RM2010 – Aims of the Workshop

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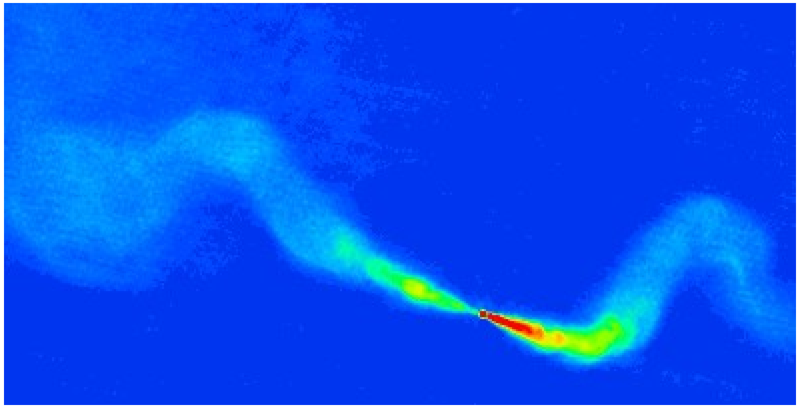


Magnetic fields: the Big Questions

- The battery problem: primordial seed fields or processes associated with the first stars, galaxies and AGN?
- The dynamo problem: how do large-scale fields grow?
- The reconnection problem: how do fields dissipate?

Where are magnetic fields important?
At least in:

- Stars
- Star formation: transfer of angular momentum; outflows
- Supernova remnants
- Spiral galaxy discs
- ISM: energy transport and cosmic-ray confinement
- Accretion discs (MRI)
- Relativistic outflows: active galaxies, microquasars, pulsars, gamma-ray bursts
- Intra-group and intra-cluster medium: conduction, AGN feedback dynamics
- Large-scale structure

Faraday rotation is a key probe of B-fields

- Rotation of the plane of polarization of linearly polarized radiation as it passes through a magnetised plasma (Faraday 1846).
- Principally due to thermal electrons (analogous effects for relativistic electrons leading to linear/circular conversion)
- Can occur in ionosphere, ISM of our Galaxy, magnetised plasma local to but in front of radio sources – hot or cool – and thermal matter mixed with synchrotron plasma.
- $\Delta\chi = 8.1193 \times 10^{-3} (\lambda/\mathrm{m})^2 \int (n_e/\mathrm{m}^{-3})(B_{par}/\mathrm{nT})\,d(l/\mathrm{kpc})$

  $= \mathrm{RM}\,\lambda^2$ (RM = rotation measure)
- $\Delta\chi$ is the change in E-vector PA, λ is the wavelength, n_e is the thermal electron density and B_{par} is the magnetic field along the line of sight.

For which the theory has long been understood ...

As in reference (10) we superpose all the radiation from the same Faraday depth and write $E(\phi)$ for the fraction of the radiation with Faraday depth ϕ and $P(\phi)$ for its intrinsic polarization. Defining the 'Faraday dispersion function' as $F(\phi)=E(\phi)P(\phi)$, we obtain the Fourier transform relation

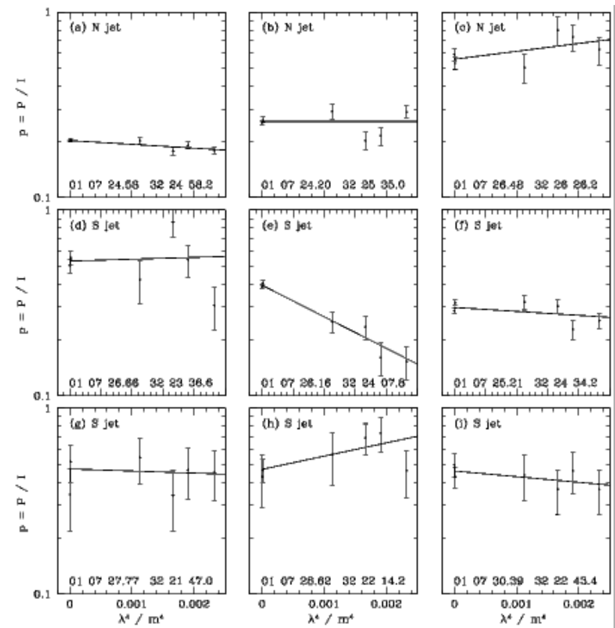
$$P(\lambda^2)=\int_{-\infty}^{\infty} F(\phi)e^{2i\phi\lambda^2}\,d\phi. \tag{11}$$

