Accretion flow onto stellar-mass black holes

Two ideas which can address the ISCO of an accretion flow around BHs

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Introduction

- Black hole nature

  Mass, and radius of Event Horizon →Spin

- In the observation
  - Mass : Orbital motion of binaries
  - Radius of an Event Horizon (they are all model dependent)
    - Gravity $\propto$ M/r : Broad and skewed iron line
    - ISCO radius from continuum spectrum
    - QPO
- Robust measurement of Radius of the Event Horizon: New breakthrough

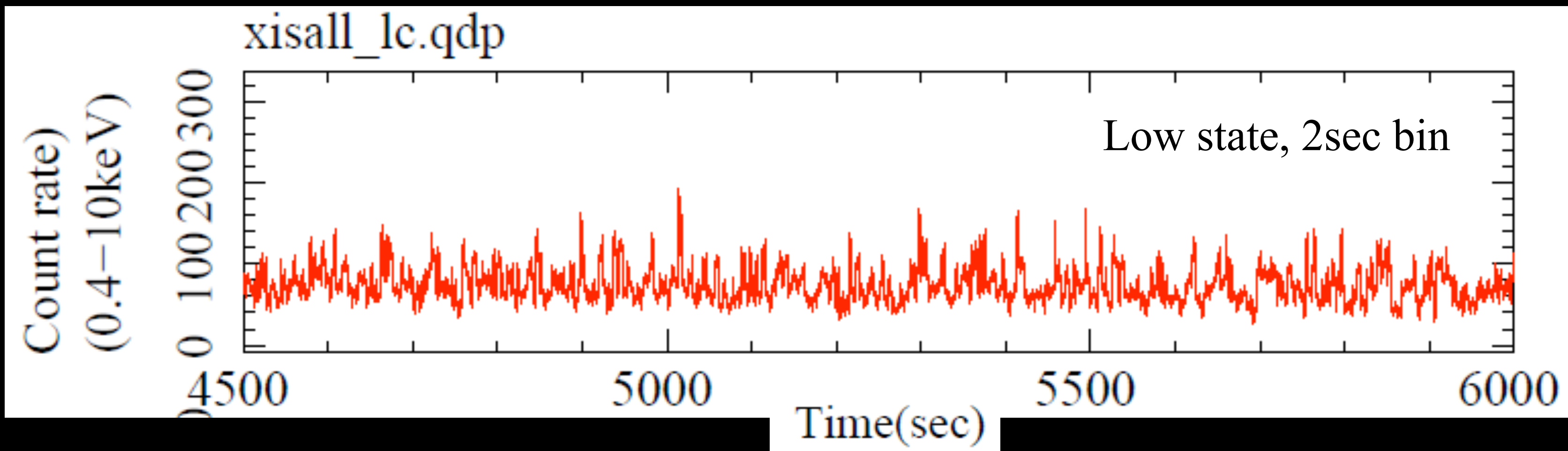
Introduction

- Another two ideas to determine the radius of the ISCO.
  - Light curve of individual short term variations (shots)
  - Short term spectroscopy of absorption dips

    - **These are still speculative and not quantitative, but I hope if it becomes a start point of new ideas.**
    - **Galactic BHs, & AGNs.**

2.Short term variation

- Light Curve of a Typical BH binary: Cyg X-1



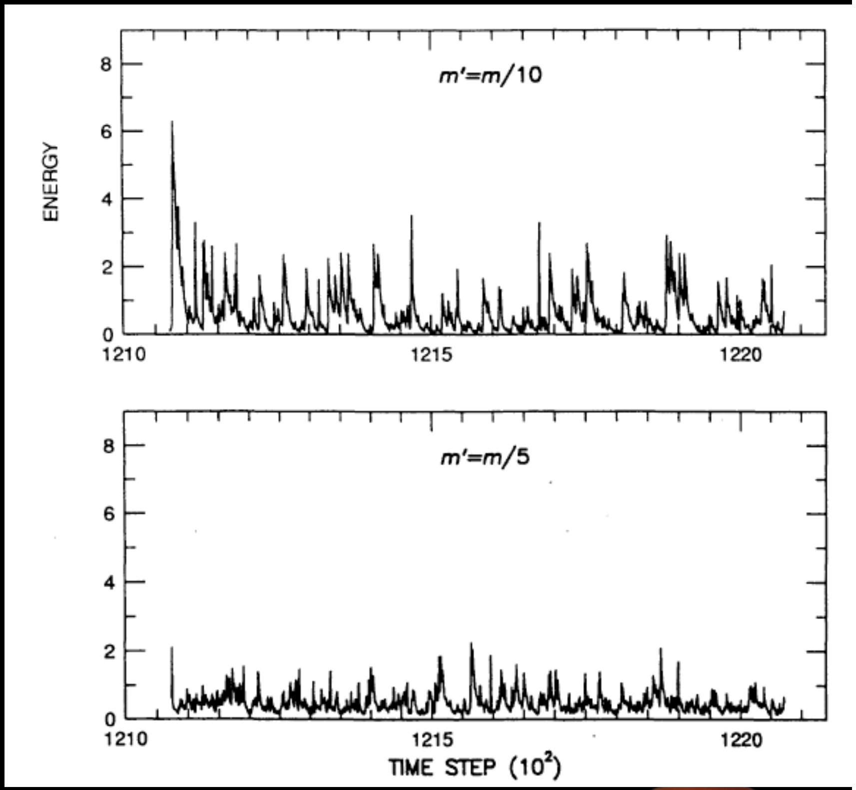
~ a few second spiky flares.

