ASTRON

Netherlands Institute for Radio Astronomy

Magnetic Fields in Starforming Galaxies:

From large scales to small

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Extragalactic Radio Surveys meeting

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Outline

Tracers of magnetic fields in galaxies

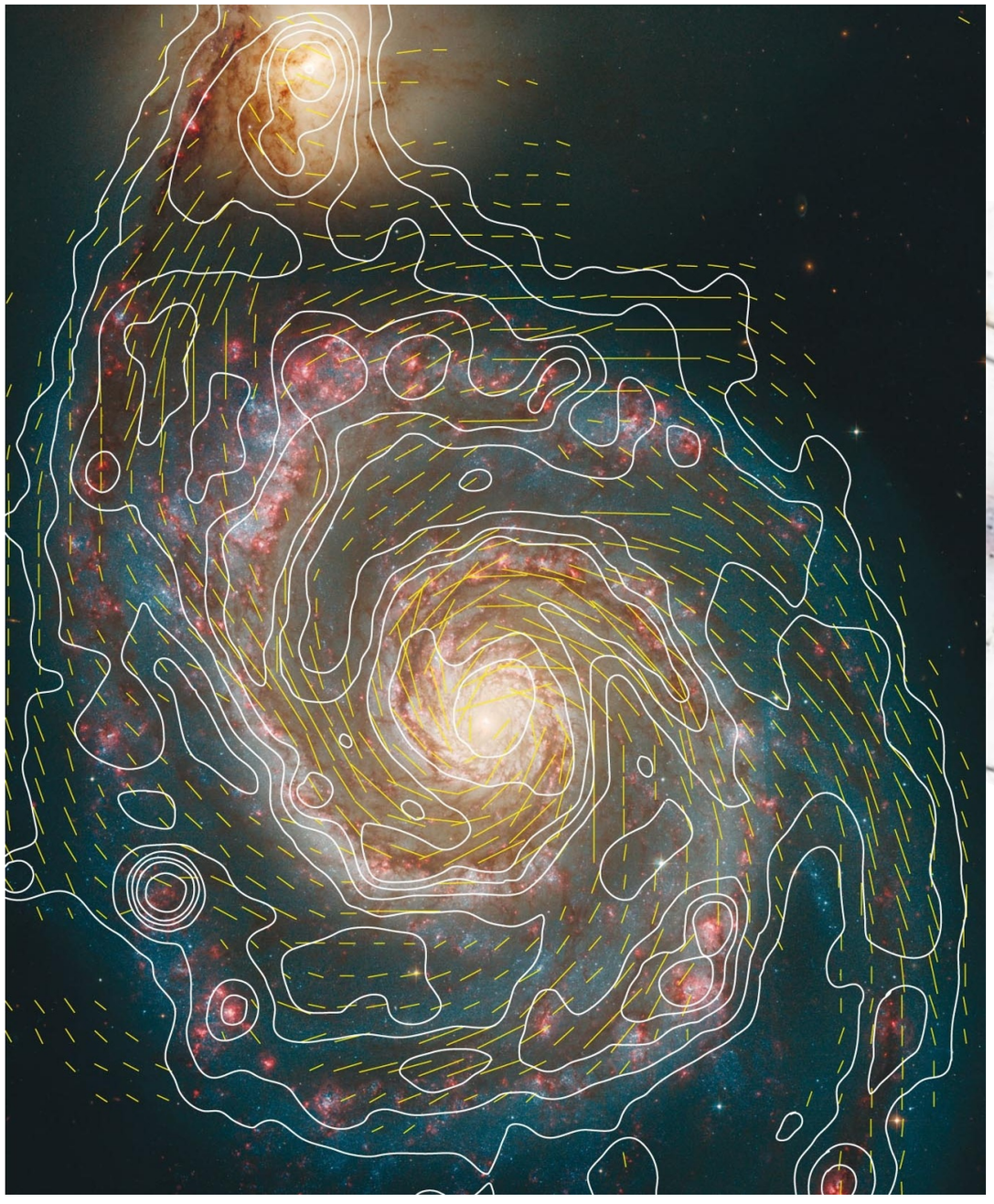
Large scale galactic magnetic fields
"Peeling the onion" in galaxies

Small scale galactic magnetic fields
The radio polarimetry frontier

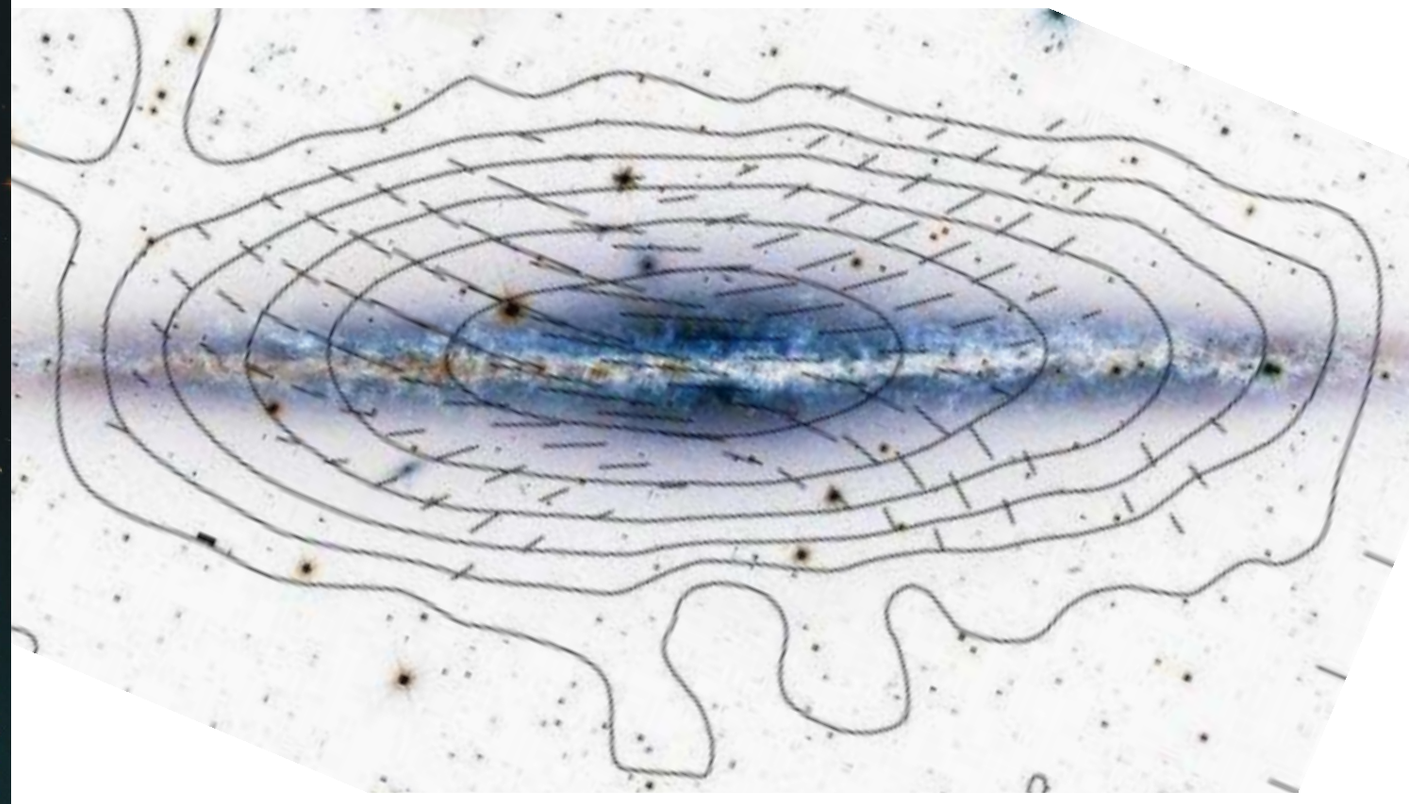
Present and future magnetism surveys

Magnetic fields in galaxies

- Broadly speaking: magnetic fields follow the optical spiral pattern, and show an X-shaped morphology in the halo



Fletcher & Beck

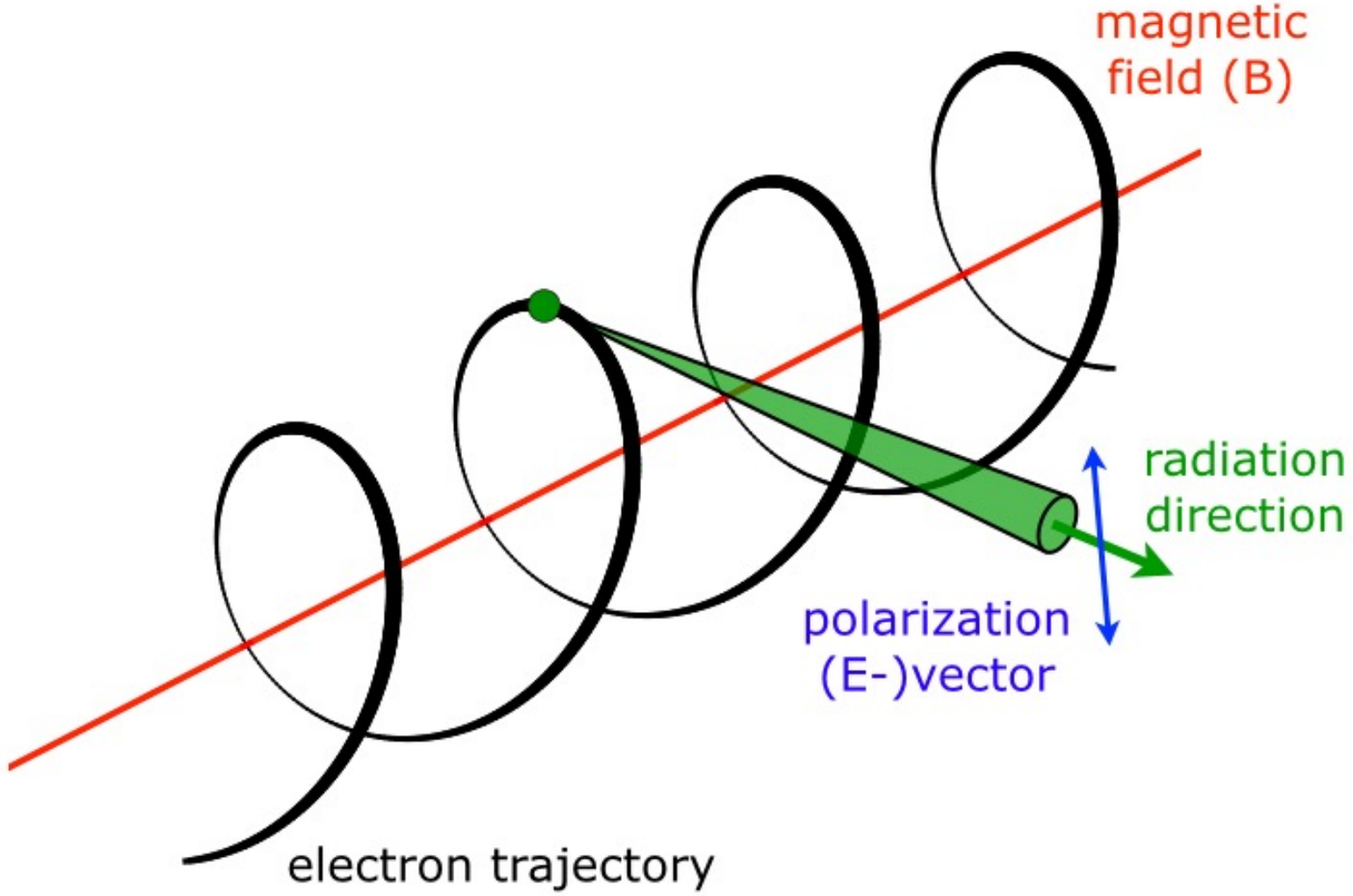


Krause

|B| ~ few μG (ordered),
~ few-10s μG (random)

Synchrotron radiation and polarization

- Synchrotron radiation: emitted by ultrarelativistic electrons accelerated by magnetic fields
  - Sensitive to B in plane of the sky
- Radiation is (partially) polarized
  - Sensitive to degree of order in field



