Stochastic modelling of cosmic ray sources for diffuse high-energy gamma-rays and neutrinos
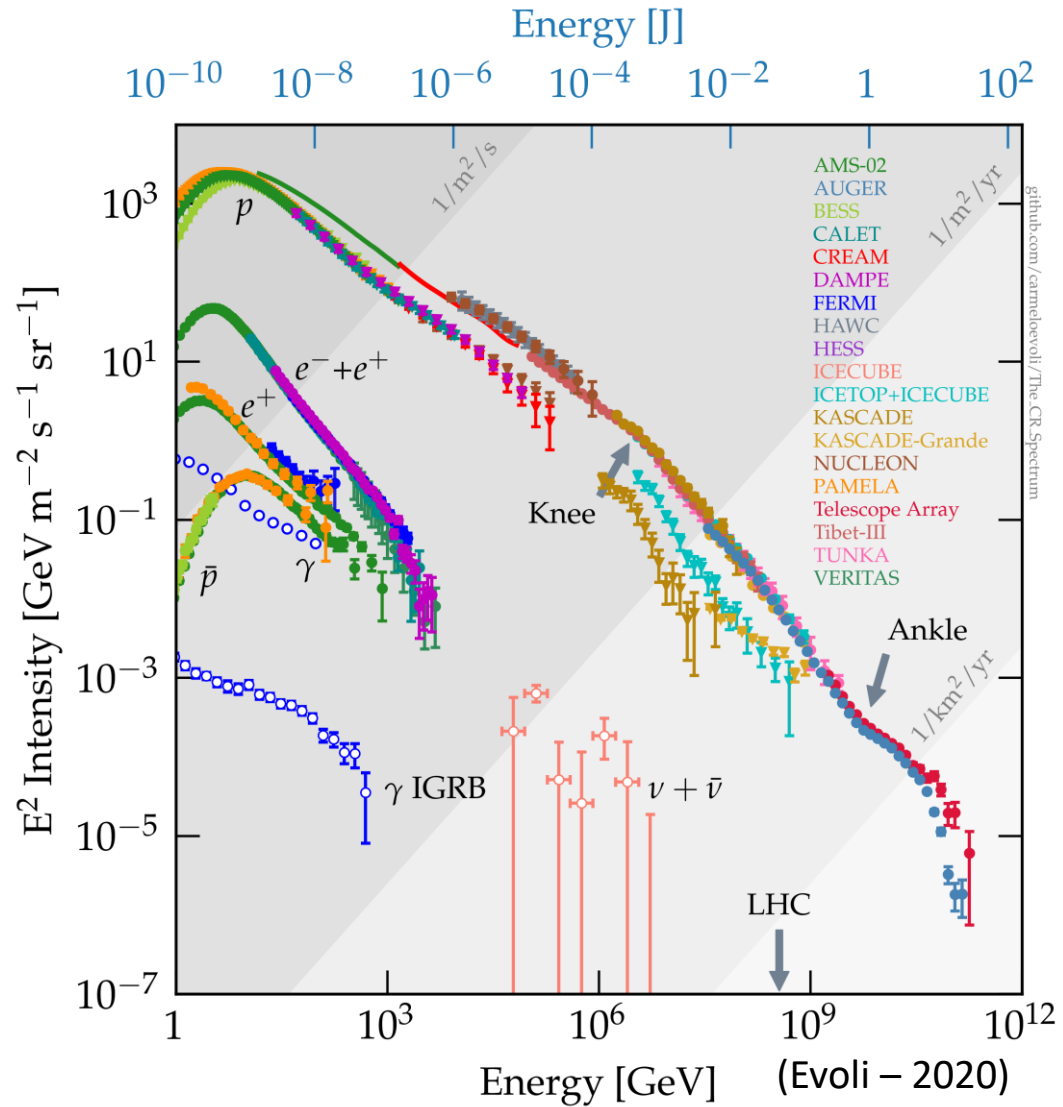
ANTON STALL, LEONARD KAISER AND PHILIPP MERTSCH

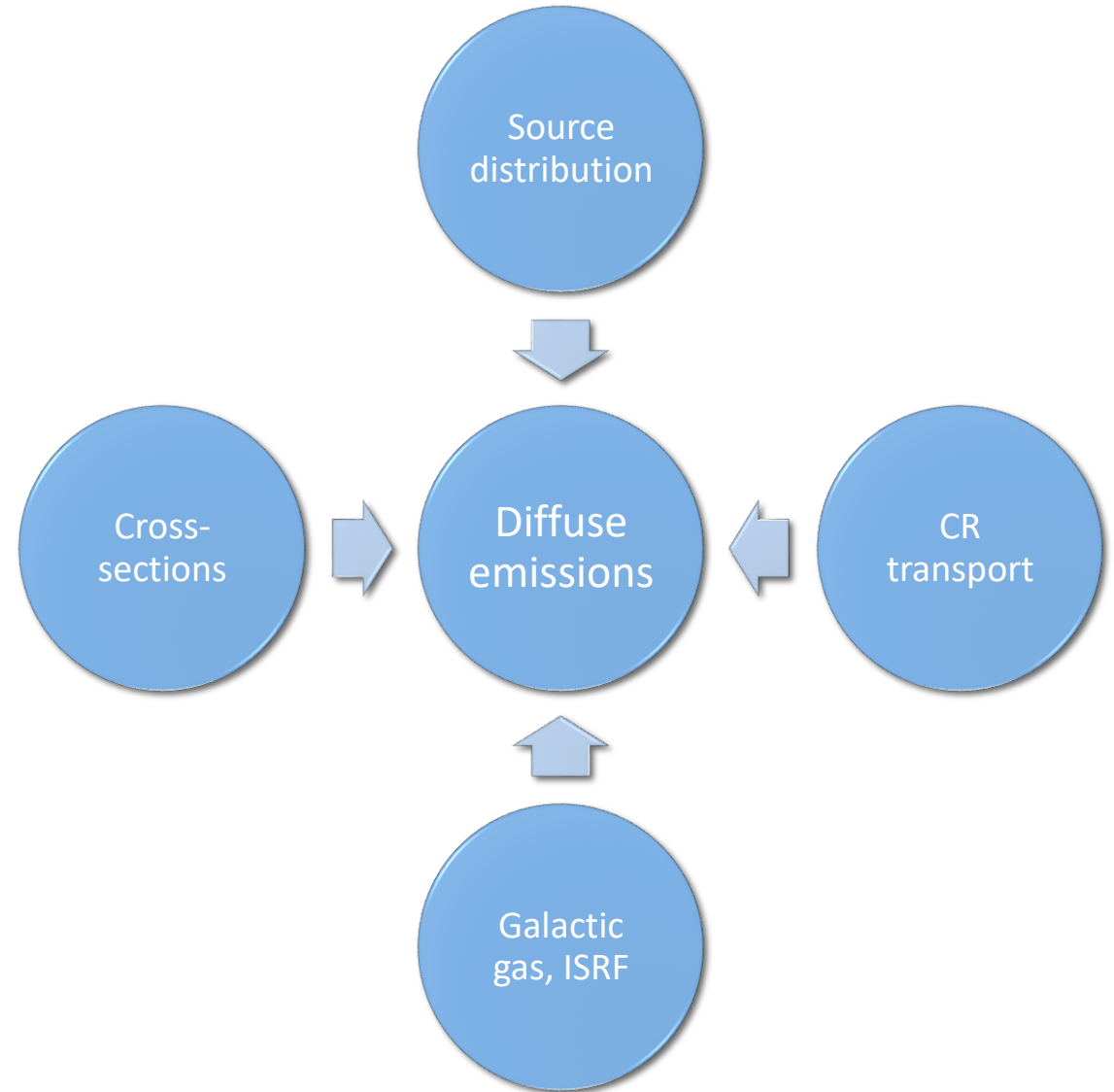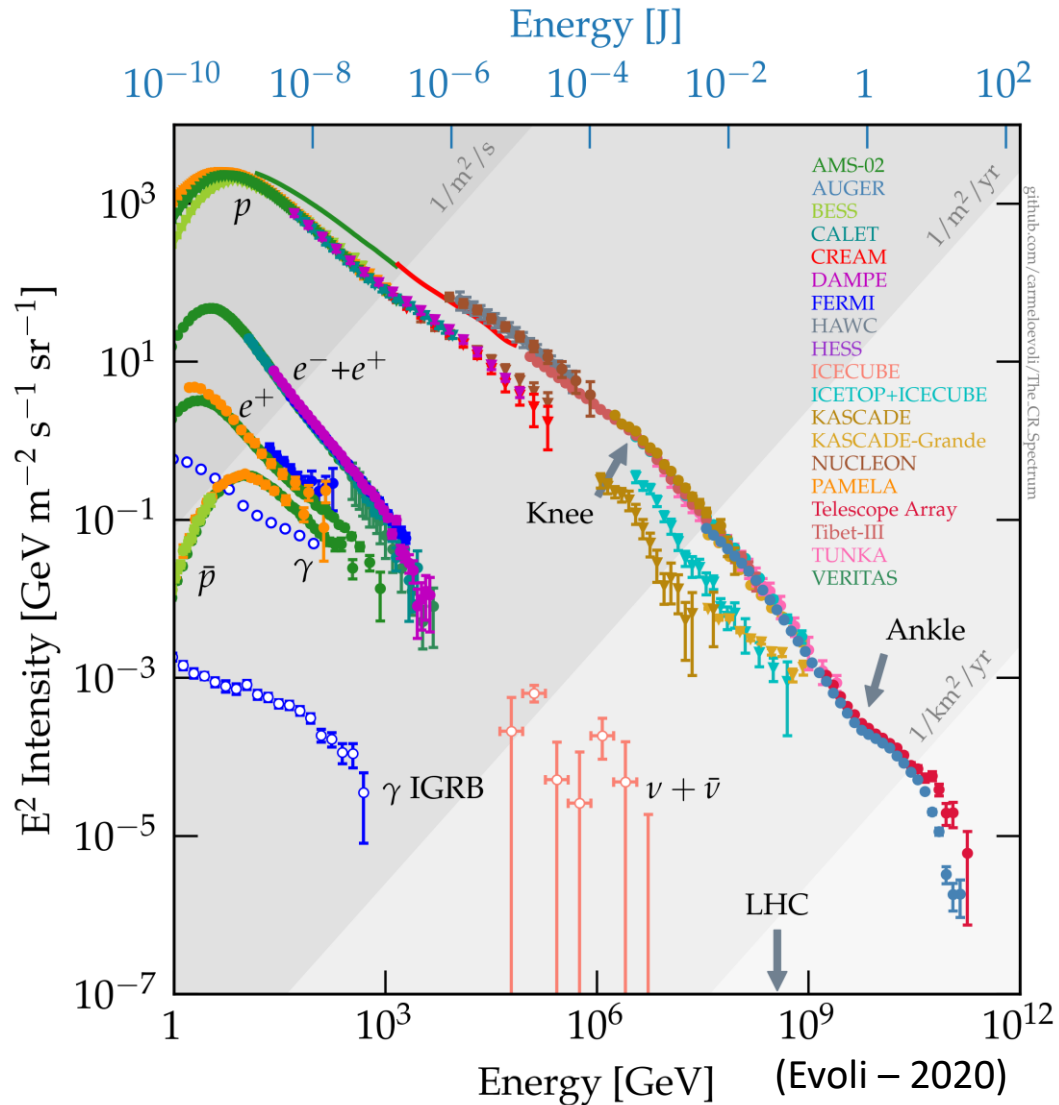INSTITUTE FOR THEORETICAL PARTICLE PHYSICS AND COSMOLOGY (TTK), RWTH AACHEN

