# BLACK HOLES (AND NEUTRON STARS) IN X-RAY BINARIES:

## Evolution and Accretion states


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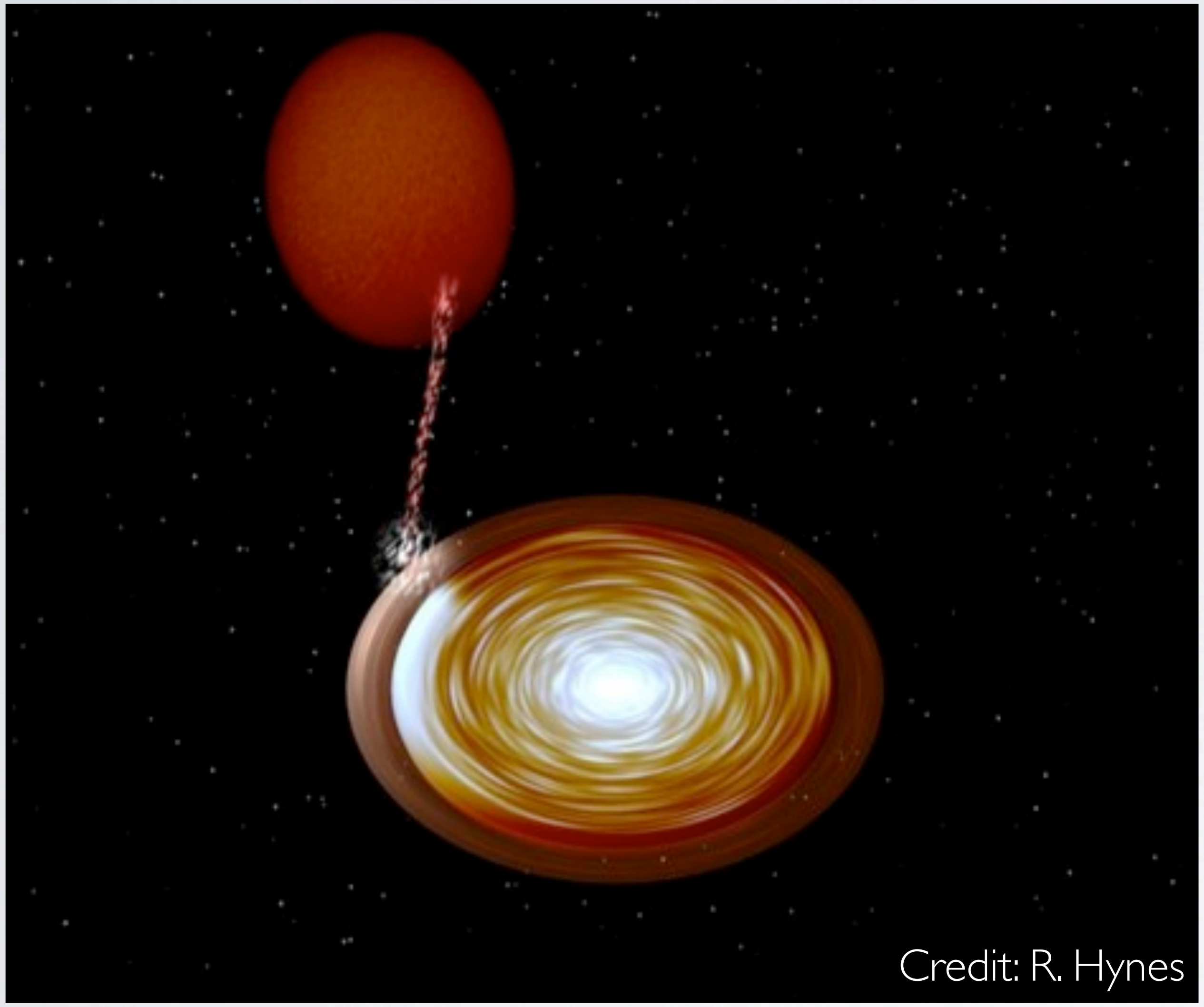
# Low Mass X-ray Binaries (LMXBs)

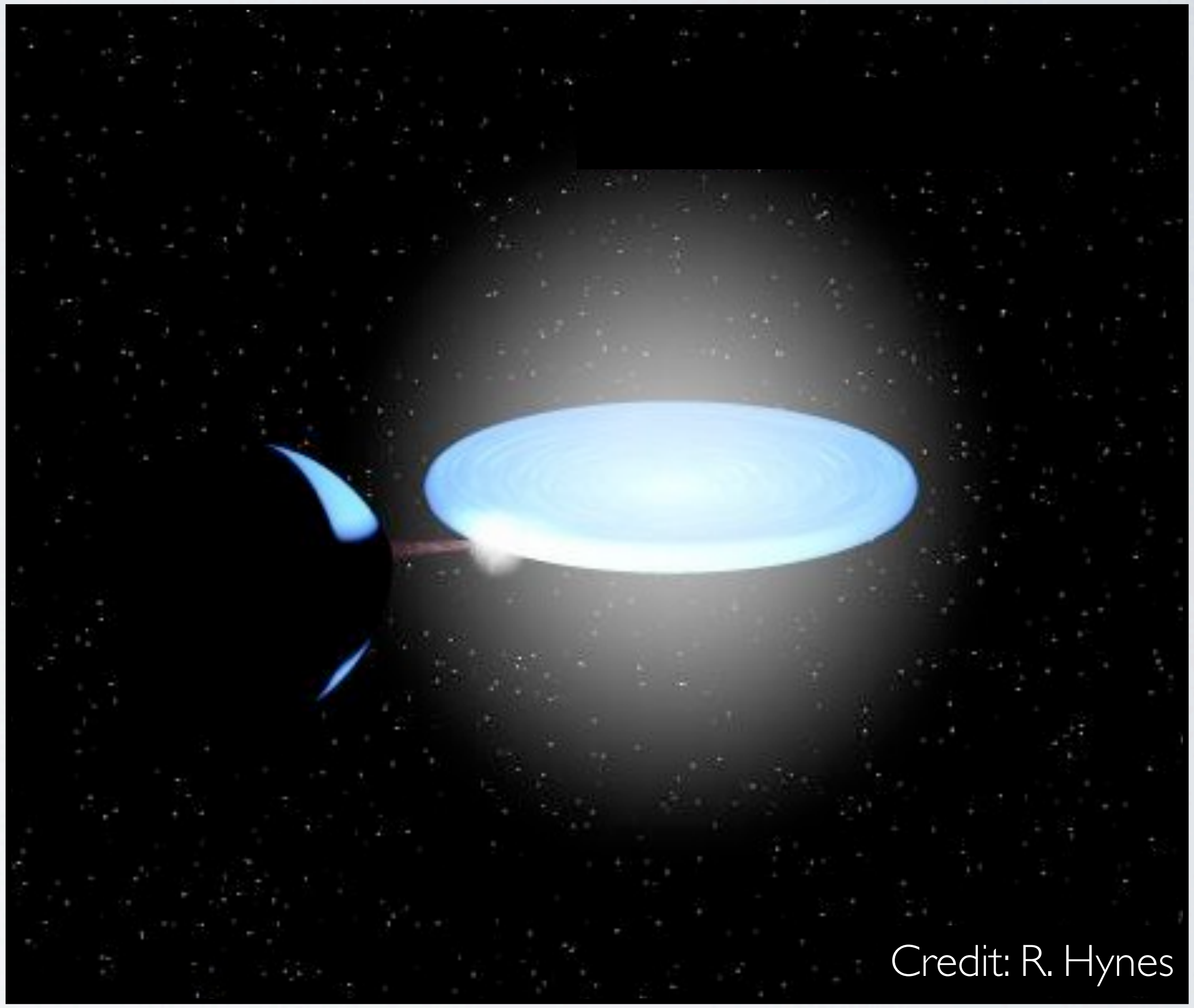
Normal ($<1 M_{SUN}$ ) star transferring matter onto a compact object (Black hole / Neutron star)

XRBs provide the best laboratories to study BH/NS

# Most of the **BLACK HOLES** are **TRANSIENT**

## Quiescence / Outburst




↓ Dynamical Studies

↓ Accretion Processes
General relativity

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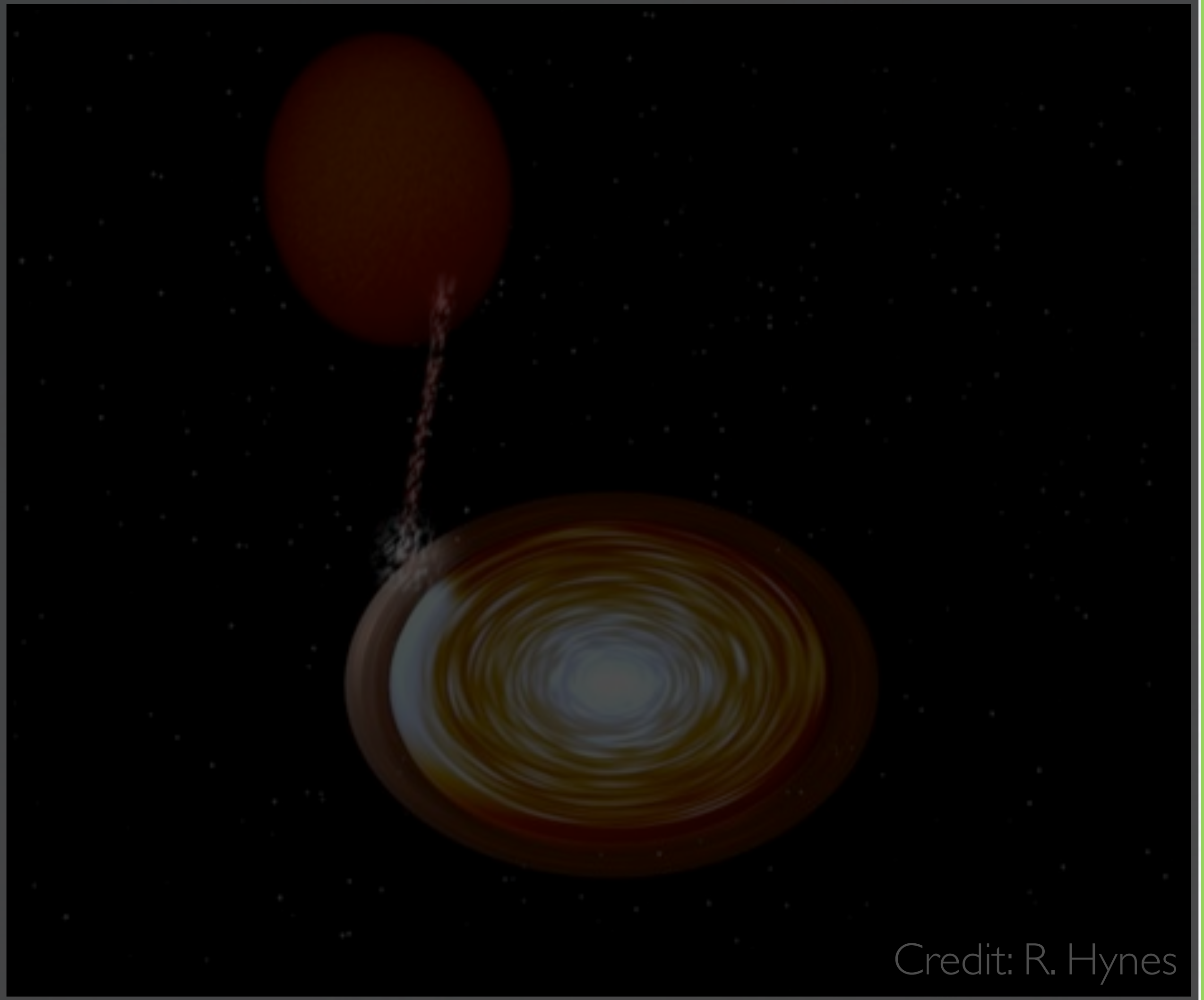
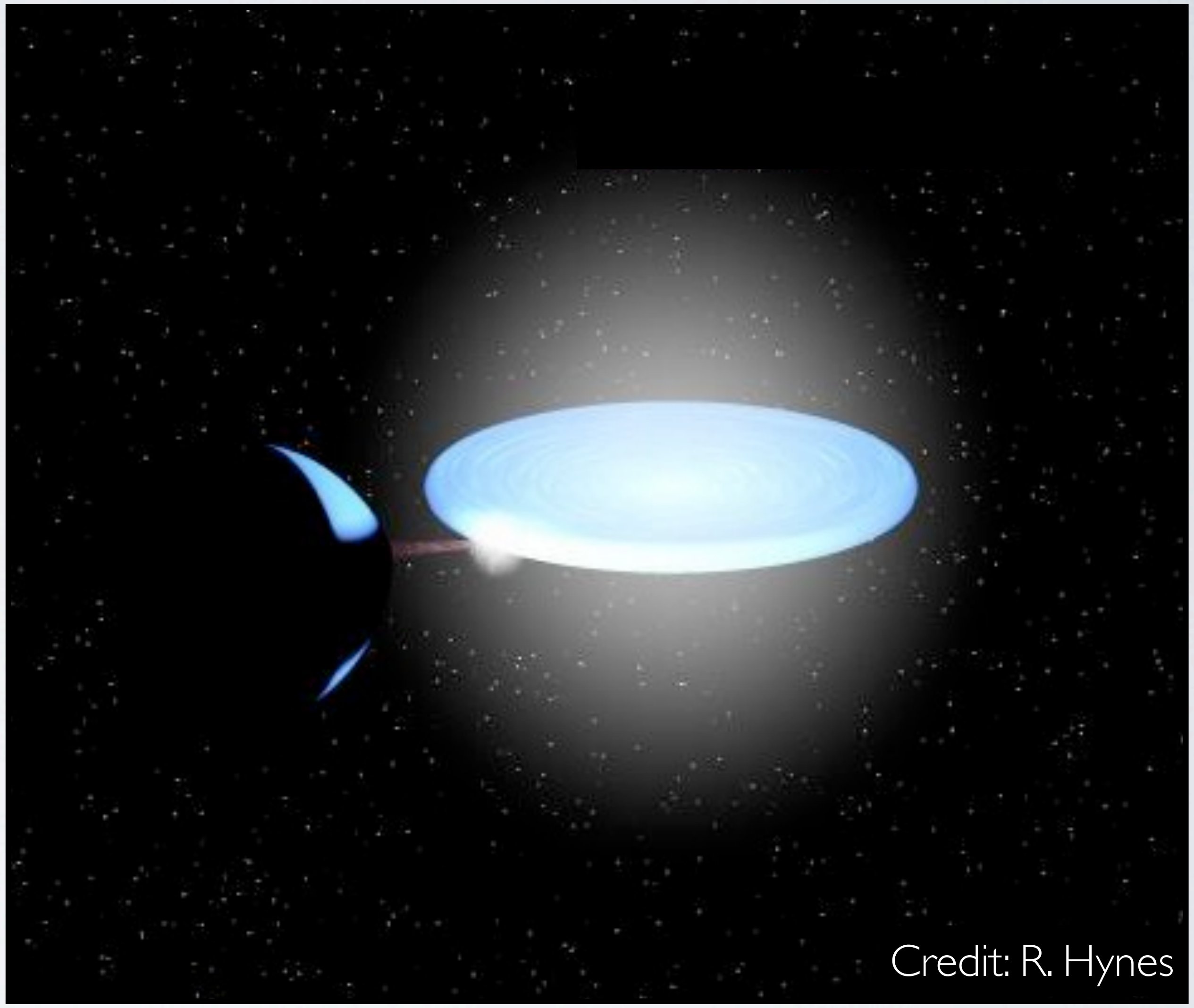
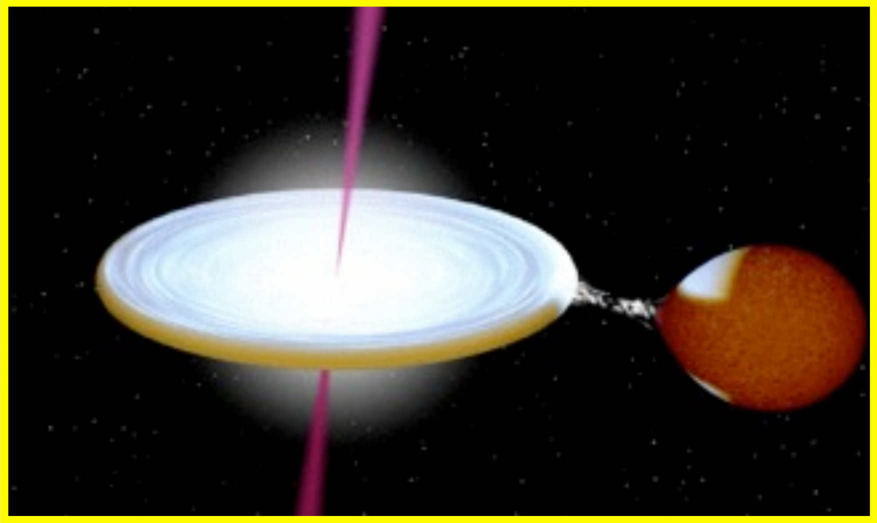