Shots (after Oda et al 1971;Terrell 1972)

Representing a behavior of the Accretion flow

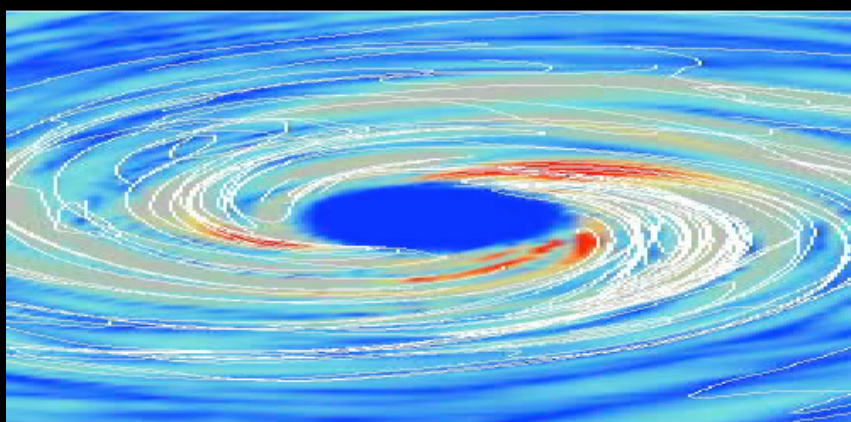
2. Short term variation

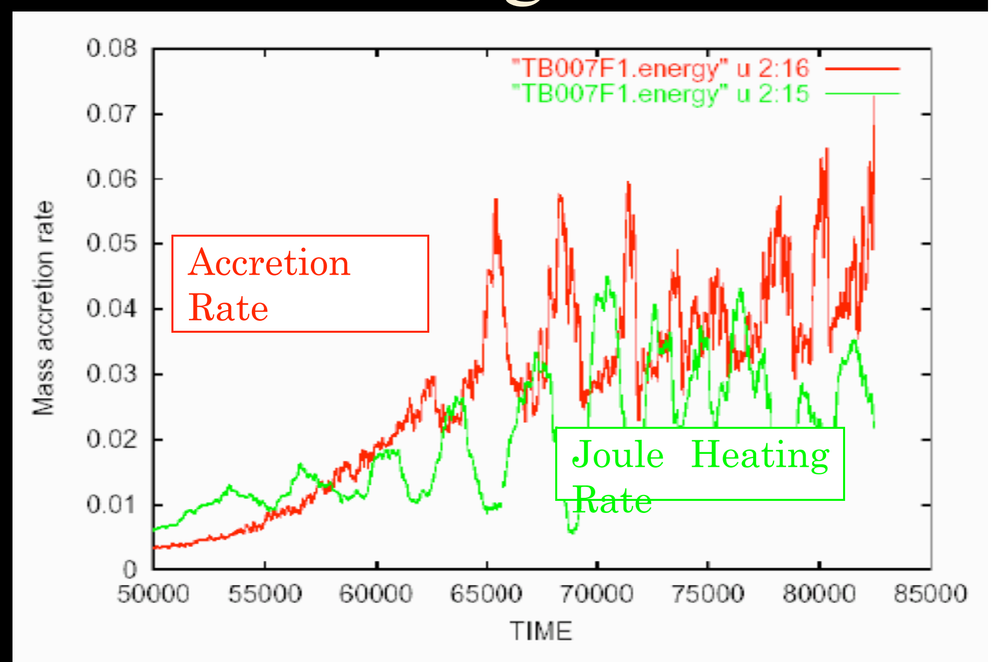
- Self Organized Criticality (SOC) (Takeuchi et al. 1995)
  - Random occurrence of flare-like phenomena at random places
  - **The cause of the flare is not specified.**



2. Short term variation

- MHD simulation   Machida and Matsumoto 2003
- Magnetic re-connections in the inner region





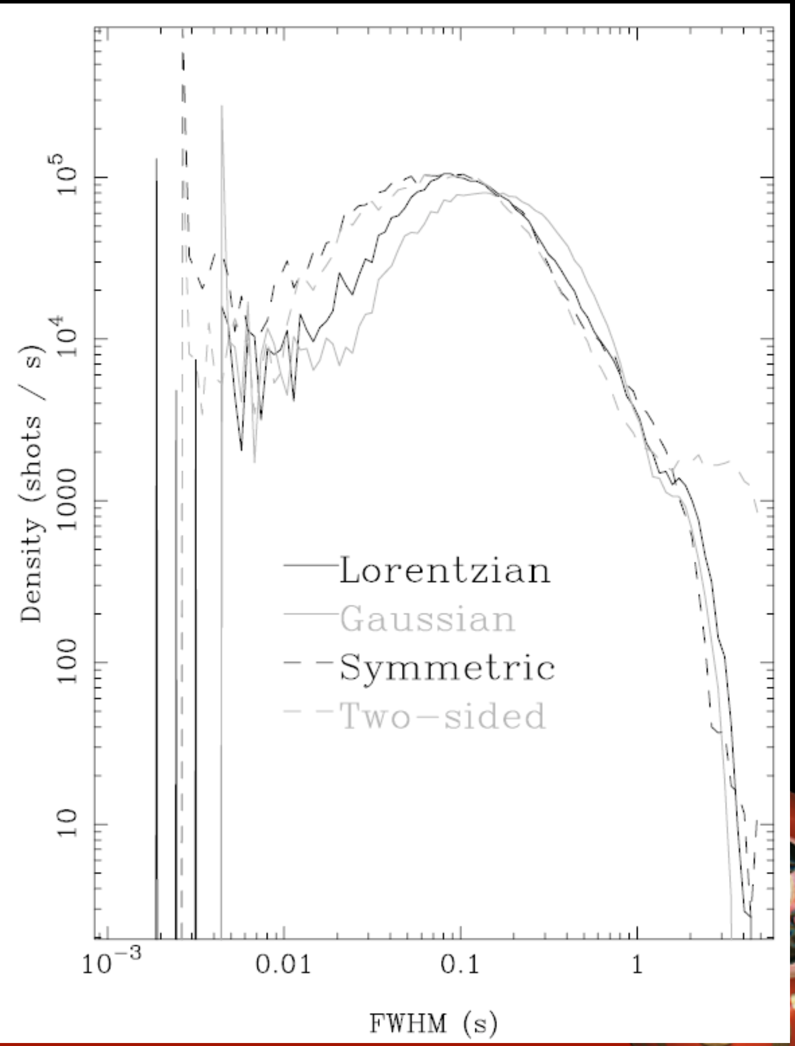
These magnetic reconnection might be a cause of the shots.

