Sub-kpc Magnetic Field Fluctuations around Cygnus A

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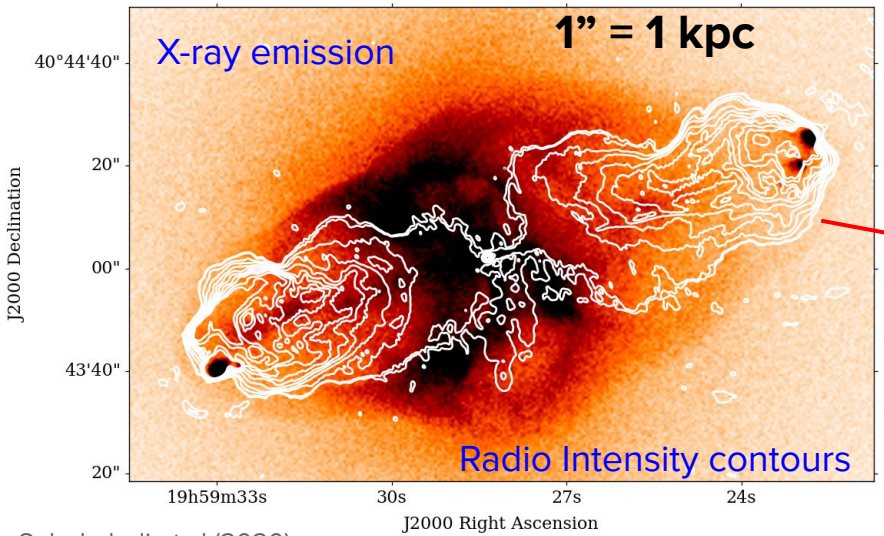
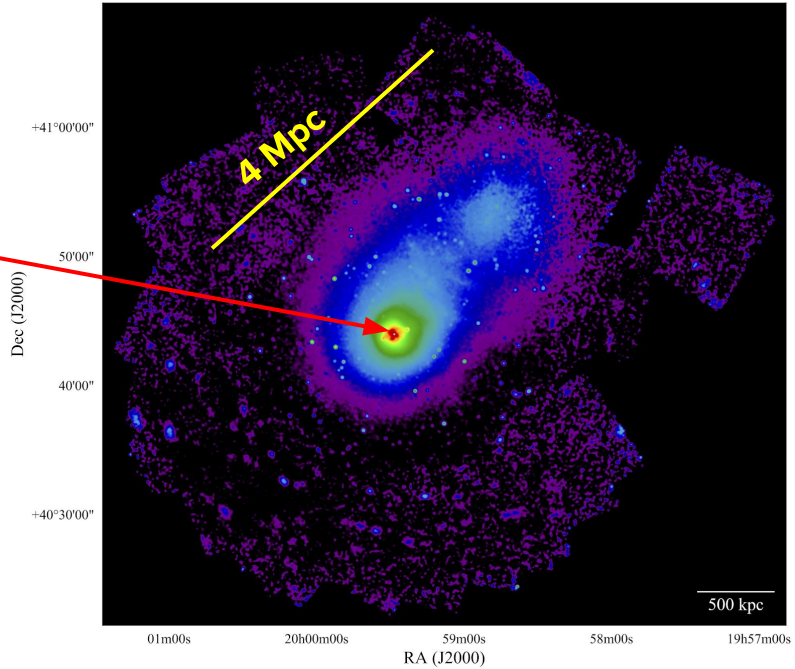
Prior Work on Cygnus A



Sebokolodi et.al (2020)



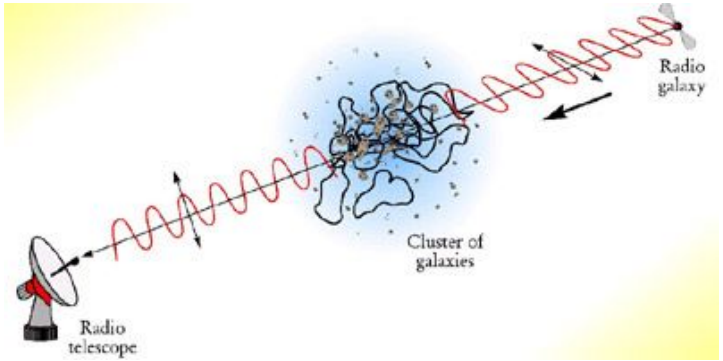
Chandra image credit: M. Wise, R. Duffy & B. Snios.

