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Different Sides of Cosmic Ray Theory

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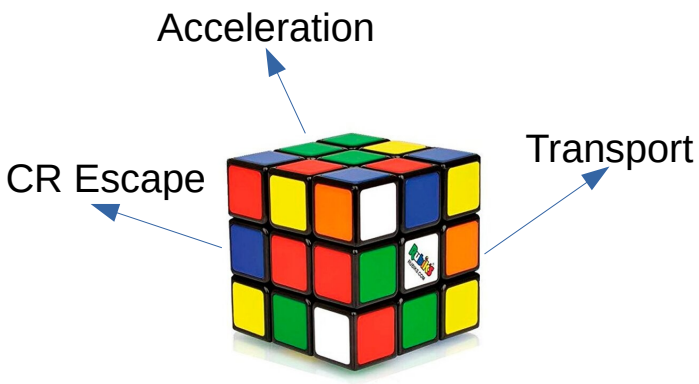
Content

Introduction to CR Theory

- CRs were discovered 100 years ago, yet remain a mystery
- The more we discover, the more questions arise
- CR theory is like a puzzle with many different sides and things to solve



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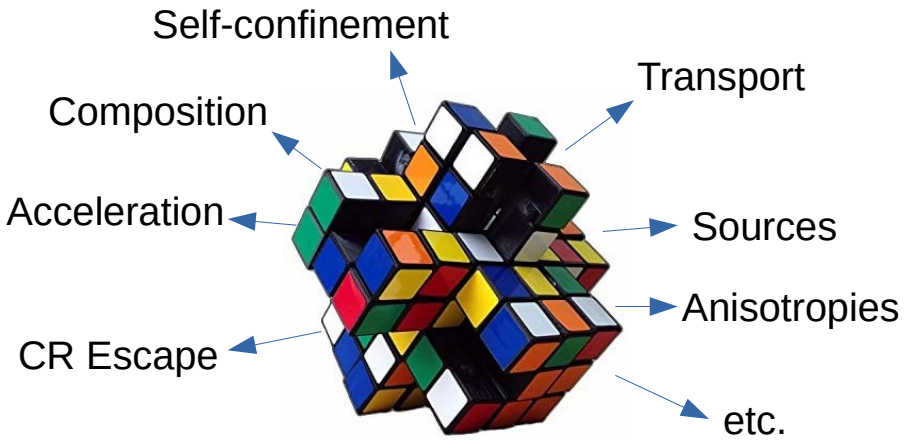

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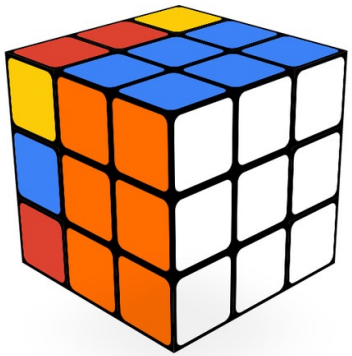
- In reality much more complicated with many different aspects



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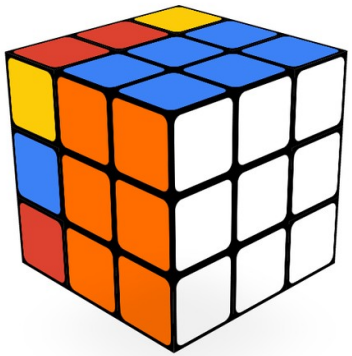

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- All of the sides are connected and contribute to each others solution

CR Escape from their Source

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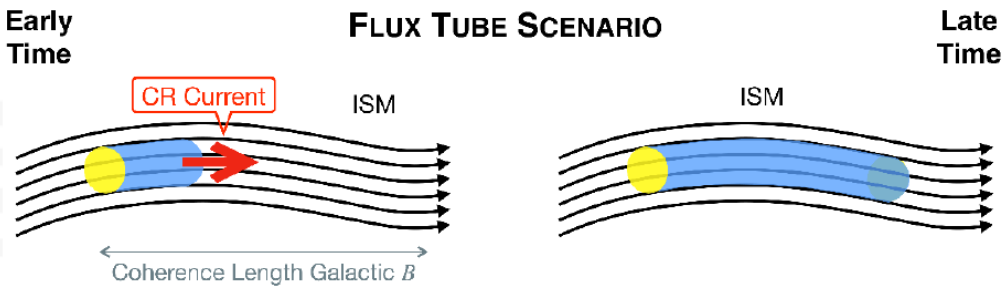
- Picture so far: Accelerated particles escape along local magnetic field lines
- Merge with "CR sea" once their density drops below average Galactic density
- Problem: Flux of escaping particles high enough to trigger magnetic instabilities



