WSRT-SINGS & Magnetic Fields in Spiral Galaxies

George Heald, Robert Braun & Rainer Beck

Magnetic fields meeting, Krakow
17 May 2010

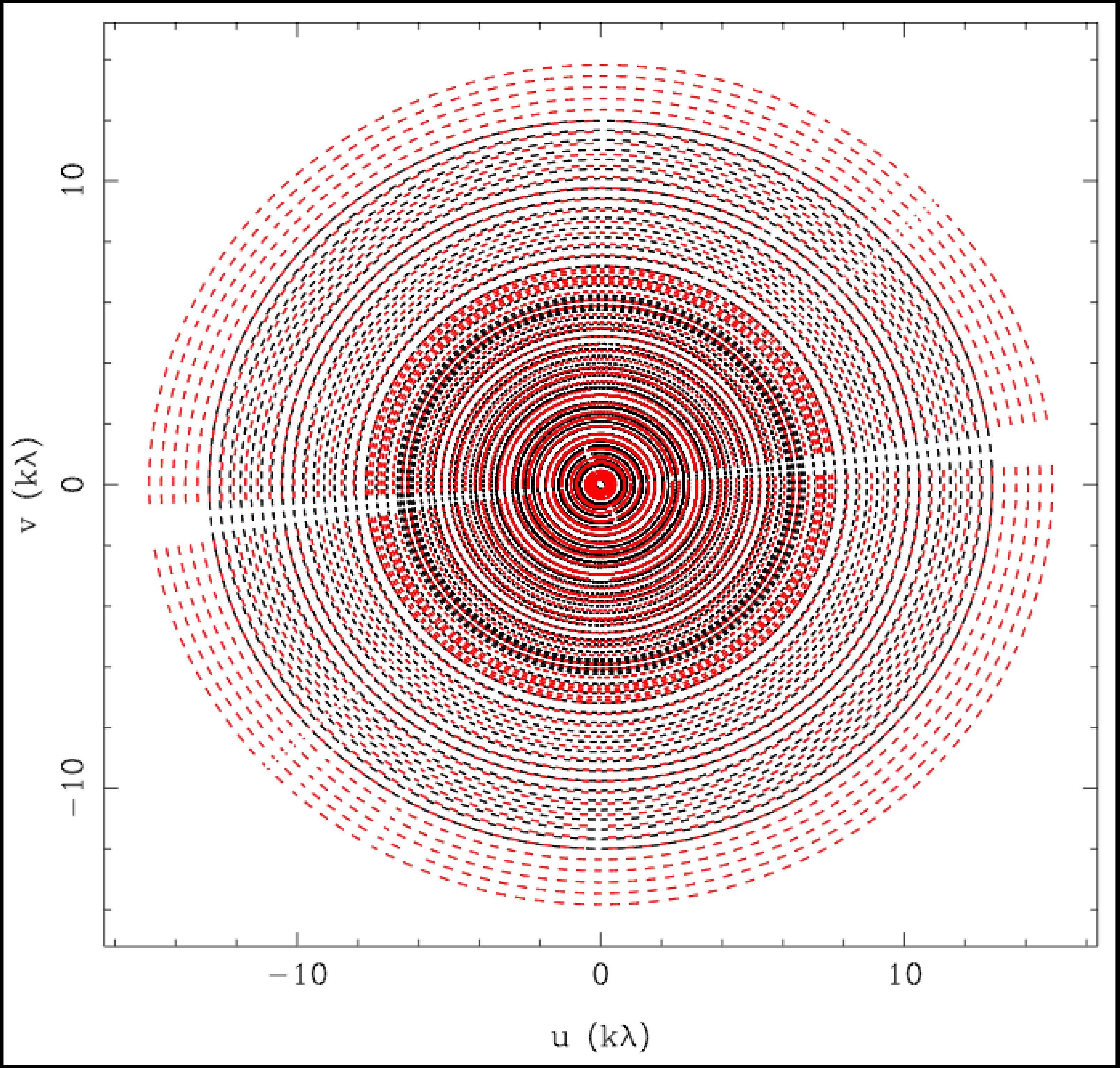
Overview

- WSRT-SINGS: data & analysis
- Trends in the observations
- Interpretation: global magnetic field geometry in spiral galaxies
- Predictions and future work

- See:
  Braun et al. 2007 (A&A, 461, 455) [WSRT-SINGS survey description]
  Heald et al. 2009 (A&A, 503, 409) [Polarization data and analysis]
  Braun et al. 2010 (arXiv: 1002.3946) [Global magnetic field geometry]

WSRT data

- 2 broad (160 MHz) bands at 18cm and 22cm (high Faraday depth regime)
- Typical noise levels ~10 μJy/beam rms (6h/galaxy/band)



WSRT data analysis

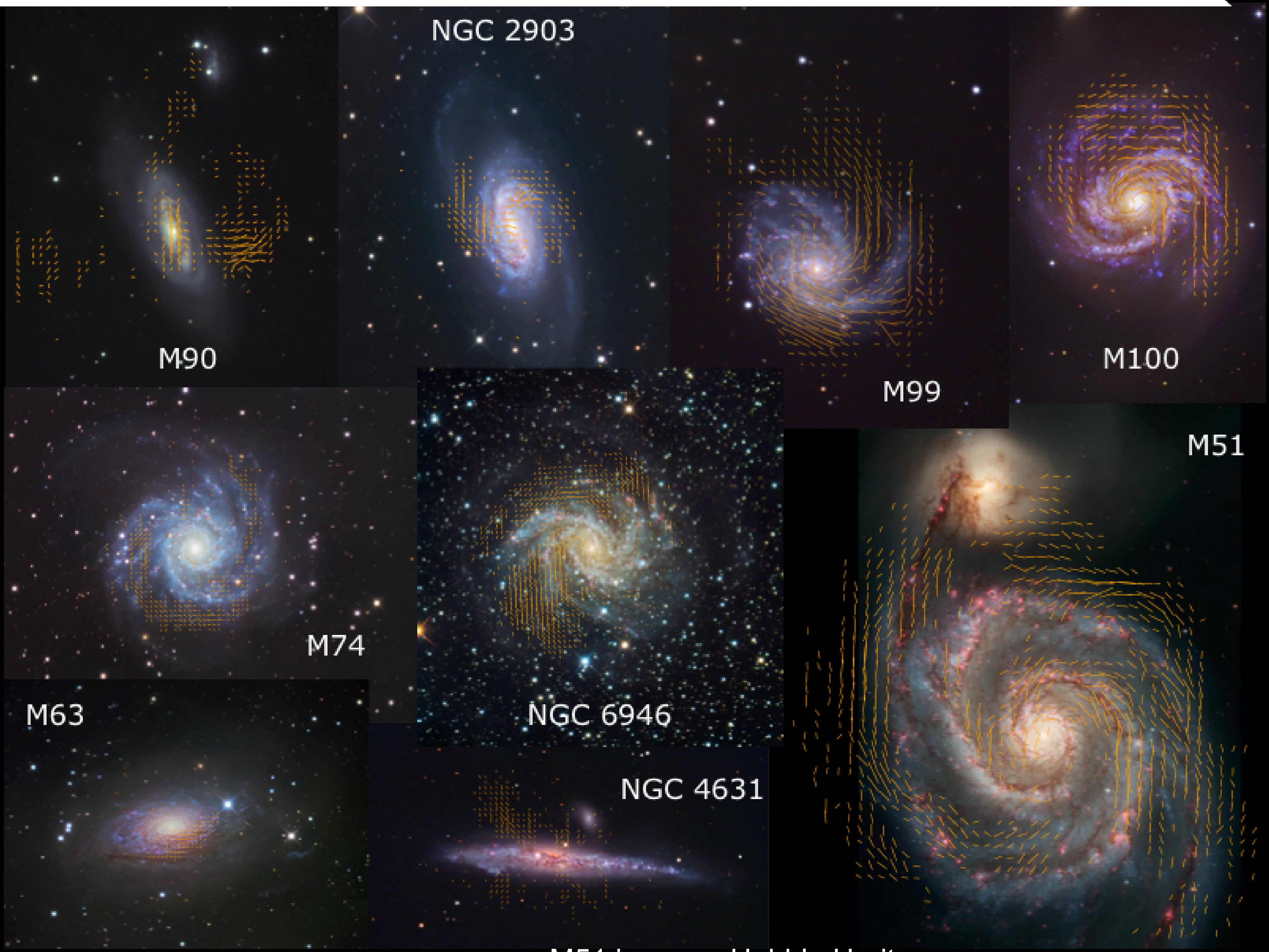
- Data analysed using Rotation Measure Synthesis (RM Synthesis) (see Brentjens & de Bruyn 2005)
  - Fourier transform of observed Stokes (Q,U) over wavelength-squared; provides complex polarization vector as a function of Faraday depth
  - Avoids nπ ambiguity problems (given sufficient frequency sampling)
  - Coherently adds across the full band, optimizing sensitivity regardless of rotation measure value
- RMSF FWHM ~ 144 rad/m^2
- Faraday dispersion functions deconvolved using RM-CLEAN (see Heald et al. 2009; code available online)
- Polarized flux and rotation measure values extracted using moment-map techniques standard in the emission line (e.g. HI) community

Results

- 28 galaxies studied
  21 detected in polarization
  - 0/4 Magellanic/elliptical
  - 21/24 spirals

