THE MAGNETIC FIELDS IN THE WARPED DISK OF CENTAURUS A

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SOFIA tele-talk

THE ROLE OF MAGNETIC FIELDS IN GALAXY EVOLUTION

Magnetic fields are amplified as a consequence of galaxy formation and turbulence-driven dynamos.

IlustrisTNG

Stage 1: Field seeds

- Generation of seed fields by Biermann battery, Weibel instability, or plasma fluctuations ($B \sim 10^{-18}$ - 10^{-6} G).

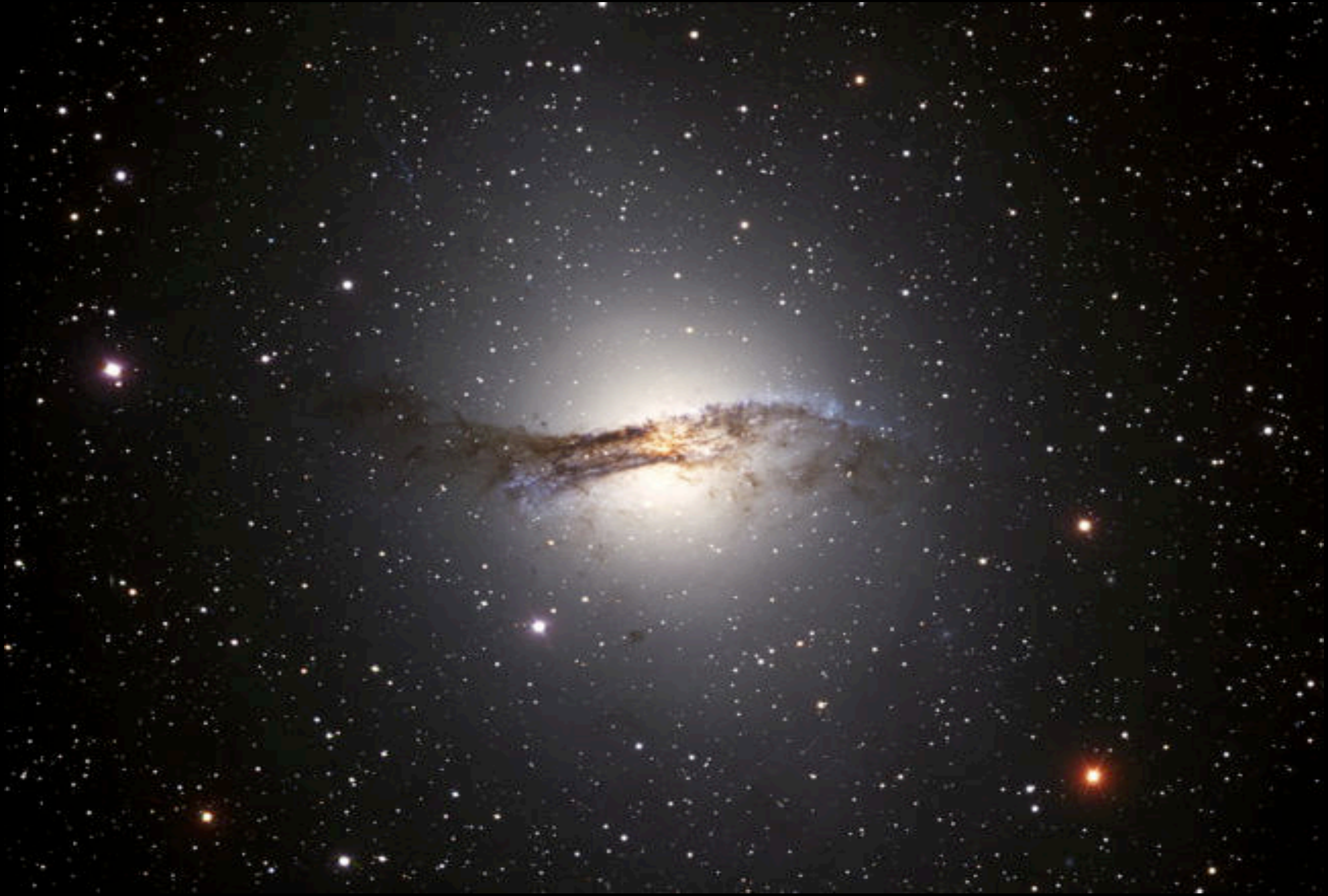
Stage 2: Field Amplification

- Amplification of seed fields by turbulent gas flows, i.e. small-scale dynamo ($B \sim 10^{-5}$ G).
- Turbulence is driven by accretion flows and SN explosions.

Stage 3: Field ordering

- Field ordered (stretched) by shear and by large-scale dynamo ($t \sim 10^9$ yr).
- Turbulence driven by SN explosions and magnetorotational instability (MRI) in galaxy disks.

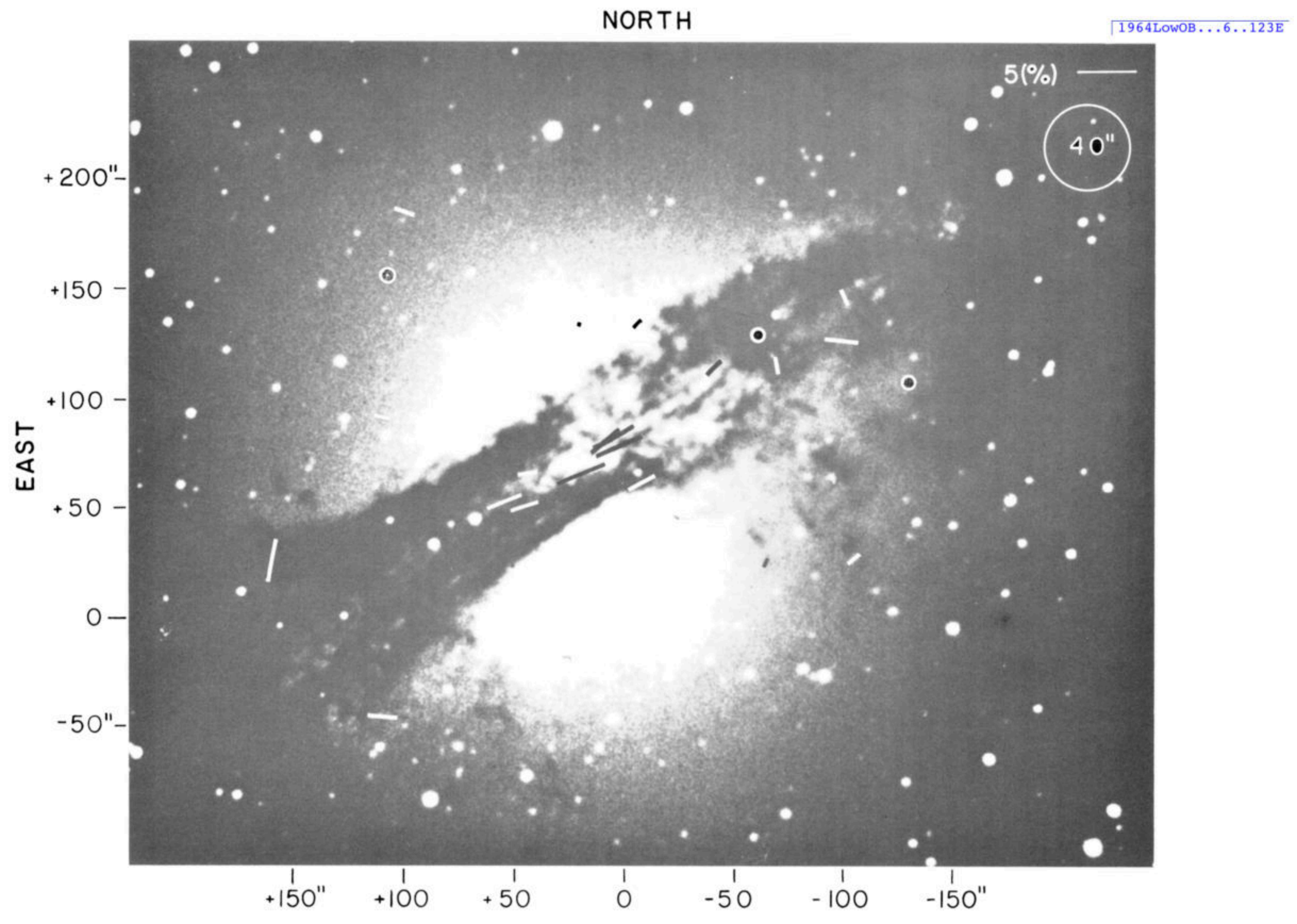
CENTAURUS A: ELLIPTICAL + SPIRAL GALAXY



Credit: A. Quillen (http://astro.pas.rochester.edu/~aquillen/agn.html)

3

MAGNETIC FIELDS IN CENTAURUS A: OPTICAL



Elvius & Hall (1964)

Optical (Photoelectric polarimeter)

- Polarization dominated by dichroic absorption
- First result invoking B-fields in the dust lane of Centaurus A

the same optical properties as the particles in the Milky Way clouds. The degree of polarization predicted in this way is in very good agreement with the polarization observed by us in the dark band. It therefore seems plausible that the polarization in this case is due to absorption in clouds of elongated particles, oriented with their shortest axis parallel to the magnetic fields in the flat layer of dark material in 5128.

As in our own galaxy, we would expect that the lines of force should be parallel to the dark band. If so, because of the nature of the radio data, the magnetic field in 5128 probably has an interesting form. It would be roughly perpendicular to the dark layer in the major part of the object outside the layer, but parallel to the layer inside the dark layer itself. Such a configuration seems possible if the layer is rotating around its axis of symmetry at a higher speed than the main body of the galaxy. This actually seems to be the case according to data obtained by Burbidge and Burbidge (20). They found the stellar system to rotate in the same direction as the layer of gas and dust about an axis perpendicular to the dust layer; the average rotational velocity of the stellar system is about 1 km/sec/second of arc as compared to a value 3-fold greater for the dust layer. There is also a significant difference in radial velocity between the gas and the stellar system. It seems most probable that the magnetic lines of force in this fast-moving gas have been stretched in the general direction of motion in the gas.

Magnetically aligned dust grains

B-fields have an ‘interesting form’

B-fields parallel to the dust lane if the dust lane is rotating

B-fields may be stretched along the gas direction.

MAGNETIC FIELDS IN CENTAURUS A: OPTICAL

FWHM: 40”
Band: visual photometer

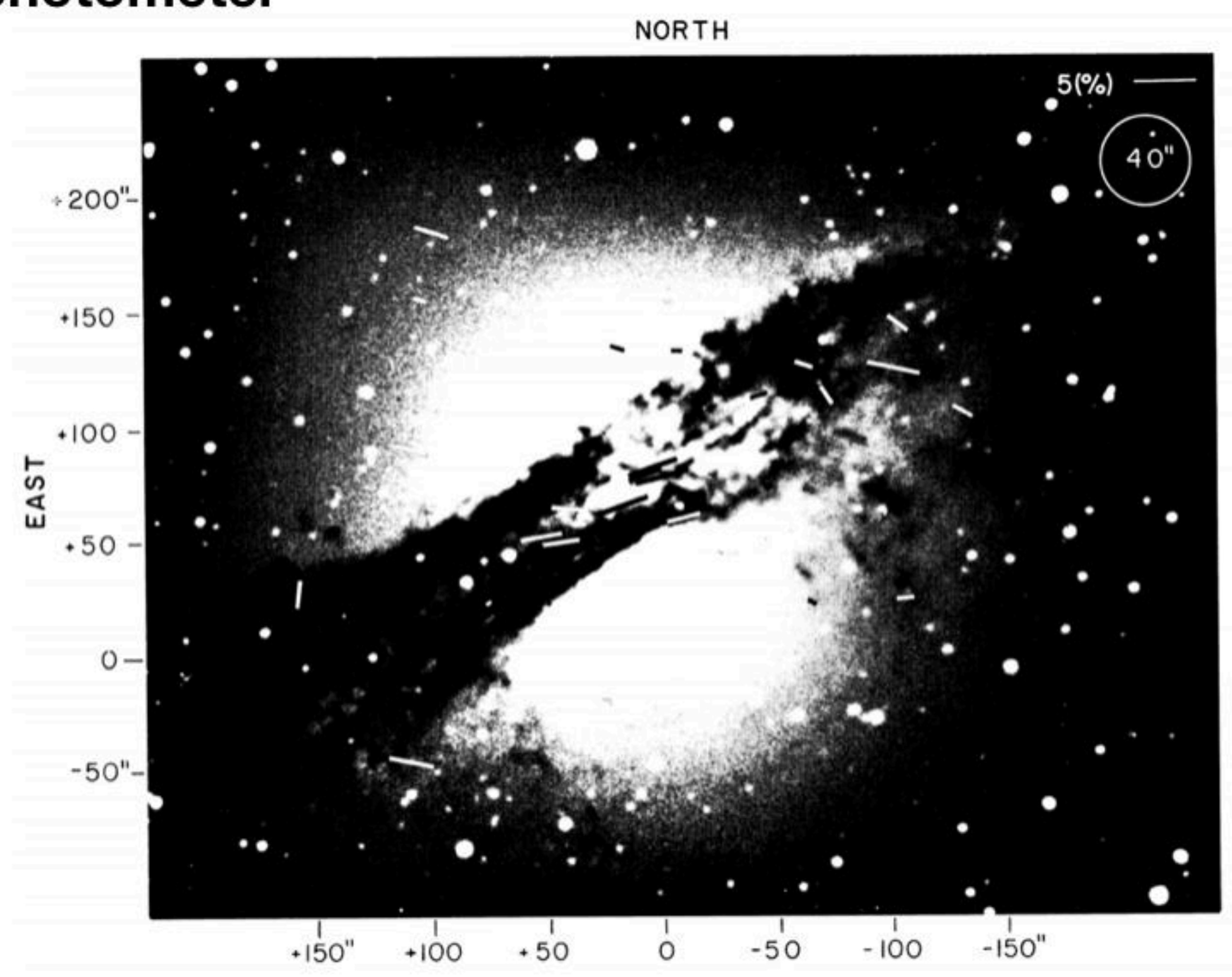
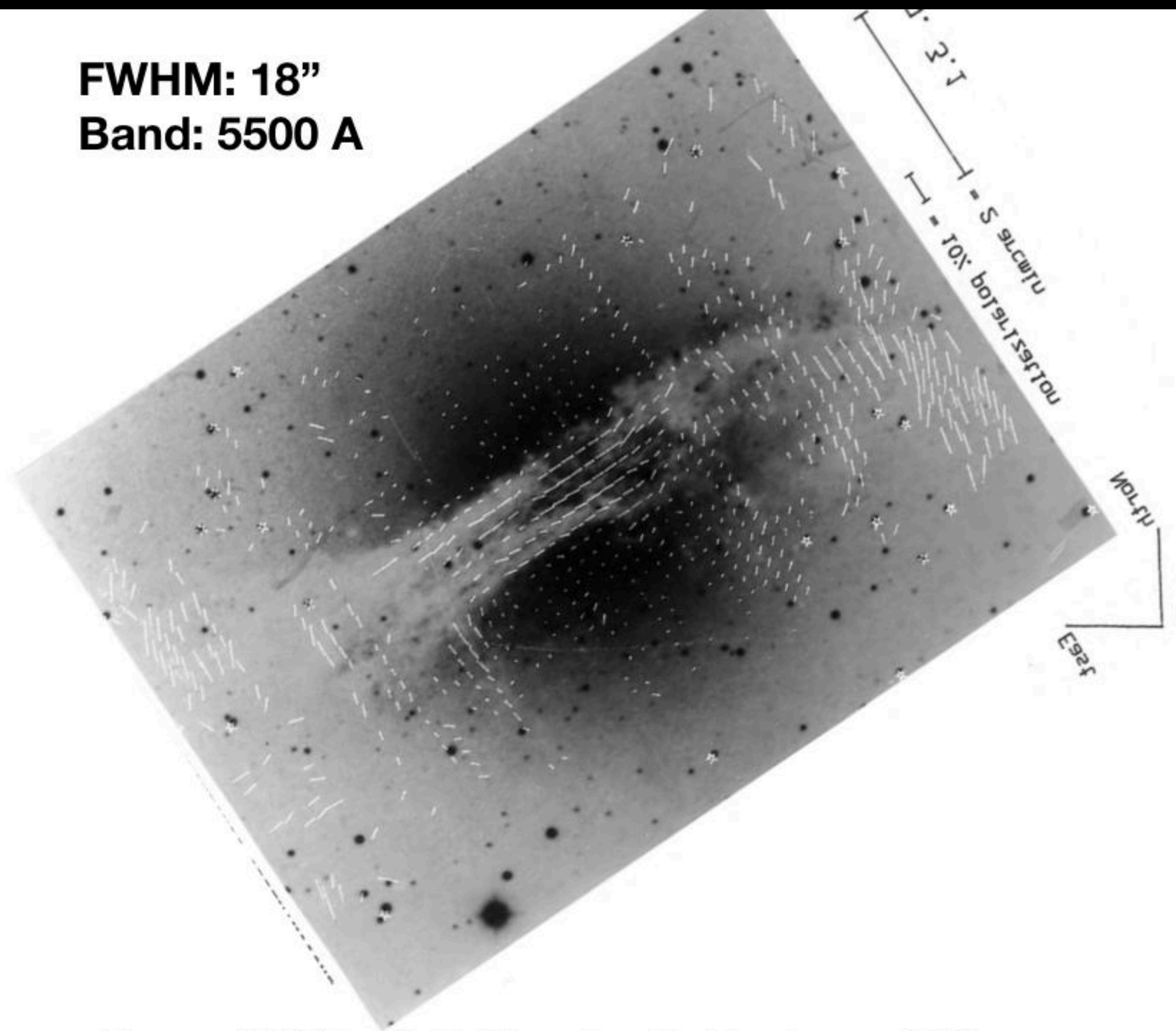


Figure 5. Polarization measures of NGC 5128 uncorrected for foreground (Milky Way) polarization. At radio wavelengths strong polarization has been observed in the northeast quadrant. Photograph—S.C.B. Gascoigne, 74-inch, 103a-D plate with Chance OY4 filter.