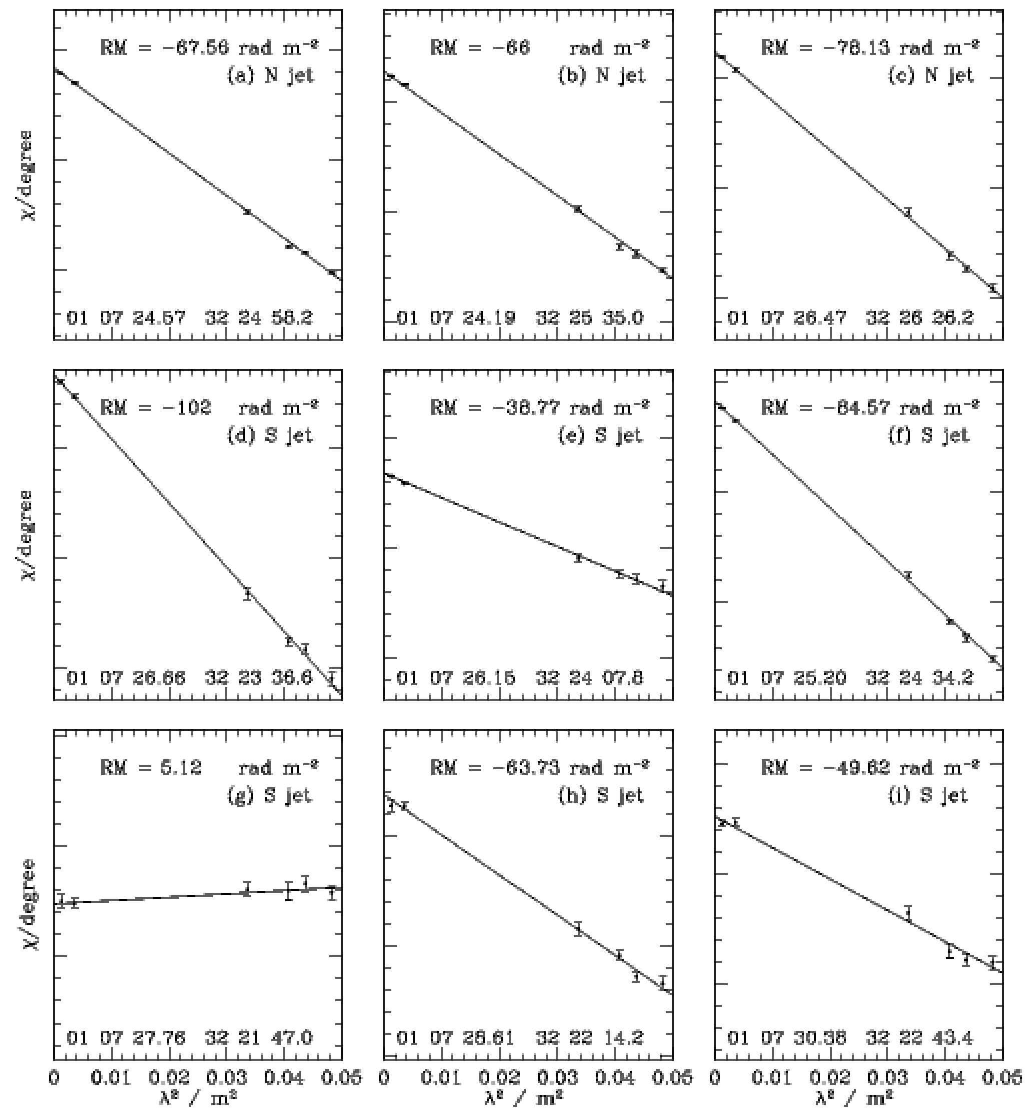
It would be very convenient to be able to invert this transform and so obtain the Faraday dispersion function from the relation

$$F(\phi)=\pi^{-1}\int_{-\infty}^{\infty} P(\lambda^2)e^{-2i\phi\lambda^2}\,d(\lambda^2). \tag{12}$$

It was once hoped that this would make it possible to measure the density of thermal electrons mixed with relativistic, synchrotron-emitting plasma. Perhaps it will one day, but ....

