# New model of the coherent magnetic halo of the Milky Way and UHECR deflections

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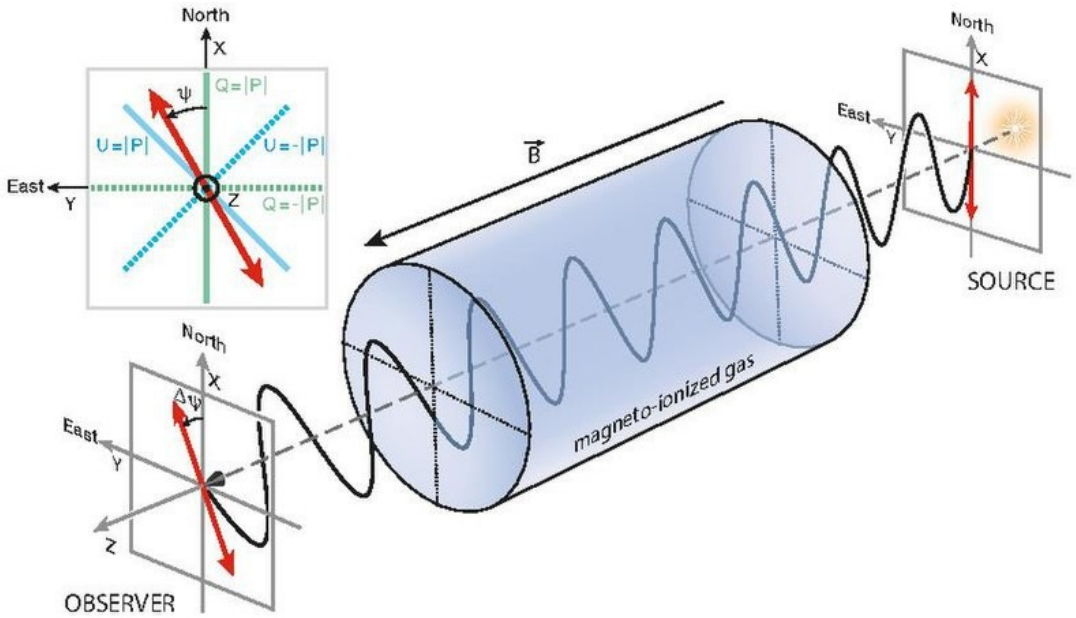
*in collaboration with Dmitri Semikoz and Peter Tinyakov, arXiv:2407.02148*

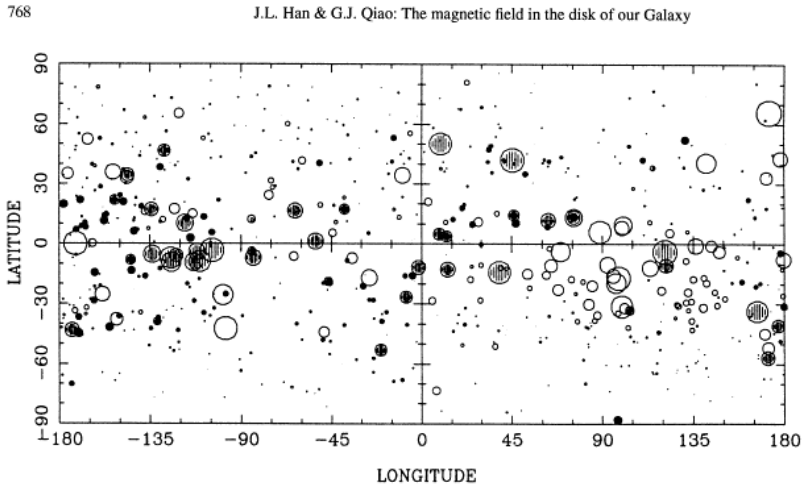
# Why do we need new model of the coherent GMF?

- Previous models do not converge to the same values
- Different statistical approaches to the data
- Large portions of the sky masked out
- Do we need “striation” = order-random field?
- Pitch angle of the disk field?
- Self-consistent modelling of GMF and cosmic rays
- UHECR deflections

