

# « Beyond » the diffusion approximation: An explanation for the anisotropies at multiple angular scales

Gwenael Giacinti (*NTNU Trondheim & APC, Paris*)

0.94    0.96    0.98    1    1.02    1.04    1.06    1.08

# Motivations, Goals

- What this talk is not about...
- Large scale / smaller scales anisotropies
- Requirements to explain the smaller scales ?

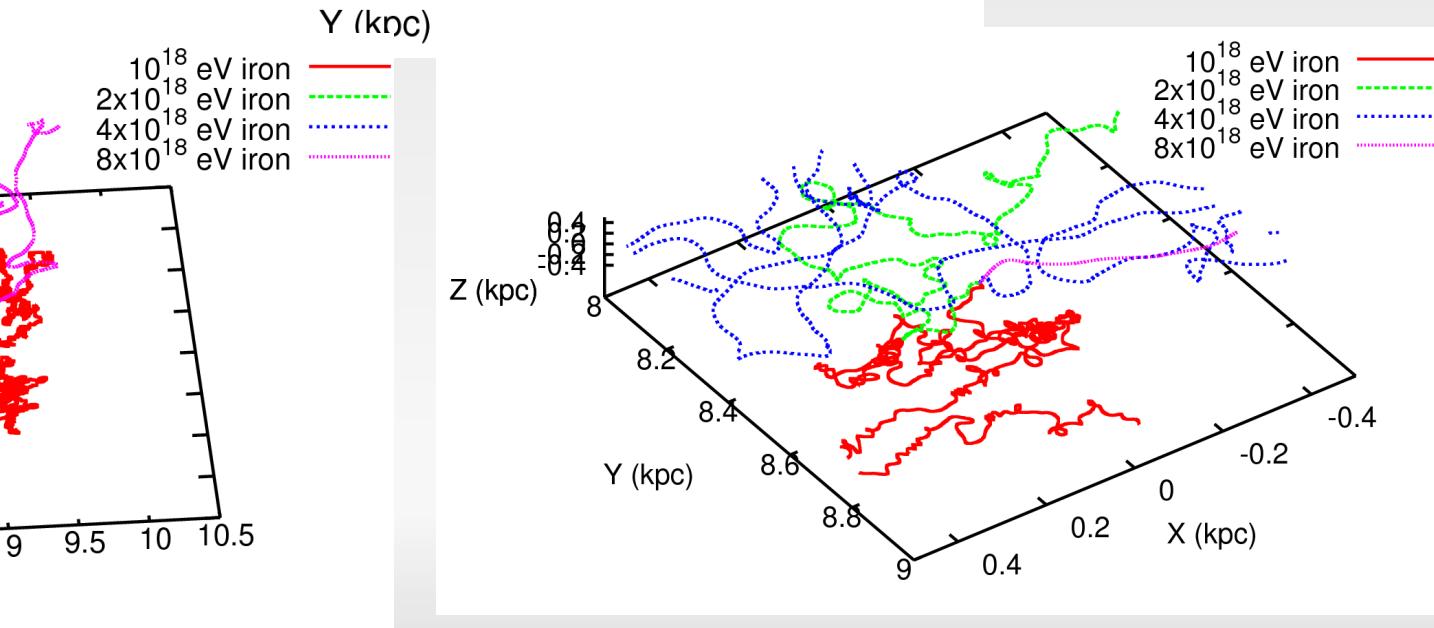
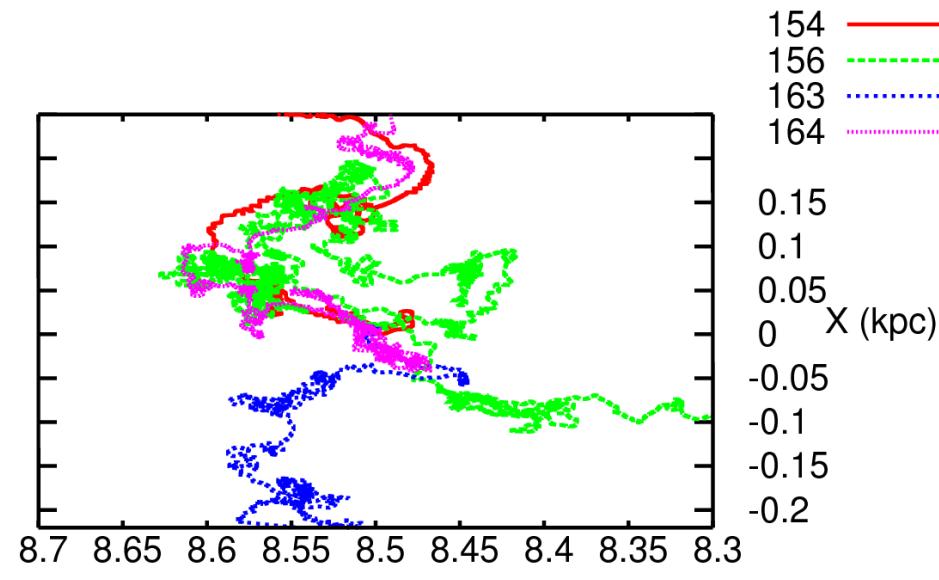
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- Energy-dependent smaller scales must *automatically* appear at multiple angular scales, provided that there is a large scale anisotropy.
- No particular assumption

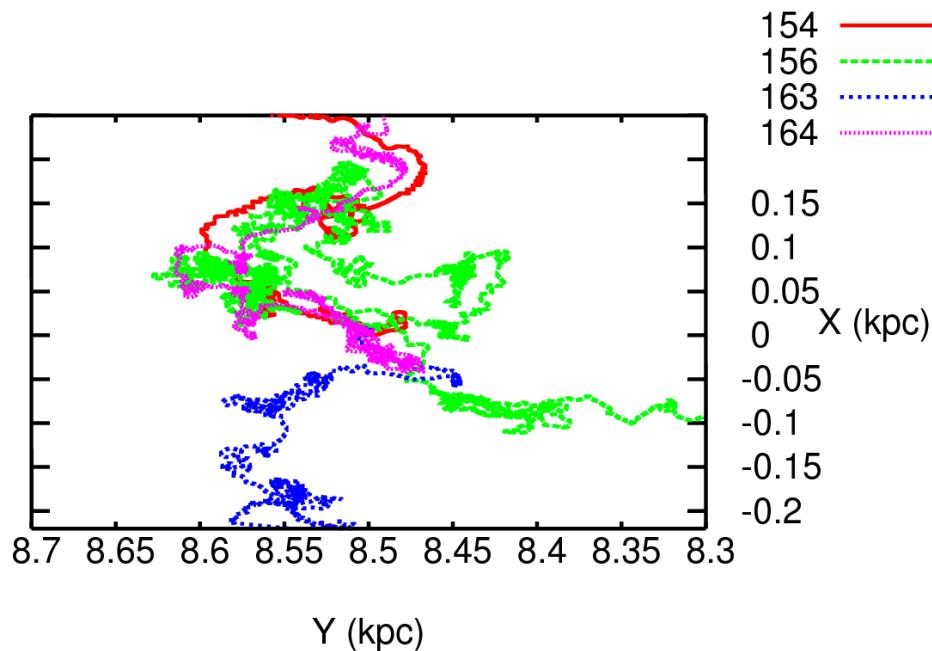
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- Requirements to explain the smaller scales ?
- Energy-dependent smaller scales must *automatically* appear at multiple angular scales, provided that there is a large scale anisotropy.
- No particular assumption
- Goal: Theoretical understanding + *Numerical simulation and proof*
- Simple case only *for clarity; can be directly generalisable*

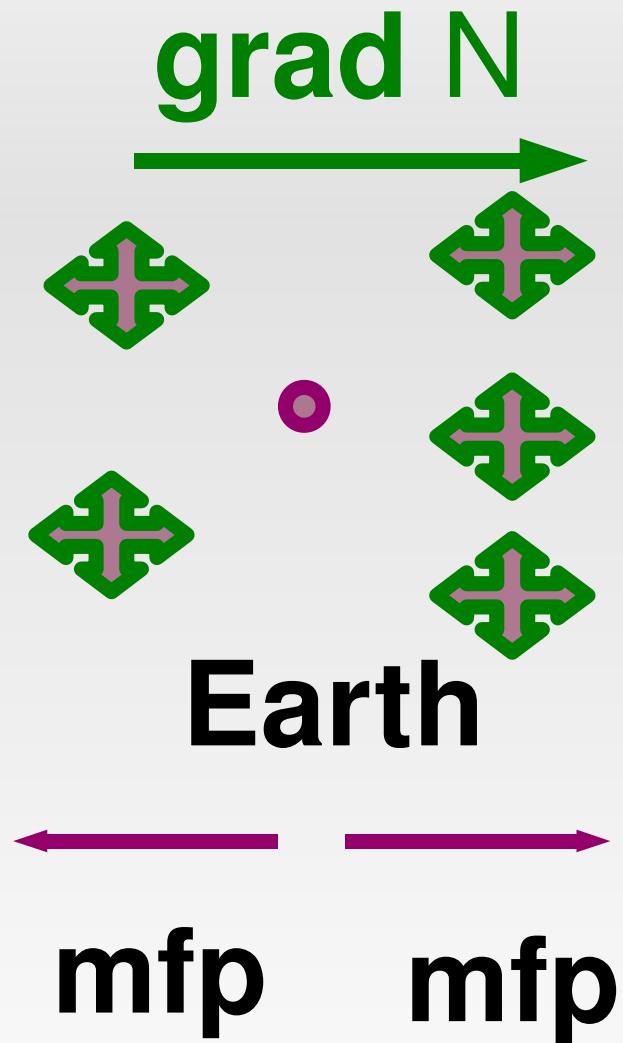
# Diffusion approximation



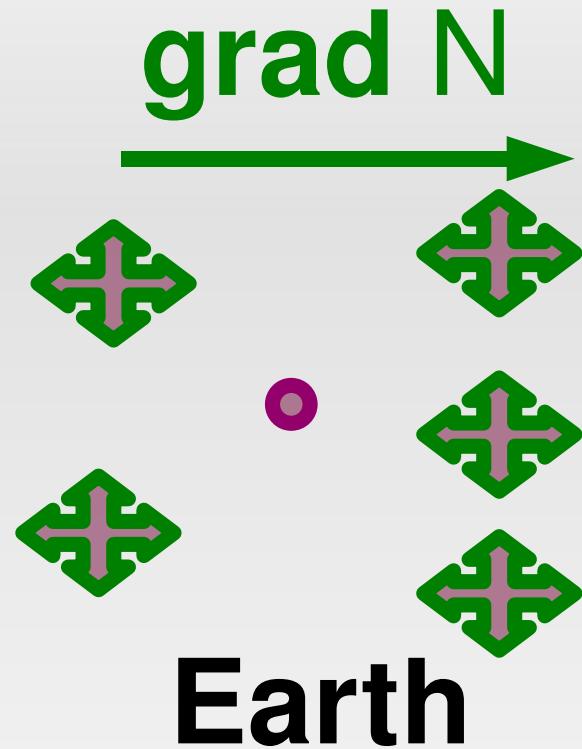
# Diffusion approximation



# Diffusion approximation (1D, 3 axes)



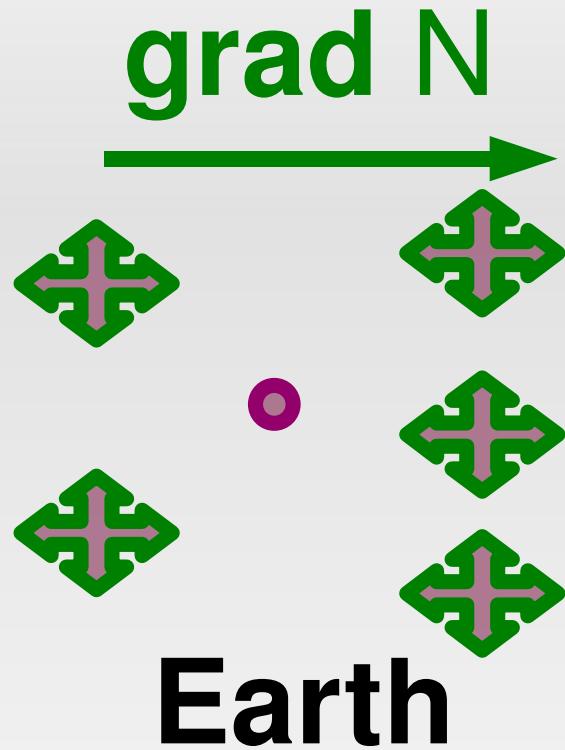
# Diffusion approximation - Dipole



$$\delta(p) \simeq \frac{3}{c_0} \frac{\mathbf{j}}{n} = \frac{3D(p)}{c_0} \frac{\nabla n}{n},$$

where  $\mathbf{j}(\mathbf{r}, p) = D(p)\nabla n$  is the CR current

# Diffusion approximation - Dipole

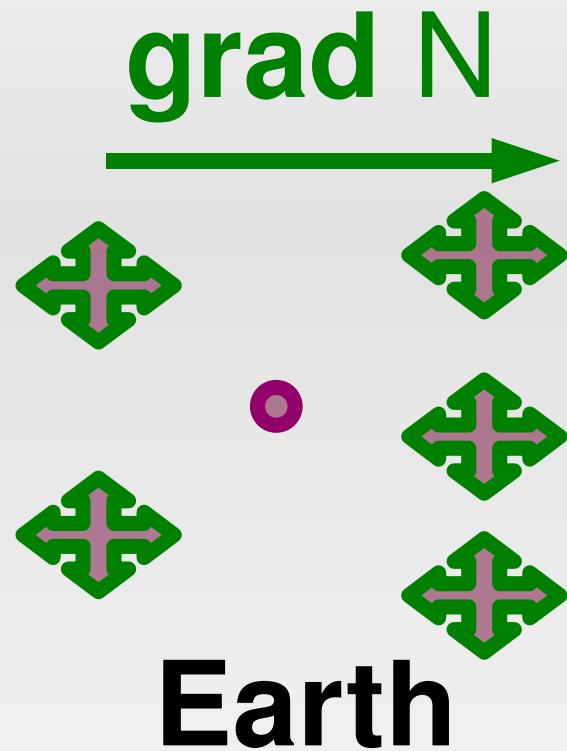


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# Diffusion approximation - Dipole

Limits!

