Polarimetric interferometry at Allen Telescope Array

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Introduction

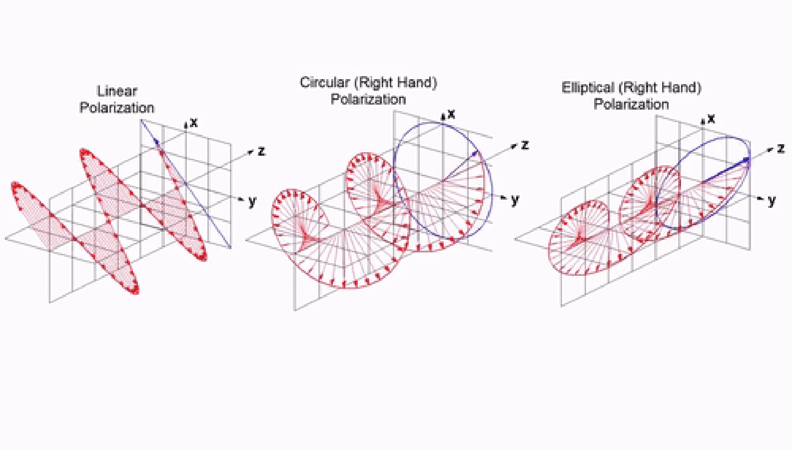
This talk is about *polarization* and:

- why it is an interesting topic related to quantum information
- how it is useful to study physical fenomena in radio astronomy
- why you might want care about it in your future radio astronomy experiments
- how to do calibrations in interferometric observations
- a test observation of the quasar 3C286 done at ATA

Paul Boven is giving today a talk about interferometry at ATA

Polarization of electromagnetic waves

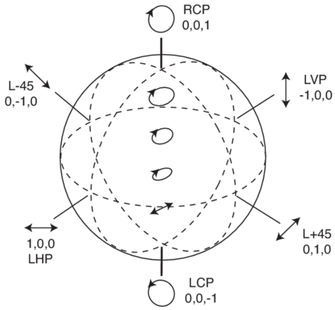
Polarization is defined by the direction in which the electric field oscillates



Source: `https://www.microwaves101.com/encyclopedias/polarization`

Representing polarization states: the Bloch/Poincaré sphere

The set of all polarizations can be represented as a sphere, with *orthogonal polarizations* as antipodal points



Source: `https://www.newport.com/t/polarization-in-fiber-optics`

Deep relations to quantum mechanics / quantum information: the polarization of a photon is a qubit, and $|0\rangle$ and $|1\rangle$ are antipodal points on the sphere

Stokes parameters

Encode the polarization (including partial polarization) and total intensity using 4 real numbers. Defined as sums/differences of the power measured by two orthogonal antennas.

$$
\begin{aligned}
I &= \leftrightarrow + \updownarrow = \nearrow + \searrow = \circlearrowleft + \circlearrowright \\
Q &= \leftrightarrow - \updownarrow \\
U &= \nearrow - \searrow \\
V &= \circlearrowleft - \circlearrowright
\end{aligned}
$$

- I is total intensity
- $L = Q + iU$ gives the linear polarization intensity and angle $\theta = \arg(L)/2$
- V gives the circular polarization intensity and handedness (sign)

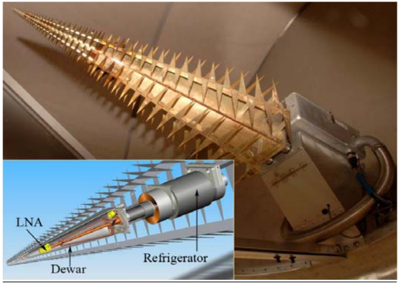
Polarization in radio astronomy

It's all about magnetic fields!

- Synchrotron radiation is linearly polarized, with direction orthogonal to the magnetic field
- Pulsars are highly polarized
- Magnetic fields in the interstellar medium plasma cause frequency-dependent rotation of linear polarization (Faraday rotation, rotation measure RM)
- Zeeman effect: under magnetic fields, splitting of spectral lines into the two circular polarizations

A dual polarization receiver

- Two antennas/feed probes sensitive to orthogonal polarizations
- Dual channel coherent receiver
- Needs calibration of gain differences, phase offset and leakage
- Can synthesize any polarization and measure Stokes parameters



Polarimetric interferometry

We have two antennas that measure two polarizations: X_1, Y_1, and X_2, Y_2. We form all four possible correlations:

- Parallel hands: $X_1 X_2$, and $Y_1 Y_2$
- Crosshands: $X_1 Y_2$, and $Y_1 X_2$.

