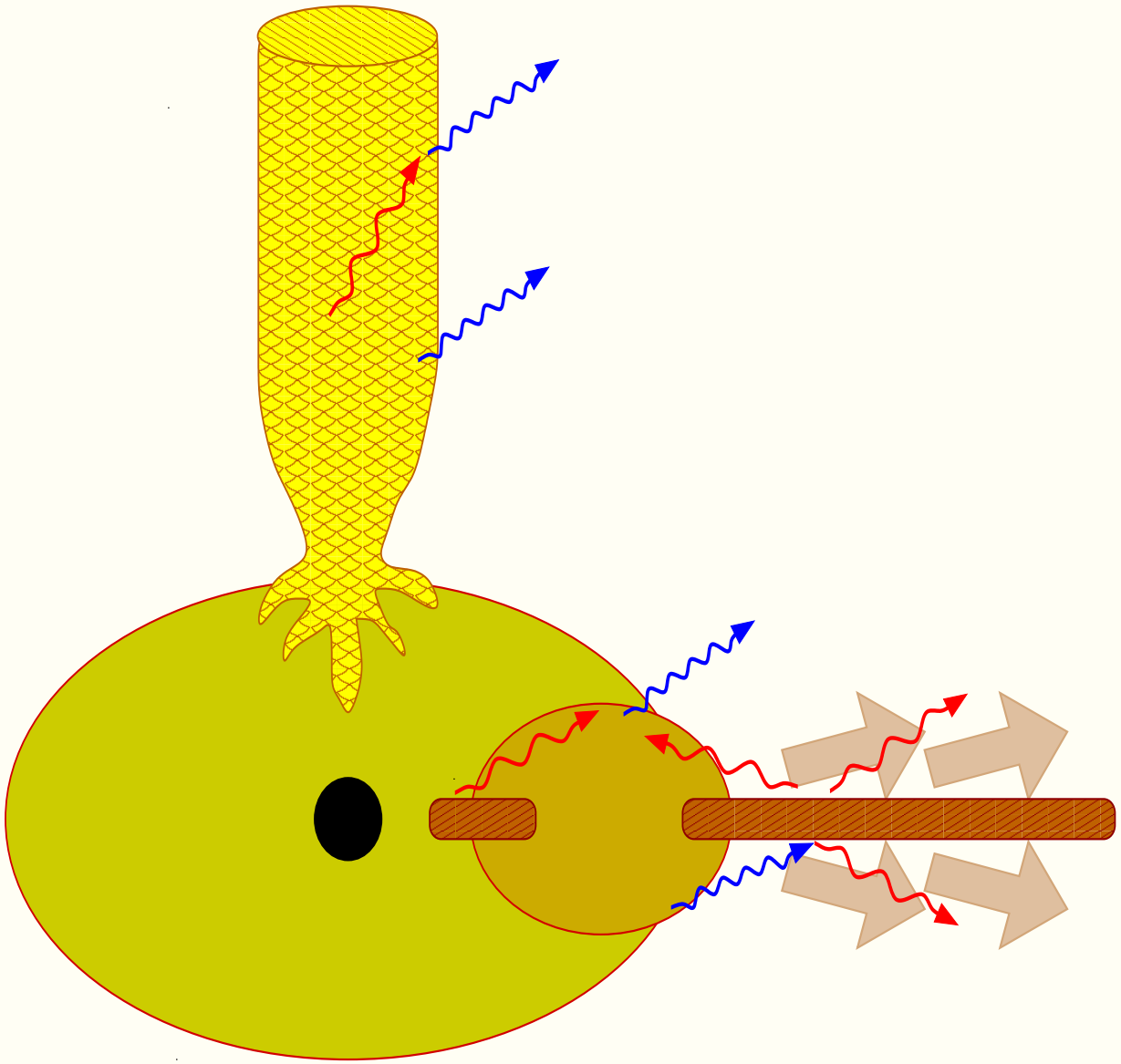


Cyg X-1; Nowak et al., 2011

the spectrum below 10 keV is a sum of power law, disk emission, emission lines, and (ionized) absorption

- below $\sim$ 1.5 keV: Absorption $\Rightarrow$ ISM & local to the system

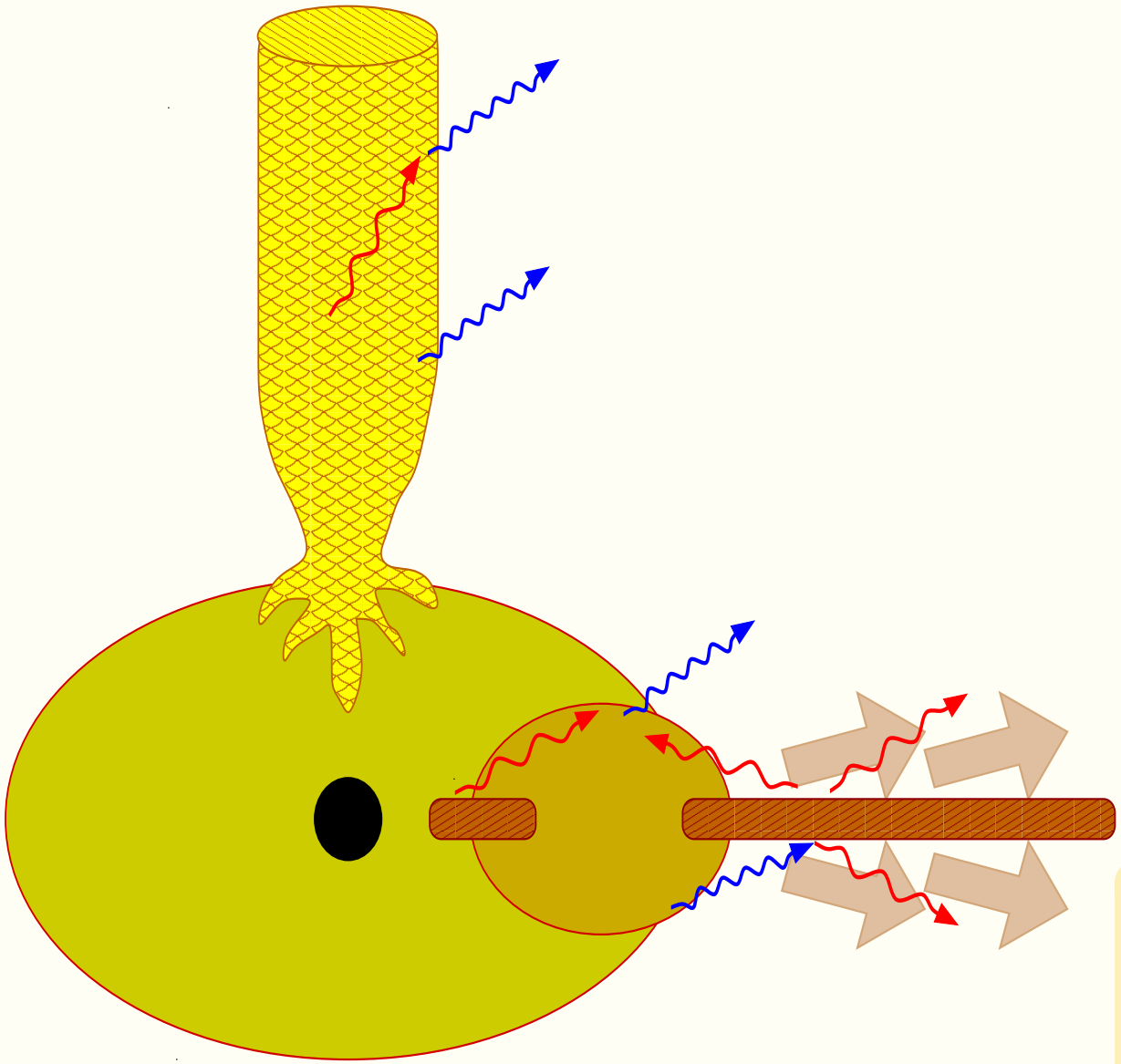
Continuum formation / “geometry”



