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# Modeling the magnetic field in the solar neighborhood

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CMB-France #7
Paris, IAP, October 15th 2025.

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*In collaboration with :*

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*Anthony J. Banday*
*Jonathan Aumont*
*Ludovic Montier*
*Douglas Marshall*



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# What is the Local Bubble ?

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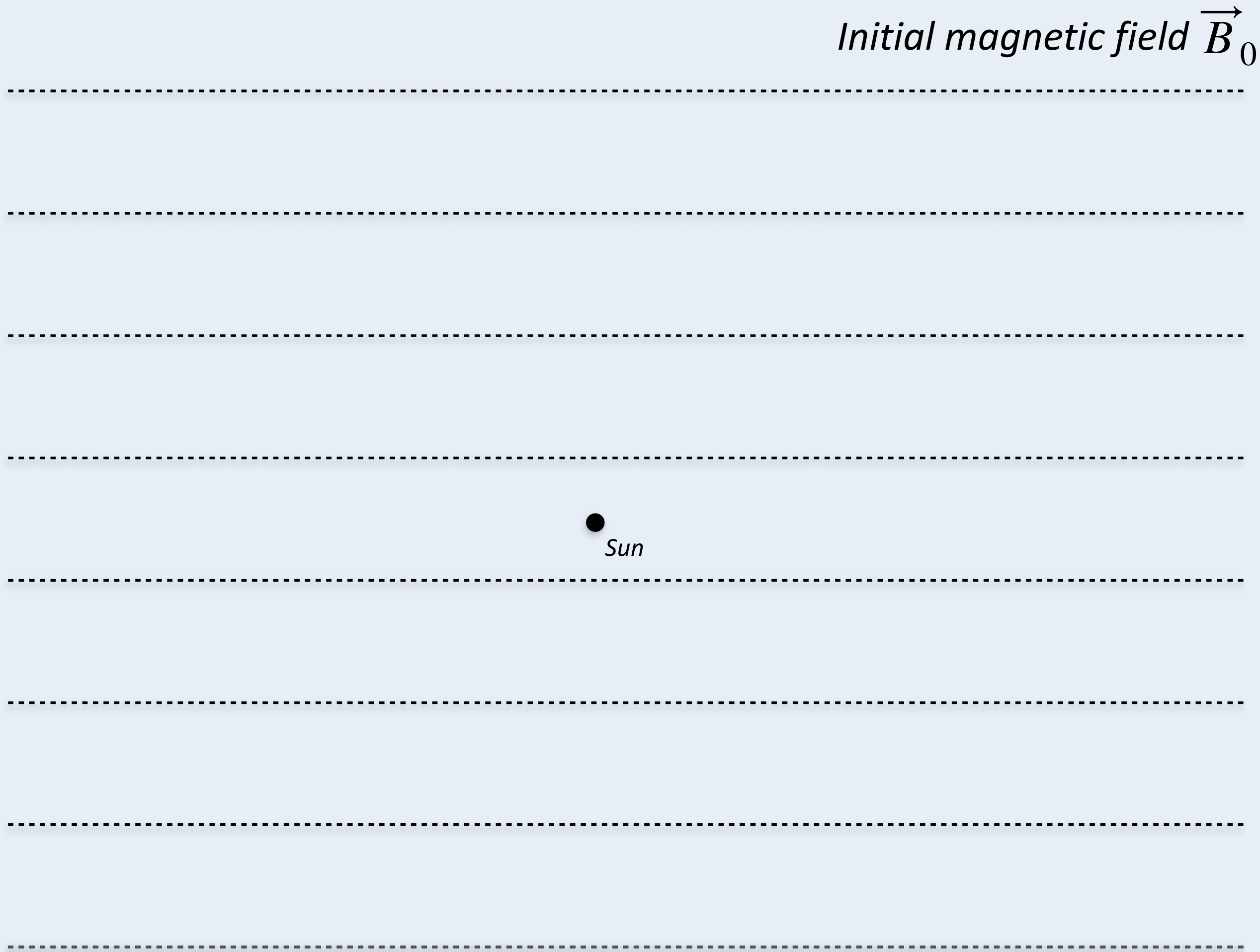




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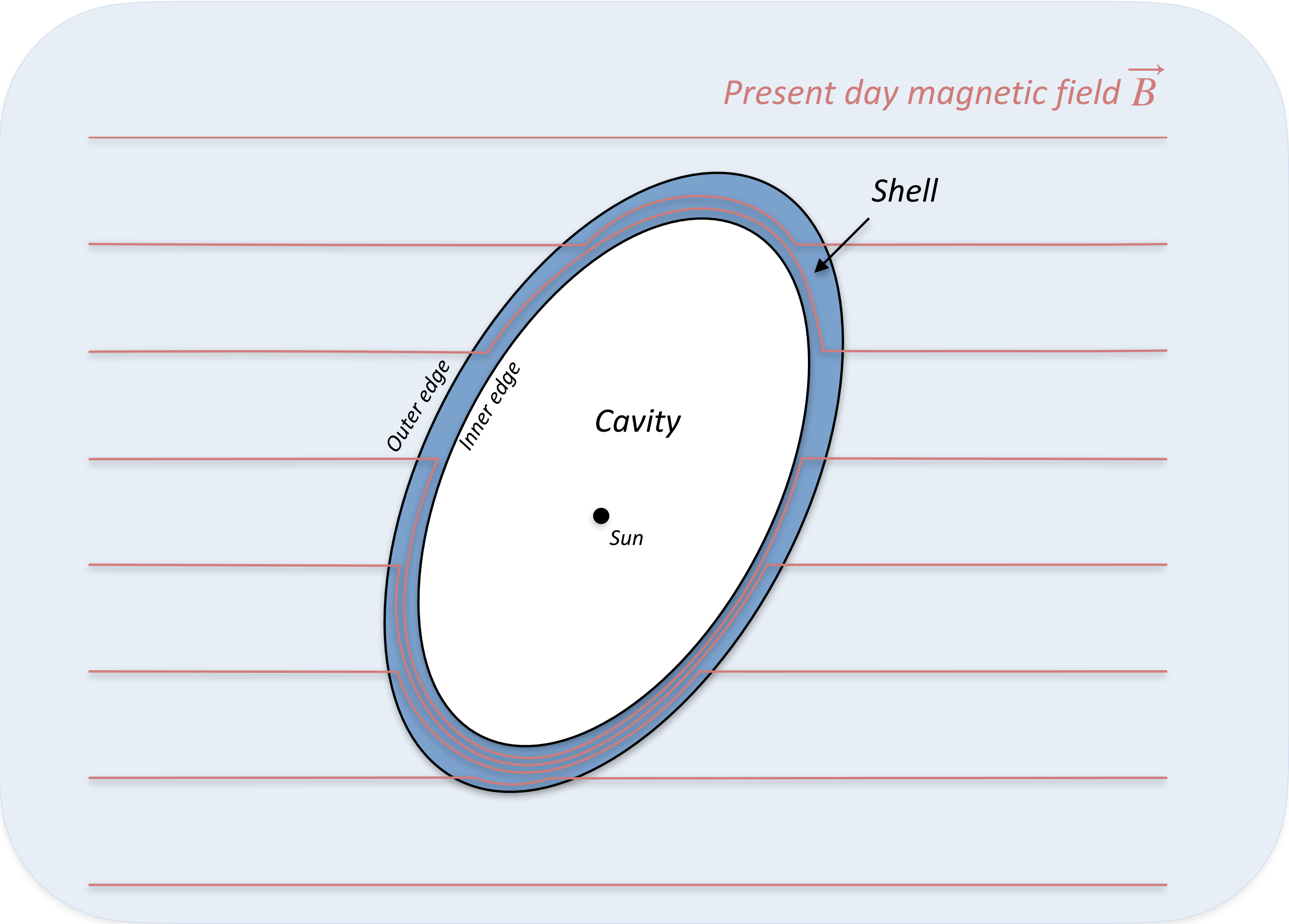
# What is the Local Bubble ?



