Evidence for a black hole accretion disc in the AGN RXJ1633+4718 in X-ray

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Abstract

We report the discovery of a luminous ultra-soft X-ray excess in a radio-loud narrow-line Seyfert 1 galaxy, RX J1633+4718, from archival *ROSAT* observations. The thermal temperature of this emission, when fitted with a blackbody, is as low as $32.5^{+8.0}_{-6.0}$ eV. This is in remarkable contrast to the canonical temperatures of ~0.1–0.2 keV found hitherto for the soft X-ray excess in active galactic nuclei (AGNs) and is interestingly close to the maximum temperature predicted for a postulated accretion disk in this object. If this emission is indeed blackbody in nature, the derived luminosity ($3.5^{+3.3}_{-1.5} \times 10^{44}$ erg s^{-1}) infers a compact emitting area with a size ($\sim 5 \times 10^{12}$ cm or 0.33 AU in radius) that is comparable to several times the Schwarzschild radius of a black hole (BH) at the mass estimated for this AGN ($\sim 3 \times 10^6\ M_\odot$). In fact, this ultra-steep X-ray emission can be well fitted as the (Compton scattered) Wien tail of the multi-temperature blackbody emission from an optically thick accretion disk, whose inferred parameters (BH mass and accretion rate) are in good agreement with independent estimates using the optical emission-line spectrum. We thus consider this feature as a signature of the long-sought X-ray radiation directly from a disk around a supermassive BH, presenting observational evidence for a BH accretion disk in the AGN. Future observations with better data quality, together with improved independent measurements of the BH mass, may constrain the spin of the BH.

The paper of this work has been published in
Yuan W., et al. 2010, ApJ, 723, 508

Background

- Accretion of matter onto a black hole (BH) via an optically thick disc (Shakura & Sunyaev 1973; Novikov & Thorne 1973) is widely accepted as the engine to power active galactic nuclei (AGNs) and black hole X-ray binaries (BHXBs) in a bright state.

- For BHXBs (BH M ~ 10 M⊙) the bulk of the disc blackbody emission, which has a maximum temperature kT_{max} ~ 0.5–1 keV, falls within the observable X- ray bandpass, and the disc model has been tested quantitatively and proven to prevail (see, e.g., Done et al. 2007 for a recent review).

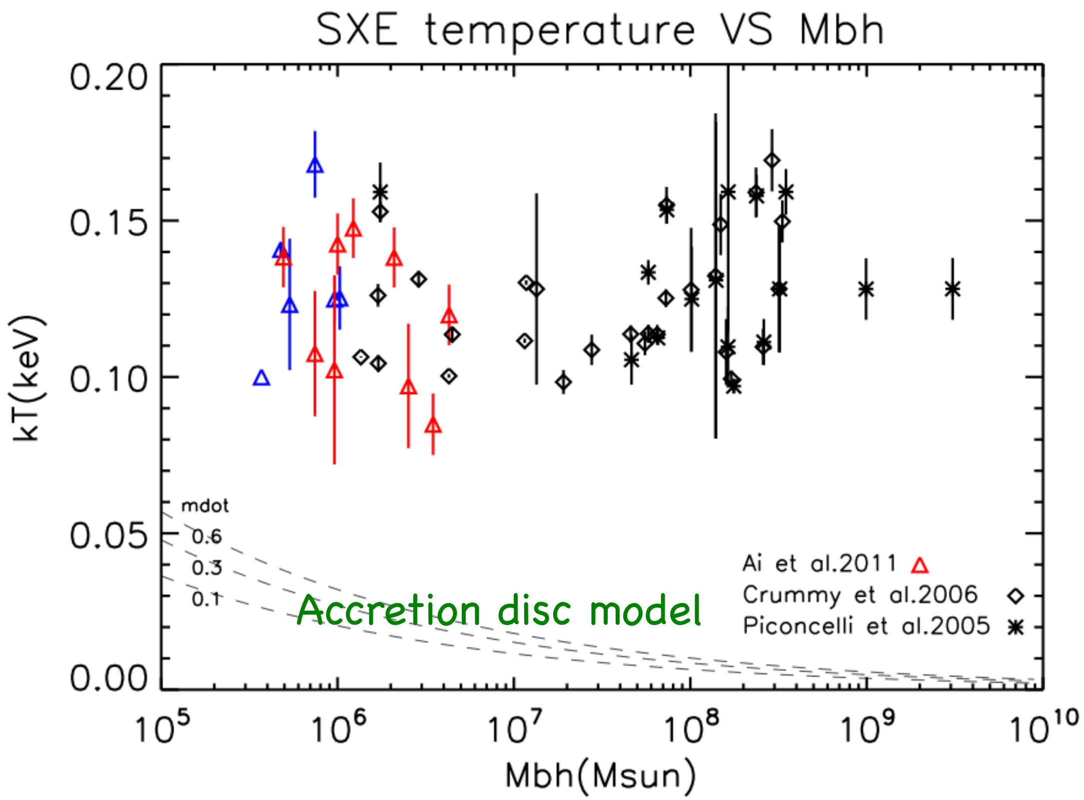
- In AGNs harboring supermassive black holes (SMBHs) with typical $M \sim 10^{6-9} M_\odot$, typically $kT_{max} \leq$ a few tens eV (10^5k), peaked in EUV, that is hard to detect. Therefore no convincing quantitative tests have been performed.

