Observations of jets in X-ray binaries

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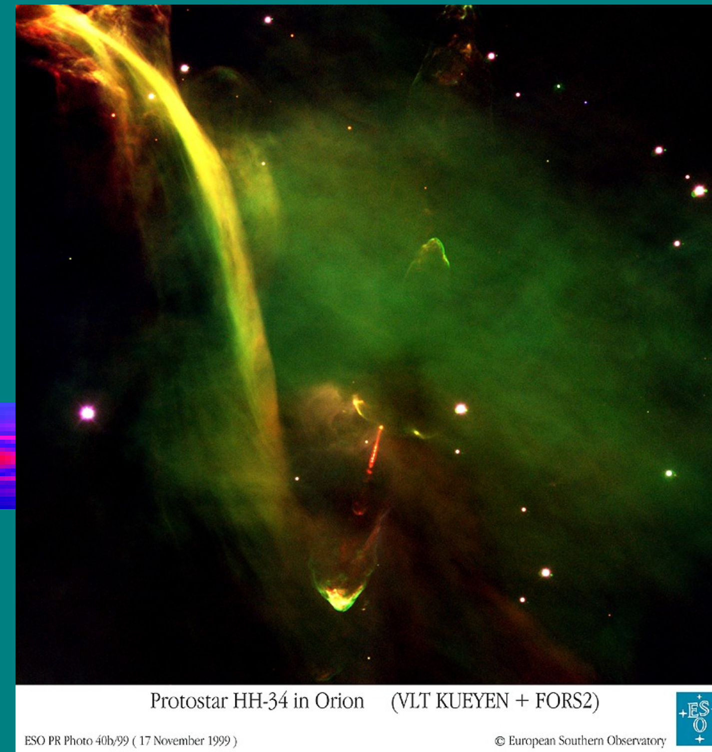
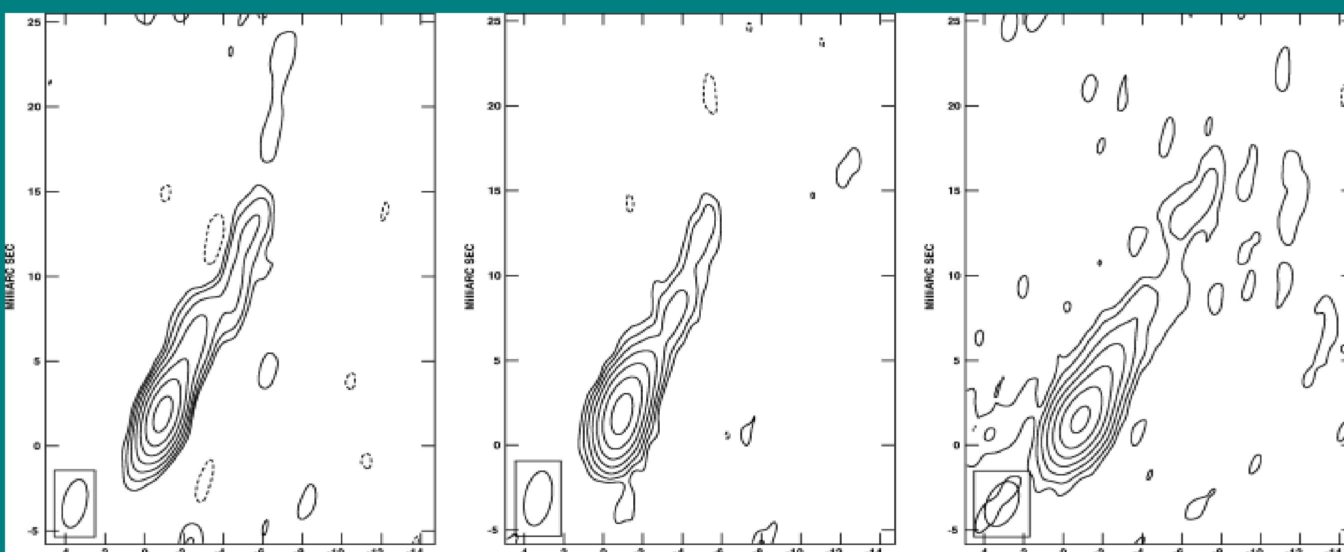
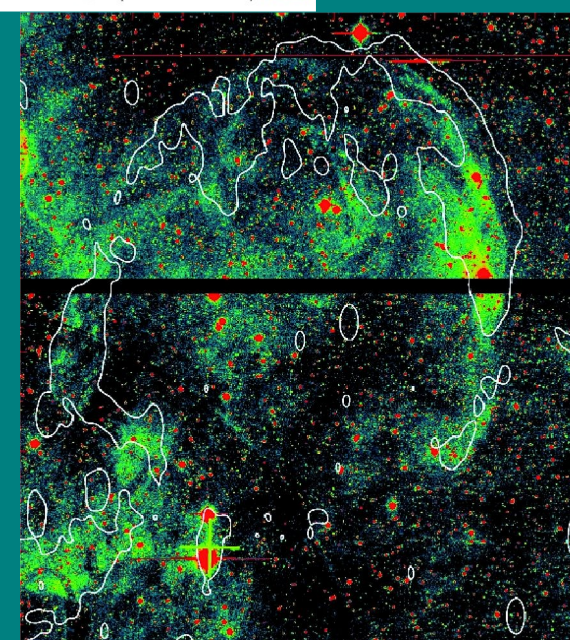


