The JVLA New Wideband, High Spectral Resolution Polarization Studies Reveal the Presence of Complex Turbulent B-Fields in Cluster Media

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ngvla Next Generation Very Large Array

SKA AFRICA SQUARE KILOMETRE ARRAY

INTRODUCTION

The upgraded Jansky Very Large Array (JVLA) has enabled long-hoped-for wide-band, high resolution polarization observations. The New studies of this kind e.g Pasetto A, et.al (2018) and our work, giving new insights into cluster magnetic fields.

In particular, our new high sensitivity polarization study of Cygnus A using 2-18 GHz JVLA data shows significant depolarization below 6 GHz at 0.75" (750 pc) resolution, as well as complicated polarization structures. Our preliminary analysis indicates multi-scale B-fields on both large (5-30 kpc) and small (< 300 pc) scales. There is a strong evidence that the dominant rotation measures (thousands rad/m/m) are due to large-scale B-fields in the ambient ICM with field strengths of order a few uG. It is uncertain where the observed depolarization occurs, but it is consistent with the small-scale turbulent structures in the ICM and/or internal/local to the lobes of field strengths of order of a few uG tens of uG, respectively, assuming a scale of 300pc. To accurately prove the external turbulent origin of the depolarization, we require wide-band observations at frequencies down to 1.0 GHz, with resolution at or better than 0.3 arcseconds. By far the best potential instruments for this type of work are the SKA and ngVLA.

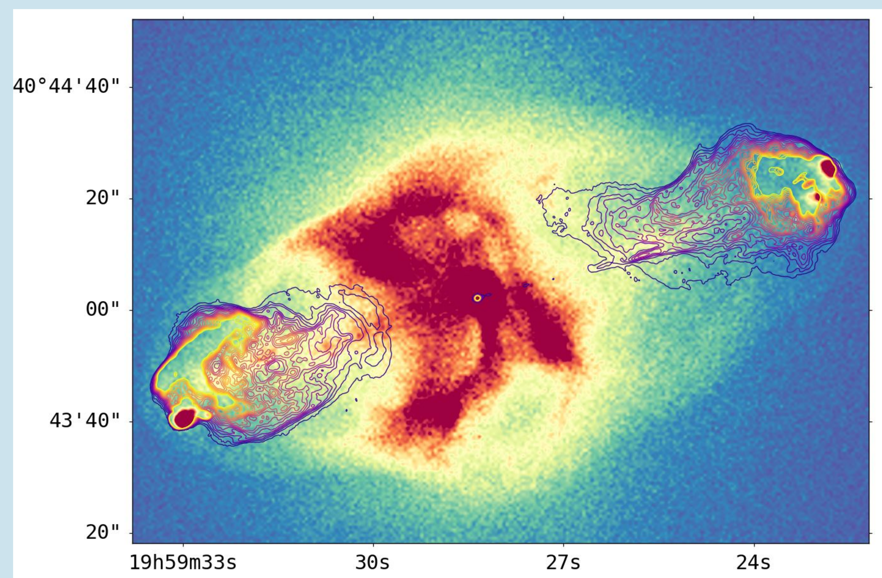

Figure 1 X-ray emission map superimposed with total intensity contours. Contour levels represent [0.001, 0.3] in steps of 0.015. (Duffy et.al (2018))

OBSERVATIONS, DATA PRODUCTS & METHODS OF ANALYSIS

- All data reductions were made using AIPS
- Data products are Stokes Q, U and I cubes at various spatial and frequency resolutions of interest. **NB: Each image plane has ~1500 independent resolution beams across the lobes.**

Instrument	JVLA
Configuration	A, B, C and D
Frequency Range	2- 18 GHz
Maximum Resolution	0.125 Arcseconds
Maximum Resolution @ 2 GHz	0.75 Arcseconds
Expected Noise	~1-2 µJy/beam

TECHNIQUES:

- RM-Synthesis
  - Fourier Transforms the complex polarized emission between frequency-space and Faraday depth-space.
- Direct fitting to Stokes Q and U
  - Using simple least-squares fitting methods
  - Multinest, a highly efficient Bayesian inference tool, (F. Feroz et.al, 2009). I

THE OBSERVED DEPOLARIZATION CHARACTERISTICS

- The following shows an example line-of-sight (LoS) but the same behaviour is seen across the lobes.

QUESTION: WHAT IS CAUSING THE DEPOLARIZATION AND NON-LINEARITIES?

