Simulating the galactic cosmic ray with non-uniform grids

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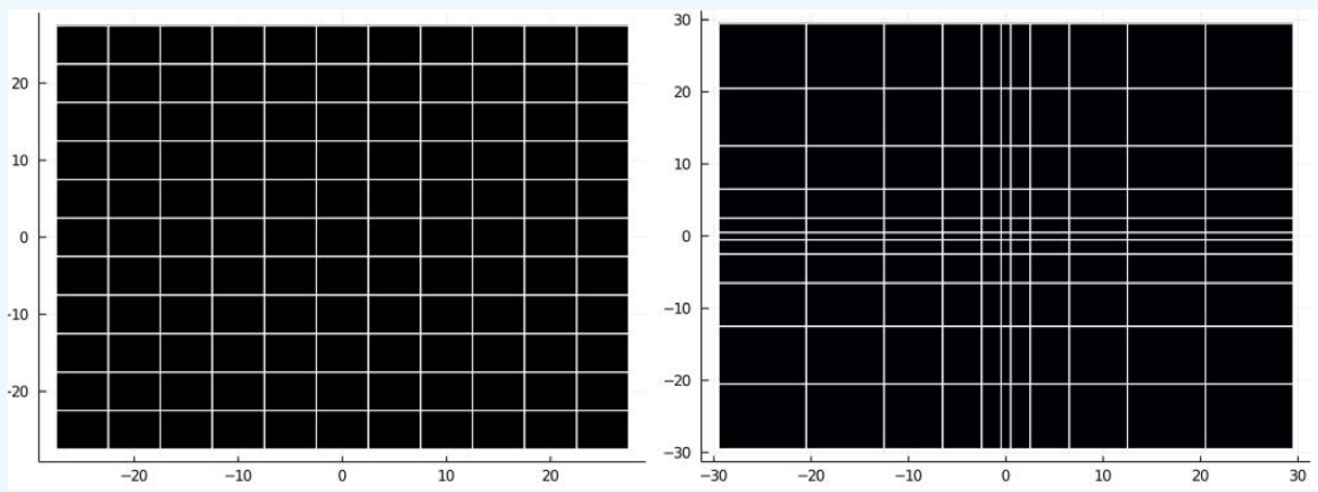
ABSTRACT

The input of local source information and propagation parameters at a scale of O(10) pc are necessary in order to accurately repeat the large scale 2D anisotropy of cosmic ray from TeV to PeV. However, simulating the CR propagation using the normal finite-difference method (FDM) with O(10) pc grids would occupy too much memory and thus could not be performed in usual servers. To solve this problem, we suggested a non-uniform-grid method to allow a set of fine enough grids in vicinity of the solar system. In this work, besides the description and validation of the method, our calculation successfully explains the observed transition of 2D cosmic ray anisotropy map between TeV and PeV energies.