PhD Summer School on Neutrinos 2023
20 July, 2023
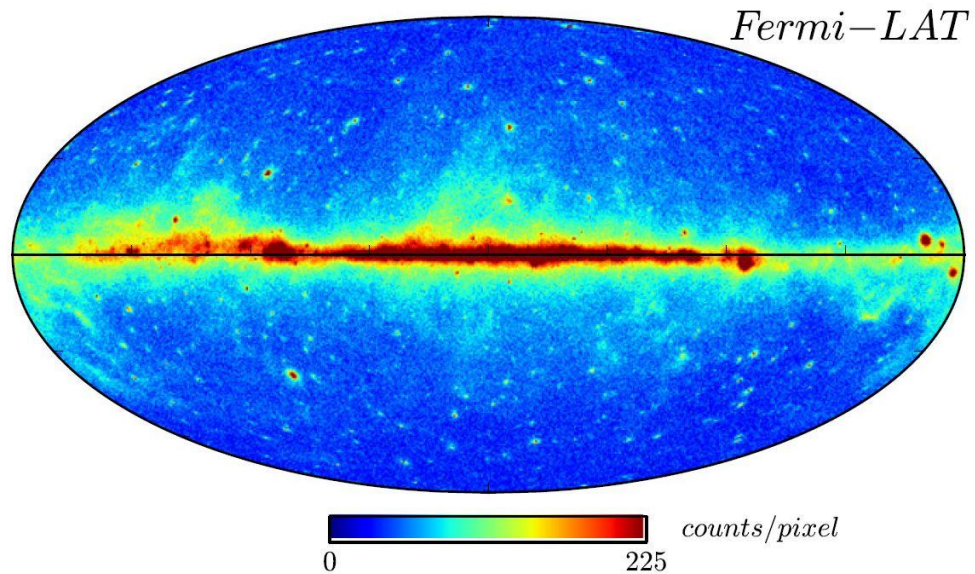Copenhagen, Denmark

Motivation

(Evoli – 2020)

Motivation

(Evoli – 2020)

Motivation

GeV energies

$Fermi-LAT$

counts/pixel

0   225

(Ackermann et al – 2016)

Source distribution

Cross-sections

Diffuse emissions

CR transport

Galactic gas, ISRF
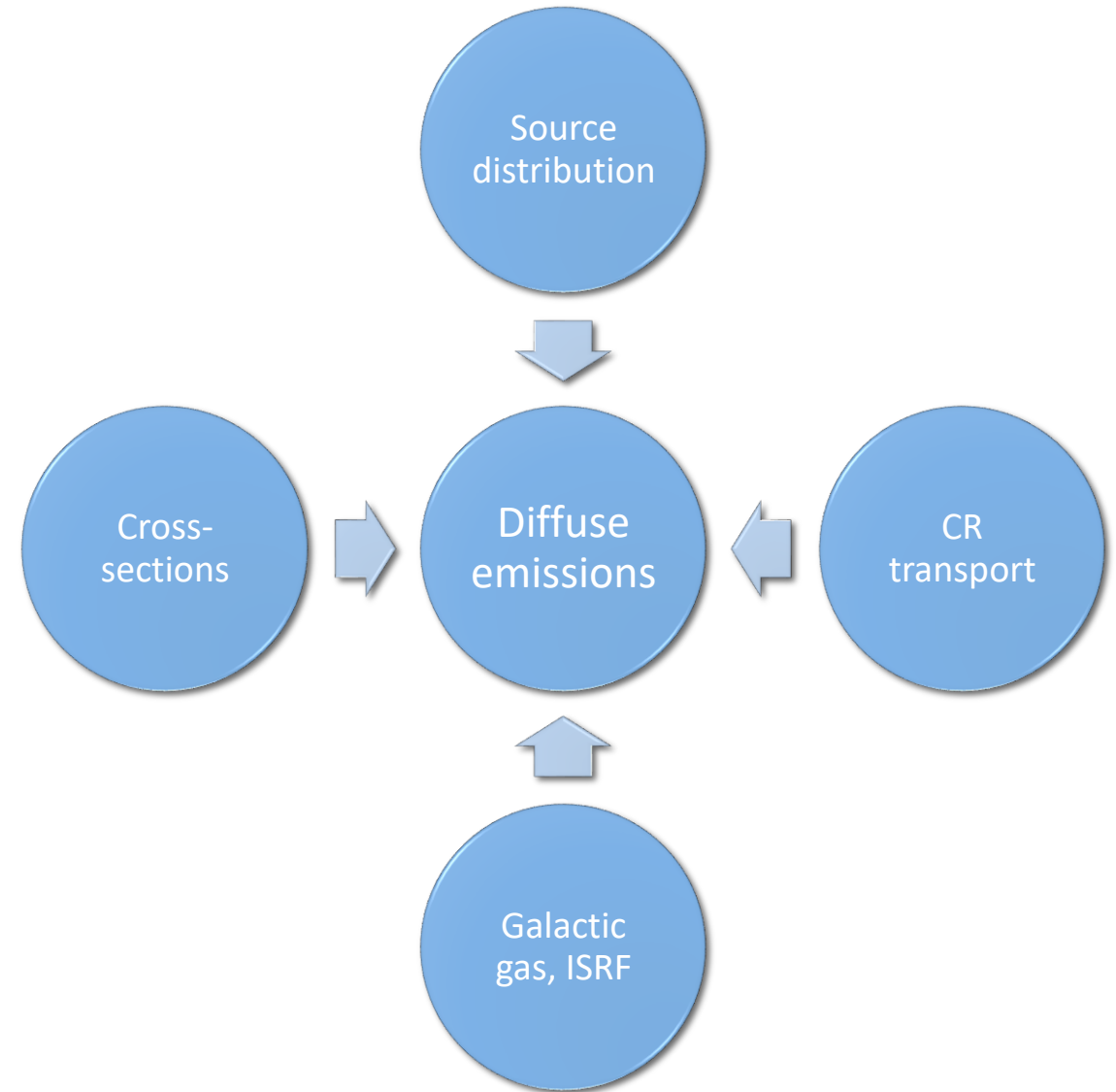
Motivation

GeV energies → **TeV energies**

Fermi−LAT

counts/pixel

0   225

(Ackermann et al – 2016)

?
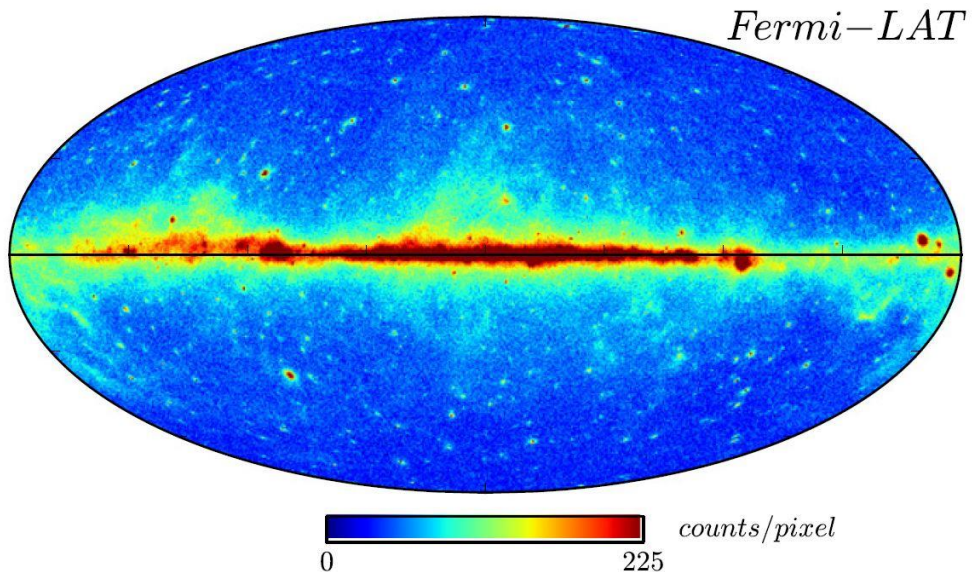
- Influence of point sources?
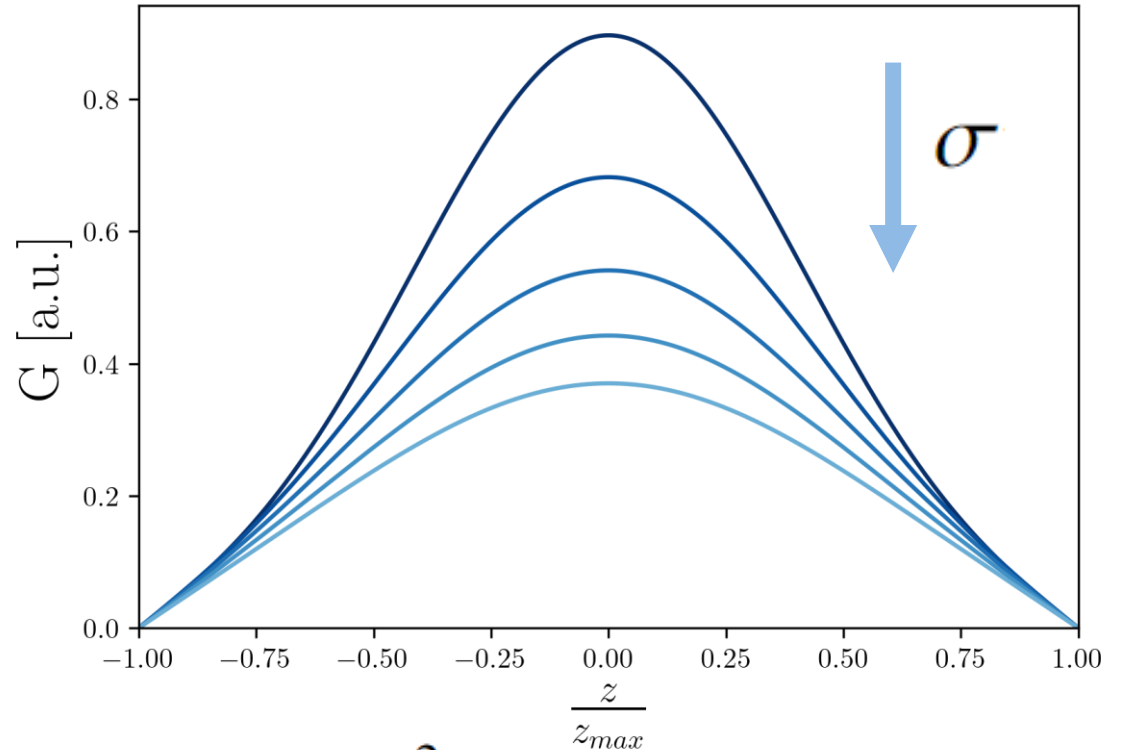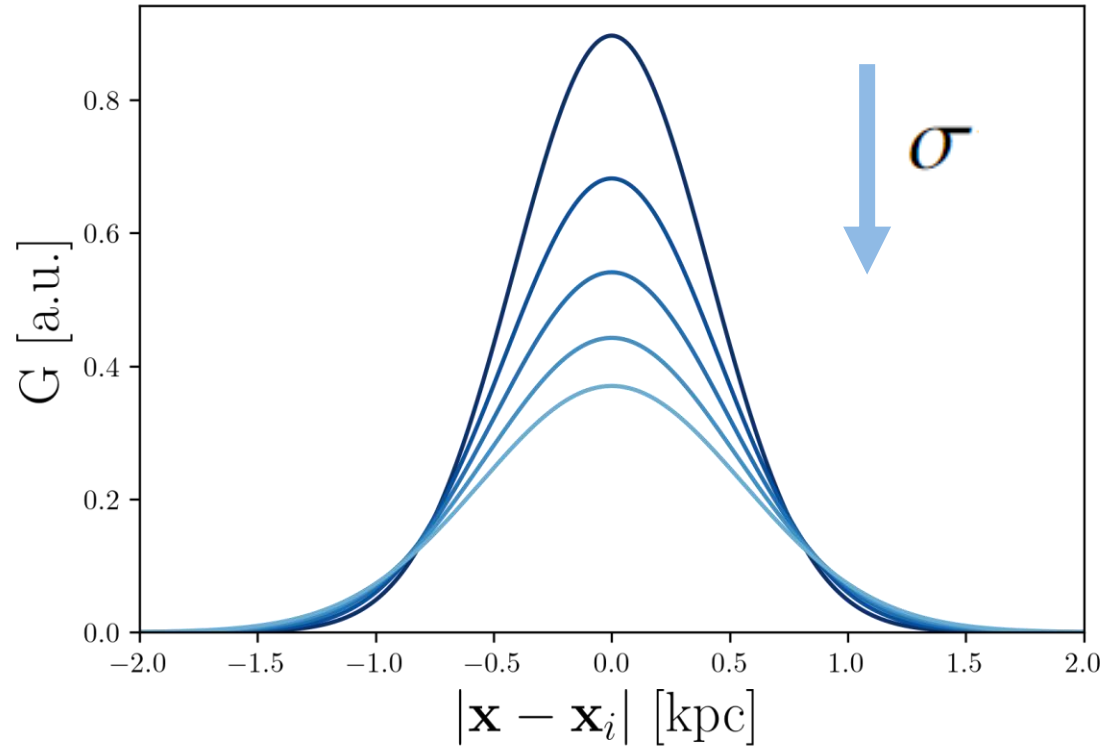- Relation between low and high energies?

