Diffuse Emission from the Milky Way with Picard

TeVPA 2023
Napoli Italy

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Julia Thaler, Andrés Ramírez & Olaf Reimer
(Universität Innsbruck)

FWF Österreichischer Wissenschaftsfonds

CR Transport Processes

- Convection
- Spatial Diffusion
- Diffusive reacceleration

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CR-Interaction with ISM

- Spallation cross sections
- Energy loss processes
- Nuclear network

$\leftrightarrow$ Galaxy model

Modelling Galactic Diffuse Emission

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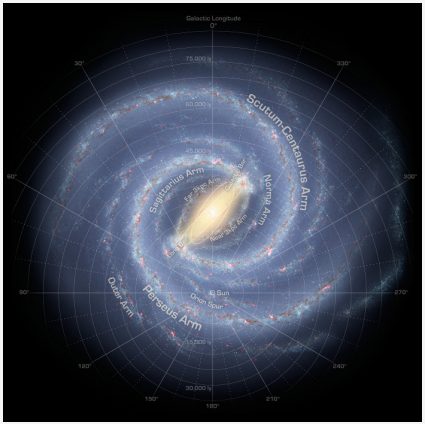
$\leftrightarrow$ Galaxy model

Galaxy Model

- Matter distribution
- ISRF
- Magnetic field

Spiral-Galaxy Model



(Credit: Spitzer / NASA)

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Observables

- Primary & secondary CRs
- Gamma rays
- Neutrinos

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CR source distribution

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$\Downarrow$

Transport solver – PICARD

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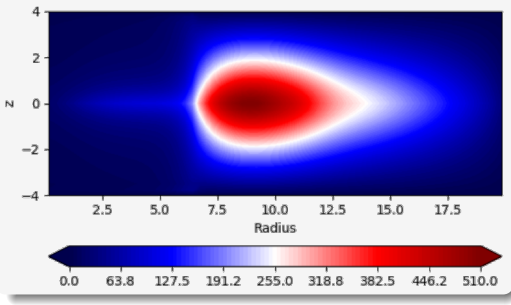

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⇓

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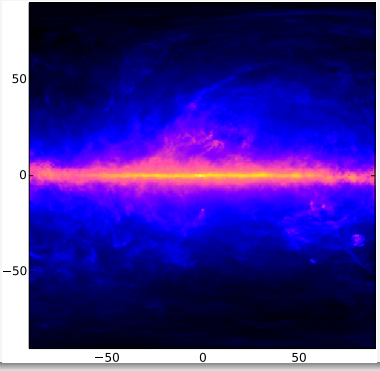
Gamma-Ray Emission



Solution Process

CR source distribution

⇓

Transport solver – PICARD

⇓

CR distribution

⇓

Gamma ray emission

Transport Equation

$$\frac{\partial \psi_i}{\partial t} =$$

Transport Equation

$$\frac{\partial \psi_i}{\partial t} = q(\vec{r}, p)$$

Transport Physics

- CR sources

Transport Equation

$$\frac{\partial \psi_i}{\partial t} = q(\vec{r}, p) + \nabla \cdot \mathcal{D} \nabla \psi_i$$

Transport Physics

- CR sources
- Spatial diffusion

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$$\frac{\partial \psi_i}{\partial t} = q(\vec{r}, p) + \nabla \cdot \mathcal{D} \nabla \psi_i + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi_i$$

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Transport Physics

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- Spatial convection

Transport Equation

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- (Adiabatic) energy changes

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Three-Dimensional Structure

- Distribution of CR sources

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Three-Dimensional Structure

- Distribution of CR sources
- Distribution of matter
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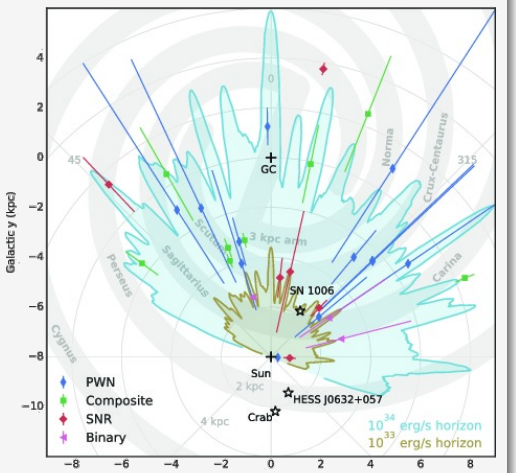
HGPS Sensitivity Limits



