AGN Variability Across the Electromagnetic Spectrum and Spatial Scales

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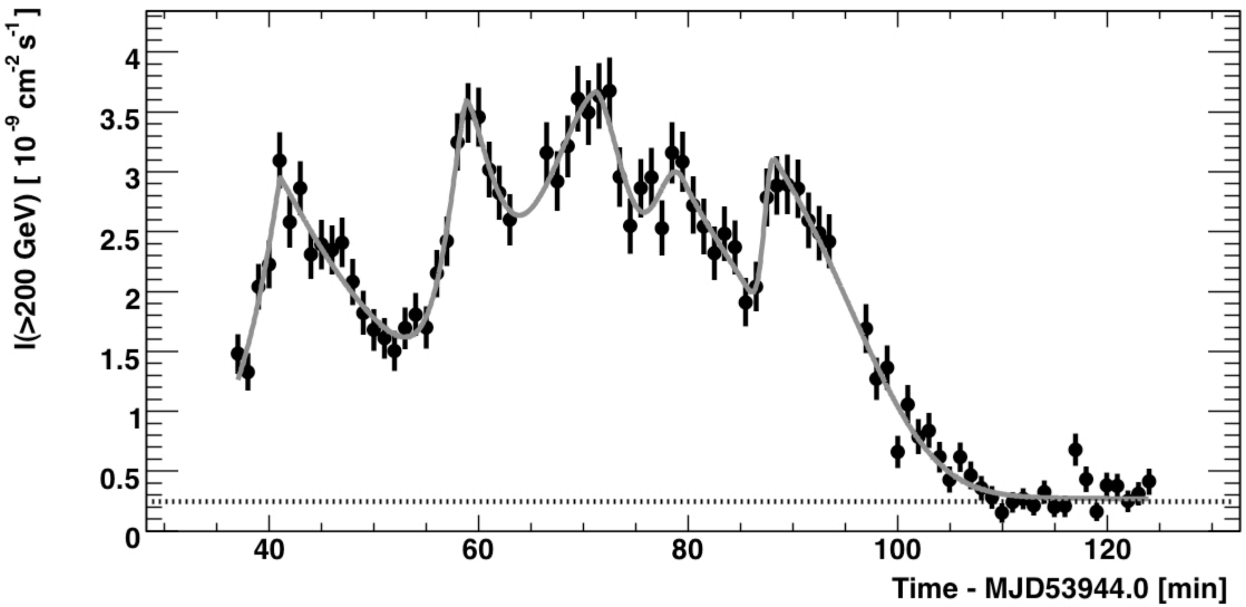
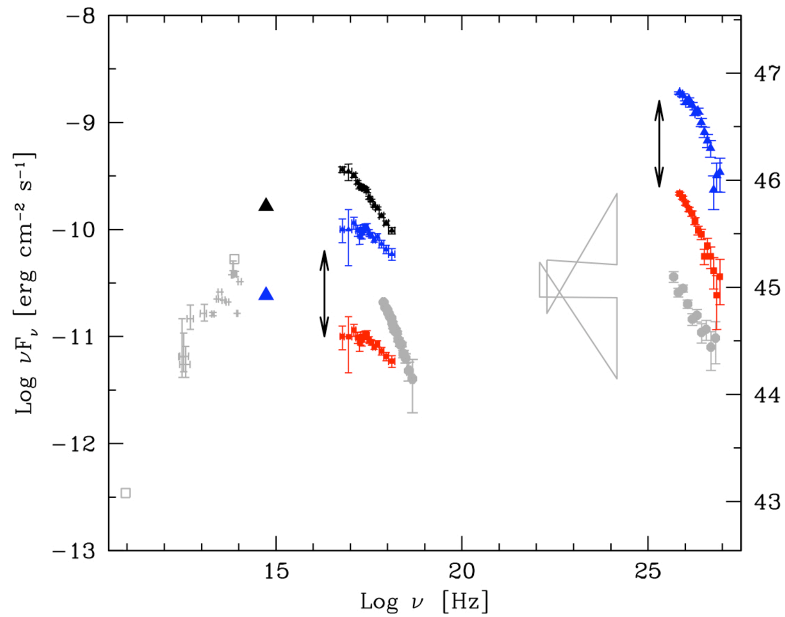
Dramatic Variability of BL Lacs



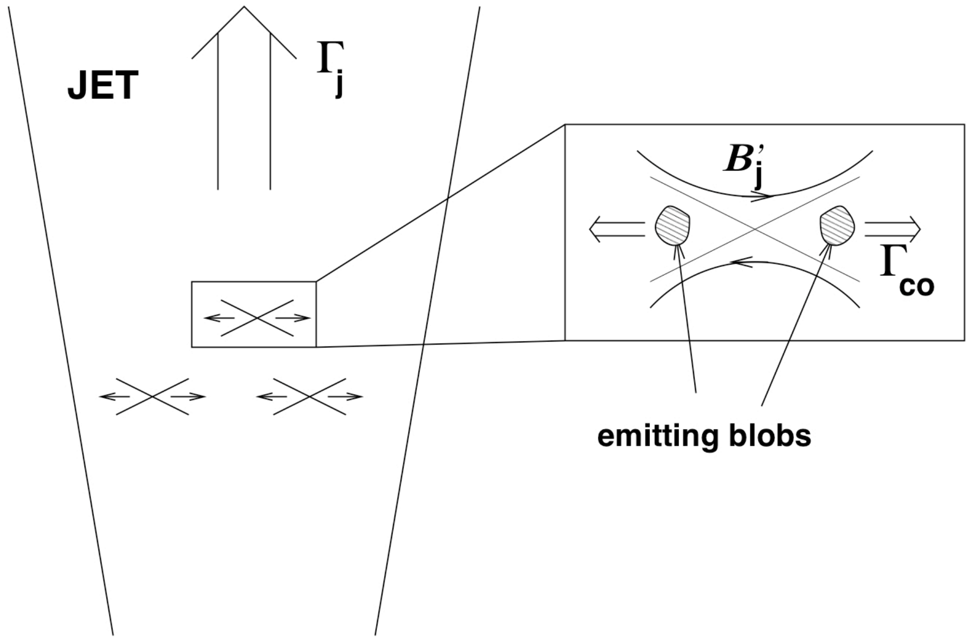
Aharonian+ 07, 09 [HESS]

PKS 2155-304: Variability is seen up to ~600 sec in the Fourier power spectrum, and well-resolved bursts varying on time scales of ~200 sec are observed.

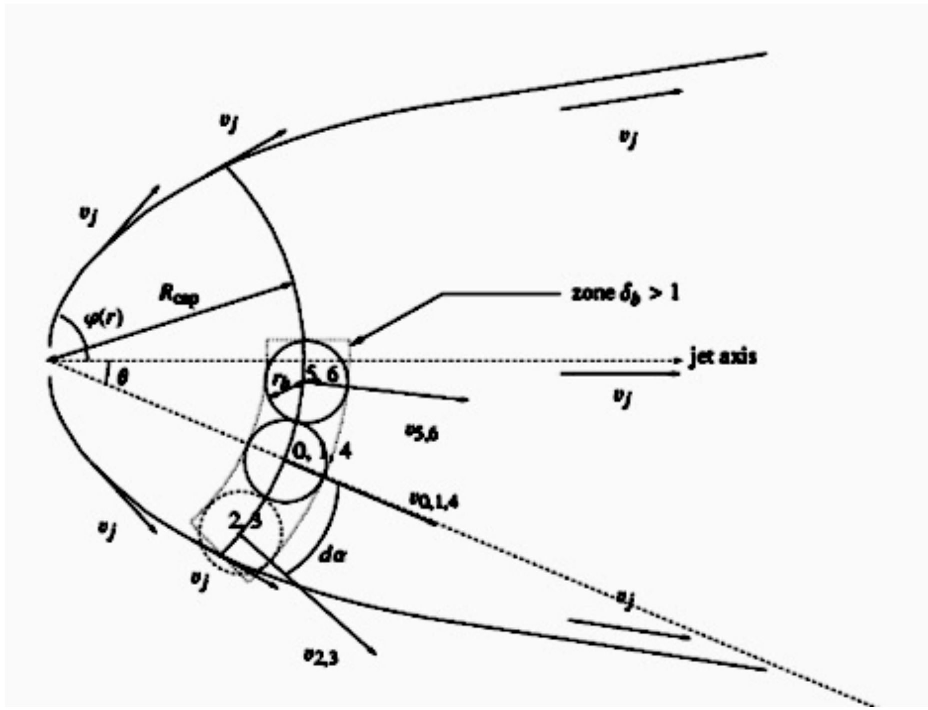
There are no strong indications for spectral variability within the data.



Outflows or Central Engine?



Jet-in-jet model by Giannios+ 09

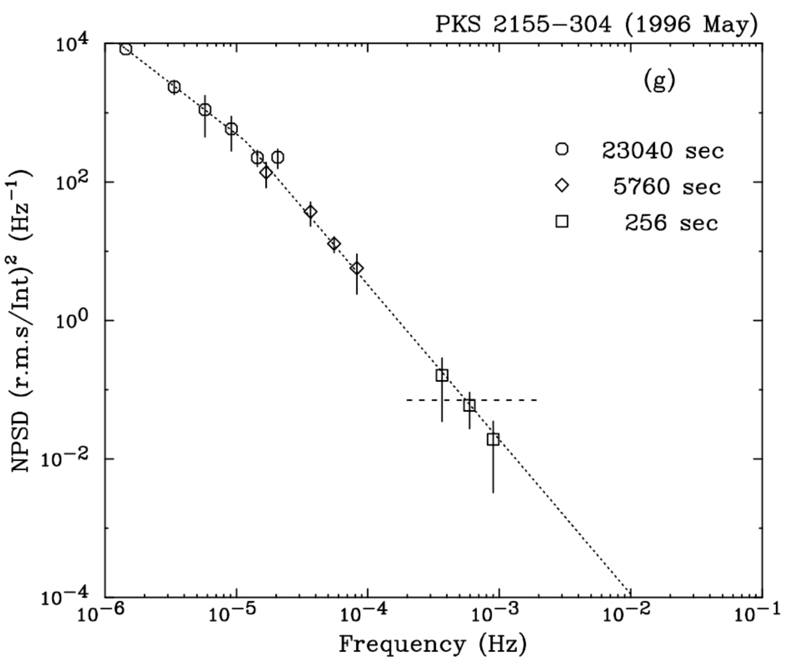


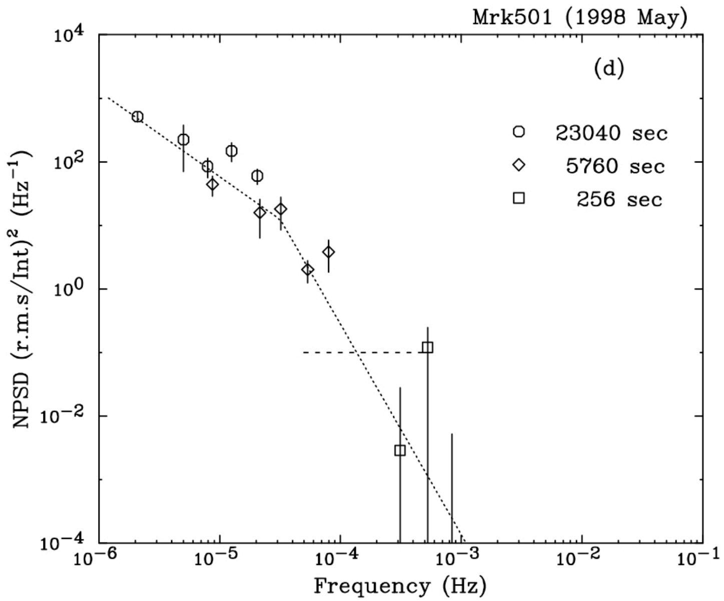
Multi-blob model by Lenain+ 08

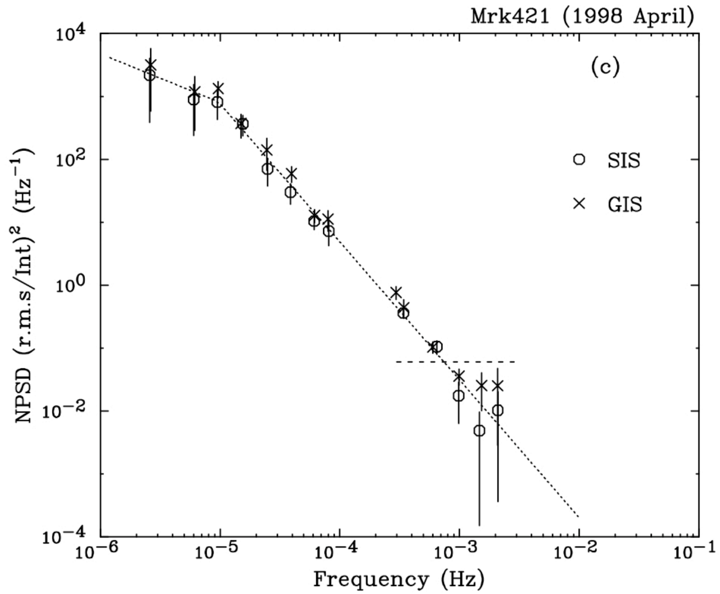
Assuming the emission region has a size comparable to the Schwarzschild radius of a ~10^9 $M_\odot$ black hole, Doppler factors greater than 100 are required to accommodate the observed variability time scales.

Is the variability shaped by the energy dissipation processes within the outflow, or by the highly unstable and intermittent activity of the central engine?

Dominant Emission Site





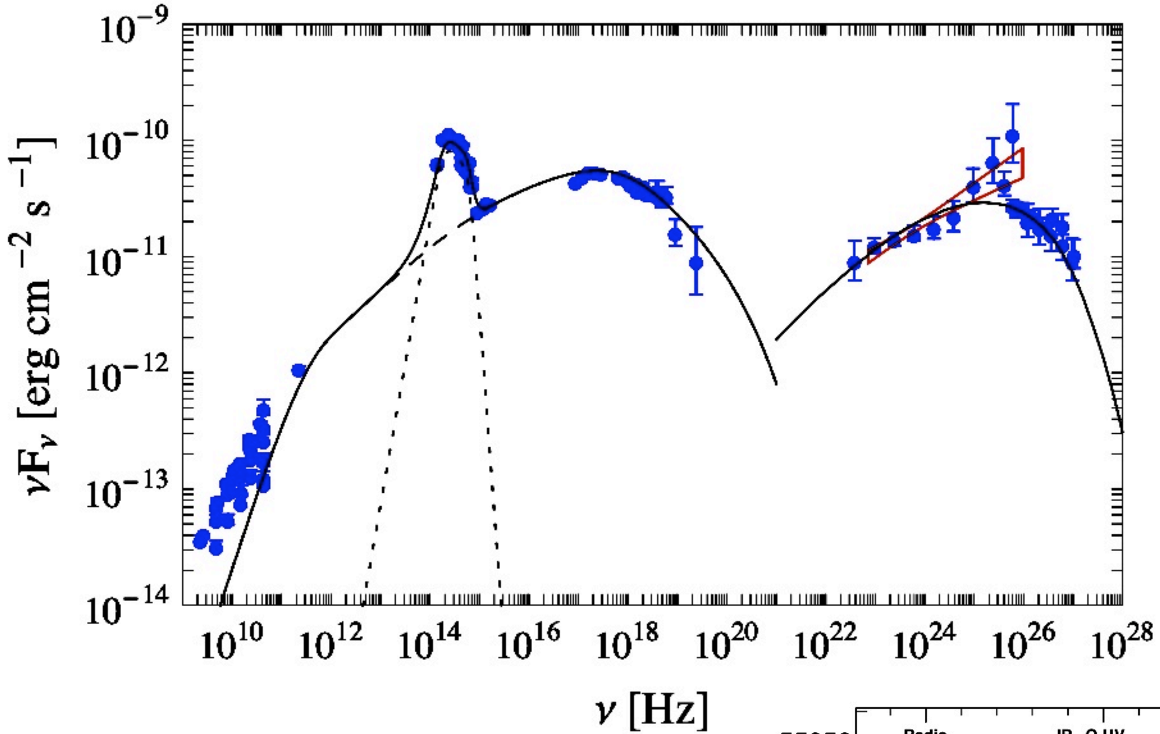


Kataoka+ 01

Analysis of the X-ray light curves for several bright BL Lacs (variability in the time domain from 10^3 to 10^8s.

