Non-thermal emissions from the Galactic magnetized halo powered by Galactic outflows

Dr. Heshou Zhang

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Based on **Zhang et al, Nature Astronomy 8, 1416-1428 (2024)**

https://ui.adsabs.harvard.edu/abs/2024NatAs...8.1416Z/abstract

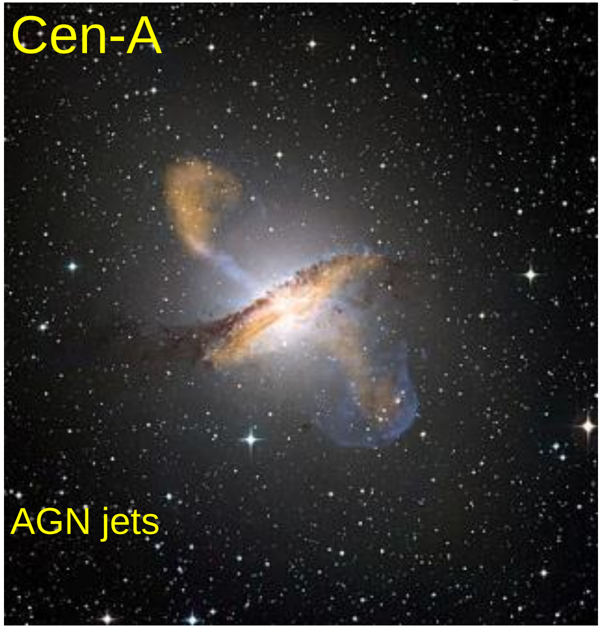
Cooperators: Gabriele Ponti, Ettore Carretti, Ruo-Yu Liu, Mark Morris, Marijke Haverkorn, Nicola Locatelli, Xueying Zheng, Felix Aharonian, Hai-Ming Zhang, Yi Zhang, Giovanni Stel, A. Strong, M. Yeung, A. Merloni

QR code to our paper

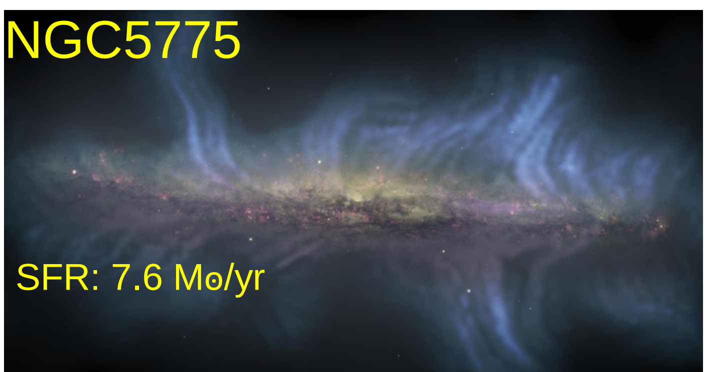
"X-riStMAs" under PNRR from MUIR funded by NextGenerationEU

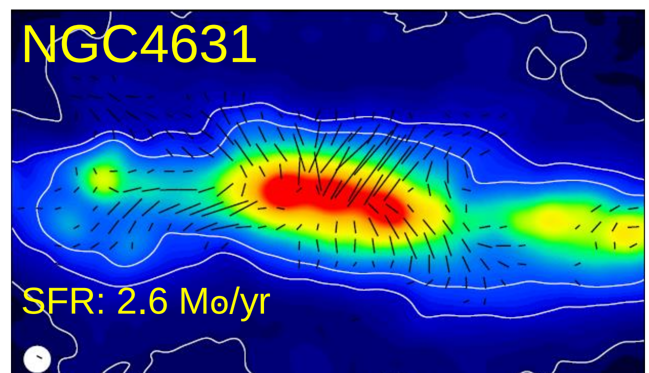
(**X-r**ay **i**n **St**udying the **M**ultiphase **As**trophysics)

Galactic outflows and magnetic halo from other galaxies



Magnetic halo





For review:
Thompson&Heckman24
Sarkar24,Krause+2020

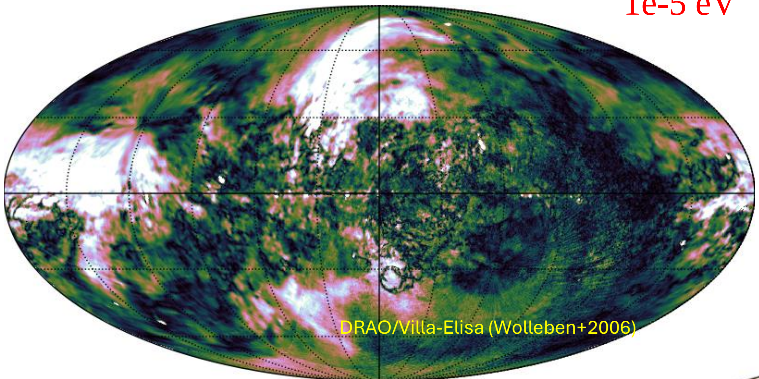
1. The era of multi-wavelength observations

For Our Milky Way:

Large scale structures in the all-sky maps in **continuum emission**

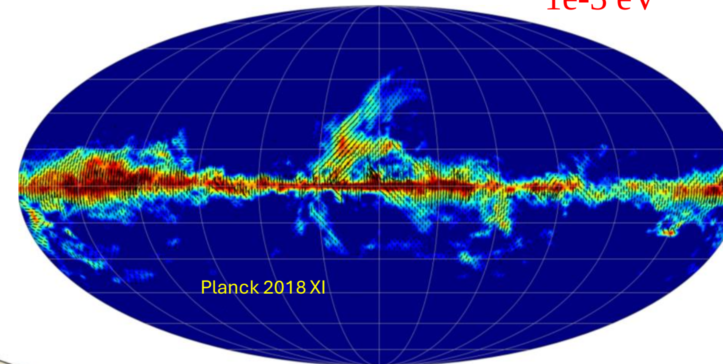
Radio sky (1.4GHz)

1e-5 eV



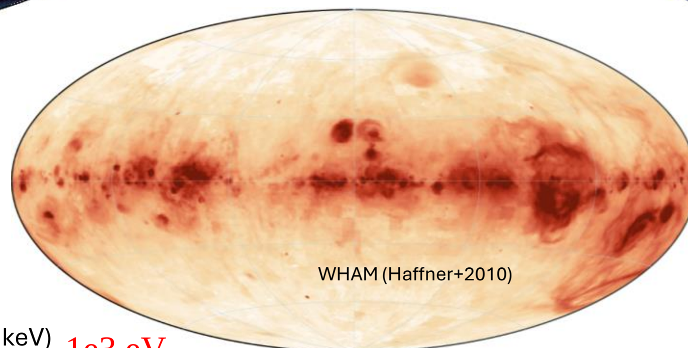
Dust sky (353 GHz)

1e-3 eV



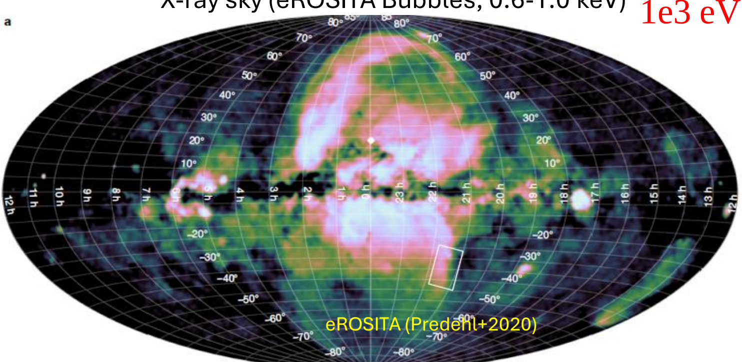
H-alpha sky (457THz)

1.9 eV



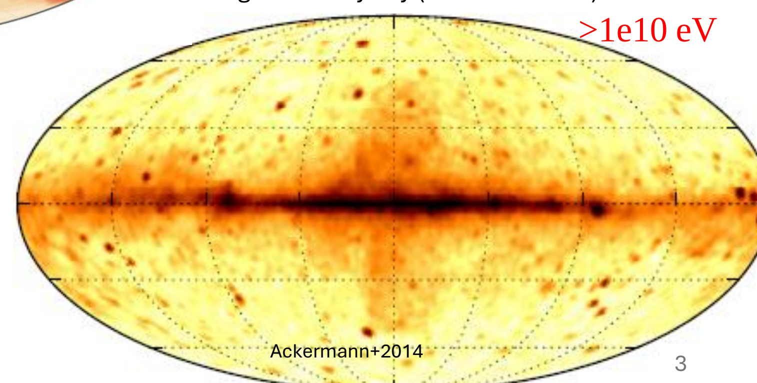
X-ray sky (eROSITA Bubbles, 0.6-1.0 keV)

1e3 eV

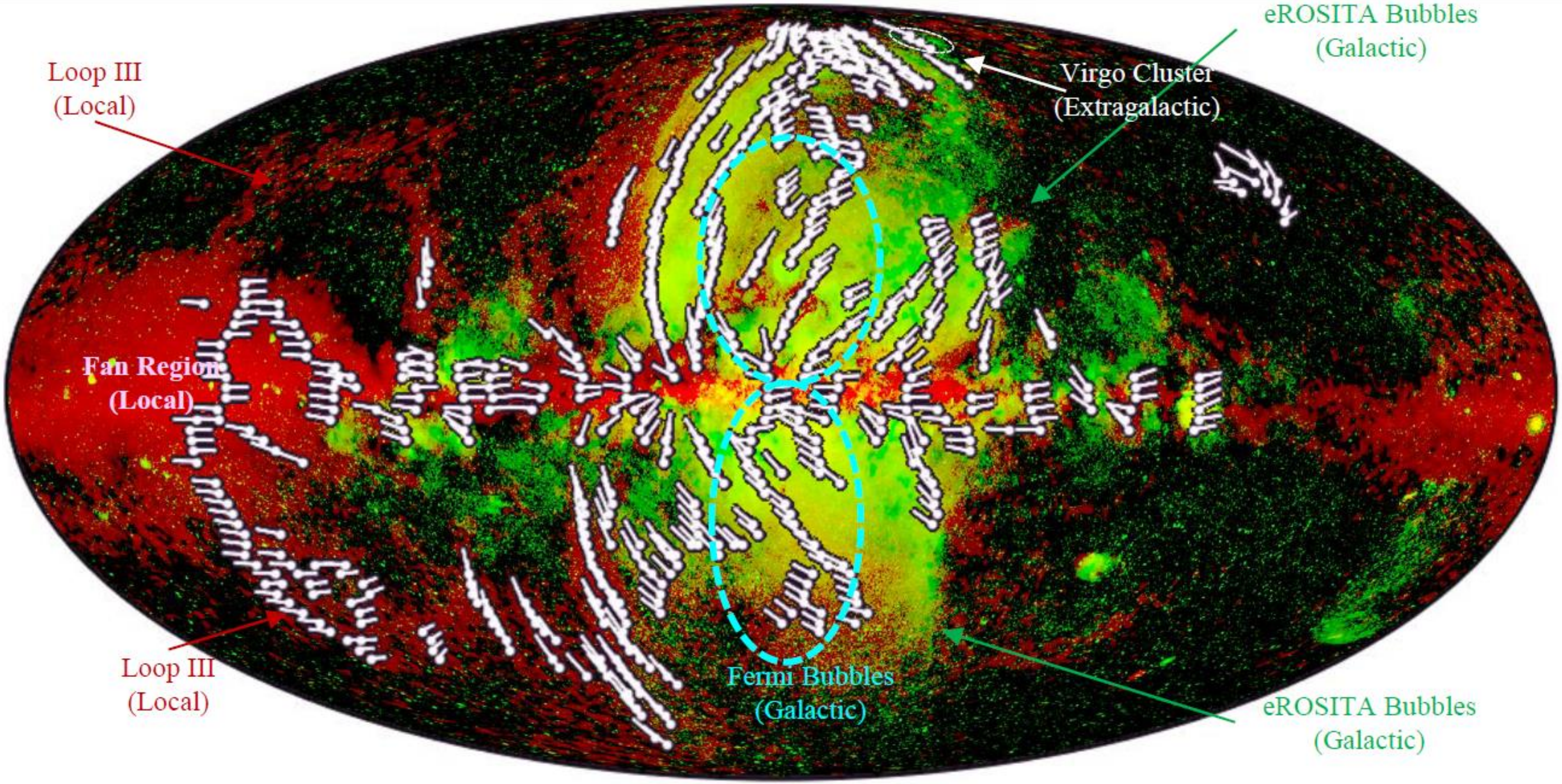


gamma-ray sky (Fermi Bubbles)

>1e10 eV



2. The Magnetic ridges vs the eROSITA Bubbles



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White bars: magnetic field (23 GHz)
Green: 0.6-1.0 keV X-ray

Are they Galactic structures beyond the disc?

