New Observational Insights into the Low/Hard state of Cygnus X-1 with *Suzaku*

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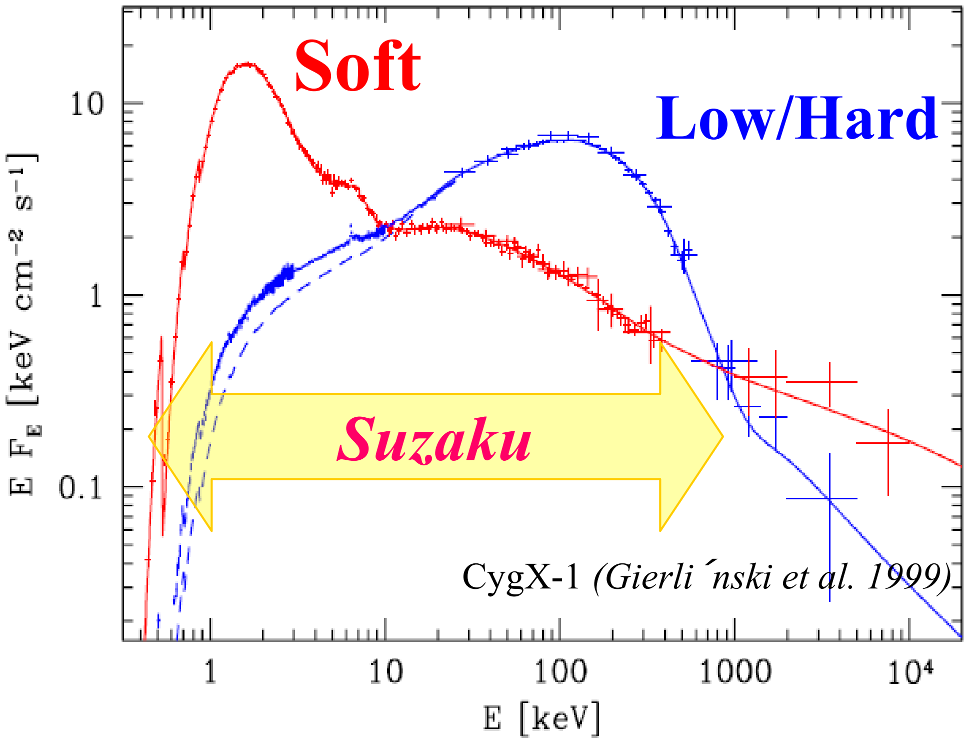
XMM-Newton: The X-ray Universe 2008, Granada

Makishima et al. astro-ph 0801.3315v1, PASJ 60, in *press* (2008)

Low/Hard state Black-Hole Binaries



Soft state

- Optically thick and geometrically thin accretion disk
- Multi-color blackbody, ~ 1 keV

Low/Hard state

- Opt. thin and geom. thick disk
- Thermal Compton cloud with Te ~ 100 keV
- Intense time variability

Size/Shape of the Compton cloud ? Seed photons?

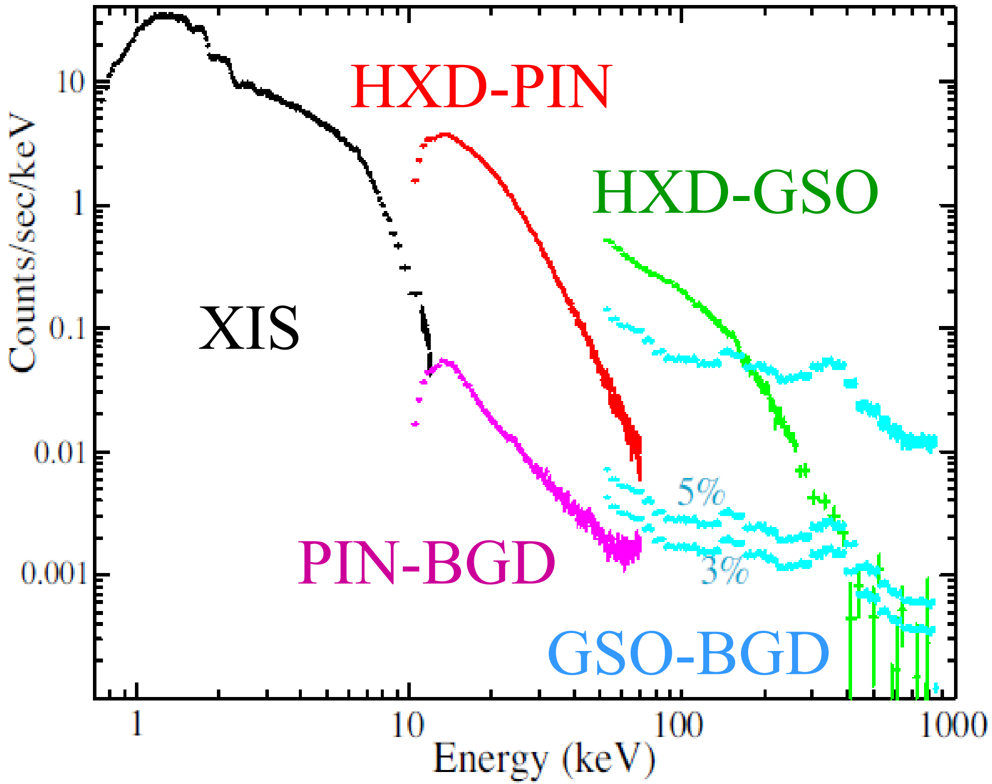
The nature of the fast variation ?

Wide-band Spectroscopy – detailed Comptonization modeling

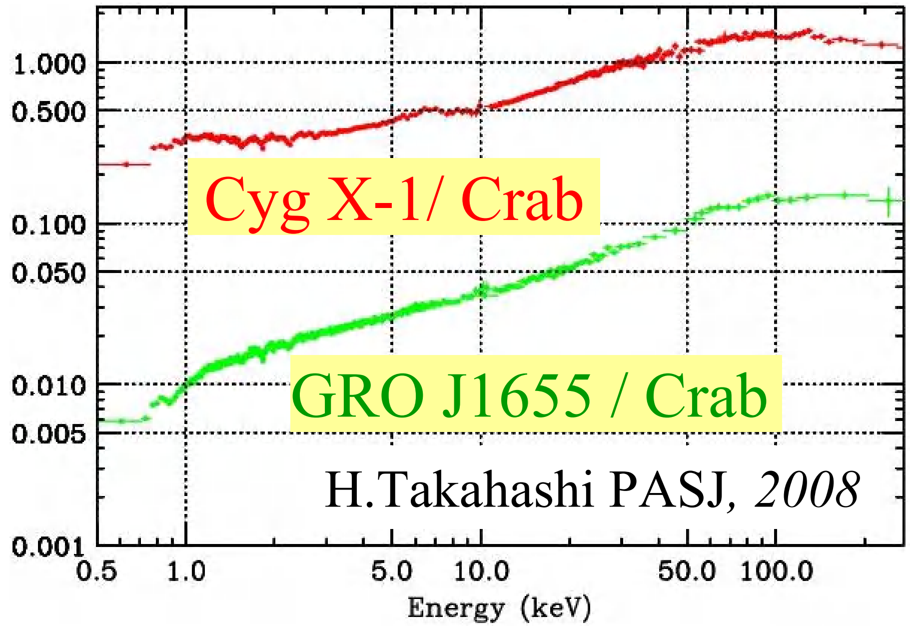
Intensity-sorted Spectroscopy -- fast changes of Comptonization

Suzaku Observation of Cygnus X-1

- Cygnus X-1
  $D \sim 2.5$ kpc, $i \sim 45$deg. $M \sim 15\ M_{\odot}$
  70% Low/Hard state
- Wide-band spectra with *Suzaku*