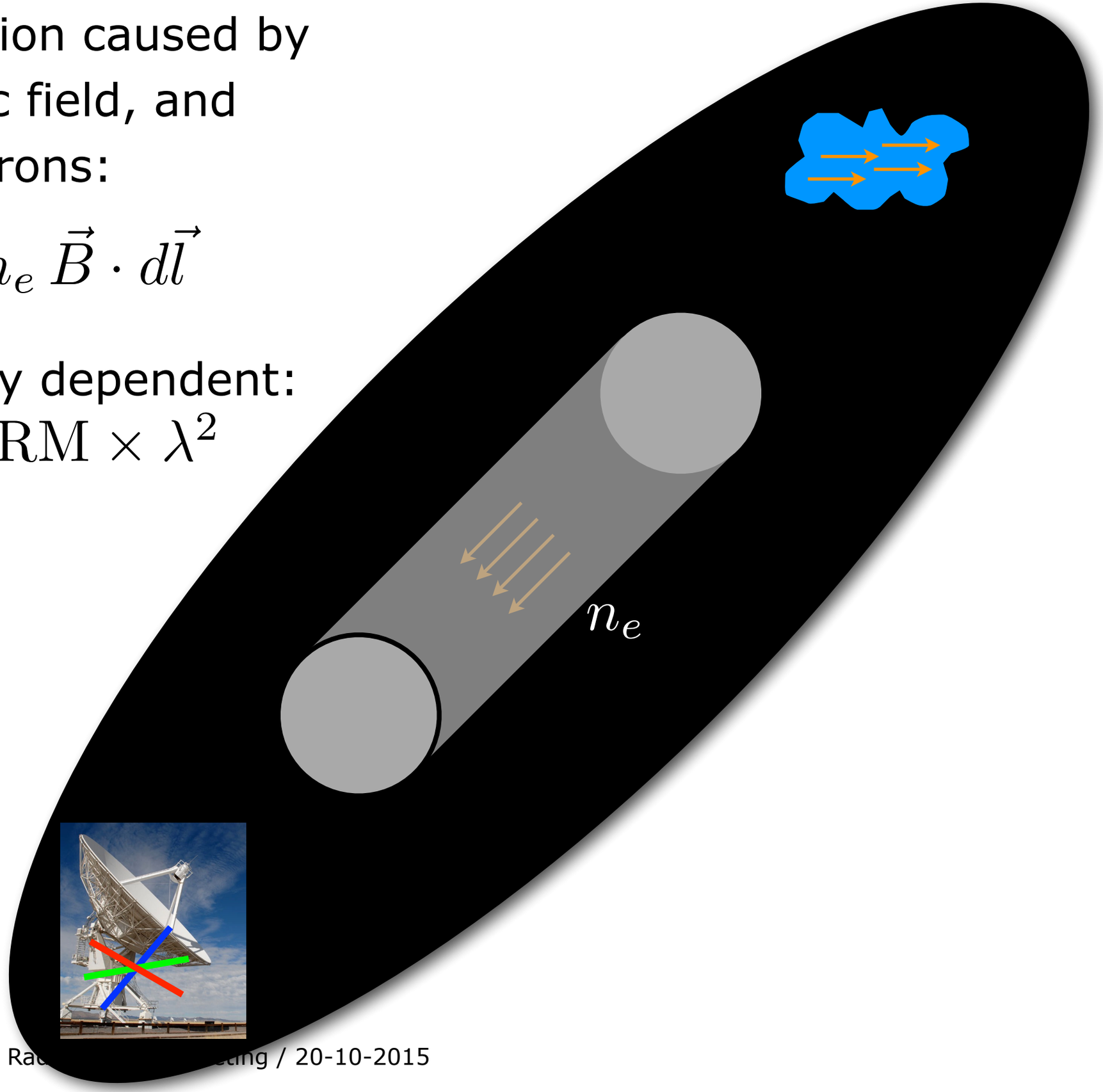
Faraday Rotation

- Faraday rotation caused by LOS magnetic field, and thermal electrons:

$$\mathrm{RM} \propto \int n_e \vec{B} \cdot d\vec{l}$$

- It is frequency dependent:

$$\chi = \chi_0 + \mathrm{RM} \times \lambda^2$$



RM Synthesis & (Q,U) fitting

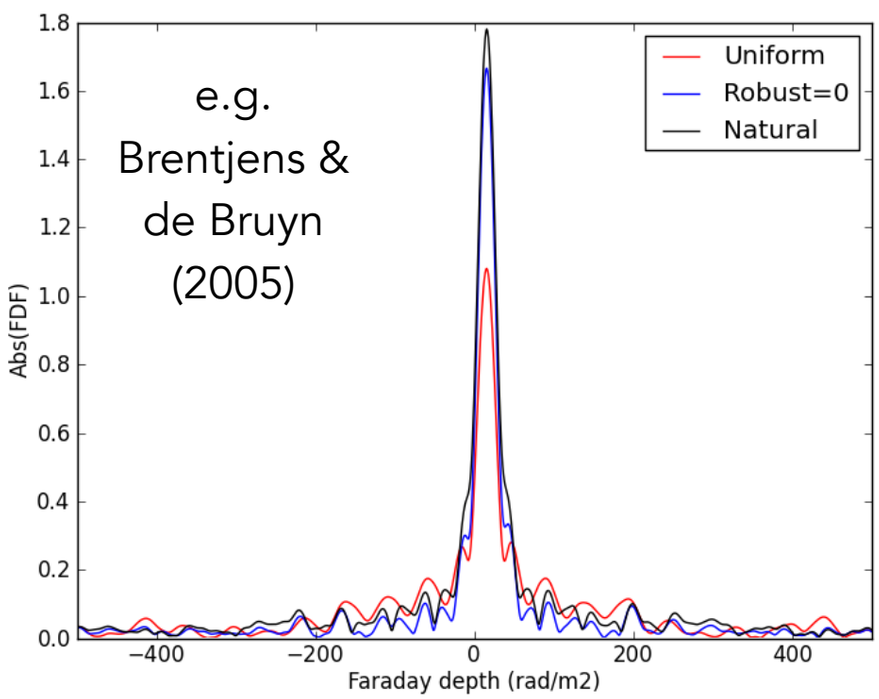
- Complex polarization vector rotated by foreground ***B*** and n_e

$$\phi \equiv \mathrm{RM} \propto \int_L n_e \vec{B} \cdot d\vec{l} \qquad P(\lambda^2) = \int_{-\infty}^{+\infty} F(\phi) e^{2i\phi\lambda^2} d\phi$$

- Results in λ^2-dependent ***Faraday dispersion*** for broadband data
- Two complementary modern techniques normally brought to bear:

RM Synthesis

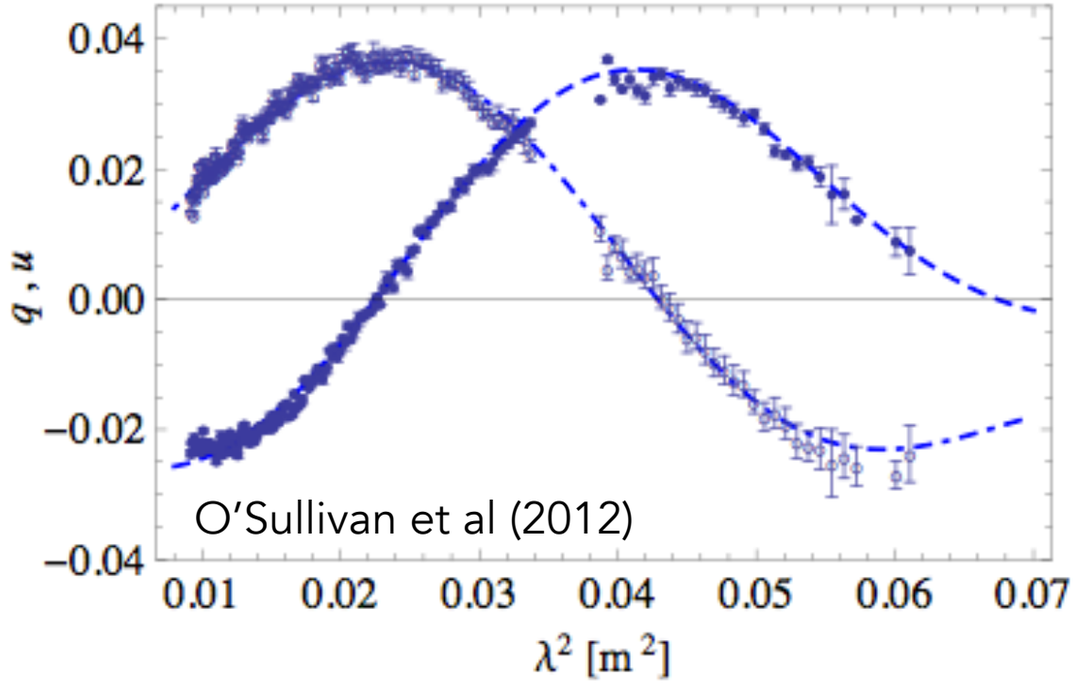
Coherent de-dispersion and RM id



- recovers signal in arbitrary cases
- systematics are often present

Q,U fitting

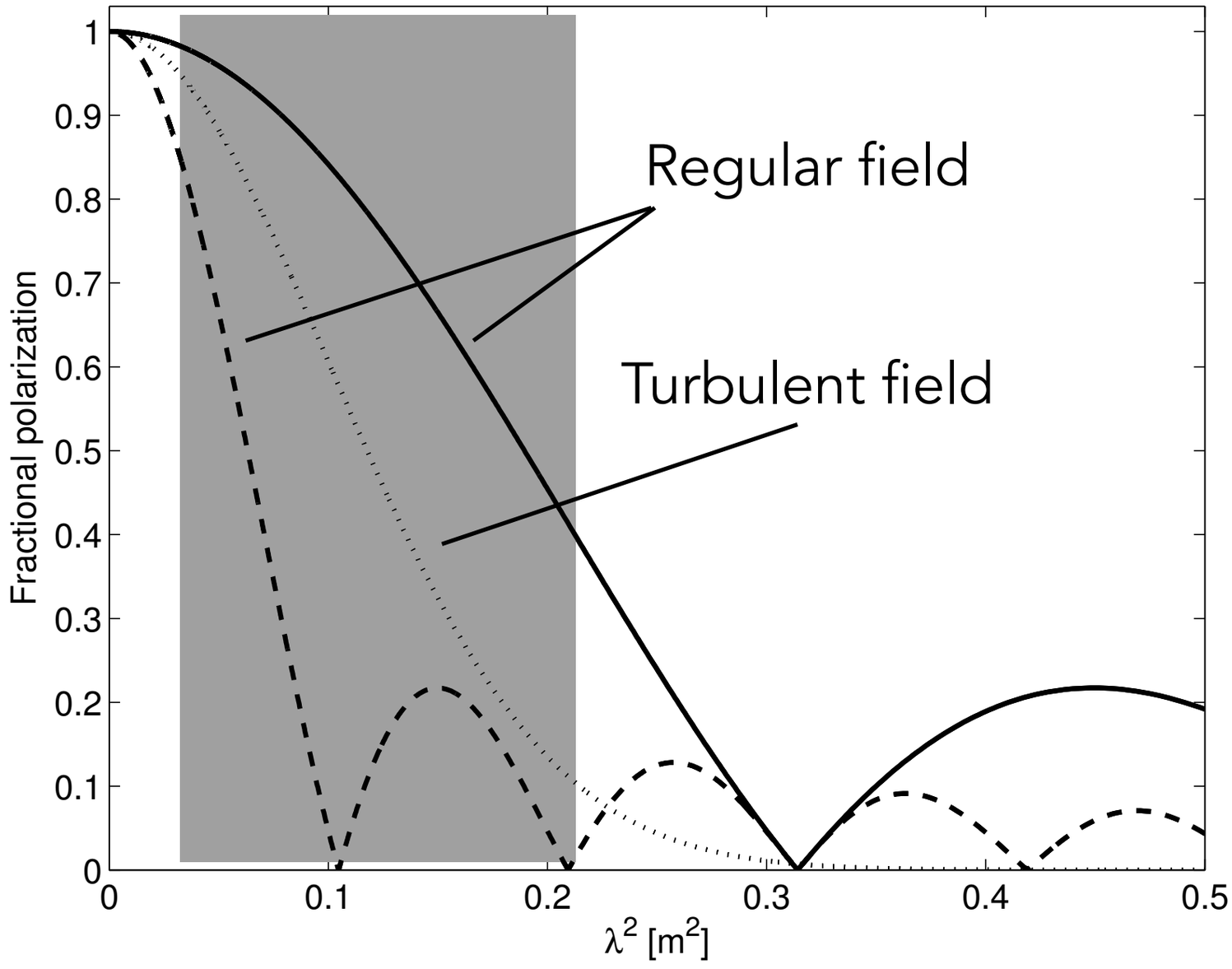
Modelling and parameter fitting



- can avoid systematics
- requires model and high S/N

Depolarization mechanisms

- Depolarization can be caused by regular and turbulent fields
  These have different observational characteristics



after Horellou & Fletcher (2014, MNRAS)

Modeled depolarization mechanisms

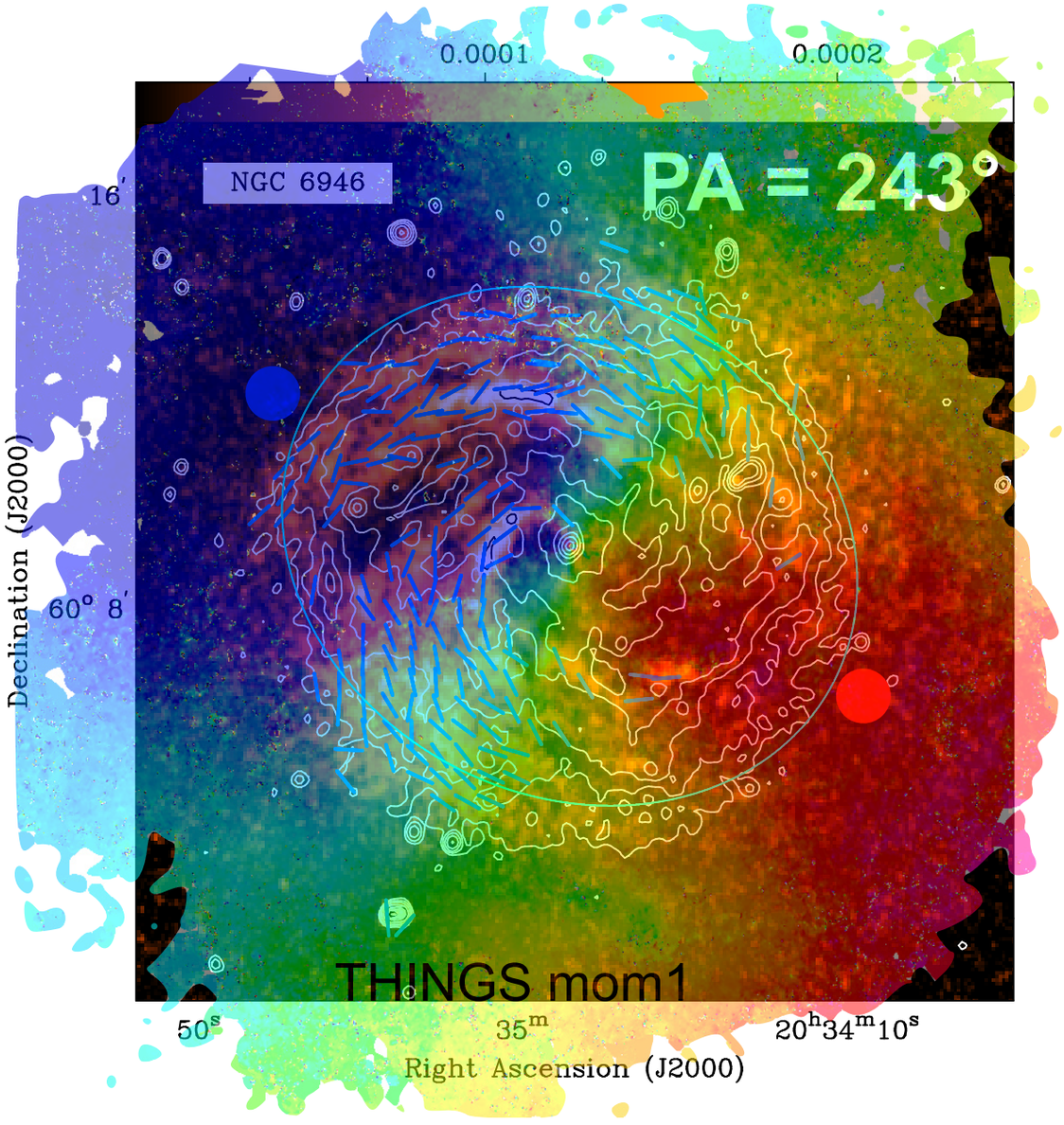
- Beam depolarization: (mostly) λ-independent