Stochastic source modelling

$2\,z_{max}$
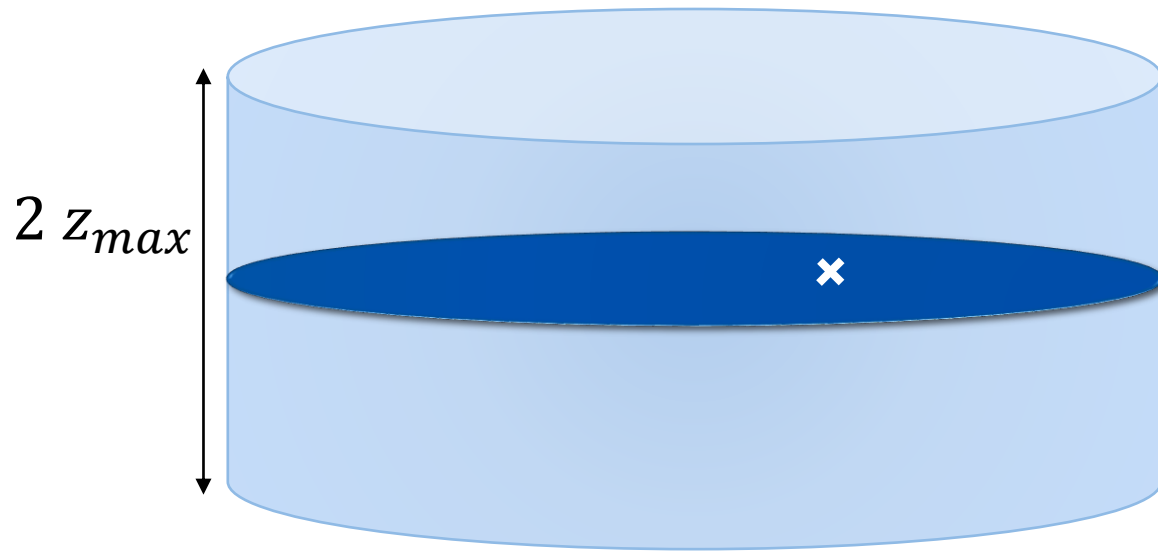
- Point sources with burst-like injection

- Isotropic diffusion coefficient $\kappa\,(\mathcal{R})$

- Free escape boundary at $\pm z_{max}$

- Analytic solution for isotropic CR density ψ using mirror charges

$$\frac{\partial\psi\,(\mathbf{x},t,\mathcal{R})}{\partial t} - \kappa\,(\mathcal{R})\cdot\nabla^2\psi\,(\mathbf{x},t,\mathcal{R}) = S\,(\mathbf{x},t)\,Q\,(\mathcal{R})$$
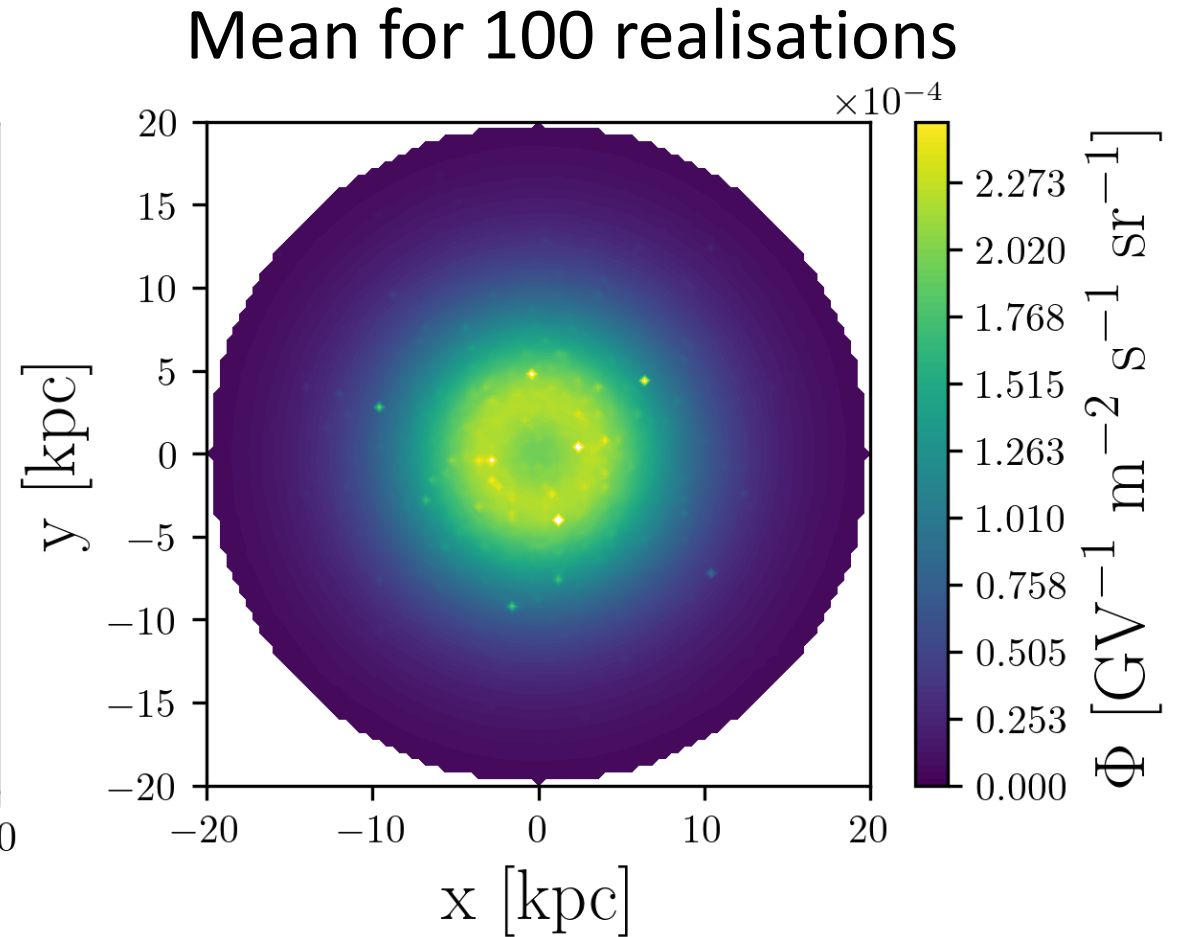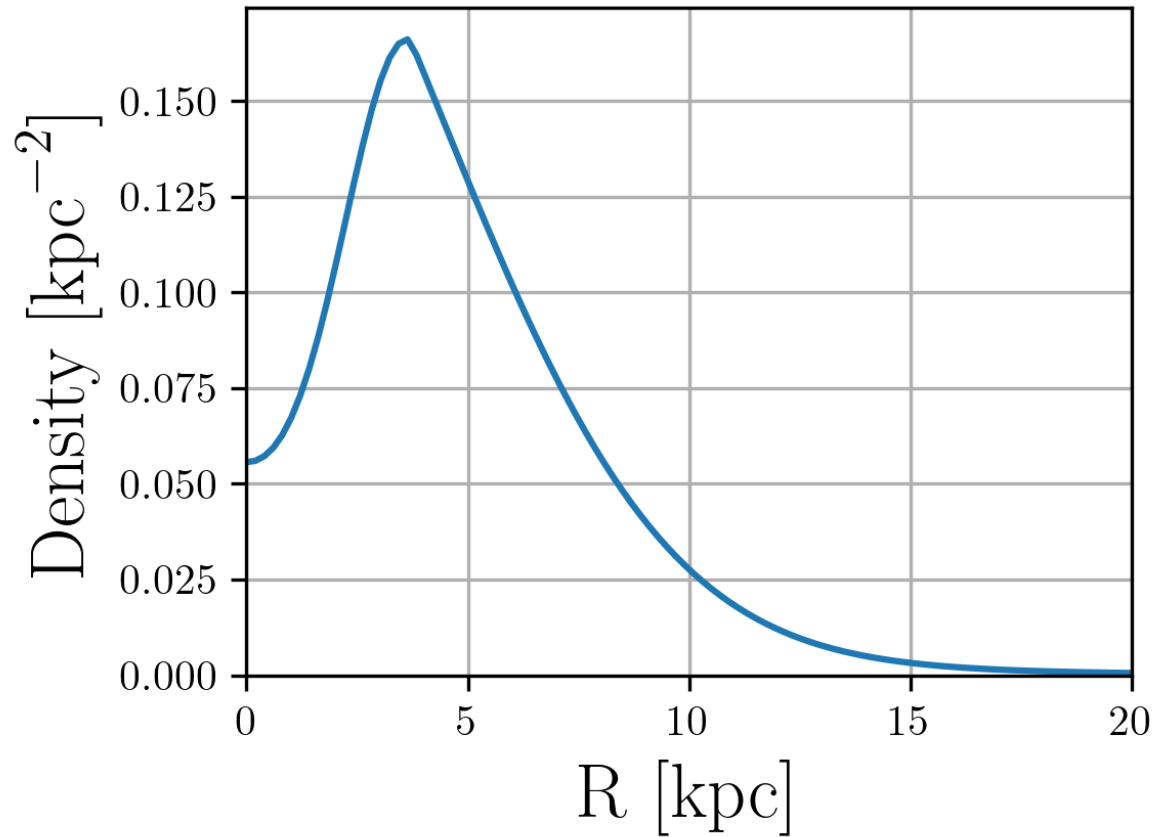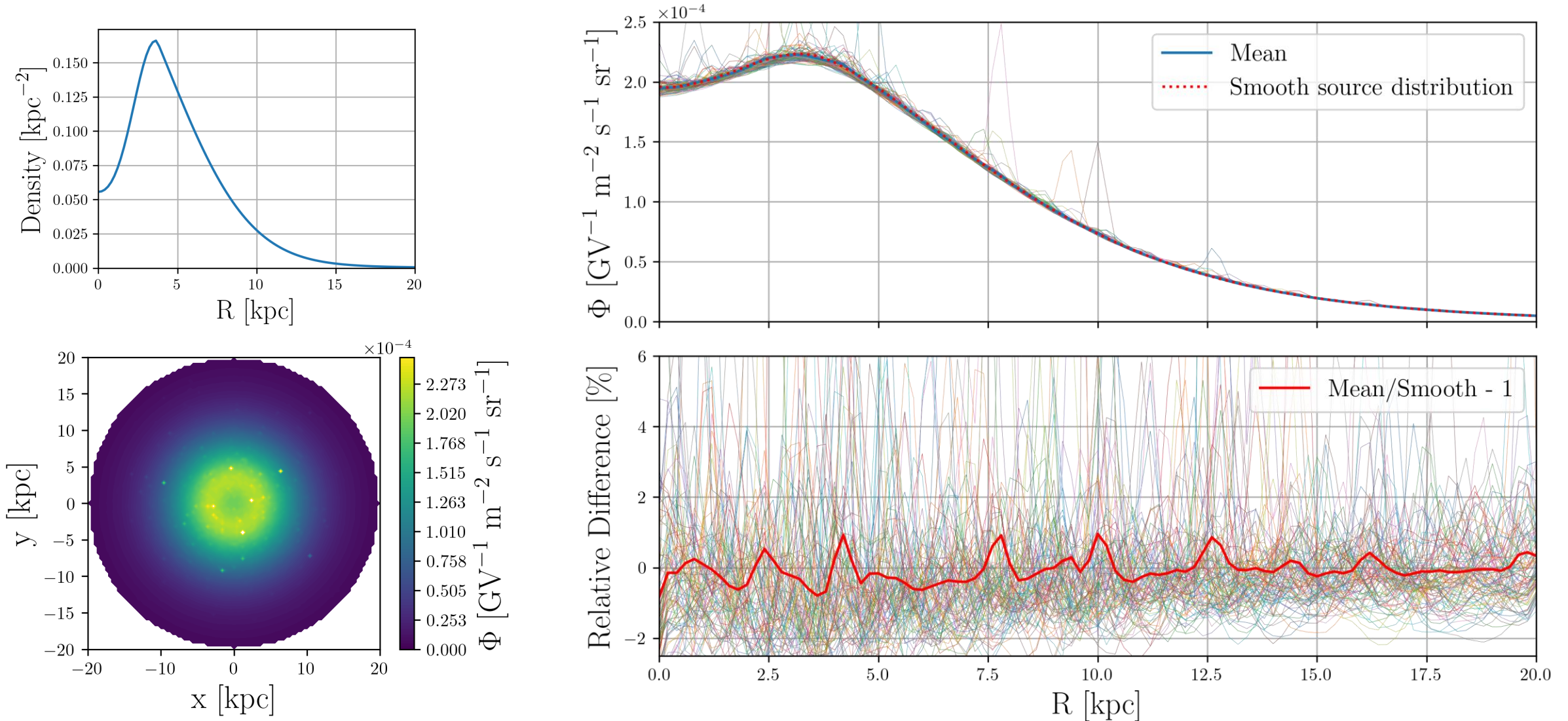
Green's function

