Max-Planck-Institut
für Radioastronomie

VNIVERSITAT DE VALÈNCIA

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Polarisation & AGN, COST, Brussels

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POLARISATION IN AGN JETS

Thanks to...

- Contributions by
  - Antxon Alberdi (IAA-CSIC/ES)
  - Talvikki Hovatta (Caltech/US)
  - Dan C. Homan (Denison/US)
  - Tuomas Savolainen (MPIfR/DE)
  - …and many others

Jets in AGN

- Jets are formed in the immediate vicinity of SMBH in AGN
- Jets consist of charged particles trapped in strongly collimated, poloidal magnetic fields

- *Open question: how are jets launched and accelerated?*

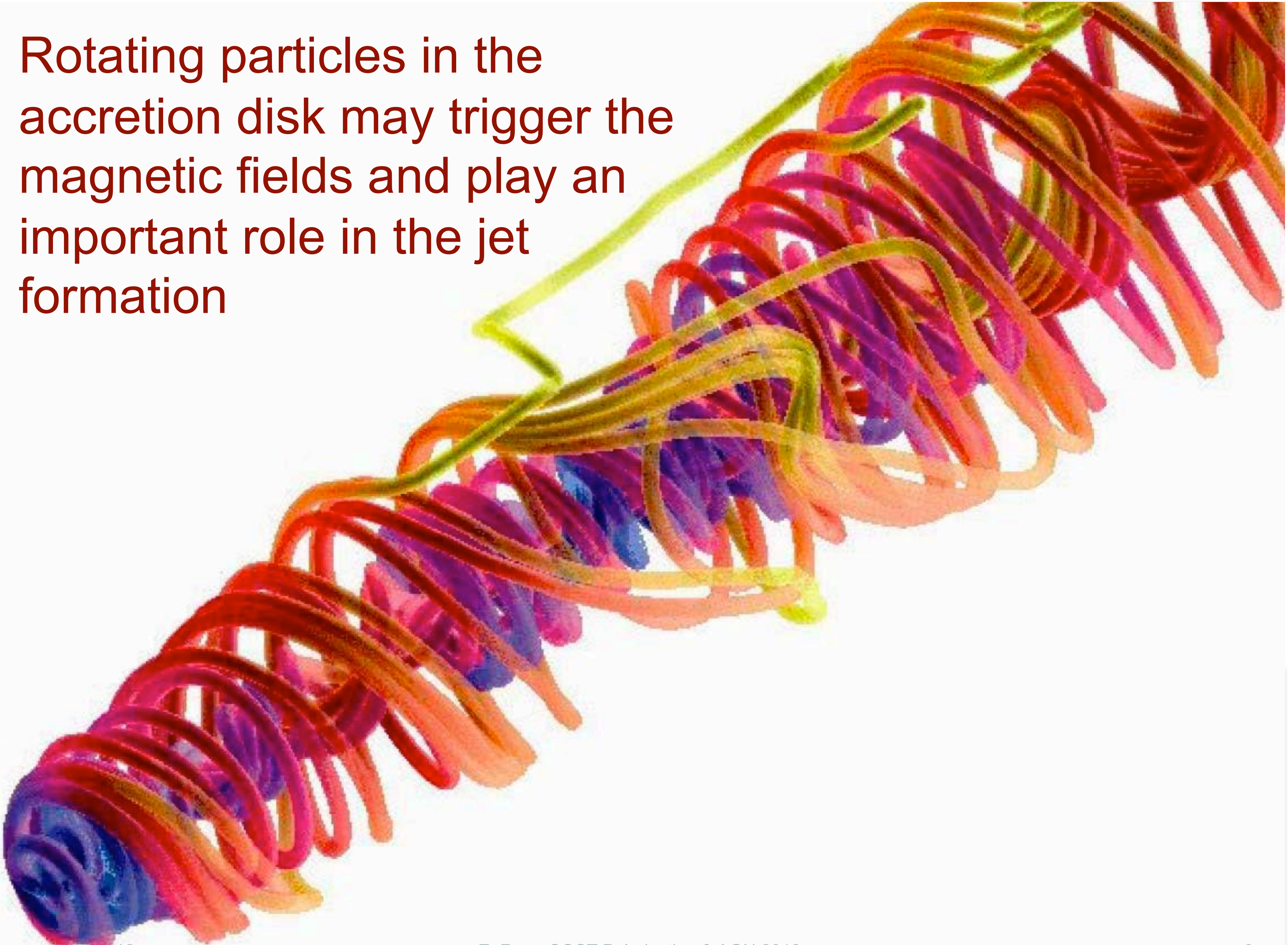
Jet acceleration and collimation

- Jets are accelerated within the first 1000 R_S
- The magnetic field is responsible for accelerating particles at parsec-scales
- Following the synchrotron theory, the magnetic field produces polarised radio emission

Main science areas

- Linear polarisation
  - Provide magnetic field strength and orientation
- Circular polarisation
  - Limitation by circularly polarised feeds
- Rotation measurement
  - Combining linear polarisation images at different frequencies
  - Issue: proper calibration and alignment

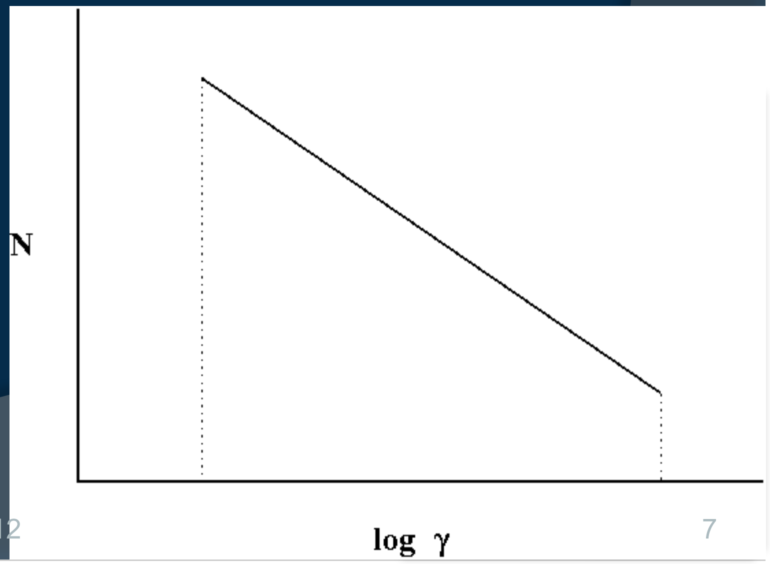
Rotating particles in the accretion disk may trigger the magnetic fields and play an important role in the jet formation



Polarisation as a Probe of Jet Physics

- Jet Structure and Composition
  - 3-D Magnetic Field Structure of Jets
    - Connection with SMBH/Accretion Disk System
  - Low energy end of particle spectrum
    - Dominates Kinetic Luminosity of Jets:
    - Important for constraining particle accel. mechanisms
  - Particle Composition of Jets
    - Electron-Proton? Electron-Positron?

$$N_{total} \propto 1/\gamma_{\min}^{2\alpha}$$



Polarisation as a Probe of Jet Physics

- Magneto-Hydrodynamics of Jets
  - Field signatures of Oblique Shocks
  - Time evolution of Field Structures
    - Compared to simulations
  - Dependence on Optical Class
- Jet Environment
  - Jet Polarization as “Backlighting”
  - Nature of Faraday Screen on Parsec Scales
    - Scale Height
    - Relation to Jet Magnetic Field
    - Are we seeing Narrow Line Clouds?

QSO 3C345

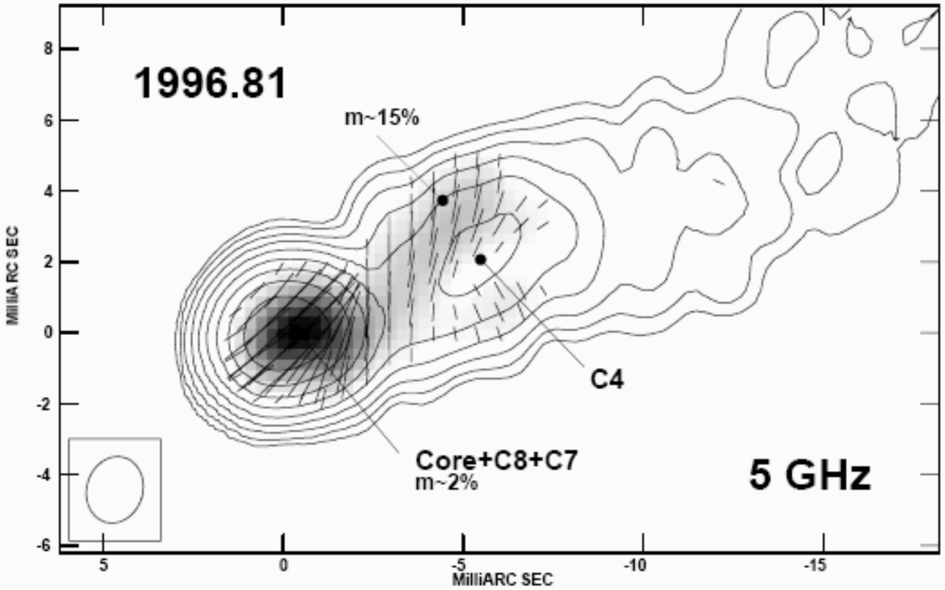


Fig. 12. Polarized intensity electric vectors (χ, length proportional to p, 1 mas in the map is equivalent to 10 mJy/beam) overlaid on total intensity (I) contours (3 mJy/beam× −1, 1, 2.24, 5, 11.18, 25, ...) and grey scale polarized intensity (p, grey scale up to the peak of brightness, 40.5 mJy/beam) images for 3C 345 at 5 GHz, epoch 1996.81. It is obvious that the electric vector is almost perpendicular to the jet at core separations from 3 to 7 mas.