Dynamical Studies




Accretion Processes
General relativity

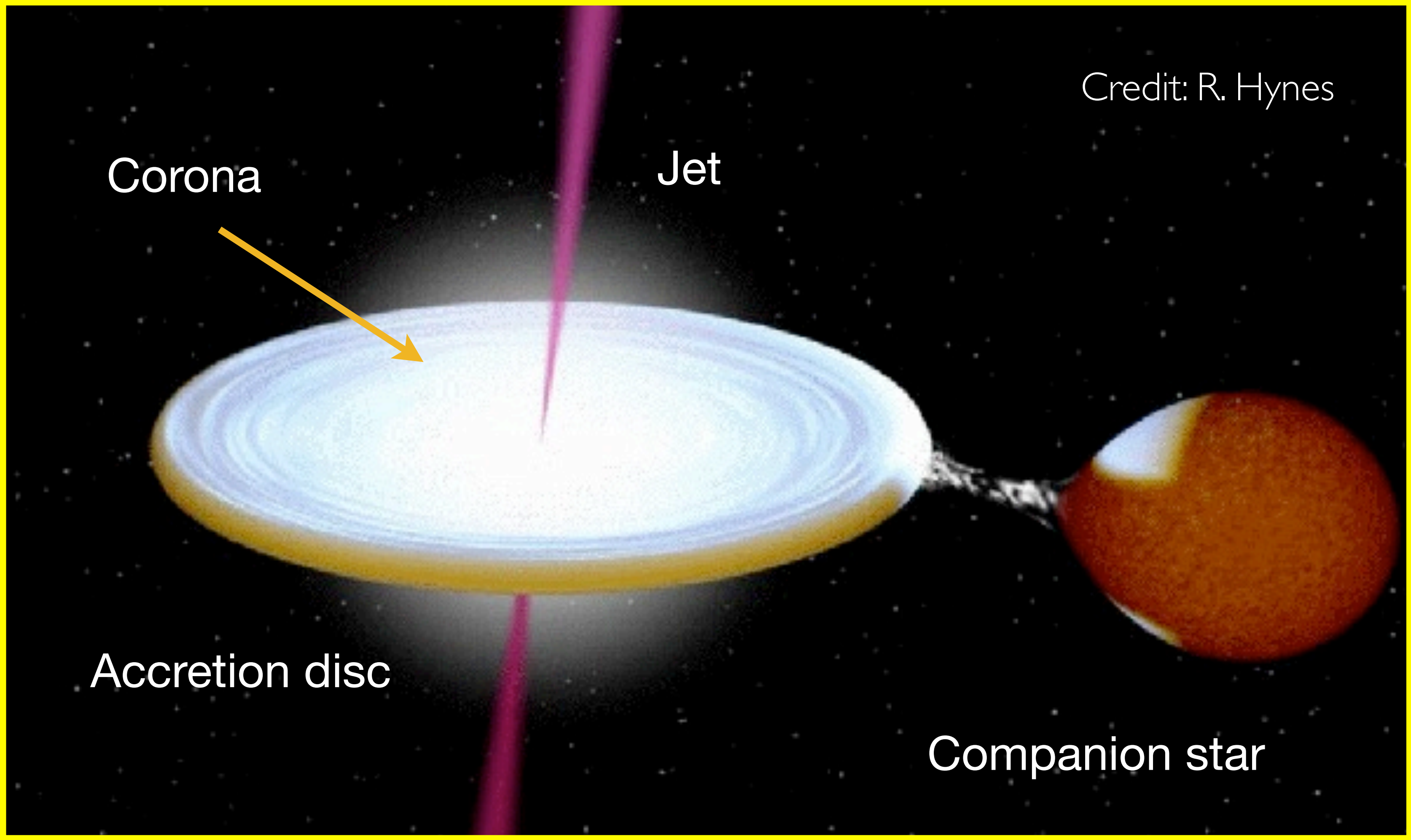


# OUTLINE

**I. Accretion state picture for black hole Binaries:** similarities to Neutron stars

**II. Inclination effects:** how they do affect the Observed outburst evolution

# Black Holes in Outburst



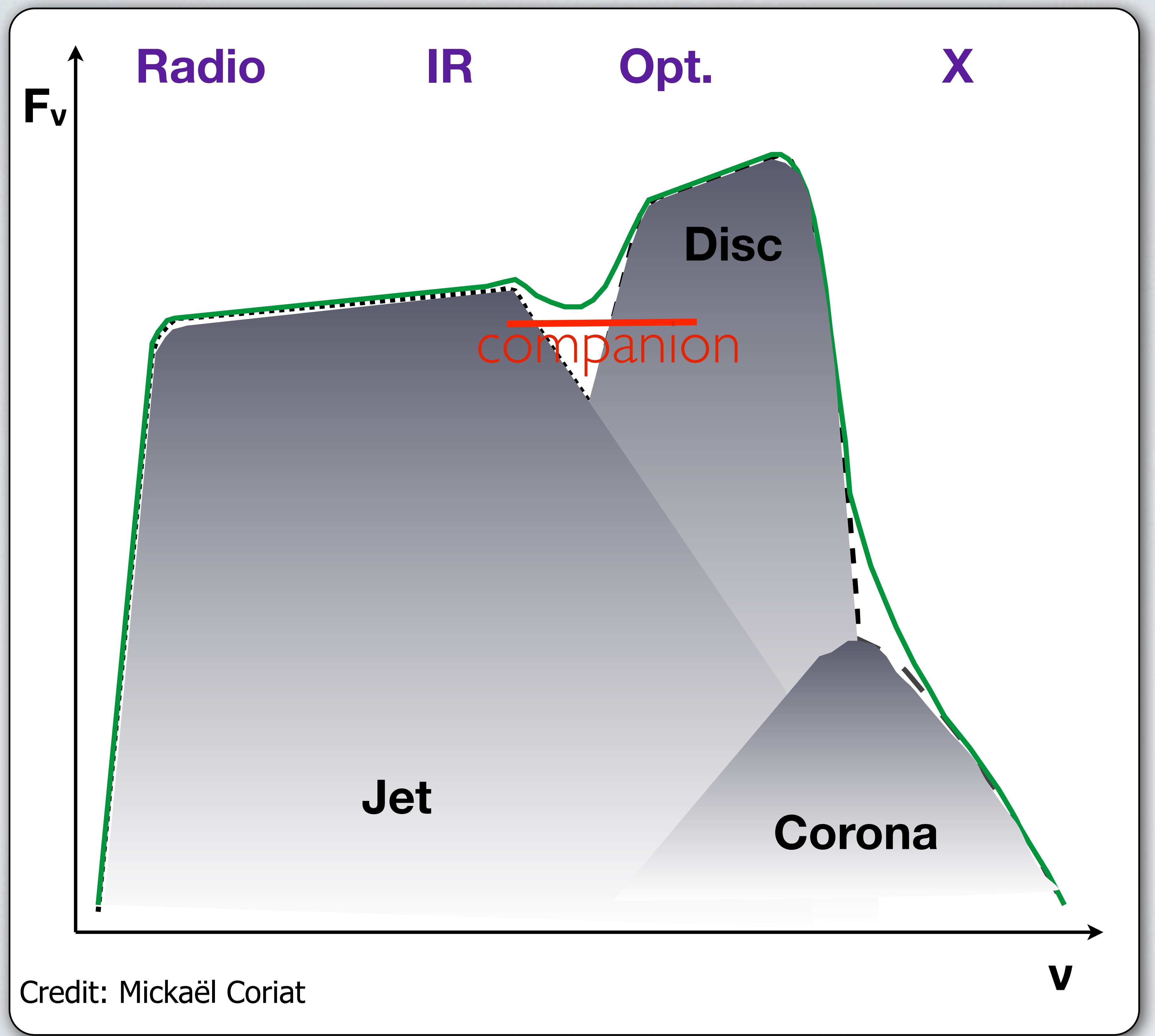

**Corona:** Hard X-rays (up to 100 keV-1MeV)

**Accretion disc:** Soft X-rays (few keV) to Infrared

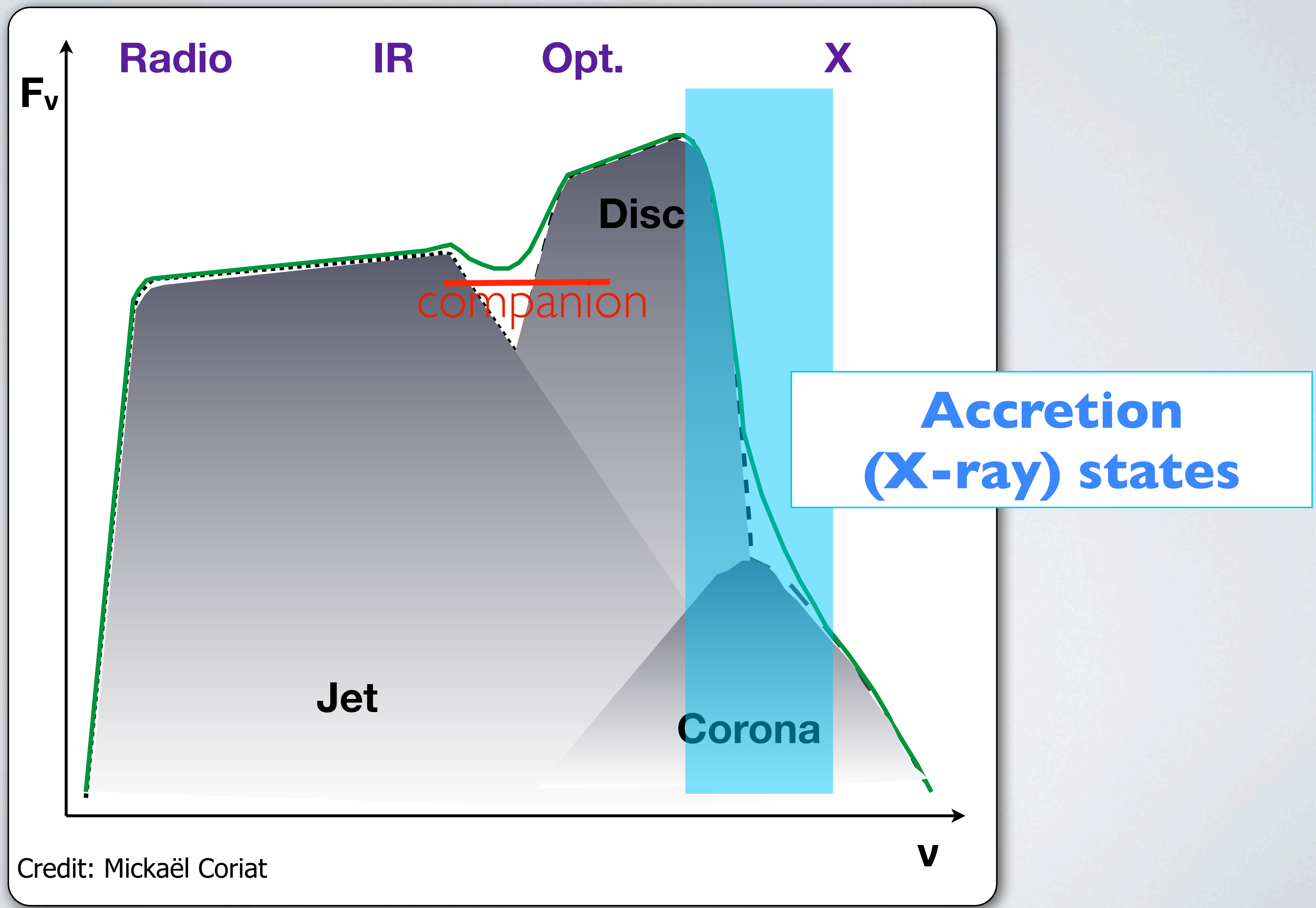
**Companion:** only through X-ray reprocessing

**Jet:** Radio to infrared/optical to high-energies(?) **[NOT ALWAYS]**

# MULTIWAVELENGTH SOURCES

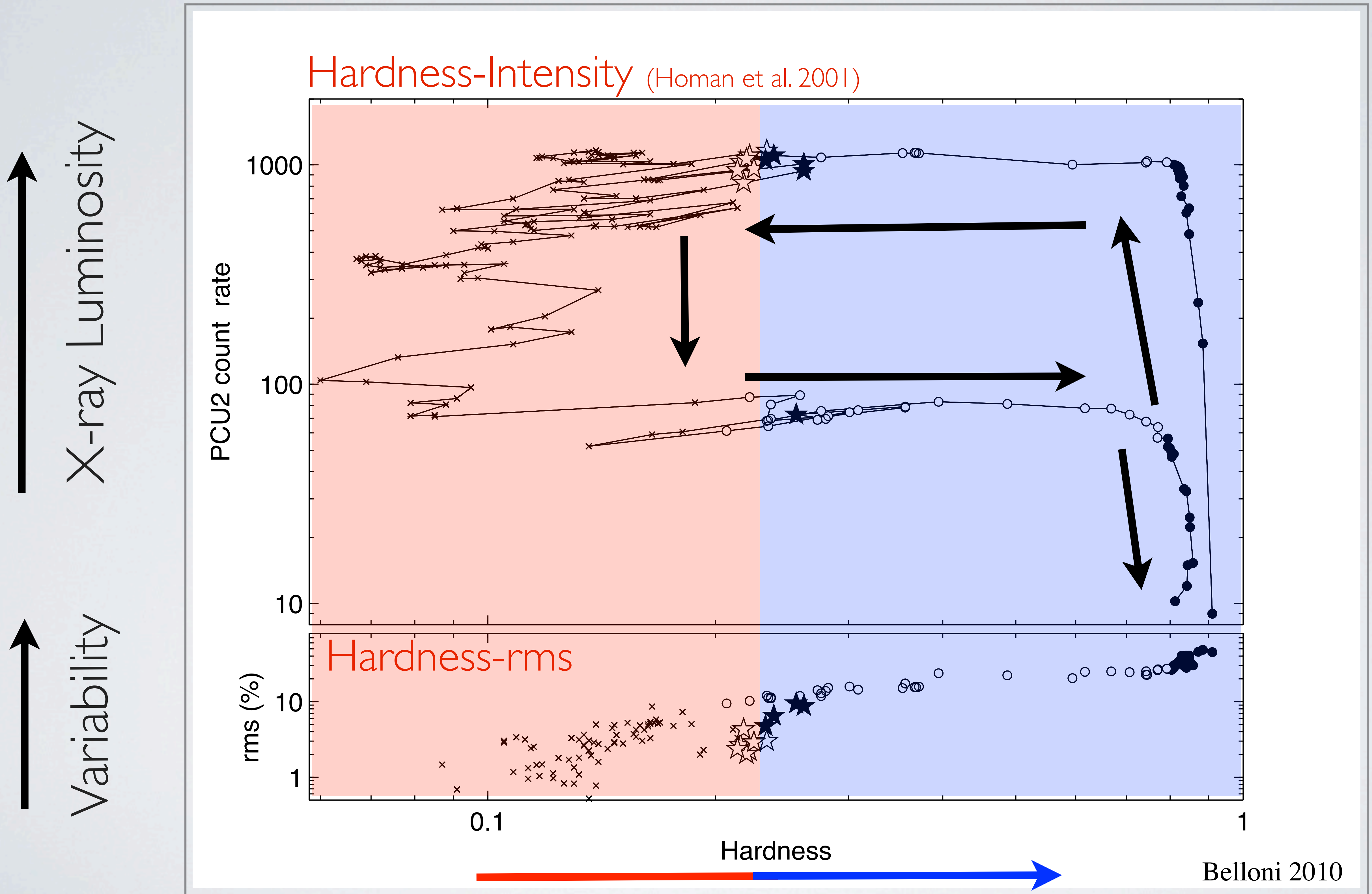


# MULTIWAVELENGTH SOURCES



# BLACK HOLE IN OUTBURST: HYSTERESIS

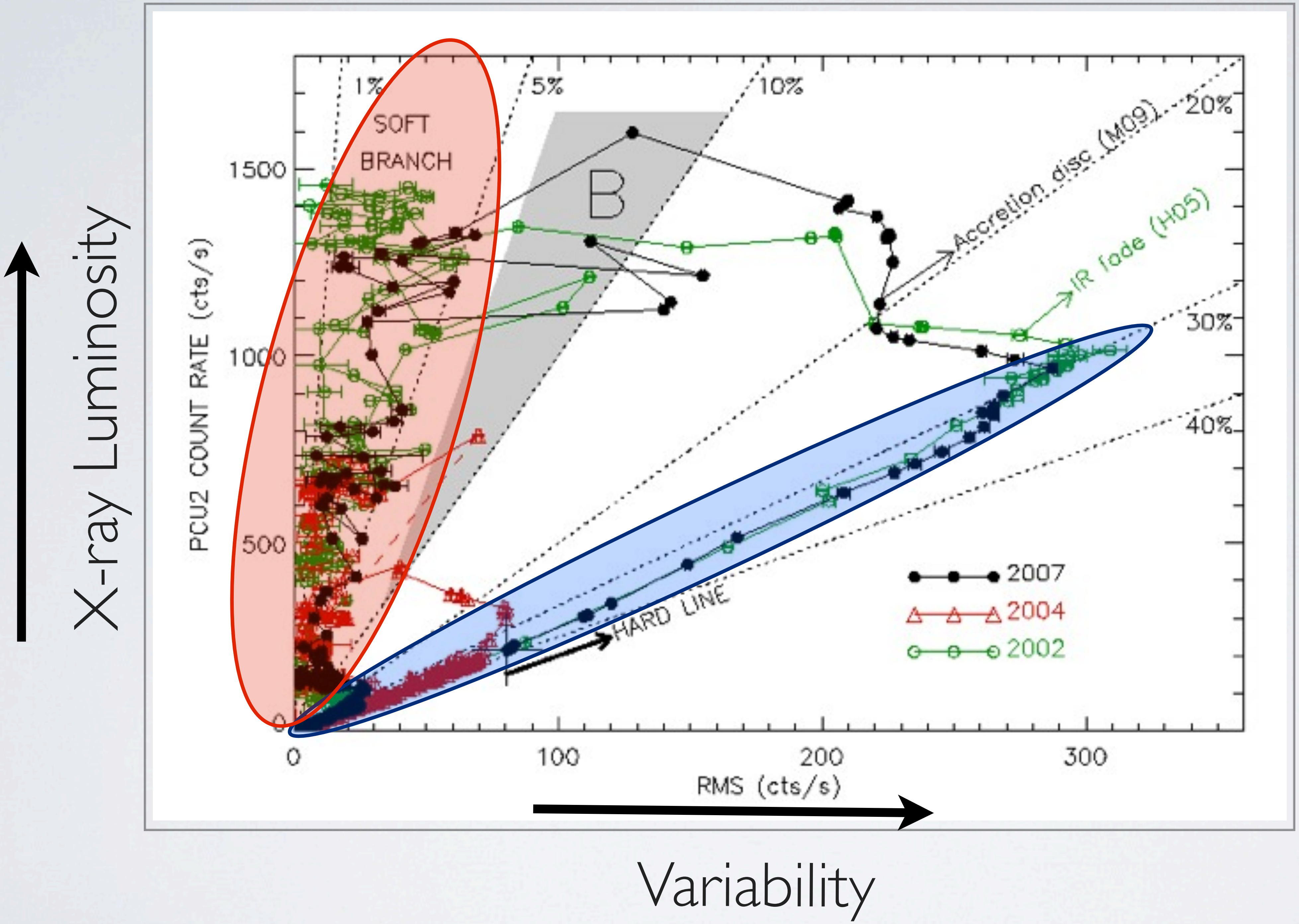
Daily basis monitoring (RXTE)