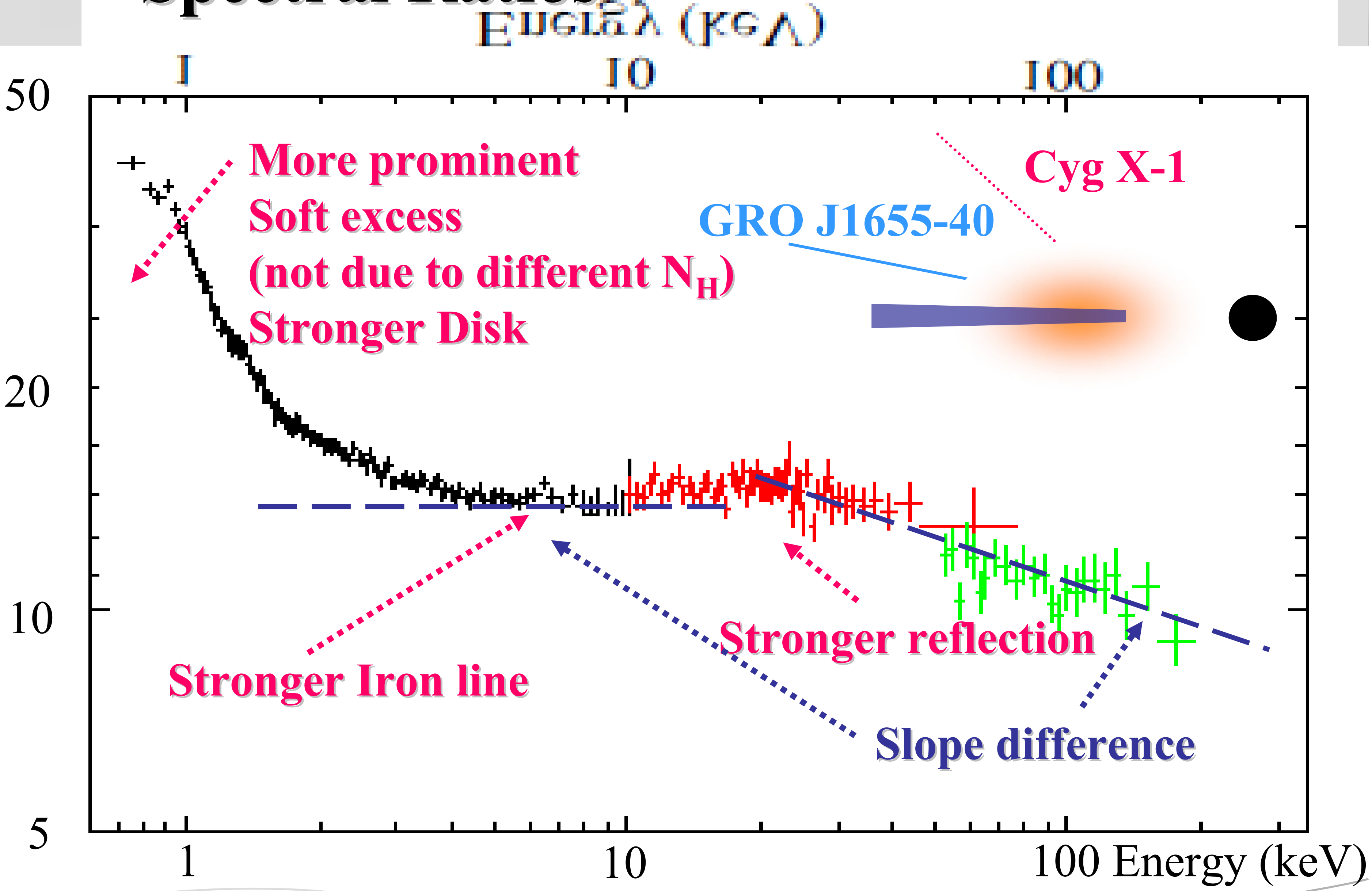


- *Suzaku* Observation
  Oct 5th, 2005 (17 ks)
  Low/Hard state
  4.7×10^{37} erg/s (2.5 kpc)
- Crab ratios



Spectral Ratios

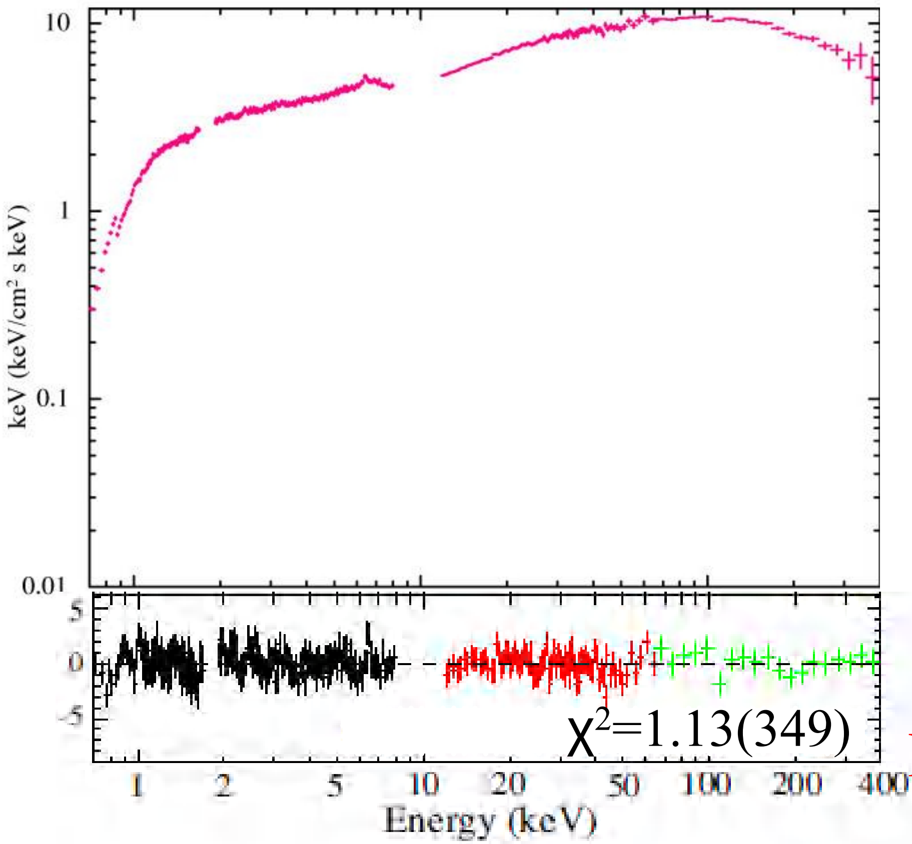
Cyg X-1



Broad-band Spectrum Modeling of Cygnus X-1

Simultaneous fitting "Double-Comptonization" (Frontera + 2001)

νFν spectrum of Cygnus X-1



- Thermal Compton (xspec *comp*PS)
  - Hard optical depth ~ 1.5
  - Soft opt. dep. ~ 0.4

  T_e ~ 100 keV, R_{seed} ~ 210 km
- Directly visible cool disk
  - T_{in} ~ 0.2 keV, R_{in} ~ 250 km

The disk is truncated at $\sqrt{R_{seed}^2 + R_{in}^2} \sim 15\ R_g$

- Weakly broadened Iron line
  - E_C 6.3 keV, EW 290 eV
  - Sigma ~ 1 keV

No "relativistic diskline" is needed.

- Reflection from the disk
  - Omega / 2π ~ 0.4

The Model reproduces the spectra of both Cyg X-1 and GRO J1655.

Best-fit Model for Cygnus X-1 with GRO J1655-40

νFν model spectrum removing N_H

- **Double-Comptonization**

Hard Compton

Soft Compton

Disk (T_{in} ~ 0.2 keV)

Weakly broadened Fe line

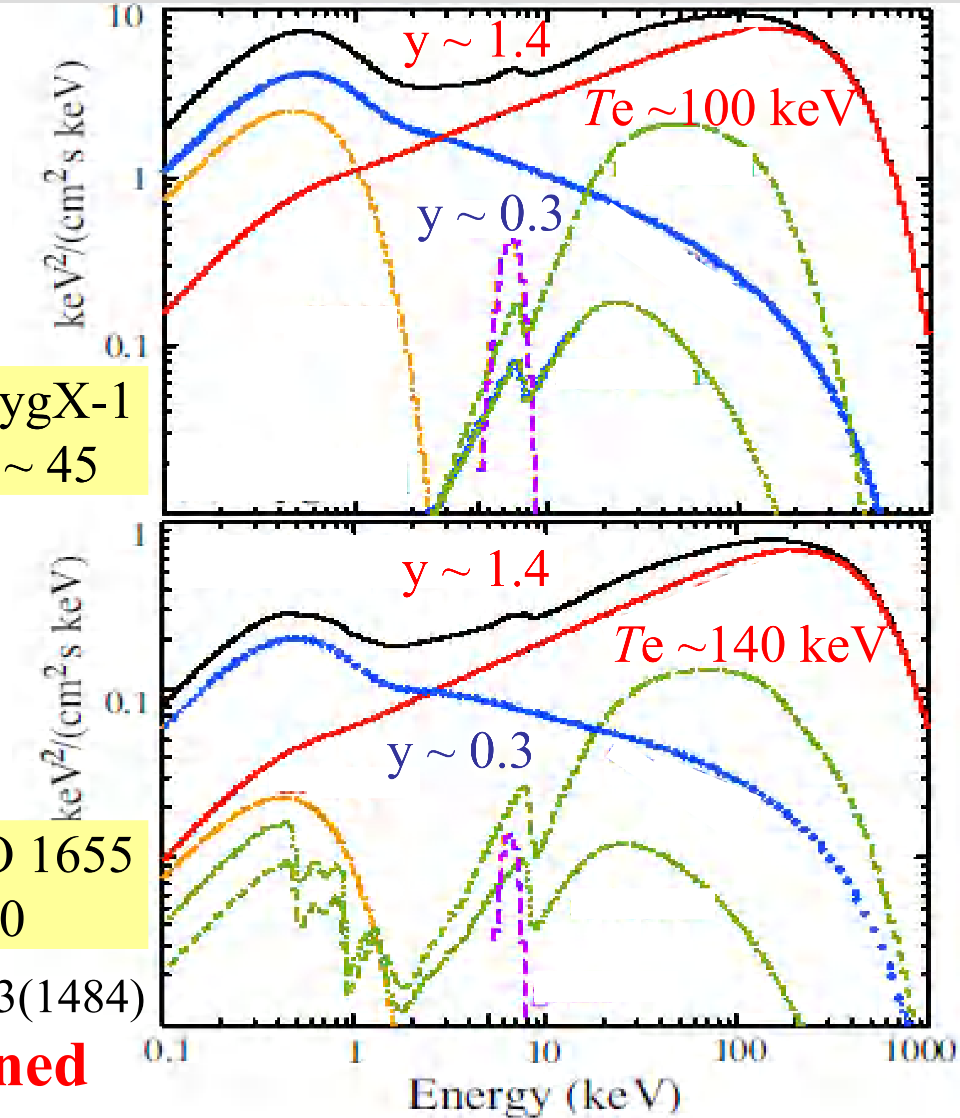
Reflection

- **Cyg X-1 has;**
  stronger diskBB,
  stronger iron line,
  stronger reflection,
  lower T_e.

CygX-1
i ~ 45

GRO 1655
i ~ 70

χ^2 =1.03(1484)



The spectral difference is explained by inclination effects and a defference of *Te*

A Possible Interpretation of the Wide-band Spectra

- **Seed photons**

  provided by the cool disk

- **Disk;**

  truncated,

  intruding into ~ half the clouds.