# **Data:** extragalactic Faraday rotation measures (RM)

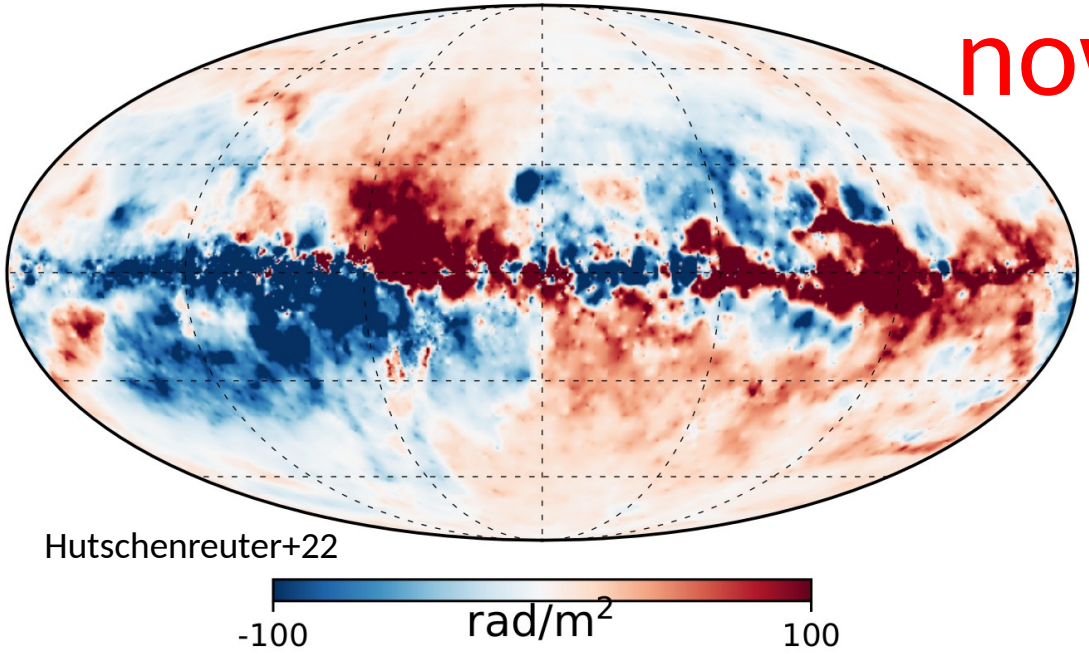



1994




extragalactic RM

now

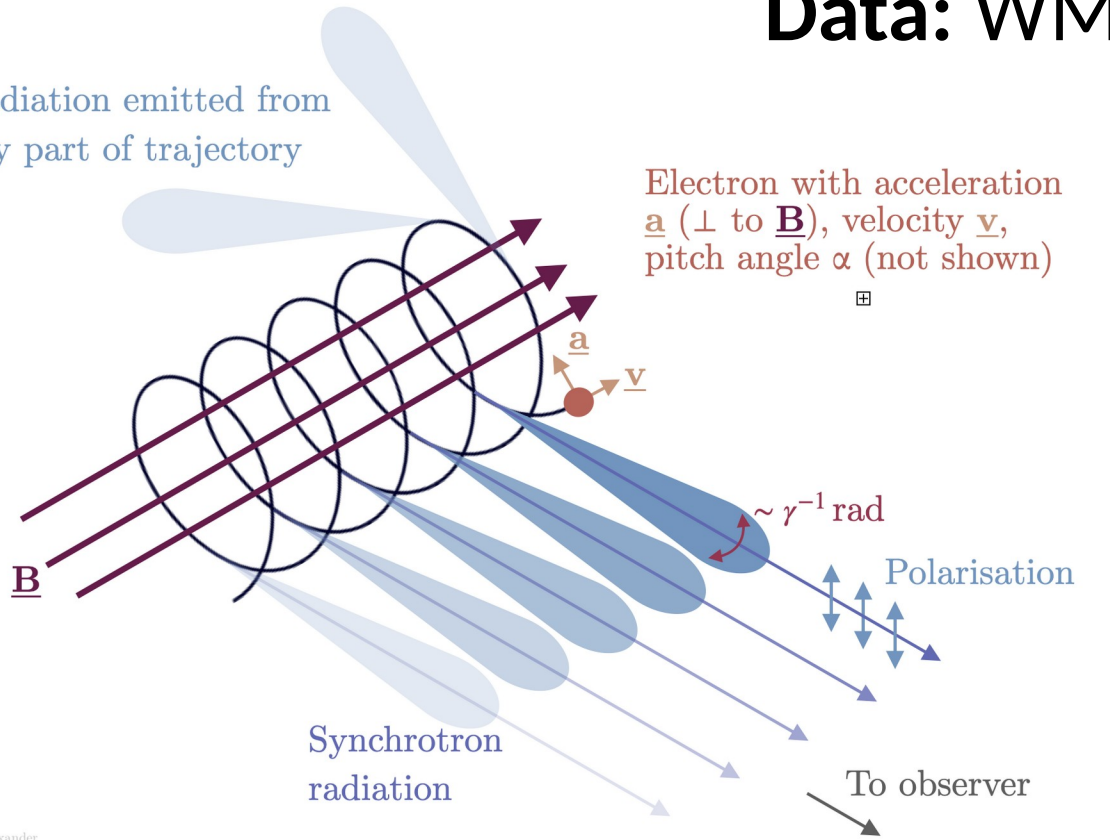


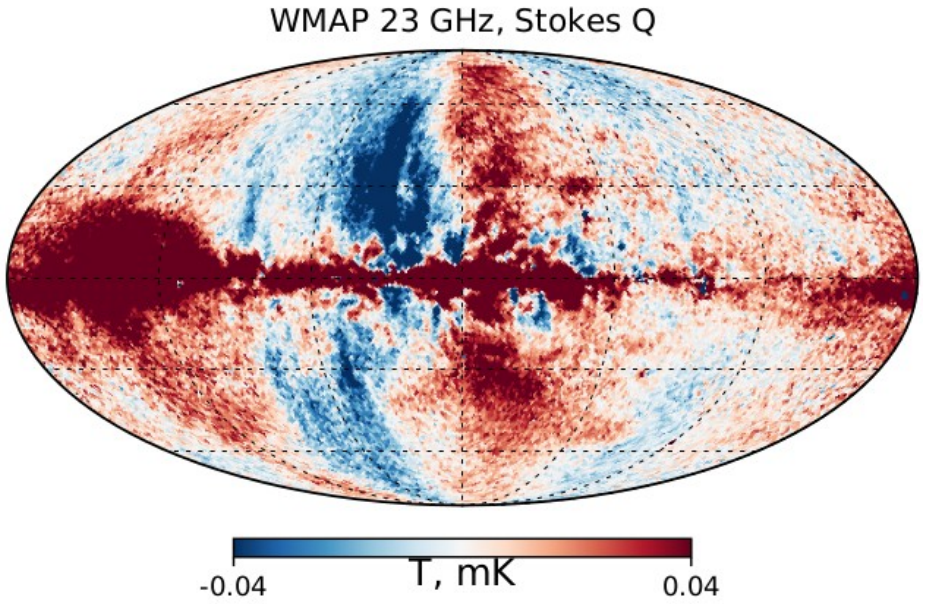

RM traces B field component parallel to LOS

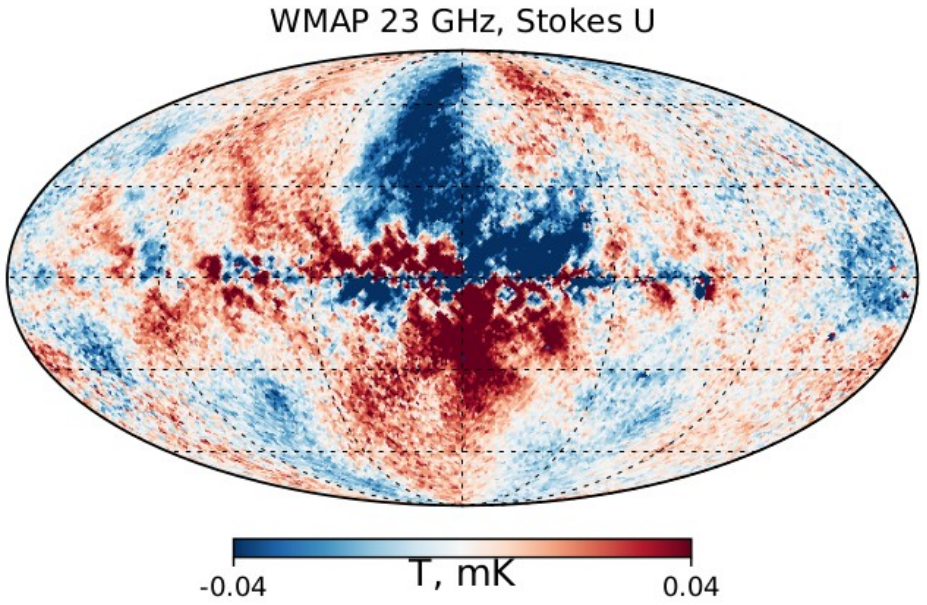
**Brown** – B mainly towards us

Blue – B mianly away from us

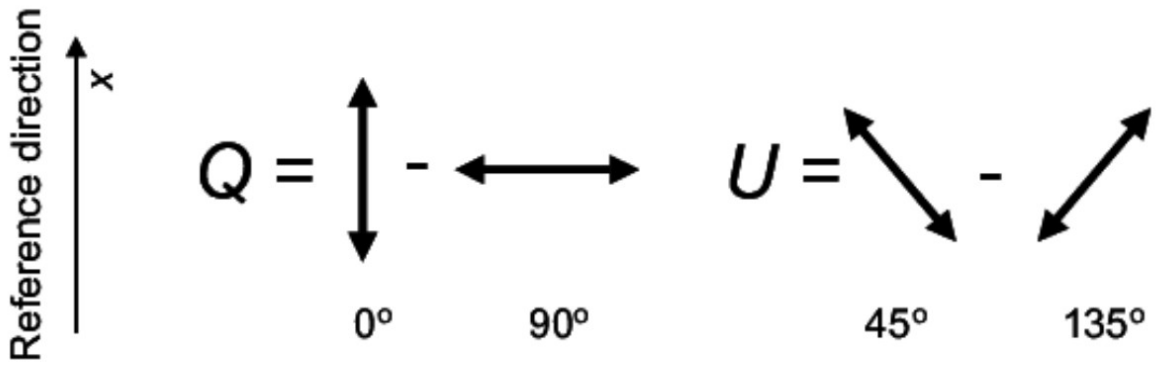
# **Data:** WMAP 23 GHz synchrotron skymaps



