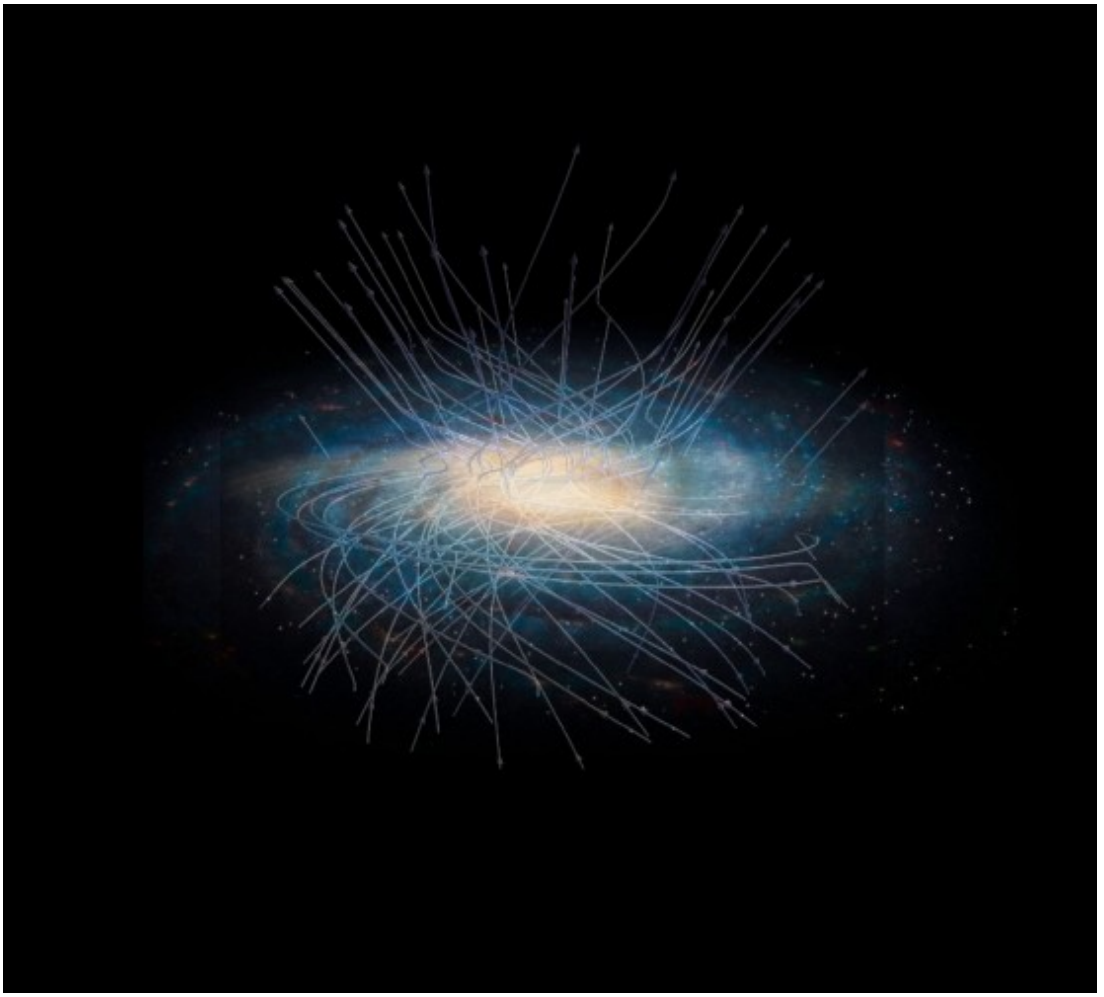
The coherent magnetic field of the Milky Way: new ideas and UHECR deflections

Alexander Korochkin
(ULB, Brussels)

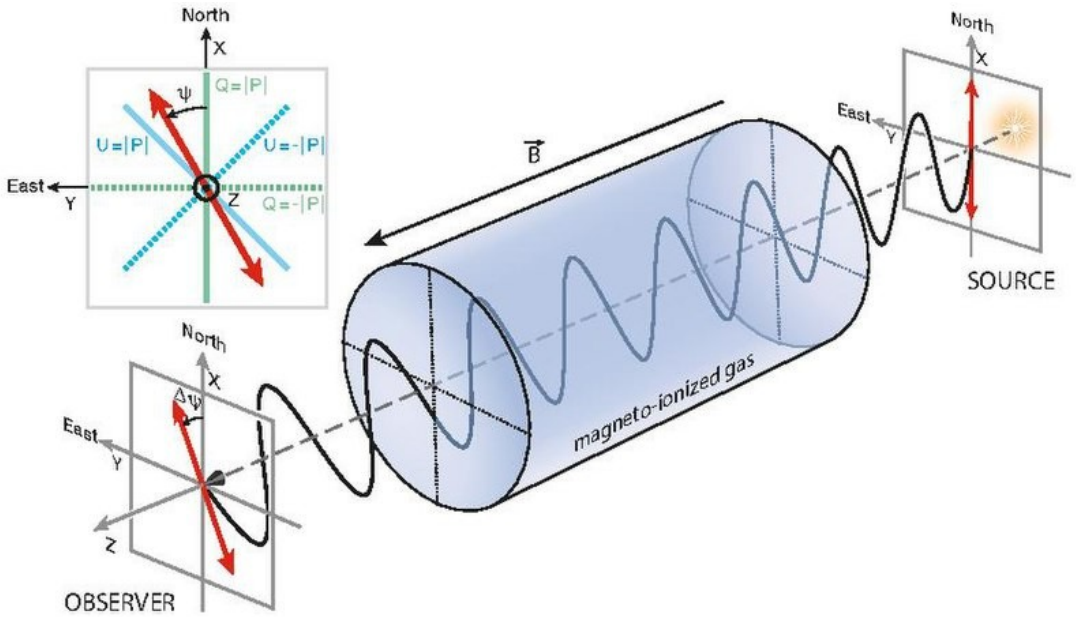
in collaboration with Dmitri Semikoz and Peter Tinyakov, arXiv:2407.02148

GMF and Galactic processes



- GMF affects star formation
- Important for cosmic ray propagation
- UHECR deflections, we still don't know the sources
- Cosmic ray leptons and dust emission – background for CMB measurements
- GMF origin? Dynamo?

Data: extragalactic Faraday rotation measures (RM)



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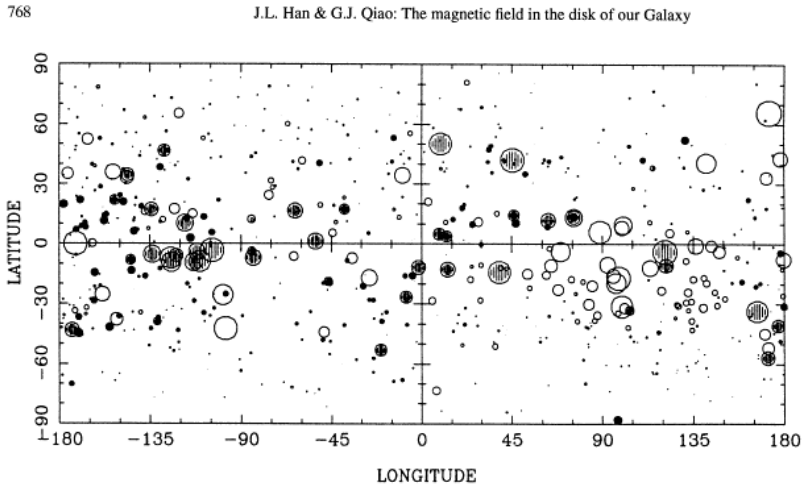
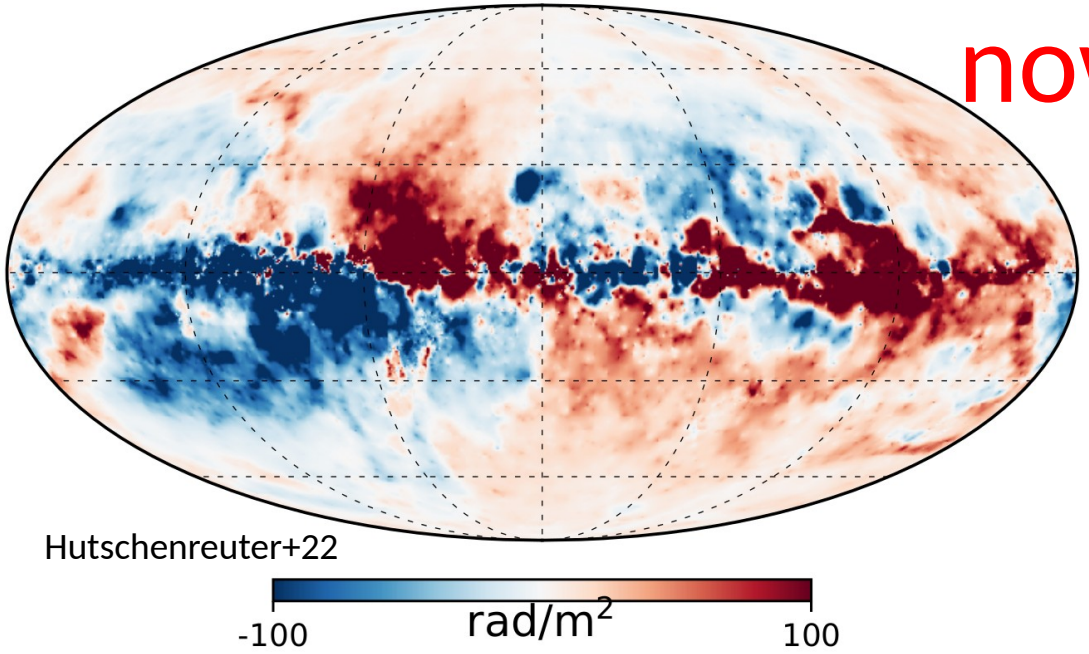


