Stellar mass black hole accretion disks in the low-hard state

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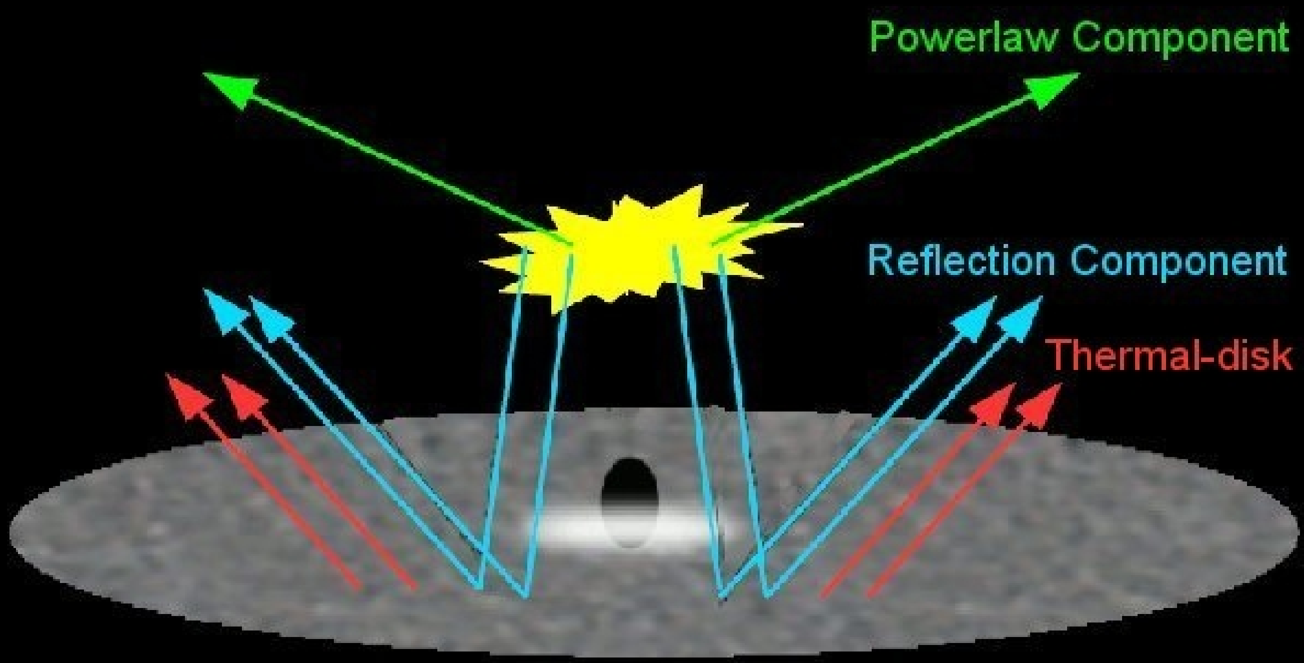
Introduction: Geometry and Spectral components



The origin of the hard powerlaw-like component is still not established:

- Base of a jet
- Patchy corona/Magnetic flares
- Advection-dominated region

The innermost extent of the accretion disk in the low-hard state (LHS) is still not established

Introduction: Shakura-Sunyaev accretion disk

Characteristic blackbody temperature can be approximated as

$$kT \sim (M/10\,\mathrm{M}_{\odot})^{-1/4}(L/L_{Edd})^{1/4}\,\mathrm{keV}$$

Stellar-mass black holes in the low-hard state

$$L \sim (0.1-1)\%\,L_{Edd}$$

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kT ~ 0.1 – 0.3 keV

Need low energy coverage

If the disk is truncated the temperature will be colder

Our approach:

Systematically investigate spectra of various X-ray binaries in the LHS

Low energy coverage (<3 keV)

↓

XMM-Newton, Chandra, Swift and Suzaku.

Physical parameters (**mass, distance and inclination)** obtained from the literature

