Jet Physics and Magnetic Field Geometry in Parsec-Scale AGN Jets

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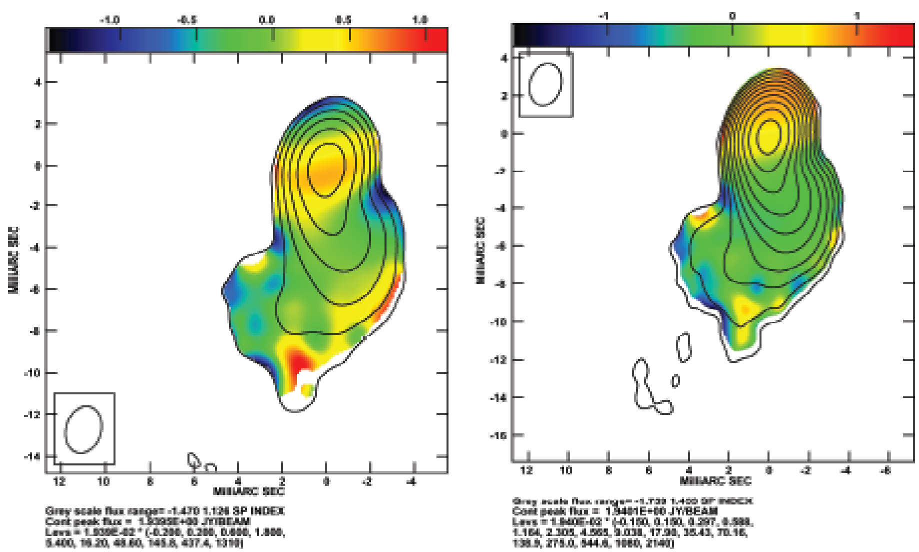
Overview

- Image Registration
  example: 1803+784
- Jet Physics from core-shift measurements
  examples: Mrk 501 and BL Lac
- Faraday rotation analysis from multi-frequency dataset
  8 frequencies from 4.6 – 43 GHz
  6 blazars: 0954+658, 1156+295, 1418+546, 1749+096, 2007+777, 2200+420
- Jet magnetic field structure

Image Registration

- Cross-correlation method of aligning images (see Croke & Gabuzda 2008)
- Comparison with phase-referencing and space VLBI observations (Jimenez-Monferrer et al. 2007, Giroletti et al. 2004)

