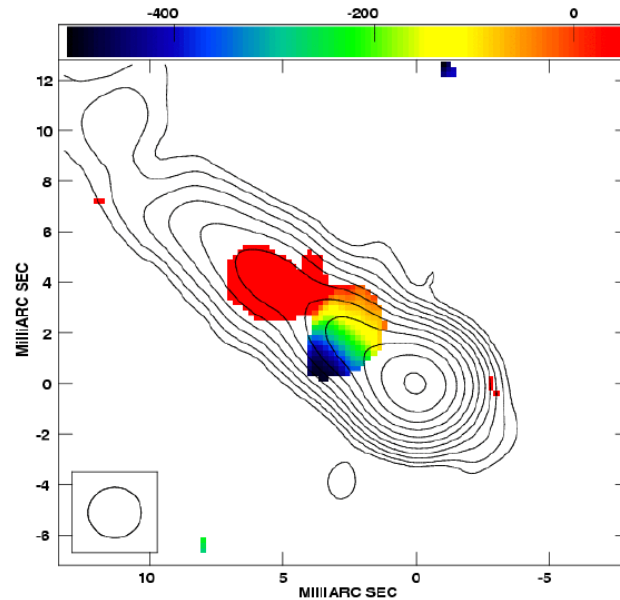


# Observational Signatures of Large Scale Magnetic Fields in Parsec Scale AGN Jets.



By Eric Clausen-Brown

Collaborators: Maxim Lyutikov (Purdue) and Preeti Kharb (RIT)

May 13, 2010

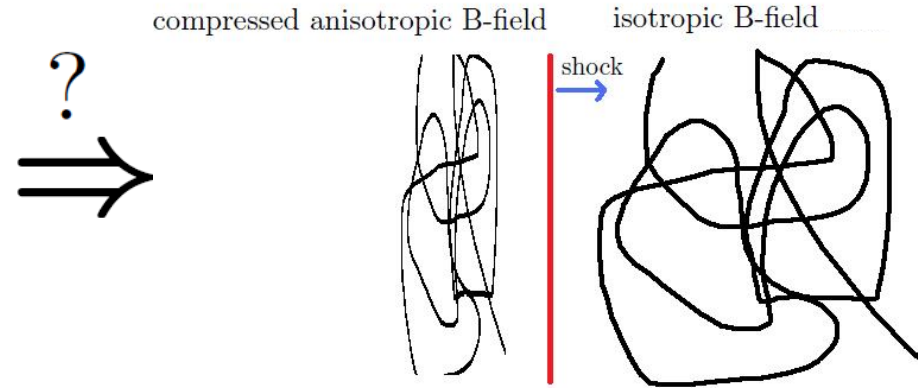
RM 2010 Workshop

Riccione, Italy

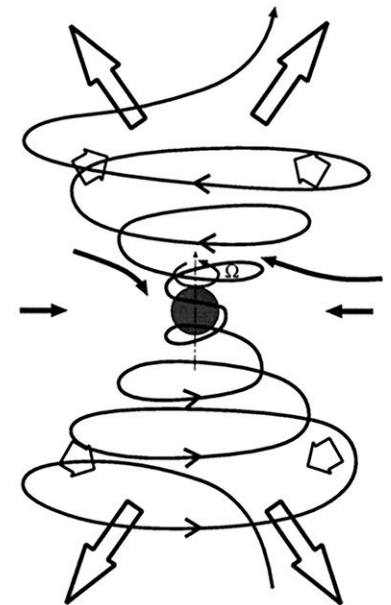
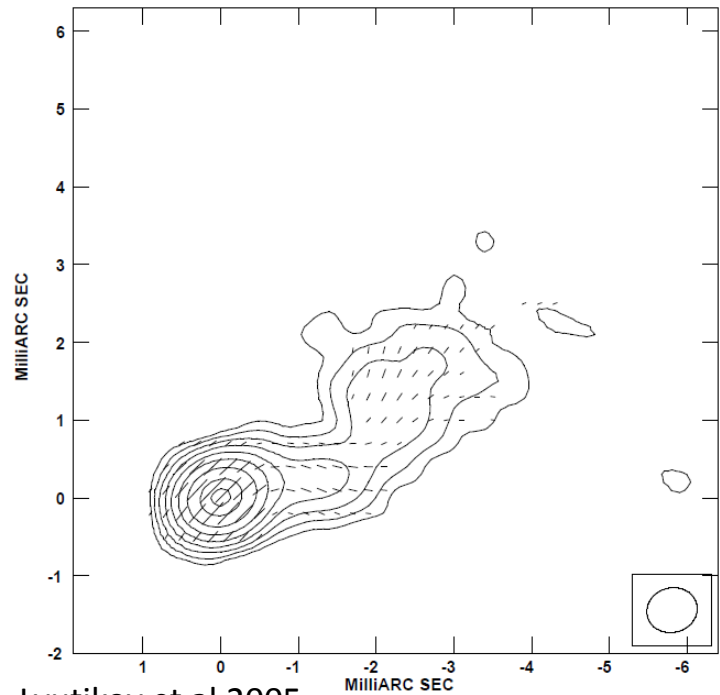
# Introduction

**Polarization and EVPA orientation can be explained by:**

- Shocks/shearing
- Helical B-Fields



BL Lac object 1749+701



Meier et al 2001

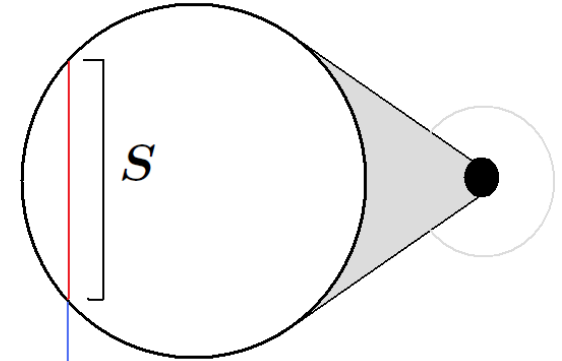
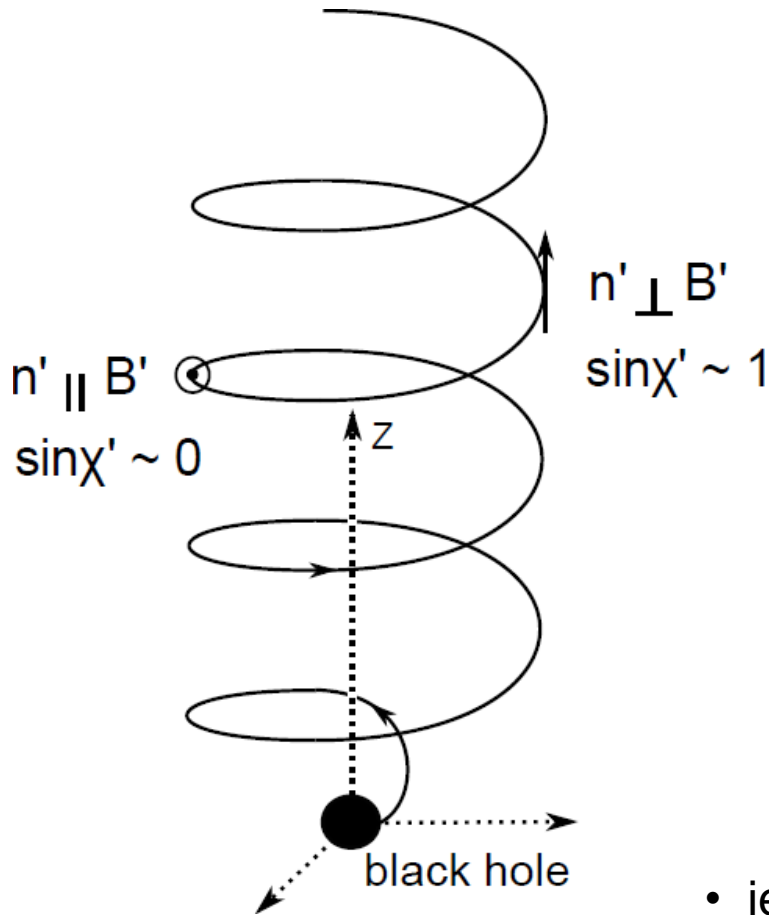
Lyutikov et al 2005

Gabuzda et al. 2001

# Outline

- Helical Fields imprint themselves on synchrotron radiation by producing asymmetries in:
  - Intensity  
Cf. Swain and Bridle (1998) and Laing (2006)
  - Polarization
  - Spectral Index?
  - Rotation Measure
- Correlations between the above observables are then expected

# Asymmetry of Helical Magnetic Field



$$\text{observable} = \int_0^S f(\mathbf{B}, \mathbf{n}, \Gamma, K_e, p) ds$$

$$dn = K_e \gamma^{-p} d\gamma$$

- jet assumed to be cylinder
- We assume jet opening angle is smaller than typical viewing angle
- Only in calculating spectral index does core distance matter