Both the power spectrum density and the structure function show a roll-over with a time-scale of the order of 1 day or longer. On time-scales shorter than 1 day, there is only small power in the variability. Thus, the dominant X-ray emitting site in the jet is located at >10^{17} cm distances from the base of the jet.

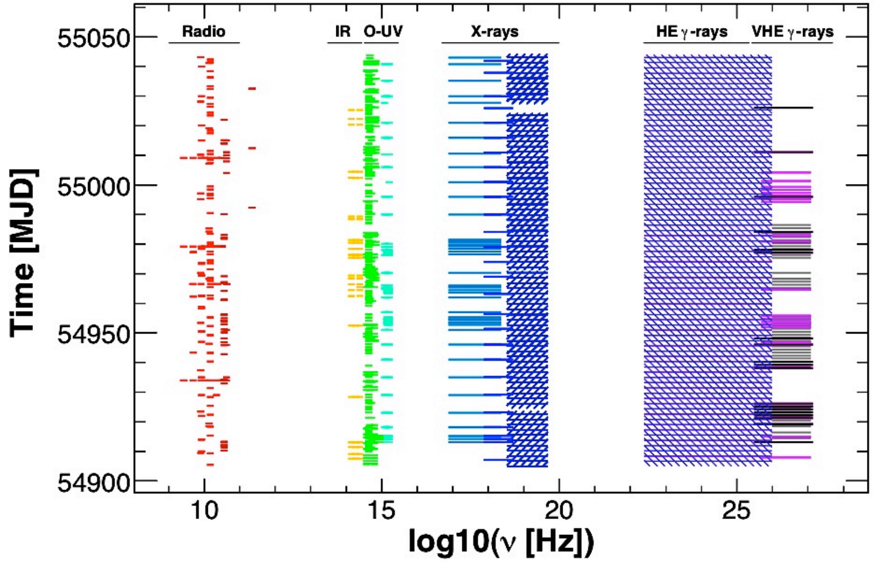
New Era with Fermi/LAT



Fermi/LAT, VERITAS & Magic++
[to be submitted]

Truly multiwavelength and simultaneous observations of Mrk 501 with the best (up to date) spatial and temporal coverage.

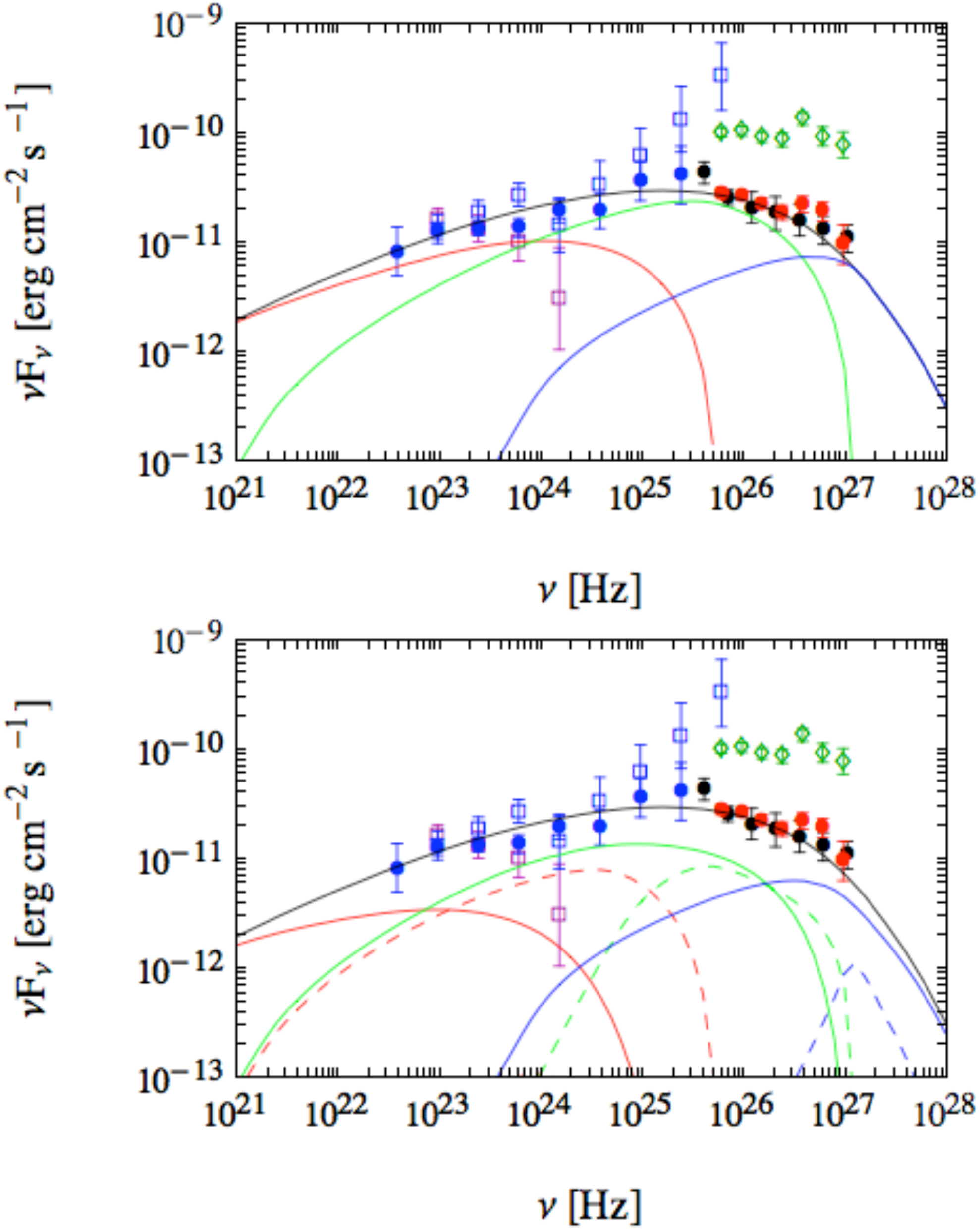
The "typical" behavior of Mrk 501: only modest and rather long-timescale flux changes



SSC Modeling

Table 2. Parameters of the blazar emission zone in Mrk 501.

Parameter	Value emerging from the SSC fit
Magnetic field	$B = 0.015\,\mathrm{G}$
Emission region size	$R = 1.3 \times 10^{17}\,\mathrm{cm}$
Jet Doppler and bulk Lorentz factors	$\Gamma = \delta = 12$
Equipartition parameter	$\eta_e \equiv U'_e/U'_B = 56$
Minimum electron energy	$\gamma_{min} = 600$
Intrinsic electron break energy	$\gamma_{br,1} = 4 \times 10^4$
Cooling electron break energy	$\gamma_{br,2} = 9 \times 10^5$
Maximum electron energy	$\gamma_{max} = 1.5 \times 10^7$
Low-energy electron index	$s_1 = 2.2$
High-energy electron index	$s_2 = 2.7$
Electron index above the cooling break	$s_3 = 3.65$
Mean electron energy	$\langle\gamma\rangle \simeq 2400$
Main variability timescale	$t_{var} \simeq 4\,\mathrm{day}$
Comoving electron energy density	$U'_e \simeq 5 \times 10^{-4}\,\mathrm{erg\,cm^{-3}}$
Comoving magnetic field energy density	$U'_B \simeq 0.9 \times 10^{-5}\,\mathrm{erg\,cm^{-3}}$
Comoving energy density of synchrotron photons	$U'_{syn} \simeq 0.9 \times 10^{-5}\,\mathrm{erg\,cm^{-3}}$
Comoving electron number density	$N'_e \simeq 0.26\,\mathrm{cm^{-3}}$
Luminosity of the host galaxy	$L_{star} \simeq 3 \times 10^{44}\,\mathrm{erg\,s^{-1}}$
Jet power carried by electrons	$L_e \simeq 10^{44}\,\mathrm{erg\,s^{-1}}$
Jet power carried by magnetic field	$L_B \simeq 2 \times 10^{42}\,\mathrm{erg\,s^{-1}}$
Jet power carried by protons[a]	$L_p \simeq 3 \times 10^{43}\,\mathrm{erg\,s^{-1}}$
Total jet kinetic power	$L_j \simeq 10^{44}\,\mathrm{erg\,s^{-1}}$
Total emitted power	$L_{em} \simeq 10^{43}\,\mathrm{erg\,s^{-1}}$
Isotropic synchrotron luminosity	$L_{syn} \simeq 10^{45}\,\mathrm{erg\,s^{-1}}$
Isotropic SSC luminosity	$L_{ssc} \simeq 2 \times 10^{44}\,\mathrm{erg\,s^{-1}}$



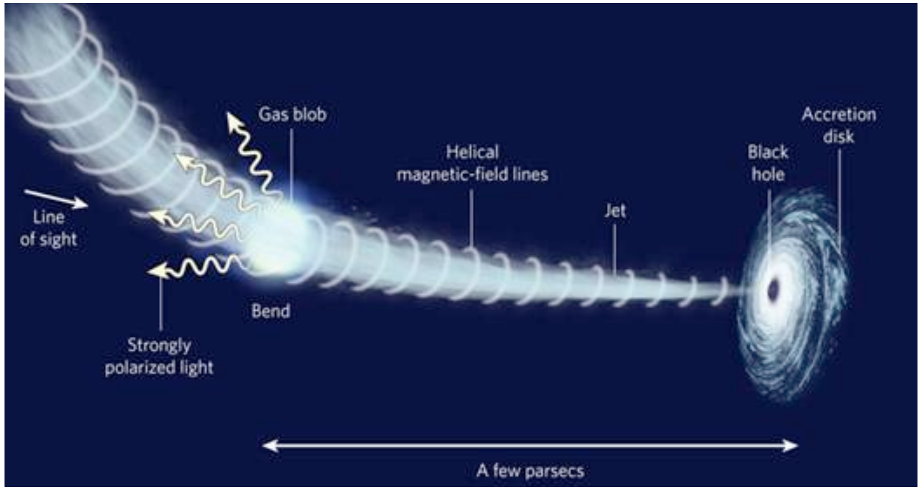
Fermi/LAT, VERITAS & Magic++
[to be submitted]

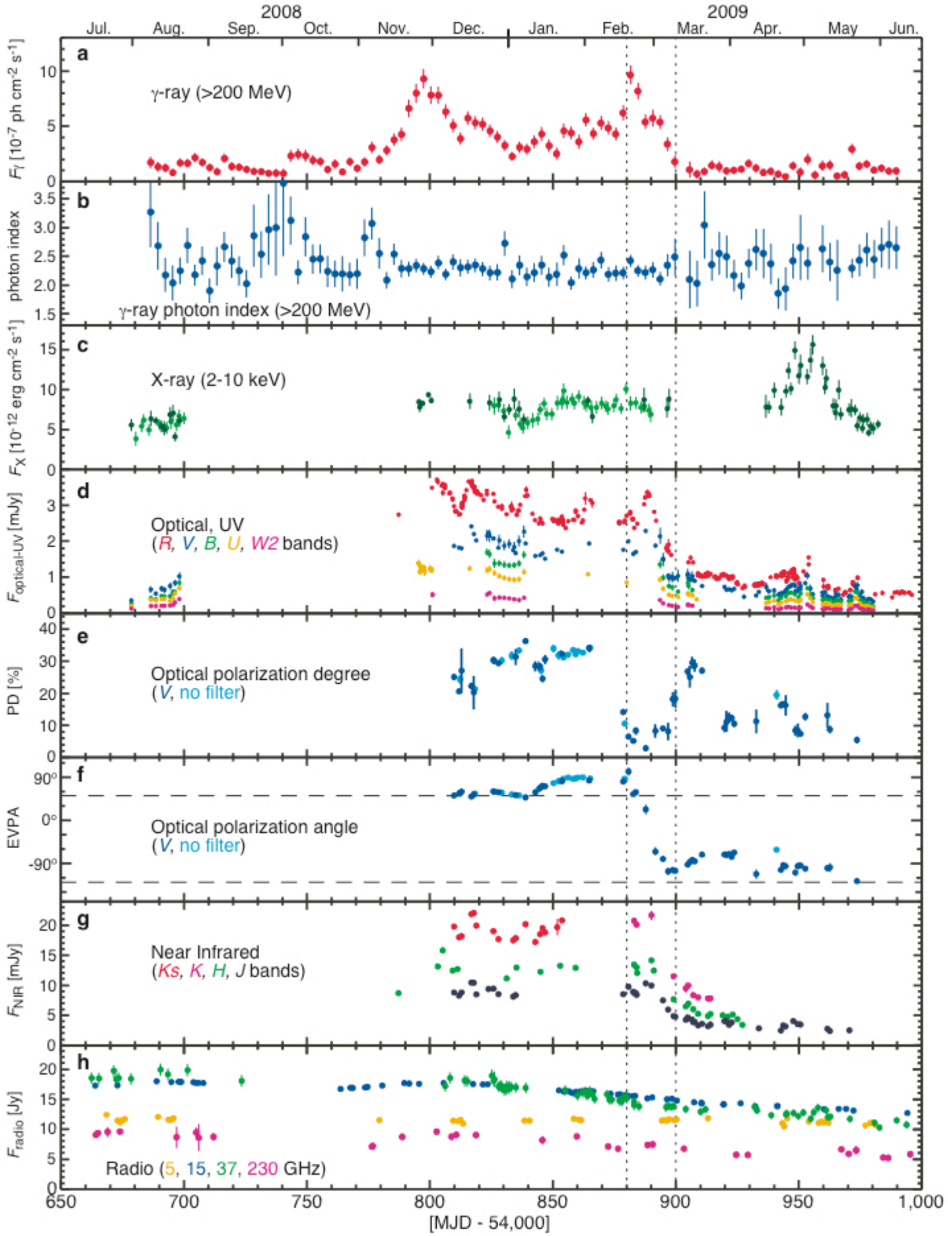
Quasar-hosted Blazars

Abdo+ 10 [Fermi/LAT]

