



Testing Radiation Models of Young Radio Sources

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Outline

- Radio Sources
- Evolution
- Observational Tests



Radio Source?

The screenshot shows a web browser window with the address bar displaying 'http://en.wikipedia.org/wiki/Radio_source'. The page title is 'Radio source - Wikipedia, the free encyclopedia'. The browser's address bar shows the URL. Below the address bar, there are several tabs: 'Gmail - In...', 'Google Sites', 'Are radio-...', 'Your NED ...', 'FSSC: Data ...', 'Chandra C...', 'https...e&zw', and 'SHERPADE...'. The main content area of the page is titled 'Radio source' and includes a navigation menu with options like 'article', 'discussion', 'edit this page', and 'history'. The text on the page explains that 'Radio source' can mean several things, including an astronomical radio source, a radio transmitter, and the Radio Open Source podcast and blog. It also lists 'See also' items: 'Radio noise source' and 'Source Radio, a radio station operating from Coventry, England.' A disambiguation note states: 'This disambiguation page lists articles associated with the same title. If an internal link led you here, you may wish to change the link article.' The page also features a sidebar with navigation links, a search box, and a toolbox.

Radio source - Wikipedia, the free encyclopedia

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

Most Visited Getting Started Latest Headlines Gmail CIAO: X-ray Data An... SDS

Gmail - In... Google Sites Are radio-... Your NED ... FSSC: Data ... Chandra C... https...e&zw SHERPADE... W

article discussion edit this page history

Radio source

From Wikipedia, the free encyclopedia

Radio source can mean:

- An **astronomical radio source**.
- A radio **transmitter**.
- The Radio **Open Source** podcast and blog.

See also

- **Radio noise source**.
- **Source Radio**, a radio station operating from Coventry, England.

This *disambiguation page* lists articles associated with the same title. If an *internal link* led you here, you may wish to change the link article.

Categories: Disambiguation pages

navigation

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search

Go Search

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- Help

toolbox

- What links here
- Related changes
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- Special pages



Radio Source?

The screenshot shows a web browser window with the address bar displaying `http://en.wikipedia.org/wiki/Radio_source`. Below it, another browser window shows the article for `http://en.wikipedia.org/wiki/Radio_galaxy`. The article content includes:

Radio galaxy
From Wikipedia, the free encyclopedia

For the UK radio network, see [Galaxy Radio](#).

Radio galaxies and their relatives, radio-loud **quasars** and **blazars**, are types of **active galaxy** that are very luminous at **radio wavelengths** (up to 10^{39} W between 10 MHz and 100 GHz). The radio emission is due to the **synchrotron process**. The observed structure in radio emission is determined by the interaction between twin **jets** and the external medium, modified by the effects of **relativistic beaming**. The **host galaxies** are almost exclusively large **elliptical galaxies**. *Radio-loud* active galaxies are interesting not only in themselves, but also because they can be detected at large distances, making them valuable tools for **observational cosmology**. Recently, a good deal of work has been done on the effects of these objects on the **intergalactic medium**, particularly in **galaxy groups** and **clusters**.

Contents [hide]

- 1 Emission processes
- 2 Radio structures
- 3 Life cycles and dynamics
- 4 Host galaxies and environments
- 5 Unified models
- 6 Uses of radio galaxies
 - 6.1 Distant sources
 - 6.2 Standard rulers
 - 6.3 Effects on environment
- 7 Terminology
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Emission processes [edit]

The radio emission from radio-loud active galaxies is **synchrotron emission**, as inferred from its very smooth, broad-band nature

Navigation sidebar includes: Main page, Contents, Featured content, Current events, Random article, search, interaction (About Wikipedia, Community portal, Recent changes, Contact Wikipedia, Donate to Wikipedia, Help), and toolbox (What links here, Related changes, Upload file, Special pages, Printable version).



Radio Source?

The screenshot shows a web browser displaying the Wikipedia article 'Radio source'. The browser's address bar shows the URL 'http://en.wikipedia.org/wiki/Radio_galaxy'. The article text is partially visible, discussing radio galaxies, lobes, jets, and hotspots. Two images are included: one of radio galaxy 3C98 and another of radio galaxy 3C31. The browser's interface, including navigation buttons and a search bar, is also visible.

Radio source – Wikipedia, the free encyclopedia
Radio galaxy – Wikipedia, the free encyclopedia

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

active galaxies. (bottom).

Radio structures

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.

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 (FR II).^[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 FR II sources were brightest at the edges. Fanaroff and Riley observed that there was a reasonably sharp divide in luminosity between the two classes: FRI sources were low-luminosity, FR IIs 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 FR IIs have faint jets but bright *hotspots* at the ends of the lobes. FR IIs 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/FR II division depends on host-galaxy environment in the sense that the FRI/FR II 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/FR II 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 FR II 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 FR II sources are interpreted as being the visible manifestations of *shocks* formed when the fast, and therefore *supersonic*, jet (the speed of sound cannot exceed $c/\sqrt{3}$) 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*.

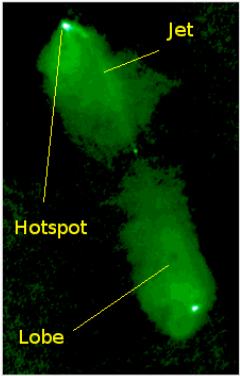
Names are given to several particular types of radio source based on their radio structure:

- Classical double refers to an FR II source with clear hotspots.
- Wide-angle tail normally refers to a source intermediate between standard FRI and FR II 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.

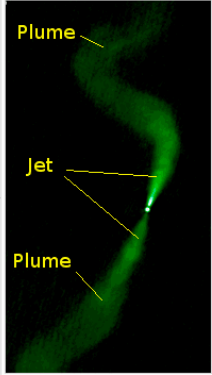
Life cycles and dynamics

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^[9]: 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 FR II sources are often close to the external thermal pressures (e.g.^[10]) 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



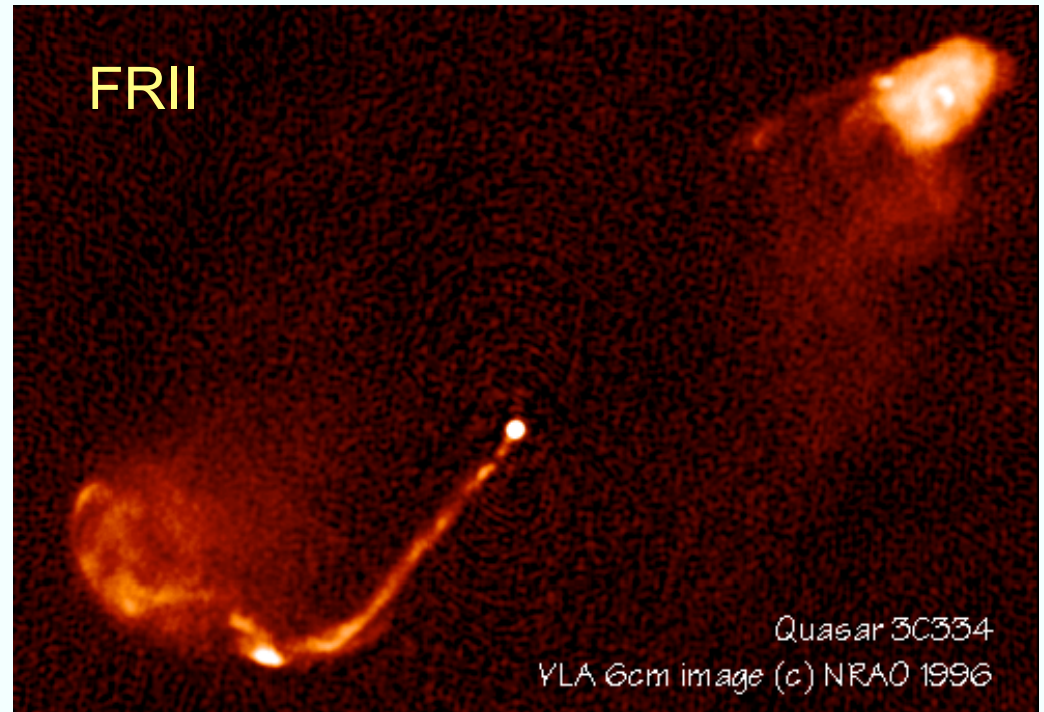
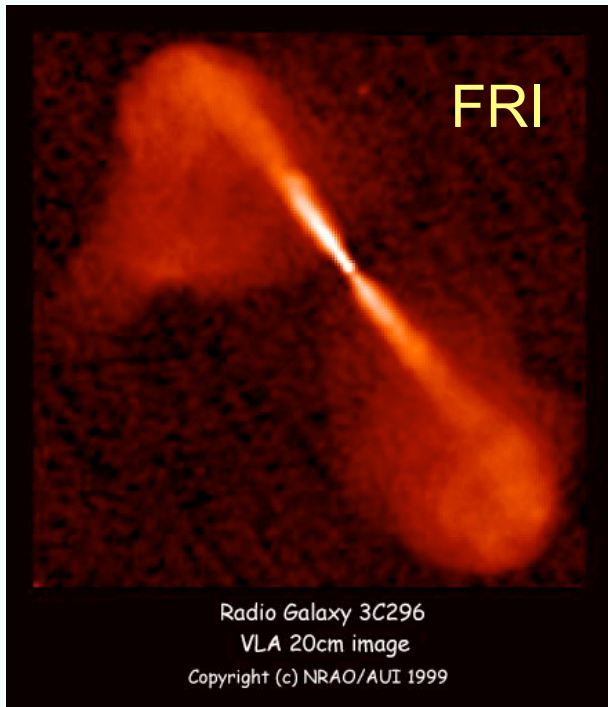
Pseudo-colour image of the large-scale radio structure of the FR II radio galaxy 3C98. Lobes, jet and hotspot are labelled.