3. Question: Local or Galactic?

A gigantic structure observed in the sky could be either within the Local Bubble in a few tens of pcs, or Galactic structure (several kpcs).

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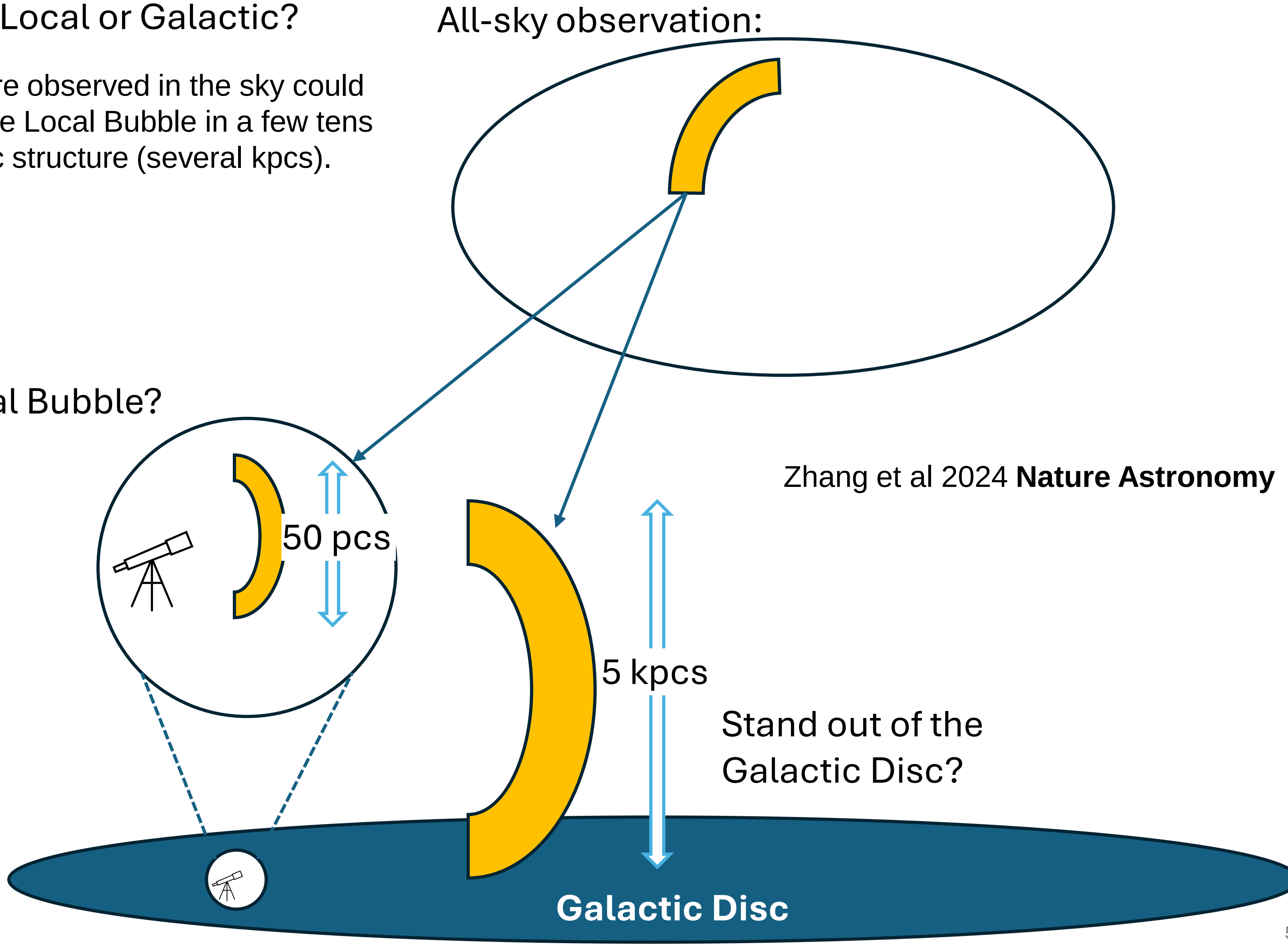
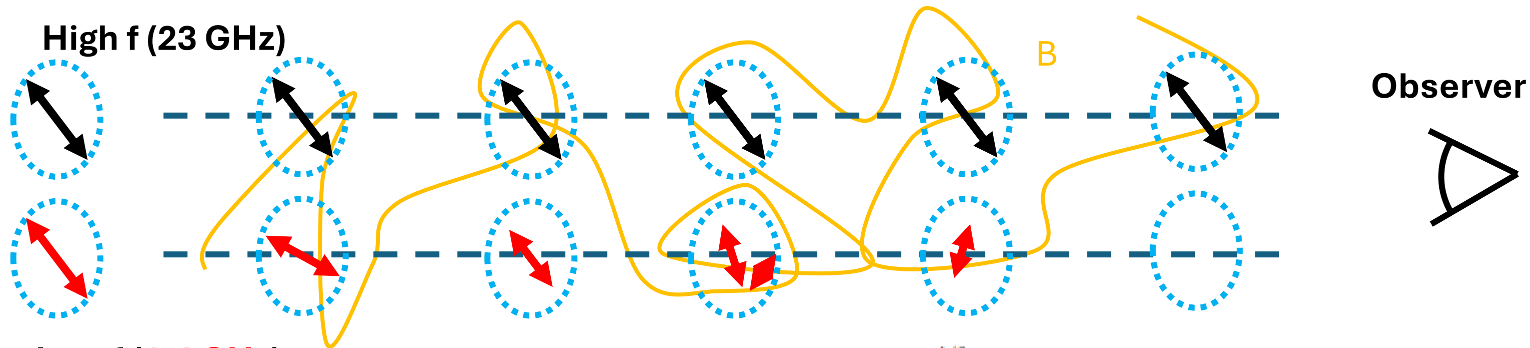


3. Question: Local or Galactic? **Answer:** The Disc will **imprint on the Galactic structure!**

Faraday Rotation Depolarization

Polarized signal from synchrotron will be Faraday rotated, Signals depolarized in turbulent foreground.



Low f (1.4 GHz)

$$f_{\mathrm{depol}} = \frac{1-\exp(-S)}{S}, \quad S \equiv 2\sigma_{\mathrm{RM}}^2 \lambda^4$$

[Burn66, Sokoloff98]

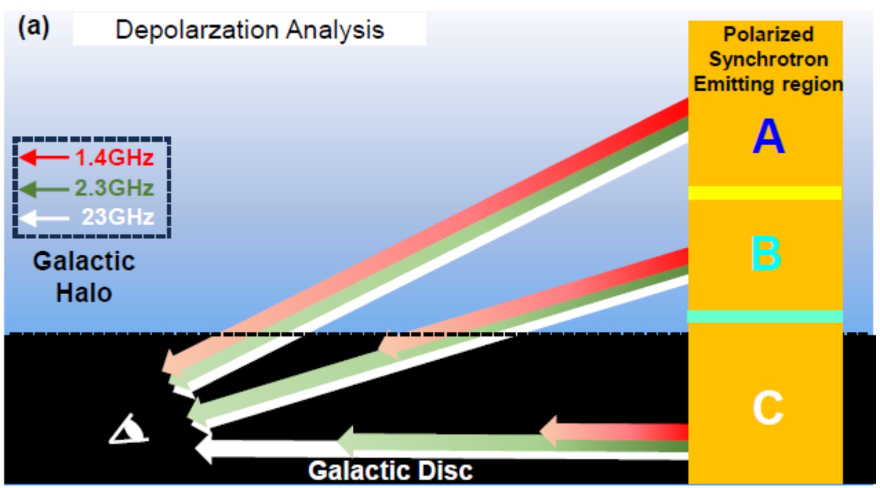
Rotation measure: $\sigma_{RM} = 0.81\,\sigma_{B\|}\, n_e\, d\, N_{\|}^{1/2}$

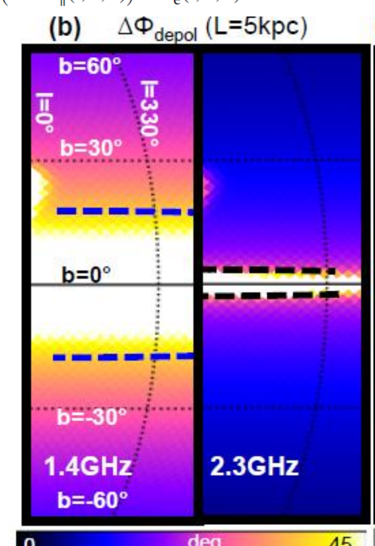
Dispersion angle: $\Delta\Phi = \sigma_{RM}\lambda^2$

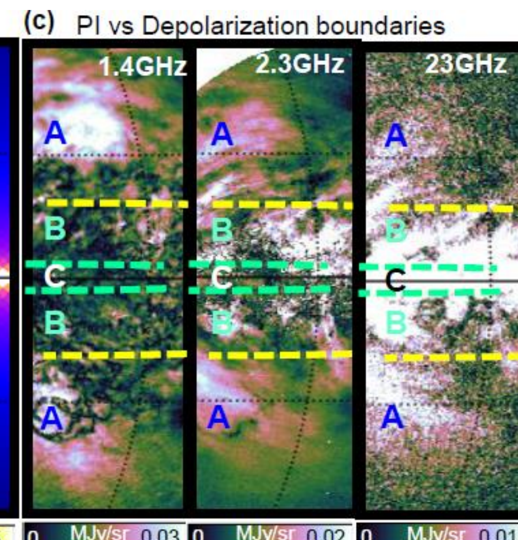
LOS Integrations: $\sigma_{\mathrm{RM}}^2 = \int_{l}^{o} (0.81 B_{\|}(l,b,L))^2\, d\, n_e^2(l,b,L)\,\delta \mathbf{L}$

Ne: YMW16, Locatelli+24

B: Sun+10, JF12, JF12_Planck (Planck2018XLII)







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3. Question: Local or Galactic?