These are related to Stokes parameters via calibrations:

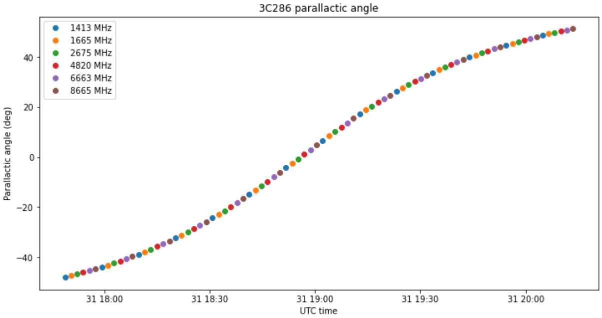
$$\begin{pmatrix} v_{xx} \\ v_{xy} \\ v_{yx} \\ v_{yy} \end{pmatrix} \approx \frac{1}{2} \begin{pmatrix} g_{xx} & g_{xx} & 0 & 0 \\ g_{xy}(d_{1x} - \overline{d_{2y}}) & 0 & g_{xy} & ig_{xy} \\ -g_{yx}(d_{1y} - \overline{d_{2x}}) & 0 & g_{yx} & -ig_{yx} \\ g_{yy} & -g_{yy} & 0 & 0 \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}.$$

For calibration, it is typical to observe a linearly polarized source over several hours. The apparent polarization angle rotates as the source moves through the sky (parallactic angle).

Observation of 3C286 at ATA

3C286 is a quasar that is often used as polarization calibrator. High polarization degree $\approx 11\%$ and stable polarization parameters. Flux 14.6 Jy at 1.5 GHz, down to 4.1 Jy at 11.3 GHz.

Test observation with ATA on 2020-10-31 over a wide range of parallactic angles and several frequencies between 1.4 and 8.7 GHz.

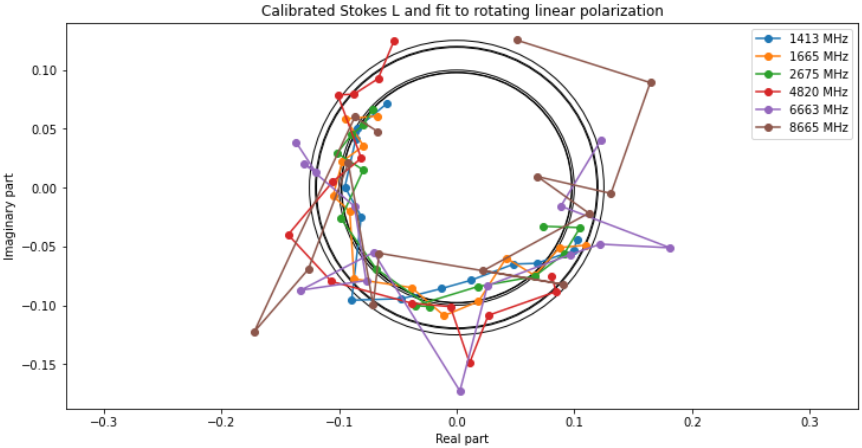


Data processing

- FX correlator with the IQ data from two USRPs N32x done in GNU Radio
- Telescope control done in Python
- Phasing of visibility data to source in Python with Astropy
- Polarimetric calibration and measurement of Stokes parameters in Python
- Comparison of calibration solution and Stokes parameters obtained with CASA

`https://destevez.net/2020/11/polarimetric-observation-of-3c286-with-allen-telescope-array/`

Some results



Polarization in amateur radio astronomy

- A dual channel coherent receiver is not so expensive nowadays
- With a single polarization receiver you're losing 50% of the signal even if not interested in polarization study
- Possible experiments to detect polarization:
    - Imitate early experiments in the 50s: Sun, supernova remnants (Taurus A...)?
    - Pulsars?
- Getting appropriate calibration sources can be challenging. Maybe satellites?