sandwich corona models/sphere+disk:
Haardt & Maraschi (1991), Dove+ (1998), . . .
⇒ Comptonization from a hot electron plasma surrounding the disk

lamppost models:
Matt+ (1992), Markoff+ (2005), . . .
⇒ Comptonization from the base of a jet

Continuum formation / “geometry”



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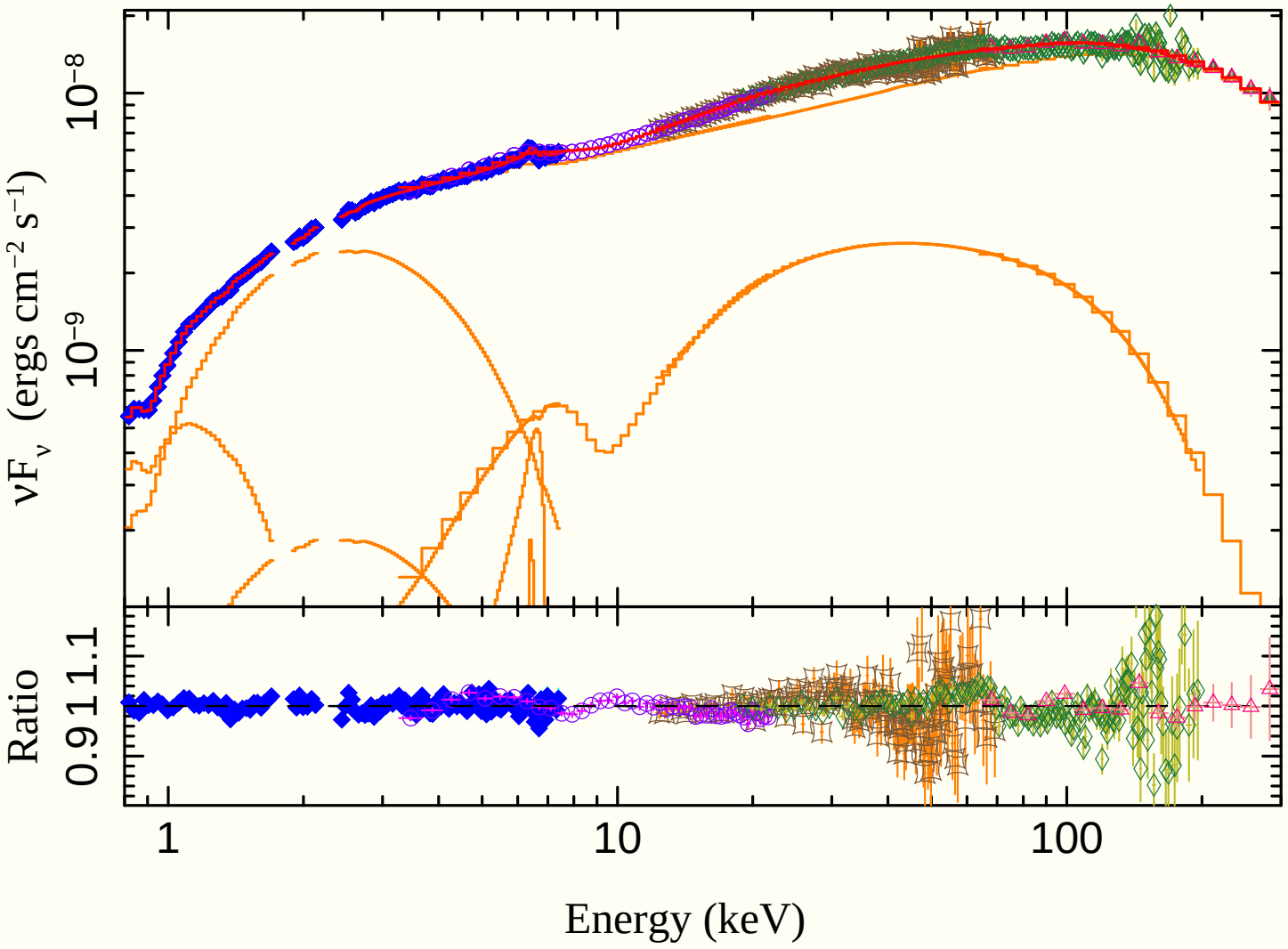
⇒ Comptonization from the base of a jet

- What is the jet contribution?
- Is the disk truncated?

