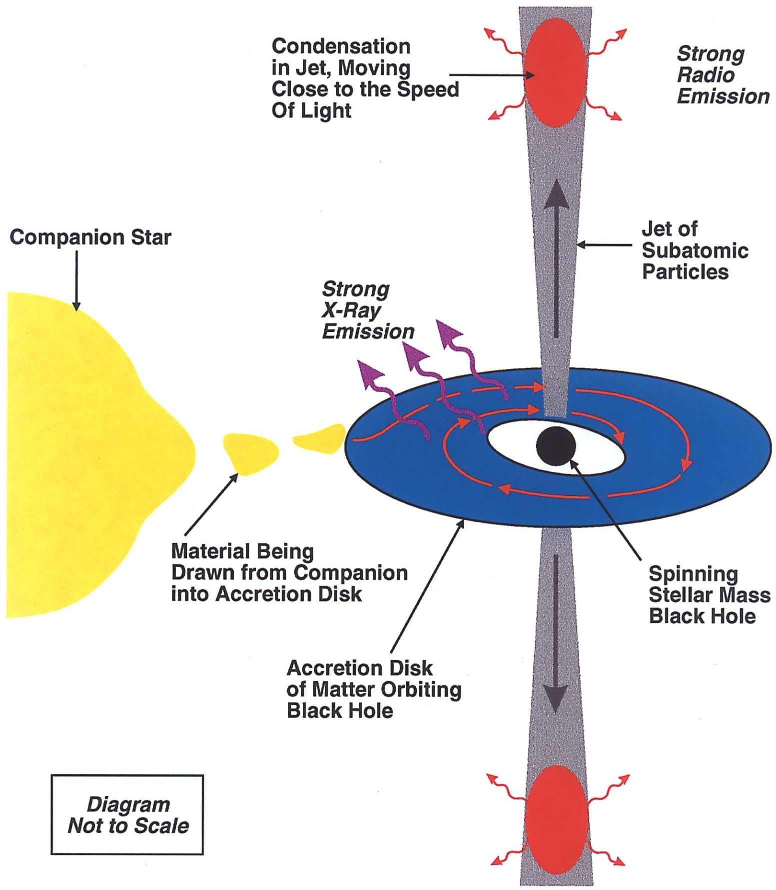
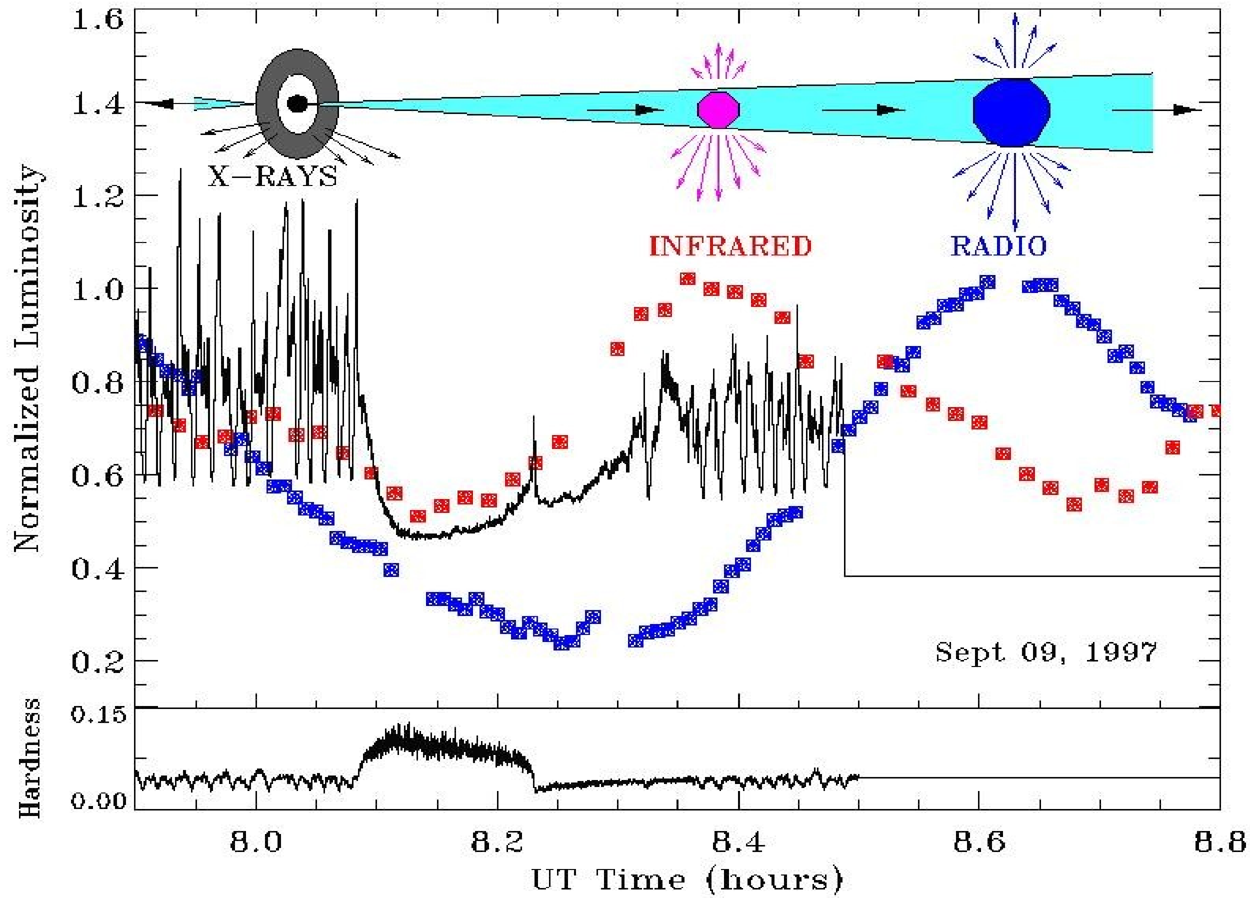
Radio Observations

ACCRETION–JET CONNECTION

$\Delta\tau \propto M_{BH}$

1 hr in GRS 1915+105 = 30 yr in SgrA* Mirabel et al. 1998





•THE TRIGGERS OF JETS ARE INSTABILITIES IN THE ACCRETION DISK (TRANSITION LOW HARD TO HIGH THE X-RAY "SPIKE" MARKS THE ONSET OF A SHOCK THROUGH THE COMPACT, STEADY JET

•ANALOGOUS ACCRETION-JET CONNECTION IN 3C 120 Marscher (2002)

Table 1. XRB systems with resolved radio jets.

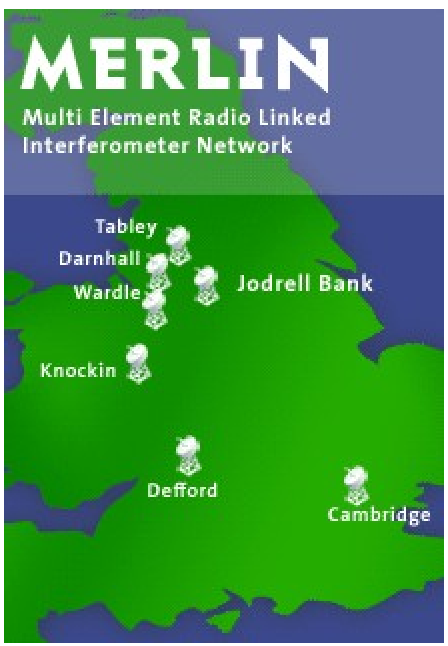
Name	Companion	Accretor	Jet size (AU)
		HMXBs	
LS I +61 303	B0V	NS/BH?	10–700
V 4641 Sgr	B9III	Black Hole	–
LS 5039	O6.5V((f))	NS/BH?	10–1000
SS 433	evolved A	NS/BH?	$10^4 - 10^6$
Cygnus X-1	O9.7Iab	Black Hole	40
Cygnus X-3	WNe	NS/BH?	10^4
		LMXBs	
Circinus X-1	Subgiant	Neutron Star	10^4
XTE J1550-564	G8-K5V	Black Hole	10^3
Scorpius X-1	Subgiant	Neutron Star	40
GRO J1655-40	F3/5IV	Black Hole	8000
GRS 1915+105	K-M III	Black Hole	$10 - 10^4$
GX 339-4		Black Hole	<4000
1E 1740.7-2942		NS/BH?	10^6
XTE J1748-288		NS/BH?	10^4
GRS 1758-258		NS/BH?	10^6

Massi (2005); Paredes (2005); Casares (2005).

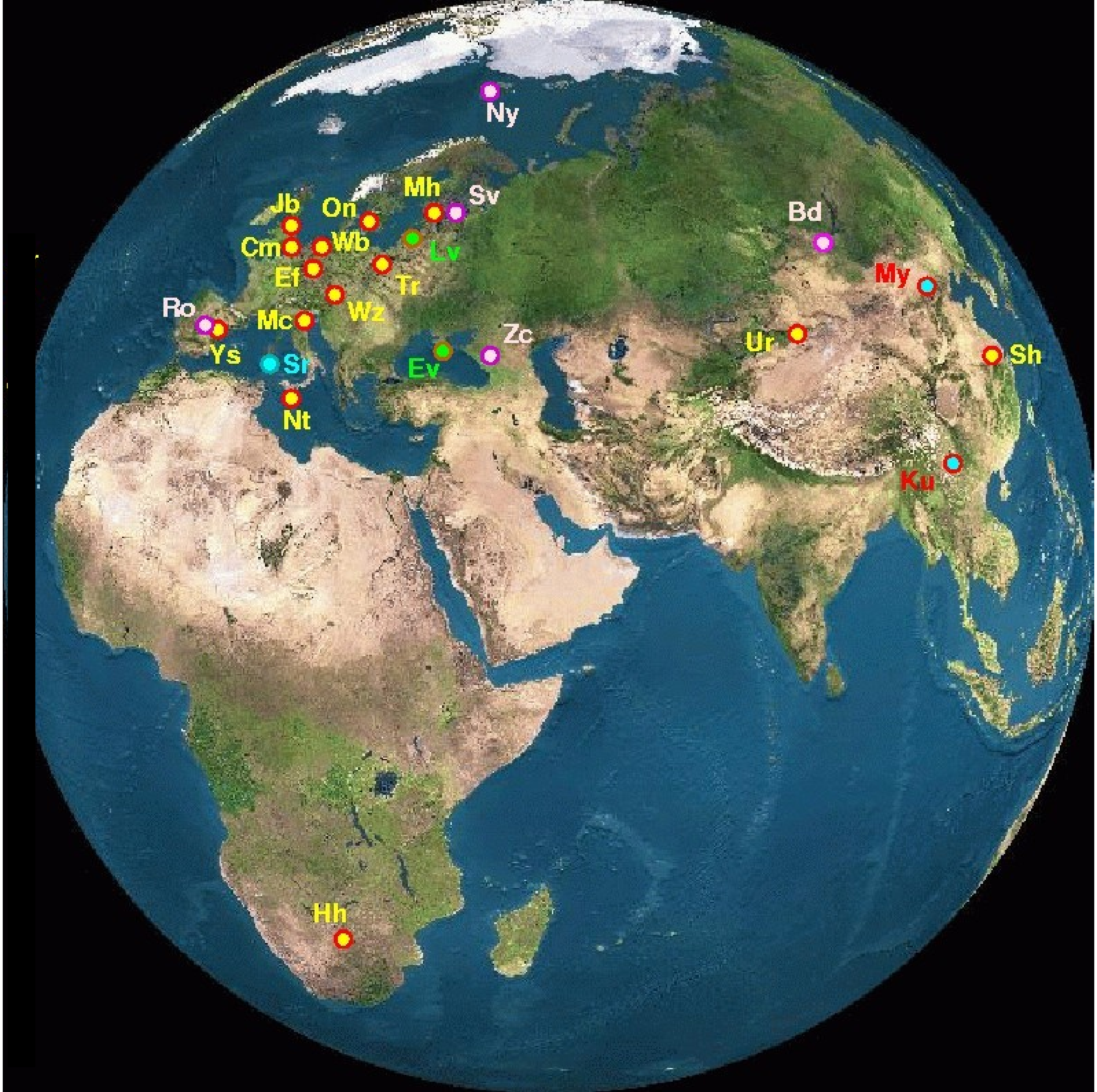
Y

VLA 27 Km

VLBA

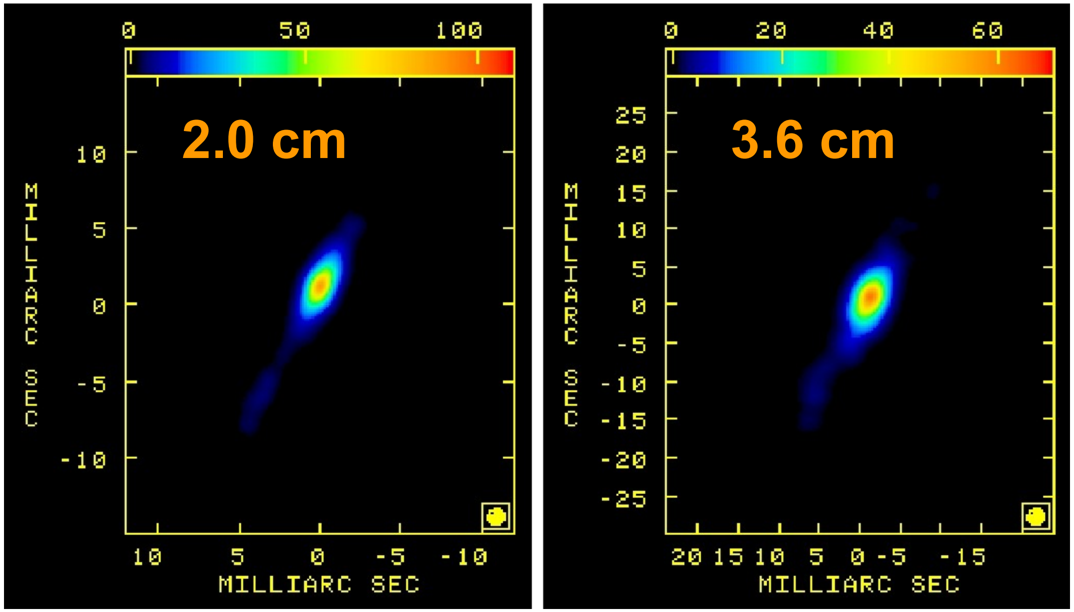


MERLIN 150 Km


Ny
Mh
Sv
Jb
On
Bd
Cm
Wb
Lv
Ef
Tr
My
Wz
Ro
Mc
Zc
Ys
Sr
Ev
Ur
Sh
Nt
Ku
Hh

COMPACT STEADY JETS

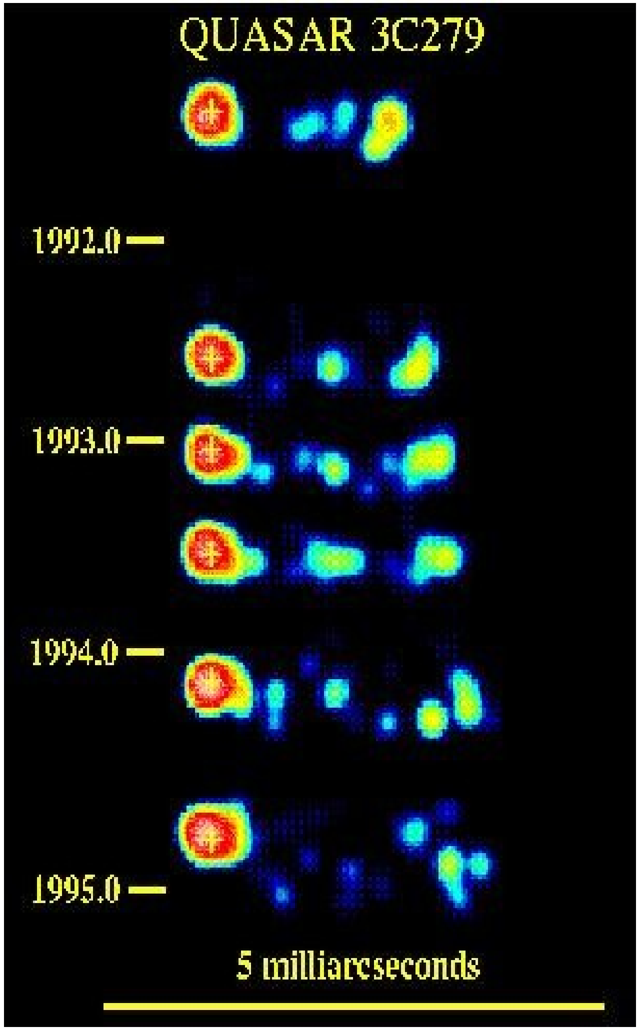
GRS 1915+105: Dhawan, Ribo & Mirabel (2006)

