Open Questions on Black Hole X-Ray Binaries

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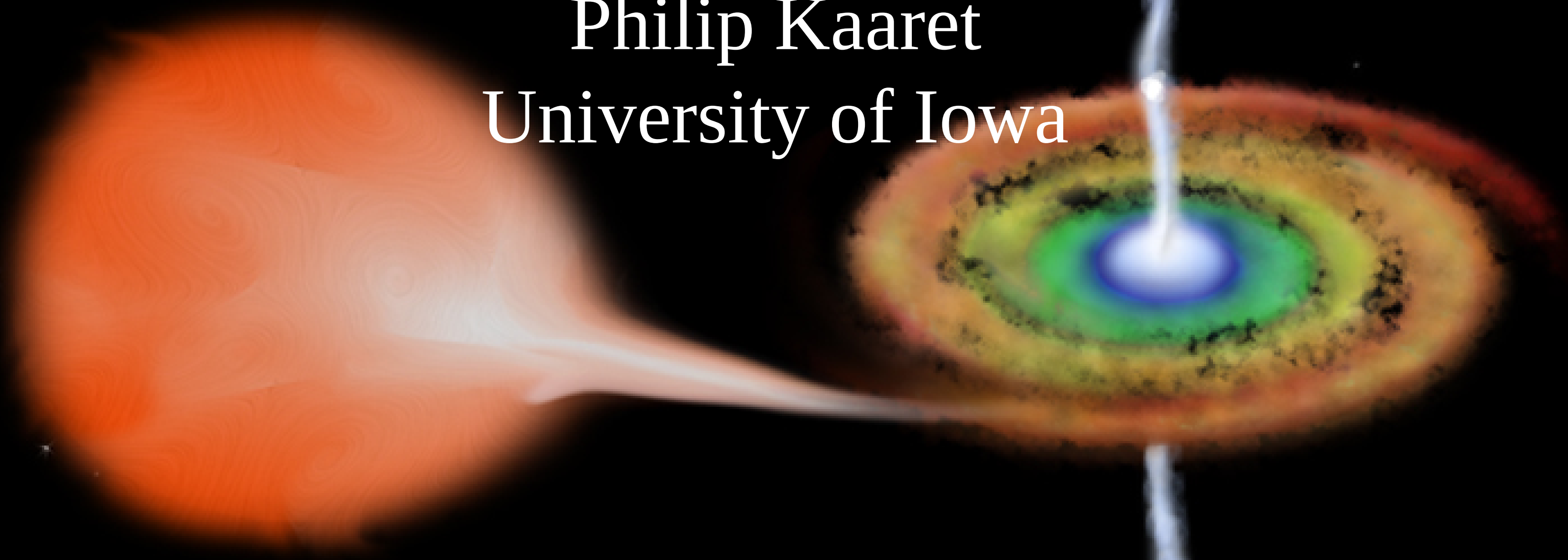
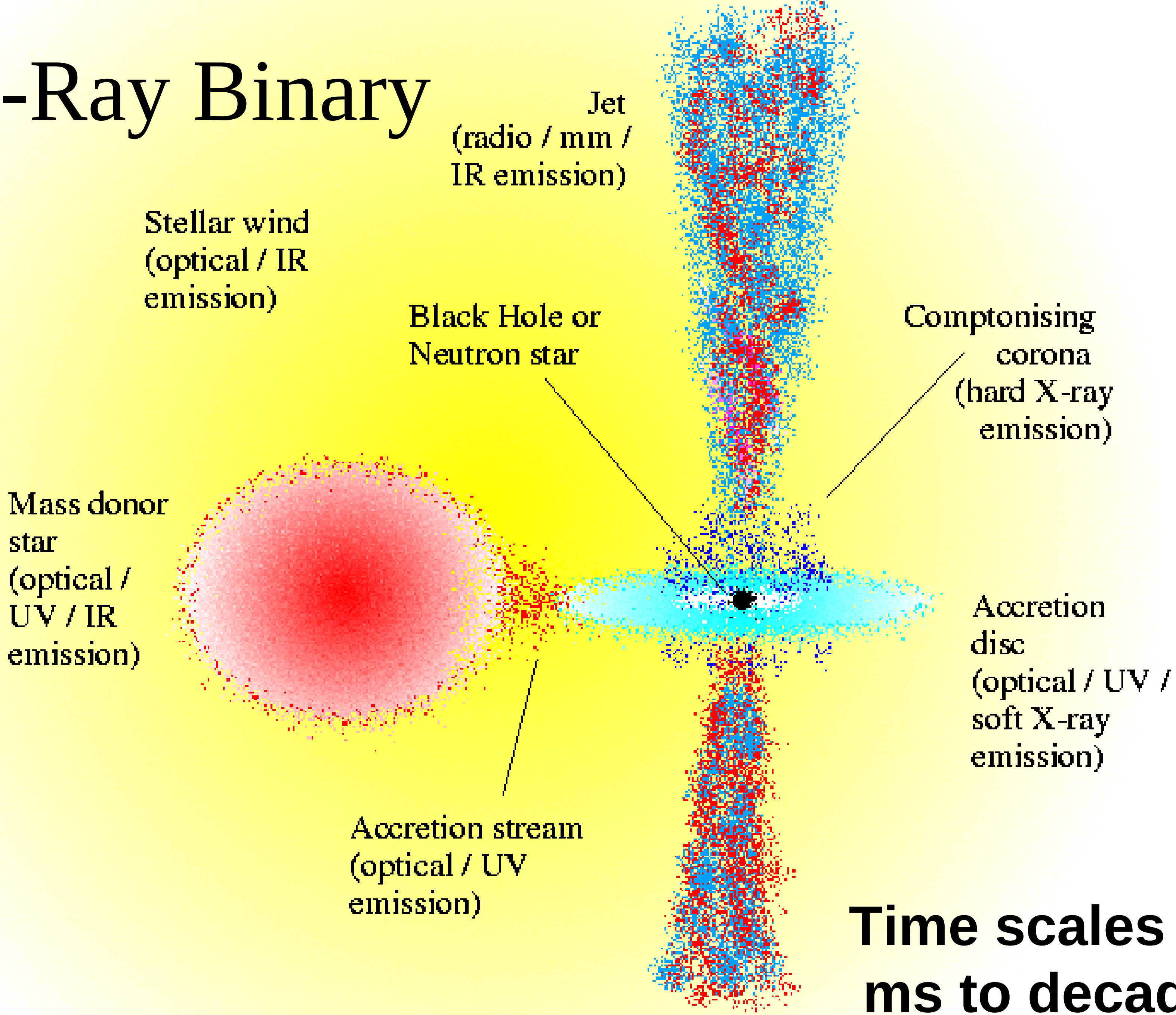


