AGN, Microquasars and Jets

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Introduction

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  - Doppler Boosting
  - AGN Paradigm
- **Microquasars**
  - Comparison with AGN
- **Jets**
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  - Formation of the Jets
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Active Galactic Nuclei (AGN)

- Typical picture :
  - Most galaxies have supermassive black-holes at their center. Masses ranges from ca. 10^6 to 10^9 Solar masses (cf. talk of S. Taubenberger).
  - Gas accreting onto the black hole releases a large amount of gravitational potential energy :

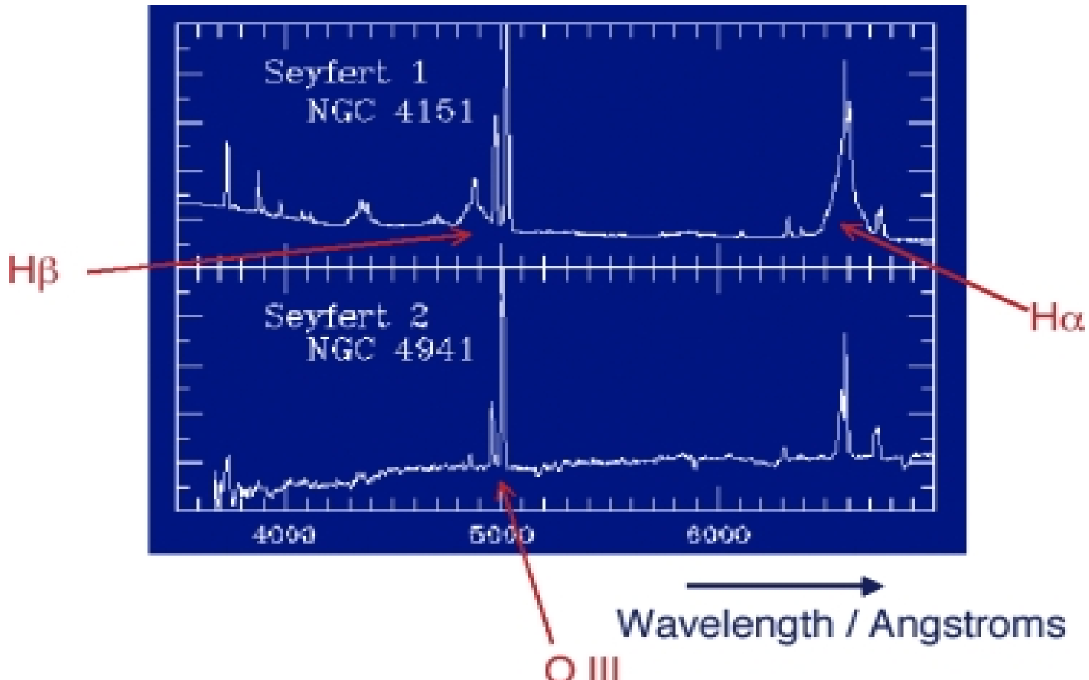
$$L = e\dot{M}c^2$$

Active Galactic Nuclei (AGN)

- Accretion processes produce several observational phenomena :
  - Very high luminosity from a point source in the nucleus
  - Broad spectral lines due to Doppler shift of gas orbiting in the accretion disk
  - X-ray emission from high temperature plasma close to the black hole
  - Mechanical power in form of outflows and jets from the central region

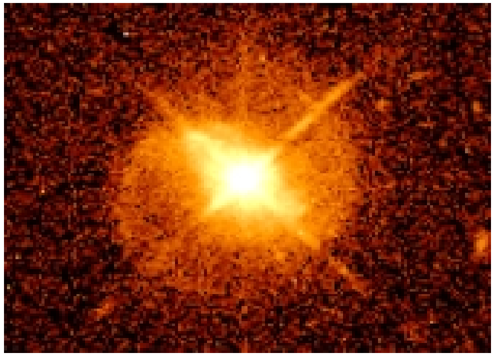
Classes of AGN

- AGN are classified into numerous types :
  - Seyfert galaxies
    - First class to be observed
    - Carl Seyfert obtained spectra of several nearby galaxies with very bright cores and found unusually broad emission lines (up to 8500 km/s)



Classes of AGN

- Quasars
  - Distant and luminous objects with highly redshifted spectra ($z=0.158$ for the brightest one, $m=13.1$)
  - Point-like sources (originally associated with radio-sources)
  - Broad spectral energy distribution, with large UV flux
  - Broad emission lines
  - High redshift (record $z=6.4$?)
  - Difficult to detect the light from the host galaxy due to the high luminosity of the nucleus