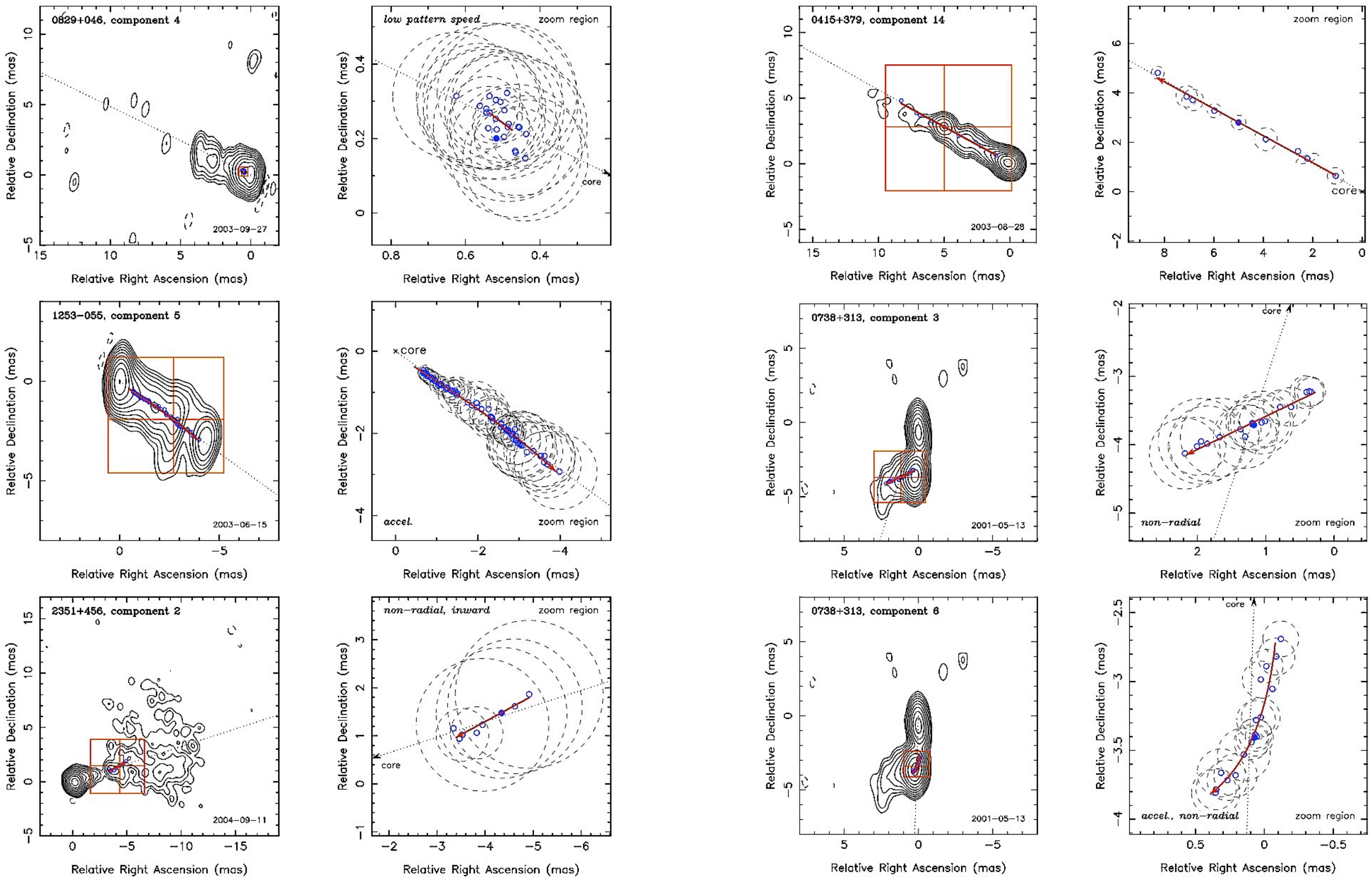
Coincidence of a gamma-ray flare with a dramatic change of optical polarization angle, occurring on the timescales of ~10 days.

The results require a non-axisymmetric structure of the emission zone, implying a curved trajectory for the emitting material within the jet, with the dissipation region located at a considerable distance from the black hole (almost pc-scales!)





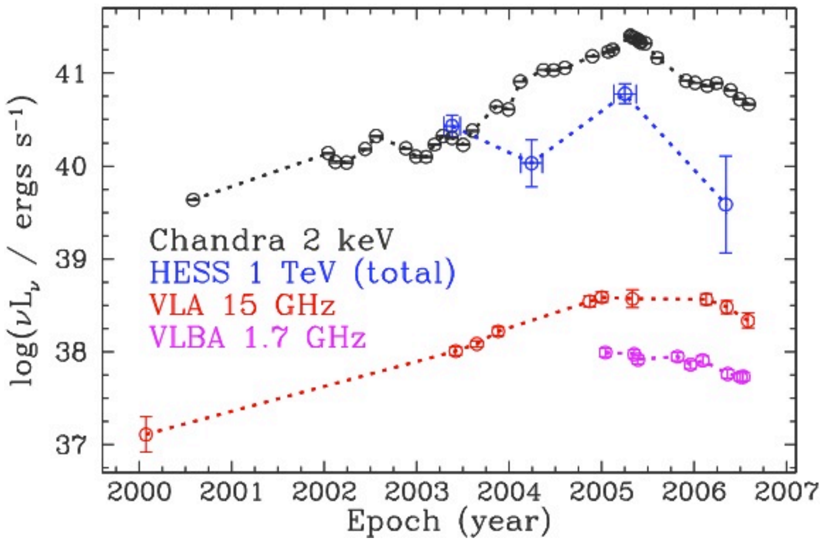
Superluminal Blobs



Lister+ 09, Homan+ 09 [MOJAVE]   Complex morphological changes on pc-kpc scales.

Interaction with the environment, variability of the central engine,
or the very nature of a steadily produced magnetized outflows?

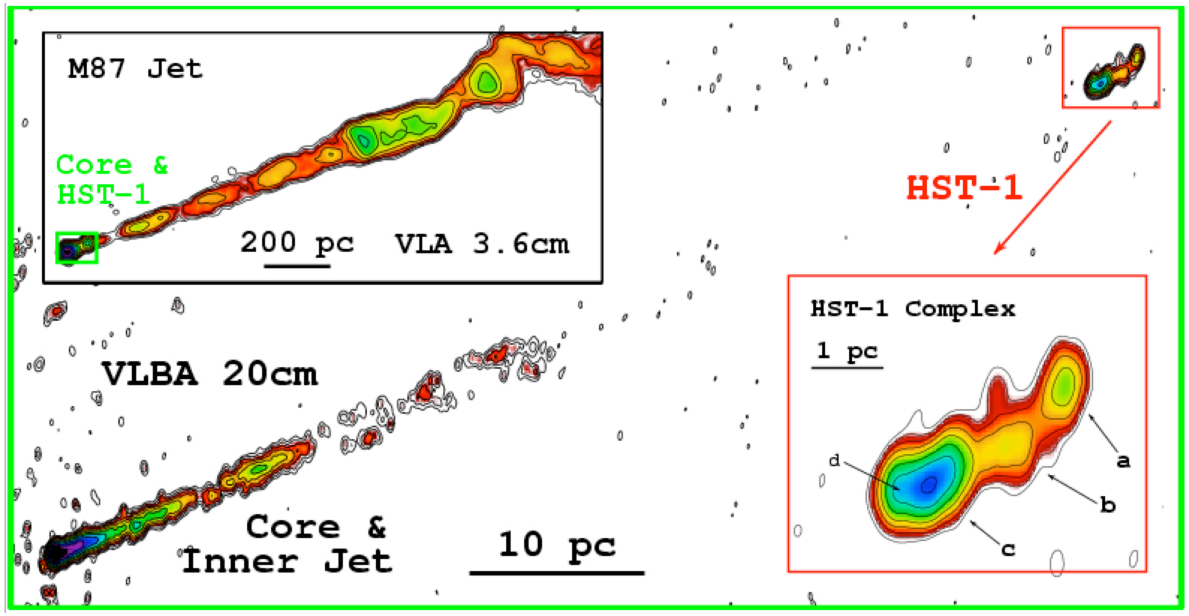
Where Are the Blobs Produced?

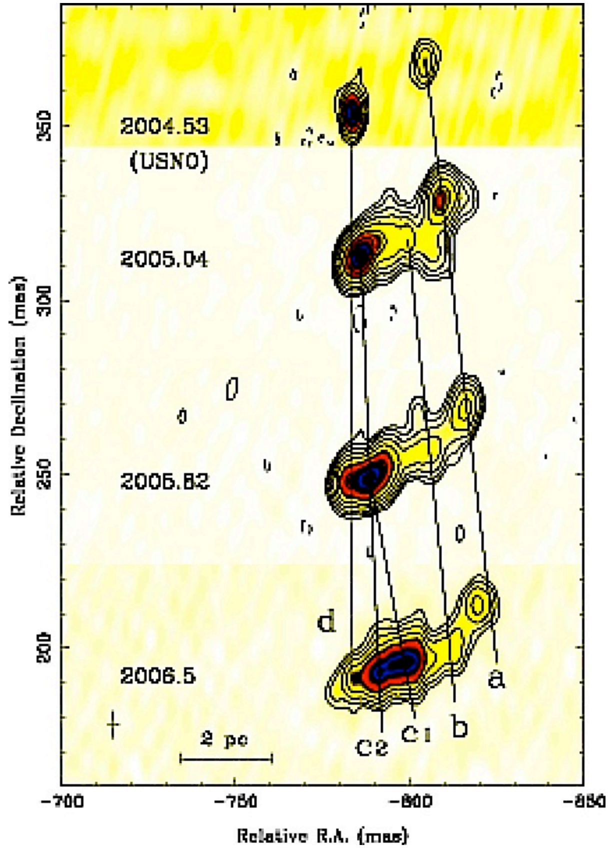


Cheung+ 07

After a huge flare, the unresolved and stationary knot HST-1 in M87 jet ejected superluminal blobs moving down the outflow.

Why does the HST-1 knot behave like a central engine?
Is the gamma-ray emission produced in HST-1 as well?



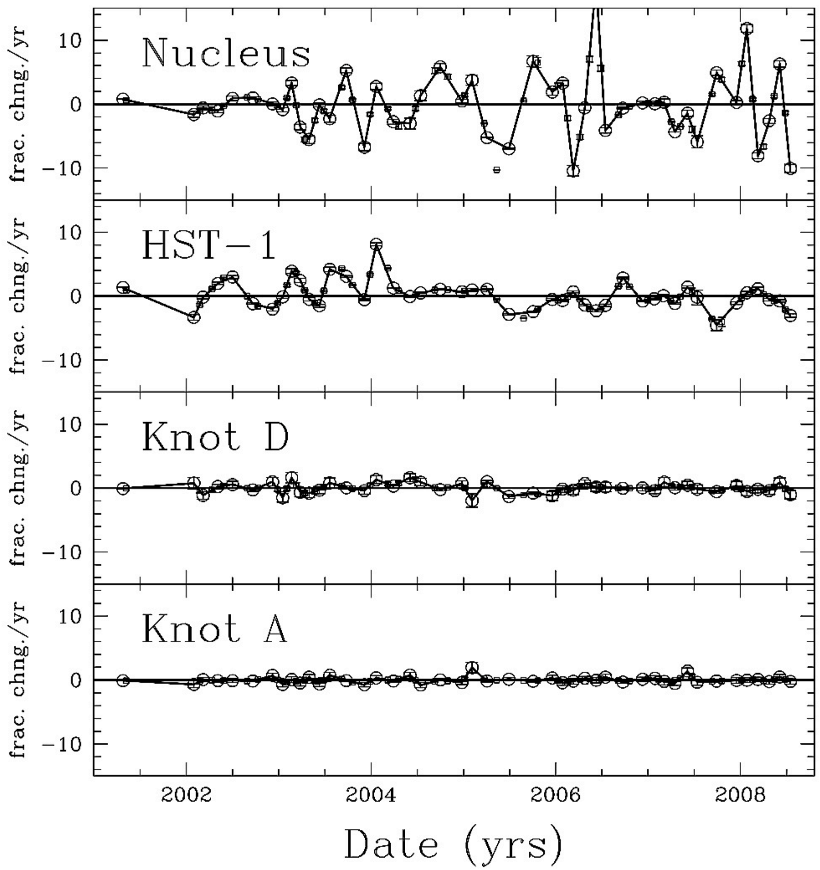


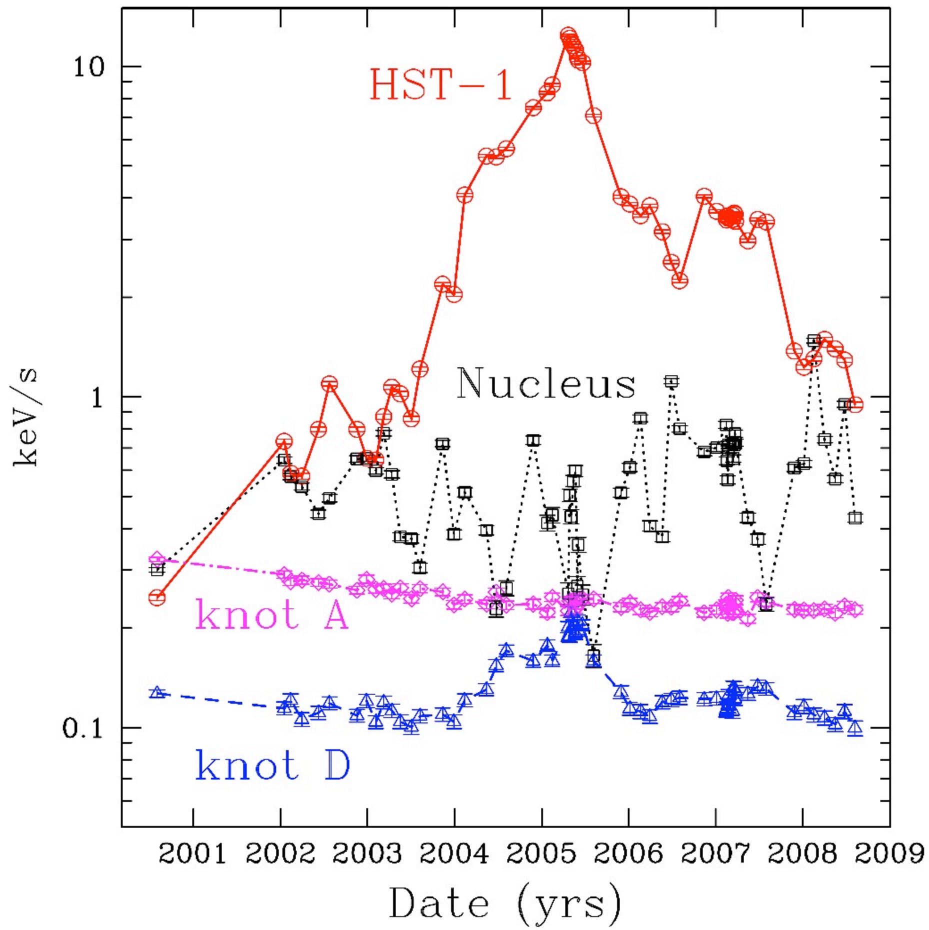
Stationary Nozzle in Jet

Harris+ 09

HST-1 knot may be understood as a nozzle of the converging (toward the jet axis) stationary reconfinement shock formed within the jet confined by the ambient pressure (LS+ 06).

