Application of Slim Disk Model to Ultraluminous Supersoft X-ray Sources

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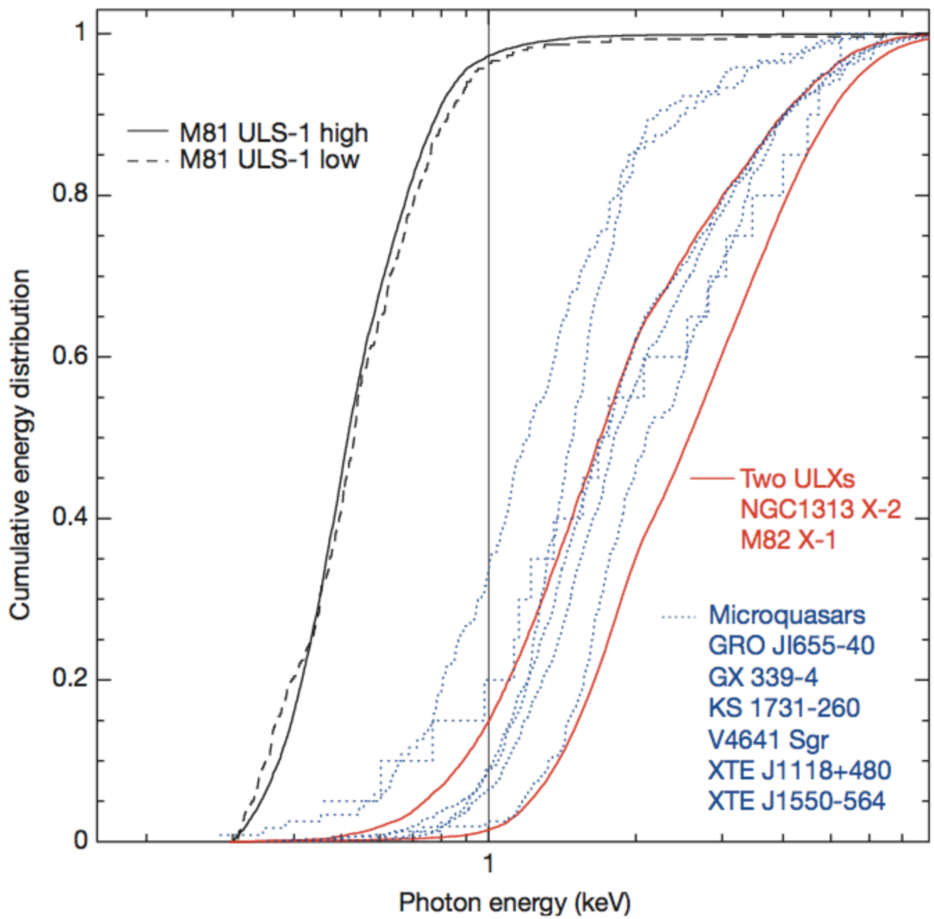
Slim Disk Workshop – 22/10/2018

Outline

- Ultraluminous supersoft source (ULS)
- Outflow model
- Our model: **Geometrically thick disk (slim disk)**
- Transition in NGC 247
- X-ray afterglow of GW170817

Ultraluminous supersoft source (ULS)

- High luminosity: a few 10^{39} erg/s
- Supersoft thermal spectrum $T_{peak} \sim 0.1$ keV



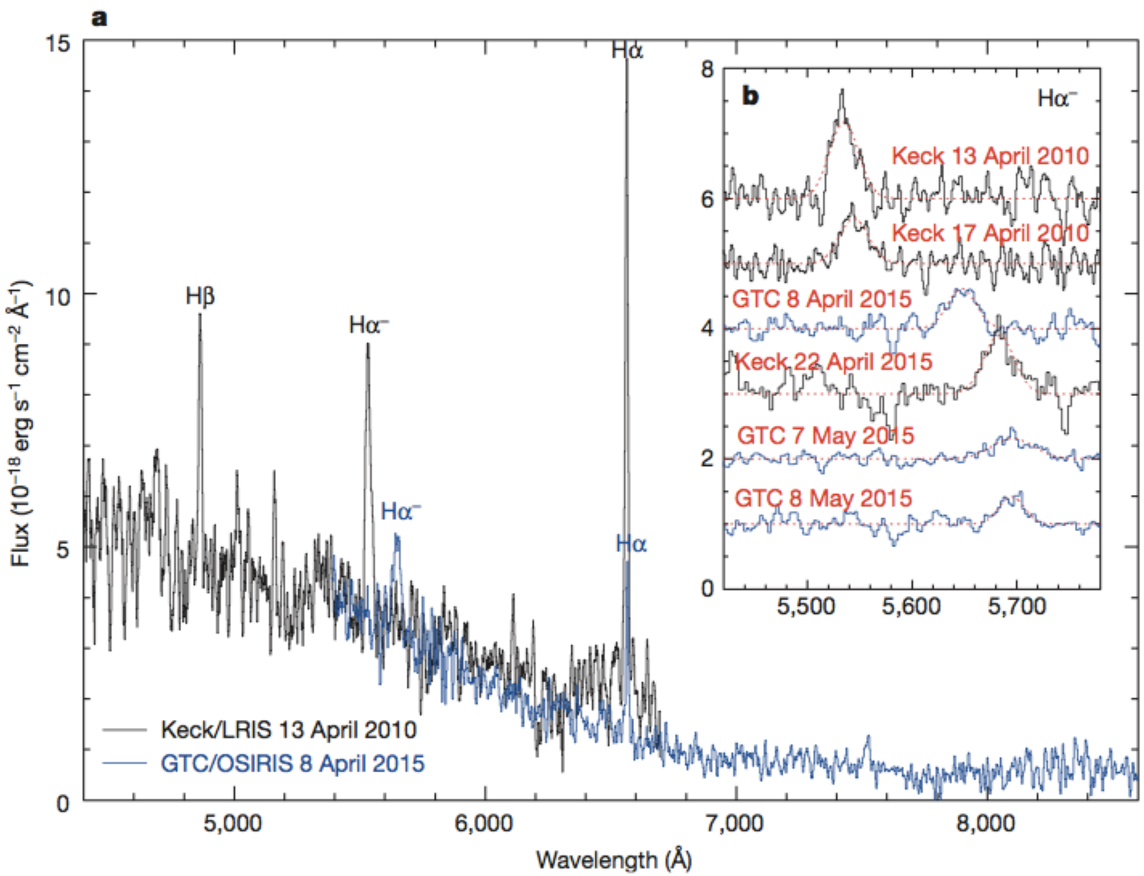
Liu et al., Nature (2015)

LETTER

doi:10.1038/nature15751

Relativistic baryonic jets from an ultraluminous supersoft X-ray source

Ji-Feng Liu[1,2], Yu Bai[1], Song Wang[1], Stephen Justham[1,2], You-Jun Lu[1,2], Wei-Min Gu[3], Qing-Zhong Liu[4], Rosanne Di Stefano[5], Jin-Cheng Guo[1], Antonio Cabrera-Lavers[6,7], Pedro Álvarez[6,7], Yi Cao[8] & Shri Kulkarni[8]

