Stochastic Fluctuations of Low-Energy Cosmic Rays

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with Florian Schulze, Philipp Mertsch, Sarah Recchia, and Stefano Gabici.

Phan et al., 2021, PhRvL, 127, 141101

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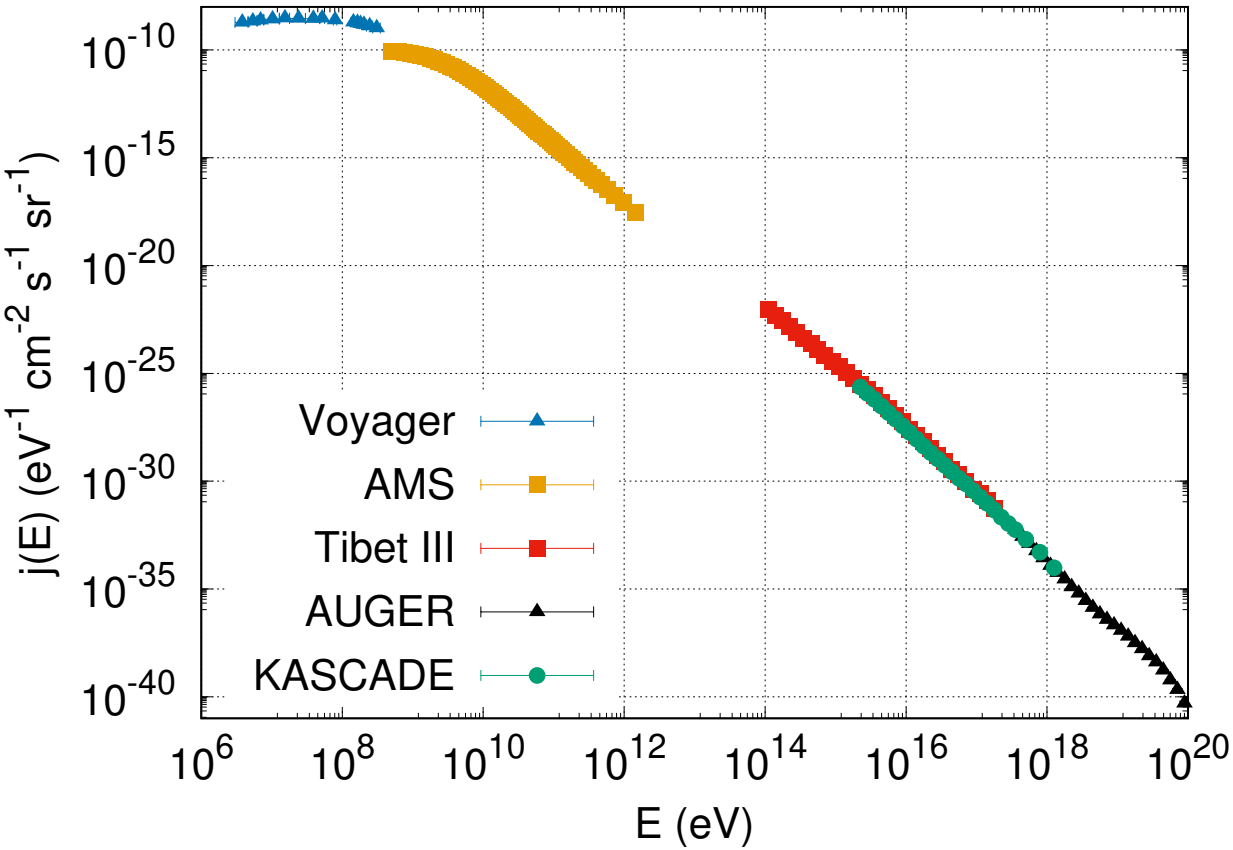
Outline

- **Physical Context**
- **Stochastic Model for Low-Energy Cosmic Rays**
- **Results and Implications for Voyager Data**
- **Conclusions and Perspectives**

- We will focus on cosmic rays of energy below 10 GeV since these particles affect the dynamics of various processes in the Universe including the formation of new stars.



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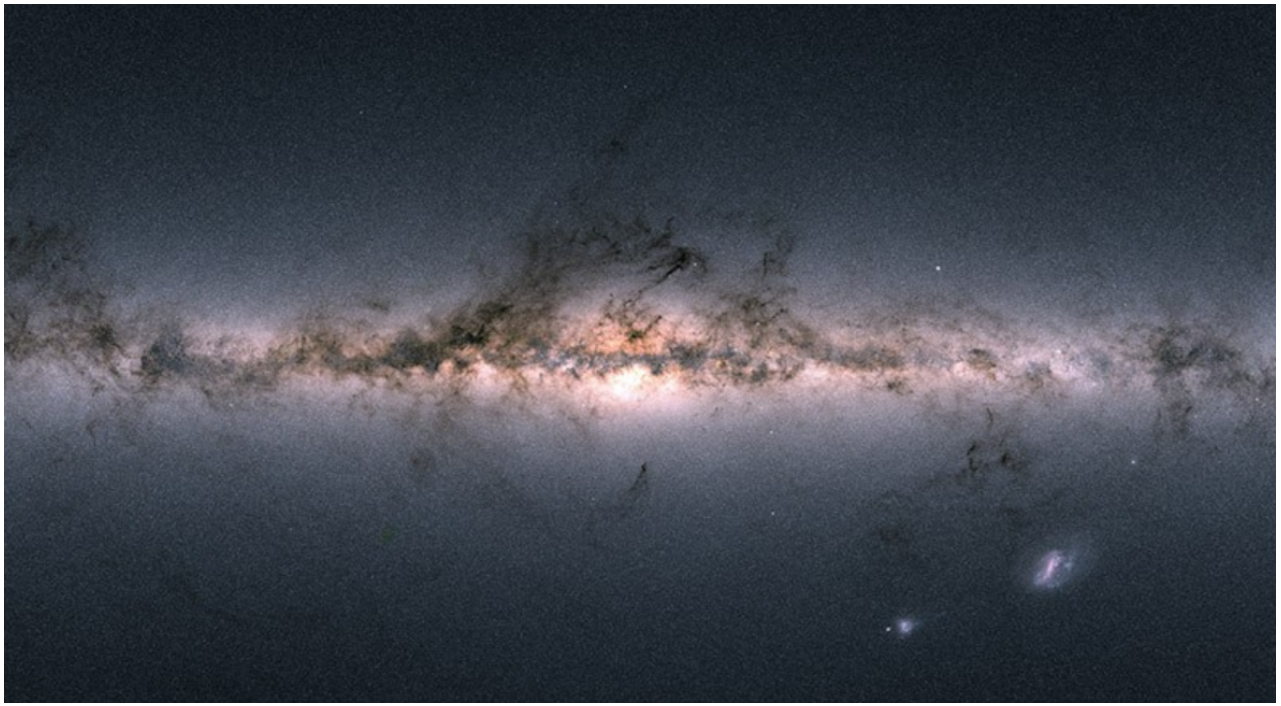

