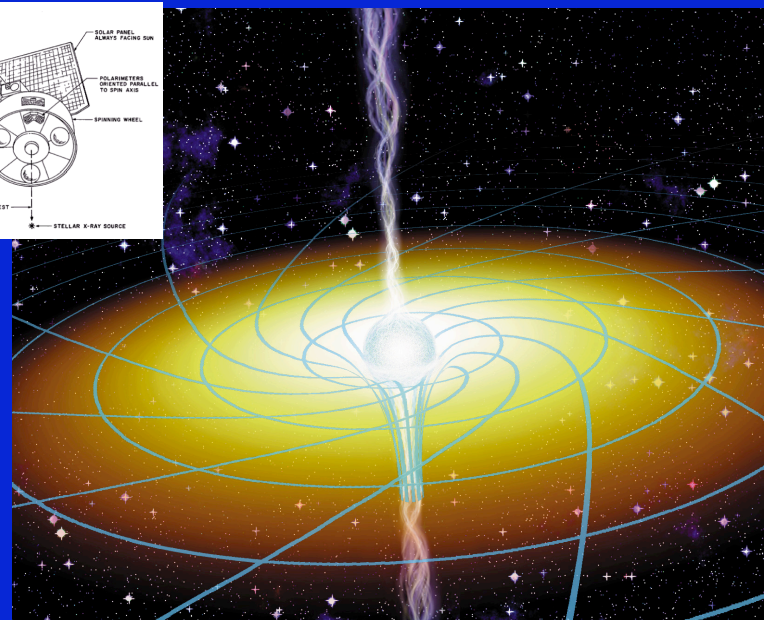
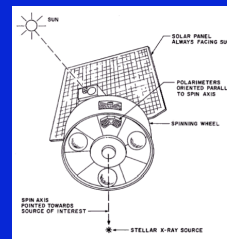
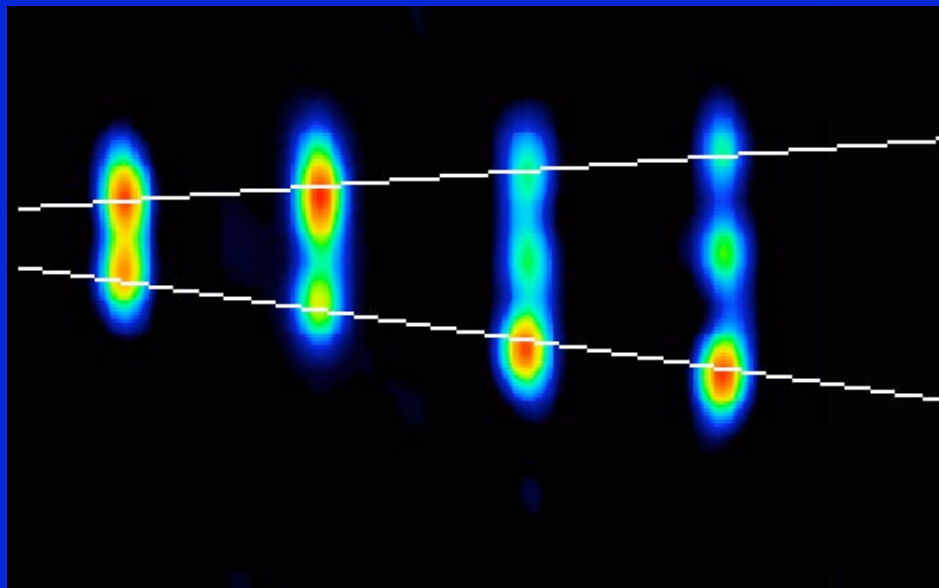
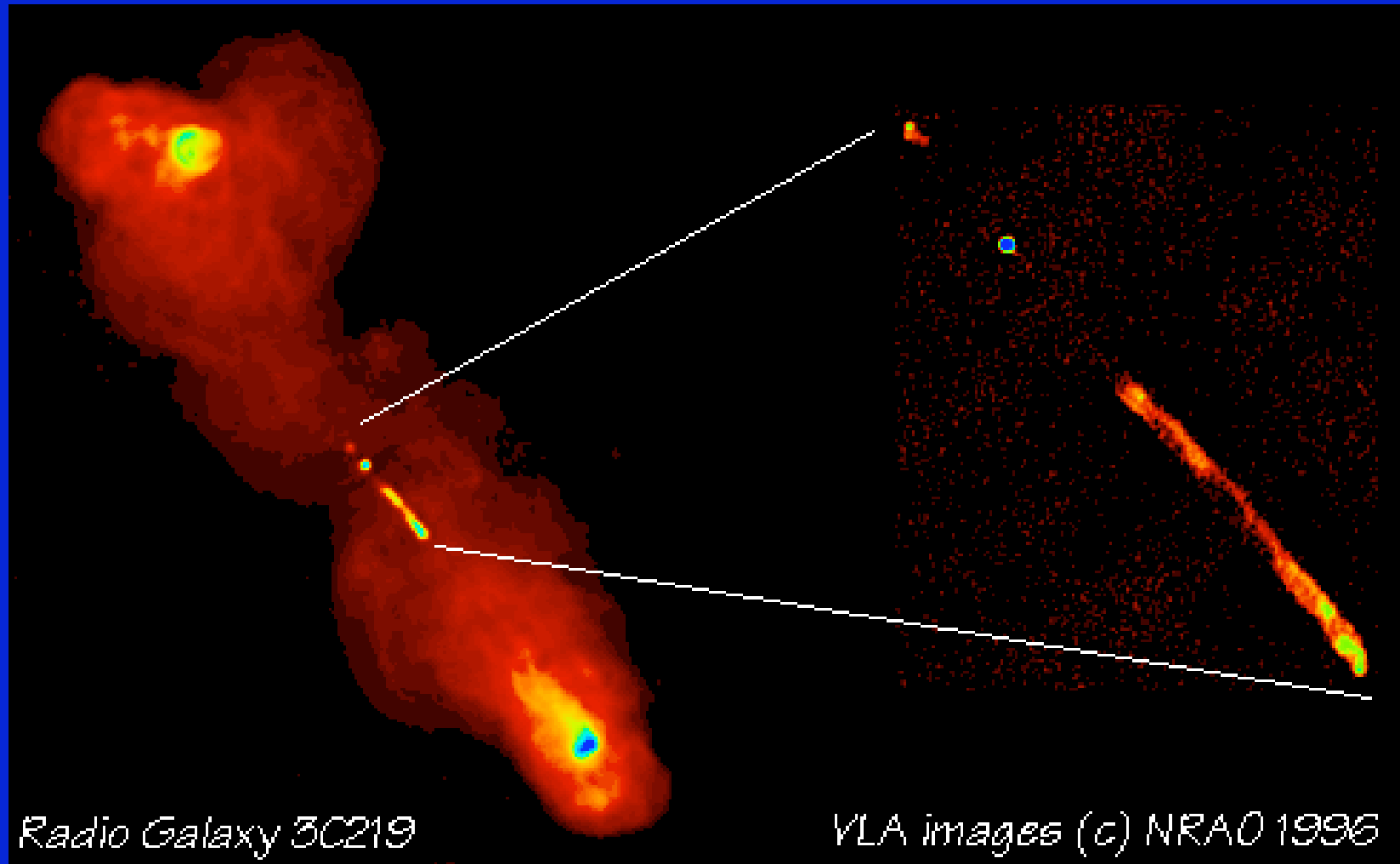


# High Energy Polarization in Blazars, II: What About Those $\mu$ -Quasars?

P. Coppi, Yale

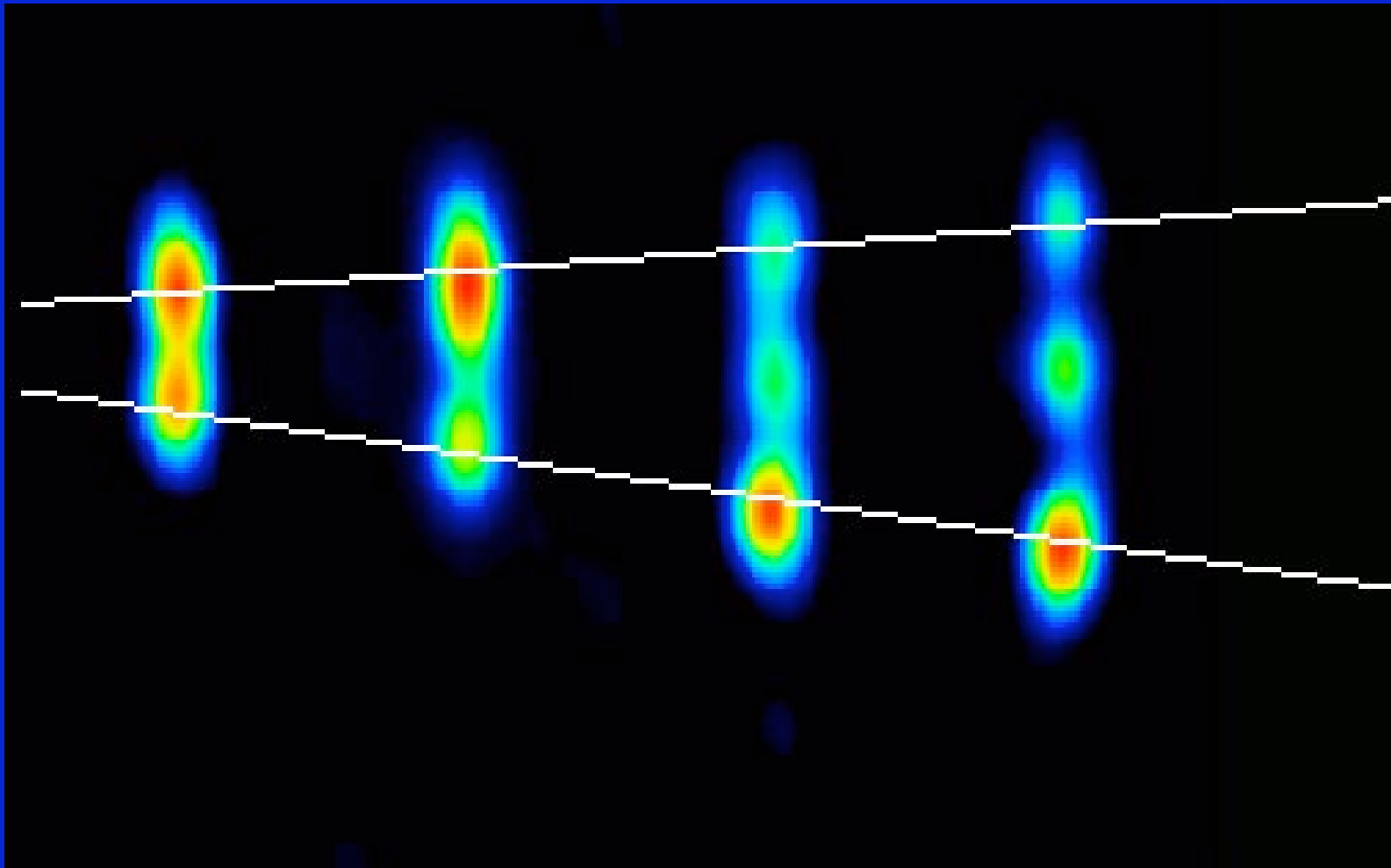


## The big brother...



The little brother:

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



The apparent velocity of motion is superluminal too!

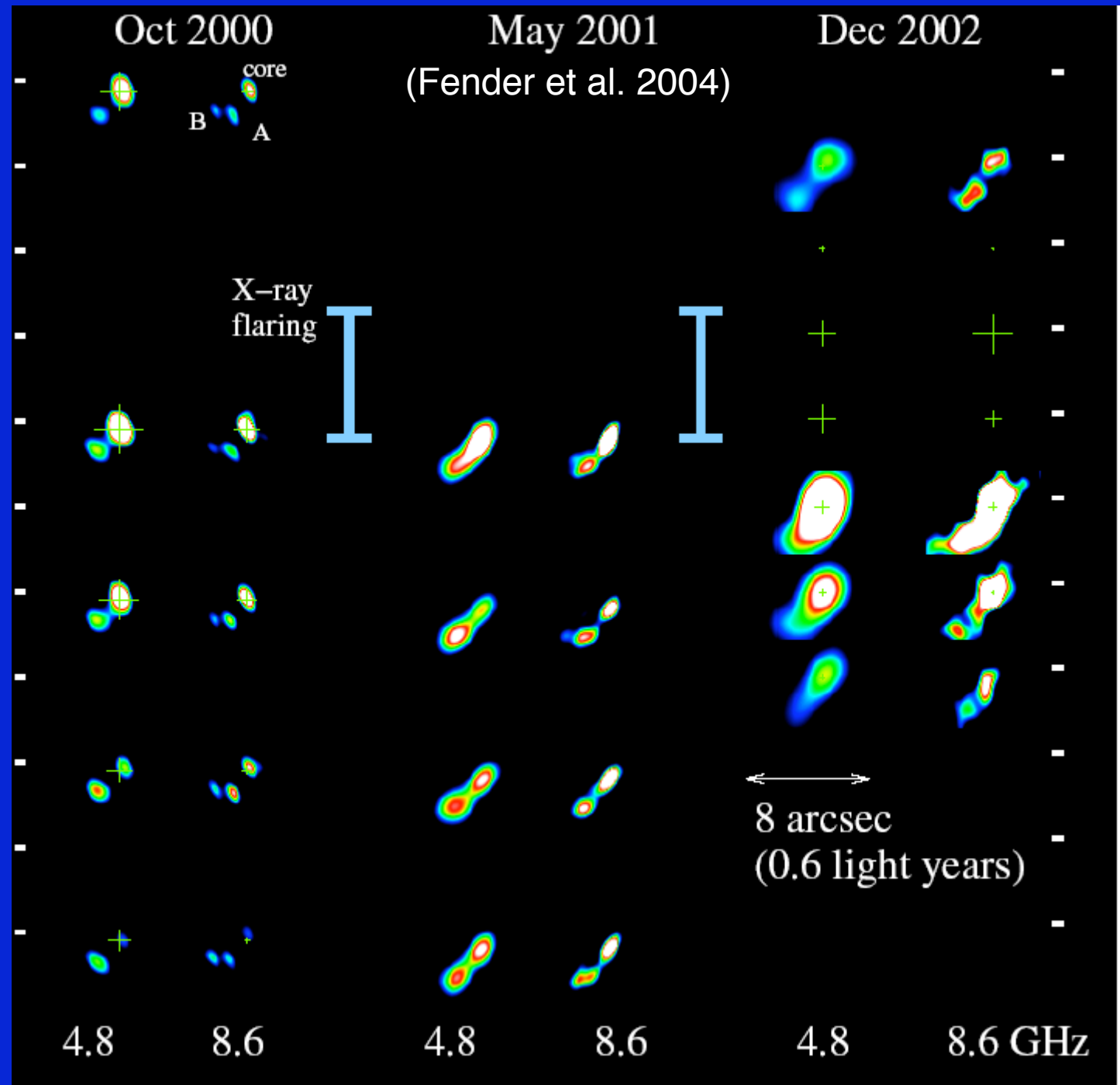
Hm...

