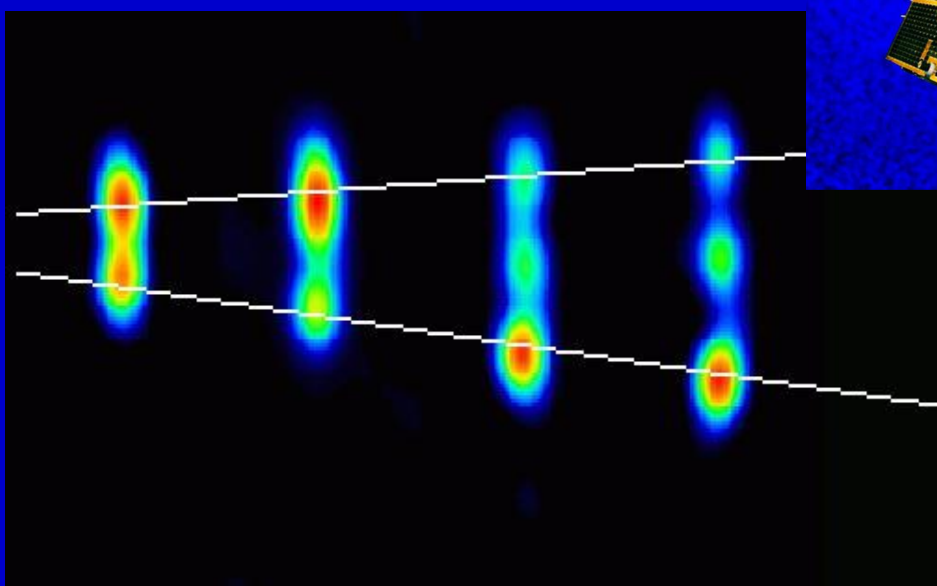
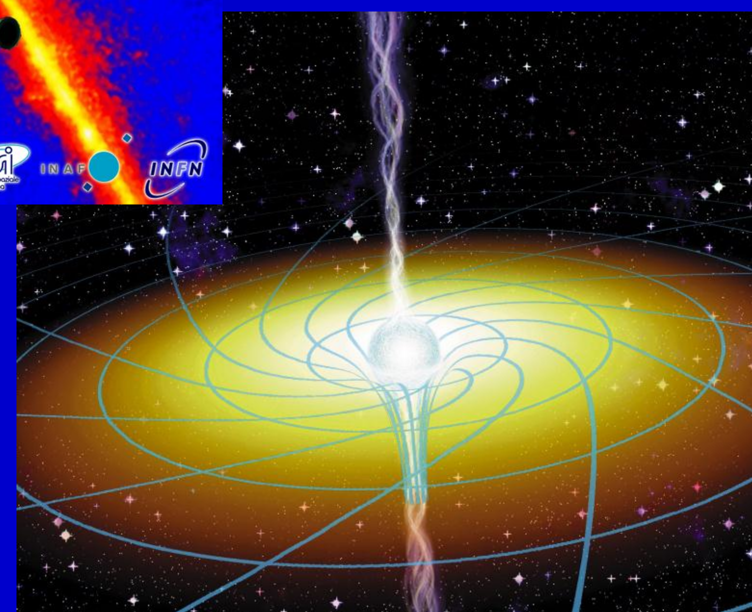
Gamma-Ray Emission from Blazars: What About Those μ–Quasars?

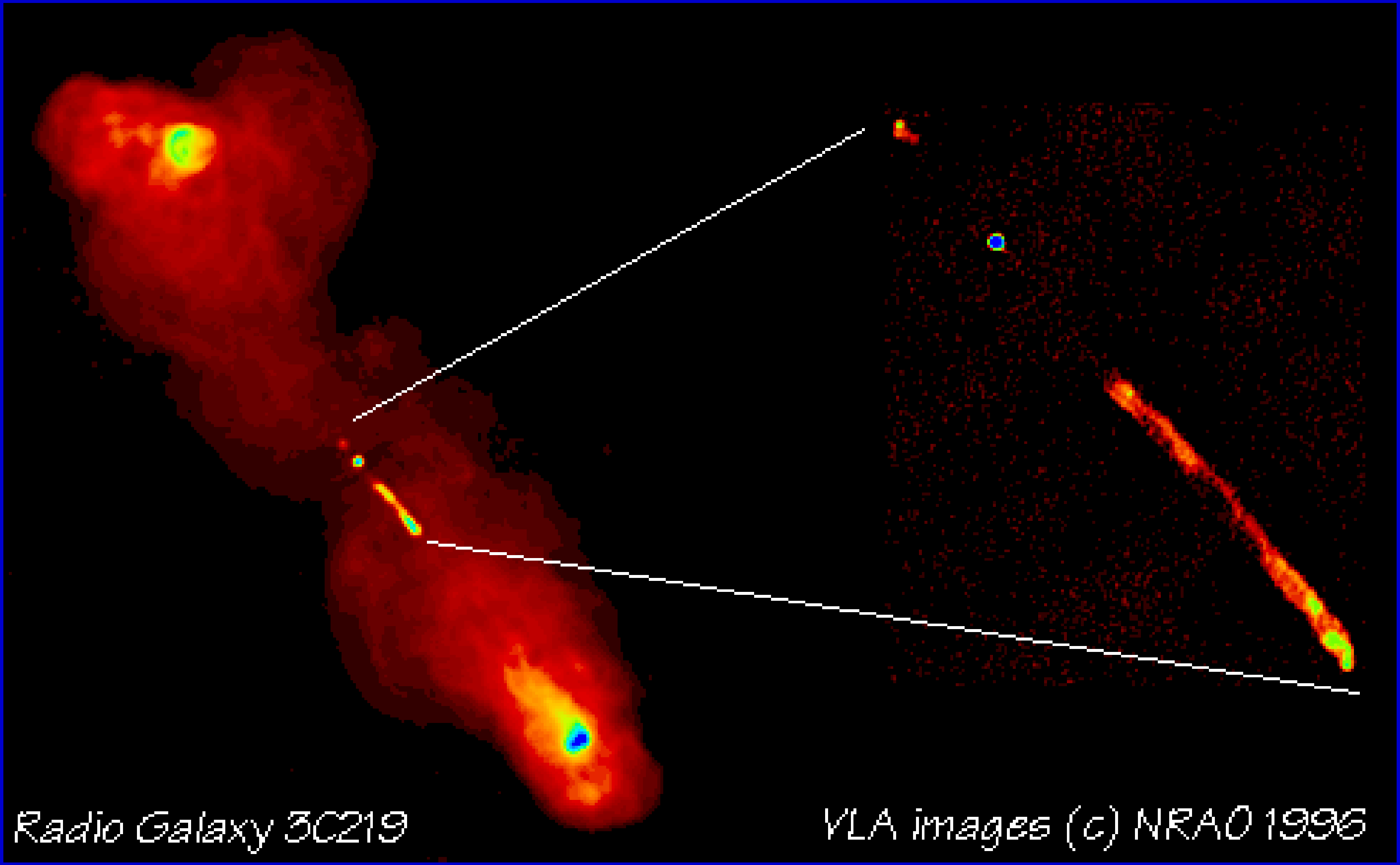
P. Coppi, Yale



?

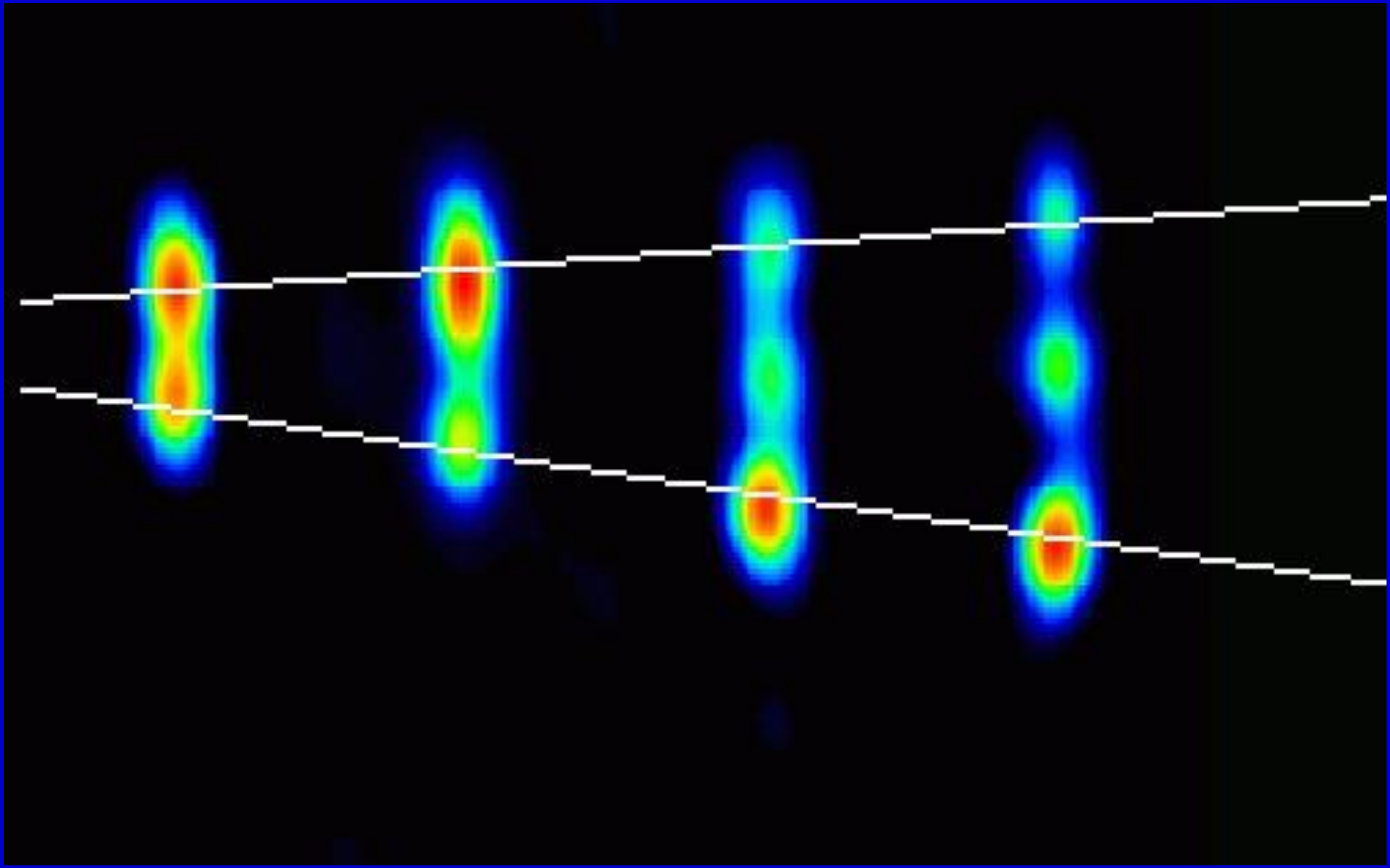


The big brother…



The little brother:

The jets of “micro-quasar” GRS-1915 as viewed by Merlin



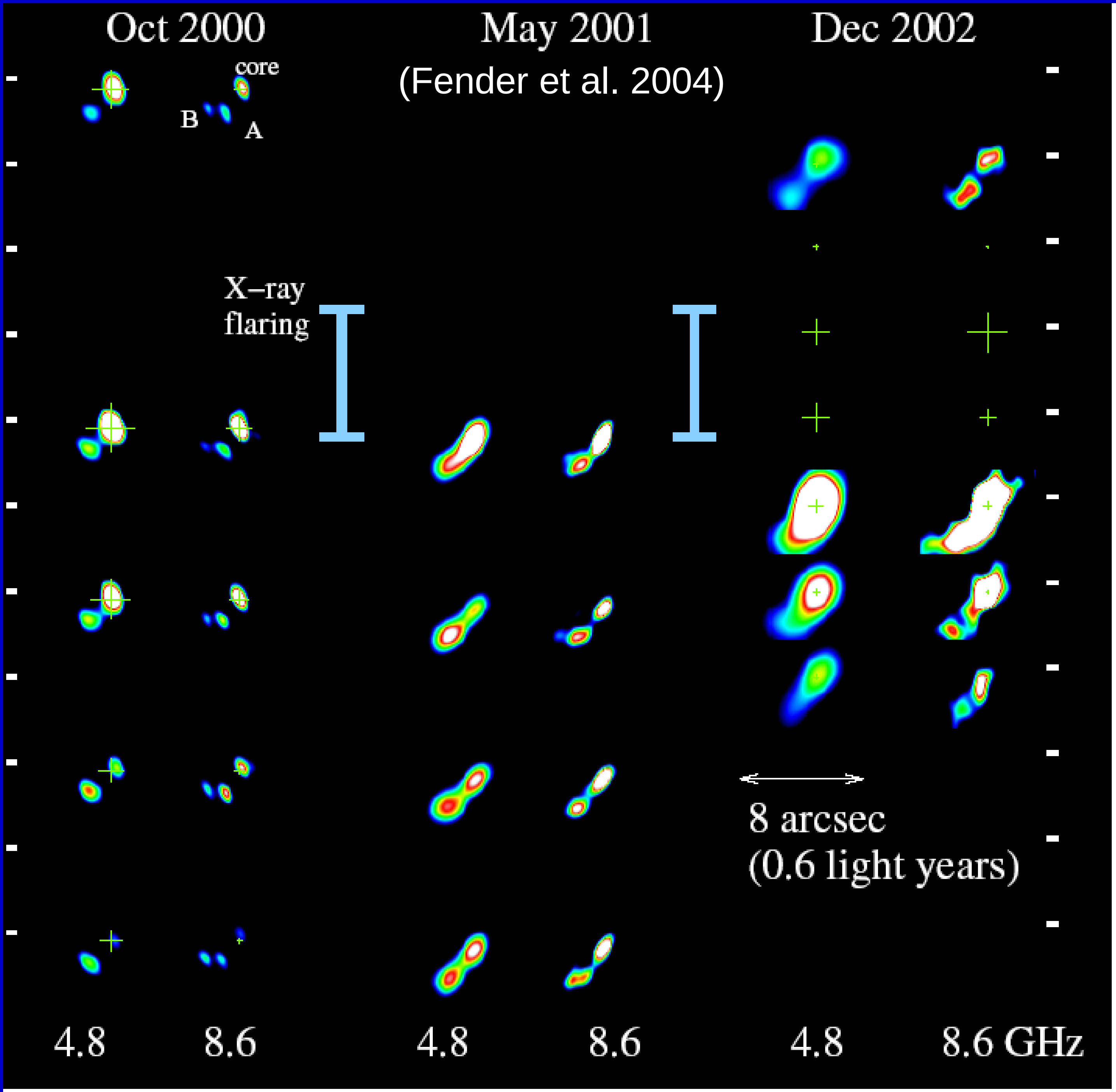
The apparent velocity of motion is superluminal too!