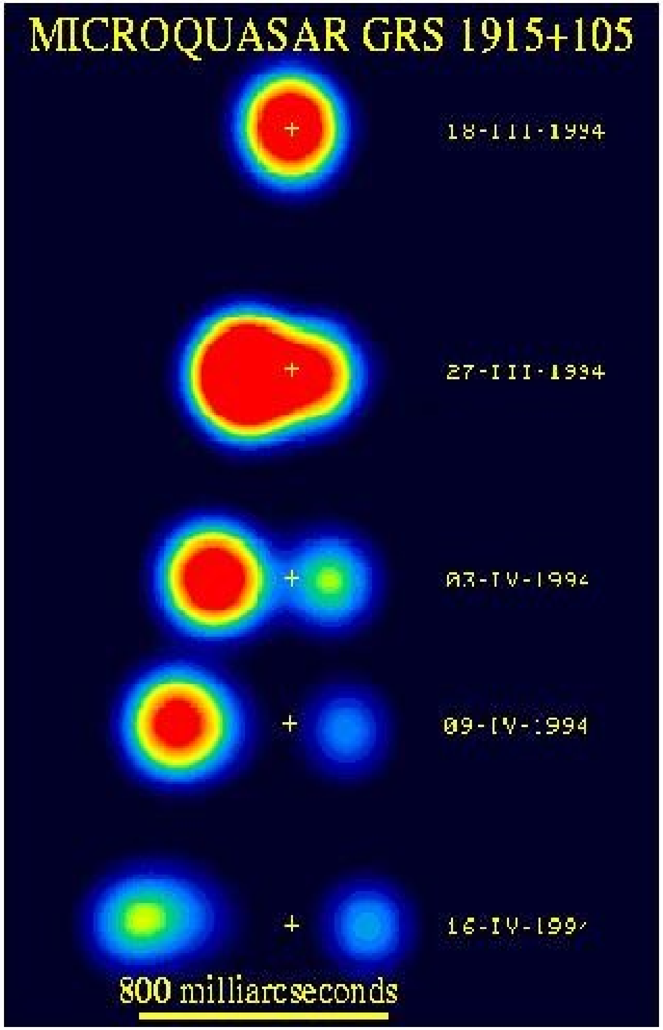


- ~100 AU IN LENGTH PRESENT DURING LOW HARD STATE
- SPEED OF THE FLOW < 0.4c (Dhawan, Ribo & Mirabel 2006)

SUPERLUMINAL MOTION IN THE GALAXY

Mirabel & Rodriguez, 1994





- μQSO JETS MOVE ON THE SKY ~10^3 TIMES FASTER THAN QSO JETS

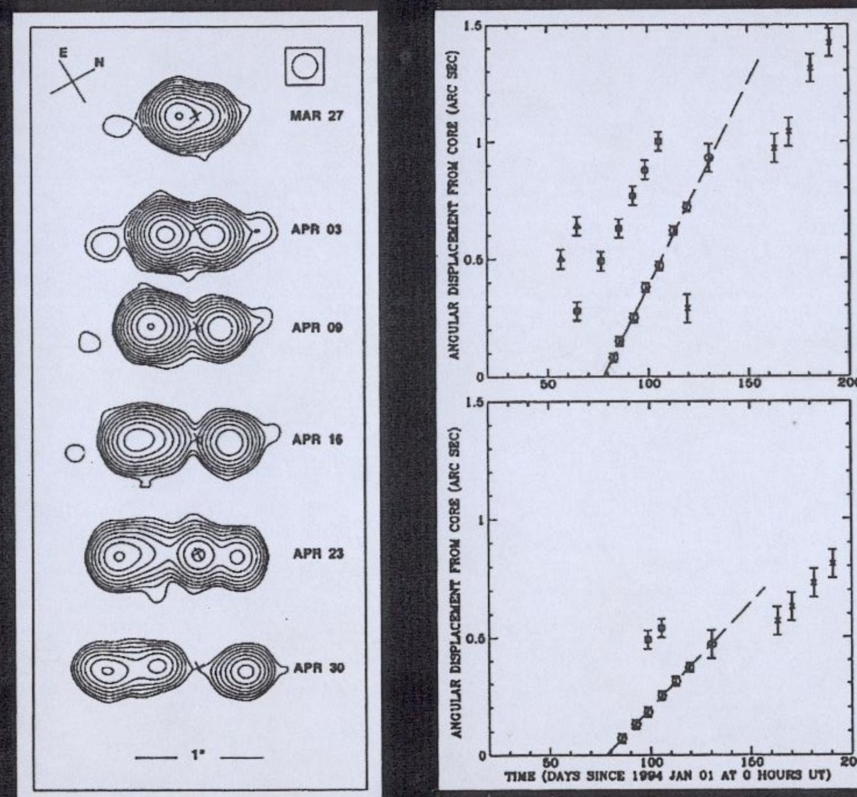
- IN AGN AT D<100 Mpc JETS ARE RESOLVED AT ~50 R_{sh} (e.g. M87,Biretta)

PHYSICS: NEED TO STUDY BHs ACROSS ALL MASS SCALES

Relativistic Jets

Relativistic jets known for many years in AGN

Spectacular examples seen recently in XRBs: Microquasars

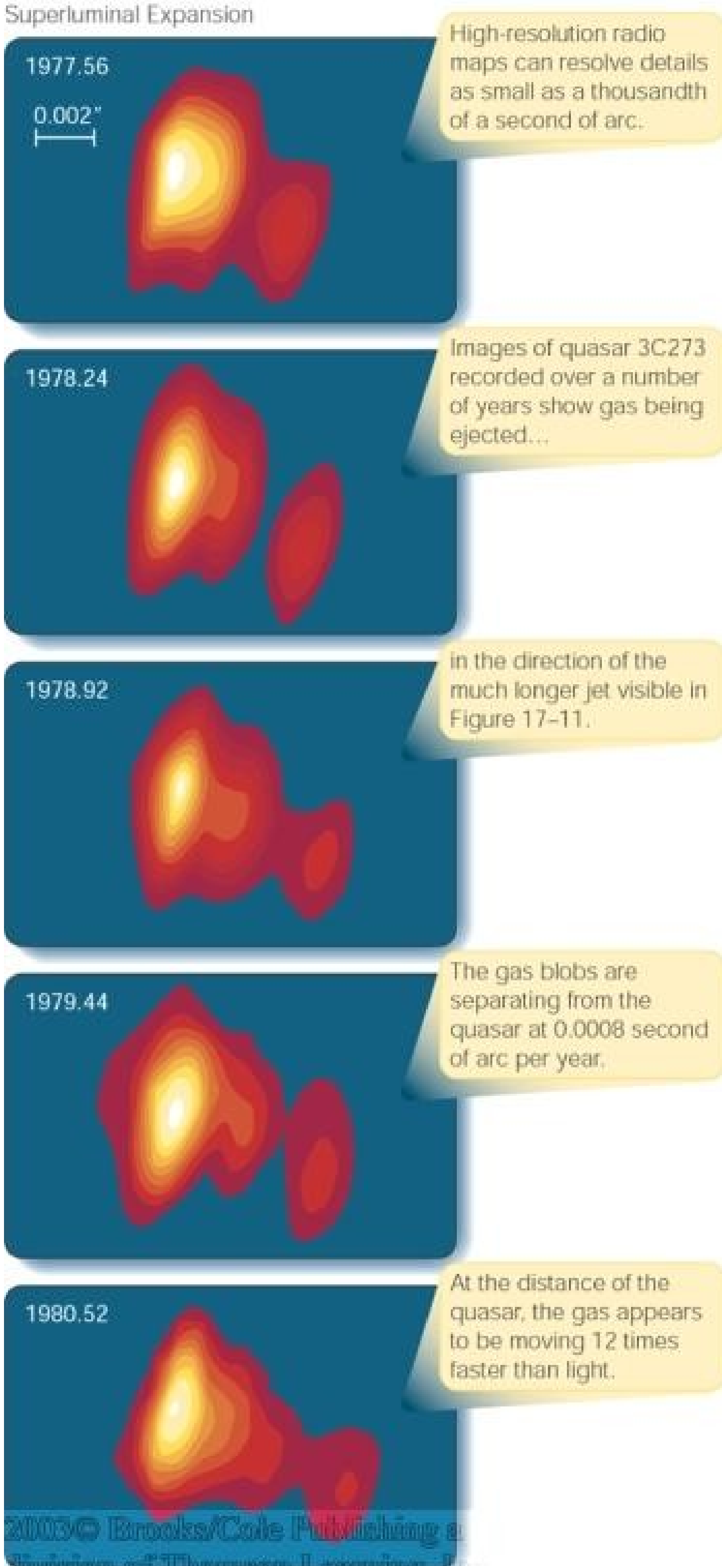


GRS 1915+105: Mirabel & Rodriguez (1995)

$\beta_a = \mu_a \frac{D}{c}$

$\beta_r = \mu_r \frac{D}{c}$

$\beta_a > 1$!



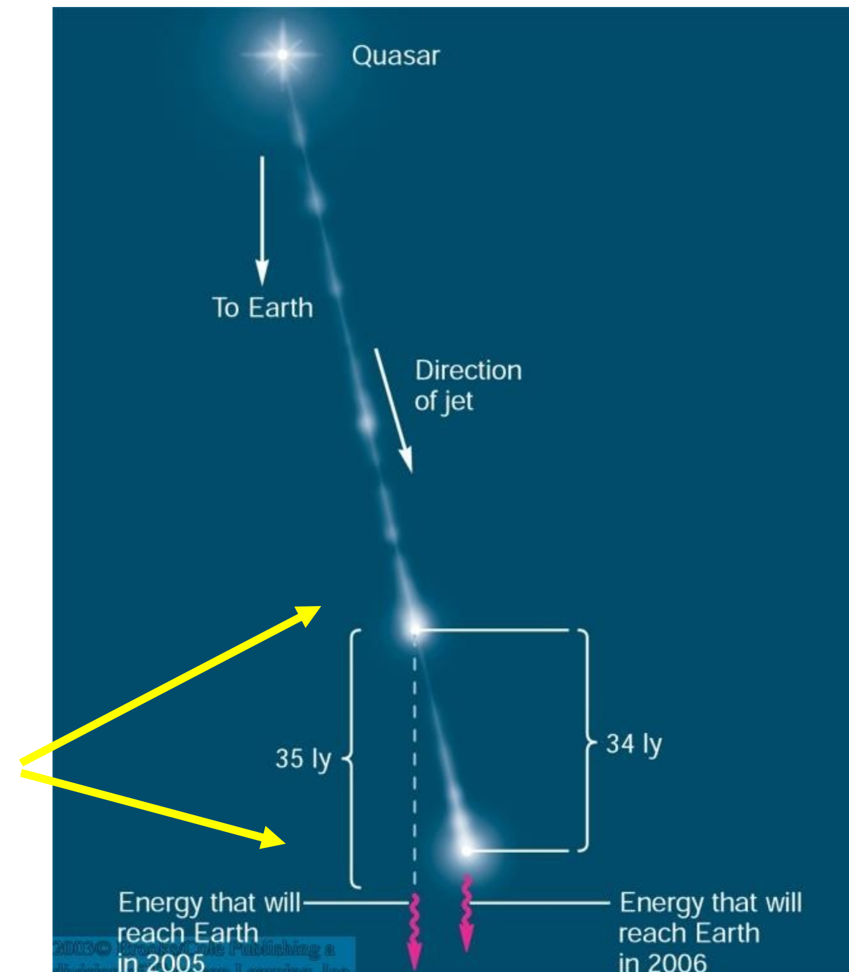
Superluminal Motion

Individual radio knots in quasar jets:

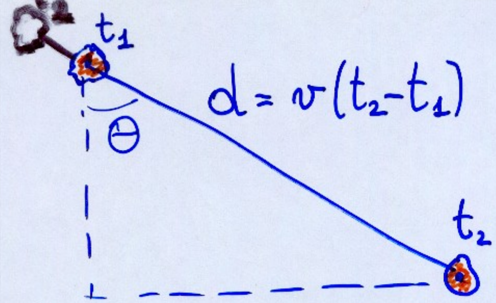
Sometimes apparently moving faster than speed of light!

Light-travel time effect:

Material in the jet is almost catching up with the light it emits



Apparent Superluminal Velocity



$$t_1' = t_1 + \frac{D}{c}$$

$$t_2' = t_2 + \frac{D}{c} - \frac{d\cos\Theta}{c}$$

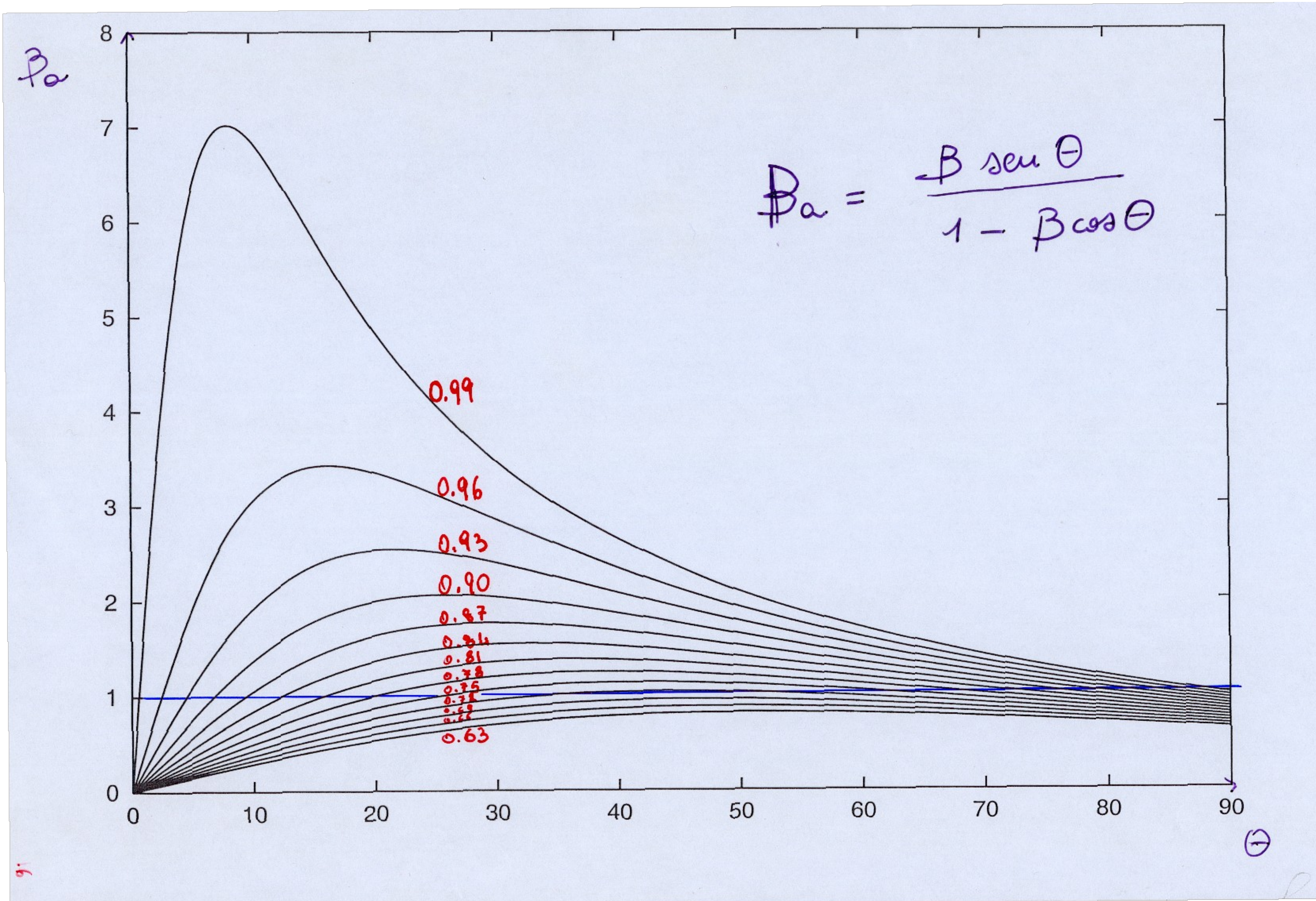
$$v_{approaching} = \mu \cdot D = \frac{d\,\mathrm{sen}\,\Theta}{t_2' - t_1'}$$

$$t_2' - t_1' = (t_2 - t_1) - \frac{v}{c}\cos\Theta\,(t_2 - t_1)$$

$$\Delta t' = \Delta t\left(1 - \frac{v}{c}\cos\Theta\right)$$

$$v_{approaching} = \frac{v\,(t_2 - t_1)\,\mathrm{sen}\,\Theta}{(t_2 - t_1) - (t_2 - t_1)\frac{v}{c}\cos\Theta}$$

$$\beta_{approaching} = \frac{\beta\,\mathrm{sen}\,\Theta}{1 - \beta\cos\Theta}$$