How hard the spectrum is

# THE VARIABILITY DIAGRAM

Muñoz-Darias, Motta & Belloni, 2011



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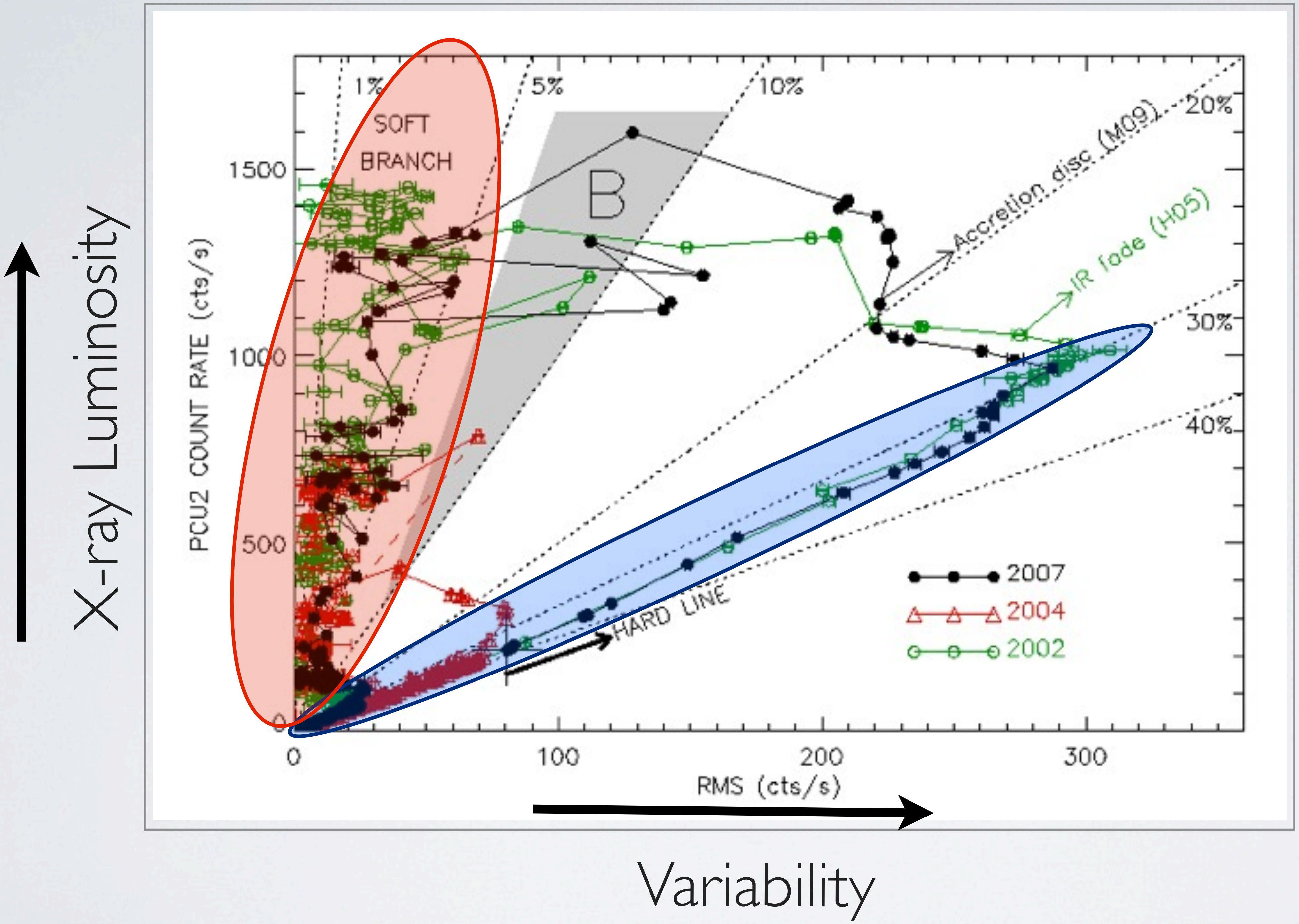
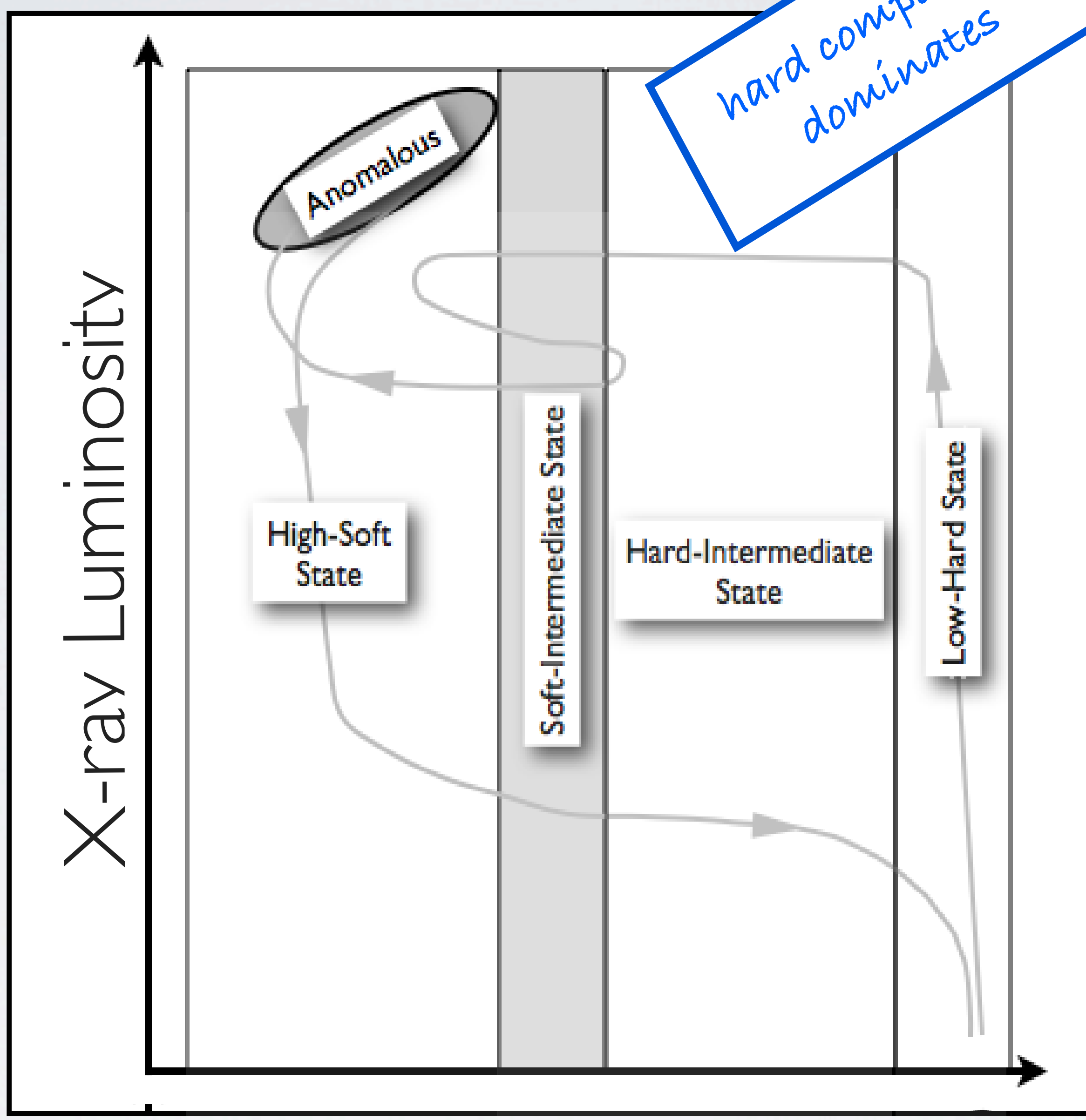



- Other state-dependent timing features (e.g. Oscillations)

# TWO MAIN ACCRETION STATES

X-ray Luminosity



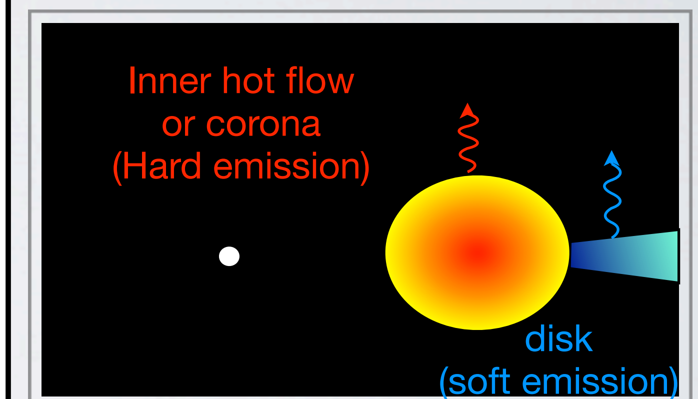

hard component dominates

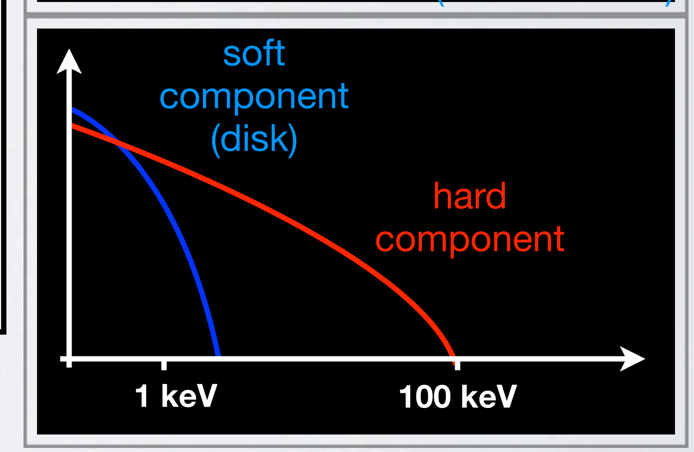
Belloni 2010

How hard the spectrum is

(Low)**Hard state:**

- hot corona
- cold disk, large inner radius



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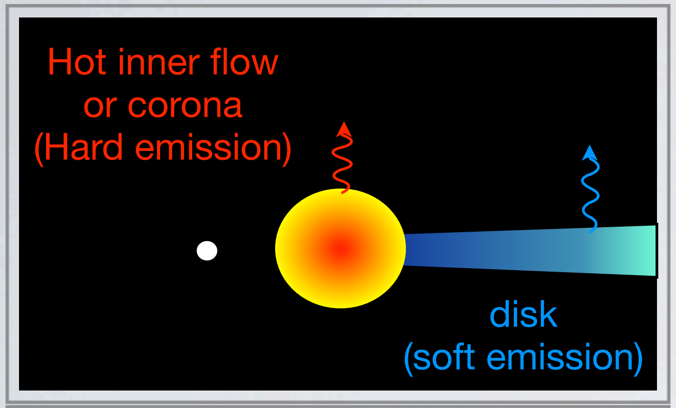
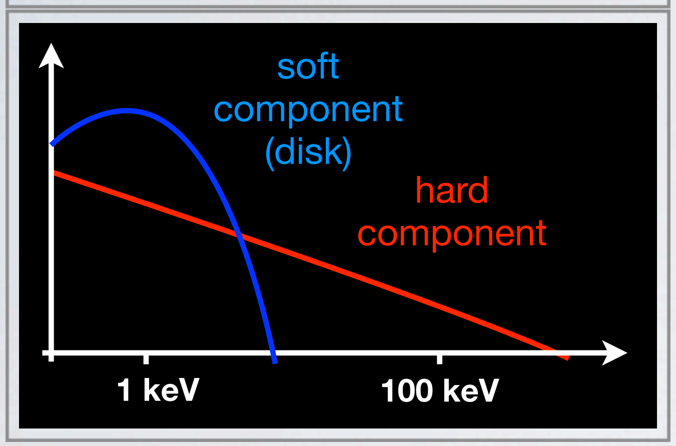
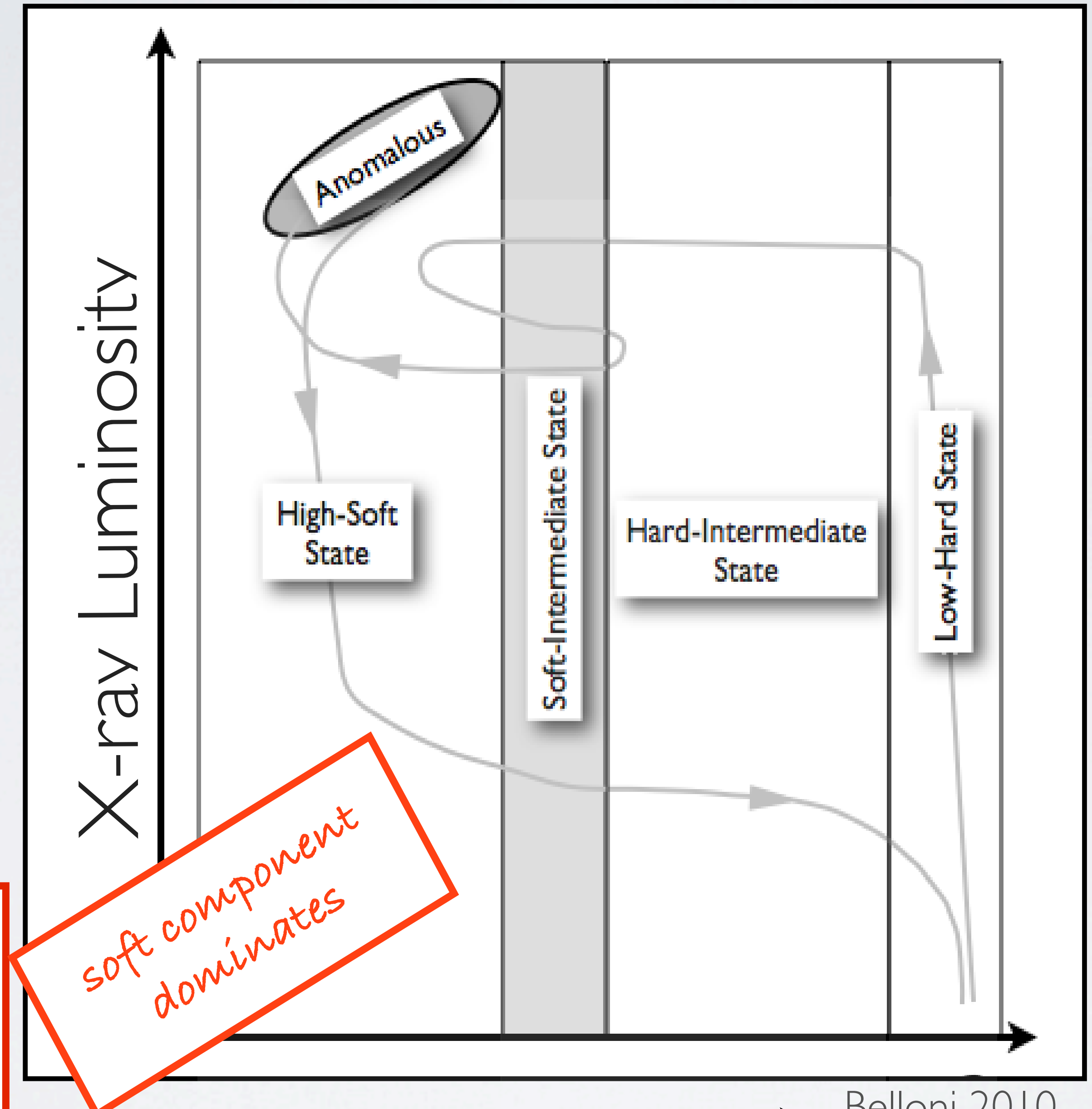


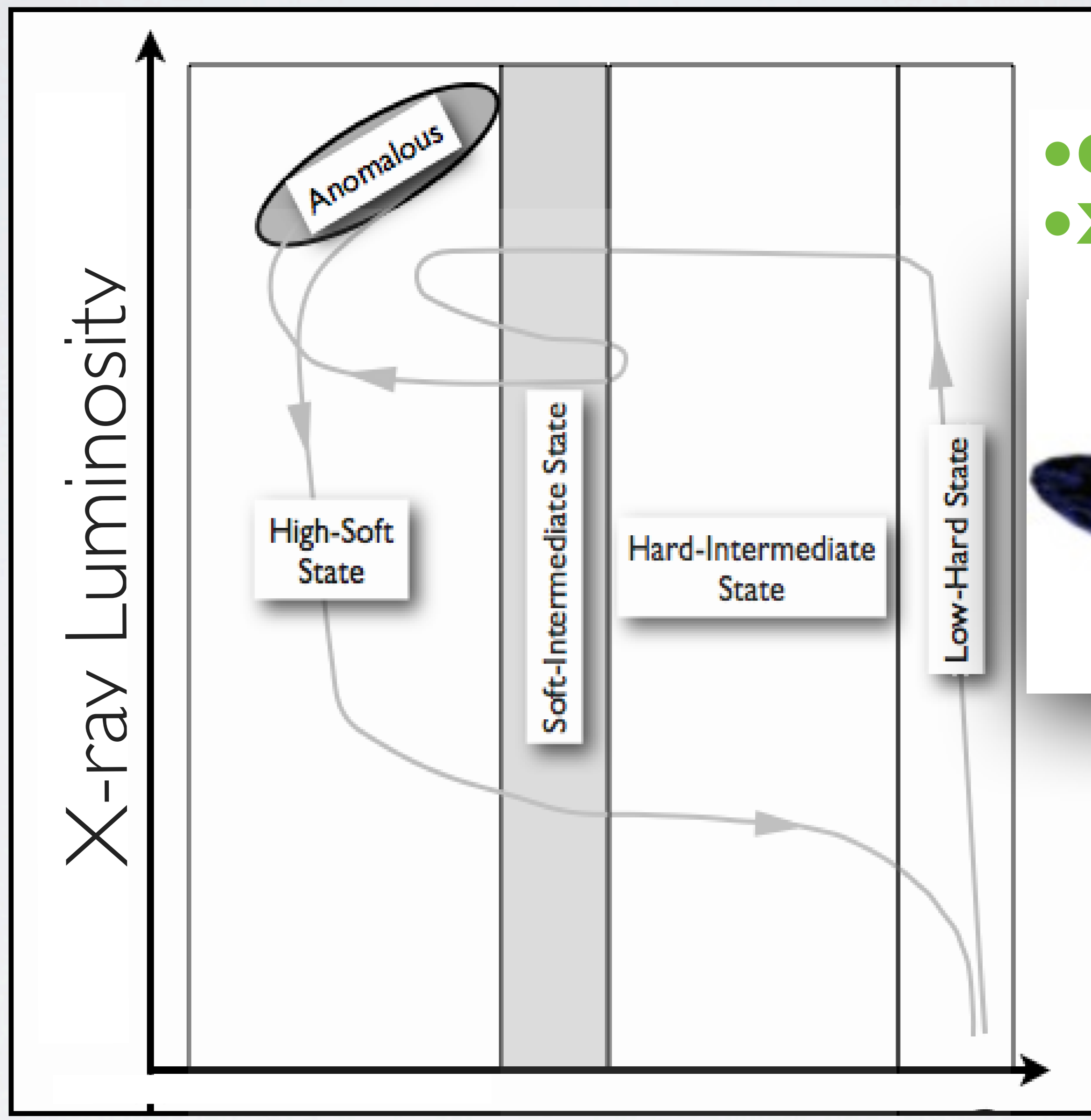

Belloni 2010

How hard the spectrum is

(High)**Soft state:**

- corona (different geometry?)
- hot disk, small inner radius

# STATE-DEPENDENT RADIO JETS



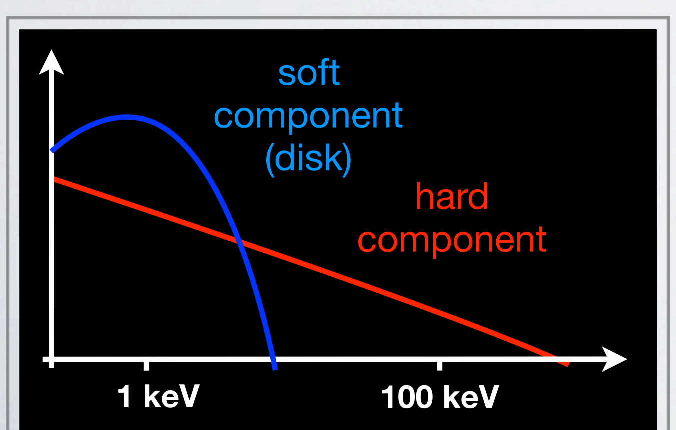

Belloni 2010

How hard the spectrum is

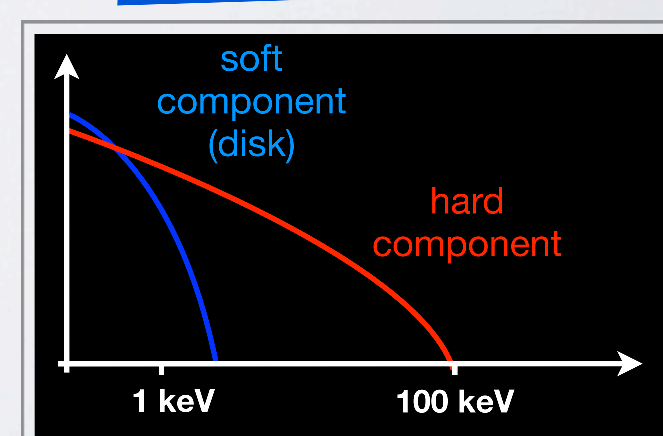
- **Compact jet**
- **X-ray/Radio correlation**