The shots have information near the ISCO.

2. Short term variation

- Shot width extends down to several msec. (Focke et al.2005)
- A few m-sec is a time scale of a light travel time across an inner accretion disk around a 10Mo black hole

$$1\mathrm{ms} \sim \frac{2G}{c^3}\frac{M}{10M_{sun}}$$



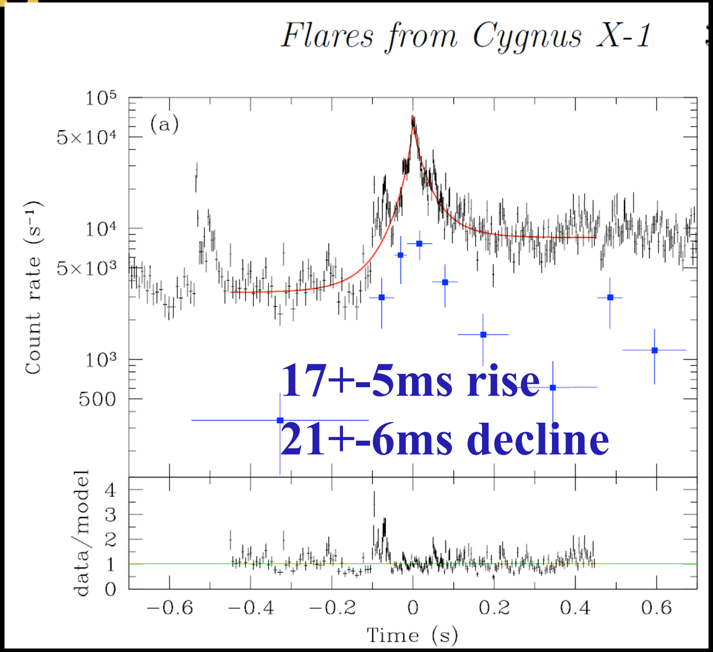
2. Short term variation

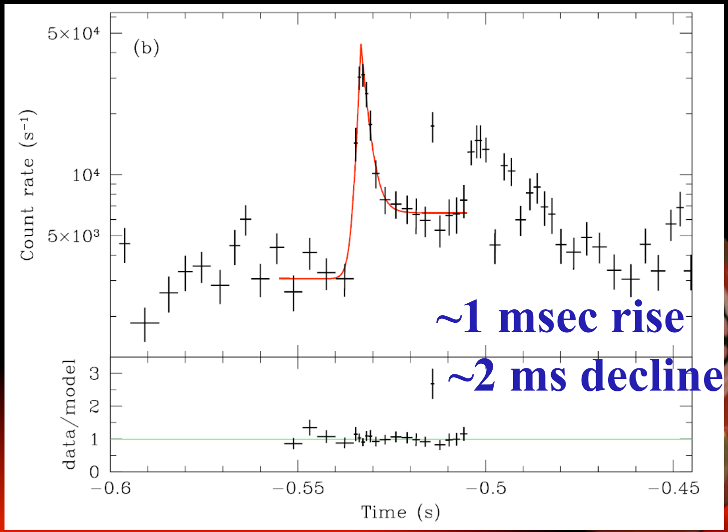
Millisecond flares (Goerlimnski et al. 2003)

- The m-sec shots must be an emission of one flare on the accretion disk near the ISCO. .

- The statistically good light curve of the individual short shots should have the modulation by the orbital motion.
- If the orbital modulation has the time scale of m-sec, they are certainly emissions from the blob orbiting around the ISCO.