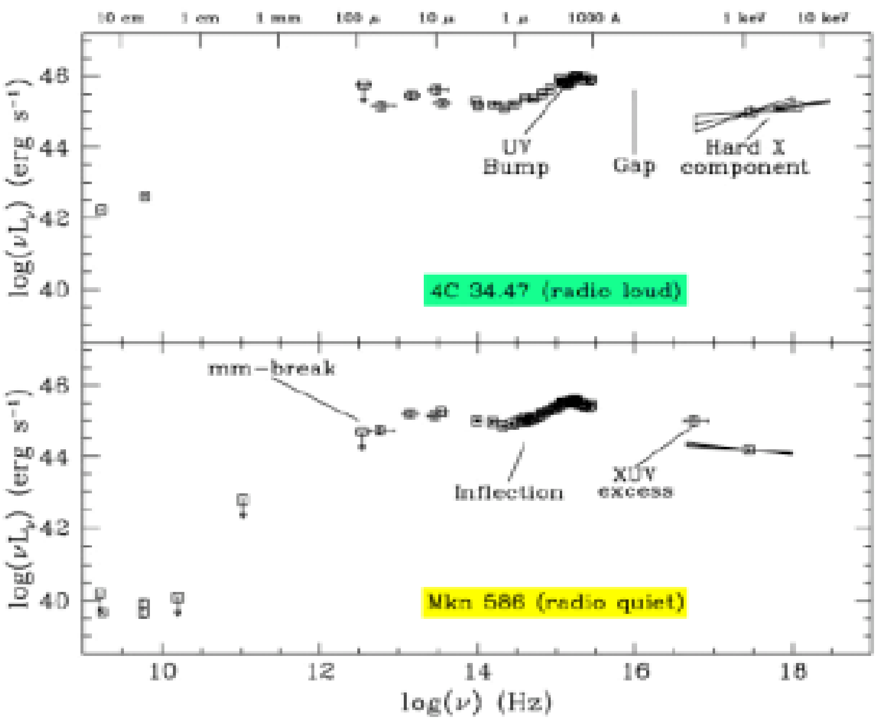


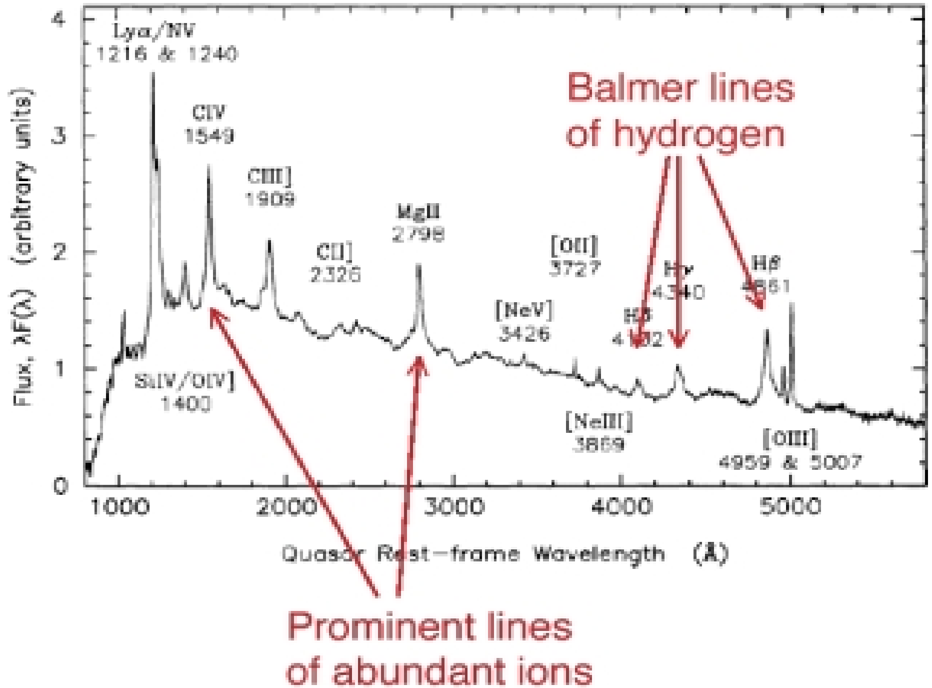
Courtesy of STScI

Classes of AGN

- Quasars spectral energy distribution
  - Roughly characterized by a power law :

$$F_\nu = C\nu^{-\alpha}$$





AGN Unification

- AGN are not spherically symmetric
- It was the discovery of superluminal motion that made realizing that the orientation of AGN is important.
- Doppler boosting is an important factor too as a relativistic effect.

Doppler boosting

- When an emitting body is moving relativistically, the radiation received by an observer is a very strong function of the angle between the line of sight and the direction of motion.

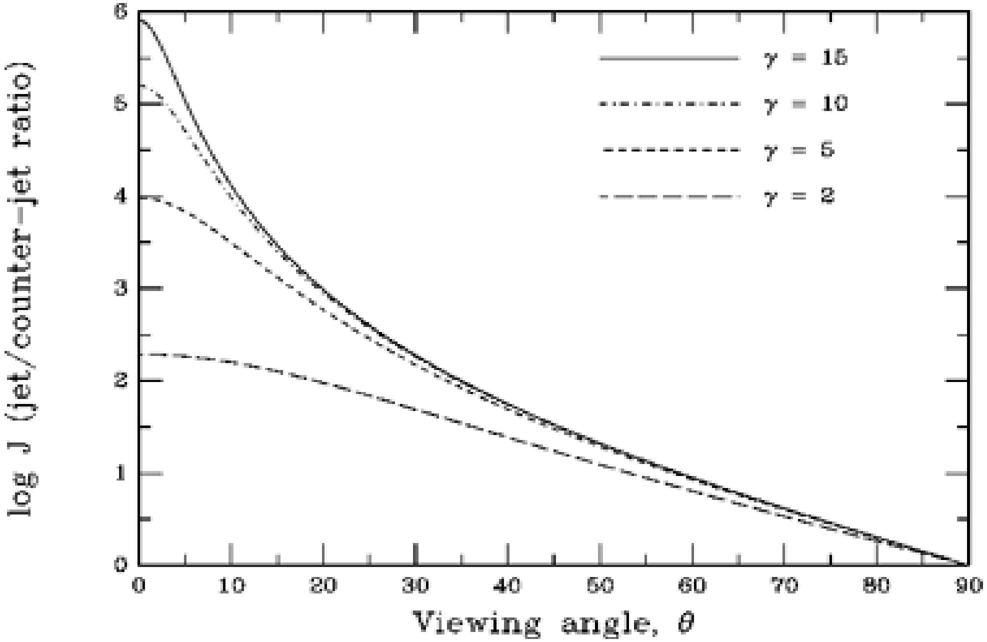
$$S_{obs} = S_{em}\delta^{(3-\alpha)}$$

  - The Doppler effect changes the energy and frequency of arrival of the photons.
  - Relativistic aberration changes the angular distribution of the radiation.
    - δ Is the Doppler factor
    - α Is the spectral index