- Review of BH binaries
- Open Questions
- Addressing the questions with XMM

X-Ray Binary



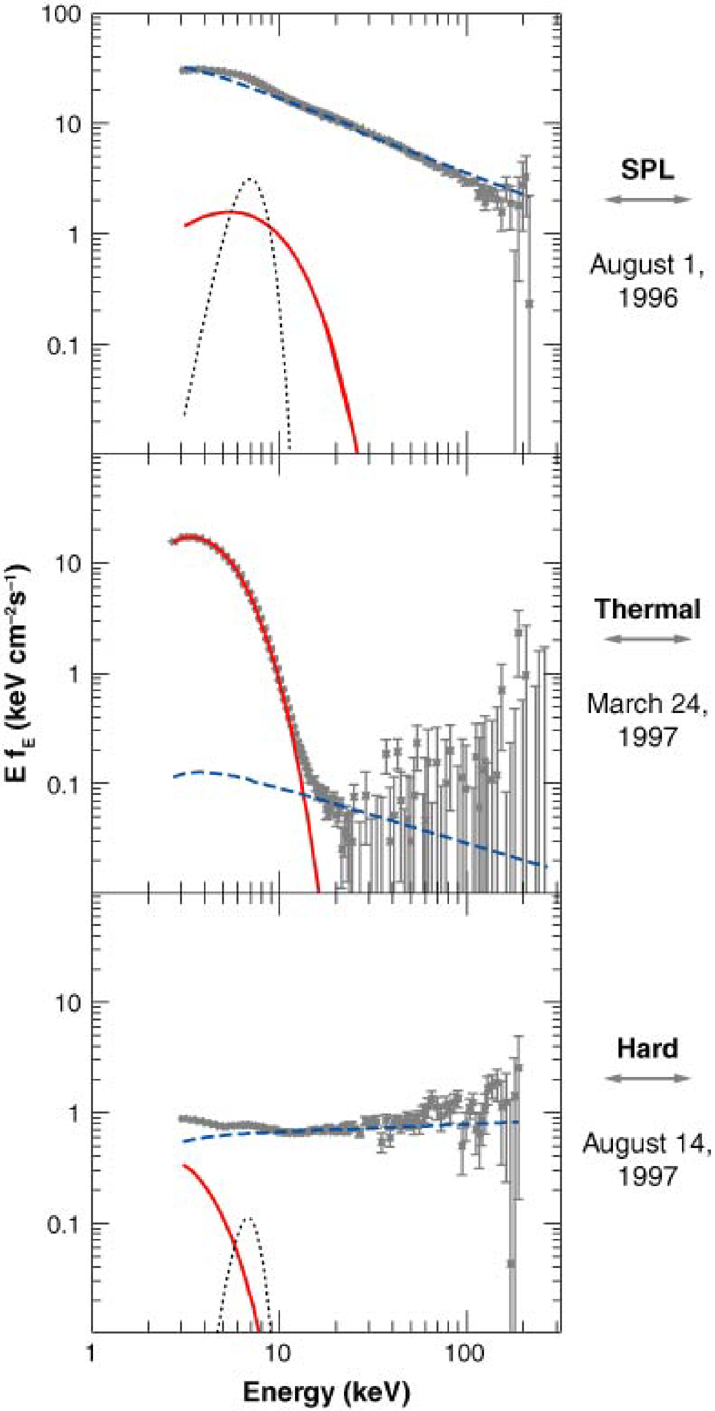
Time scales are ms to decades

X-Ray Spectral States

- **Steep powerlaw (very high)**
- **Thermal (high/soft)**
- **Hard (low/hard)**

Three spectral components:

- Thermal emission from disk - multicolor blackbody
- Emission from corona - powerlaw or Comptonization model
- Fe line



Open Questions

- Can we distinguish BH versus NS?
- Can we measure BH masses using X-rays?
- Can we measure the spins of BH?
- What is the geometry of the accretion flow?
- How are jets produced?
- How is accretion power divided between jets versus radiated energy?
- Do compact jets produce X-ray emission?
- What is the composition of BH jets?
- What are the ultraluminous X-ray sources?

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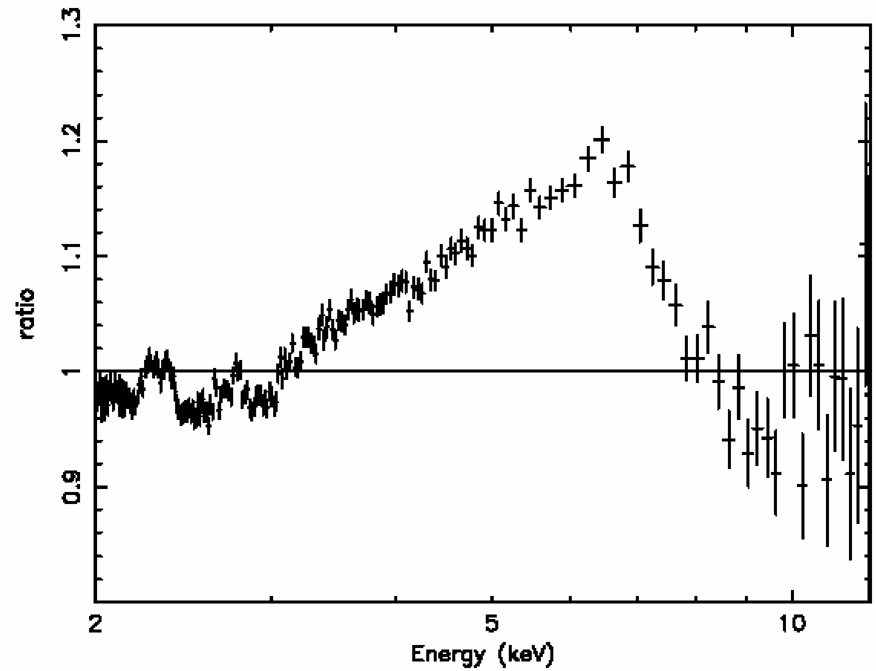
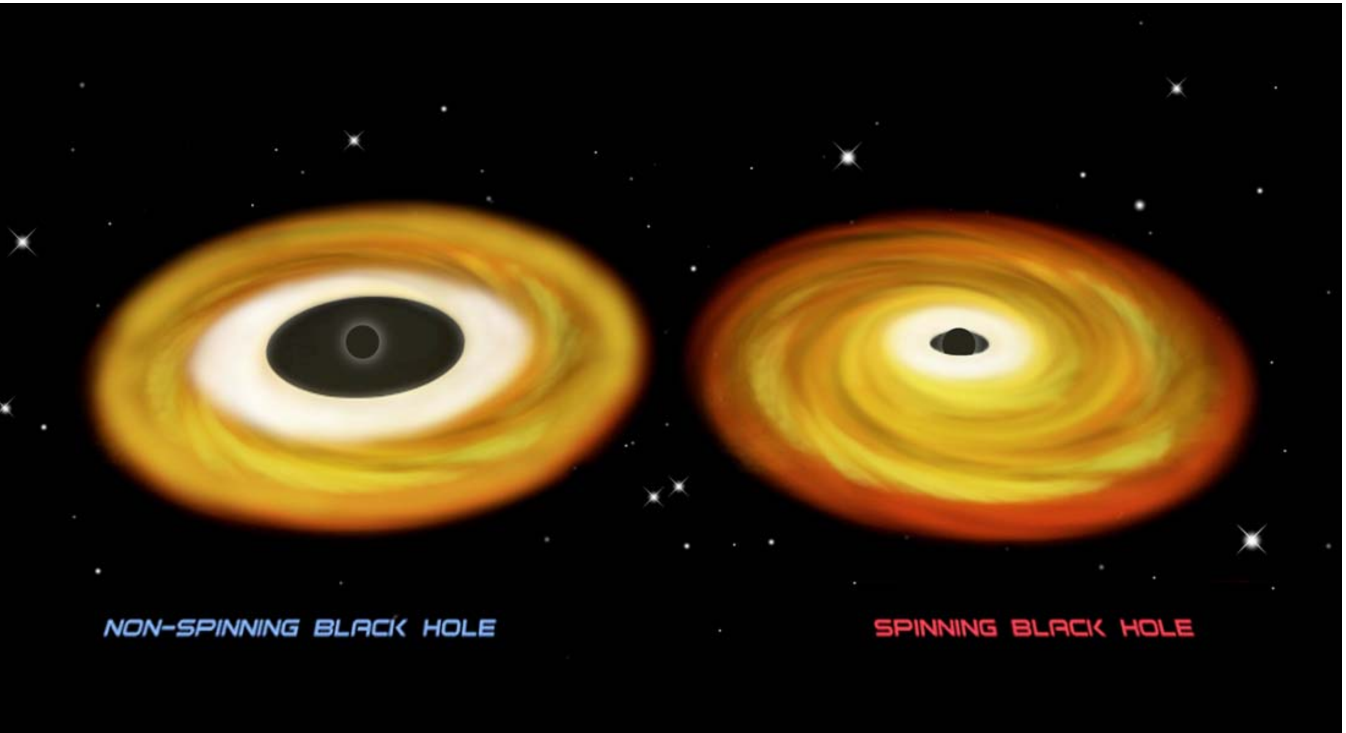
Black Hole Spins