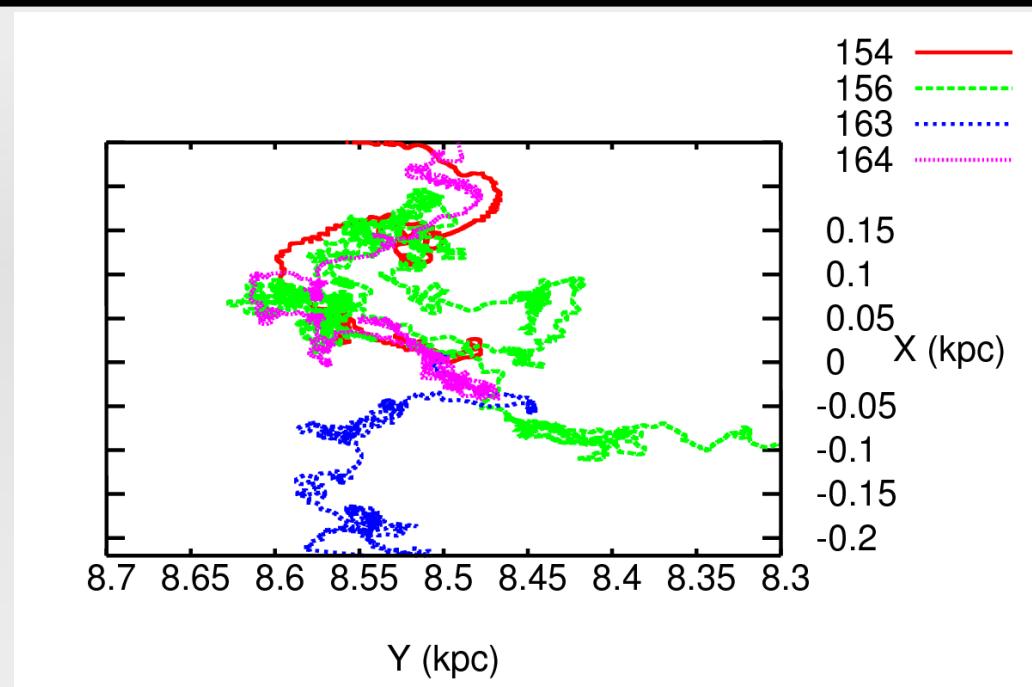


Earth

$$\delta(p) \simeq \frac{3}{c_0} \frac{\mathbf{j}}{n} = \frac{3D(p)}{c_0} \frac{\nabla n}{n},$$

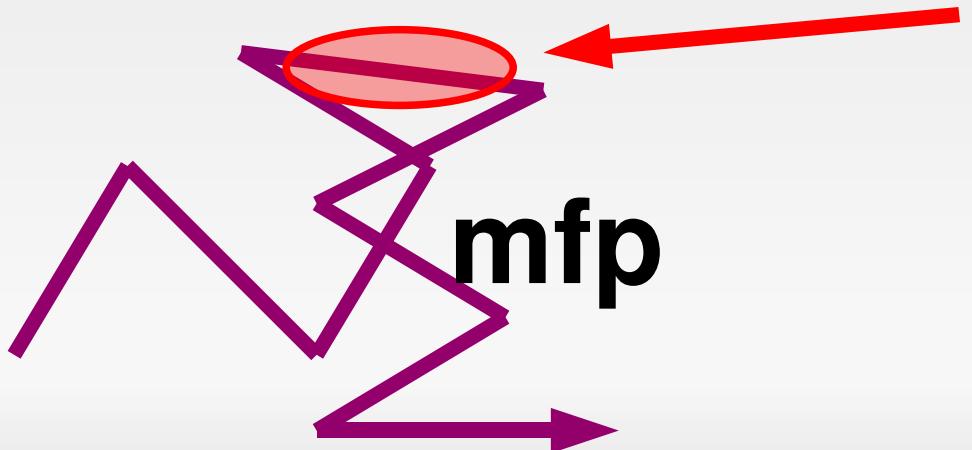
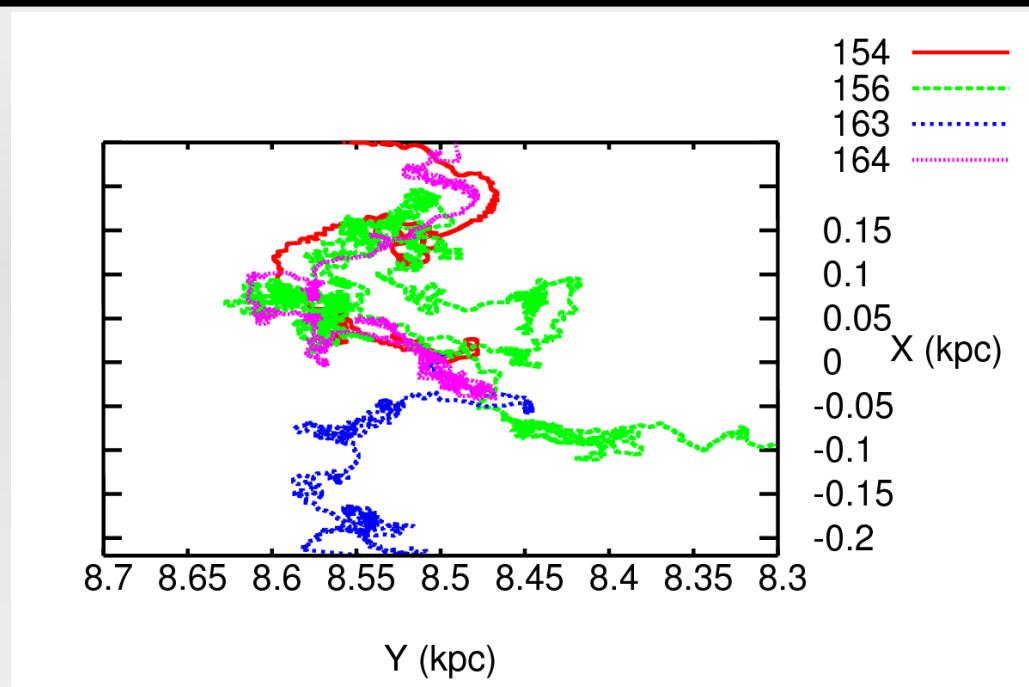
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# Diffusion approx. and beyond

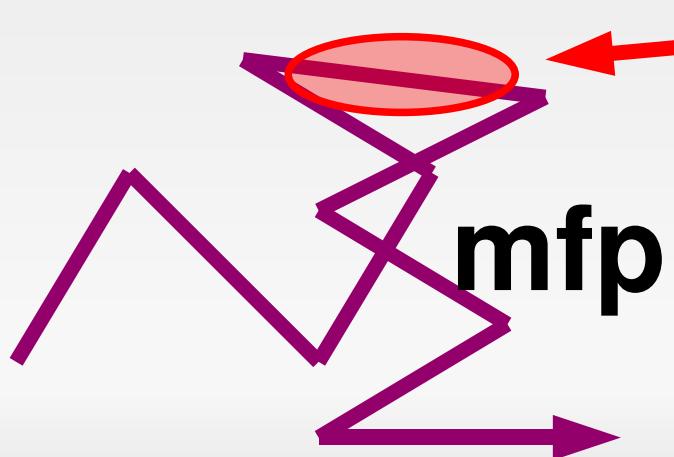
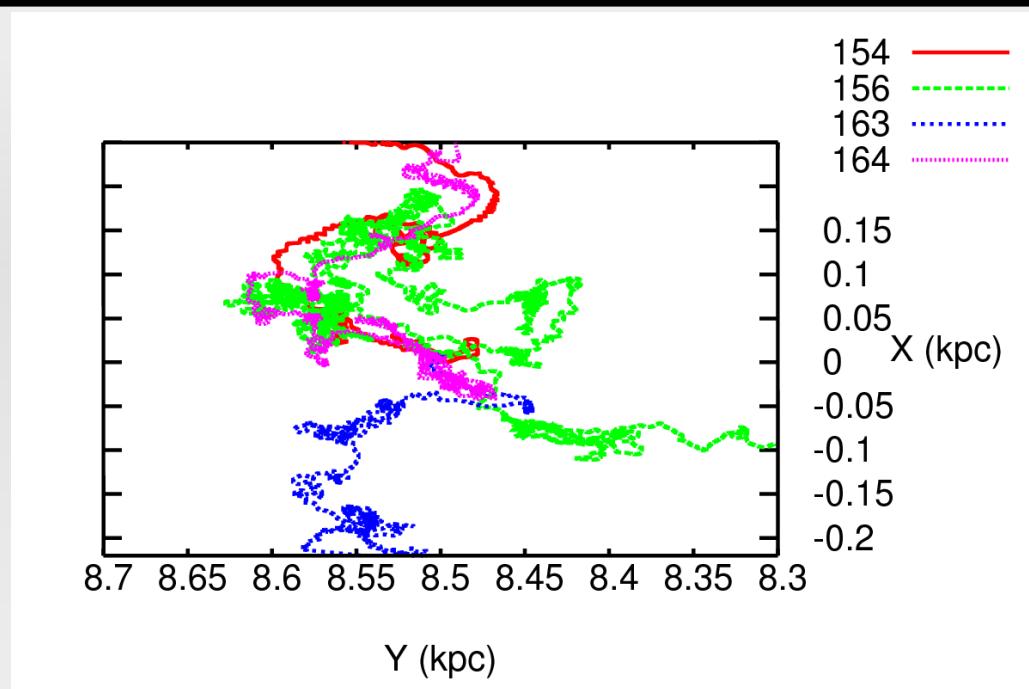


**Markovian !**

# Diffusion approx. and beyond

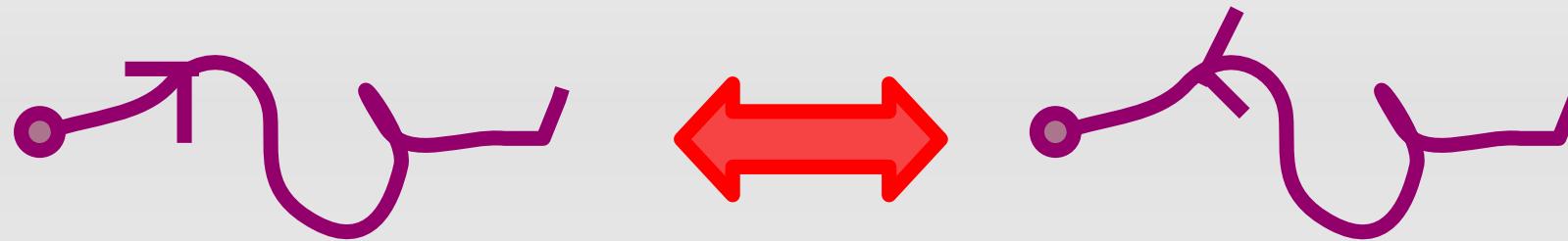


# Diffusion approx. and beyond

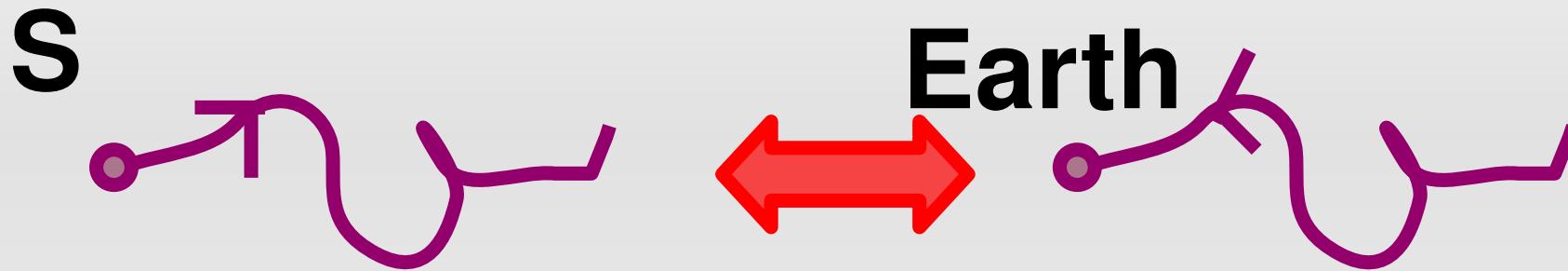


« beyond » diffusion -> Need individual trajectories

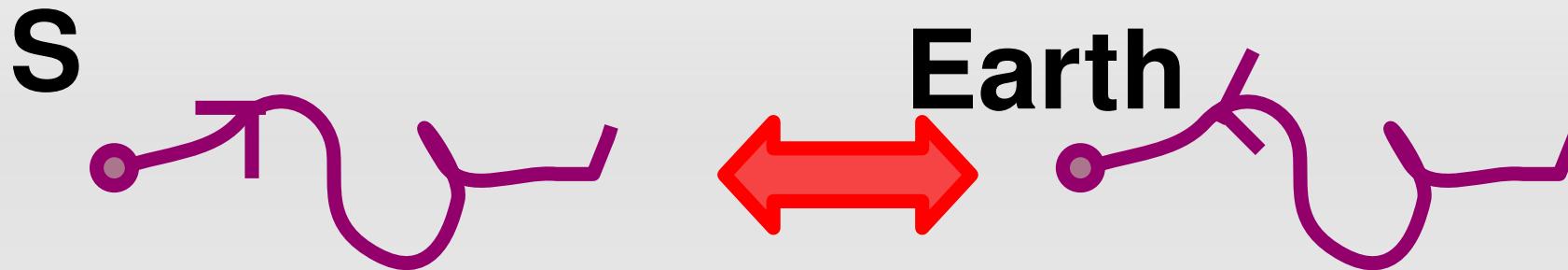
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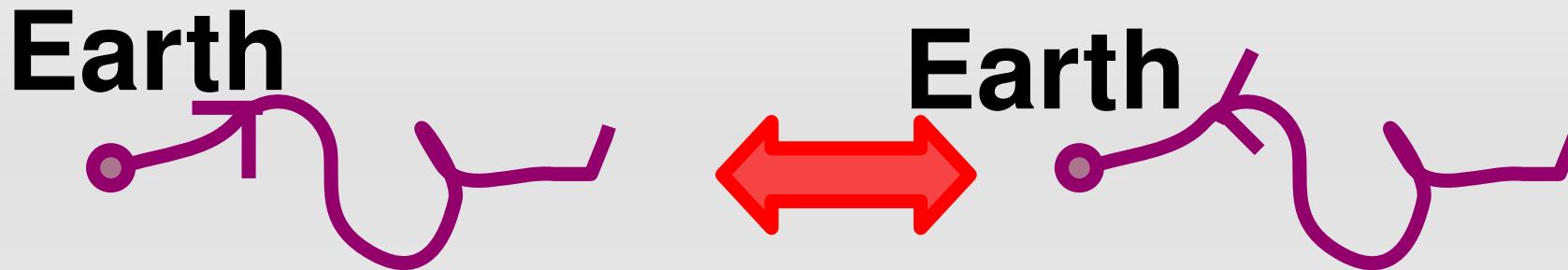


