Relativistic jets in XRBs and AGNs

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Outline (today)

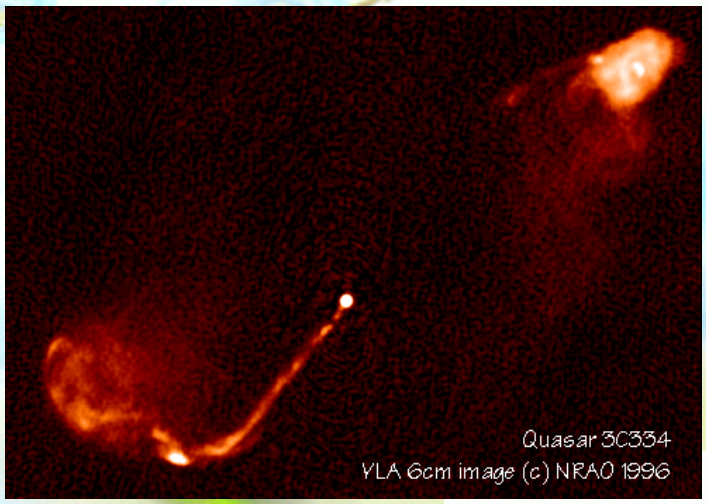
- Introduction on relativistic jets
- Accretion and spectral states in XRBs
- Relativistic ejections in microquasars and AGNs: illustrations of relativistic effects
- Compact cores in the hard state
- Unifying relativistic jet production and X-ray spectral states

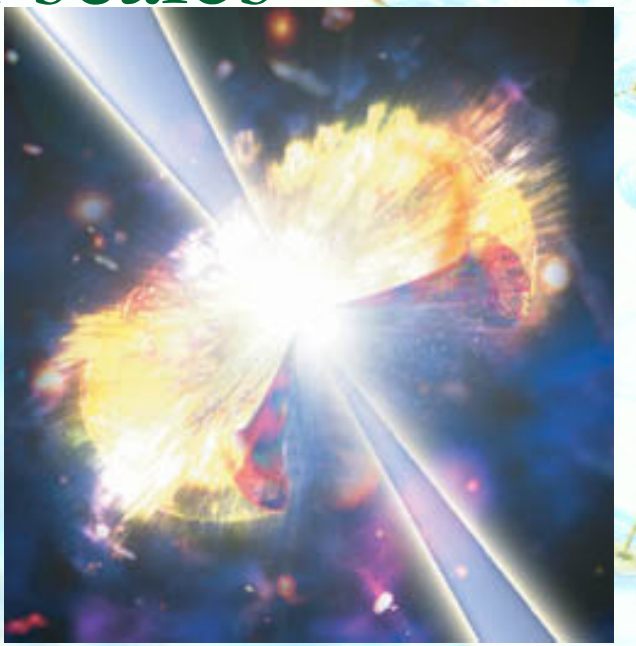
Outline for next lecture (on Monday)

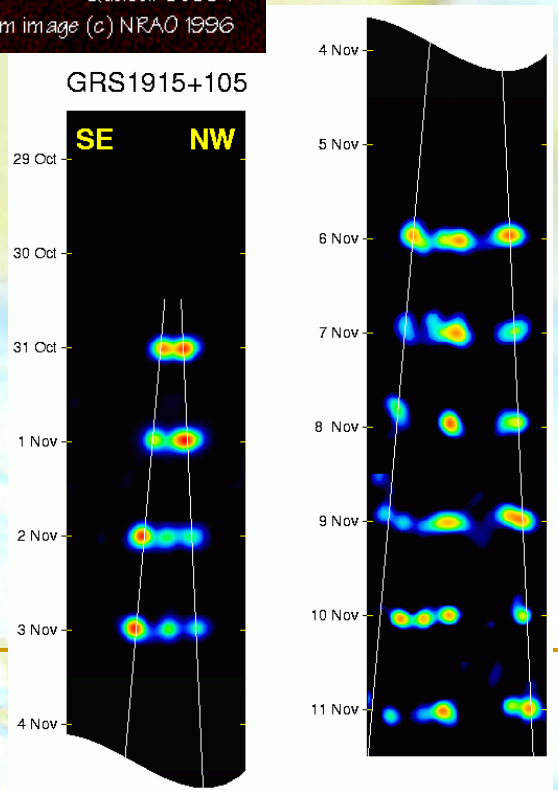
- Relativistic Jets in neutron star binaries
- Large scale jets and radio nebula
- Ultra Luminous X-ray sources (ULX)
- Active Galactic Nuclei (AGN)
- Open questions and perspectives

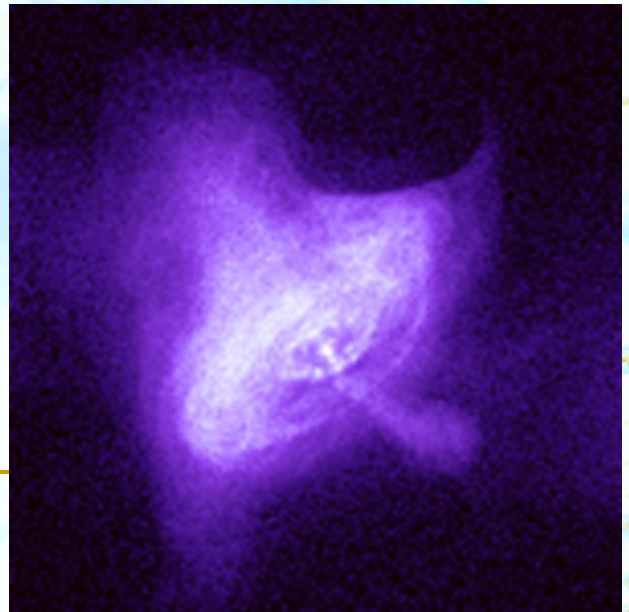
Introduction on relativistic jets

Jets are everywhere, on all scales





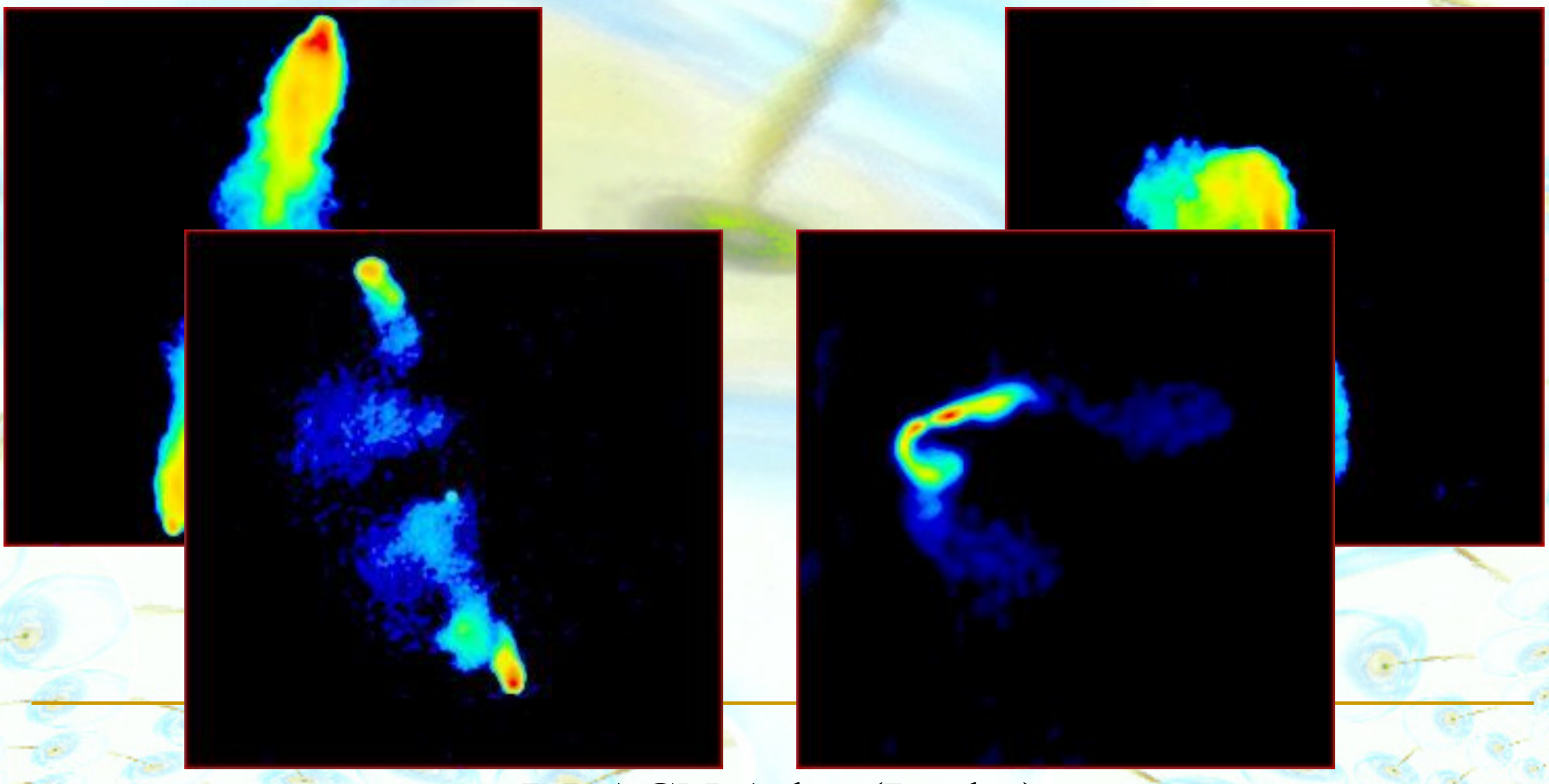




Jets are the only component of an AGN that are actually seen!

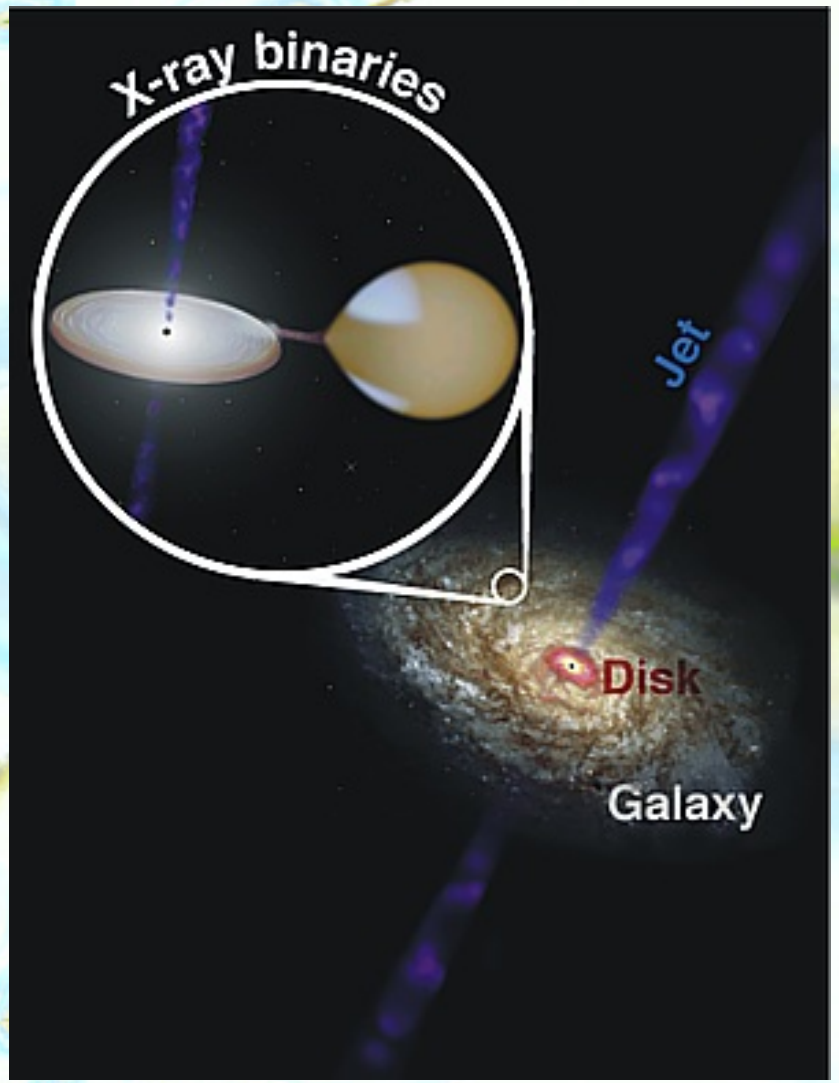
High-Power (FR II)

Low-Power (FR I)



DRAGN Atlas (Leahy)

Analogies between AGNs and XRBs



- Same ingredients: Black hole + accretion disk + jets
- Same physics on these different mass scale and geometry ??

Image: S. Heinz et al.

Accretion and spectral states in XRB

See lectures on XRBs by T. Belloni

Introduction: X-ray binaries

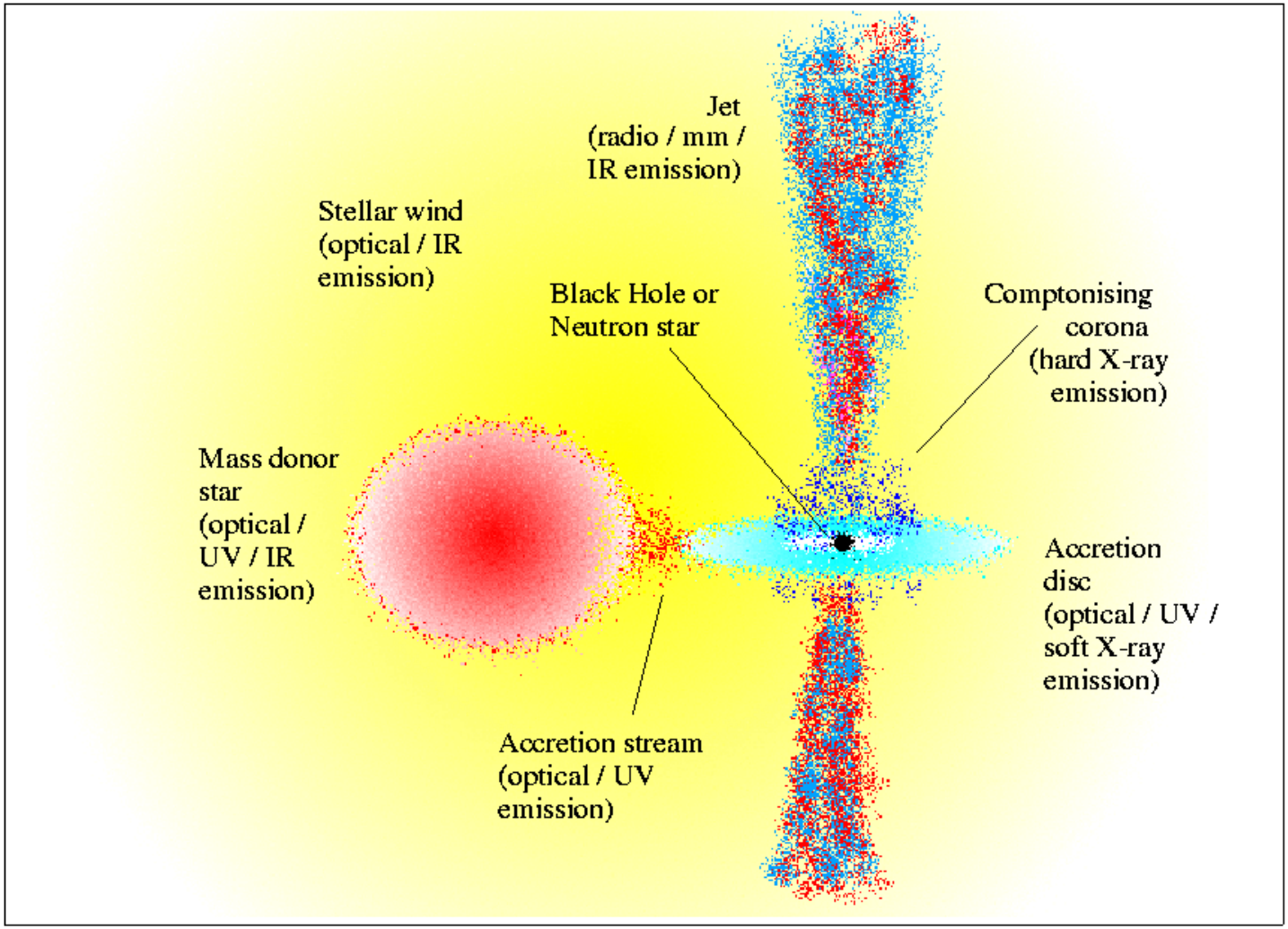
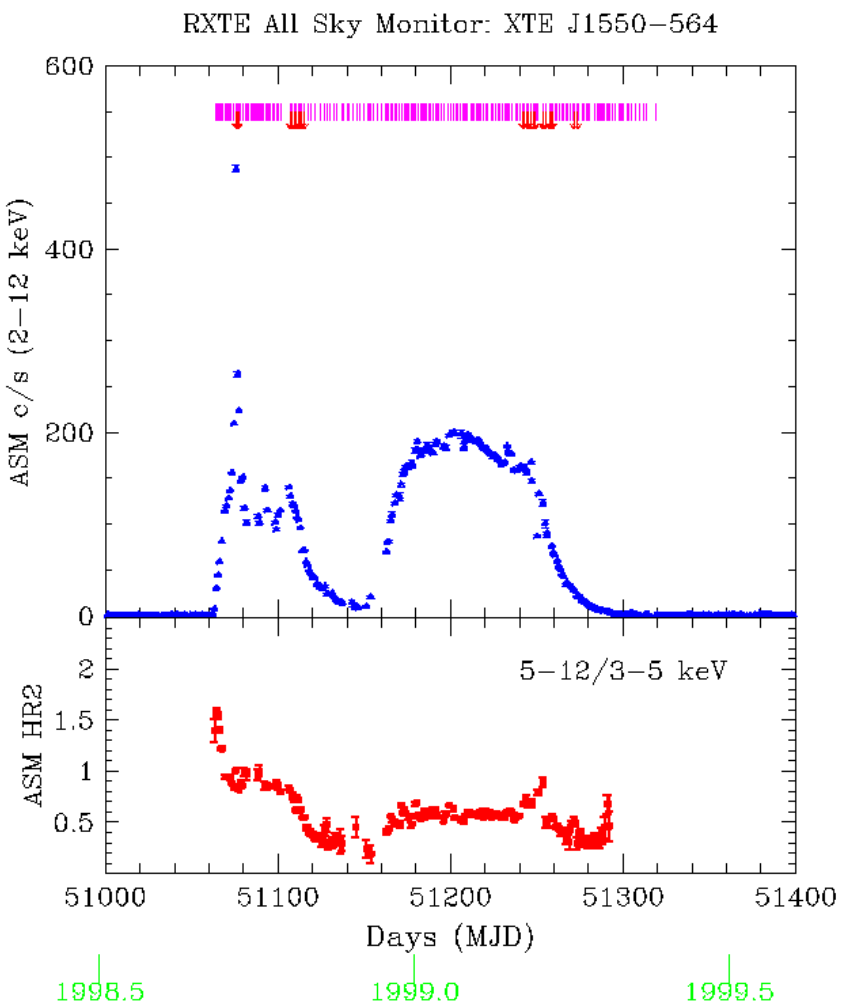
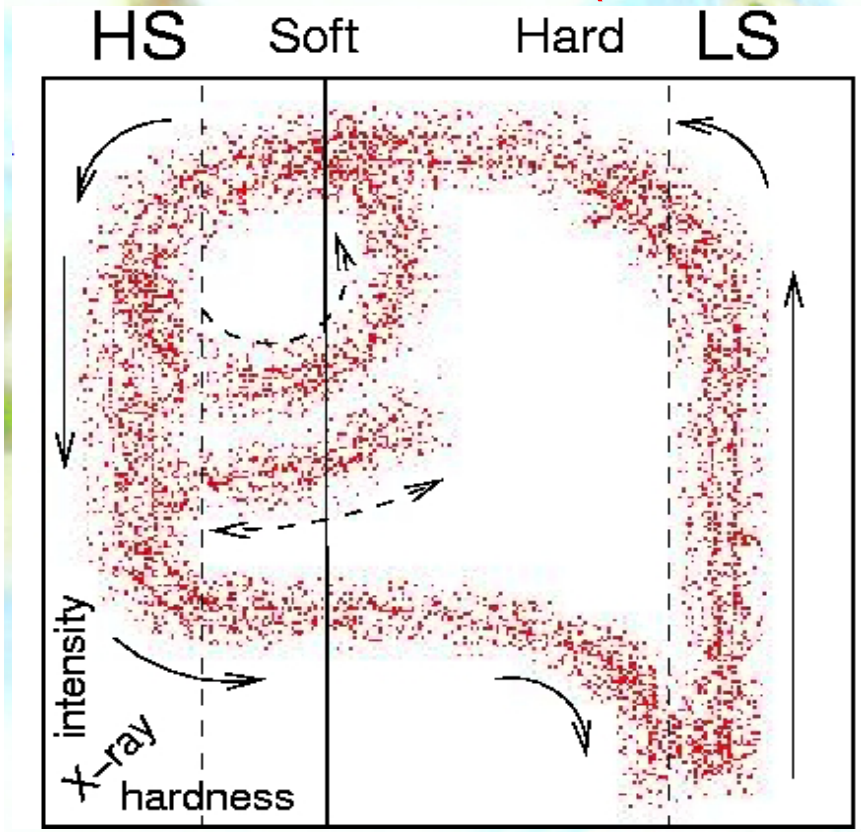


Image: R. Fender

X-ray States of Black Hole Binaries



TD SPL / IS HS (McC& Rem)

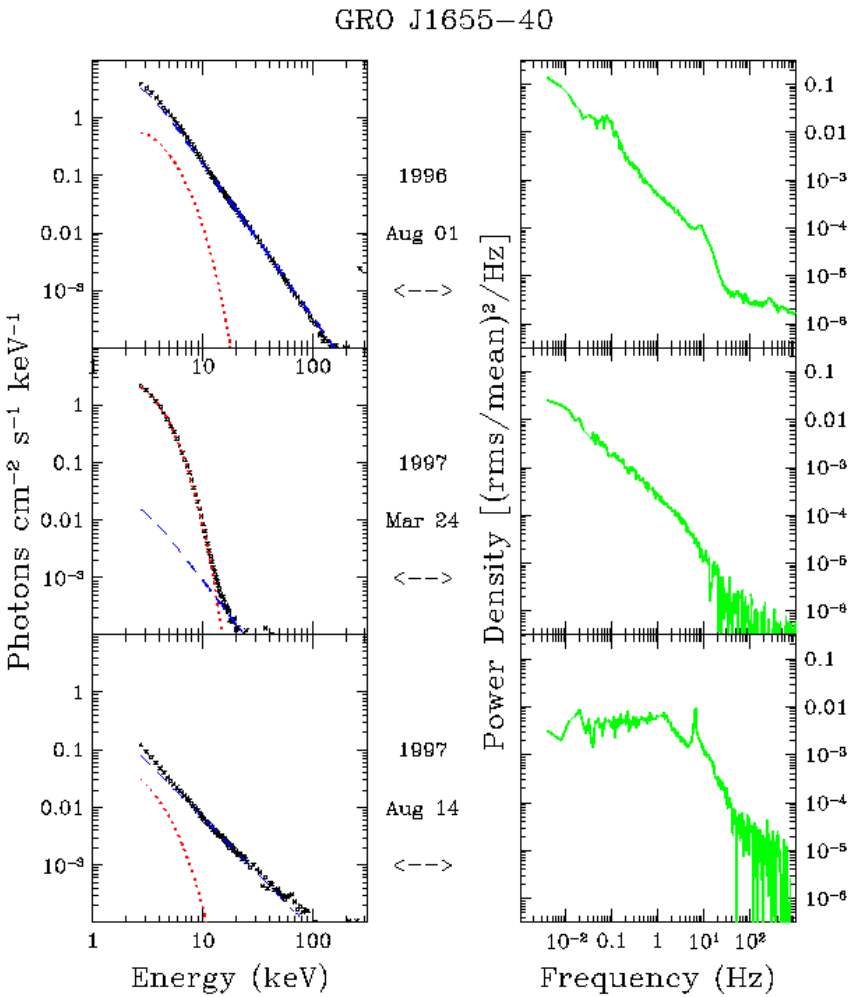


Hardness Intensity Diagram (HID)

Image: R. Remillard

Homan, Belloni et al.

