Physics and Parameters in Galactic CR Transport Models

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A. Ostermann & P. Csomos

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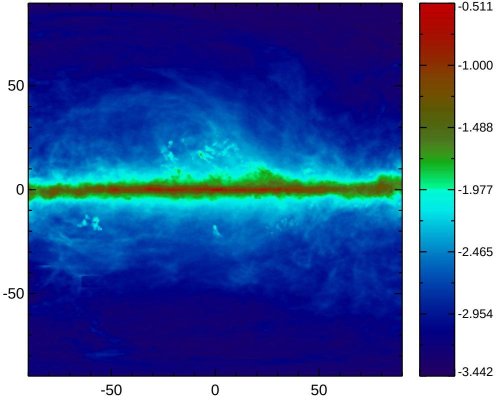


Cosmic Ray Propagation Codes

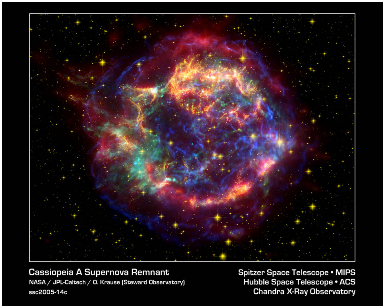
Purpose

- Explain CR spectra
- Explain secondaries
- Propagation physics

Approach

- Input
  - CR source models
  - CR propagation physics
- Output
  - CR spectra
  - Gamma sky-maps
- Statistical Analysis
  - Probability dist.
  - Refined phys. models

SNR Cas A



Available CR propagation codes

Transport Equation

$$\frac{\partial \psi}{\partial t} = q(\mathbf{r}, p) + \nabla \cdot (\mathsf{D}_{xx} \nabla \psi - \mathbf{v}\psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi - \frac{\partial}{\partial p} \left\{ \dot{p}\psi - \frac{p}{3} (\nabla \cdot \mathbf{v}) \psi \right\} - \frac{1}{\tau_f} \psi - \frac{1}{\tau_r} \psi$$

Selection Criteria

- Multiple Particles
- Particle spectra
- Galactic CRs only

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Propagation Codes

- Dragon (Desy Hamburg)
- Galprop (MPE Garching, Stanford University)
- Usine (LPSC Grenoble)

Selection Criteria

- Multiple Particles
- Particle spectra
- Galactic CRs only

Different Approaches

Galprop & Dragon

- General setup
- Numerical, slower

Usine

- Simplified setup
- Semi-analytical, faster

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Application

- Parameter fitting / tuning
- Full spatial variation
- CR distribution
- CR spectra
- Gamma-ray maps
- Neutrinos

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- Simplified setup
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Application

- CR spectra
- Stat. analysis (CRs only)
- Geometrical parameters: L, r_H
- Transport parameters: D_0, δ, V_c, v_A

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Numerical Approach: Physics or Parameters?

CR Particle Physics

- Full decay chains
- Different cross sections
- Different loss processes

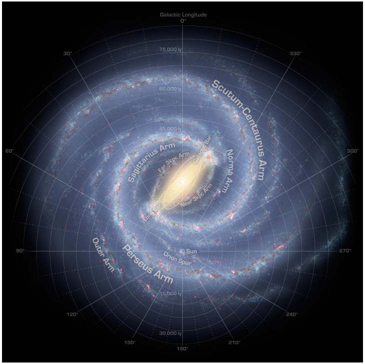
The Galaxy

- Gas distribution
- ISRF
- Magnetic field

Transport Processes

- Convection
- Diffusion
- Momentum diffusion

Galactic Model



(Illustration: NASA)

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Solution Process

Source distribution & Parameters

$\Downarrow$

Transport step

$\Downarrow$

CR distribution

$\Downarrow$

Gamma-ray emission

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Numerical Approach: Physics or Parameters?