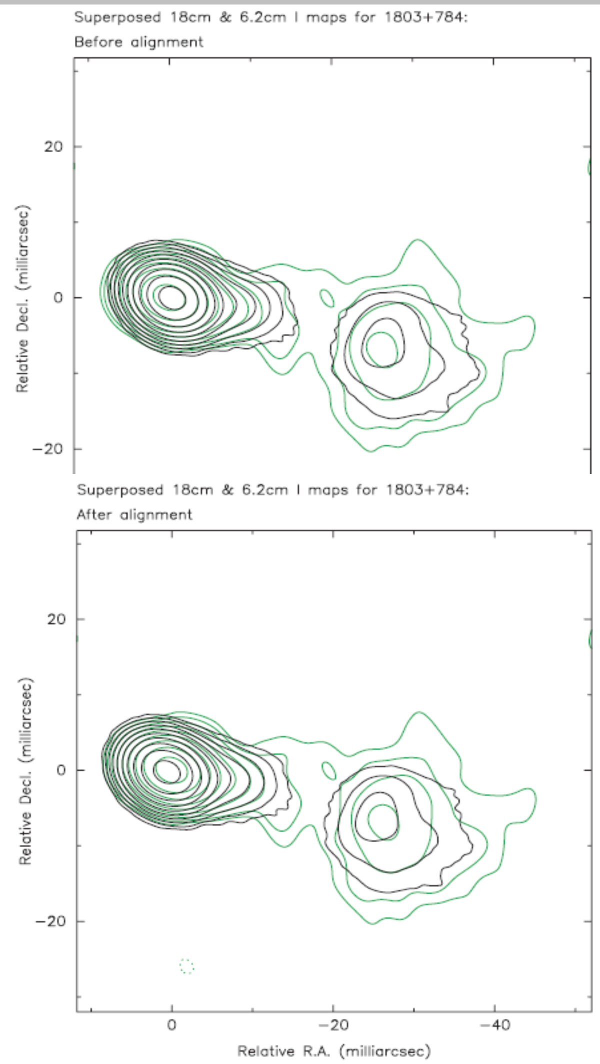


1803+784 Core Shift

- 1803+784: 1.6 – 5 GHz
  Core Shift = 1.27 +/- 0.35 mas

- Predicted core shift from
  8.4 – 43 GHz = 0.29 mas

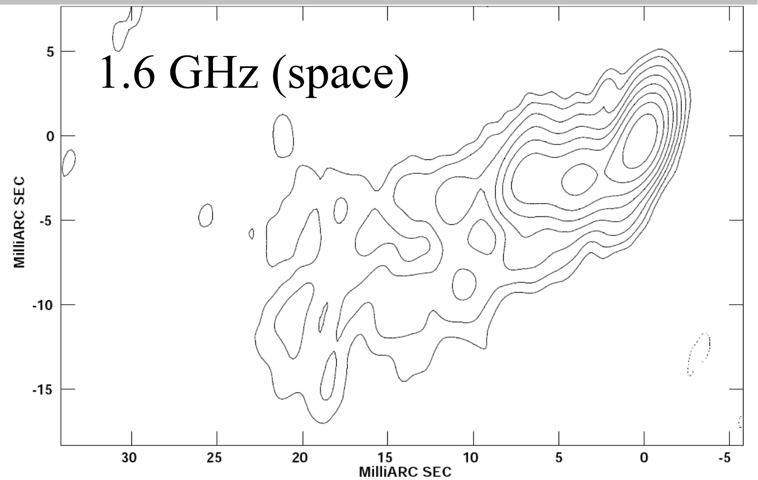
- Jimenez-Monferrer et al. (2007)
  1803+784: 8.4 – 43 GHz
  Core Shift = 0.27 +/- 0.13 mas

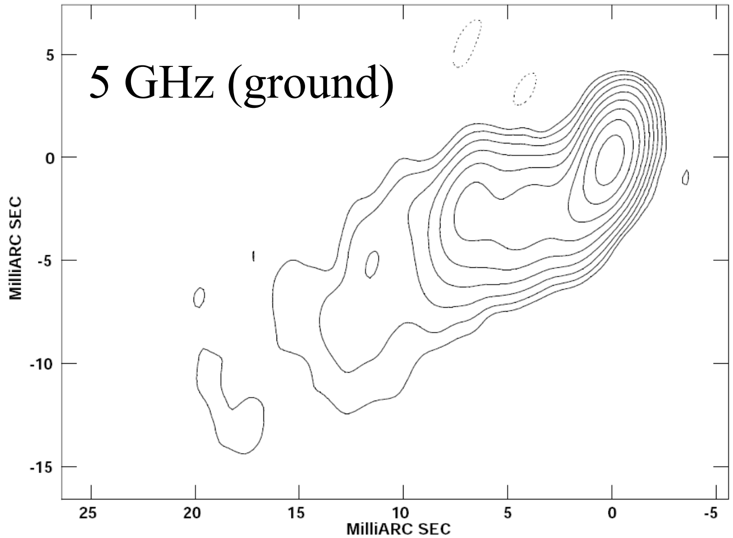


Mrk 501 Core Shift

- From Croke et al. (in prep.)
  Mrk 501: 1.6 – 5 GHz (May 1998)
  Core Shift = 0.78 +/- 0.07 mas

- Giroletti et al. (2004) (April 1998)
  Mrk 501: 1.6 (space) – 5 GHz (ground)
  Core Shift = 0.72 +/- 0.28 mas





Lobanov (1998)

$$\Omega = 4.85\times10^{-9}\frac{\Delta D_L}{(1+z)^2}\left(\nu_1^{\frac{1}{k_r}}\nu_2^{\frac{1}{k_r}}/(\nu_2^{\frac{1}{k_r}}-\nu_1^{\frac{1}{k_r}})\right)$$

$$F = (1+z)^{-1}\left(6.2\times10^{18}C_2\delta^{\frac{3}{2}-\alpha}N_1\frac{\phi}{\mathrm{Sin}[\theta]}\right)^{\frac{1}{\frac{5}{2}-\alpha}}$$

$$B_{\mathrm{core}} = \nu^{\frac{m}{k_r}}\left(\frac{\Omega}{(1+z)\mathrm{Sin}[\theta]}\right)^{\frac{k_r}{k_b}-m}F^{-\frac{1}{k_b}}$$

$$r_{\mathrm{core}} = \Omega\left(\nu^{\frac{1}{k_r}}\mathrm{Sin}[\theta]\right)^{-1}$$

