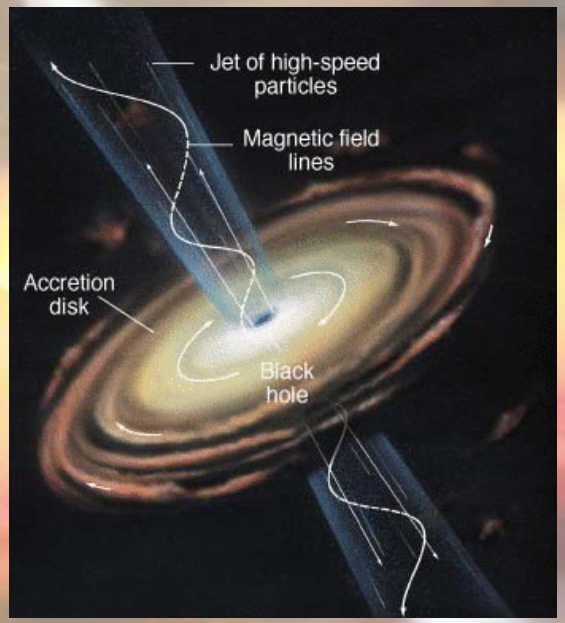
EVIDENCE FOR THE GENERATION OF HELICAL MAGNETIC FIELDS AND THEIR EVOLUTION IN ACTIVE GALACTIC NUCLEI



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OUTLINE

- Introduction
  - Overview of previous work
- Data Reduction
  - Observations, Calibration, Imaging and Rotation Measure (RM) determination
- Results – Rotation Measure (RM) gradients and their evolution
  - Sources with transverse rotation measure gradients in jets :
    0003-066, 0138-097, 0820+225, 0735+178, 0745+241, 0954+658, 1159+292, 1334-127, 1749+096, 1749+701
  - Reversal of rotation measure gradient in the jet over time: 1803+784
  - Reversal of rotation measure gradient in the jet compared to the core:
    0256+075, 0716+714, 1803+784 and 2155-152
- Connecting Magnetic Towers and Faraday Rotation gradients:
  - Using Faraday Rotation gradients to test magnetic tower models
- Conclusions

INTRODUCTION

- BL Lac objects are a type of Active Galactic Nuclei (AGN) characterized by strong and variable polarization, rapid variability in luminosity, a featureless spectrum and weak optical line emission.

- BL Lac objects show a tendency for the magnetic fields in their parsec-scale jets to be perpendicular to the jet direction (e.g. Gabuzda, Pushkarev & Cawthorne 2000).

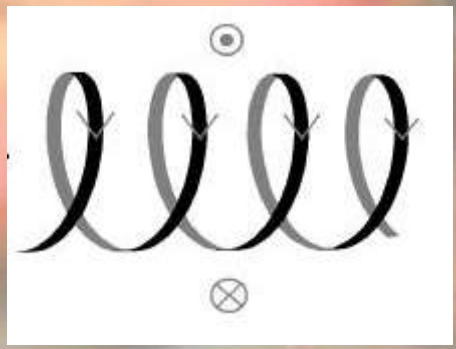
- Gabuzda, Murray and Cronin (2004), showed systematic Faraday- Rotation gradients across the parsec-scale jets of several BL Lac Objects, interpreted as evidence for helical magnetic fields – the gradients were taken to be due to the systematic variation of the line-of-sight magnetic field component across the jet.

- Rotation Measure gradients have been used by Gabuzda et al. (2008) to help in the prediction of the sign of the circular polarization, providing more evidence for the presence of helical magnetic fields.

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:

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



B • dl > 0 --------> + RM, B • dl < 0 --------> - RM

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

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

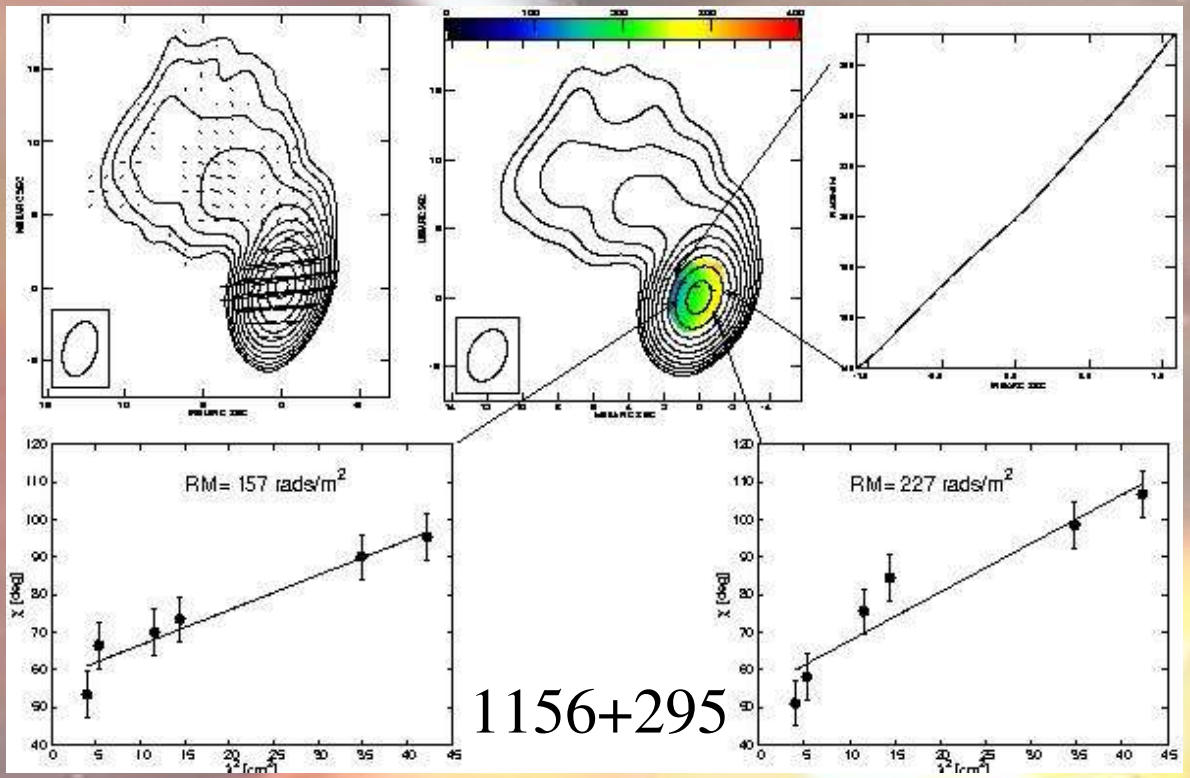
where χ_{obs} is the observed polarization angle, χ_0 is the intrinsic polarization angle observed if no rotation occurred and λ is the observing wavelength.

DATA OBSERVATION AND REDUCTION I

- VLBA polarisation observations of 37 BL Lac objects observed between August 2003 and September 2004.
- 'Snap shot' mode, each source observed for about 25-30 minutes, several scans over the observing time period.
- 6 wavelengths; 2 at each of the 2cm, 4cm and 6cm bands.
- Objective to verify earlier results and get more refined Faraday Rotation (FR) gradients and identify new sources with the FR gradients.