β_a
$\beta_a = \dfrac{\beta \operatorname{sen} \theta}{1 - \beta \cos \theta}$
0.99
0.96
0.93
0.90
0.87
0.84
0.81
0.78
0.75
0.63
0 1 2 3 4 5 6 7 8
0 10 20 30 40 50 60 70 80 90
θ

$$v_\perp(\text{apparent}) = \frac{\quad}{t(1 - v\cos\theta/c)}$$

$$\beta_\perp(\text{apparent}) = \frac{\beta\sin\theta}{1-\beta\cos\theta} \qquad (5F1)$$

For a fixed β, there is an angle θ that maximizes $\beta_\perp(\text{apparent})$. That angle satisfies

$$\frac{\partial\beta_\perp(\text{apparent})}{\partial\theta} = 0 = \frac{(1-\beta\cos\theta)\beta\cos\theta - (\beta\sin\theta)^2}{(1-\beta\cos\theta)^2}\ .$$

$$\beta\cos\theta - \beta^2\cos^2\theta - \beta^2\sin^2\beta = 0$$

$$\beta\cos\theta - \beta^2 = 0$$

Thus

$$\beta = \cos\theta \qquad (5F2)$$

and

$$\sin\theta = (1-\cos^2\theta)^{1/2} = (1-\beta^2)^{1/2} = \gamma^{-1} \qquad (5F3)$$

Inserting $\cos\theta = \beta$ and $\sin\theta = \gamma^{-1}$ into our equation for the $\beta_\perp(\text{apparent})$ yields the highest apparent transverse speed of a source

$$\boxed{\beta_\perp(\text{apparent}) = \frac{\beta\sin\theta}{1-\beta\cos\theta}} \qquad (5F1)$$

For a fixed β, there is an angle θ that maximizes $\beta_\perp(\text{apparent})$. That angle satisfies

$$\frac{\partial\beta_\perp(\text{apparent})}{\partial\theta} = 0 = \frac{(1-\beta\cos\theta)\beta\cos\theta - \ (\beta\sin\theta)^2}{(1-\beta\cos\theta)^2}\ .$$

$$\beta\cos\theta - \beta^2\cos^2\theta - \beta^2\sin^2\beta = 0$$

$$\beta\cos\theta - \beta^2 = 0$$

Thus

$$\boxed{\beta = \cos\theta} \qquad (5F2)$$

and

$$\boxed{\sin\theta = (1-\cos^2\theta)^{1/2} = (1-\beta^2)^{1/2} = \gamma^{-1}} \qquad (5F3)$$

Inserting $\cos\theta = \beta$ and $\sin\theta = \gamma^{-1}$ into our equation for the $\beta_\perp(\text{apparent})$ yields the highest apparent transverse speed of a source whose actual speed is β:

Thus

$$\beta = \cos\theta \quad (5F2)$$

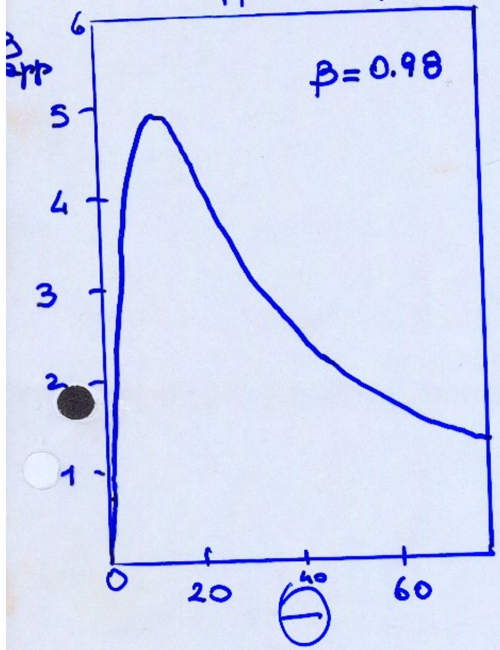
and

$$\sin\theta = (1 - \cos^2\theta)^{1/2} = (1 - \beta^2)^{1/2} = \gamma^{-1} \quad (5F3)$$

Inserting $\cos\theta = \beta$ and $\sin\theta = \gamma^{-1}$ into our equation for the $\beta_\perp(\mathrm{apparent})$ yields the highest apparent transverse speed of a source whose actual speed is β:

$$\max[\beta_\perp(\mathrm{apparent})] = \frac{\beta(1 - \beta^2)^{1/2}}{1 - \beta^2} = \beta\gamma \quad (5F4)$$

Apparent Speed vs. Angle to the line of sight



$$\beta_{app} = \frac{\beta \sin\Theta}{1 - \beta\cos\Theta}$$

$\beta_{app}^{MAX} = 4.9$ for $\Theta = 11^\circ$ $\cos\Theta = 0.98$, $\beta = 0.98$

true in general:

$\cos\Theta = \beta \longrightarrow \beta_{app}^{MAX} = \frac{\beta}{\sqrt{1-\beta^2}}$

for $\beta = 0.999$ $(\gamma = 22)$ and $\Theta = 2.5^\circ$ $\beta_{app}^{MAX} = 31$

$\beta \to 1$ and $\Theta \to 0$ largest effect! [MAXIMUM]

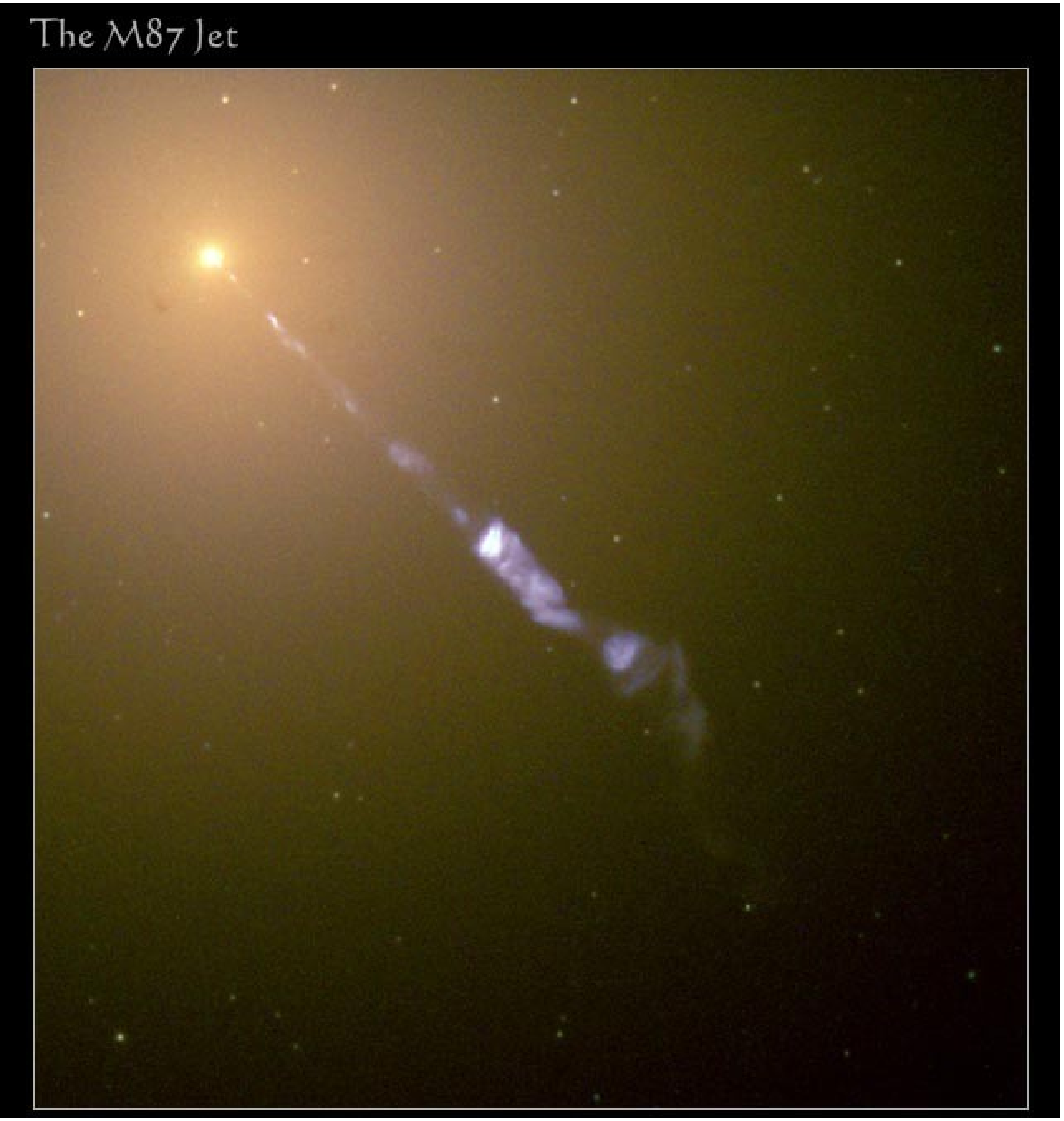
MINIMUM - sine qua non ....

To have the apparent superluminal motion:

1) $\cos\Theta = \beta$
2) $\beta \geq 0.75$

$\Rightarrow \beta_{app} \geq 1.1$

SUPERLUMINAL MOTIONS IN QSOs & AGN



- OBSERVED IN > 30 QSOs & AGN
- IN RADIO & OPTICAL WAVES
- PROPER MOTION SEEN IN YEARS
- V_{app} UP TO 30c in blazars
- One sided because of Doppler boosting

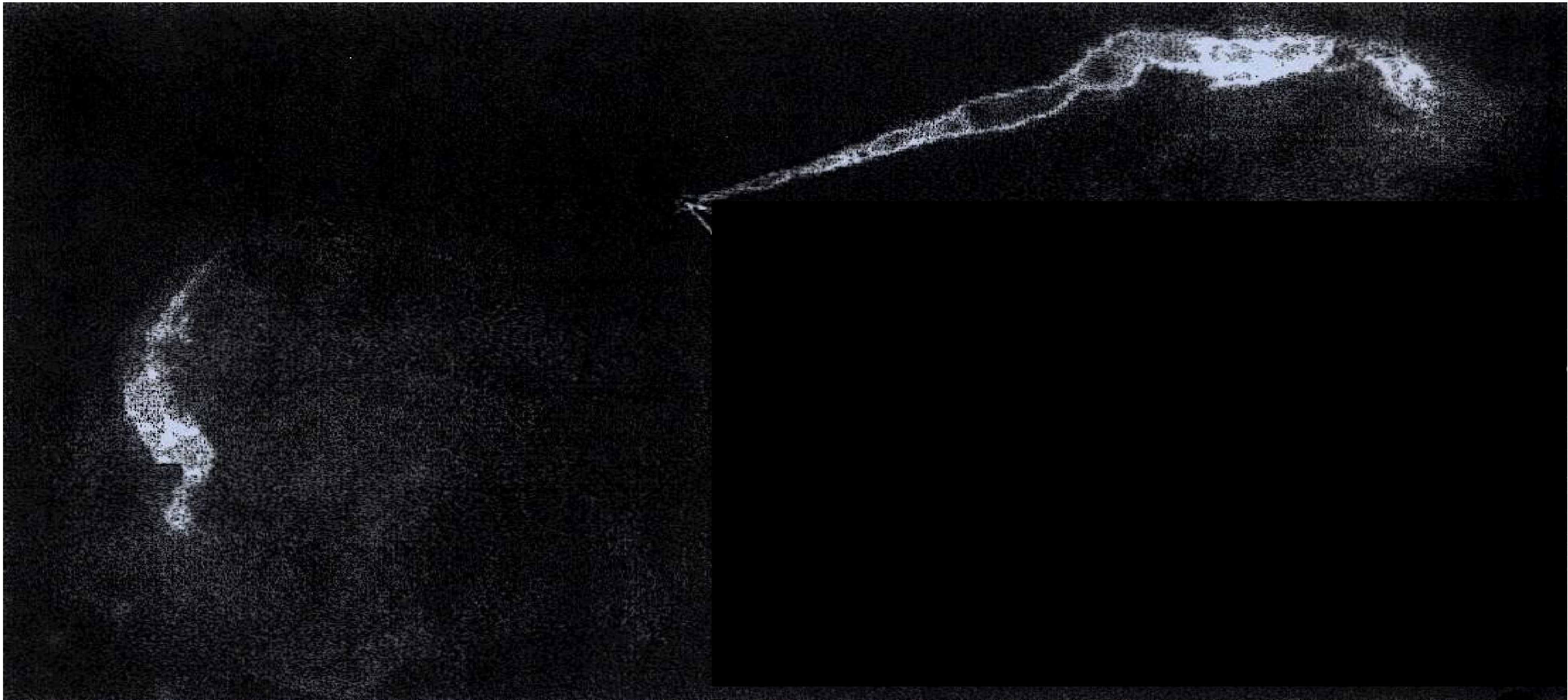
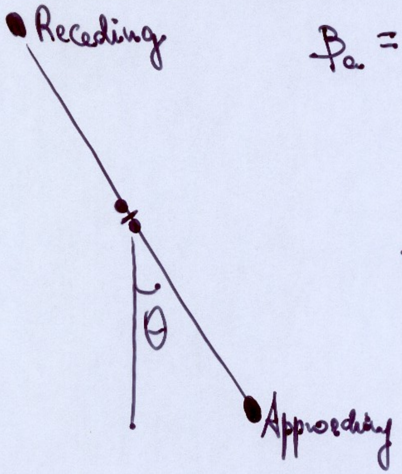


Fig. 1. The jet in the galaxy M87 displays most of the important features of relativistic jets. T
approaching northwest jet is Doppler boosted, whereas the southeast one is virtually undete al
ecause it radiates away from Earth. The lobes, consisting of decelerated jet material, radia
sotropically, and therefore both are visible. The full extent of the source projected on the sky
his image is $\sim$80 arc sec or 6 kpc. Because the source is at an angle of $<19°$ to our line of sig
ts deprojected length must be at least 20 kpc. Deep in the core (inset), the jet shows an initial wi
pening angle (60°) that decreases with distance from the core. This indicates that the accelerati
nd collimation region may be resolved. The length of the jet emission in the inset is $\sim$0.001 a
ec or 16,000 astronomical units, which is only $\sim$250 times the Schwarzschild radius of the cent
3 $\times 10^9 M_\odot$ black hole. [Images were made with the National Radio Astronomy Observatory's Ve
arge Array and Very Long Baseline Array and are courtesy of J. Biretta and W. Junor; reprinted
ermission from *Nature* (37) copyright (1999) Macmillan Magazines Ltd.]



$$\beta_a = \frac{\beta \sin\theta}{1-\beta\cos\theta}$$

$$\beta_r = \frac{\beta \sin\theta}{1+\beta\cos\theta}$$

DOPPLER BOOSTING

$$\nu_a = \frac{\nu}{\gamma(1-\beta\cos\theta)} \qquad \nu_r = \frac{\nu}{\gamma(1+\beta\cos\theta)}$$

$$S_a = S_0\left[\frac{1}{\gamma(1-\beta\cos\theta)}\right]^{k-\lambda}$$

$$S_r = S_0\left[\frac{1}{\gamma(1+\beta\cos\theta)}\right]^{k-\lambda}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$\text{Doppler factor} = \frac{1}{\gamma(1-\beta\cos\theta)}$$