Broadband Spectral Models

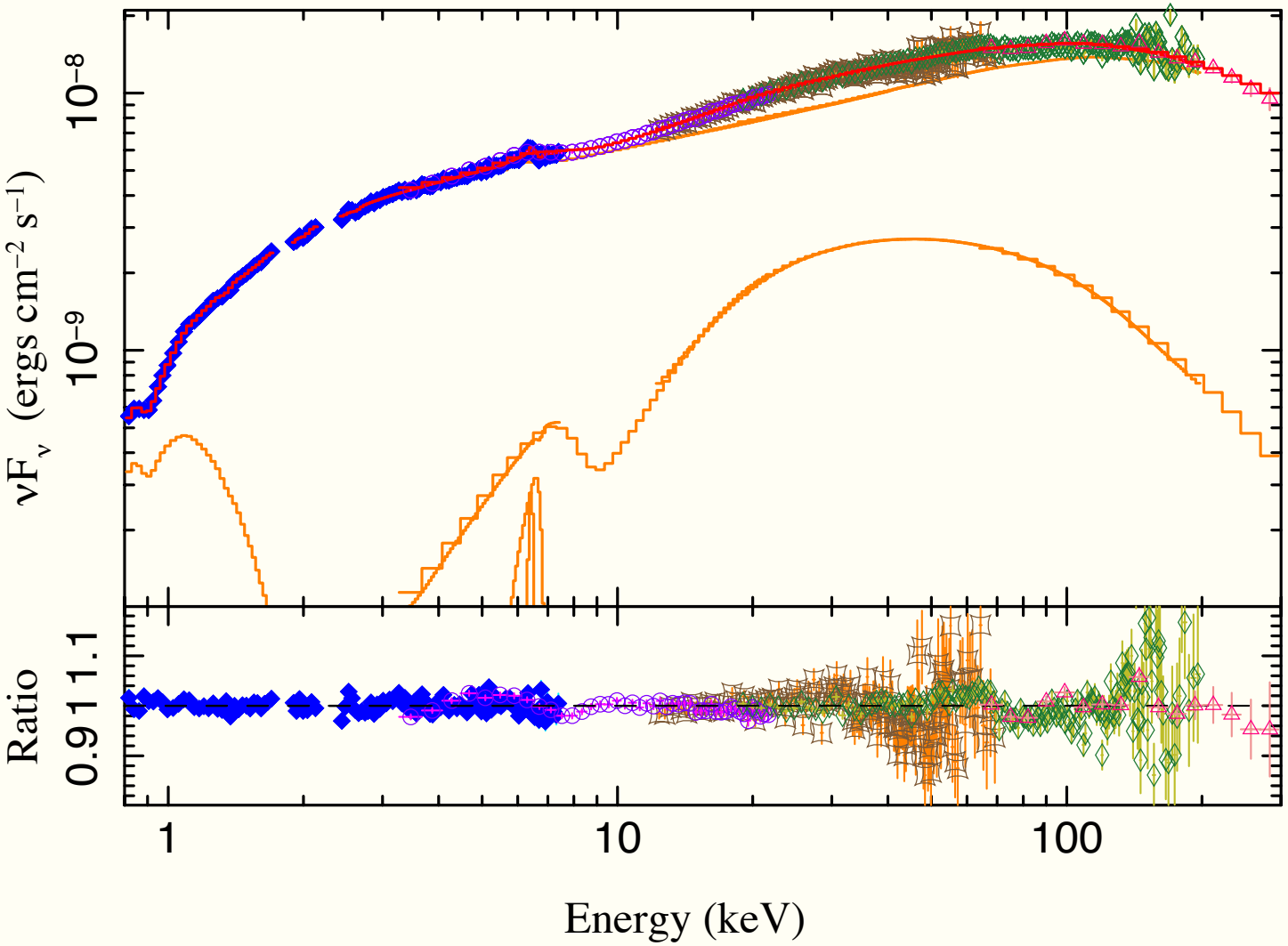
thermal Comptonization:



Cyg X-1; *Nowak et al., 2011, Fig. 4a*

Broadband Spectral Models

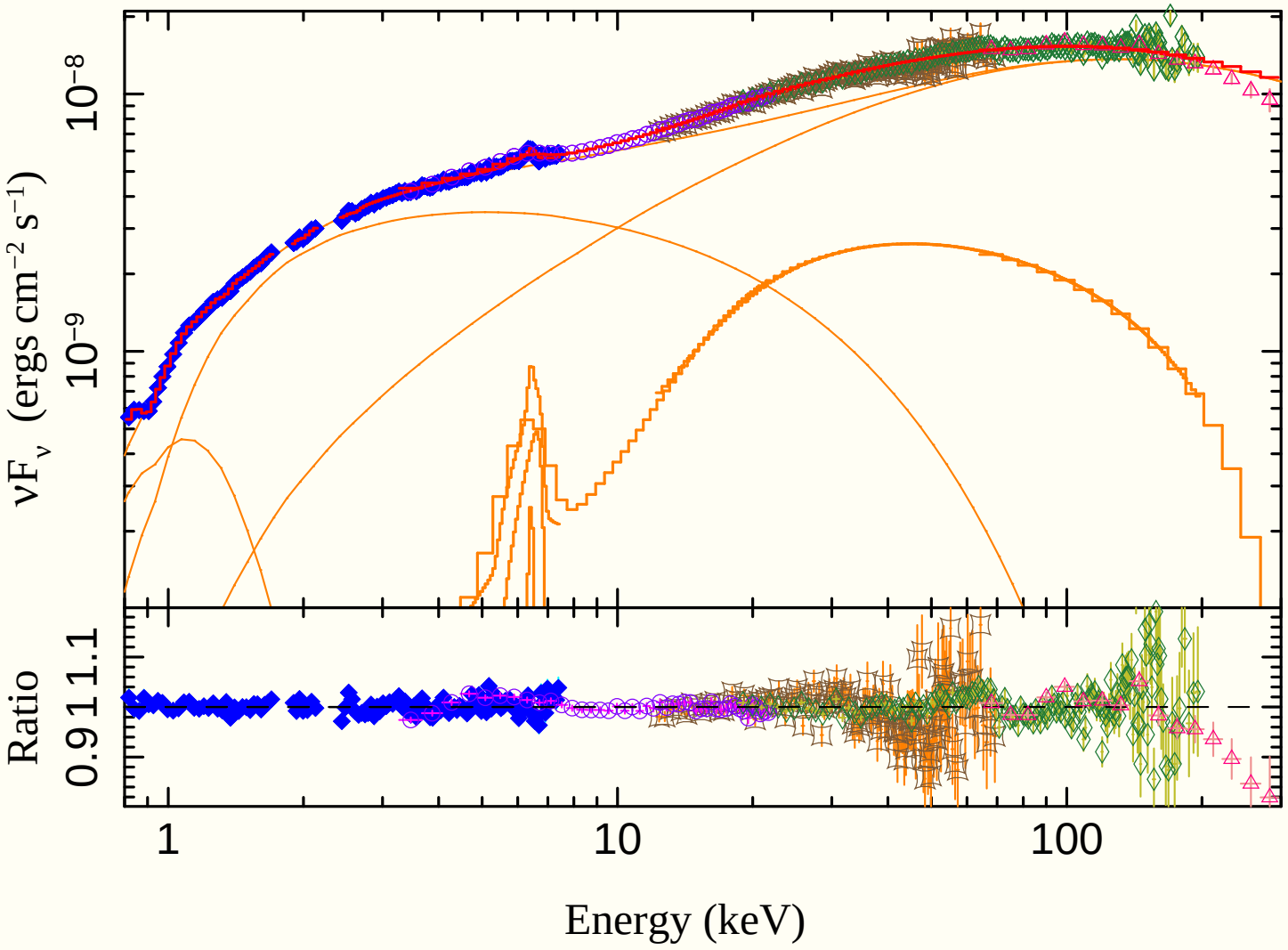
non-thermal Comptonization:



Cyg X-1; *Nowak et al., 2011, Fig. 4b*

Broadband Spectral Models

jet model (radio data at 15 MHz not shown, but used in fit):



Cyg X-1; *Nowak et al., 2011, Fig. 12*

How to differentiate between models?

better observations

esp. in the FeKα-region

- better calibration of existent data
- better data
- future satellite

different observations

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different observations

different geometries $\Rightarrow$

- different long-term evolution
- different properties above spectral cut-off
- different polarization