Physical parameters + spectral fitting

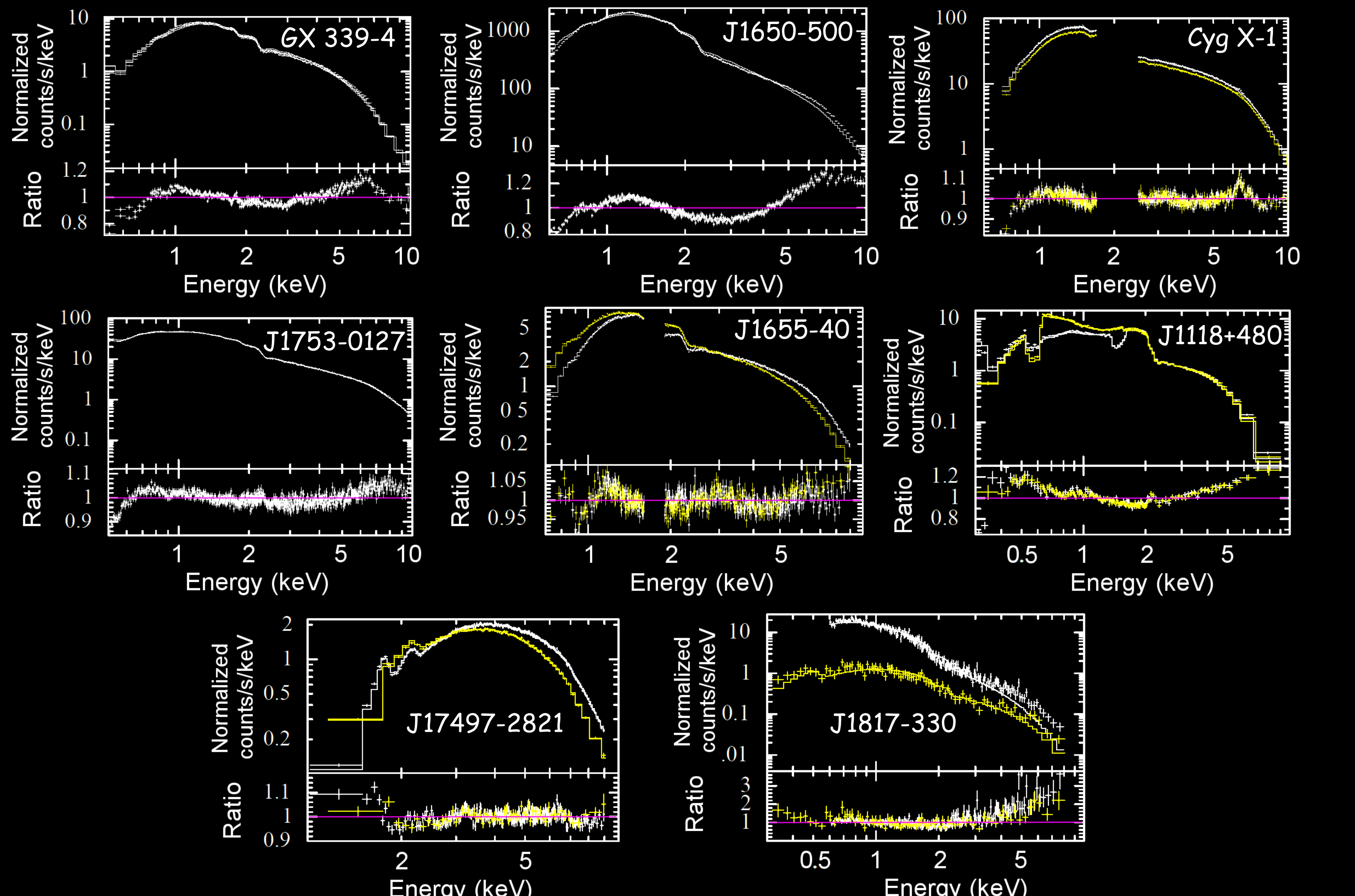
=

constraint in the position of the innermost radius of accretion

The sample:

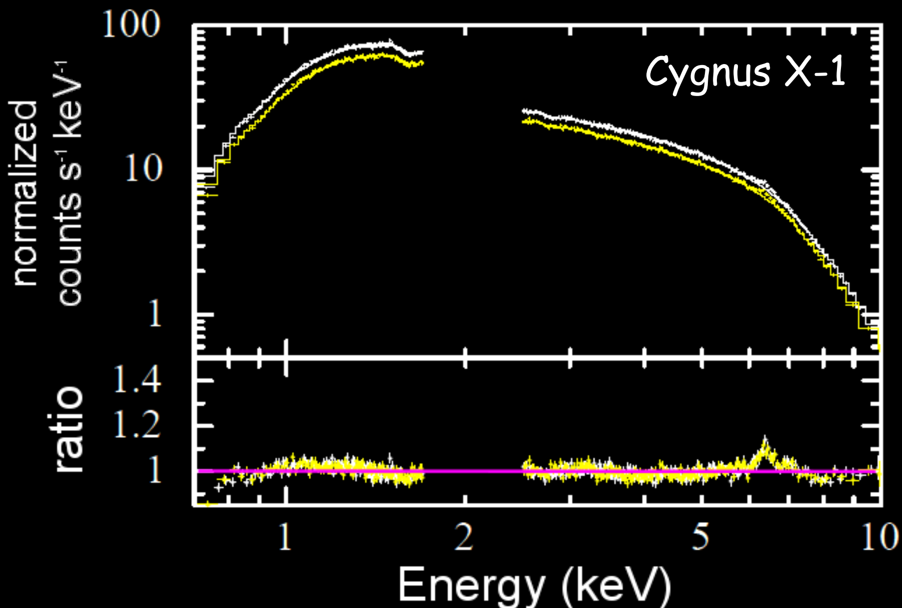
Source	Inclination (degrees)	Distance (kpc)	Mass ($M_\odot$)	
GX 339-4	10–30	6–10	10–20	*XMM-Newton*
J1650-500	47–70	1.9–3.3	5.3–11.3	*XMM-Newton*
Cygnus X-1	25–50	2.0–2.2	7–25	*Suzaku*
J1753.5-0127	49–57	7.2–10.0	4–16	*XMM-Newton*
J1655-40	68.3–87	3.0–3.4	5.8–6.8	*Suzaku*
J1118+480	60–83	1.2–2.4	7–10	*Chandra*
J17497-2821	10–80	5–10	5–20	*Suzaku*
J1817-330	10–80	1–15	4–15	*SWIFT*