High resolution → mostly foreground





$$P(\lambda^2) = P_0 \exp(2iR\lambda^2)$$

$$F(\varphi) = P_0 \delta(\varphi - R)$$

(Very nearly) pure resolved foreground rotation

3C31 (RL et al. 2008)

What have we been doing recently?

- Making better images of rotation measure (either of multiple discrete sources or extended emission)
- Checking the foreground hypothesis (yes, it usually works)
- Trying to understand the spatial variation of RM in terms of:
  - Ordered field configurations
  - Random fields (in which case, what are the spatial statistics?)
  - Geometry (source + surroundings)
- Building a lot of new telescopes with fancy correlators
- Writing AMR codes to do MHD simulations

A whole workshop on rotation measures?

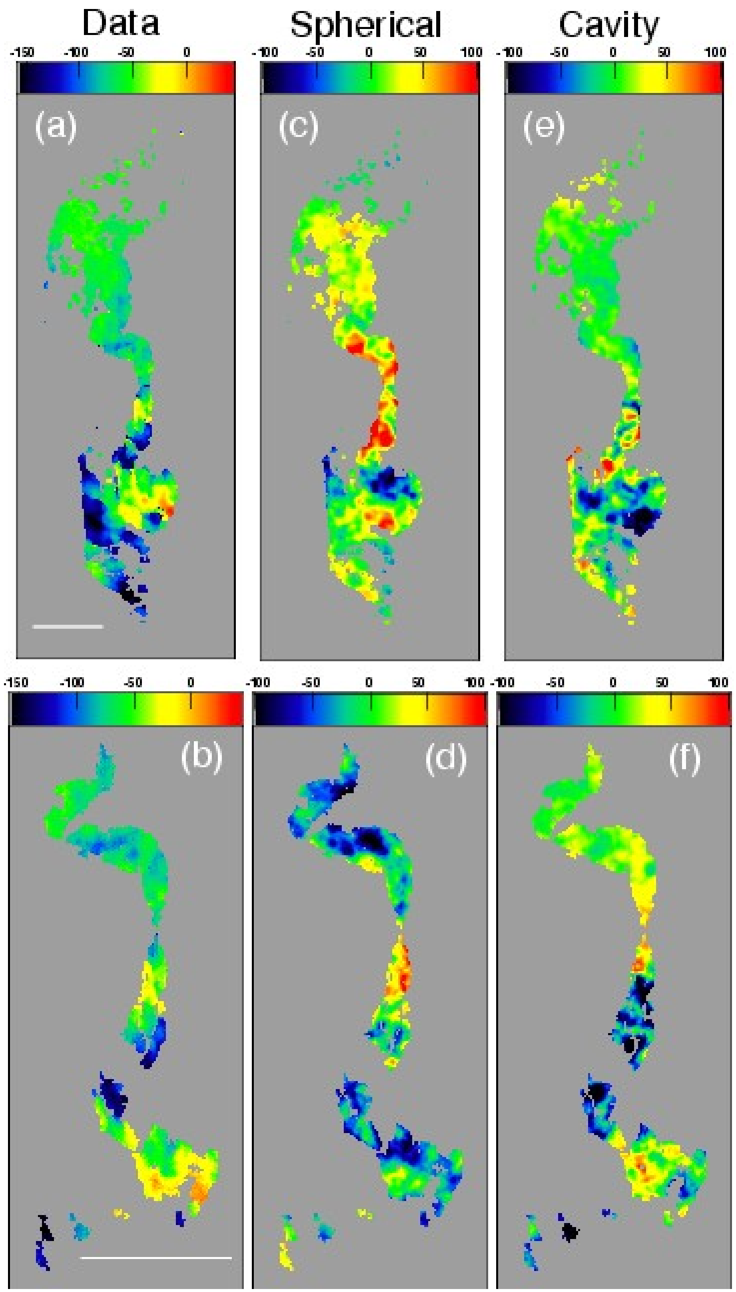
- New results on RM analysis for clusters, groups and individual radio galaxies + background sources
  - Higher resolution, better coverage of spatial scales
  - RM power spectrum: different techniques and results
  - (How) do the sources influence their surroundings?
- New results on pc-scale RM
  - Jet, interaction or unrelated foreground?
  - If jet, then important implications for collimation
  - What is the field structure?
- New techniques
  - MHD simulations of clusters of galaxies
  - RM synthesis
  - Planning for EVLA, e-MERLIN, LOFAR, (ALMA), ...