Cir X-1  
also does  
this kind  
stuff!

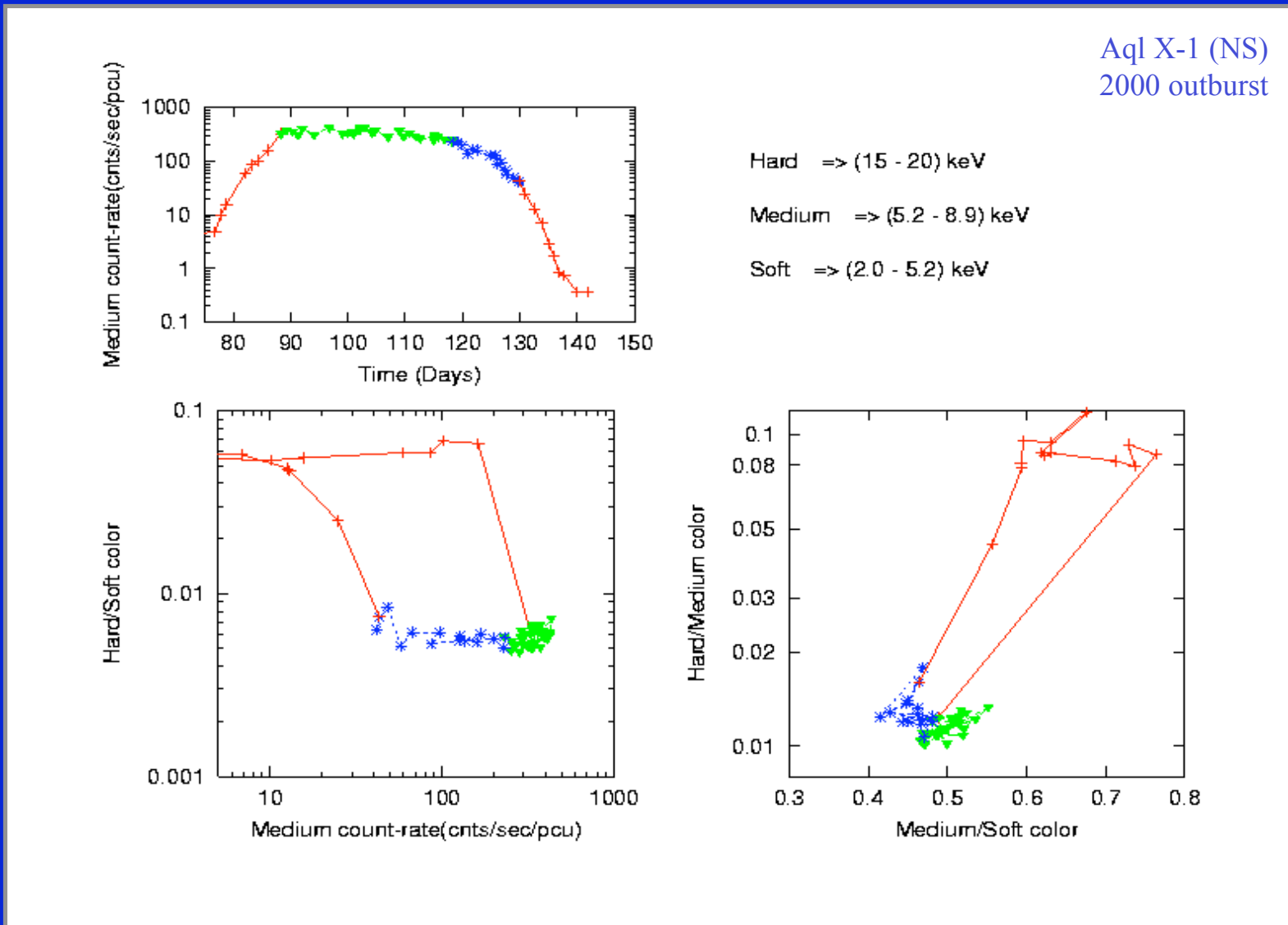
Assuming  
ejection  
starts during  
X-ray flare  
 $\Rightarrow \Gamma > 10!!$

Oops...

Isn't  
this a  
*neutron  
star??*



# “Hysteresis” in Aql X-1 2000 outburst – 2<sup>nd</sup> parameter for state transition?



Maitra et al. 2003

# XTE J1550: Black Hole

Hysteresis too!

Rodriguez et al. 2004

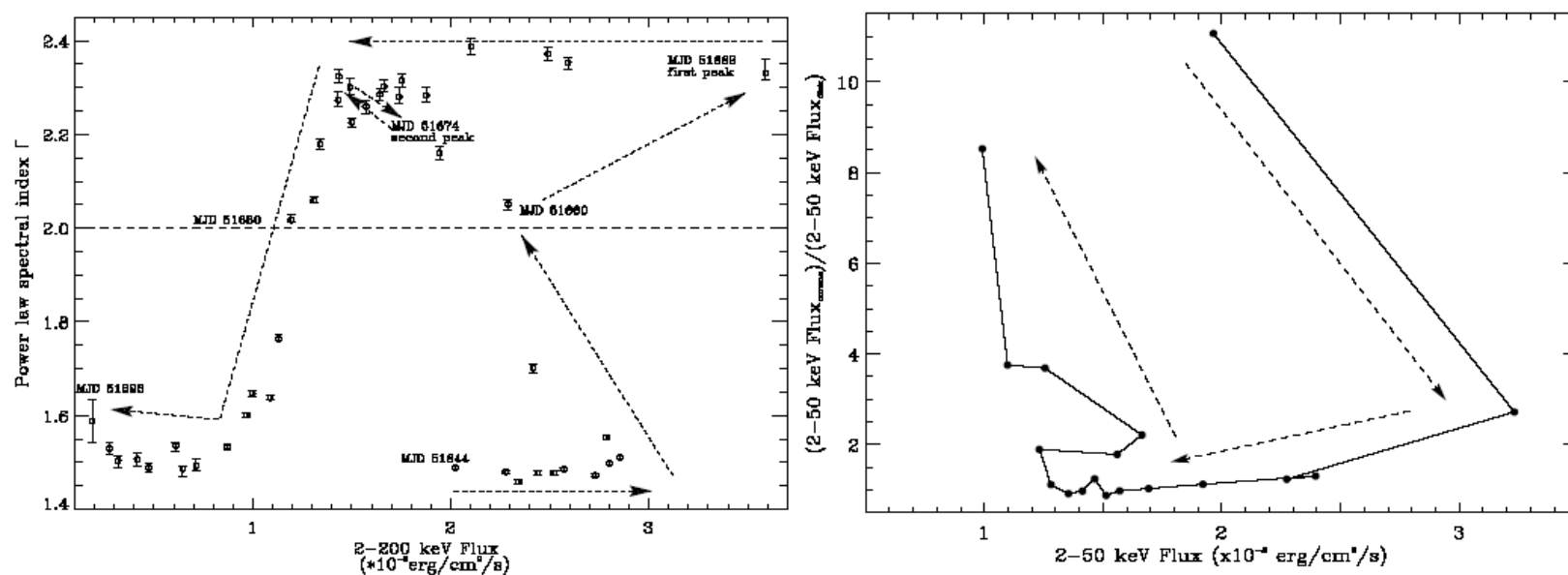
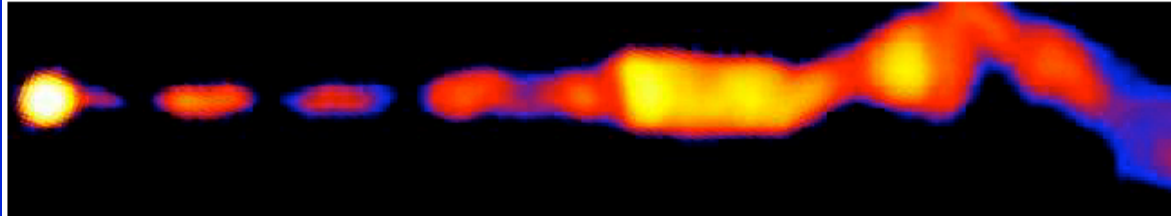


FIG. 3.— **Left** : Evolution of the power law photon index  $\Gamma$  vs. the 2-200 keV flux for the whole period of outburst. The hysteresis discussed in the text is clearly visible on this figure. The horizontal line separates the two states, and the arrows indicate the chronology of the events. Some dates, showing special events, have been reported. **Right** : Ratio of the fluxes of the powerlaw component (corona) to the multi-color disk component versus the source flux. The errors are left unplotted for the sake of clarity. This plot allows for a direct comparison with the neutron star system Aql X-1 (Maccarone & Coppi 2003). The arrows indicate the chronology of the outburst.

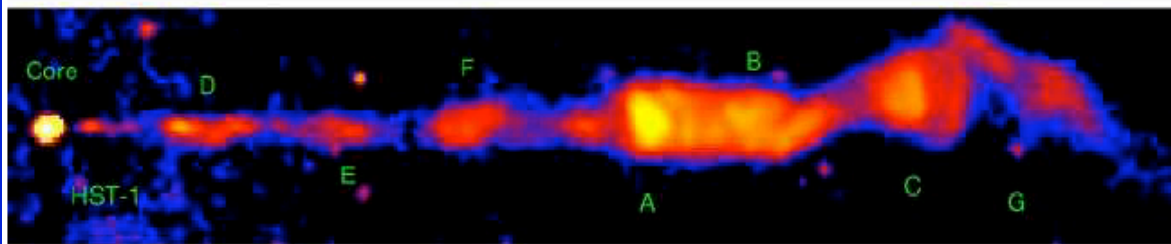
## M87 – FRI (a weak jet)

Radio

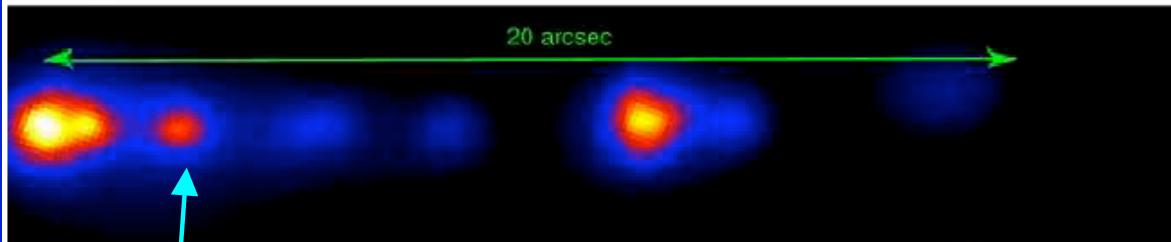


Mostly synchrotron emission?

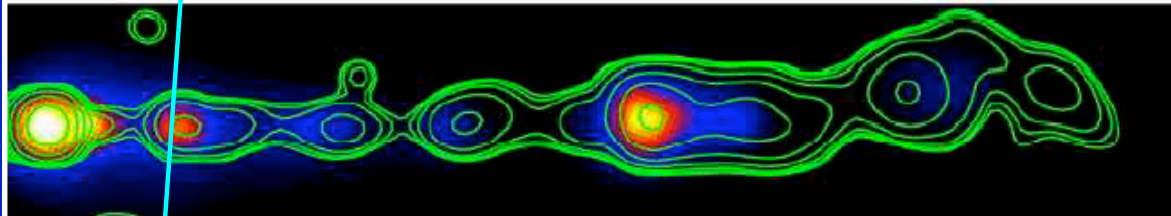
Optical



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!

