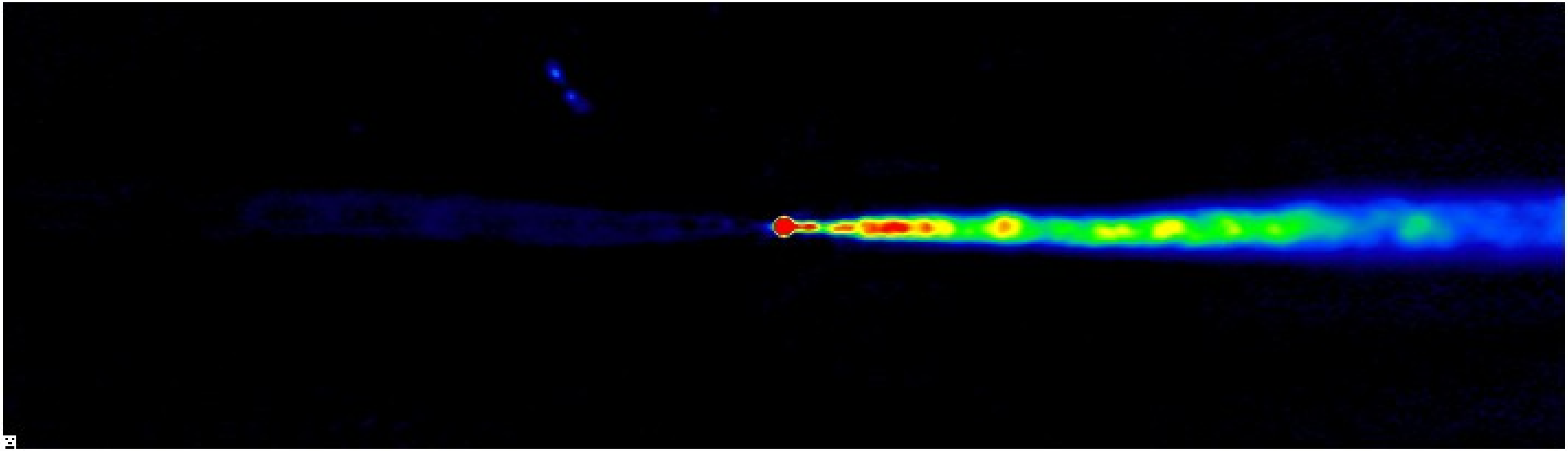
Radio Galaxies: Physics and Surveys

Robert Laing (ESO)



... or what is someone who normally works on single objects doing in a survey meeting?

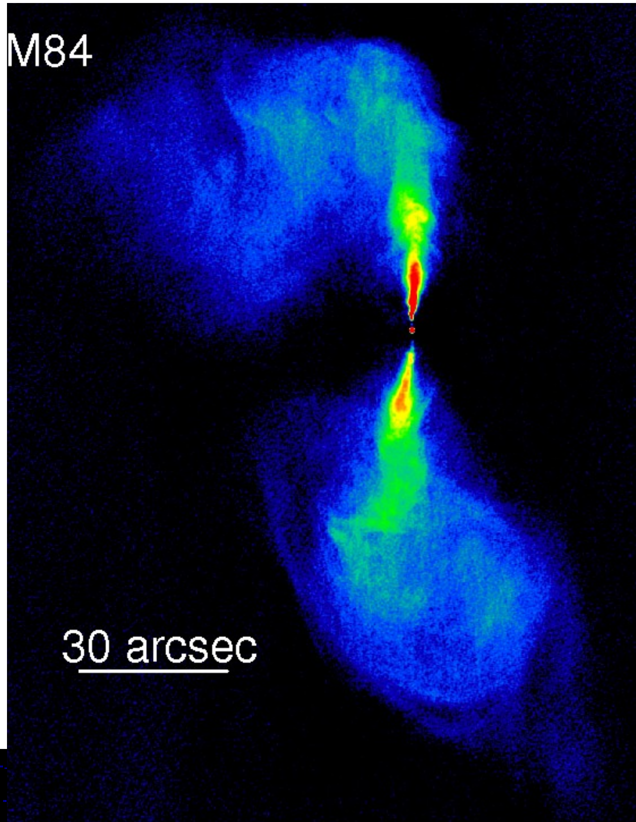
My work on radio surveys

Selected Topics

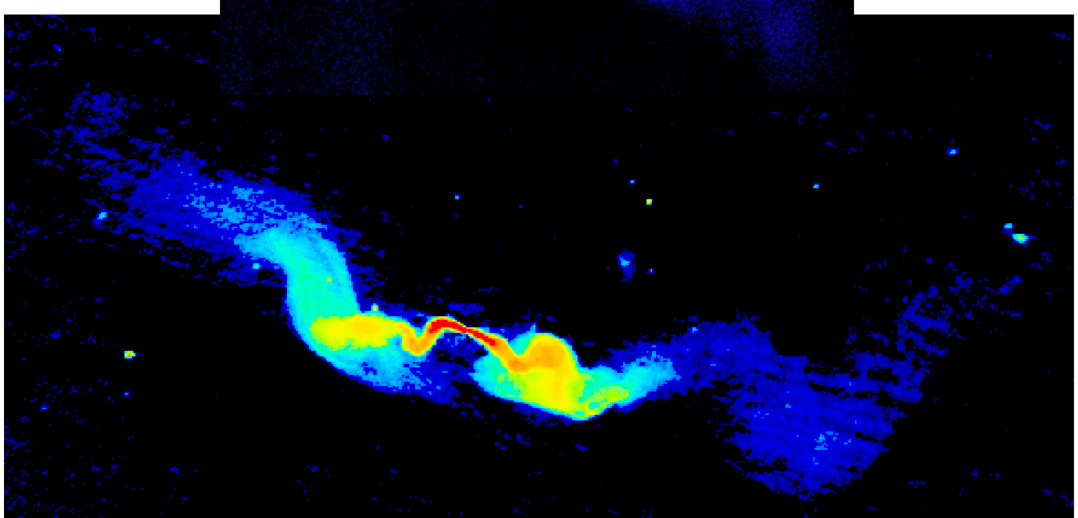
- Jet velocities and particle acceleration processes
- Magnetic fields in and around radio galaxies

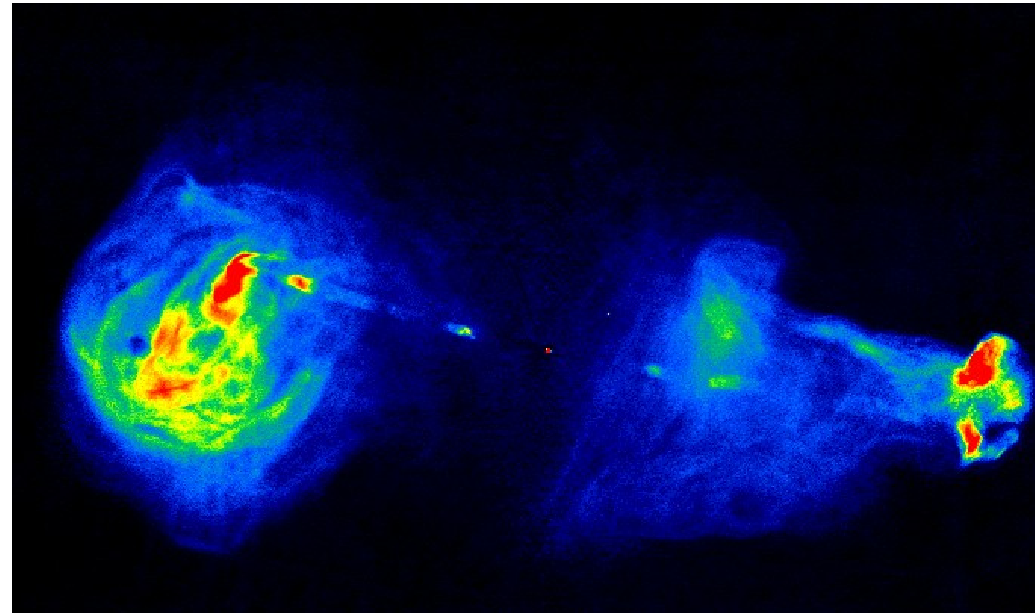
What can we learn from the combination of deep single-object observations and surveys?