$\beta \ll 1$ $\quad$ Doppler factor $\simeq 1+\beta\cos\theta$

$$\nu = \frac{\nu_0}{\gamma} \cdot \frac{1}{(1-\beta\cos\theta)} = \nu_0\frac{\sqrt{1-\beta^2}}{(1-\beta\cos\theta)} \quad (*)$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = \frac{v}{c}$$

$\beta \simeq 0$

$$f = f(0) + \left.\frac{\partial f}{\partial \beta}\right|_{\beta=0}(\beta - 0)$$

$$f(0) = \nu_0$$

$$f' = \nu_0\left[\frac{\frac{1}{2}2\beta(1-\beta^2)^{-1/2}(1-\beta\cos\theta) - (1-\beta^2)^{1/2}(-\cos\theta)}{(1-\beta\cos\theta)^2}\right]$$

$$\left.f'\right|_{\beta=0} = \cos\theta \cdot \nu_0$$

$$\nu = \nu_0 + \nu_0\cos\theta\,\beta = \nu_0 + \nu_0\frac{v}{c}\cos\theta$$

$$\nu - \nu_0 = \nu_0\frac{v}{c}\cos\theta \qquad \nu = \nu_0[\beta\cos\theta + 1]$$

$$\frac{\Delta\nu}{\nu_0} = \frac{v}{c}\cos\theta$$

$$\frac{\nu-\nu_0}{\nu_0} = \frac{\lambda_0}{c}\left(\frac{c}{\lambda} - \frac{c}{\lambda_0}\right) = \frac{\lambda_0}{c}\left(\frac{c\lambda_0 - c\lambda}{\lambda\lambda_0}\right) = \frac{\lambda_0 - \lambda}{\lambda}$$

$(*)$

$$\nu - \nu_0 = \frac{\nu_0\sqrt{1-\left(\frac{v}{c}\right)^2}}{\left(1-\frac{v}{c}\cos\theta\right)} - \nu_0$$

$$\frac{\Delta\nu}{\nu_0} = \frac{\sqrt{1-\left(\frac{v}{c}\right)^2}}{\left(1-\frac{v}{c}\cos\theta\right)} - 1$$

Superluminal motions

$$\beta_a = \mu_{app}\frac{D}{c} = \frac{\beta\sin\Theta}{(1-\beta\cos\Theta)}$$

$$\beta_r = \mu_{rec}\frac{D}{c} = \frac{\beta\sin\Theta}{1+\beta\cos\Theta}$$

$$\beta\cos\Theta = \frac{\mu_{app}-\mu_{rec}}{\mu_{app}+\mu_{rec}}$$

$$\Theta = \tan^{-1}\left[1.16\times10^{-2}\left(\frac{\mu_{app}\mu_{rec}}{\mu_{app}-\mu_{rec}}\right)D\right]$$

Doppler Boosting

$$\delta_a = \frac{\nu_a}{\nu_0} = \gamma^{-1}(1-\beta\cos\Theta)^{-1}$$

$$\delta_r = \frac{\nu_r}{\nu_0} = \gamma^{-1}(1+\beta\cos\Theta)^{-1}$$

$$\frac{S_a}{S_0} = \delta_a^{k-\alpha} \; ; \; \frac{S_{rec}}{S_0} = \delta_{rec}^{k-\alpha}$$

$$\frac{S_a}{S_r} = \left(\frac{1+\beta\cos\Theta}{1-\beta\cos\Theta}\right)^{k-\alpha}$$

Appendix A: Lower limit of β

The ratio of observed flux densities from a twin pair of optically-thin emitting jets (approaching and receding), with intrinsic velocity βc and angle between the ejection and the line of sight θ, is:

$$\frac{S_a}{S_r} = \left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)^{k-\alpha}, \quad \text{(A1)}$$

where k is 2 for a continuous jet and 3 for discrete condensations, and α is the spectral index of the source.

If we assume that the twin jets are gaussian like, then the density flux is:

$$S = \frac{\text{Peak(mJy/beam)}\Omega_{\text{source}}}{\Omega_{\text{beam}}} \quad \text{(A2)}$$

where Ω_{source} and Ω_{beam} are the solid angles of source and beam. Hence, the ratio of the flux densities of the twin components can be expressed as:

$$\frac{S_a}{S_r} = \frac{\text{Peak}_\text{a}\text{(mJy/beam)}\Omega_{\text{source}_\text{a}}}{\text{Peak}_\text{r}\text{(mJy/beam)}\Omega_{\text{source}_\text{r}}} \quad \text{(A3)}$$

If in a map we deal with the approaching jet only, we can set as upper limit for the Peak_r the 3σ level of the map. An upper limit for Ω_r is Ω_a, because the receding component is expected to be compressed with respect to the approaching one. Then we can write:

$$\frac{S_a}{S_r} > \frac{\text{Peak}_\text{a}\text{(mJy/beam)}}{3\sigma} \quad \text{(A4)}$$

Combining eq. A1 and eq. A4 we obtain:

$$\beta\cos\theta > \frac{\left(\frac{\text{Peak}_\text{a}}{3\sigma}\right)^{\frac{1}{k-\alpha}} - 1}{\left(\frac{\text{Peak}_\text{a}}{3\sigma}\right)^{\frac{1}{k-\alpha}} + 1} \quad \text{(A5)}$$

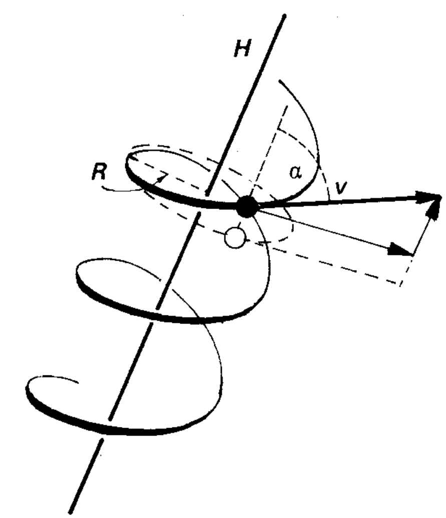
Relativistic electrons in a magnetic field

$$E = \gamma m_e c^2 \quad \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$\gamma >> 1$

For one electron, max frequency γ^2

Electron energy distribution is a power law: $N(E)dE = kE^{-p}dE$



Radiative Transfer Equation

R.T: process of transmission of the electro-magnetic radiation through the atmosphere

$$\frac{dI}{dz} = J - KI$$

J ↑ emissivity

K ↑ absorption coefficient

$I(\theta, \varphi, z, \nu)$ Intensity in erg cm^{-2} sterad^{-1} s^{-1} Hz^{-1}

Flux Density

$$S = \int I \, d\Omega$$

$$d\Omega = \sin\theta \, d\theta \, d\varphi$$

$$0 < \theta < \frac{\Theta_{source}}{2}$$

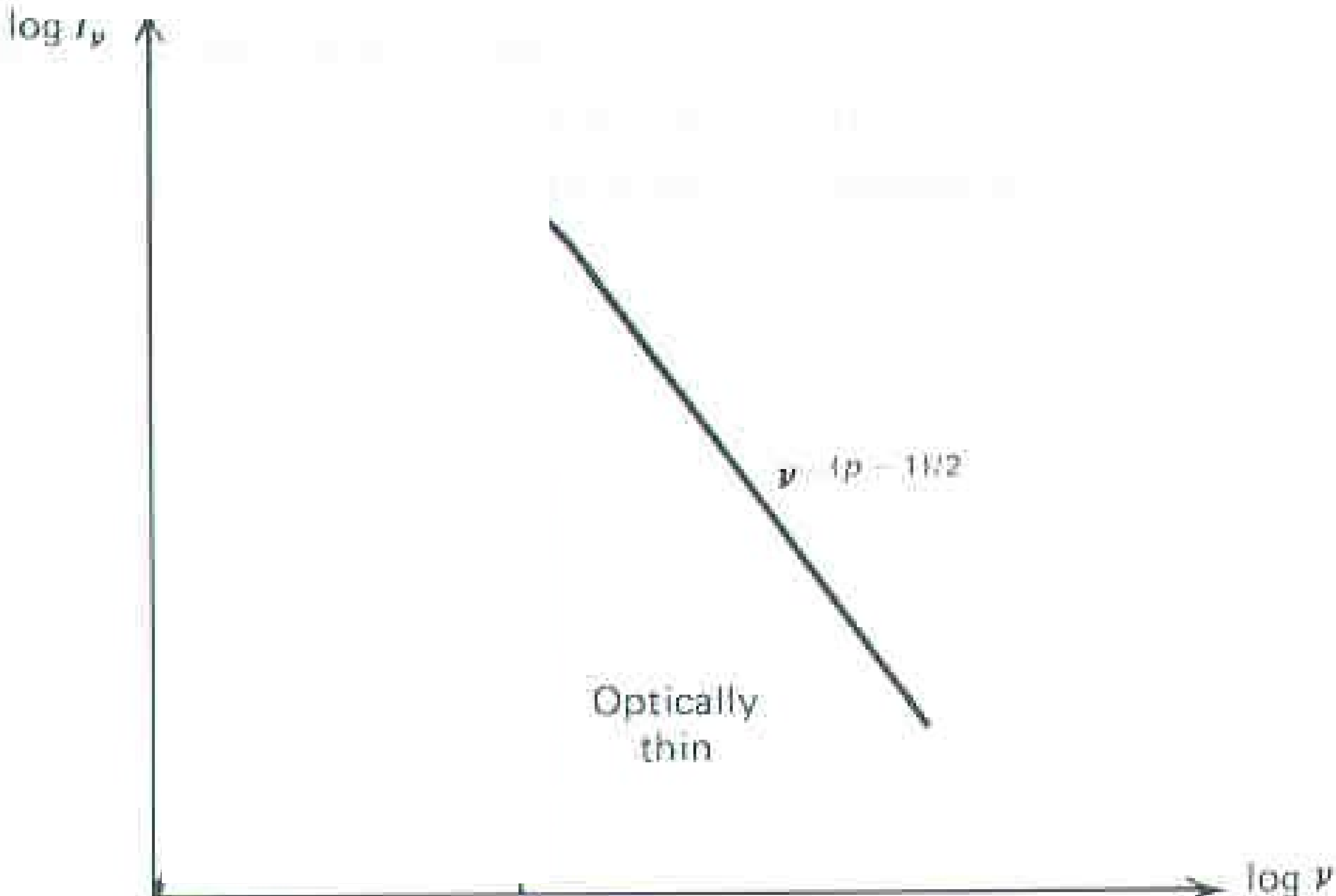
$$0 < \varphi < 2\pi$$

$$N(E)dE = CE^{-p}dE$$

In this case, we have

$$S(\nu) \propto \nu^{-\frac{p-1}{2}}$$

Flux density vs frequency



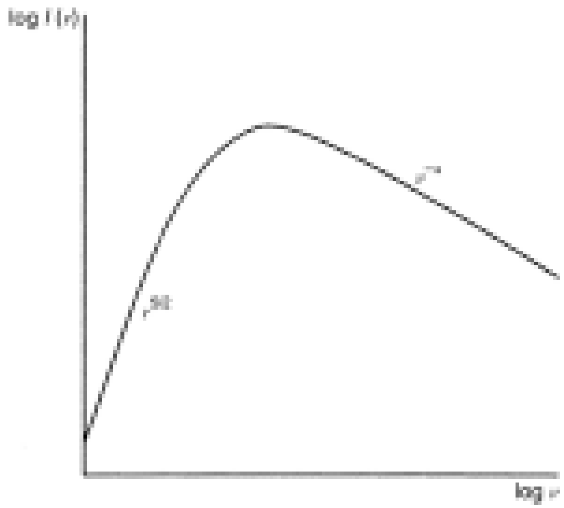
Synchrotron Self-absorption

According to the principle of detailed balance, to every emission process there is a corresponding absorption process – in the case of synchrotron radiation, this is known as *synchrotron self-absorption*.

Suppose a source of synchrotron radiation has a power law spectrum, $S_\nu \propto \nu^{-\alpha}$, where the spectral index $\alpha = (p-1)/2$. Its *brightness temperature* is defined to be $T_{\mathrm{b}} = (\lambda^2/2k)(S_\nu/\Omega)$, and is proportional to $\nu^{-(2+\alpha)}$, where S_ν is its flux density and Ω is the solid angle it subtends at the observer at frequency ν. We recall that brightness temperature is the temperature of a black-body which would produce the observed surface brightness of the source at the frequency ν in the Rayleigh-Jeans limit, $h\nu \ll kT_{\mathrm{e}}$. Thus, at low enough frequencies, the brightness temperature of the source may approach the kinetic temperature of the radiating electrons. When this occurs, self-absorption becomes important since thermodynamically the source cannot emit radiation of brightness temperature greater than its kinetic temperature.

Longair

Synchrotron Self-absorption



The important point is that the *effective temperature* of the particles now becomes a function of their energies. Since $\gamma \approx (\nu/\nu_{\rm g})^{1/2}$,

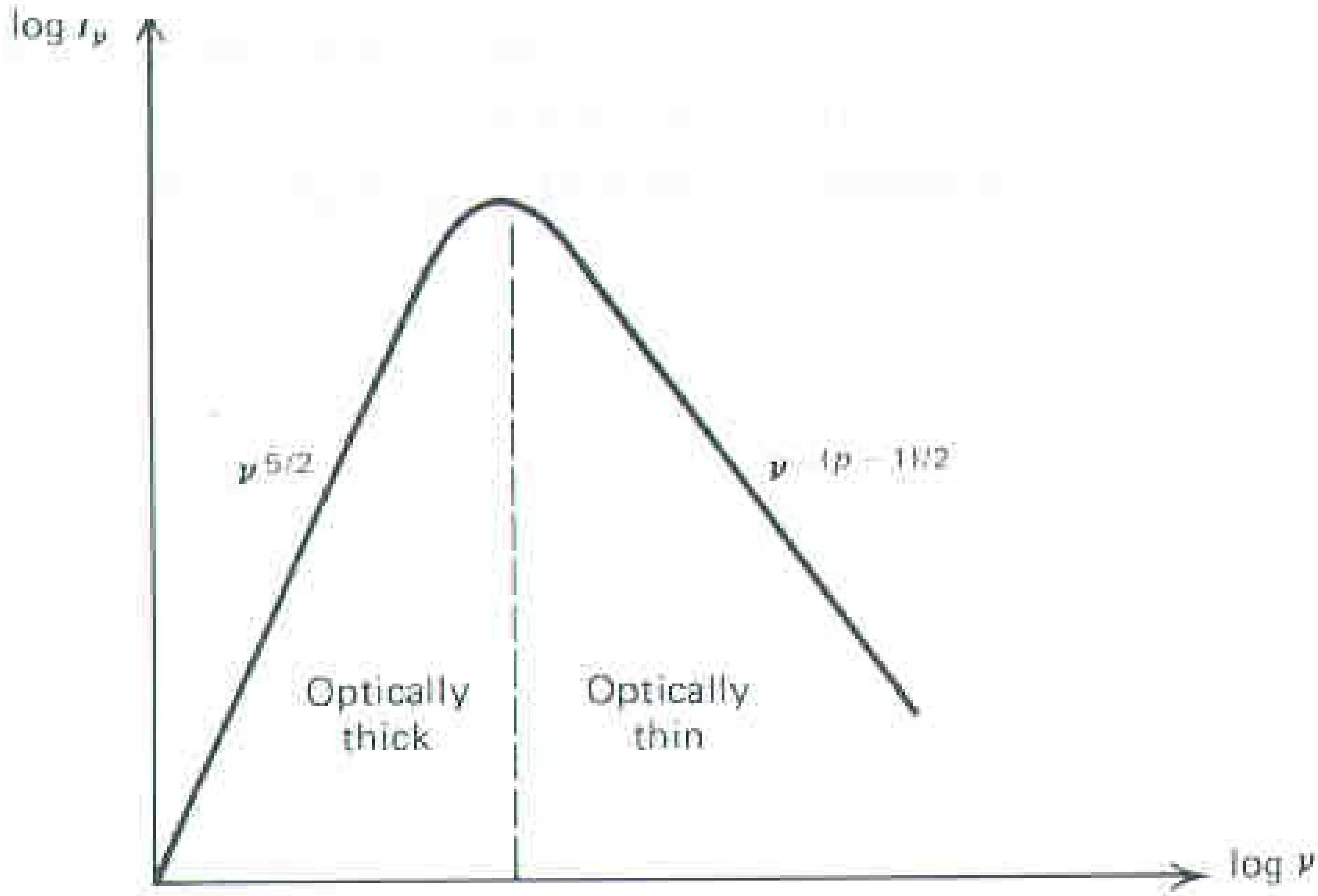
$$T_{\rm e} \approx (m_{\rm e}c^2/3k)(\nu/\nu_{\rm g})^{1/2}. \qquad (40)$$

For a self-absorbed source, the brightness temperature of the radiation must be equal to the kinetic temperature of the emitting particles, $T_{\rm b} = T_{\rm e}$, and therefore, in the Rayleigh-Jeans limit,

$$S_\nu = \frac{2kT_{\rm e}}{\lambda^2}\Omega = \frac{2m_{\rm e}}{3\nu_{\rm g}^{1/2}}\Omega\,\nu^{5/2} \propto \frac{\theta^2\nu^{5/2}}{B^{1/2}}, \qquad (41)$$

where Ω is the solid angle subtended by the source, $\Omega \approx \theta^2$. Spectra of roughly this form are found at radio, centimetre and millimetre wavelengths from the nuclei of active galaxies and quasars.