(H. E. S. S. Collaboration et al. (2018))

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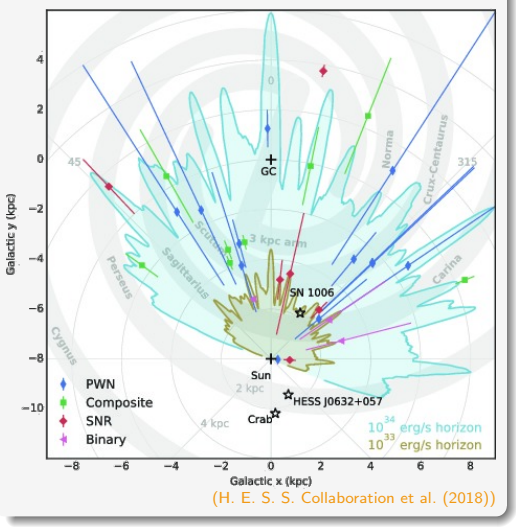

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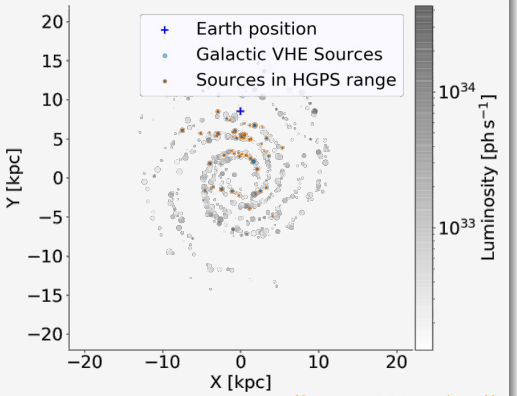
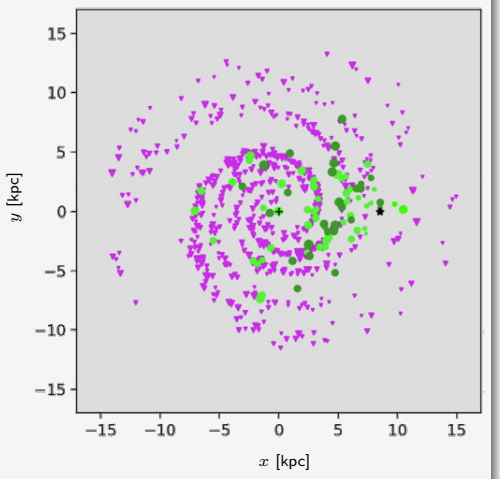
Monte-Carlo Source Distribution



(Steppa and Egberts (2020))

Example Source Model



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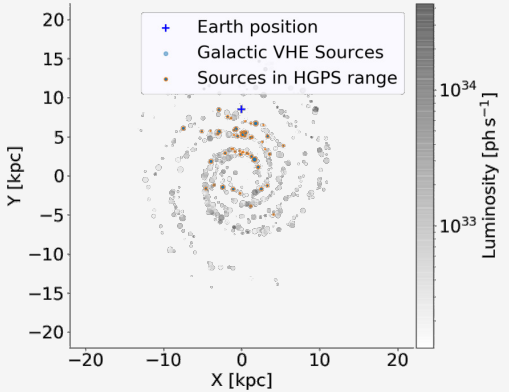

