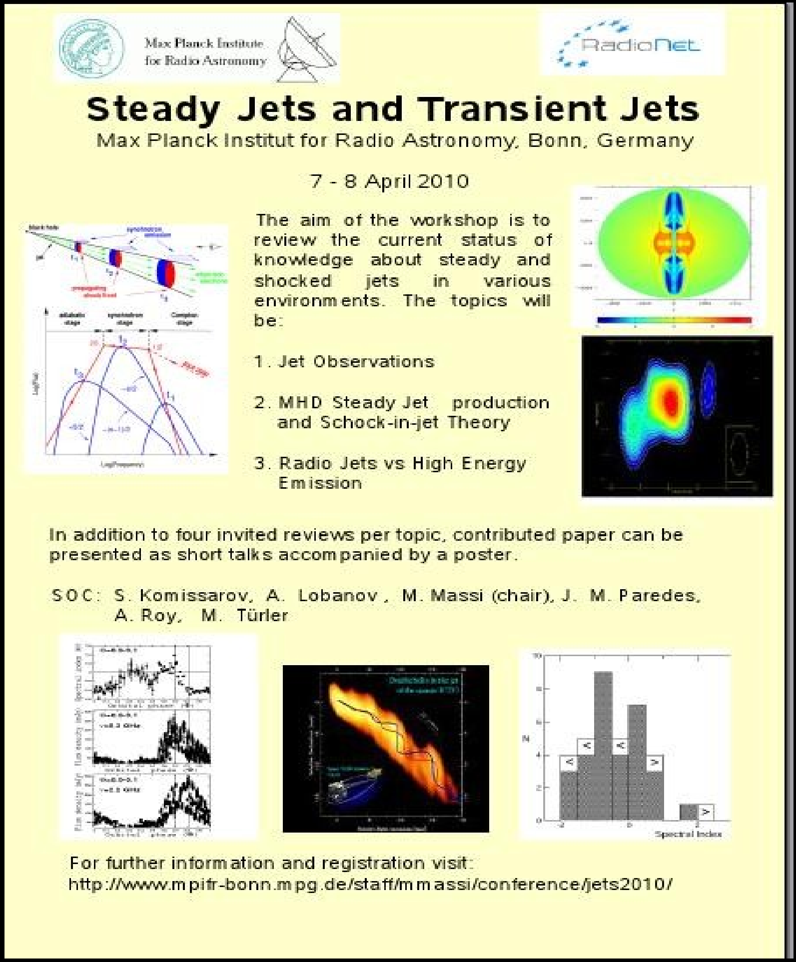
Steady Jets and Transient Jets:

Radio / X-ray Characteristics

Maria Massi
(MPIfR)



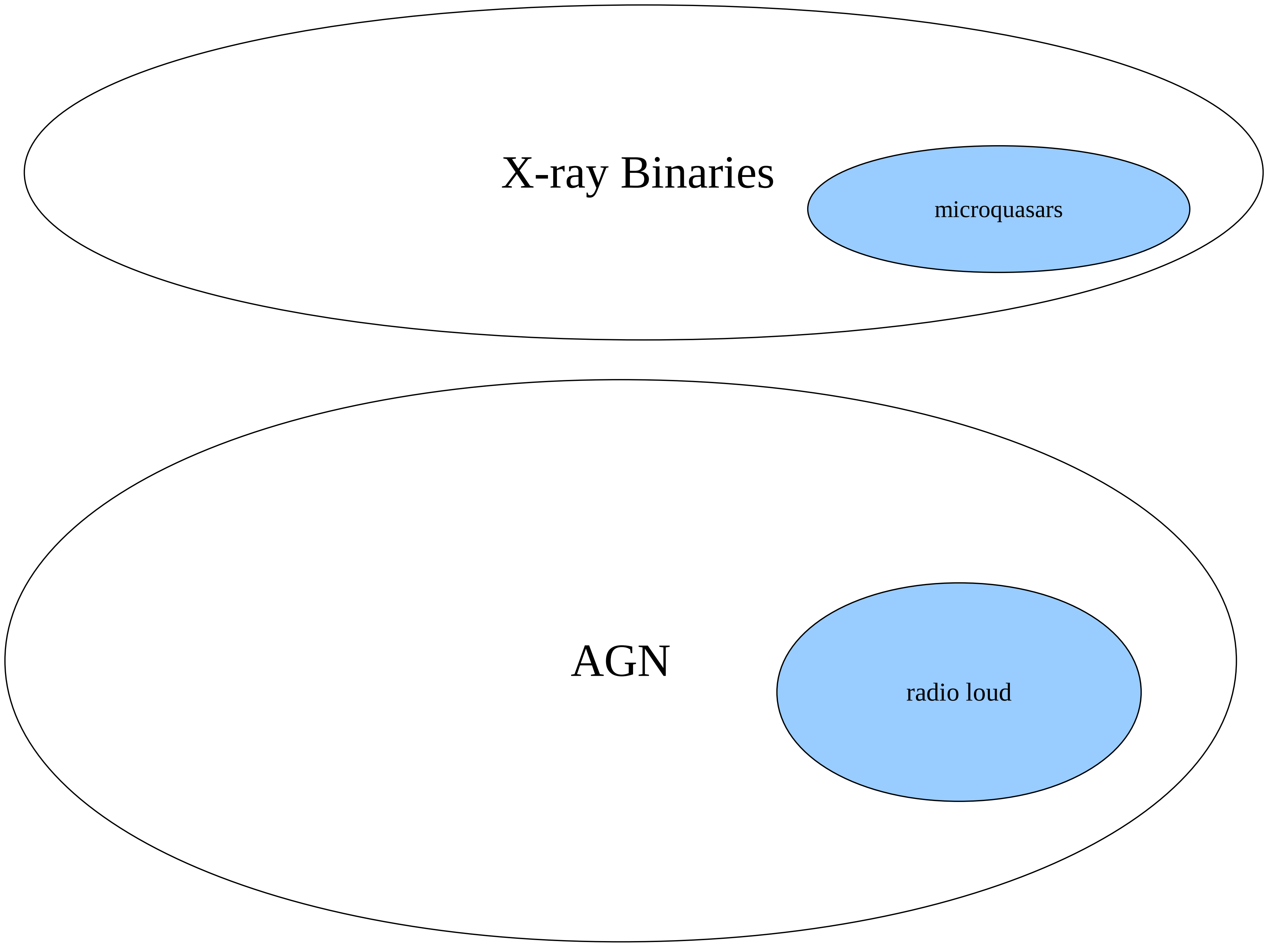
STEADY JETS AND TRANSIENT JETS

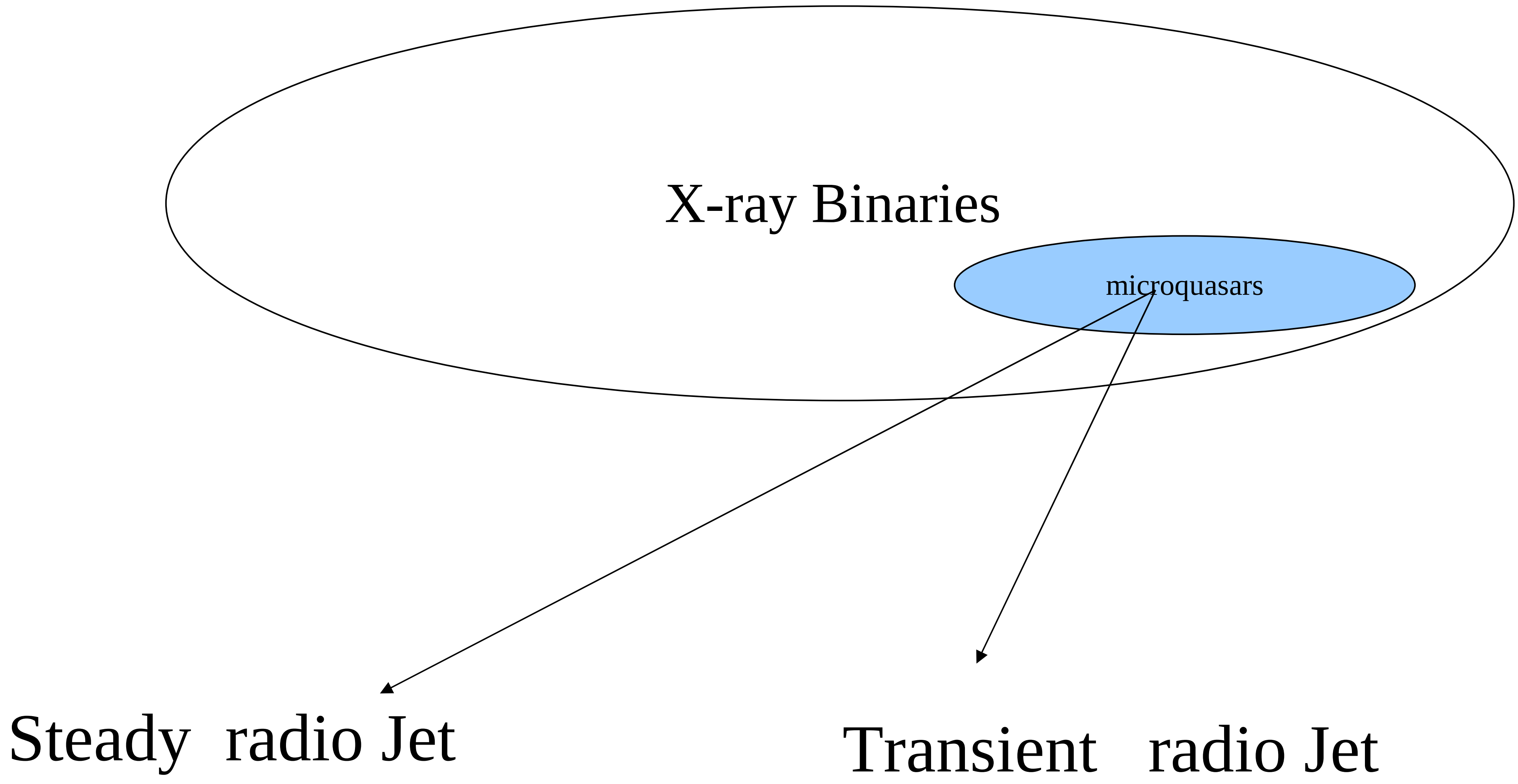
Outline

Radio/X-ray Characteristics for X-ray Binaries

Models for the Emission

Comparison with the AGNs

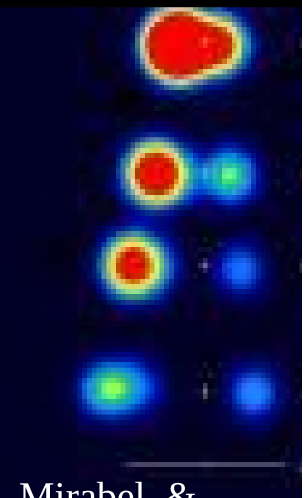

X-ray Binaries
microquasars
AGN
radio loud


X-ray Binaries
microquasars
Steady radio Jet
Transient radio Jet

TRANSIENT JETS

STEADY JETS

GRS 1915+105



Mirabel .& Rodrigez 1994

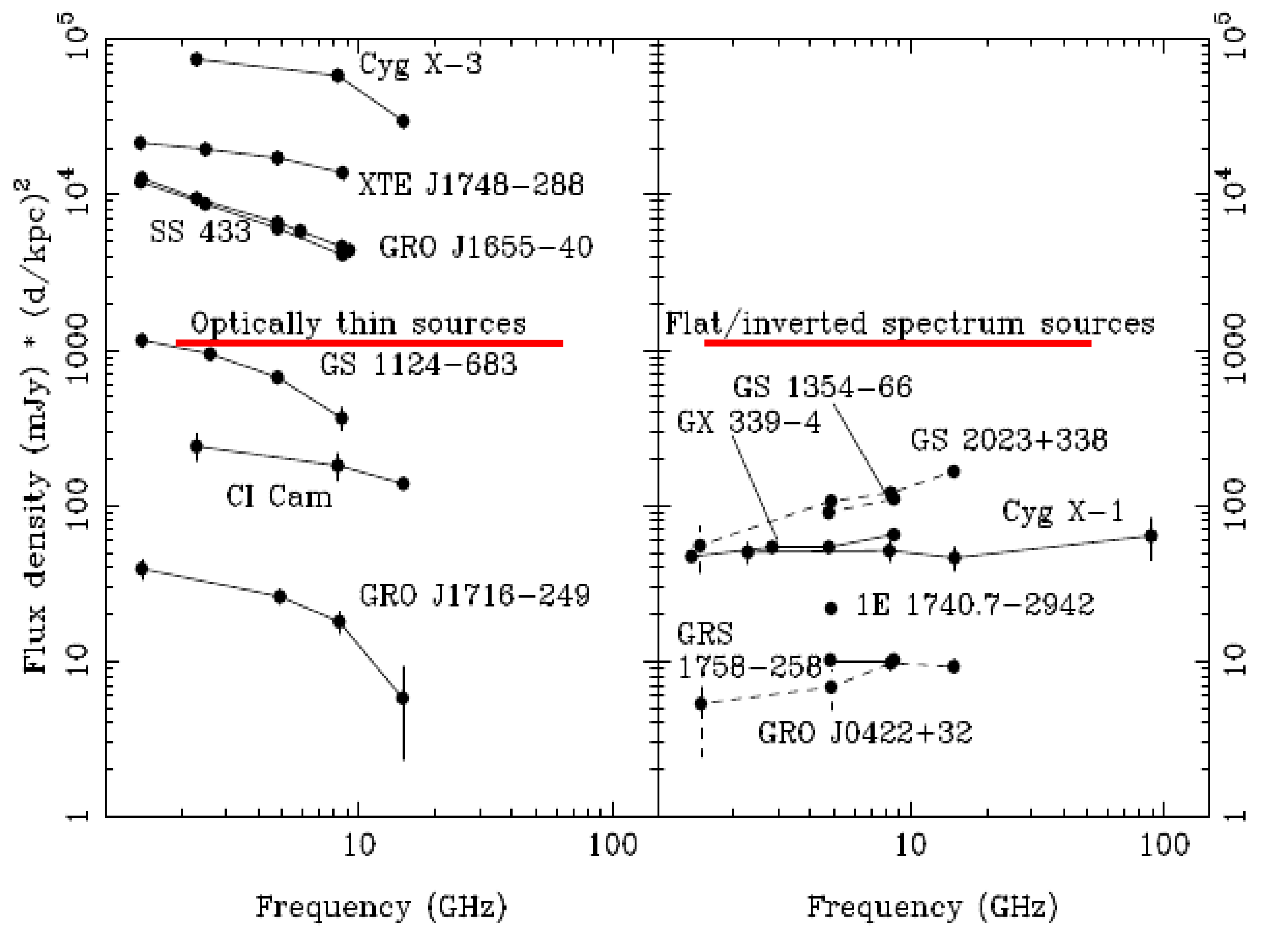
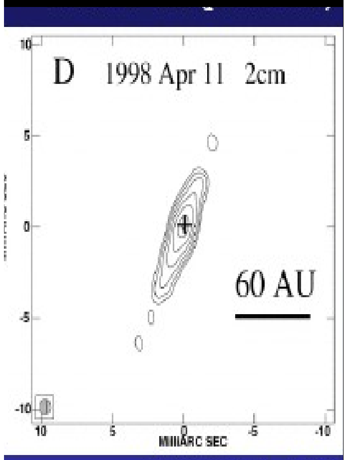


Figure 4. Optically thin (i.e. spectral index $\alpha < 0$) radio spectra from several radio-bright X-ray binaries which were *not* in the Low/Hard X-ray state at the time of the observations, compared with the flat/inverted spectra of the seven sources in Figs 1 & 4 (for the transients, the later, ie. most inverted, spectra are plotted). As well as the different spectral indices (the optically thin sources all have $-1 \leq \alpha \leq -0.2$, the source in the Low/Hard state all have $0.0 \leq \alpha \leq 0.6$), note also the much wider range of fluxes observed from optically thin emission.