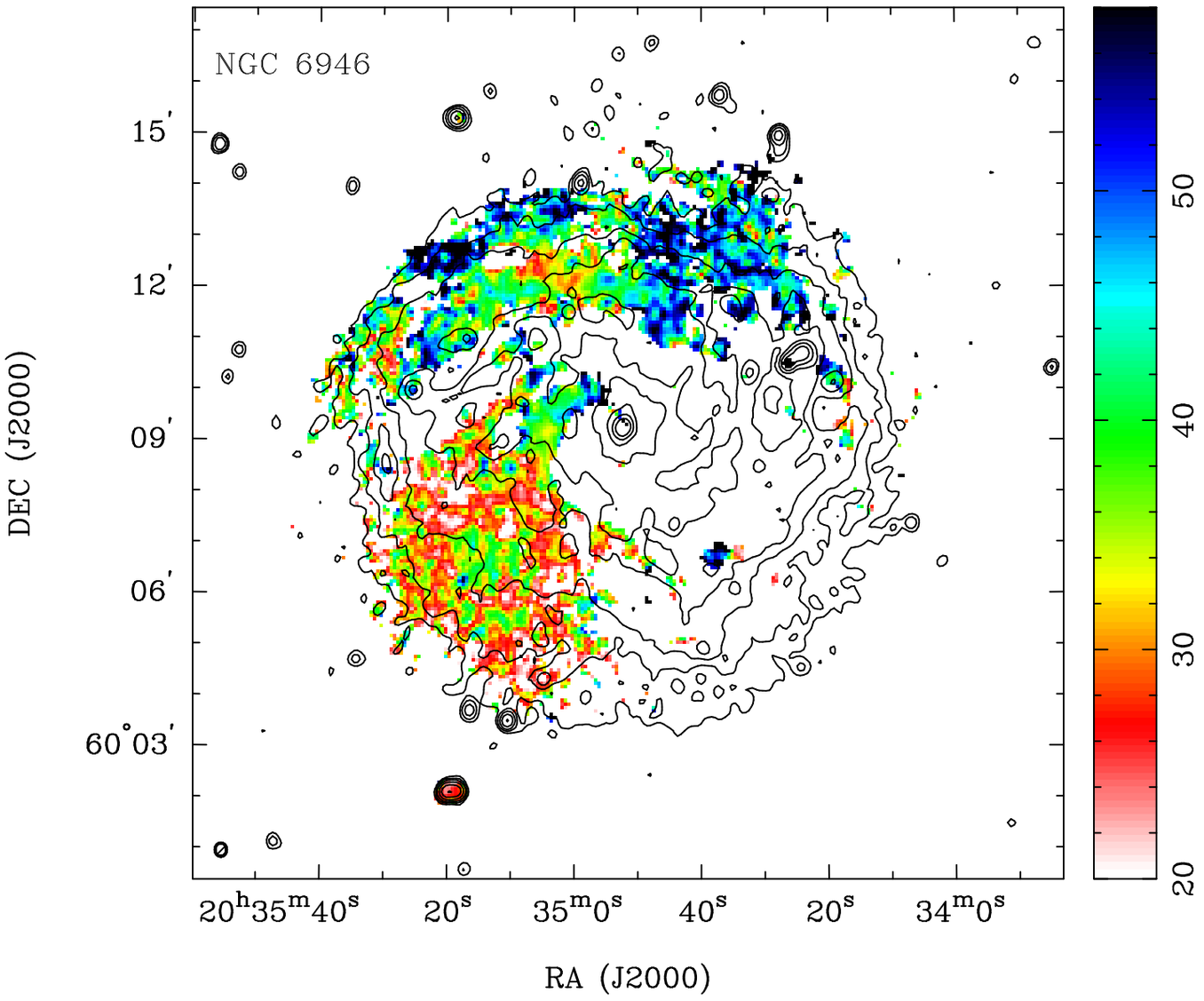
- Faraday depolarization: λ^2-dependent
  - Differential Faraday rotation (DFR)
    Regular field in a region that is both emitting and rotating
  - Internal Faraday dispersion (IFD)
    Turbulent and regular field in a region that is both emitting and rotating
  - External Faraday dispersion (or inhomogeneous Faraday screen; IFS)
    Emitting and turbulent rotating regions are separated, and the rotating screen may only cover part of the emitting source (PIFS)
  - Extended partial coverage model (Farnes et al 2014; Mod. PIFS)
    Partial coverage of a depolarizing screen as above, and a depolarizing screen associated with the emitting source

Depolarization helps to trace large- and small-scale magnetic structure

(De)polarization in NGC 6946

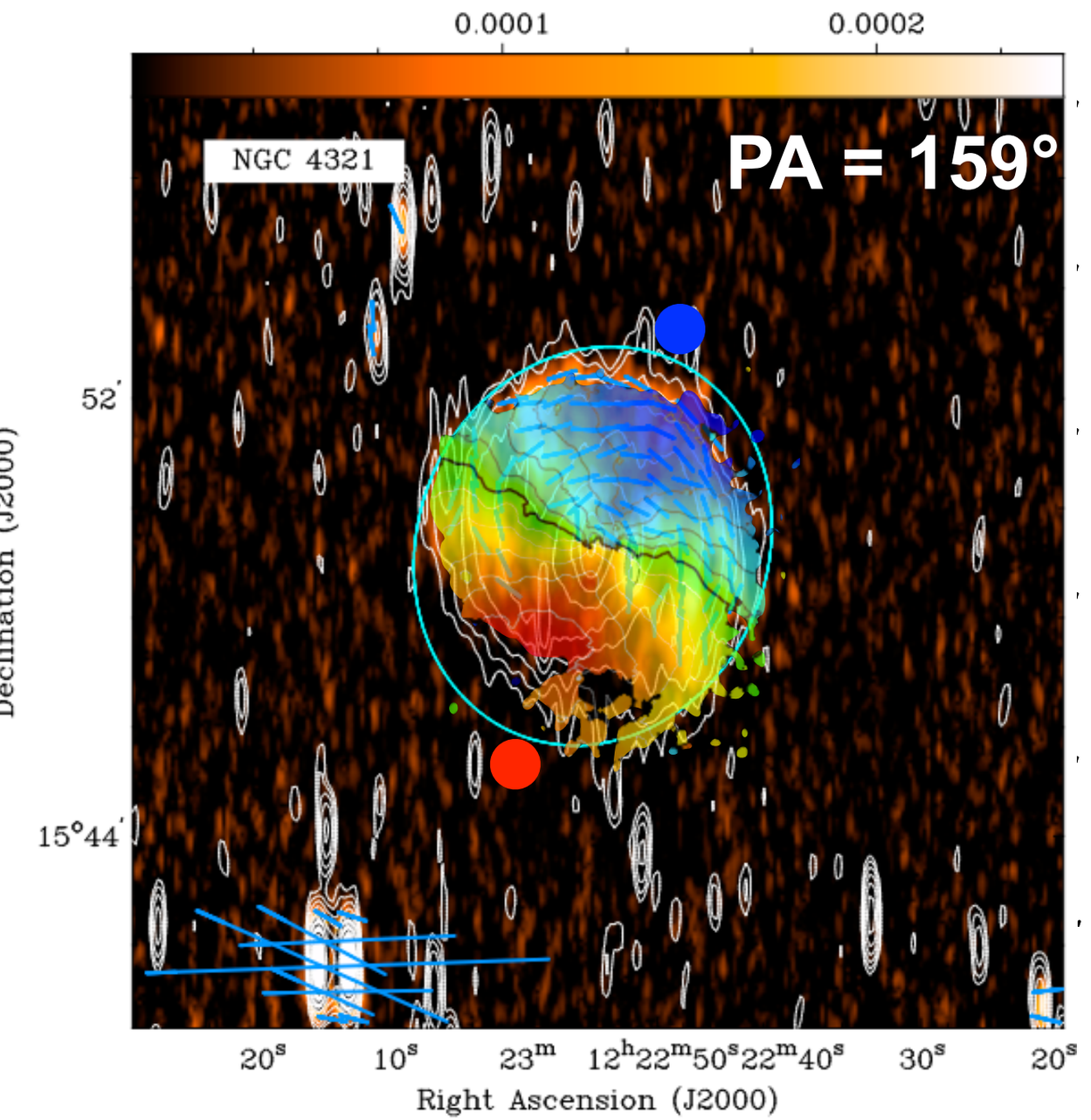
- Maps of linear polarization and Faraday RM from WSRT-SINGS (Braun+2007, Heald+2009)