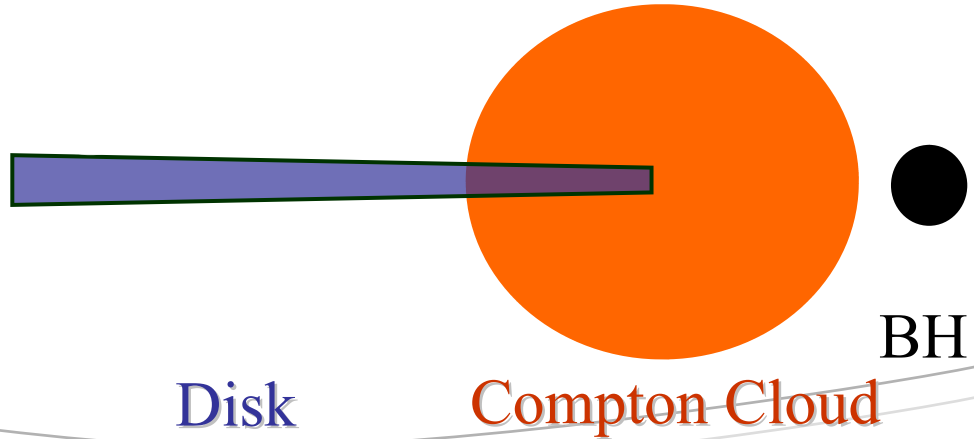
  visible through Compton Clouds

- **Compton Cloud**

  a large scale height

  inhomogeneous

  "holes"



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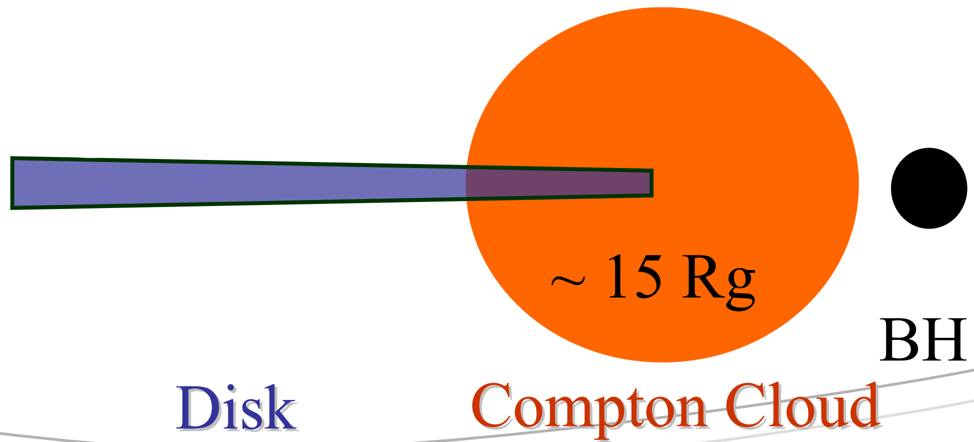

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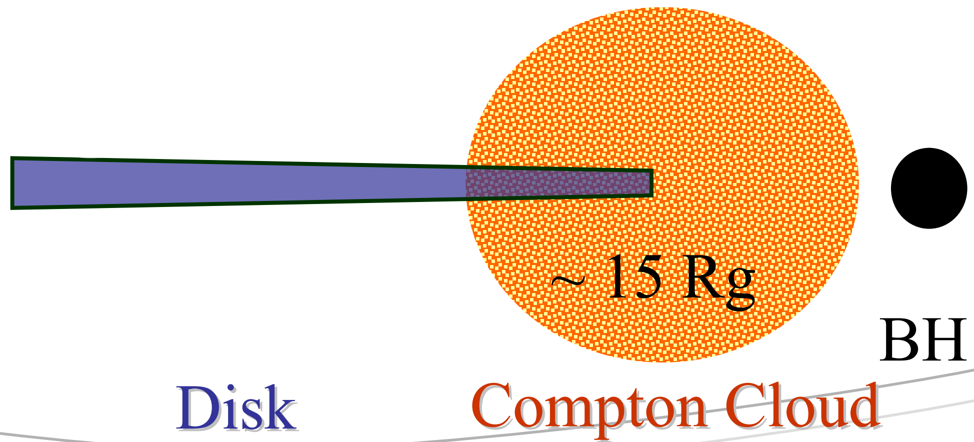
Cyg X-1

GRO J1655-40



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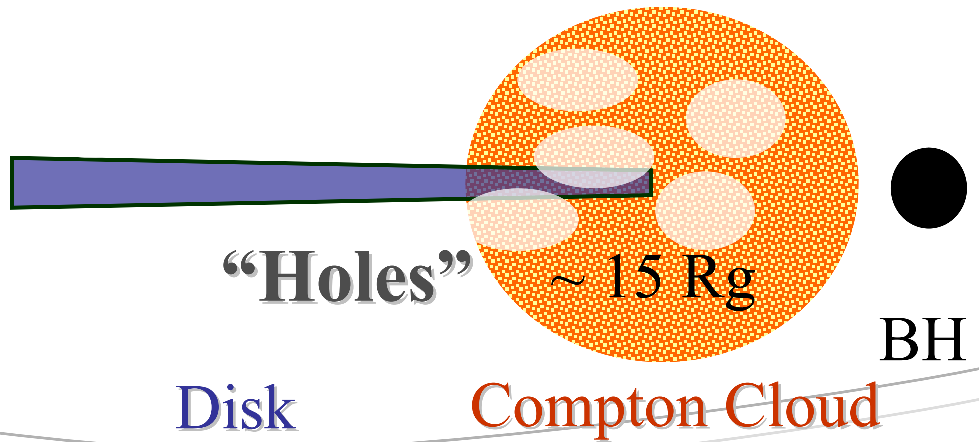