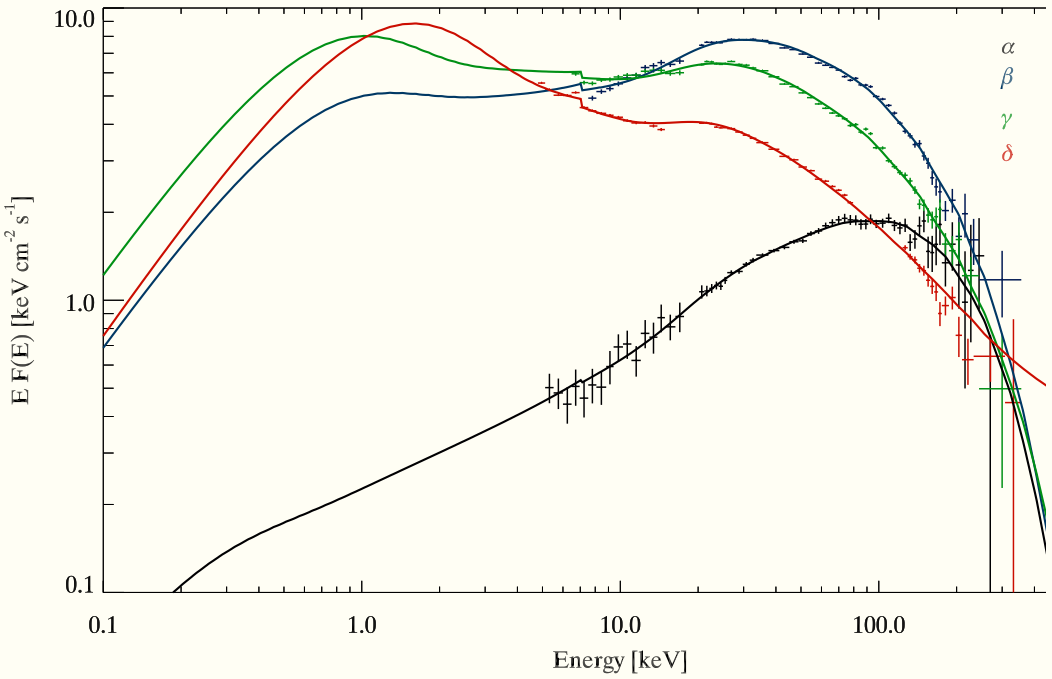
$\underbrace{\hspace{6cm}}_{\textit{INTEGRAL}}$

Long stares (at state transitions)

Long observations
⇒ parameter evolution
⇒ trace changing accretion geometry

- Swift J174510−26241 failed outburst
  Del Santo et al., 2016
- MAXI J1820+070 outburst spring 2018
- MAXI J1348-638 last observation on Monday

Swift J174510.8−26241



Del Santo et al., 2016

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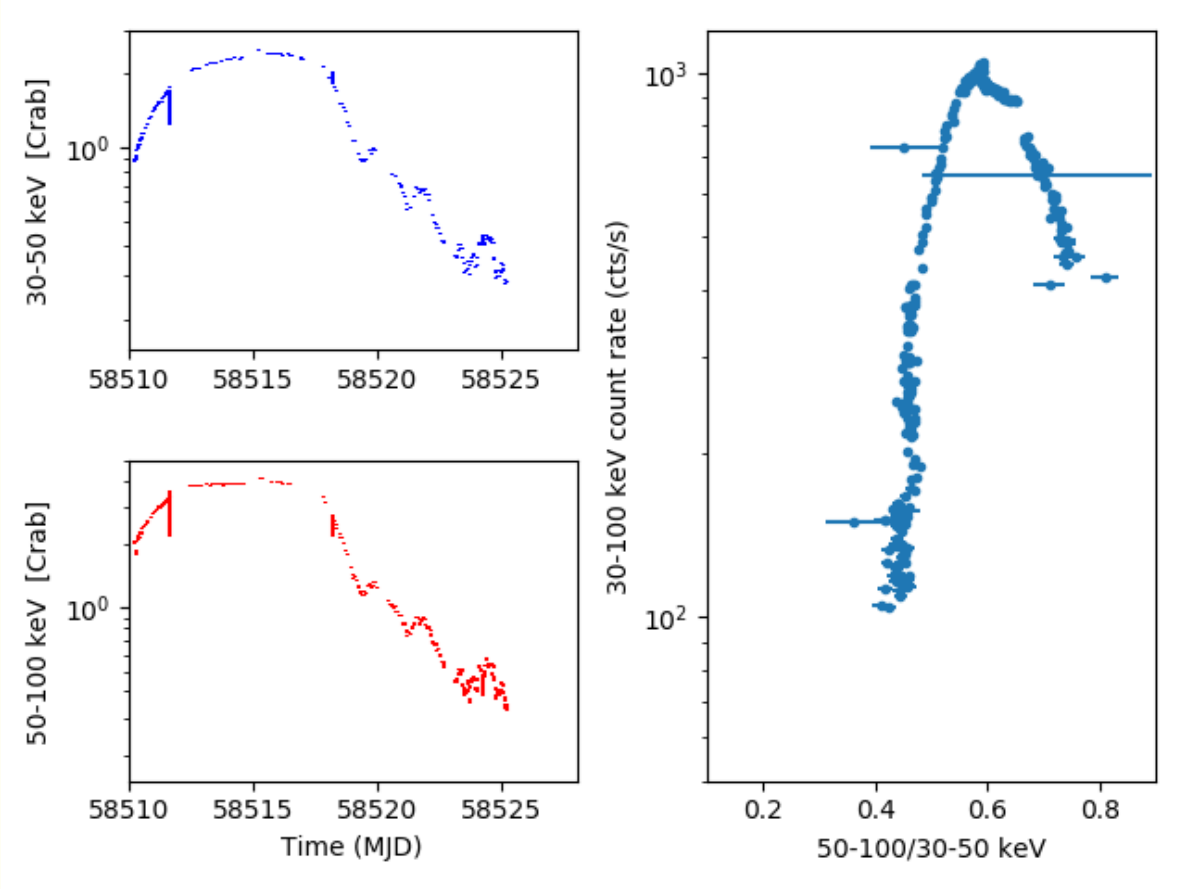
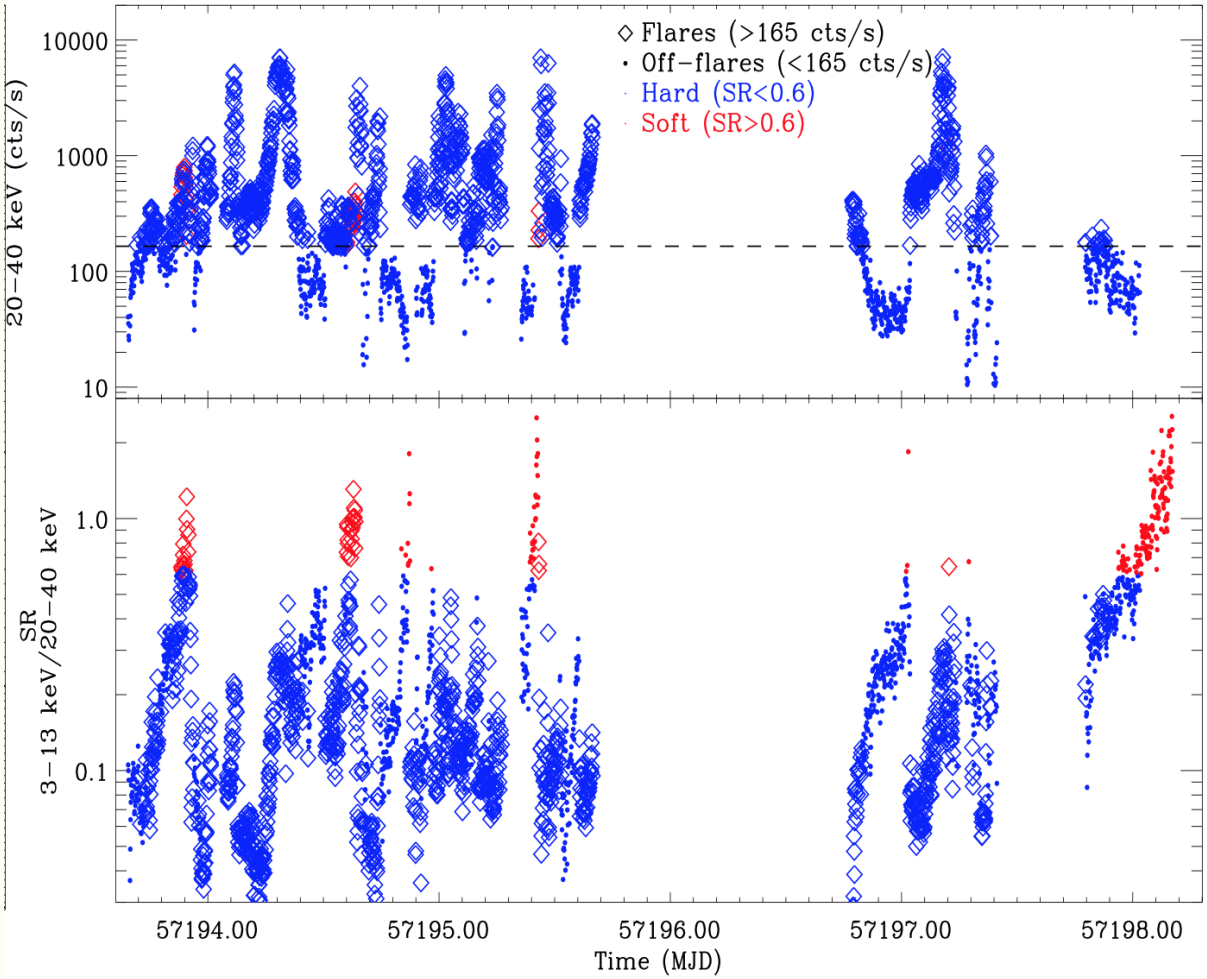
MAXI J1348-638 monitoring