# Diffusion approx. and beyond



- 1) The Earth is point-like ( $/r_L$ )
- 2) The process is (very) locally not markovian

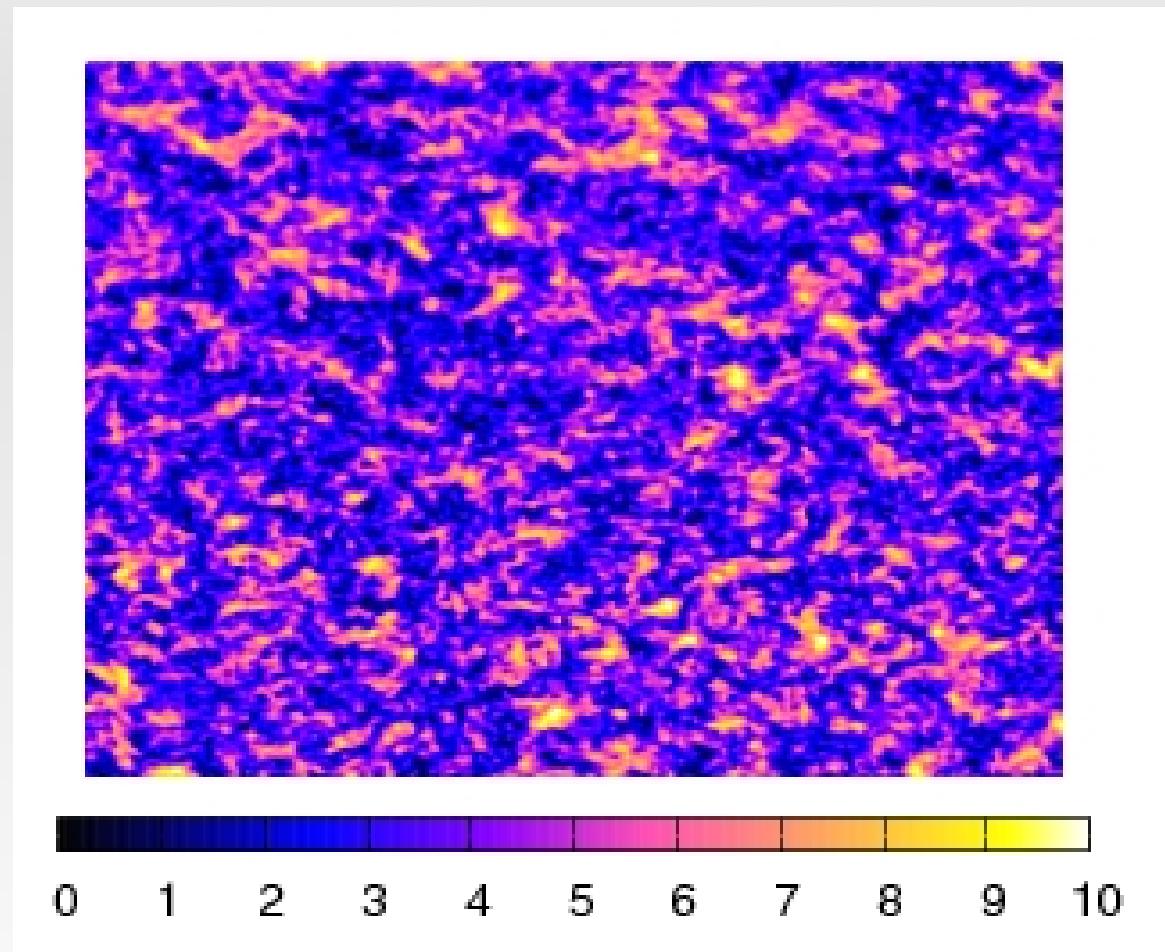
# Diffusion approx. and beyond



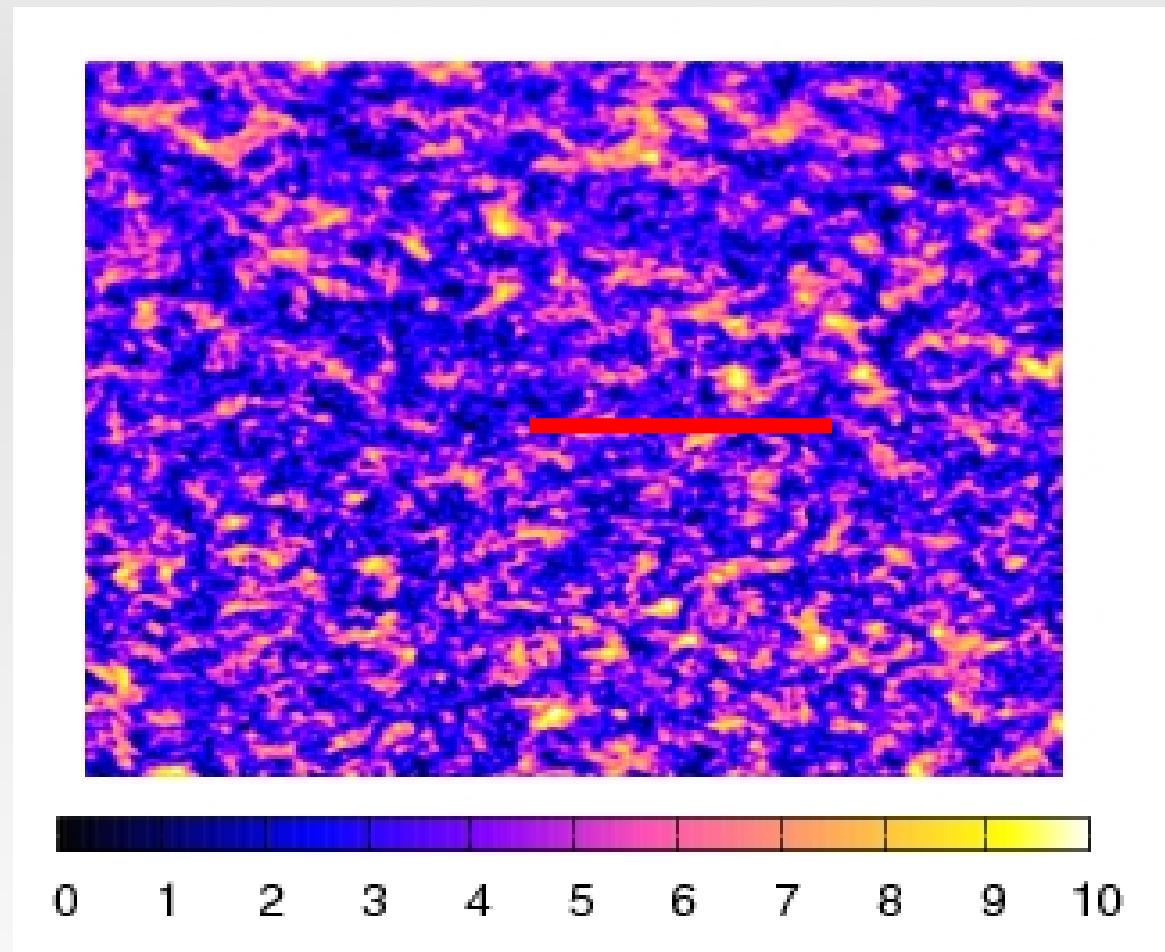
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**Forward tracing/ backtracing ?**

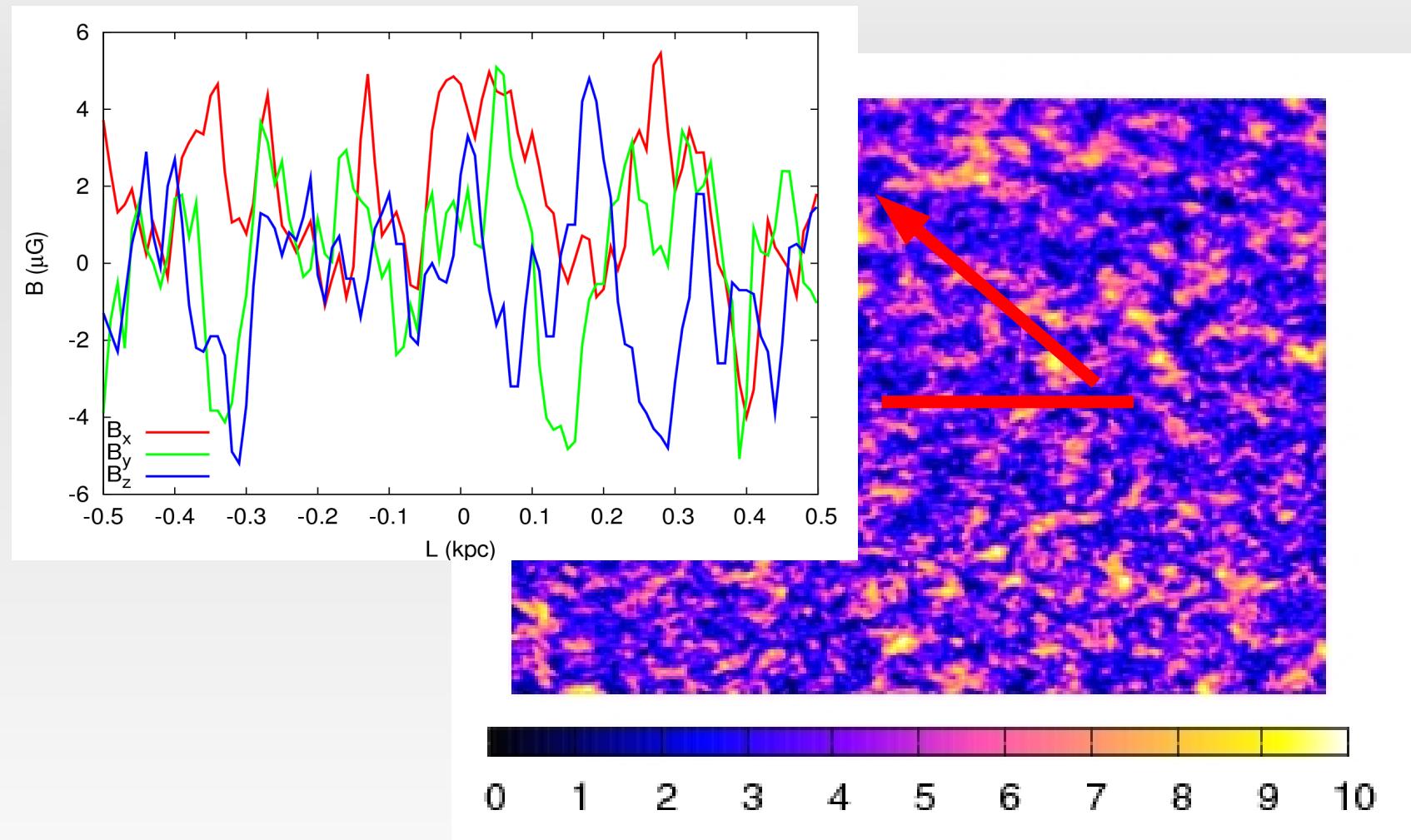
# 3D-Turbulent field generation



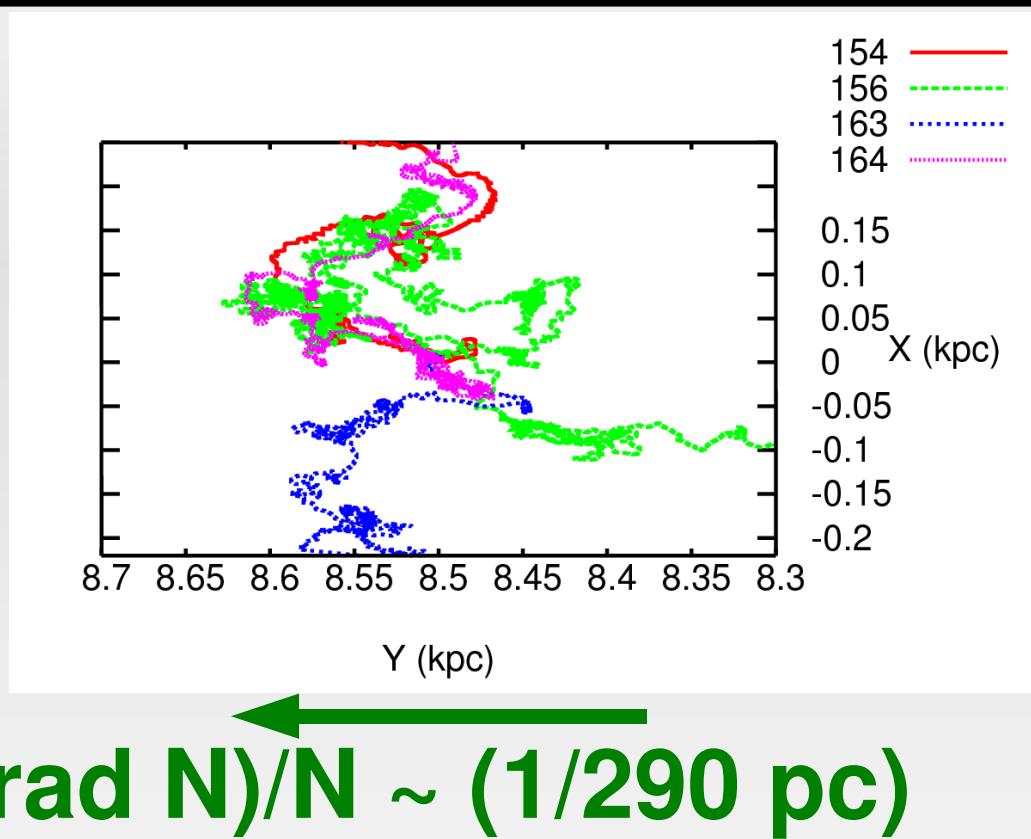
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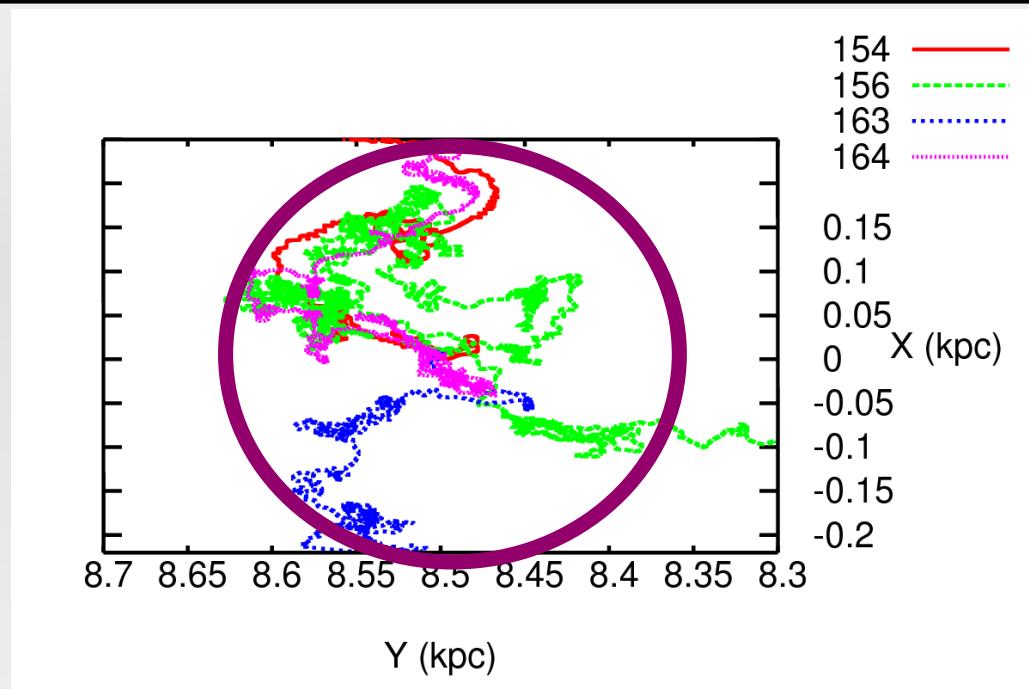


