Testing Radiation Models of Young Radio Sources

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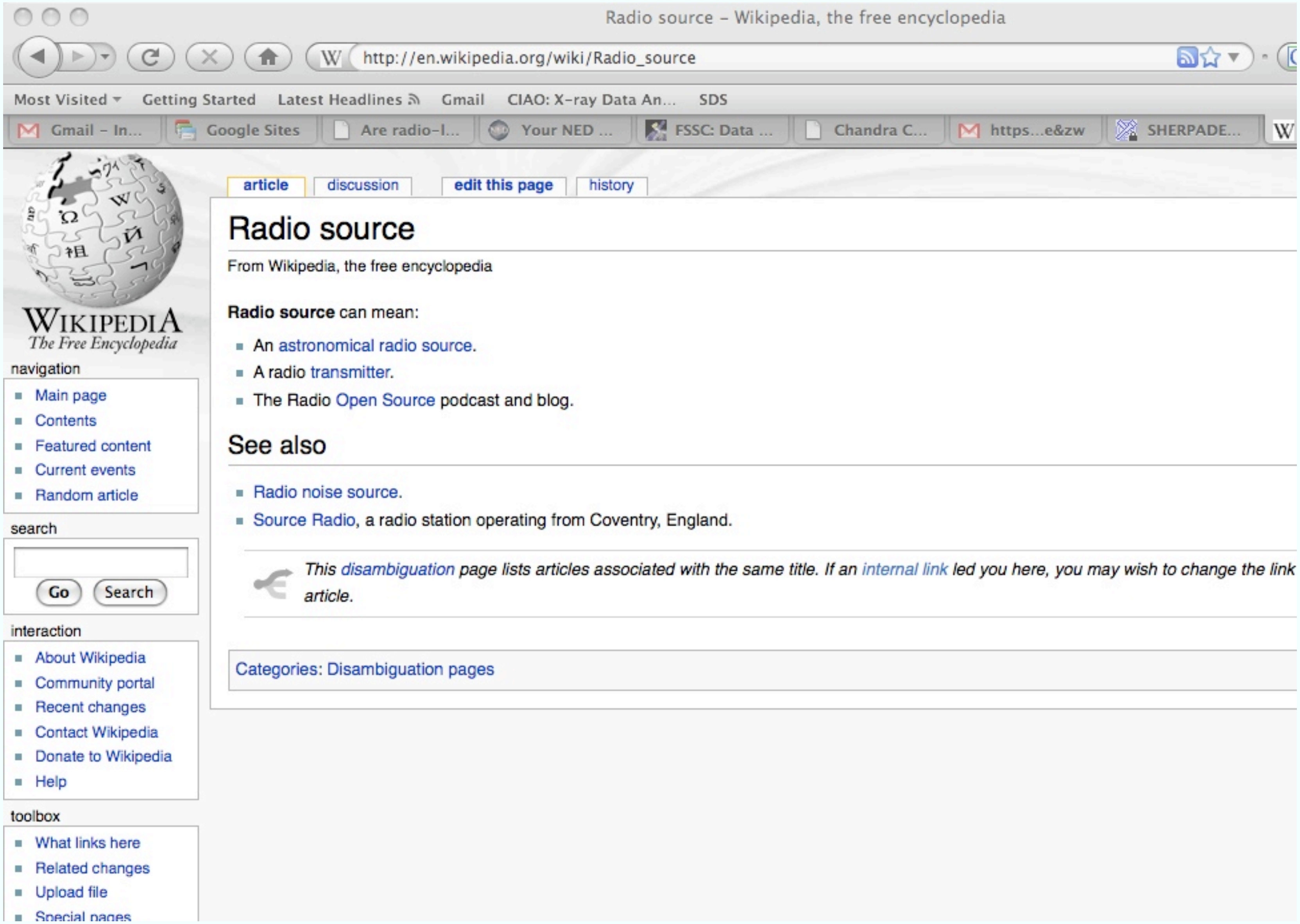
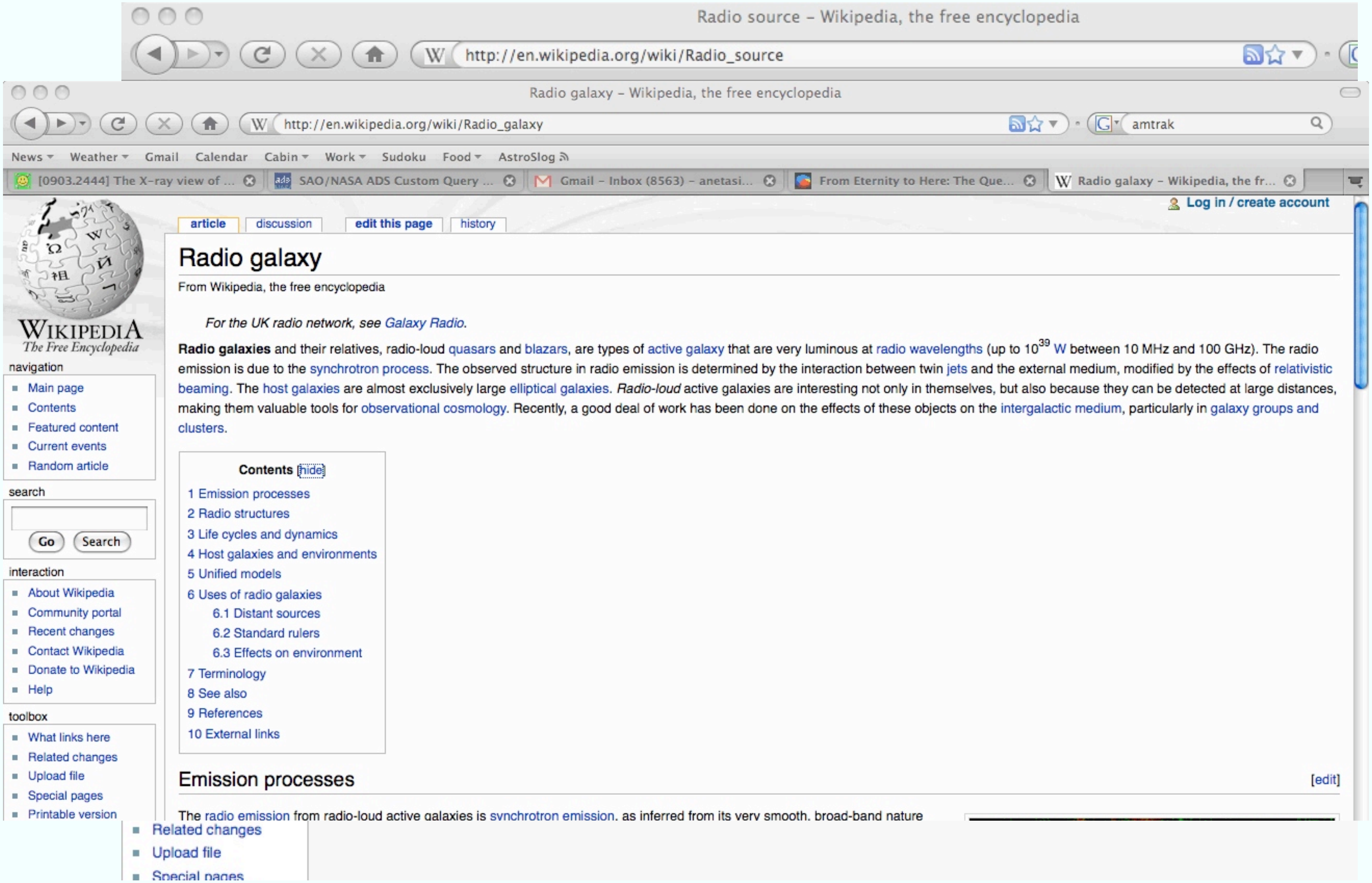
Outline

- Radio Sources
- Evolution
- Observational Tests

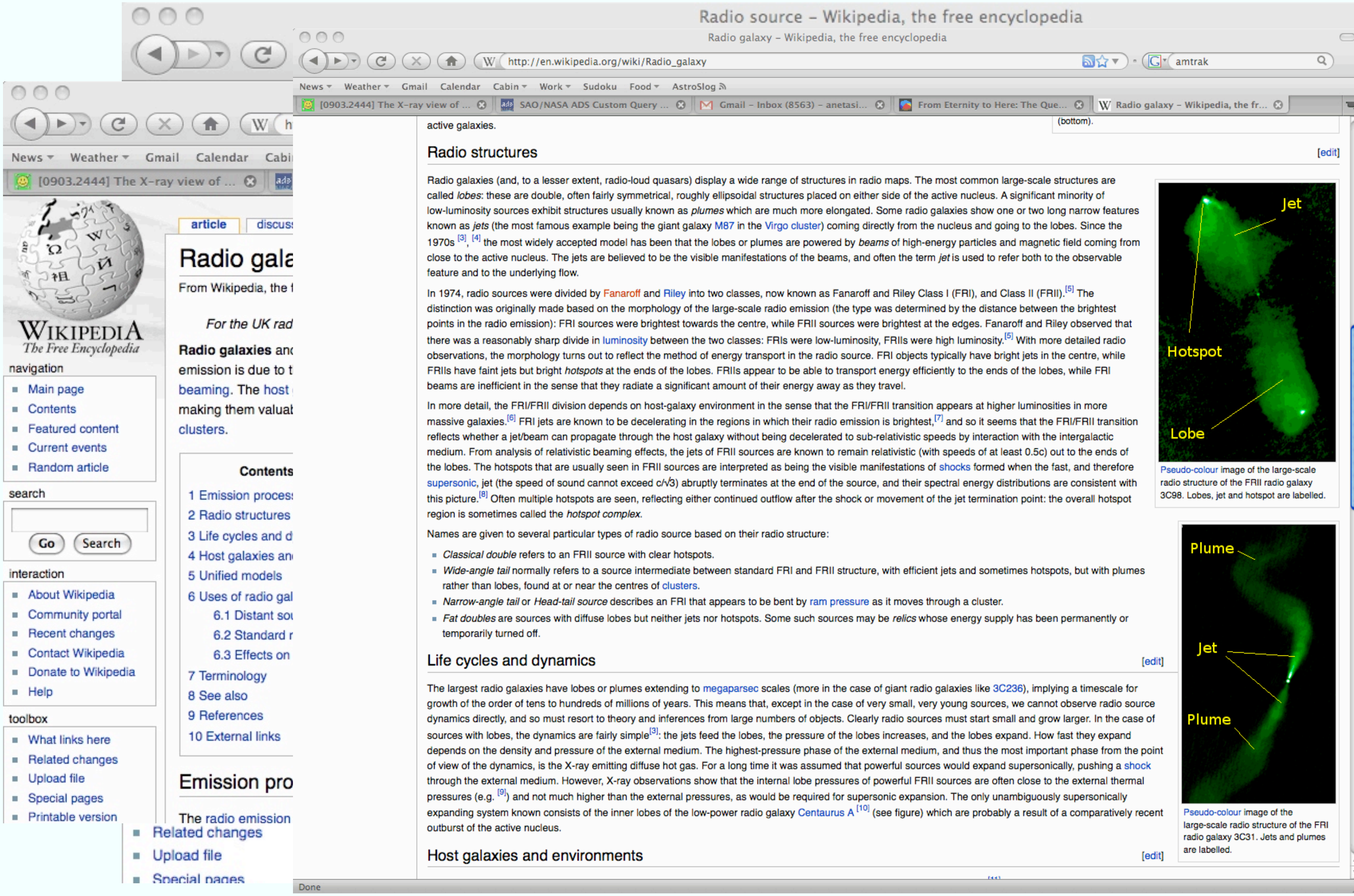
Radio Source?



Radio Source?



Radio Source?



Radio source – Wikipedia, the free encyclopedia

Radio galaxy – Wikipedia, the free encyclopedia

http://en.wikipedia.org/wiki/Radio_galaxy

active galaxies.