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# Previous studies

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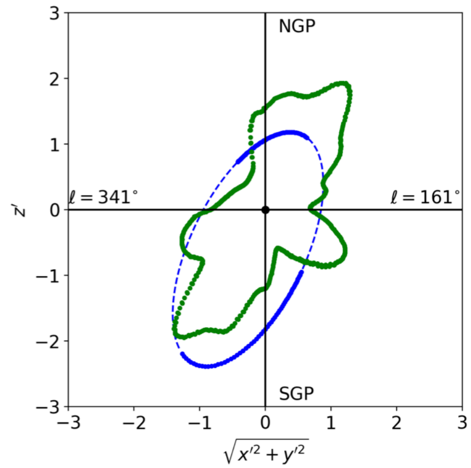
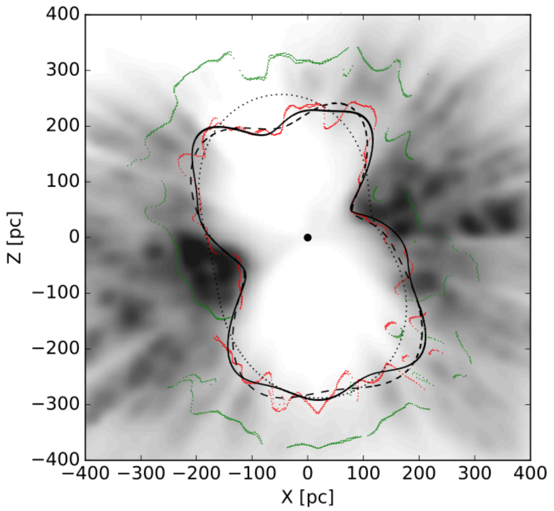
## ***Alves et al. (2018)***

Ellipsoid




## ***Pelgrims et al. (2020)***

LB shape : Lallement data (2018)

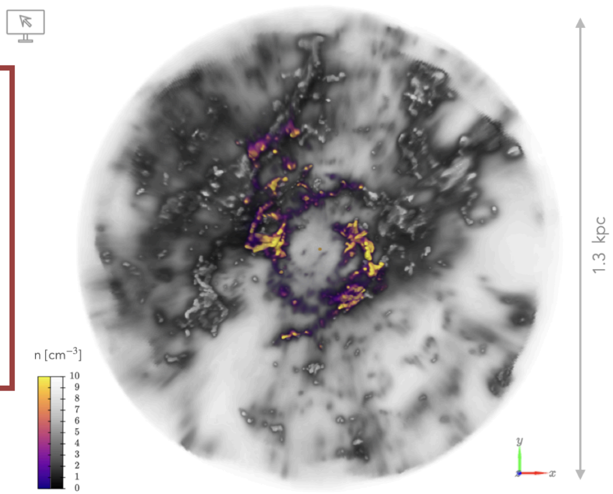



*A lot of datasets to use !*

*We aim at providing multiple estimations of the LB and predictions for Q and U*

## ***O'Neill et al. (2024)***

LB shape : Edenhofer data (2023)



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# Extracting the shape of the shell

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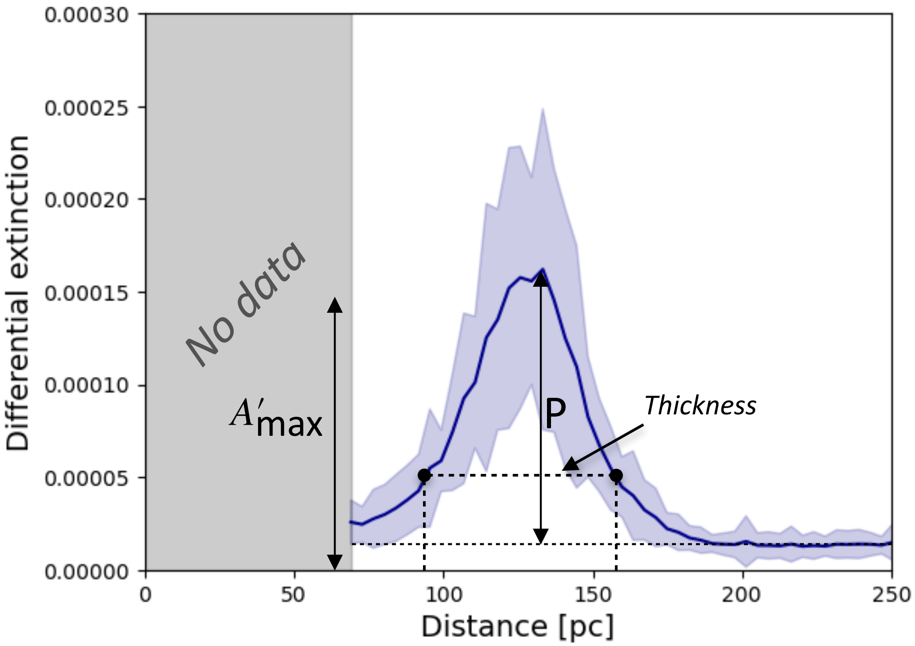
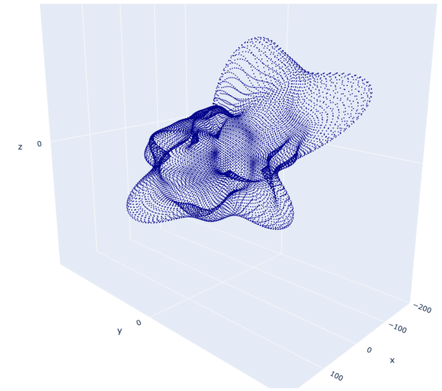
The shape of the shell has to be extracted from 3D dust density

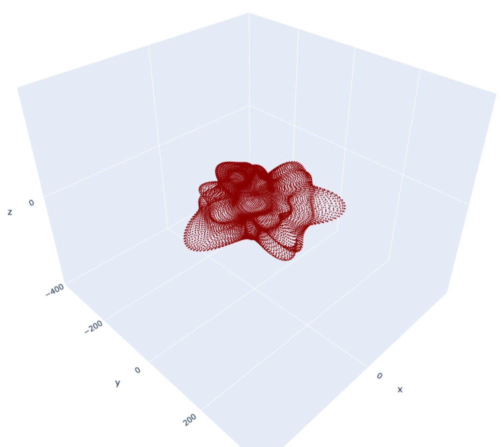



$$A'_{\alpha} = A'_{\max} - \alpha \cdot P$$

*Edenhofer and al. (2023)*



*Leike and al. (2018)*



# Displacement field

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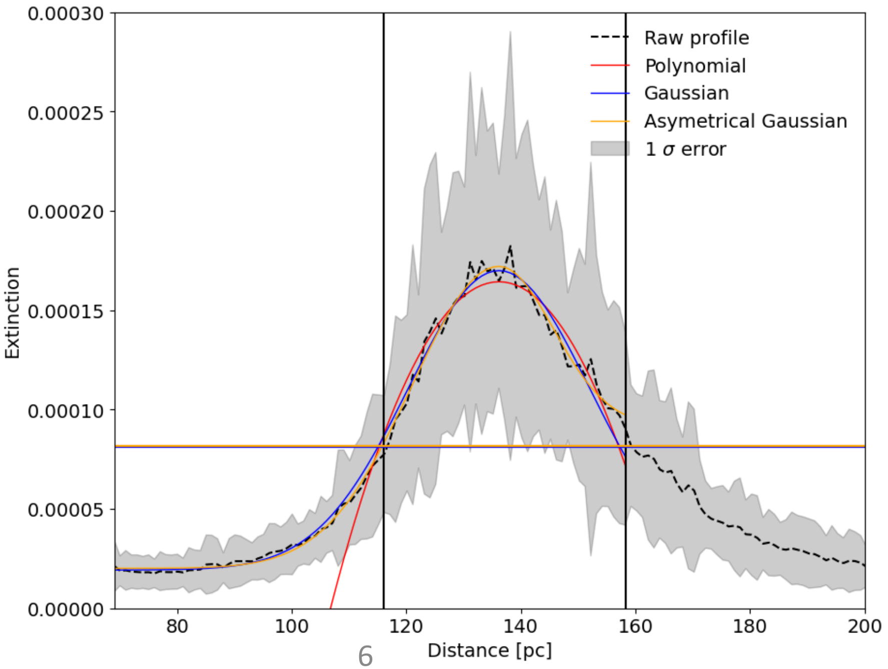
## Mass conservation :