Hm…
Cir X-1
also does
this kind
stuff!

Assuming ejection starts during X-ray flare
$\Rightarrow \Gamma > 10$!!

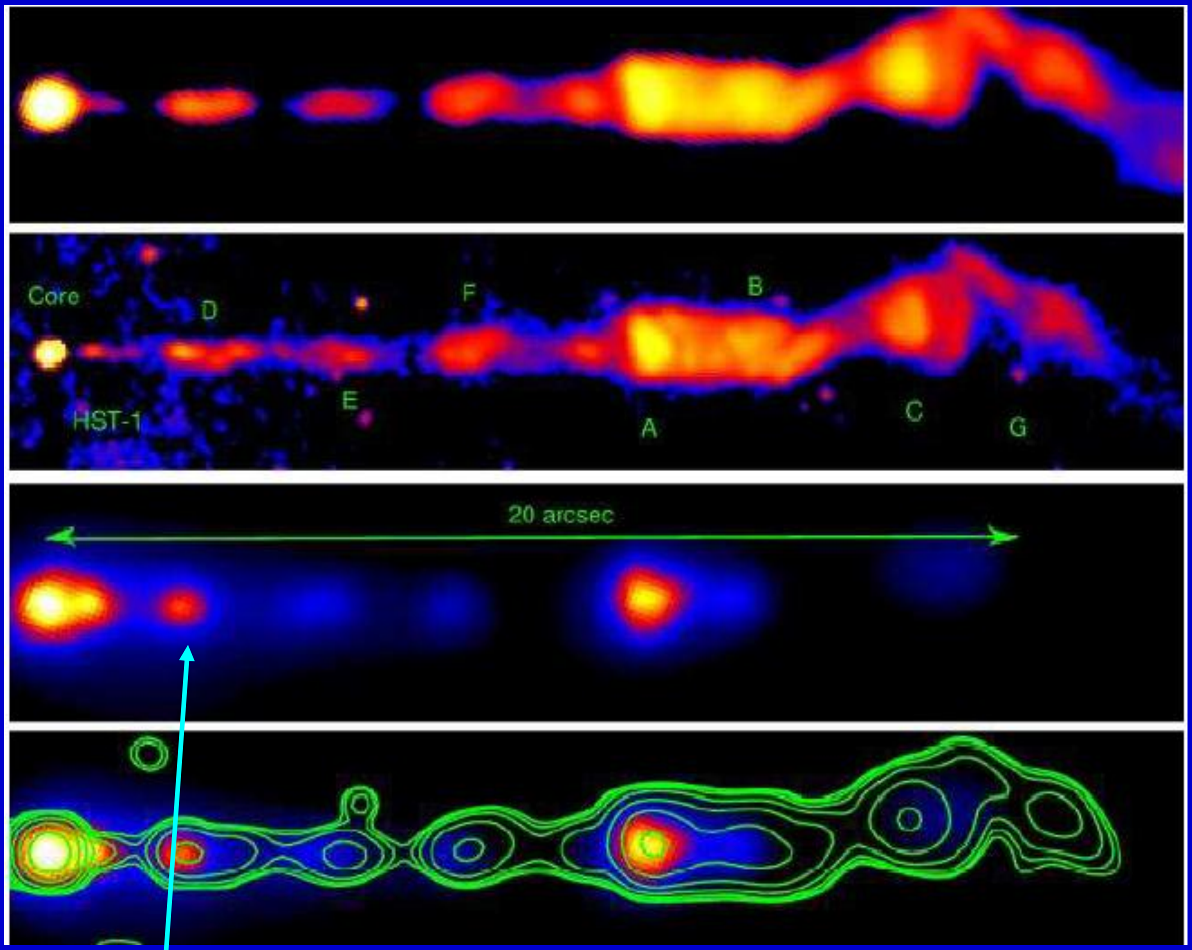
Oops…

Isn't this a *neutron star*??



M87 – FRI (a weak jet)

Radio



Mostly synchrotron emission?

Optical

X-RAY

Optical
+
X-Ray

Resolved X-ray emission -> in situ acceleration!?

But do galactic binary jets show extended *X-ray* emission?

SS433 – Yes!

Of course it is an oddball object…

With Chandra can now actually say something for more objects…

XTE J1550!

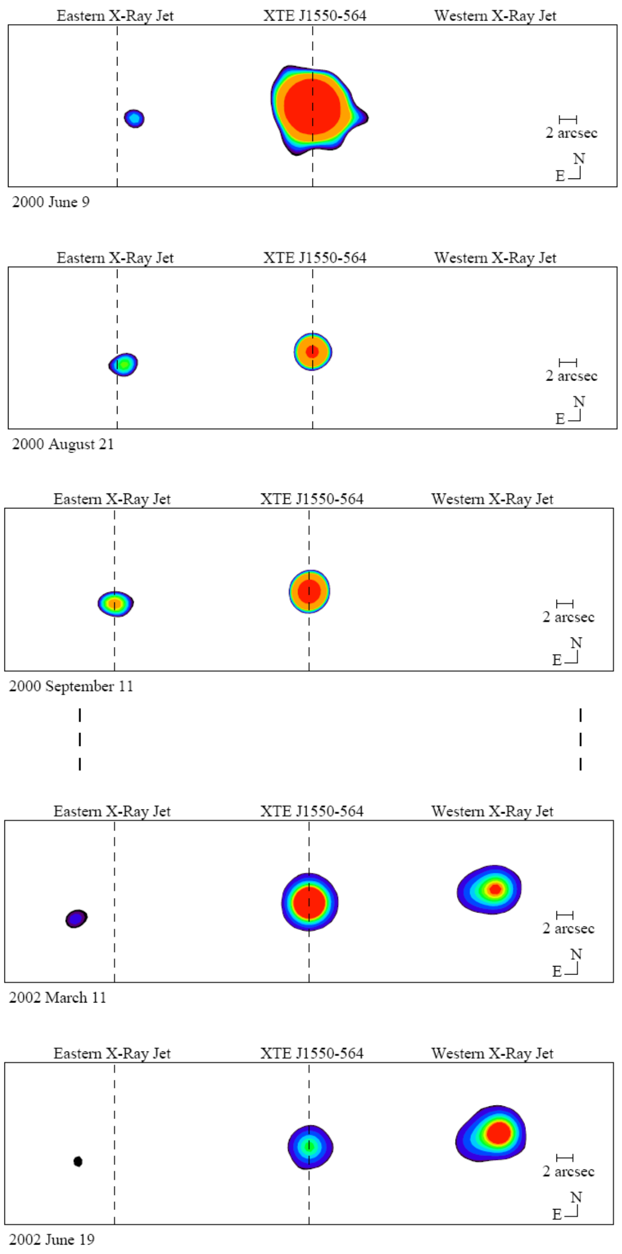


Figure 5. X-ray emission from large-scale jets produced during an outburst of the black hole transient XTE J1550564. Adapted from Corbel et al. (2002). Under minimum energy conditions, the leptons radiating in the soft X-ray band should have TeV energies.

Kaaret et al. 2003

The X-ray/Radio correlation …

GX339 - Corbel et al. 2004

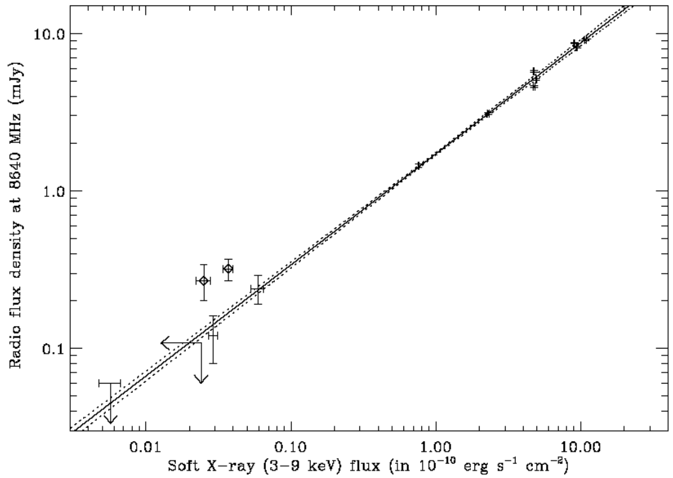


Fig. 1. The radio flux density at 8.6 GHz is plotted versus the X-ray flux in the 3-9 keV energy band. The continuous line denotes the fit to the data with the function described in the body of the paper and with the parameters estimated in Table 3, the dotted line represents the one-sigma deviation to those parameters. Upper limits are plotted at the three sigma level. The diamond points are those points that are not strictly simultaneous (1999.08.17) or maybe affected by a small reflare observed in hard X-rays (1999.09.01, see Figure 15 in Corbel et al. 2000).

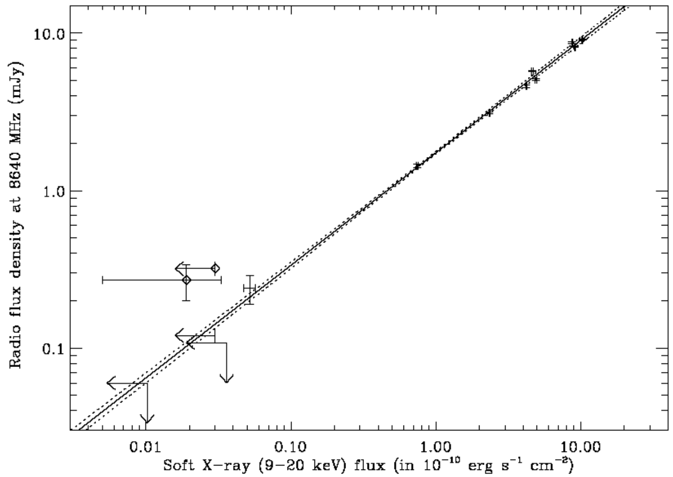


Fig. 2. Same as Fig. 1, but for the X-ray flux in the 9-20 keV energy band.

AGN !? - Maccarone et al. 2003

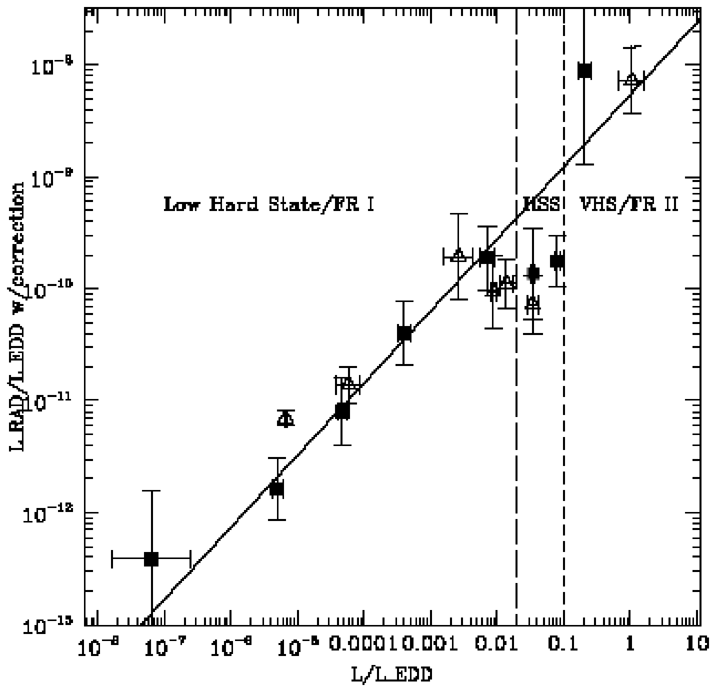
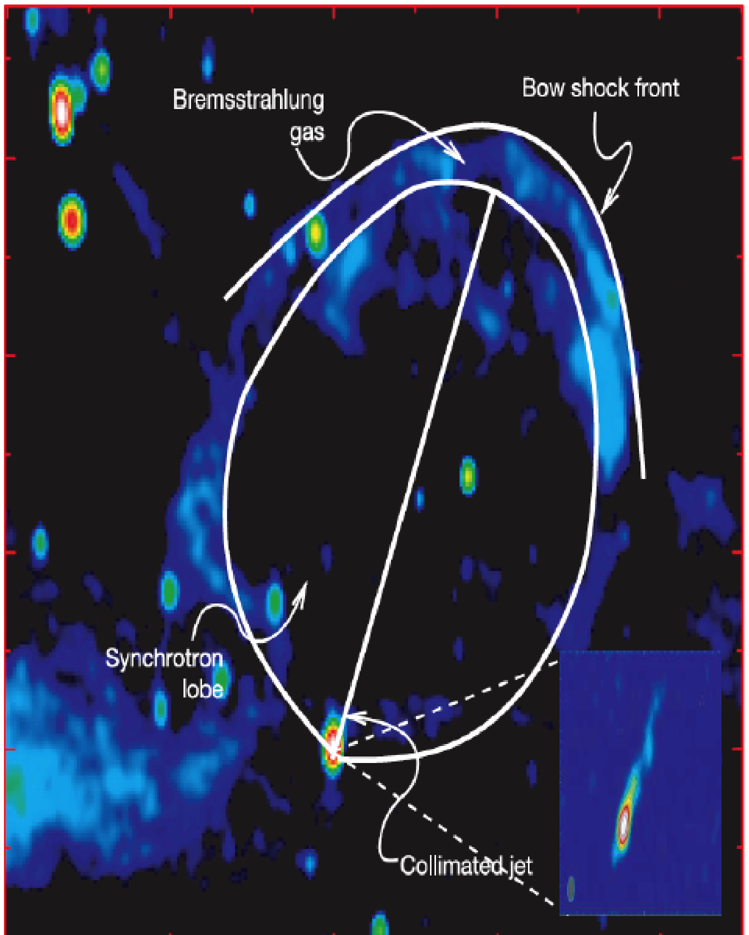