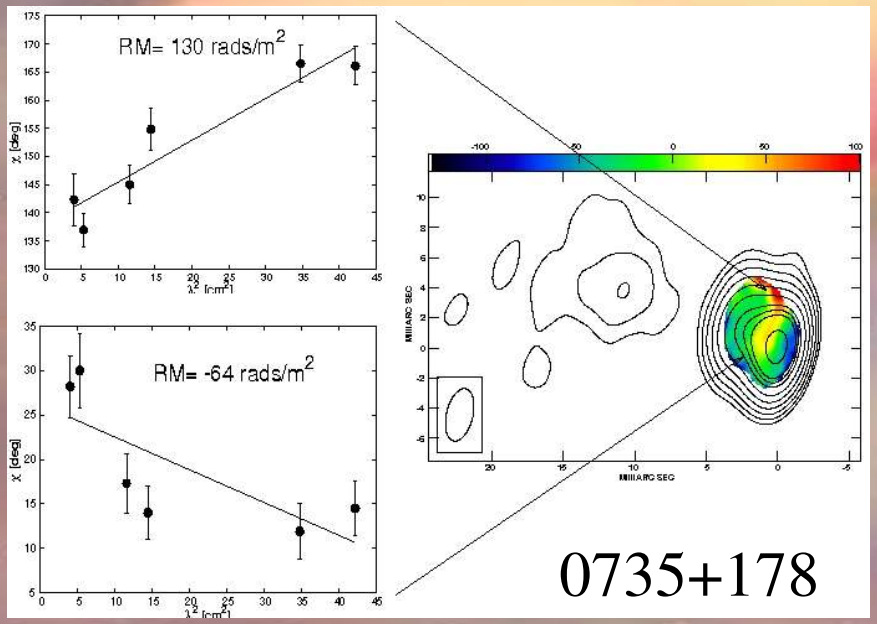
DATA OBSERVATION AND REDUCTION II

- After calibration, for each wavelength, total intensity (I) and polarization images (distribution of Stokes parameters Q and U) mapped
- Polarization angle images combined to make rotation measure maps after matching their parameters (beam size, image size, cell size)
- Before final RM maps made, contributions from known integrated (Galactic) FR subtracted at each wavelength (Pushkarev 2001).
- Calibration, Imaging and RM determination done with AIPS package using standard techniques.

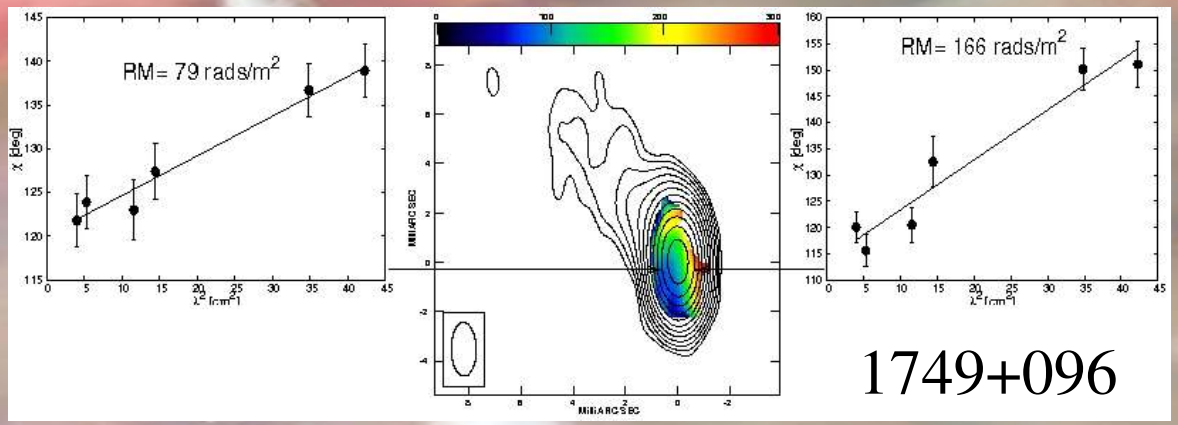


1156+295

'Spine -sheath' polarization structure of 1156+295 consistent with idea of helical magnetic fields.



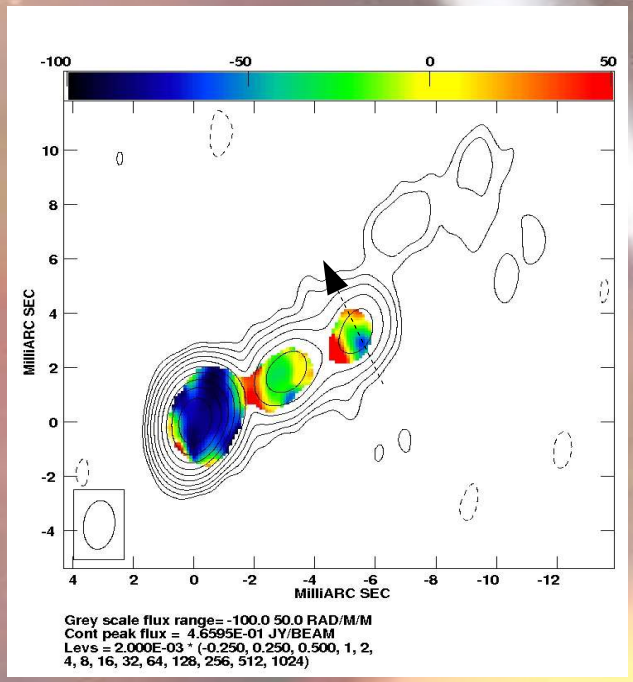
0735+178



1749+096

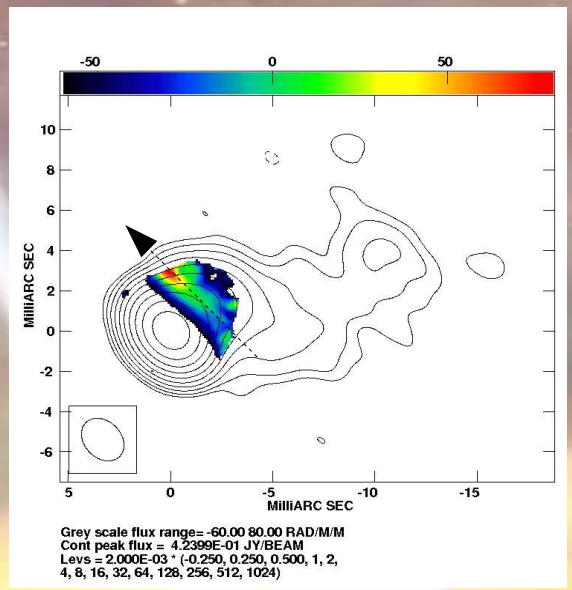
Gabuzda et al. (2008)

0745+241



Grey scale flux range= -100.0 50.0 RAD/M/M
Cont peak flux = 4.6595E-01 JY/BEAM
Levs = 2.000E-03 * (-0.250, 0.250, 0.500, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024)