# Numerical simulations



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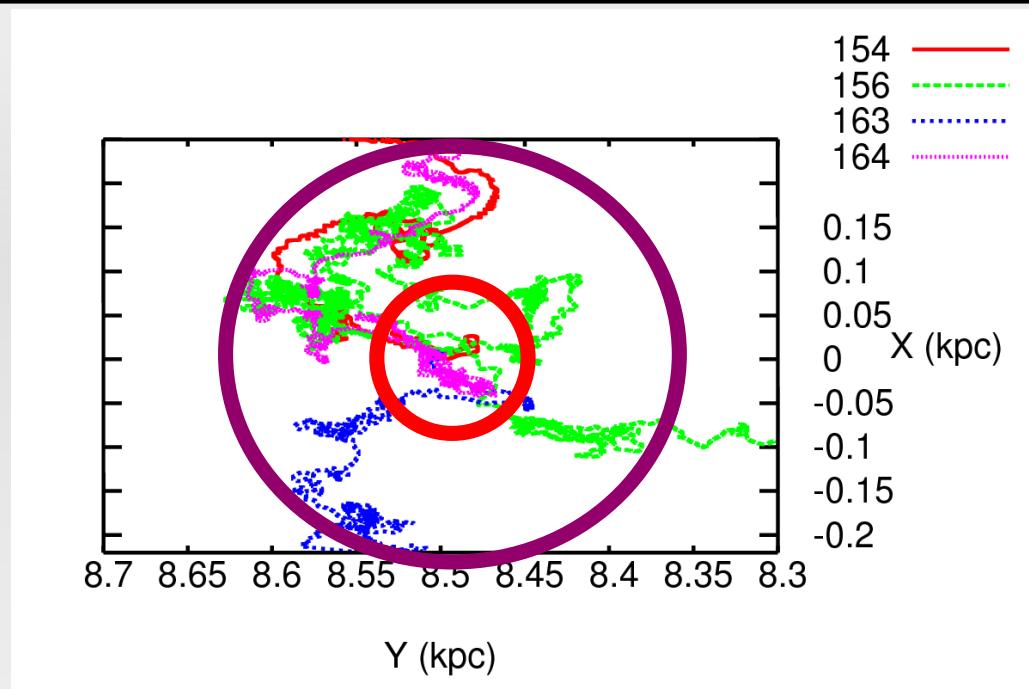
$R=250$  pc



$\overleftarrow{(\text{grad } N)/N} \sim (1/290 \text{ pc})$

# Numerical simulations

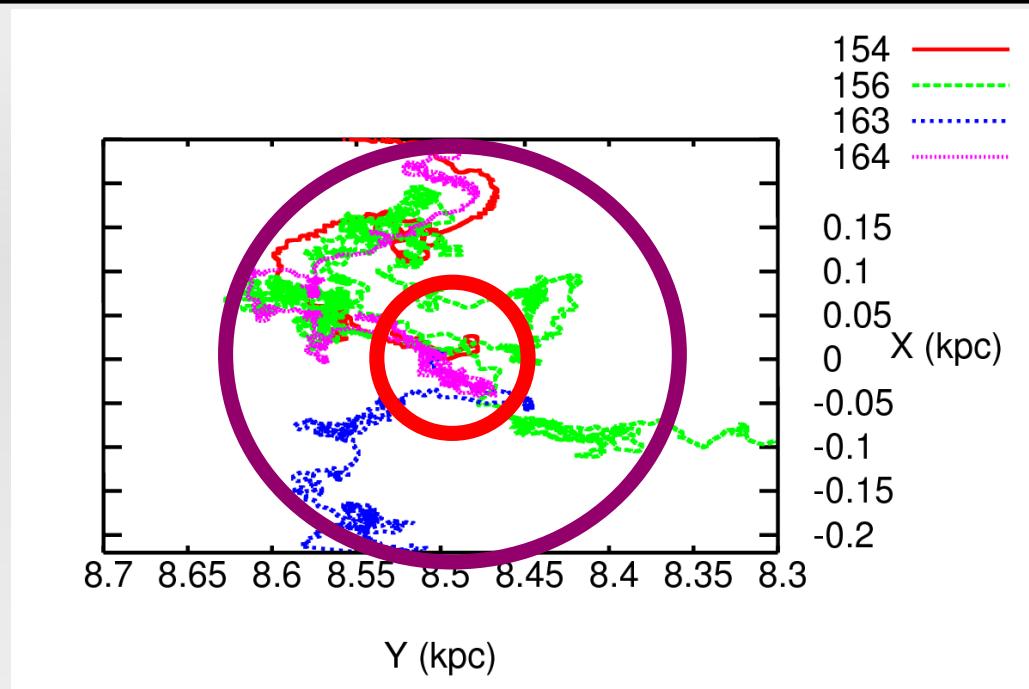
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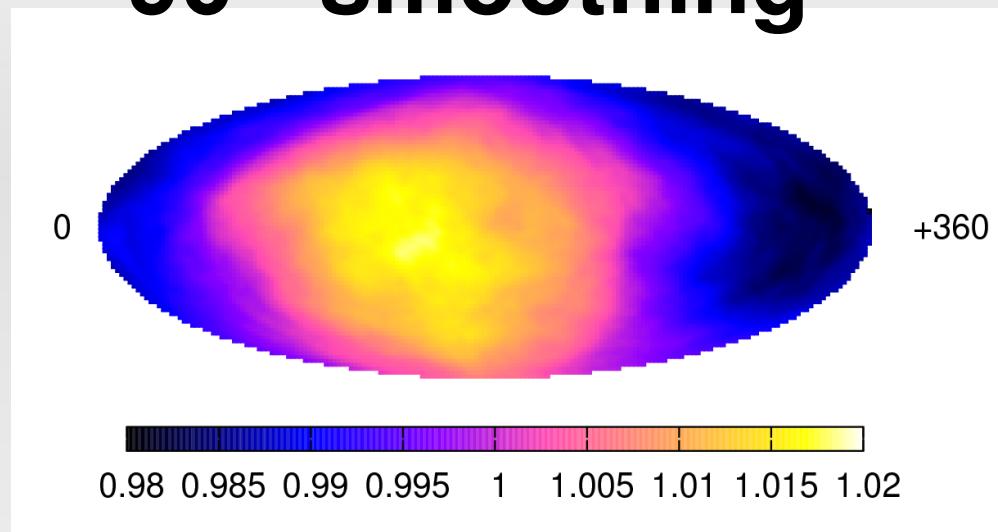
$(\text{grad } N)/N \sim (1/290 \text{ pc})$

$$E = 10^{16} \text{ eV} \rightarrow 10^{13} \text{ eV}$$

# Results

# Dipole / Smaller scales

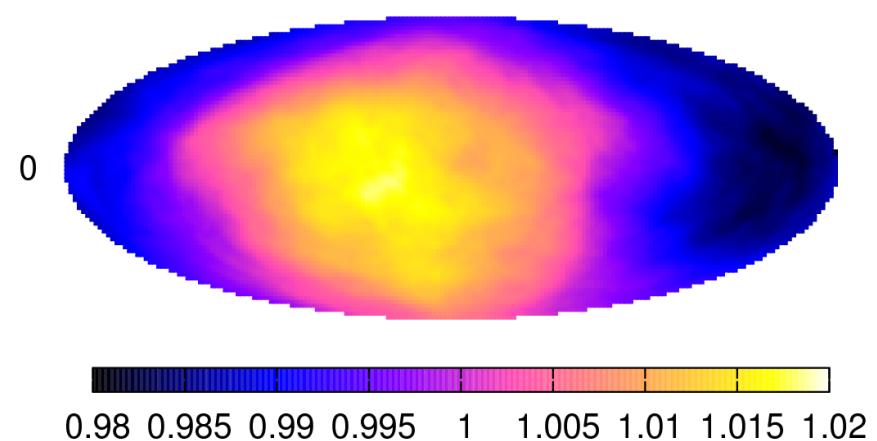
90° smoothing



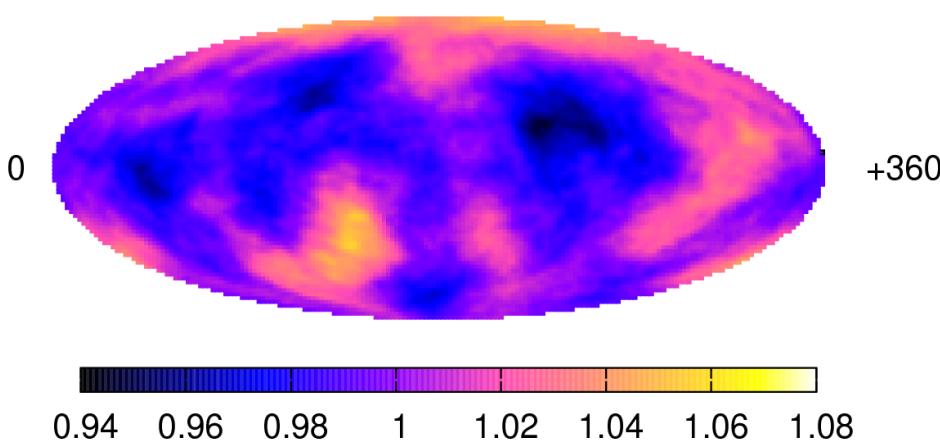
~ 6 % here

# Dipole / Smaller scales

90° smoothing

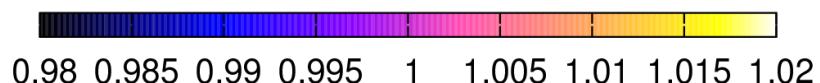
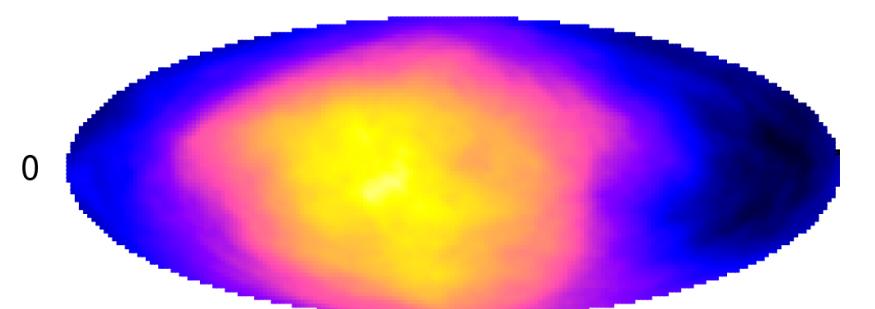


20° smoothing - Dipole

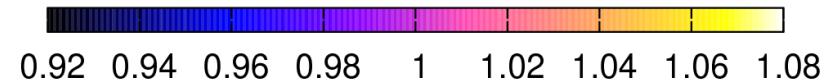
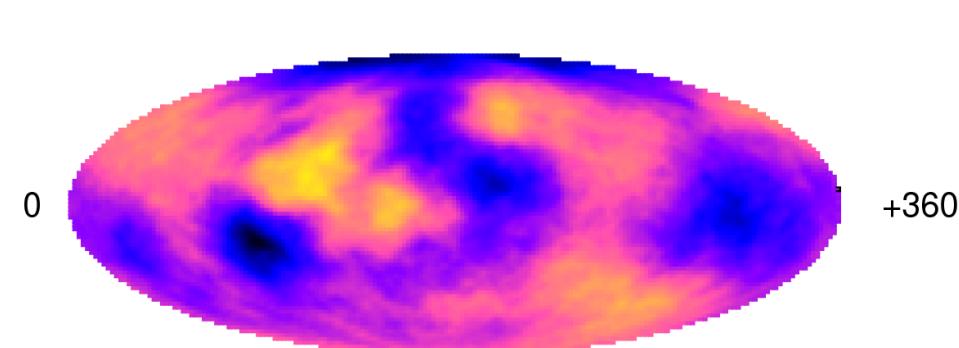
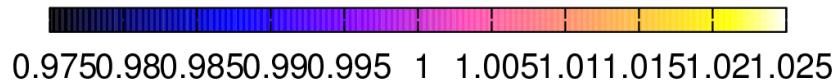
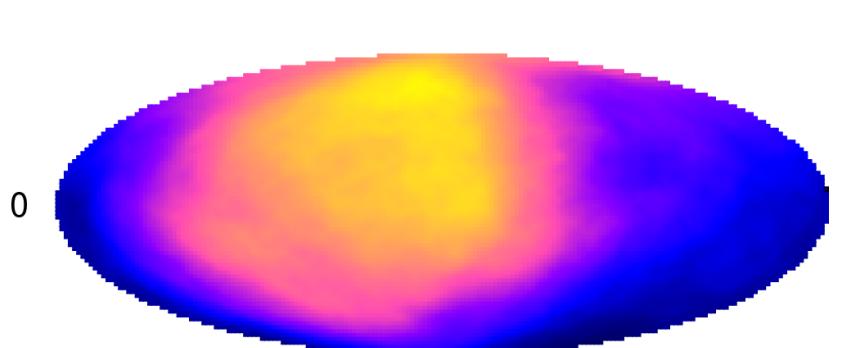
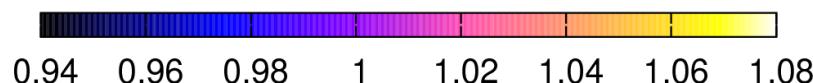
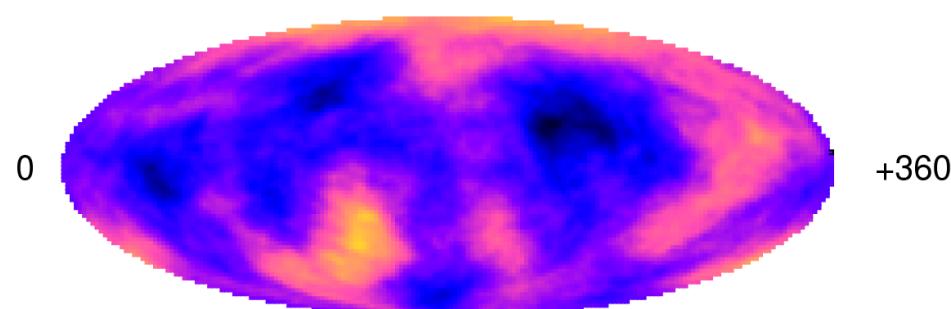