$$\underbrace{\int_0^{r_{max}} \rho_0 r_0^2 \, \mathrm{d}r_0}_{M_{initial}} = \underbrace{\int_0^{r_{min}} \rho(r) r^2 \, \mathrm{d}r}_{M_{cavity}} + \underbrace{\int_{r_{min}}^{r_{max}} \rho(r) r^2 \, \mathrm{d}r}_{M_{shell}}$$

$$r_0 = \left[ \frac{3}{\rho_0} (M_{shell} + M_{cavity}) \right]^{1/3} = f(r)$$

*We developed the analytical framework to have realistic displacement field*



# Displacement field

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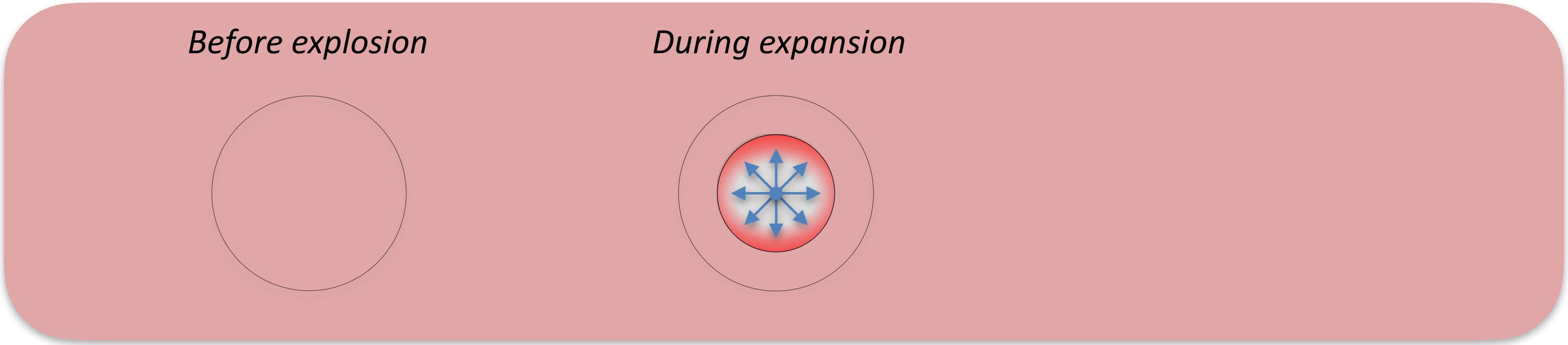


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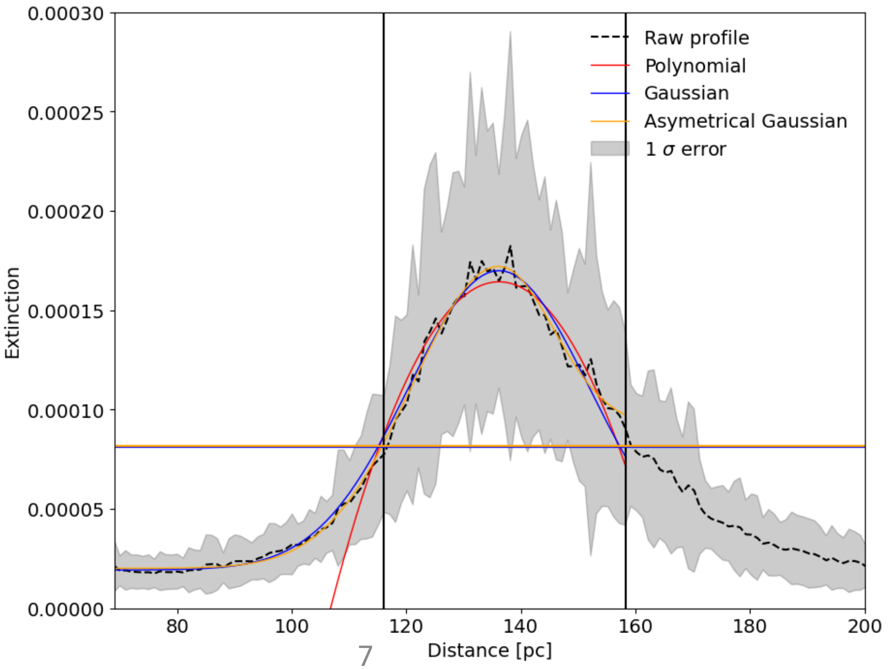




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# Displacement field

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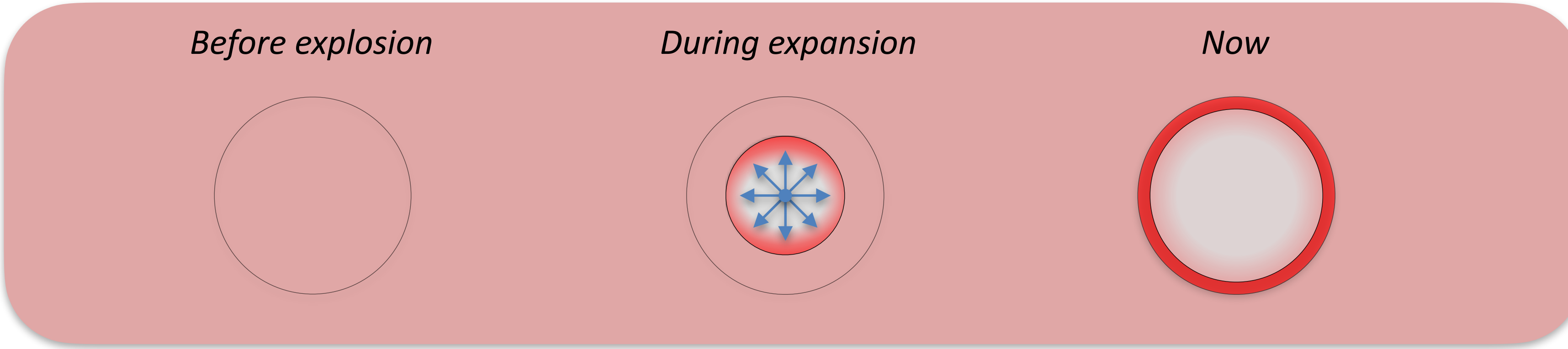


## ***Mass conservation :***

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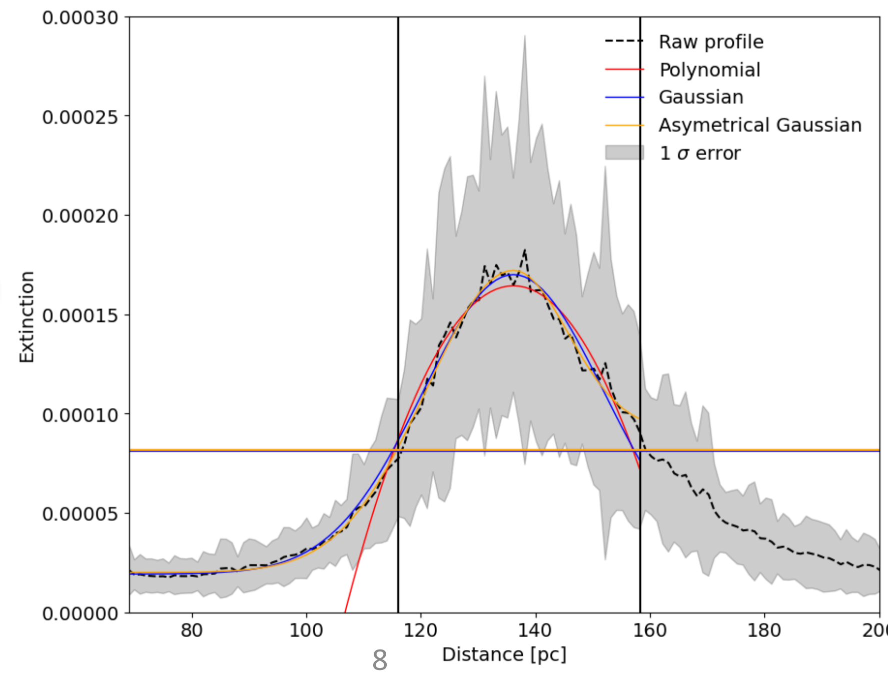