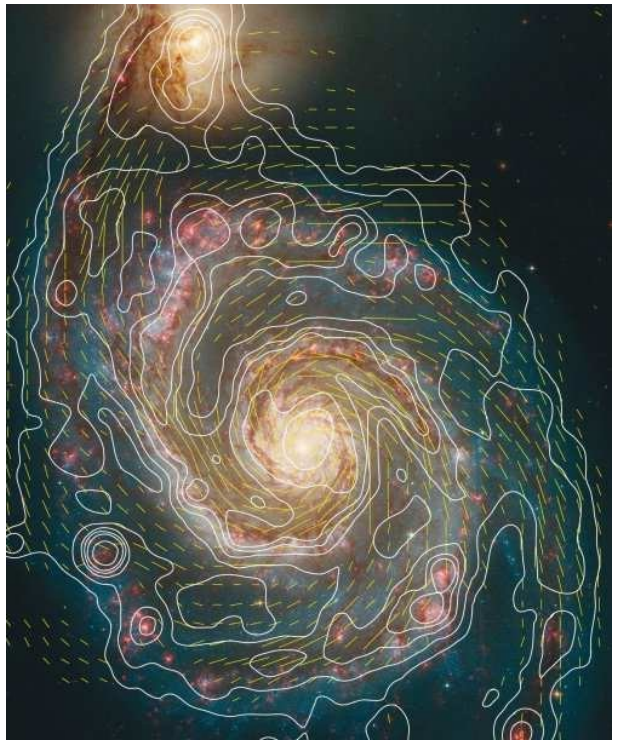



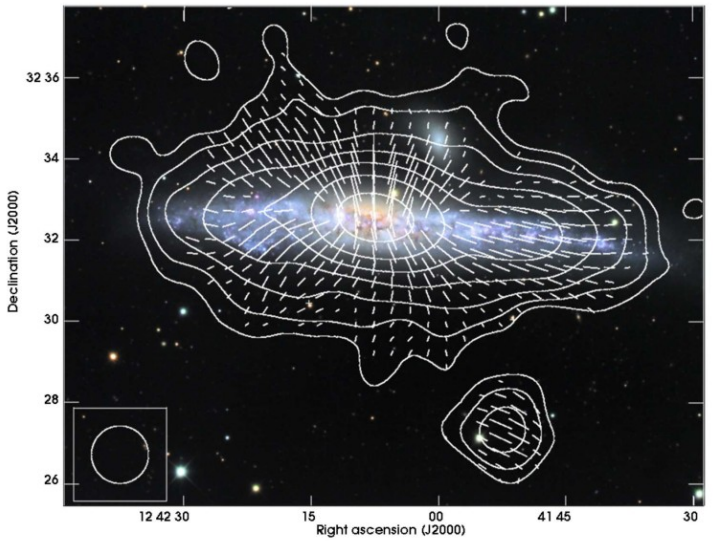

## Stokes parameters



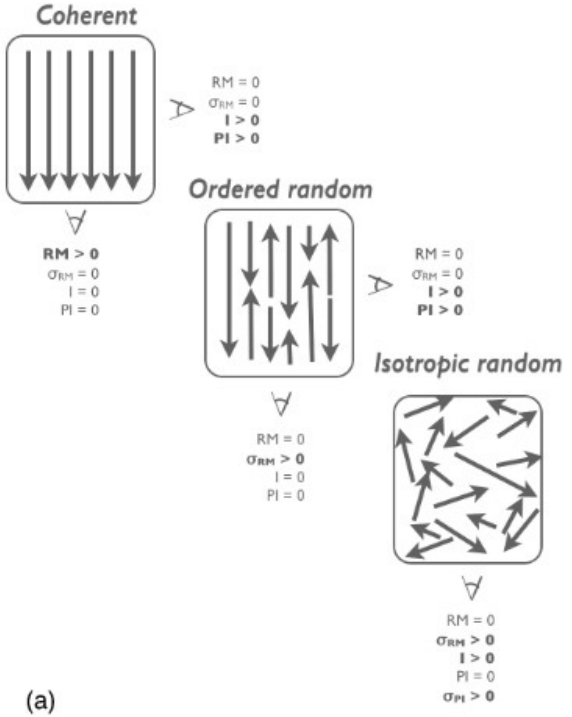
# External galaxies: summary

- 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

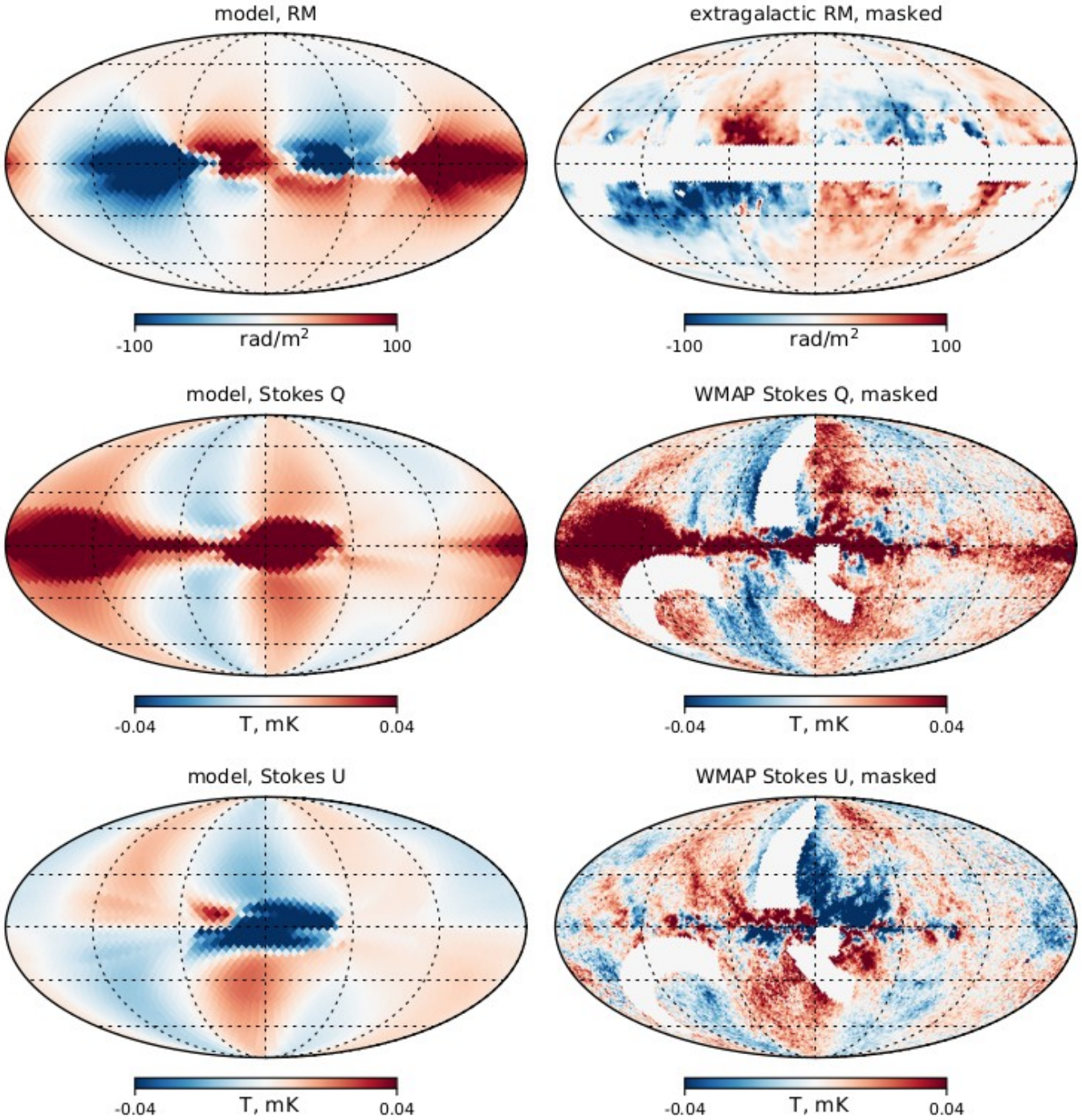




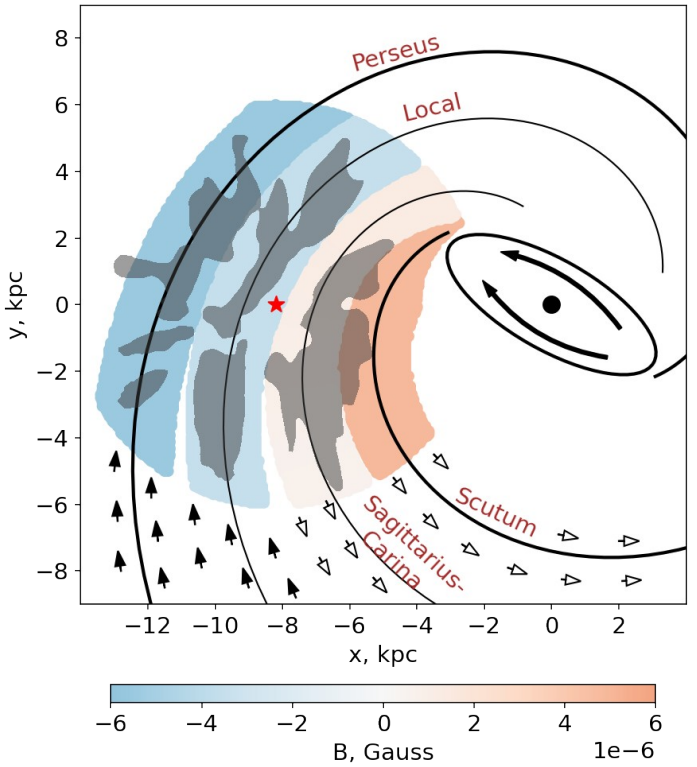

Copyright: MPIfR Bonn




Jaffe+10



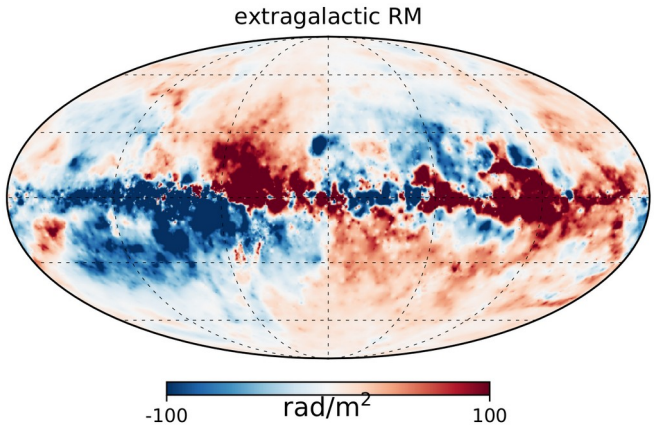

# Our new model

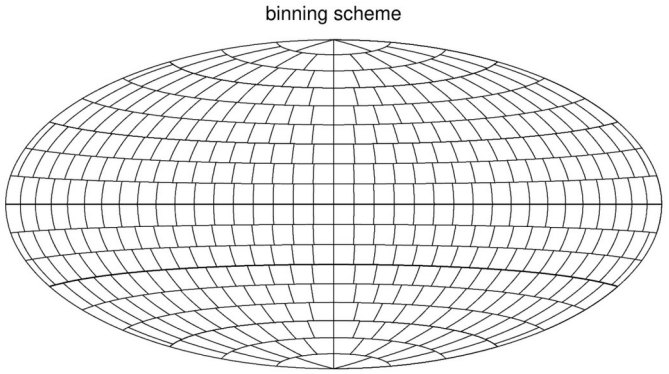


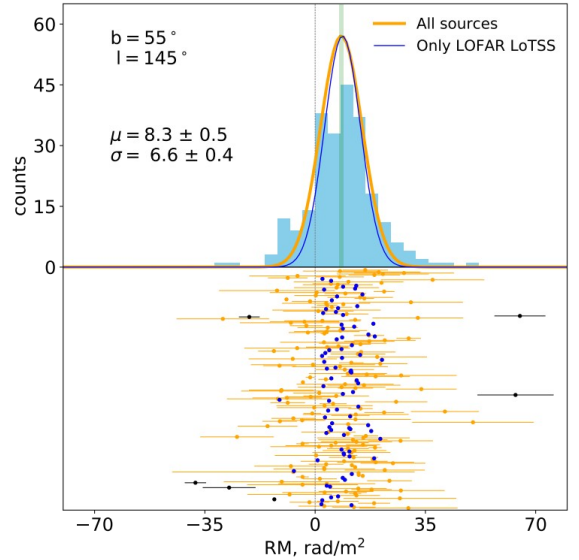

Main features:

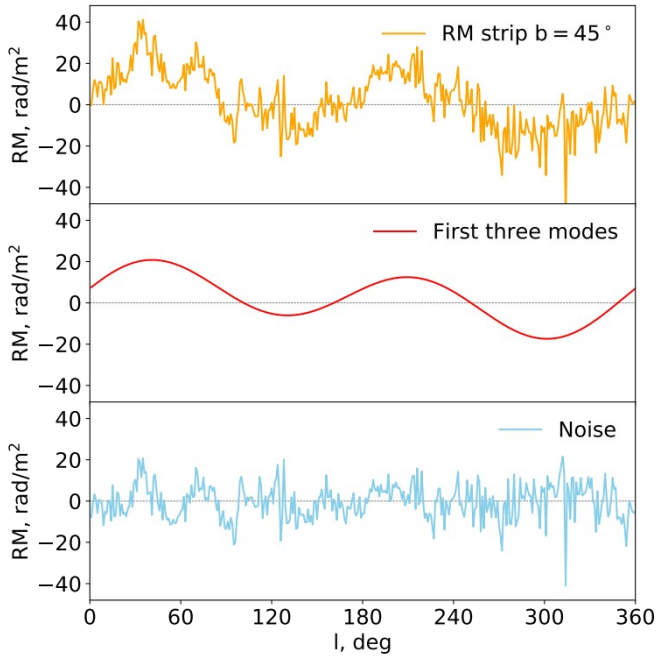
1) new statistical approach
2) larger pitch angle (~20 deg)
3) Fan Region
4) Local Bubble

# Estimation of data bins errorbars




- We are interested in global GMF structure – small details are not important
- Errors assignment procedure based on Fourier analysis

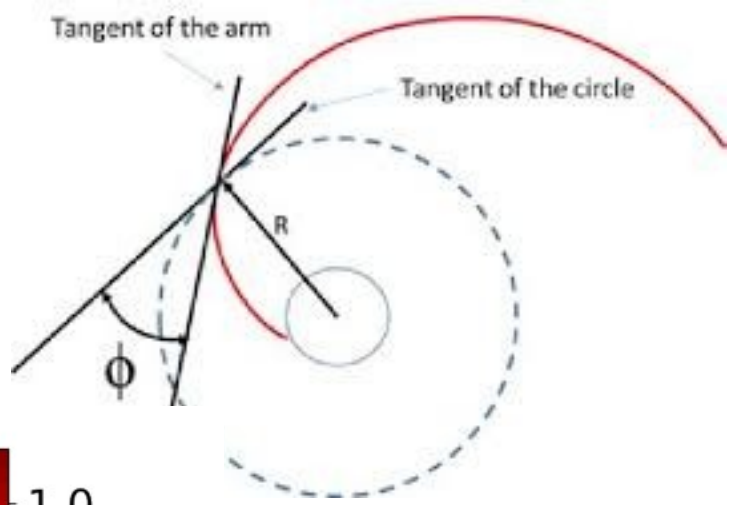
$$\sigma_{\mathrm{L}}^2 = 2 \sum_{k_0}^{\infty} \mathrm{sinc}^2\left(\frac{kL}{2}\right) S_k$$