extragalactic RM

now

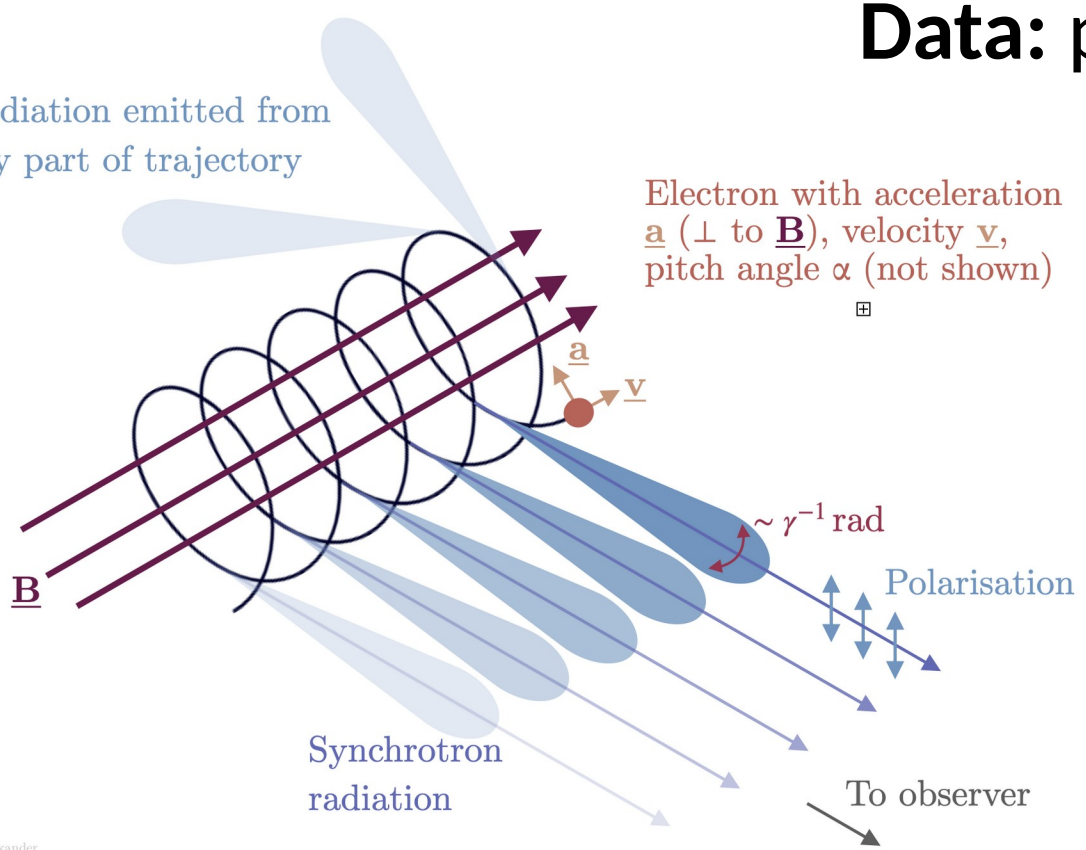


RM traces B field component parallel to LOS

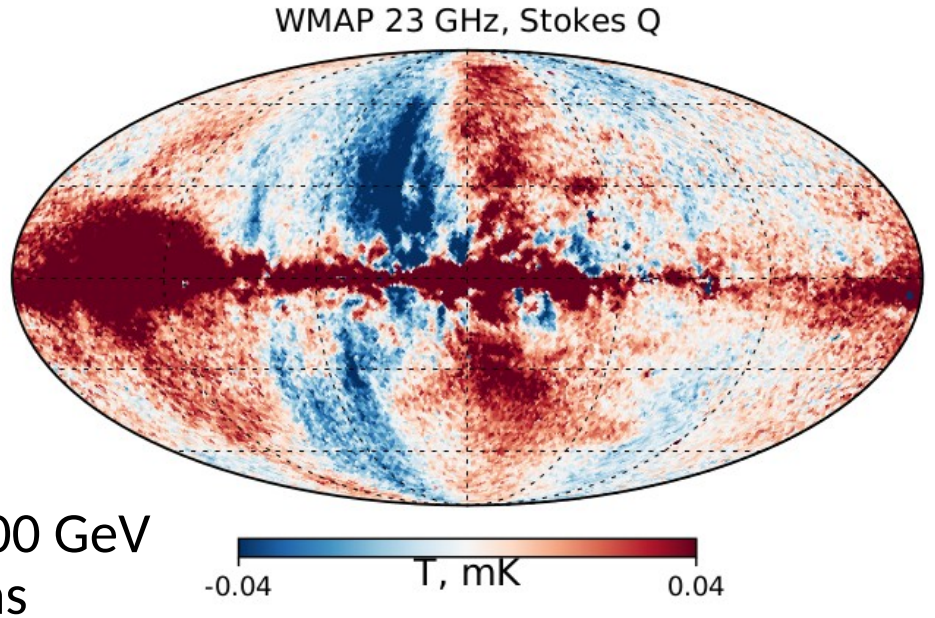
Brown – MF pointing towards us

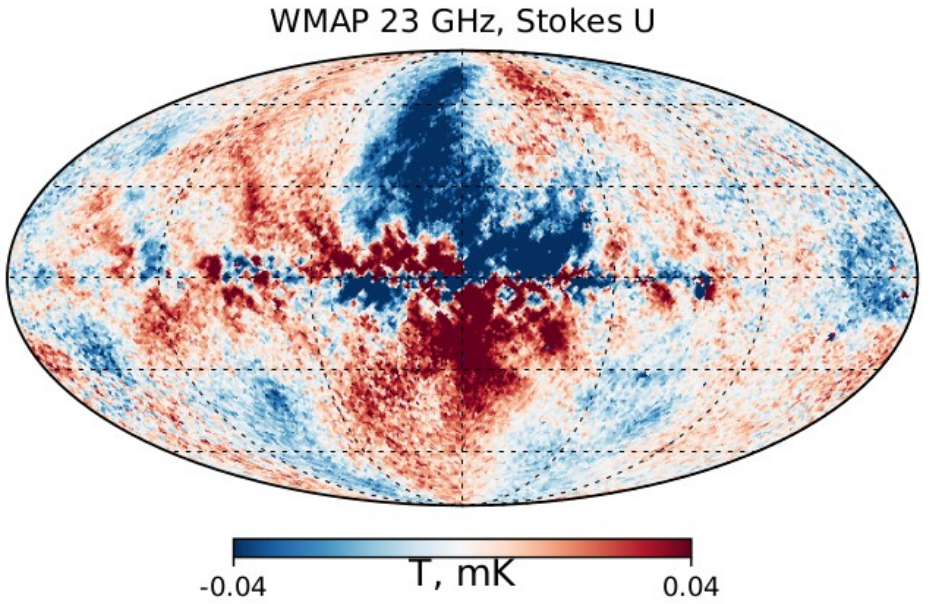
Blue – MF pointing away from us

Data: polarized synchrotron skymaps

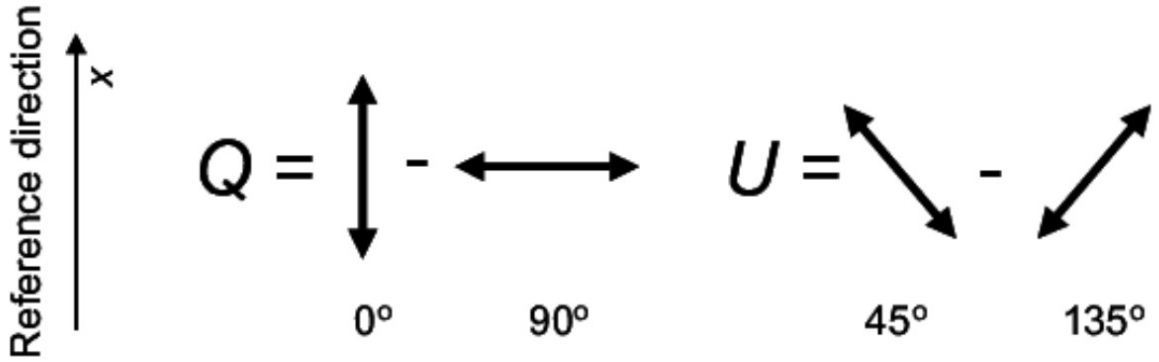


~1 GeV – 100 GeV leptons





Stokes parameters



External galaxies

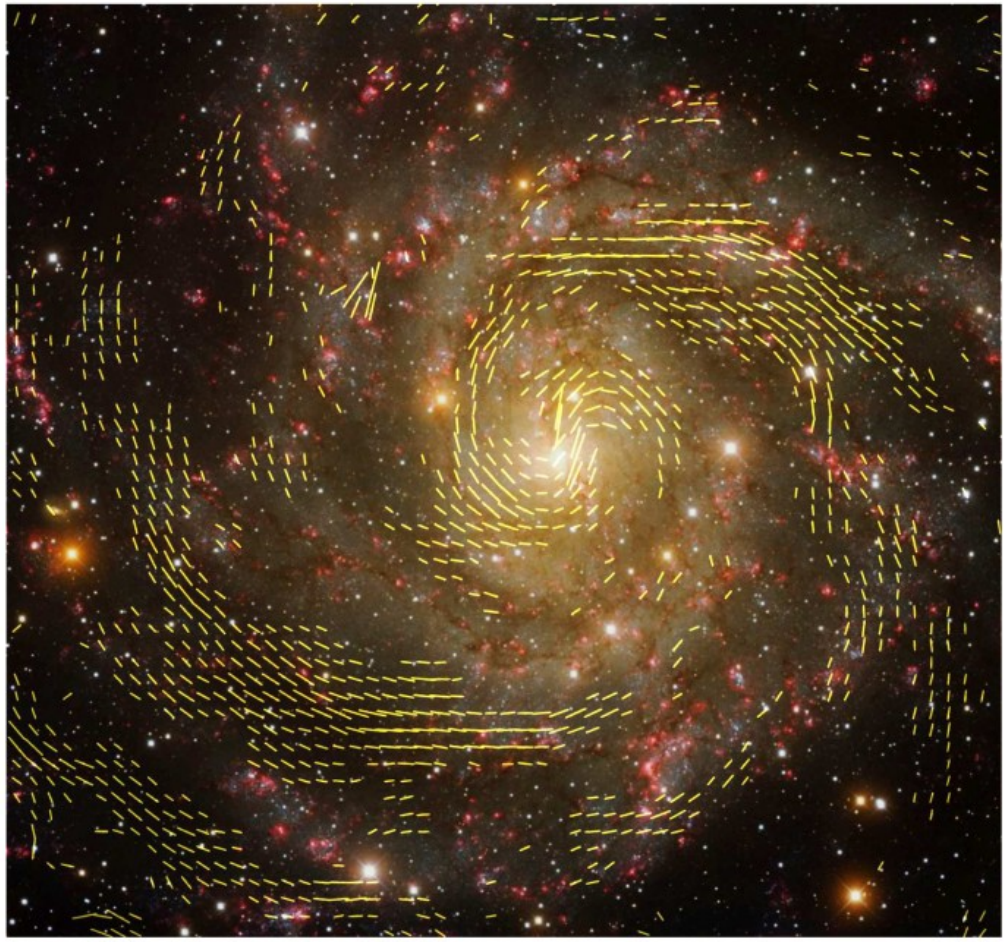
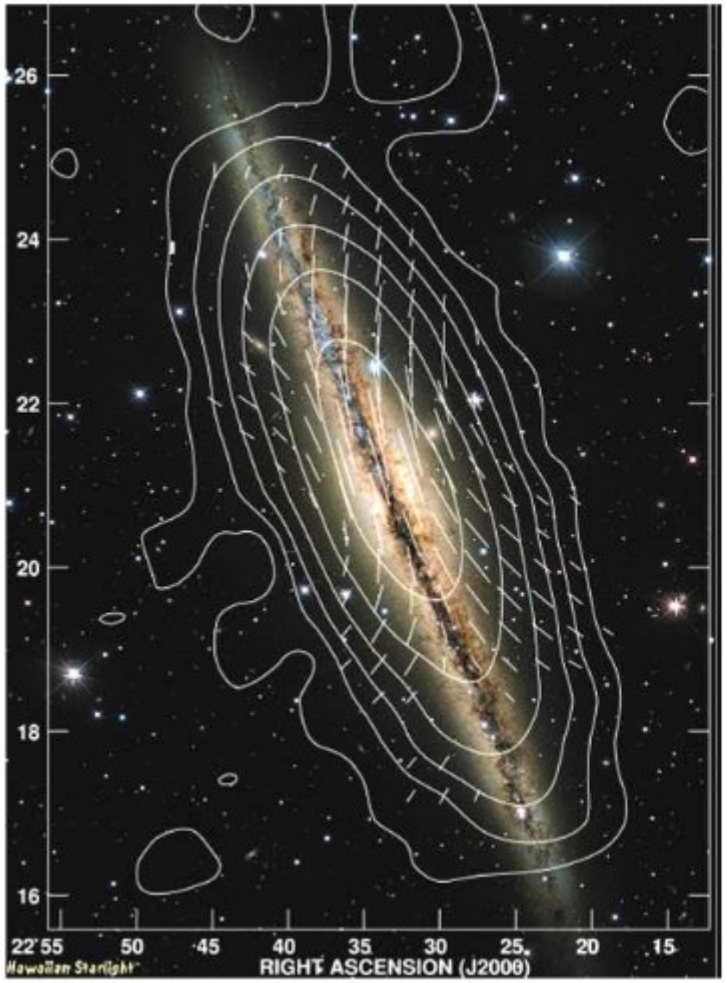


Fig. 6 Polarization B–vectors of IC 342, combined from observations at 6 cm wavelength with the VLA and Effelsberg telescopes and smoothed to 25″ resolution (from Beck (2015)), overlaid on a colour image from the Kitt Peak Observatory (credit: T.A. Rector, University of Alaska Anchorage, and H. Schweiker, WIYN and NOAO/AURA/NSF). A region of $16' \times 16'$ (about 16×16 kpc) is shown. (Copyright: MPIfR Bonn)

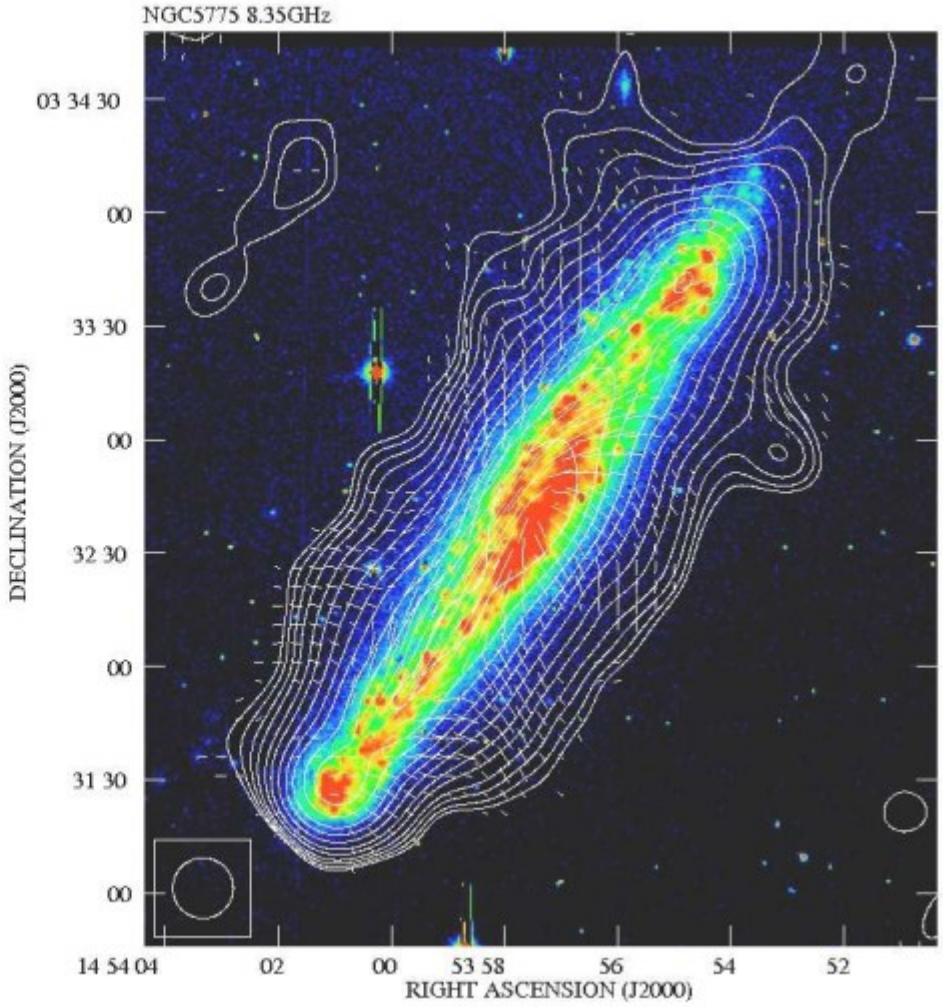
IC 342

- In a first approximation magnetic field is aligned with the spiral arms

External galaxies: edge on view



NGC 891

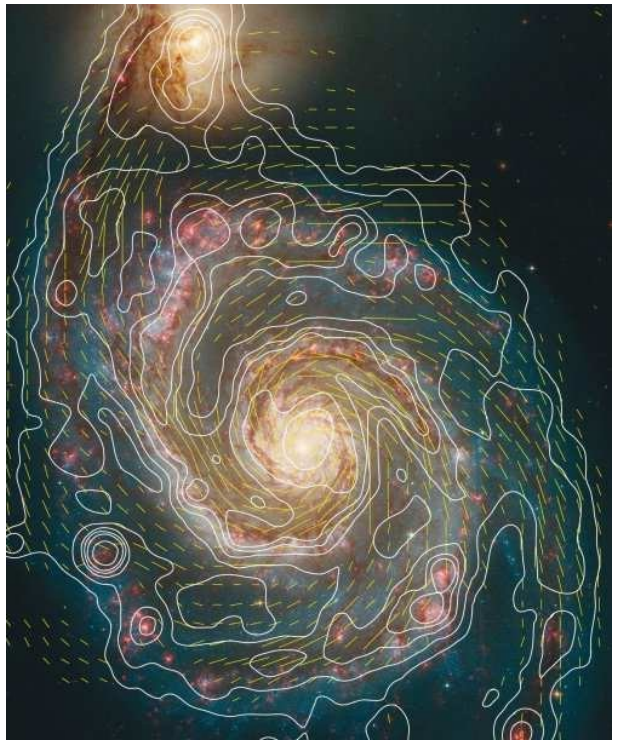


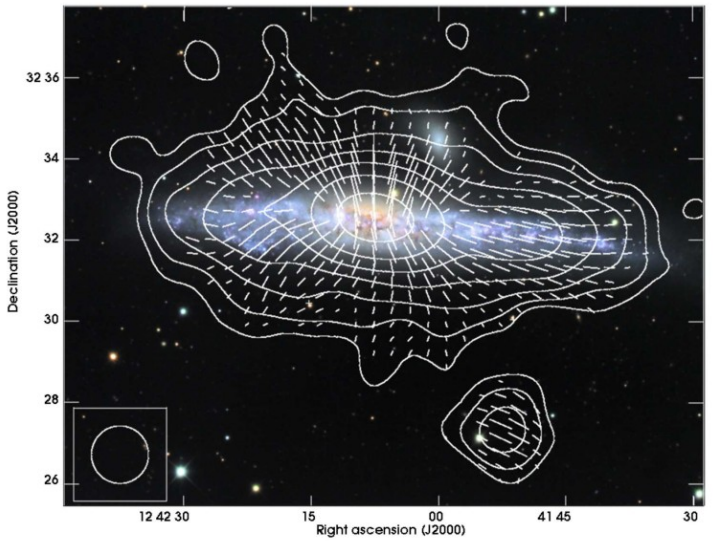
NGC 5775

Out of the plane field = X-field

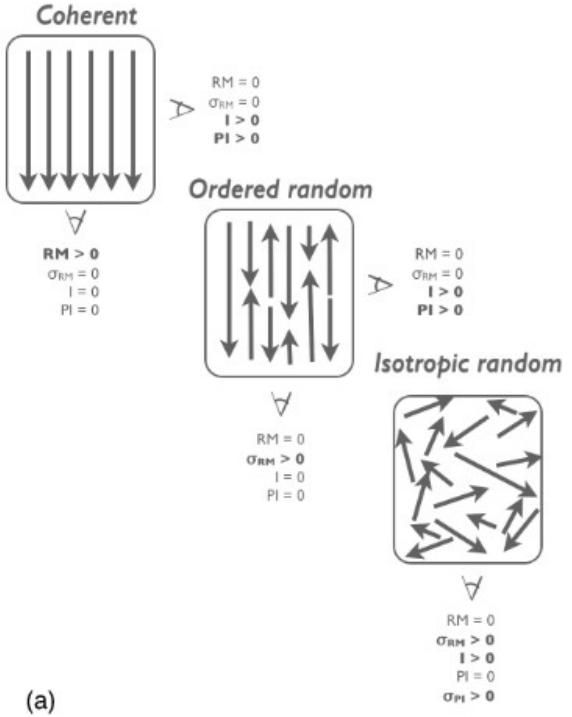
External galaxies: summary

- Turbulent and ordered B field can be identified in external galaxies
- Ordered field has several components: disk field, halo field, X-field
- We focus on the ordered field and assume that our Galaxy has the same components