- Can measure profile in different spectral states of one source
- Can measure spin via disk thermal emission.



GX 339-4

(Miller et al. 2004)

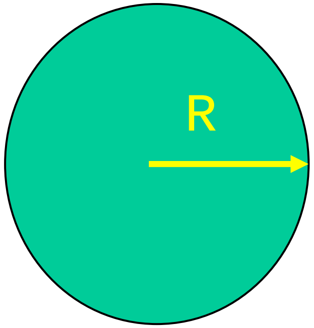


Measuring the Radius of a Star

- Measure the flux F received from the star
- Measure the temperature T (from spectrum)
- Then, assuming blackbody radiation:

$$L = 4\pi D^2 \quad F = 4\pi R^2 \sigma T^4$$

$$R = D\sqrt{\frac{F}{\sigma T^4}}$$



- F and T give solid angle of star
- If we know distance D, we directly obtain R

(McClintock 2007)

Black Hole Spins

For BH with known distance and inclination can measure size of disk.

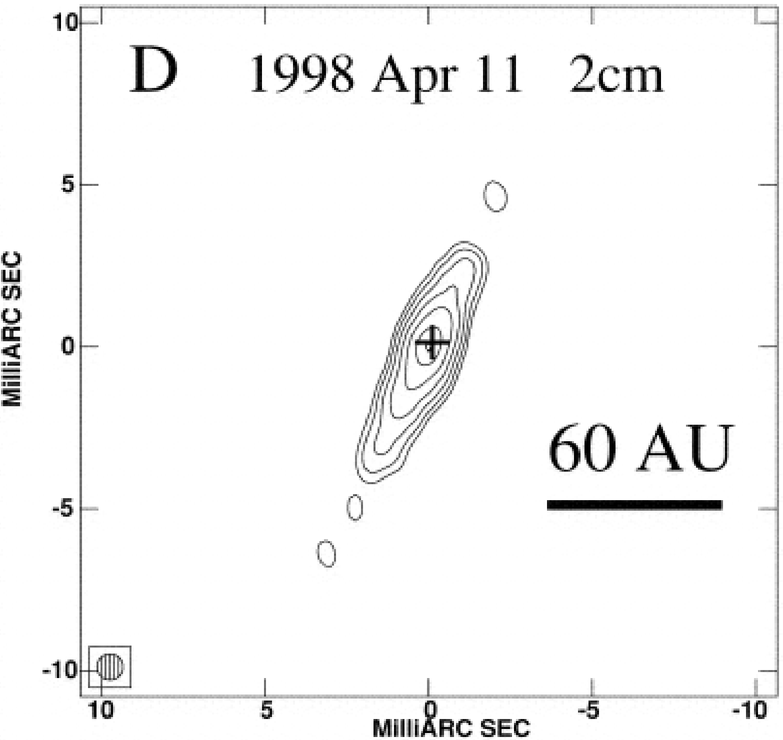
If mass is known, then can infer spin.

Source	a_*
GRO J1655-40	**0.65-0.75**
4U1543-47	**0.7-0.8**
GRS 1915+105	**0.98-1.0**
LMC X-3	**<0.26**

(Shafee et al. 2006; Davis et al. 2006; McClintock et al. 2006)

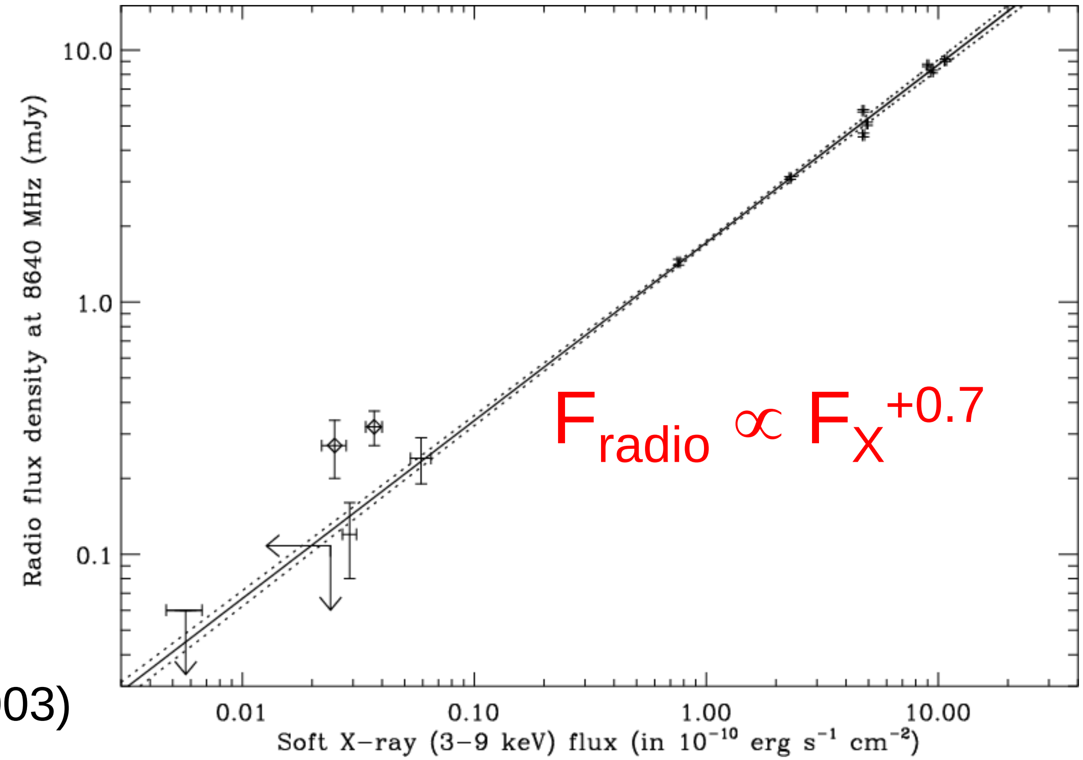
Compact jets

GRS 1915+105



Dhawan et al. (2000)