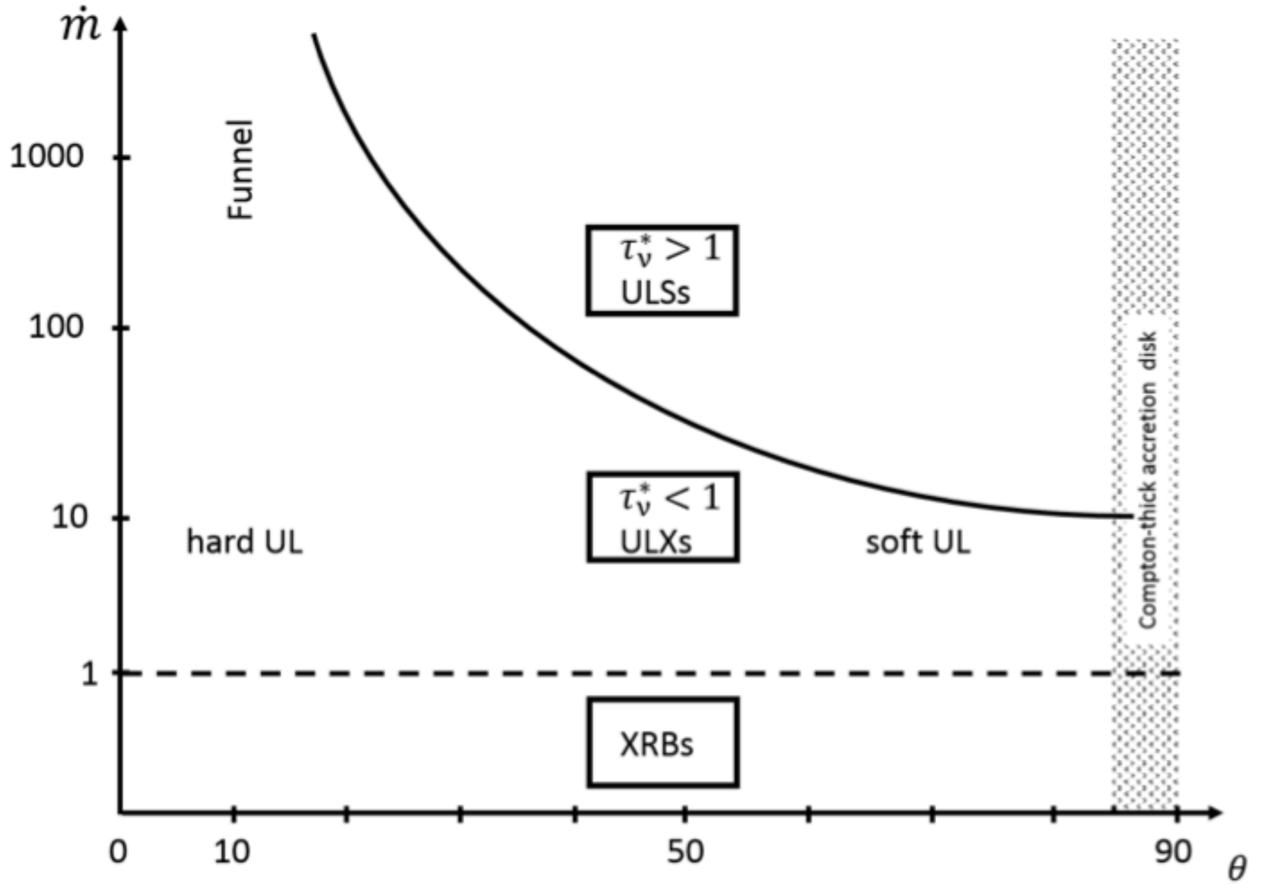


Physics of ULS

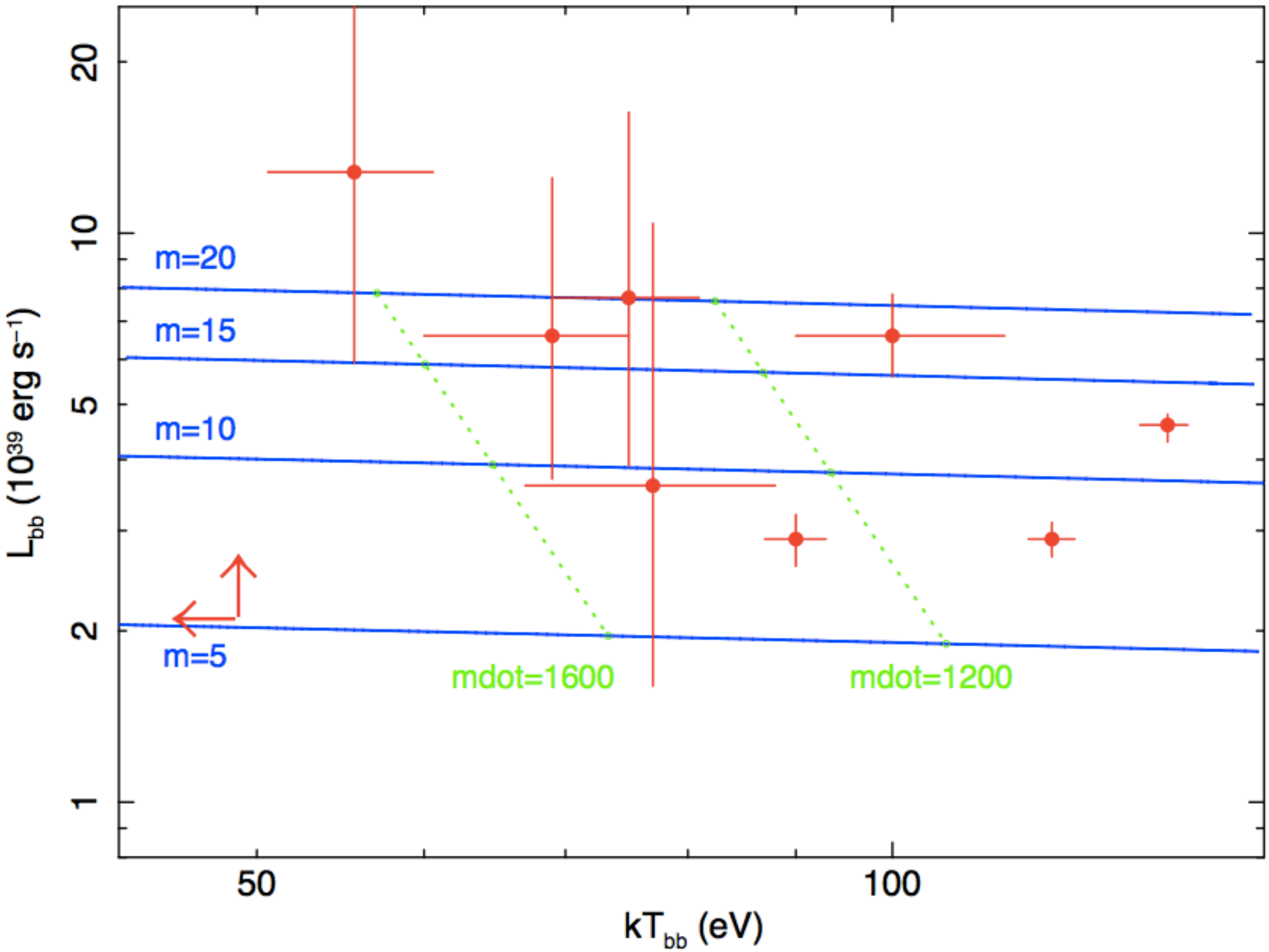
- Intermediate-mass black hole (IMBH) ×
- White dwarf ×
- Stellar-mass black hole or neutron star ?

