Surprising evolution of Faraday Rotation Gradients in AGN Jets

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Outline

- Faraday Rotation Measure (RM) gradients in parsec-scale AGN jets
- RM gradients and toroidal magnetic fields.
- Multi-epoch multi-waveband RM gradients.
- Connecting RM gradients and magnetic tower models.
- RM gradients used as observational evidence for the Poynting-Robertson Battery model.

Evidence for Toroidal Fields in AGN Jets

- Transverse B fields in many AGNs
- Characteristic longitudinal and transverse polarization (i.e ‘spine-sheath’)
- Interknot orthogonal B fields
- Core circular polarization, CP structure
- Transverse Faraday rotation (RM) gradients across jets

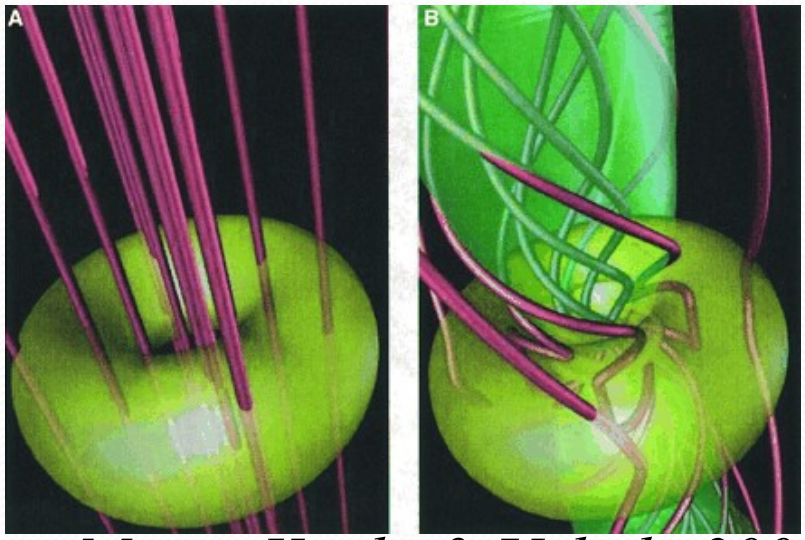
Faraday Rotation

The amount of rotation is proportional to the integral of the density of free electrons n_e multiplied by the line-of-sight magnetic field **B • dl**, the square of the observing wavelength, and various physical constants; the coefficient of λ^2 is called the Rotation Measure, RM:

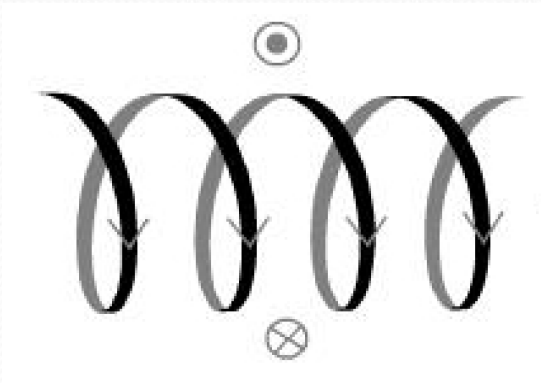
$$\Delta\chi \;\propto\; \lambda^2 \int n_e \, \mathbf{B} \cdot \mathbf{dl} \;\equiv\; \mathbf{RM}\,\lambda^2$$

The intrinsic polarization of the source, χ_0 can be obtained:-

$$\chi_{obs} = \chi_0 + \mathrm{RM}\,(\lambda^2)$$



Meier, Koide & Uchida 2001



B • dl > 0 -------> + RM,

B • dl < 0 -----> - RM

Data Observation

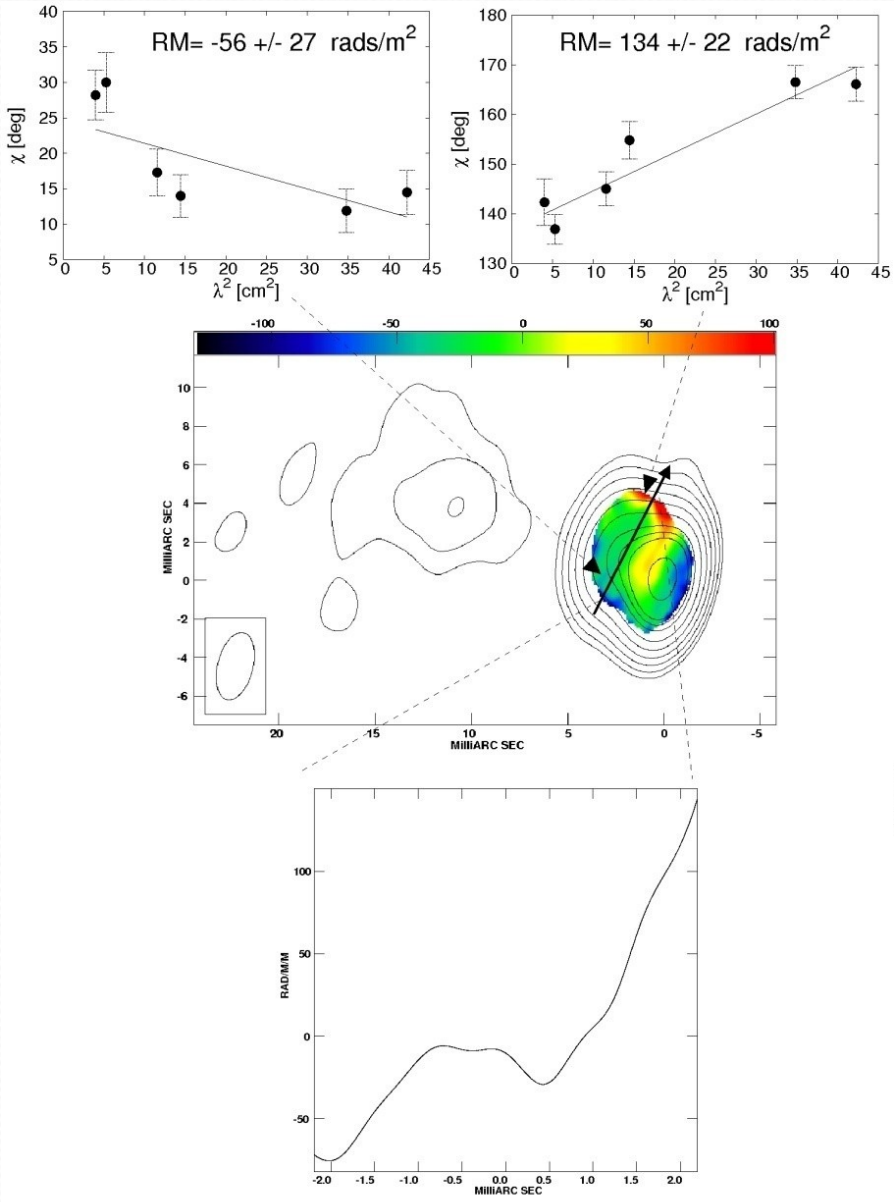
- VLBA polarization observations of 37 BL Lac objects observed between August 2003 and September 2005 at 6 frequencies 4.6- 15.4 GHz, earliar epoch in 1997 at 2,4,6 cm.