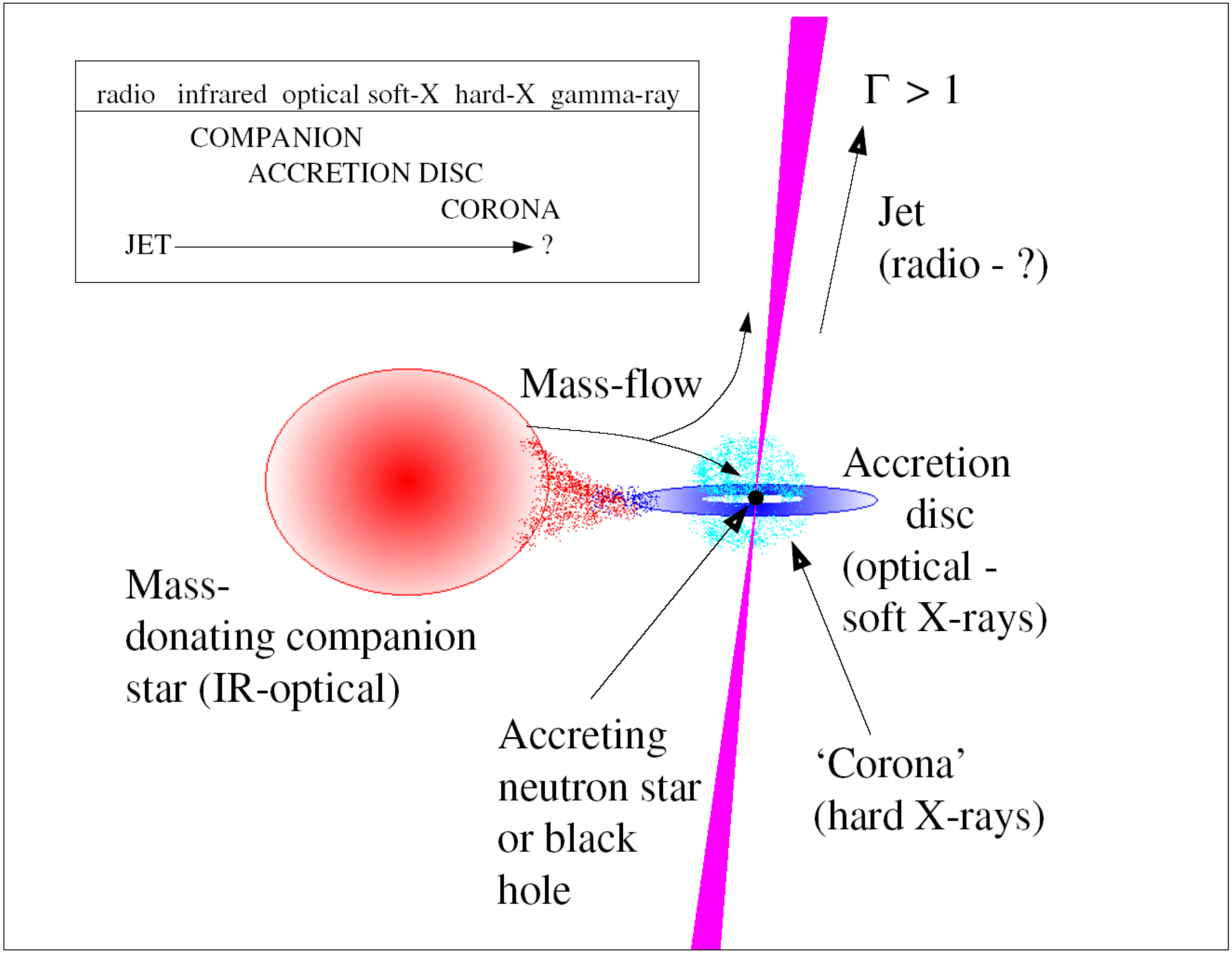
Figure 2. The same as Fig. 1b, with the X-ray binaries included. The open triangles represent the X-ray binaries. The long-dashed vertical line indicates the transition luminosity between the high/soft state (HSS) and the low/hard state as measured in Maccarone (2003) and also is very close to the transition luminosity between FR I & II galaxies as determined by Ghisellini & Celotti (2001). The short-dashed vertical line indicates the estimated state transition luminosity between the high/soft state and the very high state (VHS). The fit to the data is the same as that presented in Figure 1.

Our estimate of the jet velocity of ~10^8 cm s^{-1} agrees with that of Begelman, King & Pringle (2006) for the radiatively driven outflow from the accretion disk in SS 433. That outflow is massive enough to deflect the relativistic jet launched at the vicinity of the compact object.



Finally, Heinz (2006) found that the kinetic power of the observed radio jet is too small by 4 orders of magnitude to explain the observed large scale radio lobes of Cyg X-1 (Gallo et al. 2005). Thus, a dark outflow is required to power the radio lobes. His estimate of the velocity of that outflow agrees with ours.

From Zdziarski 2006…



Fender & Maccarone 2003

The jet explains everything…

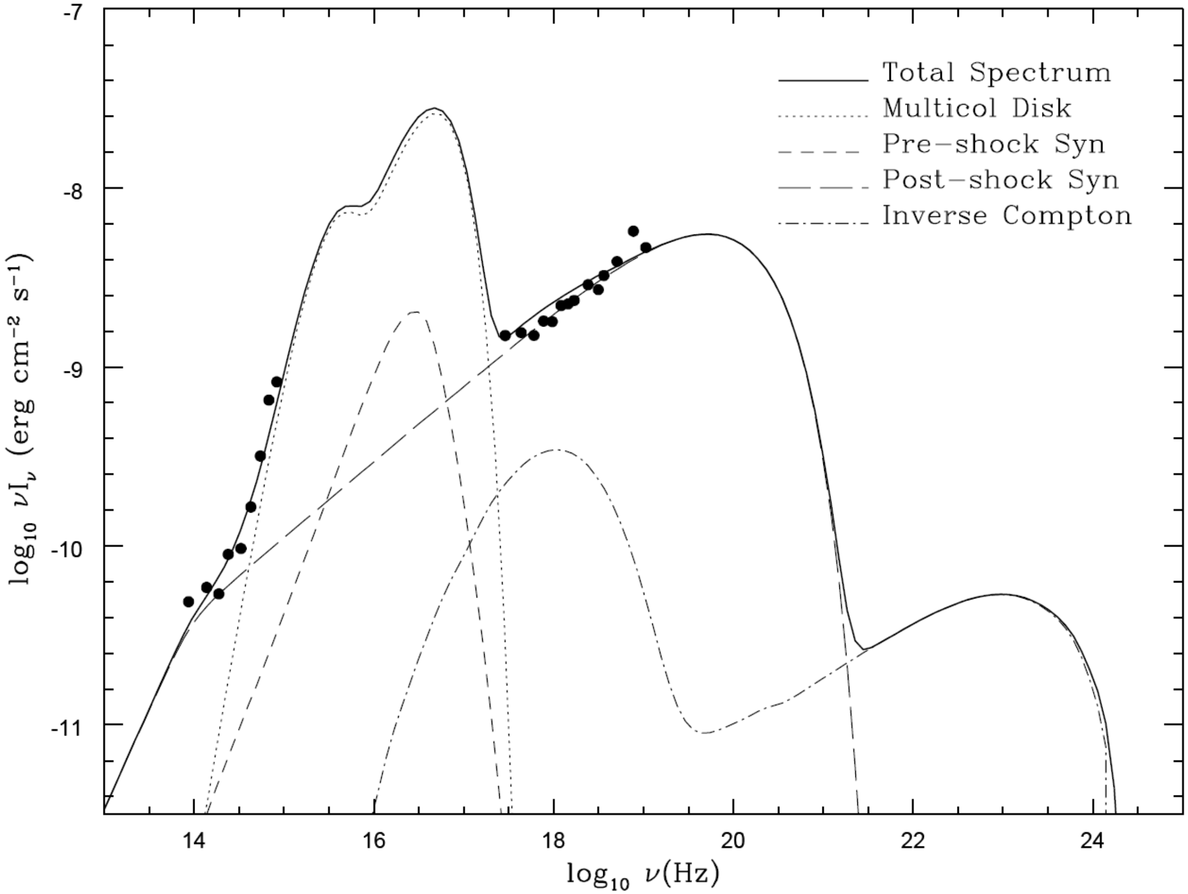
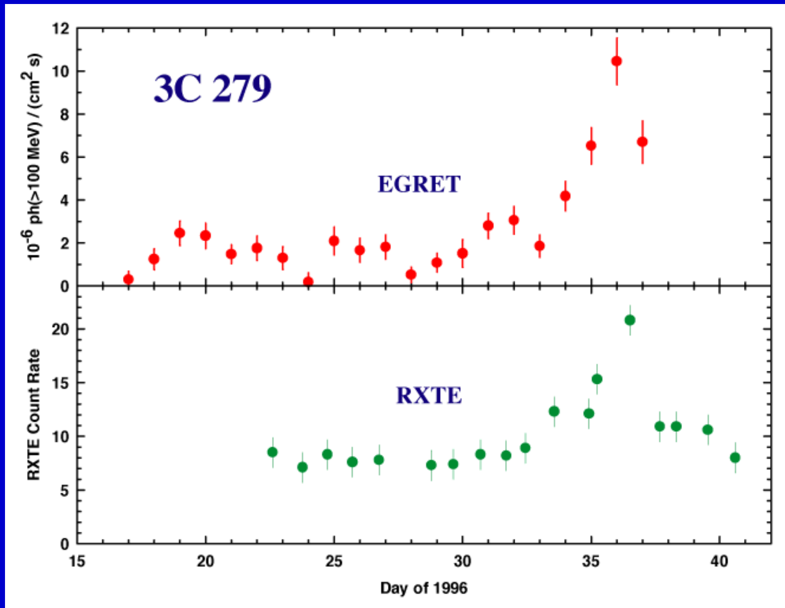
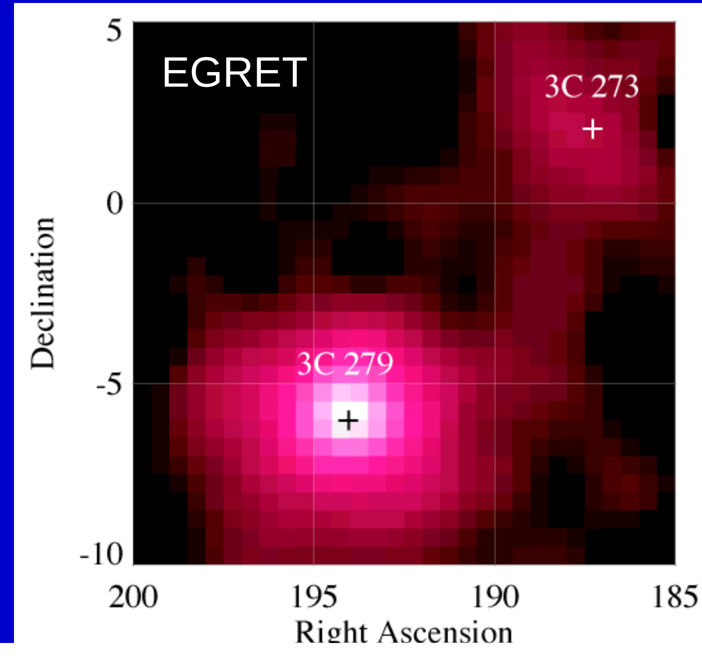


Figure 6. Figure 3 (adapted from Markoff et al. 2003), which shows the jet model fits to the 1981 radio-through-X-ray data for the bright low/hard state of GX 339-4 and predictions for the inverse Compton emission from this model.