Consequences of Boosting

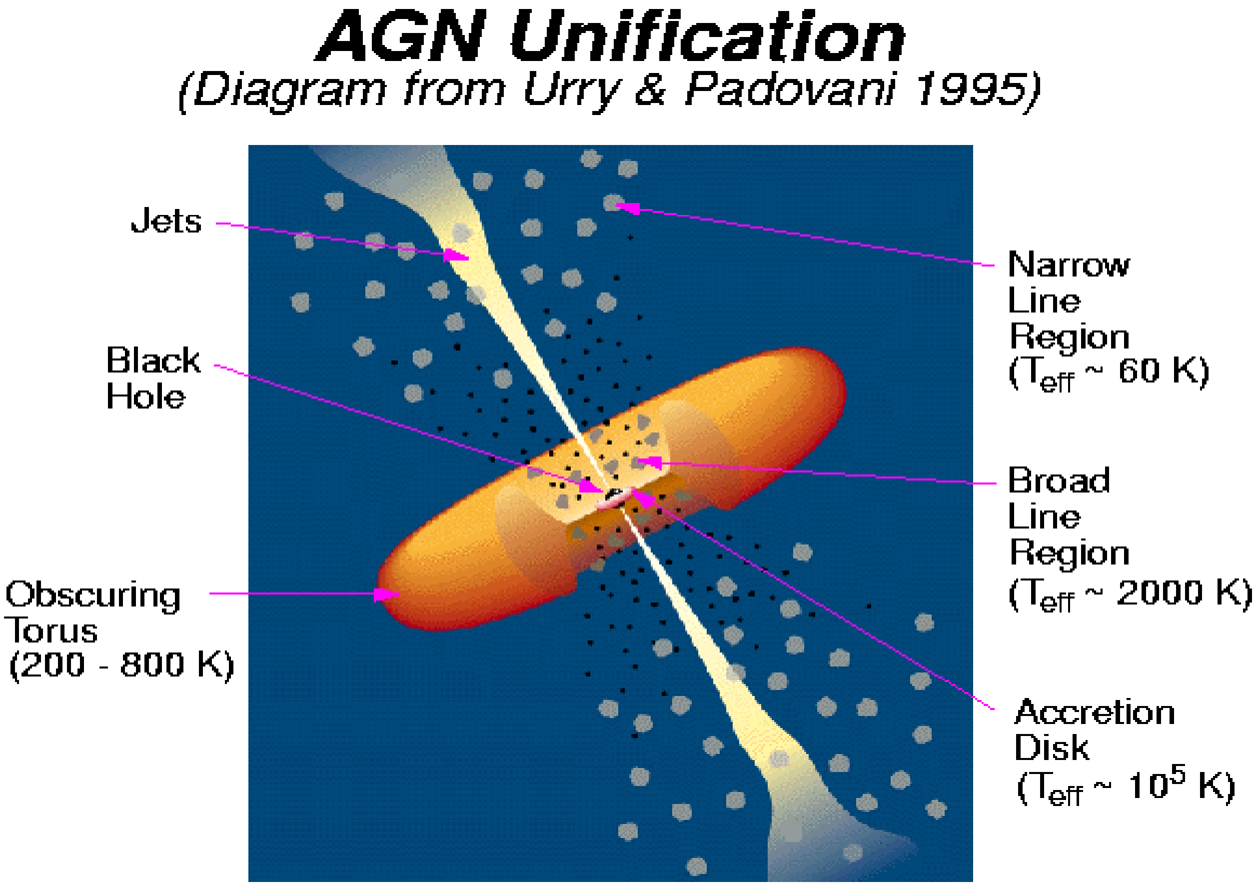
- Superluminal motion implies Lorentz factors of 5 to 10. Implies possible boosting of flux density by 100.
- Sources with the strongest cores will be those viewed with their axes at small angles to the line of sight.
- The highly boosted sources will only be a small percentage of the total population.

Doppler boosting



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

The AGN Paradigm



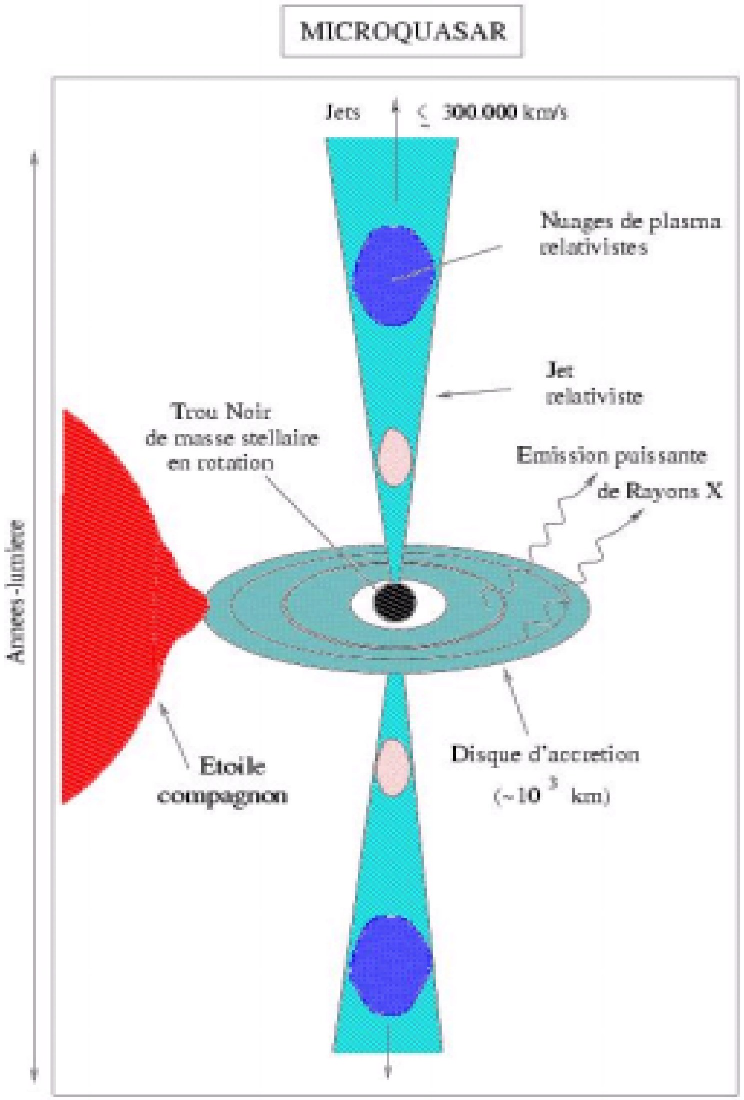
Microquasars

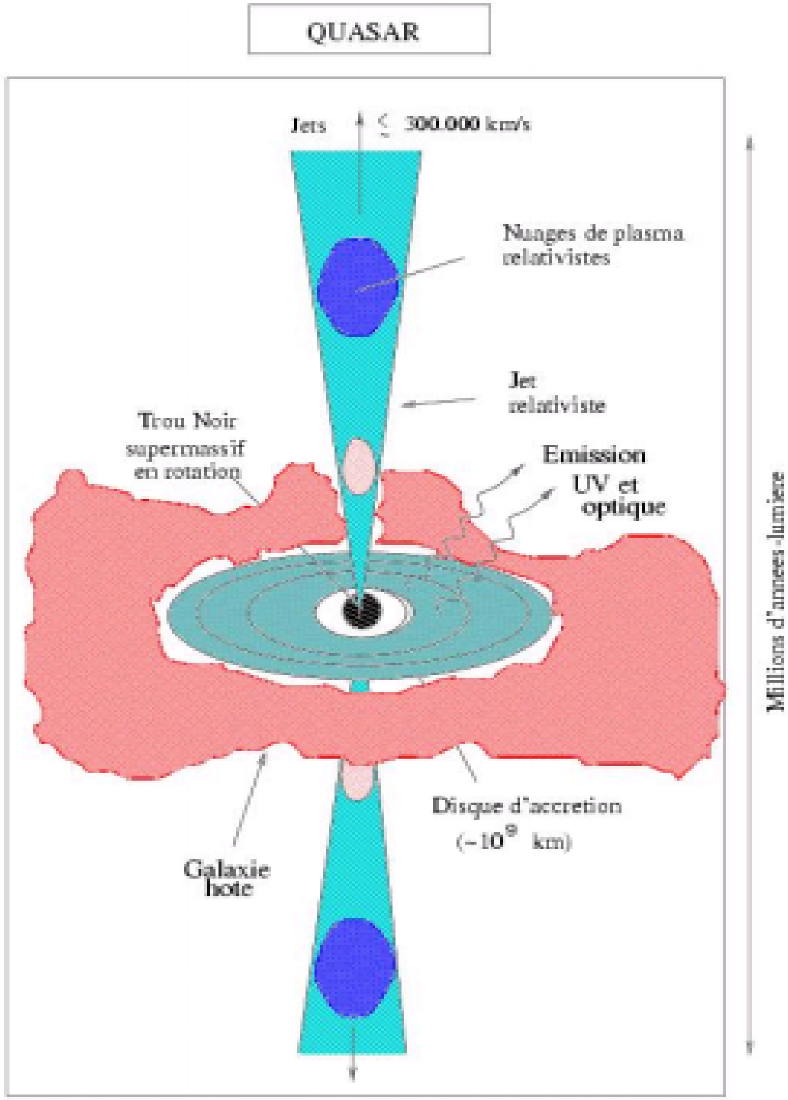
- Binary systems
- Stellar-mass black holes in our galaxy
- Mimic on a smaller scale many of the phenomena seen in quasars.
- They combine two relevant aspects of relativistic astrophysics :
  - Accreting black holes
  - Jets of particles