$$G\left(\mathbf{x}, t; \mathbf{x}_i, t_i\right) = Q\left(\mathcal{R}\right) \frac{1}{\left(2\pi\sigma^2\right)^{3/2}} \exp\left(-\frac{\left(\mathbf{x} - \mathbf{x}_i\right)^2}{2\sigma^2}\right) \cdot \vartheta\left(z, \sigma^2, z_{\max}\right)$$

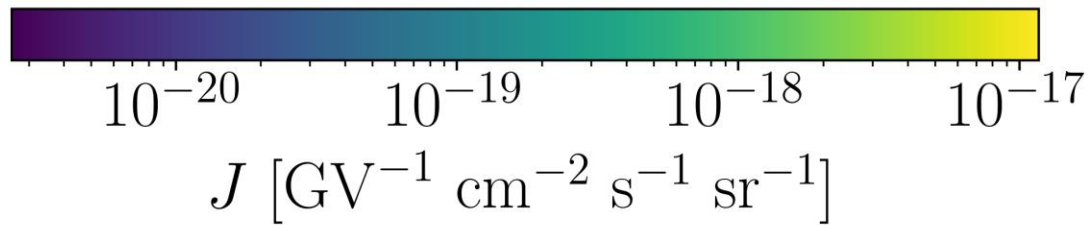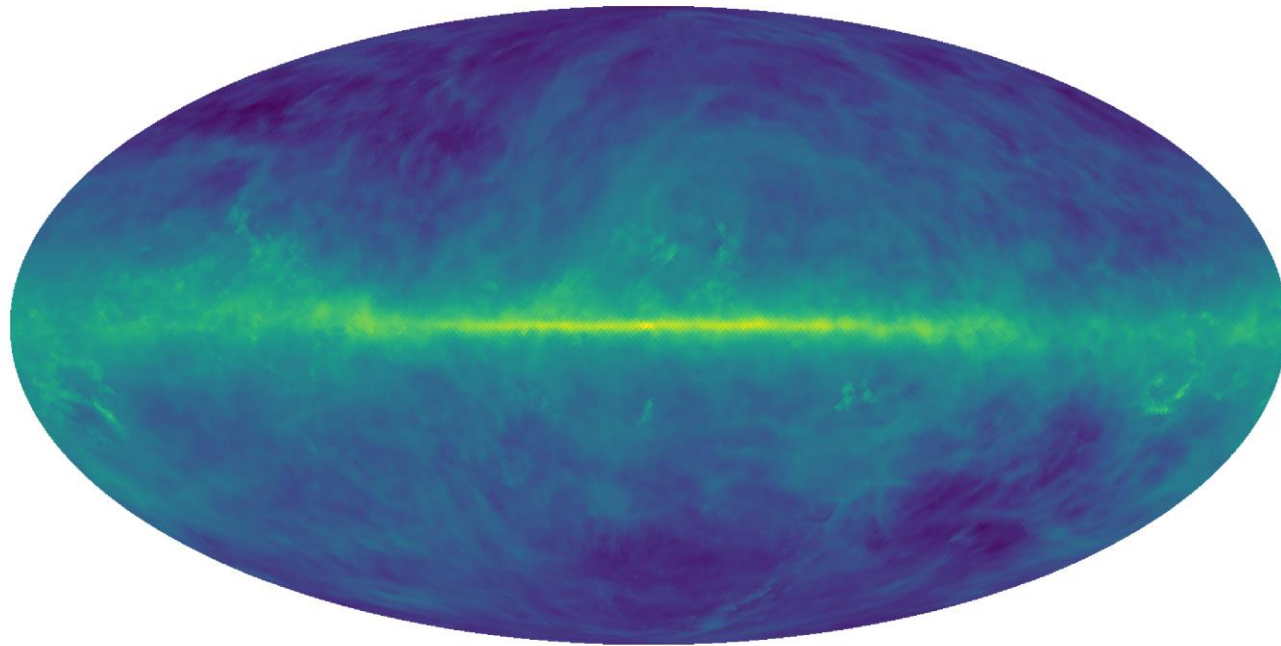where $\sigma^2\left(\mathcal{R}, t; t_i\right) = 2\,\kappa\left(\mathcal{R}\right)\left(t - t_i\right)$

Radial average proton flux Φ at 1 TV

Mean for 100 realisations

Radial average proton flux Φ at 1 TV

Hadronic diffuse emissions *J* at 100 TeV
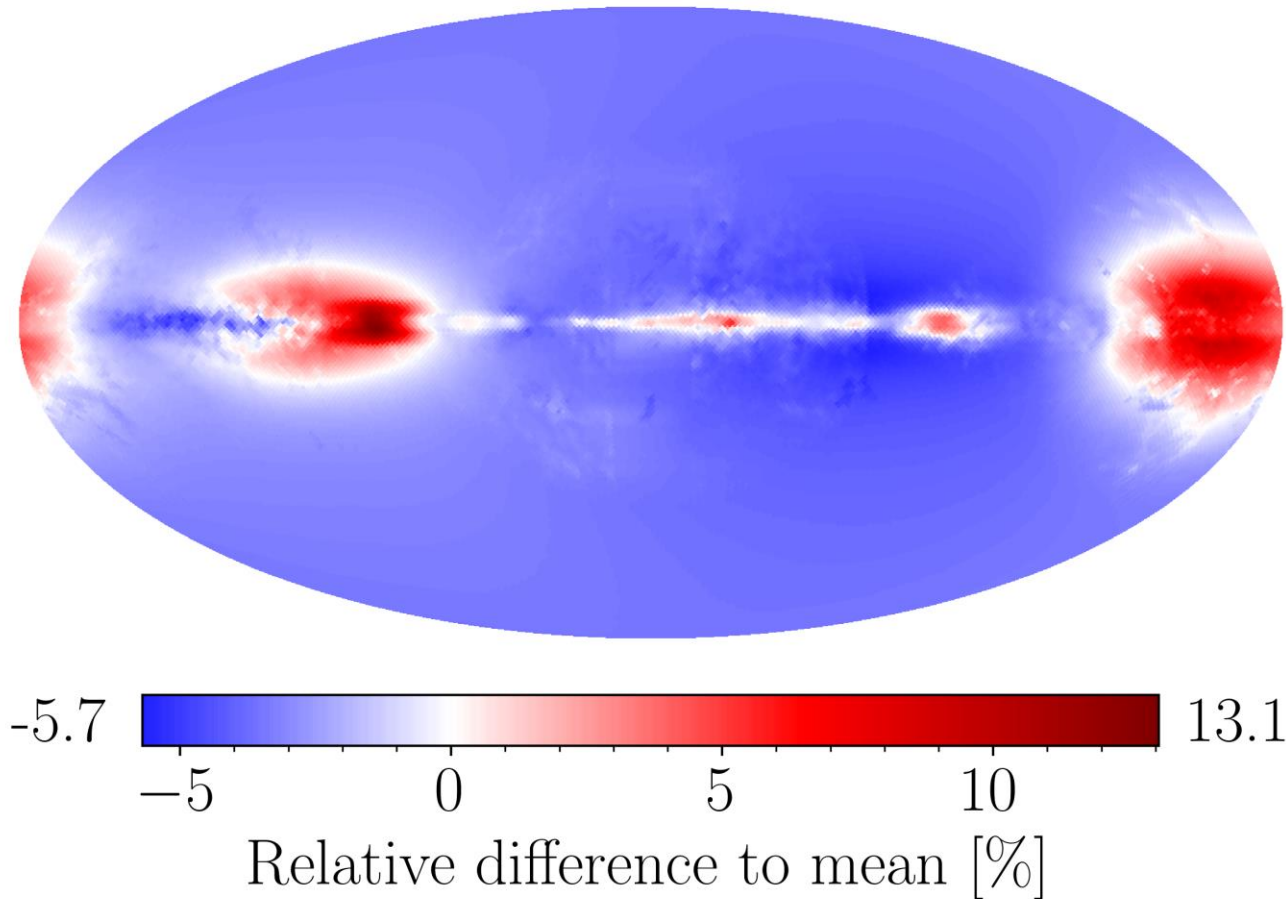