(Gallo et al. 2003)

soft component dominates

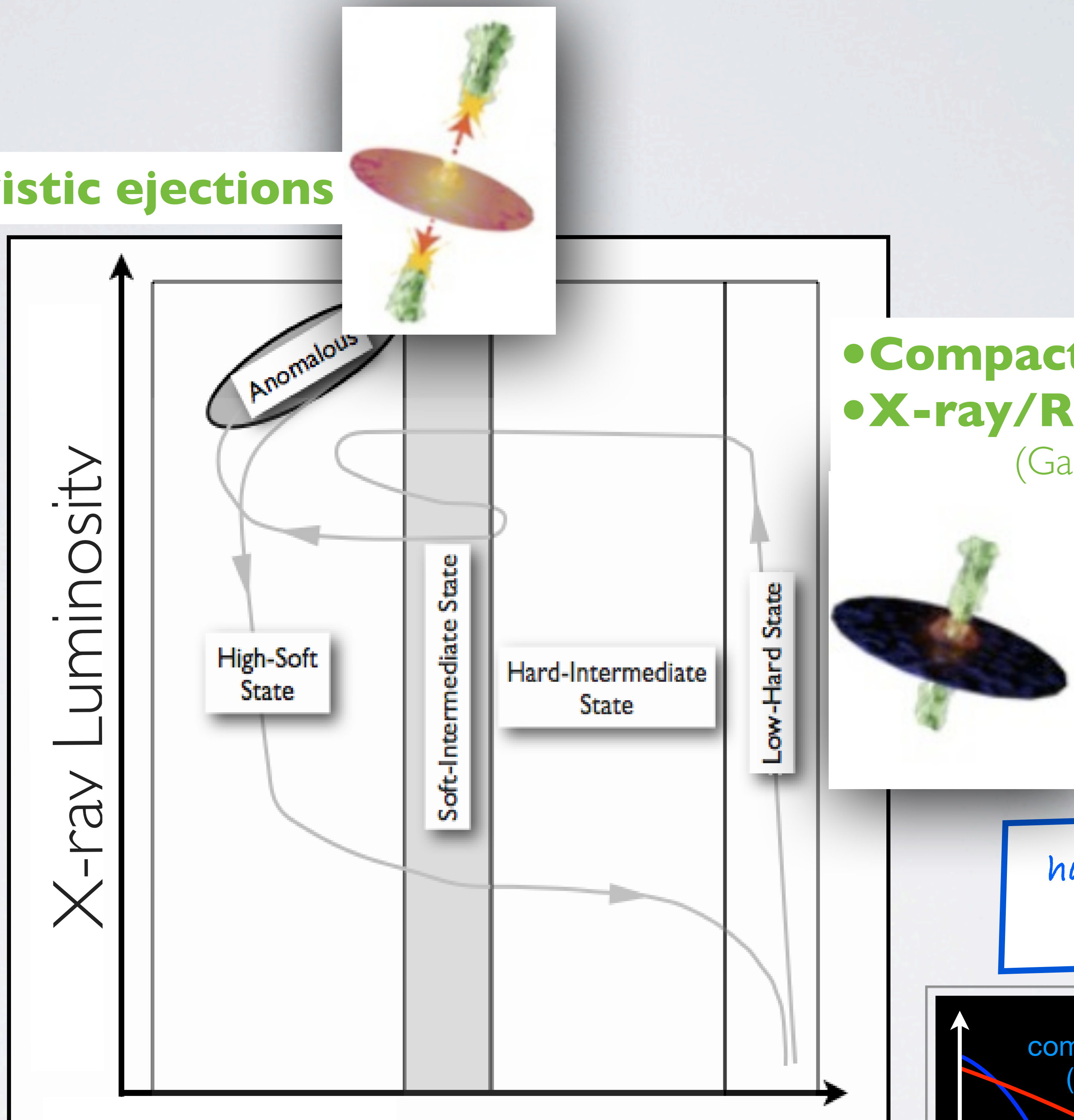



hard component dominates



# STATE-DEPENDENT RADIO JETS

**Relativistic ejections**

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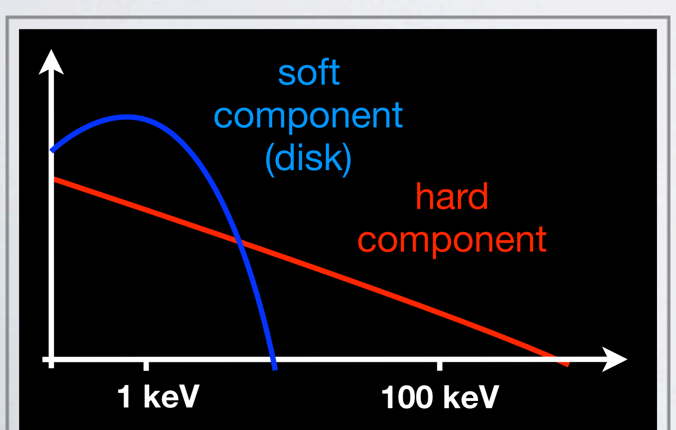
(Gallo et al. 2003)

How hard the spectrum is

*soft component dominates*

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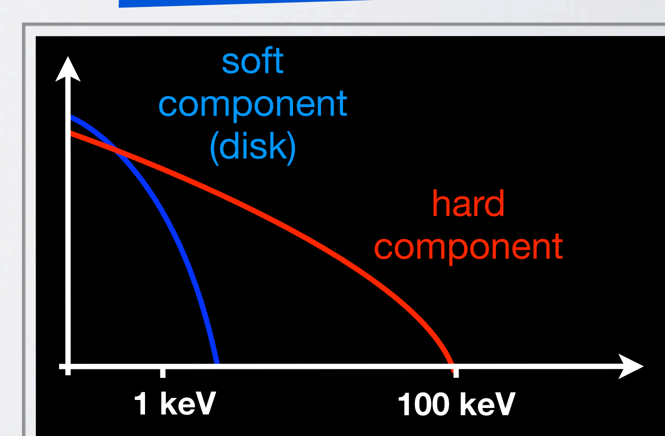

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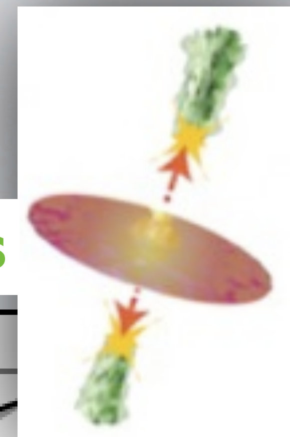
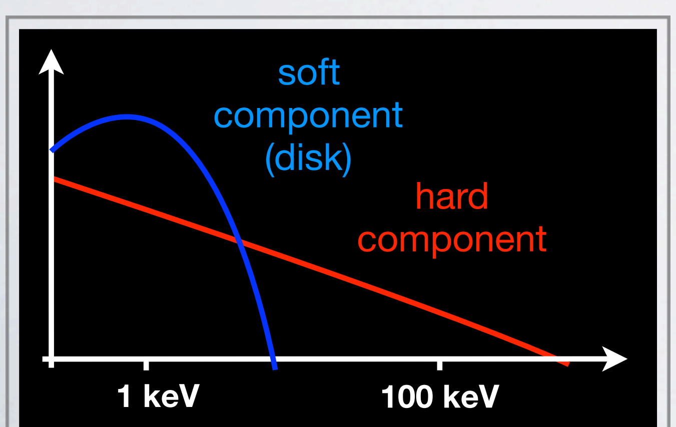


**Soft State: NO JET**
(e.g. Russell et al 2011)

*soft component dominates*





Belloni 2010

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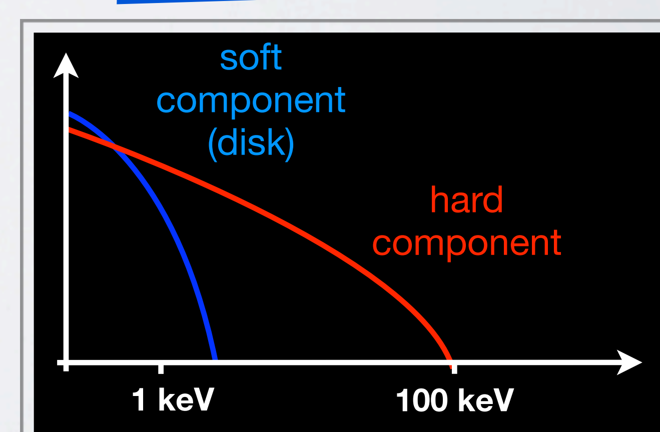
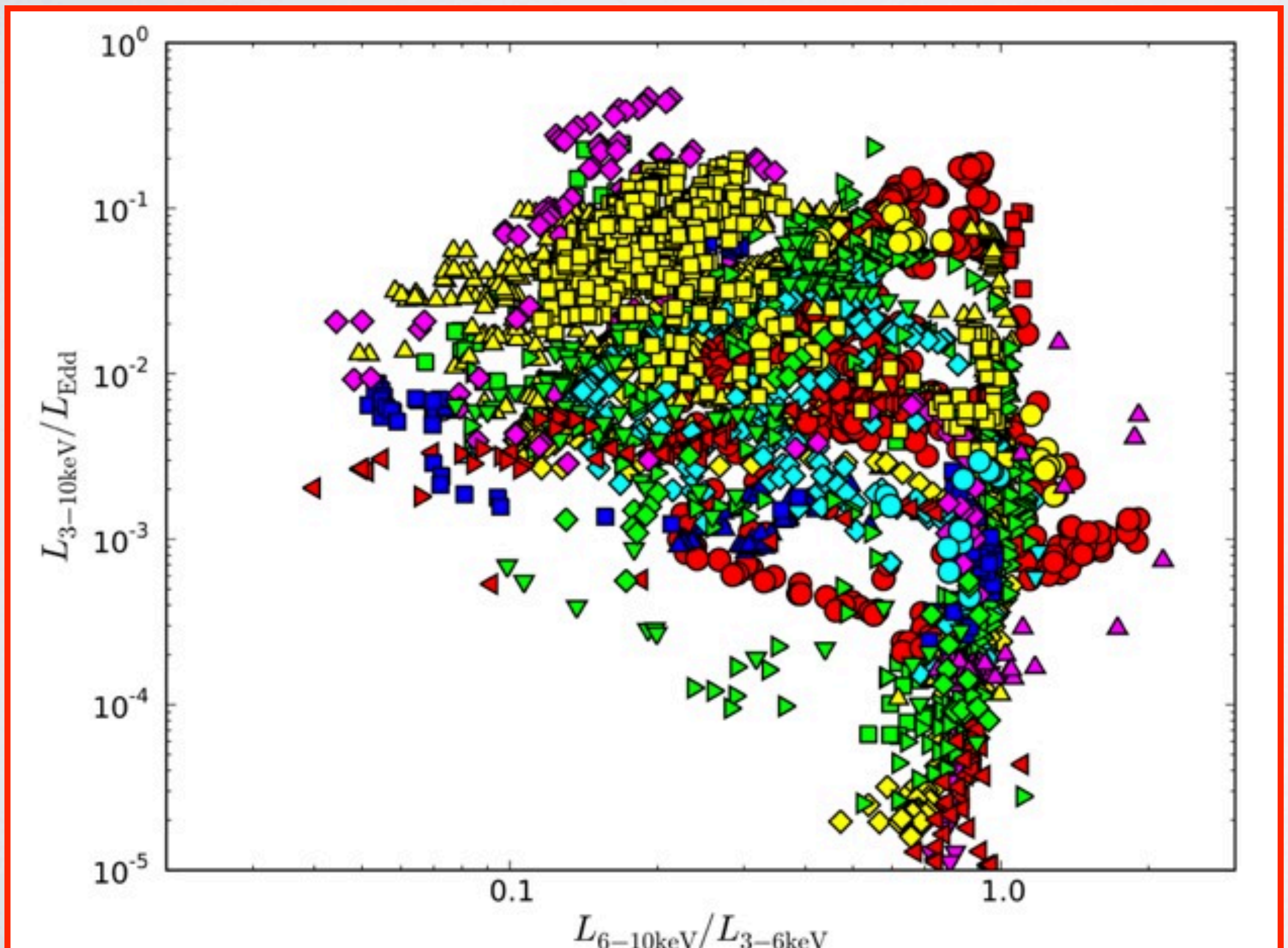


# GLOBAL STUDIES: BLACK HOLES

- Large data base (~15 years of RXTE monitoring): systematic studies
- **25 Black Hole candidate studied** by Dunn et al.

Credit: Nasa




Dunn et al. 2010

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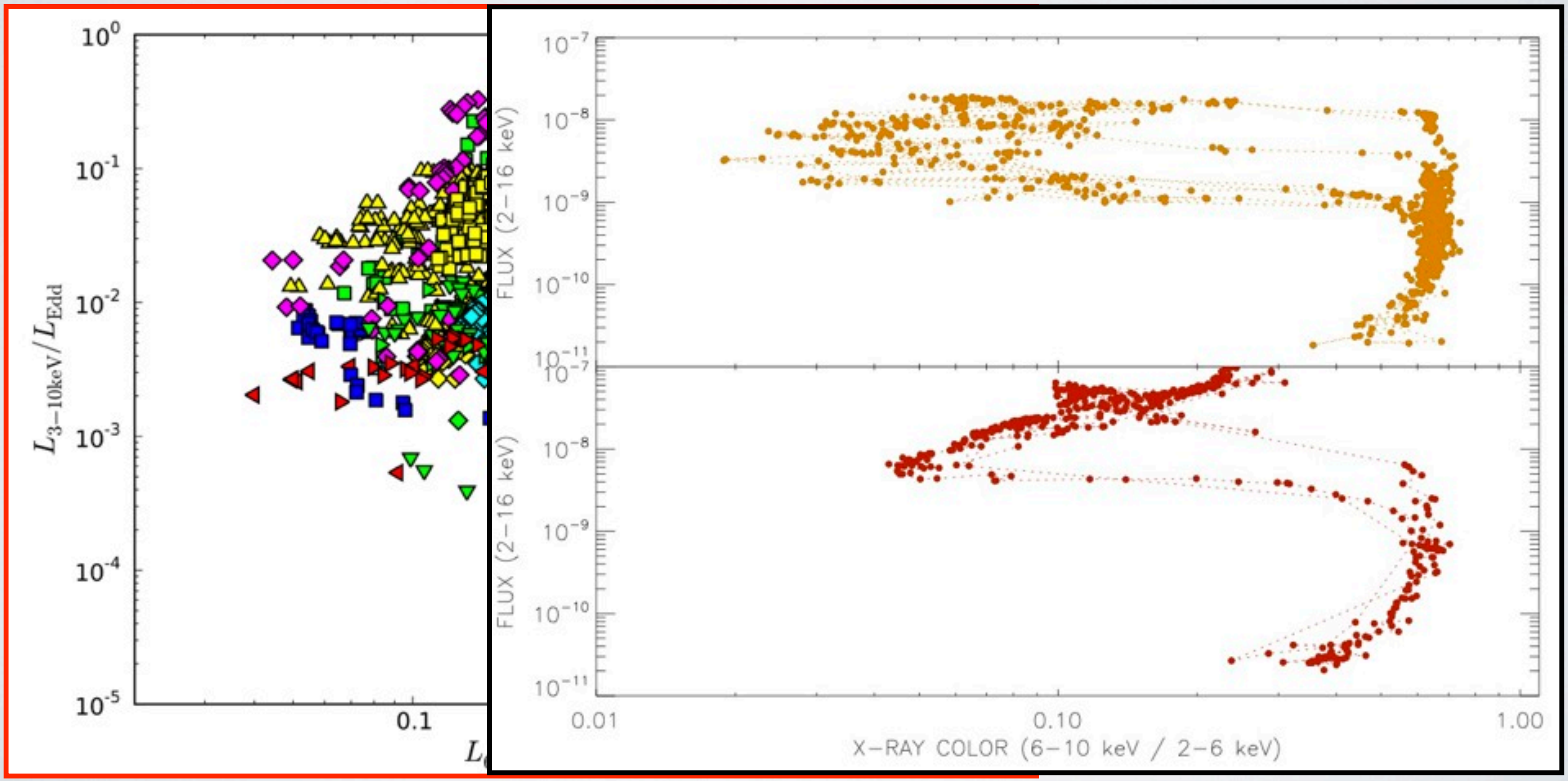
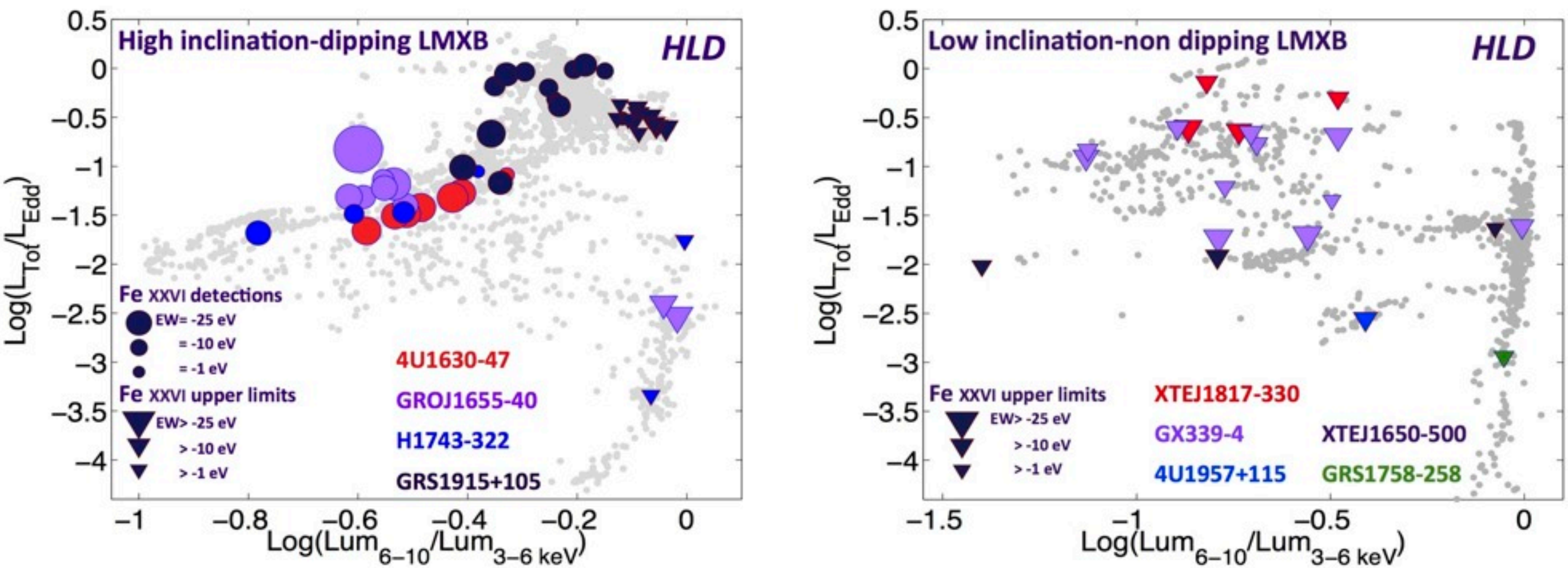