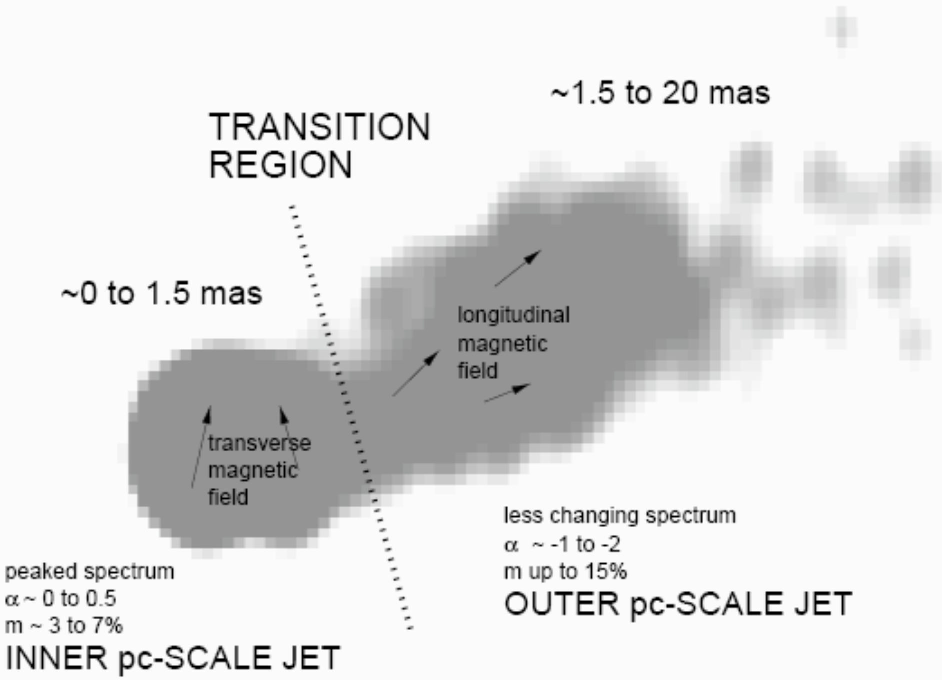
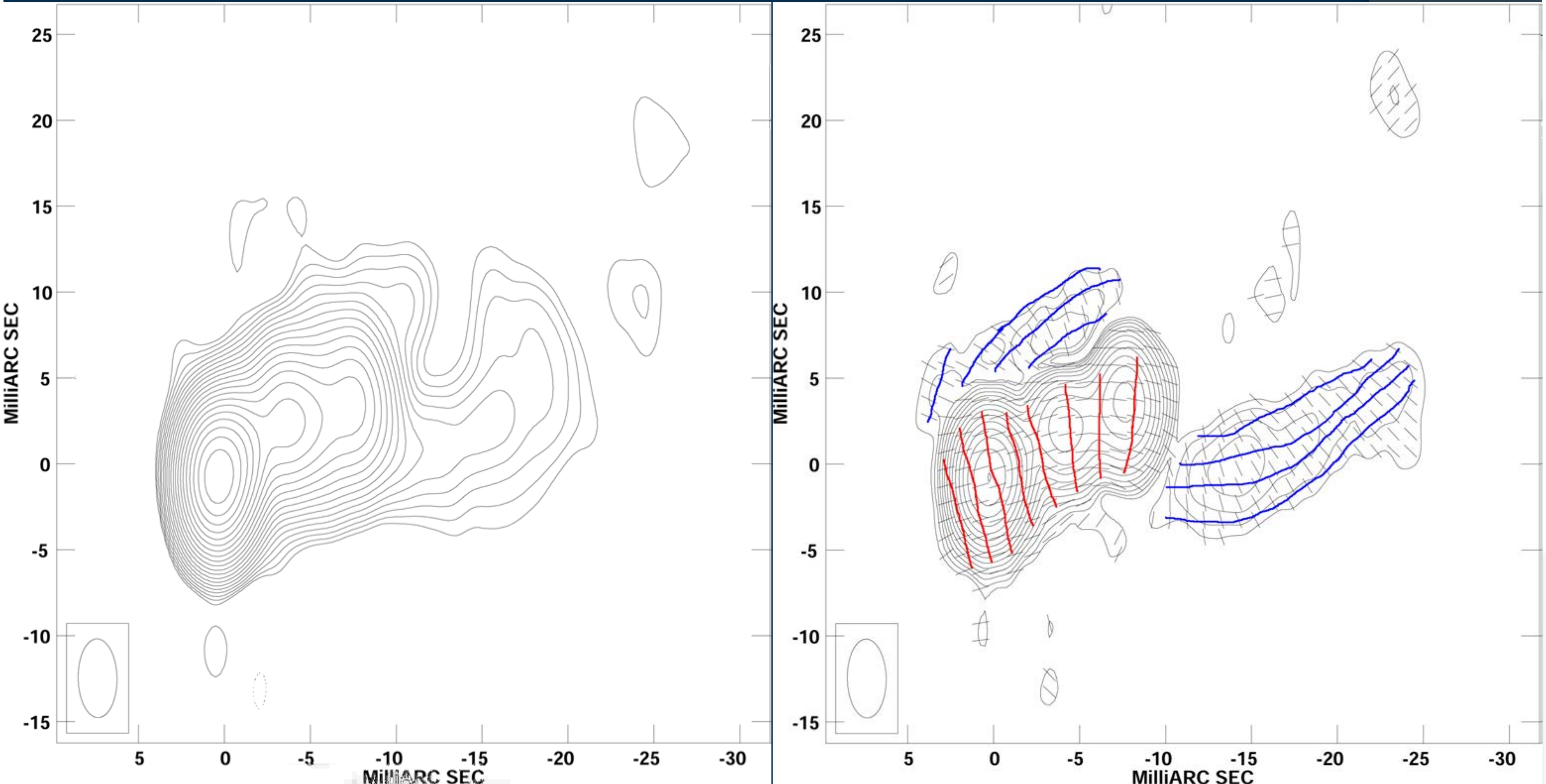


Fig. 13. Summary of physical properties observed in the two regions of the parsec-scale jet of 3C 345. The values for α and m refer to our four observing frequencies (5, 8.4, 15, and 22 GHz), in general.

Ros et al. A&A (2000)

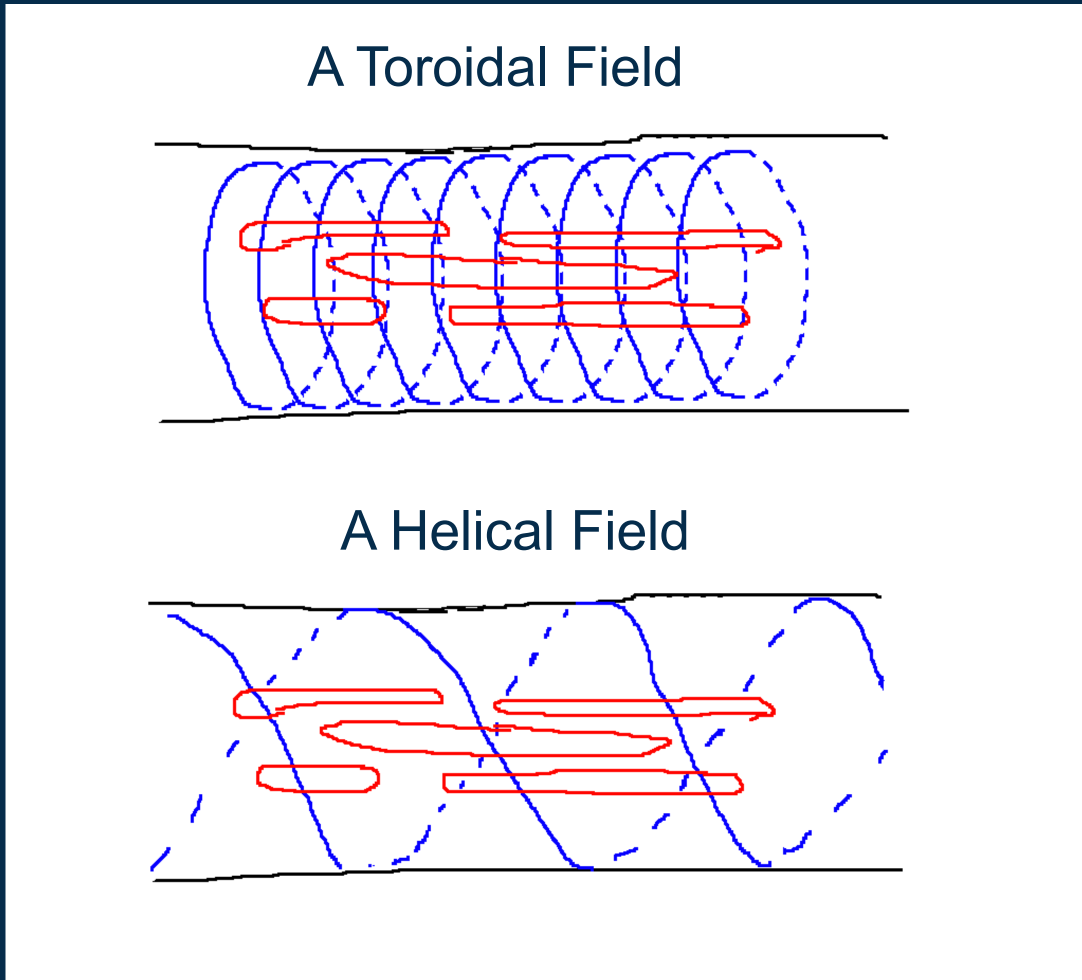
Quasar 1055+018, λ = 6 cm



Attridge 1998; Attridge, Roberts, & Wardle 1999

z = 0.889

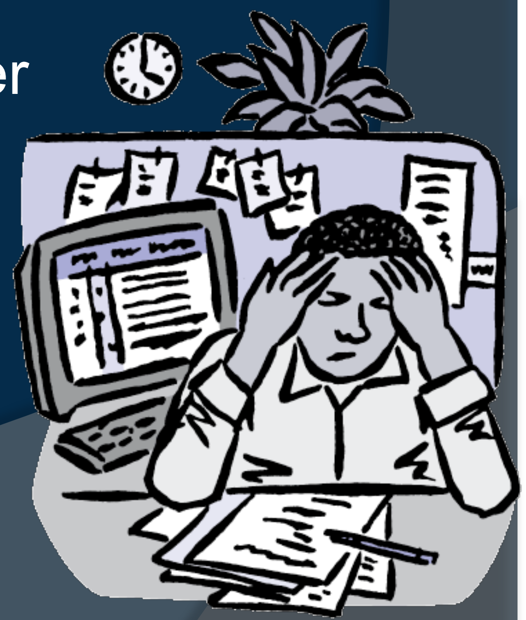
Possible Field Order in Jets



Picture: D. Homan (2003)

