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Netherlands Institute for Radio Astronomy

Magnetic fields in nearby galaxies

George Heald
Panoramic Radio Astronomy
w/ R. Braun, R. Edmonds

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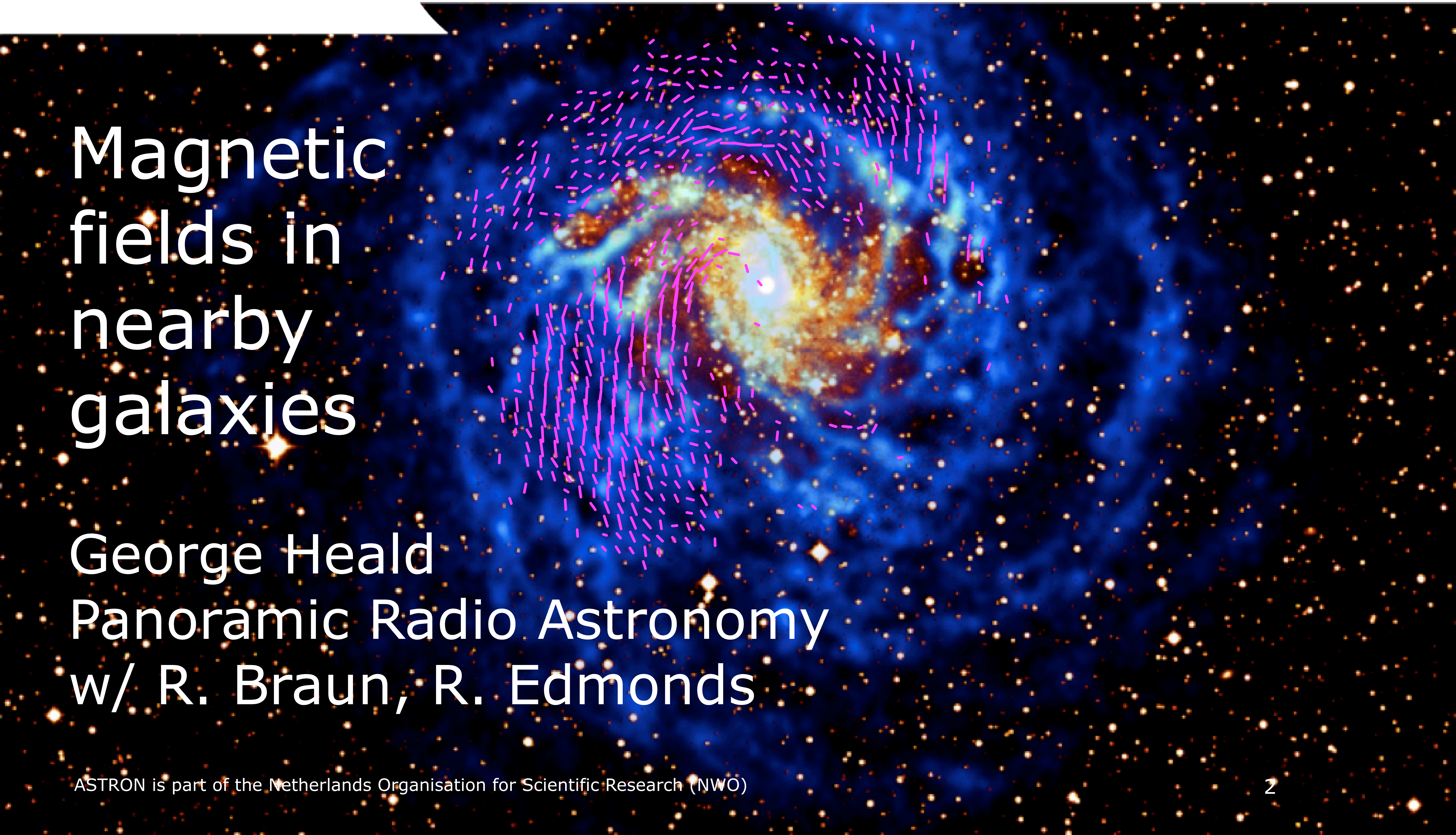

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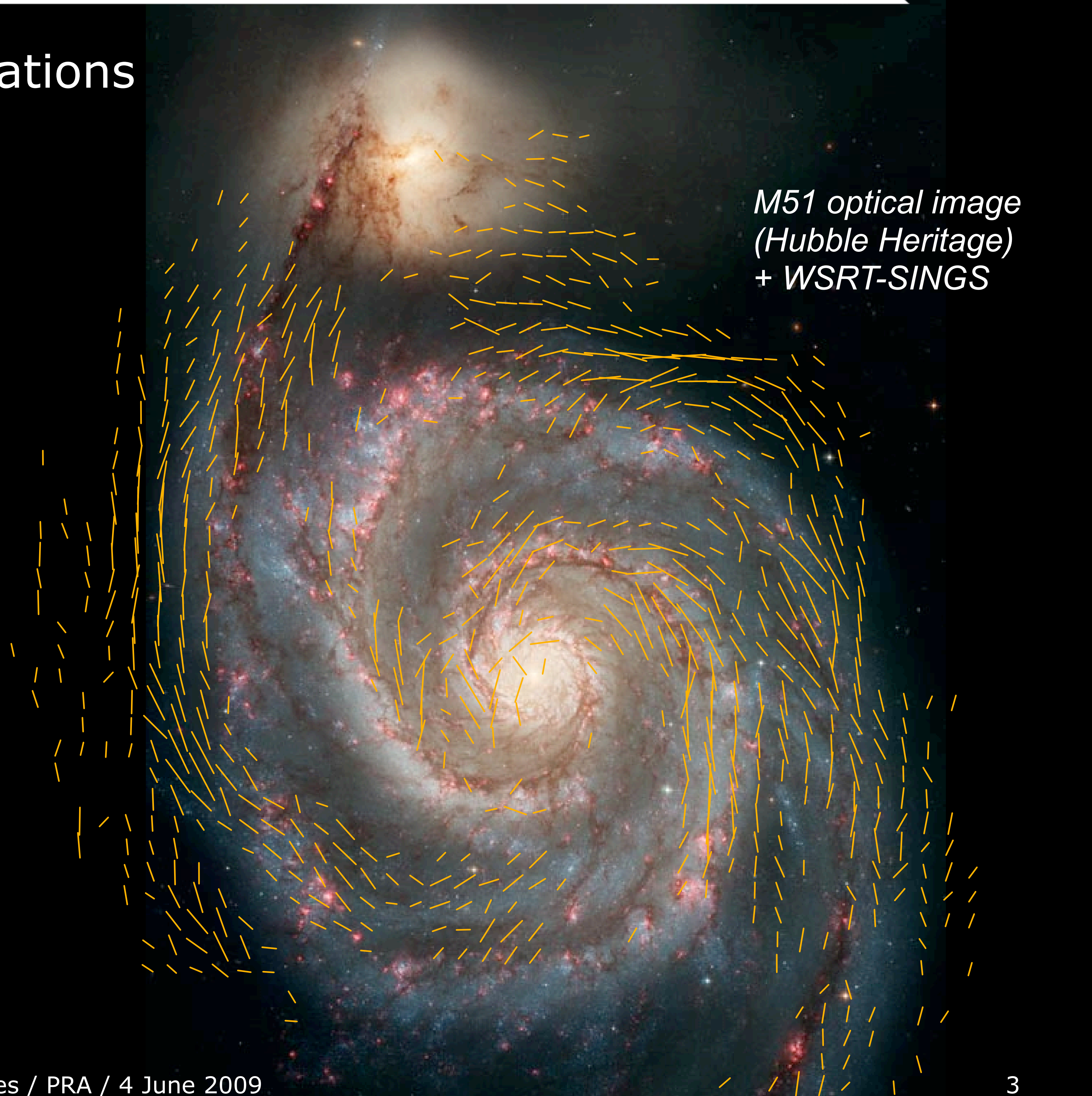
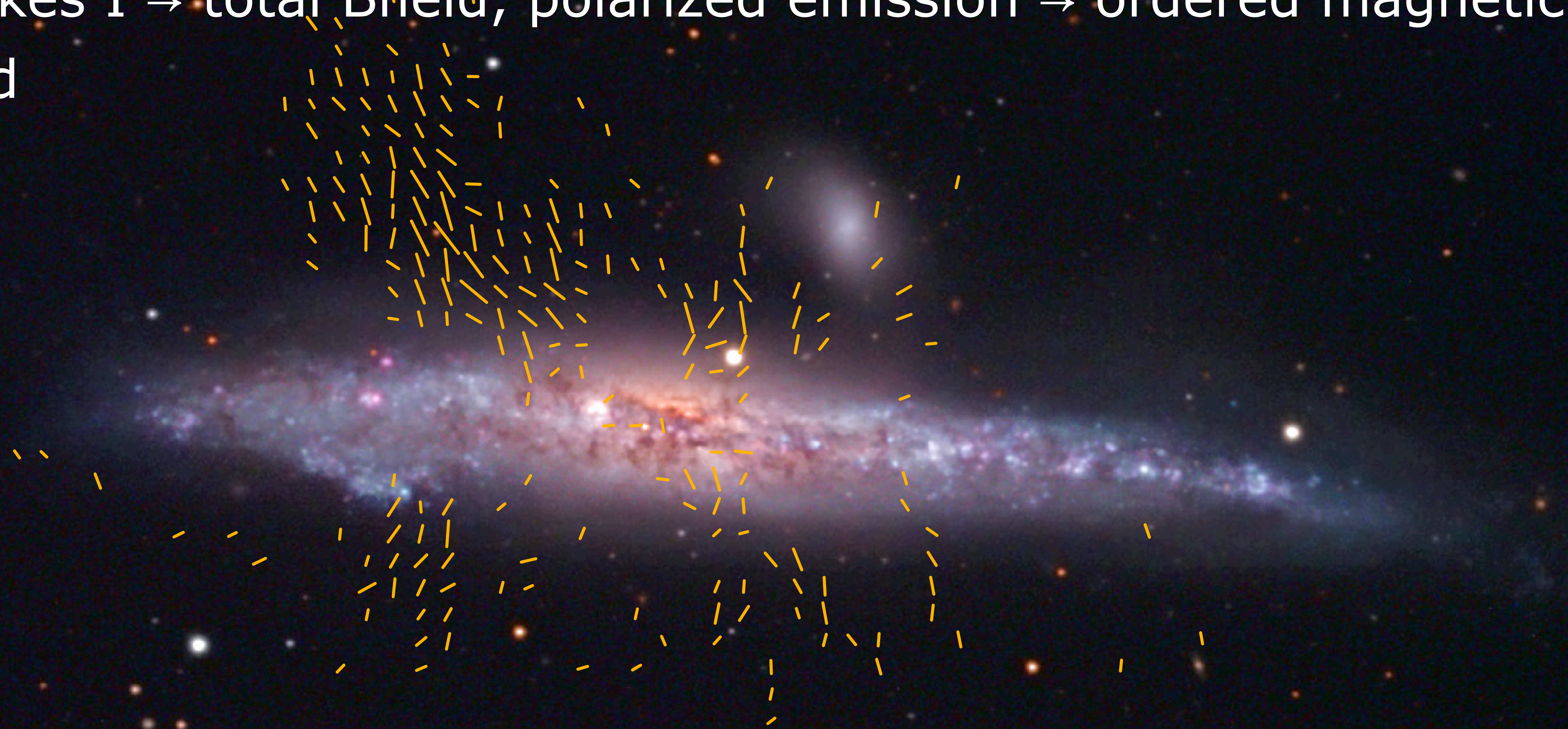
Outline

- Magnetic field observations at GHz frequencies
- WSRT-SINGS: observational trends in nearby spirals (Heald+ 2009) [arXiv:0905.3995]
- Moving forward with the new generation of L-band radio telescopes



Observations of magnetic fields

- Synchrotron emission probes magnetic fields perpendicular to LOS:
  Stokes I → total Bfield, polarized emission → ordered magnetic field



- Faraday rotation probes magnetic fields *along* LOS: sign gives direction of magnetic field

NGC 4631: Image courtesy of Robert Gendler

RM-Synthesis

- RM-Synthesis is a technique for recovering intrinsic polarization properties (the *Faraday dispersion function*), by taking advantage of a Fourier transform relation with observables:

$$F(\phi) = \int_{-\infty}^{\infty} P(\lambda^2) e^{-2i\phi\lambda^2} d\lambda^2$$

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Polarized flux in each channel

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Faraday depth

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Faraday dispersion function

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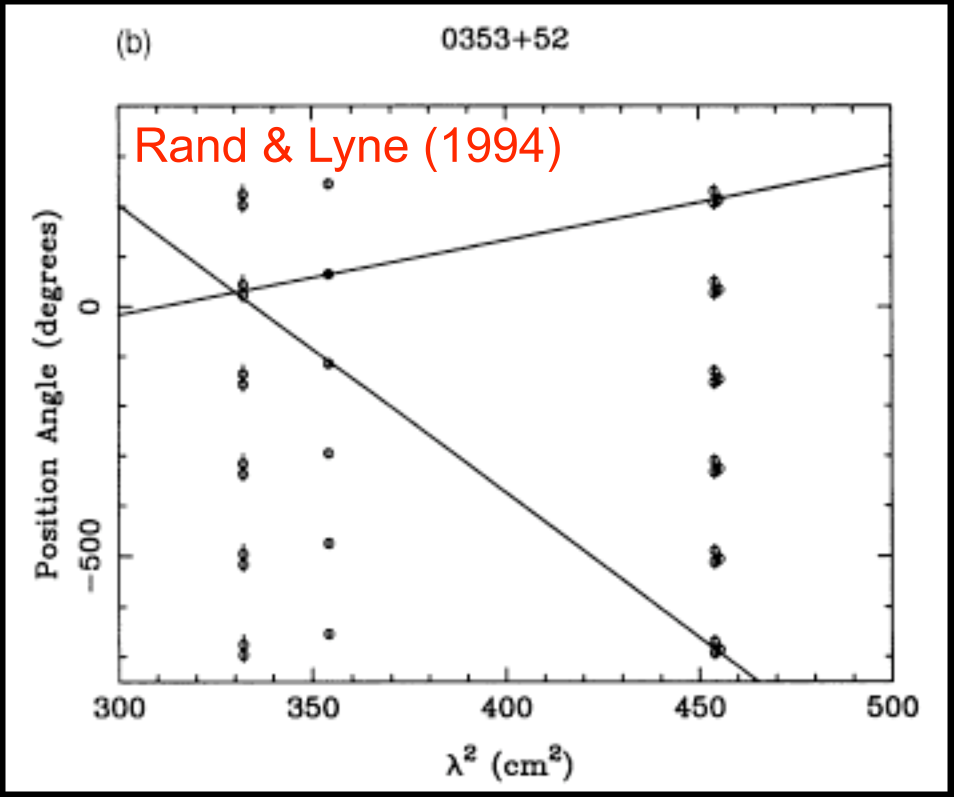
  - Avoids $n\pi$ ambiguity common to "traditional" RM method ("trial RM" interpretation)



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  - Avoids nπ ambiguity common to "traditional" RM method ("trial RM" interpretation)
  - Allows detection of polarization and its RM at faint flux levels
  - See Burn (1966), Brentjens & de Bruyn (2005), Heald et al. (2009) for description and details
  - Requirements for successful observational program: wide band, narrow channels, extension to high frequencies
    Note: RM-Synthesis maximizes polarized S/N

WSRT-SINGS

- Survey with WSRT of large northern SINGS galaxies, in 18-cm and 22-cm continuum
  (160 MHz BW x2)

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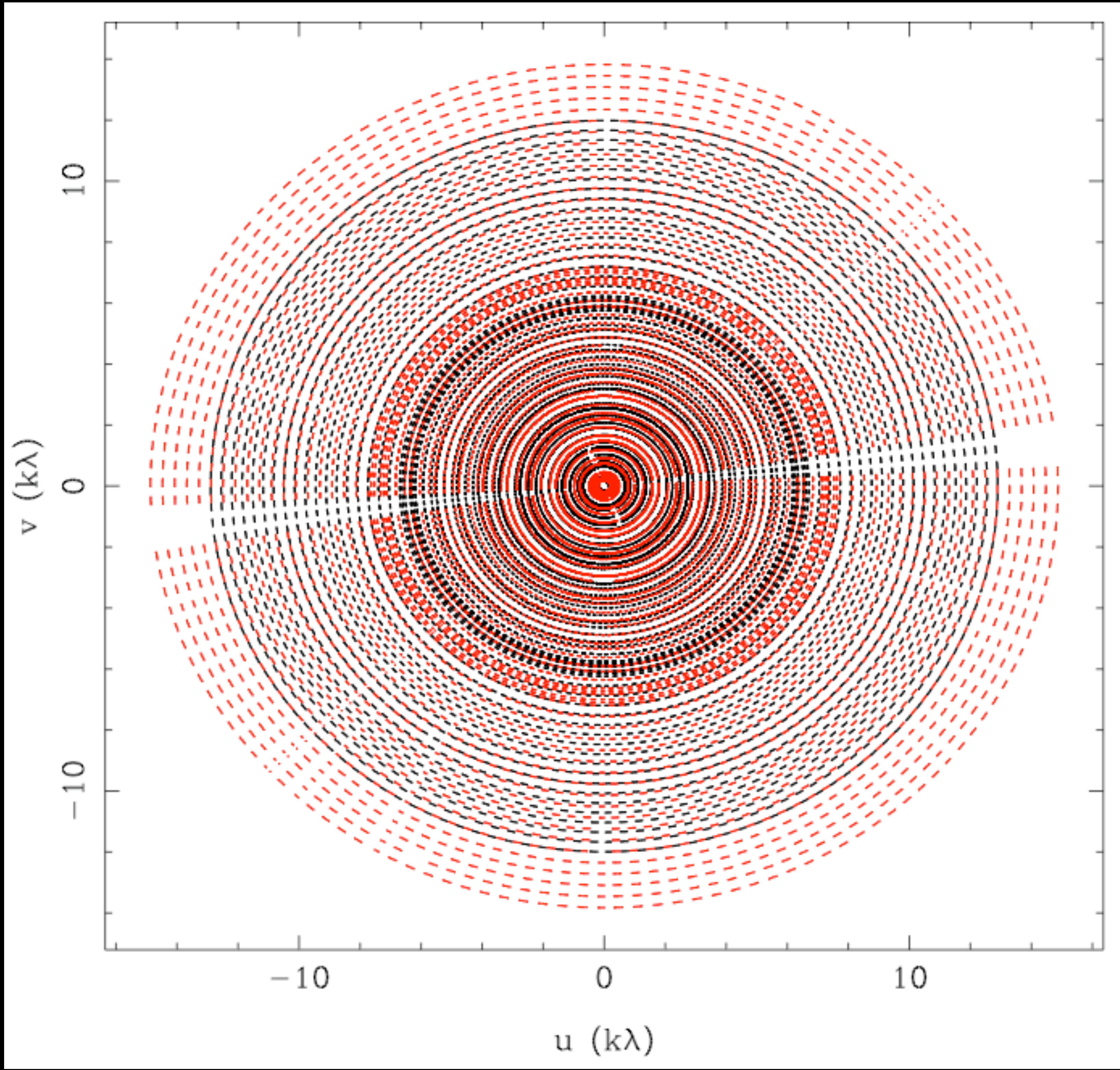

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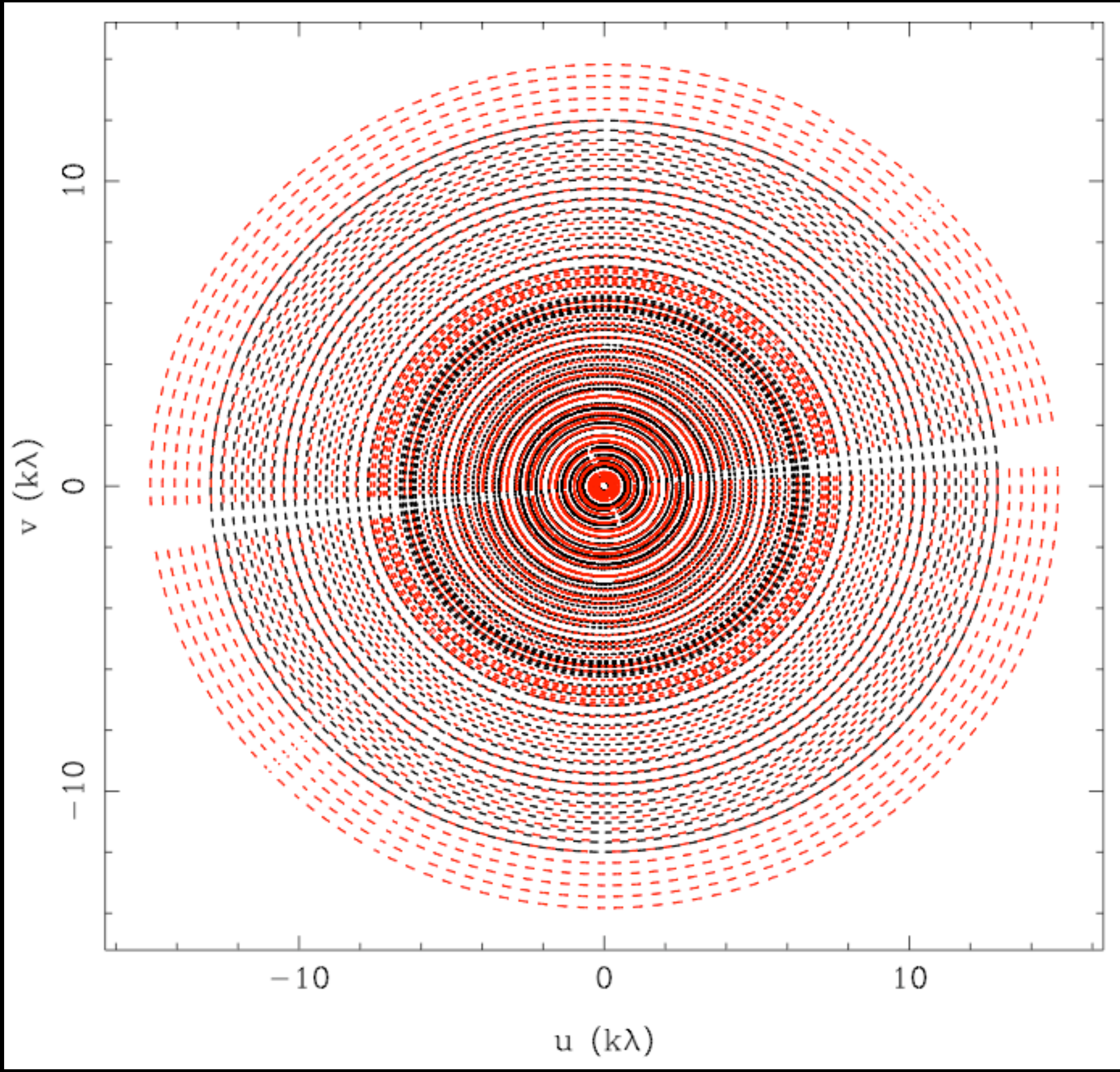