Small physical size, inverted or flat radio spectra → optically thick synchrotron emission from a self-absorbed outflow



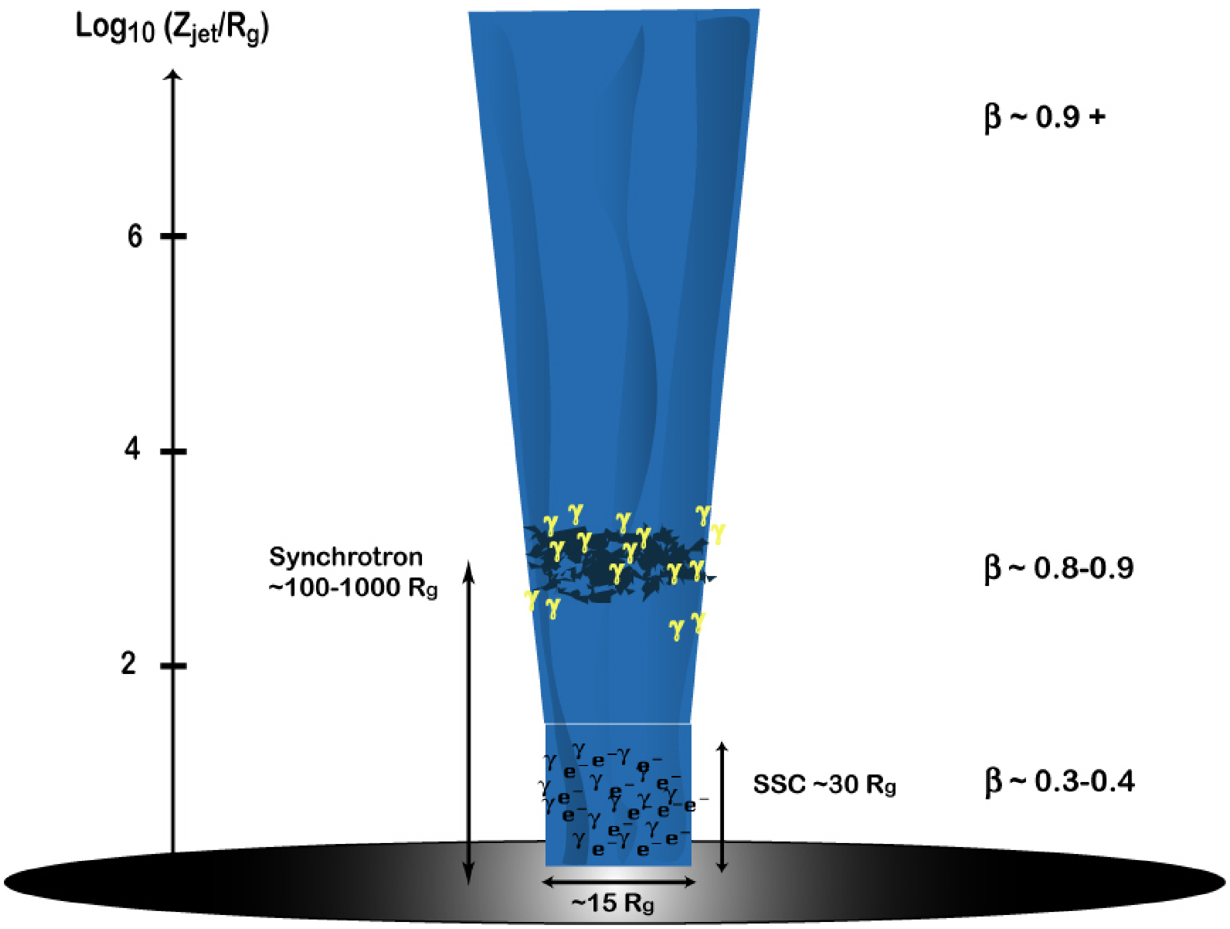
$F_{radio} \propto F_X^{+0.7}$

Corbel et al. (2000, 2003)

Compact jets

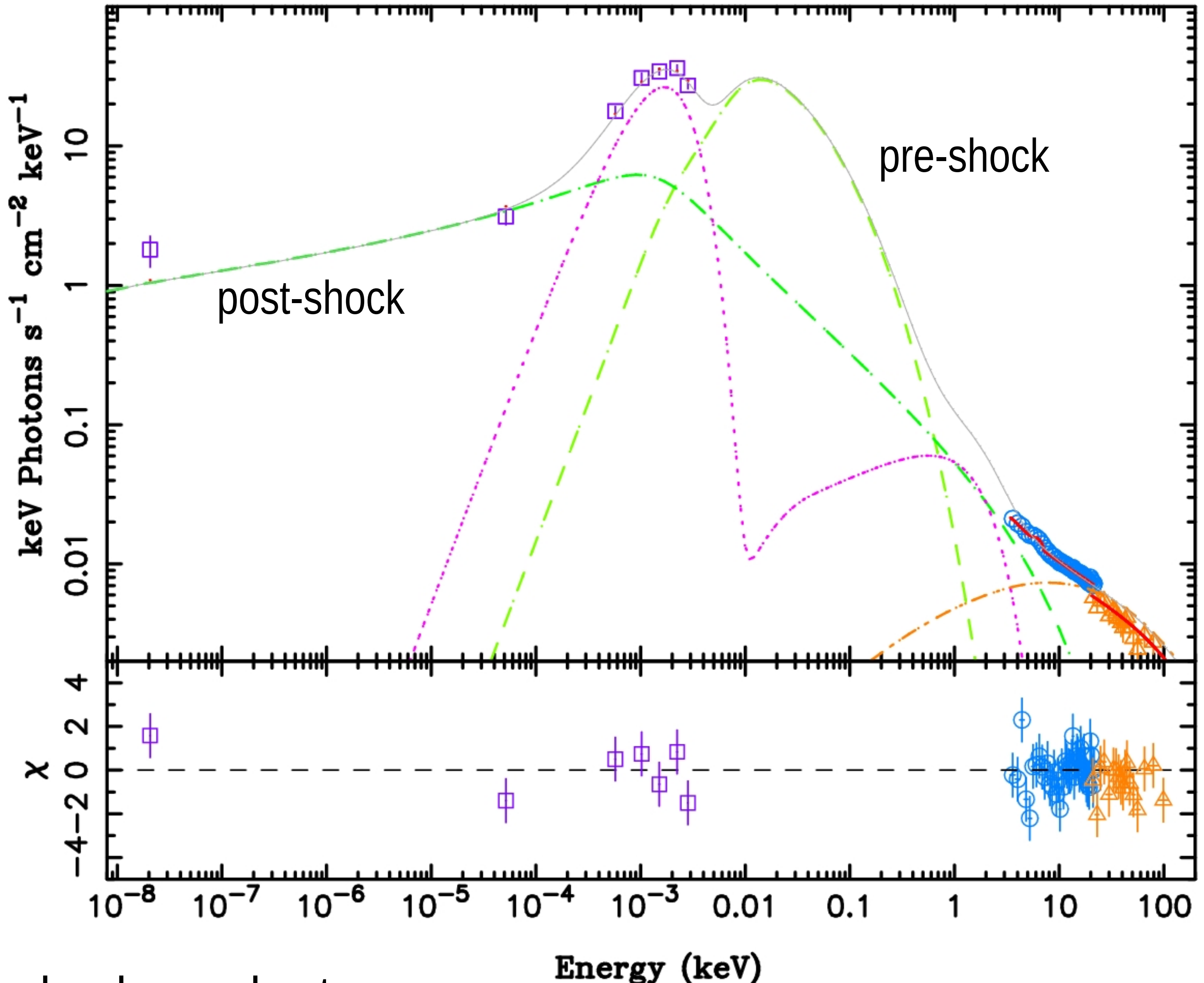
Relativistic electrons in base of jet and also after a shock within the jet.