Field orientation

- Field in jet from accretion disk: **helical**
- VLBI observations: B parallel to jet, **toroidal**
- But…
  - Magnetic field **tangled** due to re-collimation shocks or external medium interaction
  - **Relativity** can make a toroidal field in the rest frame to look like poloidal in the observer frame
  - **Faraday rotation** flips the field angle, caused by to internal or external plasma
  - Shocks can compress B preferently perpendicular to jet: apparently **toroidal**



Main survey programs including polarisation

Program	λ	$N_{sources}$	N_{epochs} & Obs.	Ref.
Boston Univ.	7mm	35	50 (2007-now)	Marscher, Jorstad +
TeV Sample	7mm (+1.3/3.6cm)	7	5 (2006-now)	Piner+ 2010 ApJ 723 1150
MOJAVE	2cm	300	20 (1994-now)	Lister+ 2009 AJ 138 1874
MOJAVE 18/21cm	18/21cm	135	1 (2009-now)	Coughlan+'11
Bologna low-z	2/3.6cm	42	2 (2010-now)	Giroletti+'11
VIPS	6cm	1127	1 (2007)	Hemboldt+'08
VIPS subsample	6cm	100	2 (2010-now)	Linford+'11
CJF	6cm	293	3 (1990s)	Pollack+'03

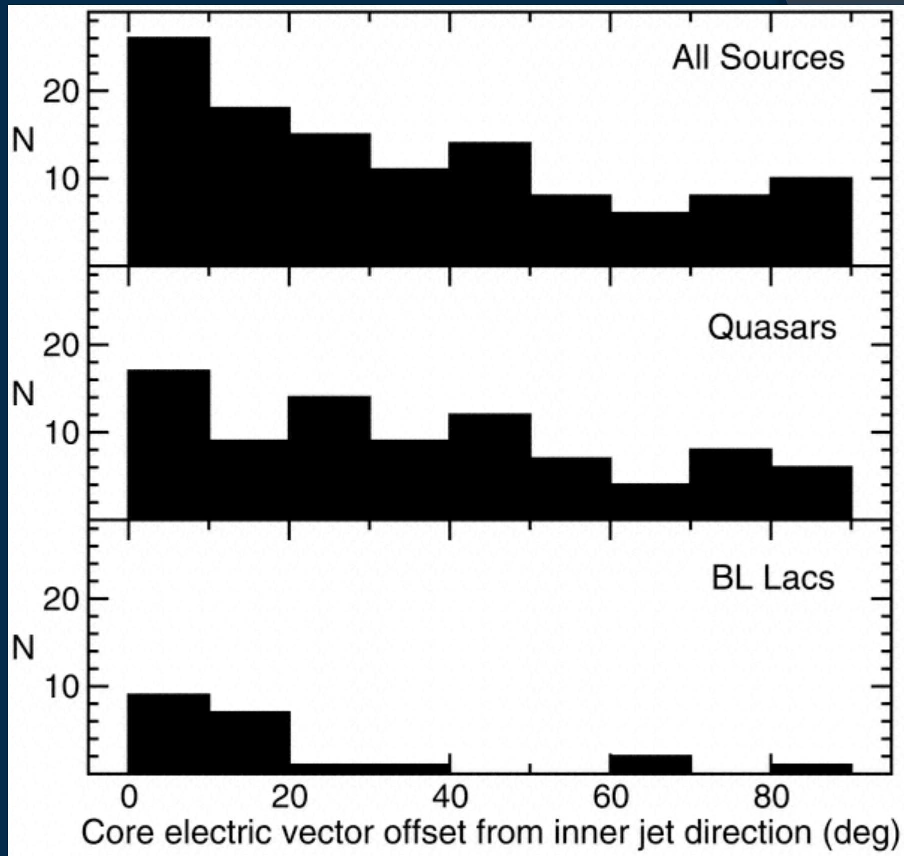
Selection criteria: usually flux and spectrum based

Observed Linear Polarization in AGN

- Fractional Polarization
  - Cores ~ few percent up to 10%
  - Jet features ~ 5-10% up to a few tens of percent
- Orientation relative to jet: $|\chi - \theta|$
  - Quasar Jets:
    - no clear relation (Cawthorne et al. (1993), Gabuzda et al. (2000), Pollack et al. (2003), Lister & Homan (2005))
  - BL Lac Jets:
    - excess near 0° (Gabuzda et al. (2000), Lister & Homan (2005))

Alignment of χ by opt. class

- MOJAVE result (see below)
- BL Lacs have the electric vector parallel to jet
- Quasars have a broader $|\chi-\theta|$ distribution



Lister & Homan MOJAVE Paper I (2005)

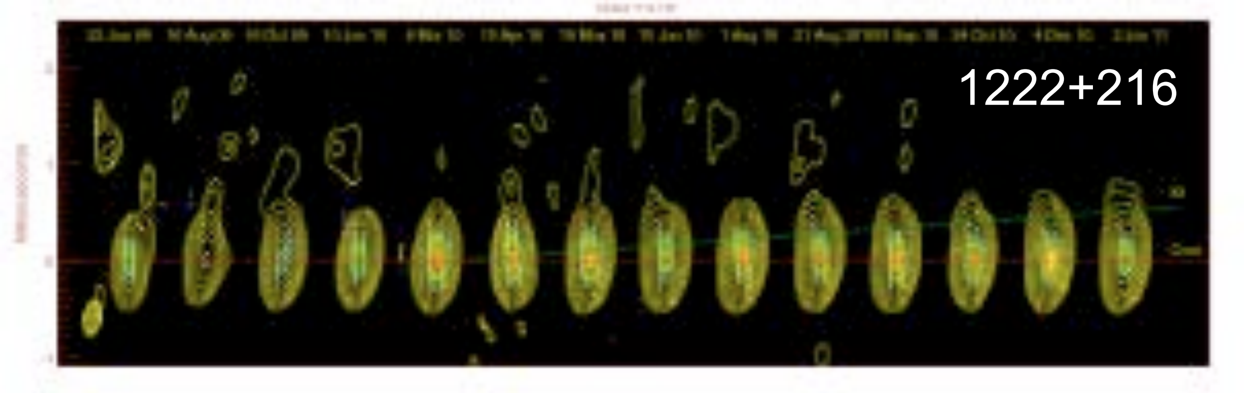
BU Blazar Monitoring

See J. Acosta Pulido's talk

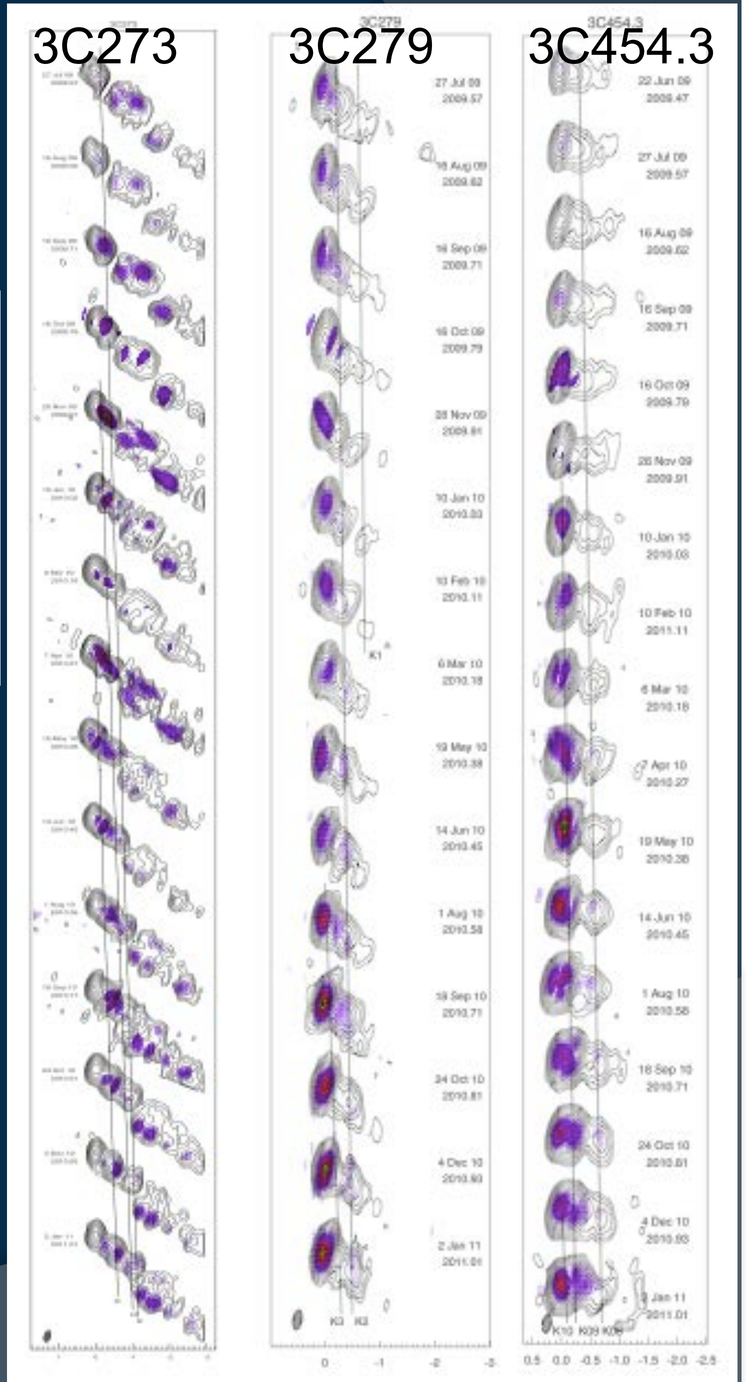
- Study of 35 blazars at 43 GHz, observed monthly by the VLBA
- High spatial and time resolution, with polarimetry
- (Lack of) opacity: closer view the core region and the birth of new features traveling downstream
- Several studies presented individually in publications
- Calibrated data are made public