The Fanaroff-Riley Division

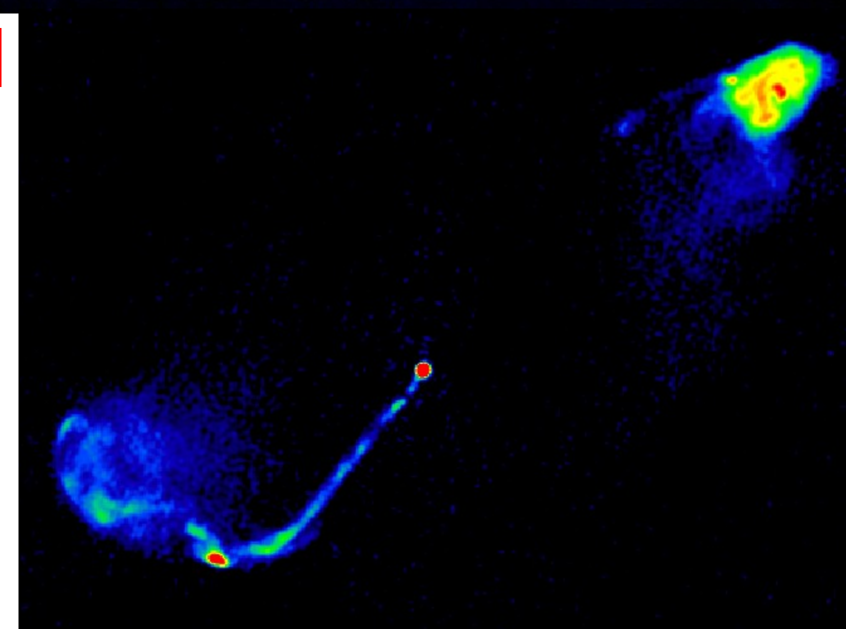


FRI

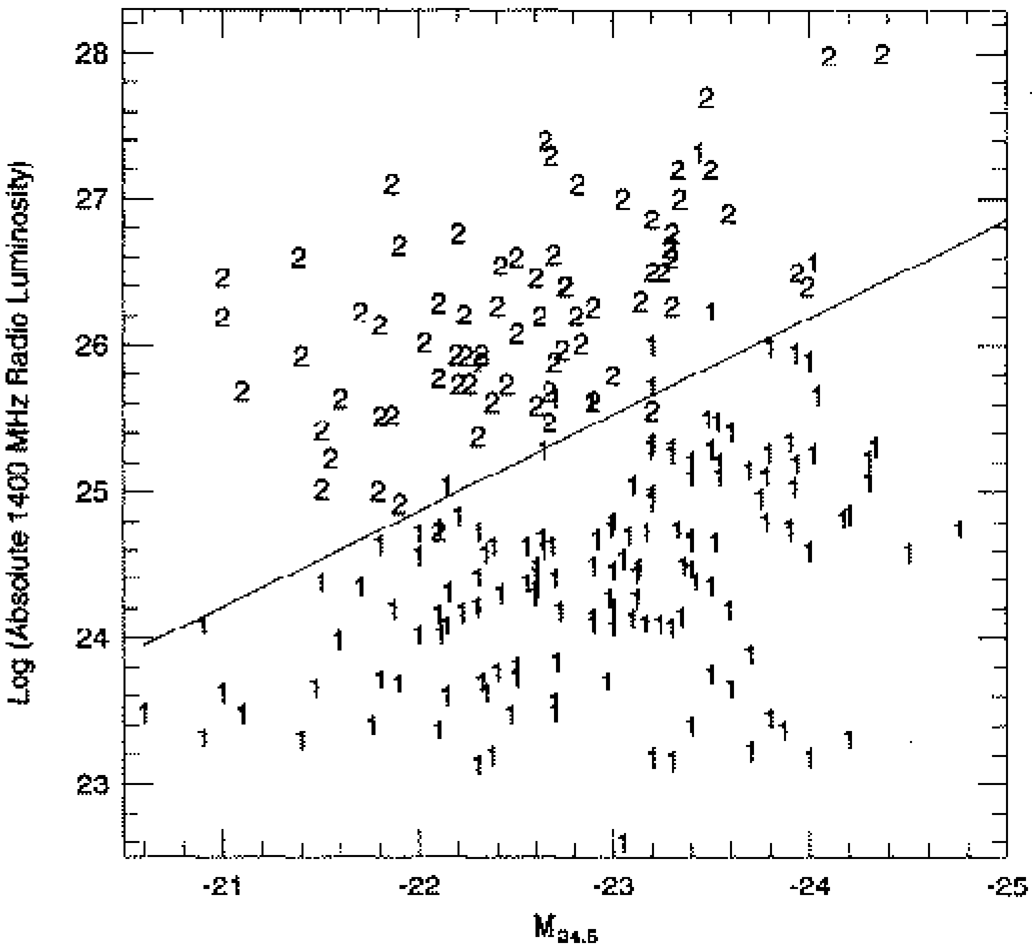




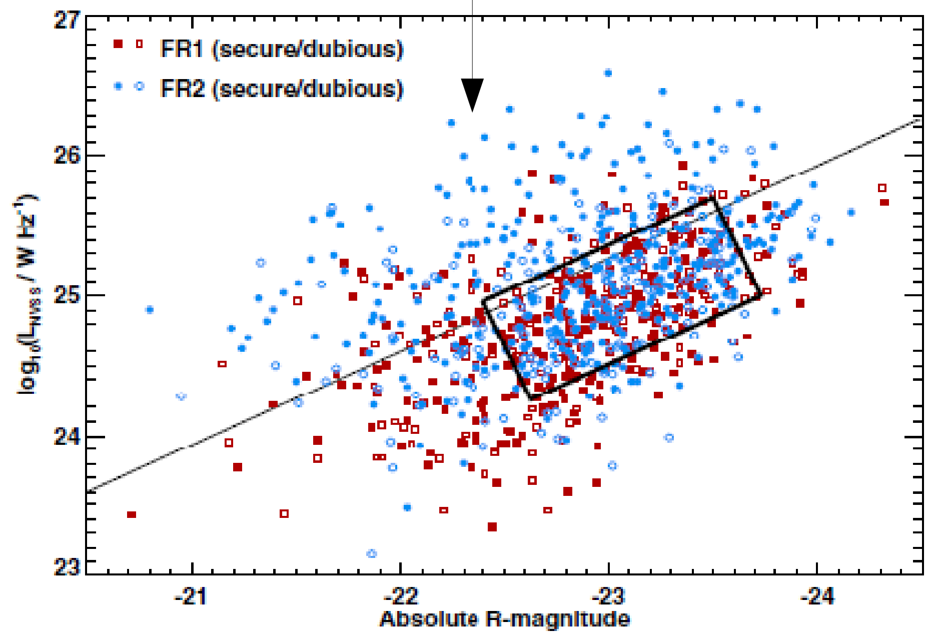
FRII



FR Division and Environment



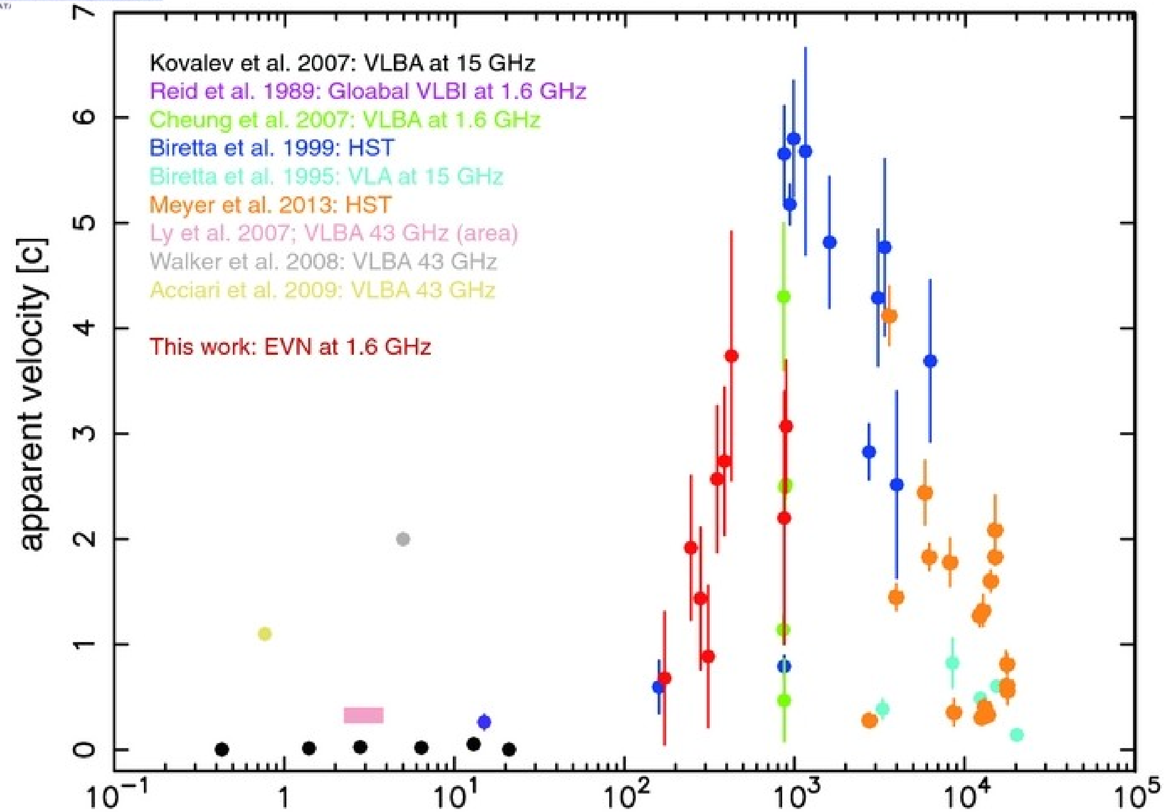
Need better radio imaging



Ledlow & Owen (1996)
Heterogeneous

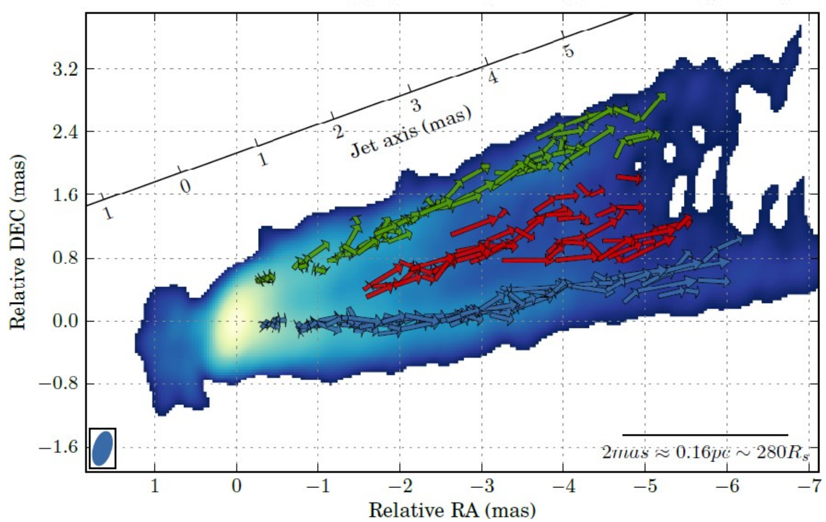
Best (2009)
SDSS/FIRST/NVSS

FRI jet acceleration and deceleration

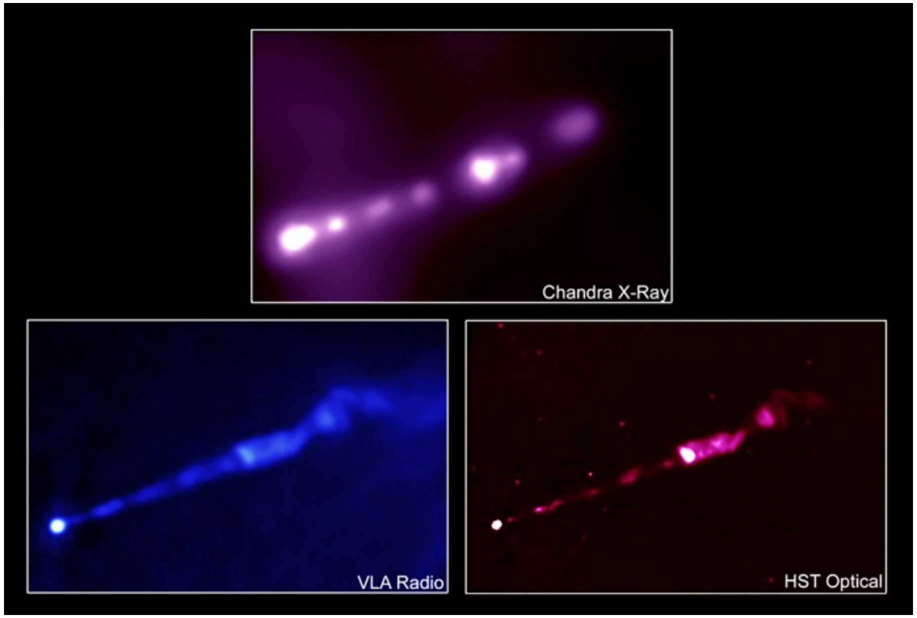


Proper motions in M87

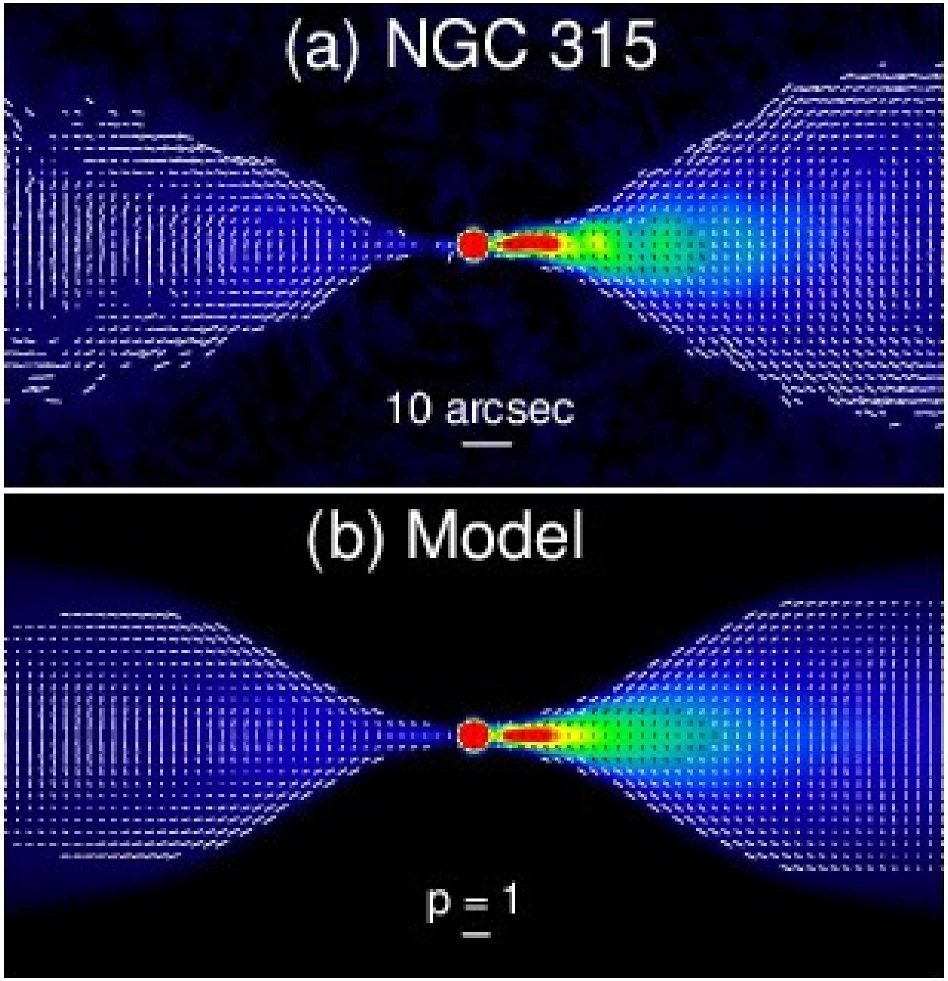
Asada et al. (2014)



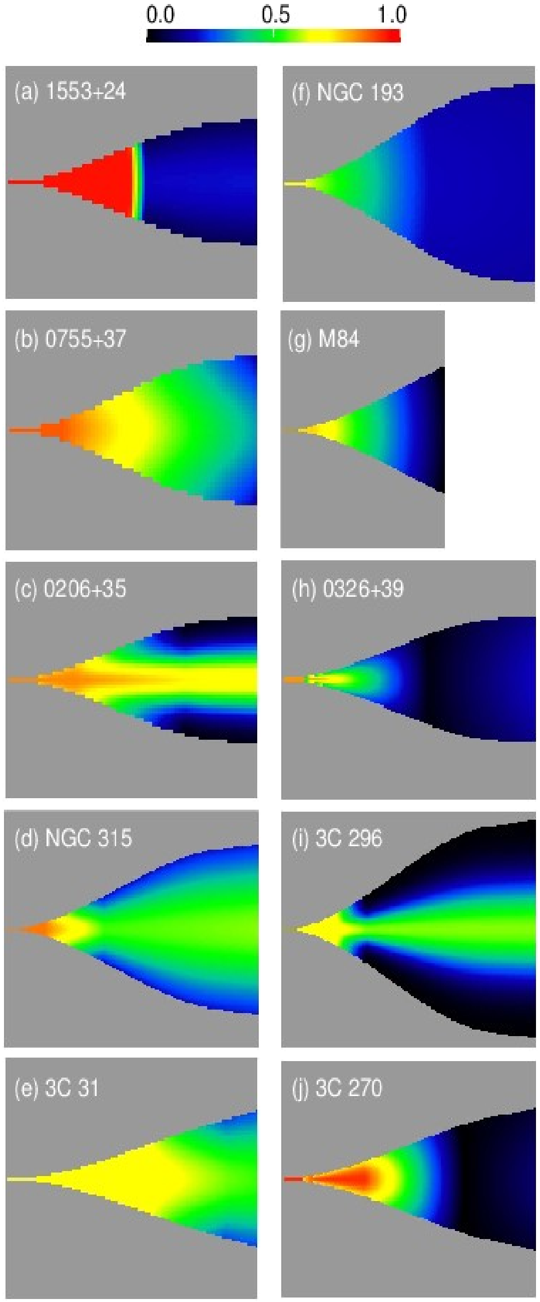
Mertens & Lobanov (2015)