Short shots





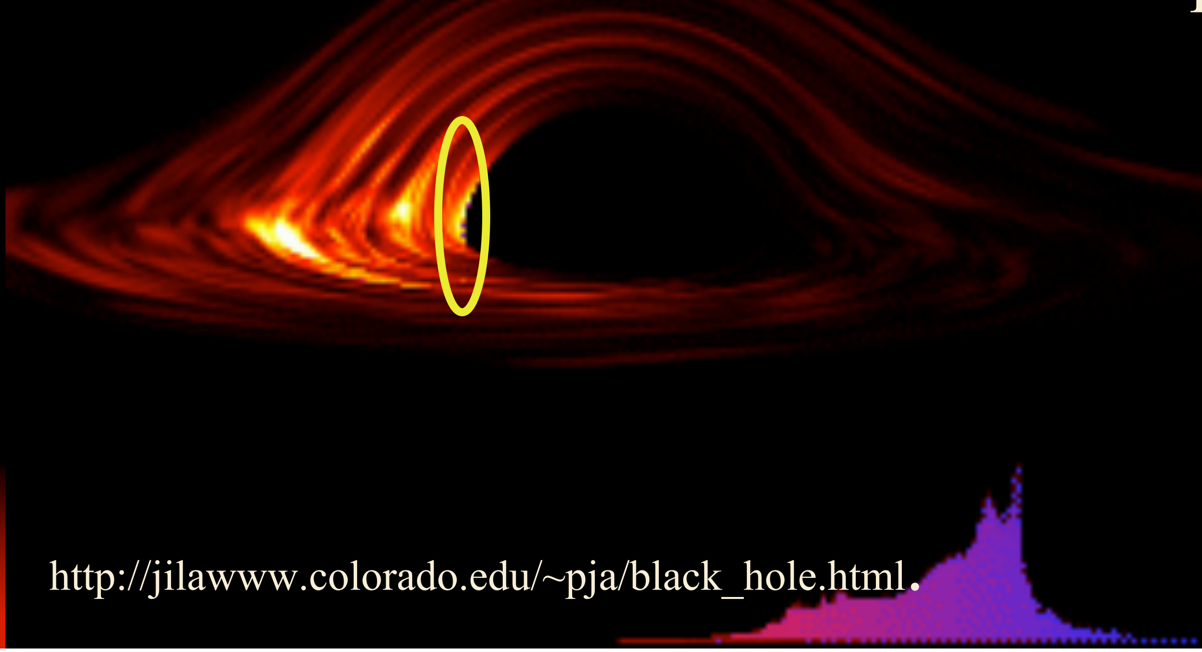
2. Short term variation

- IXO can have ~20 counts/1msec light curve for 100mCrab source
  - We can identify the emission from inner most accretion disk, from the short term light curve.
- Then
  - We can find the period of the orbital motion from the oscillation.
  - The oscillation pattern should not be a sinusoidal, because of the beaming effect.
    - Orbital velocity

If the most inner accretion disk is a ISCO, then

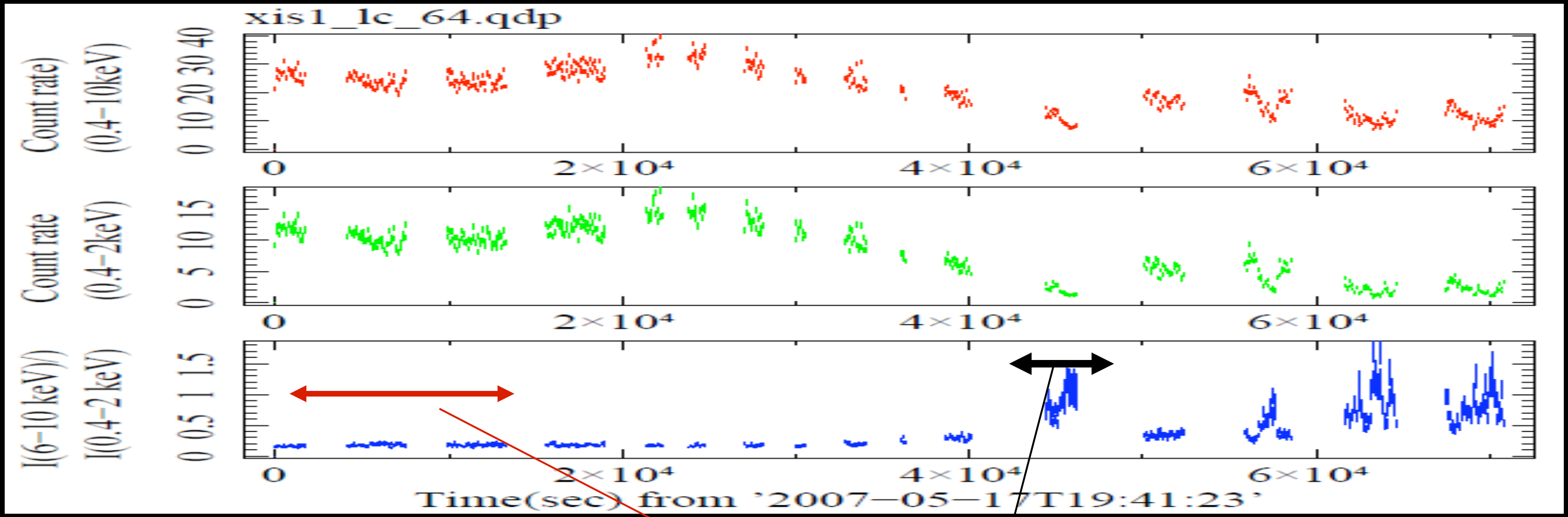
We can derive the radius of the ISCO,
From the orbital period and its velocity.

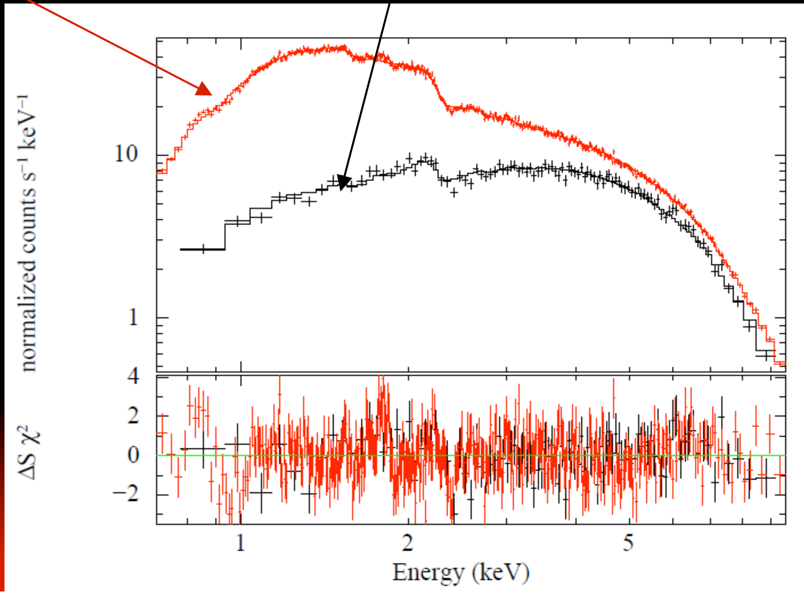
Then we can estimate the mass and spin of the BH



- http://jilawww.colorado.edu/~pja/black_hole.html.

