Understanding relativistic jets from XRBs (& …) with LOFAR.

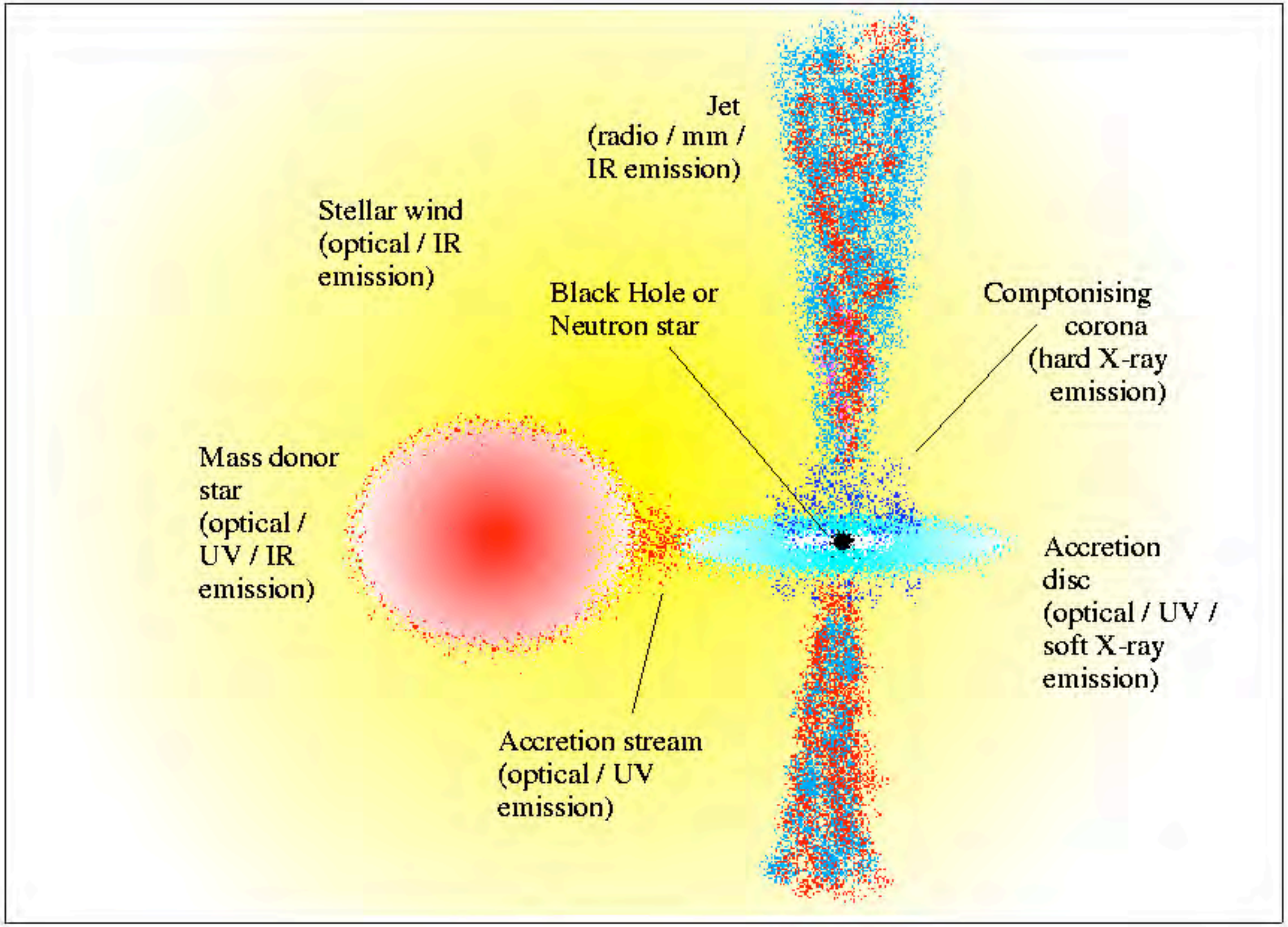
Stéphane Corbel
(Université Paris 7 & CEA Saclay)

Outline

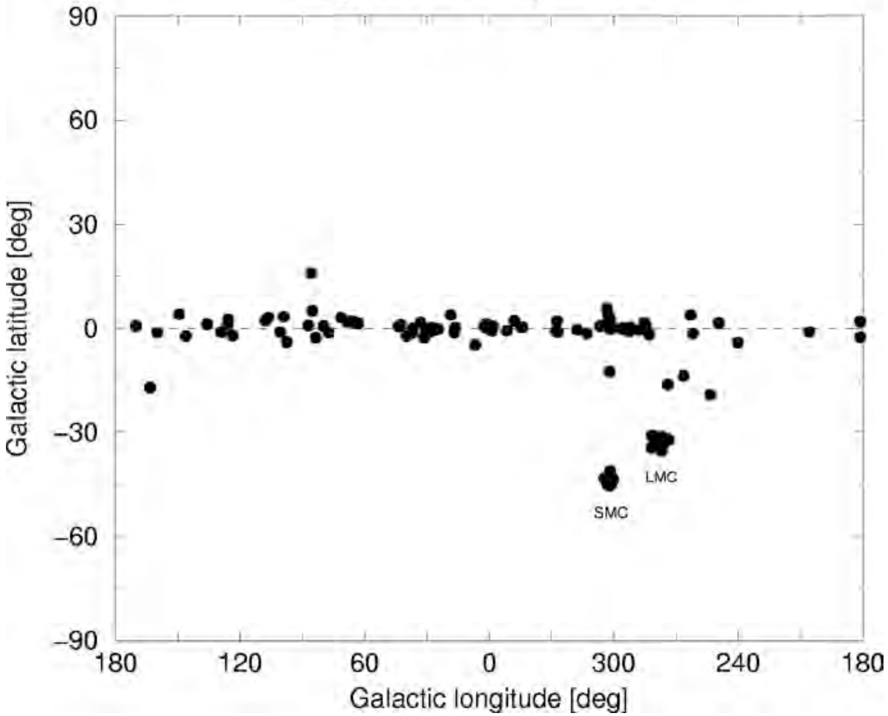
- Introduction: XRBs population and relativistic jets
- Flavors of relativistic jets
- Large scale jets (or lobes)
- LOFAR Contributions
- Conclusions

- Introduction: XRBs population and relativistic jets
- Flavors of relativistic jets
- Large scale jets (or lobes)
- LOFAR Contributions
- Conclusions

