Suzaku 2011 @SLAC

Wide-band & Intensity-related spectral analysis of Cygnus X-1 with *Suzaku*

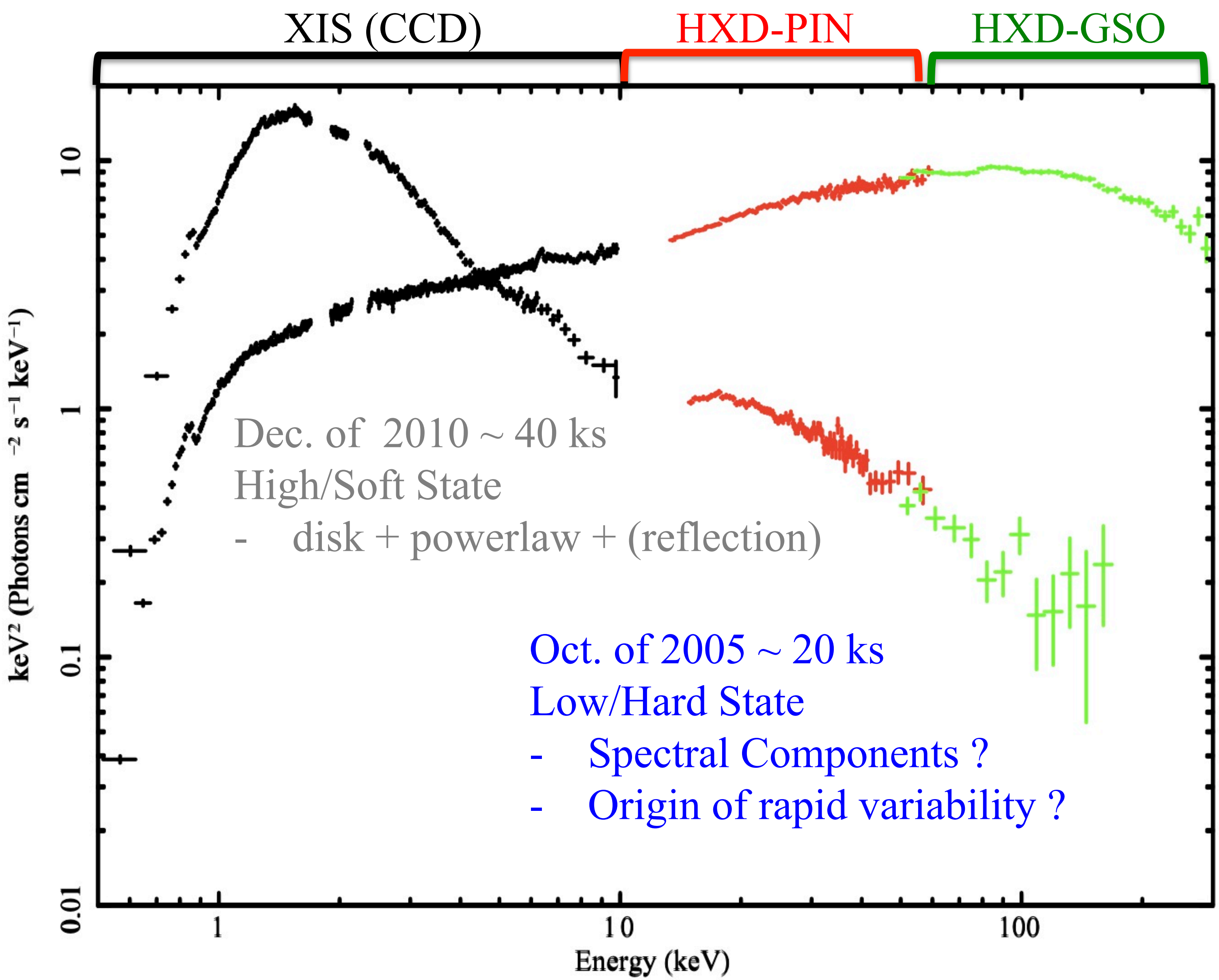
~ PhD thesis of University of Tokyo ~

Shinya Yamada

RIKEN Tamagawa group,
A member of Suzaku, Astro-H, and GEMS

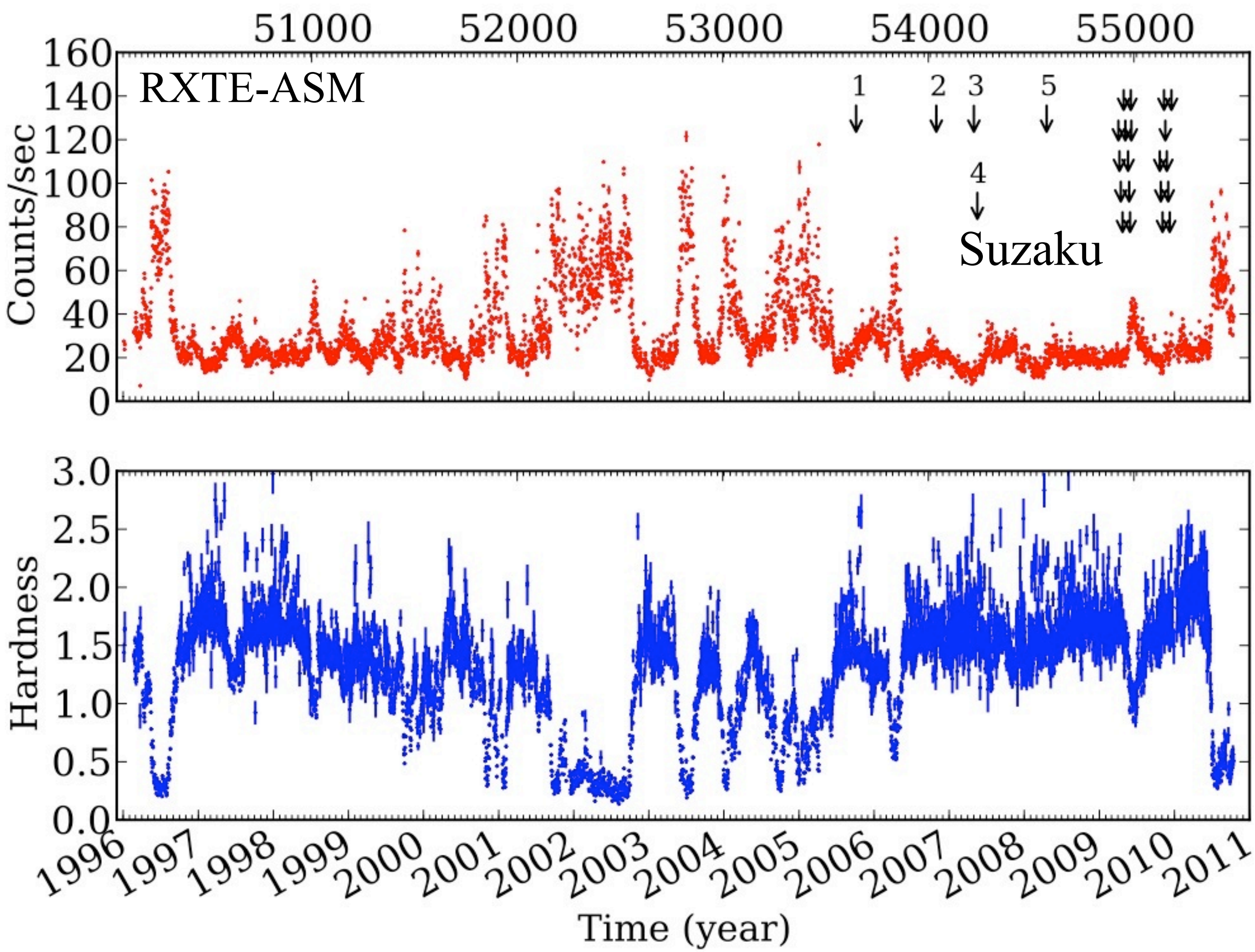
Collaborators : K. Makishima, C. Done, S. Torii, H. Noda, and H. Negoro

Wide-band *Suzaku* Spectra of Cyg X-1



Suzaku Obs. of Cyg X-1 from '05 to '09

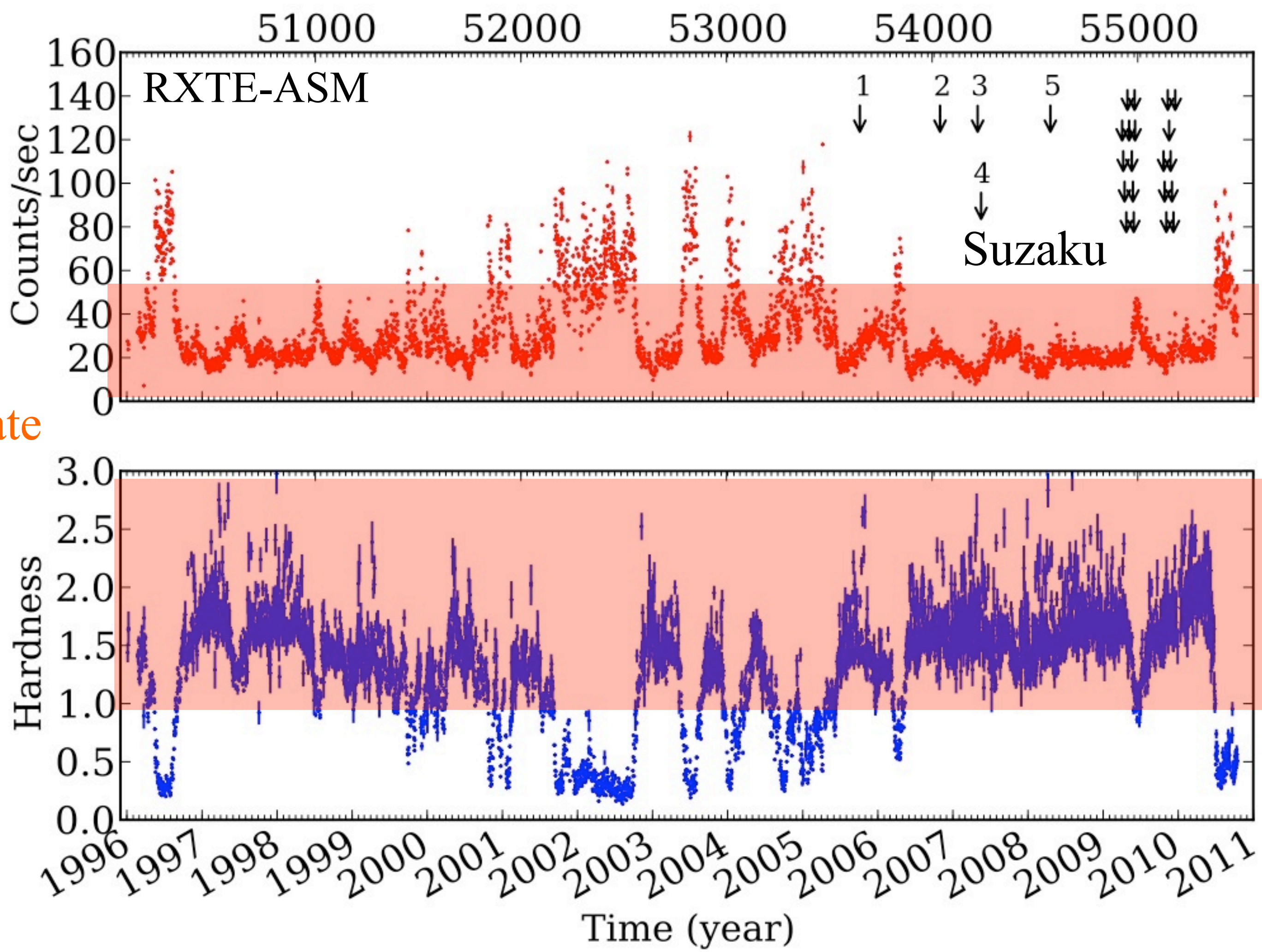
All 25 obs.; each ~ 20 ks



Suzaku Obs. of Cyg X- 1 from '05 to '09

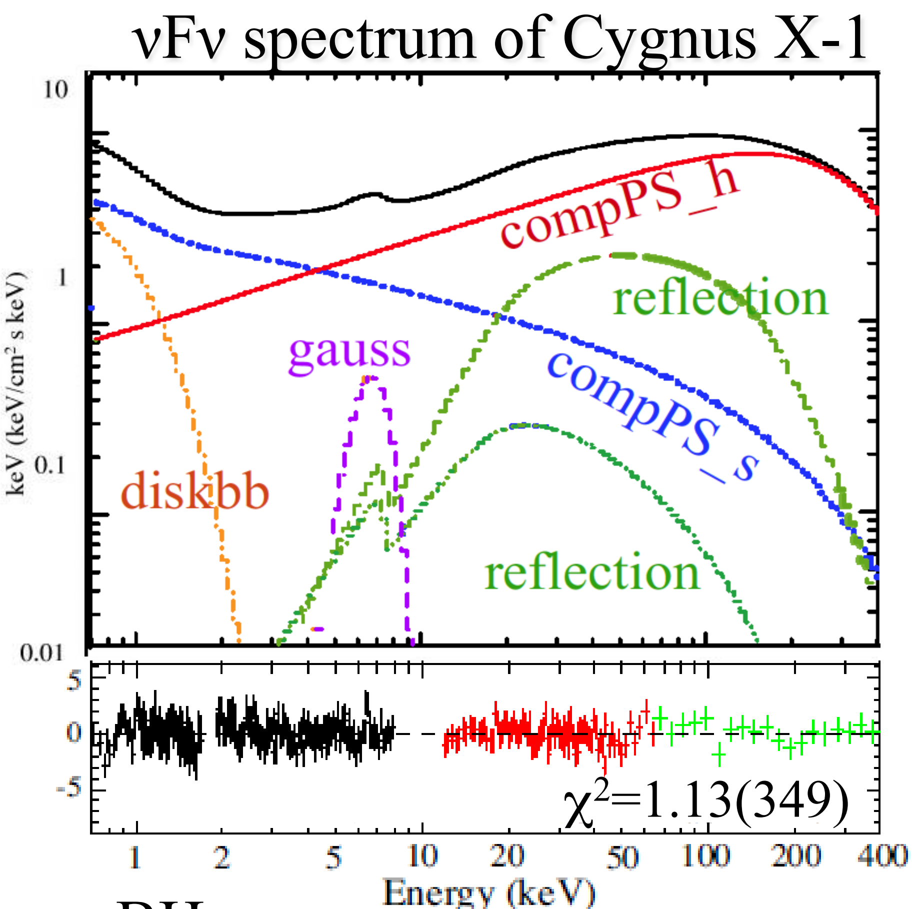
All 25 obs.; each ~ 20 ks

Hard State



25 samples of high-sensitive & wide-band spectra in Hard state.

Suzaku 1st obs. of Cyg X-1 (K.Makishima + '08)



- Two Compton continua

  τ~1.5 and τ~0.4

  T_e ~ 100 keV (common)

  R_{seed} ~ 210 km (2 comp. sum)

- Directly visible disk emission

  T_{in}~ 0.2 keV, R_{in}~ 250 km

  → In total, R_{in}/R_g~15

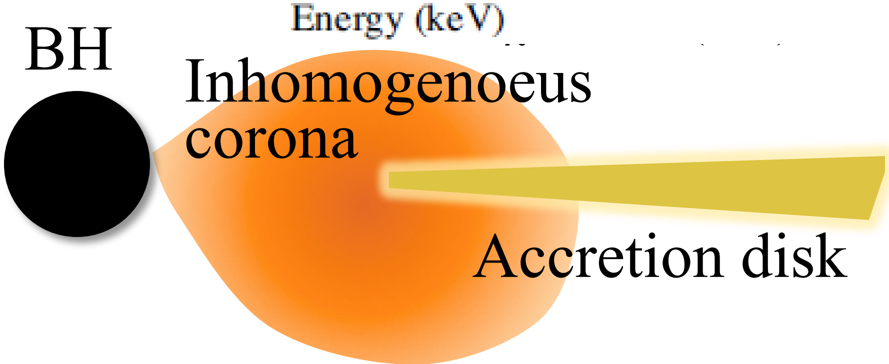
The disk is truncated at ~ 15 R_g

- ○ Mildly broadened Fe-K line

  @ 6.3 keV, EW 290 eV,

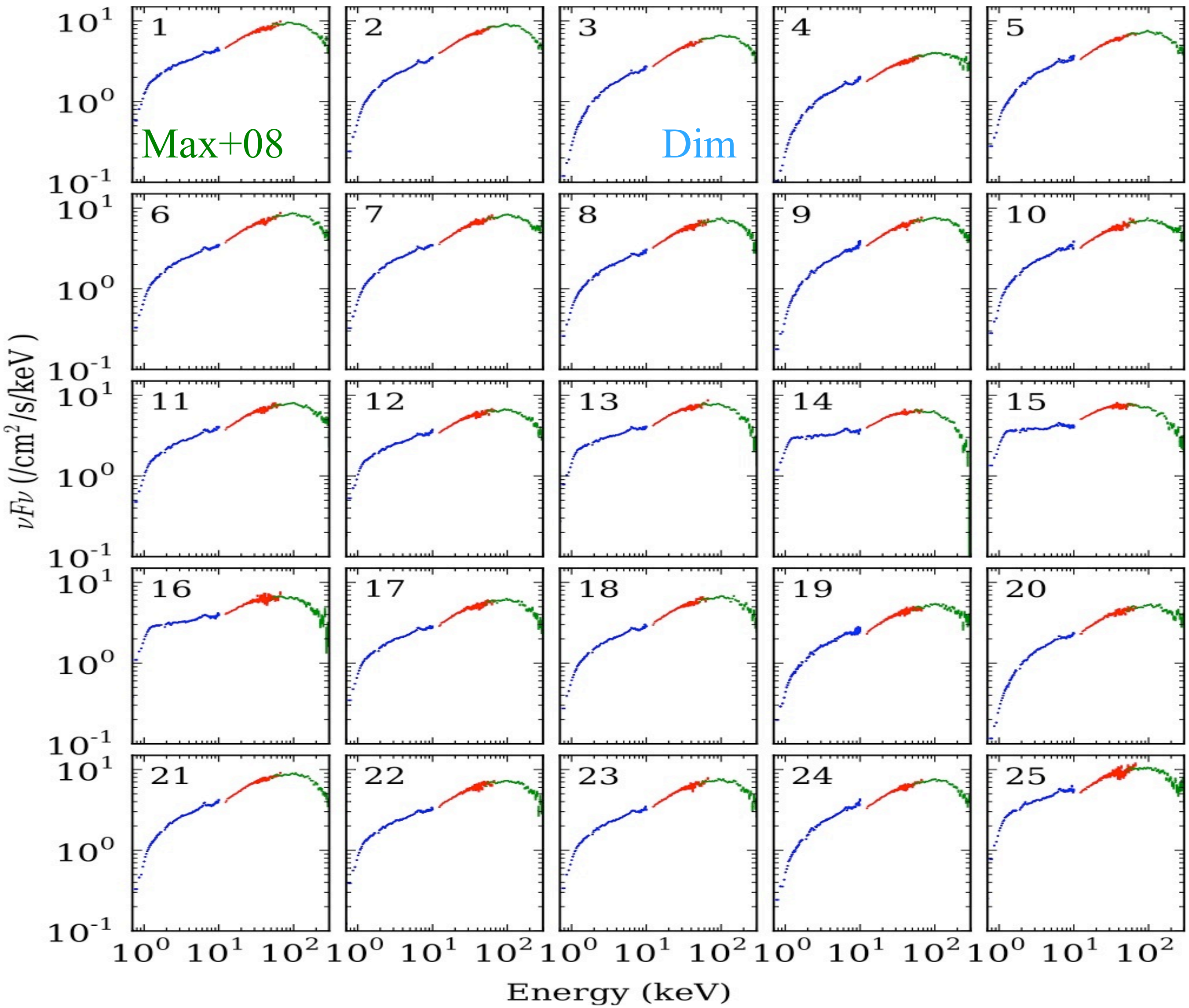
  σ~ 1 keV → R_{in}/R_g~12

- Reflection Ω/2π ~ 0.4



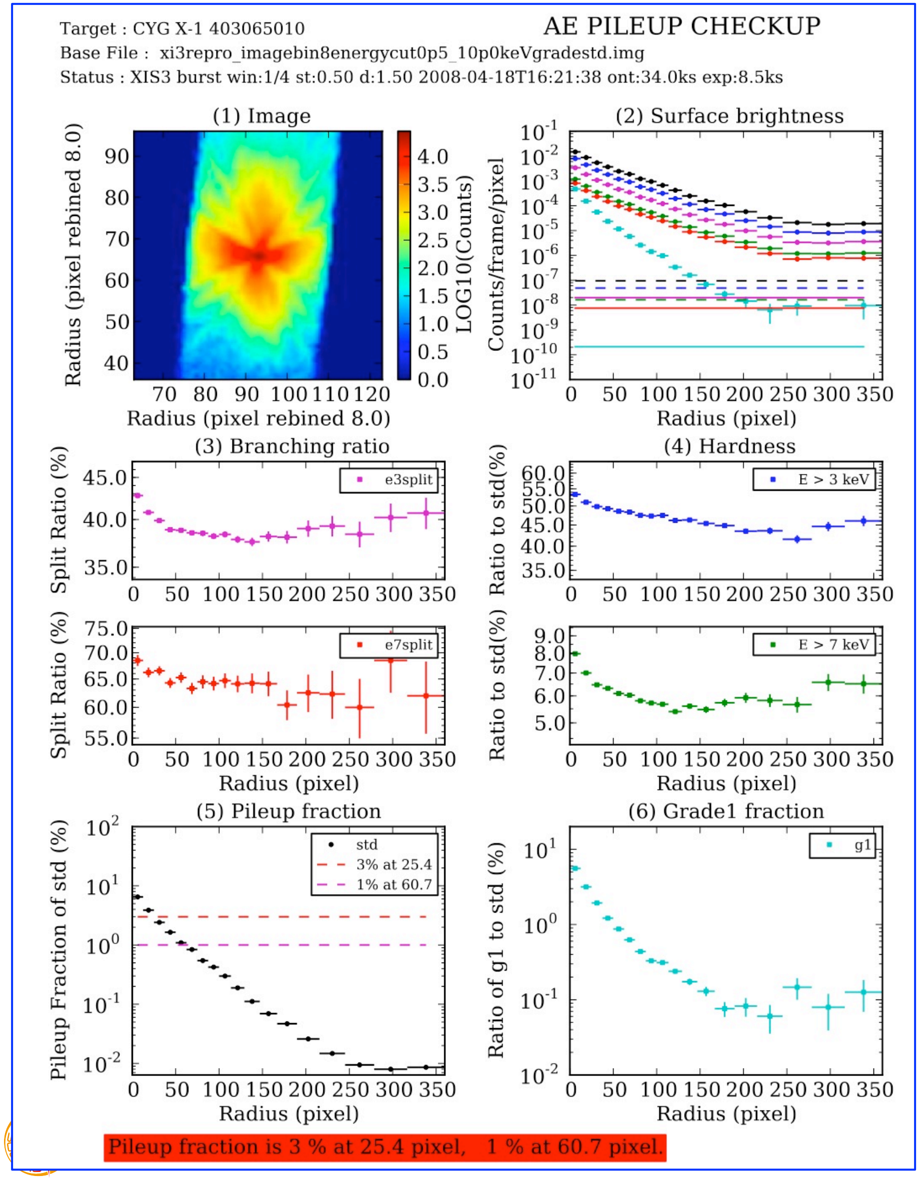
Any model-independent evidence?
(cf. Nowak+11)

Suzaku Spectra of 25 obs.