Jet deceleration on kpc scales

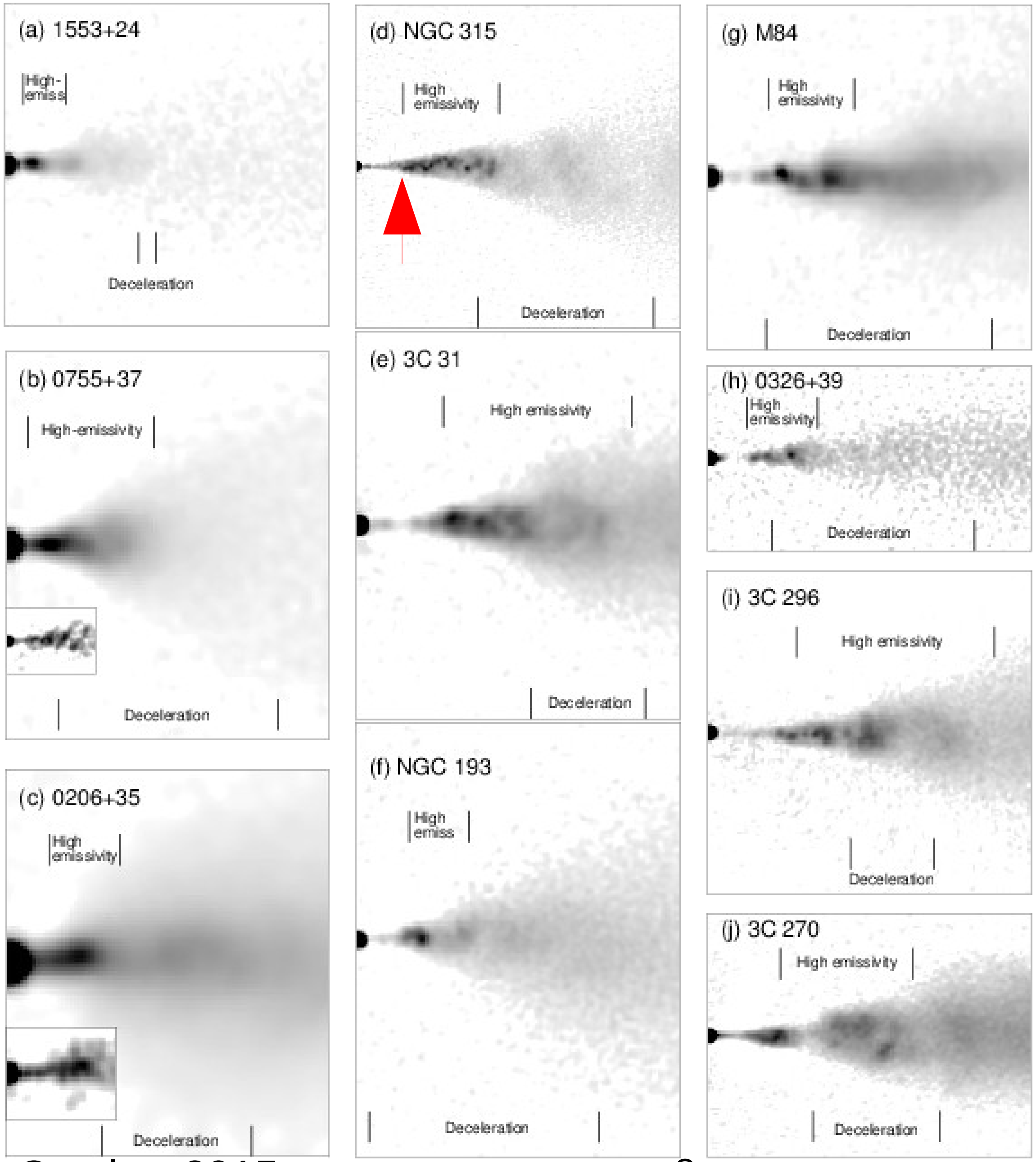


Observations + model



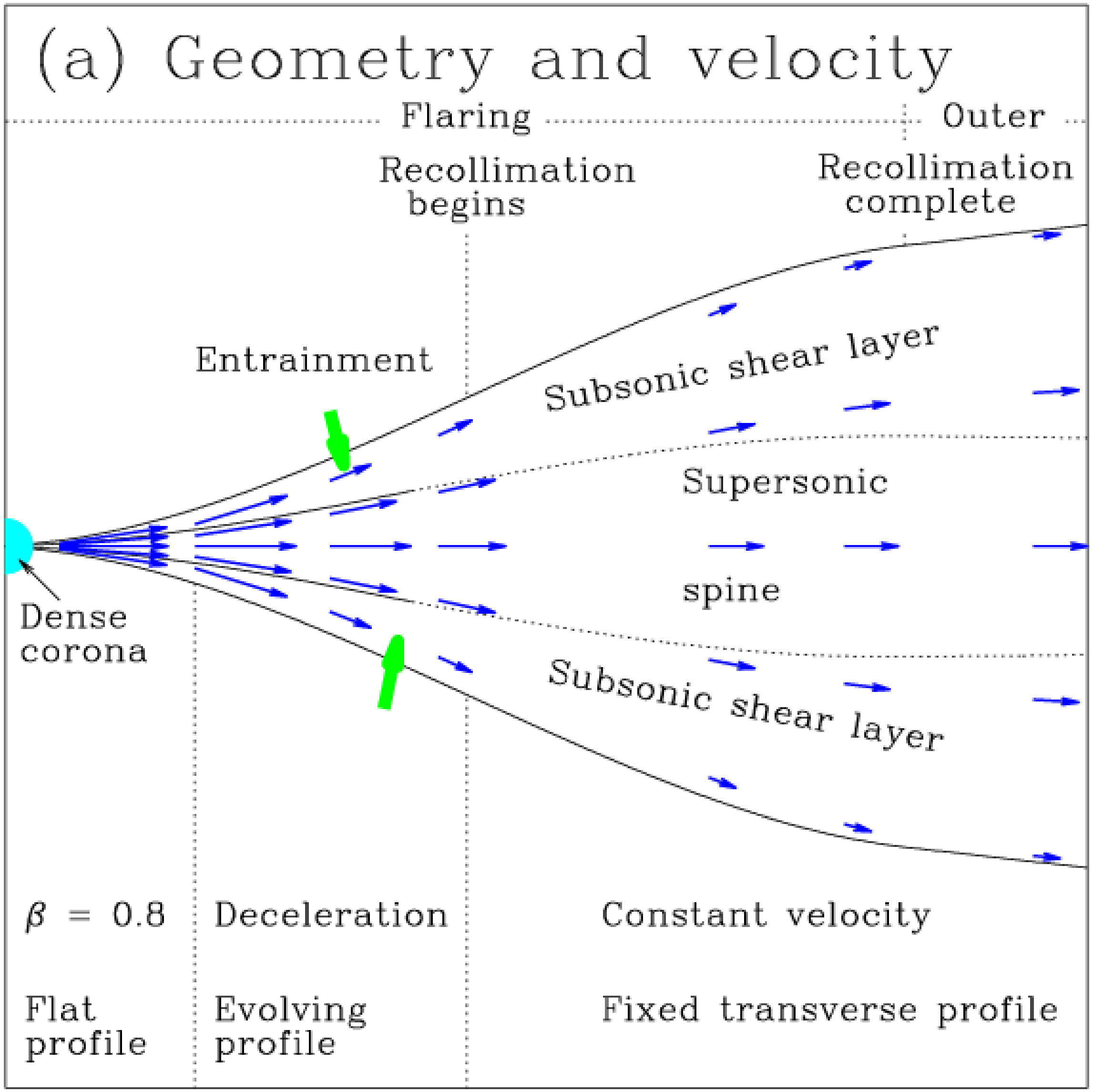
Velocity fields

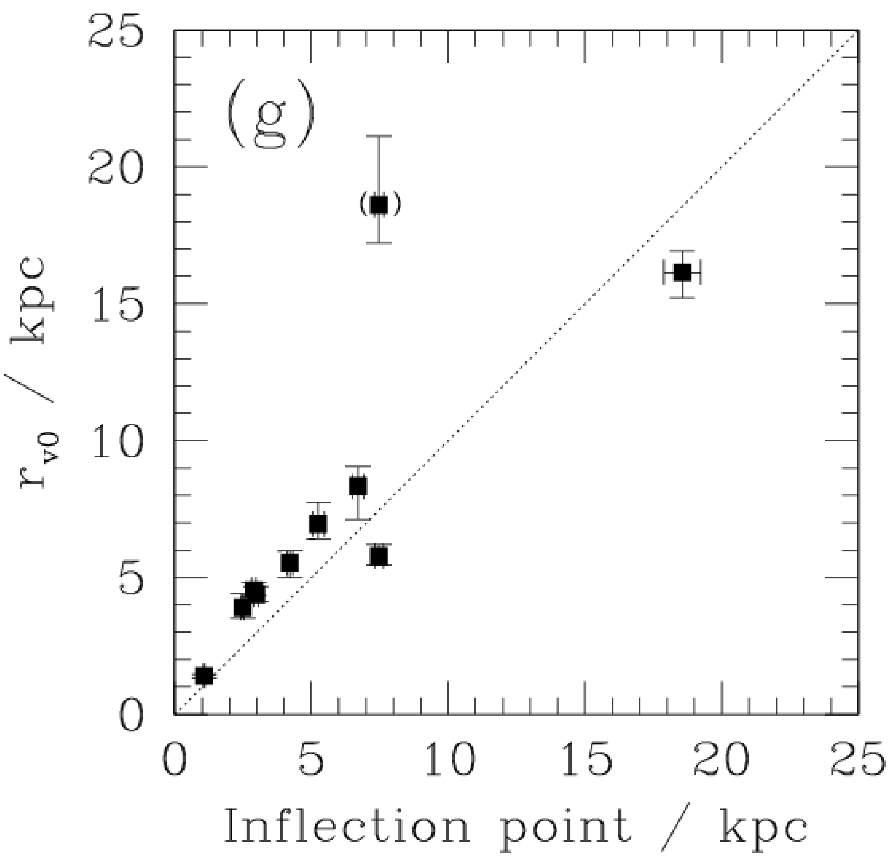
Approaching jets at high resolution



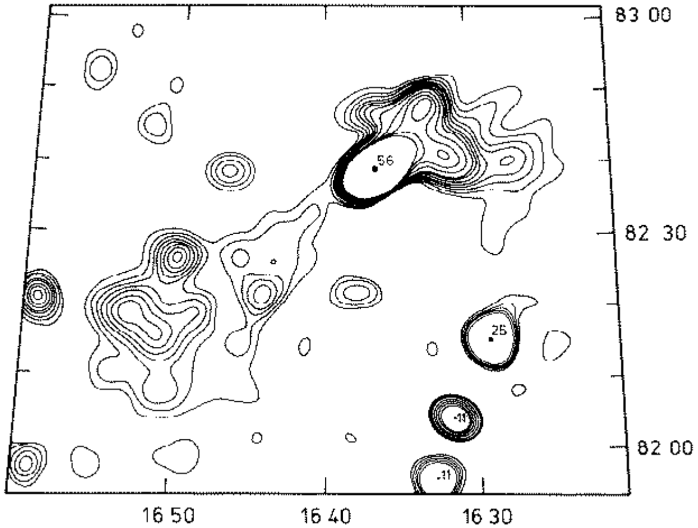
Jets brighten and start to expand more rapidly at the flaring point