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# Magnetic field equations

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We derive the models from the vector potential :

$$B_r = \left(\frac{r_0}{r}\right)^2 B_{0,r} + \frac{r_0}{r}\frac{\partial r_0}{\partial r}\left(\frac{1}{r}\frac{\partial r}{\partial \theta} B_{0,\theta} + \frac{1}{r\sin\theta}\frac{\partial r}{\partial \phi} B_{0,\phi}\right)$$

$$B_\theta = \frac{r_0}{r}\frac{\partial r_0}{\partial r} B_{0,\theta}$$

$$B_\phi = \frac{r_0}{r}\frac{\partial r_0}{\partial r} B_{0,\phi},$$

*Shear term from angular variations in the displacement field*

*Magnetic flux conservation*

- *Solution of the induction equation*
- *Divergence free*
- *Can be applied on large scale magnetic field*

- *Free parameters :*
    - *Orientation of. :* $(\ell_0, b_0)$
    - *Location of the SN explosion site*

*Hypotheses :*

- *The initial medium has uniform matter density and magnetic field strength*
- *Radial motion from the explosion center*
- *The magnetic field is frozen-in into the matter*

# Polarized emissions

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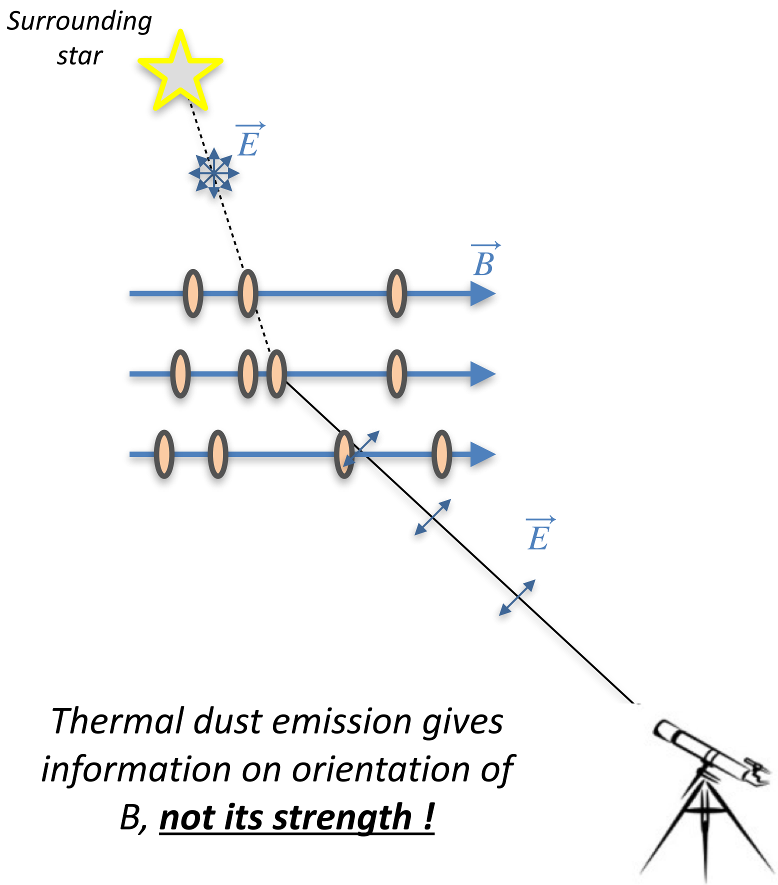
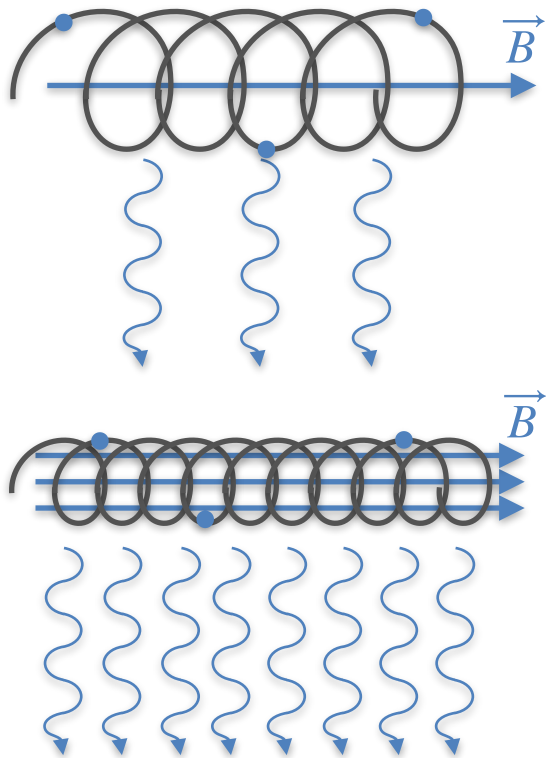
## *Thermal dust*




*Thermal dust emission gives information on orientation of B,* ***not its strength !***

## *Synchrotron*




*Synchrotron emission gives information on orientation of the magnetic field,* ***and its strength !***



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# Pipeline

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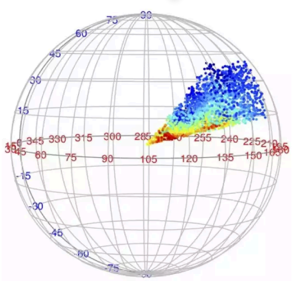
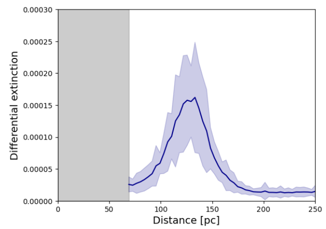
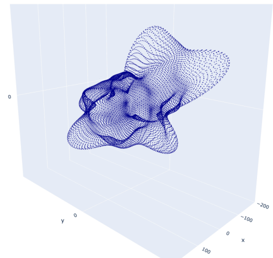
*Extracting 3D data*






*Extracting bubble shell*



*Computing orientation of B*

## *MCMC fitting*

$$\vec{\theta} = [\ell, b, x_{sn}, y_{sn}, z_{sn}, p_0]$$

$$B_r = \left(\frac{r^0}{r}\right)^2 B^0{}_r + \frac{r^0}{r} \nabla_t \Lambda \cdot \mathbf{B}^0{}_t$$

$$B_\theta = \frac{r^0}{r} \frac{\partial r^0}{\partial r} B^0{}_\theta$$

$$B_\phi = \frac{r^0}{r} \frac{\partial r^0}{\partial r} B^0{}_\phi,$$

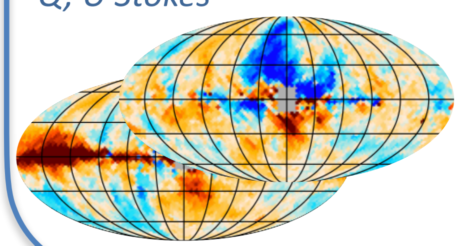
*Local polarization angle*

$$Q = p_0 \int_{shell} n_d \cos(2\gamma) \sin^2 \alpha \, \mathrm{dr}$$

$$U = p_0 \int_{shell} n_d \sin(2\gamma) \sin^2 \alpha \, \mathrm{dr}$$

*Inclination to the POS*

*Q, U Stokes*





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# Preliminary results : Thermal dust emission