Soft X-ray excess: disc blackbody emission?

Though soft X-ray excess is commonly observed in AGN, it is NOT interpreted as the expected disk emission, because……

- Blackbody temperature in a narrow range 0.1-0.2keV, higher than the predicted maximum temperature of disc
- independent of MBH
- observed X-ray luminosity inconsistent with the disc luminosity

e.g. Gierlinski & Done 2004

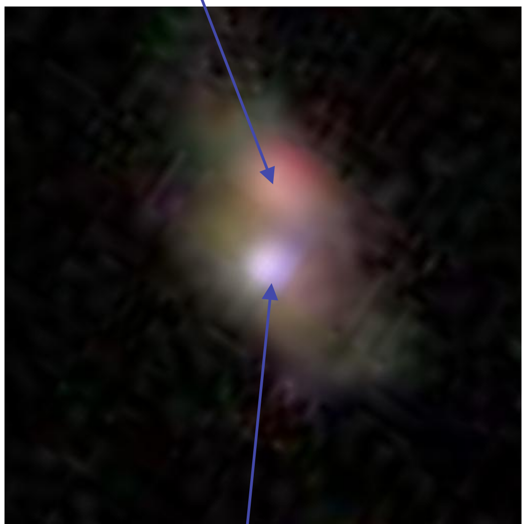


Ai, Yuan, et al., 2011, ApJ, 727, 31

The AGN RXJ 1633+4718

A RASS source identified with a NLS1 AGN (Wisotzki & Bade 1997), and a radio-loud NLS1 with blazar-like property, i.e. jet aligned close to line of sight (Yuan et al. 2008).

Starburst nucleus



AGN & radio/X-ray source

z=0.116

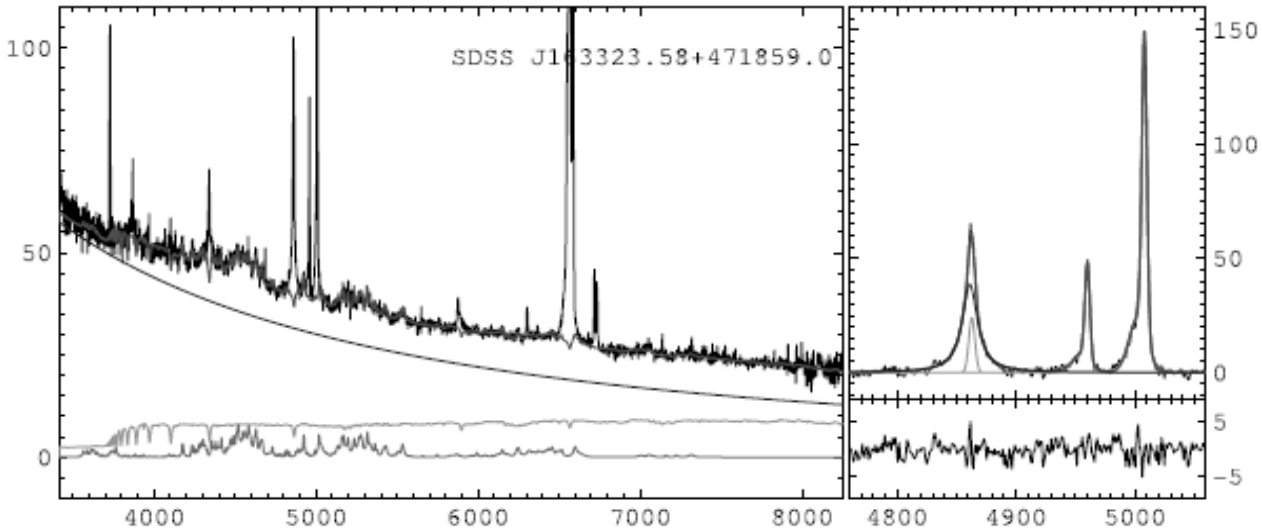
Broad line FWHM = 909 ±43 km/s

BH mass = 3 (2-4) $\cdot 10^{6}$ Msun

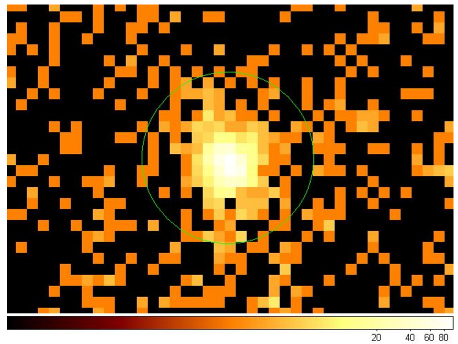
Schwar. radius Rs = 9 $\cdot 10^{11}$ cm