Kaaret et al. 2003

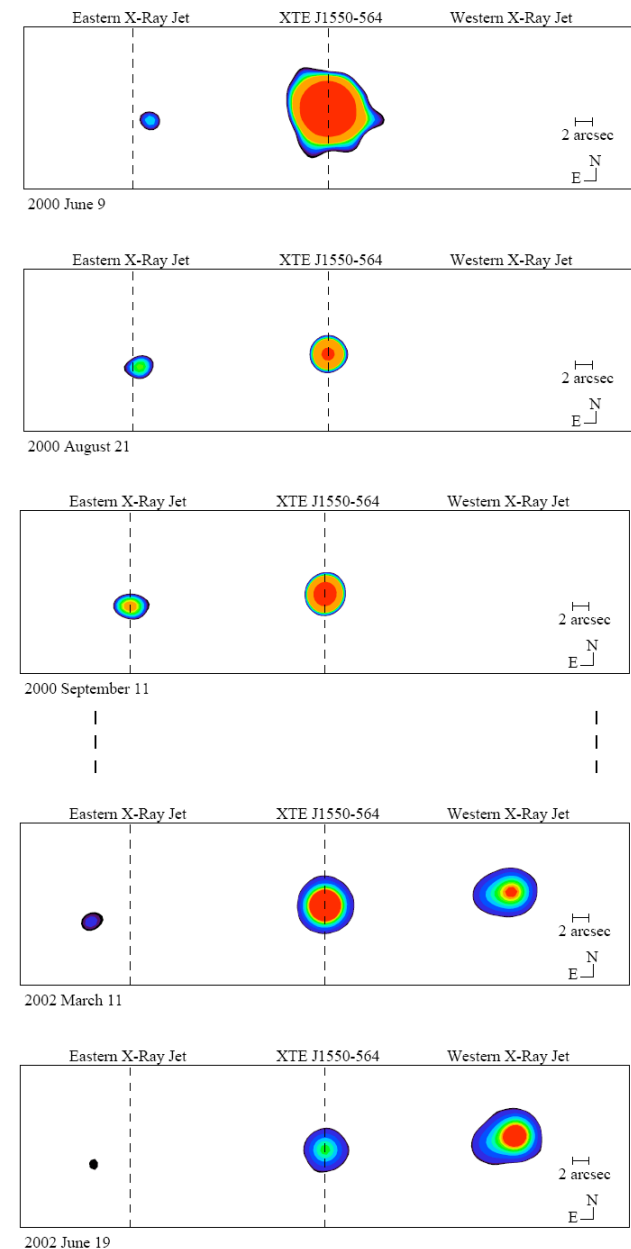
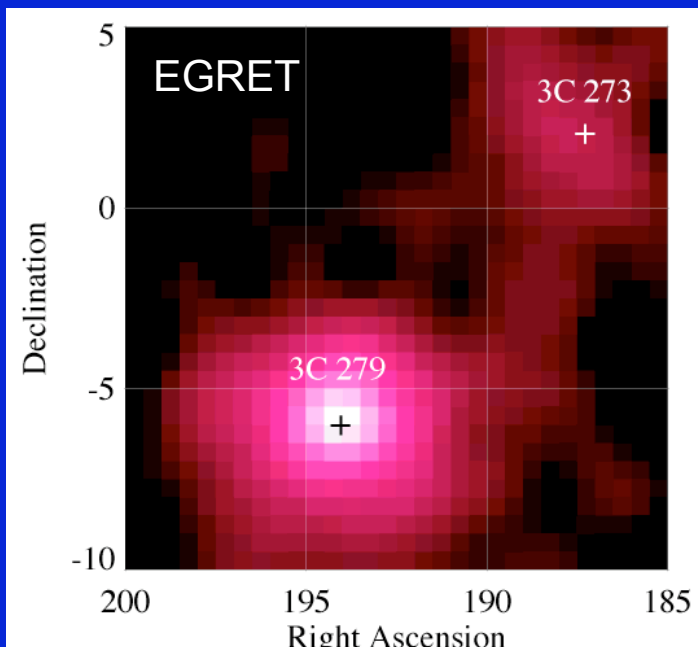
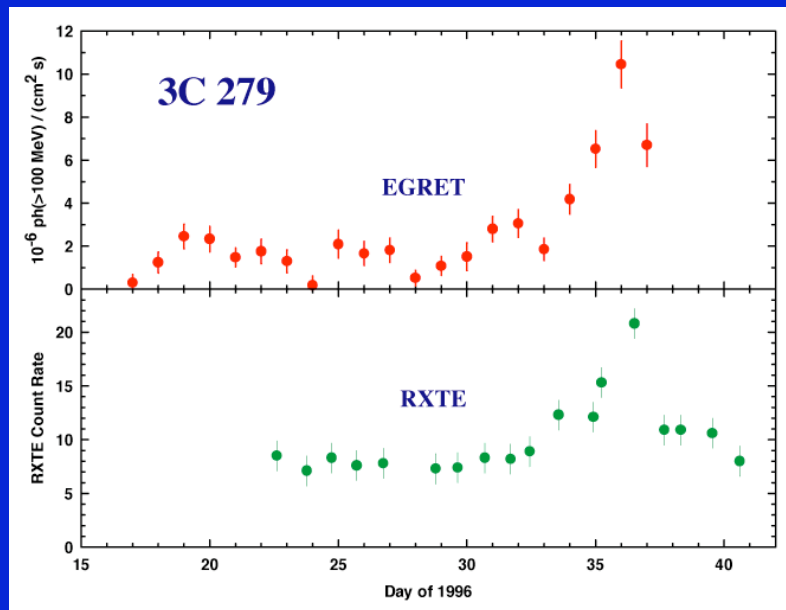


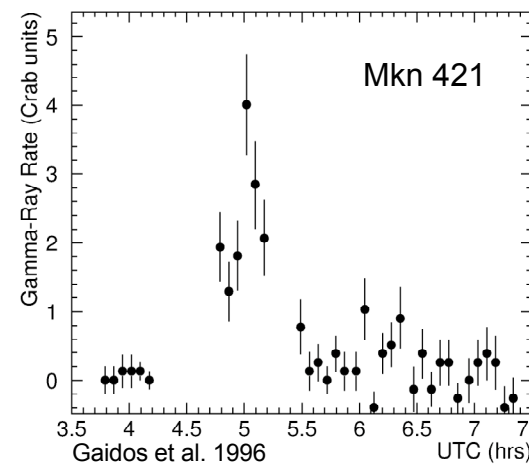
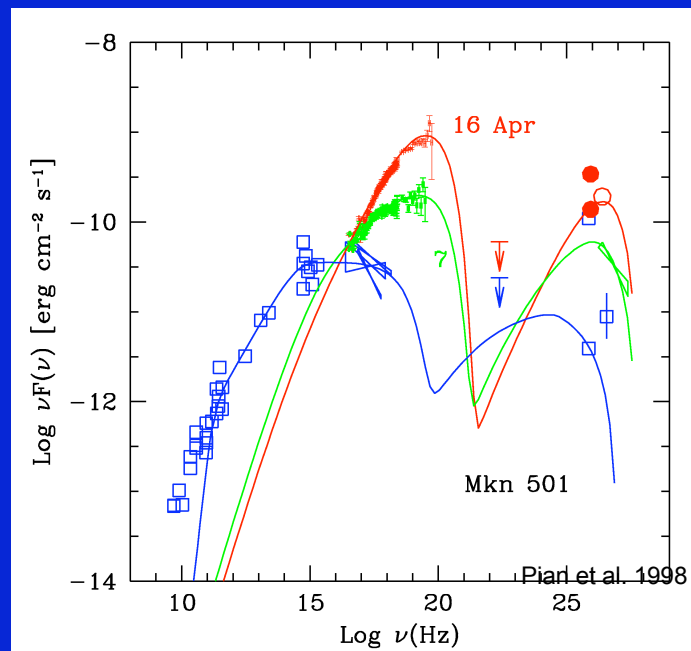
Figure 5. X-ray emission from large-scale jets produced during an outburst of the black hole transient XTE J1550564. Adapted from Corbel et al. (2002). Under minimum energy conditions, the leptons radiating in the soft X-ray band should have TeV energies.



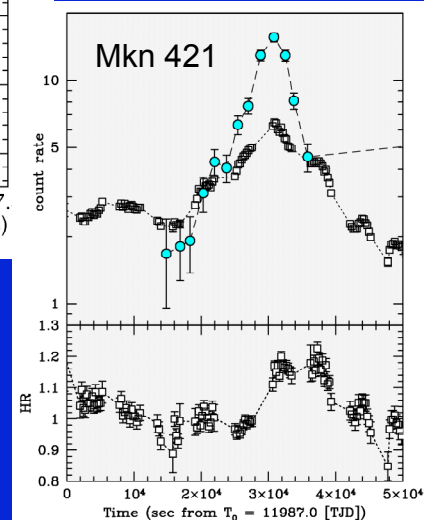
## GeV Blazars...



## TeV Blazars...

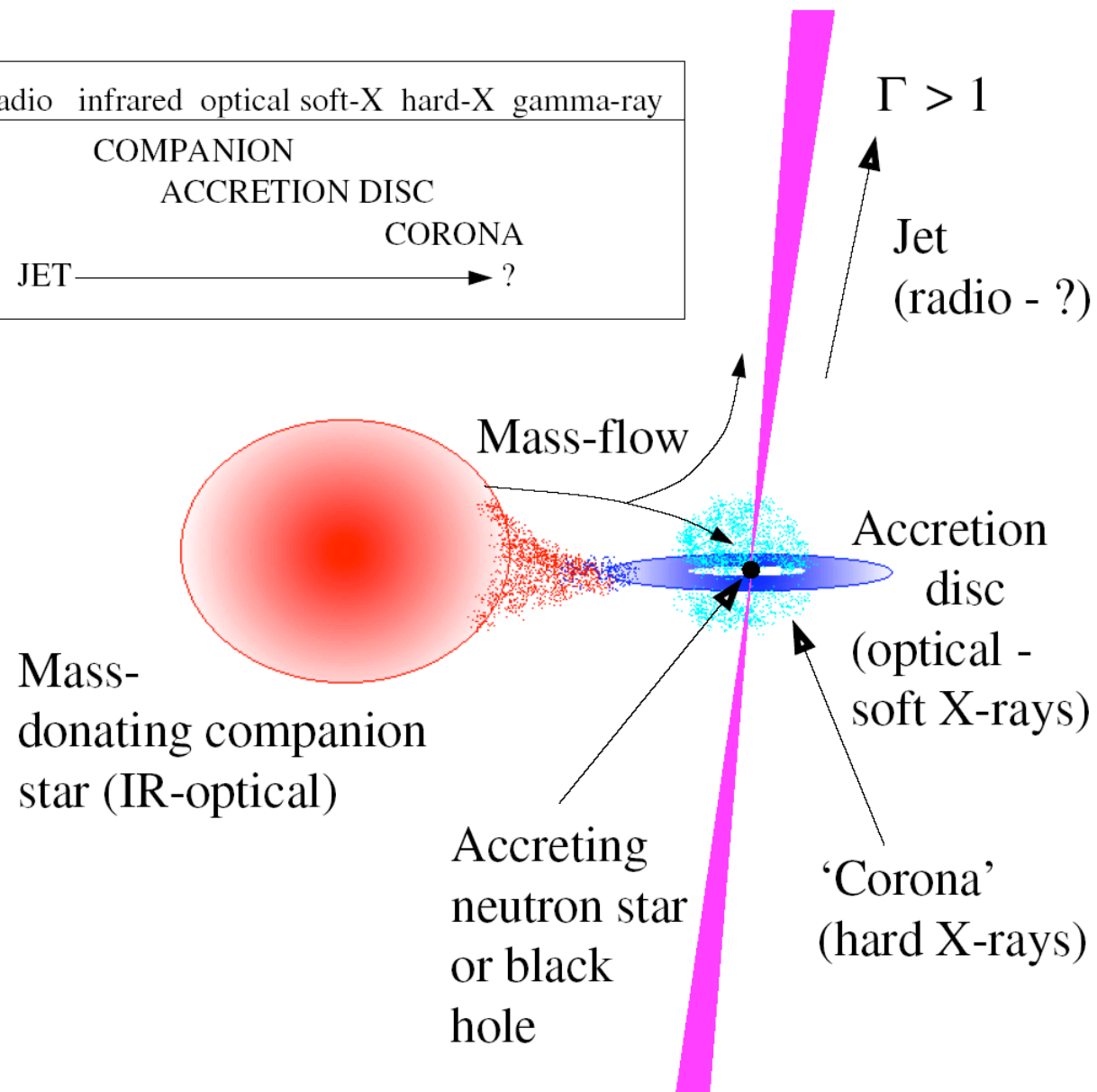


Fossati et al. 2002

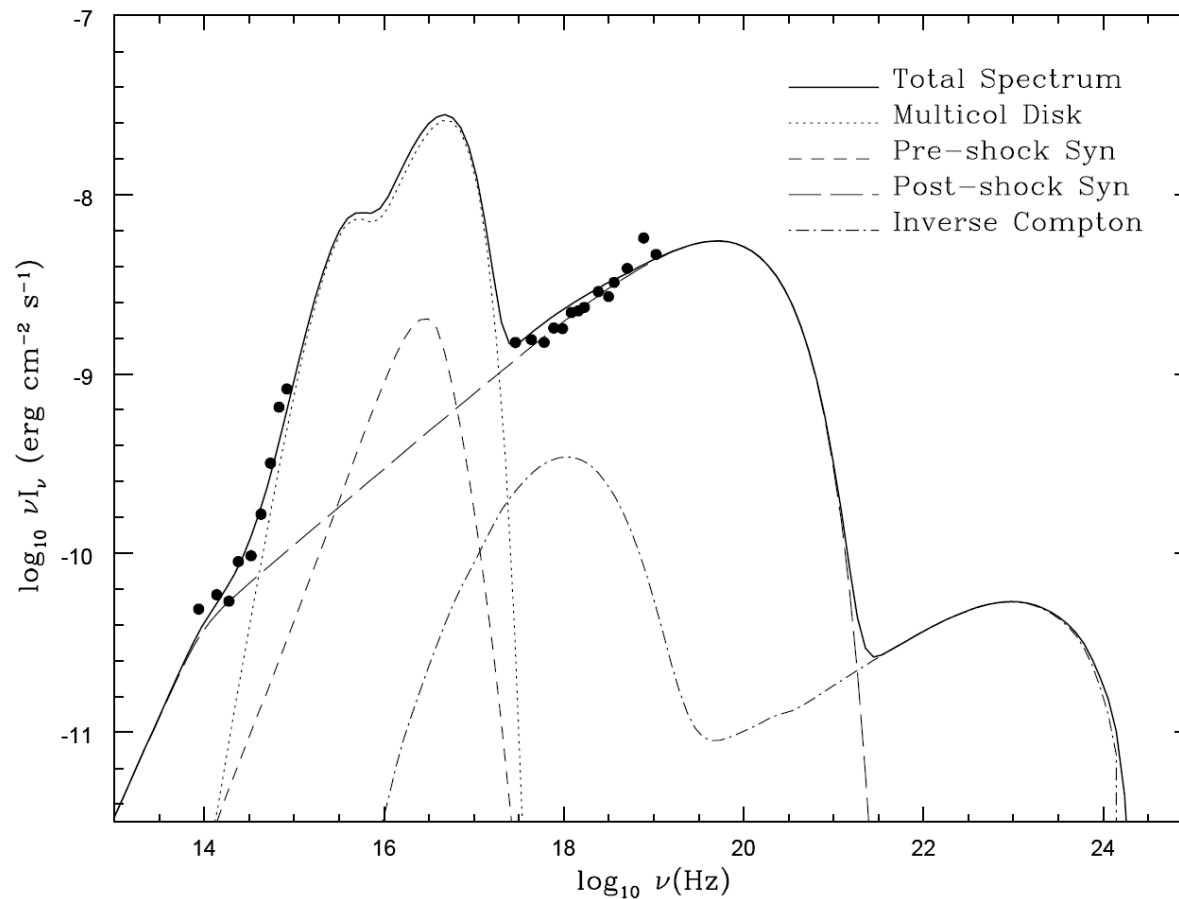


Rapid spectral variability!

radio	infrared	optical	soft-X	hard-X	gamma-ray
		COMPANION			
		ACCRETION DISC			
			CORONA		
JET					?