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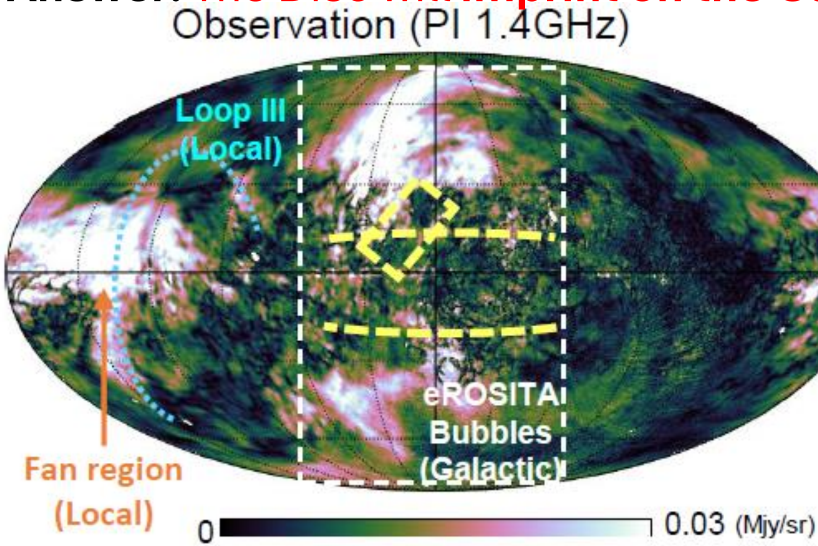
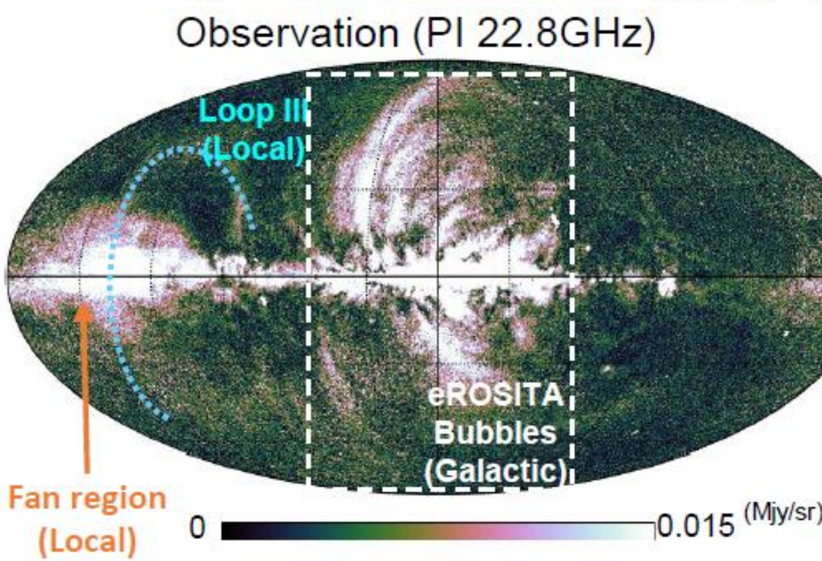
Answer: The Disc will **imprint on the Galactic structure!**

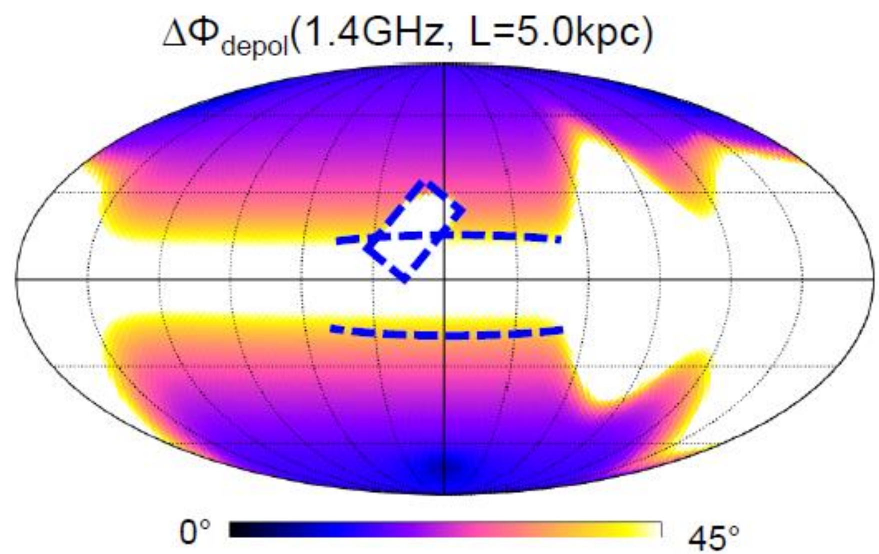




Faraday Rotation depolarization screen

Local: in front of the screen

Galactic: behind the screen (within white dashed box)



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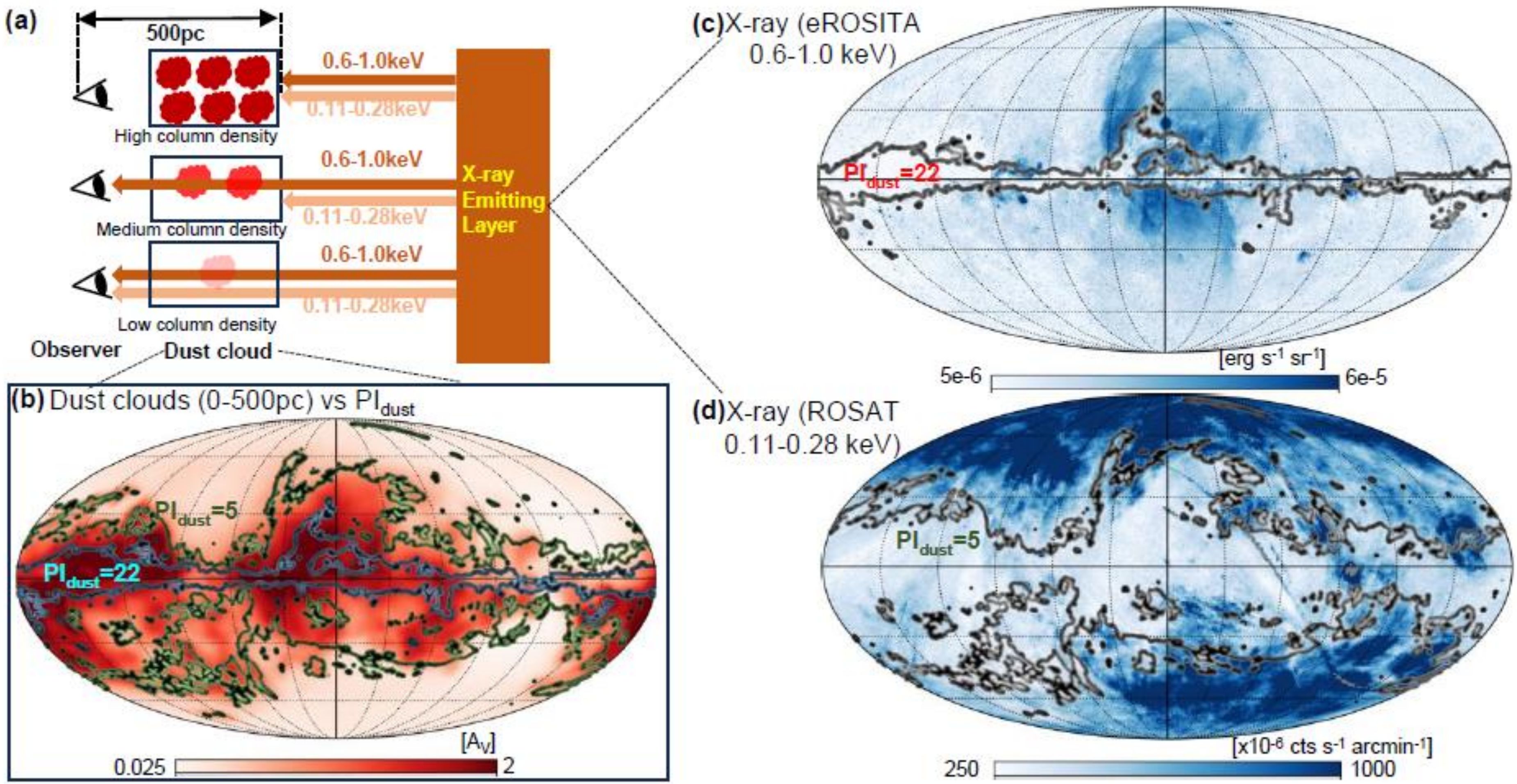
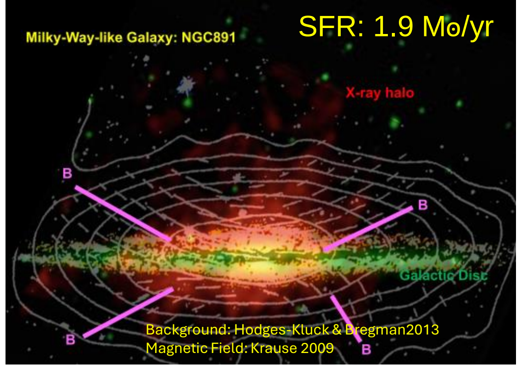


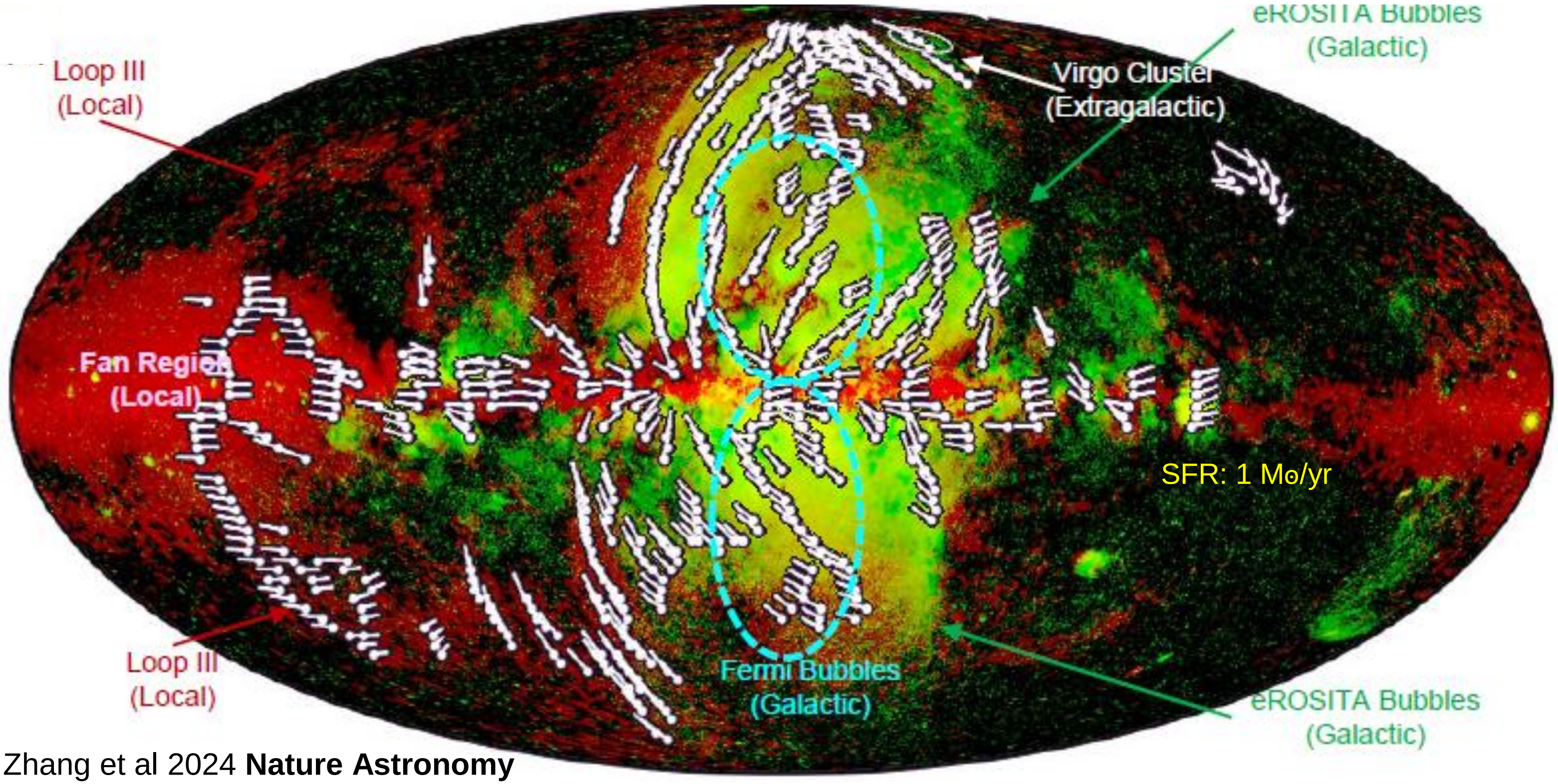
The eROSITA Bubbles - out of the Galactic plane!

Magnetic and X-ray emitting Galactic halo: The Milky Way vs other galaxies



Beyond the Galactic Disc, Coherent ridges in the central +60°>l>-60°.