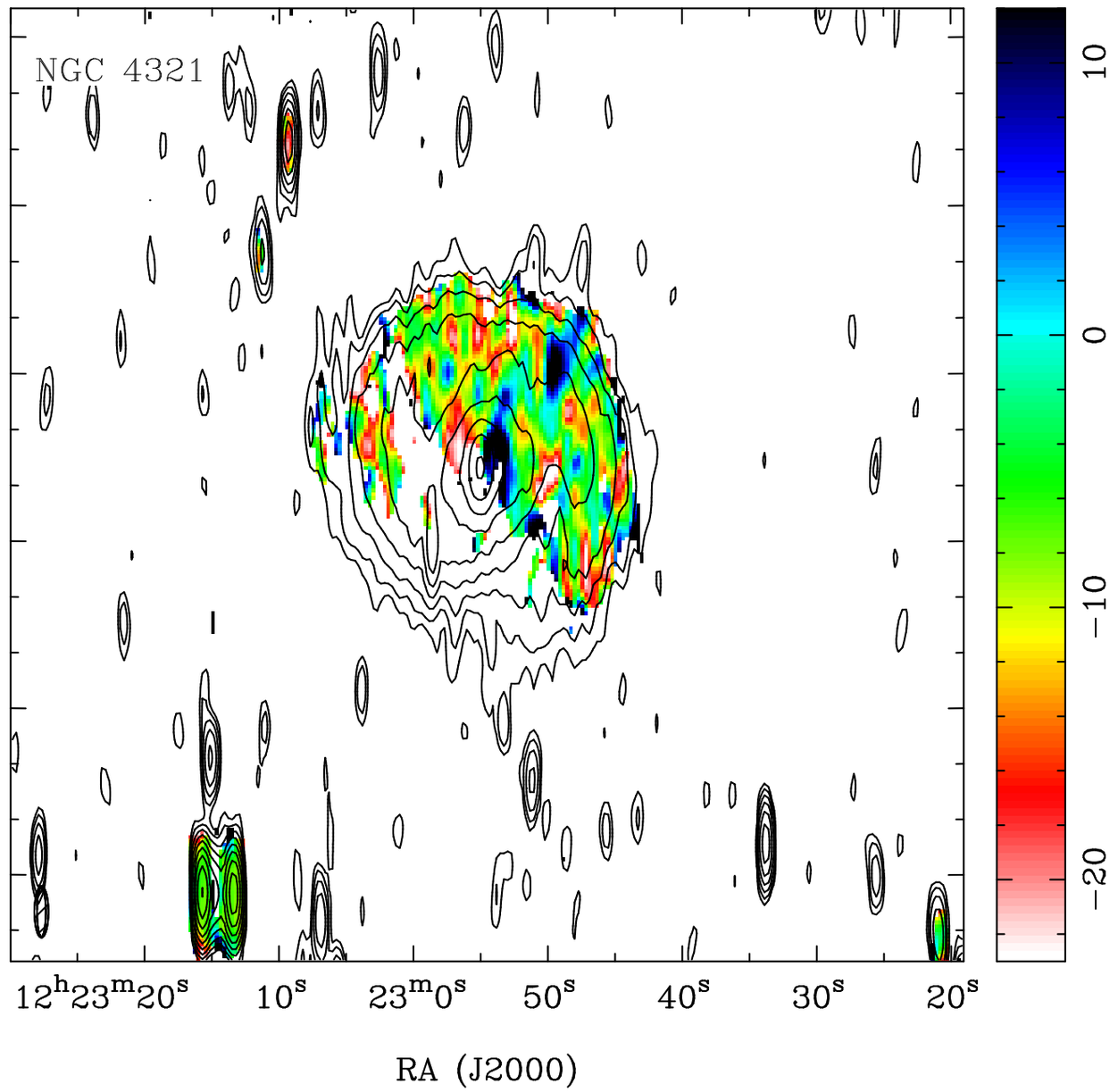




- approaching side
- receding side

(De)polarization in NGC 4321=M100





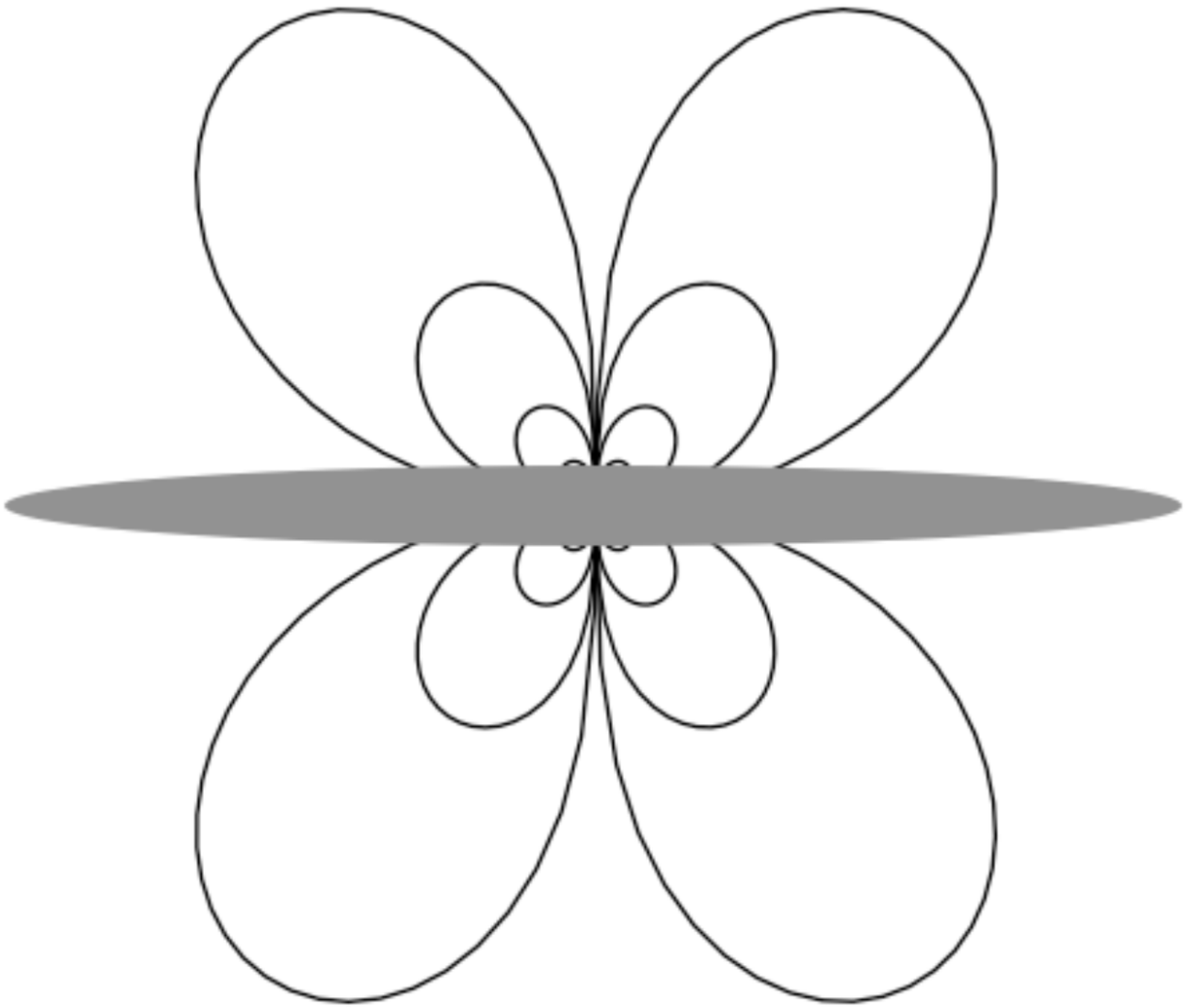
- approaching side
- receding side

HI velocity field: Haan et al (2008)

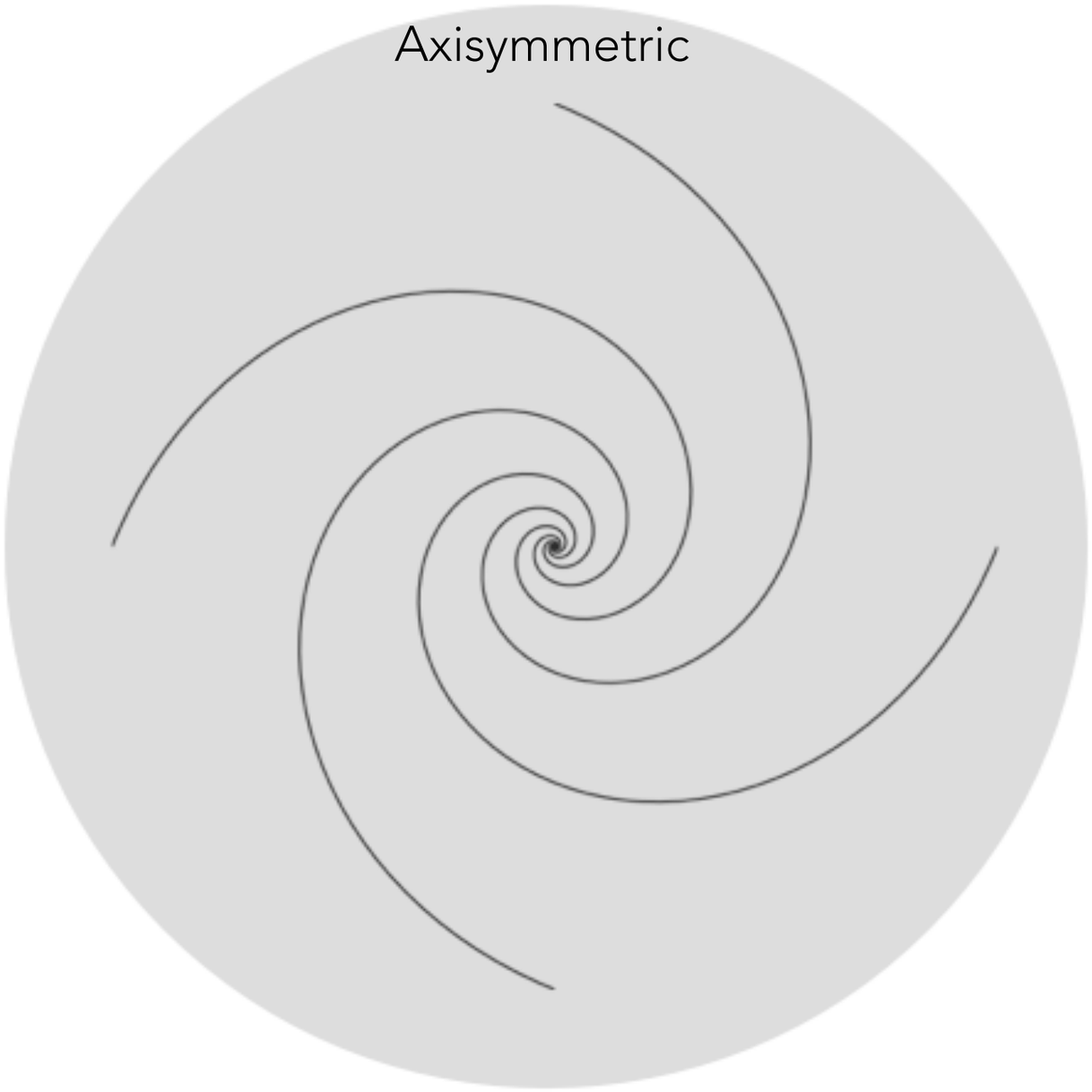
Large-scale galactic magnetic fields

- Patterns of polarization properties lead to a global picture of magnetic field morphology in spirals

Quadrupolar



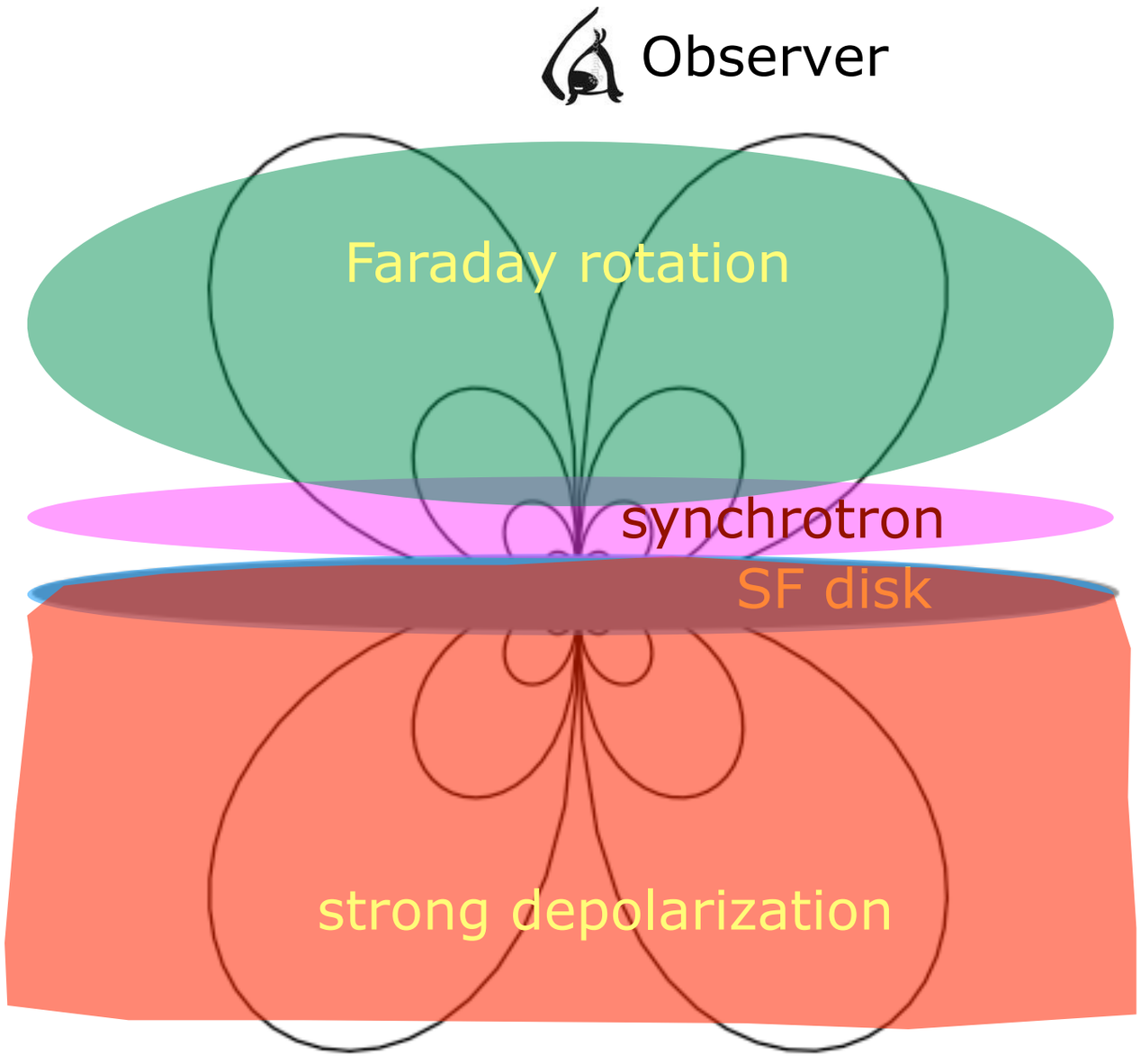
Axisymmetric



Braun et al (2010)

Interpretation

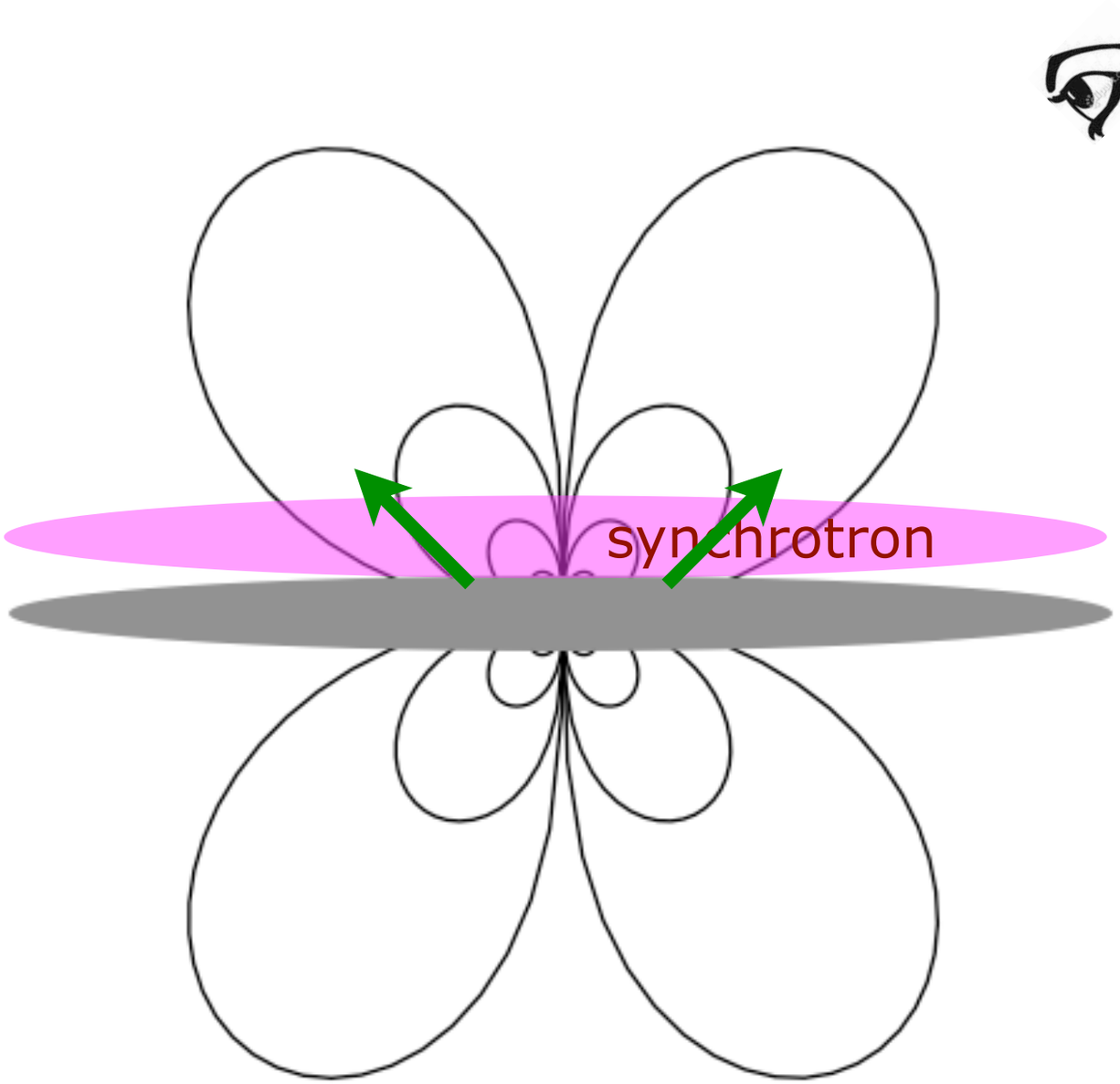
- Combination of quadrupolar field + axisymmetric spiral



