SOFIA Far-infrared Imaging Polarimetry of M82 and NGC 253: Exploring the Supergalactic Wind

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Primary Goal, study the role of magnetic fields in the interstellar medium.

Consider 3 regimes:

1. The magnetic field regulates, but does not dominate, the formation and evolution of structure in the ISM, e.g. molecular clouds as a whole (OMC1).
2. The magnetic field may dominate, strongly influencing the gas, and must be efficiently dissipated for structure to form, e.g. pre-stellar cores.
3. The magnetic field is along for the ride and reveals motion and structure in the gas and dust, e.g. M82.

Advantages and Complementarity of FIR Polarimetry

1. Optical-NIR polarimetry suffers from scattering, which is intrinsically highly polarized.
2. Radio Synchrotron has to deal with Faraday Rotation, although this can be removed in many cases.
3. Synchrotron emission samples the relativistic electrons, but FIR more closely samples the total gas and dust densities.
4. At FIR wavelengths the emission is sensitive to temperature, helping to separate different regions along the line-of-sight.

For example, consider M51

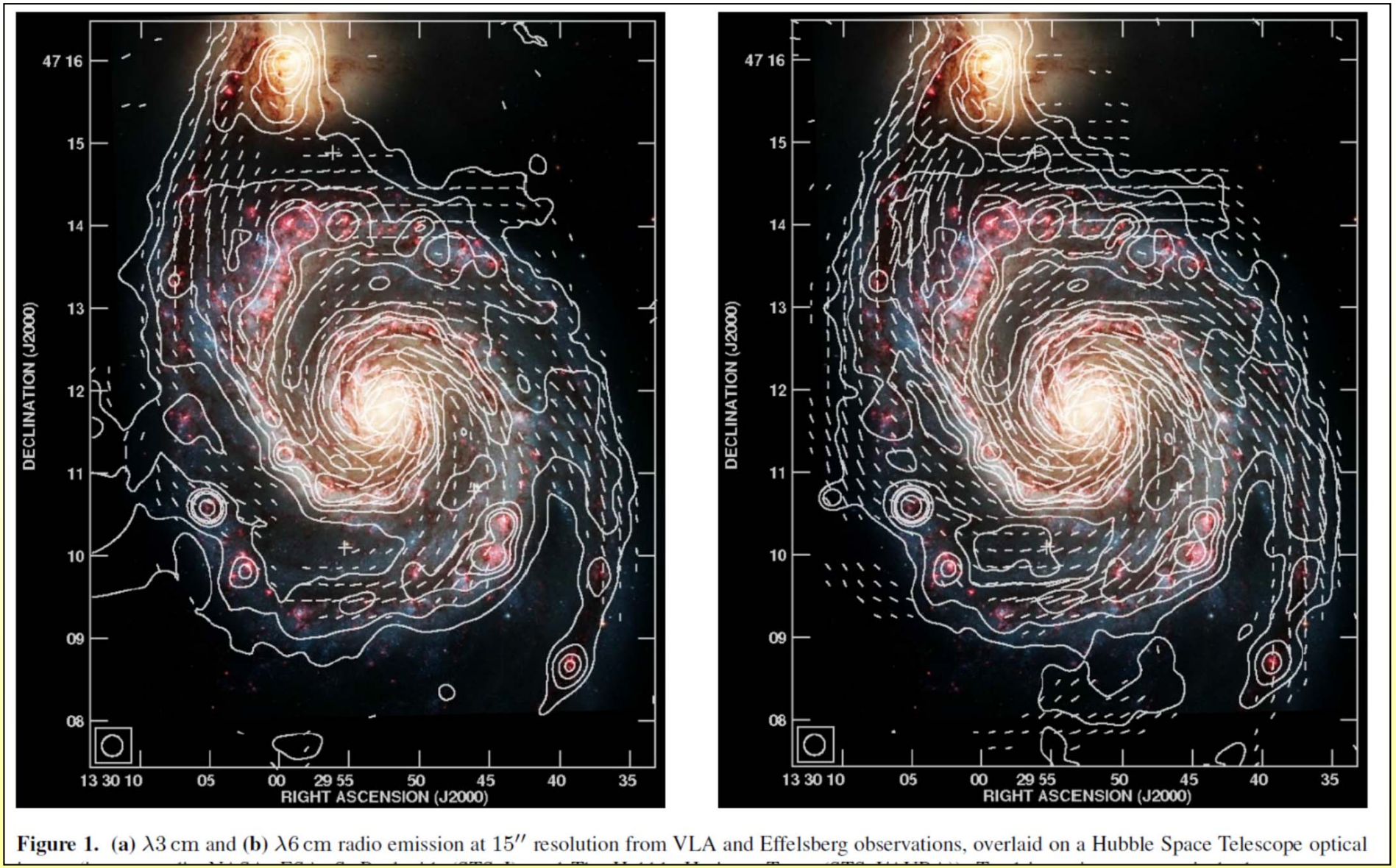
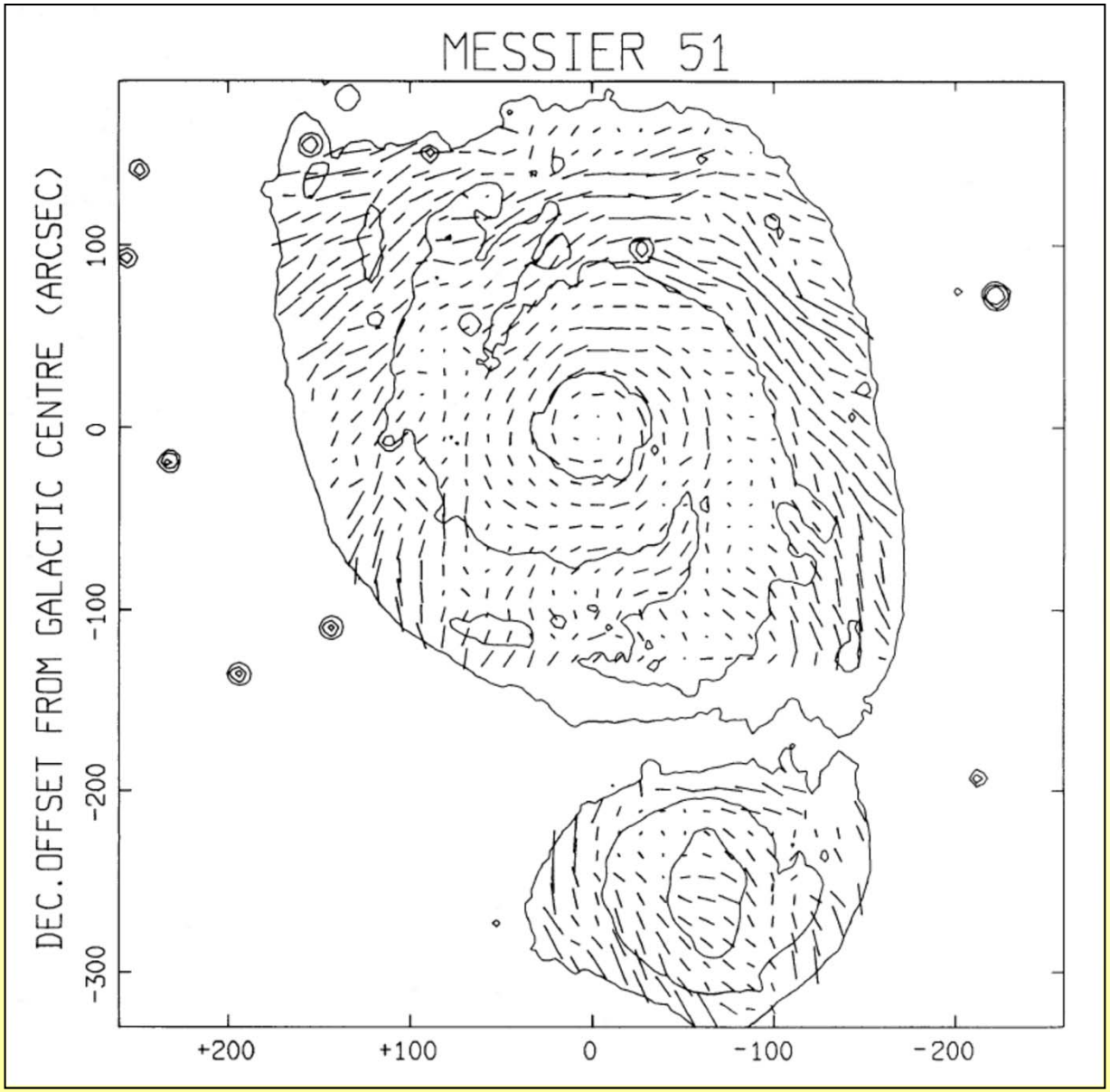