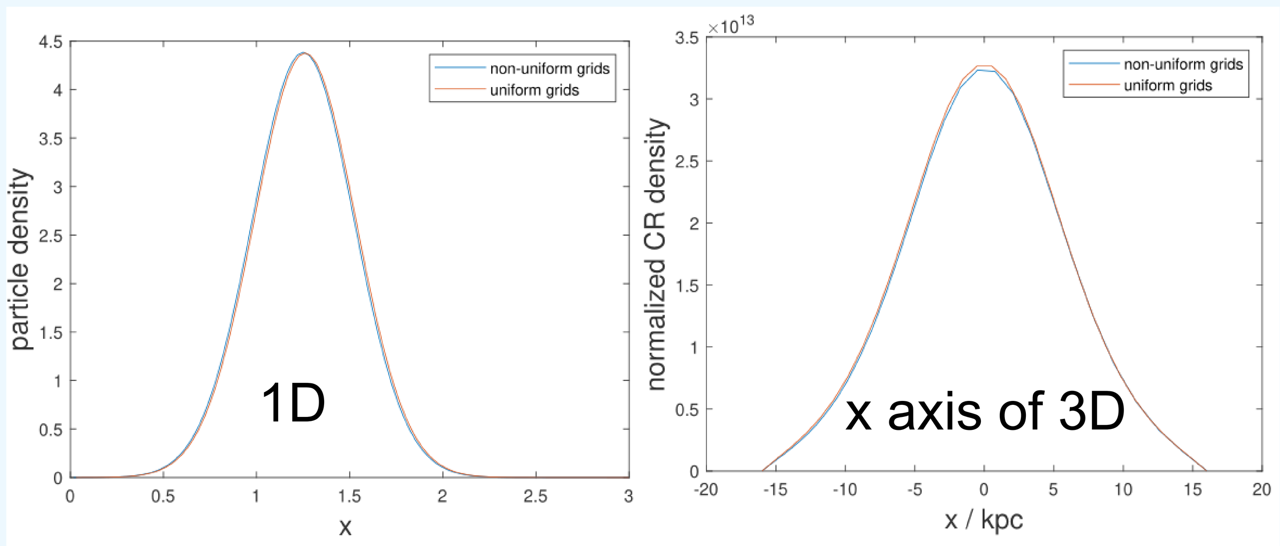
Method

In order to efficiently predict the local interstellar CR distribution with high resolution, we divide the Galaxy into non-uniform grids.



We adopt an non-linear coordinate transformation $\mathrm{x} \to \mathrm{x}' \equiv f(\mathrm{x})$ to transform these grids into non-uniform. The diffusion equation follows the formula:

$$\frac{\partial}{\partial t}\psi = q + \sum_{i,j} \frac{\partial}{\partial x_i} D_{ij} \frac{\partial}{\partial x_j}\psi \to \frac{\partial}{\partial t}\psi' = q' + \sum_{i,j} \frac{\partial}{\partial x_i} \frac{D_{ij}}{f_j'} \frac{\partial}{\partial x_j} \frac{\psi'}{f_i'}.$$



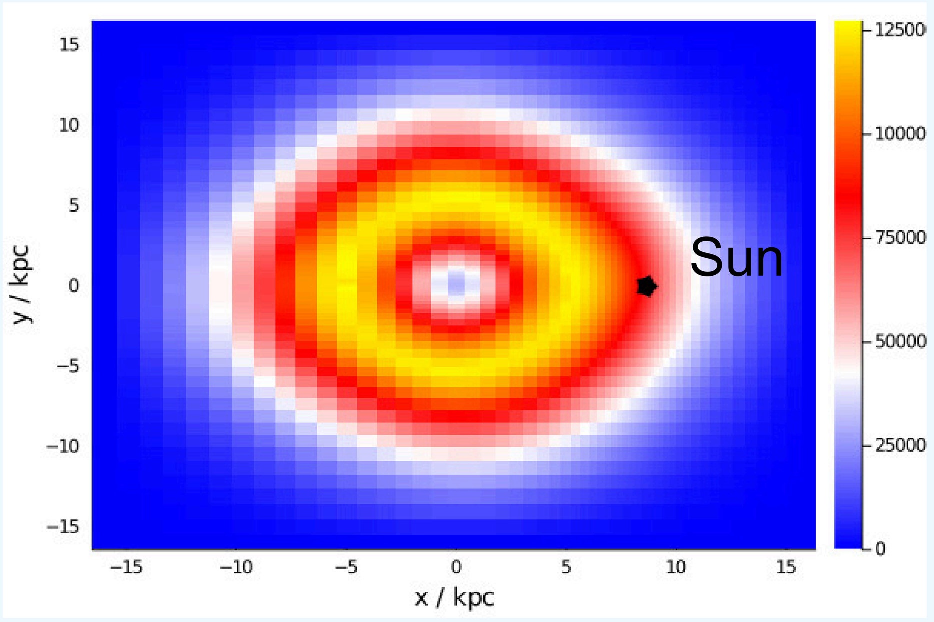
Two examples to show the validation of the non-uniform-grid method.