Braun et al (2010)

Interpretation

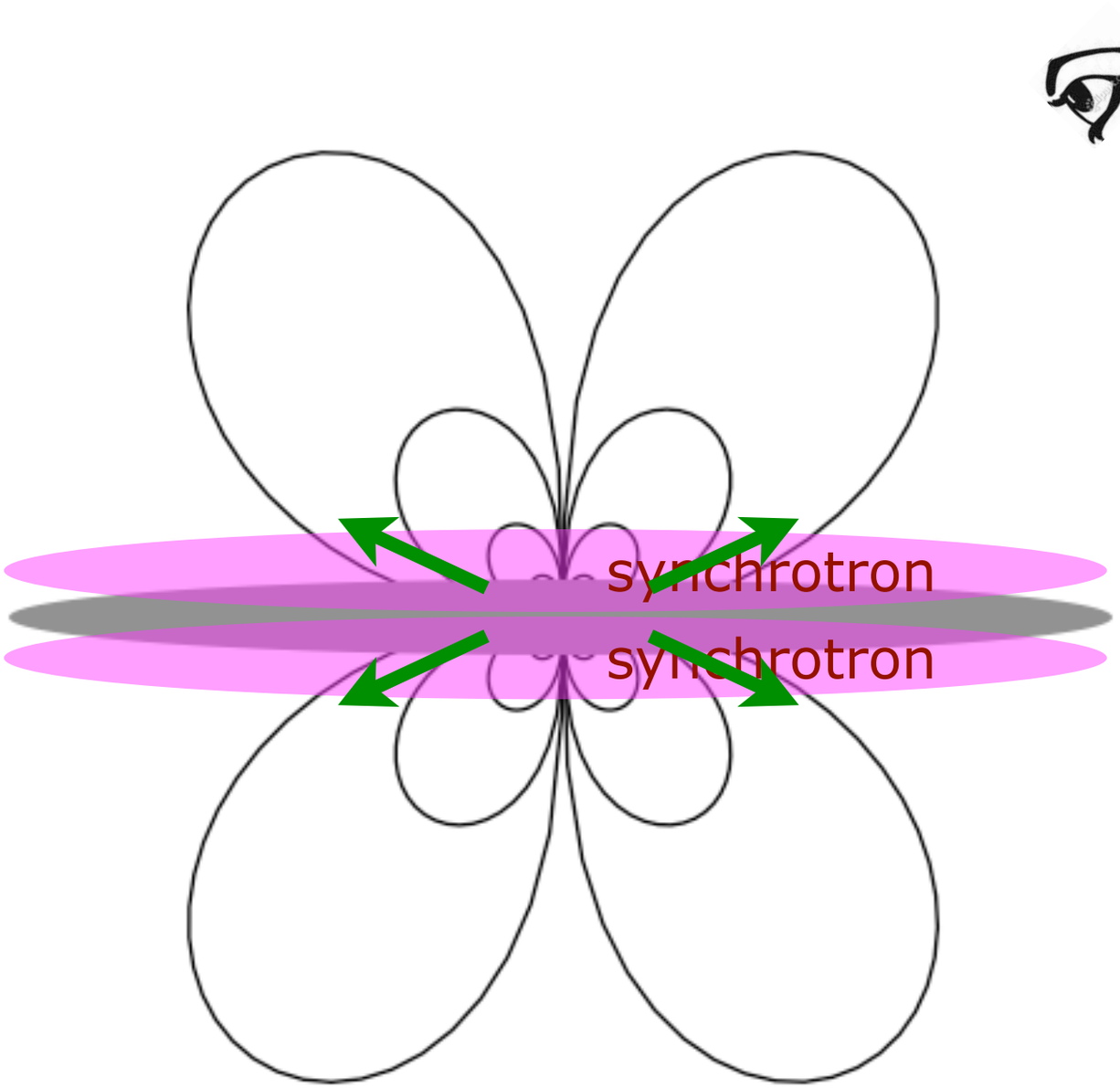
- Azimuthal asymmetry created by field projections



Braun et al (2010)

Interpretation

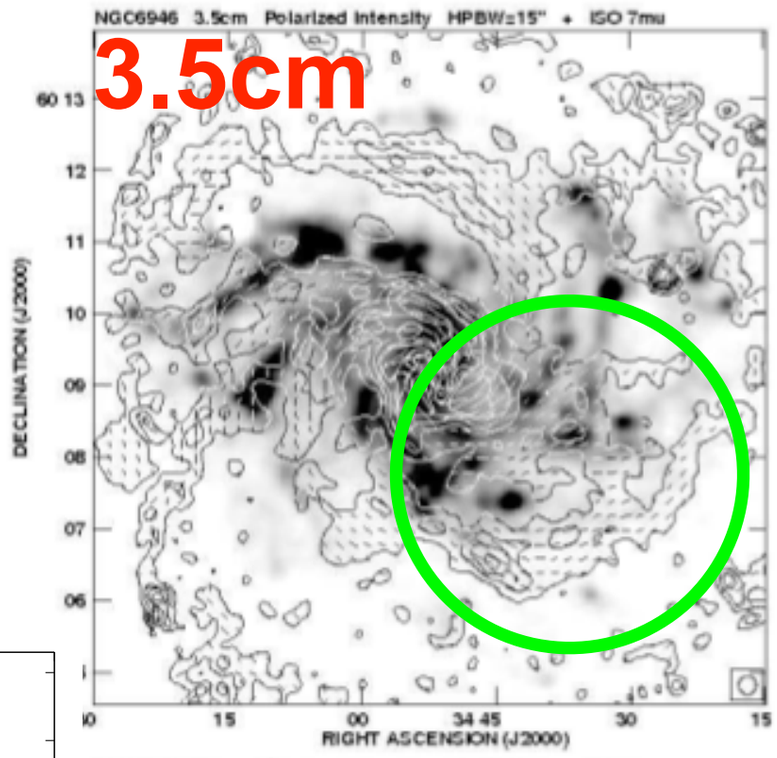
- Azimuthal asymmetry vanishes at higher frequency

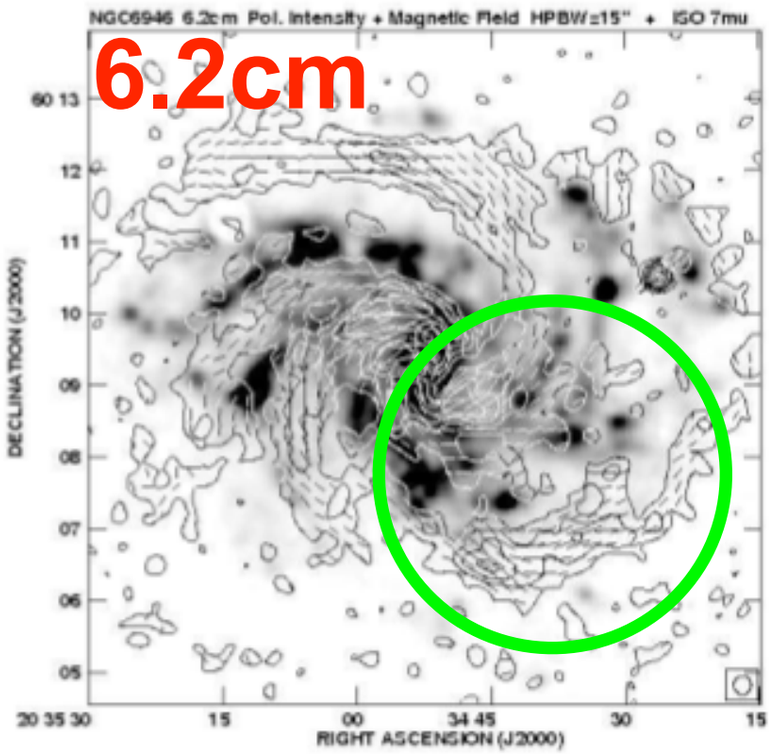


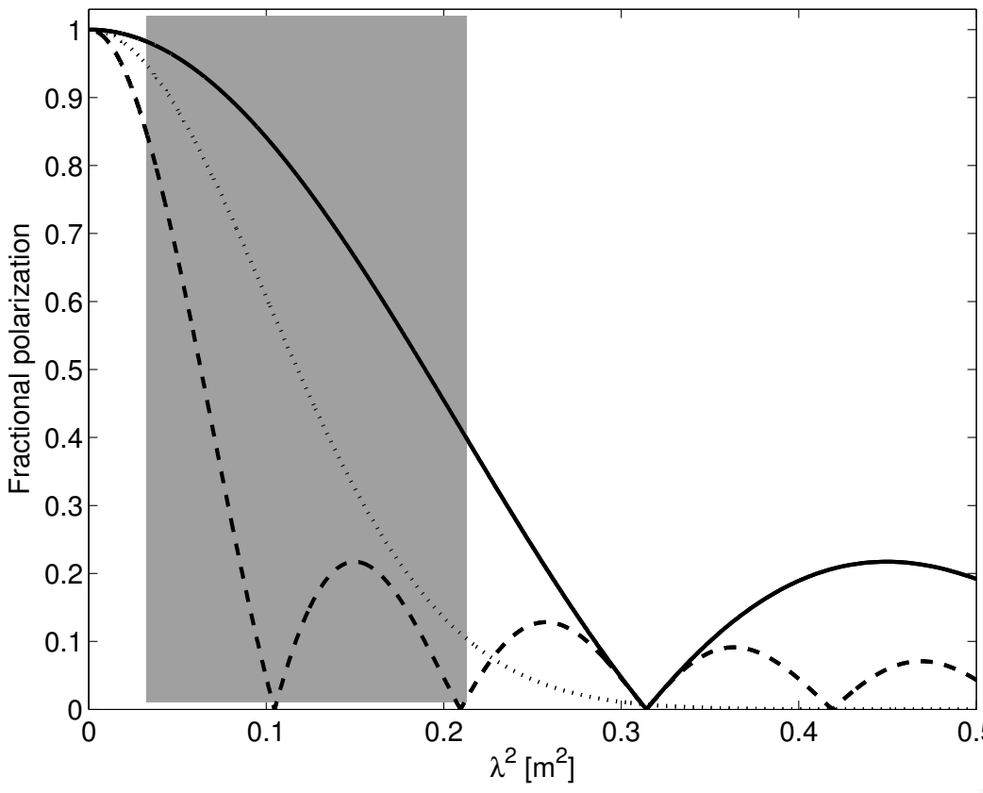
Braun et al (2010)

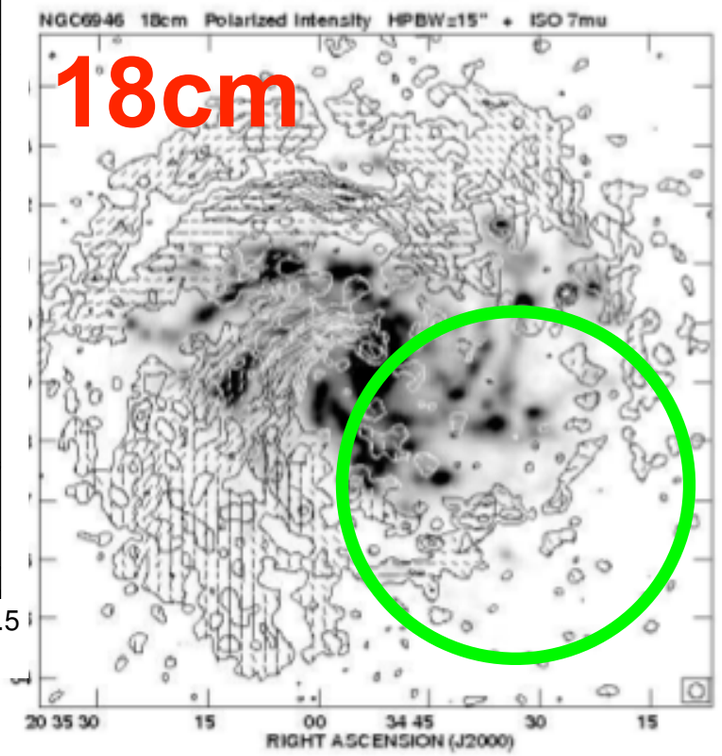
Interpretation

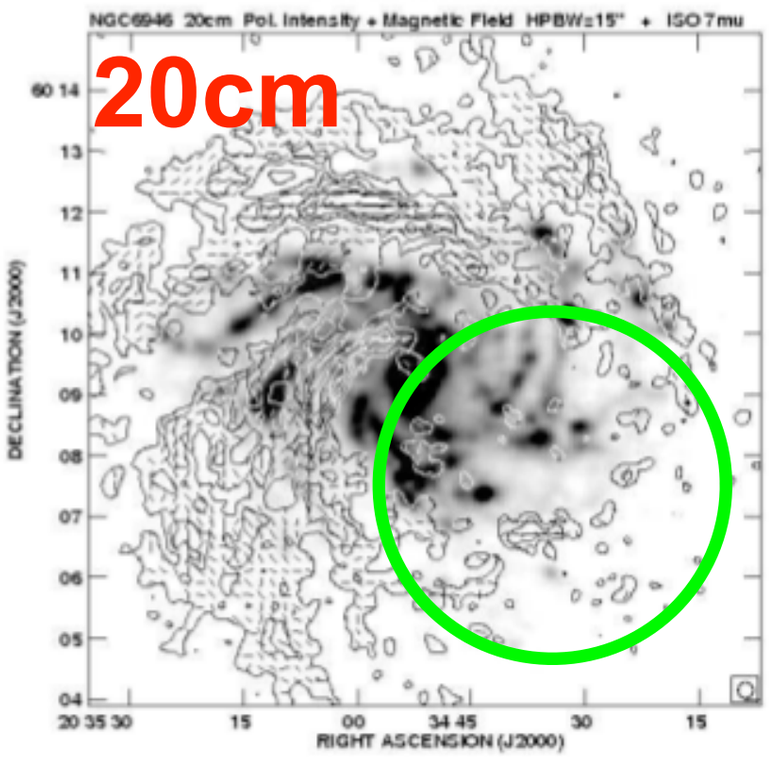
- Azimuthal asymmetry vanishes at higher frequency
- Seen clearly in multifrequency broadband polarization data for NGC 6946 (Beck 2007)