Optical image courtesy Robert Gendler

Resulting images

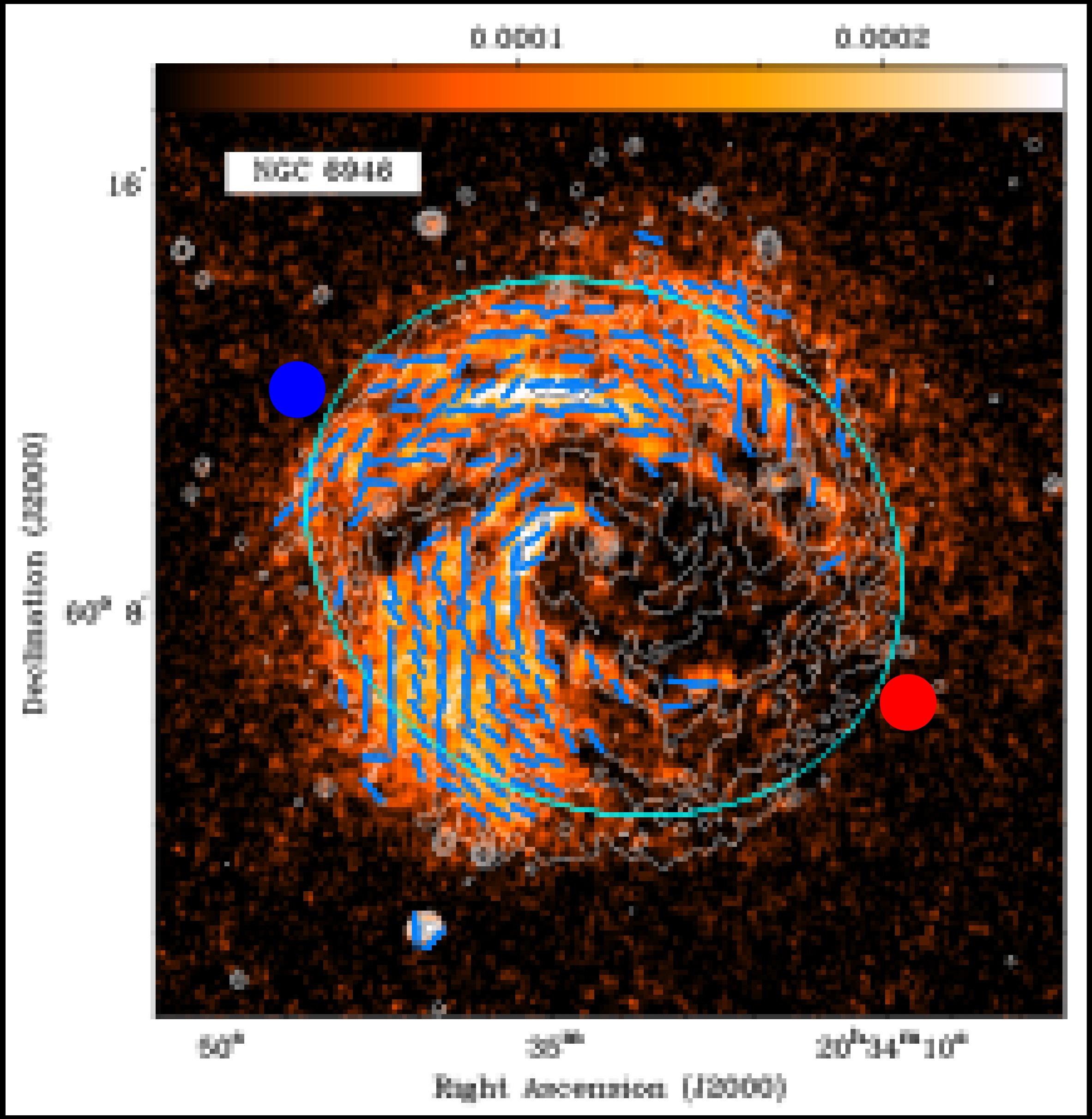


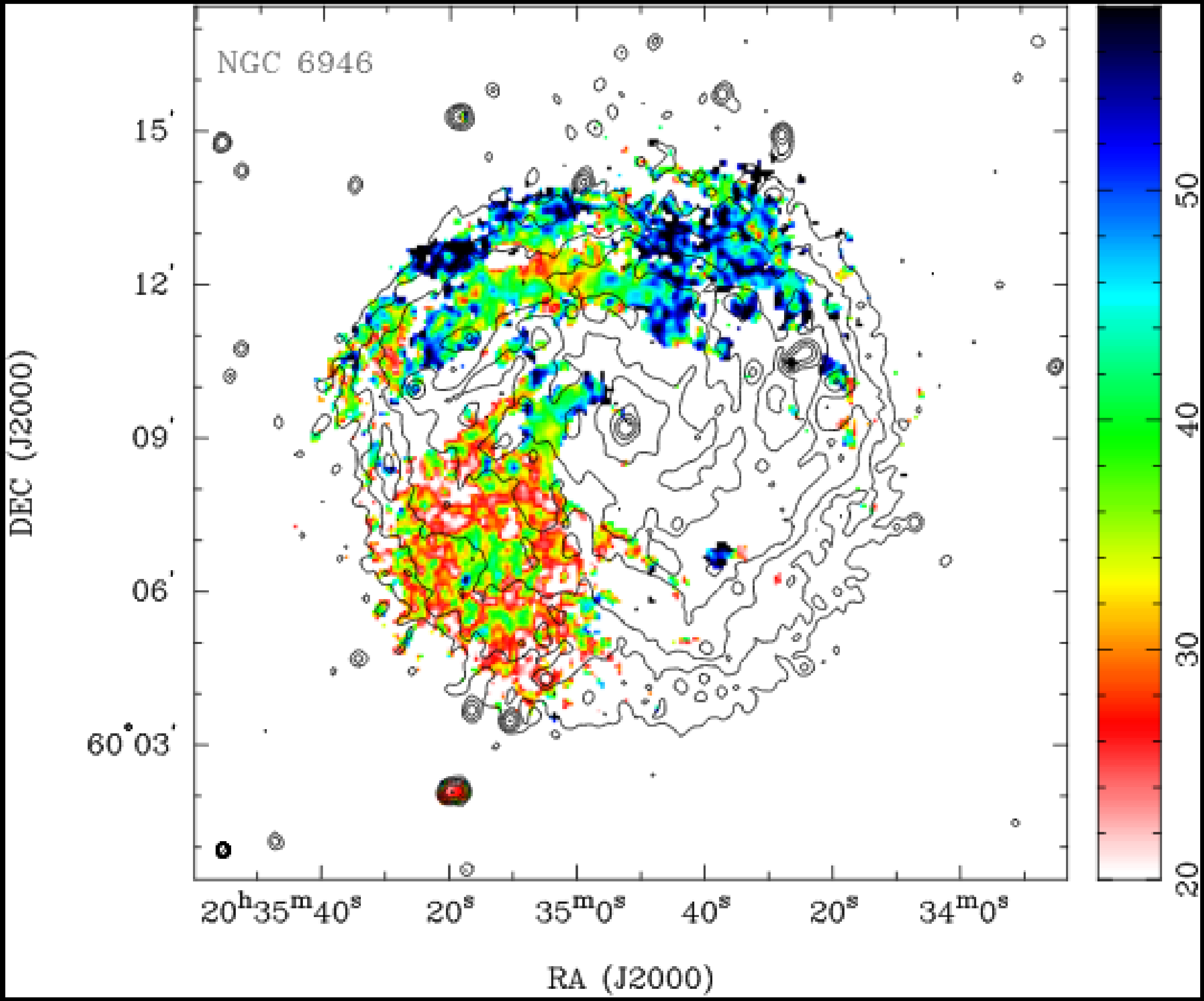
M51 image = Hubble Heritage
All others courtesy Robert Gendler