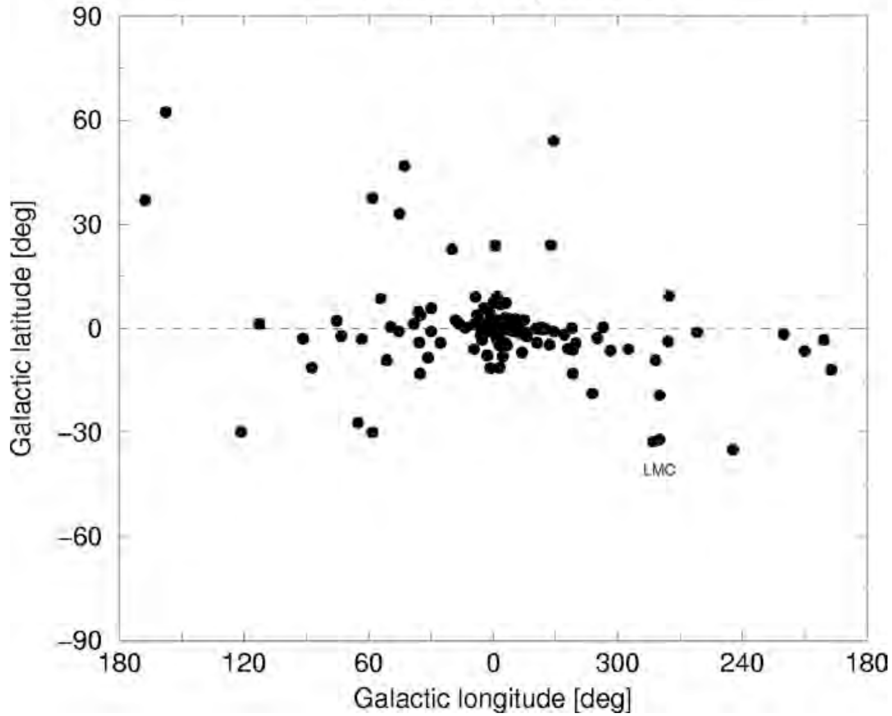
Introduction: X-ray binaries



131 High Mass X-ray Binaries



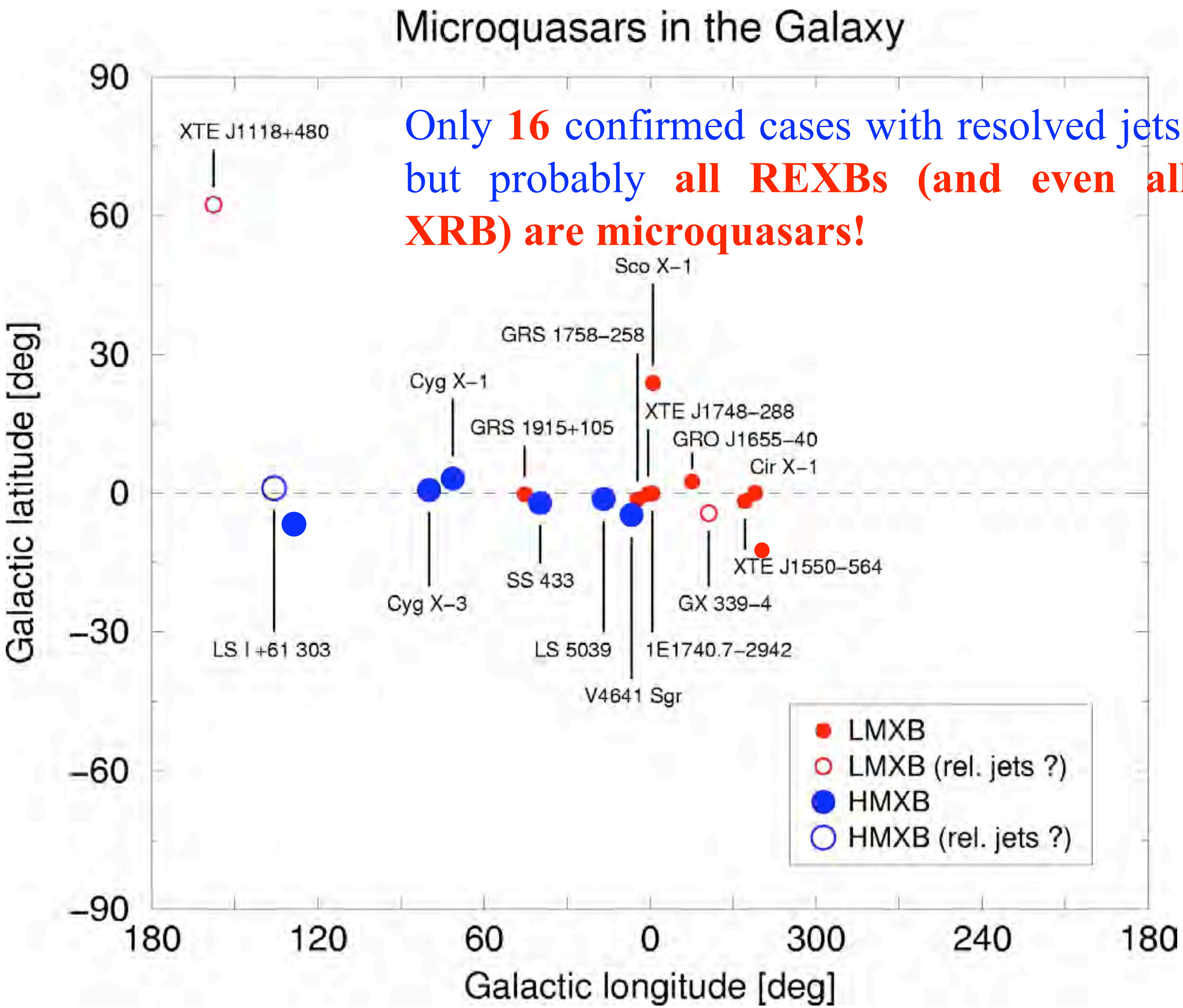
149 Low Mass X-ray Binaries



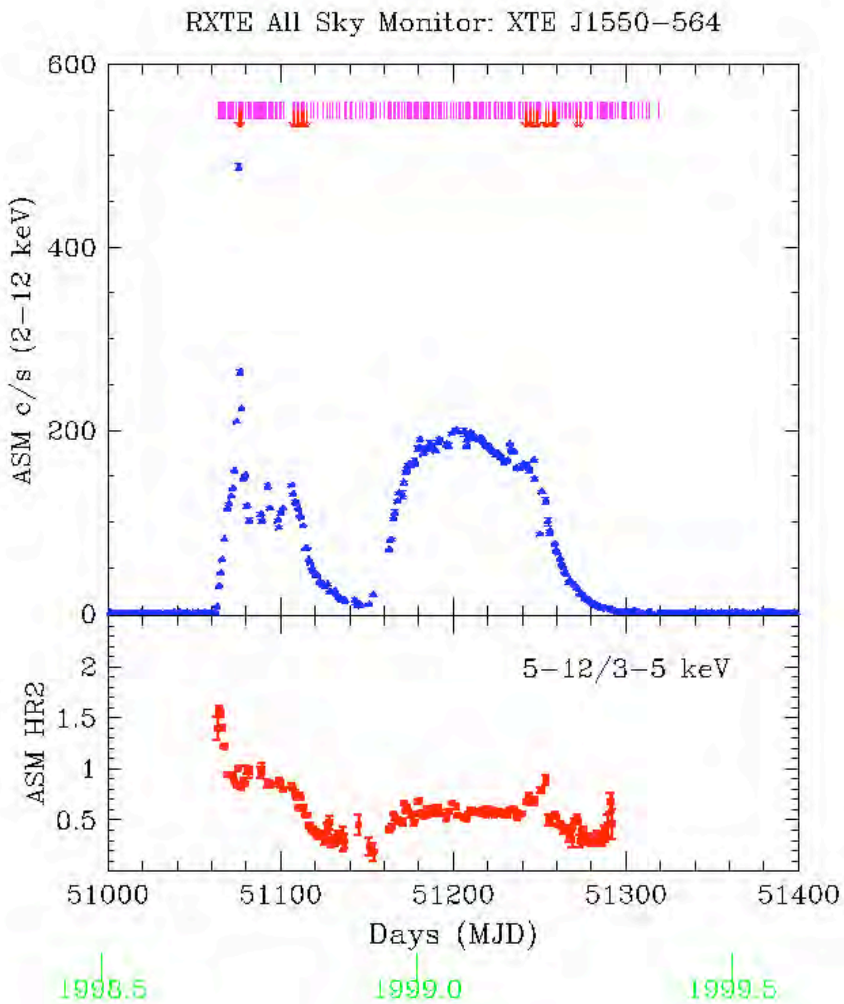
Radio Emitting X-ray Binaries (REXBs) are X-ray binaries that display radio emission, interpreted as synchrotron radiation. Around **43** of the known 280 X-ray binaries (**15%**) are REXBs, including **8** HMXBs and **35** LMXBs.

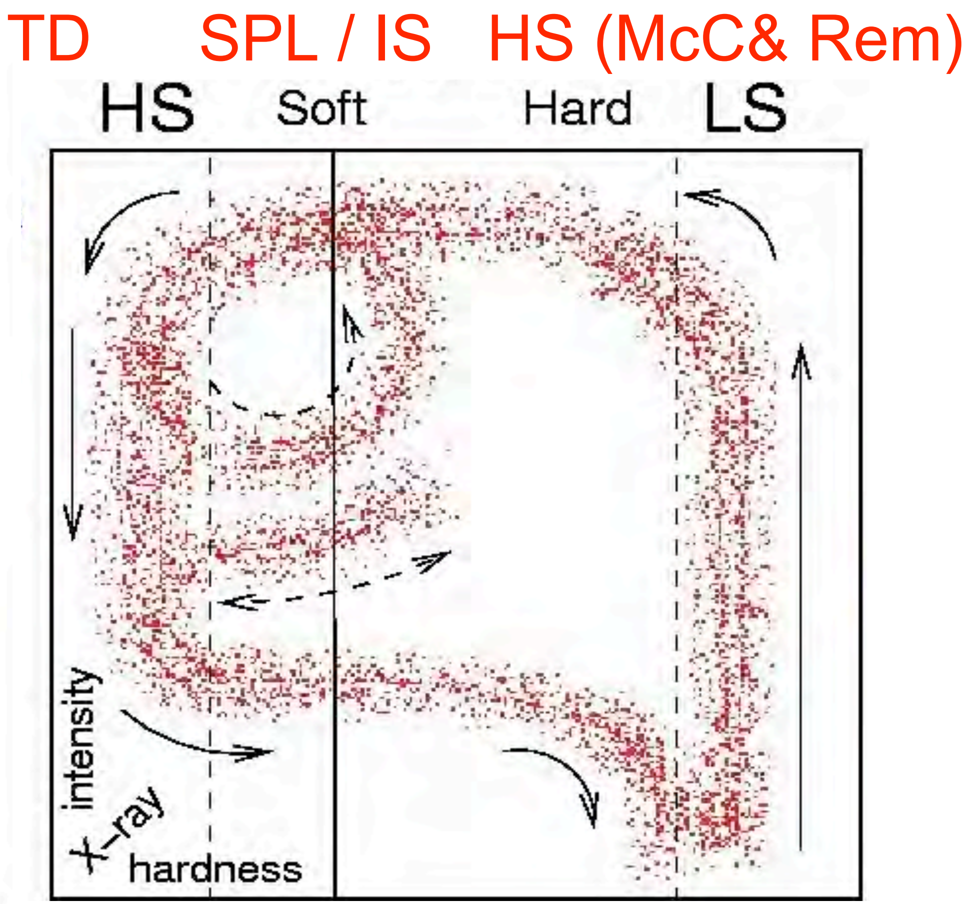
	Total	Galaxy	No X-ray pulsars
HMXBs	8/131 (6%)	8/86 (9%)	8/37 (**22%**)
LMXBs	35/149 (23%)	35/147 (24%)	34/142 (**24%**)

Only **16** confirmed cases with resolved jets, but probably **all REXBs (and even all XRB) are microquasars!**



X-ray States of Black Hole Binaries



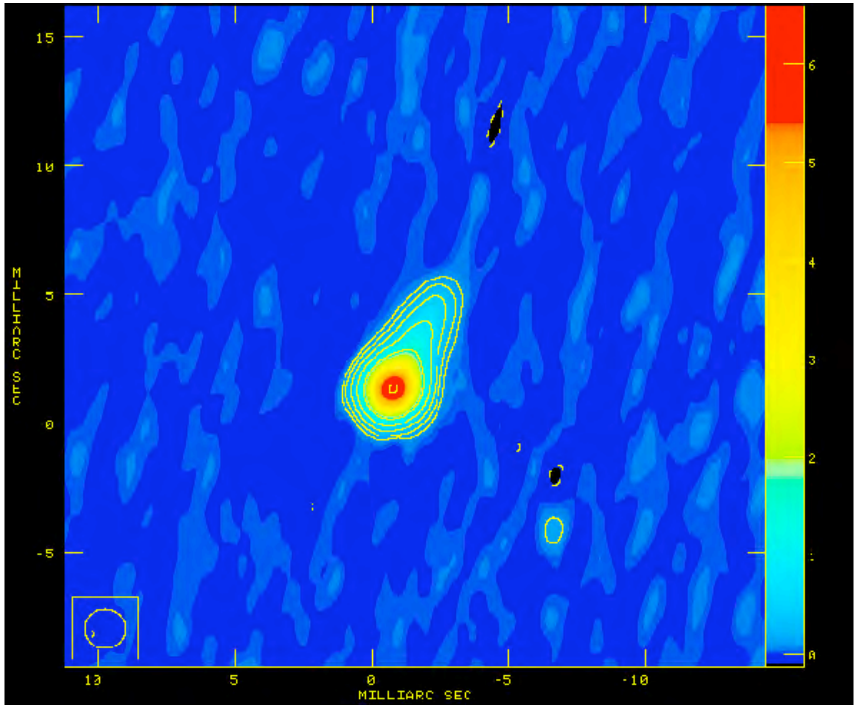


Hardness Intensity Diagram (HID)

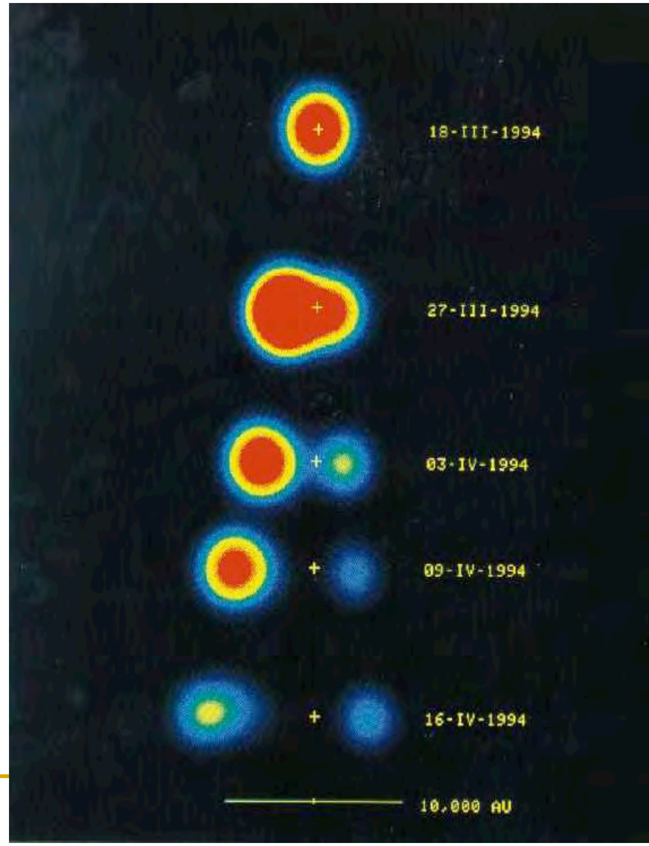
- Introduction: XRBs population and relativistic jets
- Flavors of relativistic jets
- Large scale jets (or lobes)
- LOFAR Contributions
- Conclusions

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).