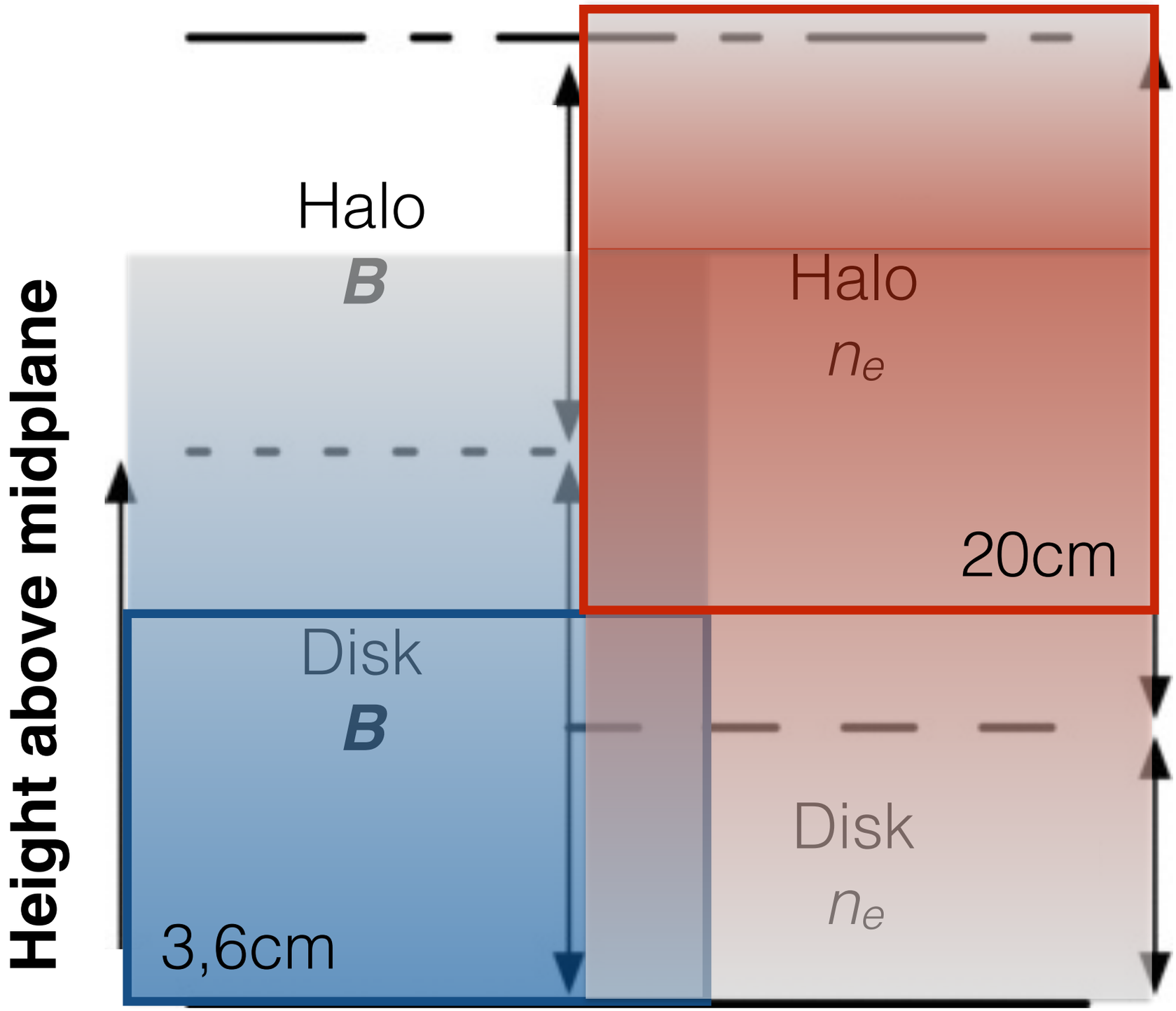


Multi-layer structure in M51

- Based on broadband polarization data at three frequencies

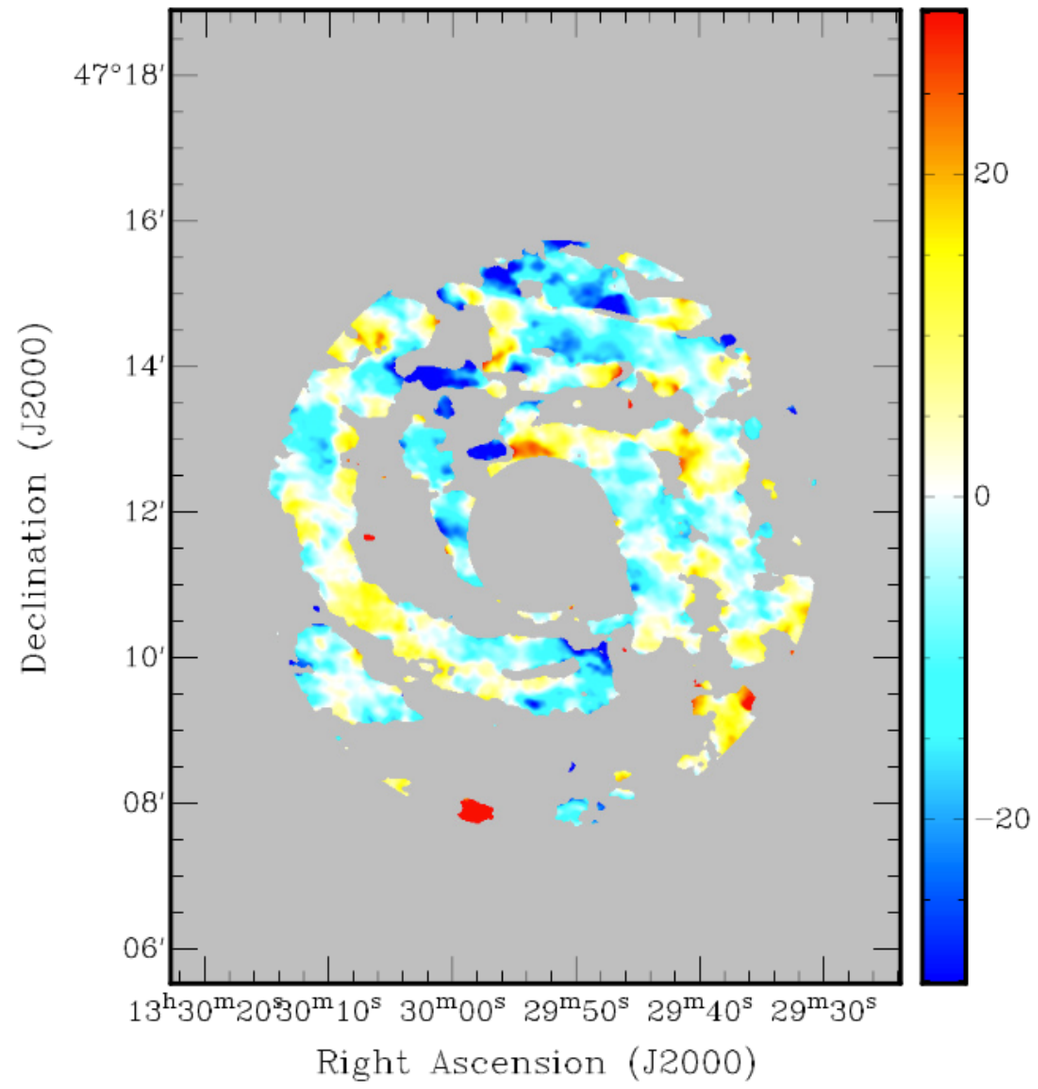
Fletcher et al (2011)

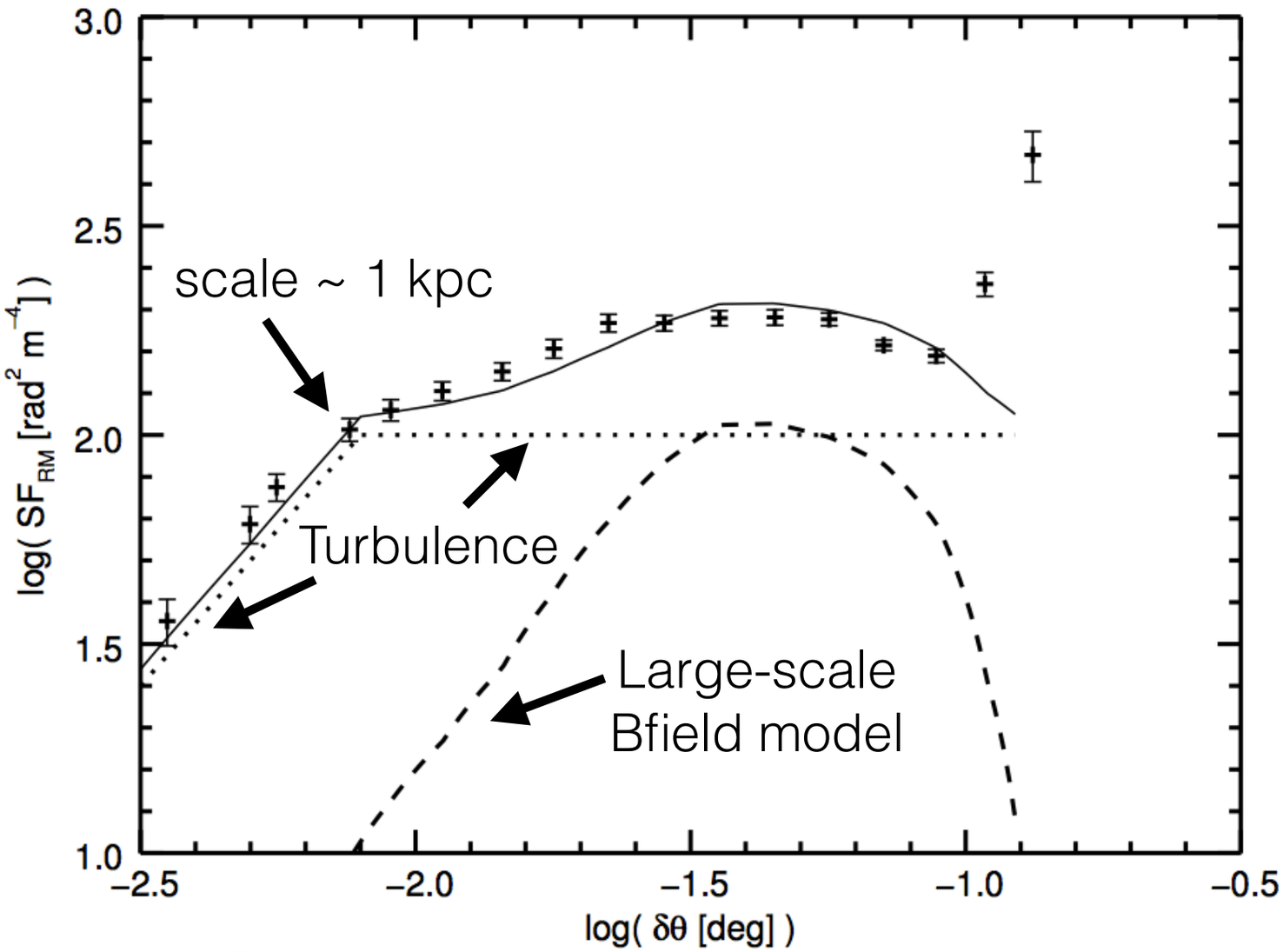
Multi-layer structure in M51



M51 halo RM structure function

- Analysis of angular structure function of L-band Faraday rotation measures in M51 (Mao et al 2015):
  - Large-scale and turbulent magnetic field components

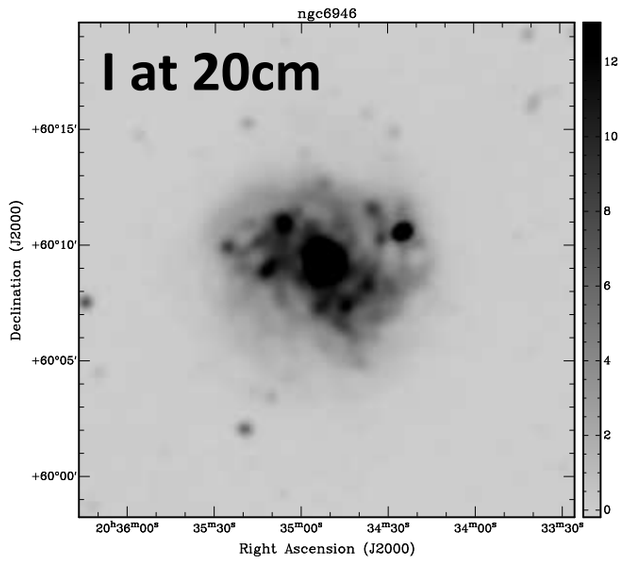


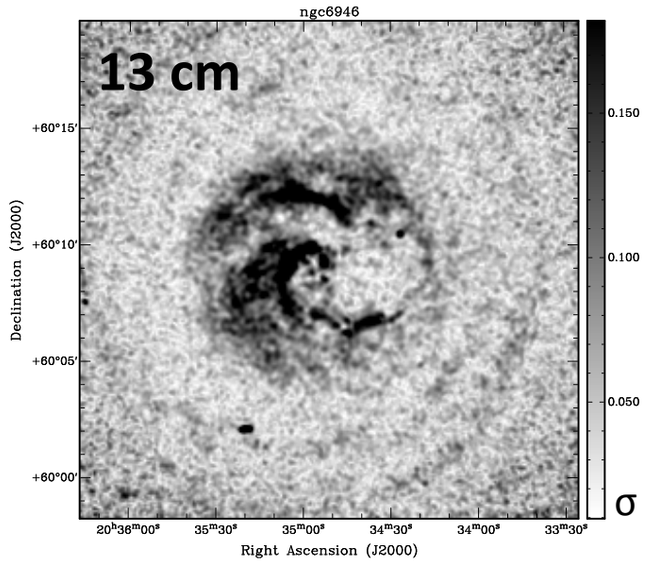


Beam size 11”
(off the scale)