X-ray States of Black Hole Binaries



McClintock & Remillard 2004

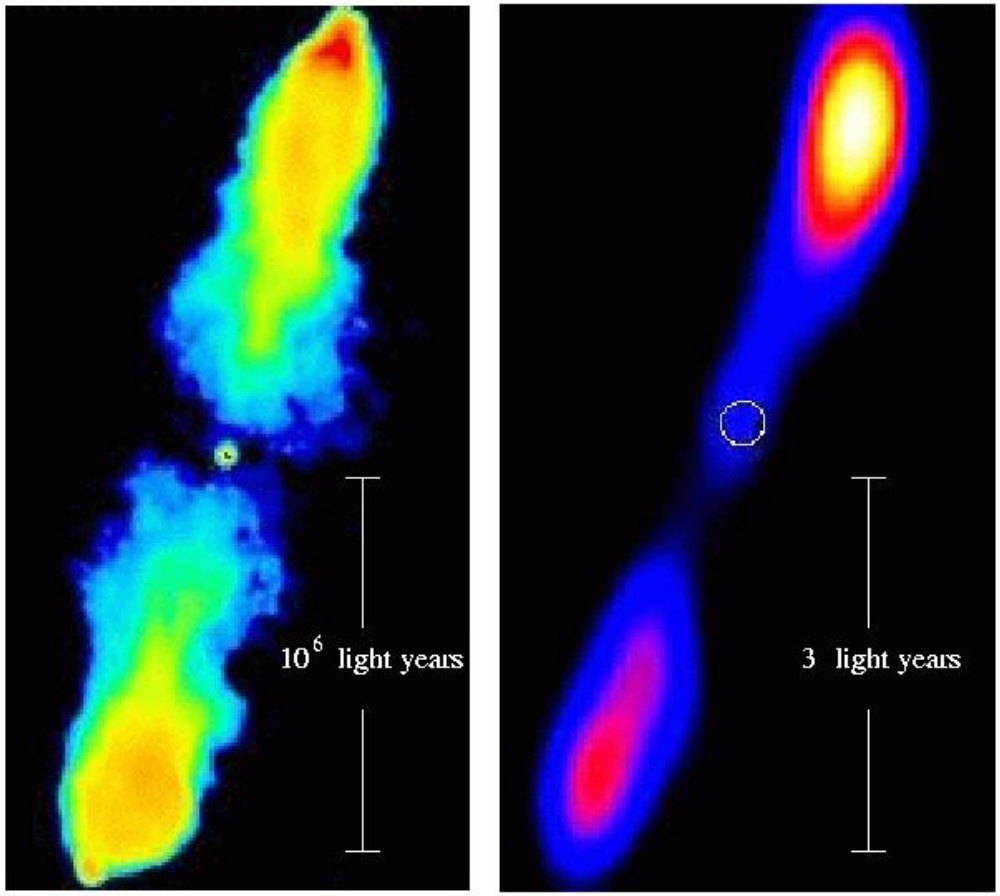
State	modified descriptions
"very high"	**"steep power law"**
power law, $\Gamma \sim 2.4$-3.0, $f_{pow} > 50\%$ or $f_{pow} > 20\%$ + QPOs	
"high/soft"	**"thermal dominant"**
$f_{pow} < 20\%$, no QPOs, *rms* (0.1-10 Hz) < 0.06 at 2-30 keV	
"low/hard"	**"hard (steady jet)"**
$f_{pow} > 80\%$ (2-20 keV), $\Gamma \sim 1.5$-2.1, broad PDS features, *rms*(0.1-10 Hz) is 10-30%	
+ "quiescent"	**"quiescent"**
$L_x < 10^{-4} L_{max}$, power law, $\Gamma \sim 1.9$	

Court. Remillard

Part II: Relativistic ejections in microquasars

Quasar – microquasar analogy

Quasar 3C 223 1E1740.7-2942



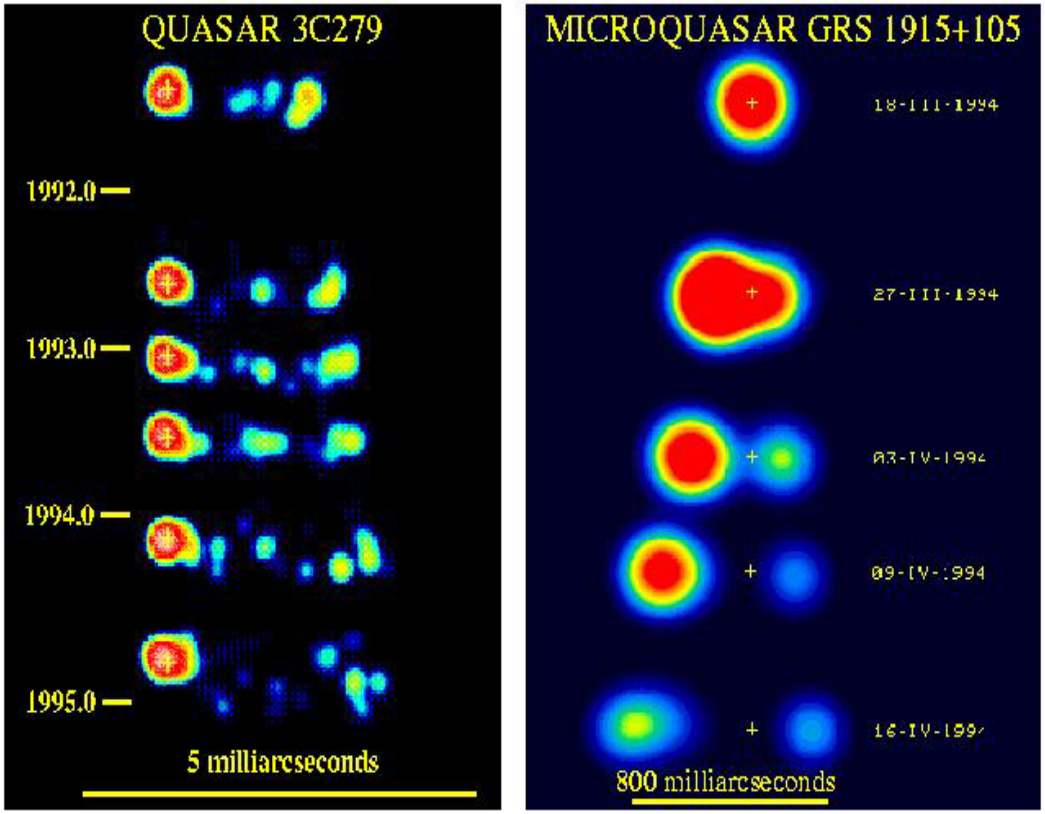
Steady jets in radio at arcminute scale

⇒ long-term action of jets on the interstellar medium

«Superluminal » ejections

VLBI at 22 GHz ~ 1.3 cm

~ milliarcsec. scale



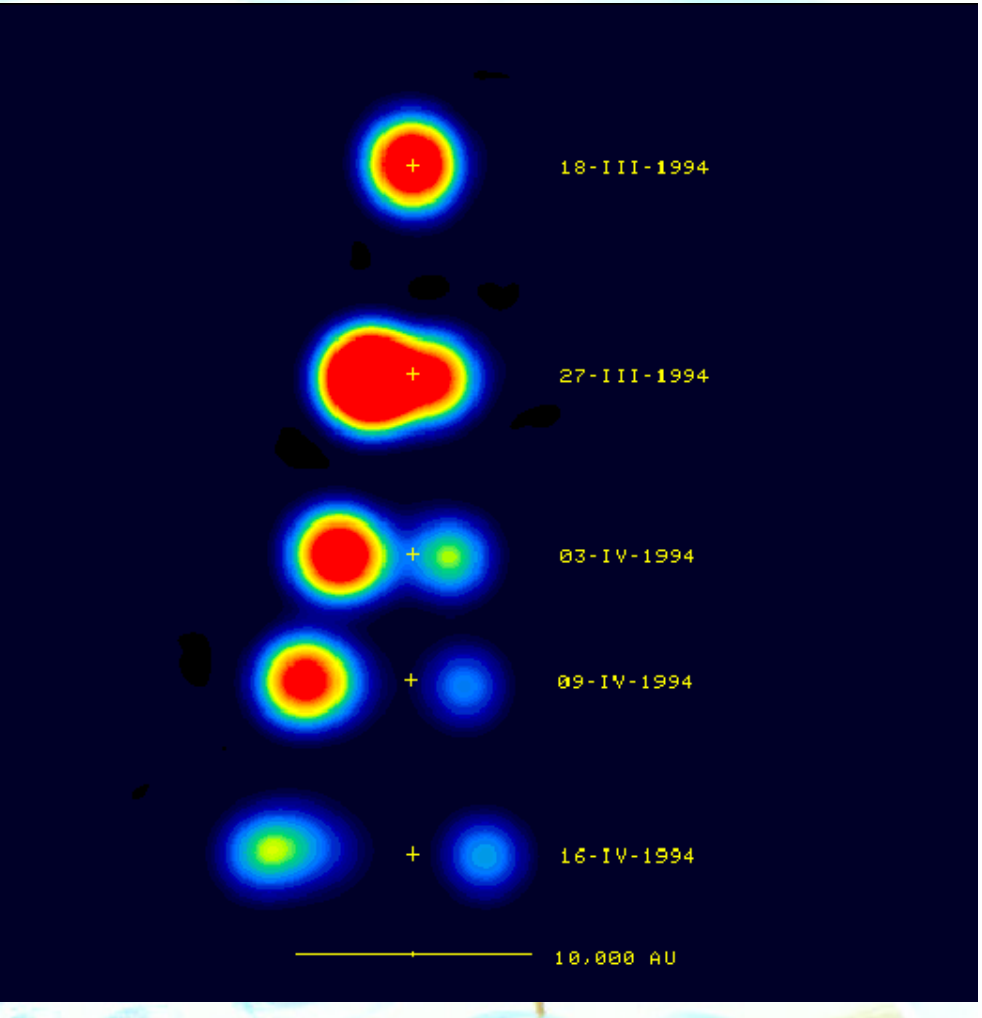
VLA at 3,5 cm

~ arcsec. scale

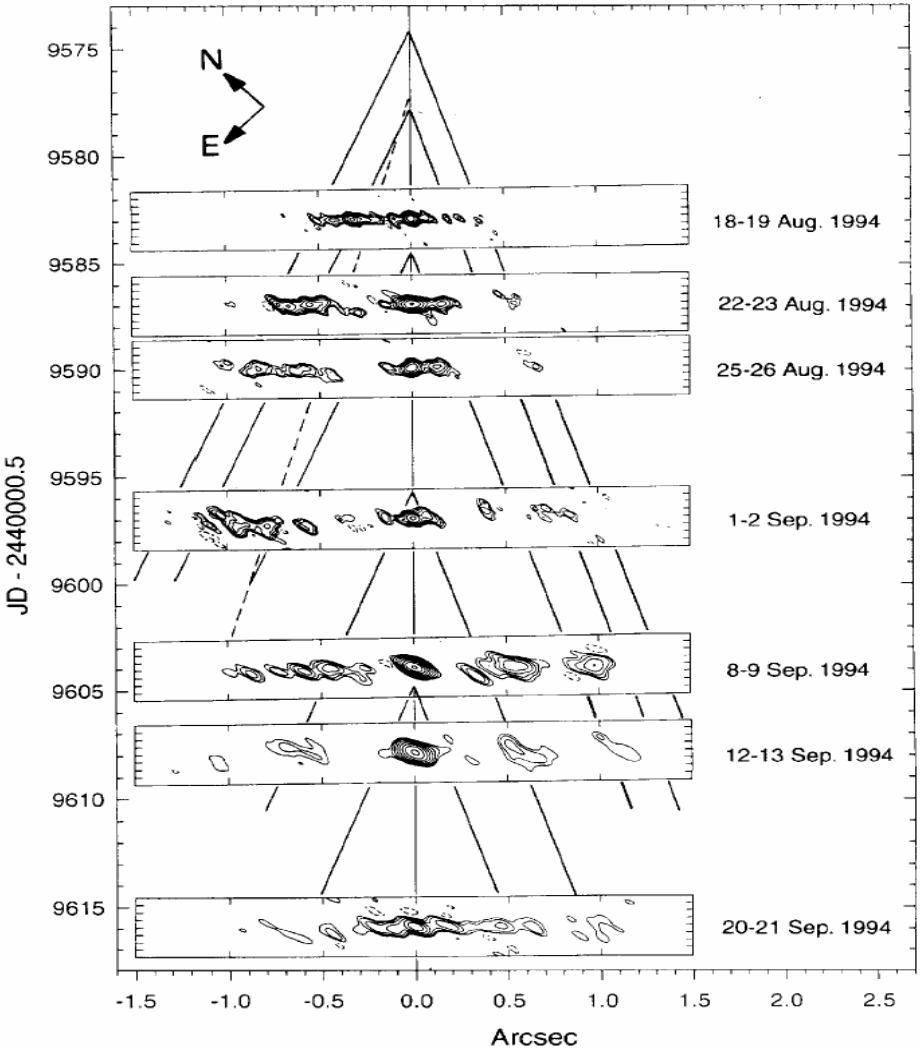
Mirabel & Rodriguez (1994)

- Move on the plane of the sky ~10^3 times faster
- Jets are two-sided (allow to solve equations ⇒ max. distance)
- X-ray outburst of new transients are usually associated with radio outburst → ejectn

Discovery of superluminal motion in GRS 1915+105 and GRO J1655-40



Mirabel & Rodriguez 1994



Hjellming et al. 1995

A reminder on relativistic effects

Relativistic Doppler effect

- The exact speed of a jet (AGN/XRB) is difficult to measure. The jet consists of non-thermal plasma where no spectral lines are visible. So Doppler-shifted lines can't be used to derive jet velocities (≠SS433).
- However, if high speed jet → possibility to use relativistic effects
- Consider a plasma blob (or shock) moving at a speed v < c at an angle θ wrt an observer, the observed spectrum will be shifted w.r.t. the emitted spectrum. In addition to this geometrical effect, time dilation has to be taken into account. A time difference Δt in the observer rest frame is related to a time difference $\Delta t'$ in the comoving frame (hereafter with ') via (cf Lorentz transformation):

$$\Delta t = \Gamma \Delta t' \quad \text{with} \quad \boxed{\Gamma = \left(\sqrt{1-\beta^2}\right)^{-1}} \quad \text{bulk Lorentz factor}$$

- Any periodic phenomenon in the moving frame (') will appear to have a longer period by a factor Γ when viewed by local observers

$$\beta = v / c$$

Relativistic Doppler effect (2)

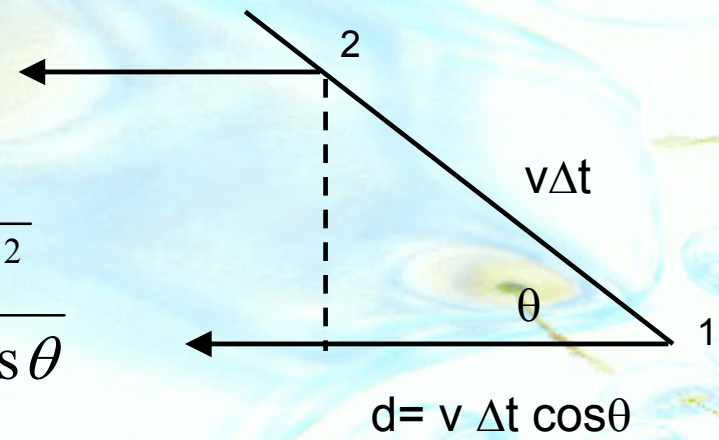
- Now, assume a source emits photon pulse at frequency ν' (period $\Delta t' = 1/\nu'$) in its rest frame
- The moving source emits one pulse as it moves from 1 to 2, then the time taken to move from 1 to 2 in the observer's frame is $\Delta t = \Gamma\, \Delta t' = \Gamma/\nu'$
- The difference in arrival time of the radiation emitted at 1 and 2 in the observer's frame is $\Delta t_A = \Delta t - d/c = \Delta t\,(1 - \beta \cos\theta)$
- The observed frequency will be:

$$\upsilon = \frac{1}{\Delta t_A} = \frac{\upsilon'}{\Gamma(1-\beta\cos\theta)}$$

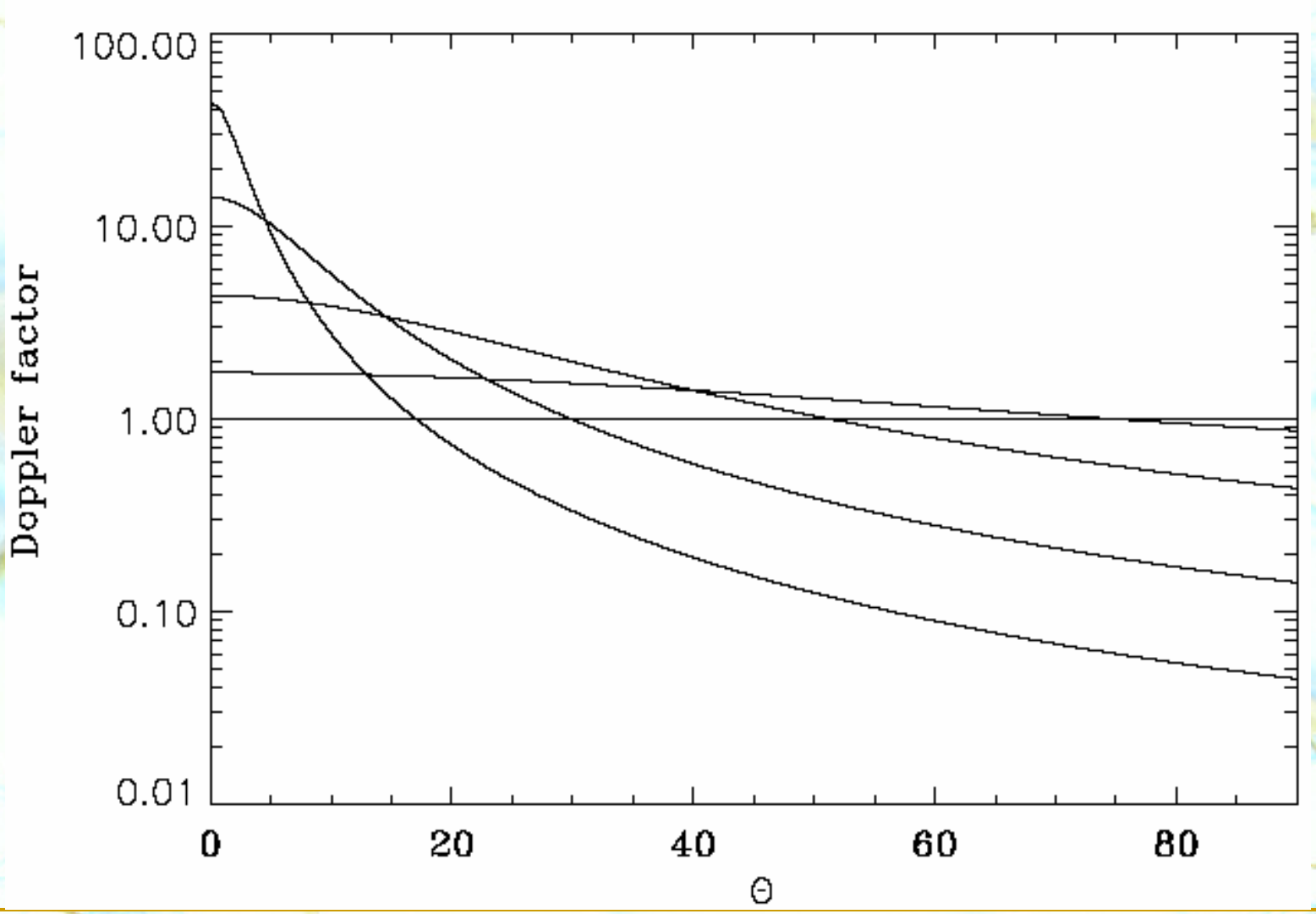
- <u>Doppler factor</u>:

$$D = \frac{1}{\Gamma(1-\beta\cos\theta)} = \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

- $\boxed{\nu_{obs} = D\,\nu_{jet}}$



Doppler factor

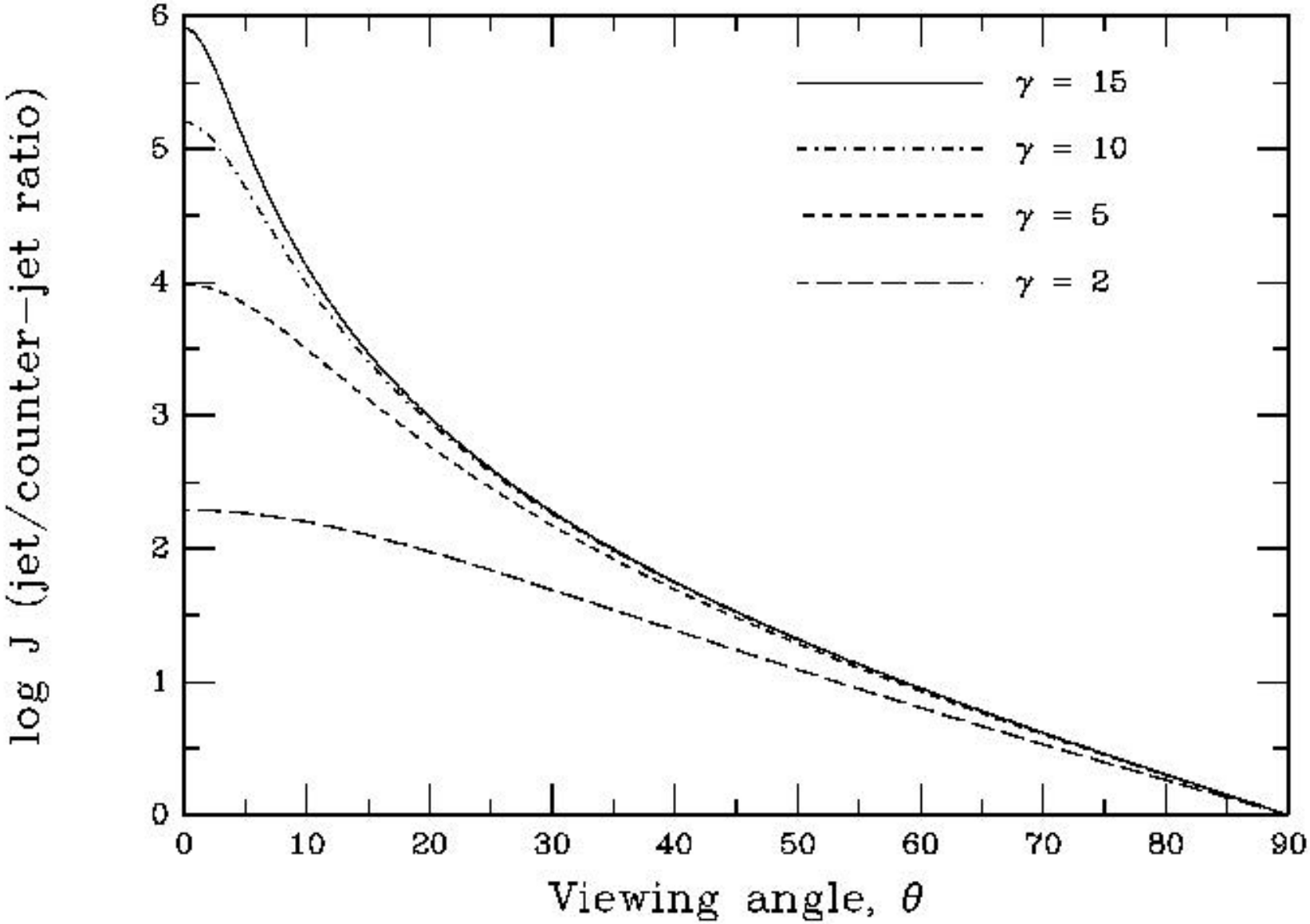


β = 0, 0.5, 0.9, 0.99, 0.999

Doppler boosting of relativistic jets

- Specific intensity: $I_\nu = dE / dAdtd\Omega d\nu$
- Flux density: $dF_\nu = I_\nu \cos\theta \, d\Omega$
- I_ν / ν^3 and F_ν / ν^3 are invariant under Lorentz transformation
- As $\nu = D\,\nu' \rightarrow F_\nu = D^3 F'_\nu$
- If flux density $F_\nu \propto \nu^\alpha$, then $F_\nu = D^{3-\alpha} F'_\nu$ (discrete ejection)
- For a continuous jet, the dependence on the Doppler factor will be reduced to D^2 (no contraction of source size)
- Therefore, one has $F_{obs} = D^{k-\alpha} F_{em}$ (k=2 for continuous jet and 3 for discrete ejection)
- Luminosity ratio between approaching and receding jets:

$$\frac{F_{app}}{F_{red}} = \left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)^{k-\alpha} \quad \text{avec } F_\upsilon \propto \upsilon^\alpha$$


log J (jet/counter-jet ratio)
Viewing angle, θ
γ = 15
γ = 10
γ = 5
γ = 2
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90