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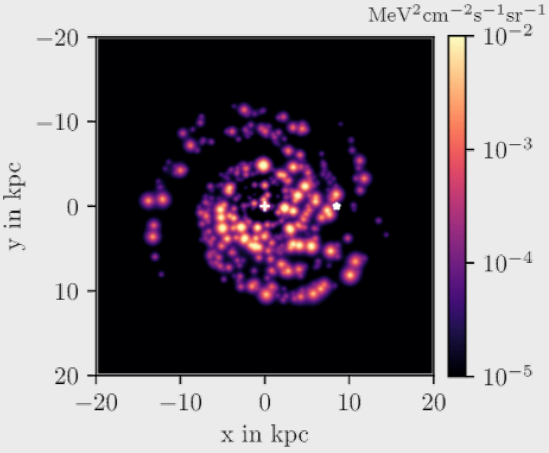
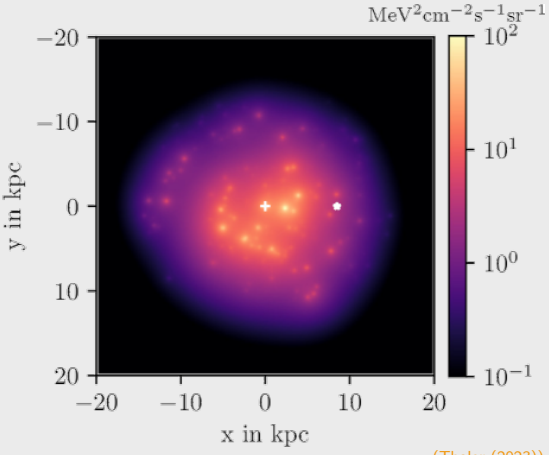
Example Source Model

Propagation Results





(Thaler (2023))

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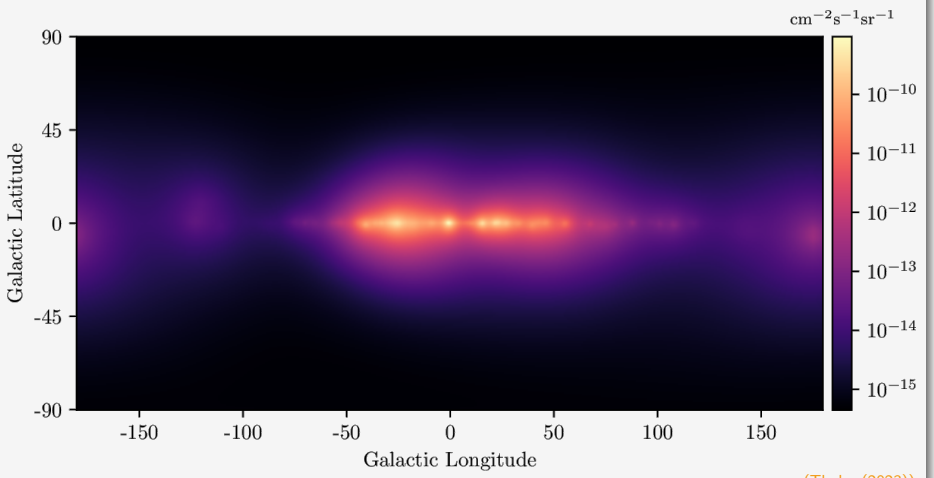
Inverse-Compton Emission



(Thaler (2023))

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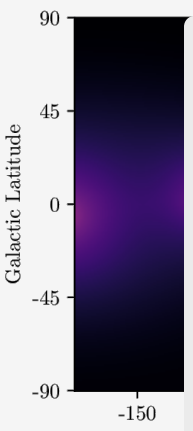
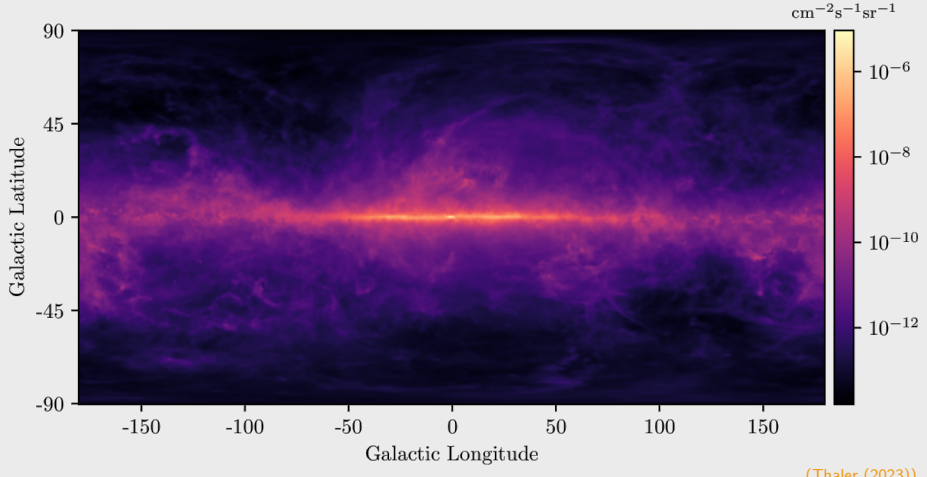