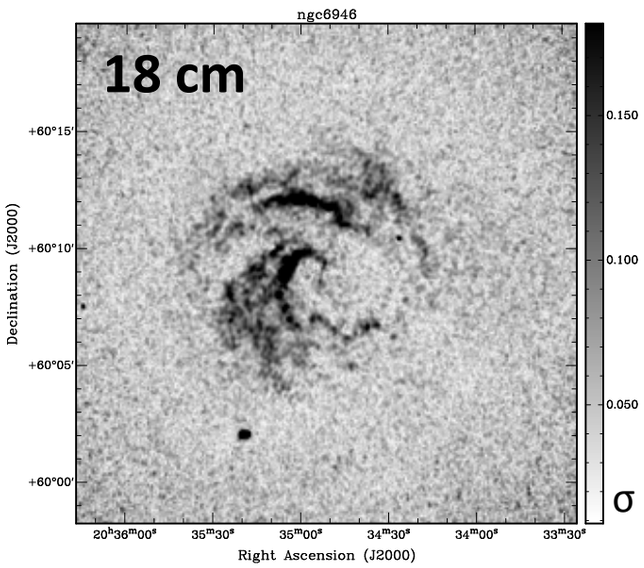
Small-scale structure in the magnetized ISM

- Polarimetric observations of NGC 6946 at λ=3,6,13,18,21 cm
  - Combination of Effelsberg, VLA, WSRT
    - WSRT data: 8x20 MHz in each band
  - Anna Williams et al, in prep

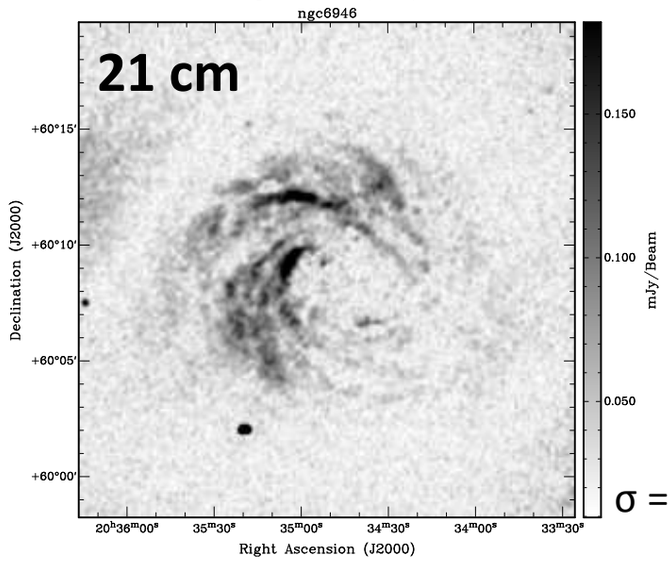




σ = 13μJy

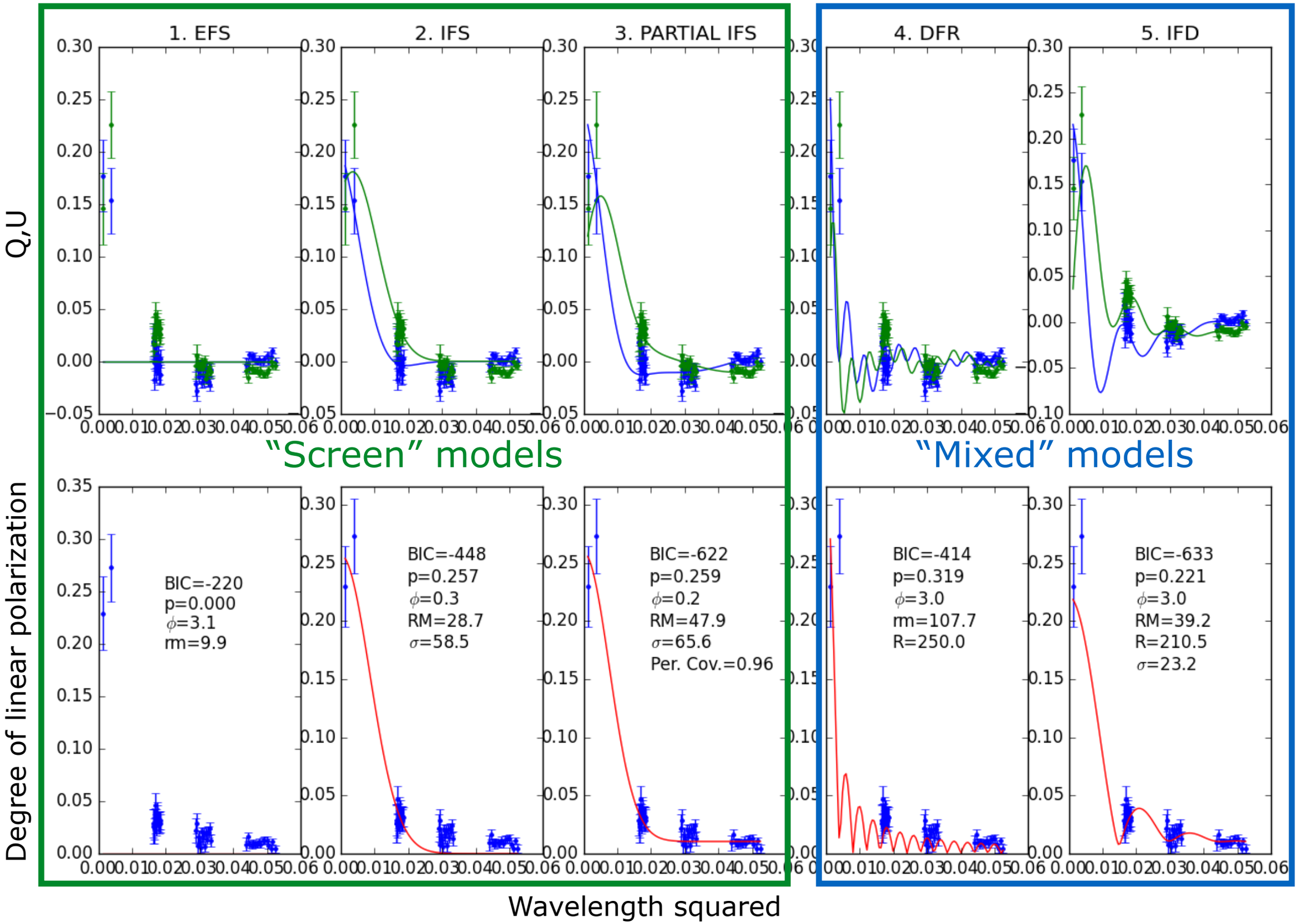


σ = 12μJy



σ = 6μJy

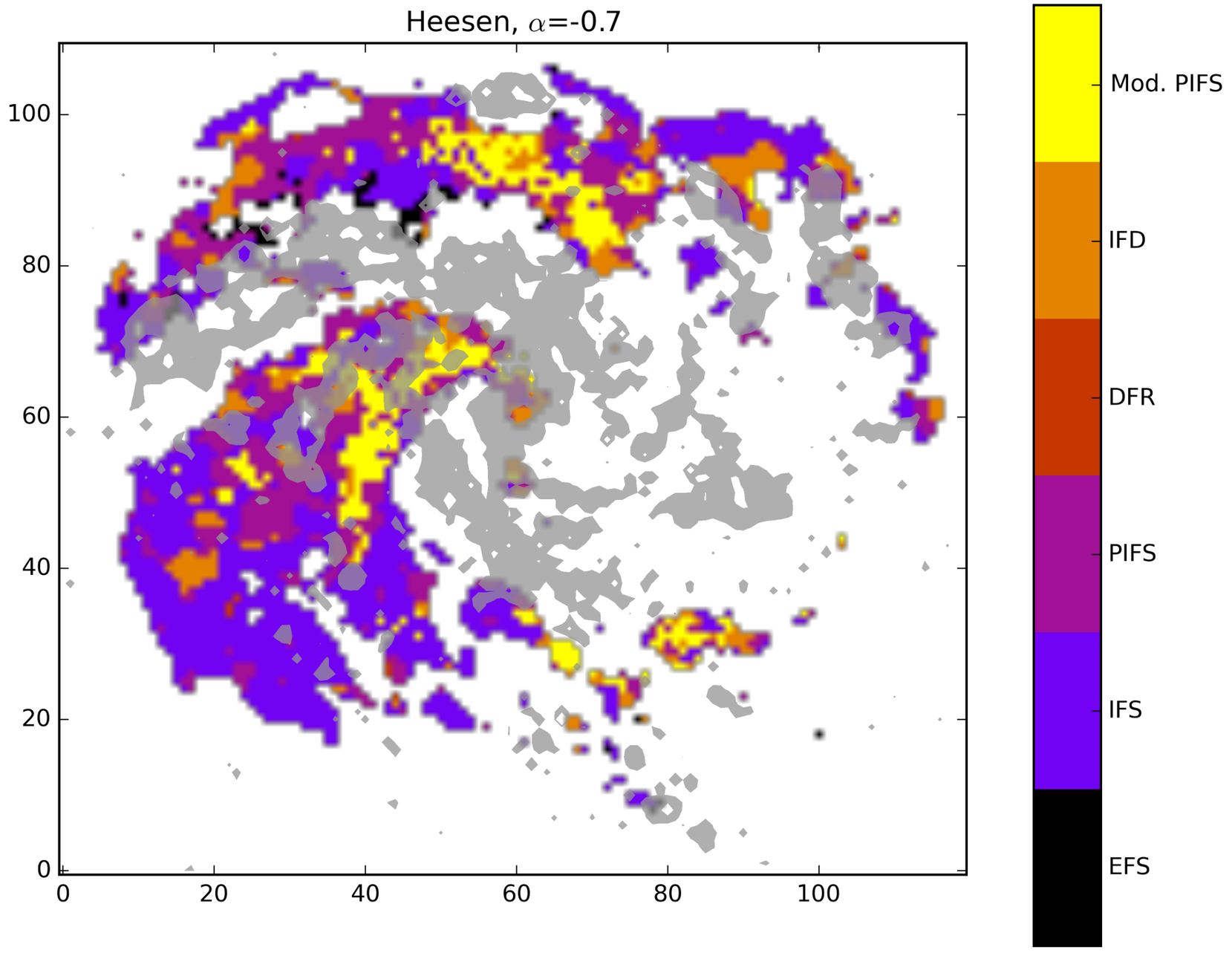
Model fitting results



Williams et al., in prep

Model fitting results

- Gray shade: Hα distribution
- Colors: depolarization model that produces best match to data