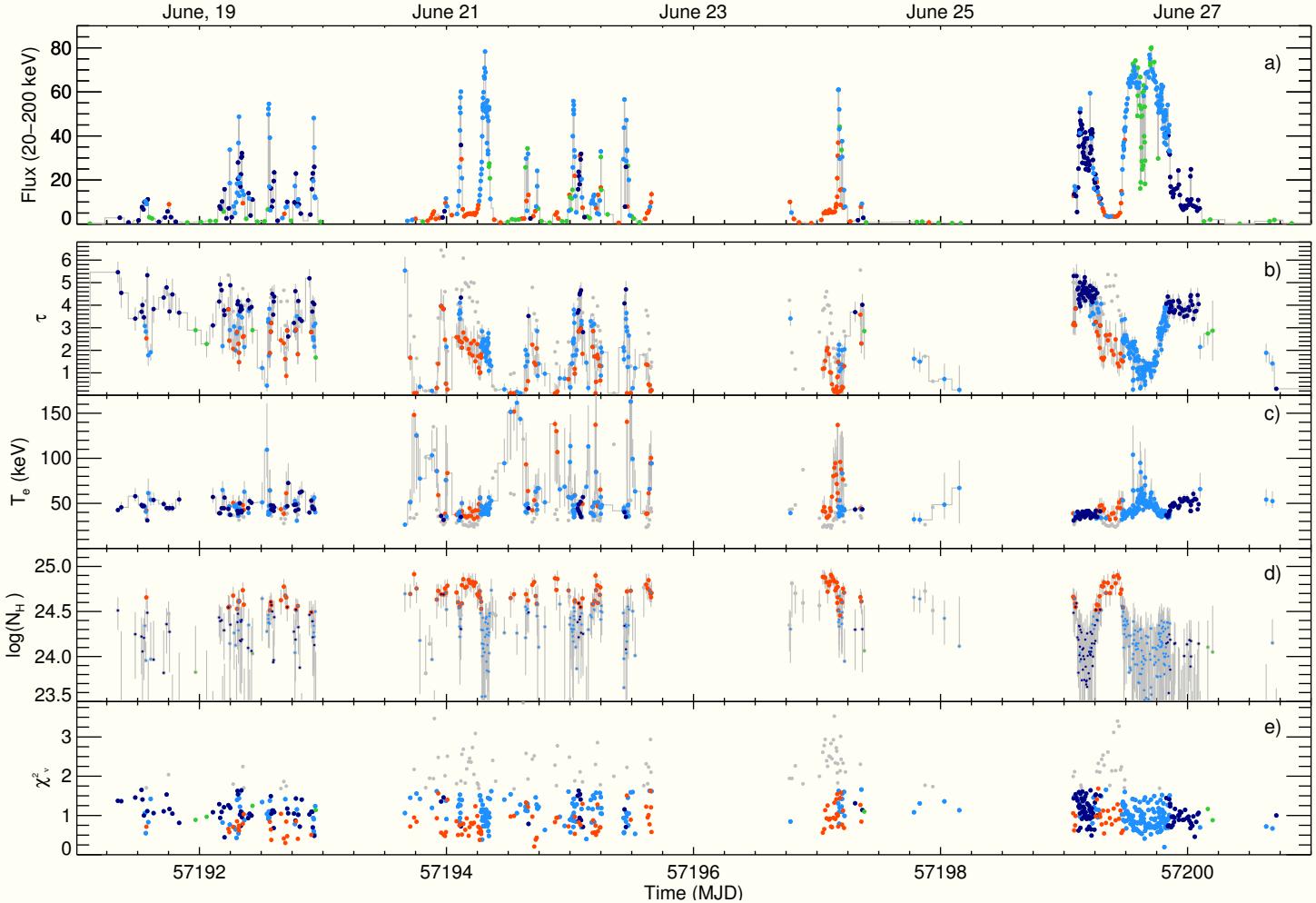
PRELIMINARY, image credit J. Rodriguez, F. Cangemi