Outflow model

- *Shen et al.* (2015)
- *Urquhart & Soria* (2016)；*Soria & Kong* (2016)



M101 X-1: extremely high accretion rate



Soria & Kong (2016)

SLIM ACCRETION DISKS

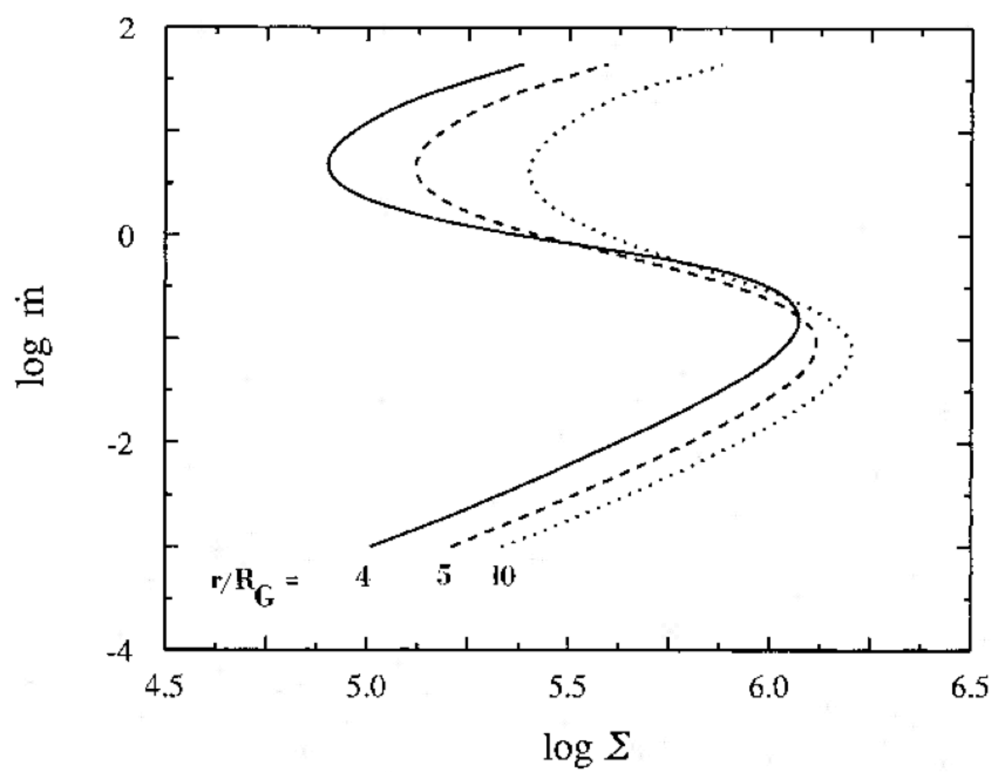
M. A. Abramowicz,[1,2] B. Czerny,[1,3] J. P. Lasota,[1,4] and E. Szuszkiewicz[1]

Received 1987 November 16; accepted 1988 February 29

ABSTRACT

We find a new branch of equilibrium solutions for stationary accretion disks around black holes. These solutions correspond to moderately super-Eddington accretion rates. The existence of the new branch is a consequence of an additional cooling due to general relativistic Roche lobe overflow and horizontal advection of heat. On an accretion rate versus surface density plane the new branch forms, together with the two "standard" branches (corresponding to the Shakura-Sunyaev accretion disk models) a characteristically S-shaped curve. This could imply a limit cycle–type behavior for black hole accretion flows with accretion rates close to the Eddington one.

Subject headings: black holes — stars: accretion



THERMAL EQUILIBRIA OF ACCRETION DISKS

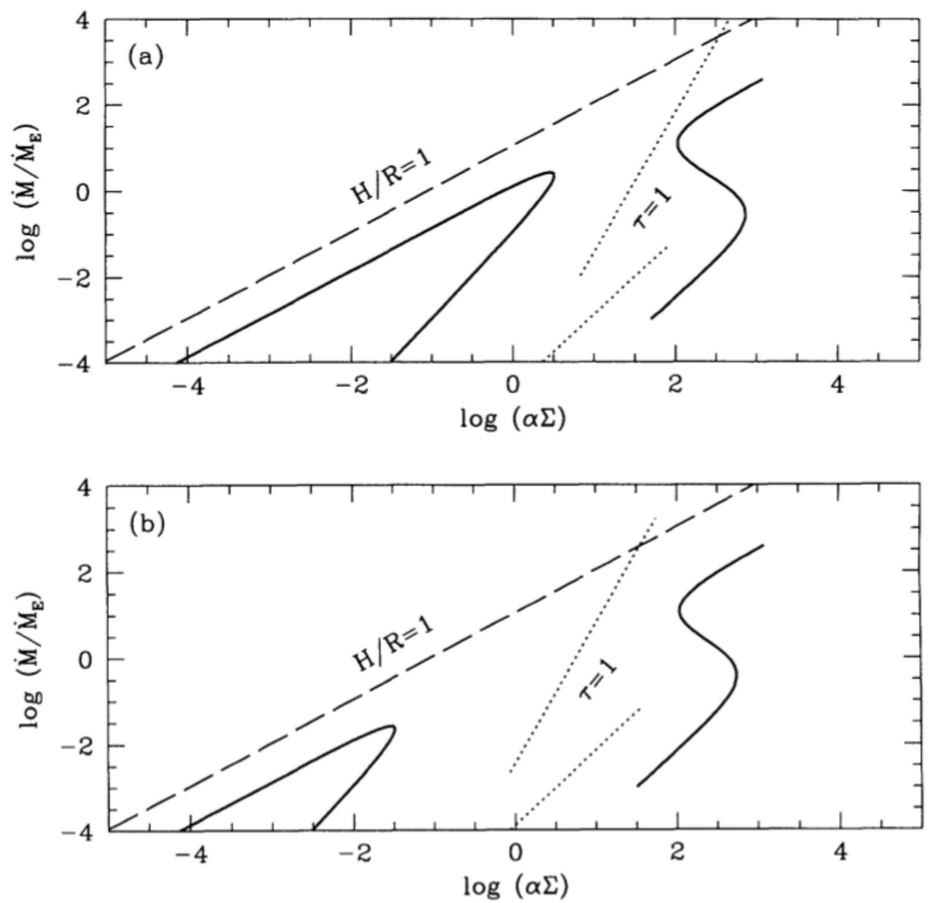
MAREK A. ABRAMOWICZ,[1,2] XINGMING CHEN,[1] SHOJI KATO,[1,3] JEAN-PIERRE LASOTA,[4,1] AND ODED REGEV[2]