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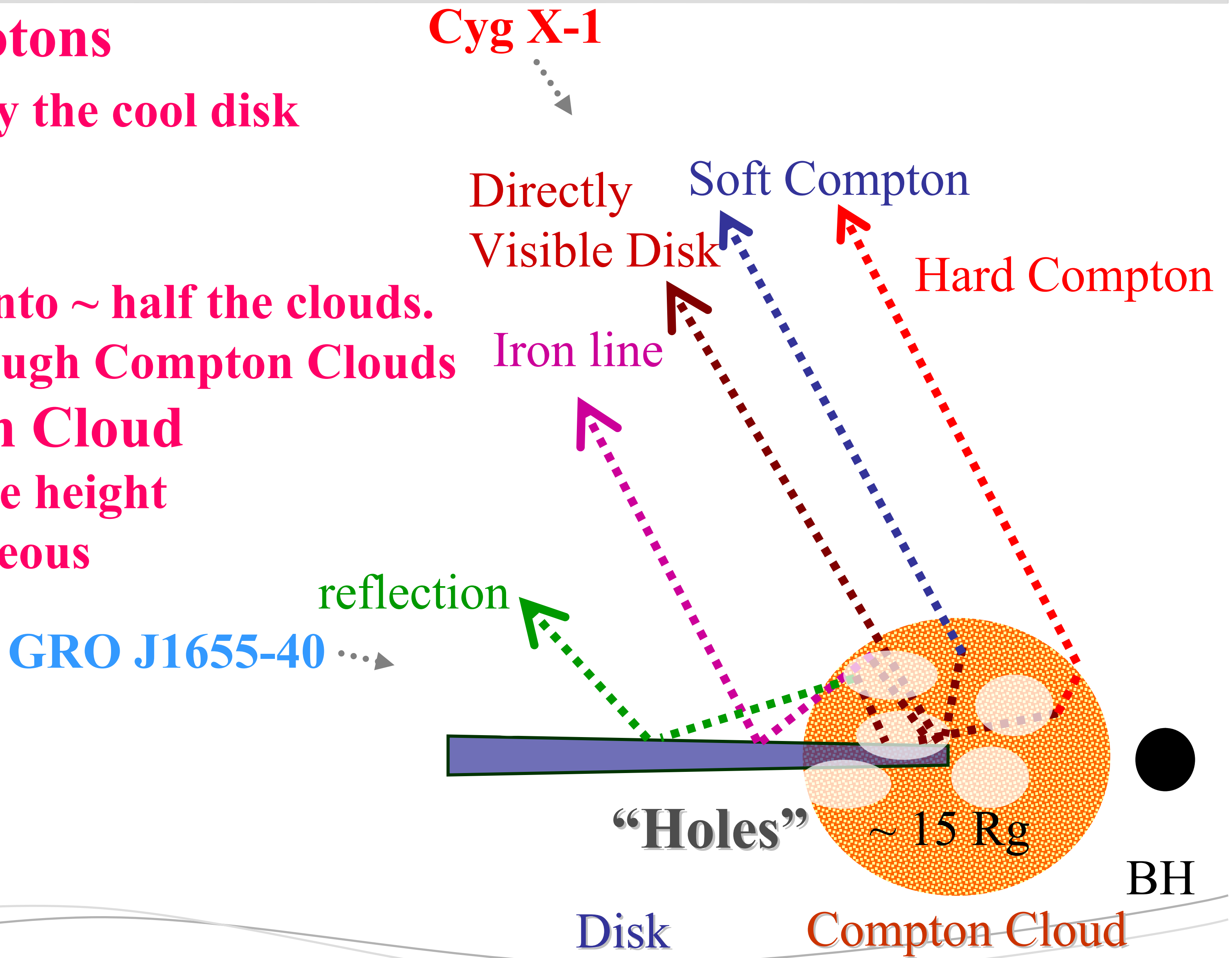
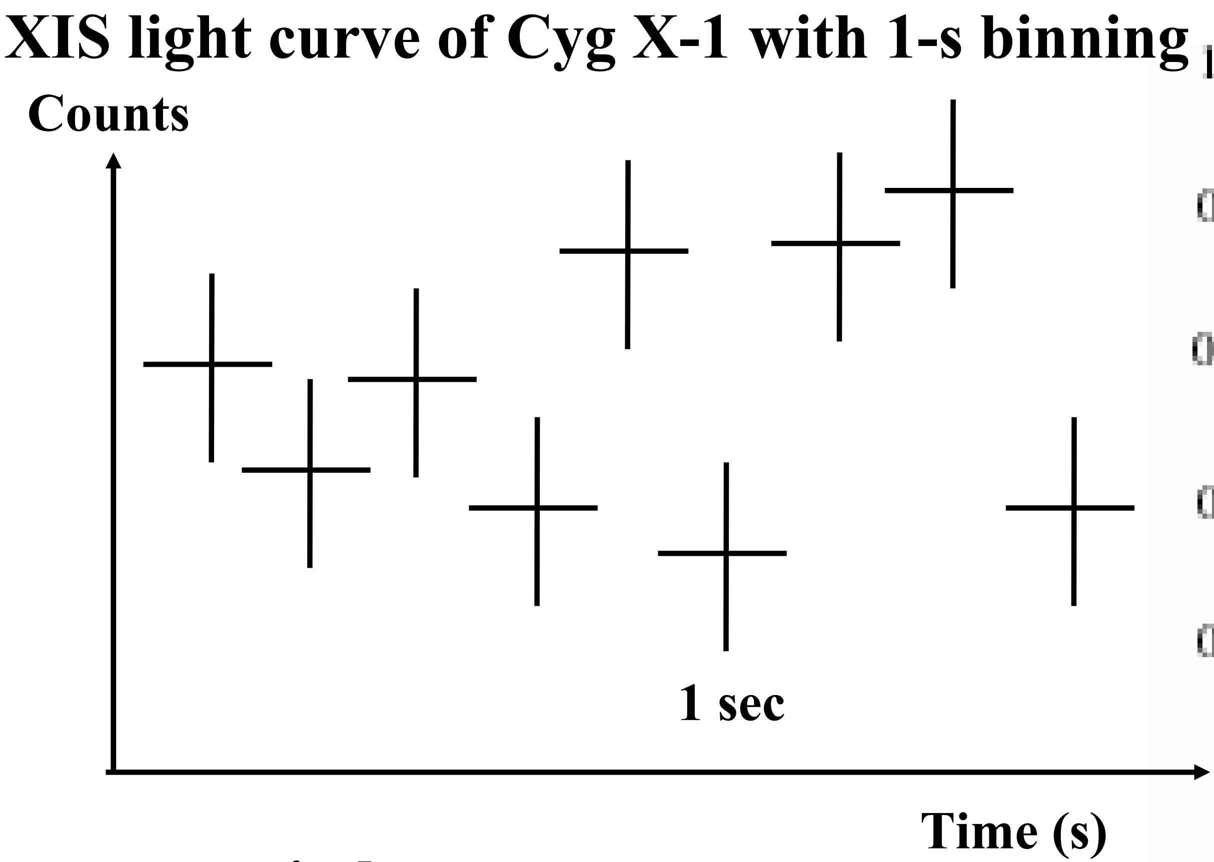
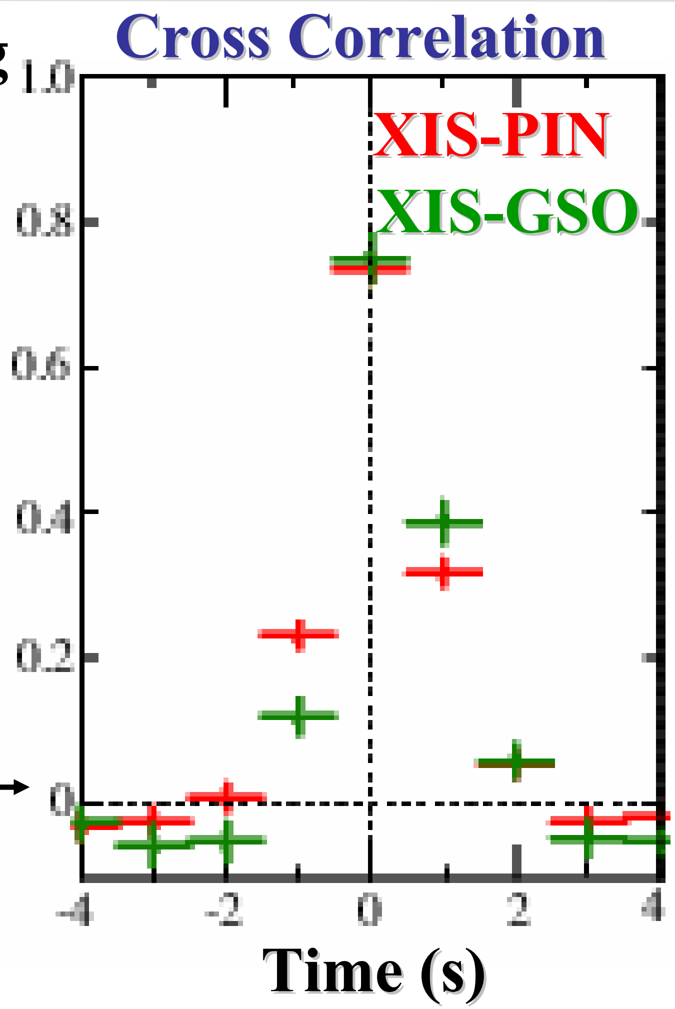


“Intensity-sorted Spectroscopy”



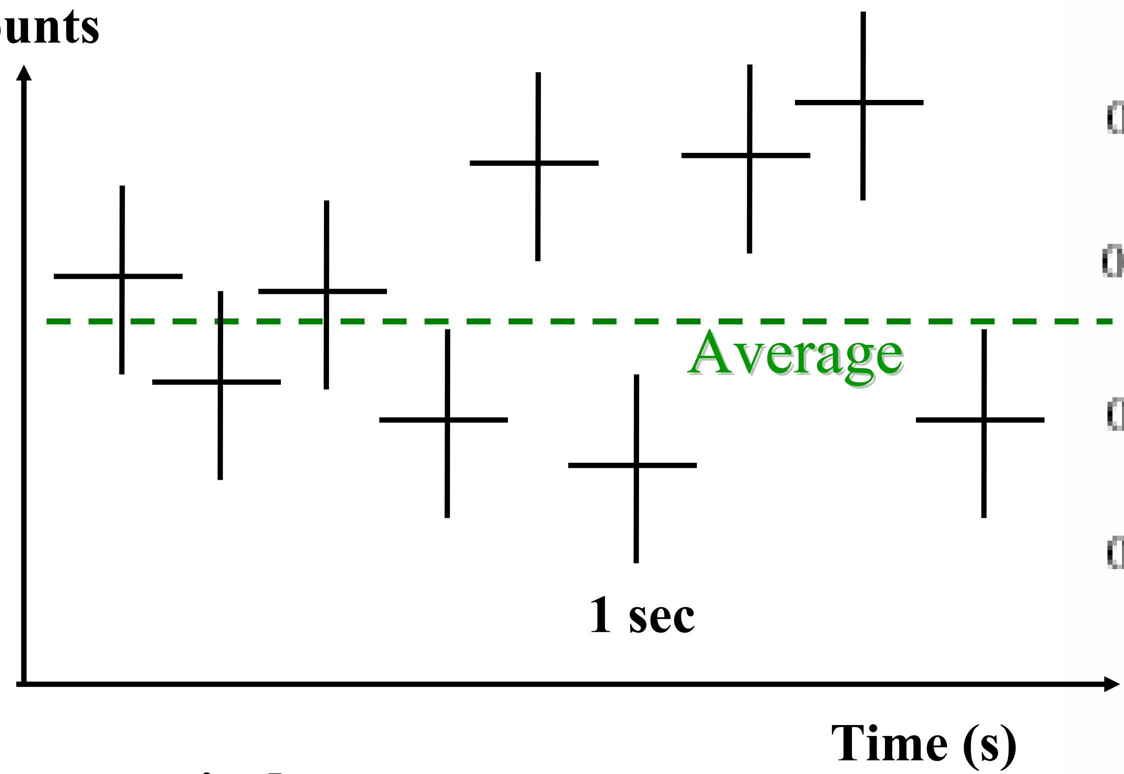


XIS 1/8 window, deltaT ~ 1sec
HXD detla T = 61 usec

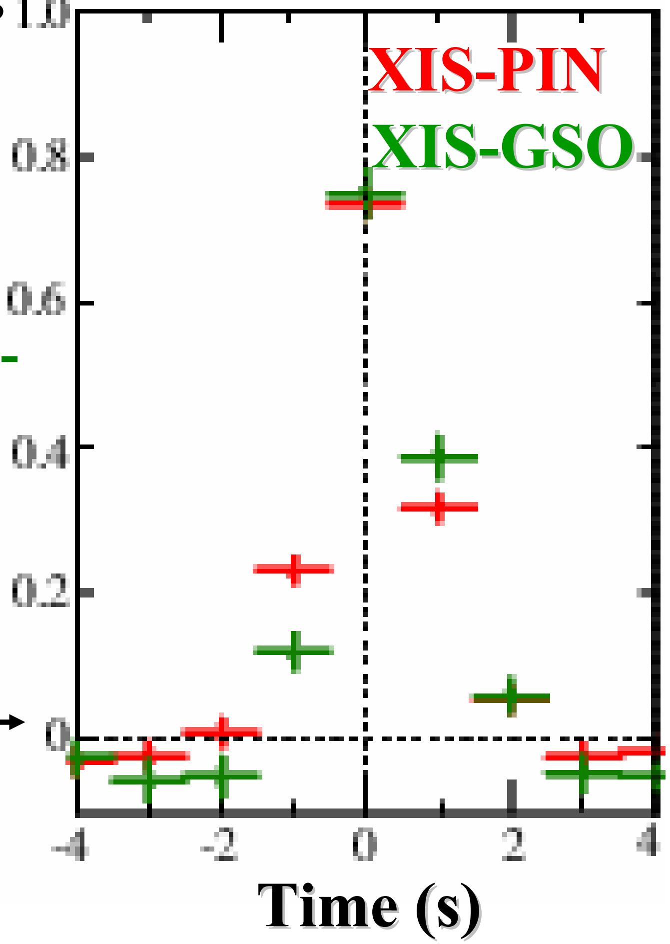
Fast variability of the thermal Comptonization can be studied