V404 Cyg: different but similar



Rodriguez et al., 2015

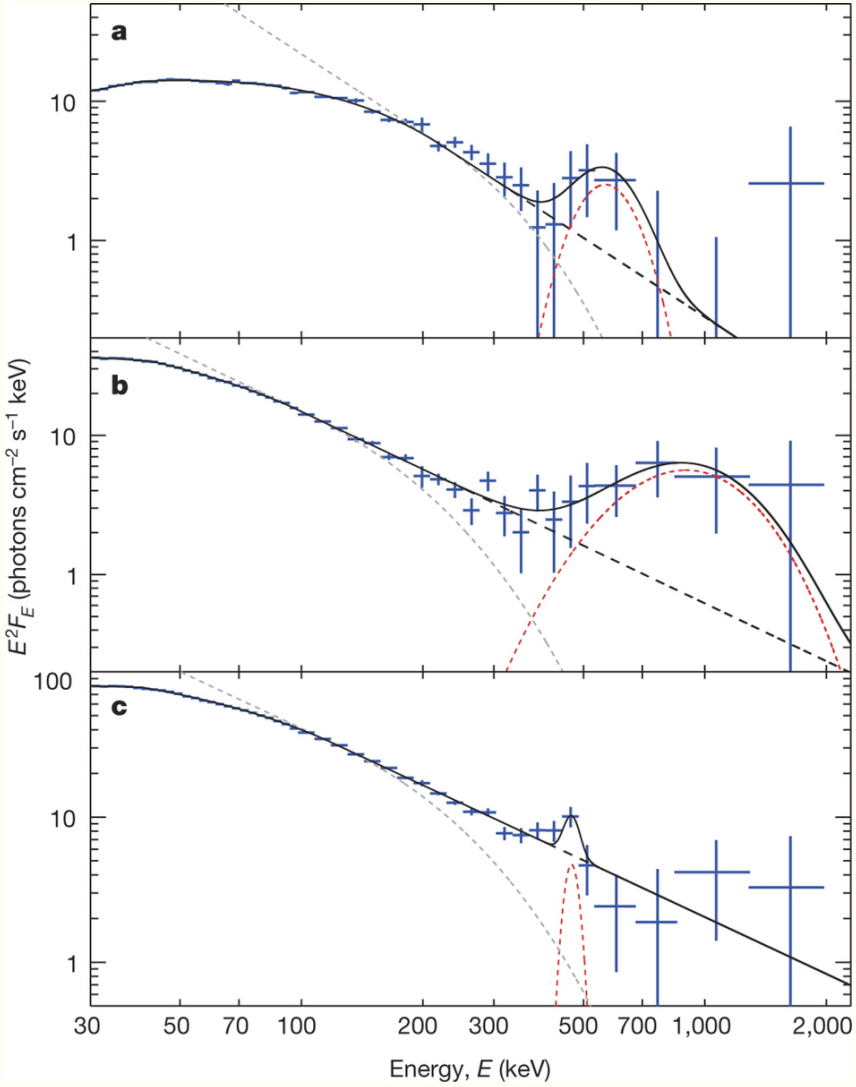
V404 Cyg: different but similar



Sánchez-Fernández et al., 2017

behavior similar to canonical BH states but high, variable absorption

V 404 Cyg: positron annihilation



Siegert et al., 2016

only 3rd microquasar with detection of high energy spectral features

High energy excess / “hard tail”

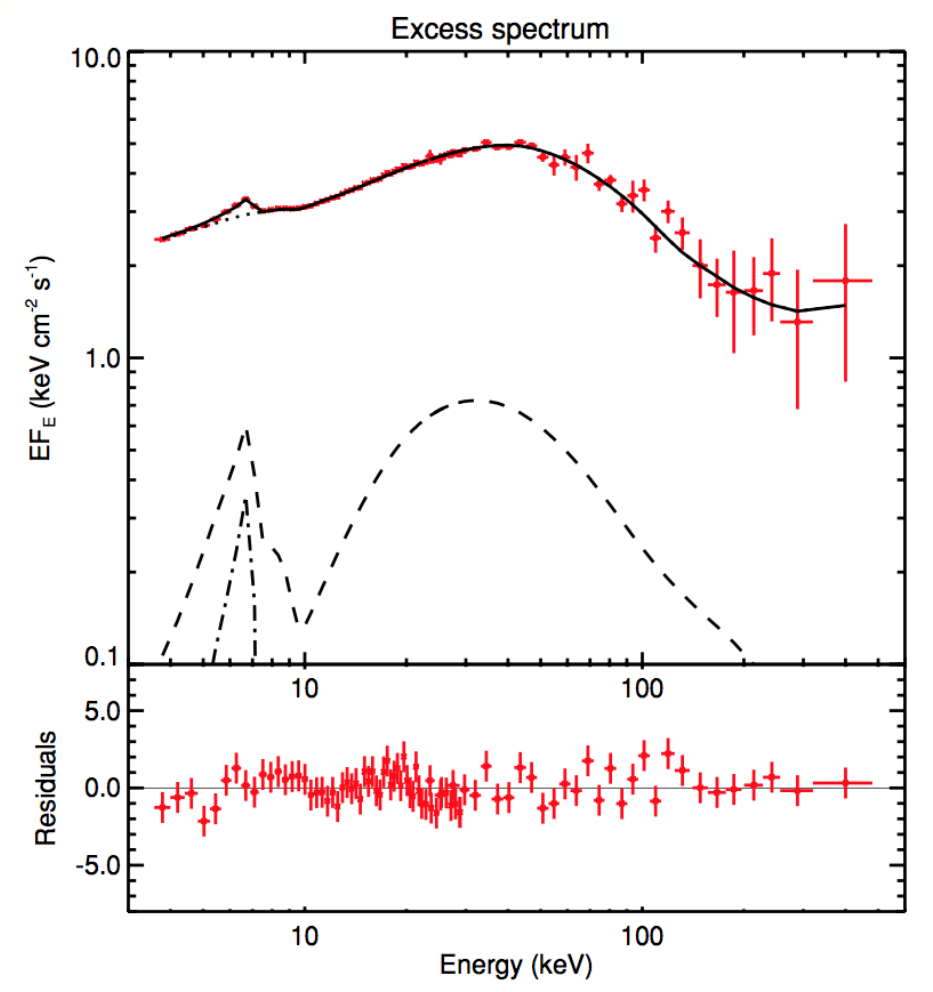
jet?

non-thermal Comptonization?