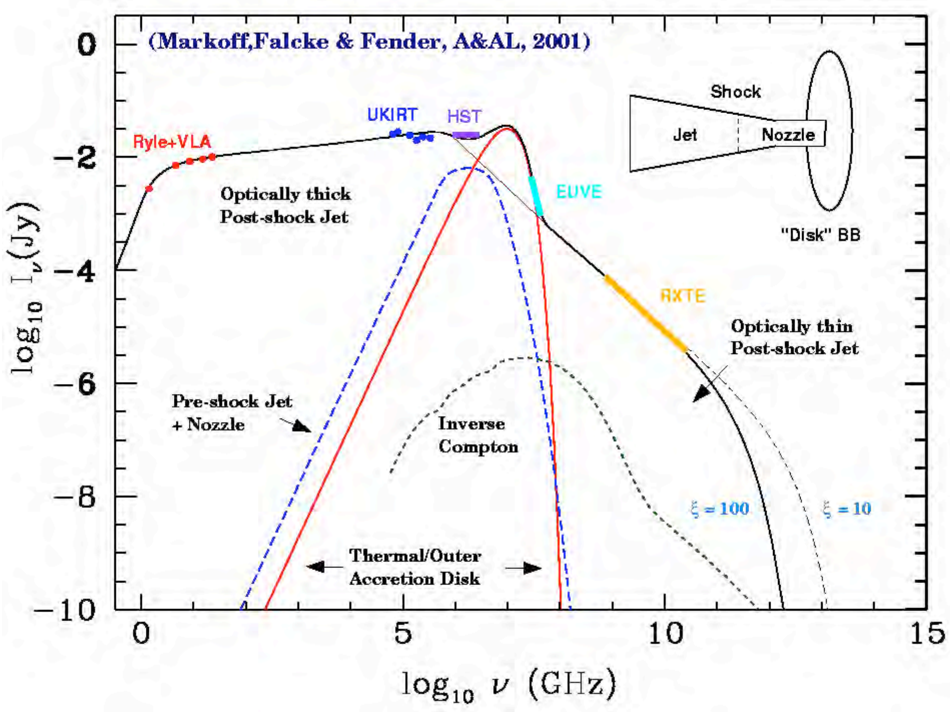


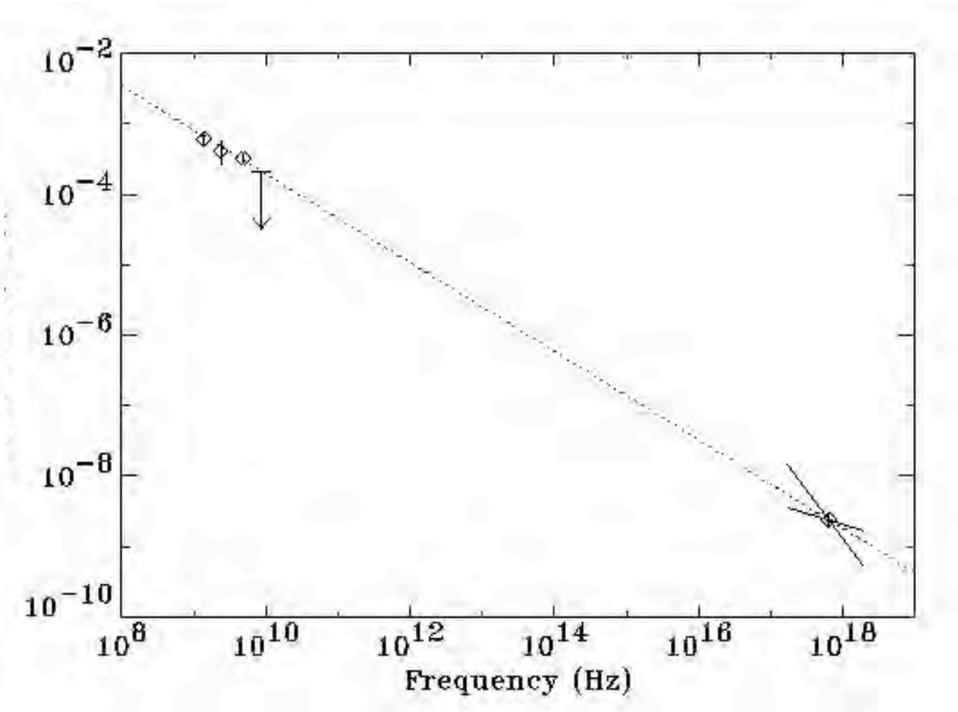
Stirling et al. 2001

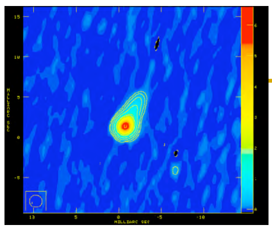


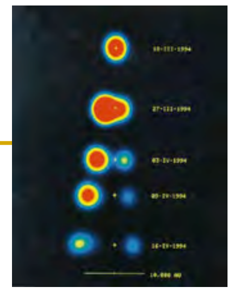
Mirabel et al. 94

Spectral extent of these small scale jets



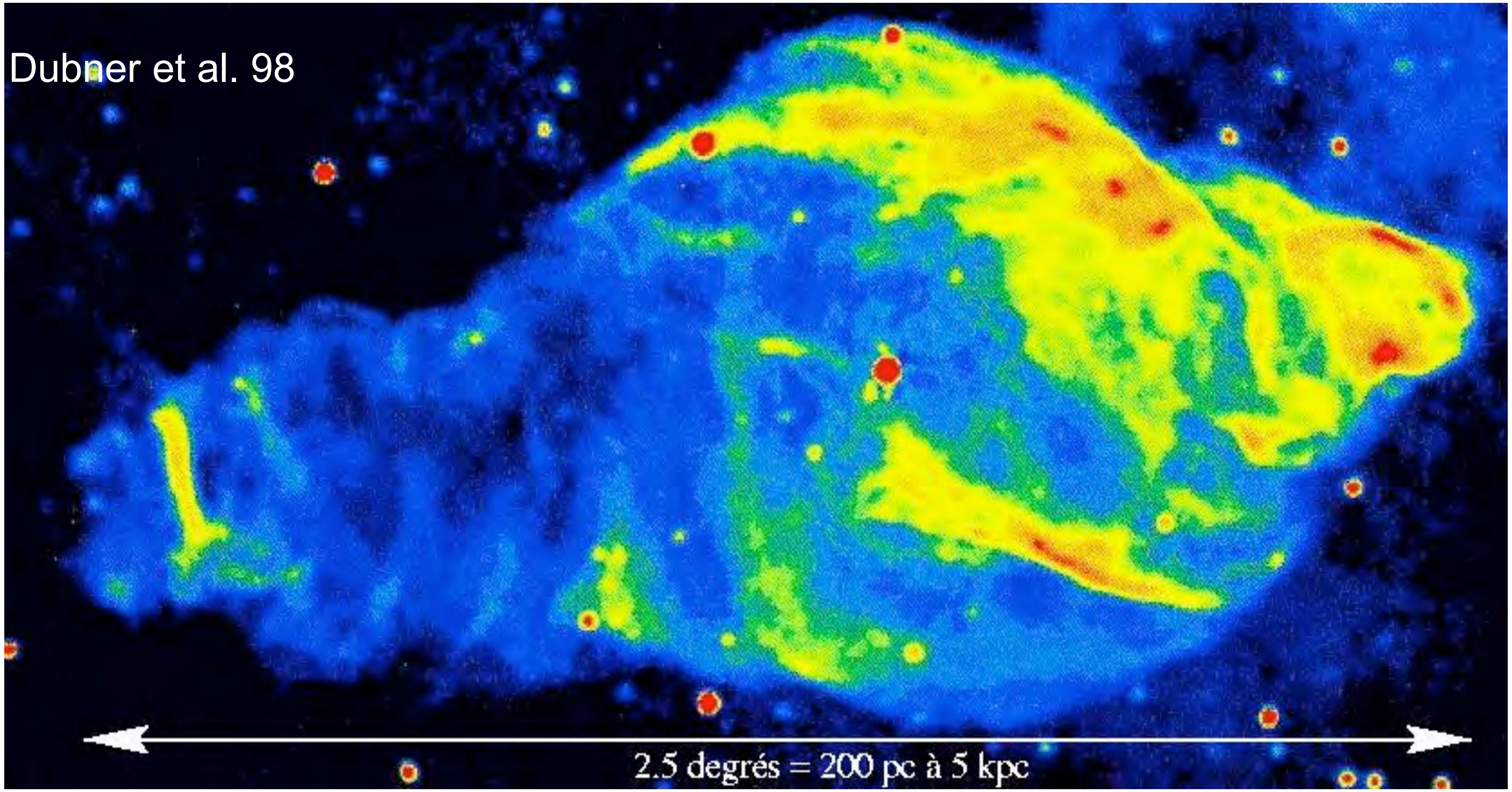






- Introduction: XRBs population and relativistic jets
- Flavors of relativistic jets
- Large scale jets (or lobes)
- LOFAR Contributions
- Conclusions

SS 433



Radio map

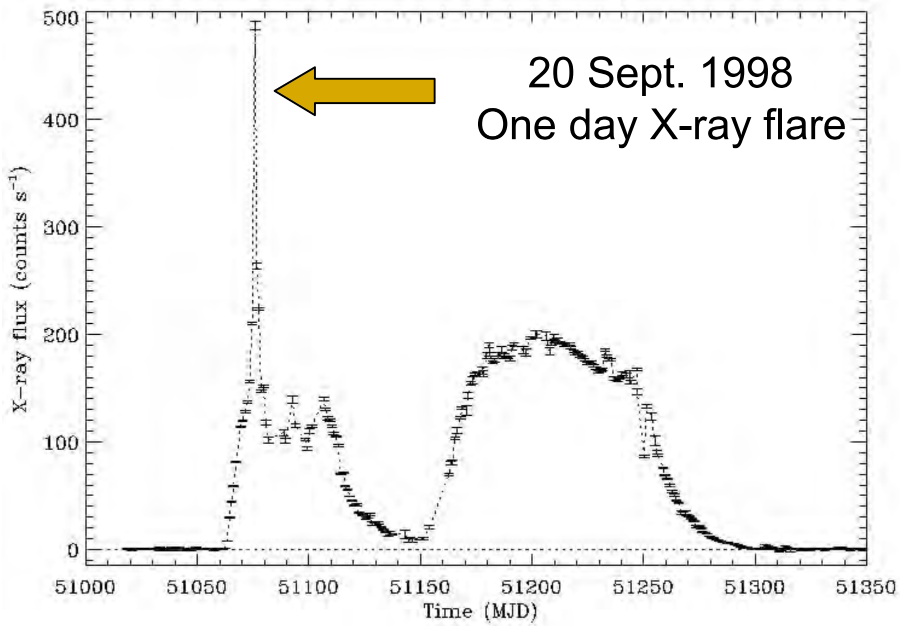
- Large scale X-ray jets (but no motion observed)