Microquasars & AGN

	Microquasar	AGN
Black hole's mass	A few solar masses	Several million solar masses
Mean thermal temperature of the accretion disk	Several million degrees	Several thousand degrees
Particles ejected at relativistic speed travel up to	Few light-years	Several million light years

Microquasars & AGN



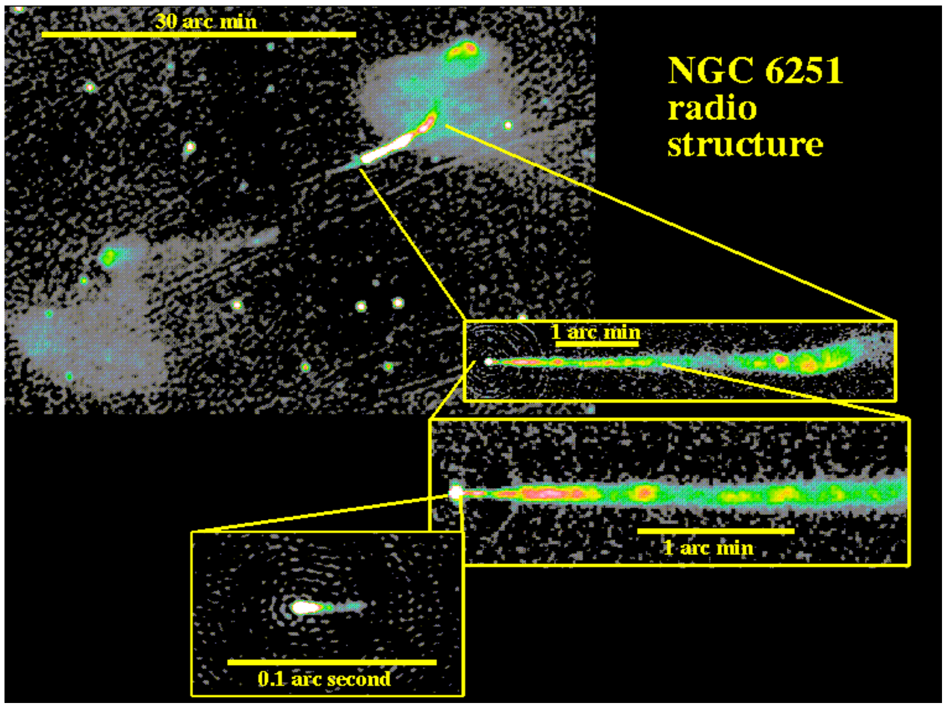


The Jets

- Collimated ejecta with opening angles less than 15 degrees.
- Discovered in AGN during the first observations with radio telescopes and by X-ray variability in MQ.
- Vehicles observational clues of the activity in the core engine
- Found in AGN and X-ray binaries (the latter is more recent)
- In both cases, it seems they are related to the presence of an accretion disk.

Properties of Jets

- Single or twin jets observed
- Rees & Blandford (1974) : lobes are fed by energy transport from the nucleus by narrow jets

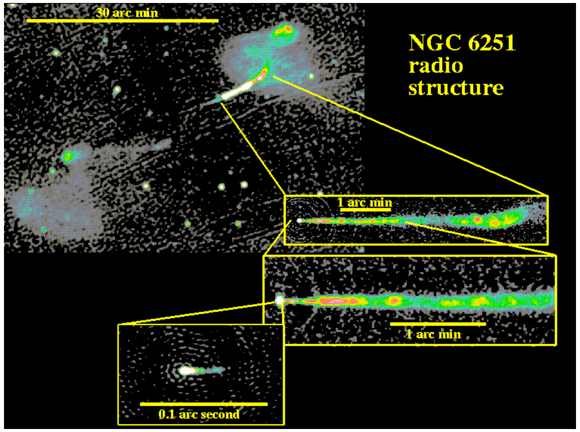


Are all jets double ?

- Some single jets are observed. Some hypotheses :
  - More fuel is pumped into one, so it is more visible.
  - Equal energy is flowing into both but one is radiating more efficiently
  - Receding jet is more suppressed than the forward jet
  - Material in the jet is moving relativistically
  - Jet is intrinsically single-sided and flips between opposite directions.

Lifetimes and energy requirements

- AGN :



  - In the case of NGC 6251, the outer lobes are 300 kpc away from the centre.
  - The right-hand jet is continuous
  - Mechanical energy required has derived from the central engine.

The physics of jets

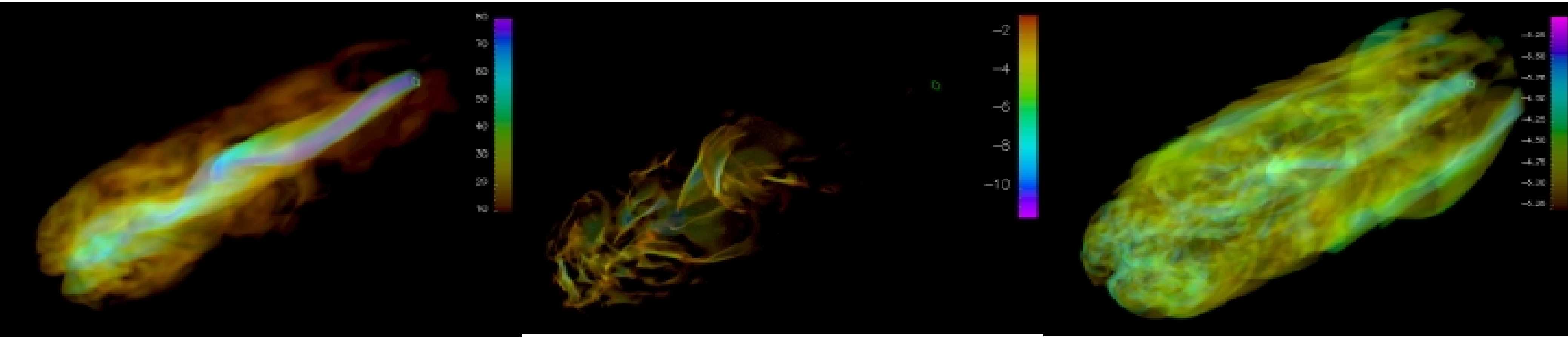
- Core emissions are very compact
- Dramatically exceeds the 10^{12} K limit for synchrotron radiation
- Emission is not anisotropic but highly beamed.
  - A synchrotron radiating ensemble of electrons has a lifetime proportional to the inverse of the electron energy and magnetic field strength.
  - A complex fluid transport of jet material should suppress synchrotron radiation by some mechanism.