# 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.

Or it's there, but not so easy to see...

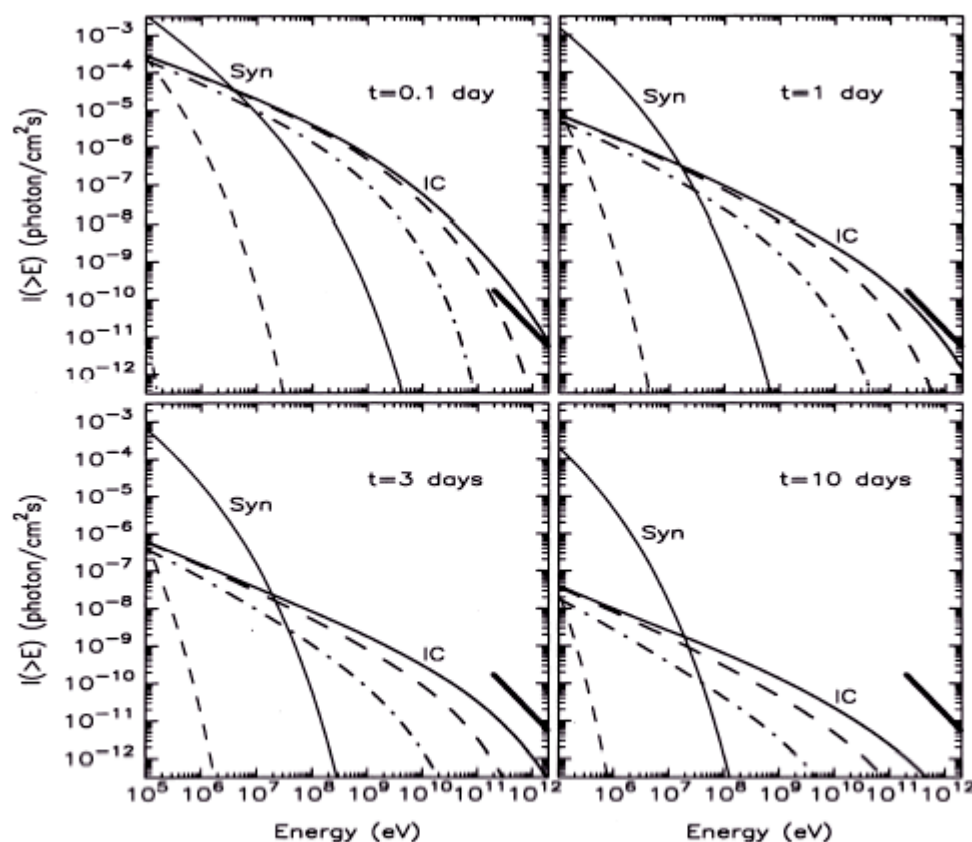
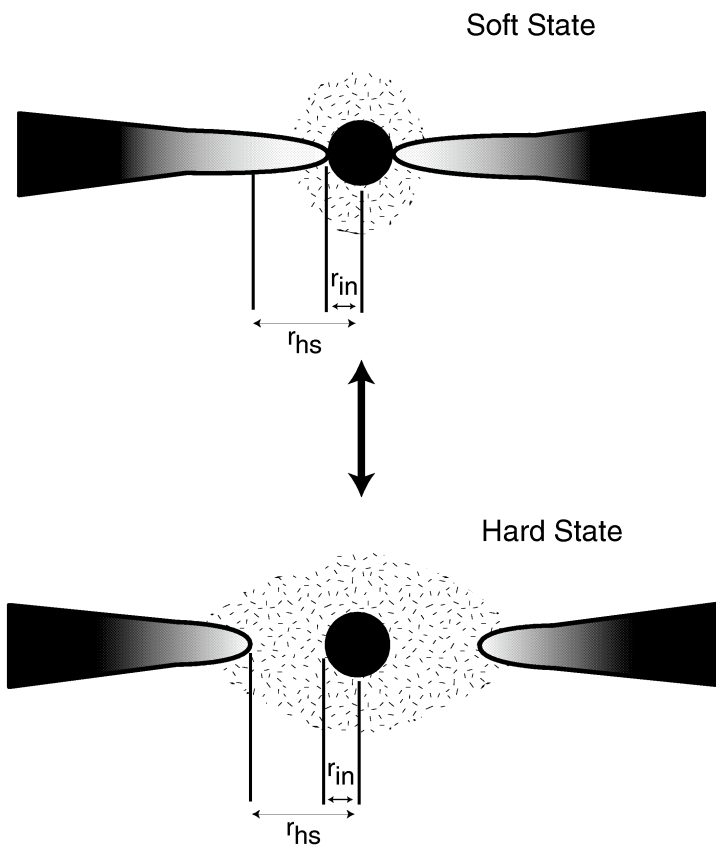


Fig. 1. Gamma ray fluxes (synchrotron – thin lines, and IC – heavy lines) expected at different stages of radio flare of GRS 1915+105 similar to March/April 1994 event, calculated for 3 different values of  $E_c$ : 20 TeV (solid), 1 TeV (dashed), and 50 GeV (dot-dashed). The level of the VHE  $\gamma$ -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

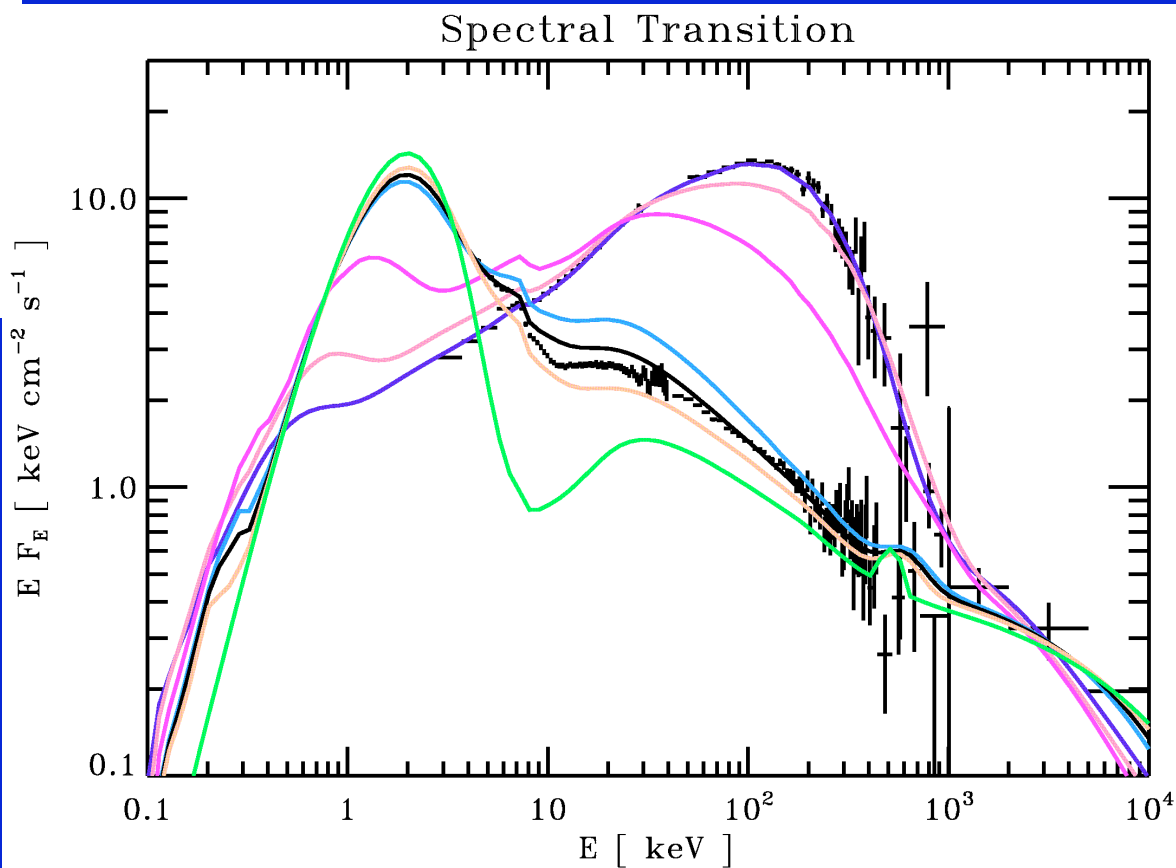


## Cyg X-1 Model

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



# The High Energy Tail?

Cyg X-1 “Low,” Hard State  
McConnell et al. 2002

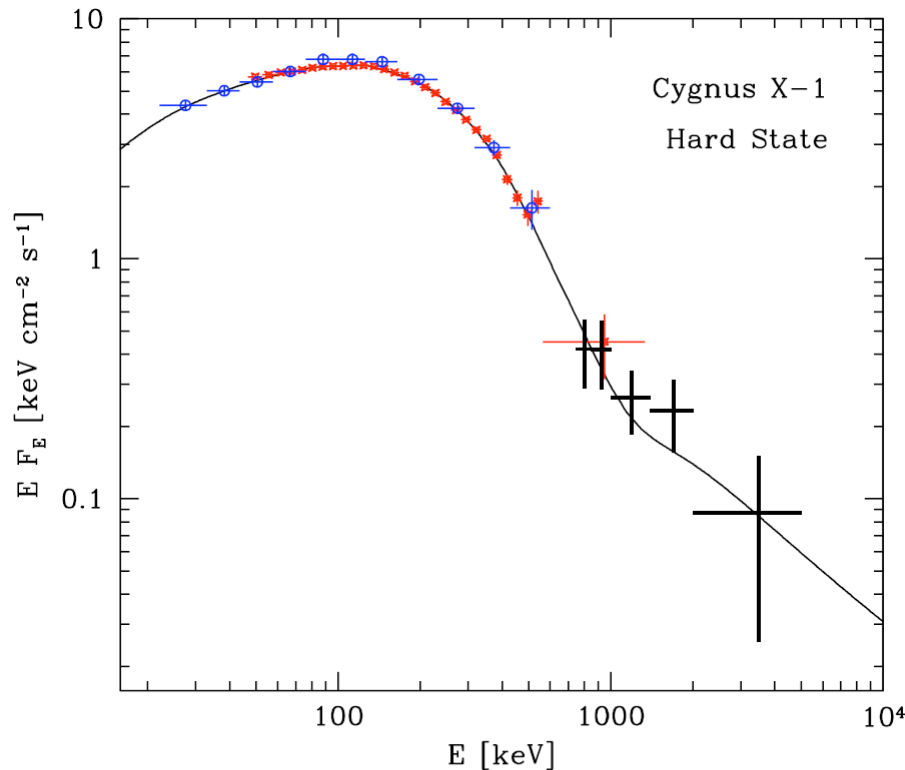


Fig. 5.— The average *CGRO* spectrum of Cygnus X-1 in the hard state fitted with the *eqpair* model (solid curve). Data points from BATSE and OSSE are represented as blue open circles and red asterisks, respectively. COMPTEL data are shown as thick crosses. All the data are normalized to that of OSSE. Upper limits have been removed for the sake of clarity.

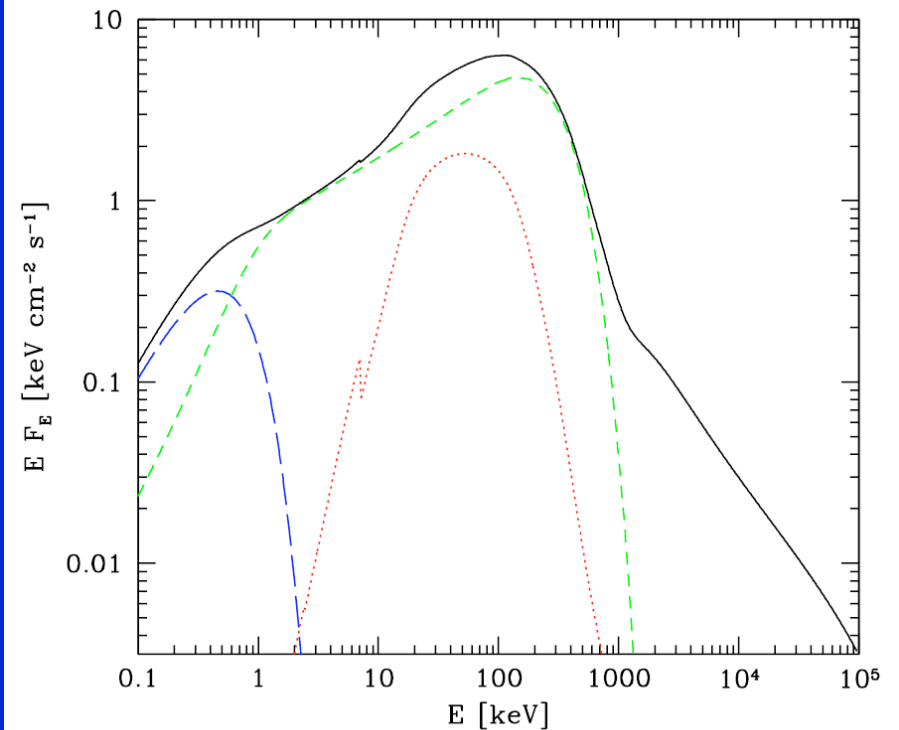


Fig. 6.— Components of the *eqpair* fit for the hard state. All spectra are intrinsic, i.e., corrected for absorption. The long dashes, short dashes, and dots correspond to the unscattered blackbody, scattering by thermal electrons, and Compton reflection, respectively. The solid curve is the total spectrum. Scattering by the nonthermal electrons accounts for the high-energy tail above the thermal-Compton spectrum given by the short dashes starting at  $\sim 1$  MeV.