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



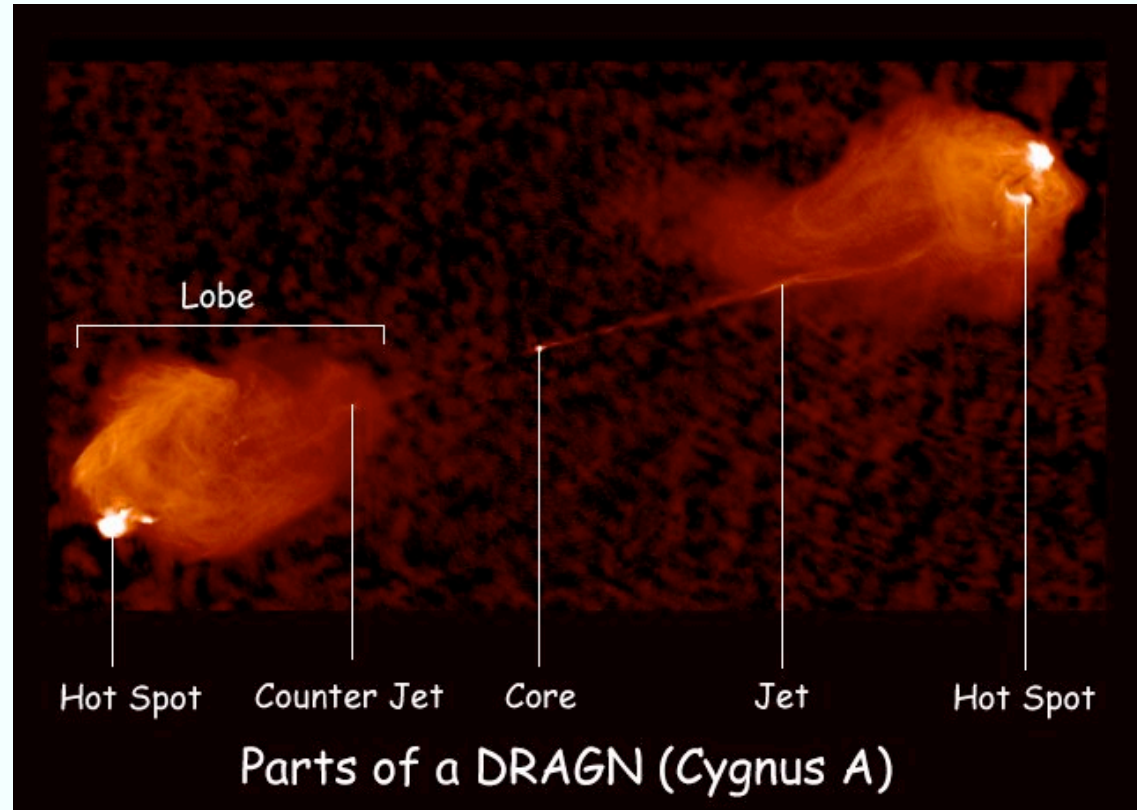
Classical Radio Sources





Radio Source Components:

- Core
- Jet
- Hot Spots
- Lobes



NRAO image on Alan Bridle's page

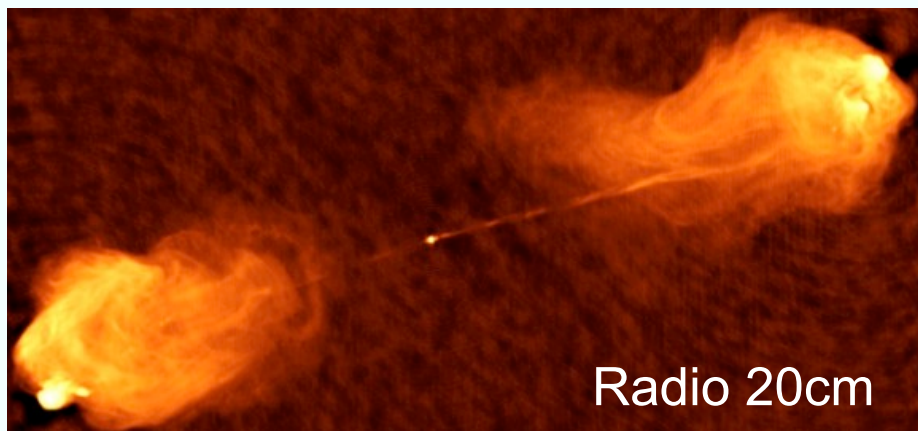
Evidence for relativistic particles => acceleration sites



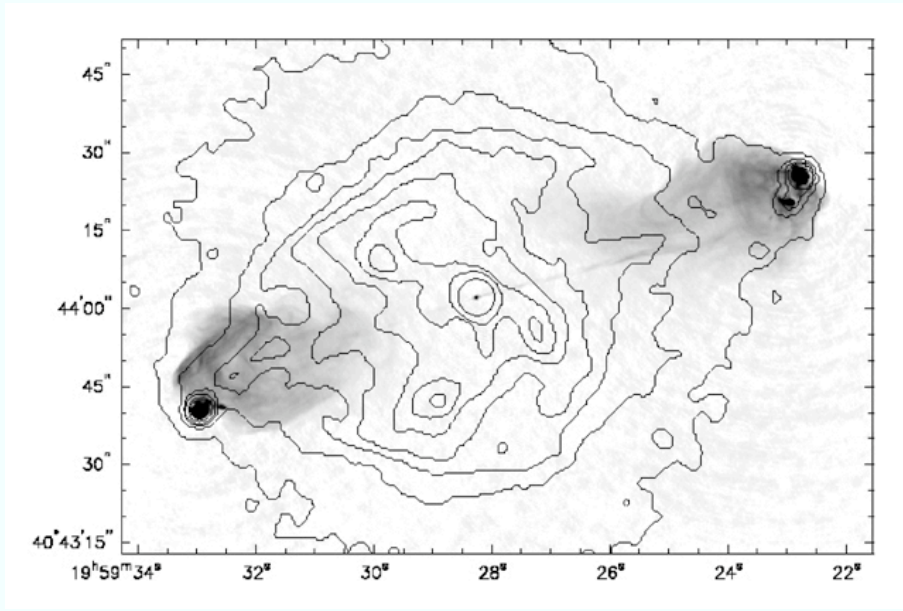
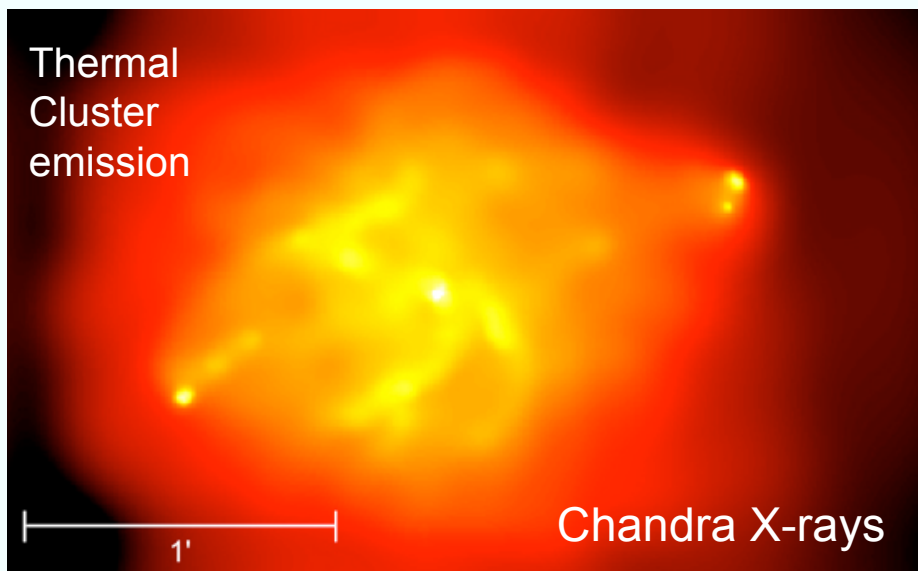
Radio Source in X-rays

