Does the Local Bubble bias Galactic magnetic field reconstructions used to backtrack UHECRs?

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UHECRs, Magnetic Fields, and the Local Bubble

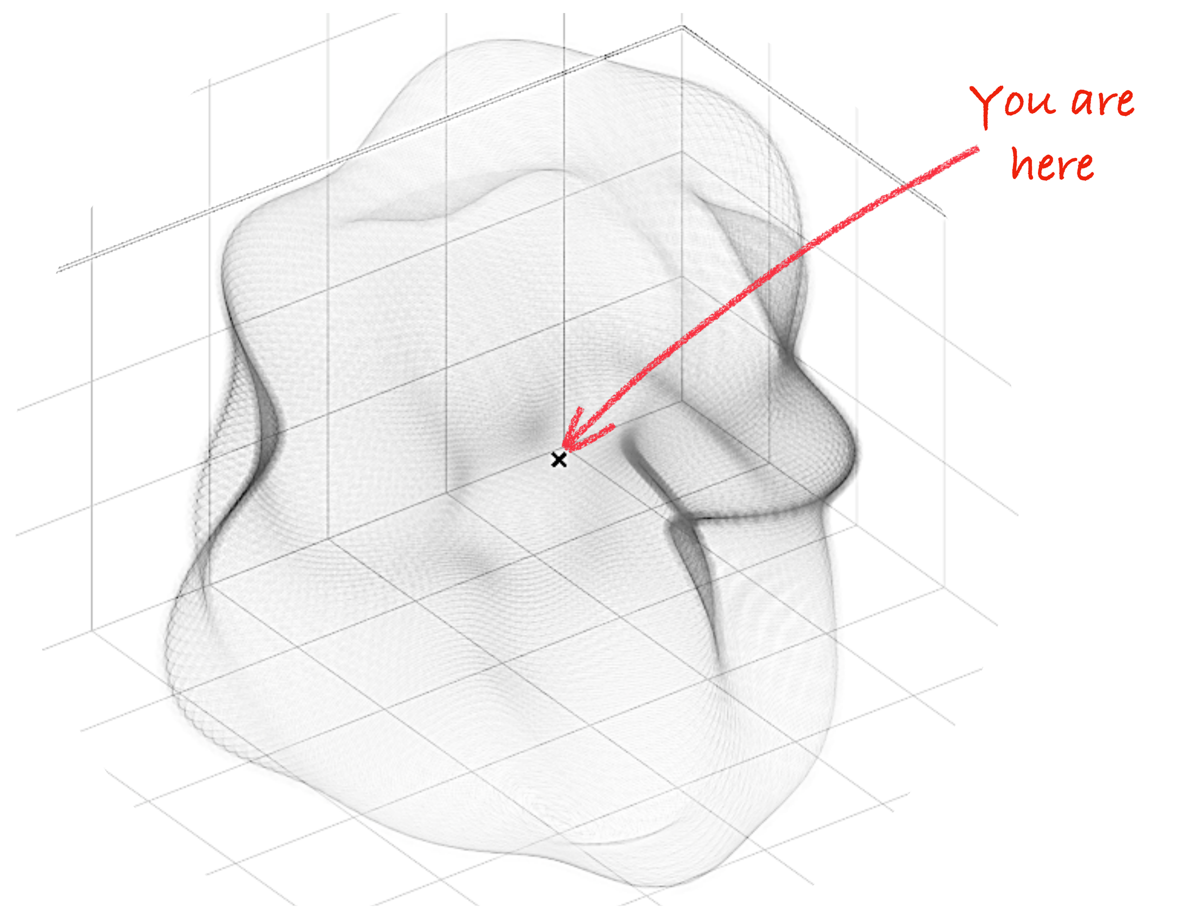
➢ The Solar system resides in the Local Bubble, a cavity of hot gas surrounded by a thick magnetized shell with a radius of 100 – 300 pc, and which results from supernovae explosions in the past 10 – 15 Myrs.