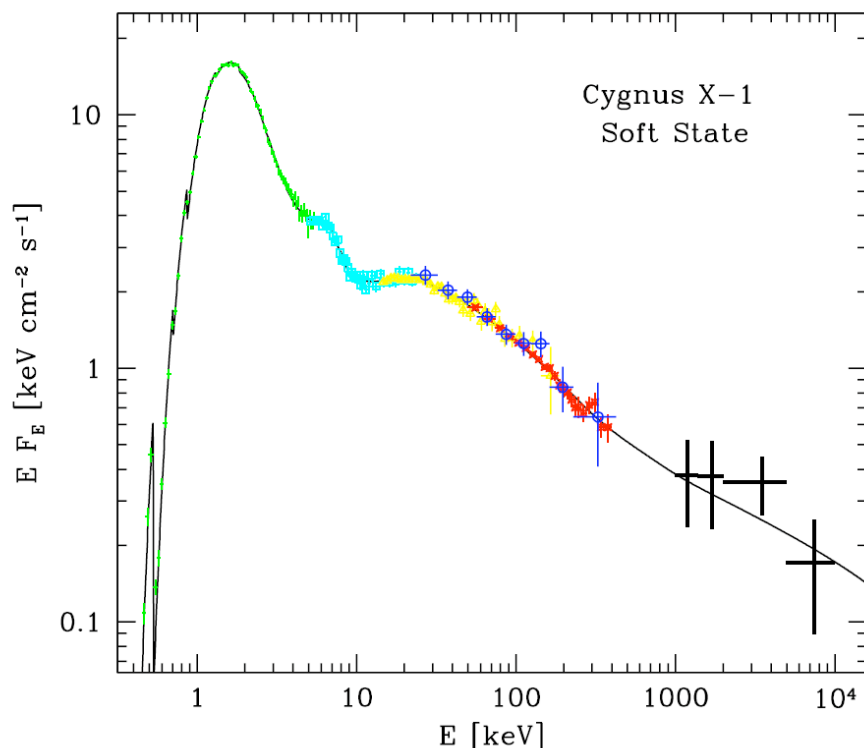


Fig. 7.— The simultaneous *BeppoSAX*-*CGRO* spectrum of Cygnus X-1 in the soft state fitted with the *eqpair* model (solid curve). Included are data from the LECS (green), HPGSPC (cyan open squares) and PDS (yellow open triangles) instruments on board *BeppoSAX* and from the OSSE (red asterisks), BATSE (blue open circles) and COMPTEL instruments on *CGRO*. All the data are normalized to that of OSSE.

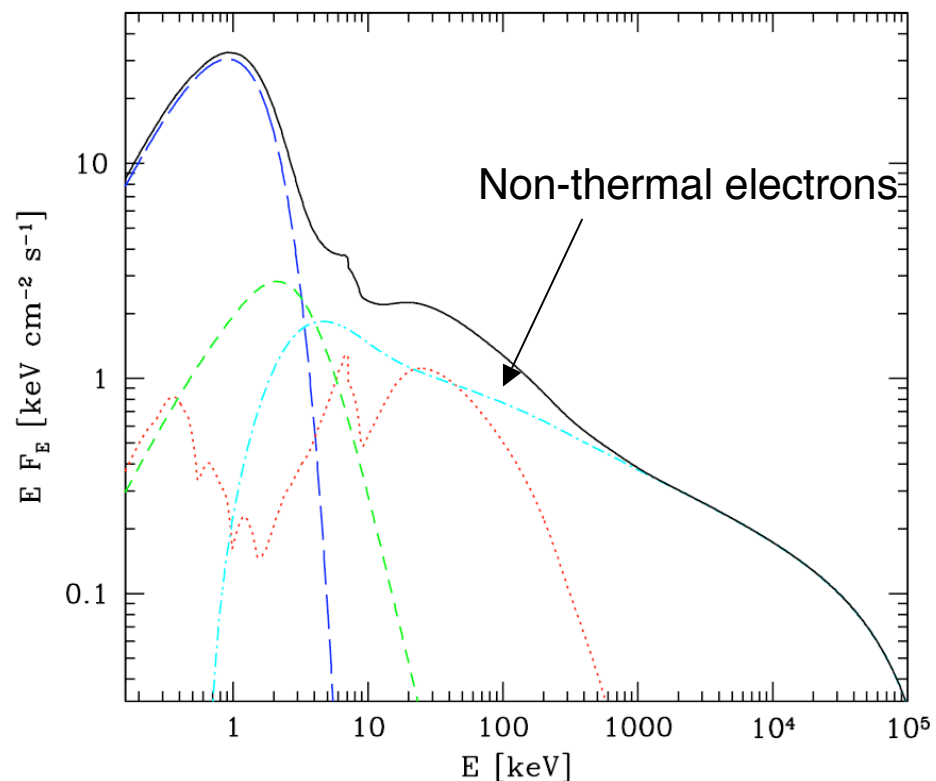
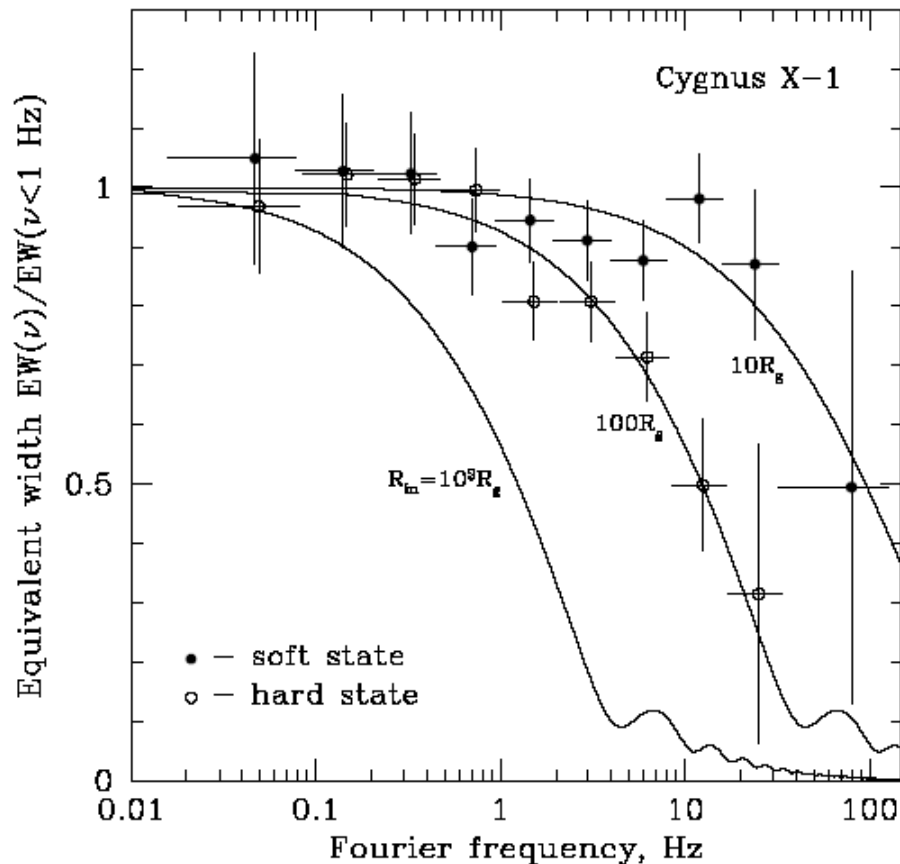


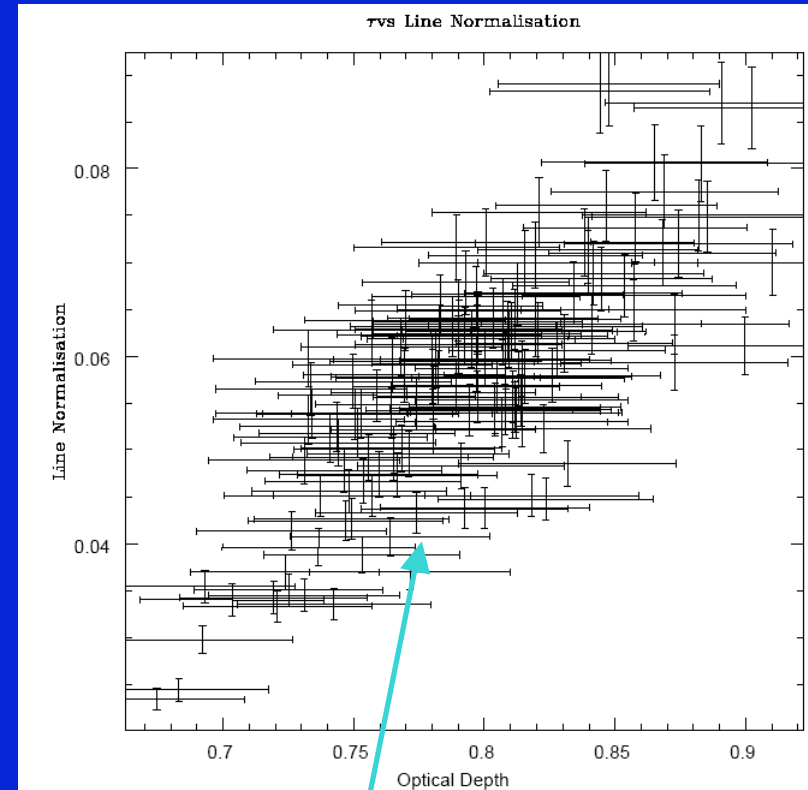
Fig. 8.— Components of the *eqpair* fit for the soft state. All spectra are intrinsic, i.e., corrected for absorption. The long dashes, short dashes, dot/dashes and dots correspond to the unscattered blackbody, scattering by thermal electrons, the scattering by nonthermal electrons, and Compton reflection/Fe K $\alpha$  fluorescence, respectively. The solid curve is the total spectrum.

# “Fourier Resolved Spectroscopy” (Gilfanov et al 2000)

[Iron line reverberation]



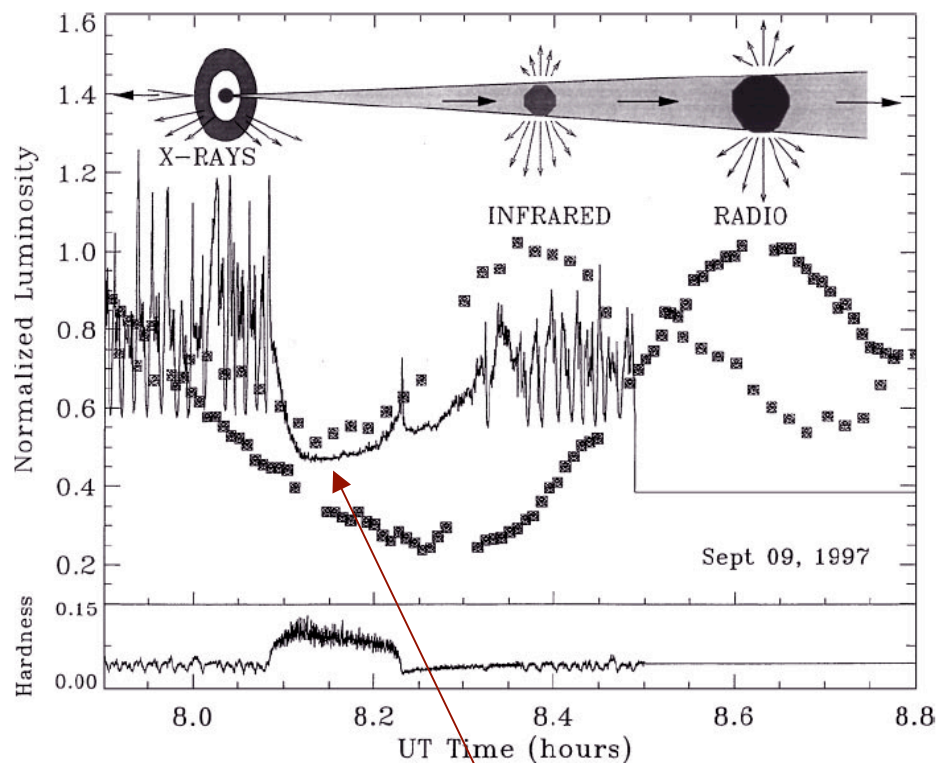
**Figure 6.** Equivalent width of the Fe fluorescent line vs. Fourier frequency. Comparison of the data with the model. The data points are the same as in Fig.3. The model curves were calculated for an isotropic point source at height  $h = 10R_g$  on the axis of a flat disk with inner radius of 10, 100 and  $1000R_g$  (assuming a  $10M_\odot$  black hole) and with inclination angle of  $50^\circ$ .