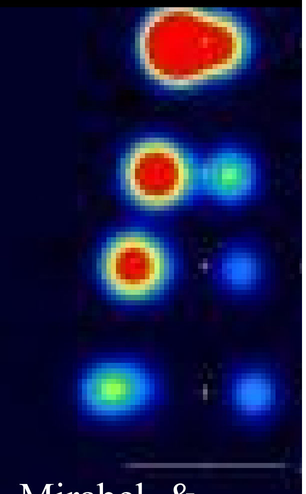
Flux density (Jy)



TRANSIENT JETS

STEADY JETS

GRS 1915+105



Mirabel .& Rodrigez 1994

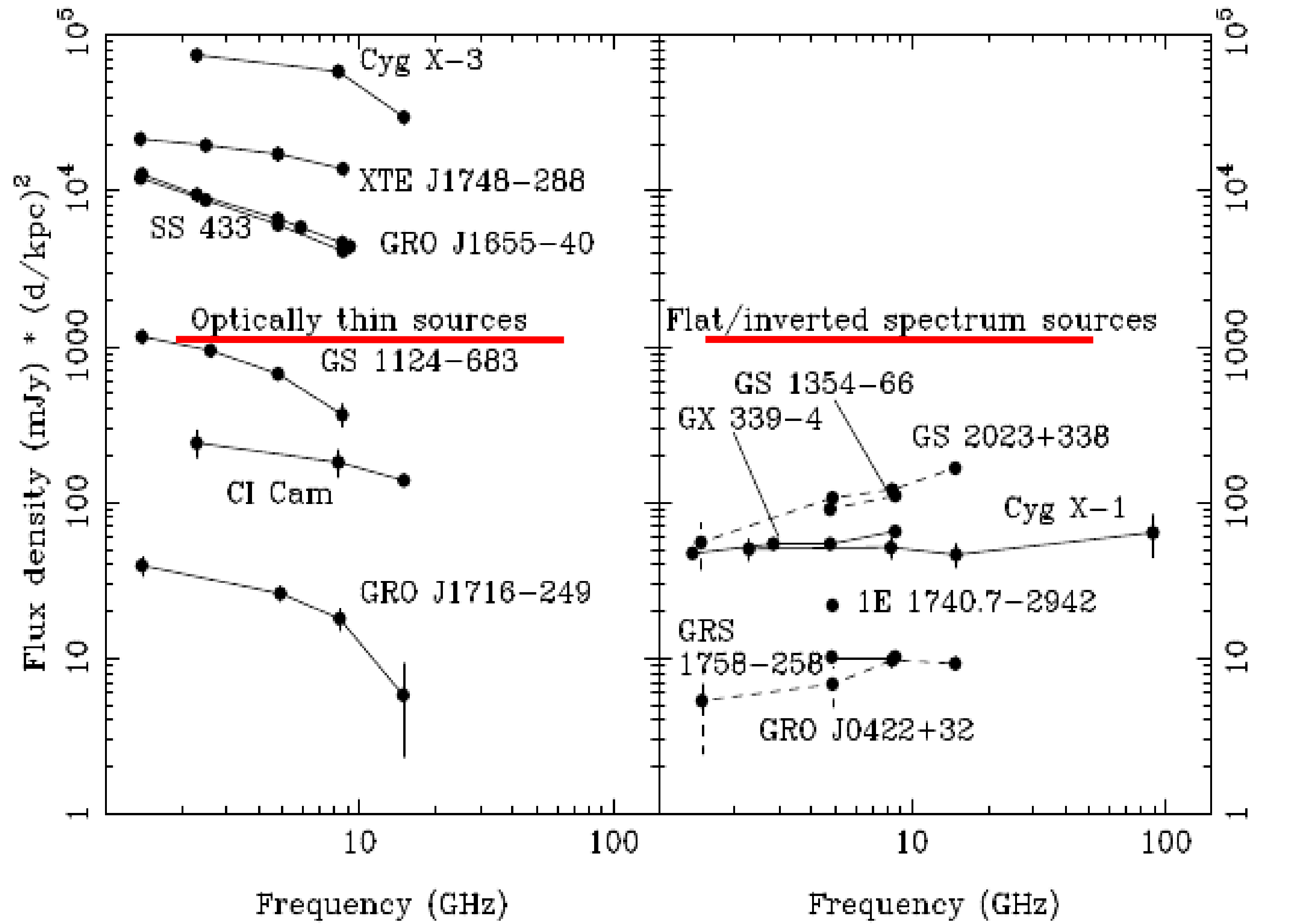
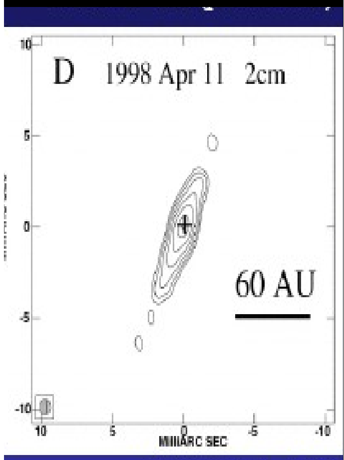


Figure 4. Optically thin (i.e. spectral index $\alpha < 0$) radio spectra from several radio-bright X-ray binaries which were *not* in the Low/Hard X-ray state at the time of the observations, compared with the flat/inverted spectra of the seven sources in Figs 1 & 4 (for the transients, the later, ie. 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

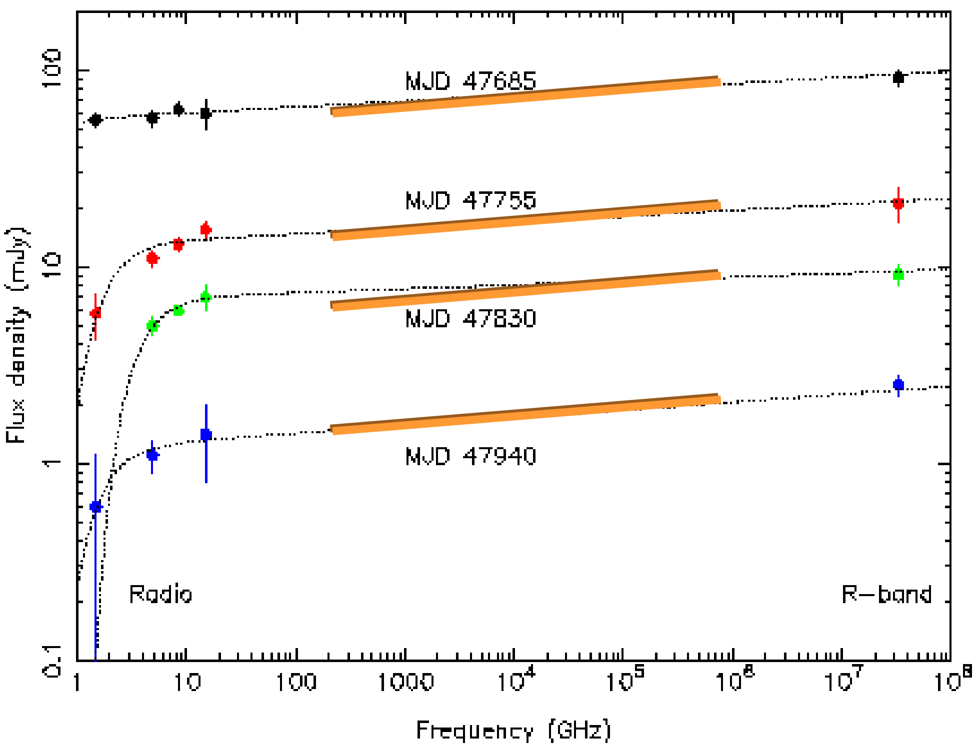
Fender et al. 2001, 2004,2006

www.astro.isas.ac.jp/conference/bh2003/program/ppt/20031029am/KyotoBH2003_Falcke.ppt

The radio-optical spectrum of XRBs

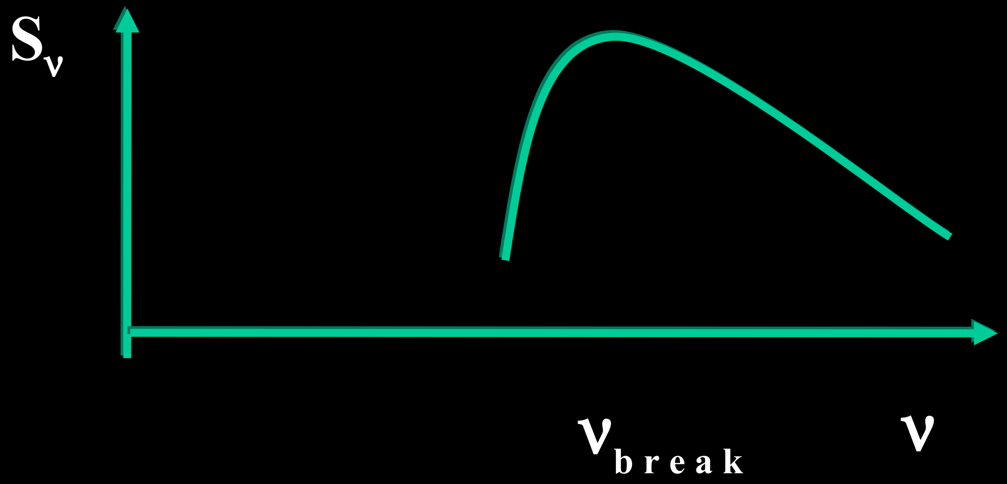
- Radio-to-NIR spectrum is flat in the hard state.

V404 Cyg



(Fender 2000)

RADIO SPECTRUM:
WHY IS IT "FLAT" ?



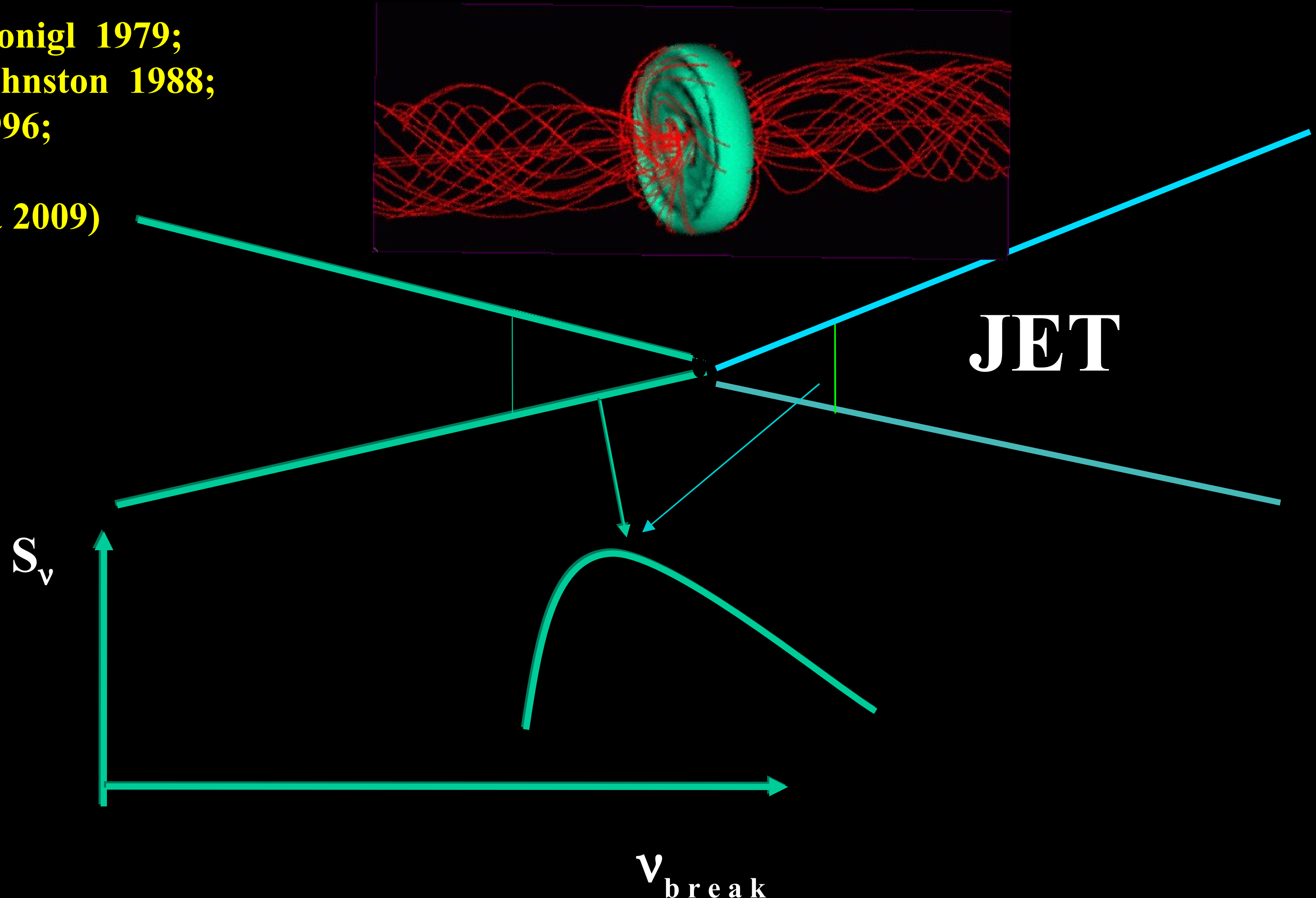
$$\nu_{peak} \approx 3.2 \times 10^7 \sin\theta \left(\frac{E_0}{1\ \mathrm{MeV}}\right)^{(2\delta-2)/(\delta+4)} \times \left[8.7 \times 10^{-12} \frac{\delta-1}{\sin\theta} NL\right]^{2/(\delta+4)} B^{(\delta+2)/(\delta+4)},$$