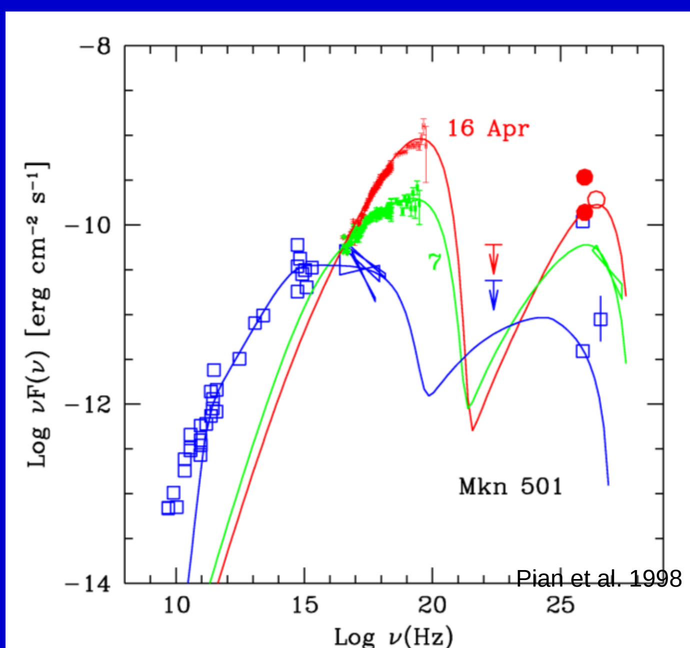
Markoff et al. 2003

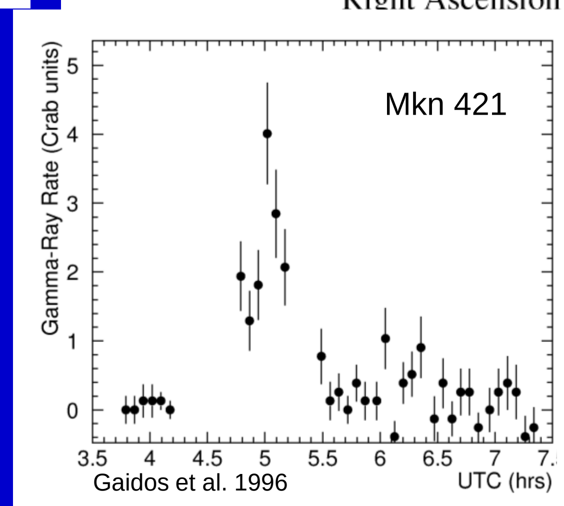
GeV Blazars…



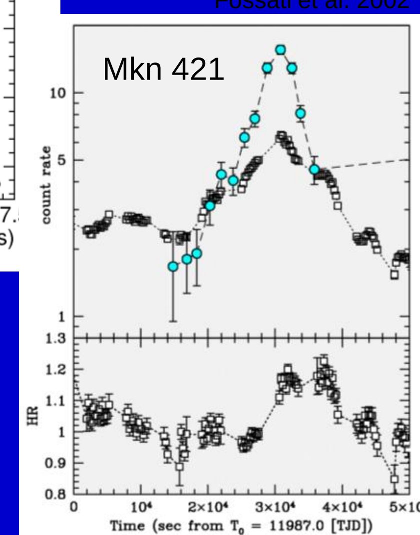


TeV Blazars…



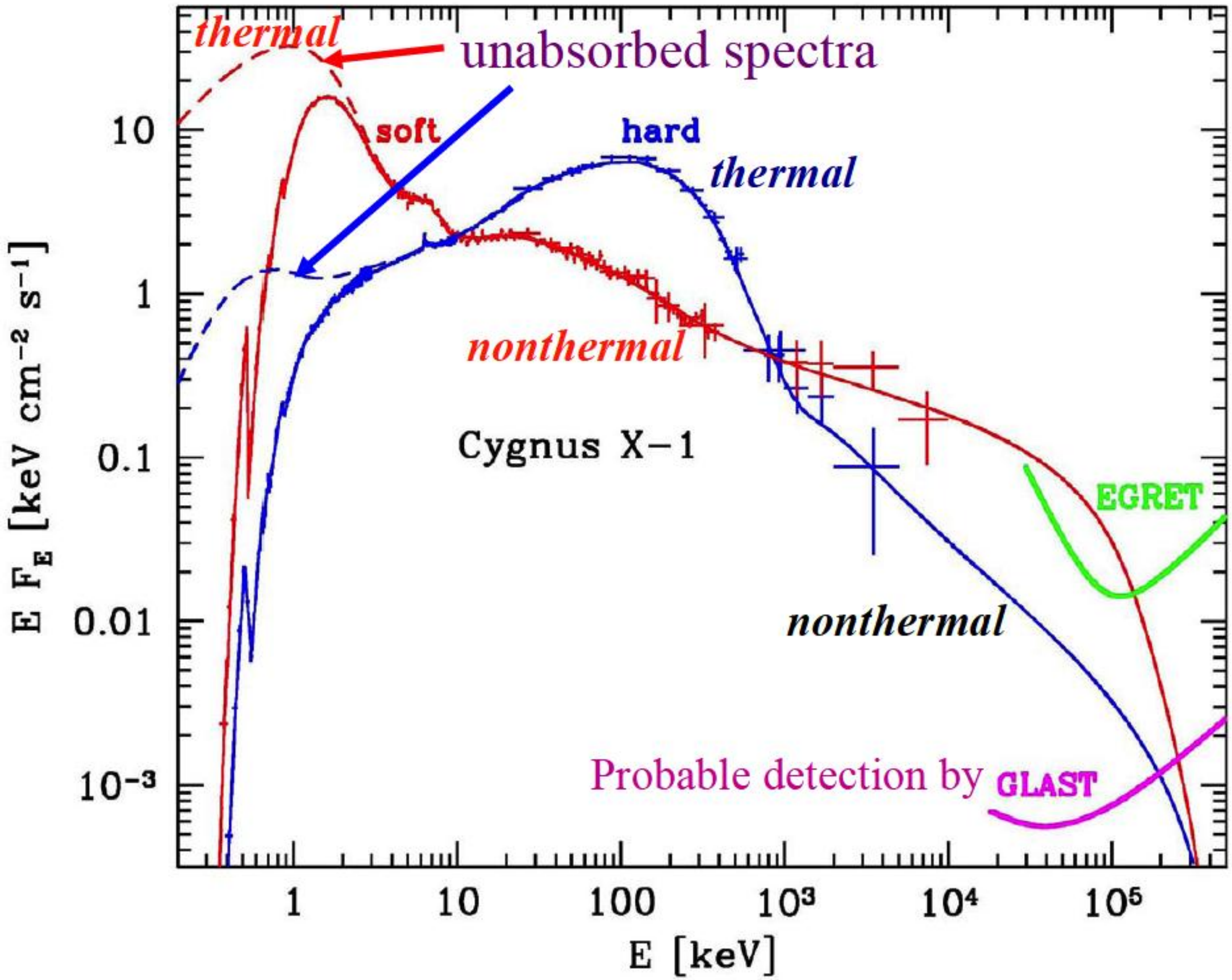


Fossati et al. 2002



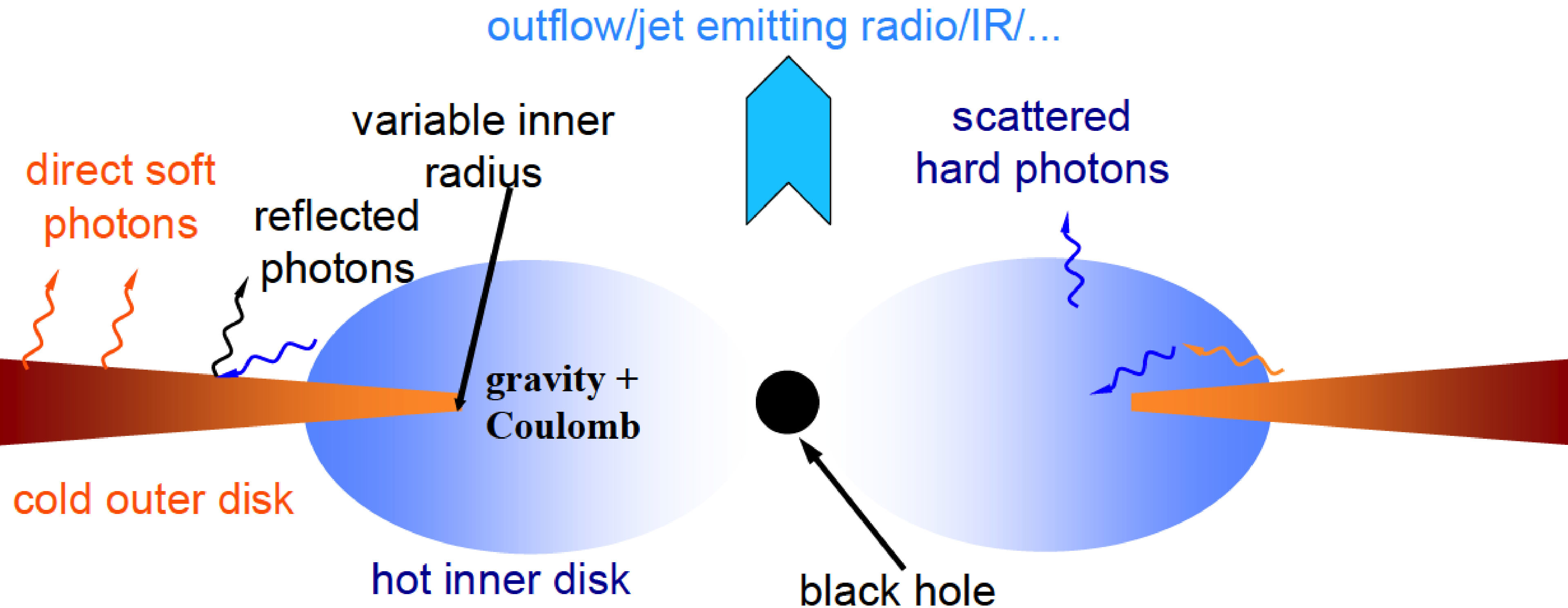
Rapid spectral variability!

Main spectral states of accreting black holes

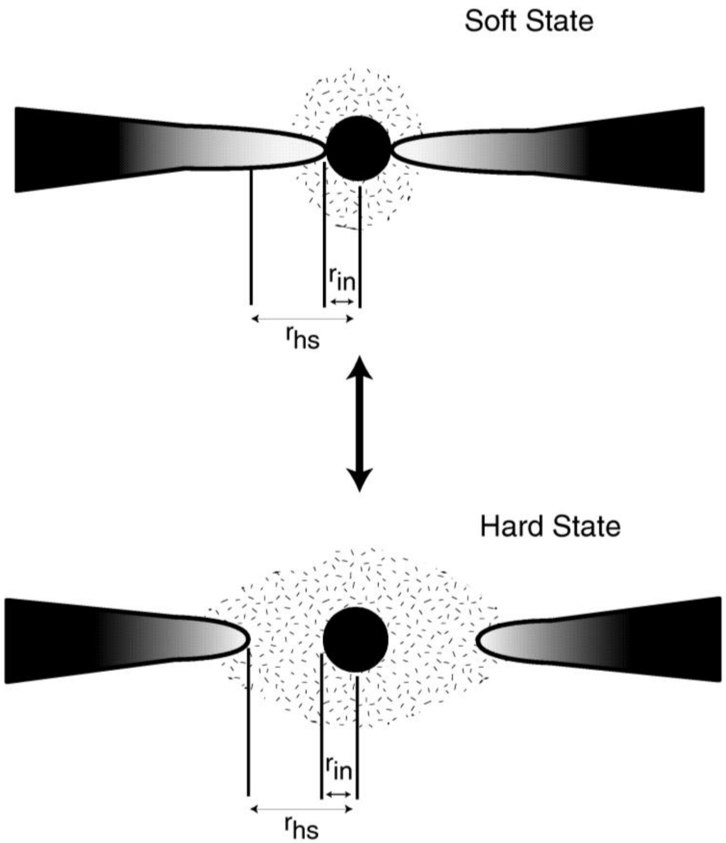


Z. & Gierliński (2004)

A likely geometry of the hard state:



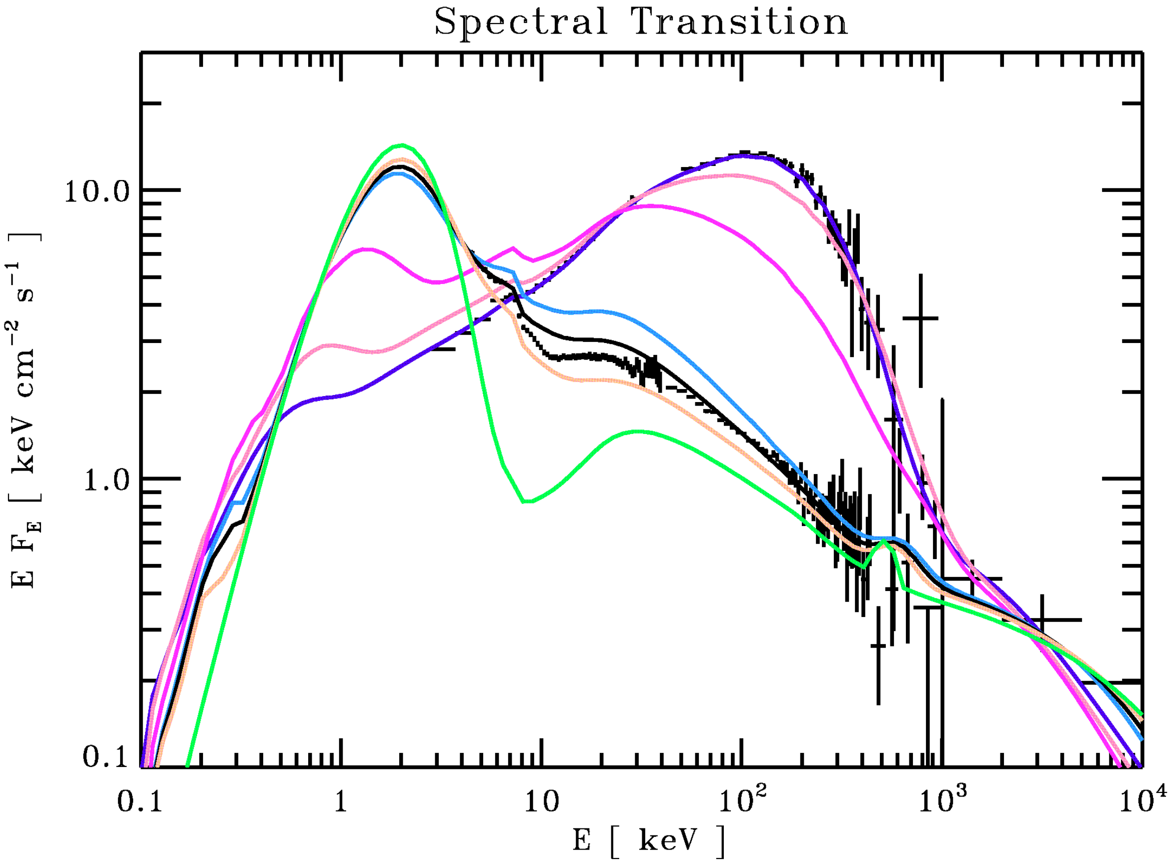
thermal plasma with $kT_e \approx 50–150$ keV in hot accretion solutions



Cyg X-1 Model

Total disk + corona thermal luminosity = constant; disk truncated at varying r_in (varying disk lum., temp).