Time Domain Version  
(Maccarone & Coppi 2002)

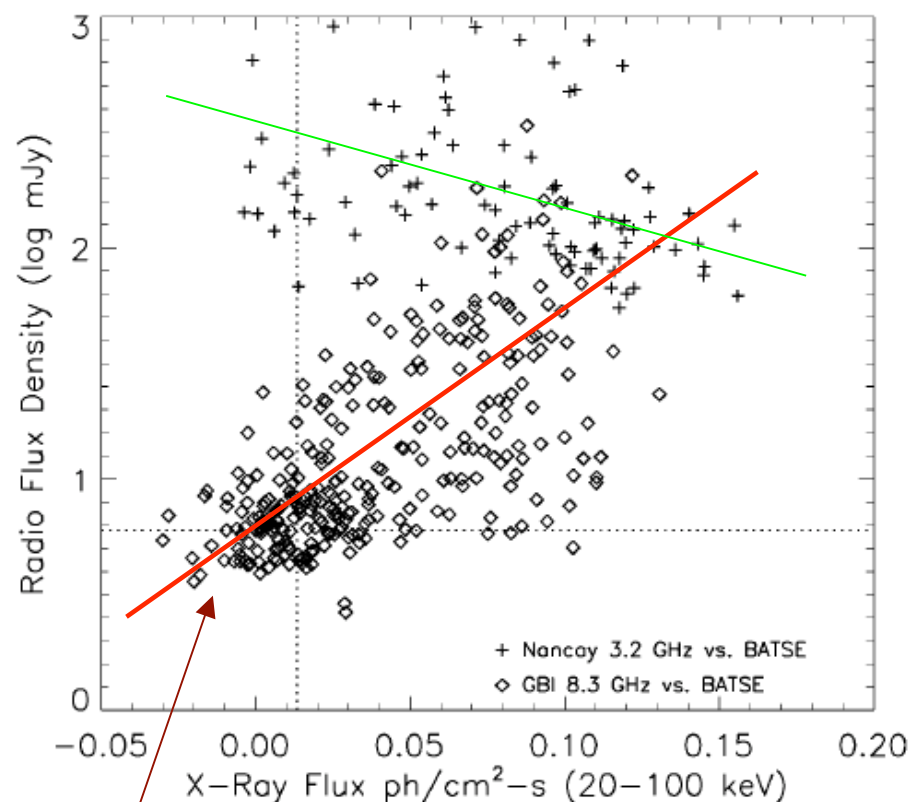


# So is there any jet emission at X/gamma energies? GRS 1915+105?



**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  $(13\text{--}60\text{ keV})/(2\text{--}13\text{ keV})$  is shown at the bottom of the figure.

Mirabel and Rodriguez 1999



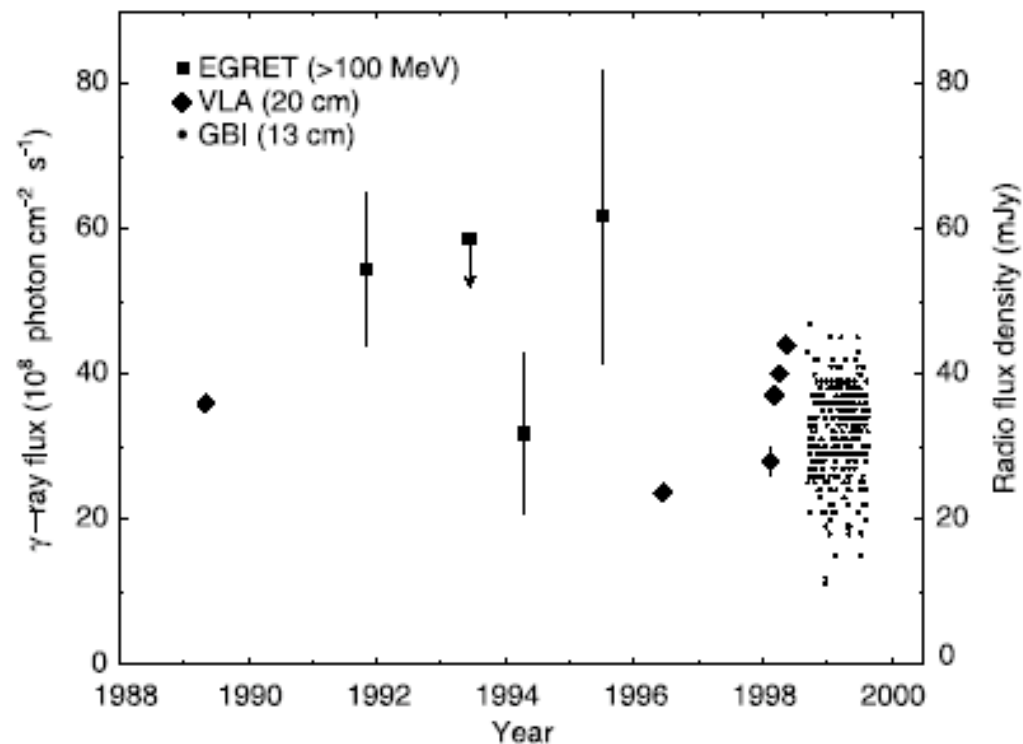
**FIG. 3.**—Nançay 3.2 GHz data from 1993 December to 1994 April and GBI 8.3 GHz data from 1994 May to 1996 March plotted vs. the BATSE 20–100 keV flux. The GBI 2.25 GHz data (not plotted) show a very similar correlation with the X-ray band. Dotted lines indicate reasonable detection thresholds ( $1\sigma$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

Harmon et al. 1997

X-rays go away during ejection, but ...

# EGRET detection of microquasar?

Fig. 3. Radio and  $\gamma$ -ray light curves of LS 5039 and 3EG J1824-1514, which we propose originate in the same object. Both LS 5039 and 3EG J1824-1514 are consistent with a persistent level of emission over the last decade. The fluxes plotted here are taken from the literature and archive data (3, 4, 19, 21). Error bars for GBI ( $\pm 4$  mJy) are not shown for clarity, whereas those of the VLA are usually smaller than the symbol size.



Paredes et al. 2000

Maybe...



# The X-ray/Radio correlation ...

GX339 - Corbel et al. 2004

AGN !? - Maccarone et al. 2003

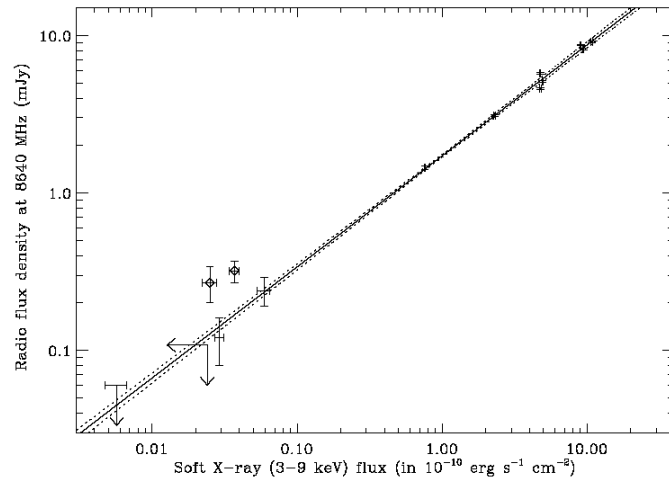


Fig. 1. The radio flux density at 8.6 GHz is plotted versus the X-ray flux in the 3-9 keV energy band. The continuous line denotes the fit to the data with the function described in the body of the paper and with the parameters estimated in Table 3, the dotted line represents the one-sigma deviation 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).

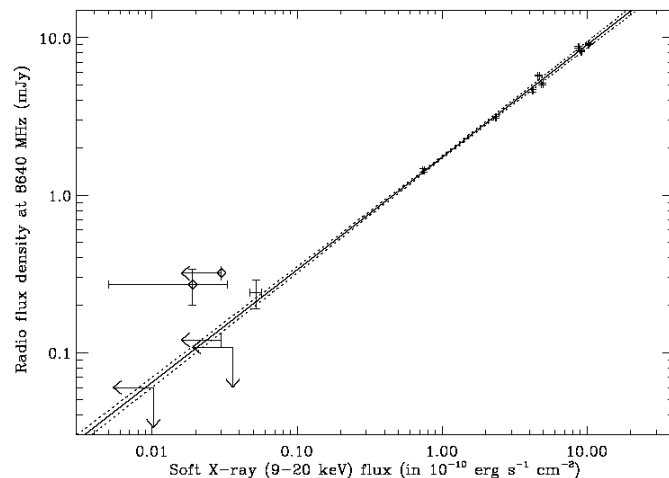


Fig. 2. Same as Fig. 1, but for the X-ray flux in the 9-20 keV energy band.

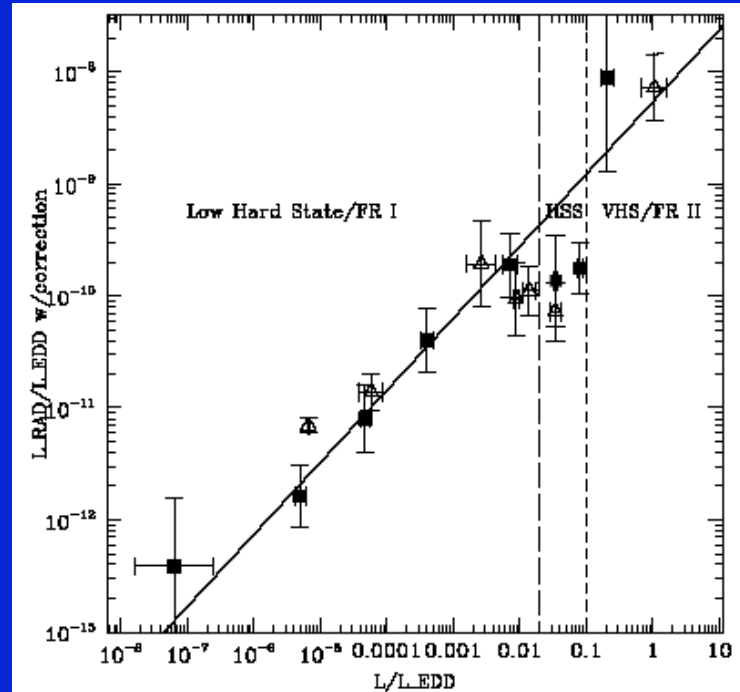


Figure 2. The same as Fig. 1b, with the X-ray binaries included. The open triangles represent the X-ray binaries. The long-dashed vertical line indicates the transition luminosity between the high/soft state (HSS) and the low/hard state as measured in Maccarone (2003) and also is very close to the transition 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.

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

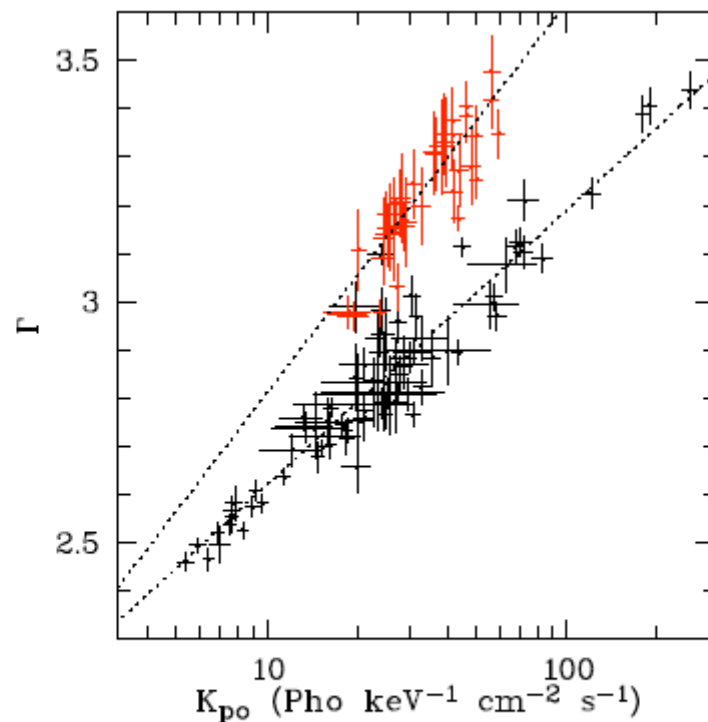


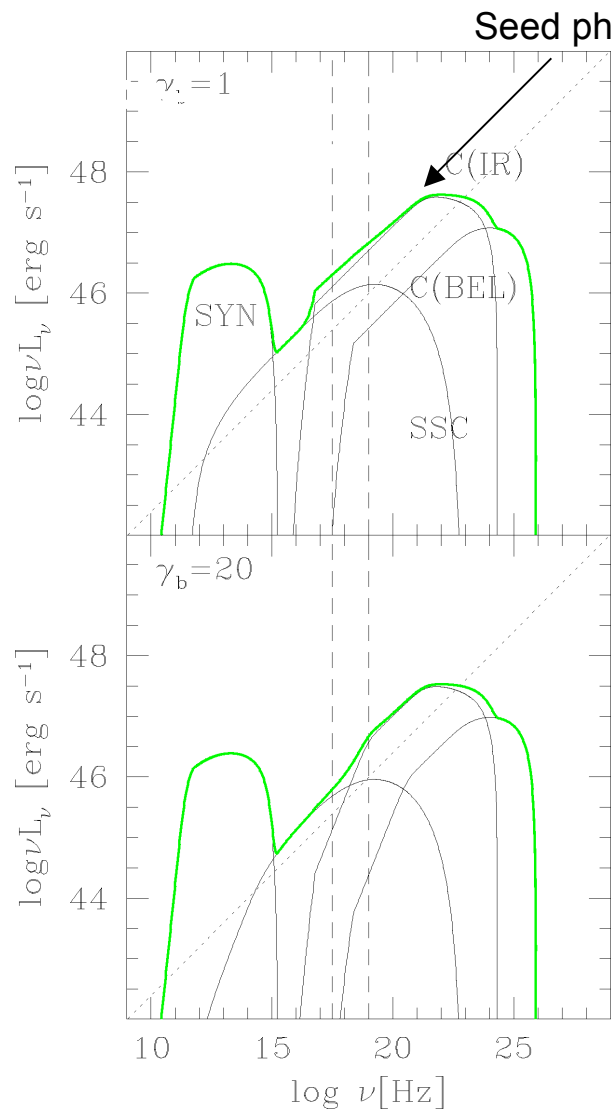
Figure 1. Power law slope,  $\Gamma$ , as a function of power law normalization,  $K_{po}$ . Each *RXTE* observation is represented by one data point. (dotted lines: correlation function)

GRS 1915, Rau & Greiner 2002

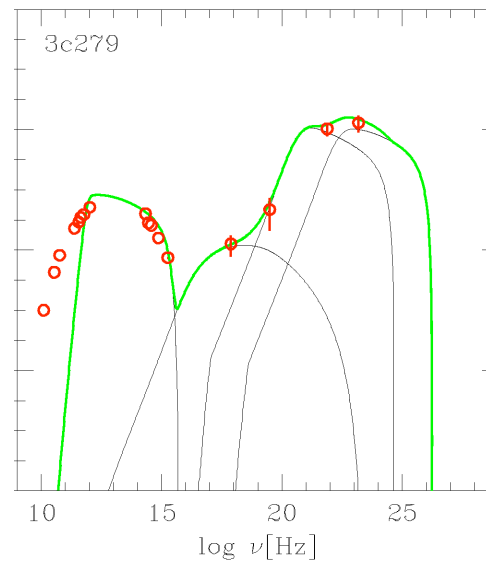
Jet and corona know each other!