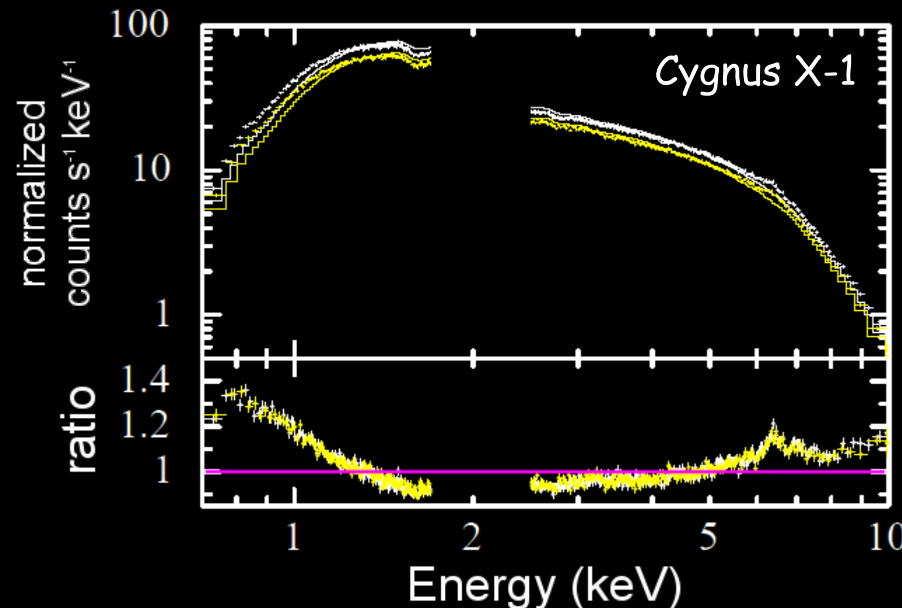
Results: 0.5-10 keV fit with absorbed PL



Results: Masking the presence of a disk…

…with an artificially low column density (N_H)





$$N_{\rm H} = 3.4 \times 10^{21}\ {\rm cm}^{-2}$$

$$N_{\rm H} = 5 - 9 \times 10^{21}\ {\rm cm}^{-2}$$

Average hydrogen column density in direction of *Cygnus* X-1 is ~7.2×10^{21} cm^{-2} (Kalberla et al. 2005)

Results: PL + Diskbb

Source	N_H ($\times 10^{22}$ cm^{-2})	Γ	kT (keV)	$N_{Diskbb} \times 10^3$	χ^2/ν
GX 339-4	0.495 ± 0.006	1.67 ± 0.01	0.254 ± 0.006	$5.02^{+0.80}_{-0.67}$	2874.0/1633
J1650-500	0.556 ± 0.004	2.10 ± 0.01	0.310 ± 0.004	55 ± 4	1507.9/1273
Cygnus X-1 (1)	0.53 ± 0.02	1.71 ± 0.01	$0.194^{+0.005}_{-0.004}$	236^{+63}_{-54}	783.1/722
Cygnus X-1 (2)	0.50 ± 0.02	1.70 ± 0.01	$0.194^{+0.007}_{-0.006}$	155^{+62}_{-49}	719.2/683
J1753.5-0127	0.197 ± 0.004	1.61 ± 0.01	$0.274^{+0.015}_{-0.014}$	$0.32^{+0.11}_{-0.08}$	1961.0/1497
J1655-40	0.63 ± 0.02	1.67 ± 0.01	0.21 ± 0.01	$5.4^{+2.7}_{-2.0}$	1618.8/1439
J1118+480	0.022 ± 0.003	1.69 ± 0.01	0.21 ± 0.01	$7.4^{+1.4}_{-1.2}$	3747.3/4246
J17497-2821	4.72 ± 0.08	1.56 ± 0.01	0.20 ± 0.01	54^{+49}_{-24}	1102.5/1182
J1817-330 (1)	0.12(f)	2.1 ± 0.1	0.20 ± 0.01	27^{+9}_{-6}	204.0/207
J1817-330 (2)	0.12(f)	1.5 ± 0.2	0.21 [illegible]	$1.3^{+1.5}_{-0.6}$	69.1/79