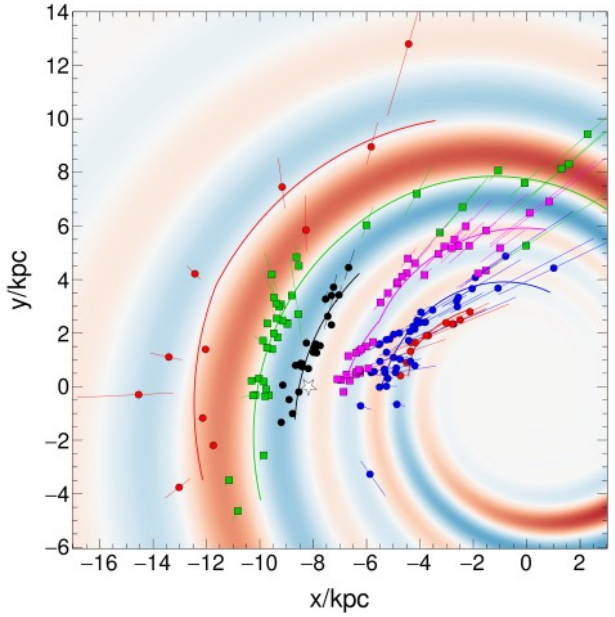
Copyright: MPIfR Bonn



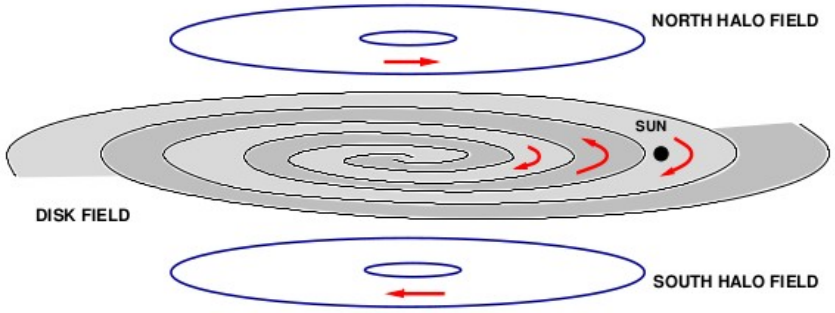
Jaffe+10

GMF models

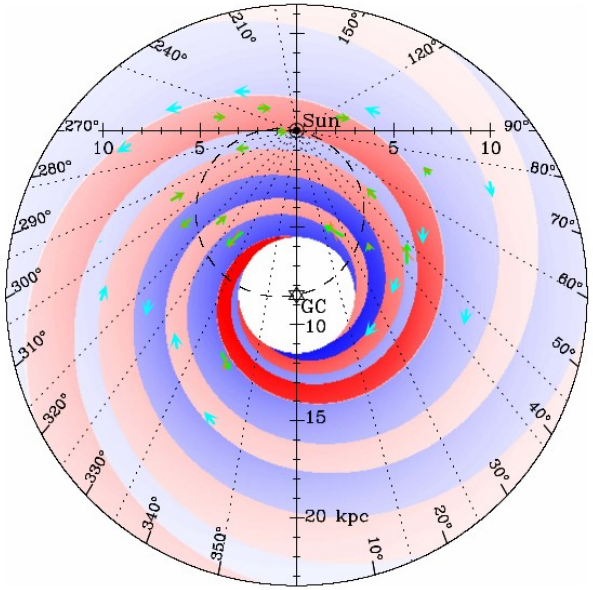
UF23



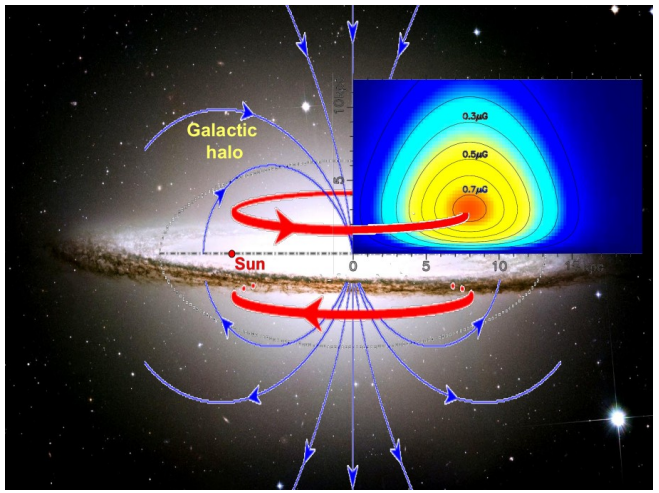
PT11



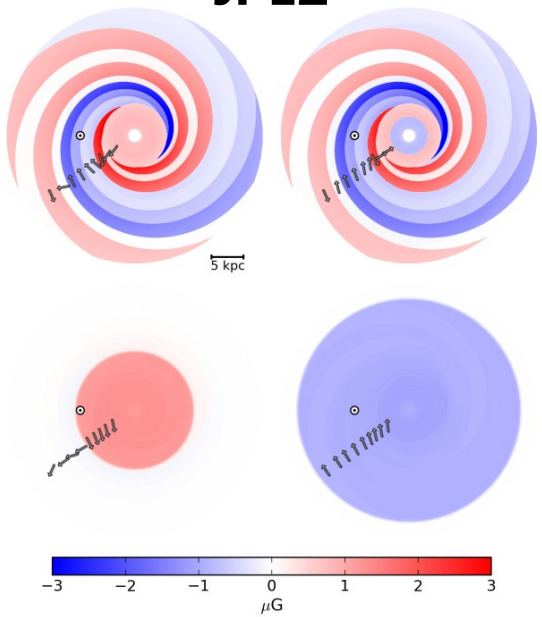
Han+18



Xu&Han+24



JF12

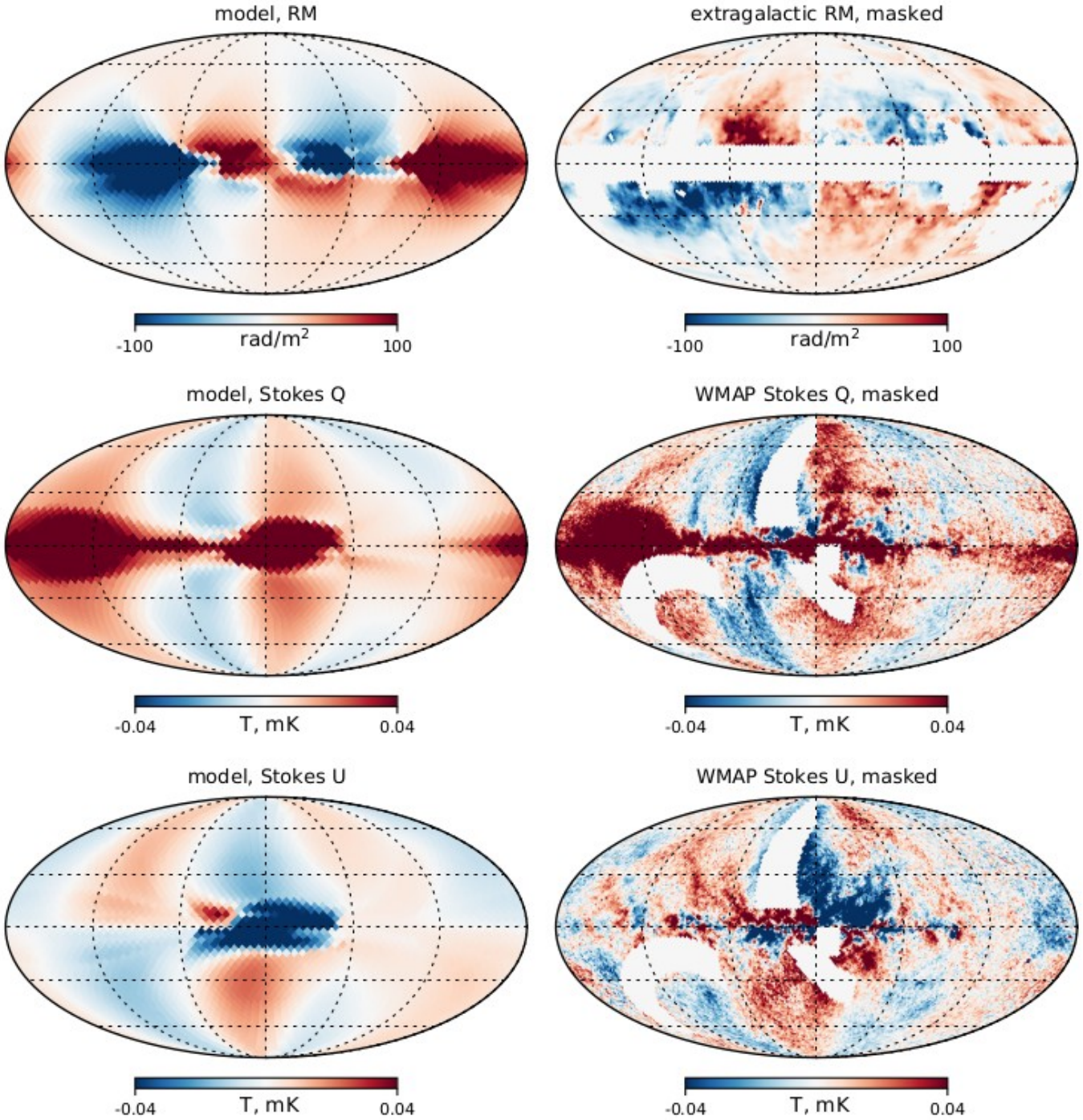


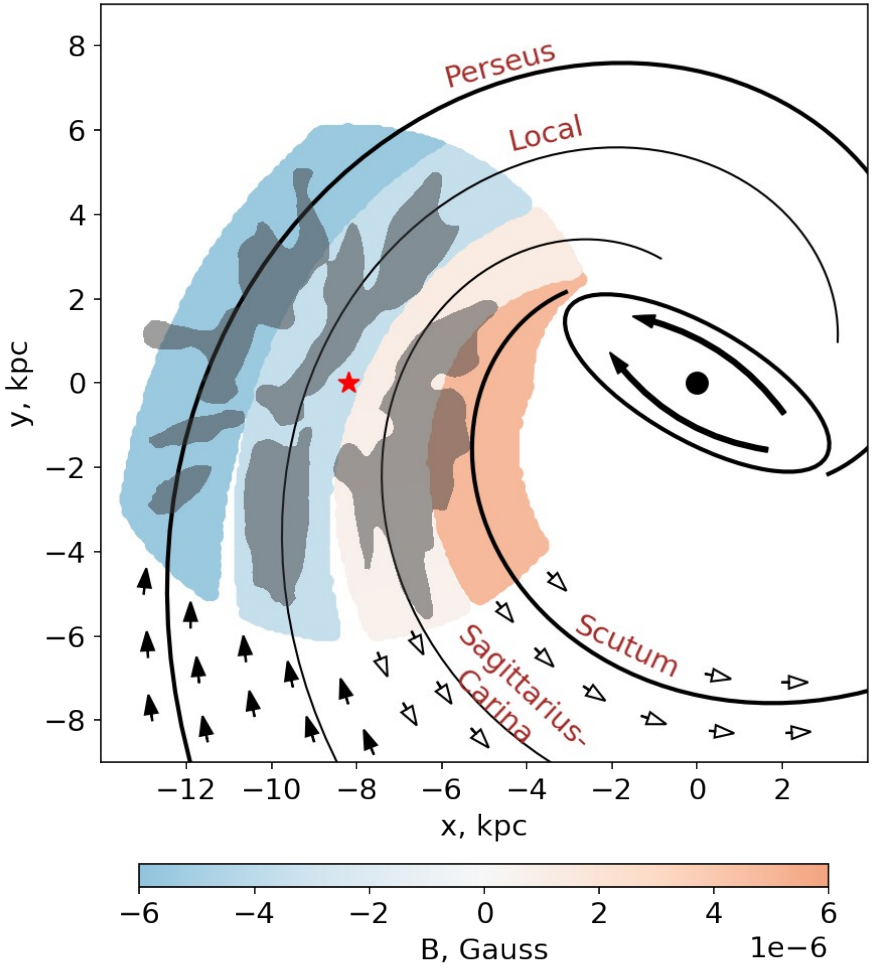
Why do we need a new GMF model?

- Previous models do not converge to the same values
- Different statistical approaches to the data
- Large masks on the data
- Do we need “striation” = order-random field
- Pitch angle of the disk field?

- Self-consistent modelling of GMF and cosmic rays

Our new model



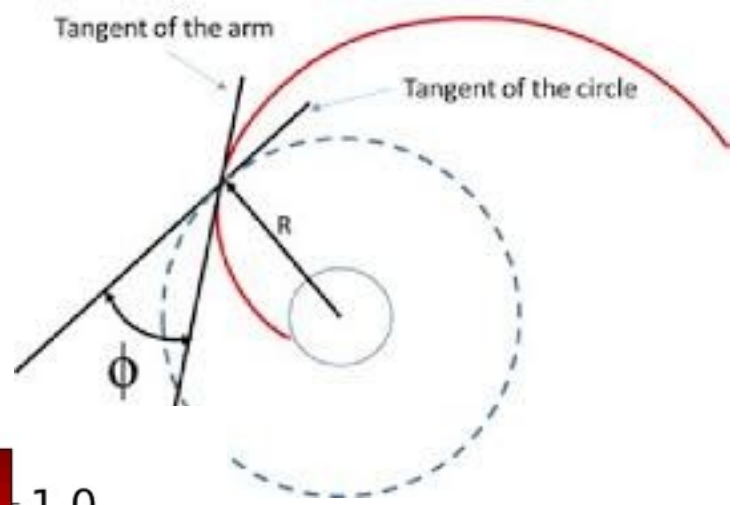


1. Disk field

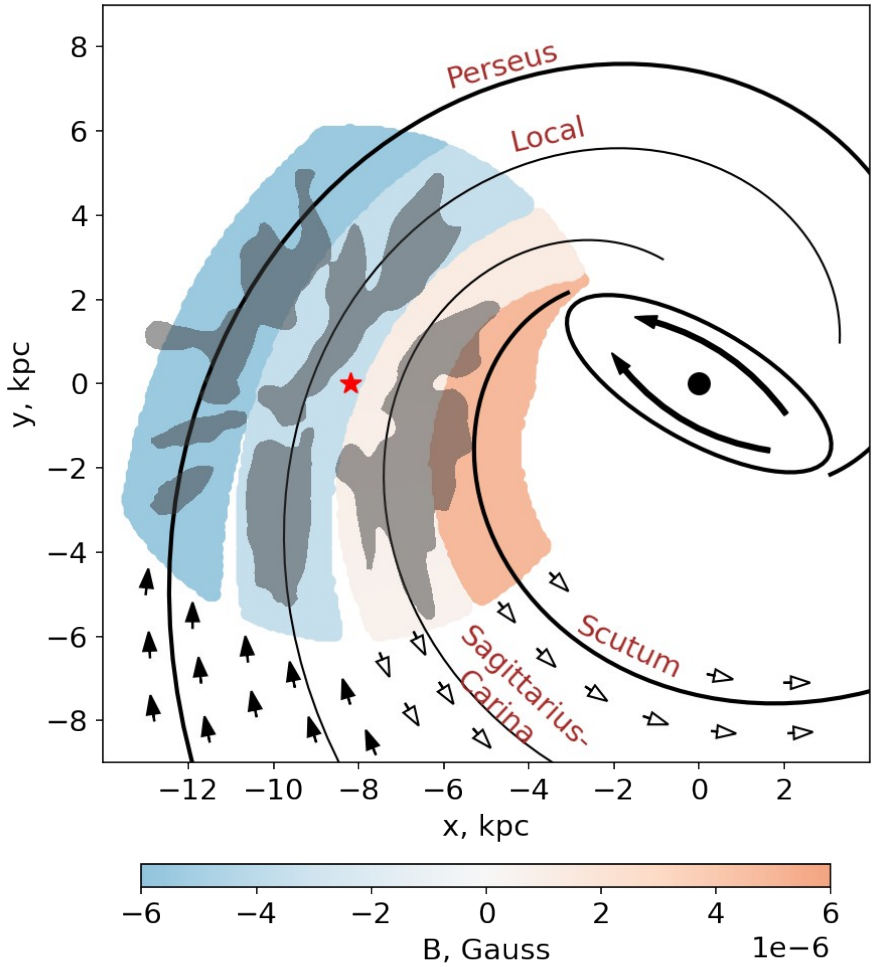
Pitch angle

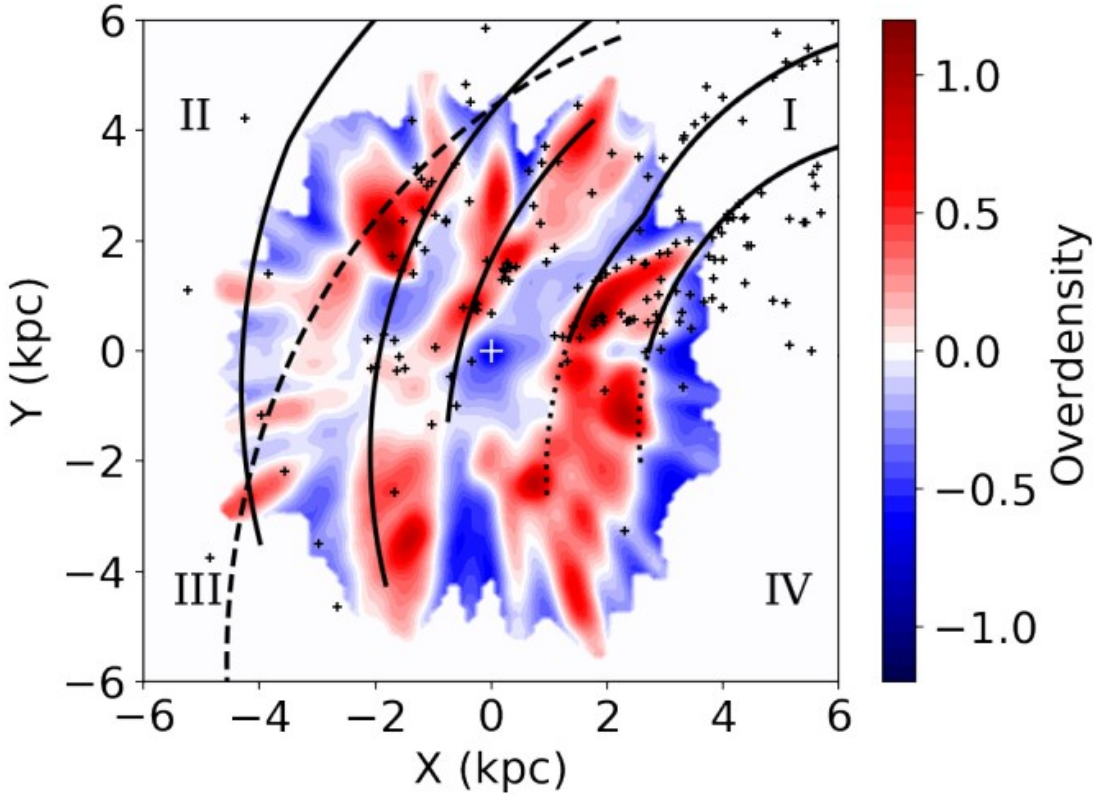
According to GAIA DR3 data the spiral arms are more inclined than previously thought

Our and Gaia pitch angle ~ 20 deg
In earlier studies pitch angle ~ 10 deg



Our model



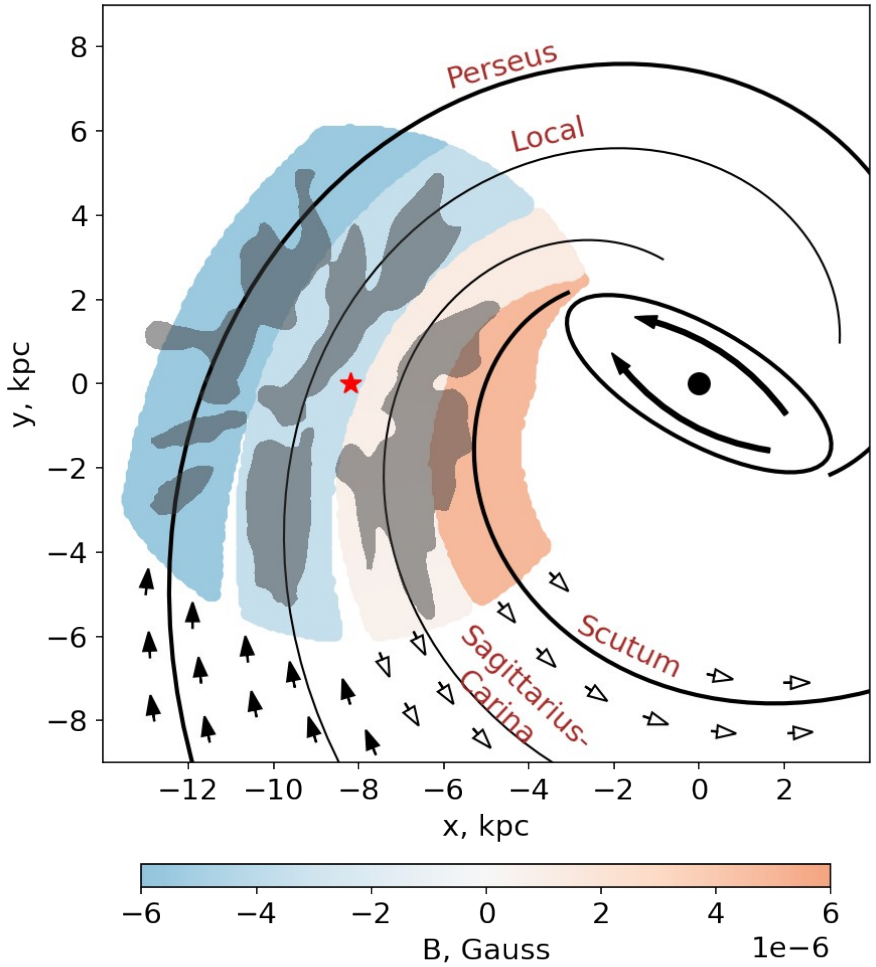


Gaia spiral arm segments, Poggio+21

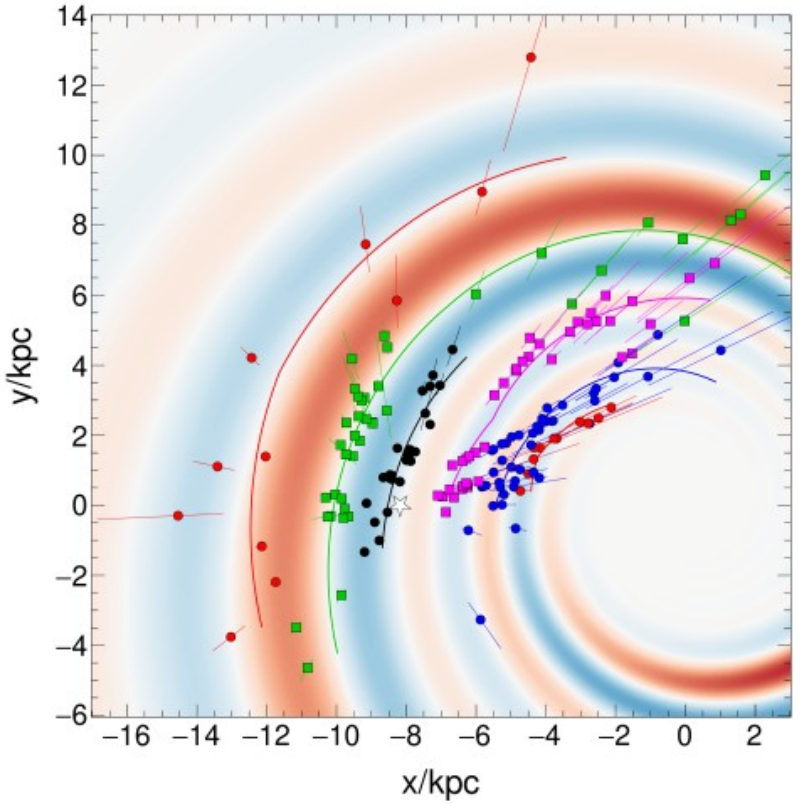
Field reversals?