➢ What contribution does the magnetized shell of the Local Bubble make to Faraday rotation measures (RM) and synchrotron emission? What is its impact on large-scale Galactic magnetic field (GMF) modeling (e.g. [1])?

➢ Significant effect on GMF modeling has been observed using a simple spherical model for the Local Bubble [2].

➢ However, the Local Bubble is highly asymmetrical [3]. Here, we explore the consequences of a more realistic Bubble shape obtained from 3D dust density map, and propose a solenoidal solution for the magnetic field in the shell [4].

The shape of the inner surface of the Local Bubble



B in the Thick Shell of the Local Bubble

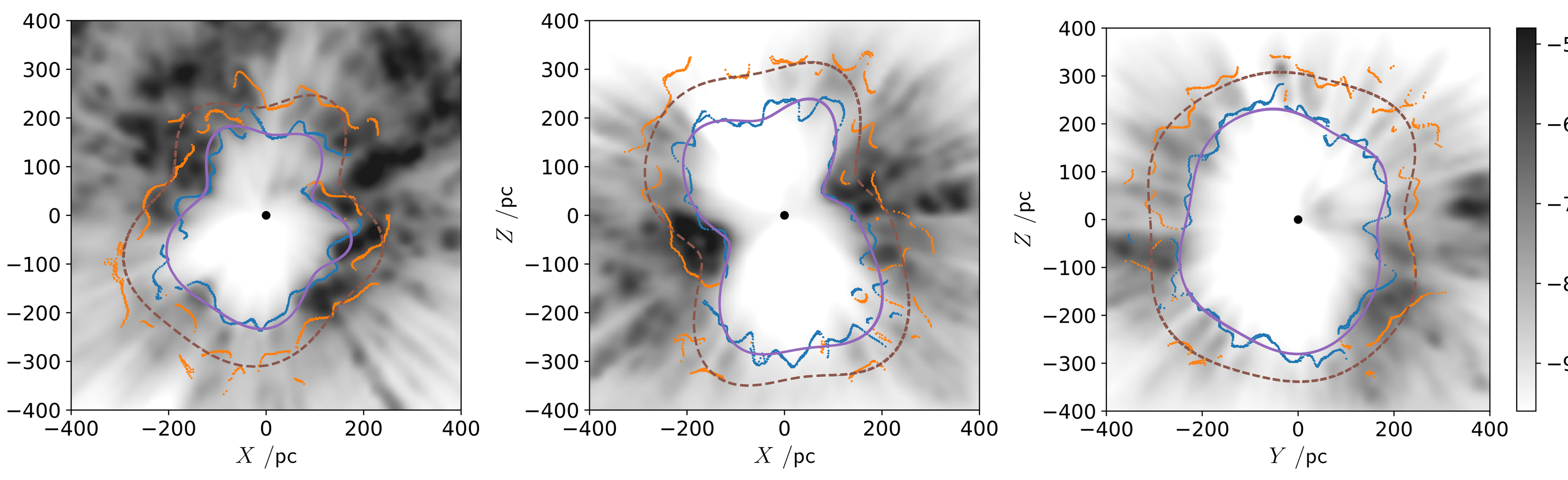
➢ A new analytical model for the divergence-free magnetic field in the thick shell of any-shaped bubble resulting from a supernovae explosion that has radially swept away matter and magnetic field line:

$$\begin{cases} B_r = \left(\frac{r^0}{r}\right)^2 B^0_r + \frac{r^0}{r}\nabla_t\Lambda\cdot\mathbf{B}^0_t \\ B_\theta = \frac{r^0}{r}\frac{\partial r^0}{\partial r}B^0_\theta \\ B_\phi = \frac{r^0}{r}\frac{\partial r^0}{\partial r}B^0_\phi \end{cases} \quad \text{where} \quad \begin{cases} r^0 = r-\Lambda \\ \mathbf{B}^0_t = B^0_\theta\,\mathbf{e}_\theta + B^0_\phi\,\mathbf{e}_\phi \\ \nabla_t\Lambda = \frac{1}{r}\frac{\partial\Lambda}{\partial\theta}\mathbf{e}_\theta + \frac{1}{r\sin\theta}\frac{\partial\Lambda}{\partial\phi}\mathbf{e}_\phi\,, \end{cases}$$

where $\mathbf{B}$ is the magnetic field in the shell, $\mathbf{B}^0$ is the initial magnetic field and $\Lambda(r,\theta,\phi)$ is the displacement field, that can be inferred from observation.