Flaring and Deceleration

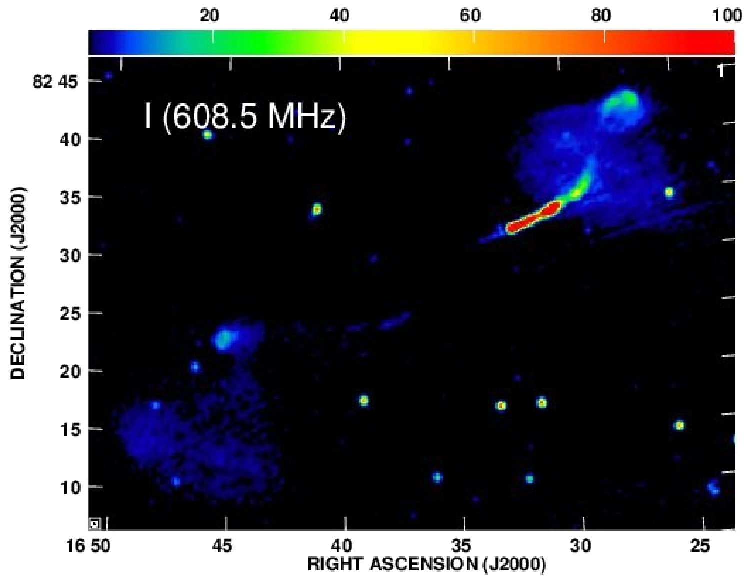




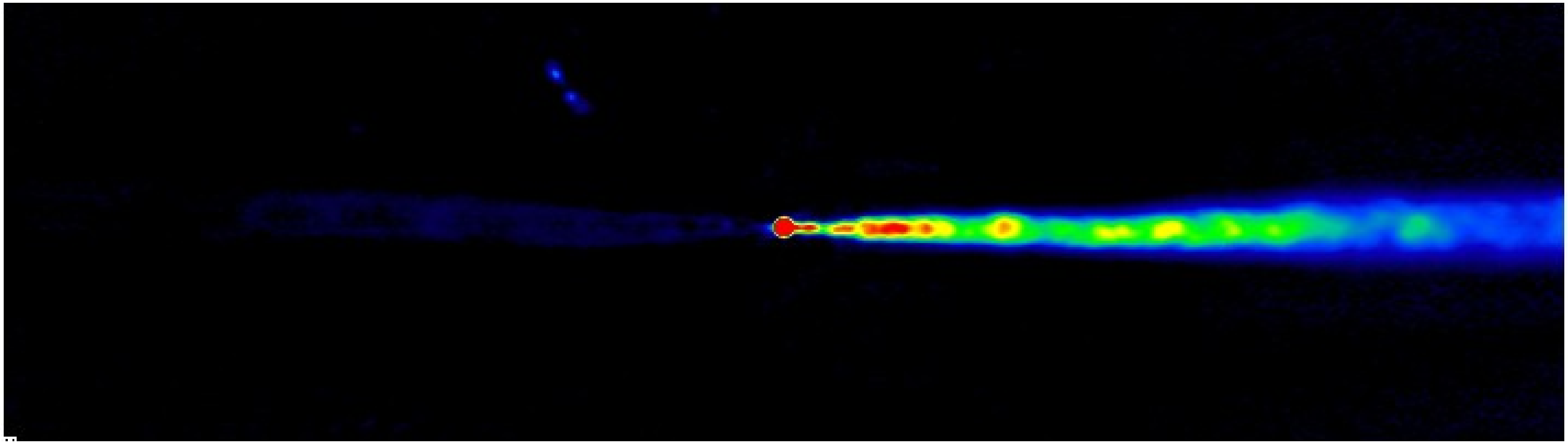
Finding interesting sources



151 MHz
(Waggett, Warner & Baldwin 1977)



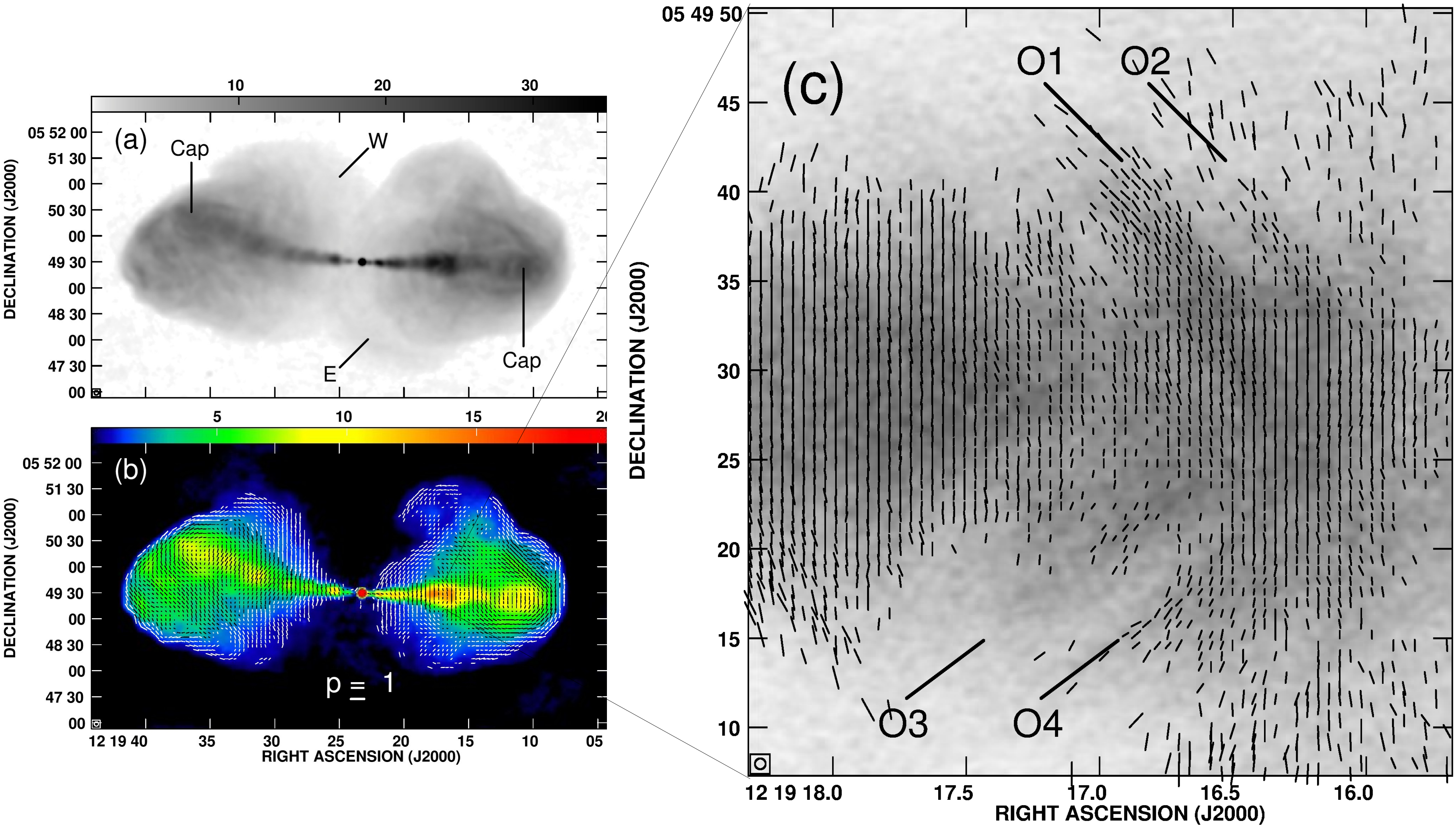
609 MHz WSRT
(Mack et al. 1997)



Jansky
VLA

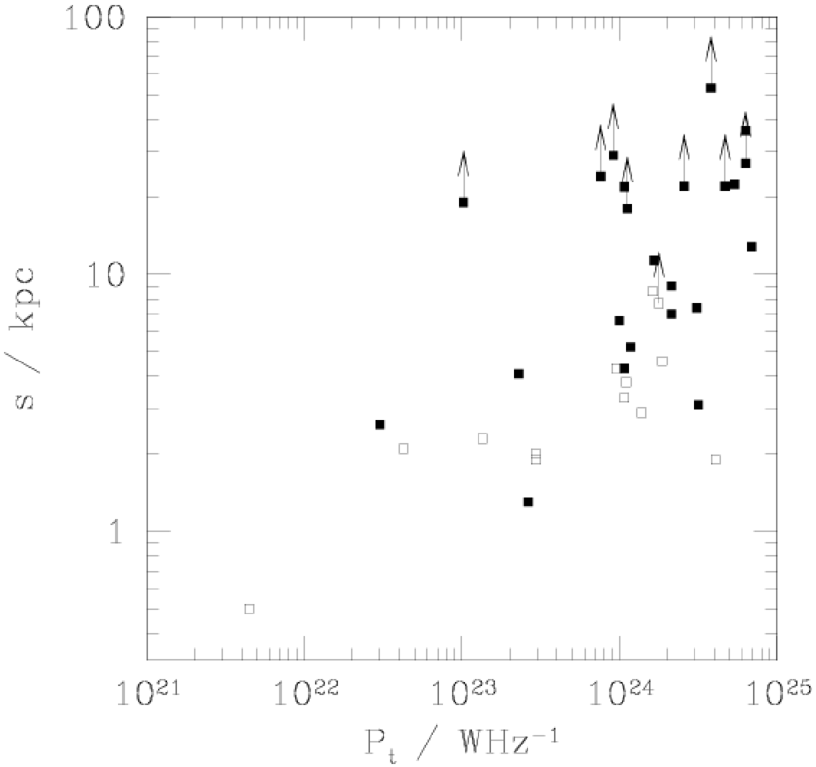
4.5-6.5 GHz

Fine-scale structure in jets



Velocities from surveys

- How do the flaring and deceleration scales in FRI radio galaxies depend on:
  - jet power?
  - galaxy mass?
  - environment (field/group/cluster/hot gas density and pressure profiles)?

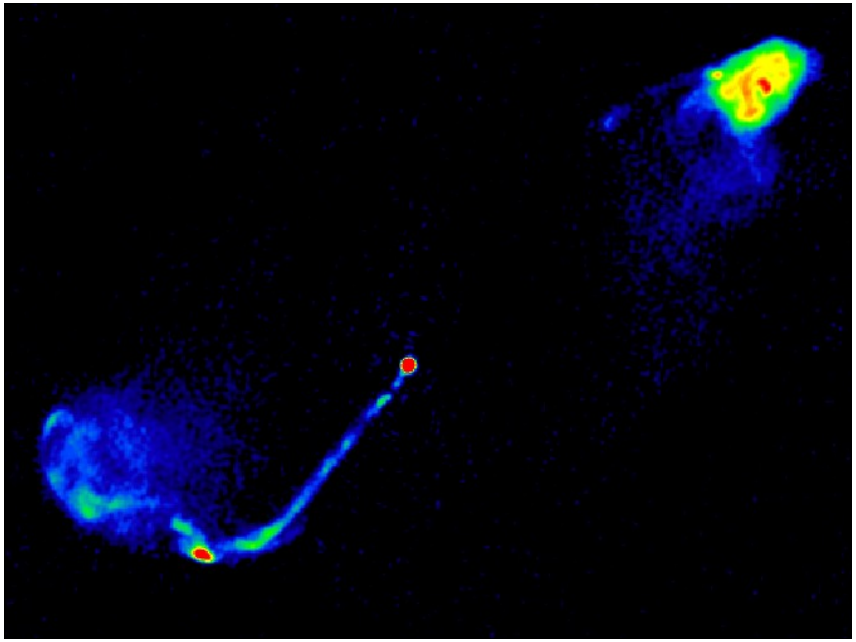


s is the distance at which the jets become symmetrical (proxy for deceleration scale)

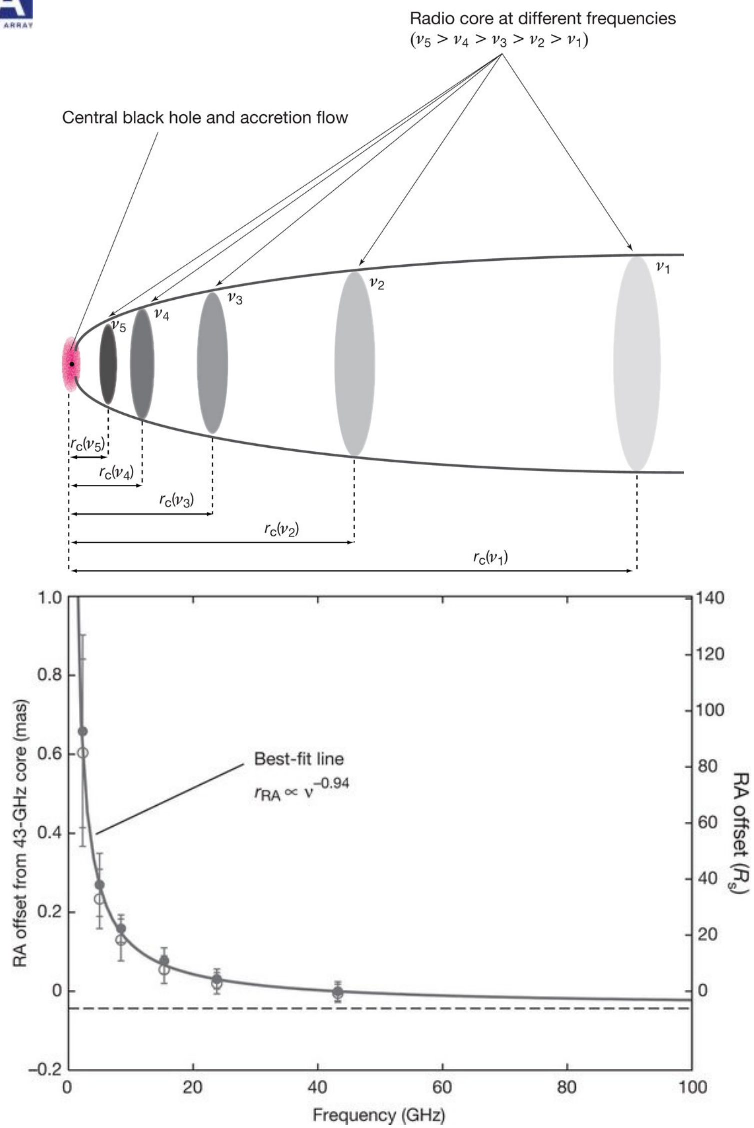
B2 sample, RL et al. (1999)