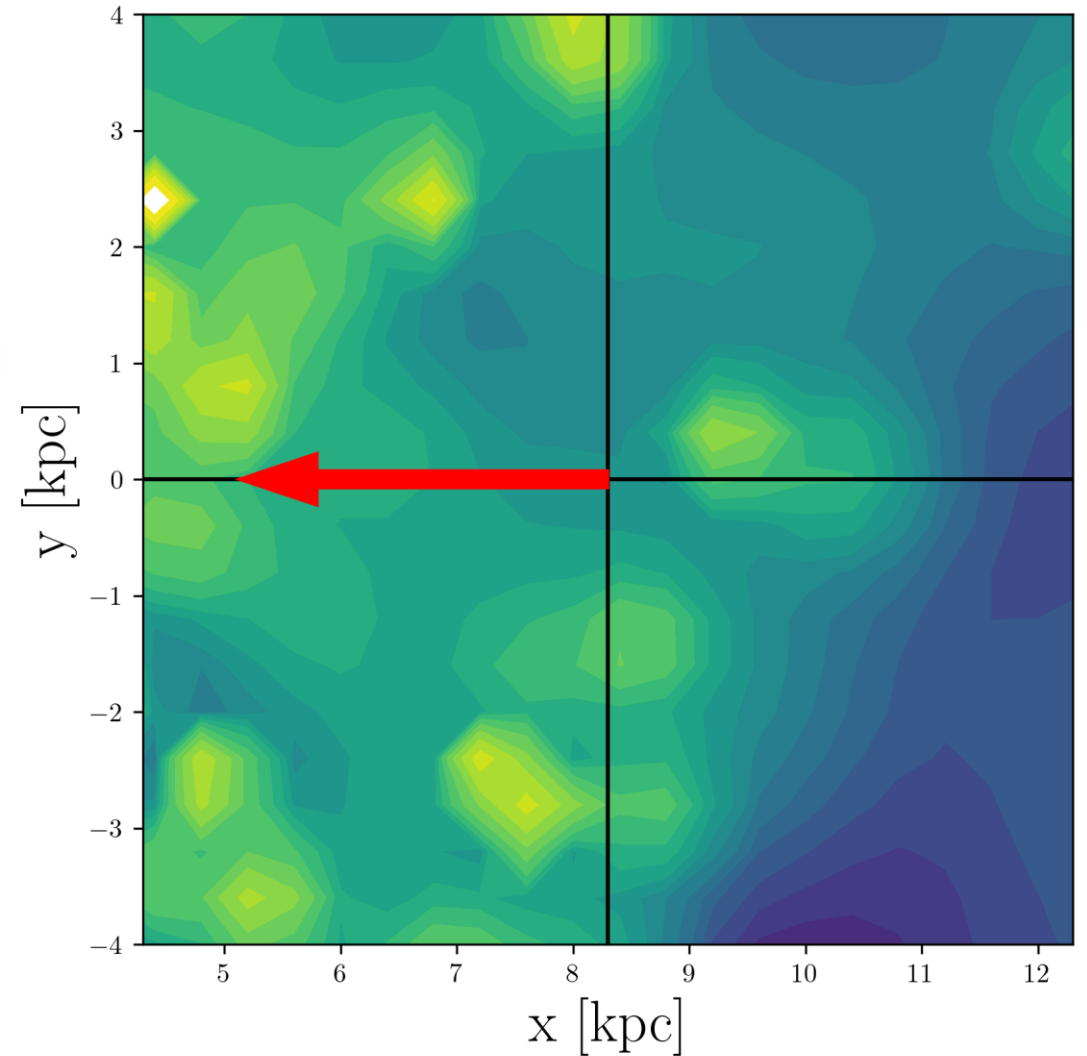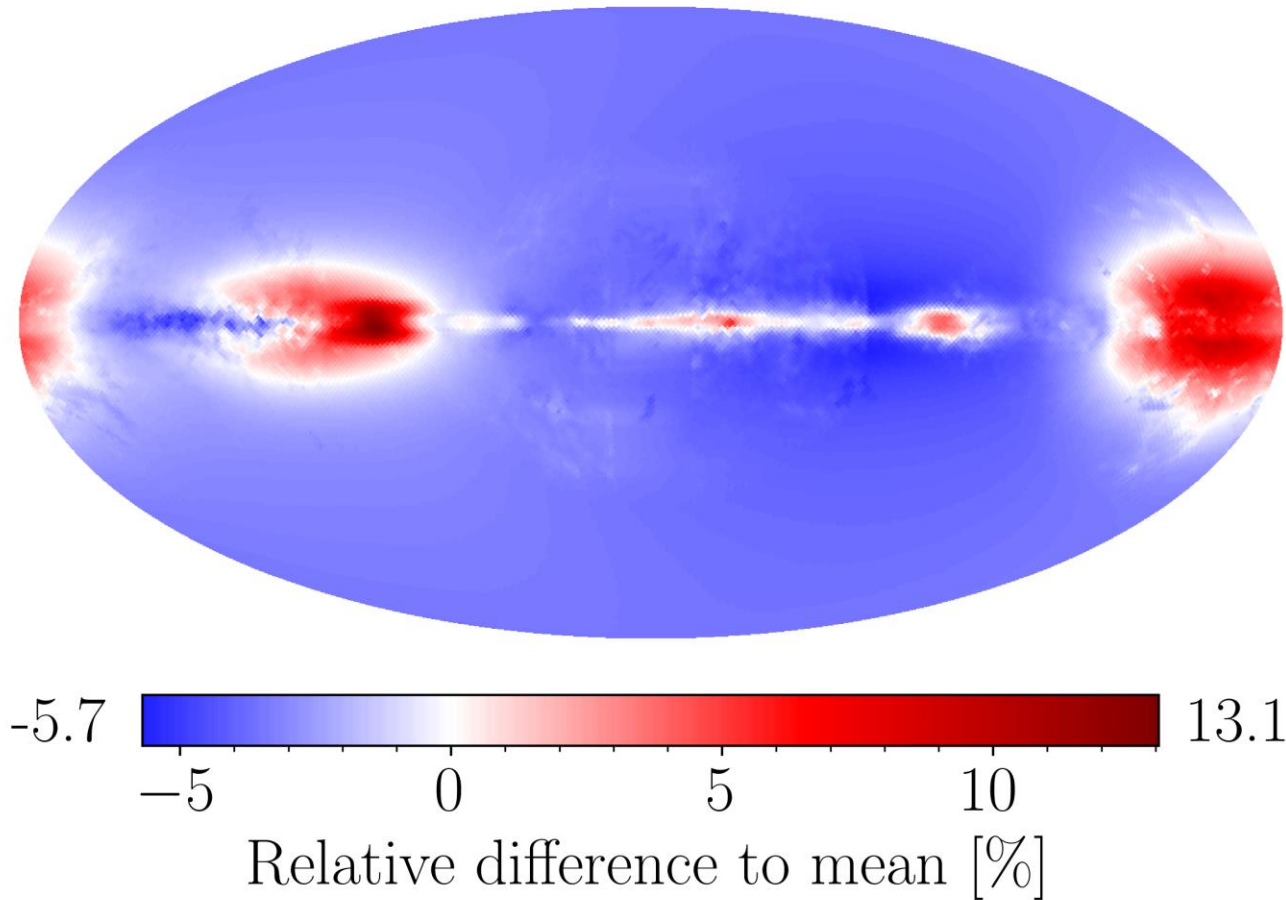$J \; [\mathrm{GV}^{-1} \; \mathrm{cm}^{-2} \; \mathrm{s}^{-1} \; \mathrm{sr}^{-1}]$