Radio structures

[edit]

Radio galaxies (and, to a lesser extent, radio-loud quasars) display a wide range of structures in radio maps. The most common large-scale structures are called *lobes*: these are double, often fairly symmetrical, roughly ellipsoidal structures placed on either side of the active nucleus. A significant minority of low-luminosity sources exhibit structures usually known as *plumes* which are much more elongated. Some radio galaxies show one or two long narrow features known as *jets* (the most famous example being the giant galaxy M87 in the Virgo cluster) coming directly from the nucleus and going to the lobes. Since the 1970s [3], [4] the most widely accepted model has been that the lobes or plumes are powered by *beams* of high-energy particles and magnetic field coming from close to the active nucleus. The jets are believed to be the visible manifestations of the beams, and often the term *jet* is used to refer both to the observable feature and to the underlying flow.

Pseudo-colour image of the large-scale radio structure of the FRII radio galaxy 3C98. Lobes, jet and hotspot are labelled.

In 1974, radio sources were divided by Fanaroff and Riley into two classes, now known as Fanaroff and Riley Class I (FRI), and Class II (FRII).[5] The distinction was originally made based on the morphology of the large-scale radio emission (the type was determined by the distance between the brightest points in the radio emission): FRI sources were brightest towards the centre, while FRII sources were brightest at the edges. Fanaroff and Riley observed that there was a reasonably sharp divide in luminosity between the two classes: FRIs were low-luminosity, FRIIs were high luminosity.[5] With more detailed radio observations, the morphology turns out to reflect the method of energy transport in the radio source. FRI objects typically have bright jets in the centre, while FRIIs have faint jets but bright *hotspots* at the ends of the lobes. FRIIs appear to be able to transport energy efficiently to the ends of the lobes, while FRI beams are inefficient in the sense that they radiate a significant amount of their energy away as they travel.

In more detail, the FRI/FRII division depends on host-galaxy environment in the sense that the FRI/FRII transition appears at higher luminosities in more massive galaxies.[6] FRI jets are known to be decelerating in the regions in which their radio emission is brightest,[7] and so it seems that the FRI/FRII transition reflects whether a jet/beam can propagate through the host galaxy without being decelerated to sub-relativistic speeds by interaction with the intergalactic medium. From analysis of relativistic beaming effects, the jets of FRII sources are known to remain relativistic (with speeds of at least 0.5c) out to the ends of the lobes. The hotspots that are usually seen in FRII sources are interpreted as being the visible manifestations of shocks formed when the fast, and therefore supersonic, jet (the speed of sound cannot exceed c/√3) abruptly terminates at the end of the source, and their spectral energy distributions are consistent with this picture.[8] Often multiple hotspots are seen, reflecting either continued outflow after the shock or movement of the jet termination point: the overall hotspot region is sometimes called the *hotspot complex*.

Names are given to several particular types of radio source based on their radio structure:

- *Classical double* refers to an FRII source with clear hotspots.
- *Wide-angle tail* normally refers to a source intermediate between standard FRI and FRII structure, with efficient jets and sometimes hotspots, but with plumes rather than lobes, found at or near the centres of clusters.
- *Narrow-angle tail* or *Head-tail source* describes an FRI that appears to be bent by ram pressure as it moves through a cluster.
- *Fat doubles* are sources with diffuse lobes but neither jets nor hotspots. Some such sources may be *relics* whose energy supply has been permanently or temporarily turned off.

Pseudo-colour image of the large-scale radio structure of the FRI radio galaxy 3C31. Jets and plumes are labelled.

Life cycles and dynamics

[edit]

The largest radio galaxies have lobes or plumes extending to megaparsec scales (more in the case of giant radio galaxies like 3C236), implying a timescale for growth of the order of tens to hundreds of millions of years. This means that, except in the case of very small, very young sources, we cannot observe radio source dynamics directly, and so must resort to theory and inferences from large numbers of objects. Clearly radio sources must start small and grow larger. In the case of sources with lobes, the dynamics are fairly simple[3]: the jets feed the lobes, the pressure of the lobes increases, and the lobes expand. How fast they expand depends on the density and pressure of the external medium. The highest-pressure phase of the external medium, and thus the most important phase from the point of view of the dynamics, is the X-ray emitting diffuse hot gas. For a long time it was assumed that powerful sources would expand supersonically, pushing a shock through the external medium. However, X-ray observations show that the internal lobe pressures of powerful FRII sources are often close to the external thermal pressures (e.g. [9]) and not much higher than the external pressures, as would be required for supersonic expansion. The only unambiguously supersonically expanding system known consists of the inner lobes of the low-power radio galaxy Centaurus A [10] (see figure) which are probably a result of a comparatively recent outburst of the active nucleus.

Host galaxies and environments

[edit]

Radio galaxy

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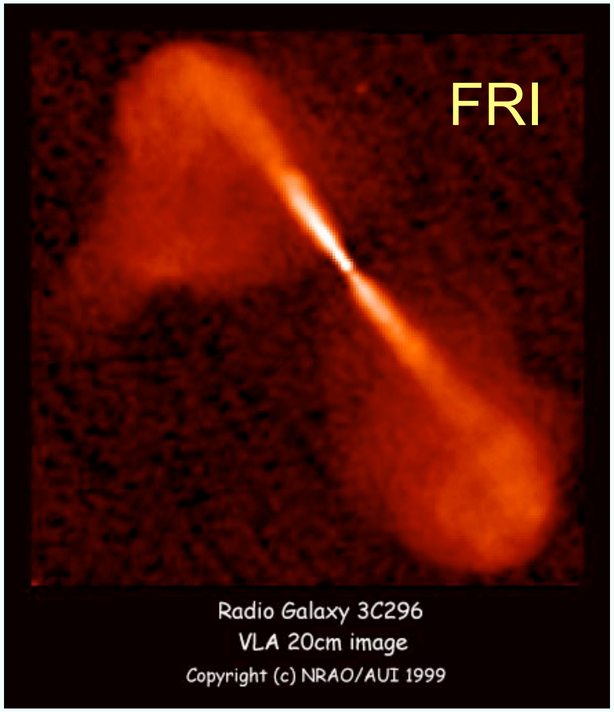
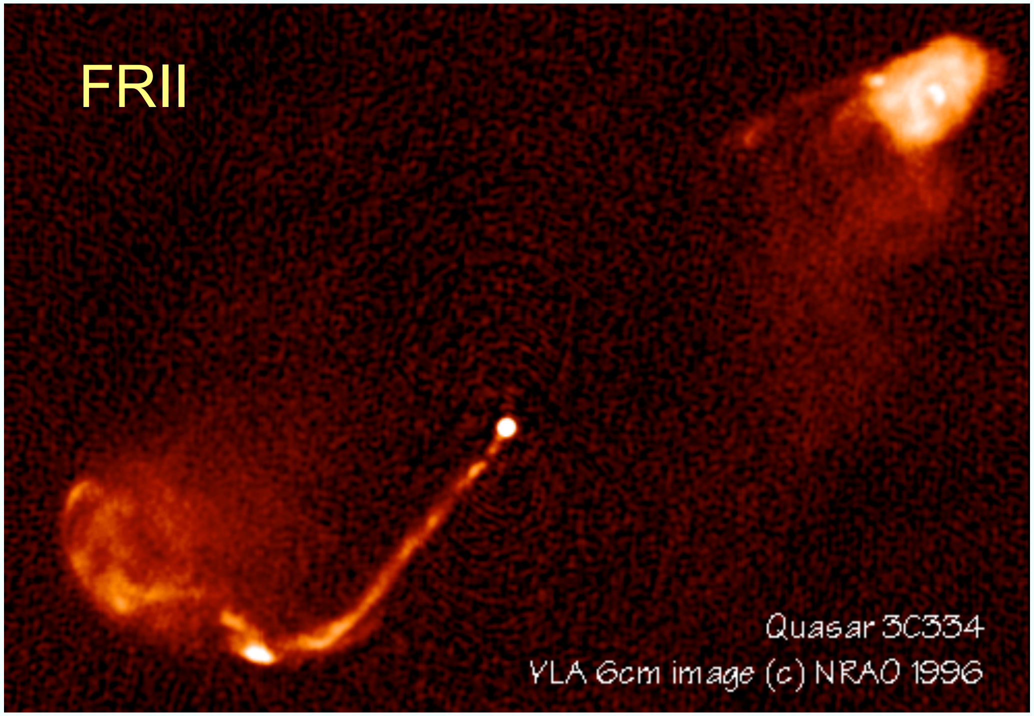
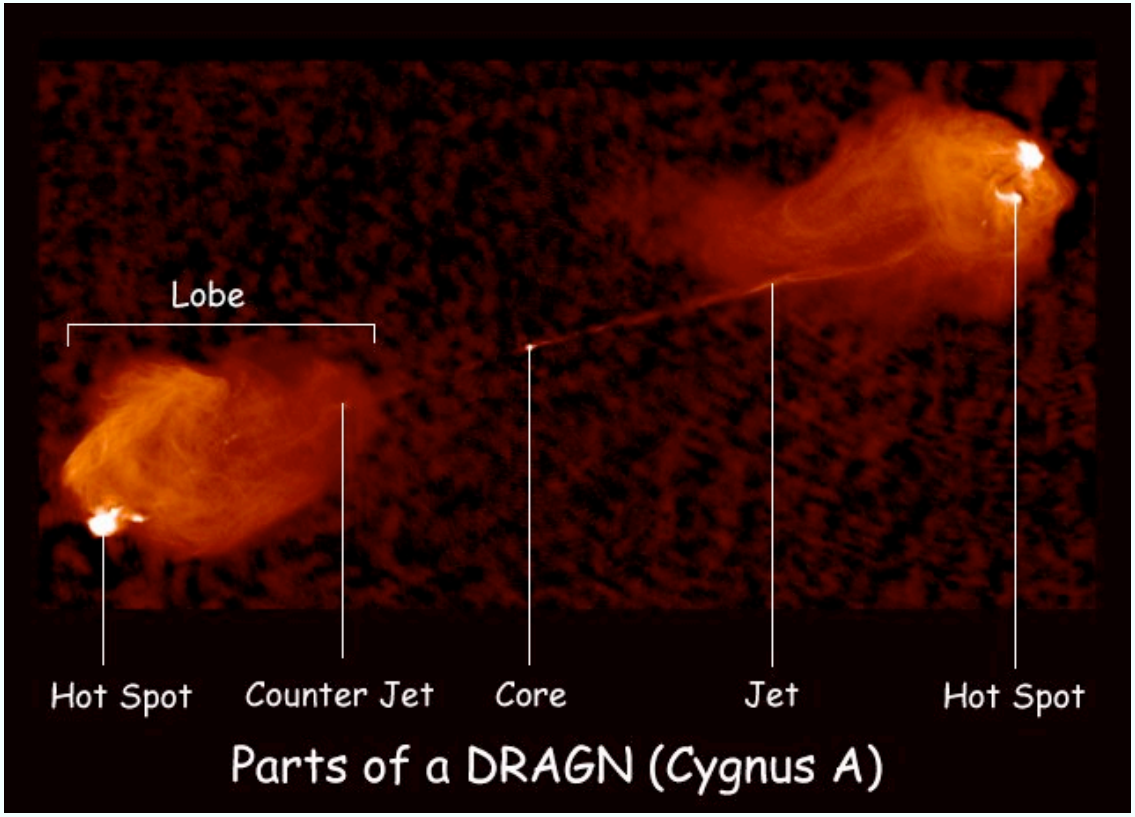
Classical Radio Sources





Radio Source Components:

- Core
- Jet
- Hot Spots
- Lobes



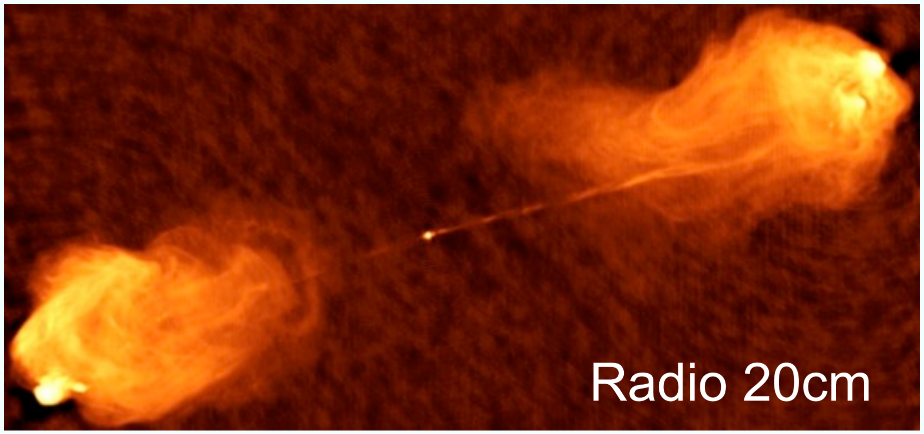
NRAO image on Alan Bridle's page

Evidence for relativistic particles => acceleration sites

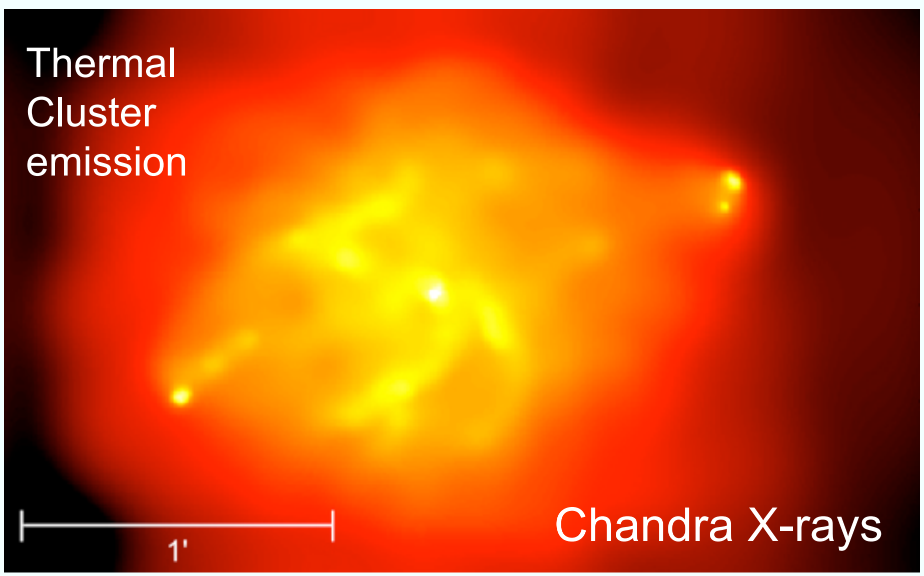
Radio Source in X-rays

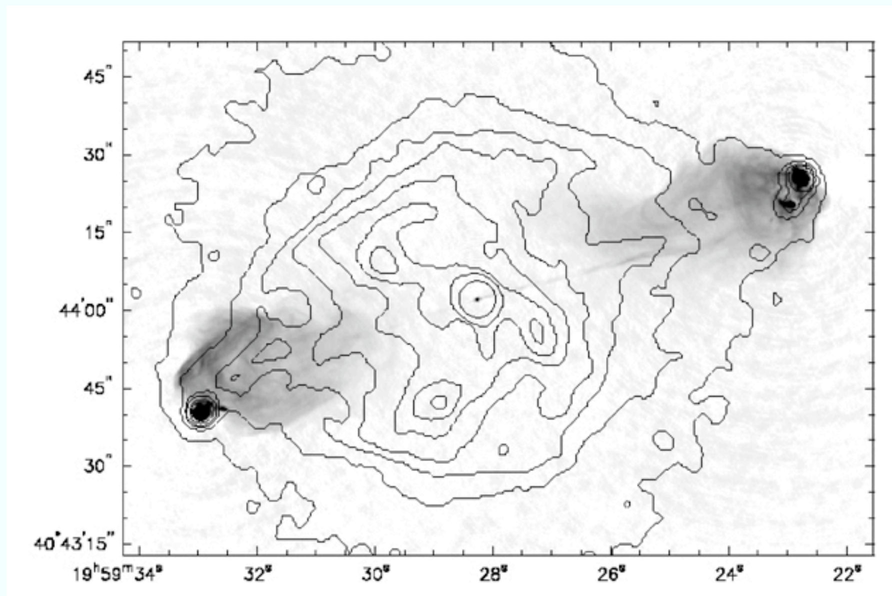
Cygnus A

FRII, z=0.056 1’ = 65 kpc



Core, Jets, Hot spots, Lobes, Shocks, cocoon and cluster gas



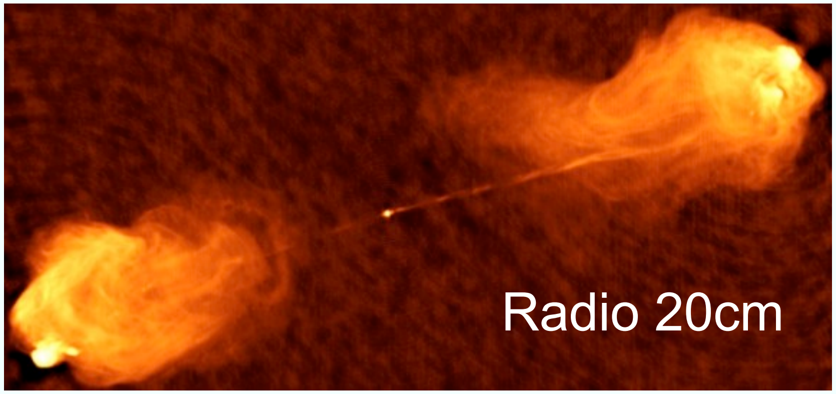


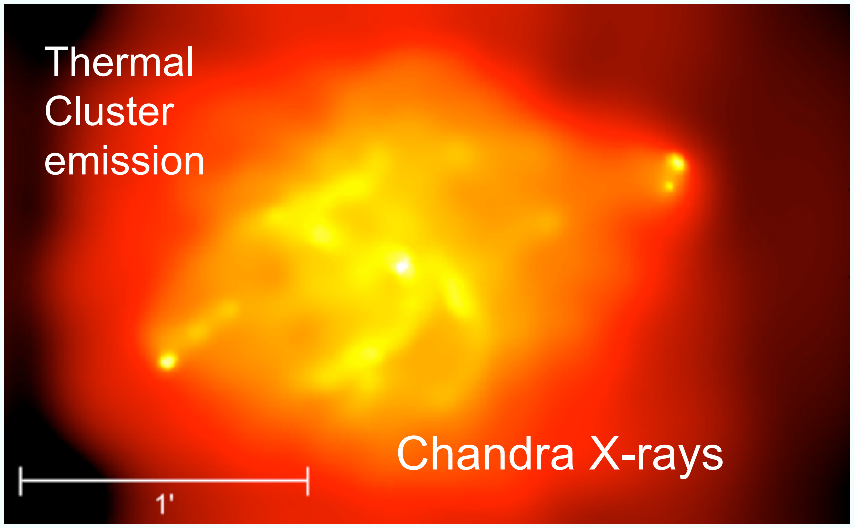
Radio Source in X-rays

Large Scale > 100 kpc

Cygnus A
FRII, z=0.056

1’ = 65 kpc





Radio Source in X-rays

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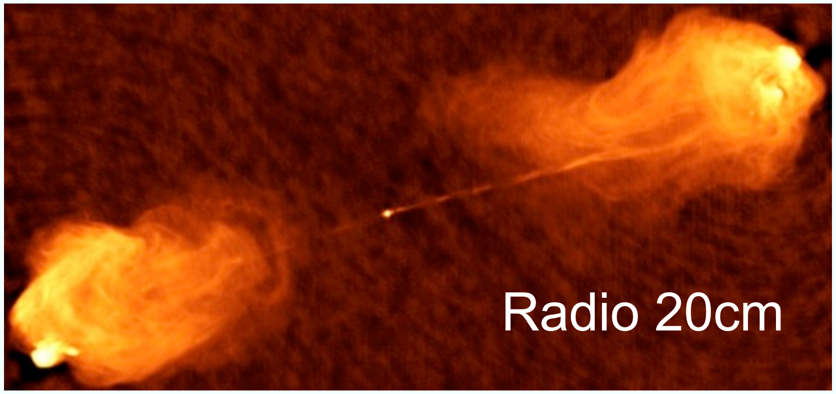
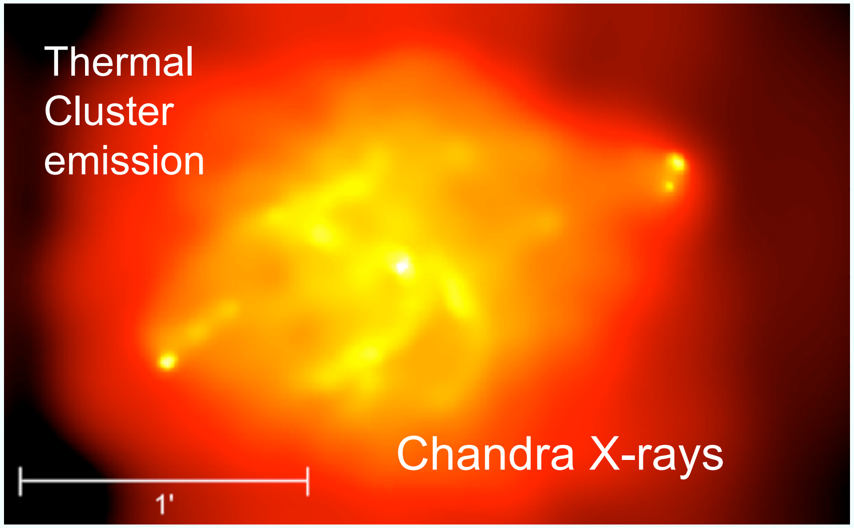
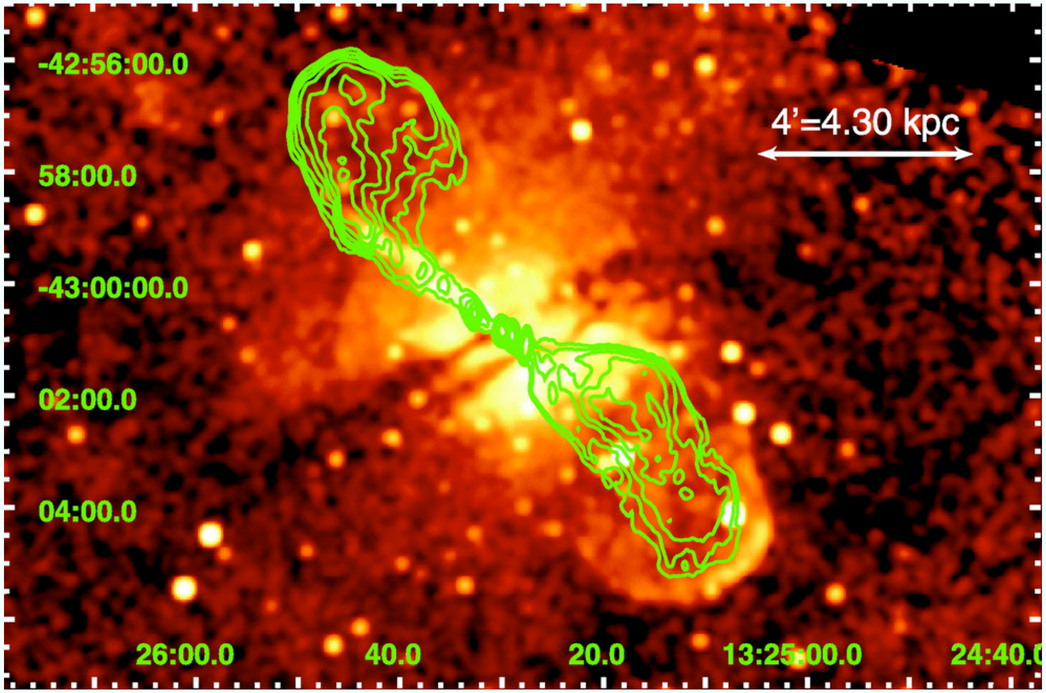