Produce X-rays via synchrotron emission or inverse-Compton scattering.



Markoff & Nowak (2004)

X-rays from jets?

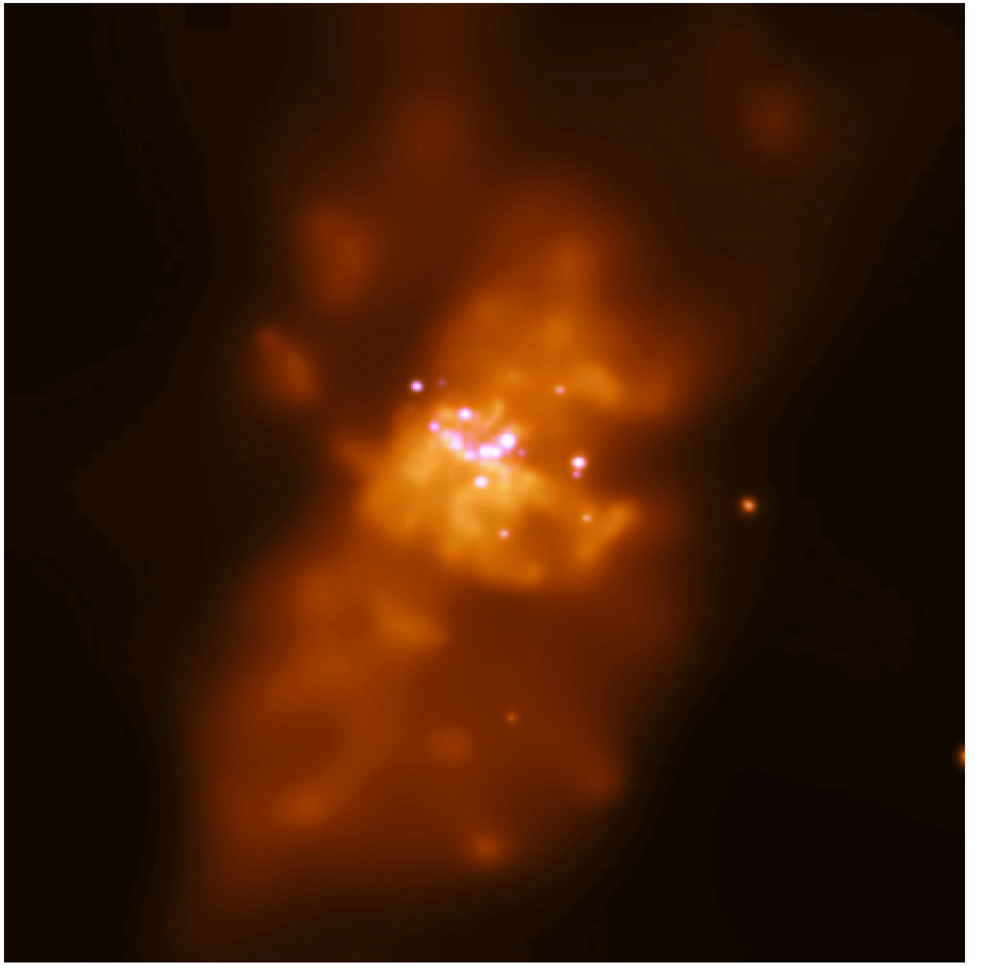


light green – jet: pre-shock synchrotron
dark green – post-shock synchrotron
orange – SSC + external Compton
purple – disk + companion star

(Migliari, Tomsick, et al. 2007)

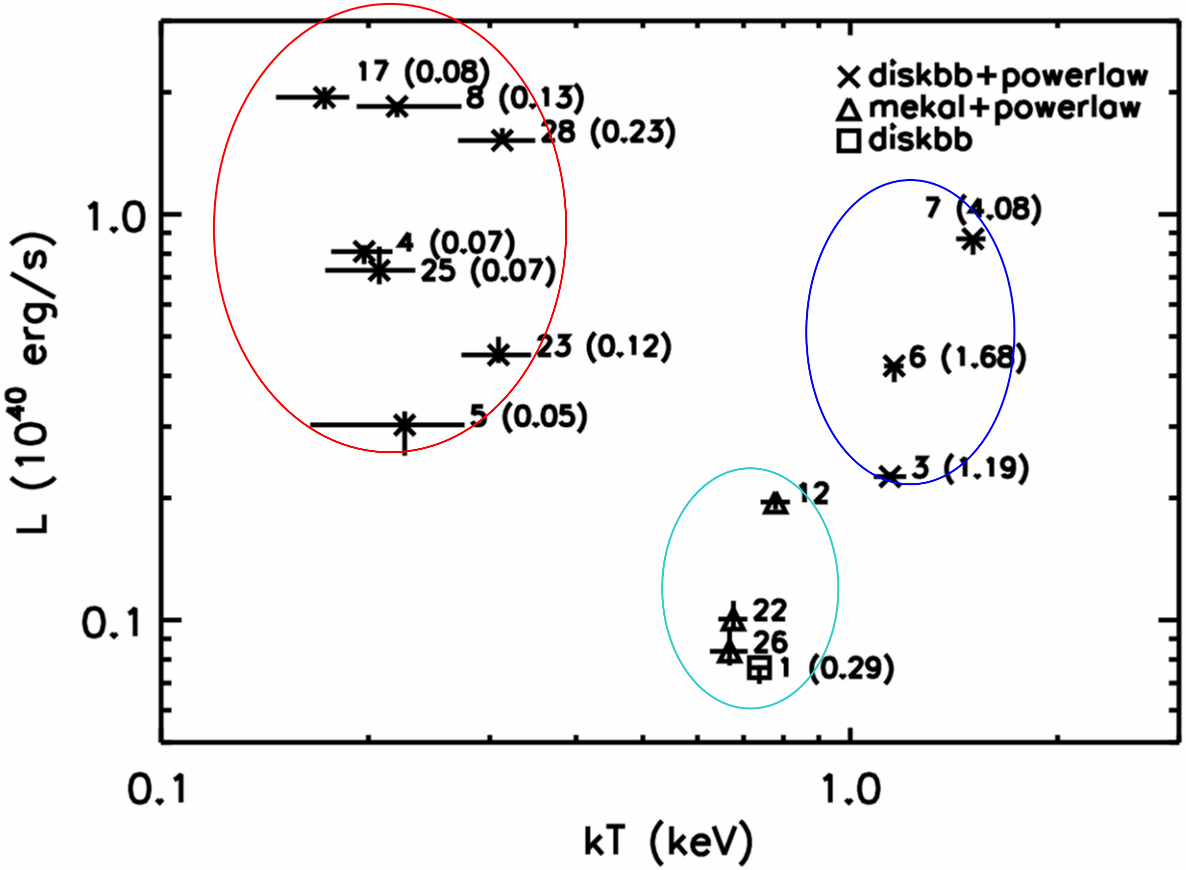
Ultraluminous X-Ray Sources

- Non-nuclear X-ray sources with $L_X > L_{Edd}$ for a 20 $M_\odot$ compact object ($L > 3 \times 10^{39}$ erg/s). Some $L \sim 10^{41}$ erg/s.
- Do ULXs contain intermediate mass black holes?
- Is the emission beamed?
- Are there multiple classes?