Dreher et.al (1987), Carilli et.al (1988) found:

- ❏ Cluster magnetic field strengths: 2-10 μG
- ❏ Field scales of 5-20 kpc (derived from the rotation measure map)

Faraday Rotation a Probe of Line of Sight Magnetic-Fields

A rotation of a plane of polarization of a **linearly polarized** wave as it passes through a **magnetized plasma**.



Fractional polarization: $|p(\lambda^2)| = p_0$

Polarization angle: $PA(\lambda^2) = PA_0 + RM\lambda^2$

In a **simple case:** purely synchrotron emitting source behind a uniform magnetized plasma, the plane of polarization will be rotated as follows:

$$p = p_0\, e^{2iPA_0} e^{2iRM\lambda^2}$$ where

Source polarization and rotation due to cluster gas:

rotation measure, $RM = 812 \int n_e\, B\, dL$ [rad m^2]

n_e electron density of the magnetized plasma.
B is the line of sight magnetic field.
dL is pathlength across the magnetized plasma.

Wideband, High Spectral Resolution Observations

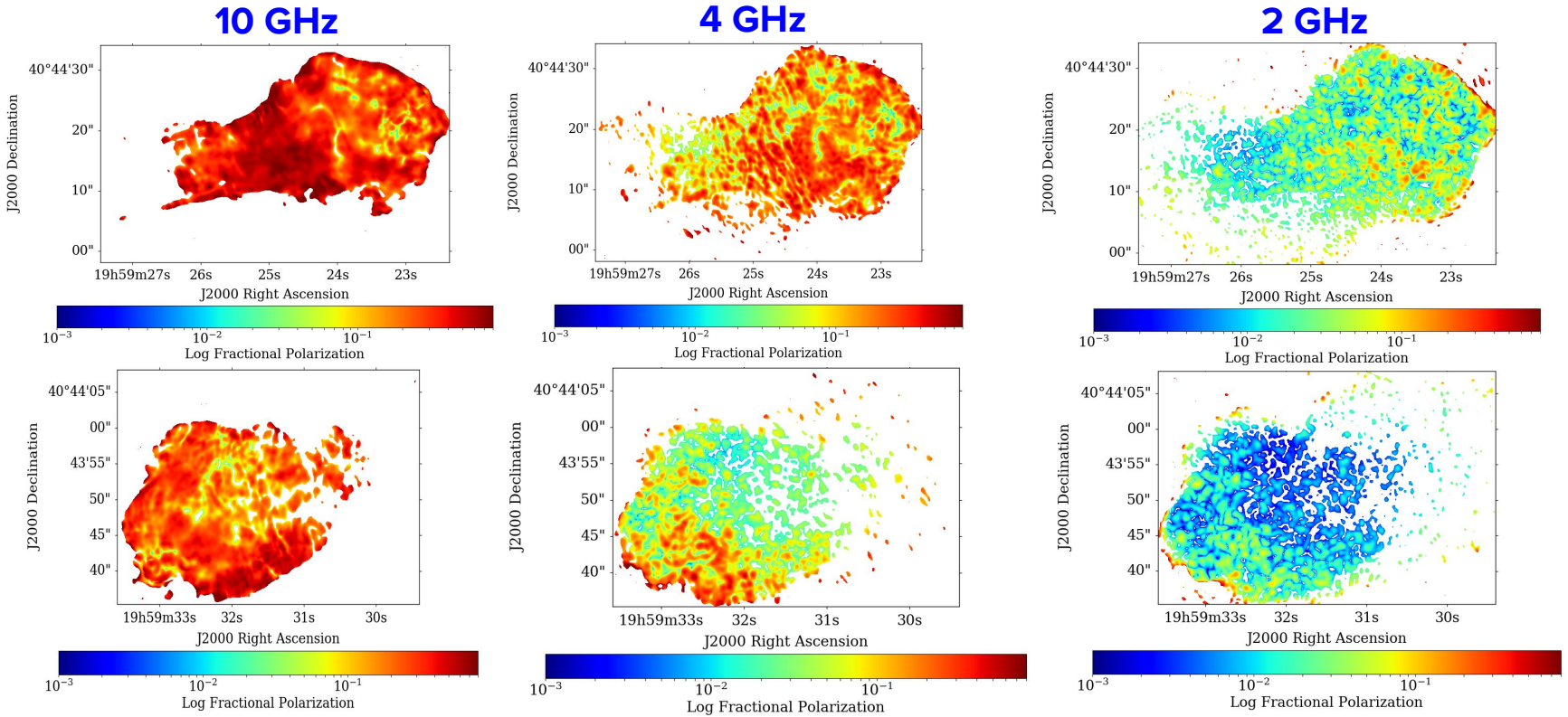
Instrument	Jansky Very Large Array
Date of Observations	Nov 2014 - Nov 2015
Configurations	A, B, C and D
Frequency bands	S, C, X and Ku **(2-18 GHz)**
On-source observing duration	44 hours