Zero or one reversal – predicted by large-scale dynamo
Many reversals – compression of primordial field

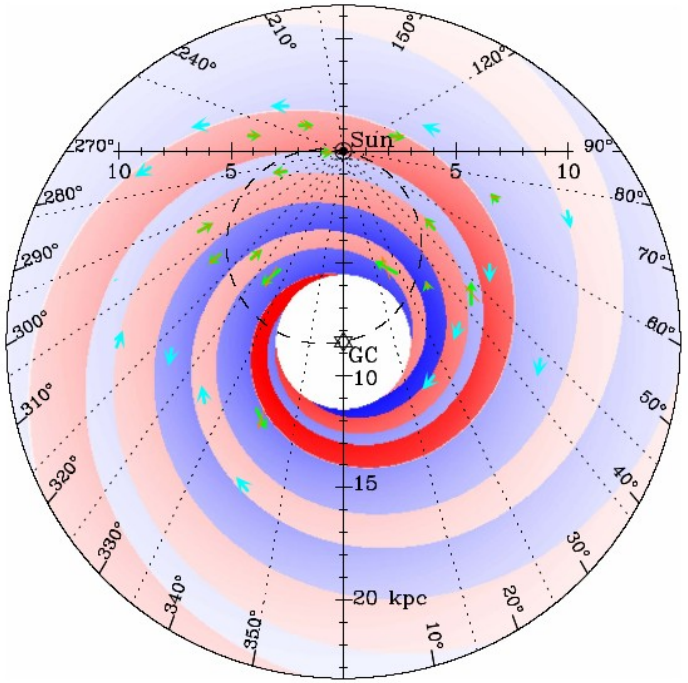
Our model



UF23 base

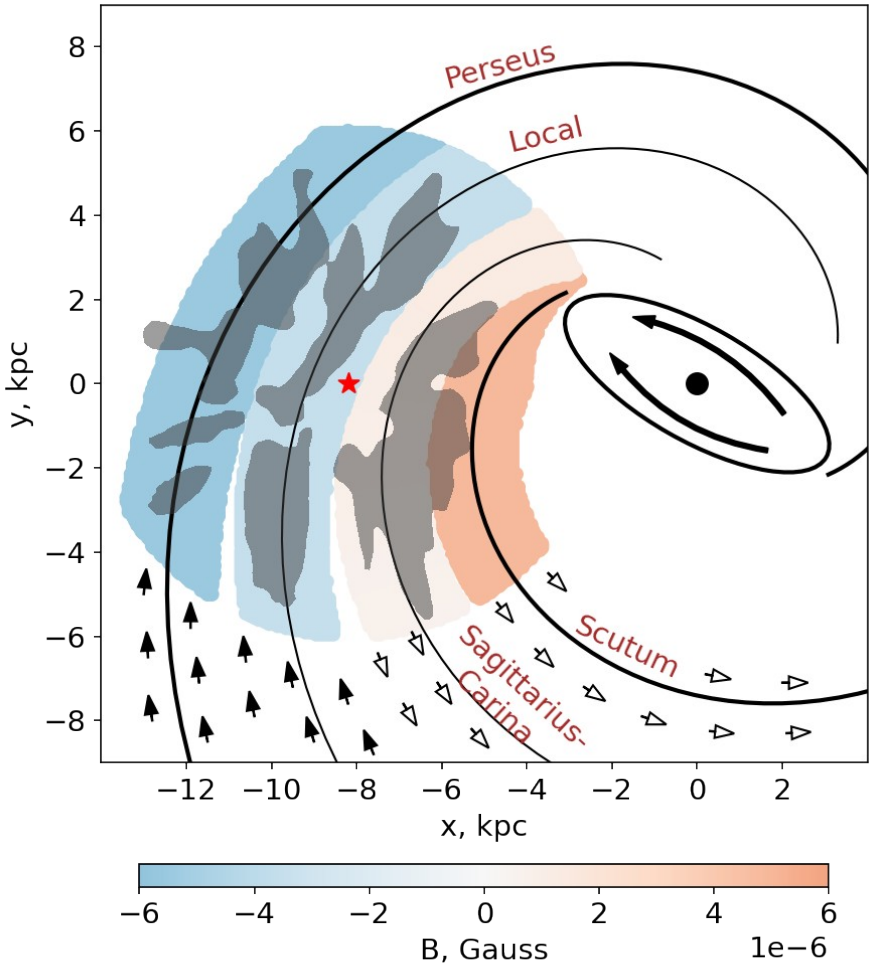


Han+18

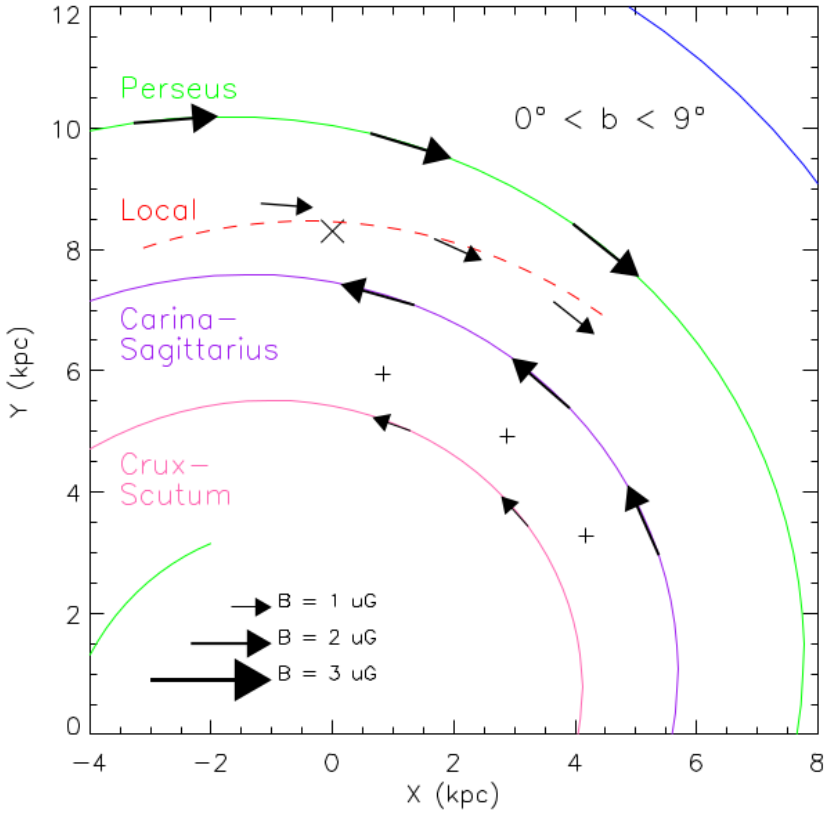


Field reversals?

