The PdBI and Polarization

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The PdBI uses dual polarization receivers

Two orthogonal linear polarizations: horizontal + vertical w.r.t. the antenna frame
Polarization basics

Wave propagates in z direction
4 Stokes parameters for a full description

\[ I = \langle E_x^2 \rangle + \langle E_y^2 \rangle, \]

\[ Q = \langle E_x^2 \rangle - \langle E_y^2 \rangle, \]

\[ U = 2\langle E_x E_y \cos \delta \rangle, \]

\[ V = 2\langle E_x E_y \sin \delta \rangle. \]

\[ \delta \] is the phase difference between \( E_x \) and \( E_y \)
### Three extreme examples

<table>
<thead>
<tr>
<th>100% Q</th>
<th>100% U</th>
<th>100% V</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>+Q</td>
<td>+U</td>
<td>+V</td>
</tr>
<tr>
<td>Q &gt; 0; U = 0; V = 0</td>
<td>Q = 0; U &gt; 0; V = 0</td>
<td>Q = 0; U = 0; V &gt; 0</td>
</tr>
<tr>
<td><img src="image4.png" alt="Diagram" /></td>
<td><img src="image5.png" alt="Diagram" /></td>
<td><img src="image6.png" alt="Diagram" /></td>
</tr>
<tr>
<td>-Q</td>
<td>-U</td>
<td>-V</td>
</tr>
<tr>
<td>Q &lt; 0; U = 0; V = 0</td>
<td>Q = 0, U &lt; 0, V = 0</td>
<td>Q = 0; U = 0; V &lt; 0</td>
</tr>
</tbody>
</table>

Note: $Q \leftrightarrow U$ via rotation of the coordinate system
Total intensity

\[ I = \langle E_x^2 \rangle + \langle E_y^2 \rangle, \]

\[ Q = \langle E_x^2 \rangle - \langle E_y^2 \rangle, \]

\[ U = 2\langle E_x E_y \cos \delta \rangle, \]

\[ V = 2\langle E_x E_y \sin \delta \rangle. \]
Linear polarization

\[ I = \langle E_x^2 \rangle + \langle E_y^2 \rangle, \]

\[ Q = \langle E_x^2 \rangle - \langle E_y^2 \rangle, \]

\[ U = 2\langle E_x E_y \cos \delta \rangle, \]

\[ V = 2\langle E_x E_y \sin \delta \rangle. \]

\[ m_L = \frac{\sqrt{Q^2 + U^2}}{I} \]

\[ \chi = \frac{1}{2} \arctan \frac{U}{Q} \]
Circular polarization

\[ I = \langle E_x^2 \rangle + \langle E_y^2 \rangle, \]

\[ Q = \langle E_x^2 \rangle - \langle E_y^2 \rangle, \]

\[ U = 2\langle E_x E_y \cos \delta \rangle, \]

\[ V = 2\langle E_x E_y \sin \delta \rangle. \]

\[ m_C = \frac{V}{I} \]
Polarimetry is limited by the correlator wiring

For each baseline only HH and VV are correlated ➔ only Stokes $I$, $Q$, $U$ are accessible
Observations are sensitive to polarization

- Linear polarization of calibration quasars becomes important
Quasars are complex sources

Cygnus A
Quasars are very active sources

Good for calibration?  **Yes** – on timescales of hours
Quasars could be highly polarized

Sources with powerlaw spectra \( S_\nu \propto \nu^{-\alpha} \) with \( \alpha \sim 0 \ldots +1 \)

have electron energy powerlaw spectra with indices \( \Gamma = 2\alpha + 1 \)

resulting in a degree of linear polarization \( m_L = \frac{\Gamma + 1}{\Gamma + 7/3} \)

- Polarizations of \(~60\%\) can be expected
- Polarization monitoring is necessary
We must quantify the impact of polarization

Non-recognized calibrator polarization can add systematic errors to the data
Each PdBI observation collects polarization information on calibration quasars.

**Vertical** (w.r.t. antenna)

**Horizontal** (w.r.t. antenna)
Exploiting the properties of polarization

\[ V \]
\[ H \]
\[ I \]
\[ q \]

\[ m_t = 7.02\% \]
\[ \chi = 176.8^\circ \]
Earth rotation polarimetry → linear polarization

\[ q(h) = \frac{V-H}{V+H} \]

\[ q(\psi) = \frac{Q}{I} \cos(2\psi) + \frac{U}{I} \sin(2\psi) \]

h: hour angle
\( \psi \): parallactic angle
Earth rotation polarimetry $\rightarrow$ linear polarization

$$q(h) = \frac{V-H}{V+H}$$

$$q(\psi) \equiv m \cos[2(\psi-\chi)]$$

$h$: hour angle
$\psi$: parallactic angle
$m$: polarization fraction
$\chi$: polarization angle

$m = 7.01 \pm 0.02\%$
$\chi = 176.6 \pm 0.1^\circ$
We test the quasar polarization for each track.