GRS 1915+105



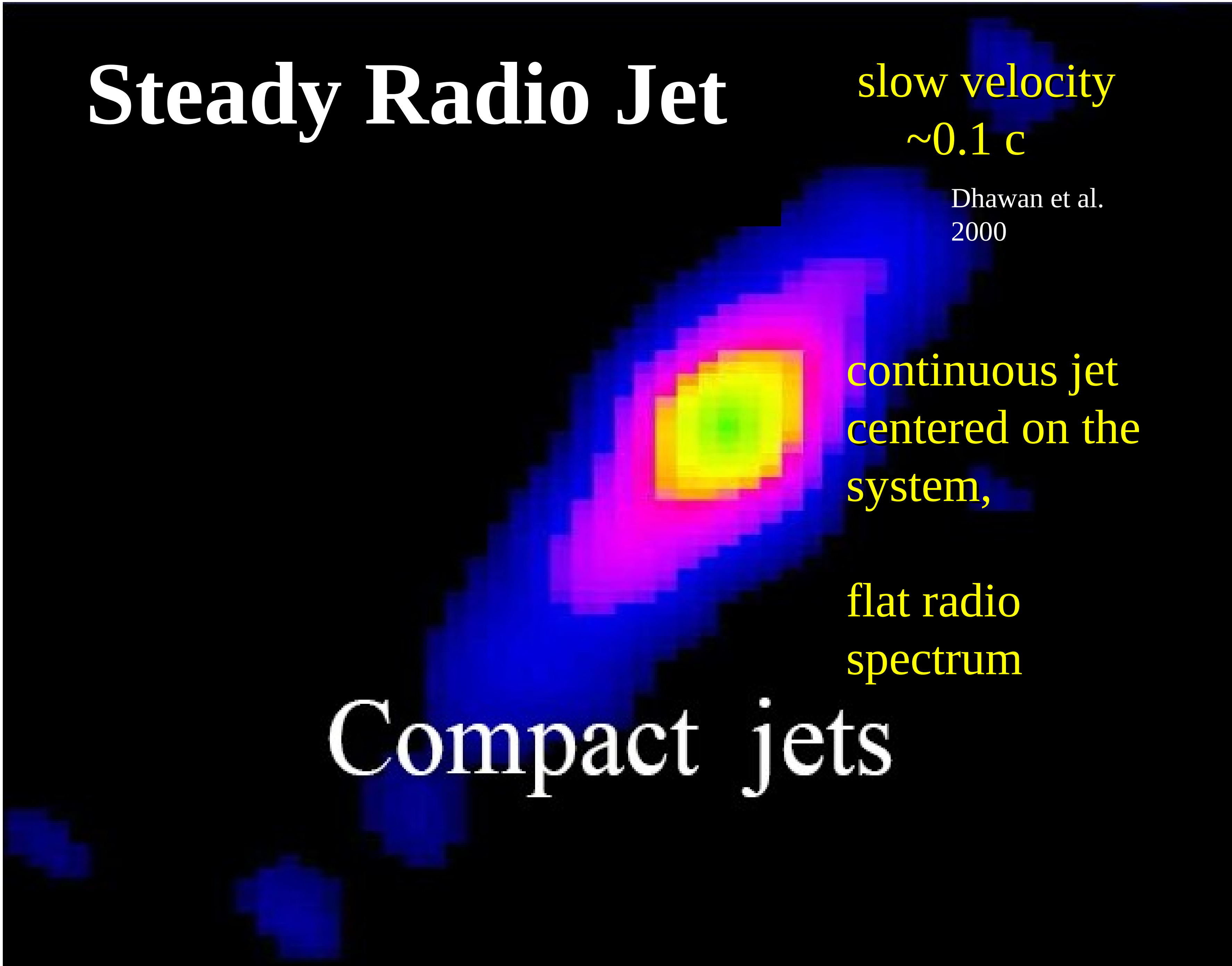
Dhawan et al. 2000

Fender et al. 2001, 2004,2006

Steady Radio Jet

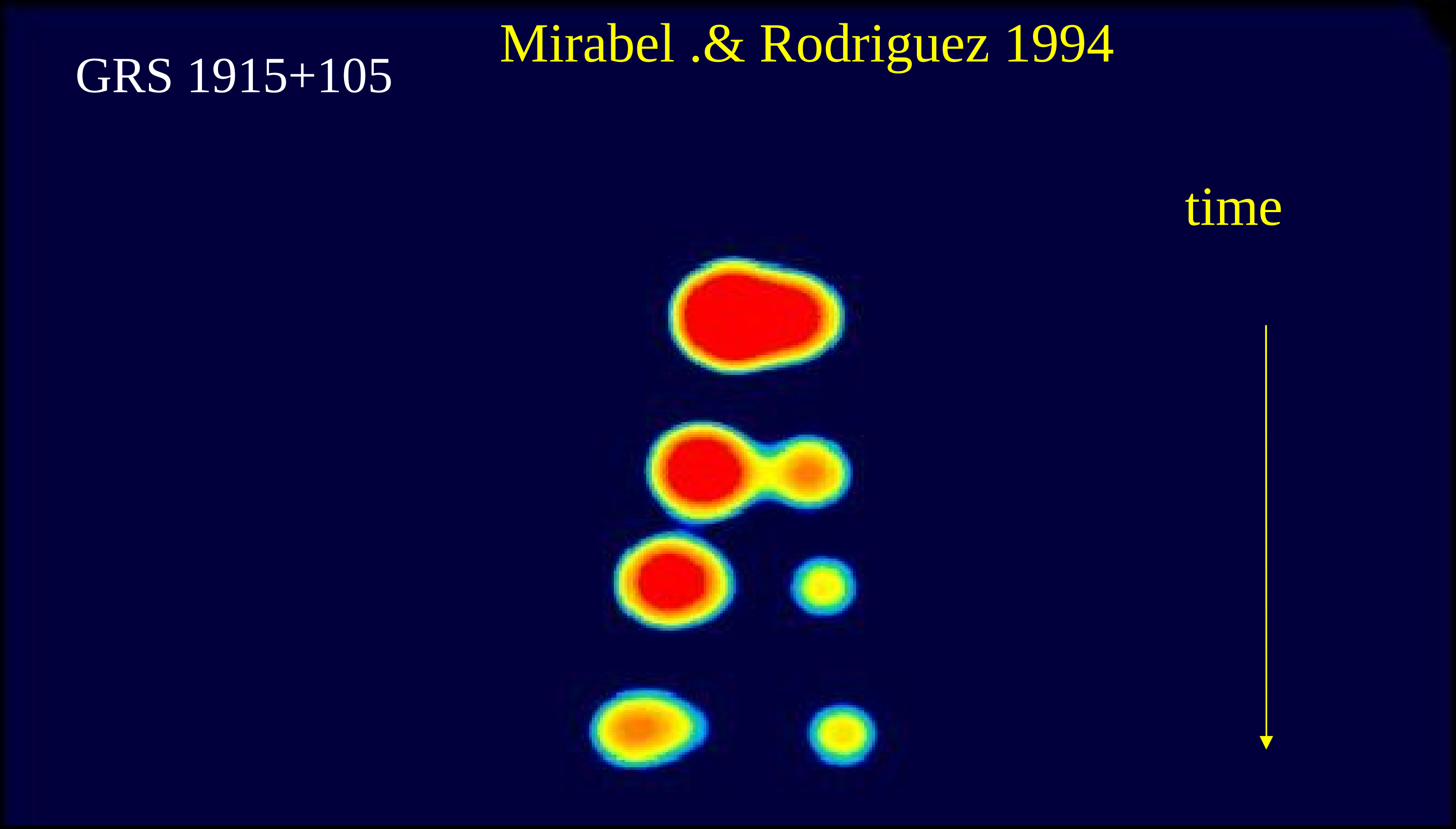
slow velocity
~0.1 c

Dhawan et al.
2000



continuous jet
centered on the
system,

flat radio
spectrum

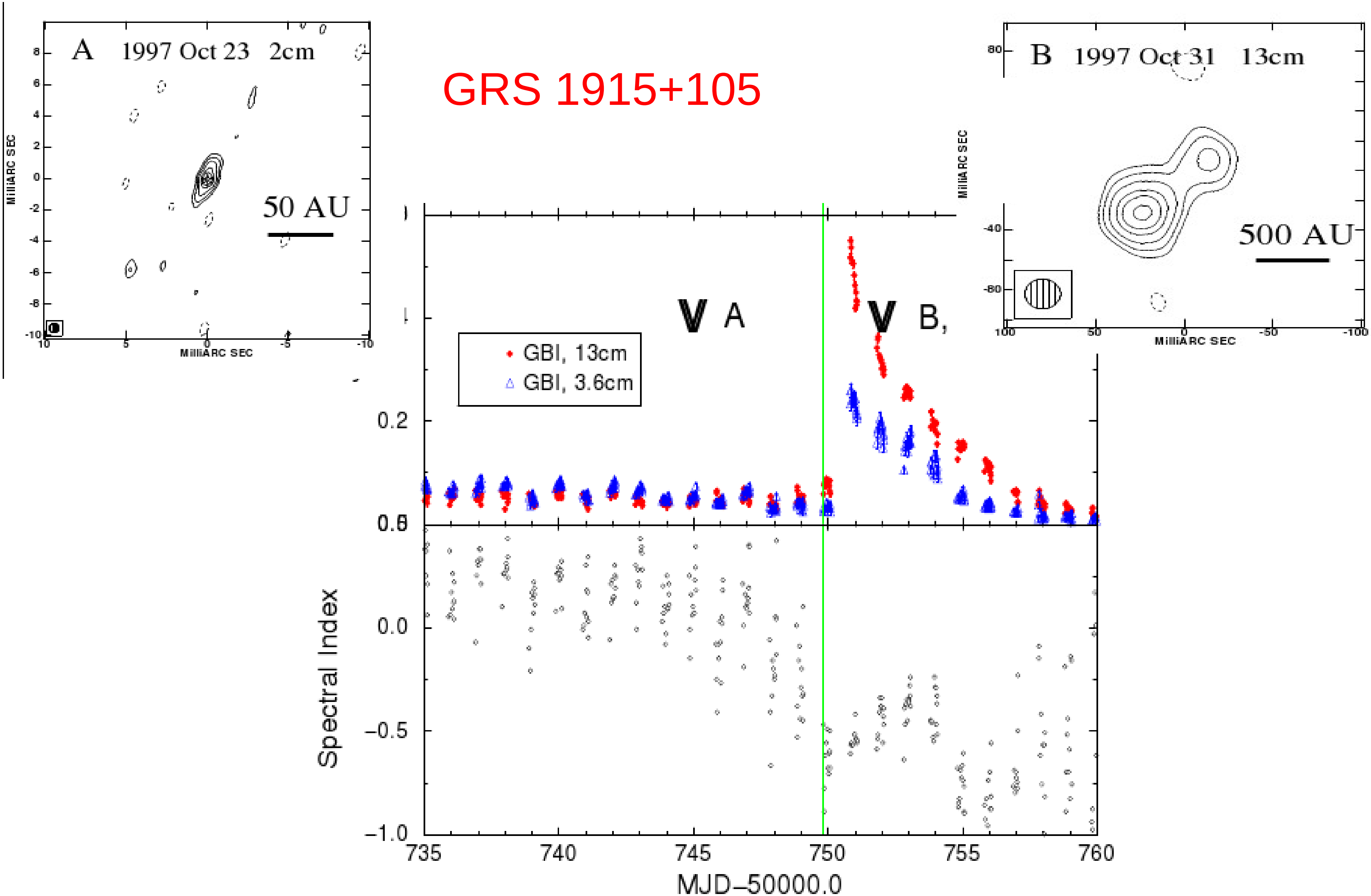


Twin pair of ejections

v/c > 0.9

optically thin radio spectrum

GRS 1915+105

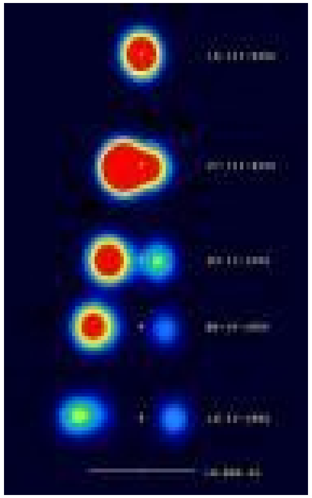


Dhawan, Mirabel and Rodriguez 2000

Two distinct radio emission states

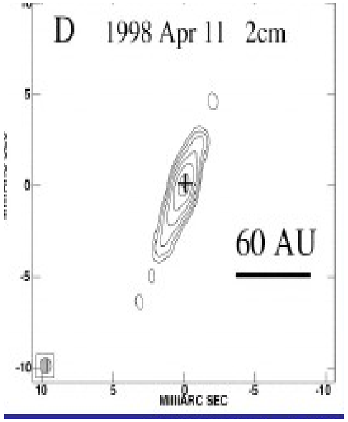
radio emission ***attached to****....................*