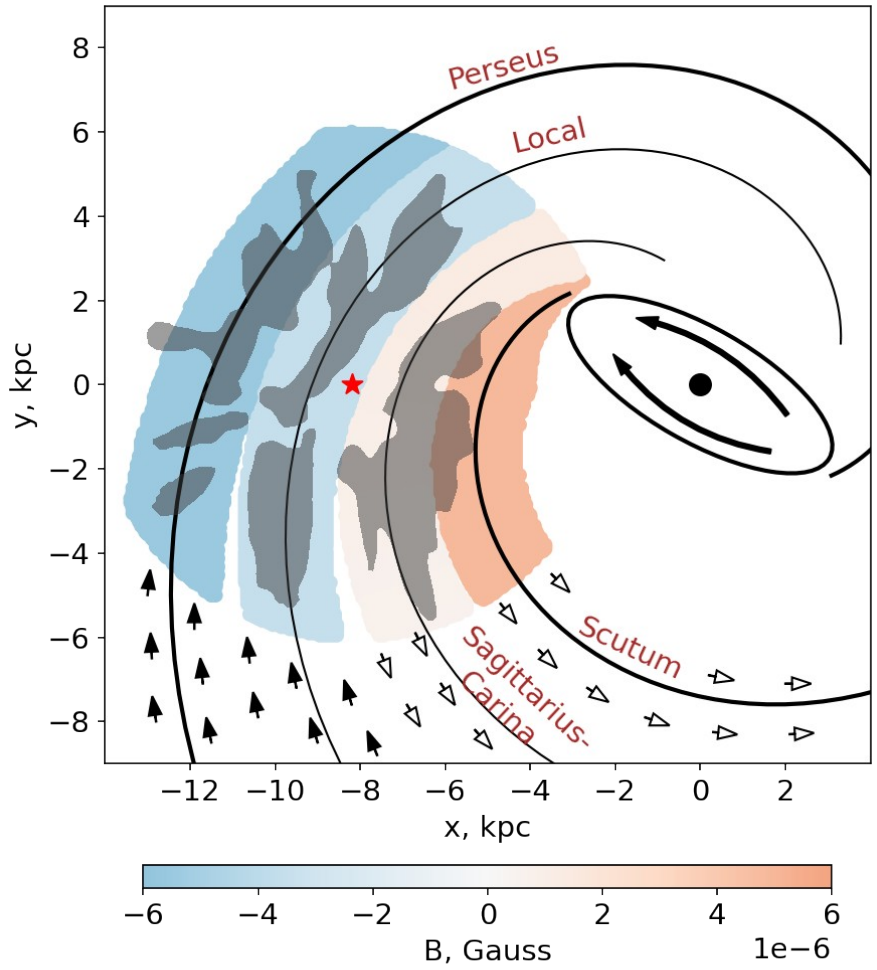
Our model

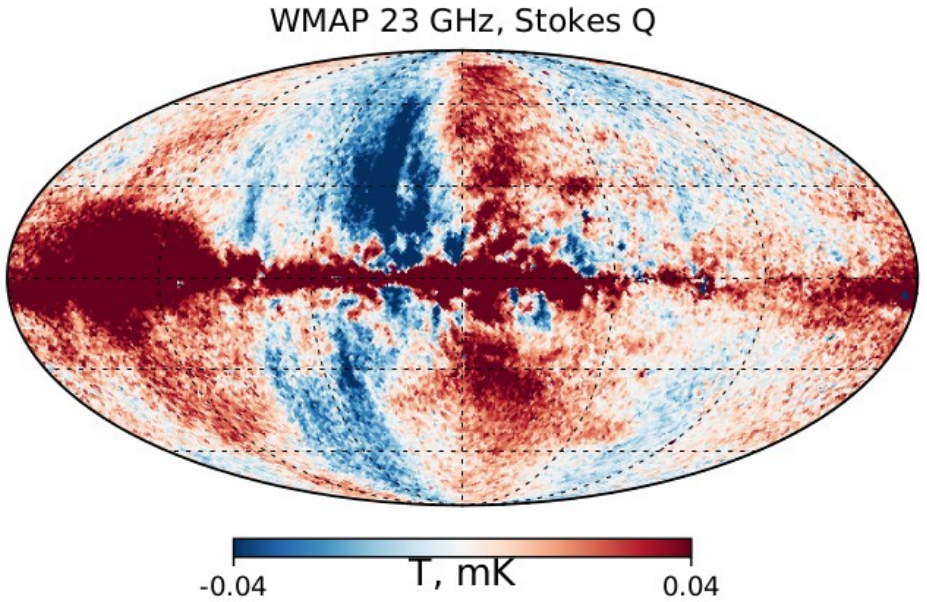


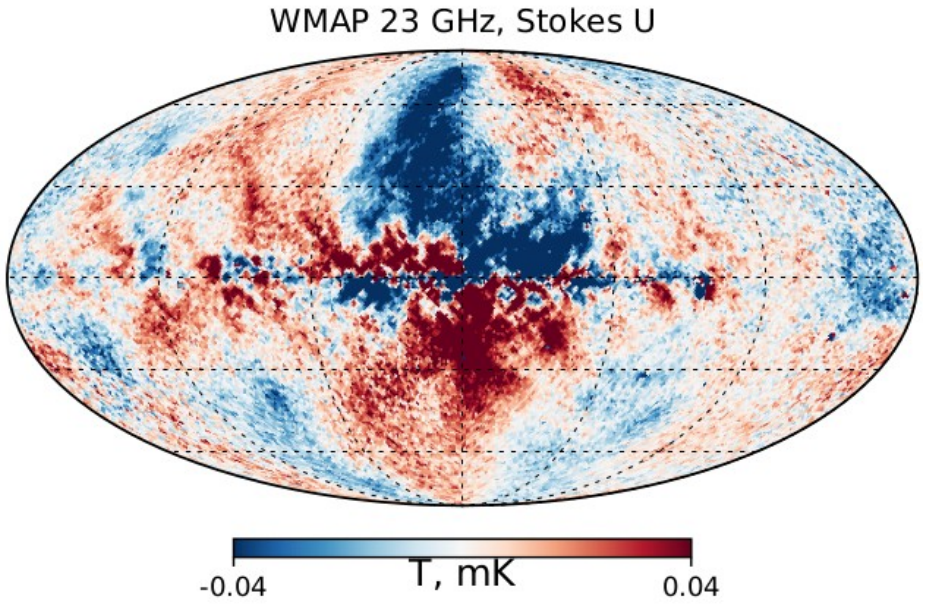
Galactic pulsars, arXiv2410.07967



Fan Region

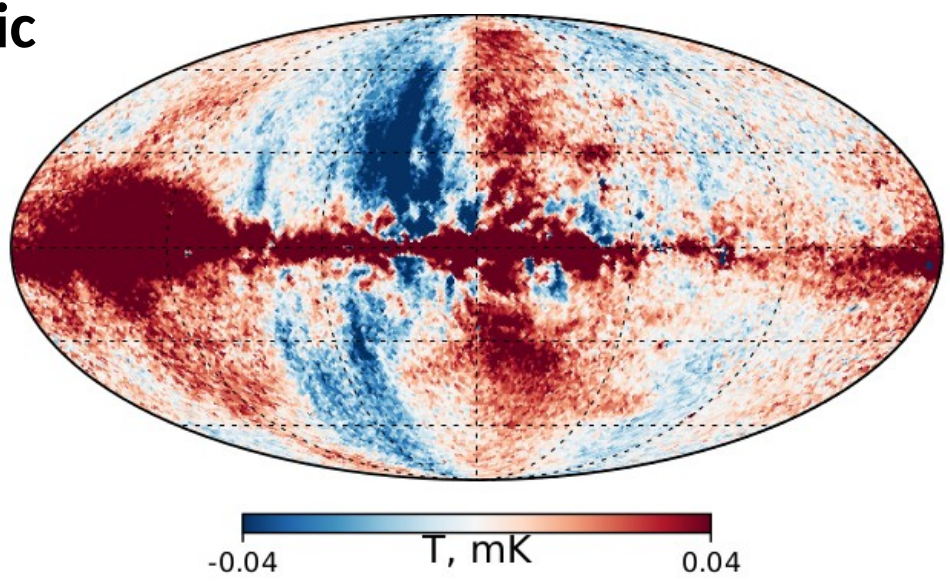

Perseus
Local
Scutum
Sagittarius-
Carina
y, kpc
x, kpc
B, Gauss
1e−6

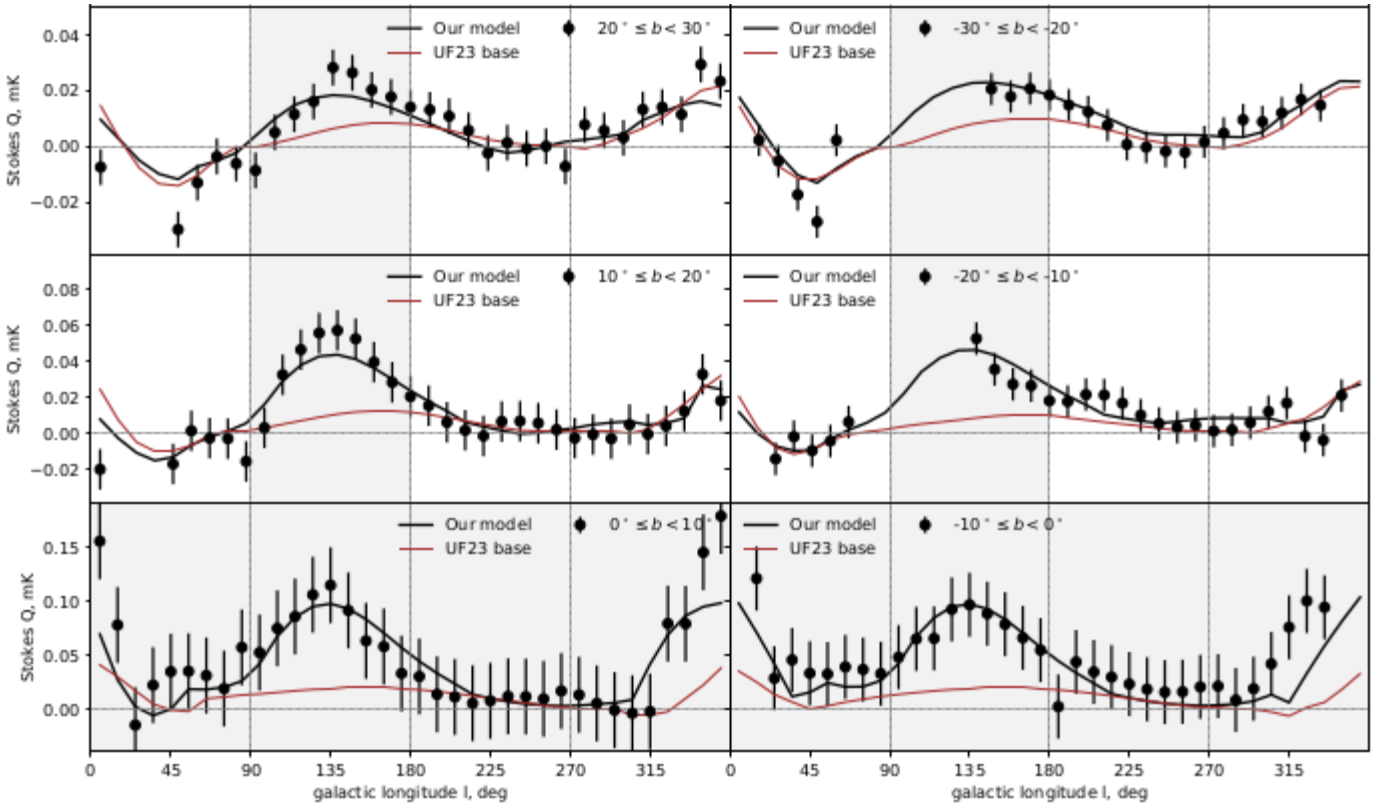

WMAP 23 GHz, Stokes Q
-0.04
T, mK
0.04

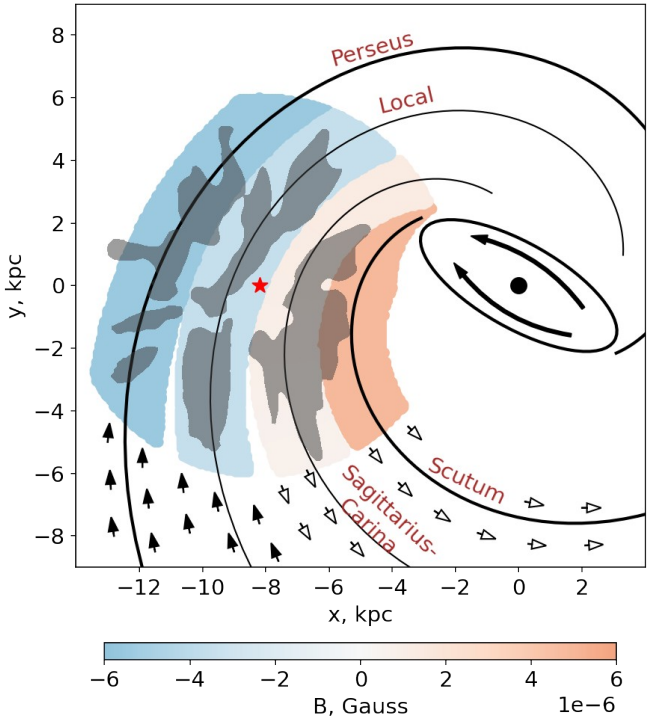

WMAP 23 GHz, Stokes U
-0.04
T, mK
0.04

Fan Region – bright red spot in Stokes Q near the Galactic plane at 90 < l < 180 deg

Hill+17: >30% of the Fan Region emission originates beyond 2 kpc from the Sun – part of the large-scale GMF

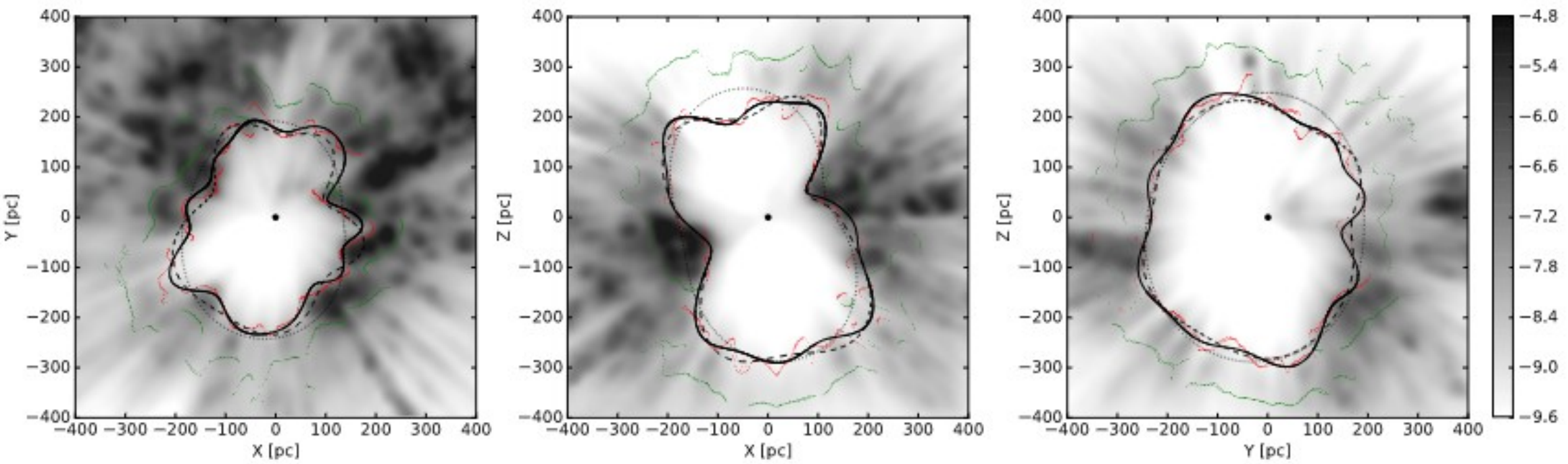






2. Local Bubble

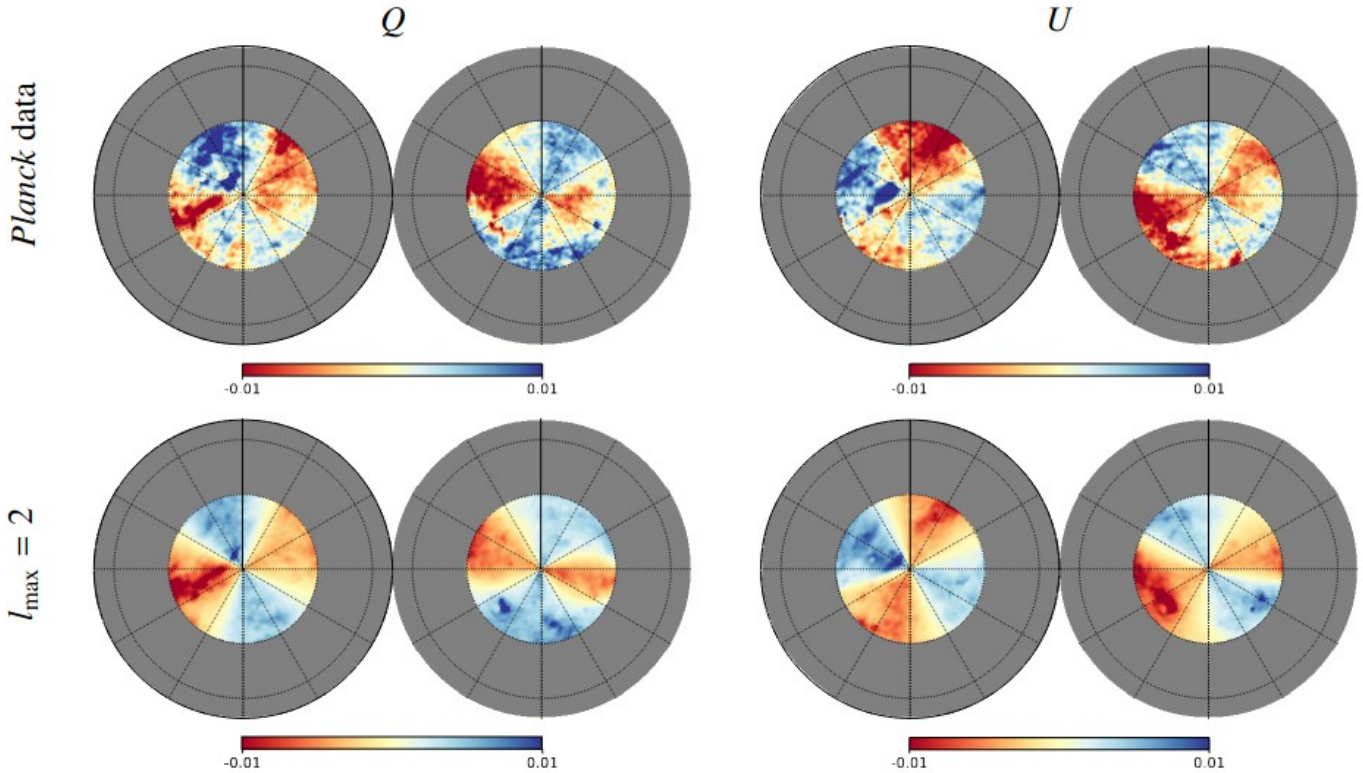
Local Bubble: shape of the wall

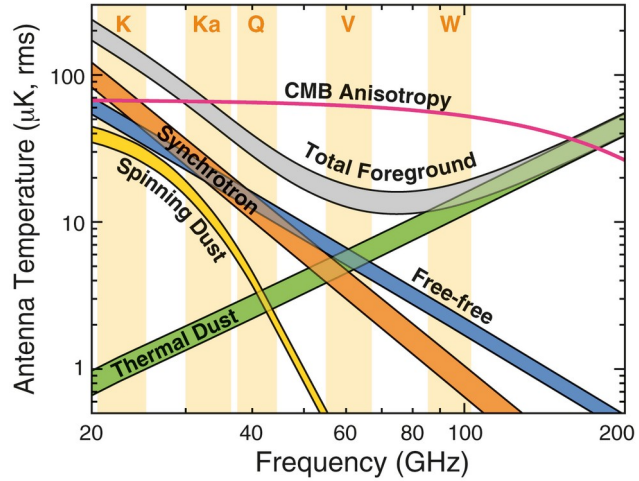


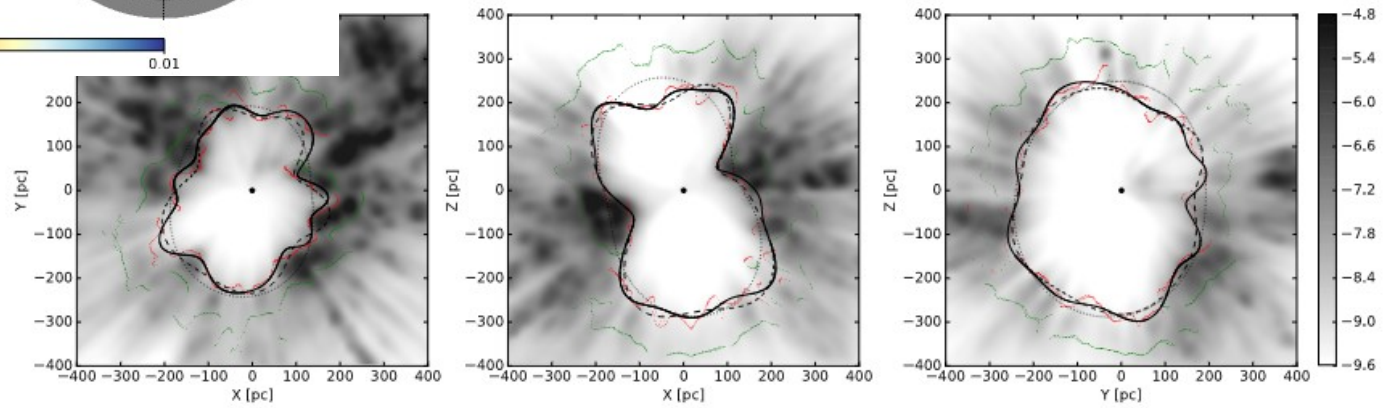
Z axis is perpendicular to the Galactic plane

Pelgrims+19

Local Bubble and Planck 353 GHz







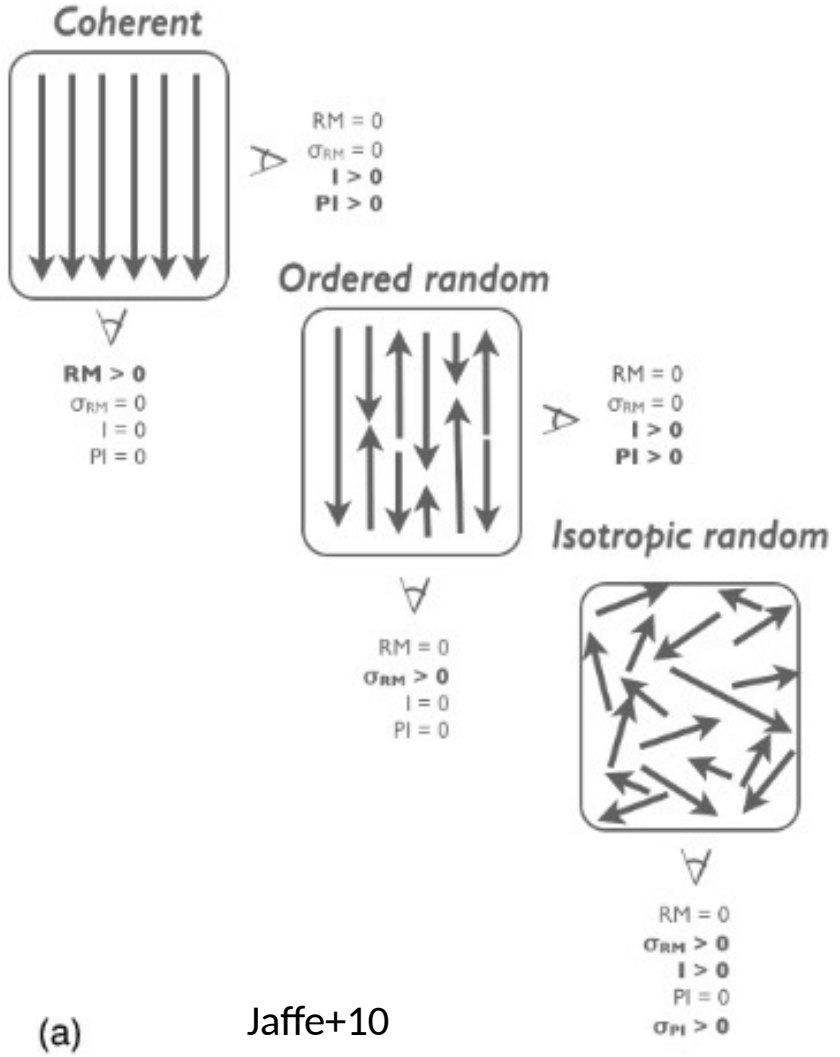
At the polar caps emission is dominated by the Local Bubble

Pelgrims+19

Where is the missing part of the synchrotron emission?