X-ray sources in M82

Three Classes of ULXs



(1) cool diskbb + PL

IMBH candidates

(2) mekal + PL

similar to recent SN

(3) hot diskbb + PL or single Compton

Source 3 (M33 X-8) like a microquasar (Foschini et al. 2004)

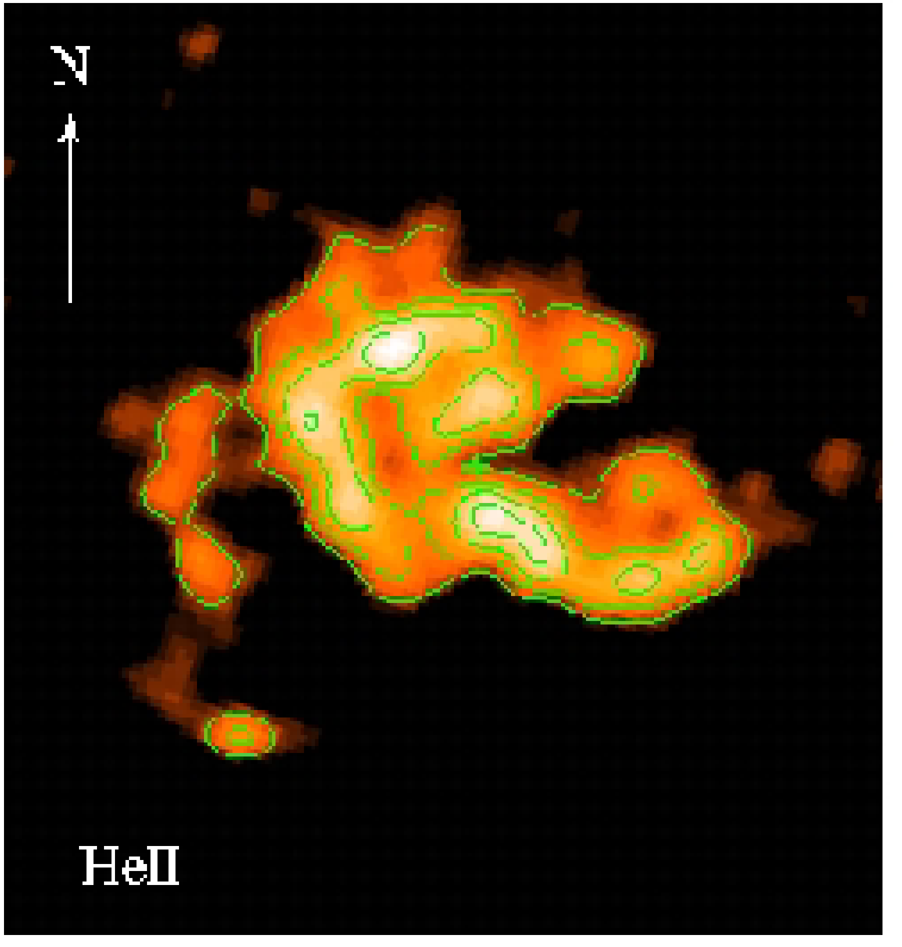
Source 3 & 7: radio counterparts

(Feng & Kaaret 2005)

Evidence for (near) isotropic emission

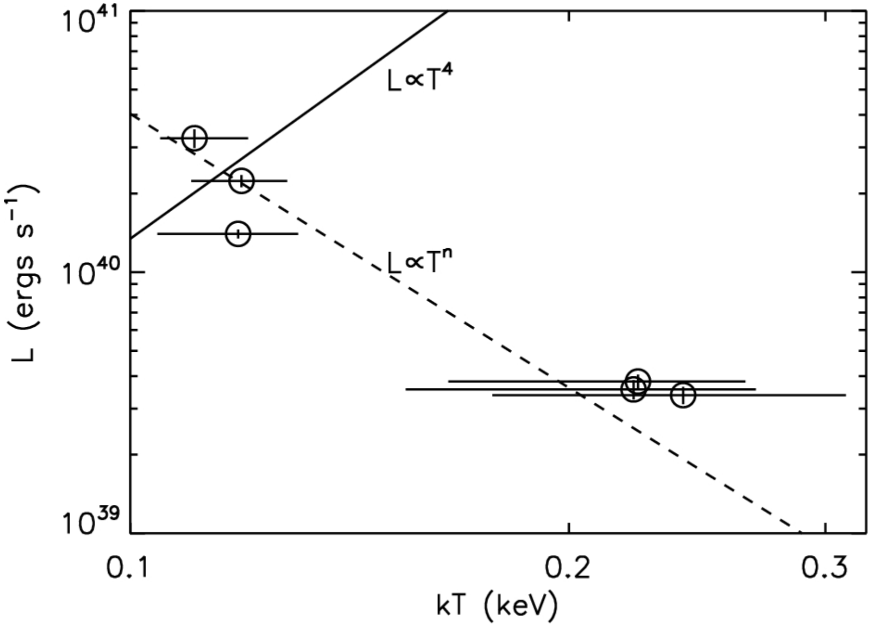
Holmberg II X-1

- He II λ 4686 emission line from nebula is X-ray photoionized by ULX
- $L_X > 4\times10^{39}$ erg/s
- Agrees within factor of 3 with isotropic assumption

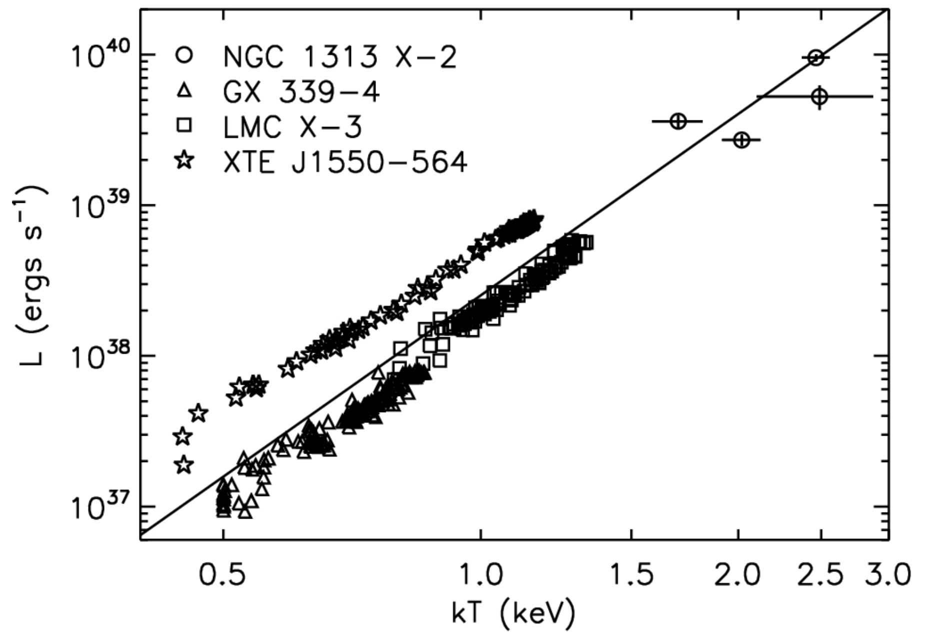


(Kaaret et al. 2004)