The Milky Way



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4. Gamma-ray counterpart of the magnetic halo

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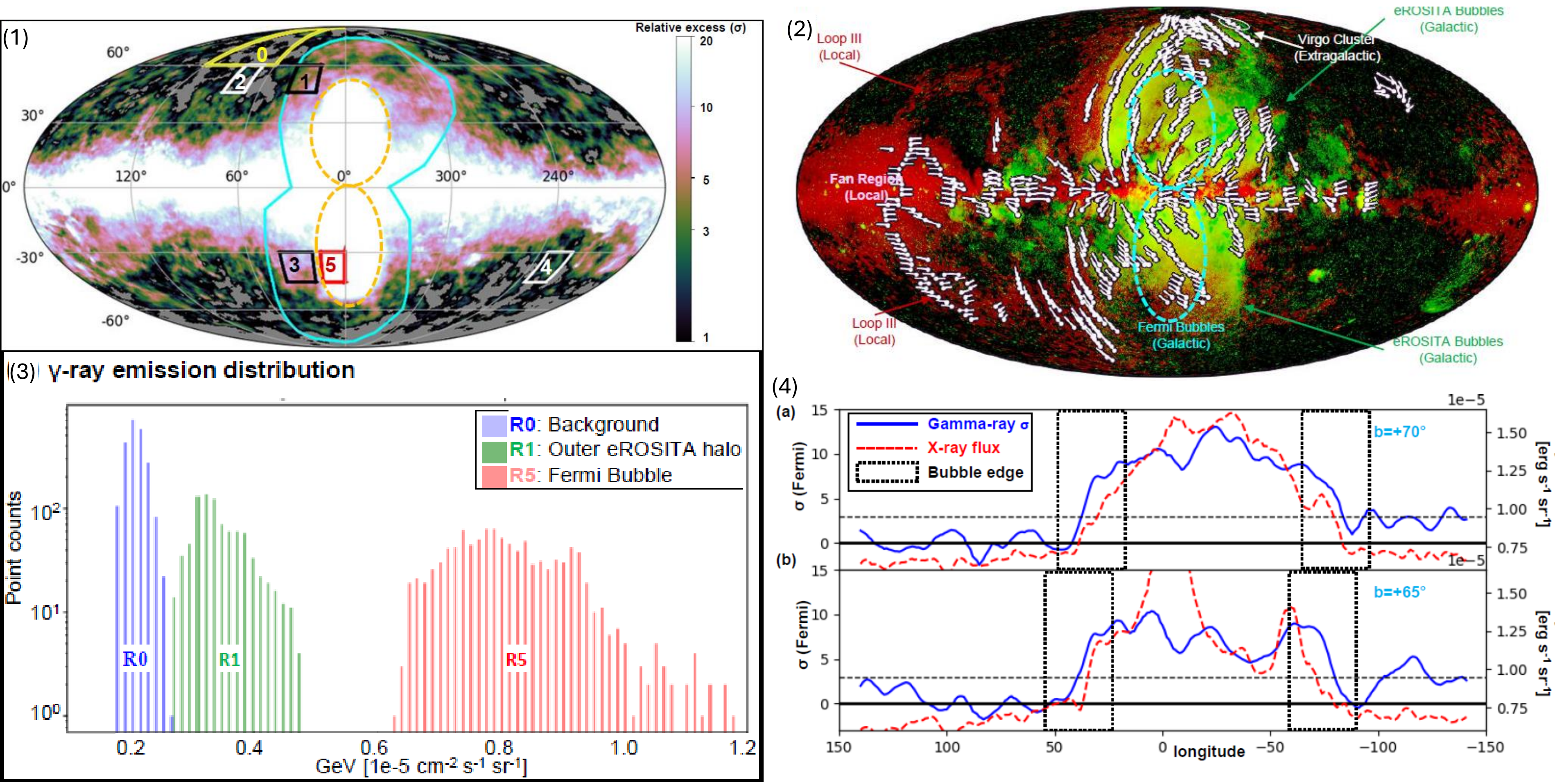
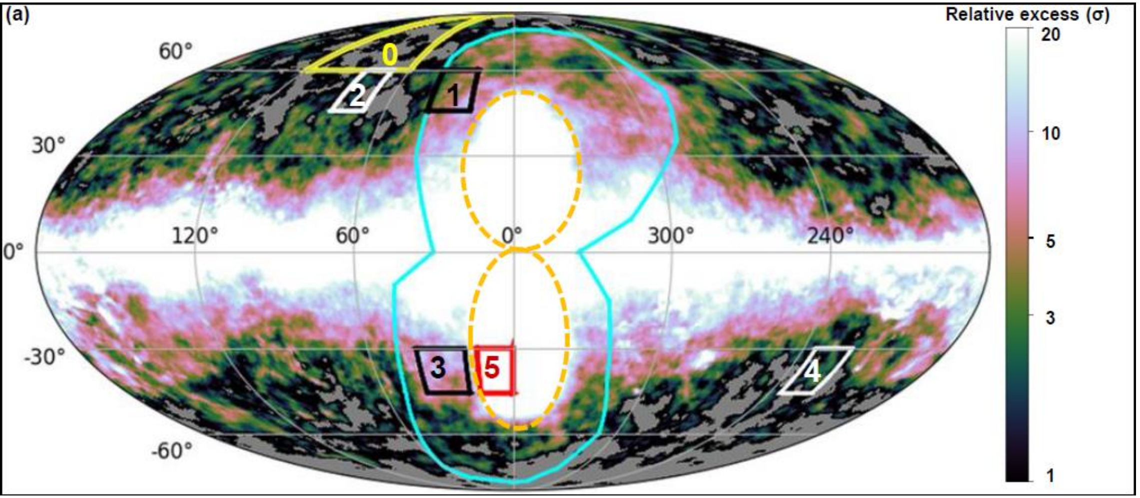


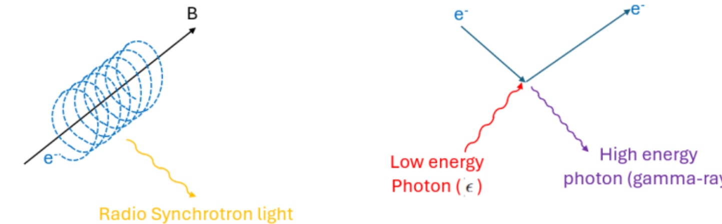
A gamma-diffuse halo (see 1), with magnetic ridges enhanced at the edges (see 2), independent of the background or Fermi Bubbles (see 3), and similar morphology to the eROSITA Bubbles (see 4)

5. Magnetic field strength measurements



Magnetic field strength diagnostic from multi-messenger approach

- Synchrotron:
  Relativistic electrons radiate when gyrating around the magnetic field
- Inverse Compton (IC):
  Relativistic electrons scatters low energy photons to gamma-ray



$E_{\rm syn} = 10^{-4}(E_e/40{\rm GeV})^2(B/1\mu{\rm G})\,{\rm eV}.$

$E_{\rm IC} \approx 3(E_e/40\,{\rm GeV})^2(\epsilon/0.4{\rm eV})\,{\rm GeV}$ — ISRF+CMB

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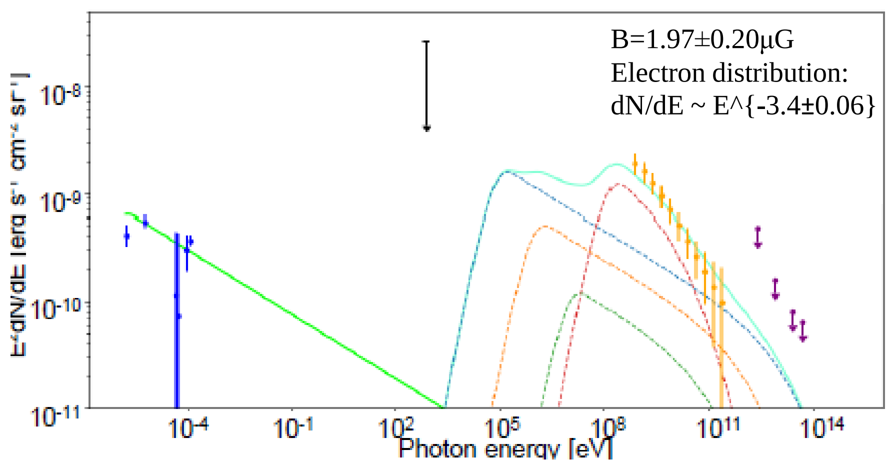
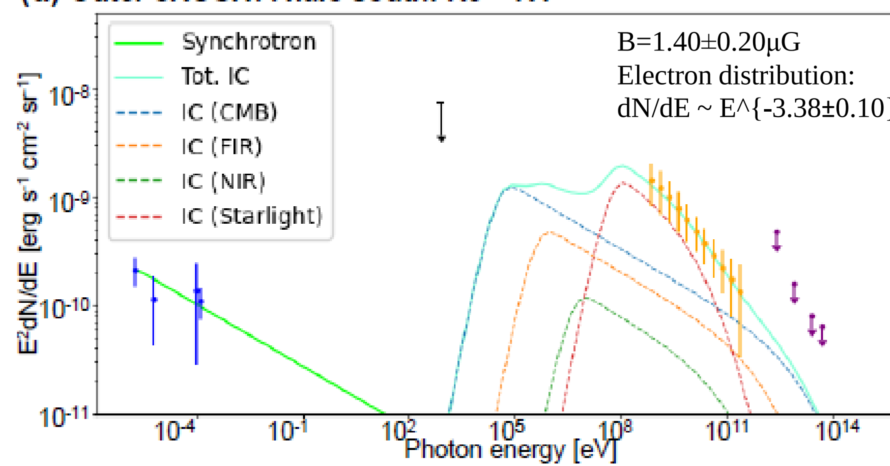
(c) Outer eROSITA halo north: R1 – R2

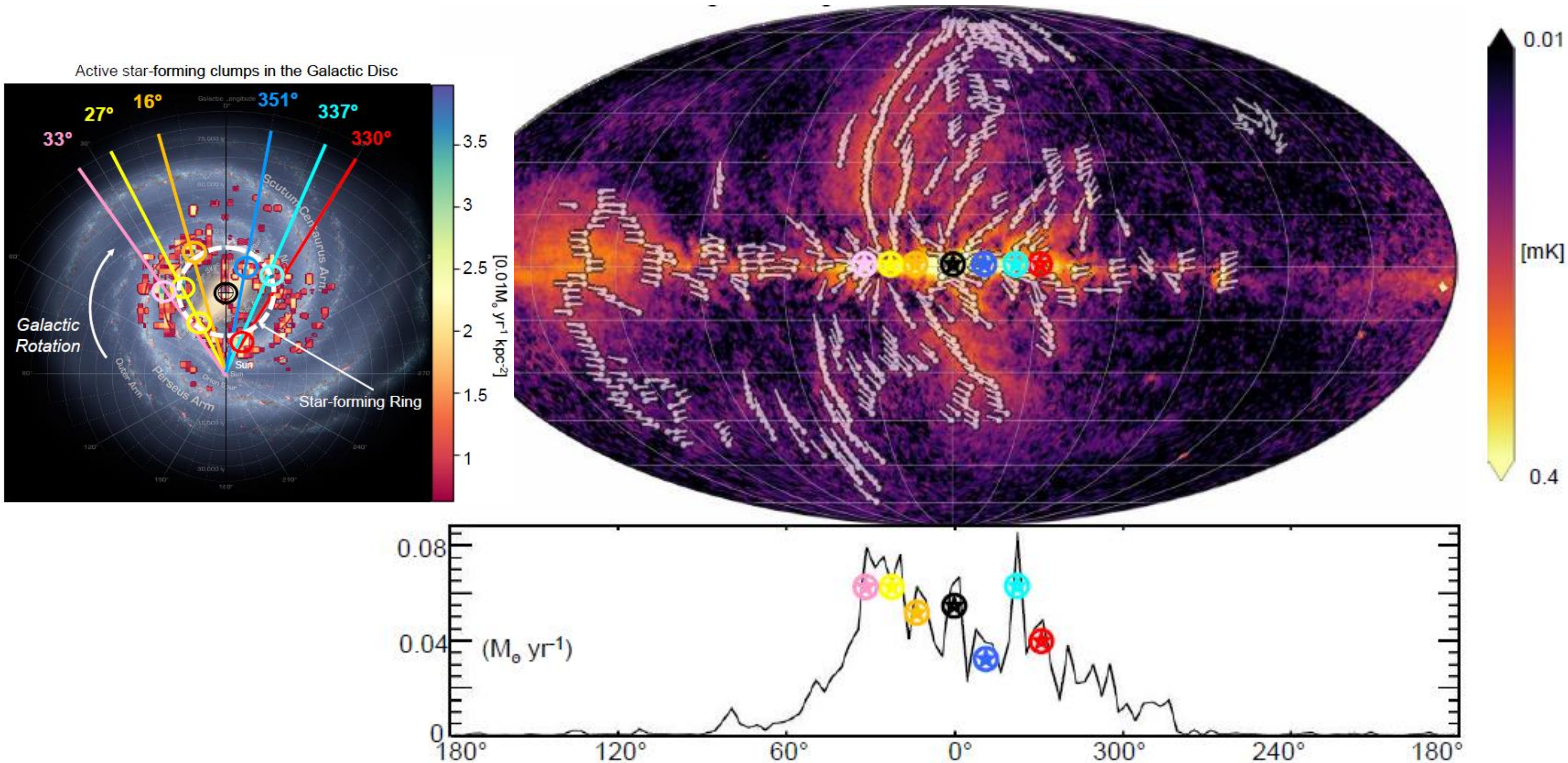


(d) Outer eROSITA halo south: R3 – R4



North-South non-thermal symmetry: **similar magnetic field, similar electron index, plasma-beta around 10**!