Yet what causes its variability on timescales from days to years, remains an open question.

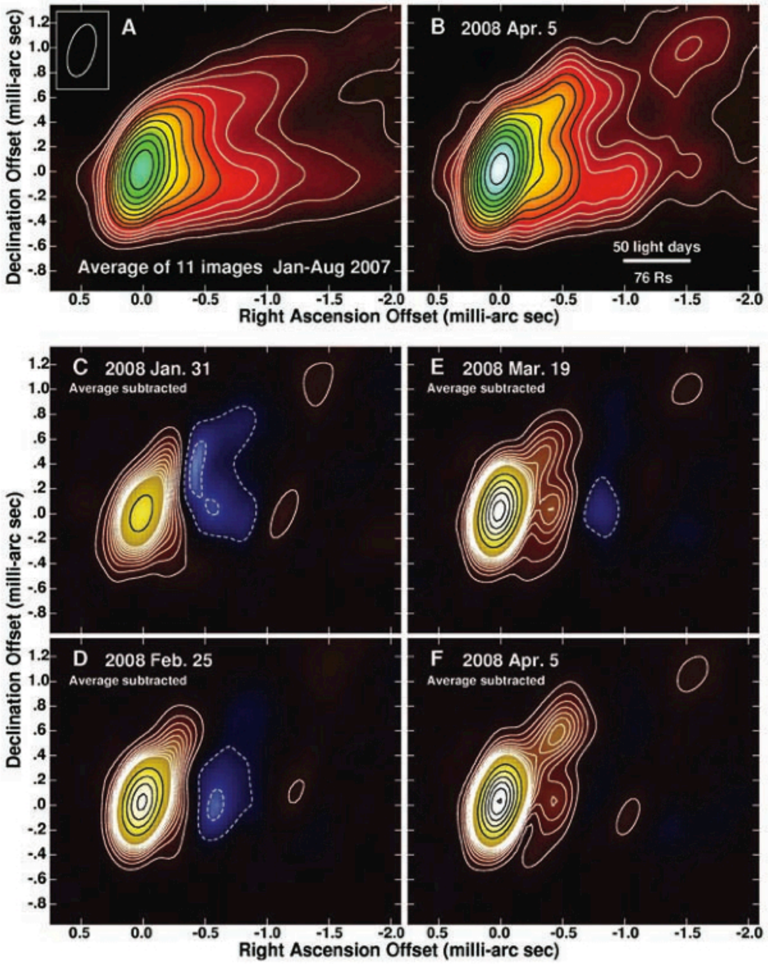


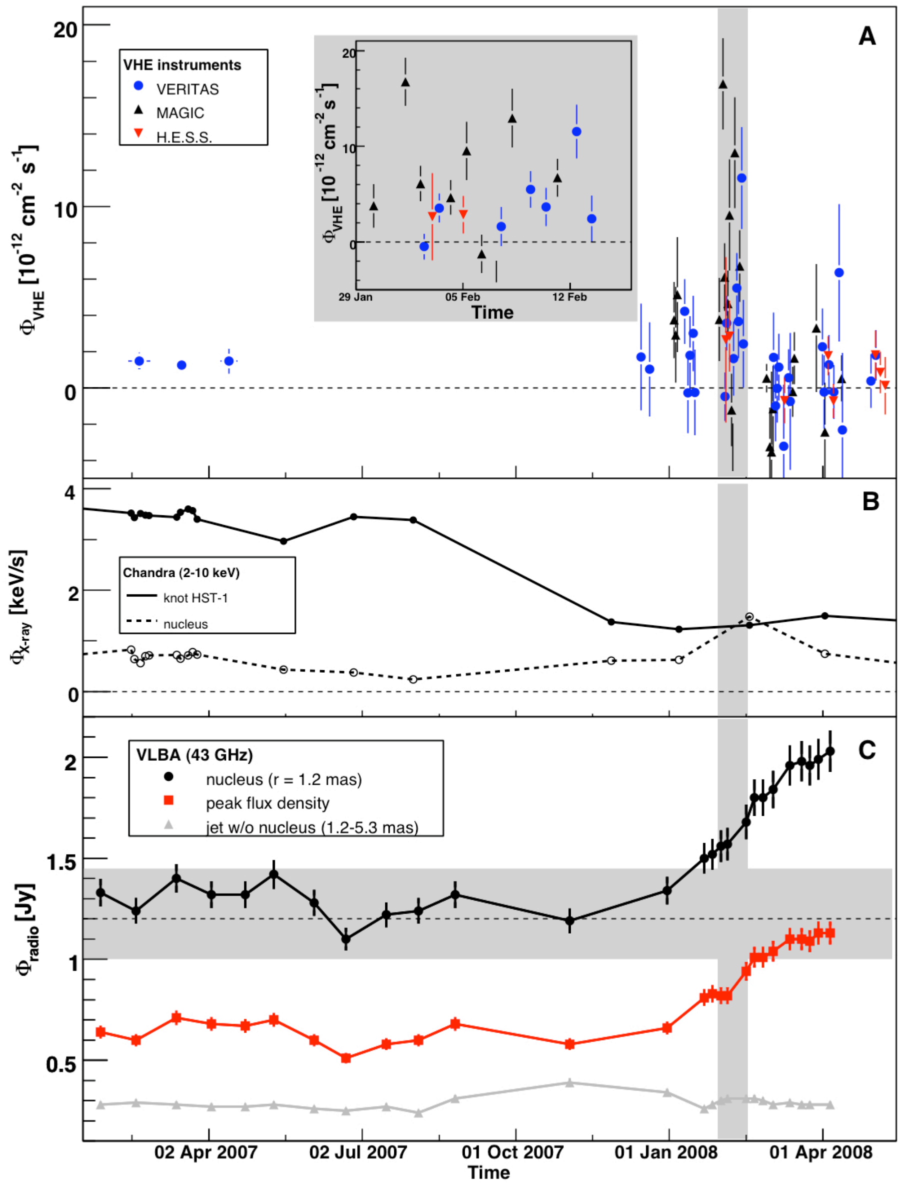


Elusive M87 Source

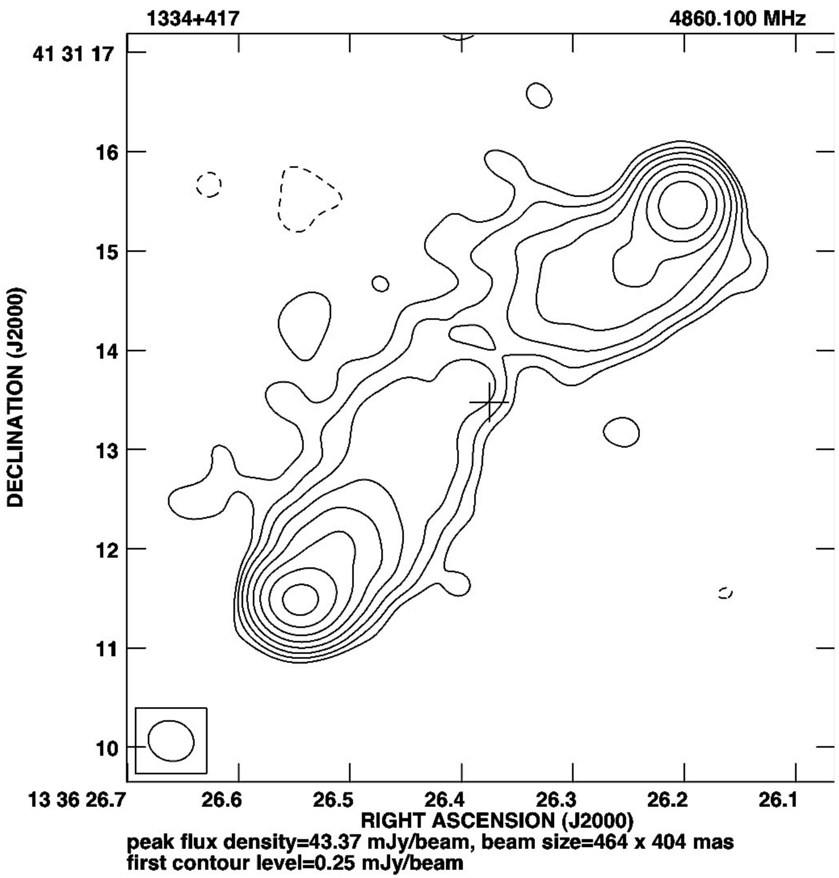
Acciari+ 09 [HESS, VERITAS & Magic]

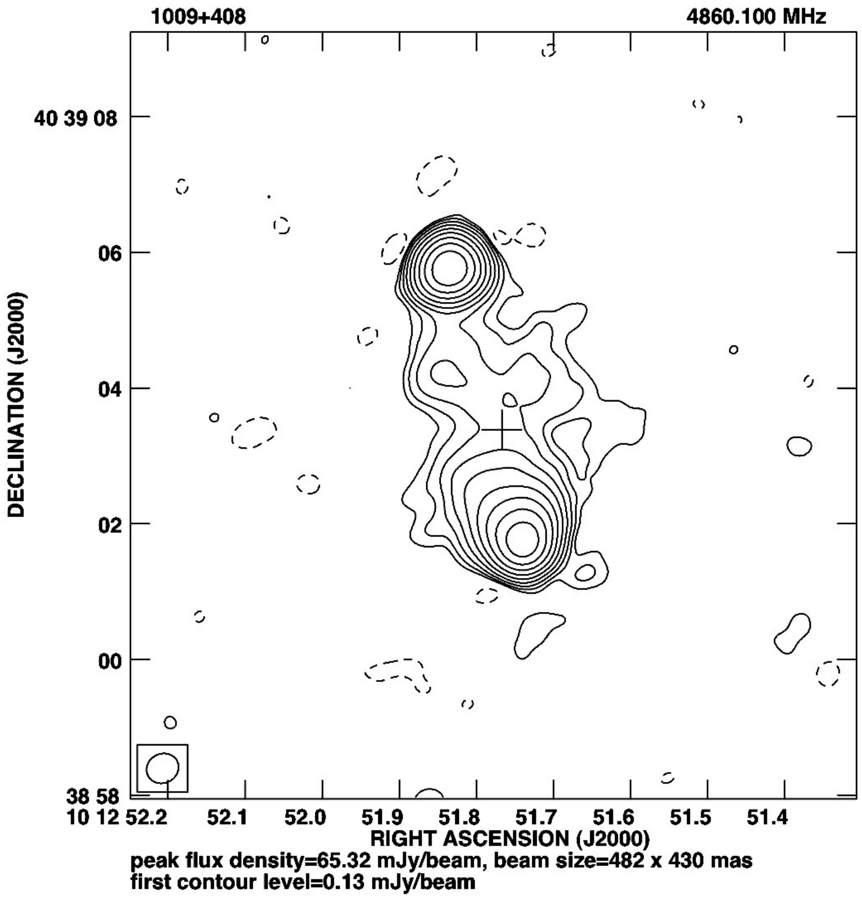
The observed gamma-rays may be instead produced in the innermost parts of the M87 jet.





Young Radio Galaxies



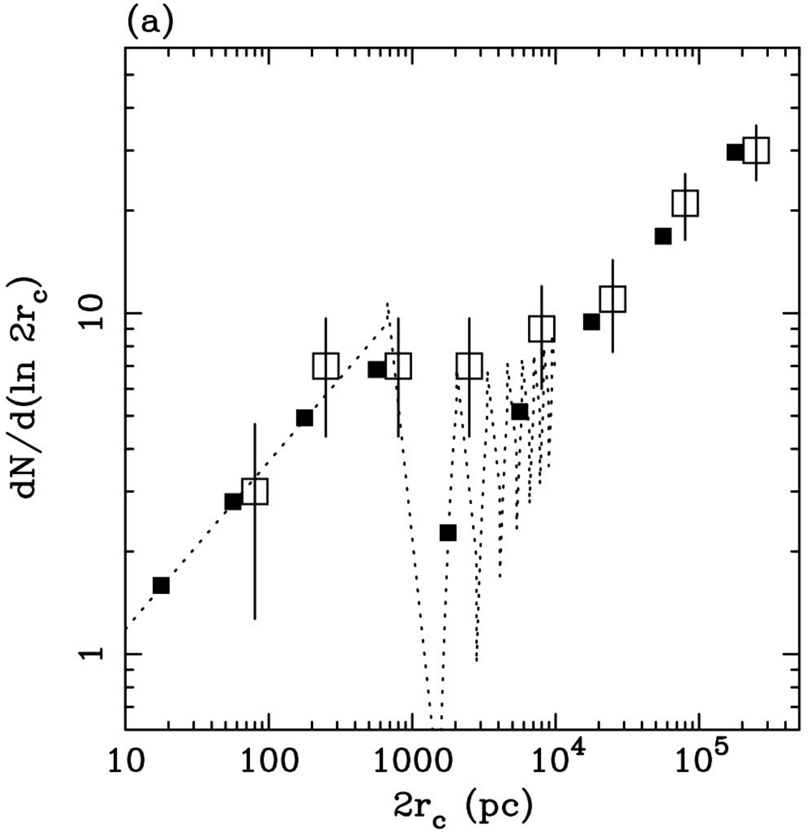


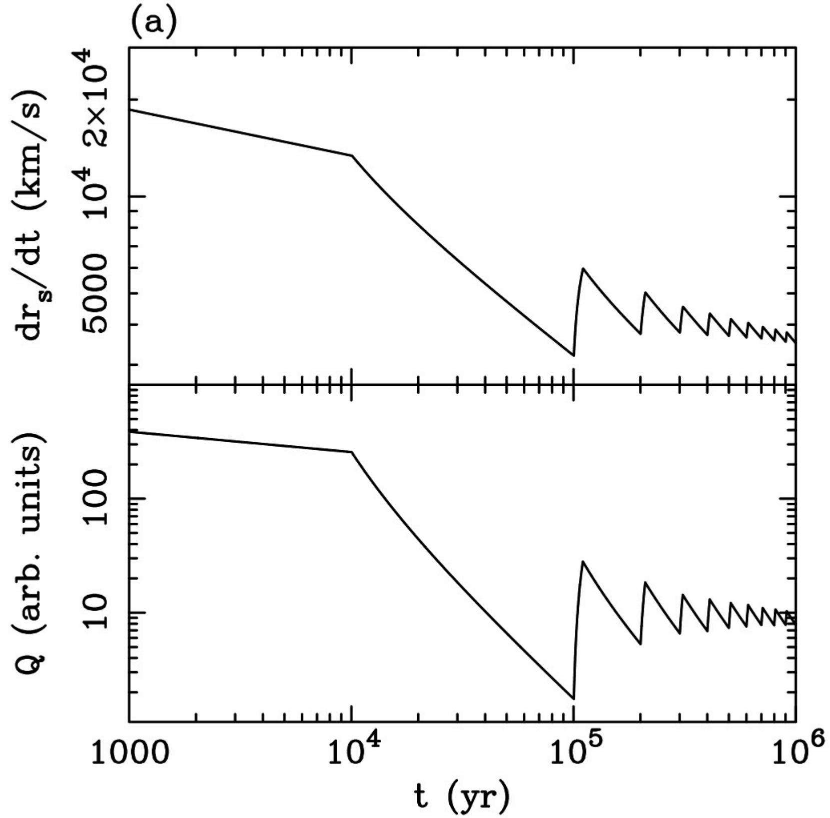
Kunert-Bajraszewska+ 05

Compact/Medium Symmetric Objects (~ Gigahertz-Peaked Spectrum/Compact Steep Spectrum sources) resemble regular (extended) radio galaxies, however on much smaller scales (0.1-10 kpc)

It is established that these are young, i.e. newly born radio sources (O'Dea 98, Siemiginowska+ 09)

Intermittent Activity?