Which photon field(s) does jet interact with???

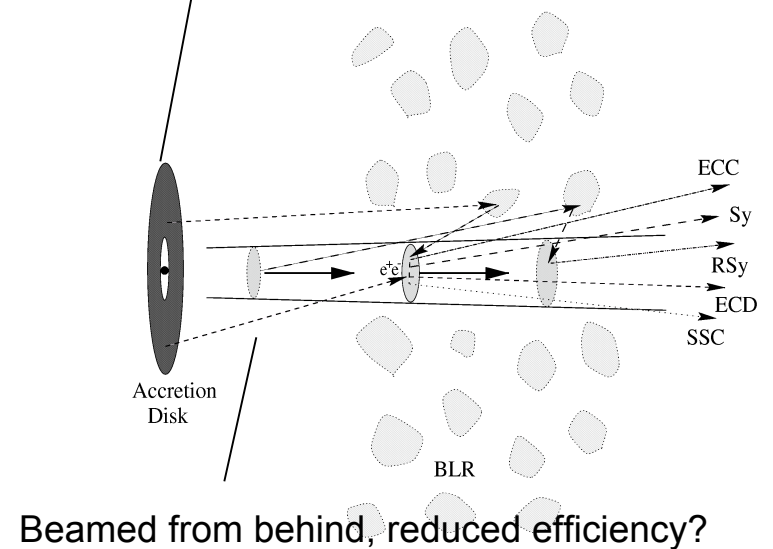
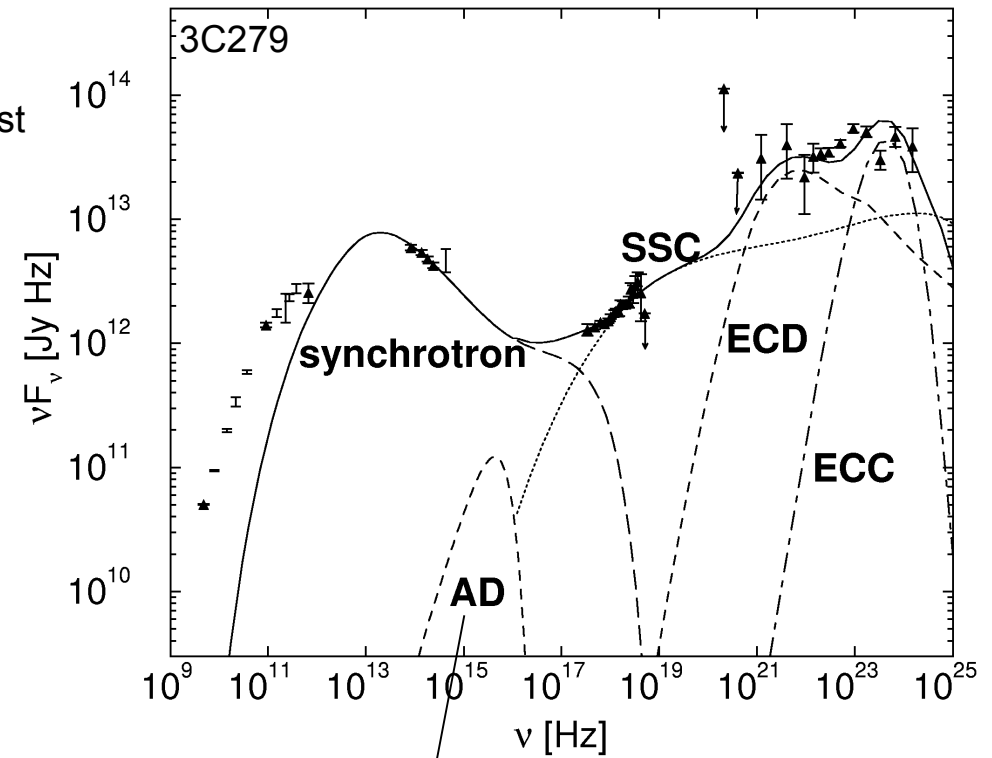
Boettcher et al. 2001



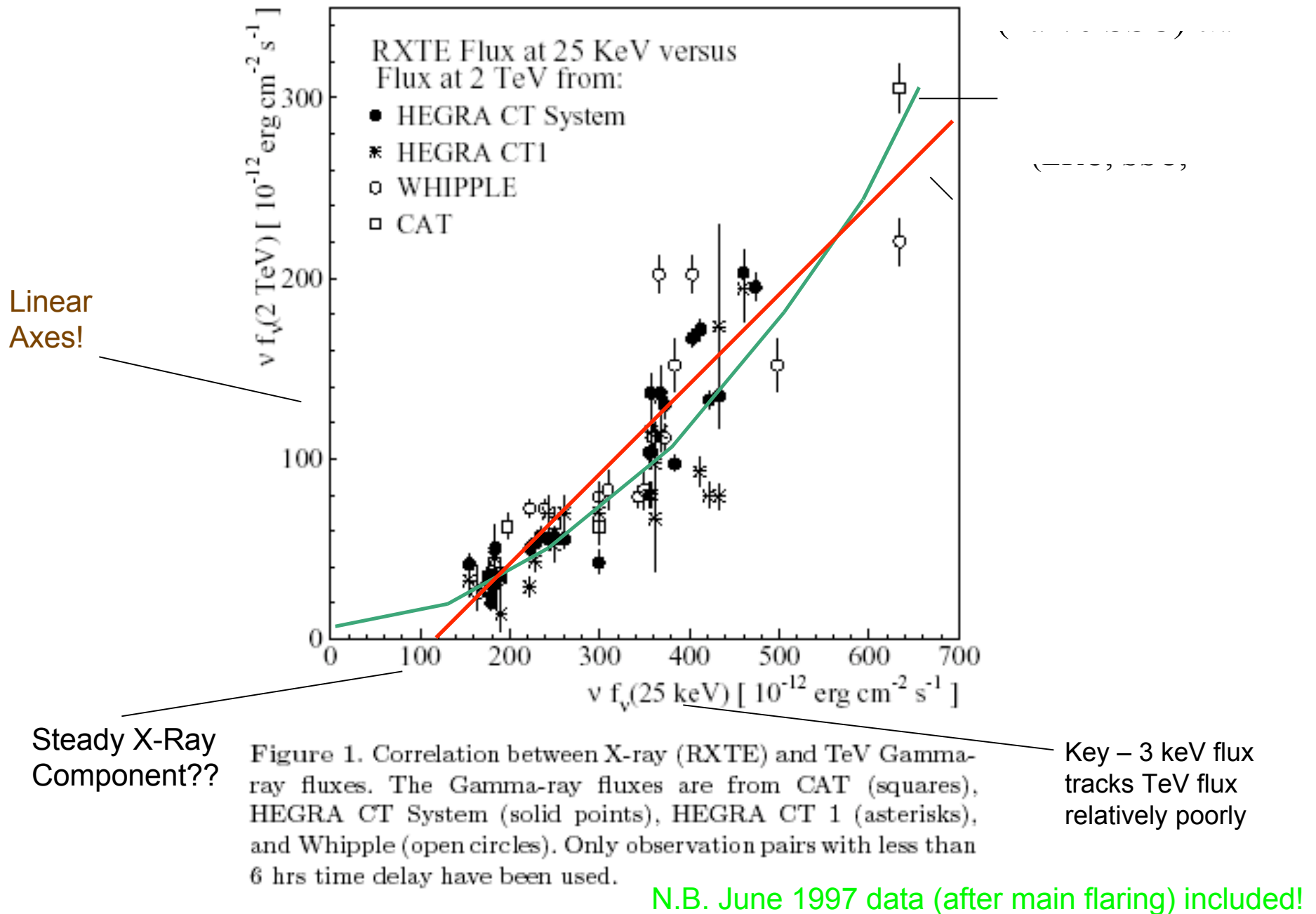
Blazejowski et al. 2000



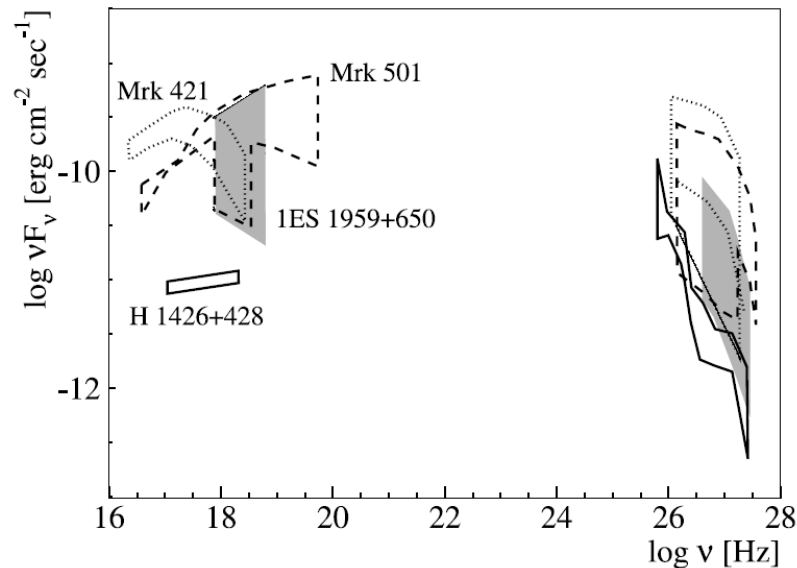
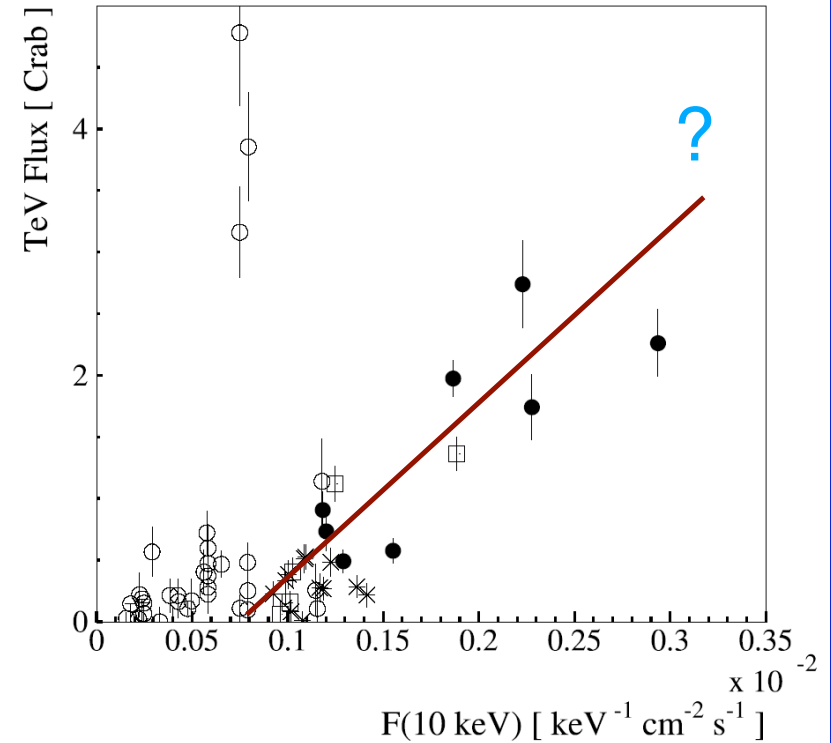
vs.



## Multiple X-Ray Emission Components in the TeV Blazar Mrk 501?



Interesting fact: **estimated black hole mass for 1959 is 1/10<sup>th</sup> mass for Mkn 501**  
 -- yet many things, including shortest variability timescales, appear very similar ... ?