- 18 cm Observations in Jan 2004

- New epochs in Dec 2008-09

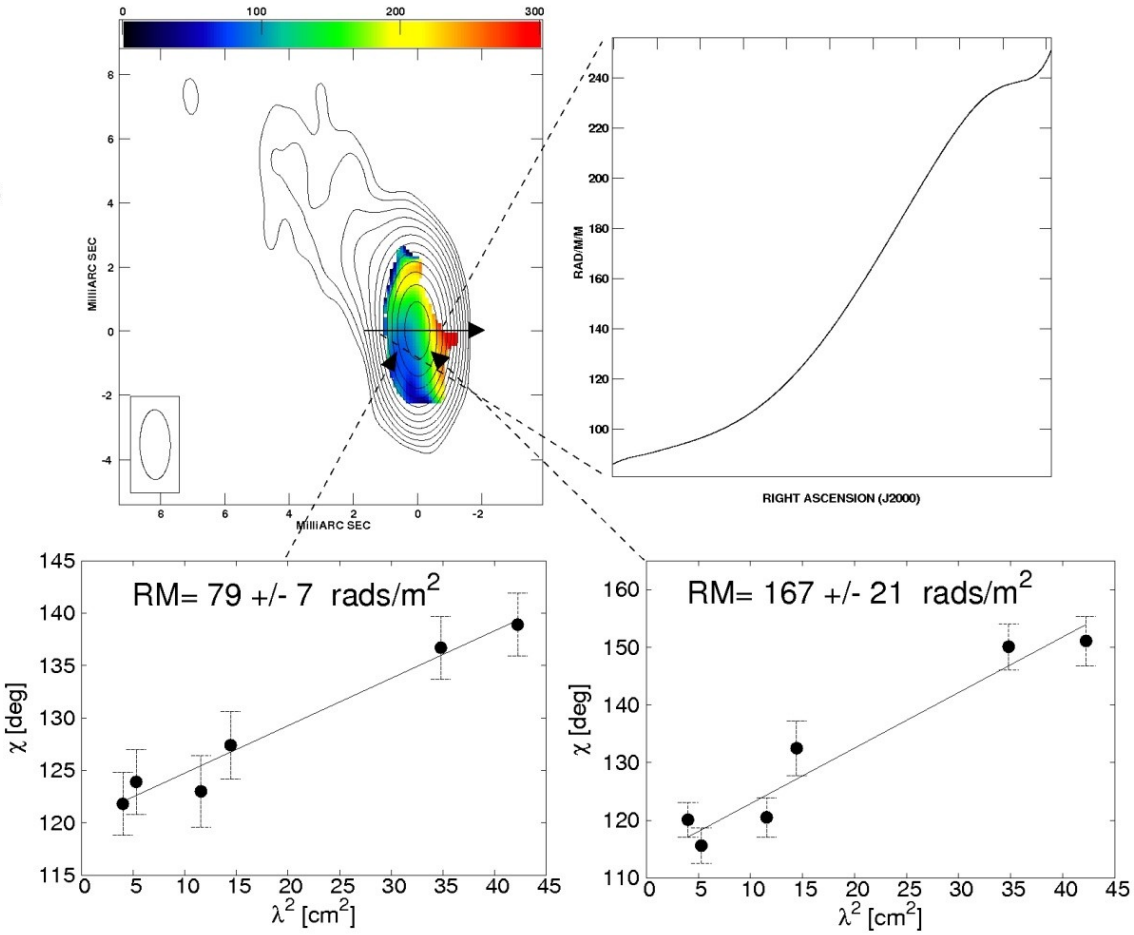
- **Objective** - more refined Faraday Rotation (FR) gradients, and monitoring various new features in FR distributions.