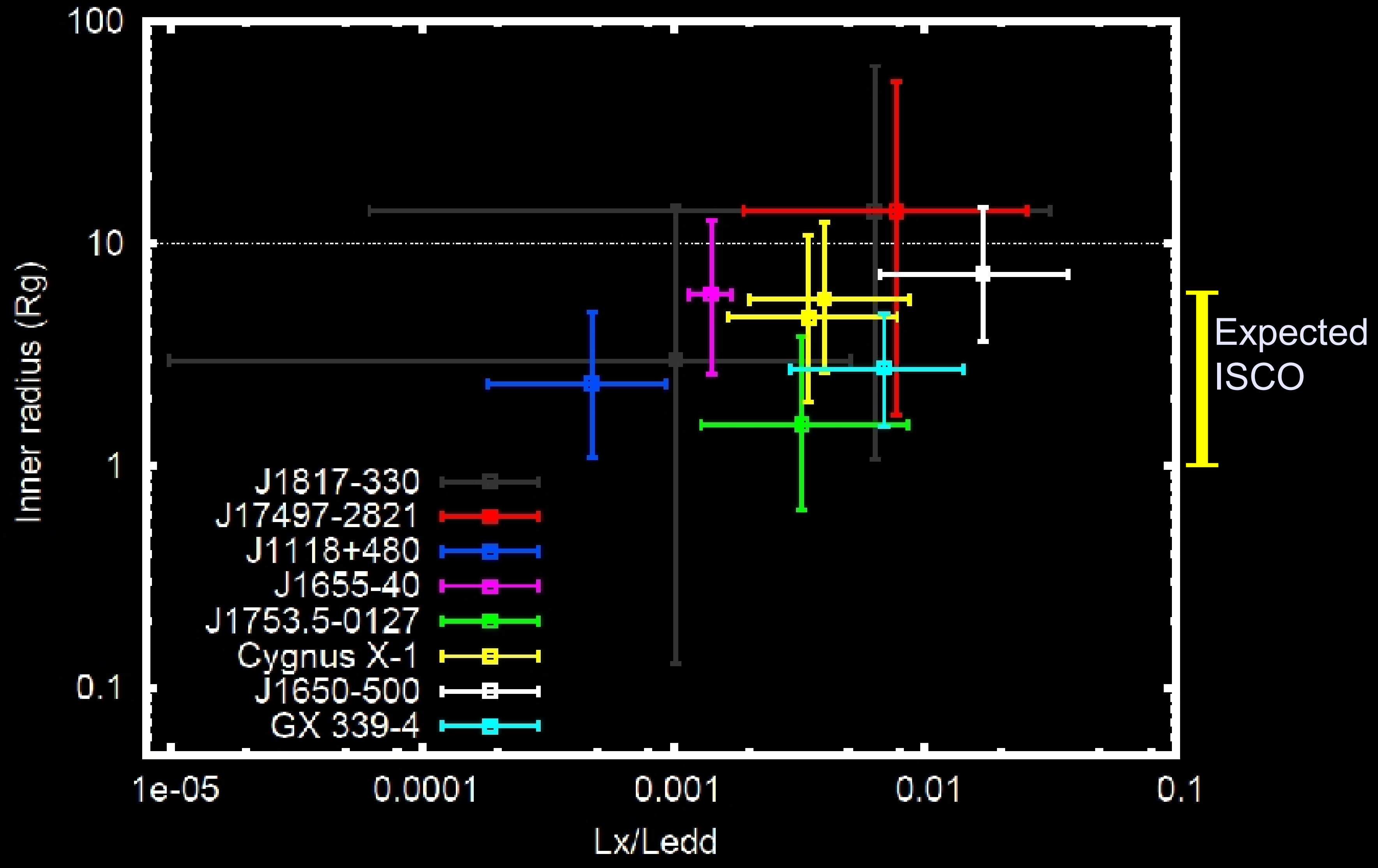
$$N = (R_{in}/D)^2 \times cos\theta$$

Use estimate of mass, distance and inclination to obtain R_{in} in gravitational radii

$R_g = GM/c^2$

Diskbb: Mitsuda et al. 1984
Ezdiskbb: Zimmerman et al. 2005

Results: R_{in} always consistent with ISCO!



Results: Can the disk be truncated at 100R_g ?

Model thermal component with DISKPN (Gierlinski et al. 1999) where R_{in} is a free parameter.

Freeze R_{in} at both 6 and 100Rg

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Models with and without truncation gives equally satisfactory fits.

Only the normalisation differs between the interpretations

Results: Can the disk be truncated at $100R_g$?

Model thermal component with DISKPN (Gierlinski et al. 1999) where R_{in} is a free parameter.

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⬇

Models with and without truncation gives equally satisfactory fits.