Standard Parameters

- Diffusion *coefficient* D_0
- Rigidity exponent δ
- Alfvén speed v_A
- Halo height z_H
- Injection index ν
- Convection v_0, $\frac{dv}{dz}$

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Properties

- No spatial variation
- No temporal variation
- Only parameter tuning

Solution Process

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Transport step

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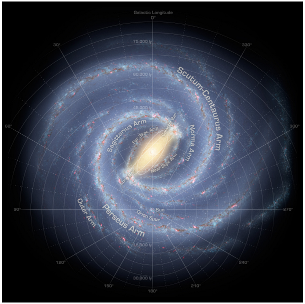
Gamma-ray emission

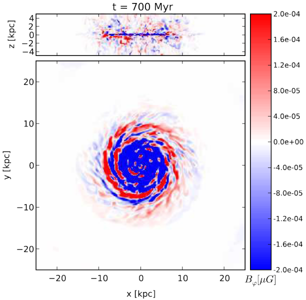
Example: The Alfvén Speed

Gas Distribution



(Illustration: NASA)

Magnetic Field Model



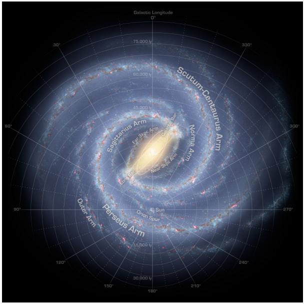
(From M. Hanasz et al. 2009 APJ **706**, L155)

Example: The Alfvén Speed

But

$$v_A = const.$$

Gas Distribution



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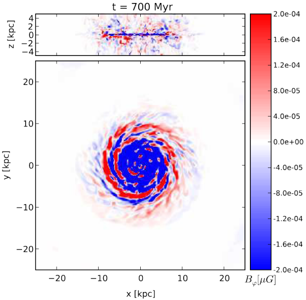

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Example: The Alfvén Speed

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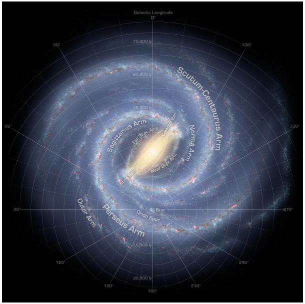
$$v_A = const. \Rightarrow B^2 \propto \rho$$

Gas Distribution



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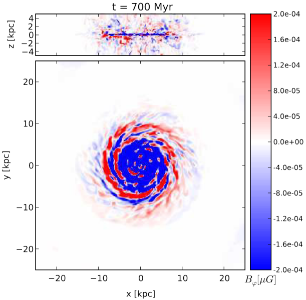

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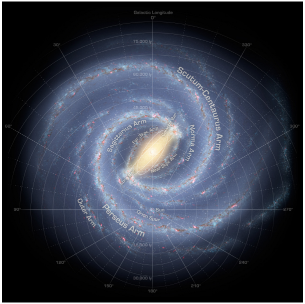

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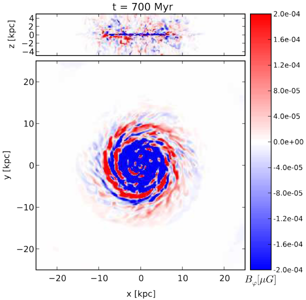

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Example: Convection Velocity

Standard Implementation

- $\mathbf{v}_{conv} = \left(v_0 + \frac{dv}{dz} z\right) \mathbf{e}_z$
- $v_0 = const$
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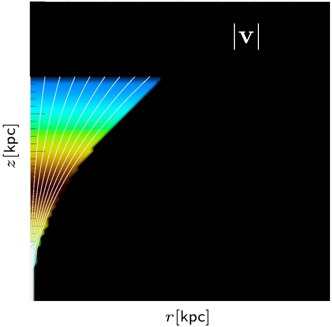
A Toy Model

- Outflow from gal. centre
- Radial expansion

Wind Toy Model



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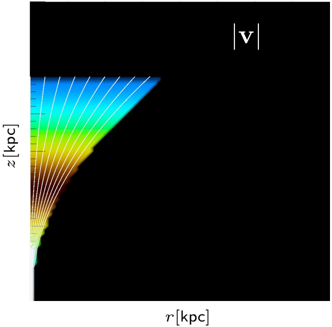
A Toy Model

- Outflow from gal. centre
- Radial expansion
- Not possible in standard codes
- First toy results

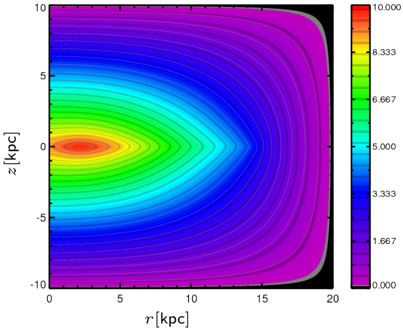
Wind Toy Model



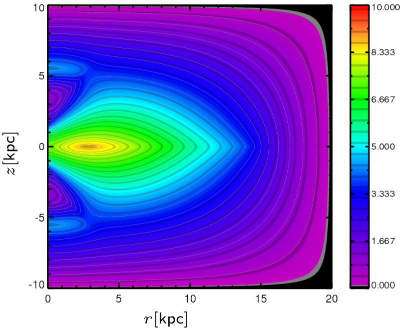
Toy Results: Wind $\leftrightarrow$ No Wind