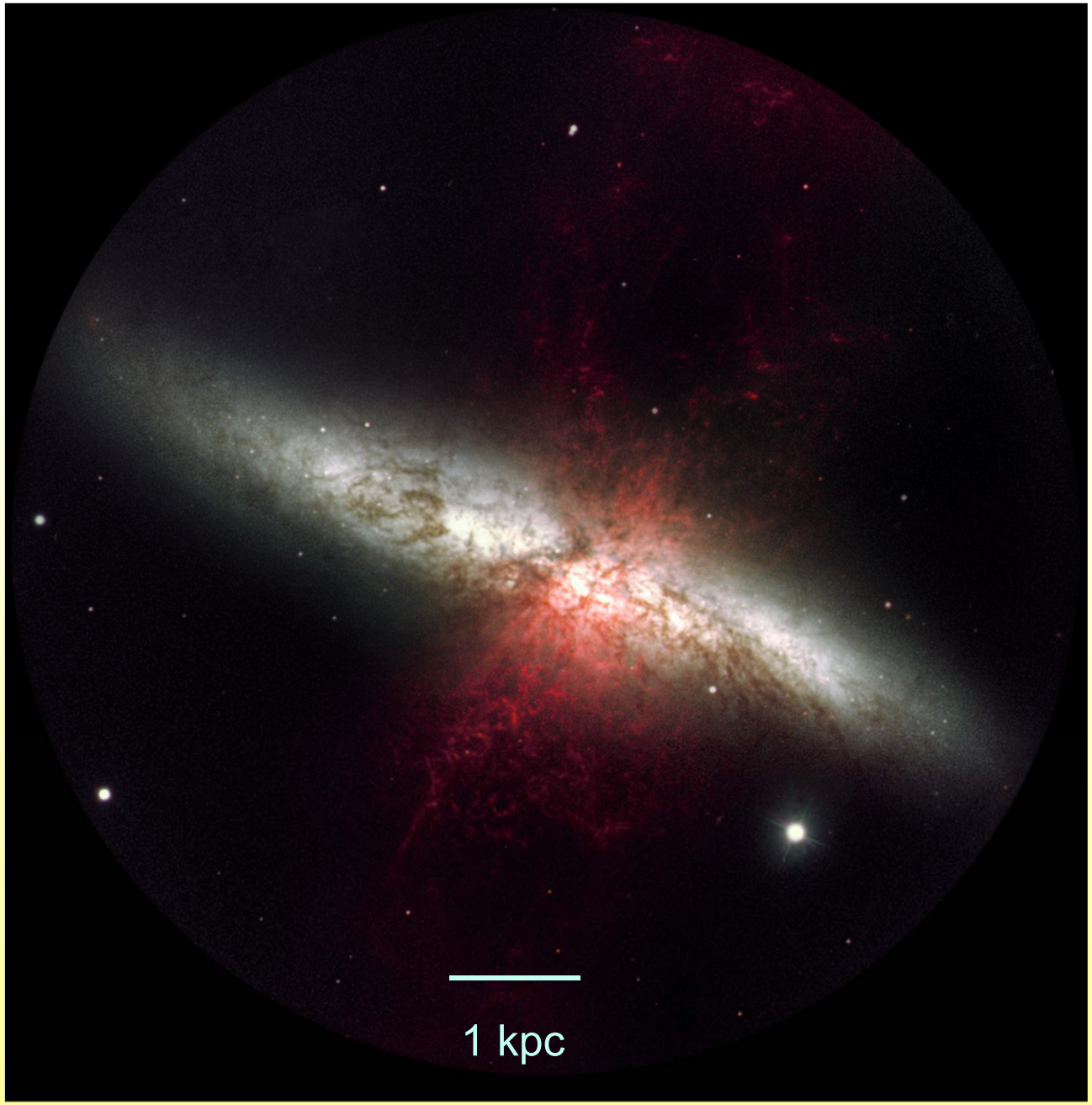
Figure 1. (a) $\lambda 3$ cm and (b) $\lambda 6$ cm radio emission at $15''$ resolution from VLA and Effelsberg observations, overlaid on a Hubble Space Telescope optical