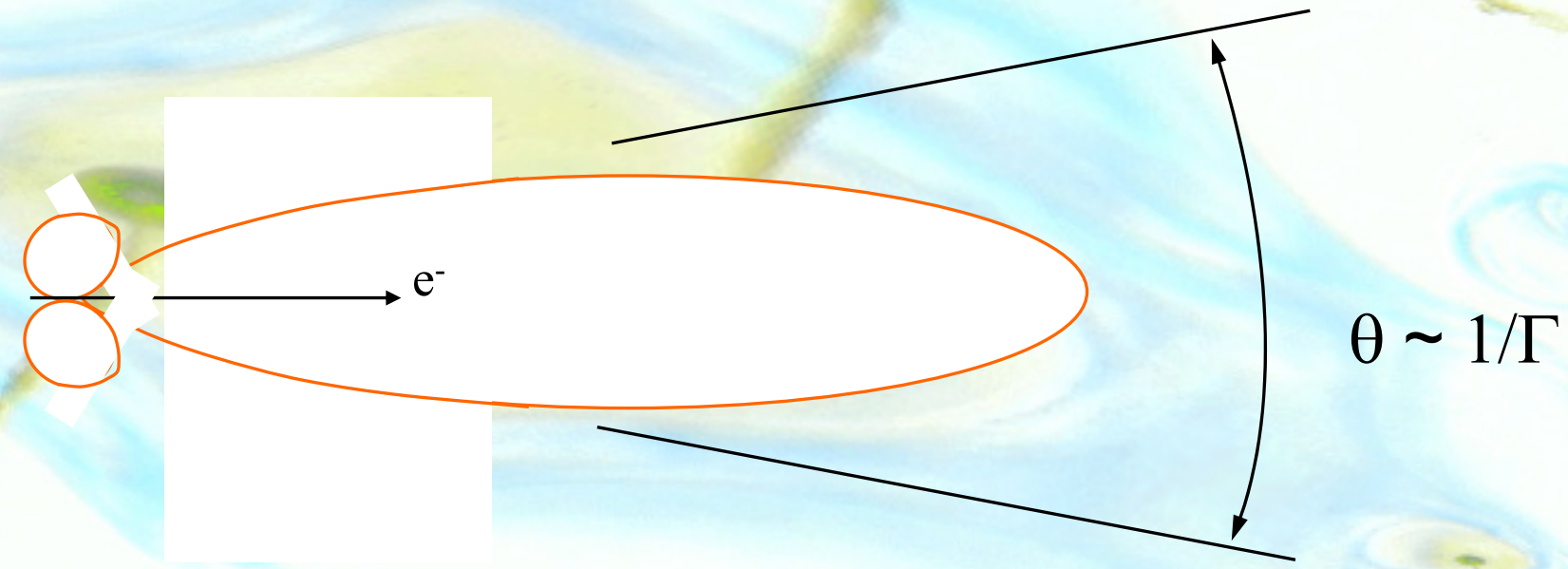
Relativistic aberration

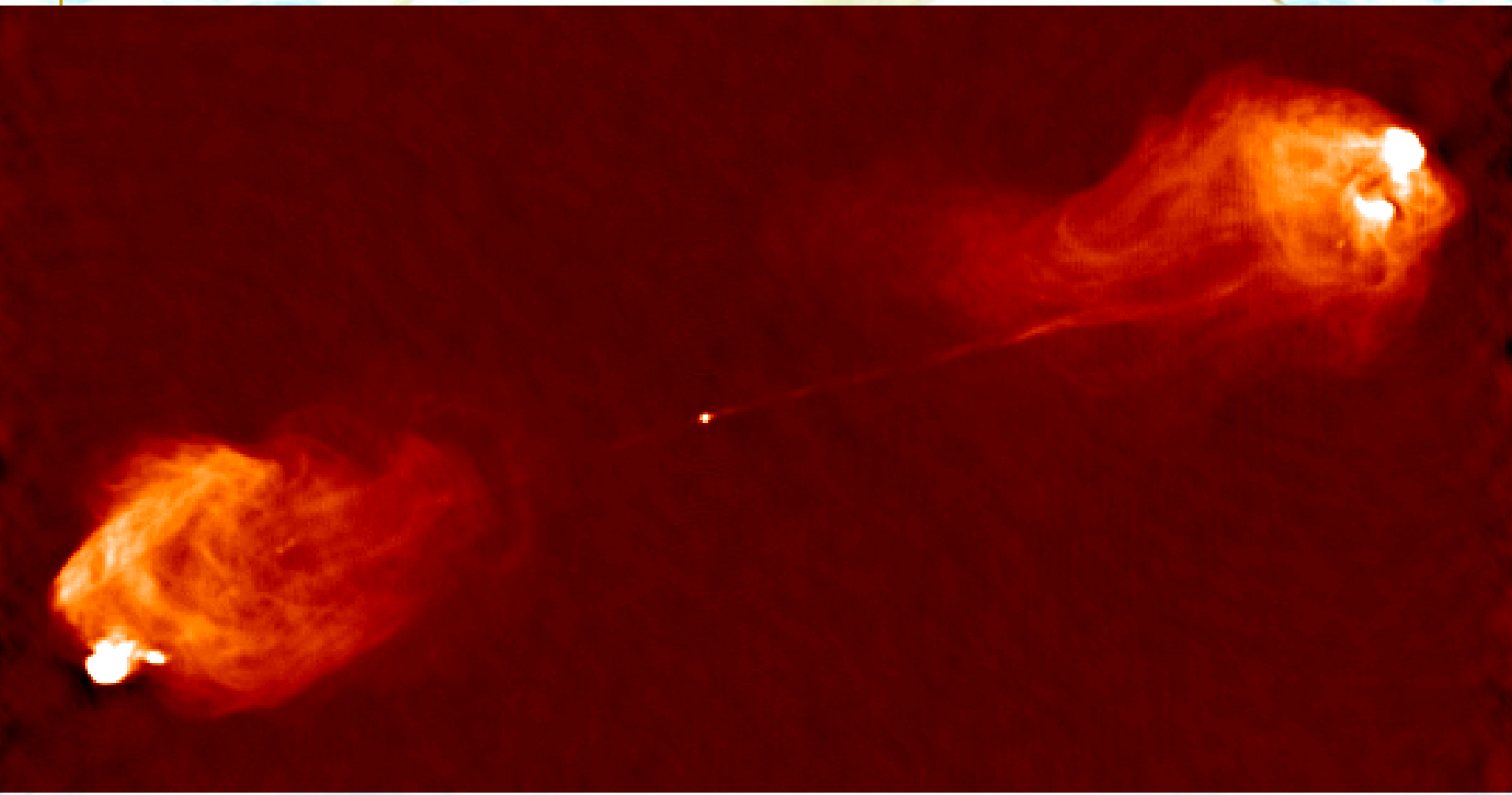
- Consider a source of radiation which emits isotropically in its rest frame and which is moving with velocity v with respect to an observer.
- The radiation is beamed in the direction of motion (cf angles are also transformed by relativistic effects).
- If emission in rest frame in angle θ', then in observer frame θ given by:

$$\tan\theta = \frac{\sin\theta'}{\Gamma(\cos\theta' + \beta)}$$

- Isotropic emission: $\theta' = \pi/2 \rightarrow \tan\theta = 1/\Gamma\beta$
- For $\Gamma >> 1 \rightarrow$ half of the emission will be emitted in a cone (boosting cone) with half opening angle: $\theta \approx 1/\Gamma$

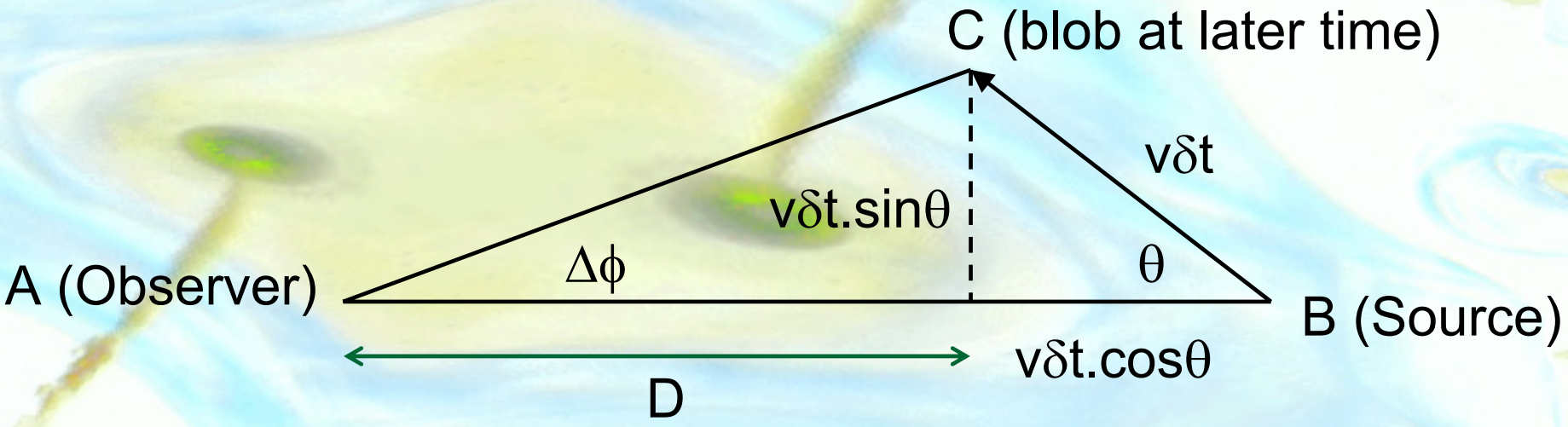
- Boosting cone:





Explanation of apparent superluminal motion

Explain apparent superluminal motion as an optical illusion caused by the finite speed of light. Consider a knot in the jet moving almost directly towards us at high speed v:



Source at position B emits a blob of gas with velocity v, at an angle θ to the line of sight to an observer at position A.

At time δt later, the blob has moved to position C.

Observer does not know v or θ. Observer measures:

- Time difference between blob being ejected and reaching position C
- Angular separation between B and C. Assuming that the distance D to the source is known, this gives the projected separation

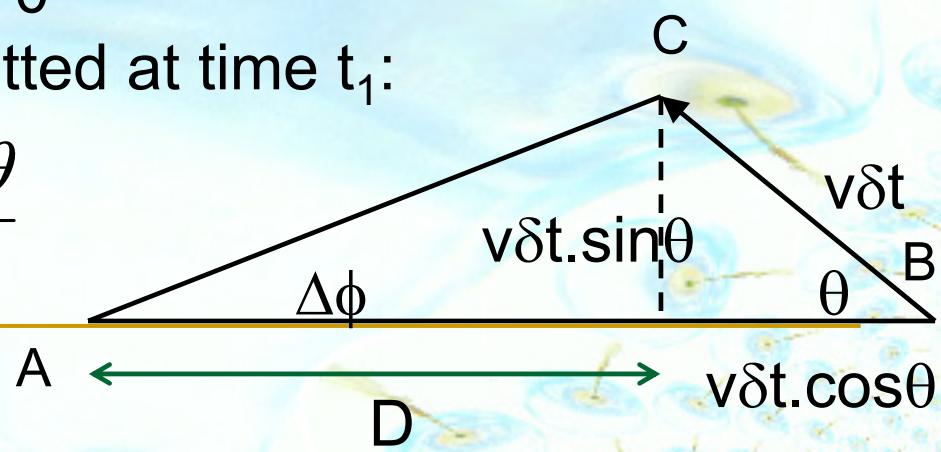
<u>Angular separation</u>: $\Delta\phi = \dfrac{v\delta t \sin\theta}{D}$

<u>Time difference as seen by the observer</u>:

Let blob be emitted at time t = 0

Observer sees blob being emitted at time t_1:

$$t_1 = \frac{D + v\delta t \cos\theta}{c}$$



Observer sees blob reach position C at time t_2:

$$t_2 = \delta t + \frac{D}{c}$$

Time difference is: $\Delta t = t_2 - t_1 = \delta t + \frac{D}{c} - \frac{D + v\delta t\cos\theta}{c}$

$$= \delta t\left(1 - \beta\cos\theta\right)$$

…where we have defined $\beta = v / c$

Observer infers a transverse velocity:

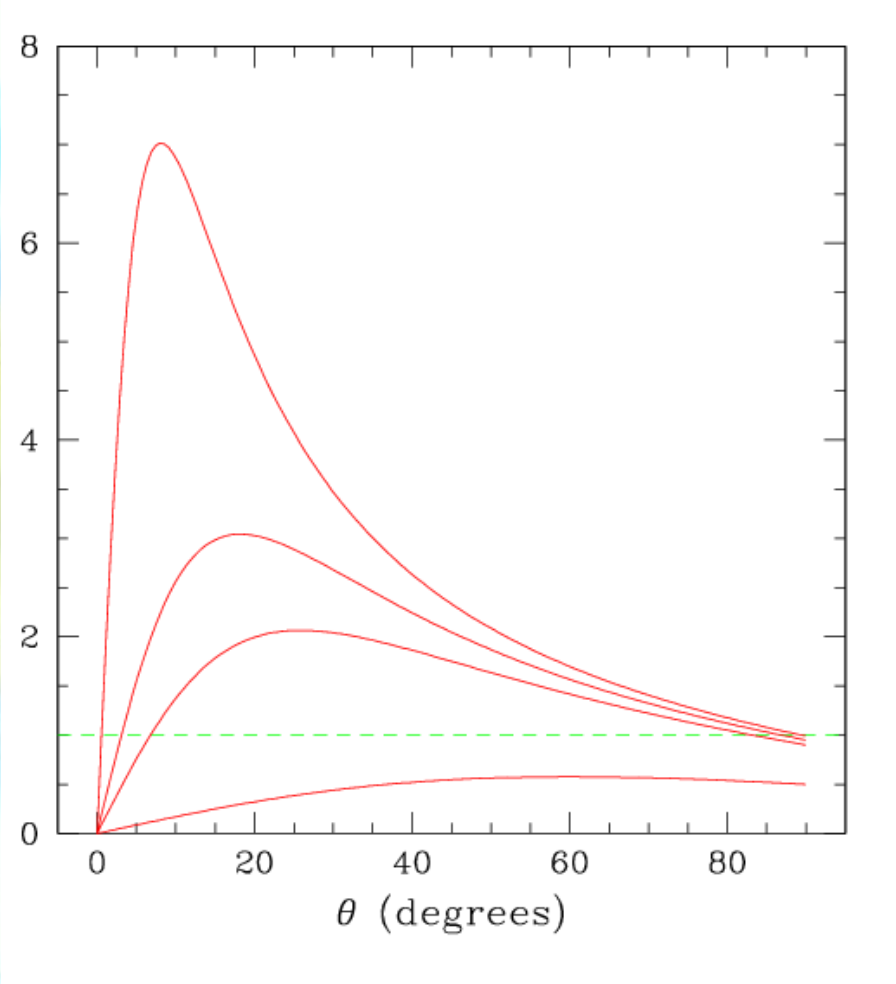
$$\boxed{\beta_{app} \equiv \frac{v_T}{c} = \frac{1}{c} \times \frac{D\Delta\phi}{\Delta t} = \frac{v\sin\theta}{c\left(1 - \beta\cos\theta\right)} = \frac{\beta\sin\theta}{1 - \beta\cos\theta}}$$

For β close to 1, and θ small, can clearly get an apparent transverse velocity $v_T > c$ (i.e. $\beta_{app} > 1$). e.g. $\beta = 0.99$, $\theta = 10$ degrees gives $\beta_{app} = 6.9$.

Apparent transverse velocity as a function of angle θ for different values of the true velocity: β = 0.5, 0.9, 0.95, 0.99

β_{app}

Apparent superluminal motion ($\beta_{app} > 1$)



If real v > 0.9 c, apparent superluminal motion will be seen in majority of sources (assuming random orientations).

True velocity must exceed a <u>critical value for superluminal motion to be observed</u> (irrespective of orientation).

First find <u>angle at which β_{app} is maximized</u>:

$$\beta_{app} = \frac{\beta \sin\theta}{1-\beta\cos\theta} = f(\beta,\theta) \qquad \frac{\partial \beta_{app}}{\partial \theta} = \frac{\beta\cos\theta}{1-\beta\cos\theta} - \frac{\beta^2 \sin^2\theta}{(1-\beta\cos\theta)^2} = 0$$

Solving this equation for $\theta = \theta_{max}$ gives: $\theta_{\max} = \cos^{-1}\beta$

Substituting this back into the expression for β_{app} :

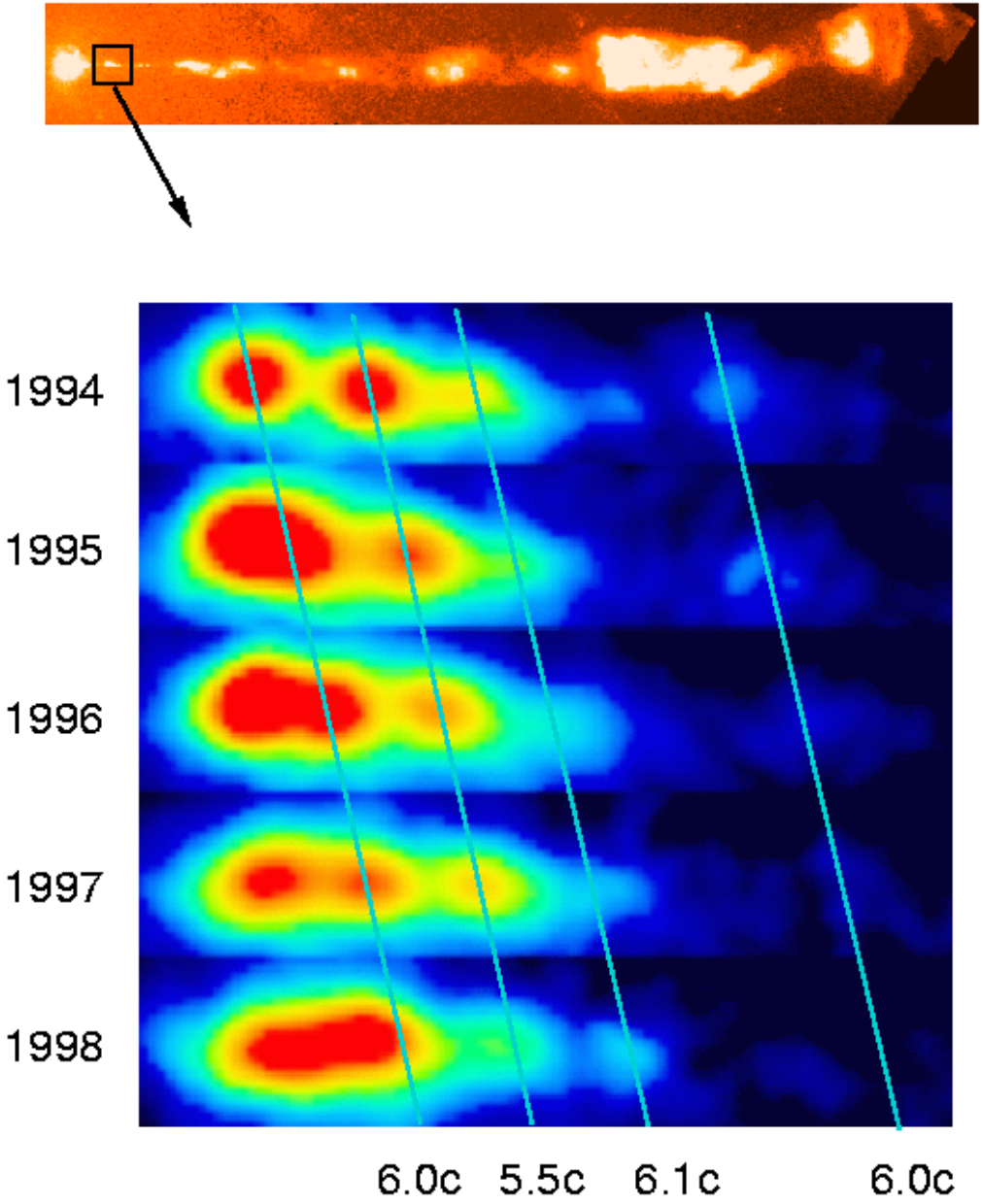
$$\beta_{app}^{\max} = \frac{\beta\sin\theta}{1-\beta\cos\theta} = \frac{\beta\sqrt{1-\beta^2}}{1-\beta^2} = \frac{\beta}{\sqrt{1-\beta^2}} = \Gamma\beta$$

Γ: Bulk Lorentz factor

Set left hand side equal to one (in order to get superluminal motion) and solve for β: $1-\beta_{\min}^2 = \beta_{\min}^2$

$$\beta_{\min} = \frac{\sqrt{2}}{2} = 0.707\ldots$$

Superluminal Motion in the M87 Jet



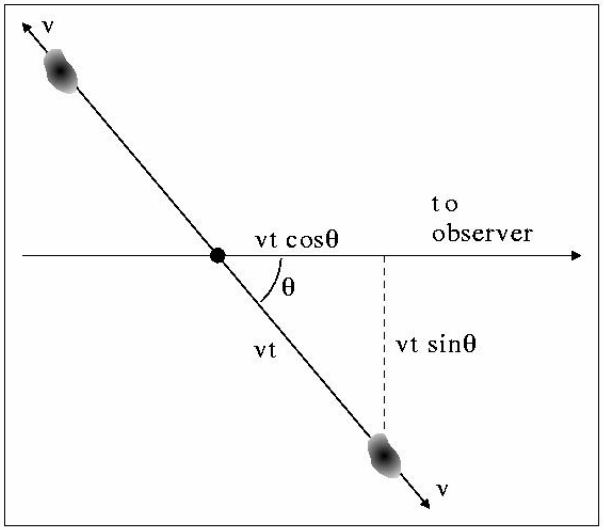
Population statistics

- The maximum value of β_{app} which can be produced by a jet arises when $\theta = \cos^{-1}(\beta)$, for which

$$\beta_{app}^{\max} = \Gamma\beta$$

- By taking the upper limit of β_{app} in large samples of quasars, we infer that the bulk motion in the jets of AGN typically has $\Gamma \sim 5$ to 10.
- The distribution of β_{app} in the quasar population can then be used to infer their distribution in line-of-sight angle. We found that quasar jets are not isotropically distributed in angle: they preferentially point towards us.