- Better treatement of errorbars – better sensitivity to the data

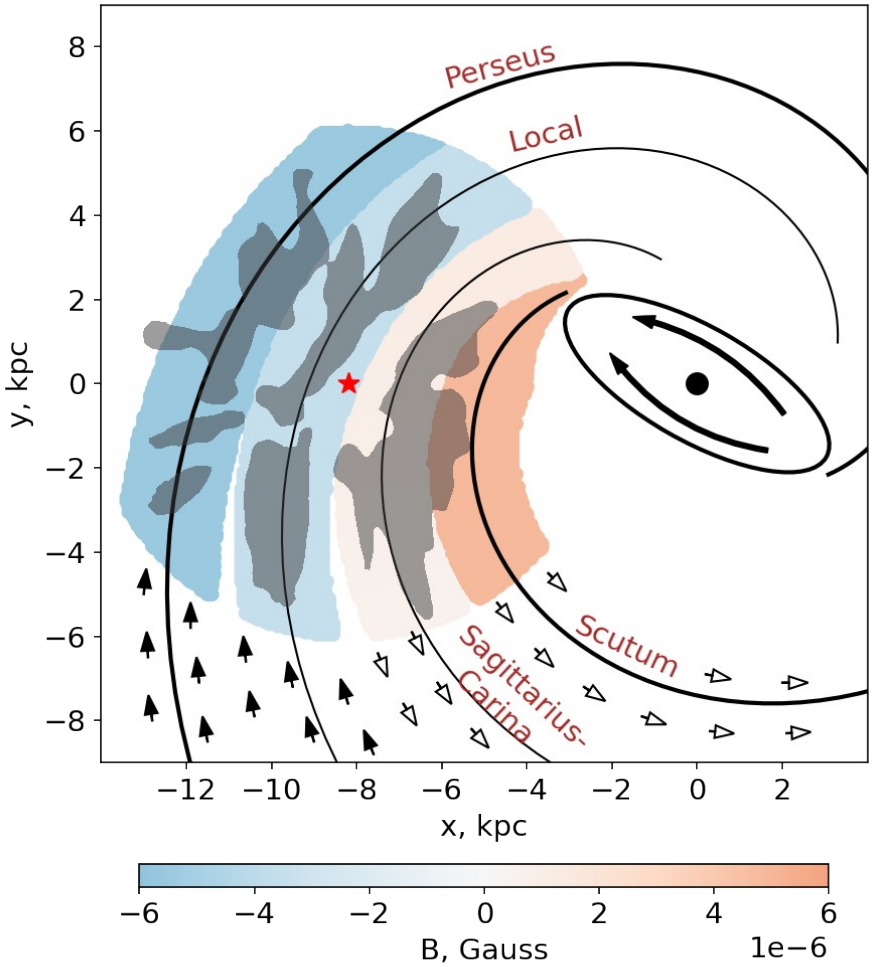
# Pitch angle

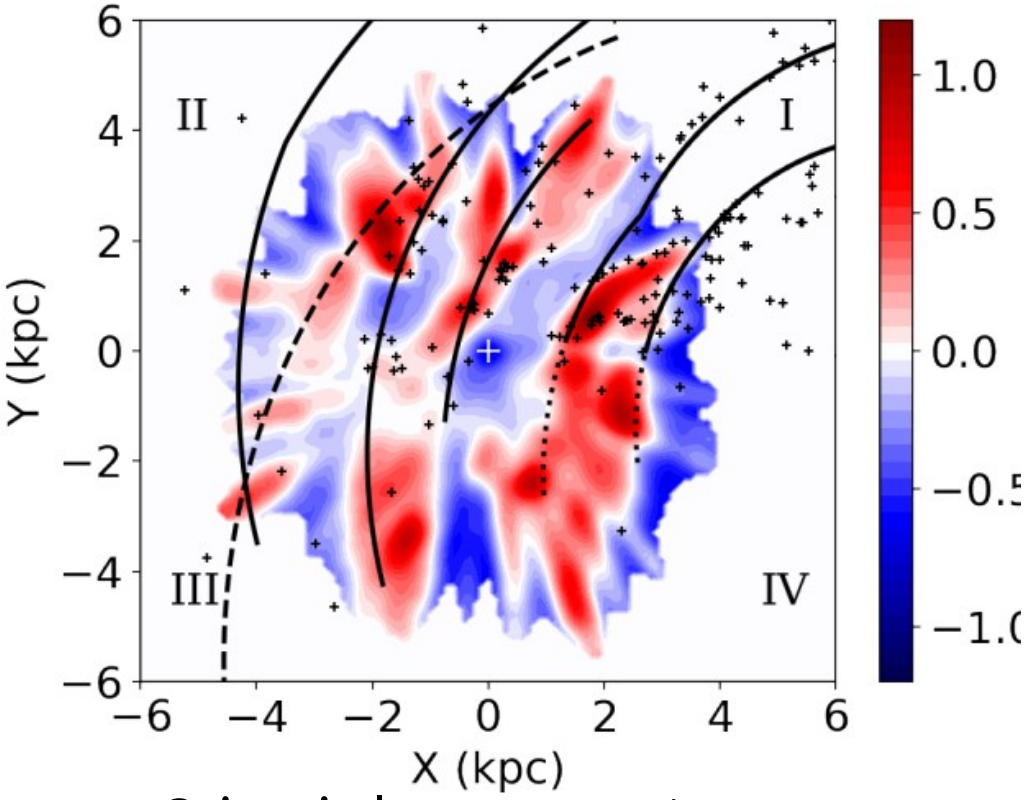
As inferred from GAIA DR3 data (Poggio+21) the spiral arms are more inclined than previously thought