and ***detached from*** *the center*



GRS 1915+105

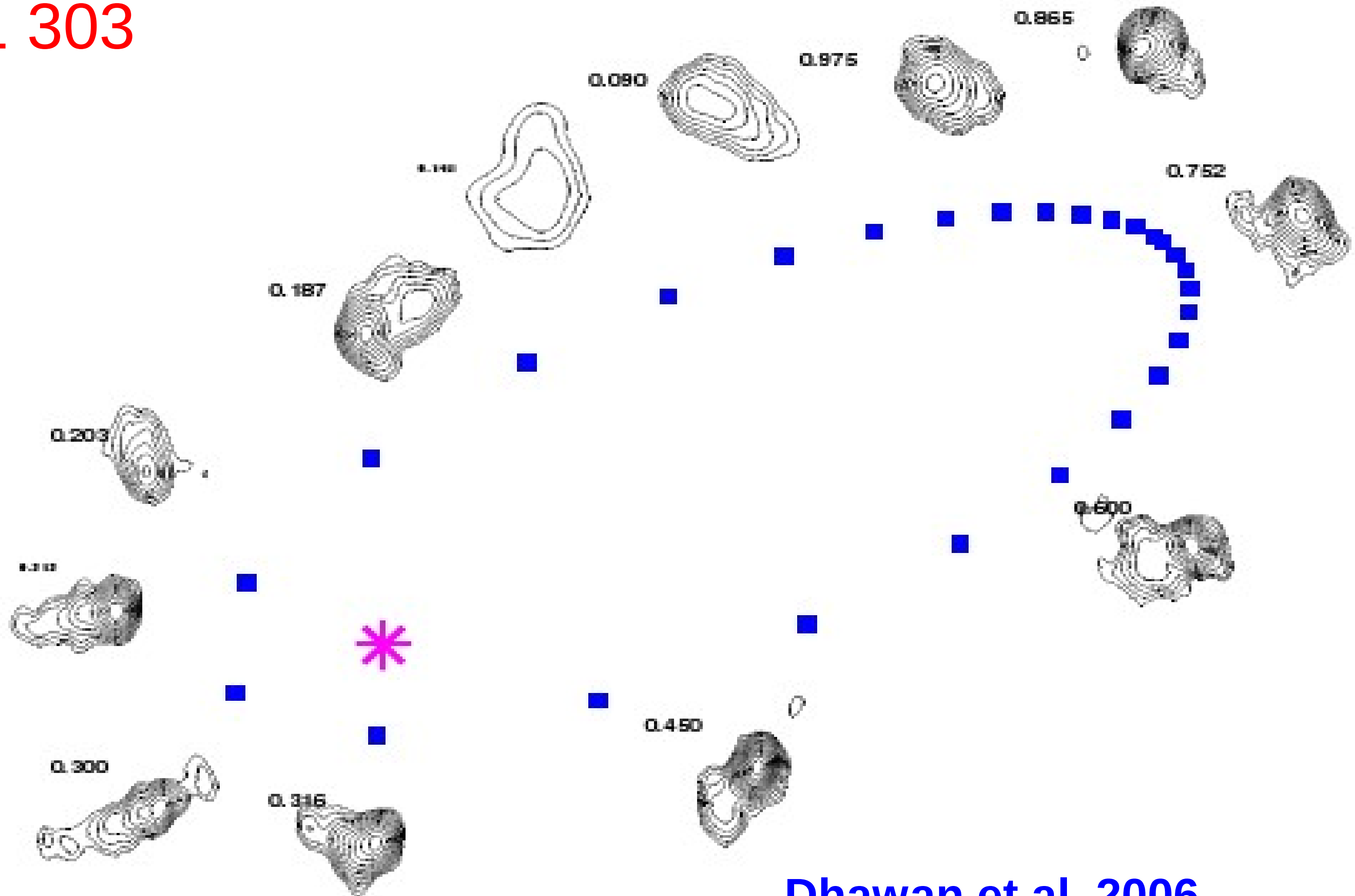
Mirabel .& Rodrigez 1994



GRS 1915+105

Dhawan et al. 2000

LS I +61 303

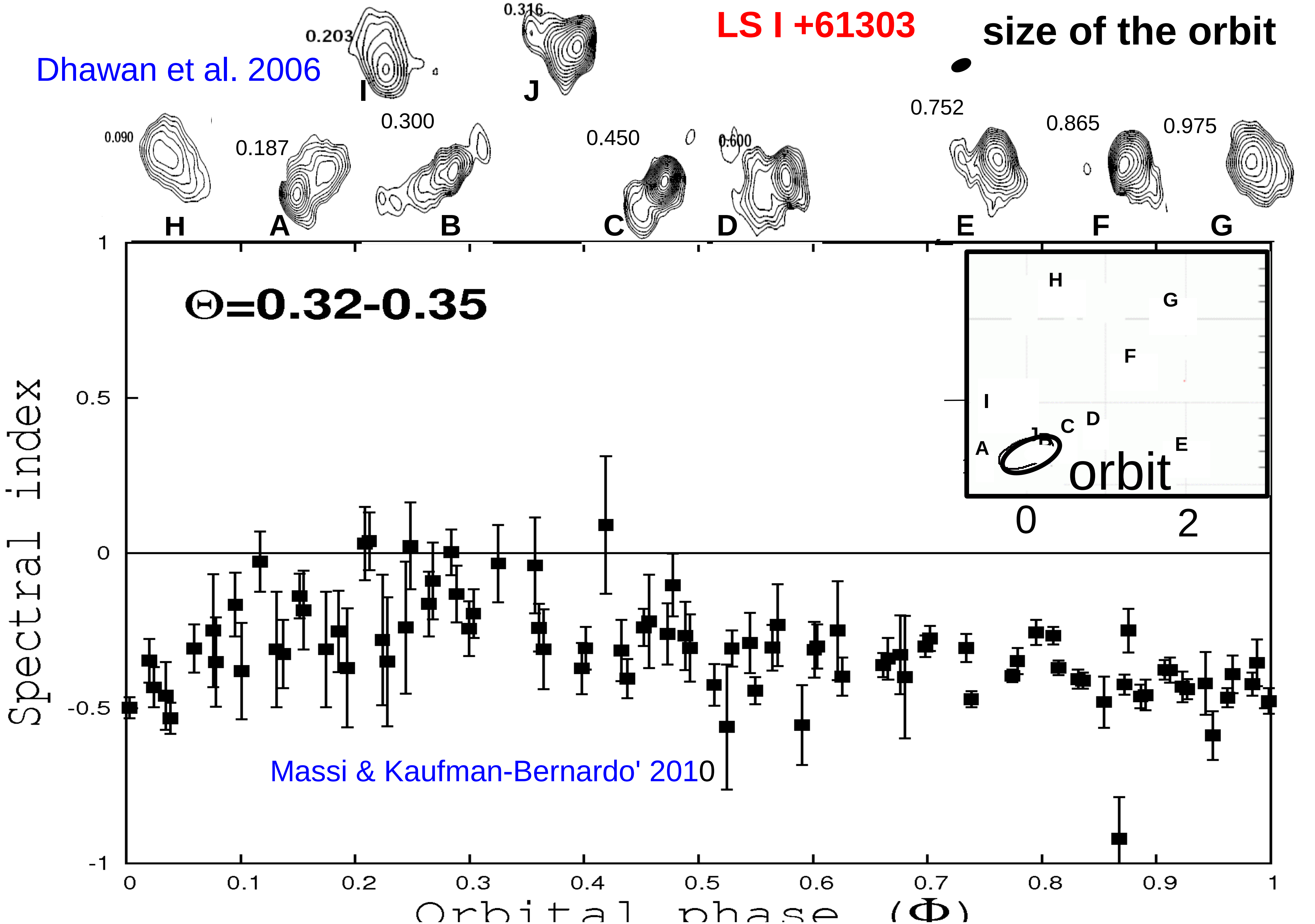


Dhawan et al. 2006

Figure 3: Images at 3.6cm arranged by orbital phase φ. Contours begin at $\pm$0.2mJy, and step by a factor $\sqrt{2}$. The resolution is 1.5x1.1 mas = 3x2.2 AU. The image locations have been adjusted for non-overlap, and are hence approximate and illustrative only. Orbit size is greatly exaggerated. Astrometric positions

Beam: 2.2x3 AU

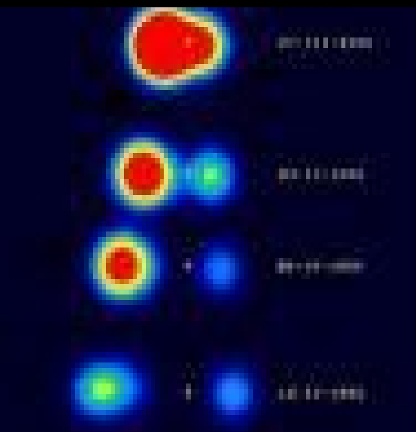
Semi-major axis:0.5 AU



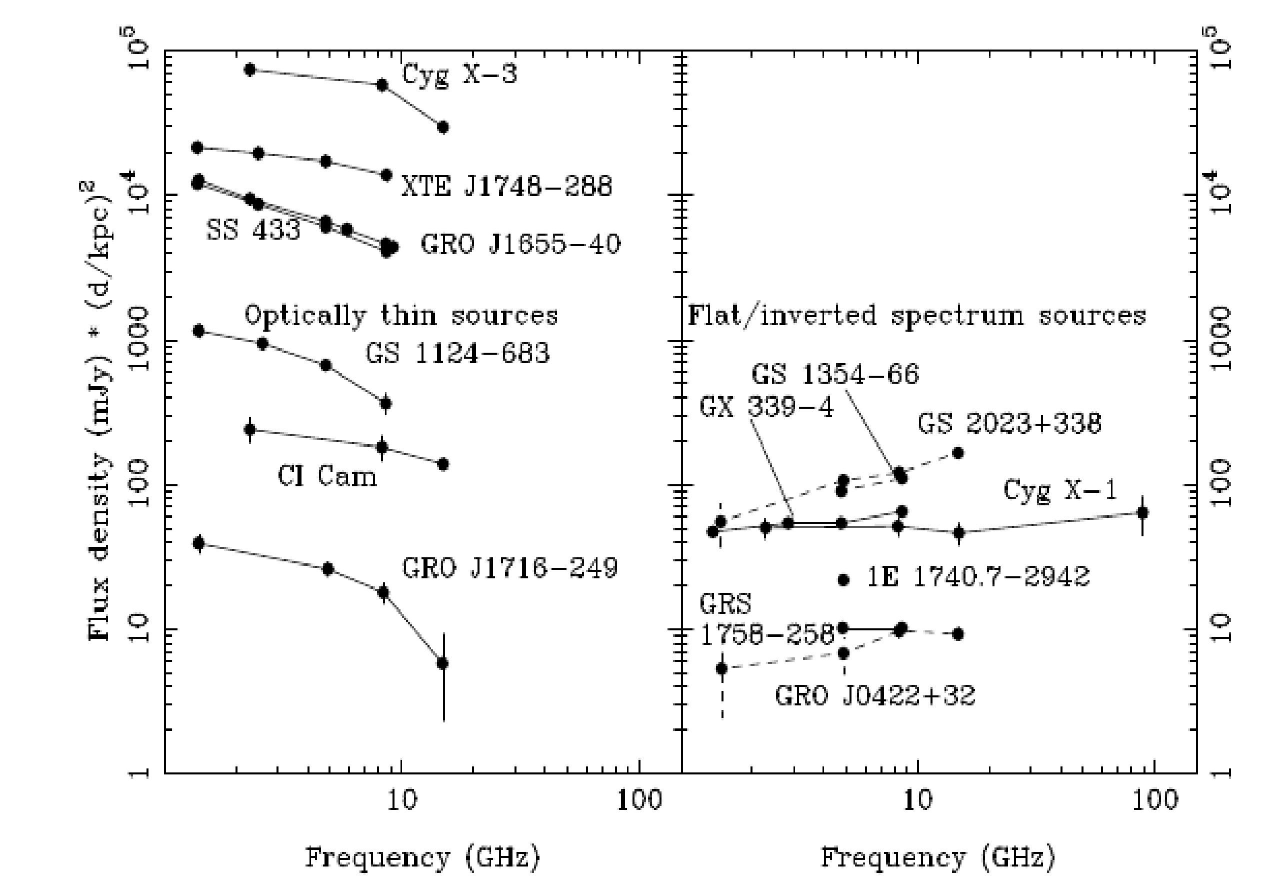
LS I +61303
size of the orbit
Dhawan et al. 2006
0.203
0.316
I
J
0.090
0.187
0.300
0.450
0.600
0.752
0.865
0.975
H
A
B
C
D
E
F
G
Θ=0.32-0.35
orbit
0
2
Spectral index
Orbital phase (Φ)
Massi & Kaufman-Bernardo' 2010

TRANSIENT JETS

STEADY JETS



Mirabel .& Rodrigez 1994



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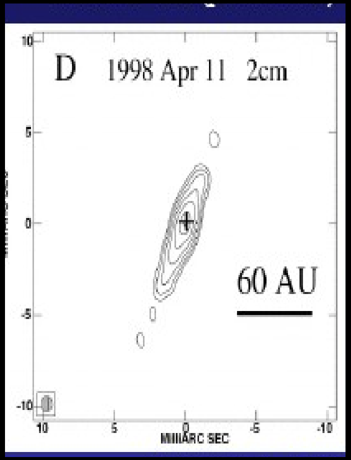


Dhawan et al. 2000

X-ray State

Steep Power-low State

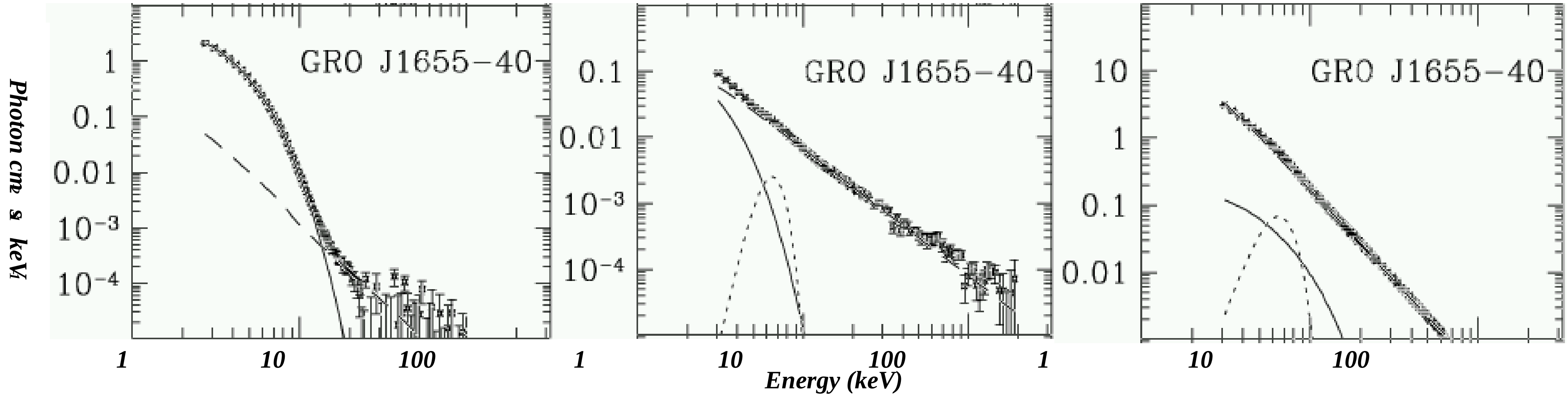
X-ray State

Low Hard

Fender et al. 2001

Accretion states

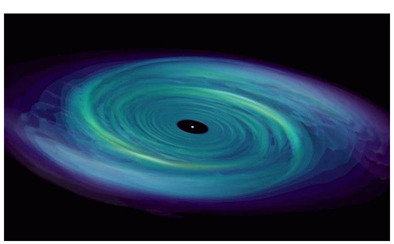
Energy spectra from McClintock & Remillard (2006)



High

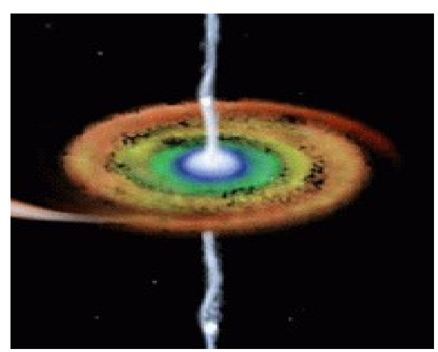
(thermal dominated)

~ 1 – 2 keV disc + PL tail



Low/Hard

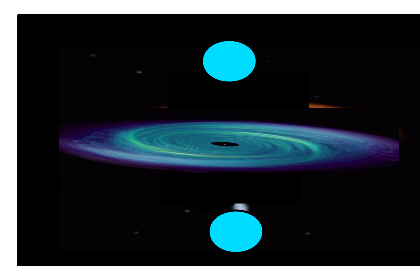
Hard PL (Γ ~ 1.5 – 2) dominant, disc absent or truncated, radio jet emission. Least luminous.



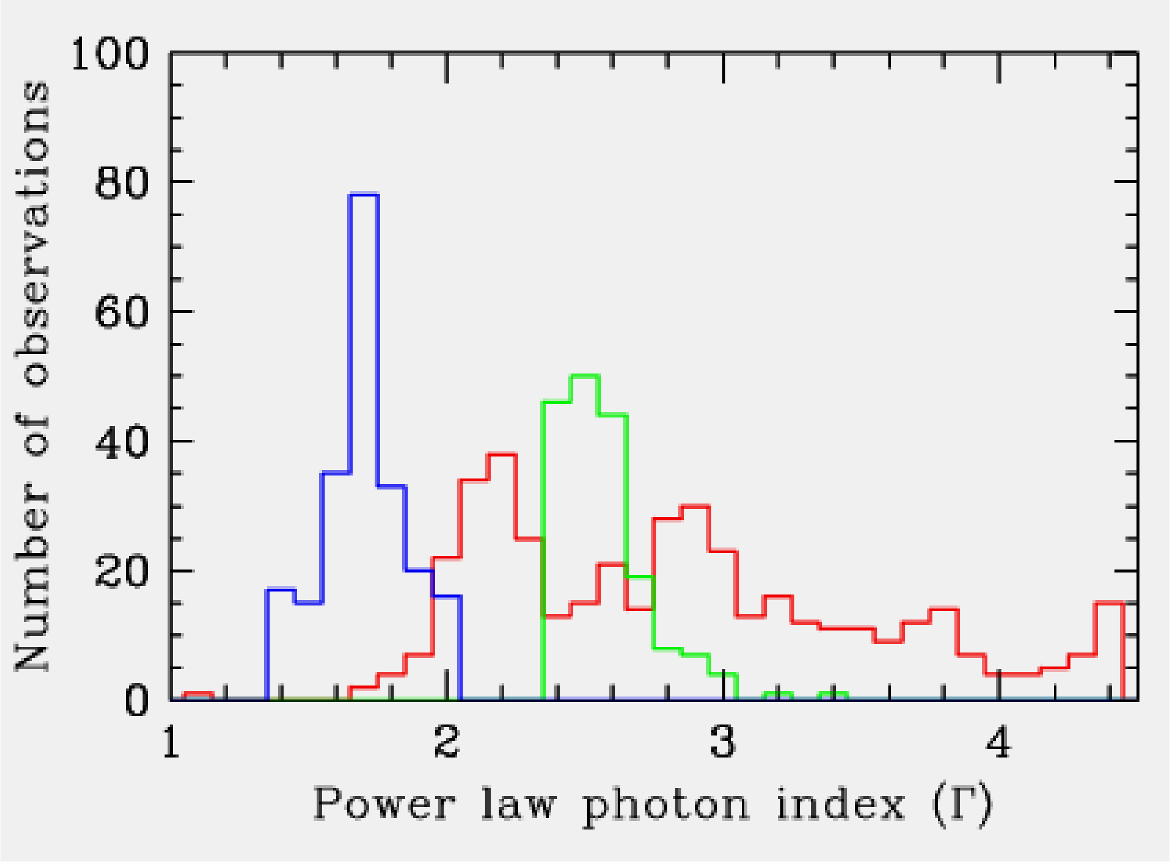
Very High

(steep power-law)

Soft PL (Γ > 2.5) plus some hot disc emission. Most luminous.