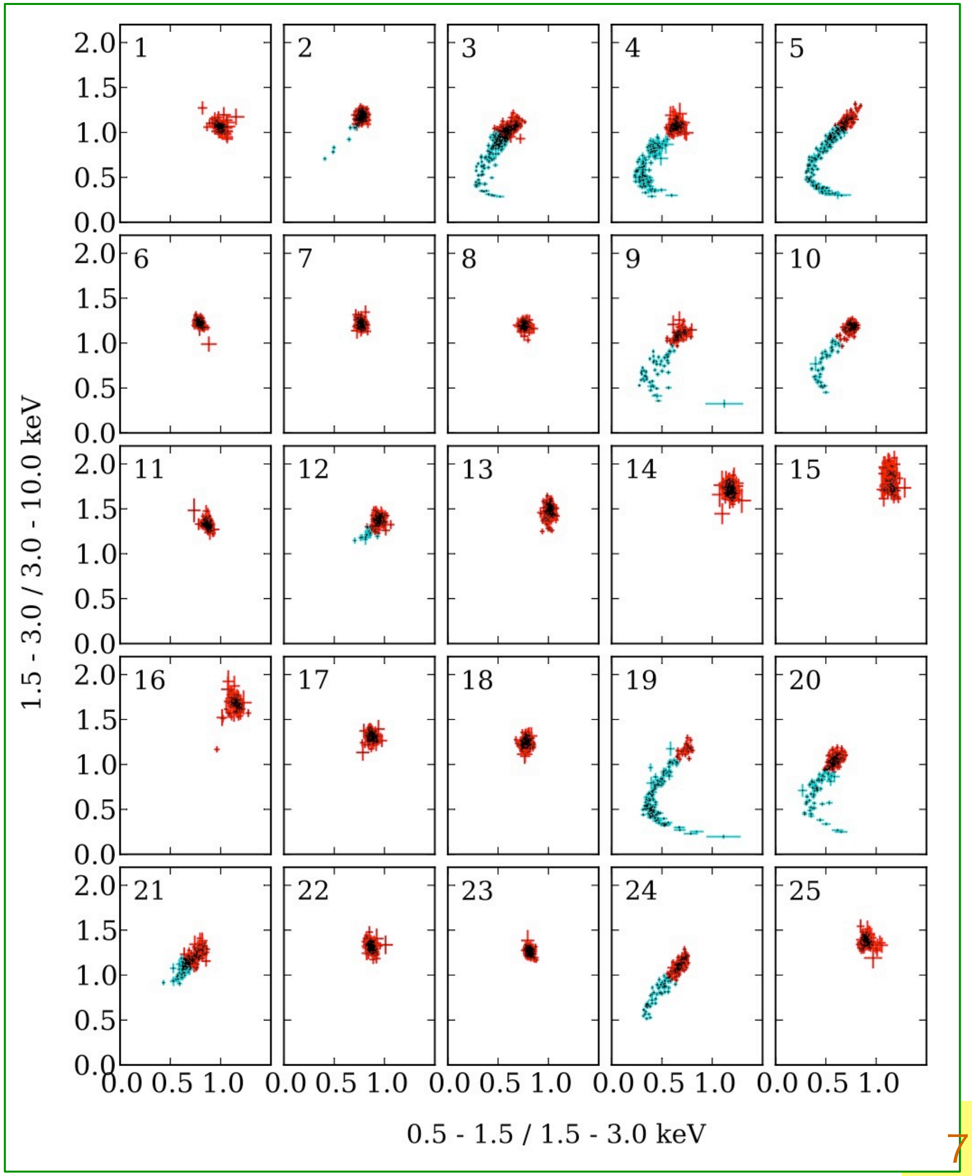


Great care for Pileup & Dipping phase

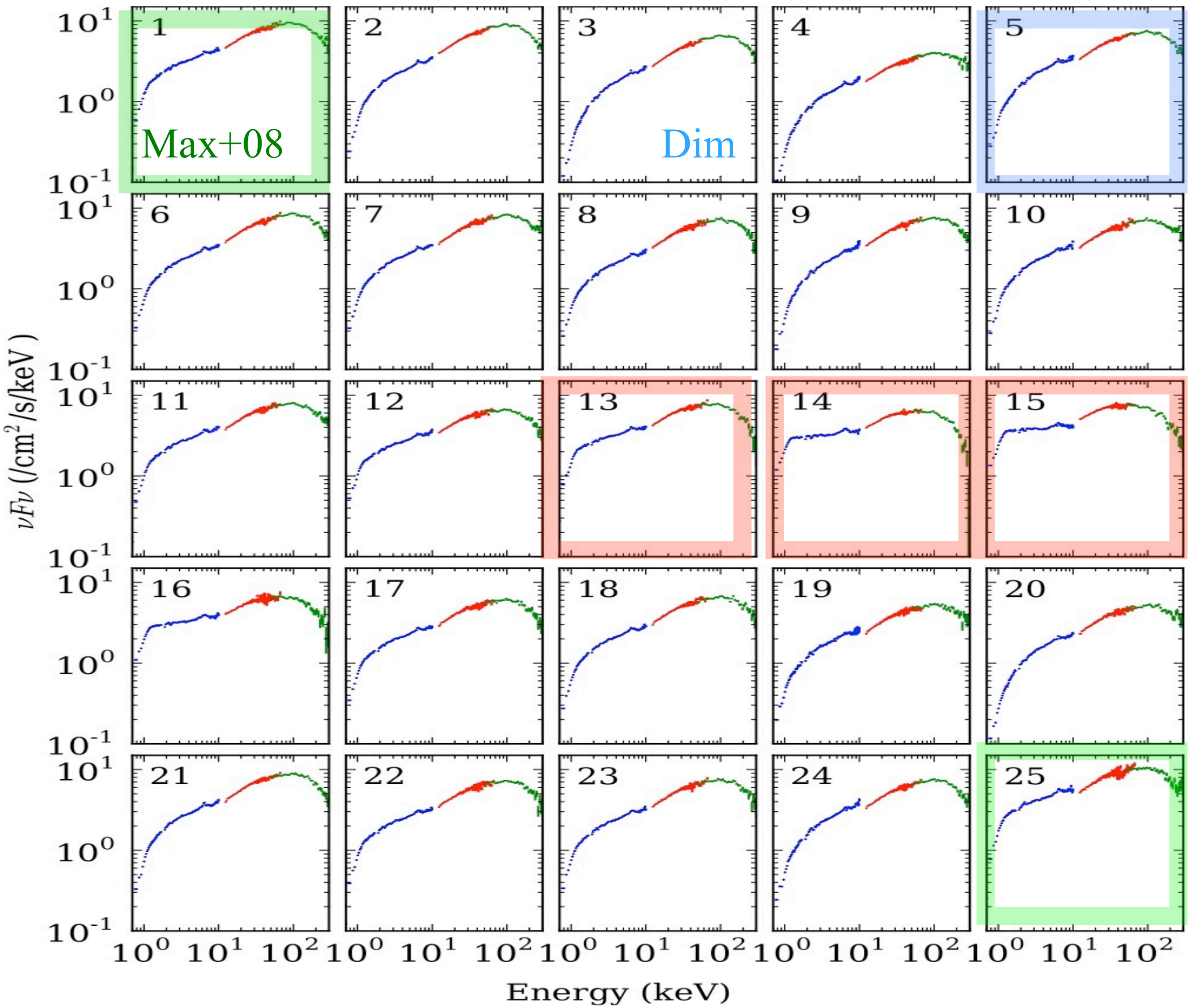
developed “aepileupcheckup.py”
automatically analyze pileup extent.



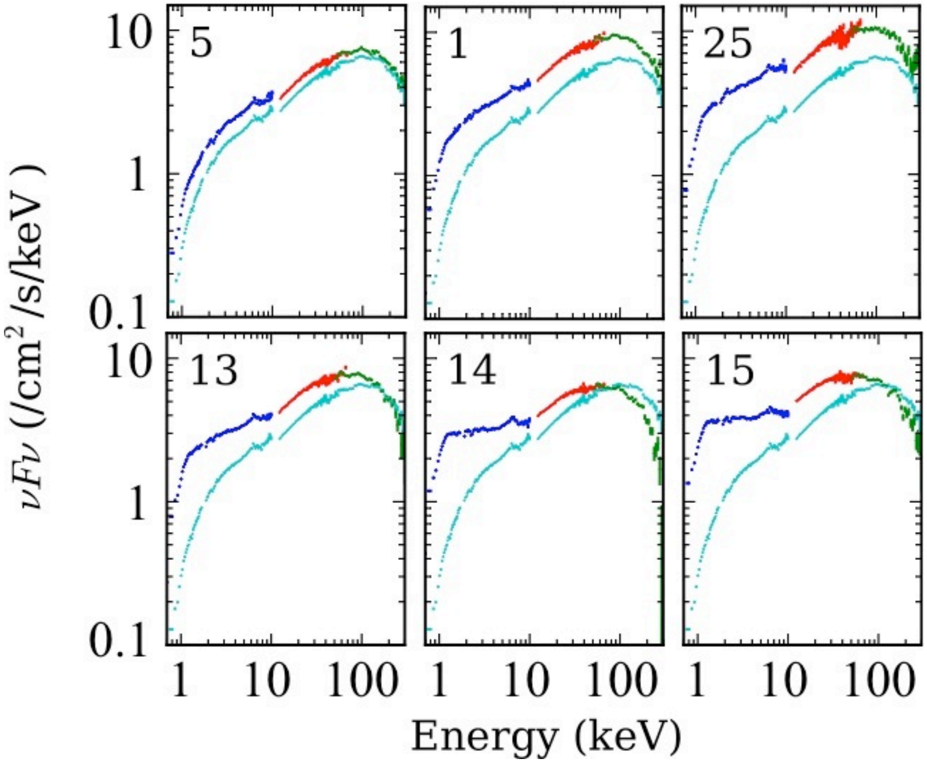
Applied “color-color plot” (Nowak+11)
to avoid dipping phases

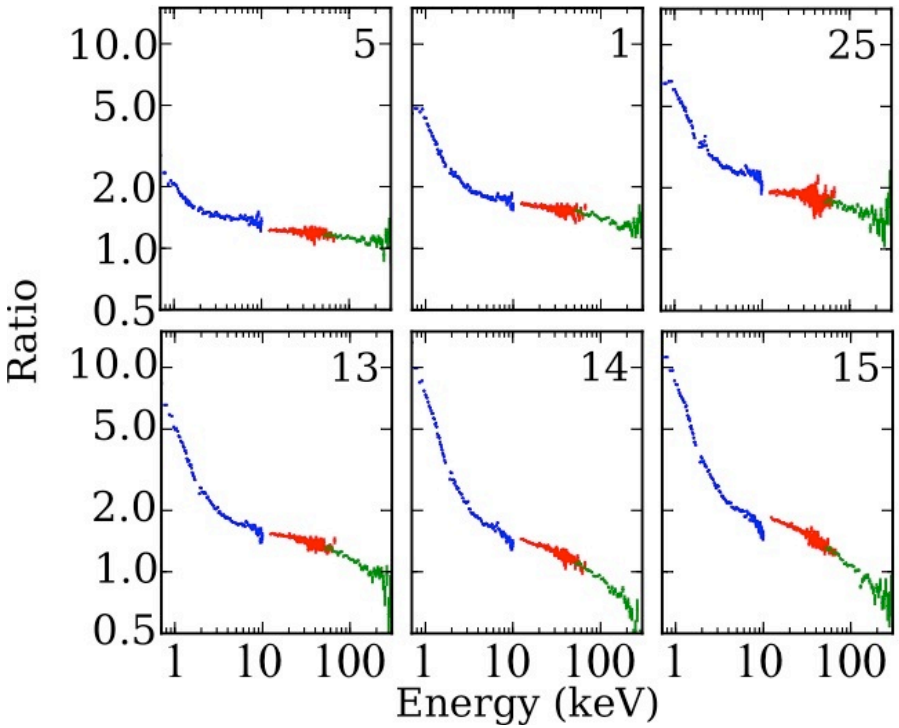


Suzaku Spectra of 25 obs.



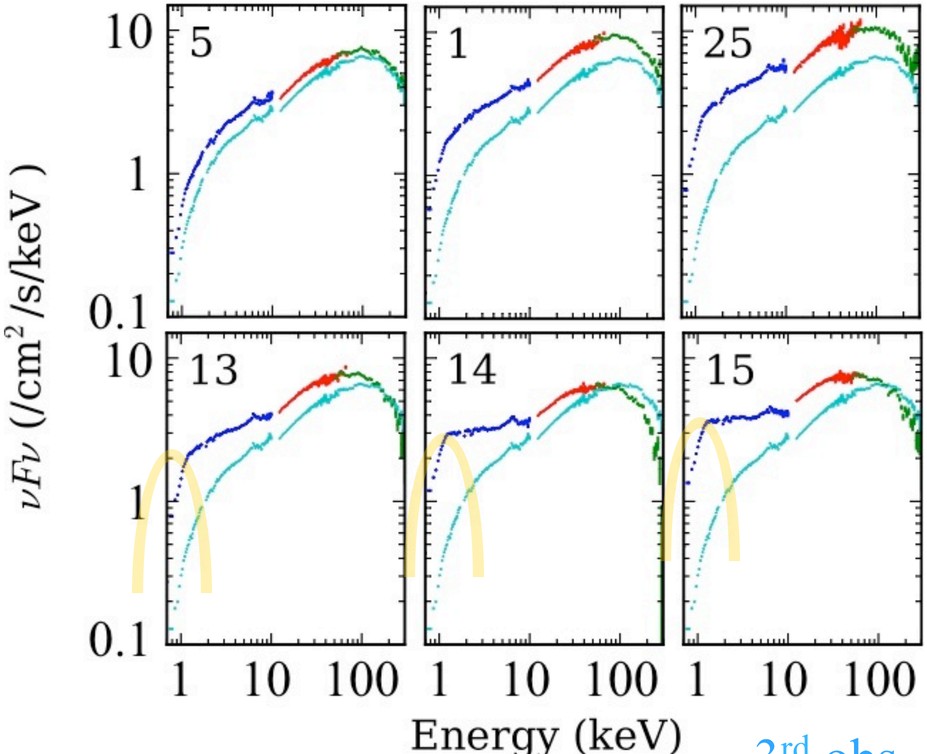
Comparison bet. spectra of Δt > days



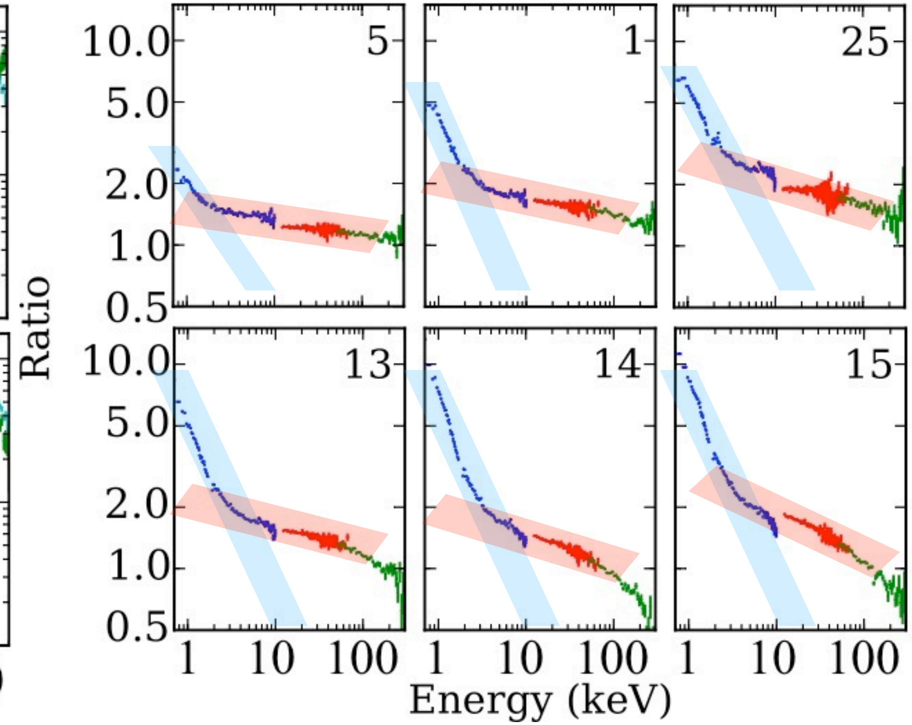


Spectral ratio to 3rd obs.

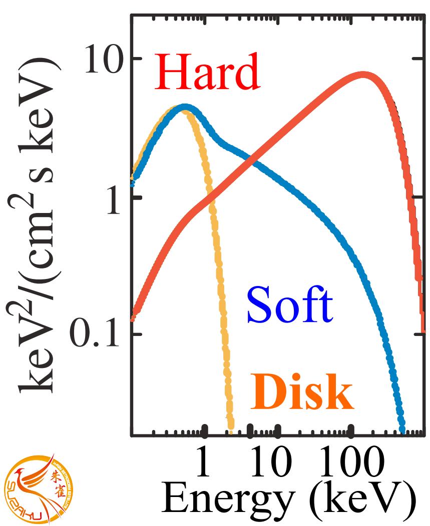
Comparison bet. spectra of Δt > days



3rd obs.



Spectral ratio to 3rd obs.