0954+658



Grey scale flux range= -60.00 80.00 RAD/M/M
Cont peak flux = 4.2399E-01 JY/BEAM
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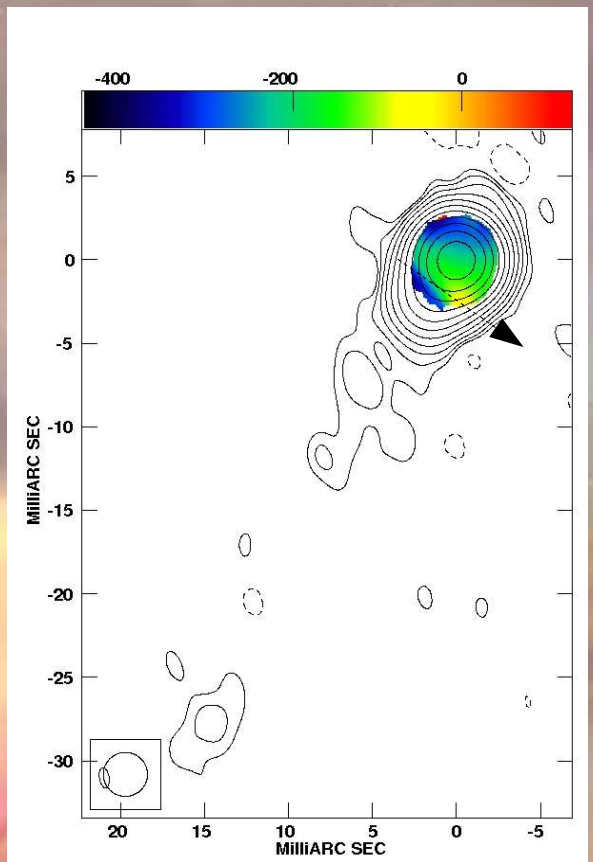
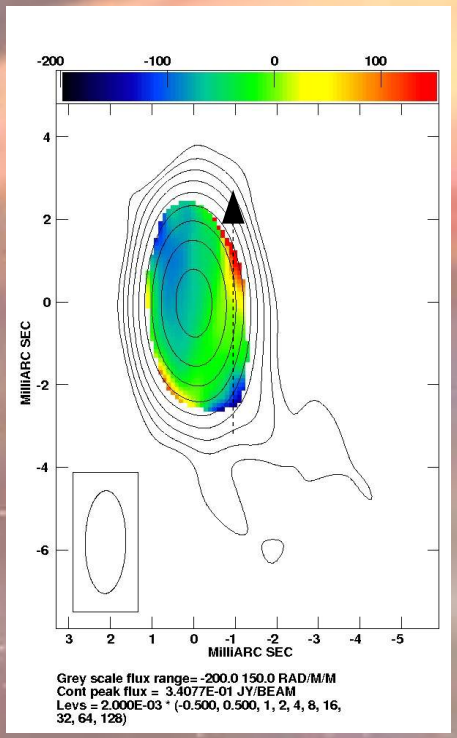
1334-127



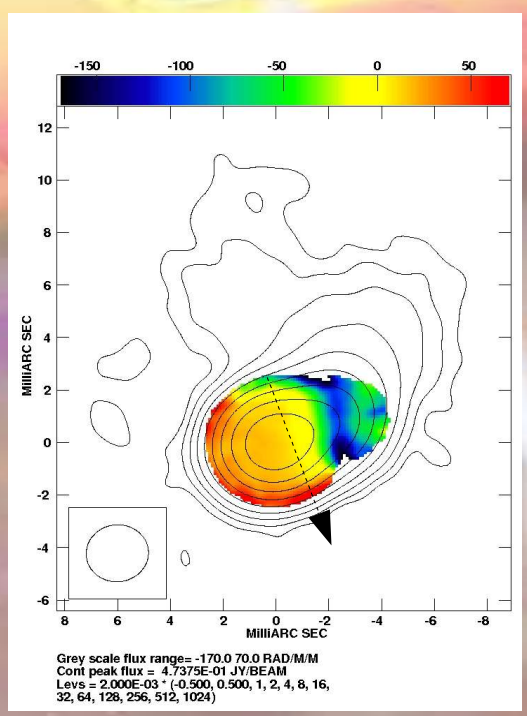
Grey scale flux range= -450.0 130.0 RAD/M/M
Cont peak flux = 3.3320E+00 JY/BEAM
Levs = 2.000E-03 * (-1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024)

0138-097



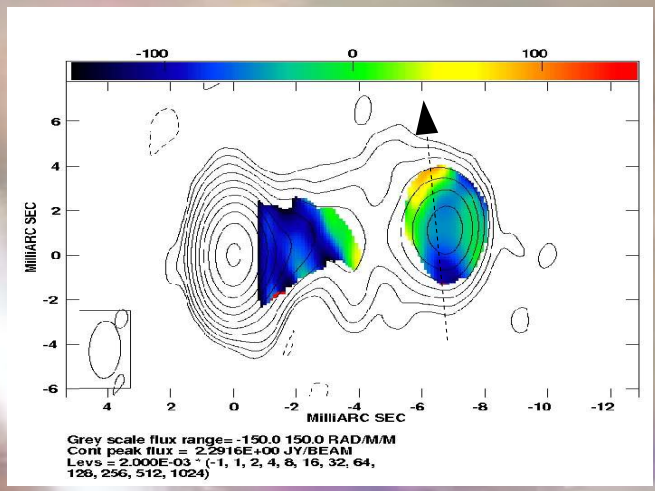
Grey scale flux range= -200.0 150.0 RAD/M/M
Cont peak flux = 3.4077E-01 JY/BEAM
Levs = 2.000E-03 * (-0.500, 0.500, 1, 2, 4, 8, 16, 32, 64, 128)

1749+701



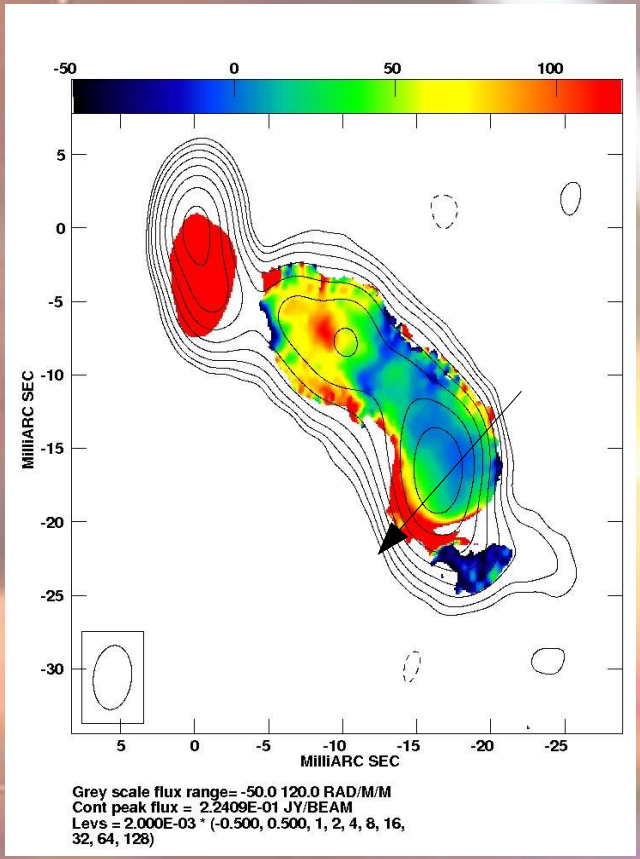
Grey scale flux range= -170.0 70.0 RAD/M/M
Cont peak flux = 4.7375E-01 JY/BEAM
Levs = 2.000E-03 * (-0.500, 0.500, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024)