# Structure of Jet

Magnetic field:

$$\mathbf{j} \times \mathbf{B} = \mathbf{0}$$

$\Rightarrow$

$$B_\phi = B_0 J_1(k\rho)$$

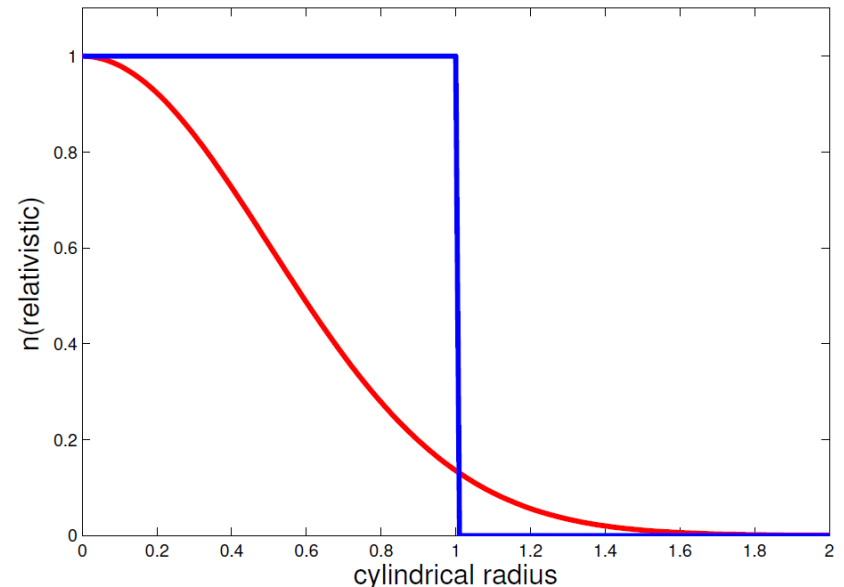
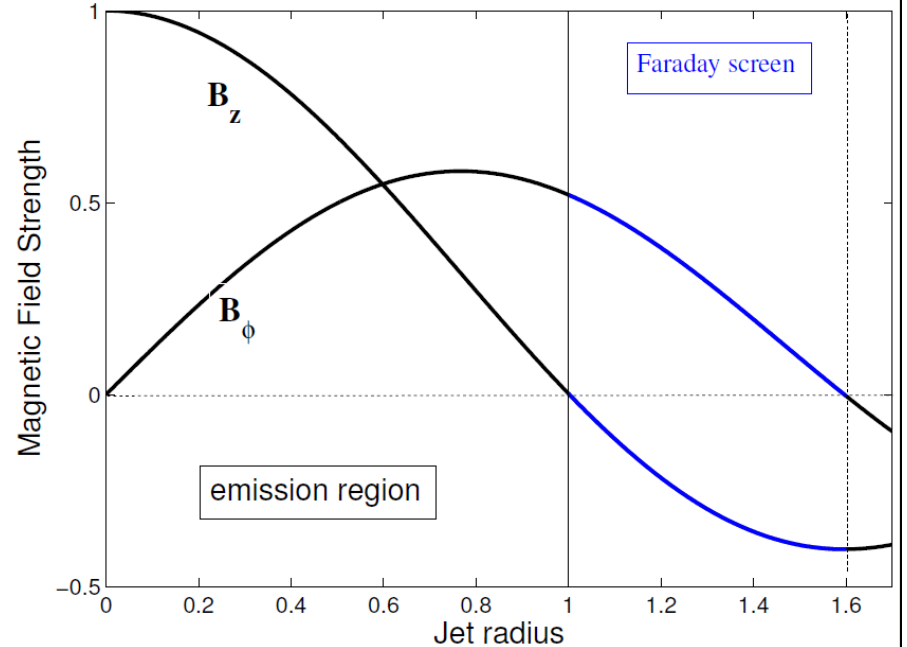
$$B_z = B_0 J_0(k\rho)$$

(e.g. Choudhuri et al. 1986)

Relativistic particle density:

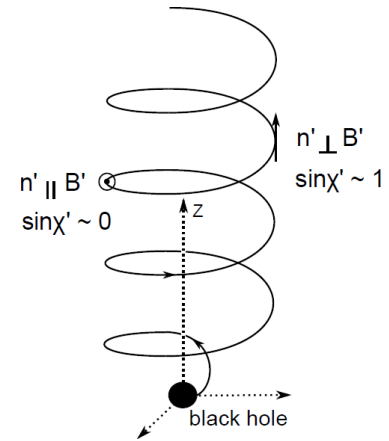
- Realistic Gaussian profile gives qualitatively identical results to constant profile

Pitch angle varies with cylindrical radius:



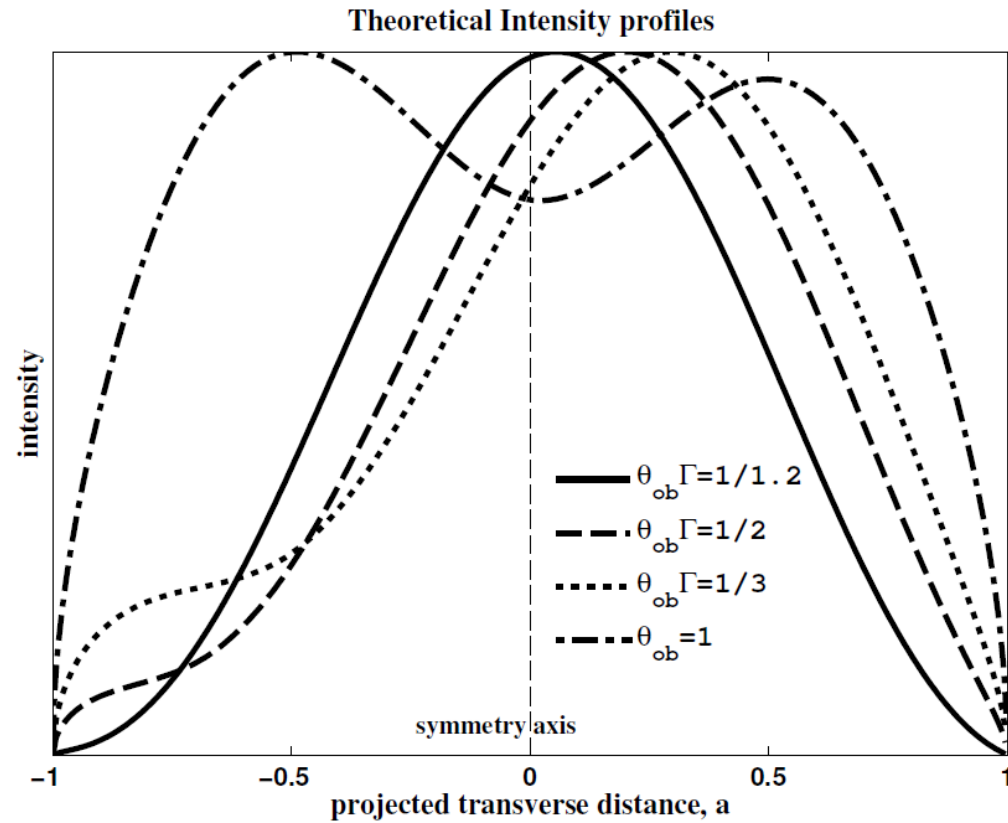
# Intensity: Theory

$$I \propto \int_0^S (B'(s) \sin \chi'(s))^{(p+1)/2} ds$$



Note that:

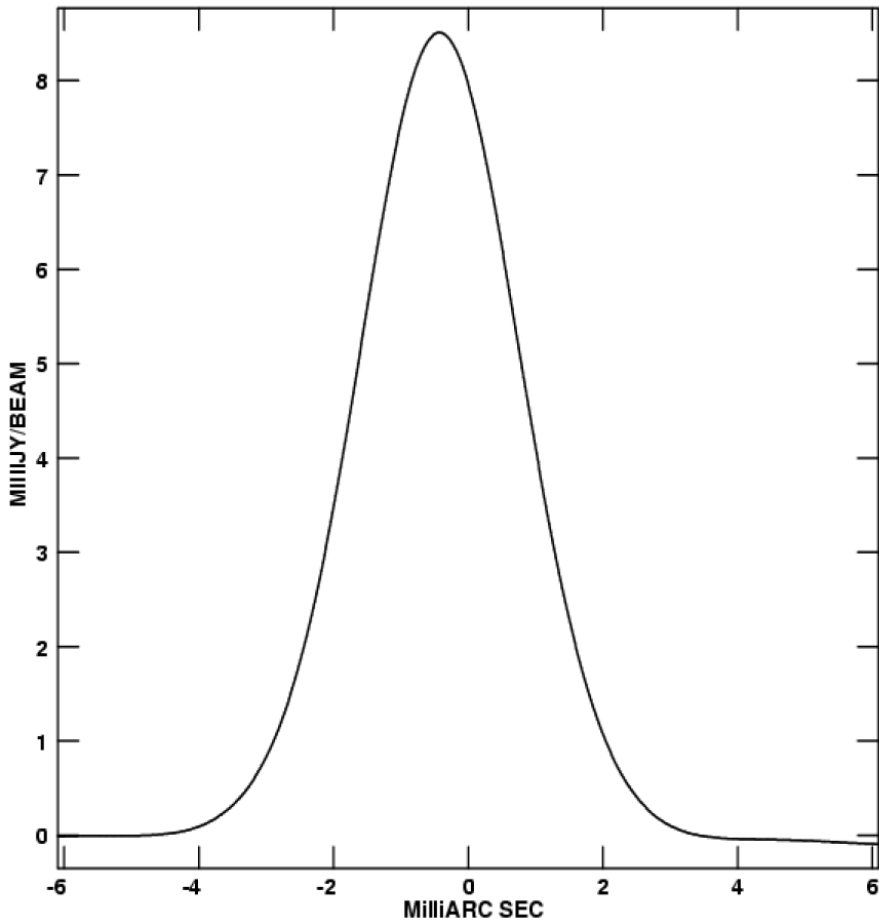
- Peaks are off center (undetectable)
- Profiles are skewed (detectable)



# Intensity: Observations

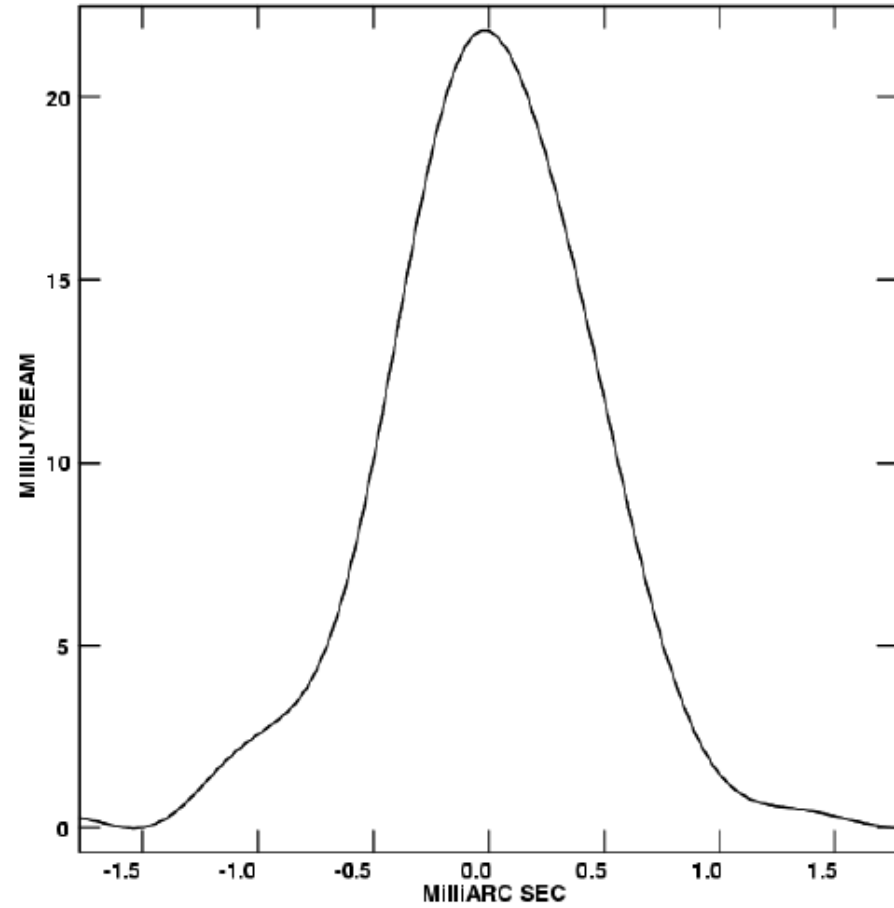
symmetric:

Parsec scale cut of 3C 78



skewed:

Parsec scale cut of NRAO 140



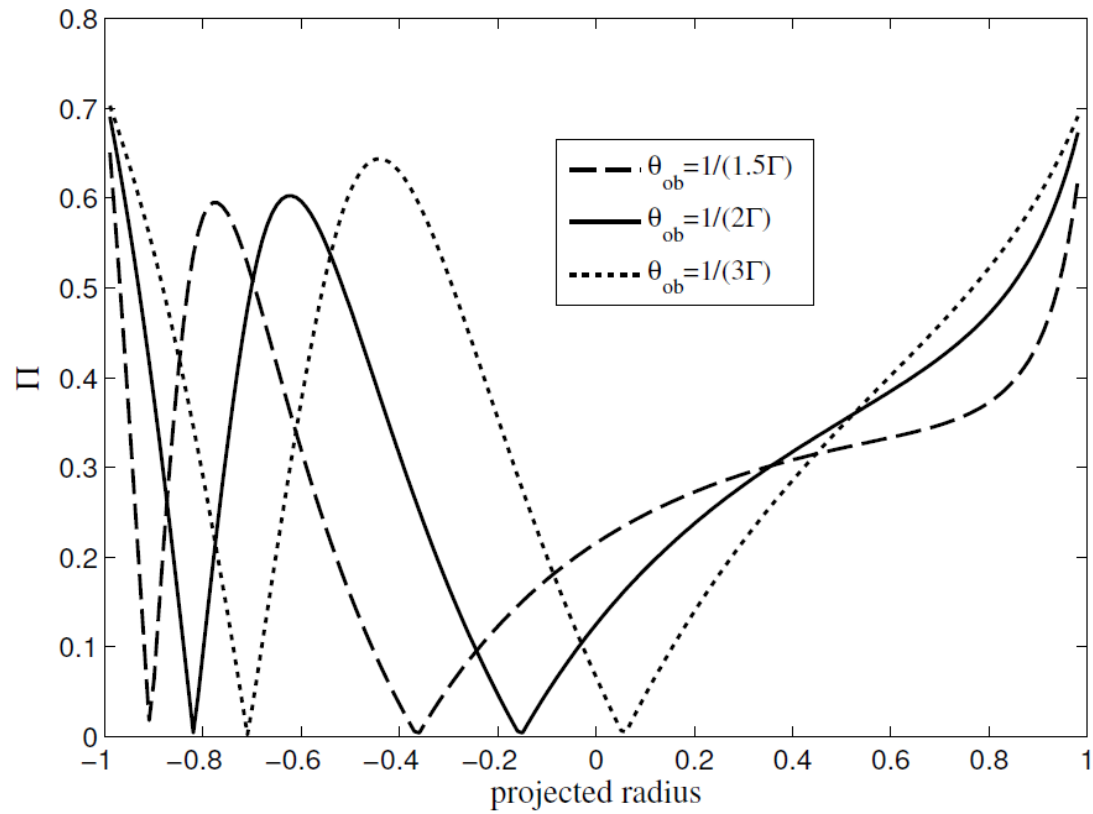
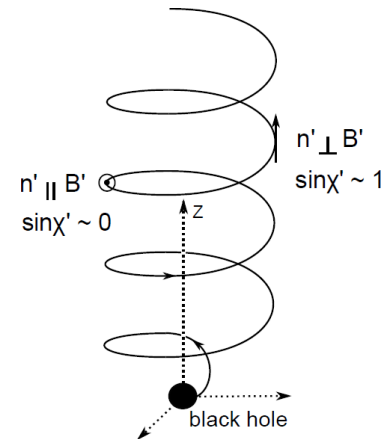
# Linear Polarization: Theory (unconvolved)

$$Q'_{int} \propto \int_0^{S'} (B \sin \chi')^{(p+1)/2} \cos 2(\tilde{\chi} - \Delta\chi_F(s')) ds'$$

$$U'_{int} \propto \int_0^{S'} (B \sin \chi')^{(p+1)/2} \sin 2(\tilde{\chi} - \Delta\chi_F(s')) ds'$$