“Intensity-sorted Spectroscopy”

XIS light curve of Cyg X-1 with 1-s binning



Cross Correlation



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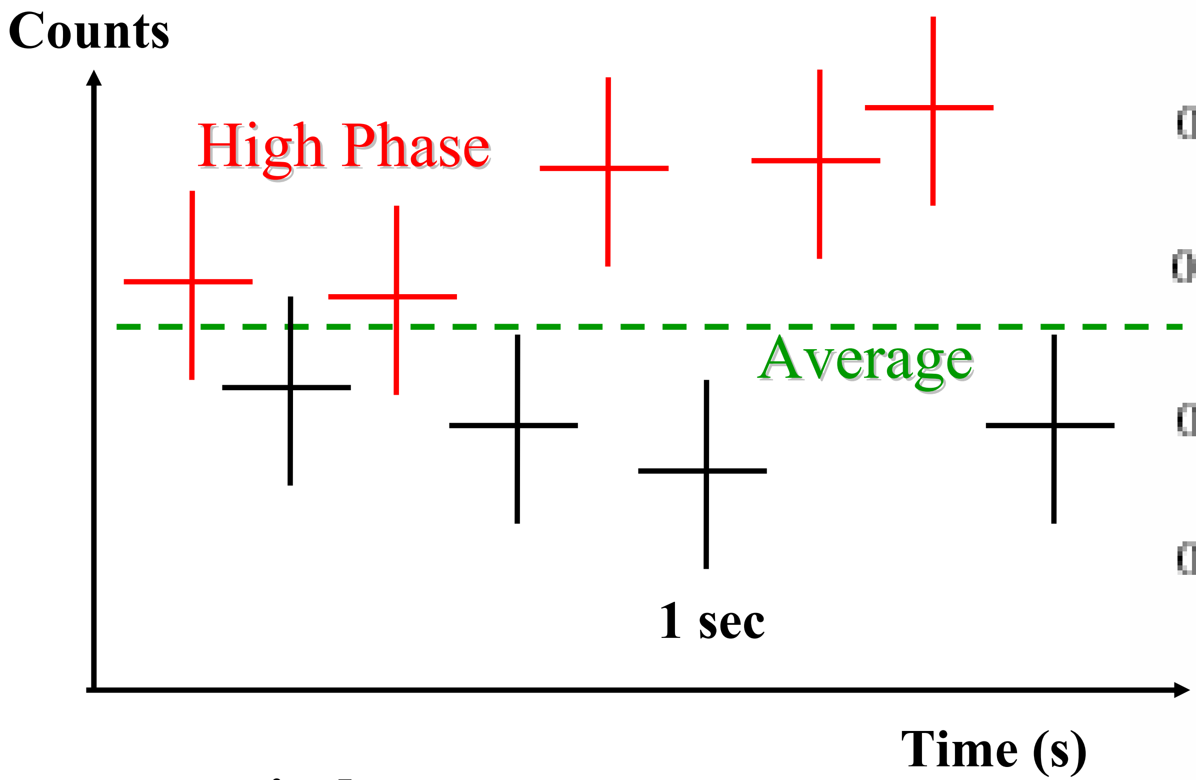

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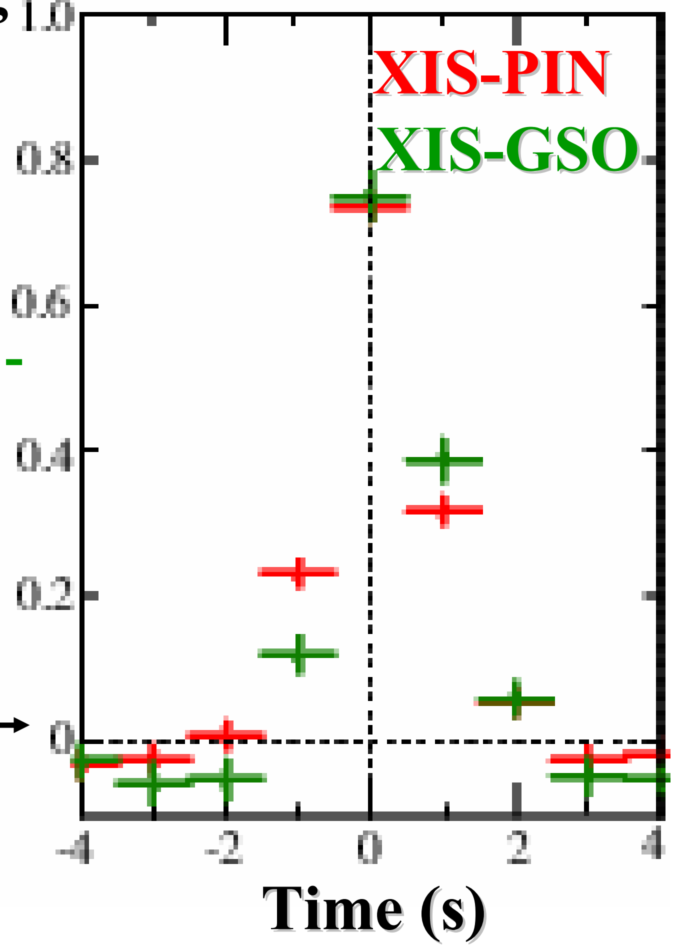

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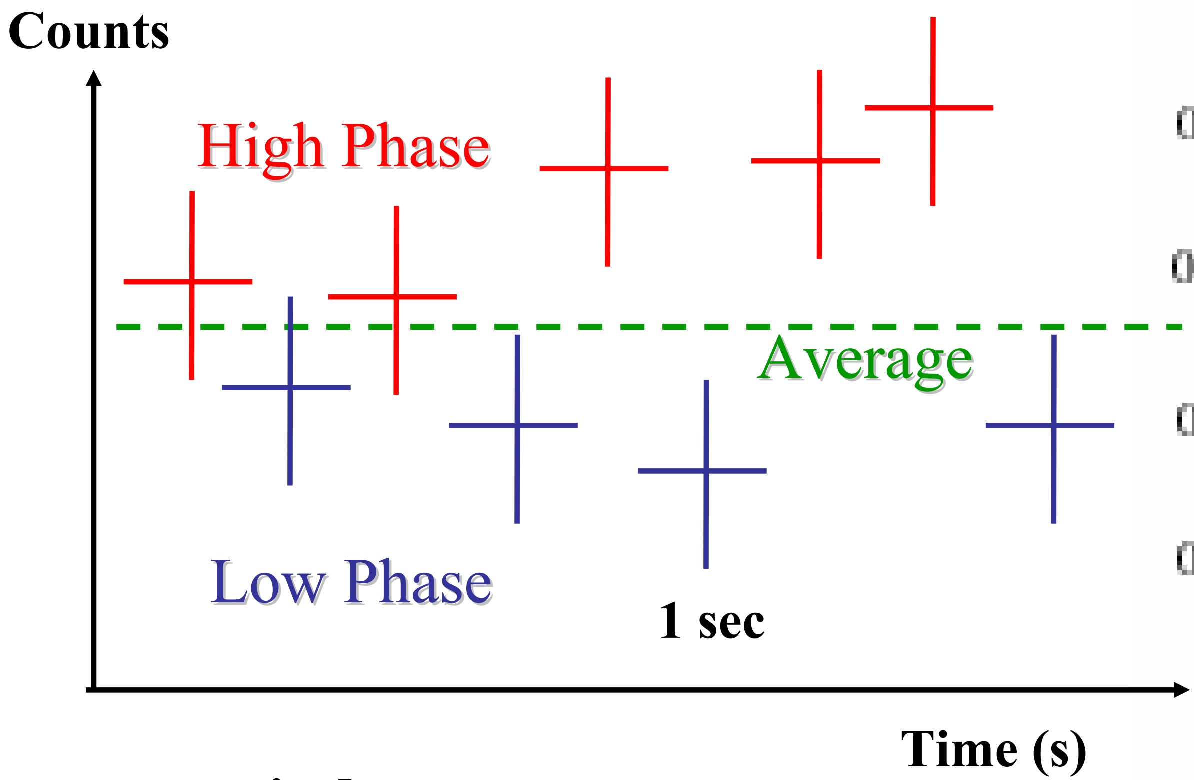