Our and Poggio+21 pitch angle ~ 20 deg
In earlier studies pitch angle ~ 10 deg

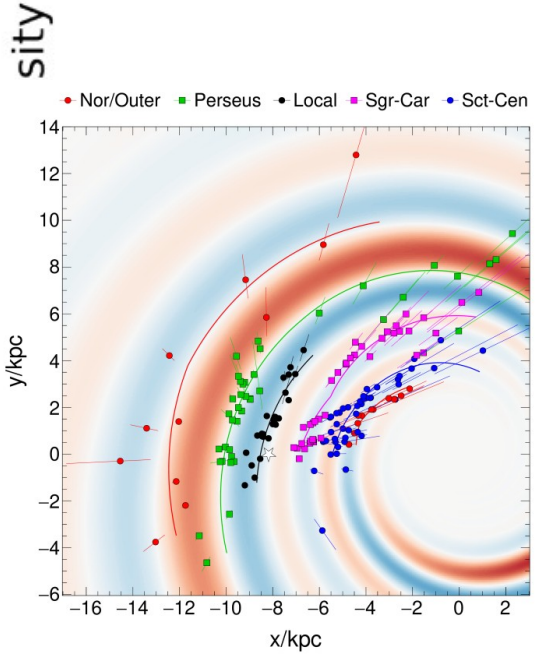



Our model



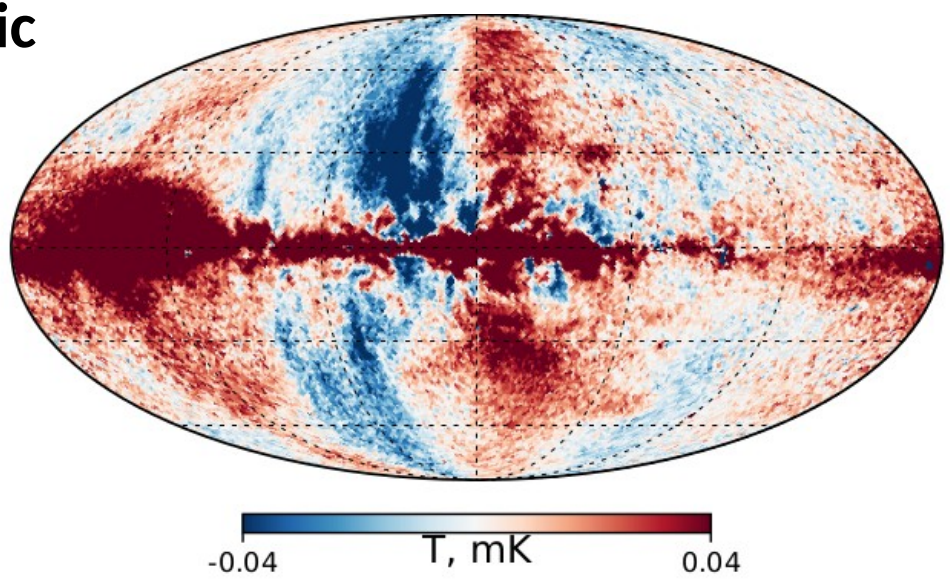

Gaia spiral arm segments, Poggio+21

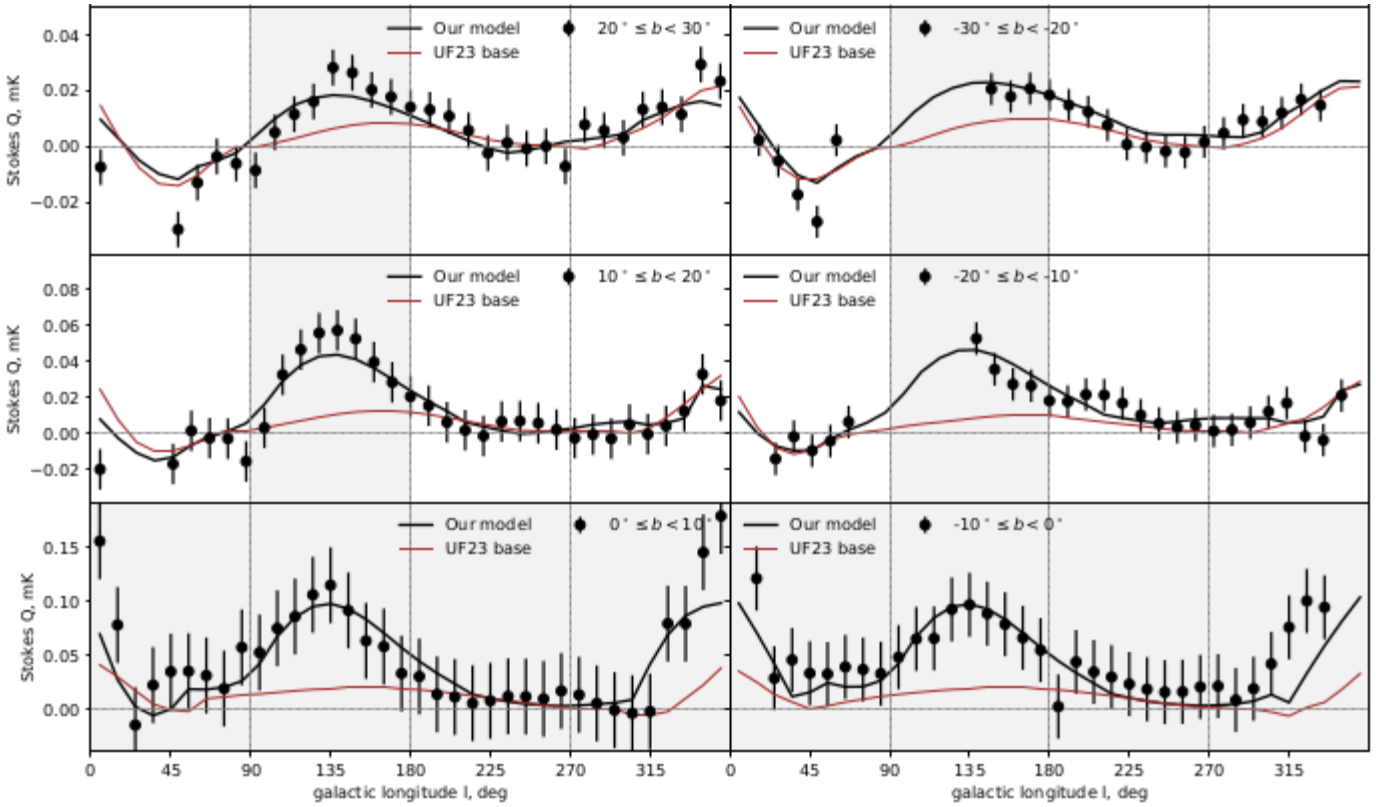


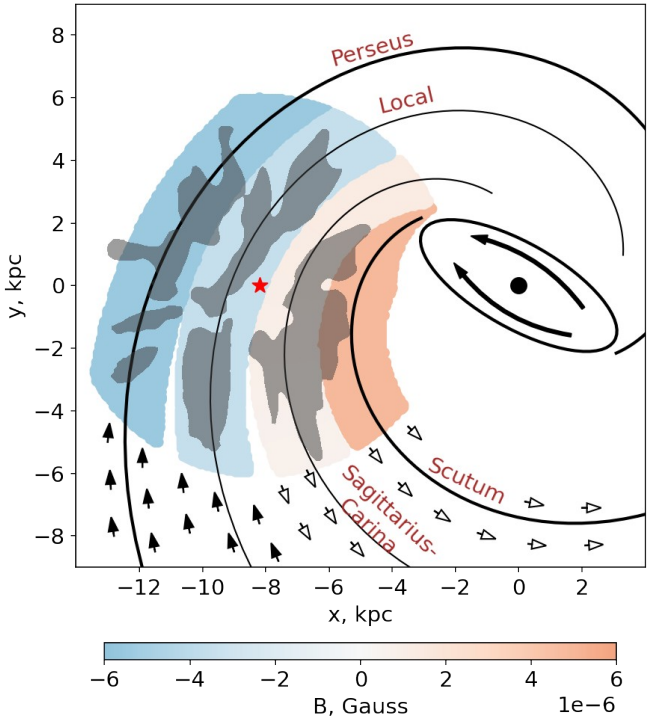

Unger&Farrar23

# 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 Sun – part of the large-scale GMF



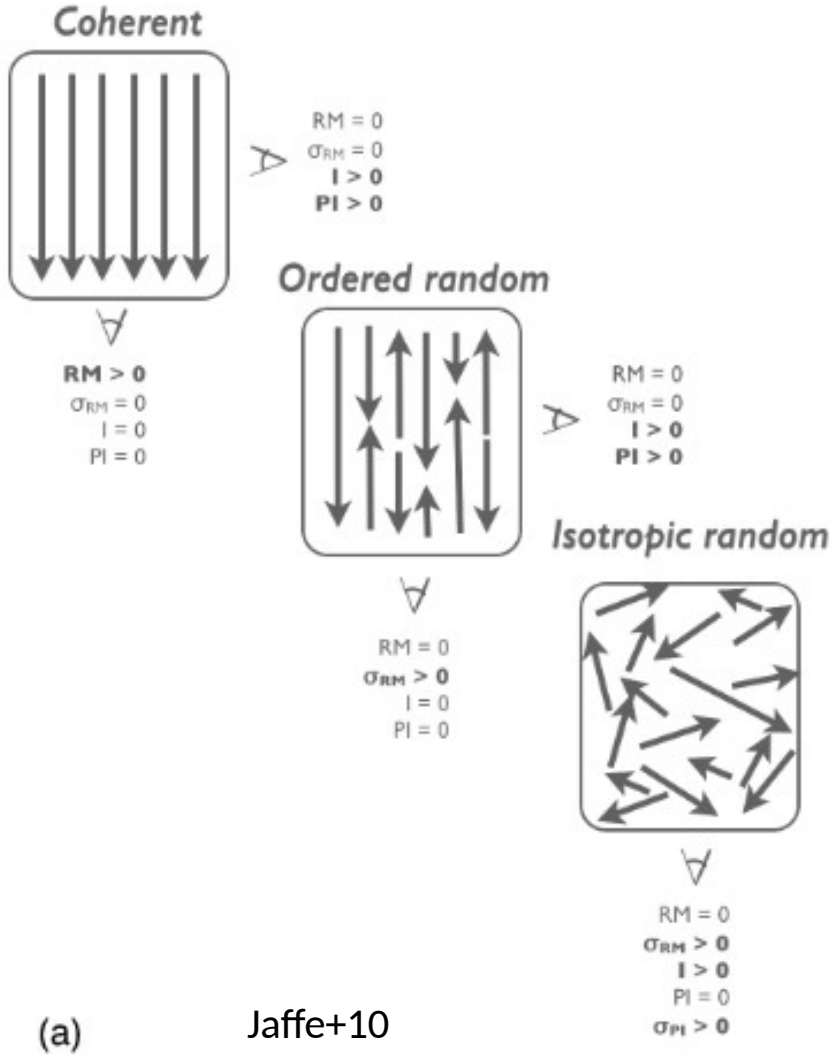



# Where is the missing part of the synchrotron emission?

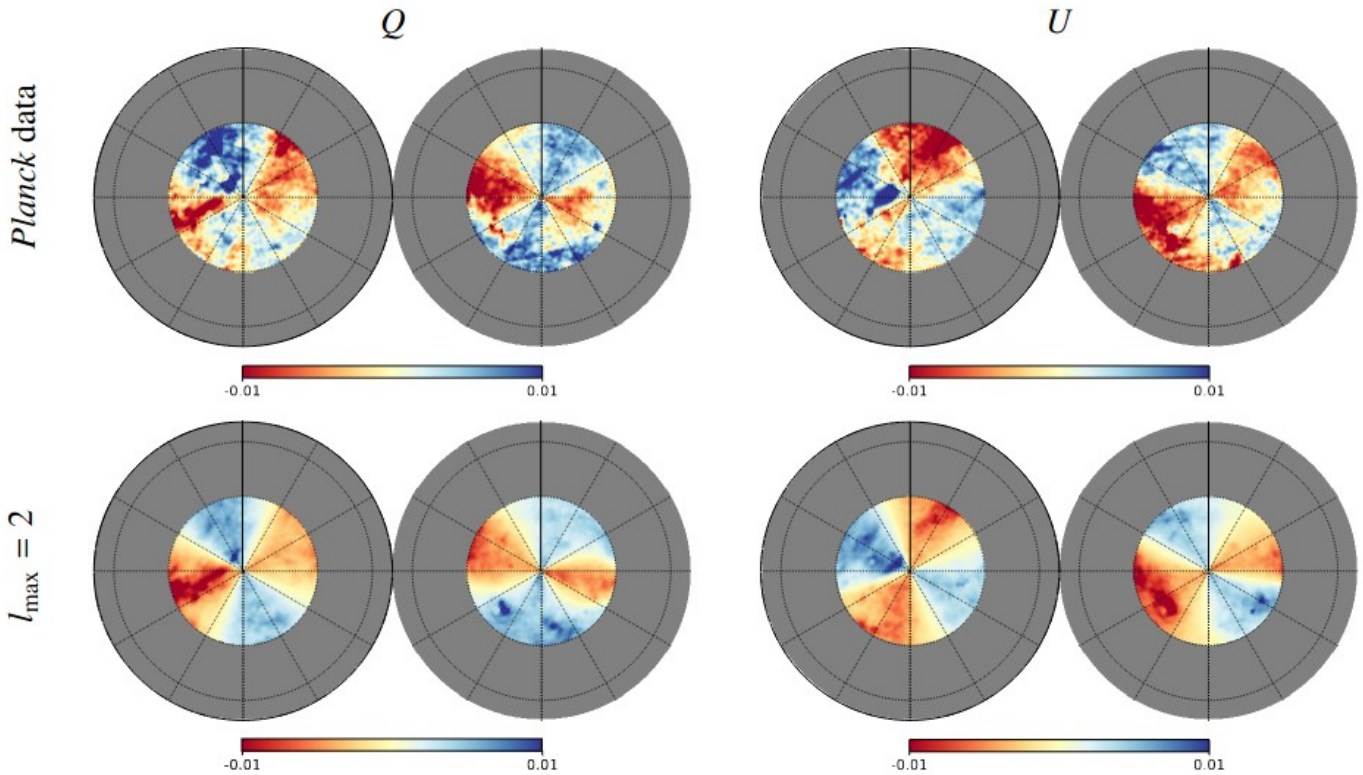
The GMF model, fitted only to RMs, does not produce sufficient synchrotron emission