Small Scale < 20 kpc

Cen A
3.7Mpc z=0.000087
1'' = 17pc



Evolution of a Radio Source

L22 BEGELMAN AND CIOFFI Vol. 345

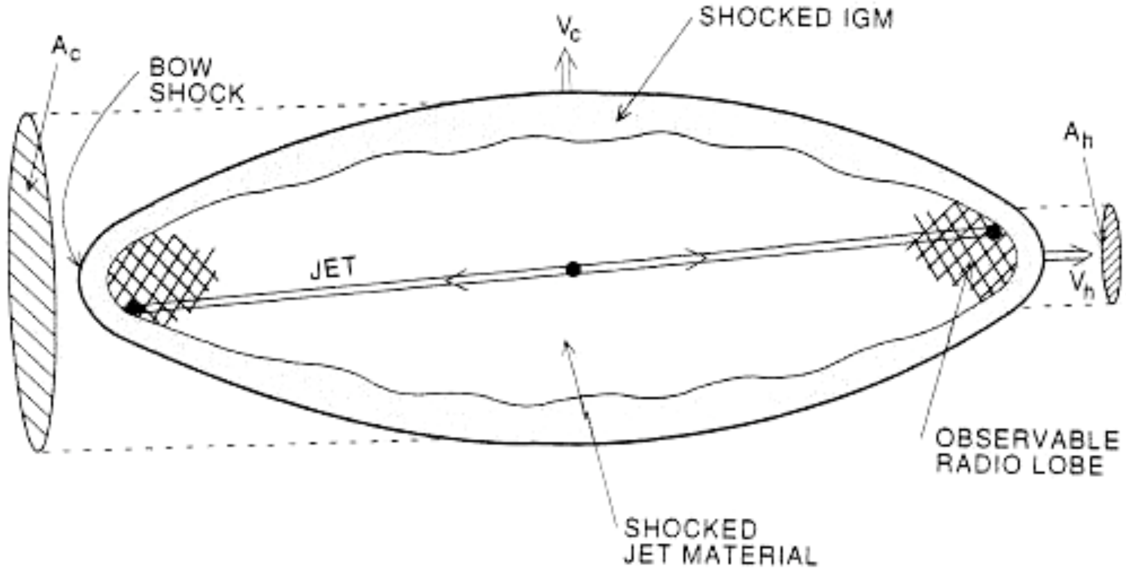
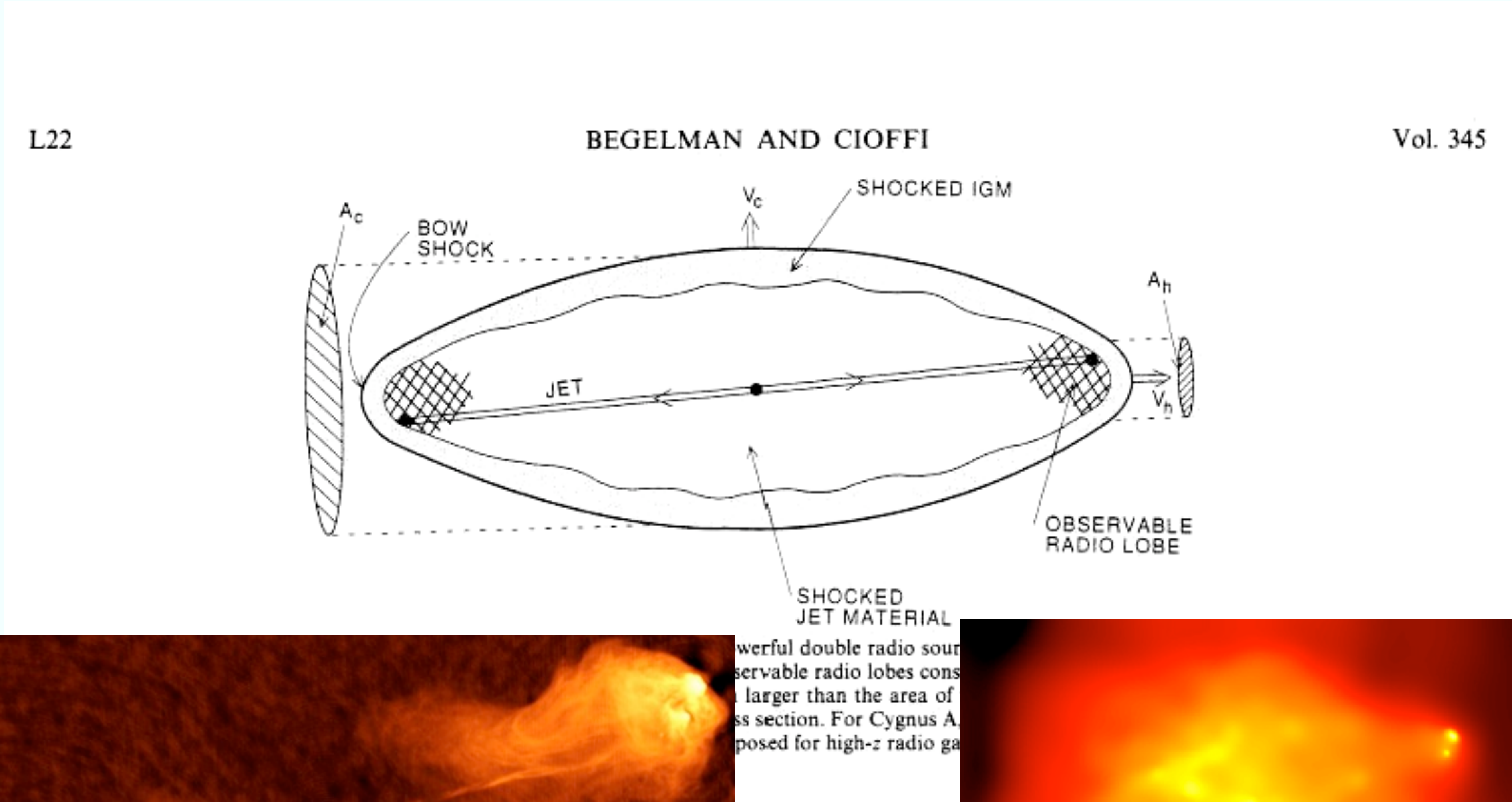


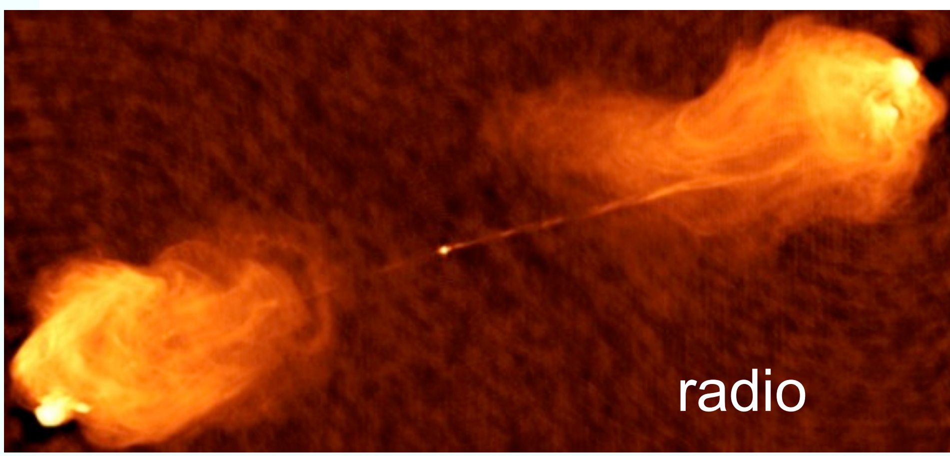
FIG. 1.—Schematic diagram of the overpressured cocoon surrounding a powerful double radio source. The shock bounding the cocoon expands into the IGM with speed v_h along the mean jet axis and $\sim v_c$ in orthogonal dirctions. The observable radio lobes constitute only a small fraction of the cocoon's volume near the ends of the jets, and the mean cross sectional area of the cocoon, A_c, is much larger than the area of the bow shock, A_h. Due to fluctuations in the jet directon, momentum is deposited over a much wider area than the instantaneous jet cross section. For Cygnus A, we estimate $A_h \sim 28$ kpc^2; the total projected length of the cocoon is ~ 120 kpc (for $H_0 = 75$ km s^{-1} Mpc^{-1}). In the multiphase IGM proposed for high-z radio galaxies, clouds could penetrate into the region of shocked jet material and star formation could occur throughout the interior of the cocoon.