Thermal L_{bol} = 2.8 (±0.6) $\cdot 10^{44}$ erg/s (from Hβ)

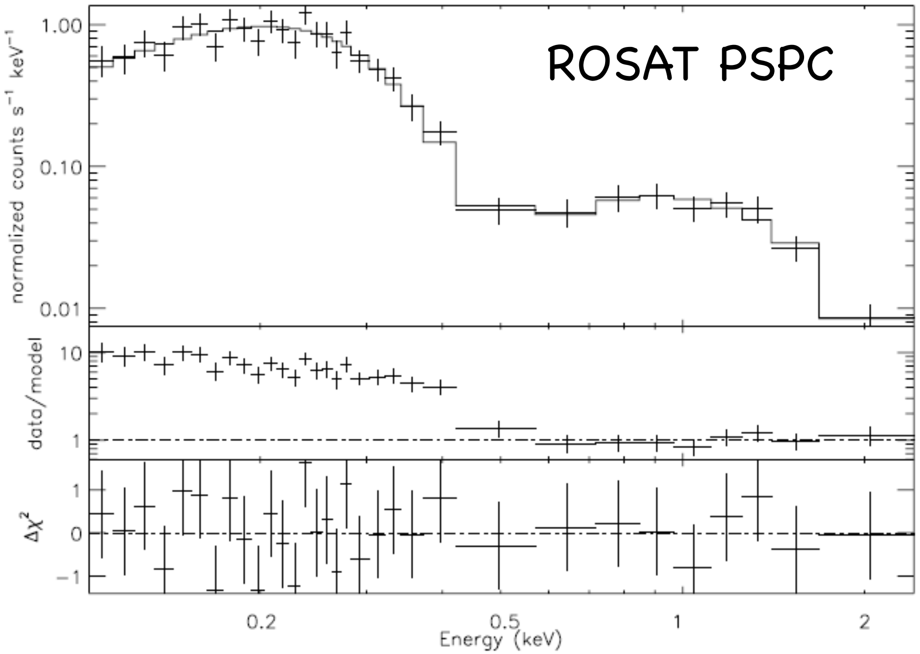
L_{bol}/L_{edd} ~ 0.69 (+0.73,-0.35)

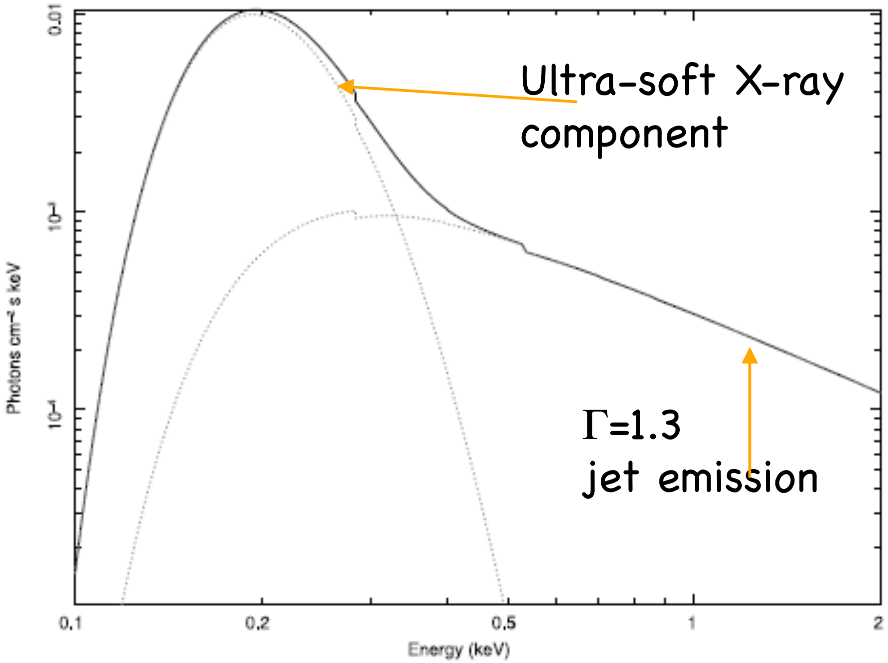


ROSAT data on J1633+4718



Pointed: exposure=3732s, ~976 source counts (1993)
RASS: exposure=909s, ~185 source counts (1992)





Prominent soft X-ray excess: extremely soft
Blackbody kT = 32 eV ! unprecedented !
L_{bb} = 3.5(+3.3,-1.5) $\cdot 10^{44}$ erg/s