Radio, Fletcher et al. (2011) overlaid on an HST image

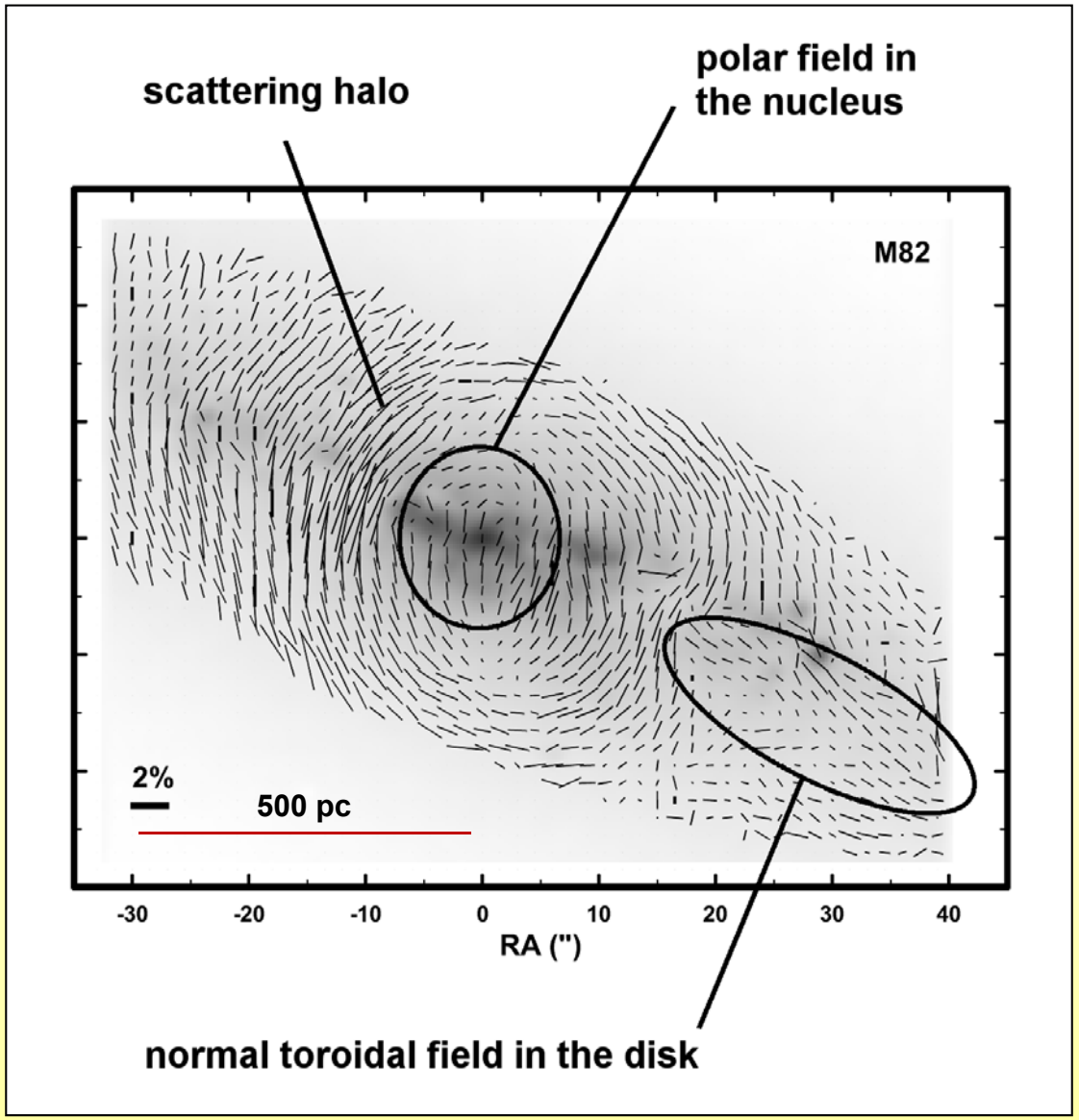
Optical

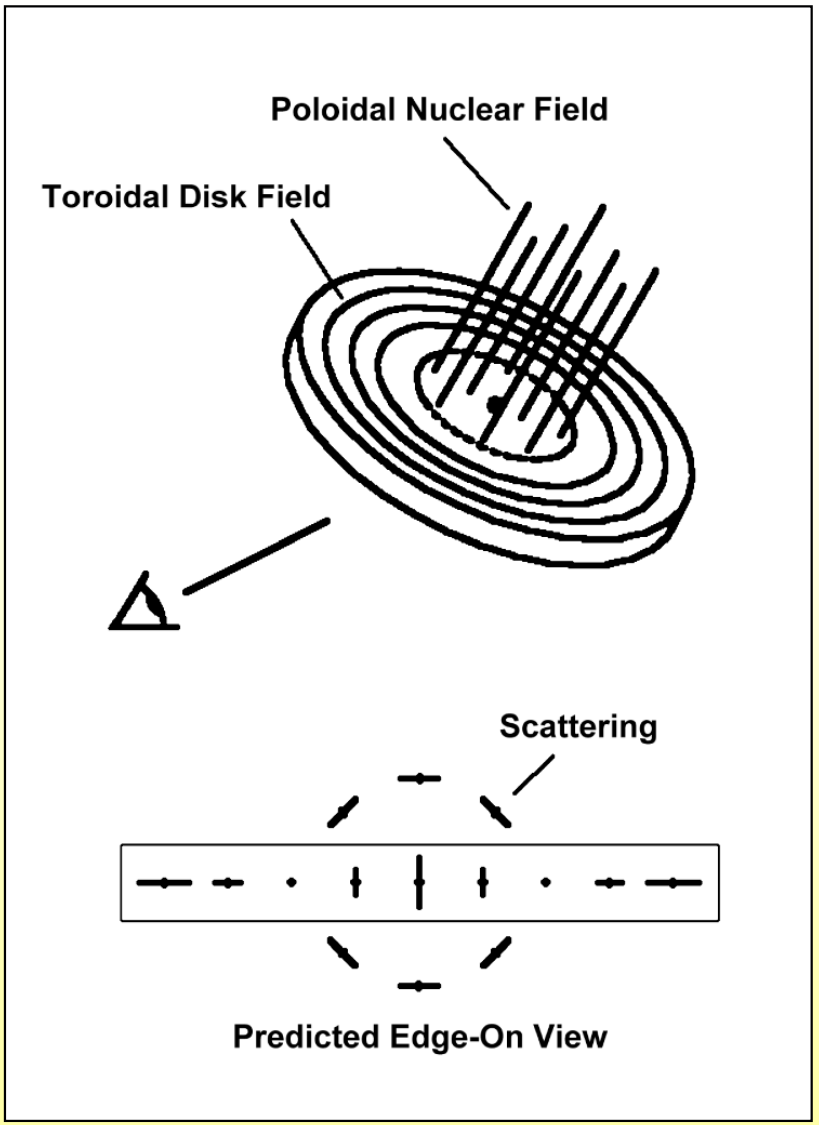


Scarrott et al. 1987 claimed to see spiral structure.
BUT! Pavel and Clemens (2012) find NOTHING at 1.65μm