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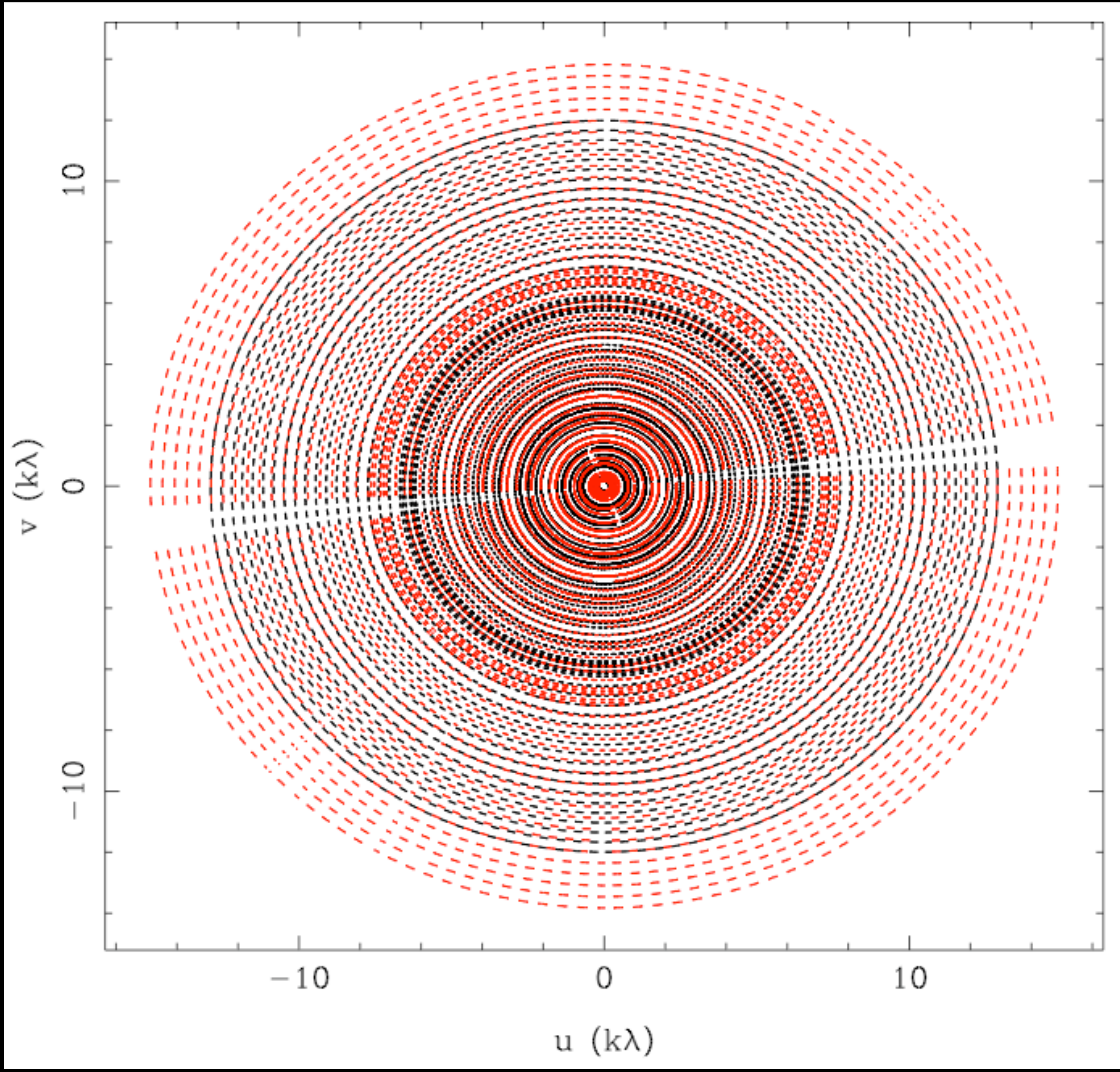

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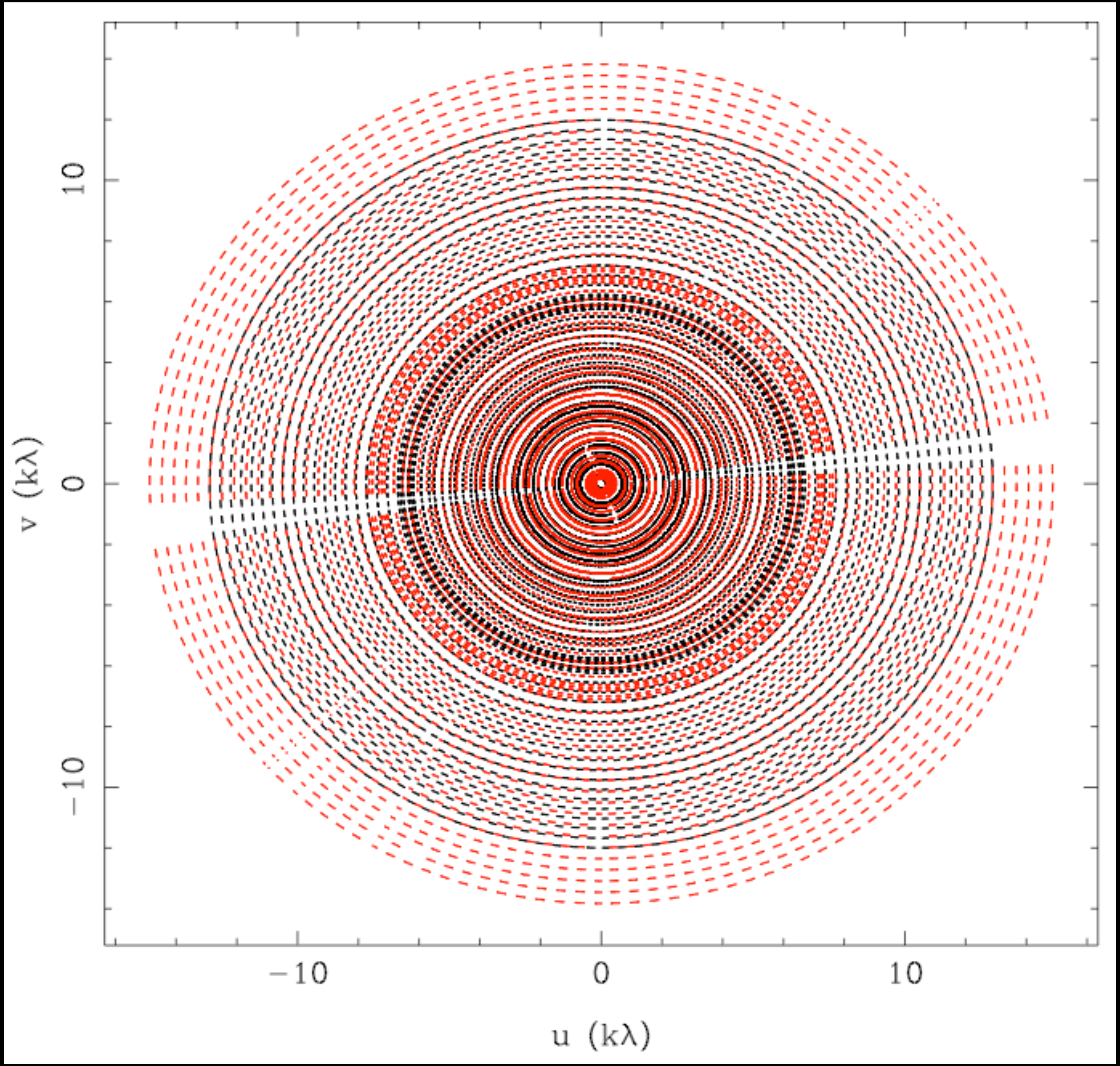
- Typical noise level in P ~10 μJy/beam rms



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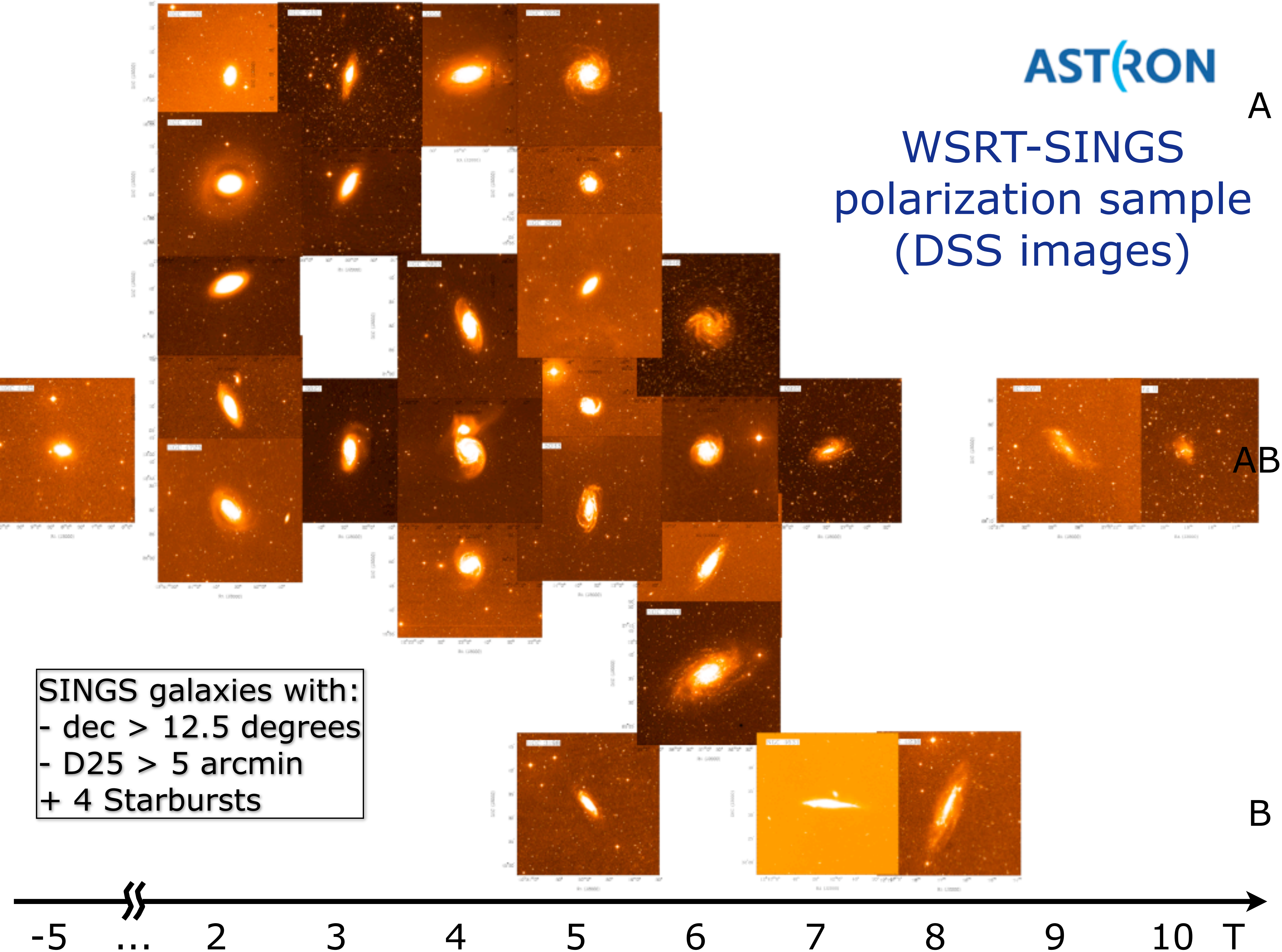
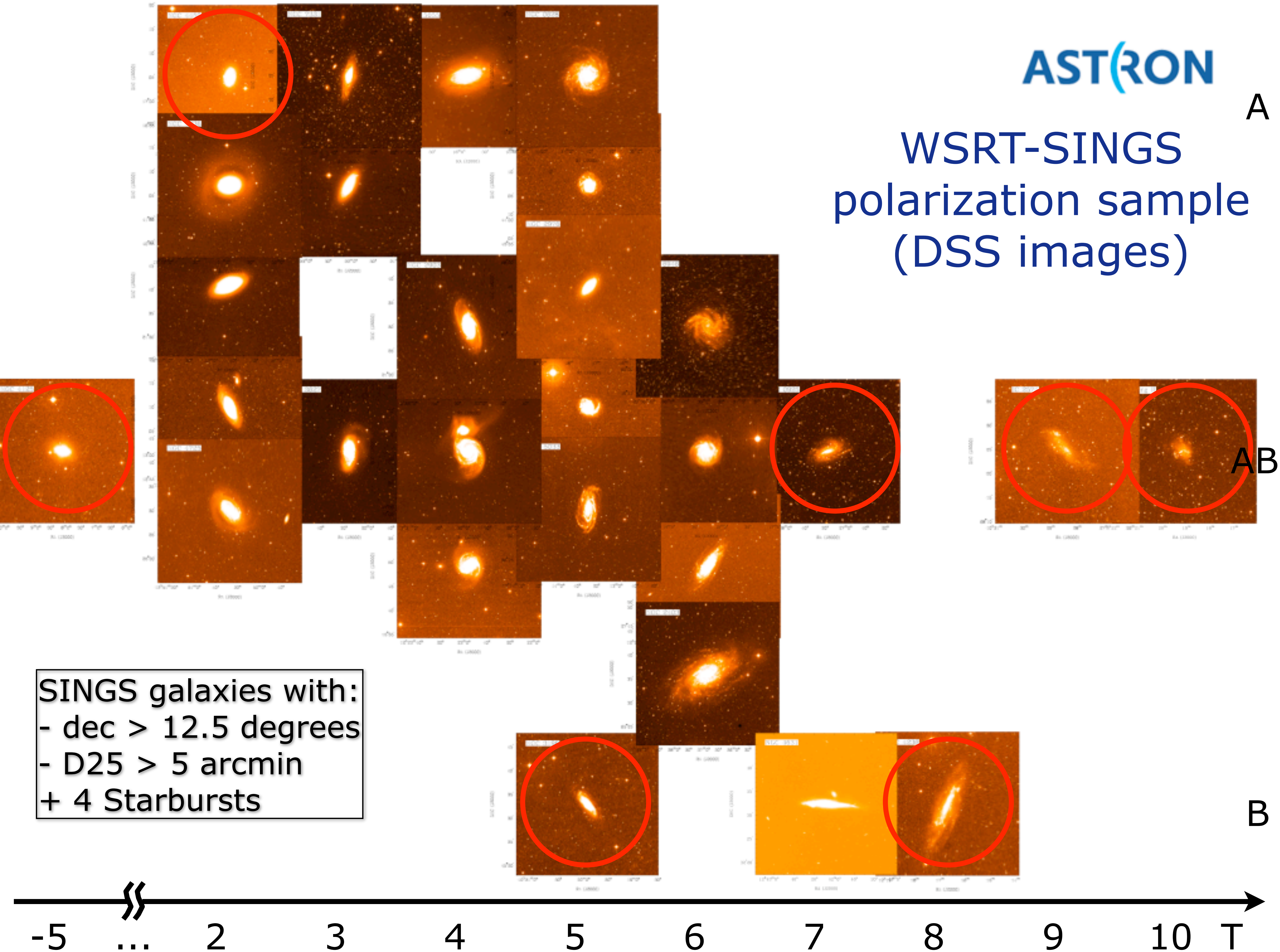
WSRT-SINGS polarization sample (DSS images)



SINGS galaxies with:
- dec > 12.5 degrees
- D25 > 5 arcmin
+ 4 Starbursts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WSRT-SINGS
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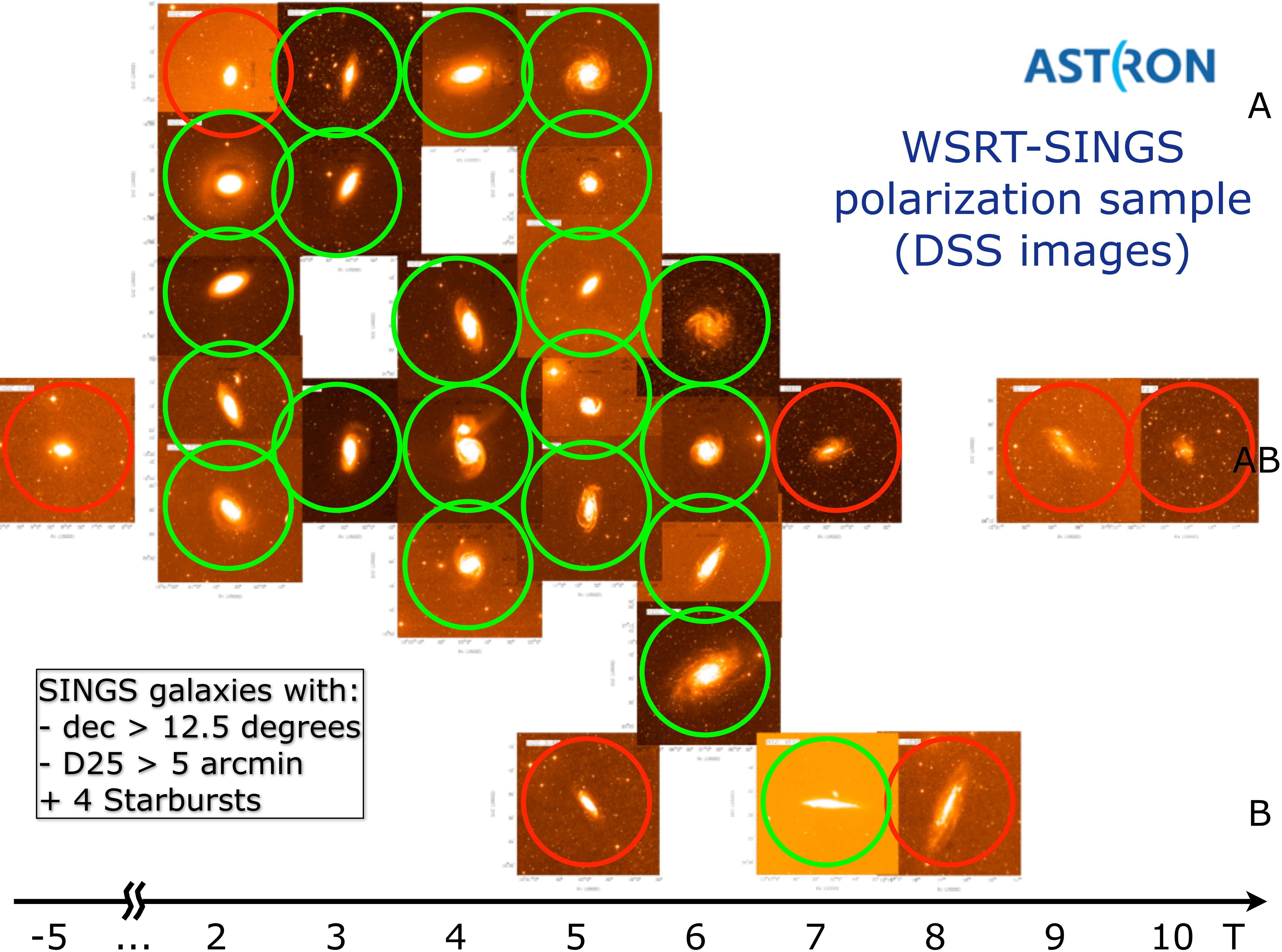

SINGS galaxies with:
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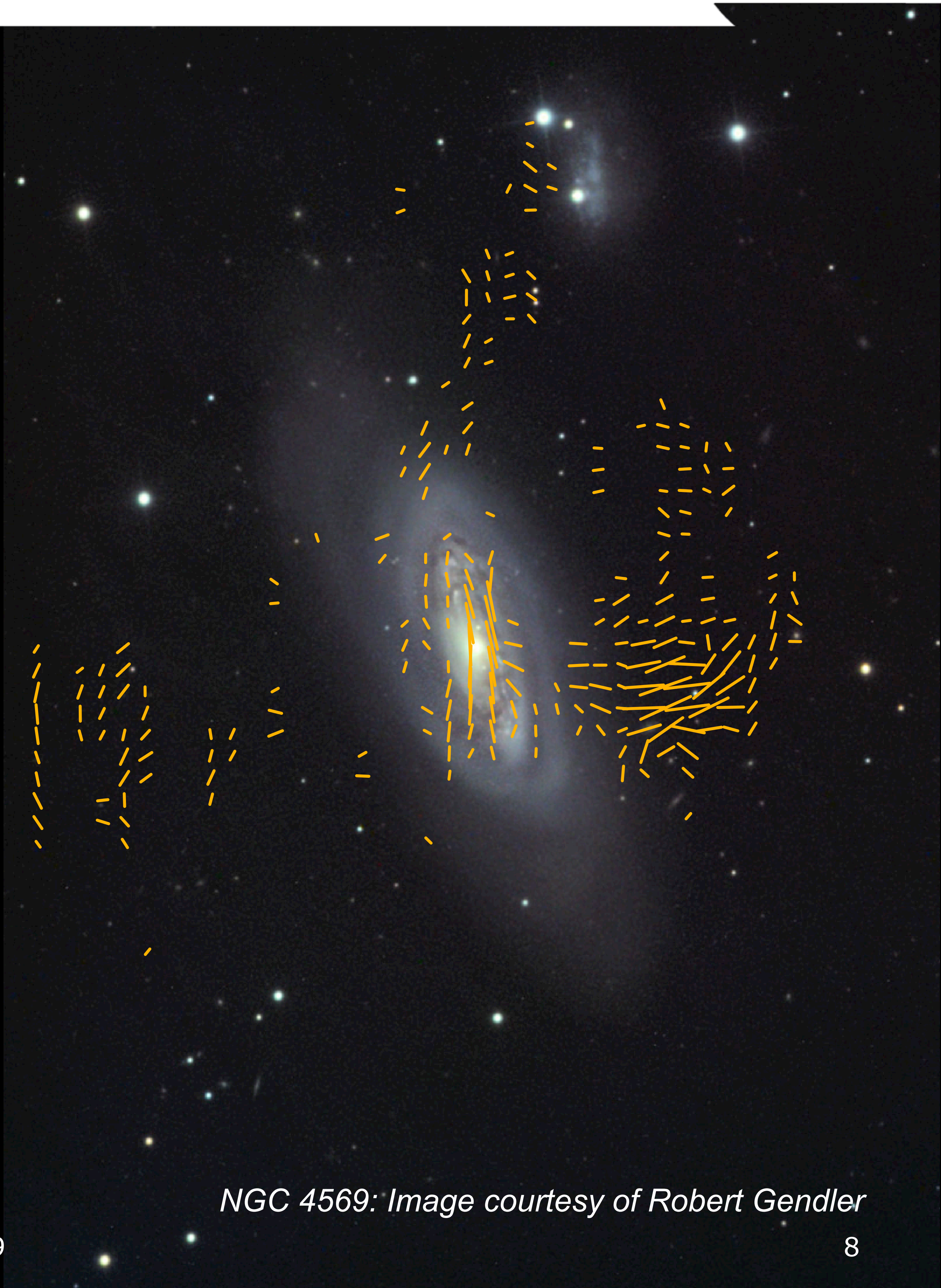
Results from WSRT-SINGS