ING archive/Nick Szymanek



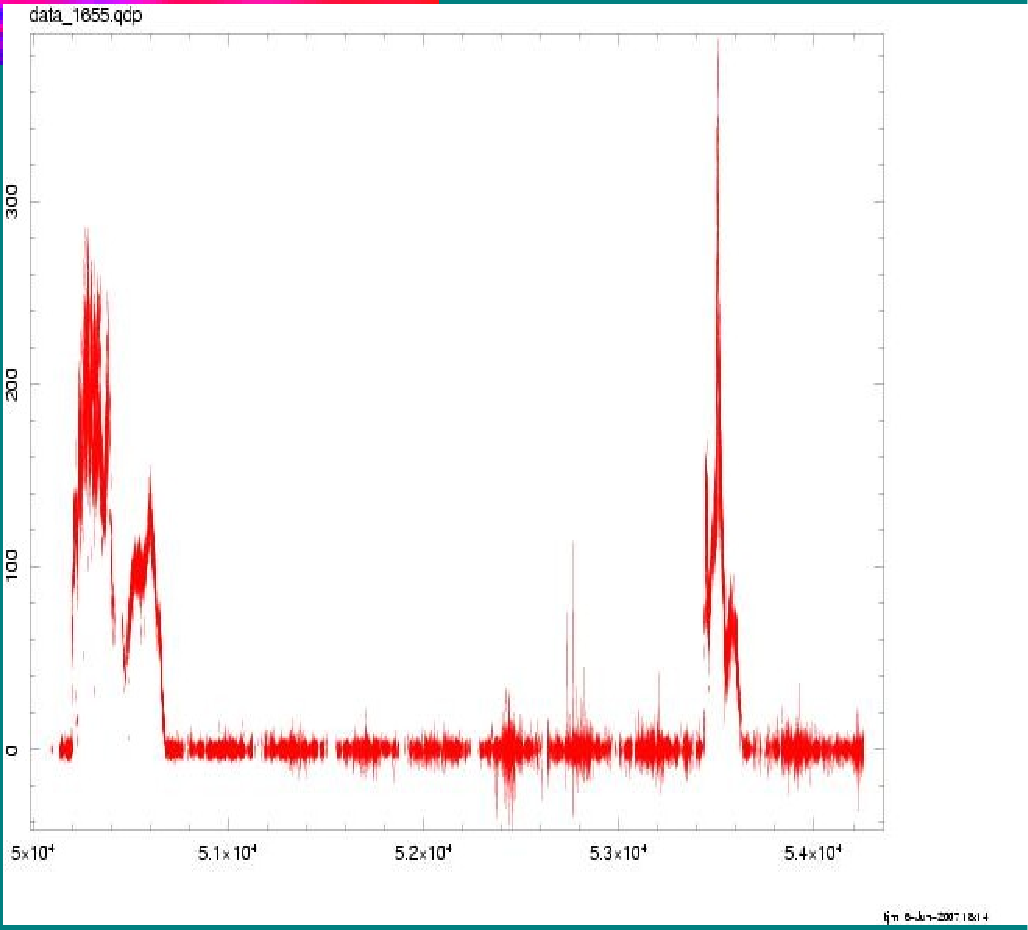
Stirling et al. 2001



Russell et al. 2007

Black Hole X-ray binaries: key sources for understanding accretion-ejection phenomenology

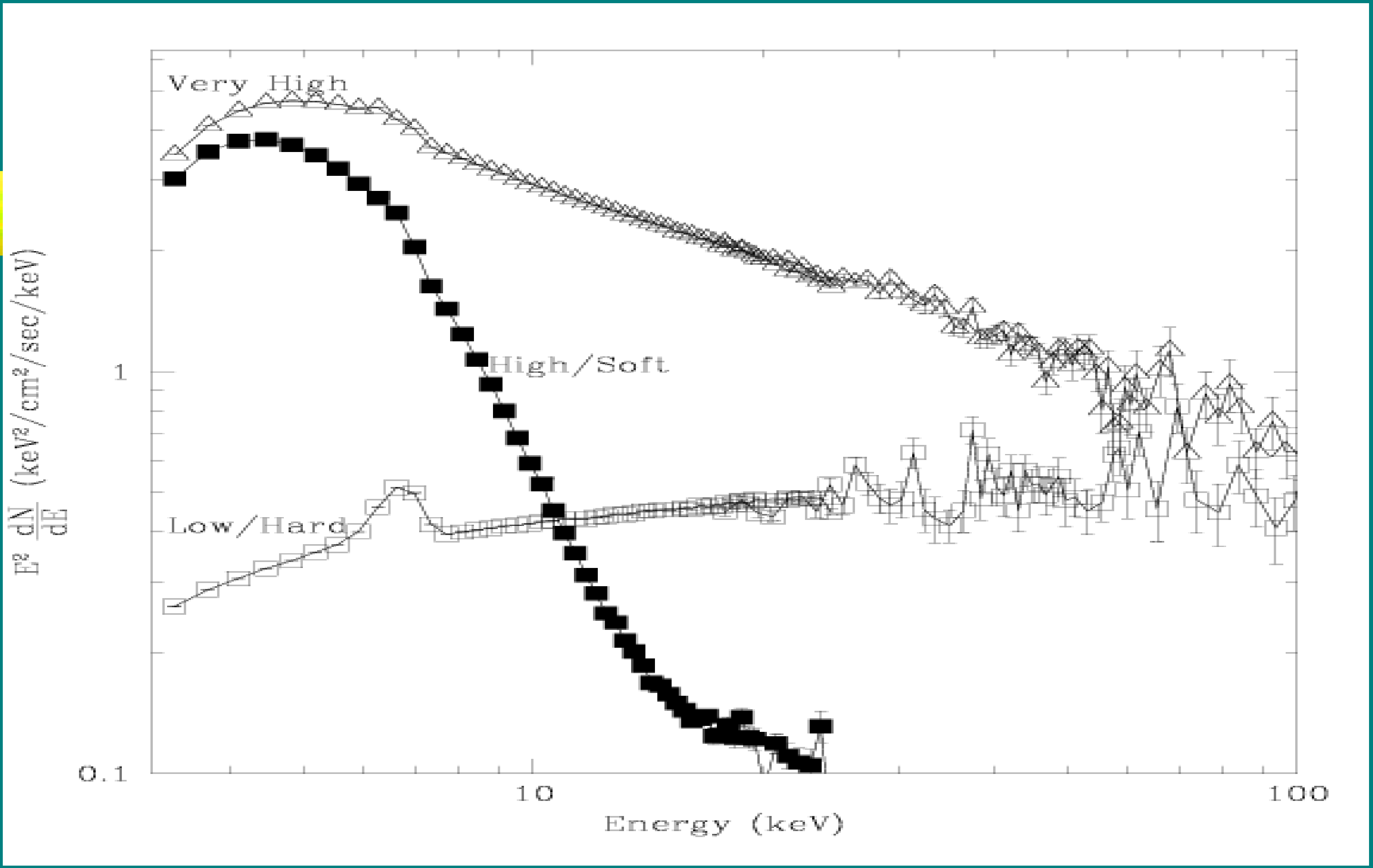
- Strong source variability
- Variability on accessible timescales
- Moderately bright radio sources
- Relatively small mass range
- Simple systems – no boundary layers or surface magnetic fields