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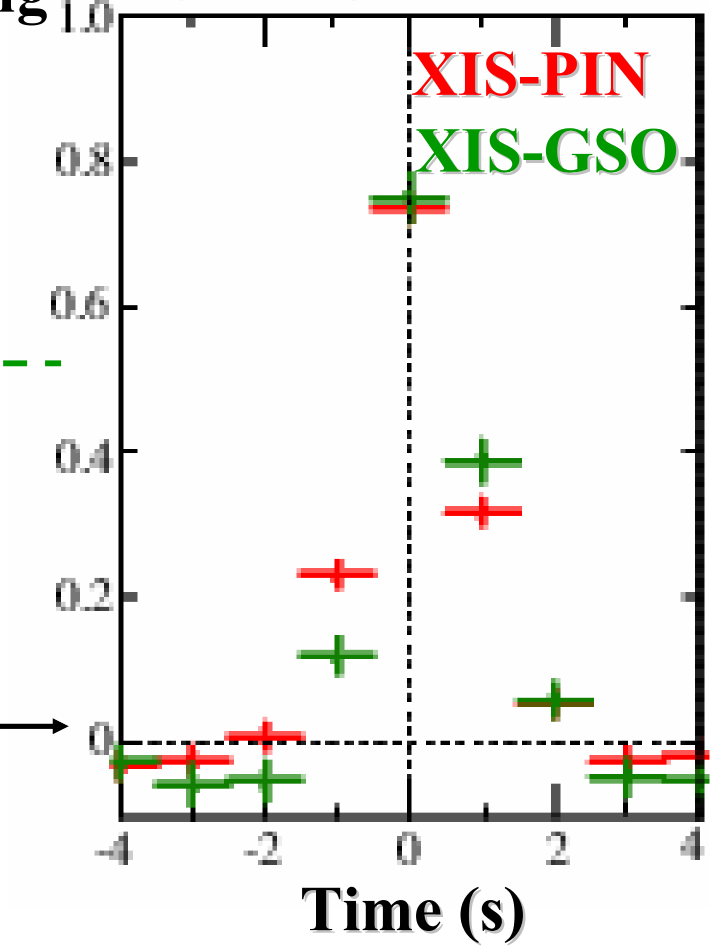

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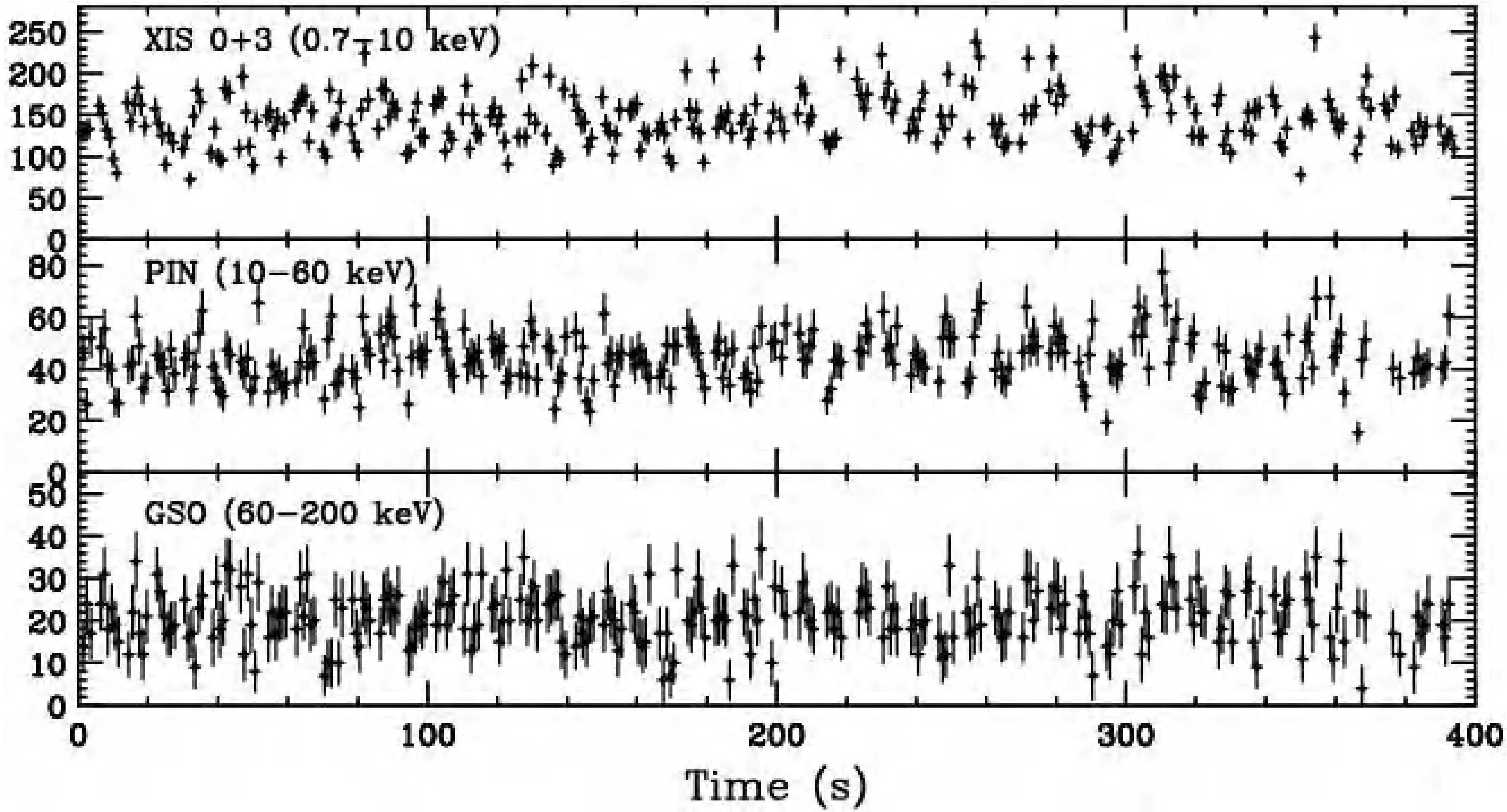
Fast variability of the thermal Comptonization can be studied

Intensity-sorting in reference to the XIS data

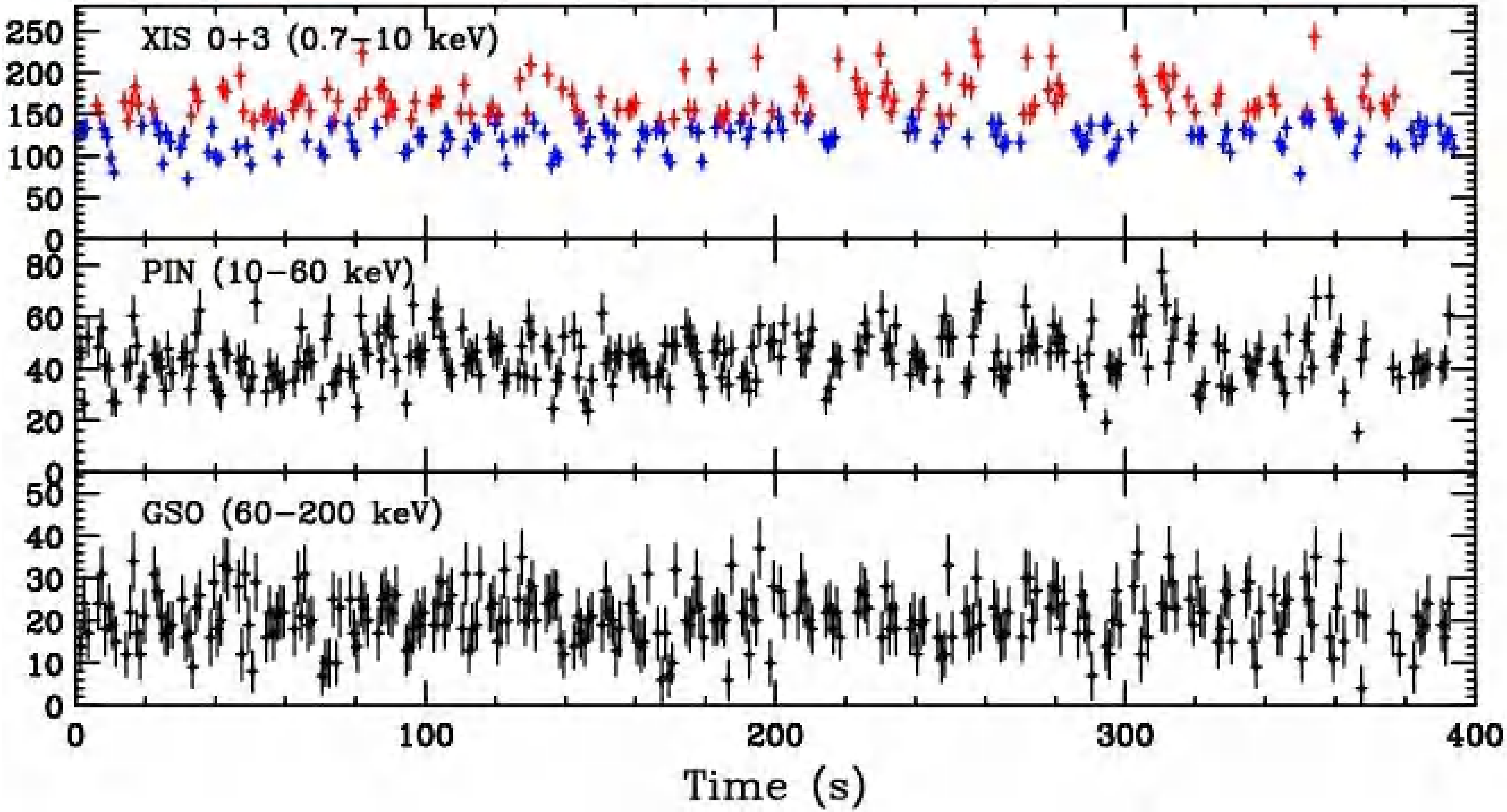
Lightcurves during 400s of Cyg X-1 with *Suzaku*



Intensity-sorting in reference to the XIS data

Fast variability is well determined by XIS.