NGC 6946

- approaching side
- receding side

PA = 243°



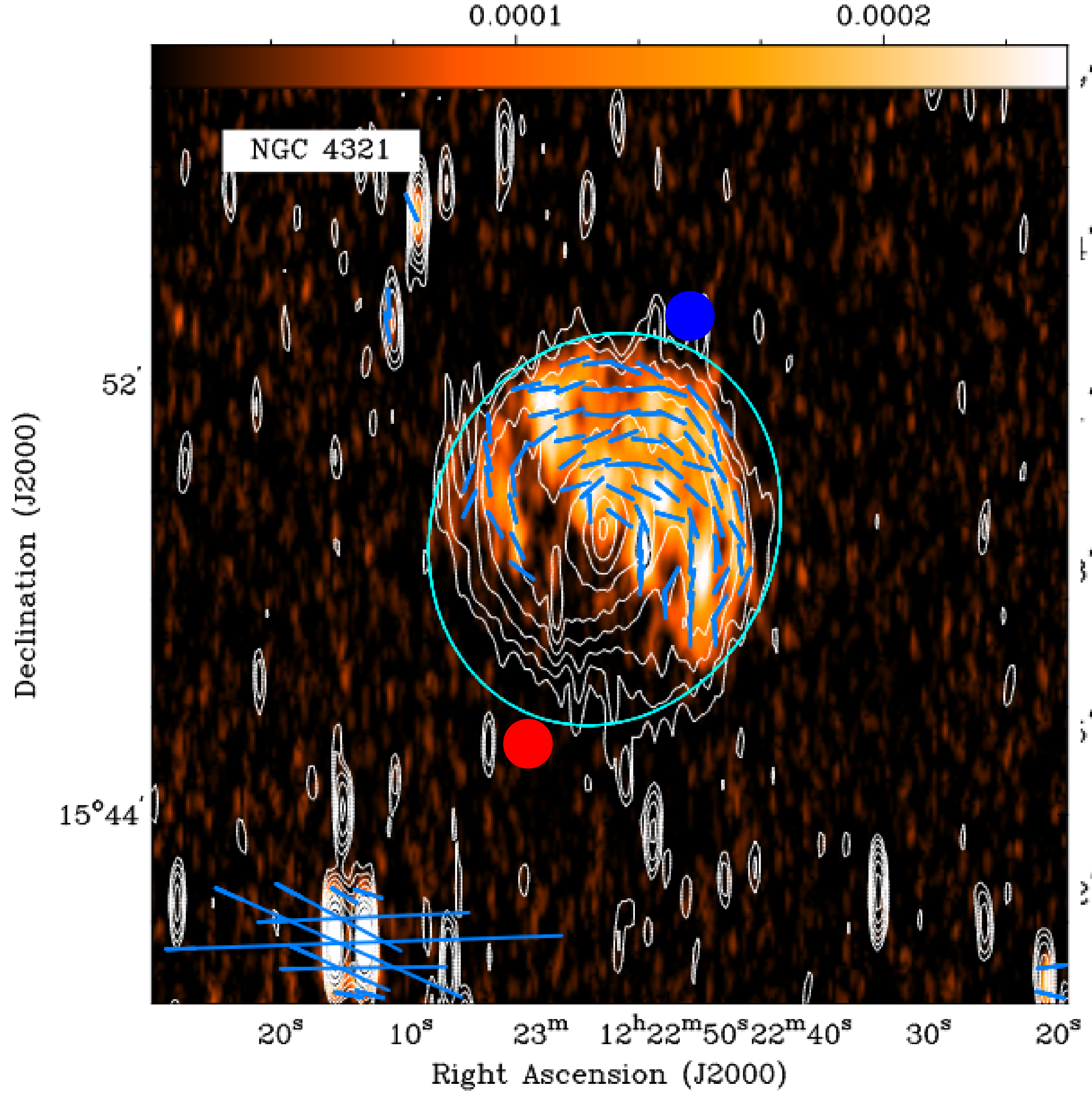


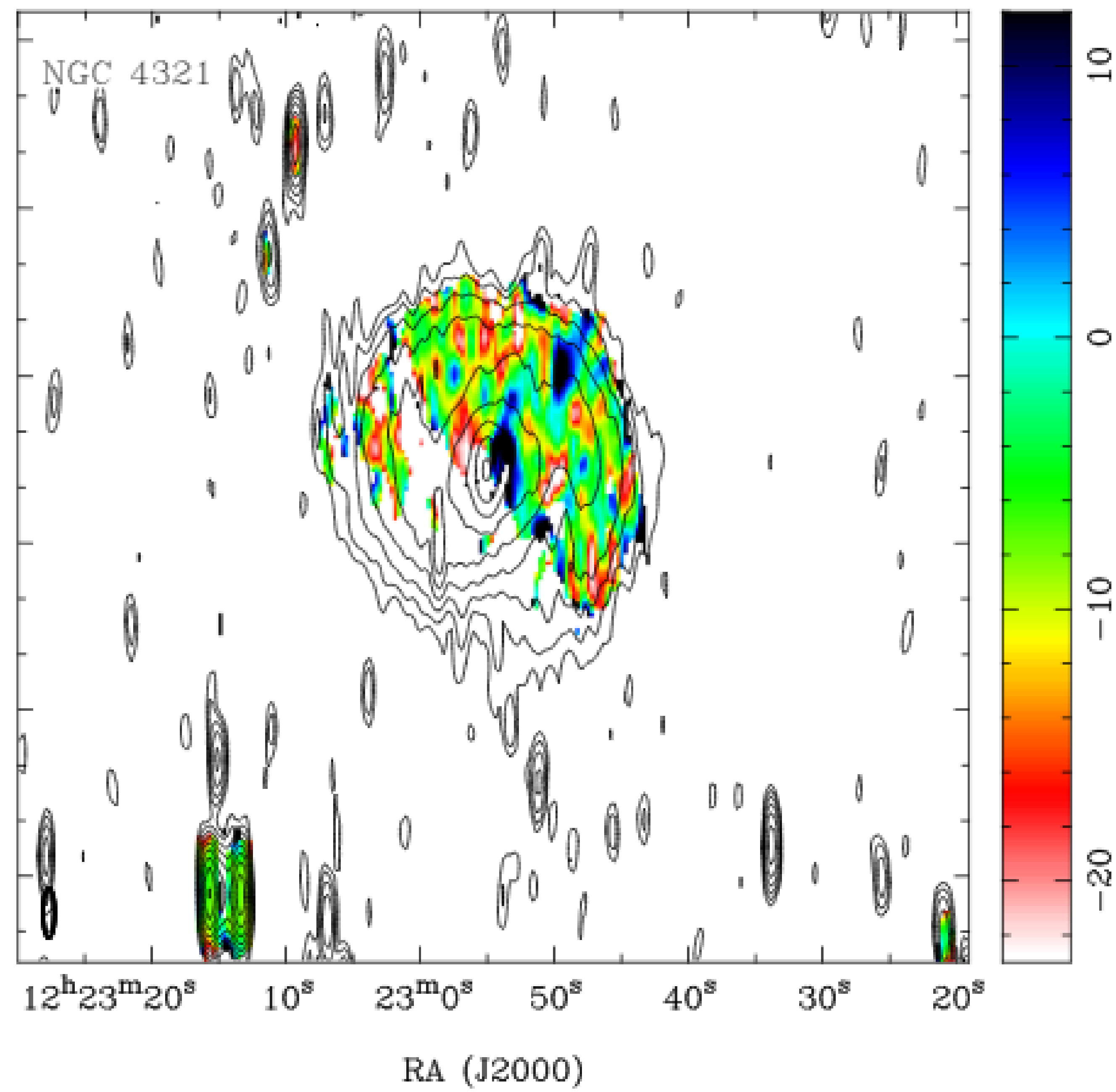
NGC 4321

approaching side

receding side

PA = 159°

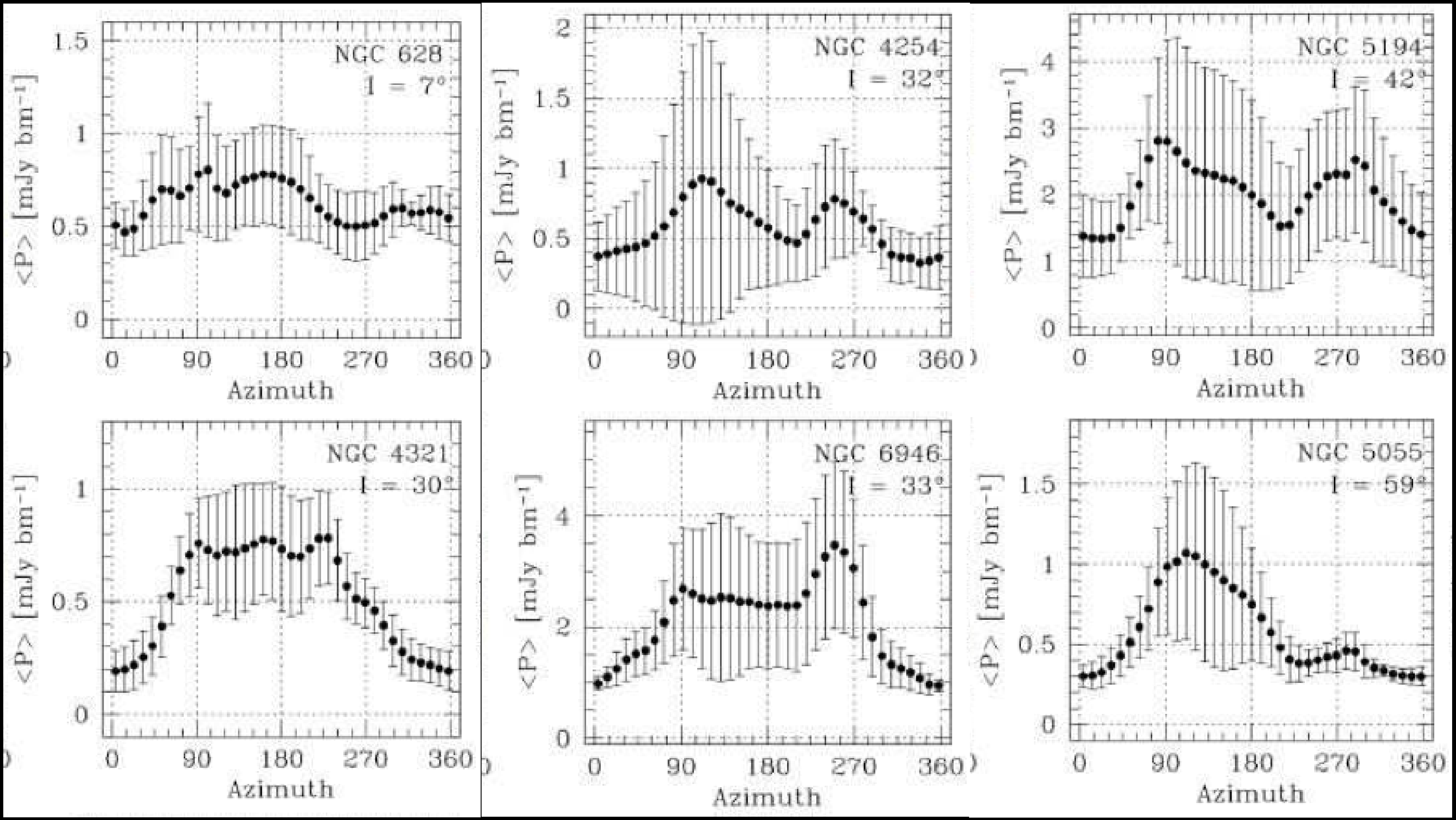




Trend in P(θ)