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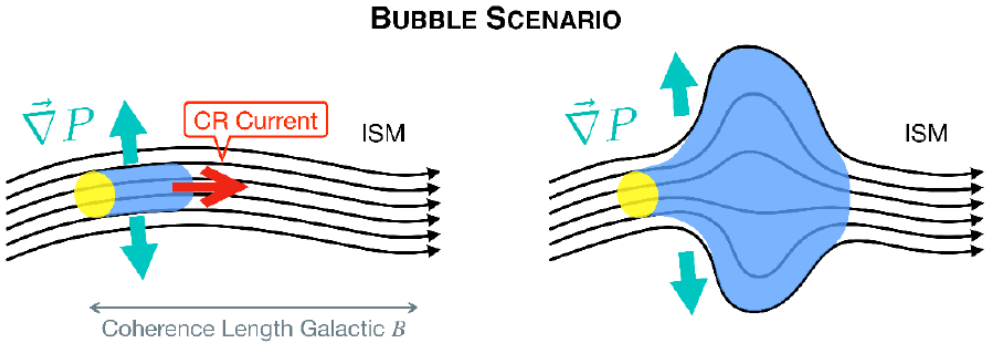
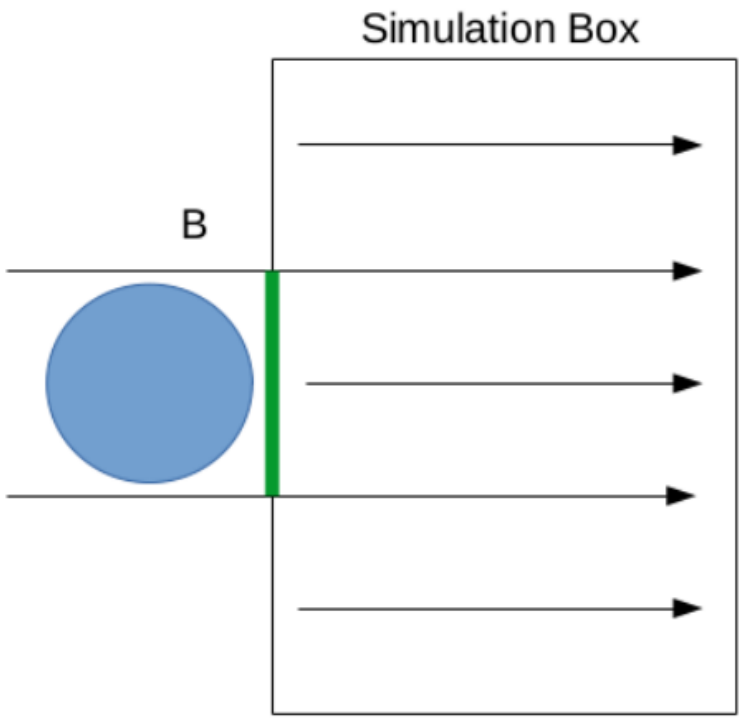
- $\Rightarrow$ Turbulent magnetic field leads to enhanced particle trapping in source environment