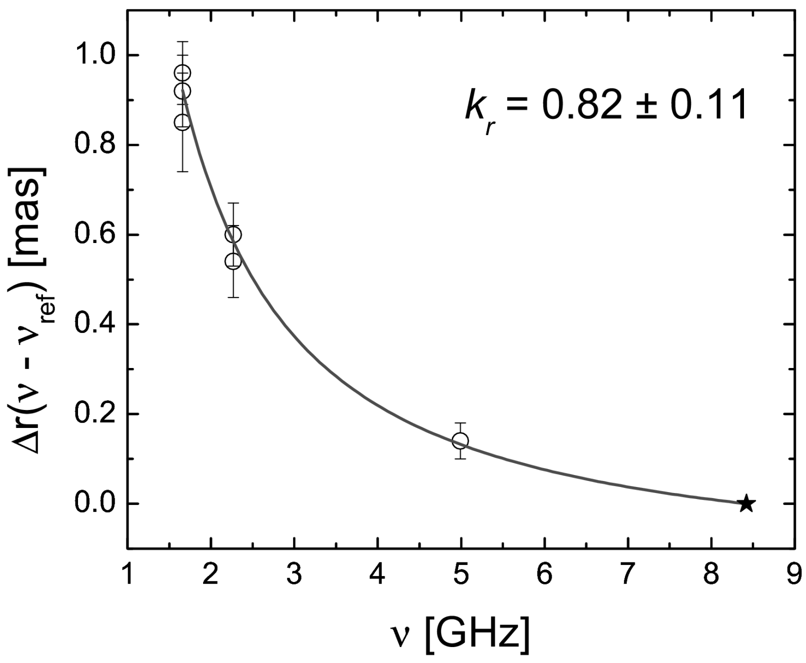
Mrk 501 Jet Physics

- Mrk 501: 1.6 – 2.2 – 5 – 8.4 GHz
- Katarzynski et al. (2001)
  $B \propto r^{-m}$ $N \propto r^{-n}$
  m = 0.9, n = 1.8, k_r *= 0.86*
- Giroletti et al. (2004)

α_j	$\phi_j(^\circ)$	γ_j	$\theta_j(^\circ)$
-0.7	10	15	15

- B_{core}(8.4 GHz) = 0.15 +/- 0.04 G

  r_{core}(8.4 GHz) = 0.8 +/- 0.2 pc



Black Hole Mass

- Kardashev(1995), Lobanov (1998)

$$M_{\rm BH} \approx 7\times10^9 B^{1/2} r^{3/2} M_{\rm Sun}$$

- Mrk 501: $M_{BH}=1.9\times10^9\ M_{Sun}$

  Barth et al. (2002): Stellar velocity dispersion

  $M_{BH}=(0.9 – 3.4)\times10^9\ M_{Sun}$

BL Lac Jet Physics

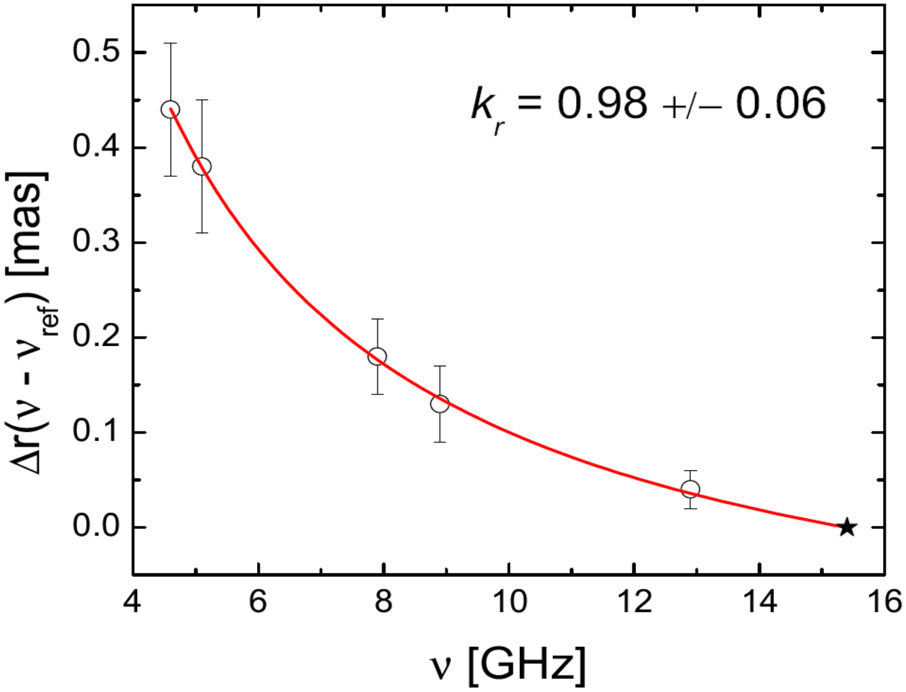
- BL Lac: 4.6 – 5.1 – 7.9 – 8.9 – 12.9 – 15.4 GHz
- Jorstad et al. (2005)