4k x 4k images, with about 1200 frequency channels at each Stokes.

Data products: Stokes Q, U, and I cube images at 0.75” (2-18 GHz), and 0.30” (6-18 GHz).

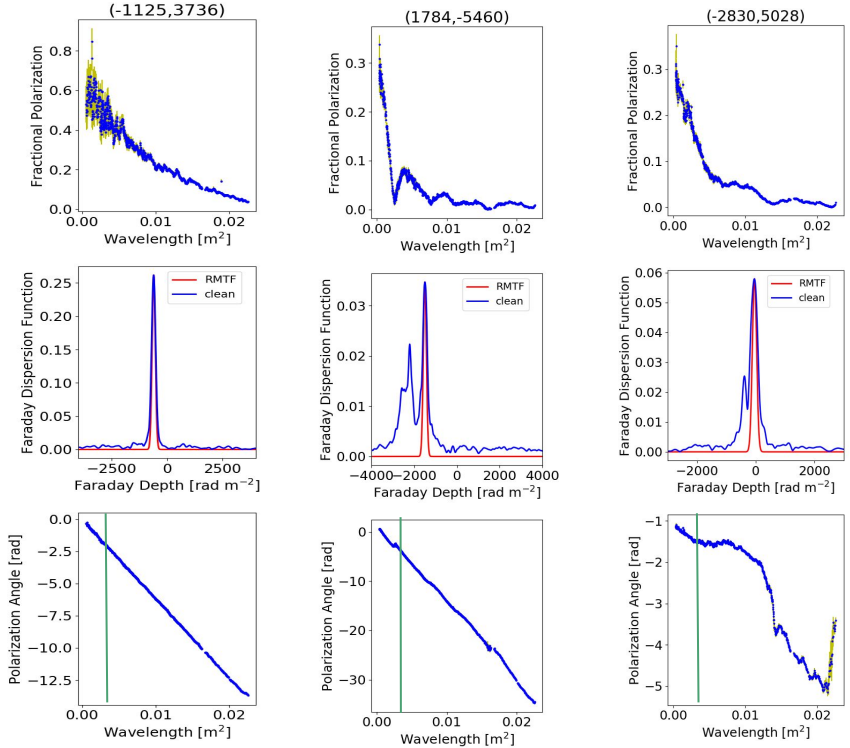
- Fractional polarization: $\sqrt{(Q^2 + U^2)}/I$
- Polarization angle: $\frac{1}{2} \tan^{-1}(U/Q)$
- Faraday dispersion function: Fourier transform of the fractional polarization