6. Magnetic Ridges in the halo vs Star Formation in the disc



Footpoints of the Magnetic ridges for Fermi Bubbles and eROSITA Bubbles are different:

Fermi Bubbles to the GC;

eROSITA Bubbles to a few kpcs from the GC!

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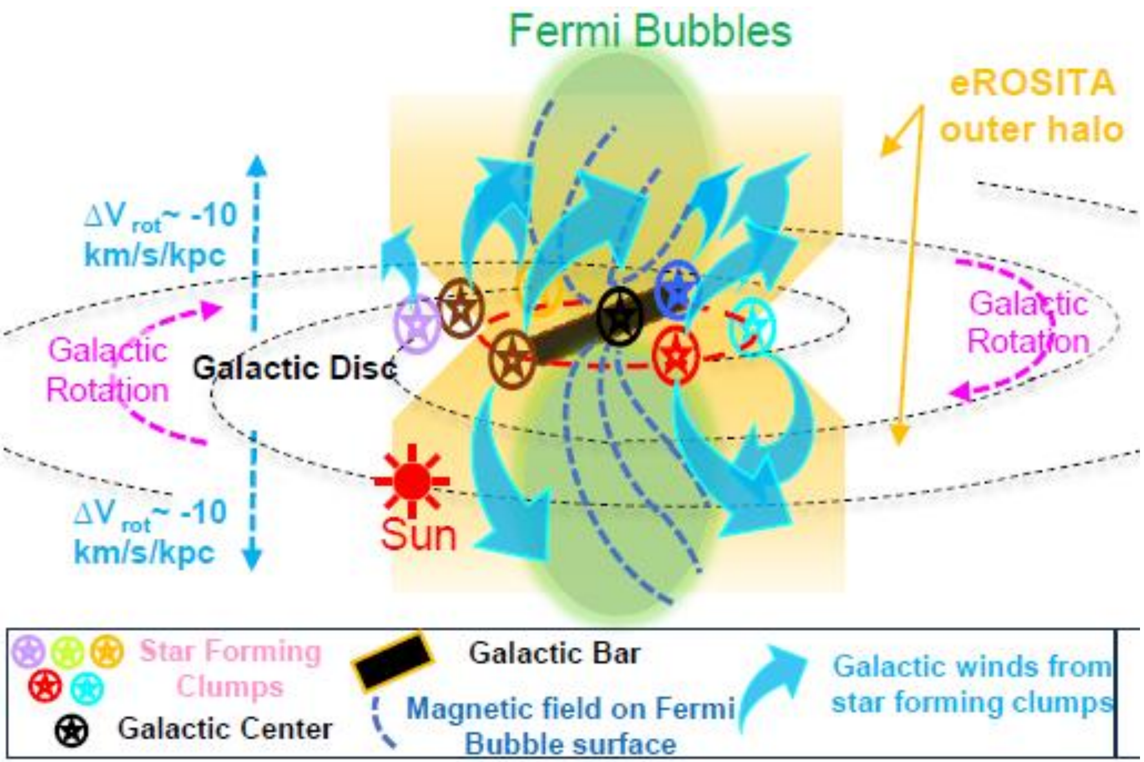
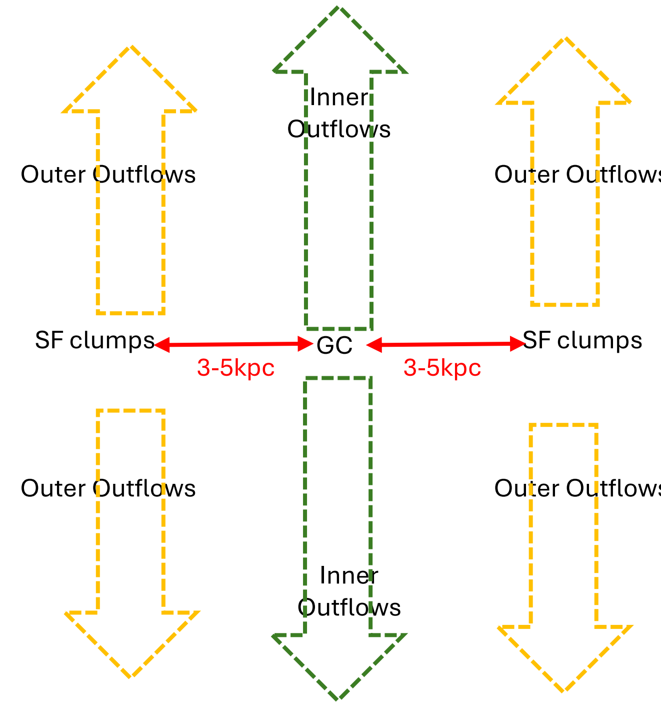
7. Magnetic halo and Galactic Outflows





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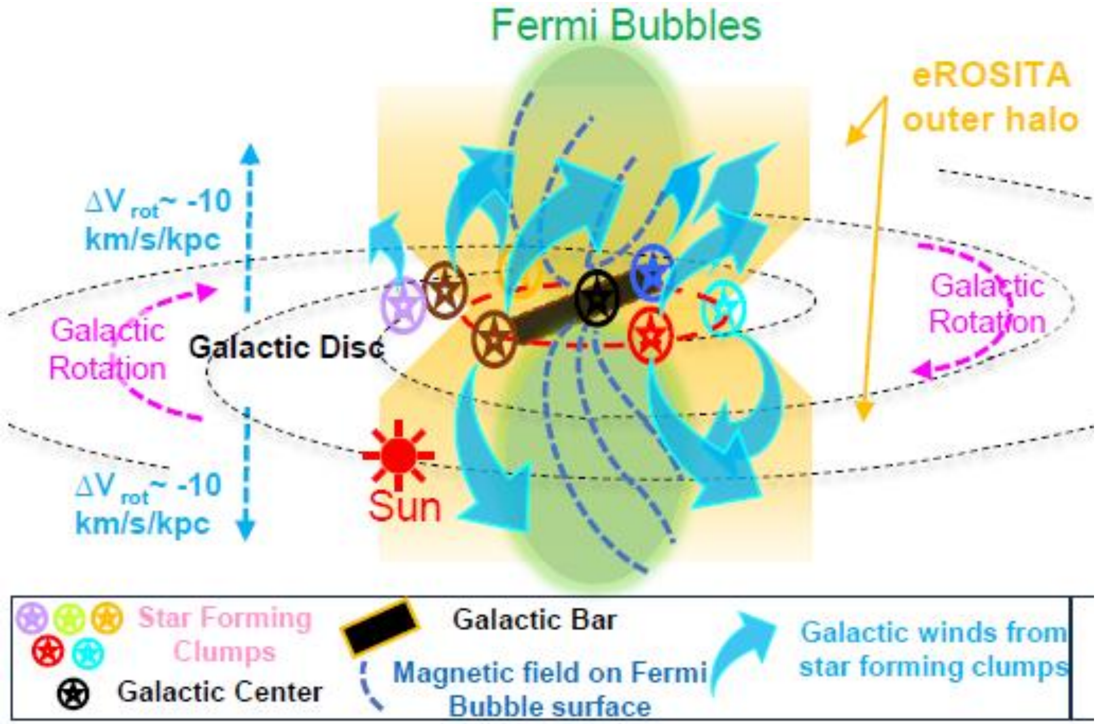

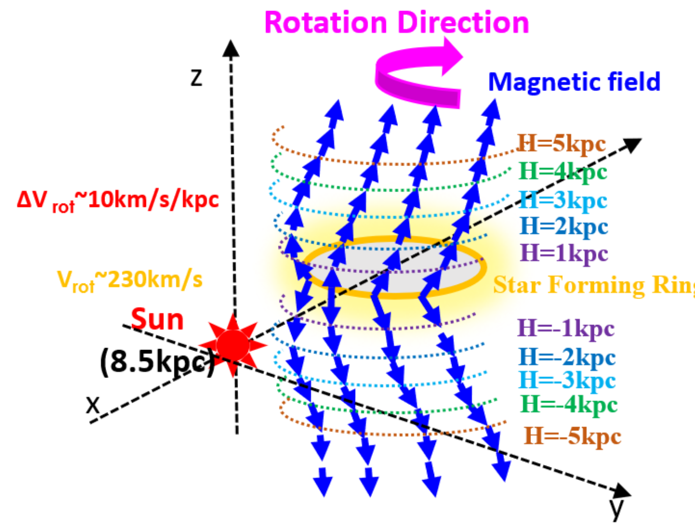

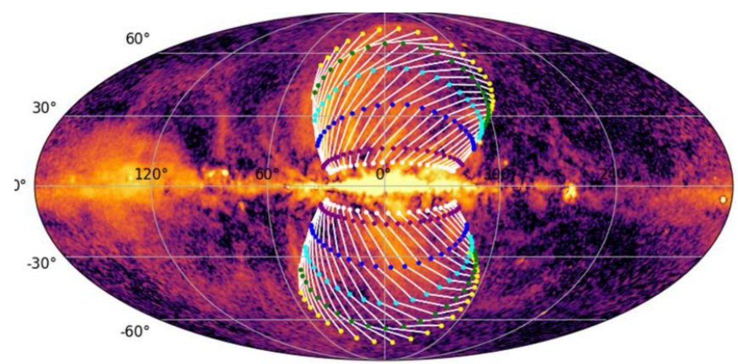

Magnetic field lines in the halo trace the Galactic outflows!