0735+178

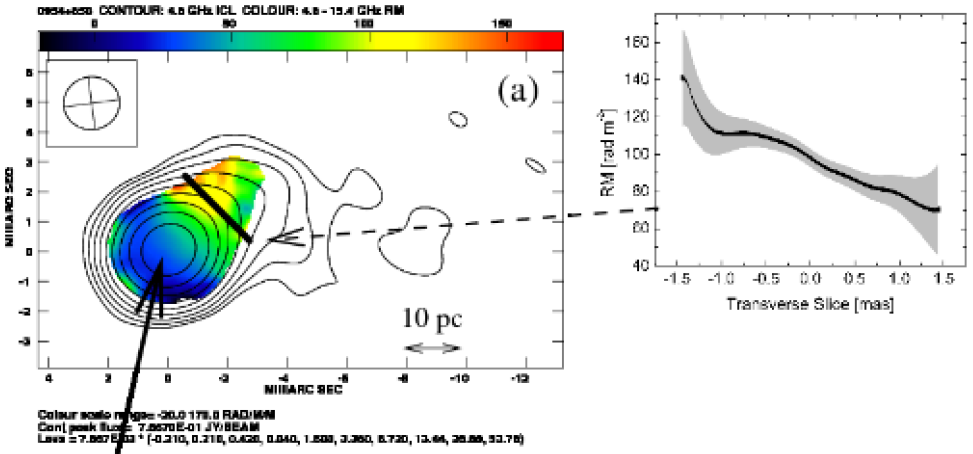


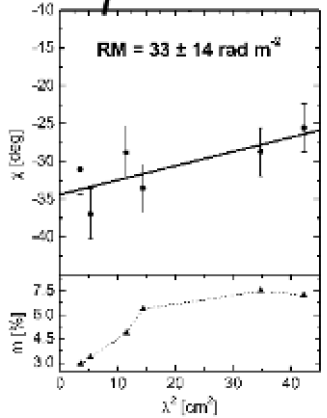
September 2004

1749+096



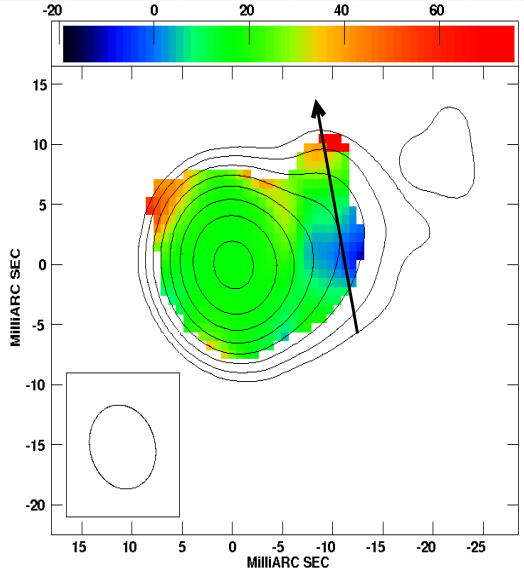
Gabuzda et al. (2008)

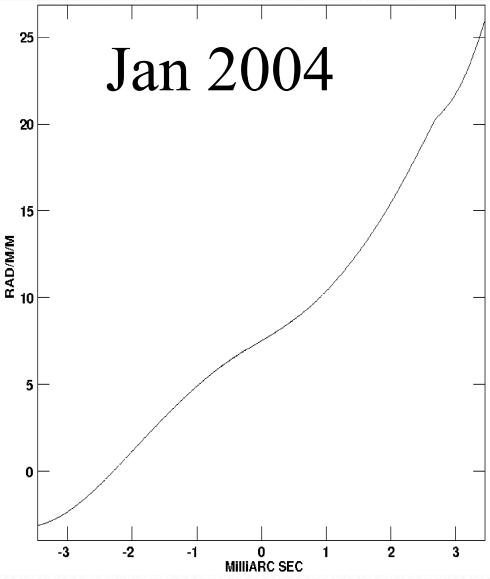




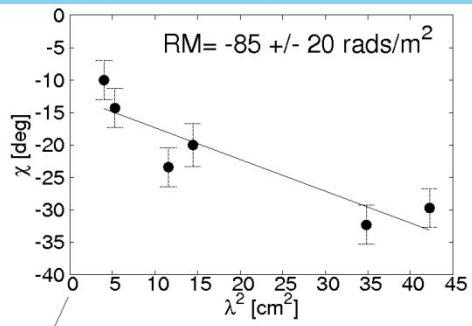
July 2006

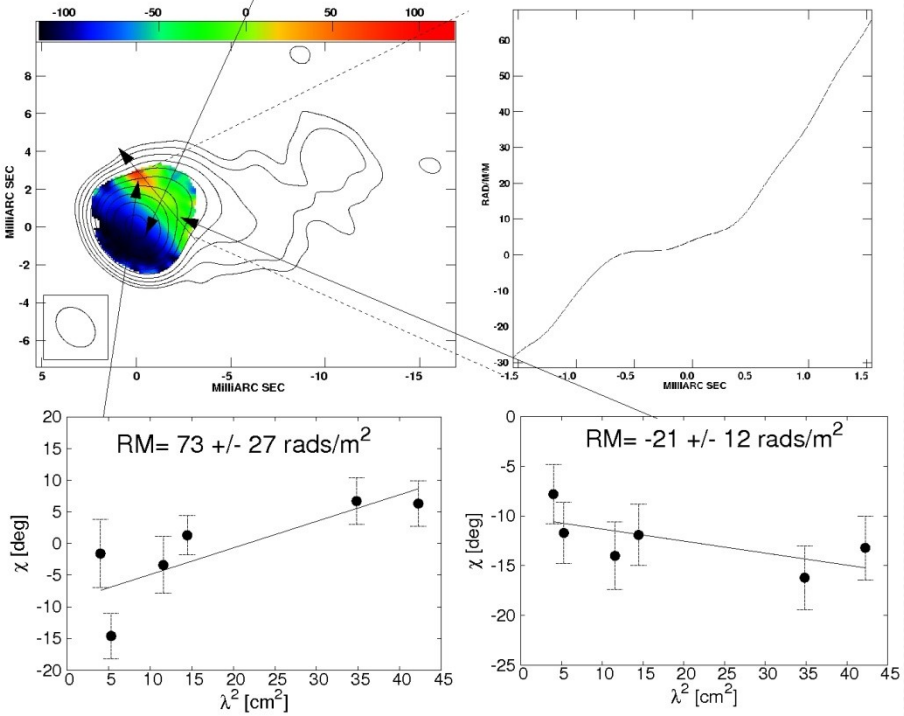
O'Sullivan & Gabuzda (2009)