ASTRON

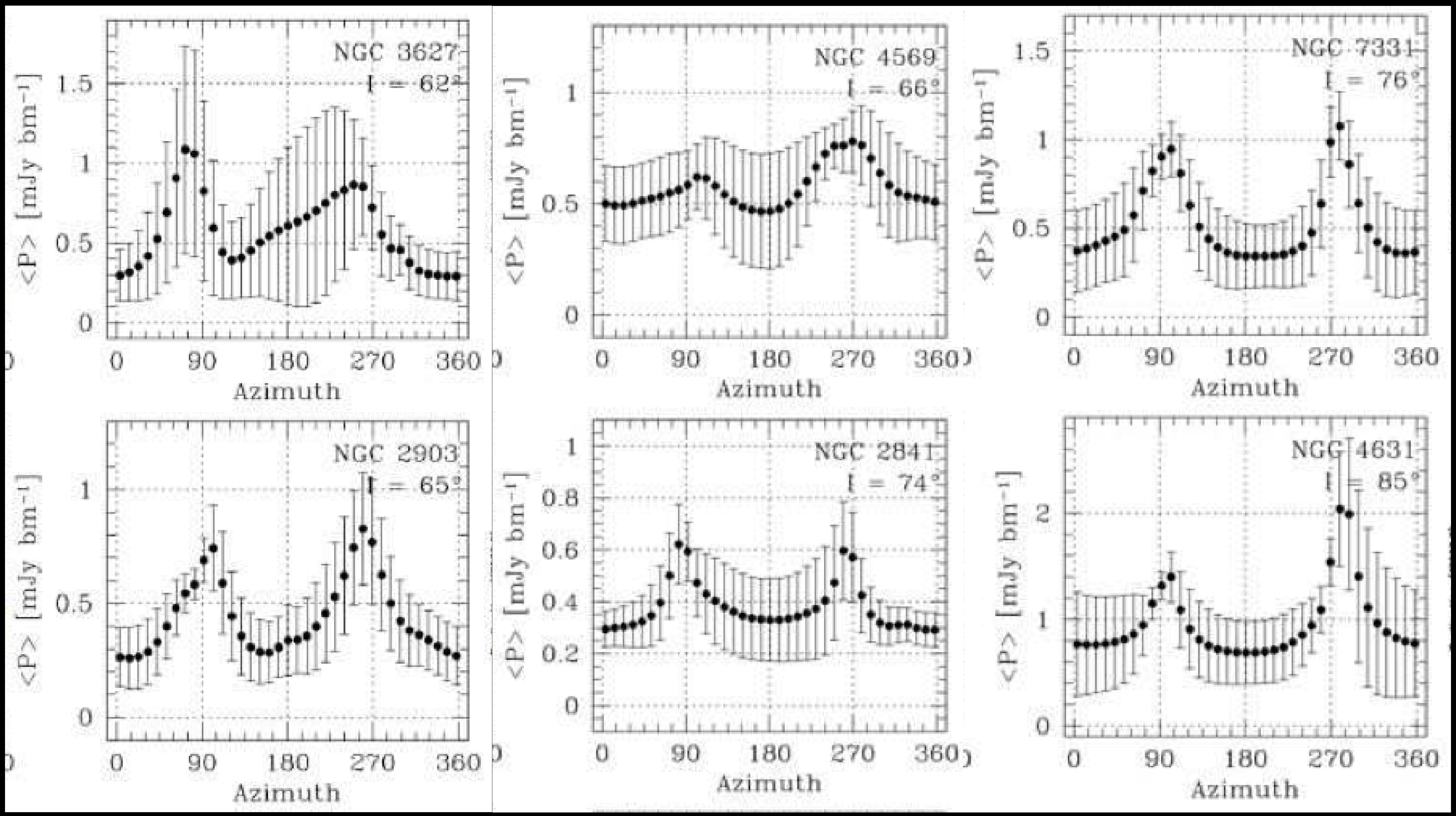
- Minimum in P consistently found on the receding major axis -- WHY?



(~Face-on targets)

Trend in P(θ)

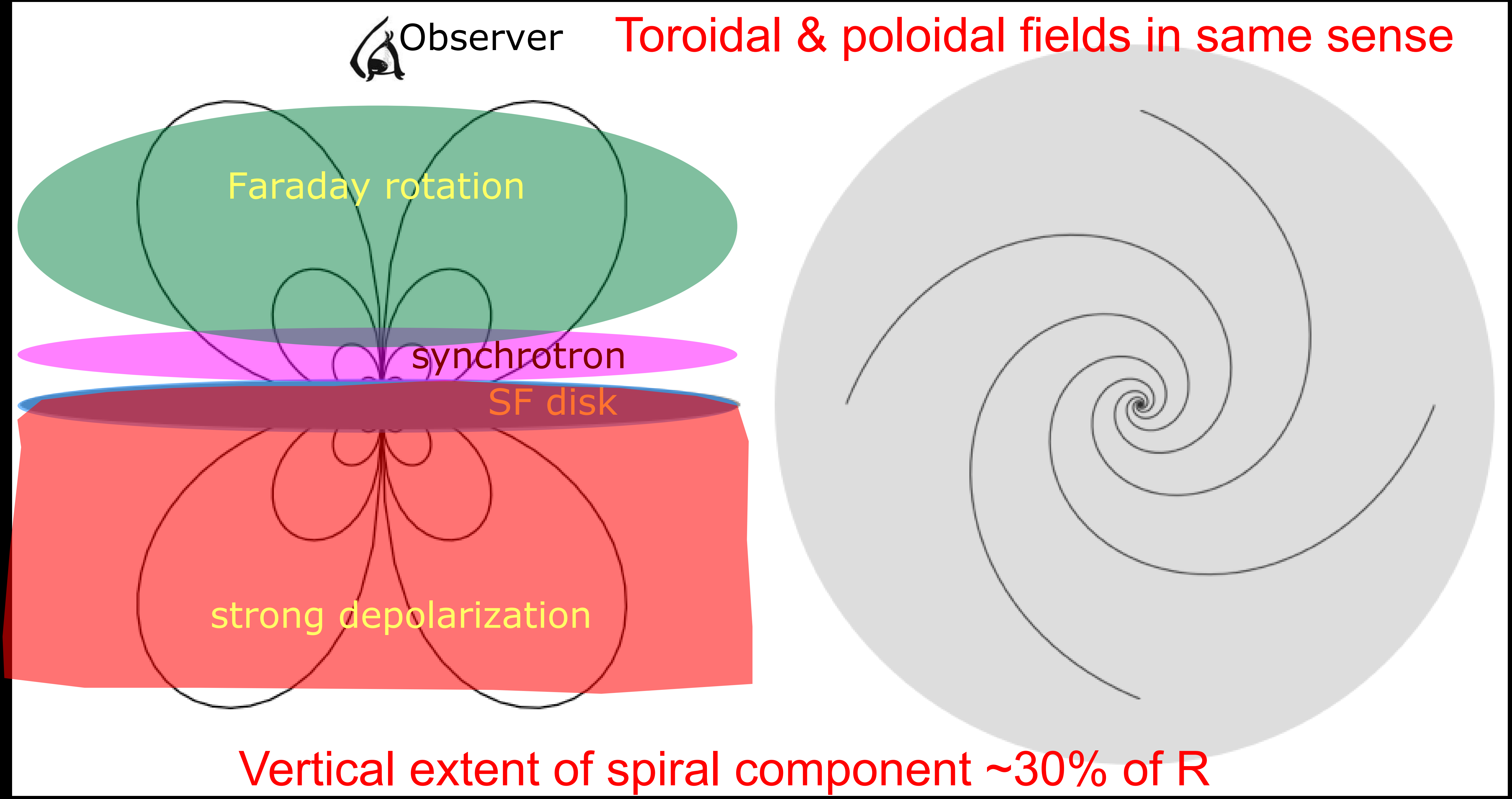
- Minimum in P consistently found on the receding major axis -- WHY?



(~Edge-on targets)