$$\Pi = \frac{\sqrt{Q^2 + U^2}}{I}$$

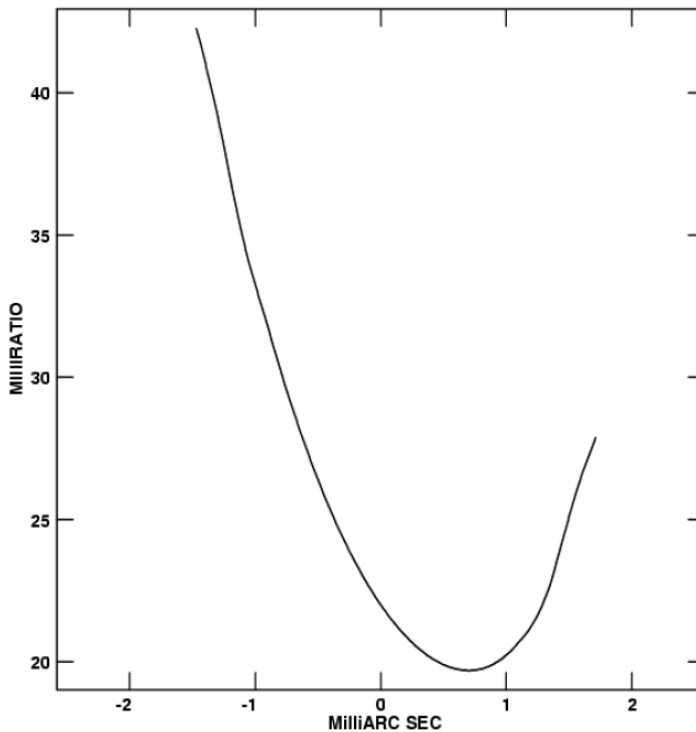
- For cylindrical jets,  $U=0$
- Bump corresponds to an EVPA parallel to the jet axis
- Outer wings correspond to EVPA perpendicular to jet axis
- Bump is not a robust result (depends on B-field config., viewing angle, etc)
- For now, no Faraday depolarization included.



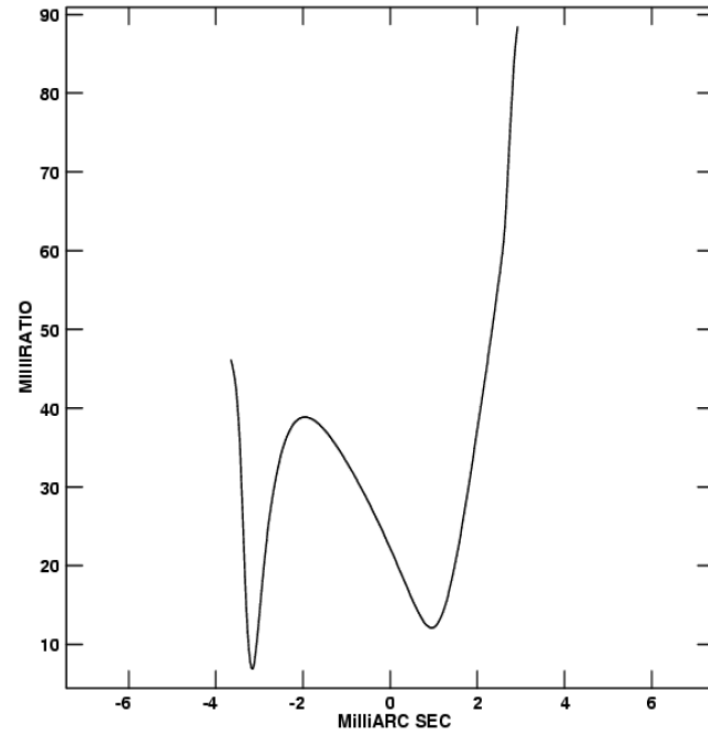
# Polarization: Observations

- Error increases towards the edge of the jet
- Sharp features are suspect considering beamwidth