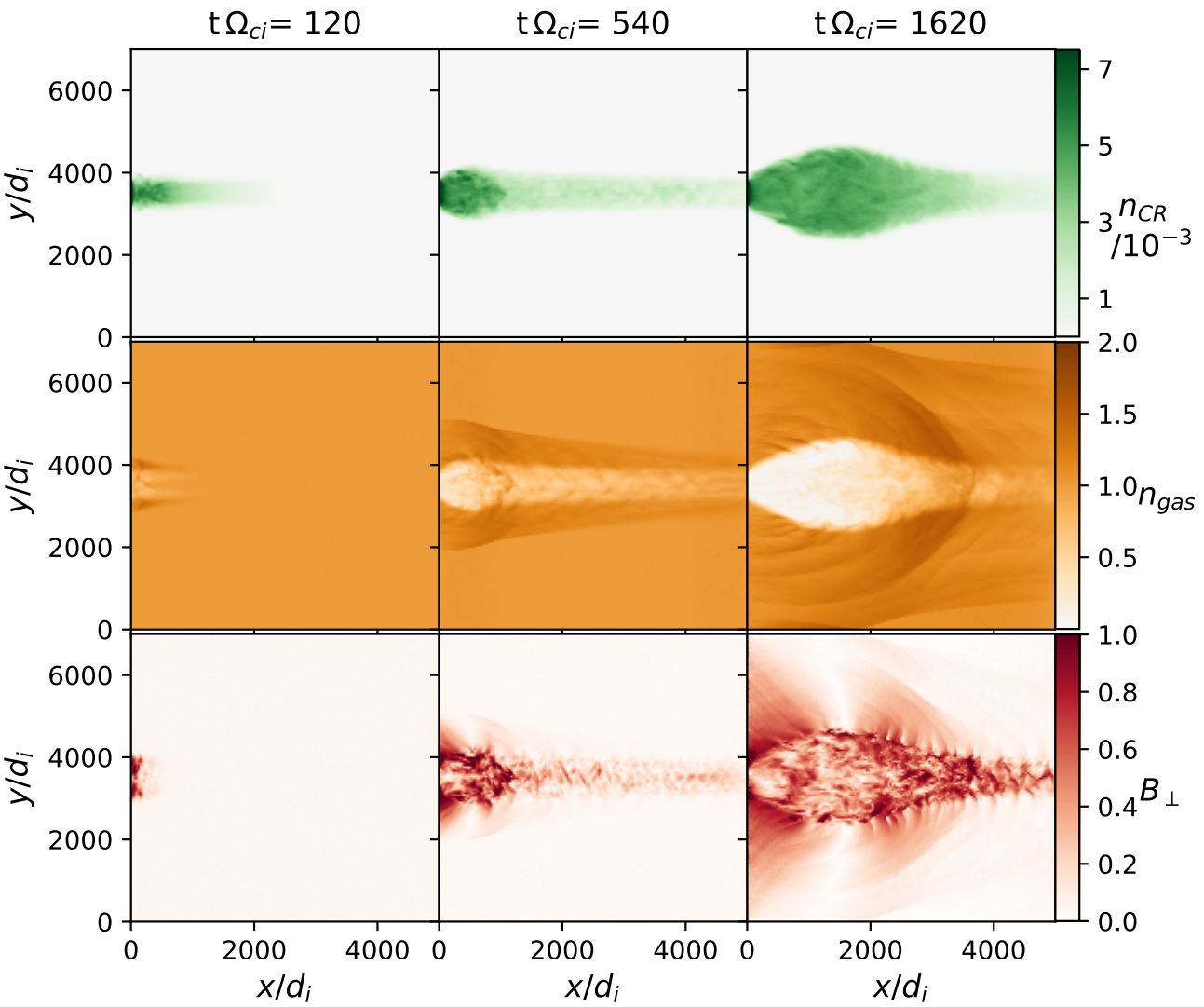


Hybrid PIC Simulation Setup

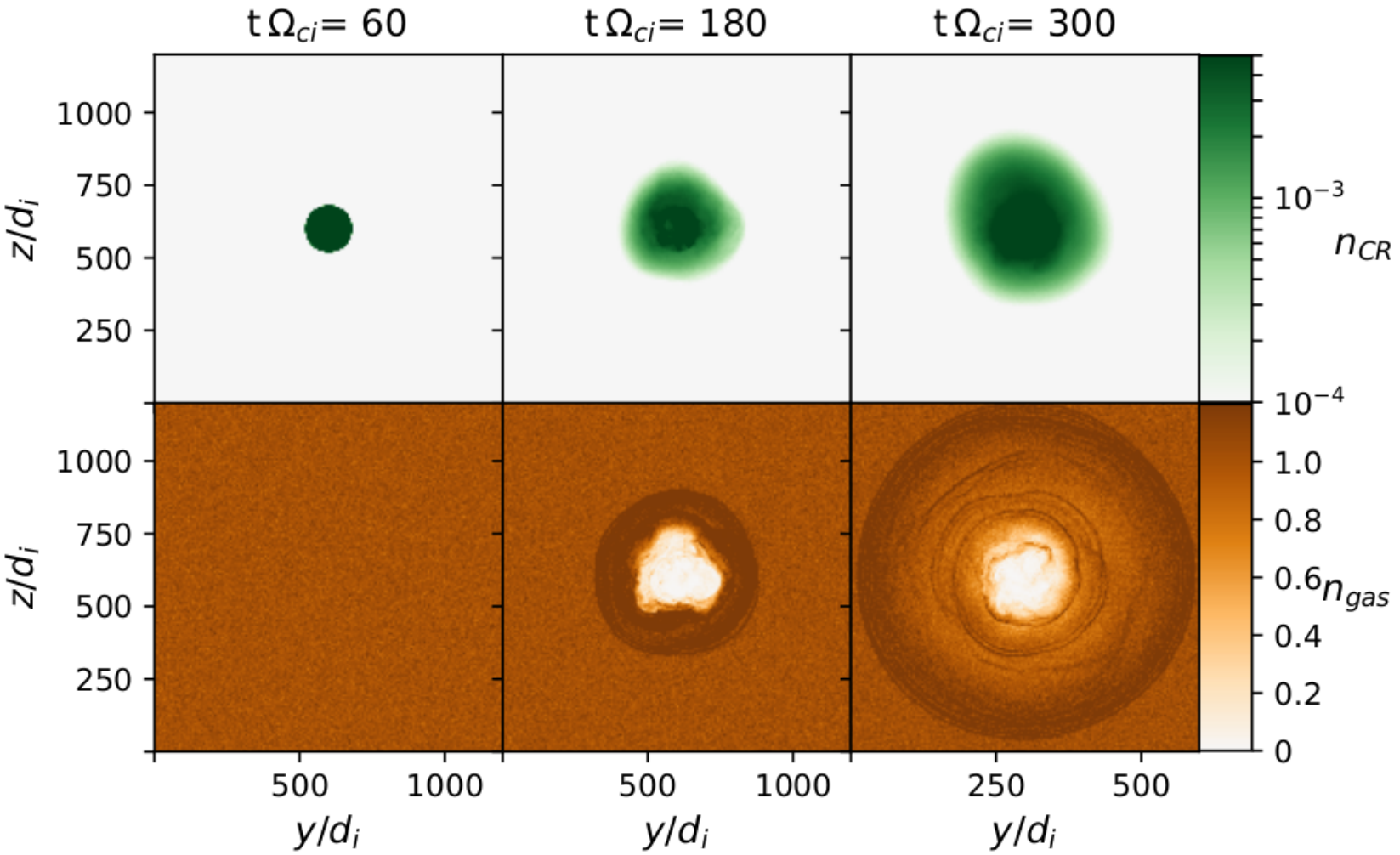
- Hybrid particle-in-cell simulation with dHybridR
- Solve Maxwell equations and equations of motion for macroparticles
- Electromagnetic fields due to moving particles