Received 1994 July 7; accepted 1994 October 17

ABSTRACT

We show that most of hot, optically thin accretion disk models that ignore advective cooling are not self-consistent. We have found new types of optically thin disk solutions where cooling is dominated by radial advection of heat. These new solutions are thermally and viscously stable.

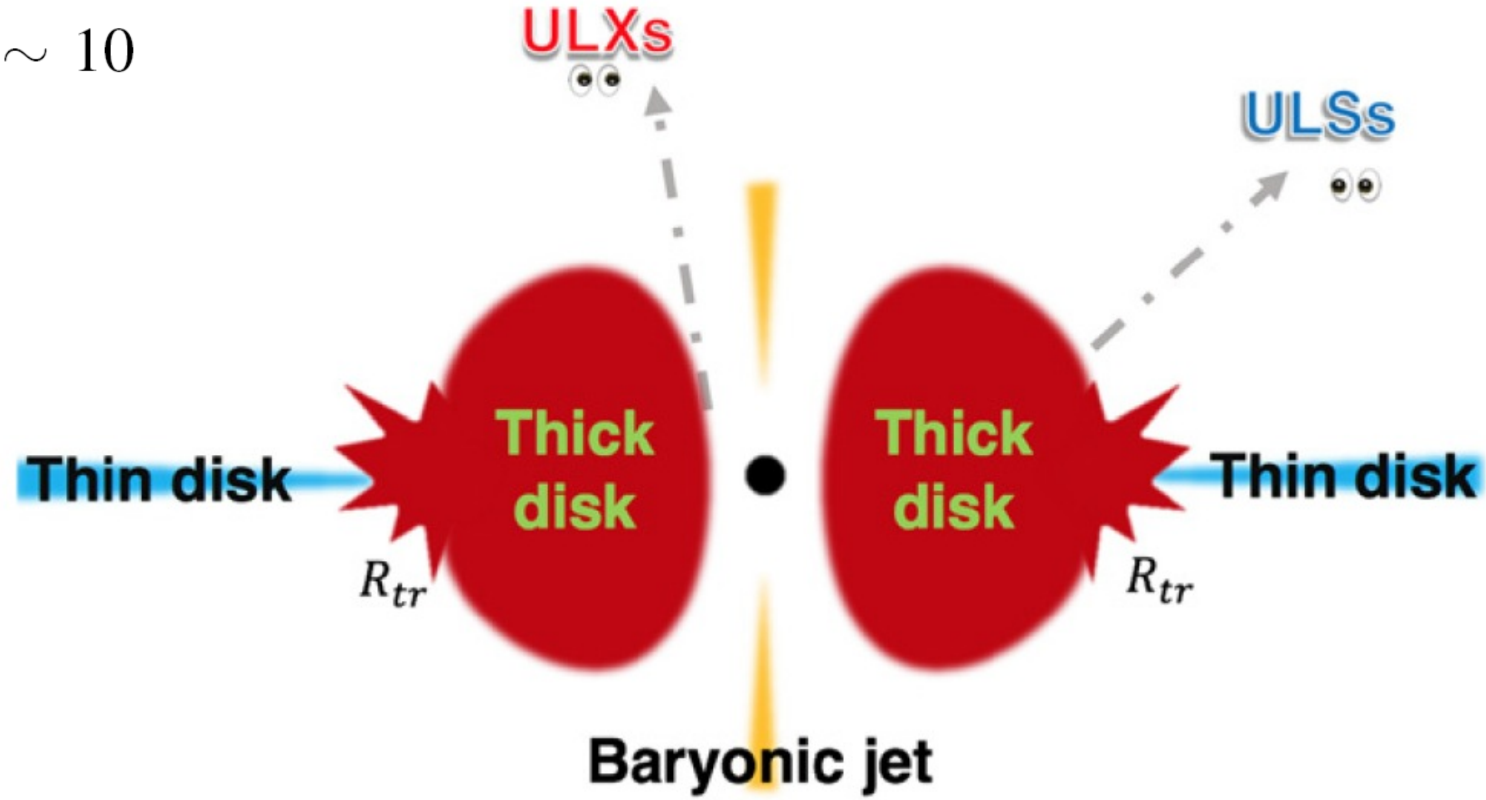
Subject headings: accretion, accretion disks — instabilities