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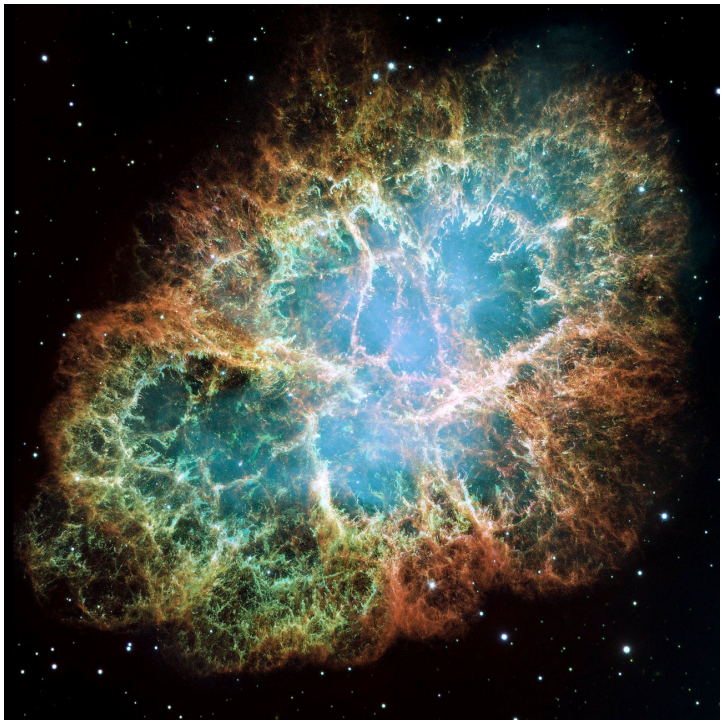
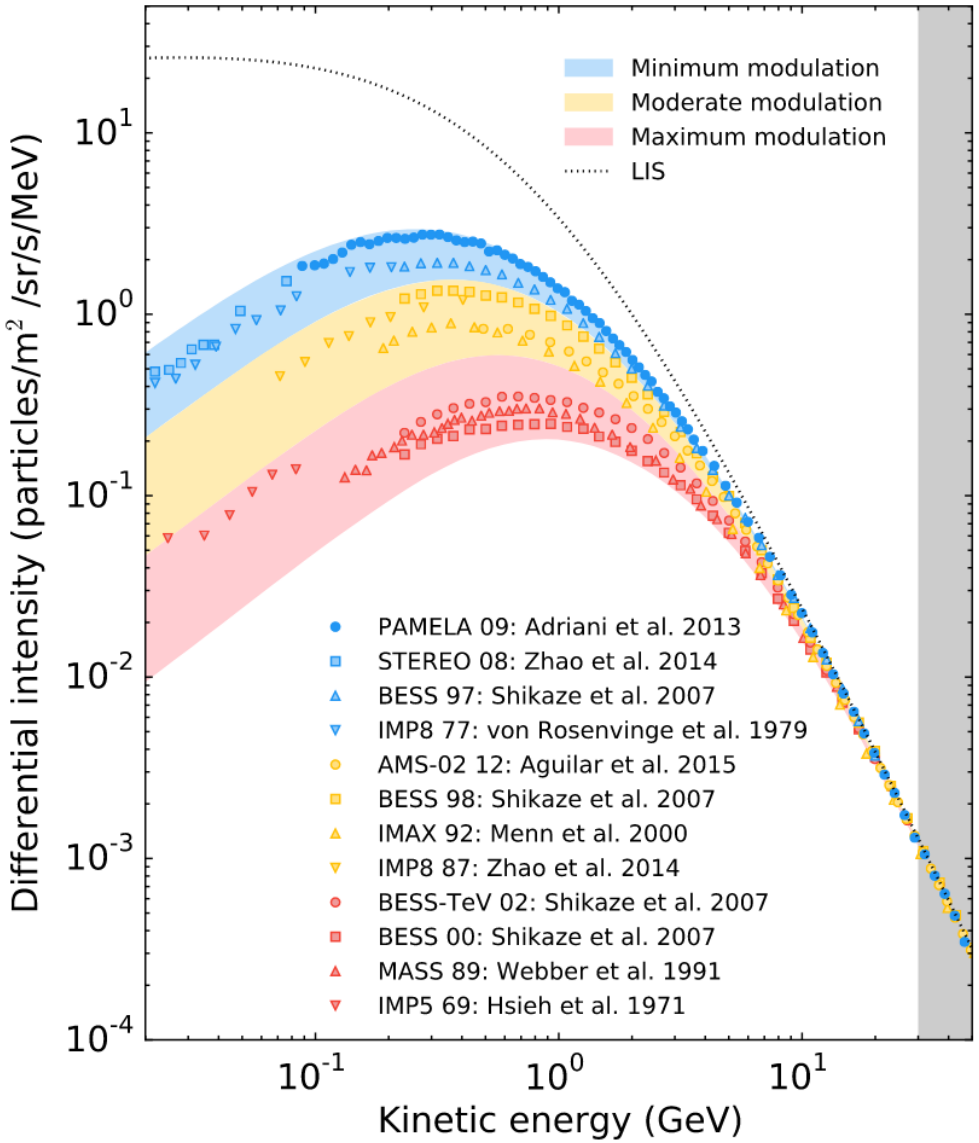
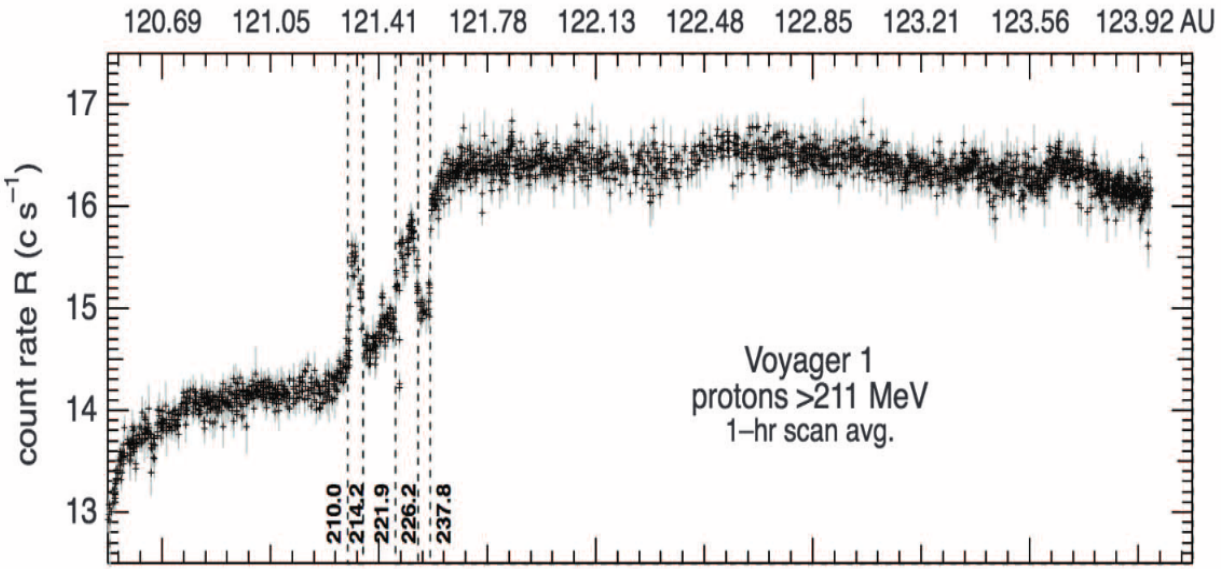


Solar Modulation



Vos & Potgieter, *ApJ*, 2015

Voyager Probes



Krimigis et al., *Science*, 2013
Strauss, *Nature Astronomy*, 2019

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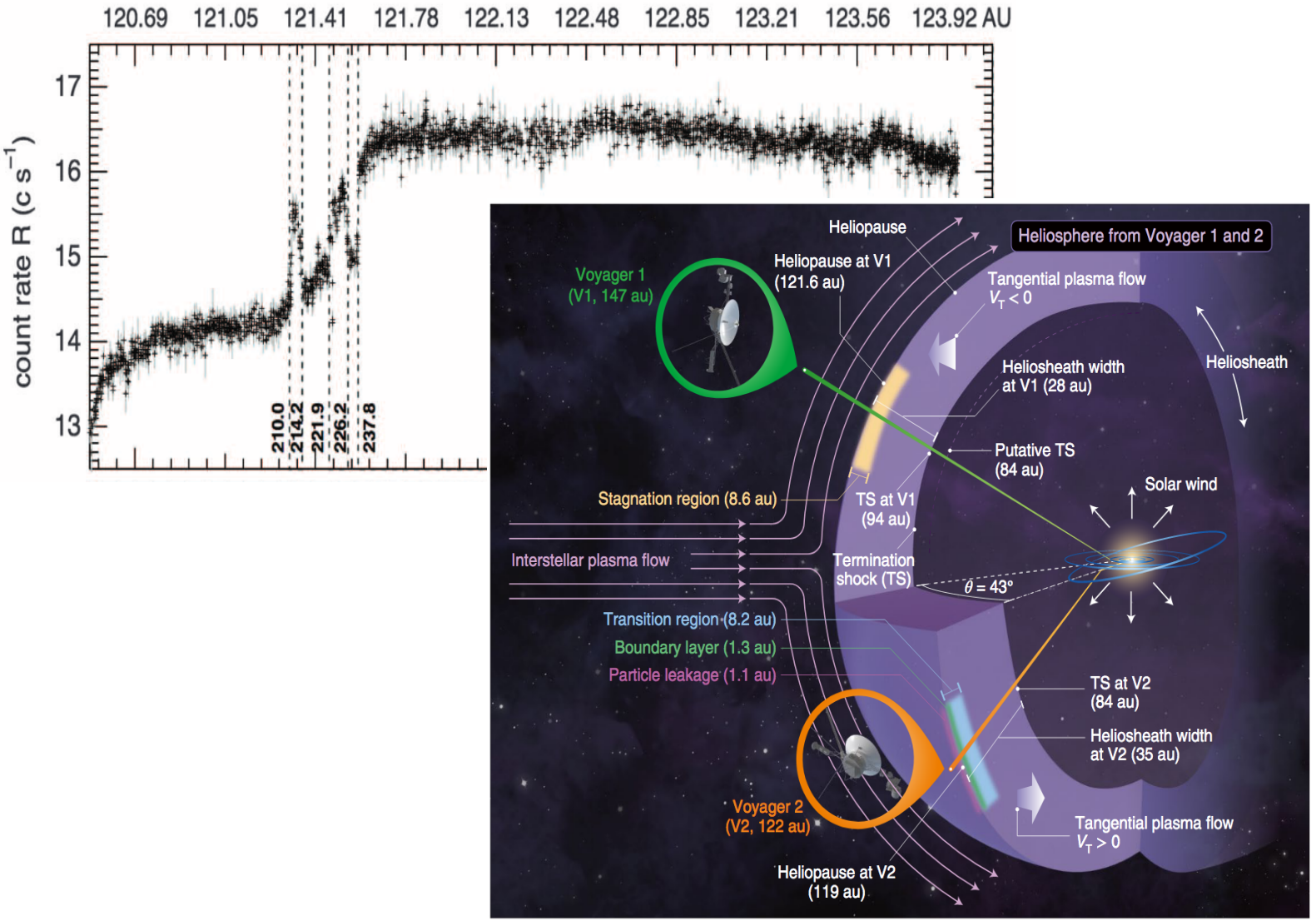