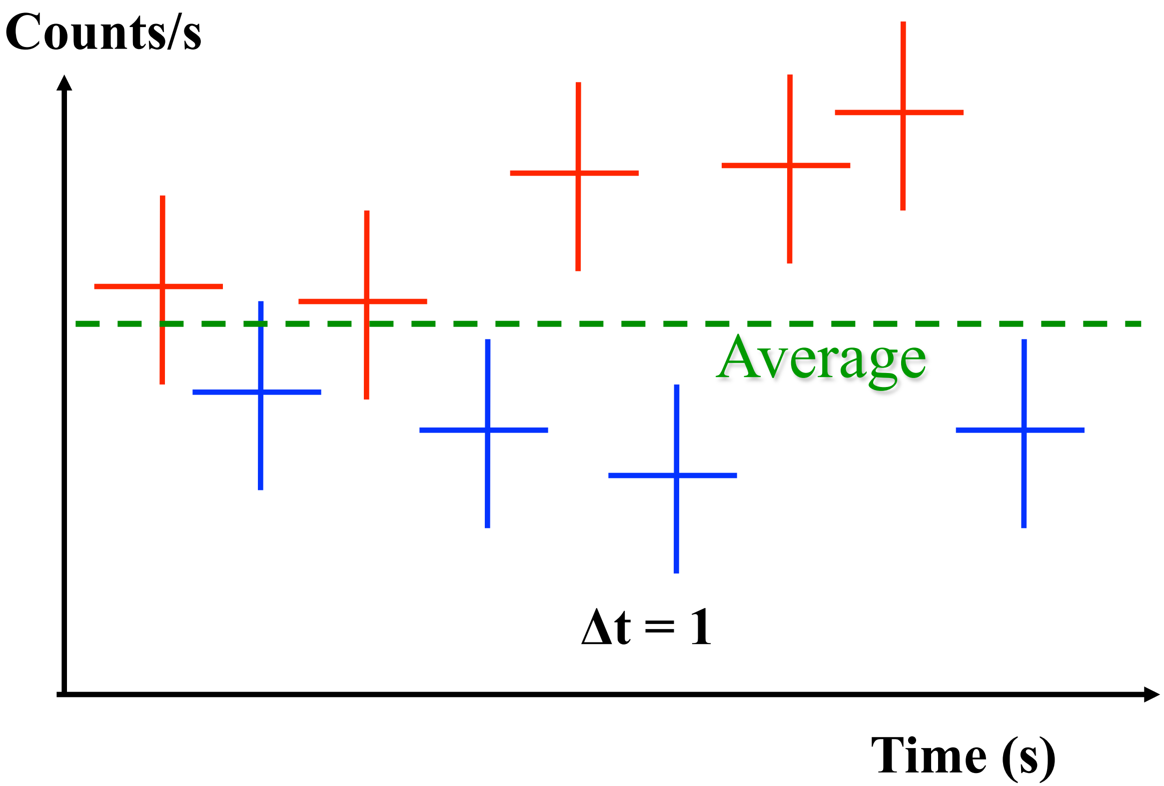
vFv (Max+08)

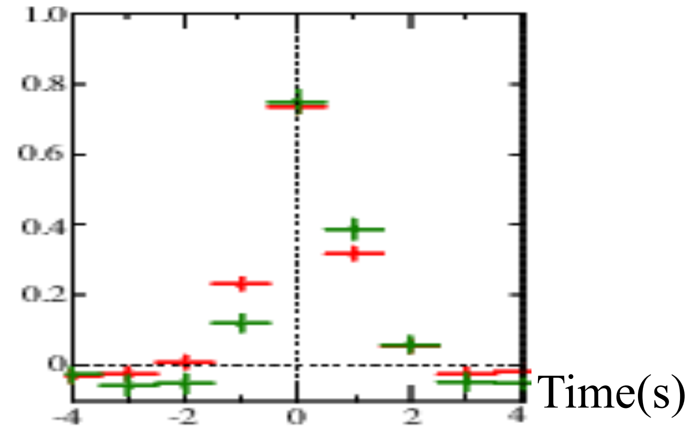
What the ratio shows

- Soft excesses below E < 10 keV
- The soft excesses increases as flux increases.
- The spectra becomes softer as it gets brighter.

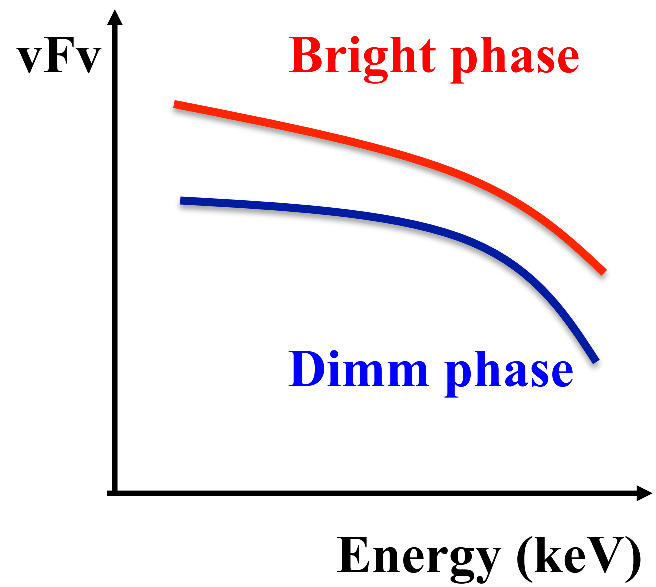
Intensity-sorted spectroscopy

1. With XIS, judging high/low phase on Δt = 1
2. Sorting the data according to 1.
3. Extracting high/low spectra.



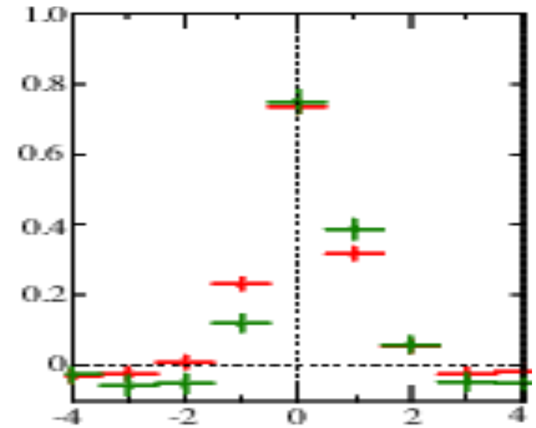


XIS vs. PIN GSO C.C.F

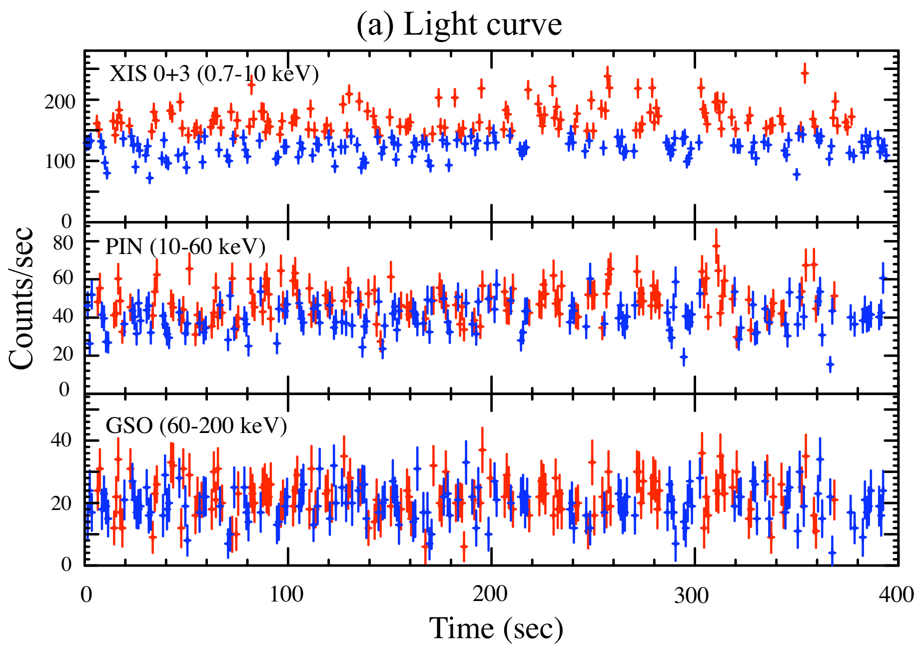


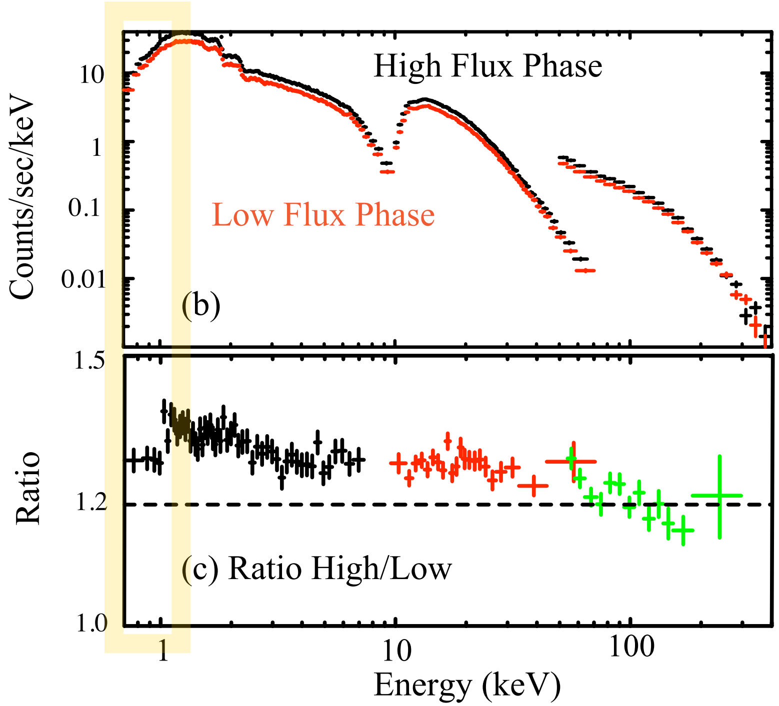
Intensity-sorted spectroscopy

1. With the XIS, judge high/low of Δt = 1
2. With the criteria, sorting the data
3. Obtaining high/low spectra.

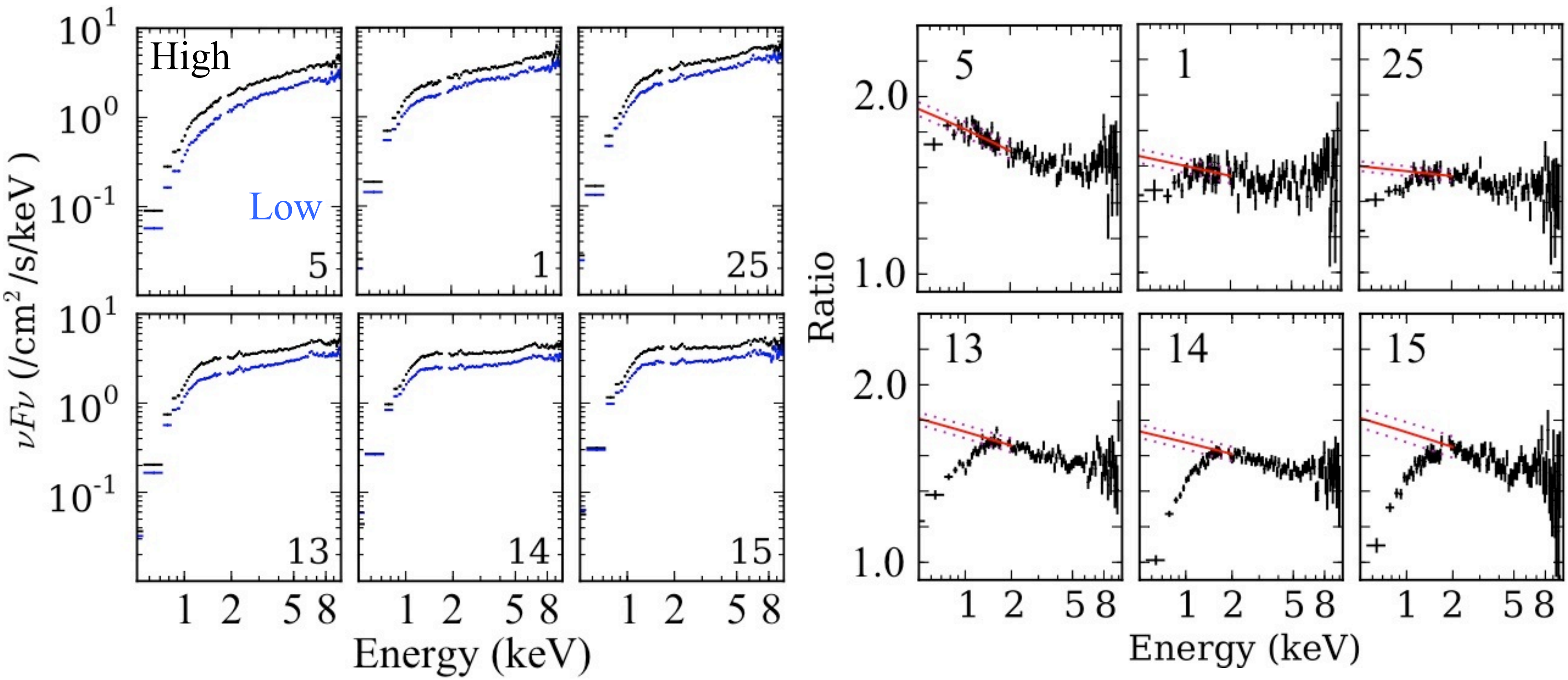


XIS vs. PIN GSO C.C.F





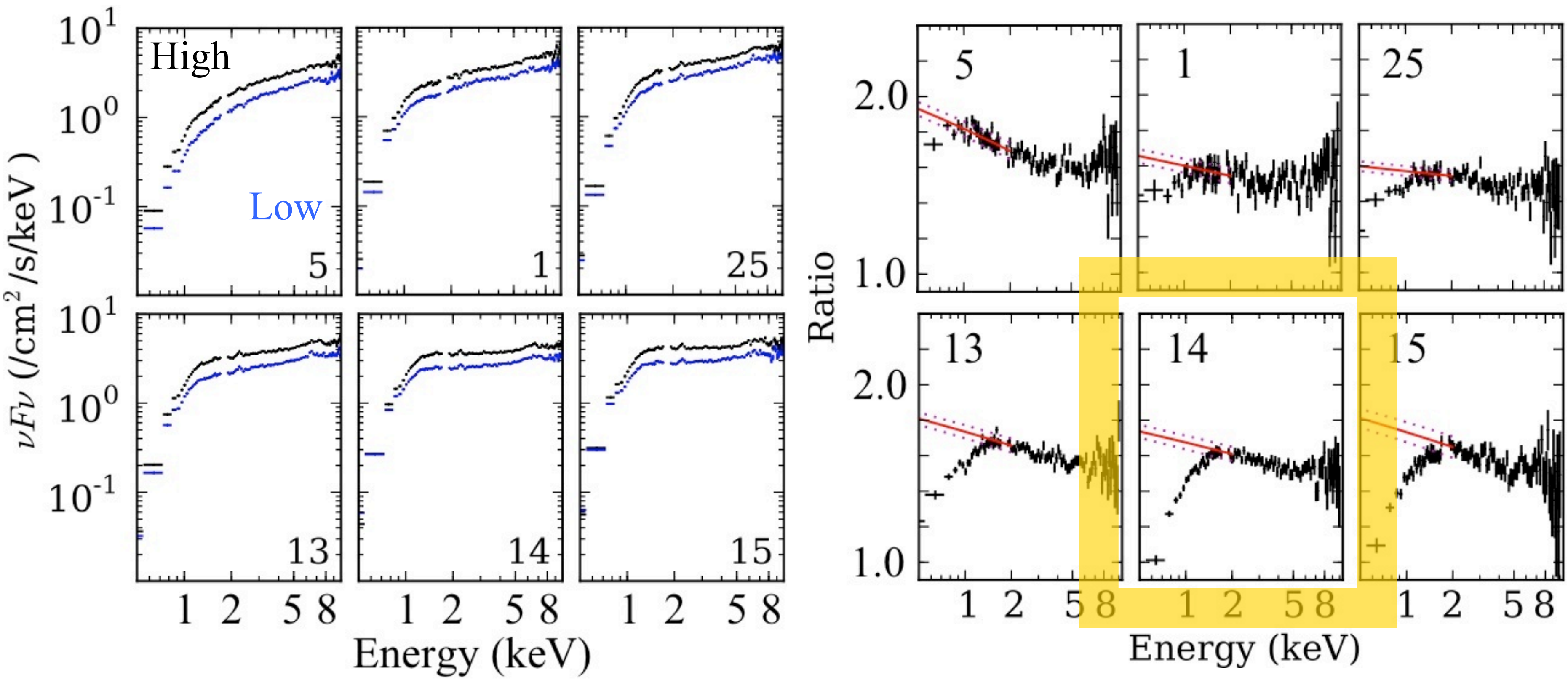
Comparison bet. Spectra with $\Delta t \sim 1$s



What the ratio shows

- Hollows below E < 2 keV
- Spectra becomes softer as the source gets brighter.

Comparison bet. Spectra with $\Delta t \sim 1$s



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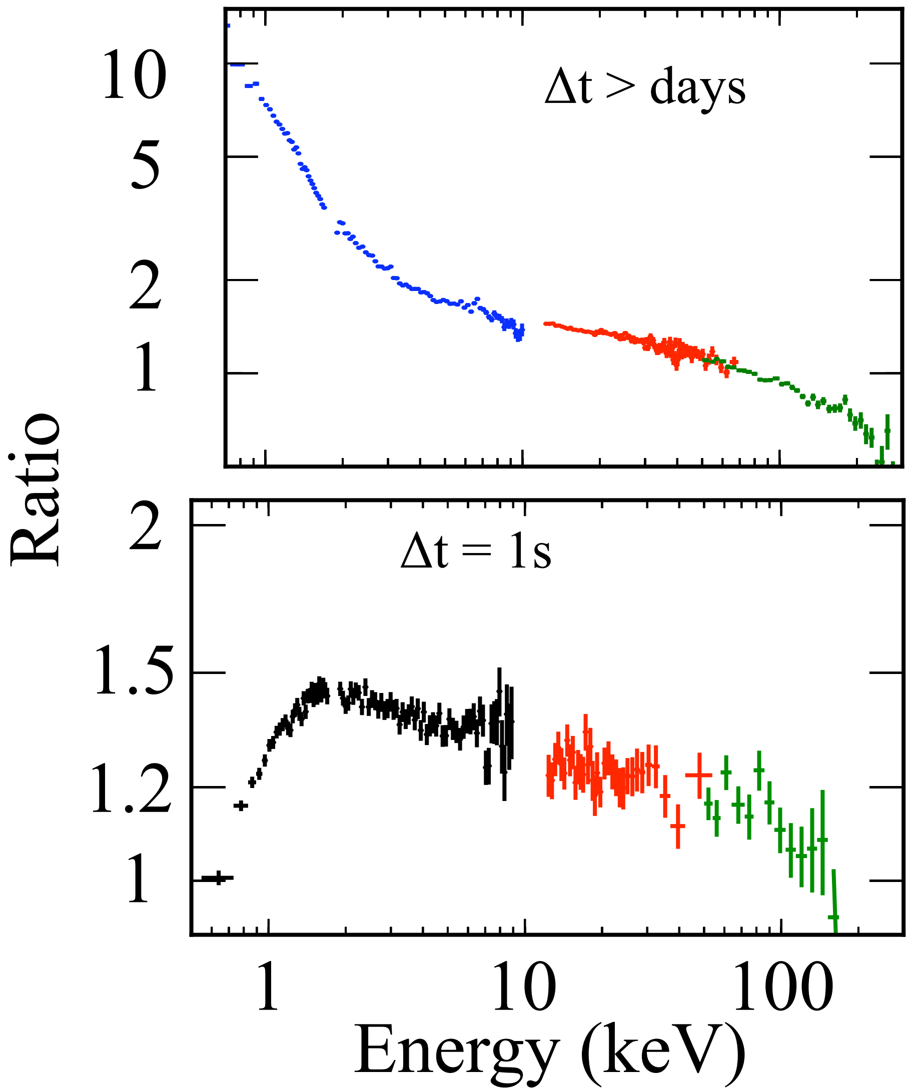
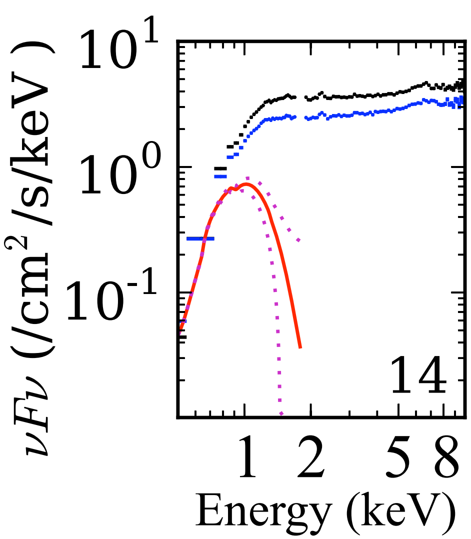
Detailed Comparison of spectra of 14th obs.



Assum.
const + pl.