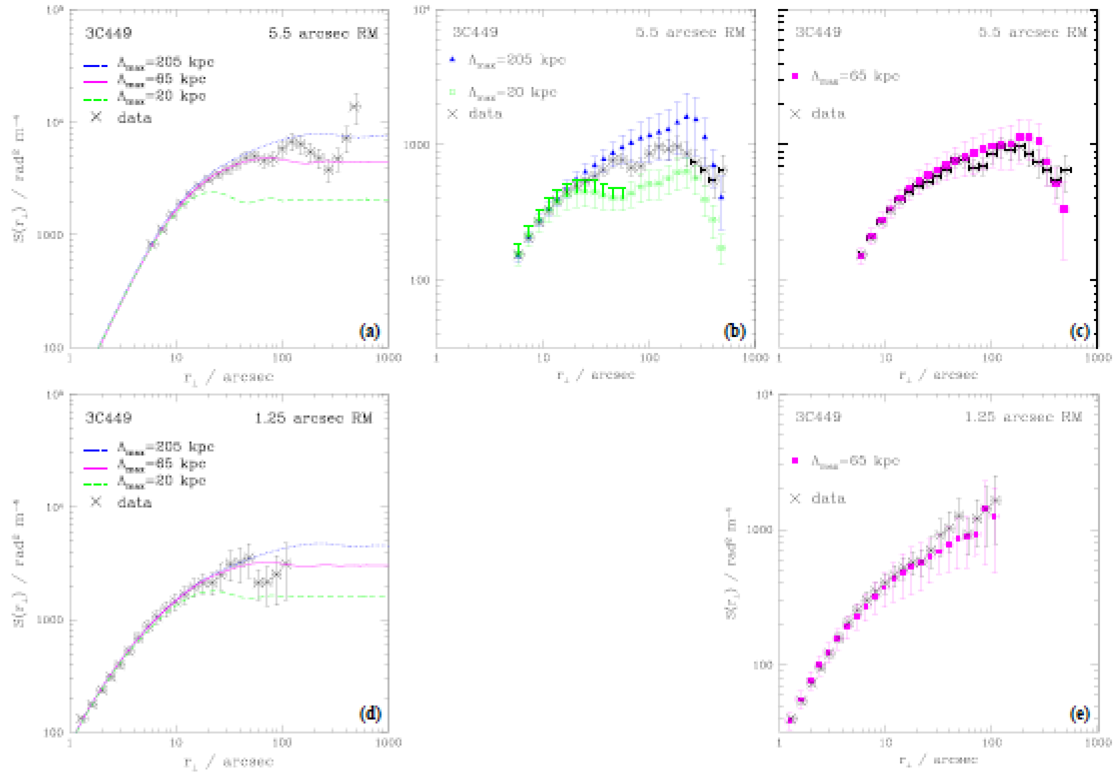
Quantifying RM fluctuations

Approaches to measuring the spatial statistics of RM fluctuations, such as structure functions and Bayesian methods

- Isotropy? Does the field have preferred directions?
- Non-Gaussianity: is RM a Gaussian random variable? Is there filamentation or intermittency?
- Real space vs Fourier space
- Structure and autocorrelation functions
- 2D and 3D simulations
- Bayesian maximum-likelihood methods
- Error bars!
- Correlations between RM fluctuations and source orientation (path length) or structure (interactions)

High-resolution RM images and simulations





Images for 3C31 (RL et al. 2008)
Structure function fits for 3C449
from Guidetti et al. (2010)