  α=-0.7 ϕ=2°

  θ=8° γ=7

- Equating B_1 to it equipartition value gives N_1=1300 cm^{-3}
- B_{core}(15.4 GHz) = 0.28 +/- 0.02 G

  r_{core}(15.4 GHz) = 1.8 +/- 0.1 pc



Information from Faraday Rotation

- VLA Faraday rotation observations to remove integrated (foreground) RM, see Pushkarev (2001)

- Important to remove in order to obtain correct sign of source RM and also if calculating properties in source rest frame RM $\rightarrow \lambda^2 \rightarrow (1+z)^2$

Information from Faraday Rotation

- Multi-frequency observations with short and long frequency spacings to uniquely constrain the RM
- Rotation must be removed to obtain intrinsic polarization orientation
- Evidence strongly in favour of majority of rotating material being external to synchrotron emitting material
- Added bonus of line-of-sight direction of magnetic field in thermal plasma surrounding the jet

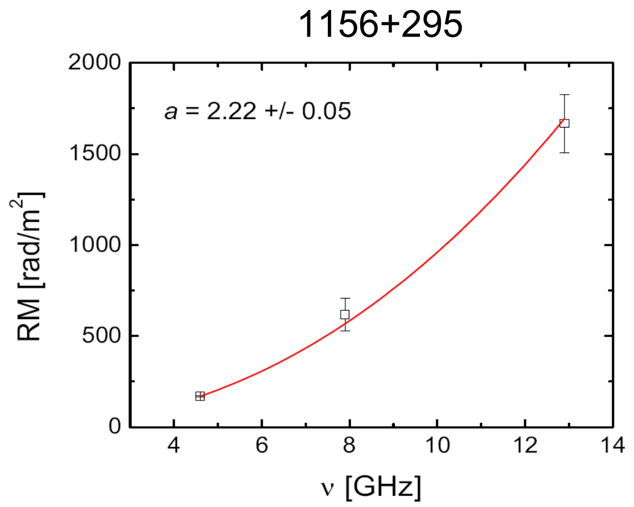
Variation in Core RM with Frequency

Source Name	$\mathrm{RM}_{\mathrm{core}}$ (Low ν range)	$\mathrm{RM}_{\mathrm{core}}$ (Mid ν range)	$\mathrm{RM}_{\mathrm{core}}$ (High ν range)	a ($\mathrm{RM}_{\mathrm{core}} \propto \nu^a$)
$0954+658$	$+33 \pm 14$	-88 ± 23	-1591 ± 265	3.84 ± 1.34
$1156+295$	$+170 \pm 5$	$+618 \pm 91$	$+1667 \pm 159$	2.22 ± 0.05
$1418+546$	$+83 \pm 11$	-501 ± 48	–	3.32 ± 0.60
$1749+096$	–	–	–	–
$2007+777$	$+638 \pm 39$	$+1904 \pm 127$	–	2.02 ± 0.16
$2200+420$	-193 ± 29	$+240 \pm 90$	-1008 ± 43	1.40 ± 0.18