  Non thermal emission poss related to jet/ISM interaction

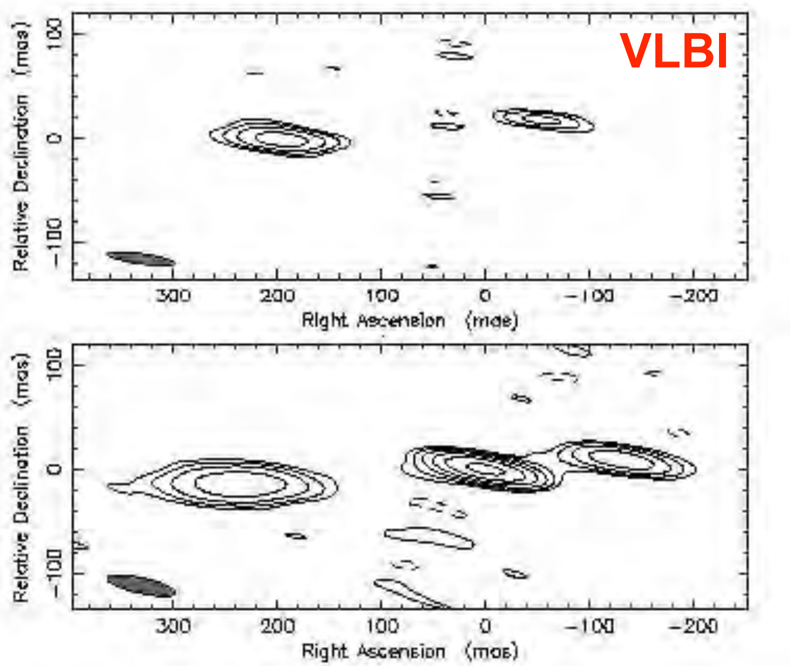
- Relativistic (0.26c) ejection on arcsec scale

Associated thermal X-rays (Marshall et 01,Migliari et al. 02)

Large-scale, decelerating relativistic X-ray jets from XTE J1550-564



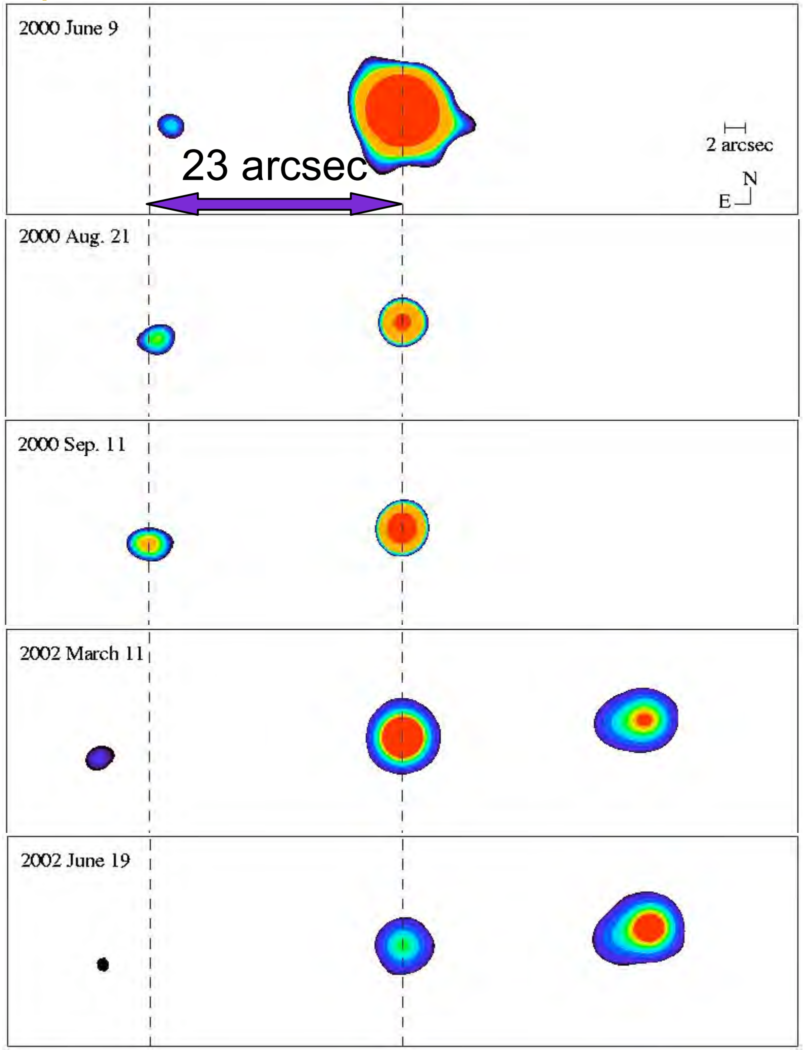
RXTE/ASM lightcurve (1998-99)

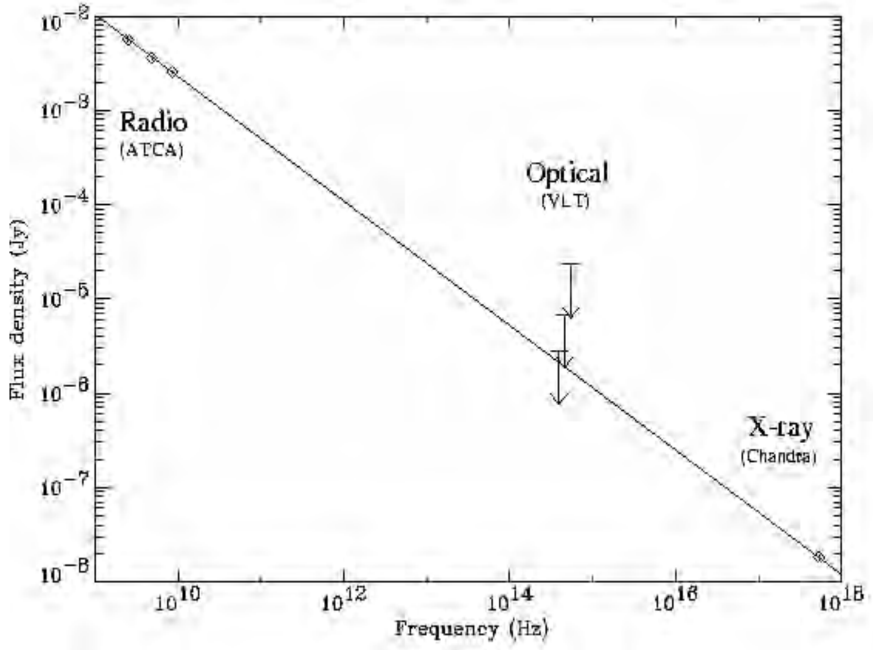


- M_{bh}= 10.5 +/- 1.0 $M_{\odot}$; d ~ 5 kpc (Orosz et al. 2002)
- 20 Sept. 1998: Strong and brief X-ray flare

Relativistic ejection imaged with VLBI (Hannikainen et al. 2001)

Chandra (0. 3 - 8 keV) 2000-2002





Synchrotron emission from the same electron dist.

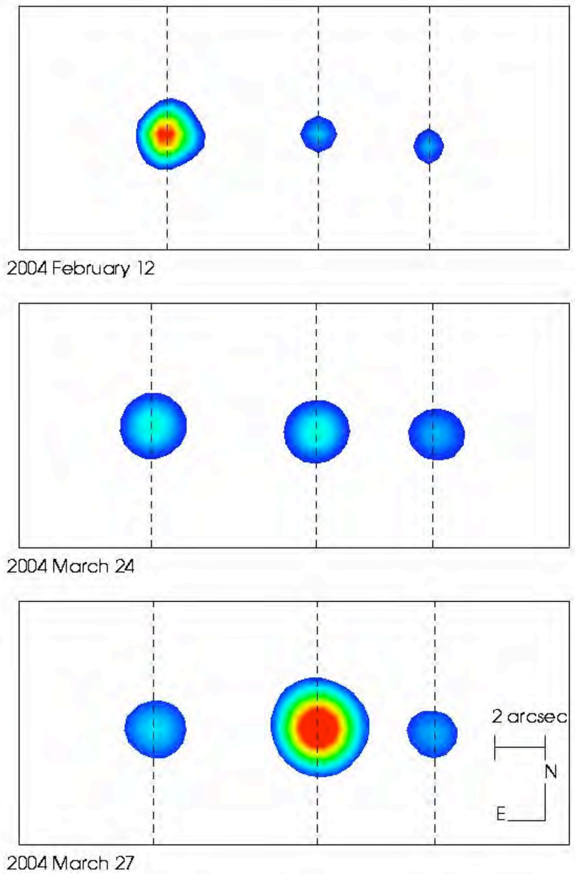
X-ray emitting electrons: Lorentz factor γ_e > 2 x10^7 (TeV electrons)

Moving X-ray sources associated with the radio lobes

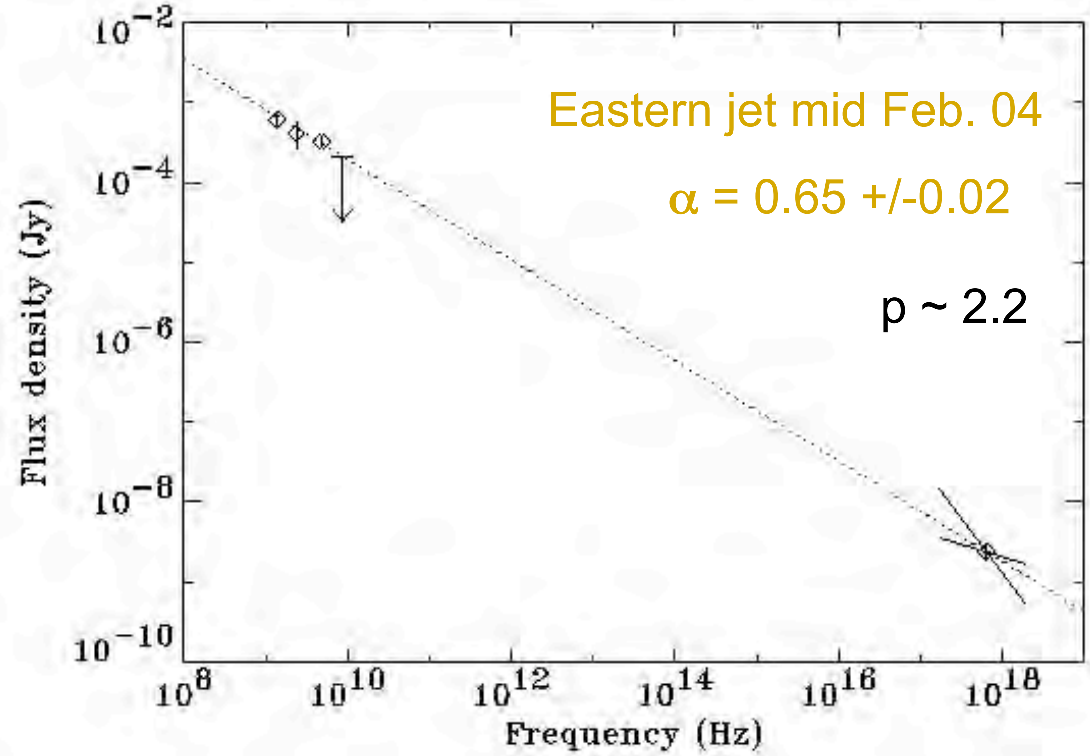
Tail , What about the low frequency e- ???