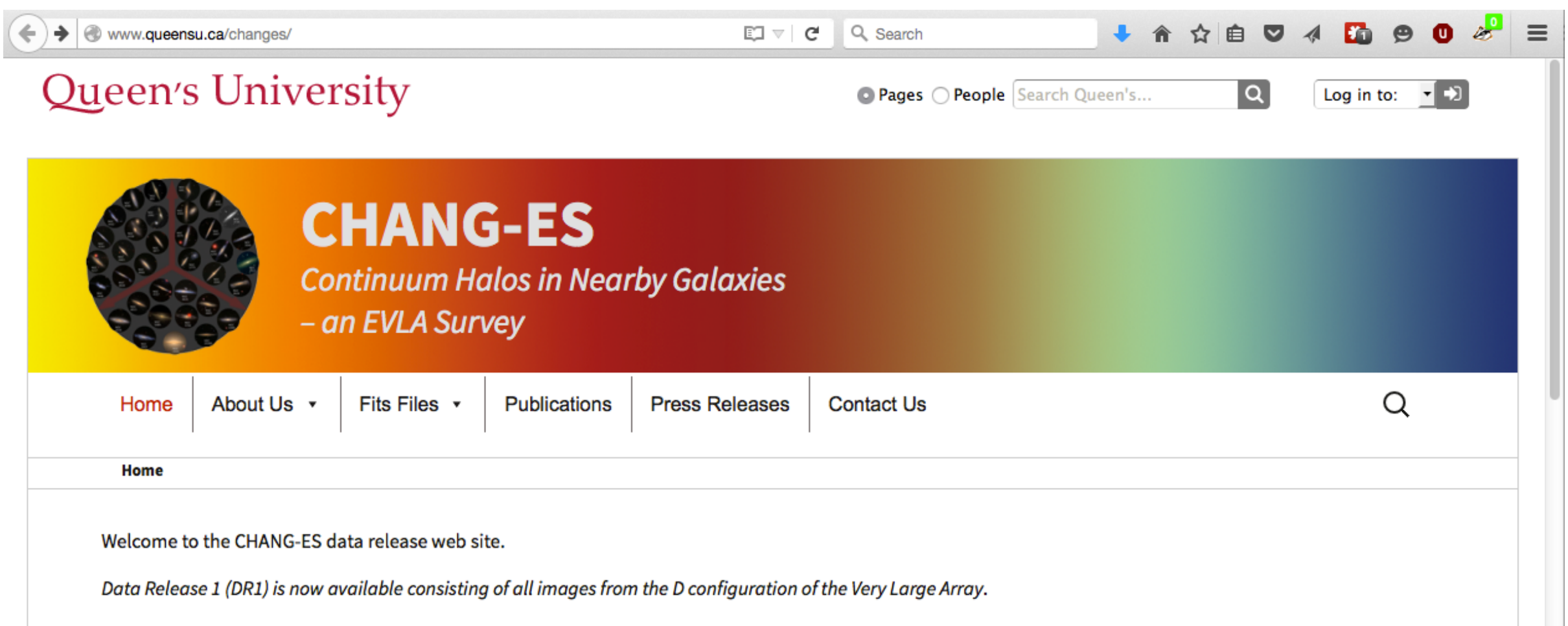
Williams et al., in prep

Williams et al., in prep

Optical image: Robert Gendler

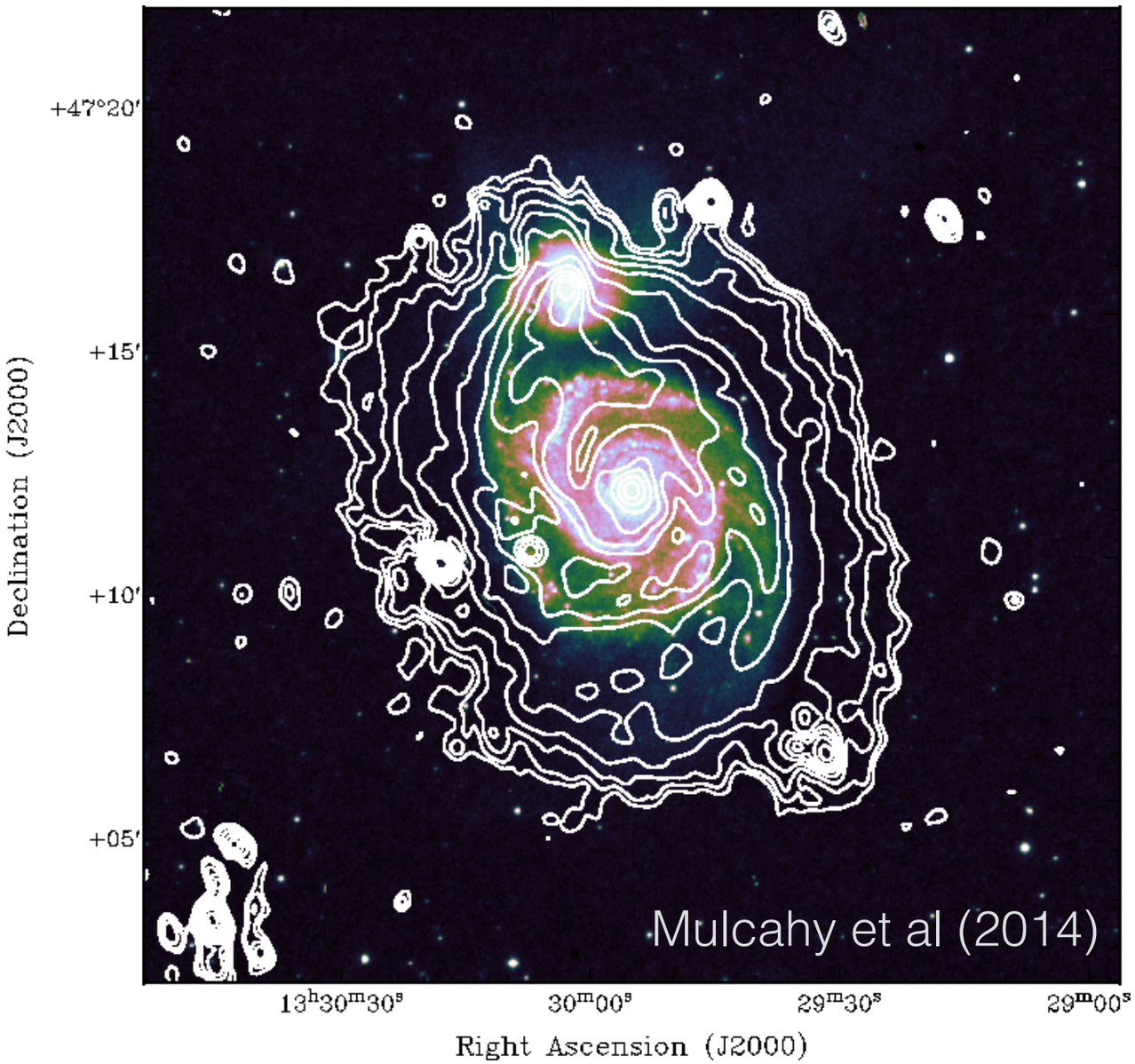
Current magnetism surveys

- CHANG-ES - http://www.queensu.ca/changes
  - Judith Irwin (Queen's University) et al
  - Used VLA to collect broadband polarization data for 35 galaxies (nominally edge-on)
  - Lband (B,C,D configurations): ~1.2-1.9 GHz
  - Cband (C,D configurations): ~5-7 GHz



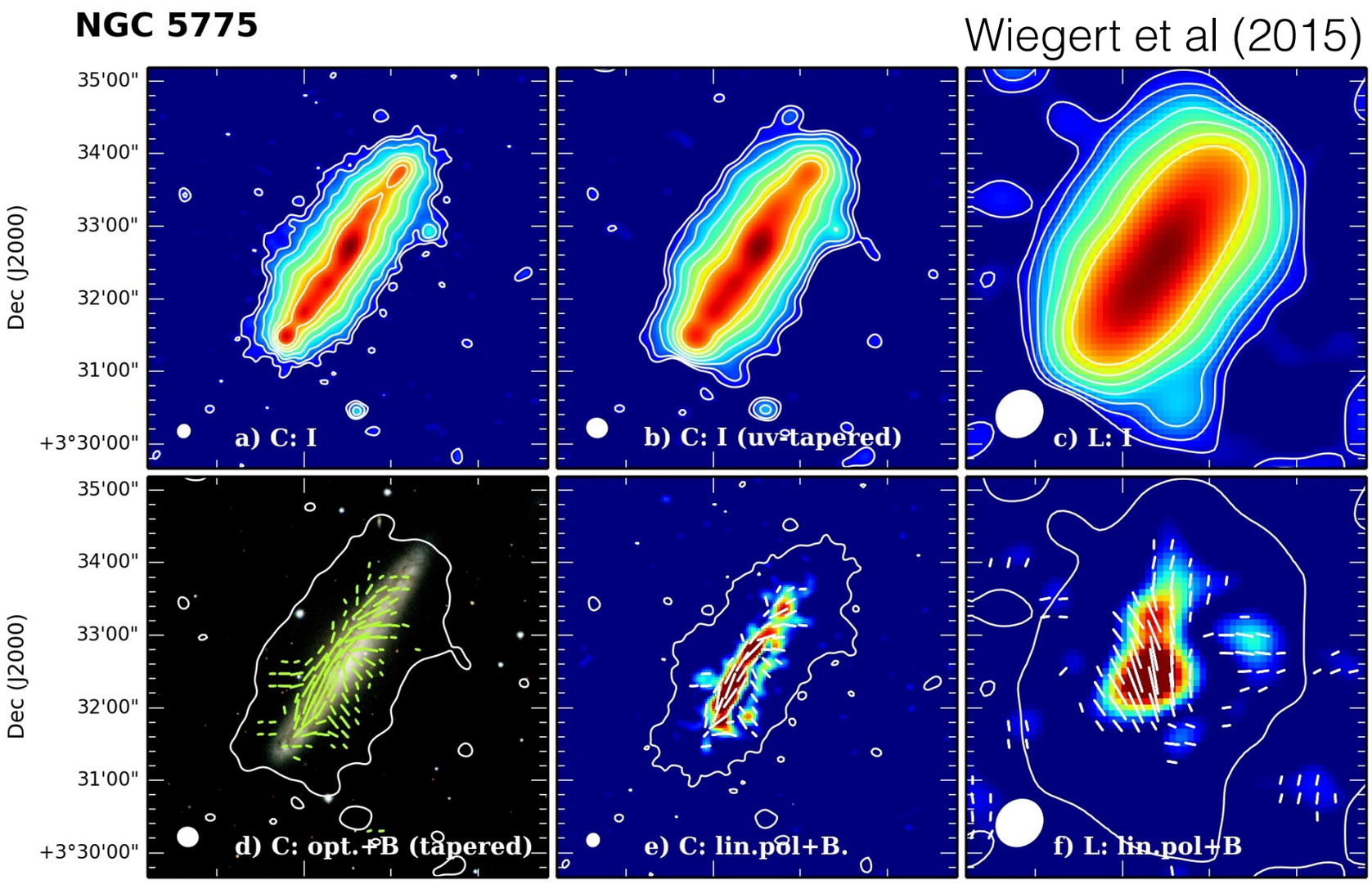
Current magnetism surveys

- LOFAR
  - Magnetism KSP: Scaife, Heald, et al
  - 4 science themes: LSS/CW, MW, NG, RG
  - Initially focused on HBA (~120-180 MHz), and some early investment in LBA (~30-80 MHz)



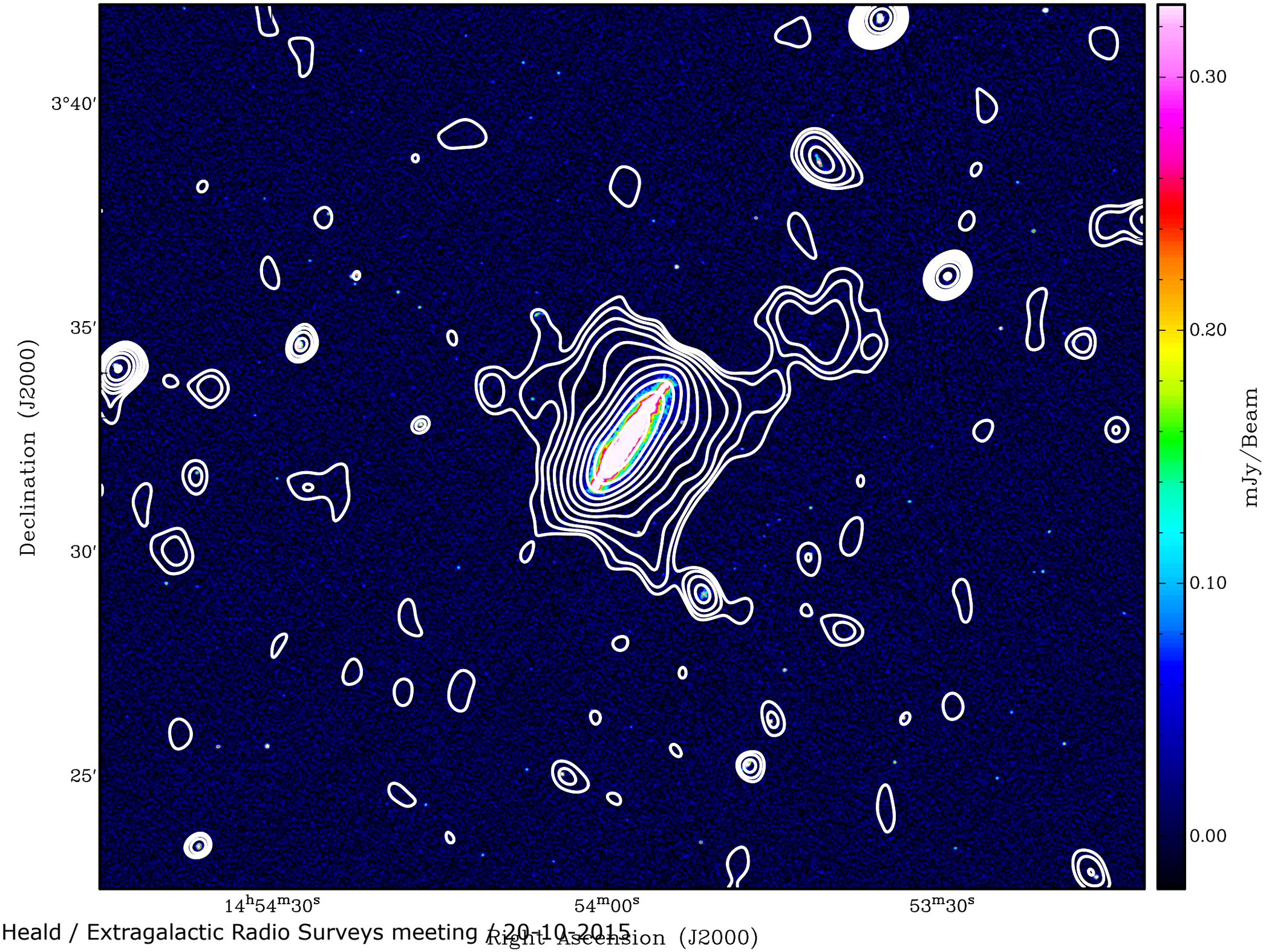
CHANG-ES & LOFAR

- CHANG-ES imaging of NGC 5775:



CHANG-ES & LOFAR

- Initial LOFAR-HBA image of NGC 5775 overlaid on CHANG-ES



Next steps and the SKA

- VLA Sky Survey (VLASS), B configuration
  - 2-4 GHz RM Grid … ~1 million polarized sources?
- SKA1-LOW: Probe far outer parts of galactic magnetic fields
- SKA1-MID:
  - Band 5 (4.6-13.8 GHz): probe star forming disk with high precision (Beck et al 2015)
  - Bands 1-2 (350-1760 MHz): probe depolarization mechanisms and unpeel the galactic onion (Heald et al 2015)
  - RM Grid: Extent of galactic magnetic fields

Take-home messages

- **Depolarization is a useful tool to "dissect" galaxies**
  - Detailed view of large- and small-scale field structures
  - Highly complementary to study of gaseous ISM

- Detailed analysis techniques under development needed to fully exploit the capabilities of the SKA
  - Current generation radio surveys exploring new territory

- SKA provides a huge step forward in studying galactic magnetism
  - SKA1: order of magnitude improvement in local Universe AND extension to a much larger volume
  - SKA2: expansion to a cosmologically interesting volume