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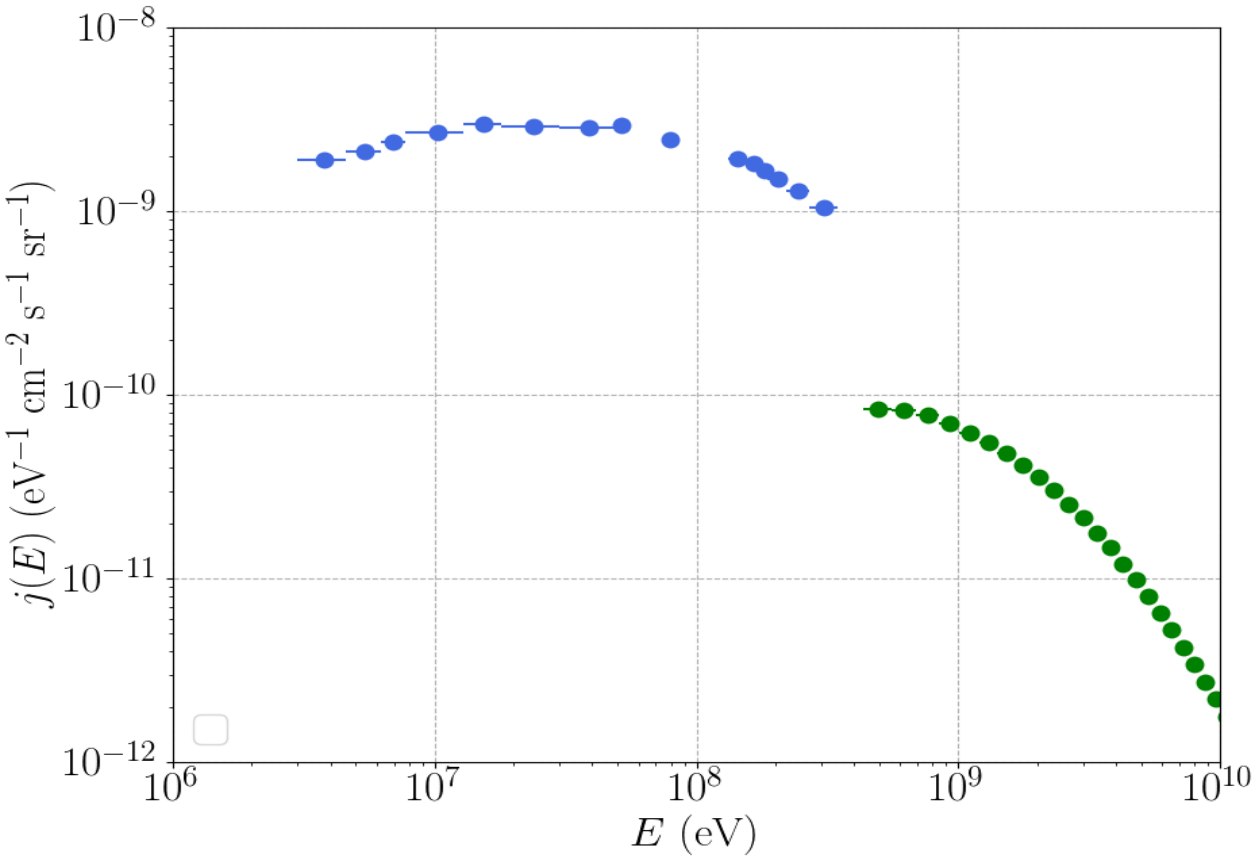
Ionization Rate in Diffuse Clouds

- Ionization rate is **the production rate of H_2^+ ions**.
- A difference of about **1 to 2 orders of magnitude** between the ionization rate in diffuse MCs estimated from the Voyager spectra and the observed data.



Cummings et al., *ApJ*, 2016

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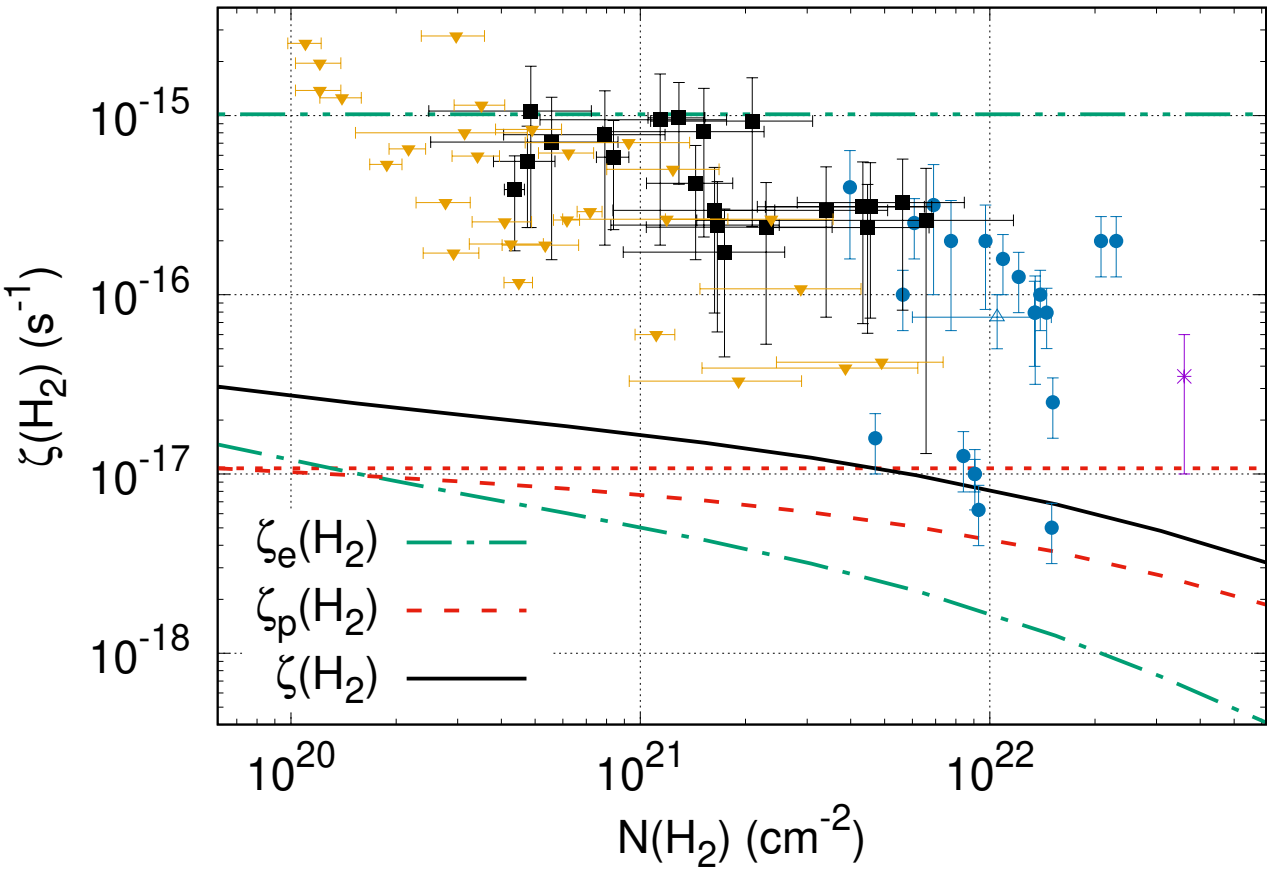
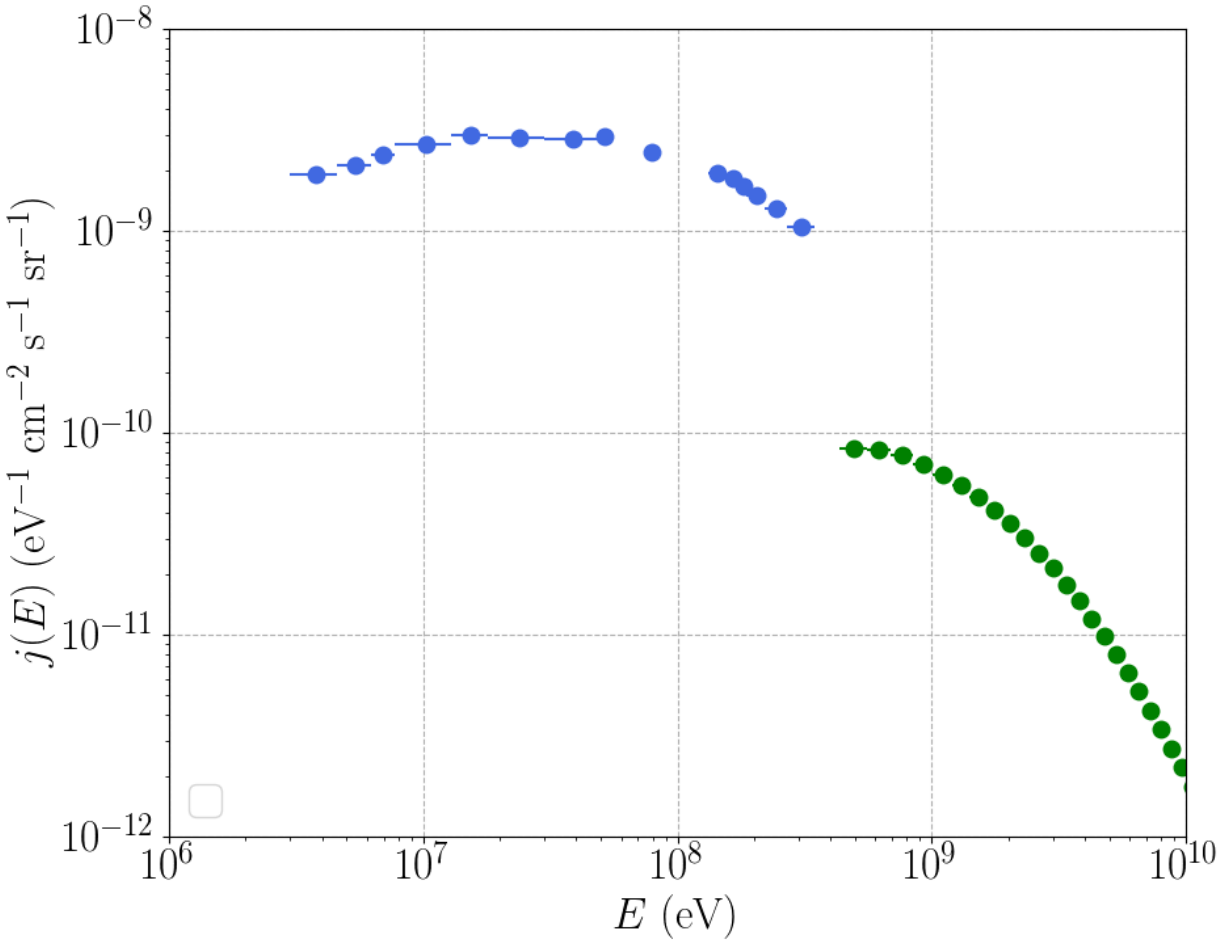


Phan et al., *MNRAS*, 2018

- The transport equation of cosmic rays:

$$\frac{\partial \psi}{\partial t} + \frac{\partial}{\partial z}\left(u\psi\right) - D\nabla^2\psi + \frac{\partial}{\partial E}\left(\dot{E}\psi\right) = q(r, z, E, t)\,,$$