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$$N = (1/f^4)(M/D)^2 cos\theta$$

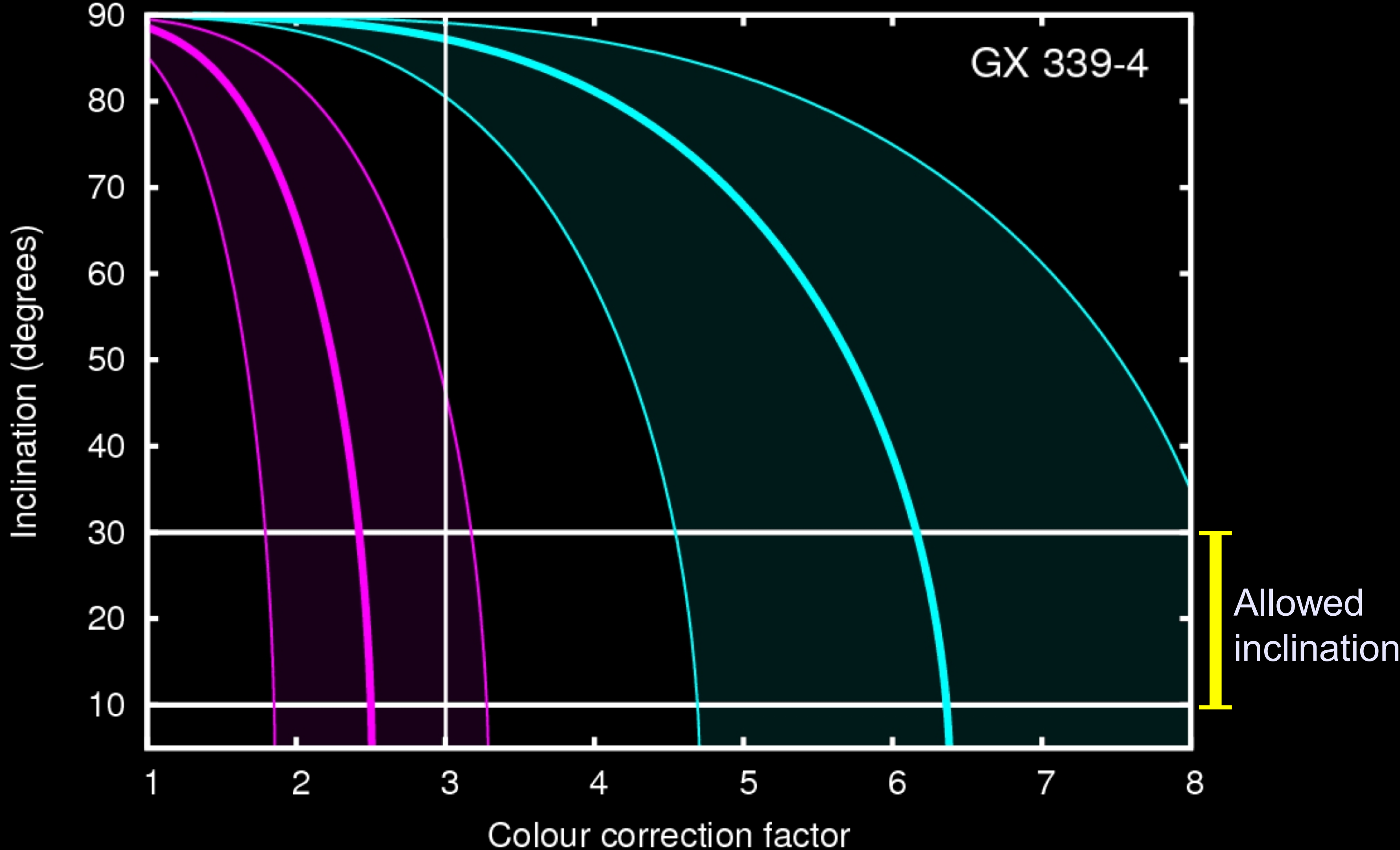
$$f = T_{col}/T_{eff} \sim 1.7$$

$$< 3$$