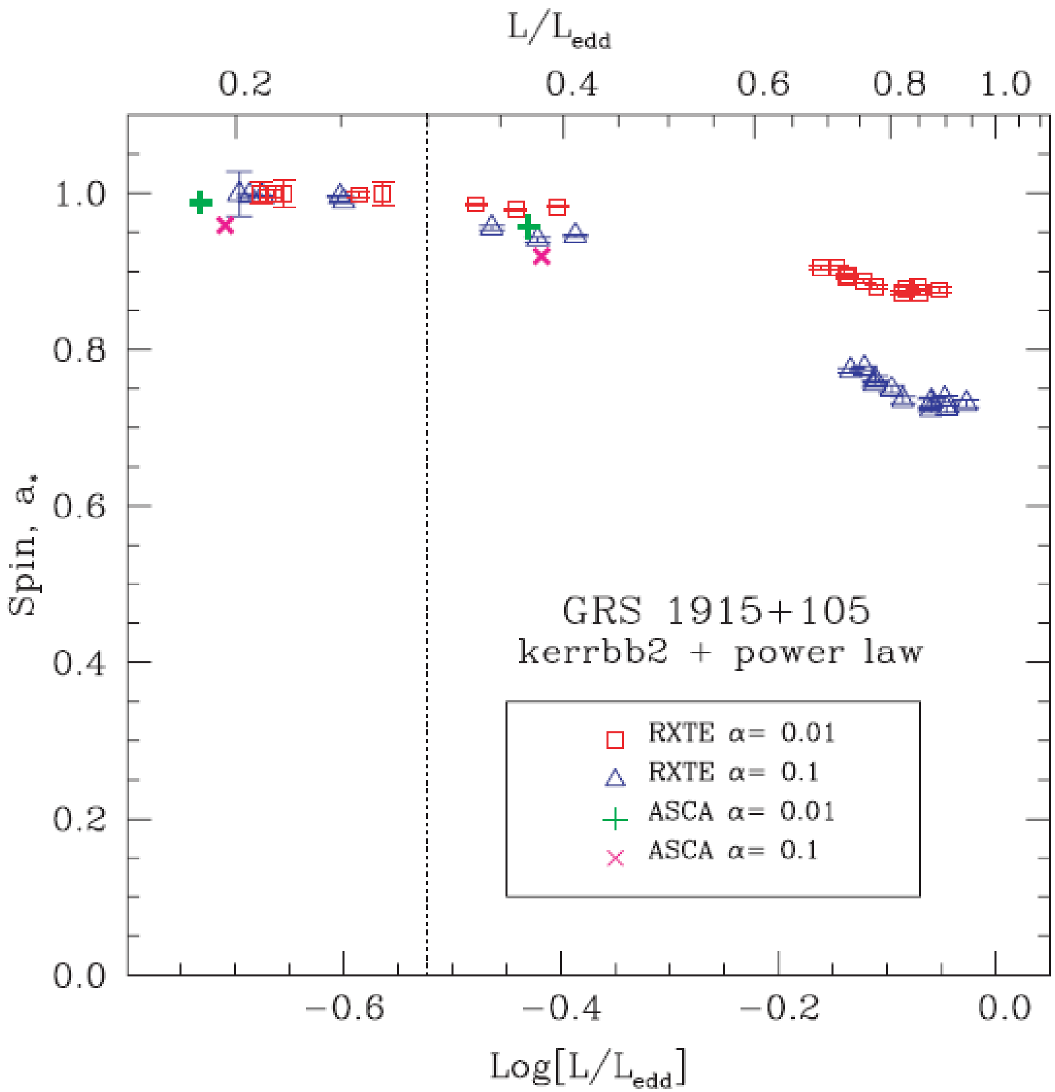
Geometrically thick disk model
(similar to the classic slim disk)

$$R_{\rm tr} = \lambda \dot{m} R_{\rm g}$$

$$\lambda \sim 10$$



Gu et al. (2016), ApJL, 818, L4



McClintock et al. (2006)

$$L_{\rm disk}^{\rm thin} \approx \int_{R_{\rm tr}}^{\infty} \frac{3GM_{\rm BH}\dot{M}}{8\pi R^3} \cdot 4\pi R \, dR = 1.2 L_{\rm Edd}$$

$$L_{\rm disk}^{\rm thick} \sim 0.5 L_{\rm Edd}$$

$$L_{\rm bol} \approx L_{\rm disk}^{\rm thin} + L_{\rm disk}^{\rm thick} = 1.7 L_{\rm Edd}$$

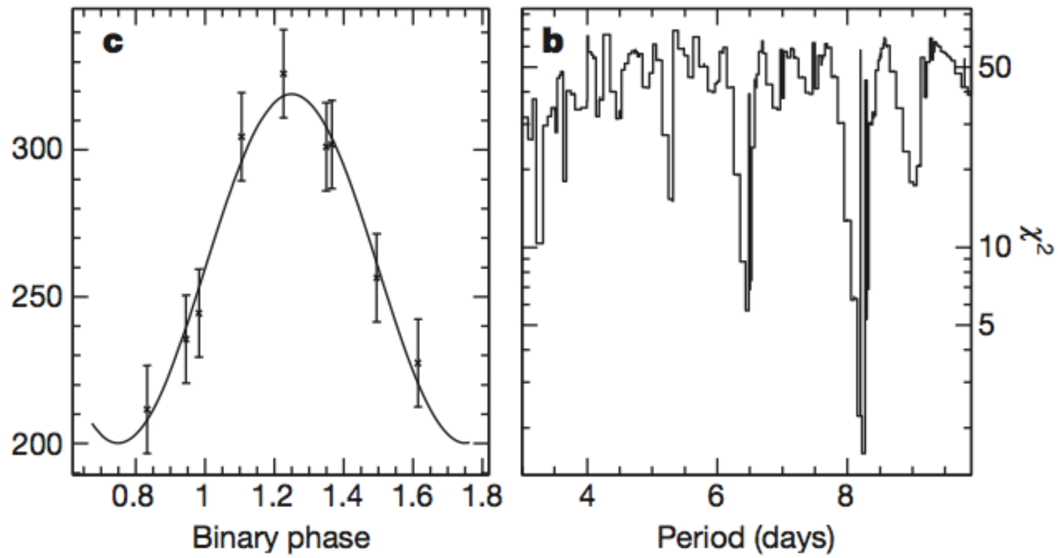
M101 X-1: $L_{\rm bol} \approx 5 \times 10^{39} \ {\rm erg \ s^{-1}}$

$\Longrightarrow$ $M_{\rm BH} \approx 23 M_{\odot}$

LETTER

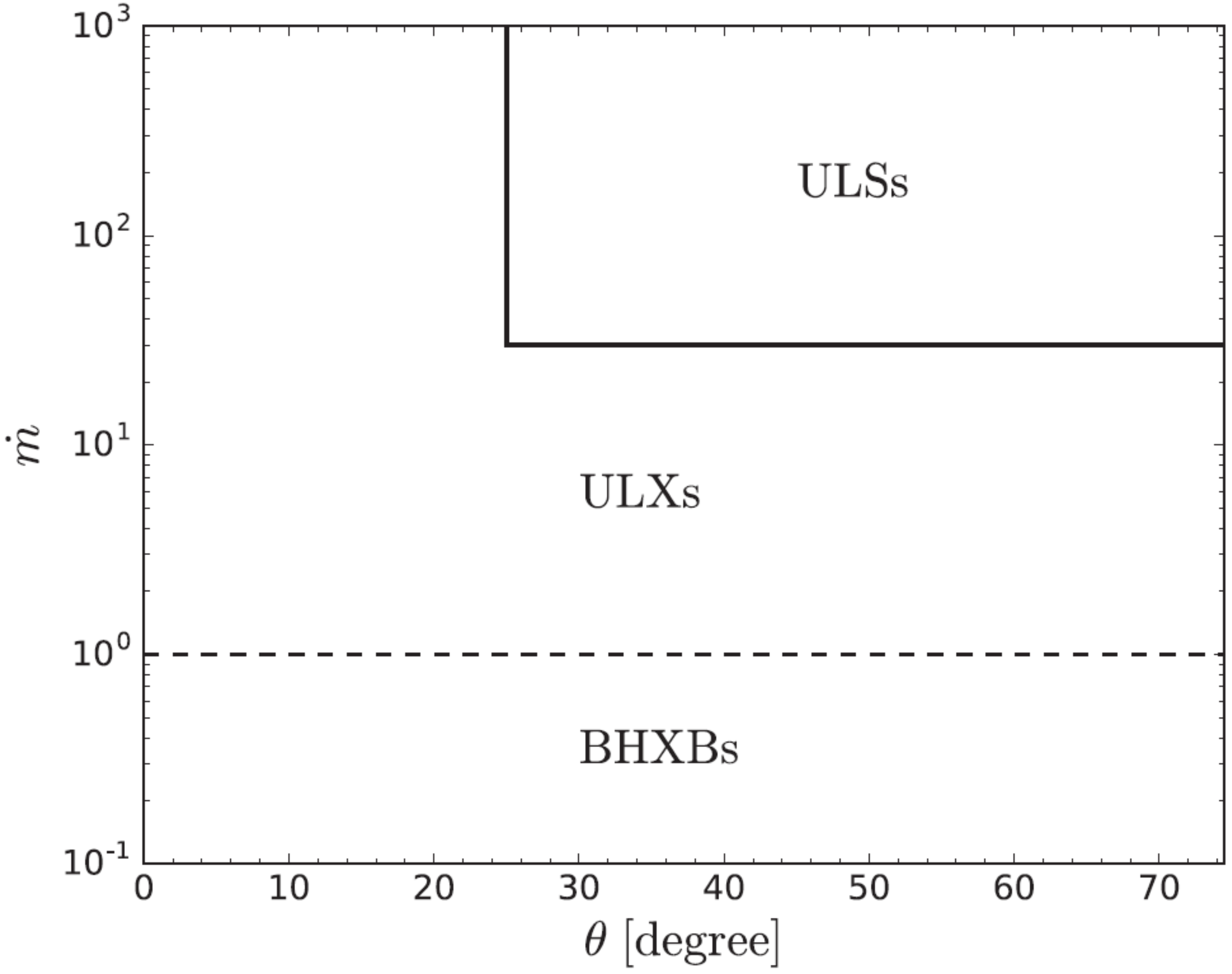
Puzzling accretion onto a black hole in the ultraluminous X-ray source M 101 ULX-1