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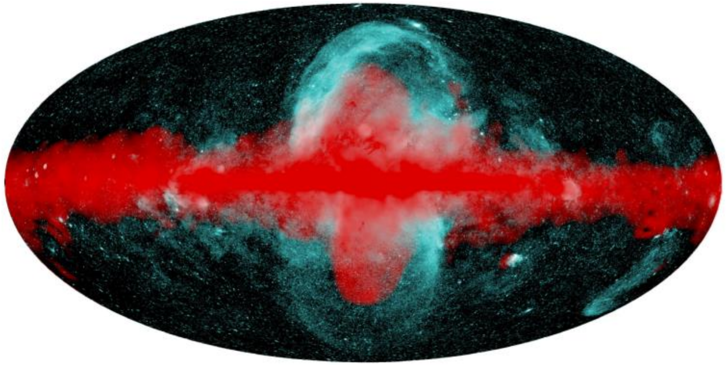
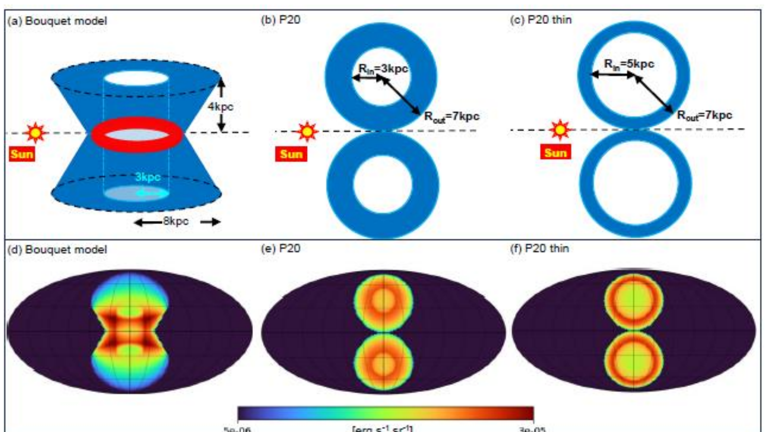
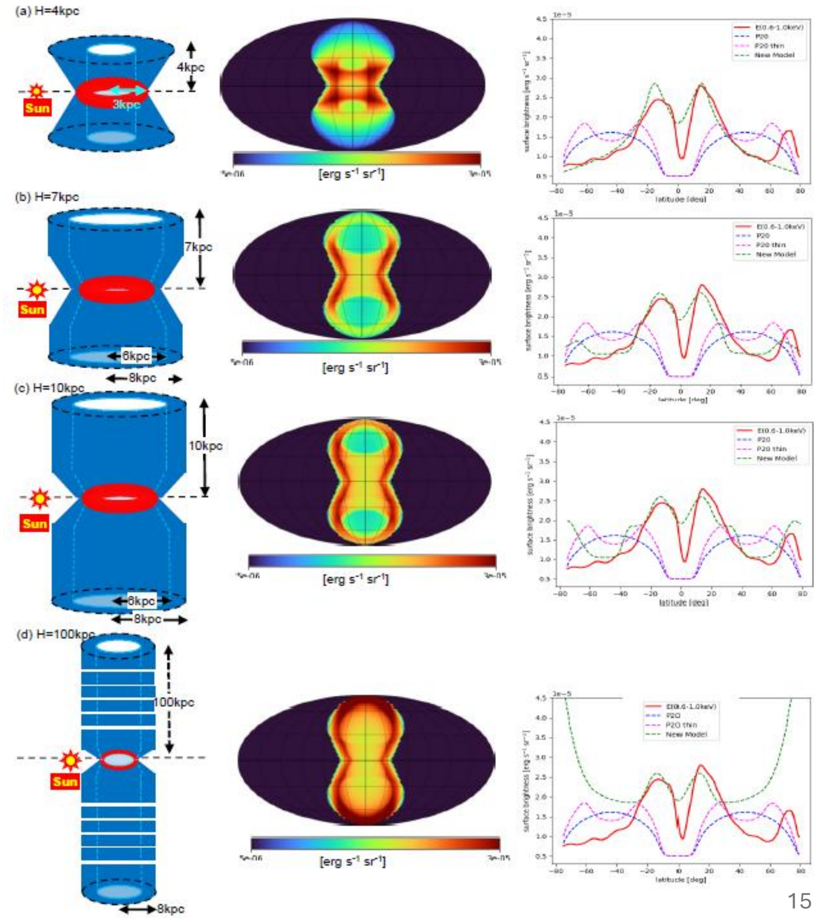
8. Some questions related to the eROSITA Bubbles

Q1. Are the eROSITA Bubbles really **Bubbles**? **Answer: No necessarily!**







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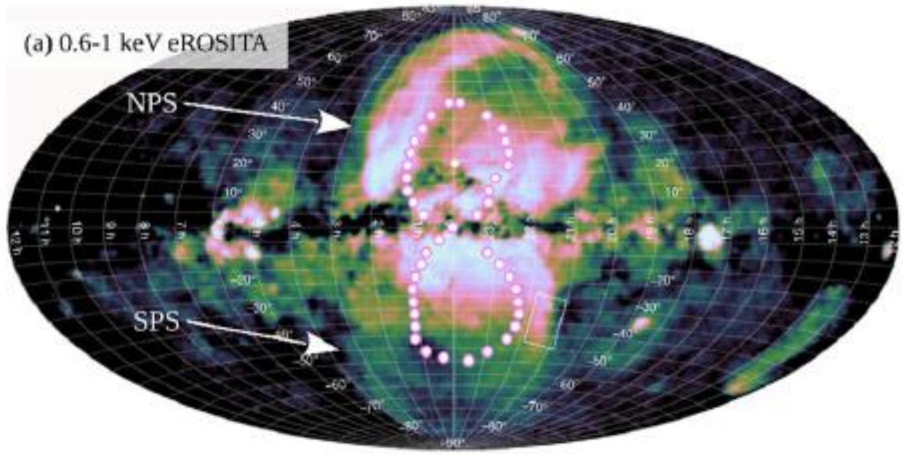
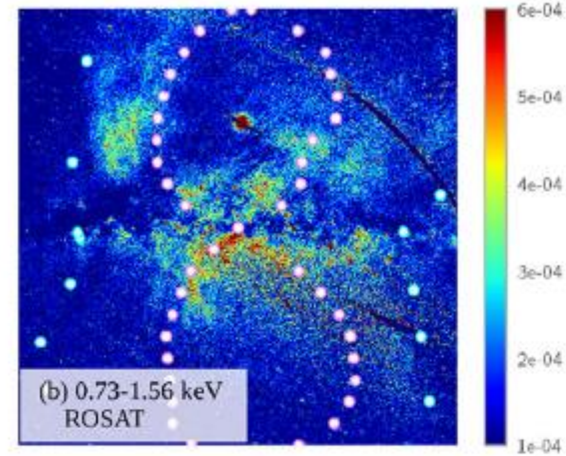
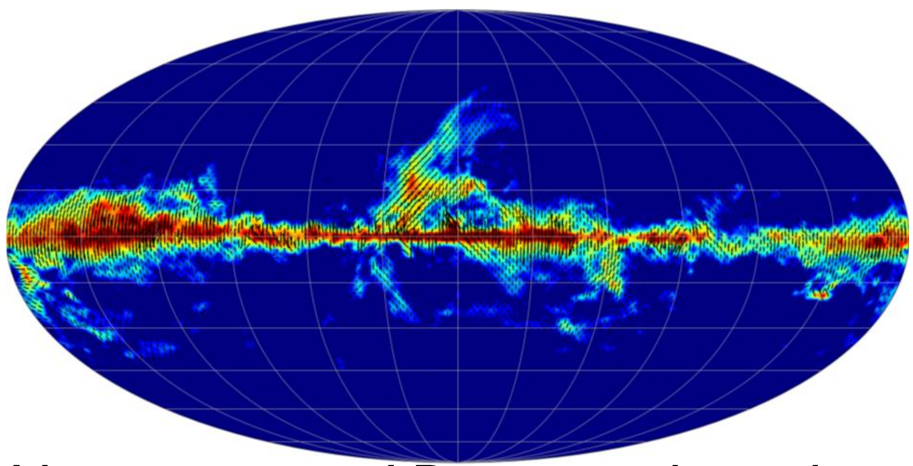
Ask me why eROSITA Bubbles caps over the Fermi Bubbles?

8. Some questions related to the eROSITA Bubbles

Q2. NPS caps over Fermi Bubbles indicates a shock front? **Answer: No necessarily!**



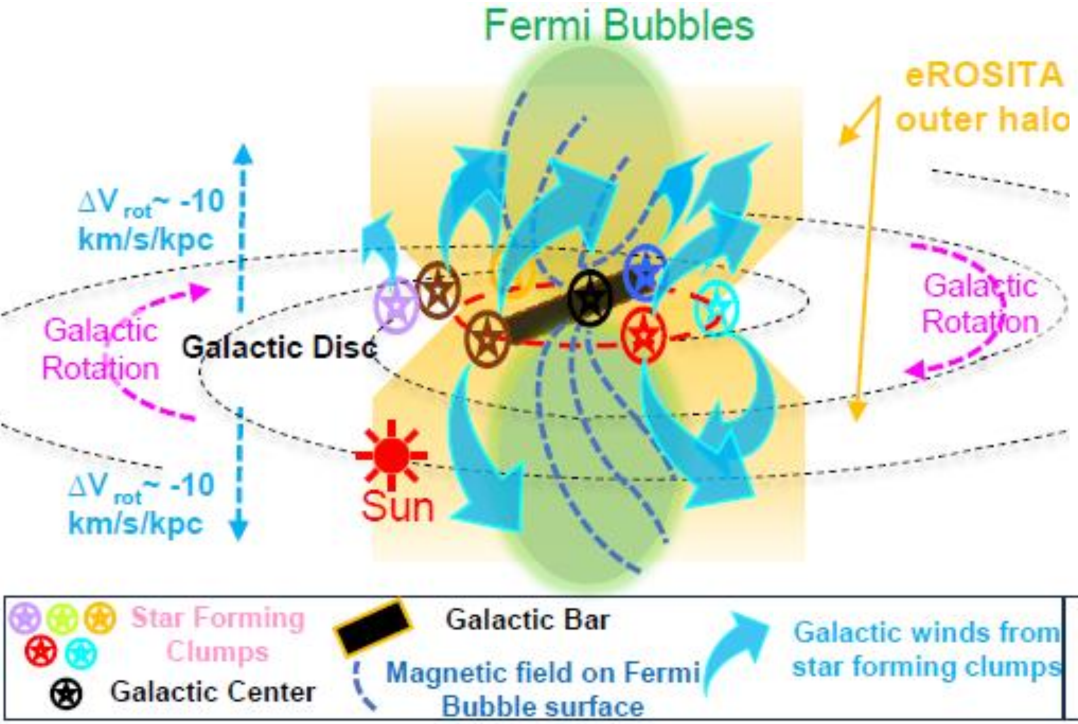




Not necessary! Because the enhancement in the upper cap can result from dust absorption!

8. Some questions related to the eROSITA Bubbles

Q3. Can 3-5kpc star forming ring fuel the multiphase outer outflows? **Answer: Yes!**



Assumptions						
H_{sys} [kpc]	4		7		10	
t_{dyn} [yrs]	10^8	10^9	10^8	10^9	10^8	10^9
Results						
E_{therm} [$\times 10^{55}$ erg]	5.9		10		14	
E_B [$\times 10^{55}$ erg]	1.5		3.3		5.3	
E_{tot} [$\times 10^{55}$ erg]	8.6		15		21	
$\dot{E}_{inj}$ [$\times 10^{40}$ erg/s]	2.7	1.4	4.7	2.5	6.6	3.5
χ_{inj} [%]	8.5	4.5	14.6	7.7	20.5	10.8
$\dot{M}_{inj}$ [$M_\odot$/yr]	0.54	0.28	0.92	0.49	1.3	0.68

The SNR rate in the 3-5 kpc star-forming ring is around 1 per century: $\dot{E}_{SFR} \simeq 3.2 \times 10^{41}$ erg/s.

1. The outer outflows can be powered by the 3-5 kpc star-forming ring by a few to 20% of their mechanical energy from SNe;
2. The mass injection rate required around 0.3 ~ 1.3 Solar mass / year.

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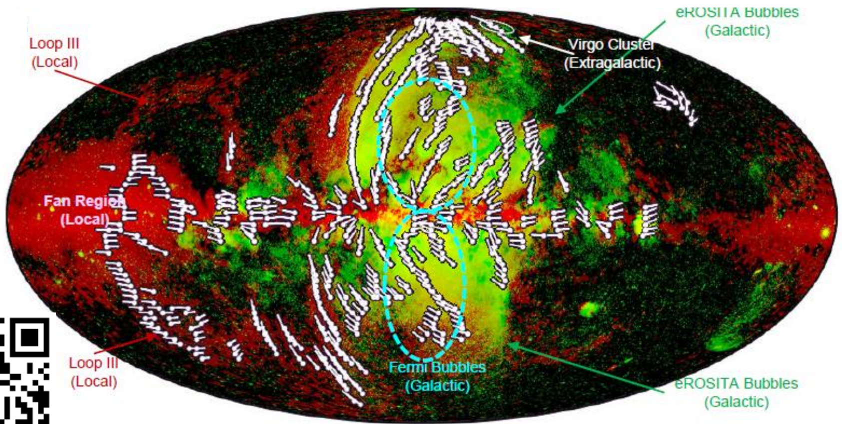
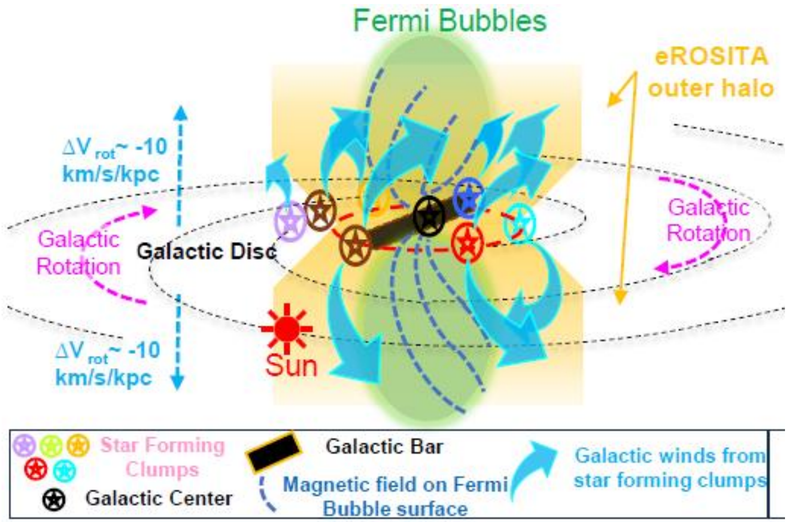
Summary