- Assuming power-law fall-off in n_e with distance from central engine

$$n_e \propto d^{-a}$$

$$|\mathrm{RM}_{\mathrm{core},\nu}| \propto \nu^a$$



Variation in Core RM with Frequency

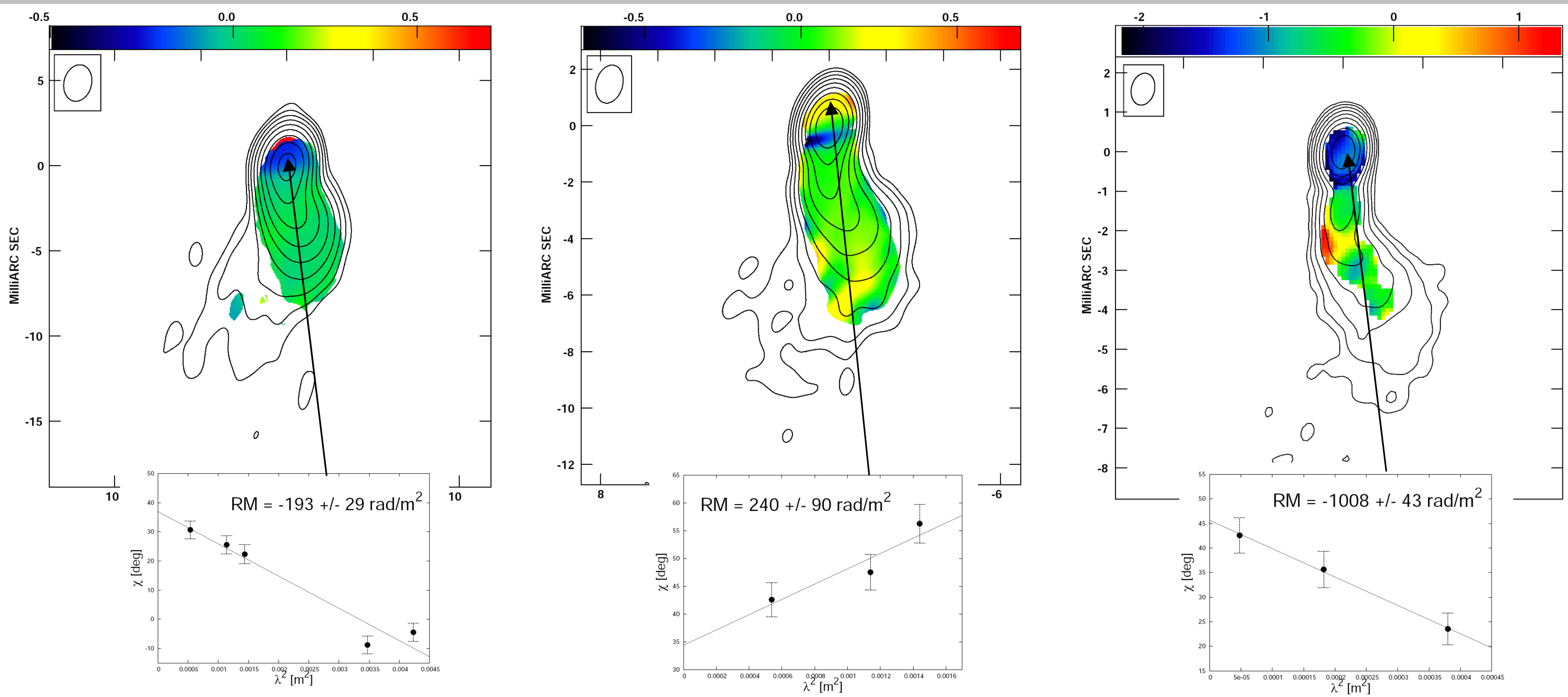
$$|\mathrm{RM}_{\mathrm{core},\nu}| \propto \nu^{a}$$

- Important constraints on the geometry of the region confining these jets
- Low values of *a*: consistent highly collimated flow in ‘funnel’ geometry (e.g., Kosmissarov et al. 2007)
- High values of *a*: consistent with confinement by thermal and/or ram pressure from spherical wind outflow (e.g., Bogovalov & Tsinganos 2005)

Variation in Core RM with Frequency

- Simultaneous observations jet
- Change in sign of core RM in different frequency intervals
- Line-of-sight magnetic field changes with distance from base of jet
- VLBI “core”: obs’d radiation mostly near $\tau = 1$ surface, which changes with freq, so different freq intervals probing different physical scales of the inner jet