http://www.bu.edu/blazars/

BU Blazar Monitoring



Jorstad et al. Fermi Symp 2011 arXiv 1111.0110



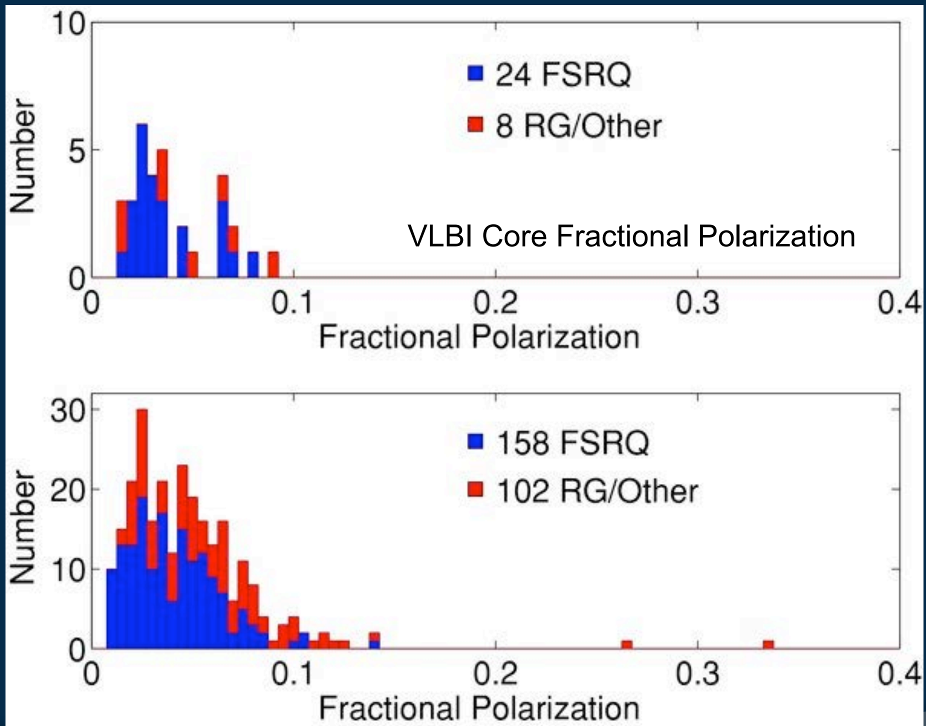
VLBI Imaging and Polarimetry Survey (VIPS)

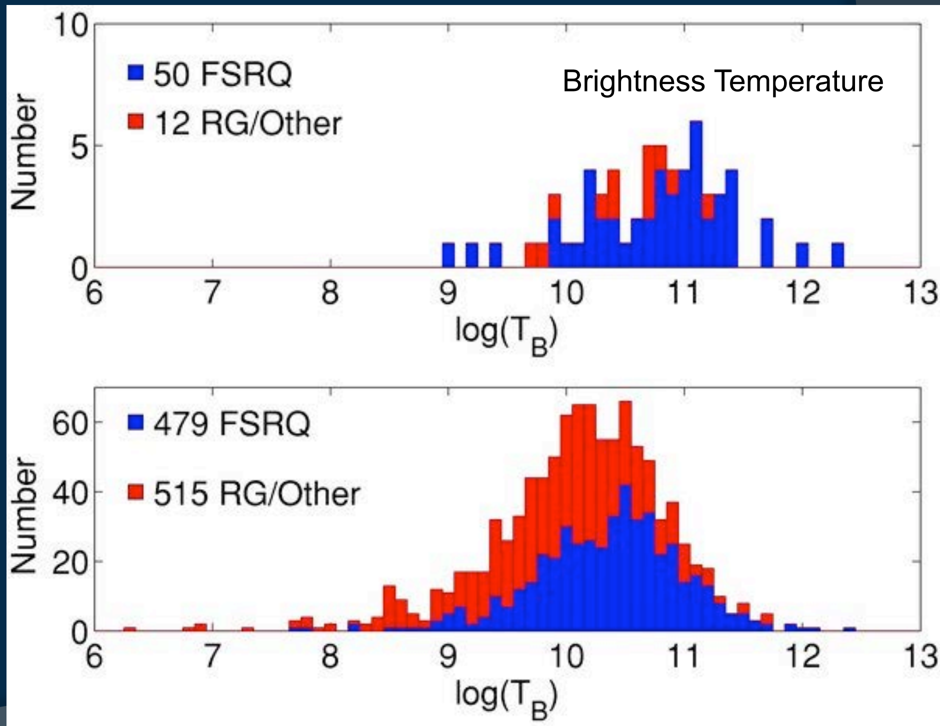
- 1127 sources at 5 GHz
- One epoch, pre-Fermi era
- Polarisation included
- Helmboldt et al. 2007 ApJ 658, 203
- Followed by VLBA observations of 100 blazars (at least two epochs) – P.I. G.B. Taylor

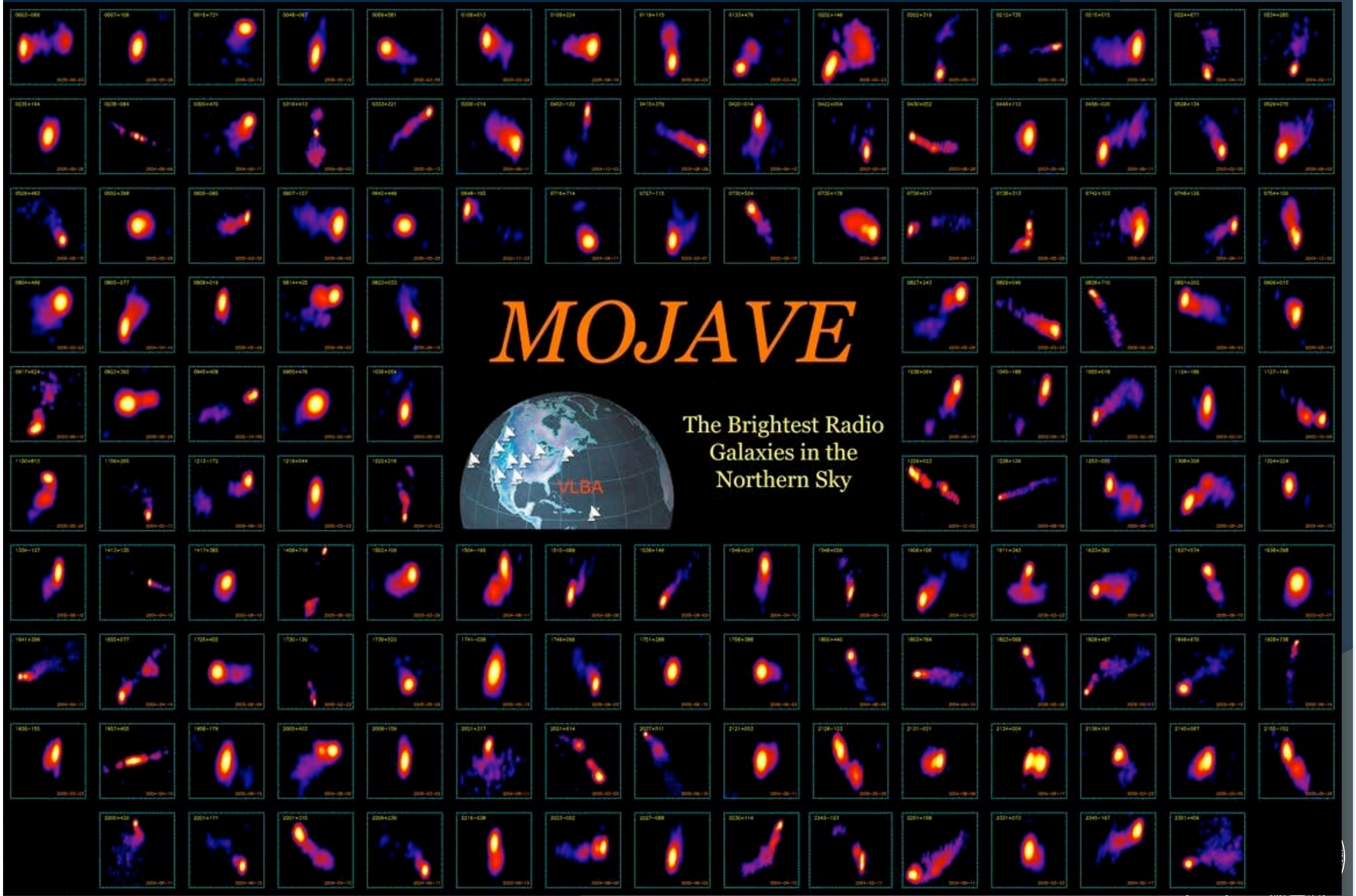
VIPS Extension (*Fermi*-related)

- Median value in core fractional polarization is 3.5% for γ-detected and 4.4% for non-γ
- Brightness temperature of γ-bright higher than non-γ

Linford et al. (2011 ApJ 726 16)