- Fast calculation using matrix multiplications and linear algebra packages

- Study deviations from smooth source distribution stochastically

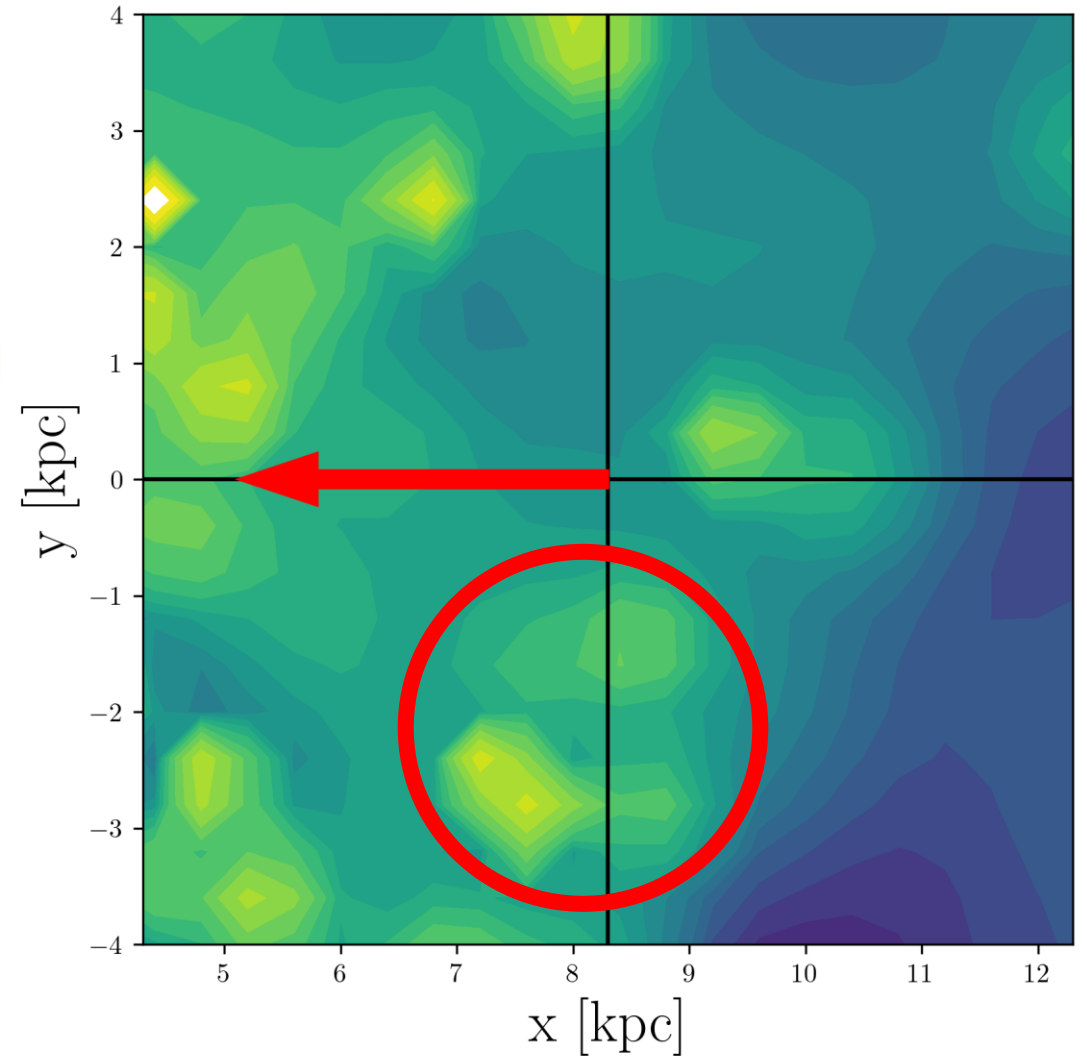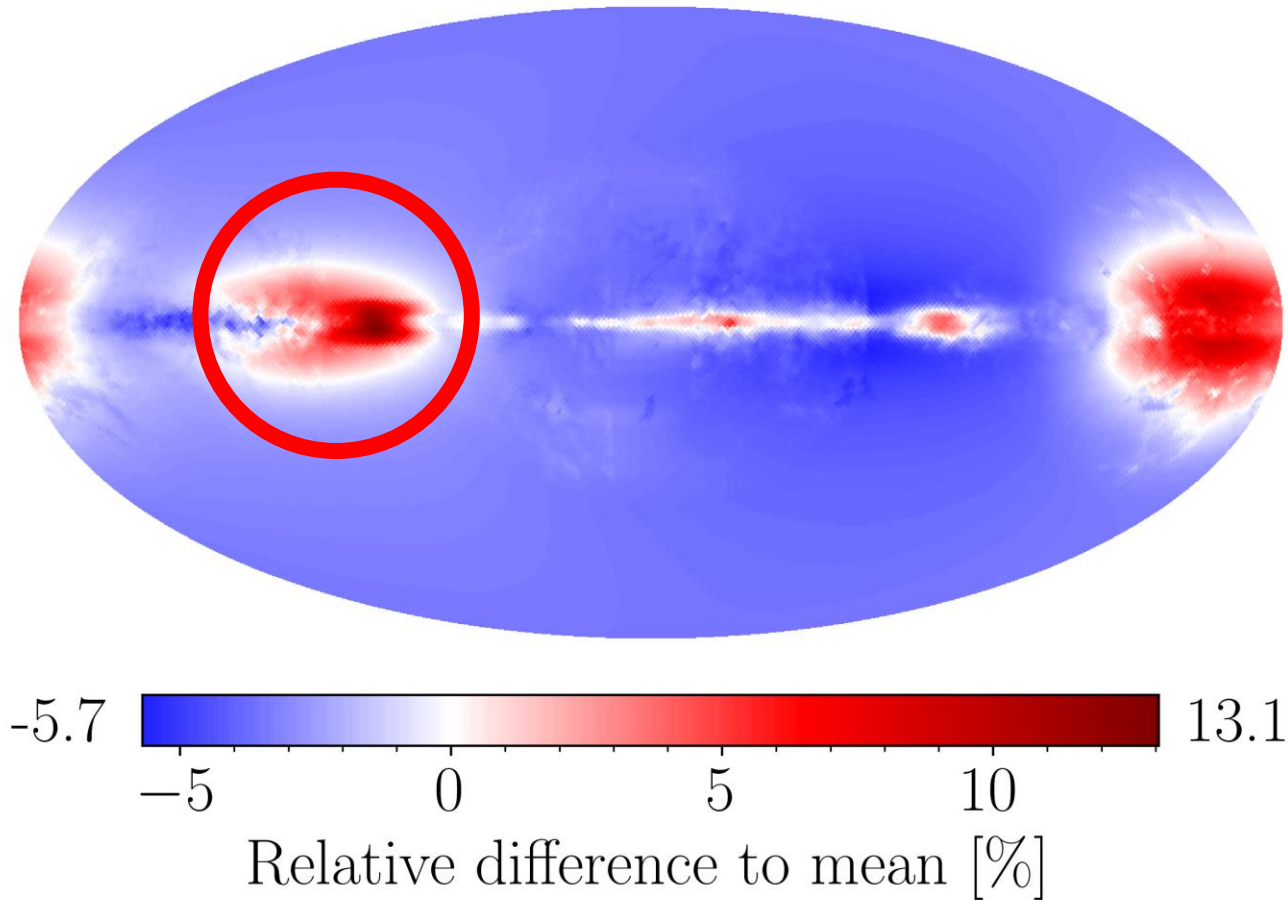# Hadronic diffuse emissions *J* at 100 TeV

- 50 realisations like this one

- Median of maximum deviation is 10.6%

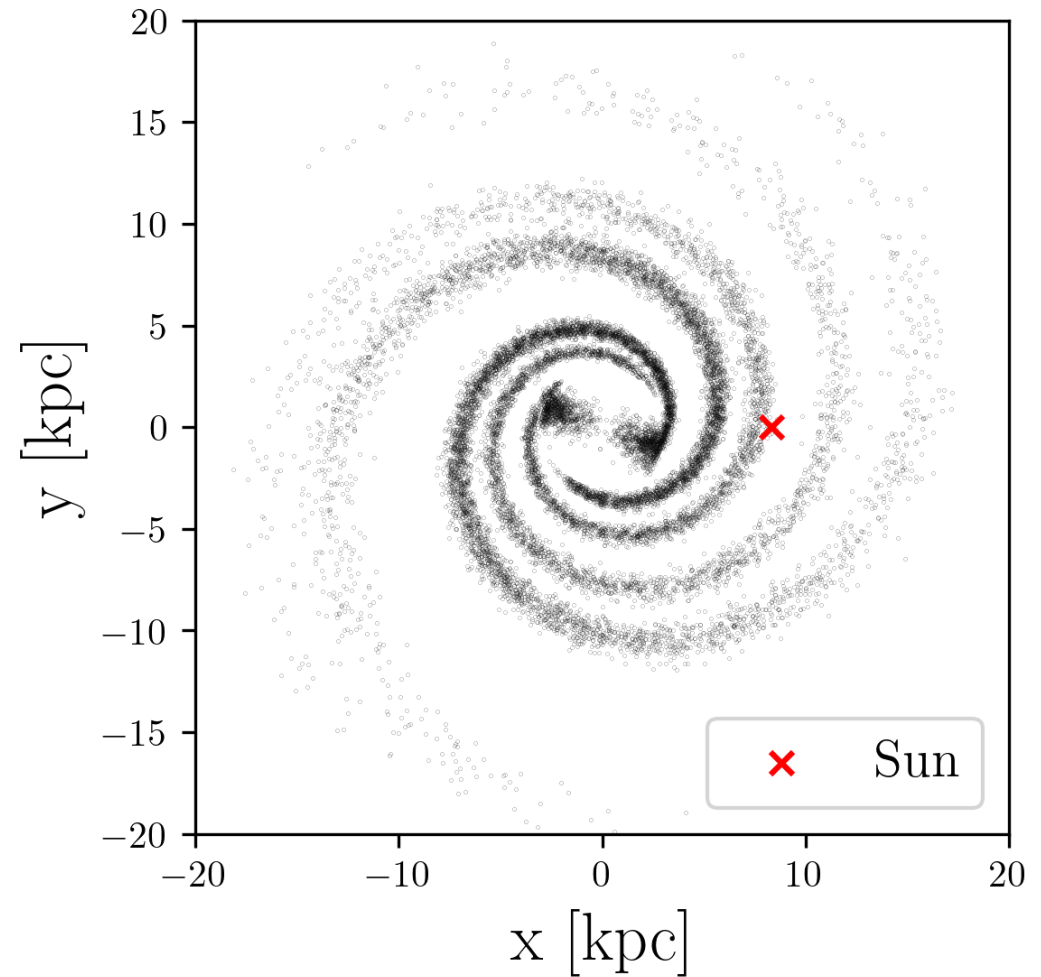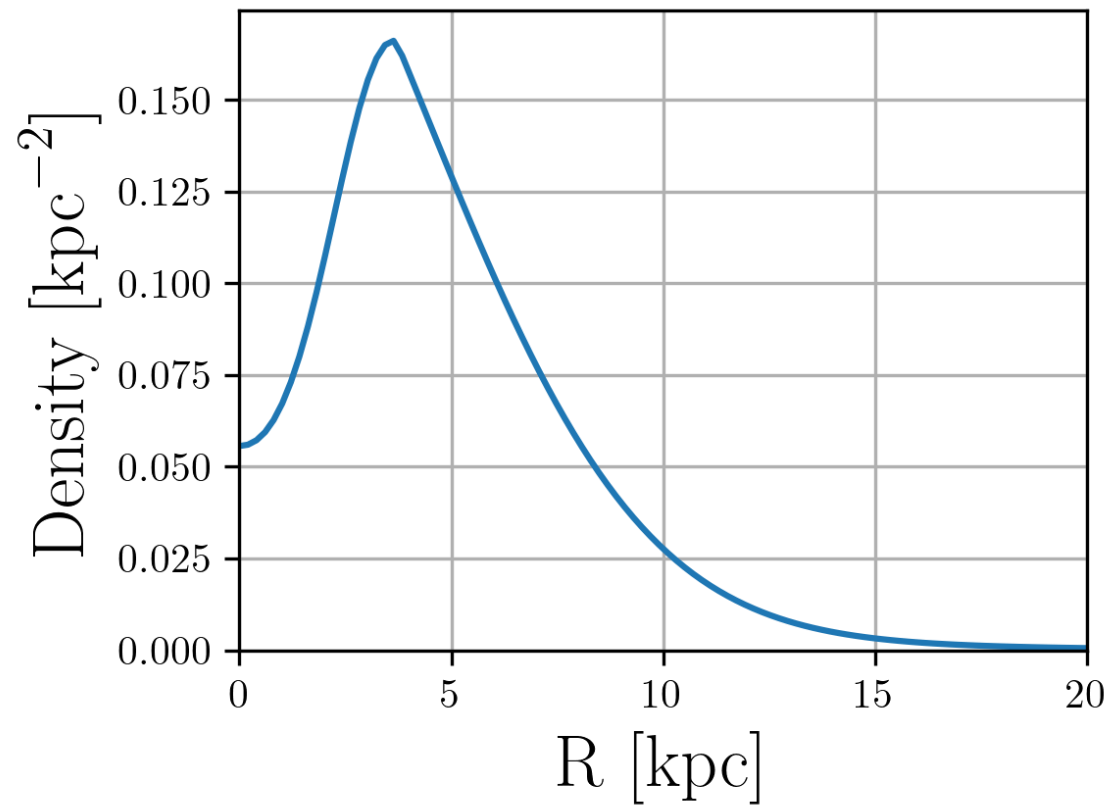- Can be attributed to young sources within a few kpc