Total Gamma-Ray Emission



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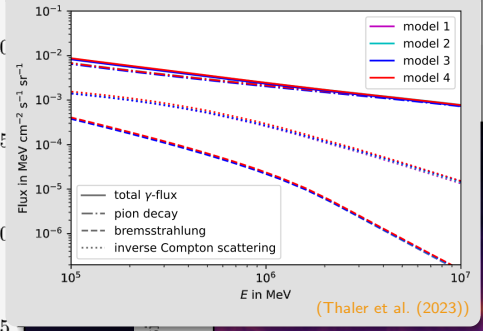
Sources

Inter-Arm Region



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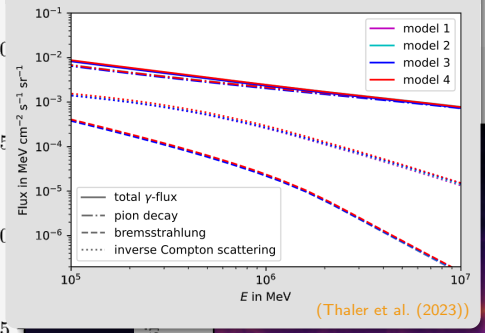

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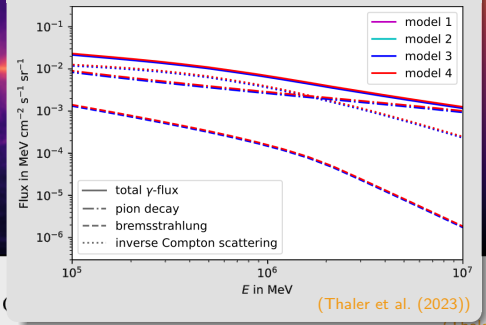
Spiral-Arm Tangent



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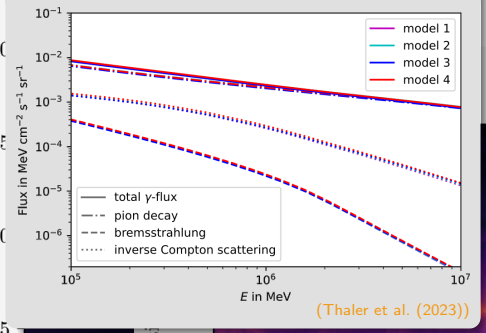

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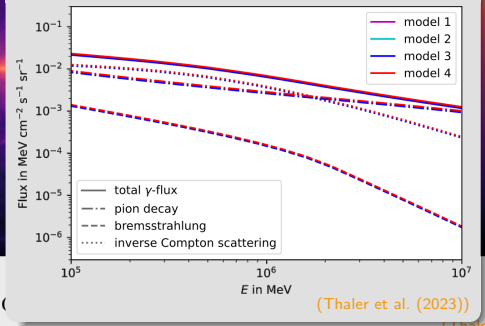


(Thaler et al. (2023))

(Thaler (2023))

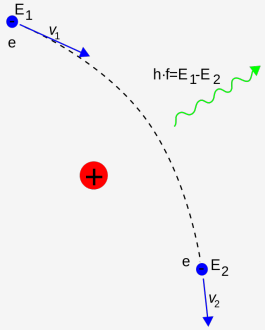
Observation

- IC (mostly) subdominant
- But: source localisation vs. resolution
- Near-source transport
- Source leakage?

Energy Losses

- Ionisation losses
- Coulomb losses
- Bremsstrahlung

Bremsstrahlung Losses



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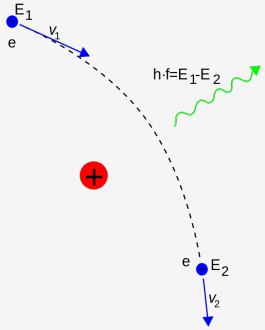
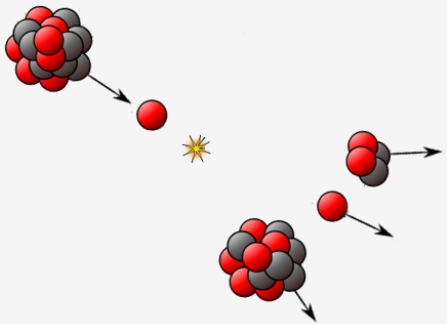