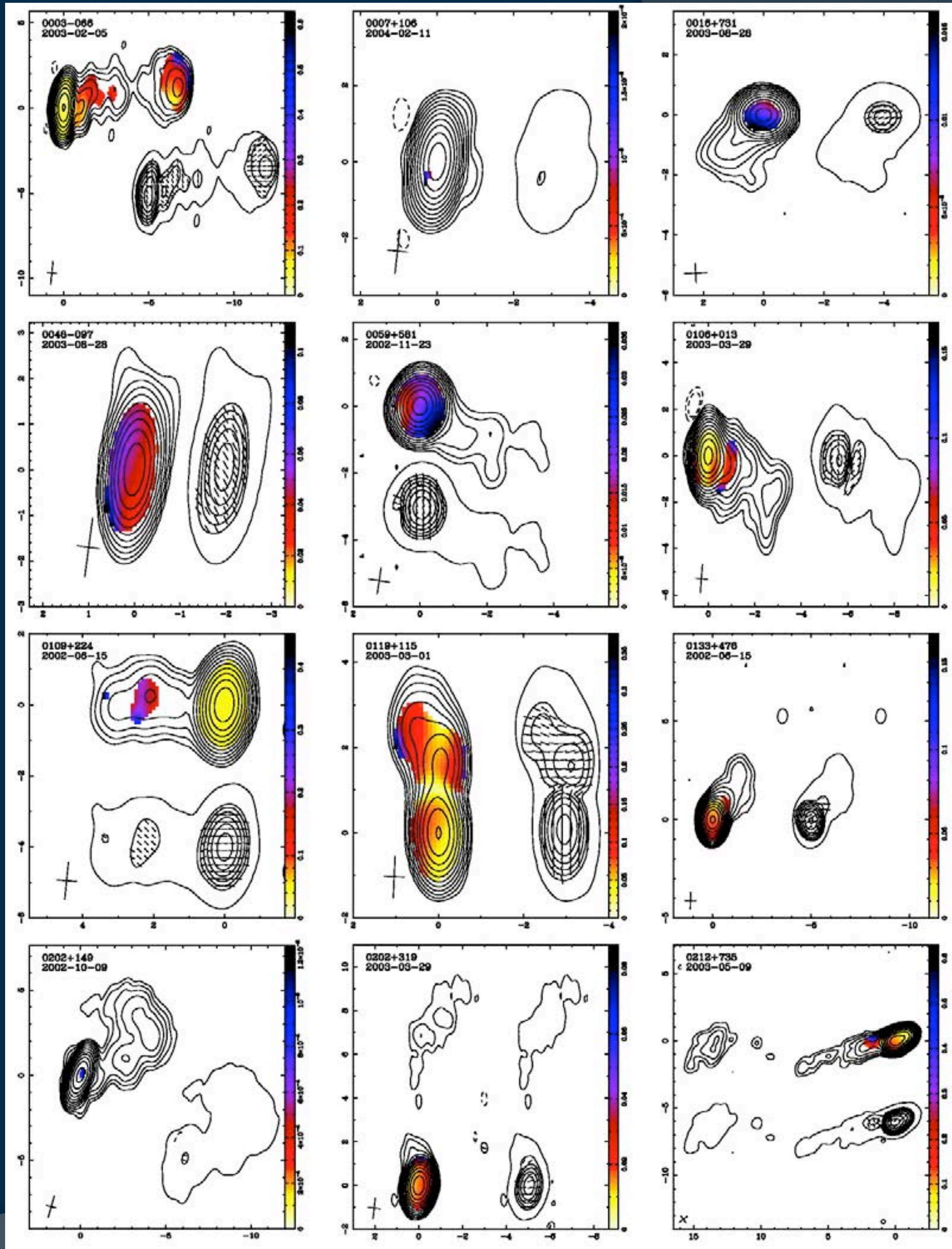

MOJAVE
VLBA
The Brightest Radio Galaxies in the Northern Sky

MOJAVE program

- Milliarcsecond-resolution, full Stokes images
- Currently ~300 sources monitored
- Continuous long-term monitoring, good sensitivity, source-specific observing cadences ➔ High-quality jet motions
- Large, well-defined sample ➔Statistics, properties of the parent population
- Calibrated data are made public

https://www.physics.purdue.edu/astro/mojave/

Lister & Homan (Paper I, 2005)



Evidence for Helical/Toroidal Fields?

- Gradients in Faraday Rotation Across Jets…
  - Due to Toroidal field structures within jets or in a boundary layer surrounding them?
  - Could they be due to external pressure gradients?

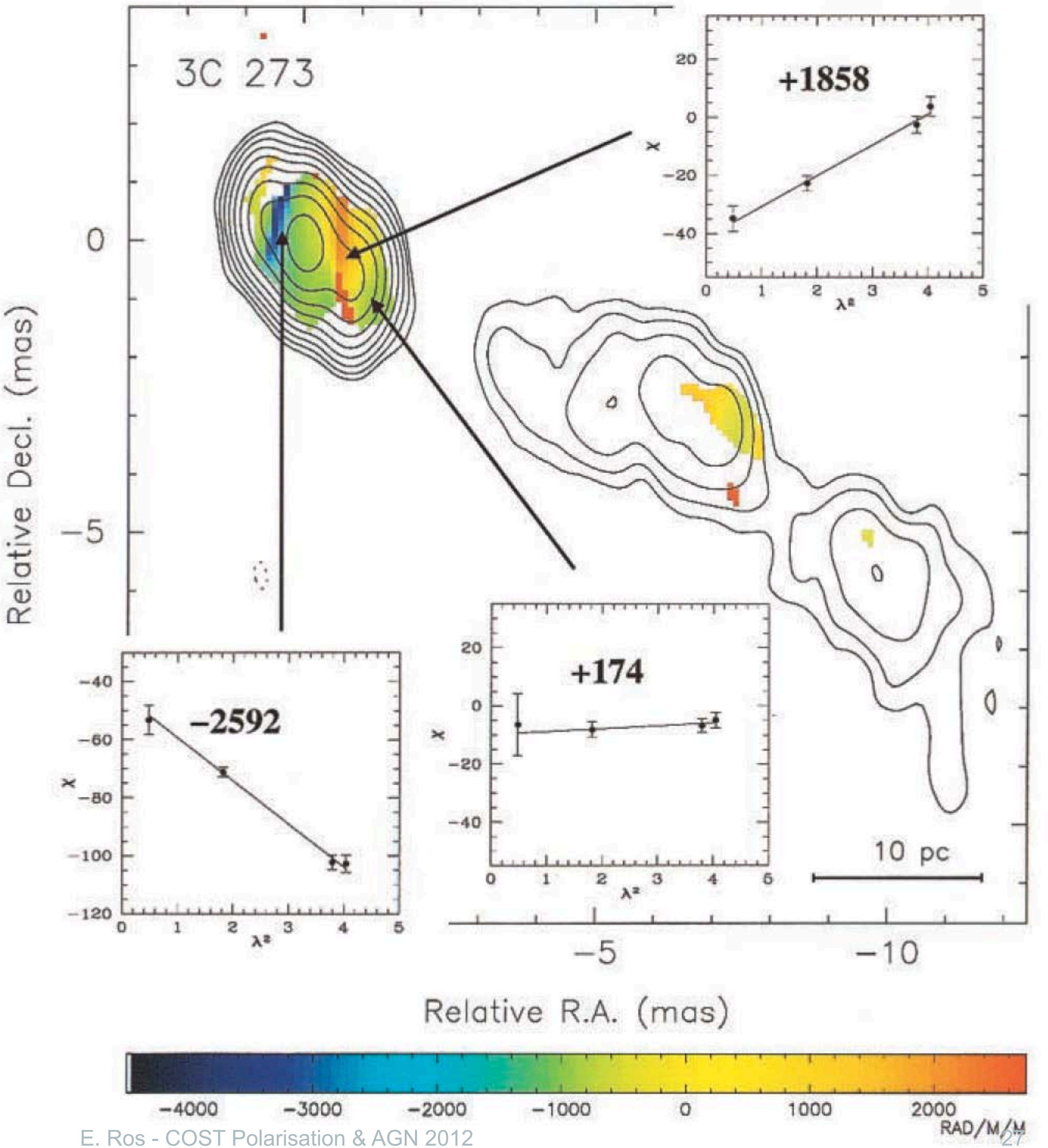
- If Toroidal Fields…
  - Role in Collimation & Acceleration
  - Jets carry a current (where is it… how does it flow?)

Faraday Rotation

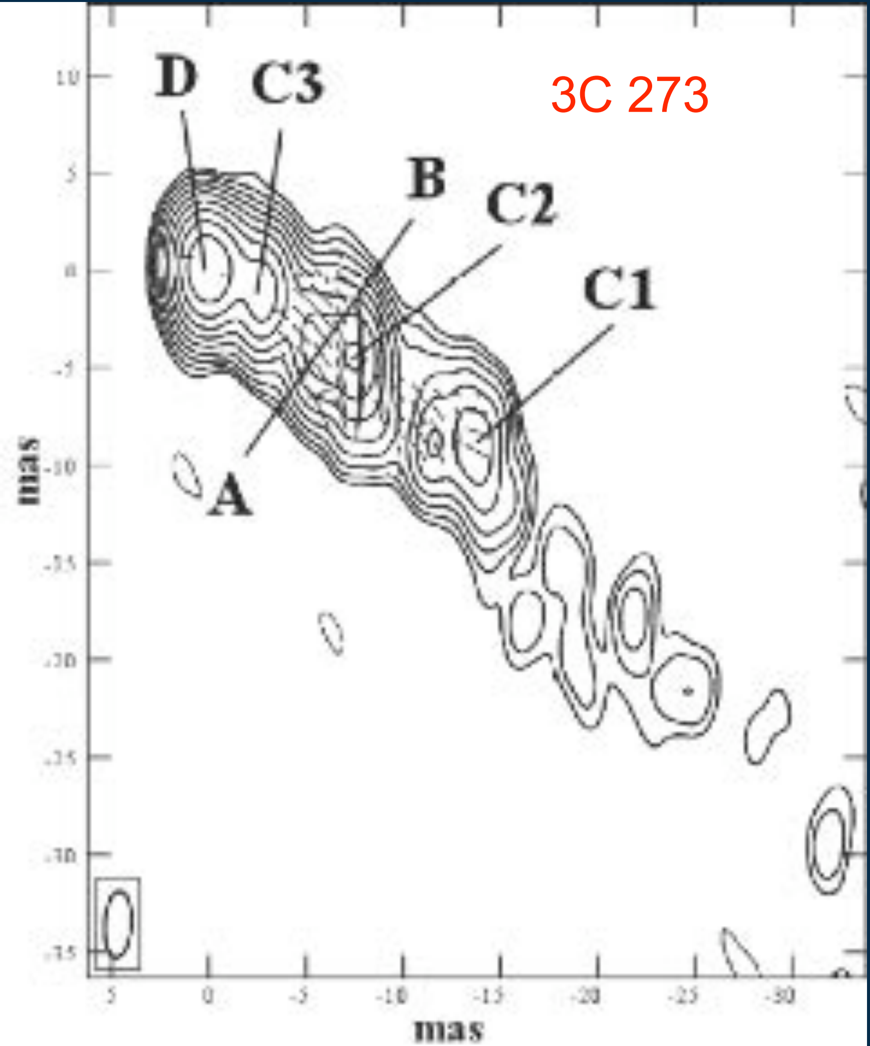
$$\chi = \chi_0 + RM \cdot \lambda^2$$

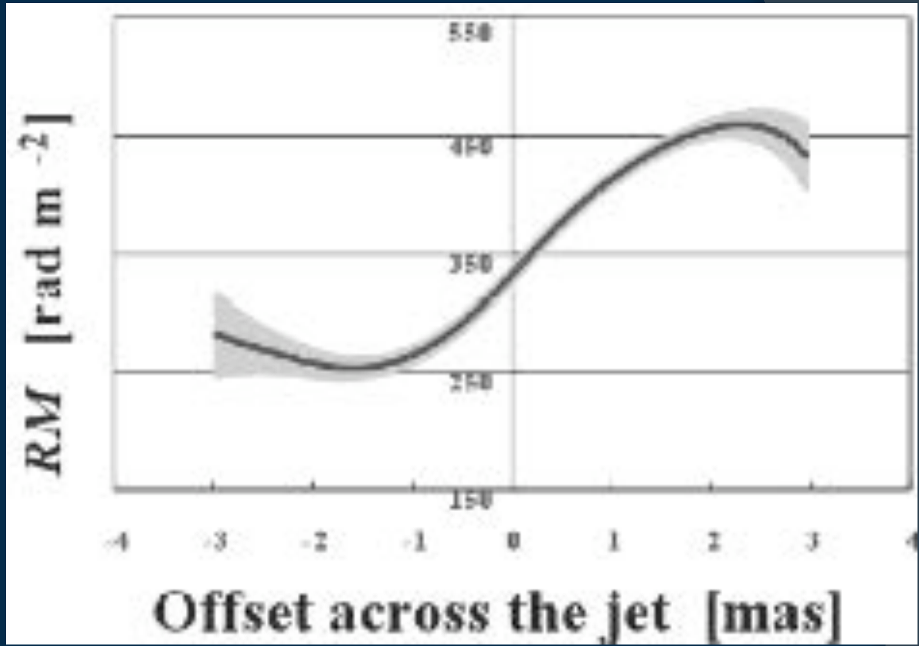
$$RM \propto \int n_e B_{\parallel} dl$$