3. .Absorption dips of Cyg X-1





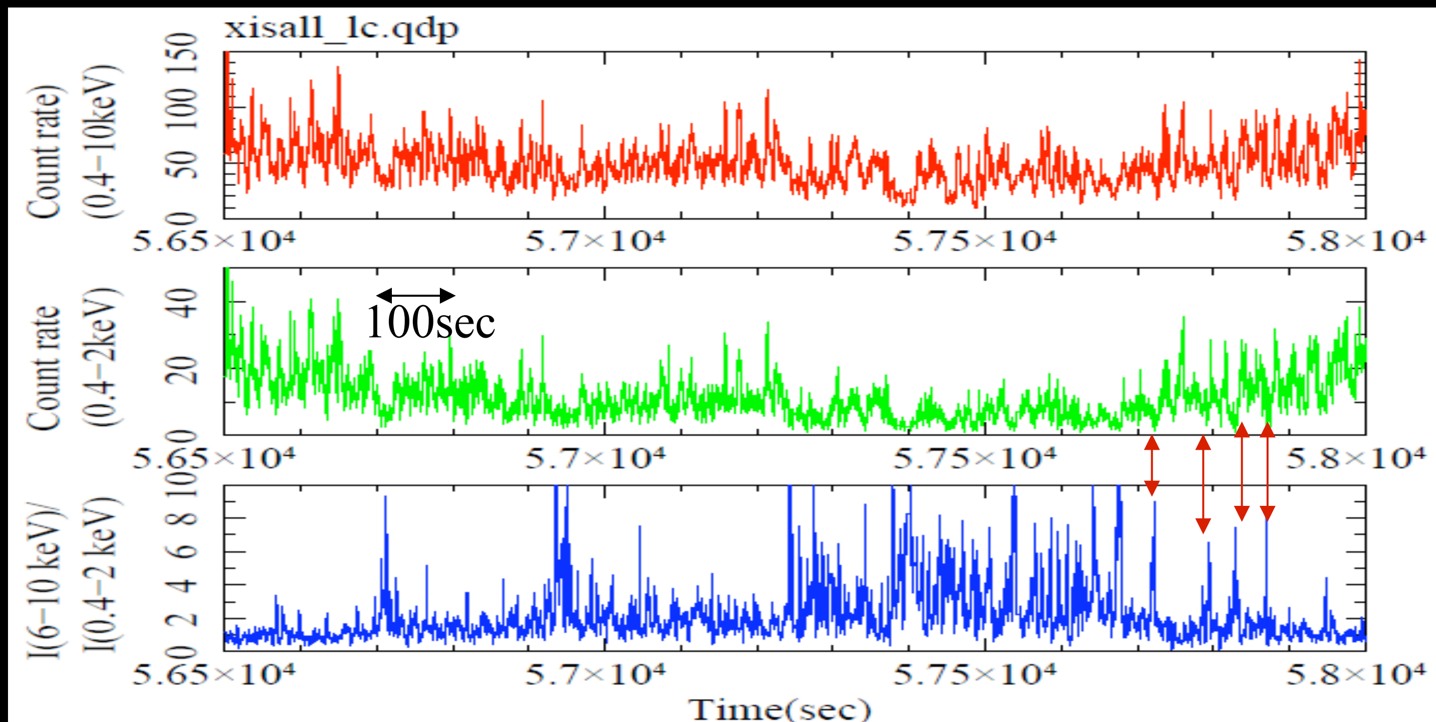
Dip spectra can be simulated
by a partial absorption model.

3. .Absorption dips of Cyg X-1

- The absorption dips of Cyg X-1 are considered to be an obscuration of the X-ray source by something above the companion star surface.
  – The dips occur around the superior conjunction of the X-ray star
  – But do not occur every orbit
- The Dip spectra can be fitted by a partial absorption model.
  – Temporally variable absorption
  – Spatially different absorption

3. .Absorption dips of Cyg X-1

- **There is a hint of very short dips in the data, with less than 10 sec.**



Short dips can be considered as an obscuration by one bunch of matter.

The evolution of the spectra can be used as a diagnostics of the brightness distribution of the accretion disk.