only accessible with direct measurements above cut-off, but

- different models
- possible model-dependency
- intrinsic (?) variability

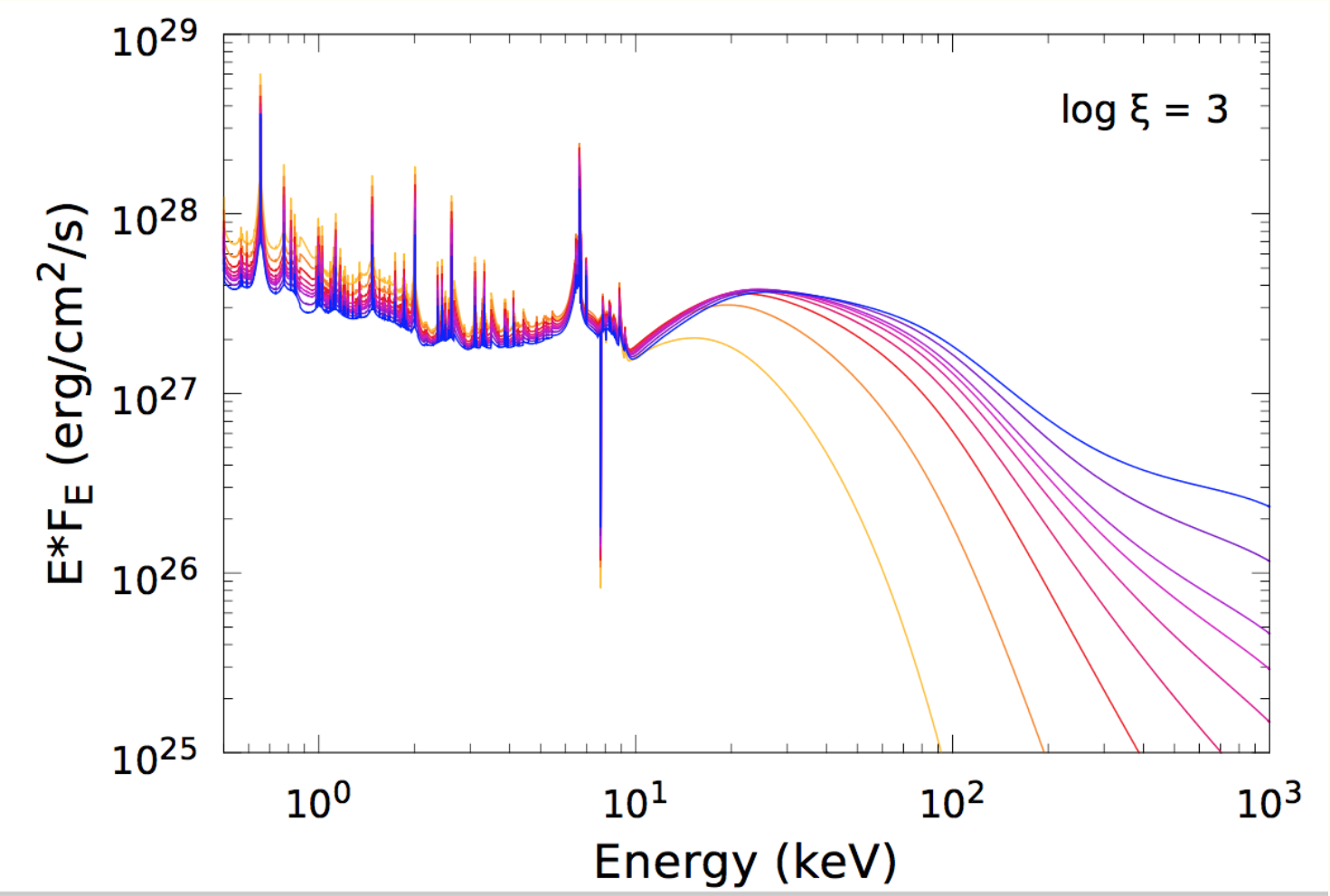
Droulans et al., 2010, Zdziarski et al. 2012, Rodriguez et al. 2015, & more



Droulans et al., 2010

High energy cut-off

cut-off can be determined from low energy features using reflection

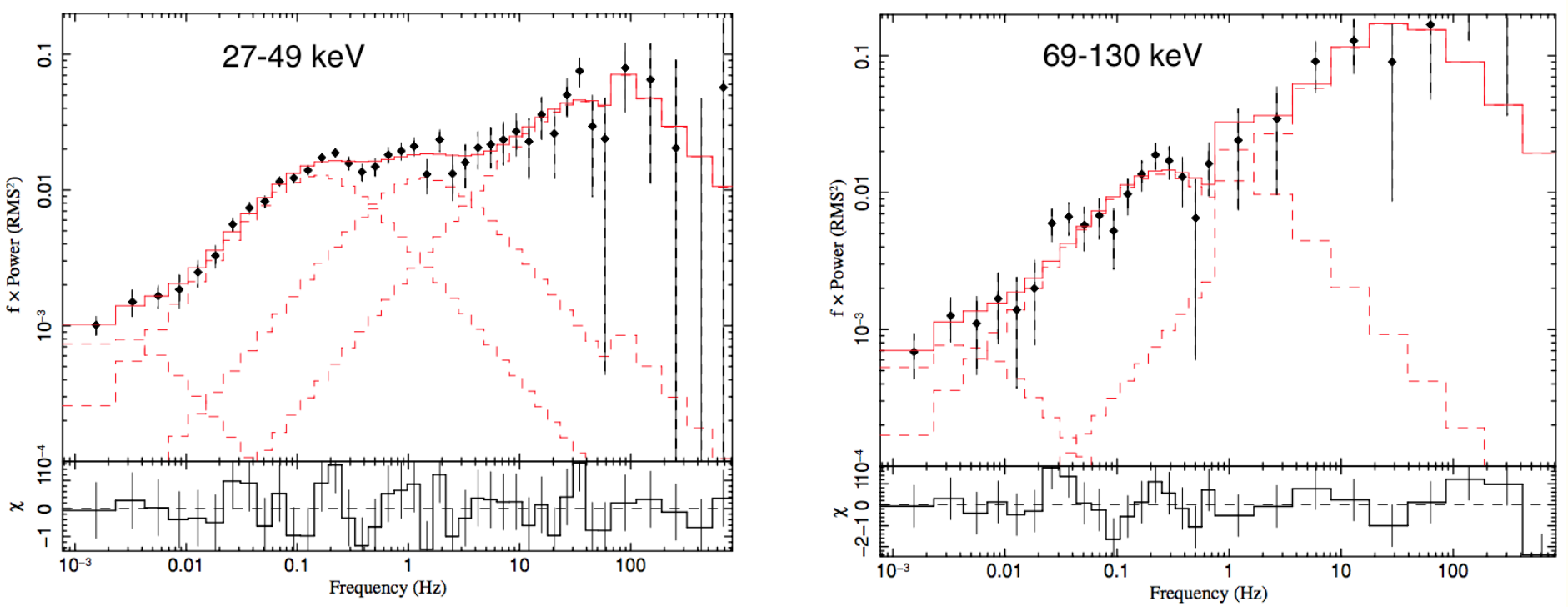


García et al., 2015

... but models need to be tested!