Spallation Reaction



Inelastic Reactions

- Spallation of particles
- Creation of secondary CRs
- $X + p \rightarrow X + p + \pi^0$

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- Ionisation losses
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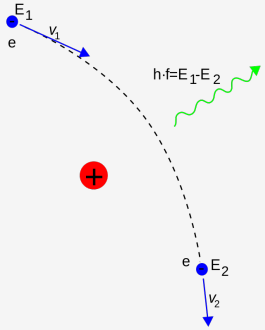
- Bremsstrahlung
  → gamma-rays

Bremsstrahlung Losses



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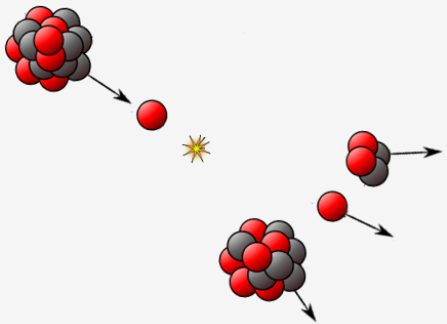

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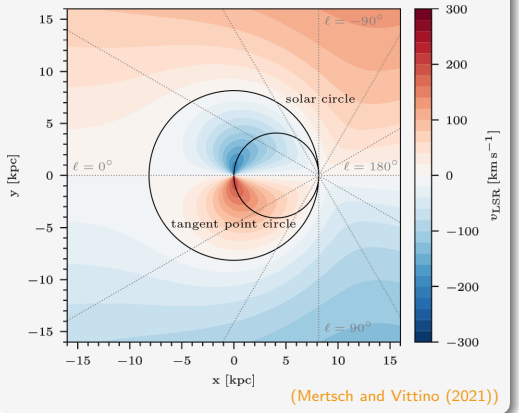
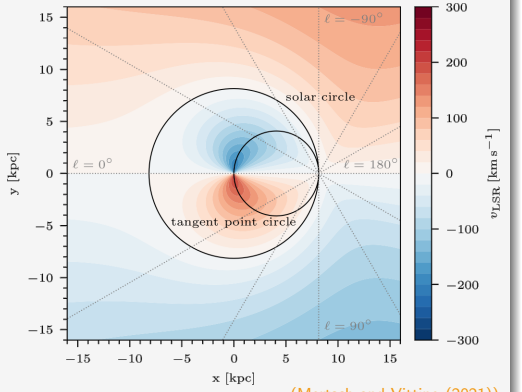
  $\Rightarrow \pi^0 \rightarrow$ gamma rays

Circular Rotation Curve



(Mertsch and Vittino (2021))

Circular Rotation Curve



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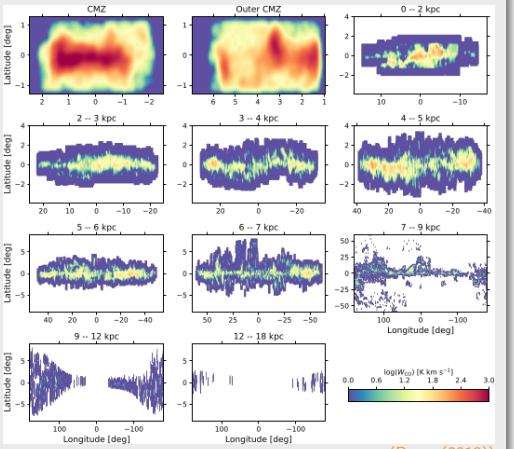
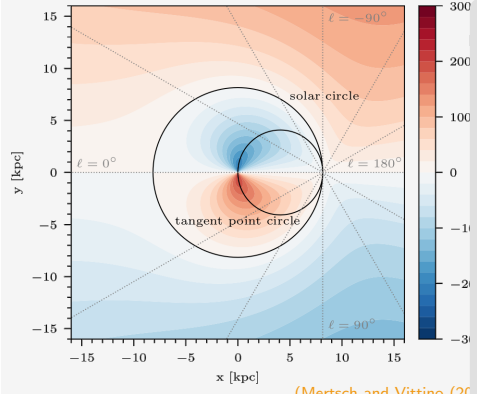
HERMES Gas Model



(Remy (2018))