Elvius & Hall (1964, LowOB, 6, 123)

FWHM: 18”
Band: 5500 A



Barry (1985, PhD Thesis, U. Durham, UK)

FWHM: 18”
Band: 5500 A

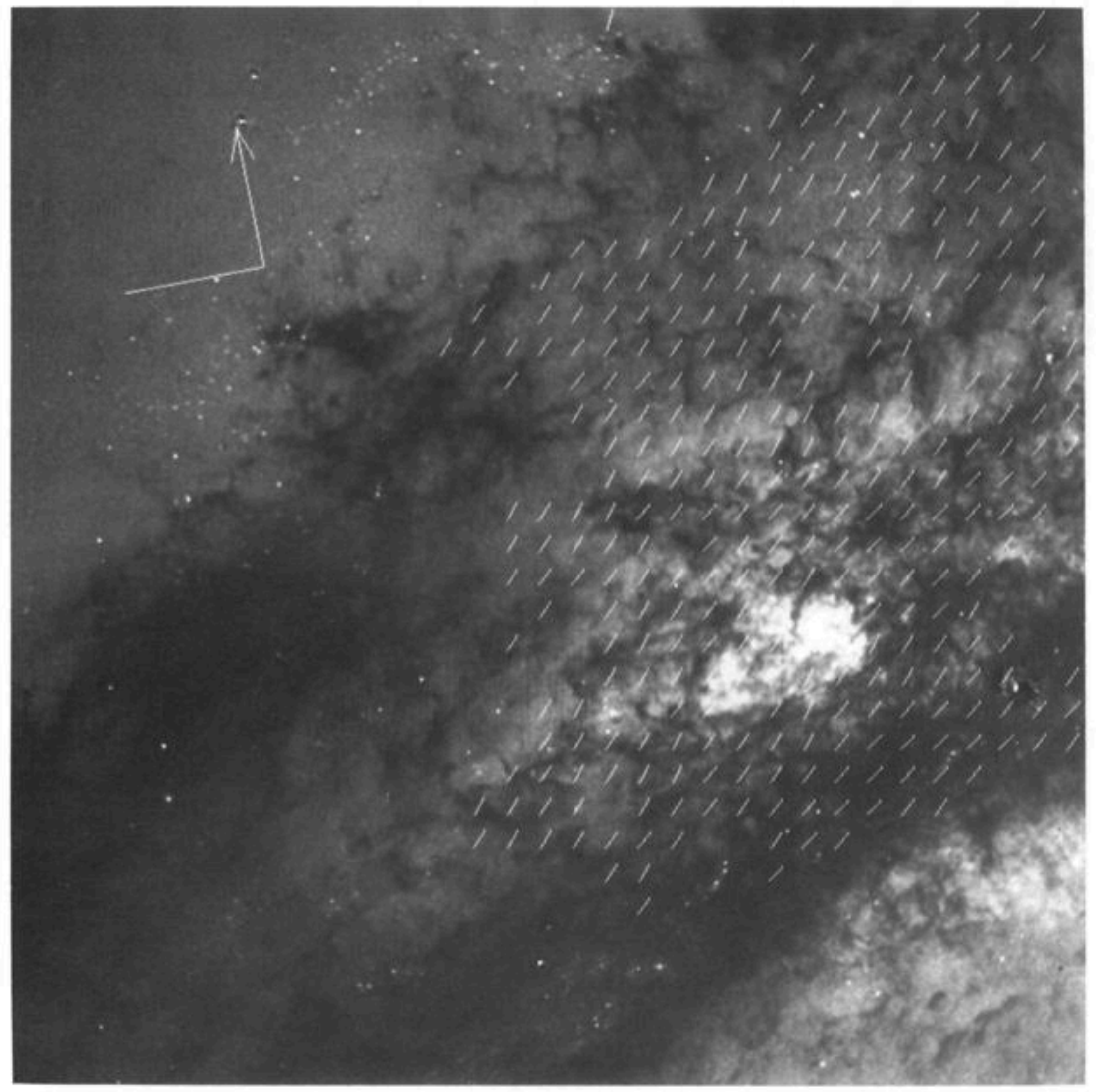


FIG. 11.—Polarization vectors at 2" resolution superimposed on the total intensity image. The vectors are constant length and not proportional to the polarization level. The field of view is 75" × 75"; the arrow is 5" in length.

SCHREIER et al. (see 459, 539)

Schreier (1996, ApJ, 459, 535)

FWHM: 10”
Band: V

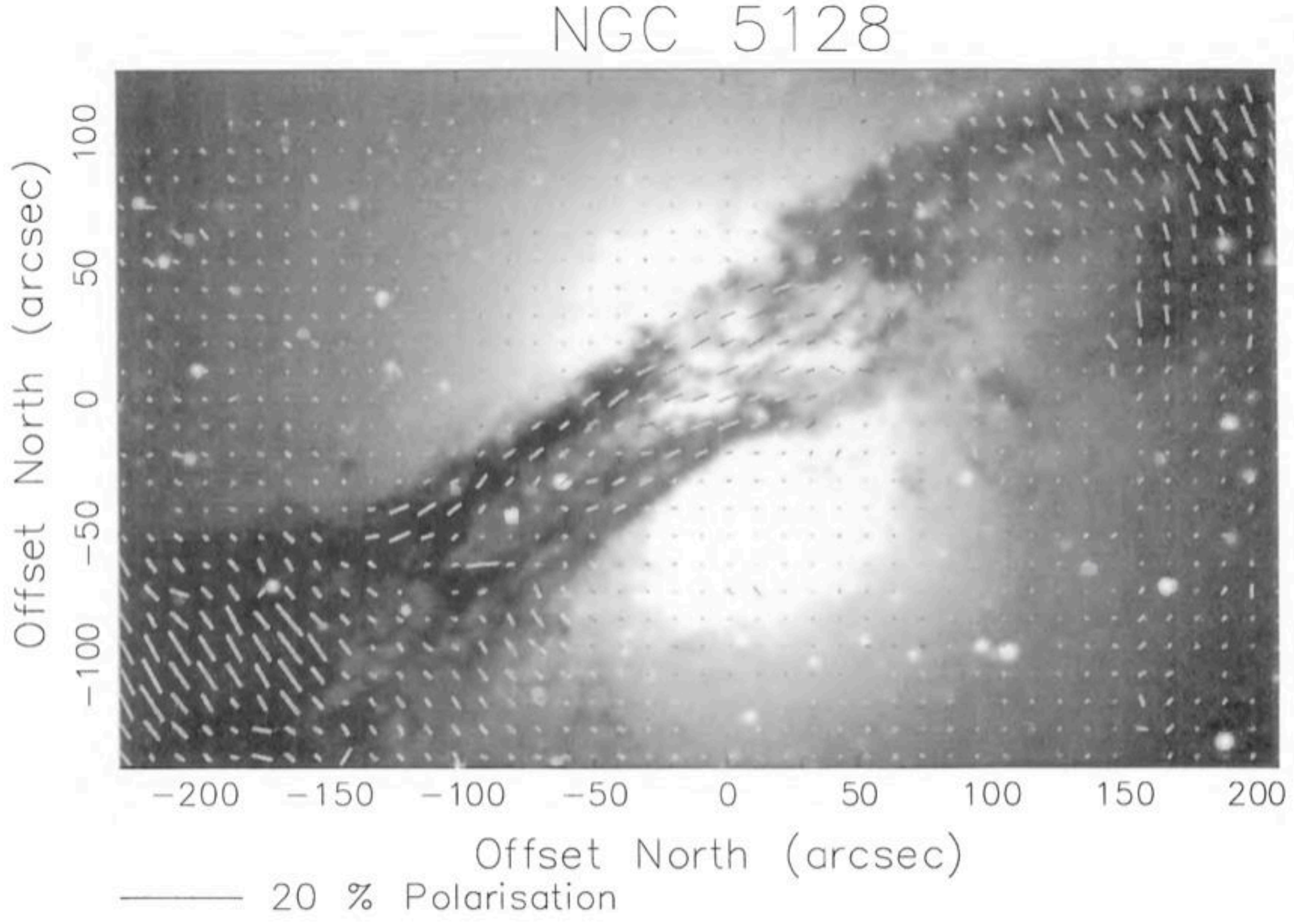


Figure 1. A *V*-waveband polarization map superposed on a greyscale image of the galaxy NGC 5128. There is significant polarization throughout the dust lane. In the central regions the polarization is typically 3 – 5 per cent and oriented parallel to the long axis of the lane, whereas, at the eastern and western extremities, the polarization levels rise up to 8 per cent with perpendicular orientations. There are intermediate null points in the polarization. The centre of the coordinate system is at RA(1950) = $13^h\ 22^m\ 27^s.7$, Dec.(1950) = $-42^\circ\ 45'\ 30''.3$.

Scarrott (1996, MNRAS, 282, 252)

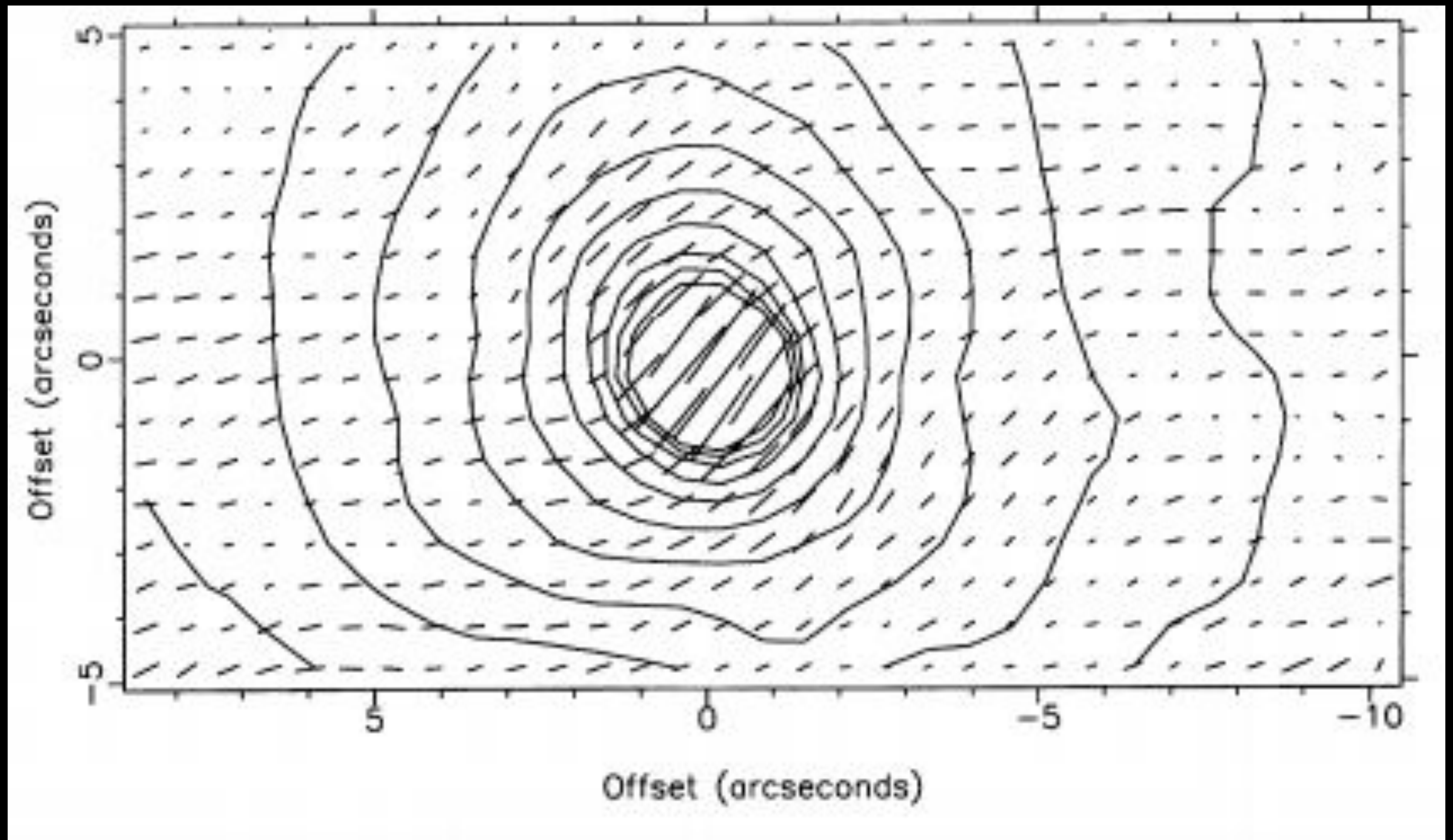
MAGNETIC FIELDS IN CENTAURUS A: INFRARED

Work mainly focused on the active galactic nuclei Bailey et al. (1986), Hough et al. (1987), Packham et al. (1996), Capetti et al. (2000)

- Highly polarized core, ~5%
- PA of polarization almost perpendicular to jet direction.
- Interpretation:
  - Magnetically aligned dust grains in the dusty torus of the AGN

AAT, K-band.

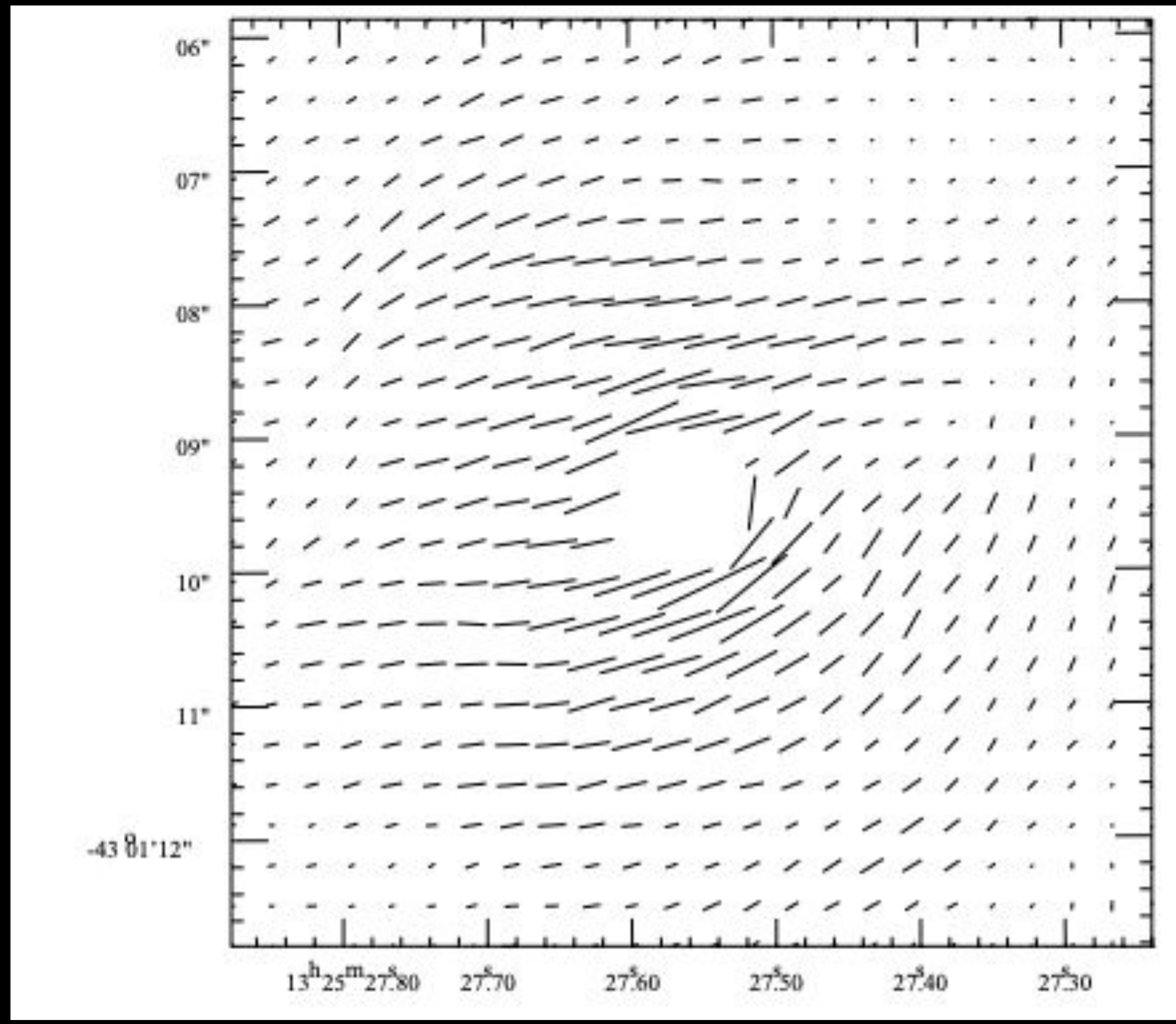
Dichroic absorption.