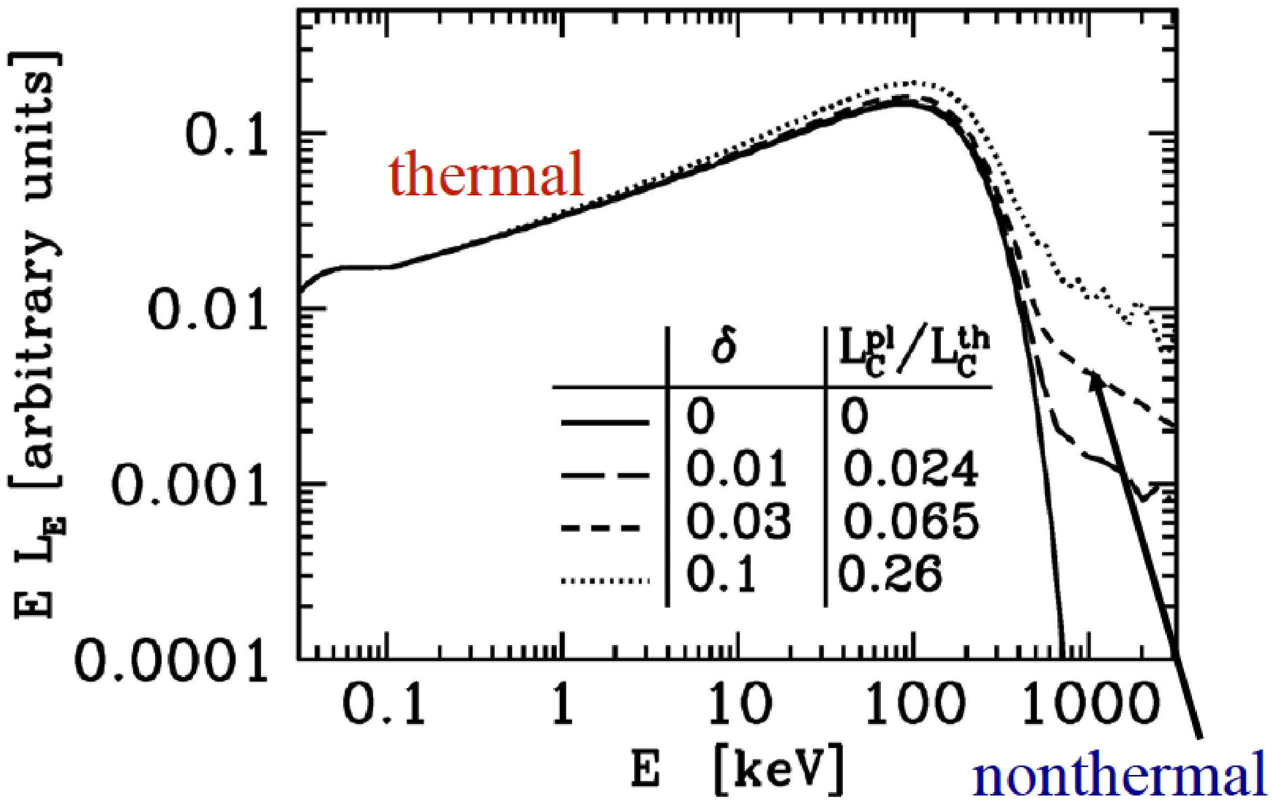
Constant non-thermal acceleration component (maybe this is jet?)

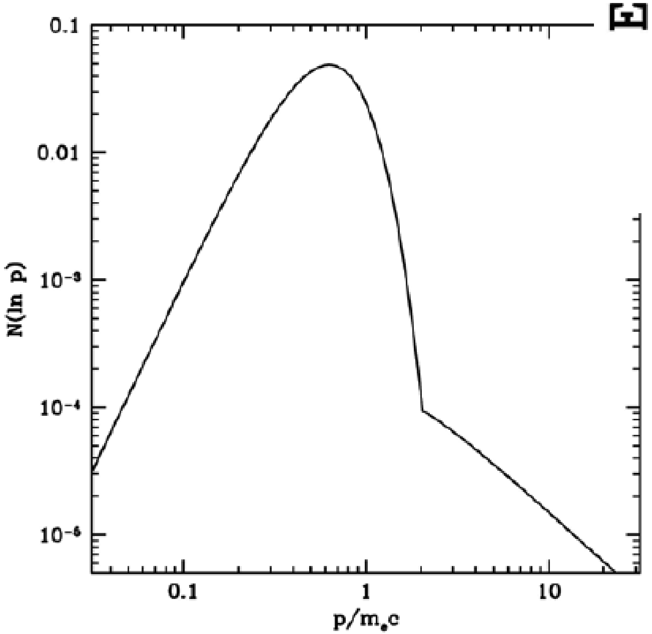


Poutanen & Coppi 1998

Hybrid Comptonization:

δ is the relative energy content in the nonthermal electrons.

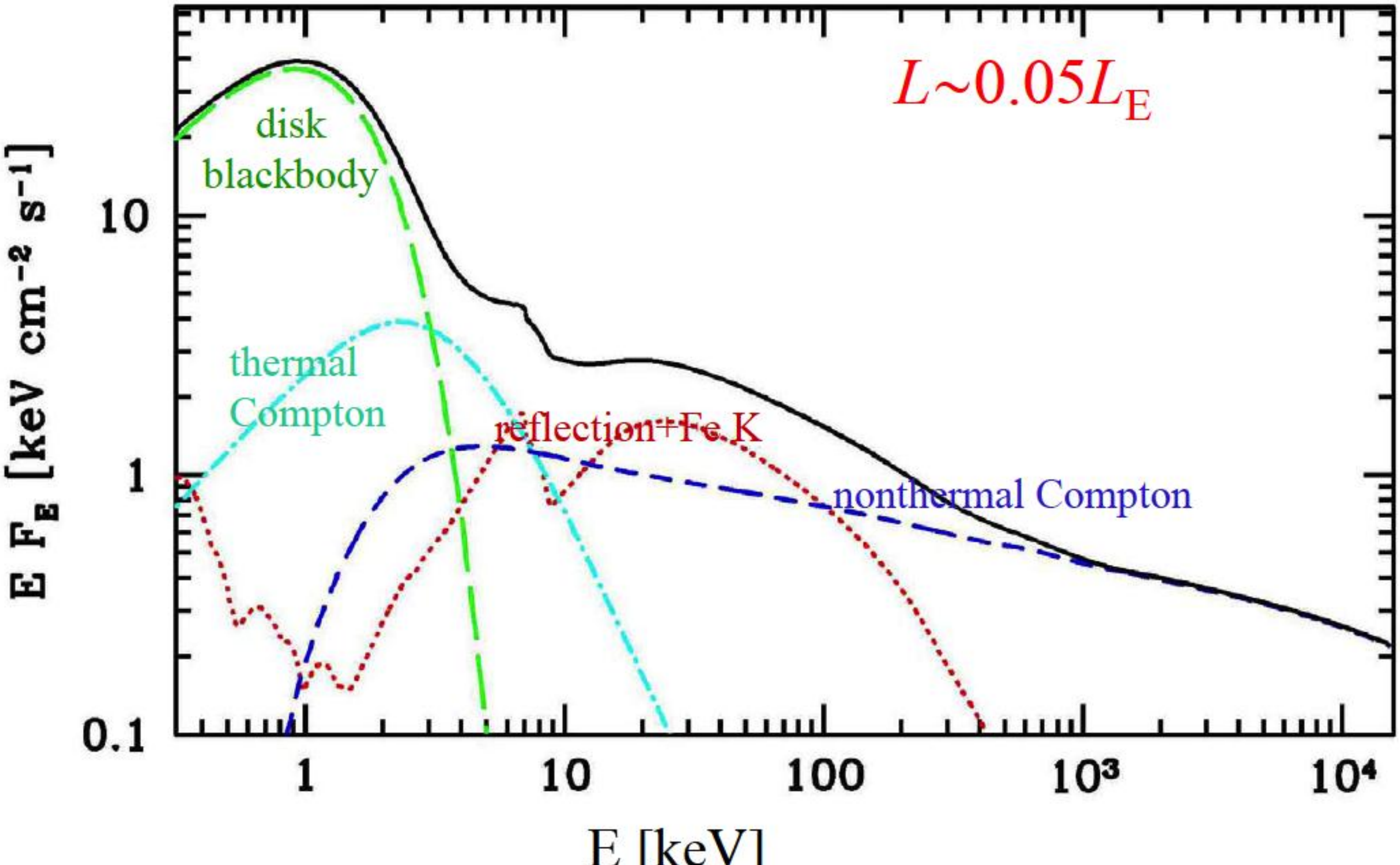




A single hybrid electron population consisting of a Maxwellian and a high-energy (power-law like) tail.

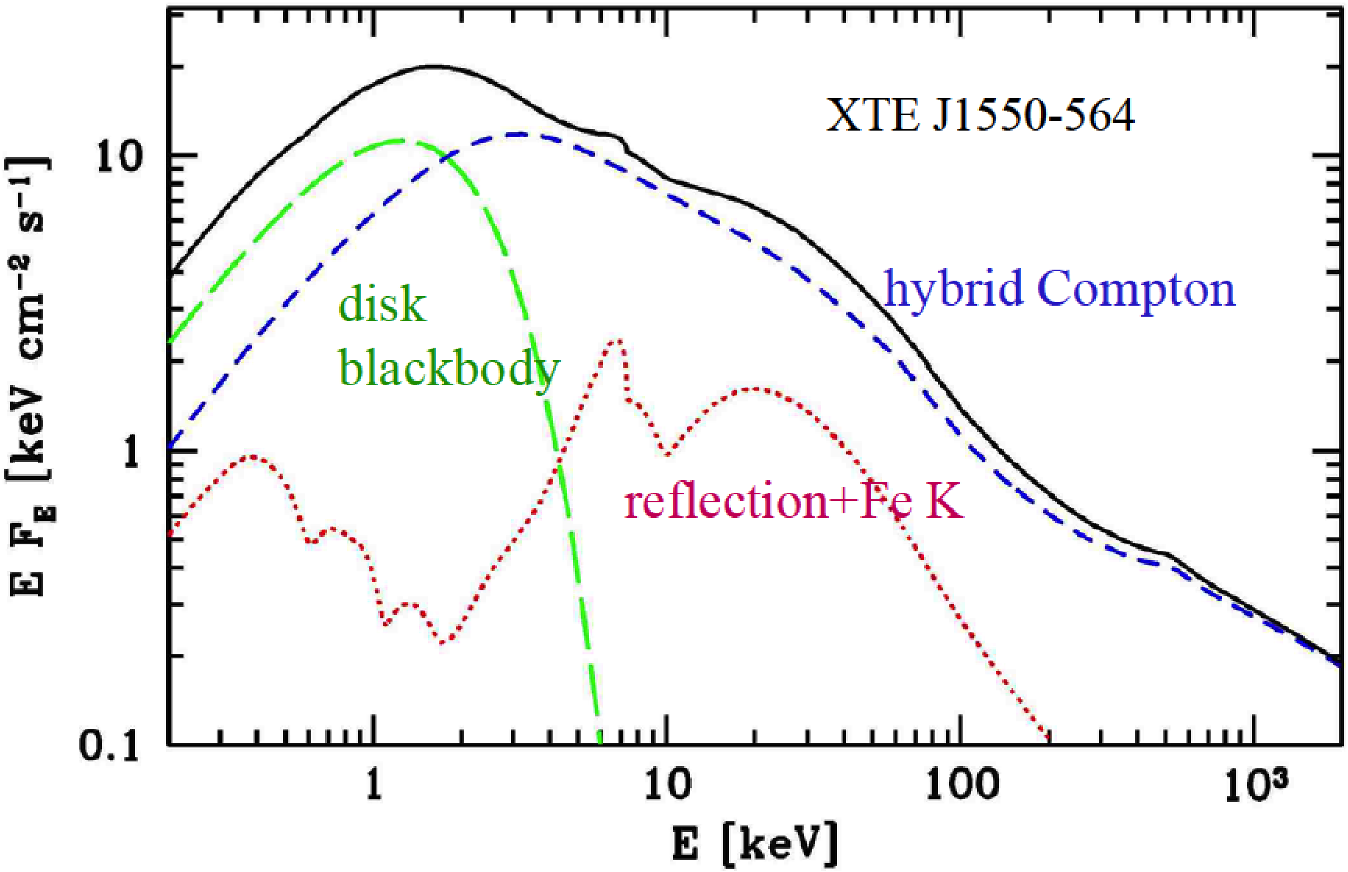
Hybrid Comptonization in the soft state of Cyg X-1