Evidence against an IMBH: NGC 1313 X-2



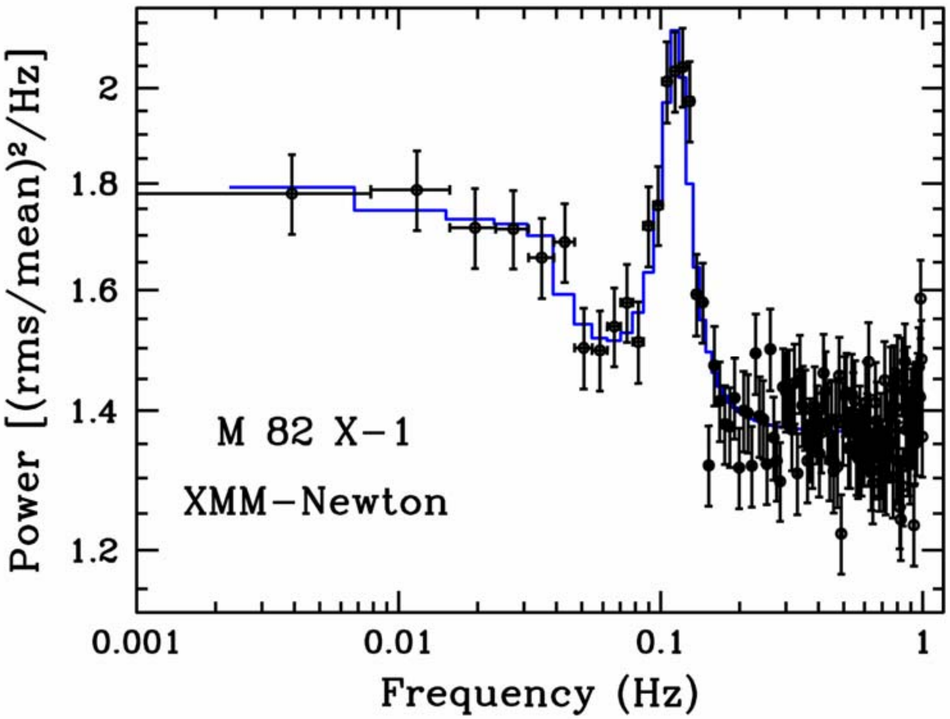
The cool thermal disk does not follow the $L \propto T^4$ relation



A hot, super-Eddington slim disk is consistent with the $L \propto T^4$ relation

(Feng & Kaaret 2007)

Oscillations from ULXs



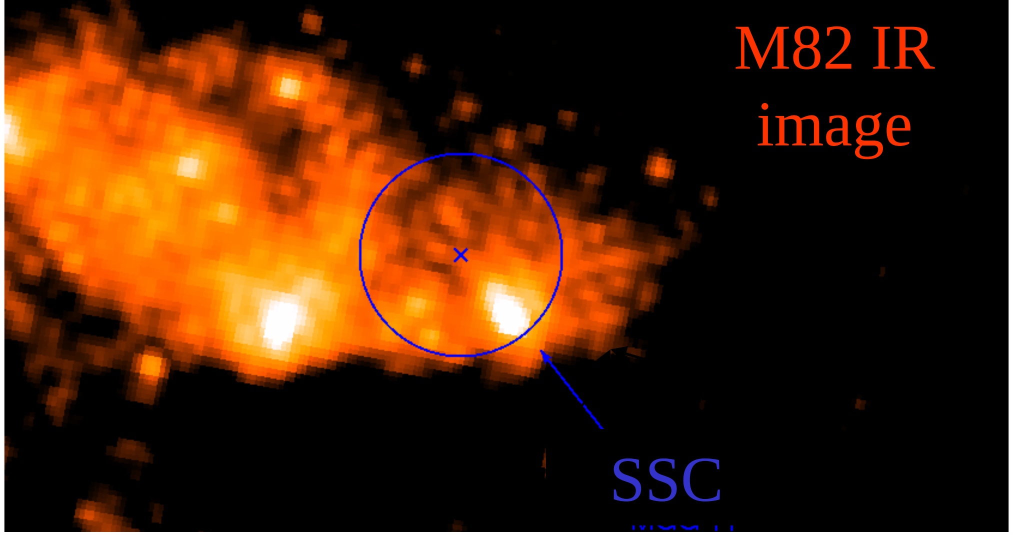
(Dewangan et al. 2005,

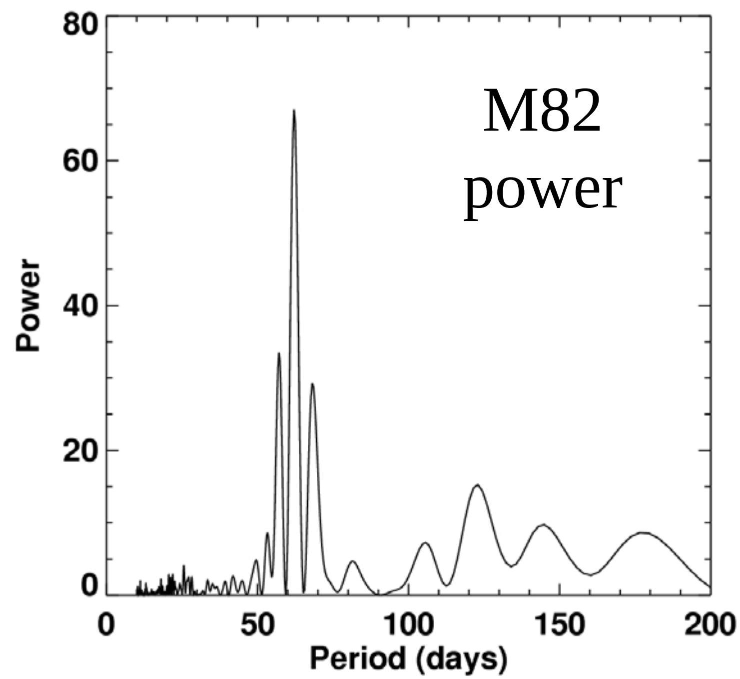
Strohmayer et al. 2003)