The physics of jets

- What causes this high degree of collimation ?
  - It should expand sideways as it moves forward
  - An extremely long beam jet must be collimated by some mechanism
  - Jet material is moving at a velocity exceeding the sound speed in the medium

The physics of jets

- Two key parameters :
  - How supersonic is the jet (Mach number)
  - Ratio of the density of the gas within the jet to that of the surrounding medium
- It seems that the emission comes from the material being transported by the jet itself.



Volume renderings of a simulated light Mach 8 MHD jet after it has propagated about 100 jet radii from its origin, shown by the square on the right in each panel. Shown left to right are: bulk flow speed, plasma compression to locate shocks, and log of magnetic pressure.
Courtesy of I. L. Tregillis, T. W. Jones , and D. Ryu

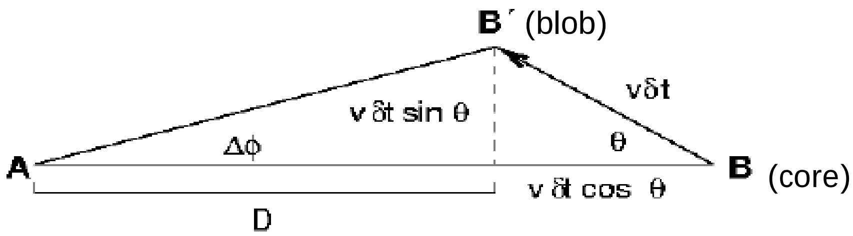
Formation of the Jets

- Blandford & Payne (1982) : the angular momentum of a magnetized accretion disk around the collapsed object is the responsible for the acceleration of plasma.
- After it is required to change the wide-angle centrifugal outflow into a collimated jet
- Most models use elements of MHD acceleration and collimation.
- First simulations show that the ejected jet has a two-layer structure.
- Steady-state MHD models don’t account for the connection between disappeareance of accretion disk and sudden ejection of condensations.
- Production of relativistic particles (synchrotron emission)

Relativistic Beaming

- Relativistic beaming must be taking place, due to the lack of X-ray emission coinciding with radio brightness temperatures exceeding the 10^{12} K limit.
- The parsec-scale jets are not smooth structures, but comprise « blobs » of emission.
- The production of new blobs of emission is linked with flares in the continuum energy output of the source.
- Astrometry on 3C345 established that the core is stationary and the blobs move outwards

Superluminal Motion



light emitted at position B and B' with time difference δt:

Observer A measures time difference:

$$\Delta t = \delta t(1 - \beta \cos \theta) \qquad (3.29)$$

Observer A measures transversal velocity:

$$\beta_{\mathrm{T}} = \frac{v \sin \theta}{c(1 - \beta \cos \theta)} = \frac{\beta \sin \theta}{1 - \beta \cos \theta} \qquad (3.30)$$

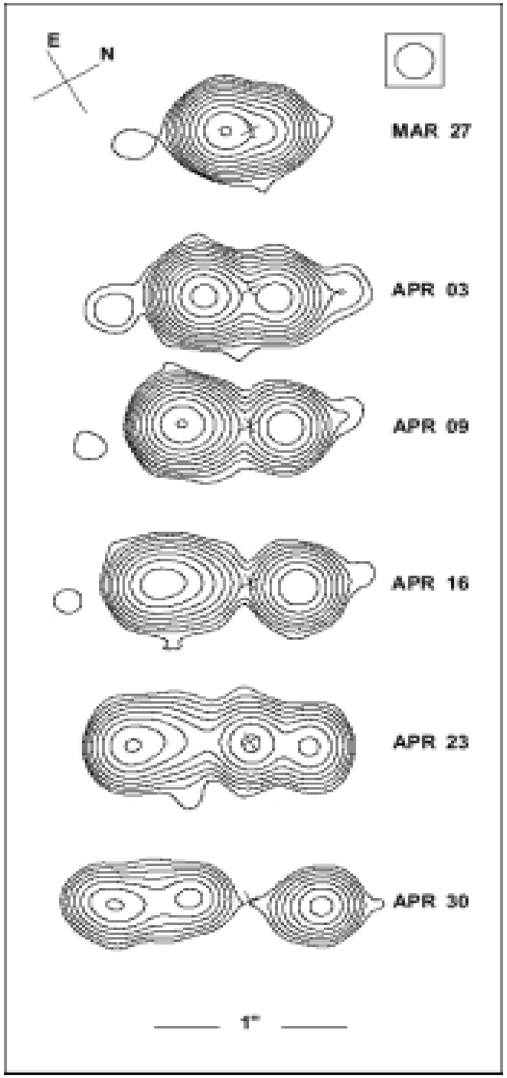
$\gamma = (1 - \beta^2)^{-1/2}$, $\beta = v/c$ with $\beta_{\mathrm{T}}^{-} = 0.65$ and $\beta_{\mathrm{T}}^{+} = 1.25$:

$$\beta = (0.92 \pm 0.08)c$$
$$\theta = (70 \pm 2)^{\circ}$$

maximum transversal velocity: $\beta_{\mathrm{T}}^{\max} = \beta\gamma \approx \gamma$