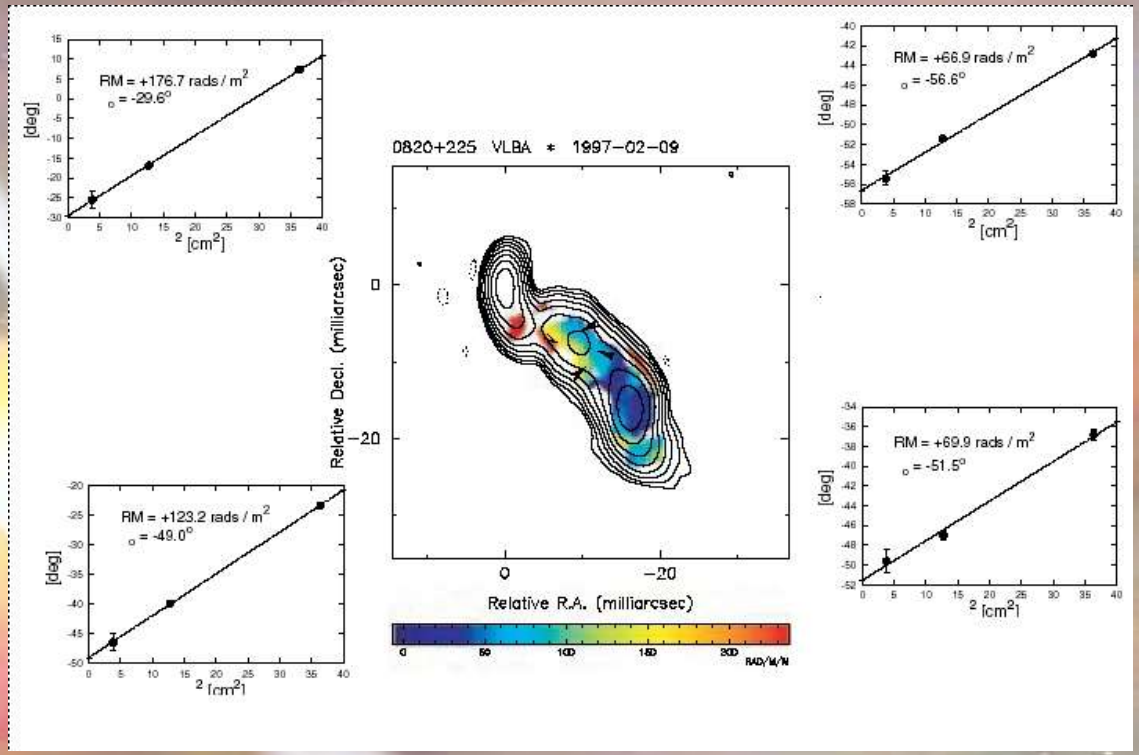
0003-066



Grey scale flux range= -150.0 150.0 RAD/M/M
Cont peak flux = 2.2916E+00 JY/BEAM
Levs = 2.000E-03 * (-1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024)

0820+225





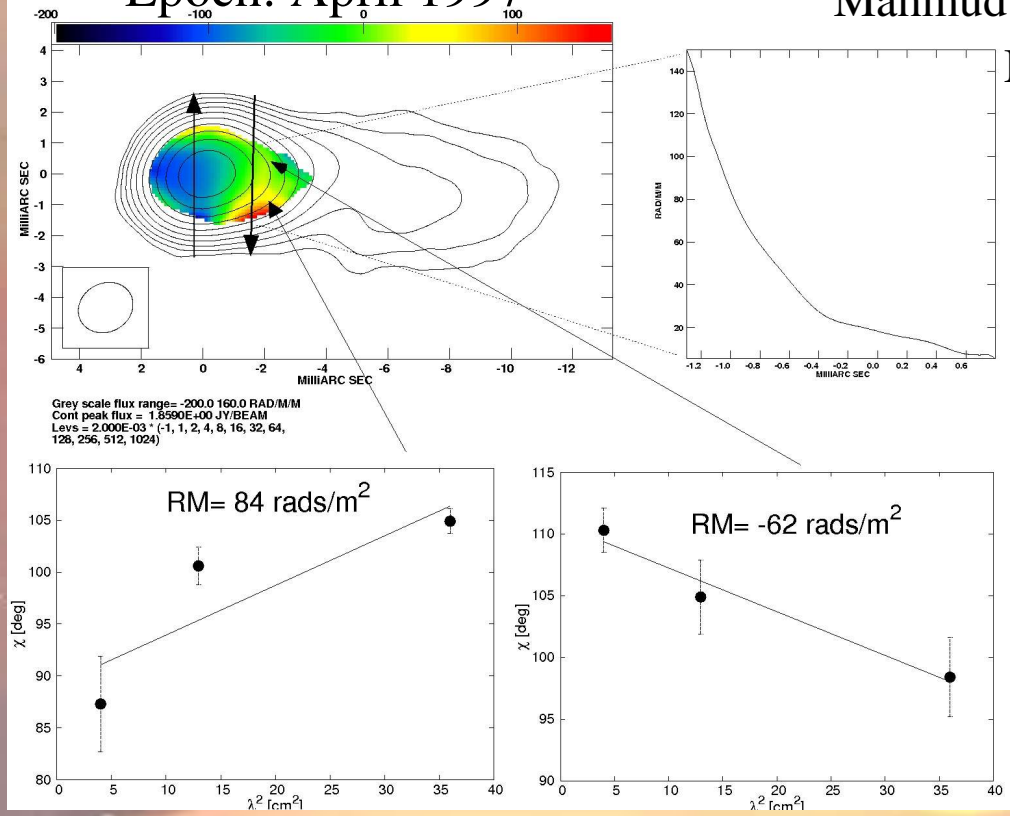
Gabuzda, Murray and Cronin (2004)

Do RM gradients propagate along jet? How do they evolve over time?

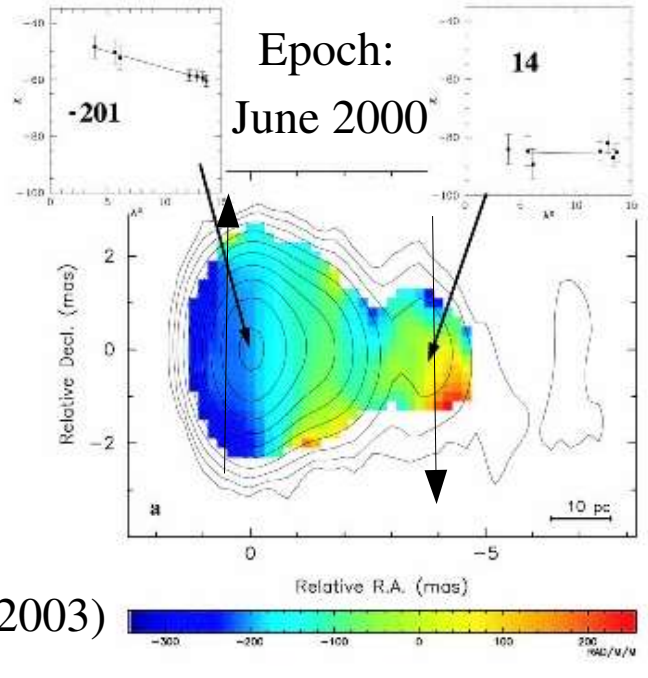
Are their magnetic fields evolving?