Circular Rotation Curve



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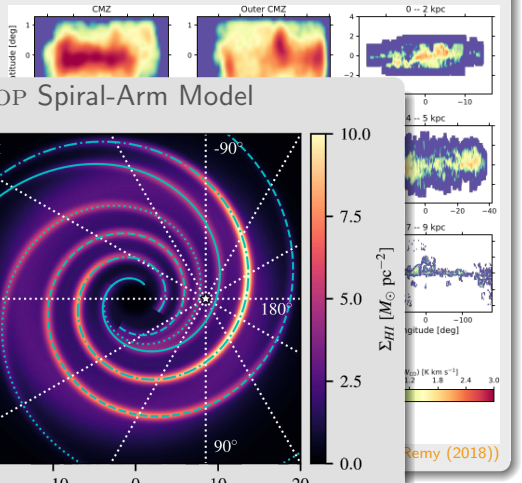

Remy (2018))

GALPROP Spiral-Arm Model

(Jóhannesson et al. (2018))

New approach (Aachen)

- Bayesian variational inference
- Different rotation curves
- Correlation of structures
- Use of NIFTY5

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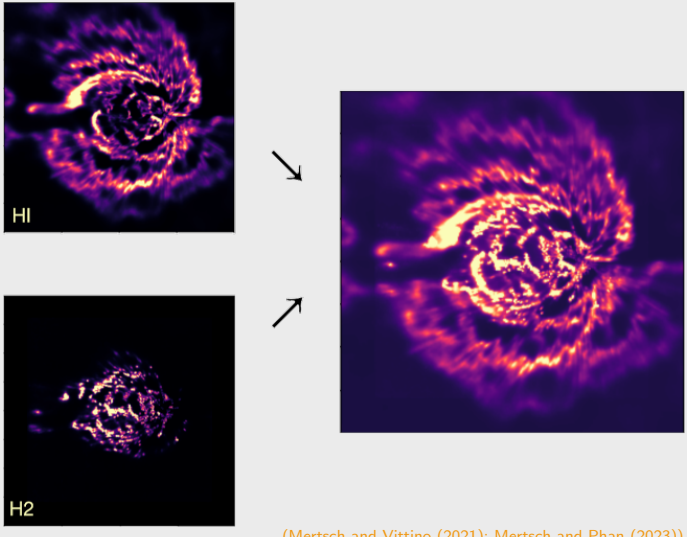
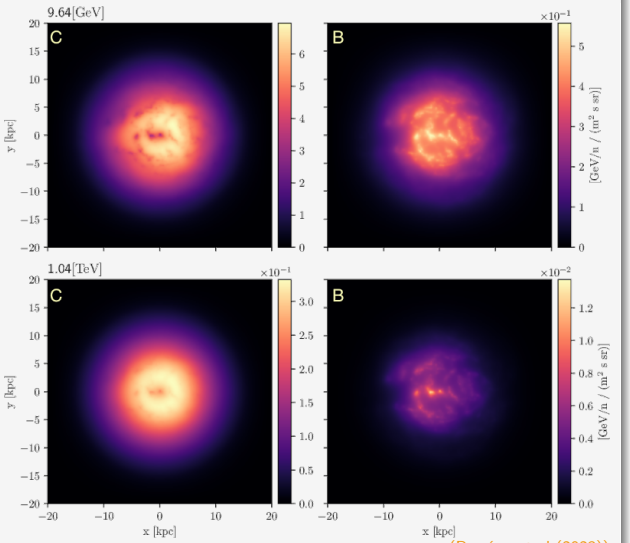
Gas Model by Aachen Group



(Mertsch and Vittino (2021); Mertsch and Phan (2023))

CR Distibution in Galactic Plane



(Ramírez et al (2023))