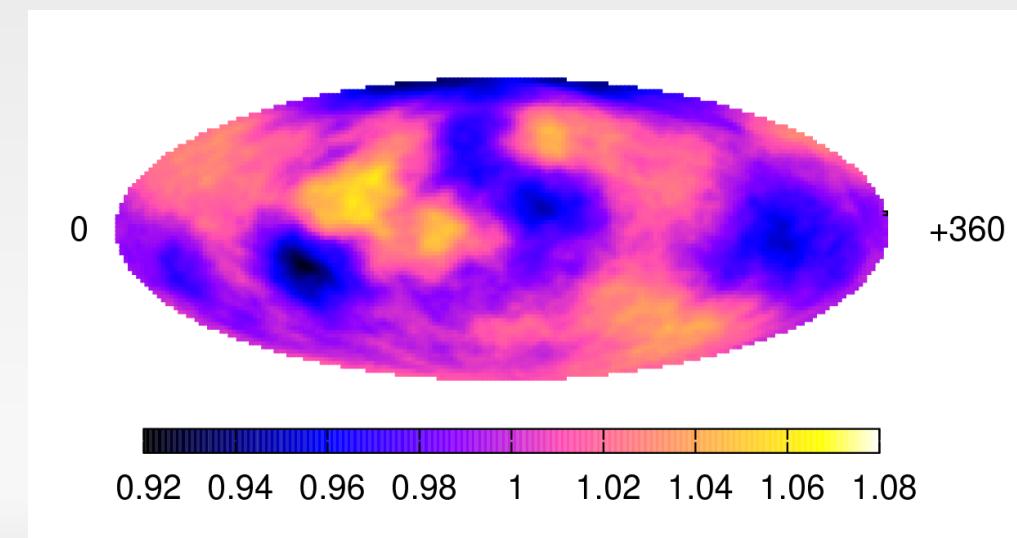
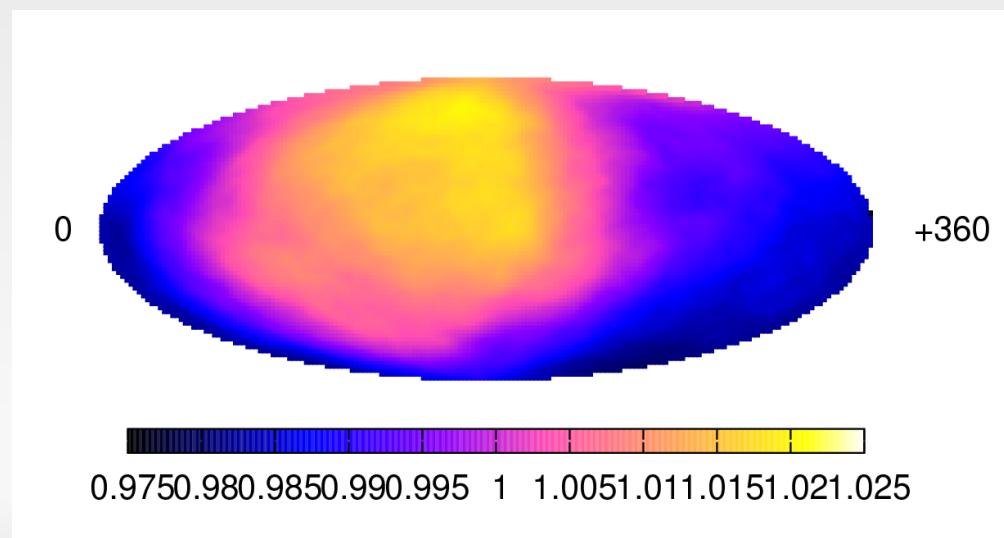
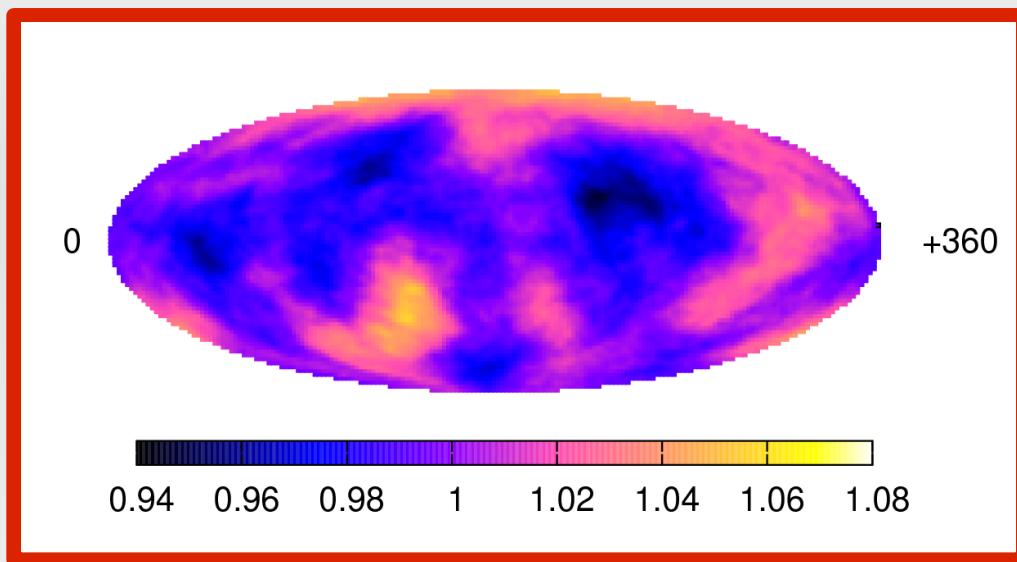
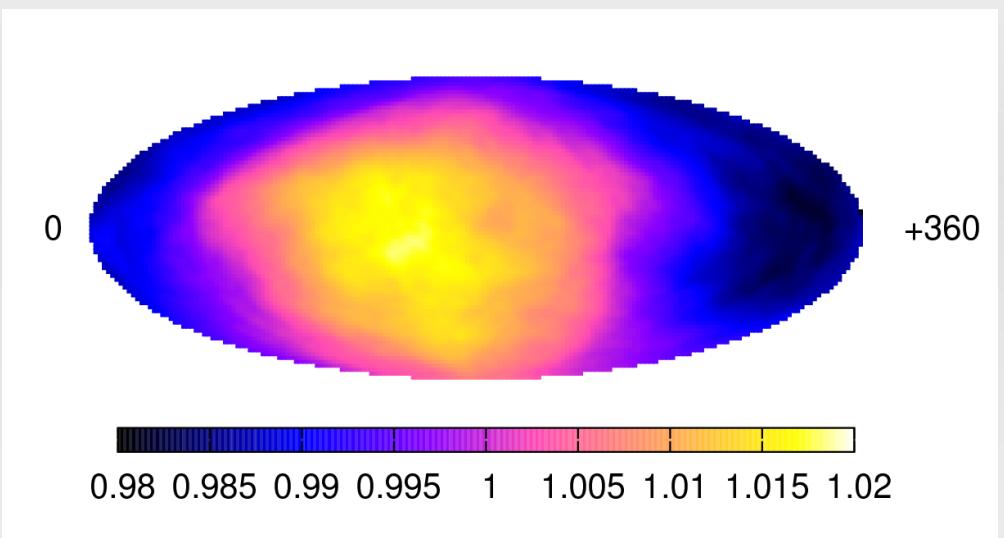
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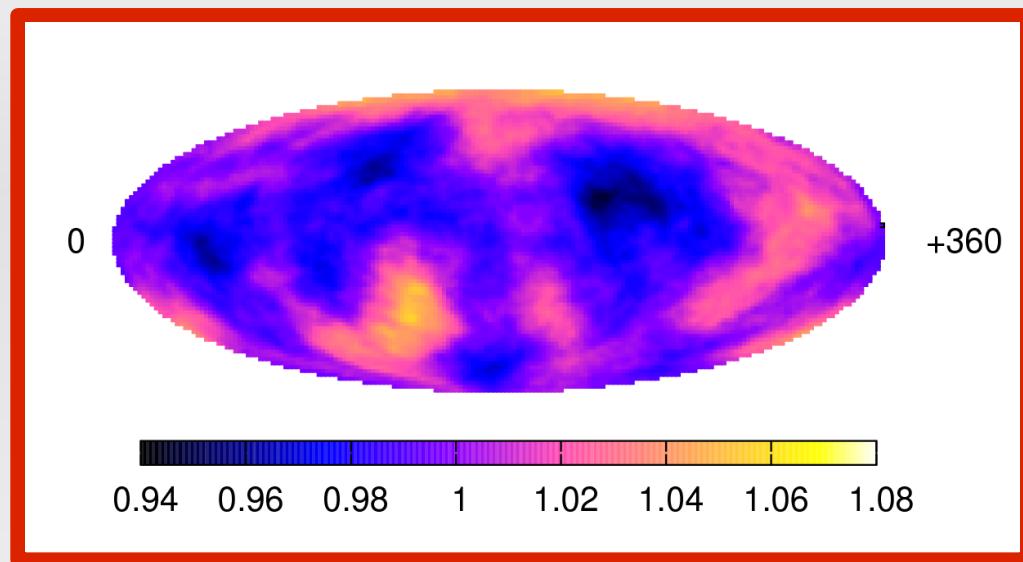
90° smoothing