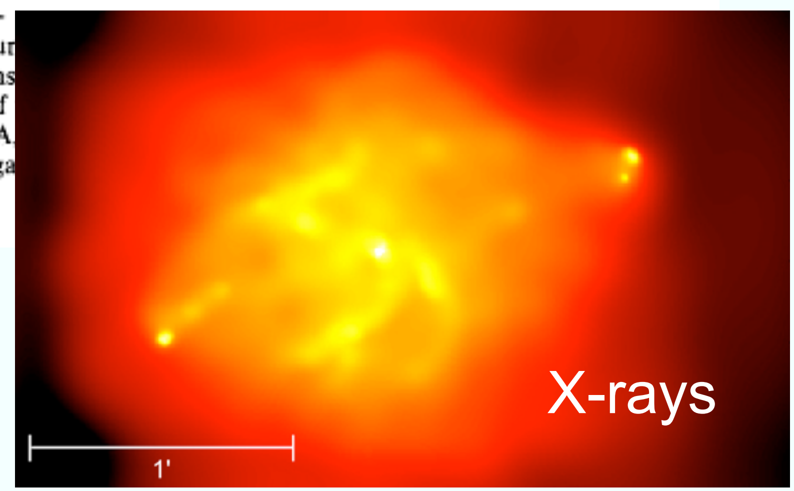
radio

X-rays

Evolution of a Radio Source

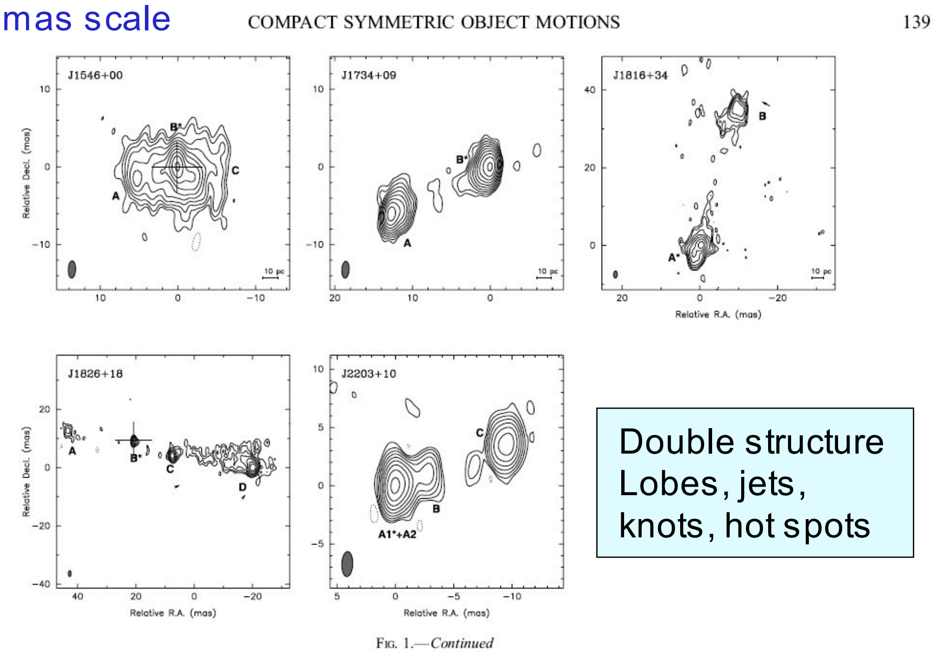






Compact Radio Sources

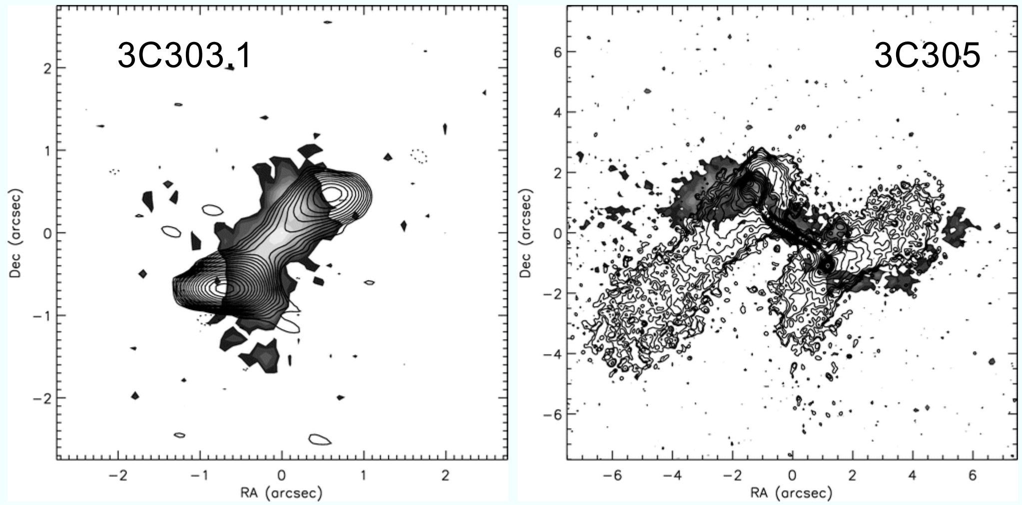
VLBA
mas scale



Double structure
Lobes, jets,
knots, hot spots

Gugliucci et al. 2005

arcsec scale



Privon et al. 2008

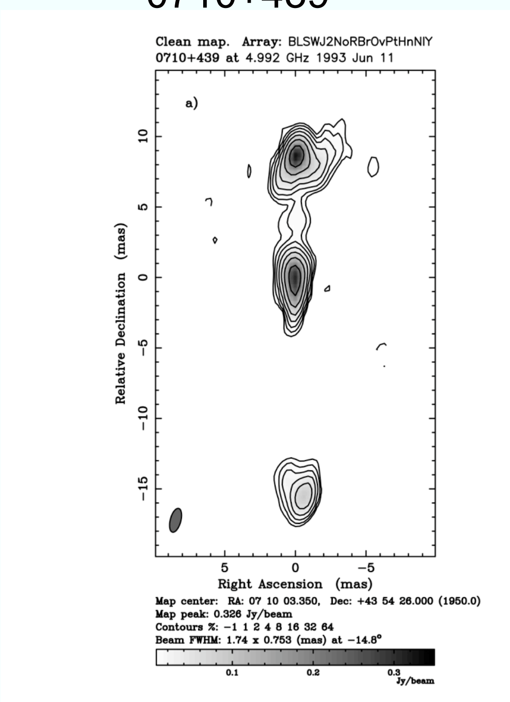
Radio/optical overlay

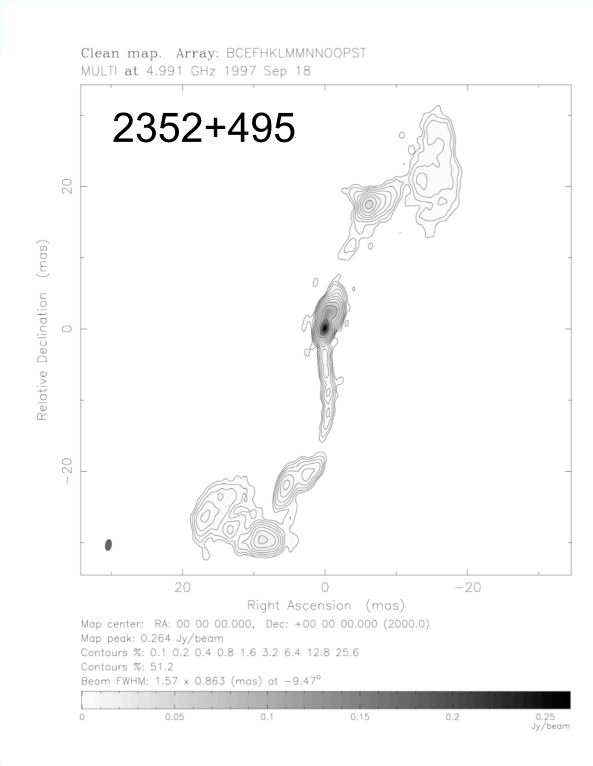
The entire radio structure contained within the host galaxy

Age Measurements

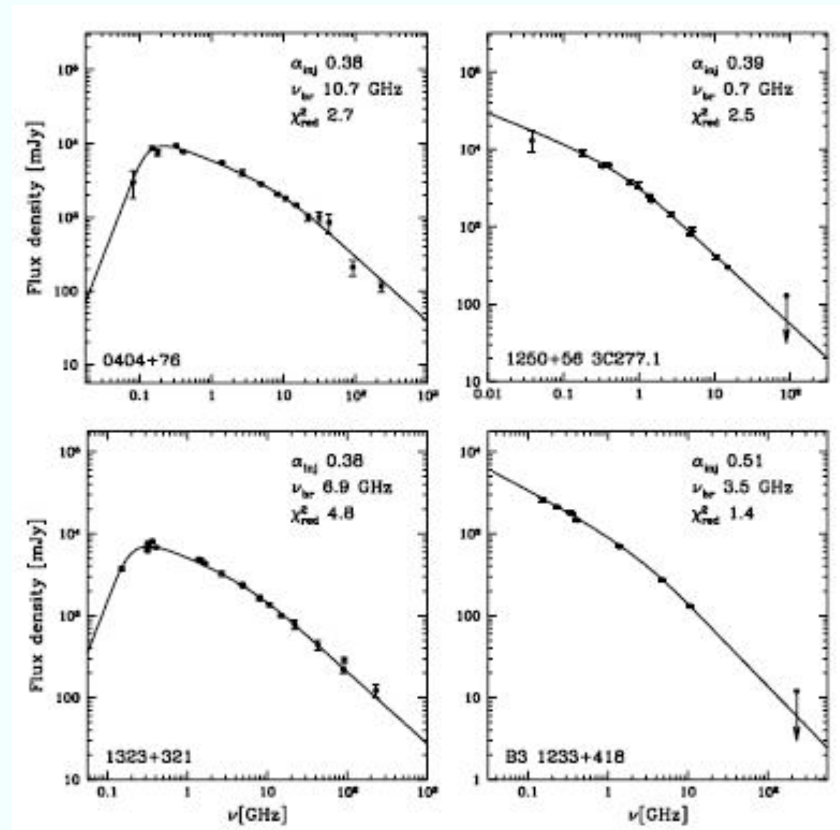
- Kinematic ages
  - monitored expansion of the hot spots in VLBI
  - Only for small, nearby sources,
  - Measurements in 27 sources reported by different groups (see Owsianik, Polatidis and Conway 1999, Gugliucci et al 2005)
- Synchrotron ages
  - modeled spectra of lobes
  - High quality Radio data needed
  - Murgia et al. 1999 completed measurements for ~47 compact sources

0710+439



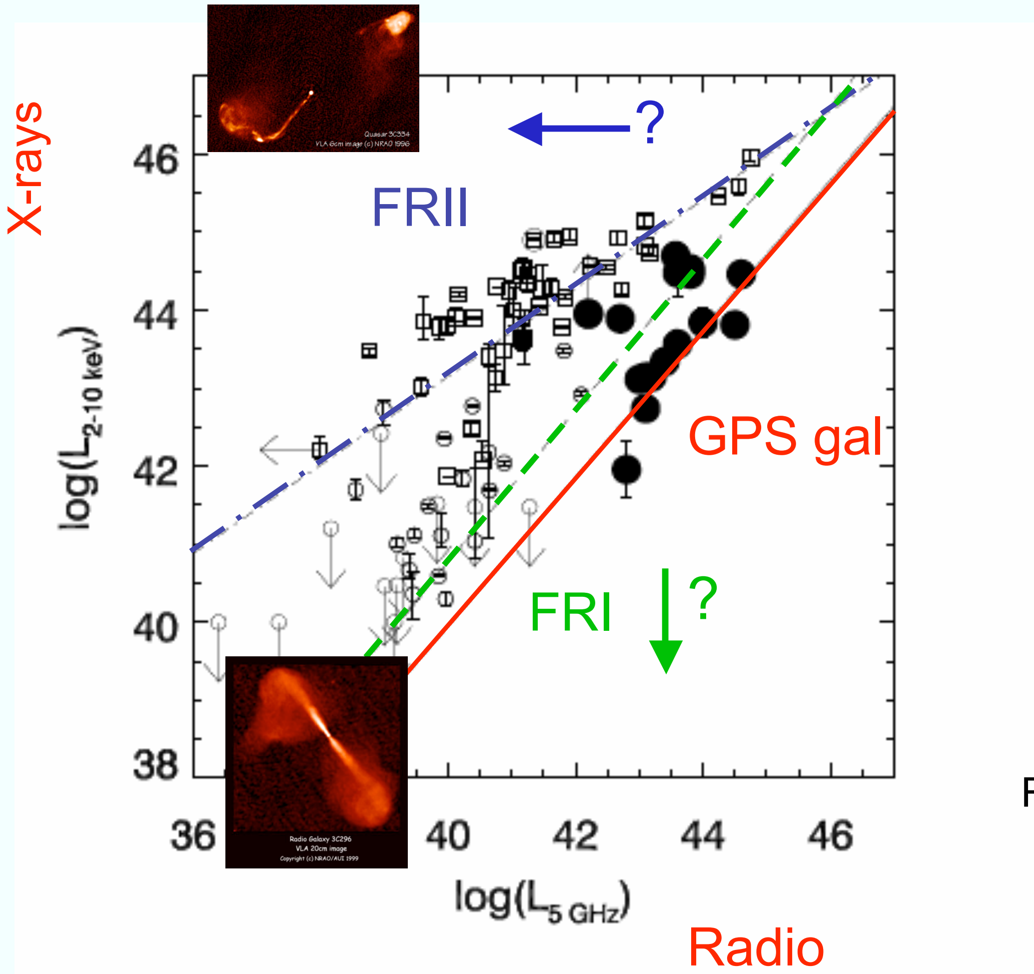


Owsianik, Polatidis and Conway 1999

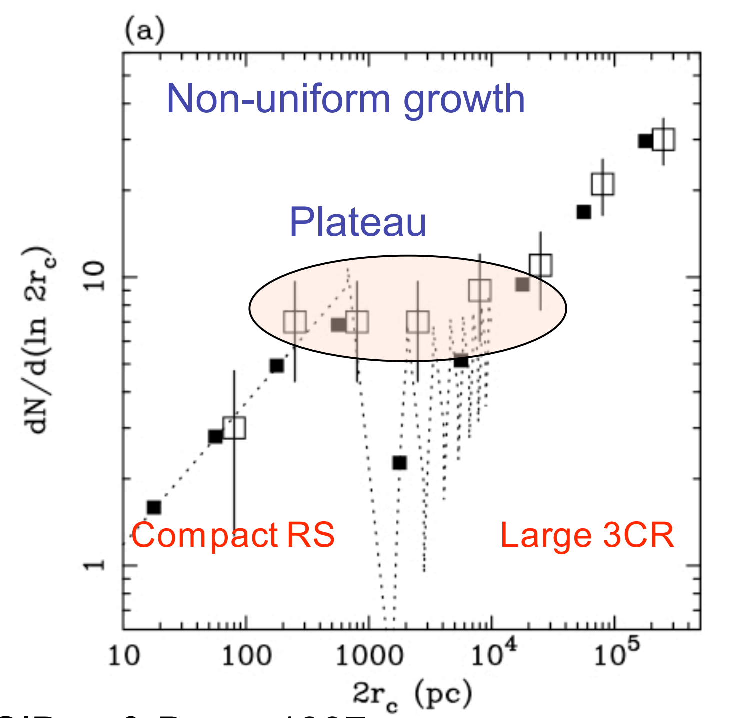


Murgia et al 1999

Radio Source Evolution?