Distributions in Photon Index



Hard **SPL** **Thermal**

Ron Remillard

STEADY JETS AND TRANSIENT JETS

Outline

✓ Radio/X-ray Characteristics for X-ray Binaries

Models for the Emission

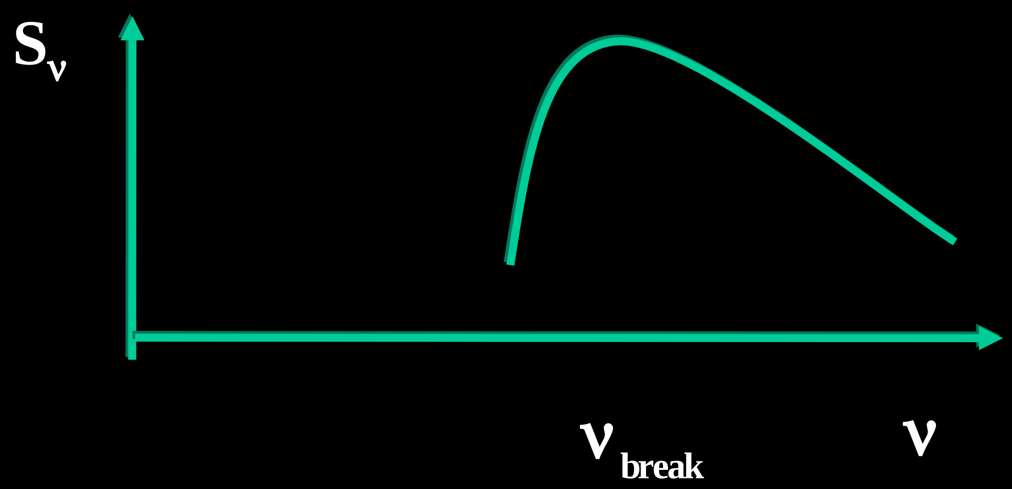
Flat Spectrum (conical jet)

Optically thin Outburst (bubble vs shocks)

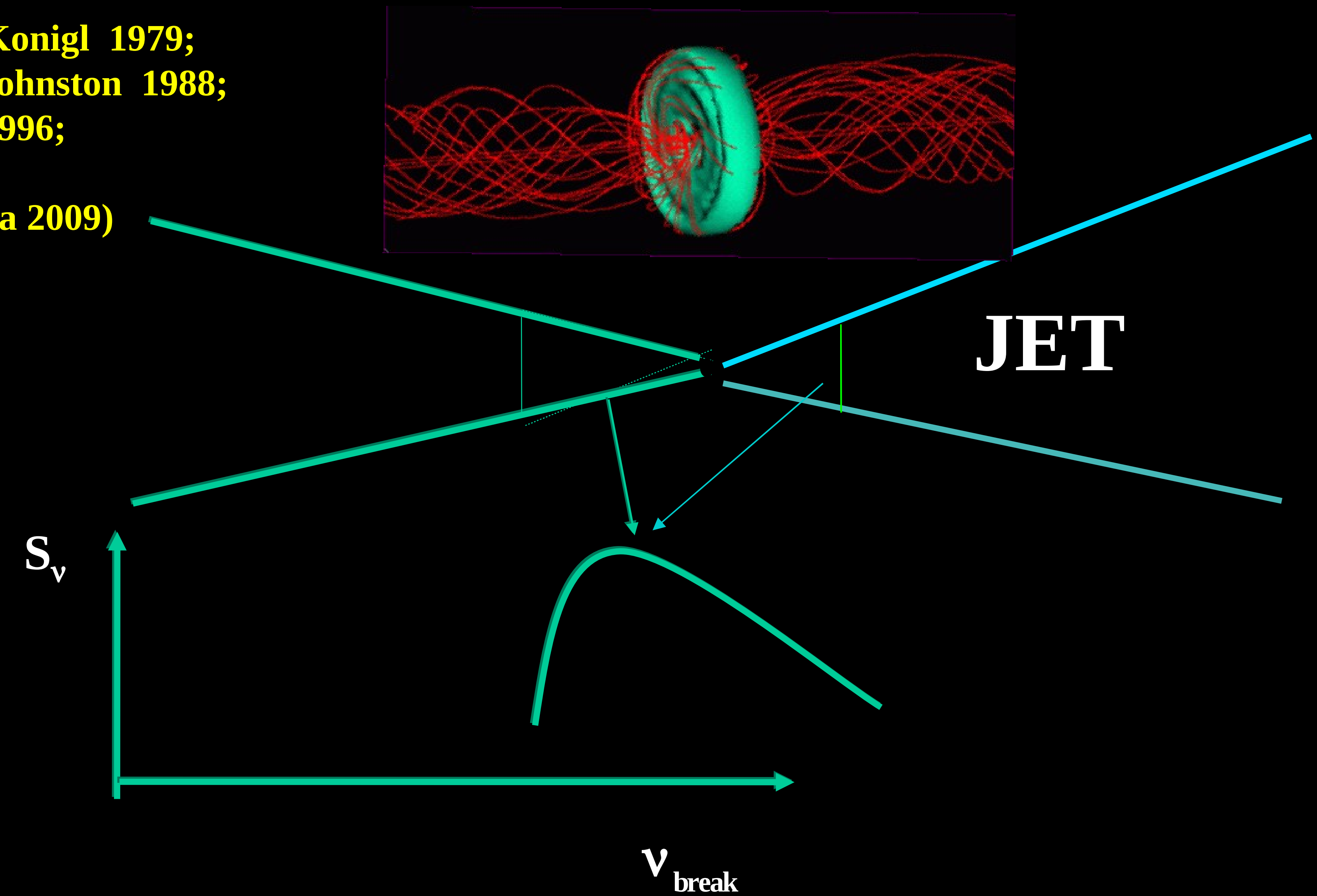
Comparison with the AGNs

RADIO SPECTRUM:

WHY IS IT "FLAT" ?



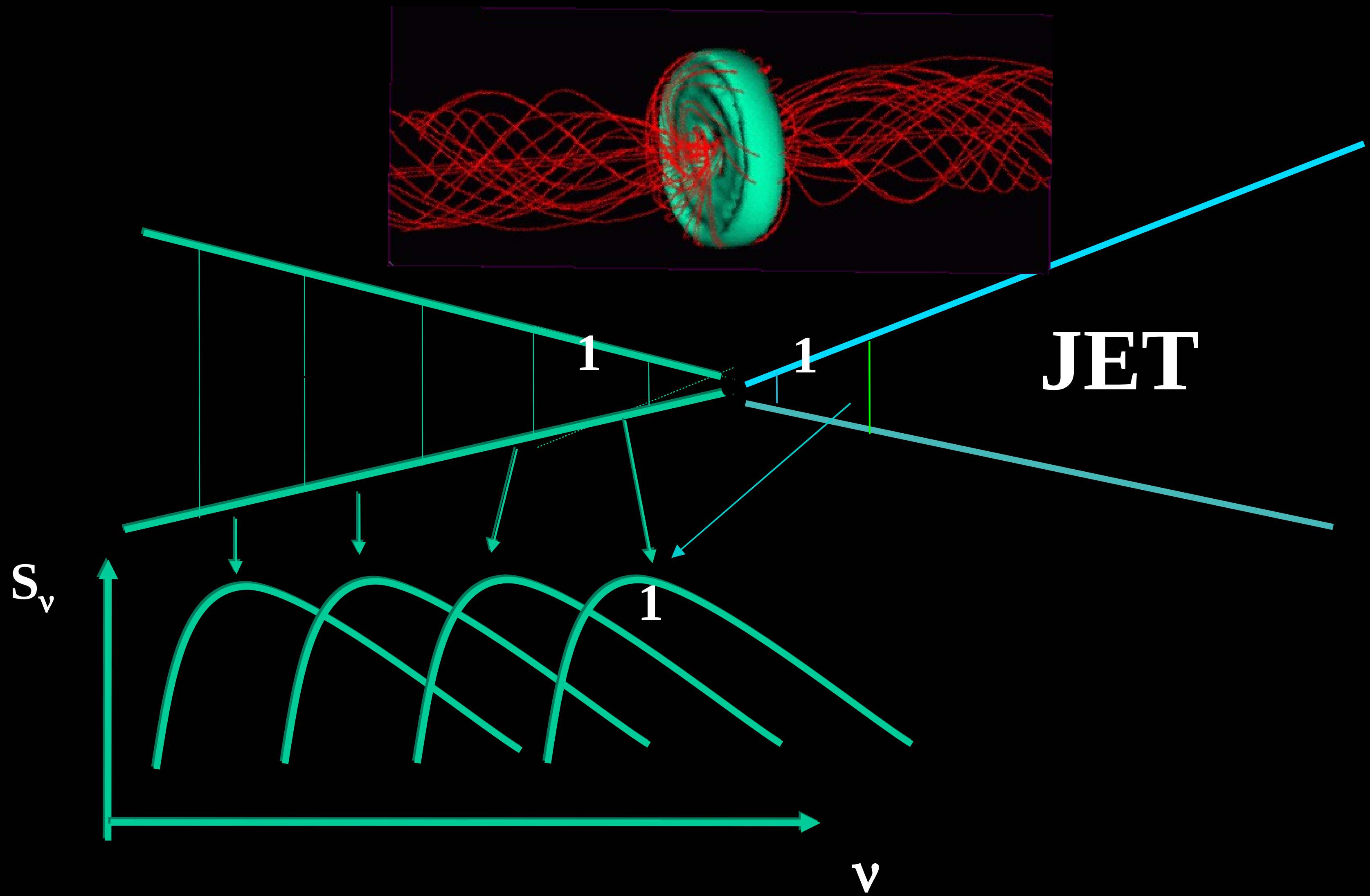
Blandford & Konigl 1979;
Hjellming & Johnston 1988;
Falcke et al. 1996;
Kaiser 2006;
Pe'er &Casella 2009)



Change of the plasma conditions along the jet:

decay of the magnetic field

change in the electron energy distribution



dependence of the “break” frequency on the changing plasma conditions along the jet

Blandford & Konigl 1979;
Hjellming & Johnston 1988; Falcke et al. 1996; Kaiser 2006; Pe'er &Casella 2009

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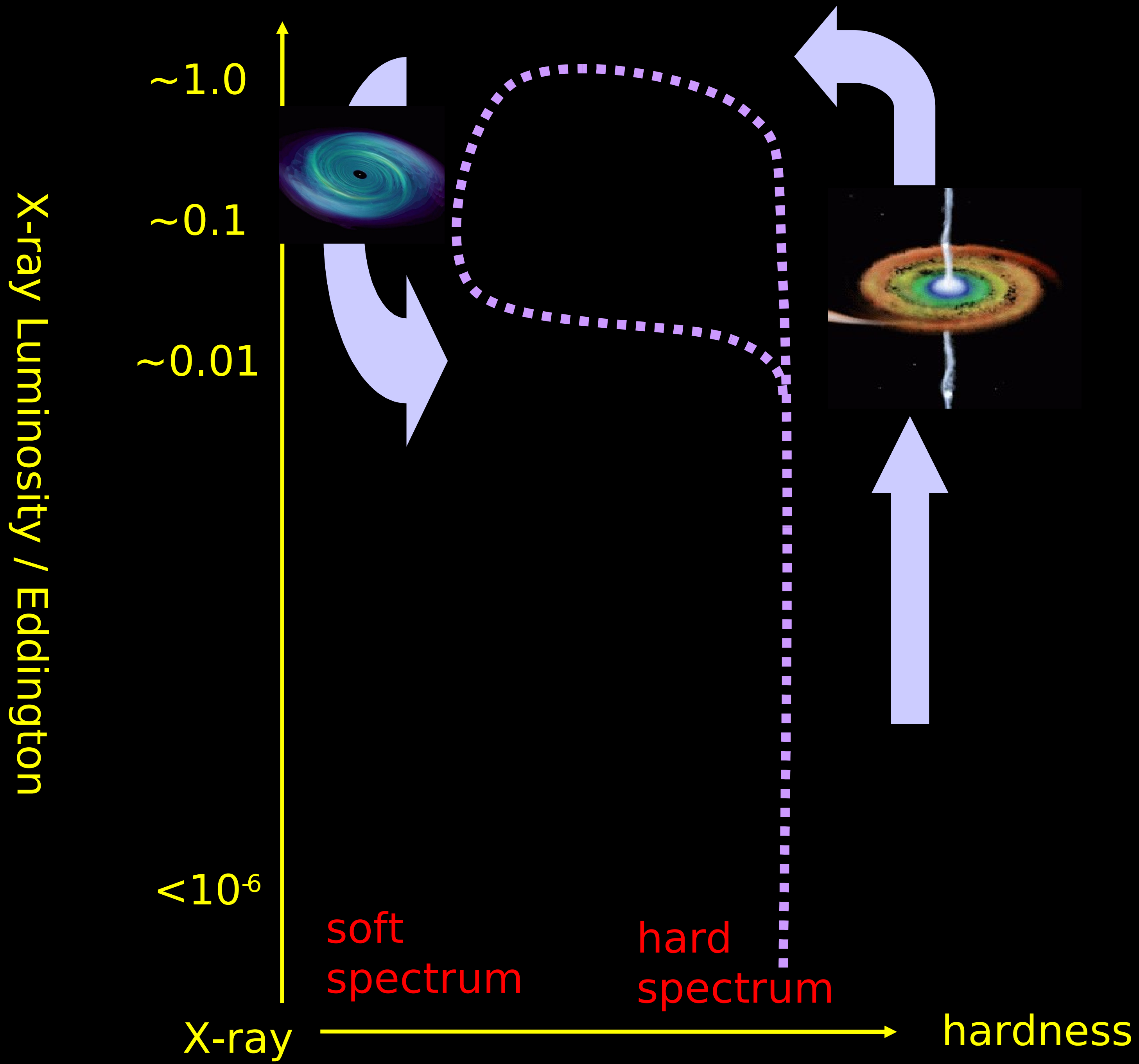
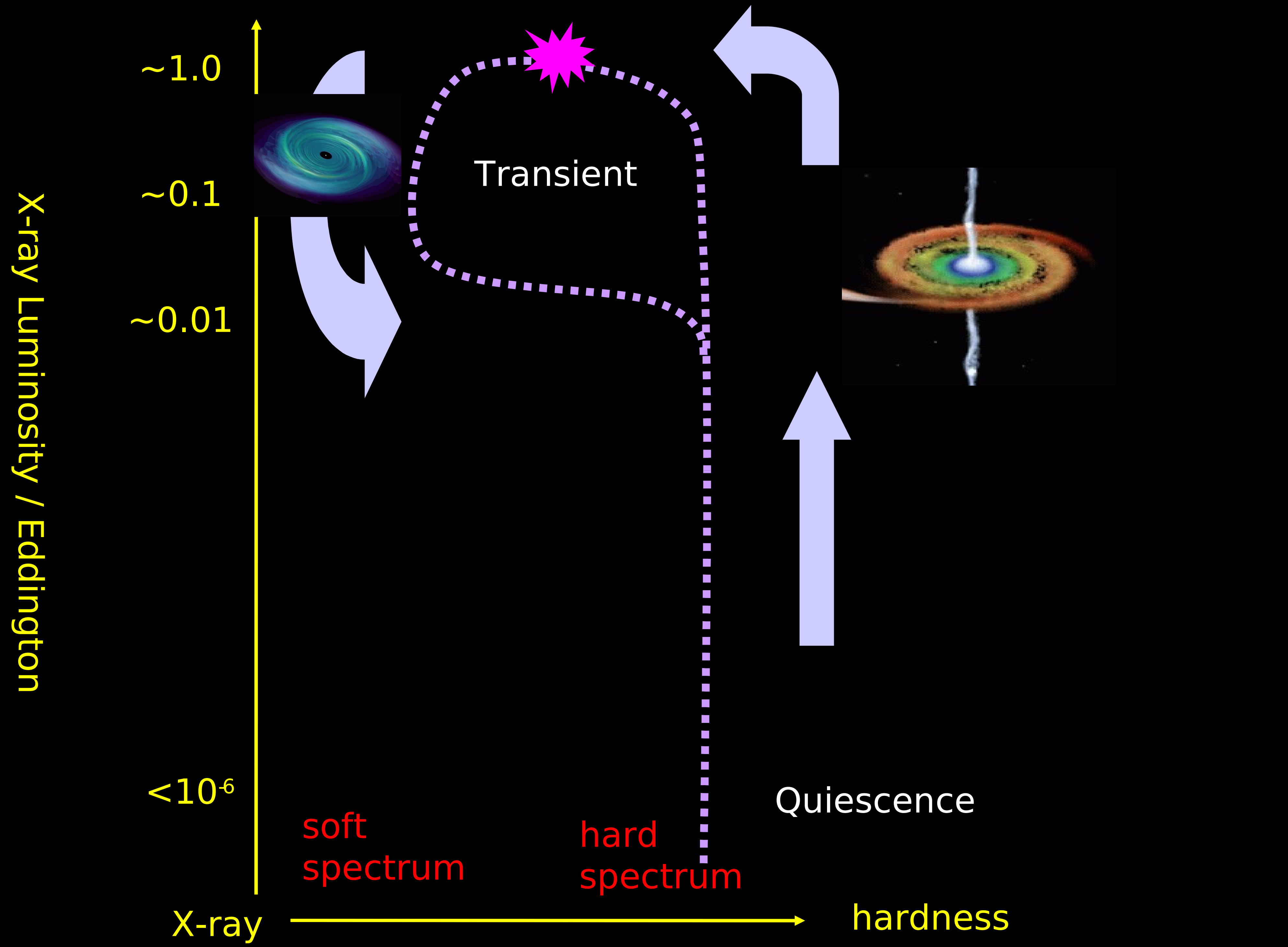