$\frac{L_{hot}}{L_{disk}} \ll 1$



Z. & Gierliński (2004)

The very high/intermediate state:

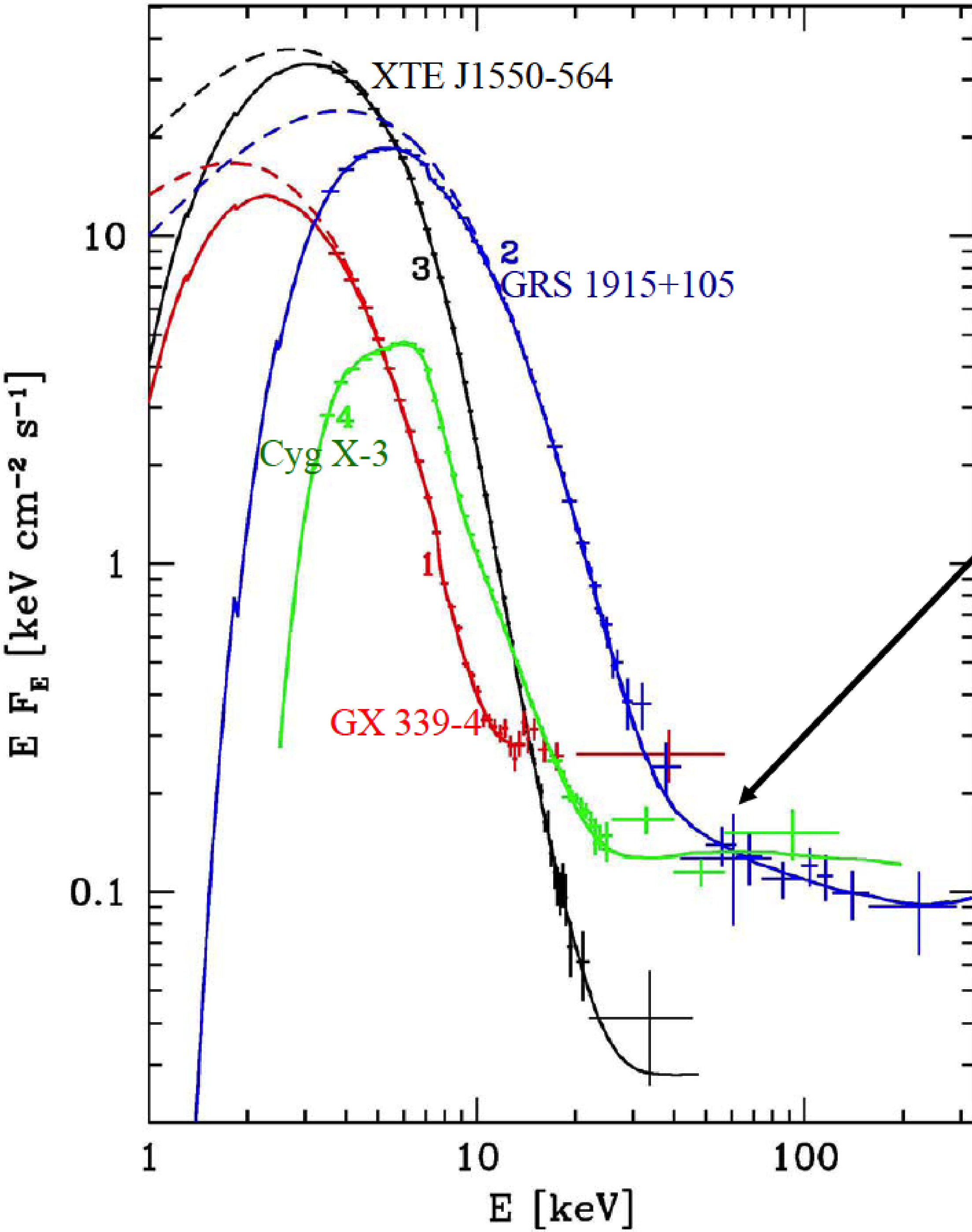


L_{hot}/L_{disk}~1

The very high state has a higher amplitude of the tail, L_{hot}/L_{disk}, indicating stronger coronal activity.

Nonthermal nature: no high-energy cutoff up to at least ~1 MeV.

Gierliński & Done (2003)



Ultrasoft states:

the origin of the flat (Γ≈2) power law?

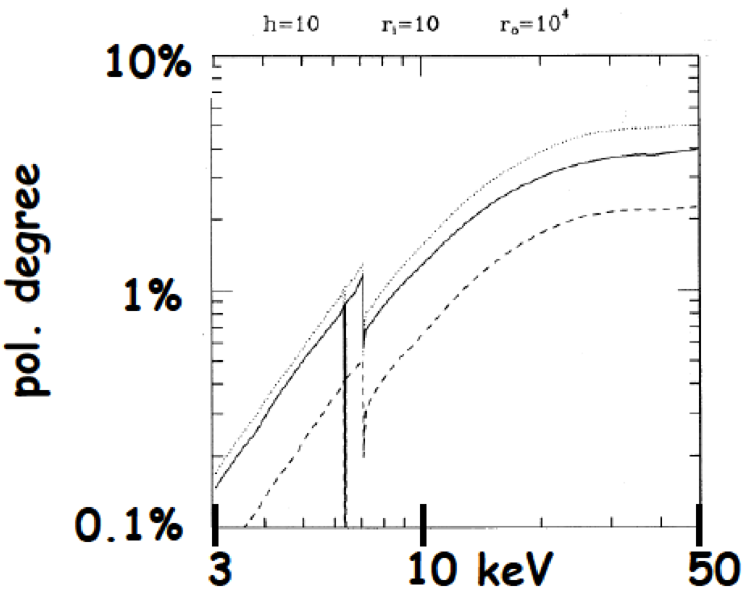
Certainly a nonthermal process, probably Comptonization.

Z. & Gierliński 2004

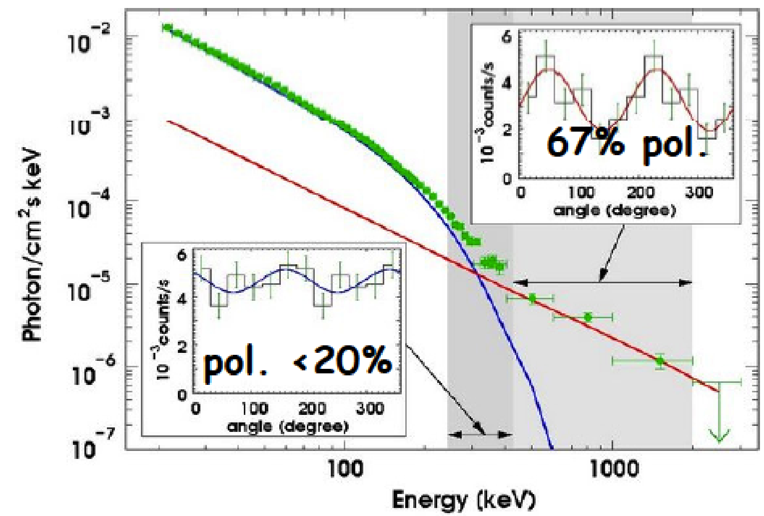
X-ray/Gamma-ray *SpectroPolarimetry*

- **Measuring energy dependent polarization is crucial to disentangle emission mechanisms**

disk reflection model (Matt+93)
pol. vector ⊥ disk



Strong polarization (67%) from
Cyg X-1 jet in HE (Laurent+11)



So is there any jet emission at X/gamma energies? GRS 1915+105?

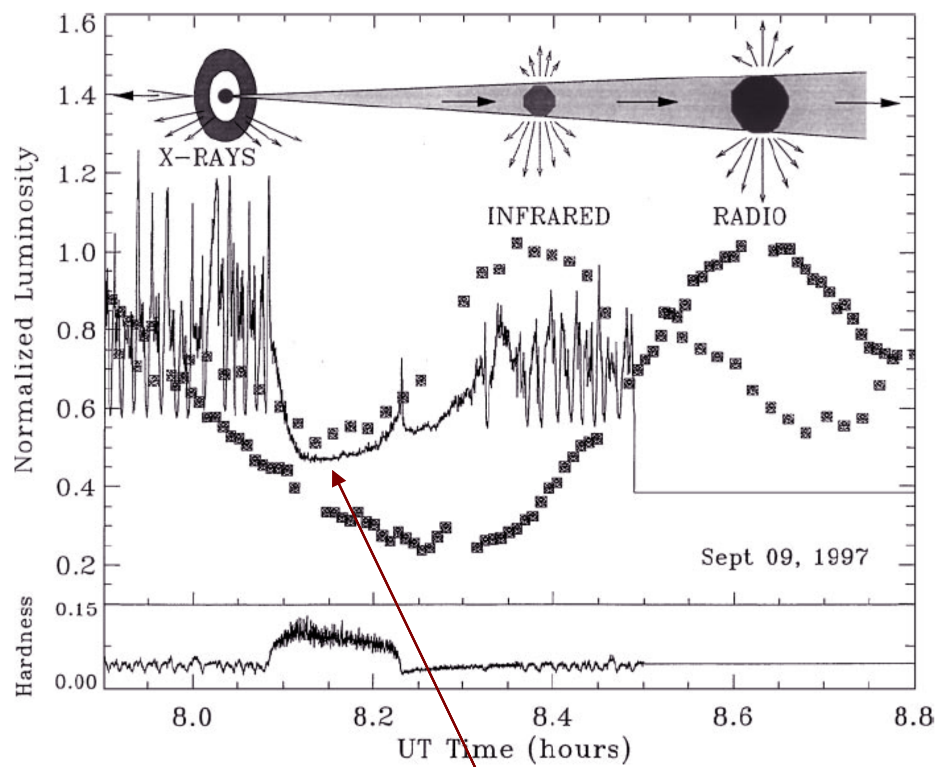


Figure 7 Radio, infrared, and X-ray light curves for GRS 1915+105 at the time of quasi-periodic oscillations on 1997 September 9 (Mirabel et al 1998). The infrared flare starts during the recovery from the X-ray dip, when a sharp, isolated X-ray spike is observed. These observations show the connection between the rapid disappearance and follow-up replenishment of the inner accretion disk seen in the X-rays (Belloni et al 1997), and the ejection of relativistic plasma clouds observed as synchrotron emission at infrared wavelengths first and later at radio wavelengths. A scheme of the relative positions where the different emissions originate is shown in the top part of the figure. The hardness ratio (13–60 keV)/(2–13 keV) is shown at the bottom of the figure.

Mirabel and Rodriguez 1999

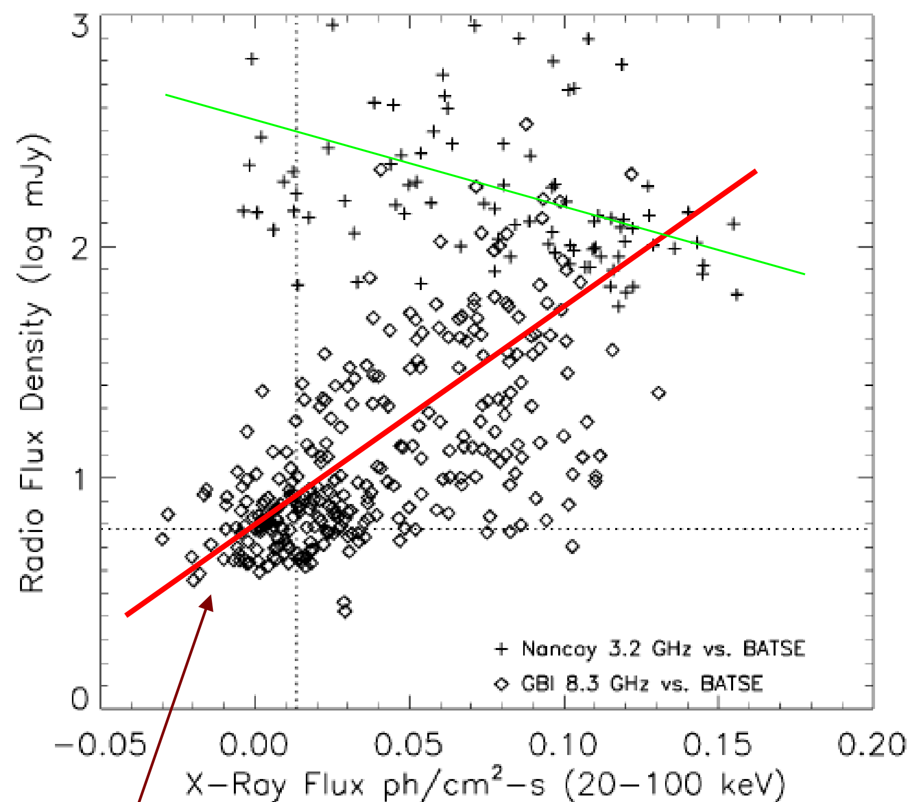


FIG. 3.—Nançay 3.2 GHz data from 1993 December to 1994 April and GBI 8.3 GHz data from 1994 May to 1996 March plotted vs. the BATSE 20–100 keV flux. The GBI 2.25 GHz data (not plotted) show a very similar correlation with the X-ray band. Dotted lines indicate reasonable detection thresholds (1 σ): approximately 6 mJy for GBI and 0.013 photons cm^{-2} s^{-1} for BATSE.