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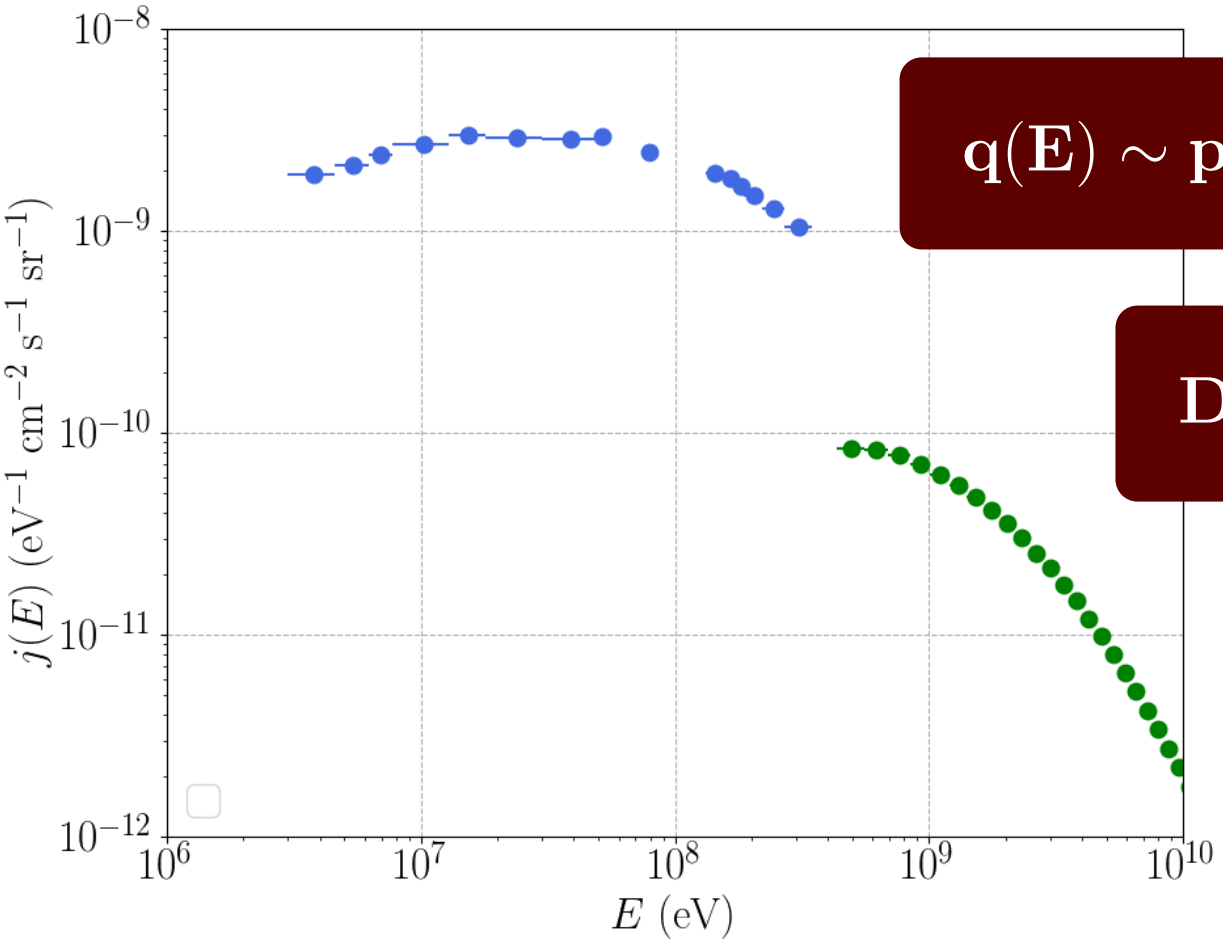

$\mathbf{q(E) \sim p^{-\alpha}}$

$\mathbf{D(E) \sim \gamma^{-\delta}}$

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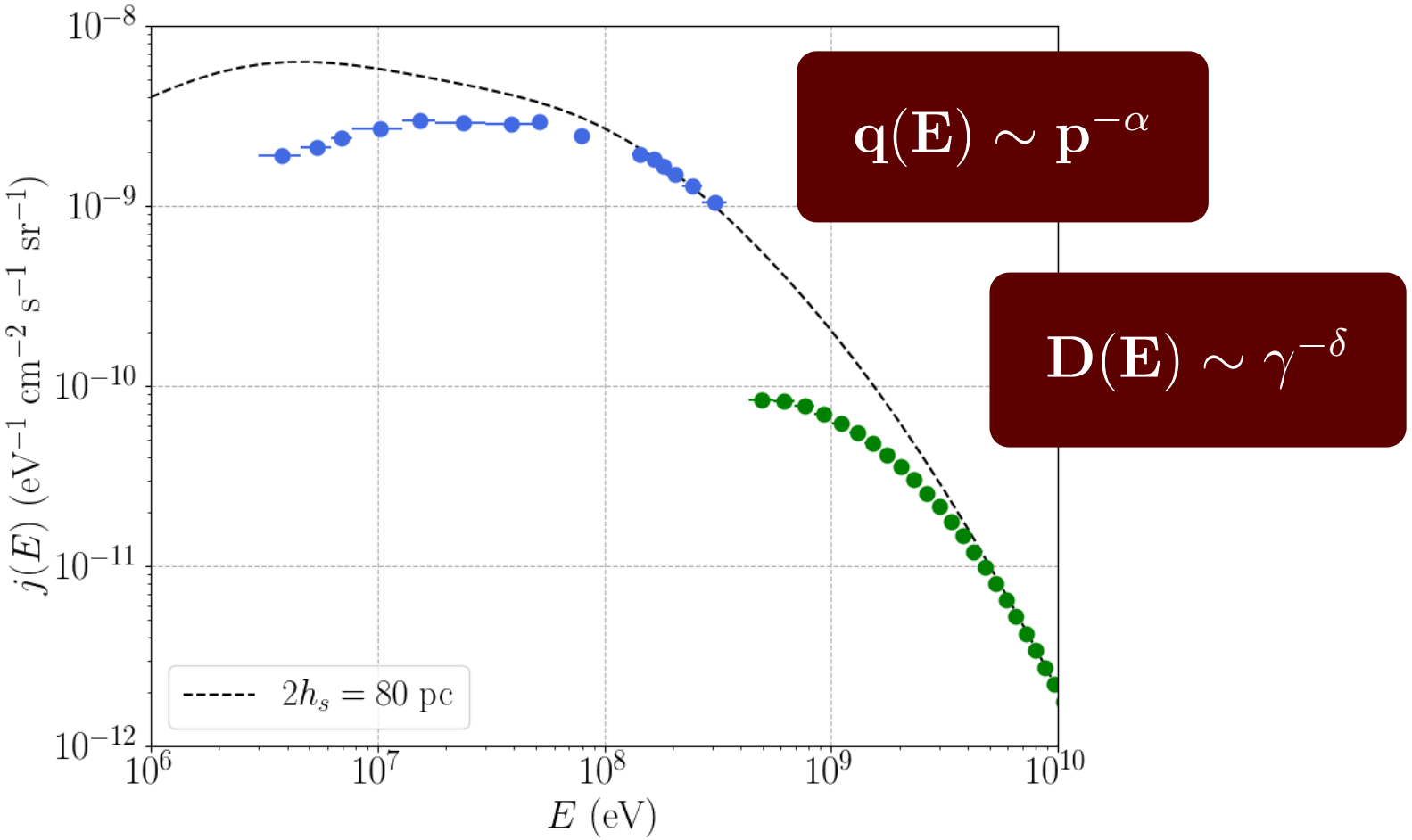
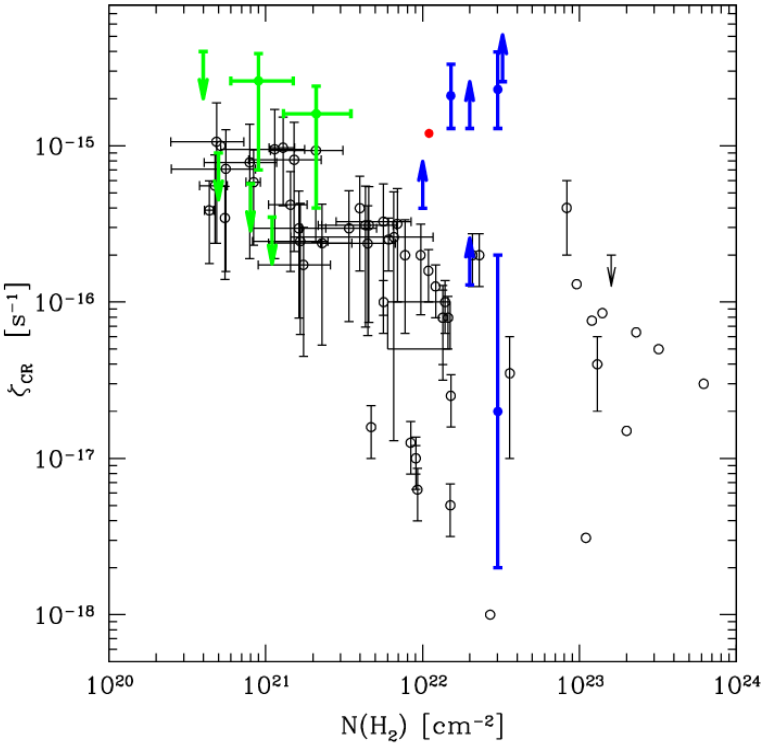
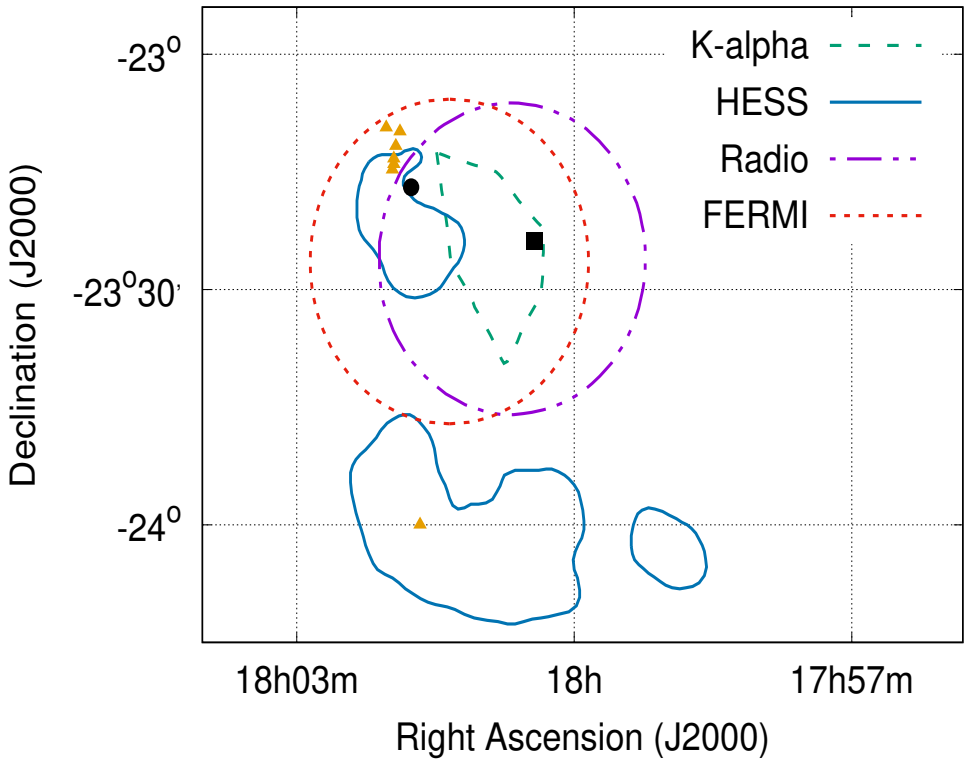