Gas Distribution

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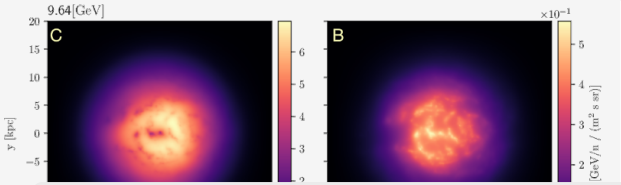
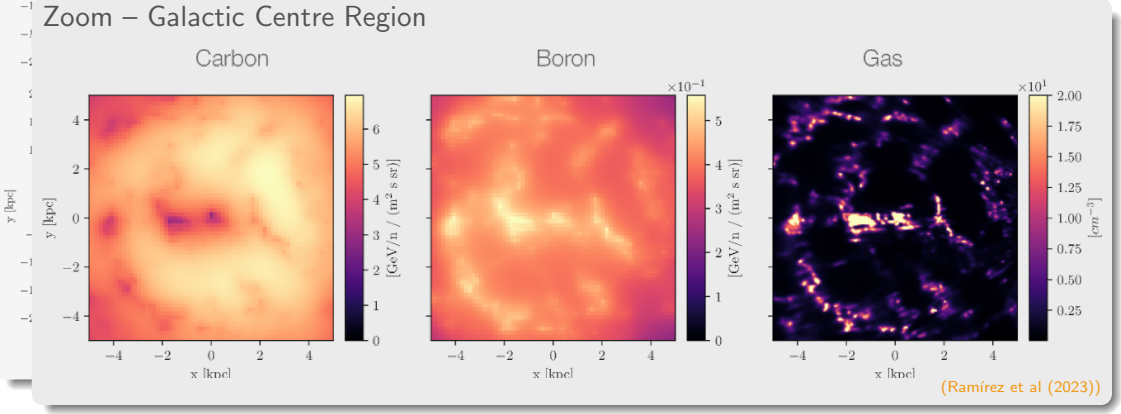


Zoom – Galactic Centre Region



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Gas Distribution

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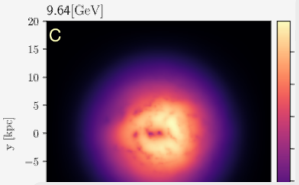
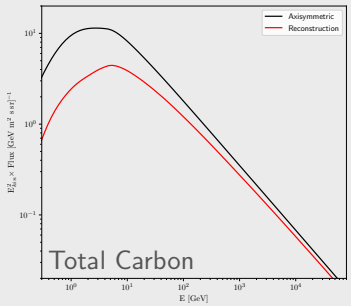


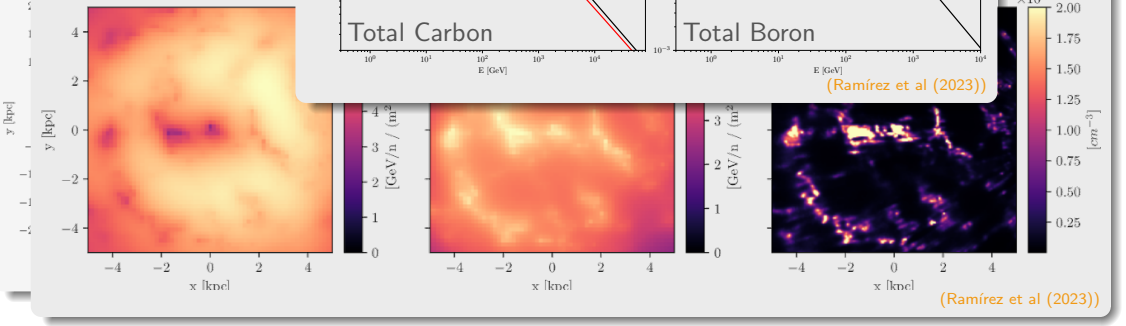
Spectra at Galactic Centre



(Ramírez et al (2023))

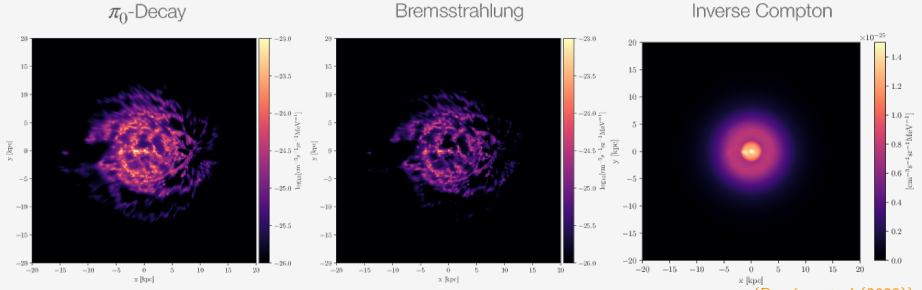
Zoom – Galactic Cen

Carbon



(Ramírez et al (2023))