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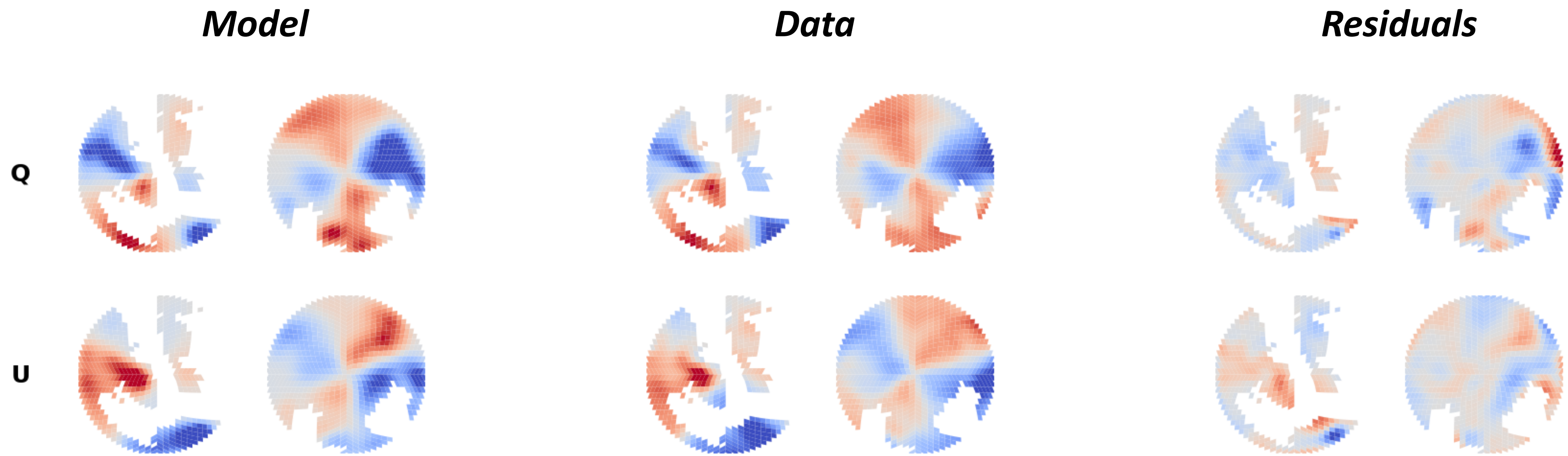
- Modelization for latitude above 50°
- We precompute the pixels where LB do not have a dominant contribution (blank mask)
- Large scale features can be explain by the emission from the LB



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# Preliminary results : Synchrotron emission

Funded by
the European Union

- Modelization for latitude above 50°
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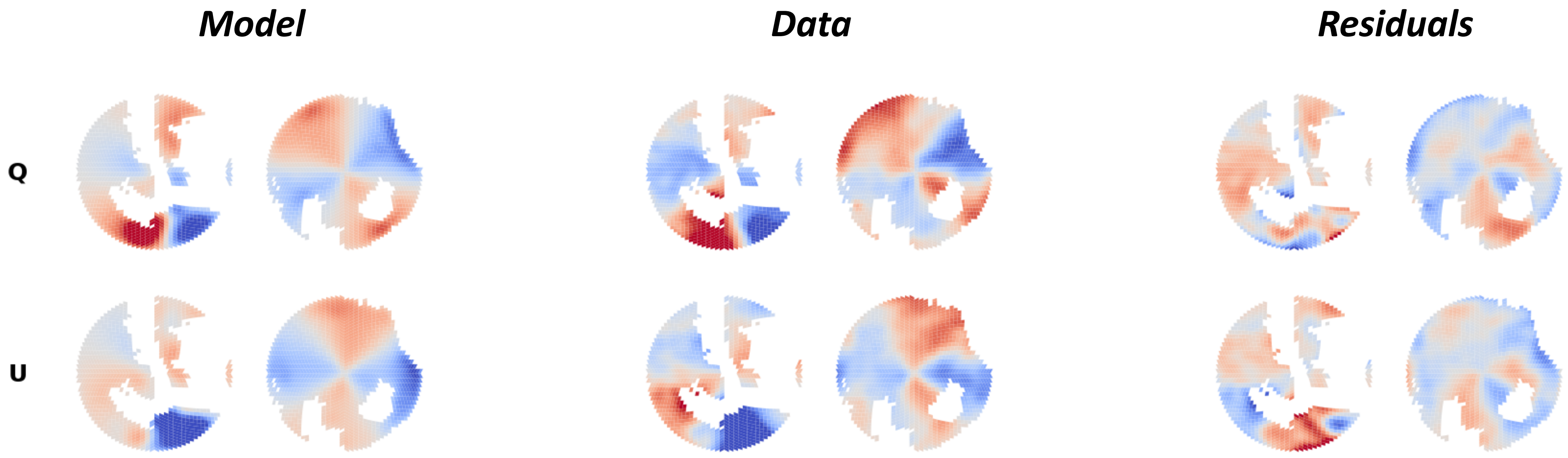
- Large scale features can be explain by the emission from the LB



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# A large-scale model

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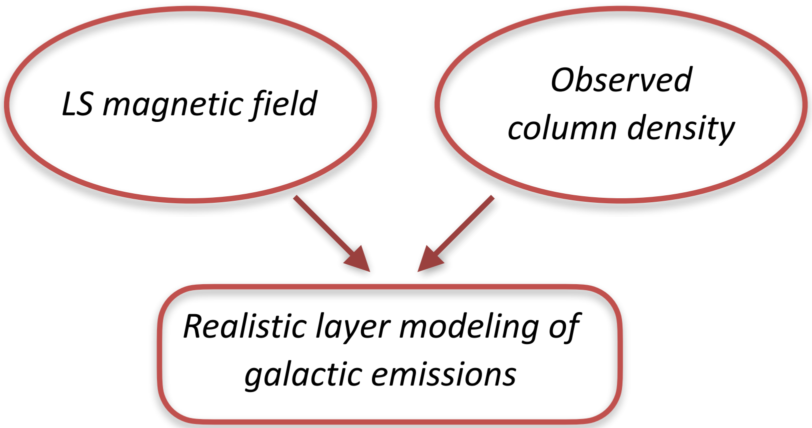
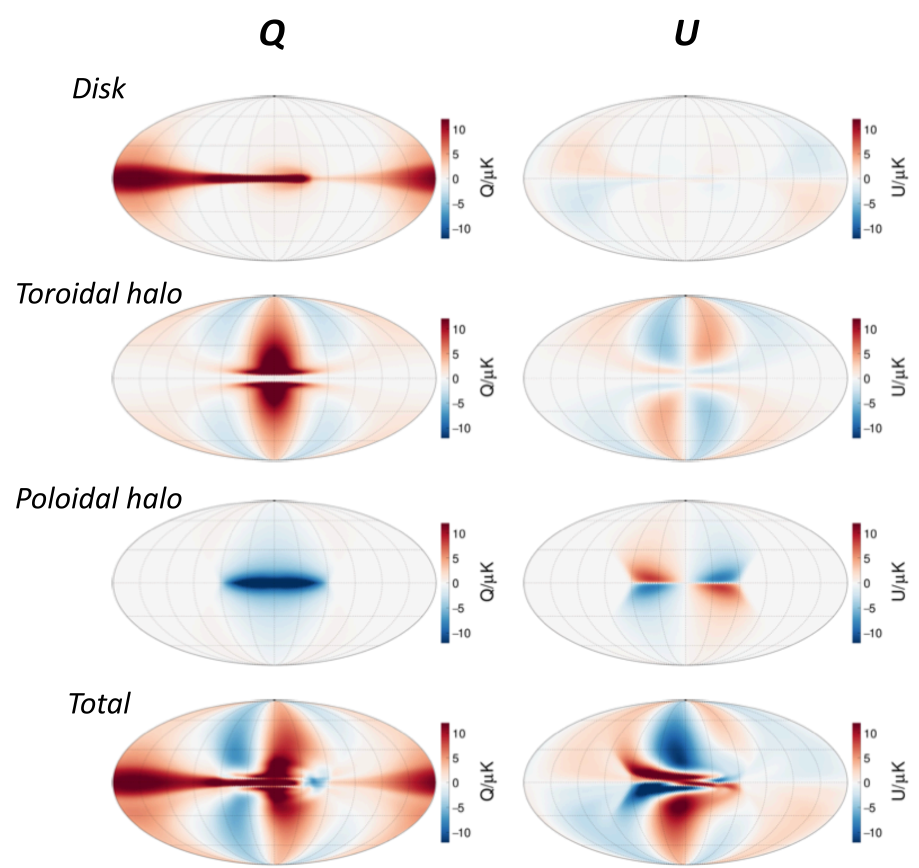
[Unger, and Farrar et al. (2023)] has developed large scale magnetic field with 2 main components :

1. Disk : logarithmic spiral field beyond a minimal radius
2. Poloidal and toroidal field from the halo

Model with 24 free parameters that has been found using synchrotron radiation.