Credit:Pablo Rodríguez-Gil (ING/IAC) and Pablo Bonet (IAC).

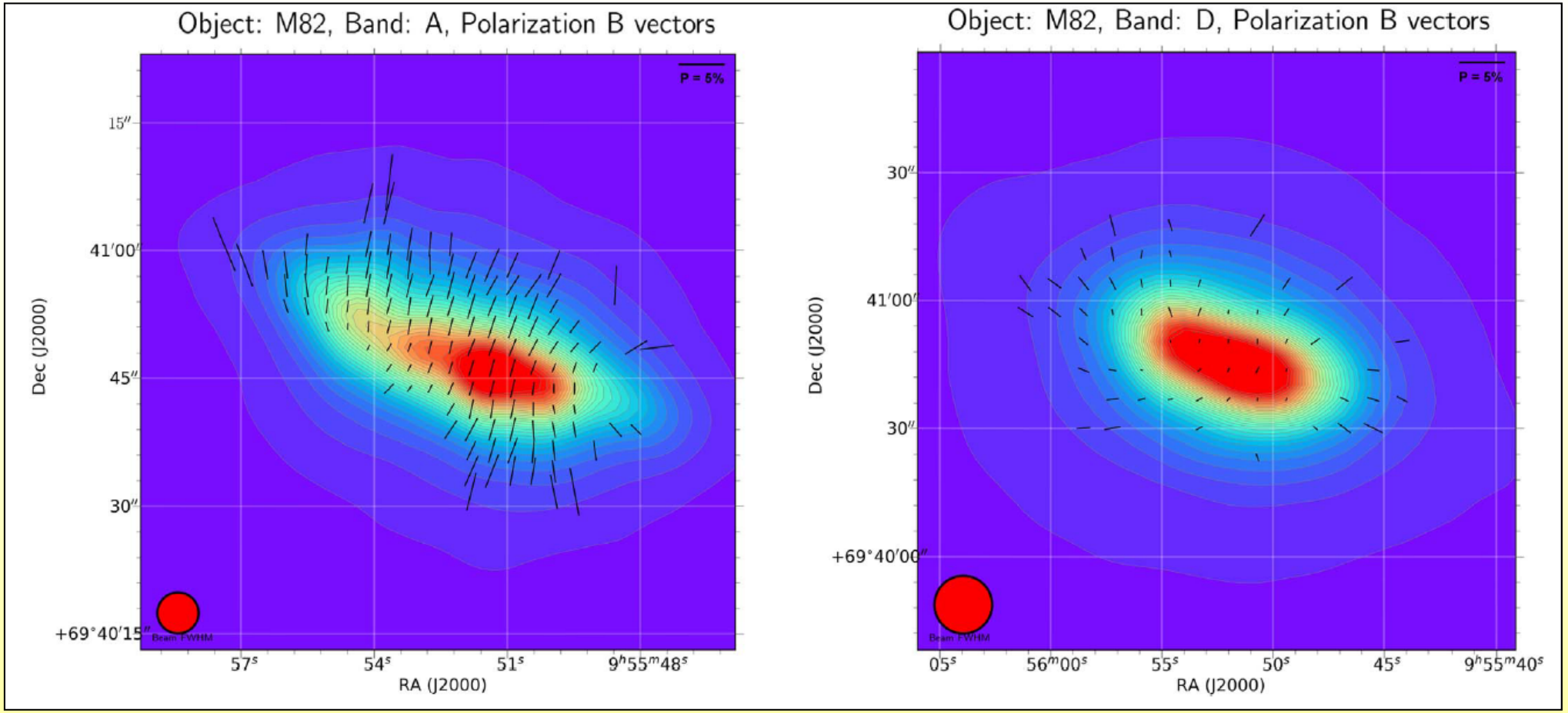


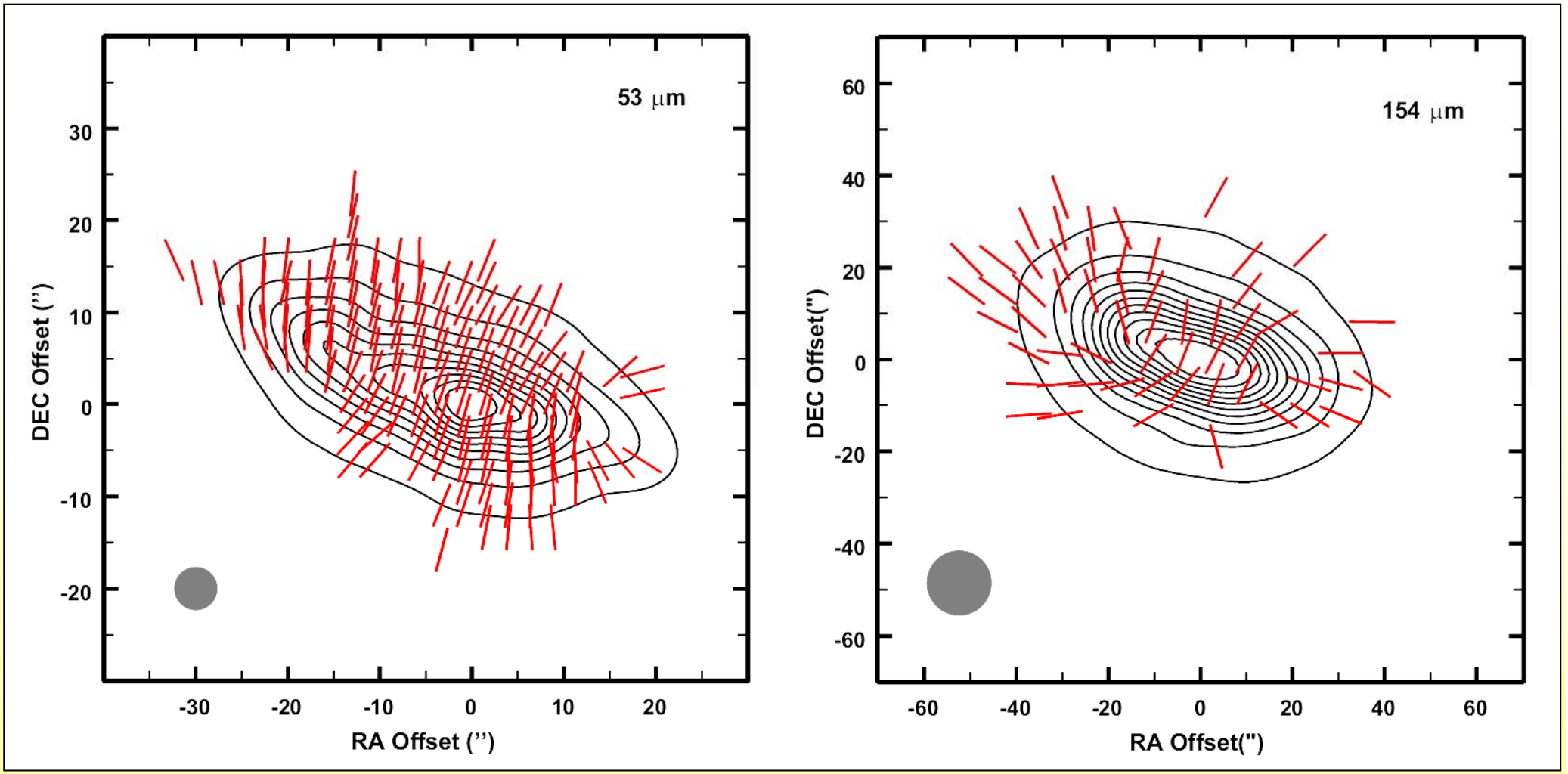


1.65 μm Jones, 2000

53 μm

154 μm


Object: M82, Band: A, Polarization B vectors
P = 5%
15″
41′00″
45″
30″
+69°40′15″
Dec (J2000)
57ˢ
54ˢ
51ˢ
9ʰ55ᵐ48ˢ
RA (J2000)