Electrons at 2.5 GeV

Standard Model



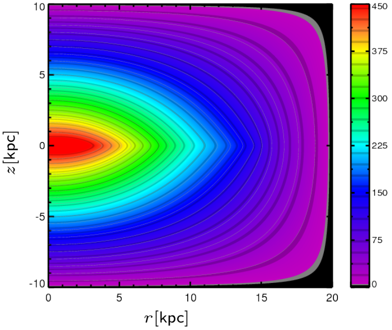
Wind Model



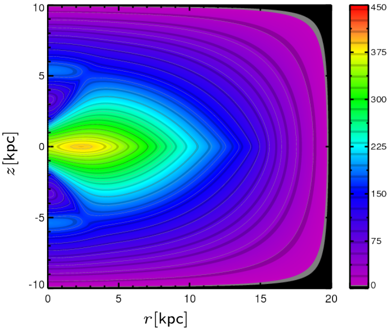
Toy Results: Wind $\leftrightarrow$ No Wind

Protons at 10 GeV

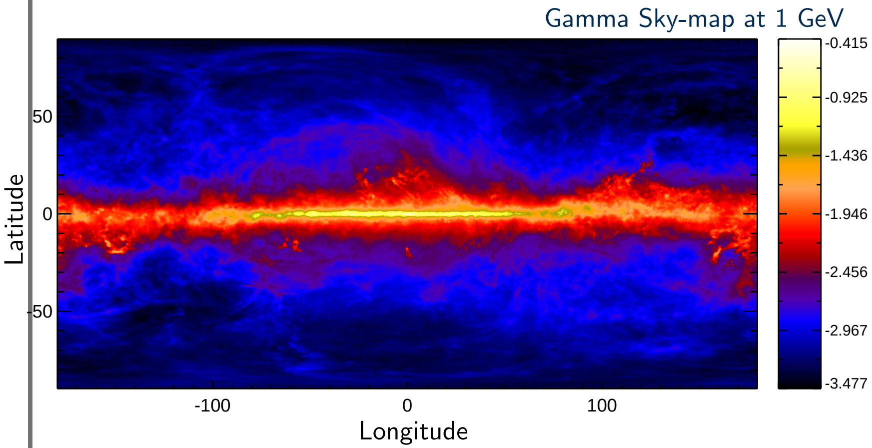
Standard Model



Wind Model



Toy Results: Gamma-Rays



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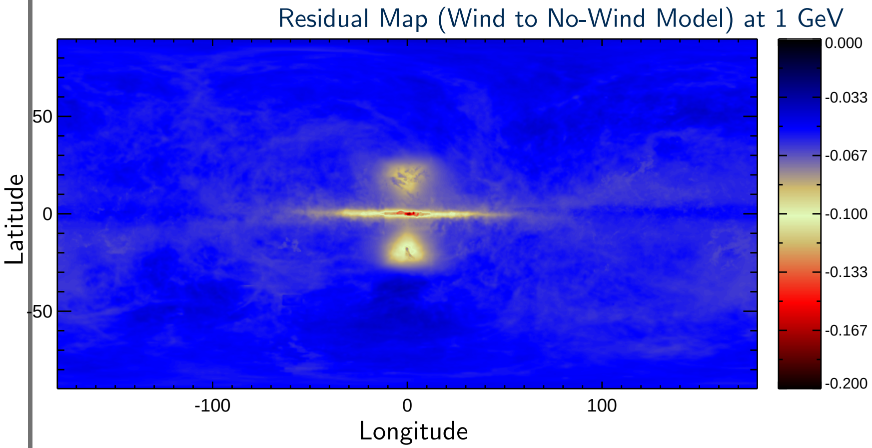