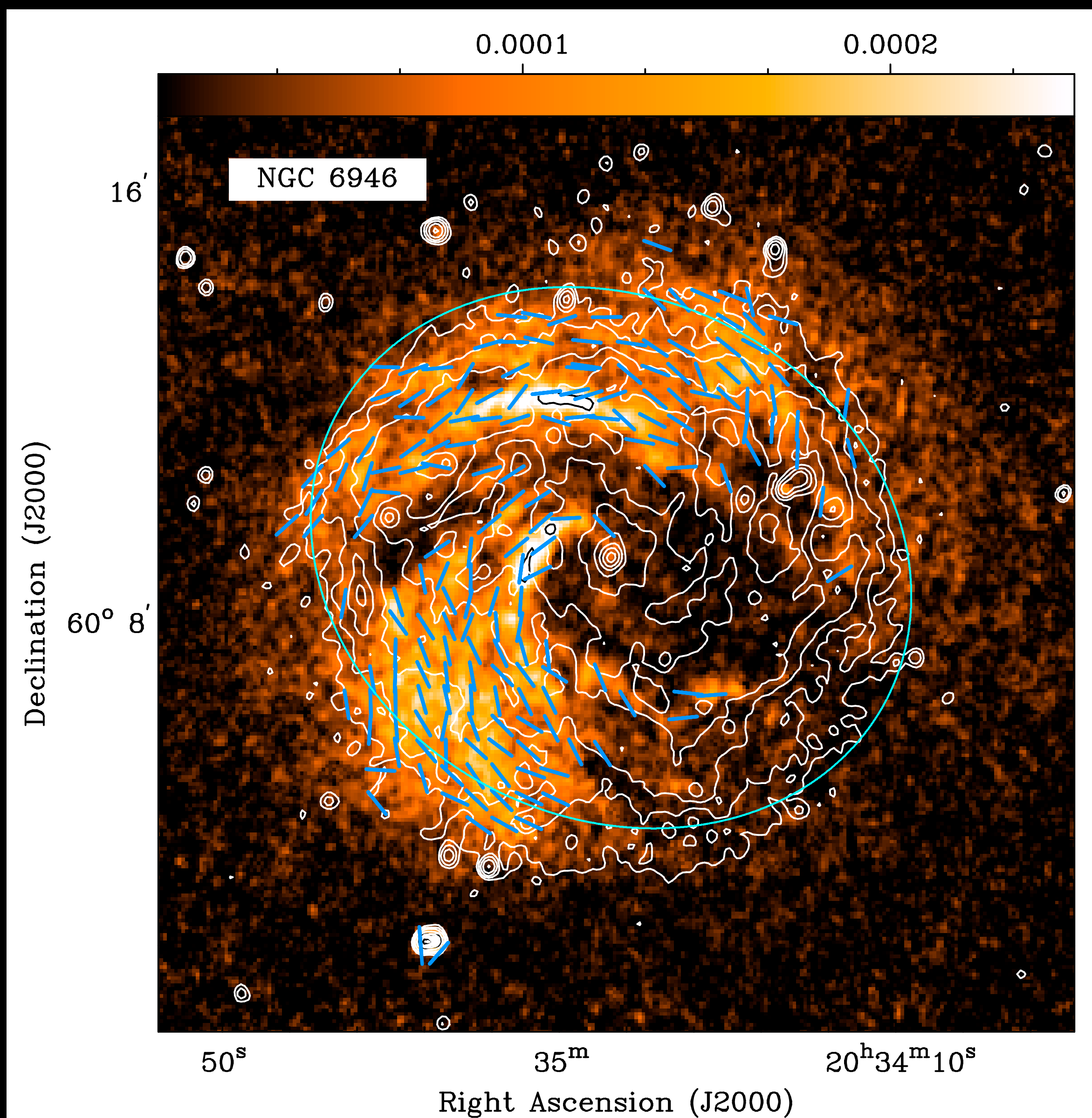
- 28 galaxies studied,
  21 detected in polarization:
  - 0/4 Magellanic & ellipticals
  - 21/24 Spirals

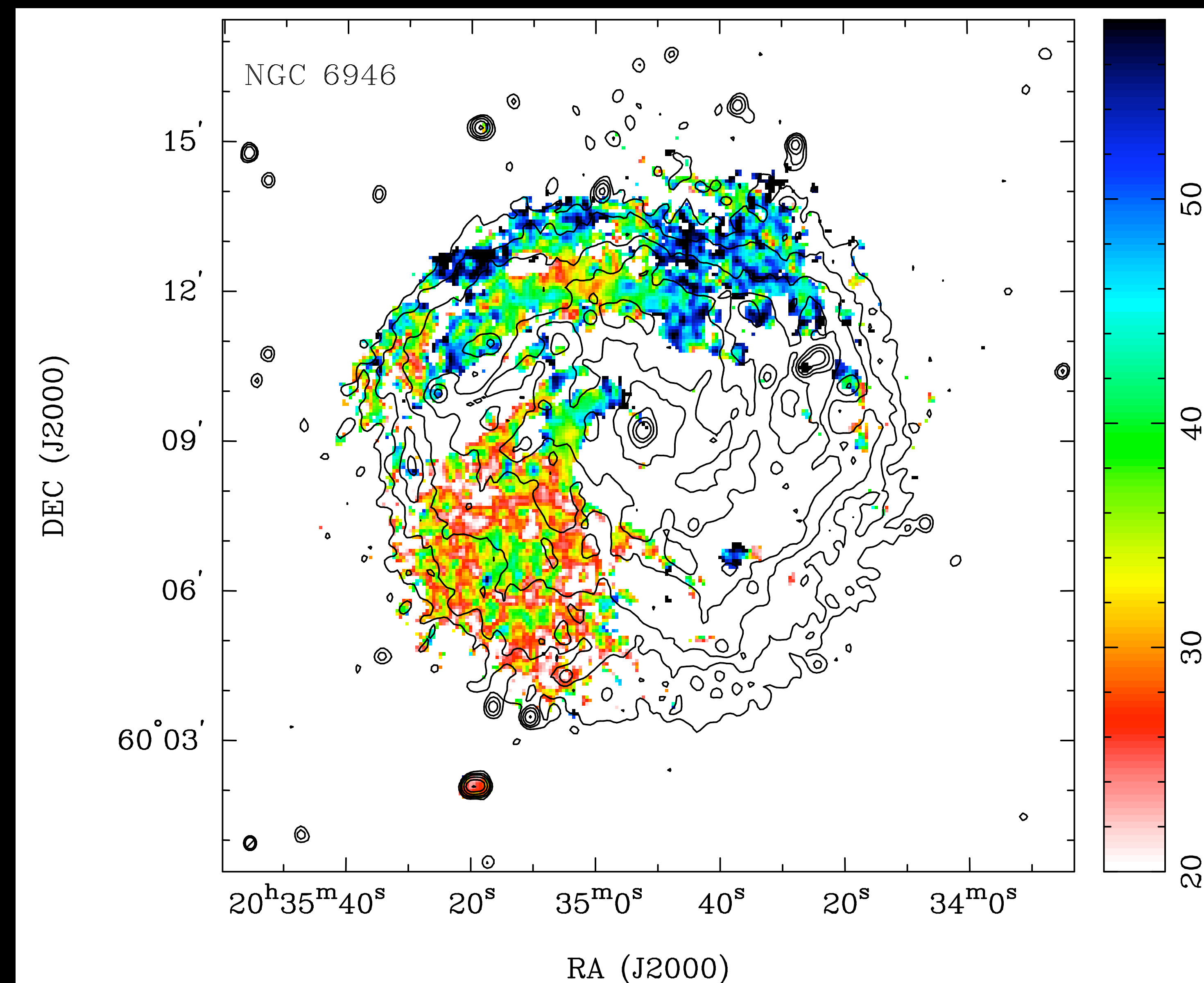
- Polarization (intensity, angle) and RM maps made for galaxies with extended polarized flux



NGC 4569: Image courtesy of Robert Gendler

WSRT-SINGS: NGC 6946

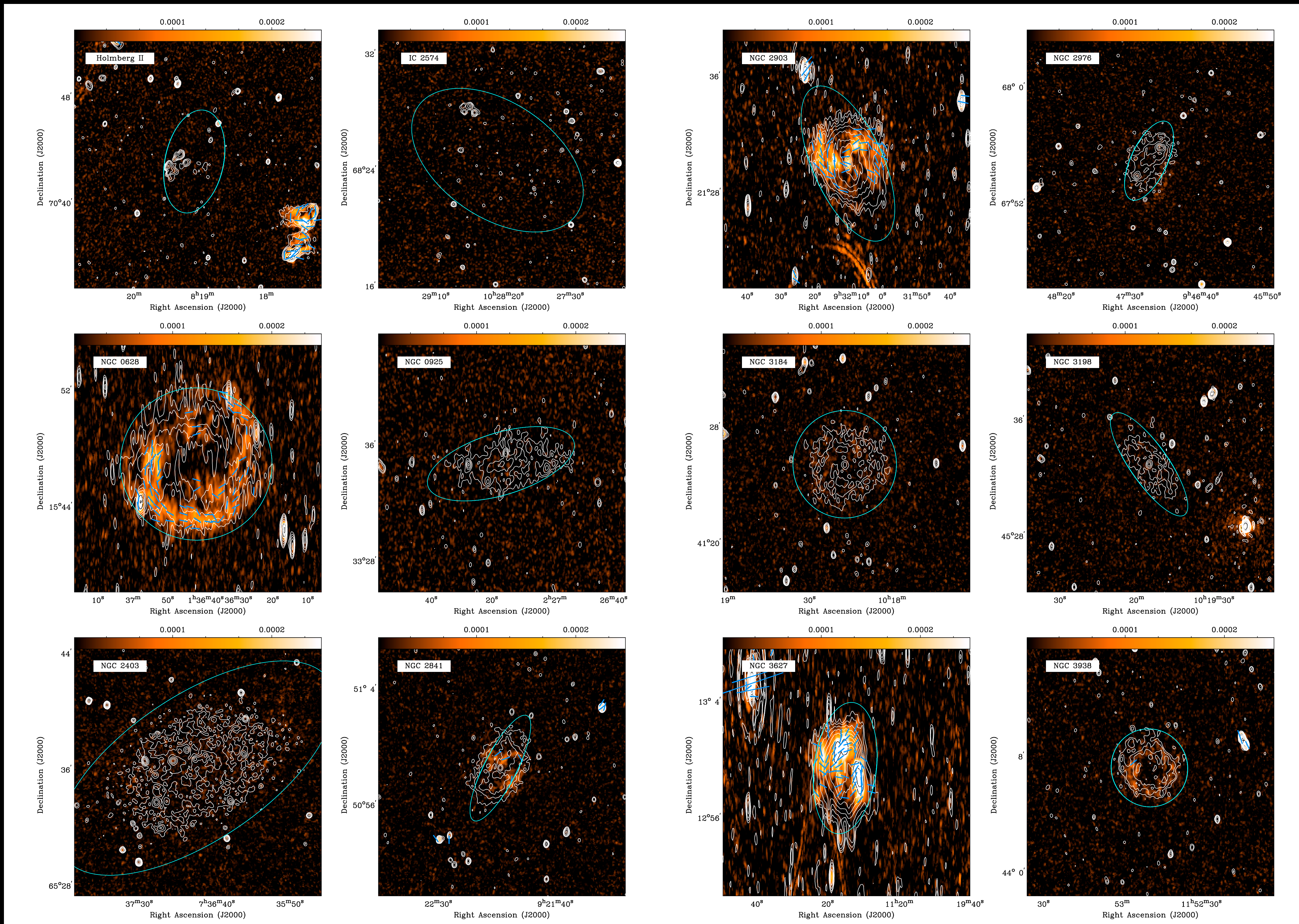




W … N

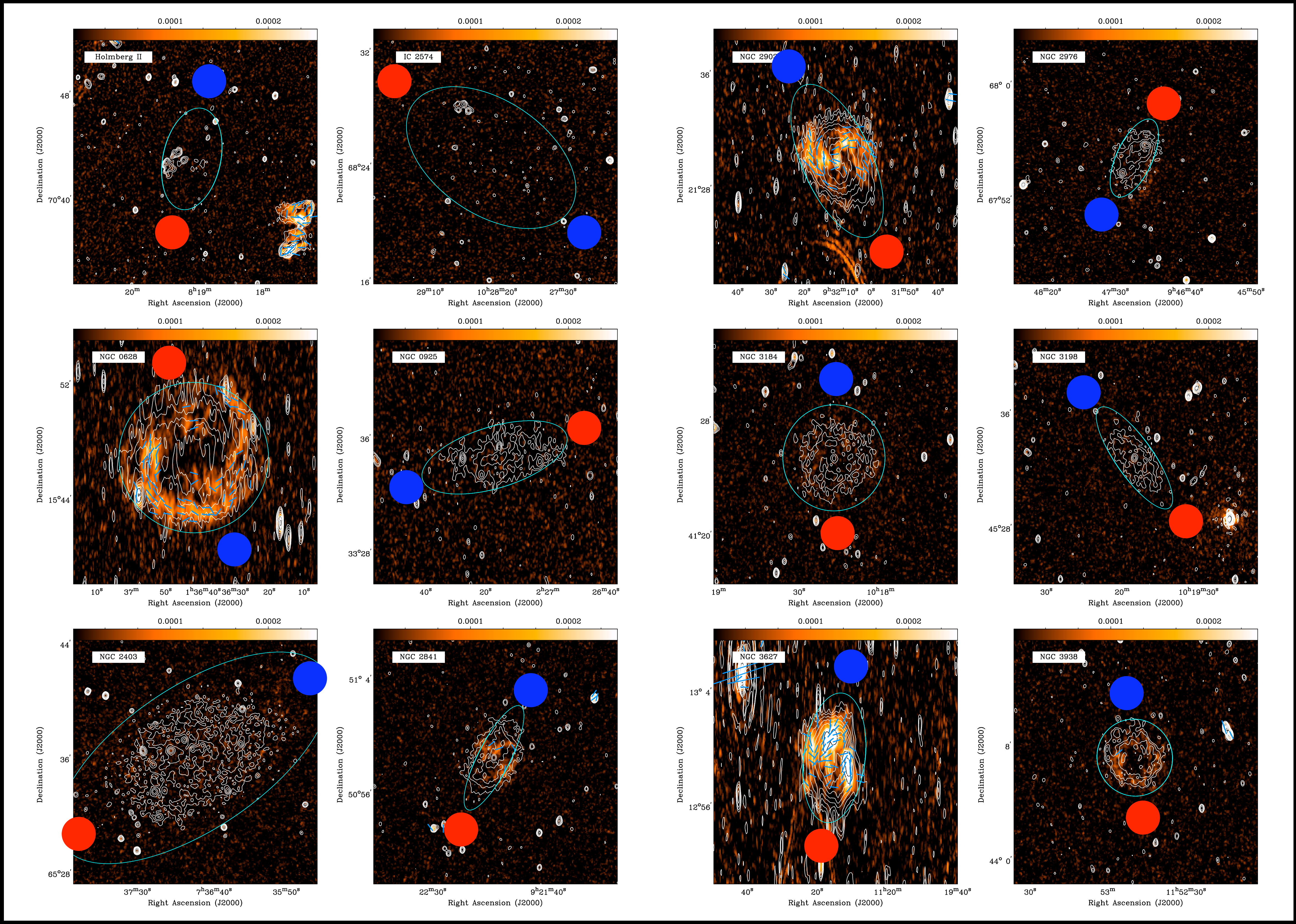

16′
60° 8′
Declination (J2000)
50
40
30
20
Image courtesy of Robert Gendler

Polarized flux



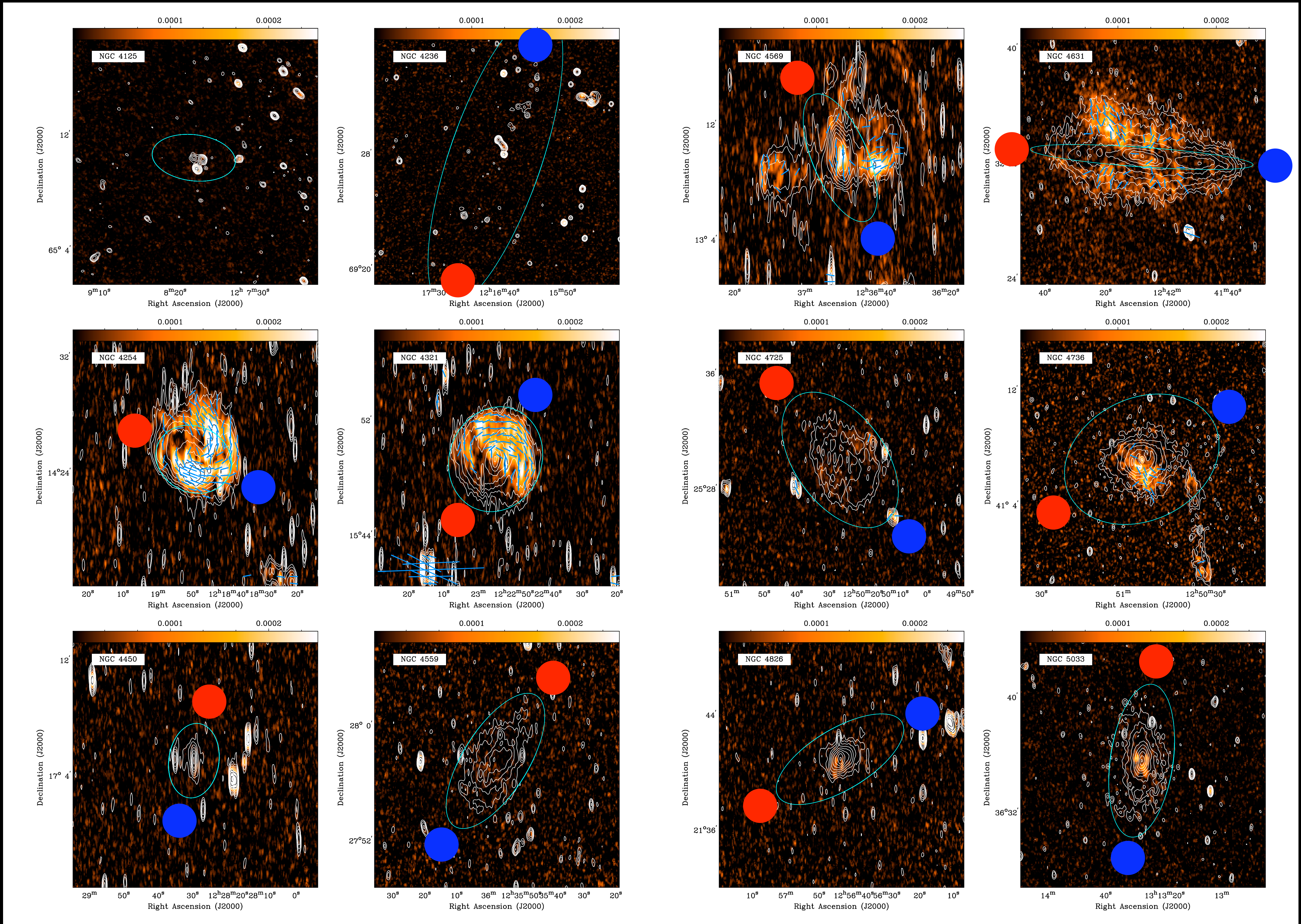
Polarized flux

approaching side
receding side



Polarized flux

- approaching side (blue)
- receding side (red)



Polarized flux

approaching side

receding side

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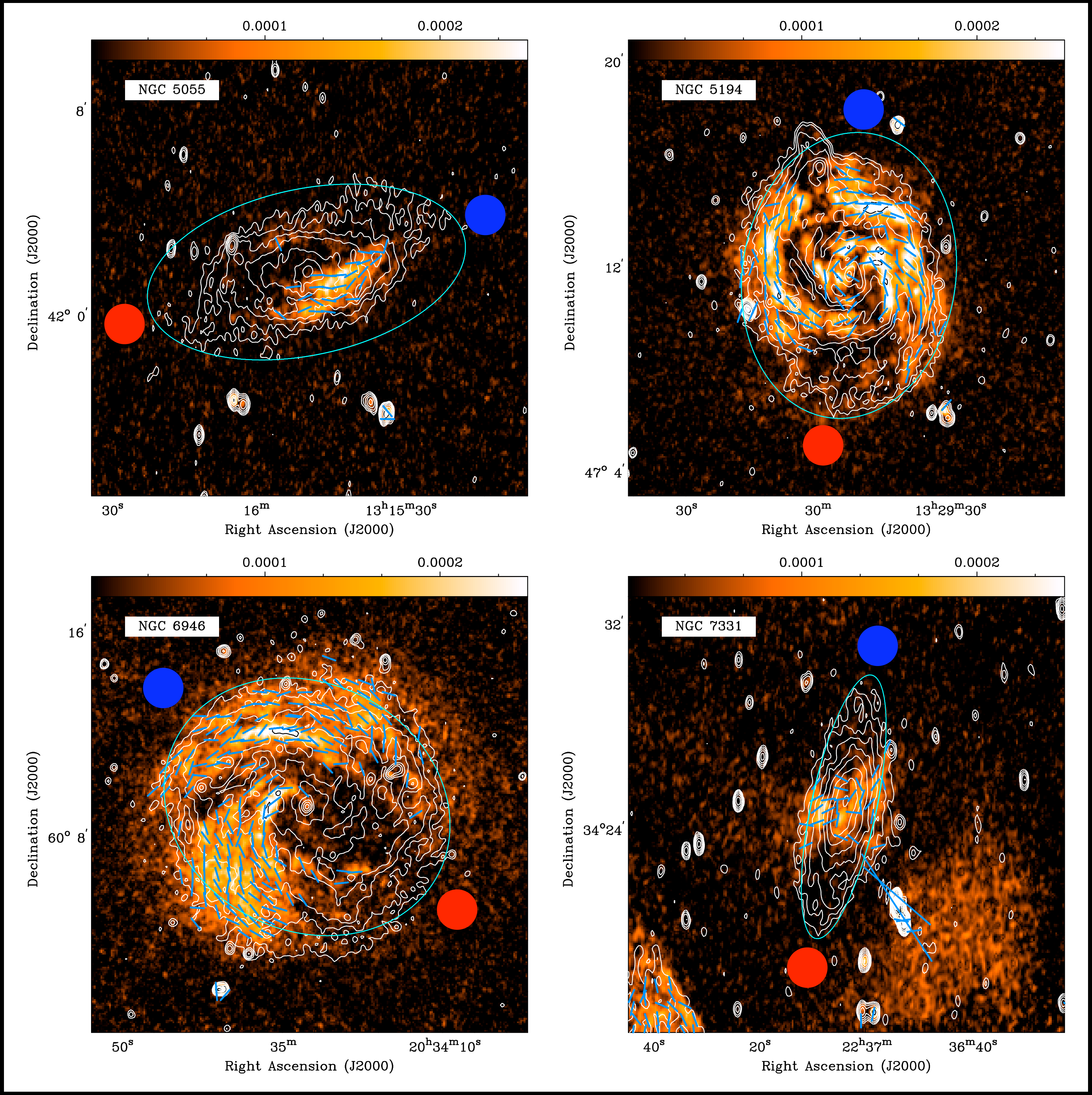
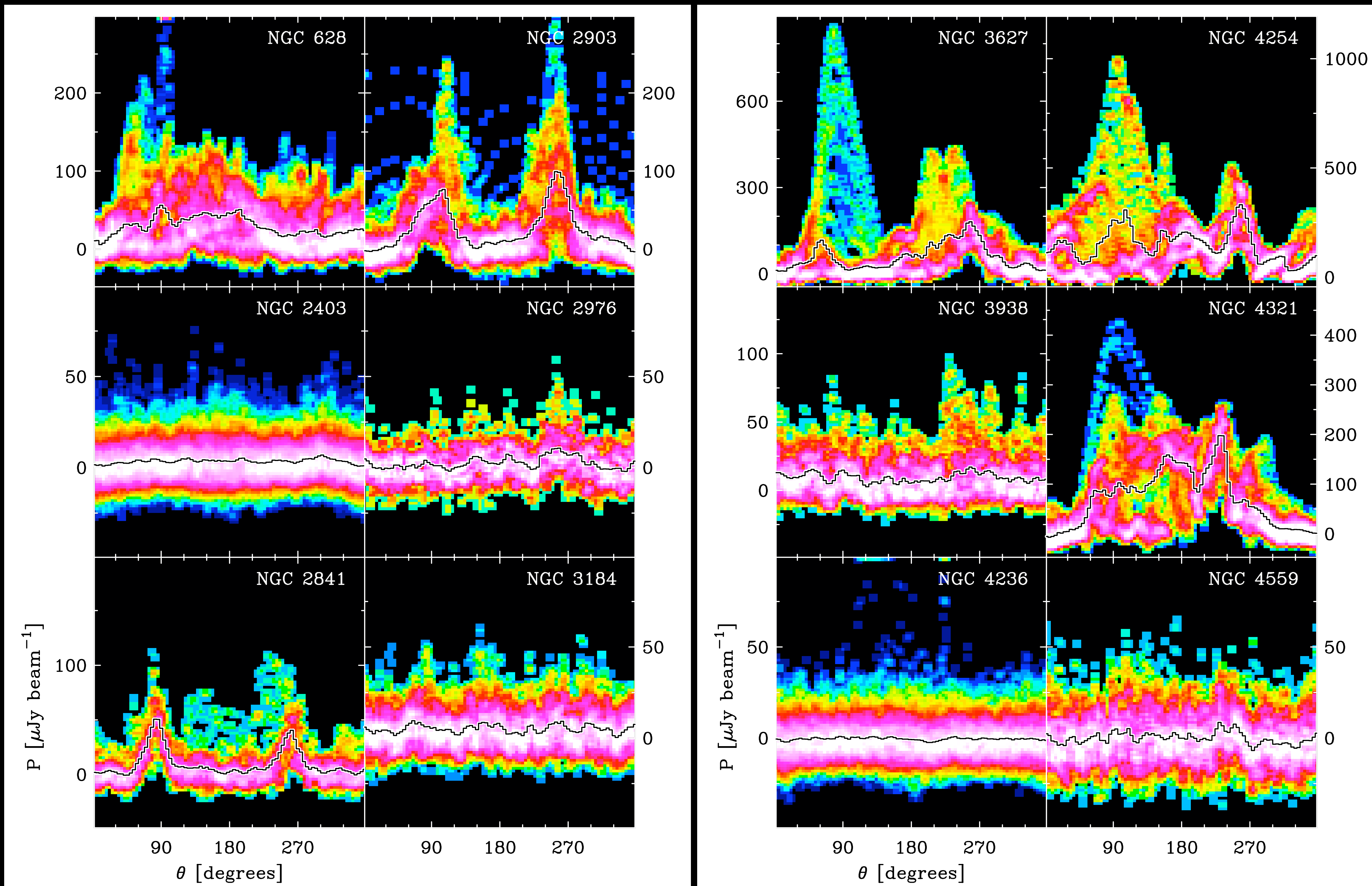