GRO J1655-40 RXTE light curve

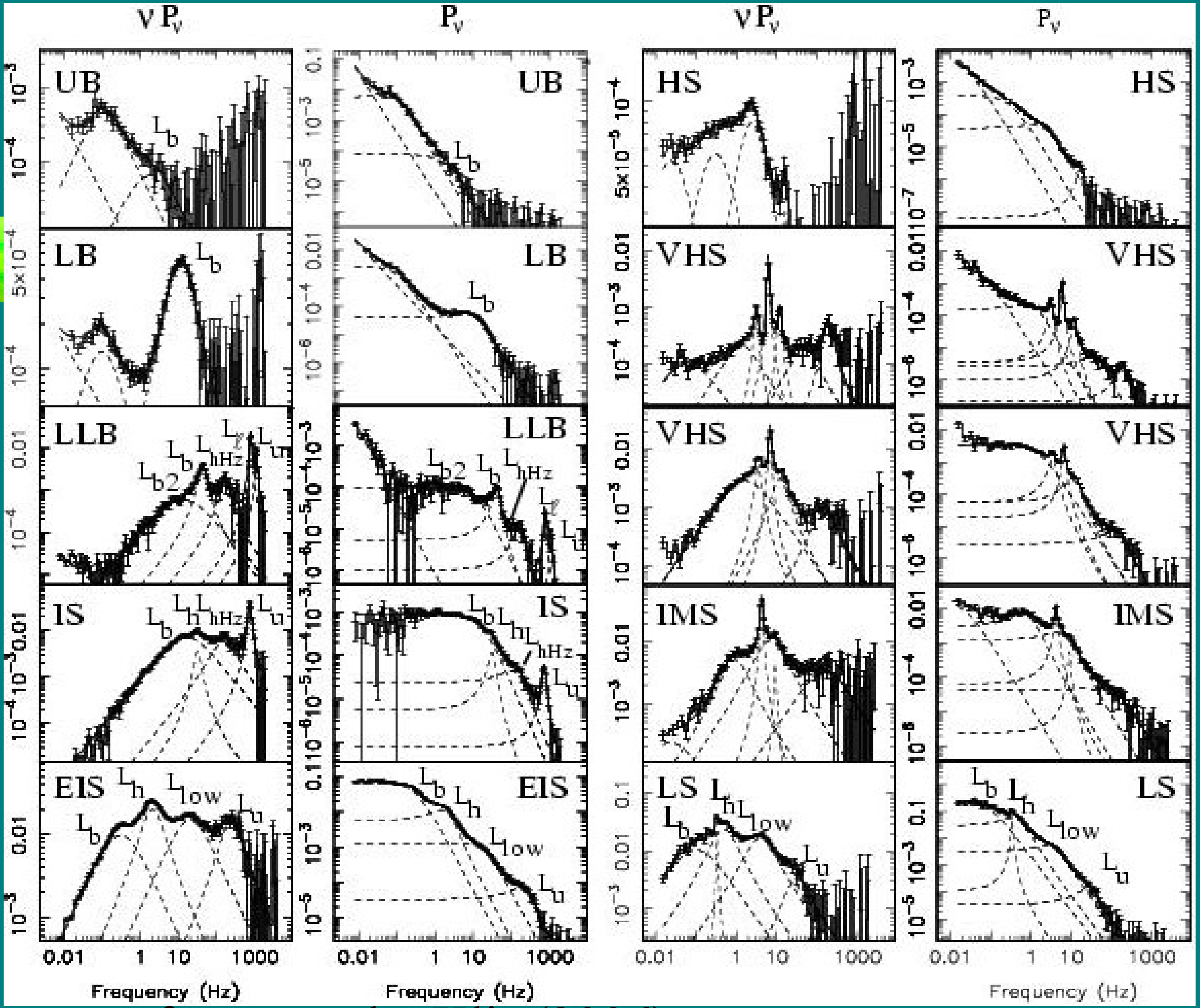
	Neutron star X-ray binaries	*Stellar mass black holes*	*Supermassive black holes*
Object Mass	1.4+-0.1 solar masses?	5-15 solar masses	10^6-10^9 solar masses
Accuracy of mass estimates	Masses in small range	Masses accurate to ~20%	Masses accurate to factors of ~2
Surface?	Solid surface, boundary layer	No surface	No surface
Surface magnetic field	B=10^8-10^{12} G	B=0	B=0
Viscous timescale	t_{visc} ~ days	t_{visc} ~ weeks	t_{visc} ~ millenia or more
Dimensionless spin parameter	j<~0.1	j~0.5-0.9??	j from -1 to 1????
Distance accuracy	Distances to ~10% in many cases	Distances to ~30% in many cases	Distances from Hubble Law
Characteristic angular scale	R_{SCH} ~ 10^{-10} arcsec	R_{SCH} ~ 10^{-10} arcsec	R_{SCH} < 10^{-5} arcsec

Spectral States - SEDs



- data from Miller et al. (2001) for XTE J 1748-288

Variability and states



from van der Klis (2006)

Low/hard state

- Characterized by cutoff power law spectrum, well modeled by thermal Comptonization (Thorne & Price 1975)
- Strong, broadband aperiodic variability
- Debate over geometry - “sphere+disk” or corona above a disk