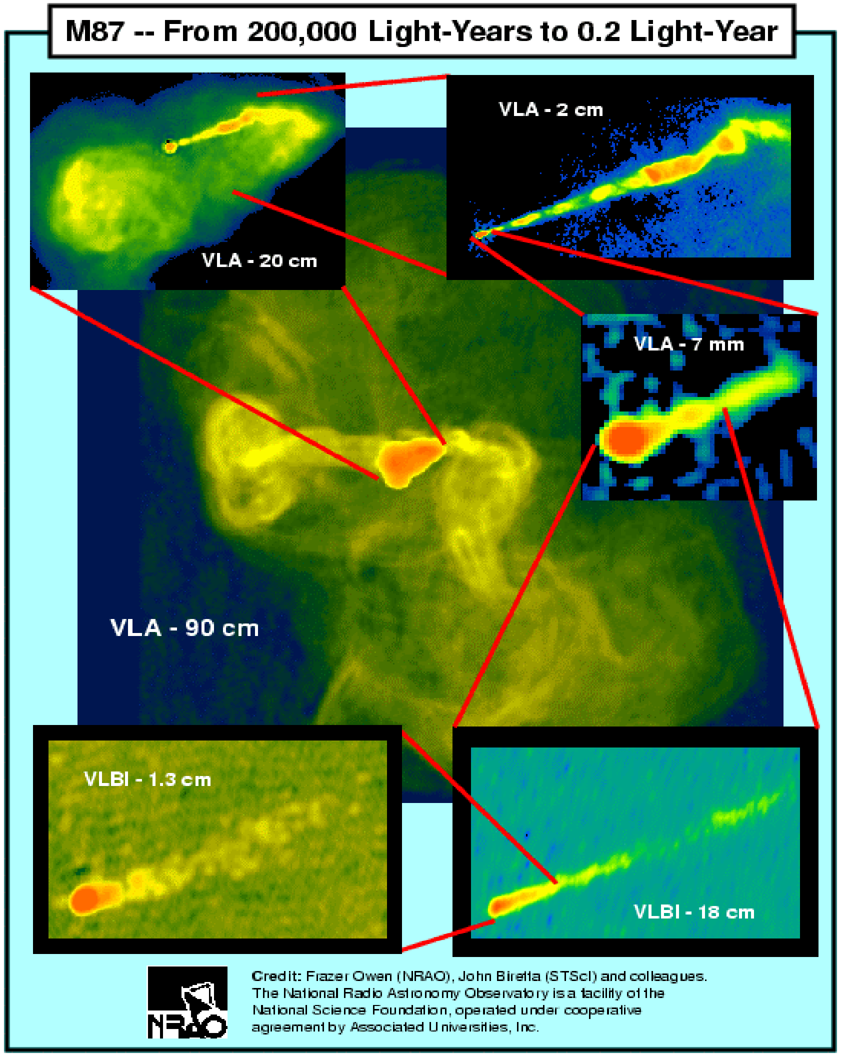
Courtesy of *Jörn Wilms*

1) Blob must be moving relativistically
2) Small θ

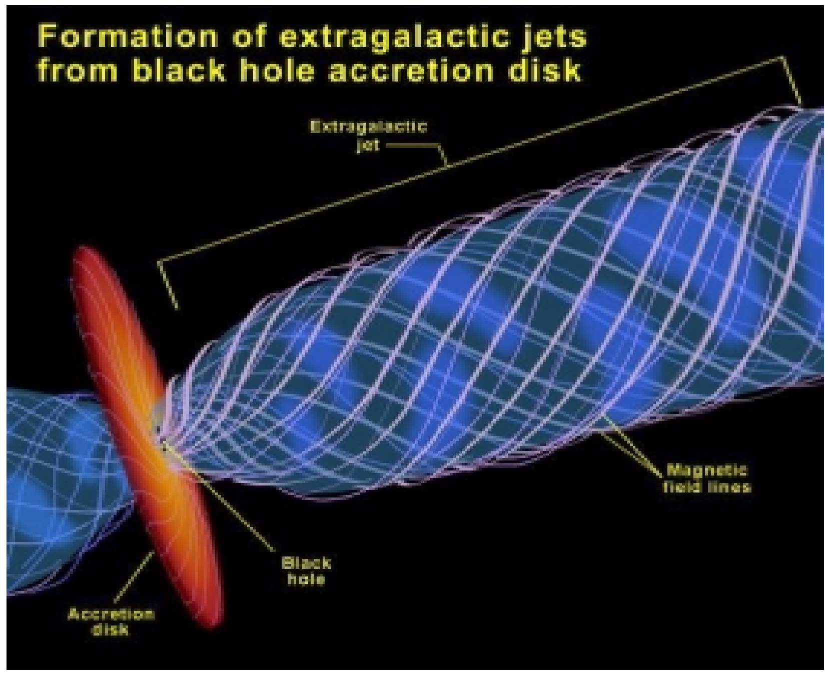


Courtesy of F.Mirablel, L.Rodriguez

M87 – Virgo A, 3C274

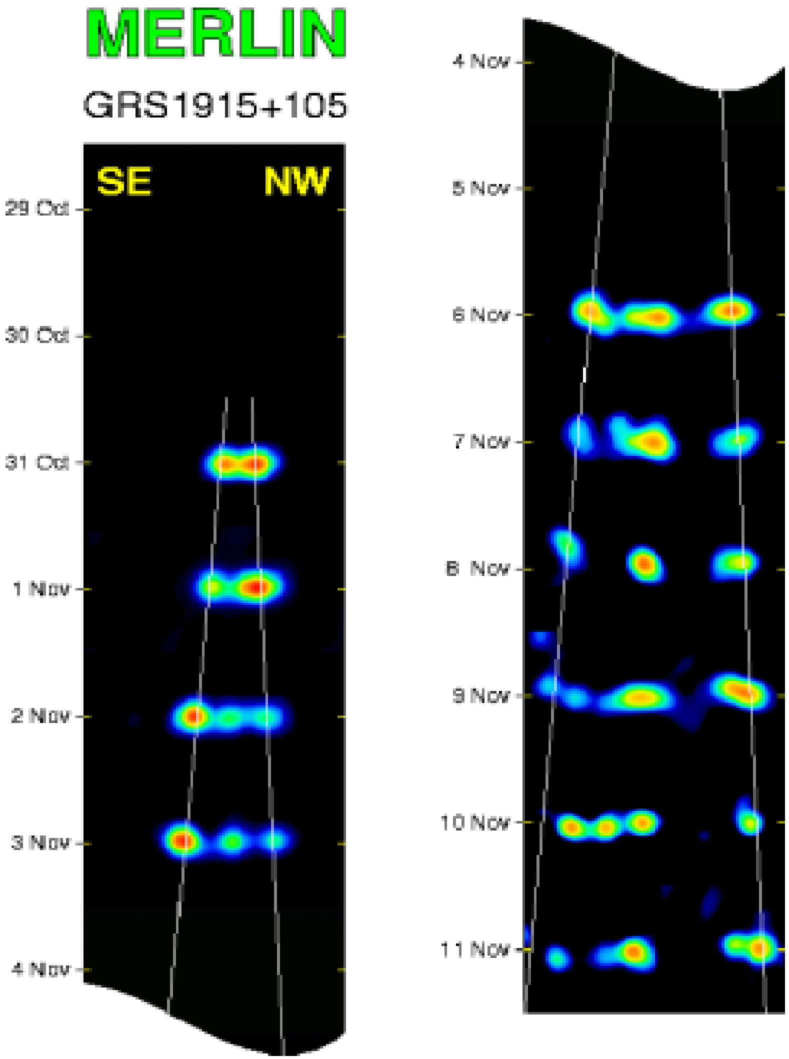


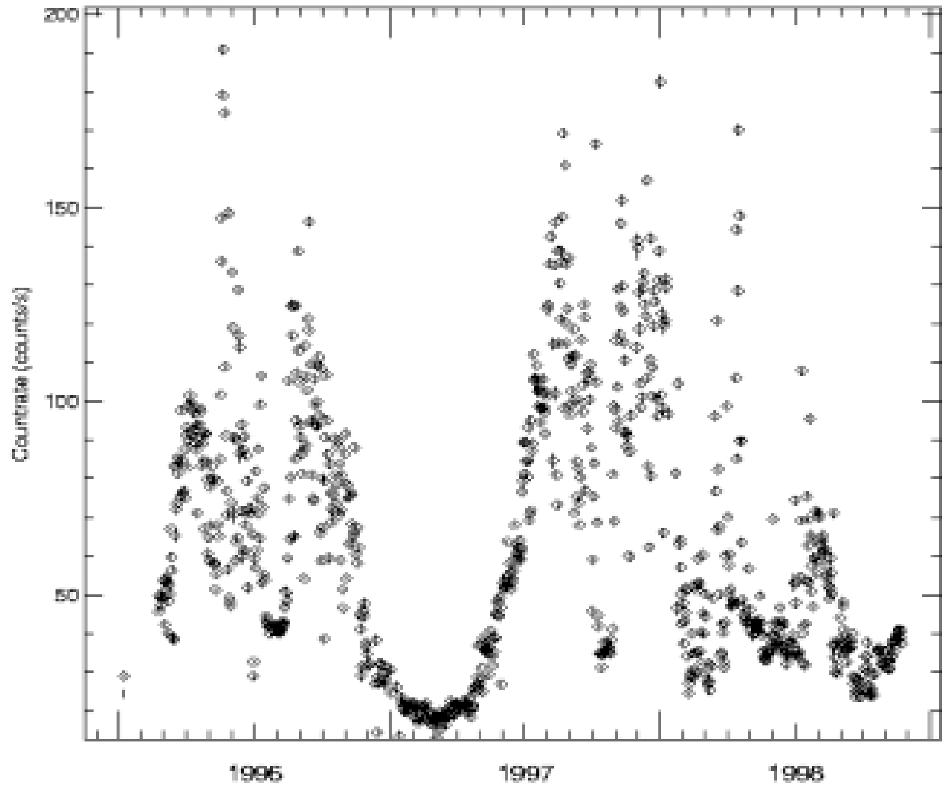
- Giant elliptical galaxy, 10^{12} M_{Θ}
- Distance of 16 Mpc
- A SMBH is present
- Plume fed by a single-sided jet.
- Presence of blobs and edge-brightened regions emitting in radio through UV.