Table 1. Results of spectral fit

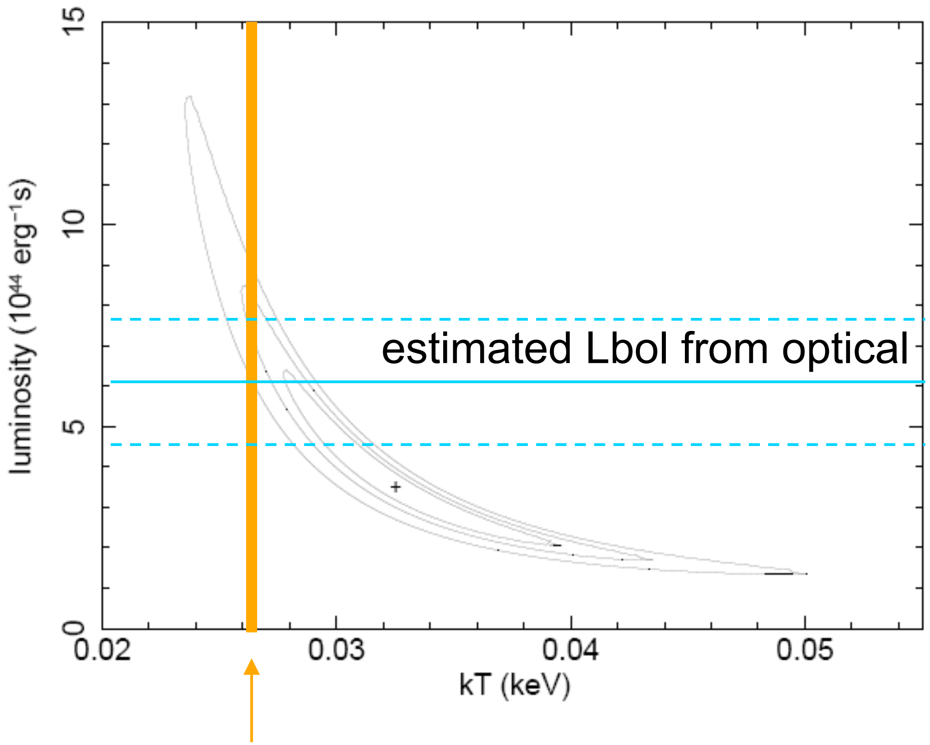
wabs * model [a]	$N_H(10^{20}\,cm^{-2})$	Γ	kT(eV) / Γ_s [b]	χ^2/d.o.f.
powl	$0.37^{+0.30}_{-0.25}$	$2.22^{+0.22}_{-0.20}$		34.1/29
powl	1.79(fixed)[c]	3.06		67.4/30
powl (0.4–2.4 keV)	1.79(fixed)	1.63 ± 0.40		4.4/9
powl + powl	1.79(fixed)	$1.04^{+0.57}_{-0.52}$	$4.83^{+1.53}_{-0.56}$	17.2/28
powl + raymond	1.79(fixed)	$1.30^{+0.42}_{-0.43}$	50^{+15}_{-11}	16.4/28
powl + zbremss	1.79(fixed)	$1.34^{+0.42}_{-0.40}$	59^{+26}_{-15}	16.7/28
powl + zbbdy	$1.1^{+4.2}_{-0.9}$	$1.30^{+0.42}_{-0.64}$	42^{+41}_{-21}	16.6/27
powl + zbbdy	1.79(fixed)	1.37 ± 0.49	$32.5^{+8.0}_{-6.0}$	16.9/28
powl + zbbdy (RASS)	1.79(fixed)	$1.47^{+0.77}_{-0.92}$	30^{+12}_{-10}	10.7/9
powl + diskbb	$1.2^{+2.5}_{-0.7}$	$1.29^{+0.40}_{-0.66}$	48^{+53}_{-27}	16.6/27
powl + diskbb	1.79(fixed)	1.36 ± 0.41	$39.6^{+12.3}_{-7.5}$	16.8/28

[a]Source model (from XSPEC) modified by neutral absorption (wabs) with column density N_H: powl – power-law with photon index Γ; raymond – Reymond-Smith thin plasma emission (abundance fixed at solar); zbremss – redshifted thermal bremstrahlung; zbbdy – redshifted blackbody with effective temperature kT; diskbb – multi-colour disc model with the (rest frame) maximum temperature kT (see text)