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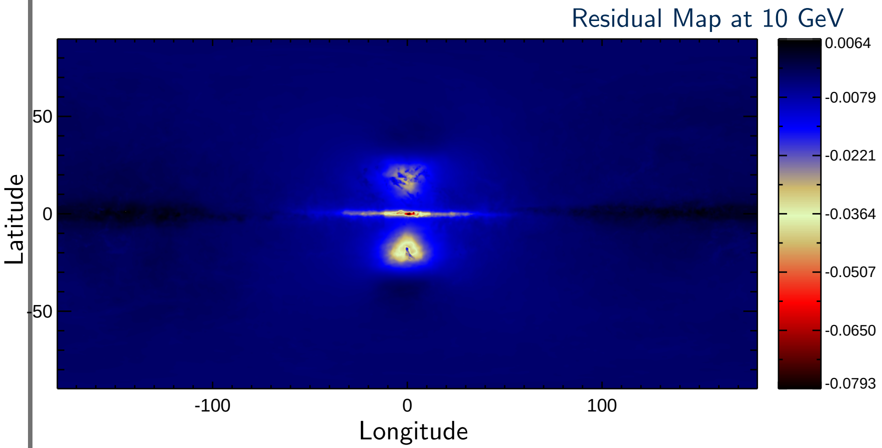
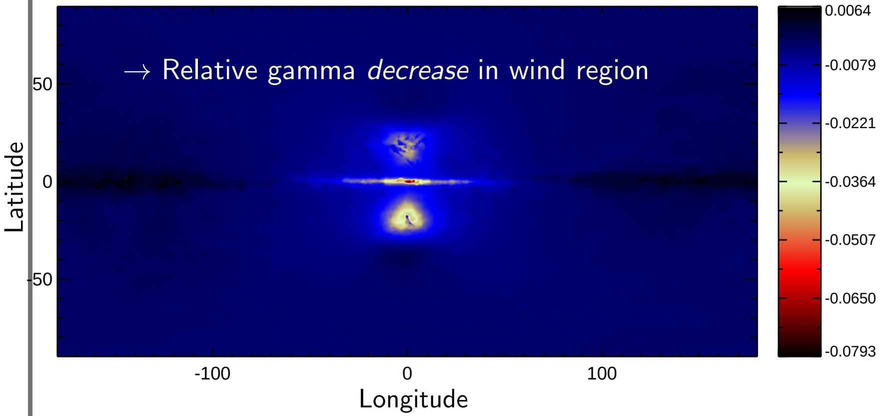


Toy Results: Gamma-Rays

Residual Map at 10 GeV



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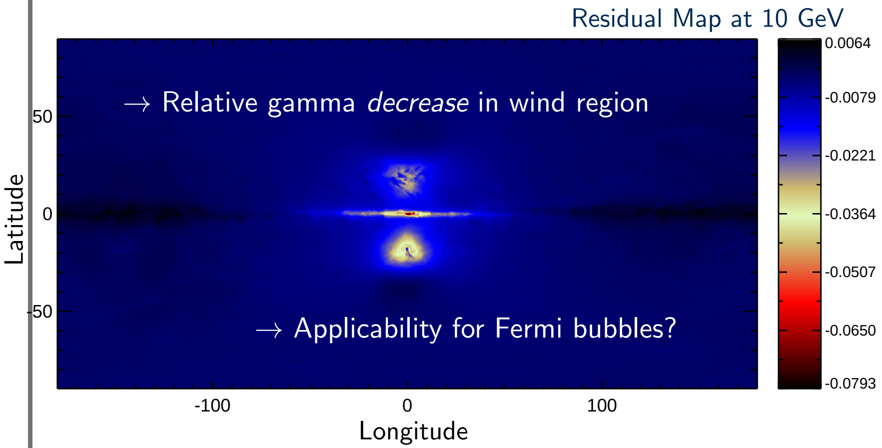
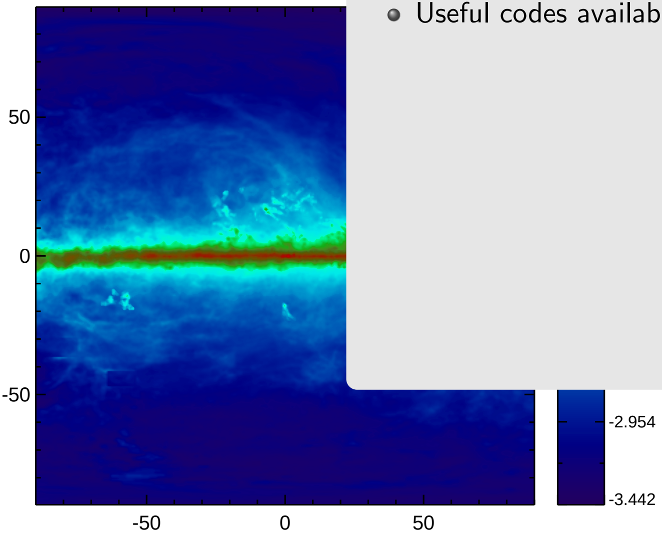
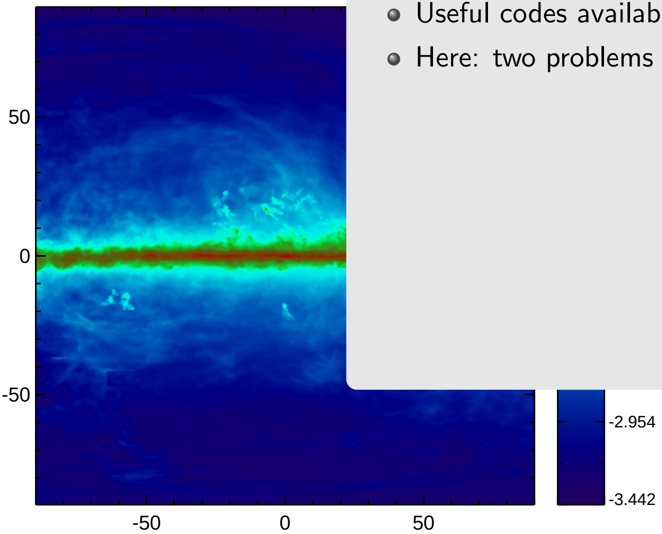