# Preliminary results : Thermal dust emission

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We apply this LS model to create thermal dust model based on :

- Observed column density profile (Bayestar)
  - Gaia parallaxes
  - Pan-STARRS 1 and 2MASS stellar photometry
- State-of-the-art LS magnetic field

$$I_d = p_0 \int_r n_d B_\nu(T) \sigma_{353} \, \mathrm{dr}$$

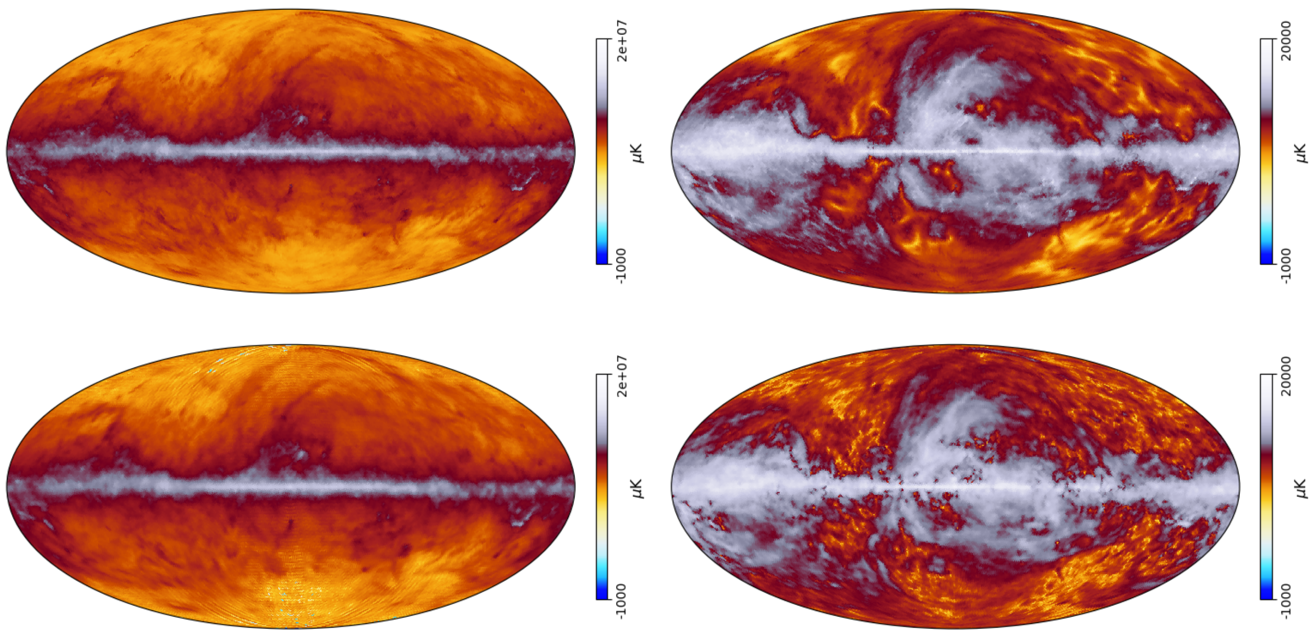
$$Q_d = p_0 \int_r n_d B_\nu(T) \sigma_{353} \cos^2 \alpha \cos 2\gamma \, \mathrm{dr}$$

$$U_d = p_0 \int_r n_d B_\nu(T) \sigma_{353} \cos^2 \alpha \sin 2\gamma \, \mathrm{dr}$$

*353 GHz template for I and P*

*Data*

*Model*



# Preliminary results : Spectral index sampling

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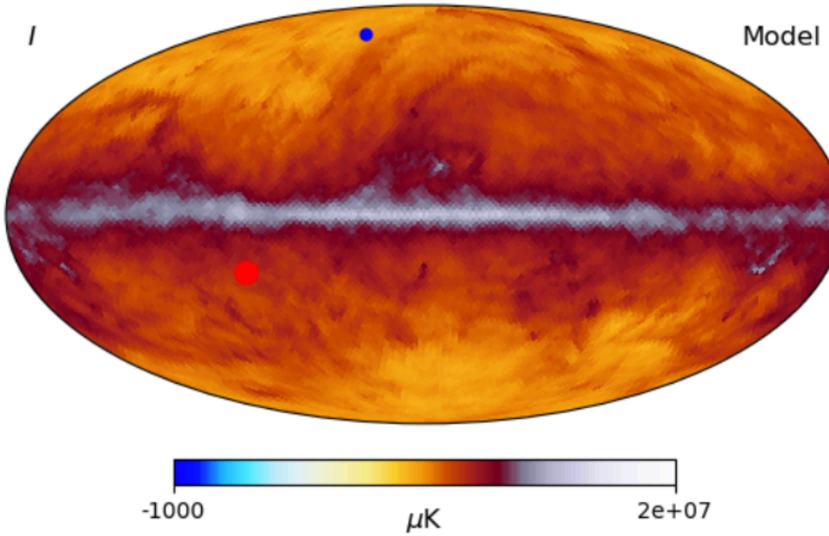
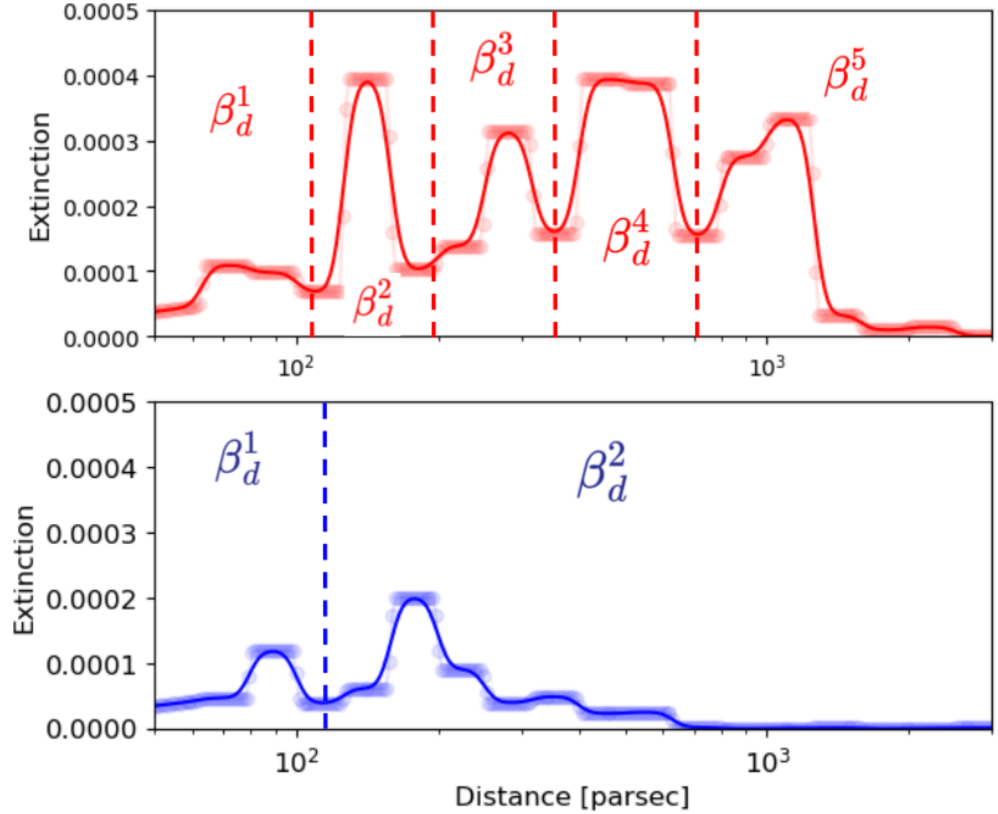
The frequency scaling is done by picking random spectral indices along the LoS.