1. The Milky Way has **inner outflows** from GC (Fermi Bubbles) and **outer outflows** from the star forming clumps (eROSITA Bubbles, footpoints span several kpc).
2. The X-ray eROSITA Bubbles are hot plasma in the Galactic halo standing kpc scales above and below the Galactic disc, showing non-thermal emitting in **radio** (by synchrotron) and **gamma-ray** (by Inverse Compton) counterparts.
3. The coherent and highly anisotropic magnetic fields are identified in the Galactic halo, tracing the Galactic outflows.
4. Stellar feedback plays important role in the Galaxy feedback.
5. ***Future modelling for CR propagation in the Galactic halo should consider these new multi-wavelength measurements!***





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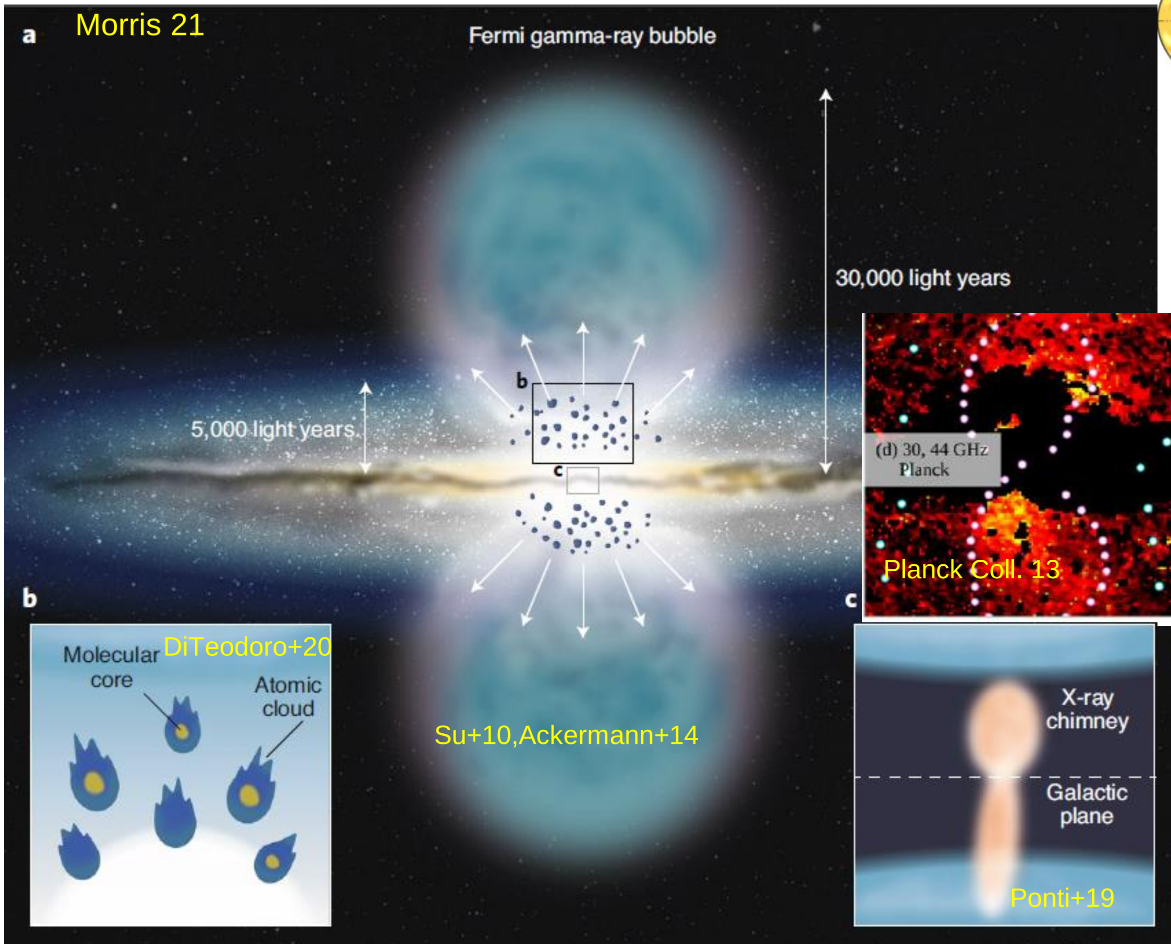
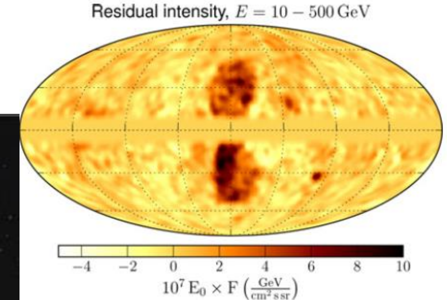
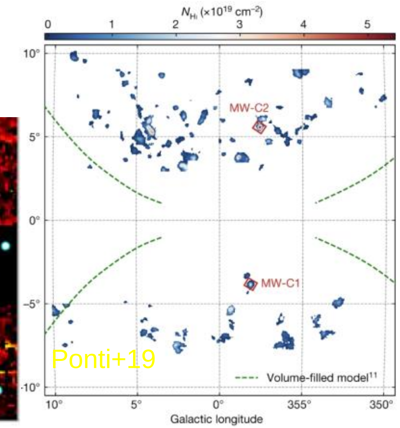
https://ui.adsabs.harvard.edu/abs/2024NatAs...8.1416Z/abstract

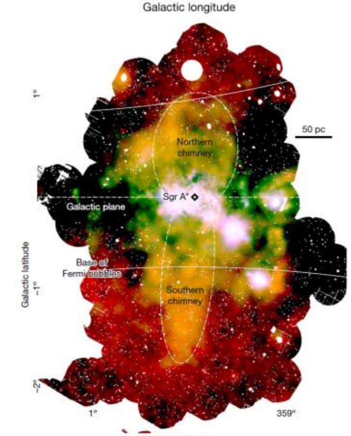
8. Some questions related to the eROSITA Bubbles

Elephant in the room: ***Fermi Bubbles***?



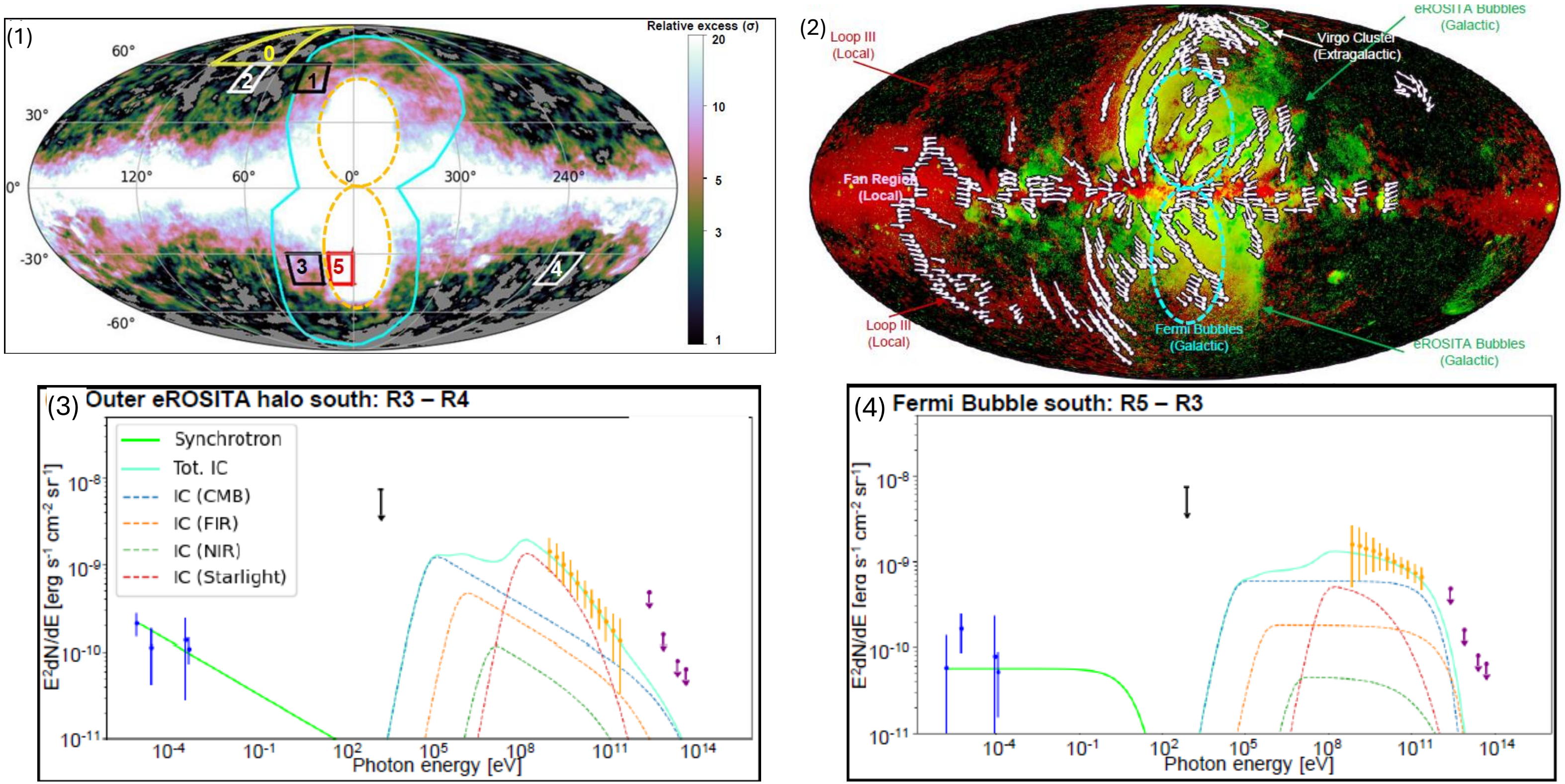






7. Magnetic halo and Galactic Outflows

SED for the Inner and Outer outflows of the Milky Way



Radio and gamma-ray fluxes in the outer region (left) is not lower than the inner region (right) at the same Galactic latitude. This indicates the injection **from the Fermi Bubbles are not enough to explain all the emission in the outer region (between boundaries of Fermi Bubbles and eROSITA Bubbles**).

The very soft index in the outer outflows indicates that **the gamma-ray extended outer halo is unlikely to be hadronic origin**!