Epoch: April 1997

Mahmud & Gabuzda (2008)
MNRAS submitted

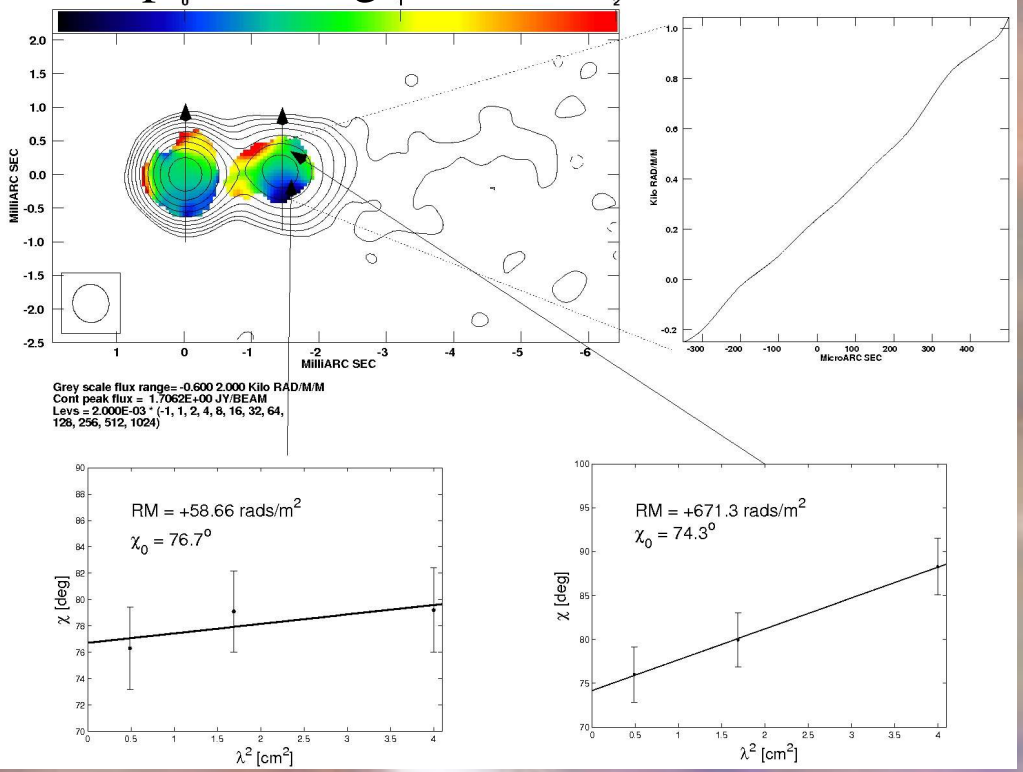


Epoch:
June 2000

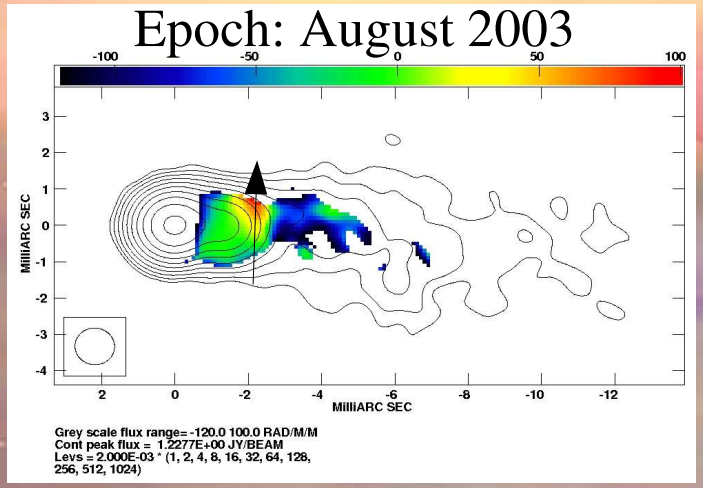


Zavala & Taylor (2003)