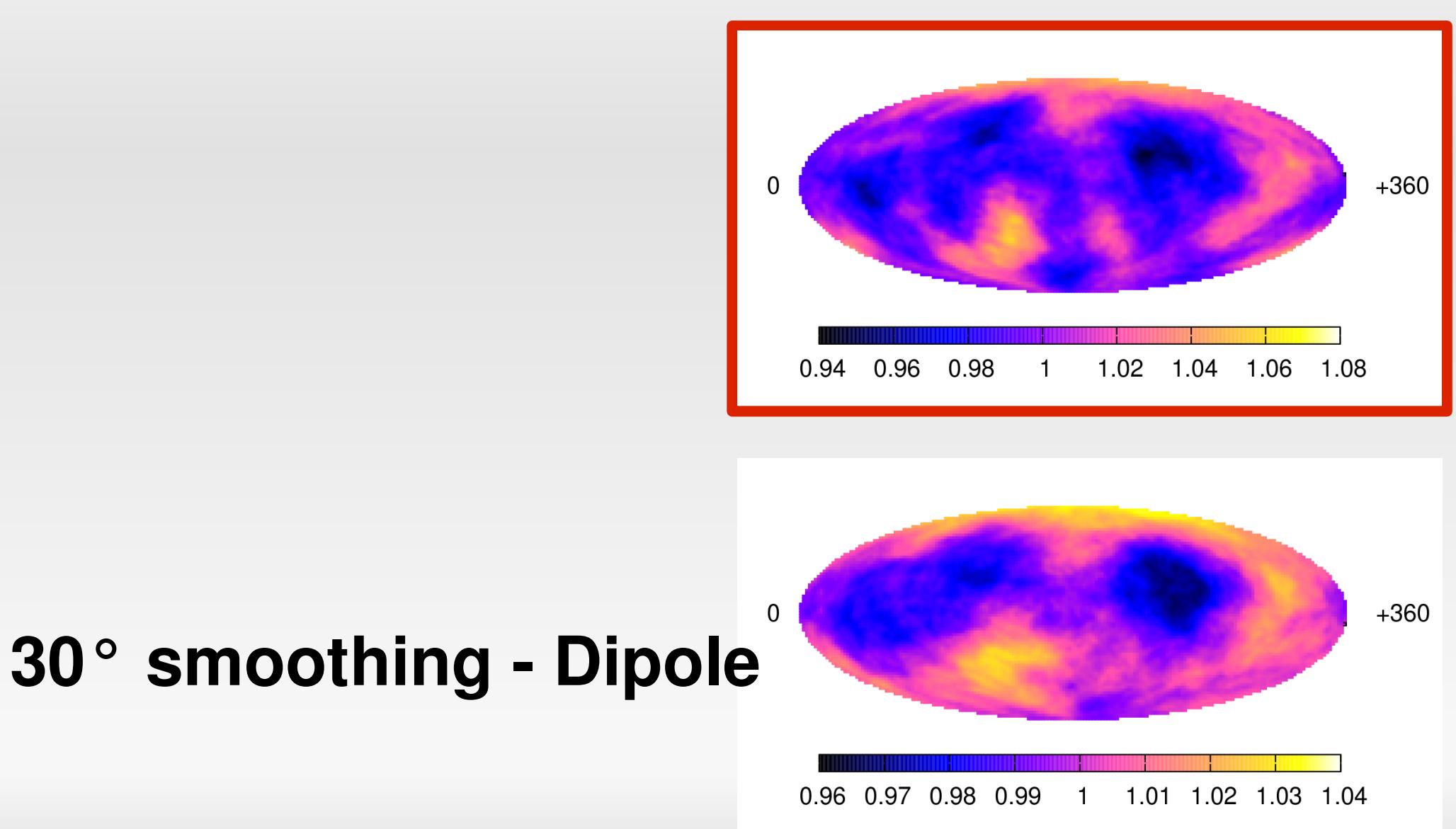


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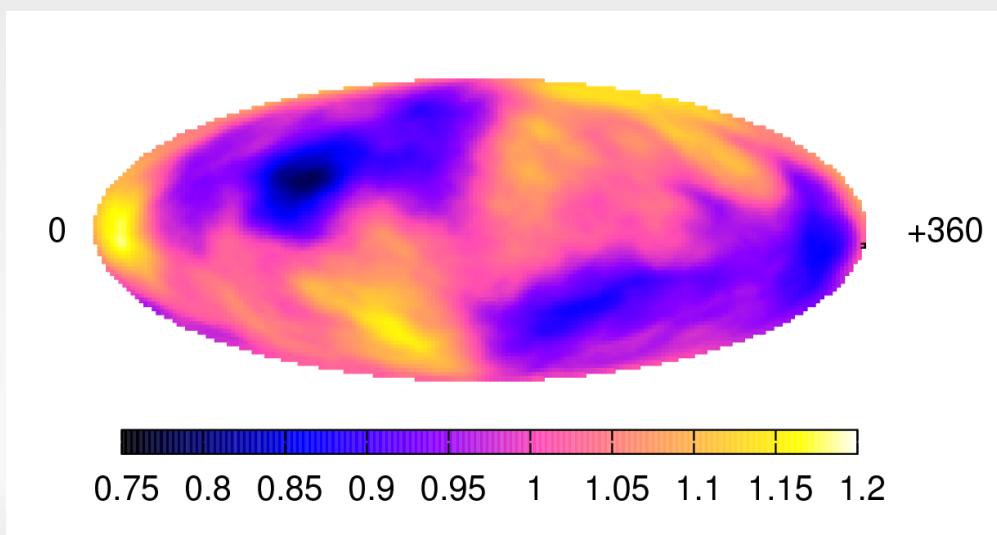
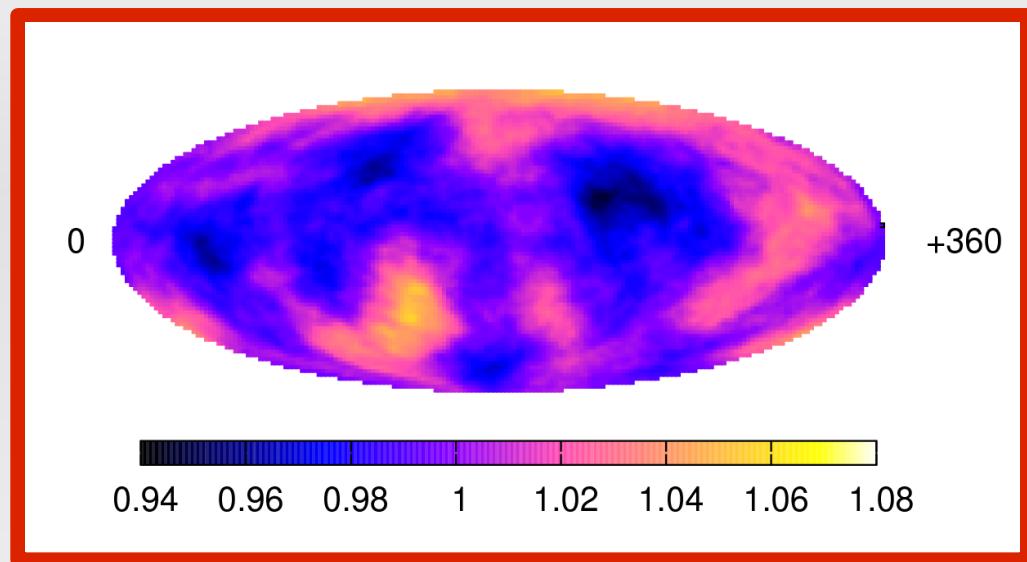




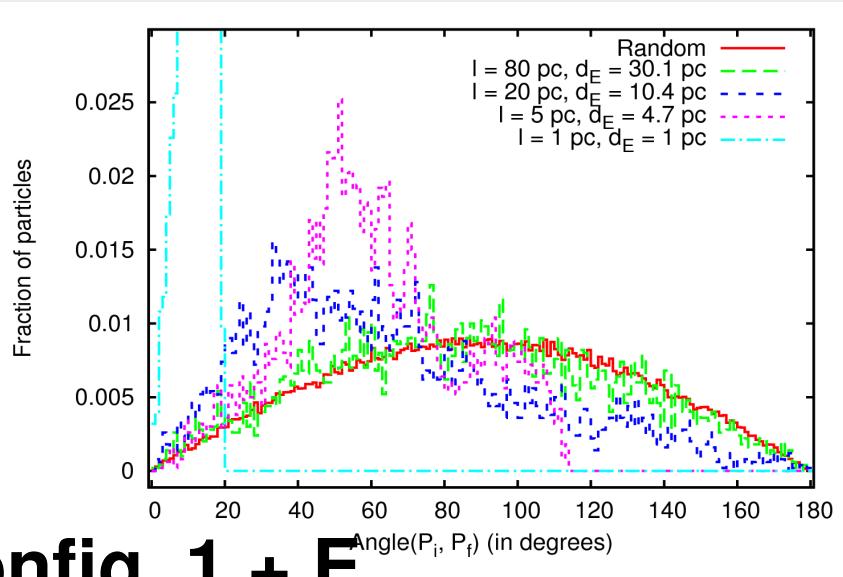




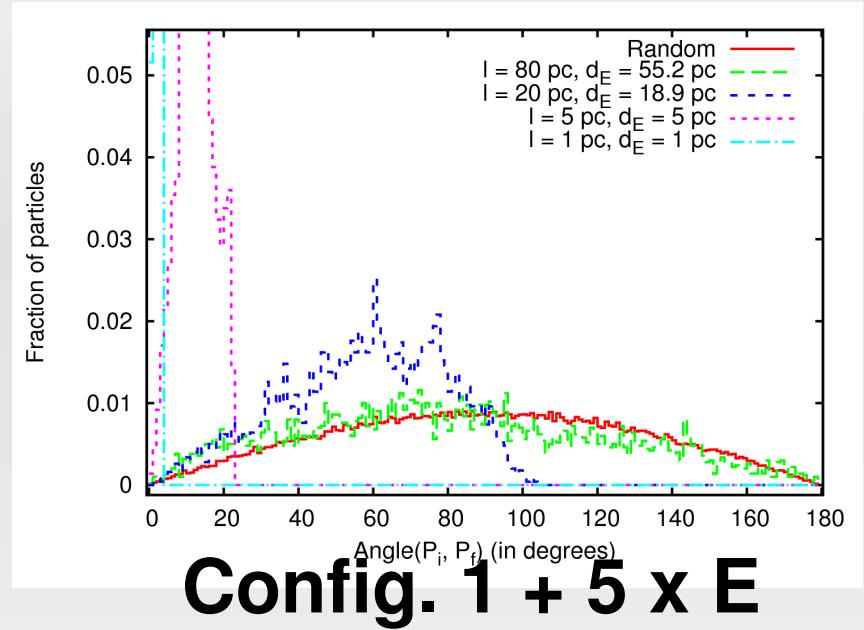
$E = 5 \times 10^{16} \text{ eV}$



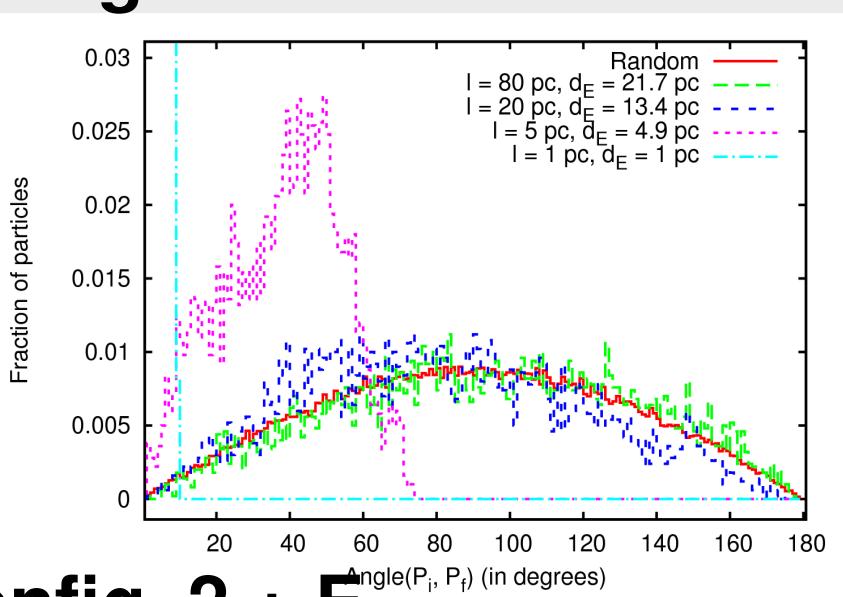
# Memoryless ?



**Config. 1 + E**

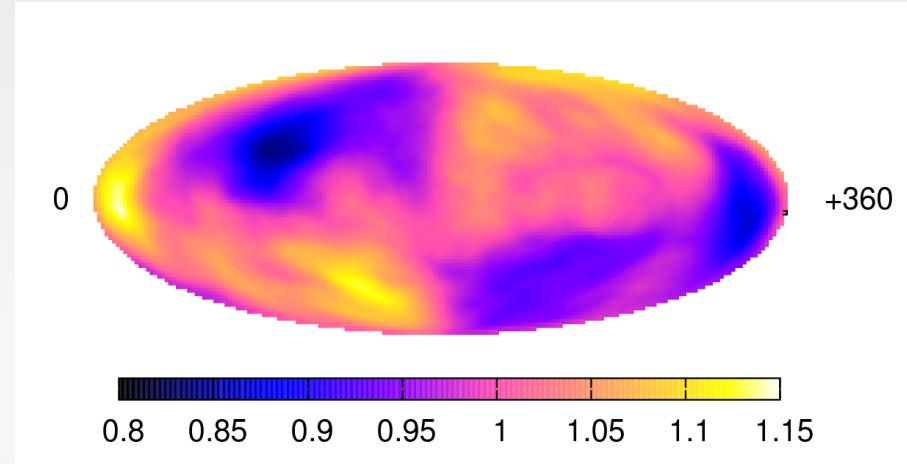
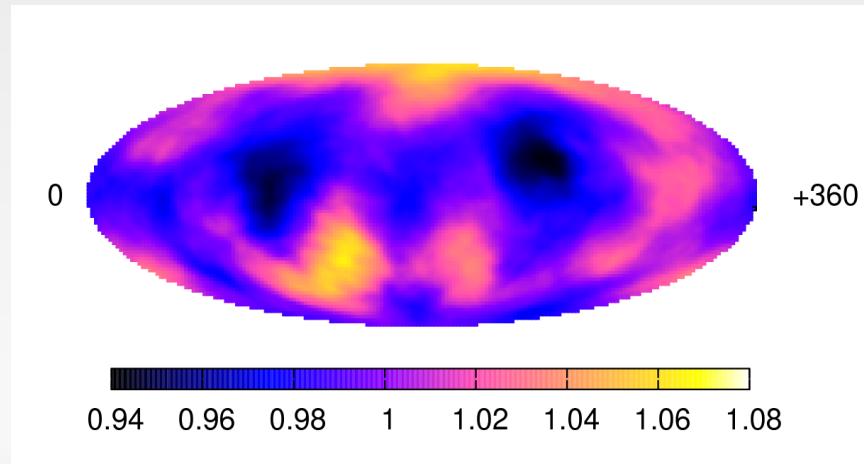
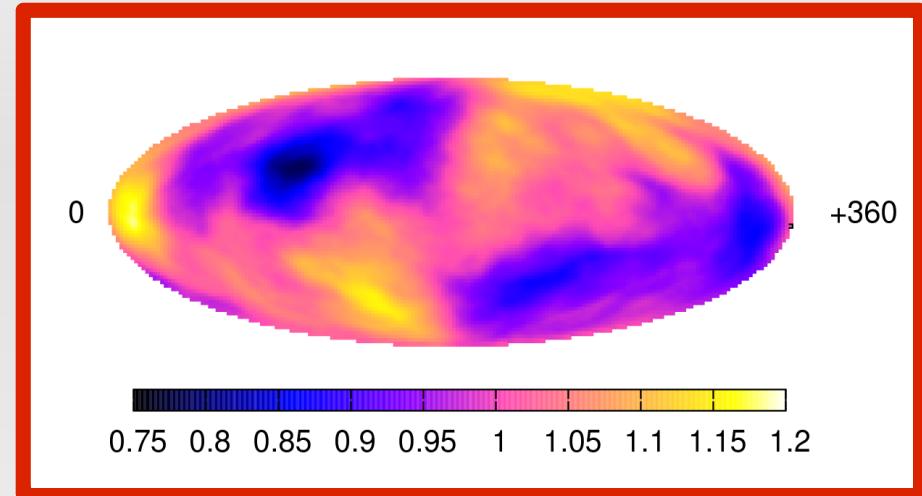
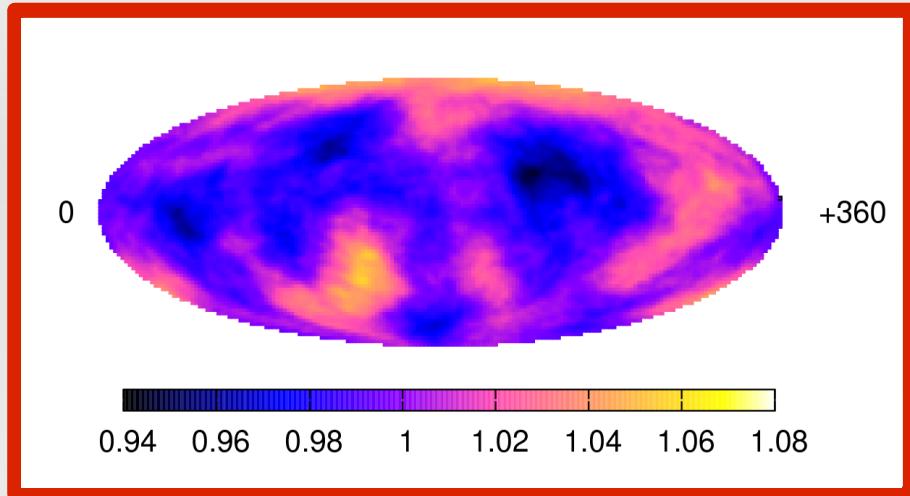