Tengstrand, Guainazzi, AS et a.l 2009, ApJ.



O'Dea & Baum 1997

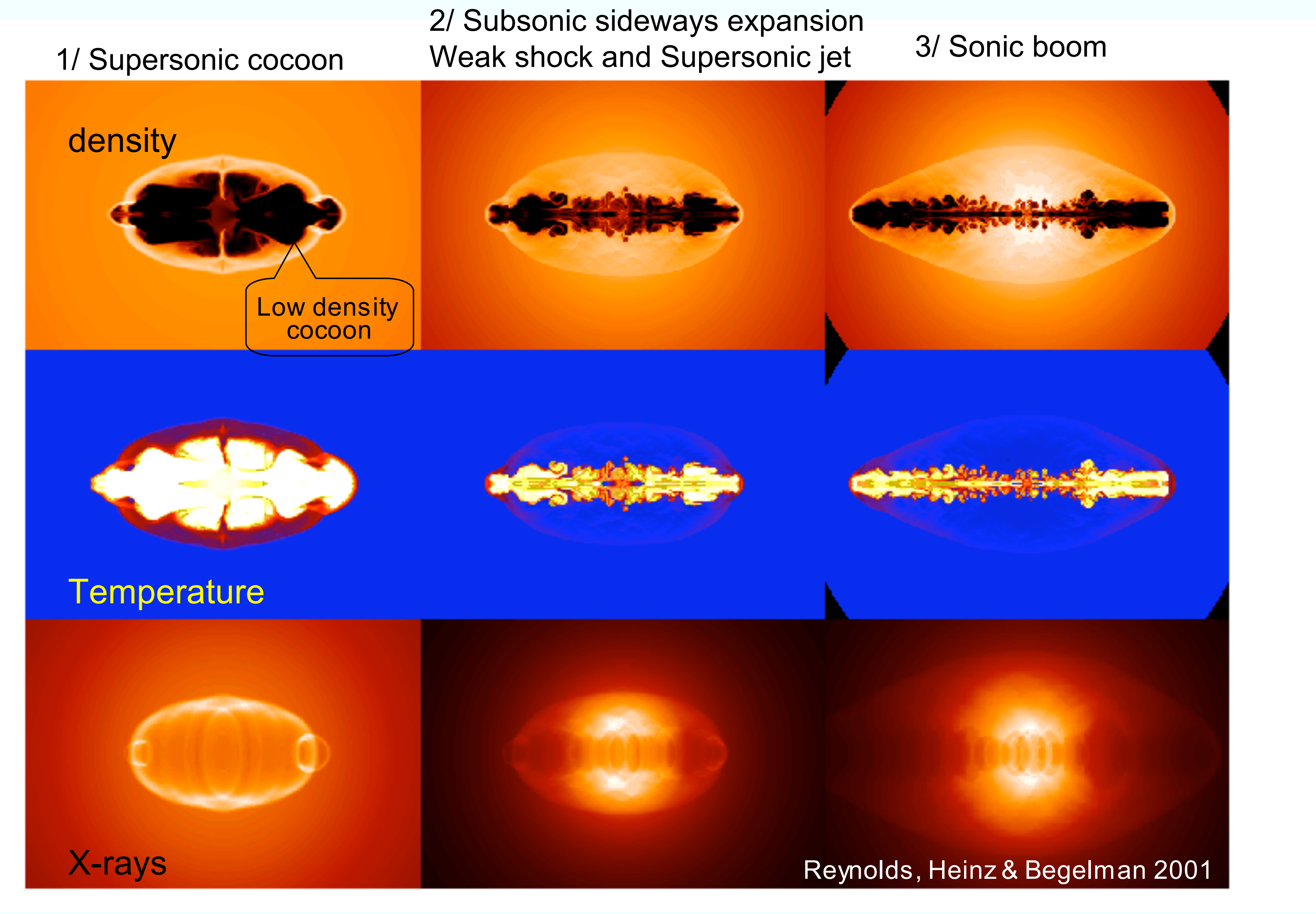
Reynolds & Begelman (1997) Size [pc]

Timescales Required to
Explain over-abundance of Small
Scale Radio Sources:

Outbursts 10^4-10^5 yrs

Burst duration: $3x10^4$yrs

Evolution of a Radio Source - Simulations



Model Predictions for X-rays & γ- rays

- Expanding radio source
  - Begelman & Cioffi(1989), Heinz, Reynolds & Begelman (1998) , Bicknell & Sutherland (2006, 2007) and others
- Spectra from double radio lobes
  - Stawarz et al (2008)
- Jet contributions in quasars (?)