Superluminal motion in galactic microquasars



- In extragalactic sources, we see components moving away from a stationary core on one side only
- Microquasars: <u>symmetric</u> ejection of two relativistic blobs:

$$\beta_{app} = \frac{\beta \sin\theta}{1-\beta\cos\theta} \qquad \beta_{rec} = \frac{\beta \sin\theta}{1+\beta\cos\theta}$$

Proper motion

$$\mu_a = \frac{\beta \sin\theta}{(1-\beta\cos\theta)}\frac{c}{D}$$

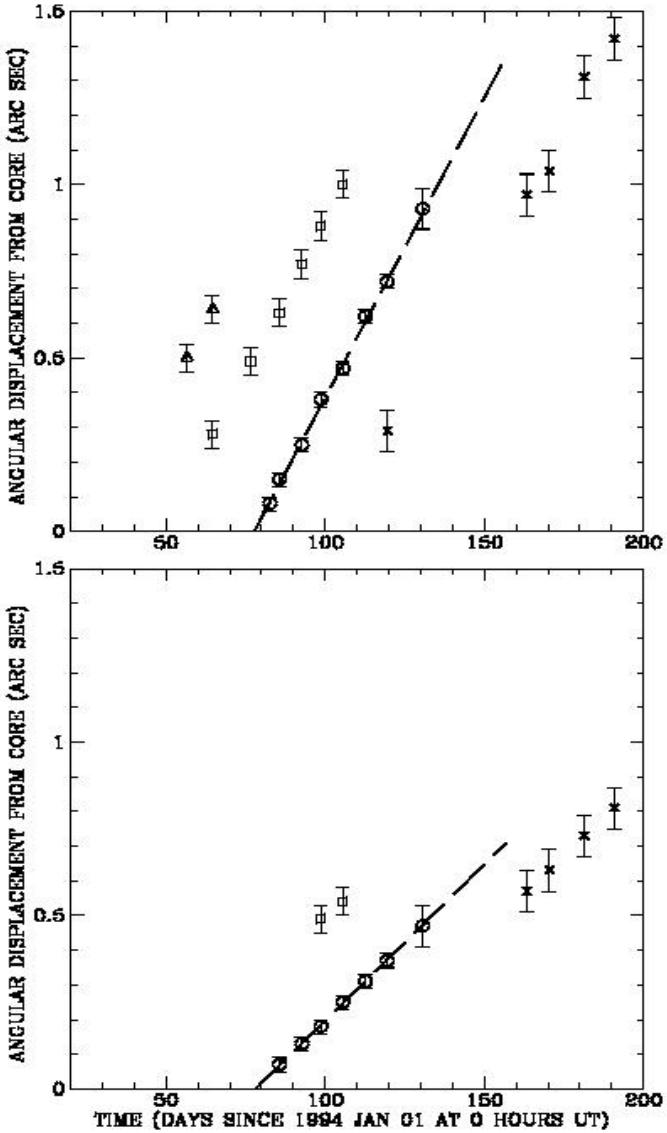
$$\mu_r = \frac{\beta \sin\theta}{(1+\beta\cos\theta)}\frac{c}{D}$$

$$\beta\cos\theta = \frac{\mu_a - \mu_r}{\mu_a + \mu_r}$$

2 equations
3 unknowns

$$D = \frac{c\tan\theta}{2}\frac{(\mu_a - \mu_r)}{\mu_a \mu_r} \le \frac{c}{\sqrt{\mu_a \mu_r}}$$

Application to GRS 1915+105



$$\mu_a = 17.6 \pm 0.4 \text{ mas/d and } \mu_r = 9.0 \pm 0.1 \text{ mas/d}$$

$$\beta \cos\theta = 0.323 \pm 0.016$$

$$\beta = 1 \Rightarrow \theta \leq 71^\circ \text{ and } \cos\theta = 1 \Rightarrow \beta \geq 0.323$$

$$D \leq 13.7 \text{ kpc}$$

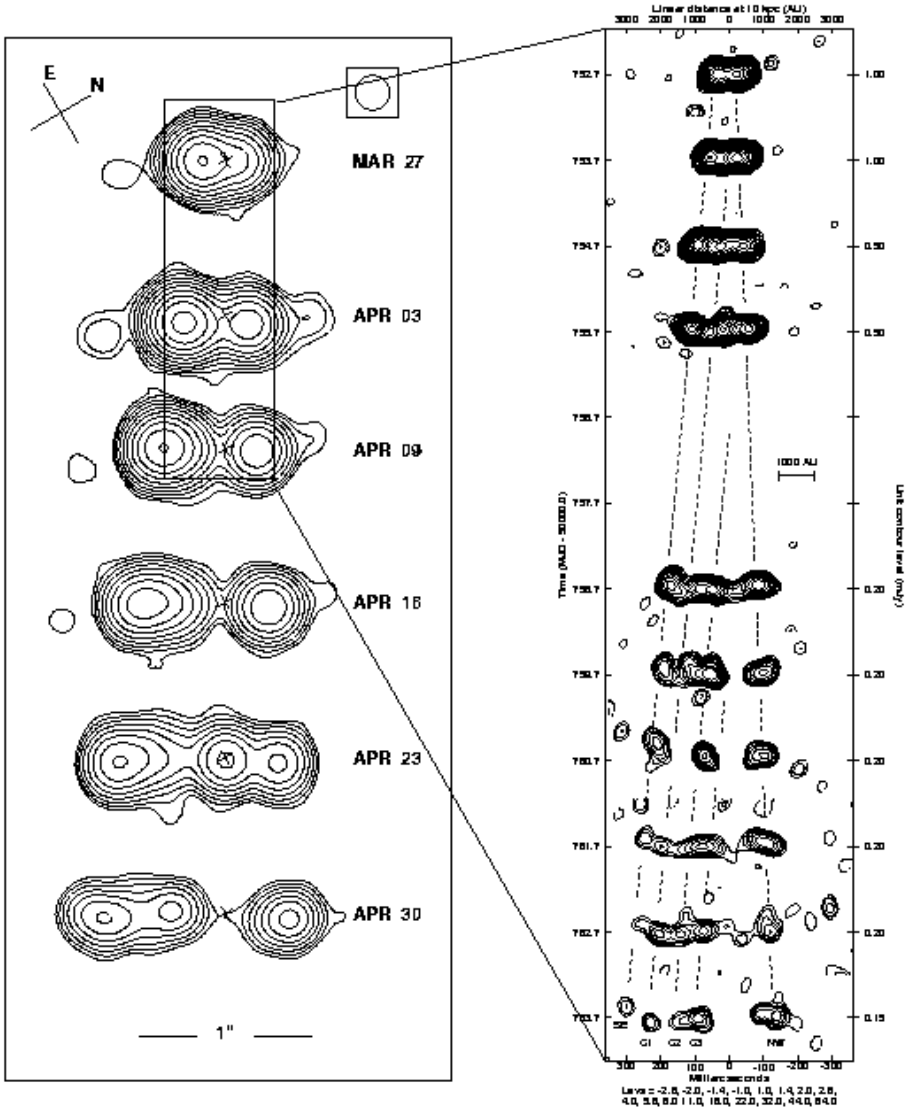
- HI abs → D = 12.5 +/- 1.5 kpc

  β_a = 1.25, β_r = 0.65

  β= 0.92 +/- 0.08 and θ = 70+/-2°
- However, distance could be as low as 6 kpc (Chapuis & Corbel 04), then no superluminal motion in GRS 1915+105 !!!

Mirabel & Rodriguez 1994, Nature

Merlin observations of GRS 1915+105



Fender et al. 1999, MNRAS

Merlin observations of GRS 1915+105

$$\mu_a = 23.6 \pm 0.5 \text{ mas/d} \quad \text{and} \quad \mu_r = 10.5 \pm 0.5 \text{ mas/d}$$

$$\beta \cos\theta = 0.41 \pm 0.02$$

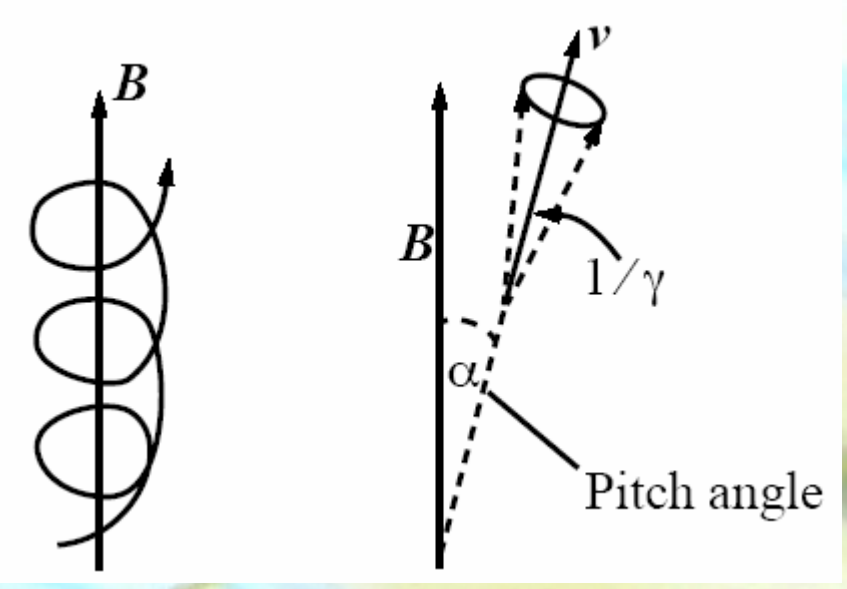
$$\beta = 1 \Rightarrow \theta \leq 66^\circ \text{ and } \cos\theta = 1 \Rightarrow \beta \geq 0.41$$

$$D_{\max} = 11.2 \pm 0.8 \text{ kpc}$$

- Merlin 1999 data imply a higher intrinsic velocity (by $\Delta\beta$ ~0.1) than 1994 VLA.
- Further confirmed by Miller-Jones et al. (2006) and VLBA (Dhawan et al. 2000) from outburst in 97, 98, 01.
- No deceleration with Merlin on scale of 50-300 mas. VLA scale: up to 800 mas: ballistic motion.
  - Result of jet precession ? Probably not.
  - Original ejection: intrinsically slower due to a denser environment that would have been later blown away ?
    - IR jets (Sams et al. 96): heating of surrounding ISM ?
    - Test: VLA obs should now measure same velocity as Merlin

Some details on synchrotron emission (with illustrative examples)

Relativistic electrons in a magnetic field



$$E_e = \gamma_e m_e c^2 \text{ avec}$$

$$\gamma_e = (1-\beta^2)^{-1} >> 1$$

$$\text{et } \beta = v/c$$

- Helical motion due to Lorentz force + emission in boosting cone.
- NB: γ_e Lorentz factor of the electrons $\neq \Gamma$ (**Bulk** Lorentz factor)
- Intensity spectrum of a single electron with maximum of emission at $\nu_{max} = 0.29\ \nu_c$ and

$$\upsilon_c = \frac{3}{4\pi}\gamma_e^{\ 2}\frac{eB}{m_e}\sin\alpha = \frac{3e}{4\pi\, m_e}\gamma_e^{\ 2}B_\perp$$

- In practical units:

$$\upsilon_c = 4.2\, B_\perp \gamma_e^{\ 2} = 16.10^6\ B_\perp E^2 \text{ (MHz)}$$

with B in Gauss and E in GeV

Synchrotron emission from an electron distribution

- Electron energy distribution is a power law:

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

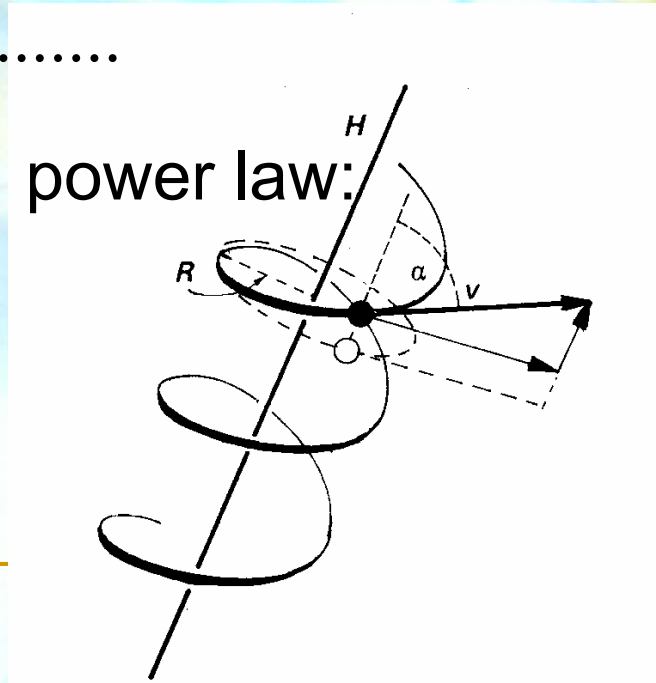
- Summing the contribution for each e$^-$:

$$P(\upsilon,\theta) \propto B^{(p+1)/2}\,\upsilon^{-(p-1)/2}\int_{\upsilon/\upsilon_1}^{\upsilon/\upsilon_2} \ldots\ldots\ldots$$

- The radio spectrum is therefore a power law:

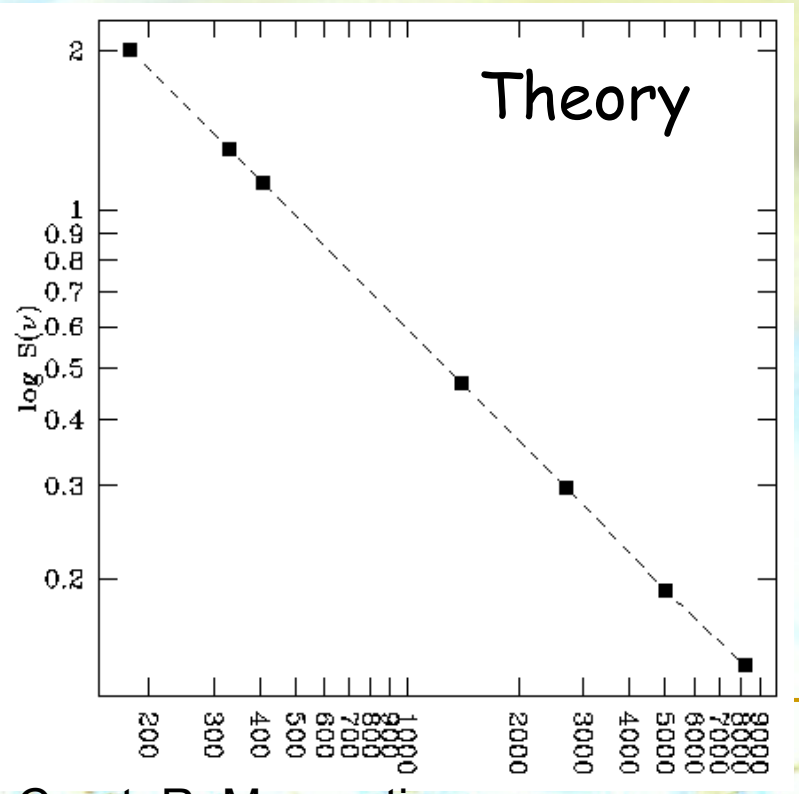
$$S \propto \upsilon^{\alpha} \qquad \alpha = -(p-1)/2$$

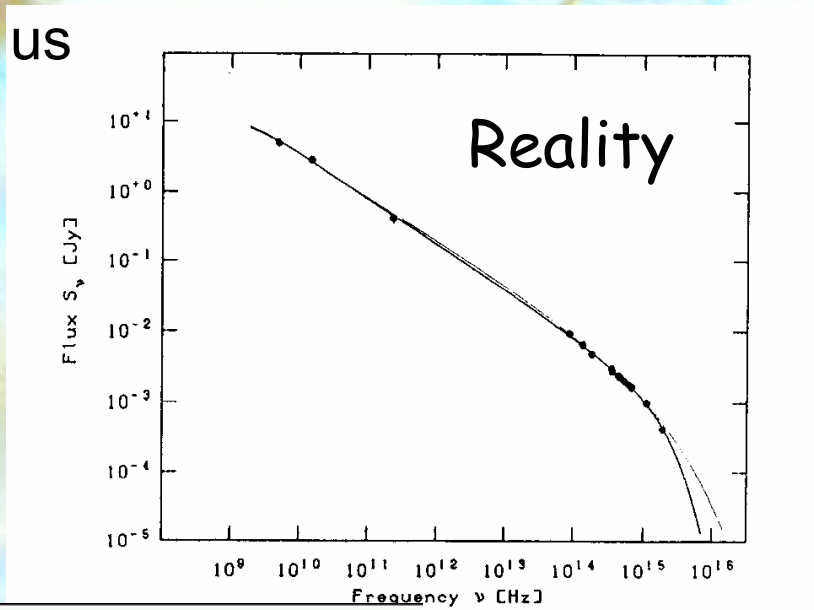
- Typical α ~ -0.6 $\qquad p$ ~ 2.2

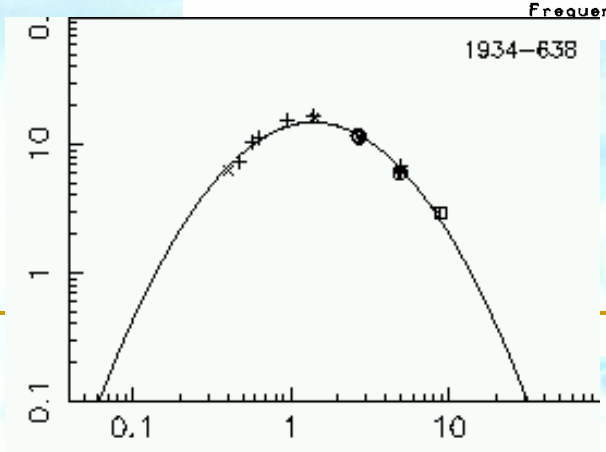


Deviation from a constant spectral index

- Energy losses
- Self-absorption in the relativistic electrons gas
- Absorption from ionized gas between us and the source (free-free absorption)







Court. R. Morganti

Energy losses

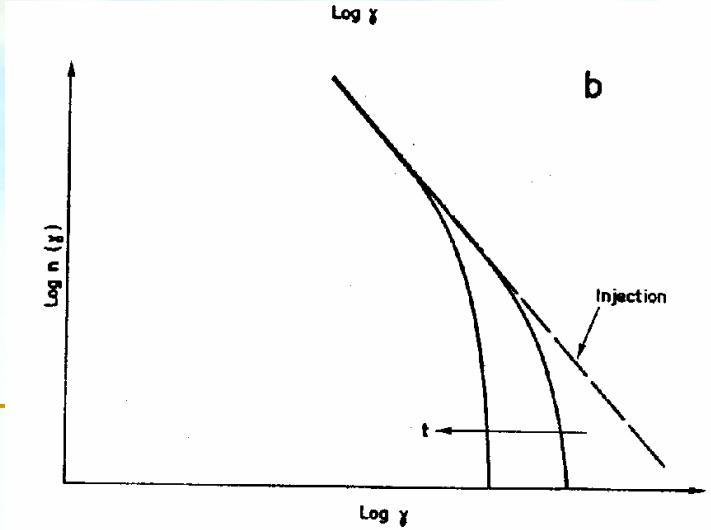
- The relativistic electrons can <u>loose energy</u> because of a number of process (adiabatic expansion of the source, synchrotron emission, inverse-Compton etc.) → the characteristics of the radio source and in particular the energy distribution *N(E)* (and therefore the spectrum of the emitted radiation) tend to modify with time.
- <u>Adiabatic expansion</u>: strong decrease in luminosity but the spectrum is unchanged
- Energy loss through radiation (<u>synchrotron loss</u>): characteristic electron half-life time (time for energy to half)

$$\tau = \frac{E_0}{-\left(\frac{dE}{dt}\right)}$$

After a time τ only the particle with $E<E_0$ still survive while those with $E>E_0$ have lost their energy.

$$\tau = 5\times10^{-13} B^{-2} E^{-1} \quad s \qquad (B \text{ in T}, E \text{ in J})$$

$$\tau = (120\, B^2 E)^{-1} \quad ans \qquad (B \text{ in G}, E \text{ in GeV})$$



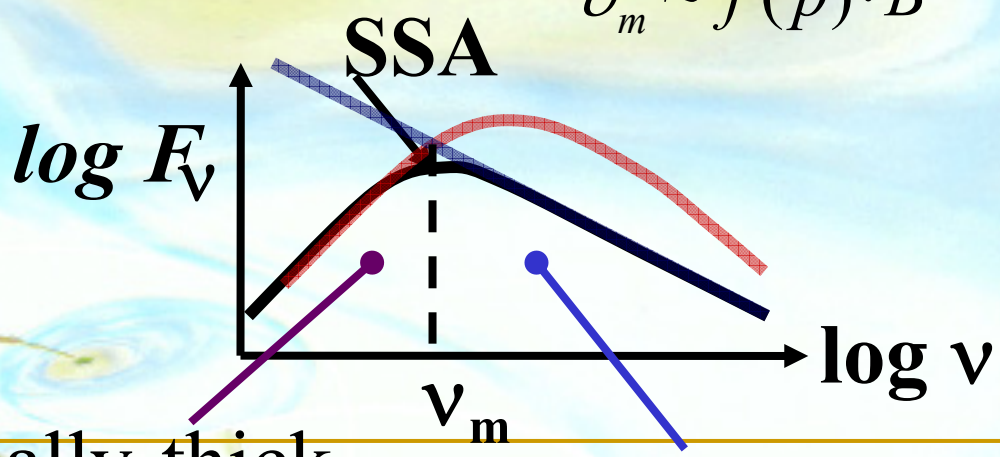
Self-absorption in the relativistic electron gas

- Optically thick case: the internal absorption from the electrons needs to be considered → the brightness temperature of the source is close to the kinetics temperature of the electrons
- The opacity is larger at lower frequency → plasma opaque at low frequencies and transparent at high

Frequency corresponding to τ=1

$$\tau >> 1 \qquad S(\nu) \propto \nu^{-5/2} B^{-1/2} d\Omega$$

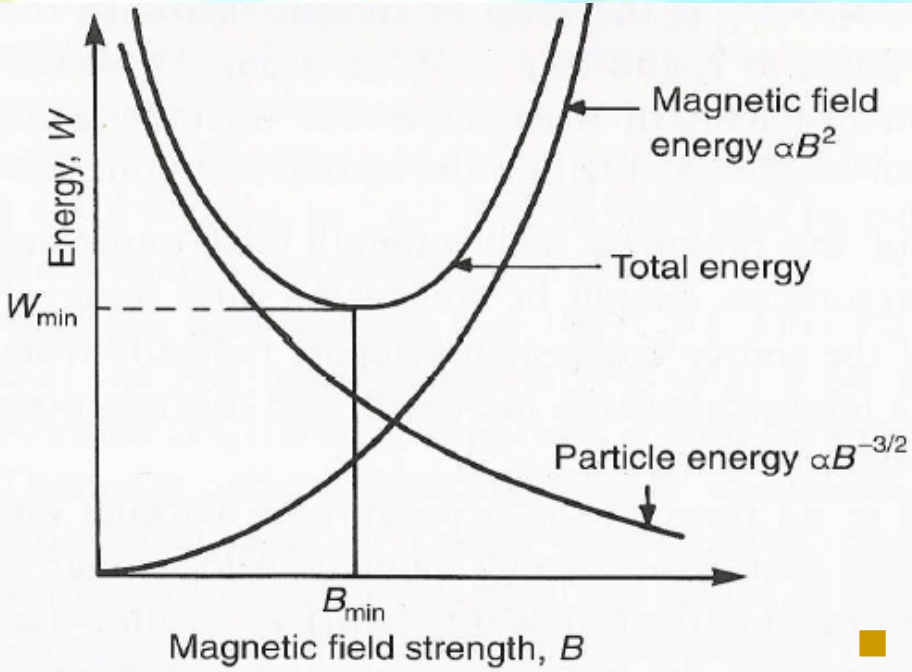
$$\upsilon_m \sim f(p) \cdot B^{1/5} S_m \theta^{-4/5} (1+z)^{1/5} \text{ GHz}$$



Optically-thick regime

Optically-thin

Energetics: definition of equipartition



Longair 1994

- The total energy stored in the plasma is divided into that stored in particles and that stored in B. To produce a given synchrotron power, one may have strong B and less energy in particles, or vice-versa. The lower limit on the total energy required is near the equipartition value
- ~ same amount of energy in particles and B (!! Not the minimum of B !!!)