Harmon et al. 1997

X-rays go away during ejection, but …

Or it’s there, but not so easy to see…

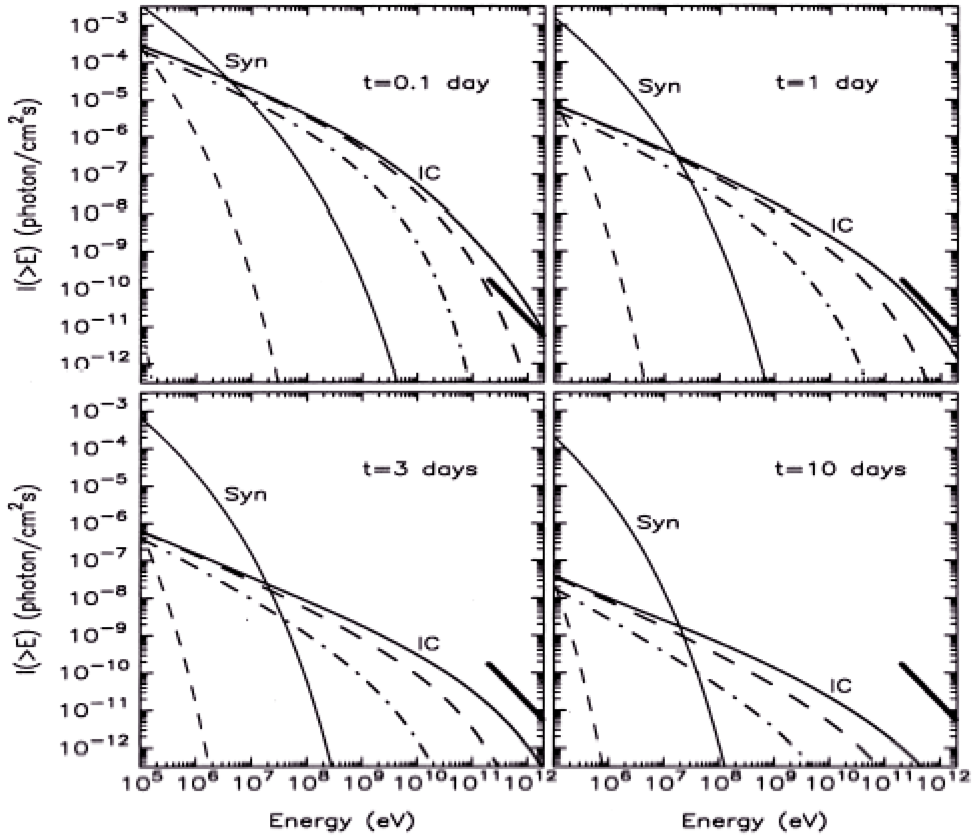


Fig. 1. Gamma ray fluxes (synchrotron – thin lines, and IC – heavy lines) expected at different stages of radio flare of GRS 1915+105 similar to March/April 1994 event, calculated for 3 different values of E_c: 20 TeV (solid), 1 TeV (dashed), and 50 GeV (dot-dashed). The level of the VHE γ-ray fluxes of the Crab Nebula are shown by the heavy bar. The model parameters for calculations are taken from Atoyan & Aharonian (1997a).

GRS 1915

Aharonian & Atoyan 1998

Spectral index – flux correlation expected in Comptonisation model (pivoting), but depends on radio state!?

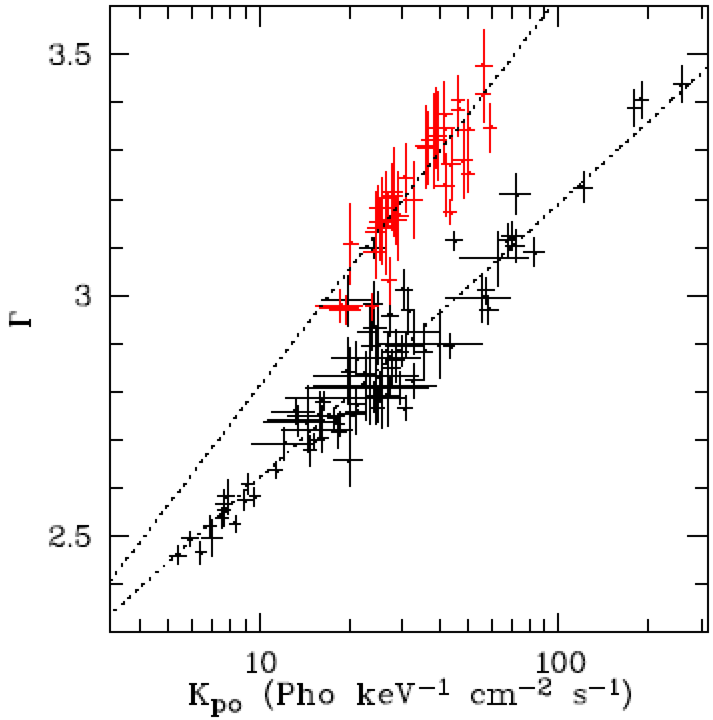
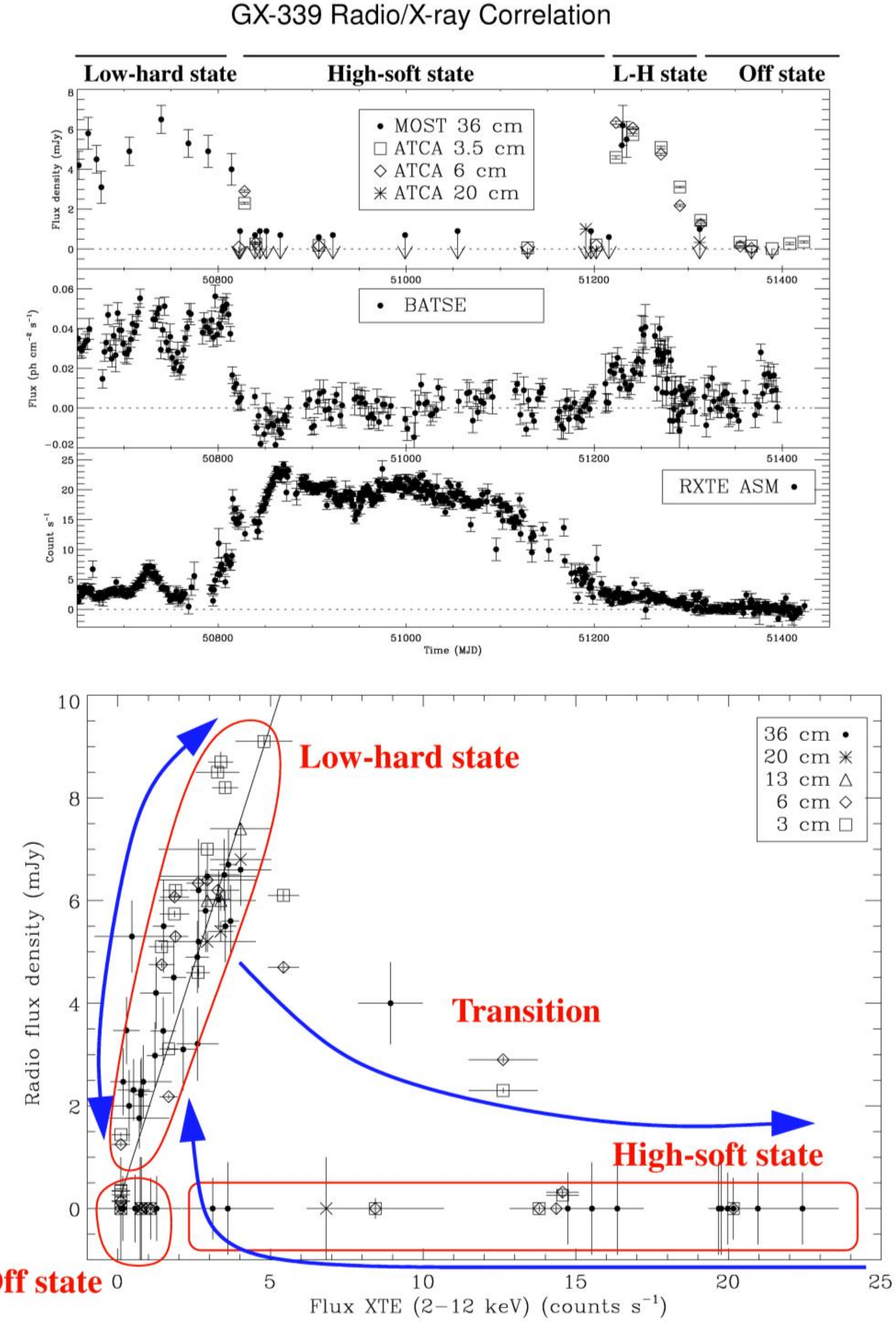


Figure 1. Power law slope, Γ, as a function of power law normalization, K_{po}. Each *RXTE* observation is represented by one data point. (dotted lines: correlation function)

GRS 1915, Rau & Greiner 2002

Jet and corona know each other!



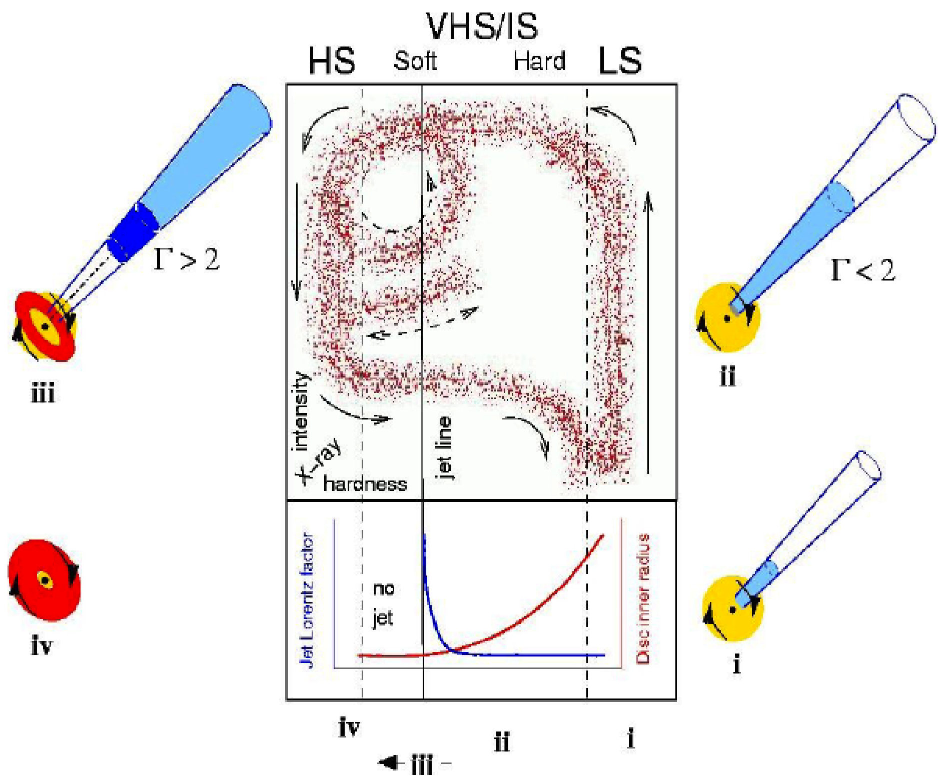
Corbel et al.2002

What's new since Fender, Belloni & Gallo (2004) ?

Empirical aspects of model have been confirmed with much larger samples (~20 c.f. ~4). No strong contradictions.

Theoretical interpretation remains more or less untested.

Much more information available about coupling to <u>variability</u> properties of accretion flow



Fender, Homan & Belloni (2009)

Summary

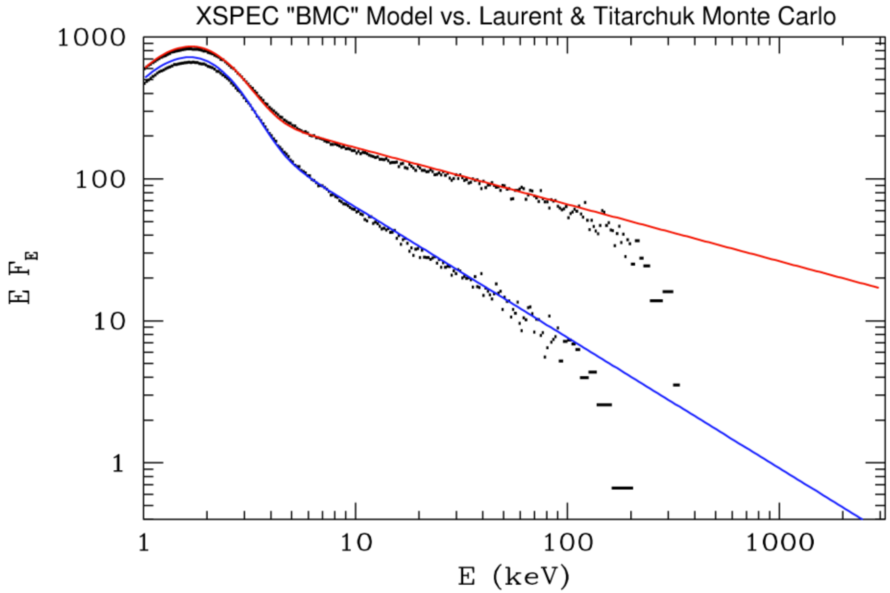
Jets seem to be ubiquitous phenomenon in accreting stellar mass black holes. Speeds are mildly to very relativistic(??, $\Gamma>10$) -- but beware of selection effects, keep finding new things! Radio polarization signatures (both circular and linear) similar to AGN jets? => *Fundamentally same process?* Microquasar studies complementary to AGN studies, e.g., outburst cycle takes months vs. thousands of years in AGN.