Dunn et al. 2010

# GLOBAL STUDIES: BLACK HOLES

- RXTE monitoring + Detailed studies using XMM and Chandra

Credit: Nasa

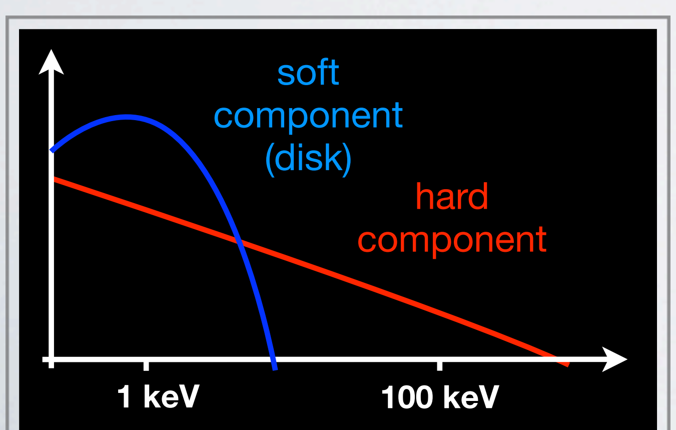


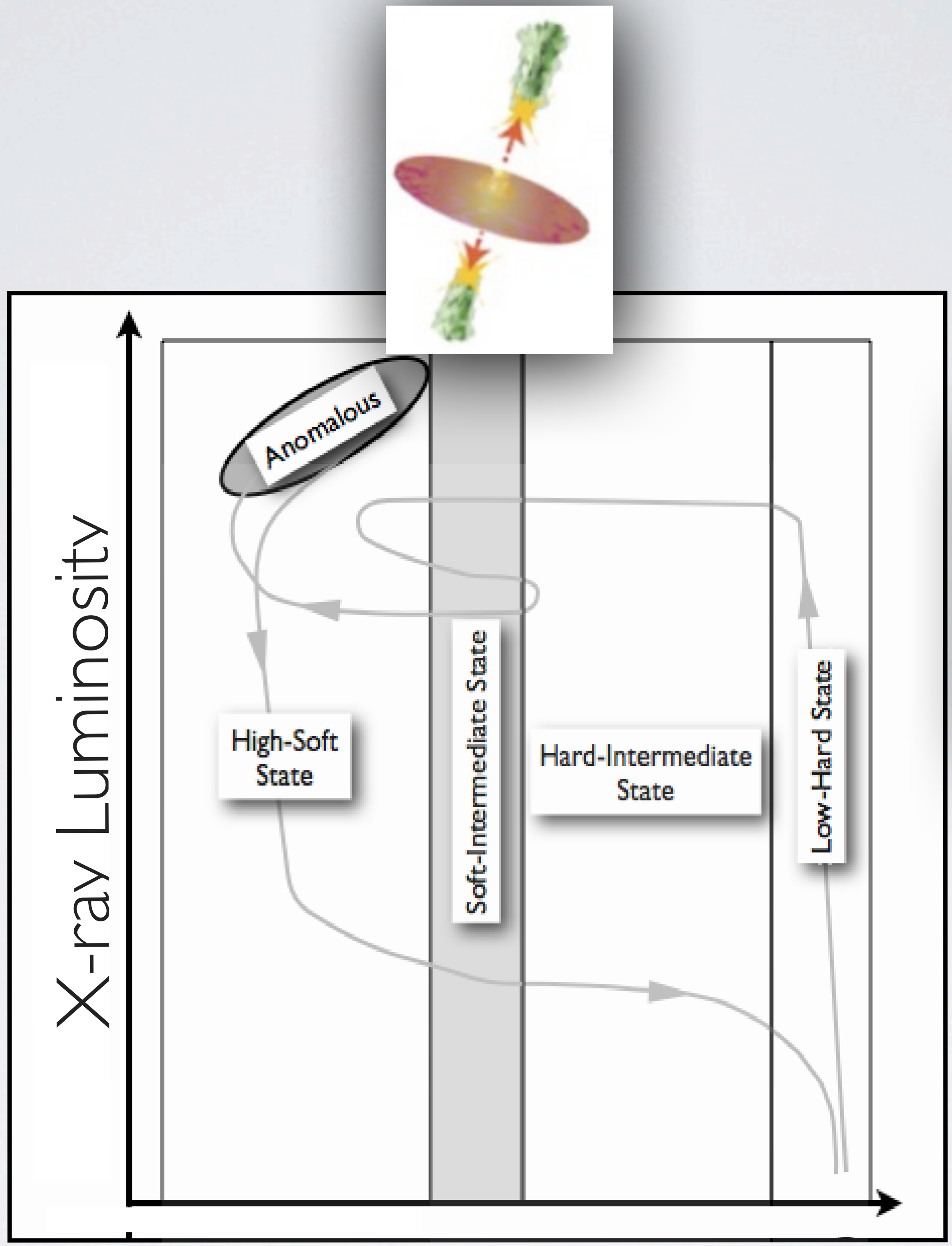

Ponti et al. 2012

# TOWARDS A MORE COMPLETE PICTURE...

**Soft State: NO JET**
(e.g. Russell et al 2011)

soft component dominates

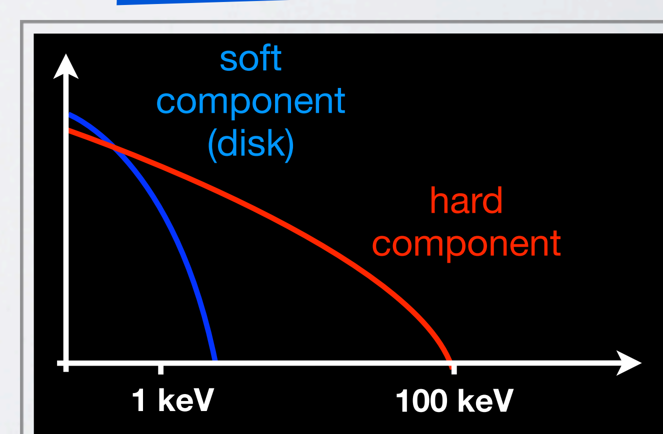



Belloni 2010

How hard the spectrum is

hard component dominates



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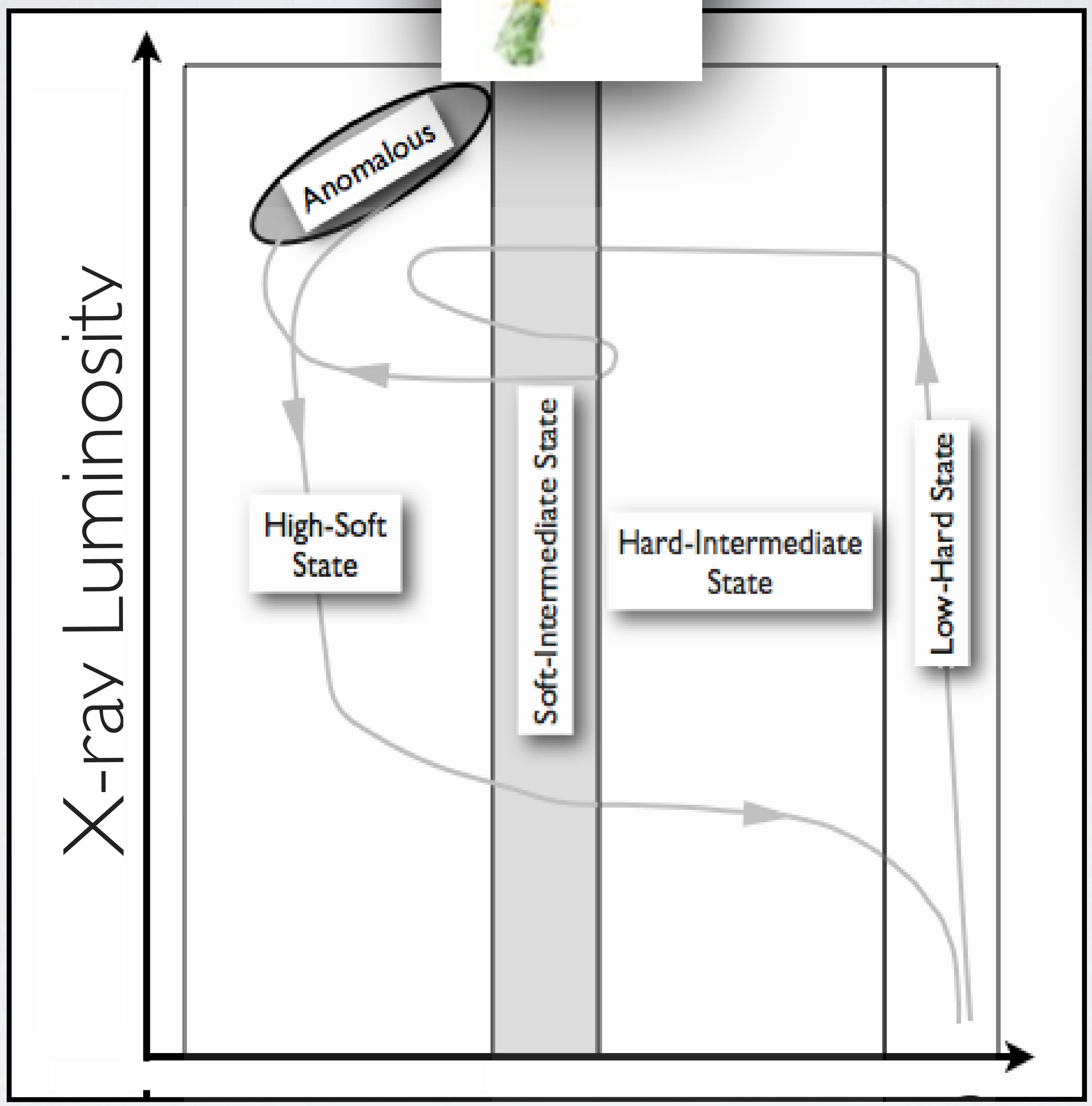
**Winds: a new key ingredient**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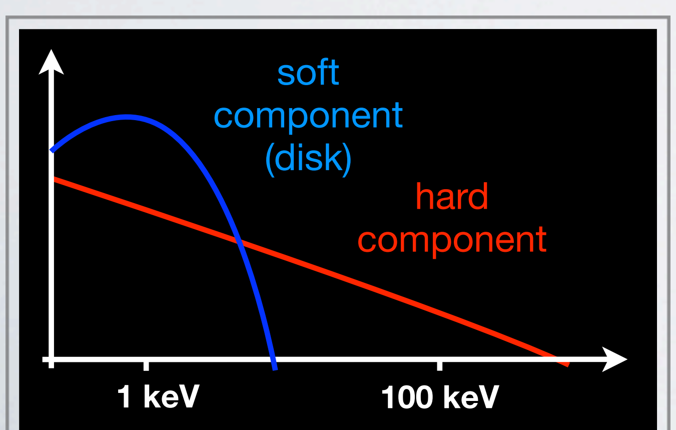


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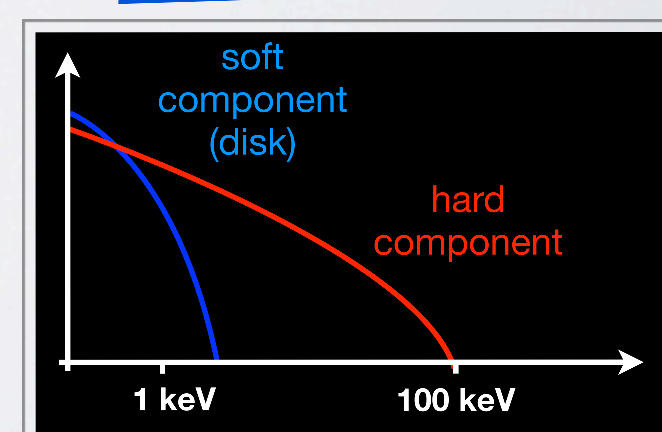
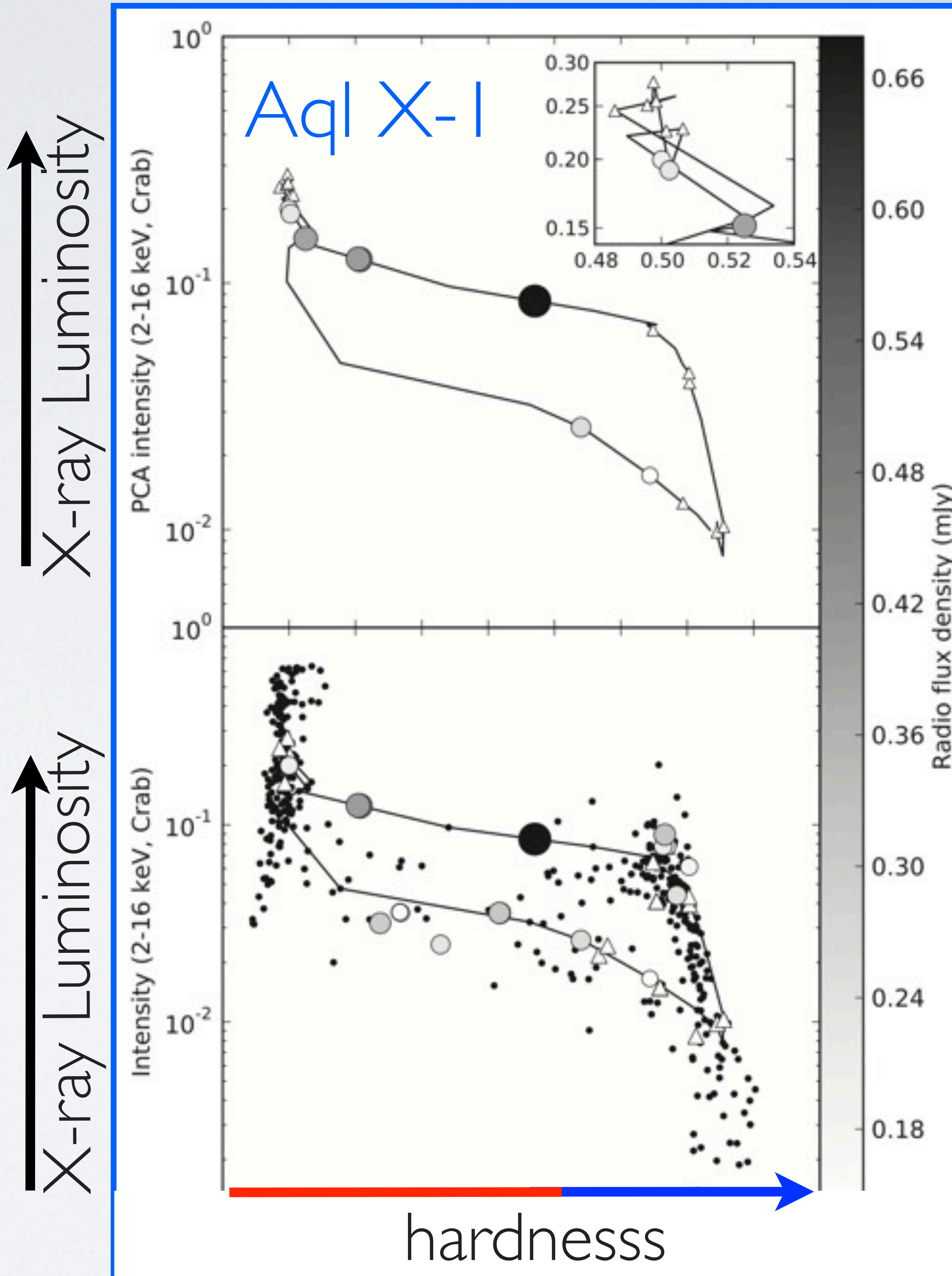


# NEUTRON STARS

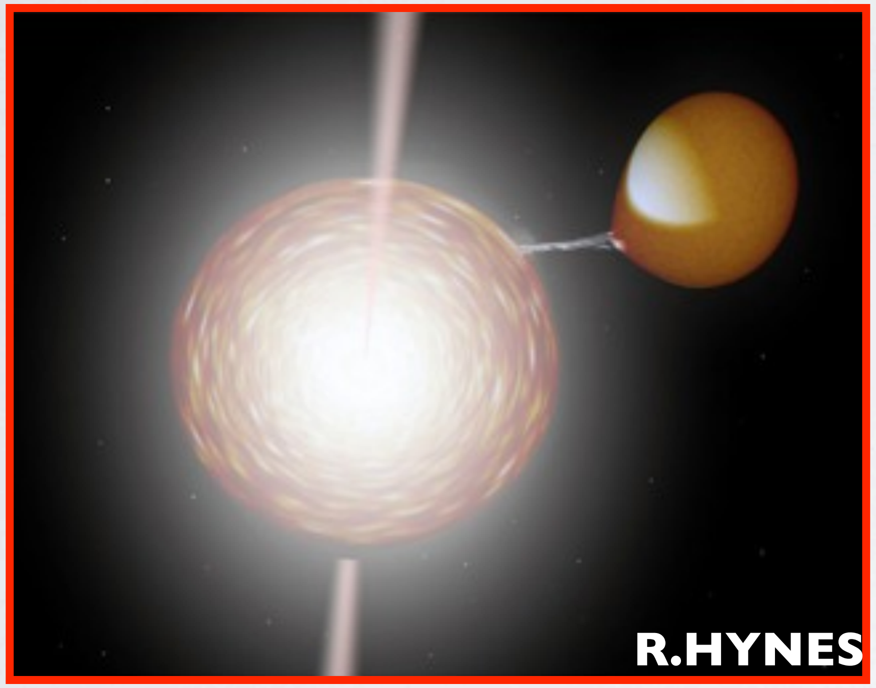
CAN BE SIMILAR

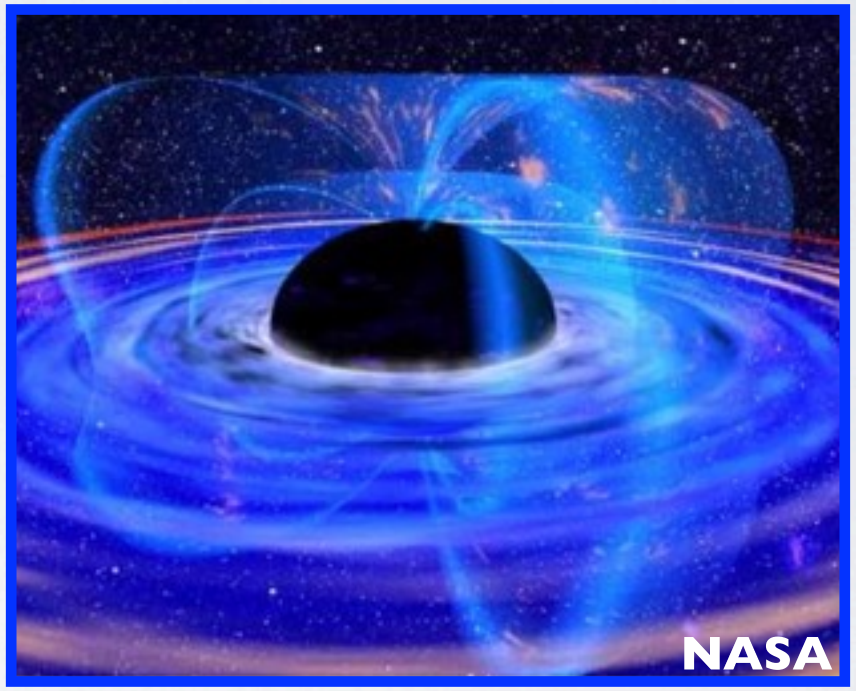
- **Brightest and more numerous: Studied first**
- More complex behaviour ( Extra component)
- Most of them are **persistent** systems (but a few transients as well)
- Some transients look similar to Black holes