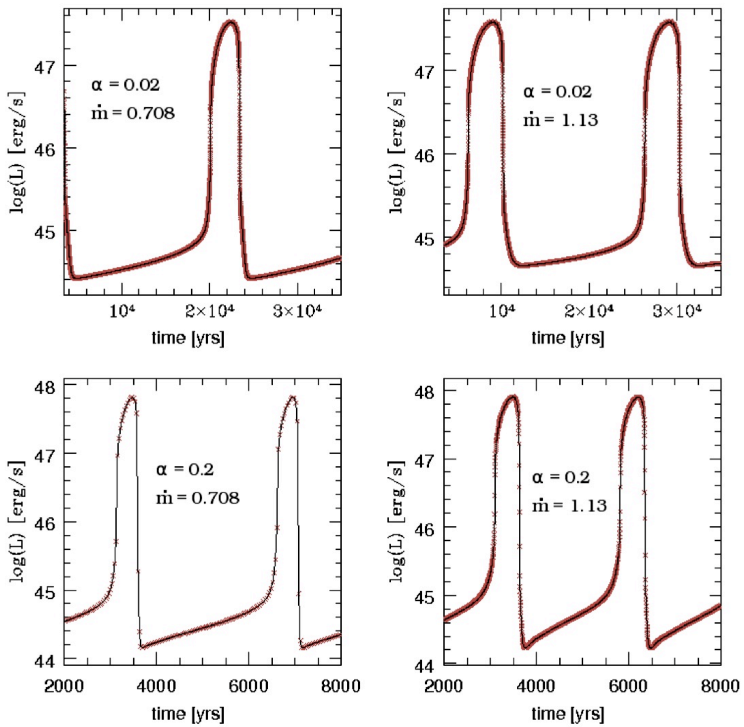


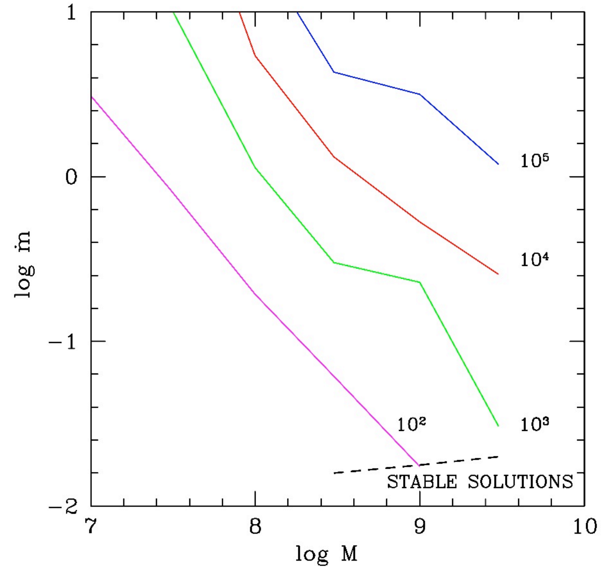
Reynolds & Begelman 97, Siemiginowska & Elvis 97

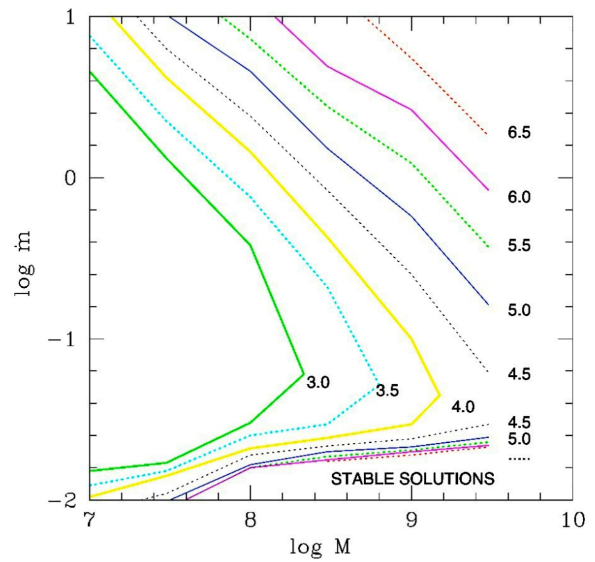
We expect that young radio sources should evolve into extended radio galaxies. However, assuming a simple evolutionary model for such one may find that there are too many young radio galaxies for the observed number of the extended objects.

This can be explained by assuming that the jet production activity is highly intermittent: ~10^3-10^4 yr activity epochs separated by ~10^4-10^5 yr quiescence epochs.

Accretion Disk Instabilities





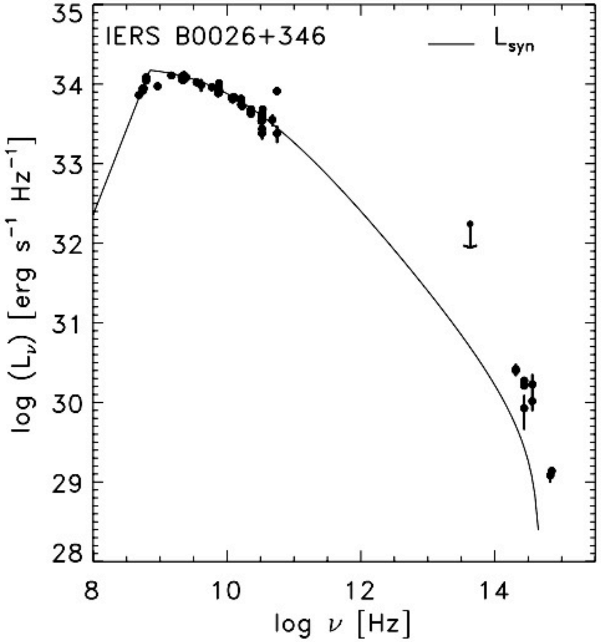


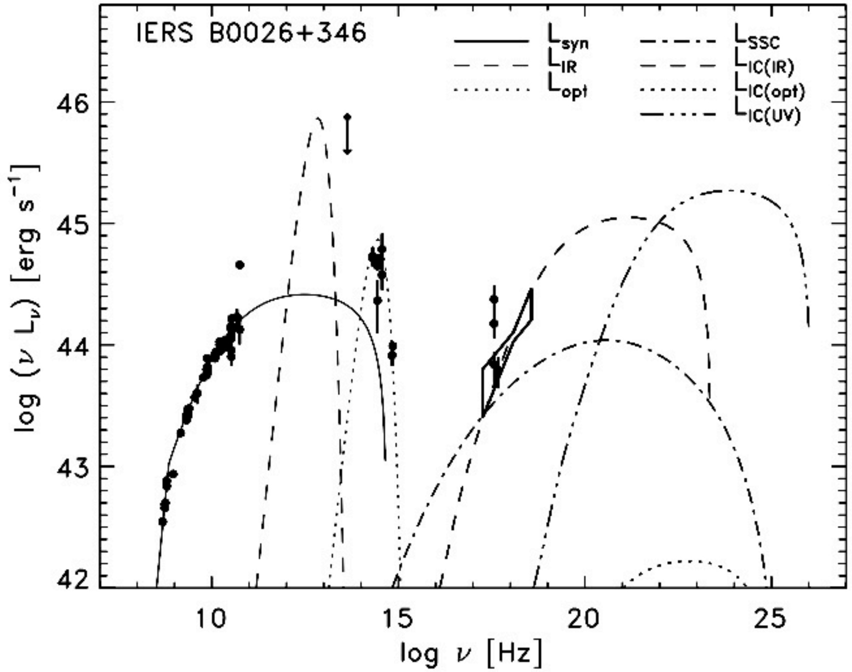
Czerny + 09

Statistics and morphological properties of young radio sources may be explained assuming that the jet activity is shaped by the instabilities operating within the accretion disk

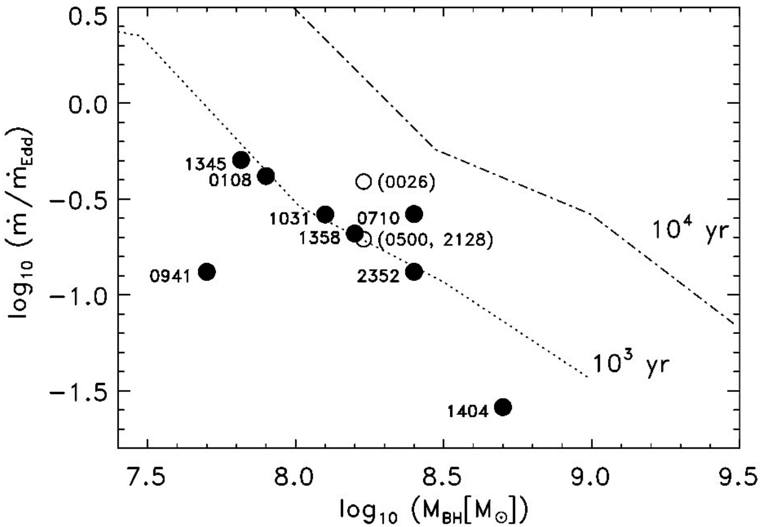
Here the radiation pressure instability is investigated ($M = 10^8\ M_\odot$, $\alpha = 0.2$)

Modelling Young Radio Galaxies





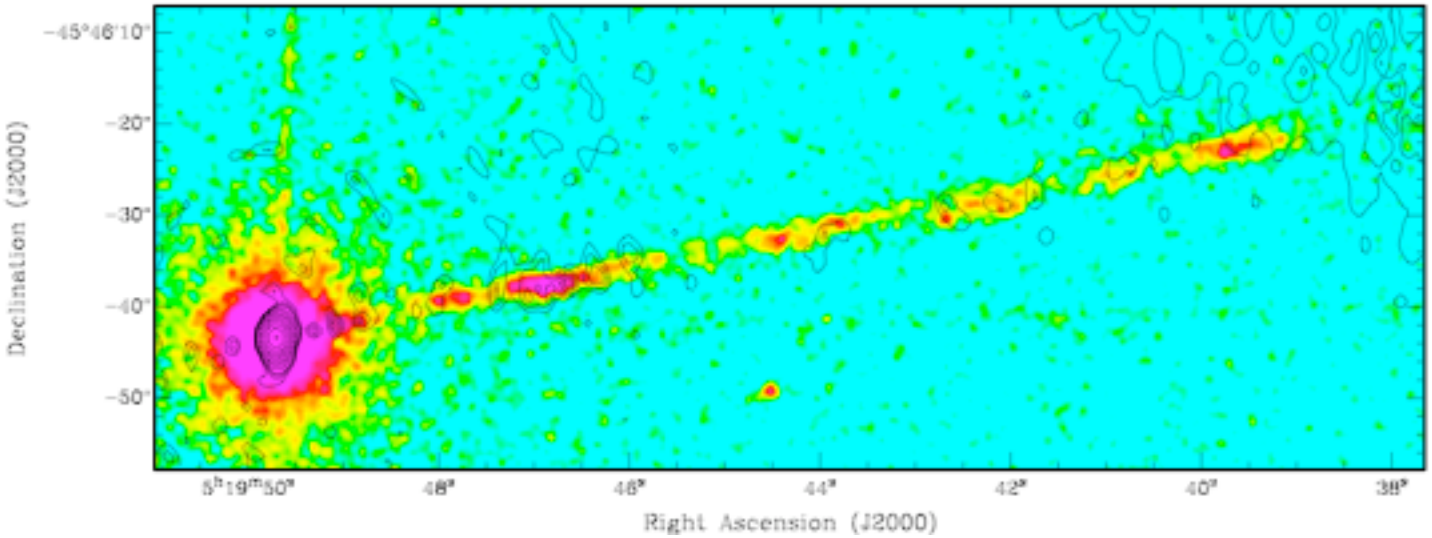
Ostorero+ 10

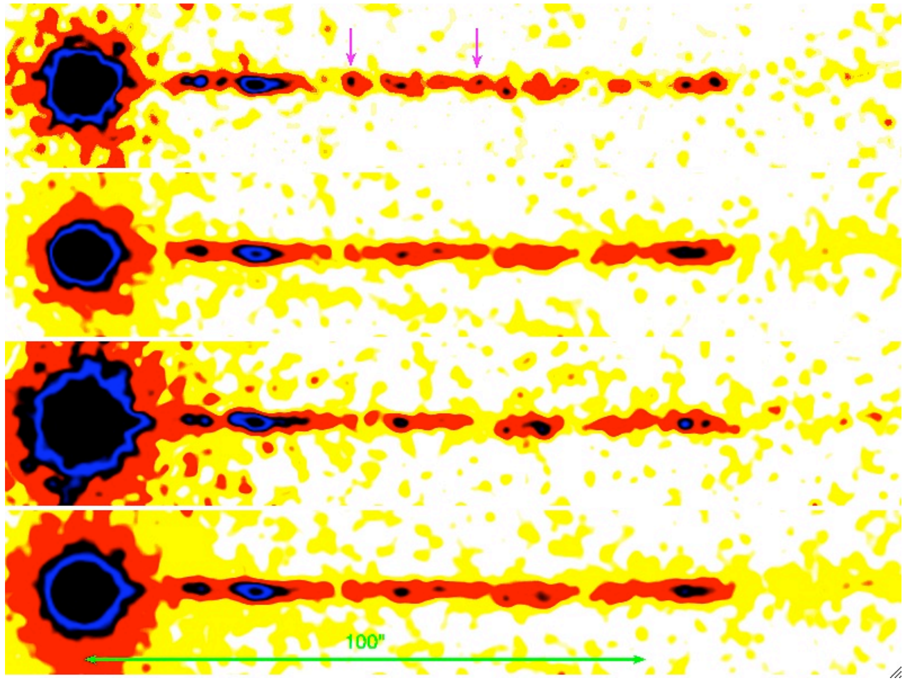


Different types of instabilities may operate in AGN accretion flows, but the pressure-driven instability operating above the threshold accretion rate of ~0.02 (in the Eddington units) is particularly promising in the context of young radio sources.