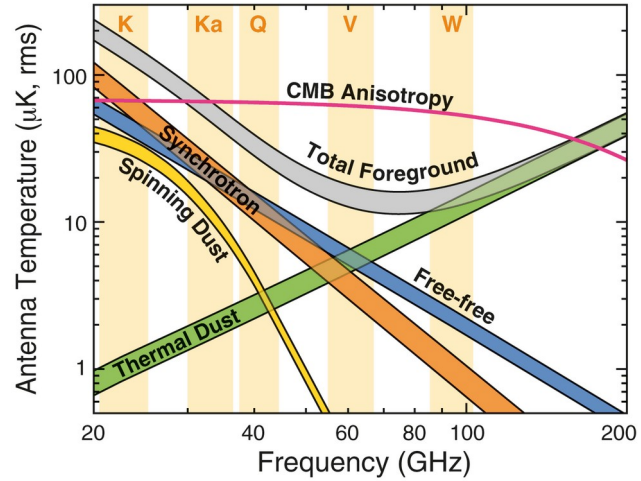
Invoking striated magnetic fields

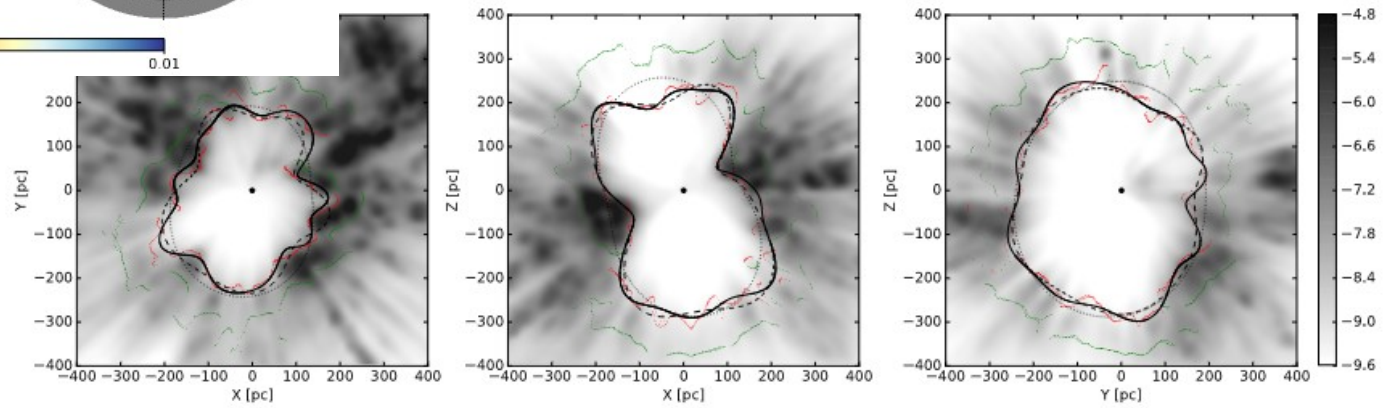



Jaffe+10

# Local Bubble and Planck 353 GHz



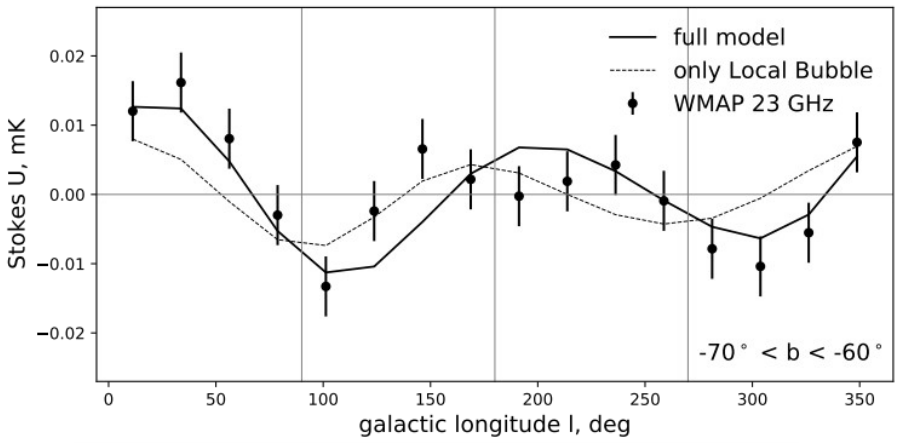



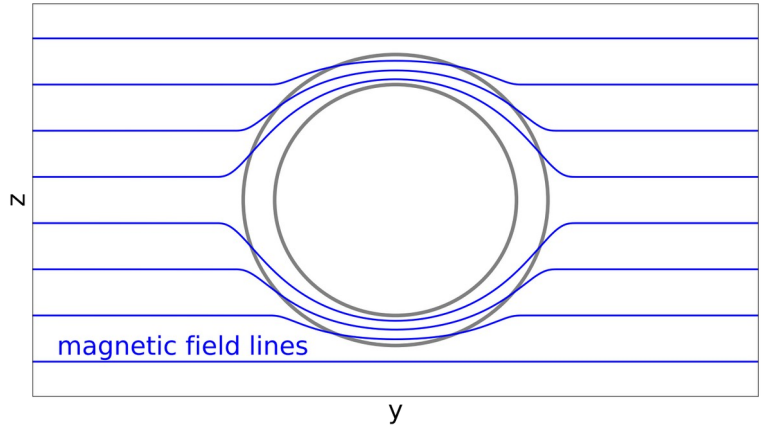




At the polar caps emission is dominated by the Local Bubble

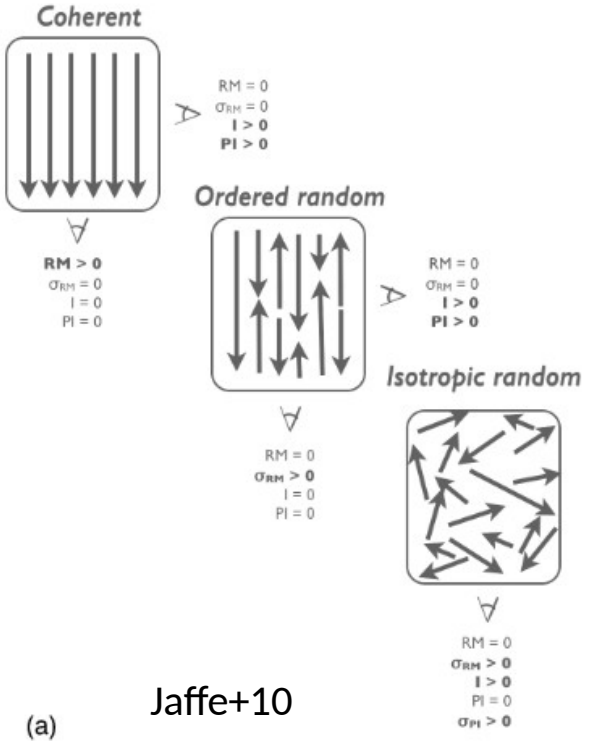
Pelgrims+19

# Local Bubble: missing part of the synchrotron emission?

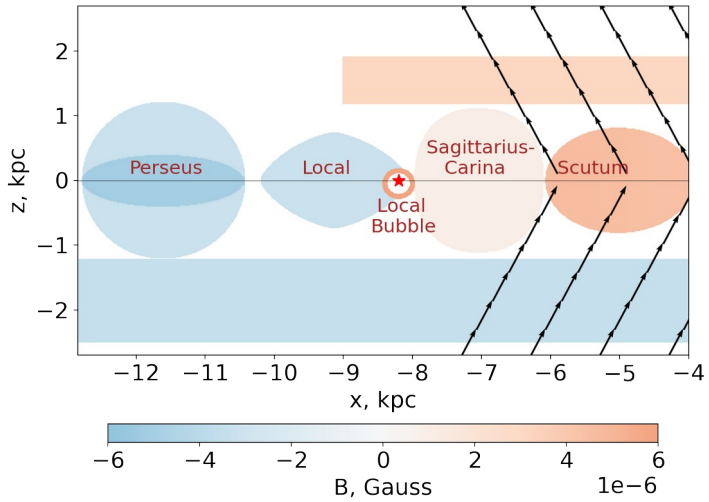



Taking into account the polarized synchrotron emission of the Local Bubble at 23 GHz, we found that striated fields (ordered random) are not needed. Local Bubble produces the missing part of the synchrotron brightness. Also it improves RM modeling and so prefered by the fit (compared to striated field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




Jaffe+10

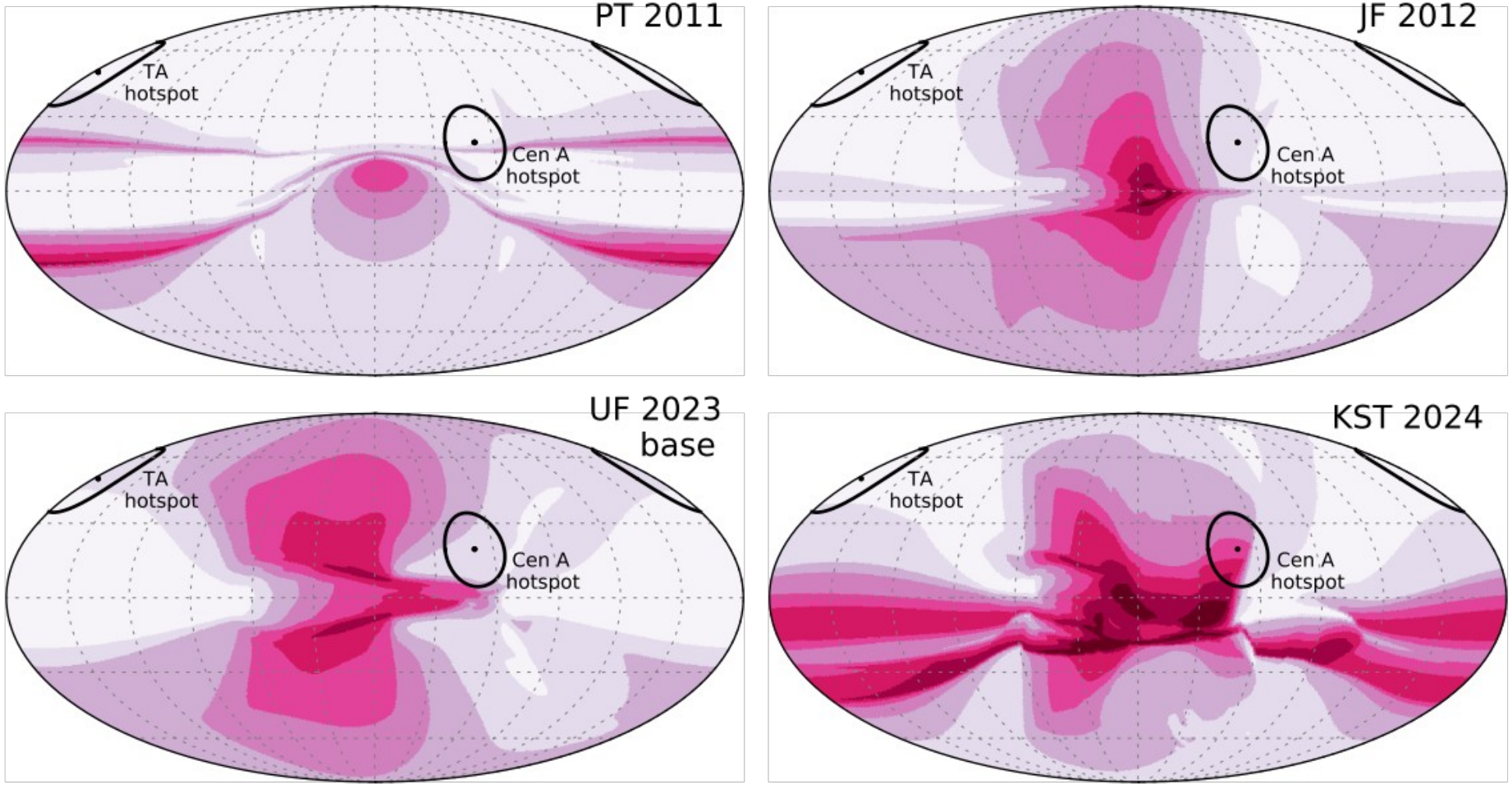



PI(Local Bubble) ~ PI(Halo)

See the poster by V.Pelgrims, M.Unger, and I.C.Maris about the Local Bubble

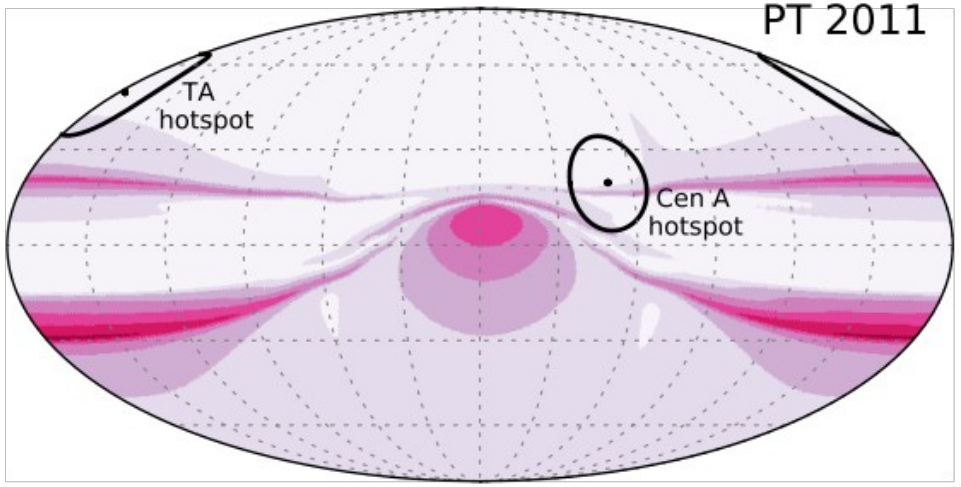
arXiv: 2411.06277

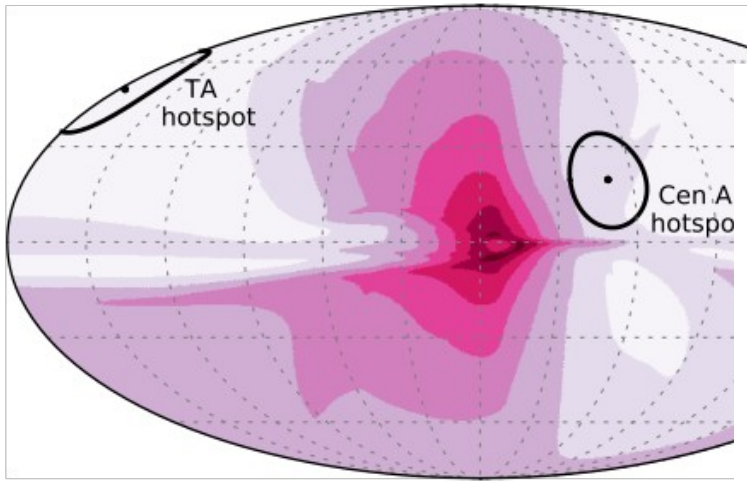
# UHECR Deflections at 20 EV: model comparison