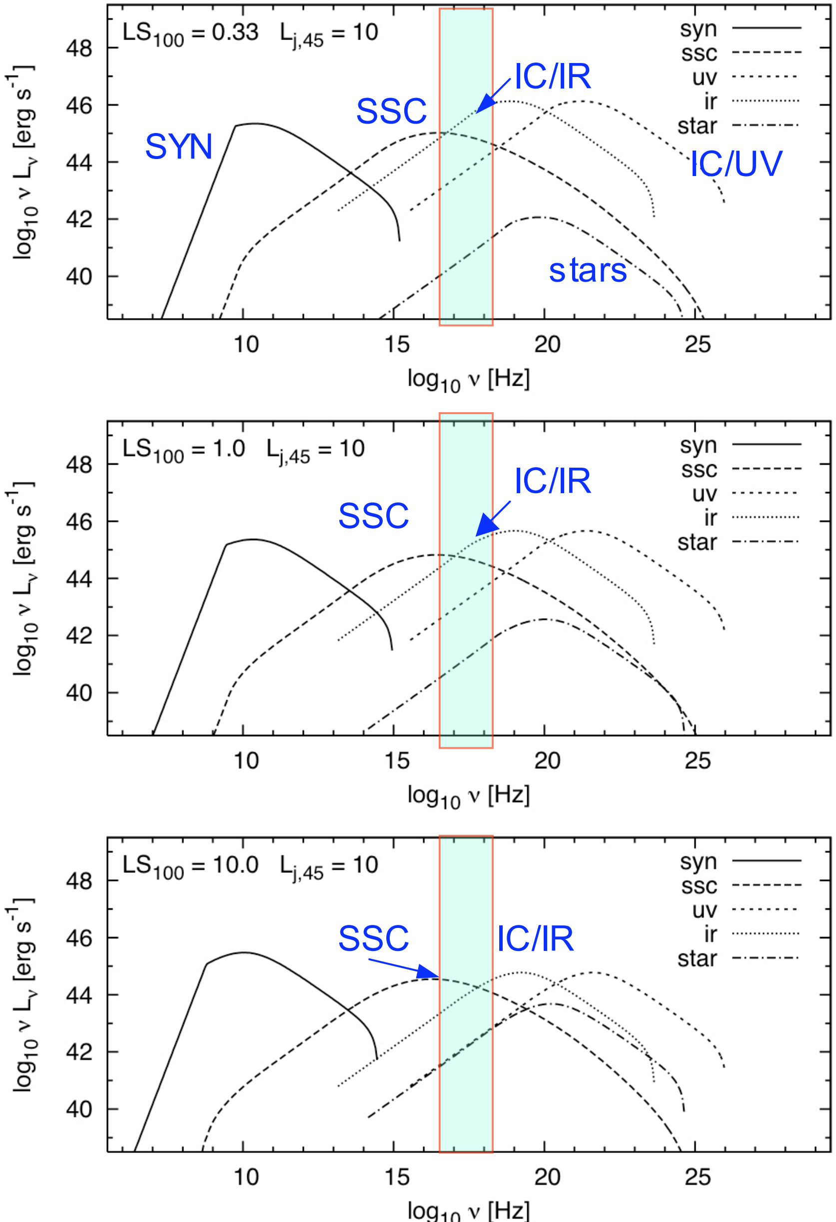
Jet power
$L_{jet}=10^{46}$ erg/s

X-rays

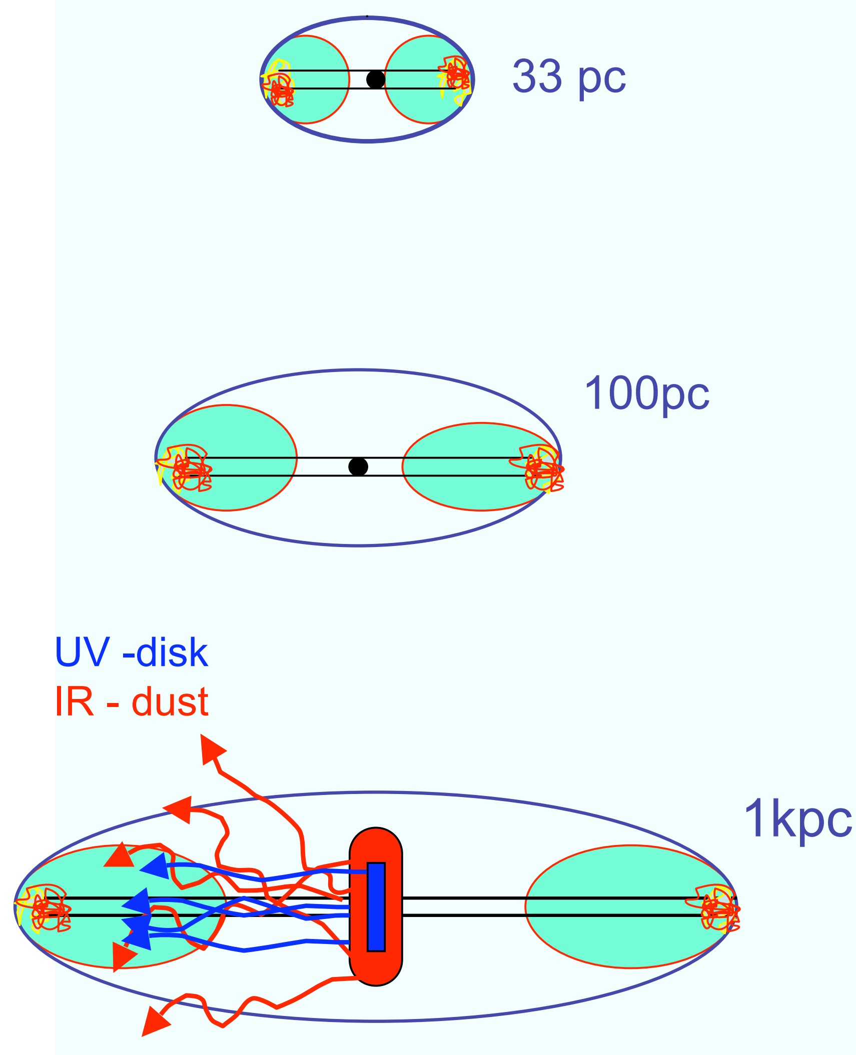
Source Evolution - Spectra

UV - disk
IR - dust

Log νL_ν



Log ν



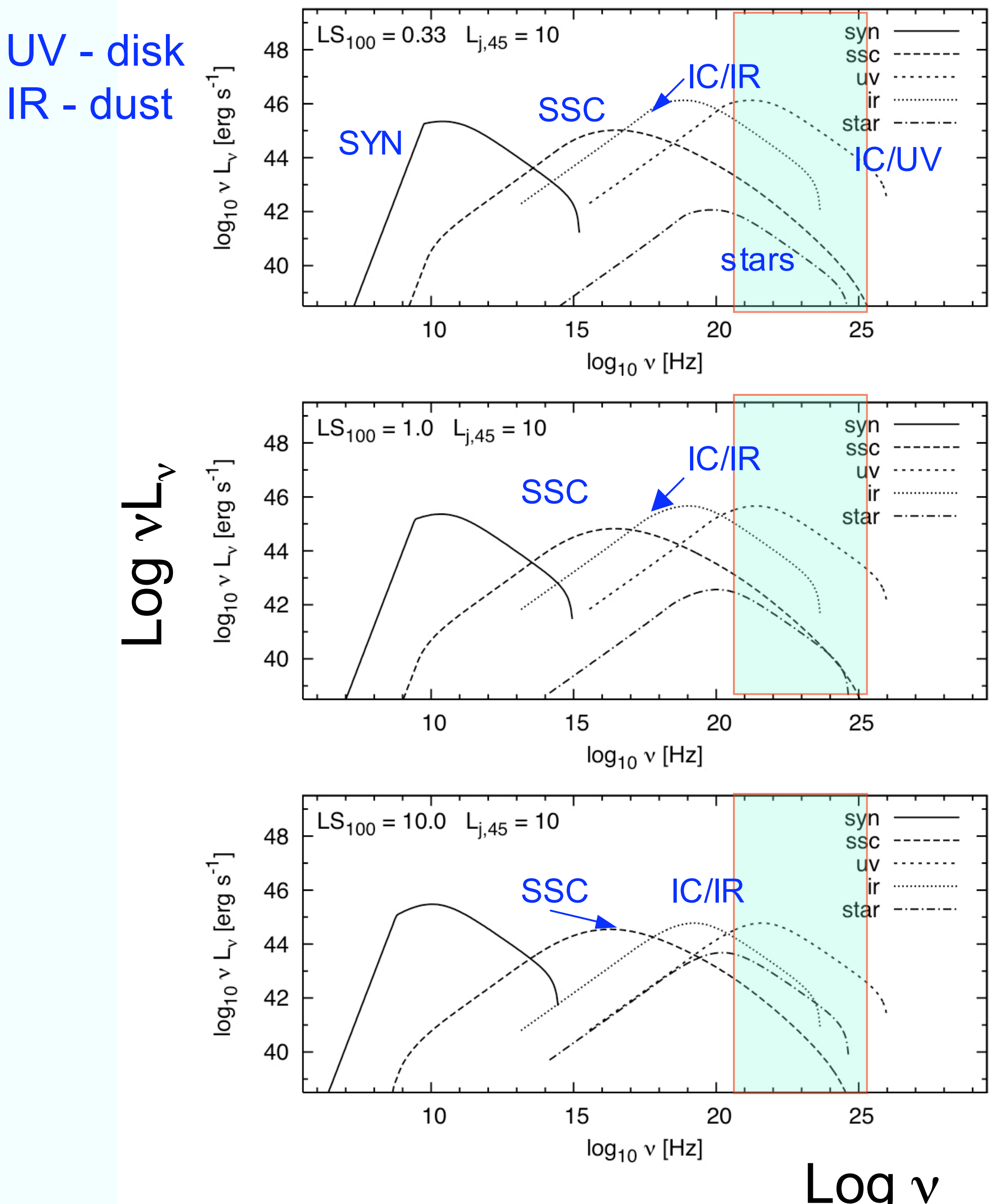
Parameters: jet power
photon fields, density of ISM