Broad-band modeling of young radio galaxies (LS+ 08) indicates that indeed all of them accrete at high rates.

Large-scale Quasar Jets



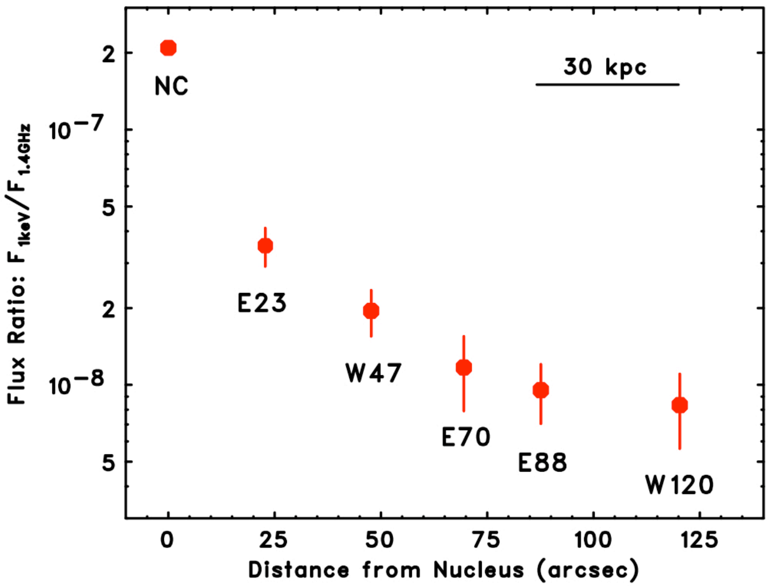


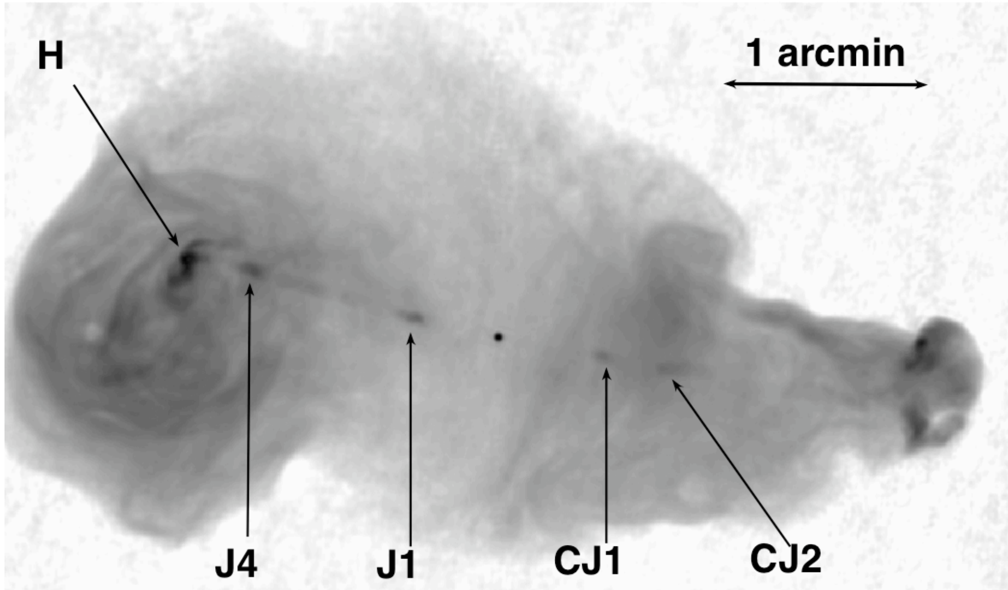
Marshall+ 10

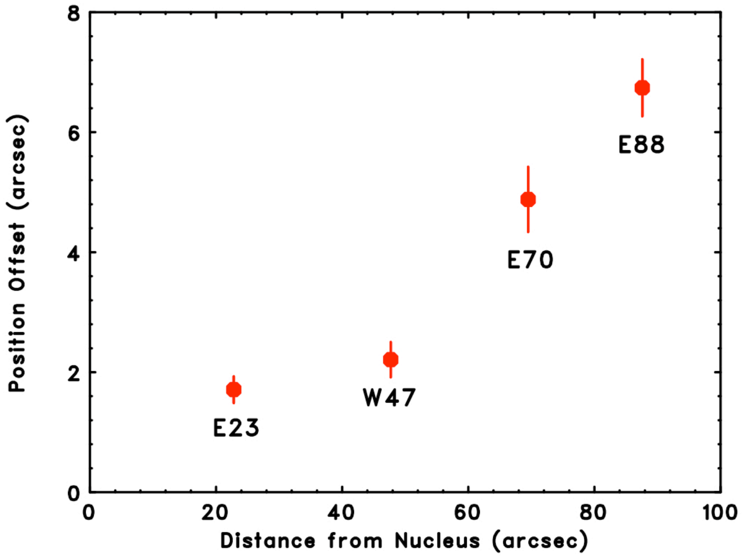
Chandra X-ray Observatory detected surprising variability of the knot in 100 kpc-scale jet of Pictor A (~4σ level).

At this scale, we expect only >10^3 yr variability timescale, but we observed 1-10 yr variability in X-rays. This suggest sub-structure of the outflow, and bulk of the observed emission produced in a tiny sub-volume of the jet.

Knots in Large-scale Jets





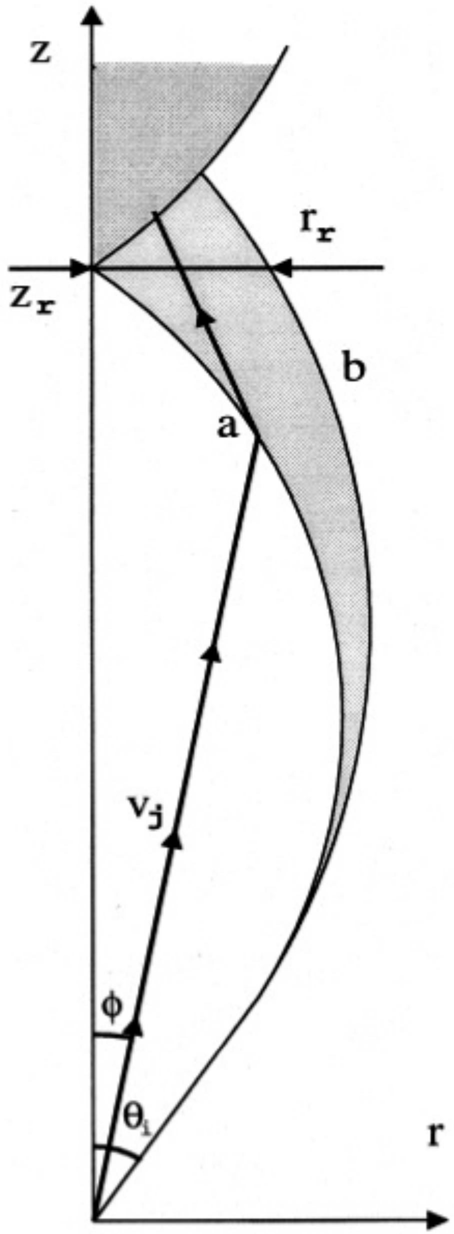


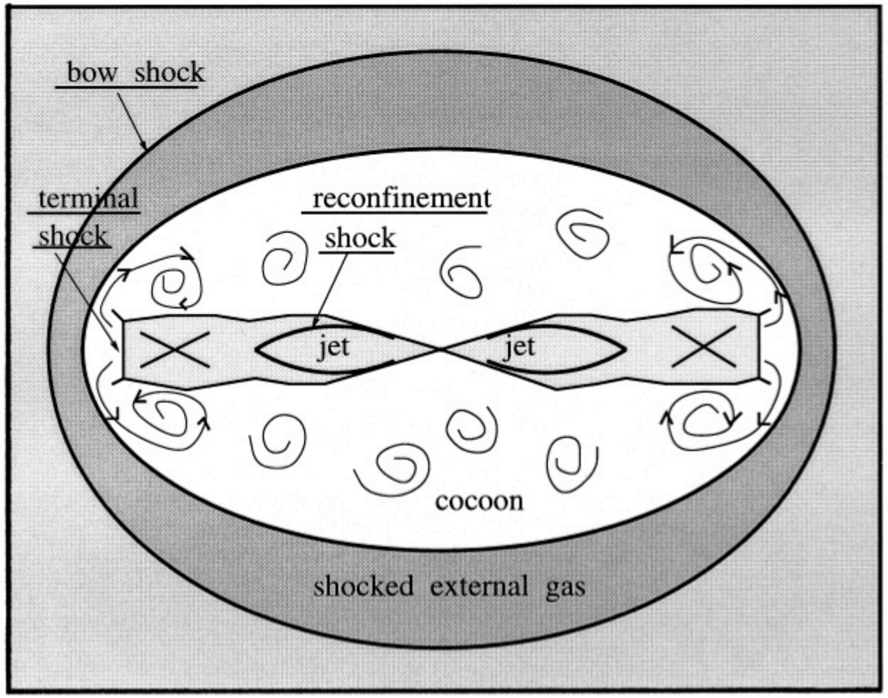
Kataoka+ 08

Chandra X-ray observations of radio galaxy 3C 353 revealed that the knots' profile are frequency independent, although the positions of radio and X-ray peaks do not coincide. These seem to be general properties of large-scale quasar jets.

What is the origin of radio/X-ray offsets? What is the origin of the knotty morphology of quasar jets?

Reconfinement Shocks?





Komissariv & Falle 98

Knots in large-scale quasar jets may be understood as a sequence of reconfinement shocks formed within supersonic outflows confined by their extended overpressured lobes.

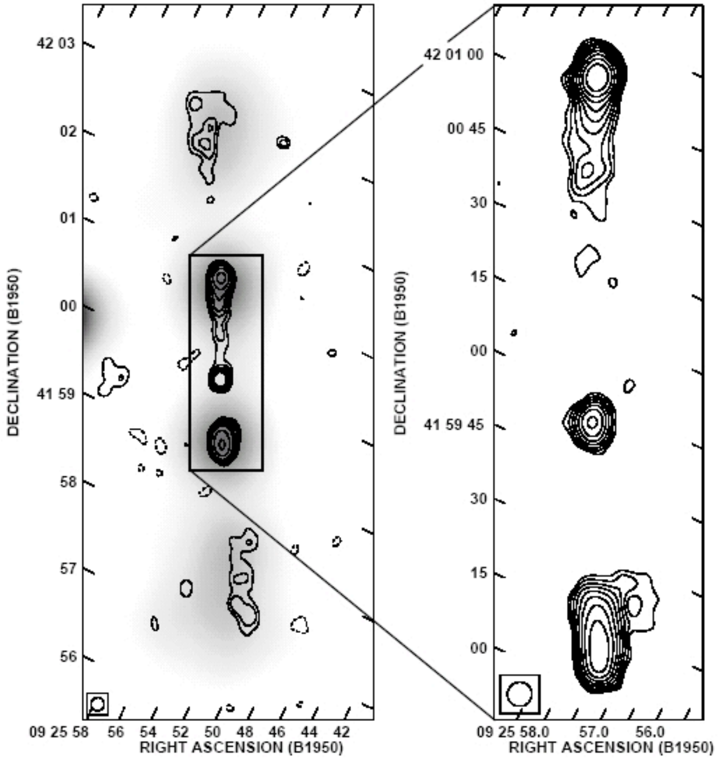
Yet the observed multiwavelength properties of the knots do not fit this picture. Alternatively, the knots may result from a modulated activity of the central engine (10^4 yr-long epochs of the enhanced activity; LS+ 04)

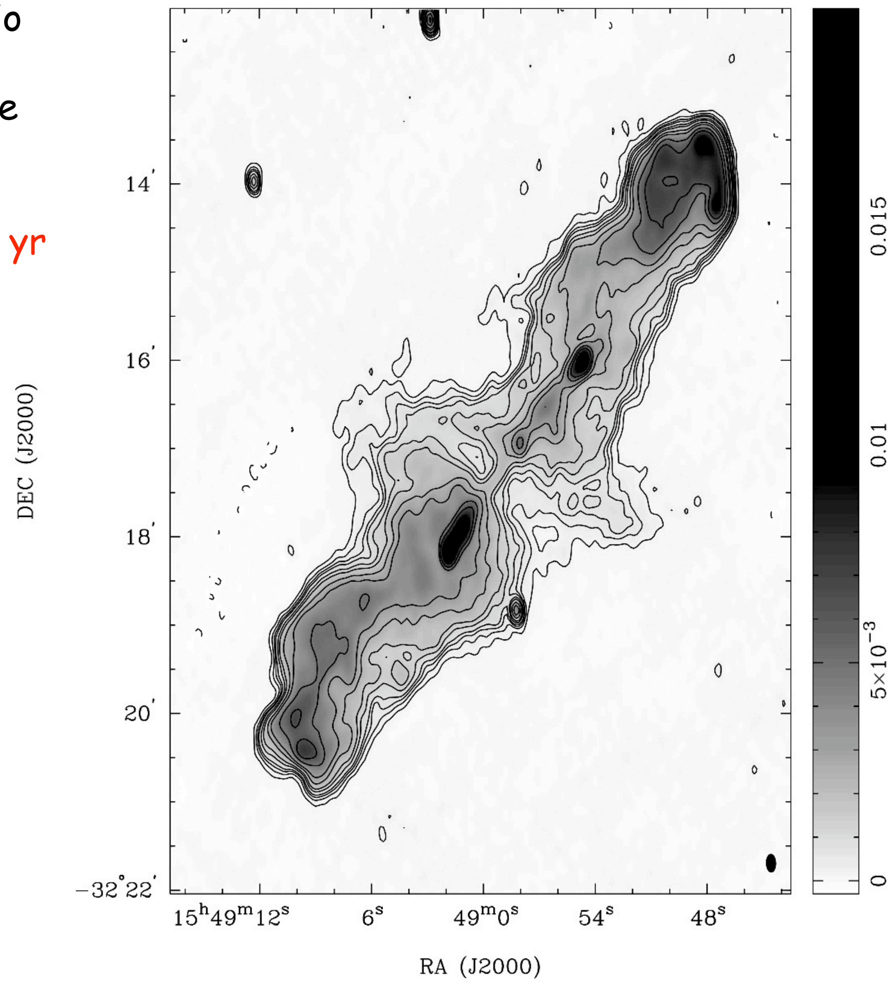
Double-Double Radio Galaxies

Schoenmakers 00, Saripalli+ 05

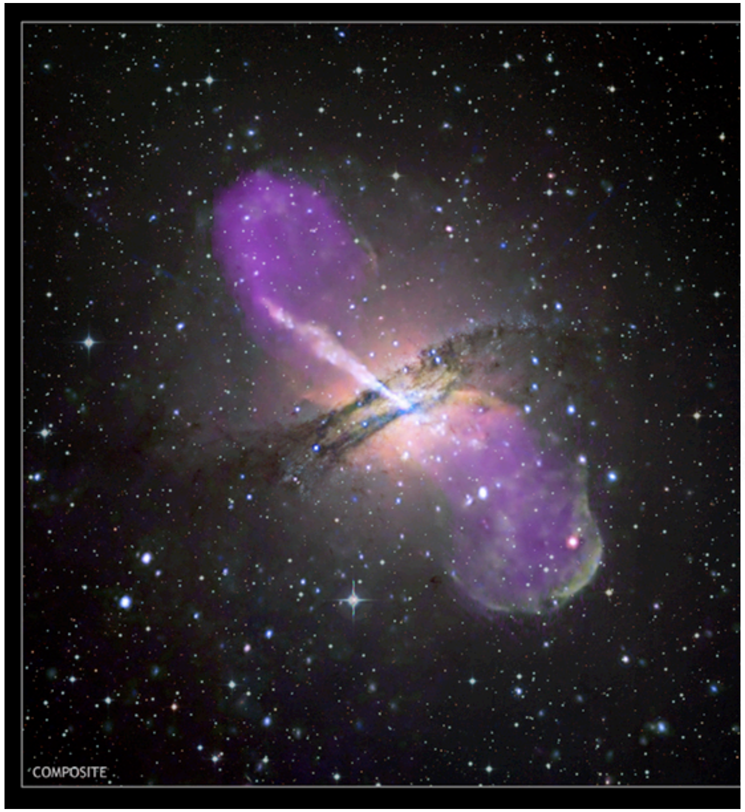
Giant radio galaxies displaying "double-double" radio morphologies are clear examples of restarted jet activity (Kaiser 00). Some of them possess GPS-like radio core (Mareski+ 03).