Epoch: August 2002

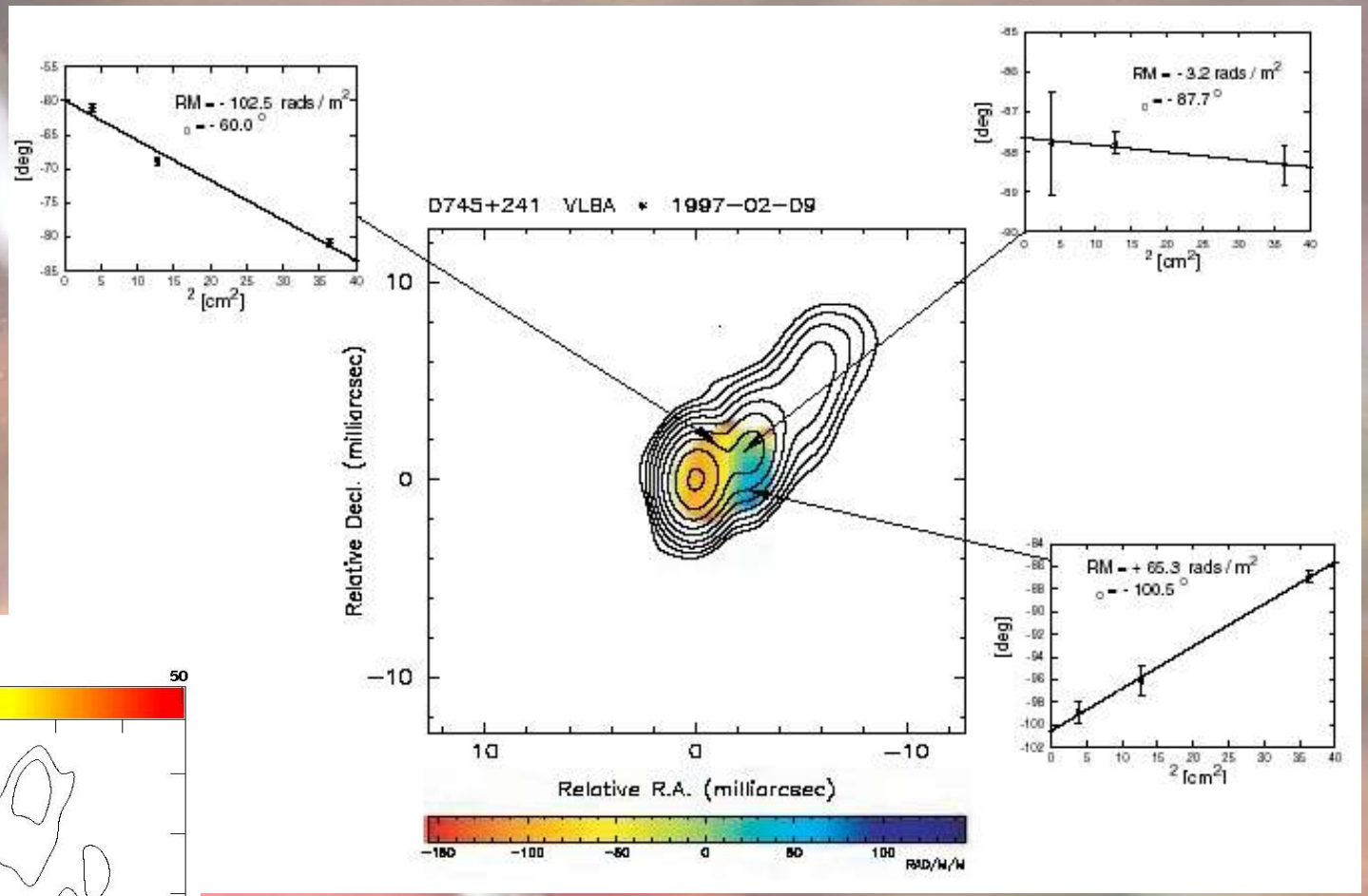


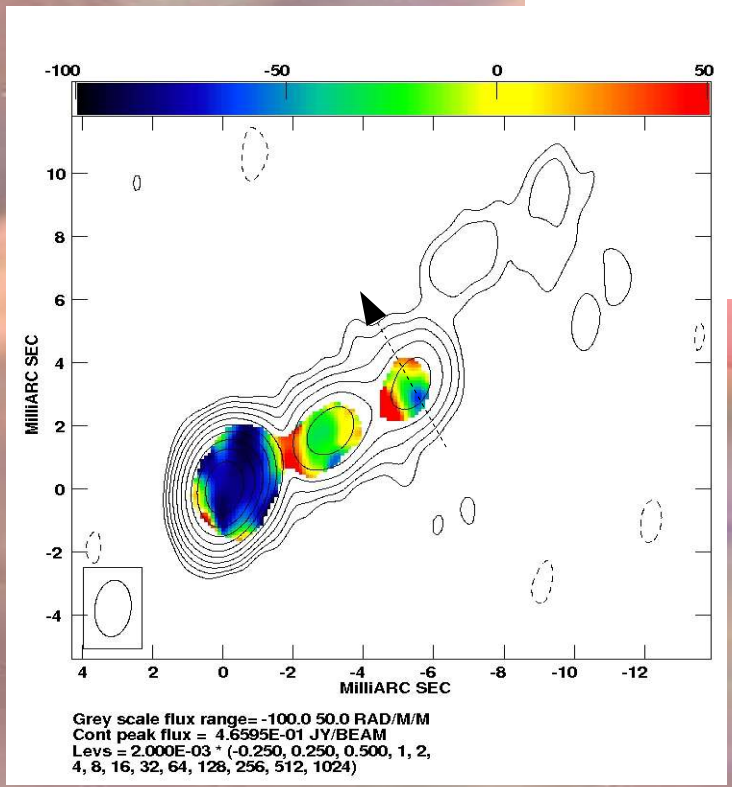
Epoch: August 2003



A flip of the RM gradient in the jet of 1803+784 between 2000 and 2002 !!