Miller-Jones et al. 2012



# BLACK HOLE EVOLUTION AND LINE-OF-SIGHTS




Muñoz-Darias, Coriat, Plant, Ponti, Fender Dunn, MNRAS, 2013

# INCLINATION EFFECTS

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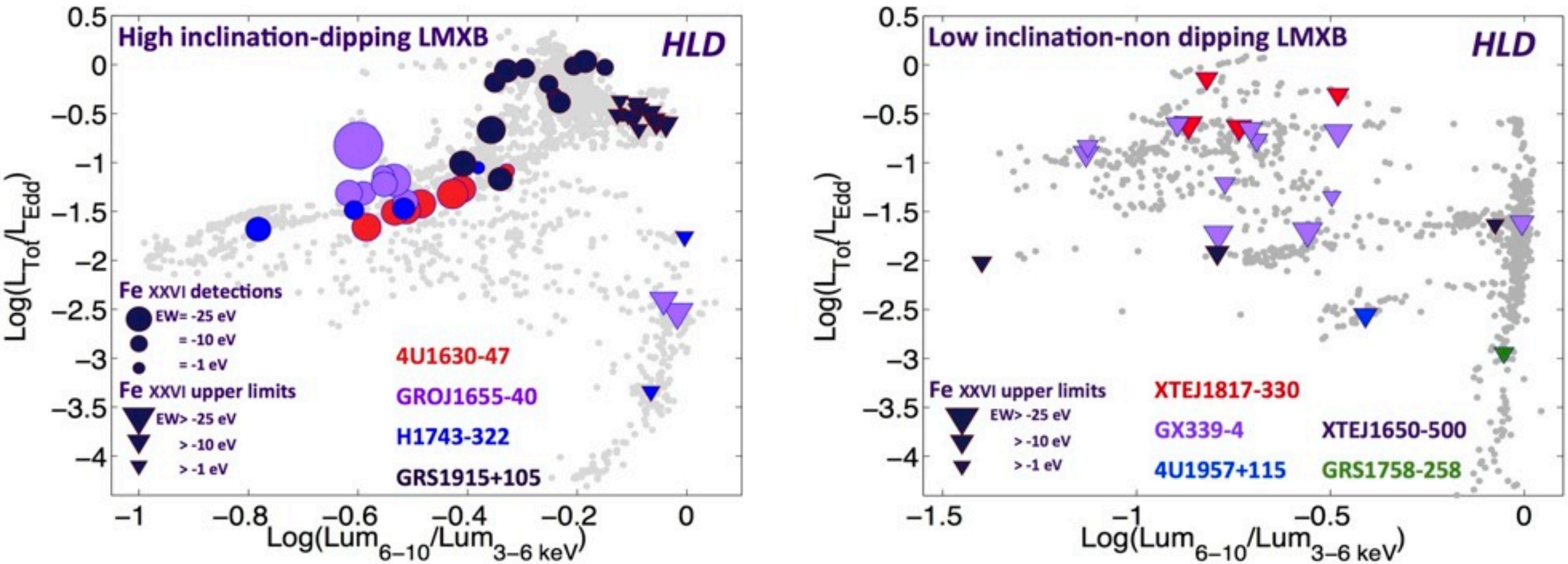
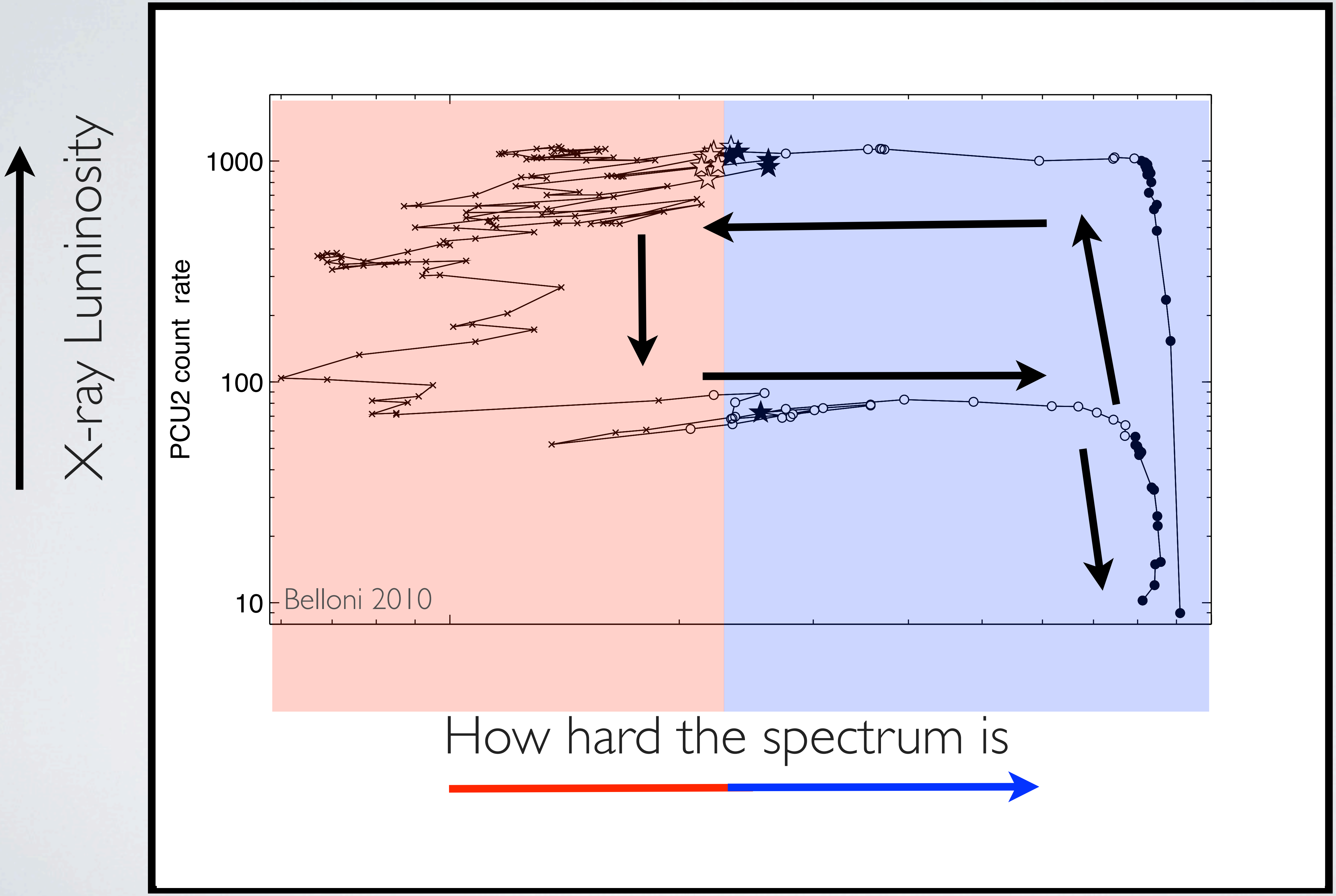



Ponti et al. 2012

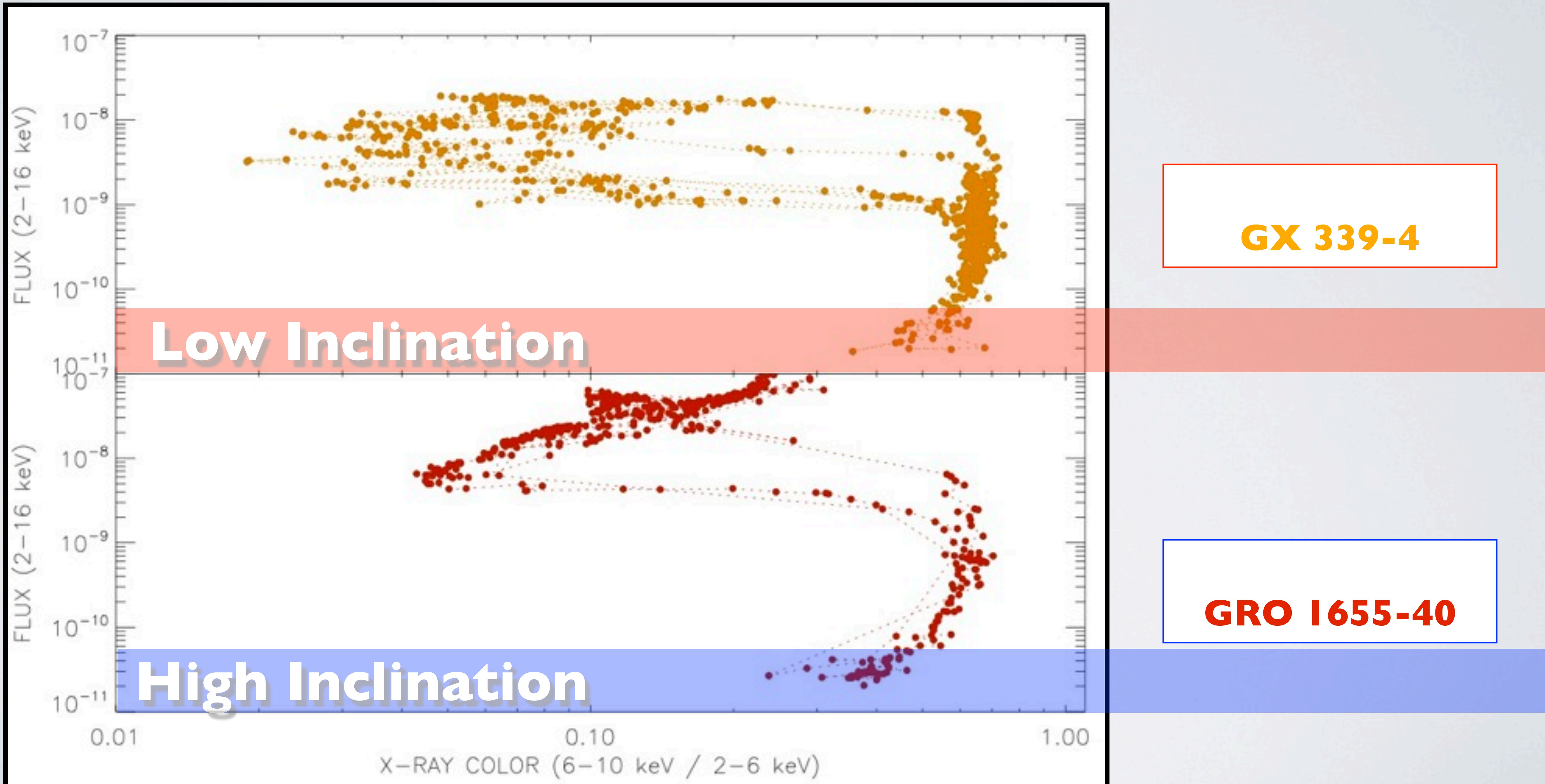
# **Inclination effects:**

how they do affect the Hardness-intensity diagrams



# A CLOSER VIEW...

- RXTE absorption corrected fluxes (Dunn et al. 2010)




Muñoz-Darias et al. 2013

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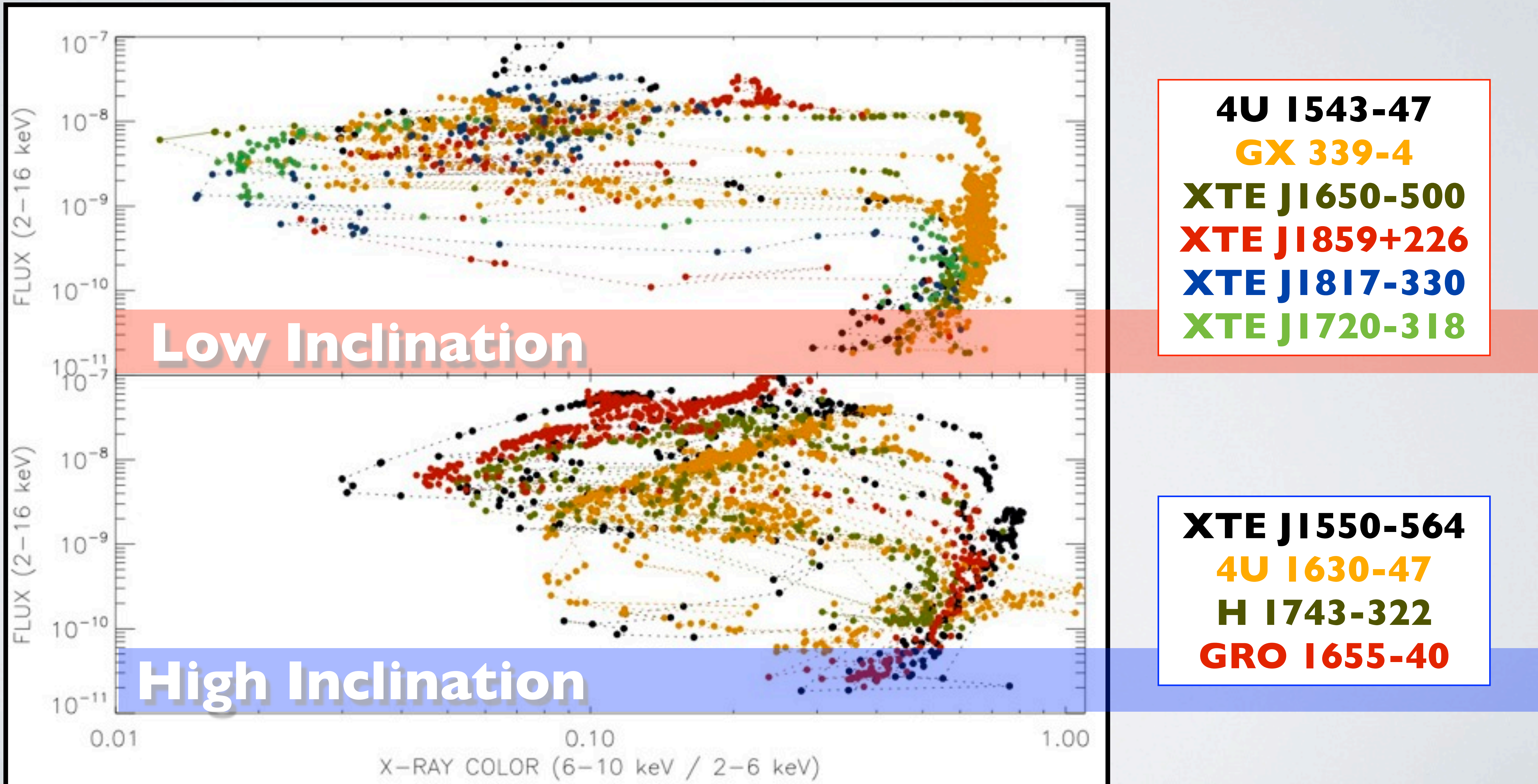