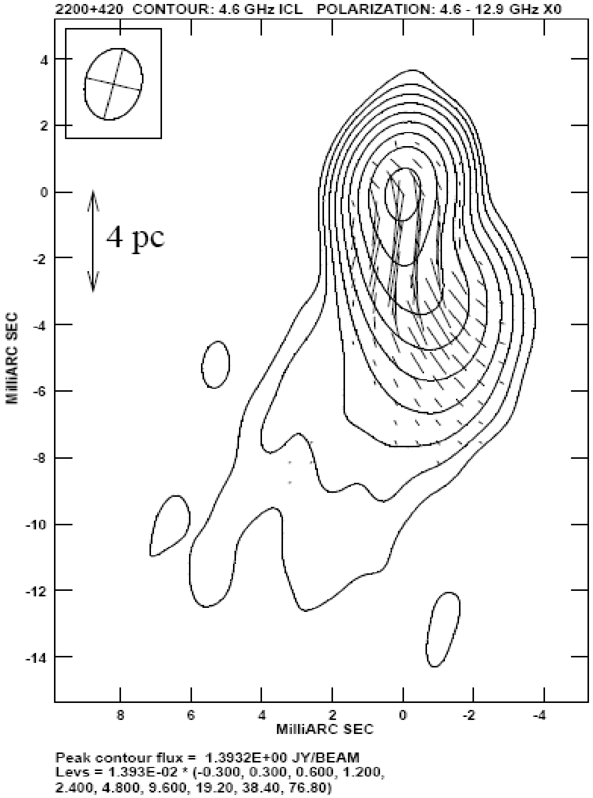
Variation in Core RM with Frequency

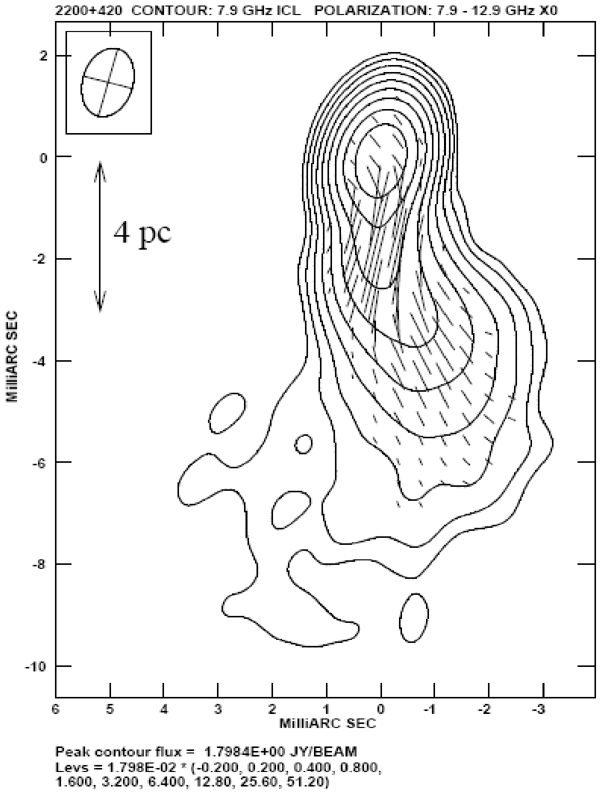


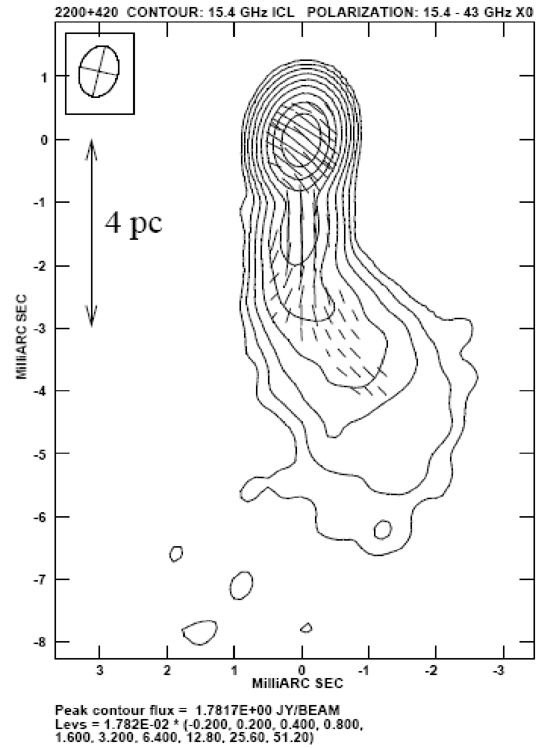
- 2200+420: 4.6 – 12.9 GHz, 7.9 – 12.9 GHz, 15.4 – 43 GHz