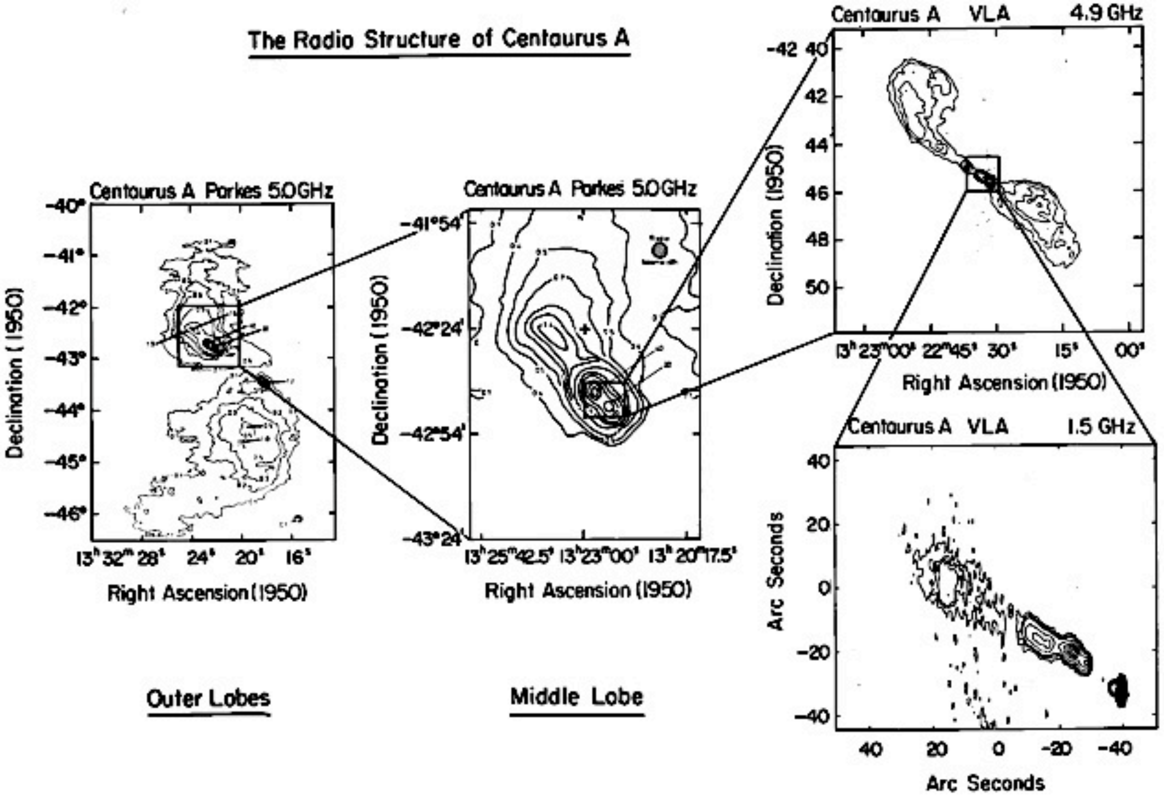
What triggers a new epoch of the jet activity (~ 10^6 yr after the previous one) along the same axis?





Multiple Lobes in Cen A





Israel 98

Complex large-scale morphology of the radio lobes in nearby radio galaxy Cen A (including its giant 100s of kpc outer lobes, 10s of kpc middle lobe, and few kpc-scale inner lobes) is due to recurrent jet activity, possibly related to the recent merger of the Cen A host galaxy with a spiral companion.

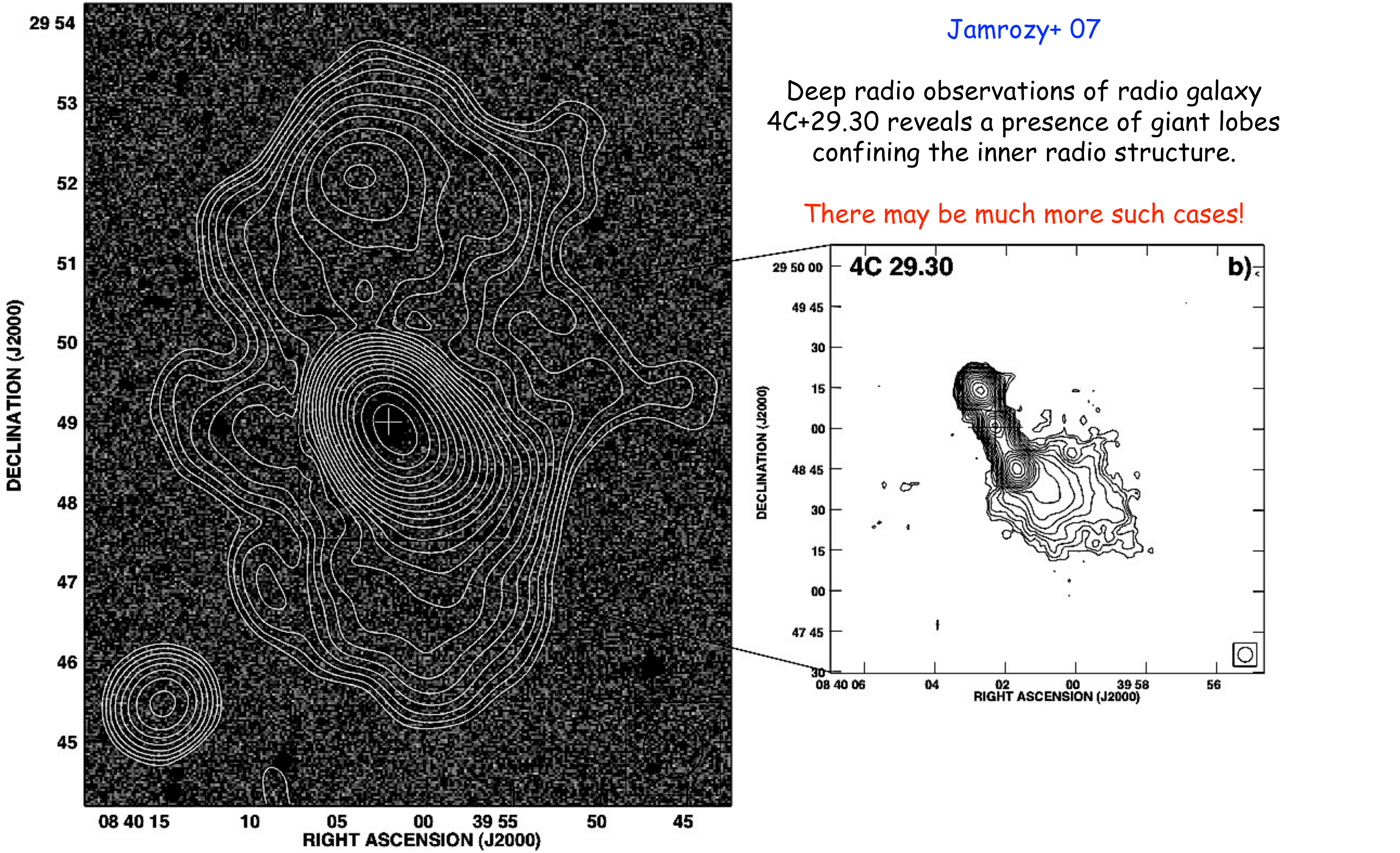
Is it a typical situation, or an exception?

Rather Typical...

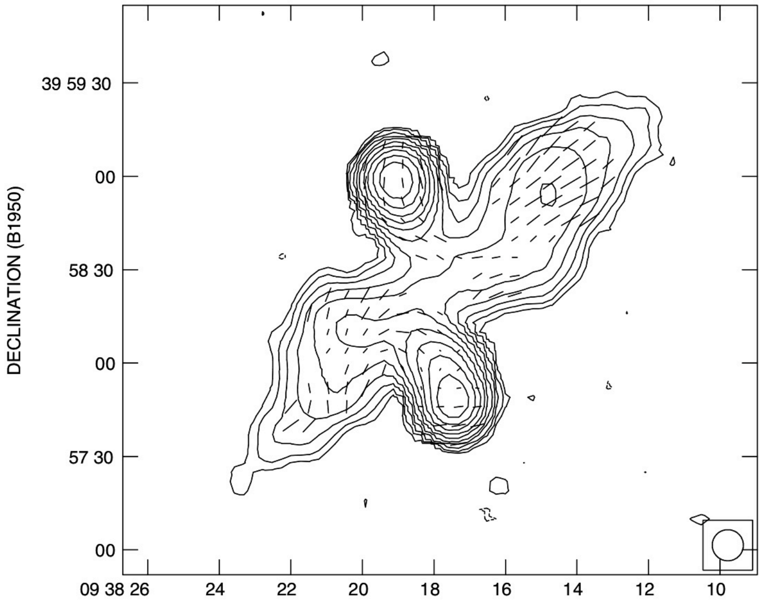
Jamrozy+ 07

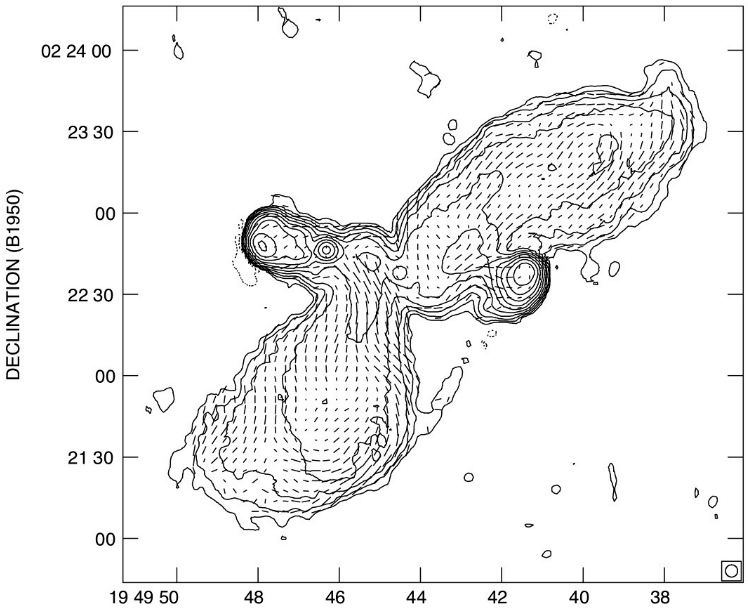
Deep radio observations of radio galaxy 4C+29.30 reveals a presence of giant lobes confining the inner radio structure.

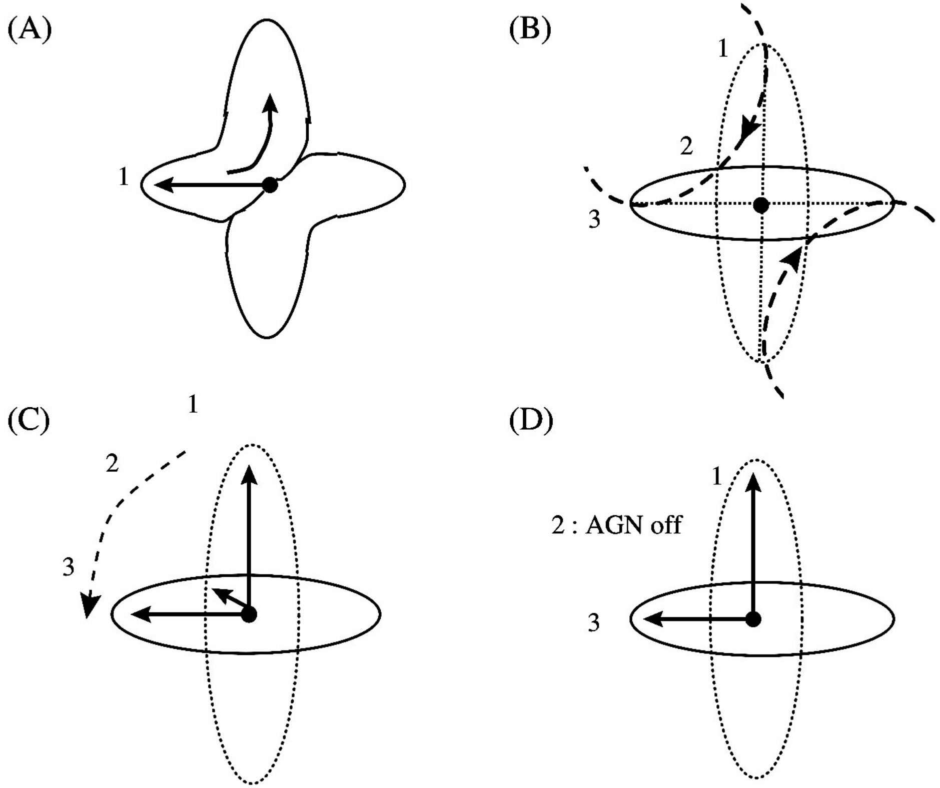
There may be much more such cases!