10 GeV Gamma-Ray Emission



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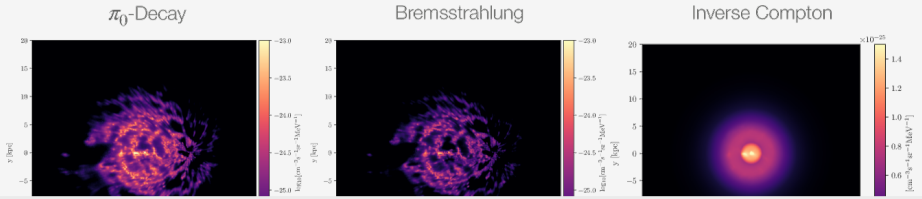
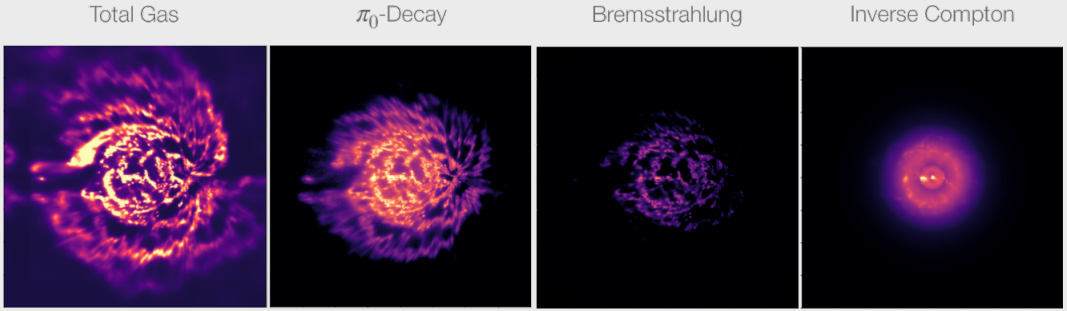


1 TeV Gamma-Ray Emission



(Ramírez et al (2023))

Gas Distribution

10 GeV Gamma-Ray Emission

π_0-Decay Bremsstrahlung Inverse Compton

Line-of-Sight Integrated Emission

π_0-Decay Bremsstrahlung

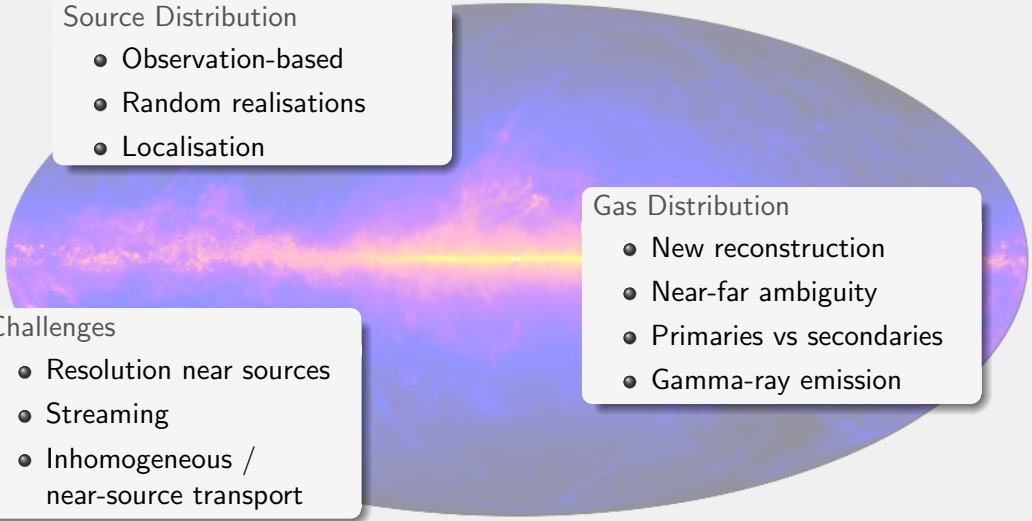
IC

(Ramírez et al (2023))

1 TeV G

Compton

(Ramírez et al (2023))



Source Distribution
- Observation-based
- Random realisations
- Localisation

Gas Distribution
- New reconstruction
- Near-far ambiguity
- Primaries vs secondaries
- Gamma-ray emission

Challenges
- Resolution near sources
- Streaming
- Inhomogeneous / near-source transport