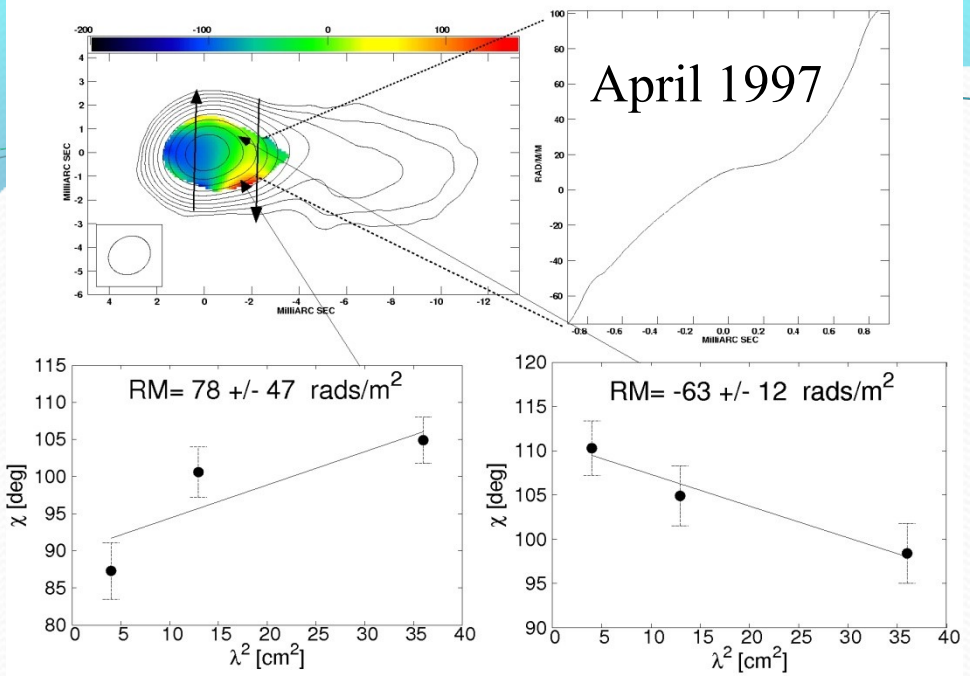
Jan 2004

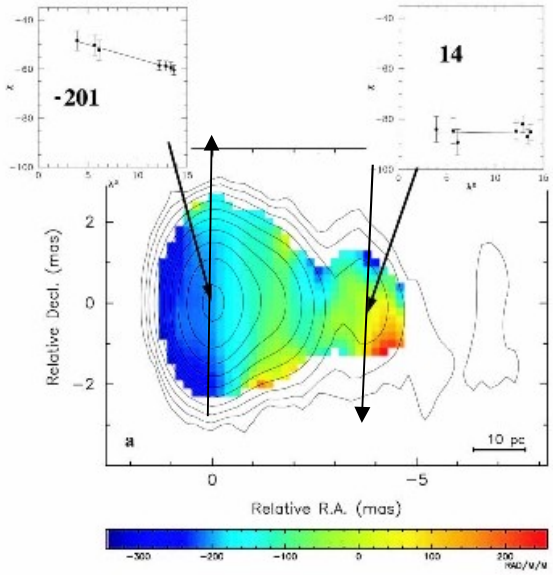




April 2004

Multi- Epoch gradients in 0954+658

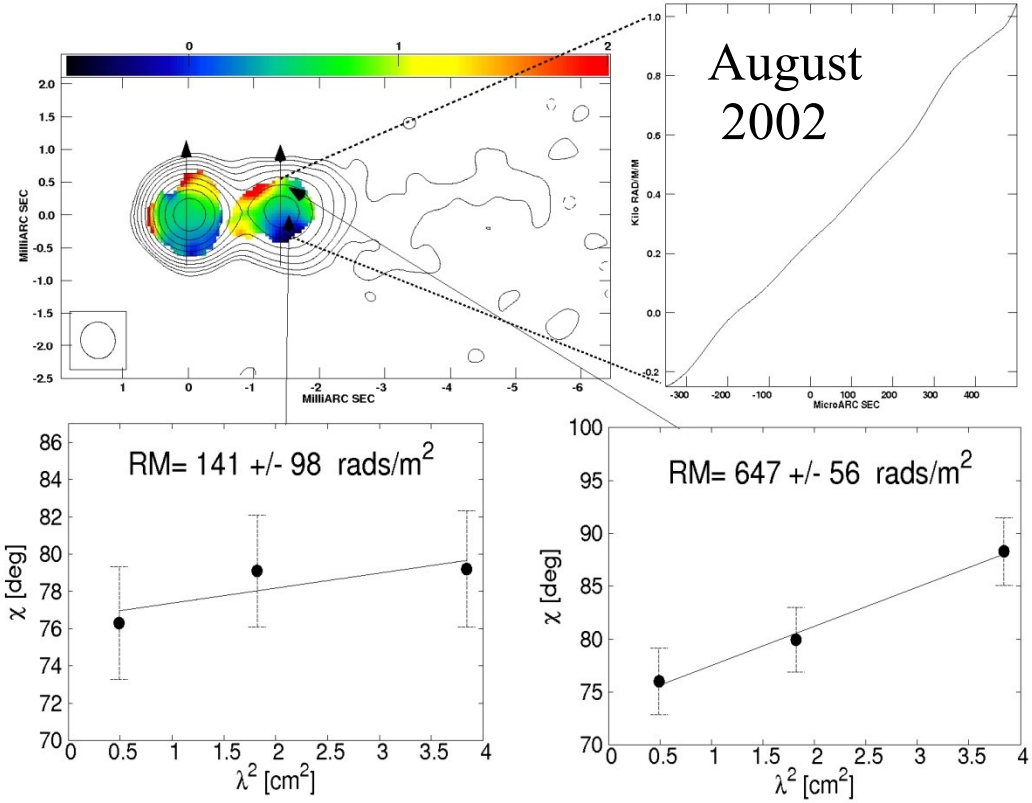


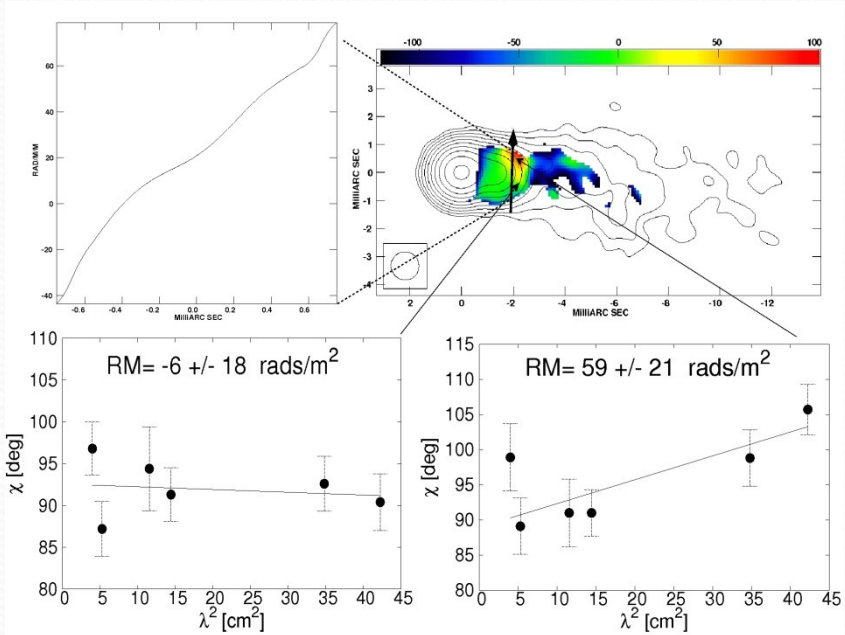


Zavala & Taylor (2003)

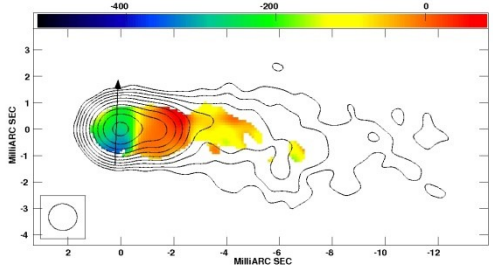
June 2000

Mahmud, Gabuzda & Bezrukovs (2009)