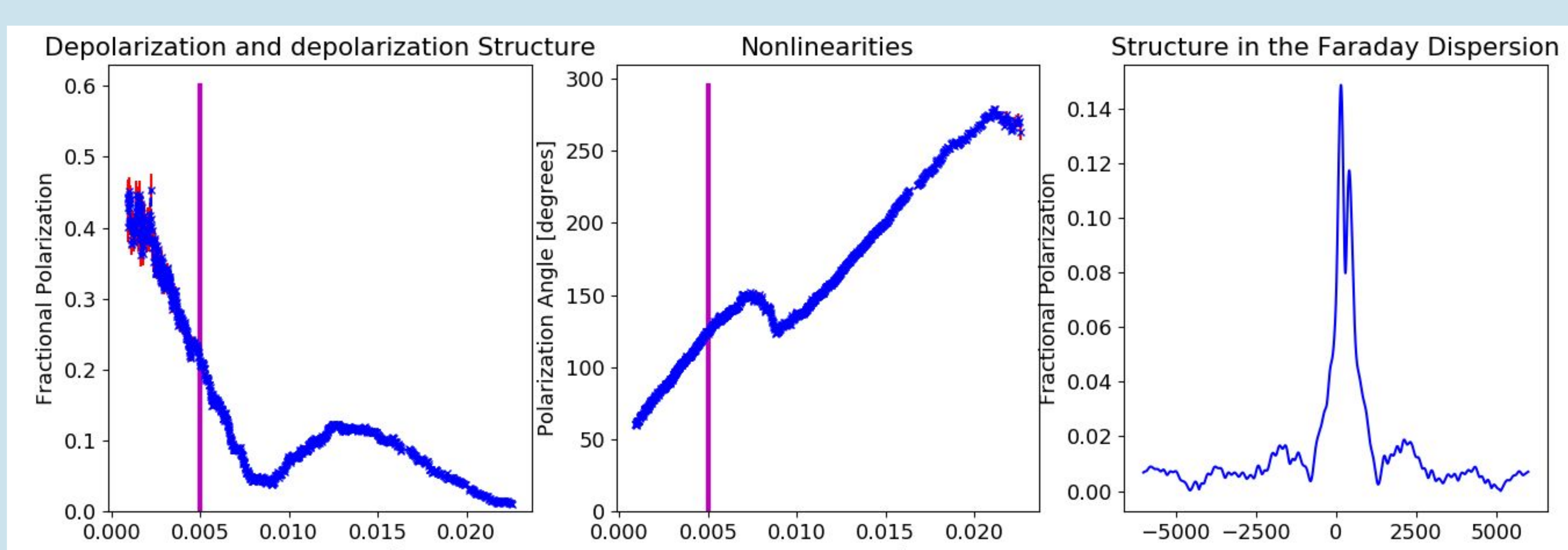

Figure 2 A result from a single line-of-sight. The left and middle plot shows fractional polarization and position angle as a function of wavelength-squared. The vertical line marks a high frequency range covered by the previous study of Cygnus A Dreher et.al (1987). The right plot is faraday dispersion amplitude obtained via rotation measure synthesis technique.

INVESTIGATION: Causes of depolarization and non-linearities

Turbulent Magnetic fields

BEAM DEPOLARIZATION

- Occurs when B-fields fluctuation scale is smaller than the beam size
- Occurs external/internal to the polarized source.
- This is a transverse effects
- Depends on transverse RM gradients . a

Uniform Magnetic -fields or Turbulent fields with a dominant cell

FARADAY-DEPTH DEPOLARIZATION

- Is due to a mixing of Synchrotron and thermal emission.
- Occurs internal to the polarized source.
- This is a line-of-sight effect.
- Depends on the LoS RM.

LARGE-SCALE B-FIELDS NOT RESPONSIBLE FOR THE DEPOLARIZATION

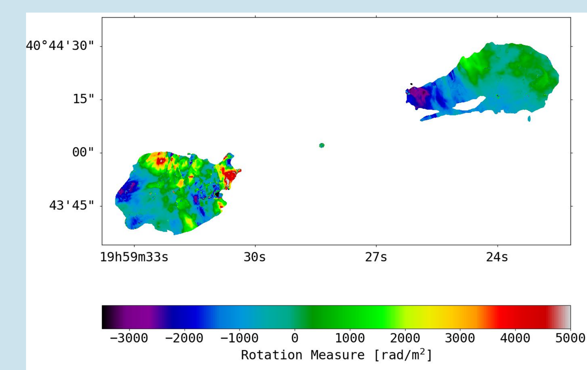

Figure 3 Rotation measure map obtained via QU fitting on the 0.3" data. There are large scale, uniform fields with scales ~ 5-30 kpc.