High Phase
Low Phase



Applying the sorting to the HXD data --

Fast variability is well determined by XIS.

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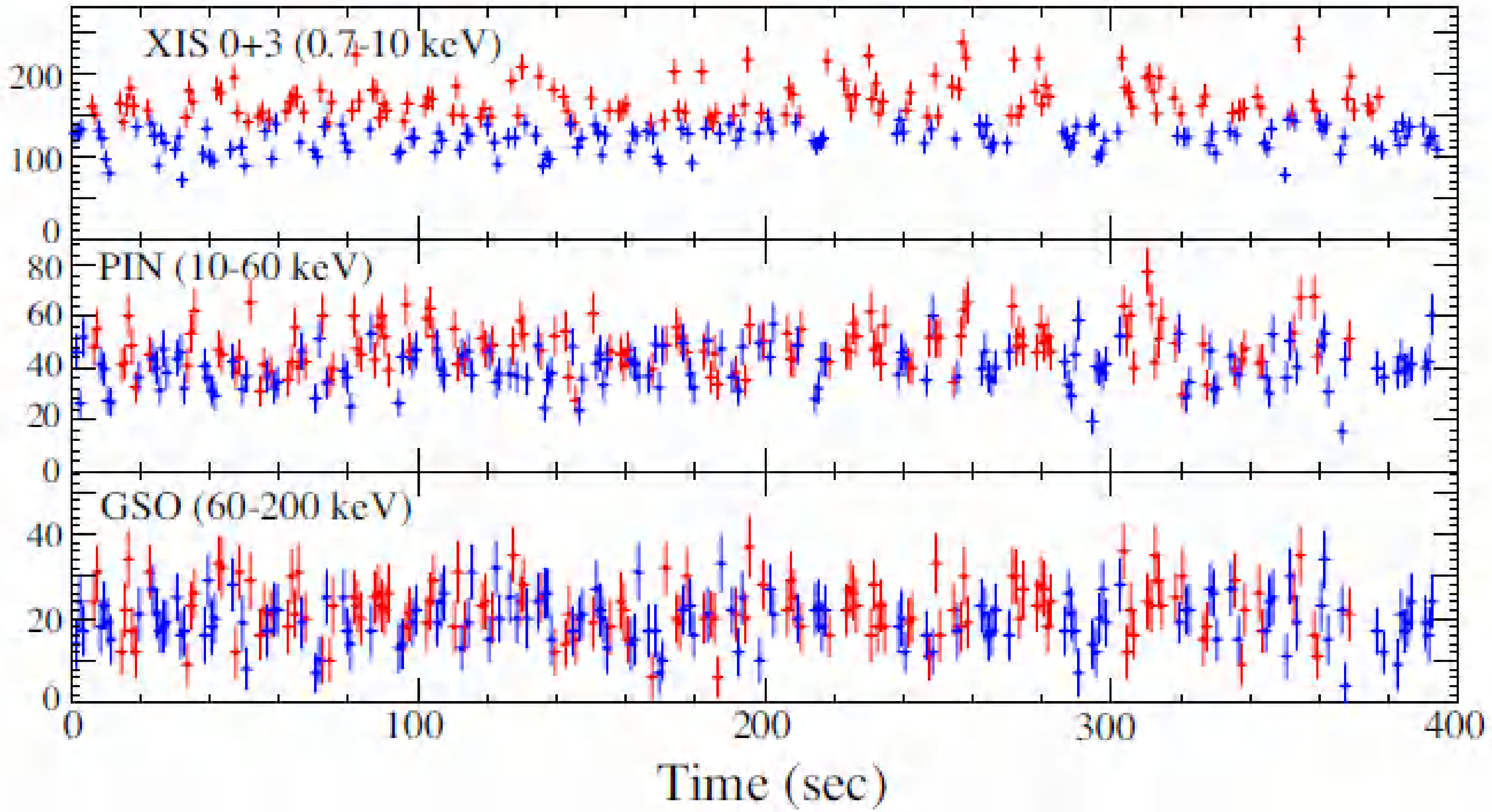
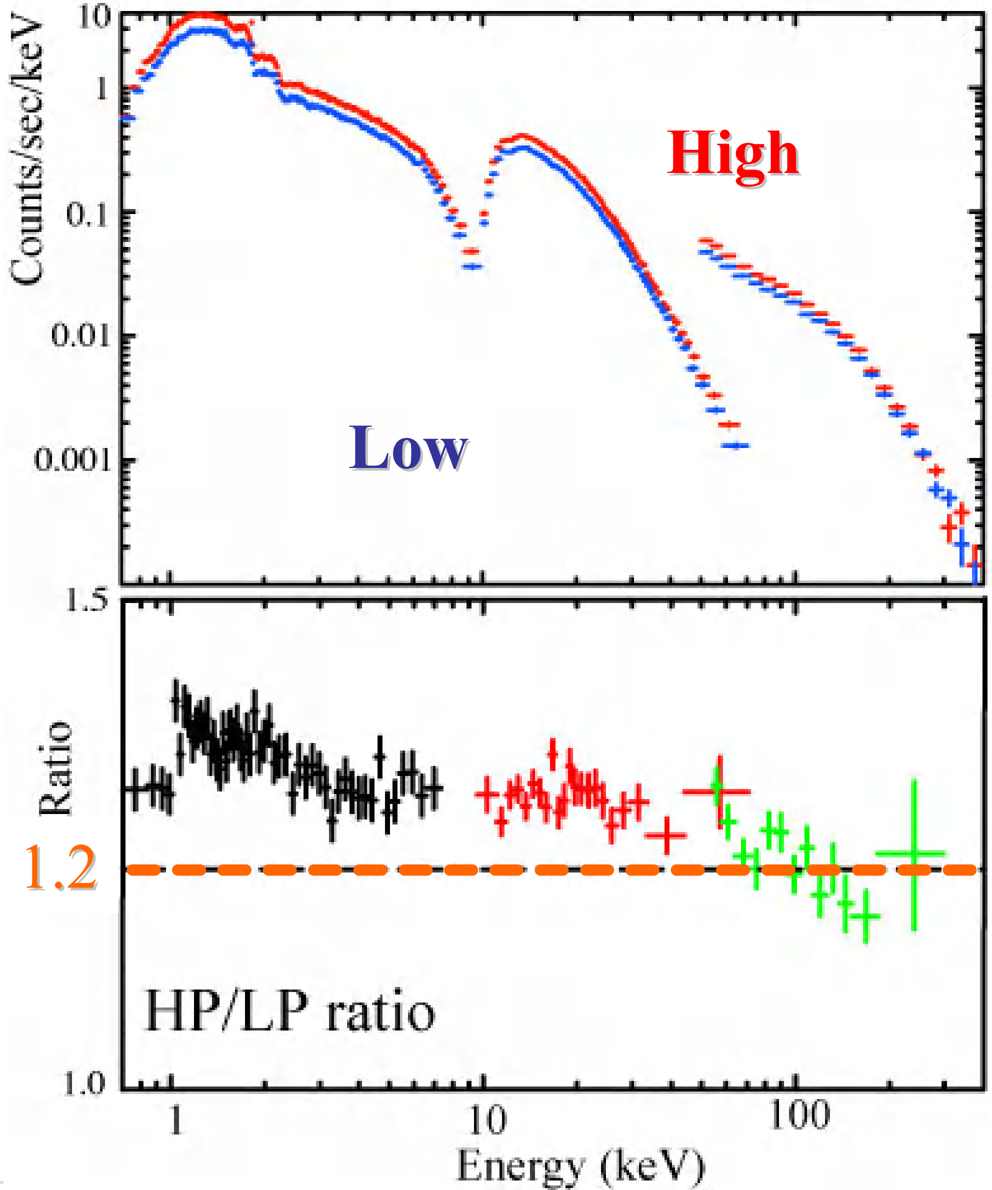


"High" and "Low" spectra

Makishima et al. astro-ph 0801.3315v1, PASJ 60, in *press* (2008)



When Cyg X-1 gets brighter,

- **Compton Cloud**
  - Seed photon ↗
  - T_e or tau, or both ↘
  - Hard/Soft →
- **Disk**
  - T_{in} →
  - L_{total} $(= L_{raw} + L_{seed})$ →
- **Iron line**
  - EW →
- **Reflection**
  - Omega / 2 pi →