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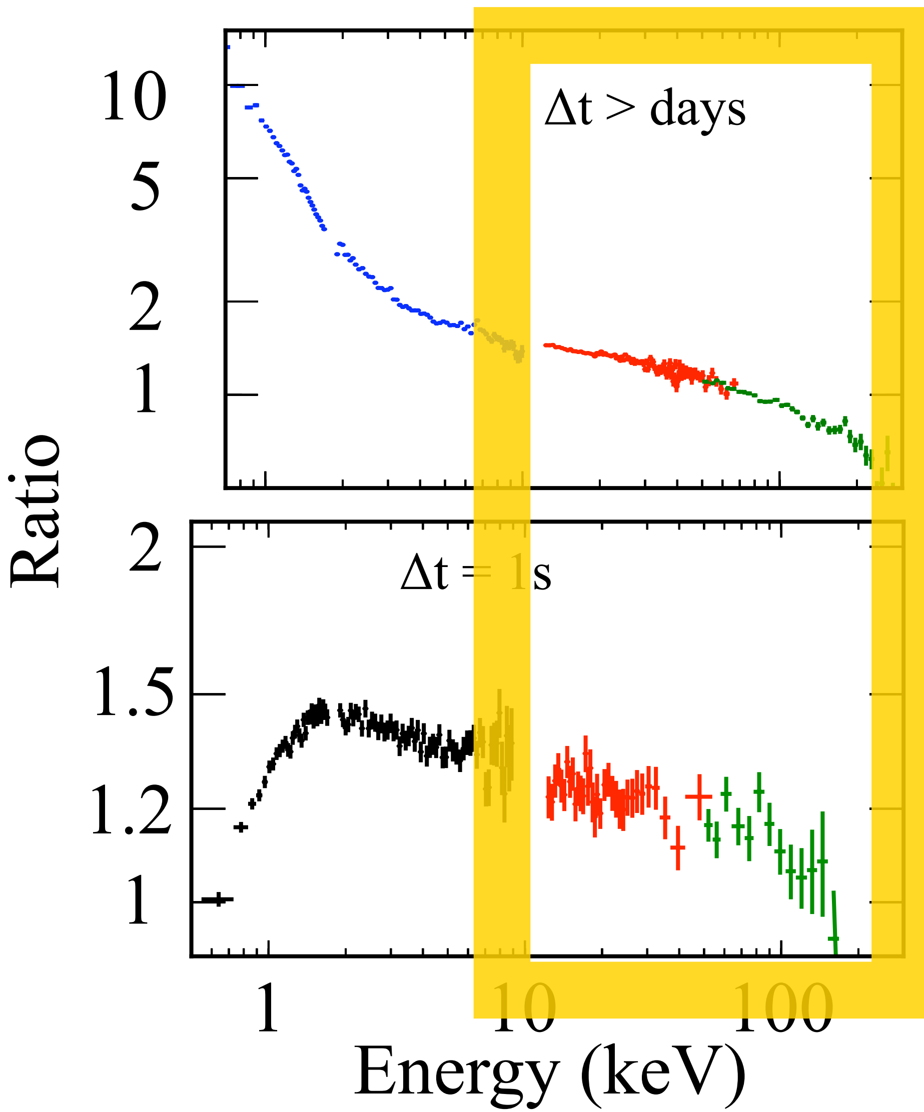

Assum.
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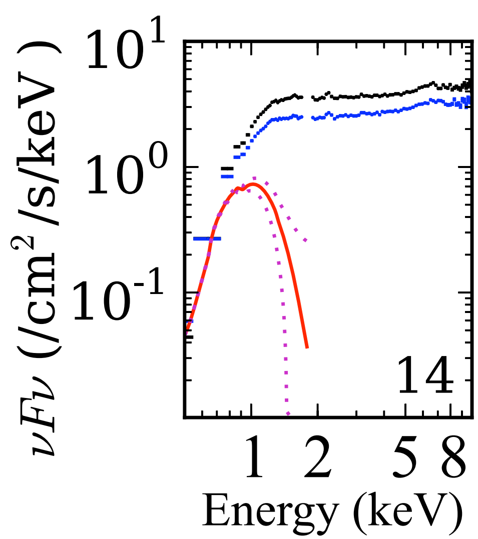
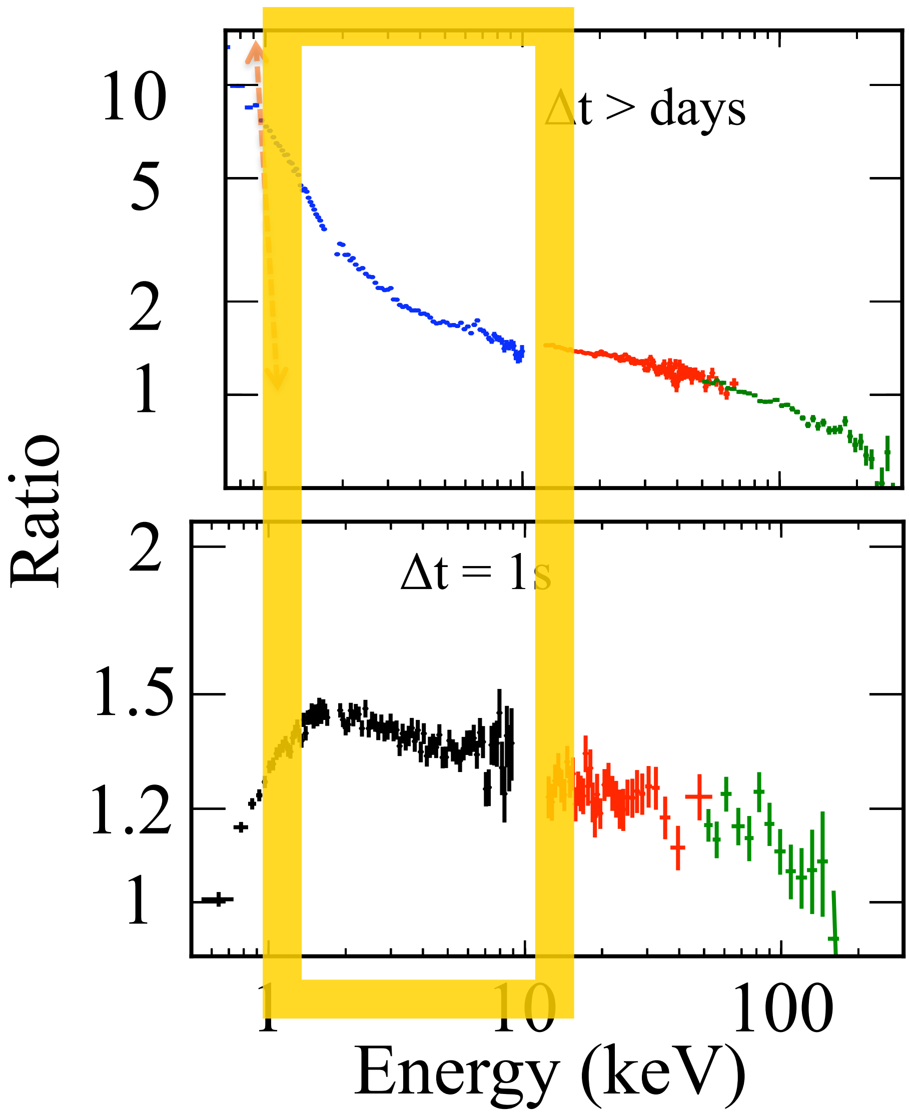
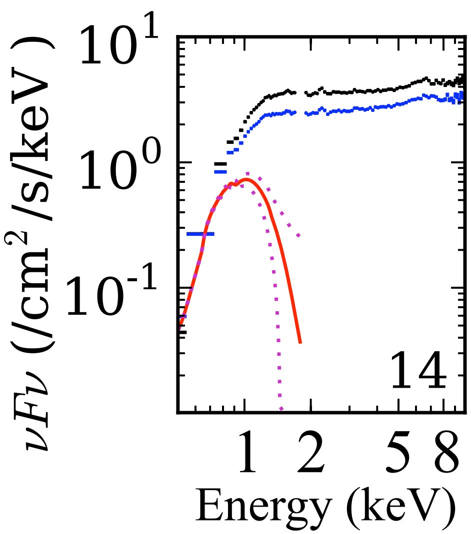


Detailed Comparison of spectra of 14th obs.



Assum.
const + pl.



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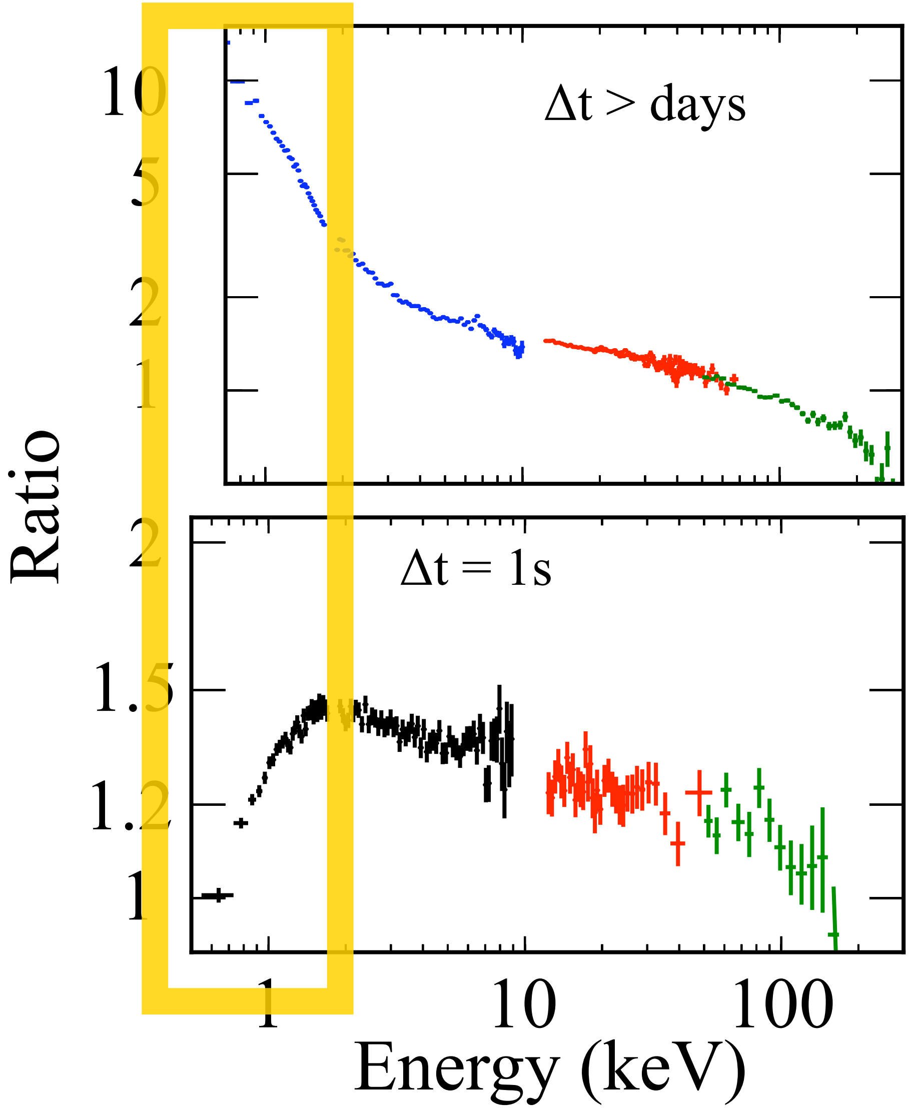

Assum.
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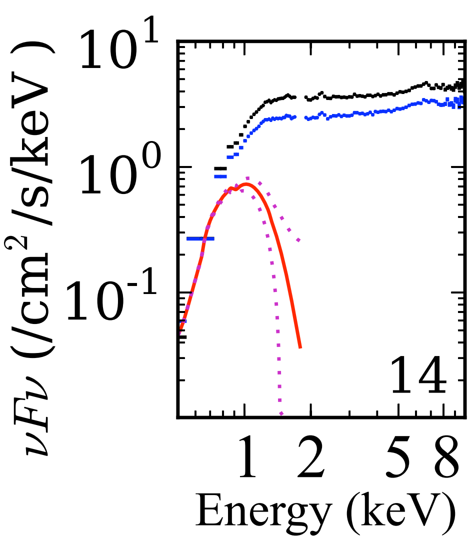

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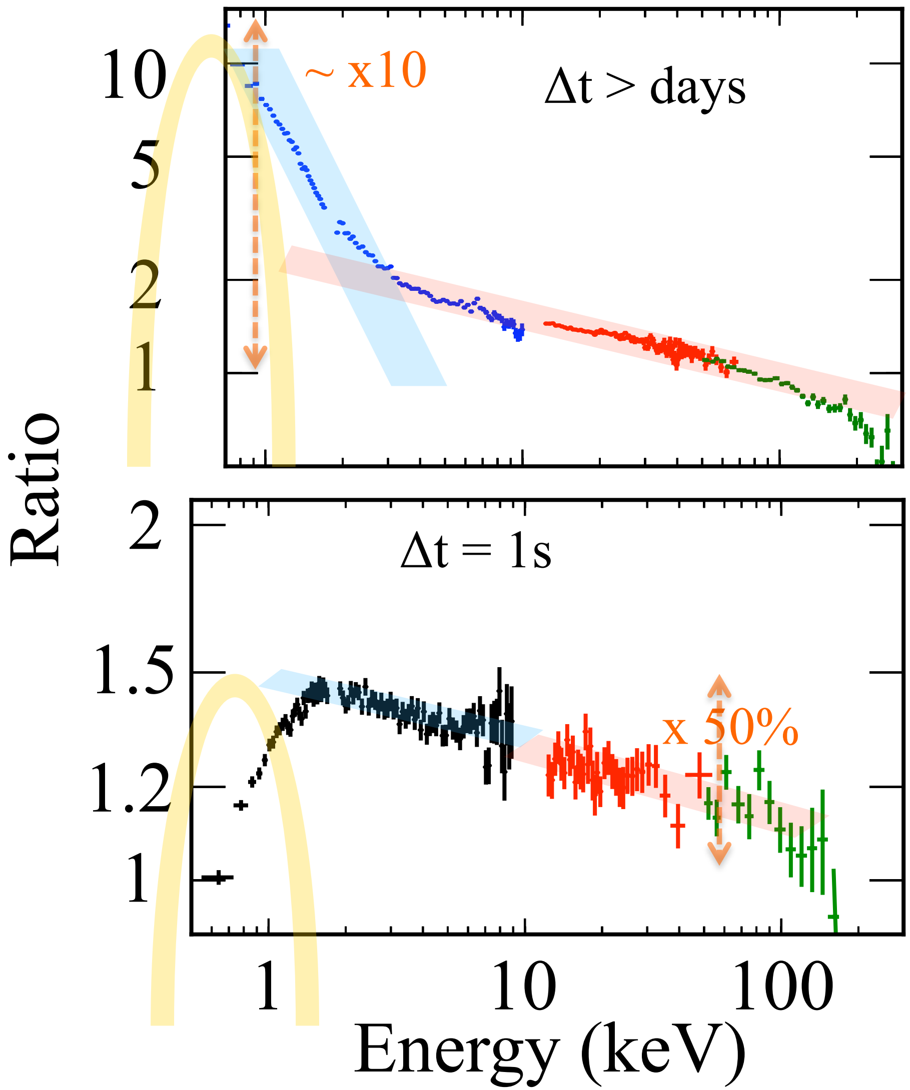

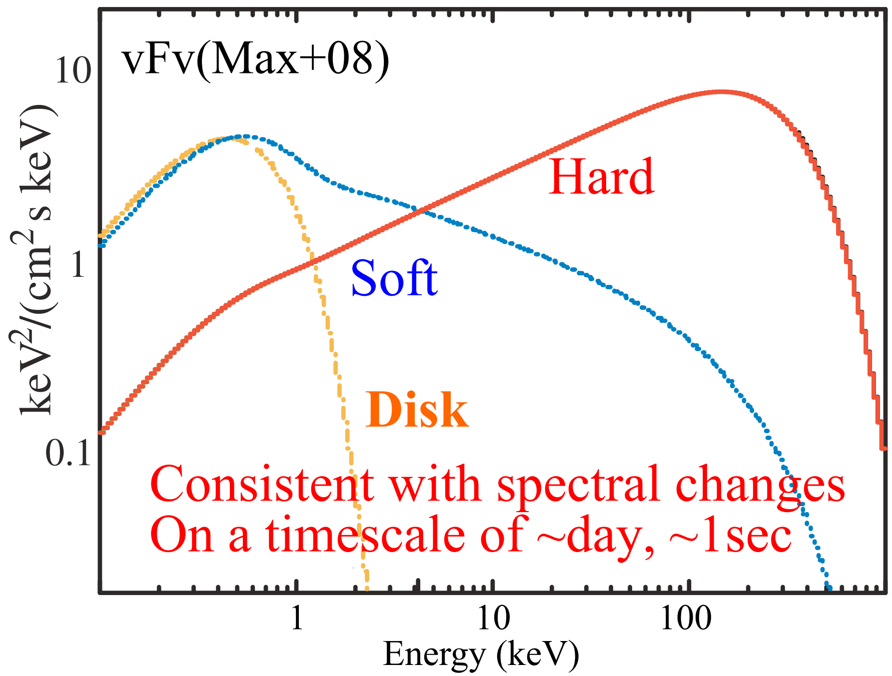

Assum.
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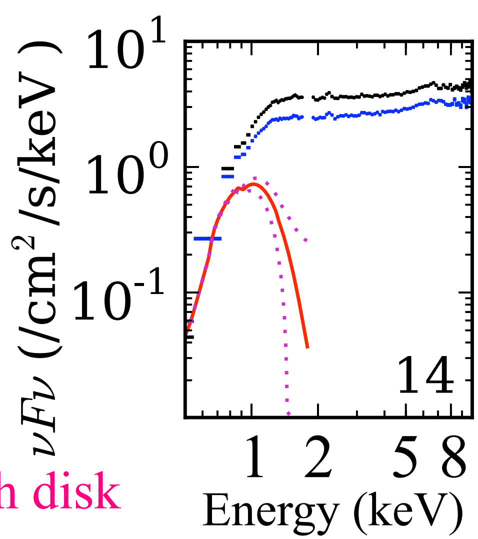
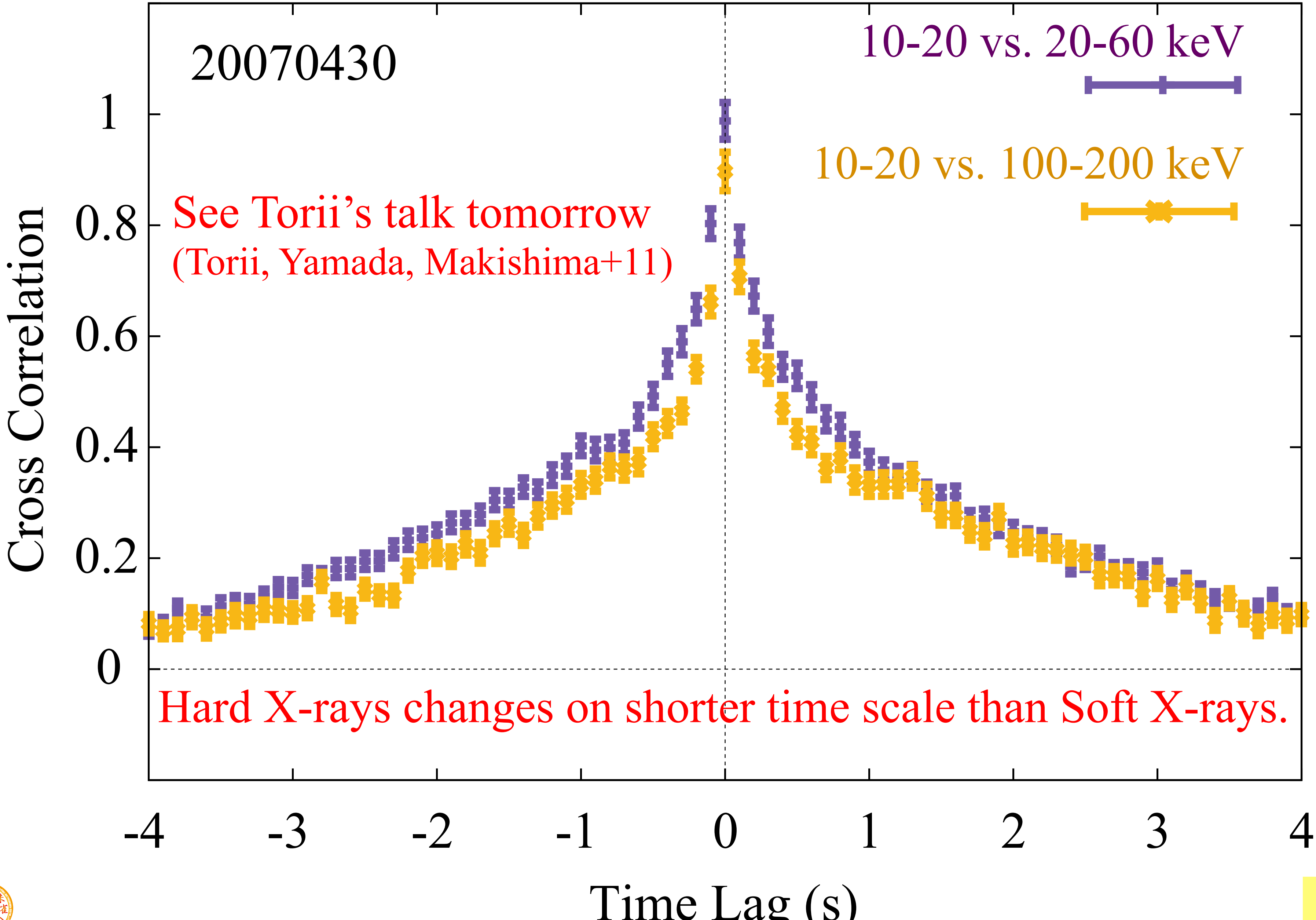