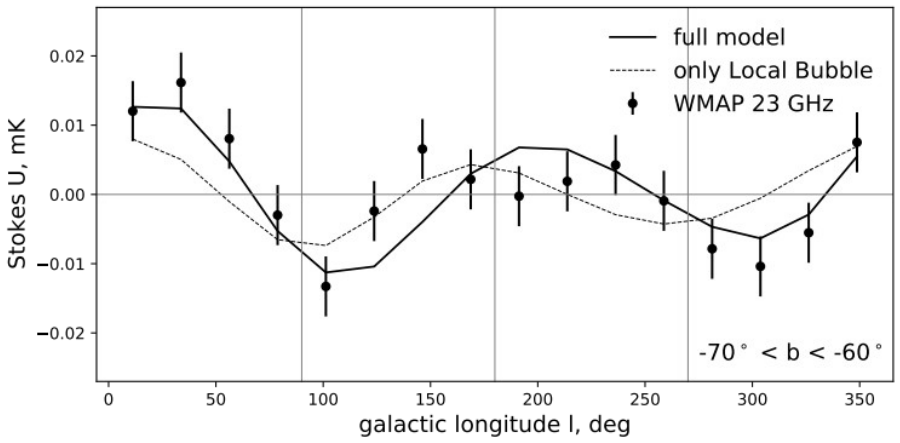
The GMF model, fitted only to RMs, does not produce sufficient synchrotron emission

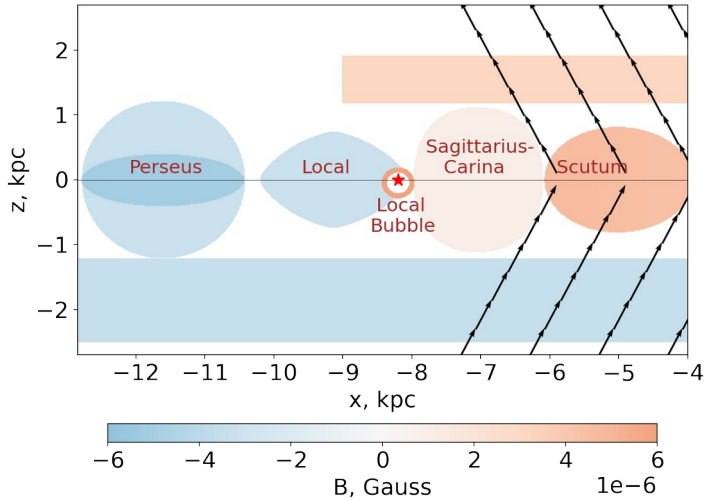
Invoking striated magnetic fields



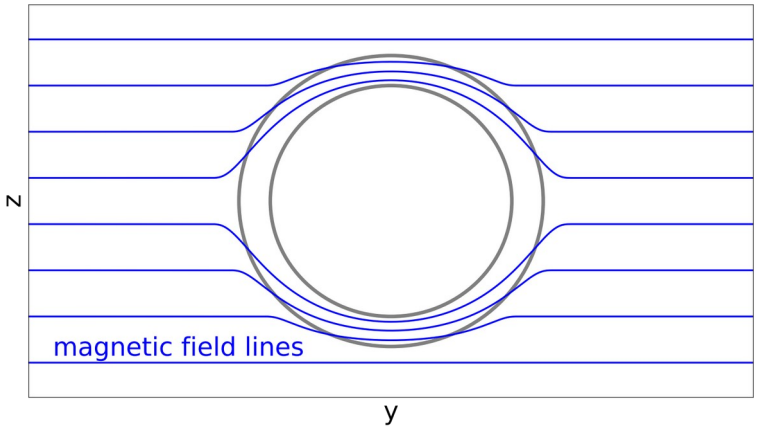
Jaffe+10

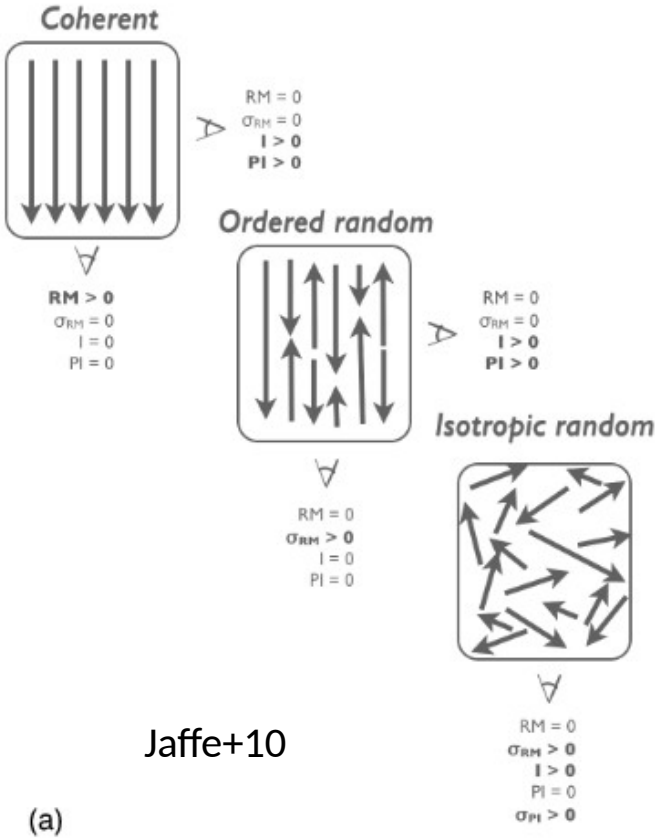
Local Bubble: missing part of the synchrotron emission?





PI(Local Bubble) ~ PI(Halo)

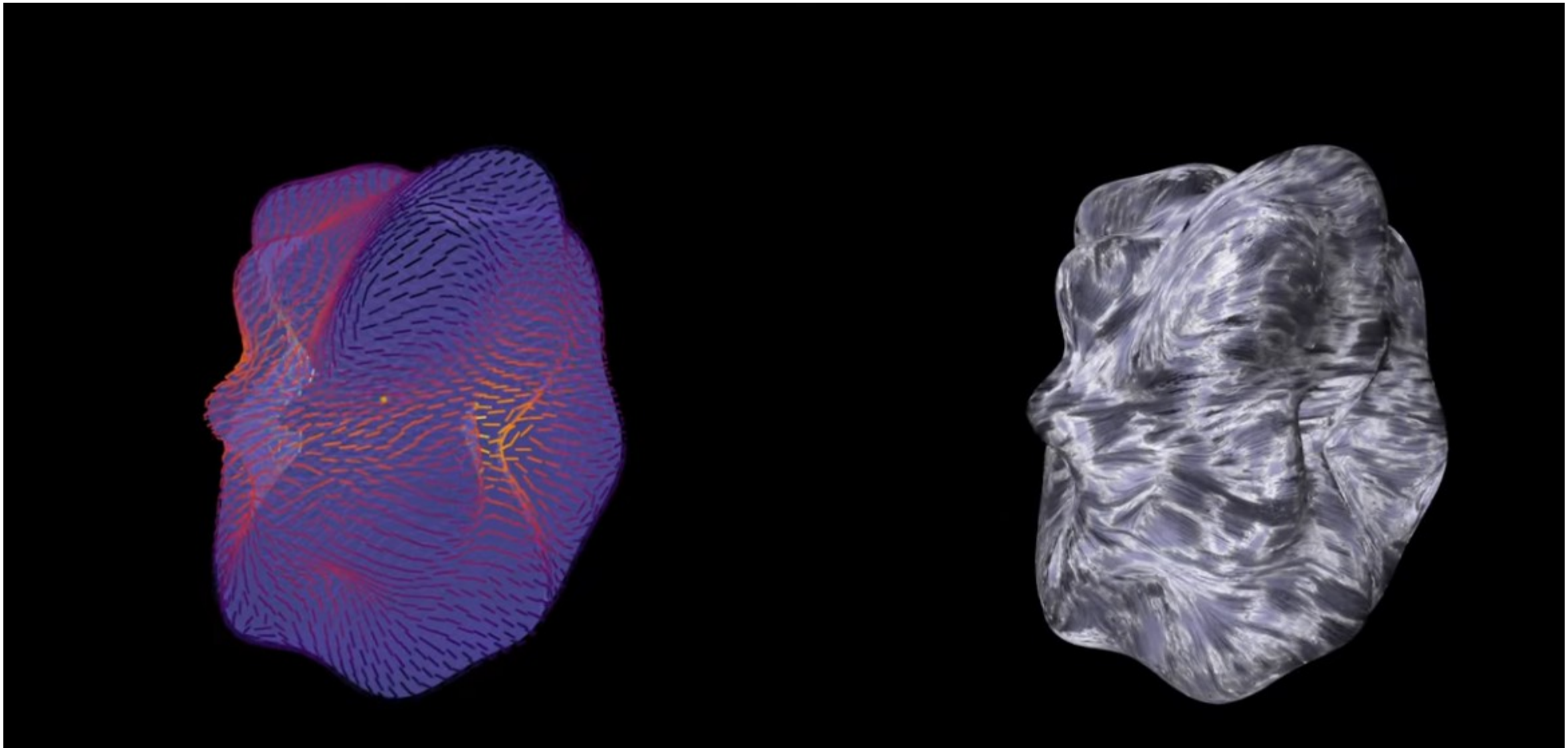




Jaffe+10

Taking into account the polarized synchrotron emission of the Local Bubble at 23 GHz, we found that striated fields (ordered random) are not needed. Local Bubble produces the missing part of the synchrotron brightness. Also it improves RM modeling and so prefered by the fit (compared to striated field which only improves synchrotron)

Local Bubble: magnetic field on the wall



O'Neill+20

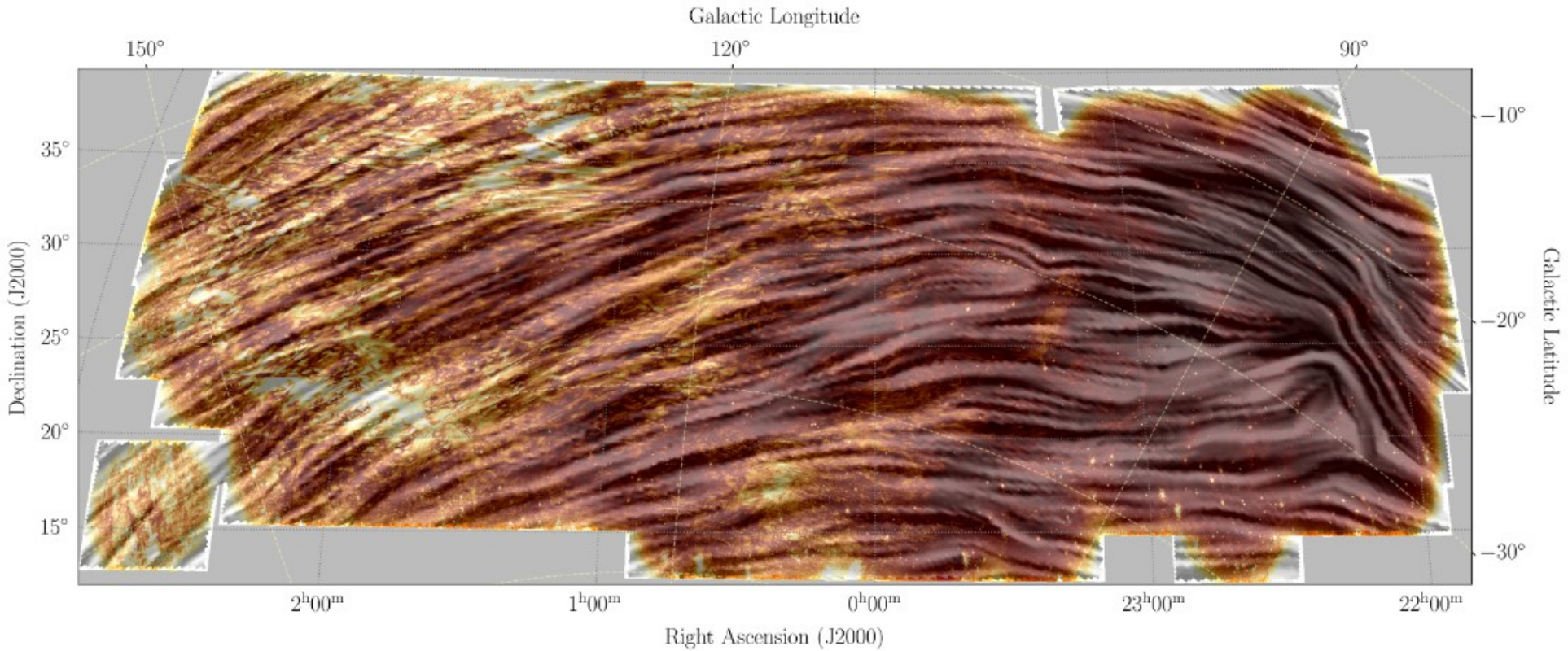


Fig. 10. Orientation of the *Planck* 353 GHz plane-of-sky magnetic field, represented by a drapery pattern overlaid on the image of maximum polarised intensity (orange).

Erceg+24

General trend: previously masked regions are parts of the large-scale GMF

Deviations from isotropic diffusion approximation:

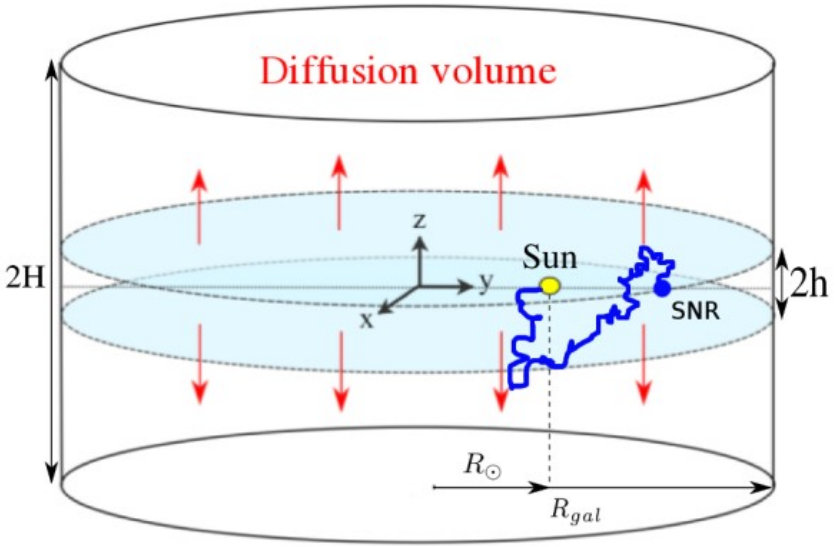
1) Loop I — Zhang 2024, Churazov 2024

2) Fan Region

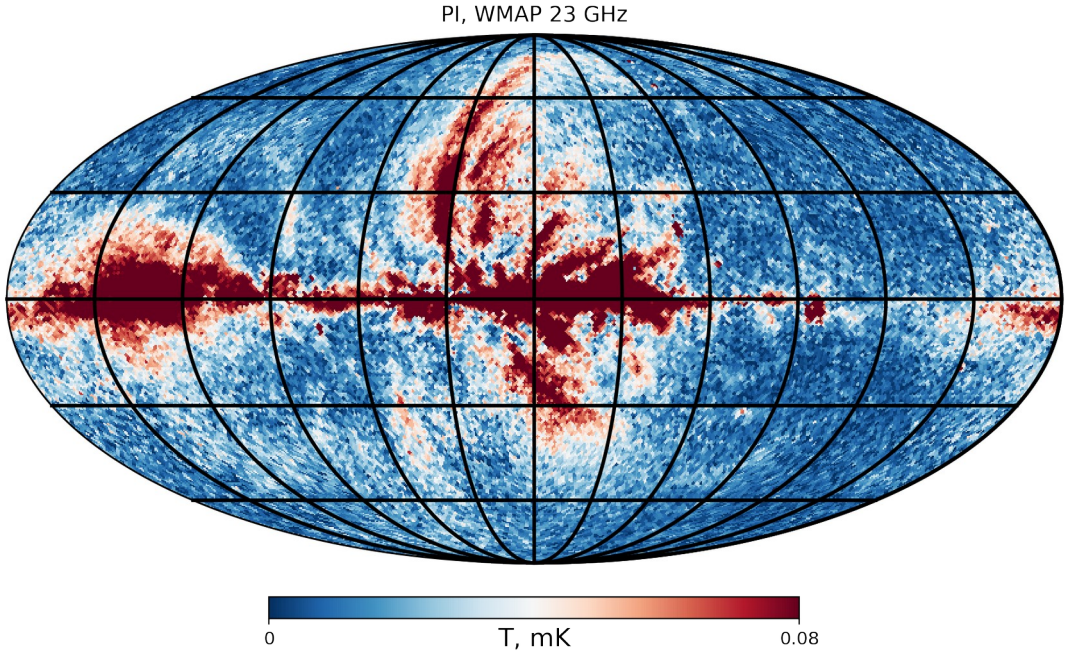
3) Local Bubble

Need to refine the CR propagation model

MHD modeling can help



Y. Genolini et al. A&A 580 (2015) A9



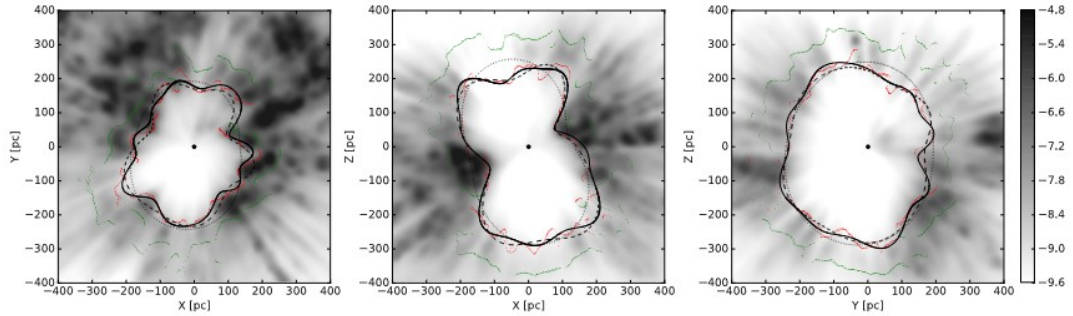
There is evidence that the Loop I is a giant outflow from the star-forming region in the central Galaxy