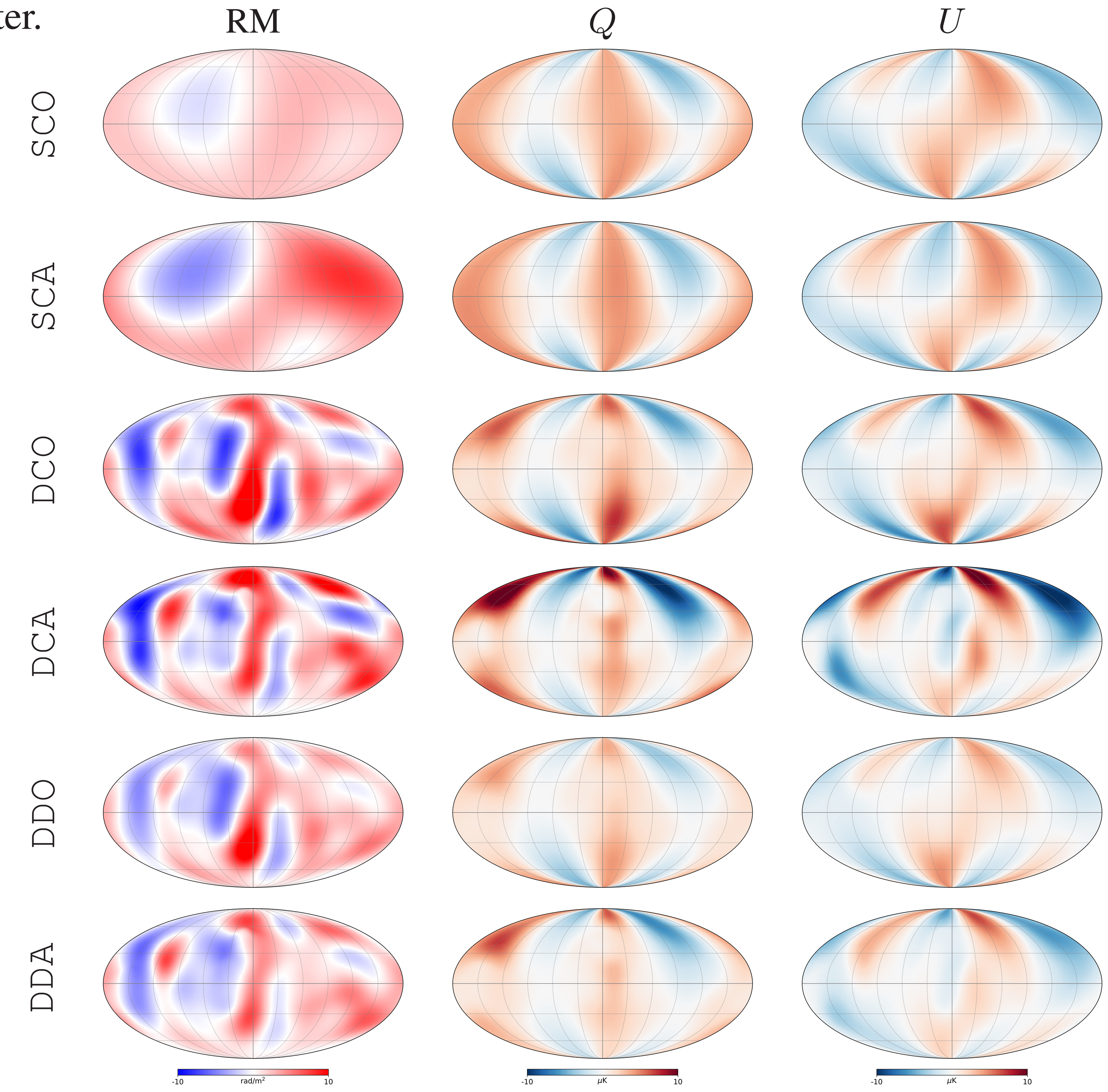
➢ Extraction and modeling of the inner and outer surfaces of the shell of the Local Bubble from the 3D dust density map of [5].