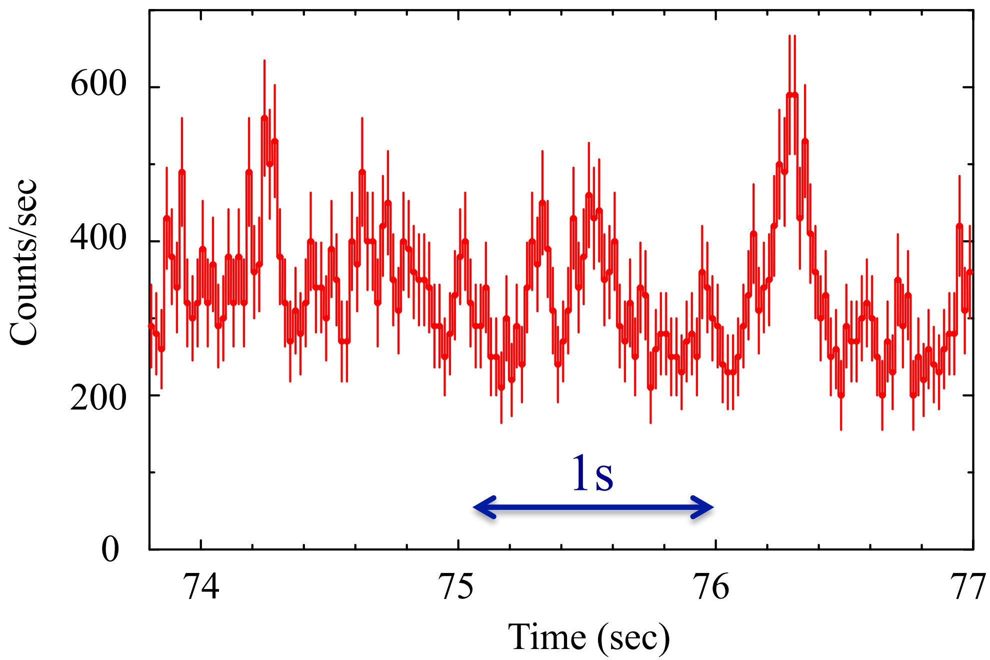
consistent with disk

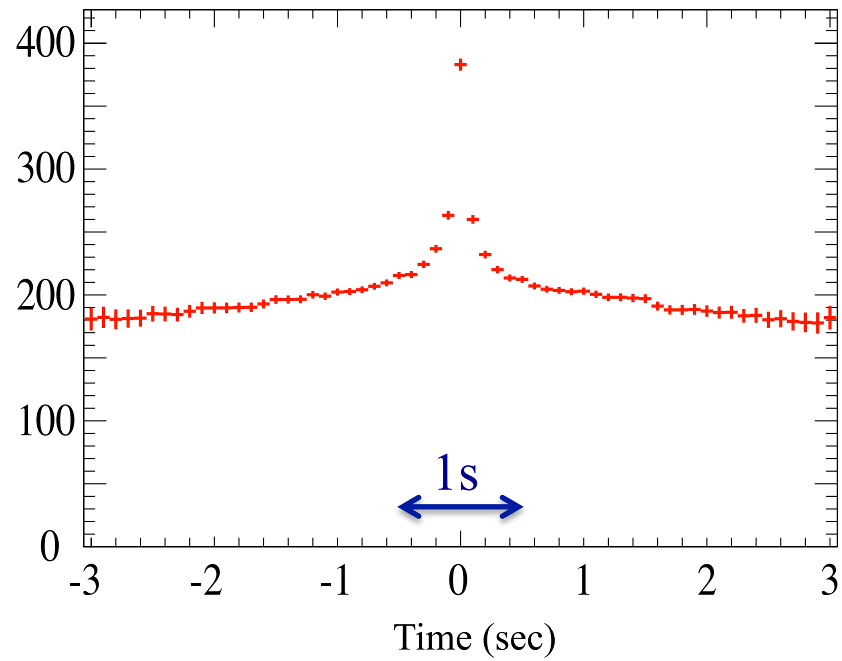
Cross.Cor. bet. 10-20 and 20-60, 100-200 keV



Applying "Shot analysis (Negoro+95)" into *Suzaku* data

- Folding lots of short flares "shot analysis" (Negoro+'95 w/ *GINGA*)

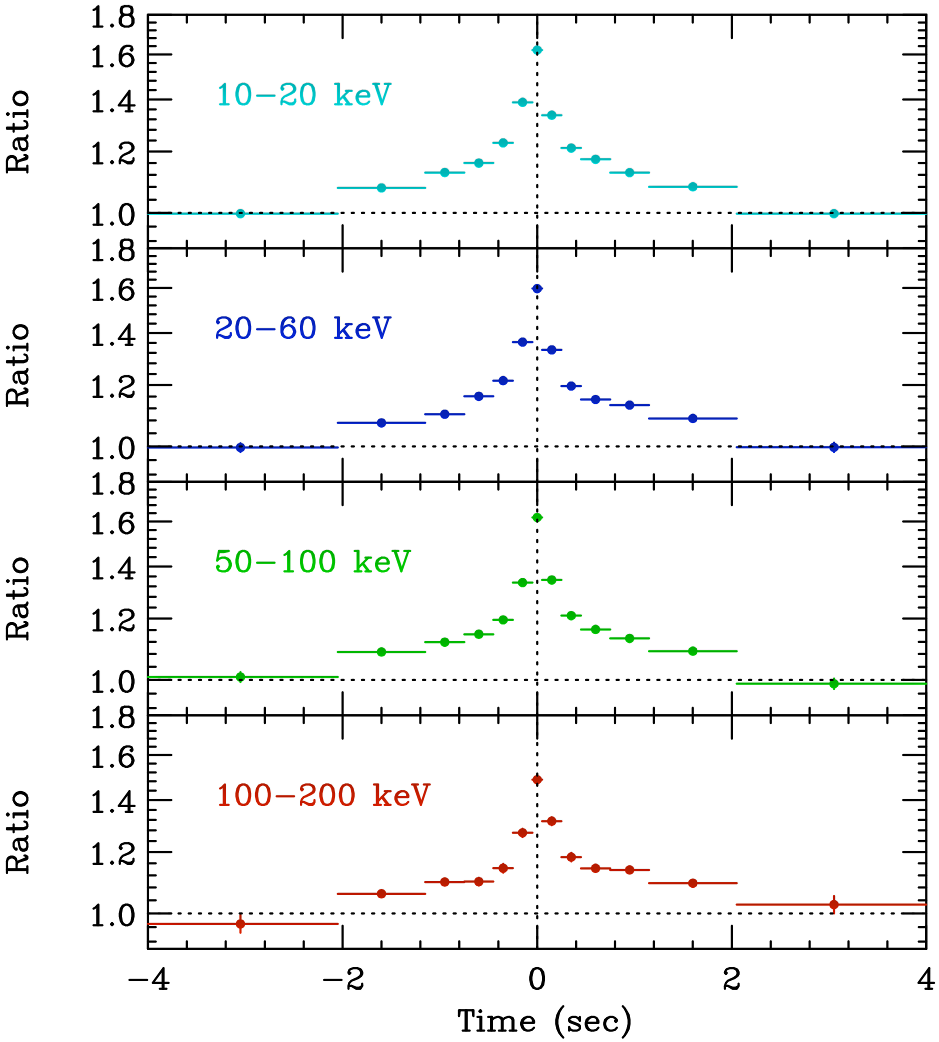




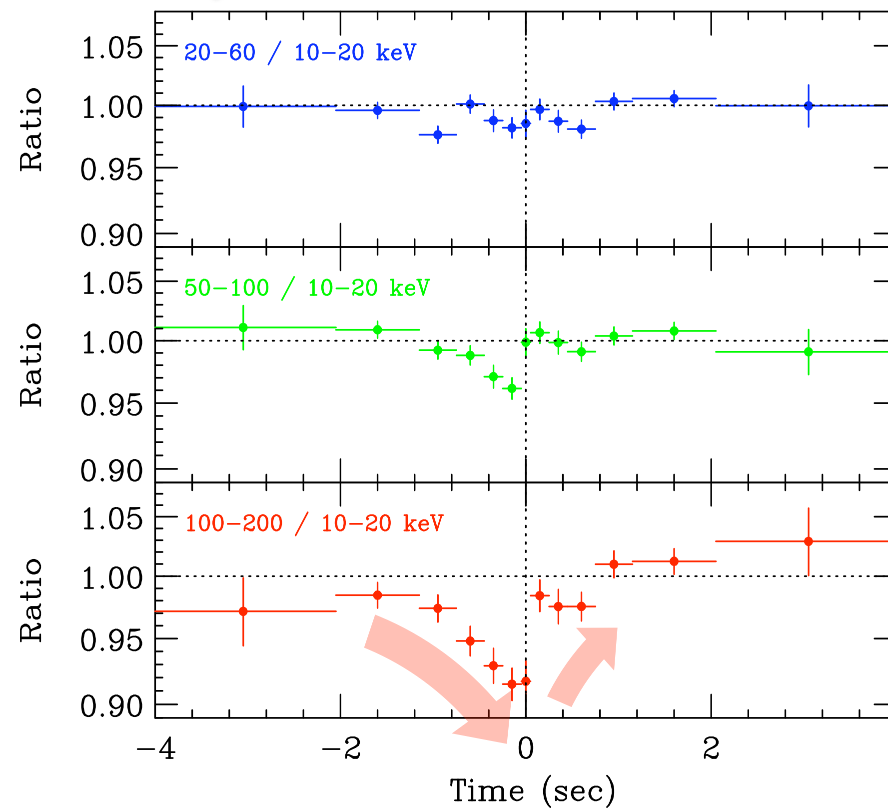
Lightcurve of P-sum of XIS (0.5-10 keV)

Shot Profiles

Applying “Shot analysis (Negoro+95)” into *Suzaku* data



- Ratio to 10-20 keV



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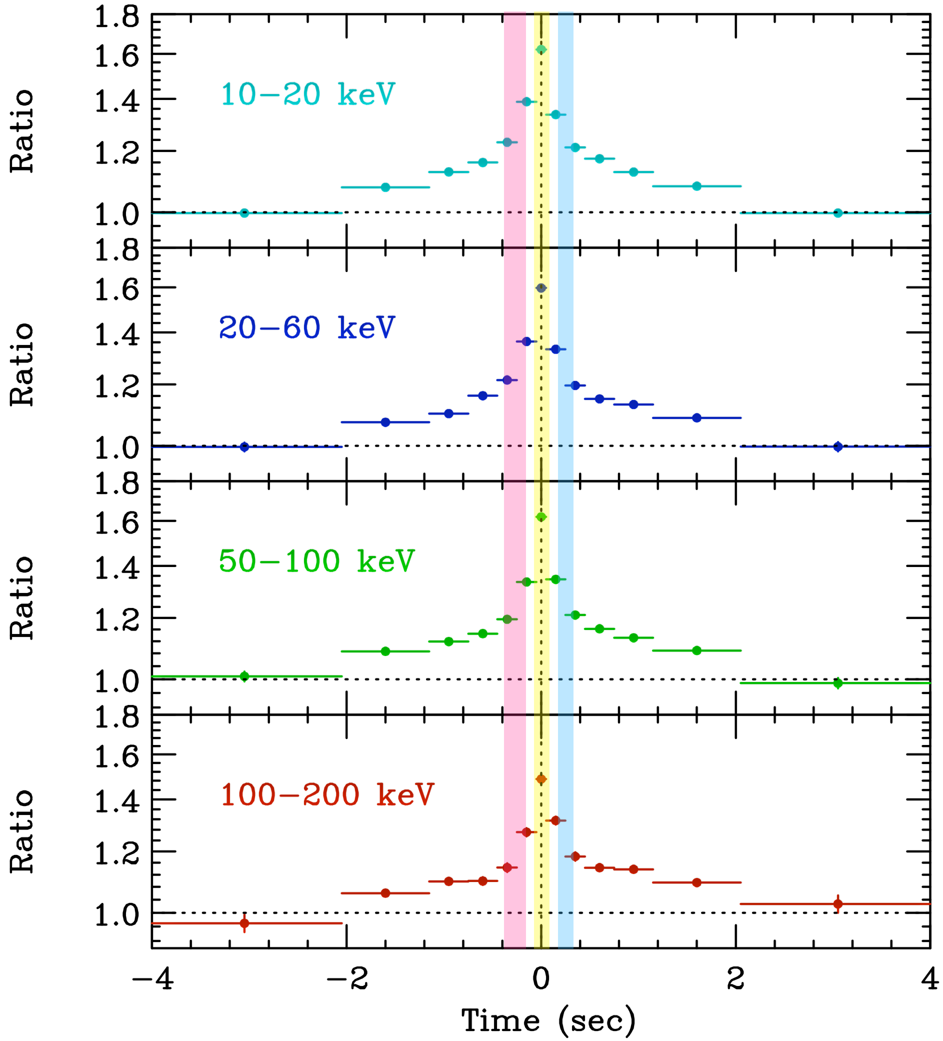
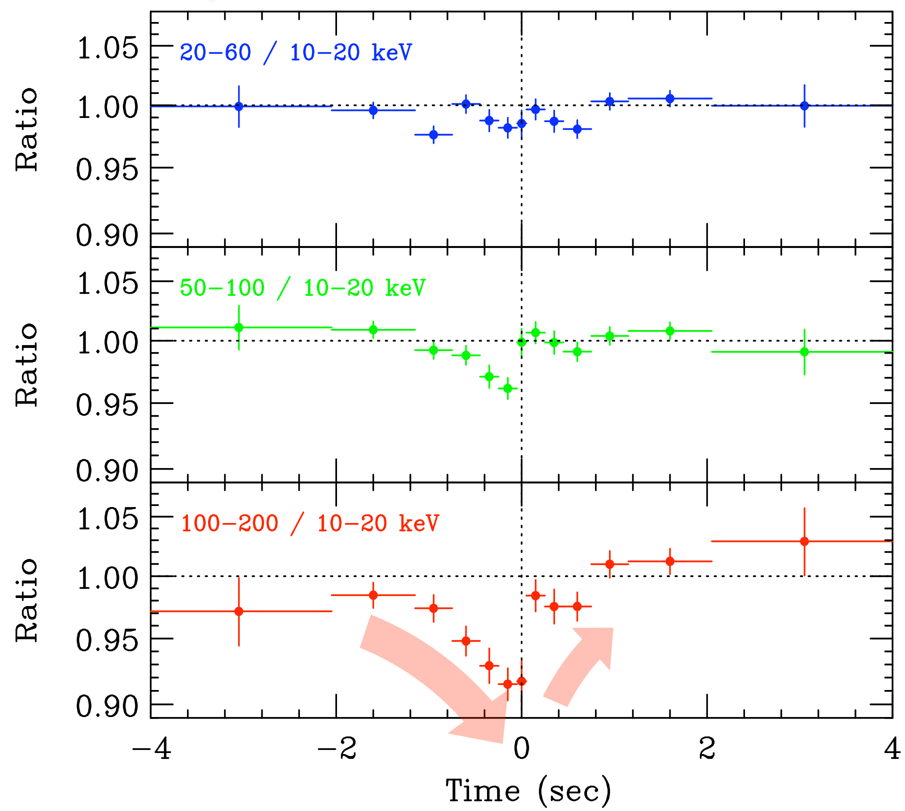
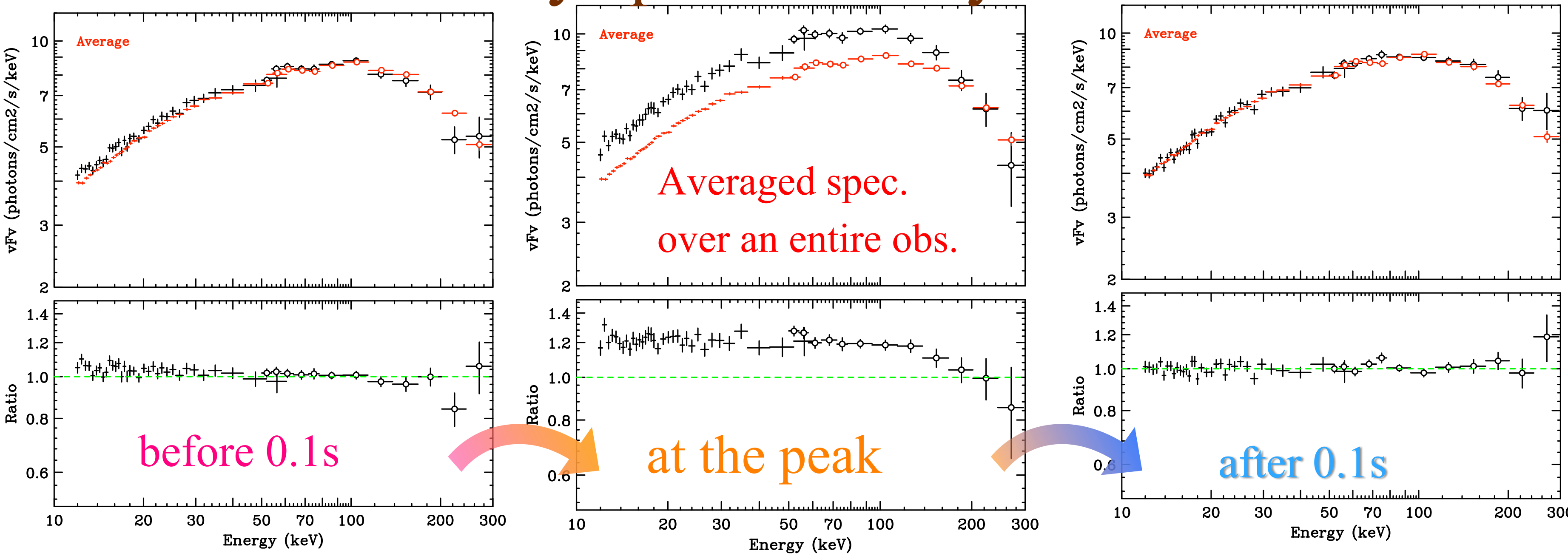


◆ Ratio to 10-20 keV



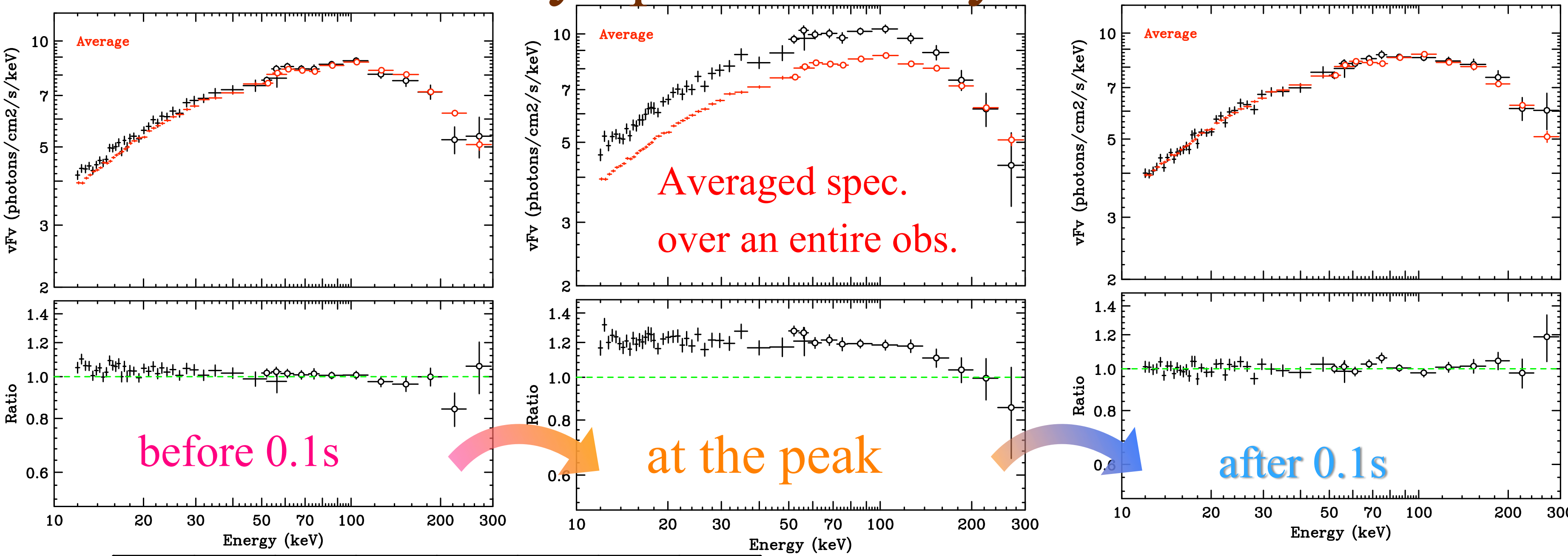
Hard X-ray spectral analysis in Δt < 4 s

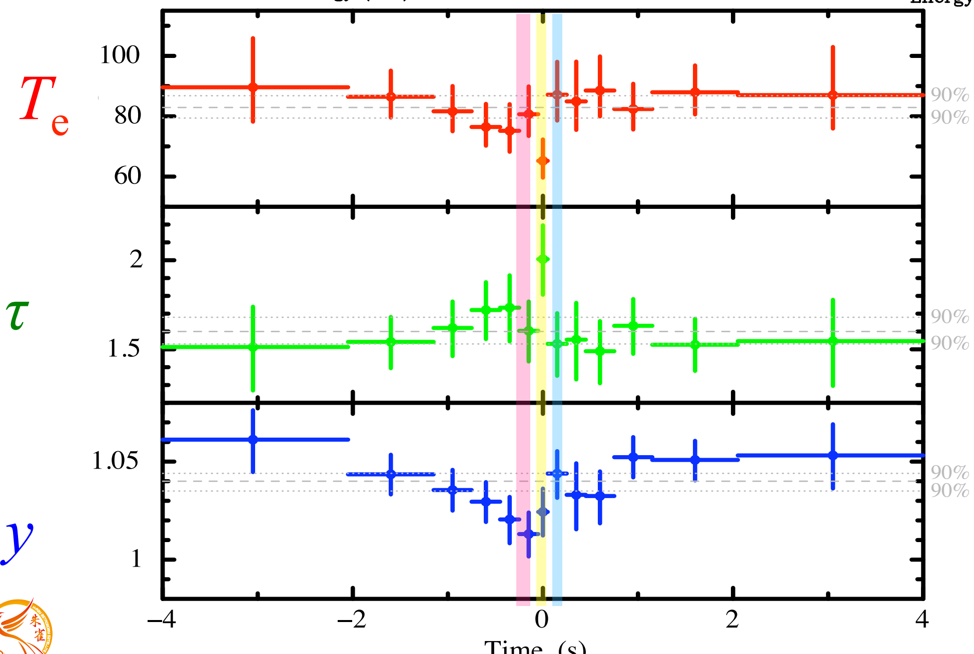


What the ratio shows

- Hollows over E > 100 keV
- Slightly softer as it gets brighter.