Packham et al. (1996)

HST, 2.0 um.

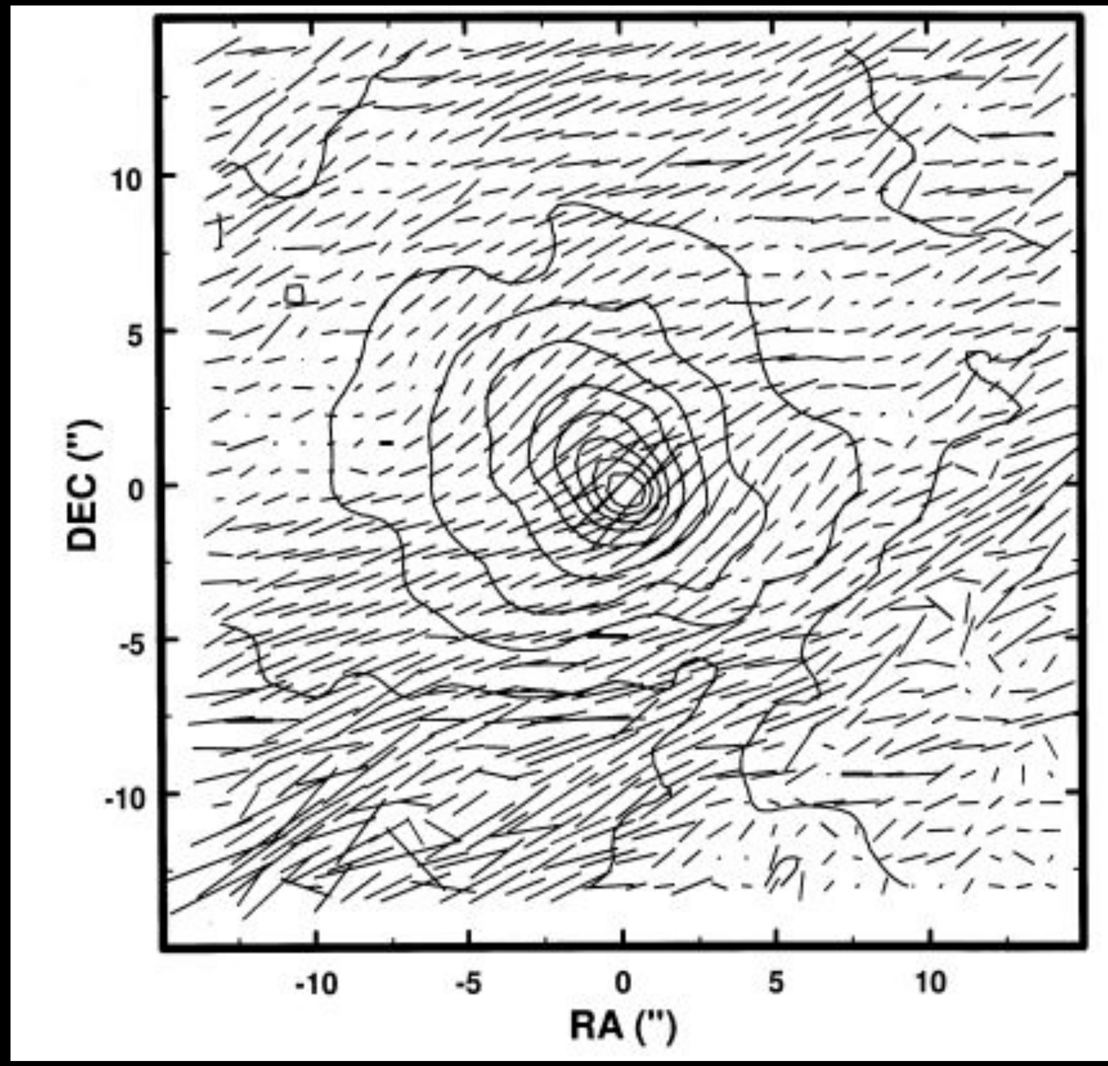
Dichroic absorption.



Capetti et al. (2000)

IRTF, K-band.

Dichroic absorption.



Jones et al. (2000)

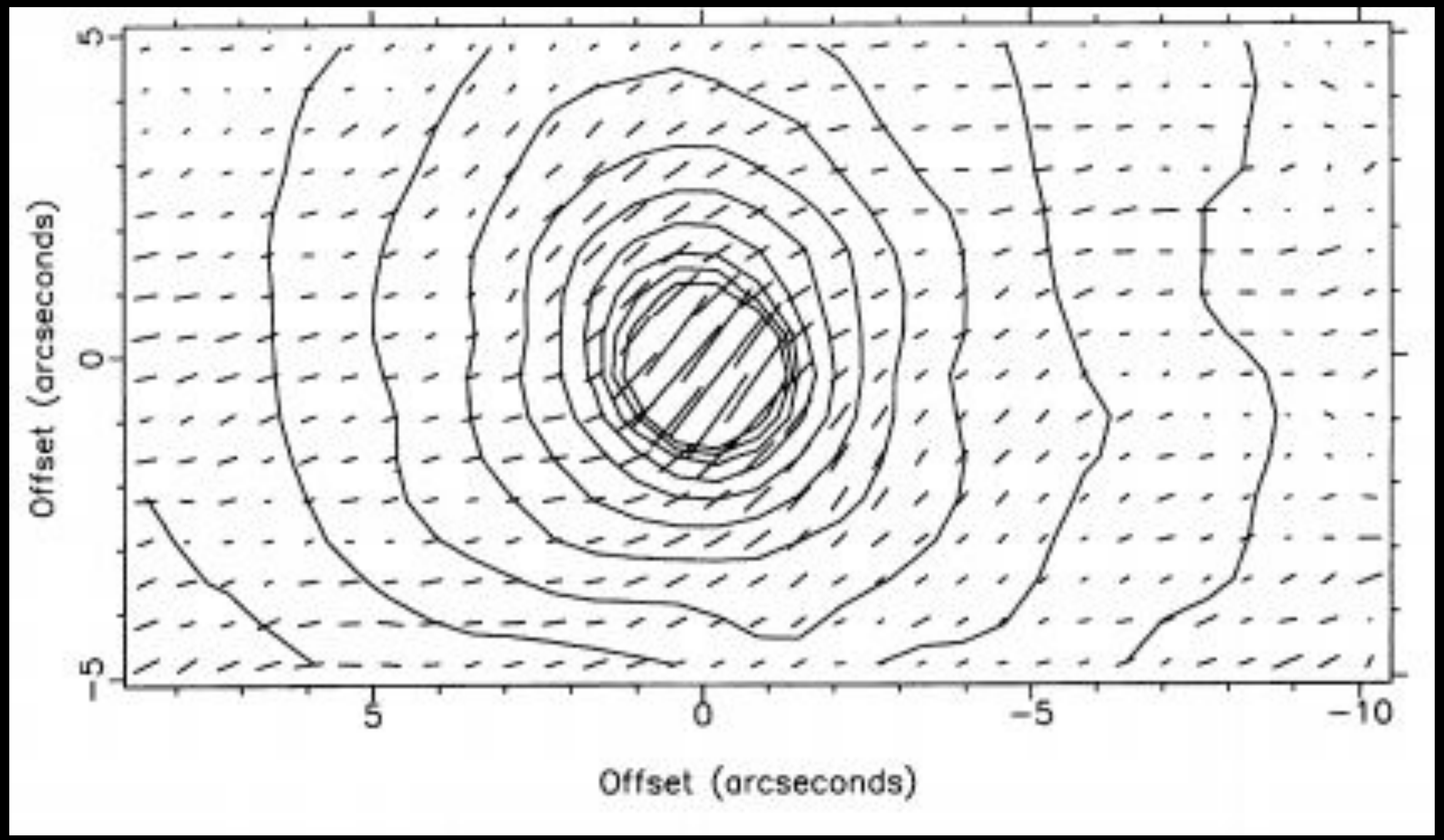
MAGNETIC FIELDS IN CENTAURUS A: INFRARED

Host galaxy Jones et al. (2000)

- PA of polarization parallel to the dust lane.
- Interpretation:
  - B-field parallel to the dust lane
  - No significant disturbance of the B-field
    - —> B-field geometry well maintained during merger, or
    - —> B-field re-established fast after merger

AAT, K-band.

Dichroic absorption.



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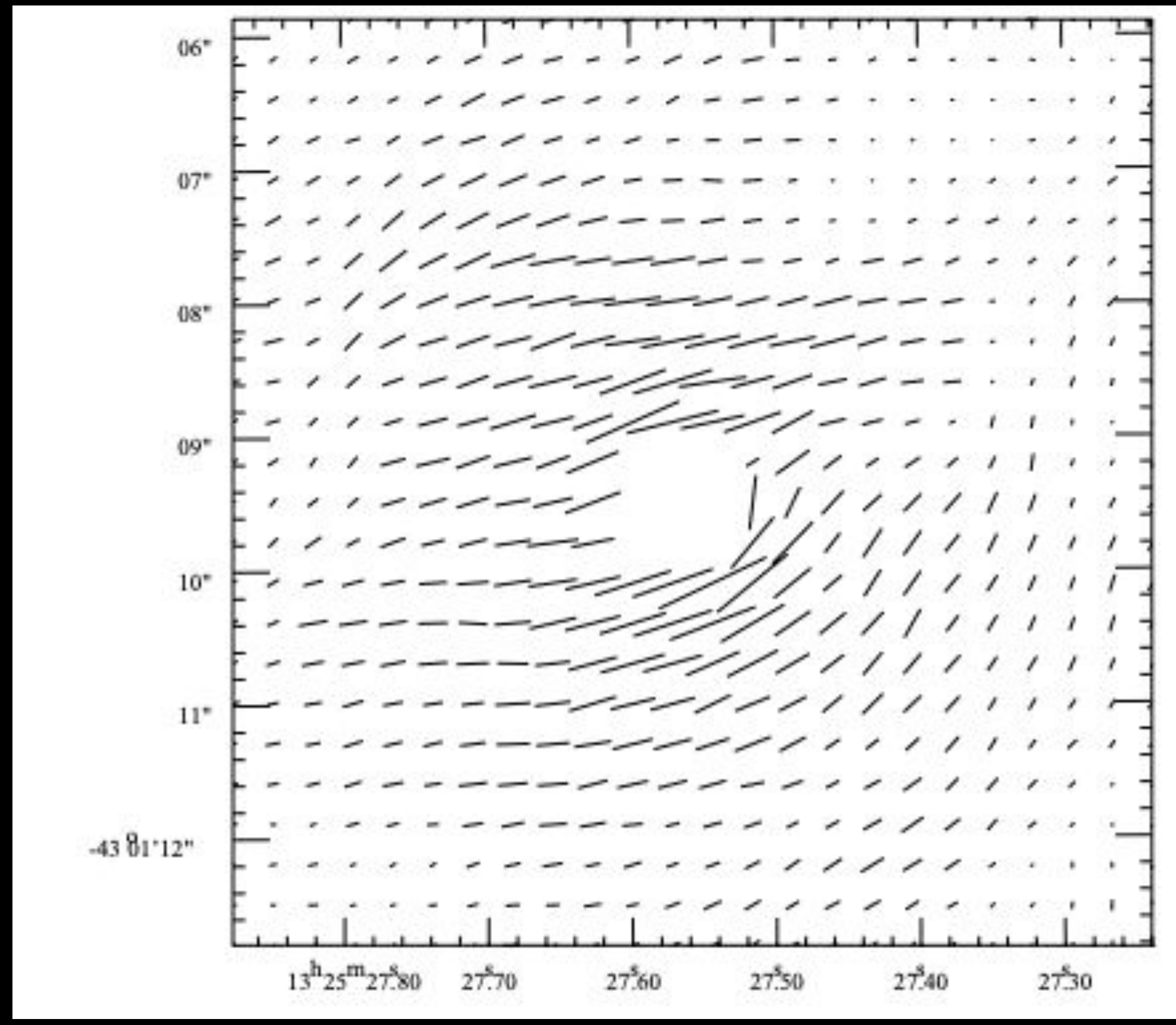