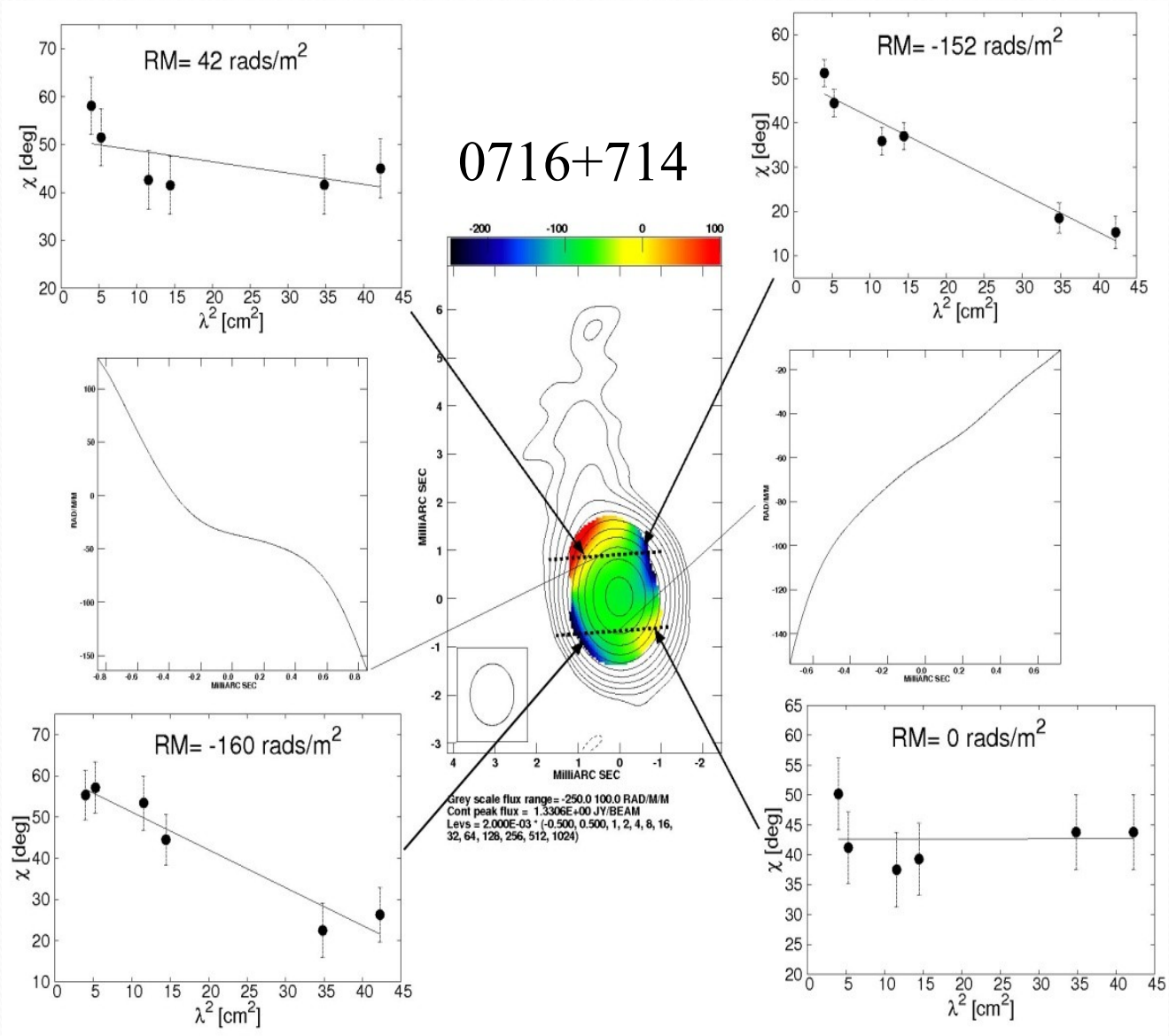




August 2003

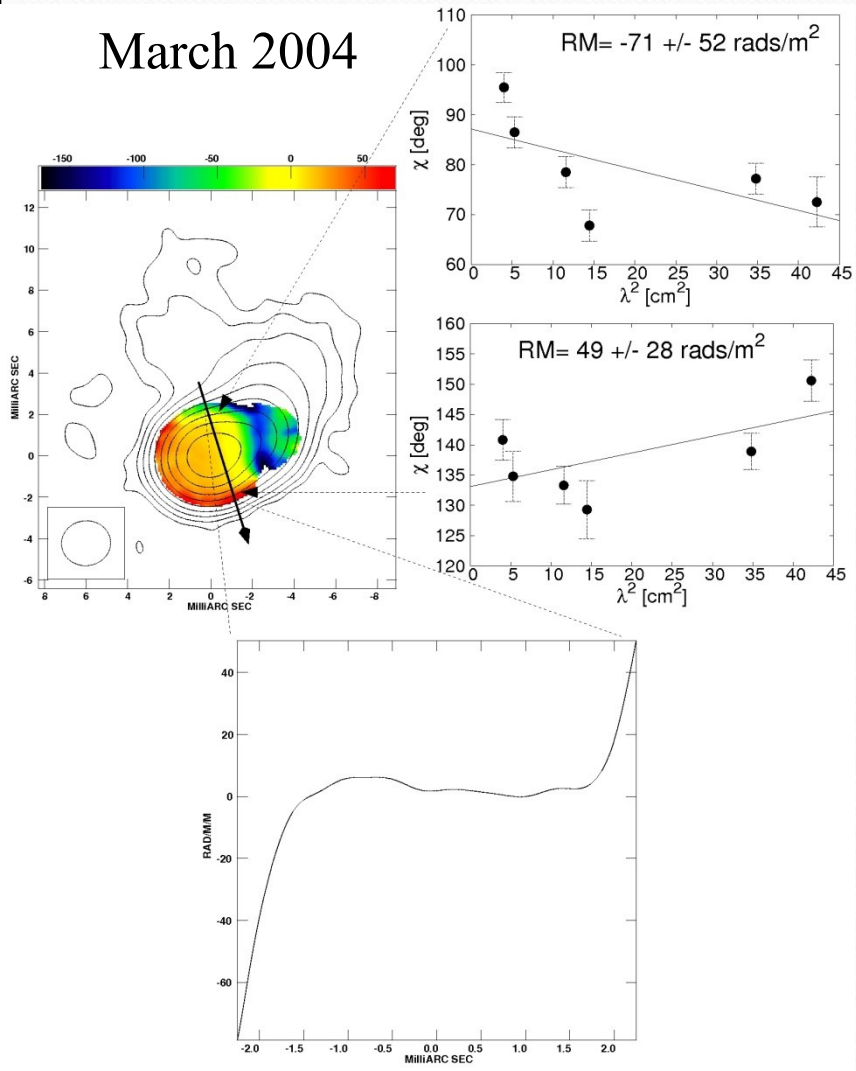


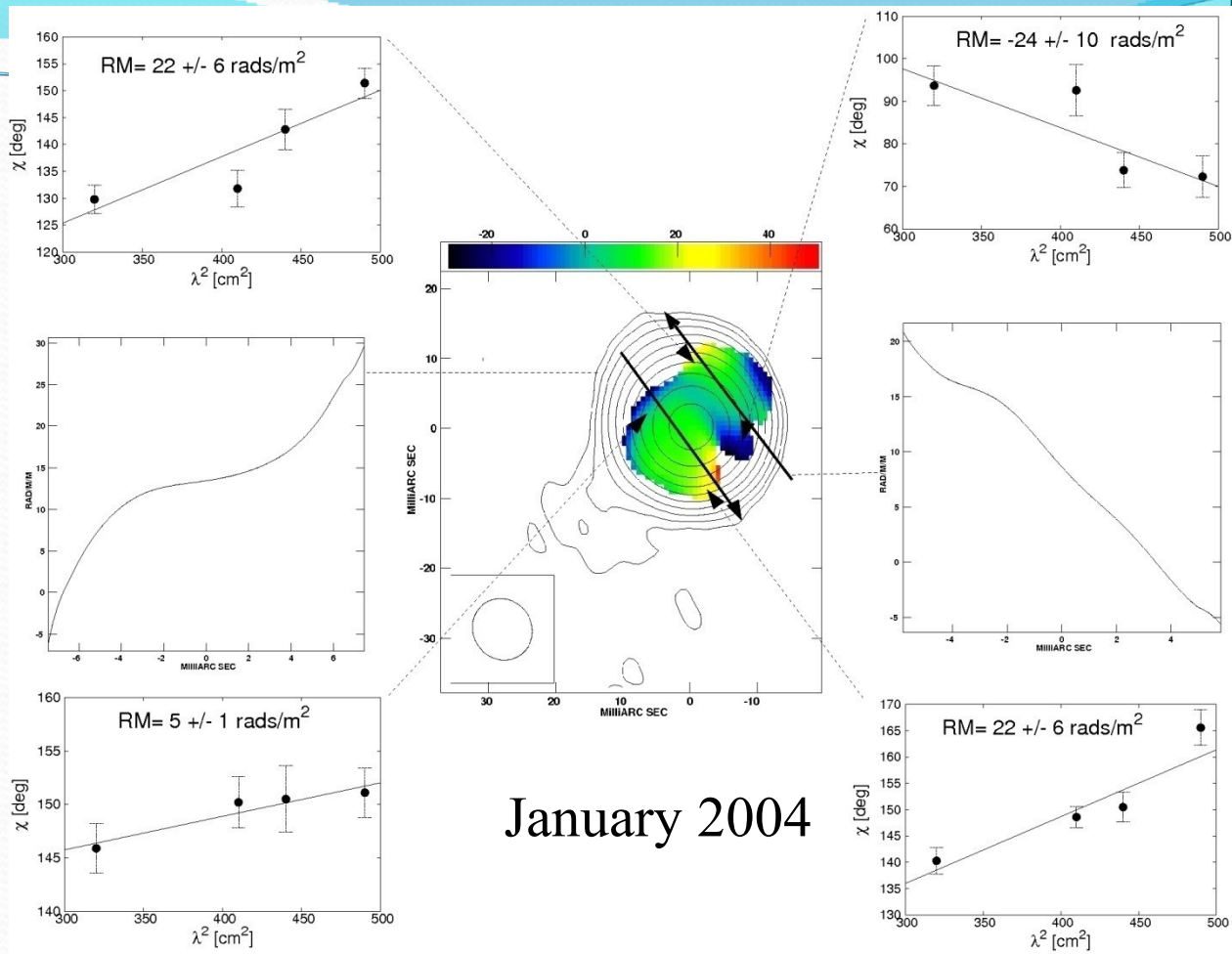
RM Gradients Reversals



1749+701

March 2004



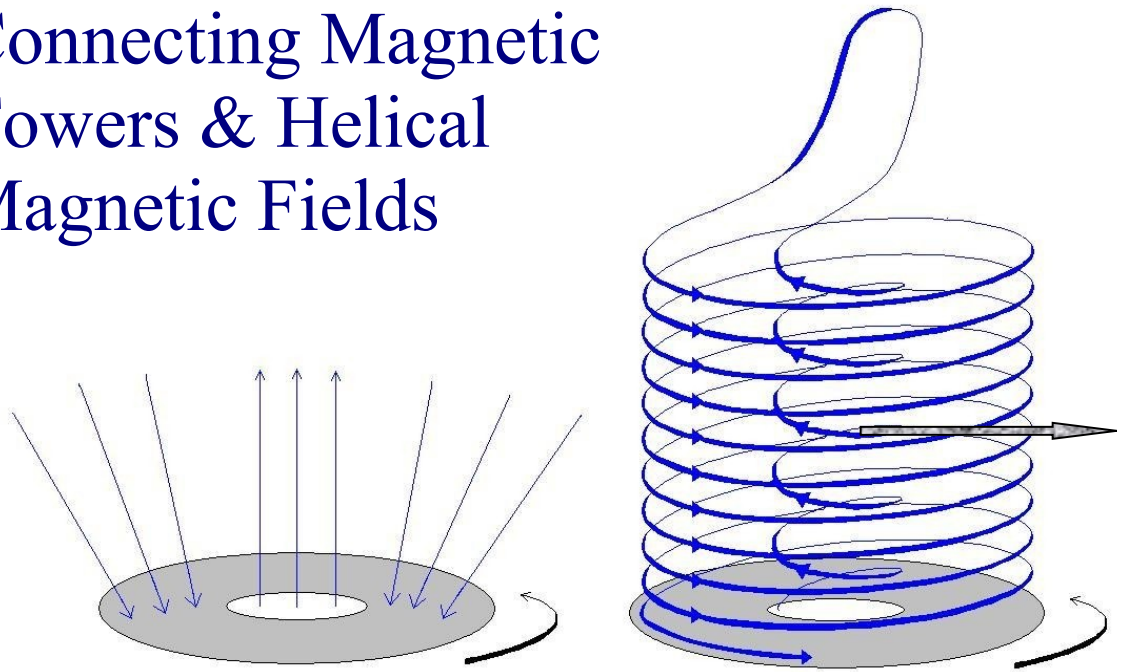


January 2004

Gradients on Deca-parsec scales

Mahmud, Gabuzda & Hallahan
(in prep)

Connecting Magnetic Towers & Helical Magnetic Fields



•If there are two 'nested' helical fields; the net RM we observe would include contributions from both fields.

• It is possible we are seeing transverse RM gradients dominated by the inner or outer helix (which would have opposite gradients) in different parts of the jet.

• E.g. Inner helix in core region, outer helix in jet.

The Poynting-Robertson battery
(Contopoulos, Kazanas, Christodoulou)

- Charges in rotating accretion disc absorb photons from central AGN

- Photons are re-radiated isotropically in rest frame of charges, radiation is "beamed" in direction of their motion in observer's frame

- Thus, they feel a reaction force: $$F_{\text{P-R}} = -\frac{L\sigma_{\text{T}}}{4\pi r^2 c}\frac{v_\phi}{c}$$