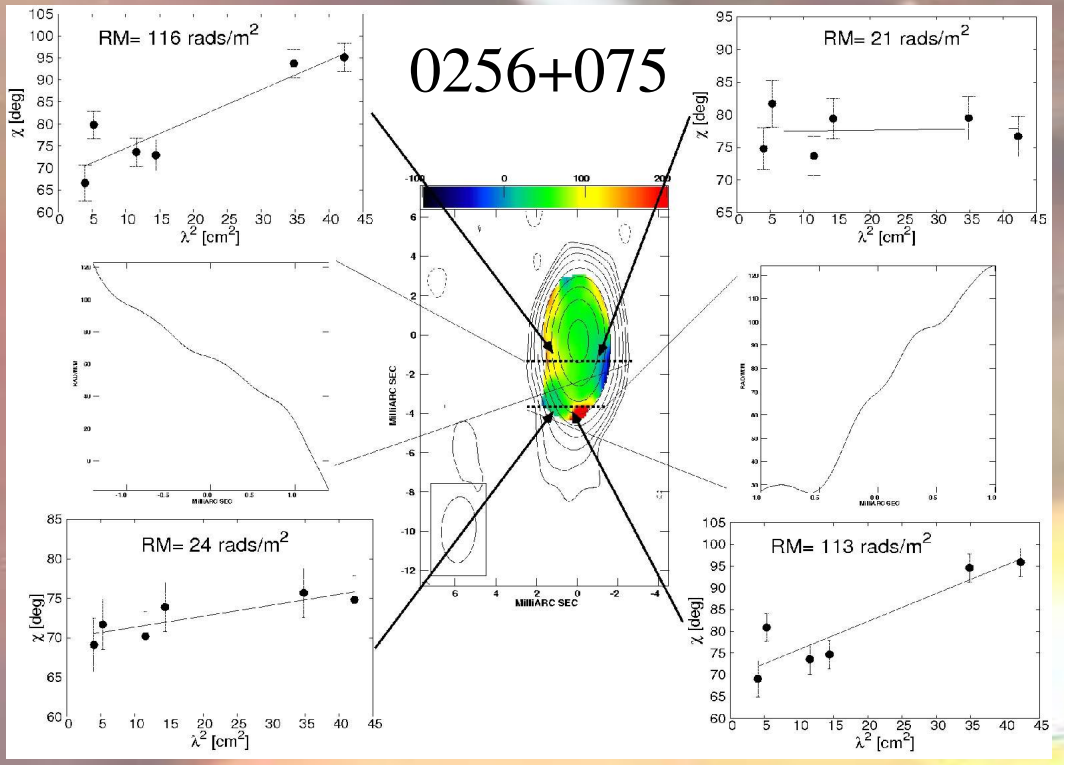
0745+241

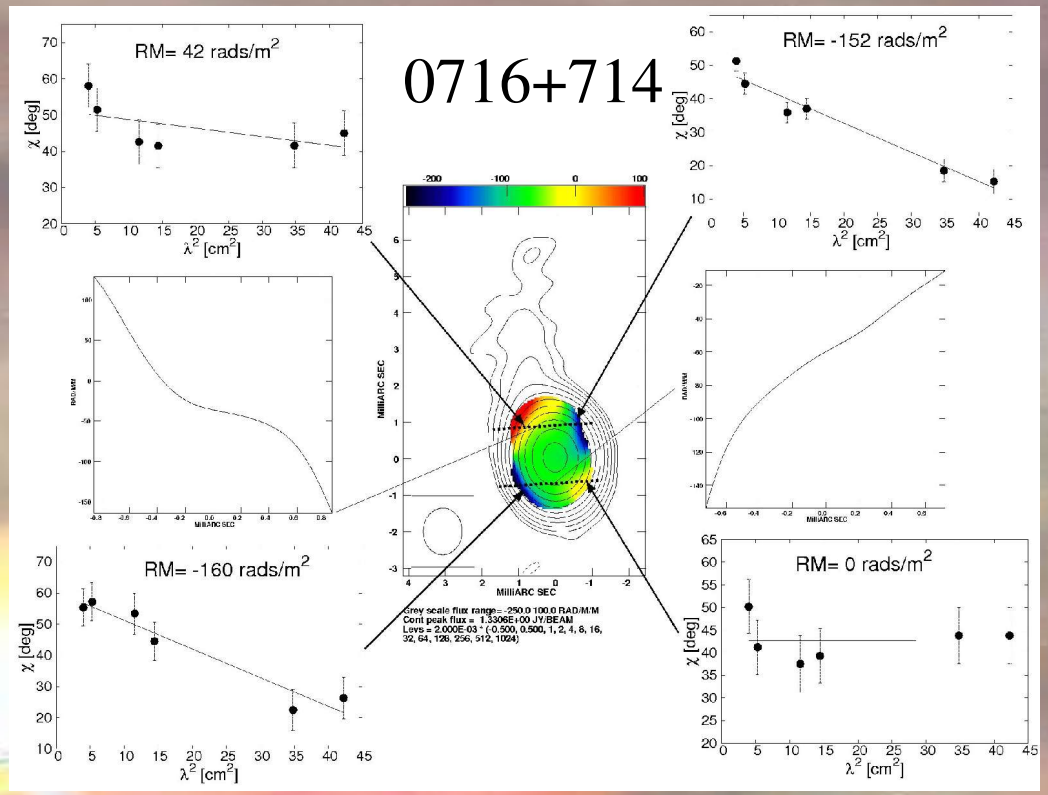




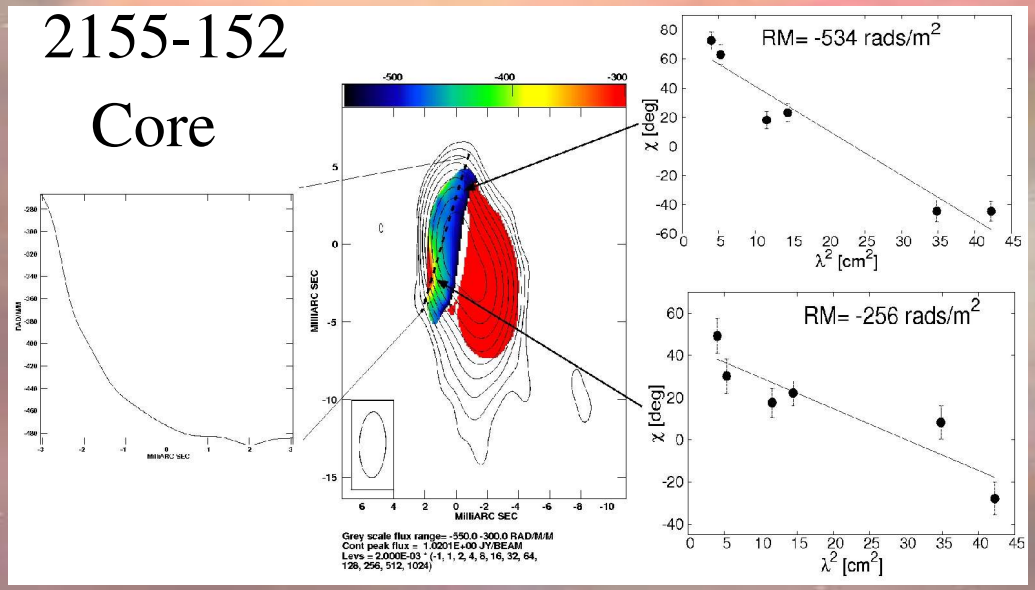
Gabuzda, Murray & Cronin 2004

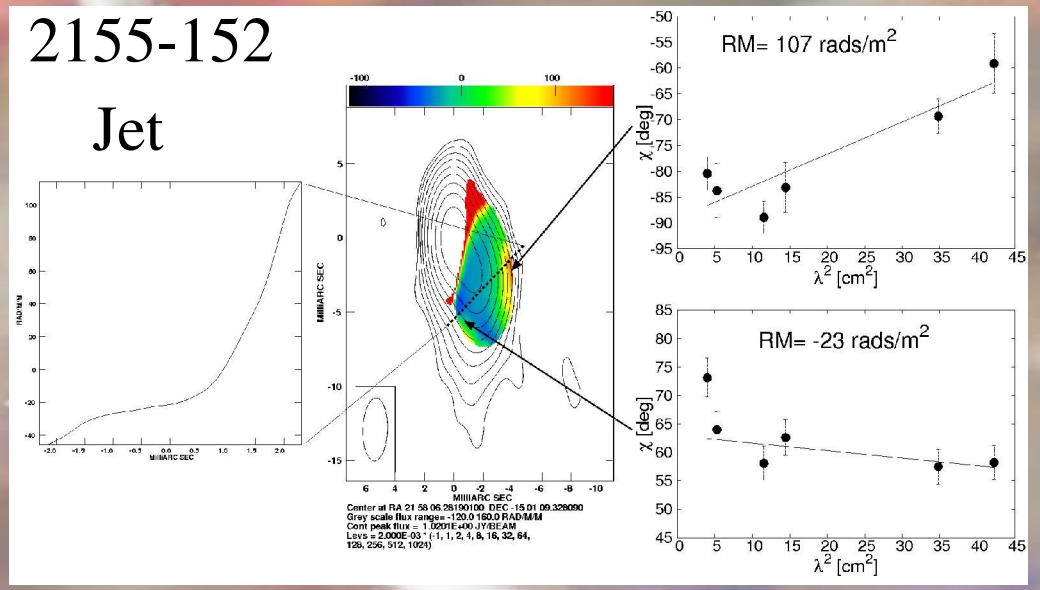
Another possible case of the RM gradient 'flipping' over time?





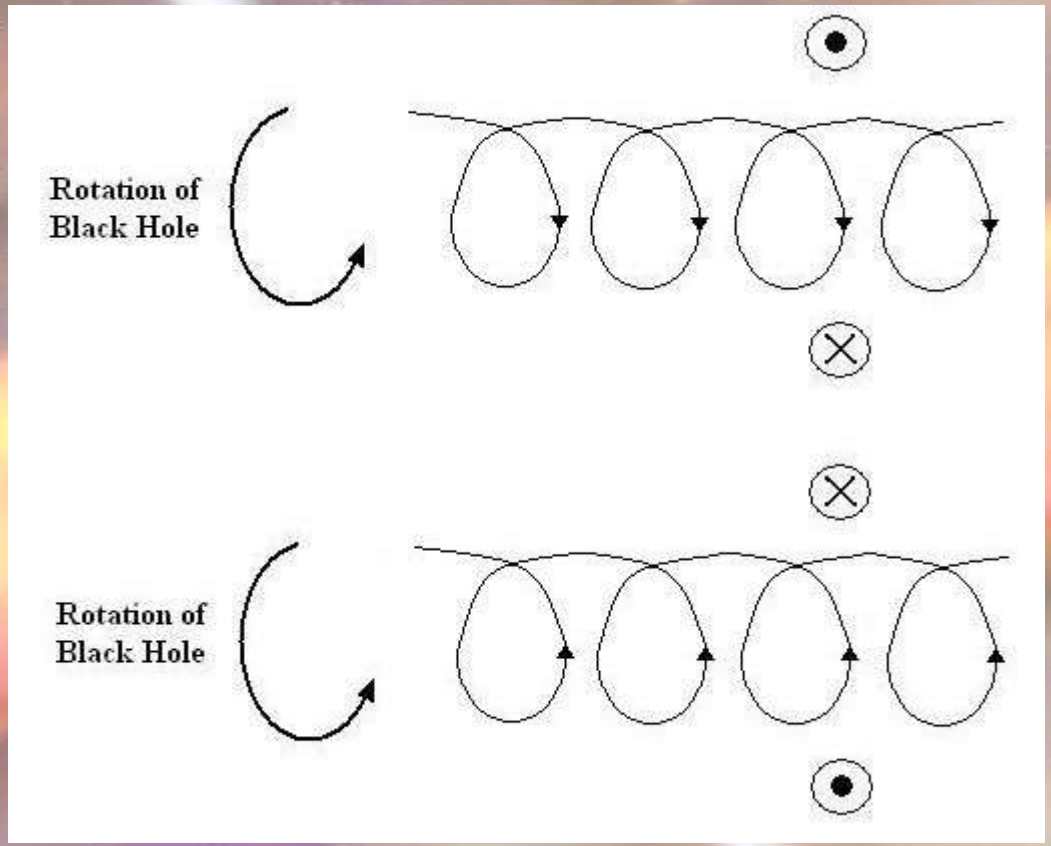
Mahmud & Gabuzda (2008) in prep, MNRAS





A change in the polarity of the black hole?