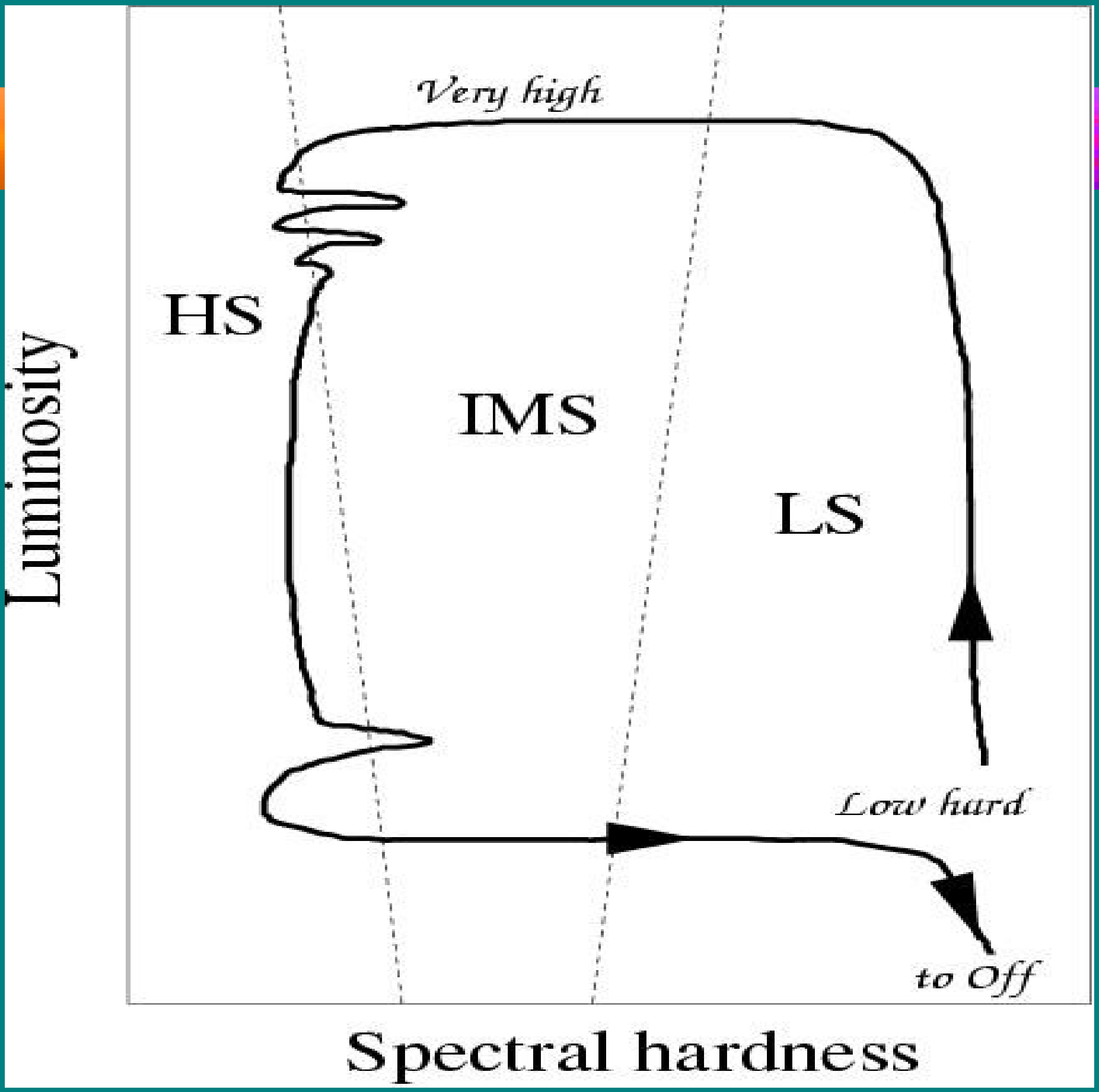
High/soft state

- Well modeled by multi-color blackbody models – i.e. standard Shakura & Sunyaev (1973)/Novikov & Thorne (1973) disks, sometimes with weak power law tails
- Very little variability seen at any frequency, and what's seen is probably driven by the power law

Intermediate states

- At transitions, intermediate states exist
  - in a few very bright sources, they can be long lived, and are called very high states
- Spectra intermediate between low/hard and high/soft states
- Variability roughly intermediate, except for strong, relatively high Q quasi-periodic oscillations which are often seen in transitions, but not in the other states

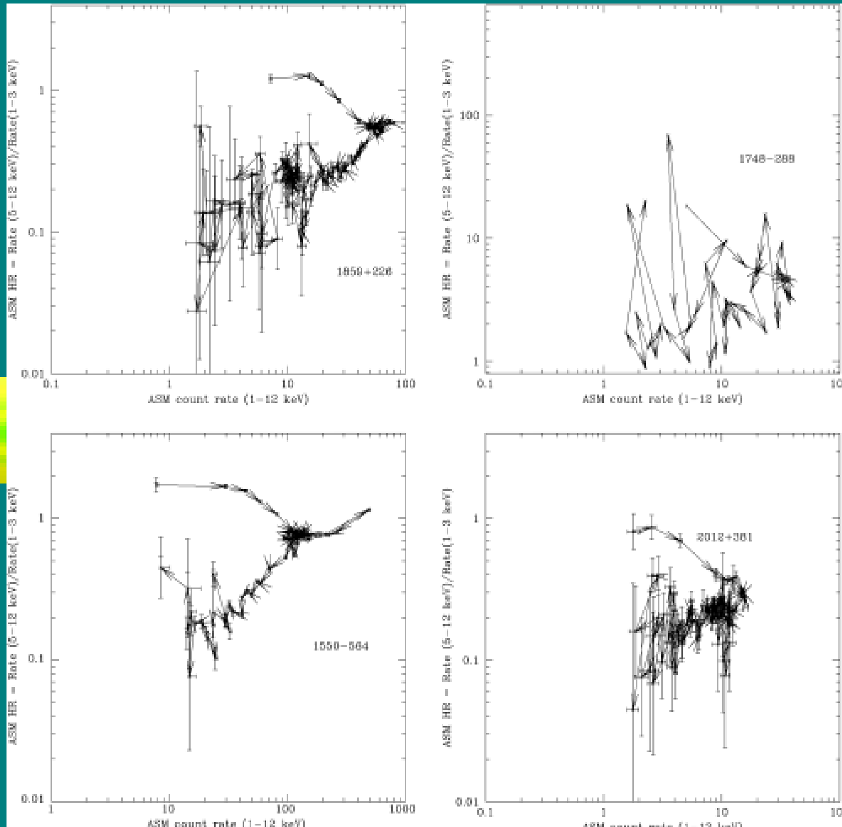
When are different states seen?