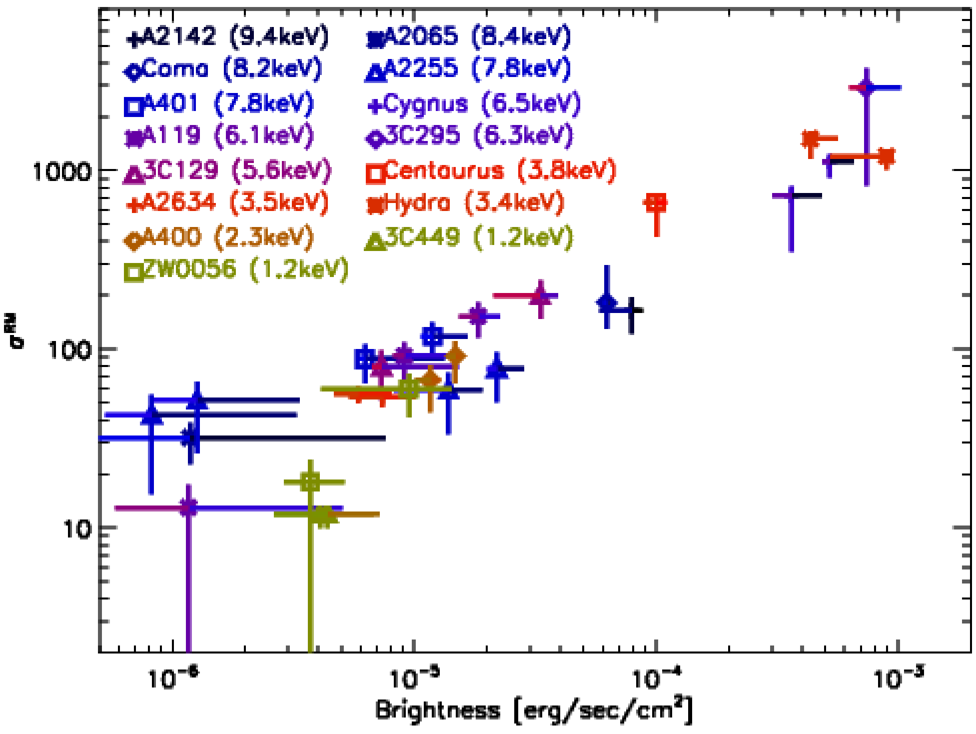
Algorithms for analysis of multifrequency polarization data

- RM synthesis: the Faraday dispersion function is the Fourier transform of the complex polarization (Burn 1966)
    - Practical implementation (Brentjens & de Bruyn 2005)
    - Wideband correlators on all new synthesis instruments
    - Coping with limited frequency sampling
    - Relation to multi-frequency synthesis
- Understanding the answers
    - The old problem: foreground vs internal
    - Effects of convolution with the observing beam

Magnetic fields around individual galaxies, groups, clusters, large-scale structure

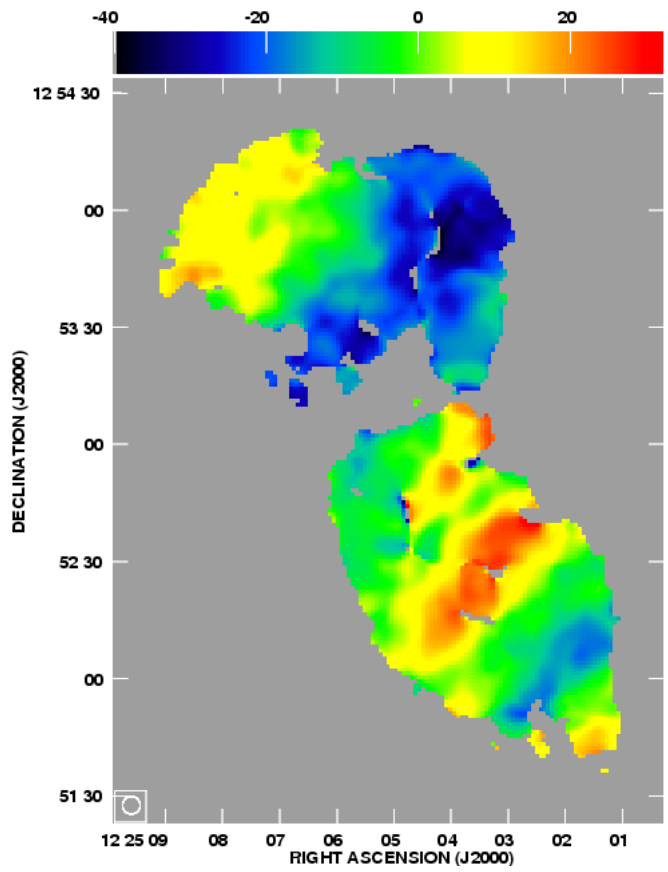
- Quantifying the field
  - Magnitude
  - Power spectrum parameters (slopes, inner and outer scales, ...) if appropriate.
- Scaling laws