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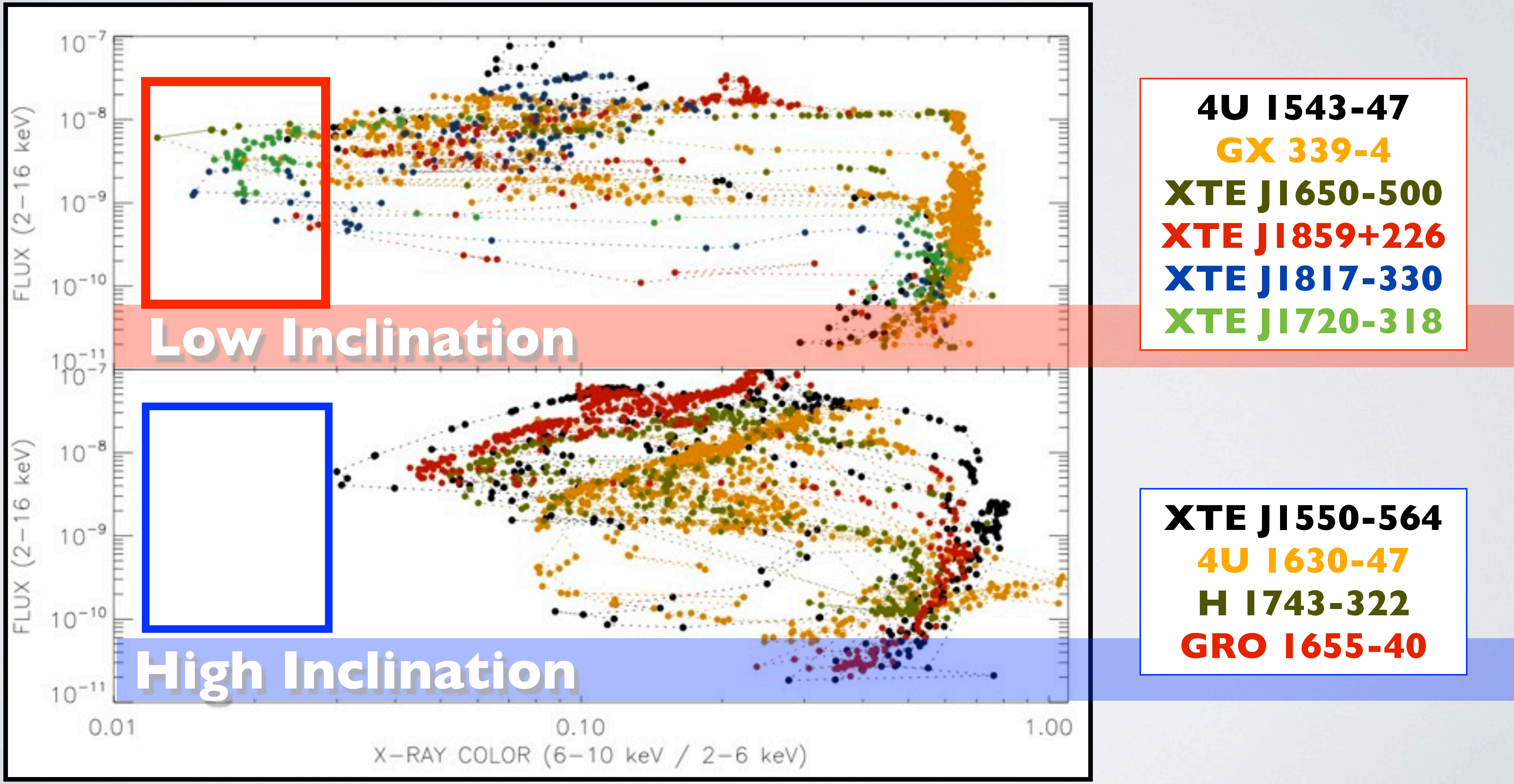
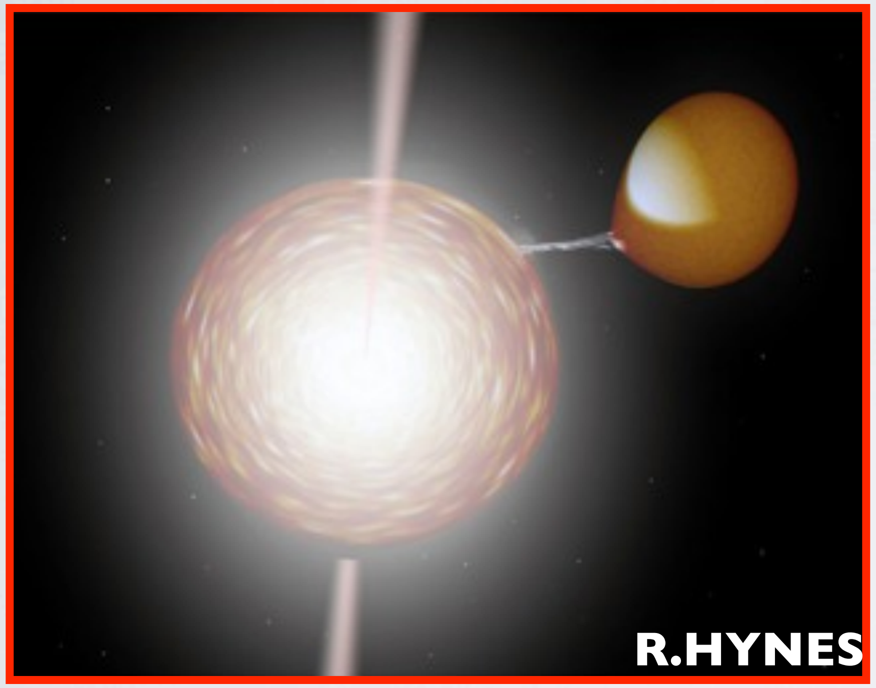
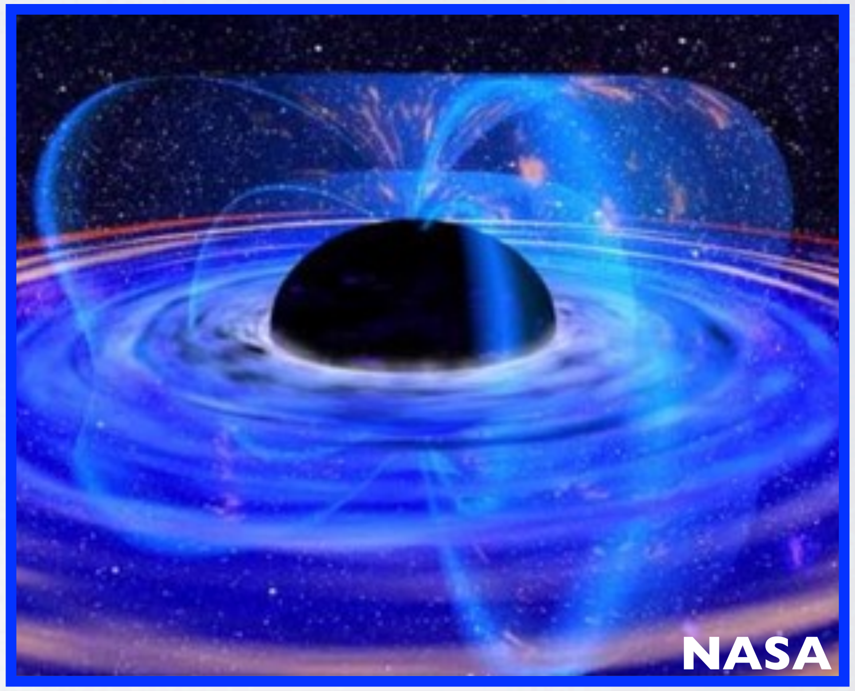


# ACCRETION DISCS AND GENERAL RELATIVITY

- Low inclination disc dominated by gravitational redshift



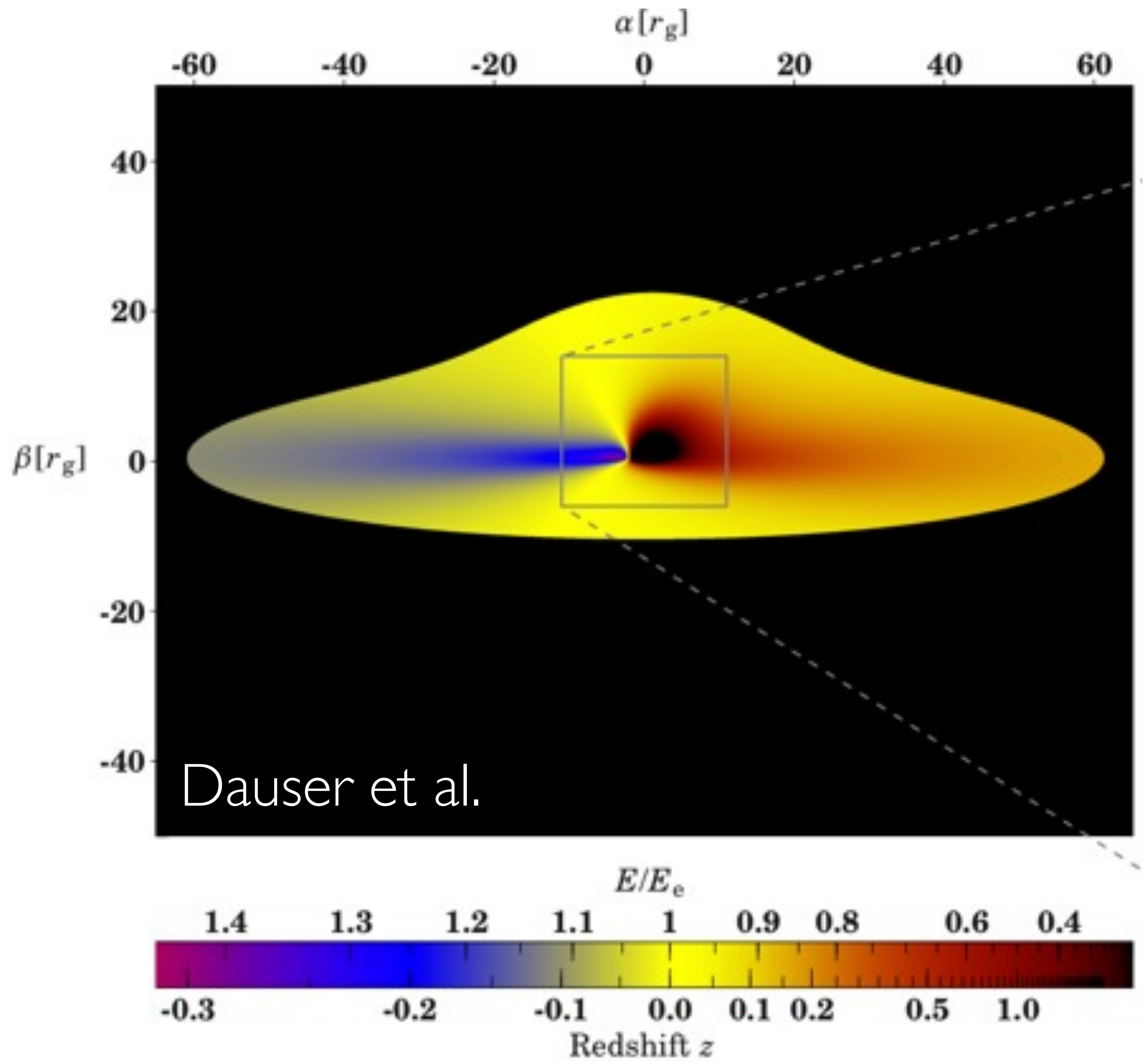




- Gravitational redshift starts to be compensated by blue shifting when looking at higher inclinations.

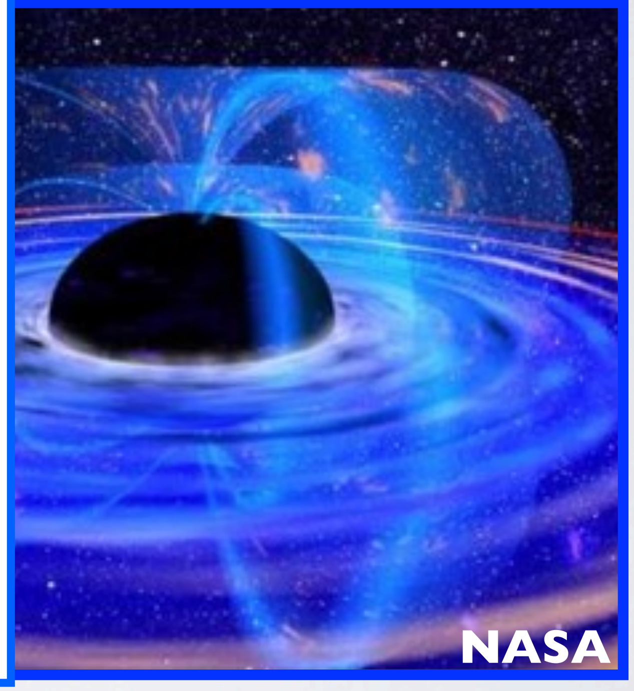
# ACCRETION DISCS AND GENERAL RELATIVITY

★Doppler beaming enhances blue-shifted light

★Light bending effects




redshift

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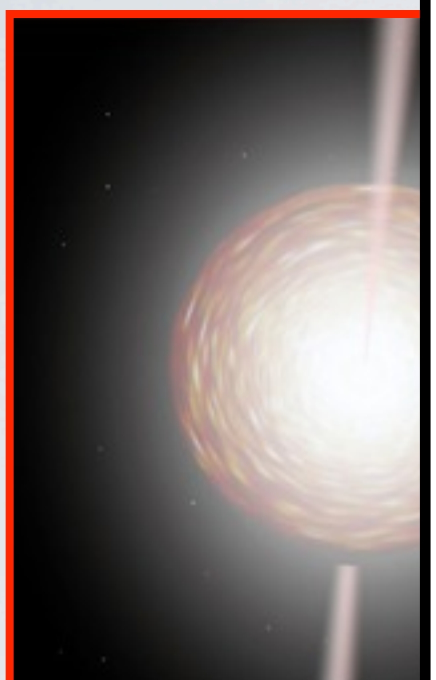
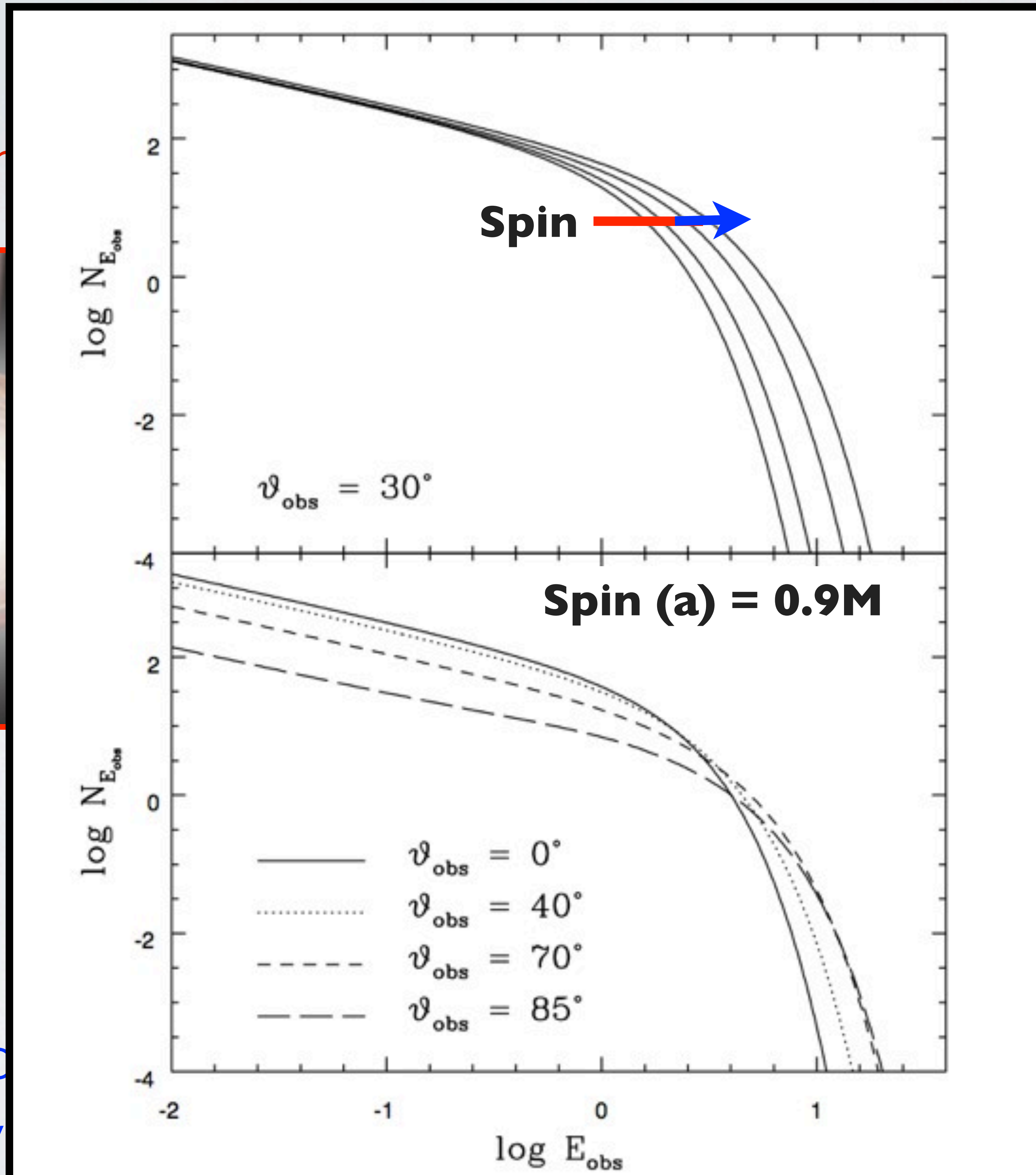






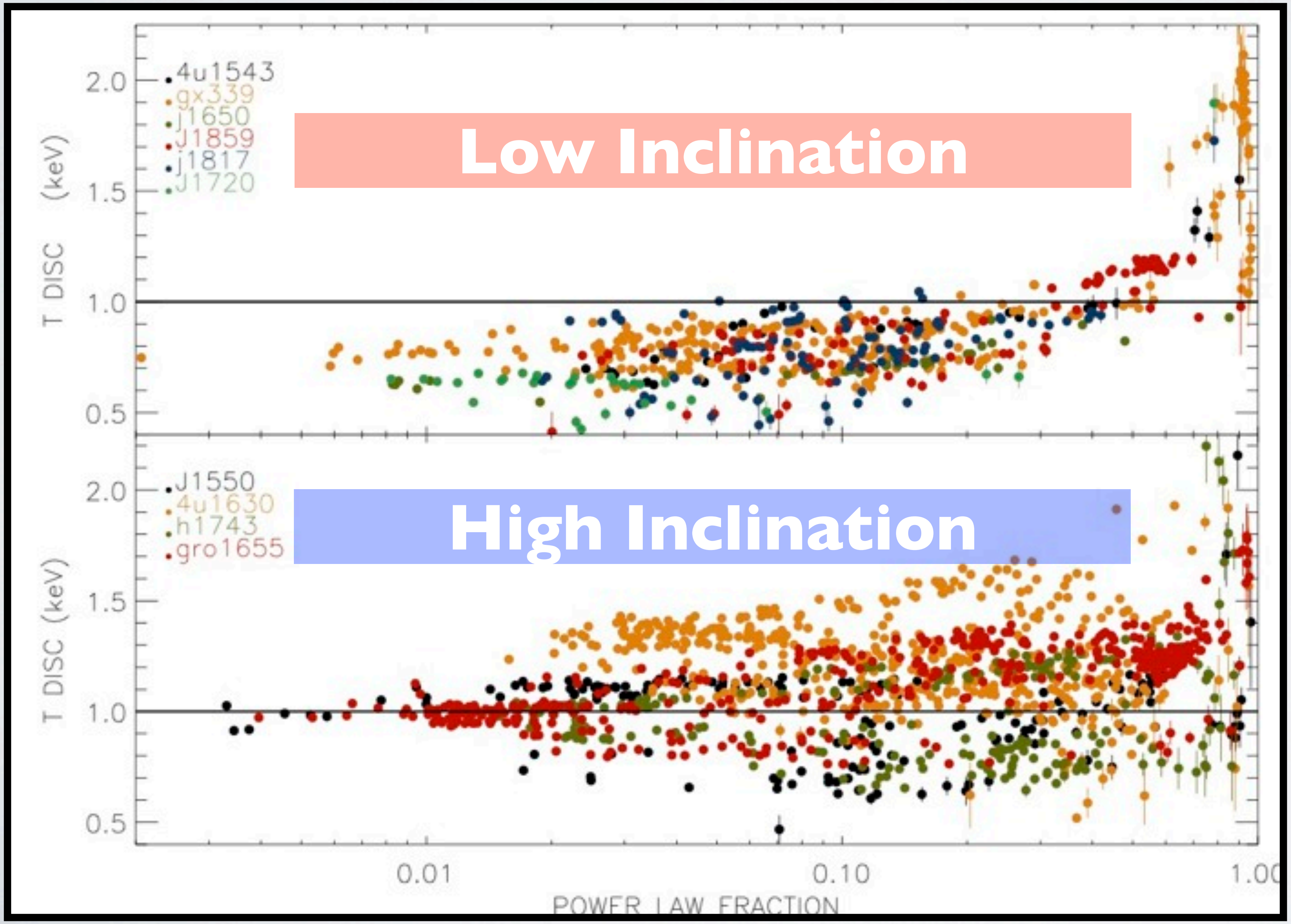
- Gravitatio … by blue shifting w …

Li et al. 2005

# DO WE REALLY SEE THAT?

Fits presented in Dunn et al. 2010 (Newtonian discs (DISKBB))

$T_{OBS} = T_{PEAK}\, f_{COL}\, \boldsymbol{f_{GR}[i,spin]}$ (see e.g. Zhang, Cui & Chen 1997; Cunnigham 1975)