X-shaped Sources





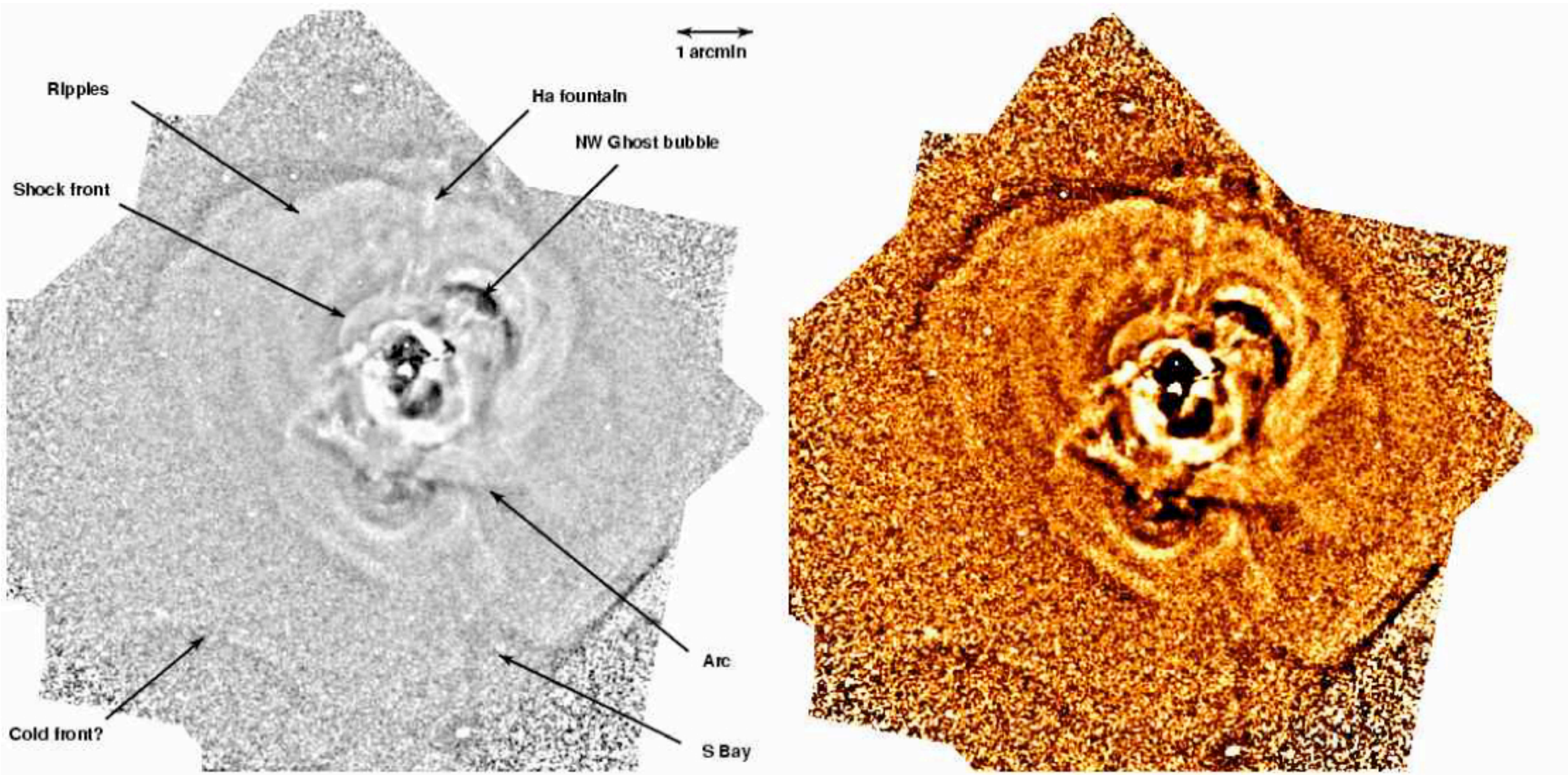


Dennett-Thorpe+ 02, Merritt & Ekers 02

Large-scale morphology of X-shaped radio galaxies suggests rapid re-orientation of the jet axis, possibly caused by the re-orientation of the black hole spin axis.

Is this re-orientation due to a merger of two black holes, or due to a tilted accretion disk?

AGN in Clusters

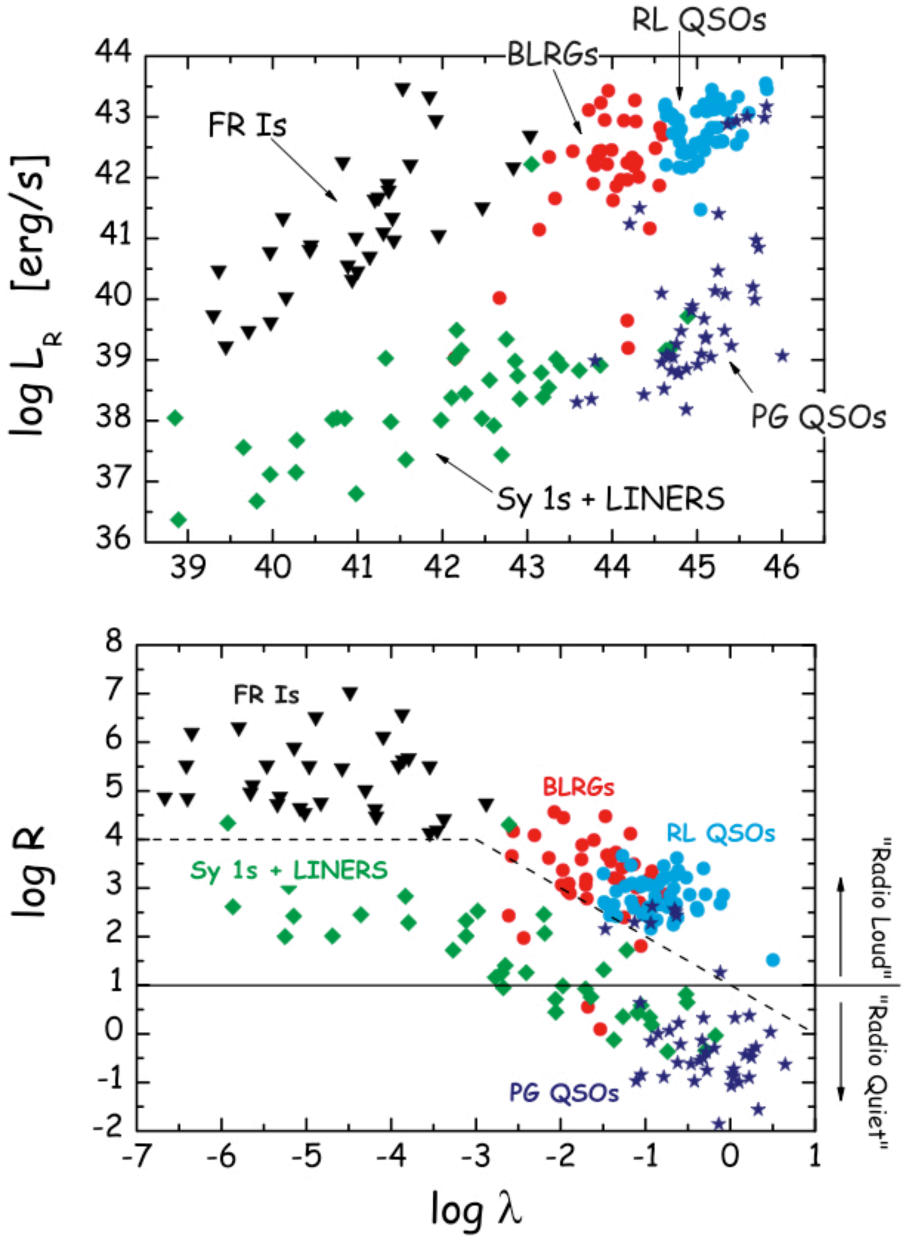


Fabian+ 06

X-ray structure of the Perseus cluster seems to suggest highly intermittent jet activity of the central radio galaxy Perseus A, involving precession of the jet axis.

The origin of such an intermittency is not clear.

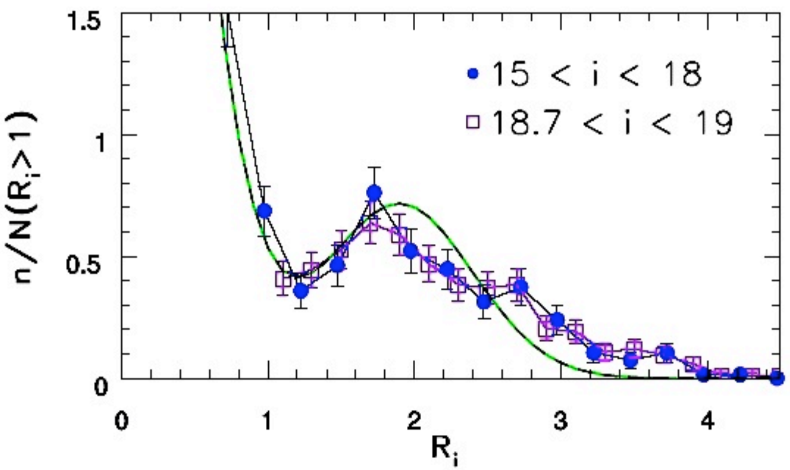
Radio Loud and Radio Quiet



Sikora+ 07

In addition to the "classic" radio-loudness bimodality of quasars (if there is any), there is an another bimodality related to a type of host galaxies.

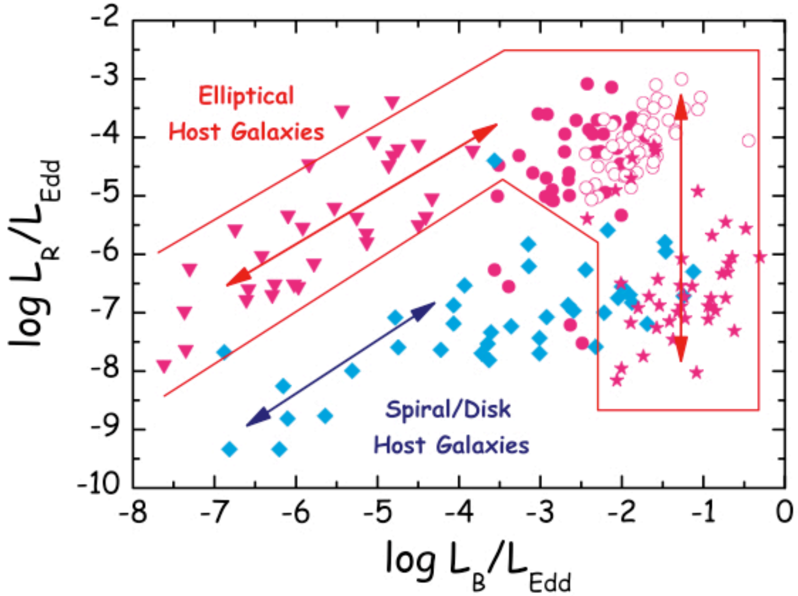
What controls the distribution of the radio-loudness parameter in AGN, i.e. the efficiency of the jet production?

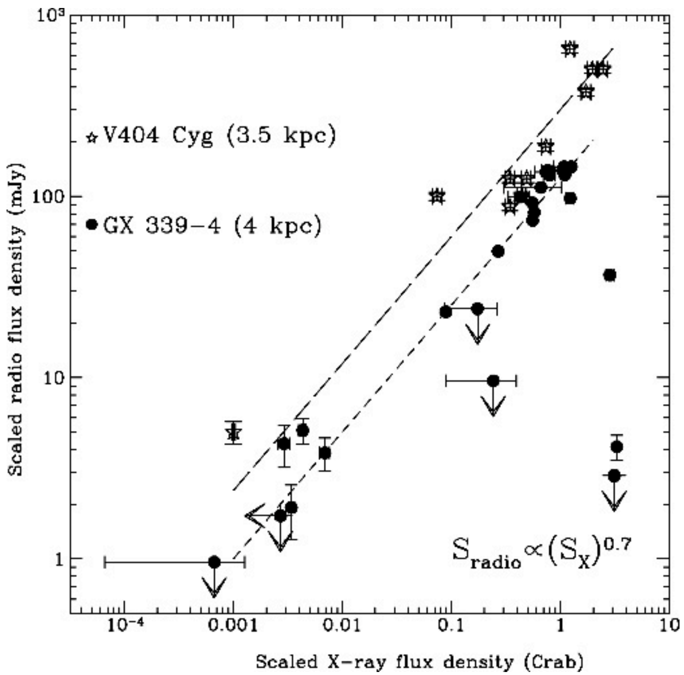


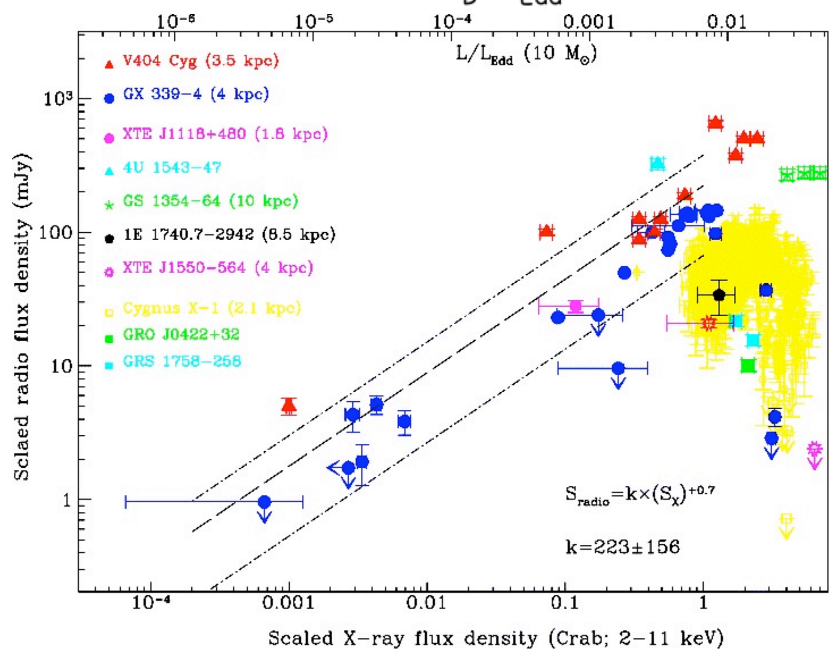
AGN and X-ray Binaries

Sikora+ 07, Nipoti+ 05, Kording+ 06

If there is any analogy between AGN and X-ray binaries regarding the jet production process (Gallo+ 03, Fender+ 04), the bimodial distribution of quasars in radio-loudness could be considered as being due to intermittent conditions for the jet launching and/or formation in systems accreting at the highest (Eddington) rates.







Variability/Intermittency

Jetted AGN are variable at different timescales, ranging from minutes to 100s of Myrs.

This variability manifests in dramatic flux and spectral changes of blazar sources, in morphological changes of pc-scale blazar jets, in diverse large-scale morphologies of extended radio structures, but also in statistics of radio-loud AGN.

Physical processes controlling AGN variability are still not fully understood and recognized, but we learned that different factor may play a role in this context (accretion disk instabilities, variable supply of the accretion fuel, MHD instabilities within the outflows, interaction of the jets with their environments, etc.).