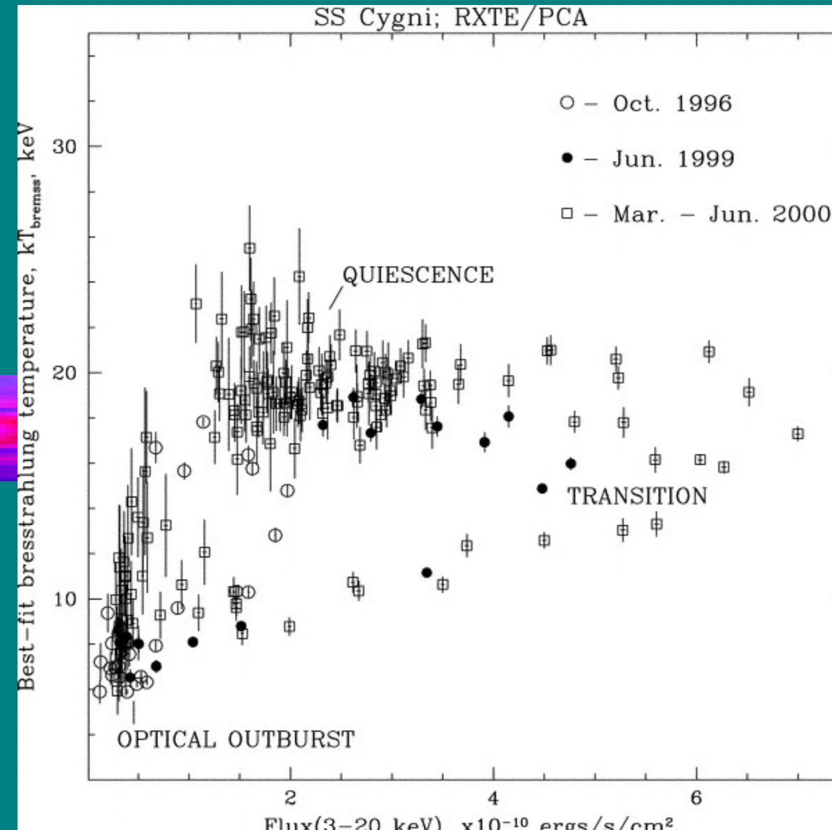
from van der Klis (2006)

HS -> LS transition – always near 2% of Eddington (Maccarone 2003)

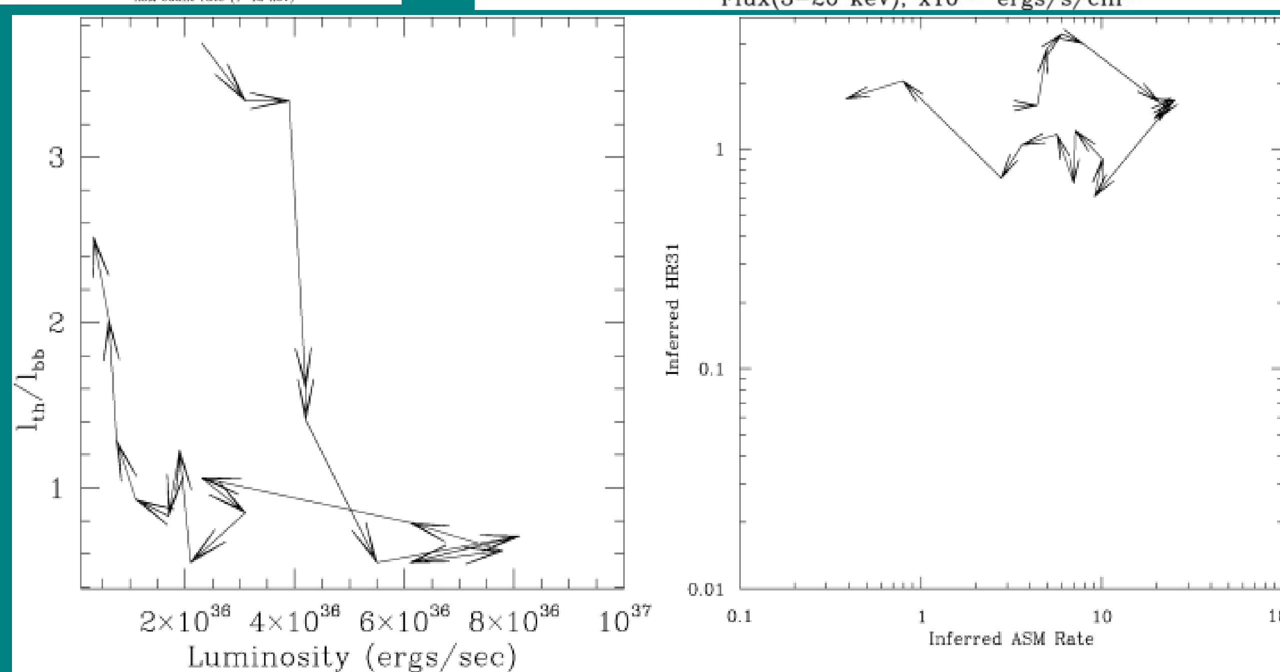
LS-> HS transition – luminosity seems to depend on size of accretion disk (Shahbaz, Charles & King 1998; Portegies Zwart, Dewi & Maccarone 2005) black hole transients from Maccarone & Coppi 2003



SS Cyg – from McGowan et al. (2003)