Cygnus A

FR II, $z=0.056$ 1' = 65 kpc



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



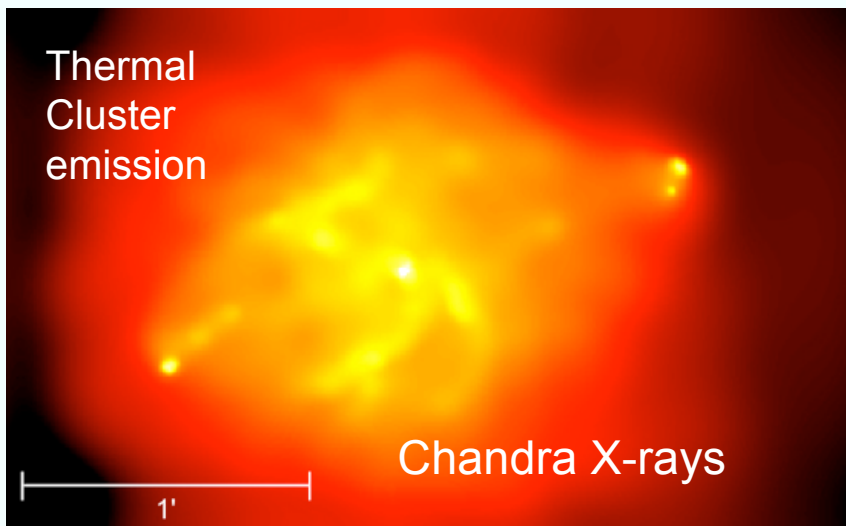
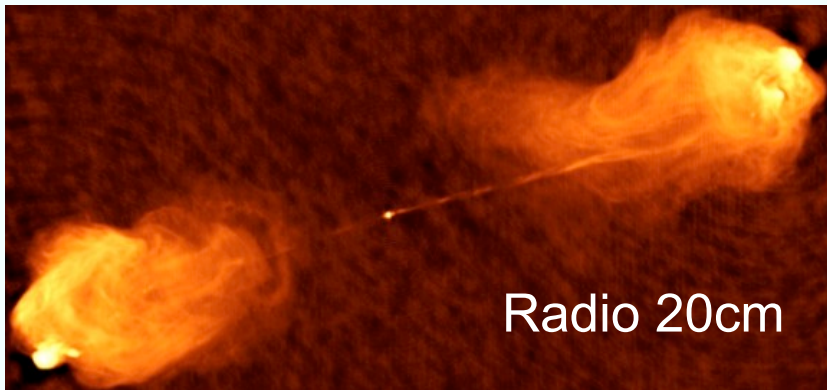


Radio Source in X-rays

Large Scale > 100 kpc

Cygnus A
FR II, $z=0.056$

$1' = 65 \text{ kpc}$





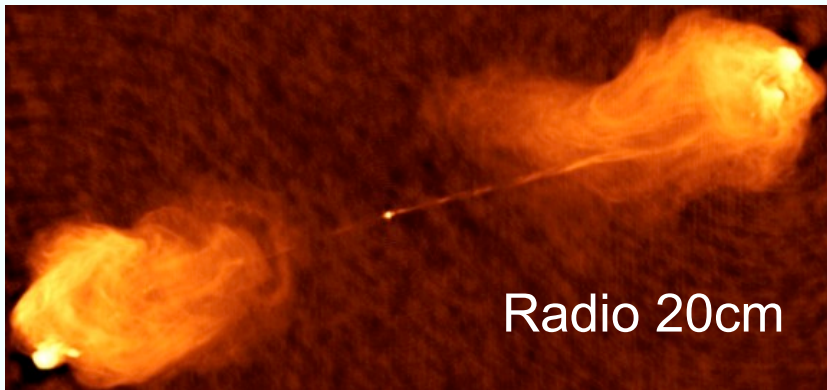
Radio Source in X-rays

Large Scale > 100 kpc

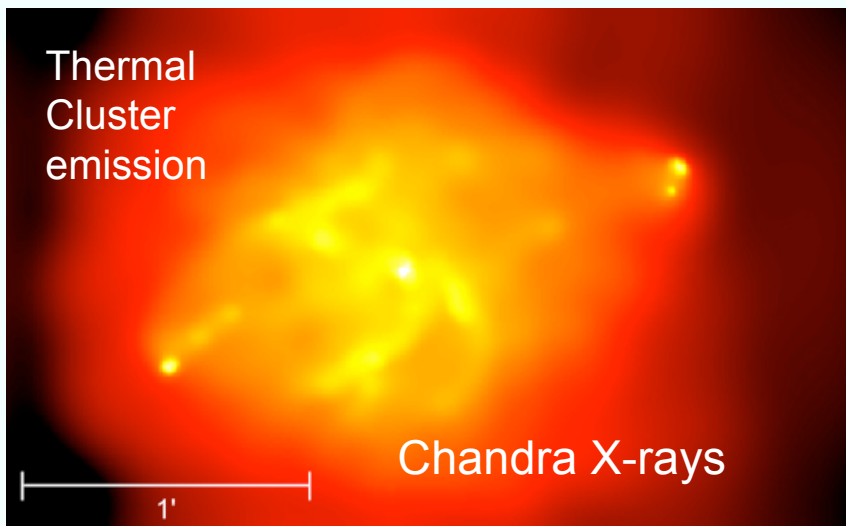
Small Scale < 20 kpc

Cygnus A
FR II, z=0.056

1' = 65 kpc



Radio 20cm

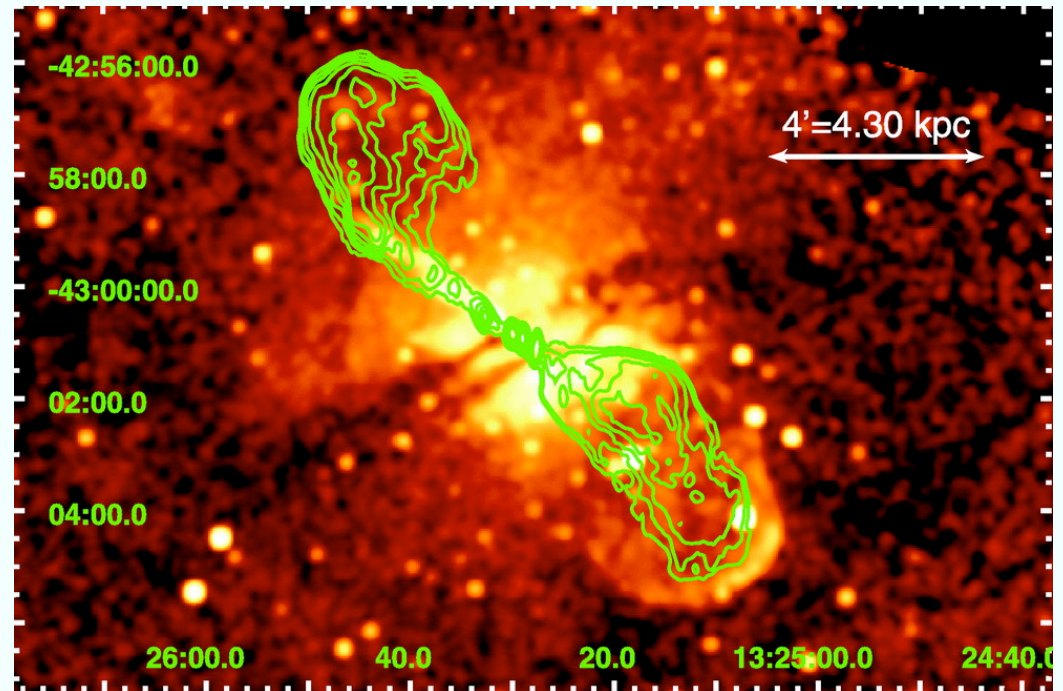


Thermal Cluster emission

Chandra X-rays

1'