Crosscuts through the Local Bubble and its surrounding dust



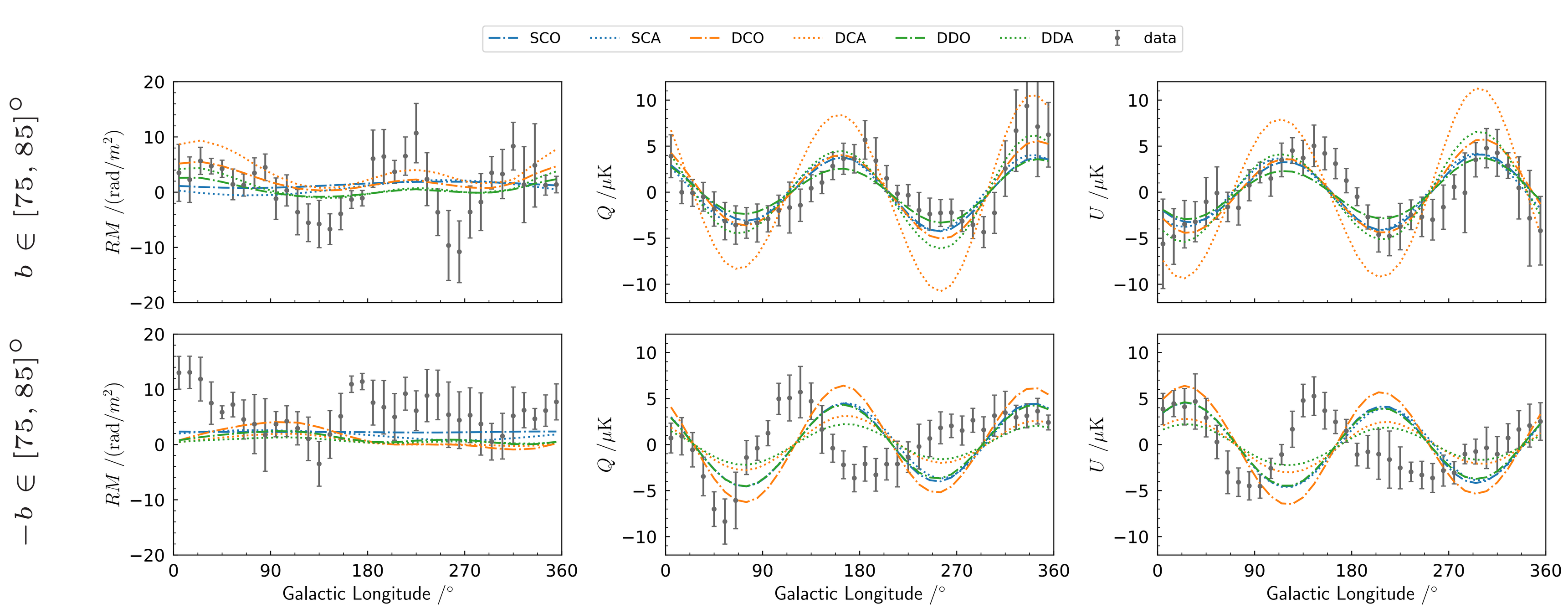
Contribution to GMF Observables

➢ Exploring various scenarios with varying shell complexity and explosion center.