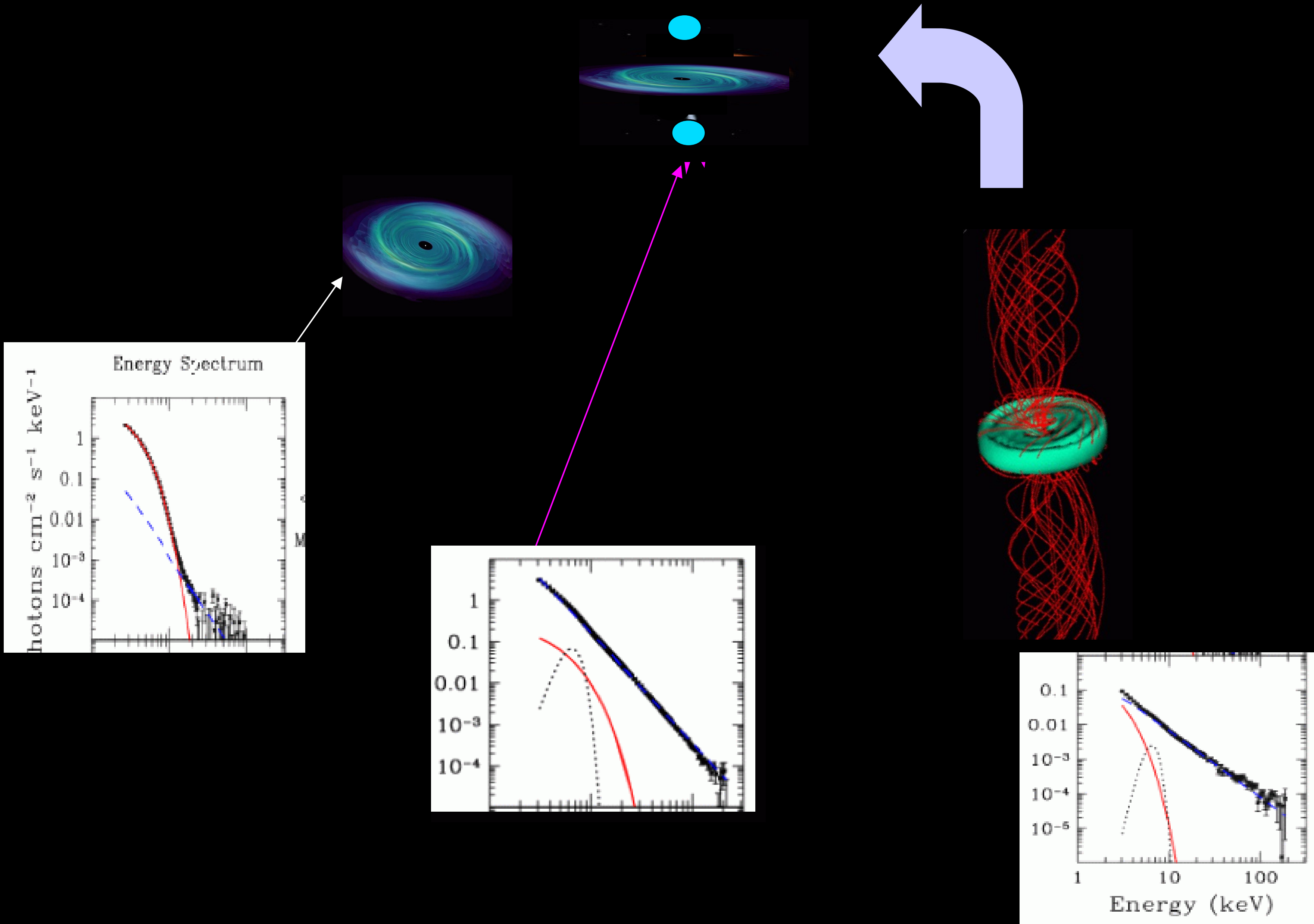
Hardness ratio:
the ratio of detector counts in two energy bands

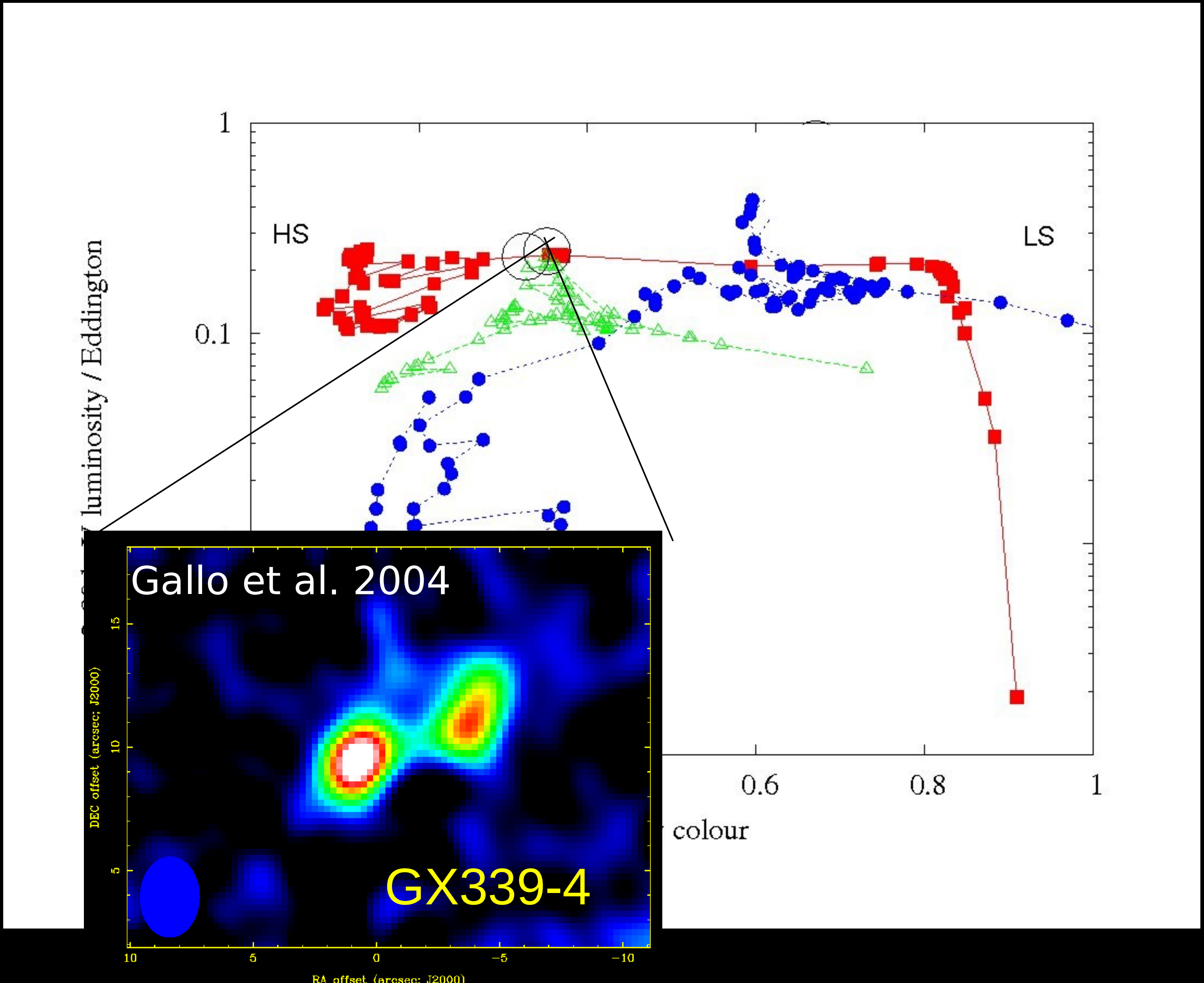
(example. the ratio of source counts at 6.3–10.5 keV to the counts at 3.8–7.3 keV)

www.astro.lsa.umich.edu/Events/Meetings/mctpwww/.../Fender.ppt



www.astro.lsa.umich.edu/Events/Meetings/mctpwww/.../Fender.ppt


Energy Spectrum
hotons cm^-2 s^-1 keV^-1
Energy (keV)



Powerful jets produced in **transition** from canonical 'low/hard' to 'high/soft' states...

Fender, Belloni & Gallo (2004)

Gallo et al. 2004

Homan & Belloni 2005

http://www.astro.lsa.umich.edu/Events/Meetings/mctpwww/contrib.html

Fender.ppt

Black Hole States: Statistics

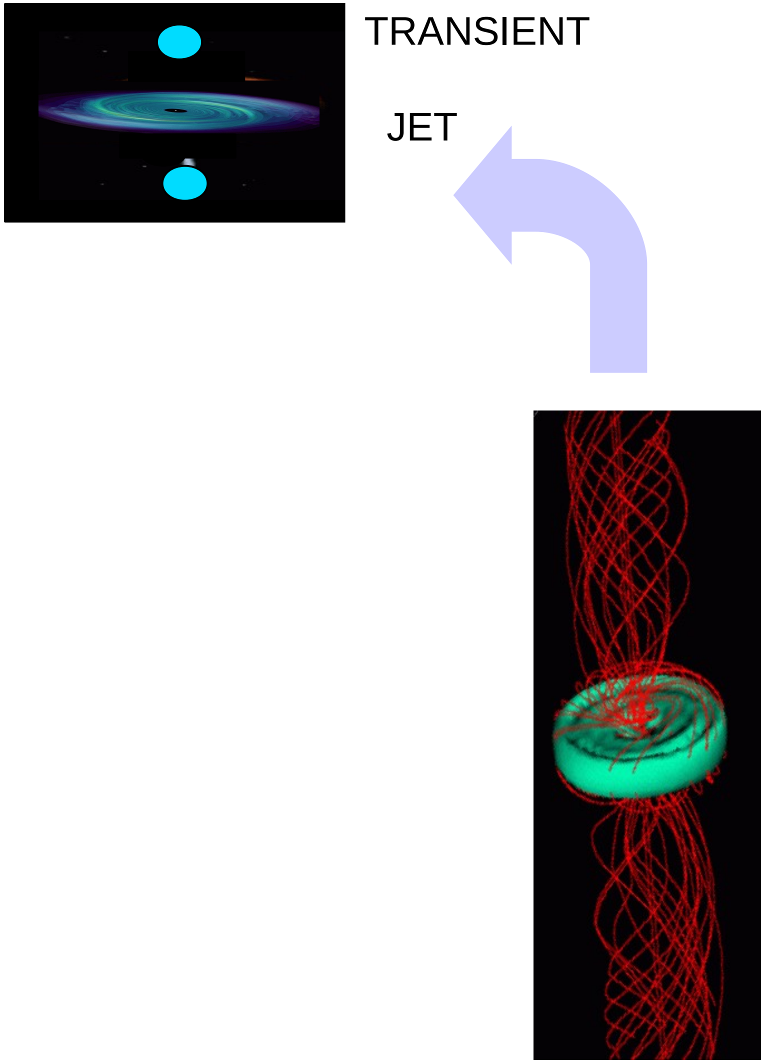
Timescales (days) for state (all BH Binaries)

	duration	transitions
Steep Power Law	1-10	<1
Low/hard	3-200	1-5

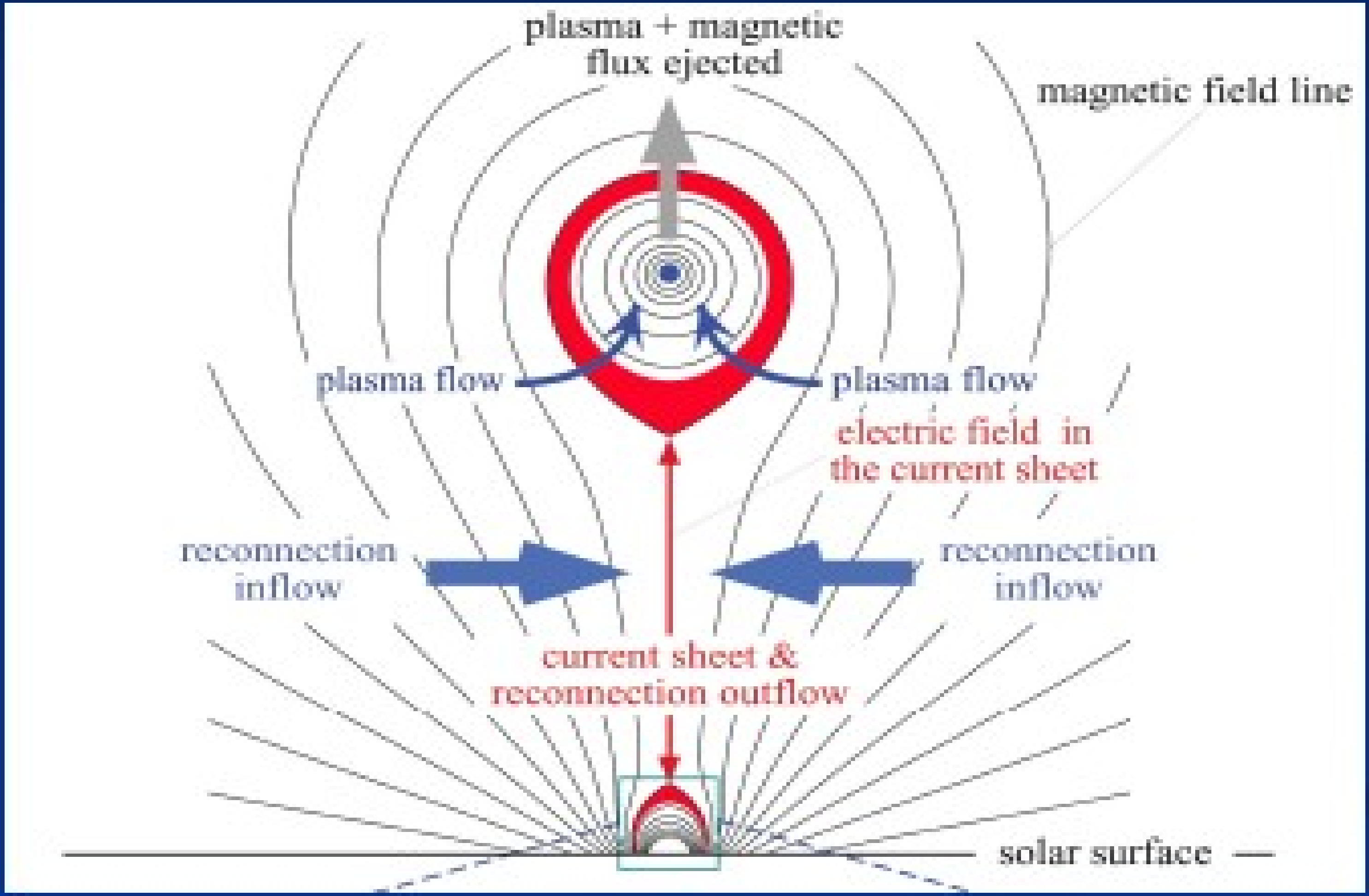
Ronald Remillard

In analogy with solar flares, magnetic energy is probably built-up and accumulated over long time scales and then dissipated in very short time

On the other hand the removal of angular momentum via the steady jet has a dramatic effect on the overall process of the accretion process, further increasing the twist of the magnetic field and making **magnetic reconnection** among tangled field lines likely to occur.