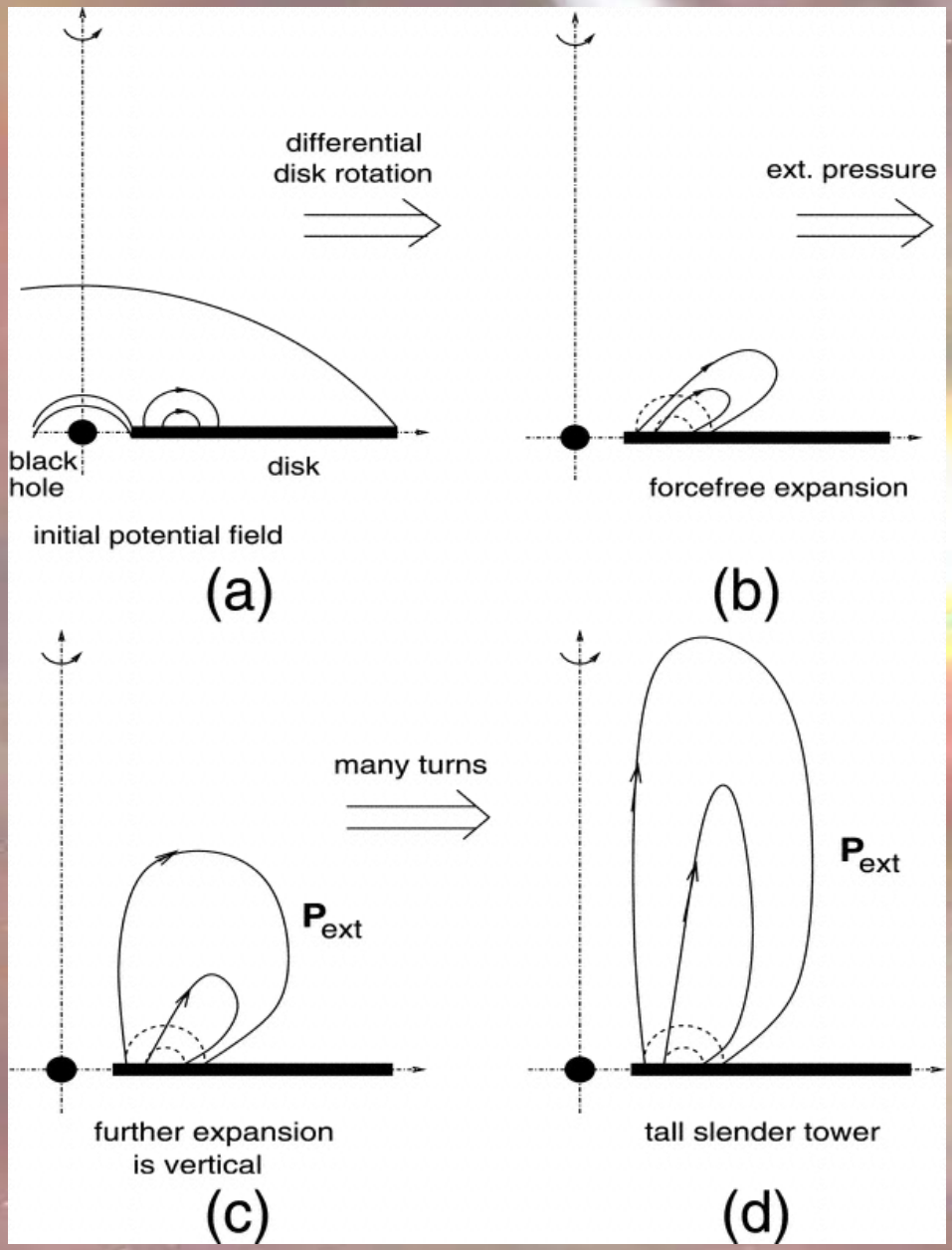
N pole



S pole

Or a change in the direction of the azimuthal magnetic field component due to torsional oscillations of the jet (Bisnovatyi-Kogan 2007)?

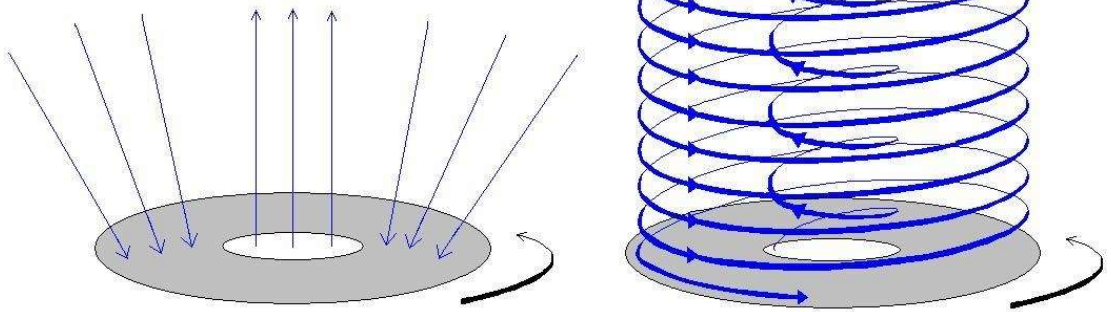
Development of a magnetic tower in Lynden-Bell's (1996) model



From The Astrophysical Journal 647(2):1192–1212.
Uzdensky & MacFadyen (2006)

- Assume that initially the magnetic field is potential and has a fully closed dipole-like topology.
- Then the expansion is uncollimated, typically along the direction making a 60° angle with respect to the rotation axis. At some point the sideways expansion is stopped.
- Unable to expand sideways, the twisted magnetosphere expands in the vertical direction, eventually forming a slender cylindrical column that Lynden-Bell termed a “magnetic tower” .
- The entire evolution is viewed as a sequence of magnetostatic equilibria, with the field being force-free inside the tower and with pressure balance between the external gas outside of the tower and the magnetic field inside.

Connecting Magnetic Towers & Helical Magnetic Fields



- If there are two 'nested' helical fields; an outer and inner helical field that occurs as a result of the differential disk rotation, 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.

CONCLUSIONS

- Transverse RM gradients in 0138-097, 0003-066, 0256+075, 0716+714, 0735+178, 0954+658, 1156+295, 1334-127, 1749+701 and 2155-152 observed for the first time, confirmed for 0745+241, 0820+225, 1749+096 and 1803+784.

- Simplest explanation is of helical magnetic fields wrapped around jet. Faraday Rotations of > 45 degrees are observed in some cases, indicating the Faraday Rotation is external.

- Spine-sheath polarization structure observed in some sources provides further evidence in favour of helical fields.

- RM gradients may evolve over time (propagate along the jet?).

- Direction of RM gradients can change over time, as well as with distance from the core.

- The observed RM gradient reversals are exciting as they relate to fundamental questions about the jet magnetic field geometries!

- This phenomenon provides new evidence to support magnetic tower models (where field lines go outwards from the central region of the accretion disk and close back in the outer region of the accretion disk) if we are detecting gradients from two helices: one nested inside the other.

- New VLBA observing time for 7 sources to test magnetic tower models recently approved! Faraday Rotation gradients are thus a totally new approach to provide evidence for these models!

ACKNOWLEDGMENTS

Denise Gabuzda, Vladislavs Bezrukovs, Patrick Cronin

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