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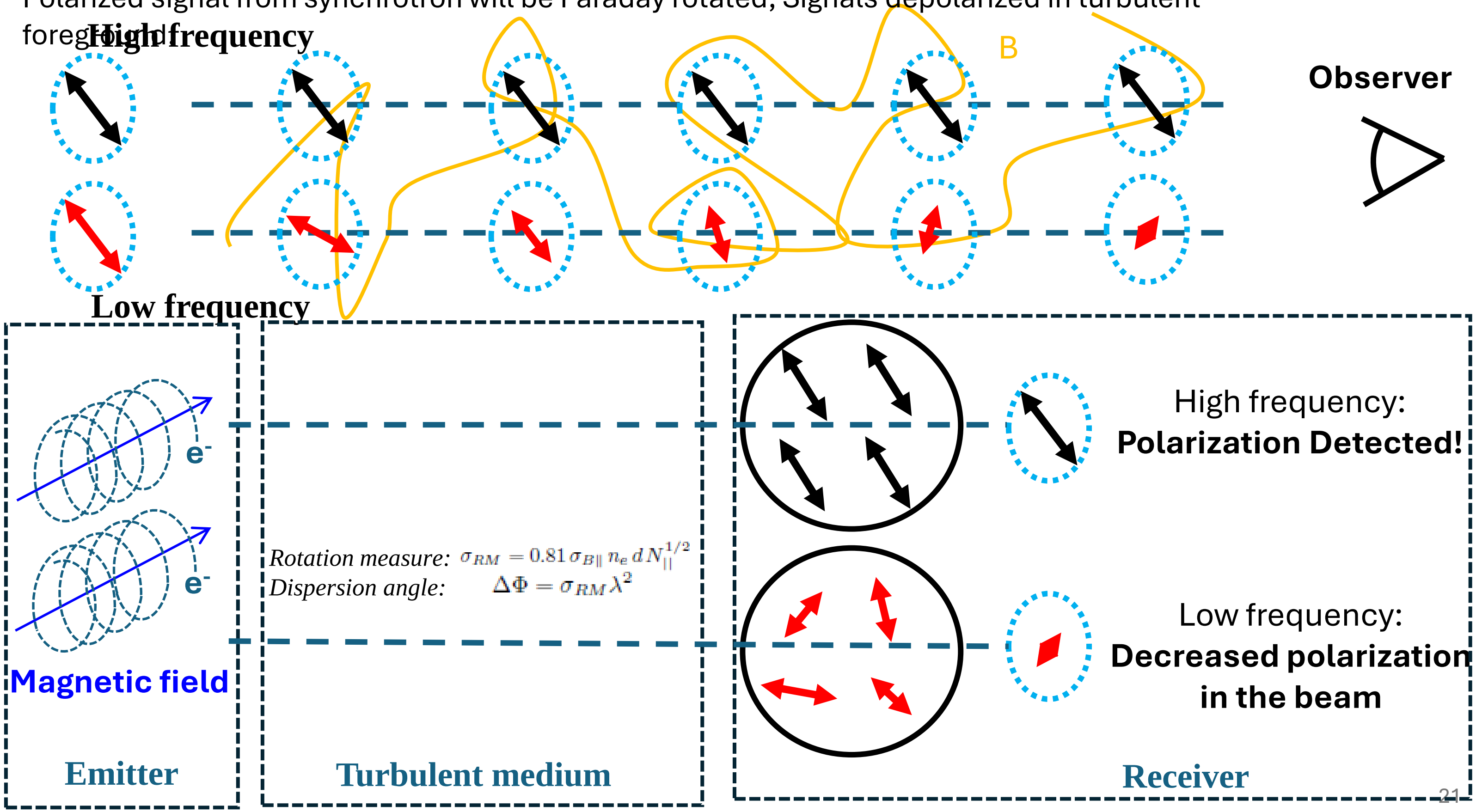
3. Question: Local or Galactic?

Faraday Rotation Depolarization

Polarized signal from synchrotron will be Faraday rotated, Signals depolarized in turbulent foreground.



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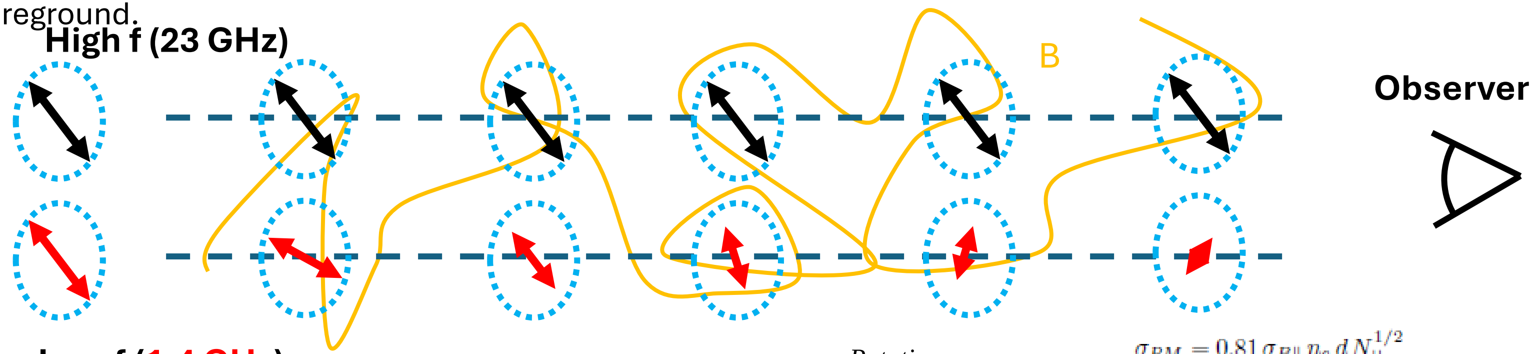

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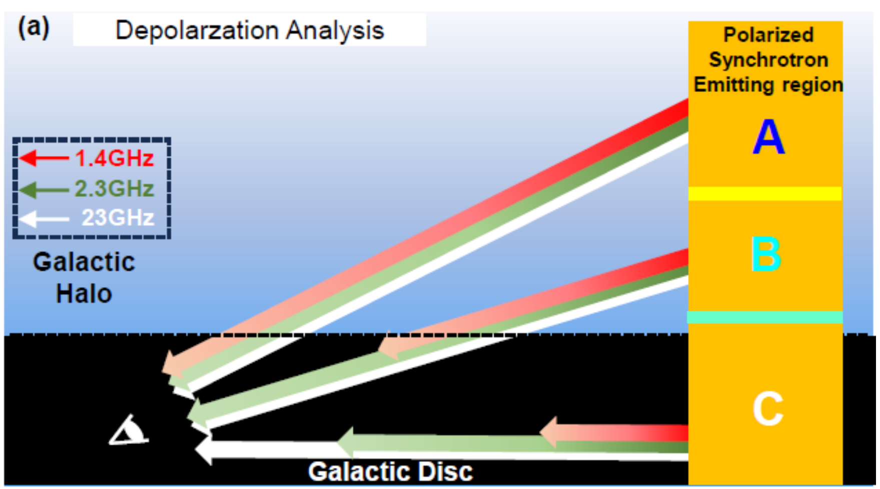
Dispersion angle: $\Delta\Phi = \sigma_{RM}\lambda^2$

LOS Integrations: $\sigma^2_{\rm RM} = \int_L^O (0.81 B_{\|}(l,b,L))^2\, d\, n_e^2(l,b,L)\delta\mathbf{L}$



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Ne: YMW16, Locatelli+24

B: Sun+10, JF12, JF12_Planck (Planck2018XLII)

The Galactic Disc will **imprint on the synchrotron structure!**

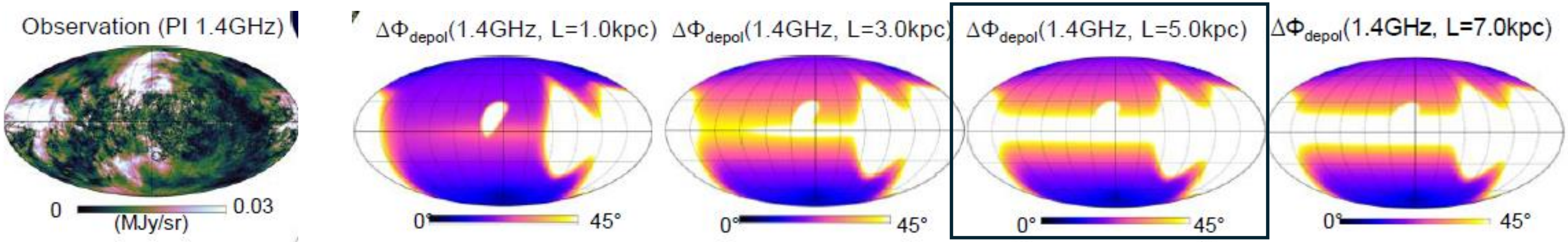
Lower frequency signal (longer wavelengths)

↓

More disc imprint

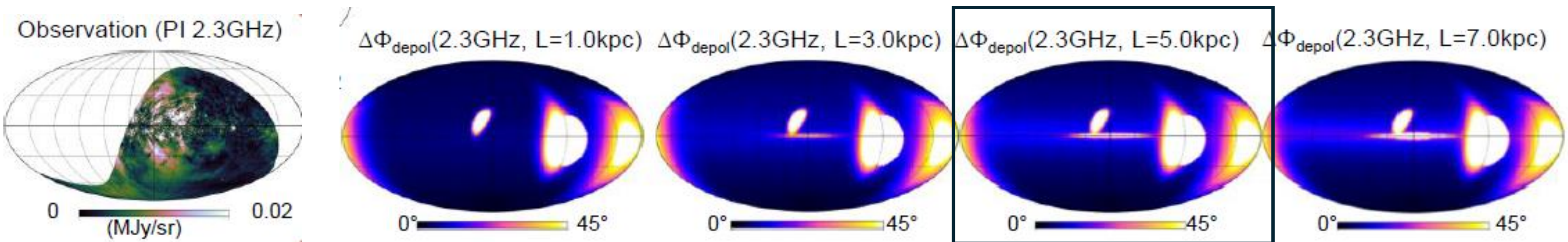
3. Question: Local or Galactic?

Depolarization screen at different distances



Depolarization screen at 5kpc anti-correlated with the observed polarized synchrotron emission.

These magnetic ridges are several kpc scales stemming out of the Galactic plane.



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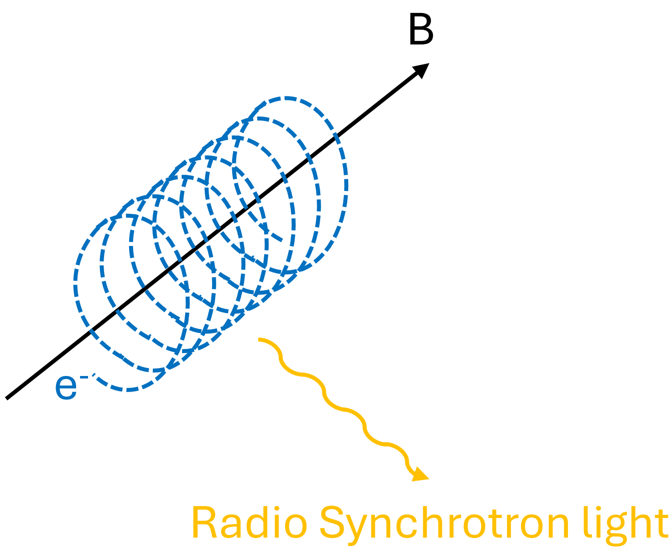
Magnetic field strength diagnostic from multi-messenger approach

- Synchrotron:

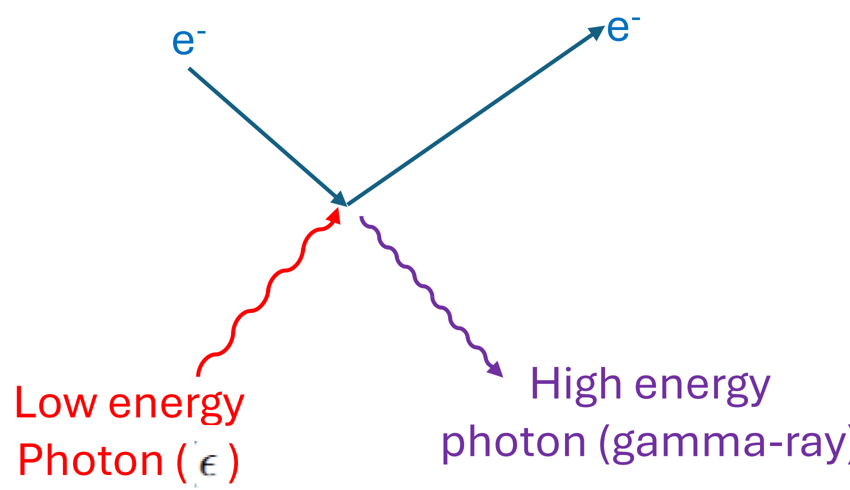
  Relativistic electrons radiate when gyrating around the magnetic field



$$E_{\rm syn} = 10^{-4}(E_e/40{\rm GeV})^2(B/1\mu{\rm G})\,{\rm eV}.$$

- Inverse Compton (IC):

  Relativistic electrons scatters low energy photons to gamma-ray



$$E_{\rm IC} \approx 3(E_e/40\,{\rm GeV})^2(\epsilon/0.4{\rm eV})\,{\rm GeV}$$

ISRF+CMB