Mass and energy of the ejecta in GRS 1915+105

- 1999 outburst (see Fender et al. 1999)
- Need to know the Lorentz factor Γ !! Take 5 for now
- Minimum energy conditions : equipartition → same energy in magnetic field and in particles. See Longair 1994
- Blob unresolved → rise time give interval during which relativistic material is injected < 12hr → $V = 4\pi(c\Delta t')^3/3$
- Filling factor (1 ?) Limits on the energy spectrum $\nu_{min} = \nu_{minradio}$?
- Contribution of proton ? (η -1 = 0) is ratio of energy in protons to that in relativistic electrons
- Minimum total energy :

$$W_{\min} \approx 3.0 \cdot 10^6 \eta^{4/7} (V/m^3)^{3/7} (\nu / Hz)^{2/7} (L_\nu / WHz^{-1})^{4/7} \text{ J}$$

- Associated magnetic field :

$$B_{\min} \approx 1.8 \left(\eta \ (L_\nu / WHz^{-1}) / (V/m^3) \right)^{2/7} (\nu / Hz)^{1/7} \text{ T}$$

- $W_{min} = 7.7 \times 10^{35}$ J = 7.7×10^{42} erg and B_{min} = 28 nT = 280 mG

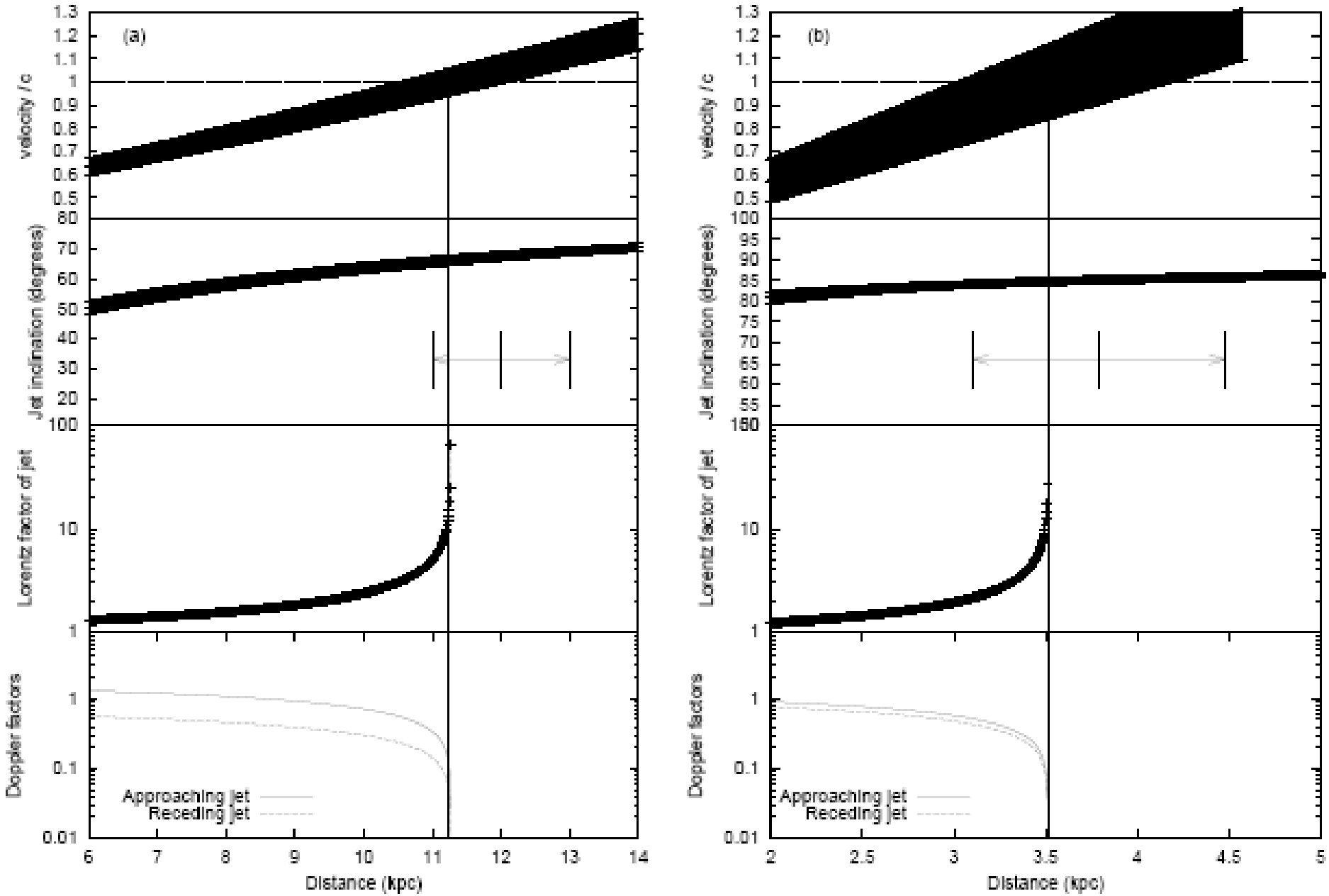
- Total number of relativistic electrons:

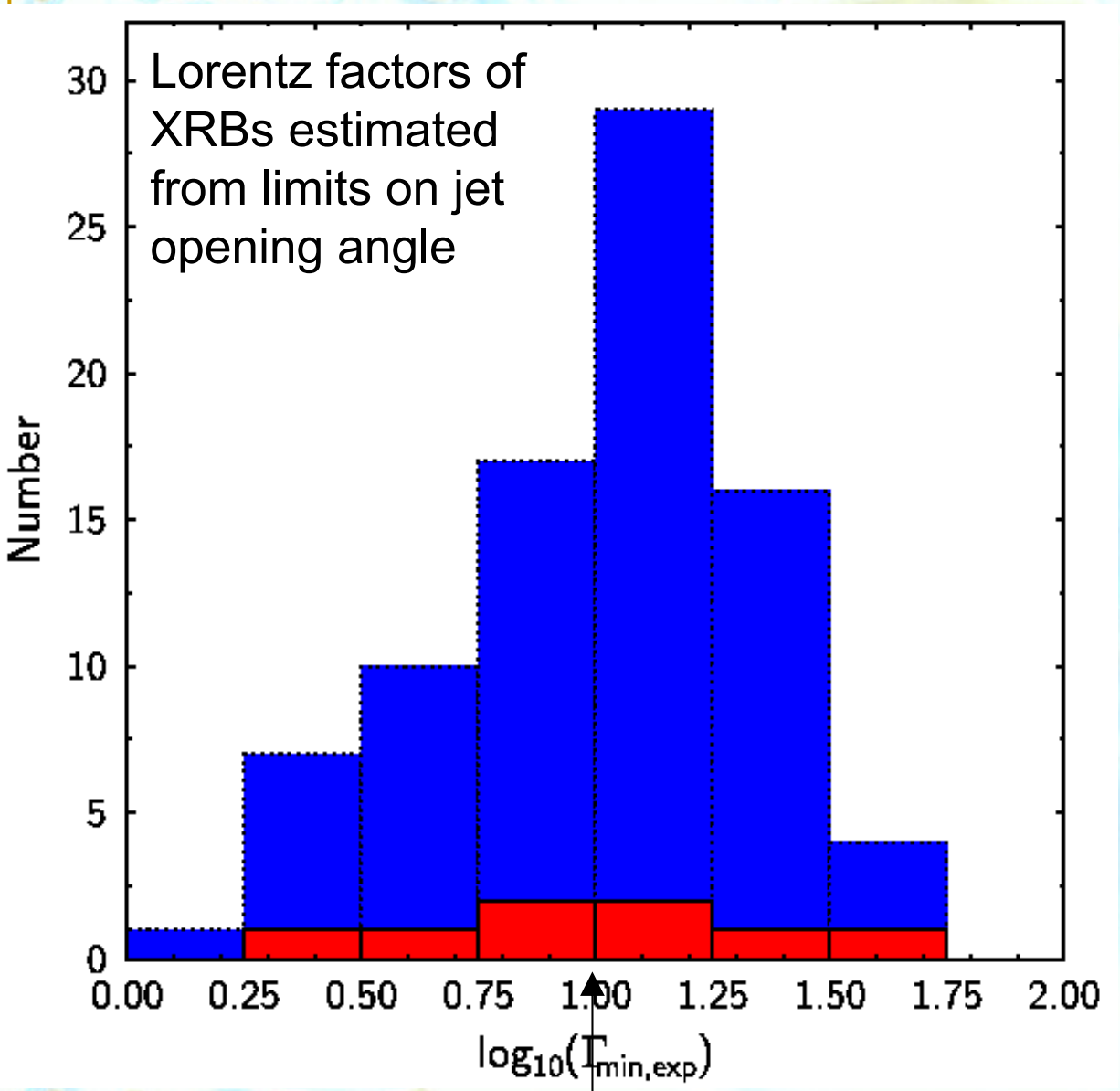
$$N_{tot} = (L_\nu / WHz^{-1}) f(\alpha)(B_{\min} / T) = 1.6 \cdot 10^{46}$$

- Associated with the bulk motion of the jet there is also the kinetic energy:
  - e^-/e^+ plasma: KE = $(\Gamma-1)\ W_{min}$= 9 x 10^{36} J = 9 x 10^{43} erg
  - If the e^-/e^+ plasma contain an additional pop. of cold p: KE = $(\Gamma-1)(\ W_{min} + N_{tot} m_p c^2)$→ x 2
  - The total KE of p could vary, either way, if the conditions were far from "minimum energy", or be substantially larger if the e- dist continue to rise to lower energies, with correspondingly more p.
- Power required = 2 Γ W_{min} in 12hr = 2 x 10^{32} W = 2 x 10^{39} erg/s (x2 if p). Require mass flow rate > 10^{18} g/s
- Limitations !!!

Limitations of relativistic jet proper motions: limits on Bulk Lorentz factor Γ

- $\beta_{VLA} = 0.92 \rightarrow \Gamma \sim 2.5$ (@ $d_{max} = 12.5$ kpc)
- $\beta_{Mer} = 0.98 \rightarrow \Gamma \sim 5$ (@ $d_{max} = 11$ kpc)
- Be aware, this is dependant of distance's estimate, always close to d_{max} !!!
- The observed proper motions only allow us to place a lower limit on the bulk Lorentz factor Γ of the flow, and therefore on the total energy associated with the ejection: $E_{tot} \sim \Gamma E_{int}$
- All significantly relativistic jets will lie very close to d_{max}!
- GRS 1915 $\rightarrow$ $2<\Gamma<30$: the power expended on particle acceleration and bulk motion during the jet formation episode could represent a significant, even dominant, fraction of the total accretion power available.


(a)
(b)
velocity / c
Jet inclination (degrees)
Lorentz factor of jet
Doppler factors
Approaching jet
Receding jet
Distance (kpc)



$\Gamma = 10$

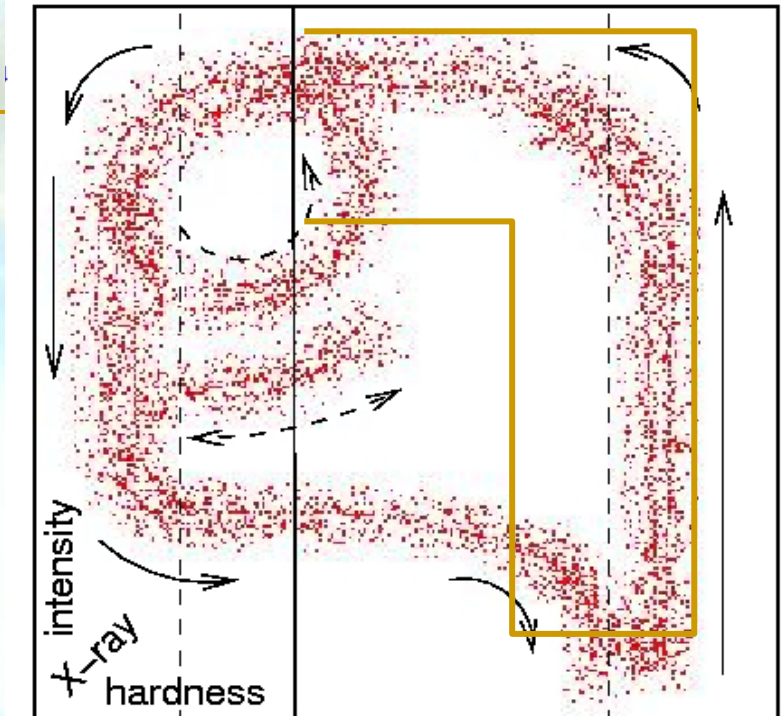
The jets may be just as relativistic as those from AGN

XRB

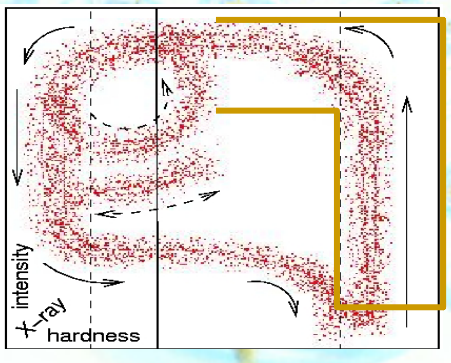
AGN (Jorstad)

Miller-Jones, Fender & Nakar (2006)

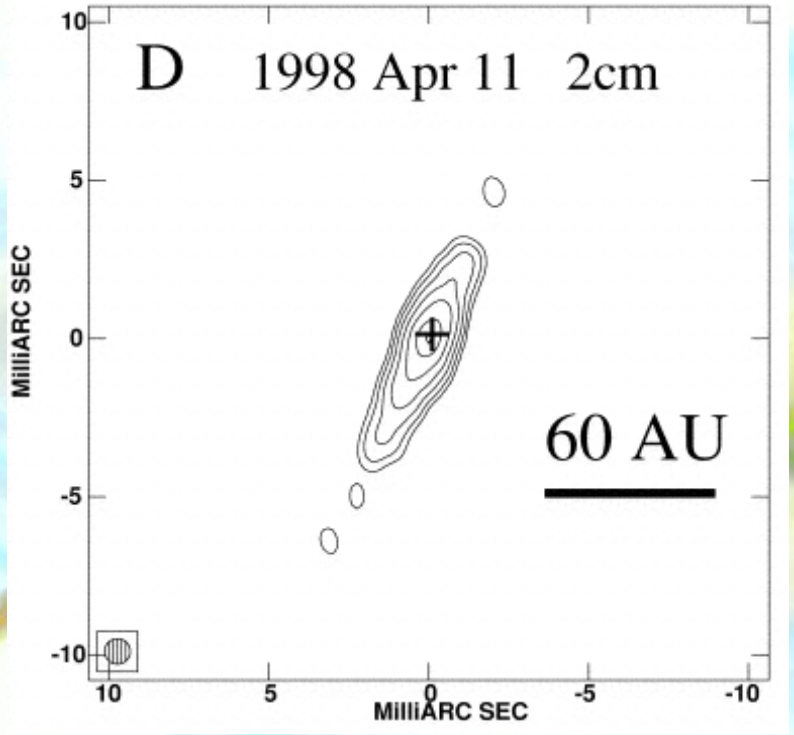
Part III: Compact cores in the hard state



Compact self-absorbed jets



GRS 1915+105 (plateau state)



Dhawan et al. (2000)

Compact jet usually not resolved, but inverted or flat radio spectra (Corbel et al. 00, Marti et al. 00, Corbel et al.01,Fender 01)

Optically thick synchrotron emission from a conical self-absorbed outflow: Blandford & Konigl (1979) , Hjellming & Johnson (1988)

Particle spectrum of a section of jets

Total synchrotron spectrum

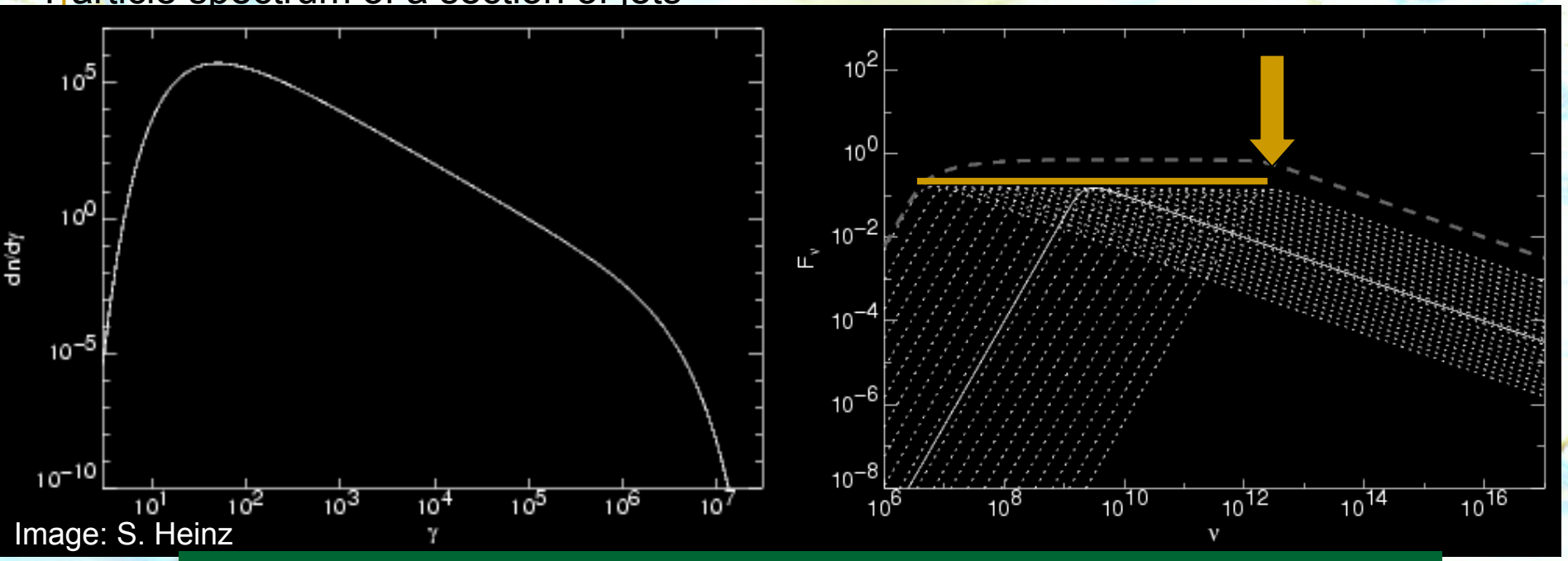
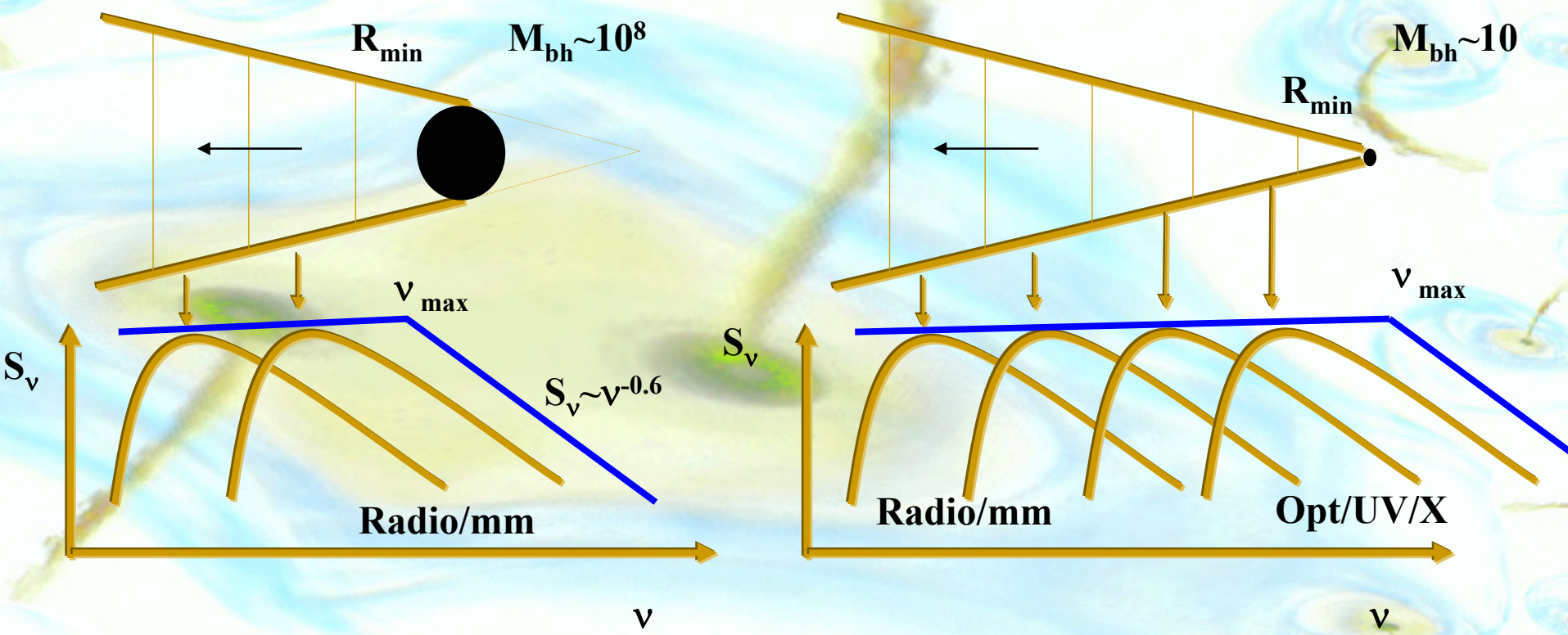


Image: S. Heinz

- A power-law in the energy distribution produces a powerlaw in the spectrum
- In the inner jet region the low-frequency spectrum is self-absorbed.
- Hence, e^- with $1 \leq \gamma_e \leq 100$ remain invisible but they make up 99% of the total electron content
- Sideways expansion at sound speed + weak accceleration (cf. longitudinal pressure gradient) → conical jet

The Synchrotron Spectrum of Jets

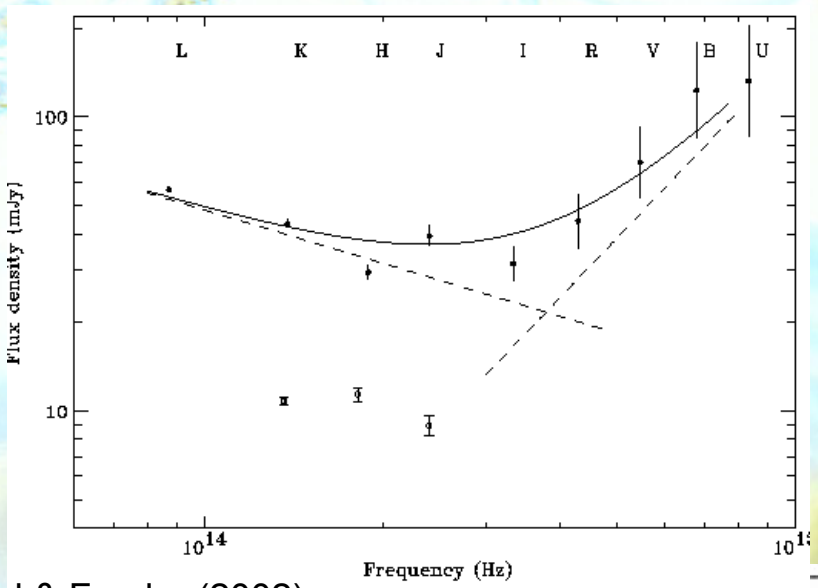


In jets $\nu \propto r^{-1} \Rightarrow \nu_{max} \propto r_{min}^{-1} \propto M_{bh}^{-1}$

$\Rightarrow$Turnover Frequency in stellar black holes >> compact core in AGN!

Court. H Falcke

Cut-off frequency in near-infrared

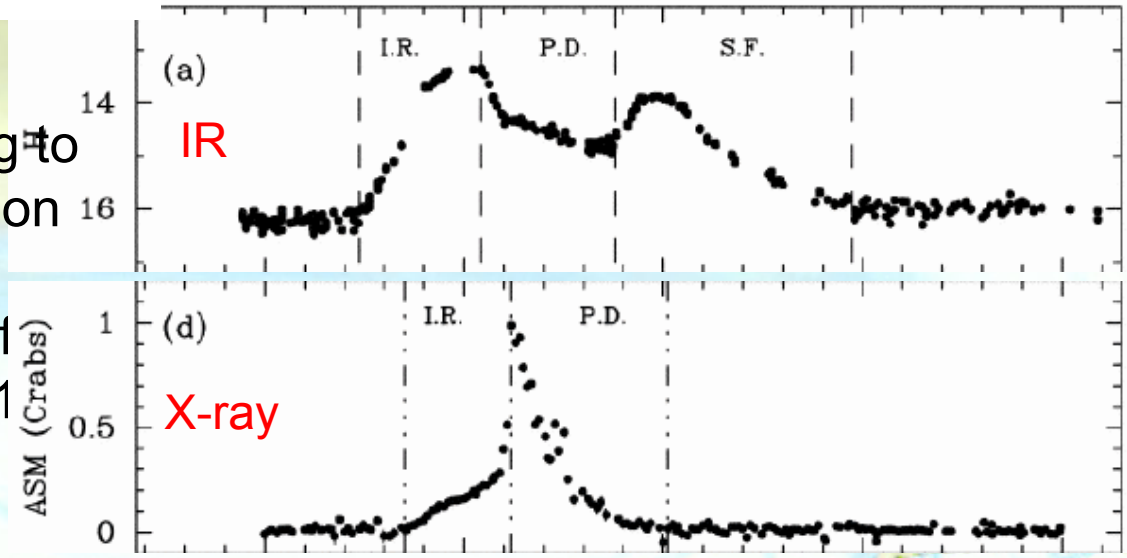


Corbel & Fender (2002)

IR synchrotron emission in GX 339-4, but also XTE J1550-564,…

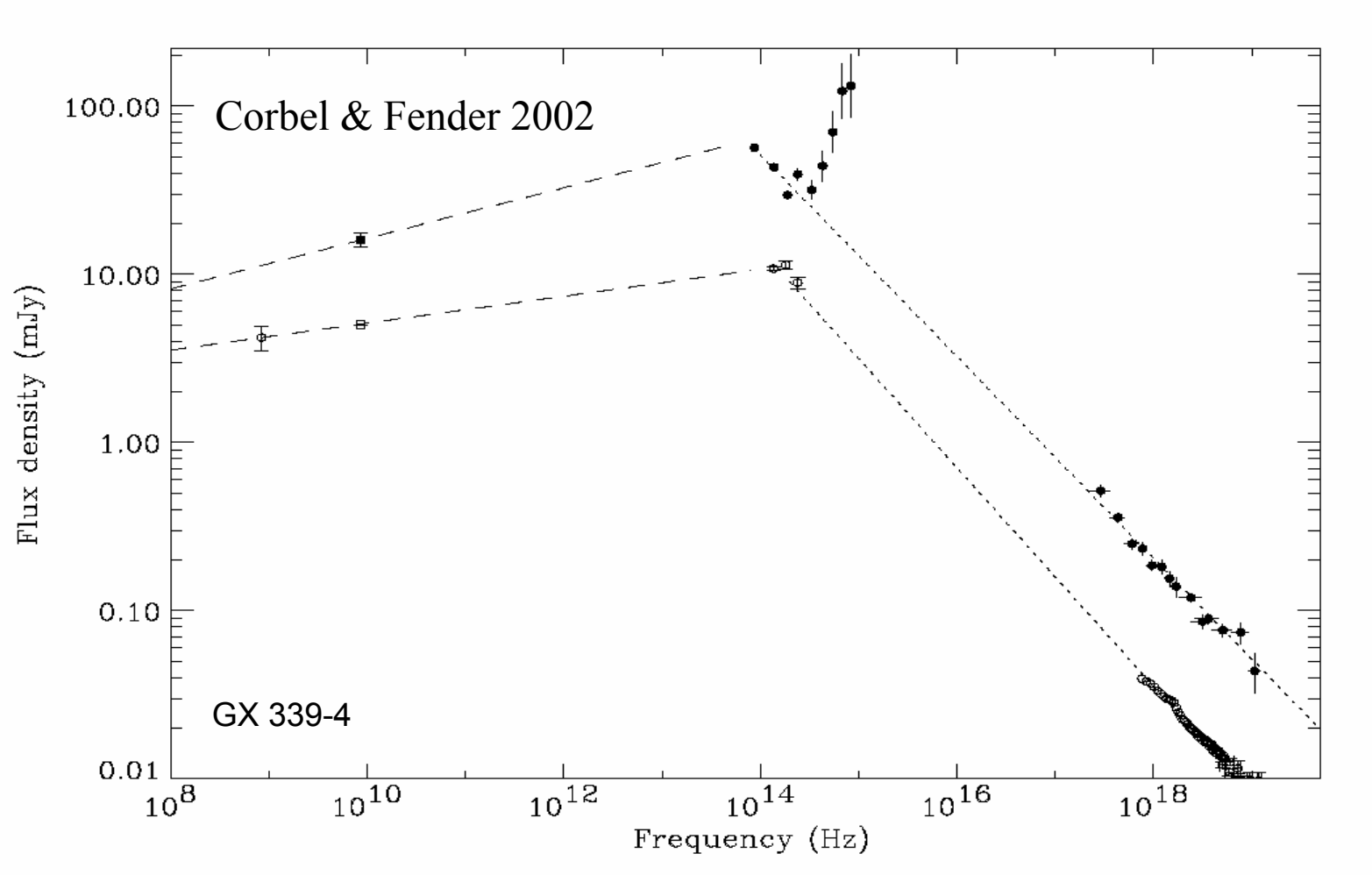
Hard state

Secondary peak (corresponding to a hard state transition) due to non thermal infrared emission associated with the formation of the compact jet (Corbel et al. 01, Jain et al. 01)