Object: M82, Band: D, Polarization B vectors
P = 5%
30″
41′00″
30″
+69°40′00″
Dec (J2000)
05ˢ
56ᵐ00ˢ
55ˢ
50ˢ
45ˢ
9ʰ55ᵐ40ˢ
RA (J2000)

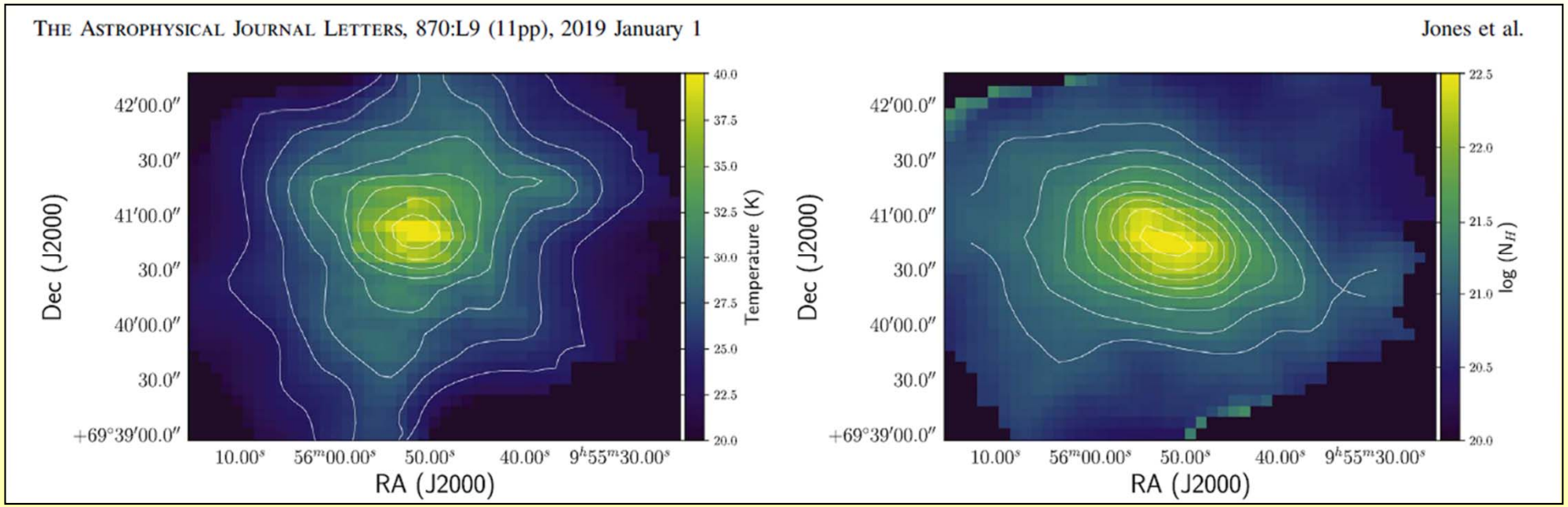

53 μm
DEC Offset (")
RA Offset (")
30
20
10
0
-10
-20
-30
-20
-10
0
10
20
154 μm
DEC Offset(")
RA Offset(")
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