Ji-Feng Liu[1], Joel N. Bregman[2], Yu Bai[1], Stephen Justham[1] & Paul Crowther [3]



that the system contains a Wolf-Rayet star, and reveal that the orbital period is 8.2 days. The black hole has a minimum mass of $5M_\odot$, and more probably a mass of $20M_\odot-30M_\odot$, but we argue that it is very unlikely to be an intermediate-mass black hole. Therefore, its excep-

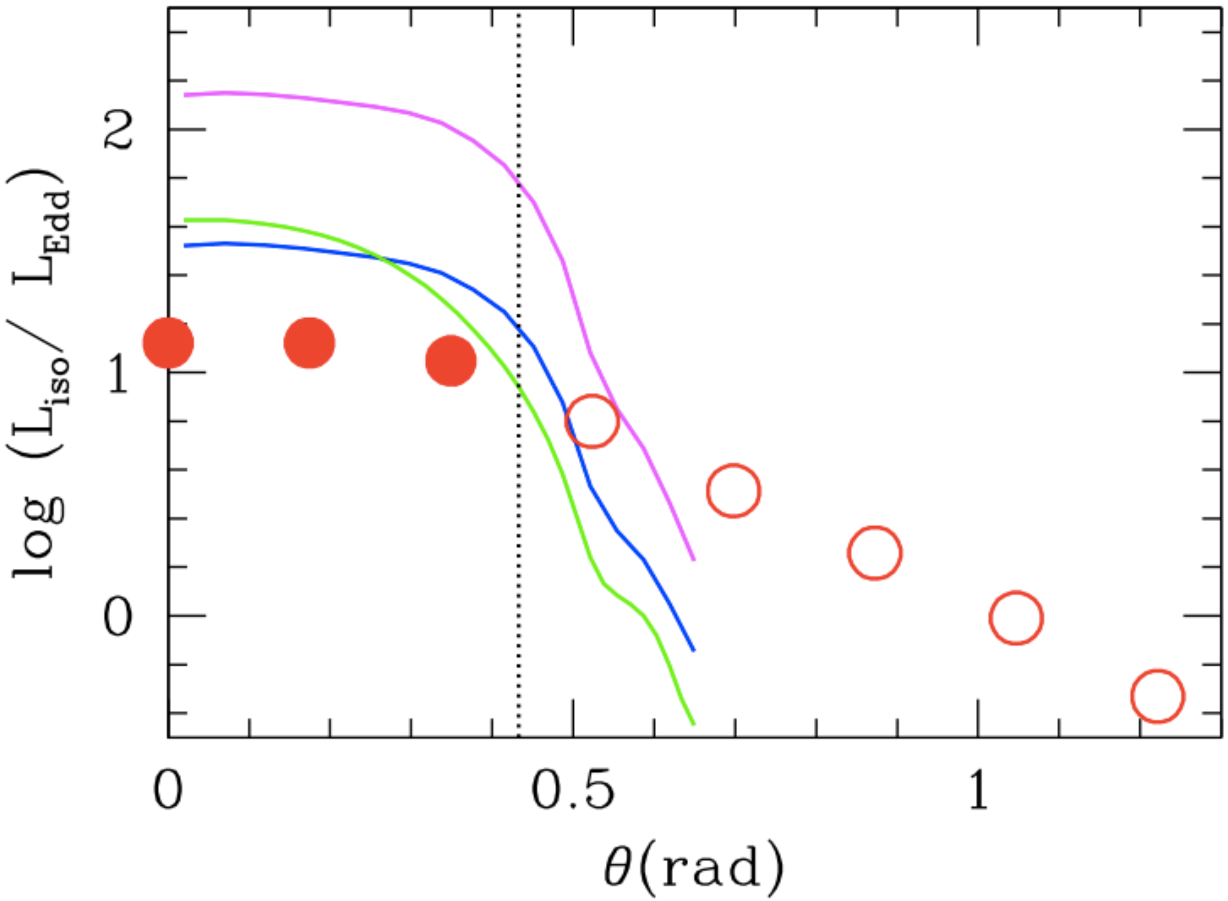
Unified description of ULSs, ULXs, and BHXBs