Parsec scale cut of 3C 78: location 1

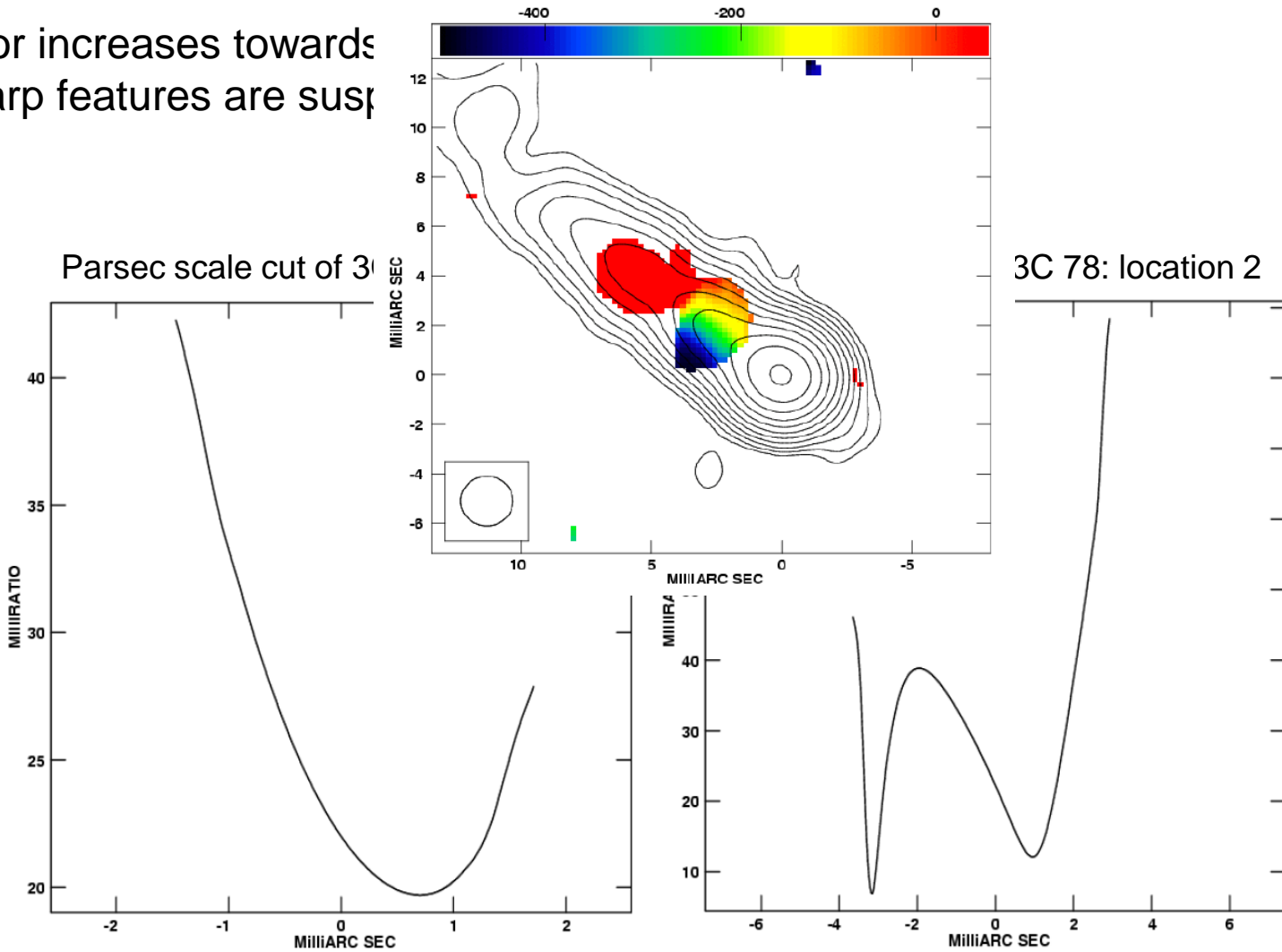


Parsec scale cut of 3C 78: location 2



# Polarization: Observations

- Error increases towards
- Sharp features are suspicious



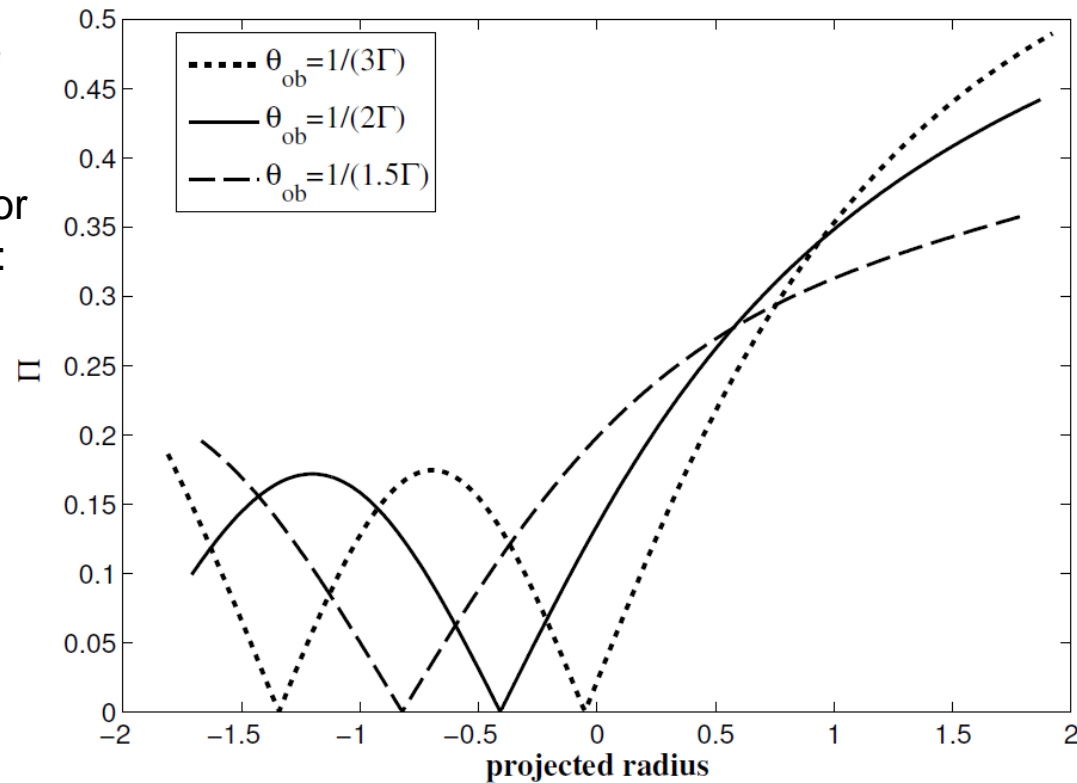
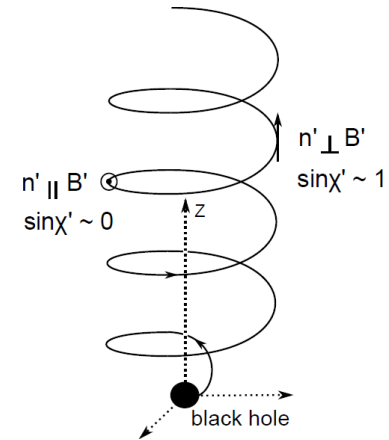
# Polarization: Theory (convolved)

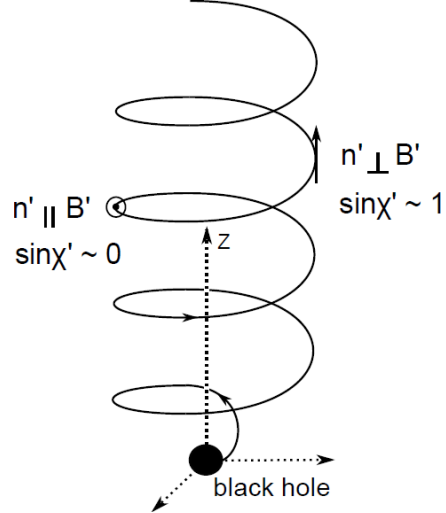
## Calculation details:

- Jet width  $\sim 4$  beamwidths (FWHM).
- Stokes I, Q, U each separately convolved with beam.

## Results:

- Polarization lower on one side than the other
- Characteristic bump difficult to obtain for some beamsizes and other uncertainties: B-field profile and  $n$ (relativistic)





## Spectral Index Gradients, $F_\nu \propto \nu^{-\alpha}$

- Optical depth depends on angle between B-field and LoS
- Left side of jet is thinner than right side

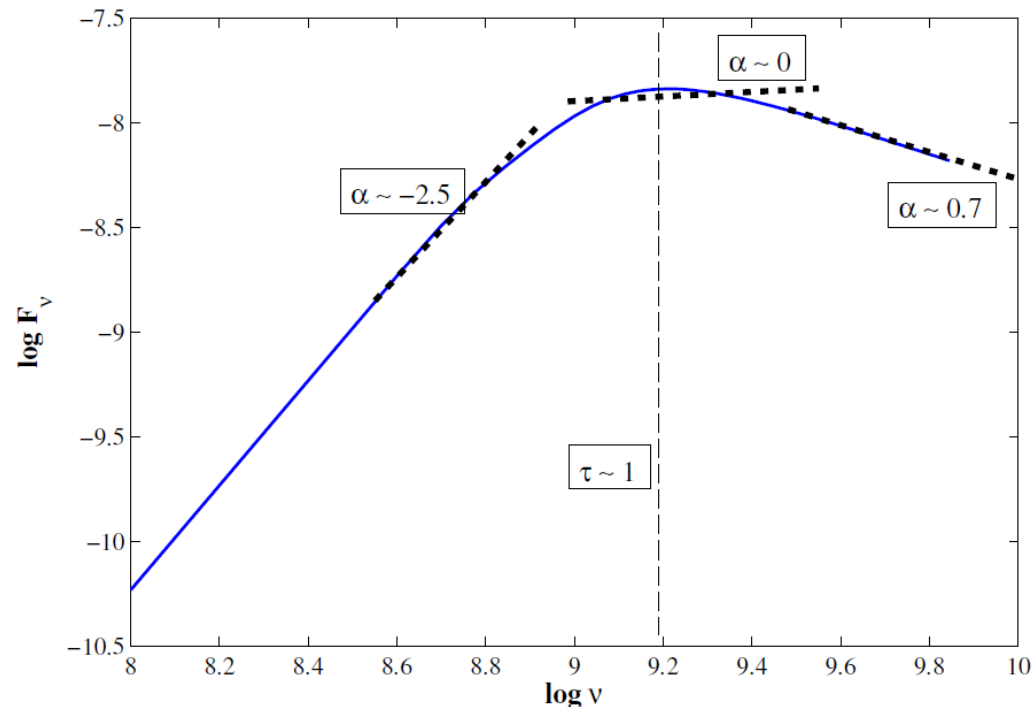
$$\kappa \propto |\sin \chi'|^{(p+2)/2}$$

In the  $\tau \sim 1$  region:

- left side has optically thin index
- right side has optically thick spectrum

Alternative scenario:

- asymmetric electron distribution function (see e.g. Lloyd & Petrosian 2000)



# Spectral Index Gradients

Expected result depends on core radius:

- Symmetric core → spectral index gradient (tau ~ 1 region) → symmetric optically thin region

Calculations:

- To show transitions we add the following scaling to the absorption coefficient and the emission function:

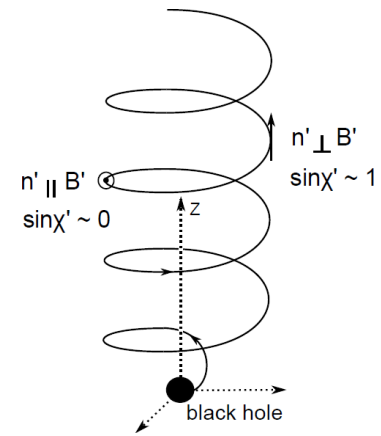
$$\kappa \propto z^{-\left(\frac{p+6}{2}\right)}$$

$$j \propto z^{-\left(\frac{p+5}{2}\right)}$$

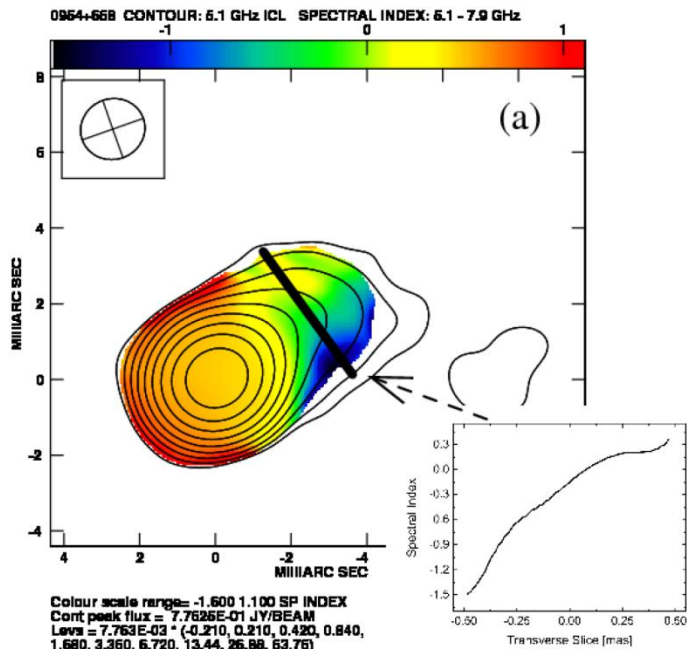
- Derived from typical conical jet scalings ( $B \sim 1/z$ ,  $\rho \sim 1/z^2$ )
- Numerically solved polarization transfer equations for Stokes parameters using polarized absorption and emission coefficients.