Coronal Mass Ejection

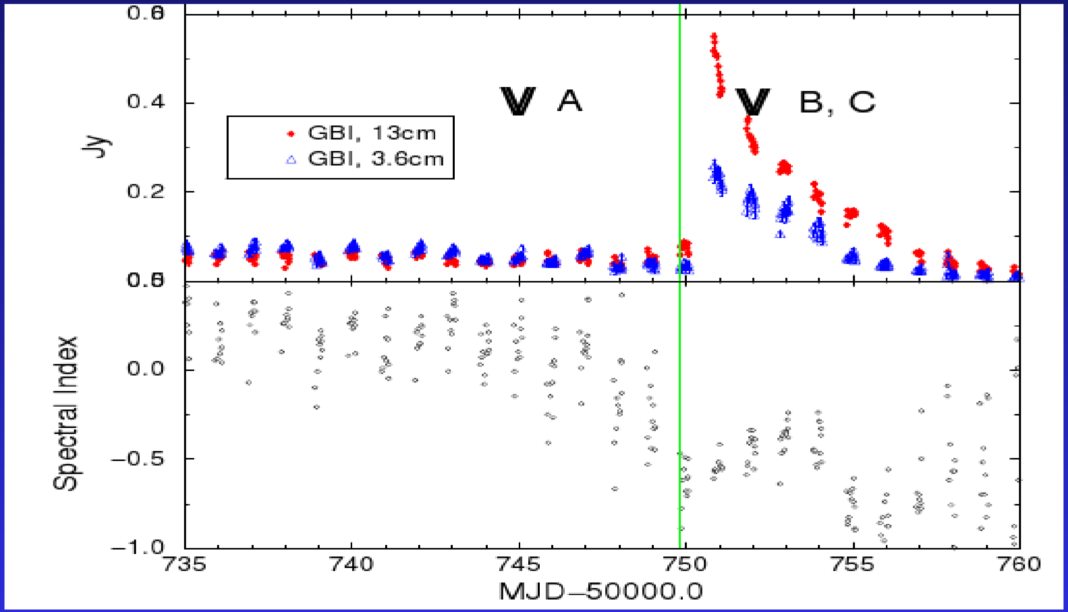


Lin & Forbes 2000, JGR

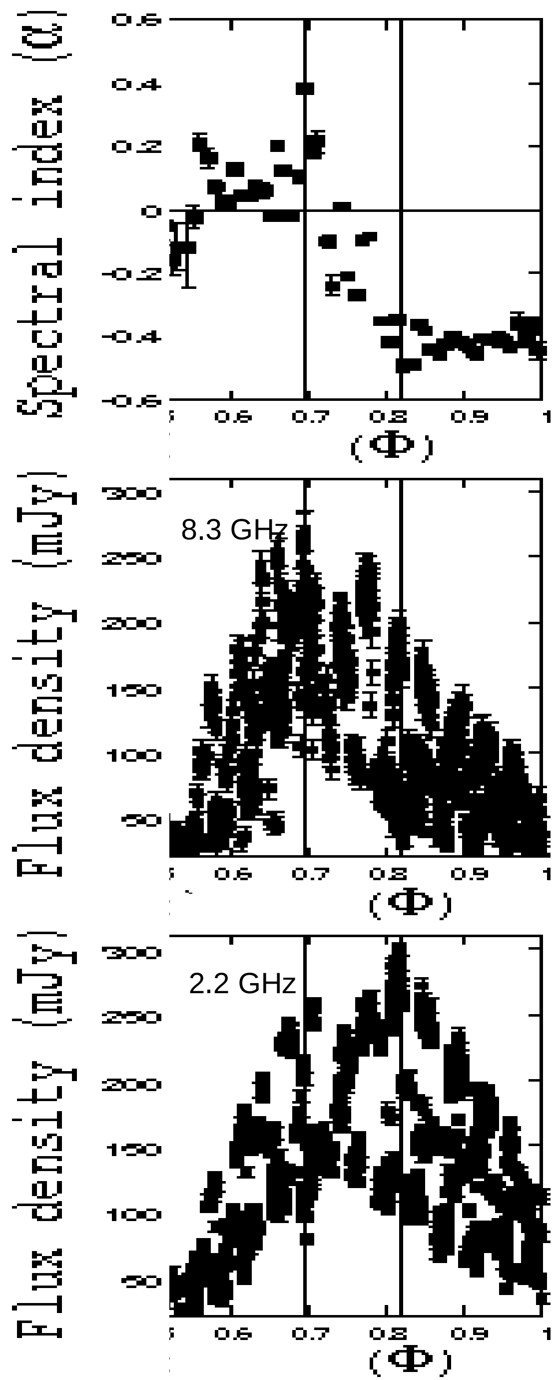
Which is the primary energy output in reconnection?
Is it in the form of relativistic electrons in random motion or is a possible fraction going into bulk motion ?

We can assume that the initial blob, sufficiently compact to be optically thick, afterwards expands and becomes optically thin.

However, following van der Laan (1966) this model predicts that the self-absorption turnover peak frequency will move to lower frequencies, and the peak flux density will decrease (i.e. the flare amplitude decreases towards lower frequencies)



Observations: Outburst peaks at lower frequencies



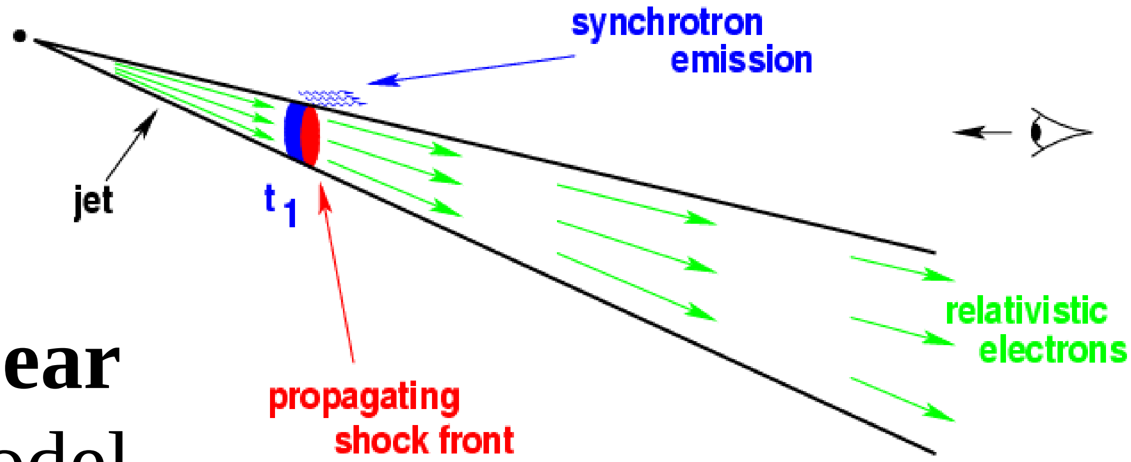
LS I +61303

optically thick outburst

-peak at 8.3 Ghz
-delayed, decreased peak at 2.2 GHz

followed by the optically thin outburst

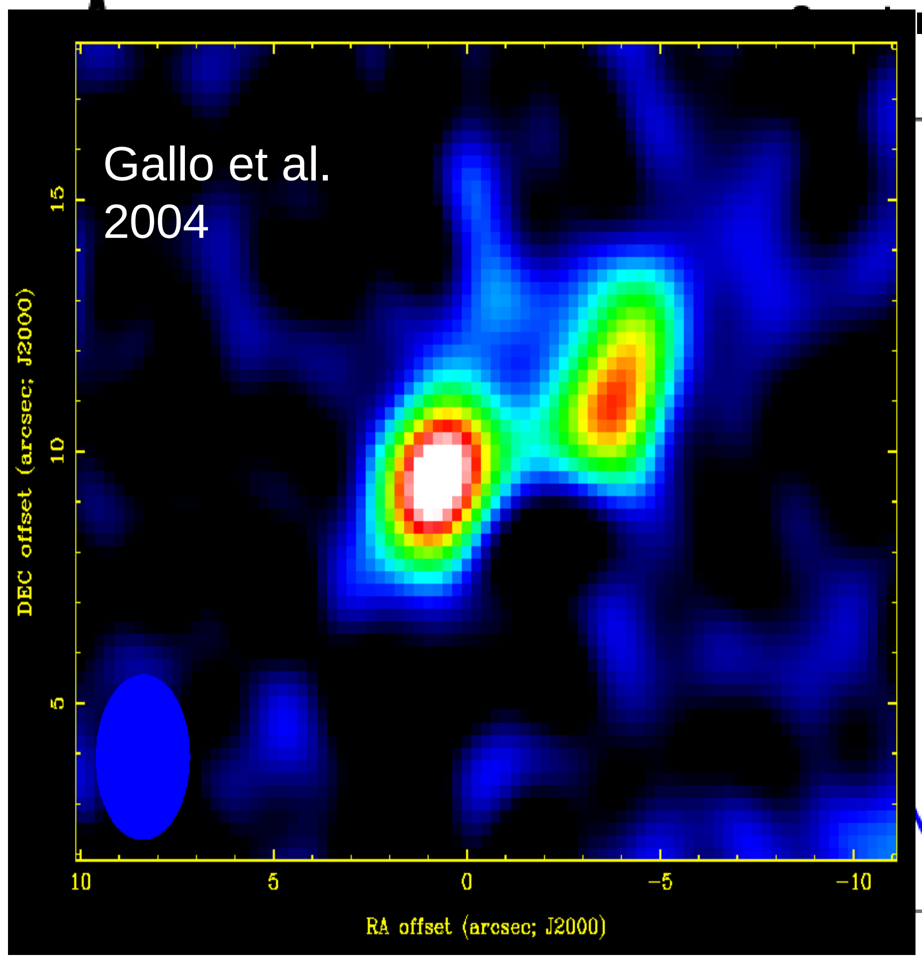
Massi & Kaufman Bernado 2009



Marscher & Gear

shock-in-jet model (1985)

http://isdc.unige.ch/~turler/jets/

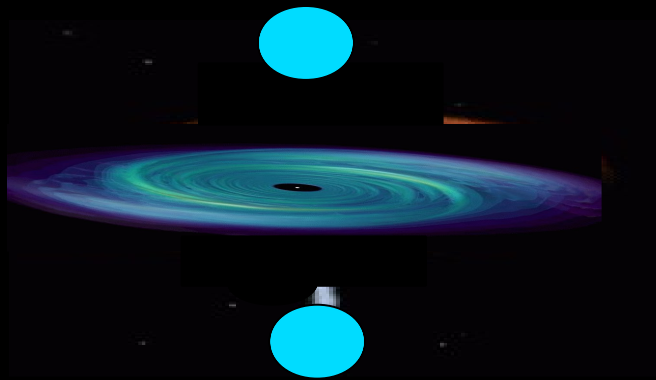


Marc Türler's review

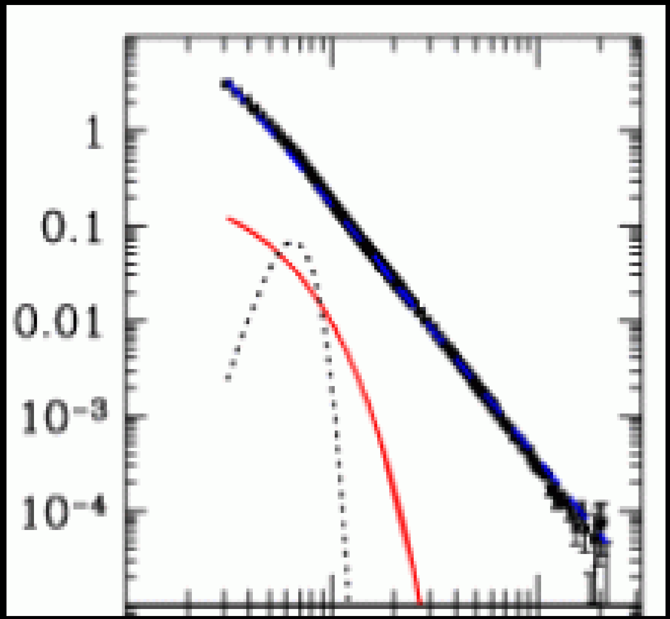
New highly-relativistic plasma catches up the **pre-existing slower-moving material** of the **steady jet** **giving rise to shocks...**

..that produce the optically thin outburst.