Polarization Decreases with Decreasing Frequency: 0.75”



Lines of Sight Polarization Behavior at 0.75”

Smooth decay (33%) Sinc-like (12%) Complex (42%)



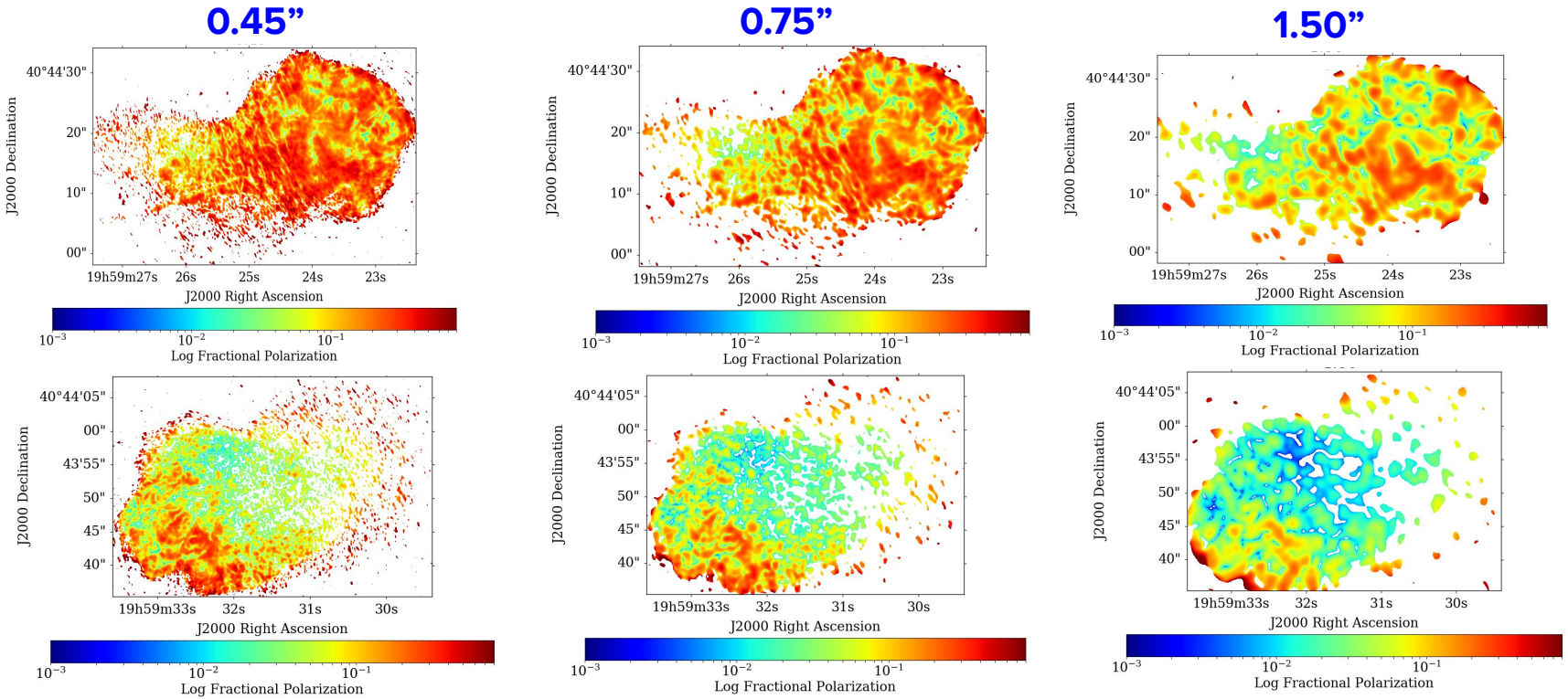
The observed:

- ❏ All 2000 lines of sight depolarizes.
- ❏ Depolarization behaviors have no spatial preference.
- ❏ Single peaks, broadening, or multi-peaks in the Faraday dispersion functions.
- ❏ Deviations from linearity in PA vs. λ^2

Possible explanations for the depolarizations:

- ❏ Unresolved sub-kpc fluctuations in the Faraday rotating medium.
- ❏ Mixing of thermal and synchrotron gas causing differential rotation.