Hadronic diffuse emissions J at 100 TeV
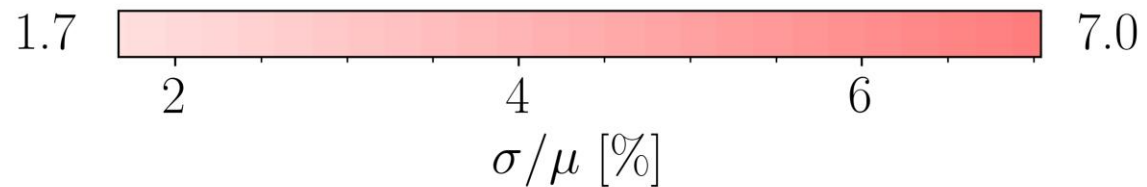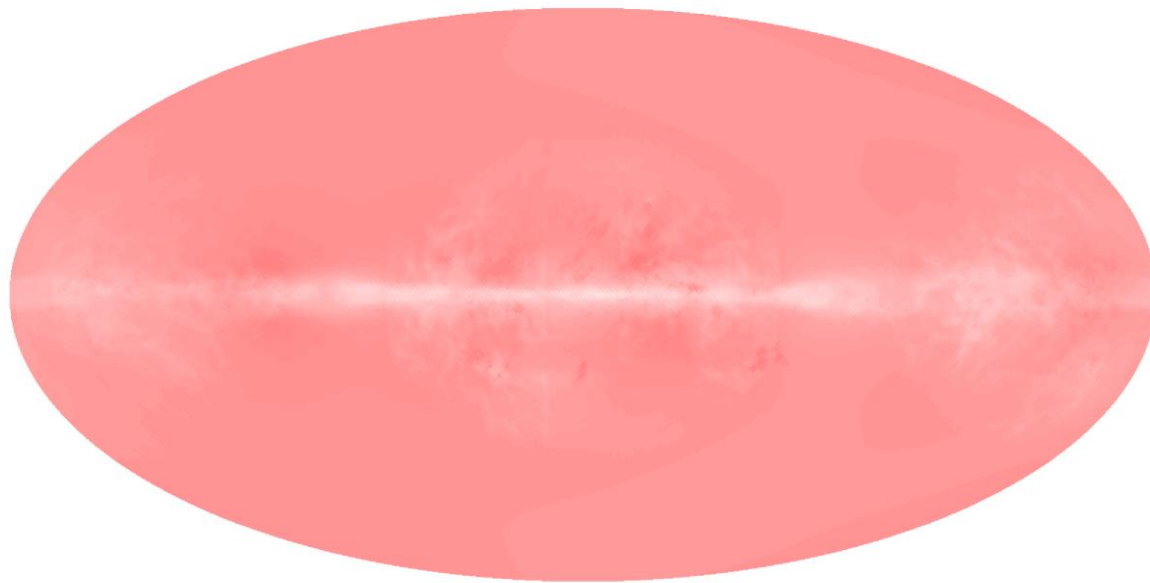
Hadronic diffuse emissions J at 100 TeV

Deviations for a spiral model

Deviations for a spiral model
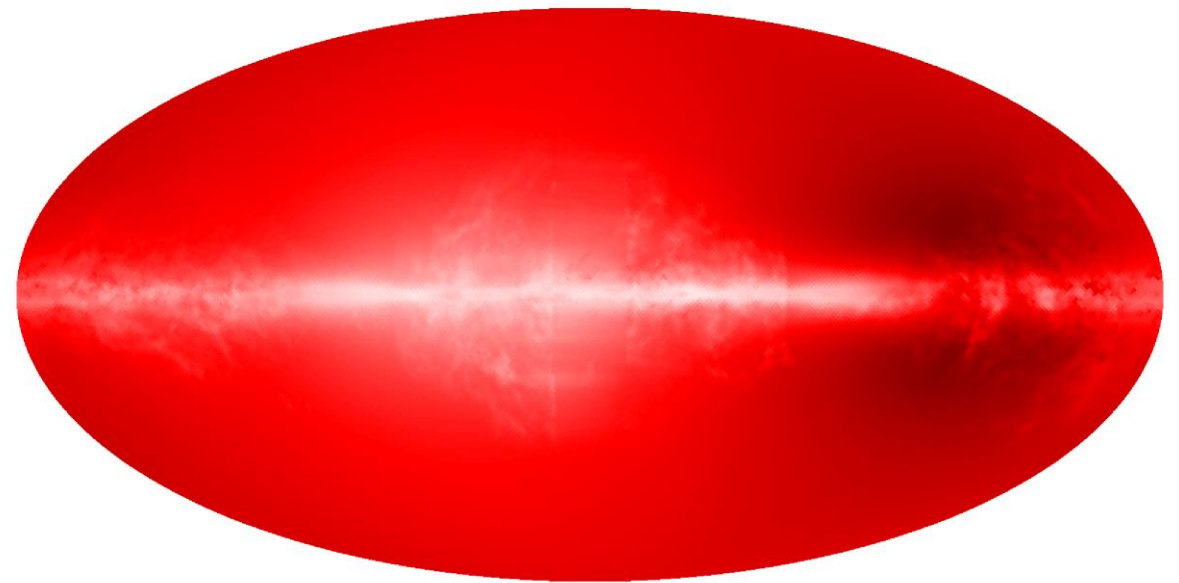
Axi-symmetric model
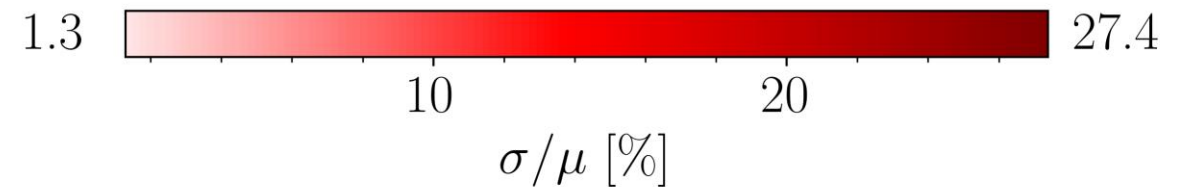
Spiral model

σ/μ [%]

σ/μ [%]

Correlation of different energies

$$J_{\text{high}} = X \cdot J_{\text{low}}$$

$$J_{\text{low}} = \bar{J}_{\text{low}} + \Delta J \quad \Longrightarrow \quad J_{\text{high}} = X \cdot \bar{J}_{\text{low}} + X \cdot \Delta J = \bar{J}_{\text{high}} + X \cdot \Delta J$$
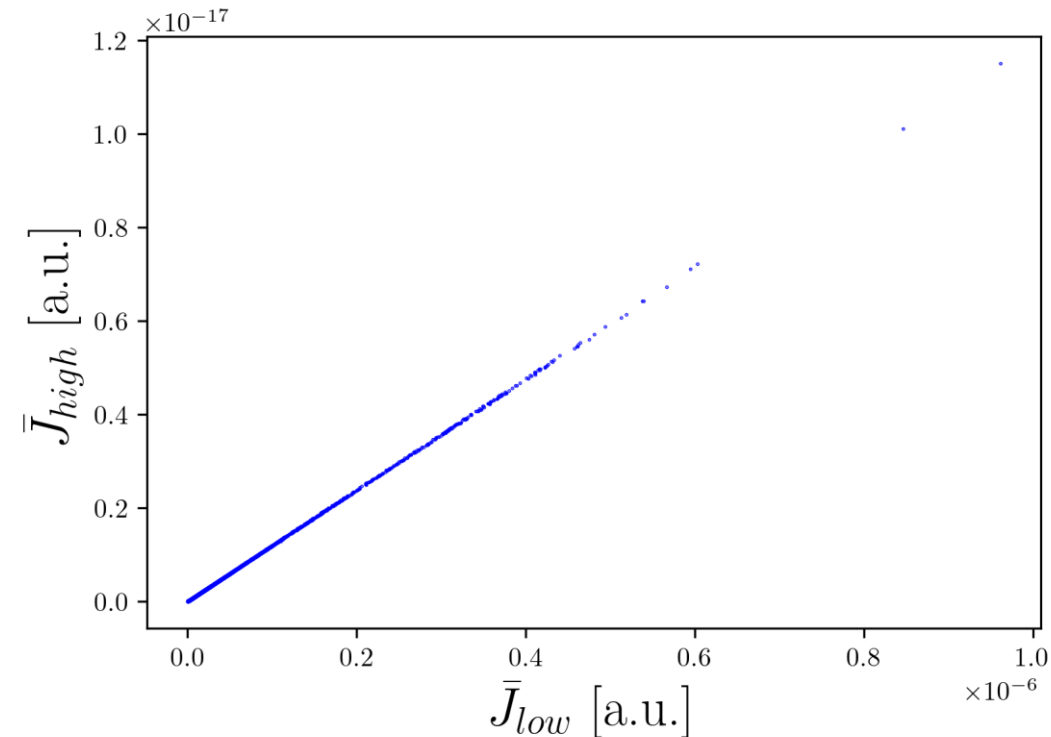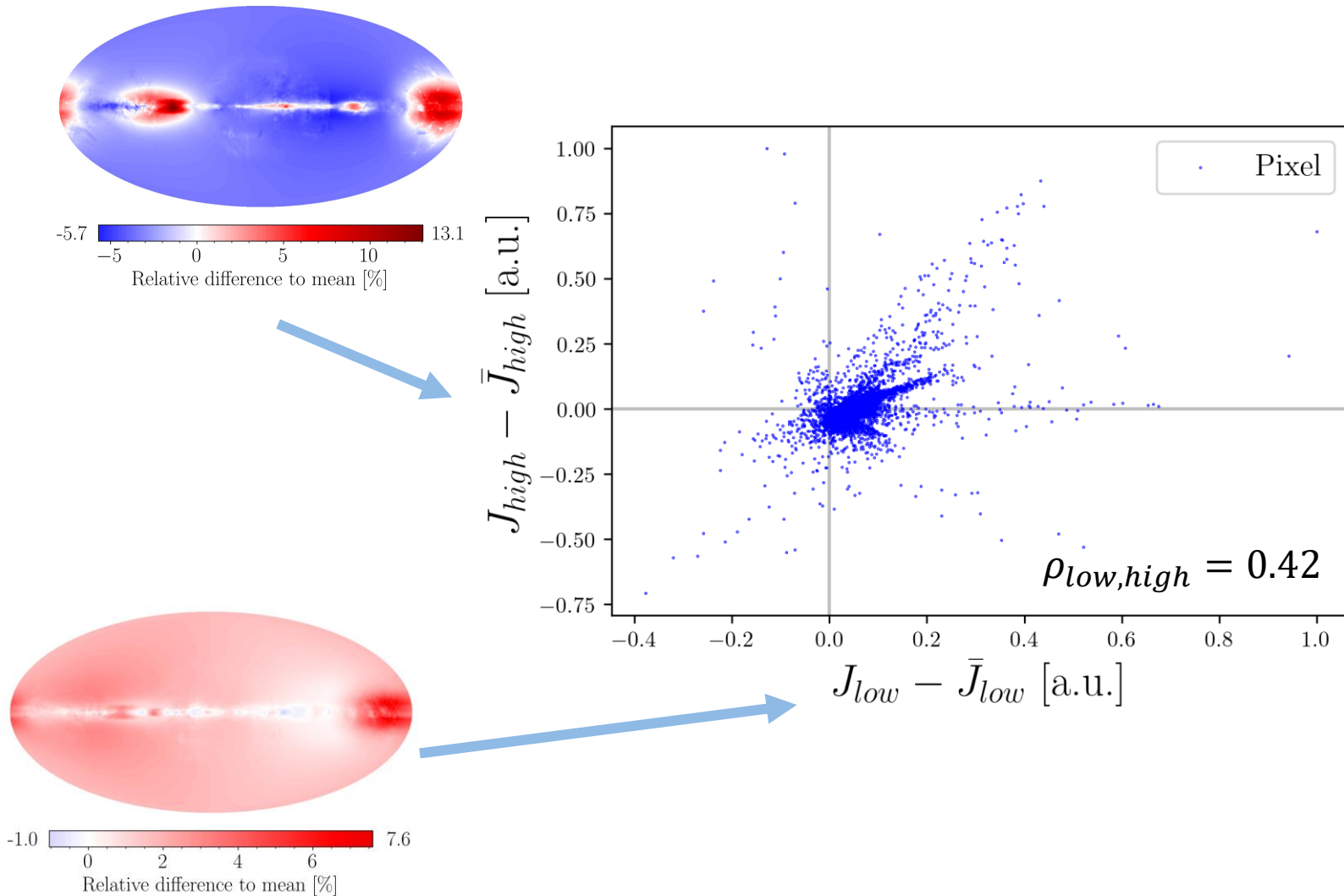
Correlation of different energies