**Config. 1 + 5 x E**



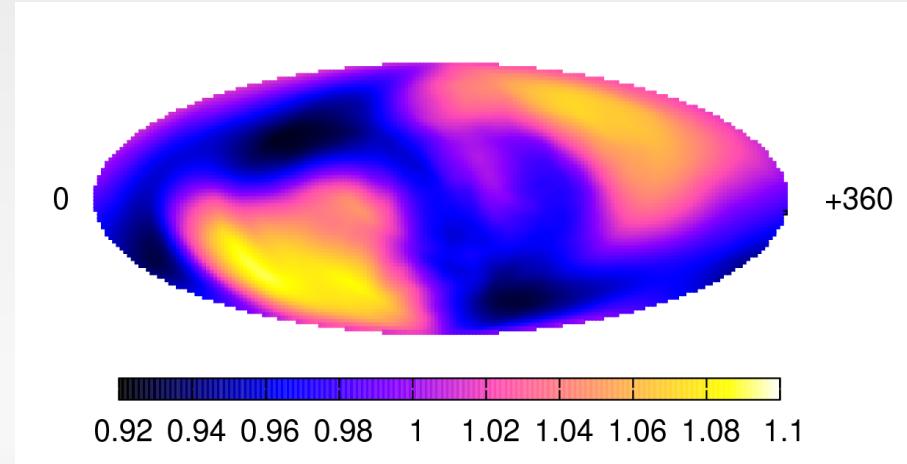
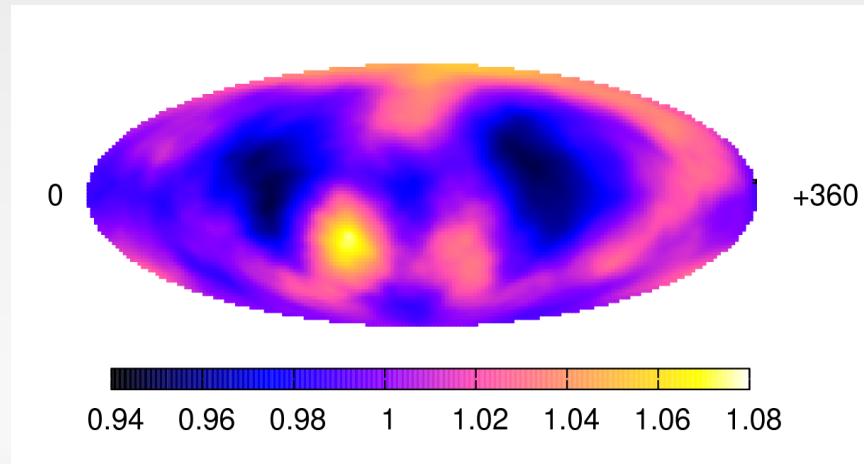
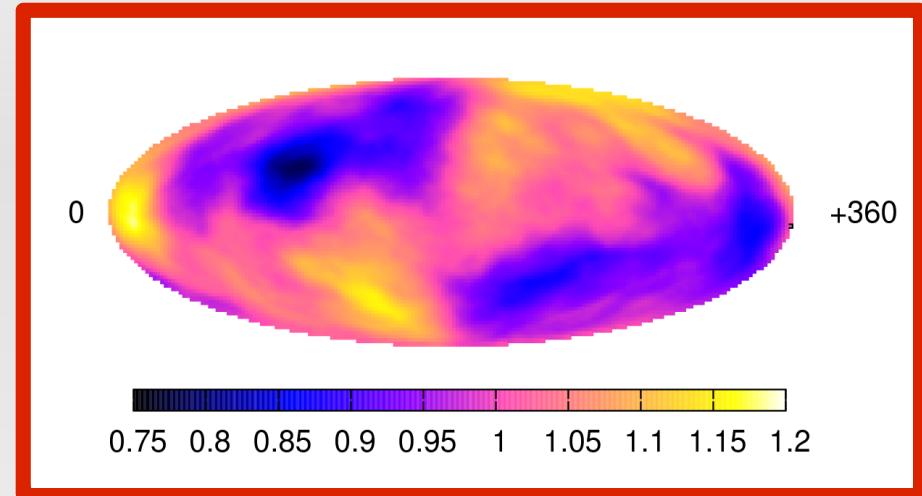
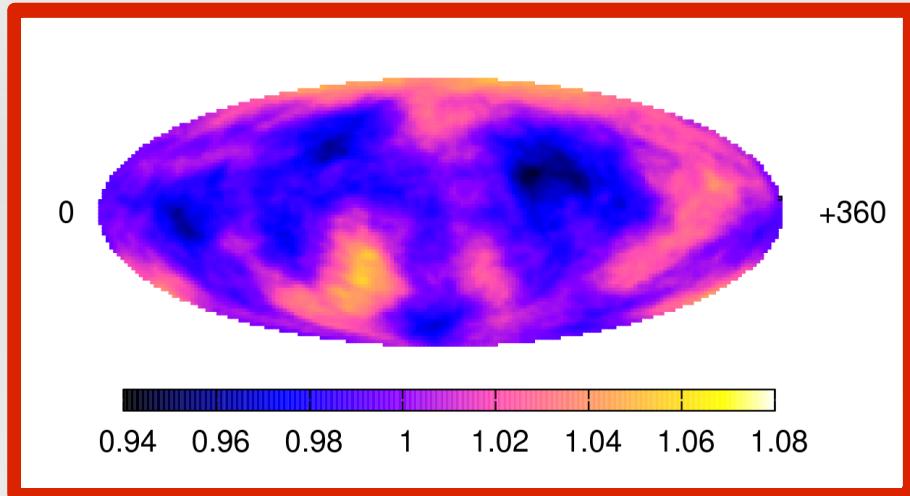
**Config. 2 + E**

# Dependence on the « boundary » radius



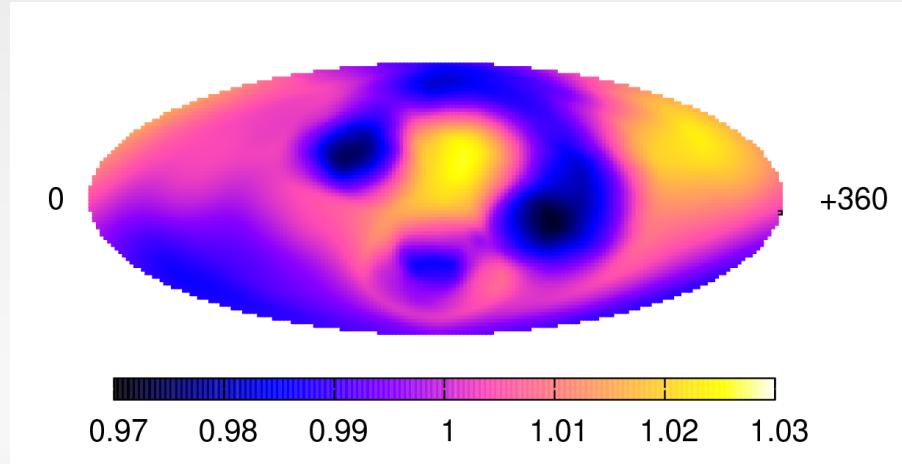
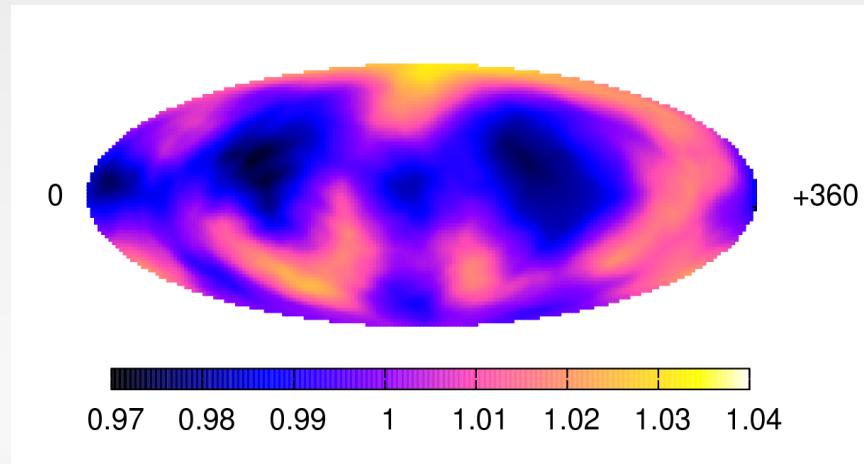
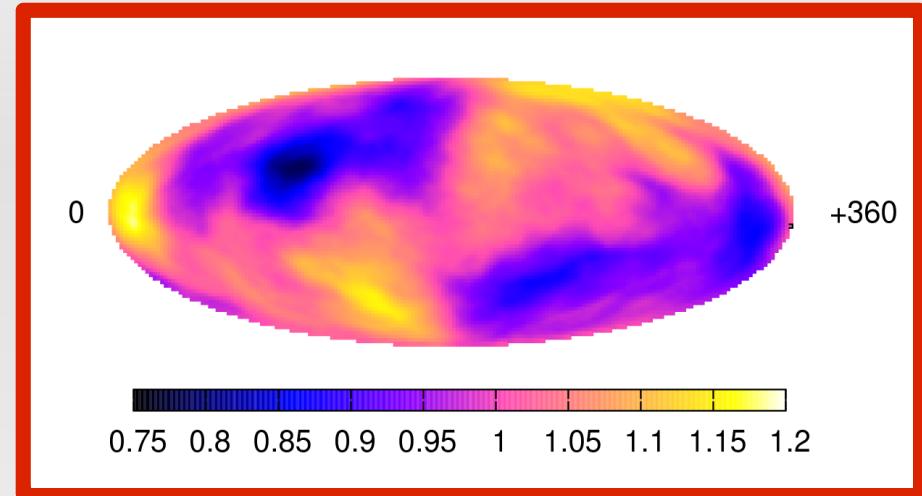
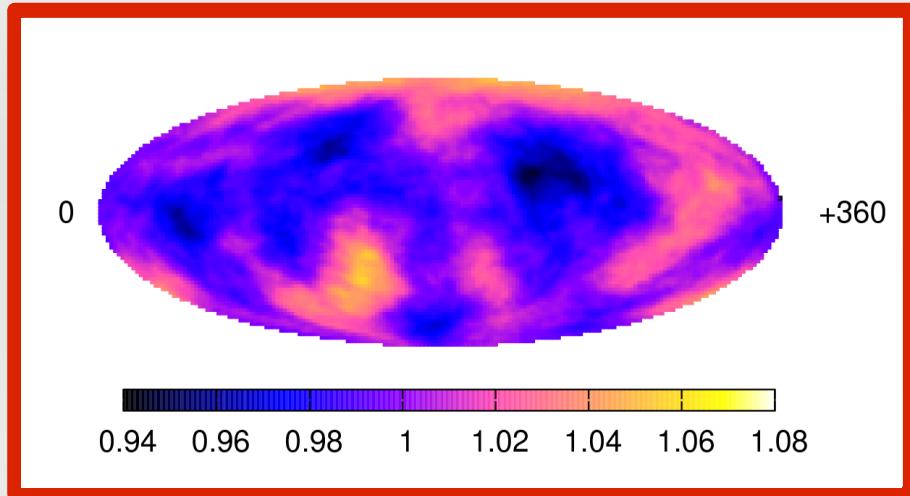
100 pc

# Dependence on the « boundary » radius



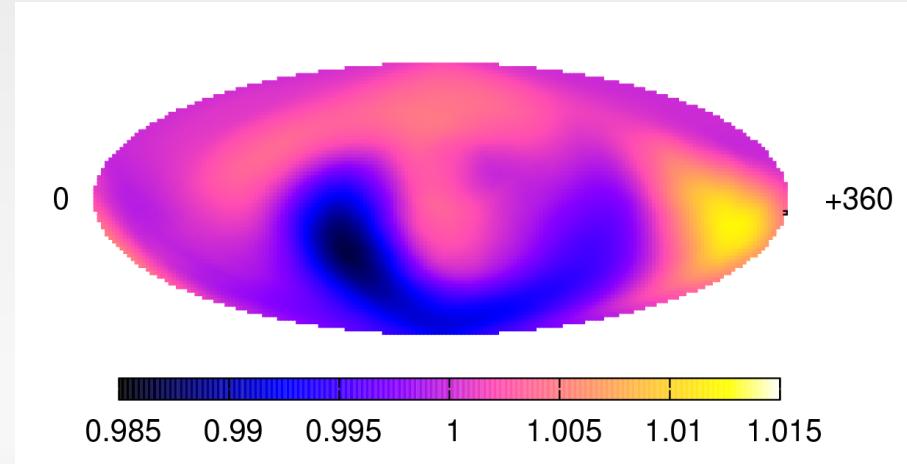
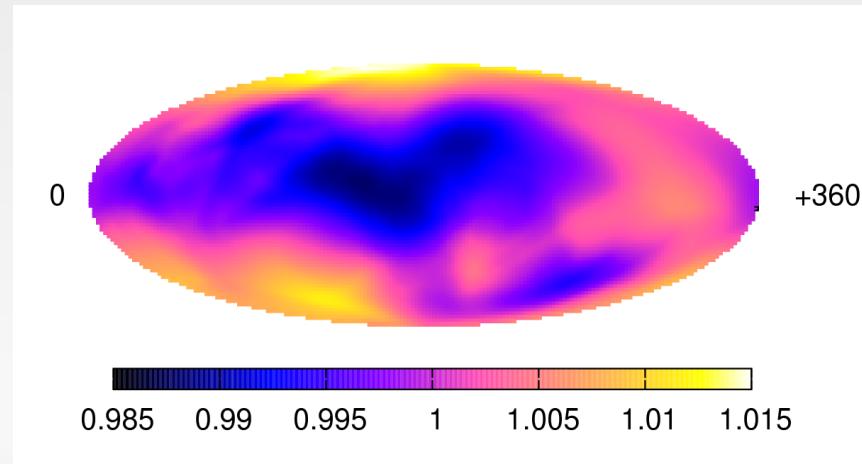
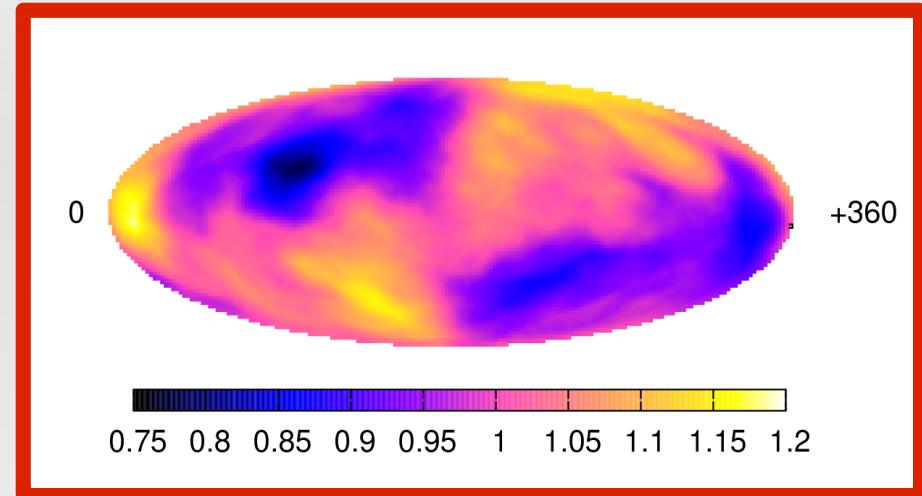
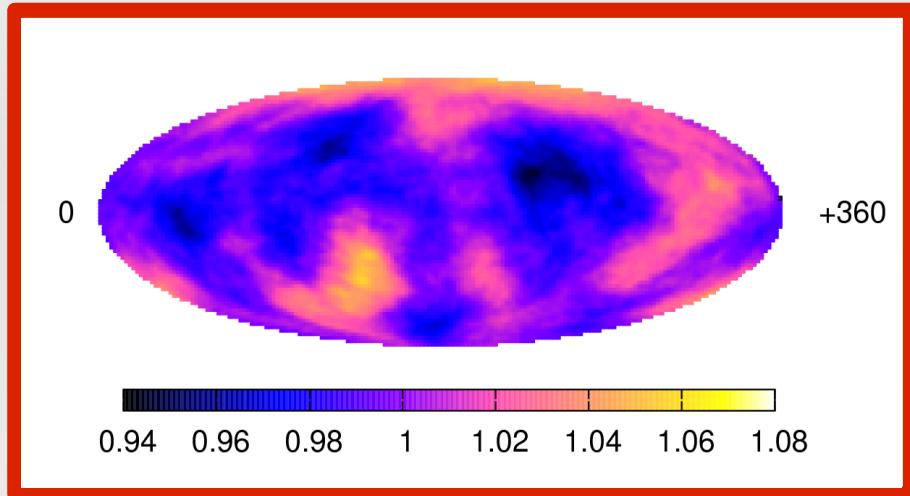
50 pc