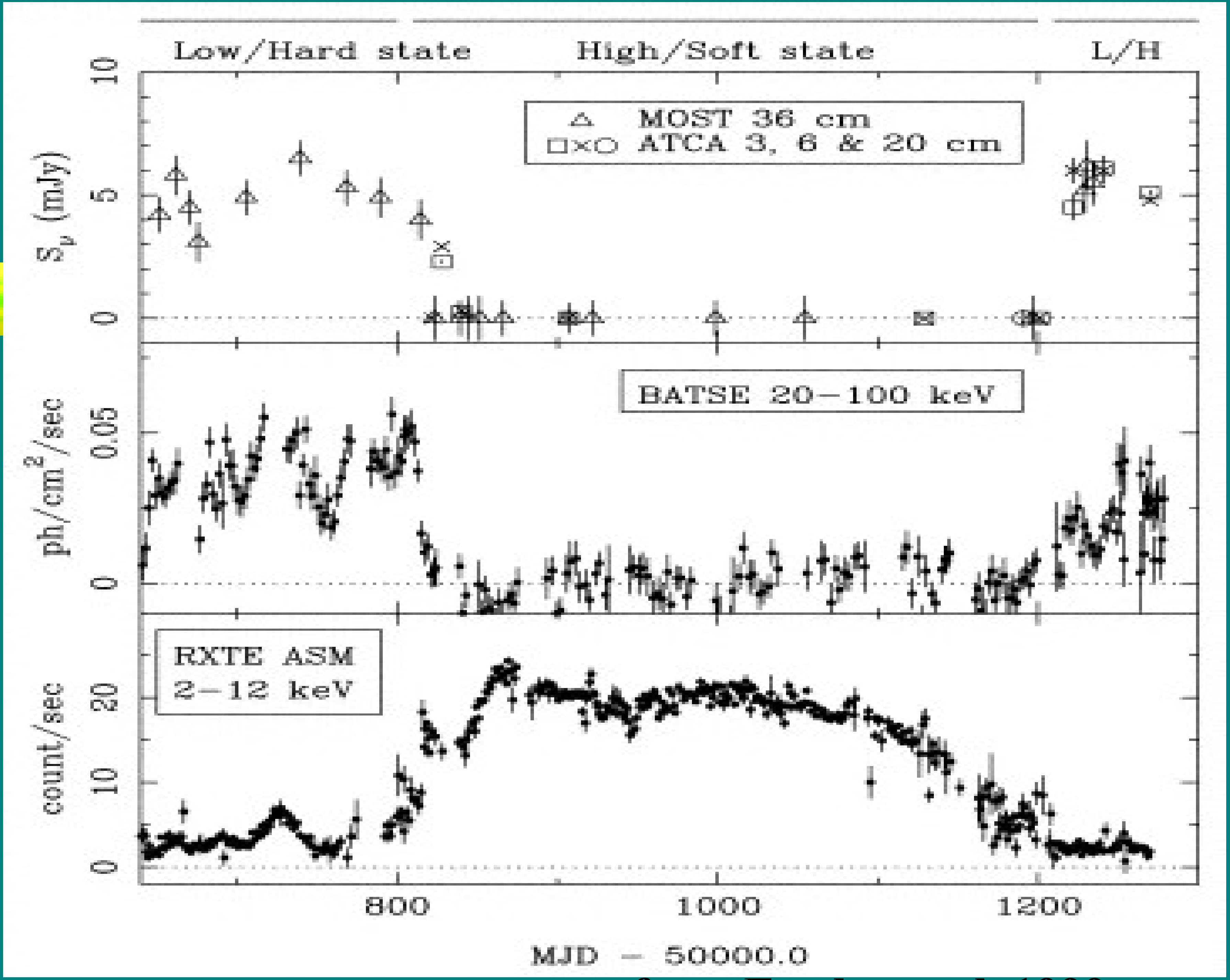


Aql X-1, from M&C 2003



When are jets seen (and not seen)?

- Steady jets seen in low/hard states
- Seen as transient, high luminosity, highly relativistic episodes in hard very high states
- "Quenched" in high/soft states (Tananbaum et al. 1972; Harmon et al. 1995; Fender et al. 1999)