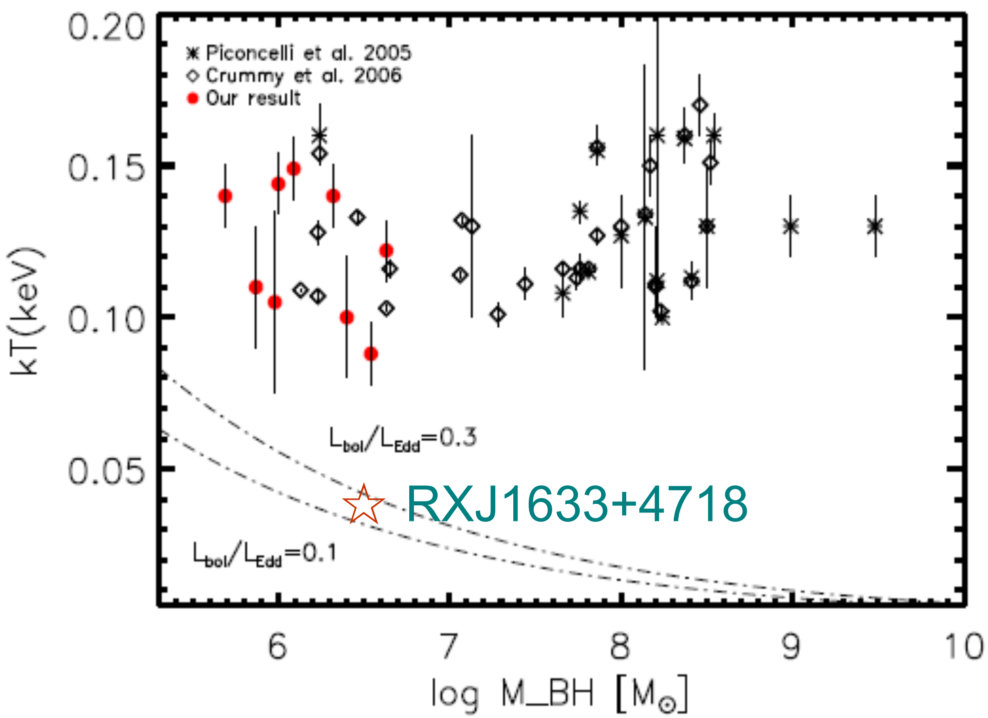
Blackbody temperature and luminosity

blackbody kT = 32 eV !
L_{bb} = 3.5(+3.3,−1.5) $\cdot 10^{44}$ erg/s

The low kT of RXJ1633+4718 is extra-ordinary !



Predicted disc T_{max} from optical



Order of magnitude estimation of the Size and temperature of the emitting region

assuming blackbody emission

- Emitting area A, $L=\sigma T^4 A$

Lbb = 3.5(+3.3,-1.5) $\cdot 10^{44}$ erg/s

R~ 5-7 $\cdot 10^{12}$ cm (sphere or disc) 0.33AU
→ 6-8 Rs ! Rs = 9 $\cdot 10^{11}$ cm extremely compact
i.e. X-ray from a compact region very close to the BH

- Maximum temperature of disc

predicted: T_{max} = 26 eV
Observed: Tbb = 32(+8,-6) eV

$$T_{\rm eff}(R) = \left[\frac{3GM\dot{M}}{8\pi\sigma R^3}\left(1-\sqrt{\frac{R_{\rm in}}{R}}\right)\right]^{1/4}$$

- Energy budget

Predicted disc luminosity ~2.9 $\cdot 10^{44}$ erg/s (assuming Rin=3Rs)
observed thermal Lbol ~ 2.8 (±0.6) $\cdot 10^{44}$ erg/s