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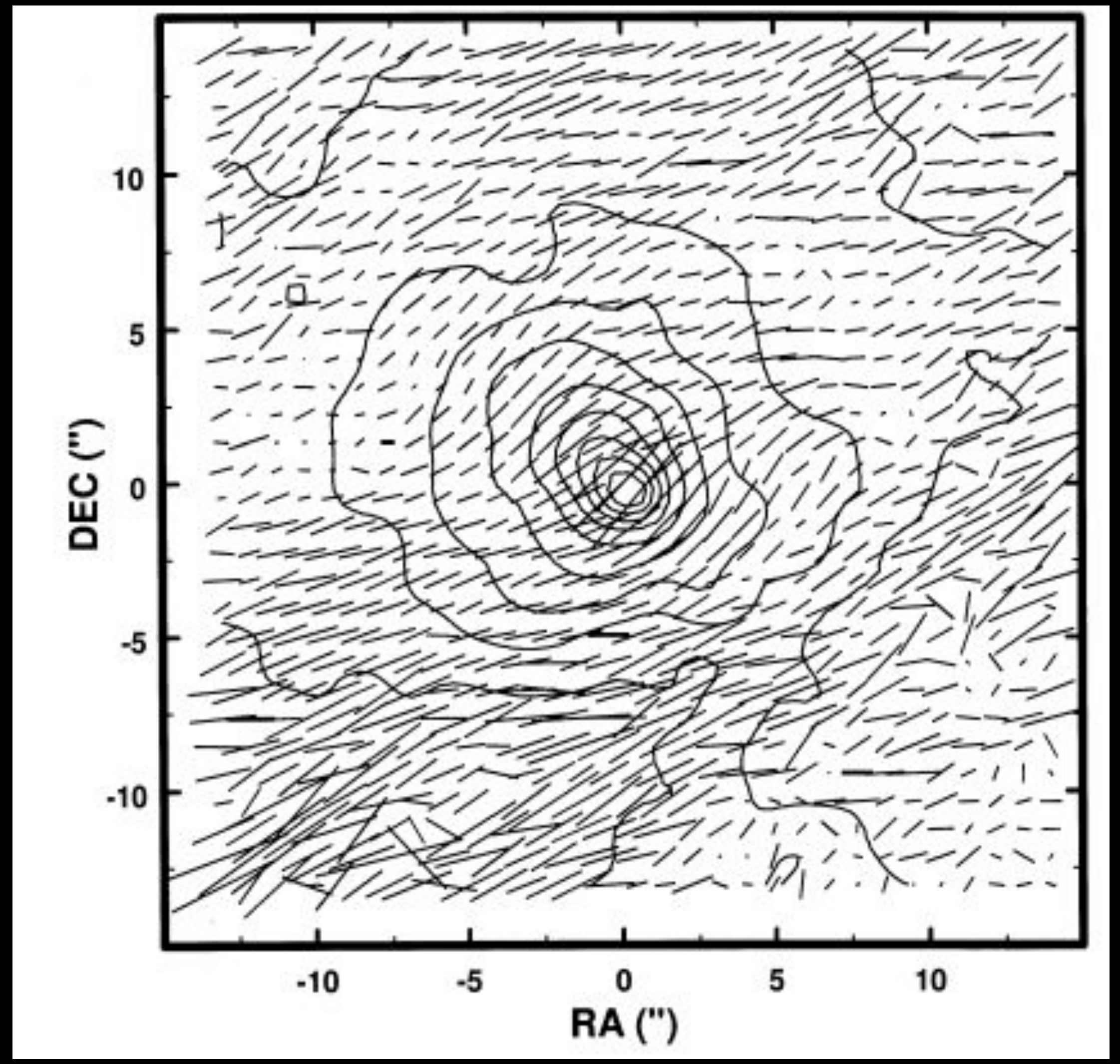
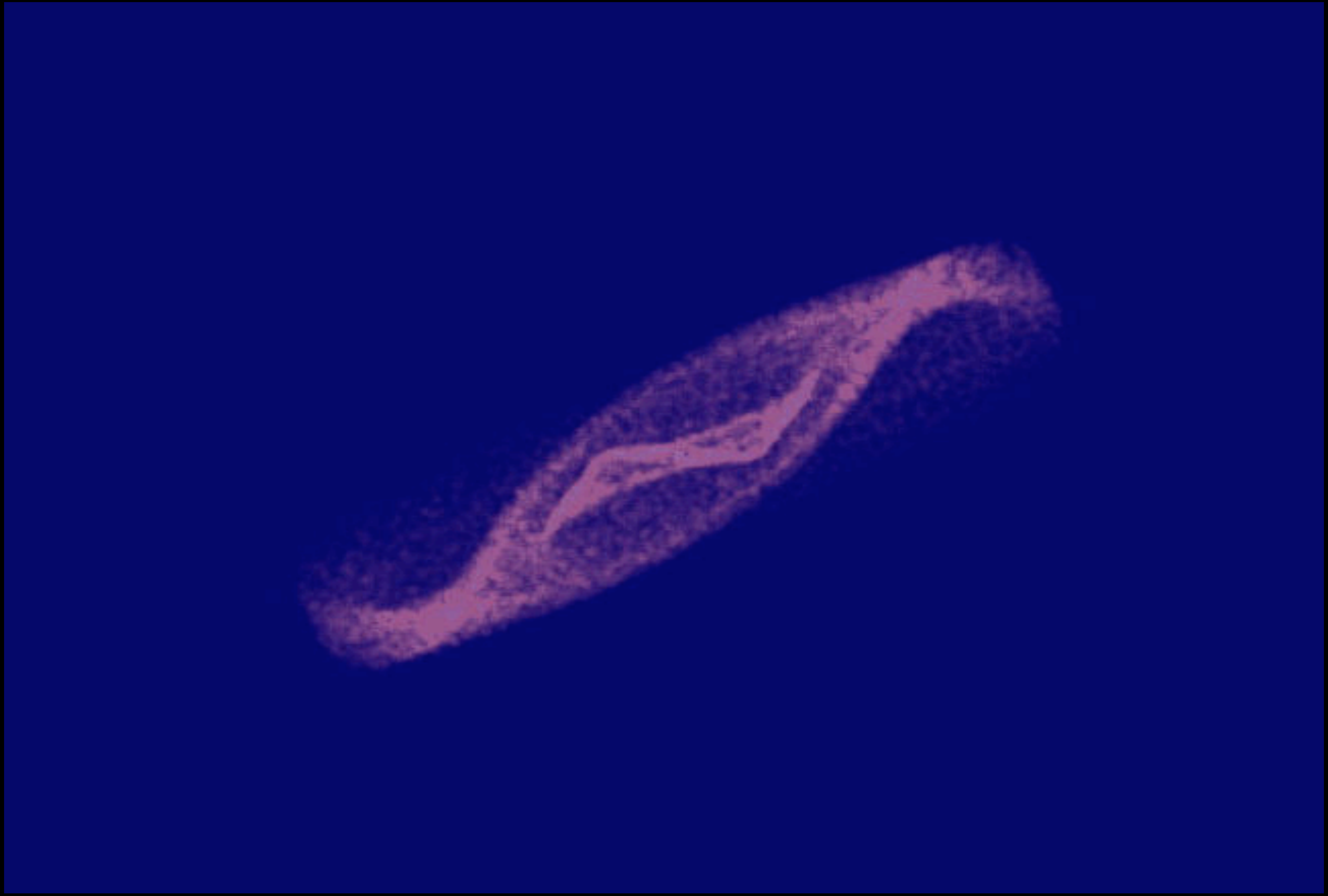


Jones et al. (2000)

INFRARED OBSERVATIONS SHOW A WARPED DISK

Credit: A. Quillen (http://astro.pas.rochester.edu/~aquillen/agn.html)

THE WARPED MOLECULAR DISK CENTAURUS A



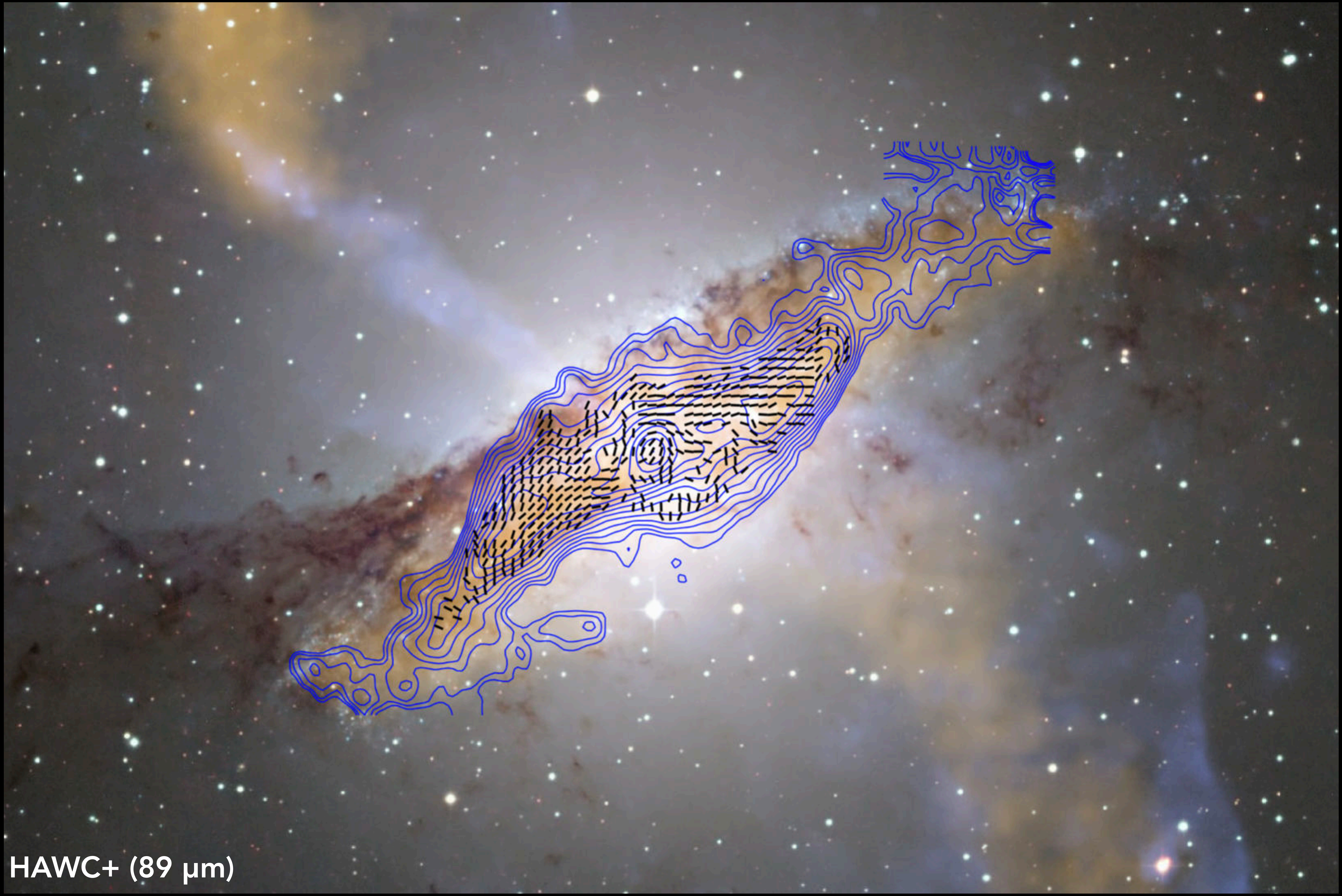
Credit: A. Quillen (http://astro.pas.rochester.edu/~aquillen/agn.html)

Quillen et al. (1992, 1993, 2010)

HAWC+/SOFIA OBSERVATIONS OF THE B-FIELD OF CENTAURUS A

Beam size: 7.8", 128 pc

THE B-FIELD TIGHTLY FOLLOWS THE WARPED MOLECULAR DISK



Beam size: 7.8", 128 pc

11

LARGE-SCALE REGULAR AXISYMMETRIC SPIRAL MAGNETIC FIELD

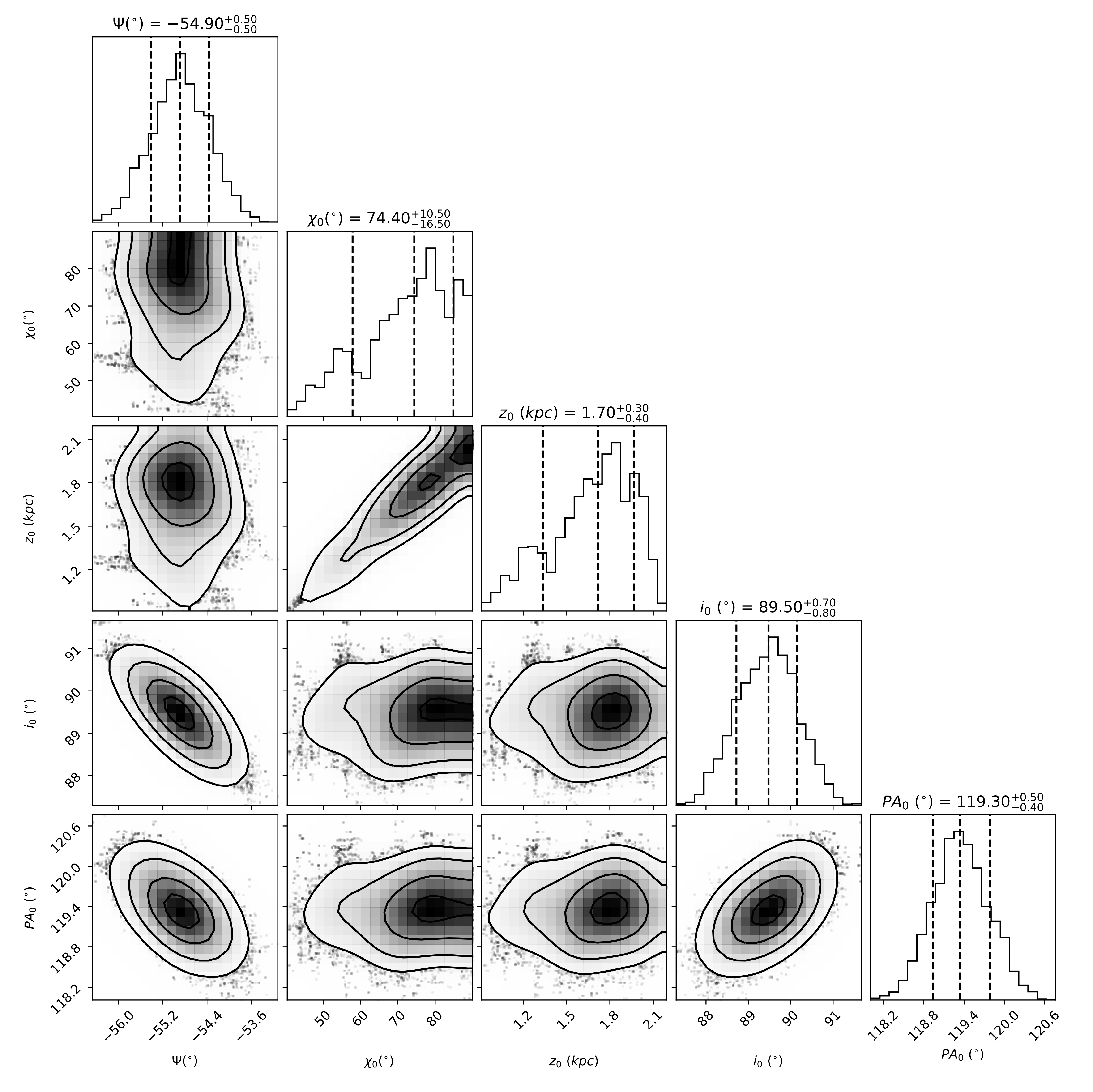
Bayesian fitting to the B-field orientation of the HAWC+/SOFIA data

Regular B-field

$$B_r = B_0 \sin\psi_0 \cos\chi_z$$
$$B_\rho = B_0 \cos\psi_0 \cos\chi_z$$
$$B_z = B_0 \sin\chi_z$$

with helical component:

$$\chi_z = \chi_0 \tanh\left(\frac{z}{z_0}\right)$$



Pitch angle

Helical pitch angle

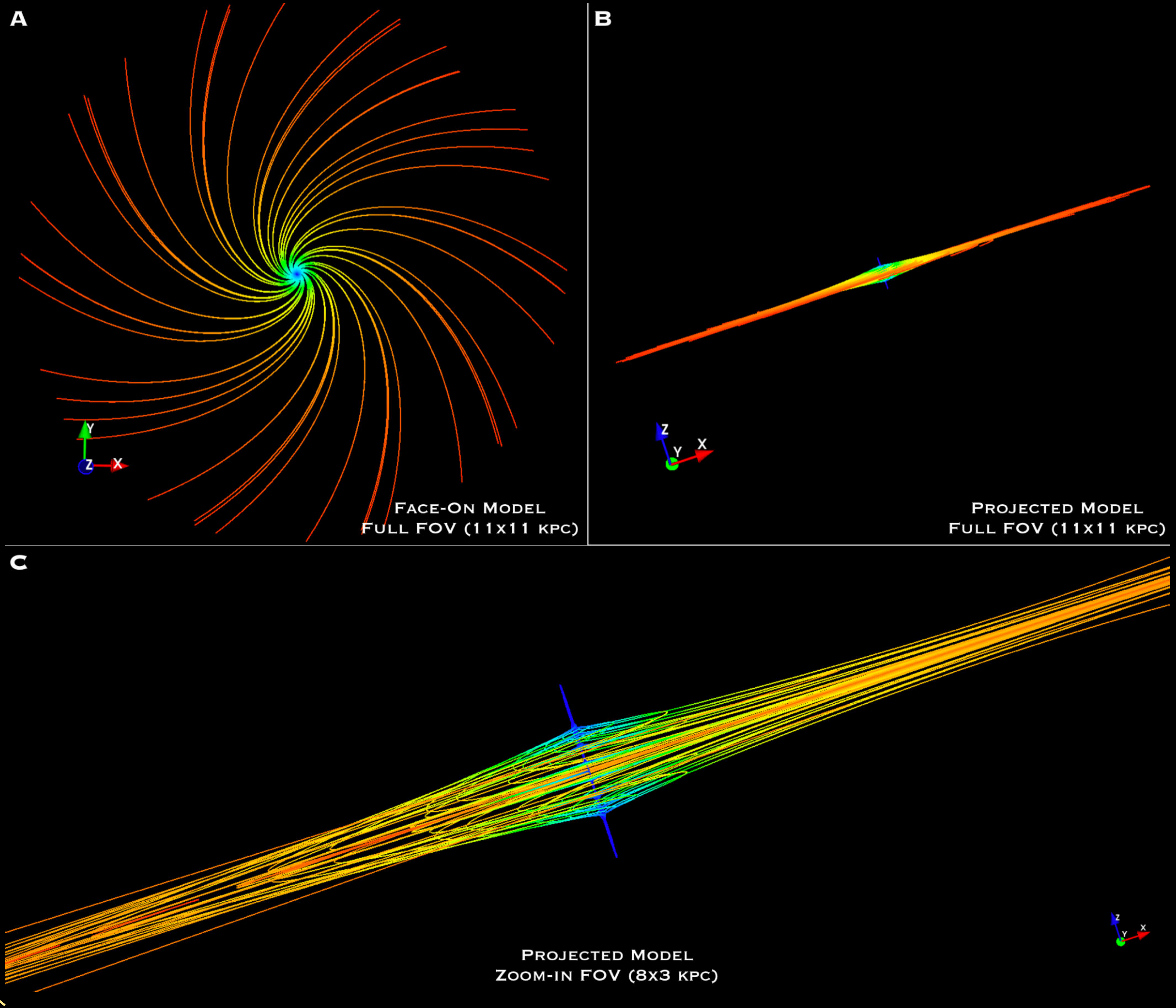
Helical scale height

Inclination

Tilt angle on the plane of the sky

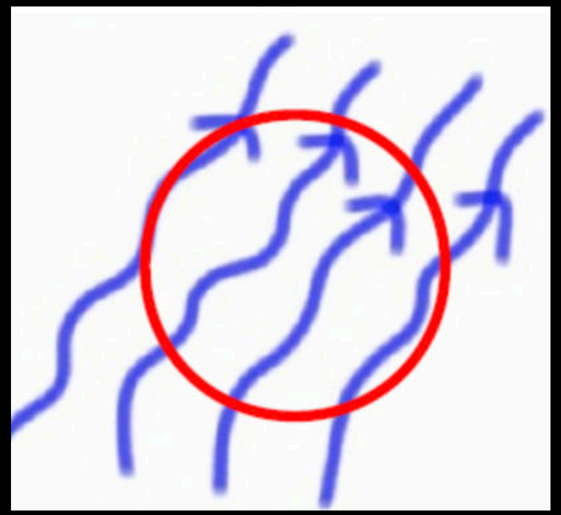
12

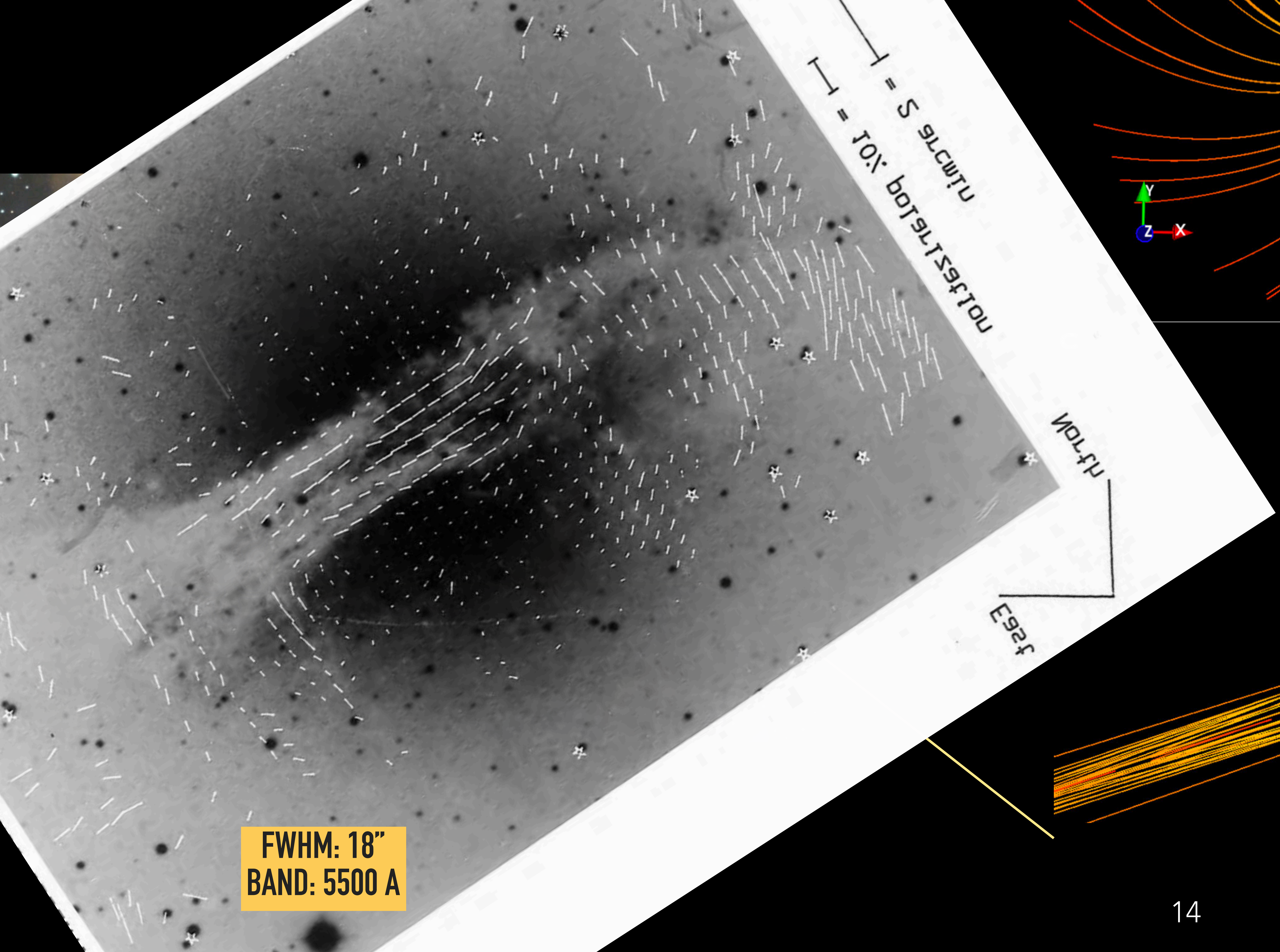
LARGE-SCALE REGULAR AXISYMMETRIC SPIRAL MAGNETIC FIELD