Velocities: open questions

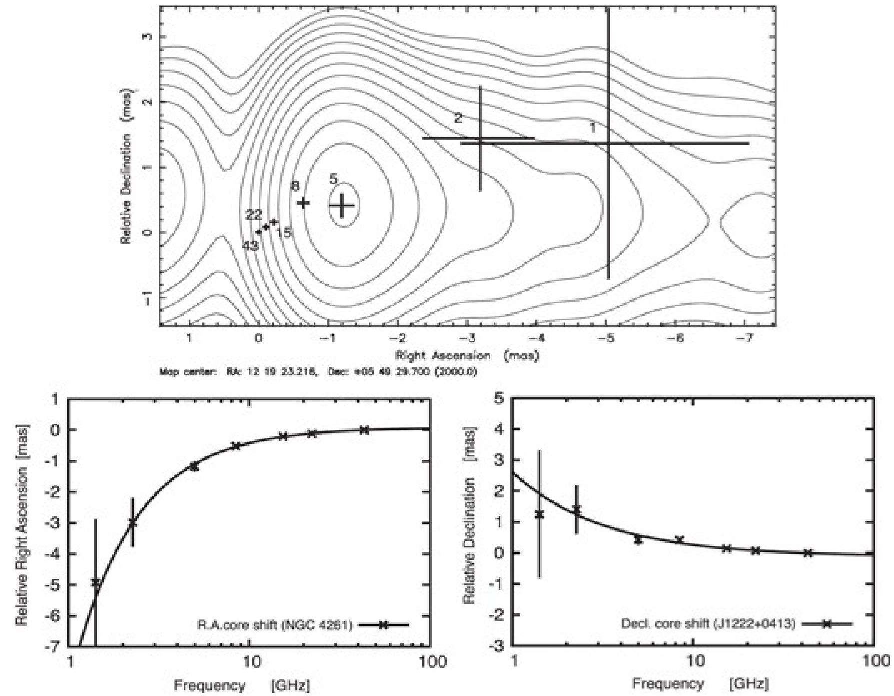
- What are we measuring with proper motions?
  - components moving with the flow?
  - or at some other speed?
  - stationary features (e.g. shocks)?
- Is there bulk acceleration on pc scales, or are we seeing material entrained into a faster flow?
- How fast are FRII jets on kpc scales?
  - Probably need SKA2 for this



Where do jets light up?
Very close to the black hole



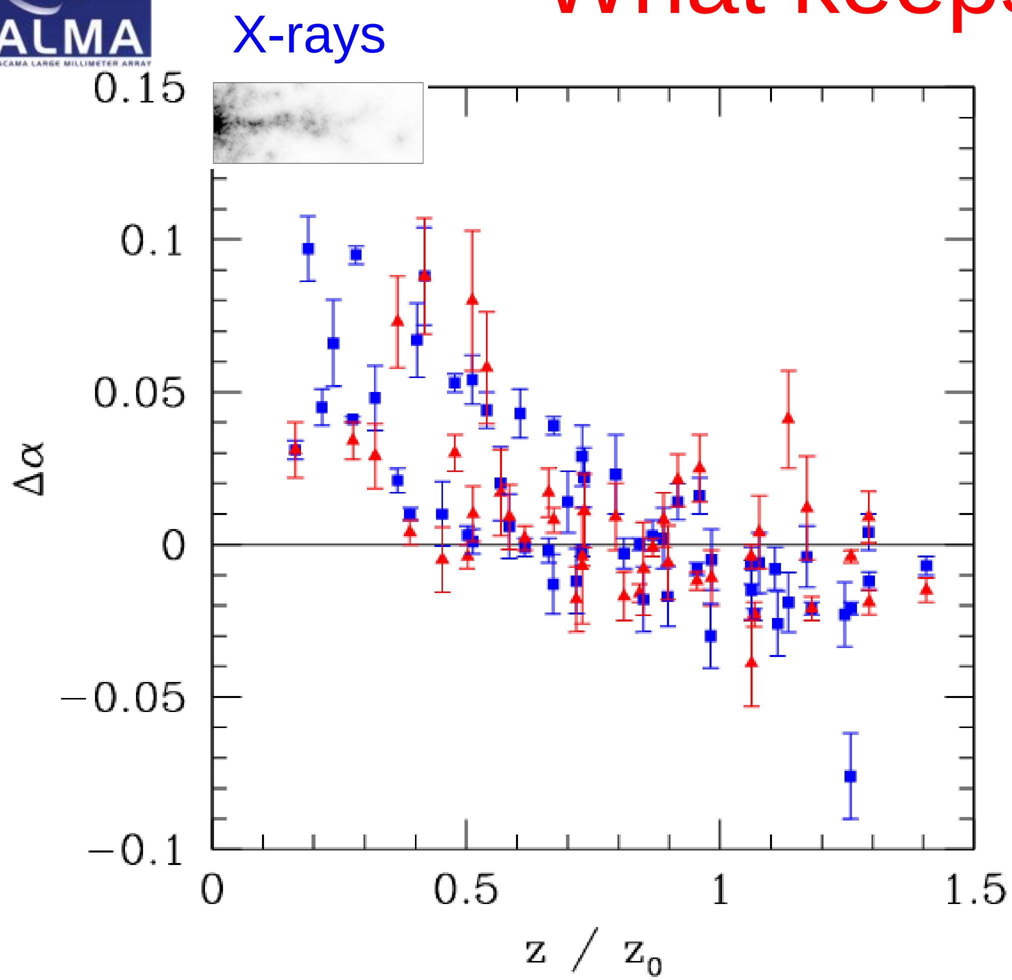
M87: Hada et al. (2011)

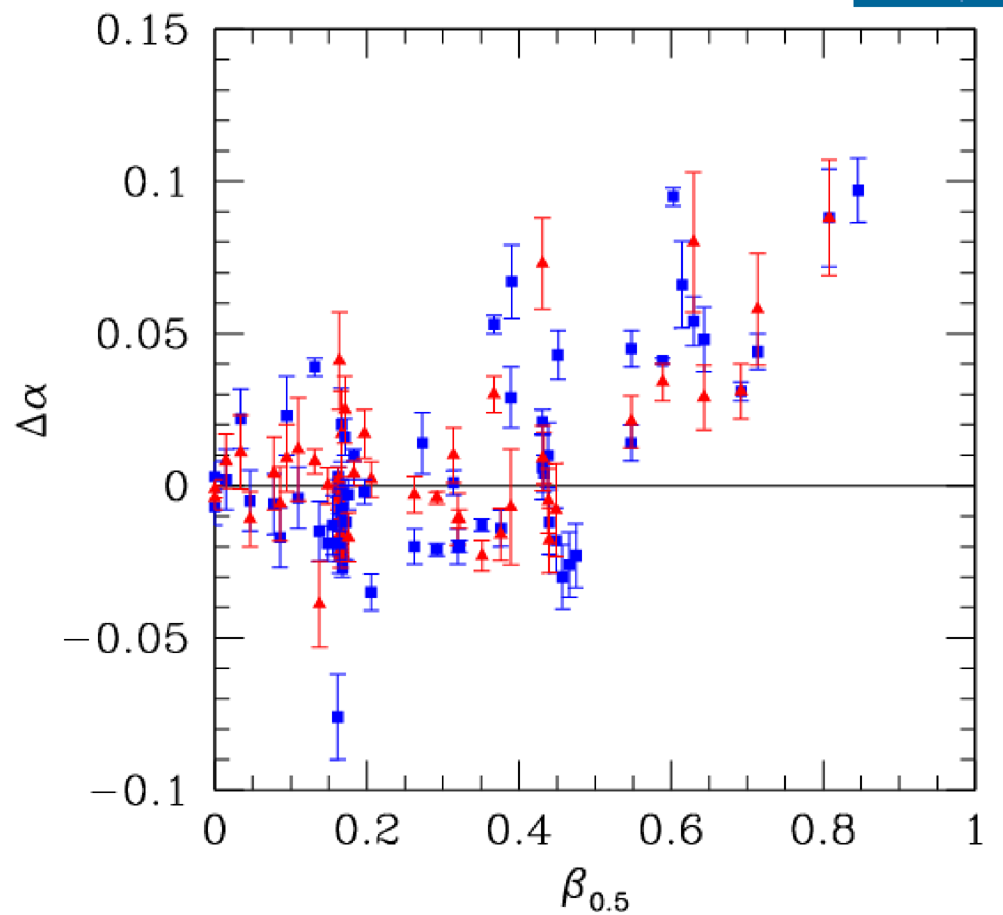


3C270: Haga et al. (2015)

Core shift: measuring the position of the τ = 1 surface as a function of frequency

What keeps jets lit up?





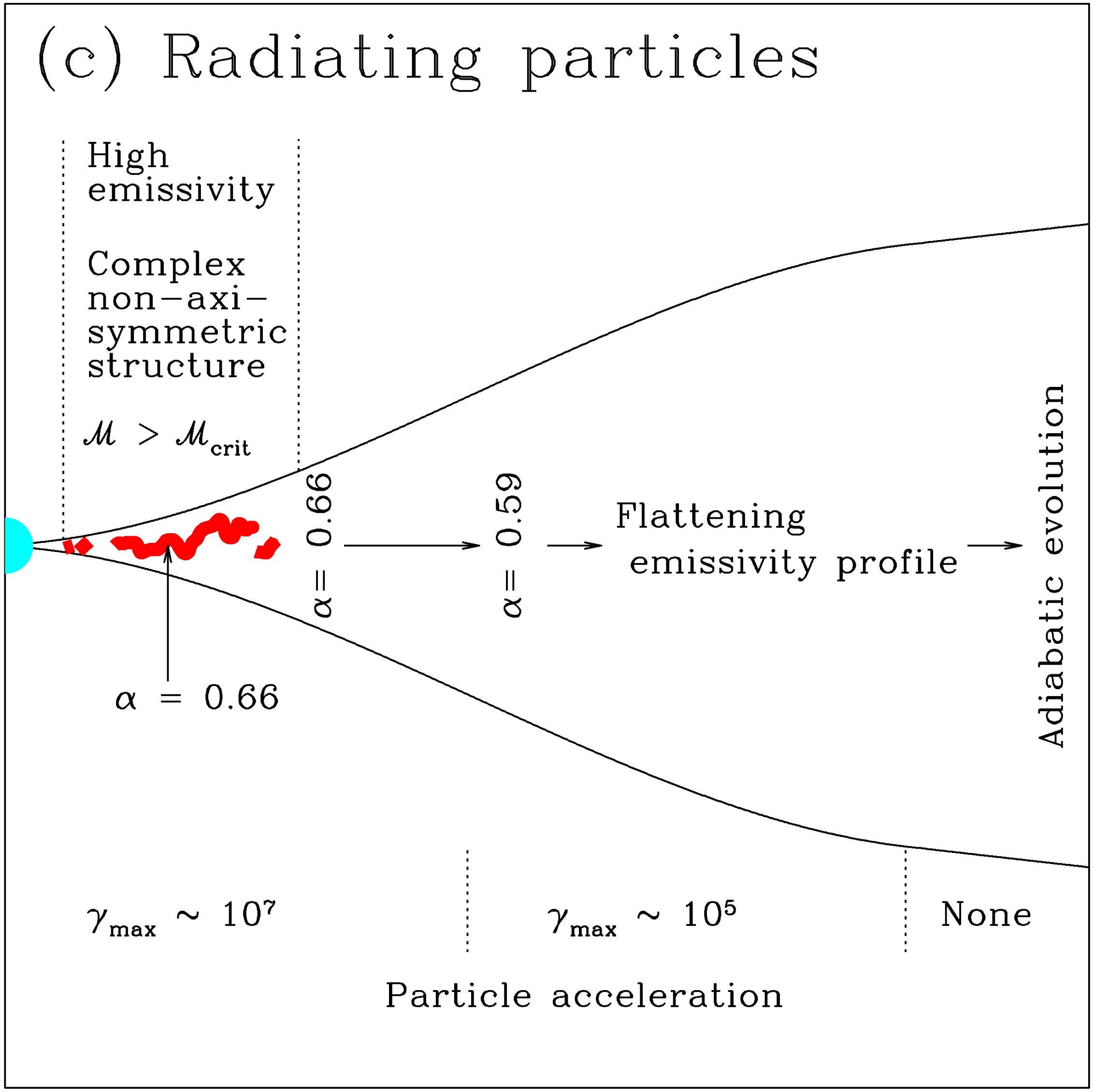
Spectrum becomes flatter with increasing distance from AGN