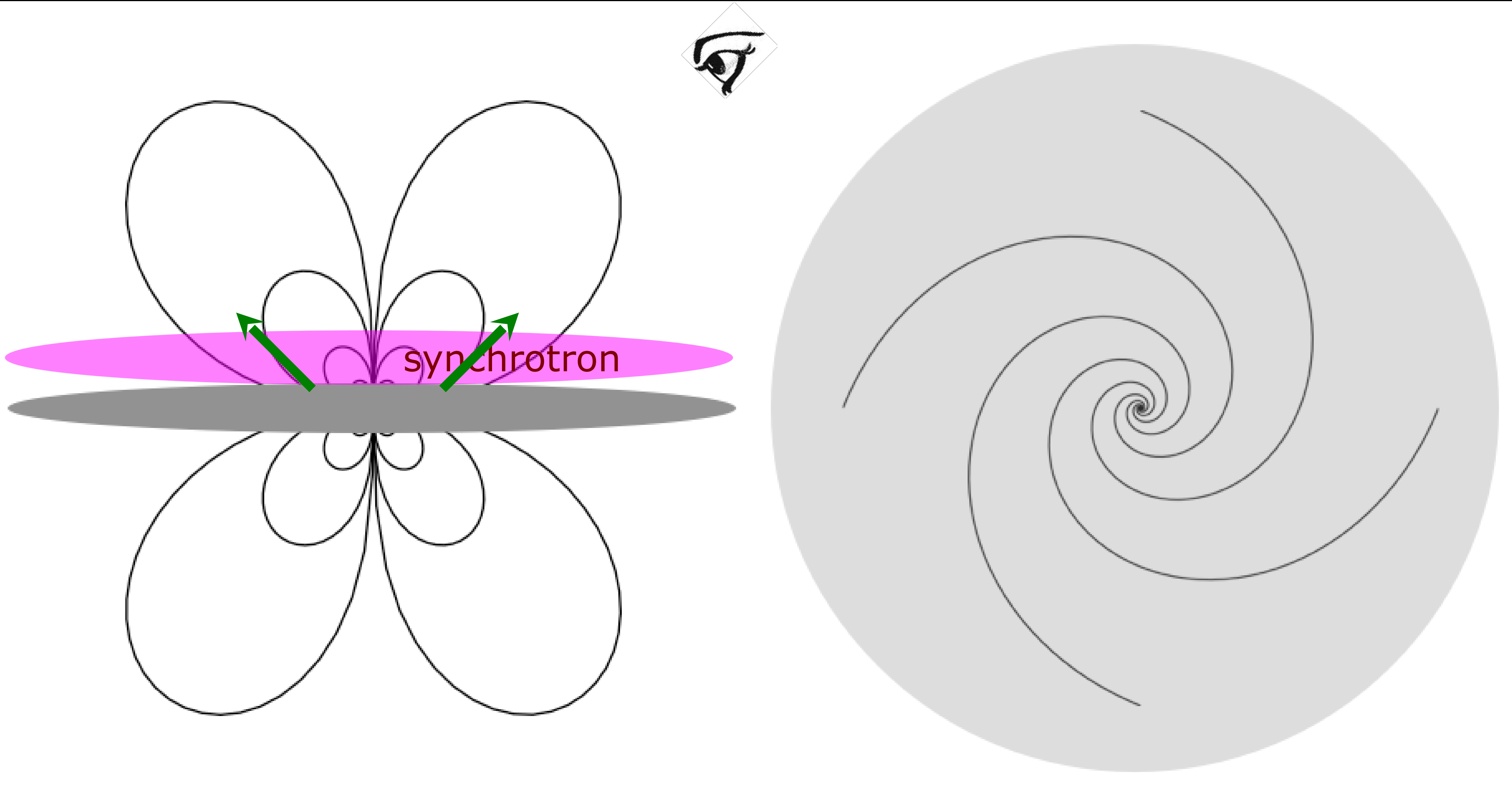
Interpretation

- Combination quadrupolar field + axisymmetric spiral (NB: *geometry only*)



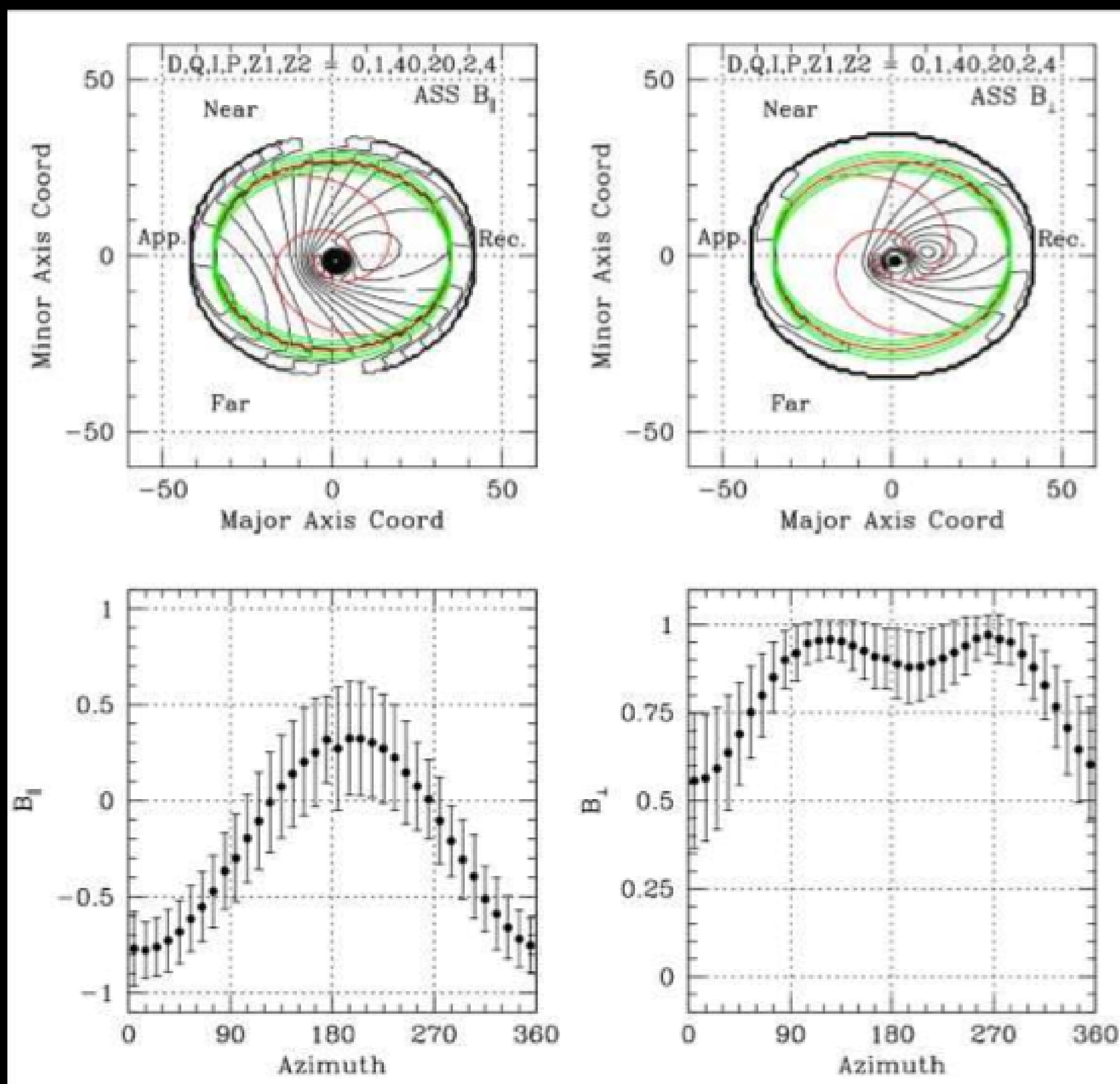
Interpretation

- Azimuthal asymmetry by field projection ("bendy microphone model")

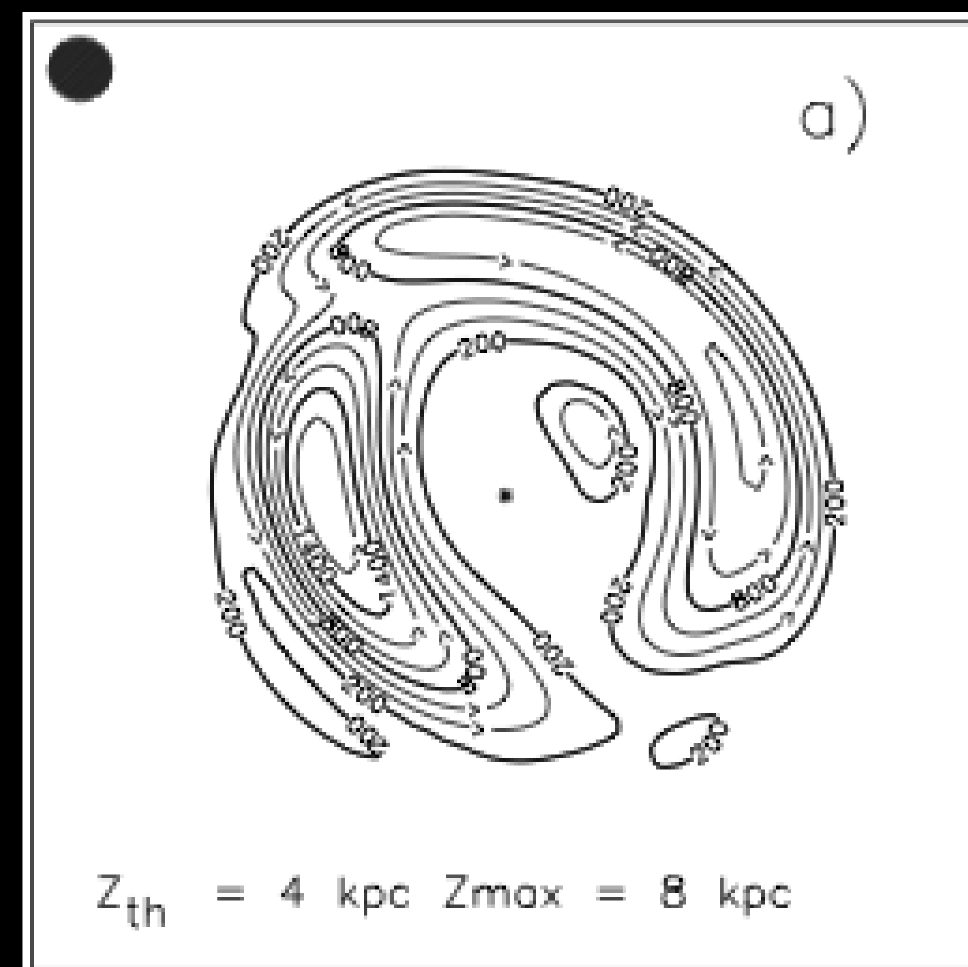


Interpretation

- Such a geometrical model reproduces the correct effect (see also Urbanik et al. 1997, who showed a similar model)