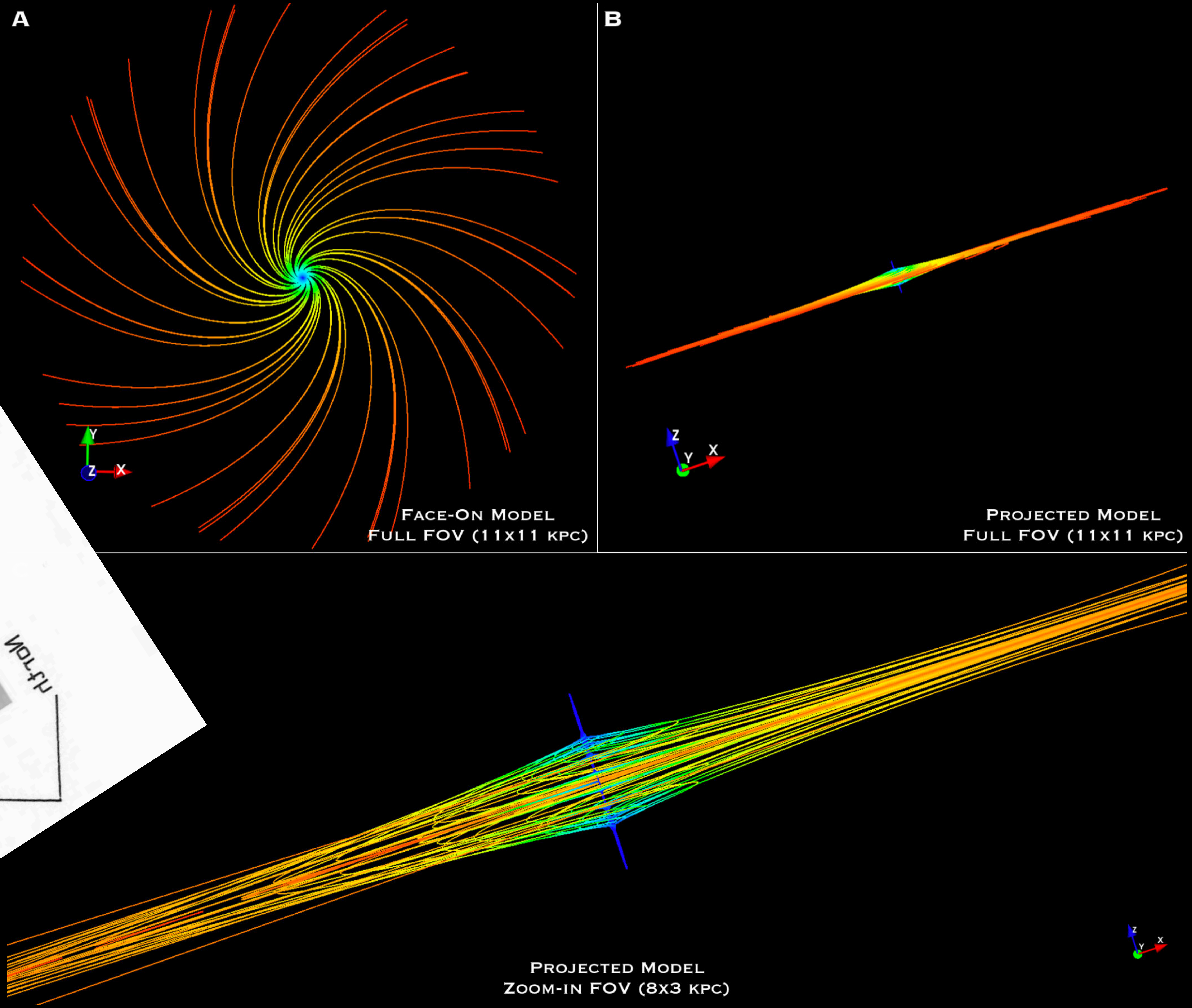


LARGE-SCALE REGULAR AXISYMMETRIC SPIRAL MAGNETIC FIELD

Large-scale ordered field in the host galaxy

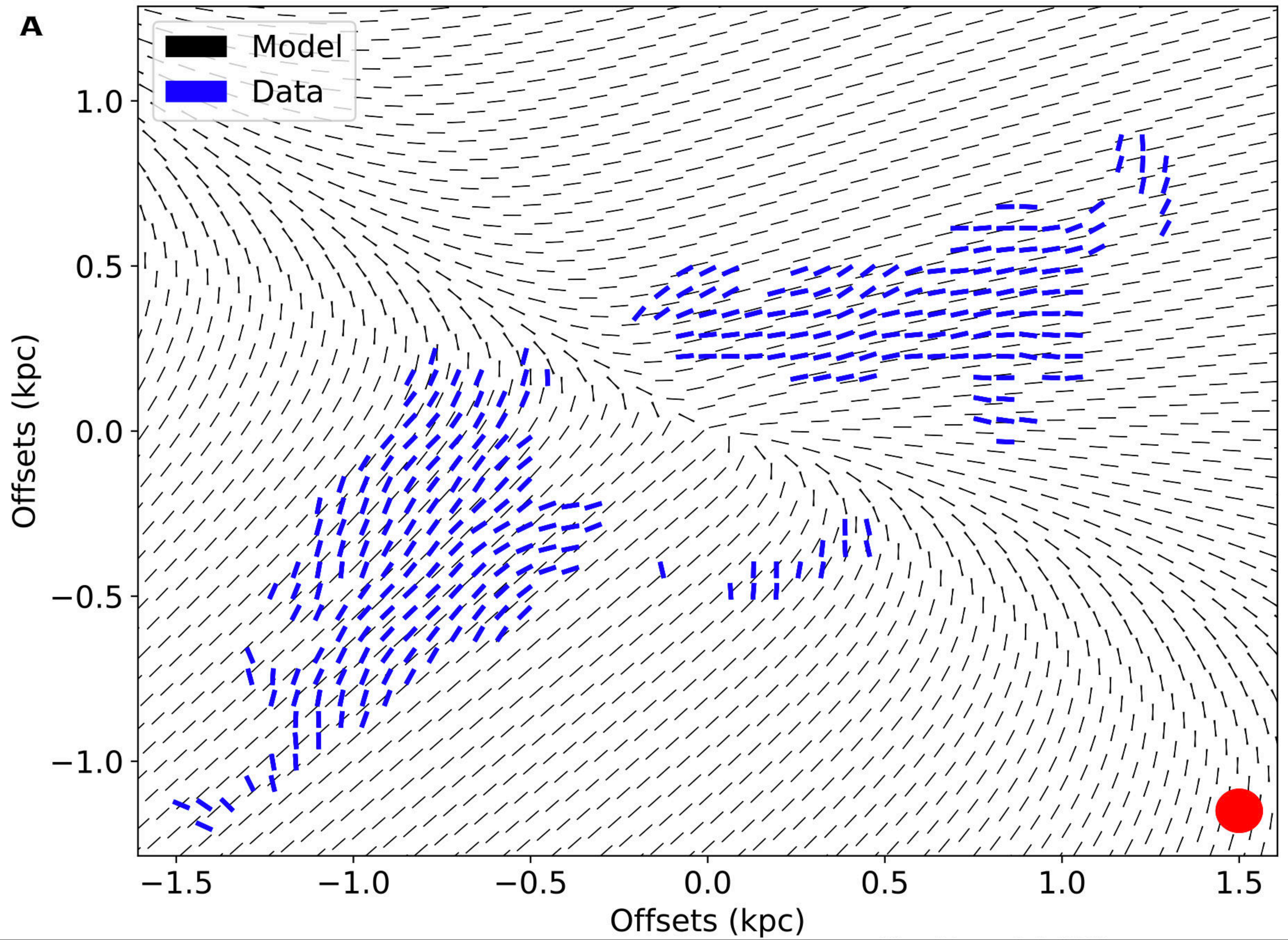




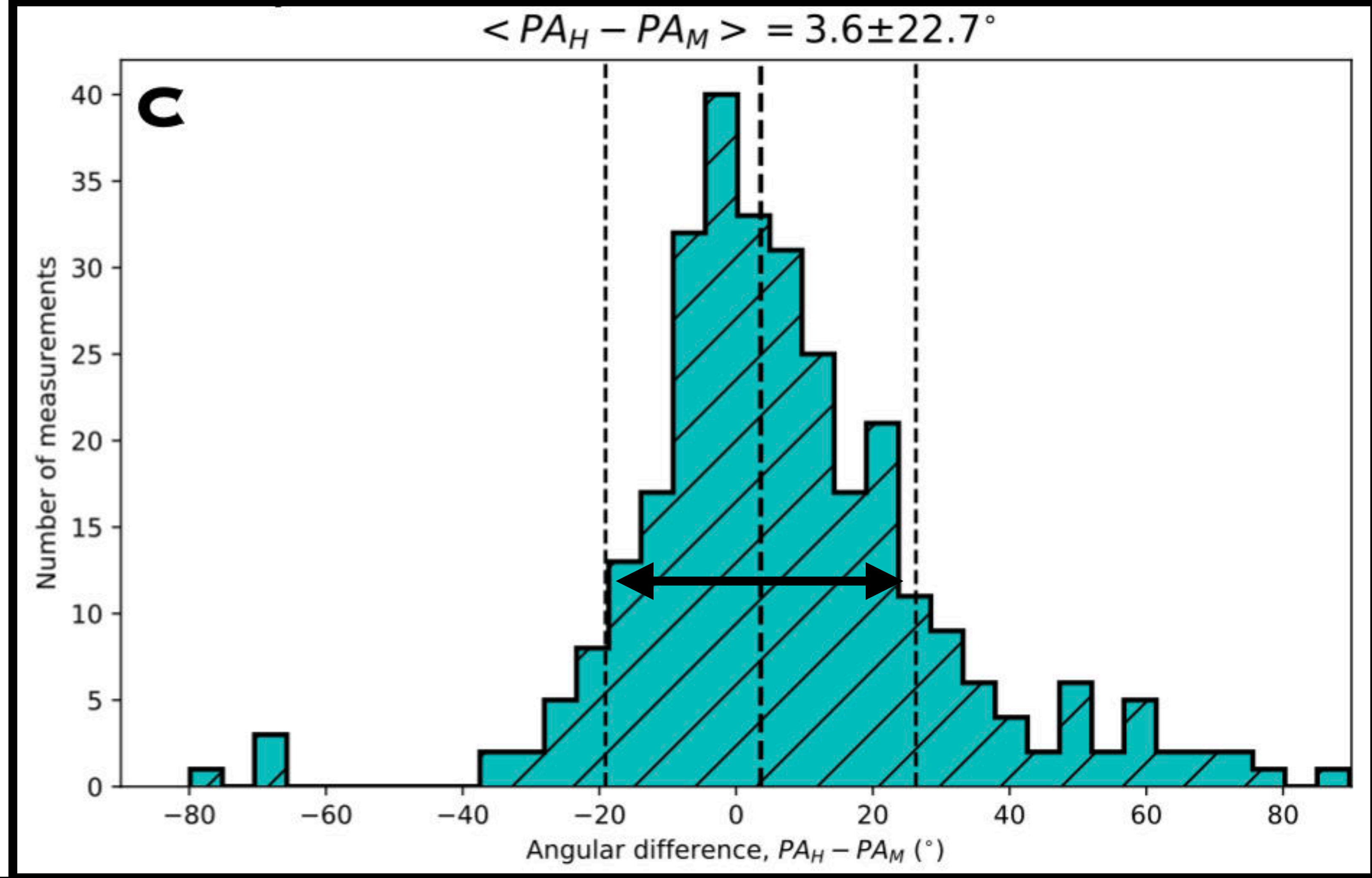


14

A LARGE-SCALE REGULAR AXISYMMETRIC FIELD CANNOT FULLY EXPLAIN THE OBSERVED IR B-FIELD

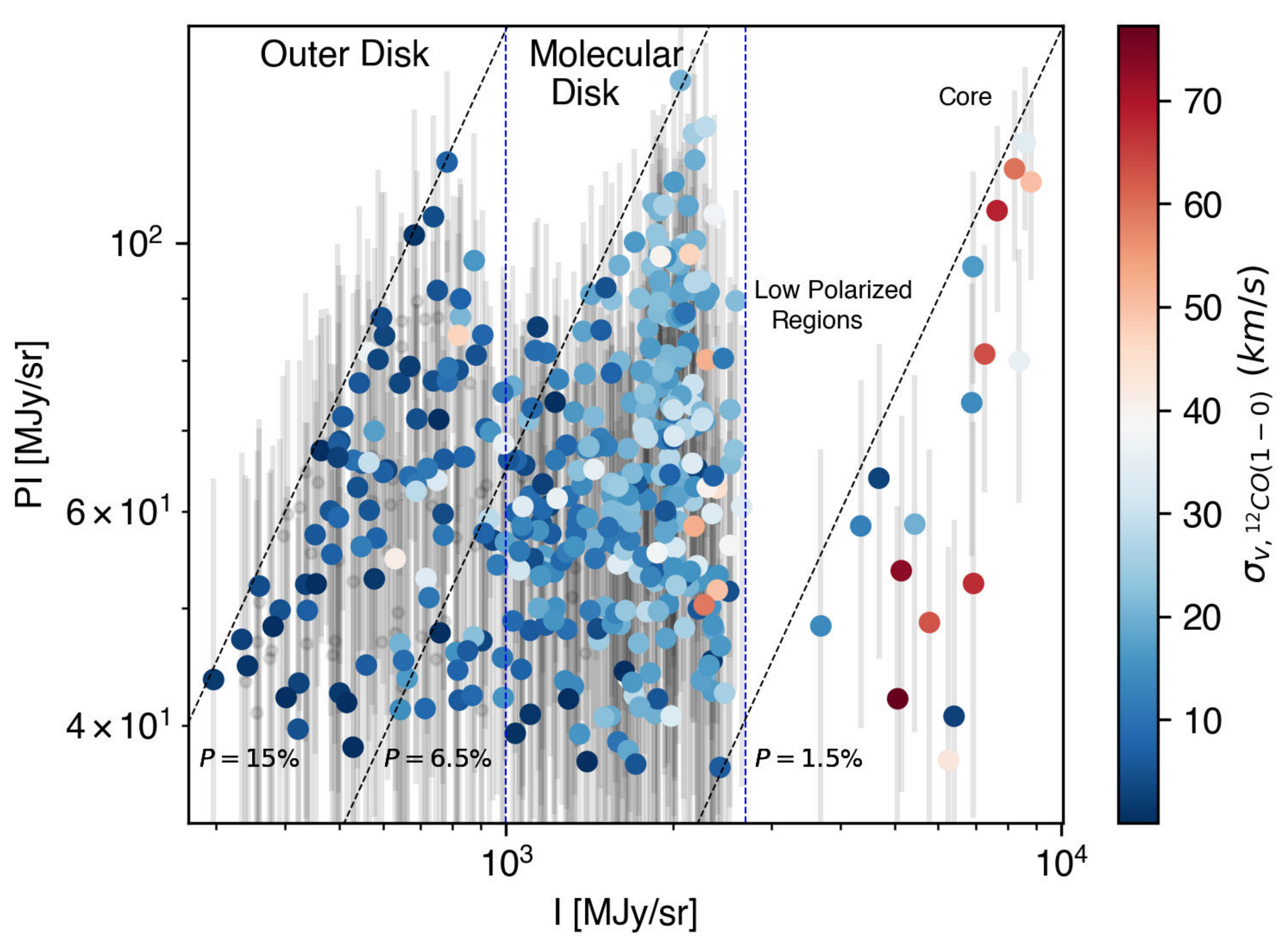


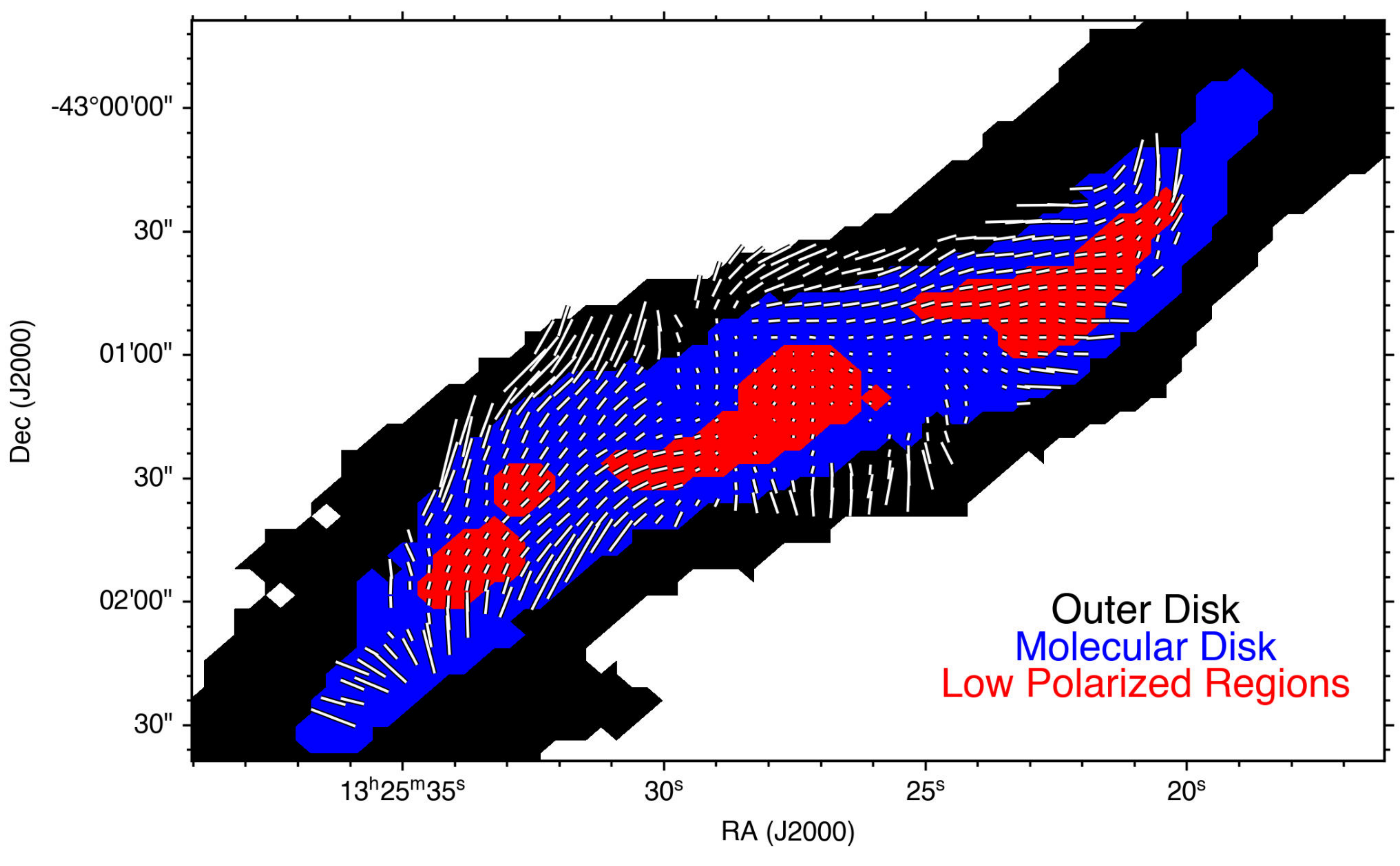
Angular dispersions (22.7°) are larger than those from observational uncertainties (<5°).



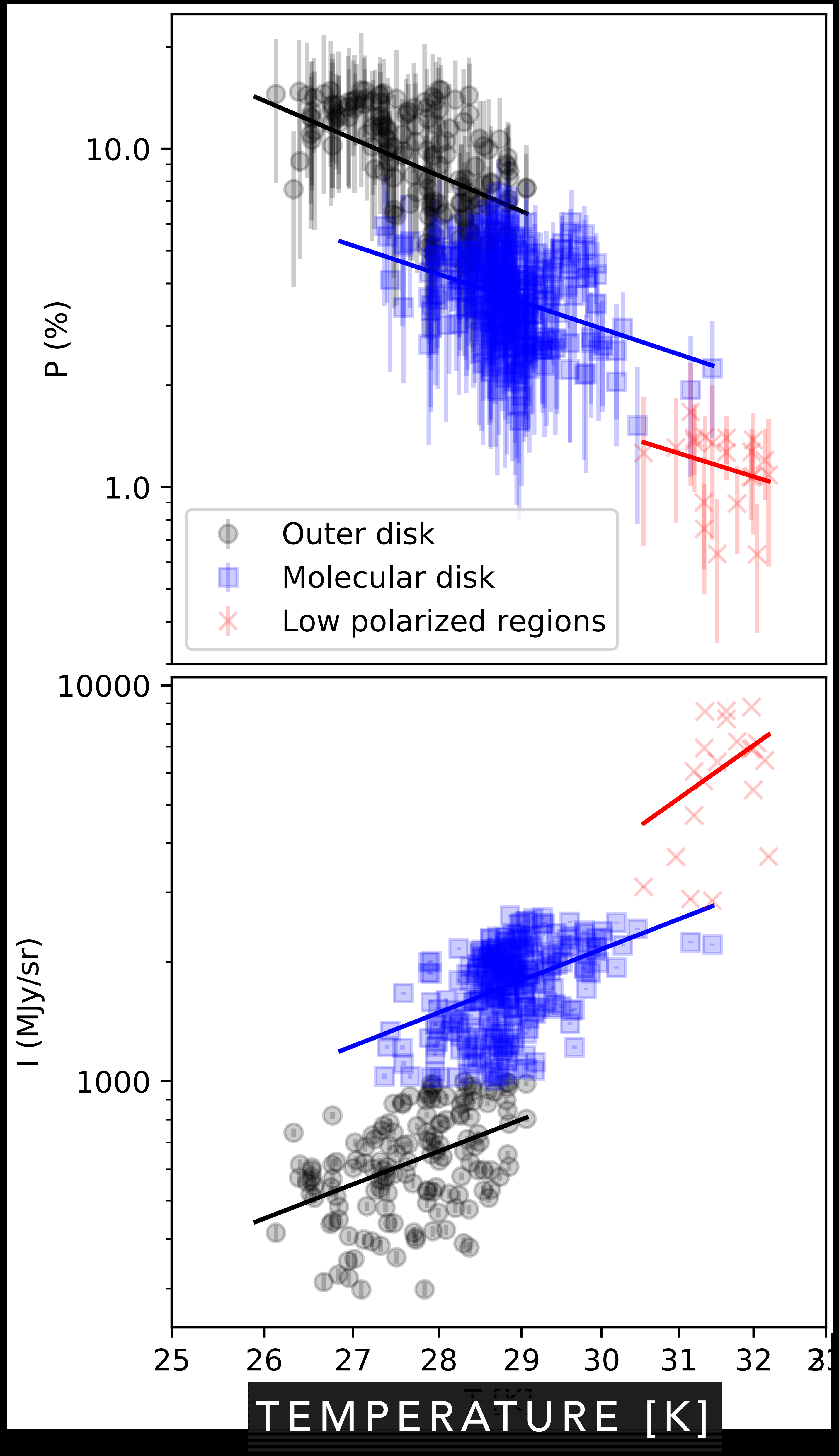
15

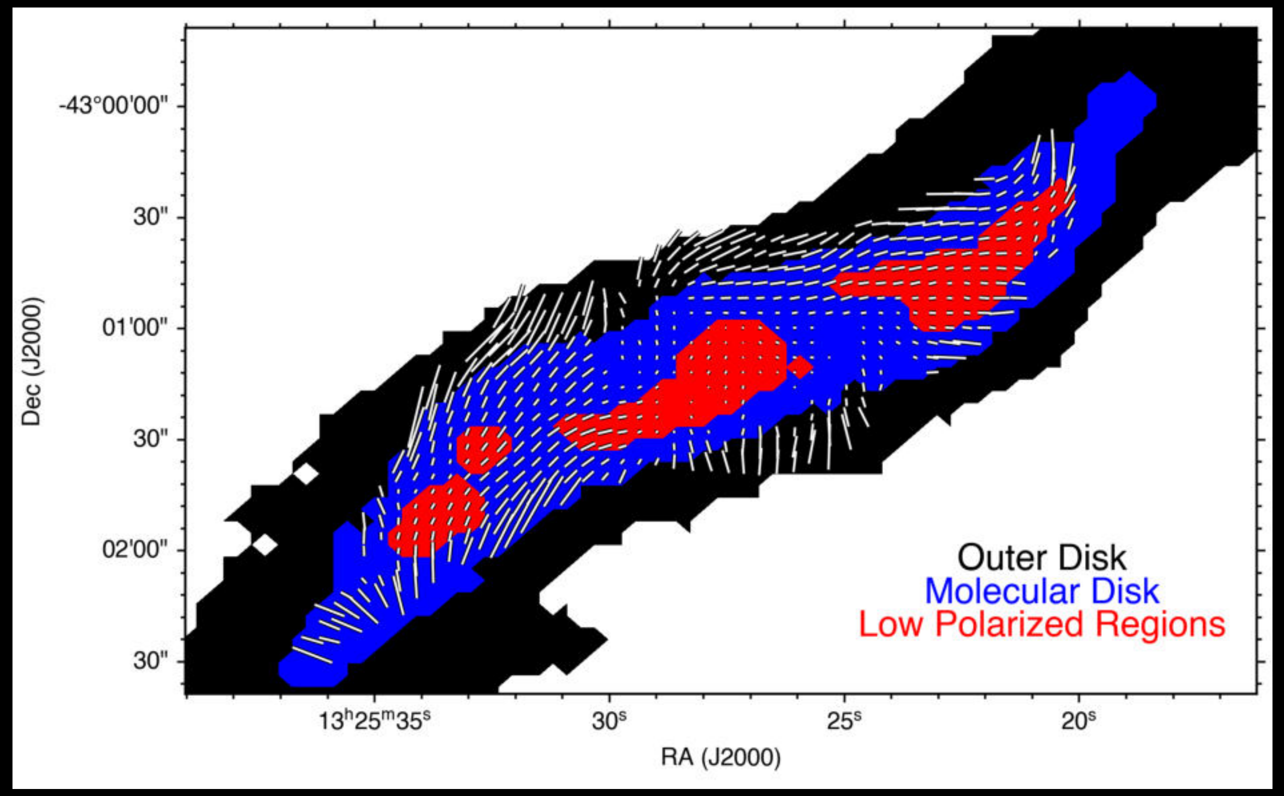
THE GALAXY CAN BE SEPARATED IN THREE PHYSICAL ZONES