$$n(E) = KE^{-\delta},$$

where K is related to N, the number of electrons per cubic centimeter

Dulk (1985), Ann. Rev. Astronomy & Astrophysics, 23, 183

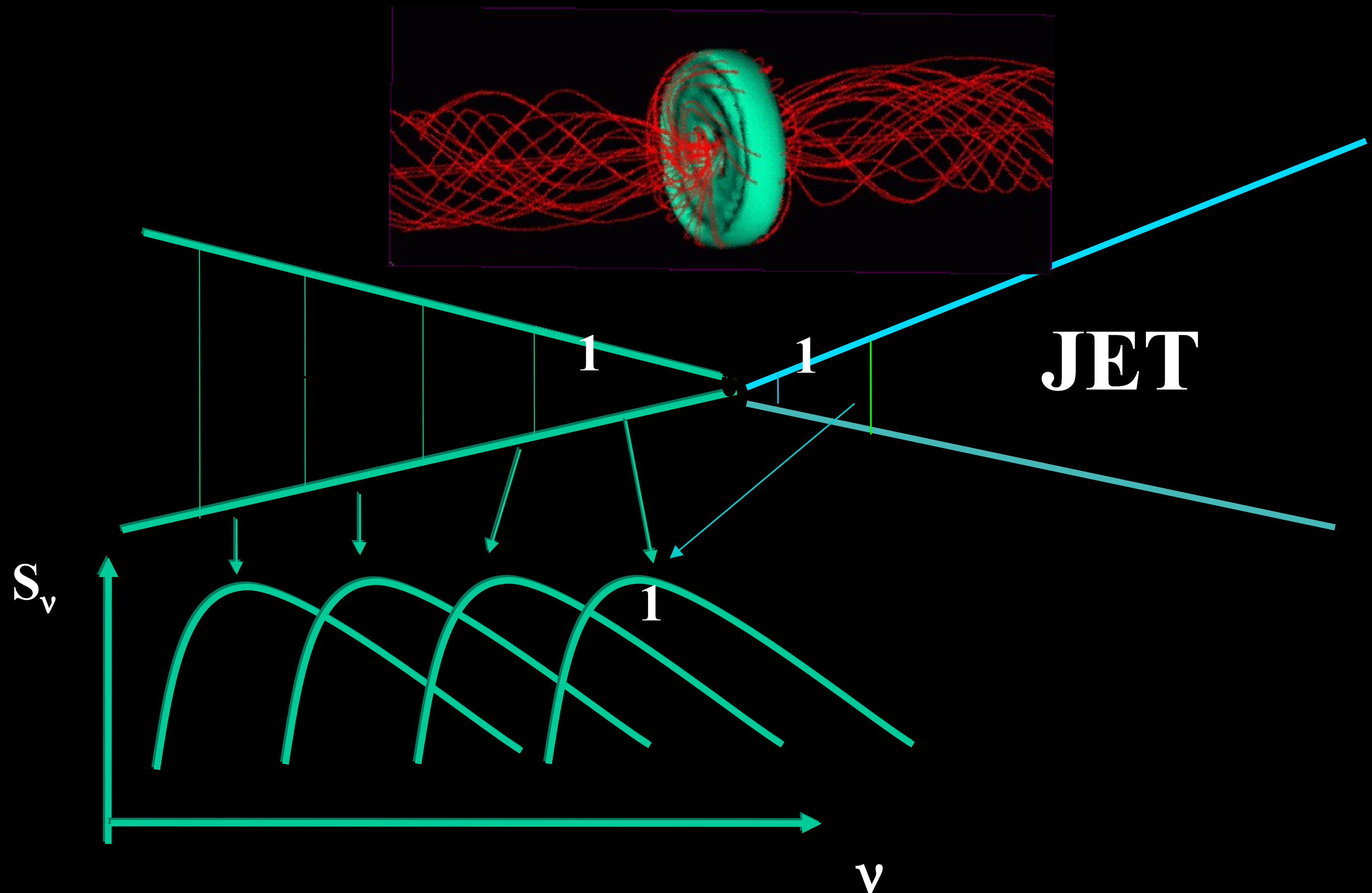
Blandford & Konigl 1979;
Hjellming & Johnston 1988;
Falcke et al. 1996;
Kaiser 2006;
Pe'er &Casella 2009)



Change of the plasma conditions along the jet:

decay of the magnetic field

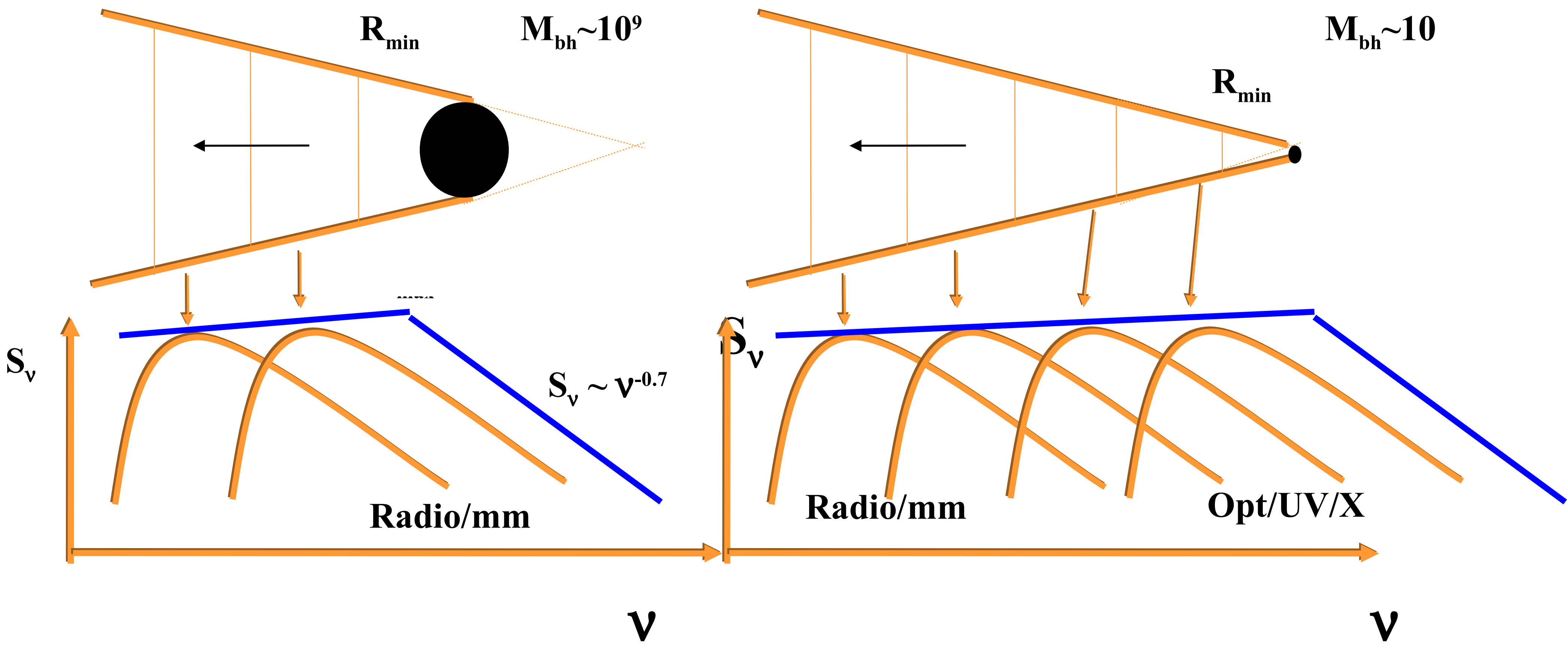
change in the electron energy distribution



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

www.astro.isas.ac.jp/conference/bh2003/program/ppt/20031029am/KyotoBH2003_Falcke.ppt

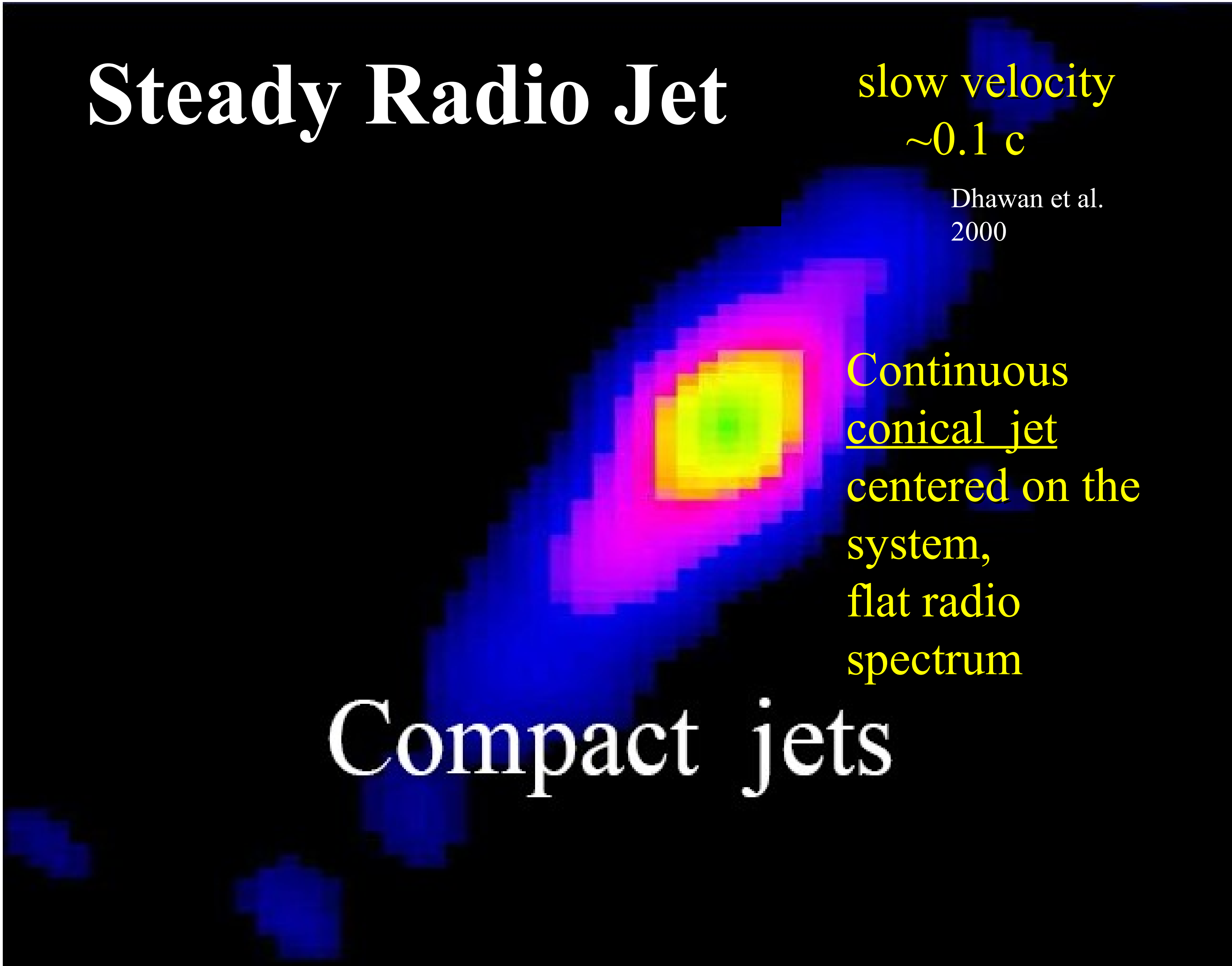


turnover frequency in stellar black holes > blazars ($B_{XRB} >> B_{AGN}$)

Steady Radio Jet

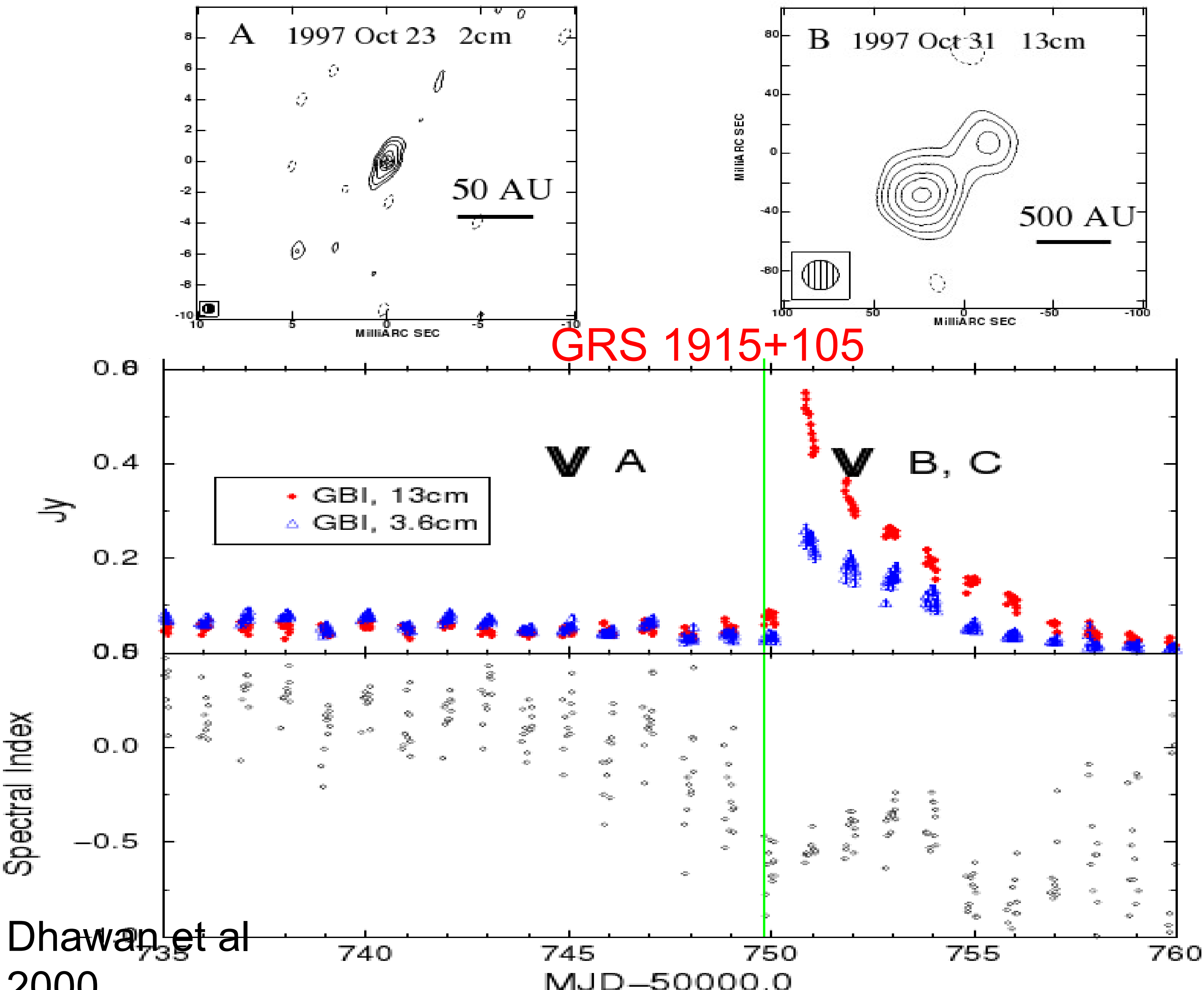
slow velocity
~0.1 c

Dhawan et al.
2000



Continuous
<u>conical jet</u>
centered on the
system,
flat radio
spectrum

GRS 1915+105

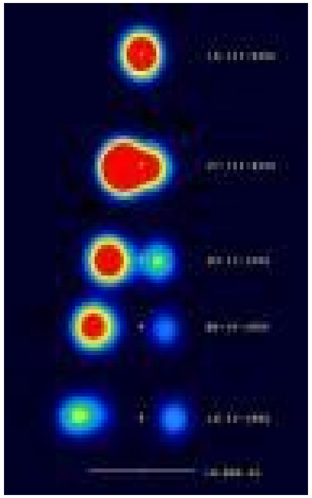


Dhawan et al 2000

Two distinct radio emission states

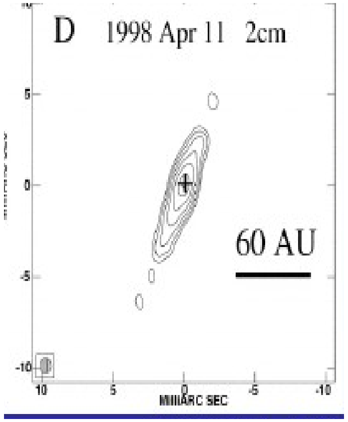
radio emission ***attached to**.....................*