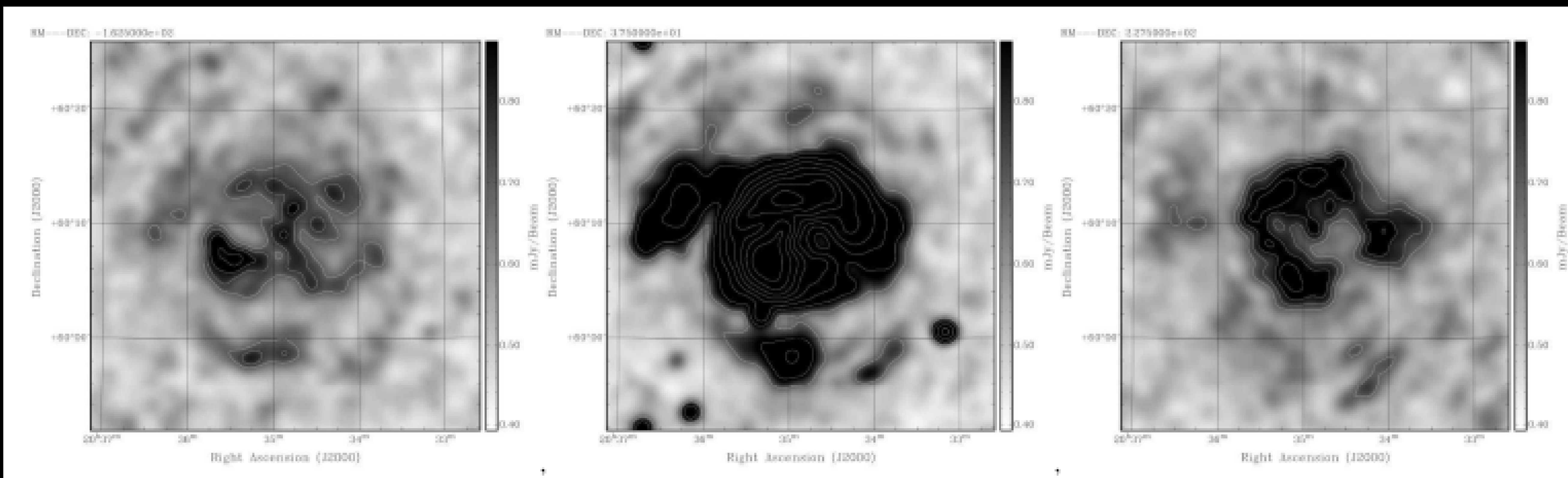
Braun et al. (2010)



Urbanik et al. (1997)

A faint view of the disk backside

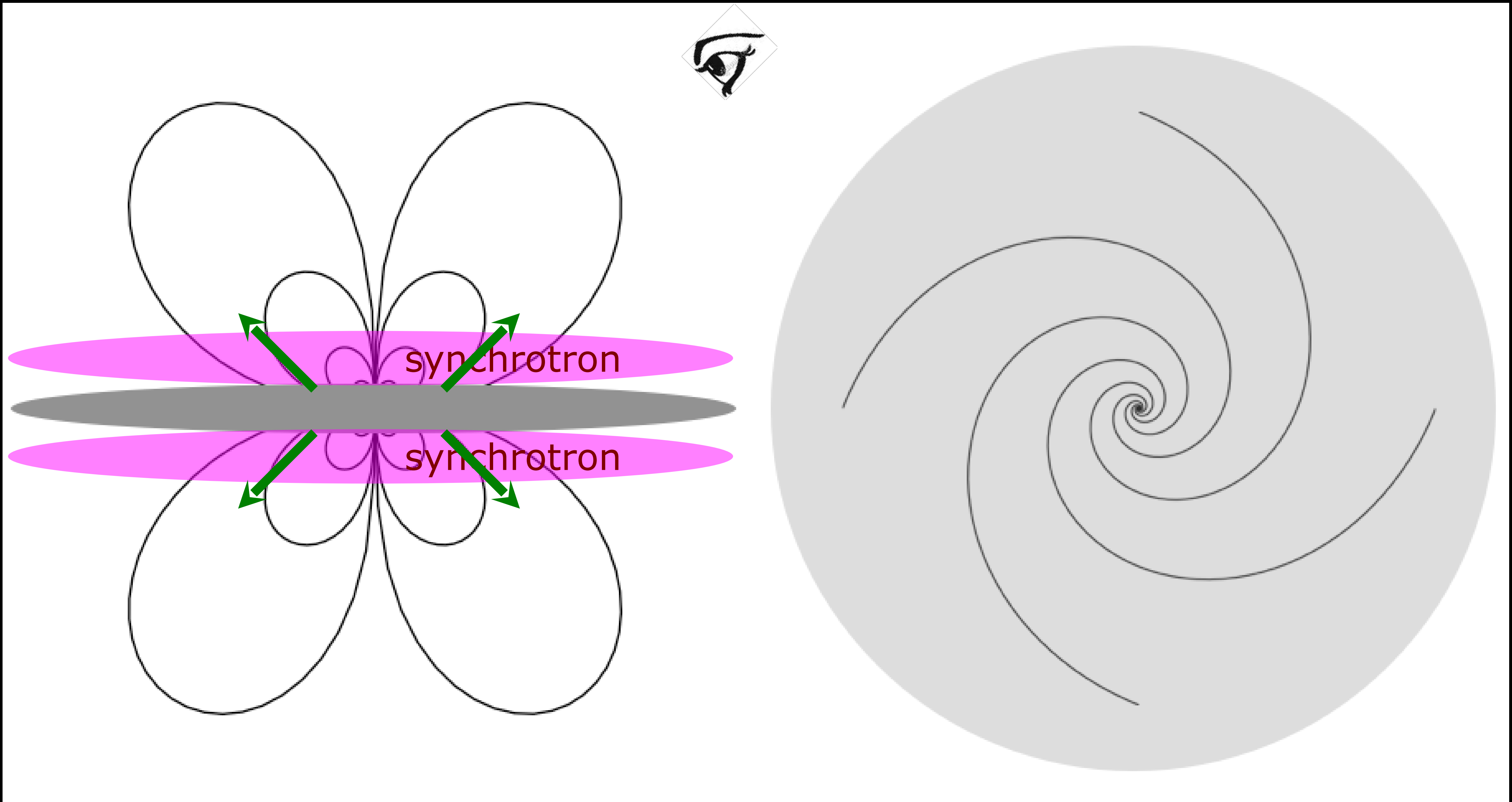
- RM Synthesis reveals polarized emission at extreme values of Faraday depth – possibly originating from behind the depolarizing medium