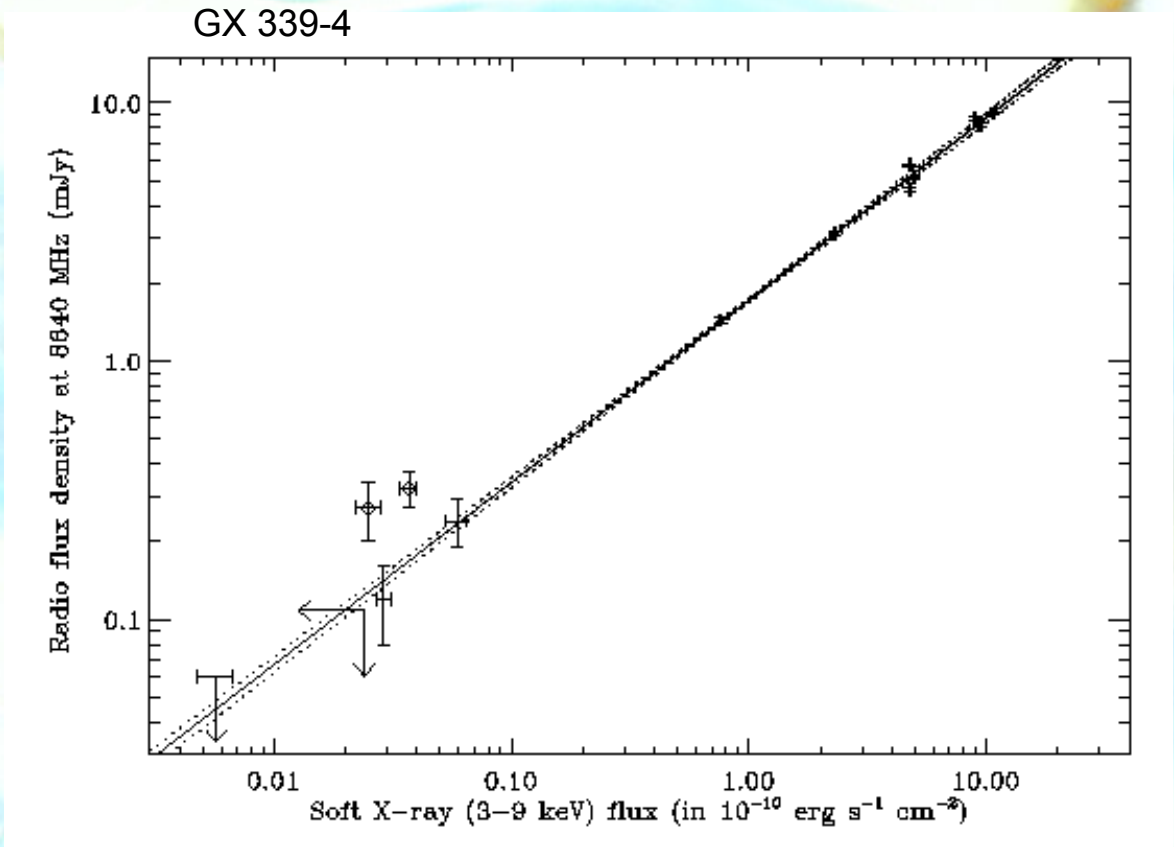
2000 outburst of XTE J1550-564 (Jain et al. 01)

See also 4U 1543-47, GX 339-4 (Buxton & Bailyn 04)



Above this frequency: the X-ray spectra are consistent with an extension of a powerlaw from the IR: optically thin synchrotron emission in X-rays?

Radio/X-ray flux correlation



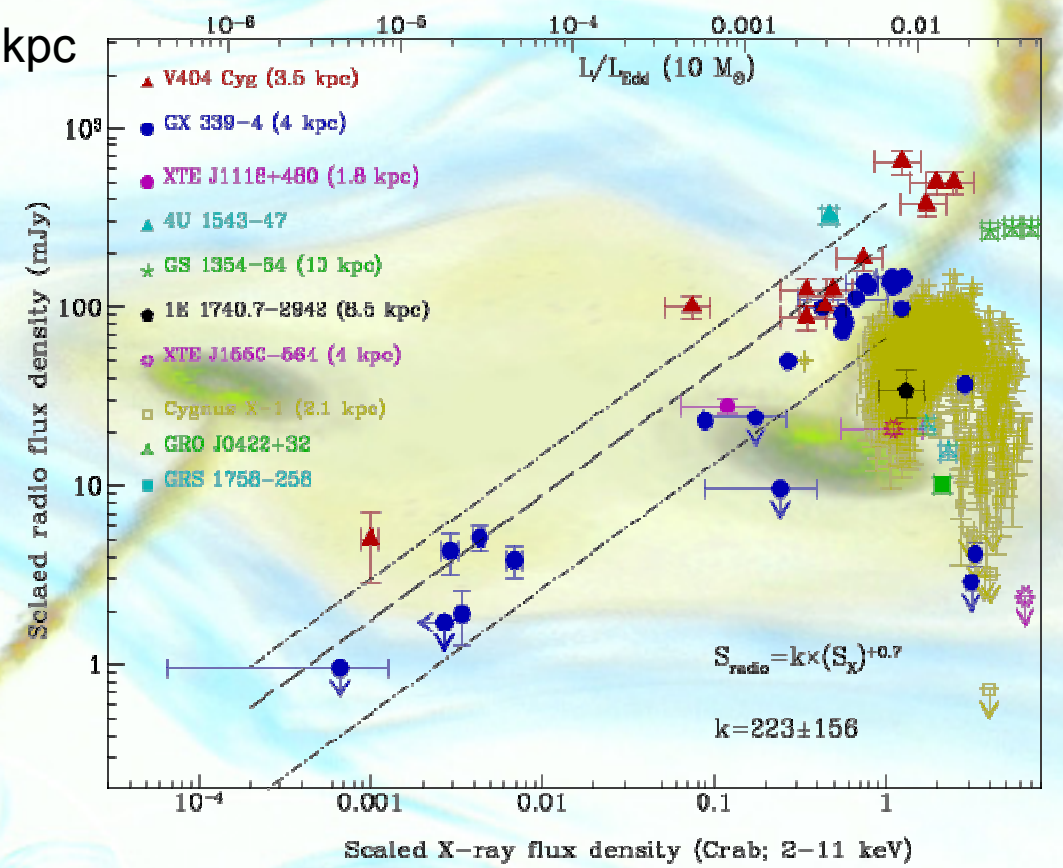
Corbel et al. (2000), Corbel et al. (2003)

Very strong correlation between radio and X-ray emission over more than 3 decades in flux (down to quiescence !!!)

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

A universal radio/X-ray correlation

1 kpc



Gallo, Fender, Pooley (2003)

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

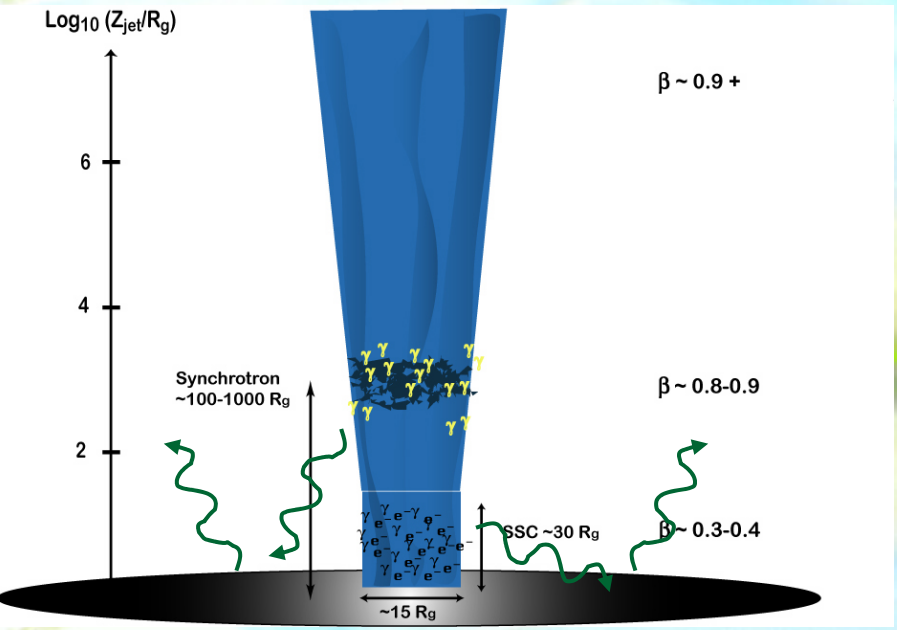
→ Same coupling !!!

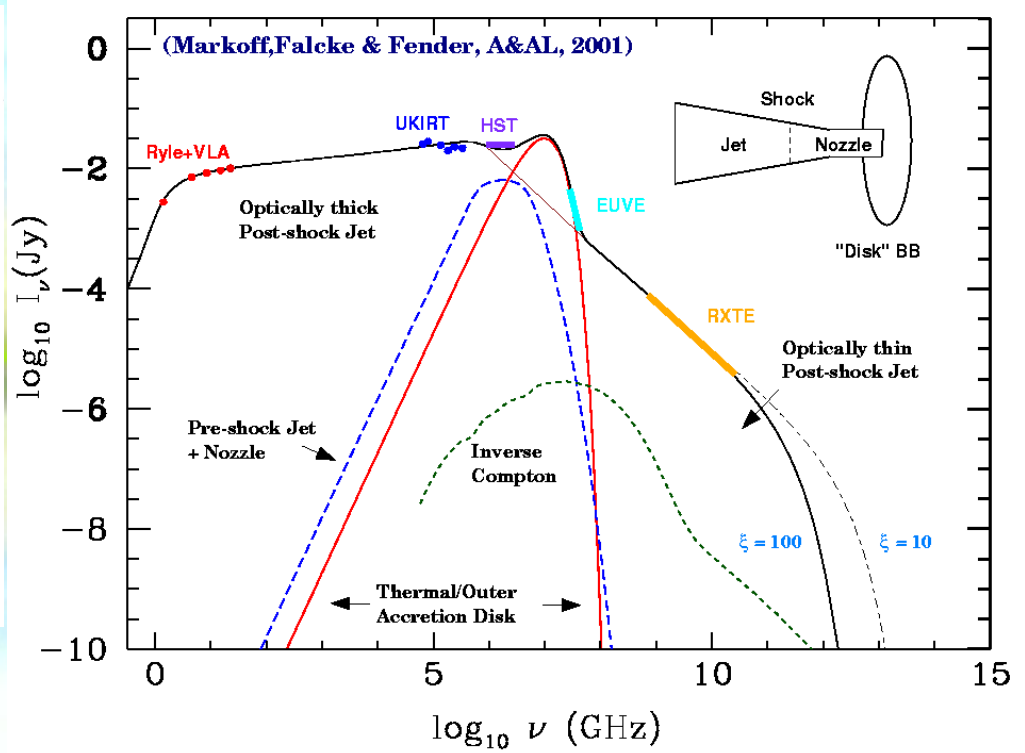
No strong Doppler boosting: low velocity jet ($\beta < 0.8$ c)

Important for understanding of accretion/outflow coupling: role of jets at higher energies ?

Jet model with SSC and reflection

XTE J1118+480





Markoff & Nowak (2004)

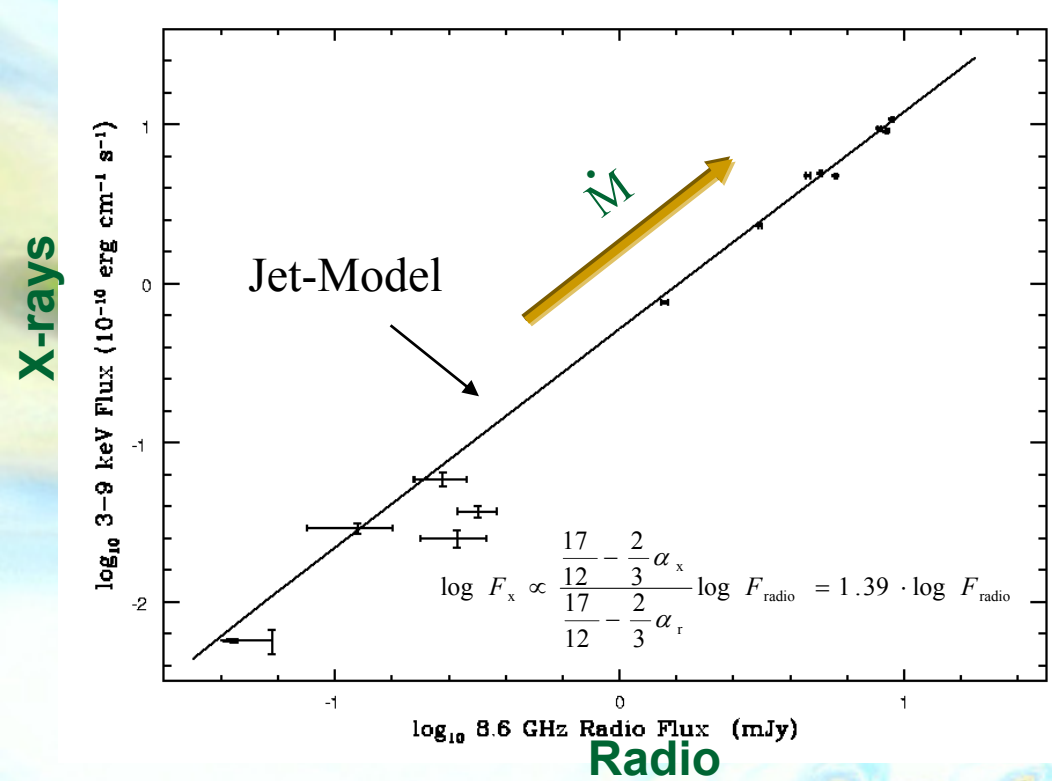
If jet emission extends up to optical band, jet has > 10% of all power (> 90% if up to X-rays) !!!

Jet model and the GX 339-4 correlation

- The X-ray emission in GX339-4 seems to tightly follow the radio emission.
- The slope is non-linear with α=1.40 (!!! X vs radio !!!).
- Mass = cte
- Analytic theory predicts α=1.39.

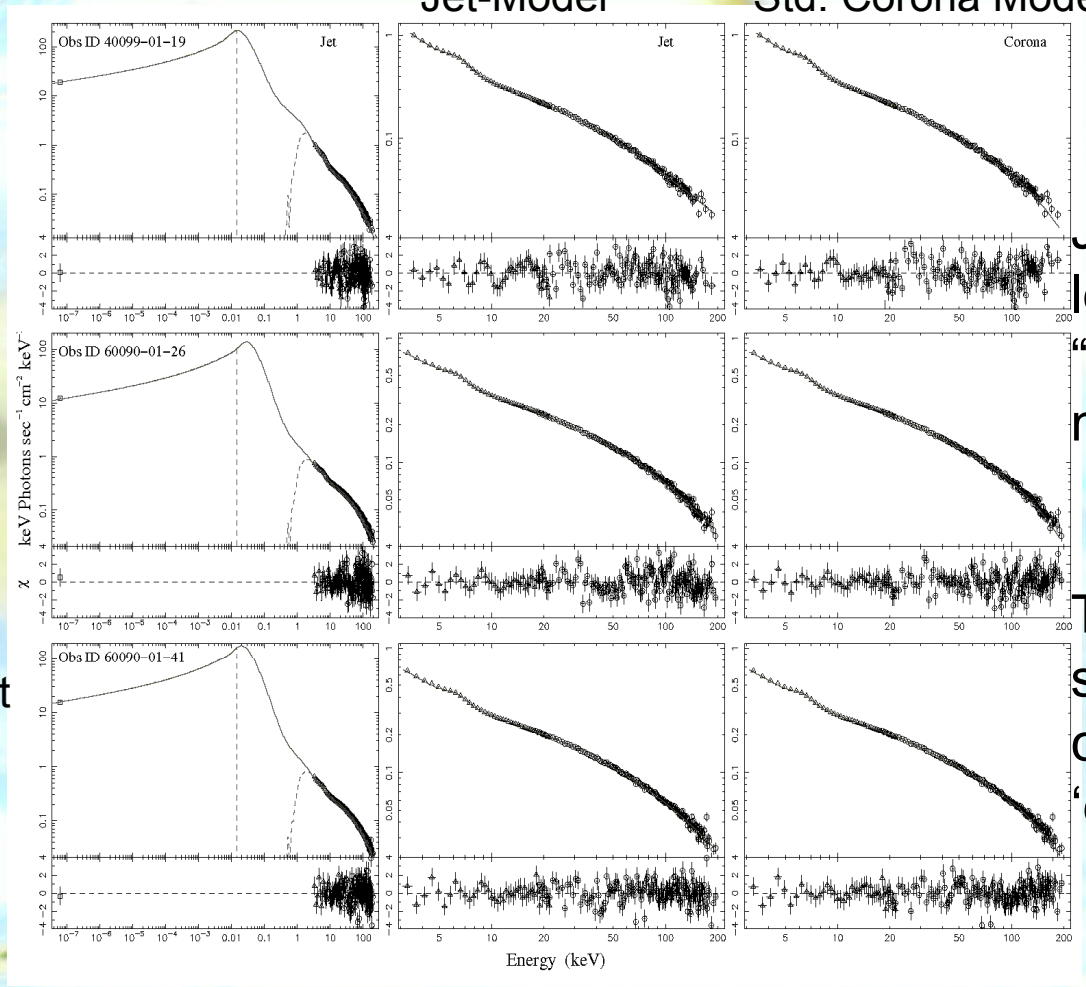
⇒ Jet scaling laws reproduce radio-x-ray slope perfectly.

X-ray vs. Radio correlation (GX339-4)



Fitting Cyg X-1 with a jet model

Jet-Model Std. Corona Model



Jet-fits to actual X-ray data of Cyg X-1:

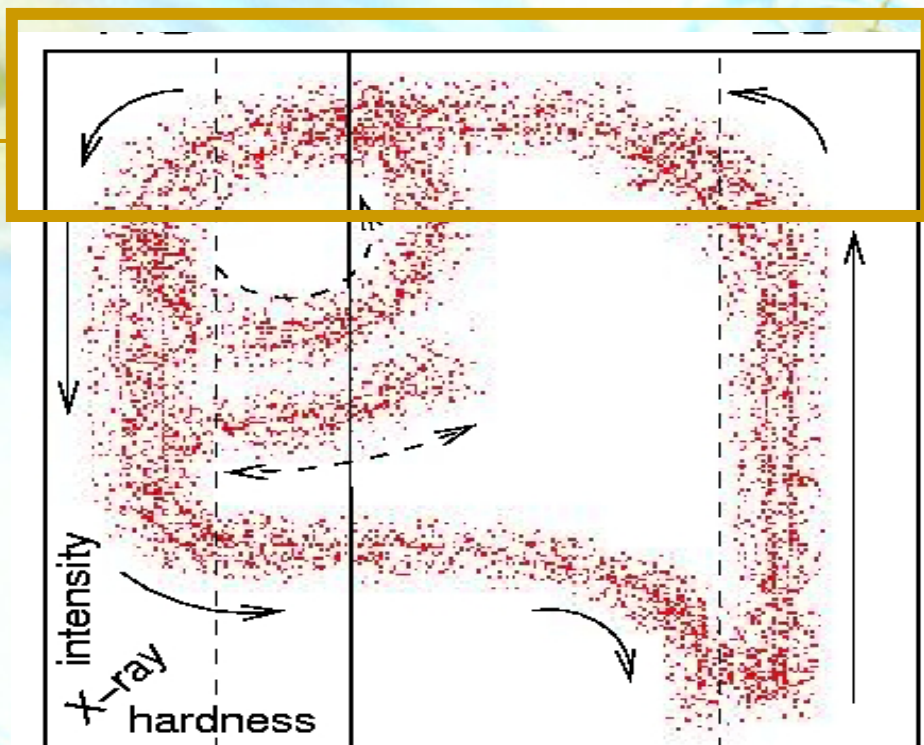
- synchrotron
- reflection from base of jet
- inverse compton from jet

Jet-models are at least as good as "traditional" models.

The jet base can subsume the conventional 'corona'.

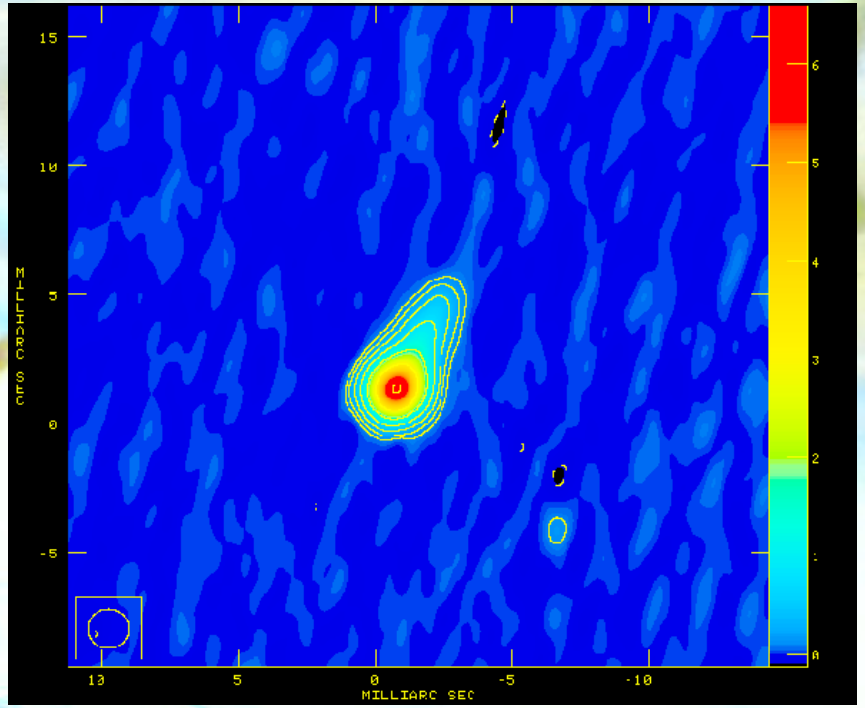
Markoff, Nowak, Wilms (2005)

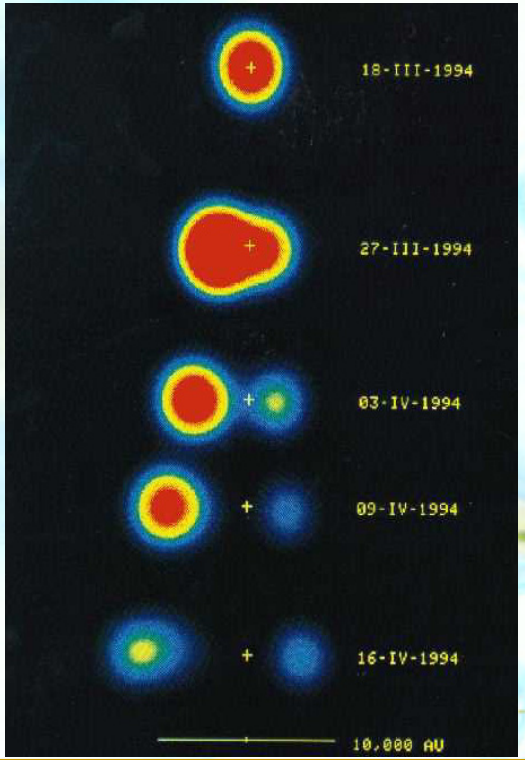
Part IV: Jets production and spectral states : a unified view



Two flavors of relativistic jets from microquasars: two very different scales !!!!

- Compact, self-absorbed jets (on mas scale = 10s a.u.).
- Discrete ejections (superluminal, ballistic).

