Multi-wavelength VLBI
Circular Polarisation Measurements of AGN

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Radio Emission of AGN is synchrotron radiation due to motion of relativistic electrons through region with magnetic field.

Synchrotron radiation can be highly linearly polarised, up to 75% in uniform B field.

The observed polarisation angles $\chi$ depend on:

• underlying B field direction

• optical depth (thick: $\chi \parallel B$, thin: $\chi \perp B$)

• Faraday rotation along line of sight

If Faraday rotation is measured, and optical-depth regime is known, can infer underlying B field direction.
Intrinsic degree of circular polarisation (CP) of synchrotron radiation is low, < 1% for B fields ~ 1 G.

More efficient mechanism: Faraday conversion of linear to circular polarisation when linearly polarised EM wave passes through magnetised plasma.

Physical basis of Faraday conversion:
— Describe wave’s E field using components parallel to \((E_\parallel)\) and orthogonal to \((E_\perp)\) magnetic field in medium \(B_{\text{med}}\)

— Free charges in medium can be accelerated by \(E_\parallel\), but not by \(E_\perp\): \(E_\parallel\) is absorbed+re-emitted (delayed) while \(E_\perp\) is not \(\Rightarrow\) circular polarisation
Delaying one $E$ component relative to the other is equivalent to introducing a circularly polarised component.
No Faraday conversion when plane of linear polarisation (E) is

— fully orthogonal to $B_{\text{med}}$ (electrons in medium cannot move orthogonal to $B_{\text{med}}$, E not absorbed)
— fully parallel to $B_{\text{med}}$ (total E is absorbed and re-emitted)

Best situation for Faraday conversion: $E_{\text{synch}}$ not too close to parallel or orthogonal to $B_{\text{med}}$. 
Favourable geometry for conversion provided by a helical B field:

Linear polarisation from far side of jet can be converted to circular polarisation when passes through near side of jet.
Although “intrinsic” synchrotron CP can yield degrees of CP ~ a few tenths of a percent at cm wavelengths for B fields of ~1 G, Faraday conversion is much more efficient (could yield $m_c$ an order of magnitude greater)

⇒ Faraday conversion taken to be more likely mechanism
Expected spectrum for degree of CP in simplest case of uniform source:

— $\nu^{-0.5}$ for intrinsic (“synchrotron”) CP from homogeneous, optically thin synchrotron source

— $\nu^{-3}$ for Faraday conversion in homogeneous source

Until recently very few multi-frequency CP measurements available, virtually none simultaneous in time.

Circular-polarisation measurements require accurate relative calibration of R and L gains (Homan & Wardle 1999).

We applied “classic” technique of Homan & Wardle: R/L gain ratios estimated as function of time using calibrators with zero CP, interpolated and applied to data for targets (“gain-transfer” method).
Results: first parsec-scale CP measurements at 43 GHz!

• Measured CP at $\sim 2\sigma$ level or higher in core region of about half a dozen AGN.

• Degrees of core CP at 43 GHz range from $\sim 0.3\%$ to $\sim 2.8\%$!

• Degree of core CP typically higher at 43 GHz than at 22 and 15 GHz.
Tentative detection of transverse CP structure in several objects:

1334-127, 43.14GHz

1055+018 43.14GHz
Transverse CP structure consistent with CP generated in helical jet B-field geometry:
Core-region CP measured at 2 or 3 wavelengths in 9 sources

Degree of CP at 43 GHz always > degree of CP at 22, 15 GHz; no clear trend between 15 and 22 GHz

**Table 5. CP spectra ($|m_c| \propto \nu^{\alpha_c}$)**

<table>
<thead>
<tr>
<th>Source</th>
<th>15 GHz $m_c$ (%)</th>
<th>22 GHz $m_c$ (%)</th>
<th>43 GHz $m_c$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0133+476</td>
<td>−0.32 ± 0.09</td>
<td>−</td>
<td>−0.33 ± 0.19</td>
</tr>
<tr>
<td>0851+202</td>
<td>−0.19 ± 0.08</td>
<td>−0.20 ± 0.13</td>
<td>+0.55 ± 0.26</td>
</tr>
<tr>
<td>1055+018</td>
<td>+0.52 ± 0.10</td>
<td>+0.27 ± 0.17</td>
<td>*</td>
</tr>
<tr>
<td>1253−055</td>
<td>+0.83 ± 0.10</td>
<td>+0.62 ± 0.25</td>
<td>+1.21 ± 0.37</td>
</tr>
<tr>
<td></td>
<td>+0.26 ± 0.09</td>
<td>+0.20 ± 0.15</td>
<td>−1.03 ± 0.16</td>
</tr>
<tr>
<td>1334−127</td>
<td>+0.28 ± 0.09</td>
<td>+0.40 ± 0.24</td>
<td>*</td>
</tr>
<tr>
<td>1510−089</td>
<td>−</td>
<td>+0.44 ± 0.19</td>
<td>−2.43 ± 0.40</td>
</tr>
<tr>
<td>1633+382</td>
<td>−0.34 ± 0.06</td>
<td>−0.83 ± 0.17</td>
<td>−</td>
</tr>
<tr>
<td>2145+067</td>
<td>−0.45 ± 0.09</td>
<td>−0.34 ± 0.13</td>
<td>−</td>
</tr>
<tr>
<td>2230+114</td>
<td>−0.61 ± 0.08</td>
<td>−1.26 ± 0.21</td>
<td>−</td>
</tr>
</tbody>
</table>
Expectation for CP from synchrotron mechanism and Faraday conversion: $m_c$ should decrease with increasing frequency — opposite to observed trend!

Possible explanations?

— Several regions with different CP signs contribute to observed “core” CP [e.g., 43 GHz map of 1055+018, 15 and 22 GHz maps of 3C84 (Homan & Wardle 2005)]

— Reflects intrinsic inhomogeneity of “Blandford-Konigl” type jet; BK scaling of $B$ and $n_e$ with distance along jet ($B \propto r^{-1}$, $n_e \propto r^{-2}$) predicts $m_c \propto \nu^{+1}$ (Wardle & Homan 2003)

⇒ May be fruitful to search for CP at relatively high frequencies!
SUMMARY

• First VLBI CP measurements at 43 GHz, CP detected in core regions of about half a dozen AGN; degrees of core CP at 43 GHz range from ~ 0.3% to ~ 2.8%

• Transverse CP structure consistent with CP generated in helical jet B-field geometry is observed in several AGN

• Have measured pc-scale CP spectrum in 9 AGN:
  — Results contrary to expectation - degree of CP higher at 43 GHz than at 15 and 22 GHz, possibly due to complex CP structure on smaller scales or intrinsic inhomogeneity of jet structure.
  — Further multi-wavelength CP measurements needed, including at 43 GHz.