CR anisotopy

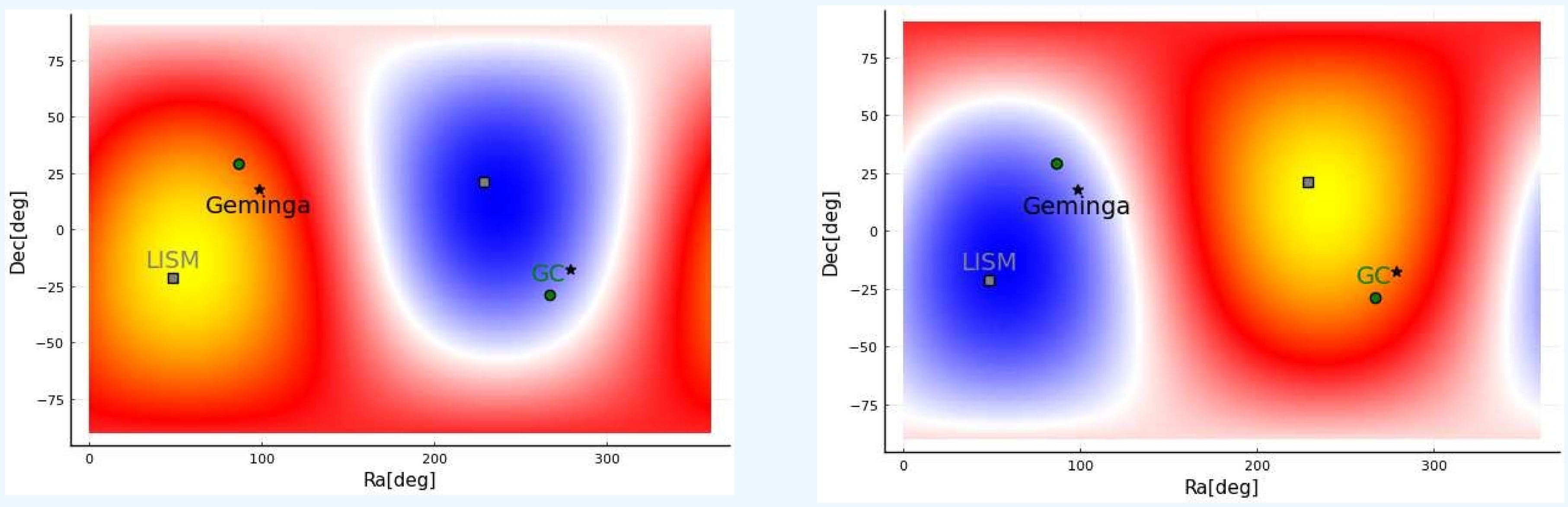
The CR particles are supposed to propagate faster along the Galactic large scale regular magnetic field. The diffusion tensor that could describe this anisotropic diffusion model is

$$D_{ij} = D_\perp \delta_{ij} + (D_{/\!/} - D_\perp) B_i B_j / |\mathbf{B}|^2.$$

Then we apply our method to simulate the propagation of Galactic Cosmic ray. The CR particles are globally confined in a ring as there is a spiral compnent in the Galactic regular field. Our simulation could show more details around the solar system (8.3 kpc, 0 kpc).



we then perform a simulation for an injection at the position of Geminga. We consider the contribution from this source to derive the 2D CR anisotropy observed at the earth.



The 2D CR anisotropy predicted at 2.5 TeV (left) and 1.6 PeV (right）

It could be seen that the direction of the excess of CR flux is reversed along the LISM as the energy increased.

CONCLUSIONS

In this work, we introduced a non-uniform-grid method to approach a high-resolution simulation around the sun. Our method is designed for saving computing resource. We performed two simple cases to verify the validity of this method. This method is then applied to an anisotropic diffusion model described by a realistic Galactic large-scale regular magnetic field. Taking into account the nearby source in this model, we preliminarily reach an explanation of the phase transition on CR anisotropy observation.