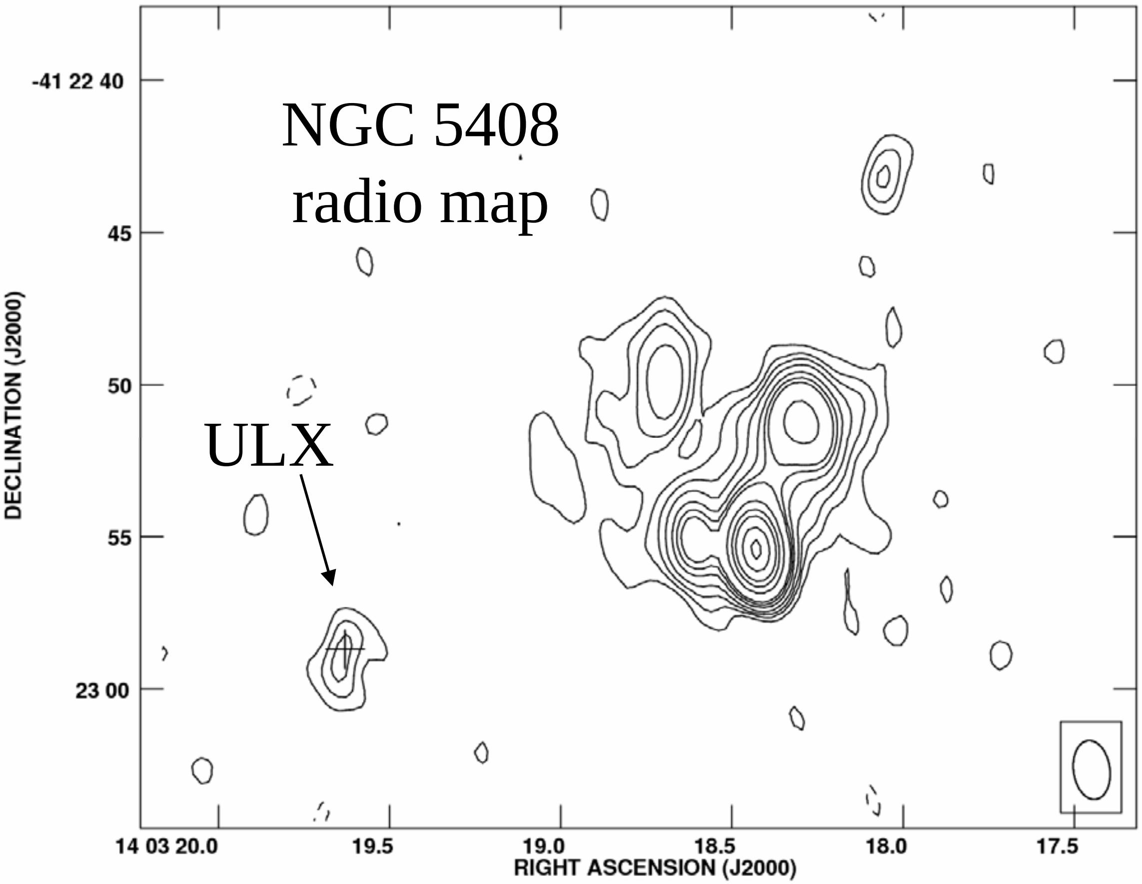
M82 X-1 (X41.4+60) shows QPOs at 50-120 mHz.

NGC 5408 X-1 shows QPOs at 15 and 20 mHz.

Frequencies suggest intermediate mass black holes.



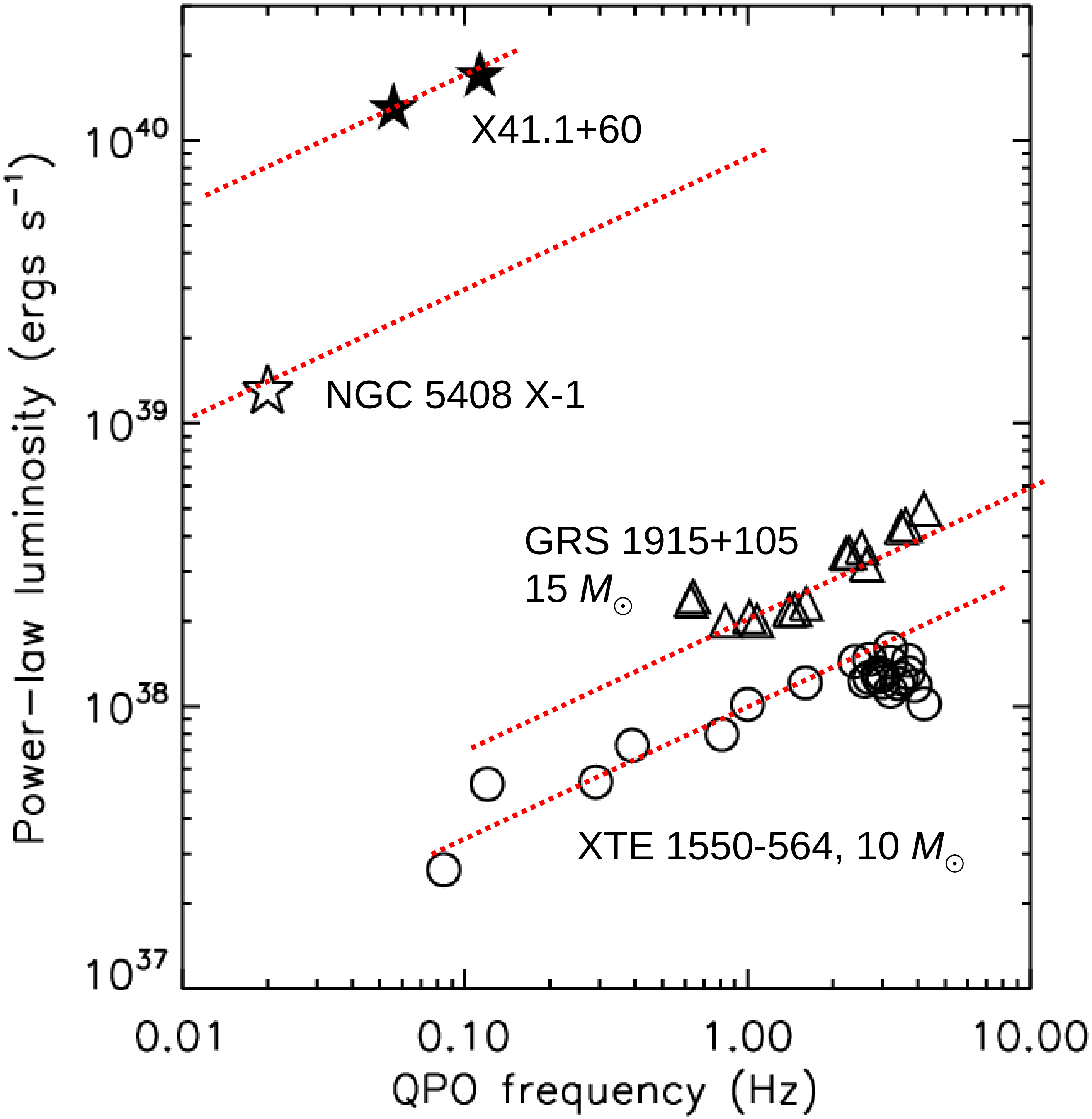




X41.4+60 shows 62 day period and lies in or near superstar cluster expected to host an IMBH.

NGC 5408 has a radio nebula 100x as luminous as SS433+W50.

L vs. ν



X41.1+60
NGC 5408 X-1
GRS 1915+105
15 $M_\odot$
XTE 1550-564, 10 $M_\odot$
10^{40}
10^{39}
10^{38}
10^{37}
Power−law luminosity (ergs s^{-1})
0.01
0.10
1.00
10.00
QPO frequency (Hz)

Future observations

- Target of opportunity observations are essential. Series of TOOs for BH transient, one per week for about 2 months, ~50 ks/obs, ~0.5 BH/year (total ~200 ks/year).
- Capability to look at bright sources is essential.
- XMM is the best observatory for spectral and timing studies of ULXs. Need multiple observations of individual targets. For each of 5-10 ULX do 6-8 observations of 50-100 ks each.