Azimuthal variation in polarized intensity

- "Histogram images"



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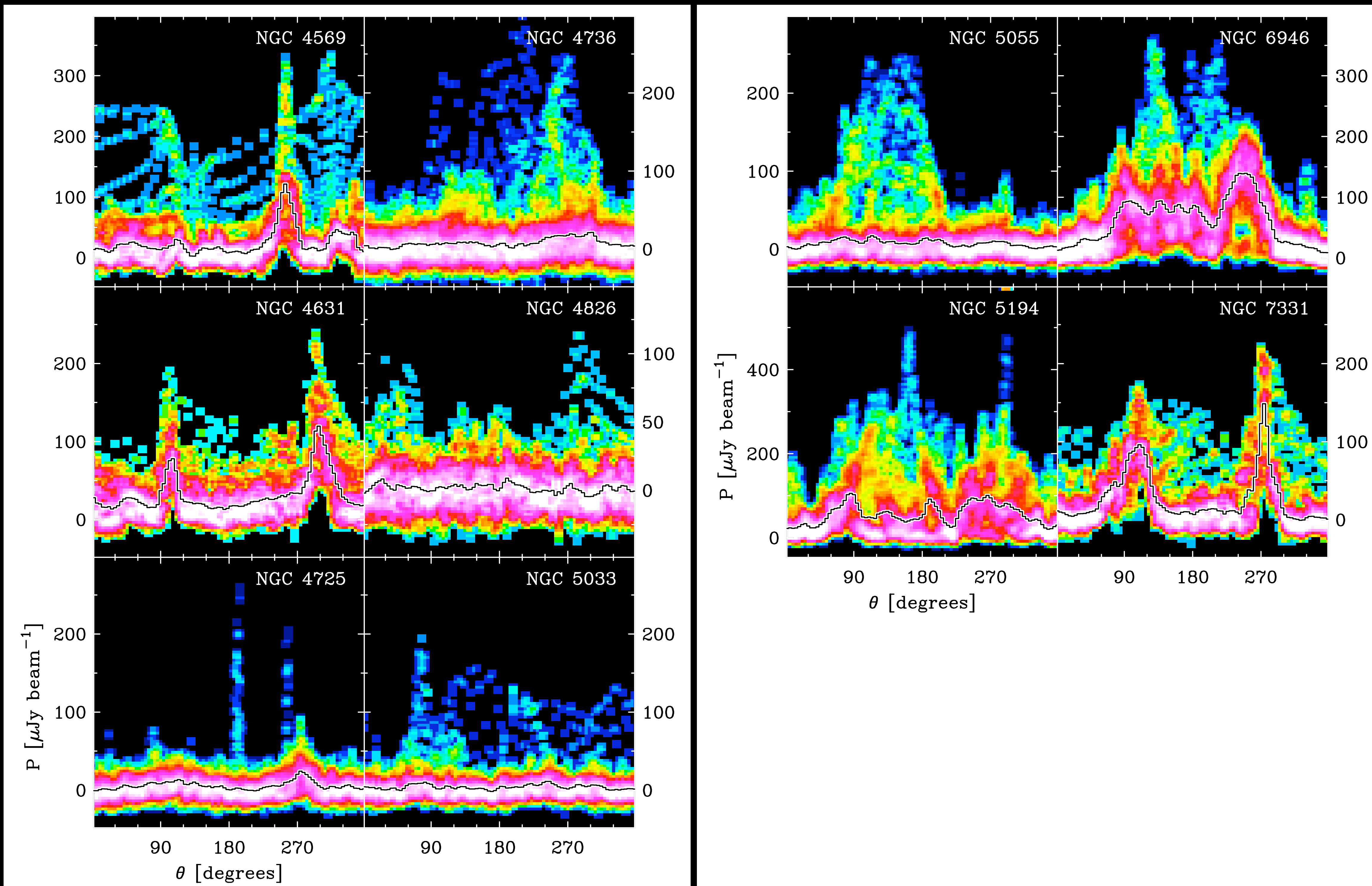
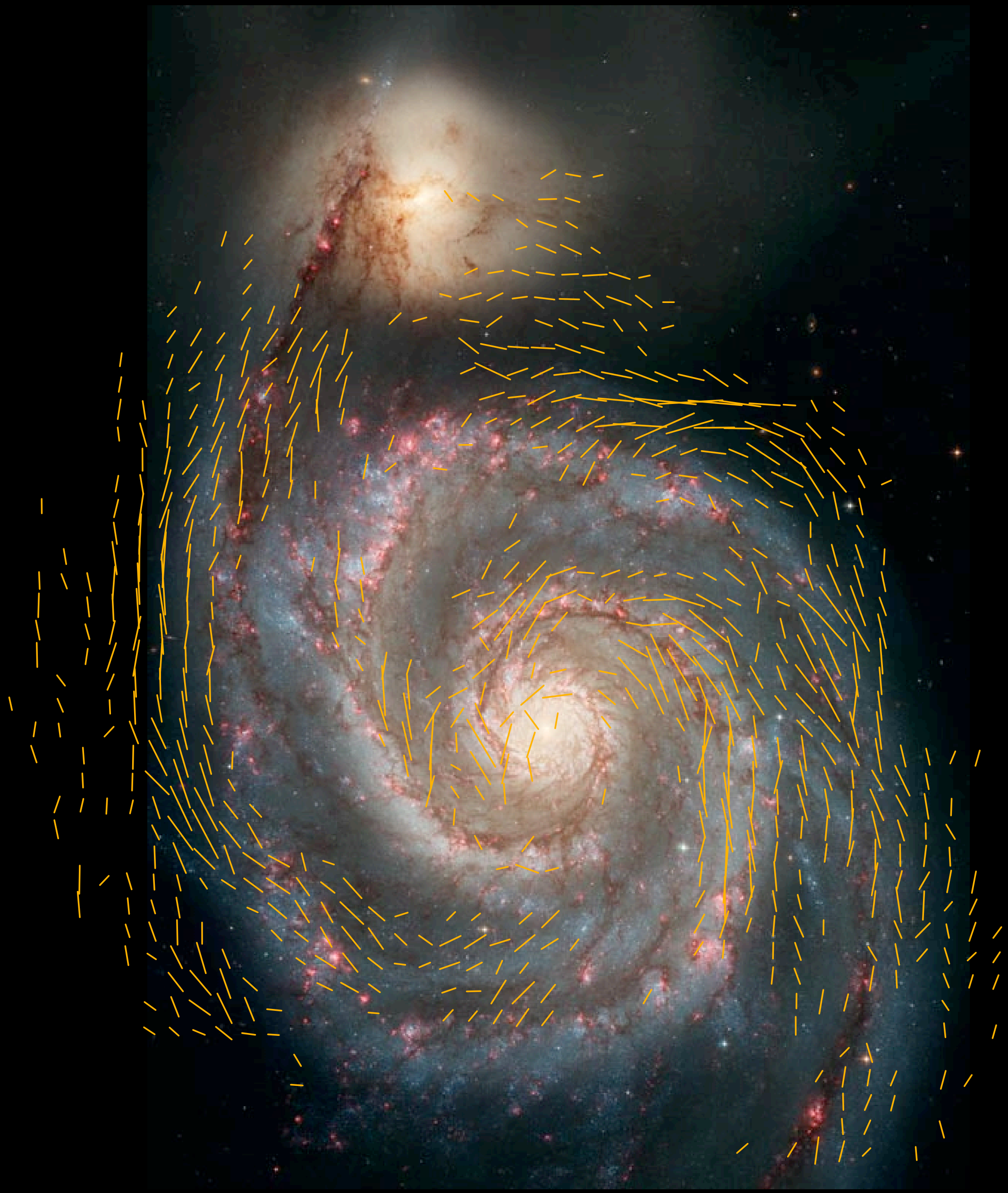
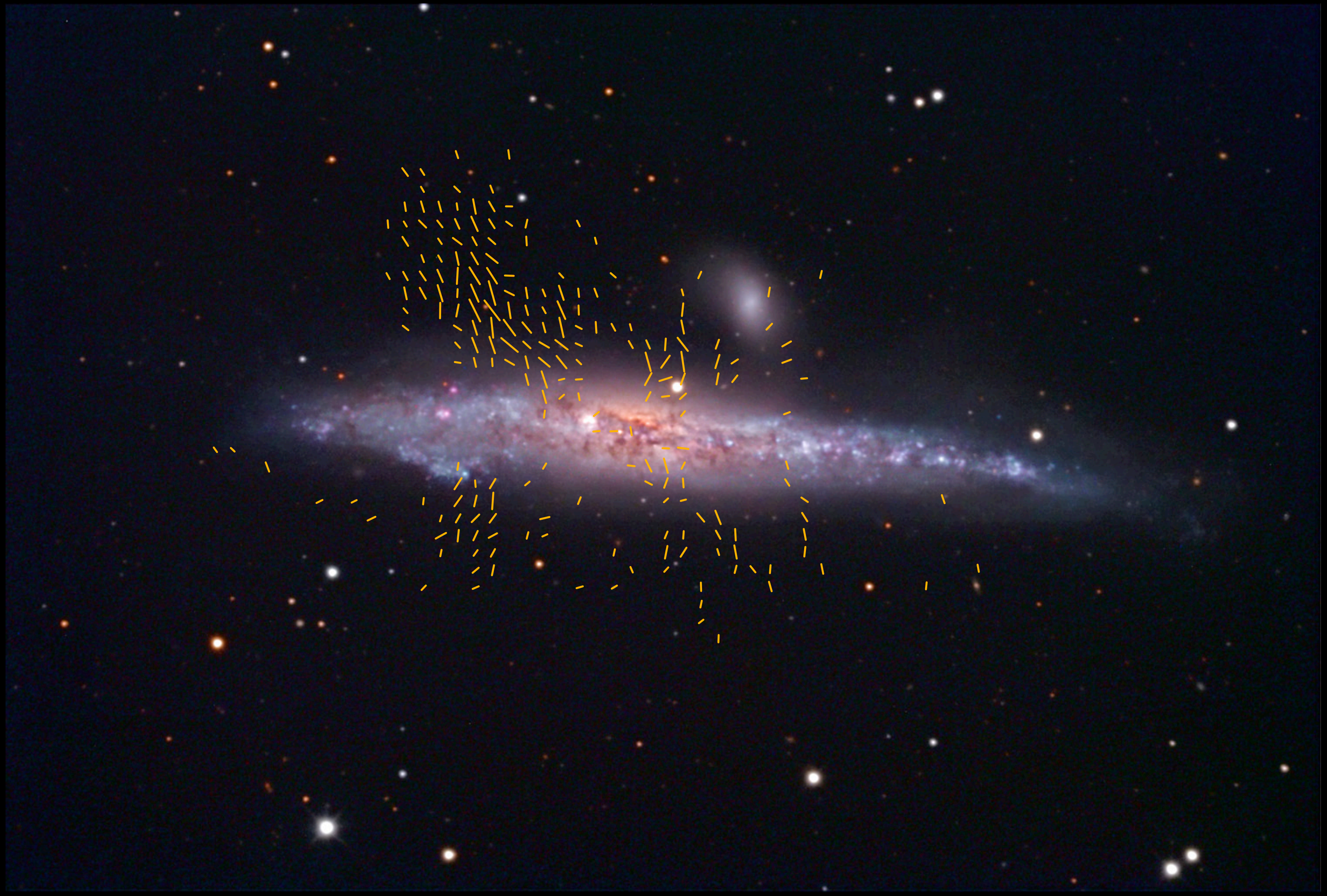


Global magnetic field geometry

- What is already clear (and supported by WSRT-SINGS);
  - magnetic field lines follow the spiral pattern in the disk
  - X-shaped pattern in edge-ons





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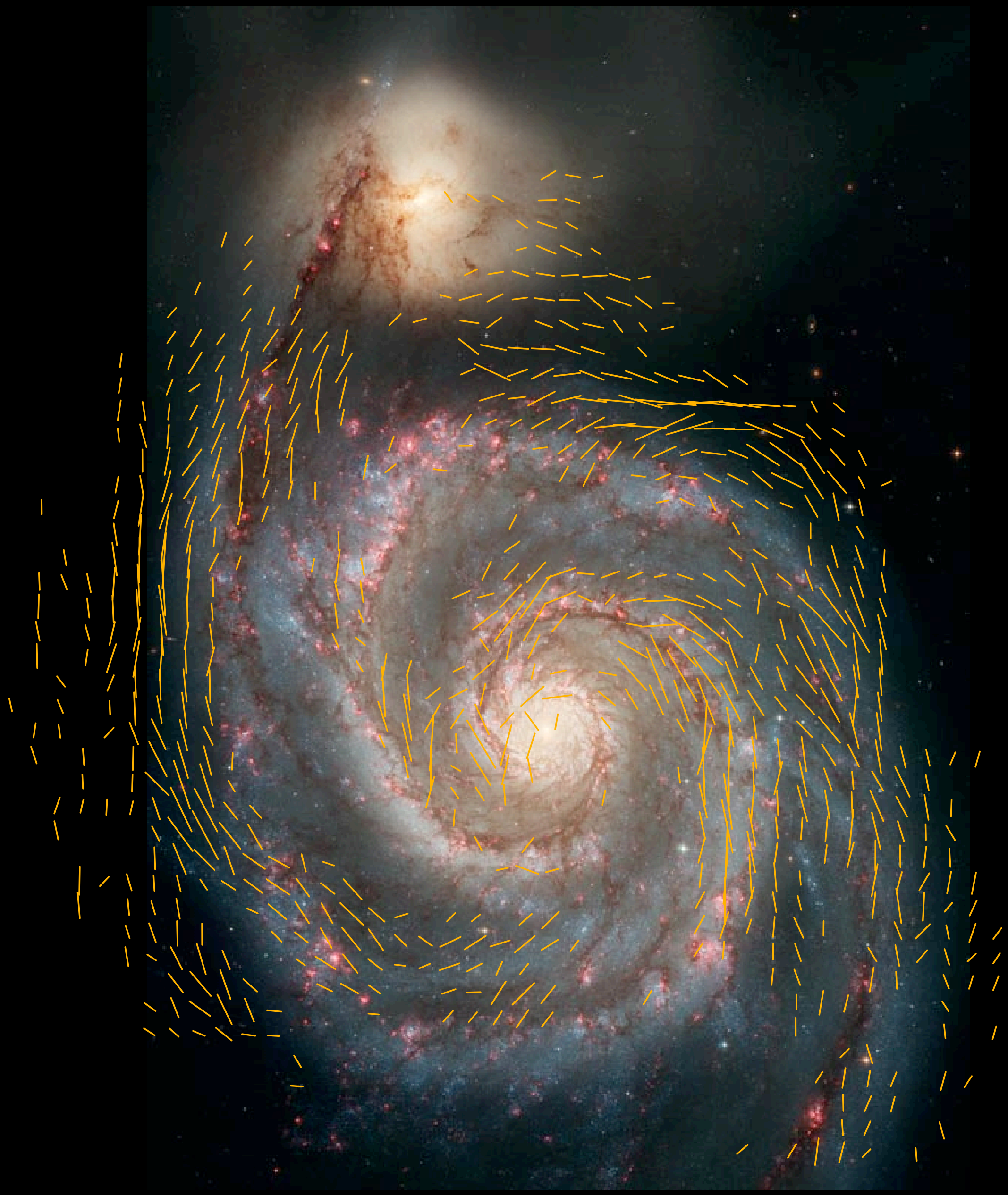

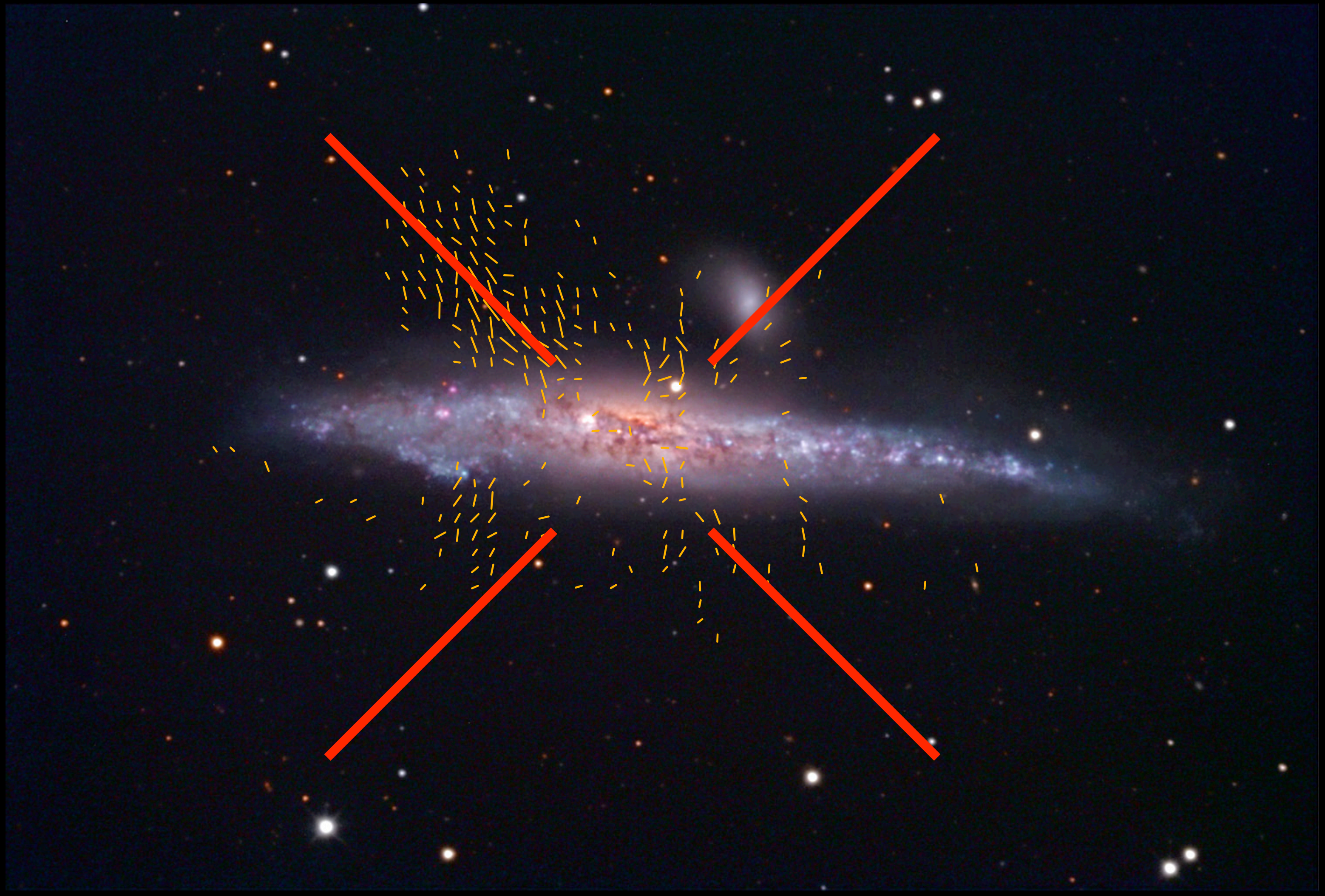

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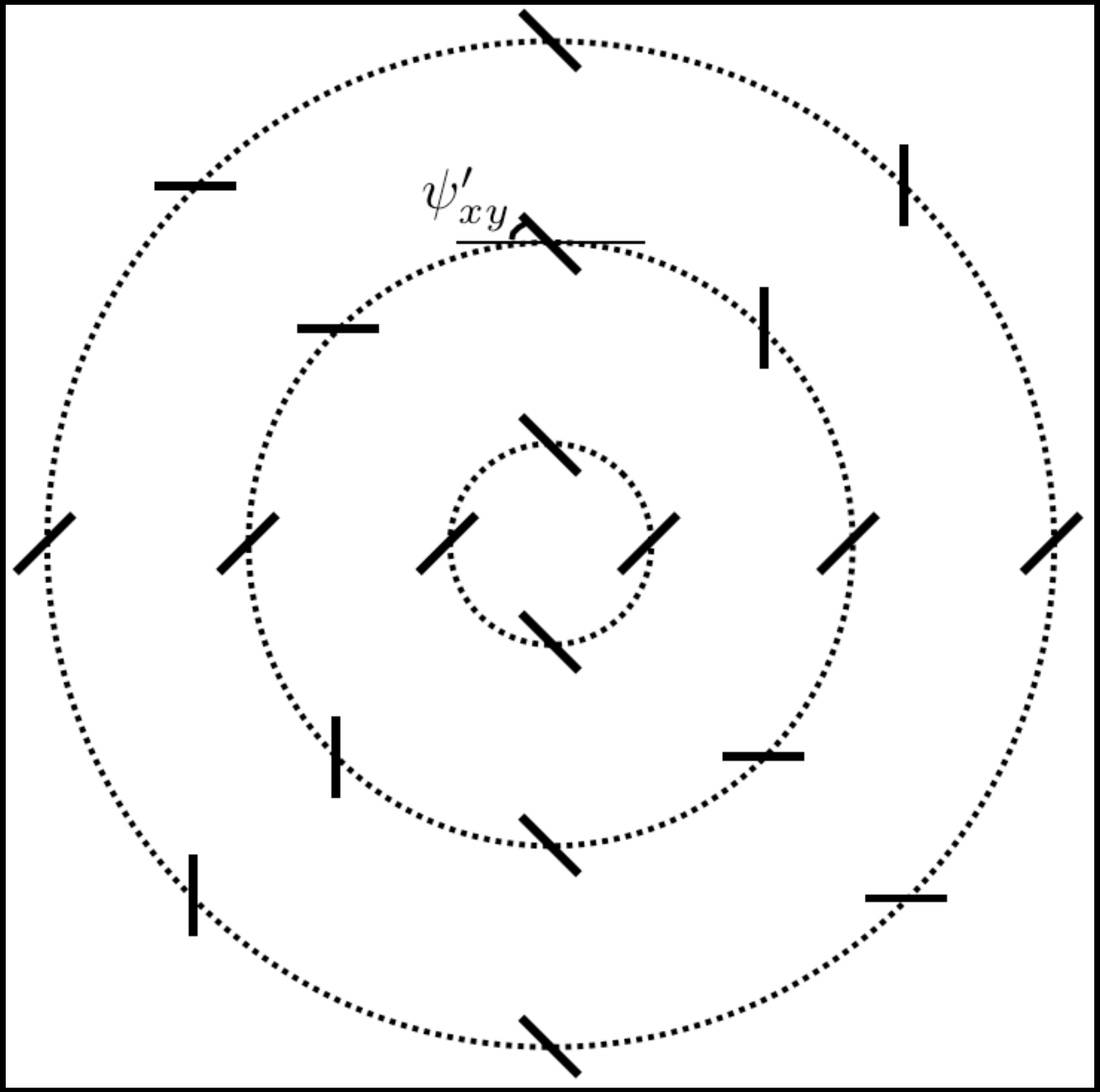