Future prospects: Local cartography

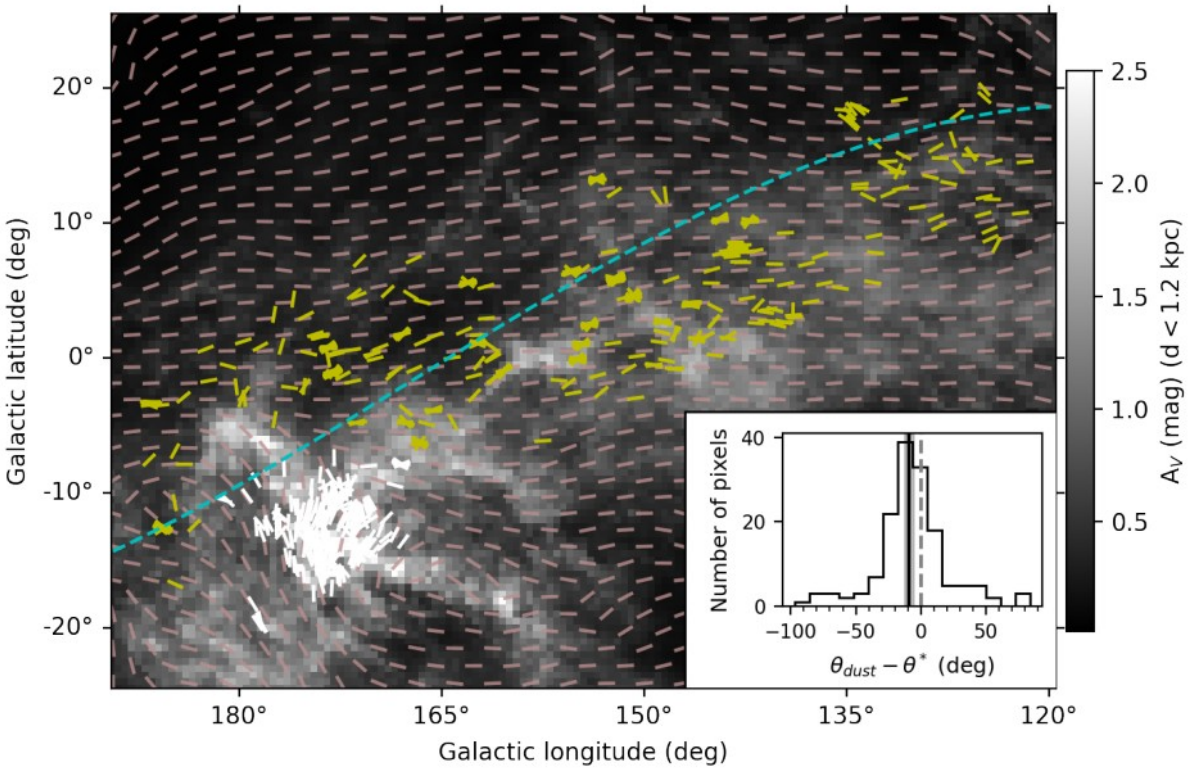
Use dust observations to map the direction of the magnetic field in local ~1 kpc

Include this information into the large-scale GMF models

Local Bubble

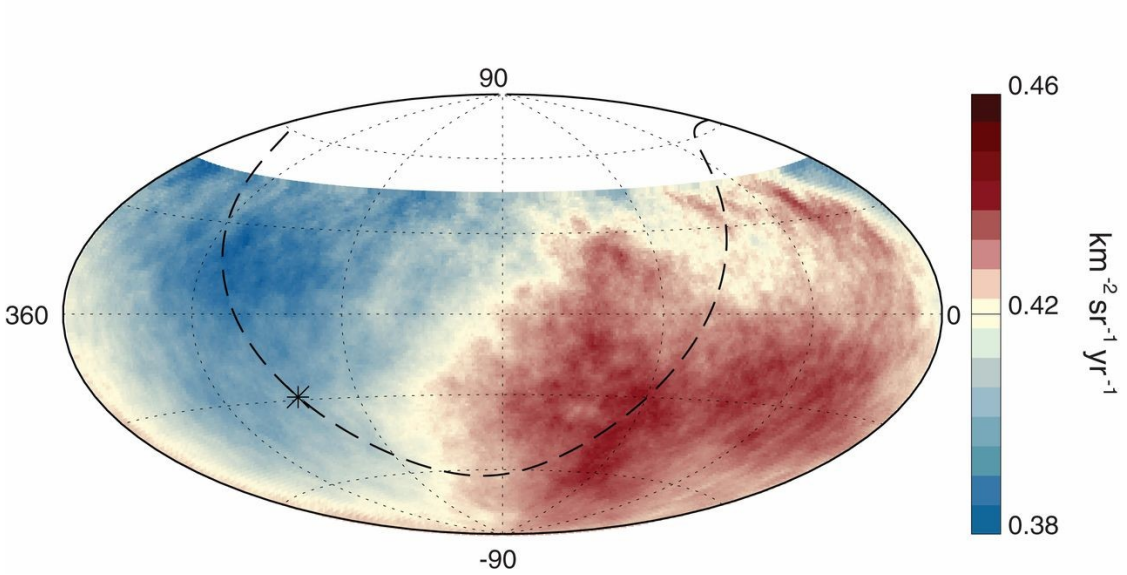


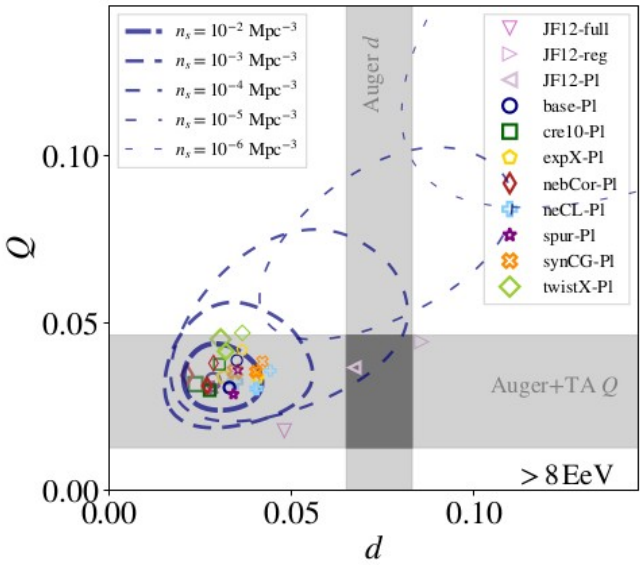
Example: Radcliffe Wave

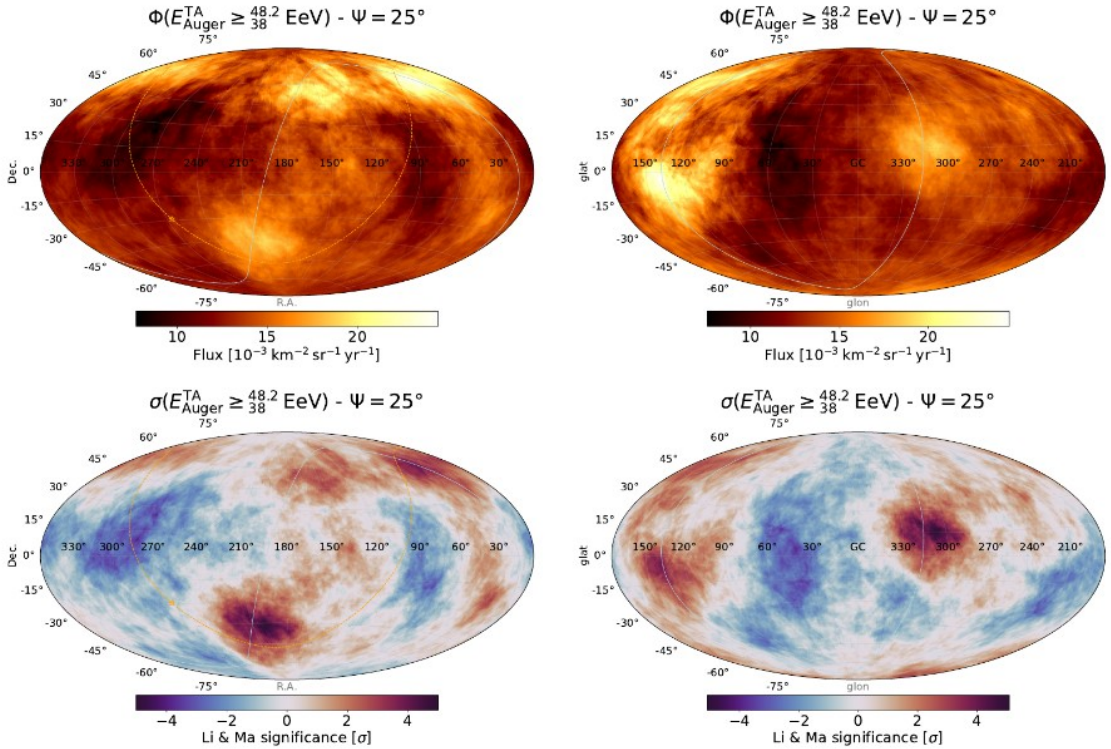


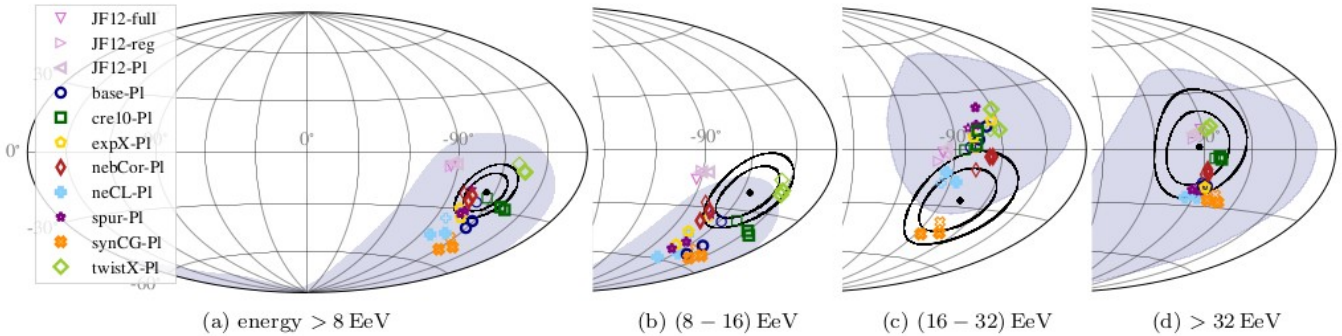
Panopoulou+24

UHECR anisotropies



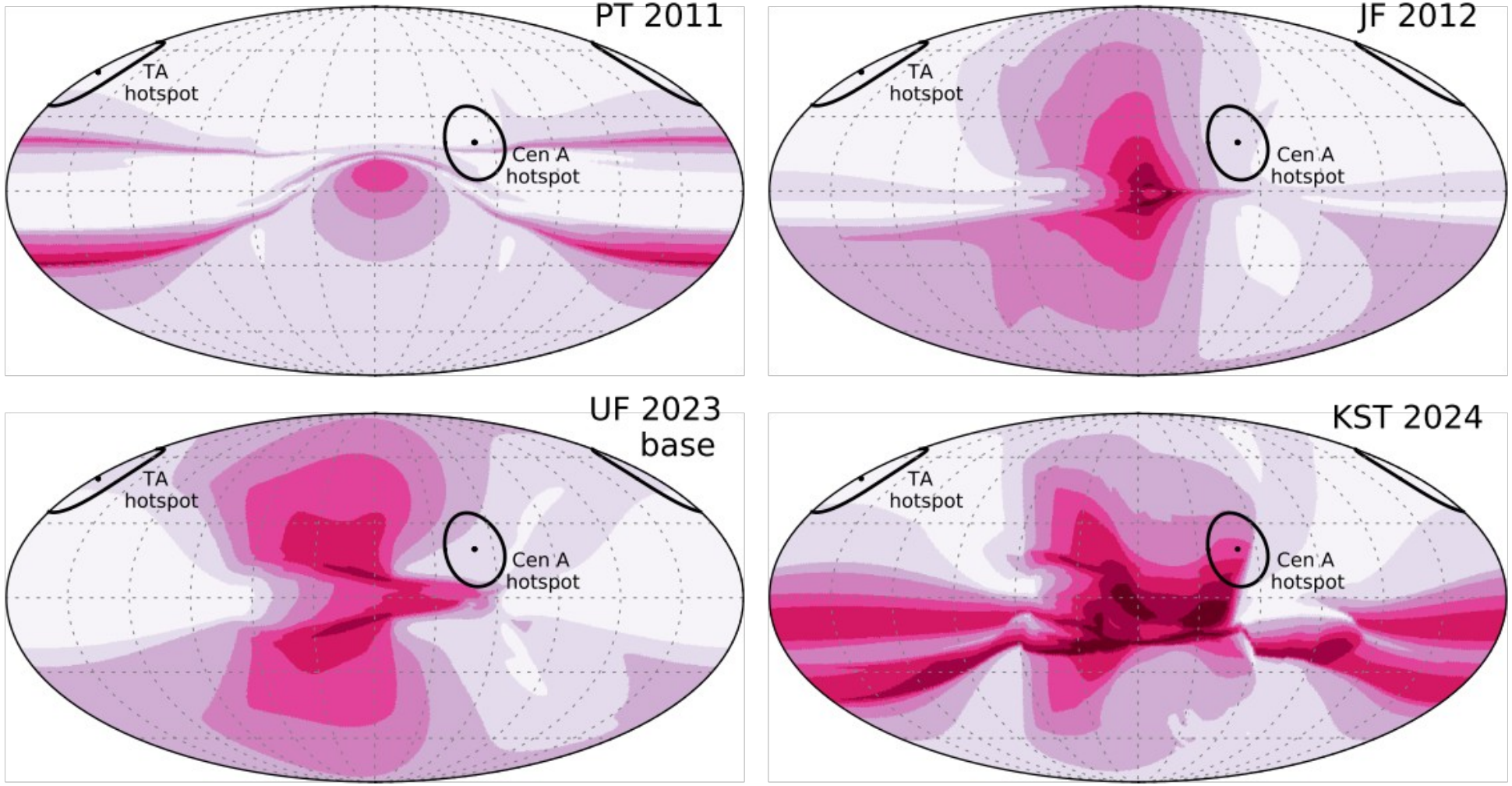






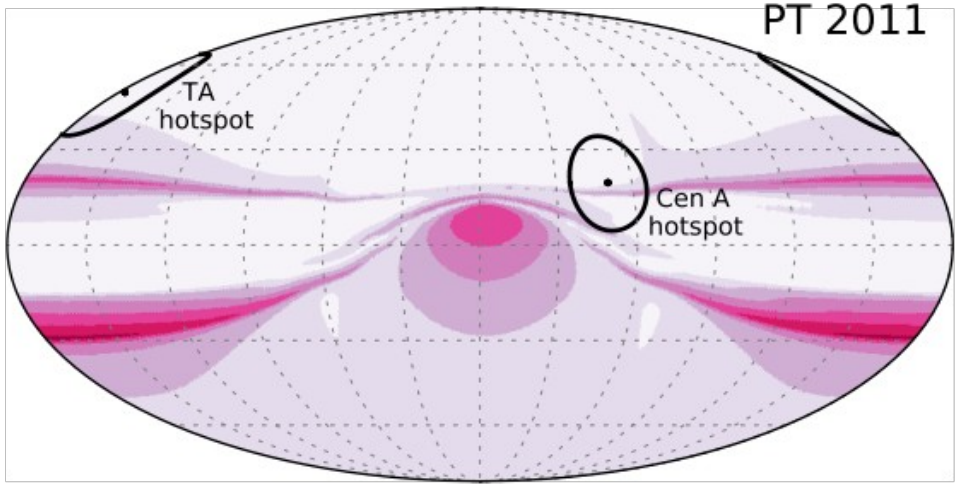
Bister, Farrar, Unger 2024

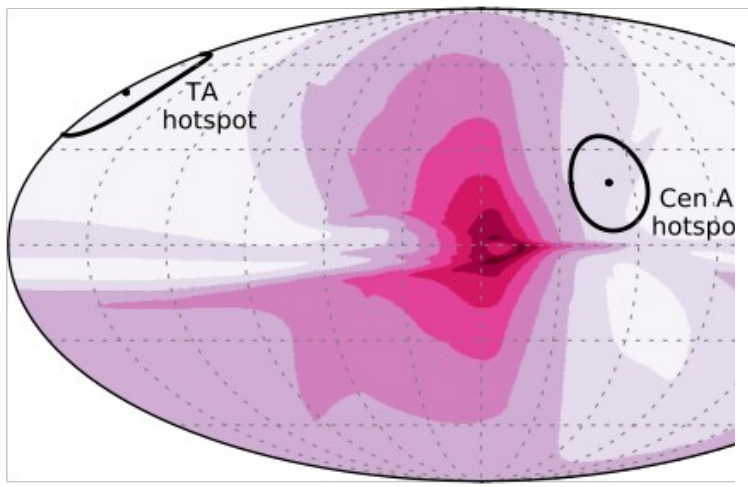
UHECR Deflections at 20 EV: model comparison