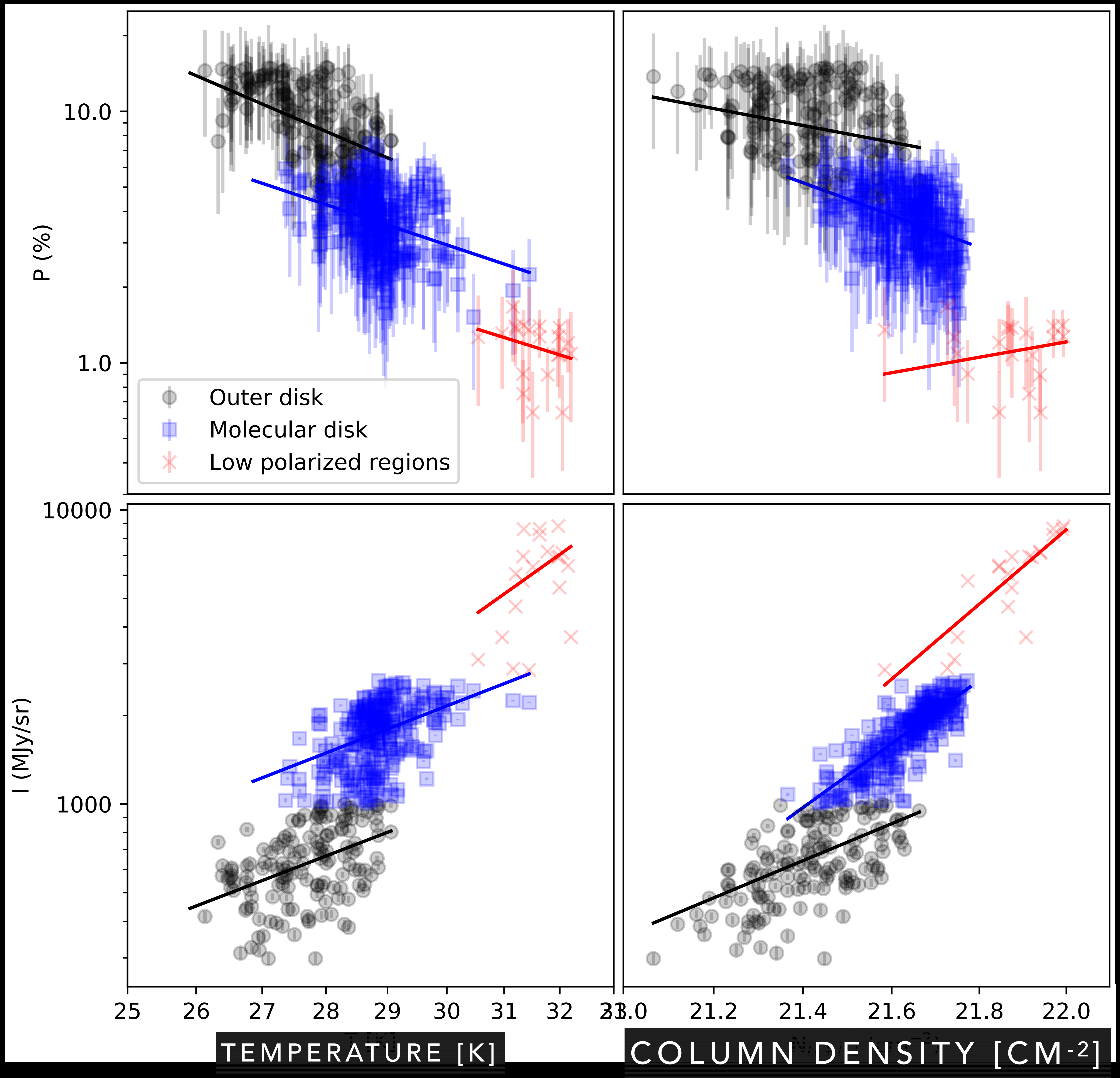


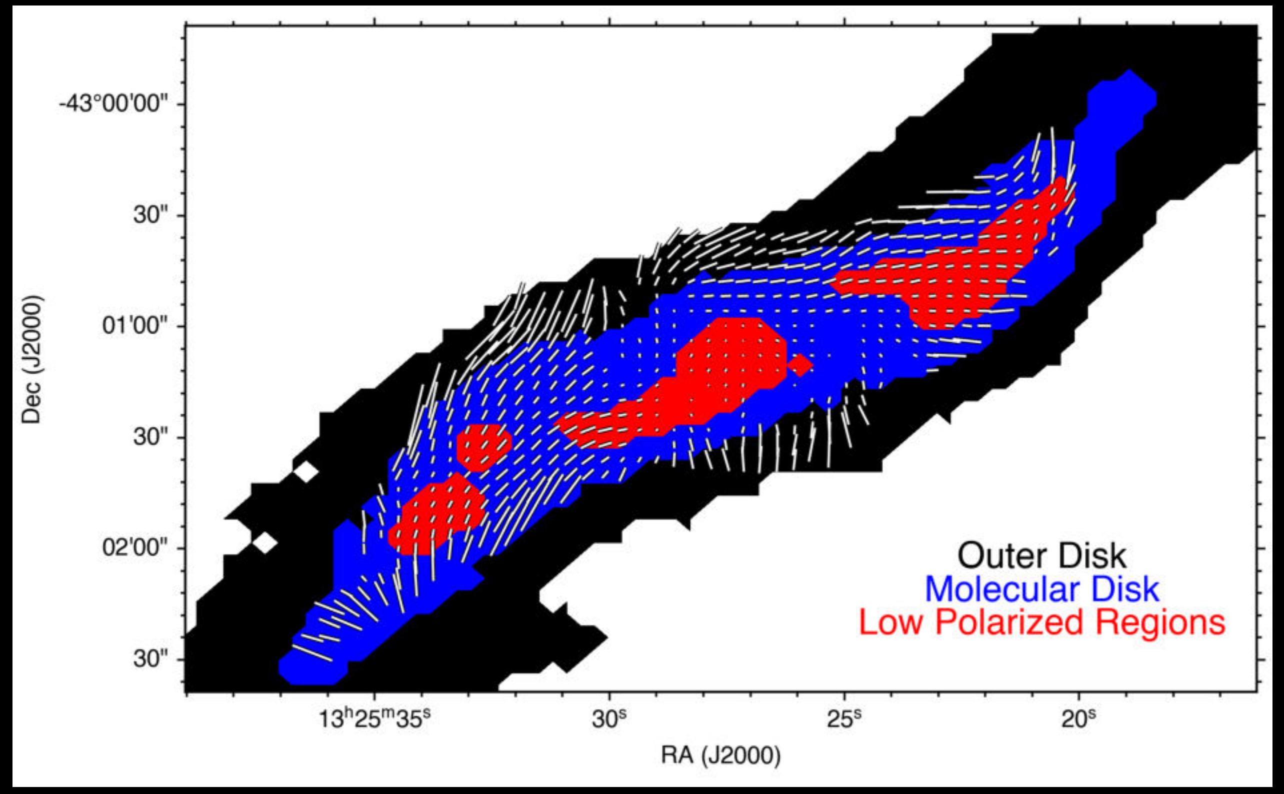
POLARIZATION DECREASES WITH INCREASING TEMPERATURE OF THE ISM





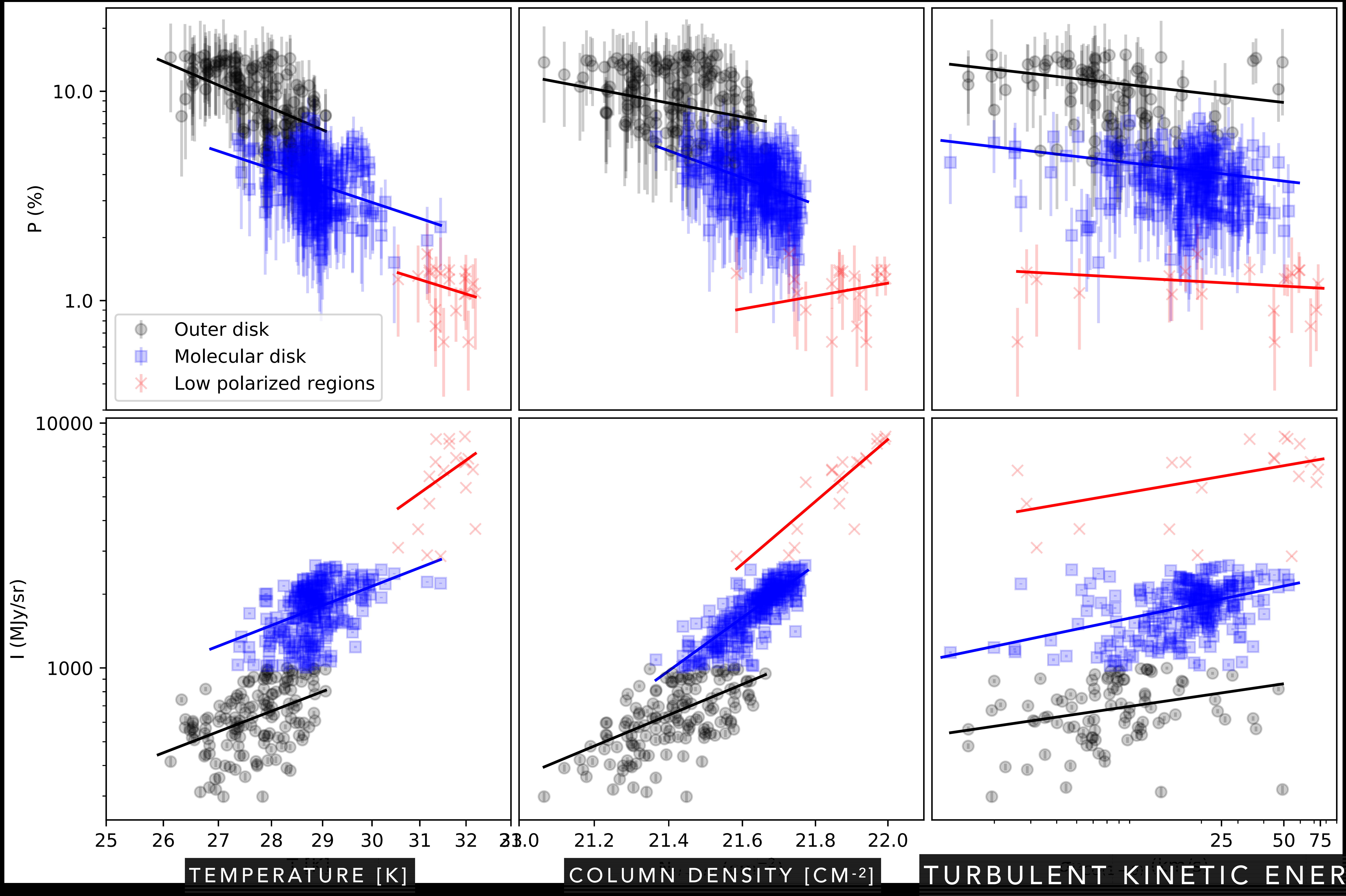
POLARIZATION DECREASES WITH INCREASING DENSITY OF THE ISM

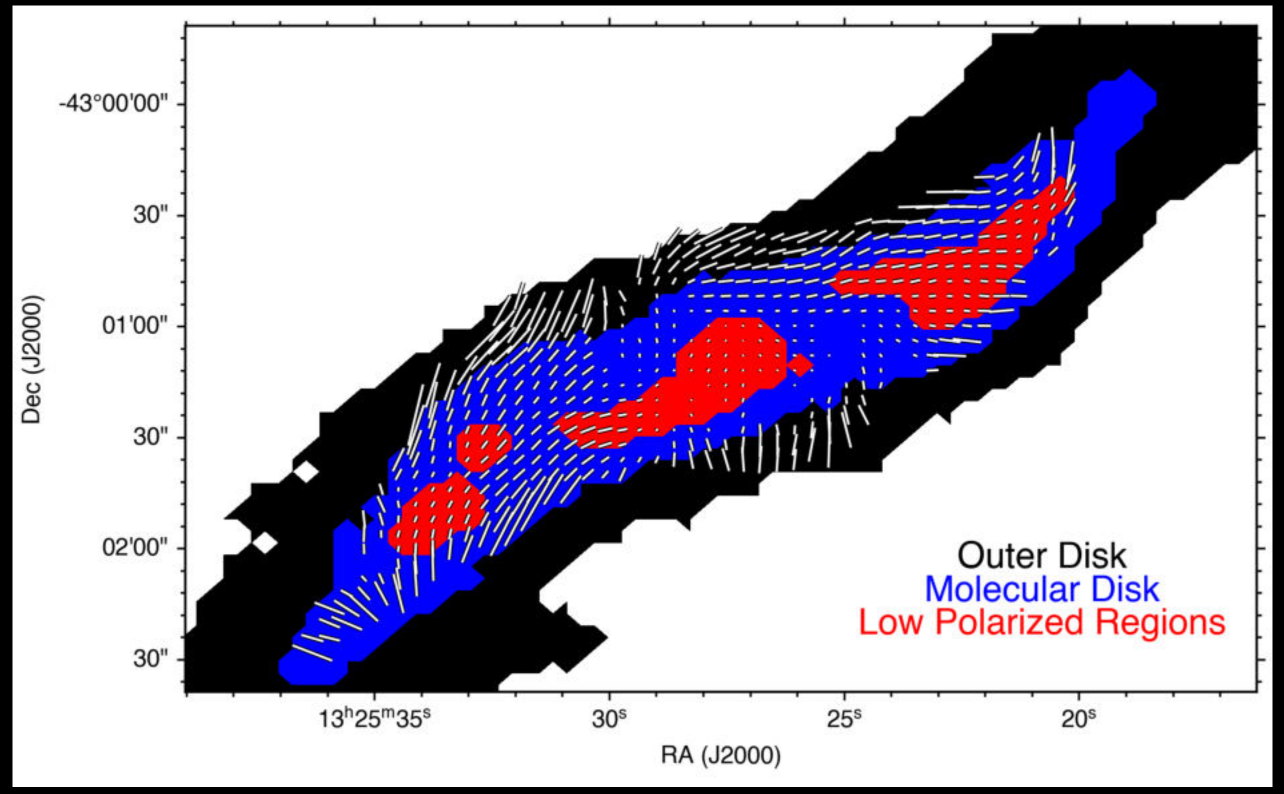




18

POLARIZATION DECREASES WITH INCREASING TURBULENT KINETIC ENERGY OF THE ISM

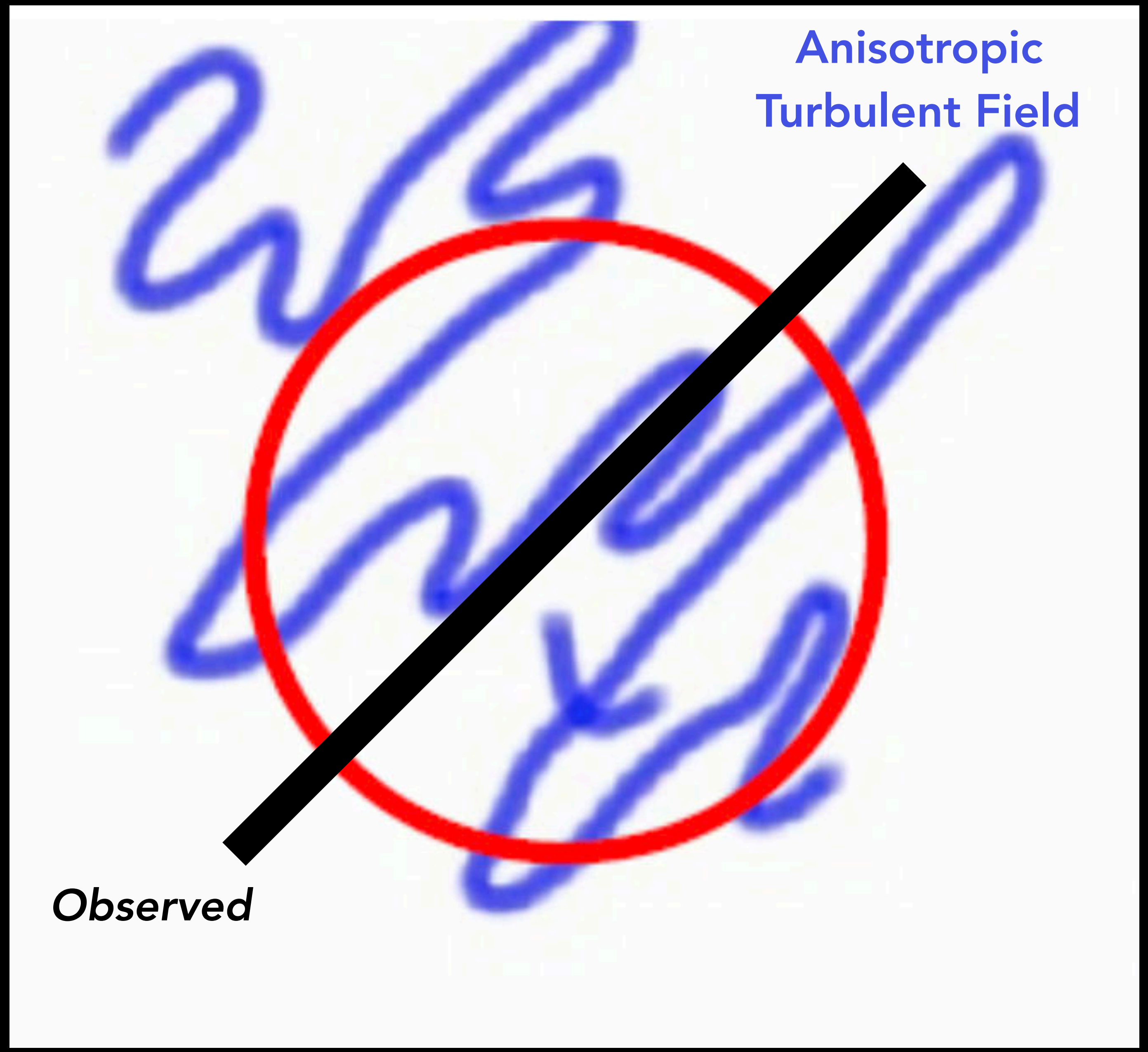




19

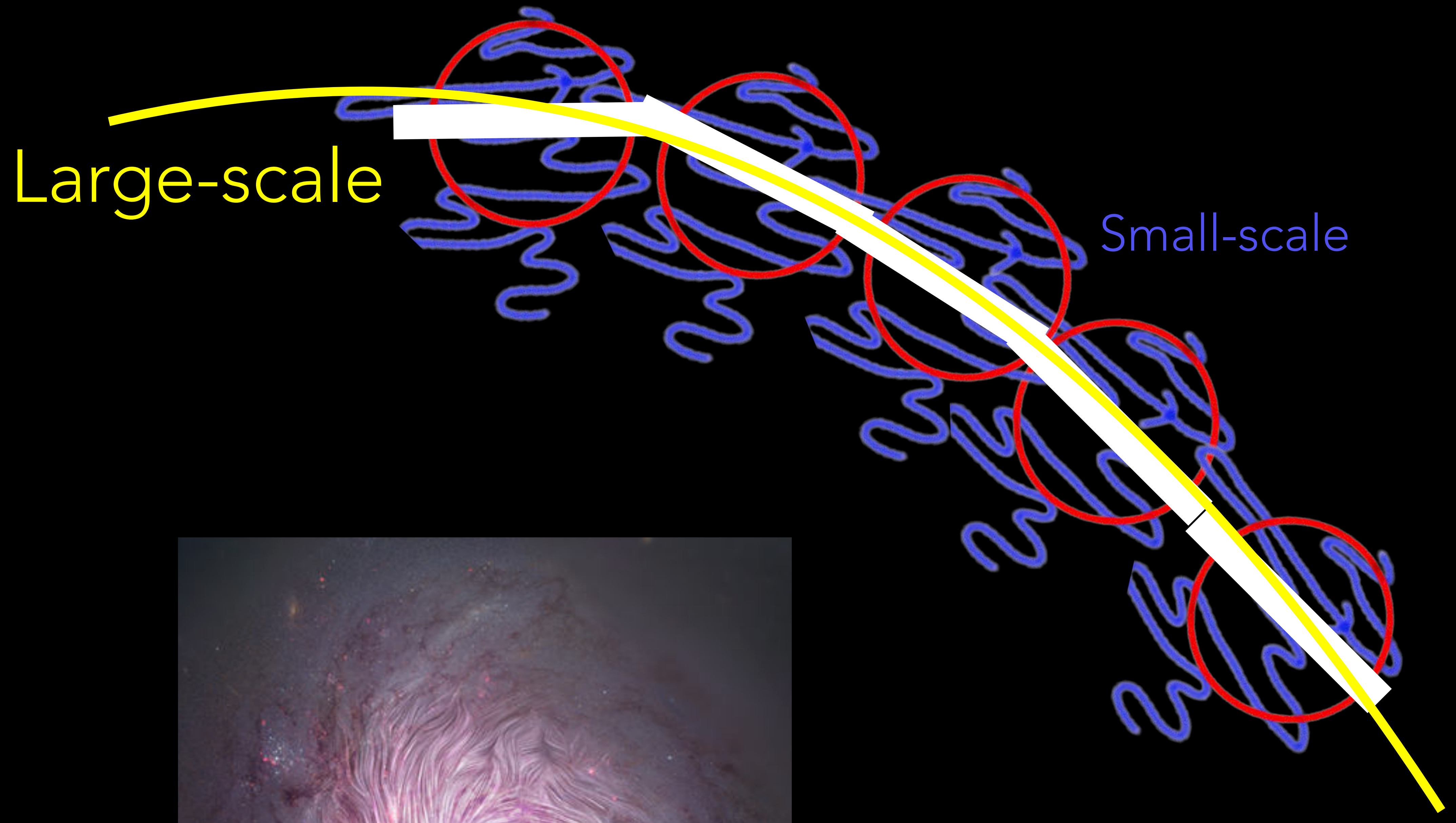
NGC 1068: LARGE-SCALE ORDERED FIELD DOMINATES

Example of B-field within a resolution element



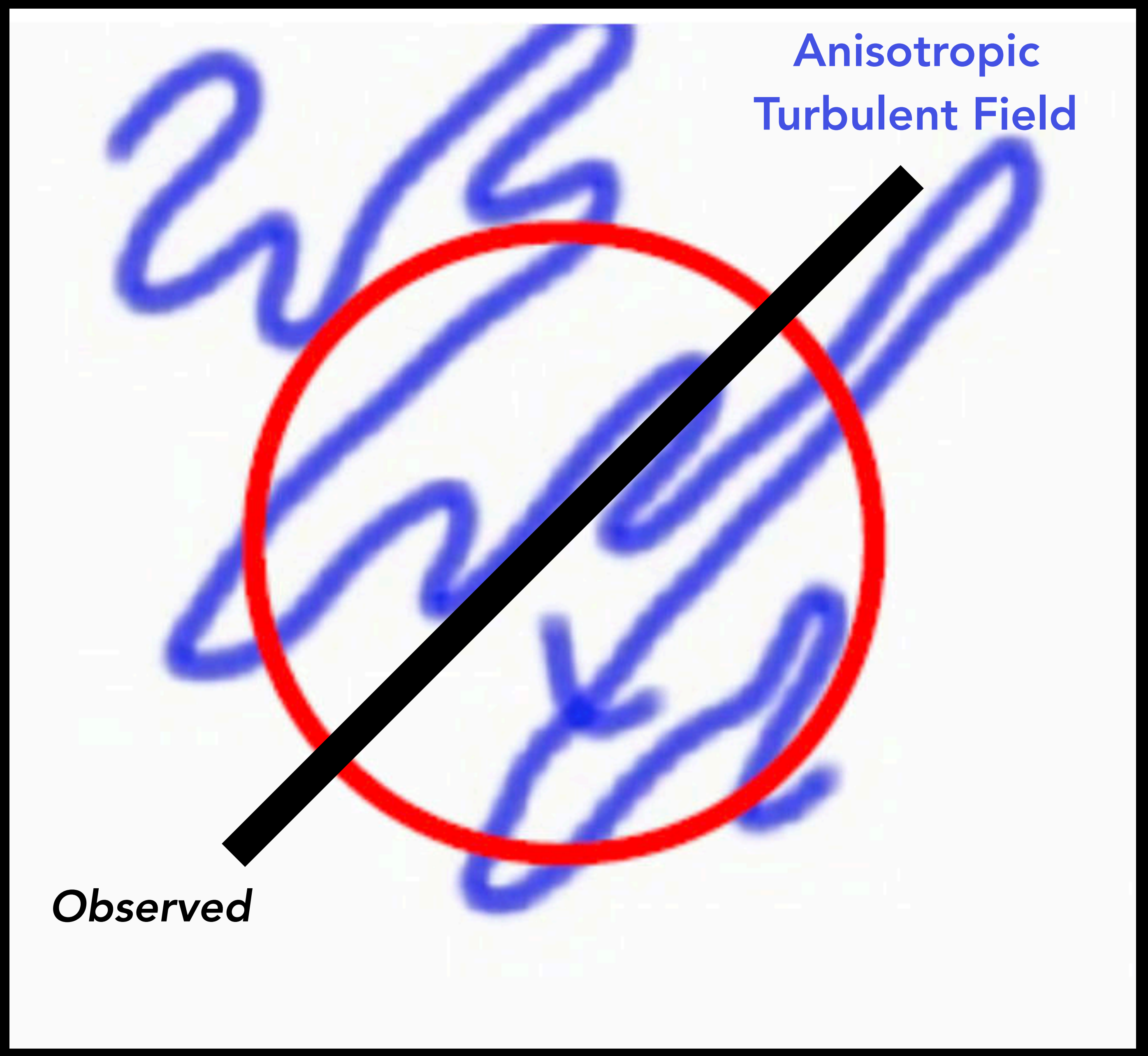