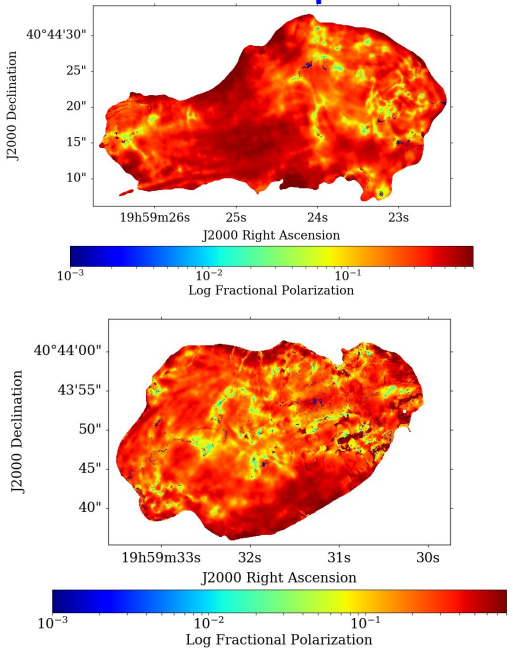
Polarization Decreases with Decreasing Resolution: 4GHz



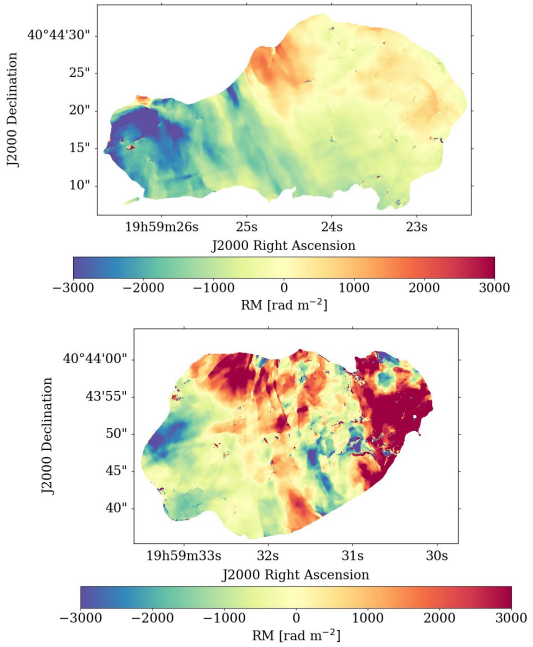
Faraday Rotation Study: 0.30” and 6-17 GHz

Fit depolarization model: $p = p_0 e^{2iPA0} e^{2iRM\lambda^2} e^{-2\sigma^2\lambda^4}$, σ is RM dispersion = 812 B_{rad} L/√N [rad m^2]