500 pc

500 pc

Temperature

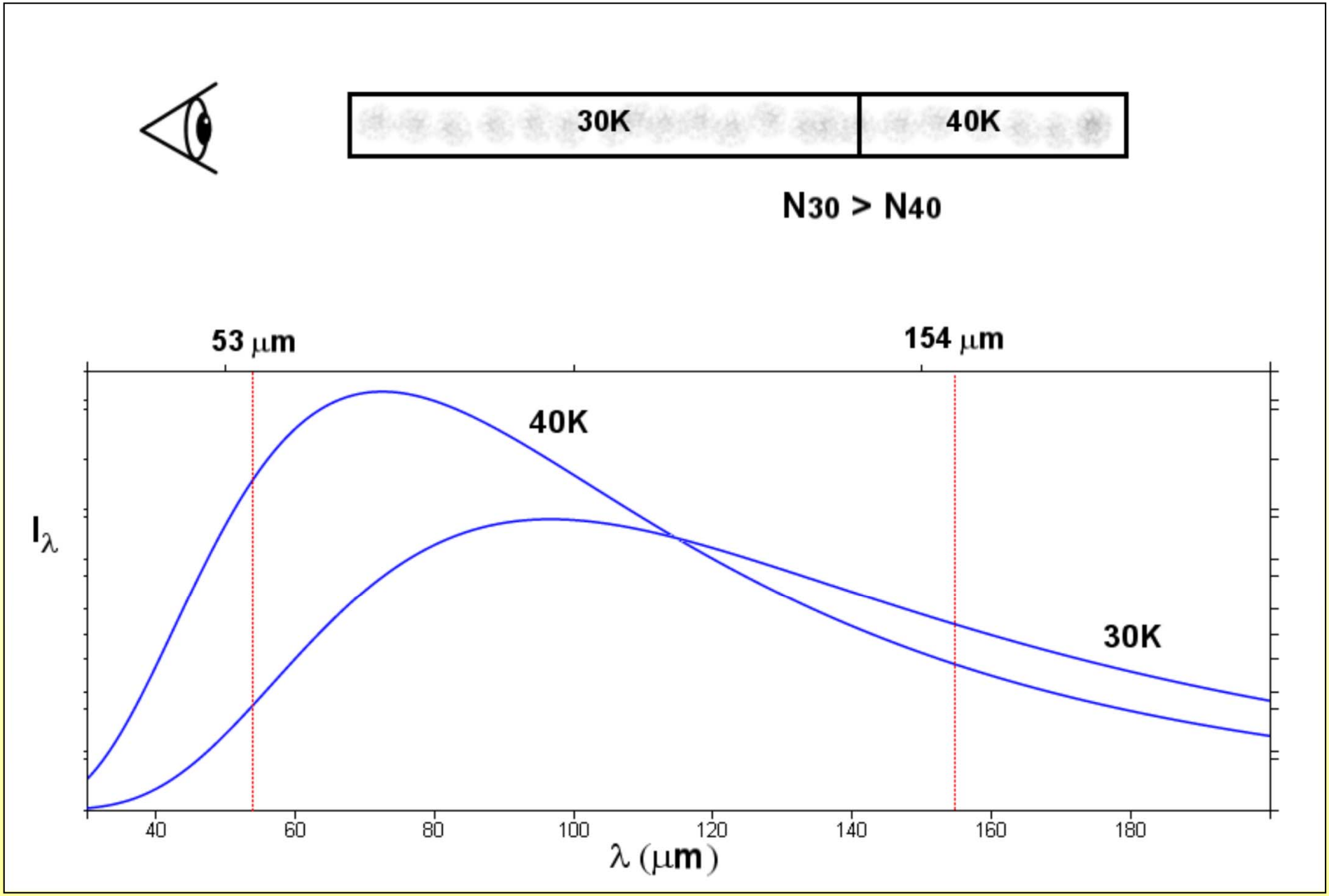
Column Density

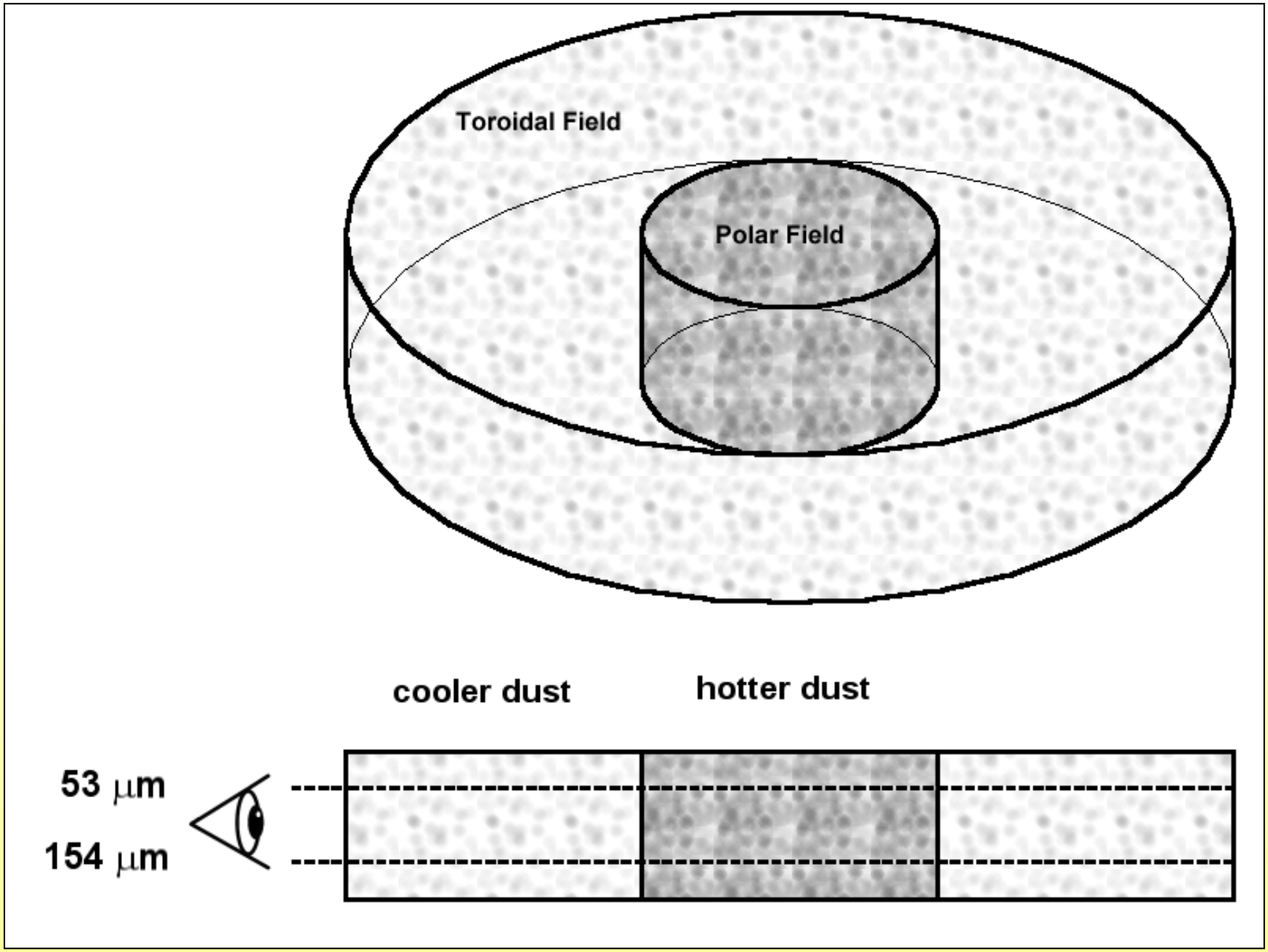