Sources of Low-Energy Cosmic Rays?



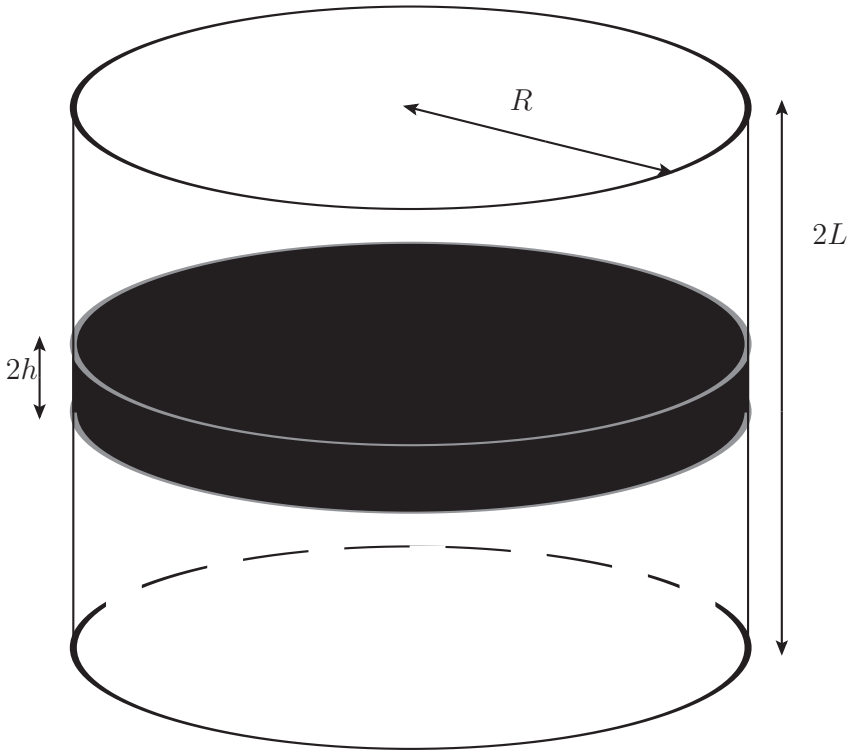


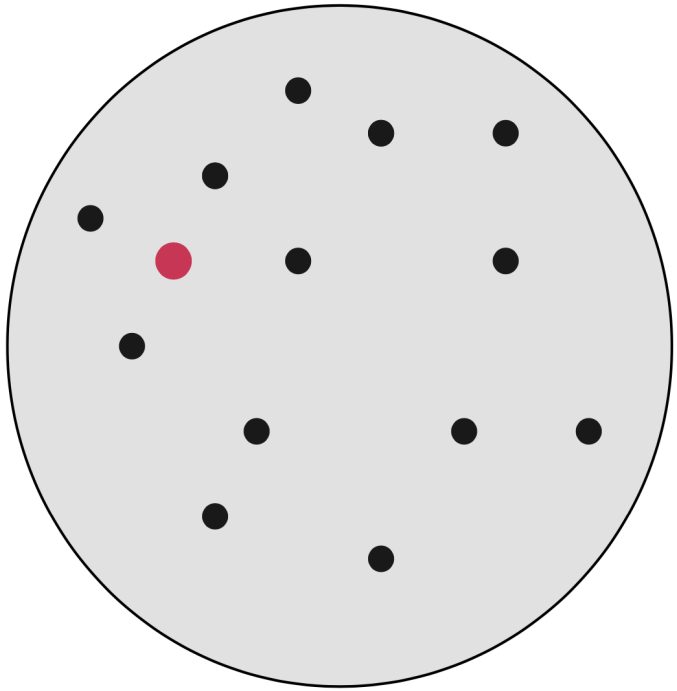
Gabici & Montmerle, *Pos ICRC*, 2015
Phan et al., *A&A*, 2020

- The transport equation of cosmic rays for discrete sources in the disk:

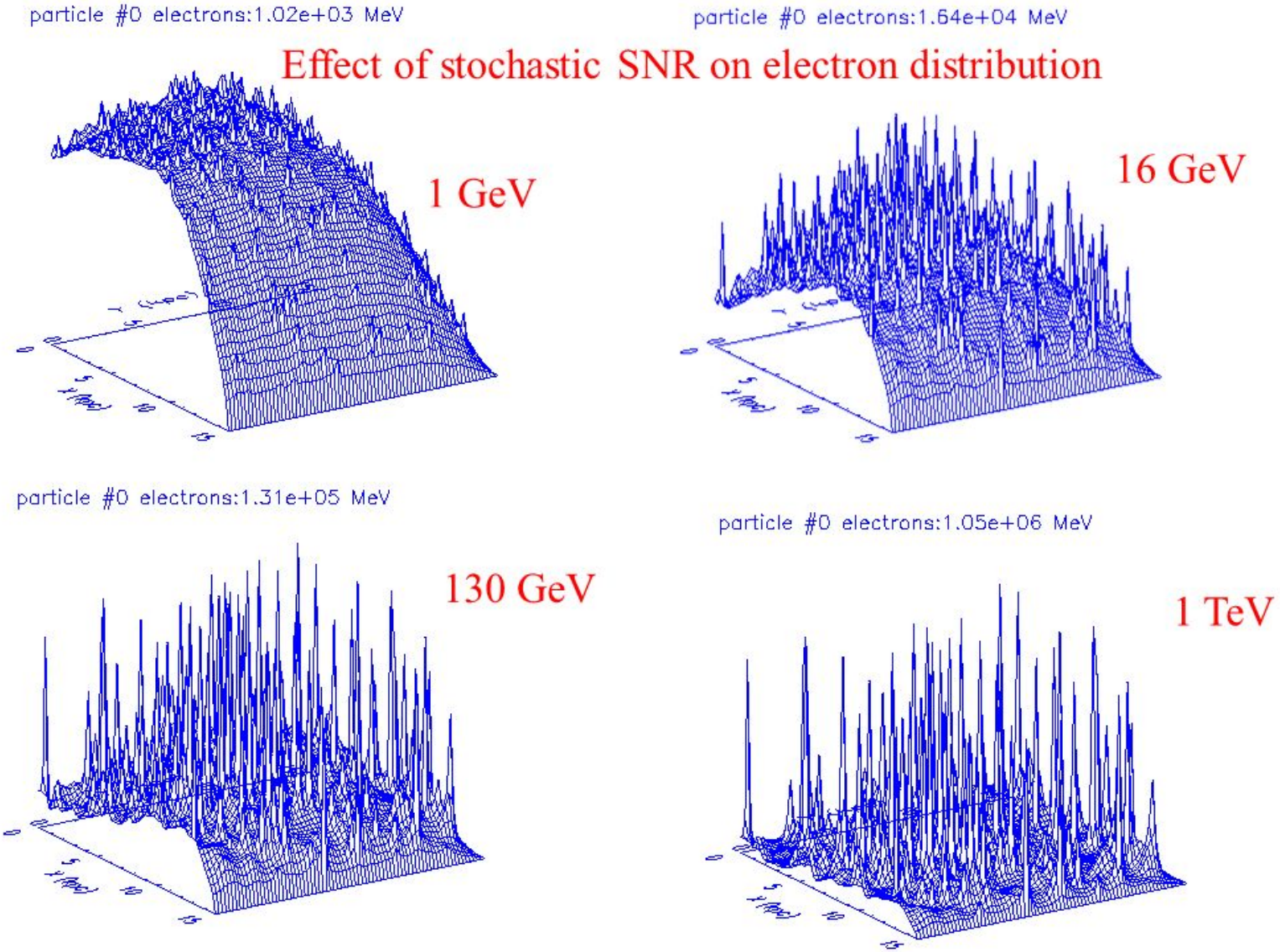
$$\frac{\partial \psi}{\partial t} + \frac{\partial}{\partial z}\left(u\psi\right) - D\nabla^2\psi + \frac{\partial}{\partial E}\left(\dot{E}\psi\right) = q(r, z, E, t)\,,$$

$$q(r, z, E, t) = \sum_{i=1}^{N_s} Q(E)\frac{\delta(r - r_i)}{2\pi r_i}\delta(z - z_i)\delta(t - t_i)\,.$$