$$\beta_d^i = \mathcal{N}\left(\beta_d^{Planck}, \Delta\beta_d\right)$$

The model account for :

- The number of "cloud" along the LoS
- The average spectral index along the LoS is the one measured by Planck PR3 (GNILC)



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# Preliminary results : Simulated frequency maps

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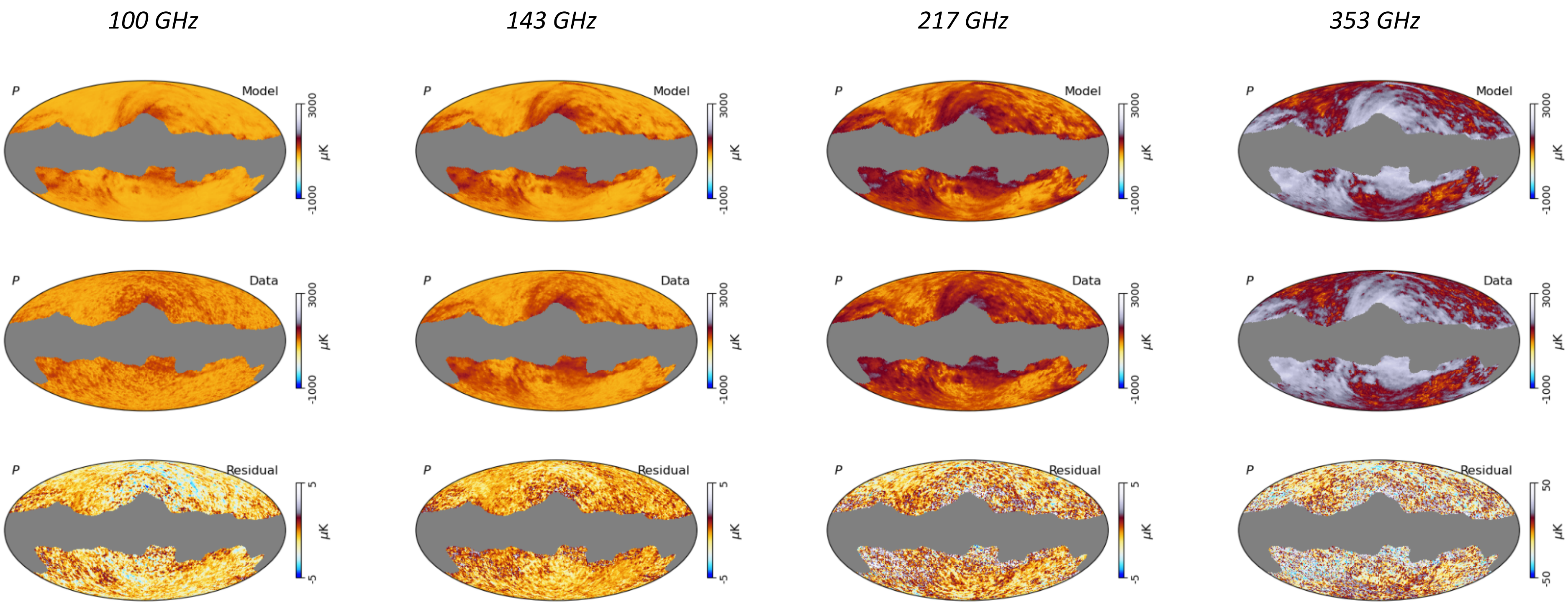

# Preliminary results : Impact on the tensor-to-scalar ratio

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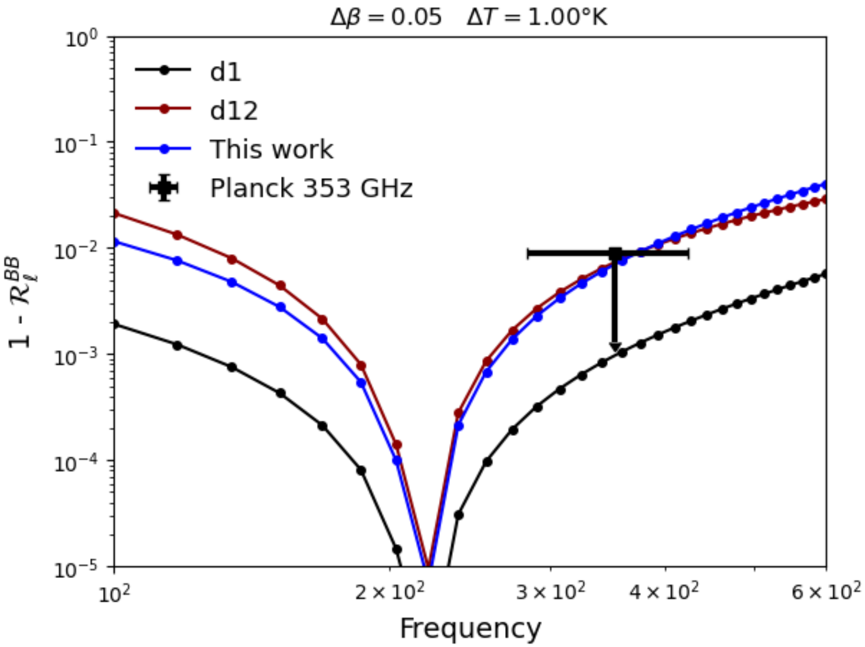
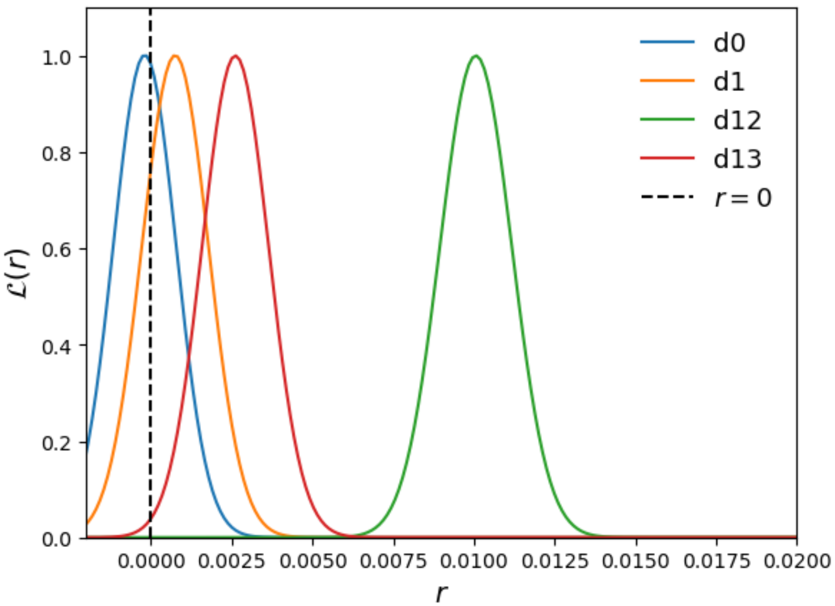
We performed very basic component separation* based on LiteBIRD configuration (15 frequency bands from 35 to 450 GHz), simulating several scenarios for the thermal dust.

| *Complexity* | *Low* | *Medium* | *High* | *High* |
|---|---|---|---|---|
| *Models* | *d0s0* | *d1s1* | *d12s1* | *This work + s1* |