# Spectral index gradient: theory vs. observation

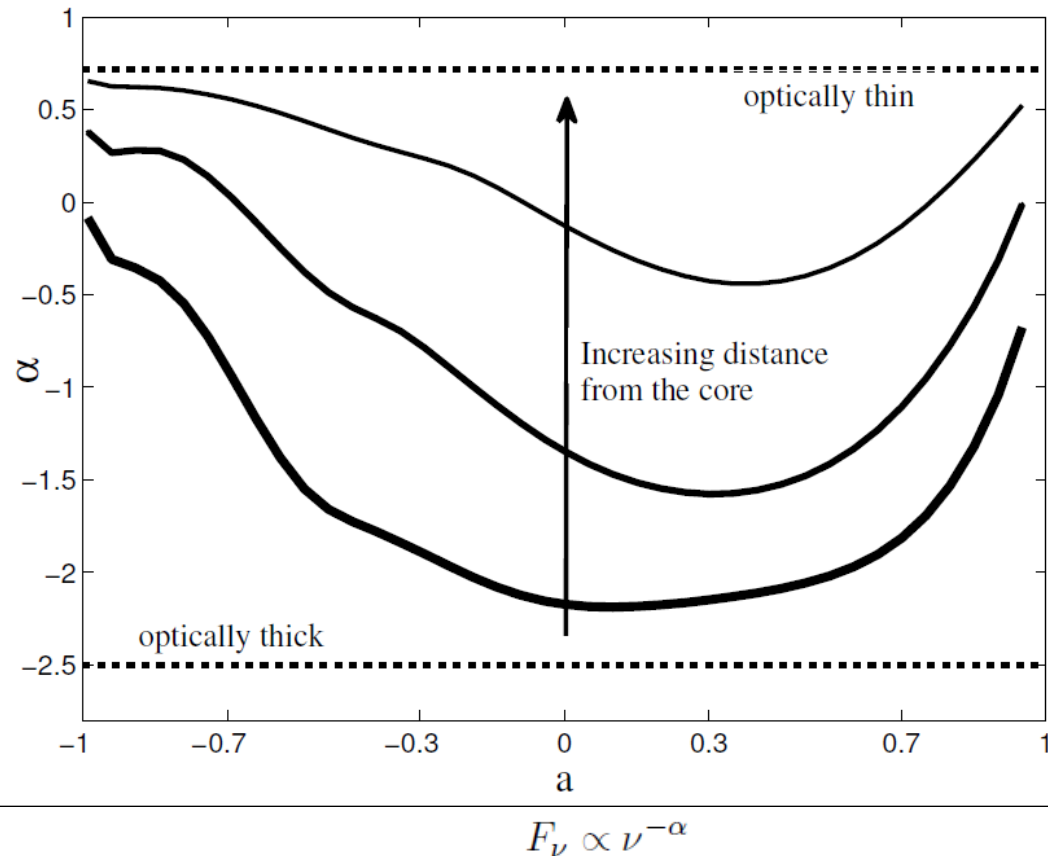
- Theoretical scenario (thick  $\rightarrow$  asymmetry  $\rightarrow$  thin) consistent with BL Lac 0954+658, but not 3C 78.



BL Lac 0954+658

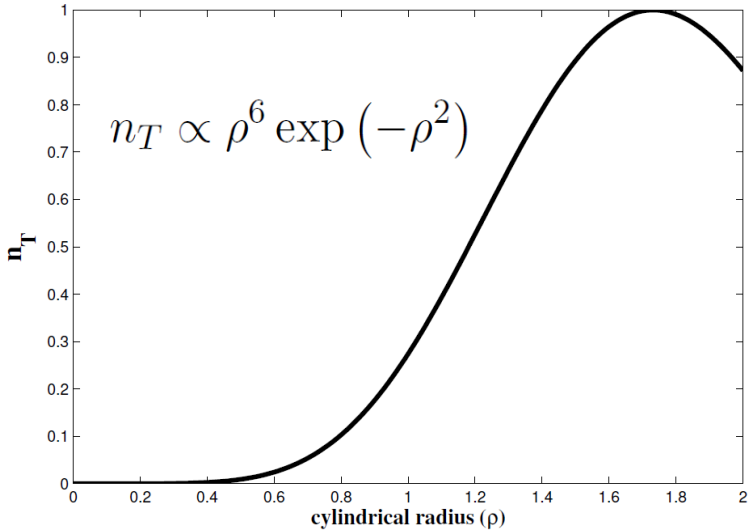


Theory

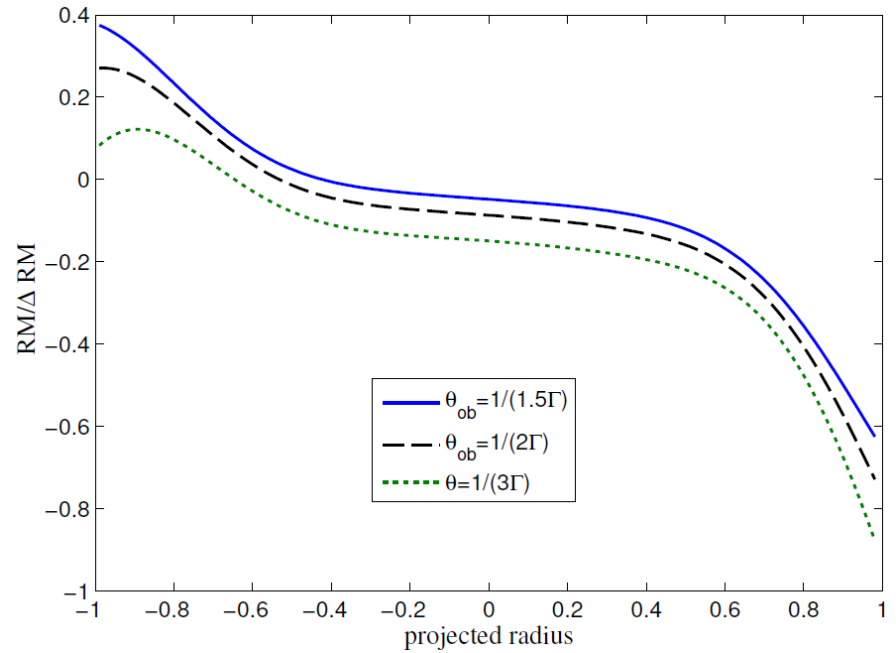


# Rotation Measure

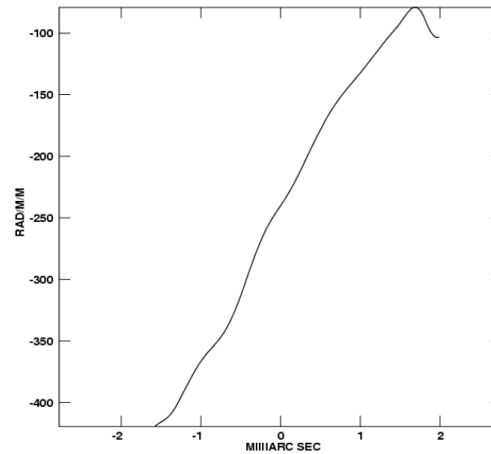
$$\Delta\tilde{\chi} = \frac{16\pi^3 e^3}{m_e^2 c^4} \lambda^2 \int n_T' B_{\parallel}' ds'$$



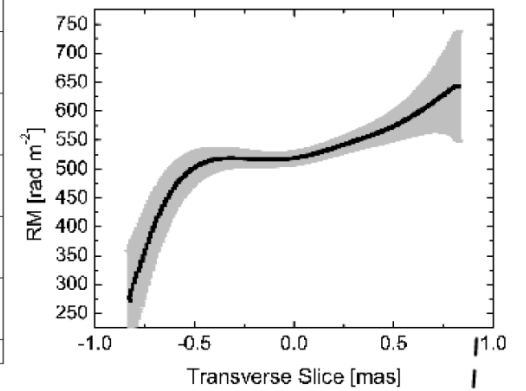
## Theory



## Observed 3C 78



## Observed OVV 1156+295



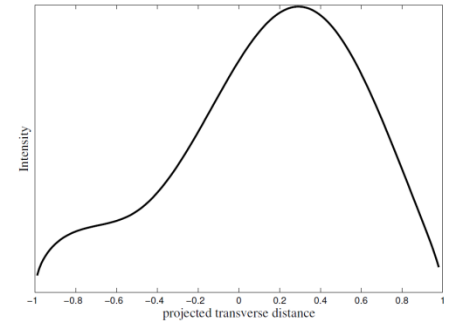
- Shape of RM profile (linear-ish or bendy) depends on thermal plasma density profile.

Left: Clausen-Brown et al

Right: O'Sullivan & Gabuzda 2009

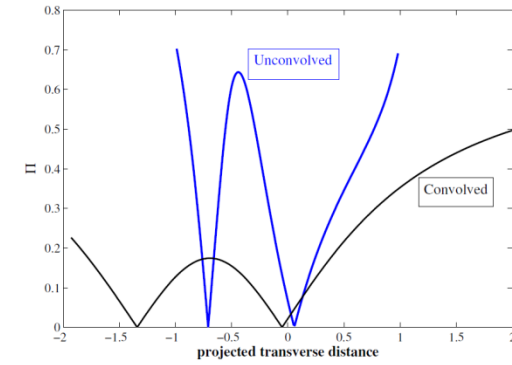
# Correlations

Intensity profile has long tail on left.