An Example for Stochasticity



Strong & Moskalenko ICRC2001

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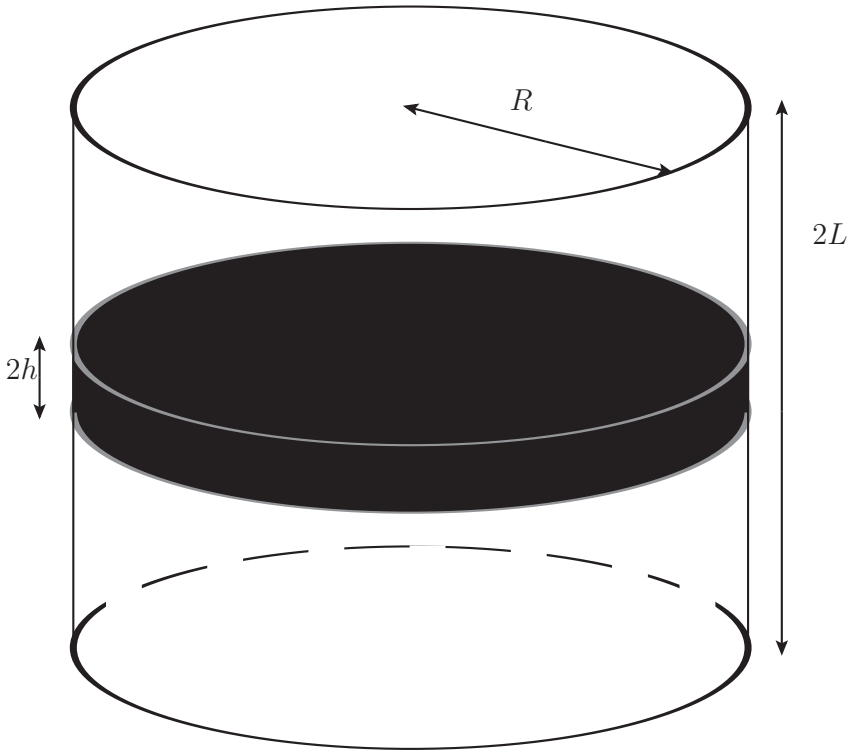
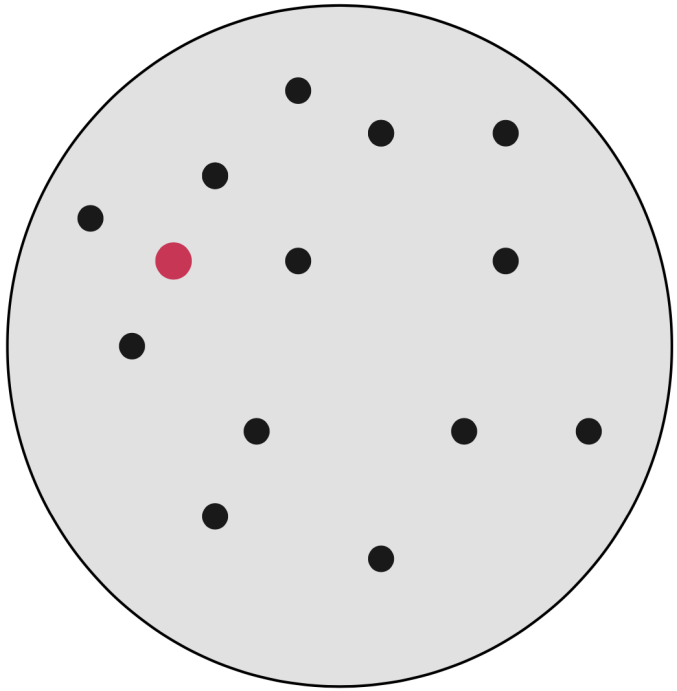
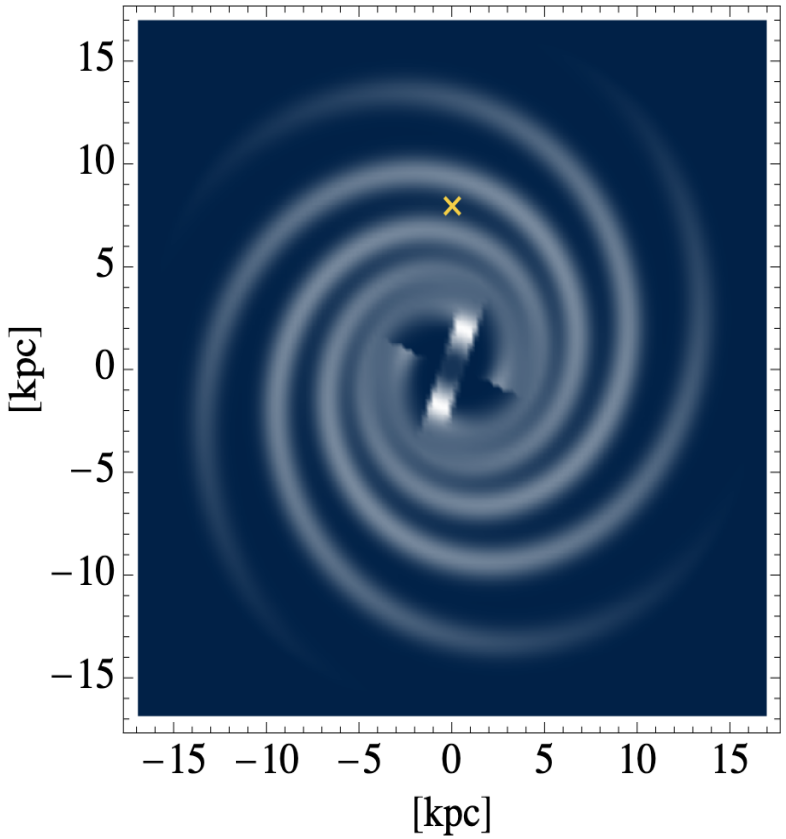
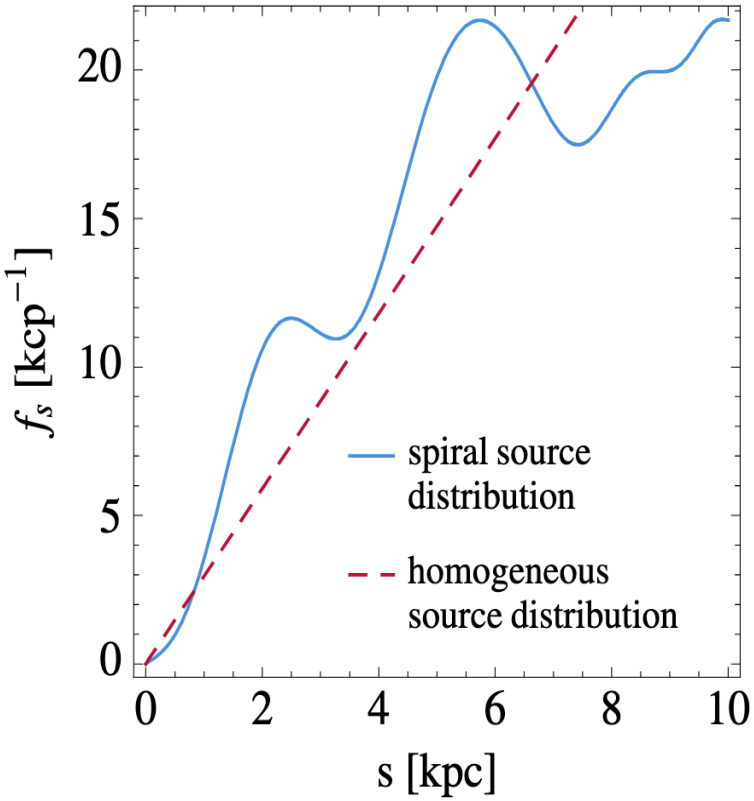