* we use FG-Buster [Stompor et al. (2008)], assuming Nside = 8 for the spectral indices pixelization



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# Conclusion

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✳ Local Bubble :

- Dominate the emission at high galactic altitude (b > 50°)
- More refined model integrating :
  - Thickness integration
  - Physical displacement field
- Can be included in a larger scale magnetic field

✳ Large scale magnetic field :

- Use different component (disk, poloidal and toroidal halo)
- Use 3D observed column density for dust
- We've build a multifrequency model with random spectral index along the LoS
- Not a fixed number of different cloud per pixel : depends on the observed column density
- Shows the same amount of frequency decorrelationthan d12 with smaller error on spectral indices
  - Already written in PySM3 format : need to be tested

✳ Next steps :

- Include LB model within the LS magnetic field model
- Produce synchrotron maps

} ***On going***



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# Back-up : Position of the explosion center

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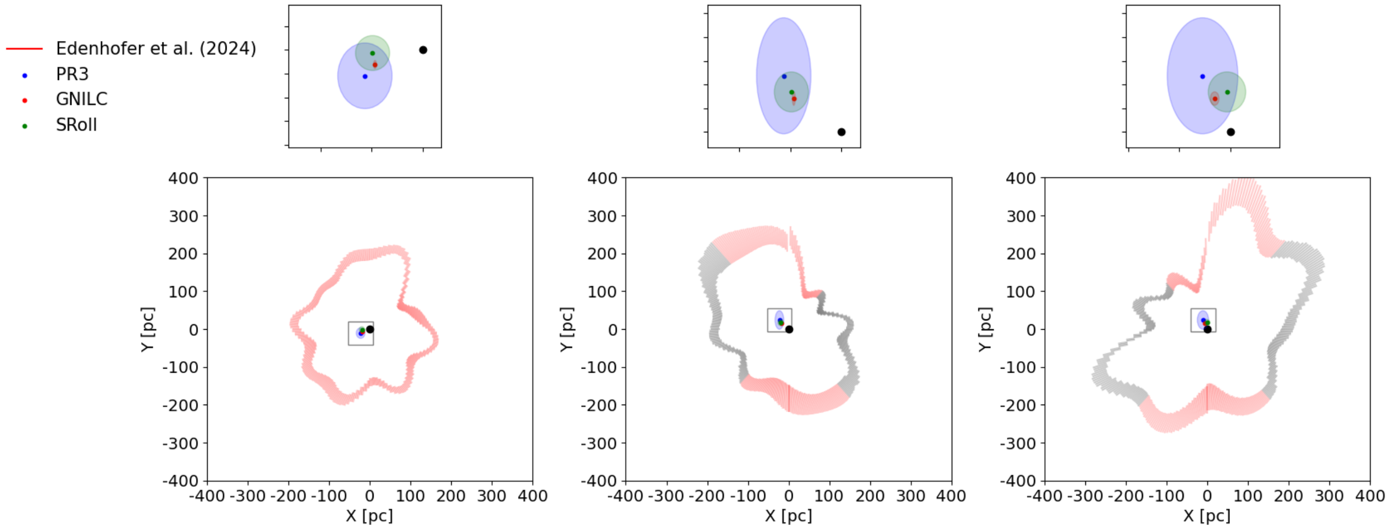
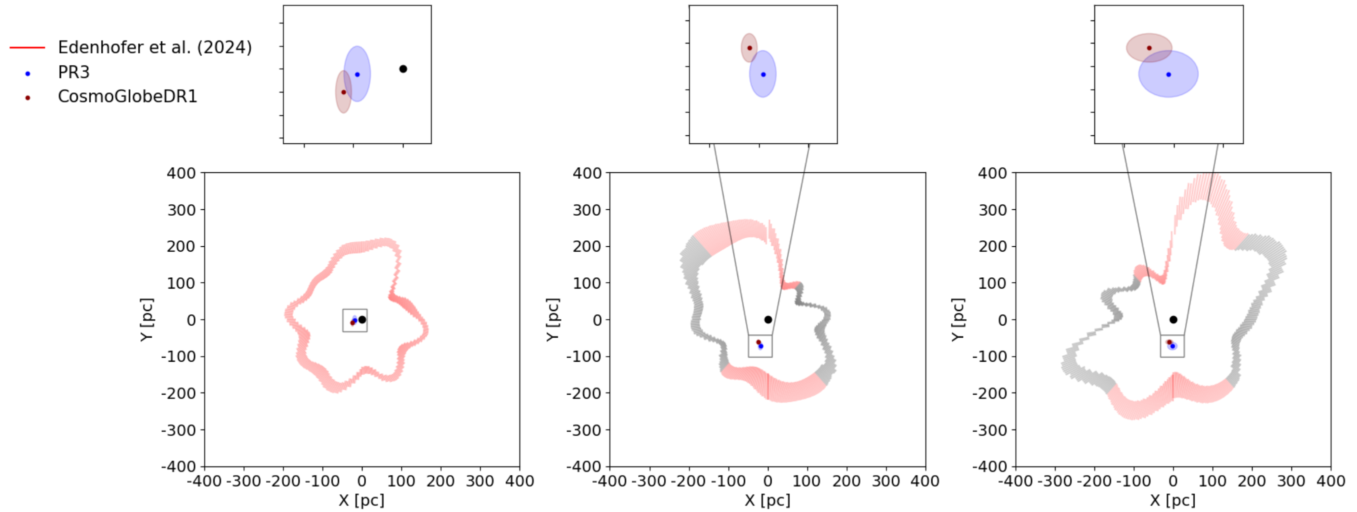
*Thermal dust*




*Synchrotron*



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# Back-up : Orientation of the initial magnetic field

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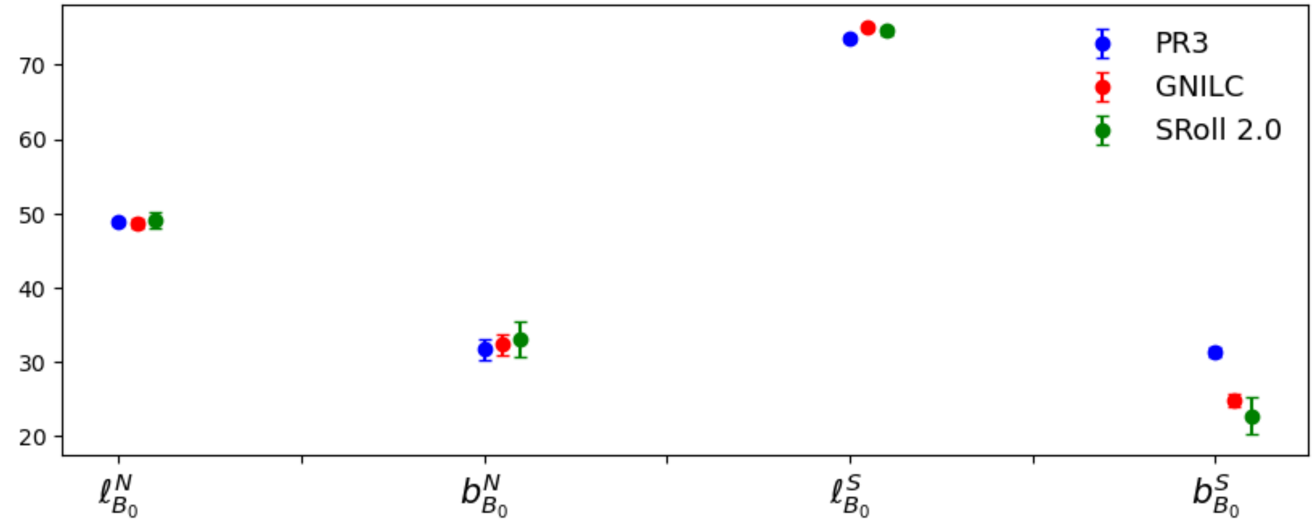
***Thermal dust***




***Synchrotron***