Opposite to effect of synchrotron losses $S \propto \nu^{-\alpha}$

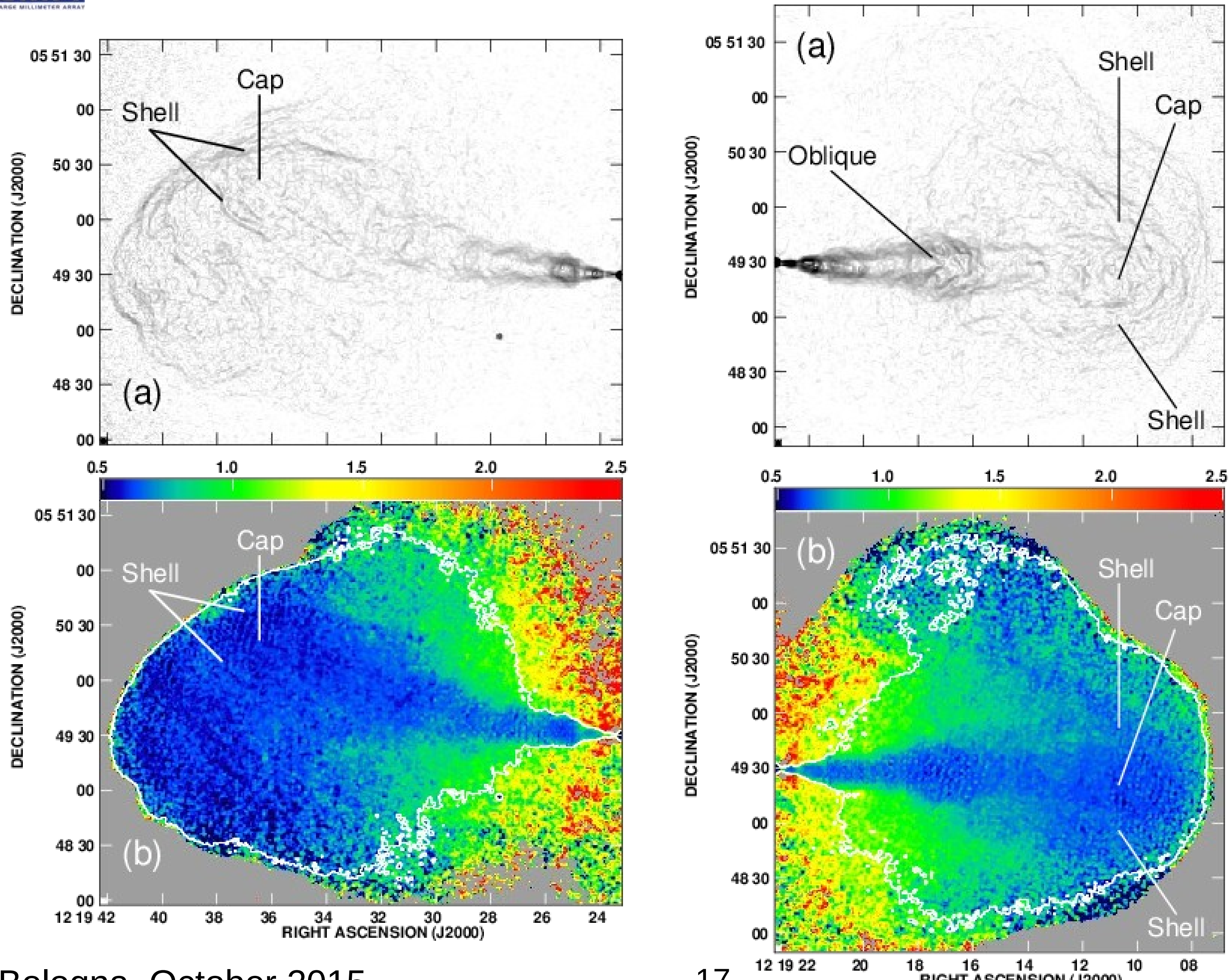
Velocity-dependent particle acceleration

Mildly relativistic shock network: close to Bohm diffusion?

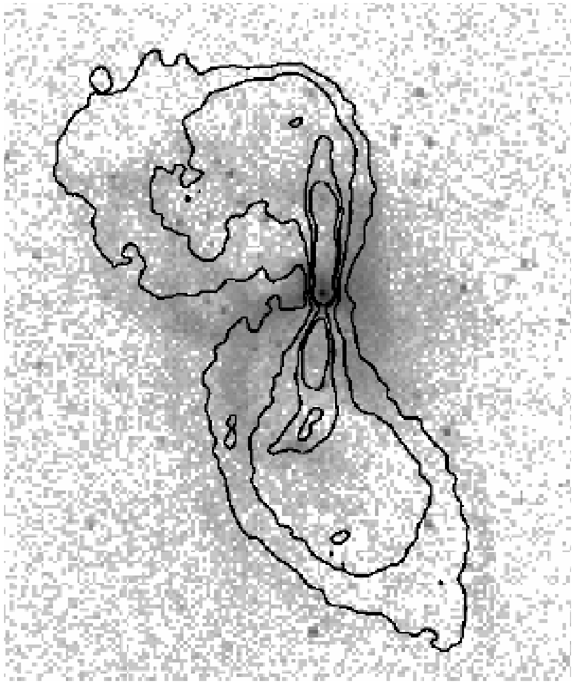
Particle Energy Evolution

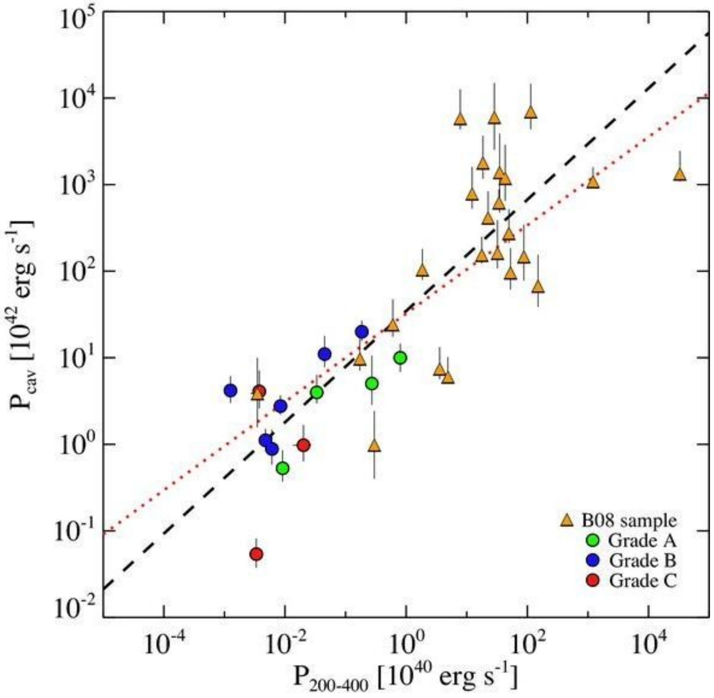


Energy loss processes



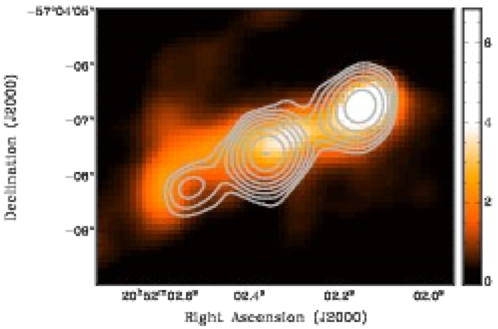
The impact of jets on hot and cold gas

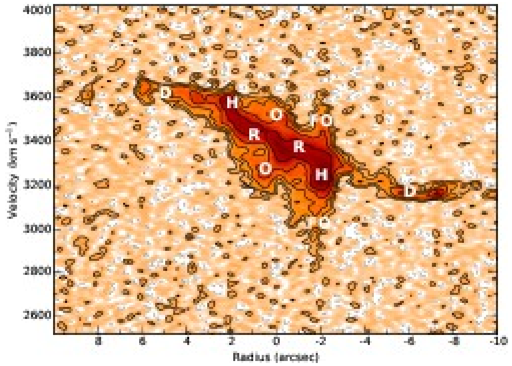




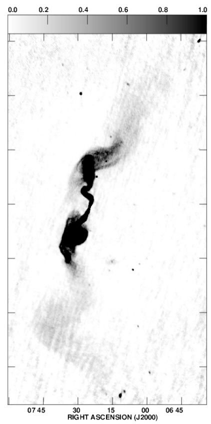
M84 (Finoguenov et al.; Hydra A (Mcnamara etal.); Cavagnolo et al.

IC5063
ALMA CO2-1 and
230GHz continuun
Morganti et al. (2015)