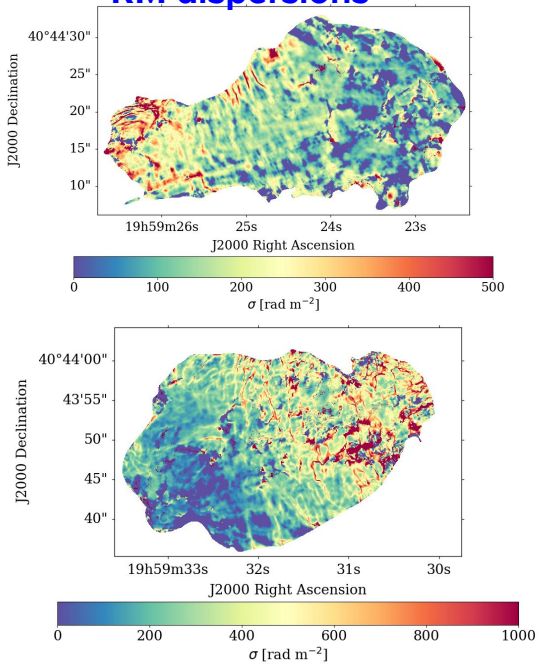
Intrinsic fractional polarization



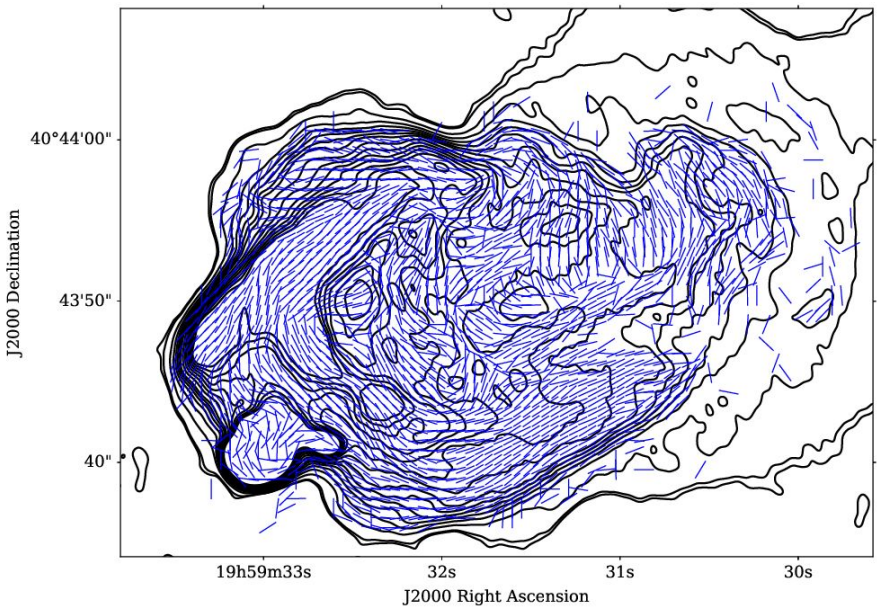
Rotation measures

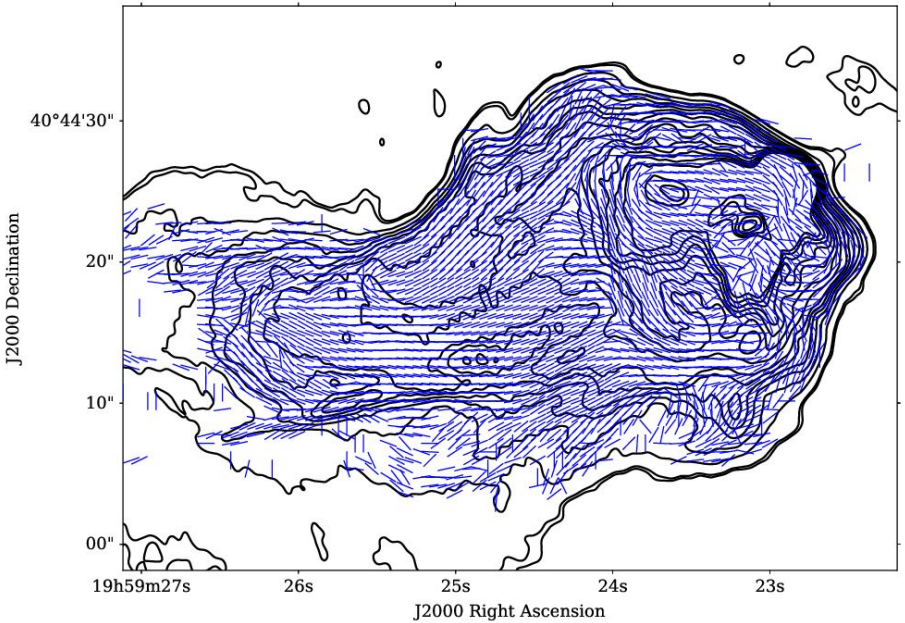


RM dispersions



Intrinsic Magnetic Field Orientation Derived from PA_0





Predictions of Polarizations at Longer Wavelengths

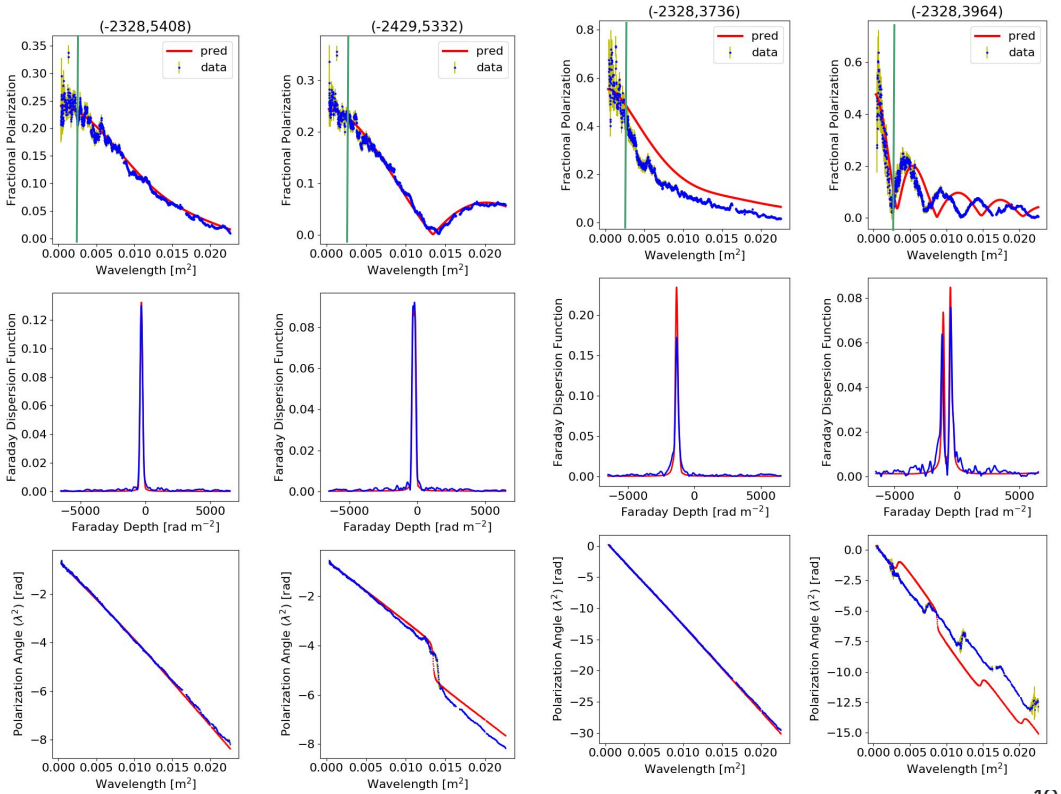
Assumption: p_0 and PA_0 maps at 0.30” represent the true source emission, and RM is the true Faraday rotating screen.

Step 1: $p = p_0 e^{2i\,PA_0} e^{2i\,RM\,\lambda^2}$

Step 2: Derive Stokes q and u.

Step 3: Convolve q and u to 0.75”

These show that the fluctuations within the RM map at 0.30” accurately predict longer wavelength, low resolution data for the majority of the lines of sight.



Summary

- ❏ We observed Cygnus A using JVLA: A, B, C and D configuration spanning 2-18 GHz bandwidth.
- ❏ We find significant decrease in the fractional polarization with decreasing frequency in all lines of sight (LoS) across the lobes.
- ❏ There is oscillatory structure in the depolarization for the majority of the LoS.
- ❏ The lobes also depolarize significantly with decreasing resolution.
- ❏ A simple model of RM screen at 0.30”, high frequency data is remarkably effective in predicting the low frequency 0.75” data.
- ❏ This is a strong indication that the majority of the depolarizations are caused by sub-kpc fluctuations present in the Faraday rotating medium.