3. .Absorption dips of Cyg X-1

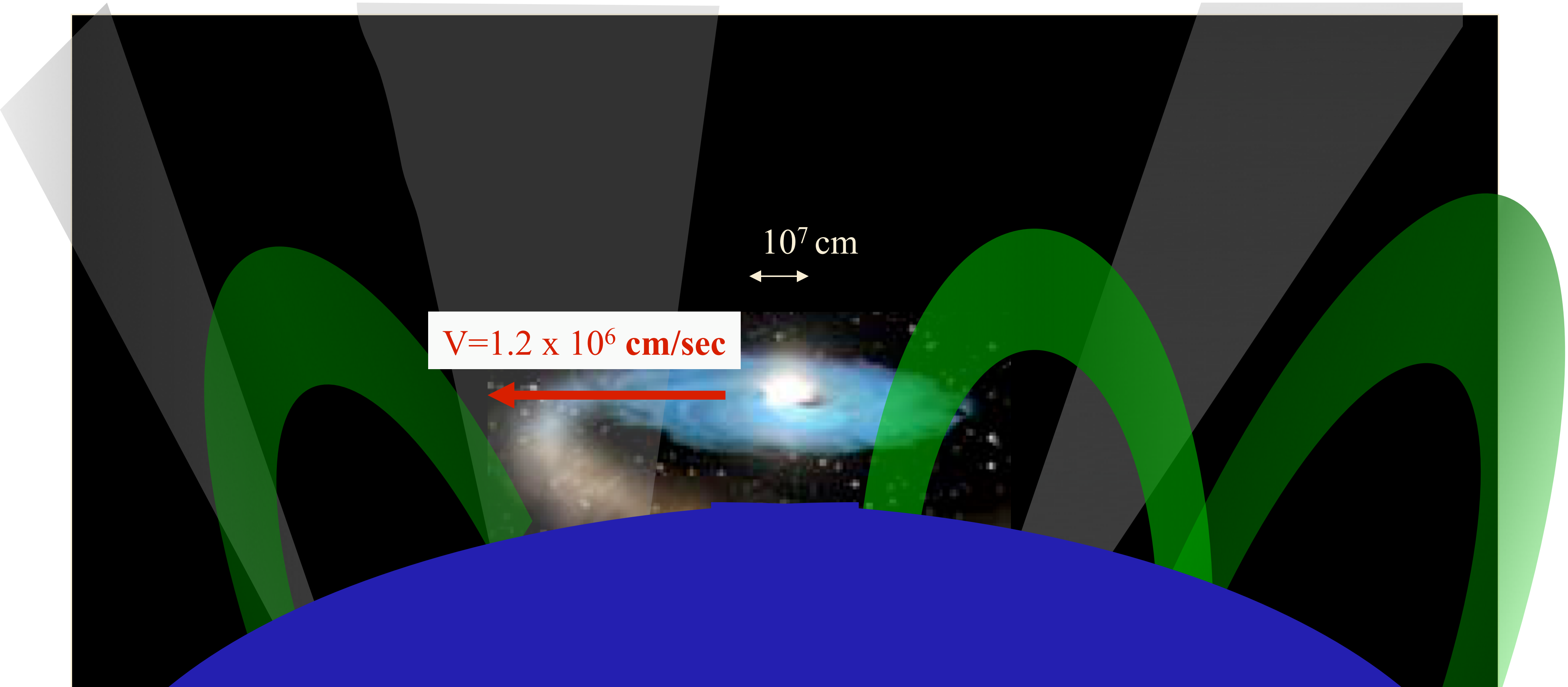
- If we assume the relative speed is that of the orbital motion of the binary.
- Thus the Relative speed is V_{orbit}~7.5×10^6 cm/sec
  - Cyg X-1 5.6 days
  - a sin i ~8.3Ro (Gies,Bolton et al. 2003)
  - V_{orbit}~7.5×10^6 cm/sec
- 1sec time resolution corresponds to the 7.5×10^6 cm of the accretion disk

Note :

Radius of ISCO of a 10Mo Schwartzchild BH is 10^7cm!!

Fast timing spectroscopy by IXO can resolve the accretion disk structure

- We can do a possible modeling of the brightness distribution of the accretion disk with a spatial resolution of $\sim 10^7$ cm.
- We can derive the radius of the inner most accretion disk.



The diagnostics of the accretion disk by absorption dip

Measurement of the inner most disk radius

ISCO or truncated?

We can discuss the spin of the BH.

4.Summary

○Short term variation (shots) of BHs

We can address the nature of the ISCO.

period of an orbital motion

velocity of an orbital motion

investigate the BH mass, and spin,

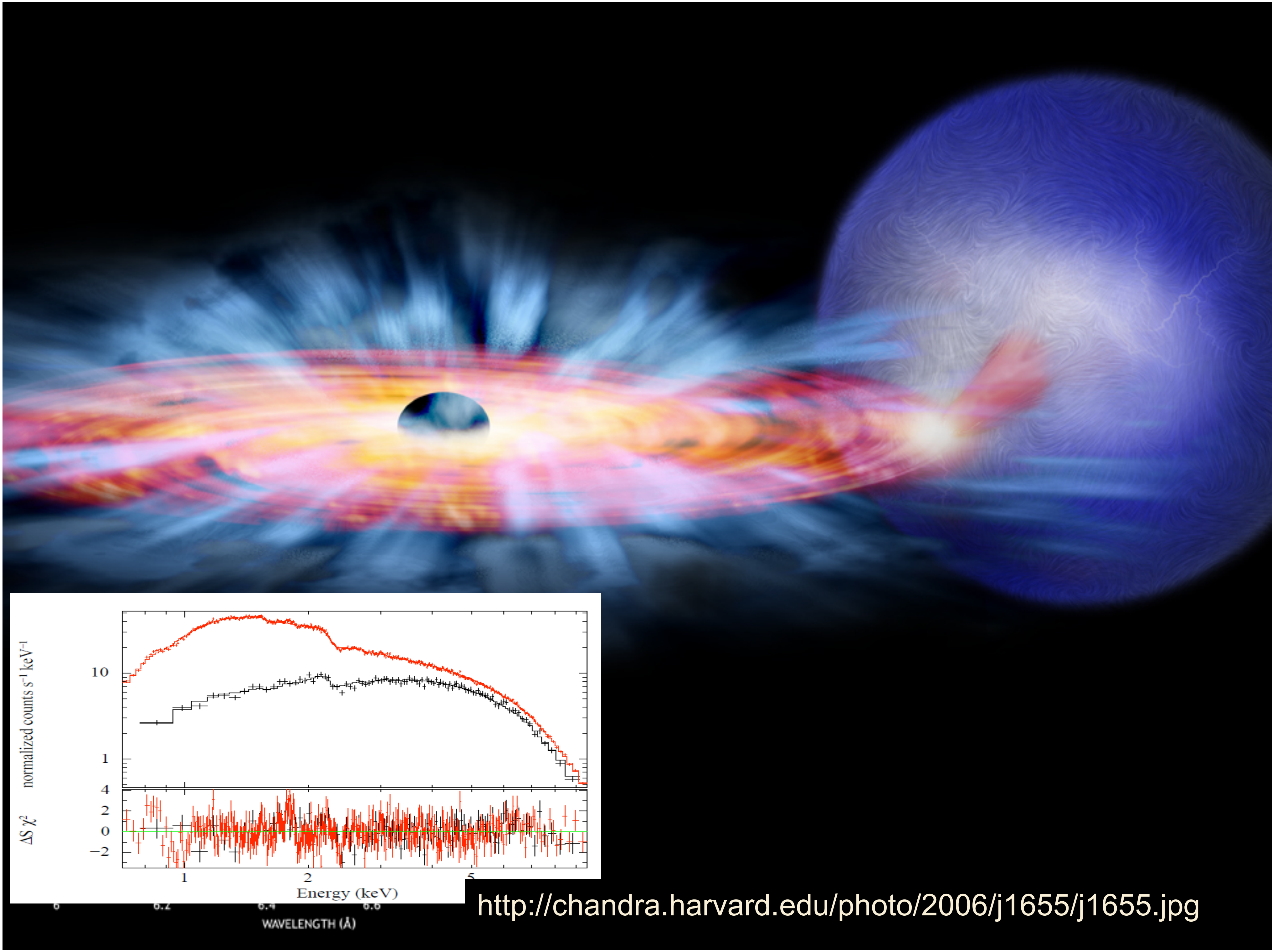
.