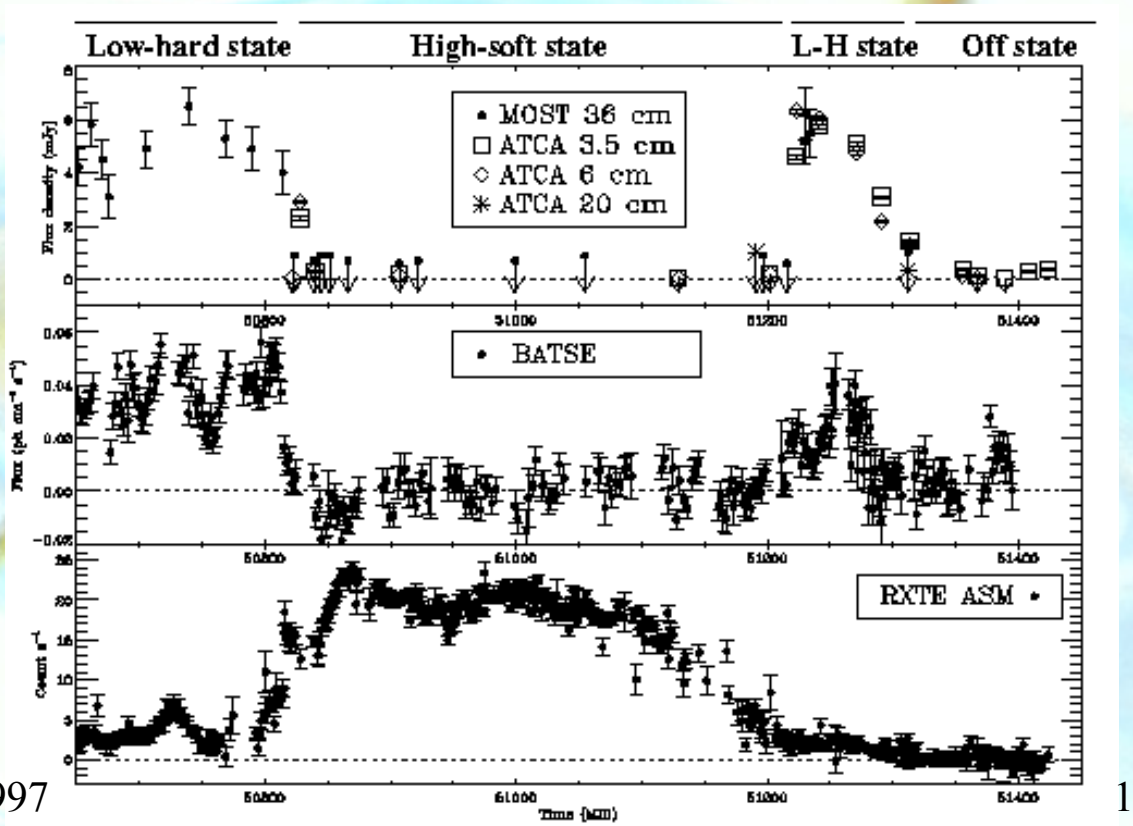




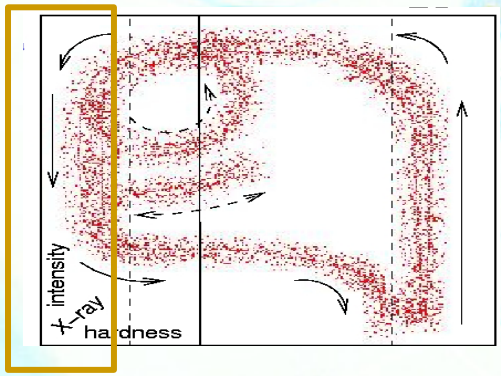
Stirling et al. 2001

Mirabel et al. 94

Quenched radio emission in the high/soft state (or TD state)



1997 1999



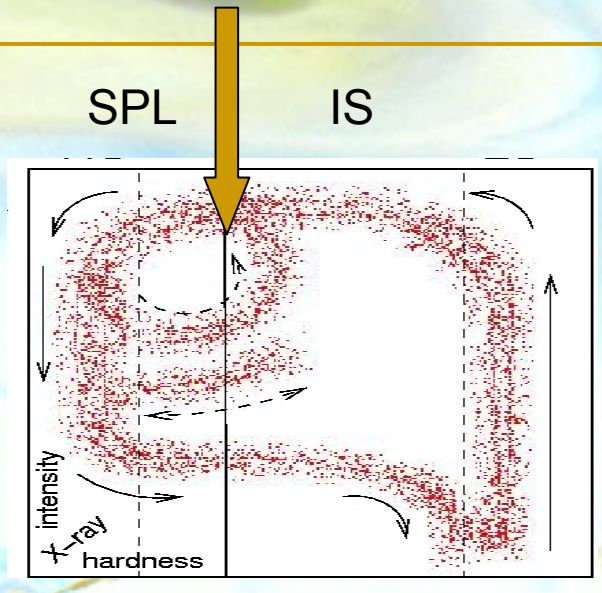
Fender et al. (1999), Corbel et al. (2000)

Quenched radio emission also in Cyg X-1 (Tannanbaum et al. 72)

Similar to GRS 1915+105: « Soft X-ray states are never associated with bright radio emission » (Klein-Wolt et al. 02)

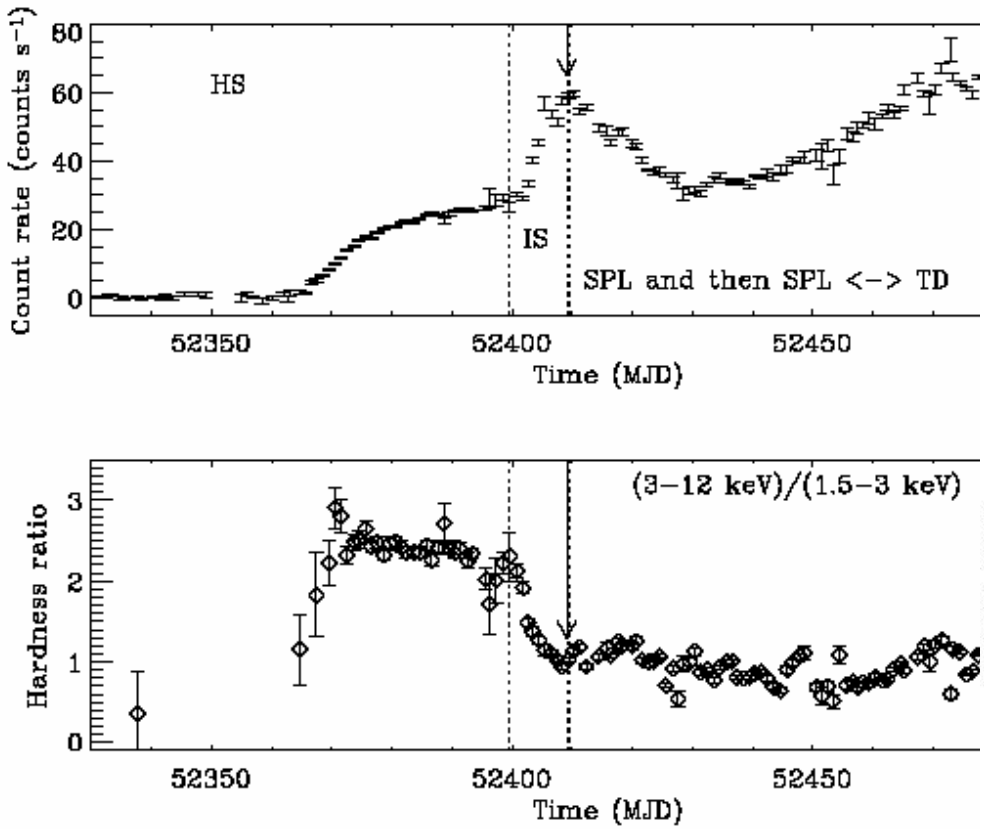
Transient ejection events: when ?

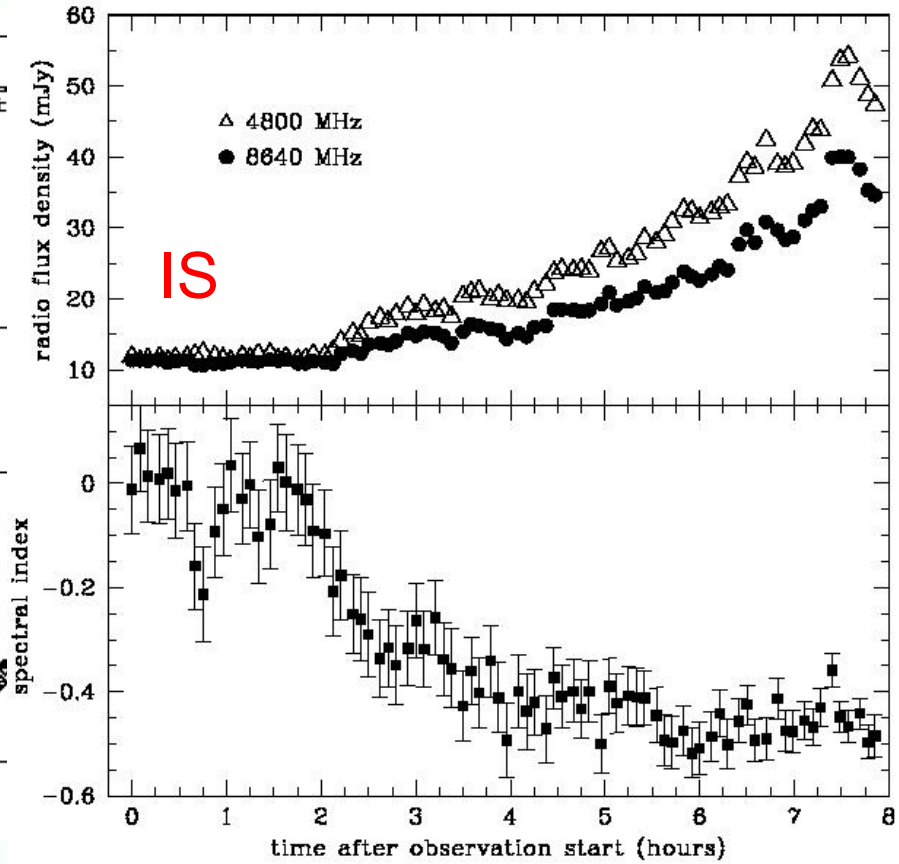
→ on the nature of the SPL and IS states



GX 339-4: 2002 outburst

Radio flare in May 2002



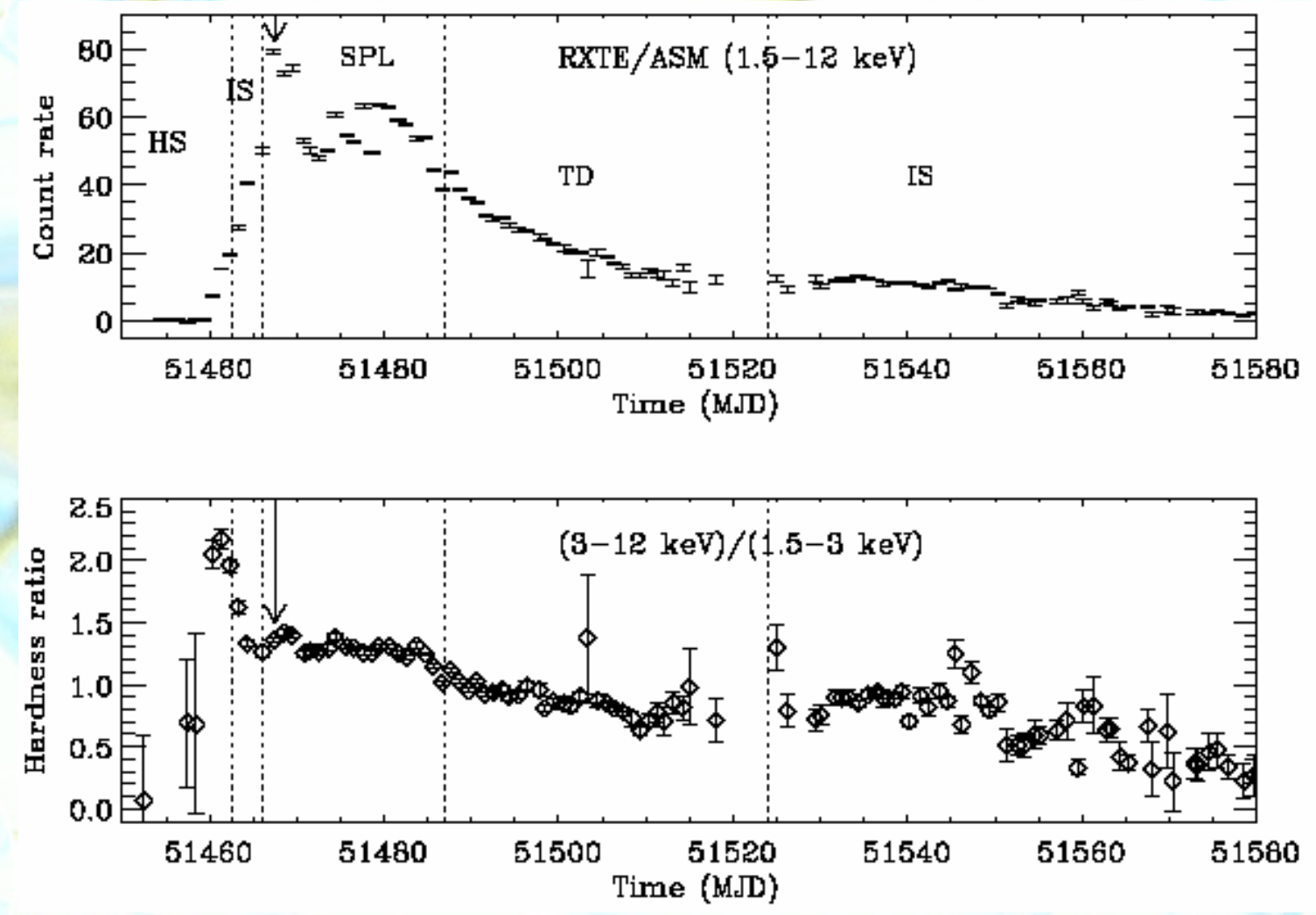


Corbel et al. 2004

Gallo et al. 2004

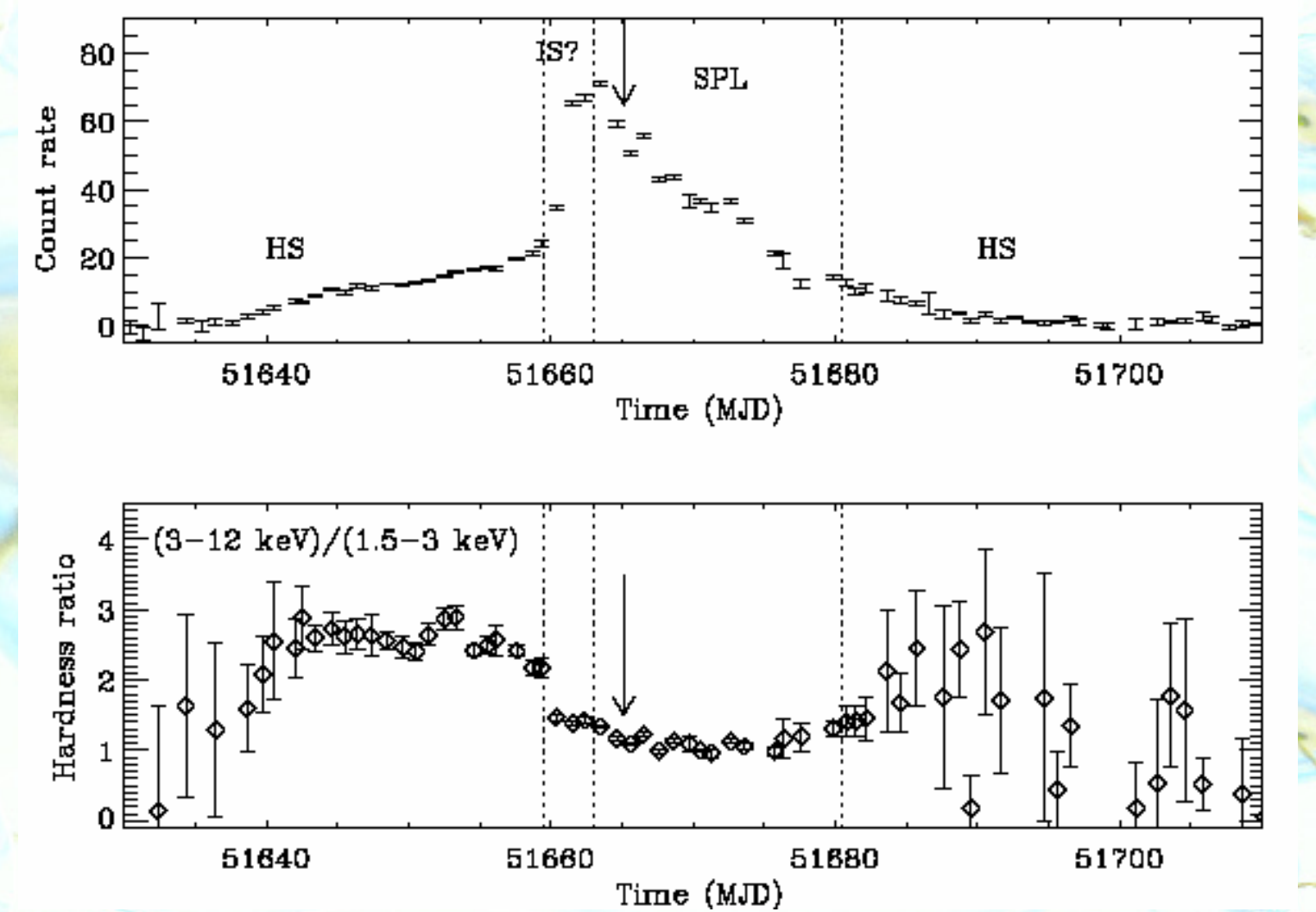
Compact jet « survives » in the IS + massive ejection during IS/SPL state transition (Corbel et al. 2004)

XTE J1859+226



Corbel et al. 2004

XTE J1550-564 (2000)



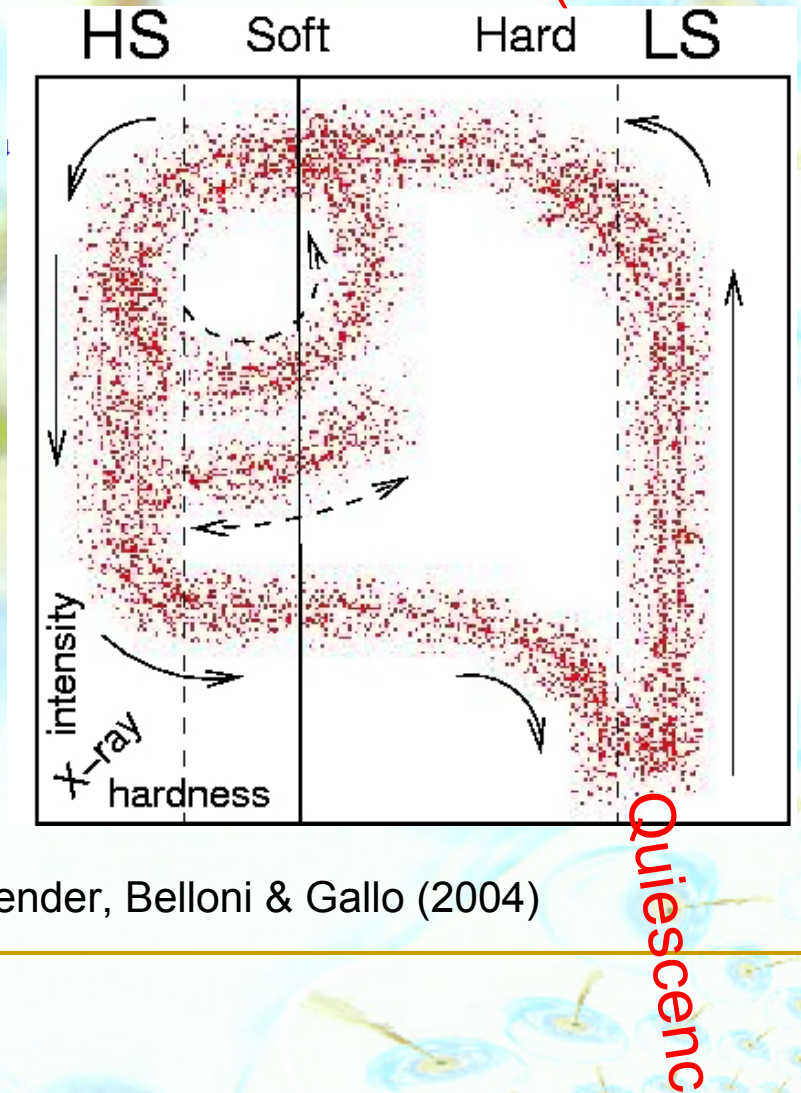
Corbel et al. 2004

On the relation of relativistic jets with the X-ray spectral states

- Compact jet in the HS and IS (hard) X-ray state.
- Discrete ejections during the transition from IS (hard) to SPL state.
- No jet in the TD (or HS) state.

Corbel et al. (2004)

TD SPL / IS HS (McC& Rem)

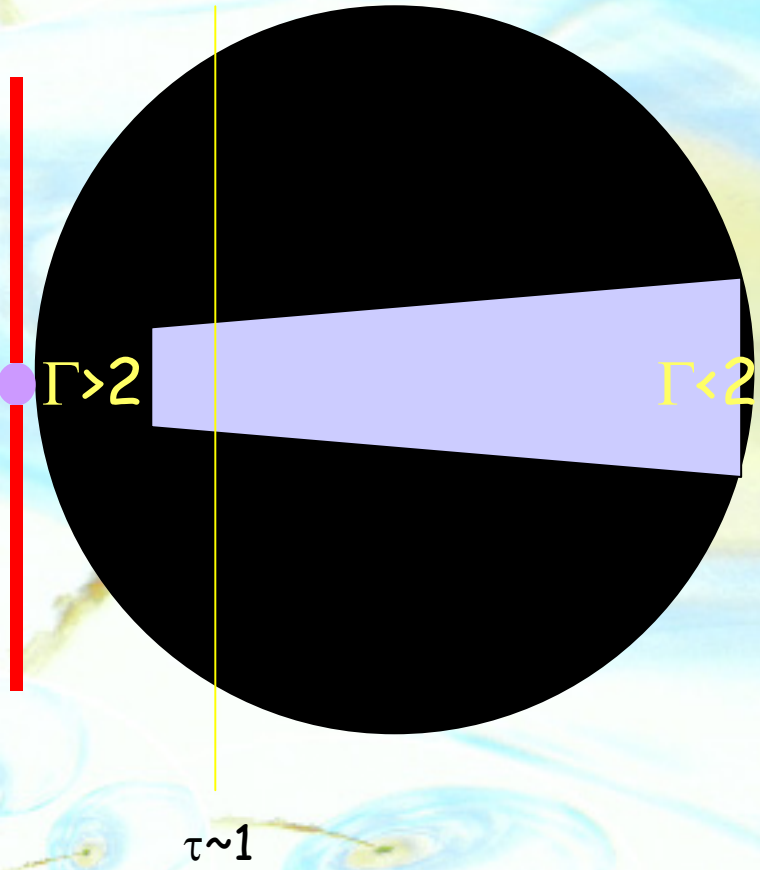


Fender, Belloni & Gallo (2004)

Origin of the transient jets ???

Court. R. Fender

Disc moves in, Γ_{jet} increases → Internal shock



1. 'Hard' X-ray state: steady, $\Gamma<2$, self-absorbed jet

2. Disc moves in, 'softening' the X-ray spectrum. A transient, high-Γ flow collides with the slower pre-existing jet →internal shocks.