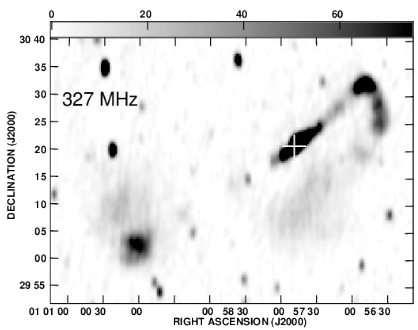




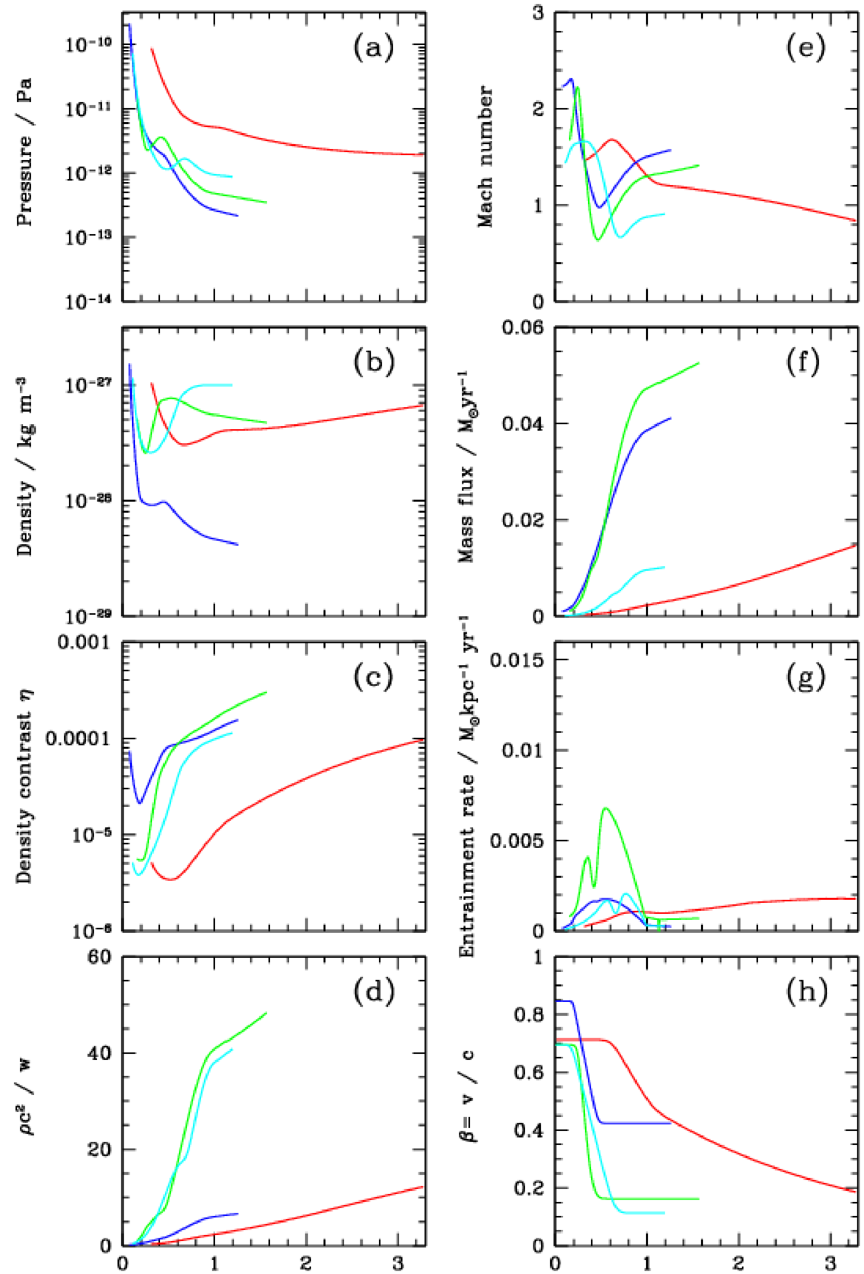
Jet entrainment

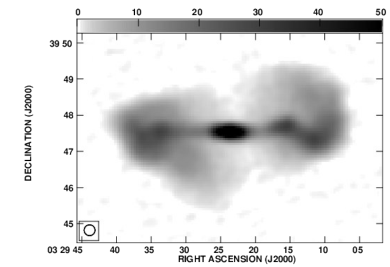


3C31

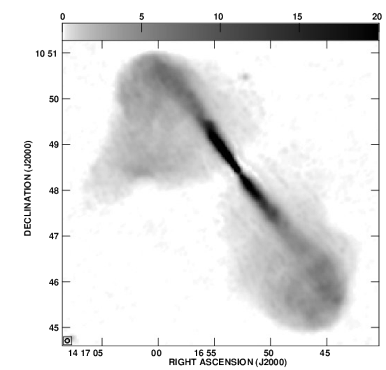


NGC315





B2 0326+39



3C 296

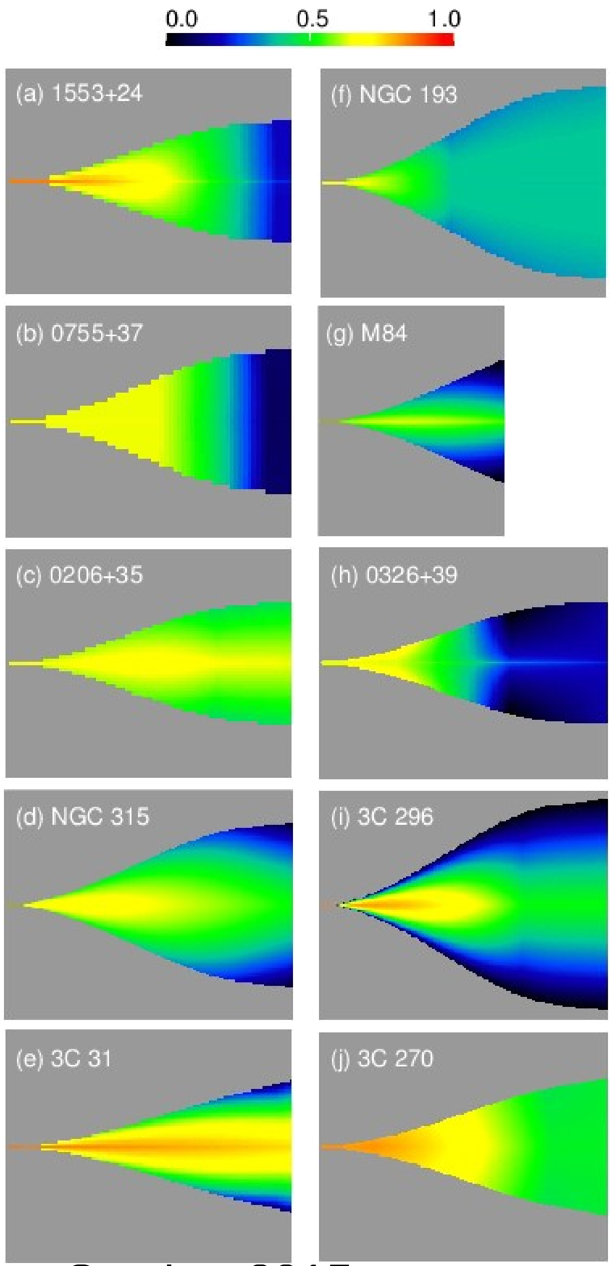
Velocity fits from Laing & Bridle (2014)
Conservation-law analysis following Laing & Bridle (2002)

Magnetic Field Strength and Geometry

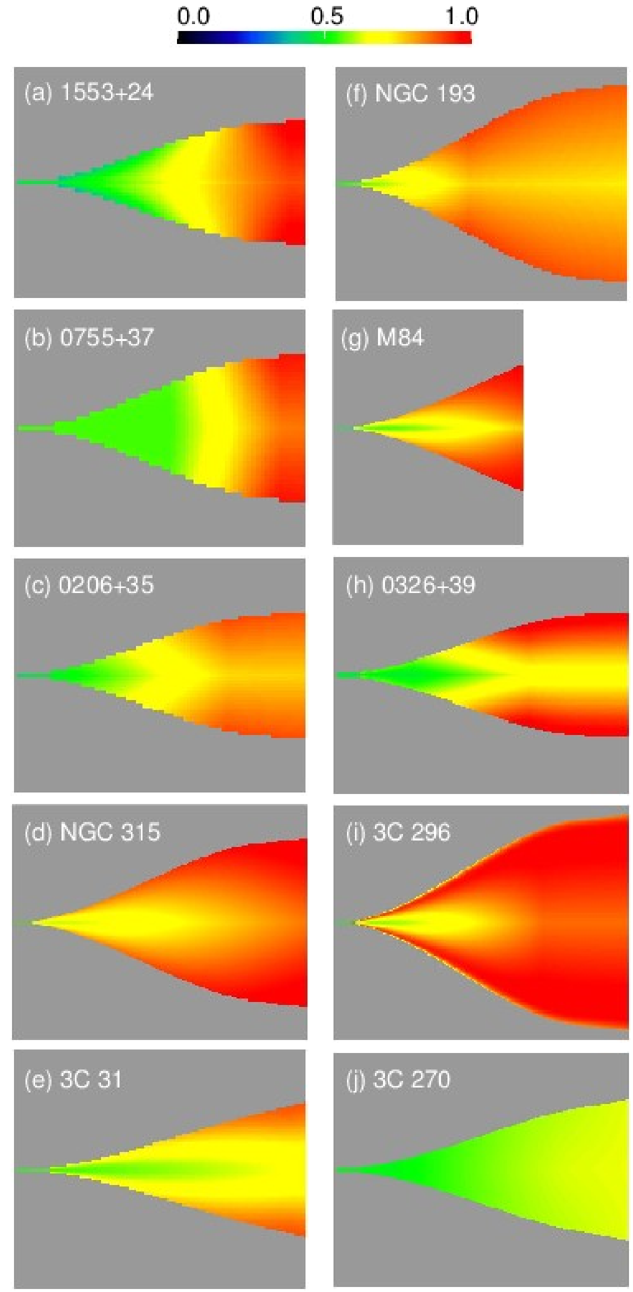
- kpc scales
  - FRI jets: evolution from longitudinally to toroidally dominated; not a globally ordered helix; e.g. ordered toroidal + longitudinal with many reversals (Laing & Bridle 2014)
  - Field strength estimates from equipartition ~1-30 μG); inverse Compton constraints not very useful
  - FRII jets: integrated apparent field usually longitudinal; one resolved case: longitudinal + toroidal in boundary layer
- pc scales
  - Core shift method gives magnetic field strength at ~1 pc (and, with additional assumptions, the magnetic flux; Zamaninasab et al. 2014; Zdziarski et al. 2015) = **M**agnetically **A**rrested **D**isks
  - Field geometry debated: helical/toroidal + rms longitudinal/disordered and anisotropic. Likely to evolve with distance.

B-field geometry in FRI jets

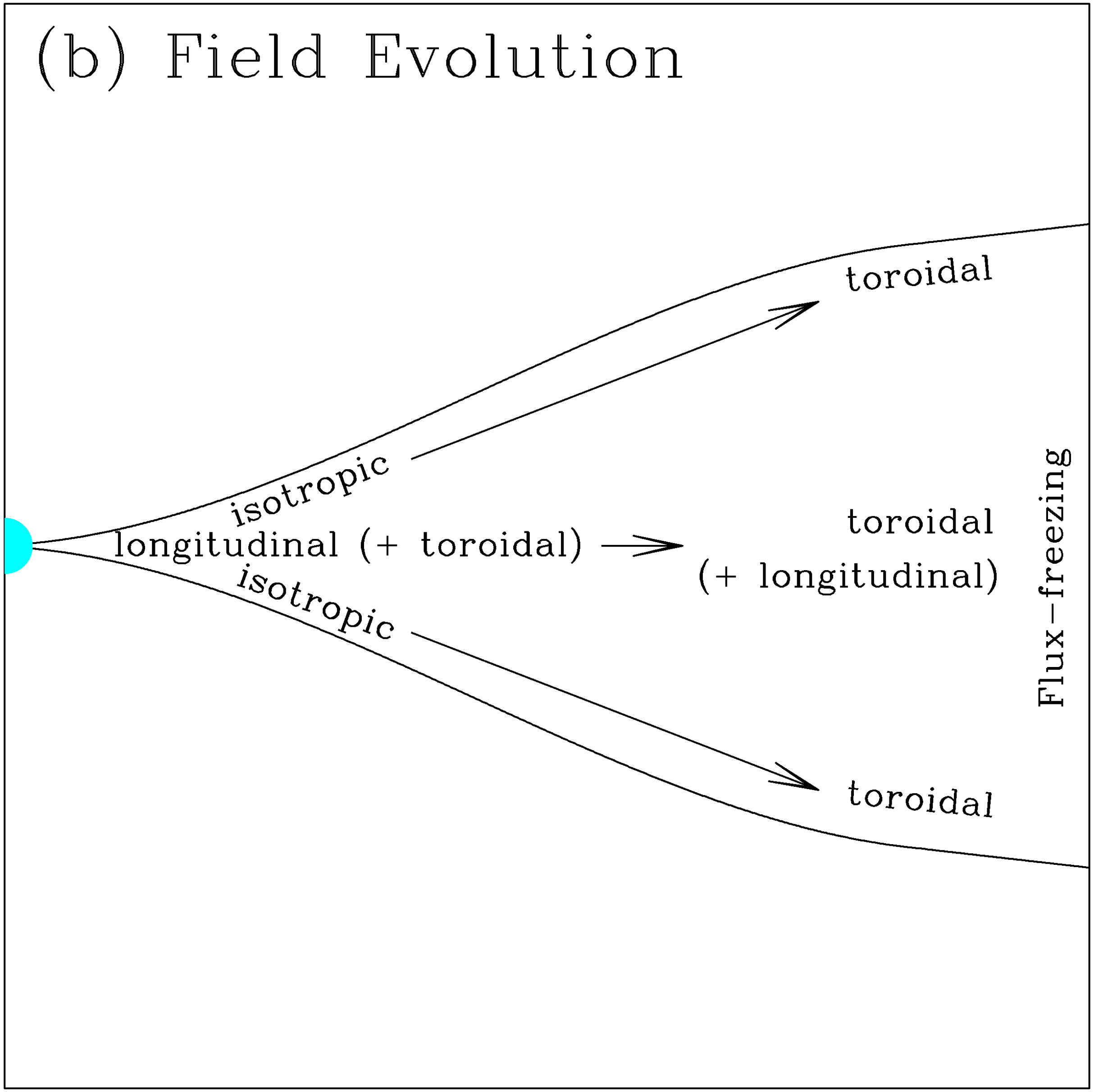
Longitudinal



Toroidal



Field Evolution



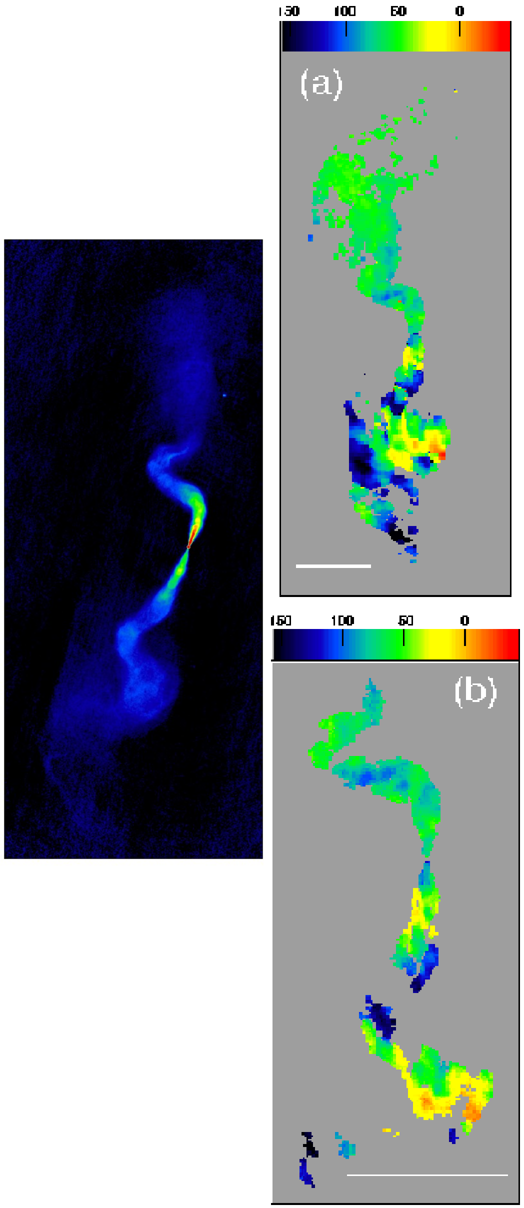
Ordered toroidal component preserved from pc scales

+

Longitudinal component with many reversals

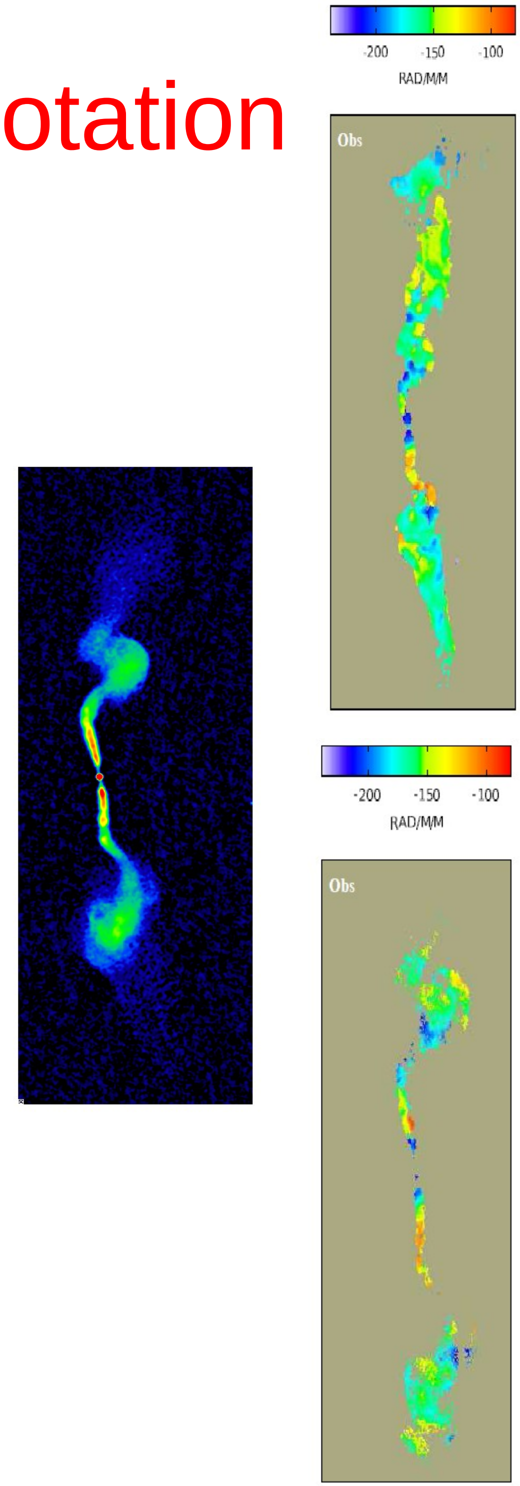
?