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



4' = 4.30 kpc



Evolution of a Radio Source

L22

BEGELMAN AND CIOFFI

Vol. 345

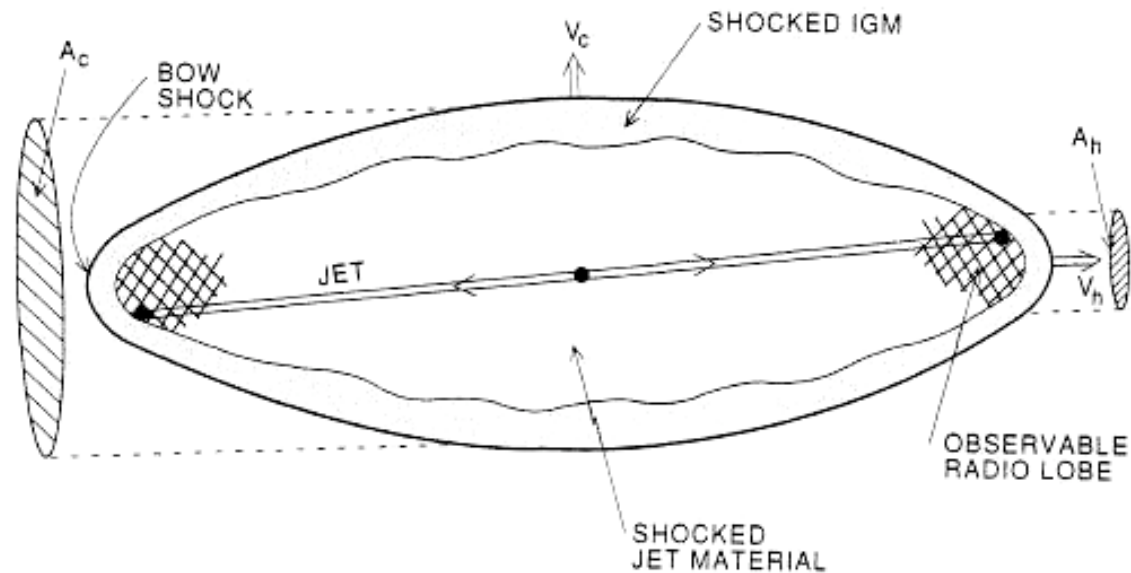


FIG. 1.—Schematic diagram of the overpressured cocoon surrounding a powerful double radio source. The shock bounding the cocoon expands into the IGM with speed v_h along the mean jet axis and $\sim v_c$ in orthogonal directions. The observable radio lobes constitute only a small fraction of the cocoon's 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 direction, momentum is deposited over a much wider area than the instantaneous jet cross section. For Cygnus A, we estimate $A_h \sim 28 \text{ kpc}^2$; the total projected length of the cocoon is $\sim 120 \text{ kpc}$ (for $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$). 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

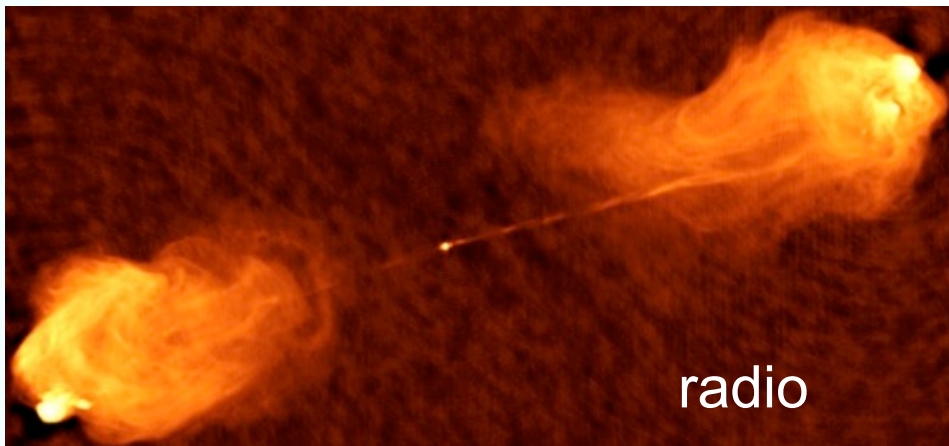
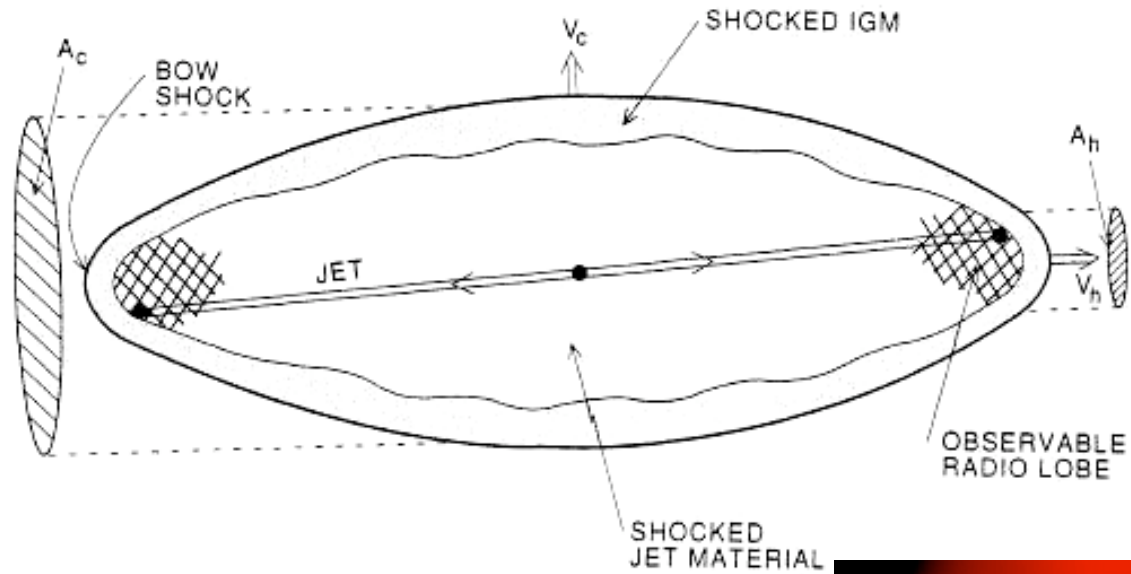


Evolution of a Radio Source

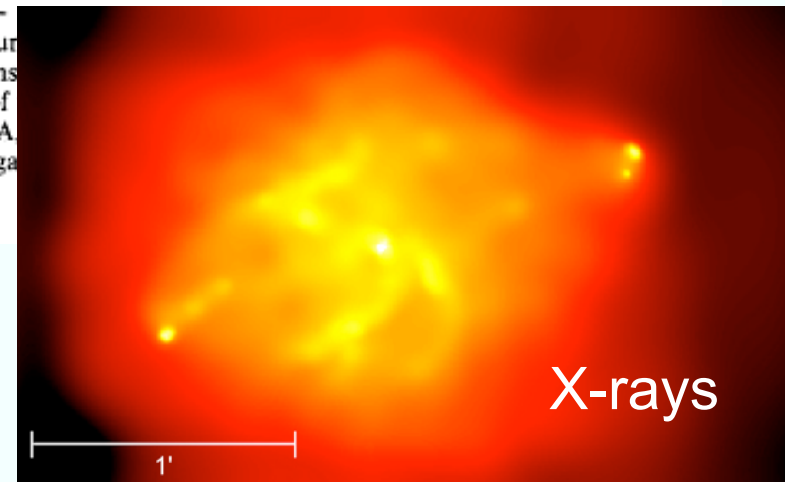
L22

BEGELMAN AND CIOFFI

Vol. 345



powerful double radio source
 observable radio lobes consist
 larger than the area of
 cross section. For Cygnus A,
 proposed for high-z radio galaxies