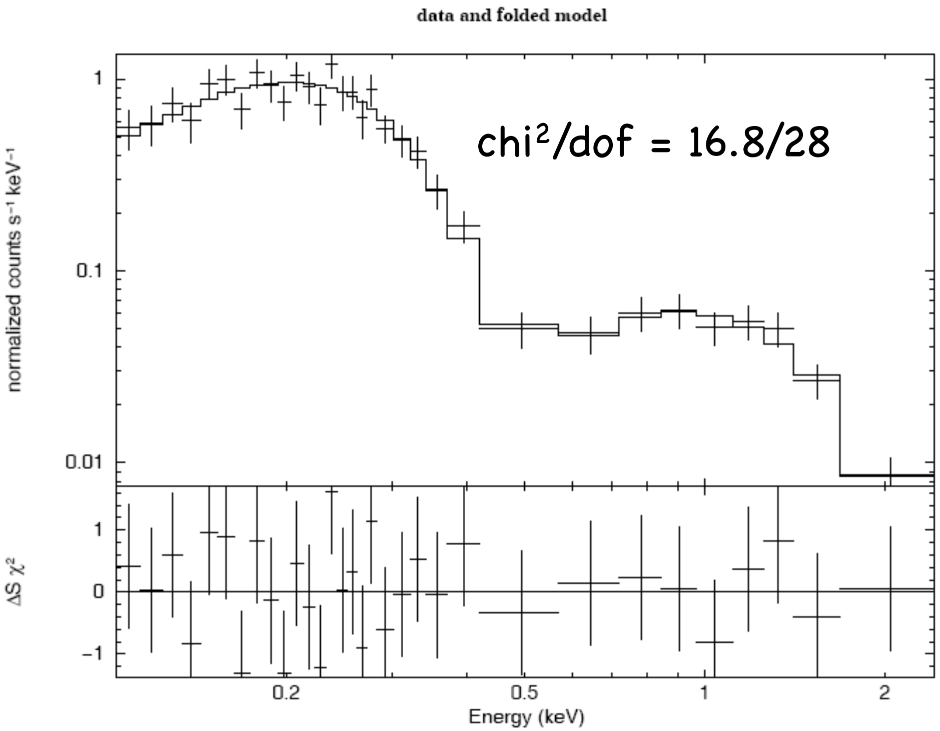
Spectral fit with disc blackbody model

Multi-color disc (MCD) model

3 free parameters: T_{in}, R_{in}, θ

$$T_{\rm in}^{\rm obs}=39.6^{+12.3}_{-7.5}\ {\rm eV}$$

$$R_{\rm in}^{\rm obs}\sqrt{\cos\theta}=3.0^{+2.9}_{-1.4}\times 10^{12}\ {\rm cm}$$



Correction to observed parameters

$$T_{\rm eff}(R_{\rm max})=\frac{1}{k}T_{\rm in}^{\rm obs},\quad R_{\rm in}=\xi k^2 R_{\rm in}^{\rm obs}.$$

k~1.7 spectral hardening (Compton scattering)

ξ= 0.41 inner boundary condition ignored in MCD

Kato et al. 1998, Ross et al. 1992, Shimura & Takahara 1995

Derived disc parameters from X-ray and comparison with the optical estimates: T_{max} & R_{in}

Disc maximum temperature

$T_{\rm max}=23.3^{+7.2}_{-4.4}\,{\rm eV}$

c.f. Tmax=26 eV

Radius of inner disc boundary

$R_{\rm in}\sqrt{\cos\theta}=3.6^{+3.4}_{-1.7}\times 10^{12}\,{\rm cm}$

c.f. Rs=9 ×10^11 cm from optical

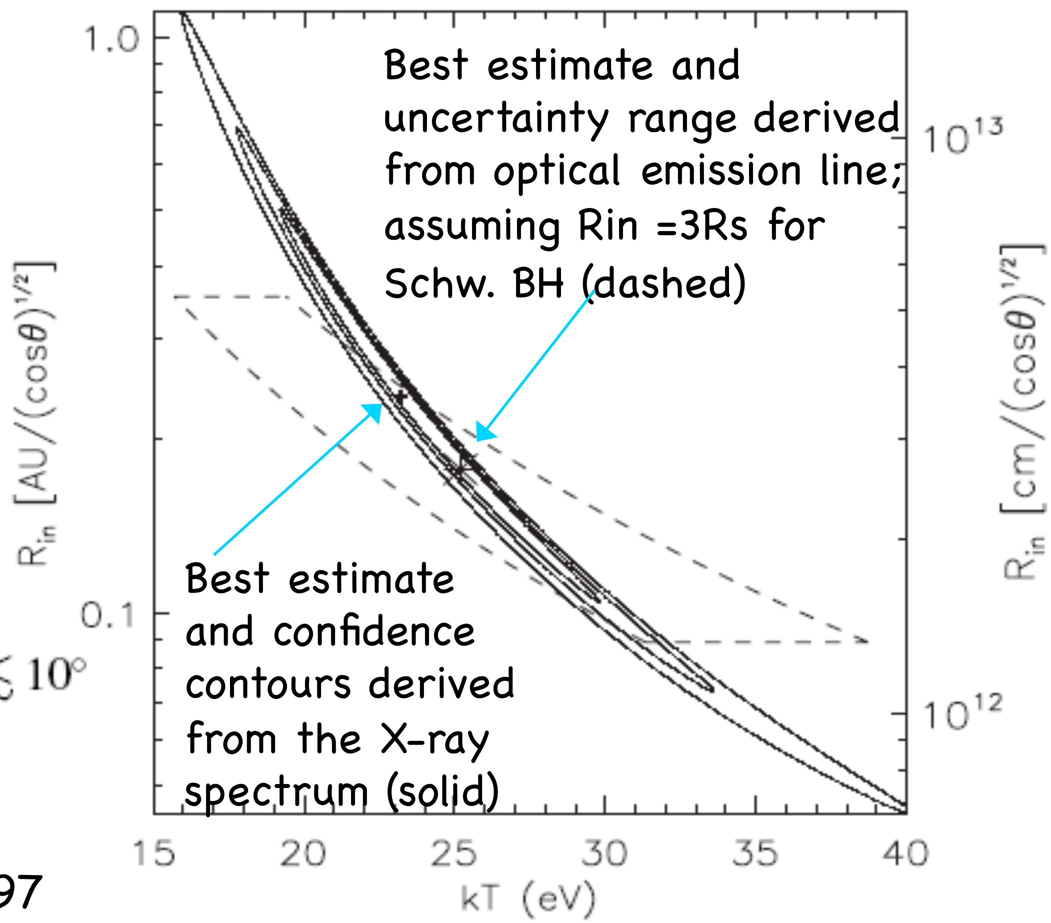
type 1 AGN→ $\theta < 30^\circ$ blazar-like→ $\theta \lesssim 10^\circ$