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



GRS 1915+105

Mirabel .& Rodrigez 1994

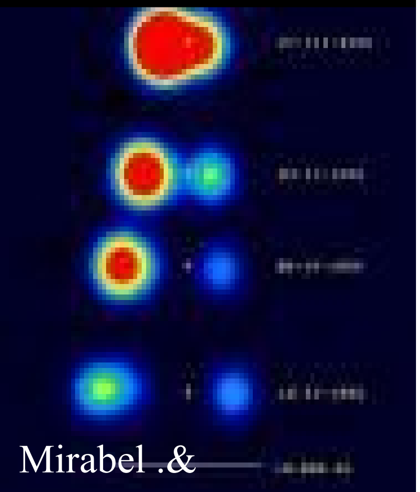


GRS 1915+105

Dhawan et al. 2000

TRANSIENT JETS

STEADY JETS



Mirabel .& Rodrigez 1994

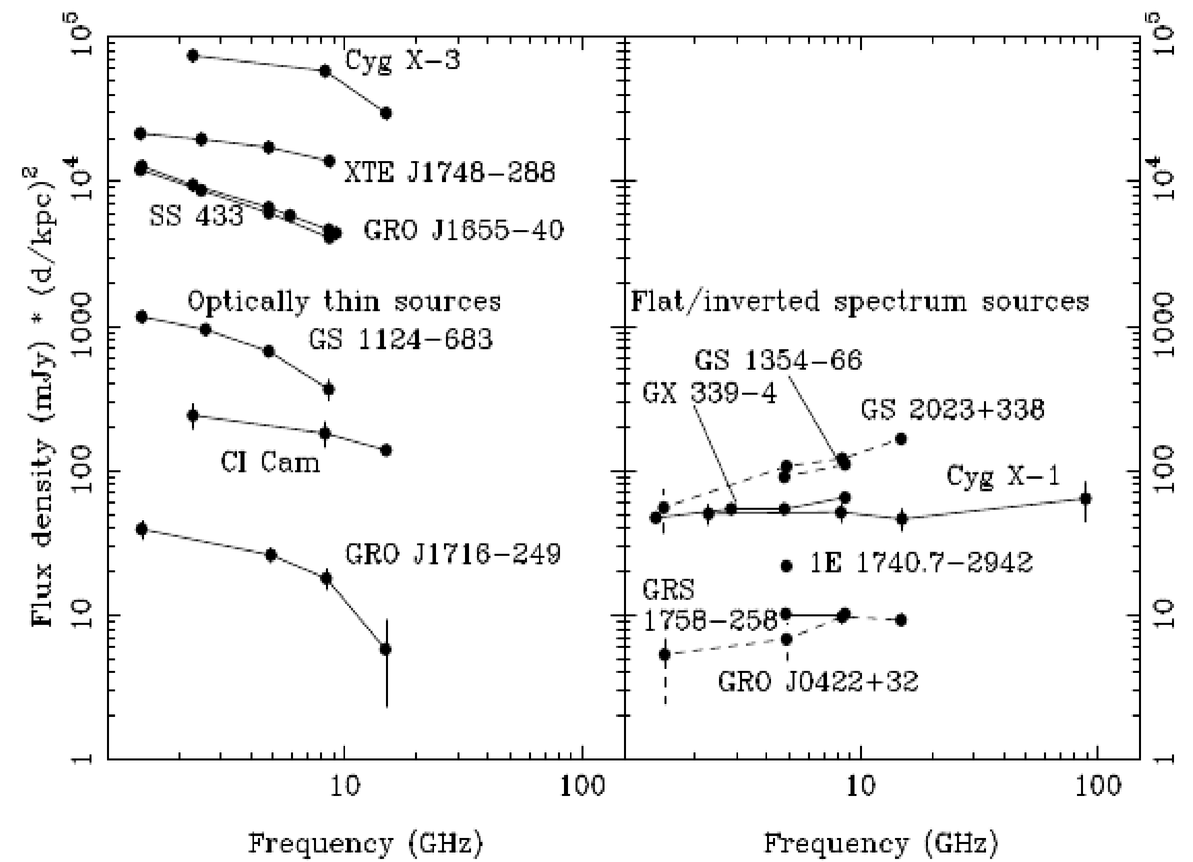
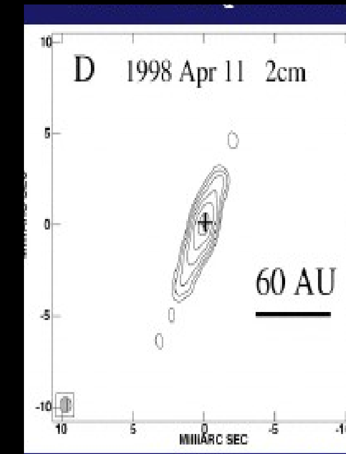


Figure 4. Optically thin (i.e. spectral index $\alpha < 0$) radio spectra from several radio-bright X-ray binaries which were *not* in the Low/Hard X-ray state at the time of the observations, compared with the flat/inverted spectra of the seven sources in Figs 1 & 4 (for the transients, the later, ie. 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.



Dhawan et al. 2000

X-ray State

Steep Power-low State

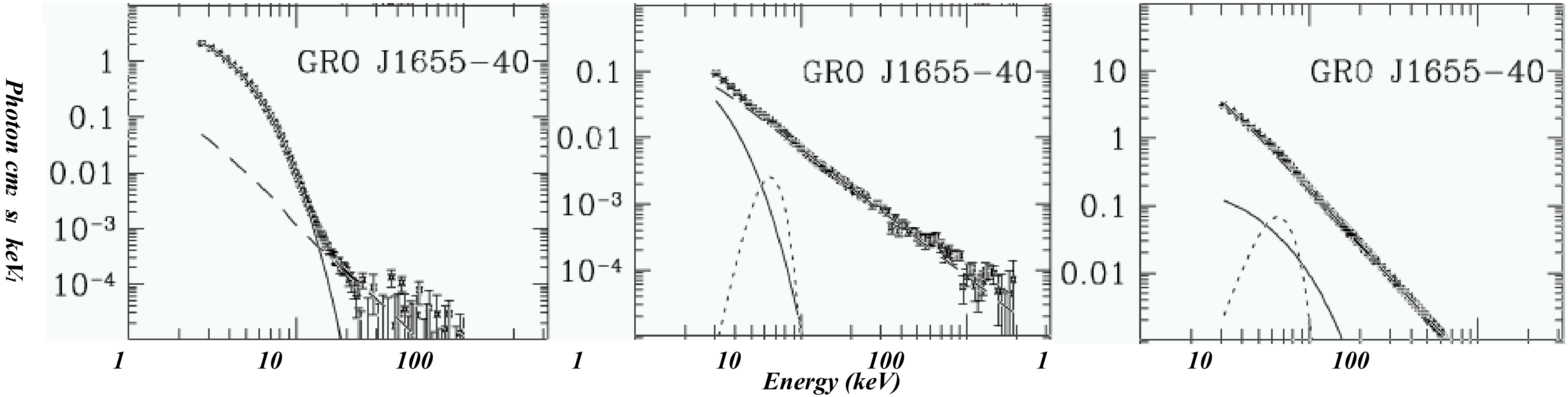
X-ray State

Low Hard

Fender et al. 2001

Accretion states

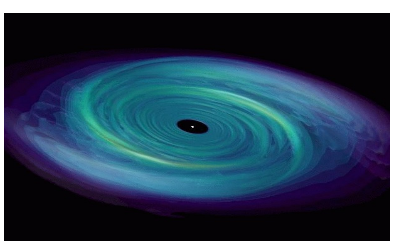
Energy spectra from McClintock & Remillard (2006)



High

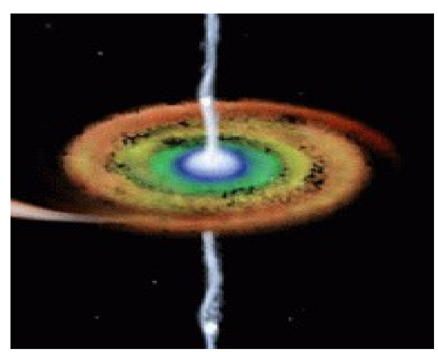
(thermal dominated)

~ 1 – 2 keV disc + PL tail



Low/Hard

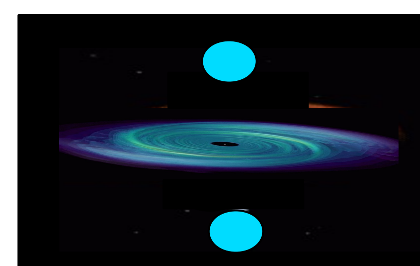
Hard PL (Γ ~ 1.5 – 2) dominant, disc absent or truncated, radio jet emission. Least luminous.



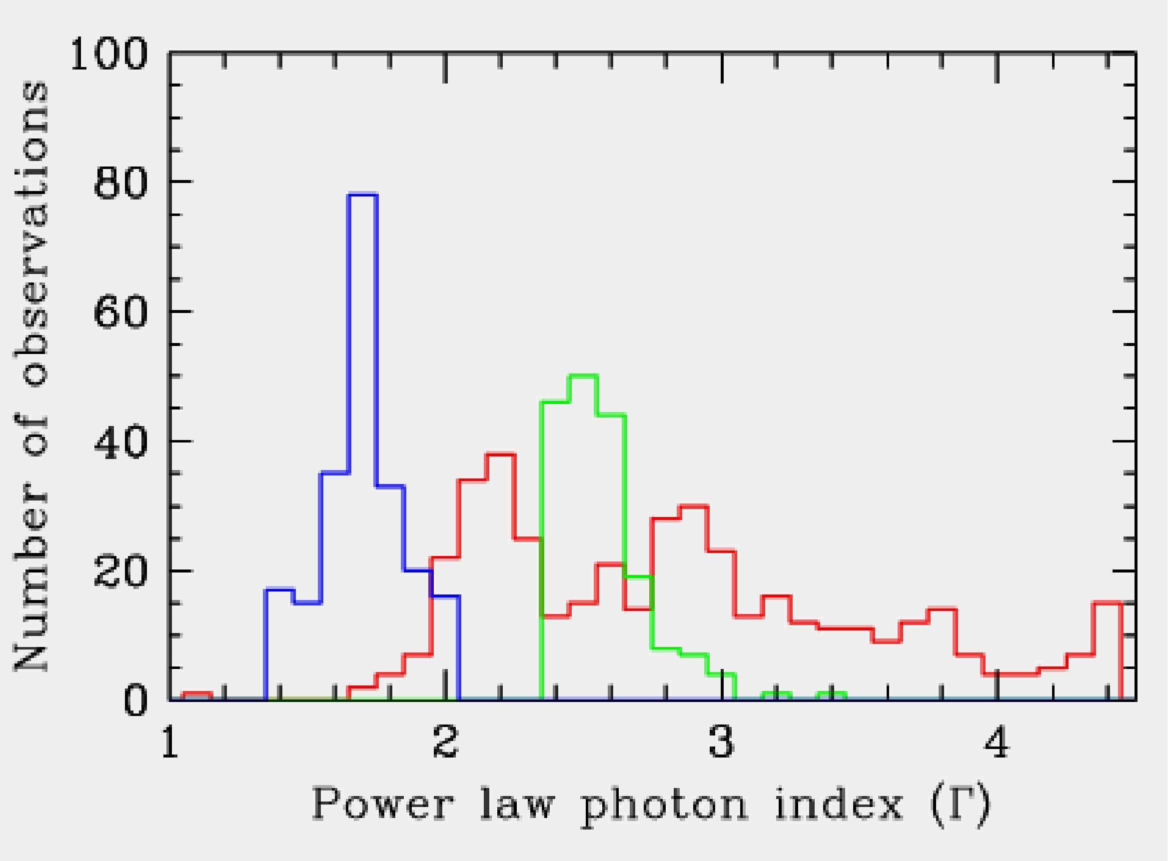
Very High

(steep power-law)