# Dependence on the « boundary » radius



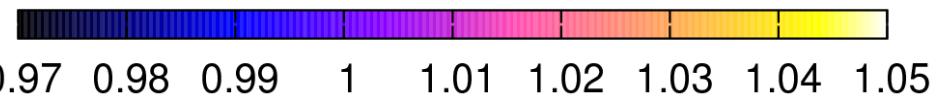
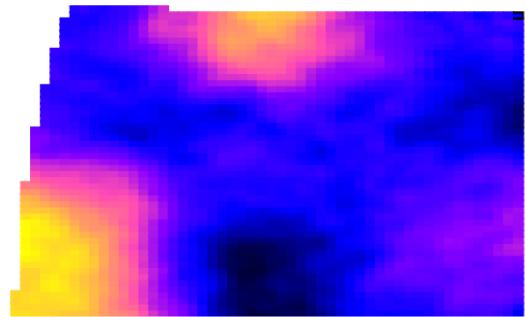
25 pc

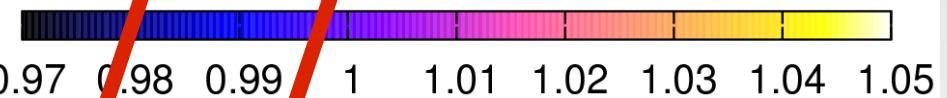
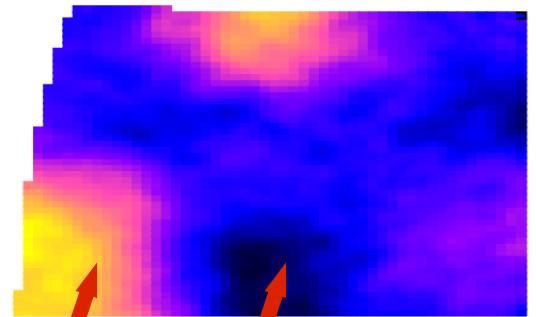
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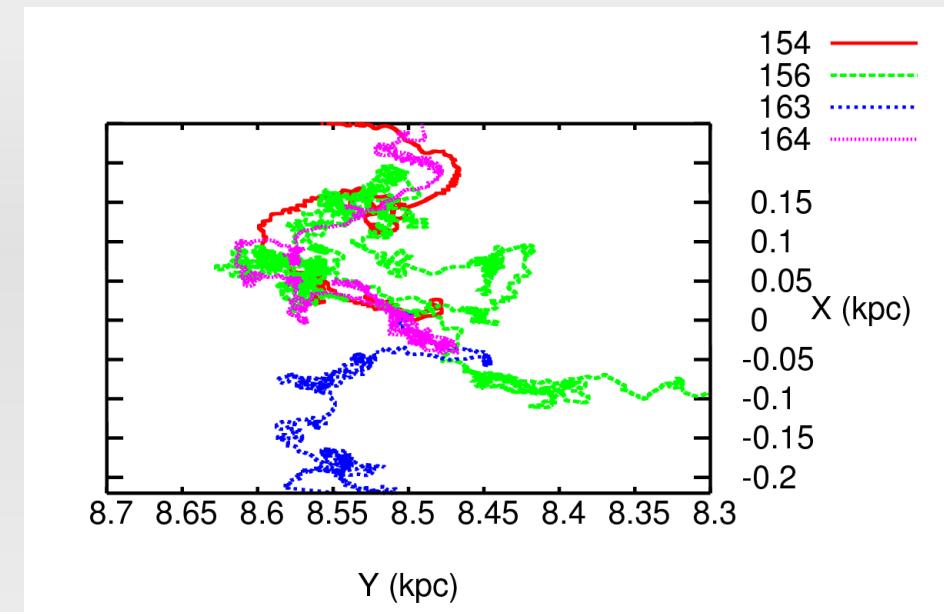
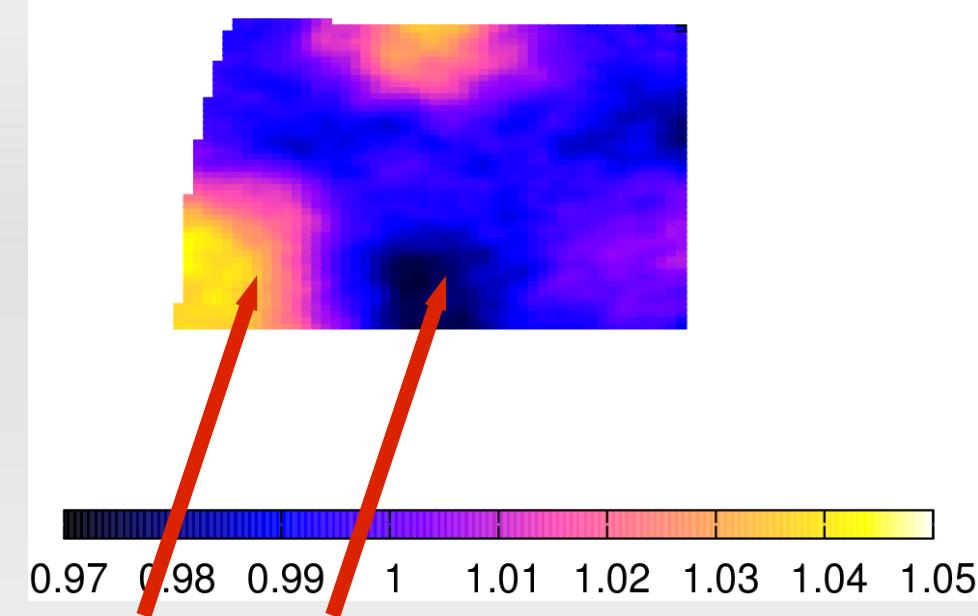


**10 pc**

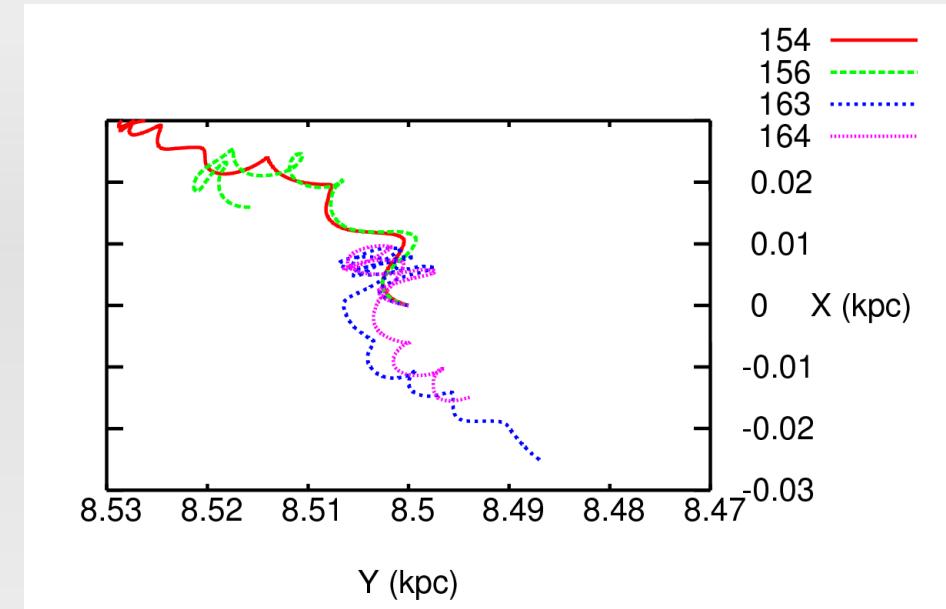
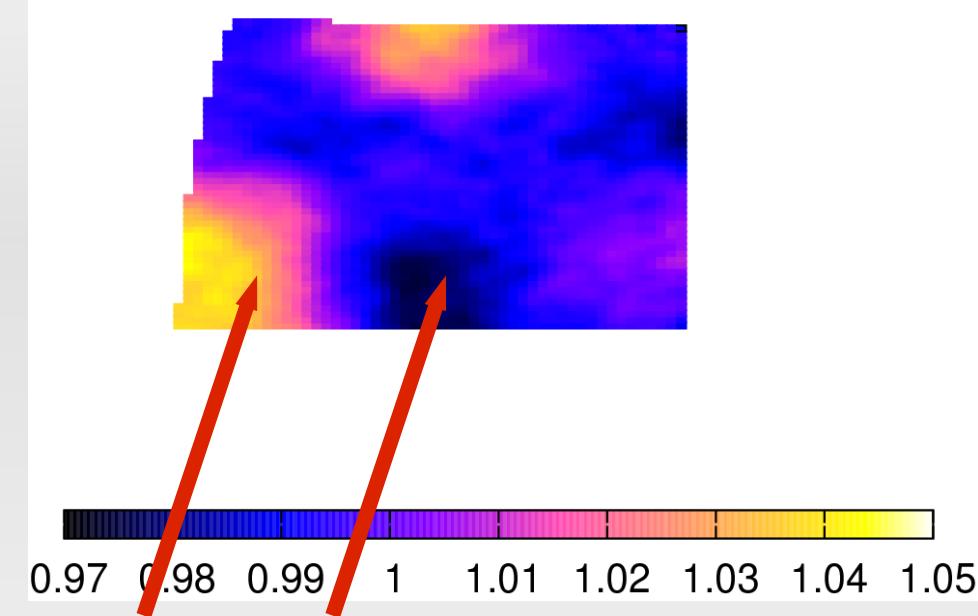
# Local trajectories

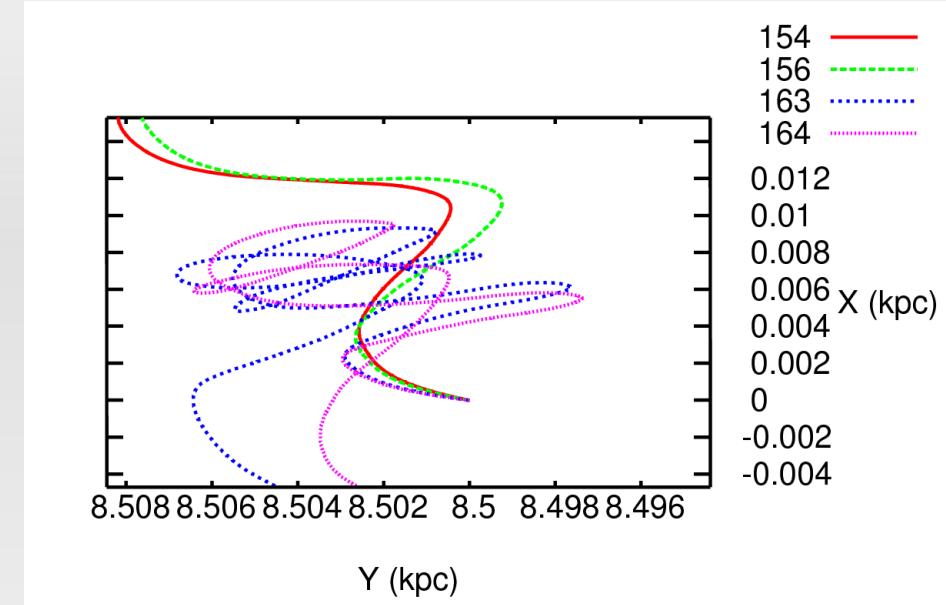
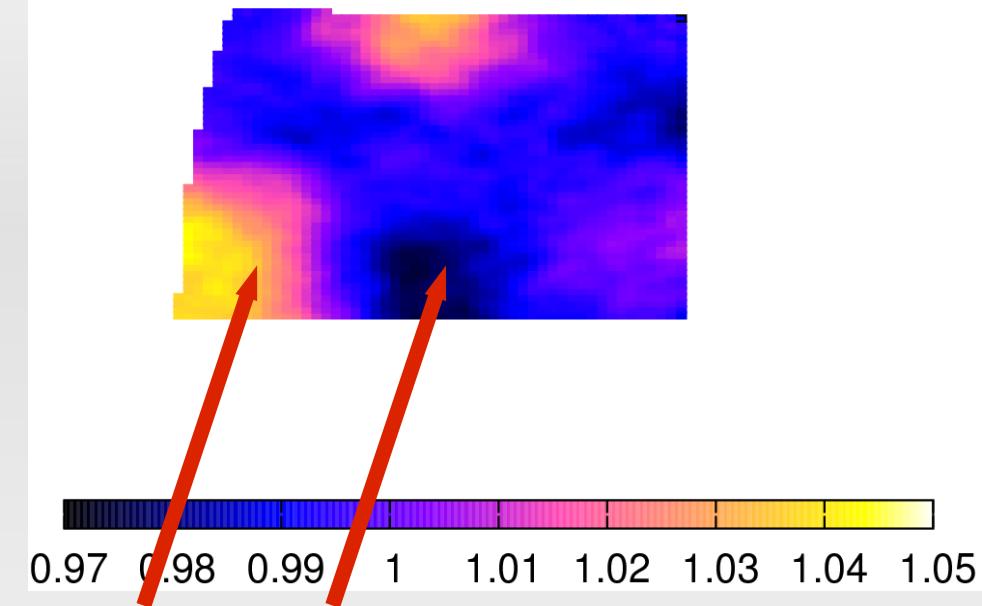






←  
**grad N**





# Conclusions, perspectives

- Smaller scale energy-dependent anisotropies appear at multiple scales, provided that there is some large scale anisotropy
- Numerical simulation to prove it,
- Future works to do,
- Implications:
  - CR anisotropies,
  - CR propagation.