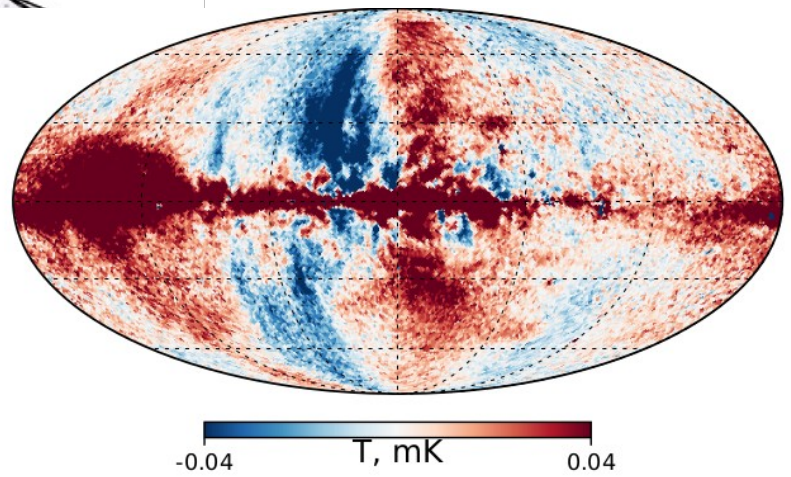


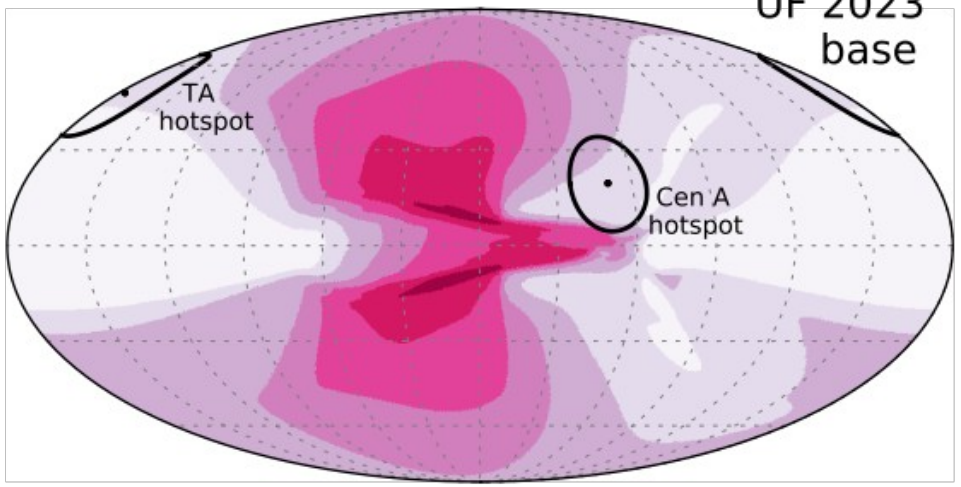

**R = 20 EV**

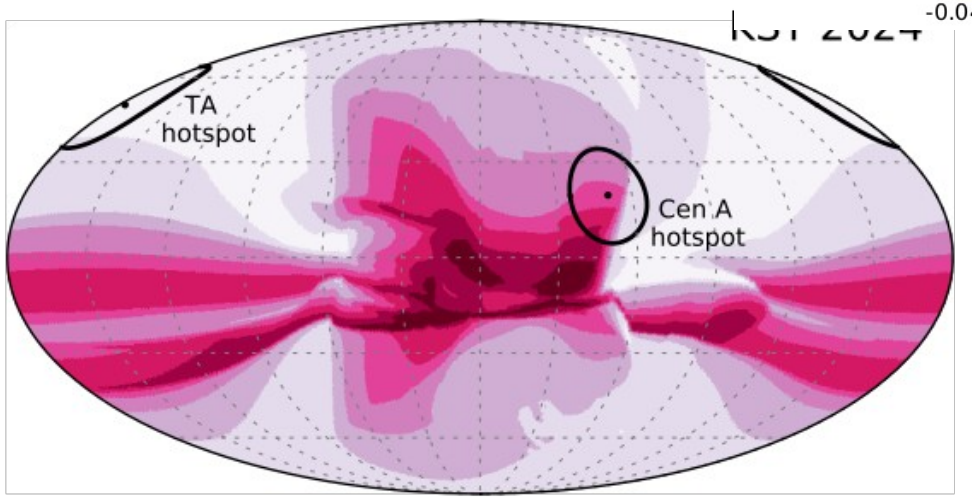
# UHECR Deflections at 20 EV: model comparison