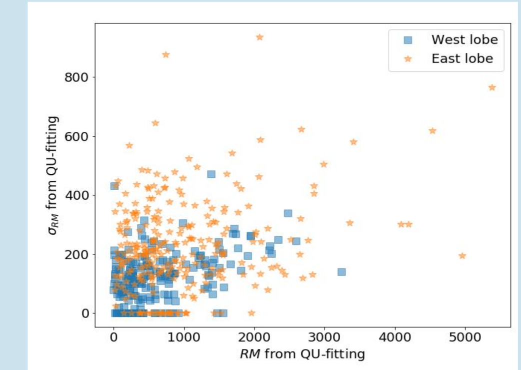

Figure 4 The observed large RMs as a function of the dispersion.

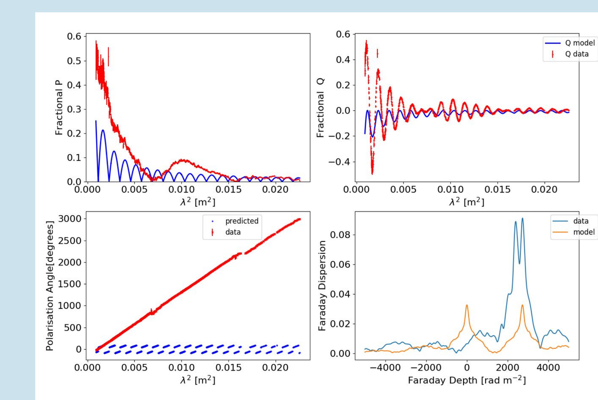

Figure 5 Example of QU fitting of internal depolarization model with no external Faraday screen.

TRANSVERSE OR LINE-OF-SIGHT EFFECT?

Fractional polarization as a function of resolution at different frequencies.

The idea is that if we resolve the structure, then the fractional polarization must asymptote to a value corresponding to the intrinsic (internal) polarization.

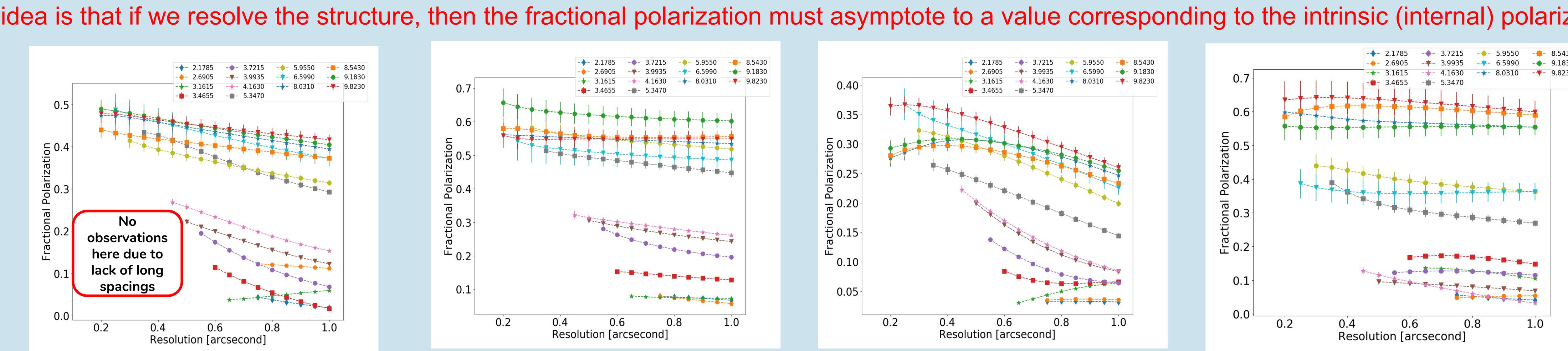

Figure 6 Four LoS examples. Fractional polarization as a function of resolution. It is evident that we have insufficient resolution esp at lower frequencies.