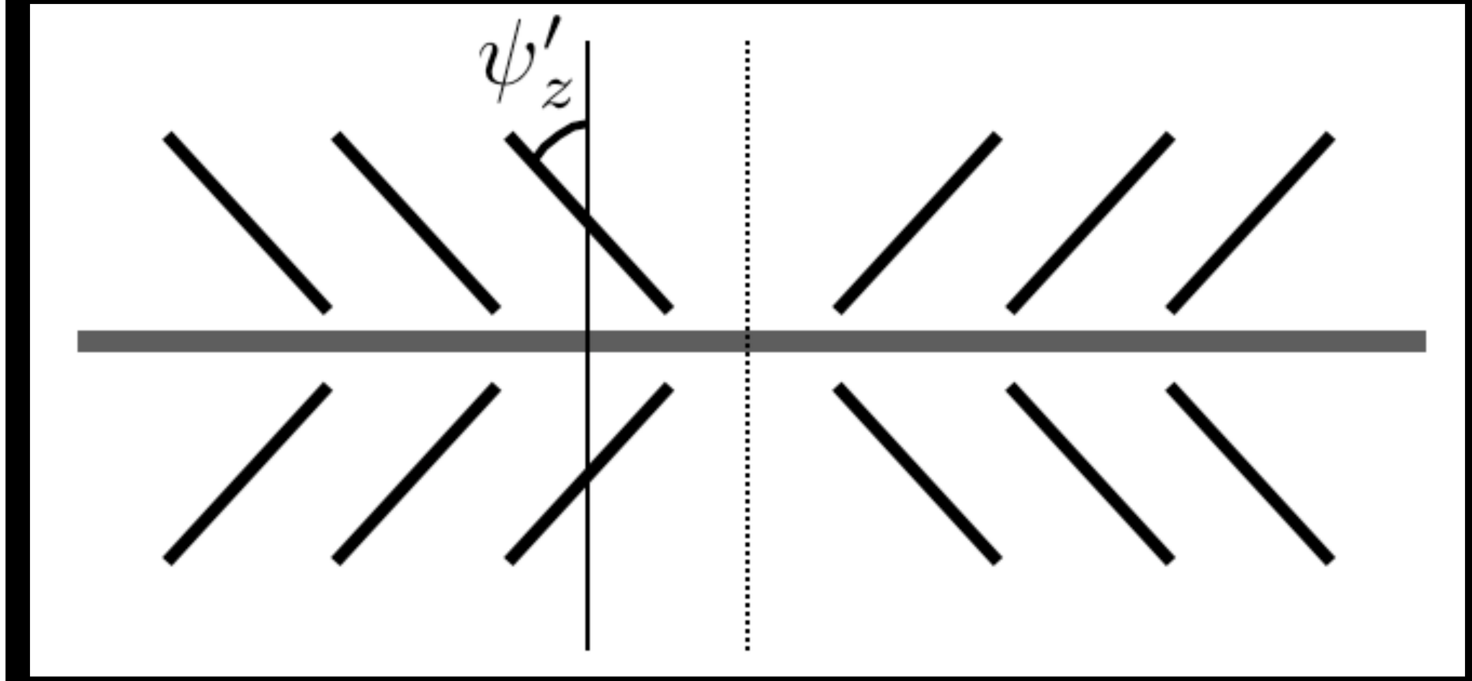

Braun, Heald & Beck (2009, in prep.)

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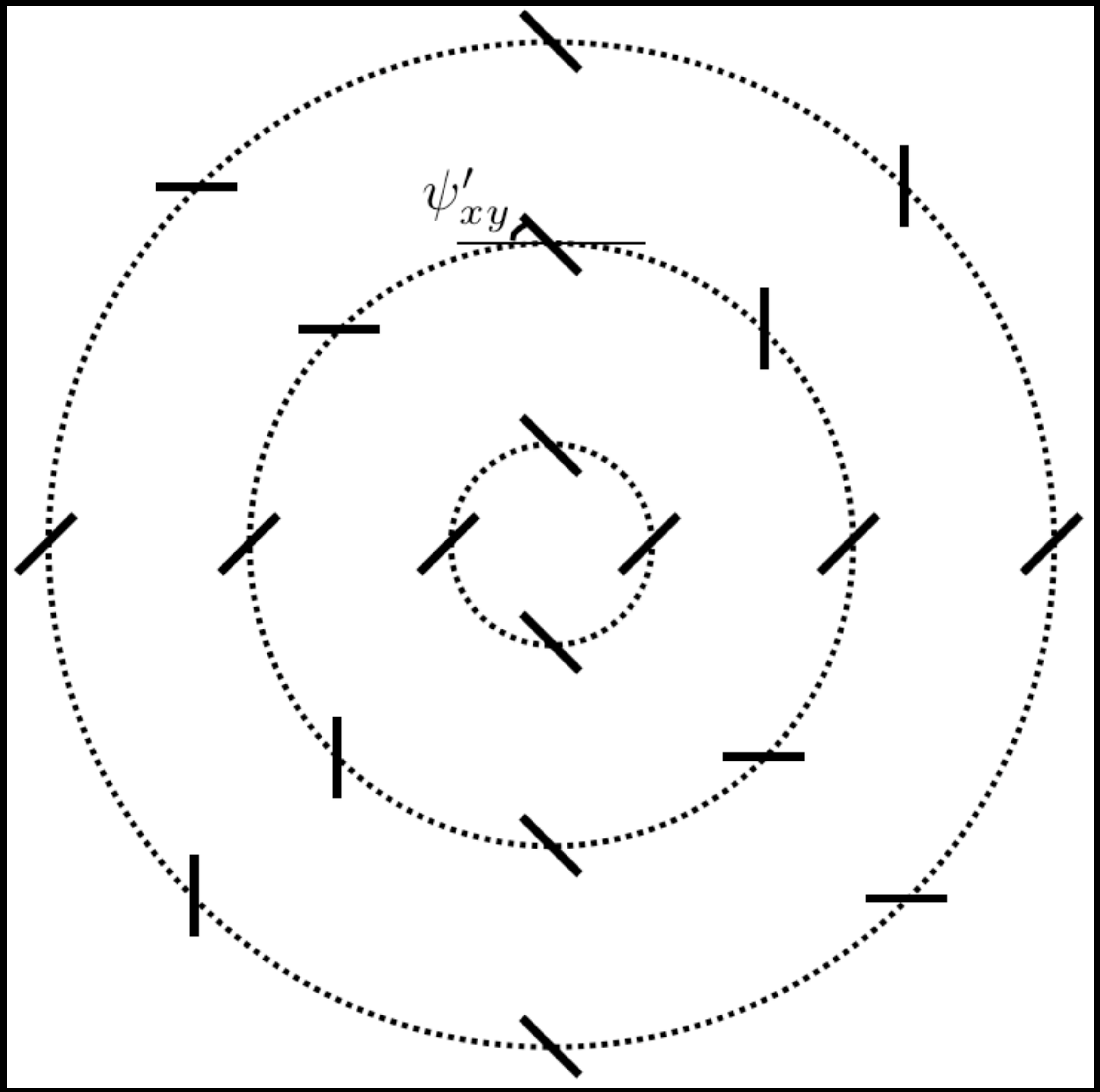

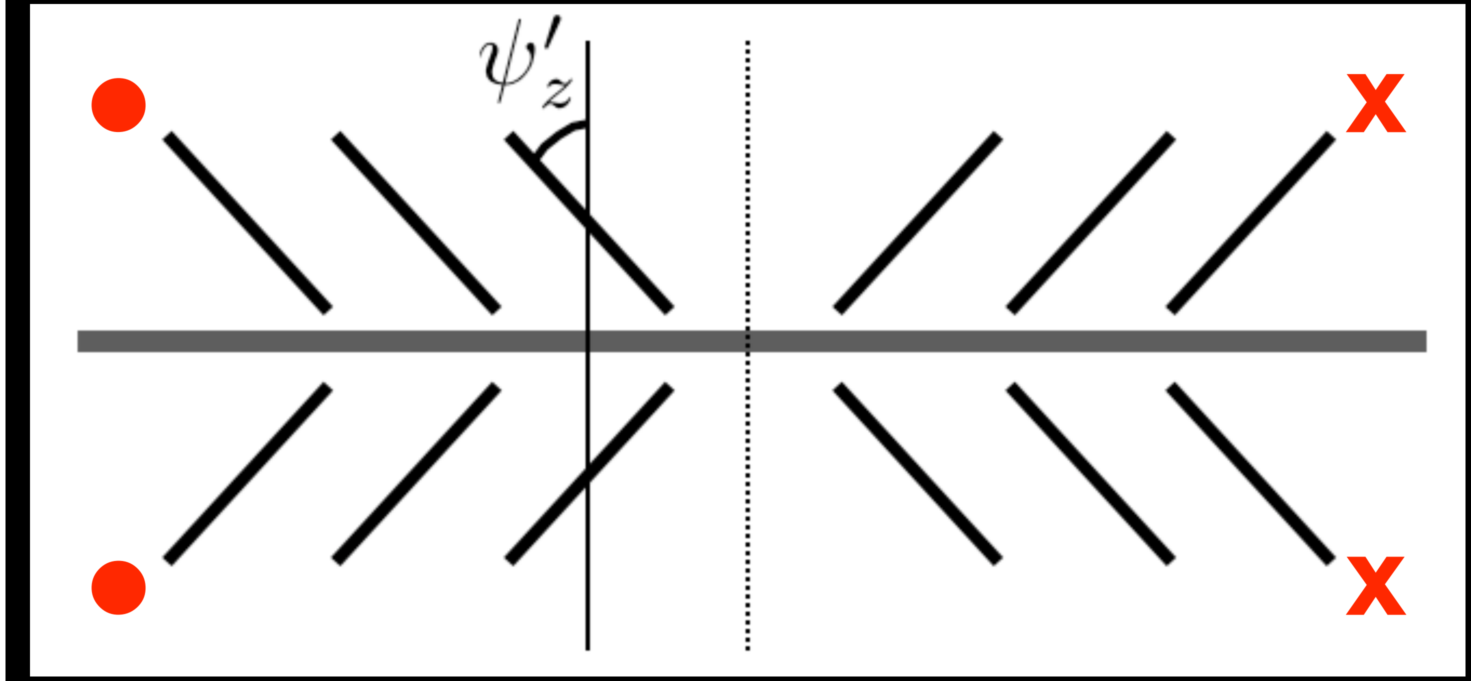

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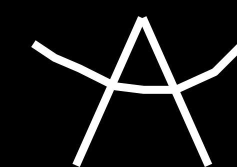

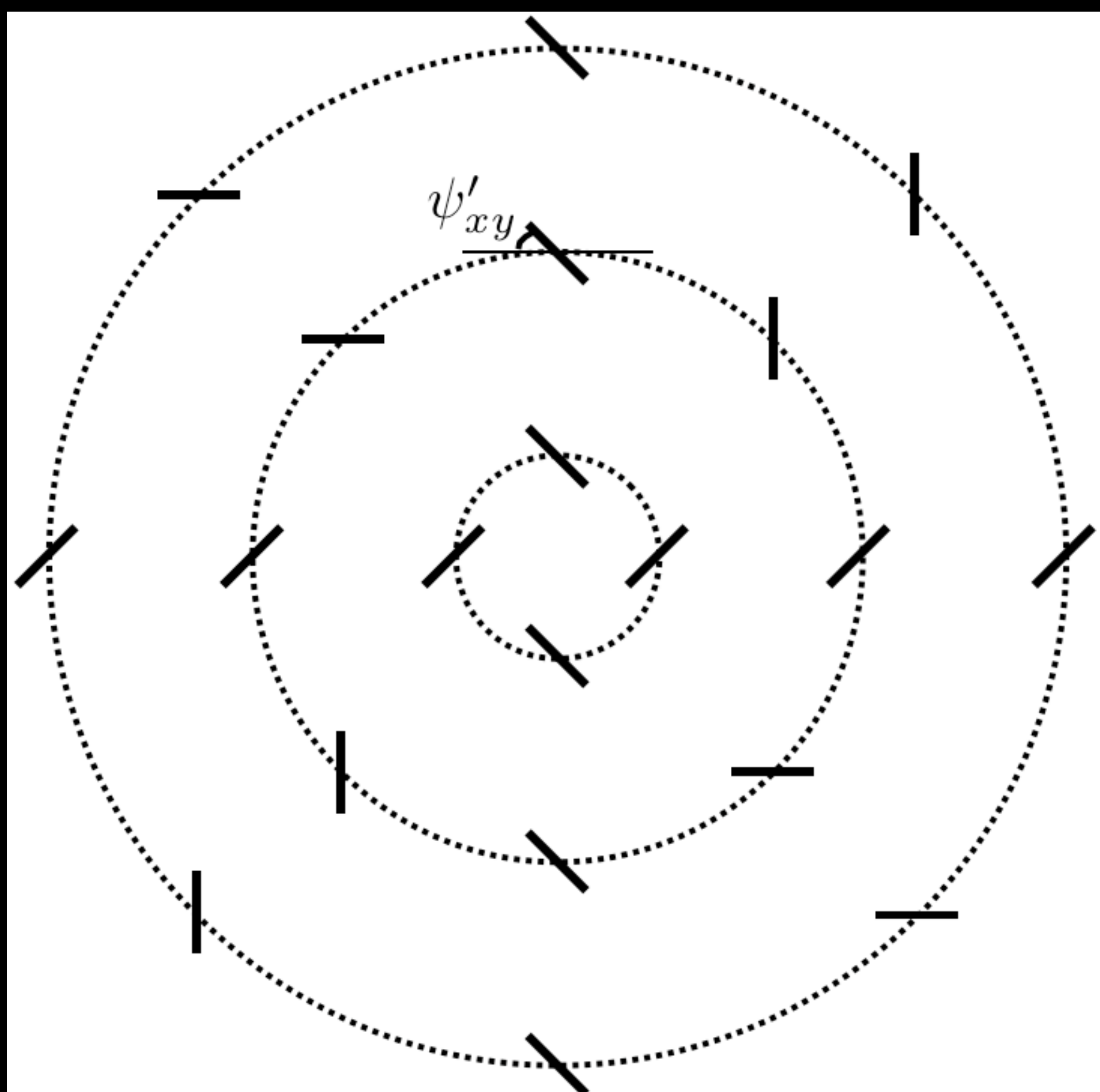

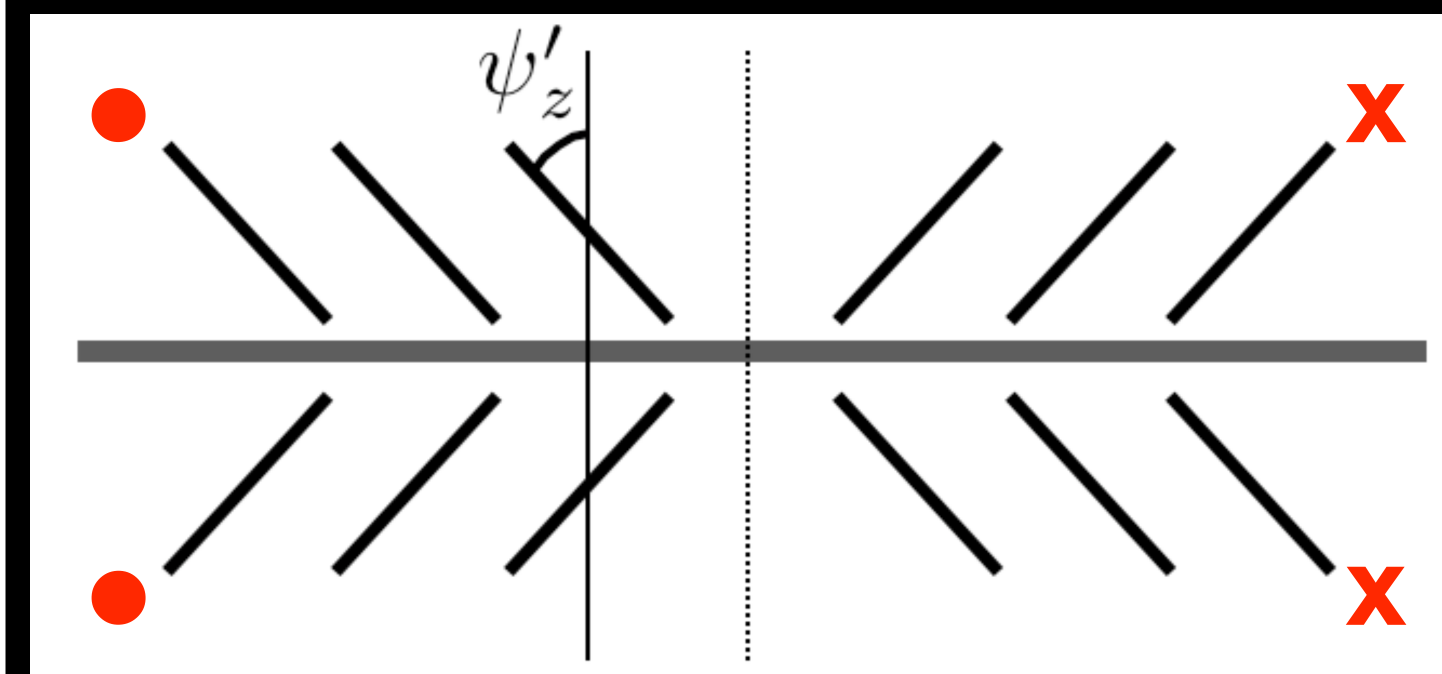

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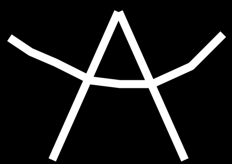