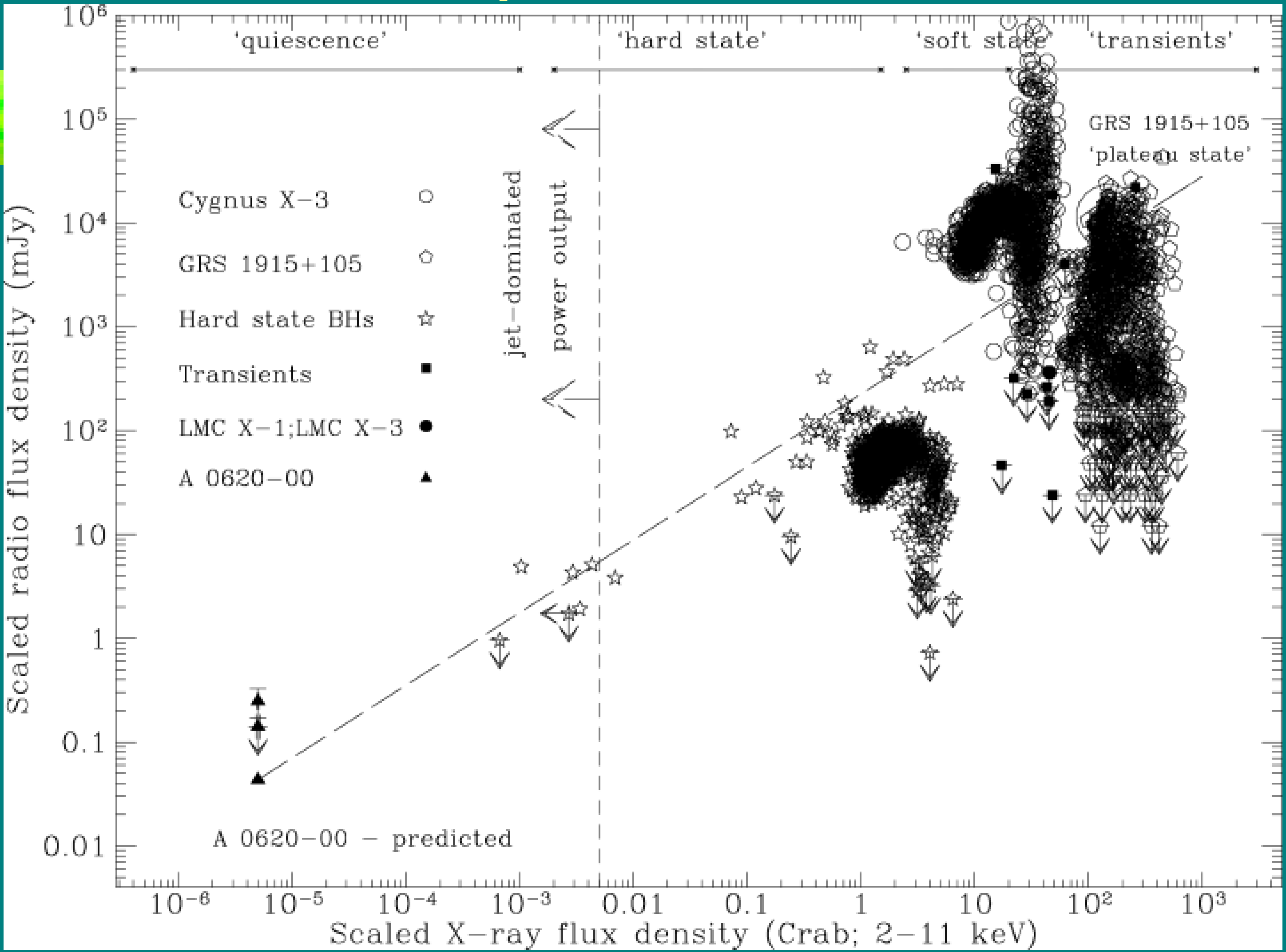


from Fender et al. 1999

Jet Properties in Low/Hard State

- Radio luminosity correlates with X-ray luminosity in low/hard state
  - $L_r \propto L_x^{0.7}$ (Corbel et al. 2003; Gallo, Fender & Pooley 2003)
    - only Cygnus X-1 has been imaged
  - Flat radio spectrum (i.e. f_ν approx constant) with break typically in the infrared

Jet-disk coupling in the low/hard state



from Gallo, Fender & Pooley (2003)

Jet Properties in Intermediate states

- Transient, "bullet-like" episodes often seen
- Sometimes very highly extended
  - Where spectra are measured, usually, but not always, steep spectrum (i.e. $f_\nu \sim \nu^{-0.7}$)
- Sometimes seen in X-rays
- Apparent superluminal motions can imply $\beta > 0.9$ in several cases (e.g. Mirabel & Rodriguez 1994; Hjellming & Rupen 1995)
- External shocks against low state jet? (Vadawale et al. 2001; Fender, Belloni & Gallo 2003)