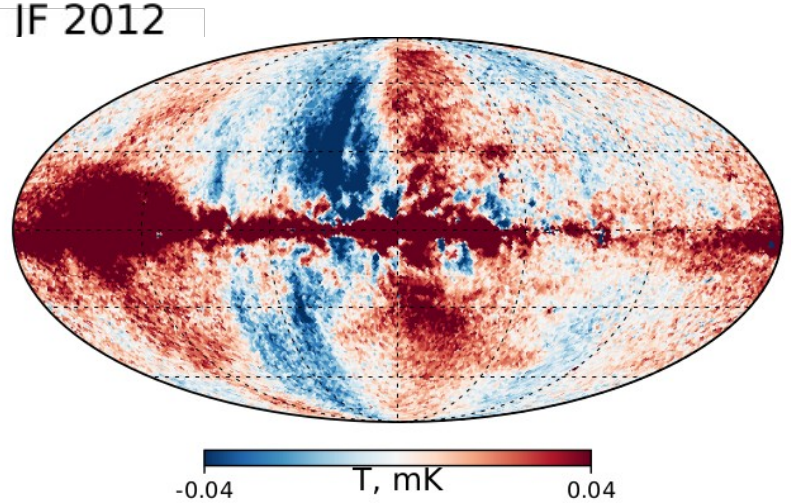


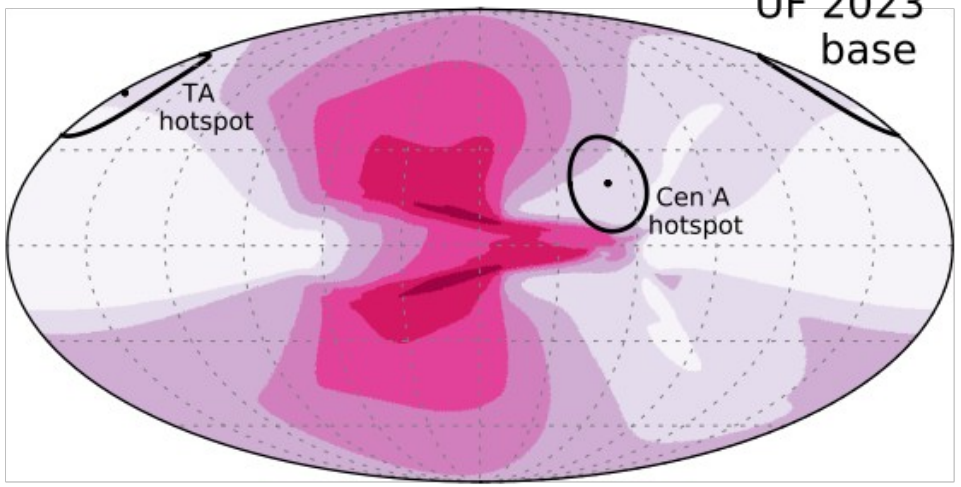
R = 20 EV

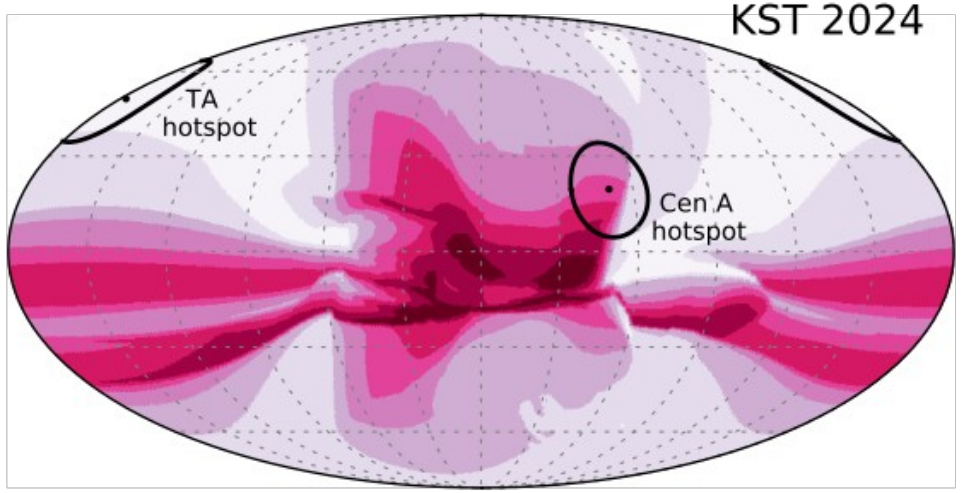
UHECR Deflections at 20 EV: model comparison

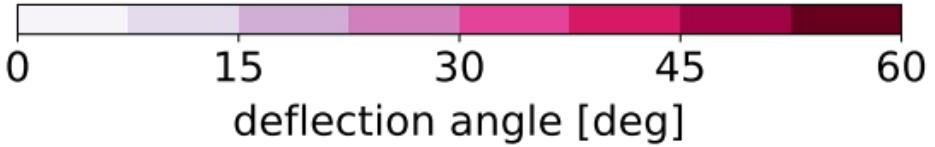






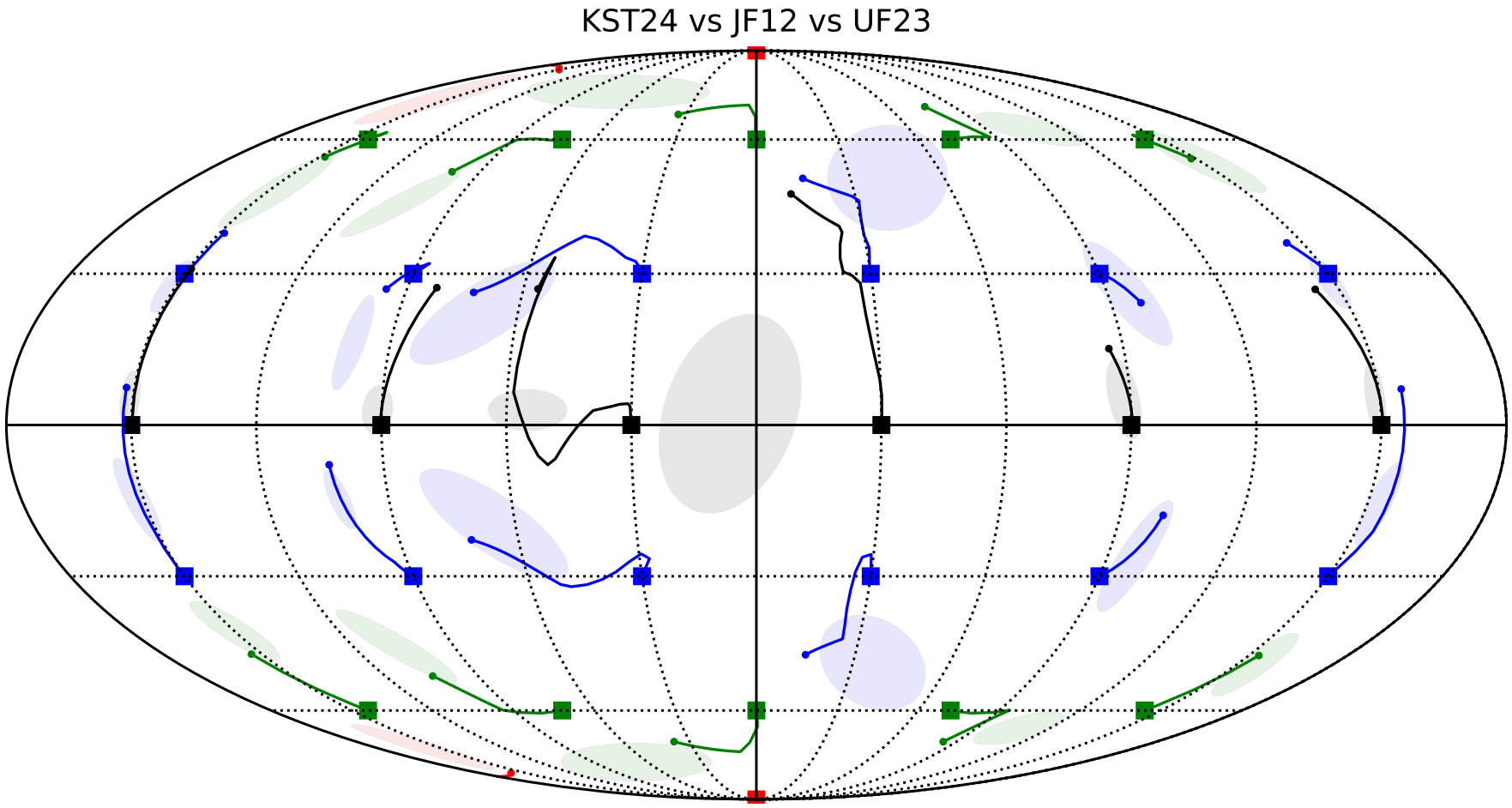


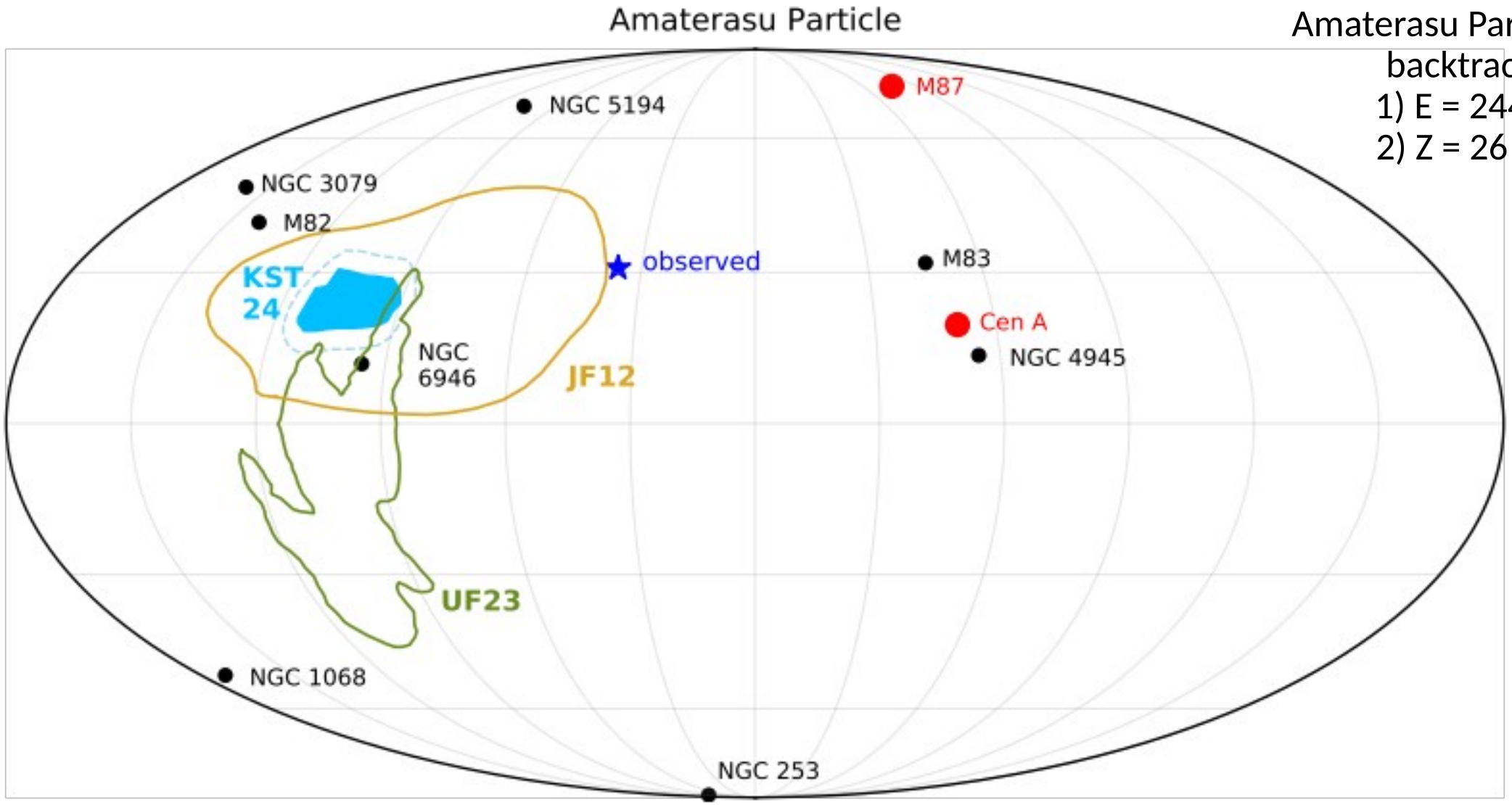




R = 20 EV

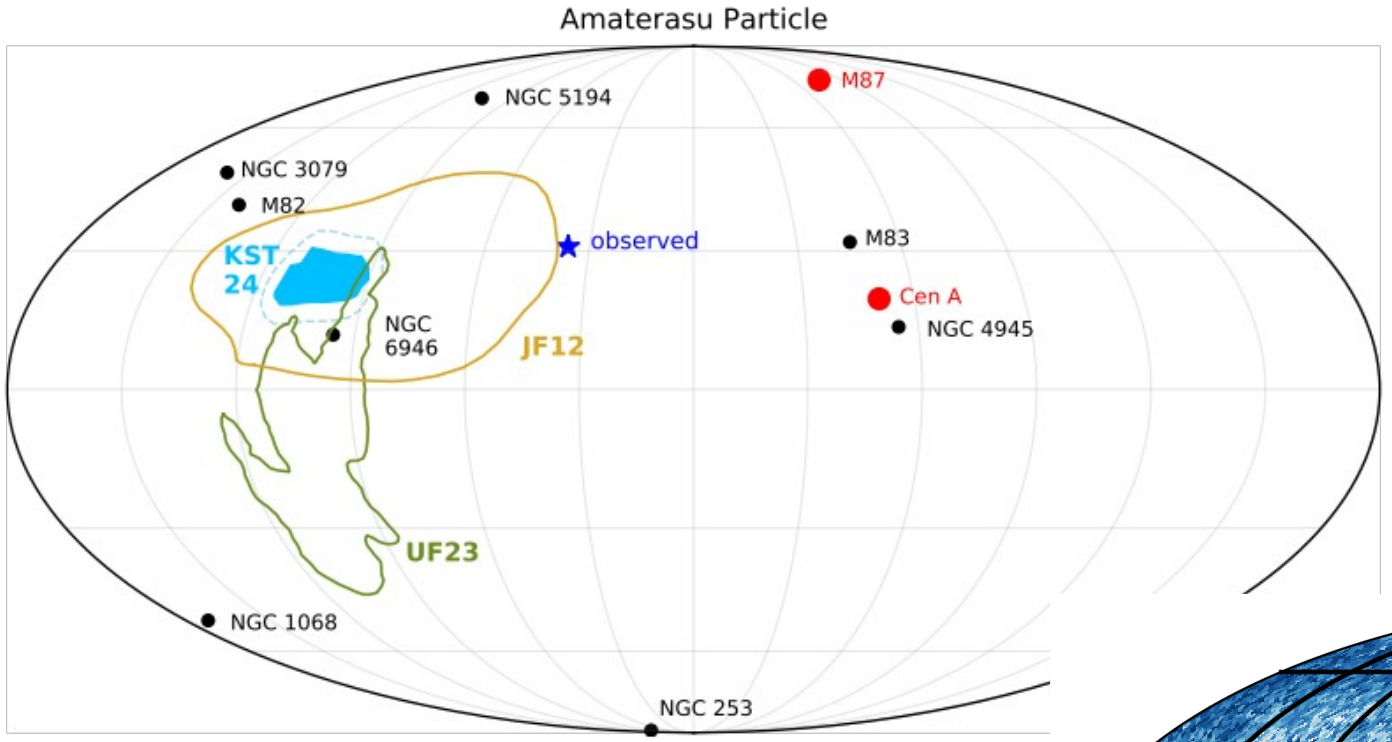
UHECR Deflections at 20 EV: uncertainties





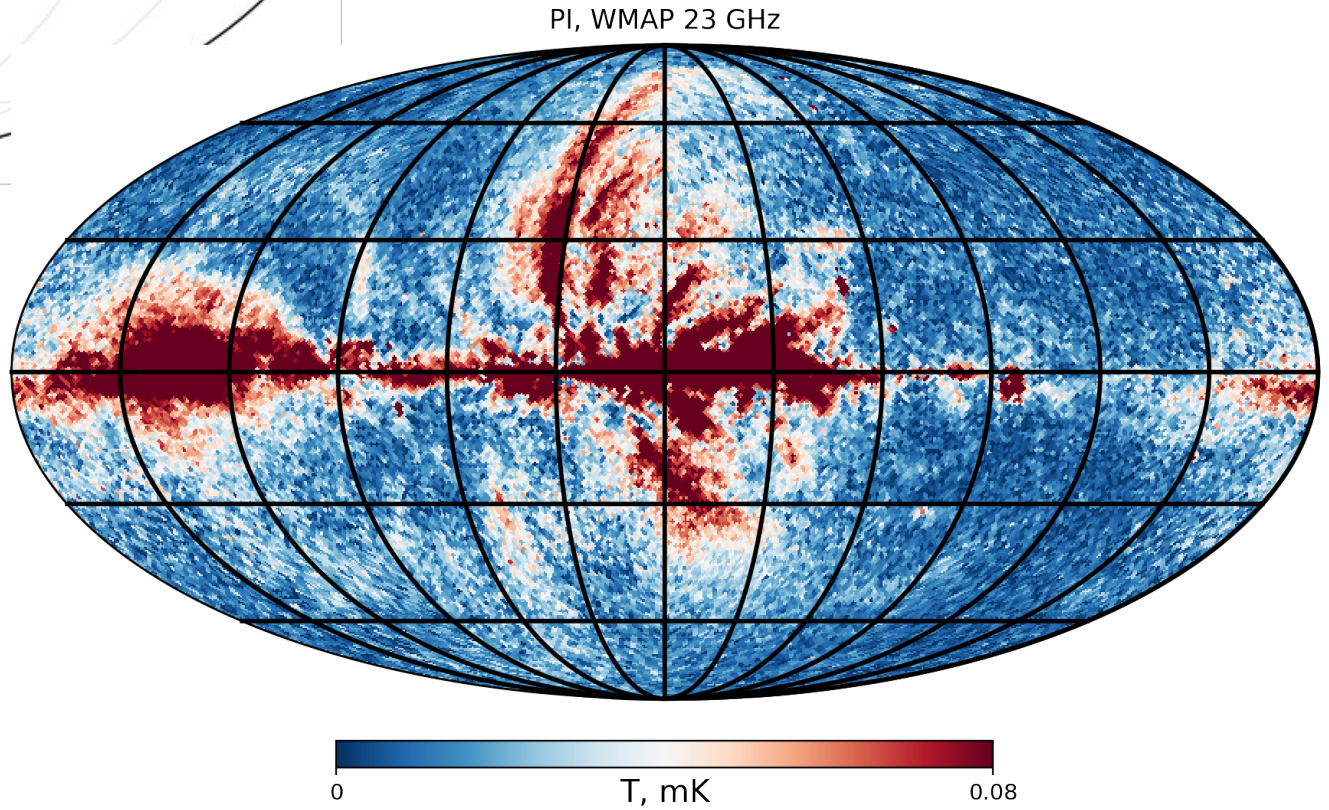
Amaterasu Particle KST24 backtracking:
1) E = 244 EeV
2) Z = 26 (iron)

Kuznetsov 2023,
Unger&Farrar 2023,
Bourriche&Capel 2024



Loop I – Galactic scale outflow?

It was masked in all existing GMF models, including ours



Zhang 2024
Churazov 2024

Conclusions

- We developed new statistical procedure that allow us to treat all datasets on the same footing
- We pitch angle of the disk field was found to be 20 deg in agreement with Gaia data
- The Fan Region is naturally incorporated into the large-scale structure of the GMF
- Local Bubble is taken into account – no striated fields needed
- There are regions in the sky there JF12, UF23 and KST24 predict similar small deflections - ‘windows’

Thank you for your attention!