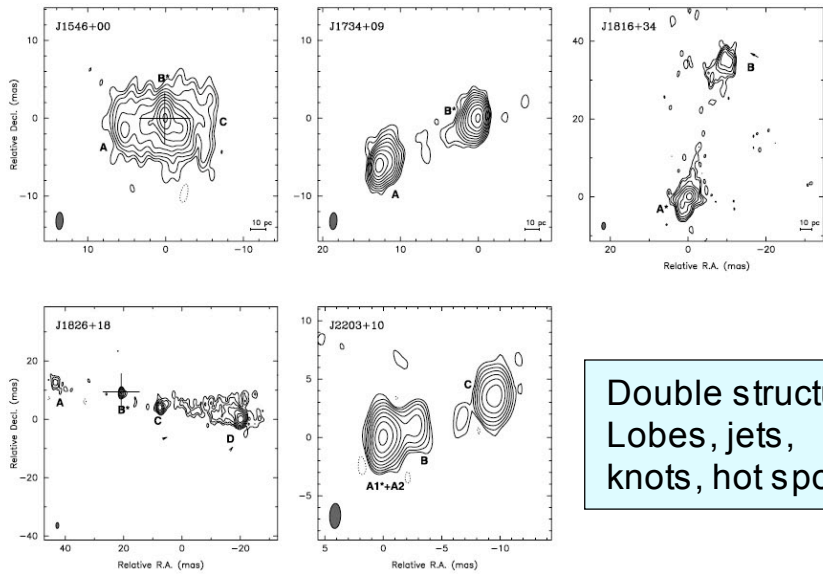


Compact Radio Sources

VLBA
mas scale

COMPACT SYMMETRIC OBJECT MOTIONS

139

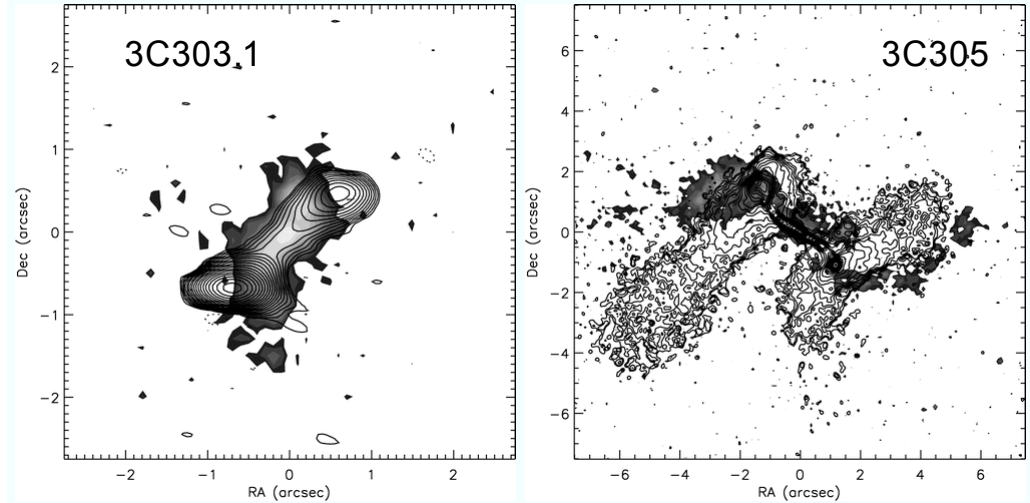


Double structure
Lobes, jets,
knots, hot spots

FIG. 1.—Continued

Gugliucci et al. 2005

arcsec scale



Privon et al. 2008

Radio/optical overlay

The entire radio structure contained within the host galaxy



Age Measurements

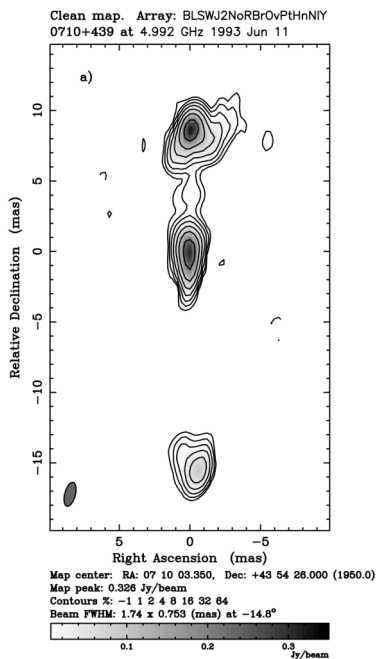
Kinematic ages

- 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

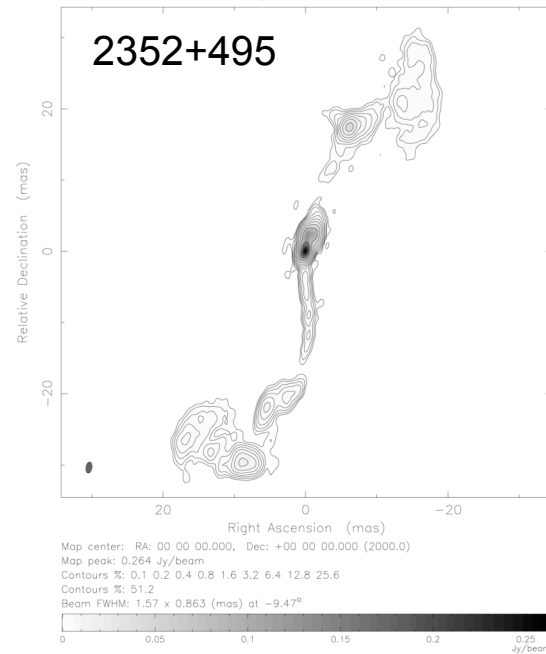
- modeled spectra of lobes
- High quality Radio data needed
- Murgia et al. 1999 completed measurements for ~47 compact sources

0710+439

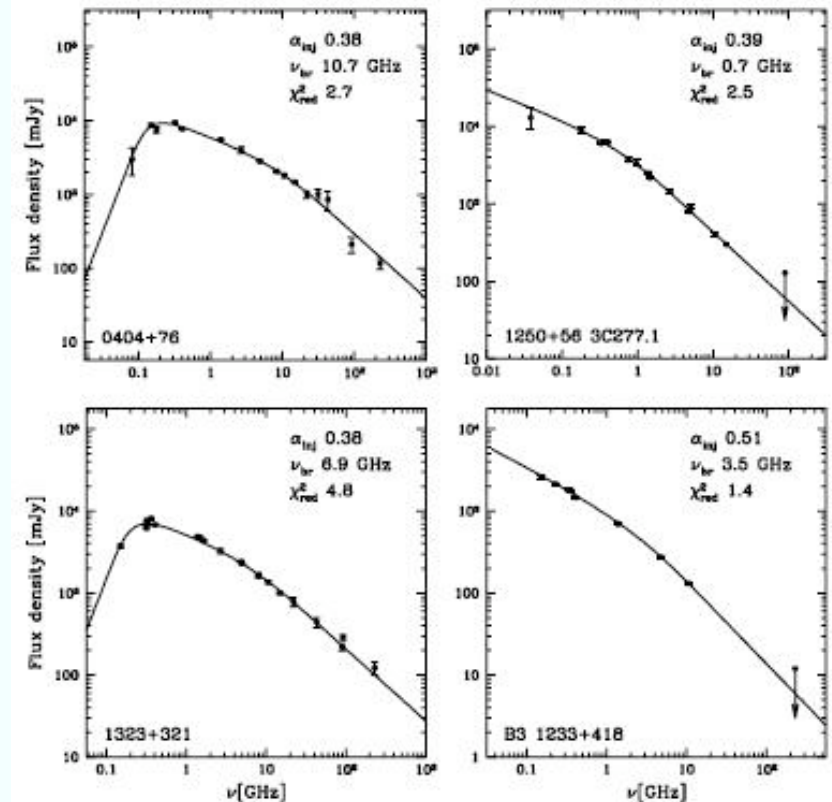


Clean map. Array: BCEFHKLMMNNOOPST
MULTI at 4.991 GHz 1997 Sep 18

2352+495



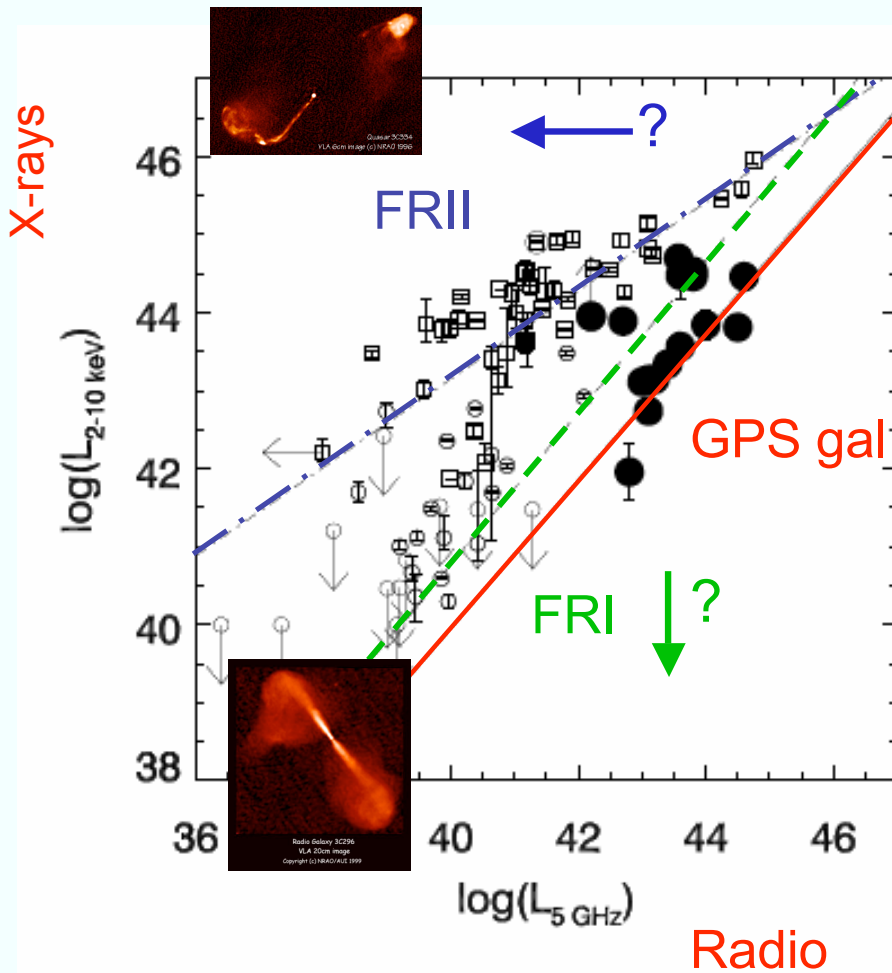
Owsianik, Polatidis and Conway 1999



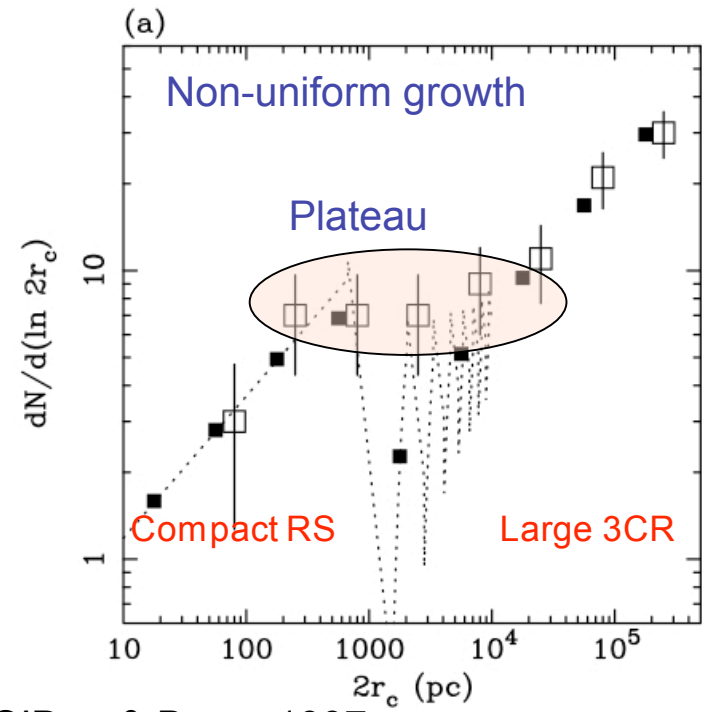
Murgia et al 1999



Radio Source Evolution?