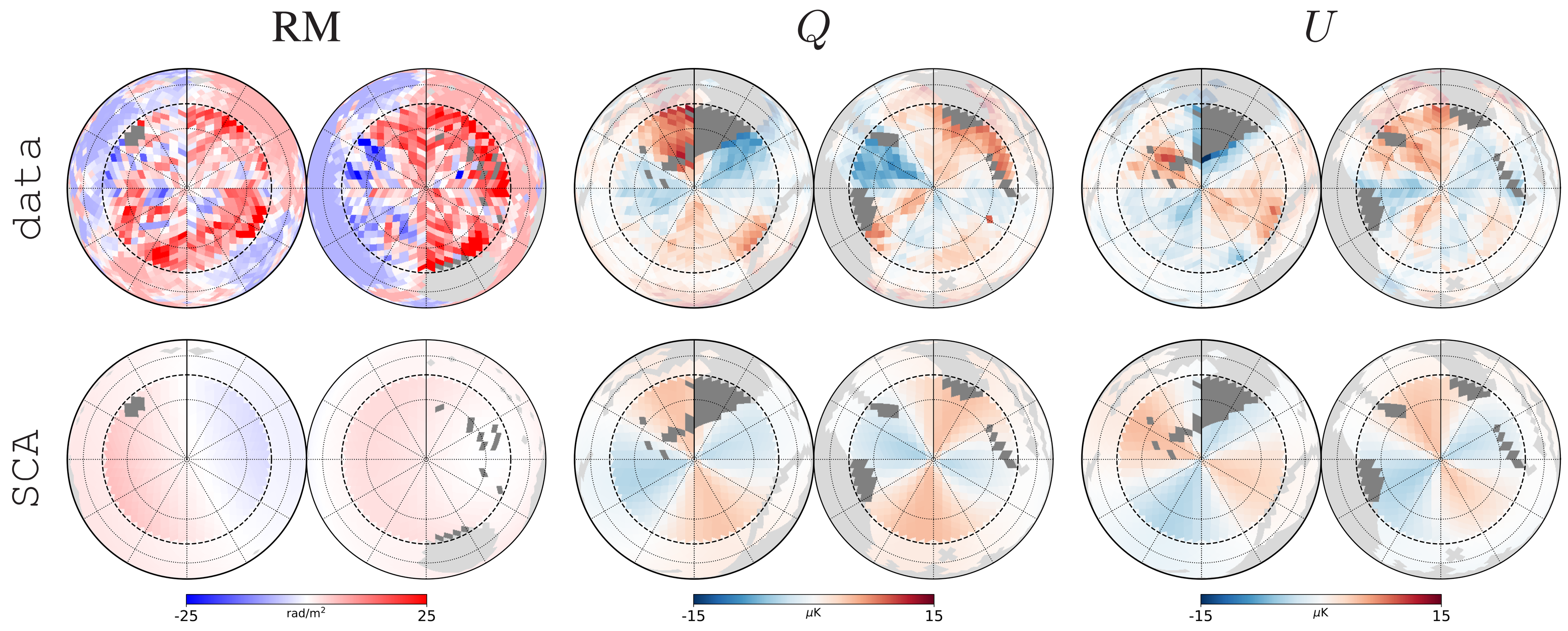


Comparison between Scenarios and with Data

Longitude profiles for $75° < b < 85°$ (top) and $-85° < b < -75°$ (bottom)



Orthographic view of the data [1] and SCA model



Conclusions

- Theoretical calculation of magnetic field deformations for a realistic shape of the Local Bubble obtained from a 3D dust density map.
- The thick shell of the Local Bubble contributes significantly to synchrotron emission (Q and U) at $|b| \gtrsim 45°$, with a qualitative match of the phase and amplitude of the signal. The contribution to Faraday rotation measure is minimal.
- Specifics of the Local Bubble shell and explosion center are key parameters in model predictions.

References

[1] Unger & Farrar 2024, ApJ, 970, 95
[2] Korochkin, Semikoz & Tinyakov 2024, arXiv:2407.02148
[3] Pelgrims et al. 2020, A&A, 636, A17
[4] Pelgrims, Unger & Mariş 2024, submitted to A&A, arXiv:2411.06277
[5] Lallement et al. 2019, A&A, 625, A135