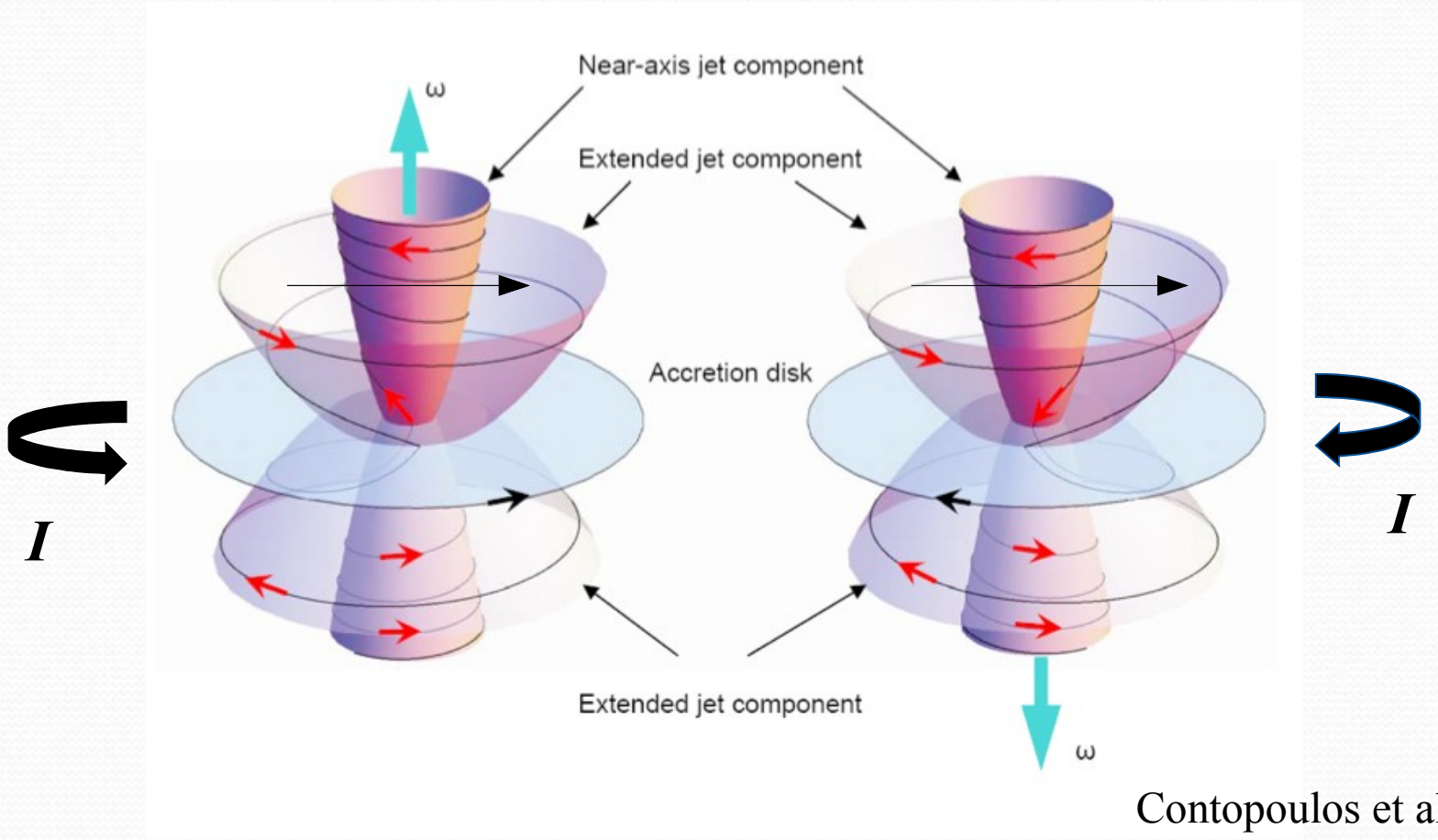
Force on electrons

- Force on e^- >> force on p due to dependence on mass ($\sigma_T \propto m^{-2}$)

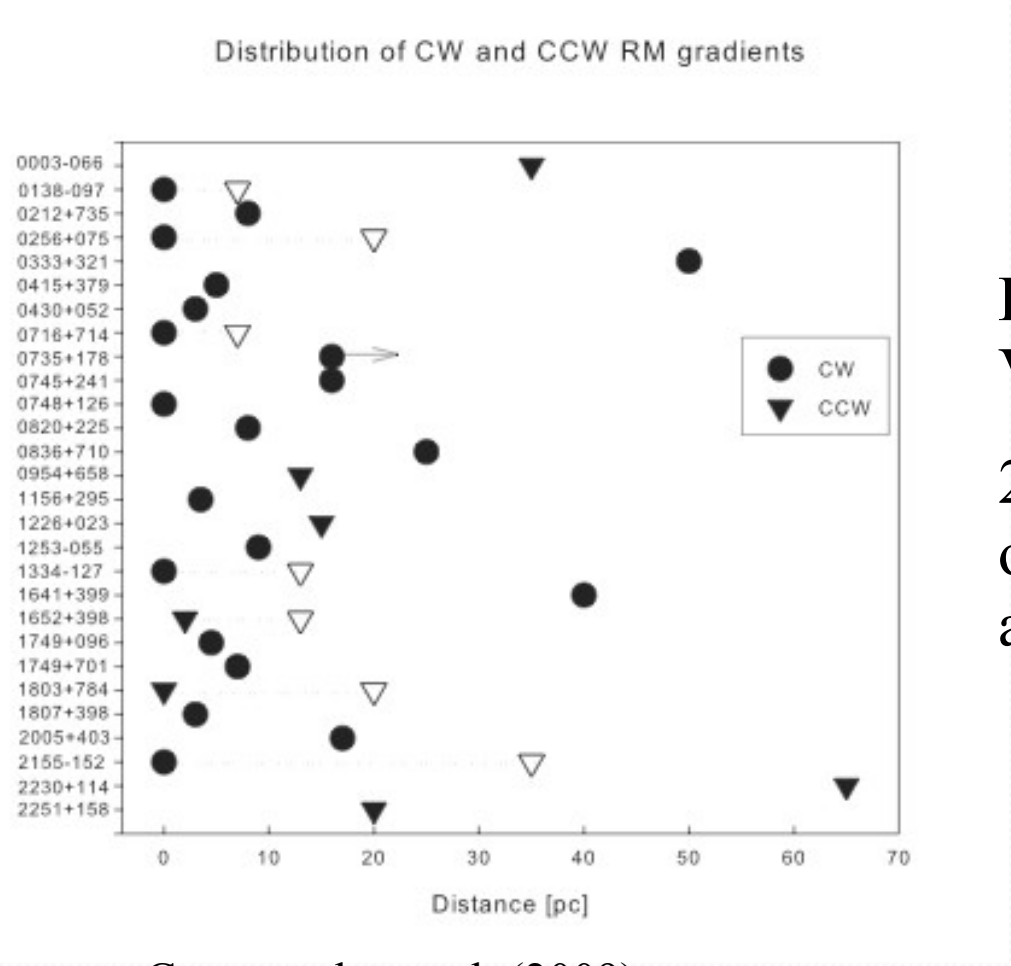
$\Rightarrow$ Electric current in direction of rotation

This mechanism relates the polarity of the poloidal B-field to the angular velocity of the accretion disk, resulting in a ***unique*** *direction for the toroidal B-field induced by disk rotation.*

In PR battery picture, RM gradient due to inner helical field is always CW relative to jet base, RM gradient due to outer helical field is always CCW, independent of direction of rotation of accretion disc:



Contopoulos et al. (2009)



Contopoulos et al. (2009)

For RM gradients detected closest to VLBI core:

21 CW, 7 CCW; Probability of observing 21 or more CW gradients among a total of 28 by chance :

~ 0.6%

Conclusions

- Transverse RM gradients in several sources.
- Simplest explanation : toroidal magnetic fields.
- Direction of RM gradients can change over time, as well as with distance from the core.
- Multi-epoch data confirms the presence of these gradients: overall "global" structure of the jet magnetic field.
- The observed RM gradient reversals are exciting as they relate to fundamental questions about the jet magnetic field geometries!
- Intriguing assymetries in direction of RM gradients: new evidence for the Poynting- Robertson Battery Model.

Current Work

- VLBA observations (December 2008) for 7 sources with Faraday Rotation gradients- a totally new approach to provide evidence for magnetic-tower models!

- VLBA observations for 1803+784 at 5-43 GHz to trace the RM distribution over a wider range of distances at a single epoch.