$$\begin{cases} \dot{m} \gtrsim 30 \\ \theta \gtrsim 25^\circ \end{cases}$$

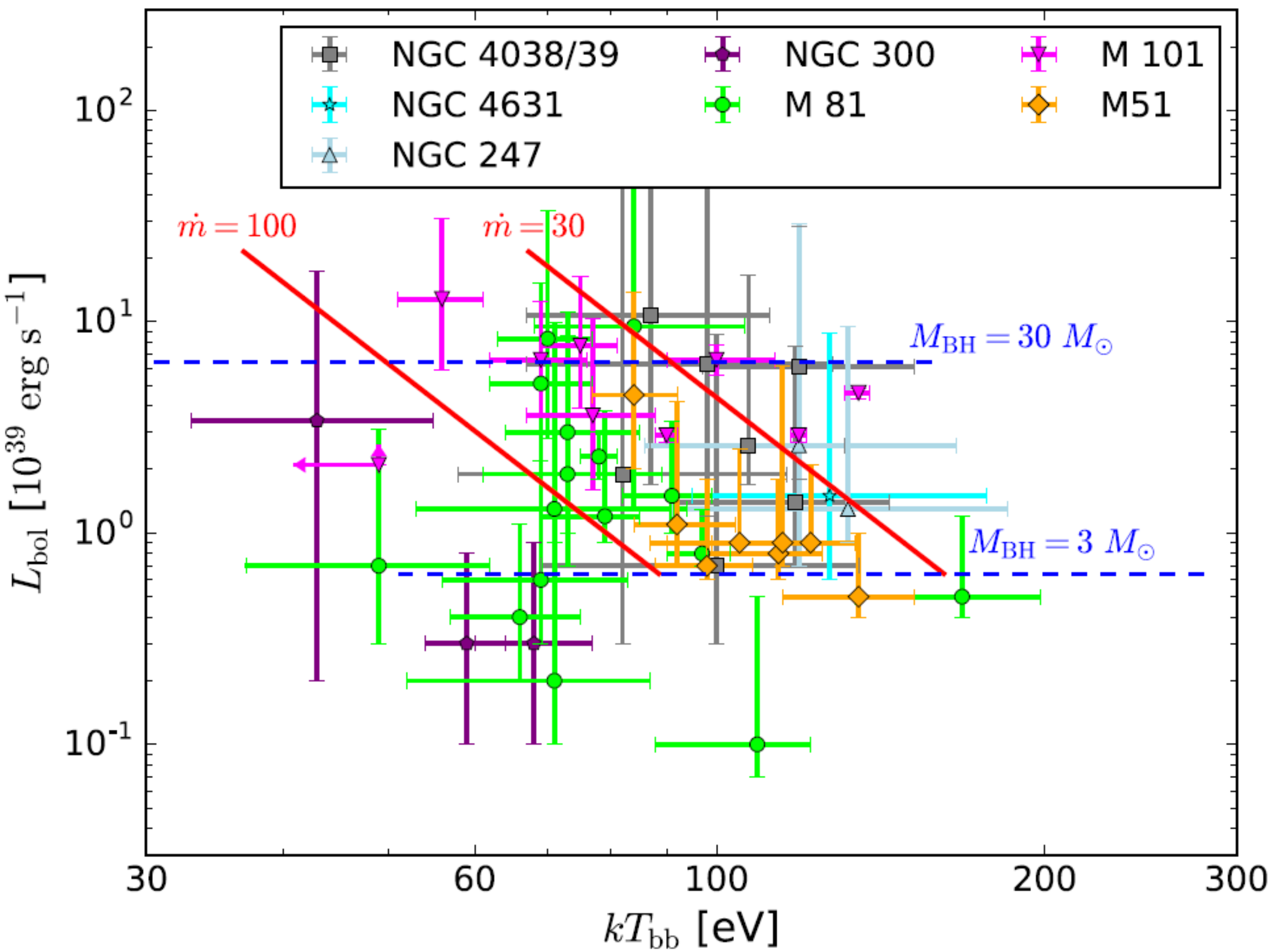
HEROIC: 3D General Relativistic Radiative Postprocessor with Comptonization for Black Hole Accretion Discs

Ramesh Narayan[1*] Yucong Zhu[1], Dimitrios Psaltis[2*], Aleksander Sądowski[3*]



Vertical dotted line: Nominal edge of the optically thin funnel region.

$$kT_{\rm bb} \approx 660\ \dot{m}^{-\frac{1}{2}} \left(\frac{M_{\rm BH}}{10 M_\odot}\right)^{-\frac{1}{4}}\ {\rm eV}$$



Simulations

Publl. Astron. Soc. Japan (2017) 69 (2), 33 (1–9)

Radiation hydrodynamic simulations of a super-Eddington accretor as a model for ultra-luminous sources

Takumi OGAWA,[1,*] Shin MINESHIGE,[1] Tomohisa KAWASHIMA,[2] Ken OHSUGA,[3,4] and Katsuya HASHIZUME[4]

Abstract

nearly face-on direction. The high luminosity ($\sim 10^{39}$ erg s^{-1}) and the very soft blackbody-like spectra with temperatures around 0.1 keV, which are observed in the ULSs, can be explained if the super-Eddington flow with $\dot{m}_{\rm acc} \sim 10^2$–$10^3$ is viewed from large viewing angles, $\theta \gtrsim 30^\circ$.

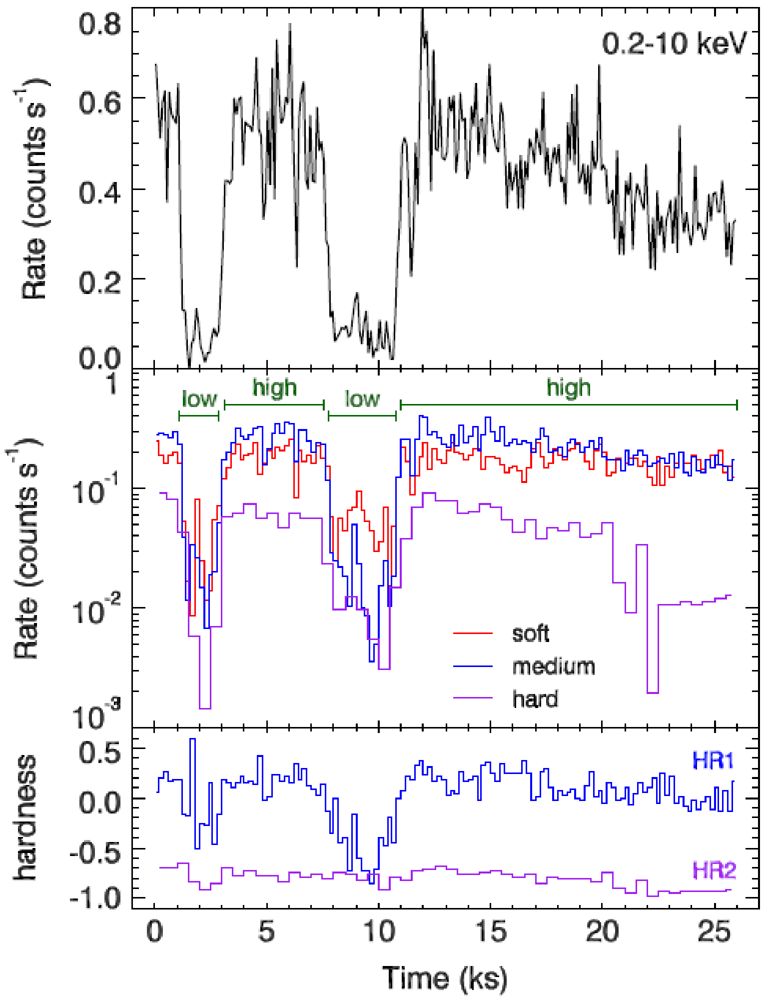
$$\dot{M}_{\rm Edd} \equiv L_{\rm Edd}/c^2$$ **Ogawa et al. (2017)**

$$\dot{M}_{\rm Edd} = L_{\rm Edd}/(\eta c^2) \quad \eta = 1/16$$ **Gu et al. (2016)**