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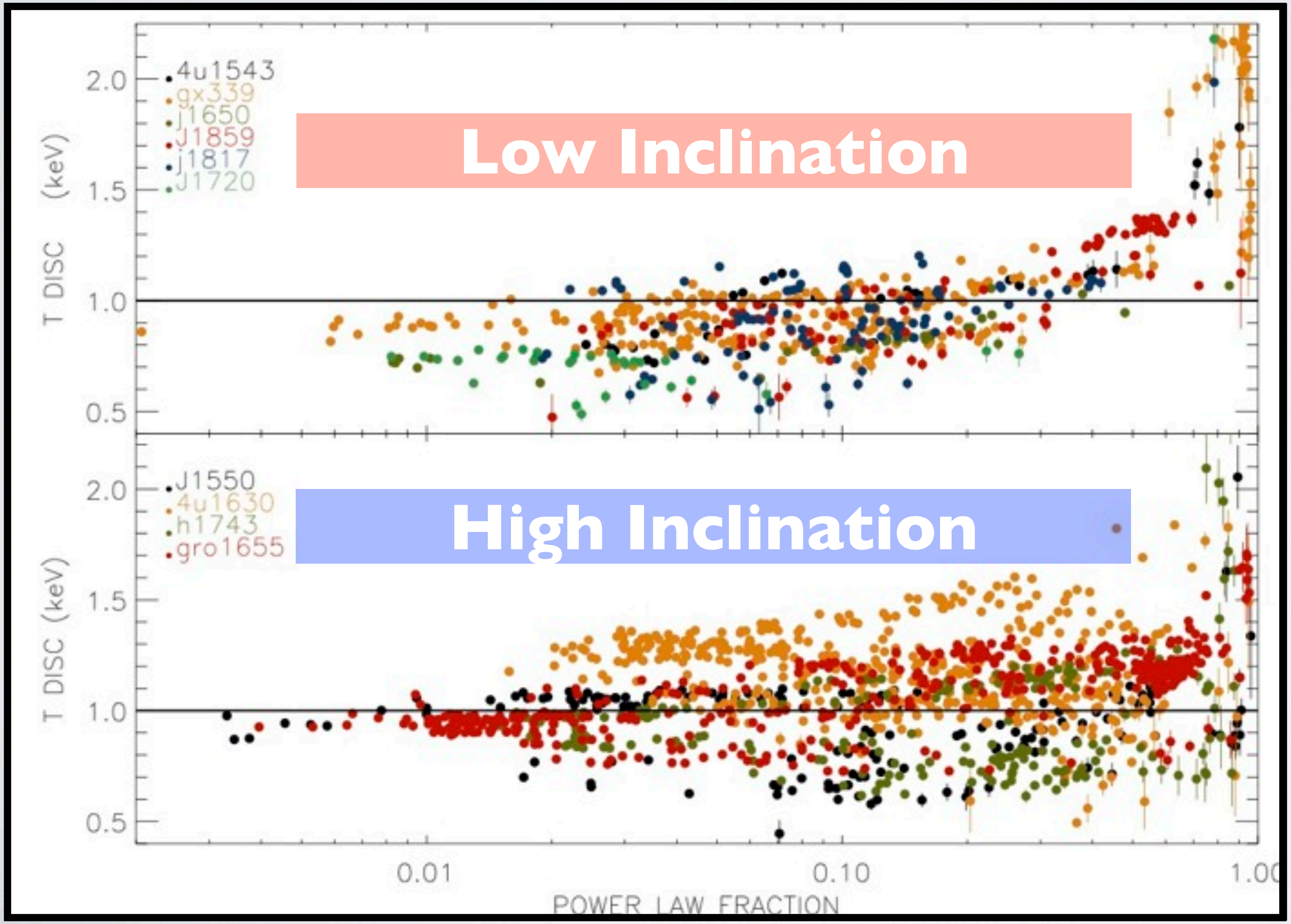


$f_{GR}$ [i,a=0.0]

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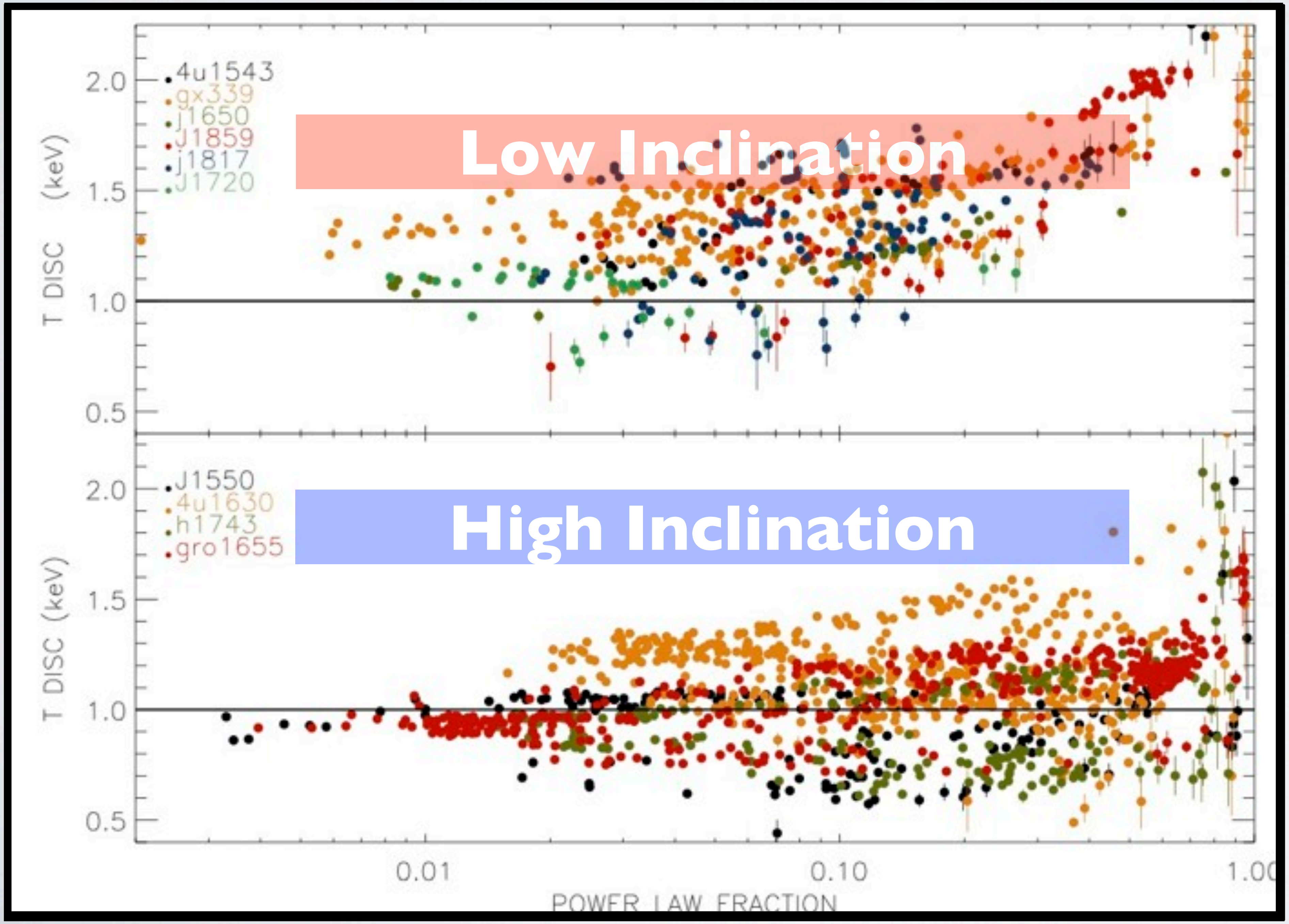
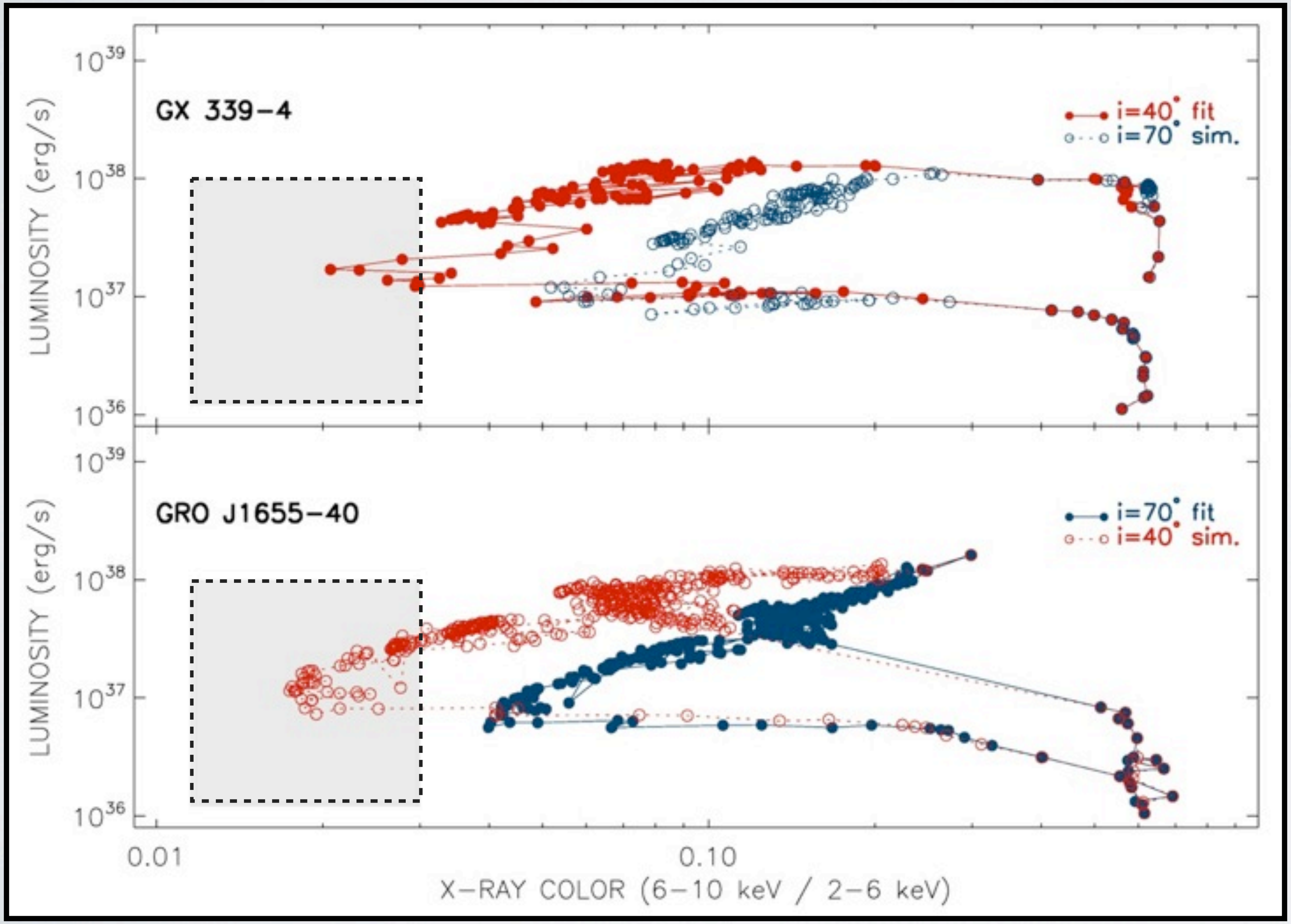



$f_{GR}$[i,a=0.998]

# DOES IT EXPLAIN EVERYTHING ?

★Simulations using a KERRBB fully relativistic modeling



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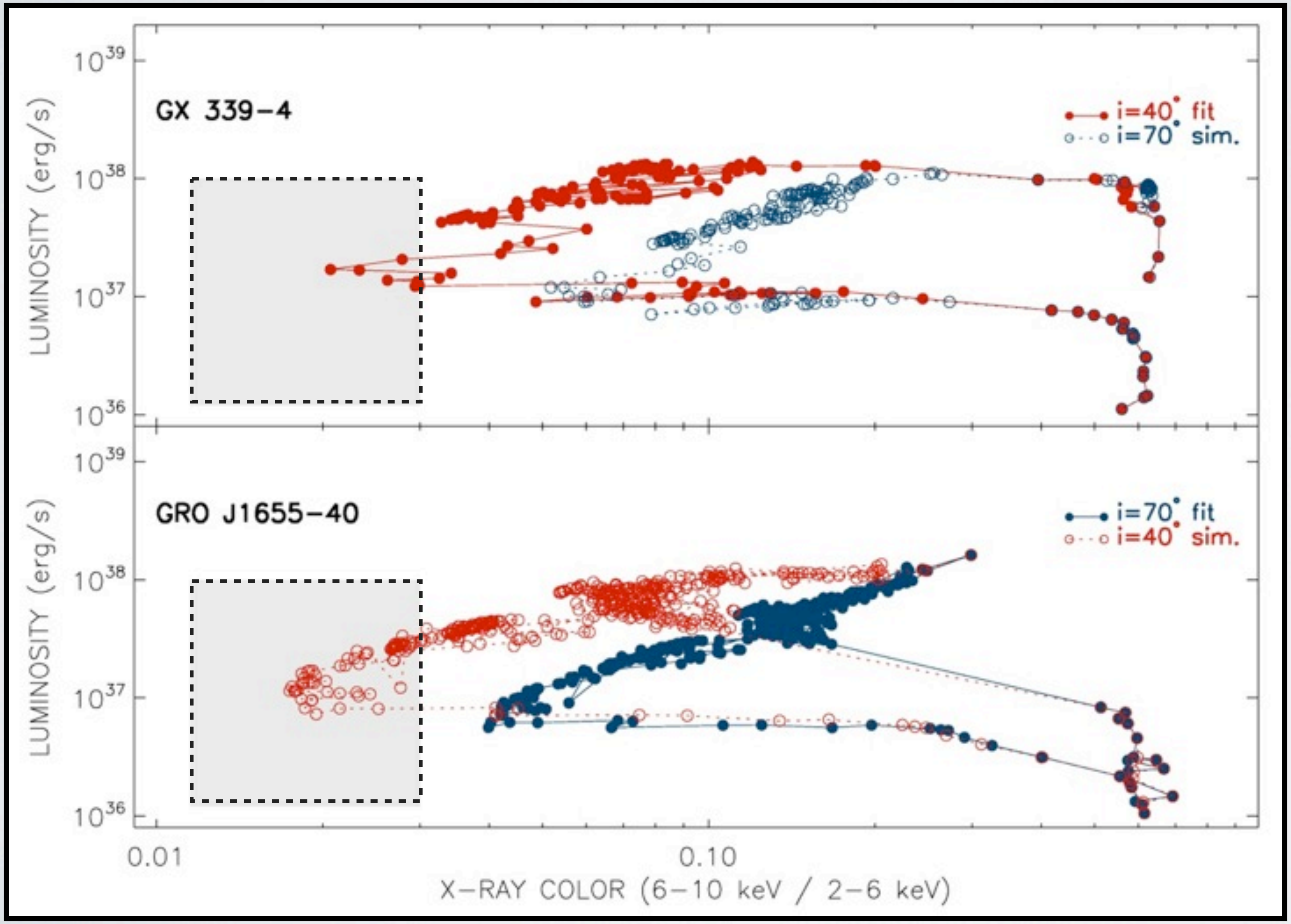
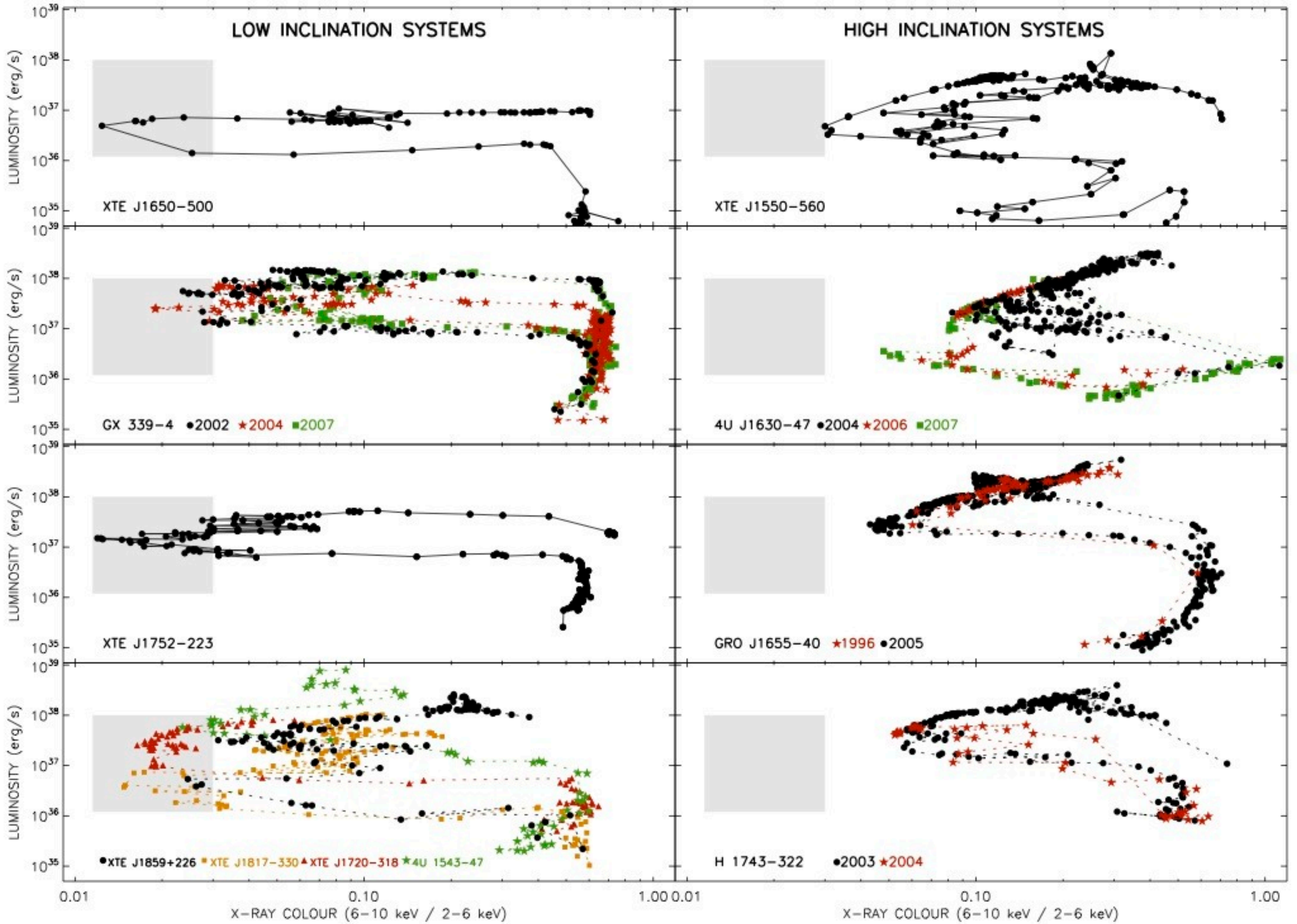



*Other factors?*



LOW INCLINATION SYSTEMS
HIGH INCLINATION SYSTEMS
LUMINOSITY (erg/s)
XTE J1650-500
XTE J1550-560
GX 339-4 •2002 ★2004 ■2007
4U J1630-47 •2004 ★2006 ■2007
XTE J1752-223
GRO J1655-40 ★1996 •2005
•XTE J1859+226 ■XTE J1817-330 ▲XTE J1720-318 ★4U 1543-47
H 1743-322 •2003 ★2004
X-RAY COLOUR (6-10 keV / 2-6 keV)