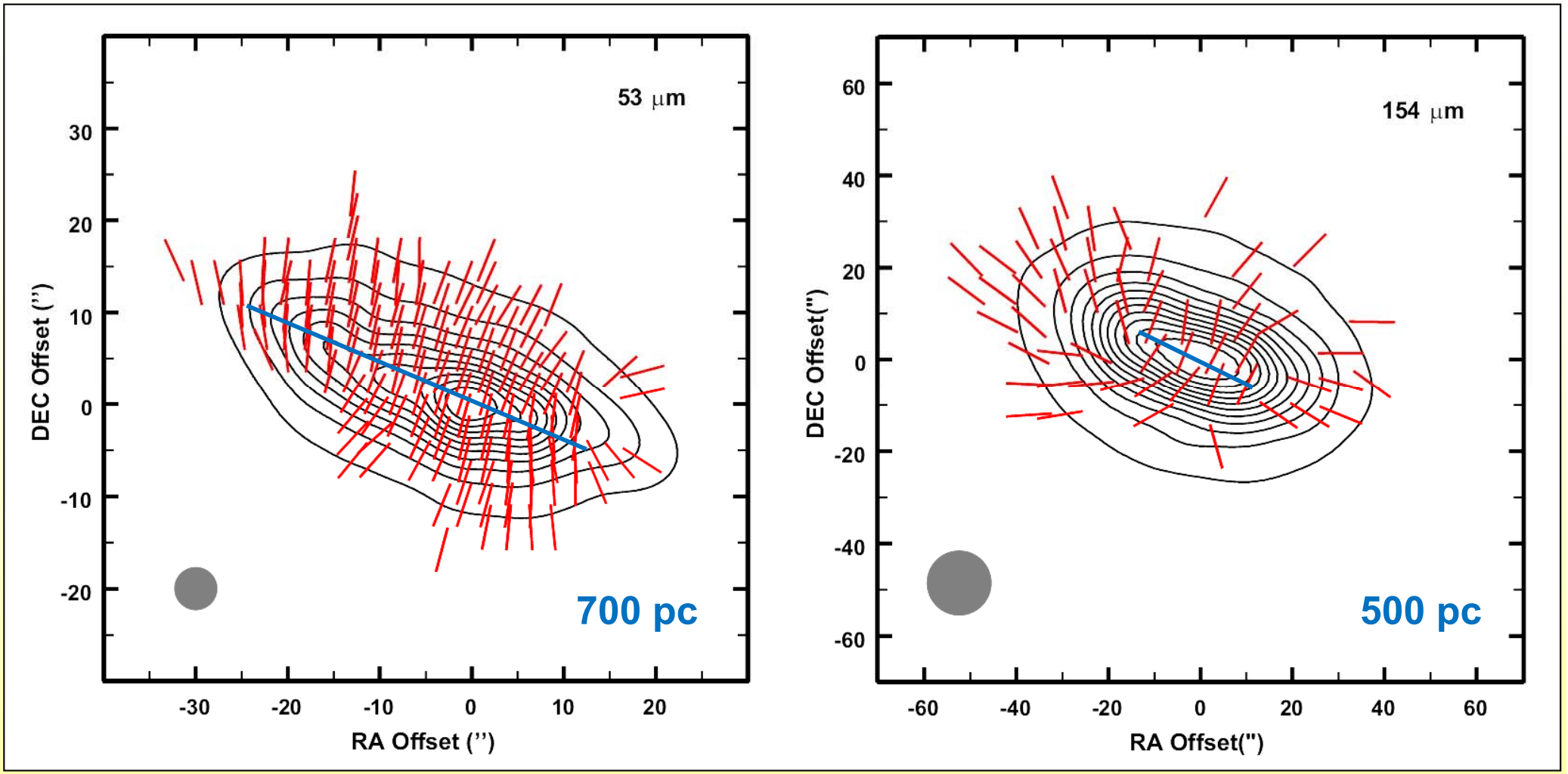
25 – 40K

1 kpc

1 – 30 A_V


30K
40K
N30 > N40
53 μm
154 μm
40K
30K
Iλ
40
60
80
100
120
140
160
180
λ (μm)