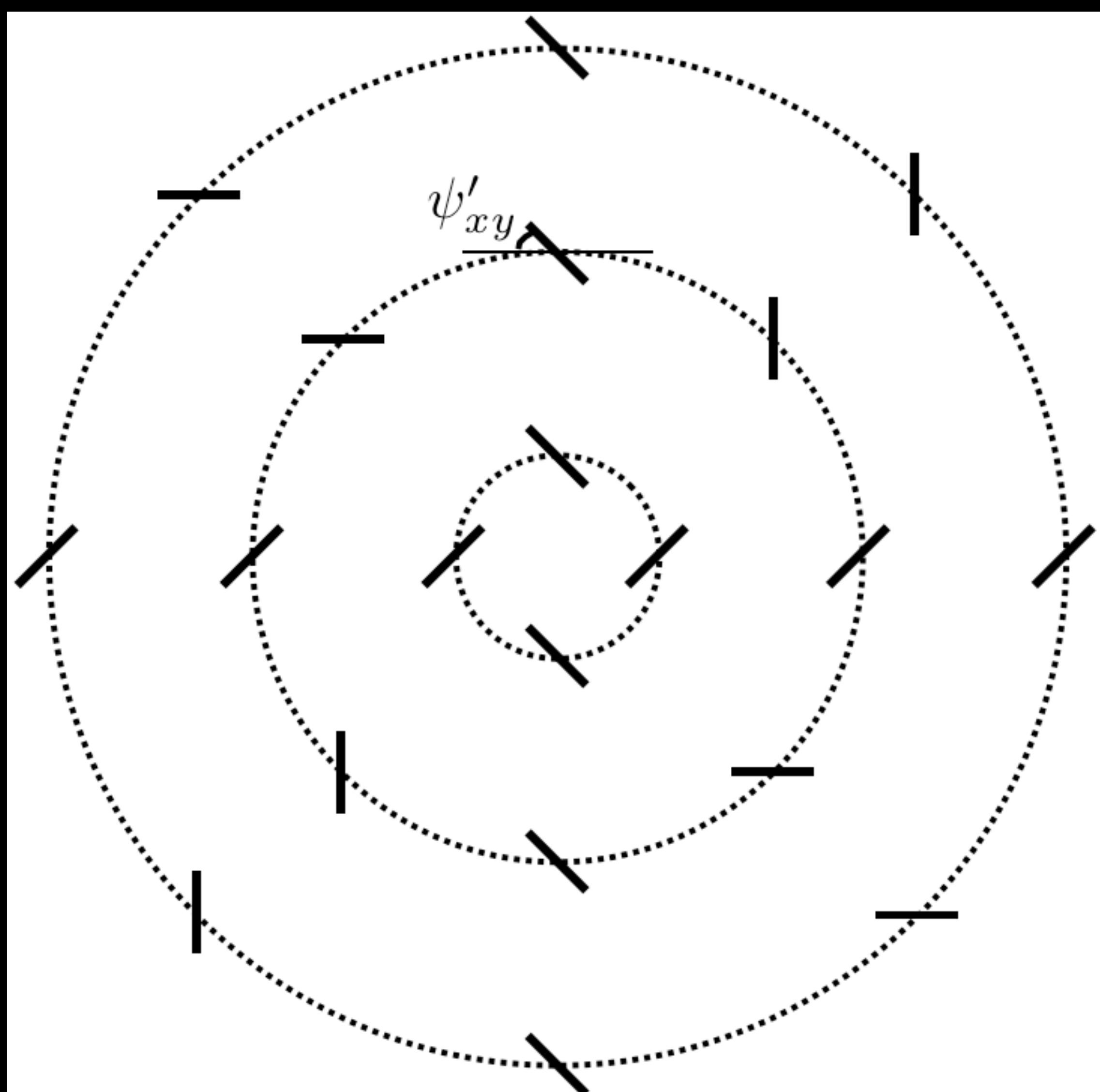

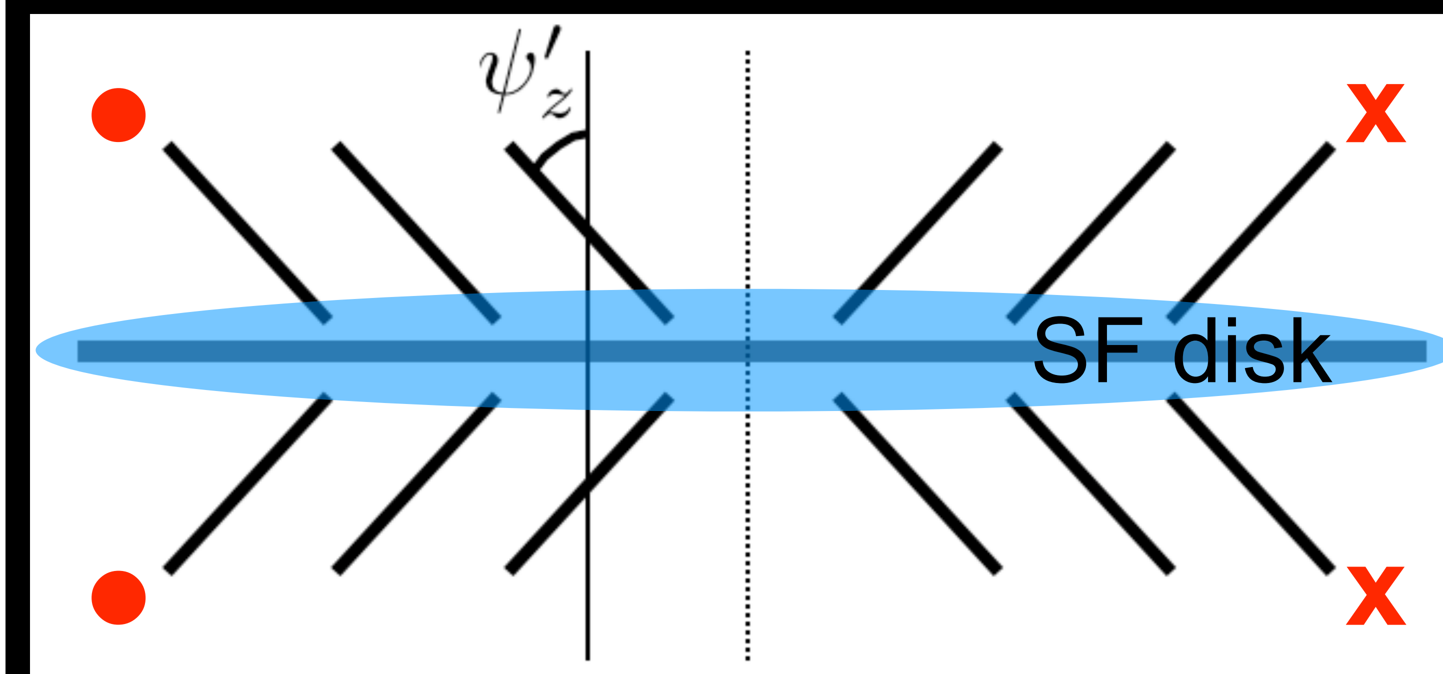

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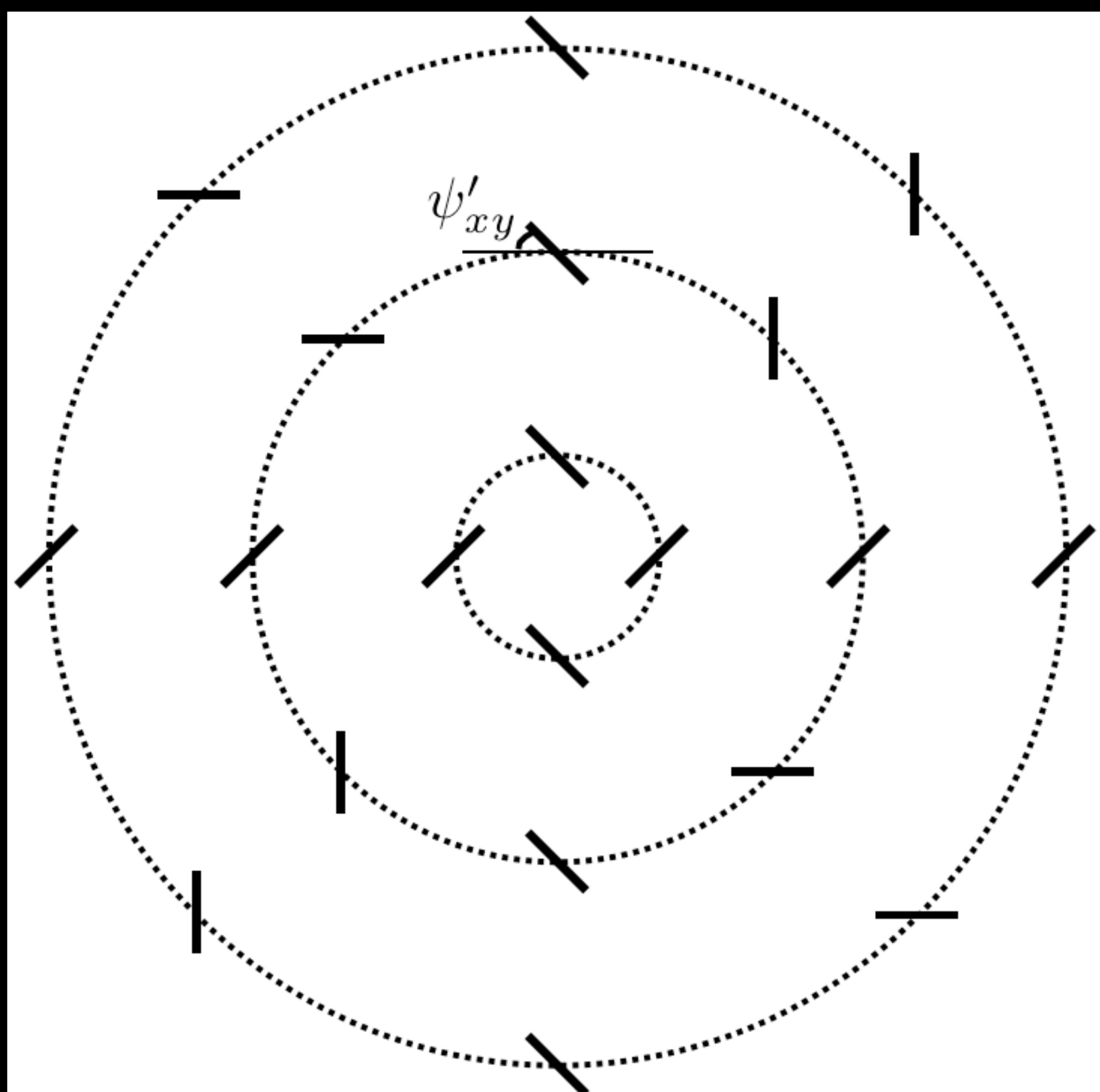

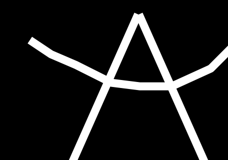

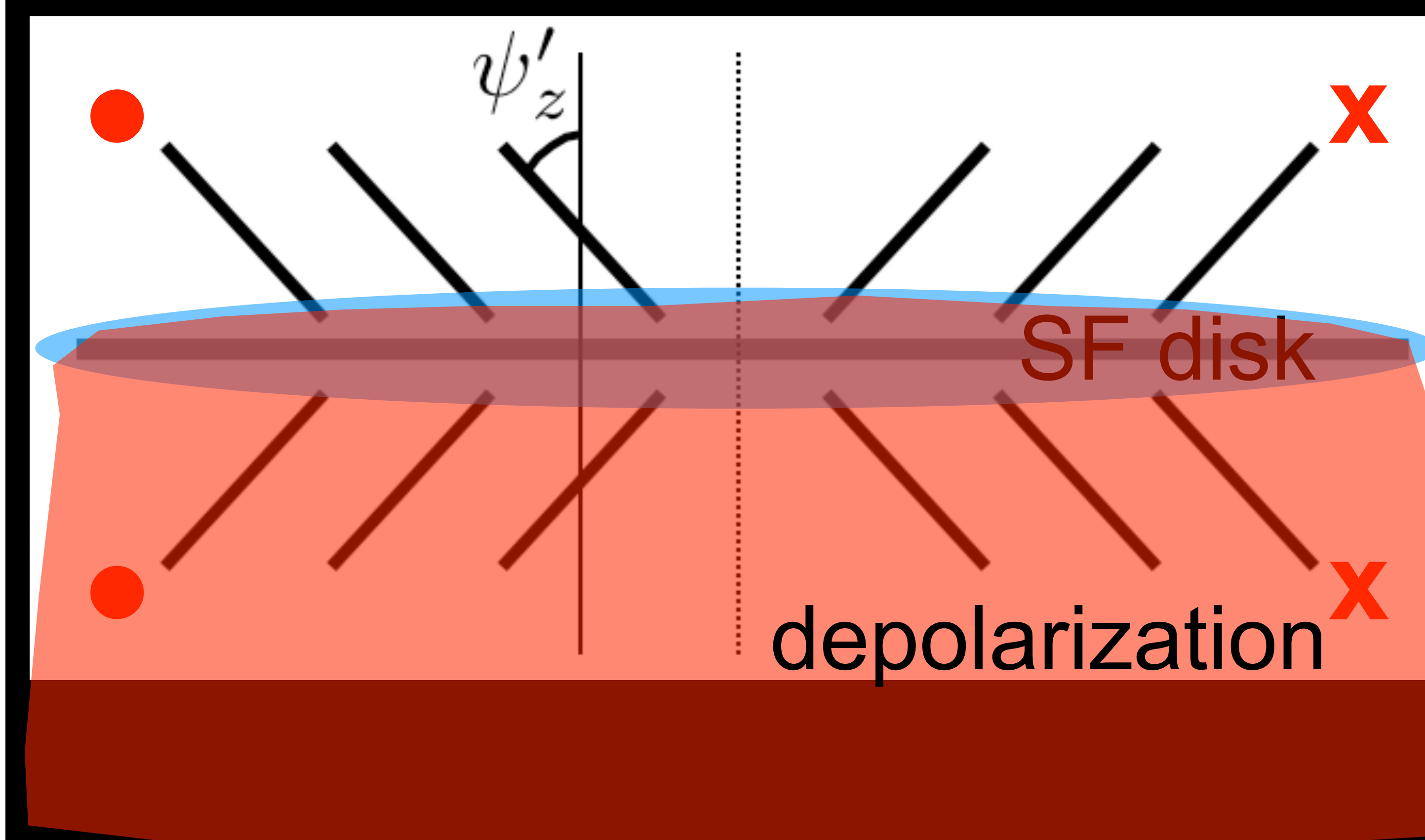

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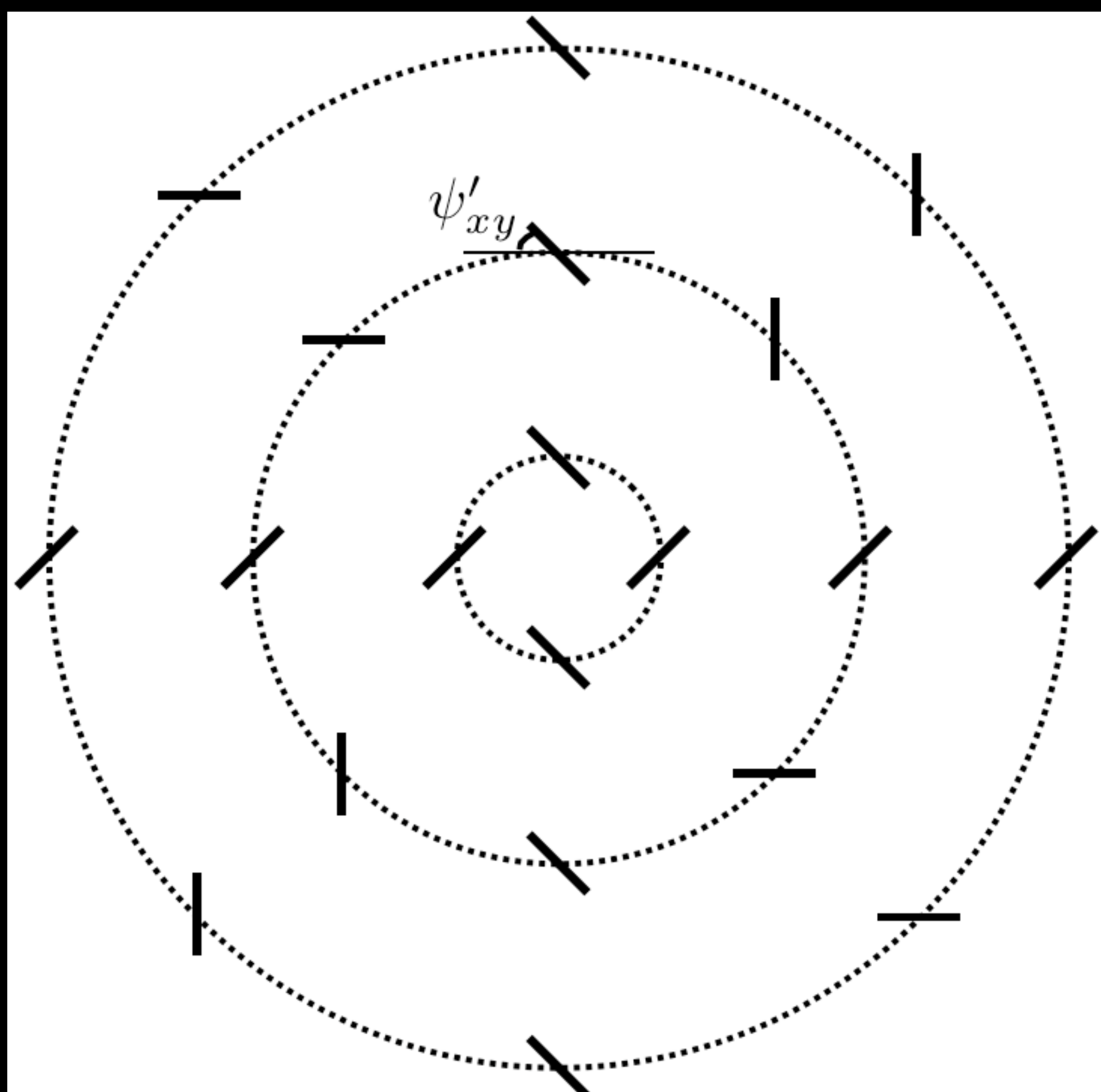

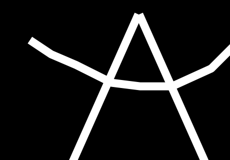

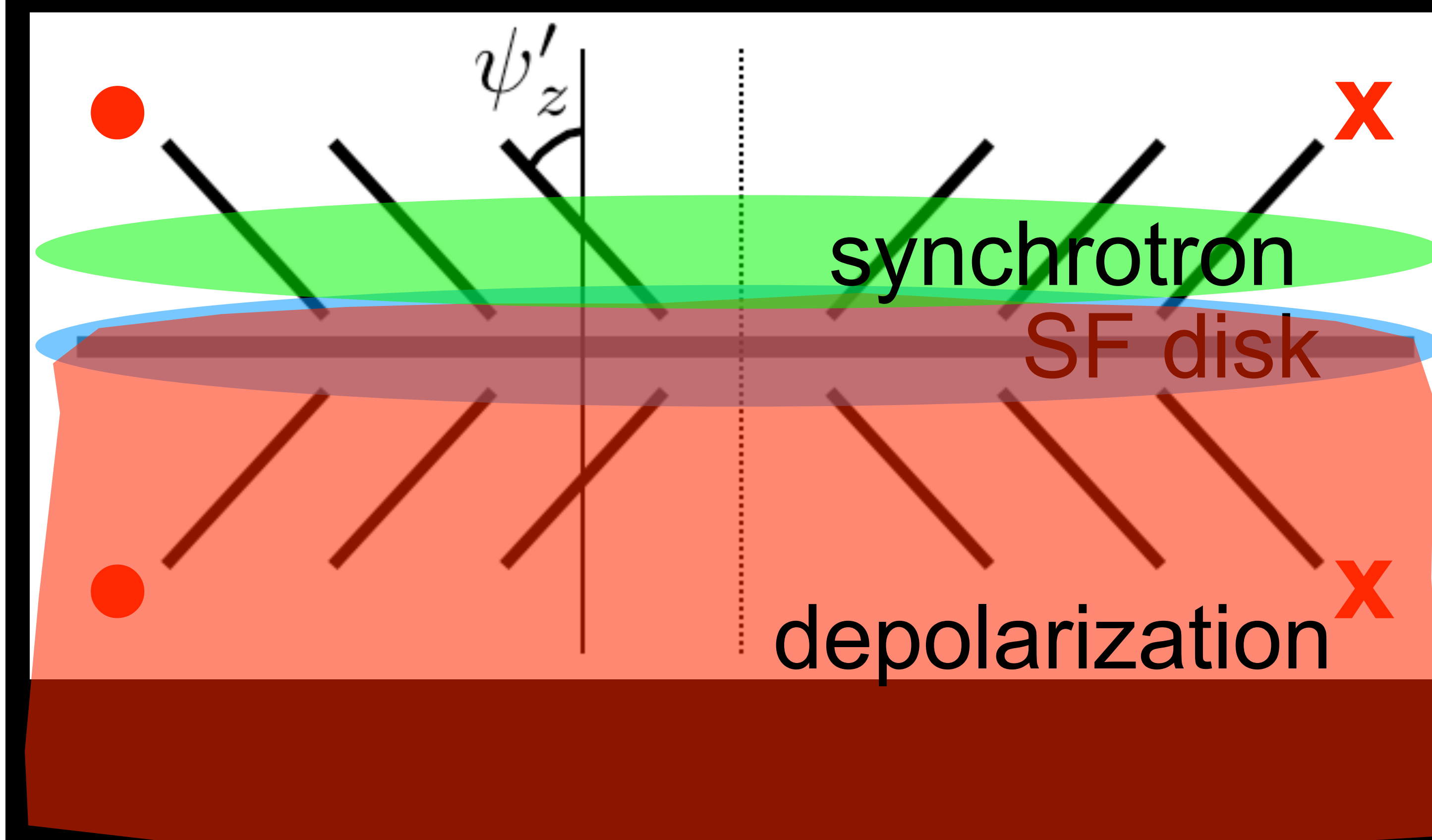

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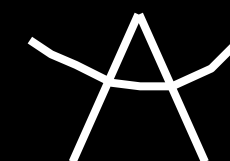

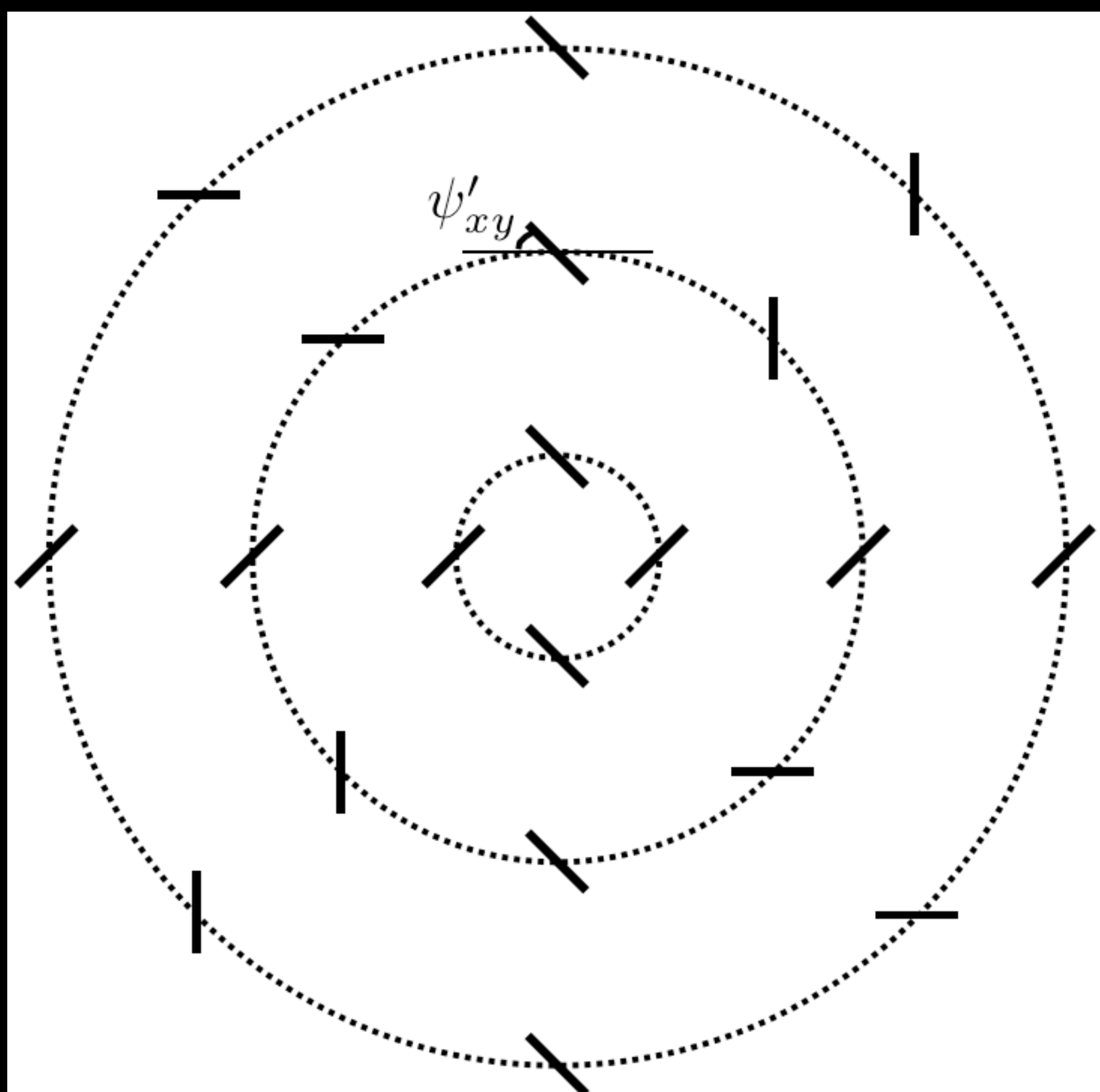

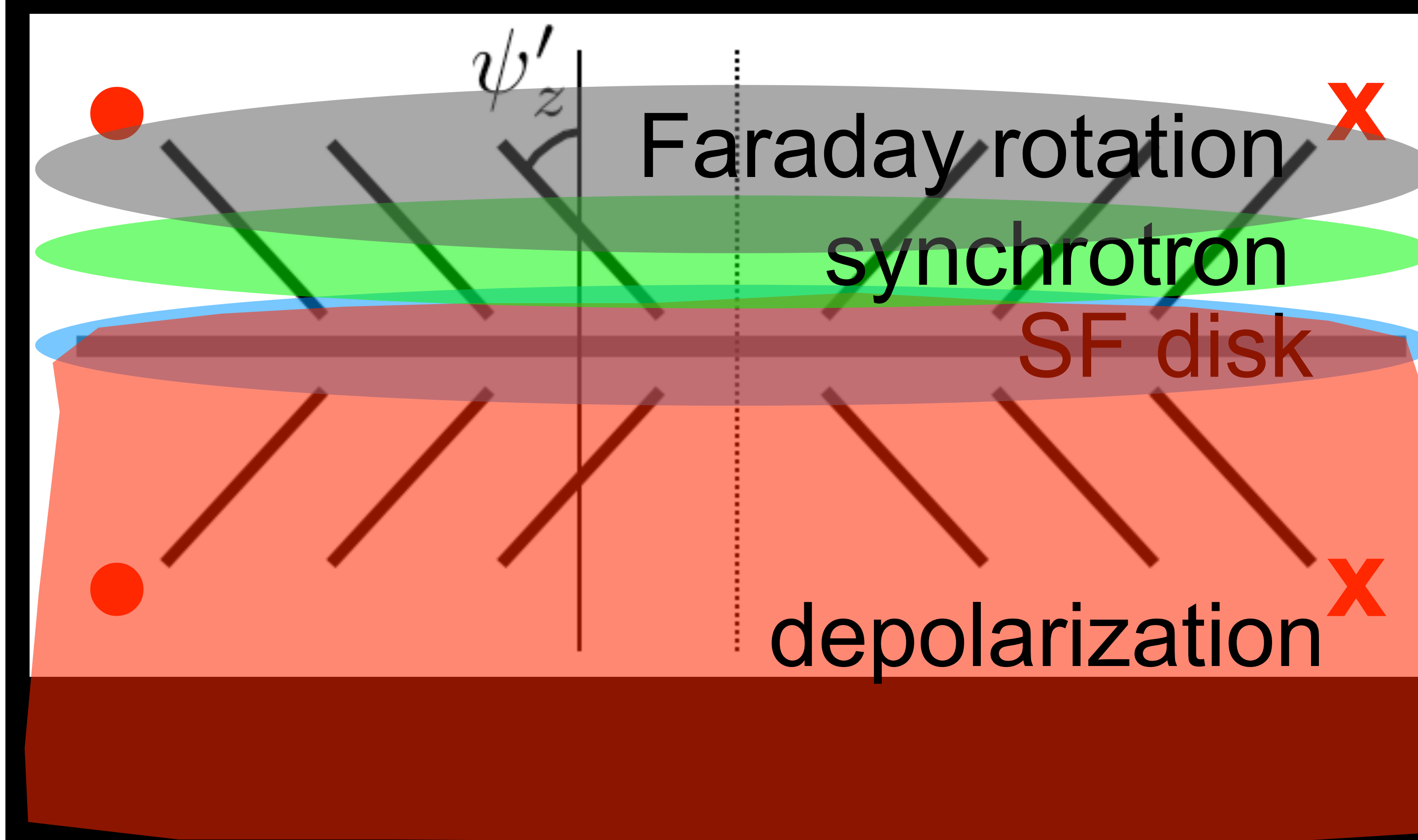

Braun, Heald & Beck (2009, in prep.)