-162 rad/m^2 +38 rad/m^2 +228 rad/m^2

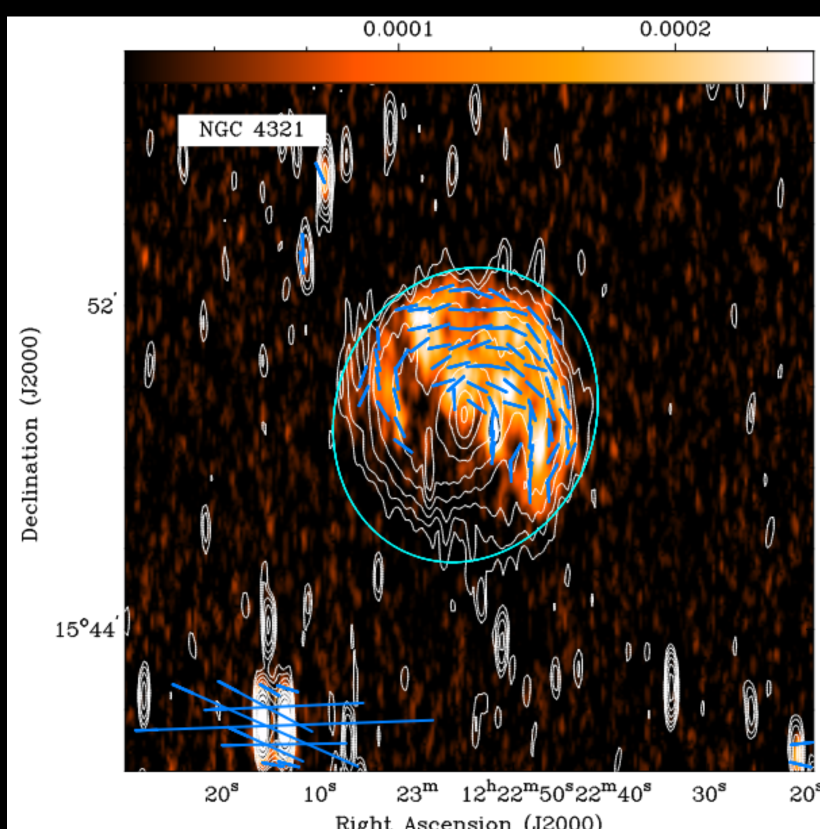
Interpretation

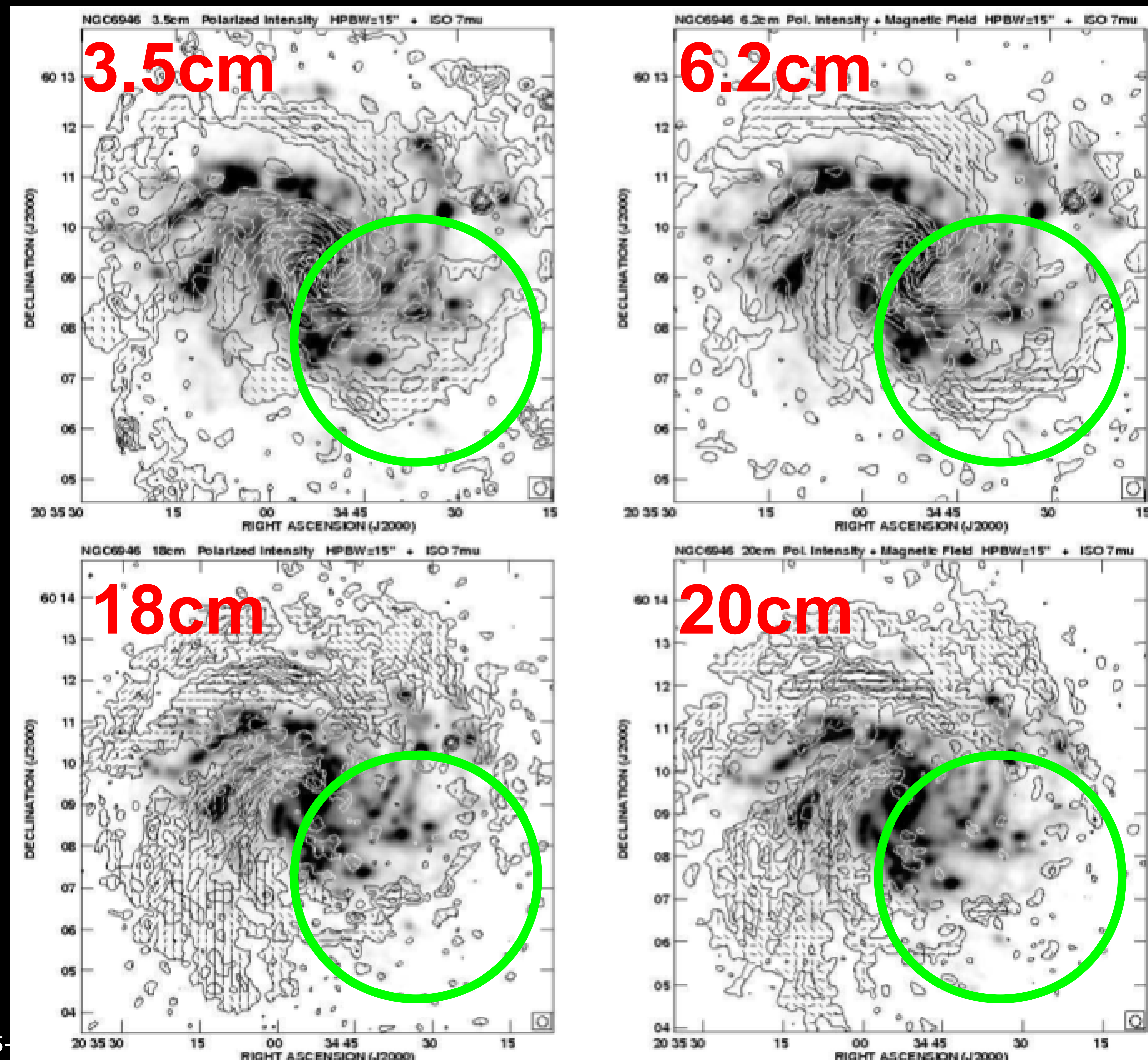
- Prediction: azimuthal asymmetry vanishes at higher frequency



Interpretation

- Prediction: azimuthal asymmetry vanishes at higher frequency
- Seems to be the case in NGC 6946 (Beck)
- True for others? (NGC 4321?)





Significance

- A combination of planar and poloidal field such as this is predicted by dynamo theory (e.g. Widrow 2002)
- Dominance of axisymmetric over bisymmetric, and quadrupolar over dipolar, should give strong constraints to dynamo models

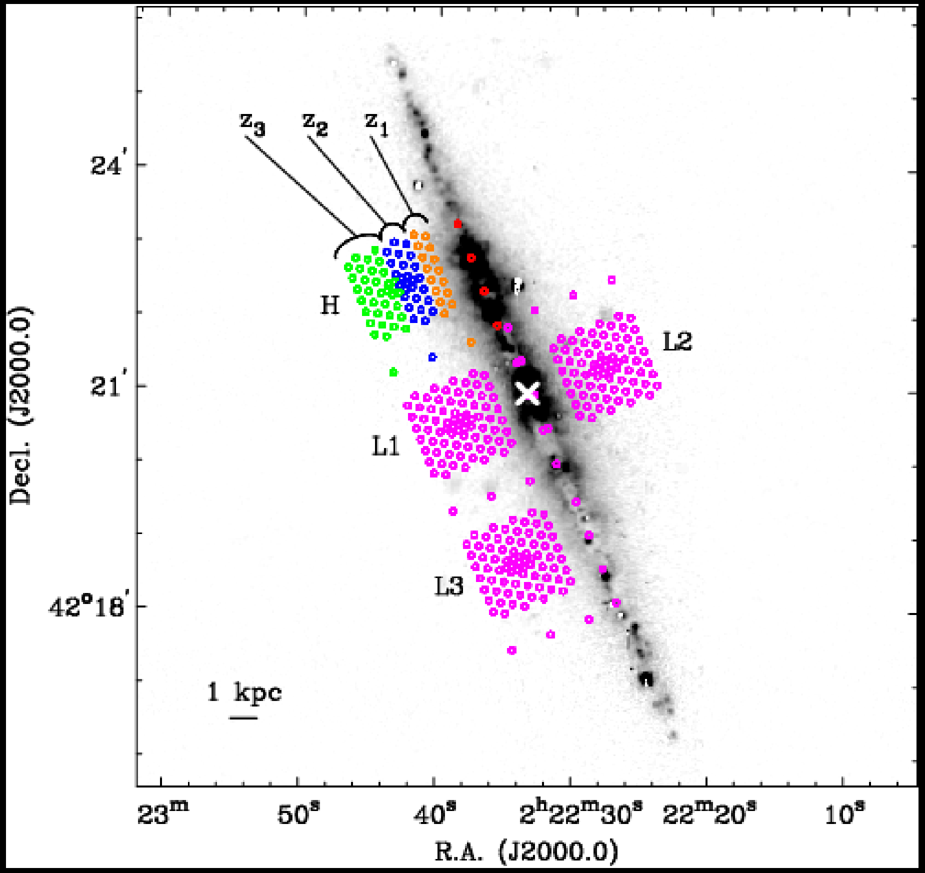
Significance

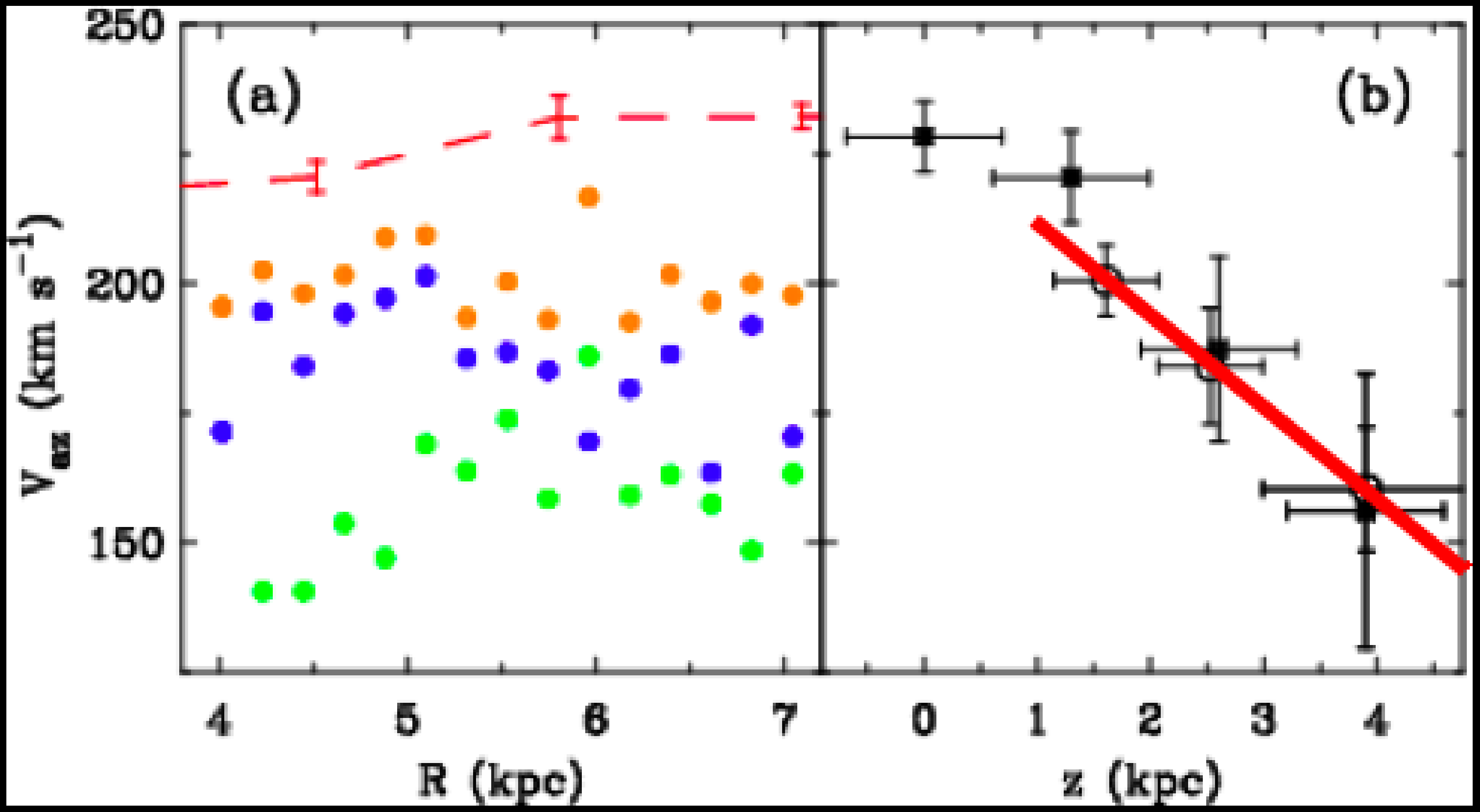
- A combination of planar and poloidal field such as this is predicted by dynamo theory (e.g. Widrow 2002)
- Dominance of axisymmetric over bisymmetric, and quadrupolar over dipolar, should give strong constraints to dynamo models

- Note that our edge-on targets actually show evidence for *dipolar* magnetic fields in the outer halo - again, predicted by dynamo theory. Why the difference? Signature of dipolar outflow?