$$J_{\text{high}} = X \cdot J_{\text{low}}$$

$$J_{\text{low}} = \bar{J}_{\text{low}} + \Delta J \quad \Longrightarrow \quad J_{\text{high}} = X \cdot \bar{J}_{\text{low}} + X \cdot \Delta J = \bar{J}_{\text{high}} + X \cdot \Delta J$$
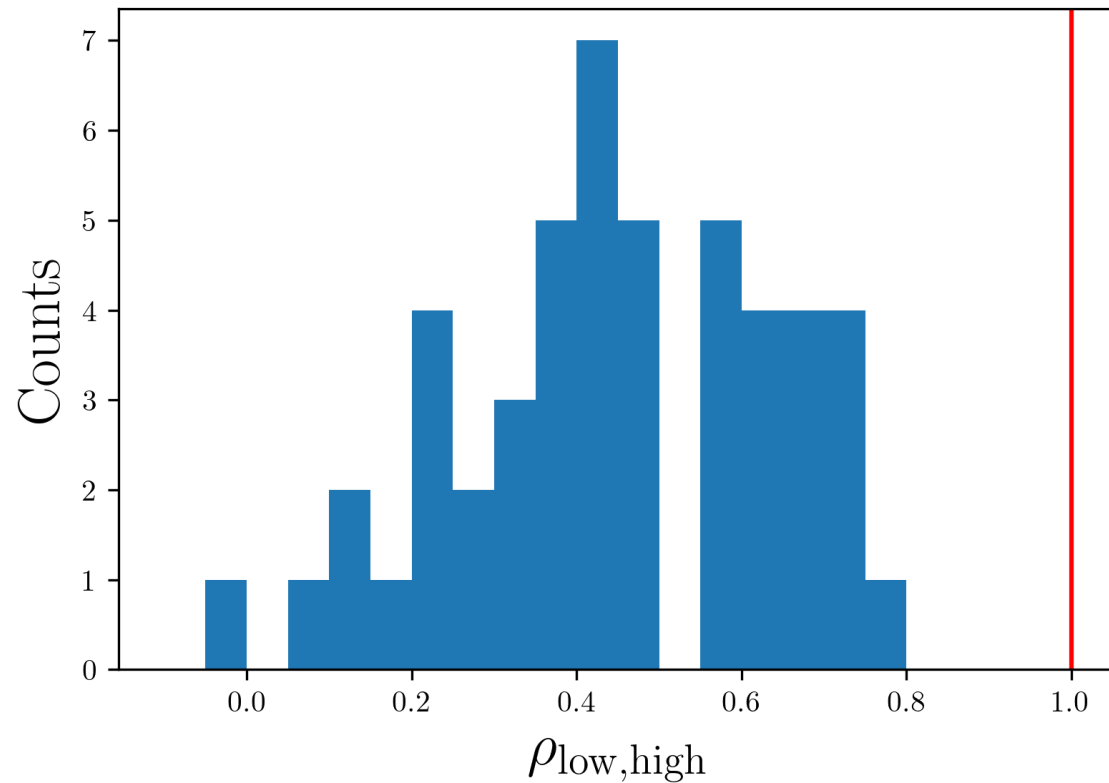
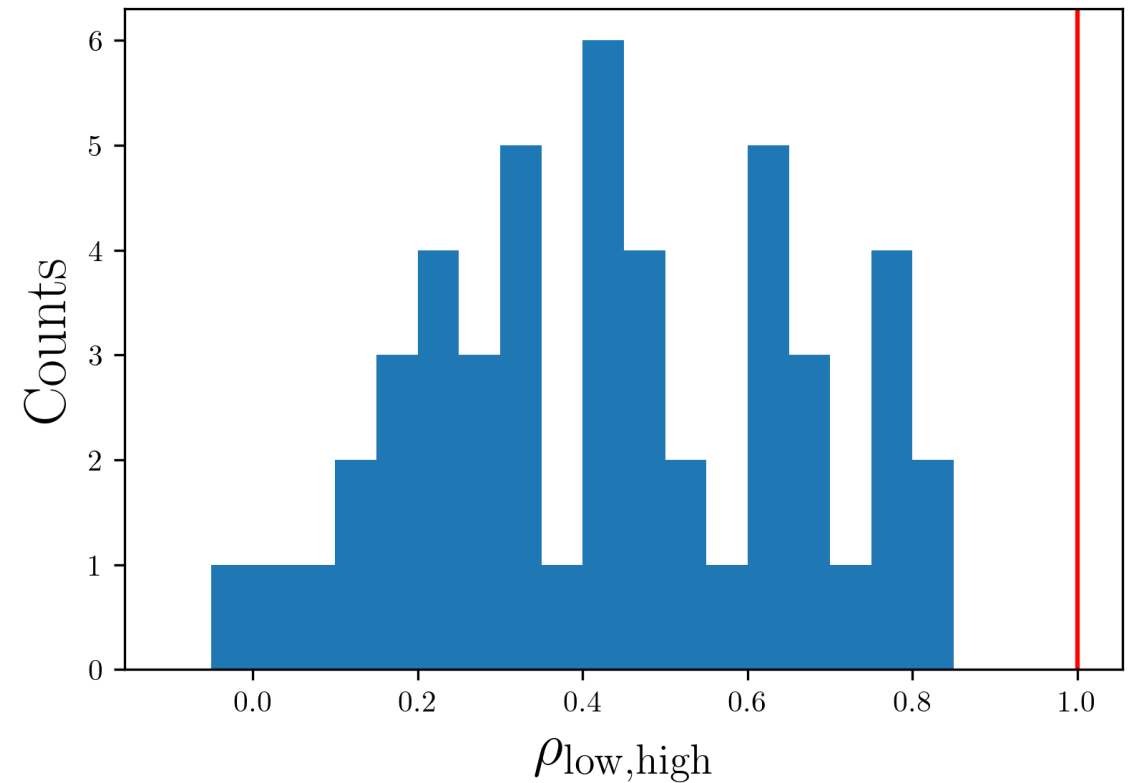# Correlation of different energies

Calculate correlation coefficient between pixel values $\rho_{low,high}$ for each of the 50 realisations

Correlation of different energies

Axi-symmetric model

Spiral model

Outlook

- Several source populations

- Time-dependent escape from sources (Blasi, Amato – 2012)

- More realisations through optimised computations

- Inclusion of other CR species
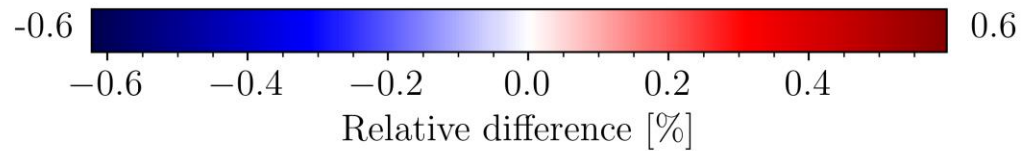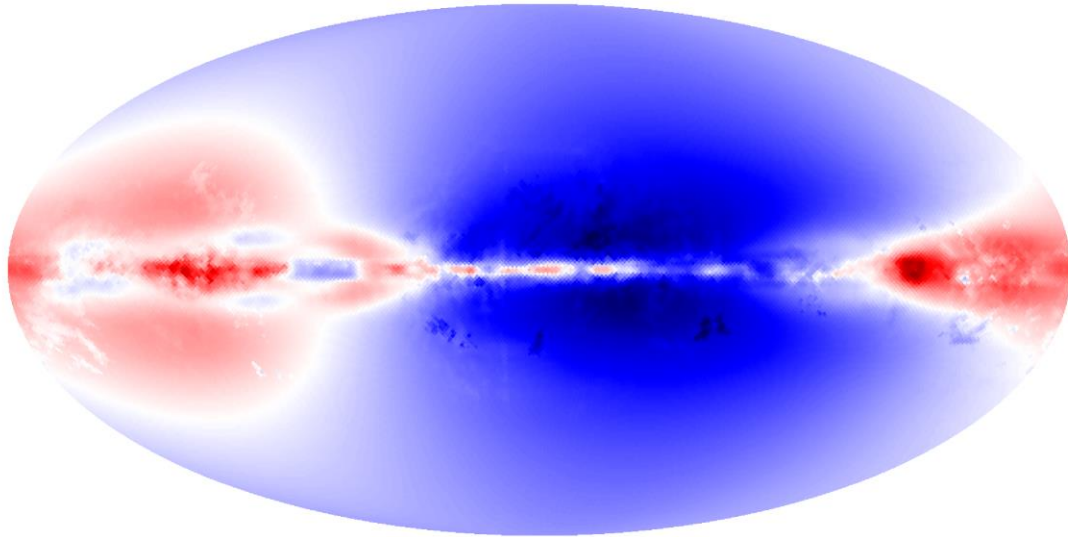
- Extend CR transport model

Outlook

- Several source populations

- Time-dependent escape from sources (Blasi, Amato – 2012)

- More realisations through optimised computations

- Inclusion of other CR species

- Extend CR transport model

Thank you!
Questions?

Backup – Difference of mean to smooth

10 GeV

100 TeV