Zavala & Taylor 2001



Rotation Measure Gradients



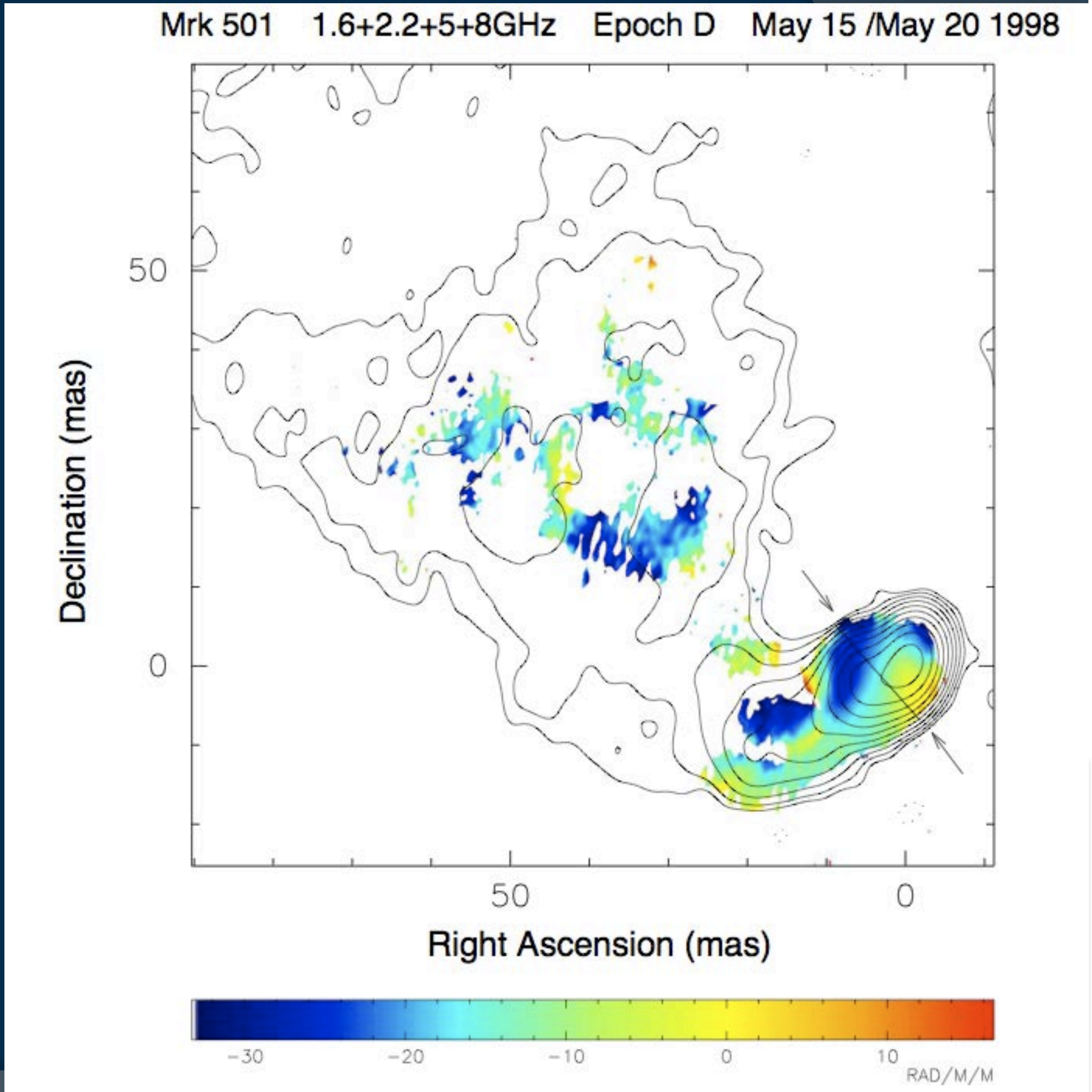


Asada et al. 2002

Multiple Scales and Epochs:
Zavala & Taylor 2005;
Attridge et al. 2005 with mm VLBI;
Asada et al. 2008

TeV Blazar: Markarian 501

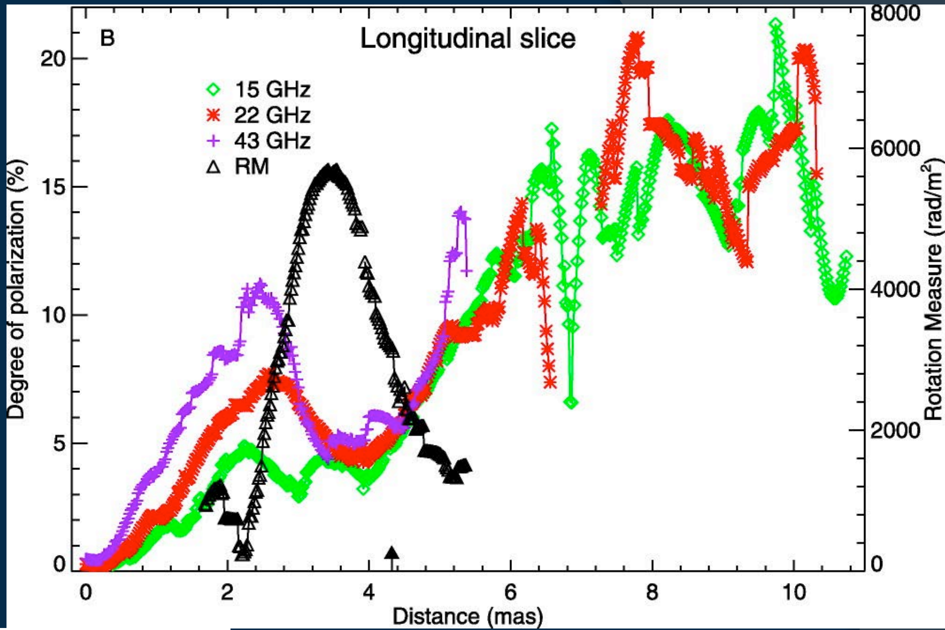
(Croke et al. 2010)

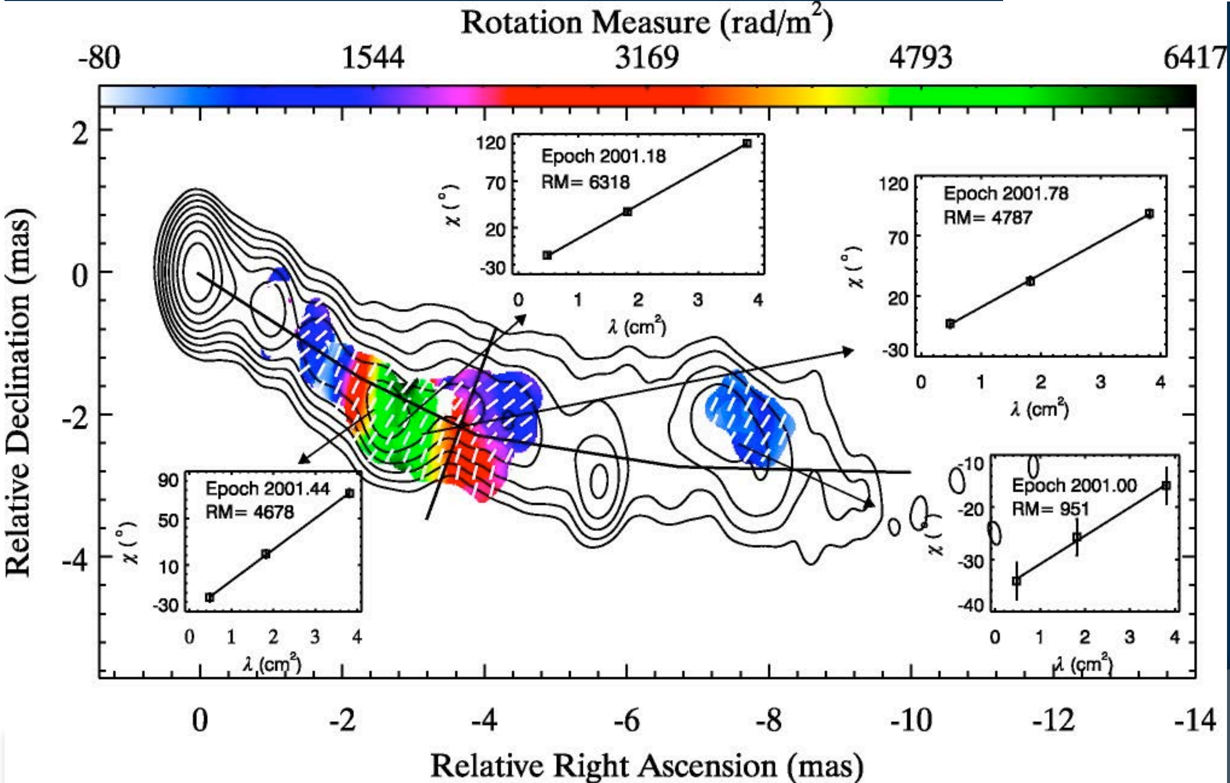


Other Jets:
Gabuzda et al. 2004;
Asada et al. 2008;
Gomez et al. 2008;
O'Sullivan & Gabuzda 2009;
Mahmud et al. 2009;
Asada et al. 2010