Corbel et al., Science (2002),298, 196

New large scale X-ray jets in H1743-322

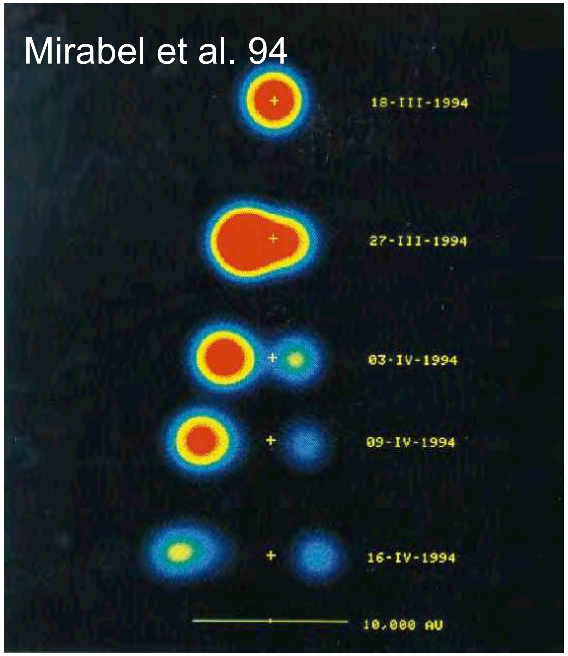


E. jet W. Jet



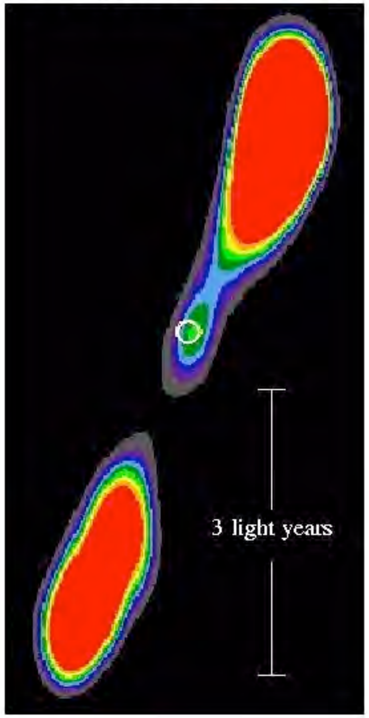
Similar properties to the X-ray jets of XTE J1550-564, but decay much faster (Corbel et al. 2005).

Jet morphological evolution in microquasars?



Arcsec scale (<0.1 pc) superluminal jets in GRS 1915+105 or other SXTs

MICROQUASAR 1E1740.7-2942

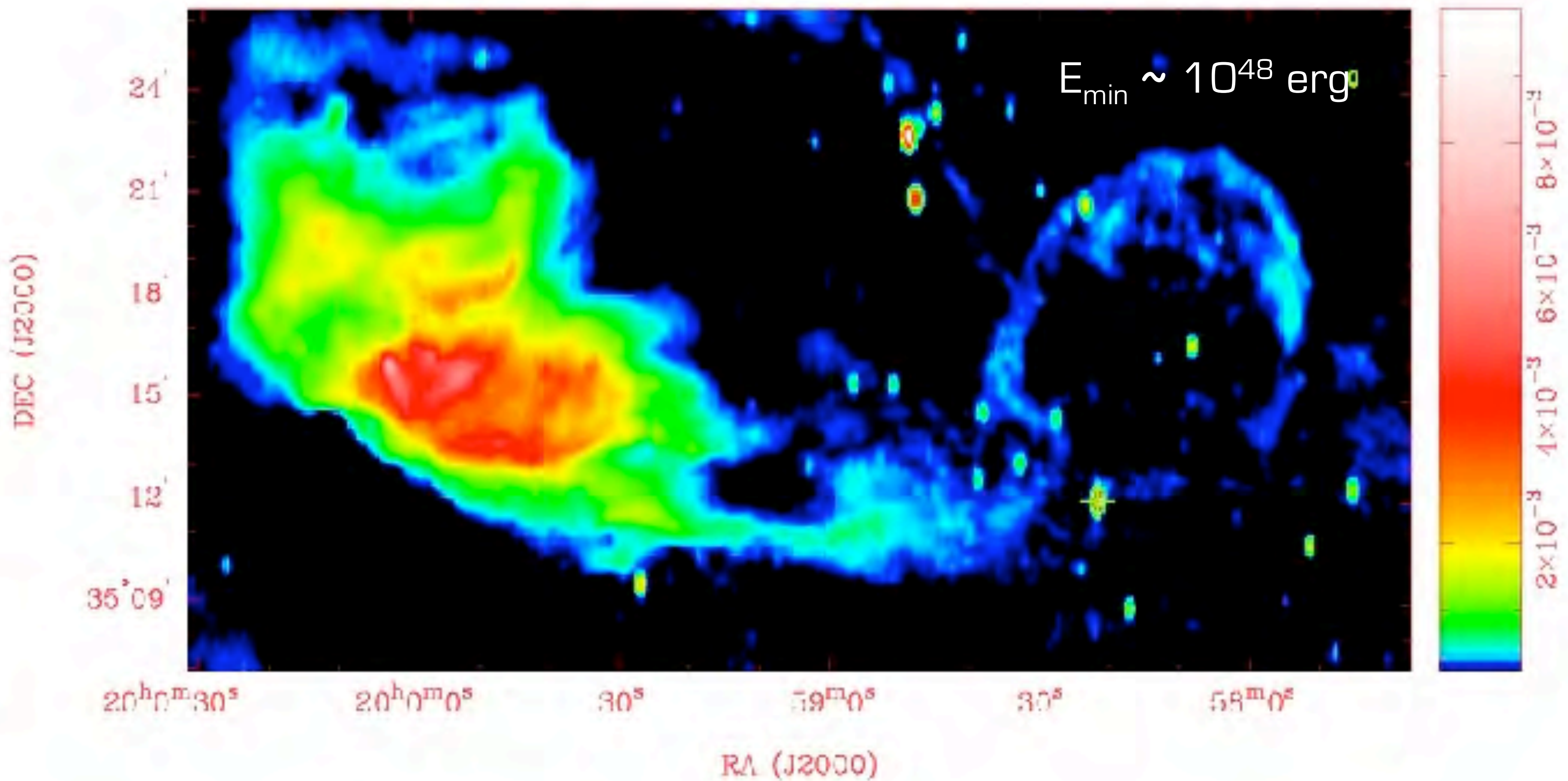


« Stationary » large scale (1 - 3 pc) radio jets in 1E 1740.7-2942 or GRS 1758-258 or X-ray jets in 4U 1755-33

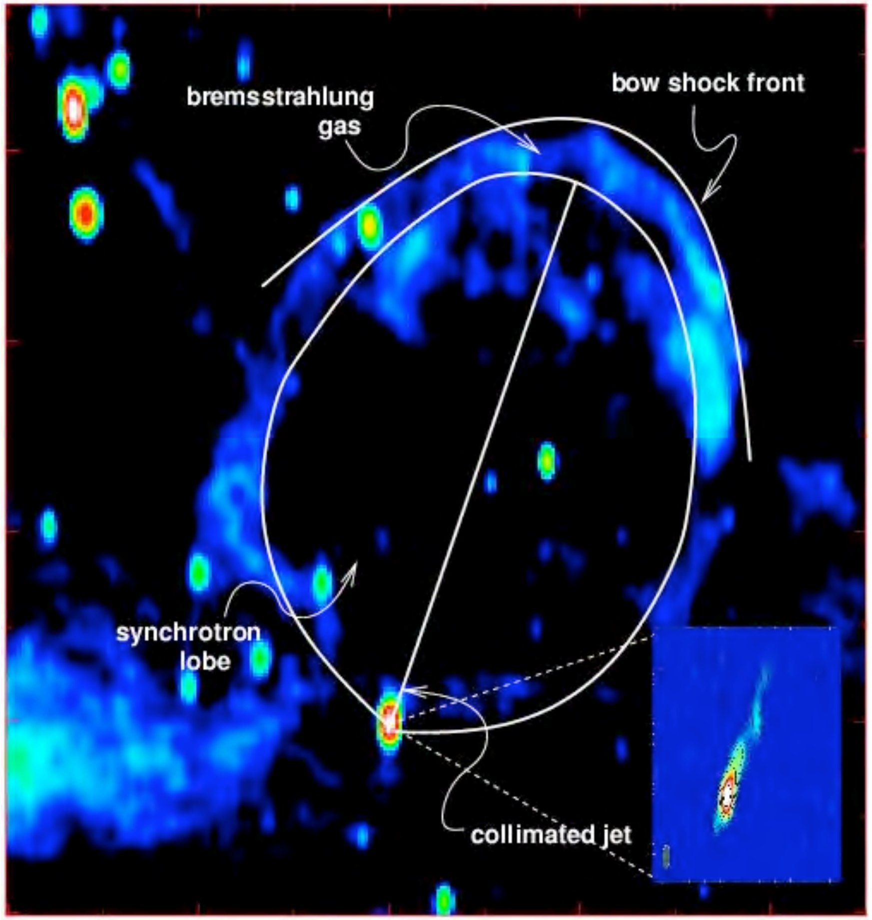
- Jets of XTE J1550-564 (0.5 - 0.8 pc), H1743-322: intermediate size. Morphological evolution ?
- Large scale lobes = long term action of impulsive relativistic events.