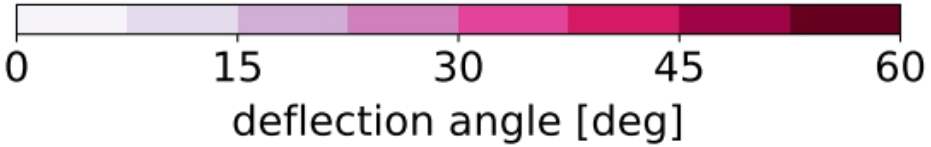


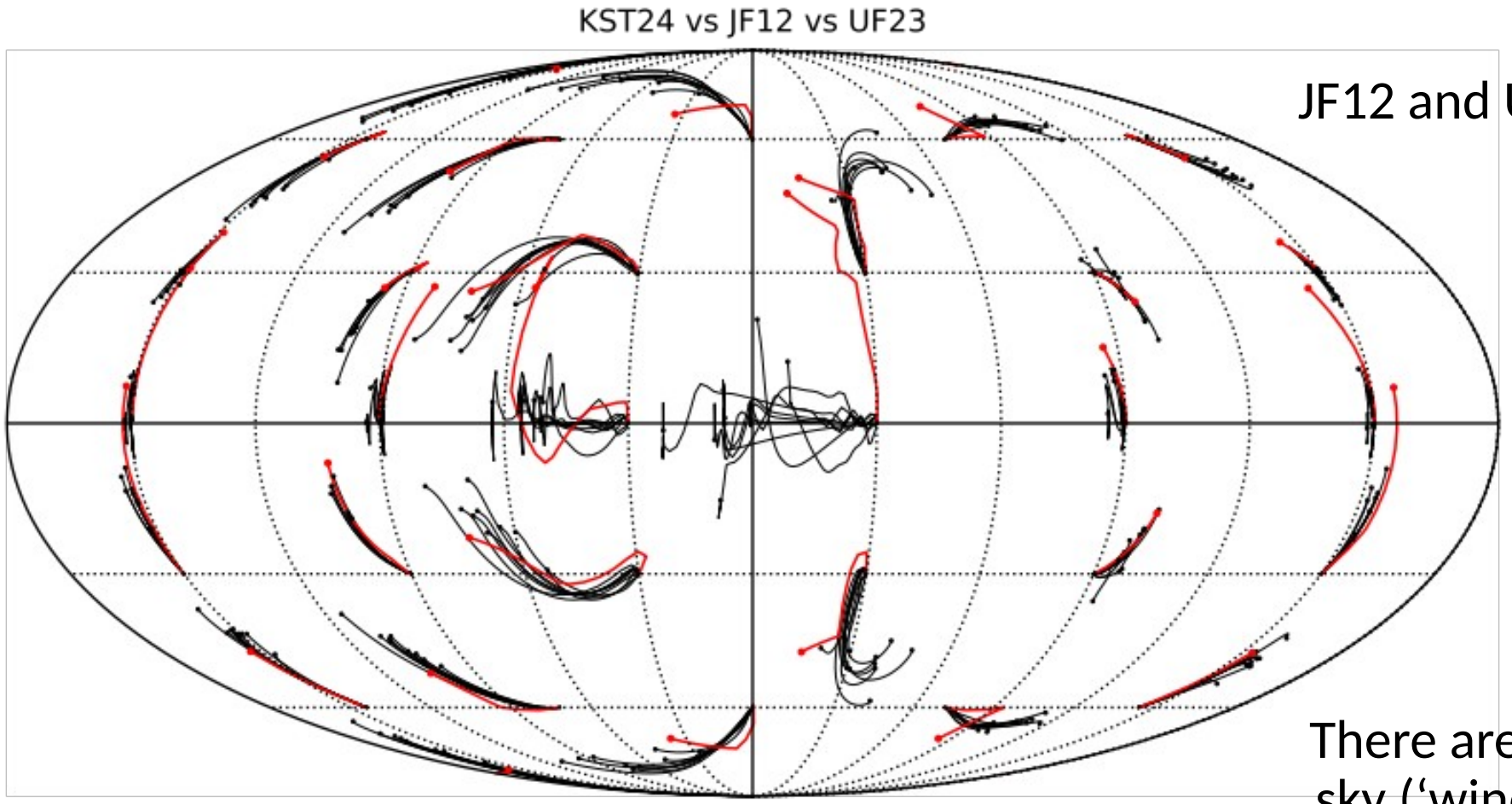




**R = 20 EV**

# Comparison with JF12 and UF23

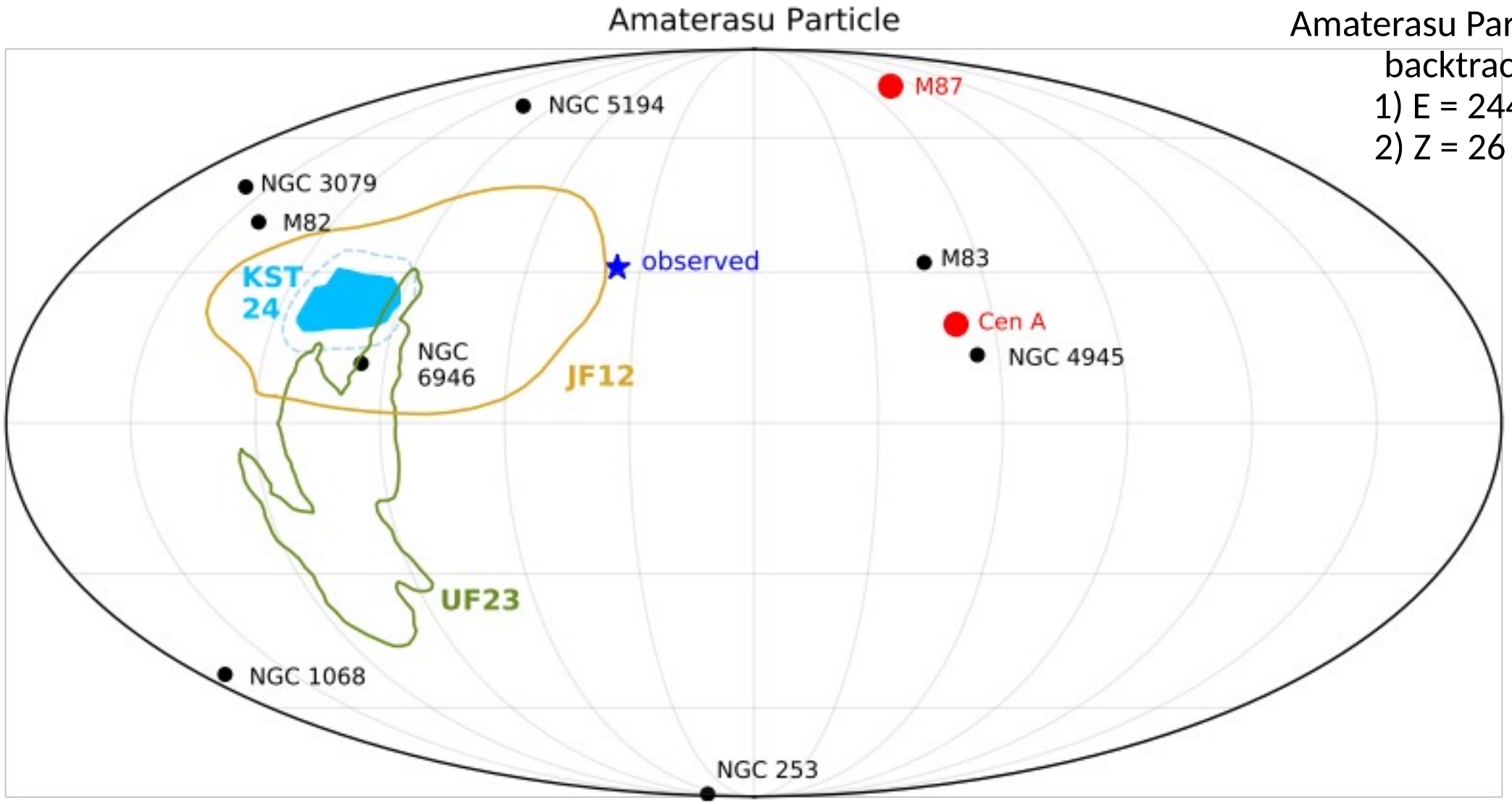



KST24 – red

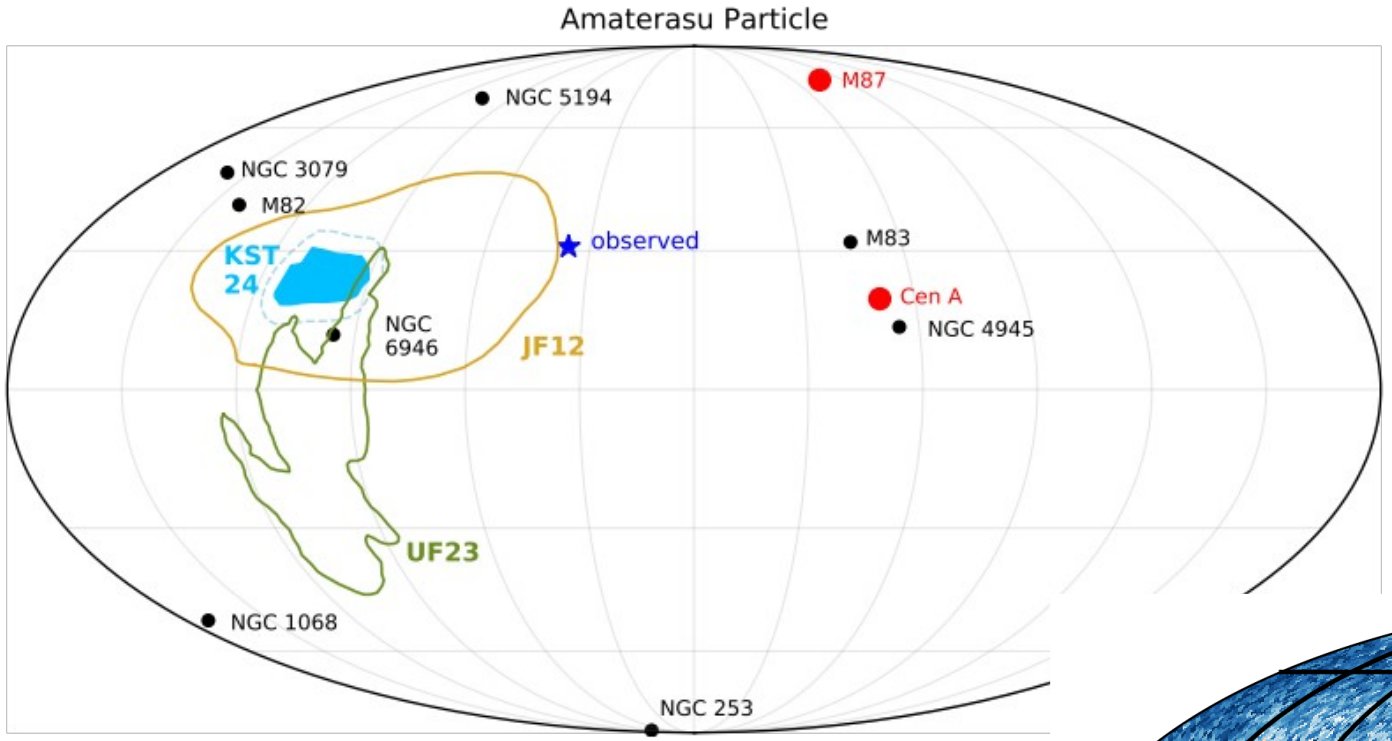
JF12 and UF23 collection - black

There are stable regions in the sky (‘windows’) where UHECR deflections are similar across all models

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

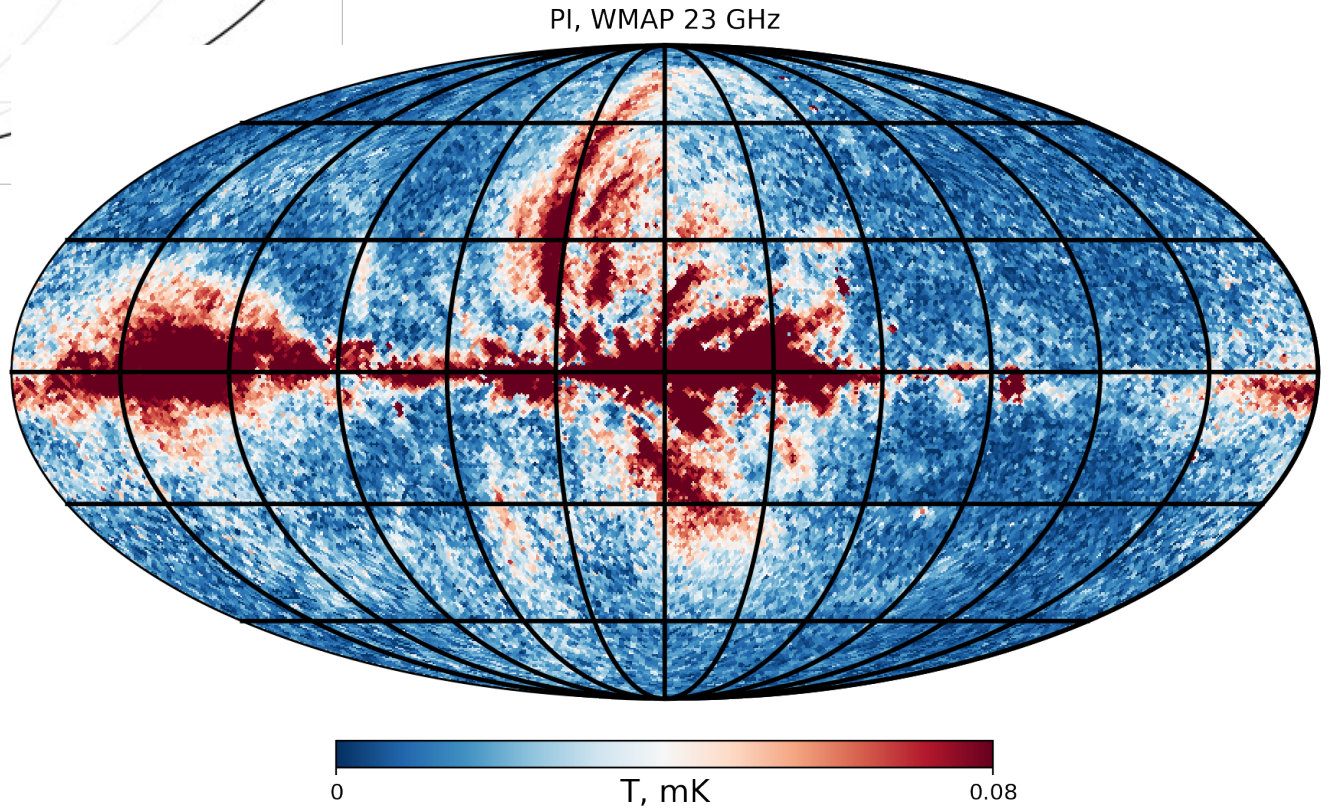



Kuznetsov 2023,
Unger&Farrar 2023,
Bourriche&Capel 2024




Loop I – Galactic scale outflow?

It was masked in all existing GMF models, including ours




Zhang 2024
Churazov 2024

# Conclusions

- We developed a new model of the coherent Galactic magnetic field
- We pitch angle of the disk field was found to be 20 deg in agreement with the pitch inferred from Gaia data
- The Fan Region can be naturally incorporated into the large-scale structure of the GMF – stronger deflections in the outer Galaxy
- Local Bubble is taken into account – no striated fields needed
- There are regions in the sky where three models (JF12, UF23 and KST24) predict similar small deflections – ‘windows’
- Amaterasu particle – backtracking through the Loop I