X-ray surface brightness vs rms RM (Dolag 2006)



Coherent RM structures

- What are they? How are they formed?



RM in M84 (Laing & Bridle 1987)

Simulations of magnetic-field evolution in galaxy clusters

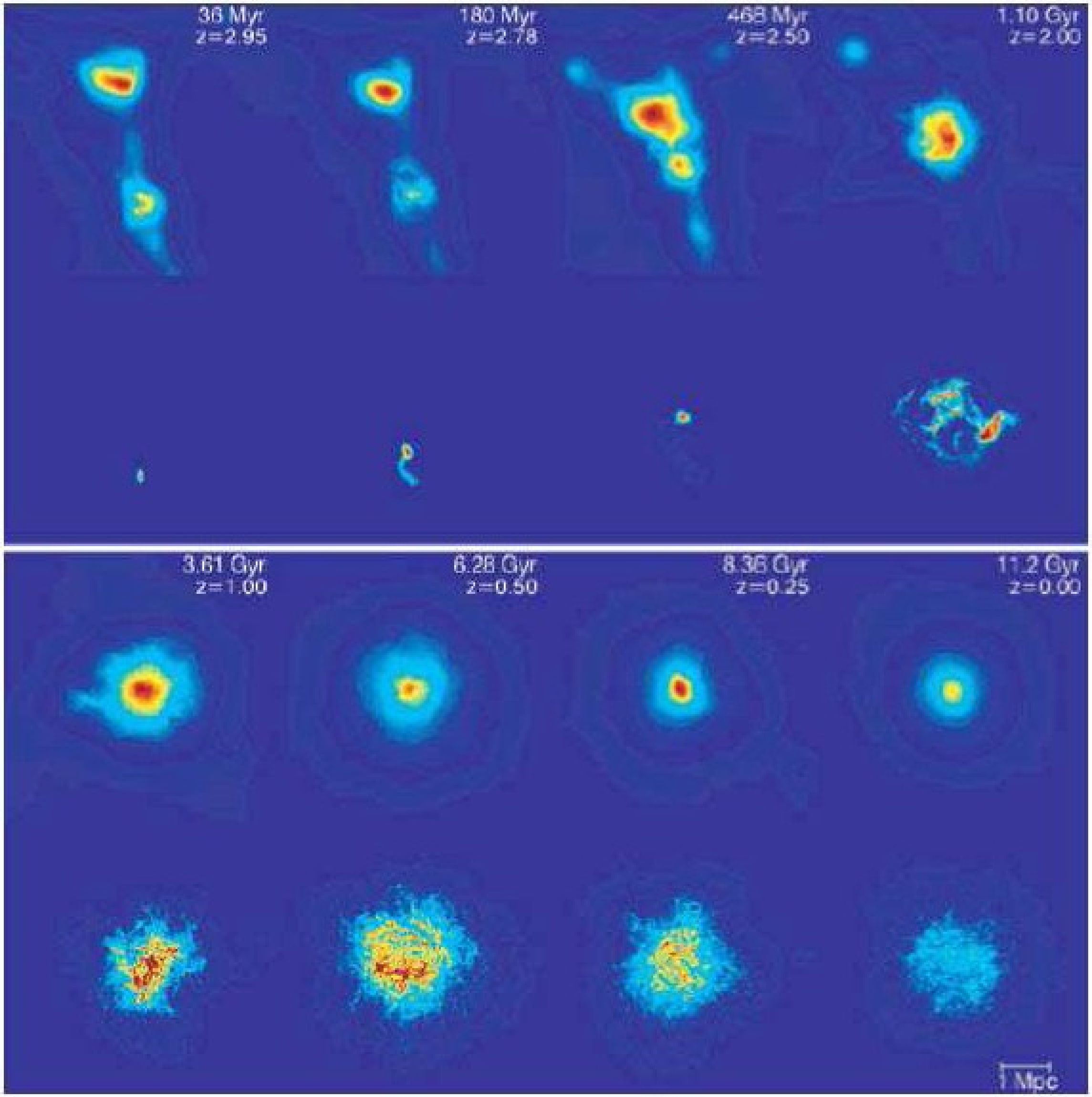
Projected baryon density

Magnetic energy density

Xu et al. (2009)

AGN injection event at z = 3; merger at z = 2

Can we test this?



Observations of Faraday Rotation on pc scales

- Gradients in RM across jets on pc scales
  - 3C273 (Asada et al. 2002)
  - Now many more sources (Gabuzda et al.; Zavala & Taylor, ..)