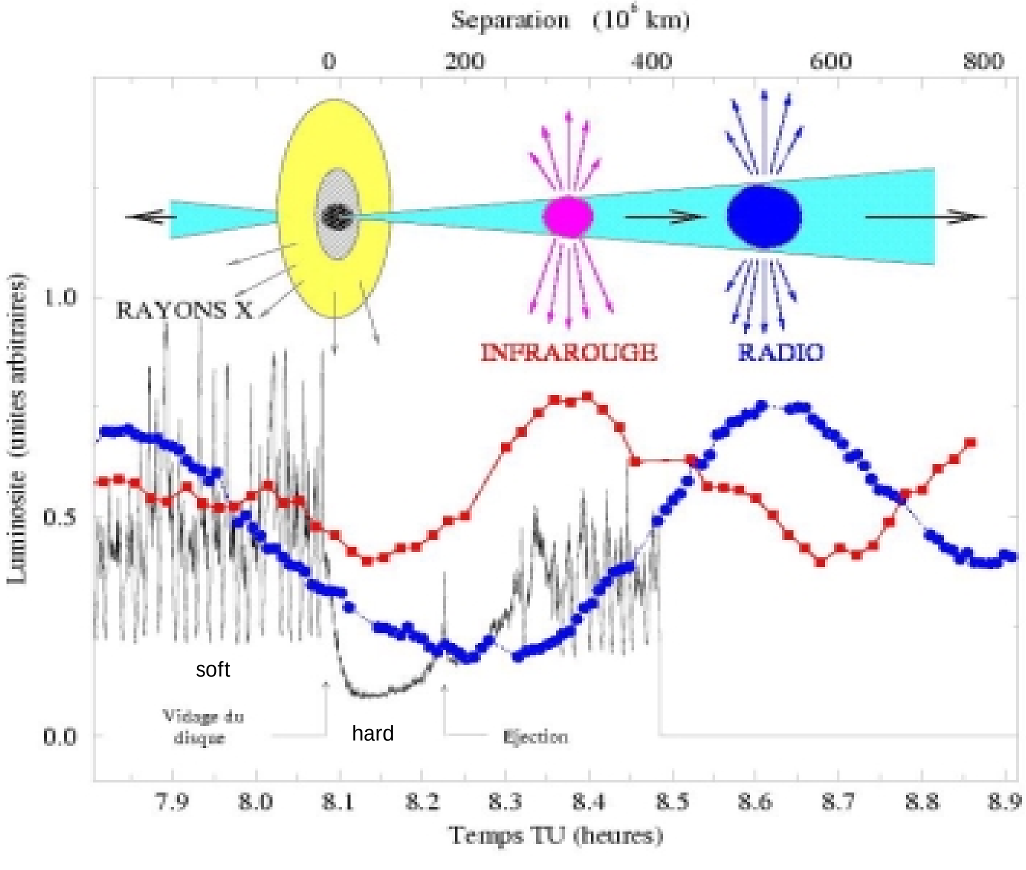
Nature, Oct.1999

Microquasar : GRS 1915+105





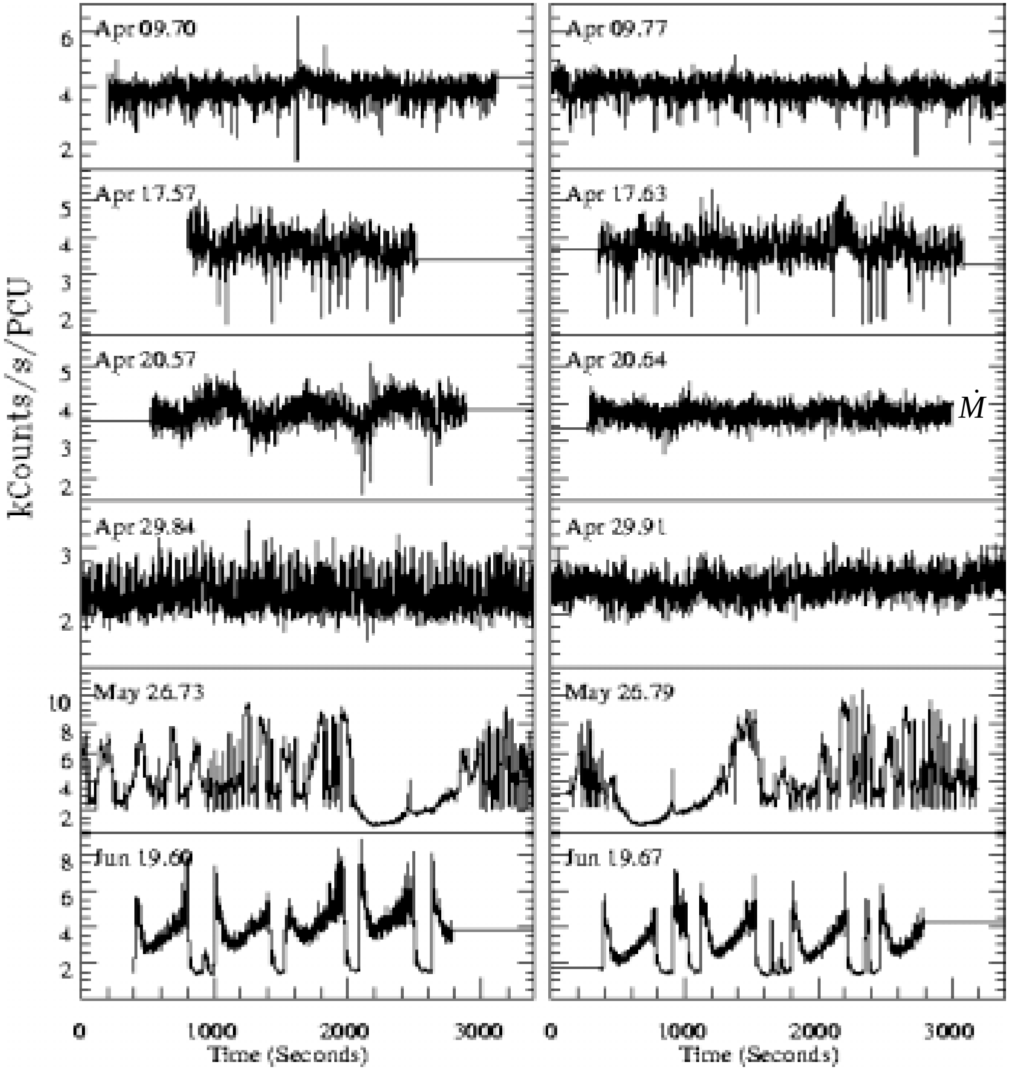
Microquasar : GRS 1915+105



Courtesy of F.Mirabel

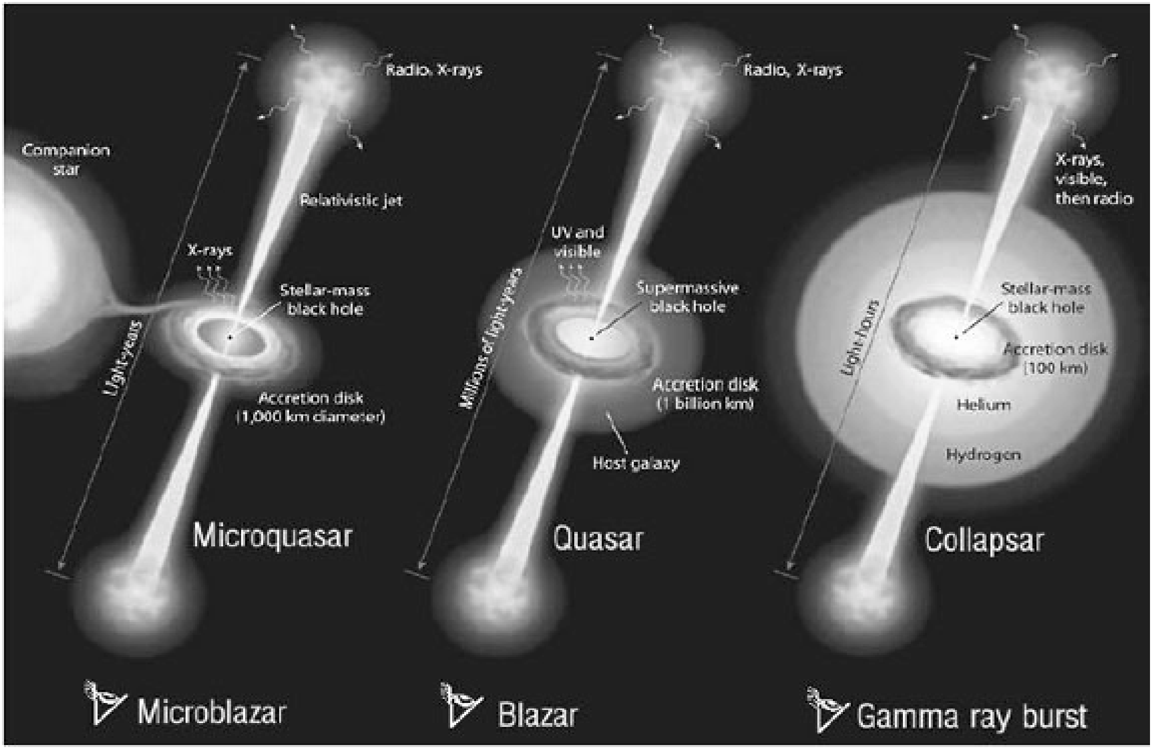
- *Multi wavelength lightcurves of a typical plasma ejection at the time of QPO*
- *Shows*
  - *the connection between the rapid disappearence and follow-up replenishement of the inner accretion disk seen in X-rays*
  - *The ejection of relativistic plasma clouds observed in different wavelengths*

Microquasar : GRS 1915+105



- Short-time variability: « brightness sputters »
- Possible explanation due to fast-emptying out of accretion disk and slow refill via $\dot{M}$?
- QPO maximum stable frequency seems to be linked to the spin of stellar-mass black-holes.

MQ as Sources of high energy phenomena



- Universal mechanism at work in all sources of relativistic jets in the universe ?

Perspectives

- MQ provide a new method to determine distances by the way of special relativity
- MQ are an opportunity to study the mechanism of ejection of jets
- High sensivity X-ray spectroscopy are currently developed with the help of X-ray space-borne observatories (Chandra-MEG, XMM-RGS)
- QPOs could be of a certain help to study stellar-mass black-holes.

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