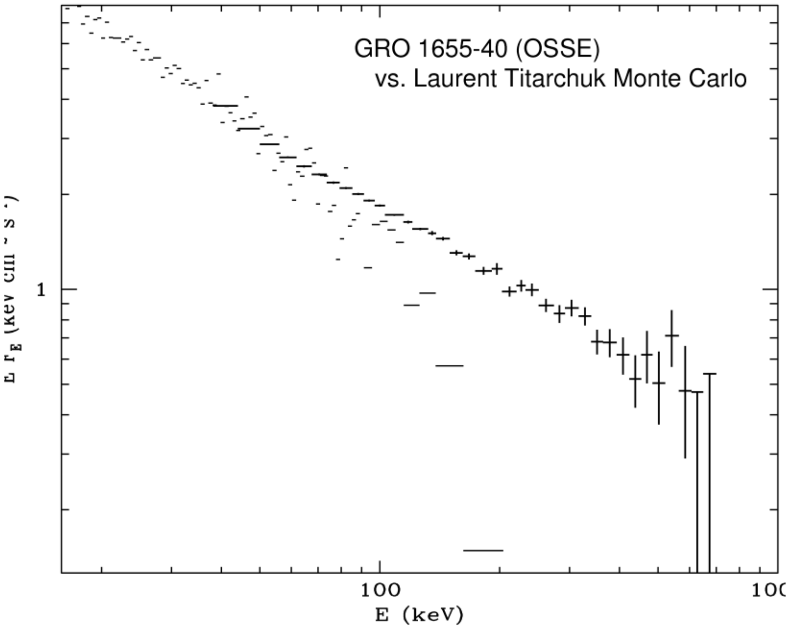
Neutron stars can show jets too! => Ultimately accretion disk phenomenon?

Disentangling accretion disk and jet emission currently a problem. X/gamma-ray emission NOT as obvious as in AGN. Typical observed emission is probably from disk or corona (standard interpretation). But clearly there exists jet/outflow – disk/corona correlation. Corona =" base of jet?" Polarization measurements can definitely help sort out emission components.

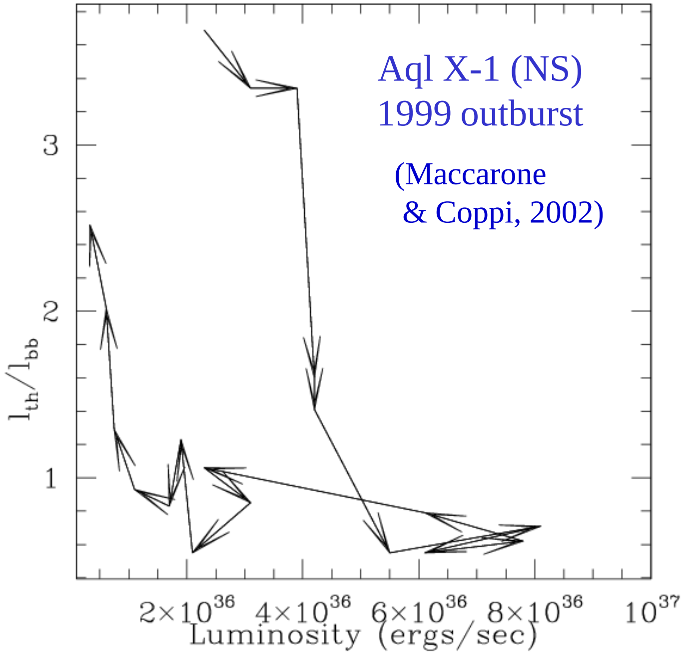
Glass half-full! Yes, gamma-rays from binaries – rare … but it's also (very) rare in AGN! AGILE (+FERMI+MAGIC) detection, esp. Cyg X-3 when expect jet ejection, proves jet/jet interaction with surroundings can accelerate high particles!

Jet emission rare but we have more to discover, e.g., Golenetskii et al. 2003 (=> rapid, ~hr long events?). More suprises in store … !

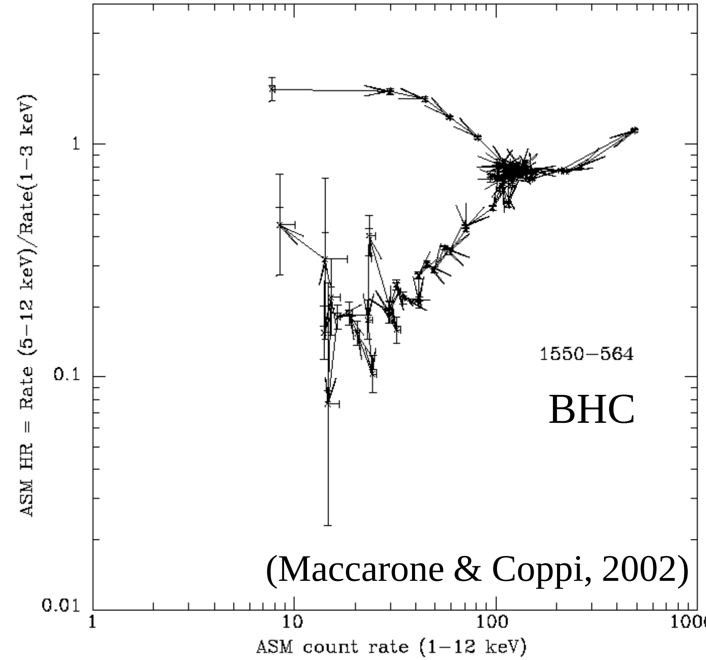




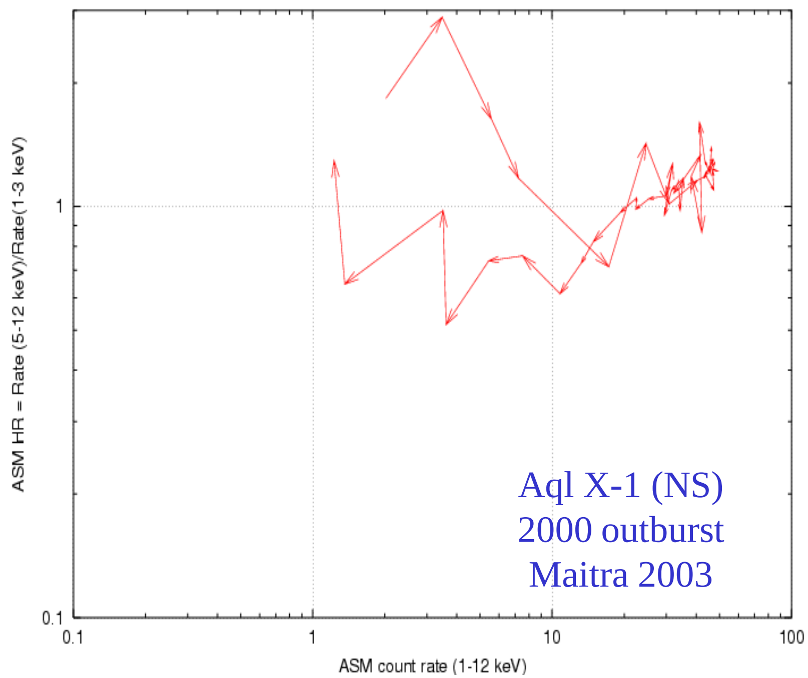
Zdziarski 2002



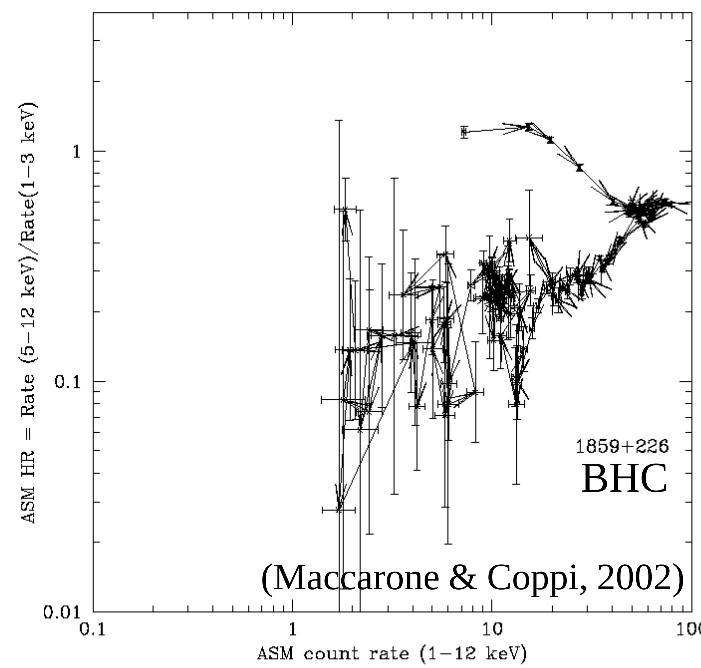
Aql X-1 (NS)
1999 outburst
(Maccarone
& Coppi, 2002)
l_{th}/l_{bb}
1
2
3
2×10^{36} 4×10^{36} 6×10^{36} 8×10^{36} 10^{37}
Luminosity (ergs/sec)



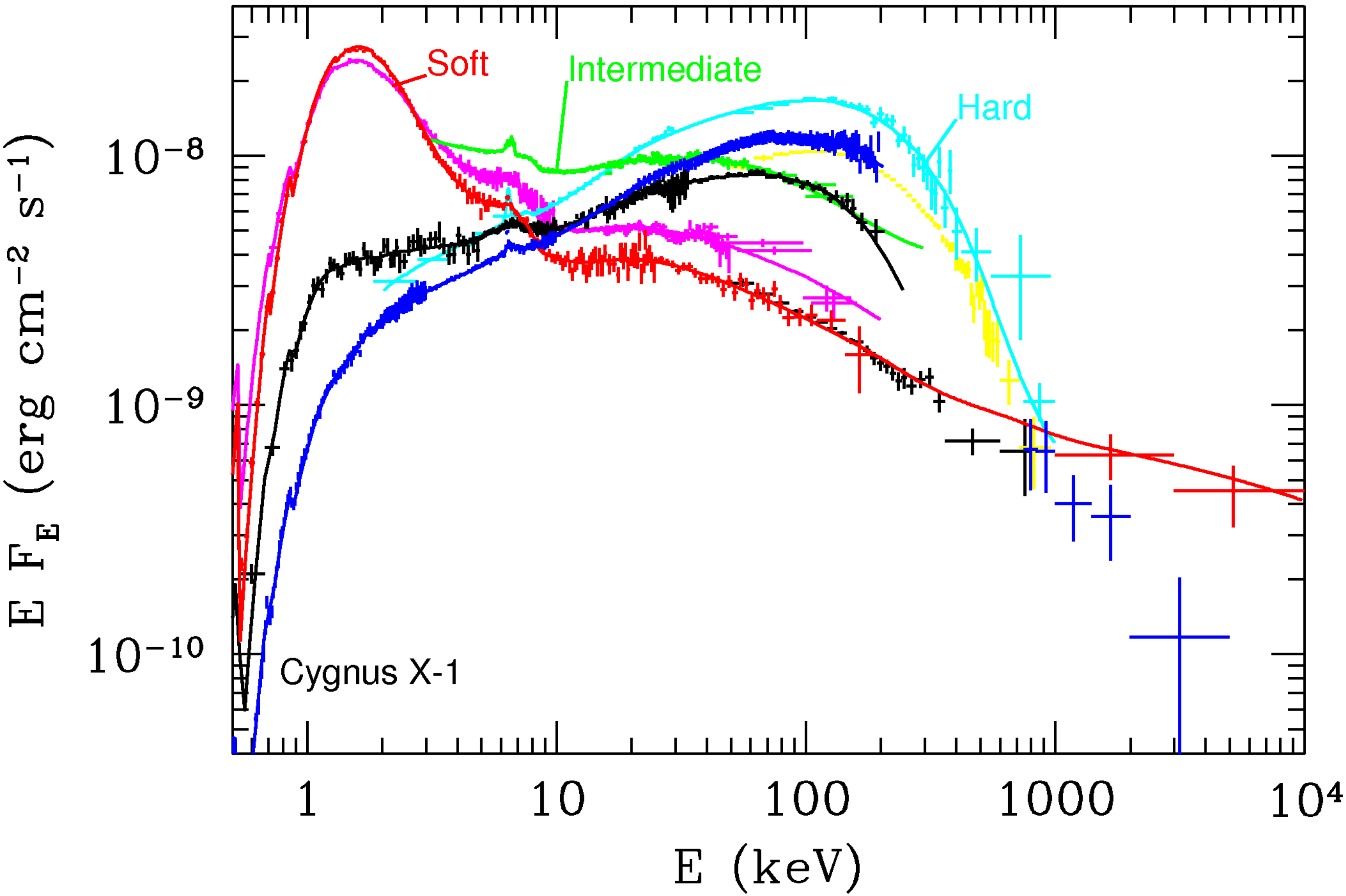
ASM HR = Rate (5-12 keV)/Rate(1-3 keV)
1
0.1
0.01
1550-564
BHC
(Maccarone & Coppi, 2002)
1
10
100
1000
ASM count rate (1-12 keV)



ASM HR = Rate (5-12 keV)/Rate(1-3 keV)
1
0.1
Aql X-1 (NS)
2000 outburst
Maitra 2003
0.1
1
10
100
ASM count rate (1-12 keV)



ASM HR = Rate (5-12 keV)/Rate(1-3 keV)
1
0.1
0.01
1859+226
BHC
(Maccarone & Coppi, 2002)
0.1
1
10
100
ASM count rate (1-12 keV)



Compilation by A. Zdziarski

Basic ingredients that seem to be relevant for galactic black holes, MOST of the time (maybe not during ejection event)