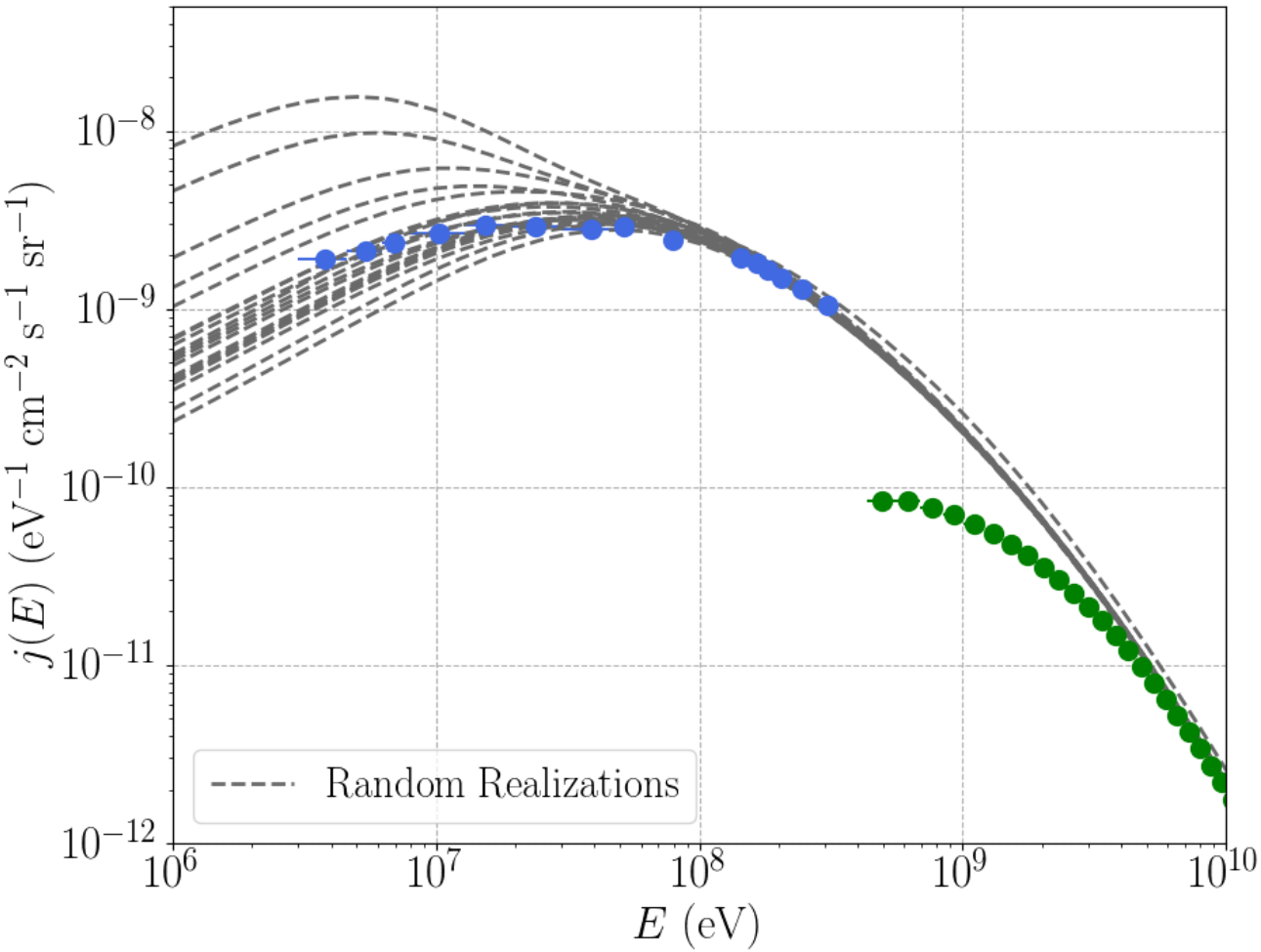
Radial Distribution of Sources



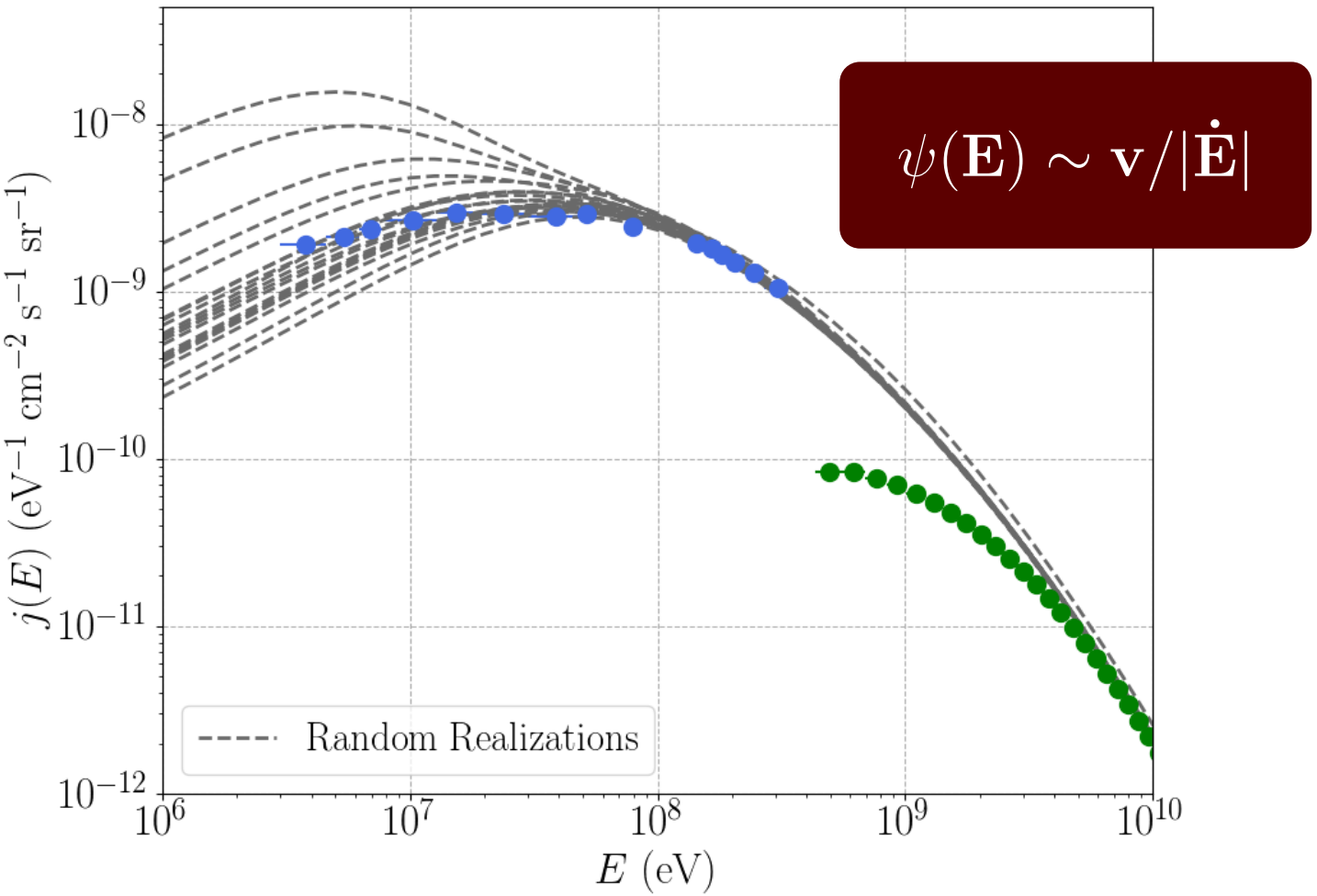


Mertsch, *JCAP*, 2011
Ahlers et al., *PhRvD*, 2009

Spectral Behaviours



Phan et al., *PhRvL*, 2021



Phan et al., *PhRvL*, 2021

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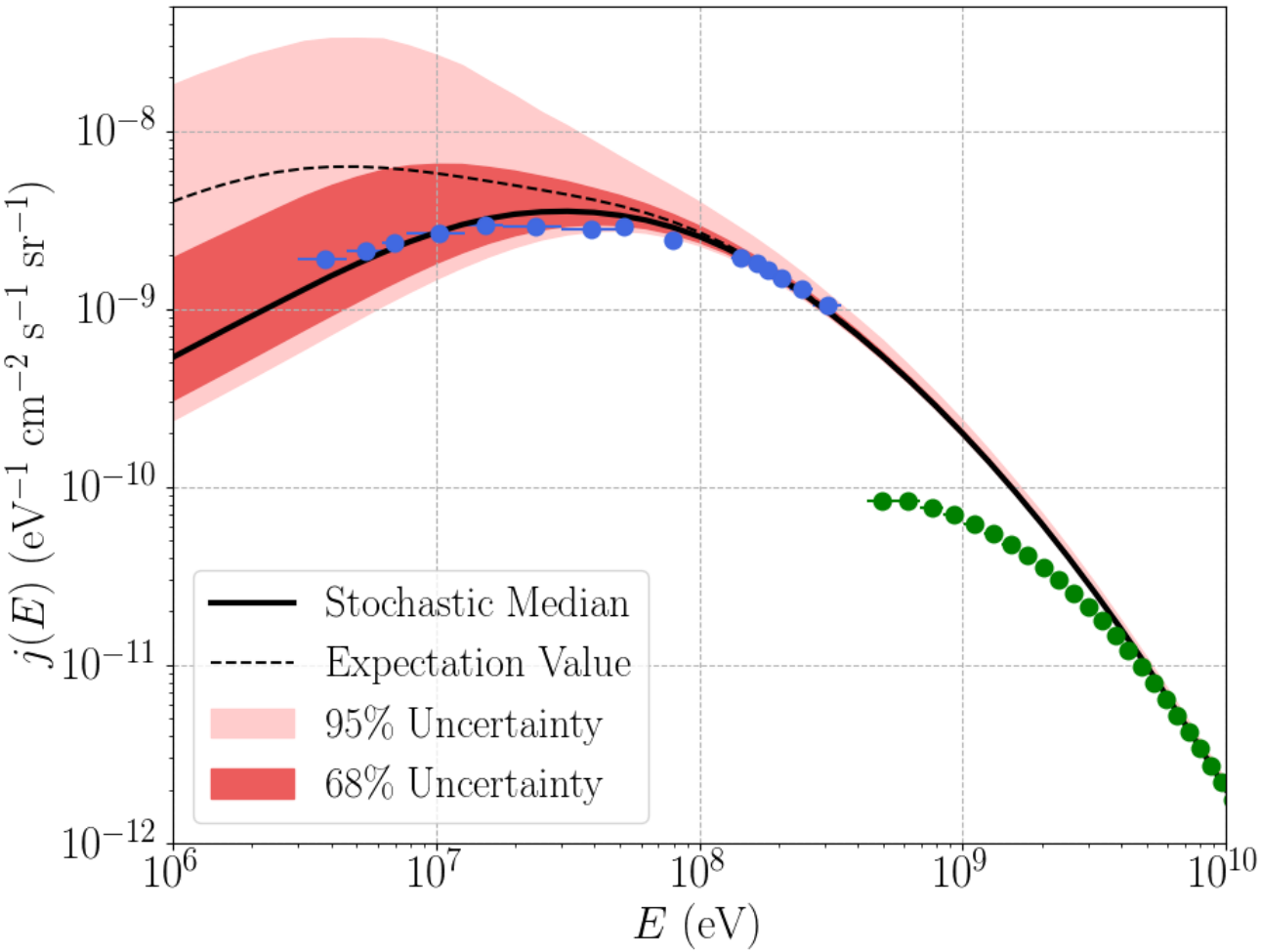
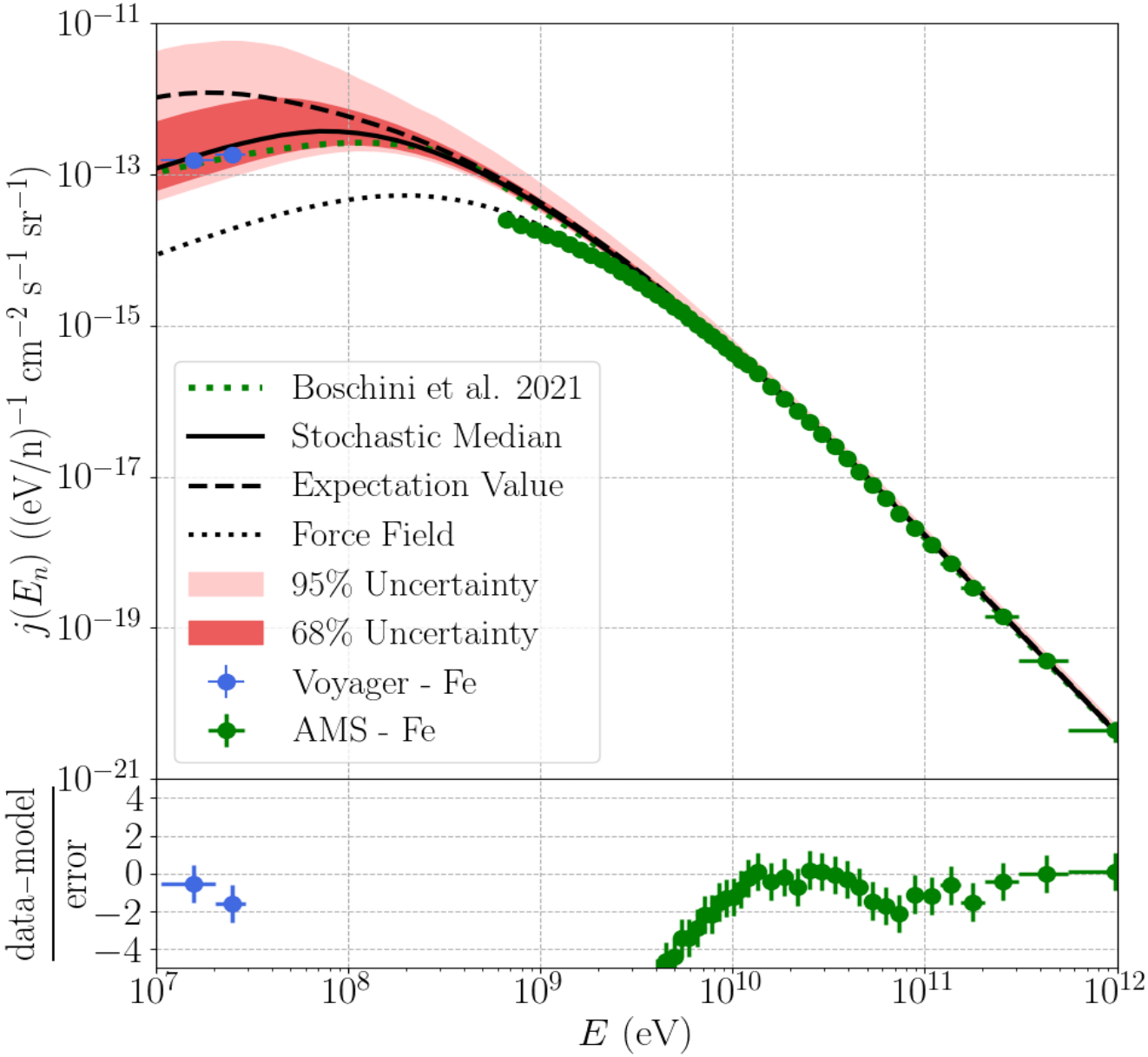
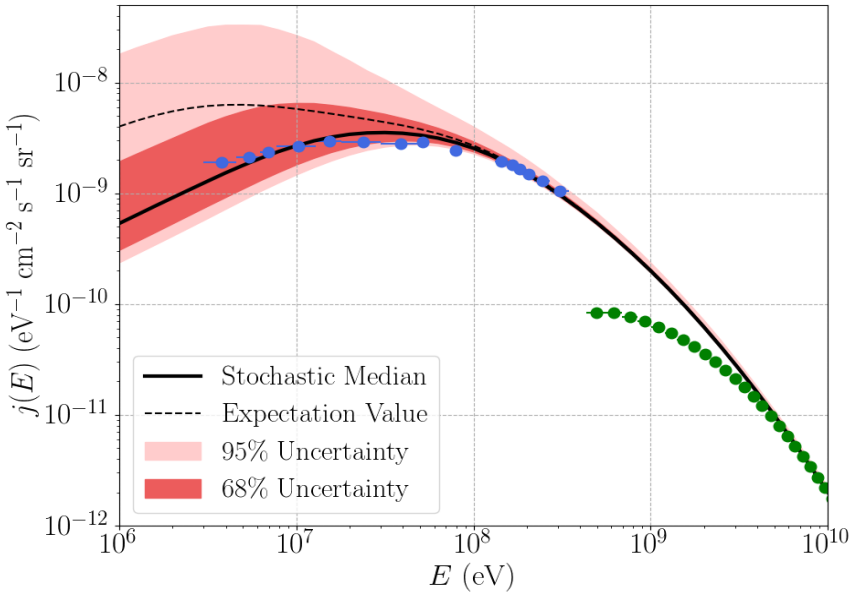