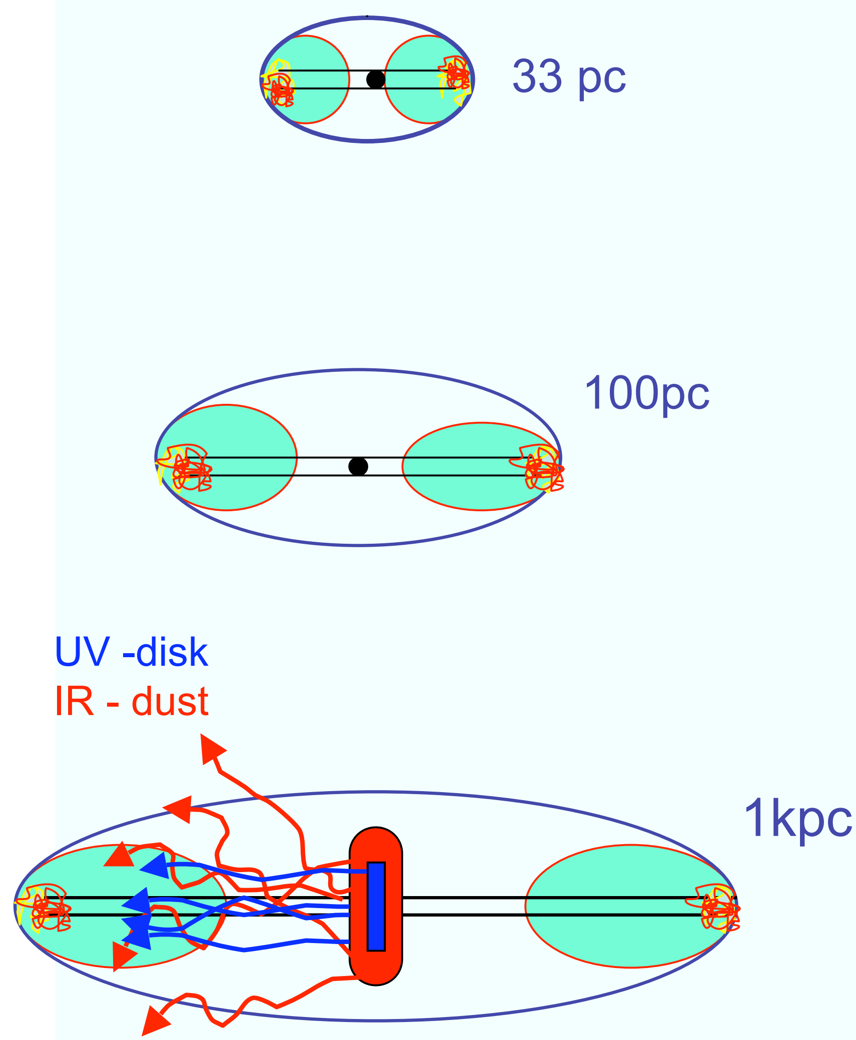
Stawarz et al 2008

Source Evolution - Spectra

Jet power
$L_{jet}=10^{46}$ erg/s

γ-rays
Fermi



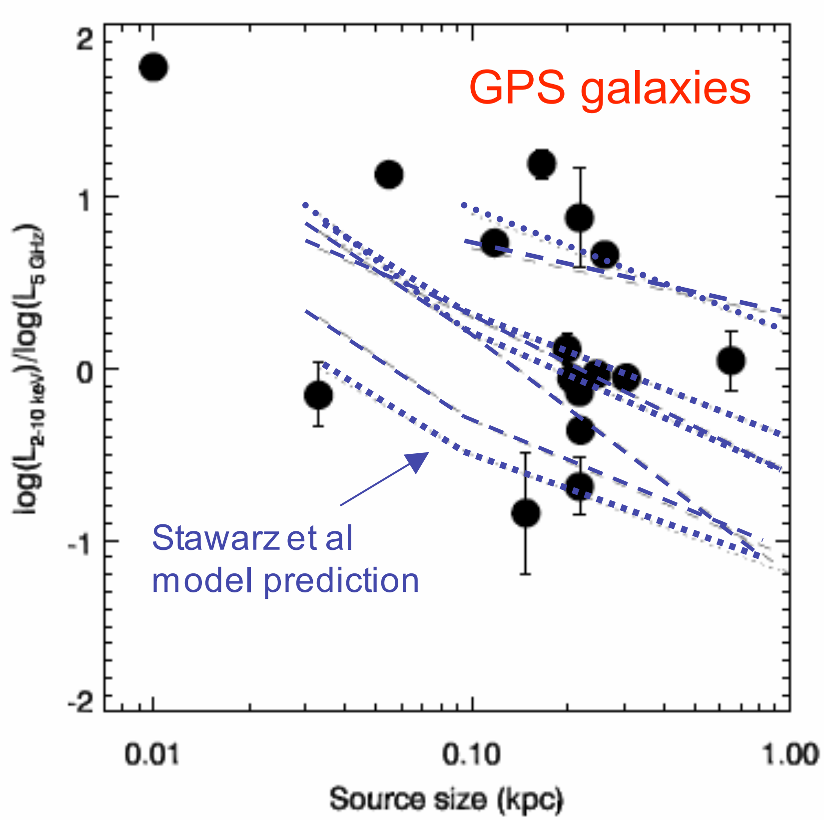


Stawarz et al 2008

Parameters: jet power
photon fields, density of ISM

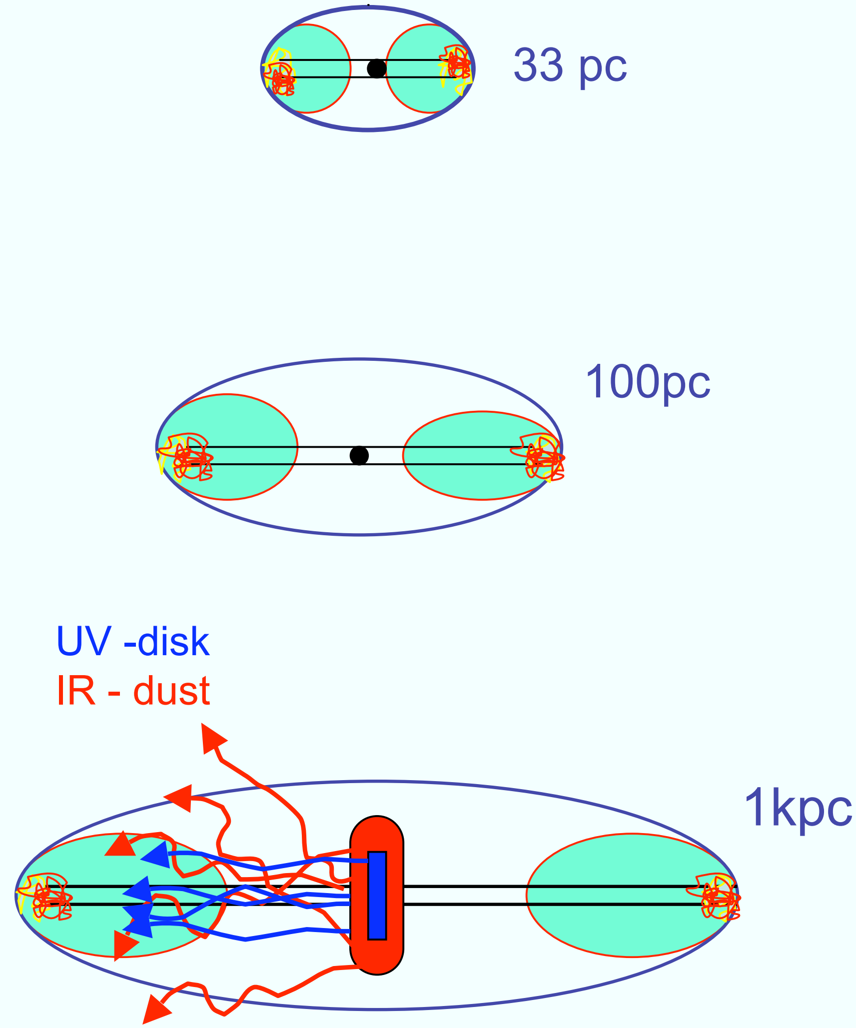
Luminosity vs Size

X-ray/Radio



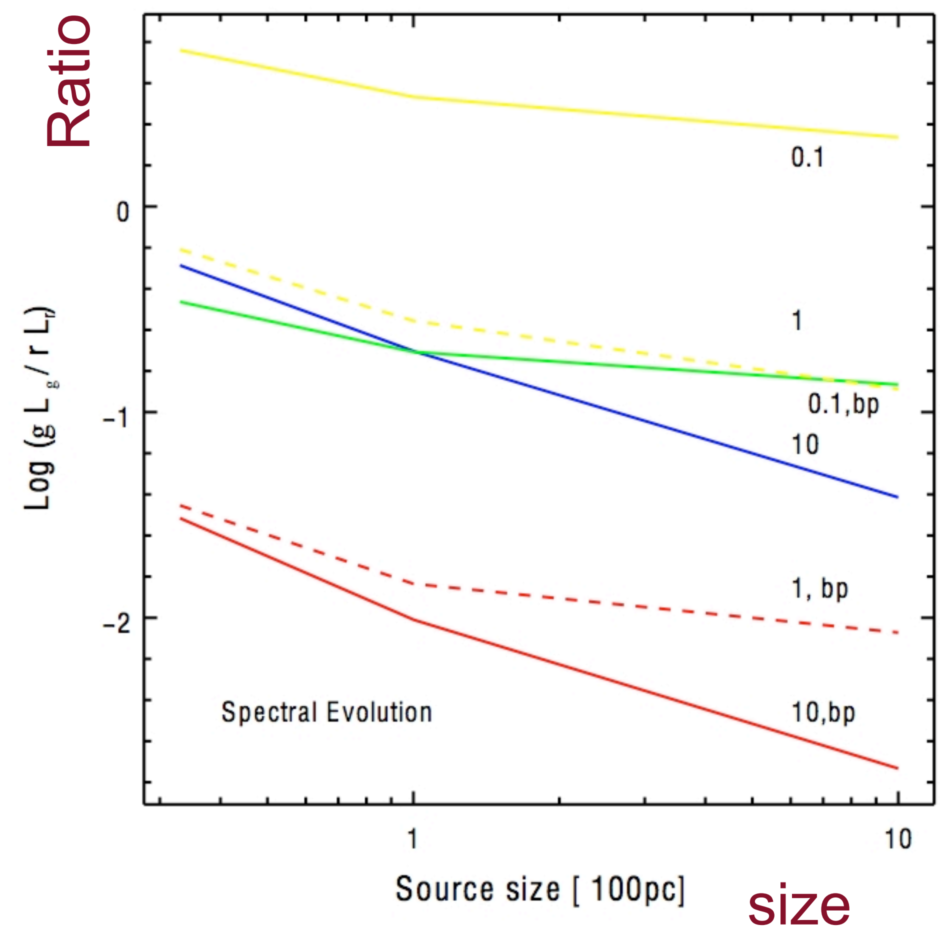
Radio Size

Spectral predictions
Stawarz et al. 2008



Parameters: jet power
photon fields, density of ISM

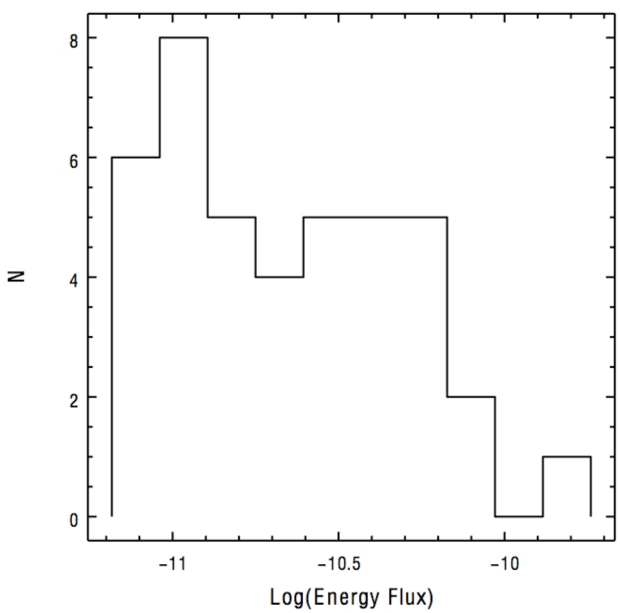
Spectral Evolution: γ-rays Model Predictions



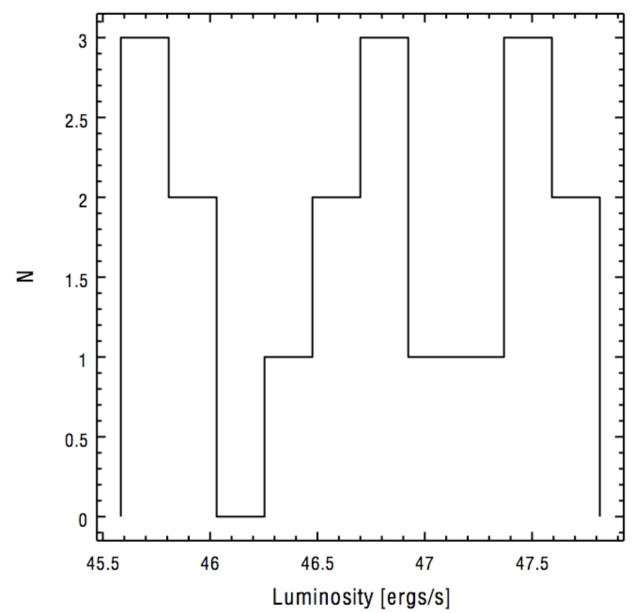
Fermi Detections

42 sources detected in the first 11 month
More sources expected in next years

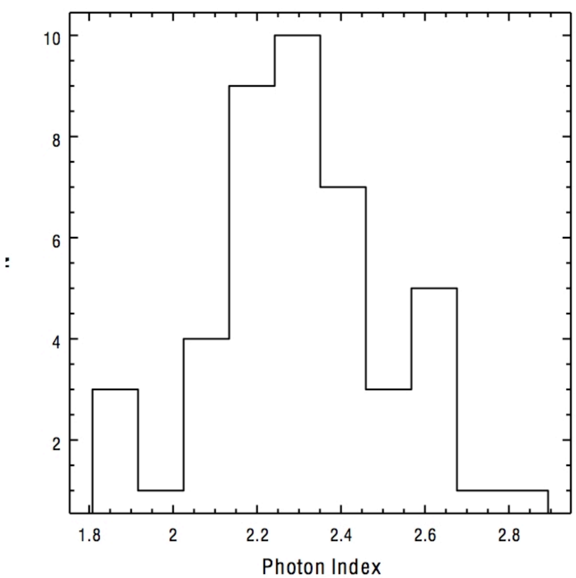
Observed by Fermi



Emitted by a Source



Observed



Building a Model

- What do we know:
  - radio sources in many samples
  - model predictions for the luminosity in Fermi band
- What do we want to know:
  - distribution of gamma-ray luminosity for the radio samples
  - Number of source that can be detected
  - Contribution to the background radiation in gamma-rays

$$F(L_{radio}, \text{redshift}) \Rightarrow F(L_{gamma\text{-}rays}, \text{ emission model})$$

More model parameters:

inclination angle, radio structure, radio size

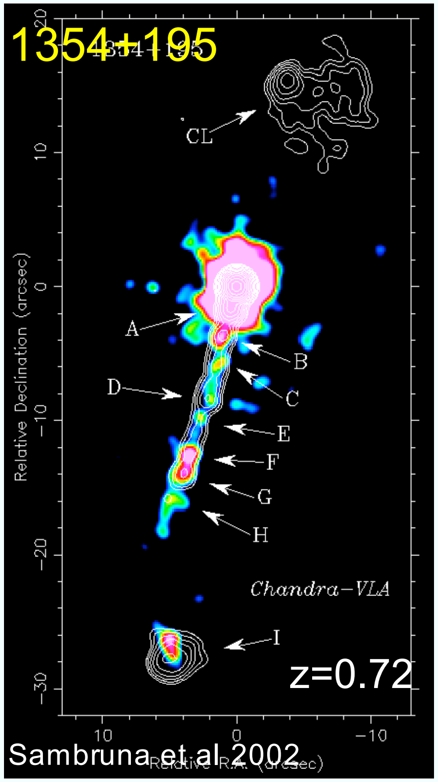
Summary

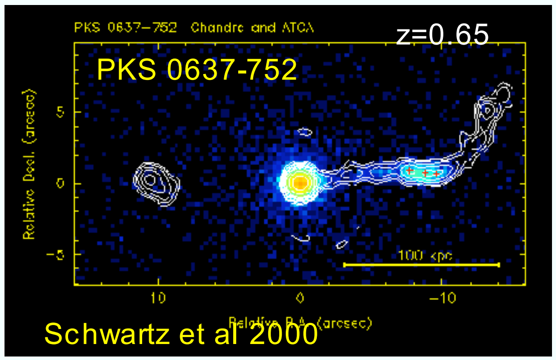
- Studies of radio sources of different size or age
- Populations of radio sources to understand their evolution - one expansion phase or many active outbursts, so intermittent jets
- Model high energy emission to understand the early stage of the source evolution:

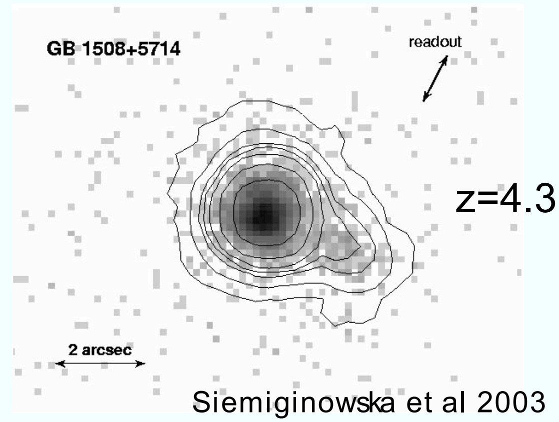
  - composition of radiating particles
  - total energy generated close to a black hole
  - dissipation of this energy
  - impact on the large scale environment and structure formation

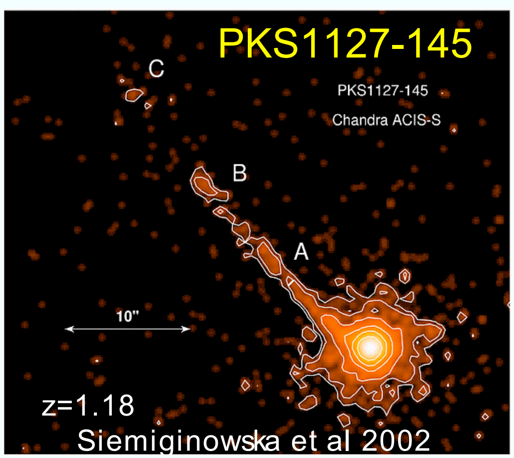
X-ray Jets

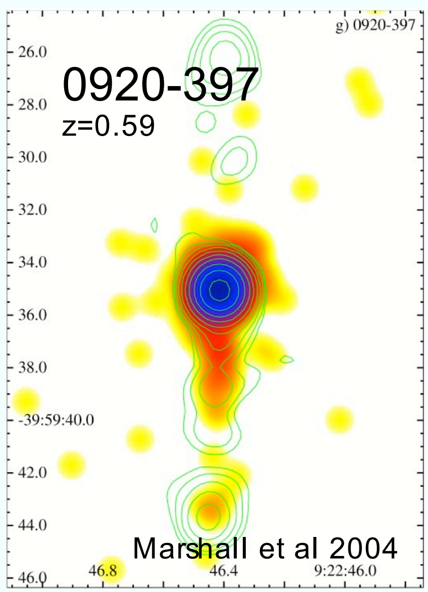
- > 85 X-ray Jets on the XJET Web page (Dan Harris): http://hea-www.harvard.edu/XJET/index.cgi
  FRI/FRII, Lobe Dominated and Compact Quasars

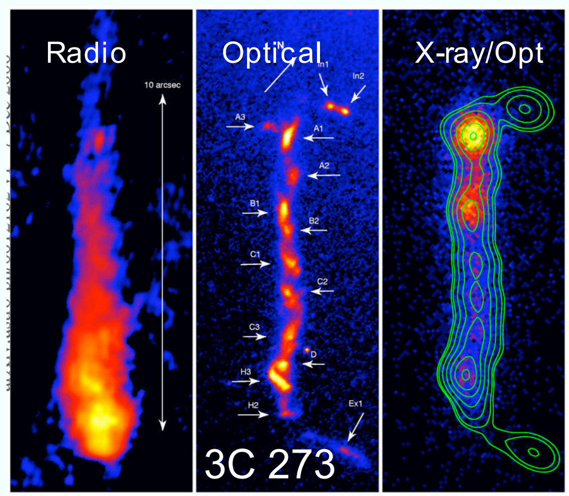












Marshall et al 2001