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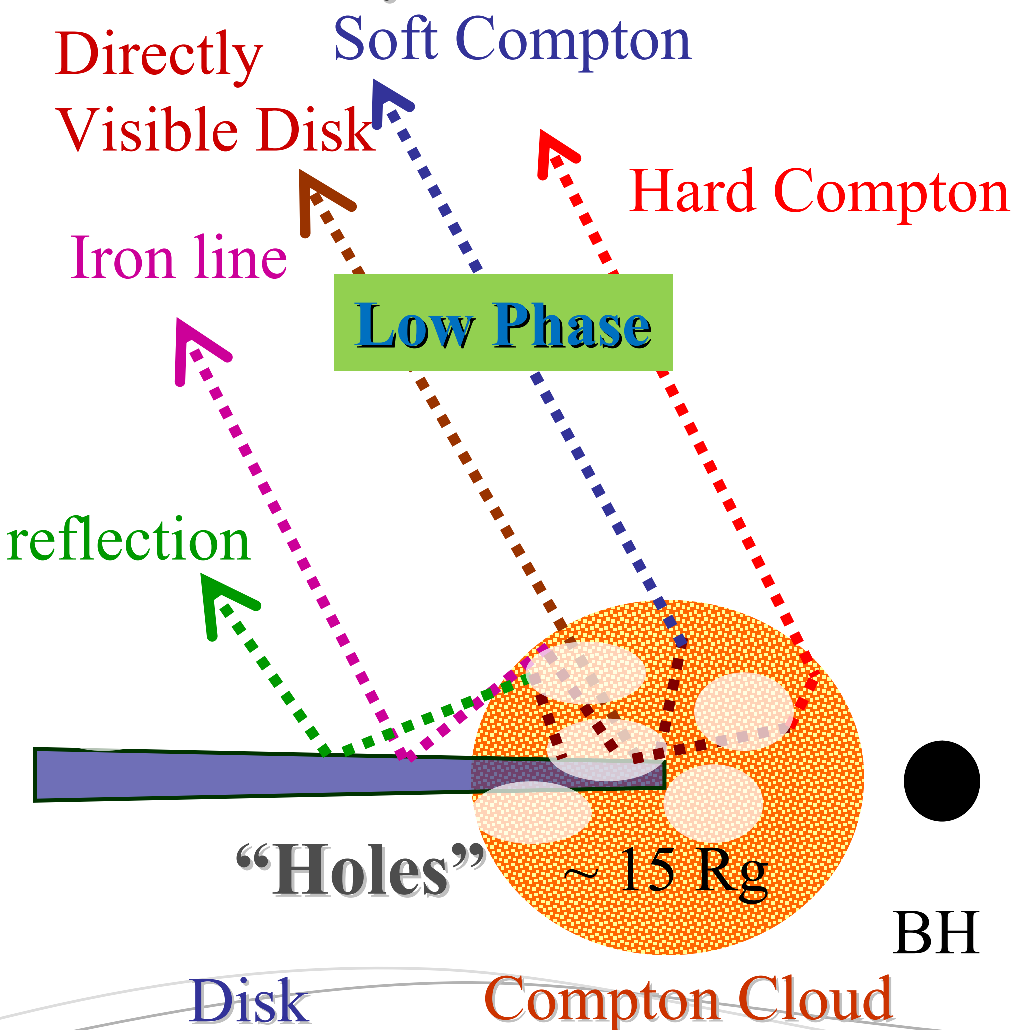

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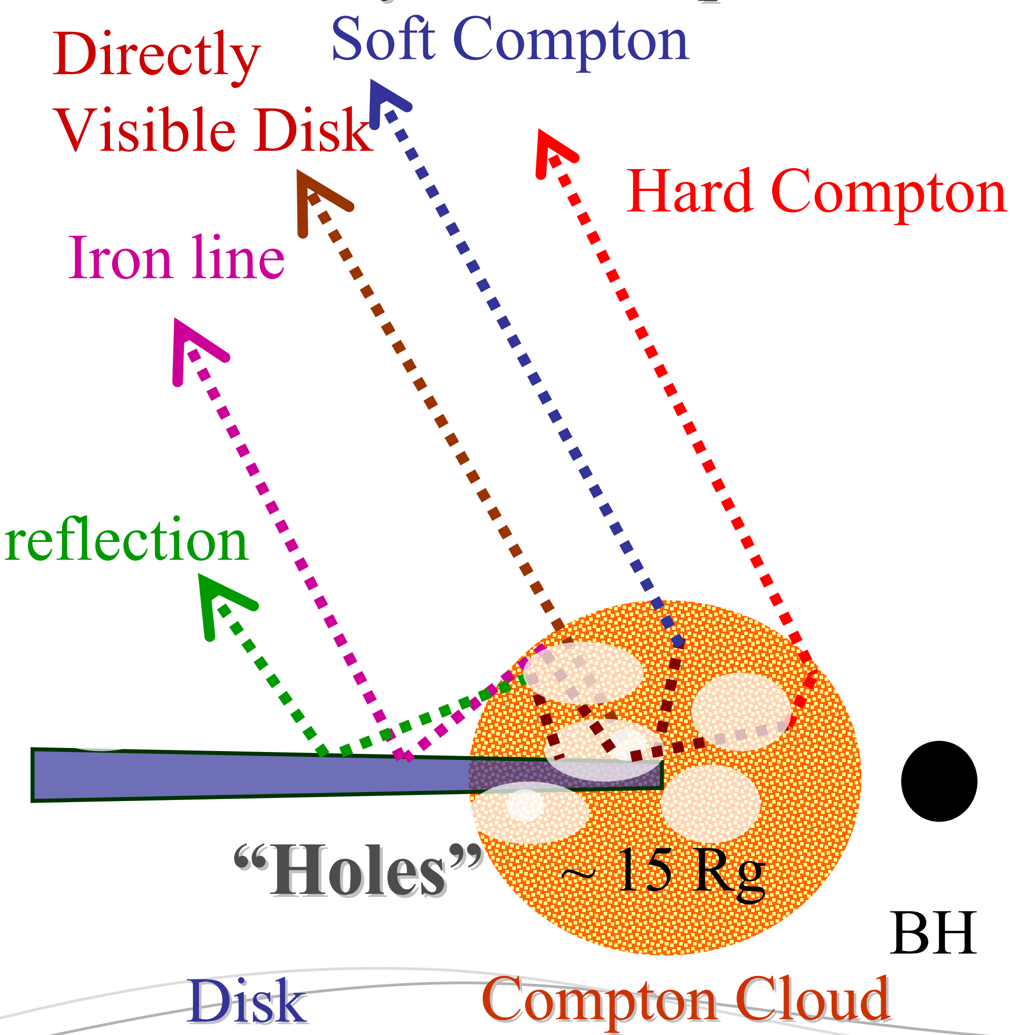

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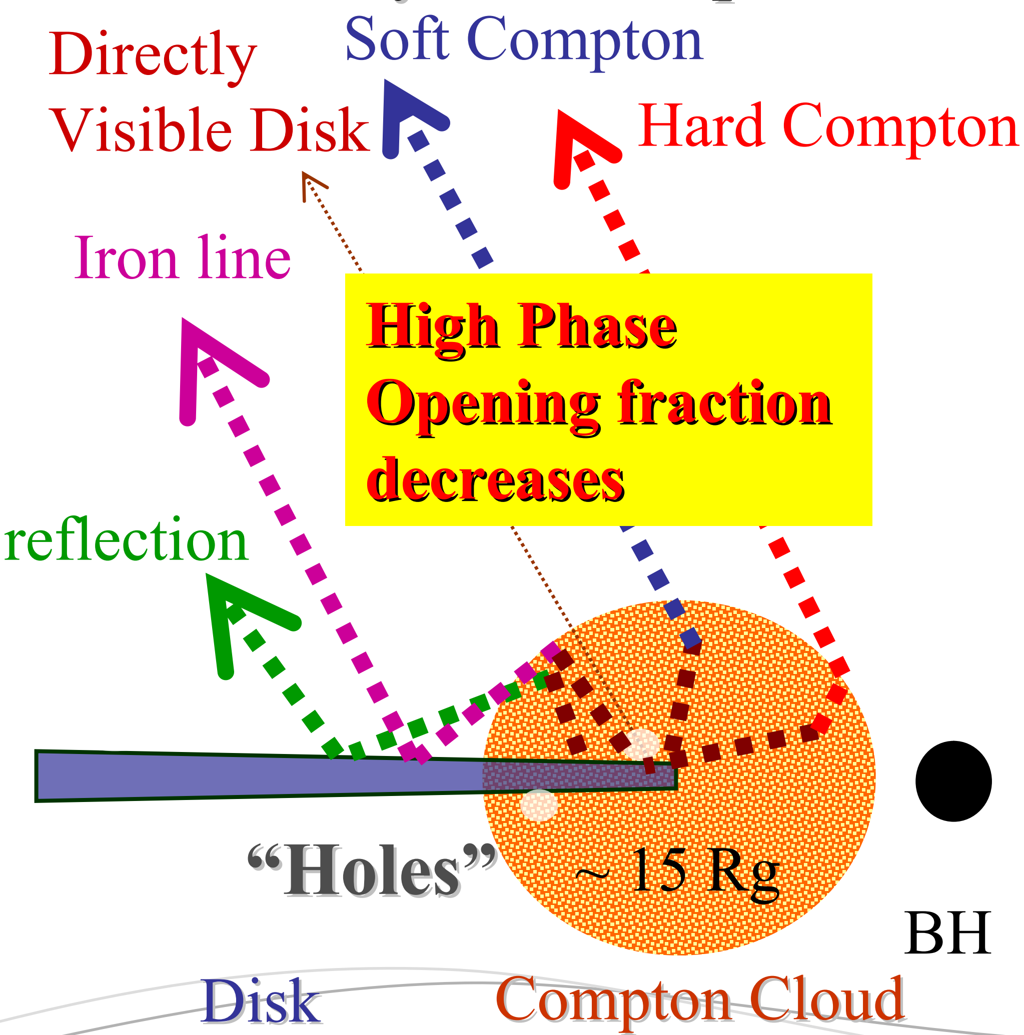

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Summary

- The 0.7-400 keV Cyg X-1 spectrum with Suzaku is reproduced by “Double-Comptonization” model. The accretion disk is truncated at ~ 15 Rg. No diskline is needed.
- Difference between GRO J1655-40 and Cyg X-1 can be explained by the inclination effects; flat disk, and inflated Compton cloud.
- When Cyg X-1 becomes brighter on ~ 1 sec, the seed photon supply to the clouds increases, and the cloud Te (or tau) decreases slightly.
- The Compton cloud is suggested to be highly inhomogeneous, and its opening fraction is varying.

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