Krawczynski et al. 2003



# Polarization can disentangle components....

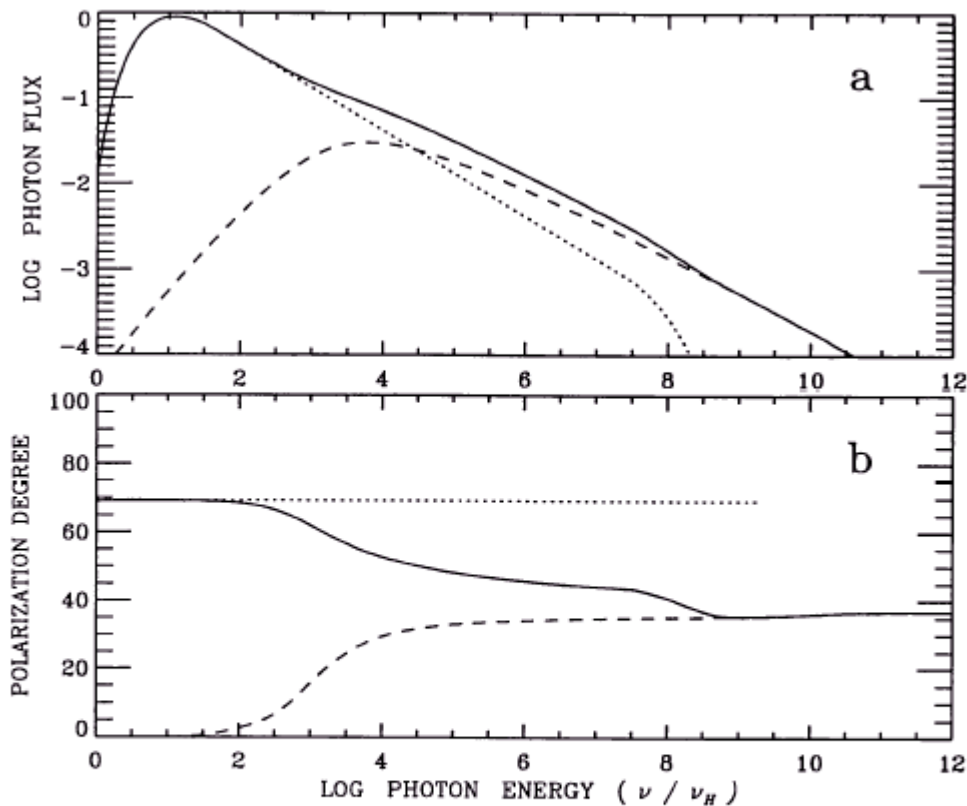


FIG. 1.—(a) Intensity and (b) polarization of synchrotron self-Compton radiation. *Dotted lines*—initial synchrotron radiation; *dashed lines*—inverse Compton scattered radiation; *solid lines*—intensity and polarization of the total radiation. Here  $\tau = 0.1$ ,  $\alpha = 0.5$ ,  $\sin \zeta = 1$ , and  $\gamma_{\min} = 10$ .

[ N.B. EC polarization may be very low if jet not cold, well-collimated...]

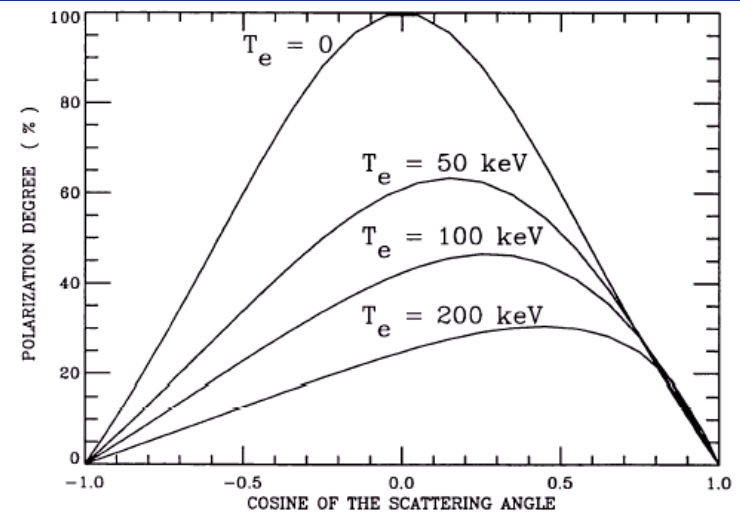


FIG. 2.—Polarization degree of radiation scattered by relativistic jet as a function of the cosine of the scattering angle.

Poutanen 1994

# 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.

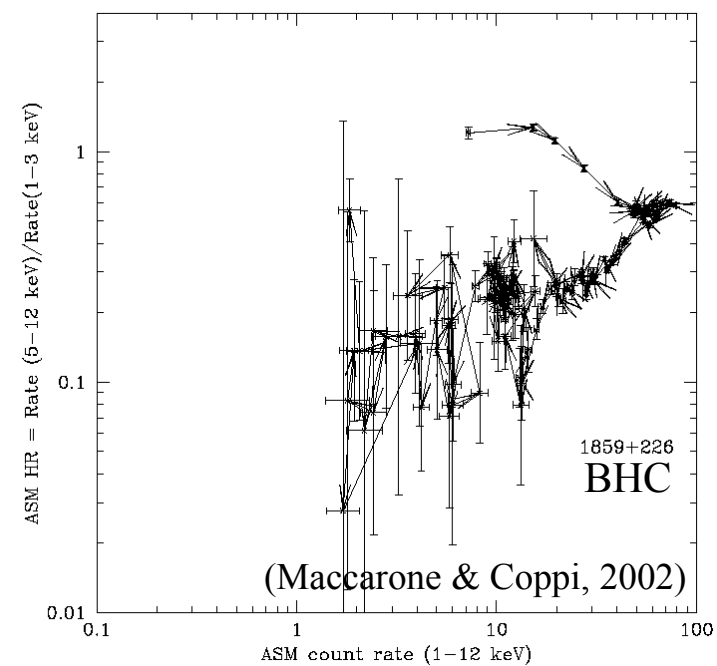
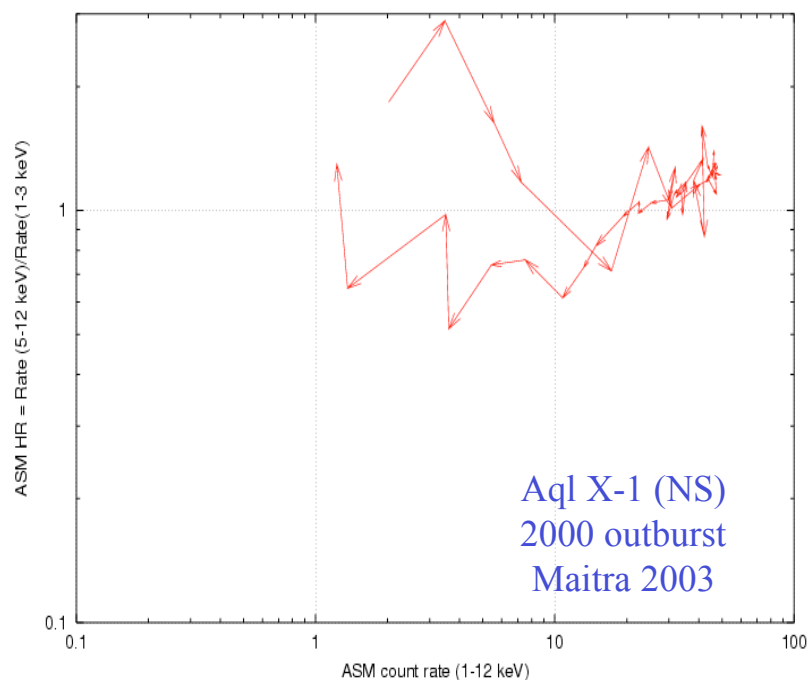
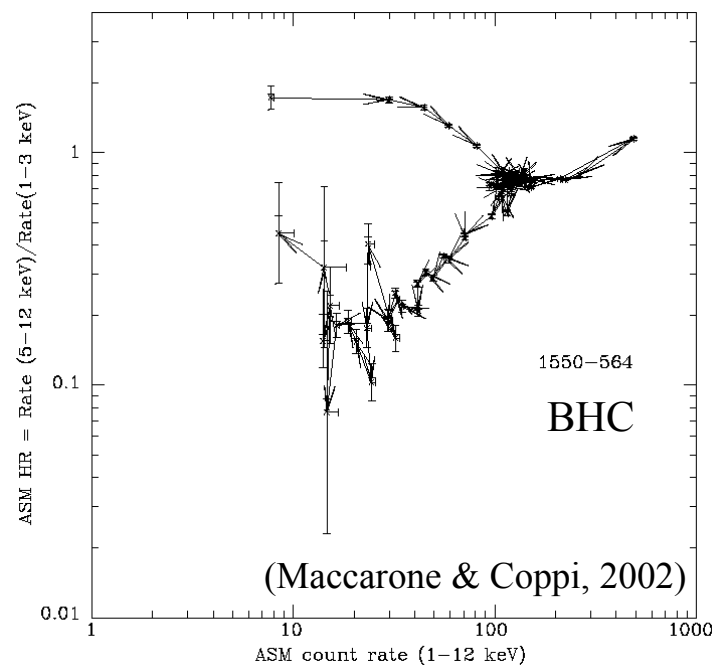
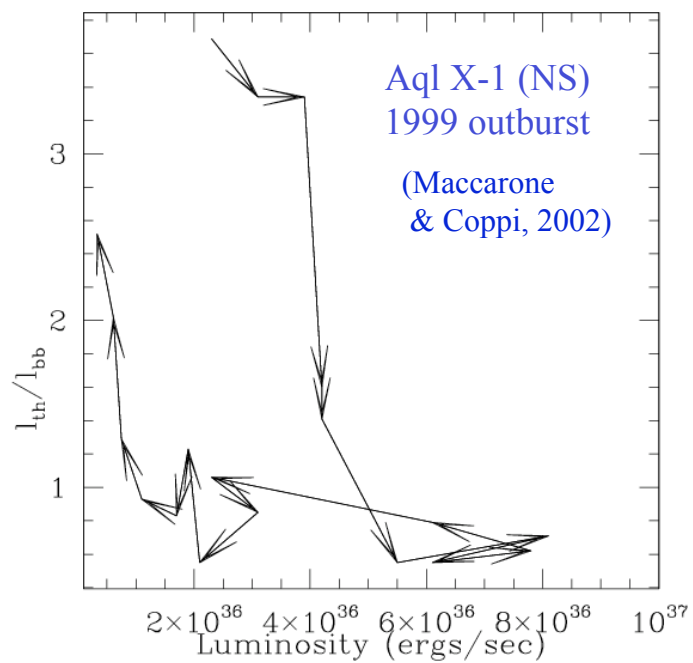
Neutron stars can show jets too! => Ultimately accretion disk phenomenon?

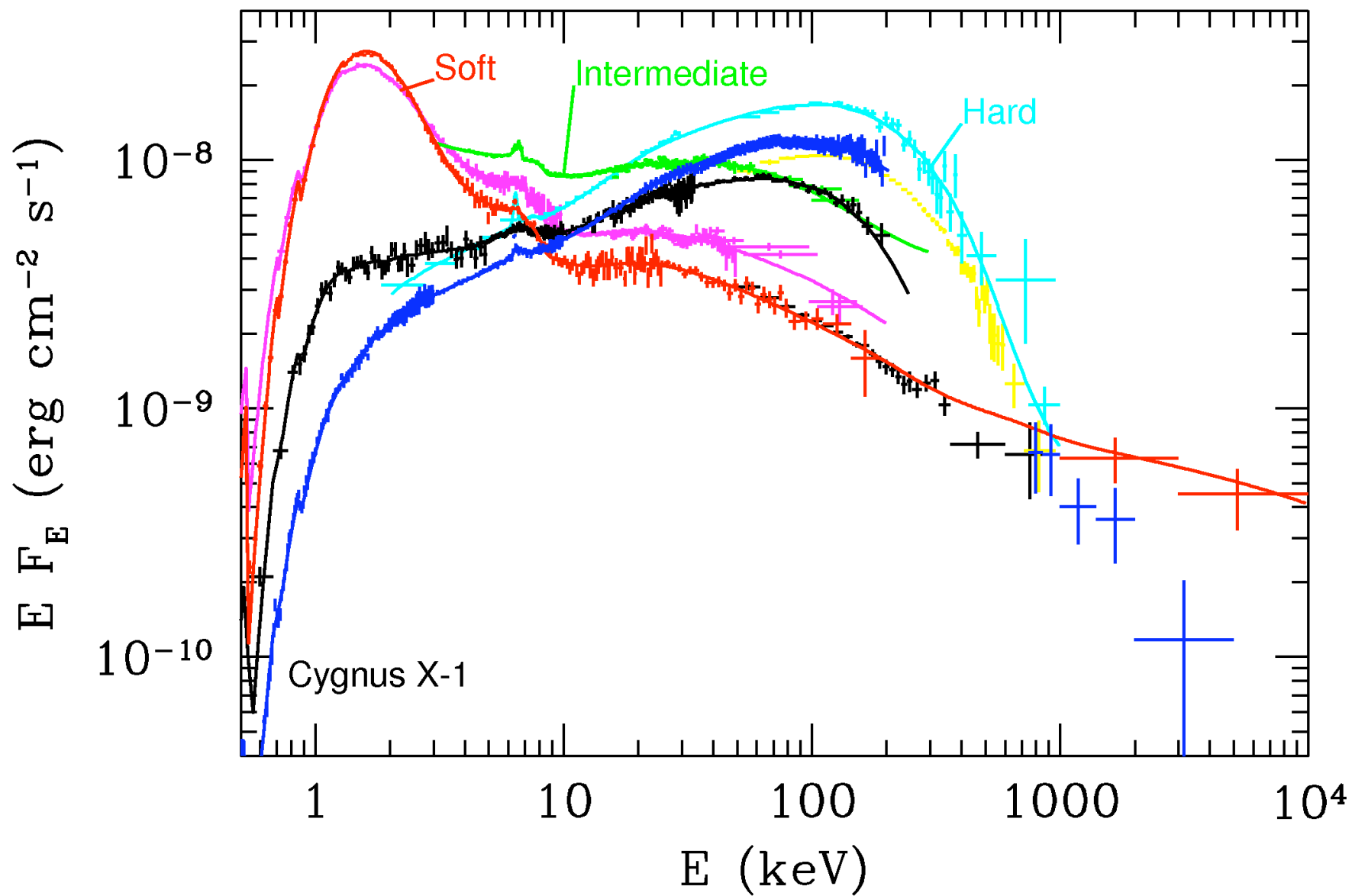
Disentangling accretion disk and jet emission currently a problem. X/gamma-ray emission NOT as obvious as in AGN. Typical observed emission is probably from disk or corona (standard interpretation). But clearly there exists jet/outflow – disk/corona correlation. Corona = “base of jet?” Polarization measurements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

First principles prediction of expected polarization signatures difficult! (Too many parameters, processes, *bad spatial resolution = confused emission components*.) Most useful polarization information may be the energy and *time dependence*, especially in microquasars where things vary quickly. Tells us when and where something is changing.

Advantages of X-ray polarimetry: probes innermost regions of jet/disk, highest energy particles; X-rays/gamma-rays not subject to most plasma/opacity (e.g., Faraday depolarization) effects that cause problems in radio.

Zdziarski 2002





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