  - Associated with the jets or consistent with random foreground?
  - Evidence for toroidal (helical) fields?
  - Where are these fields? Probably outside most of the synchrotron-emitting volume. How do they relate to the field in the jet?

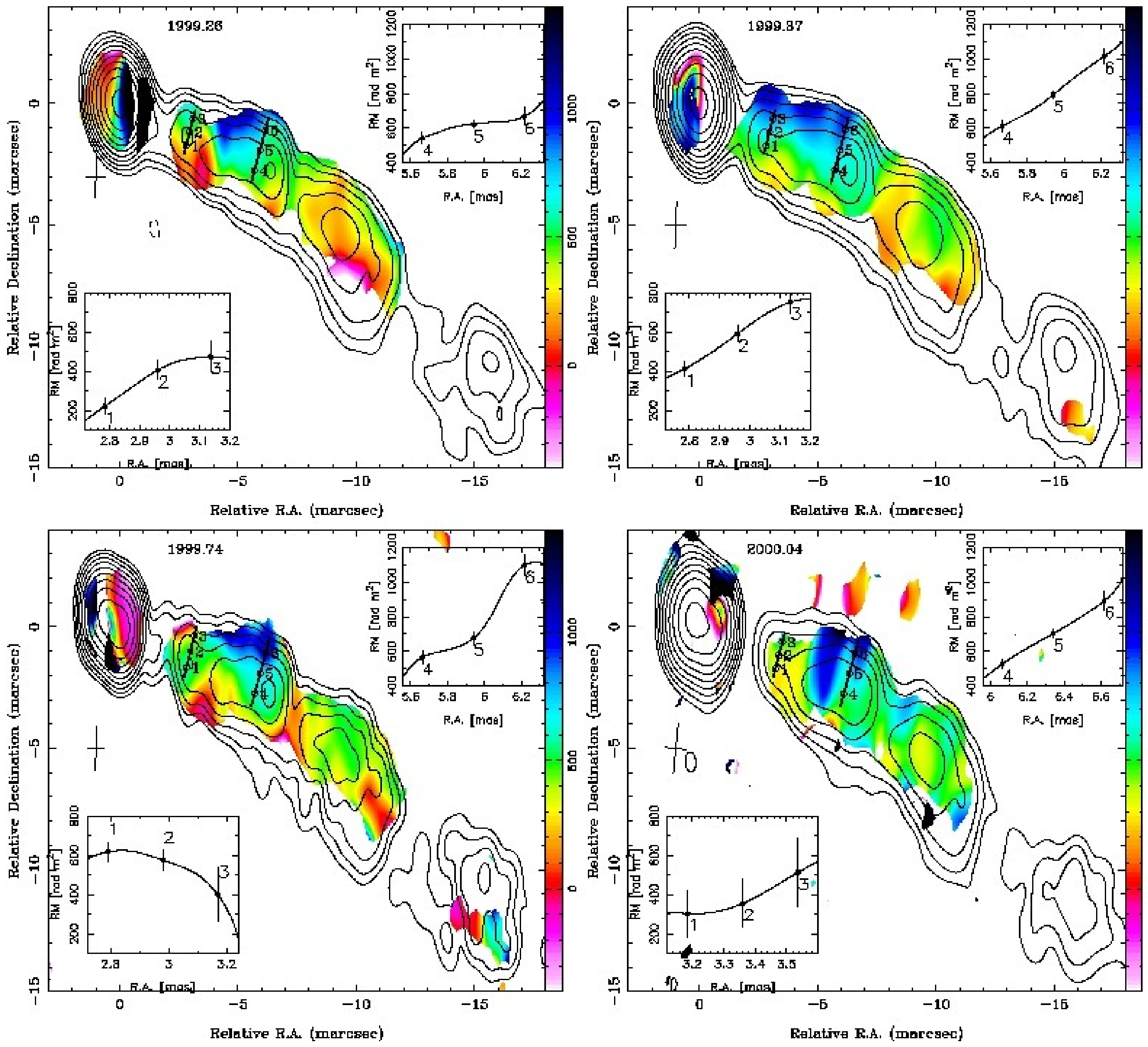
ii) Multifrequency observations can detect variations in Faraday rotation over a jet. In particular, (1) If the field is ordered in the sense of § I (e.g., a helical or CH field) and thermal matter is distributed uniformly throughout the jet, then the rotation measure, ρ, defined by