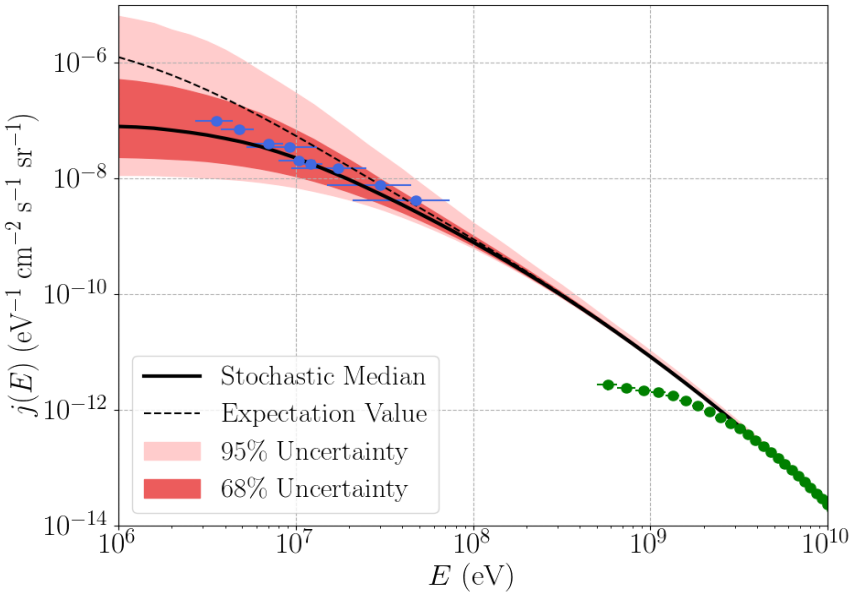
Phan et al., *PhRvL*, 2021

Premilinary Results on Cosmic-Ray Iron



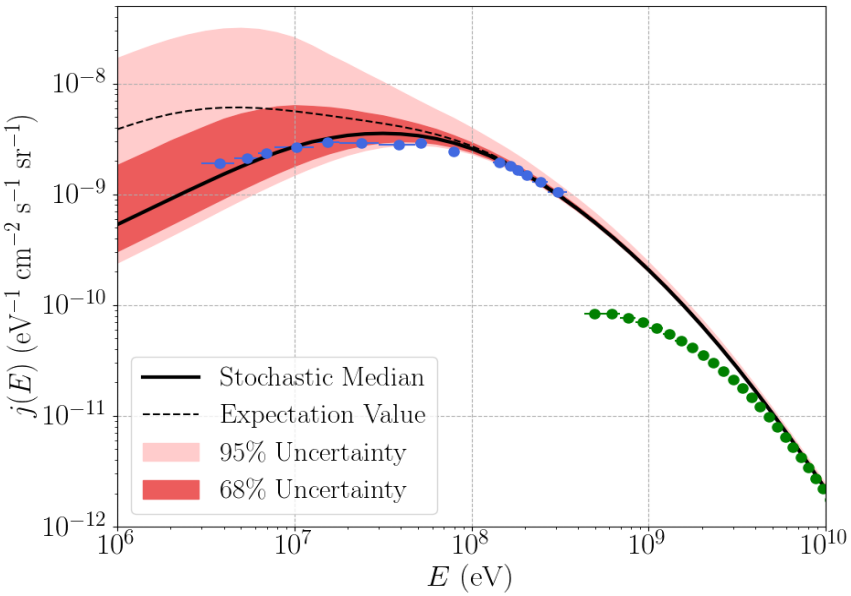
- Stochasticity is important for the modelling of low-energy cosmic rays and this effects allows us explain the Voyager data without requiring any unphysical breaks.

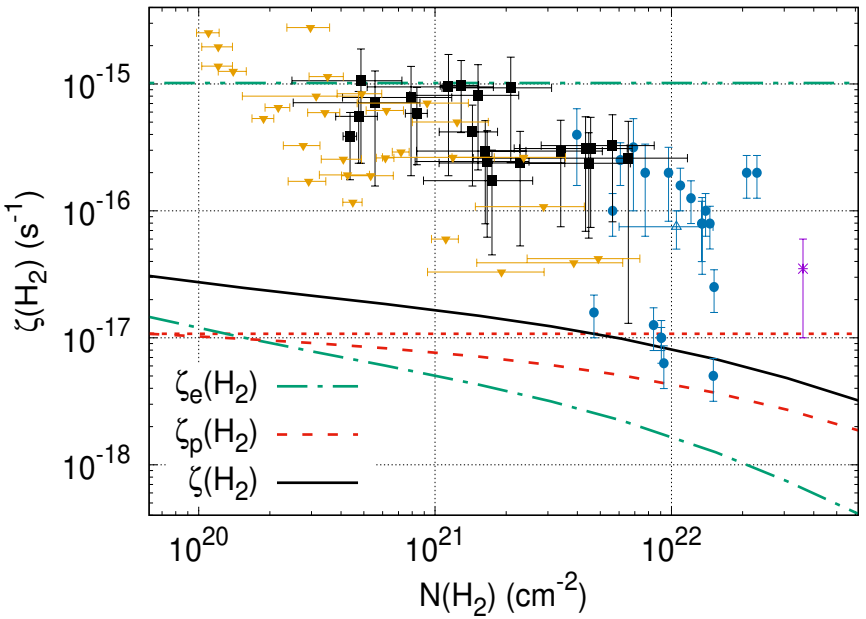




Phan et al., *PhRvL*, 2021

- The stochastic fluctuations might open up a way to explain both **the Voyager data** and **the ionization rate**.





Voyager data

Ionization rate data