Variation in Core RM with Frequency

- Intrinsic magnetic field dominated by transverse component

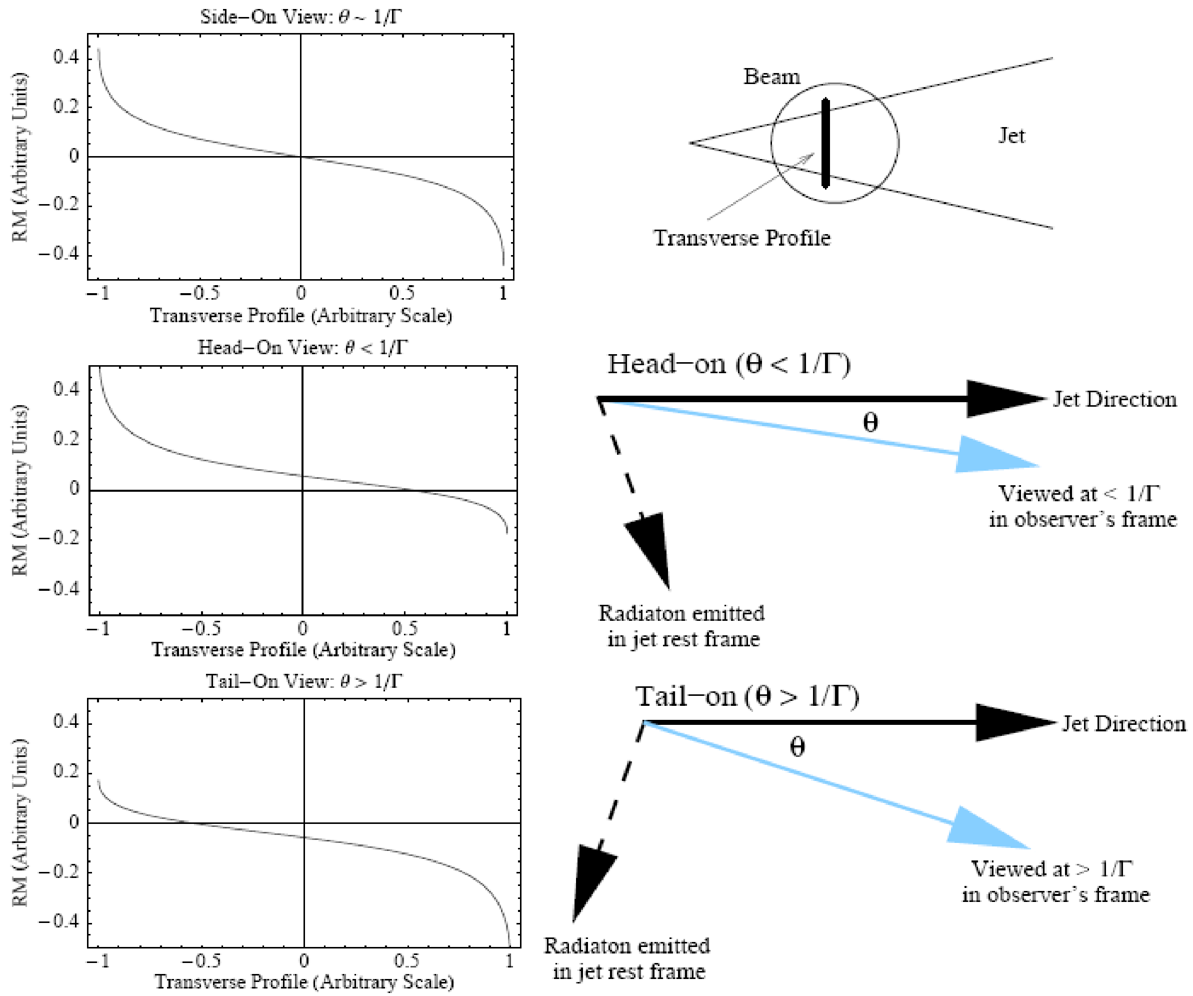






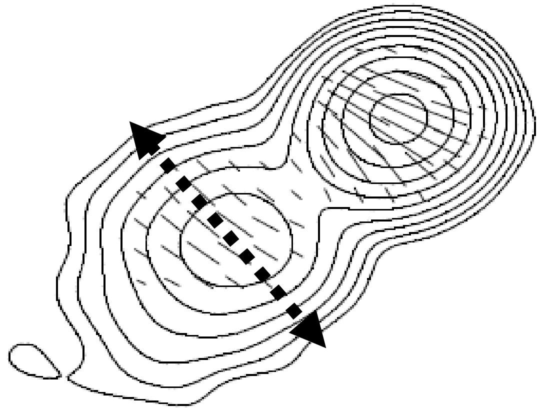
Variation in Core RM with Frequency

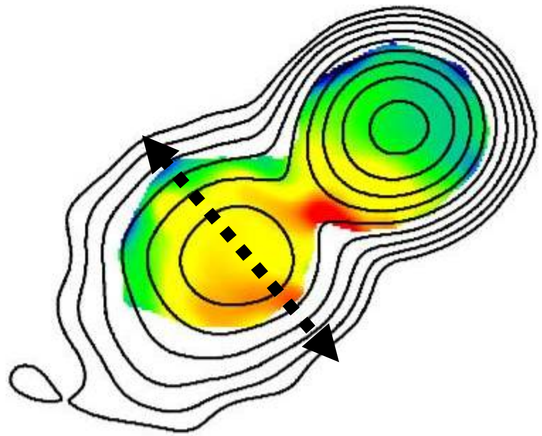
- Change in sign of RM due to changes in jet direction
- Also possible if jet accelerates (e.g., Jorstad 2005)
- Konigl (2007): distinguishing characteristic of MHD flows over hydrodynamic

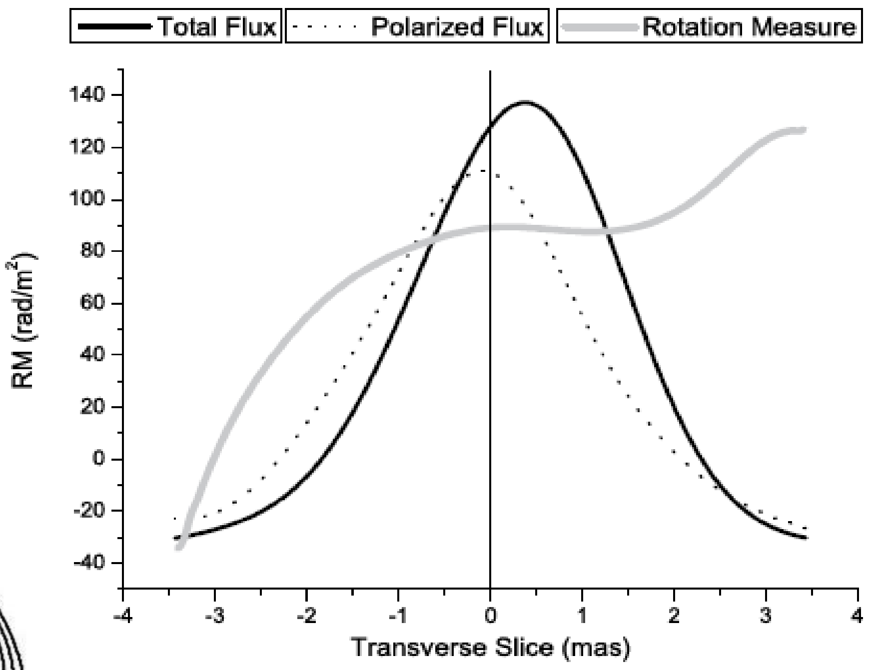


Transverse Jet Structure

- RM: information on thermal plasma surrounding jet
- Total Intensity and polarization: information on synchrotron emitting plasma







1418+546

Conclusions

- Magnetic field strengths: of order mG in jet (from core-shift) mG in rotating material surrounding the jet (from RM)
- Magnitude of core RM follows power-law
- Helical magnetic field model:
  Transverse RM gradients
  Core RM sign changes
  Total intensity and polarization structures
  Extended acceleration regions
  Circular polarization generation

Thank You