The jet/ISM interaction in 4U1755-33 might be similar to that seen in XTE J1550-564, provided the jet were being ejected quasi-continuously over its 25 years X-ray activity

Jet-blown bubbles in the ISM: Cygnus X-1



Gallo et al. Nature 2005

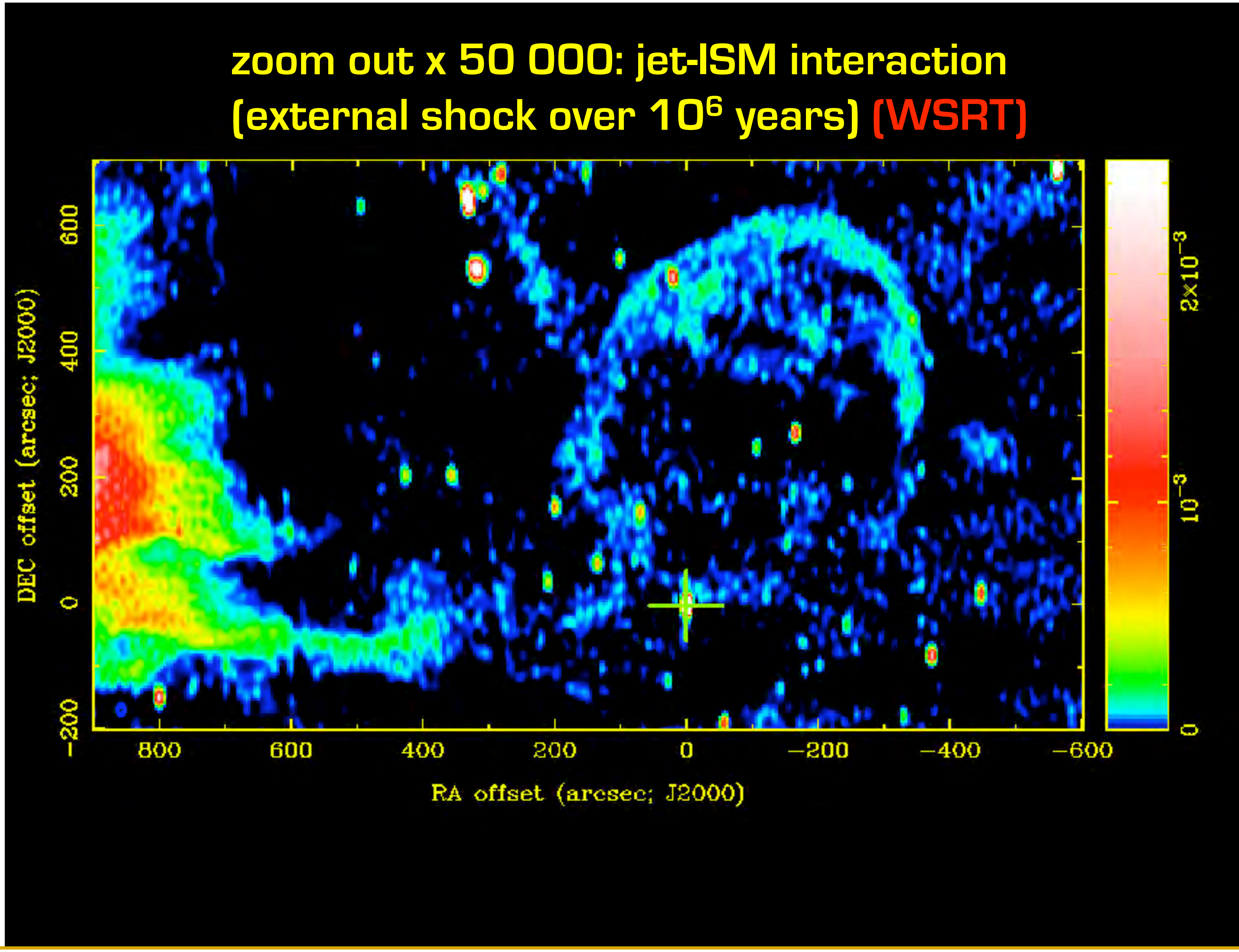


- Large scale (5pc) radio ring inflated by the inner radio jet
- Bremsstrahlung emission from the shock that dvlp at the location where the collimated jet strikes the ISM
- ISM = effective jet calorimeter → <8x10^{35} to 10^{37}erg/s>
- Total power carried by the compact jet of Cyg X-1: 9x10^{35} to 10^{37}erg/s
- The total power dissipated by the jets in the form of kinetic energy can be as high (6 to 100%) as the bolometric X-ray luminosity
- Power output of low-luminosity of stellar BH is dominated by the kinetic energy of dark outflows

Gallo et al. 05

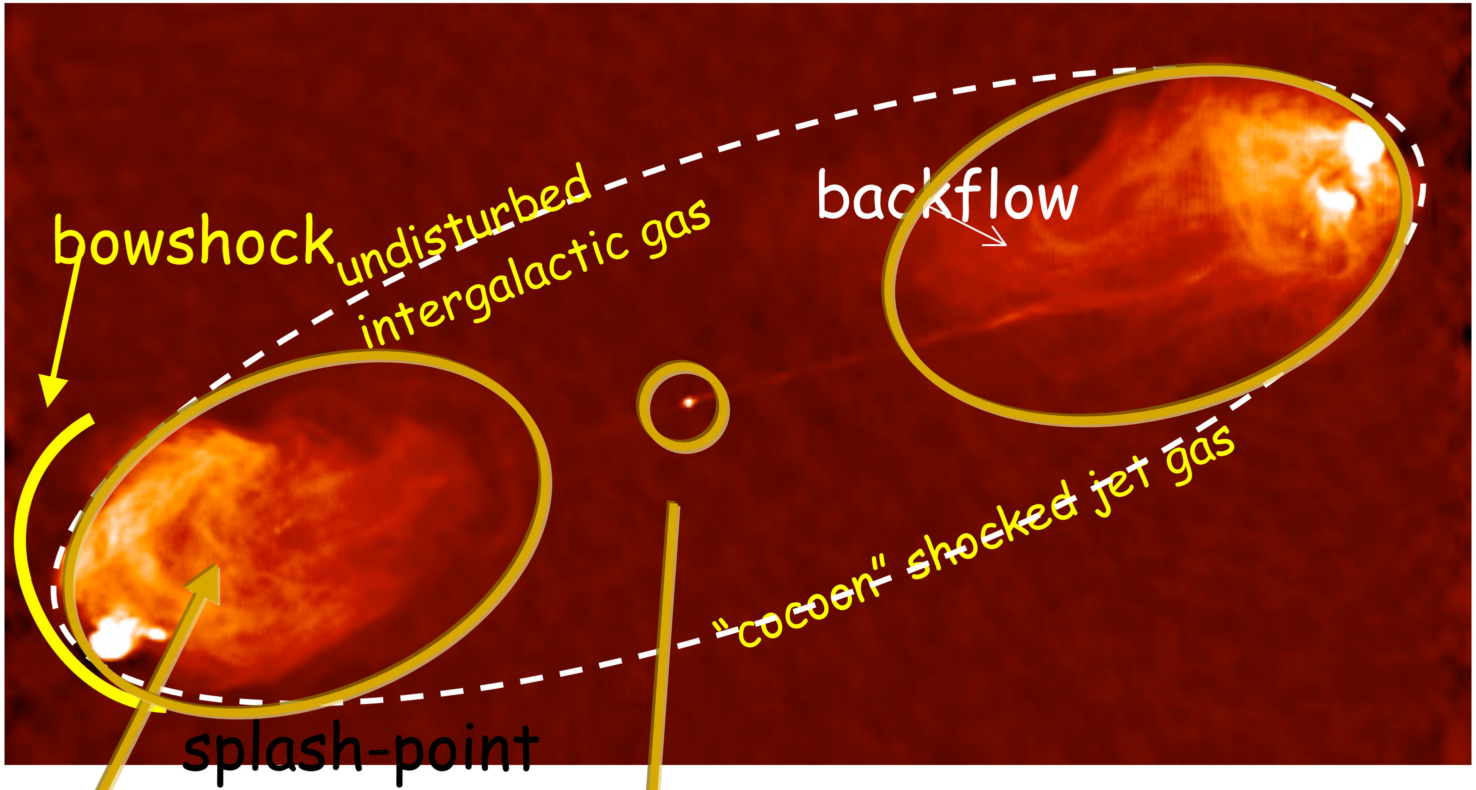
ISM = calorimeter → measure of the total energy deposited

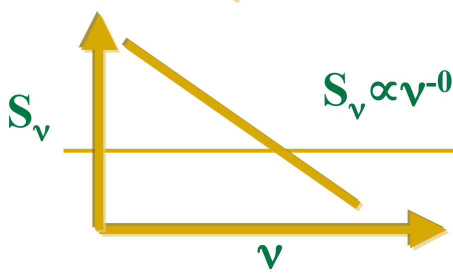
Generic sketch for jet production in XRB

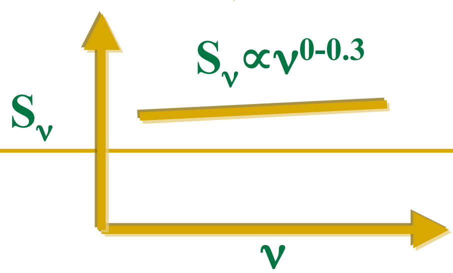


(Stirling et al. 2001; Fender et al. 2006; Gallo et al.2005)

A prototypical radio galaxy: Cyg A

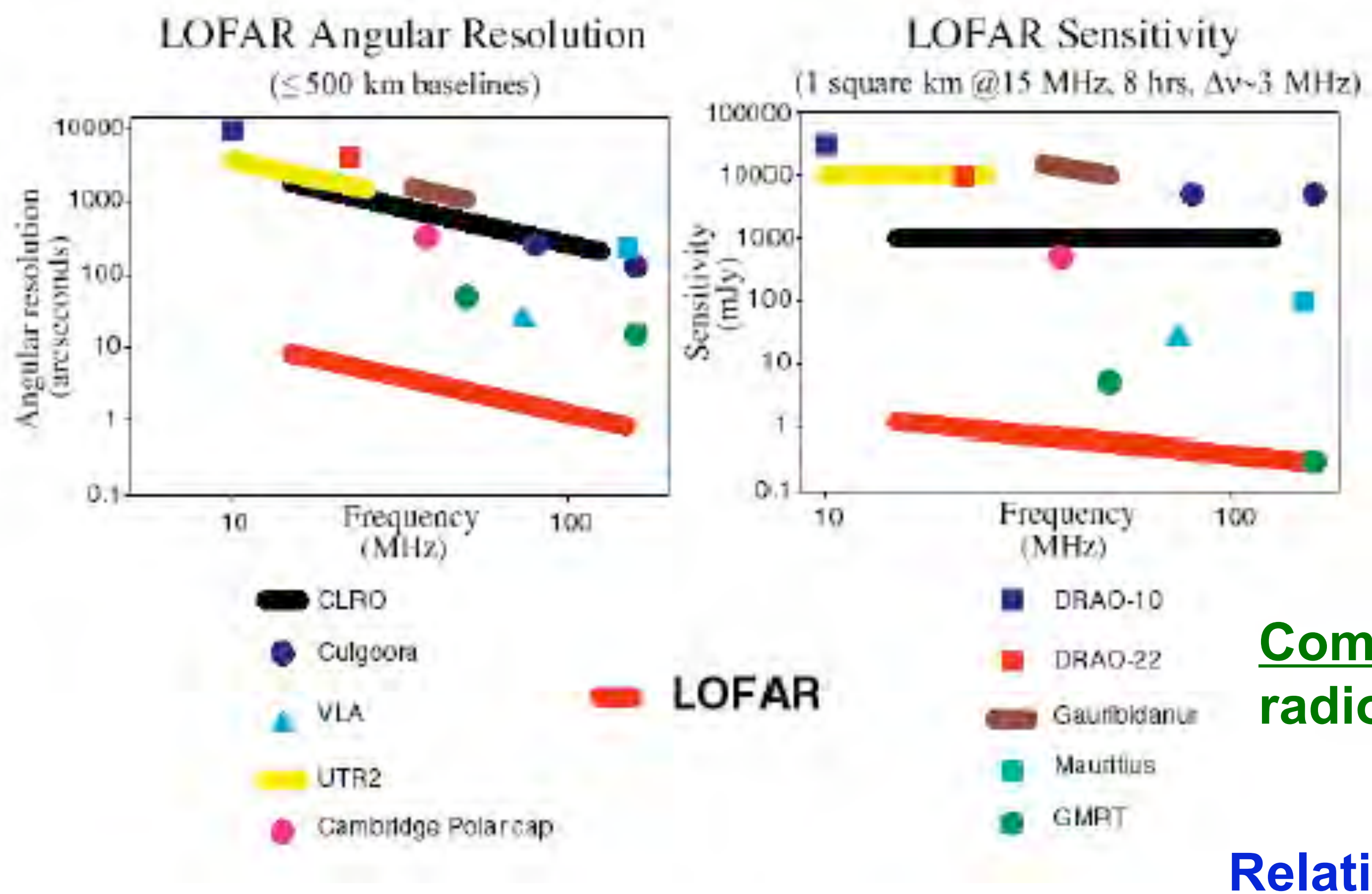






- Lobes (steep spectrum)
- Core (flat spectrum)
- Jet (opt thin)

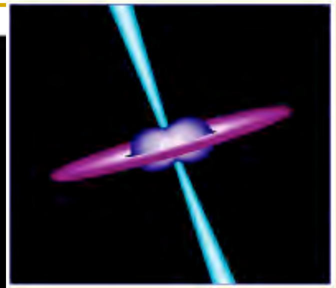
- Introduction: XRBs population and relativistic jets
- Flavors of relativistic jets
- Large scale jets (or lobes)
- LOFAR Contributions
- Conclusions



Compact jets: flat radio spectrum

Relativistic ejections and large scale lobes: radio spectrum rising in LOFAR freq range.