Conclusion



Propagation Models

- Useful codes available, but:



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- Here: two problems

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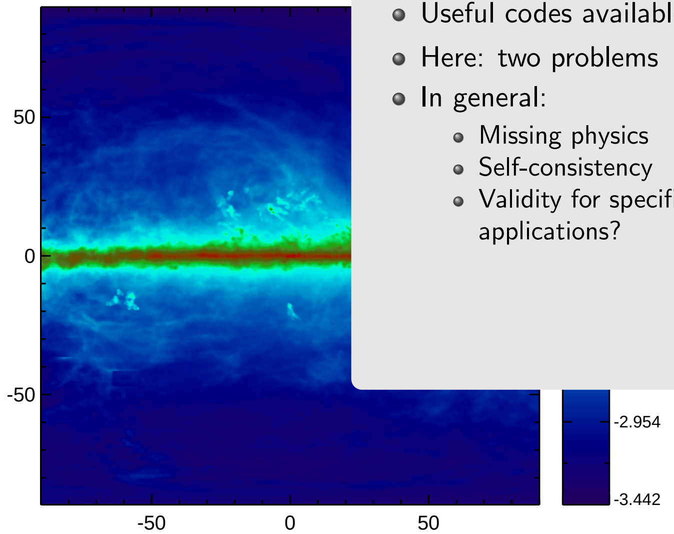

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- In general:
  - Missing physics
  - Self-consistency
  - Validity for specific applications?

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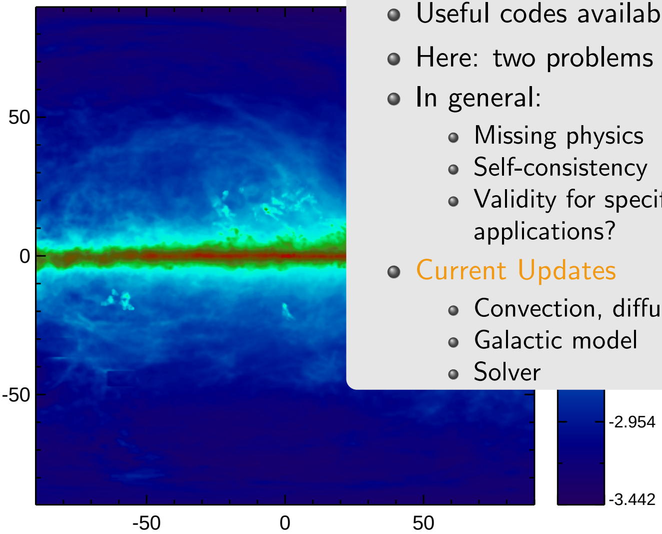

Propagation Models

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- In general:
  - Missing physics
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  - Validity for specific applications?
- Current Updates
  - Convection, diffusion
  - Galactic model
  - Solver