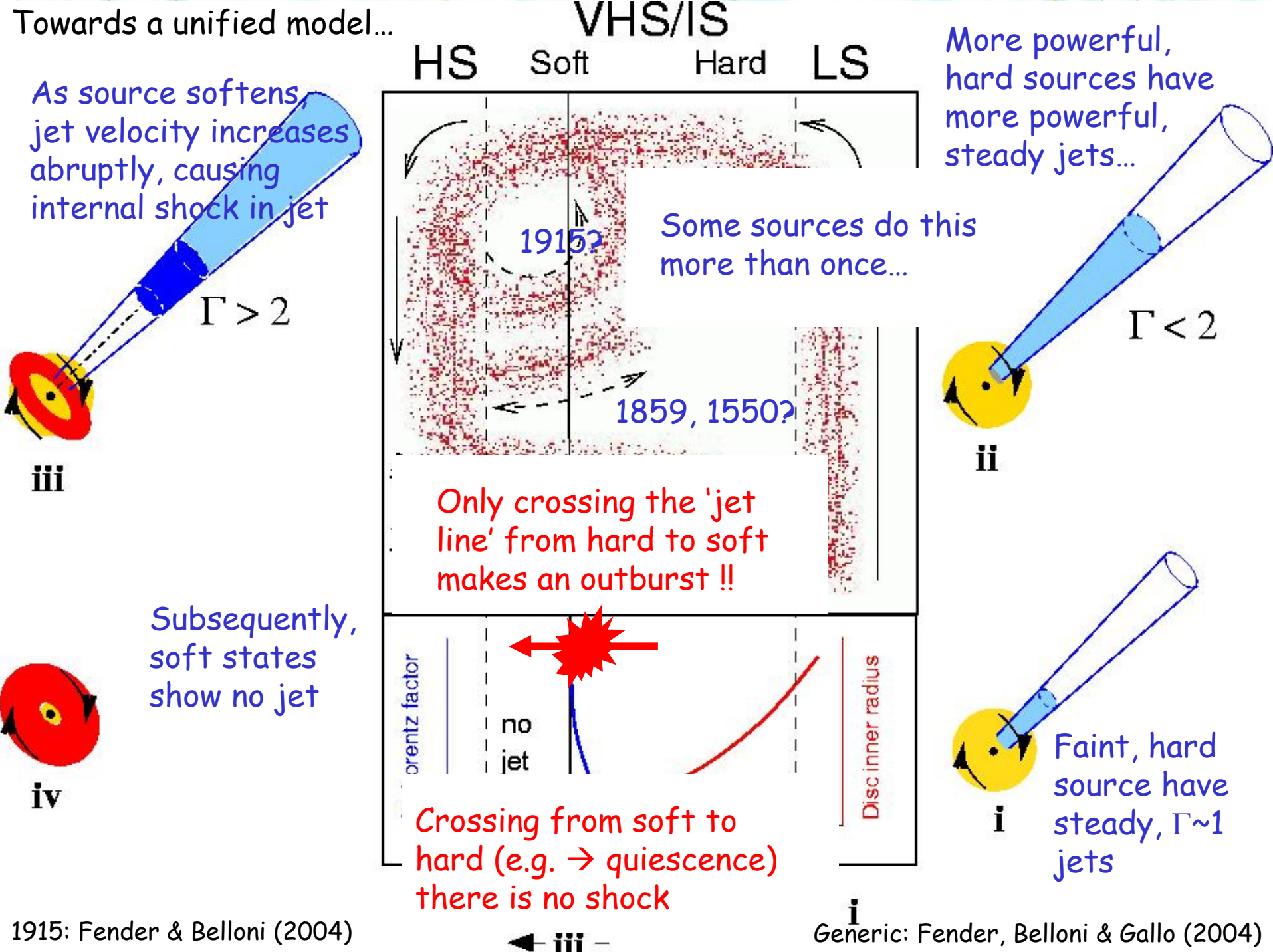
'Corona', <u>not disc</u>, ejected (i.e. GRS 1915+105)

Obviously you only get the shock when $\delta\Gamma>0$ (so only one flare per 'cycle')

(almost like an 'external' shock with steady jet as ambient medium → efficient)

(see also Kaiser, Sunyaev & Spruit 2000; Vadawale et al. 2004; Turler et al. 2004)

Towards a unified model…

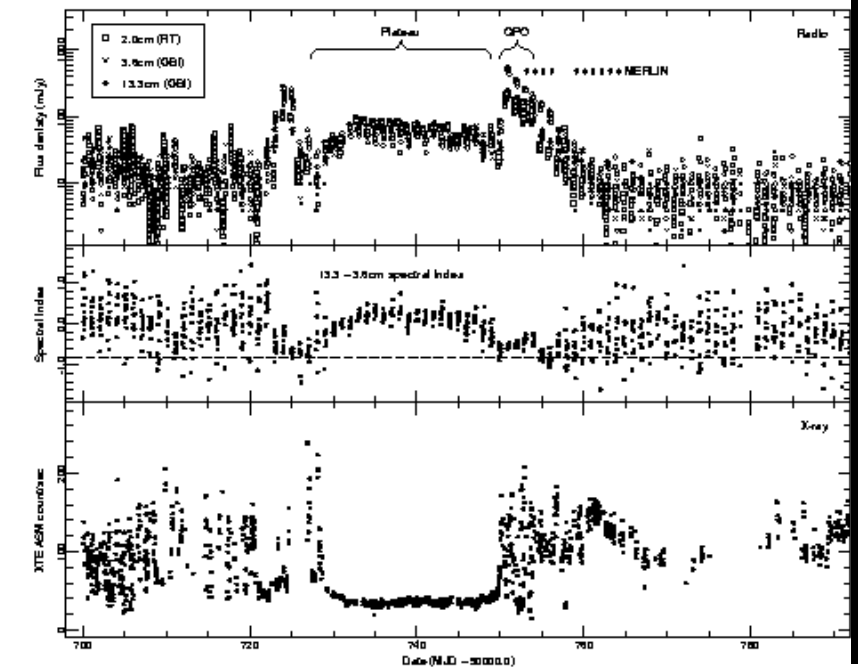


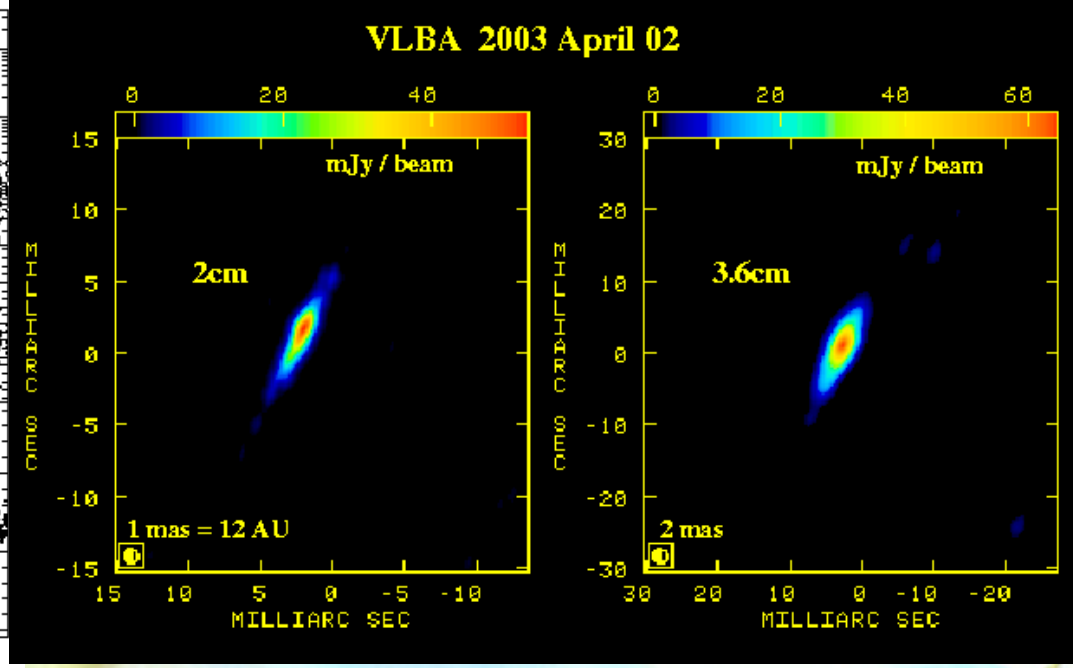
1915: Fender & Belloni (2004)

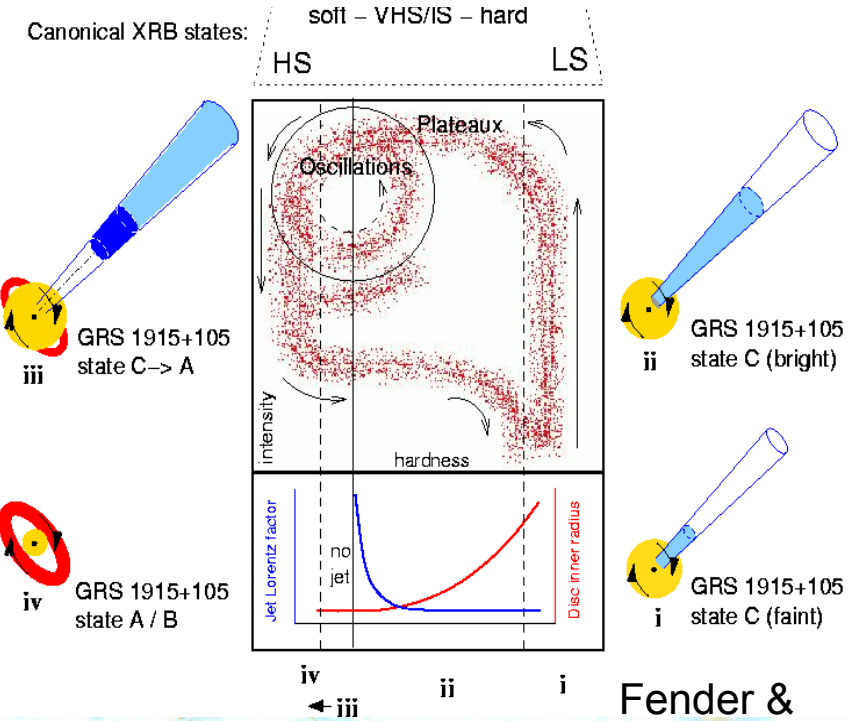
Generic: Fender, Belloni & Gallo (2004)

What about GRS 1915+105 ?

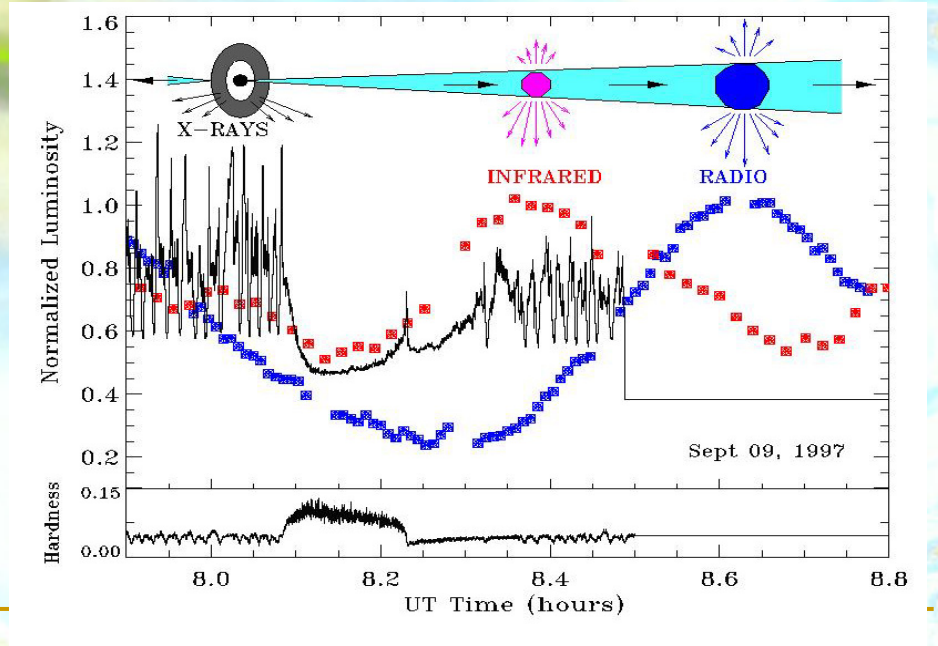
- Plateau state: steady (hard state C or χ) X-ray emission associated with compact jets (Foster et al. 96, Dhawan et al. 2000; Fuchs et al. 2003)
- Pre-plateau: optically thin radio flare
- Post-plateau: larger optically thin radio flare → Massive ejections event with superl motion (Fender et al. 99).
- Quasi periodic radio and IR oscillations (Fender, Pooley, Eikenberry, Mirabel…) with period of tens of mn → synchrotron origin: hard X-ray dip followed by an IR flare, a radio flare (decreasing τ) (Klein-Wolt et al. 02)
- Unification picture of GRS 1915+105's ejection properties
- See more in T. Belloni's lectures





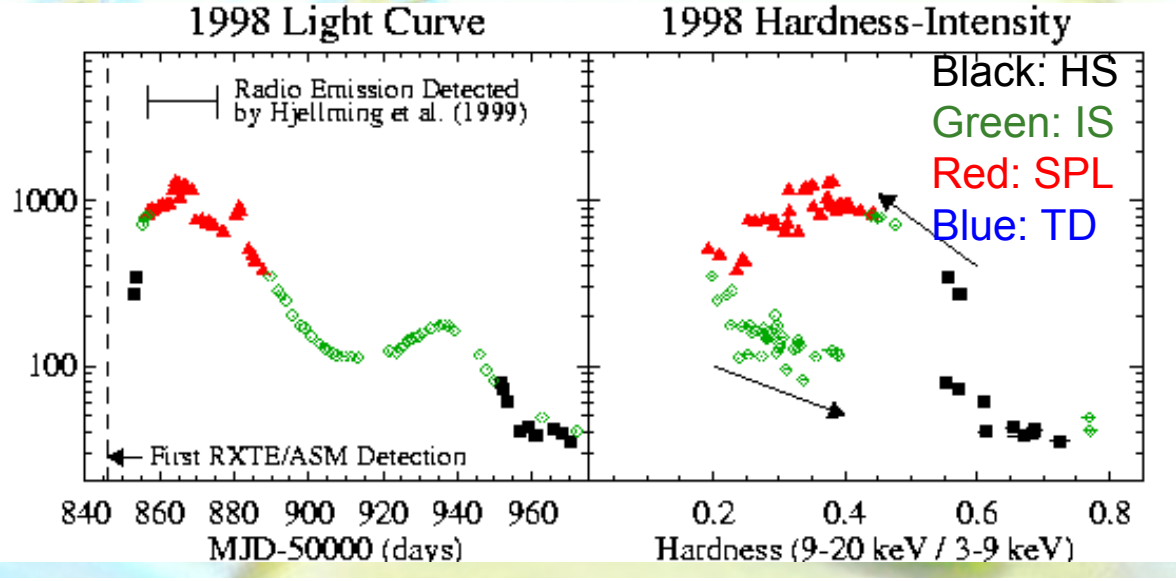


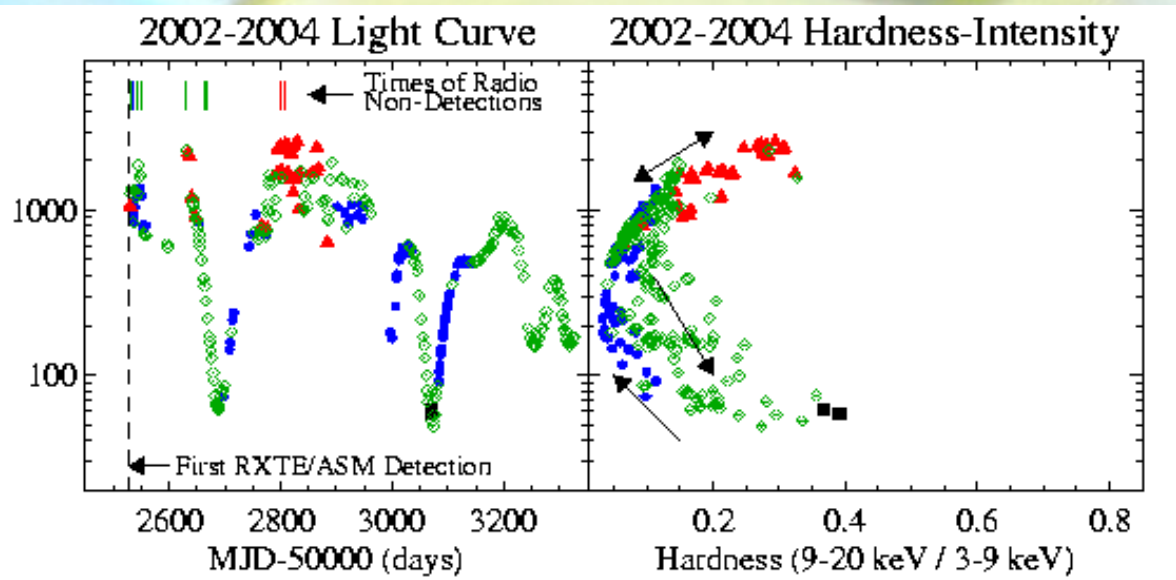
Fender & Belloni



Mirabel et al. 1998

Application to 4U 1630-47

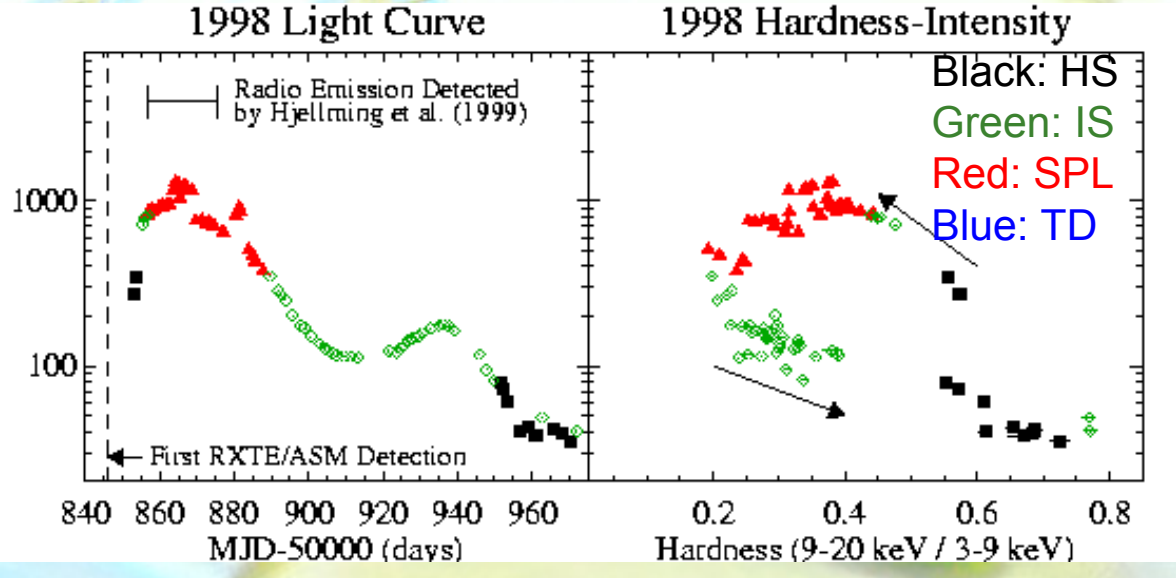


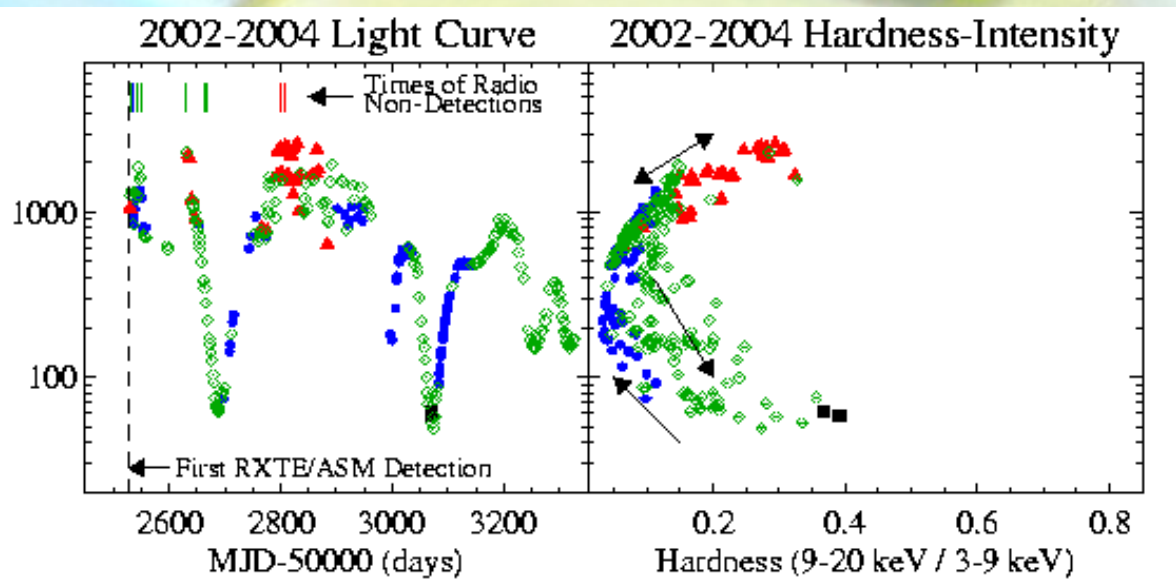


Tomsick et al. 2005

- 1998: typical pattern in HID (motion counter-clockwise black points) with bright initial HS → IS → SPL (ejection)
- One of its brightest and longest outburst from 02 to 04: no radio flare detected compared to 1998 outburst

Application to 4U 1630-47

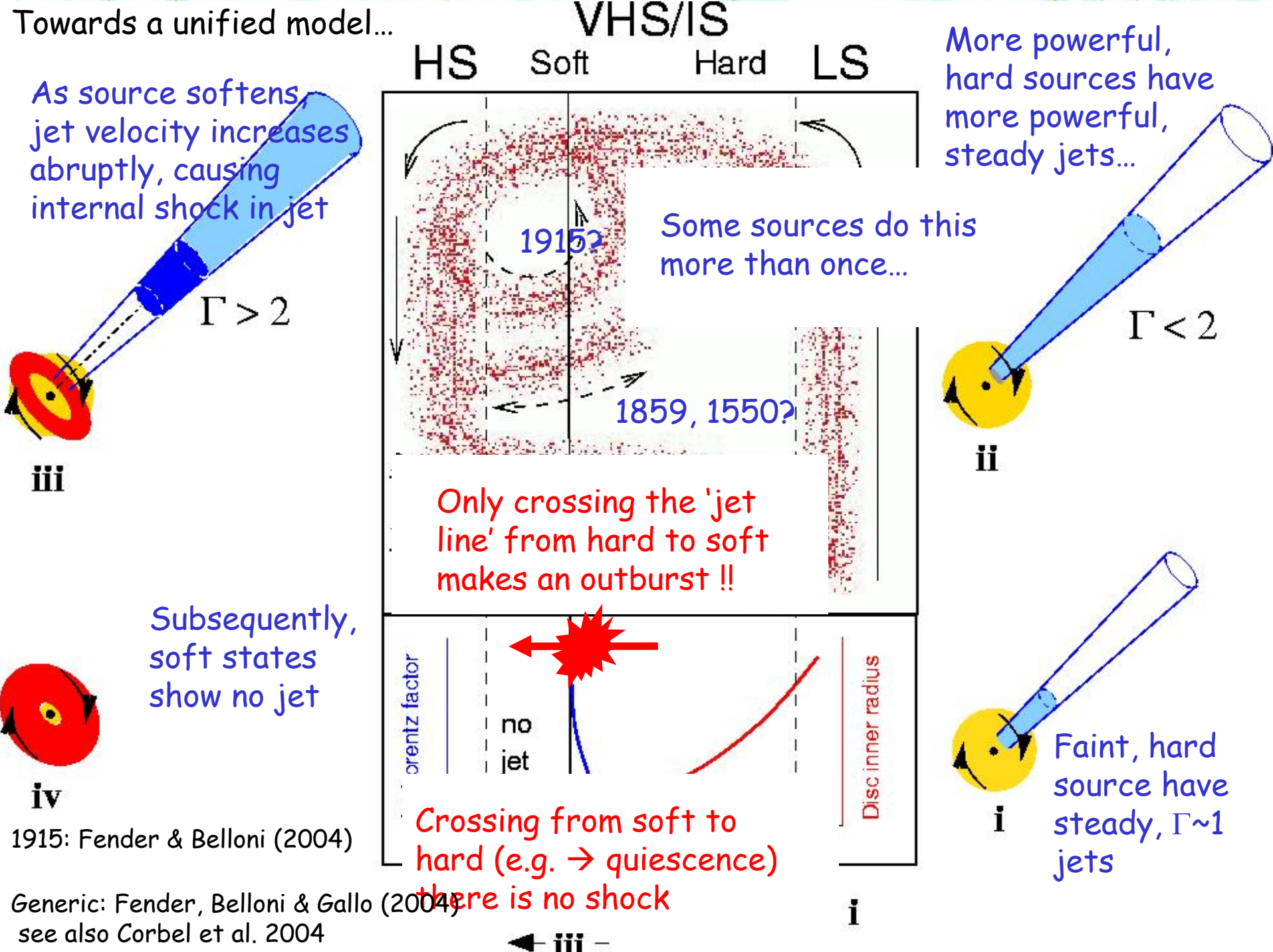




Tomsick et al. 2005

- 2002-04: sharp contrast
  - Fast rise of the outburst
  - No initial HS
  - Motion initially clockwise in HID
  - No HS → no compact jet → no internal shock possible → no massive ejection ?

Towards a unified model…



1915: Fender & Belloni (2004)

Generic: Fender, Belloni & Gallo (2004)
see also Corbel et al. 2004