LOFAR transients



Virtual core All Sky Monitor

20 to 120 degrees FWHP f.o.v.

very high time resolution (< nsec)

processing of data

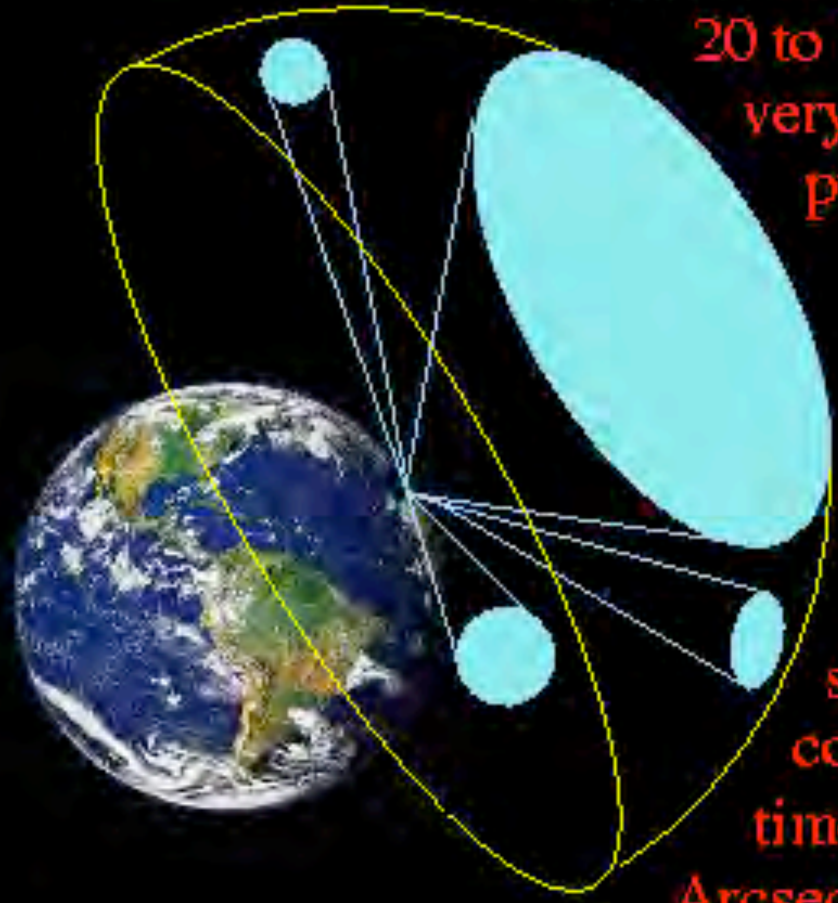
↓

Detections with `ASM'

can be rapidly (<sec)

followed up with full array

↓

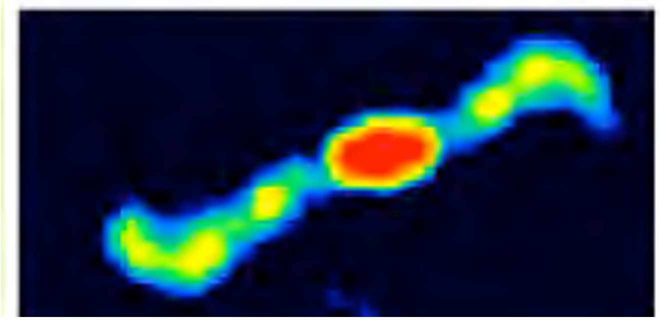


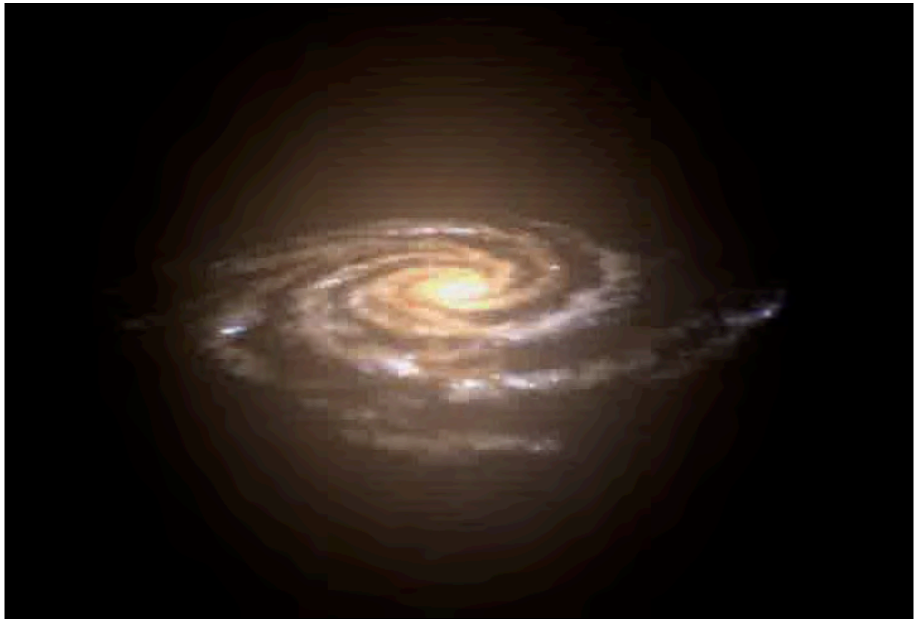
1–8 individual LOFAR beams:

standard data products can be continuously scanned (minutes timescales) for variable events.

Arcsec positions achievable.

Black holes, neutron stars and gamma-ray bursts: mapping out in-situ particle acceleration





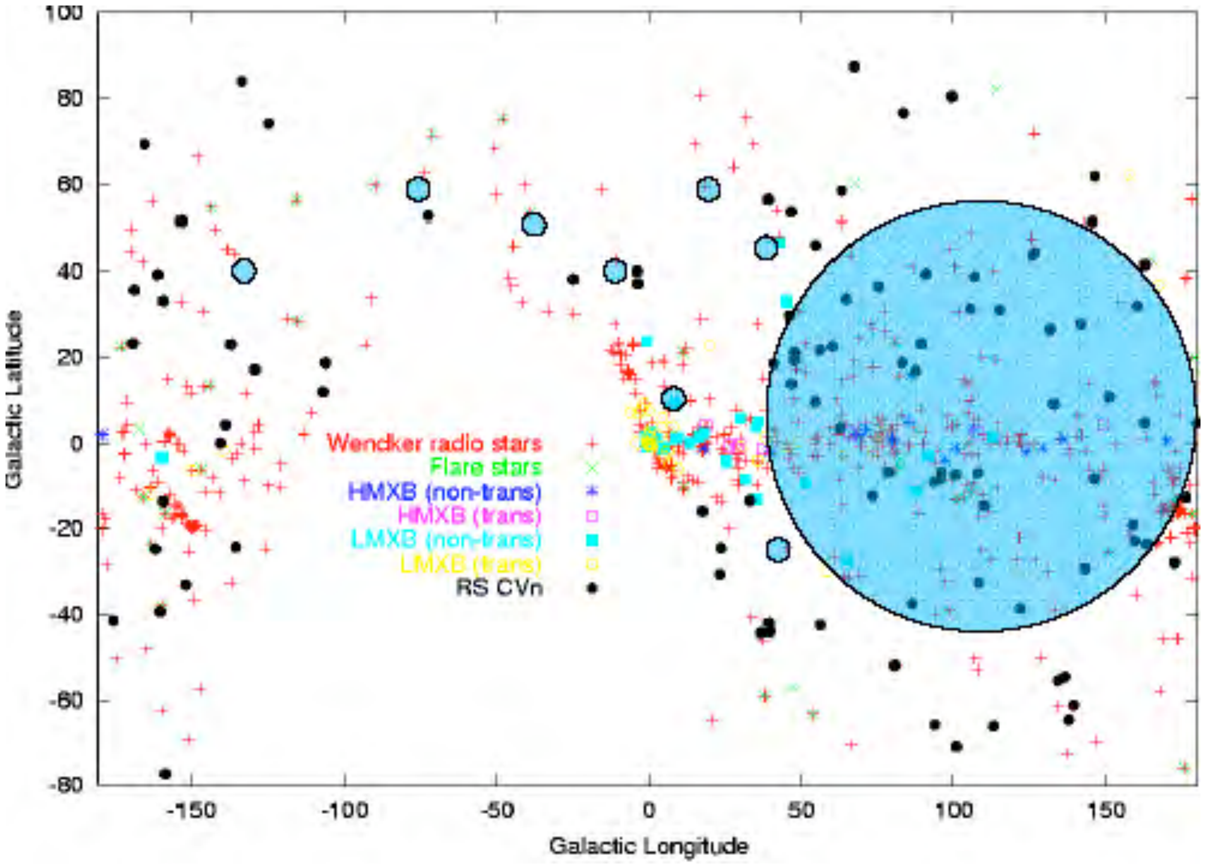
Decelerating relativistic jets from a black hole binary system → in-situ acceleration of particles to TeV energies via deceleration of the jets…

Comparing directly to current X-ray all-sky monitors, LOFAR will be x10 more sensitive and provide (very rapidly) ~arcsec positions.

This will be the instrument providing the alerts for Target-of-Opportunity observations with 'pointed' instruments e.g. *Chandra*, *XMM-Newton*, H(JW)ST, VLT, VLBI etc.

Sky distribution of *known* flare stars and X-ray binaries north of -30

Many of these variable sources will be detected + GRB + new transient sources + serendipitous discoveries !!!!