$R_{\rm in}\sqrt{\cos\theta}\approx R_{\rm in}$ $\sqrt{\cos\theta}\approx 1$

General relativity effect correction:

Zhang et al. 1997

$kT_{\rm max}=27\,{\rm eV}, R_{\rm in}\sim 2.9\times 10^{12}\,{\rm cm}$



Derived disc parameters: M_{bh} & accretion rate

Assuming Rin = 3Rs for Schw. BH

$$M_{\rm bh}^{\rm x}\sqrt{\cos\theta} = 4.1\times10^{6}\,M_{\odot}$$

c.f. MBH = 3 (2-4) $\times10^{6}$ Msun

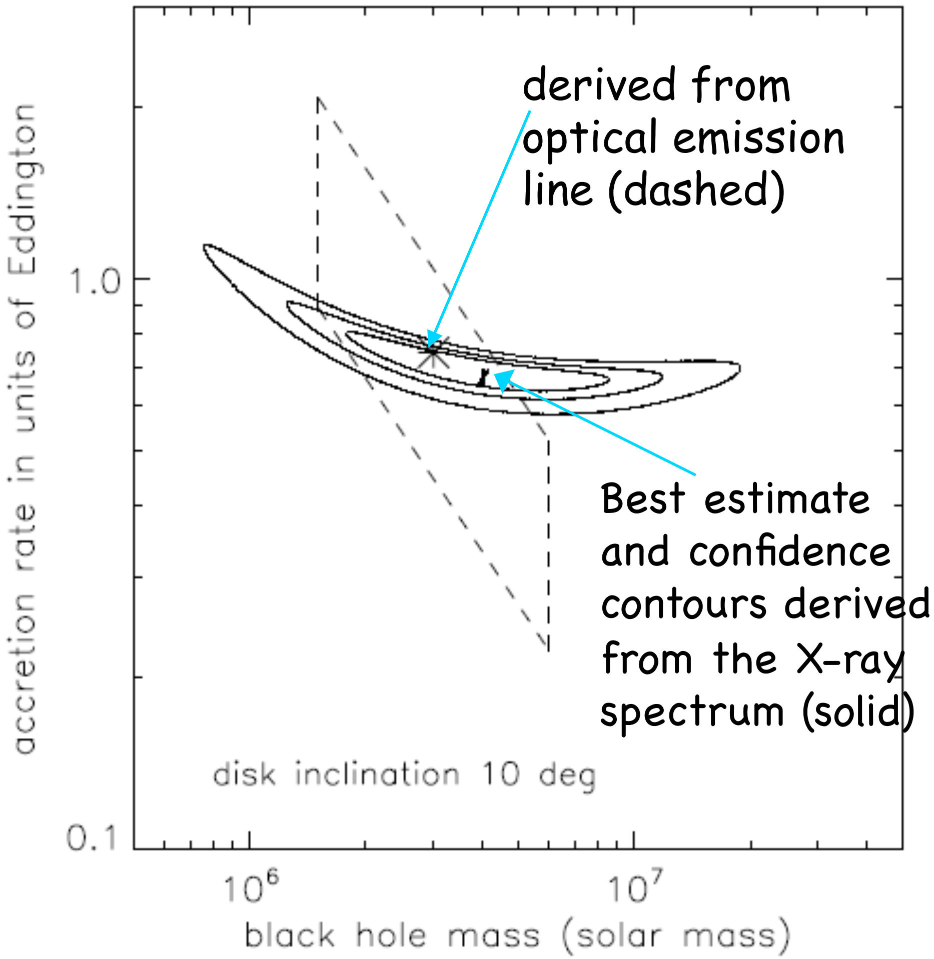
$$\dot{m}\sqrt{\cos\theta}=0.68$$

c.f. L/Ledd ~ 0.69 (+0.73,-0.35)