Hard X-ray spectral analysis in Δt < 4 s





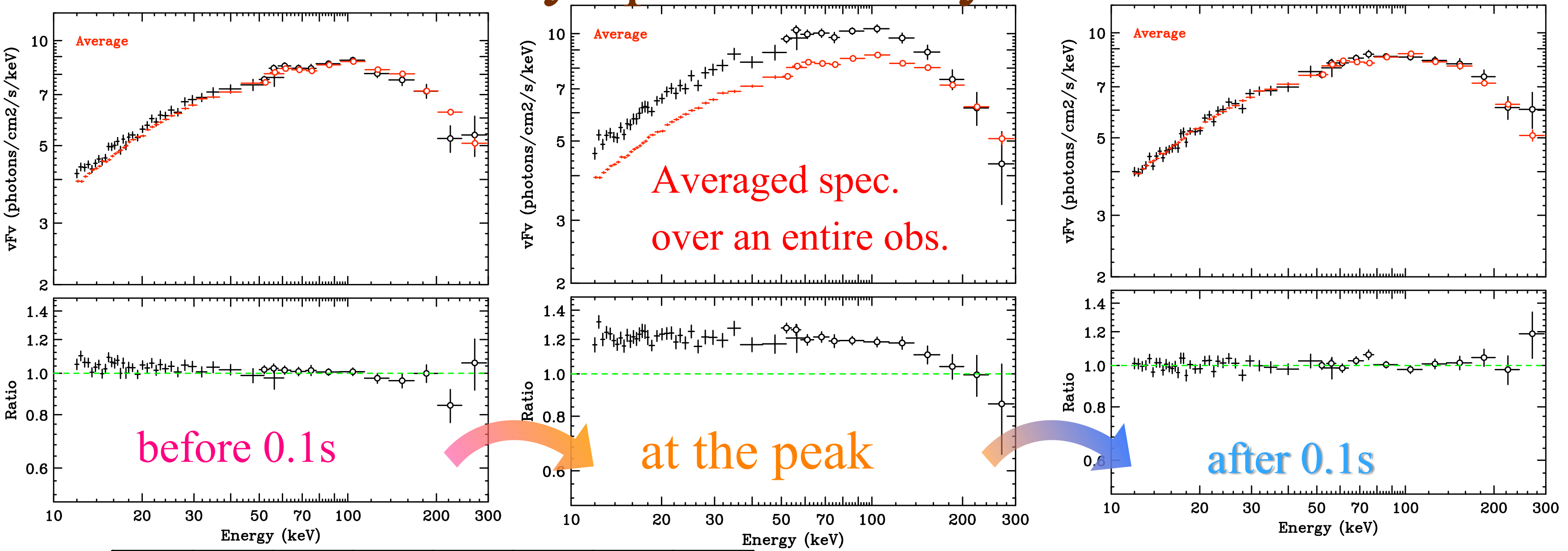
What the ratio shows

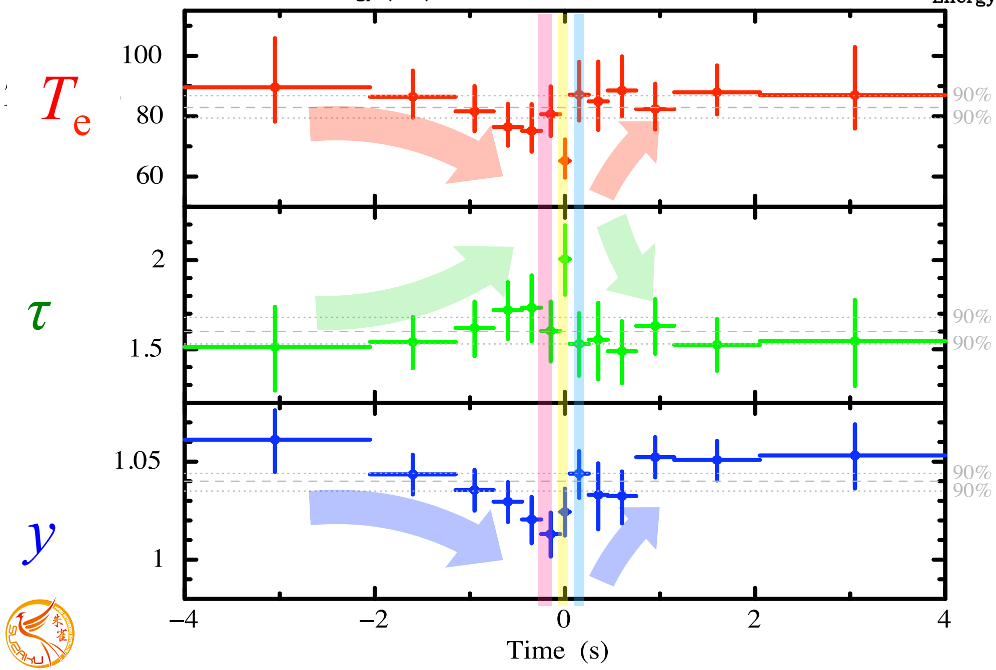
- Hollows over E > 100 keV
- Slightly softer as it gets brighter.

What the fits show

- *Te* decreases before the peak.
- Opt. depth. increases before the peak.
- Instantly recover after the peak.

Hard X-ray spectral analysis in $\Delta t < 4$ s





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- Hollows over E > 100 keV
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- Te decreases before the peak.
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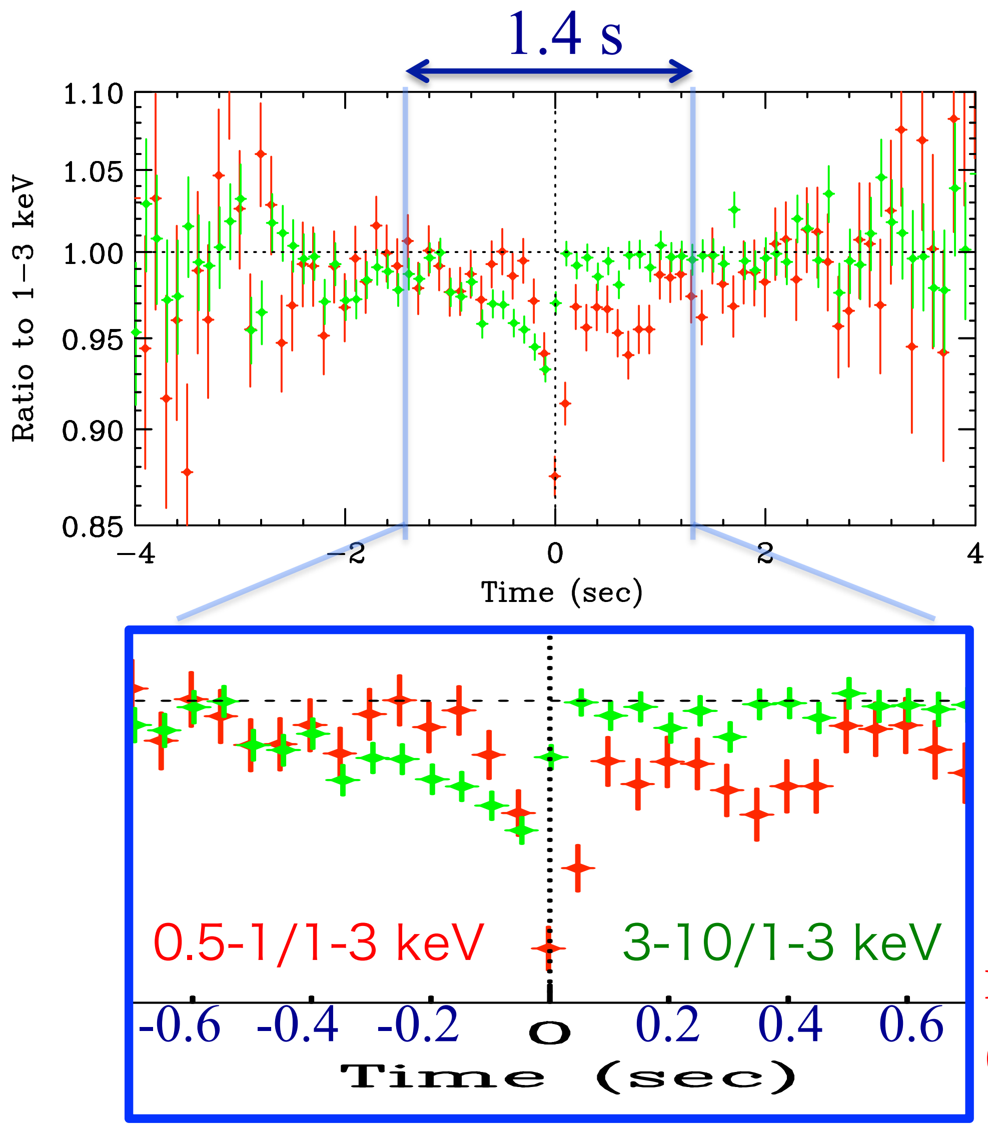
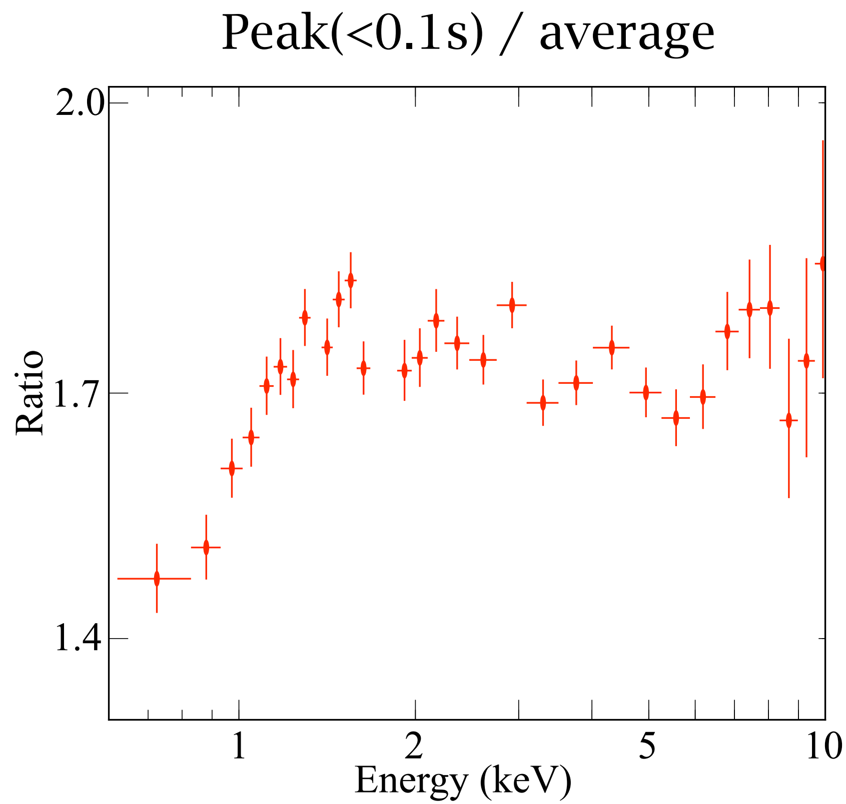
Shot Analysis from 0.5 to 10 keV

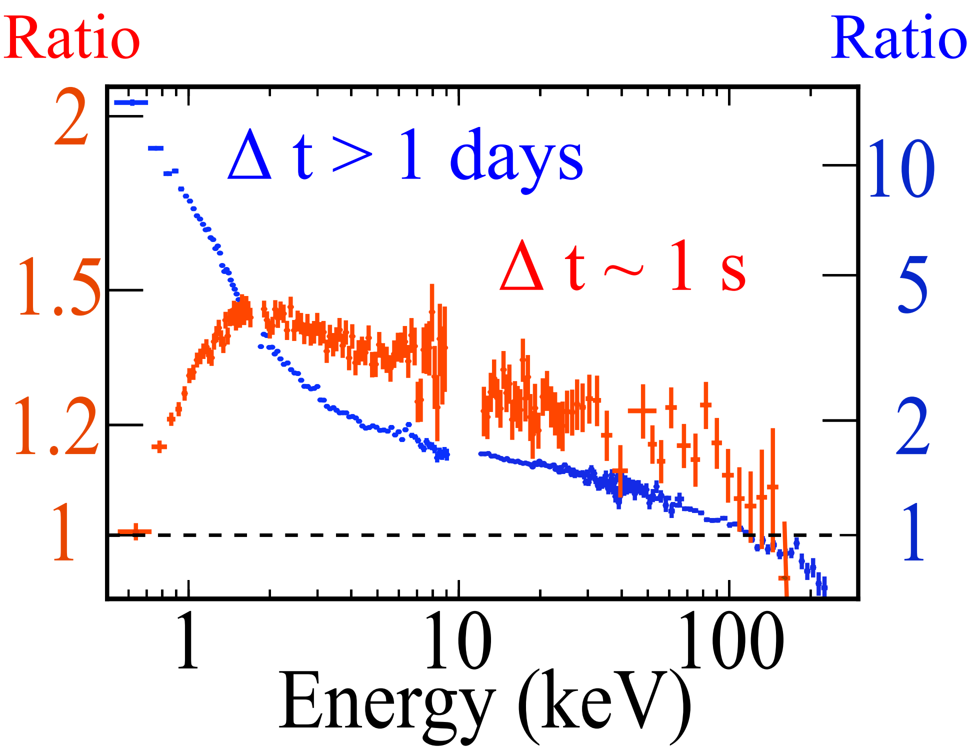


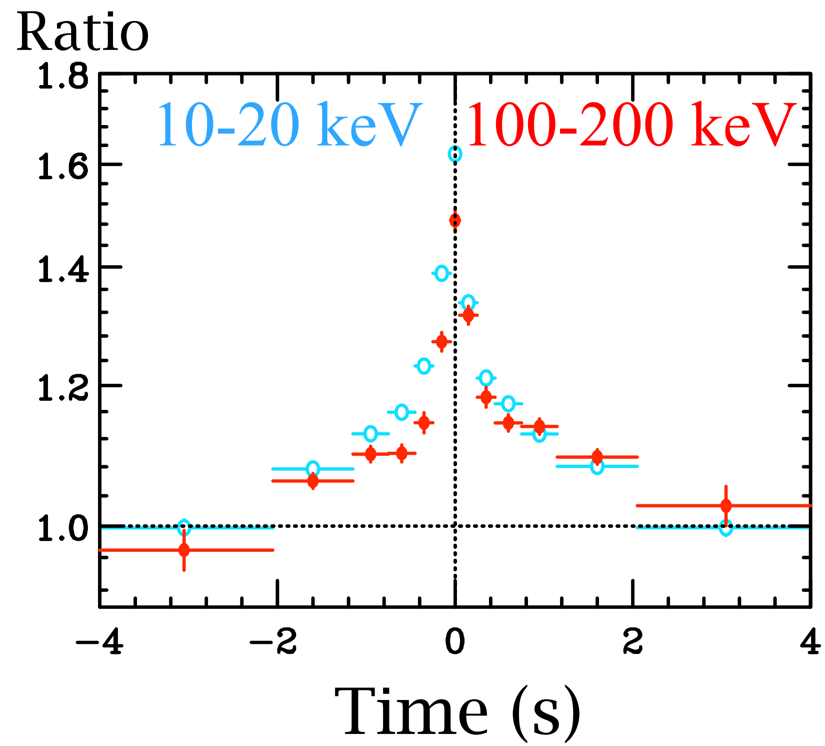


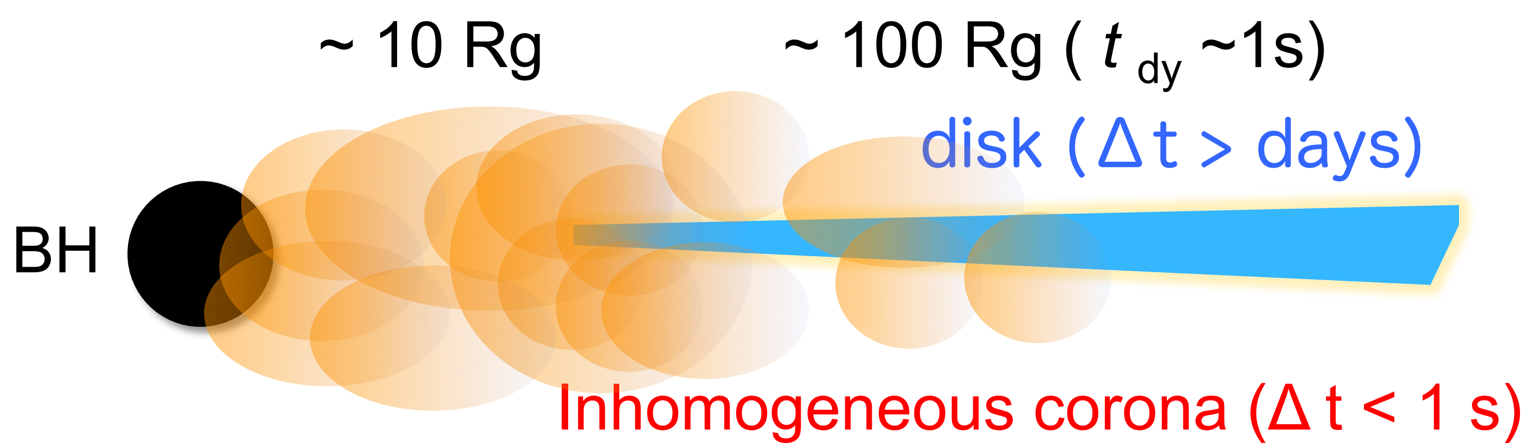
non-scattered disk emission exists.
(possibly)
seed photons provided by disk