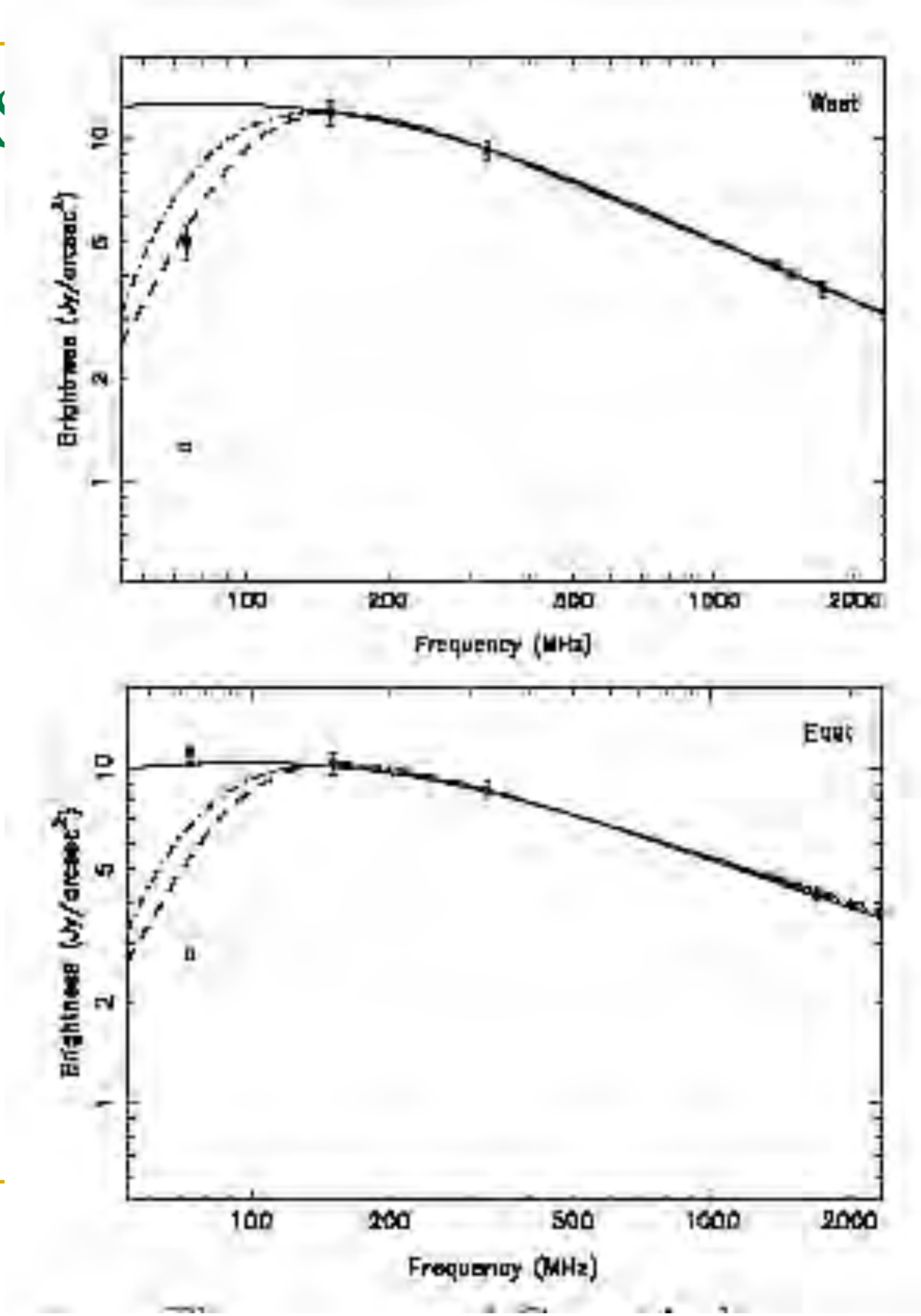


(Geers & Fender 2003)

Scientific interest for low frequency radio obs

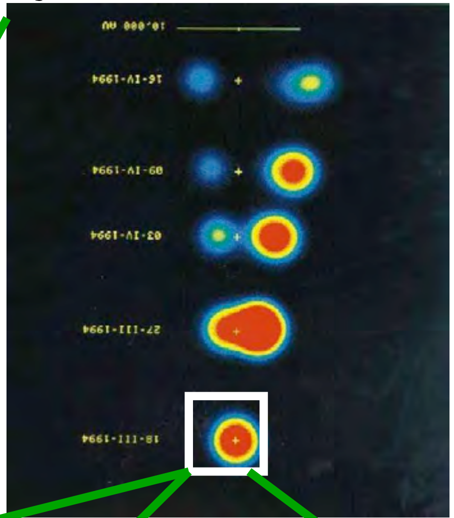
- Very rare observations in this range
- Simultaneous observations at low and high frequency of an ejection event: → compare decay rates: radiative or expansion losses ?
- Extent of the non-thermal electron spectrum: N(E)dE a E^{-p} with p ~2: g $_e$ ~ 150 @ 5 GHz → g $_e$ ~ 25 @ 150 MHz. Energetics dominated by kinetic energy of cold proton. Determination of minimum g $_e$
- Energy deposited in lobes (cf Cyg X-1): KE → U in shock: steep spectrum : many new lobes
- Low freq abs processes (TR or free-free) : B + n_e
- Unique capability to focus "a posteriori" to some specific event (GRB: prompt emission)

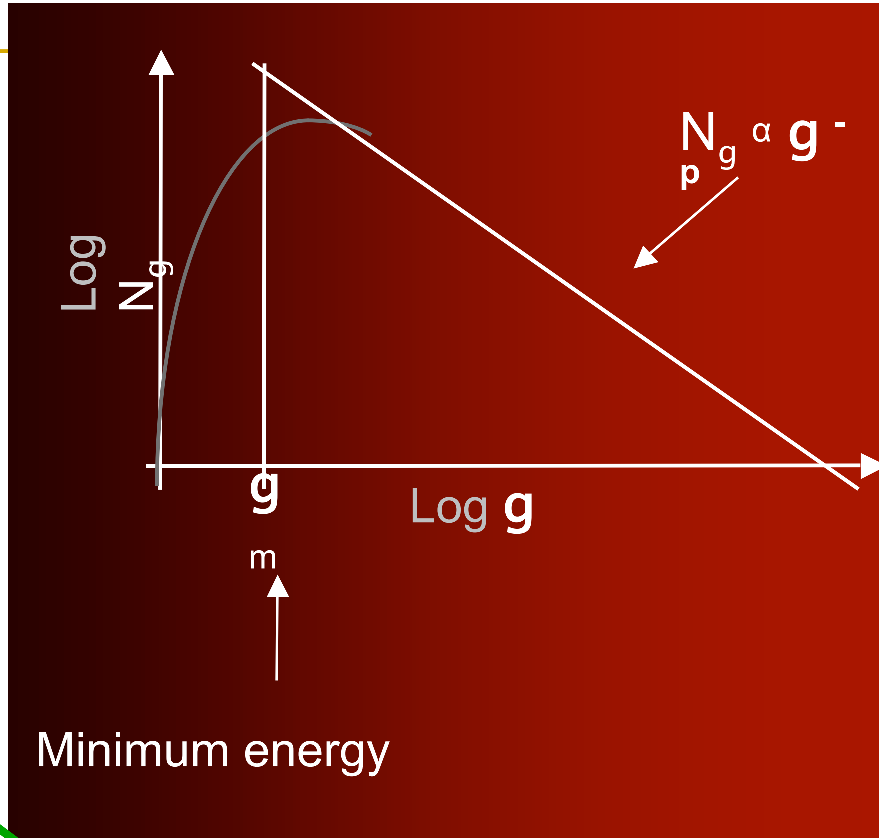
frequency radio obs



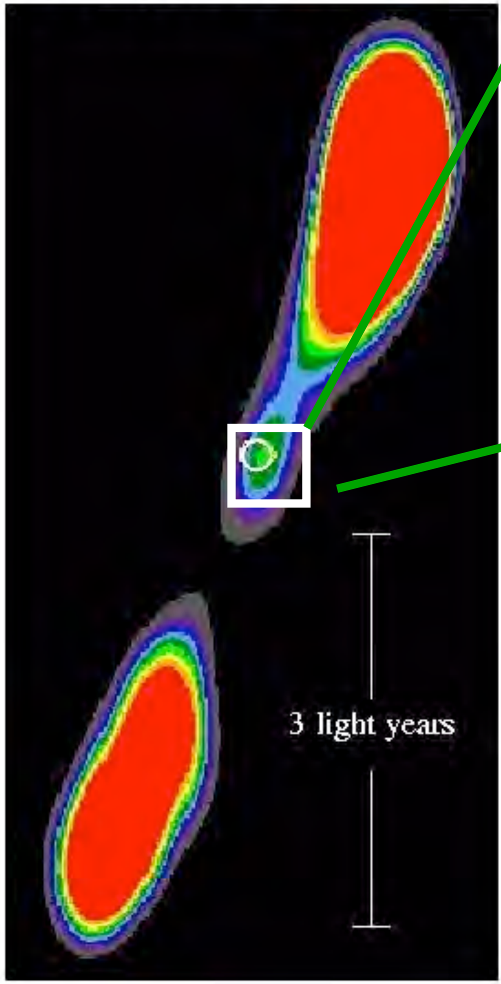
Conclusions

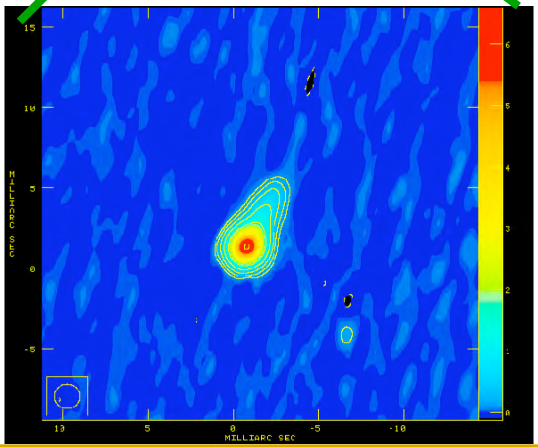
Relativistic ejections

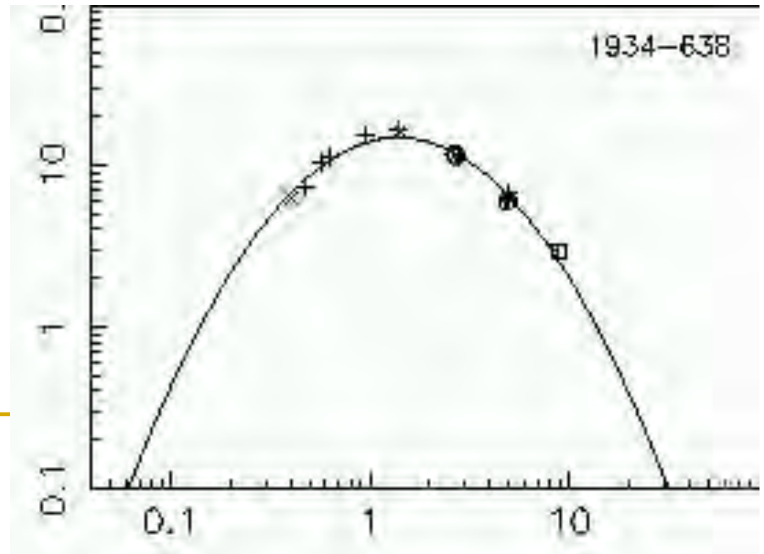




MICROQUASAR 1E1740.7-2942







Large scale lobes

Compact jet