Time domain: fast X-ray timing

Variability as tracer of physical origin
e.g., variable power law in soft state in Cyg X-1 *Grinberg et al., 2014*

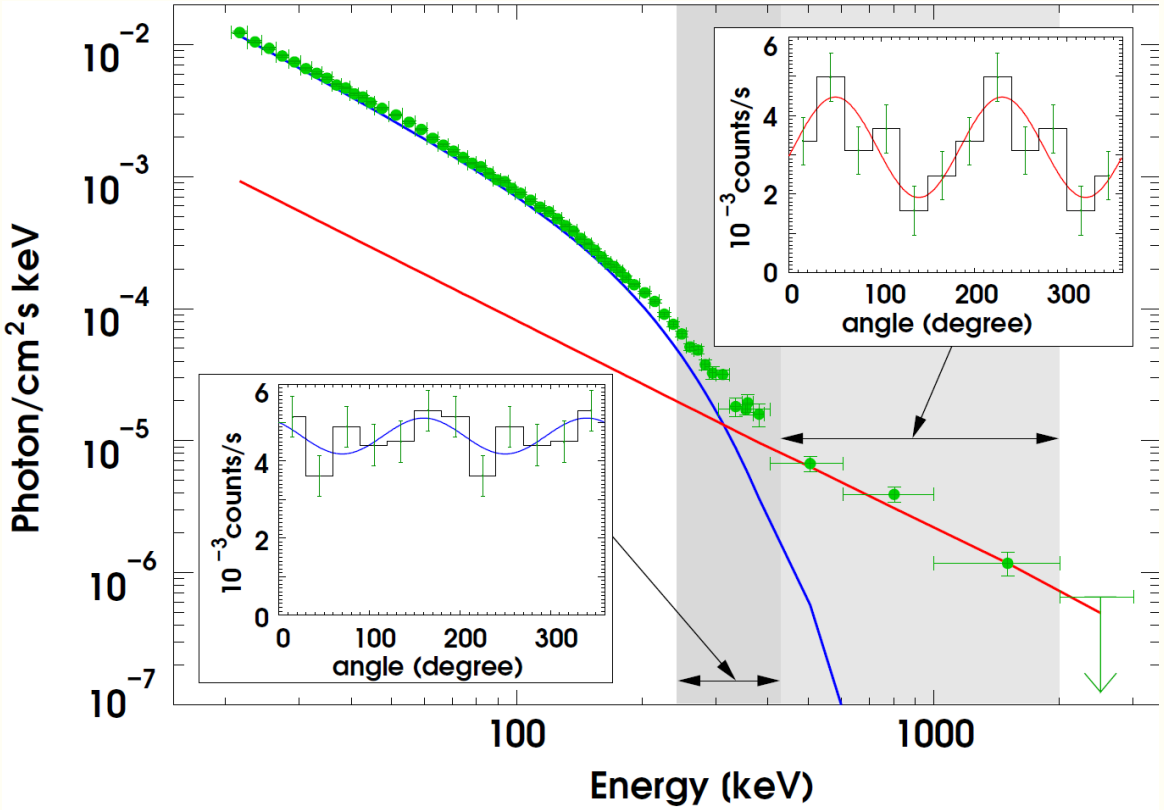


Cabanac et al., 2011

See also Pottschmidt et al. 2006 (Cyg X-1), Grinberg et al. 2011 (extraction methods), Huppenkothen et al. 2017 (V404 Cyg)

γ-ray polarization

Laurent, ..., VG, 2011



INTEGRAL/IBIS:

5 Ms

- $\lesssim$ 400 keV: power law; polarization fraction $<$ 20%
- $\gtrsim$ 400 keV:hard tail, polarization fraction 67$\pm$30 %

$\Rightarrow$ jet (synchrotron) as source for hard tail

For more details & new work: Talk by F. Cangemi

γ-ray polarization

Laurent, ..., VG, 2011

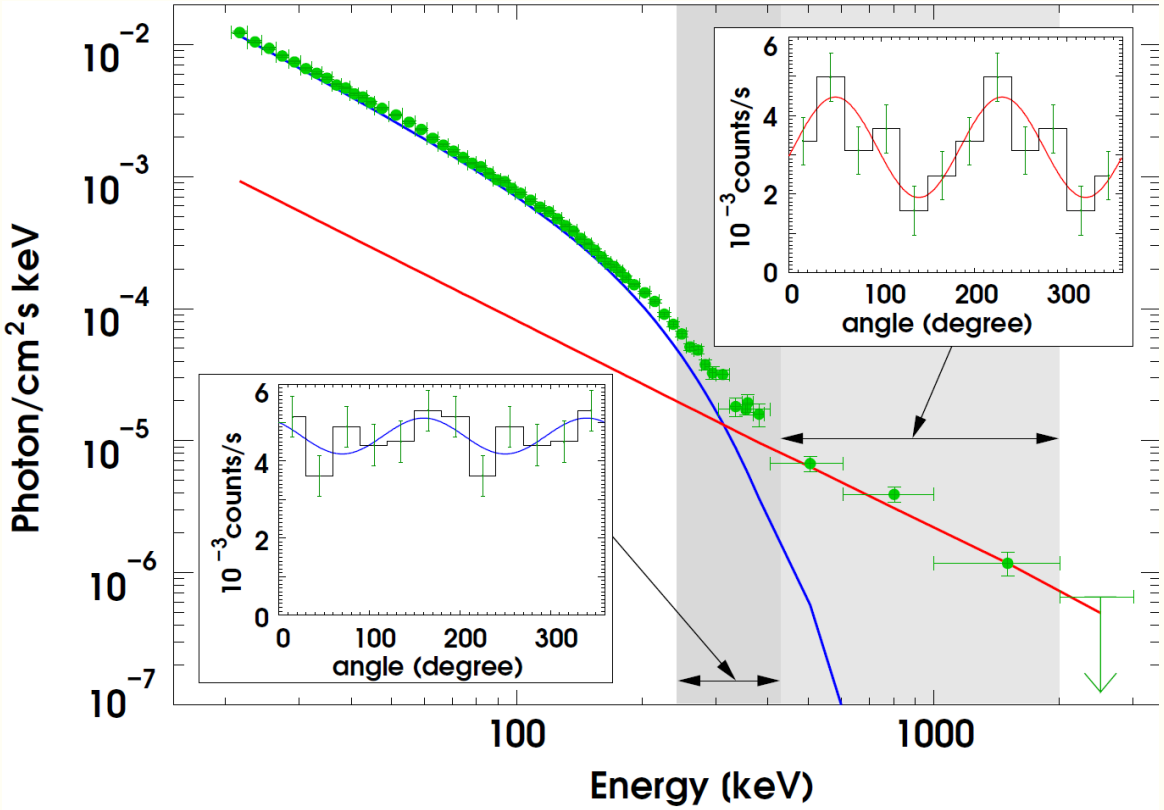
define state for every $\sim$30 min observation (science window) in 2003–2012

Grinberg, et al. 2013

$\Rightarrow$ *Rodriguez, VG, et al. 2015*

INTEGRAL/IBIS:

8 Ms, with 4.3 Ms hard



- $\lesssim$ 400 keV: power law; polarization fraction $<$ 20%
- $\gtrsim$ 400 keV:hard tail, polarization fraction 82$\pm$38 %

$\Rightarrow$ confirmation of polarizaion in hard sttae

$\Rightarrow$ jet (synchrotron) as source for hard tail

For more details & new work: Talk by F. Cangemi

Take home points

We do not yet fully understand
the geometry of accretion & ejection flows in stellar mass black holes

different geometries $\Rightarrow$

- different long-term evolution
- different properties above spectral cut-off
- different high-energy polarization

INTEGRAL
... but what comes next?!