3C 120

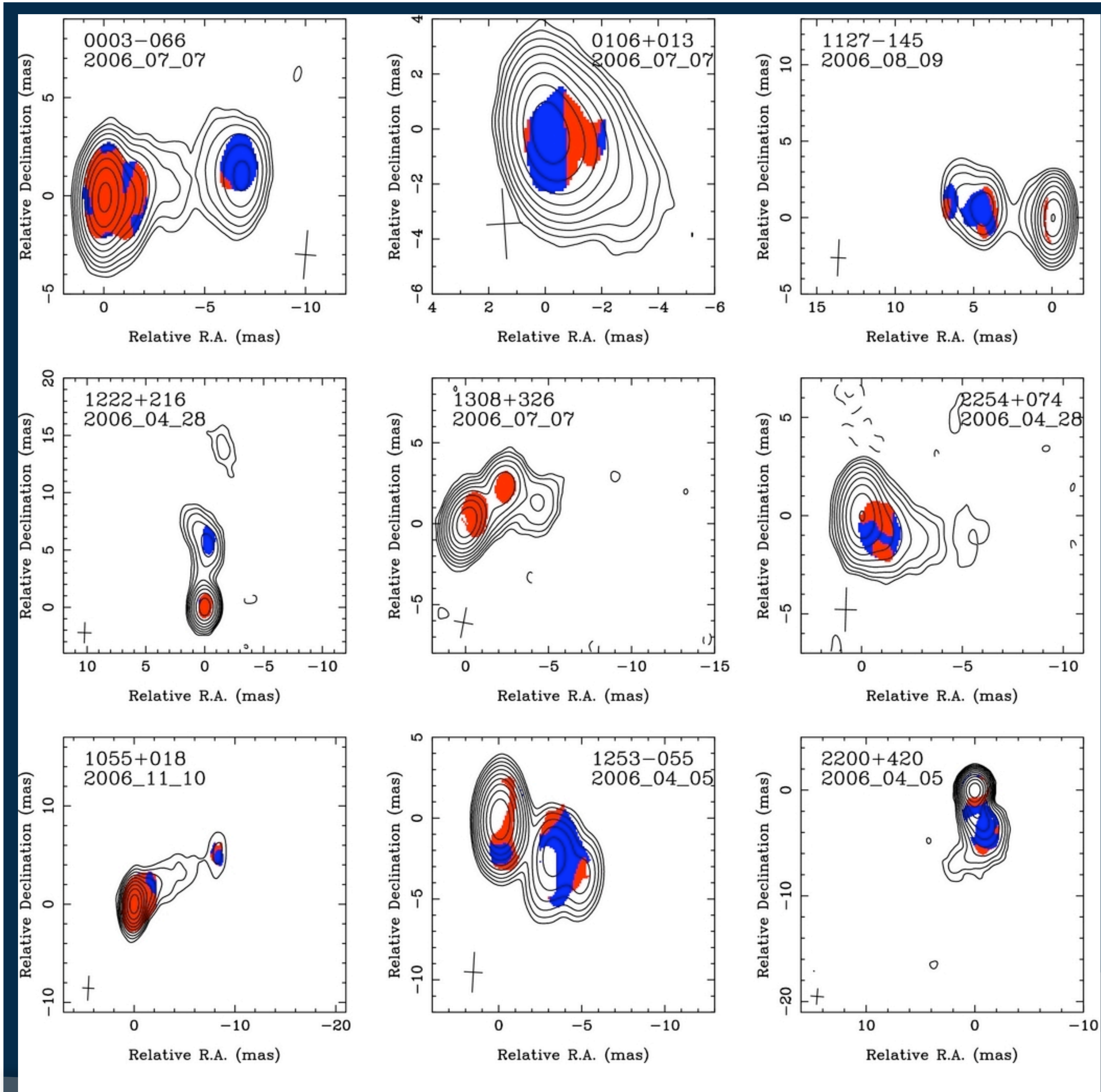
Polarisation degree increasing with distance from core
Jet interacts with a cloud at 2-3 mas. Dominant poloidal B-field.





Data consistent with helical field in a two-fluid jet model.
Inner emitting jet and sheath containing non-relativistic electrons.

Gómez et al. (2008)



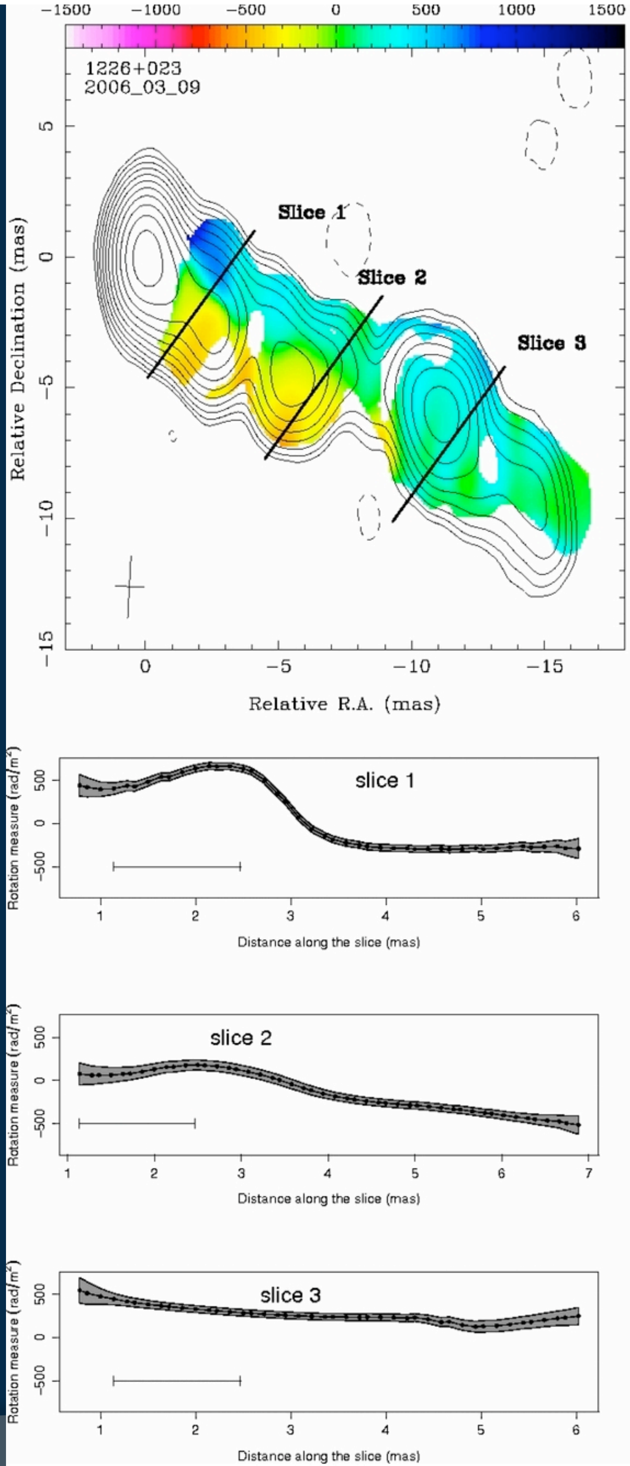
MOJAVE RM results

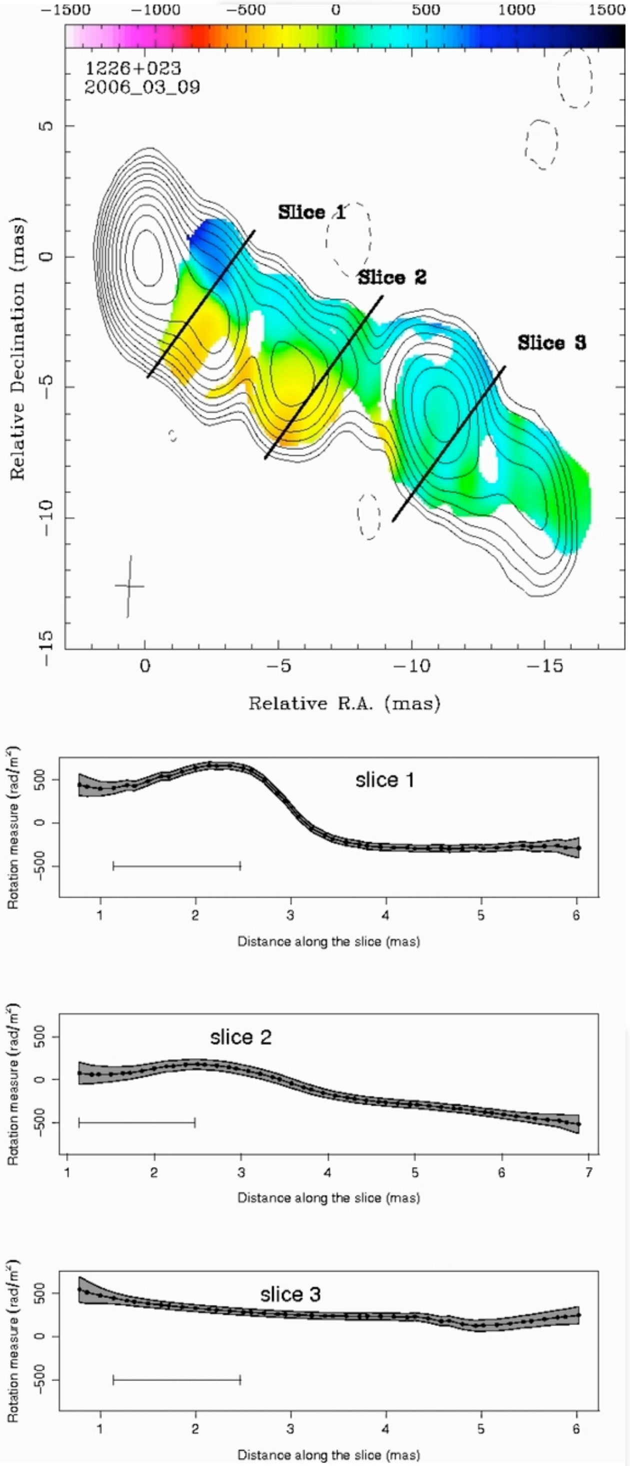
Transverse gradients found in 4 souces

Hovatta et al. (2012)

3C 273 RM

Hovatta et al. (2012)