Aside: rotation of halo gas

- Multiphase gas at large vertical distances above the midplane commonly observed in nearby galaxies
- Rotation of this extraplanar gas reveals a linear decrease in rotation speed with height – halos differentially rotate, but with a slower amplitude than the underlying disk (Fraternali et al. 2005; Heald et al. 2006, 2007)
- Connection between kinematics of gaseous halos and the vertical structure of the halo gas? (see Heald et al. 2007)

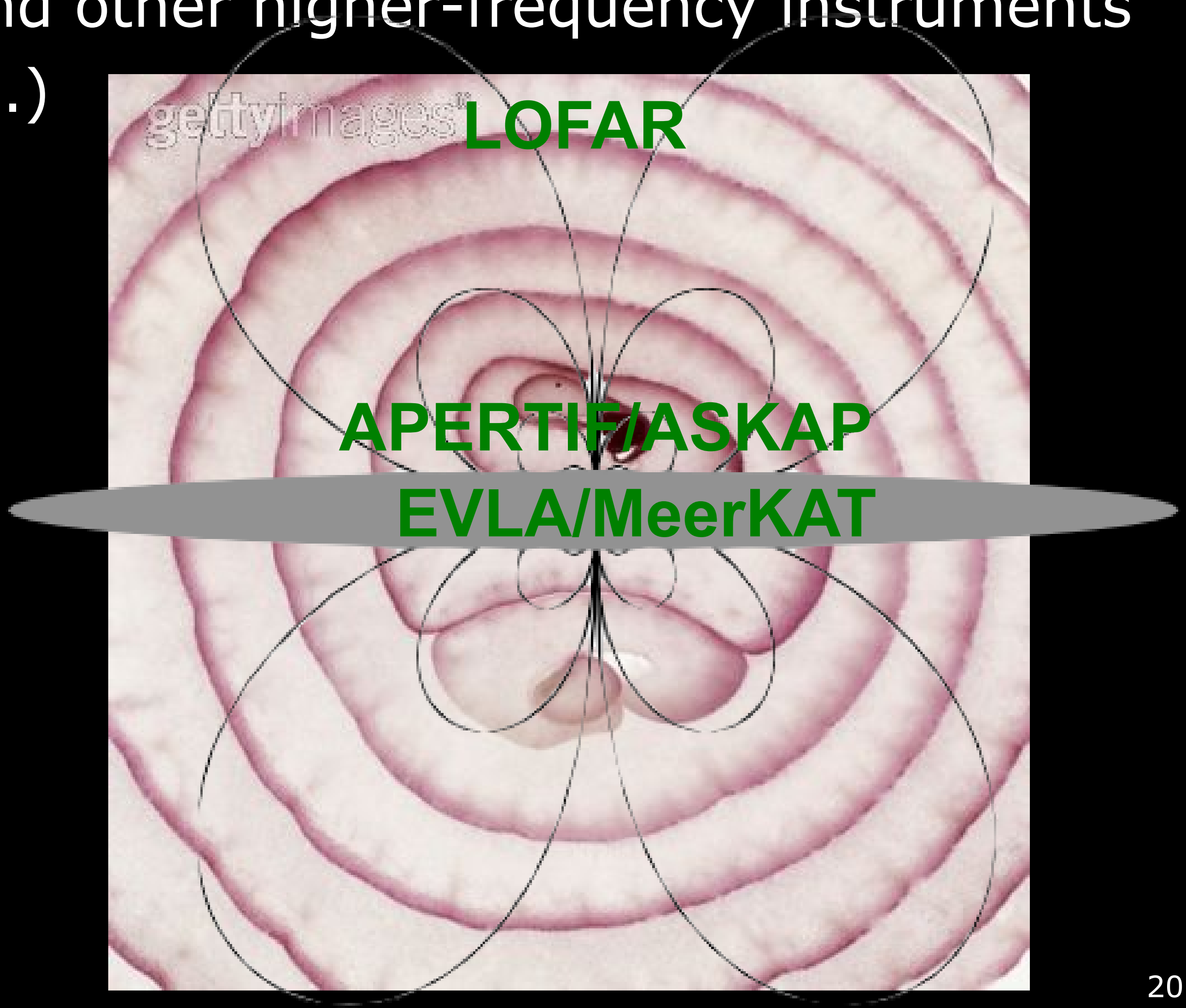




Prospects for LOFAR

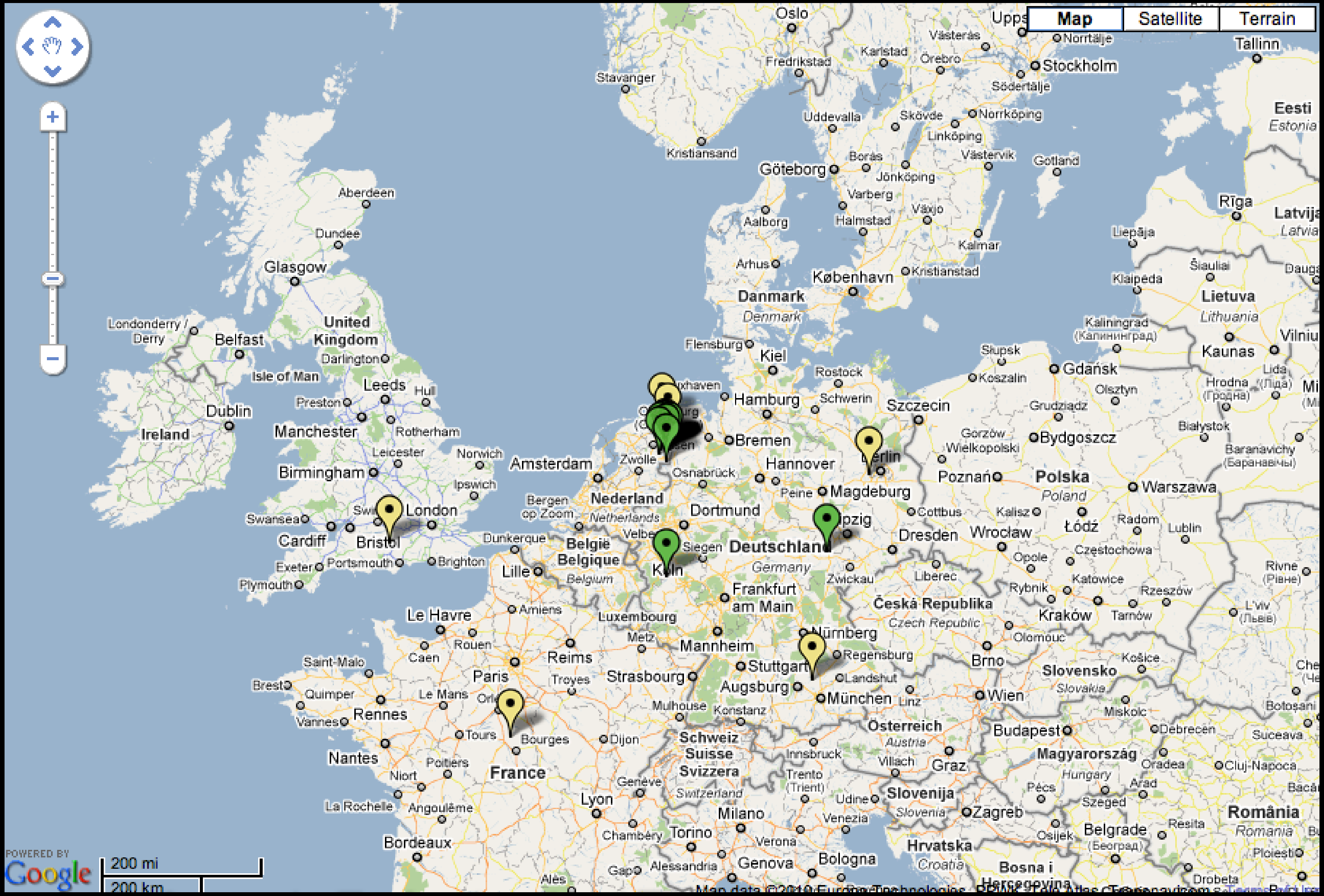
- LOFAR will probe the outer disks and halos of a large number of nearby galaxies, characterizing the global magnetic field geometry
- Do halo fields become predominantly dipolar in the far outer parts?
- How far do the halo fields extend?

- Complementarity between LOFAR, and other higher-frequency instruments (APERTIF, ASKAP, MeerKAT, EVLA, ...)
  - each probes a different 'zone' of the galaxy
  - gives an onion-peel view of galactic magnetic field structure!



LOFAR today

LOFAR station status visible online at
http://www.astron.nl/~heald/lofarStatusMap.html



Interferometry mode works well (fringes on 600-km baselines @ 30 MHz!);
Imaging pipeline in good shape; official opening 2nd week of June 2010

LOFAR today

LOFAR station status visible online at
http://www.astron.nl/~heald/lofarStatusMap.html

Interferometry mode works well (fringes on 600-km baselines @ 30 MHz!);
Imaging pipeline in good shape; official opening 2nd week of June 2010

Summary

- Asymmetry in polarized intensity in nearby galaxies caused by combination of toroidal and poloidal components
  - Minimum P/I on receding side: consequence of *trailing spiral arms*
  - Asymmetry expected to vanish at higher frequency
- New observational programs with LOFAR and other (higher frequency) new telescopes will allow us to learn much more about the full 3-D structure of galactic magnetic fields