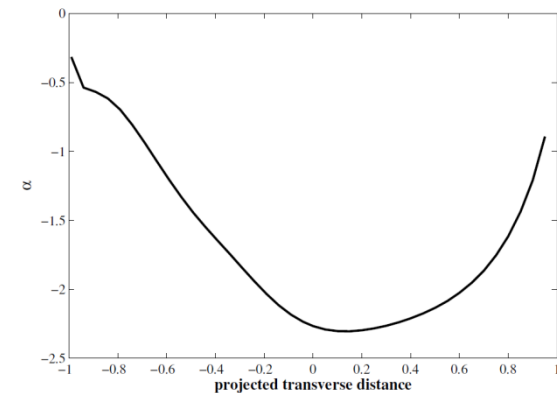


Then:

Sharper gradient to left.  
Polarization lower of left

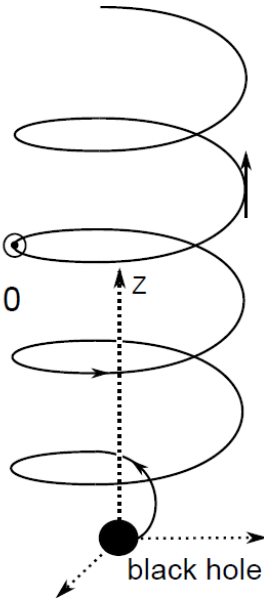


Closer to optically thin spectrum on left.



If:

$$n' \parallel B' \\ \sin\chi' \sim 0$$

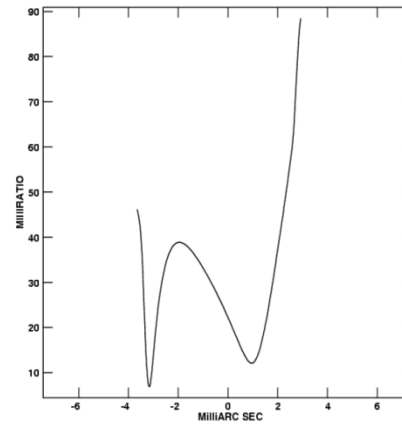
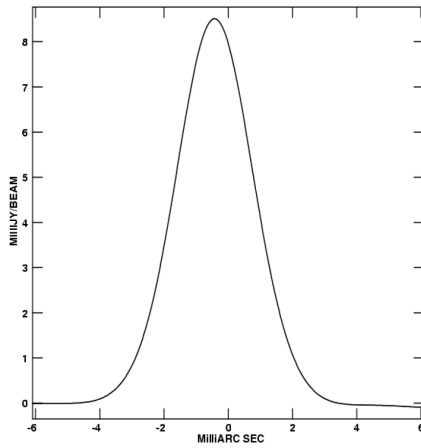


$$n' \perp B' \\ \sin\chi' \sim 1$$

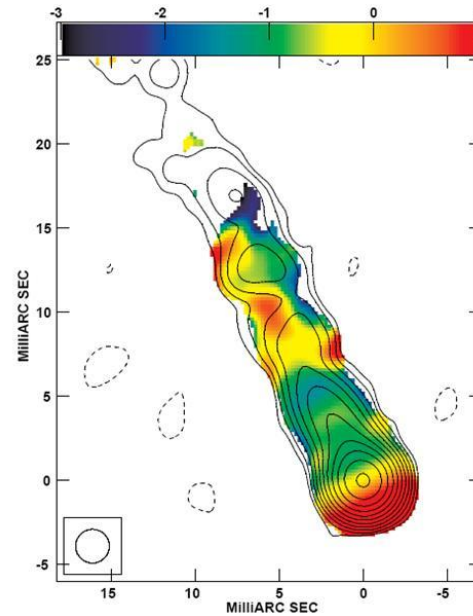
**Caveat: Intensity/Polarization applies in optically thin case. Can't compare with spectral index gradients in the same cut**

# Correlations: inconsistent with helical fields for 3C 78

symmetric



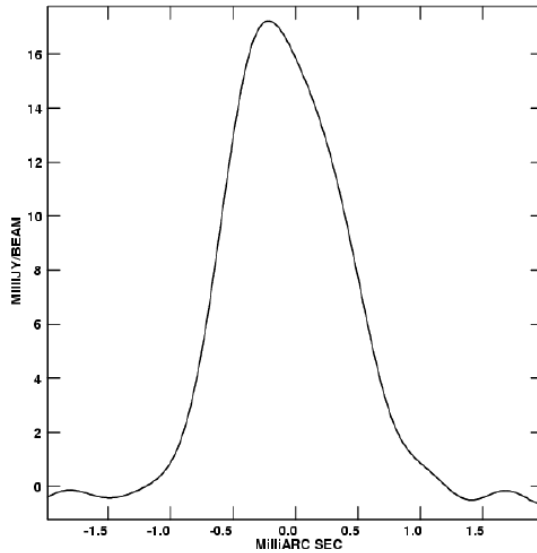
Lower polarization on left side



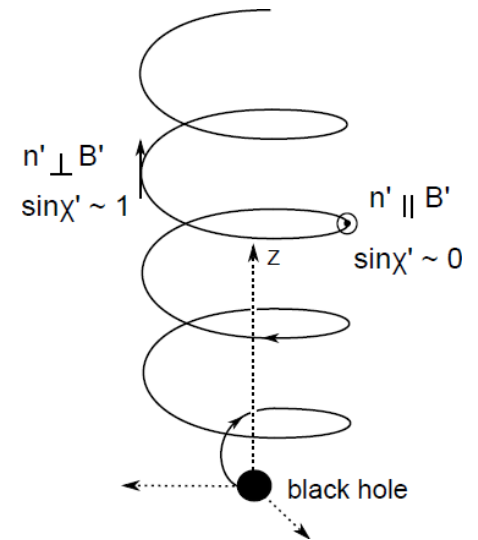
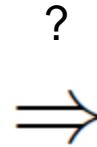
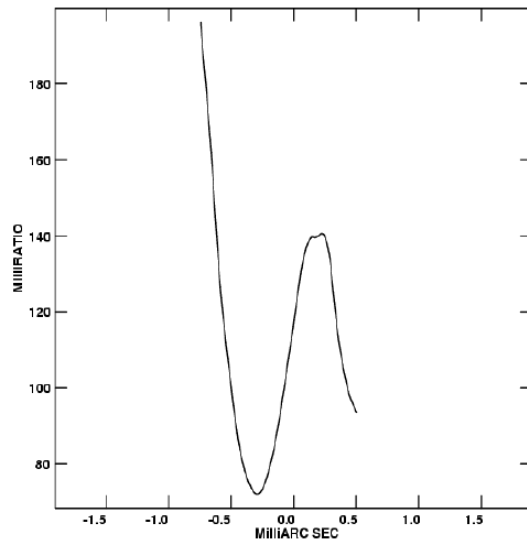
Optically thin on right side further down the jet