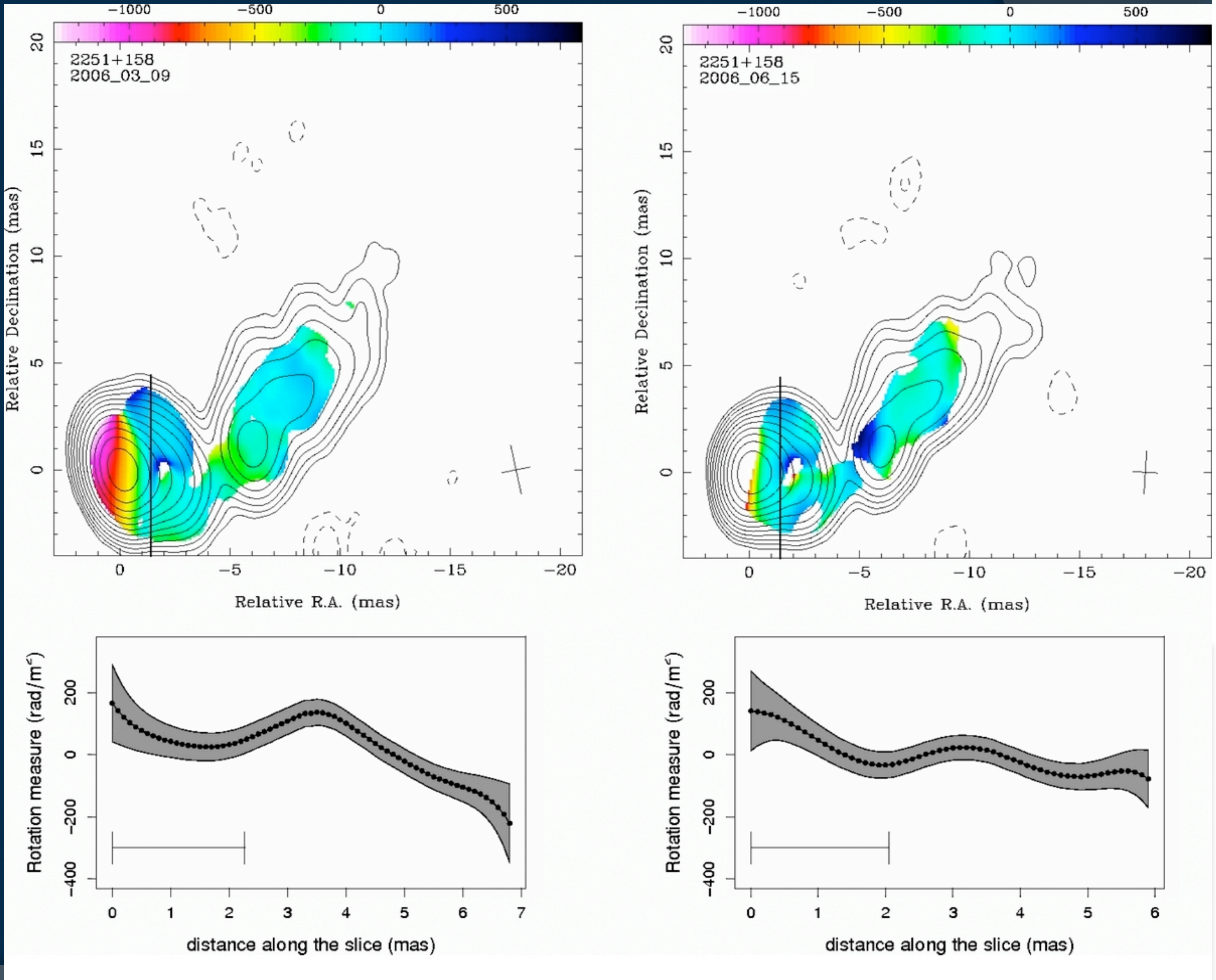




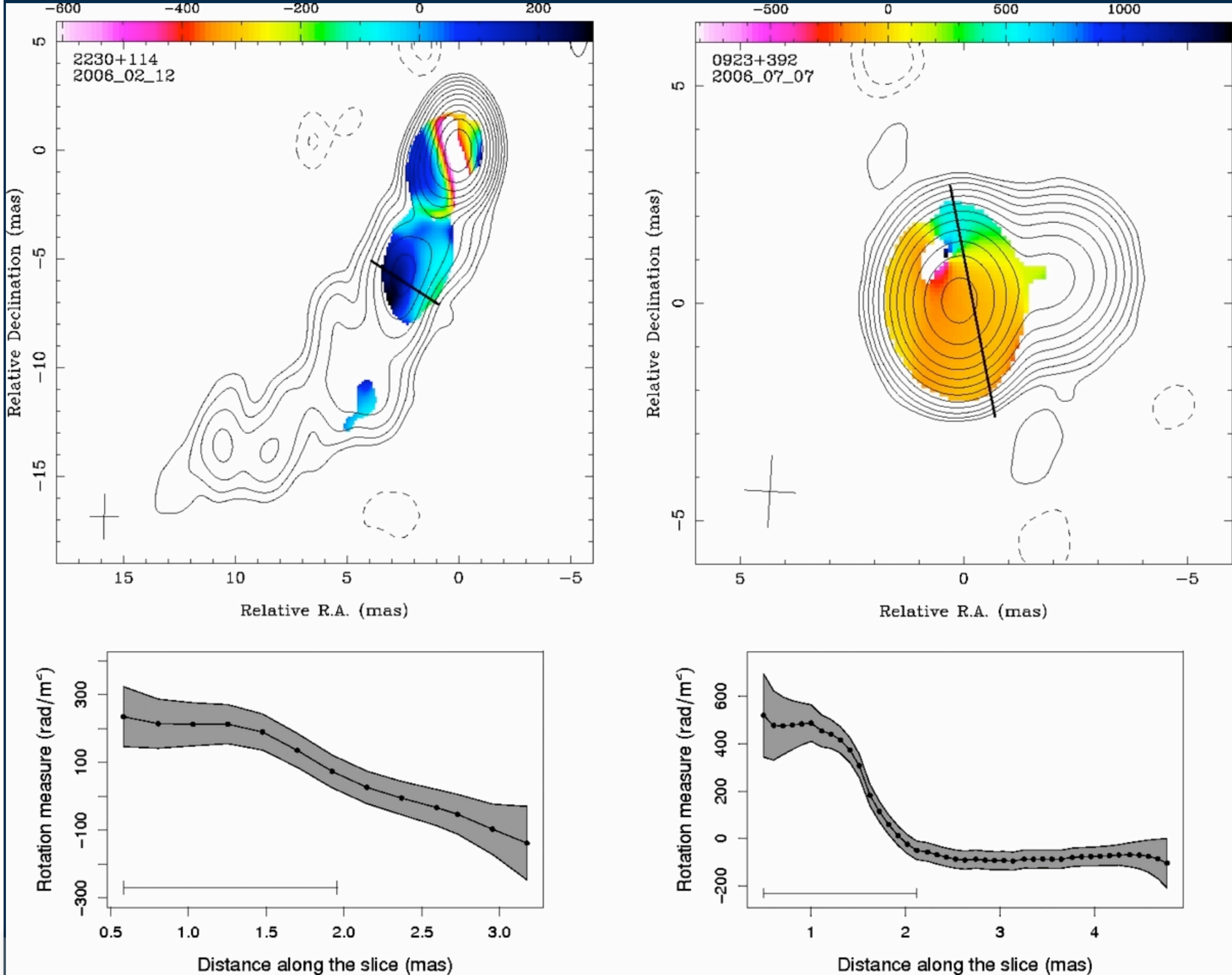
3C 454.3 RM maps

Hovatta et al (2012)

Clear transverse gradient (see also Zamani-nasab et al. in prep)



BL Lac & 4C 39.25 RM



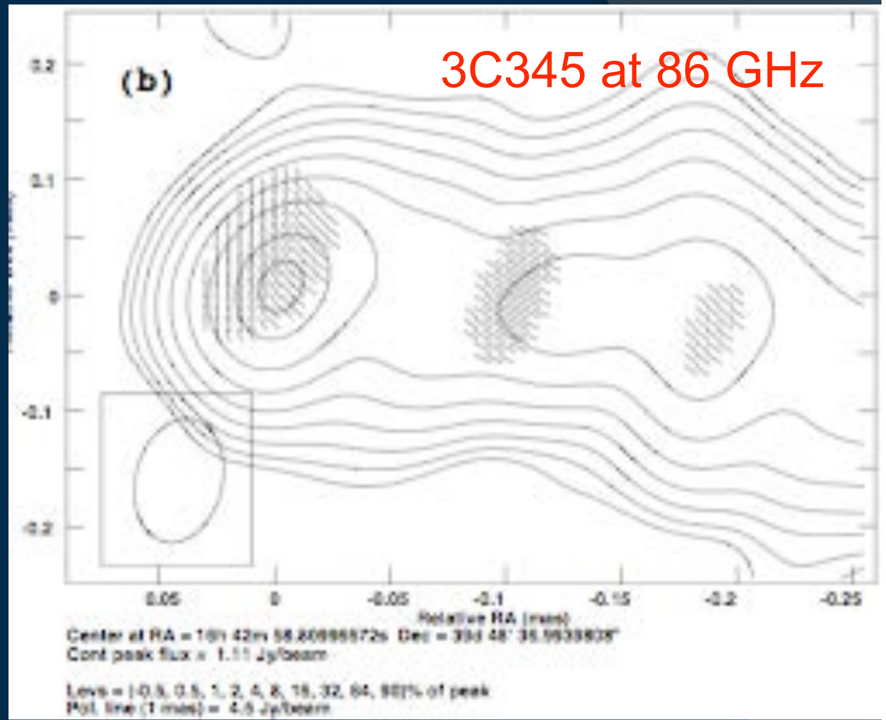
Hovatta et al. (2012)

Summary:
AGN Science with Polarization

- 3-D magnetic field structure of jets
  - Role in collimation & acceleration of jets
  - Connection with SMBH/Accretion Disk?
- Low energy particle population
  - Particle acceleration mechanisms
  - Particle content & kinetic luminosity of jets
- Tracer of jet flow and hydrodynamics
  - Shock, shear, aberration, etc…
- Probe of material + fields external to jets
  - Sheath or boundary layers
  - Narrow line region

Outlook

- Improvements in sensitivity by bandwidth and performance enhancements
- Improvements in resolution:
  - 86 GHz new calibration methods (see Martí-Vidal et al. 2012)
  - RadioAstron observations



Martí-Vidal et al. (2012)

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Dank je!

Merci!

¡Gracias!