$$\chi(\lambda)=\chi(0)+\rho\lambda^2(|\rho\lambda^2|\lesssim\pi/4),$$

where $\chi(\lambda)$ is the *E*-vector P.A. of polarized radiation at wavelength λ, should vary smoothly across the jet. Note that any rotation at the edge of a jet is probably due to intervening matter (e.g. in our galaxy) because the path length through the jet will be very small. In contrast, a field with many reversals along the line of sight (§ III) should give

RL (1981)

Multi-epoch RM imaging of 3C273

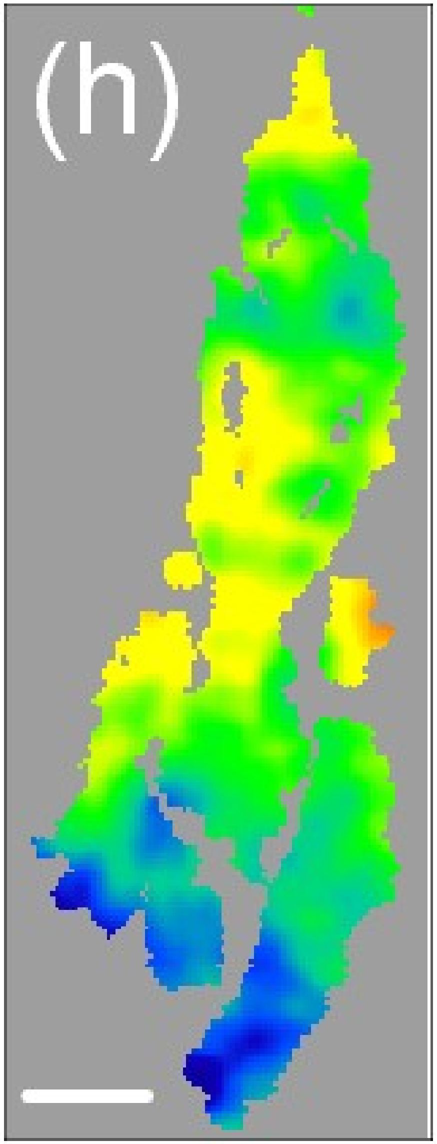


Wardle (2006)

Challenges of Relativistic Jets

(Cracow)

But is it all that different from ...



How do we want to run the workshop?

- Scope is restricted deliberately to allow plenty of time for discussion in depth
- Democratic: no invited/contributed distinction
- Informal
- Speakers: please leave time for immediate questions after the talk.
- There are general discussion periods scheduled: please think about topics
- No proceedings, but we will collect all presentations and put them on the web