USING HIGH RESOLUTION, HIGH FREQUENCY DATA TO PREDICT WIDEBAND, LOW RESOLUTION DATA

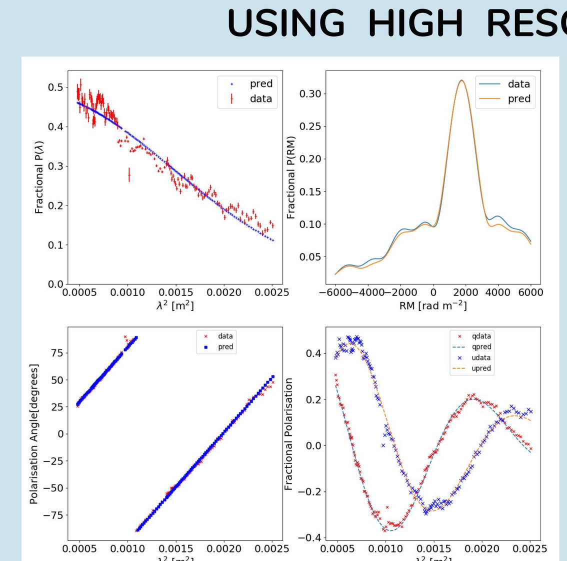

Figure 7 QU-fitting beam depolarizaiion model: $p_0 \exp(2i\Psi_0 + 2i\mathrm{RM}\lambda^2) * \exp(-2\sigma^2\lambda^4)$ to 0.30" 6-14 GHz data.

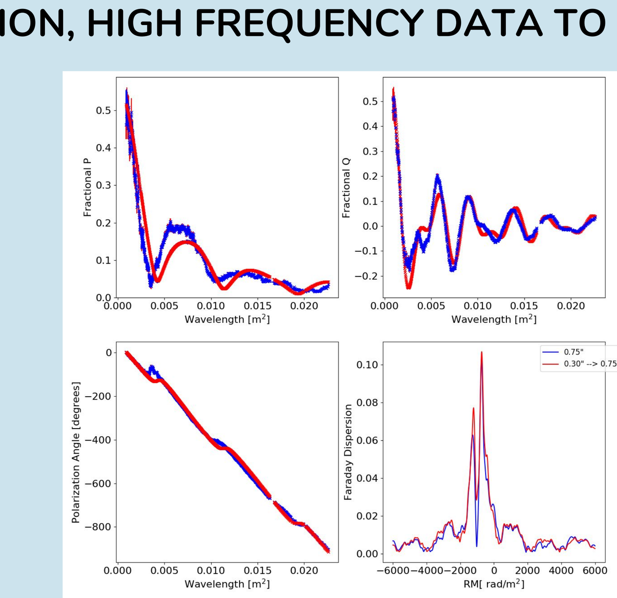

Figure 8 We used parameters po, PA, RM derived from QU-fitting to 0.30" data (see Figure 7) to predict a model cube across frequency of fractional Q, U. These model cubes are convolved to the same resolution as the lower frequency (0.75") data. The data and predicted data are compared. .

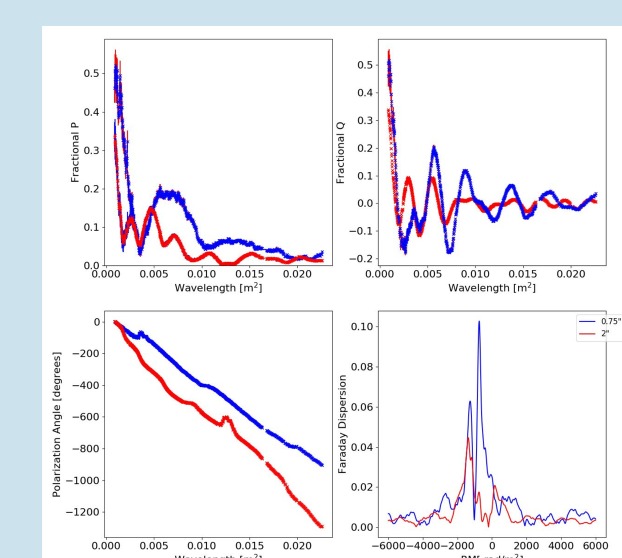

Figure 8 0.75" data convolved to 2".

CONCLUSION AND FUTURE

1. There are large-scale fields in the ICM which are responsible for the large RMs but cannot explain the observed depolarization.
2. The origin of the depolarization is consistent with beam depolarization.
3. The depolarization still occurs at 0.30", and the data are best modelled using beam depolarization model shown in Figure 7. Small-scale fields are thus < 300 pc.
4. In the near future, we want to apply, for the first time, power-spectrum analysis to Cygnus A data, in order to qualitatively determine the field scales involved.

ACKNOWLEDGEMENTS

Support for this work was provided by the National Aeronautics and Space Administration through Chandra Award Number GO5-16117B issued by the Chandra X-ray Center, which is operated by the Smithsonian Astrophysical Observatory for and on behalf of the National Aeronautics Space Administration under contract NAS8-03060, as well as the South African Radio Astronomy Observatory. A special thank you also to AAS FAMOUS grant.

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