Global magnetic field geometry

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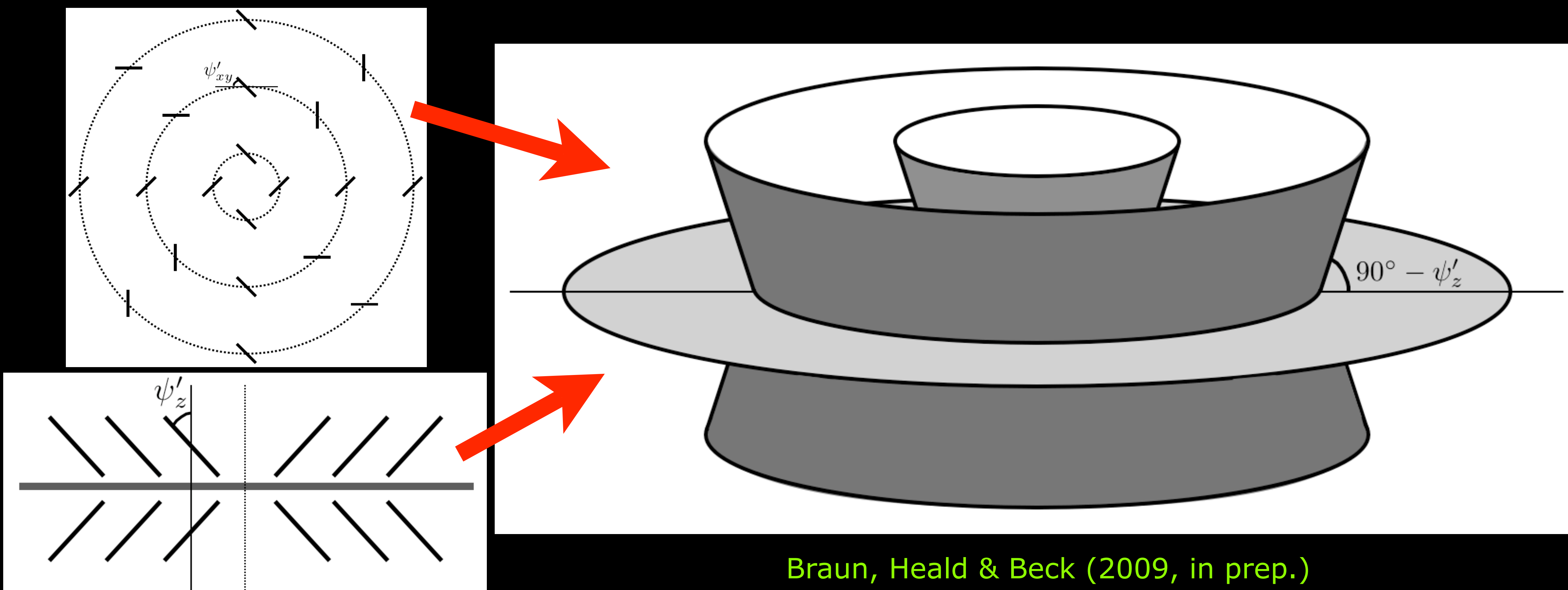
- Interpretation:
  - conical field geometry, with spiral pattern
  - depolarization on far side due to turbulence in SF disk
  - field projections yield observed asymmetry in polarization



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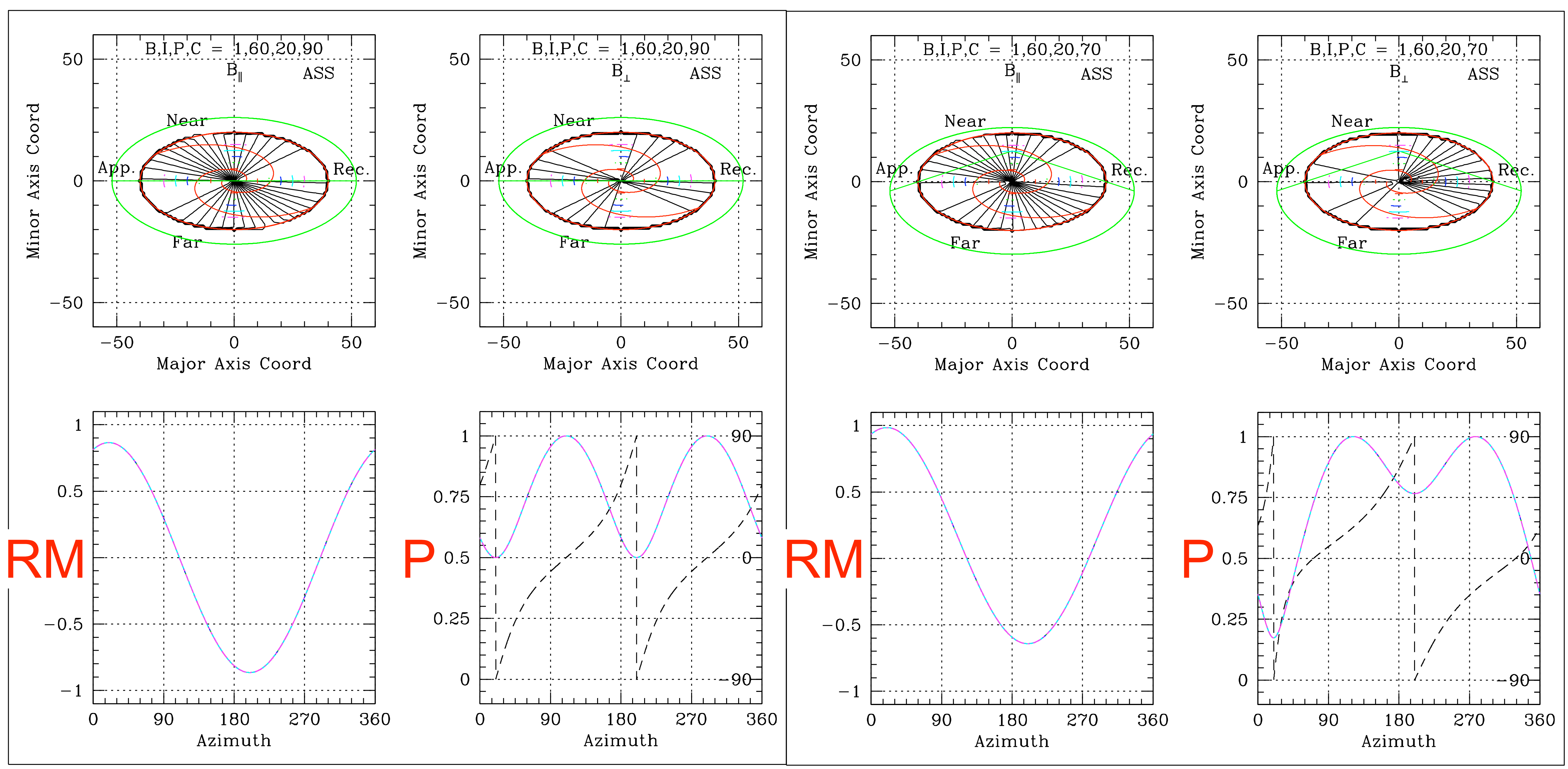
Field geometry modeling

- A spiral field, with a vertical component, can give the right trends provided that turbulence in the disk depolarizes the emission on the far side (example, inclination=60°)



Field geometry modeling

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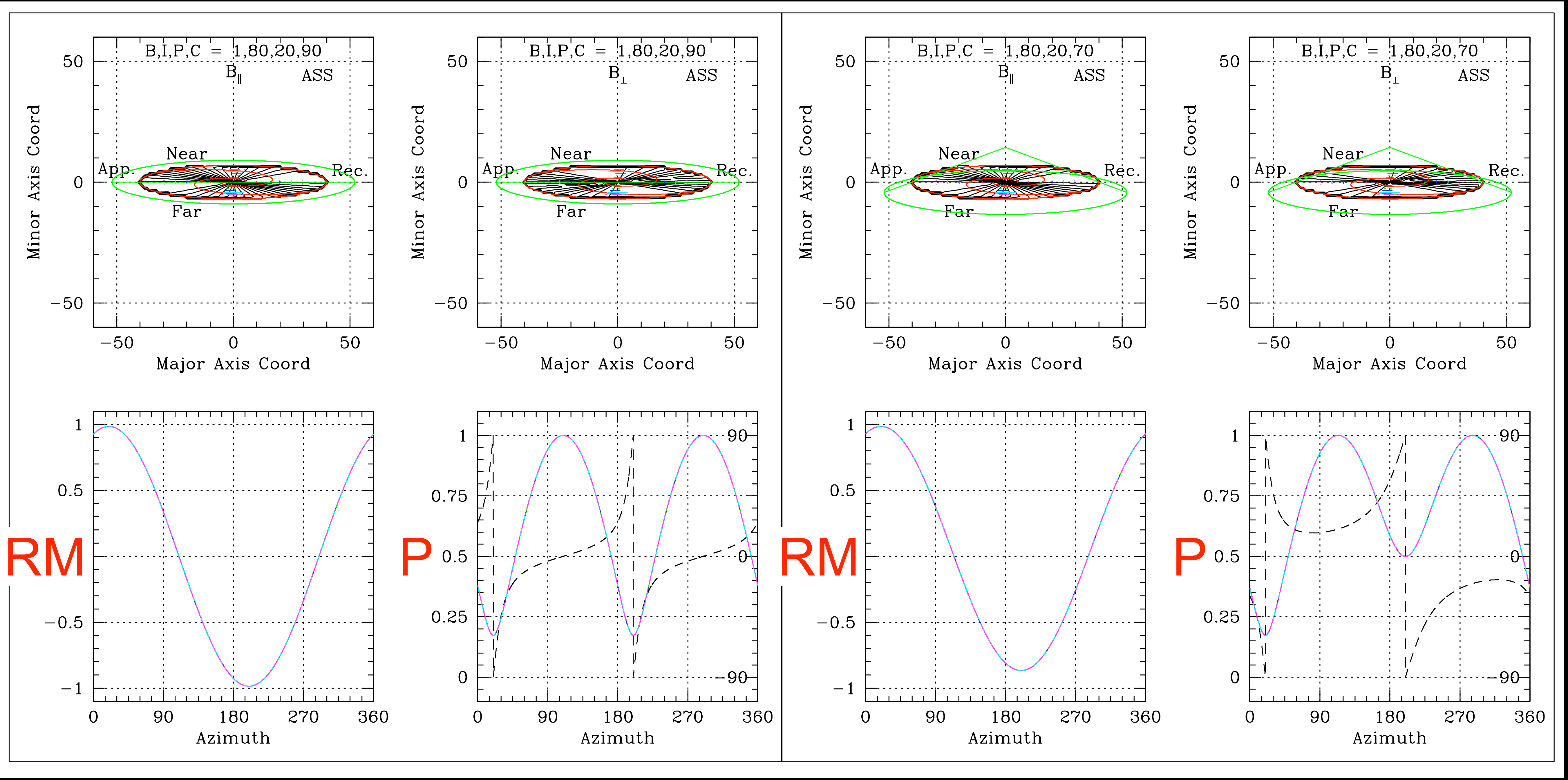

Consequences

- At higher frequencies, where depolarization effects are weaker, the aysmmetry between receding and approaching sides should disappear (seems to be the case for NGC 6946)

- Probing outer parts of galaxies with nonthermal emission... Complementarity with HI work, which reveals *gaseous* content of halos and outer disks

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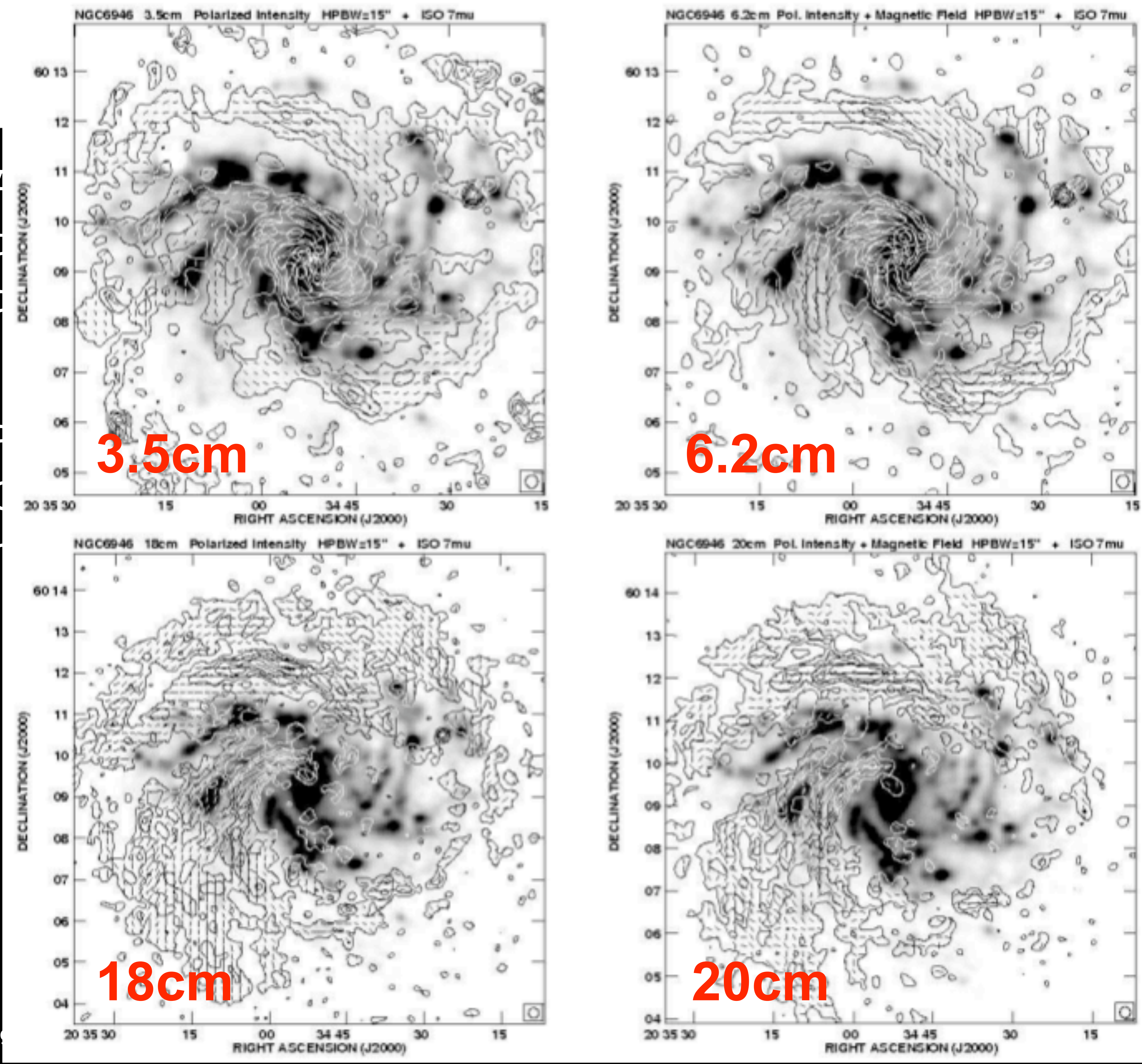

Beck (2007)

C RON

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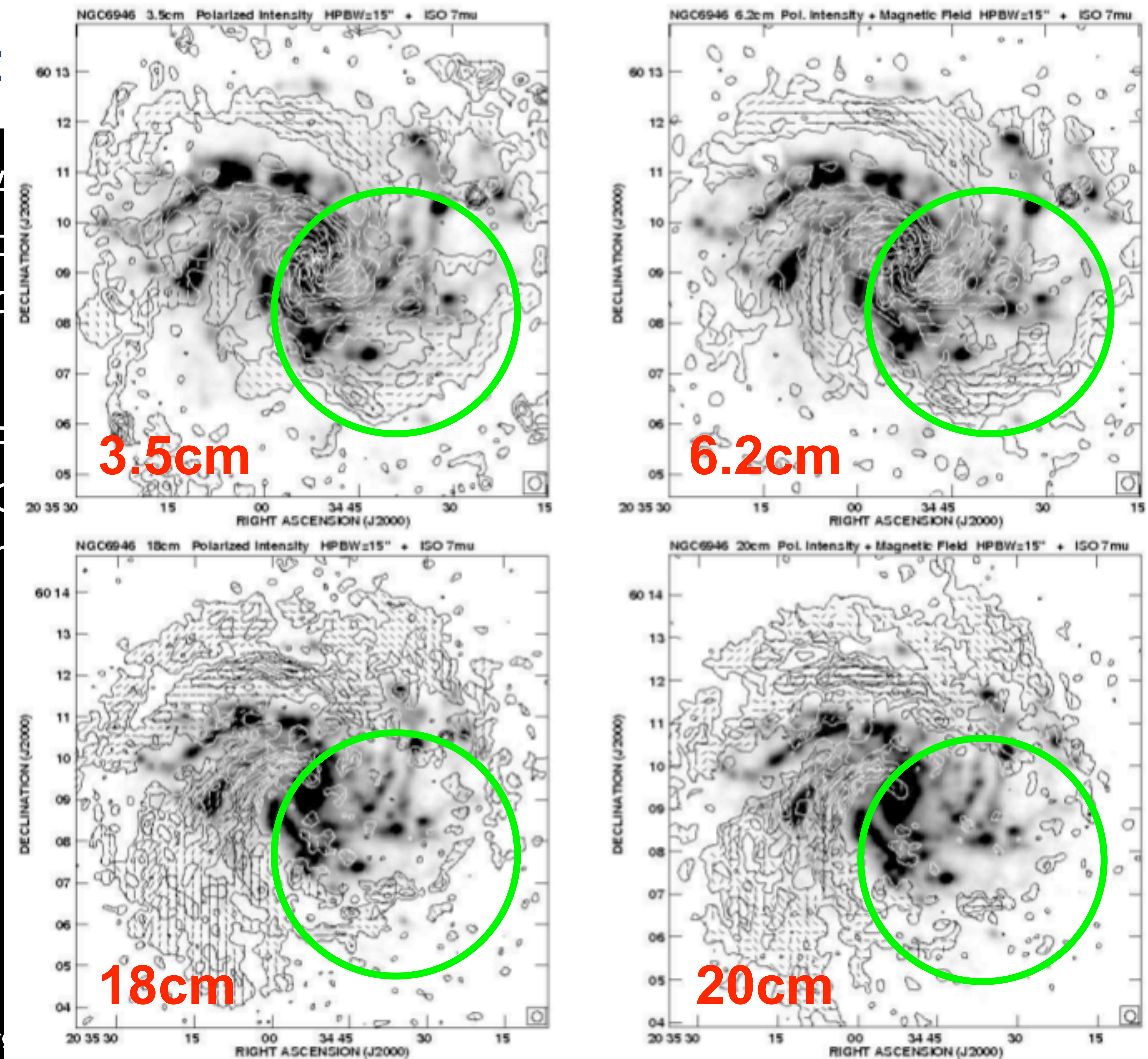

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Plug: WSRT HALOGAS Survey

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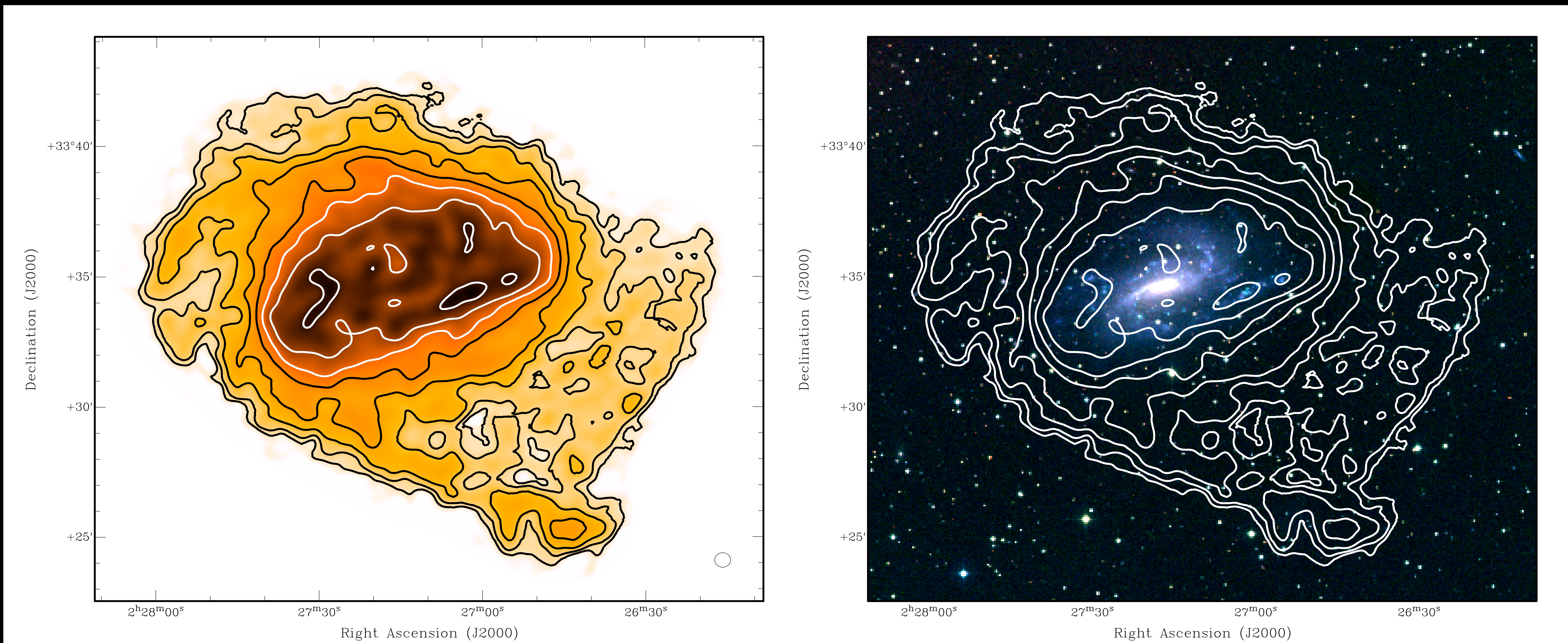
- WSRT Hydrogen Accretion in Local Galaxies (HALOGAS) Survey