Radio



X-ray and Gamma- ray



Shock-in-jet model

Compton stage of the schock:

Dominant cooling mechanism is Inverse Compton losses (Synchrotron self-Compton, SSC) producing gamma rays

Reviews on high energy emission

STEADY JETS AND TRANSIENT JETS

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- ✓ Radio/X-ray Characteristics for X-ray Binaries
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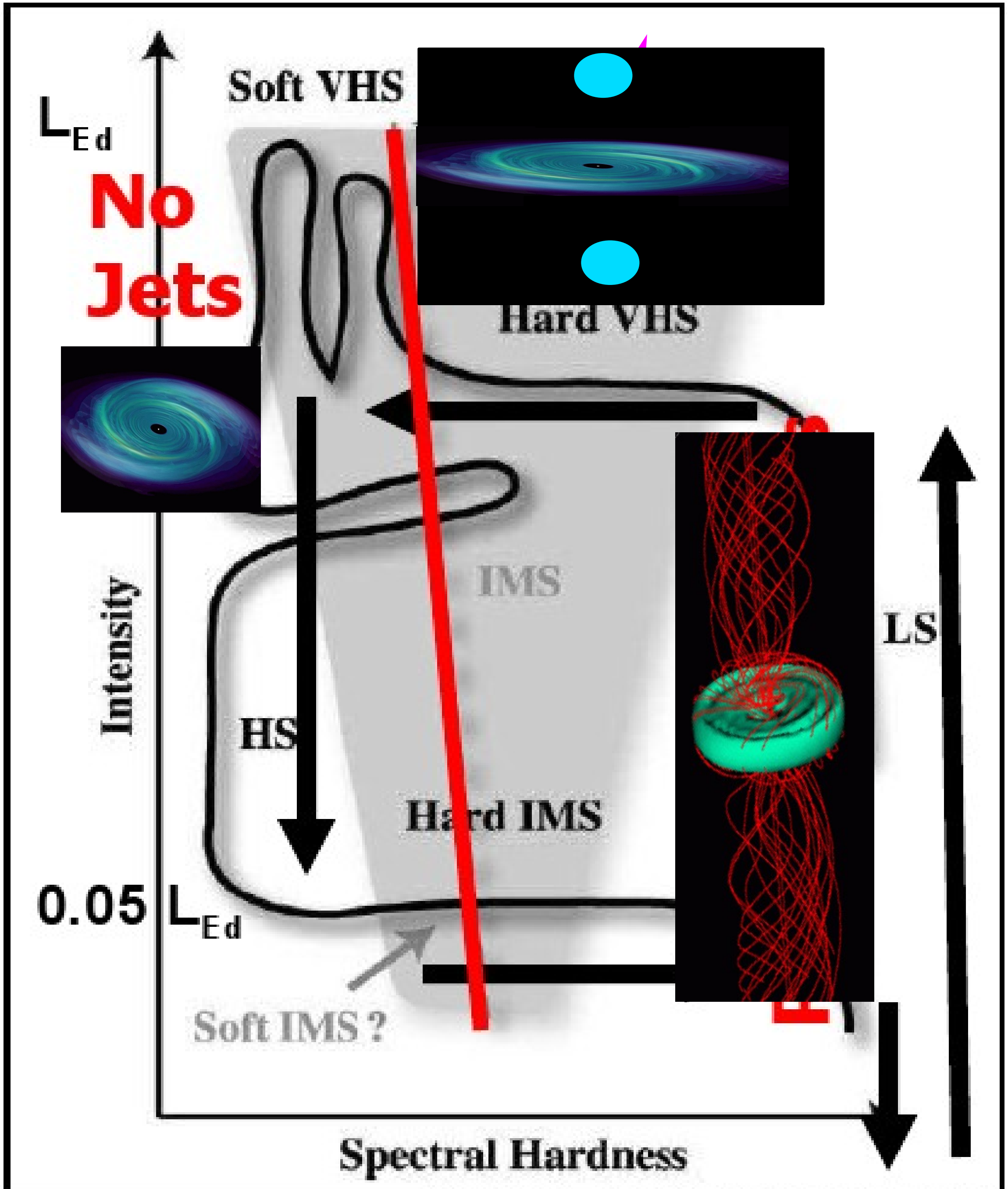
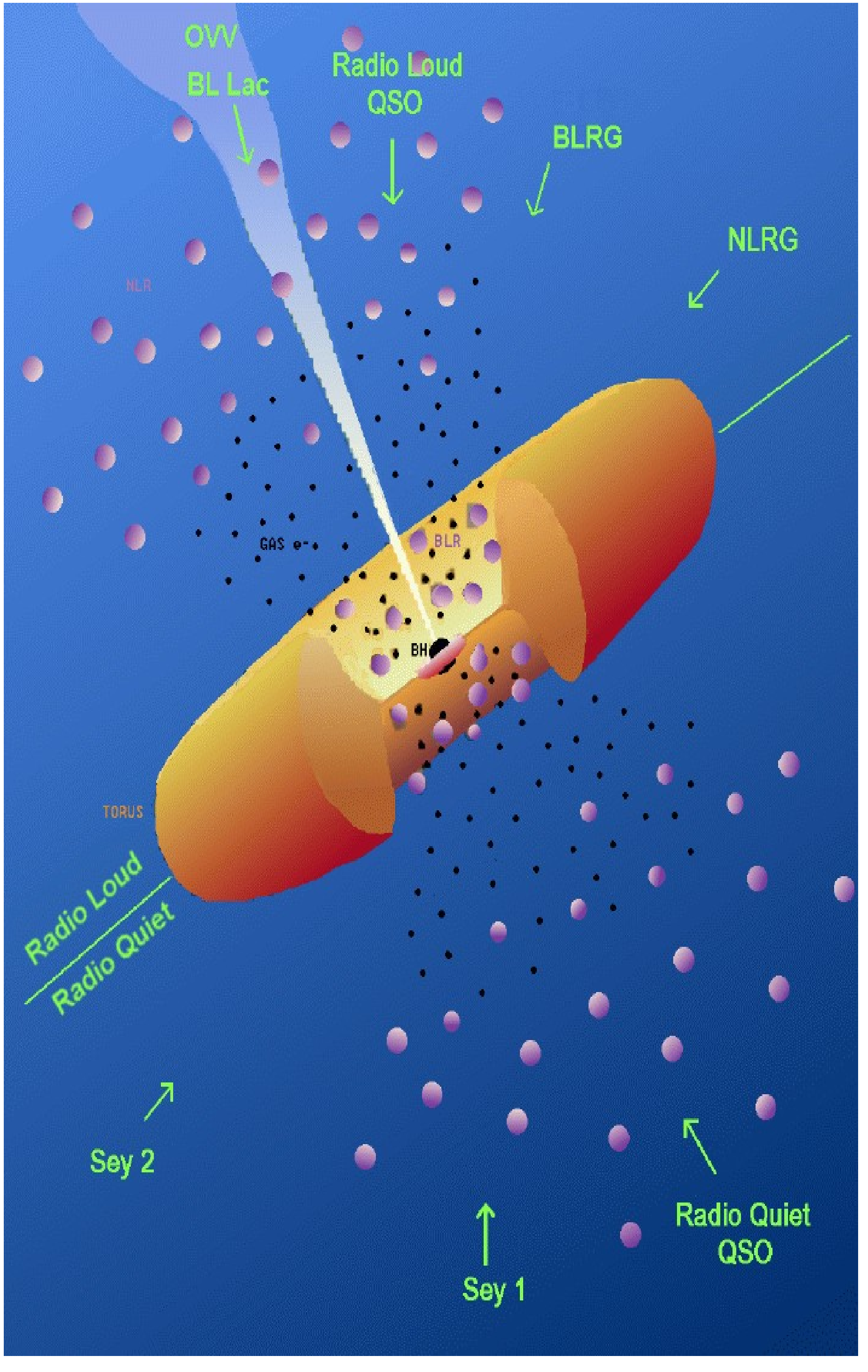
Accretion
States
μQuasars
➔
Hysteresis
in
Intensity
and Hardness
for
accretion
events

Camenzid 2008



Fender, Belloni & Gallo 2004

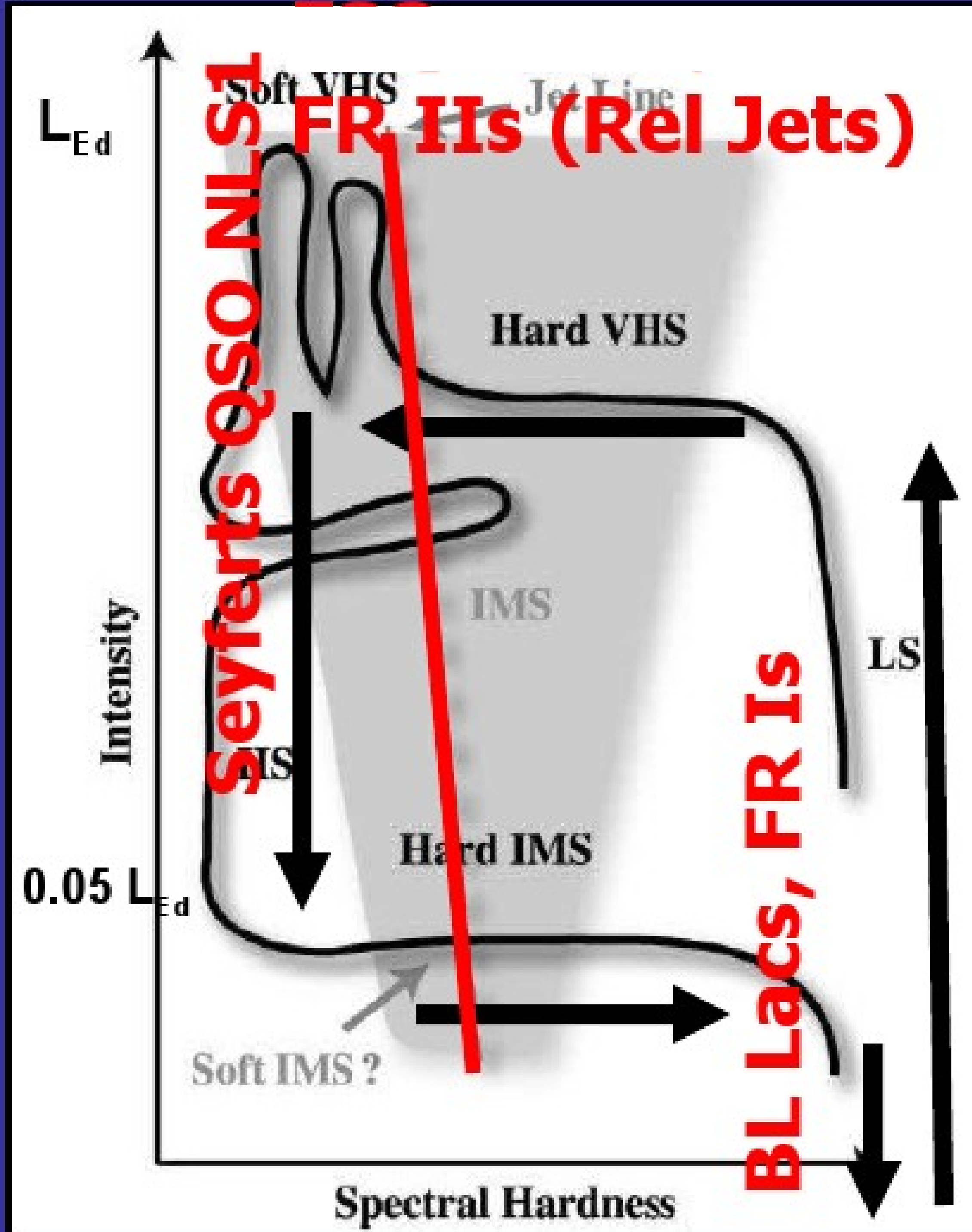


Some of the differences are due to the angle at which the AGN is observed

But clearly one cannot explain the division between radio loud and radio-quiet AGN with the geometry.

From Urry & Padovani (in bepposax/calendar)

Accretion States of AGN - Location in Intensity and „Hardness“ for accretion events



Koerding et al. 2006; …. ; Camenzind 2008

JETS in AGNs:

We may have emission associated to different outbursts and completely detached from the present activiy of the core

Complex scenario, where the shocked regions appear as

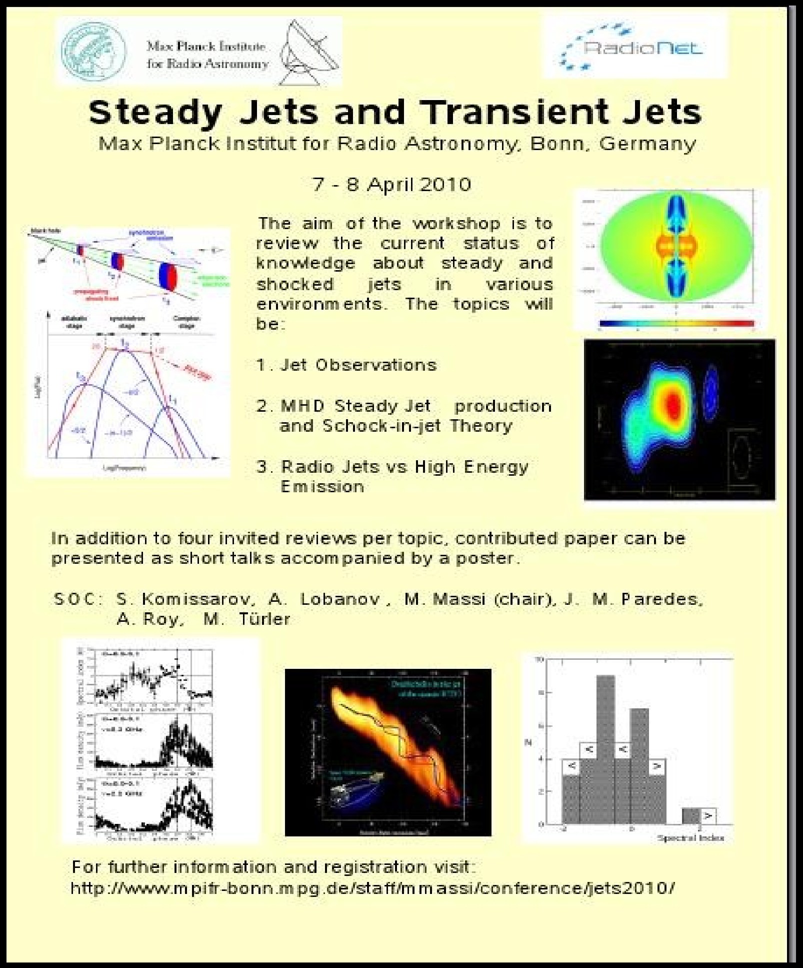
a sequence of bright
optically thin features
that move at relativistic velocity,

embedded in the steady jet, called for this reason in the AGN comunity, “underlying flow”.

Steady Jets and Transient Jets:

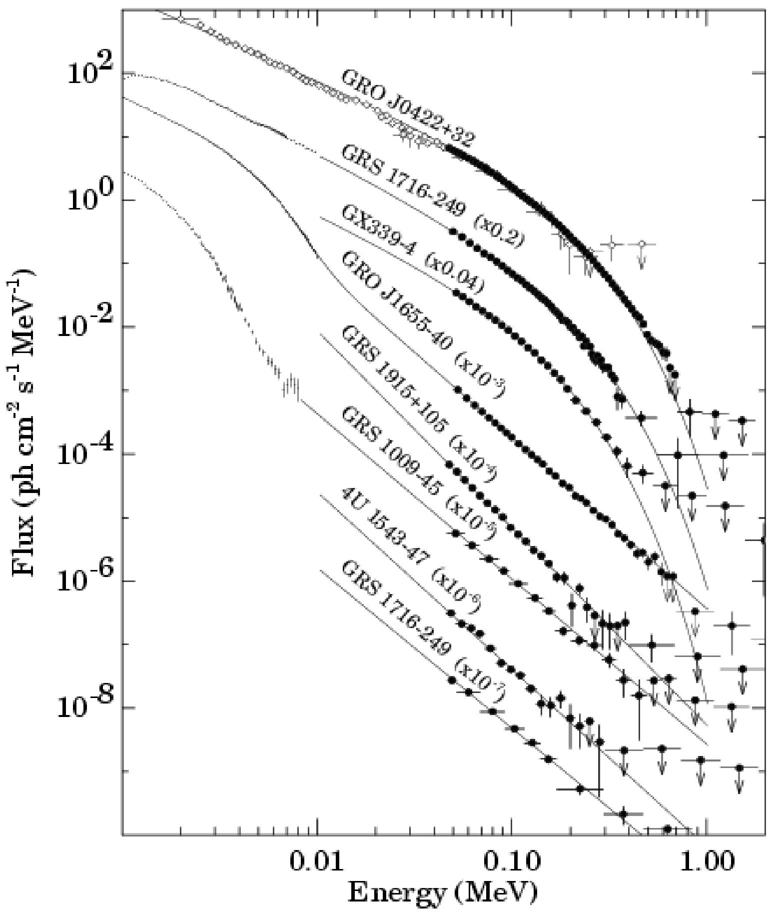
Radio / X-ray Characteristics

THANK YOU !