Tengstrand, Guainazzi, AS et al 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: 3×10^4 yrs

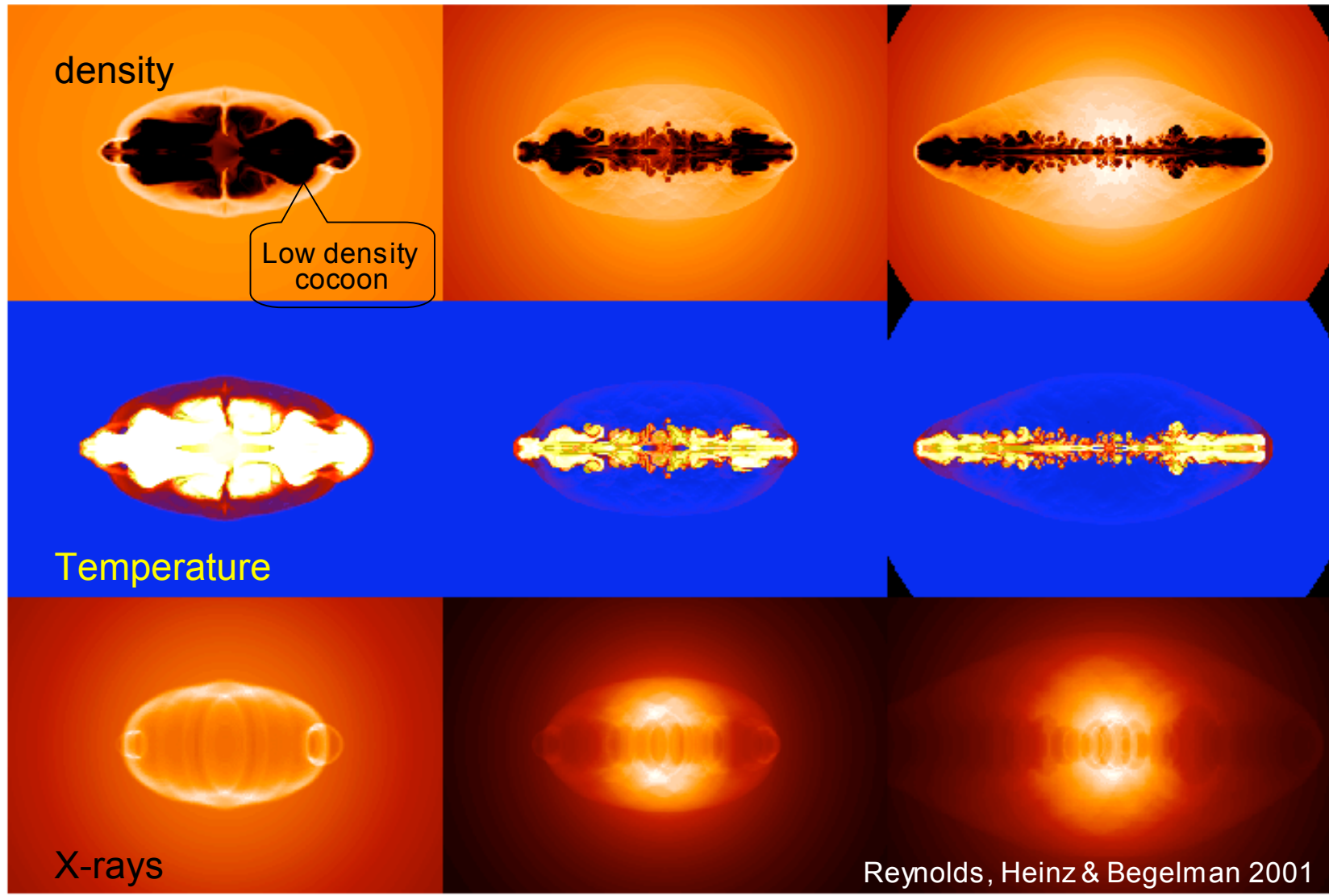


Evolution of a Radio Source - Simulations

1/ Supersonic cocoon

2/ Subsonic sideways expansion
Weak shock and Supersonic jet

3/ Sonic boom



Reynolds, Heinz & Begelman 2001



Model Predictions for X-rays & γ - rays

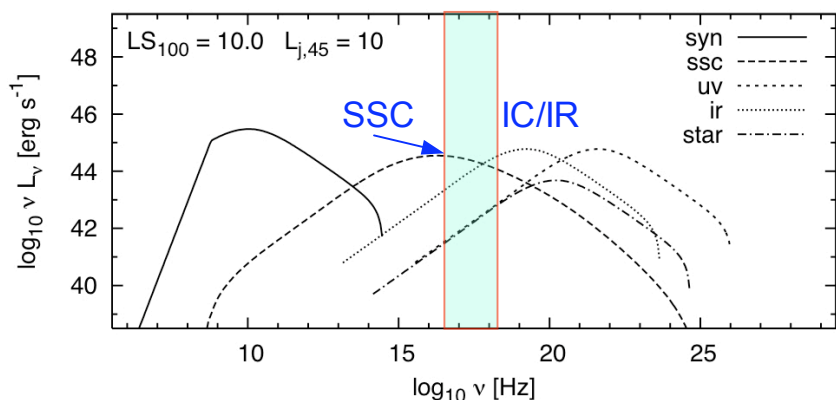
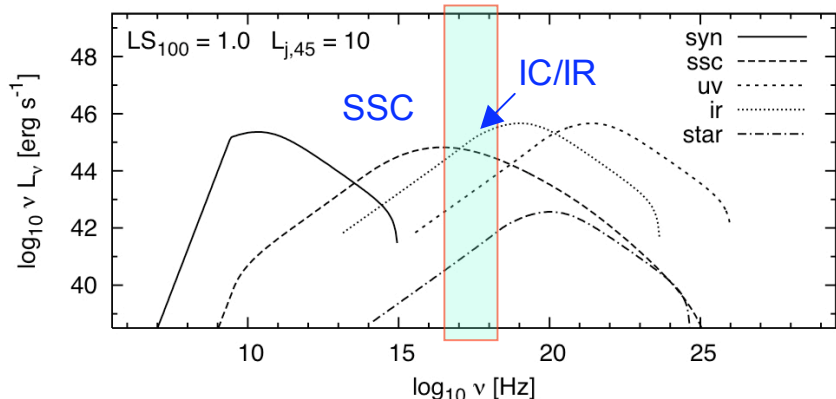
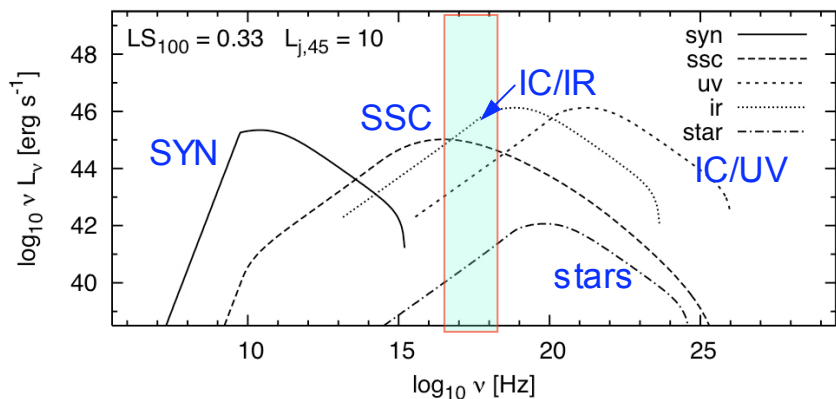
- Expanding radio source
 - Begelman & Cioffi(1989), Heinz, Reynolds & Begelman (1998) , Bicknell & Sutherland (2006, 2007) and others
- Spectra from double radio lobes
 - Stawarz et al (2008)
- Jet contributions in quasars (?)