HALO
Hydrogen Accretion in LOcal GAlaxieS
GAS

Pilot observation:
NGC 925

contours start at
$N_{HI}=1.8\mathrm{x}10^{19}$ cm^{-2}

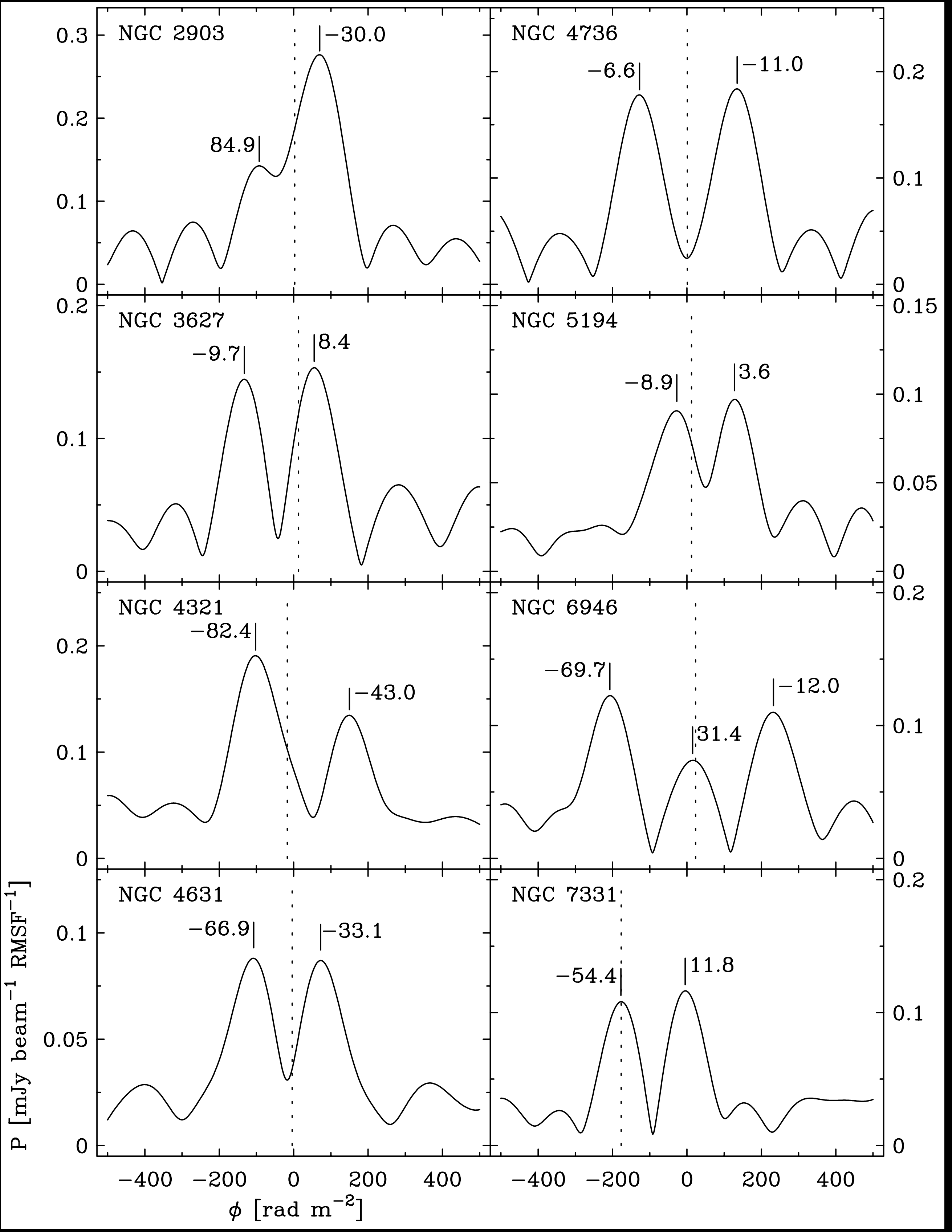


What's left to learn...

- With a larger sample of galaxies, we can learn:
  - Are we seeing what we think we're seeing?
    Overlap with HI surveys
  - How does the magnetic field geometry change with parameters like Hubble type, rotation speed, etc
  - Does the observational picture change as expected with SFR (i.e. the turbulence)?
  - Is there any change in the picture with redshift?
- Note the clear connection with the HI surveys - the relation between rotation sense and distribution of polarized flux can be examined for all reasonably well resolved spiral galaxies
- With polarization surveys using e.g. Apertif & ASKAP (POSSUM, PI Gaensler) we reach ~ the same rms in polarized intensity

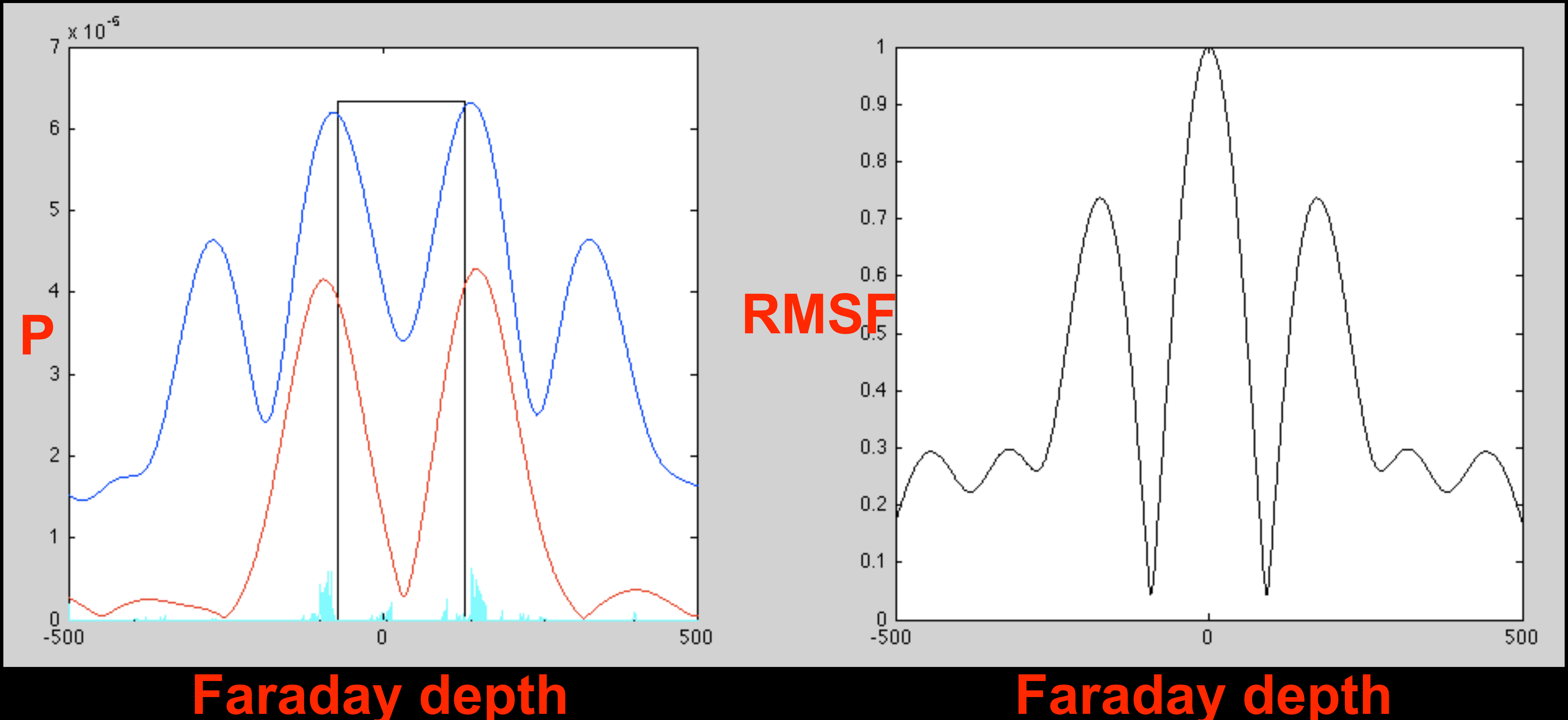
Galactic nuclei

- Central regions of galaxies show *multi-peaked Faraday dispersion functions*, iff there is compact nuclear polarized flux. No correlation with nucleus type from Ho et al (1997).
- Is this a sign of two distinct magnetic field components, or instead a region of mixed synchrotron emission and Faraday rotation (Faraday thick emission)?
- Latter not distinguishable with our frequency coverage.



WSRT-SINGS frequency coverage

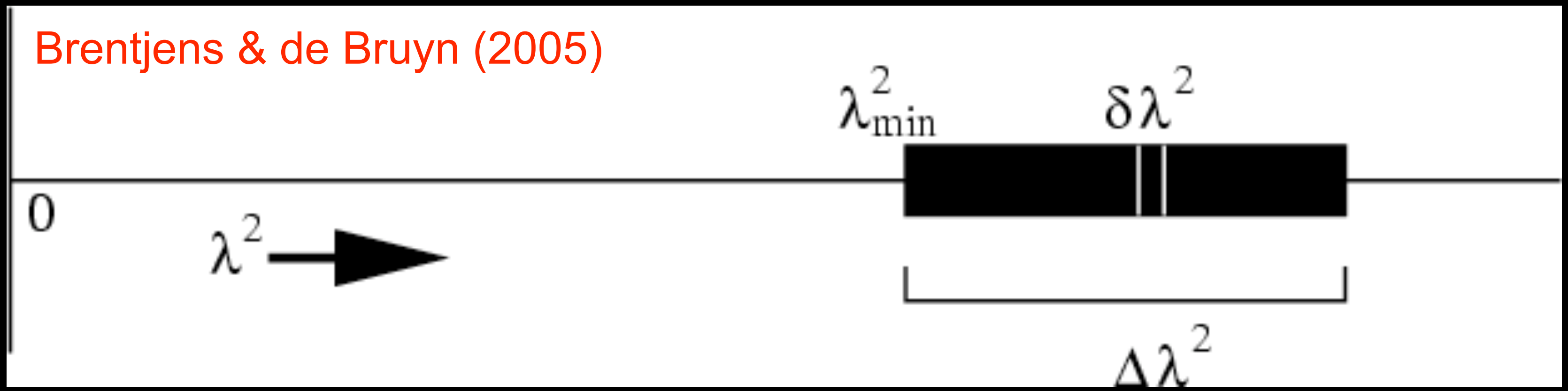
- Two bands 1300-1432 MHz, 1631–1763 MHz.
- Response to a “Burn slab”:



- Lack of data at short wavelengths

Nuclear profiles

- To recover Faraday thick emission, need $\lambda^2_{\rm min} < \Delta\lambda^2$



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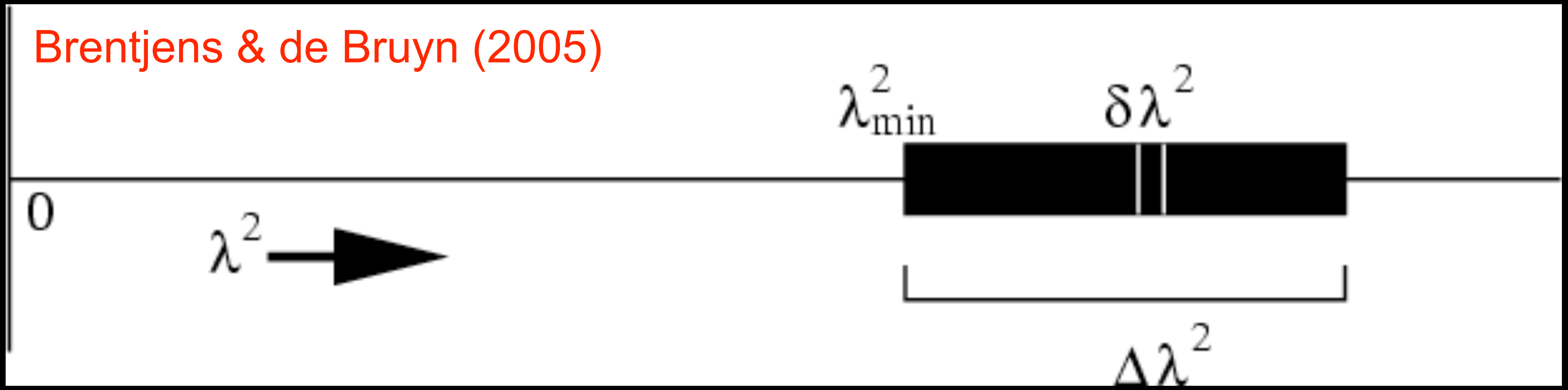

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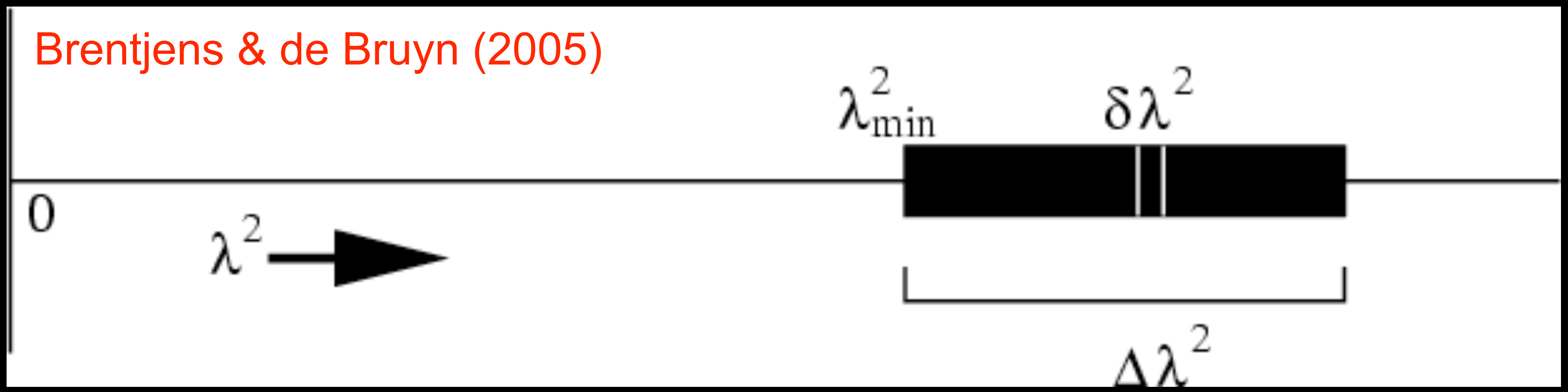

- For 1000 MHz - 1700 MHz (e.g. APERTIF):

$$\lambda^2_{\min} = 0.035\,\mathrm{m}^2, \Delta\lambda^2 = 0.055\,\mathrm{m}^2$$

Nuclear profiles

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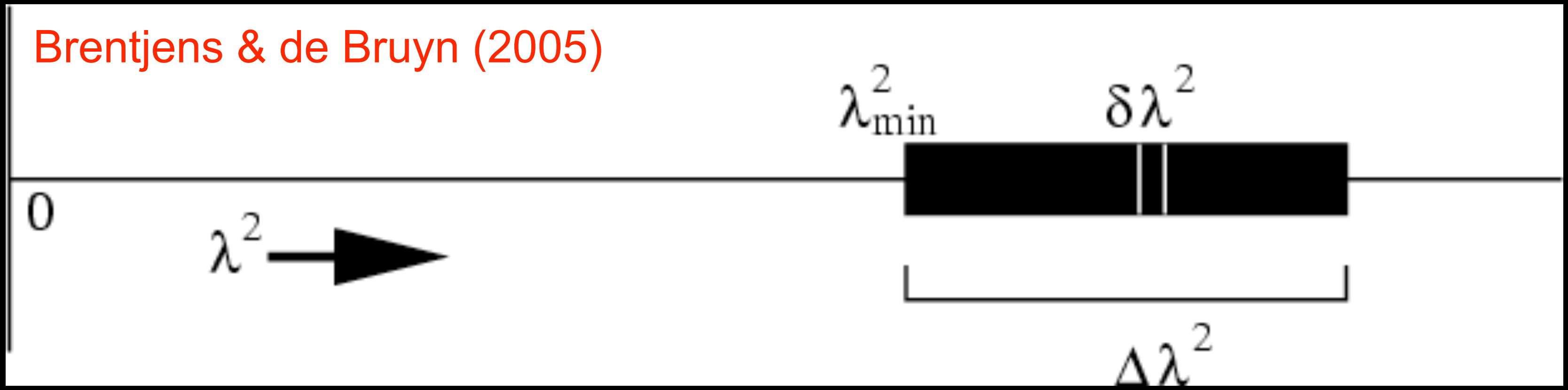

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- But for 1000-1300 MHz:

$$\lambda^2_{\rm min} = 0.053\,{\rm m}^2, \Delta\lambda^2 = 0.037\,{\rm m}^2$$

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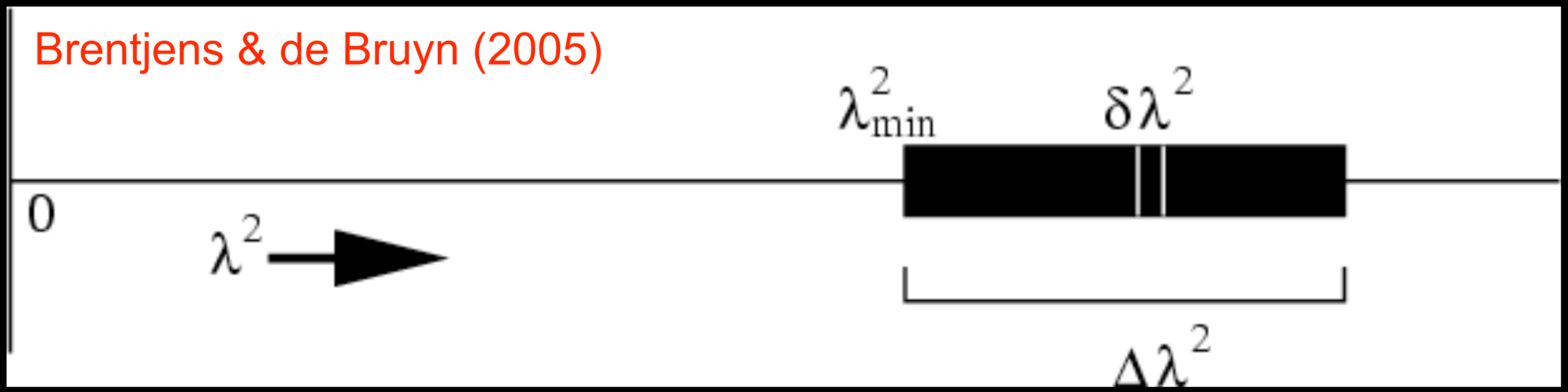

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Nuclear profiles

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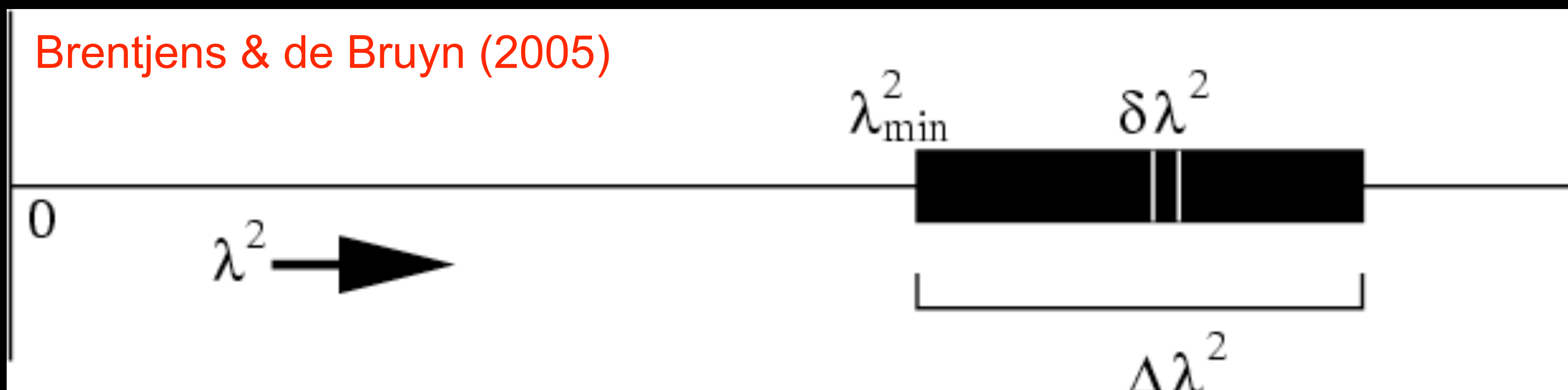

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- To recover Faraday thick emission, need wide band (2x300 MHz)
- Note ASKAP 700-1800 MHz:

$$\lambda^2_{\min} = 0.028\,\mathrm{m}^2, \Delta\lambda^2 = 0.156\,\mathrm{m}^2$$

Polarization purity...

- Polarization purity required for
  - Diffuse polarized emission detected in galaxies at arbitrary locations within the FoV
  - Background sources (RM grid): to obtain accurate rotation measures for polarized background sources, the polarization purity across the field must be controlled
- As was pointed out earlier this week, weights applied to FPA elements (Apertif, ASKAP) can be selected to make the compound X and Y beams as similar as possible, limiting instrumental polarization

Future goals

- WSRT-SINGS provides the first polarization survey of a large number of nearby galaxies to ~ 10 µJy/beam rms, and illustrates interesting new observational trends...
  - Polarization surveys using e.g. Apertif and ASKAP will provide similarly deep data for a far larger sample
  - Followup with MeerKAT/eVLA: not just for deeper targeted followup, but for *higher frequency* followup, where Faraday effects are less severe (see through turbulent depolarization)
  - Adding LOFAR data: weaker fields, outer regions of galaxies
- Deep widefield images in Stokes Q,U with *polarization purity*
- Narrow frequency channels, and wideband, for RM-Synthesis
- Detection of faint polarization with precise RM, no $n\pi$ ambiguity
- RM modeling: a better handle on Faraday thickness (nuclei)
- Full sky? For MW RM grid, yes.
- Optimizing polarization purity: what effect on continuum survey?