The Extended Jet from XTE J1550-564

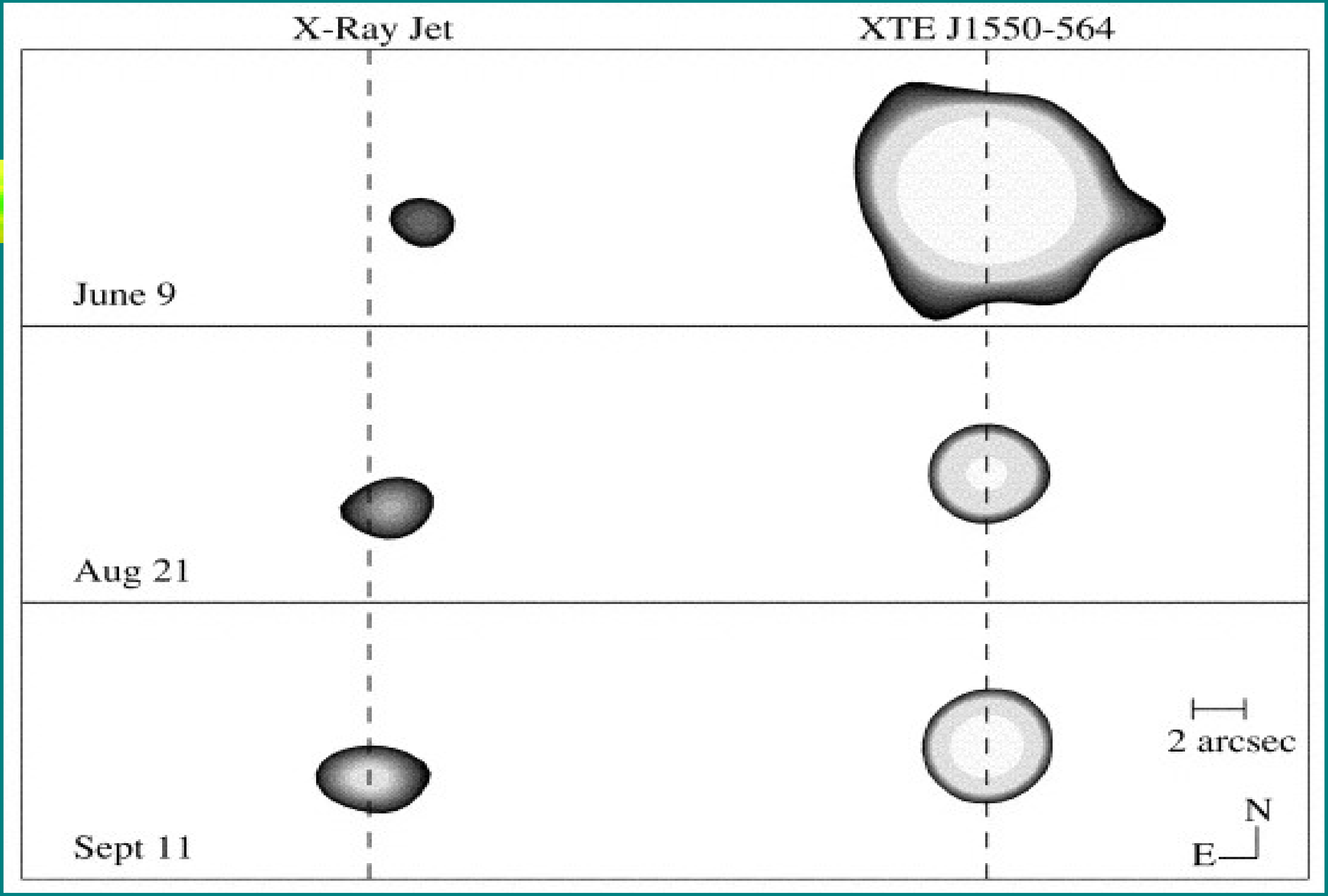
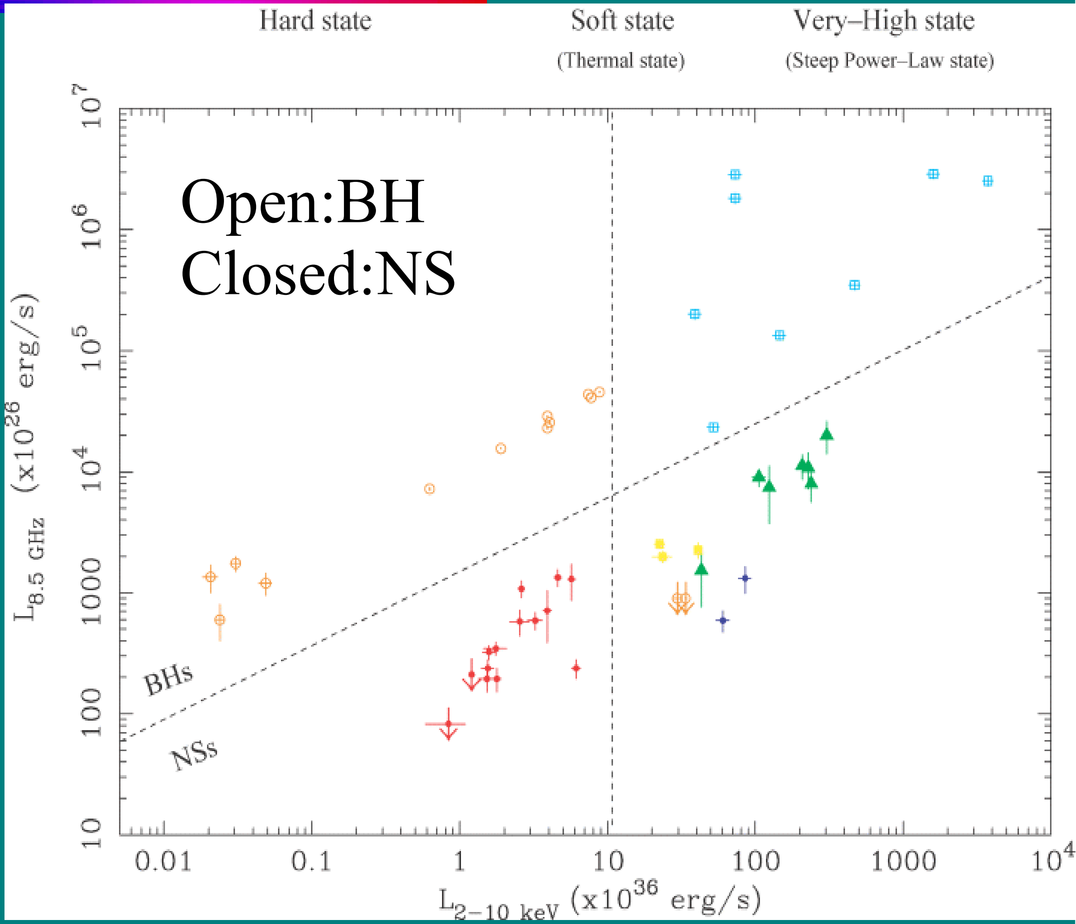


figure from Tomsick et al. (2003)

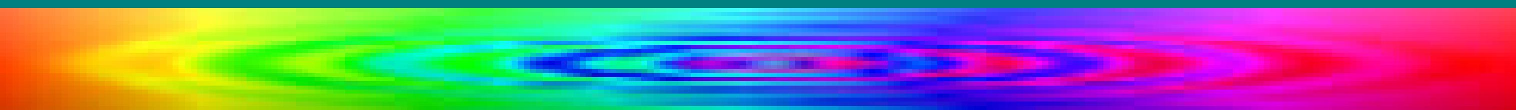
Neutron star jets

- Fainter than black holes when hard X-rays are strong
  - consistent with square of black hole relation, implying advection in black holes (Koerding et al. 2006)
  - Brighter than black holes in soft states
  - not yet well understood
  - Some data from ultracompact X-ray binaries. Is this important?
- Seen only from low B neutron stars (i.e. not HMXB pulsars)



from Migliari & Fender 2006

Some speculation



- Boundary layers: the key to “soft state” jets?
- Seen in the bright neutron stars, supersoft sources, and T Tauri stars, and also recent SS Cyg radio observation
- Not seen in black holes
- The “central energy source” of Livio (1999)?
  - or, a way to generate large scale height magnetic fields without a geometrically thick disk?
  - Or, magnetic field of neutron star/WD seeds jet production?

Jet kinetic power

- Upper limit can come from state transitions
  - Luminosity is continuous across state transitions, so kinetic power at the transition cannot be large compared to radiative power (Maccarone 2005)
- Lower limit from multiple methods
  - Equipartition of energy in jets
  - Odd coupling of optical and X-ray variability in XTE J 1118+480 (Malzac, Merloni & Fabian 2004)
- Roughly equal jet kinetic power and total accretion flow radiative power at state transition
- Seems to be true in neutron star systems as well, and even in SS Cyg (various papers by Koerding et al)

Conclusions

- X-ray binaries provide an important probe of accretion in general
- There are dimensions of the problem of jet formation accessible from observations of X-ray binaries, but not observations of AGN
  - Long timescale variability, effects of solid surfaces, effects of different chemical composition of materials
- Most stellar mass black hole sources fit a well-defined pattern for jet behavior as a function of X-ray source behavior; Low B neutron stars follow this pattern less well, high B neutron stars are completely different, data on white dwarfs is quite spotty
- Solid surfaces may help promote jet formation in some cases, harm formation in others