First measurement of shot profiles of E ~ 0.5-1.0 keV

Short Summary and Possible Interpretation

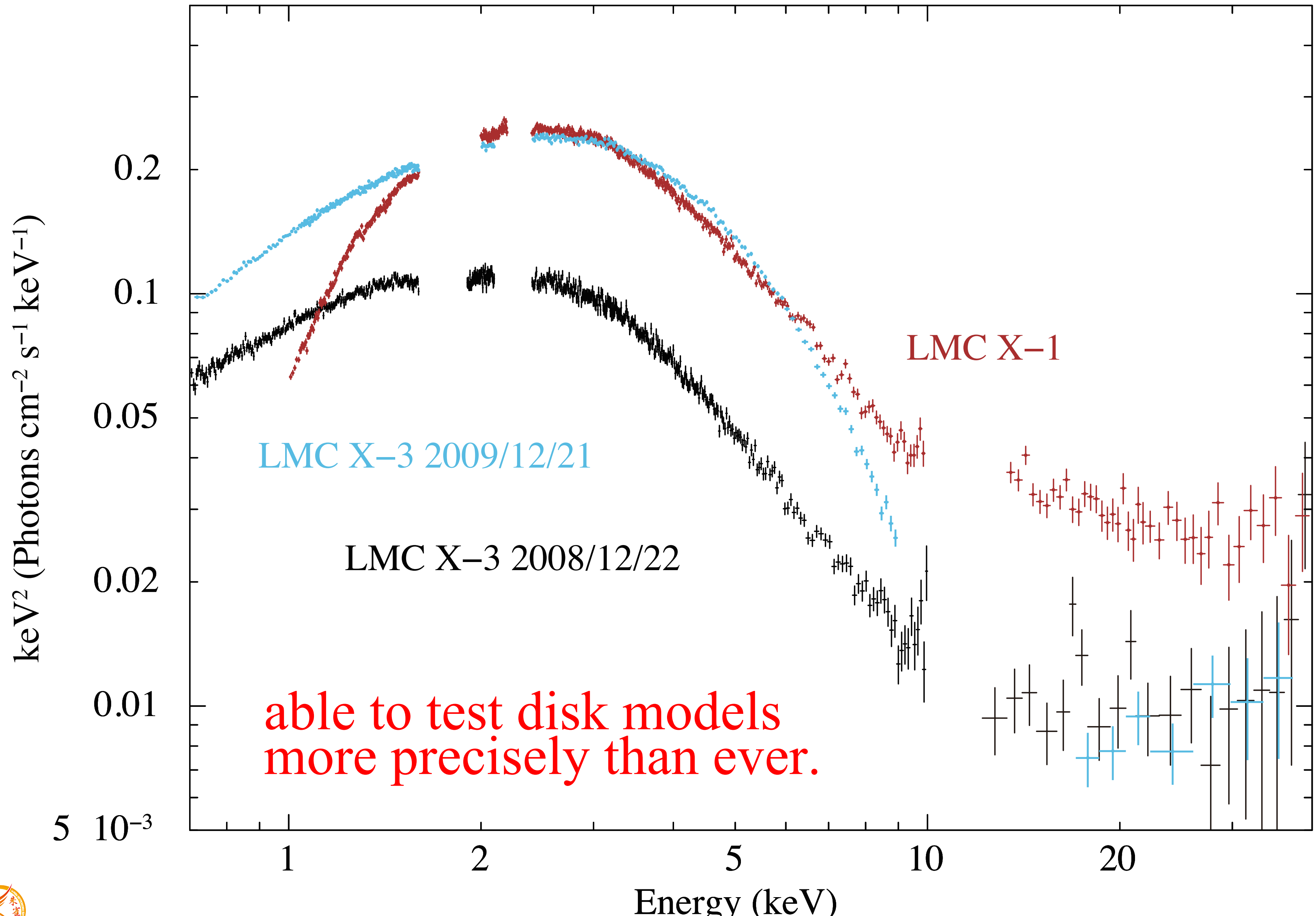




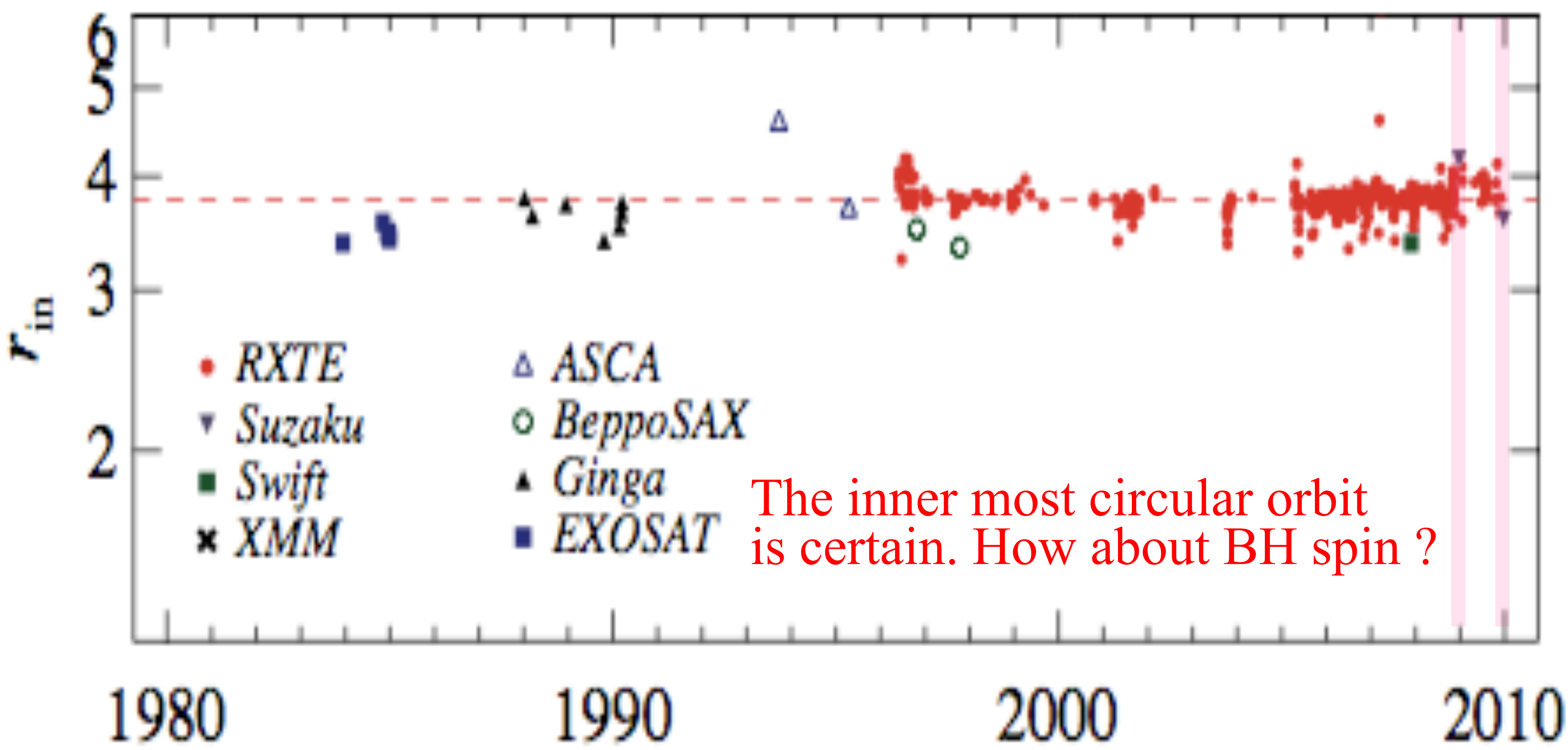


Other latest results from *Suzaku*

BHB spectra in High/Soft State with *Suzaku*

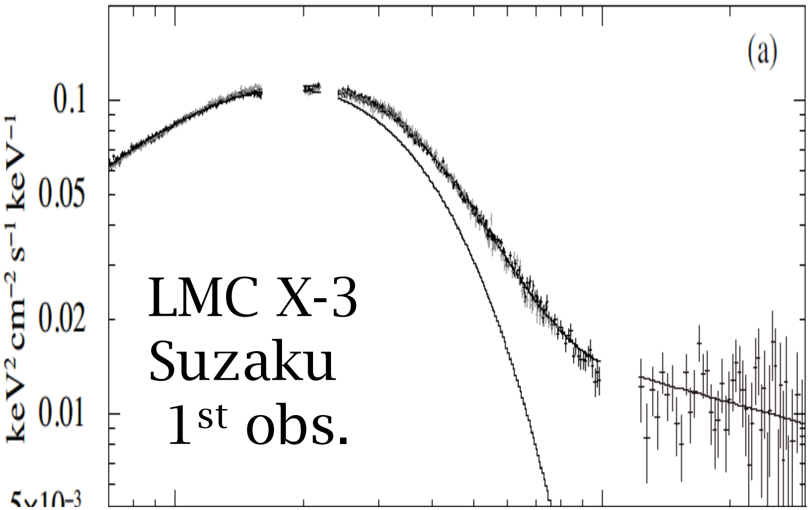


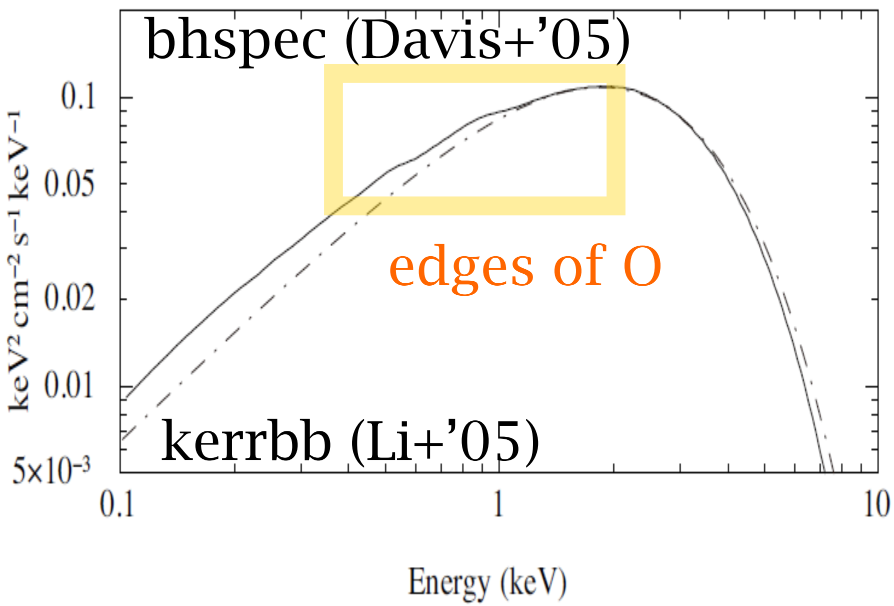
Constancy of the inner radius of LMC X-3

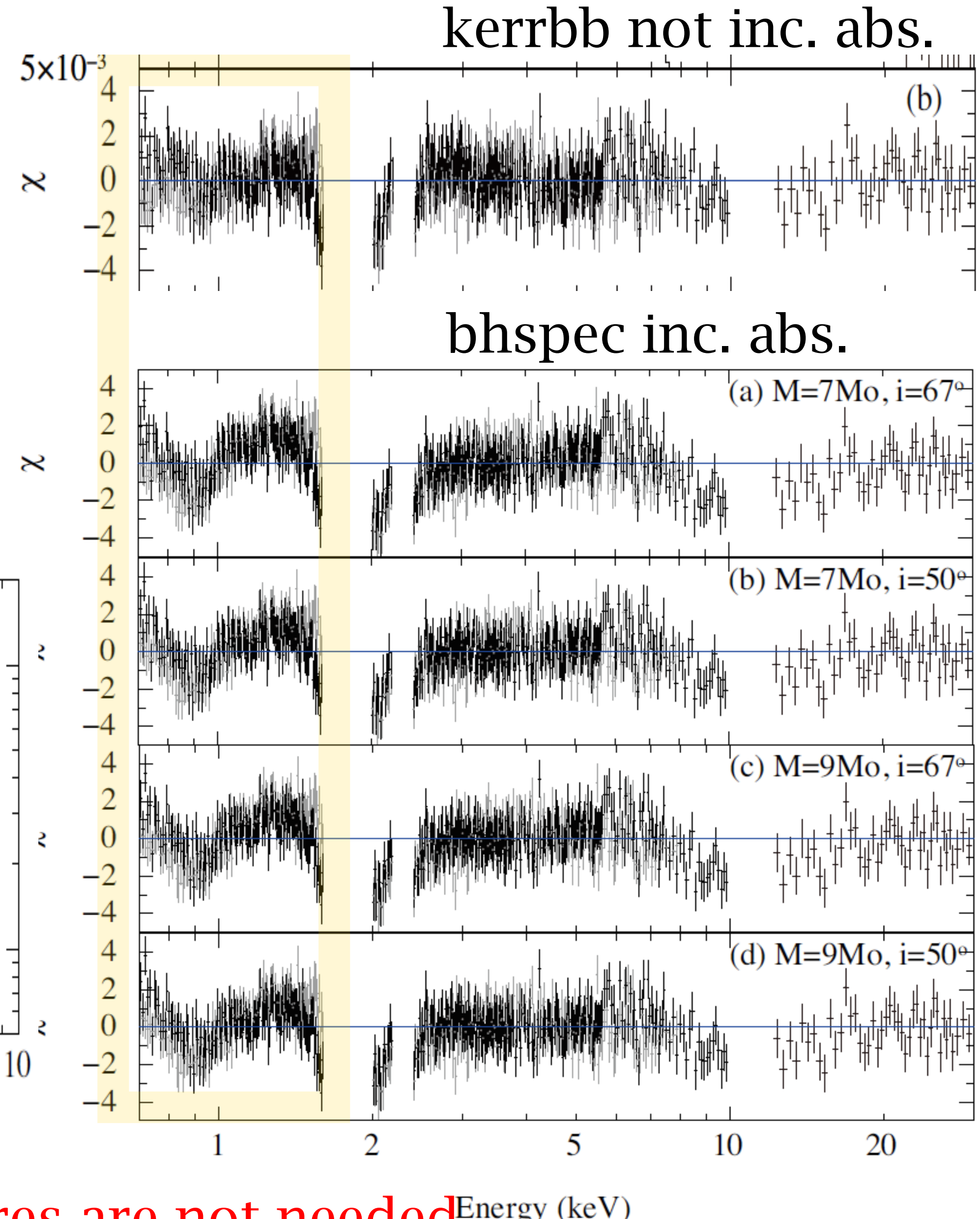


Steiner+ 2010
Jeff M., Narayan, Lijun, Ron. R., Yamada

Testing the latest disk model (Kubota+10)

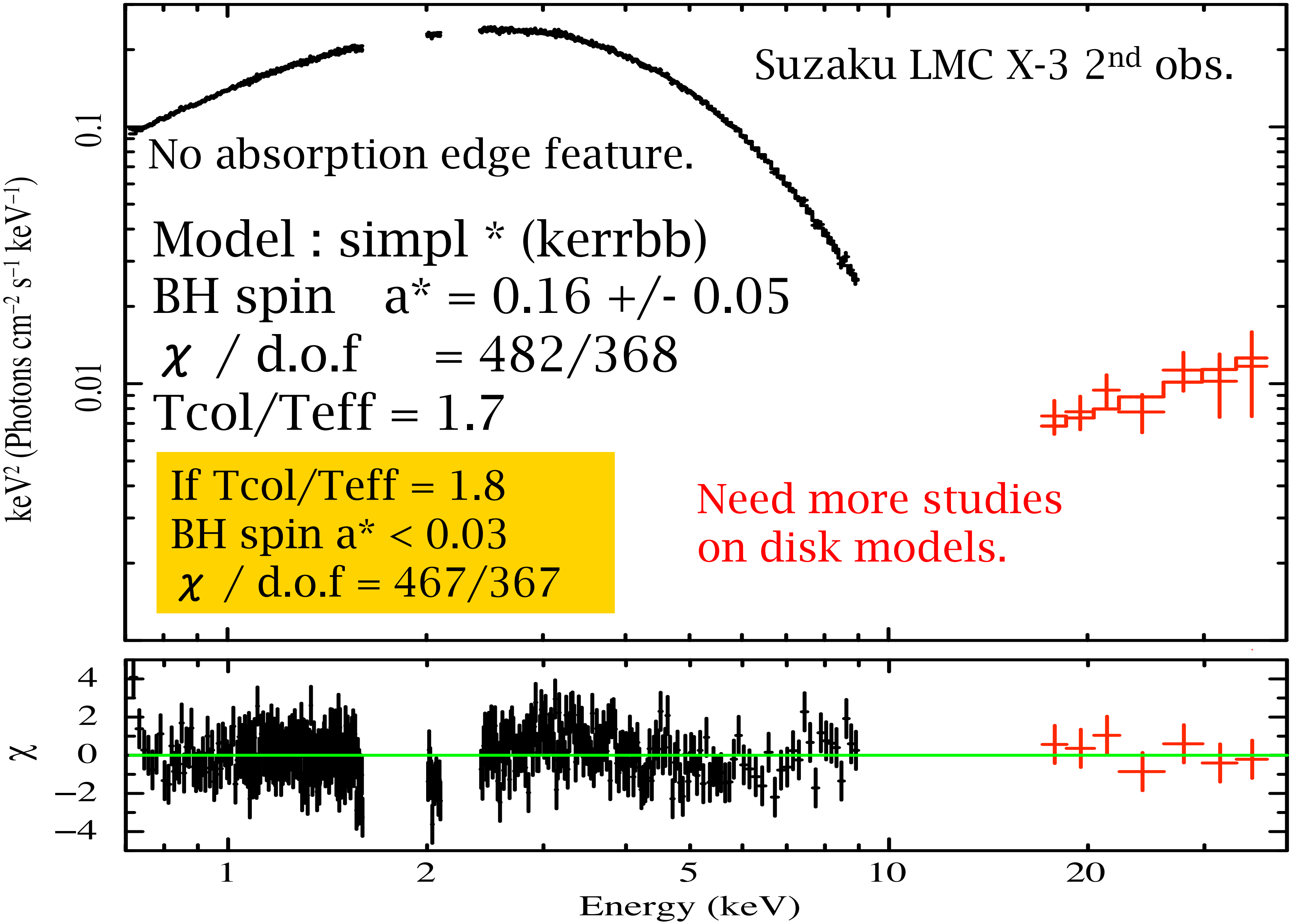






absorption edge features are not needed.

Is it possible to determine a BH spin ?

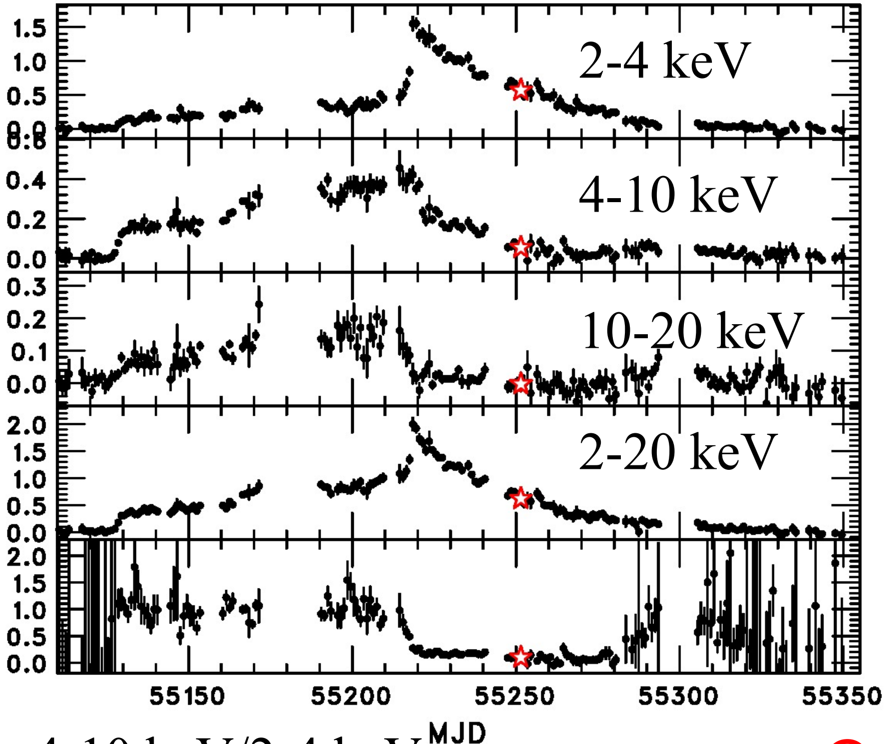


Collaboration between *MAXI* and *Suzaku*

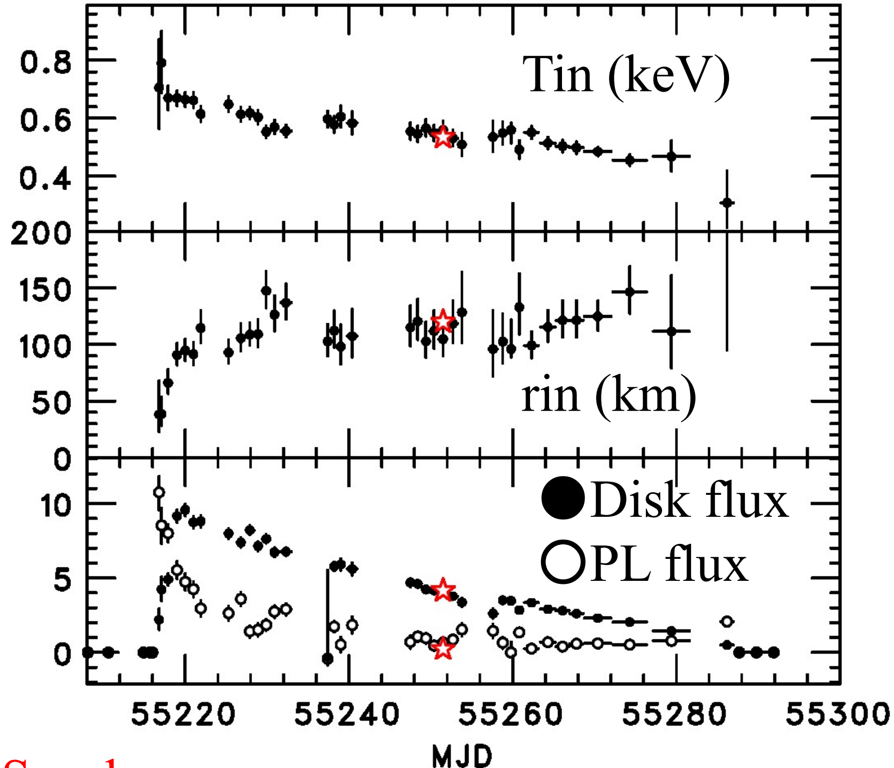
MAXI successfully observed the whole outburst of XTE J1752-223

A entire burst for ~8 months

MAXI can trace evolution of Tin, Rin
Rin is constant at ~116 km.