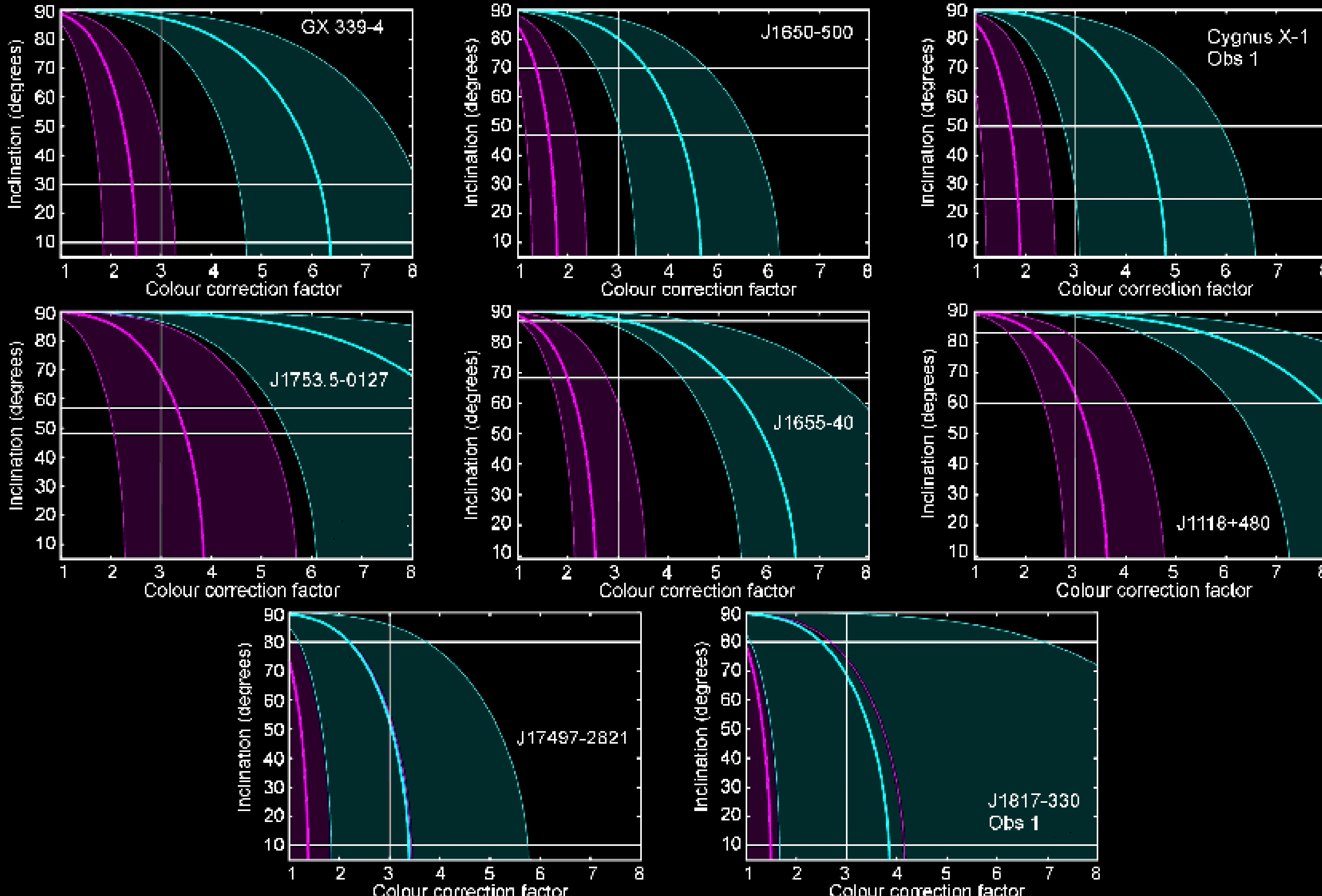
Look at inclination as a function of *f*

Results:

$$cos(\theta) = (ND^2/m^2)f^4$$



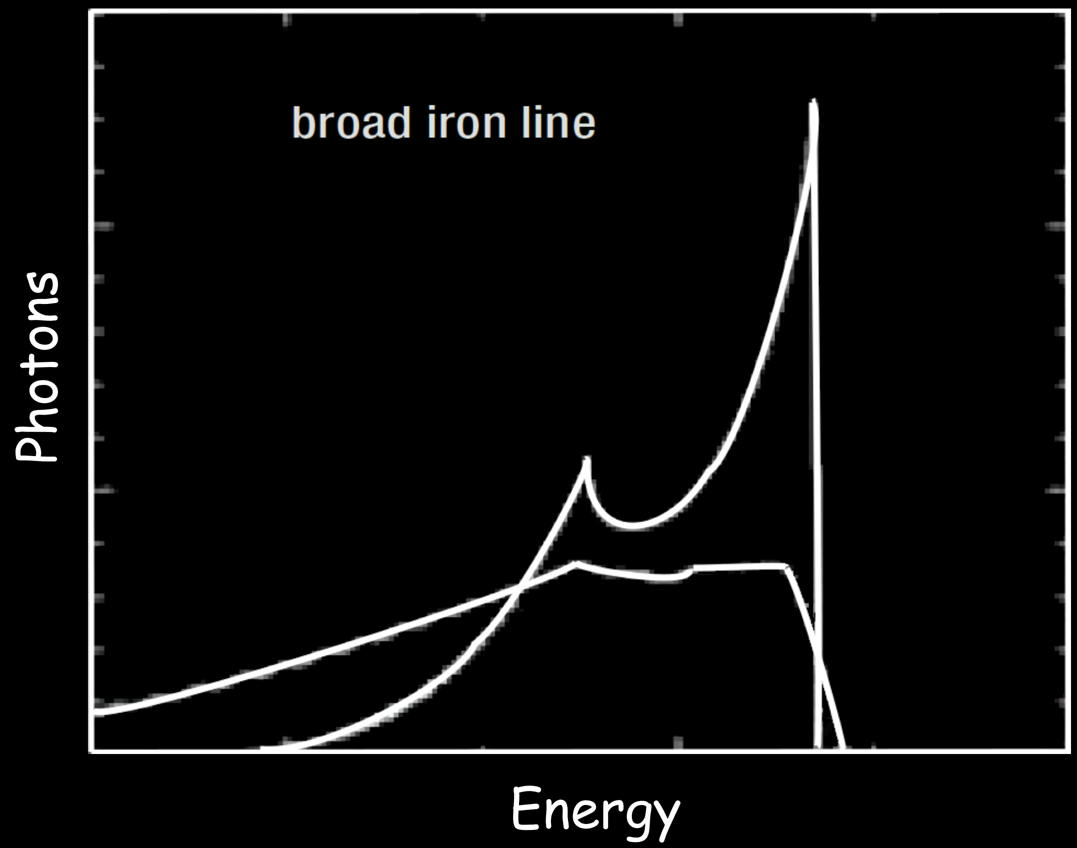
Results:



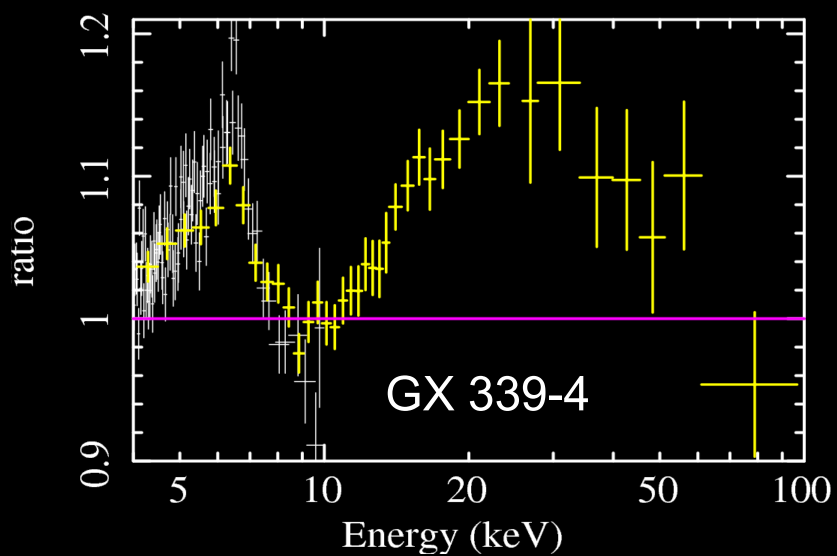
GX 339-4
J1650-500
Cygnus X-1
Obs 1
J1753.5-0127
J1655-40
J1118+480
J17497-2821
J1817-330
Obs 1
Inclination (degrees)
Colour correction factor

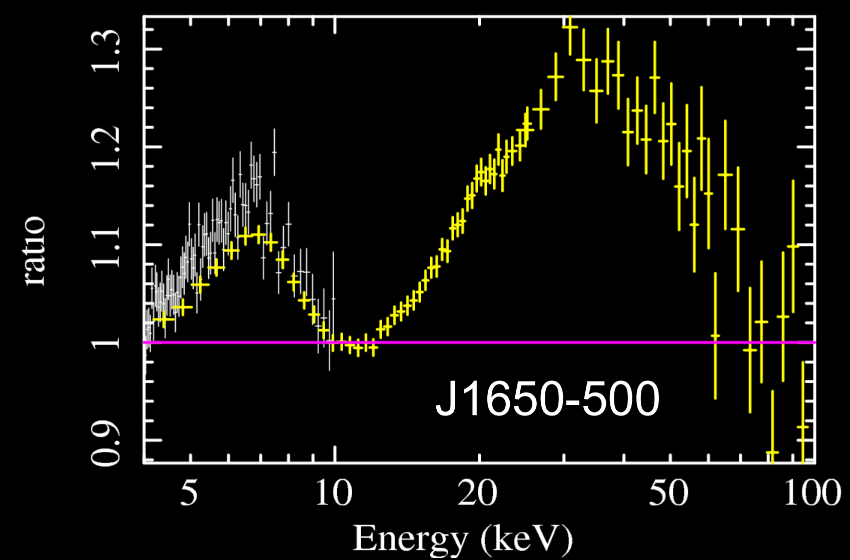
Results: Inner radius from reflection

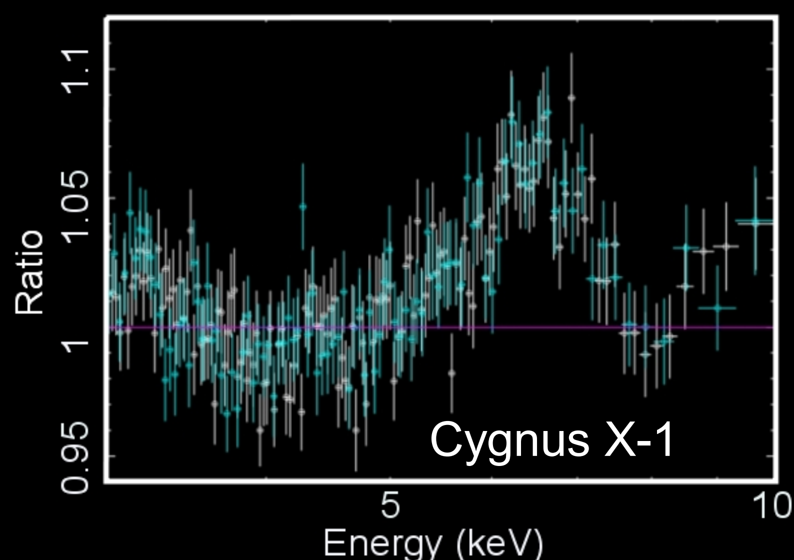
Constraints on the disk geometry can also be found using reflection signatures