○Short term spectroscopy of Absorption dips

We can do a modeling the brightness distribution of the accretion disk

We can measure the inner most disk radius

- ISCO or truncated?
- Discuss the BH spin



http://chandra.harvard.edu/photo/2006/j1655/j1655.jpg

HTRS (High Time Resolution Spectrometer)

- Energy Range 0.3-20 keV
- Time resolution 10us
- Energy Resolution <150 eV at 6 keV
- 1 Crab count rate ~200 000counts/sec
- Count rate capability >10Crab
- Dead-time & pileup <1% @ 1Crab

Introduction

Many excellent Proposals from experts. (Science White Papers)

- Spin and other relativistic phenomena around black hole
  - C.S. Reynolds & J. Miller et al
- Fundamental Accretion Astrophysics
  - J.M. Miller, & C. S. Reynolds
- Stellar-Mass Blacj Holes and Their Progenirors
  - J. M. Miller, C.S. Reynold, P. Uttley
- The Behavior of Matter Under Extreme Conditions
  - Paerels et al.
- NS equation of state
  - Mendez, M.

Introduction

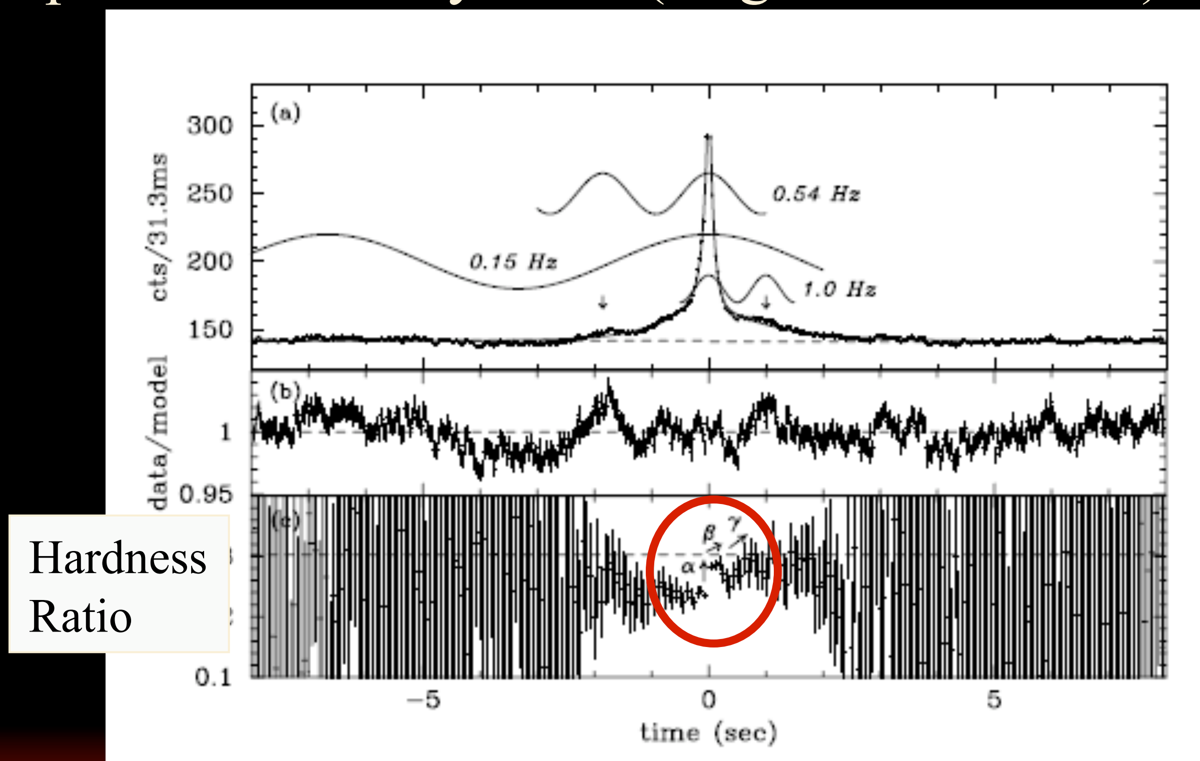
- 1.Broadening and skewing of the disk reflection feature
  - Black-hole spin, deviation from the prediction of GR
- 2. Accretion disk continuum
  - Inner most stable circular orbit
- 3.X-ray QPO
  - Spin measurement ? ISCO and spin
- 4.X-ray Polarimetry

Introduction

- 5. Iron line “arcs” being traced out on the time-energy plane
  - Reverberation of X-ray flares across the accretion disk
  - Size scale
  - Unambiguous proof of the origin of the X-ray lines as reflection feature
- 6. Low-energy time-delayed “tail”
- 7.Absorption due to orbiting material
- 8.X-ray Burst
  - Atomic photoelectric absorption in the burst spectra
  - QPO
  - Burst rise oscillation (Strohmayer et al. 1998)
- 9.Lag measurement

2. Short term variation

- The spectral study of the shots
  - Superposition of many shots (Nagoro et al. 2001)



•Spectral hardening at the peak

IXO can unambiguously access the emission from near the ISCO.