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

X-rays

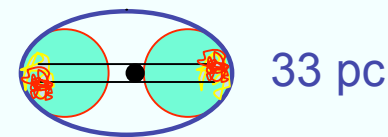
UV - disk
 IR - dust



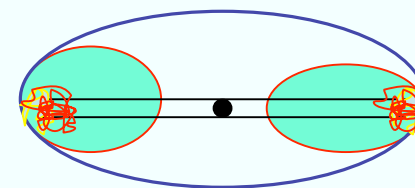
Log νL_ν

Log ν

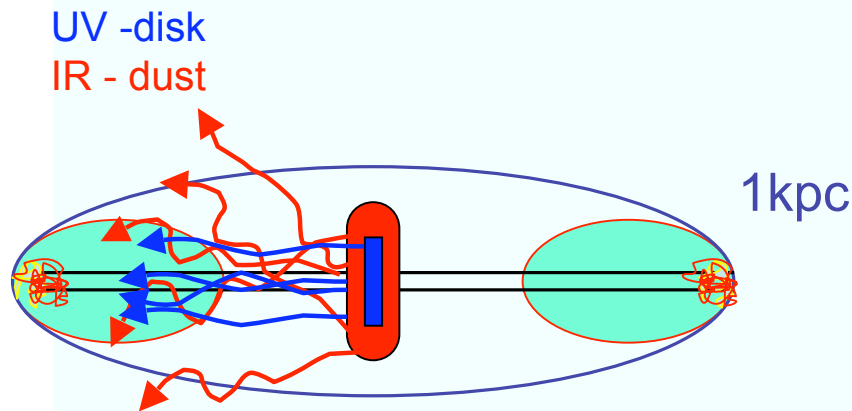
Source Evolution - Spectra



33 pc



100 pc



1kpc

UV -disk
 IR - dust

Parameters: jet power
 photon fields, density of ISM

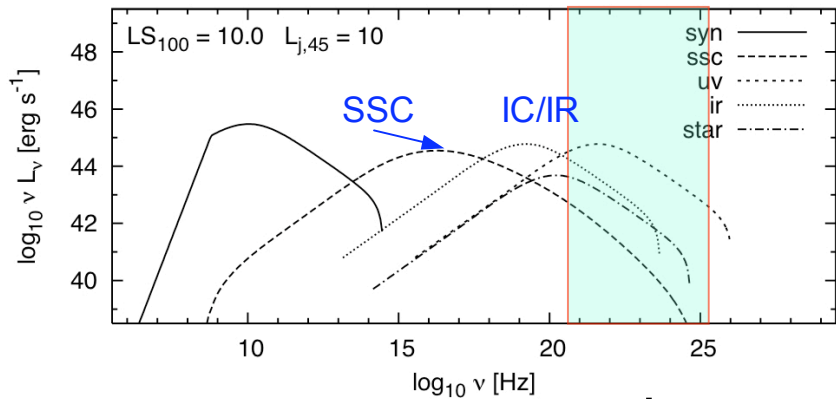
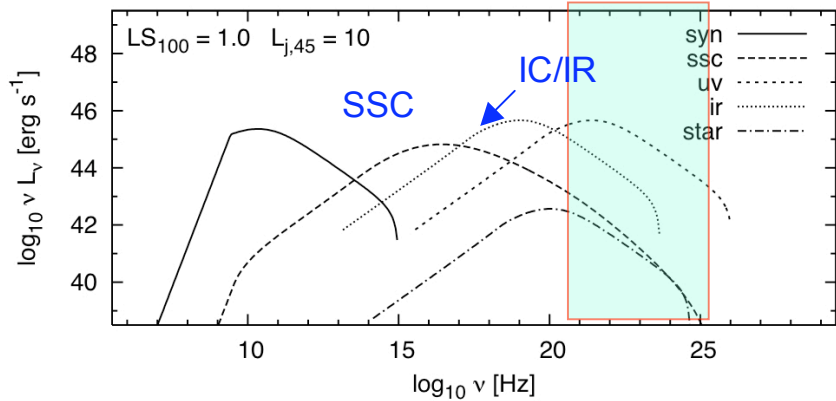
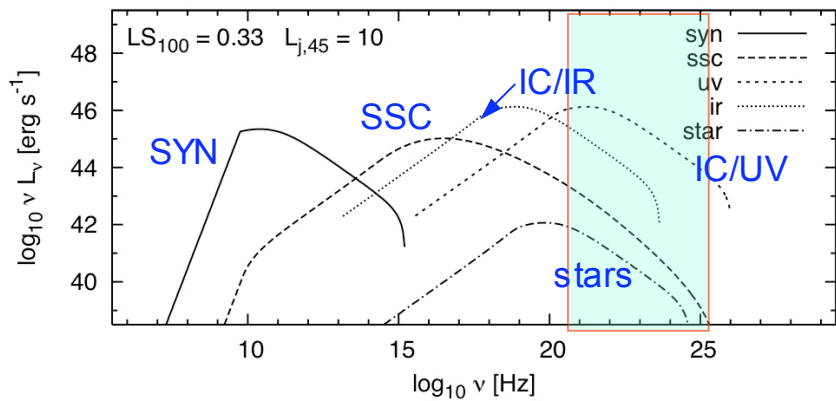
Stawarz et al 2008