Steep Power Law

-



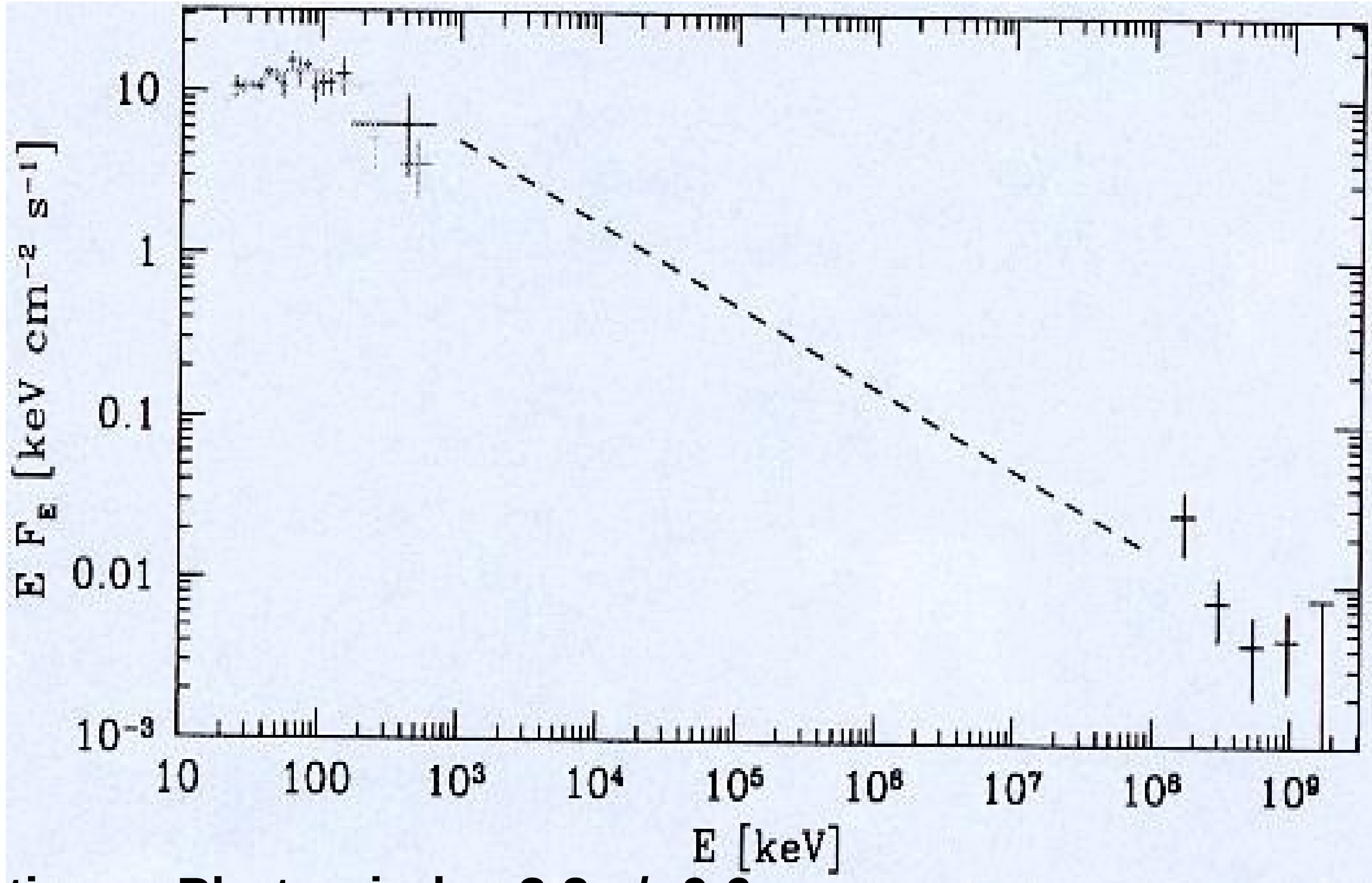
Grove et al. 1998

The physical origin of the SPL state remains one of the outstanding problems in high-energy astrophysics.

McClintock & Remillard 2006

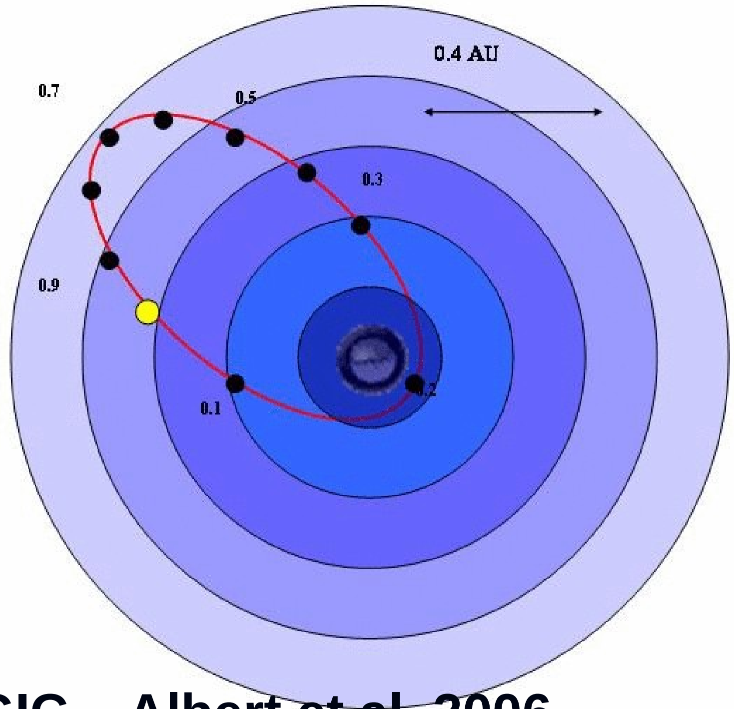
Malzac et al. 2008

Cyg X-1



MAGIC observations : Photon index 3.2 +/- 0.6
Tev emission can be extrapolated down to the Mev range with a power law with photon index 2.5 (Fig. 6 in Malzac et al. 2008).

& Sunyaev 1973). However, it has been found that the soft state of Cyg X–1 is not consistent with a thermal interpretation (Zhang et al. 1997b), and this has caused considerable confusion as to the proper way to understand Cyg X–1 and/or describe the HS state. In seeking a physical basis for describing X–ray states, it turns out that Cyg X–1 is not a good choice as a prototype, and further remarks about the states in Cyg X–1 are given in a separate section below (§4.3.9). **McClintock & Remillard 2006**



MAGIC Albert et al. 2006

- The average emission has a **maximum at phase 0.6**.
- Power law: Photon index ~ 2.6

„...We detect a simultaneous outburst at X-ray and VHE bands, with the peak at phase 0.62 and a similar shape at both wavelengths..........suggests that in LS I +61 303 the X-rays are the result of synchrotron radiation of the same electrons that produce VHE emission as a result of inverse Compton scattering of stellar photons...“
(MAGIC , Anderhub et al. 2009)

Emission at TeV energies

High/ Soft state

thermal X-ray emission from the accretion disk

no radio emission

Steep power-law state

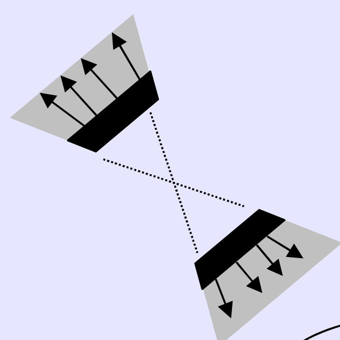
unbroken power law with
Γ~2.5-3.0

X-ray SSC/synchrotron emission
gamma-ray SSC emission

radio emission:

transient jet

$\alpha < 0$



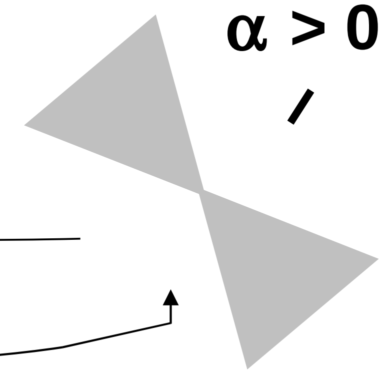
Low/Hard state

power law with
Γ~1.7 and cut-off at ~0.1 MeV
X-ray IC emission

radio emission:

steady jet

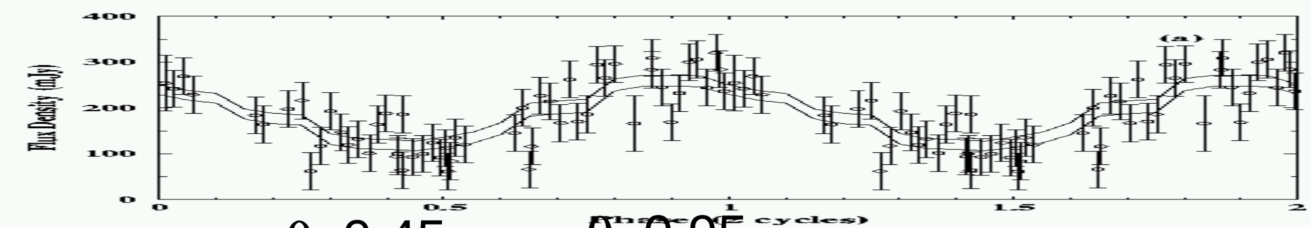
$\alpha > 0$



LS I + 61303

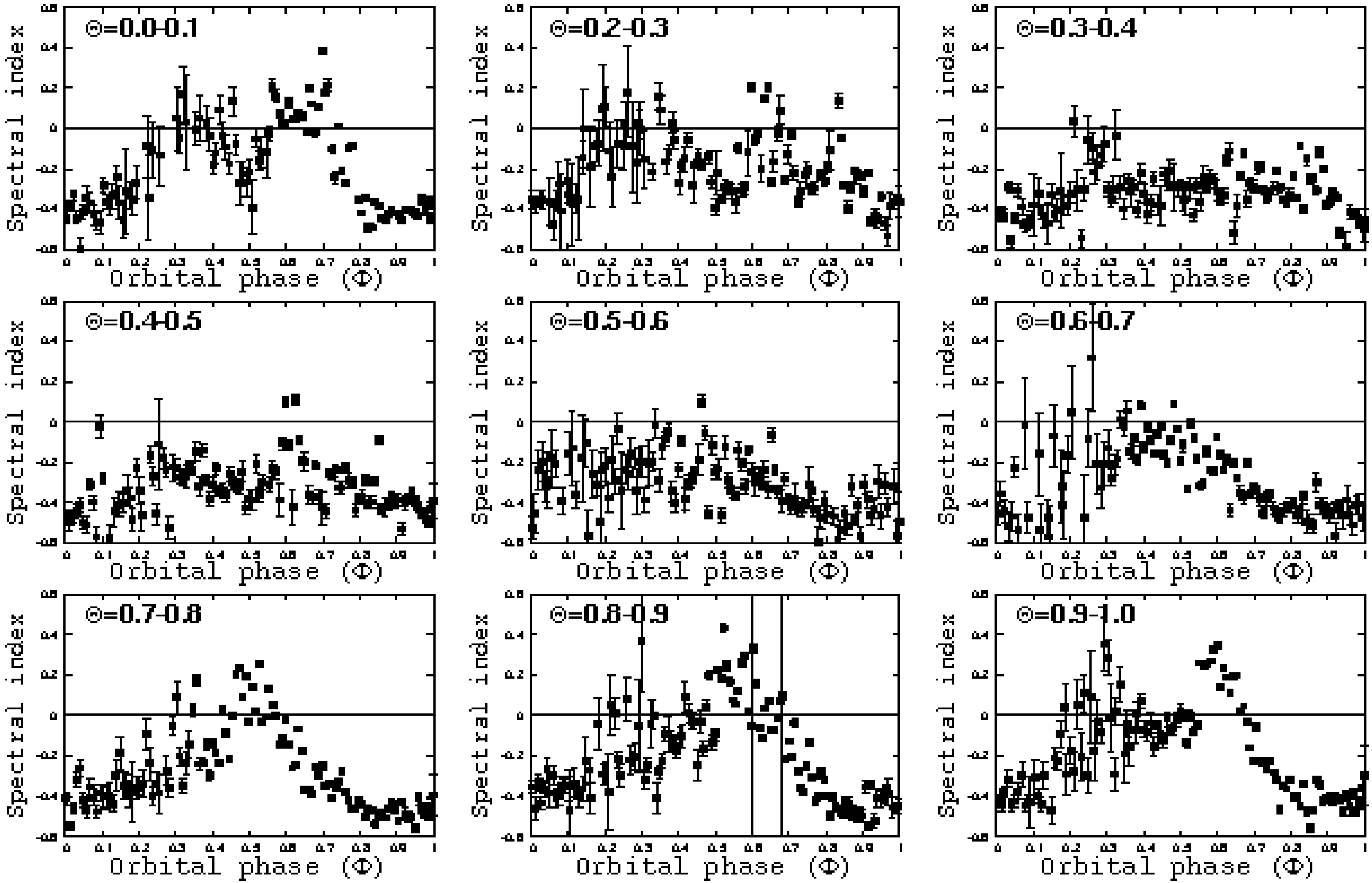
Massi & Zimmermann
2010

Hardness



4.6 yr

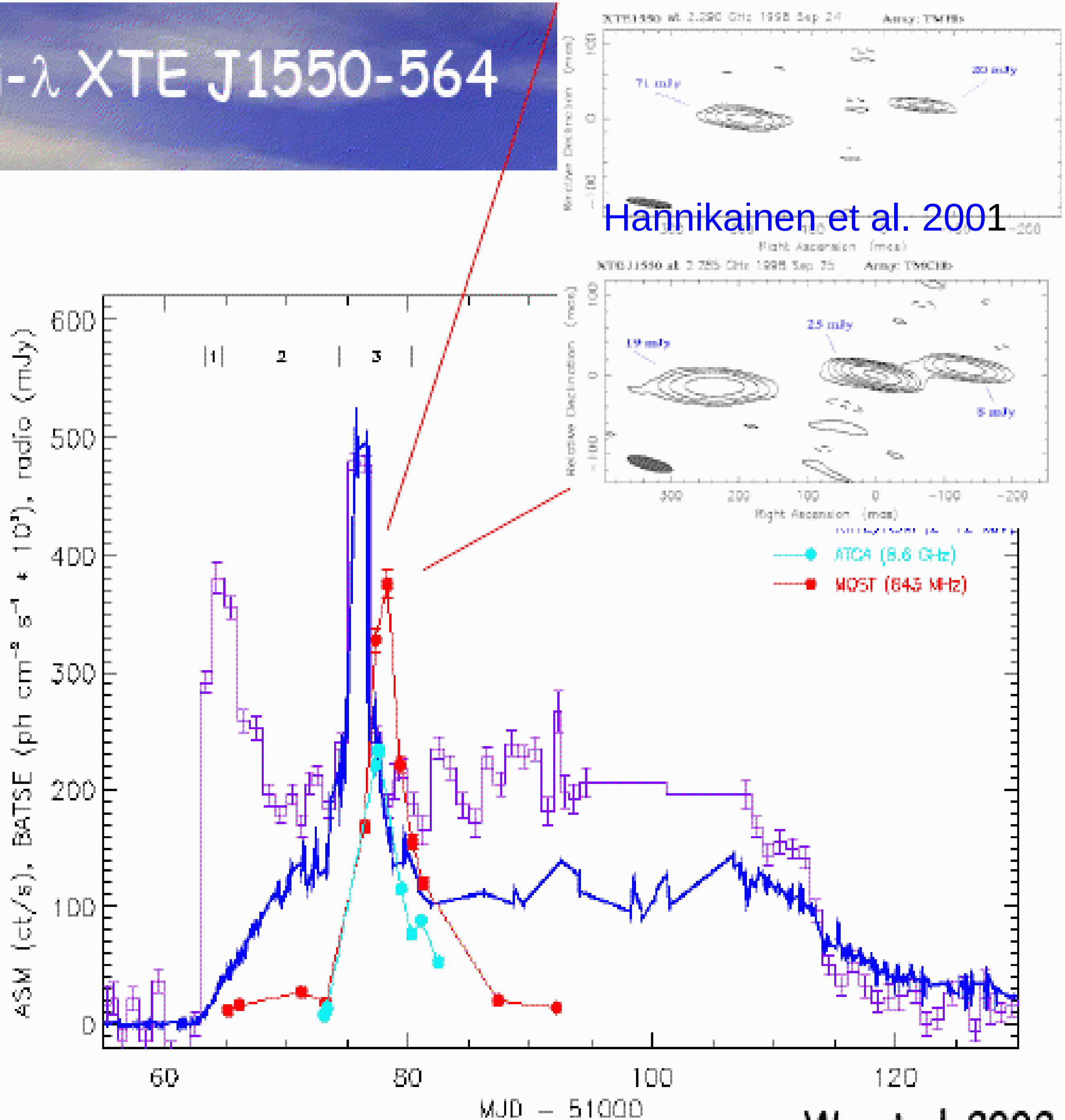
θ=0.45 θ=0.95



Massi & Kaufman Bernado 2009

Multi-λ XTE J1550-564

DH et al. 2001



Wu et al. 2002