- Shot: local phenomena on the accretion disk
  - magnetic reconnection etc.
- Shot : accretion of an individual mass cramp.
- Short shots with a few m-sec are flares around the ISCO.
  - Time scale with a few m-sec is a time scale of a light travel time across an inner accretion disk around a 10Mo black hole
    - $1\mathrm{ms} \sim \frac{2G}{c^3}\frac{M}{10M_{sun}}$
  - The Kepler orbit has the velocity of
    - $v_k = c\sqrt{\frac{r_s}{2r}}$
    - $P_{orb} \sim 5(\frac{M}{10M_{\mathrm{sun}}})\mathrm{ms}$ a t $3r_s$

IXO can unambiguously access the emission from ISCO

Energy Spectra of the short shots (especially Iron Line)

~20 counts/1msec/100mCrab by IXO

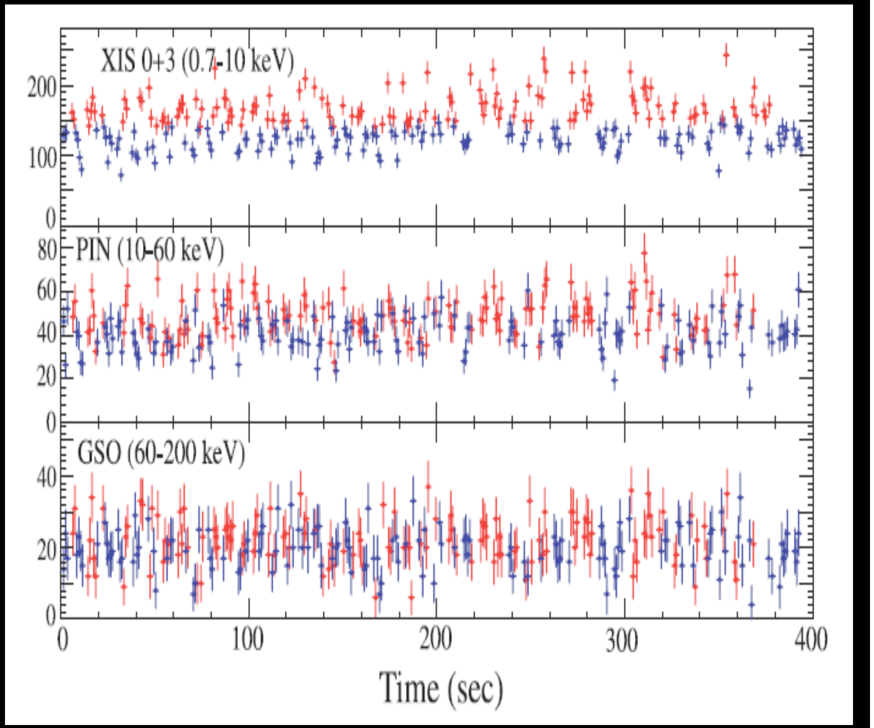
Extract shots and composite 1000 short shots

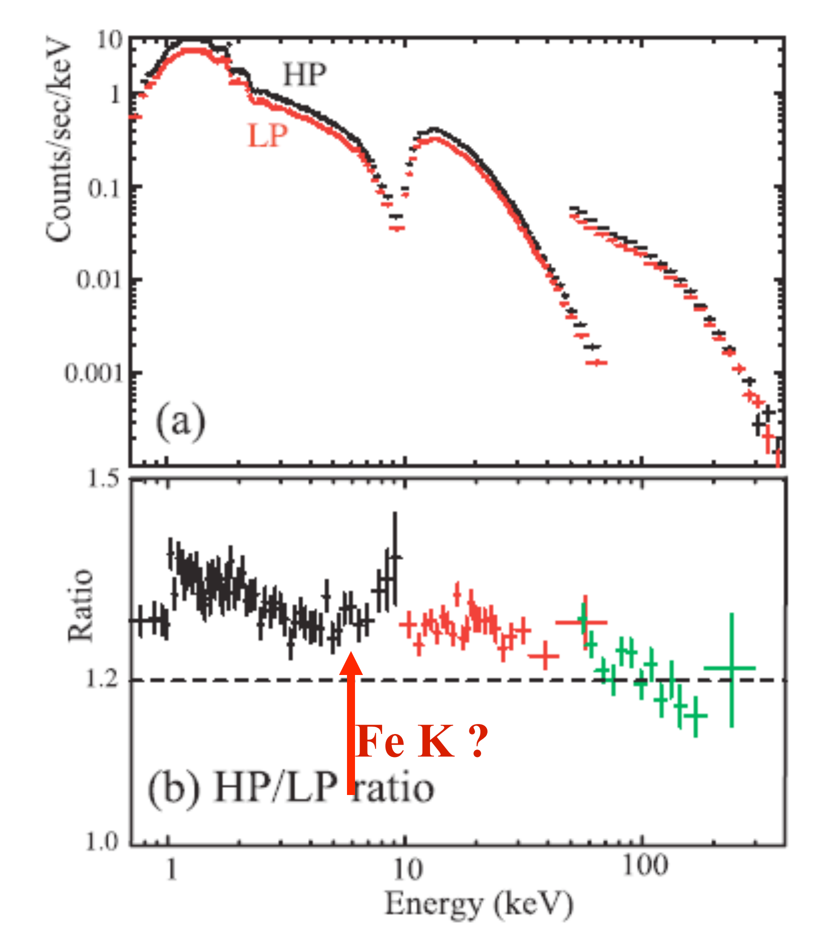
Spectral evolution with 1msec resolution

Extract iron line behavior around the ISCO

Unambiguous evidence of the iron lines from ISCO.

IXO can unambiguously access the emission from ISCO





Hint of an Iron line emission (Makishima et al. 2007)