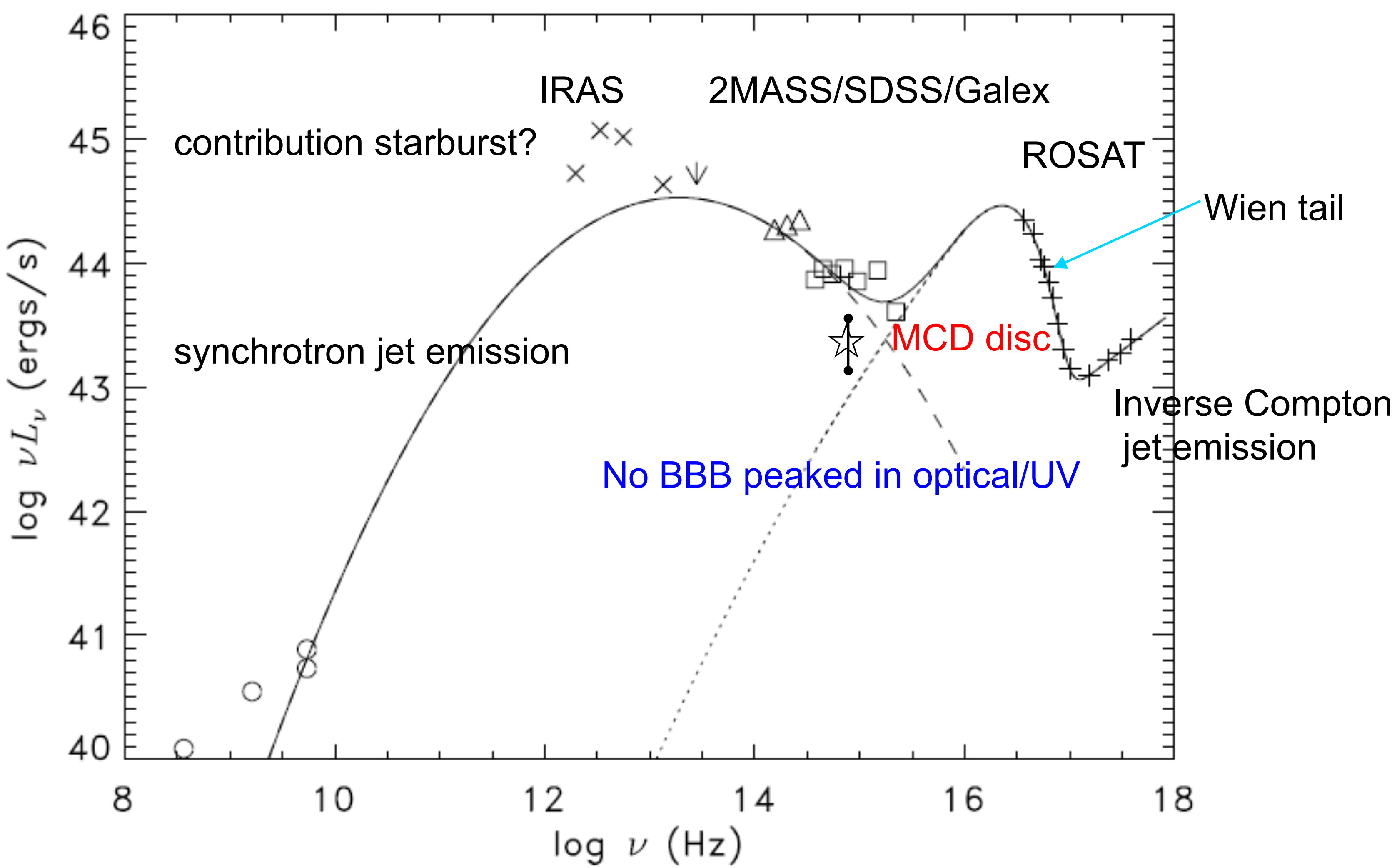
GR correction:

$$M_{\rm x}\sim3.3\times10^{6}\,M_{\odot} \qquad \dot{m}\sim1.0$$

derived parameters from X-ray (T_{max}, M_{bh}, accretion rate) agree well with those from the optical data
→ most likely we are seeing X-ray emission from an accretion disc



Fit the broad band SED data



SED consistent with the MCD model and the blazar property of J1633+4718

Summary

- an ultra-soft X-ray excess discovered in RXJ1633+4716
- self-consistently described by thermal emission from an optically thick accretion disc around a SMBH.
- derived parameters from X-ray (T_{max}, M_{bh}, accretion rate) agree well with independent estimates from optical spectrometric data.
- a signature of X-rays from an accretion disc around a SMBH!

  → promising evidence for BH accretion disc in AGN

Implications and future work

- RXJ1633+4716 is an AGN analog of BHXBs at the high/soft state (emission dominated by disc)
- Soft x-ray excess: different origins
- New observations to be performed by XMM-Newton at 4 epochs
- More realistic modeling
  - Better X-ray data
  - e.g. kerrbb (Li L.X. et al. 2005), BH spin?
  - slim disc? (e.g. Li, G.-X., et al. 2010)
- Possibly a good laboratory to test jet formation theory:

  future improved measurement of R_in and independent MBH can constrain BH spin (as for BHXB)

  → jets form in high-spin black hole system?

Question: why are RXJ1633+4716 type objects so rare?

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