Toroidal Field
Polar Field
cooler dust
hotter dust
53 μm
154 μm

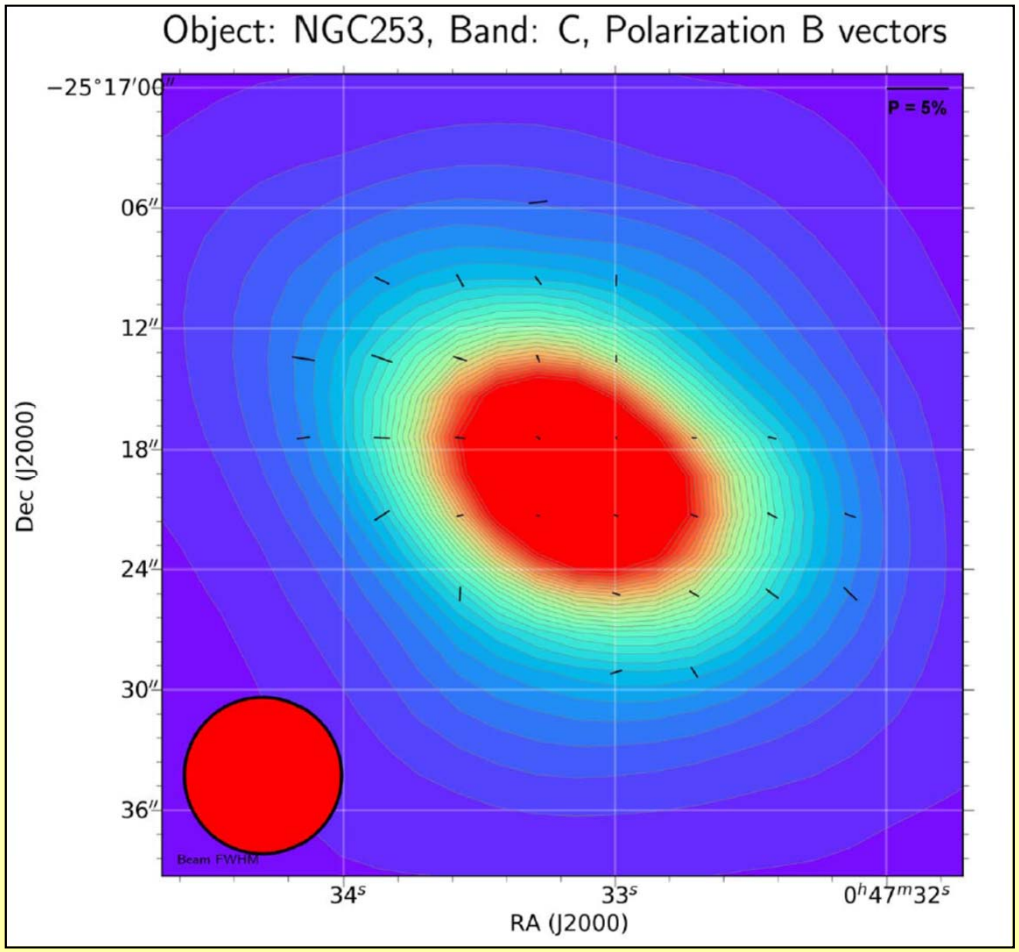

53 μm
DEC Offset (")
RA Offset (")
700 pc
154 μm
DEC Offset(")
RA Offset(")
500 pc

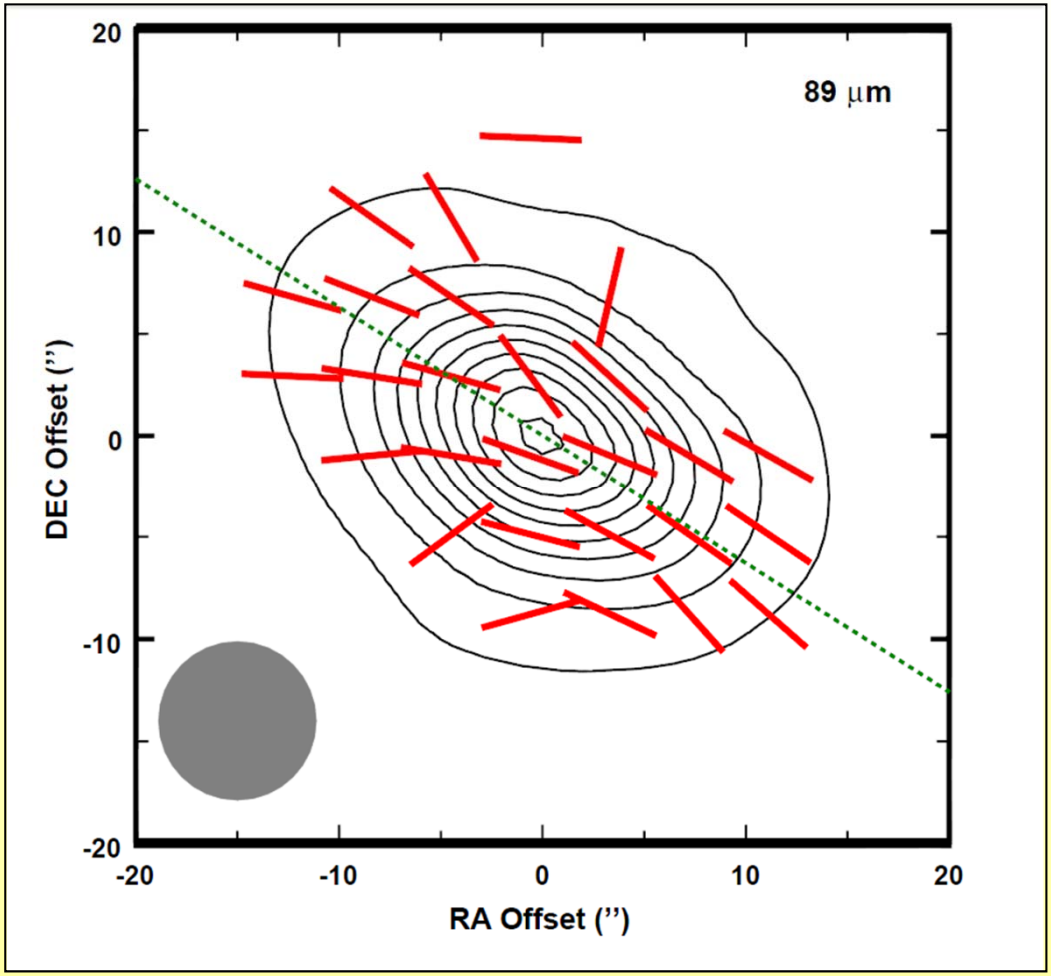
500 pc

500 pc

NGC 253 APD - R. Jay GaBany

89 μm


Object: NGC253, Band: C, Polarization B vectors
P = 5%
−25°17′06″
06″
12″
18″
24″
30″
36″
Dec (J2000)
34ˢ
33ˢ
0ʰ47ᵐ32ˢ
RA (J2000)
Beam FWHM


89 μm
20
10
0
-10
-20
DEC Offset (")
-20
-10
0
10
20
RA Offset (")

Summary:

1. HAWC+ is a very effective instrument for measuring the FIR polarization of extragalactic sources.
2. The FIR has advantages over synchrotron polarimetry and interstellar polarization in transmission (optical-NIR).
3. A 700 pc region in M82 has a vertical magnetic field stretching at least 200 pc above and below the plane.
4. The transition from vertical to parallel field geometry along the disk is wavelength dependent, with the transition taking place sooner at the longer wavelength.
5. The hotter dust contributes more to the 53μm emission, and indicates the vertical field geometry is associated with the central region.
6. This outflow sits within a larger, cooler disk with a more typical planar geometry.
7. NGC 254 may show a similar geometry, but the observations are inconclusive. Its tilt may reduce the contrast between the polarized emission in the outflow and in the disk.

Conclusion:
HAWC+ is Awesome!