Results: Inner radius from reflection





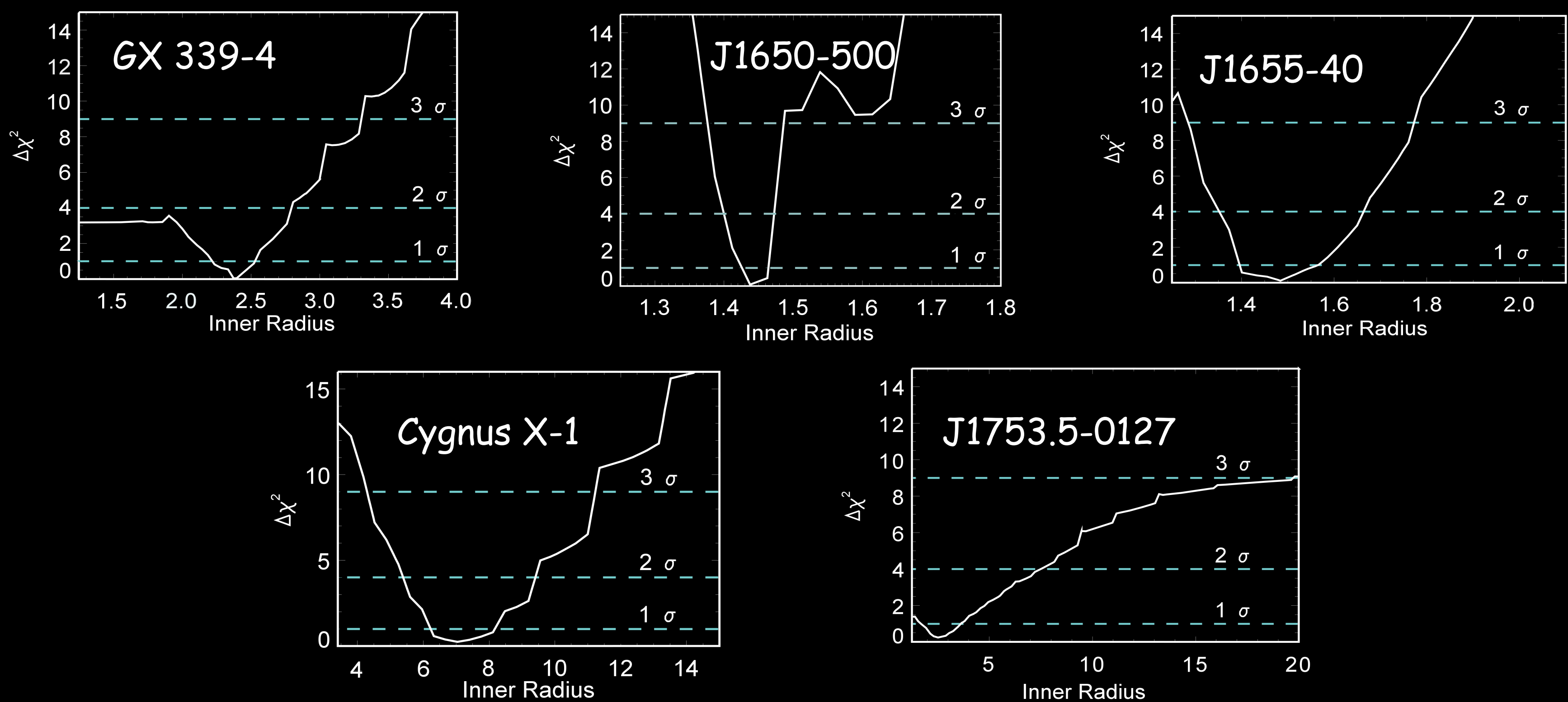


Results: Inner radius from reflection

An inner radius extending to **within 6Rg** is found in
GX 339-4, J1650-500 and J1655-40

For Cygnus X-1 the radius is constrained to **within 12Rg**

In J1753.5-0127 an inner radius greater than 20Rg is excluded at the 3σ level



Summary:

- We present a study of 8 black holes in the LHS.
- A thermal disk continuum is clearly detected in all eight sources, down to ~$5 \times 10^{-4} L_{Edd}$.
- In six sources, disk models exclude a truncation radius of $10R_g$.
- Iron-K fluorescence line emission is observed in half of the sample, down to luminosities of ~$1.5 \times 10^{-3} L_{Edd}$.
- Detailed fits to the line profiles exclude a truncated disk in each case.

If the inner disk evaporates in the LHS, it must happen at or below ~$1.5 \times 10^{-3} L_{Edd}$.