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



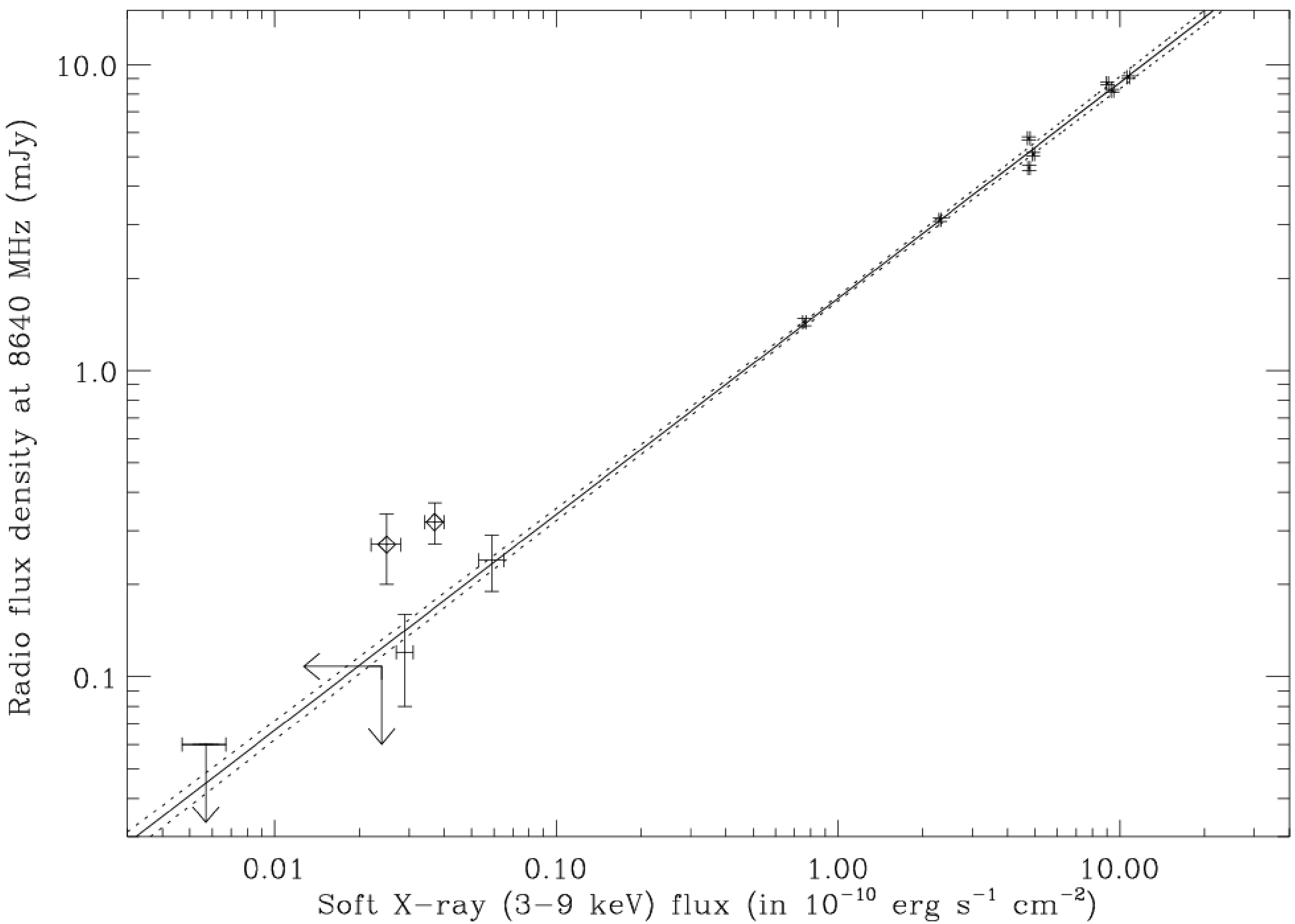
Distributions in Photon Index



Ron Remillard

Hard **SPL** **Thermal**

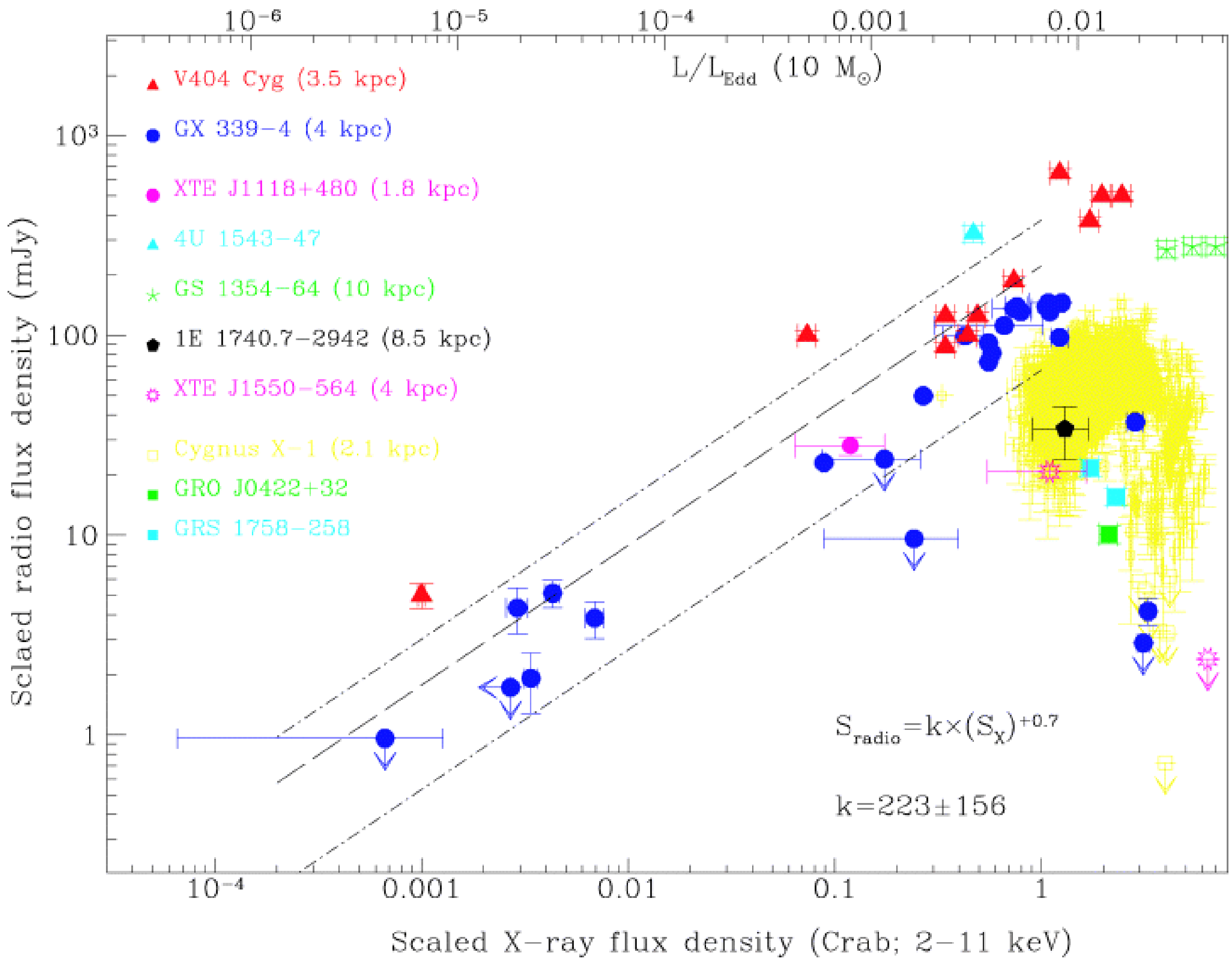
Radio/X-ray Flux Correlation



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

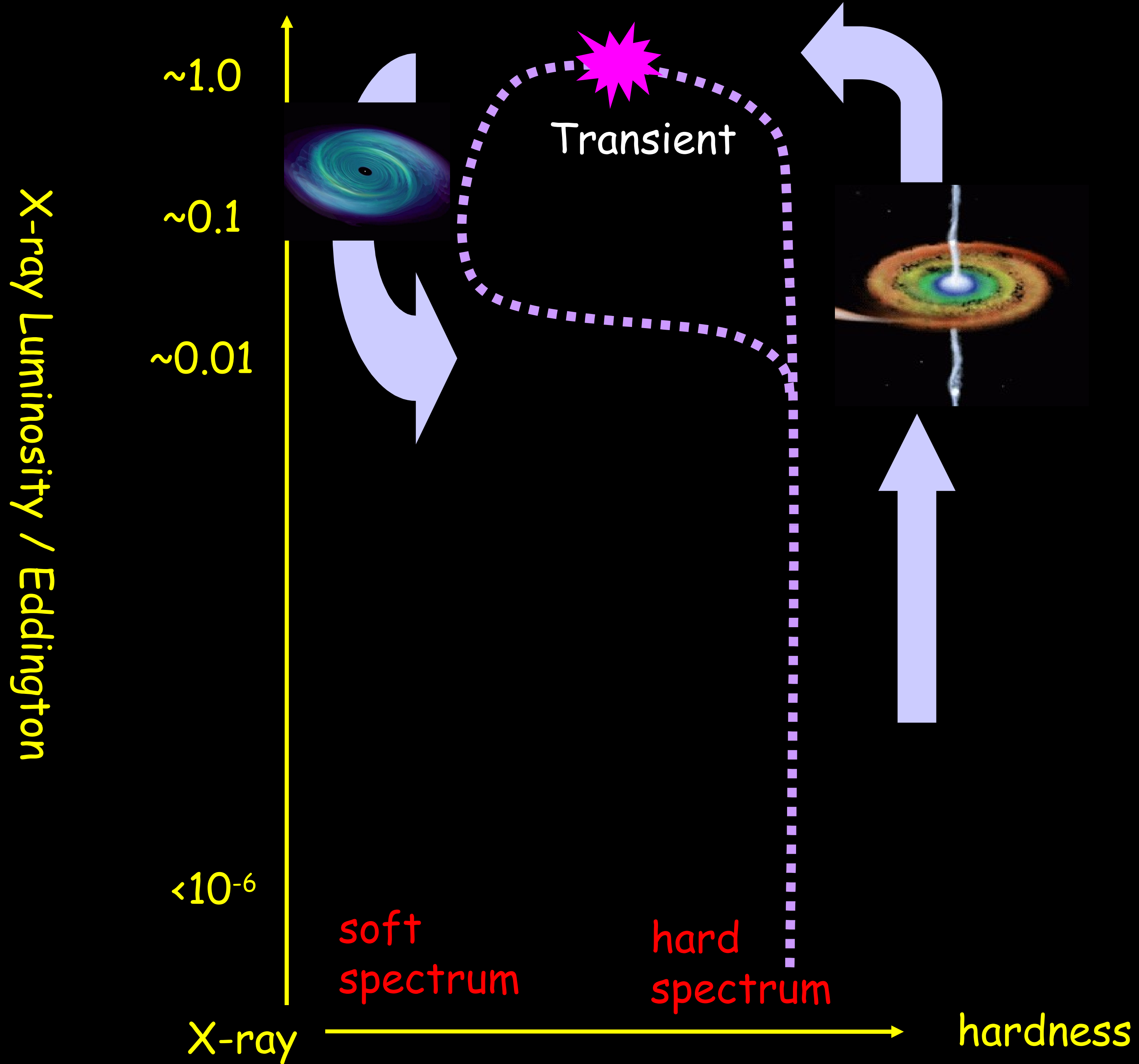
Corbel et al. (2000,2003)

Radio/X-ray Flux Correlation



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

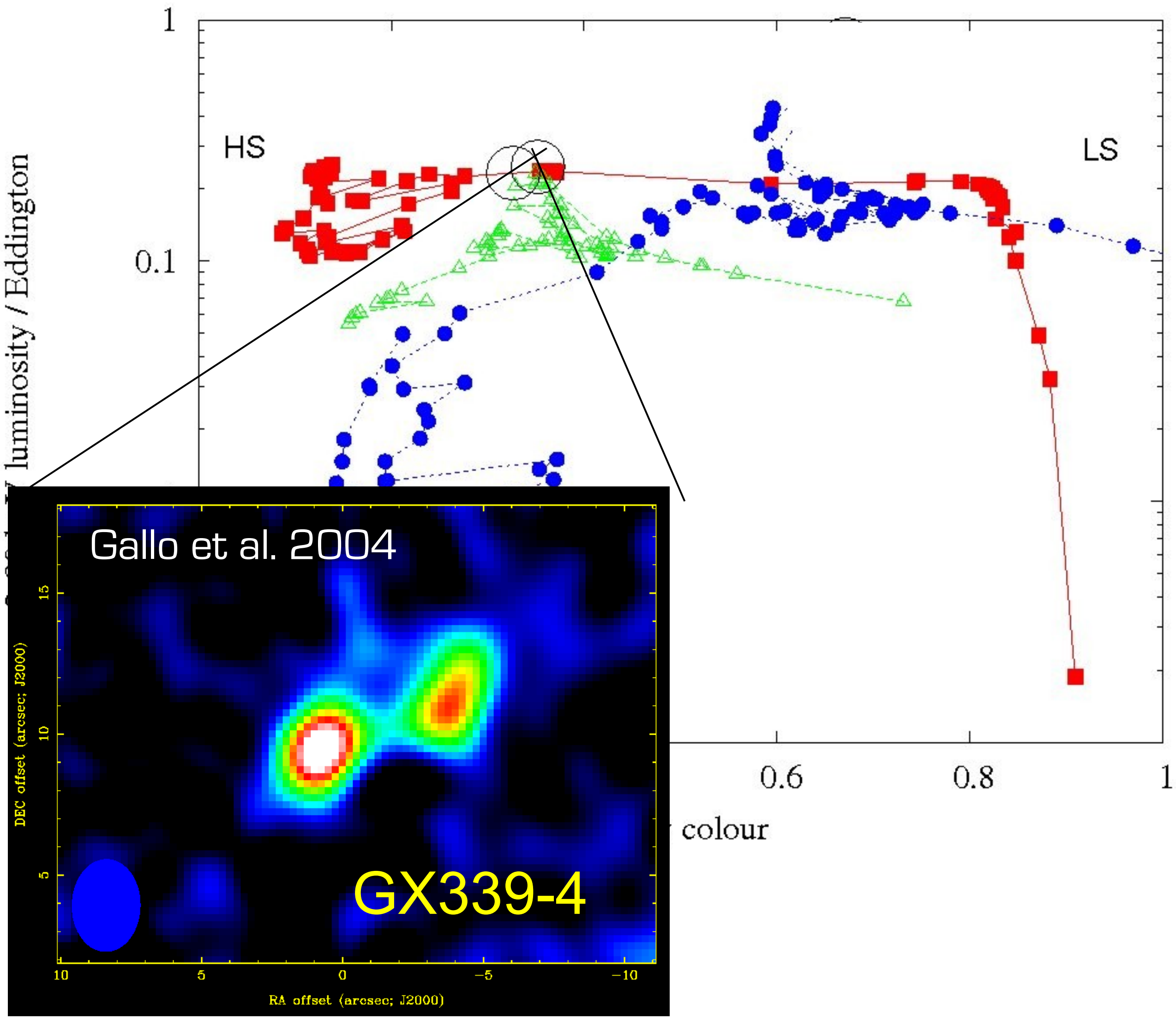
Corbel et al. (2000,2003)



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



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

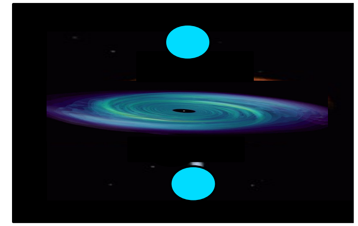
Timescales (days) for state (all BH Binaries)

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

Ronald Remillard

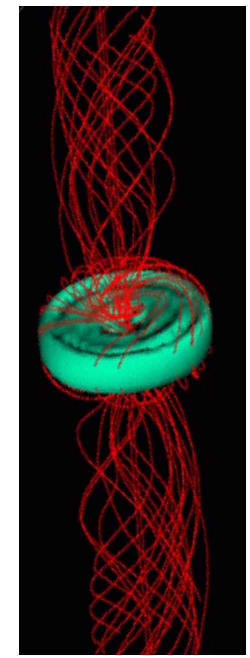
In analogy with solar flares, magnetic energy is probably built-up and accumulated over long time scales and then dissipated in very short time

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.

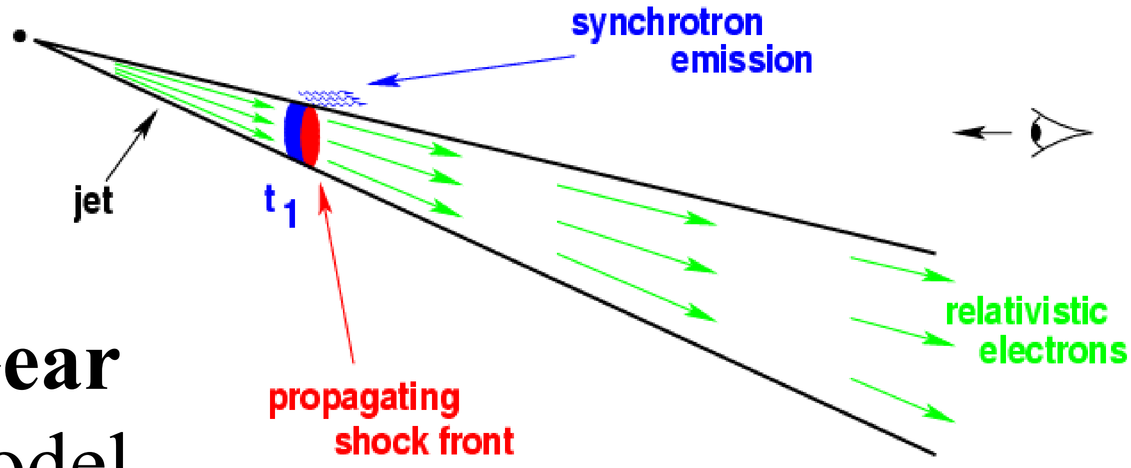


TRANSIENT

JET



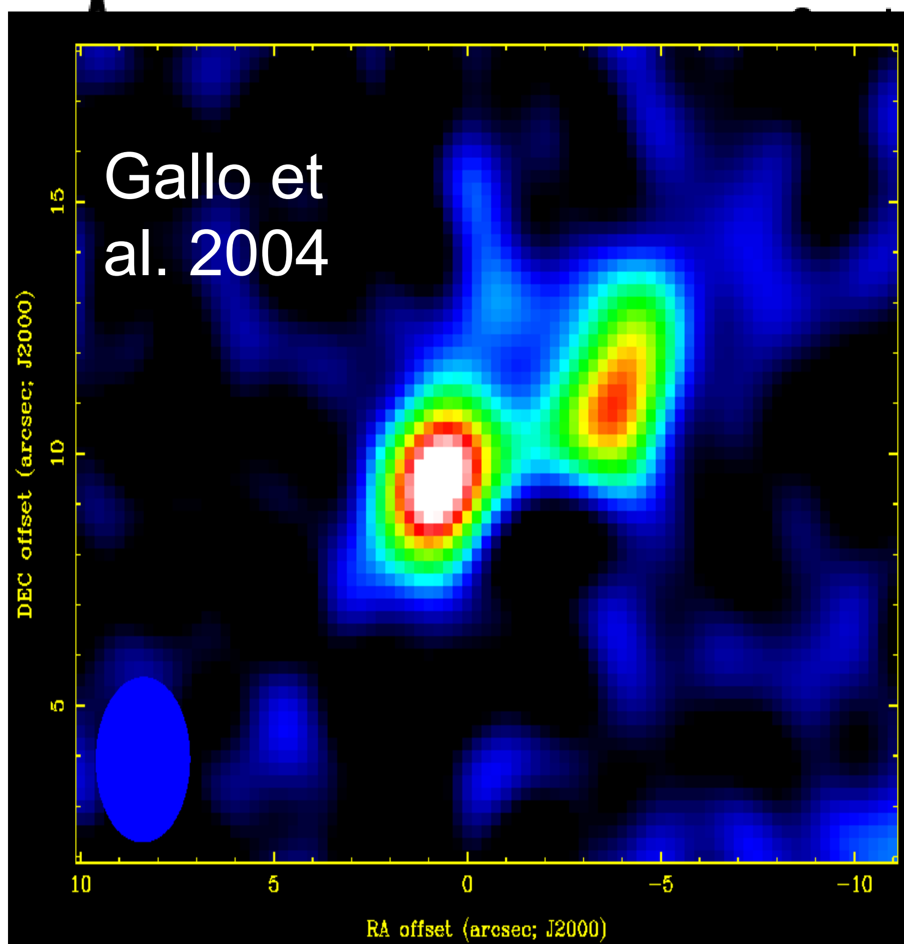
STEADY JET



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

Marscher & Gear

shock-in-jet model (1985)



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.