The Astrophysical Journal, 831:117 (13pp), 2016 November 10 doi:10.3847/0004-637X/831/2/117

NATURE OF THE SOFT ULX IN NGC 247: SUPER-EDDINGTON OUTFLOW AND TRANSITION BETWEEN THE SUPERSOFT AND SOFT ULTRALUMINOUS REGIMES

Hua Feng[1], Lian Tao[2], Philip Kaaret[3], and Fabien Grisé[4]



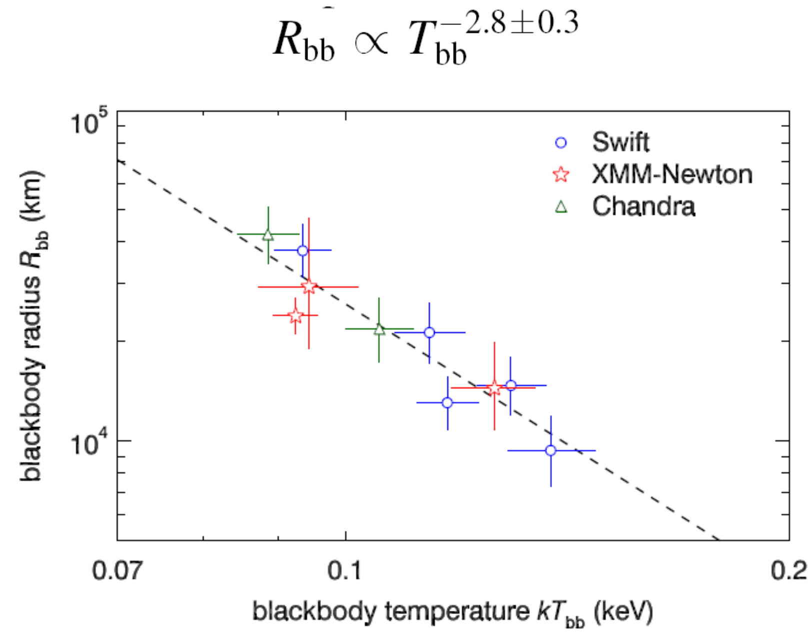
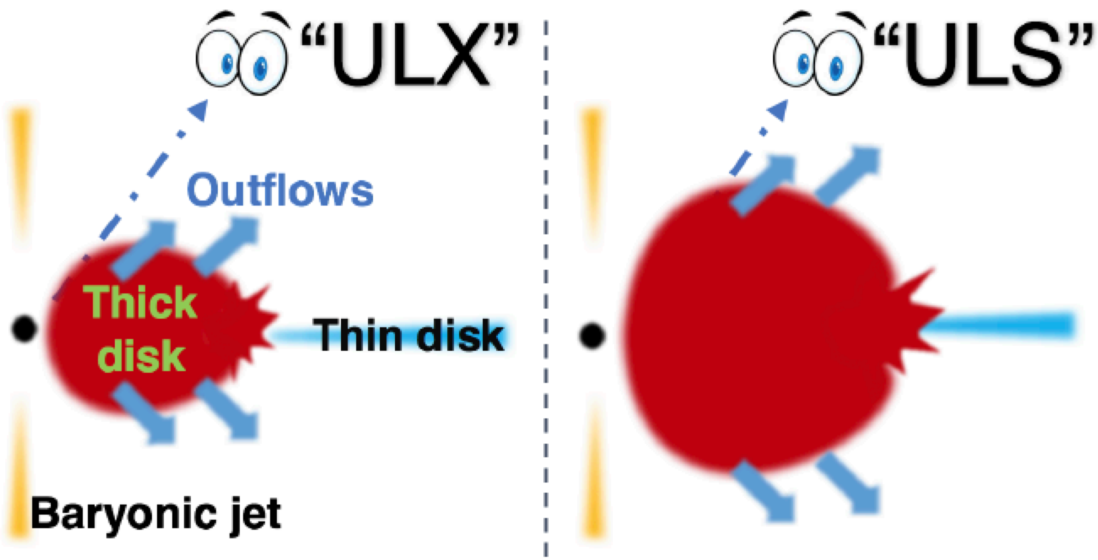
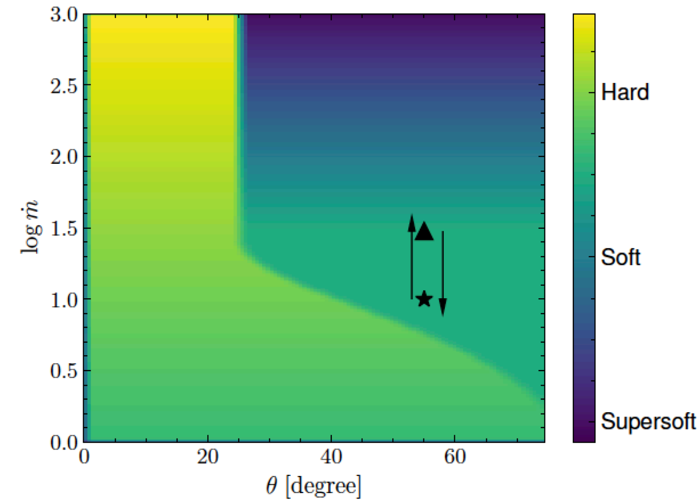


Figure 1. *XMM-Newton* PN light curves of NGC 247 ULX from the 2014 observation in the longest continuous and clean time interval with an exposure of 26.1 ks. Top: light curve in the full band (0.2–10 keV). Middle: light curves in the soft band (0.2–0.75 keV), medium band (0.75–1.5 keV), and hard band (1.5–10 keV). Bottom: hardness ratios defined as HR1 = (medium − soft)/(medium + soft) and HR2 = (hard − medium − soft)/(hard + medium + soft). The light curve has a time step of 100 s for the full band, 200 s for the soft and medium bands, and 500 s for the hard band.

Flux dips with a transition timescale of ~200 s

$$t_{\rm vis} \sim 110 \frac{0.01}{\alpha} \left(\frac{R}{H}\right)^2 \left(\frac{M_{\rm BH}}{23 M_\odot}\right)^{-\frac{1}{2}} \left(\frac{R}{1.4 \times 10^9 \ {\rm cm}}\right)^{\frac{3}{2}} \ {\rm s}$$





Guo, Sun, Gu & Yi (2018), submitted

Conclusion

- Two necessary conditions for ULSs:

  accretion rate: mdot > 30

  inclination angles: $\theta > 25°$

  For the other cases: ULXs

- Lower mdot is required compared with the outflow model

- Application to NGC 247

- X-ray flare of GW170817

Thanks!