# Correlations: consistent with helical fields for Mrk 501

Positively skewed

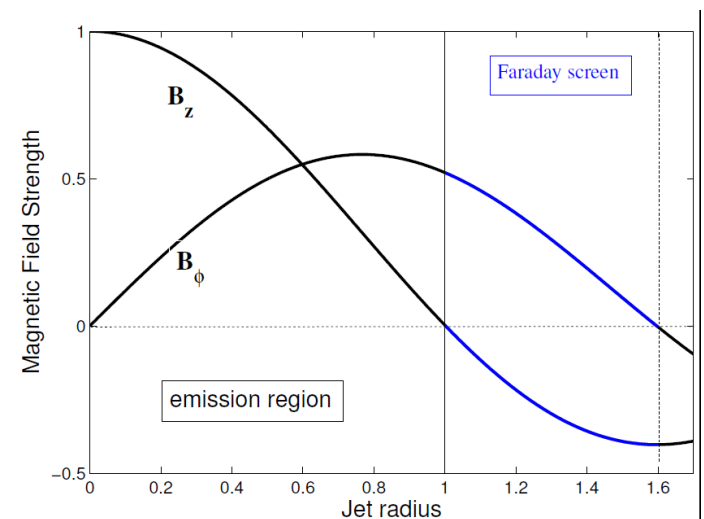
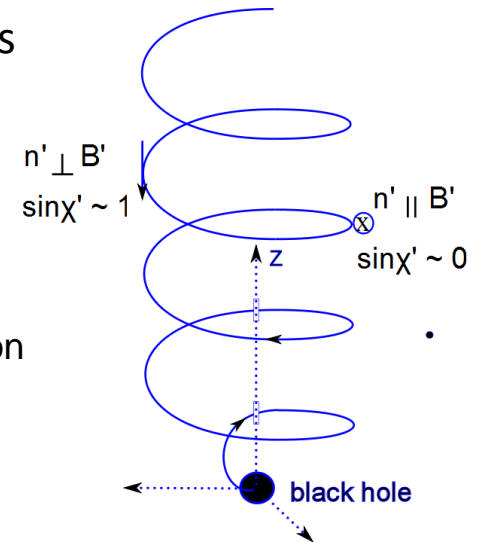
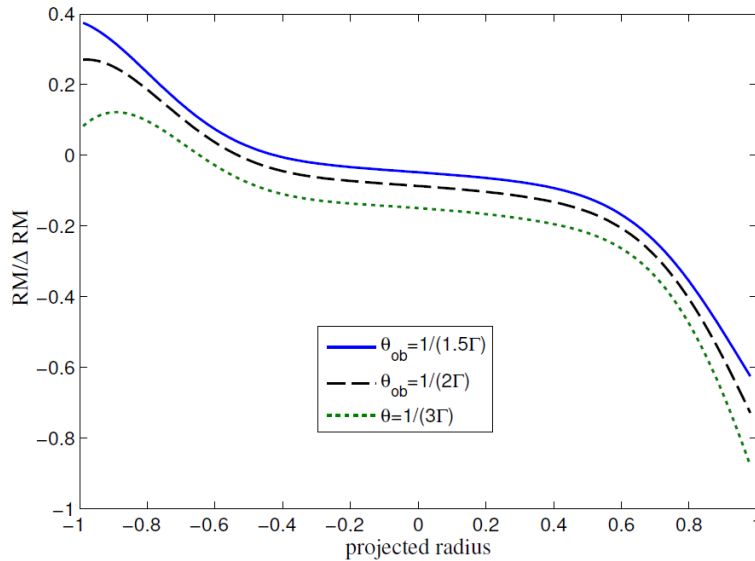


Lower Polarization on right side



# Correlations and RM

- RM gradient direction gives information polarity of B
- Which side has a greater  $|RM|$  gives direction on which side is



# Conclusions

- Correlations between intensity, polarization, and sometimes spectral index allow us to infer:
  - the presence of helical fields
  - Which side of the jet has  $B \parallel n$
- RM profile reveals how sheath B-field is correlated with jet B-field.
- Future work: Statistics from MOJAVE.

# REFERENCES

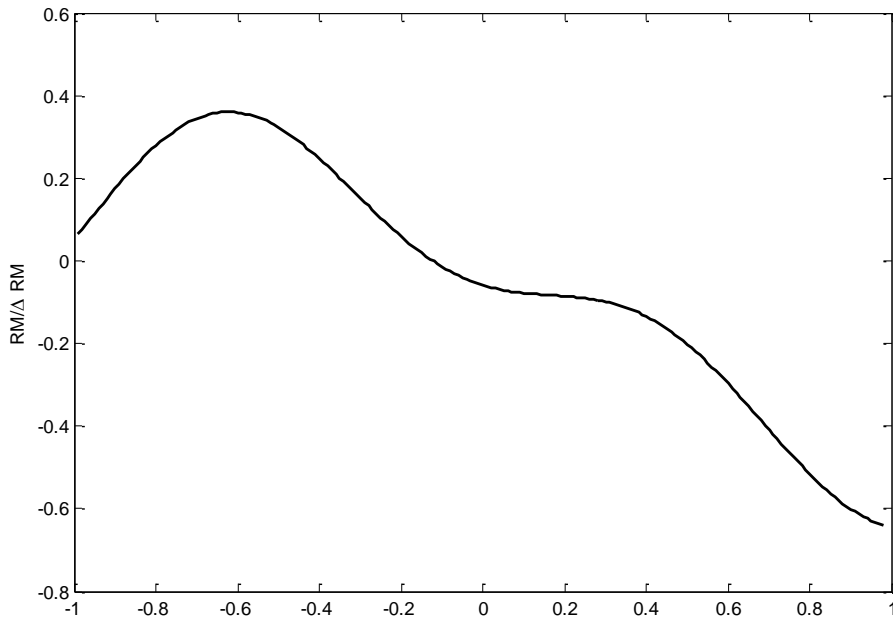
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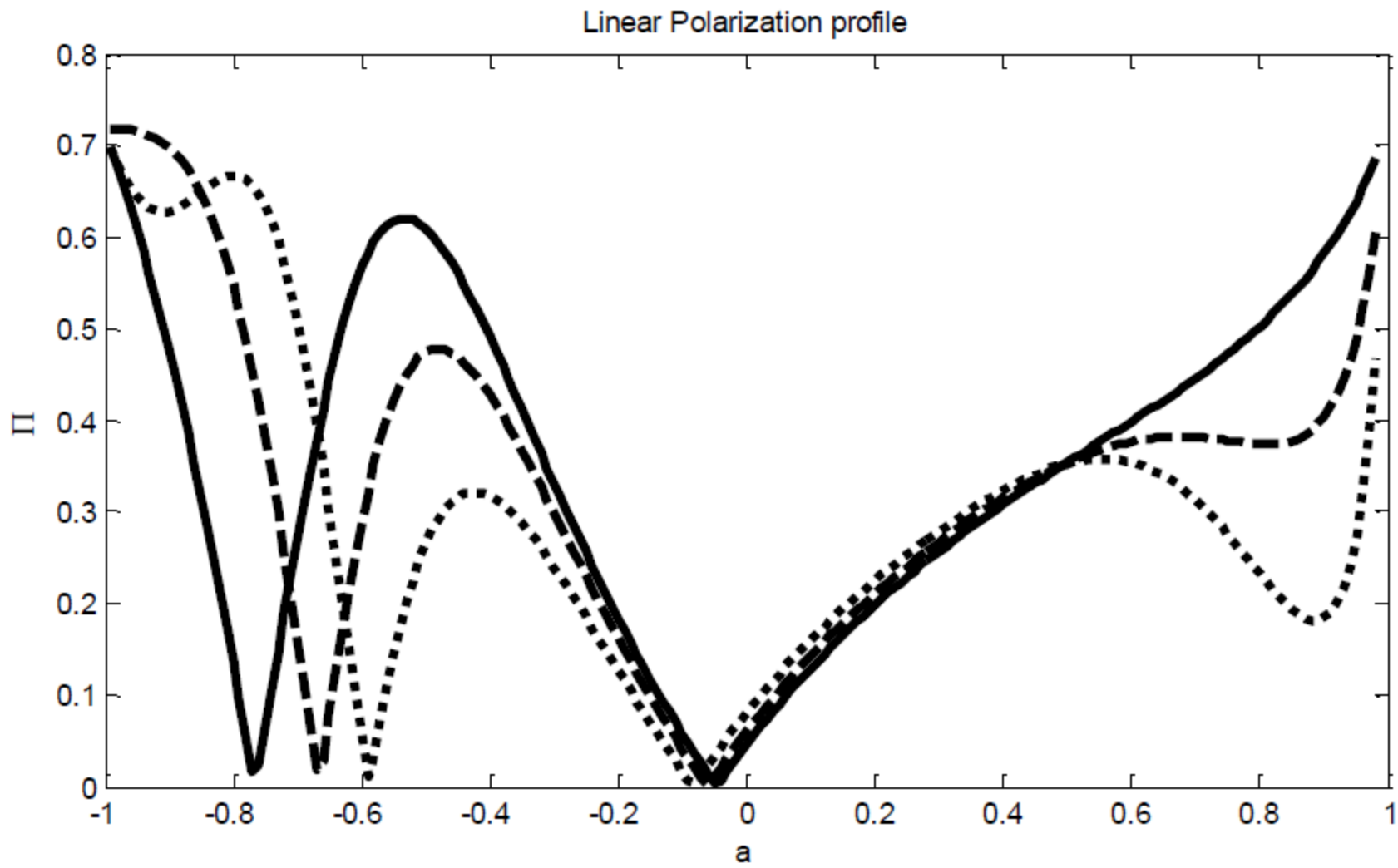
B is parallel to Line of Sight on left side of jet = Bpara Left.      B is parallel to Line of Sight on right side of jet = Bpara Right.

	Left side of jet	Right side of jet
Polarization is lower on _____ (Gradient is steeper on _____). Bump (if it exists) is on the _____	Bpara Left	Bpara Right
Intensity profile is longer on the _____	Bpara Left	Bpara Right
Closer to steep spectrum on the _____	Bpara Left	Bpara Right

# Extras-RM

$$n_T \propto \rho^2 \exp(-\rho^2)$$





**Figure 1 With internal Faraday rotation**