Decisive CLIC variable: “do_avpol”
A negative test result
Project

Observed on 20-SEP-2010 Configuration 5Dq
(N11W08W05N07E03)

Automatic calibration report by CLIC @ x_calib

September 20, 2010

Scan range: 0 to 100.00
Use phase correction: YES (22GHz)
Minimum quality: AVERAGE
Auto. flag procedure: YES (0 scans)
WVR interference check: YES (0 in 267 scans)

Averaged polarization mode for amplitude calibration: NO

1 Summary

1.1 Calibrators

<table>
<thead>
<tr>
<th>Name</th>
<th>Flux (Jy) @114.1 GHz</th>
<th>Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0923+392</td>
<td>4.31</td>
<td>Computed</td>
</tr>
<tr>
<td>3C84</td>
<td>10.70</td>
<td>Fixed</td>
</tr>
<tr>
<td>1146+596</td>
<td>0.15</td>
<td>Computed</td>
</tr>
</tbody>
</table>

1.2 Efficiencies

Antenna 1 (A1) 25.4 Jy/K (0.93)
Antenna 2 (A2) 23.7 Jy/K (0.99)
Antenna 3 (A3) 24.2 Jy/K (0.98)
Antenna 4 (A4) 23.4 Jy/K (1.01)
Antenna 5 (A5) 24.4 Jy/K (0.97)

1.3 Observed Source(s)

observed for Hour Angles -7.4 to -3.2
2 calibrations for 2 polarizations
A positive test result
Project Observed on 19-SEP-2010 Configuration 5Dq (N11W08W05N07E03)

Automatic calibration report by CLIC @ x_calib

September 19, 2010

Scan range: 0 to 10000
Use phase correction: YES (22GHz)
Minimum quality: AVERAGE
Auto. flag procedure: YES (0 scans)
WVR interference check: YES (0 in 295 scans)

Averaged polarization mode for amplitude calibration: YES

<table>
<thead>
<tr>
<th>Receiver 1</th>
<th>Bandpass: Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase:</td>
<td>Excellent</td>
</tr>
<tr>
<td>Seeing HOR:</td>
<td>0.96</td>
</tr>
<tr>
<td>Seeing VER:</td>
<td>0.96</td>
</tr>
<tr>
<td>Amplitude:</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

1 Summary

1.1 Calibrators

<table>
<thead>
<tr>
<th>Name</th>
<th>Flux (Jy) @ 90.2 GHz</th>
<th>Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWC349</td>
<td>1.13</td>
<td>Fixed (model = 1.19)</td>
</tr>
<tr>
<td>1749+096</td>
<td>2.72</td>
<td>Computed</td>
</tr>
<tr>
<td>1418+546</td>
<td>0.69</td>
<td>Computed</td>
</tr>
<tr>
<td>3C454.3</td>
<td>33.95</td>
<td>Computed phase/amp (detected polarization)</td>
</tr>
</tbody>
</table>

1.2 Efficiencies

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Flux (Jy/K)</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>25.0</td>
<td>(0.87)</td>
</tr>
<tr>
<td>A2</td>
<td>24.7</td>
<td>(0.88)</td>
</tr>
<tr>
<td>A3</td>
<td>23.7</td>
<td>(0.92)</td>
</tr>
<tr>
<td>A4</td>
<td>24.3</td>
<td>(0.88)</td>
</tr>
<tr>
<td>A5</td>
<td>26.0</td>
<td>(0.84)</td>
</tr>
</tbody>
</table>

1.3 Observed Source(s)

[Blank] observed for Hour Angles 2.7 to 6.7
1 calibration for $I = H + V$
Statistical accuracies are very good

median $\delta m : \sim 0.1\%$

median $\delta \chi : \sim 1^\circ$
We see polarization (almost) everywhere

316 out of 441 measurements (73 out of 86 QSOs) detect polarization
We see polarization (almost) everywhere
Different source types are slightly different

No dichotomy radio loud vs. radio quiet $\Rightarrow$ similar emission region properties
PdBI, present day:
Only parallel-hand correlations
PdBI, 2010/2011:
Also cross-polarization correlations
PdBI, 2010/2011: Also cross-polarization correlations

6 antennas → 8 configurations for one full cycle
The goal: polarimetric mapping
The PdBI uses dual linear polarization receivers → observations are sensitive to source and calibrator polarization

Only parallel-hand polarizations correlated → Earth rotation polarimetry

Check calibrator polarization for each track in order to prevent systematic errors

AGN monitoring finds that most sources are polarized with $m \sim 1 - 19\%$

PdBI prepared for full Stokes polarimetry → polarimetric mapping