Faraday rotation



◀ 3C31
$\theta \approx 52^o$

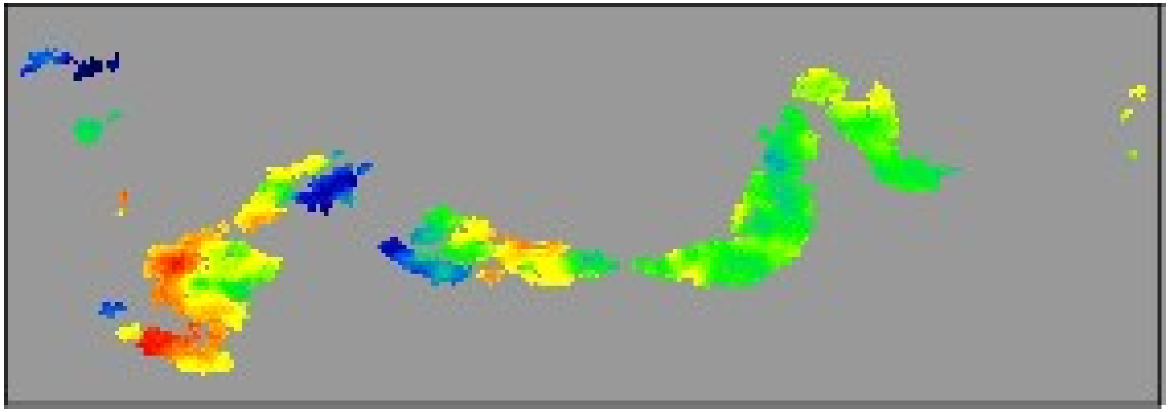
RL et al. 2008

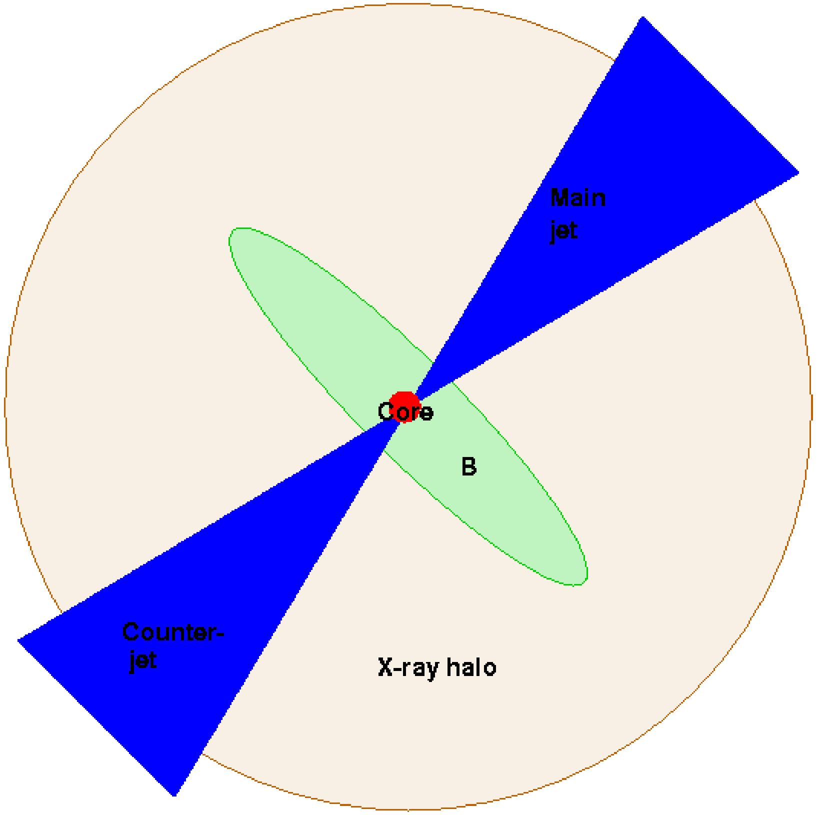


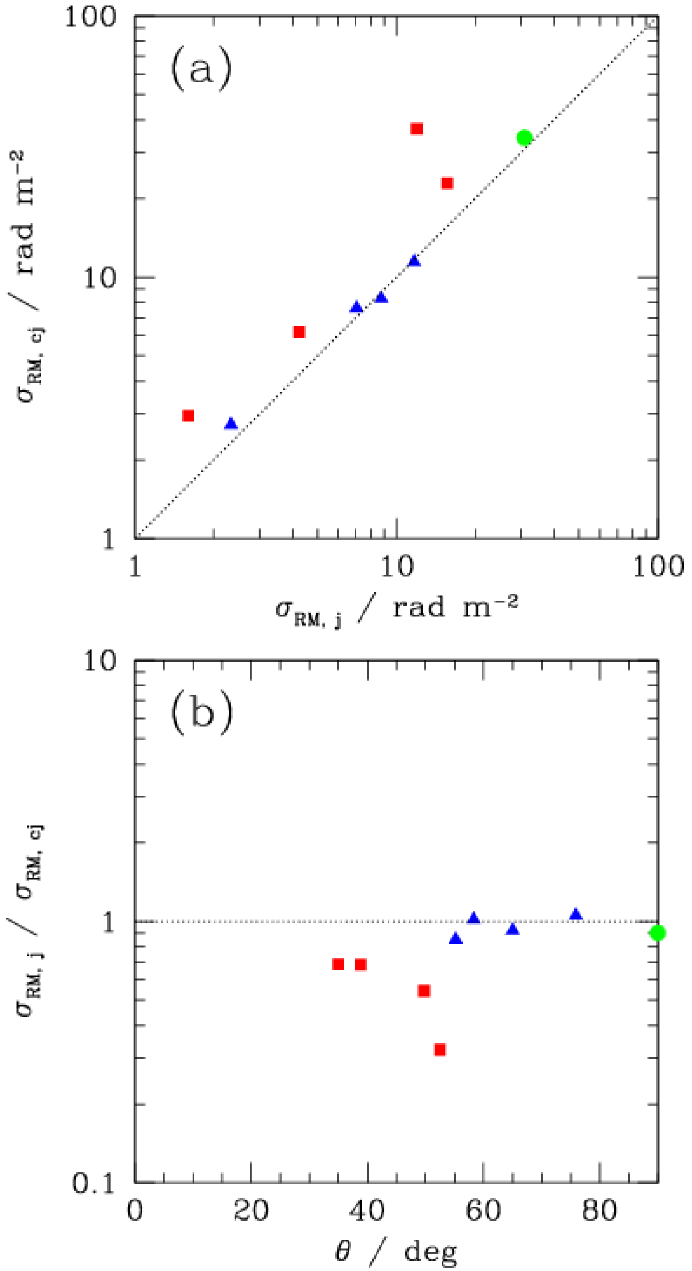
◀ 3C449
$\theta \approx 90^o$

Guidetti et al. 2010

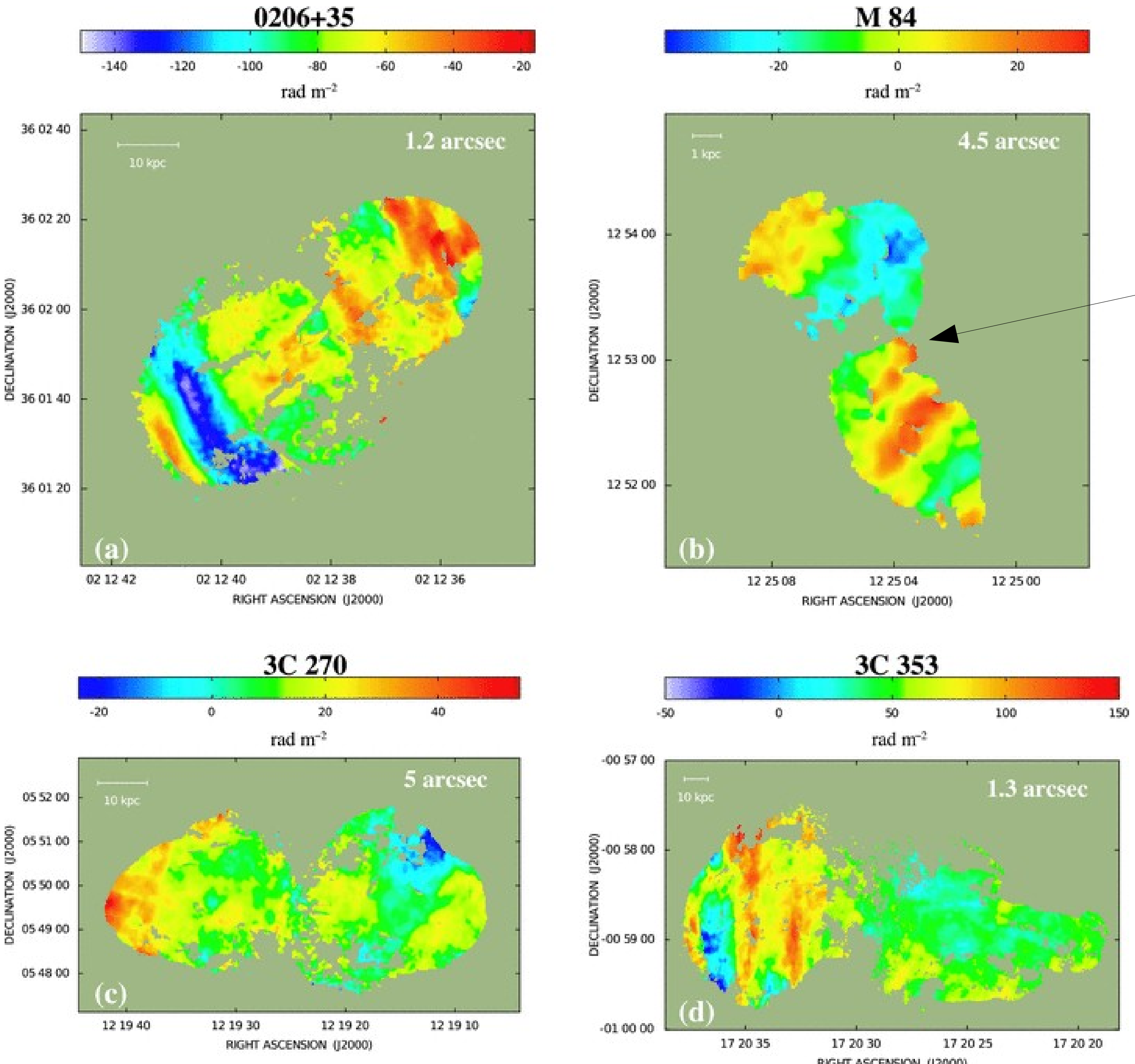
Faraday rotation geometry







Rotation Measure Bands



M84 in Virgo cluster

Guidetti et al. (2011, 2012)

3C353 on edge of rich cluster

Faraday Rotation Surveys

- Which radio galaxies show ordered RM patterns and why?
  - Actively driven lobes?
- What is the range of B-field power spectra in disordered RM distributions?
  - Flatter than Kolmogorov?
  - Inner and outer scales?
  - Scaling with n_e?
  - Field strength? Energy density compared with thermal plasma?
- Resolution <500 pc
- Frequency range matched to the RM

Single-object dinosaurs can coexist with younger, faster survey mammals*

* at least until the extinction event.