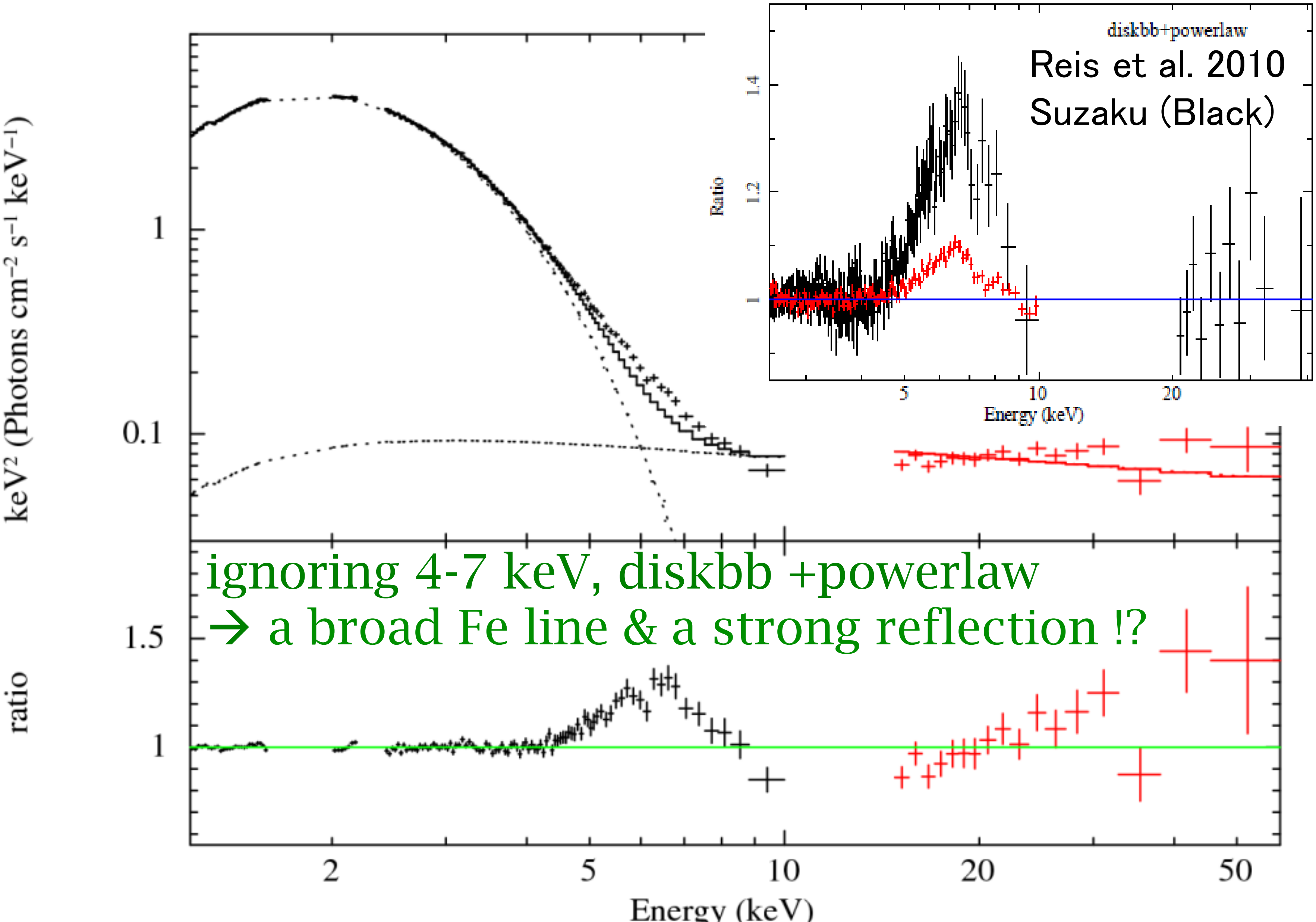


4-10 keV/2-4 keV



○ Suzaku

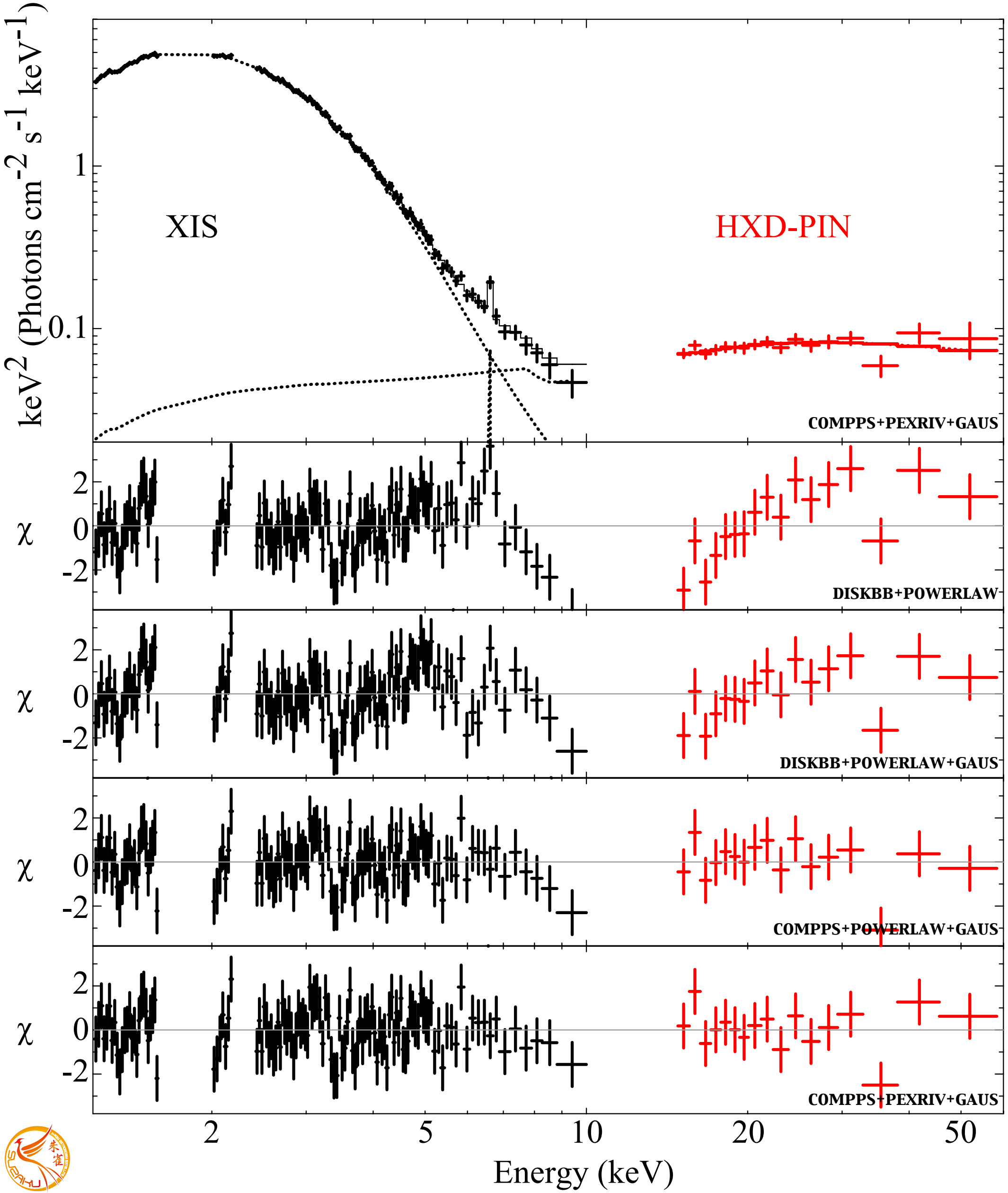
Suzaku results on XTE J1752-223



ignoring 4-7 keV, diskbb +powerlaw

→ a broad Fe line & a strong reflection !?

Suzaku results on XTE J1752-223



A weakly Comptonized disk reproduces the data (131.4/133) w/o a broad Fe-line.

Nakahira, Koyama, Yamaoka 2011, submitted

diskbb+powerlaw

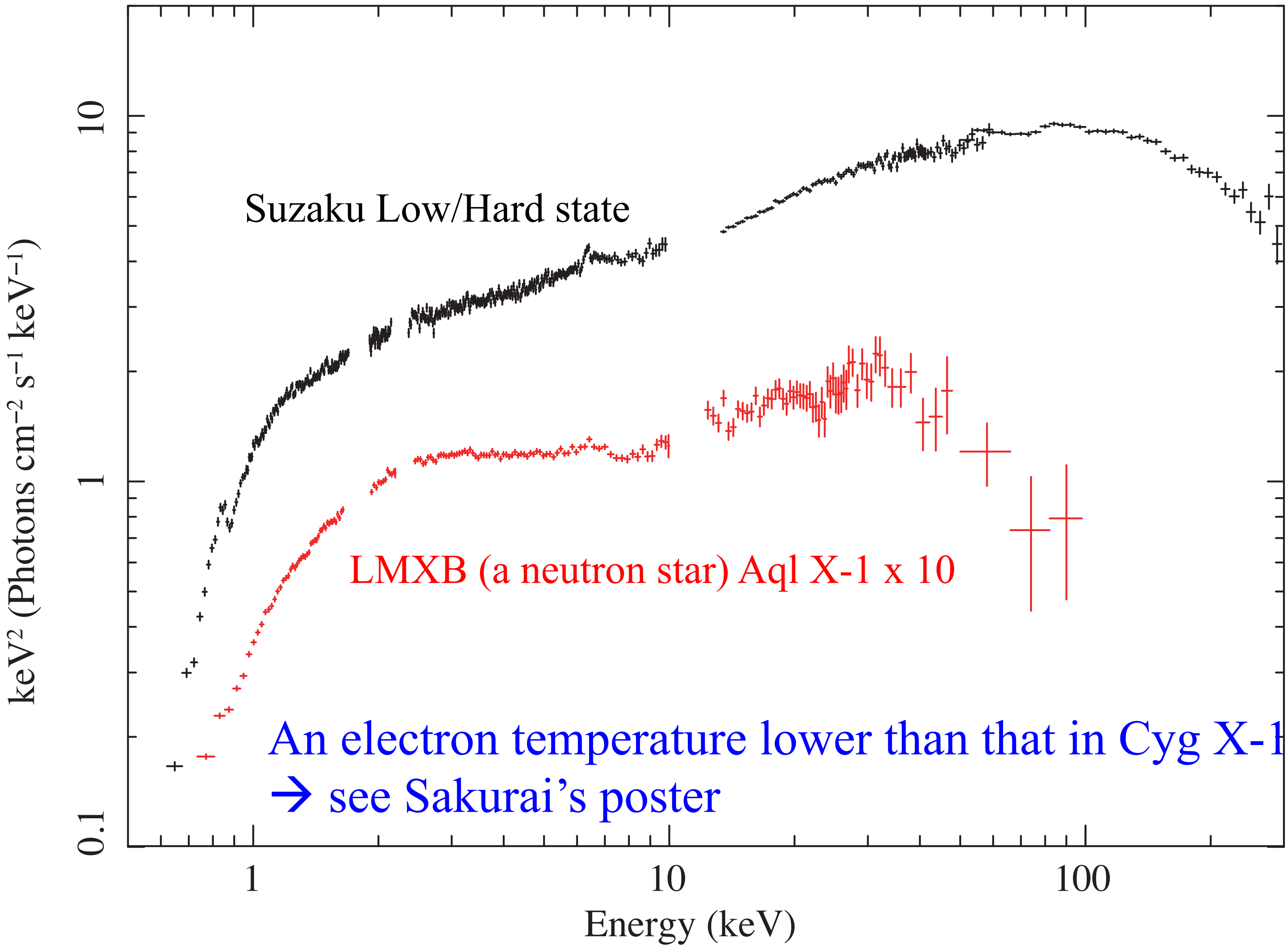
diskbb+powerlaw+gauss

compps+powerlaw+gauss

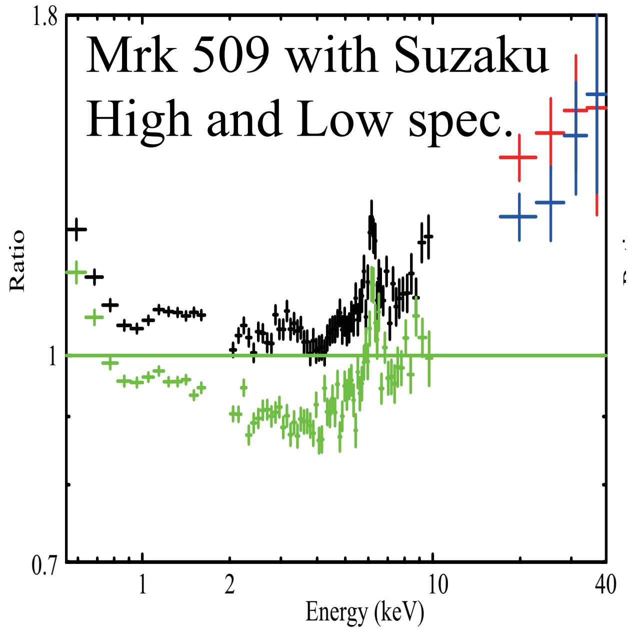
compps+pexriv+gauss

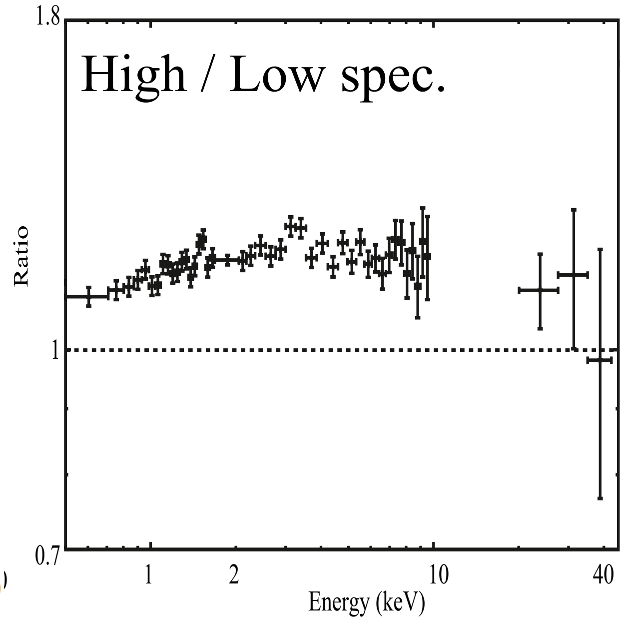
$\tau \sim 0.2$, Te ~ 10 keV

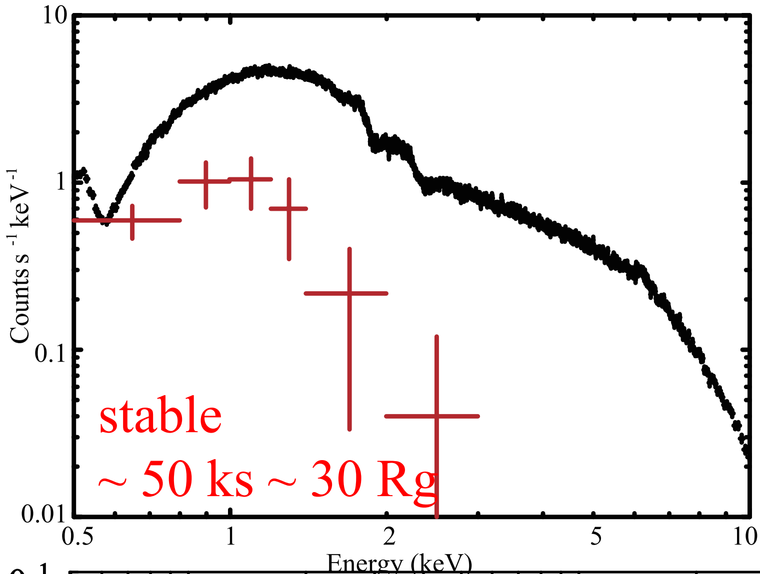
Comparison bet. BHB and a Neutron star

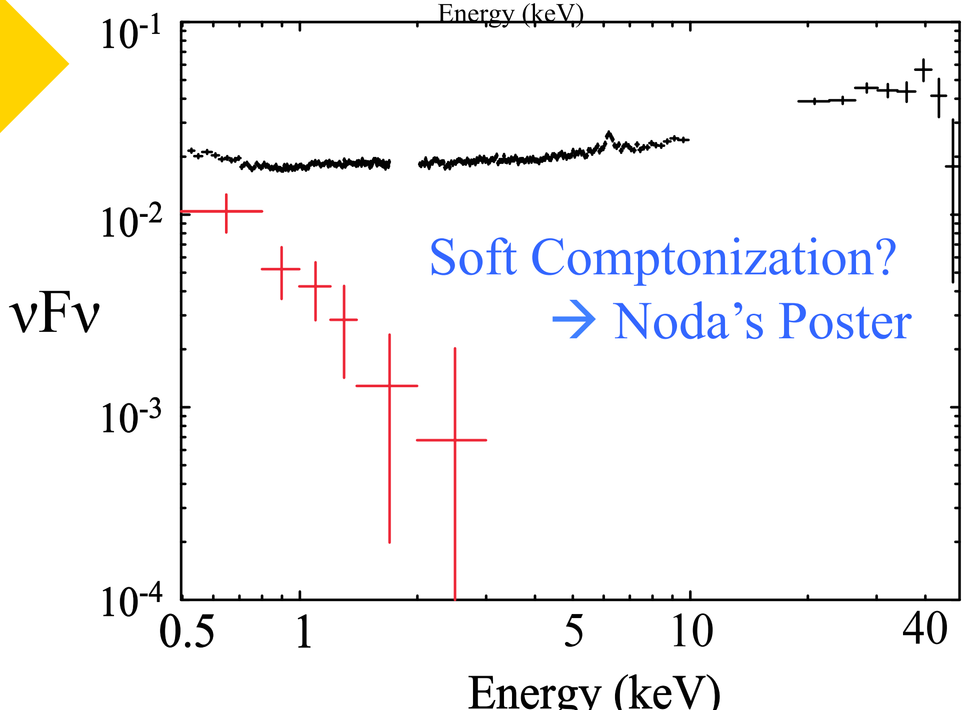


Application of Intensity-sorted ana. into AGN









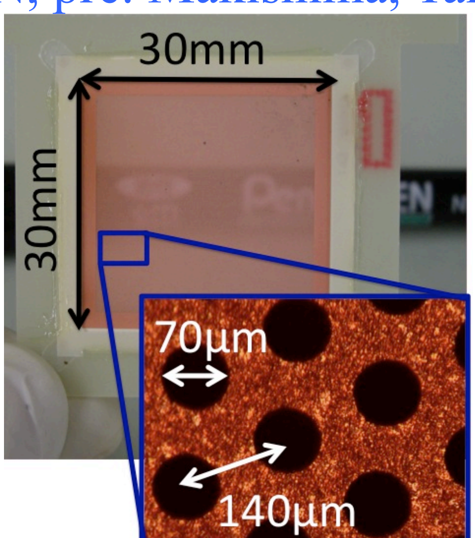
Summary

- The decomposition of disk + hard Compton + soft Compton, is consistent with the spectral variability.
- As Cyg X-1 gets brighter within 1s, the spectral cutoff at ~ 100 keV decreases, return to the average in shorter than ~0.1 s after the peak.
- Disk models and its relation to powerlaw should be more studied.
- Suzaku have been revealing more on continuum and its variability for neutron stars and AGNs, as well as black hole binaries.

Future Prospects

Polarization GEMS 2014~

Gas Electron Multiplier (GEM) developed by RIKEN, pre. Makishima, Tamagawa group



Astro-H 2014~