Beck et al. (2019)

NGC 1068: LARGE-SCALE ORDERED FIELD DOMINATES



NGC 1068

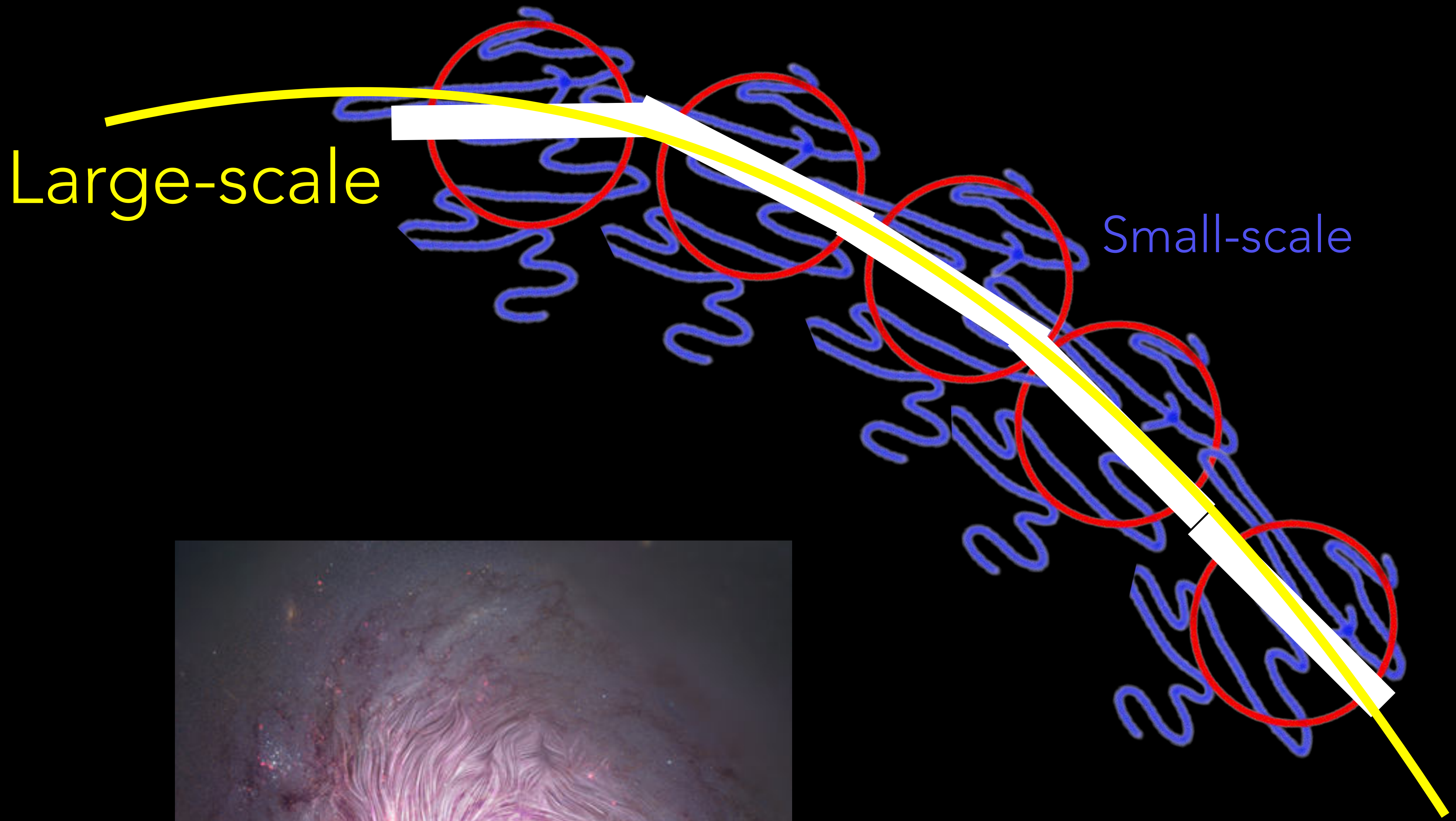
Example of B-field within a resolution element

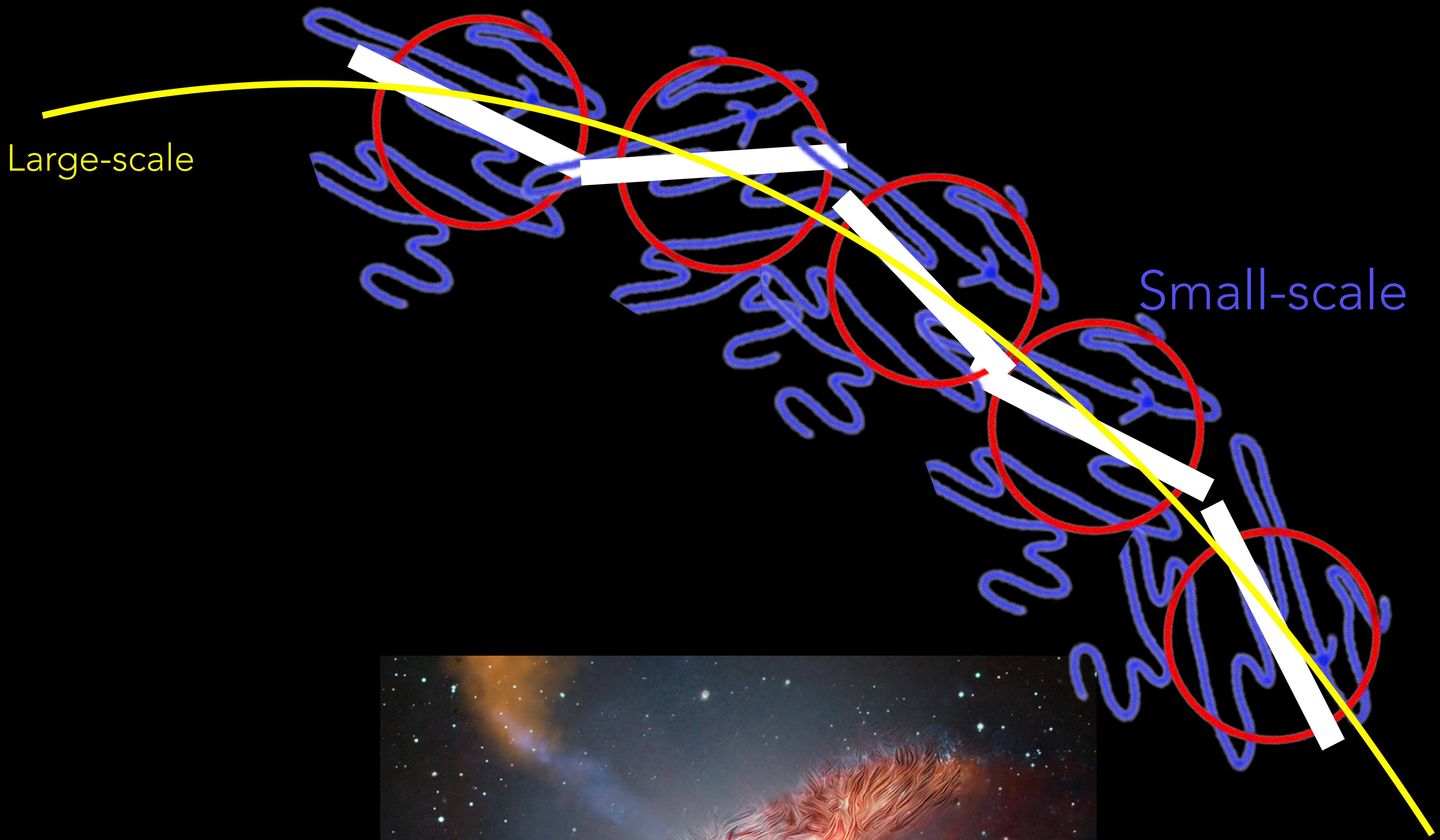


Beck et al. (2019)

21

CENTAURUS A: ANGULAR DISPERSION DUE TO SMALL-SCALE TURBULENT FIELDS





NGC 1068

Centaurus A

22

Leslie Proudfit, SOFIA   Lopez-Rodriguez (2021a, Nature Astronomy)

CENTAURUS A
MERGER GALAXY AND ACTIVE NUCLEI

- Turbulent B-field across the warped disk.

- B-field arises from small-scale dynamo action.

- Due to Large turbulence kinetic energy and fast rotating disk.