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

γ -rays
 Fermi

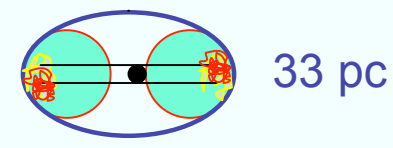
UV - disk
 IR - dust



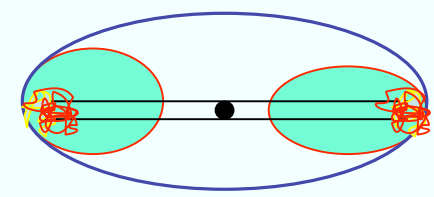
Log νL_ν

Log ν

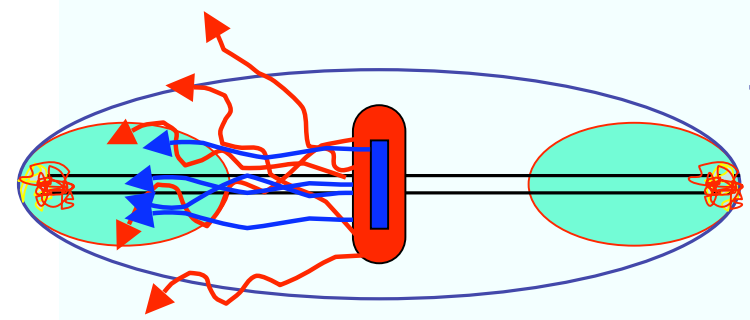
Source Evolution - Spectra



33 pc



100 pc



1 kpc

UV -disk
 IR - dust

Parameters: jet power
 photon fields, density of ISM

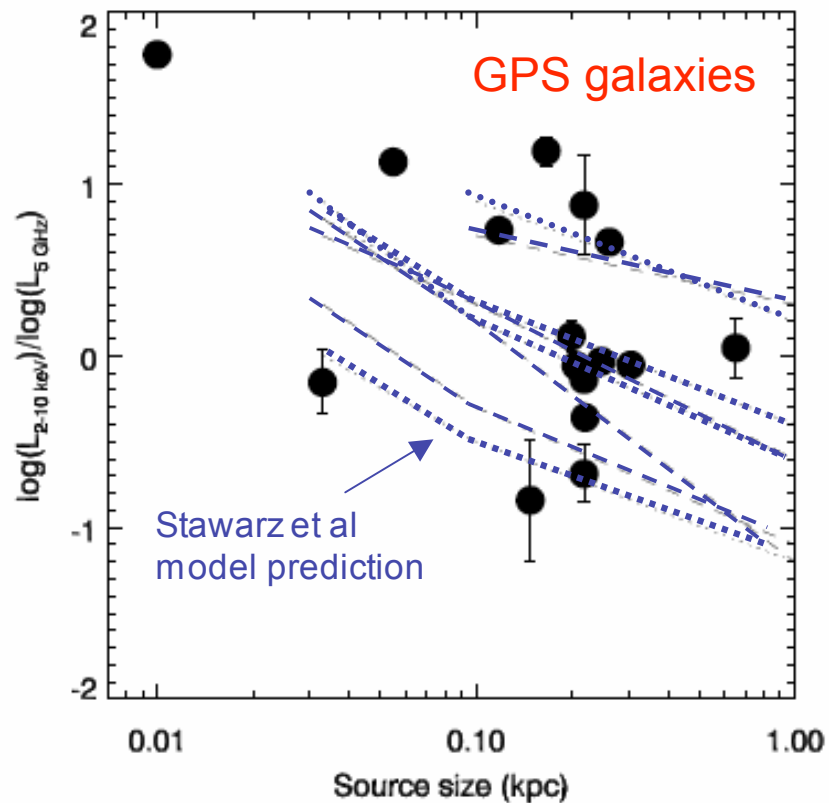
Stawarz et al 2008



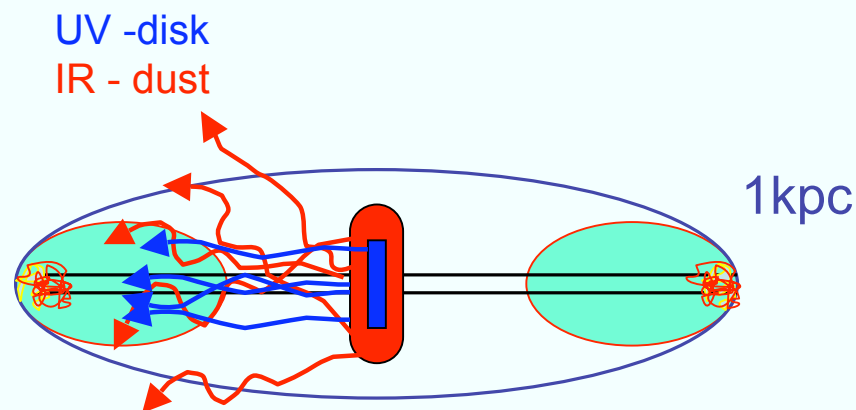
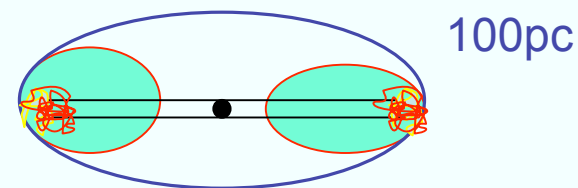
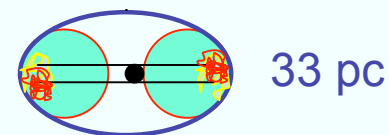
Luminosity vs Size

Spectral predictions
Stawarz et al. 2008

X-ray/Radio



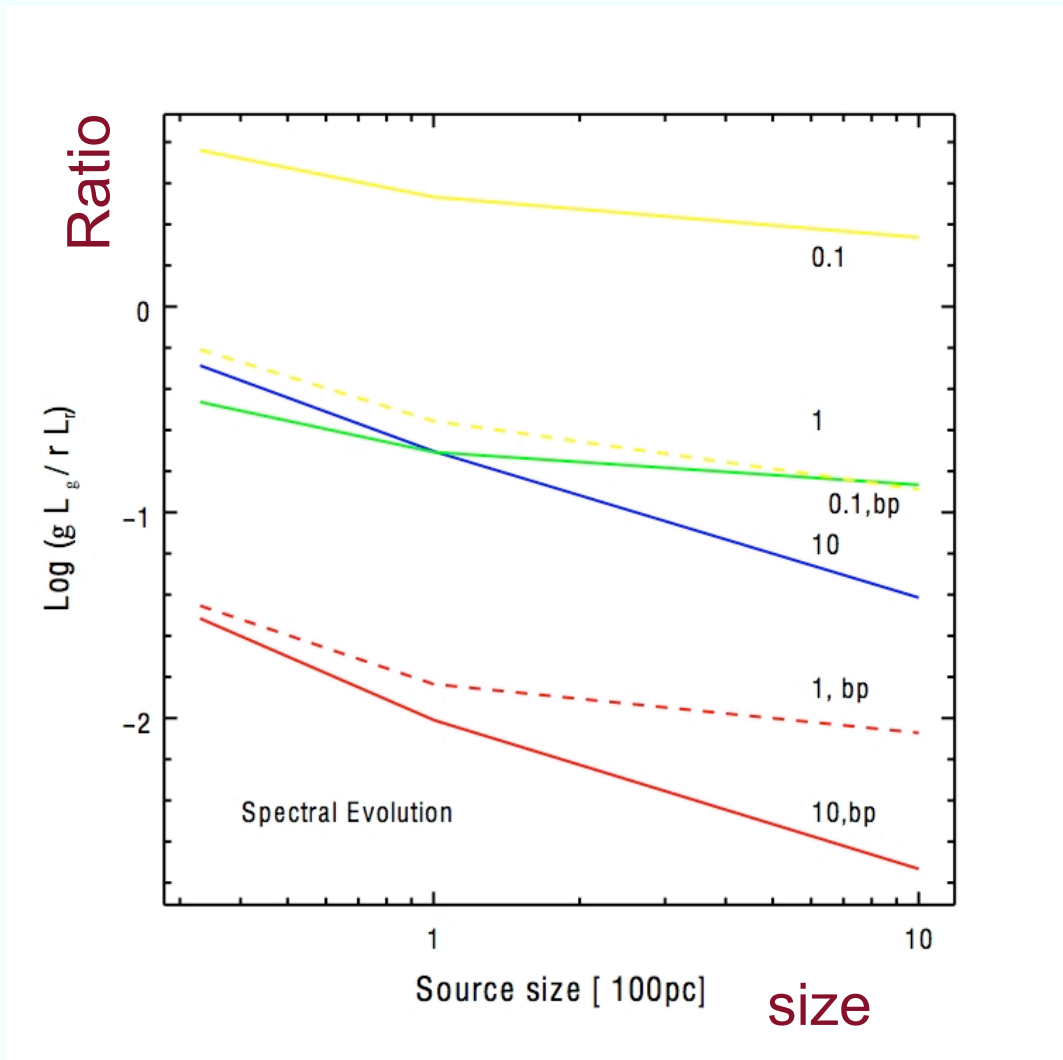
Radio Size



Parameters: jet power
photon fields, density of ISM



Spectral Evolution: γ -rays Model Predictions

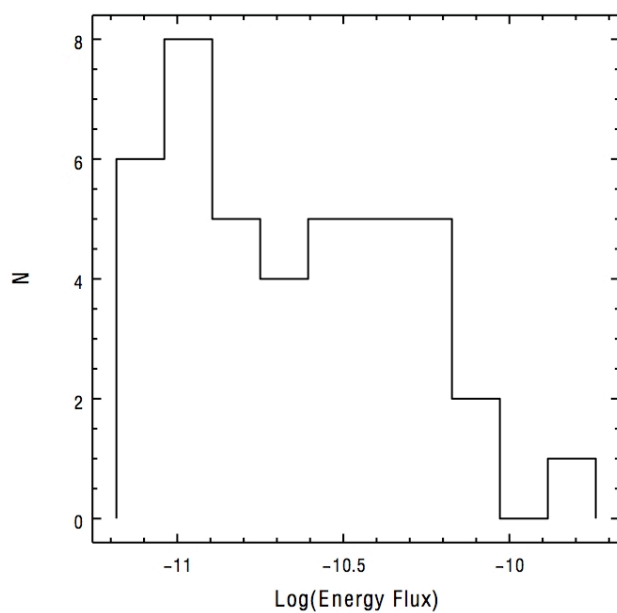




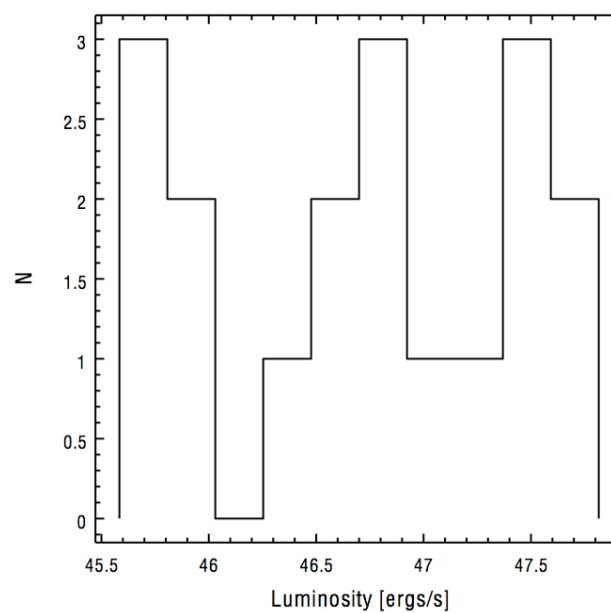
Fermi Detections

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

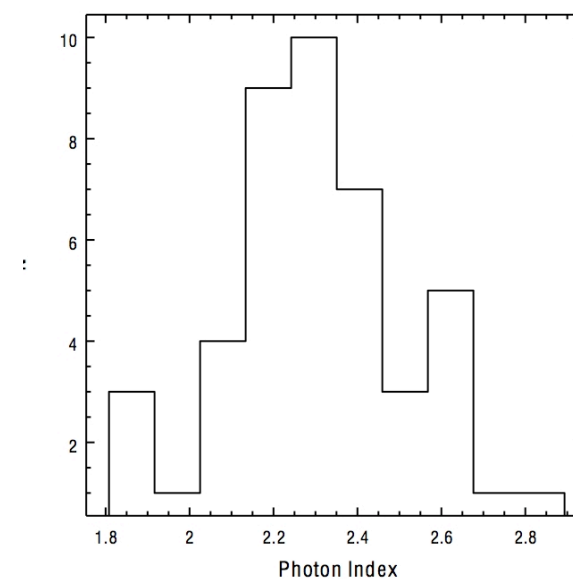
Observed by Fermi



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

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

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