Evolution in 2D



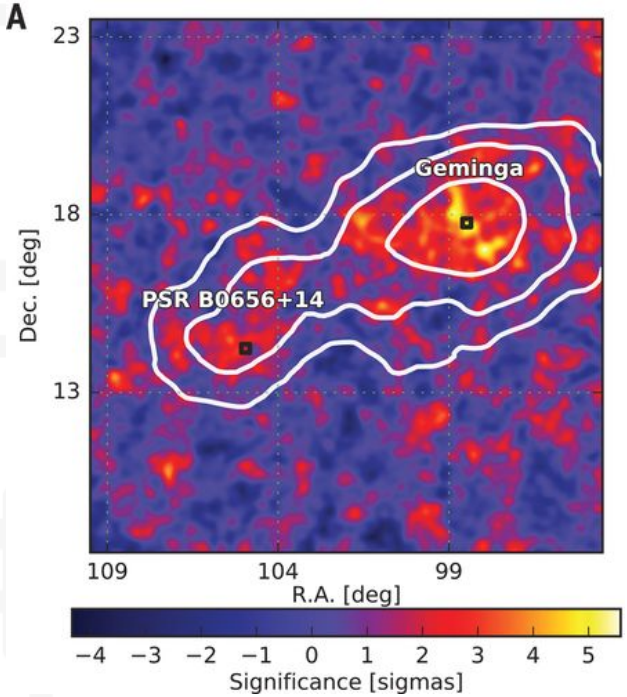
Evolution in 3D



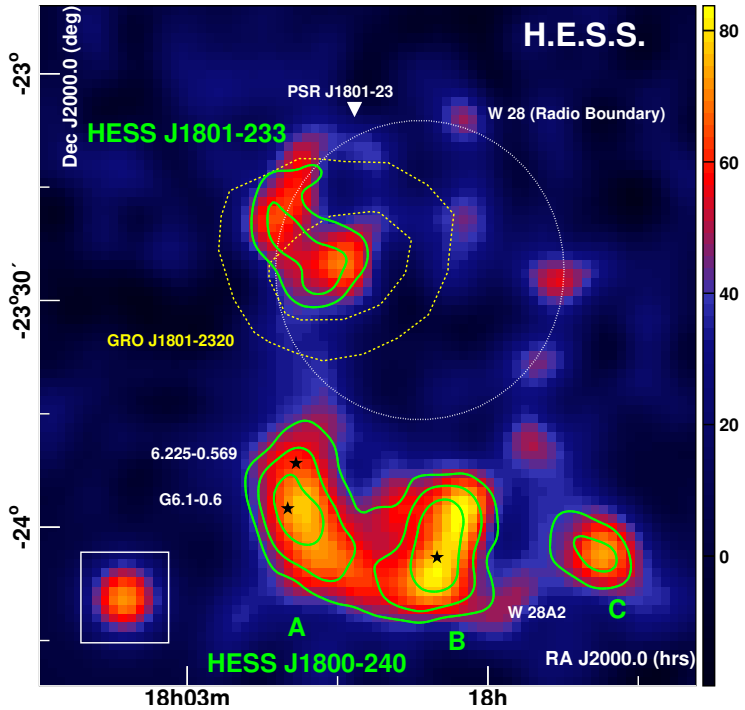
[Schroer et al. PoS(ICRC2021)]

Observation

- Important part of a theorist's work: How do your results relate to reality?



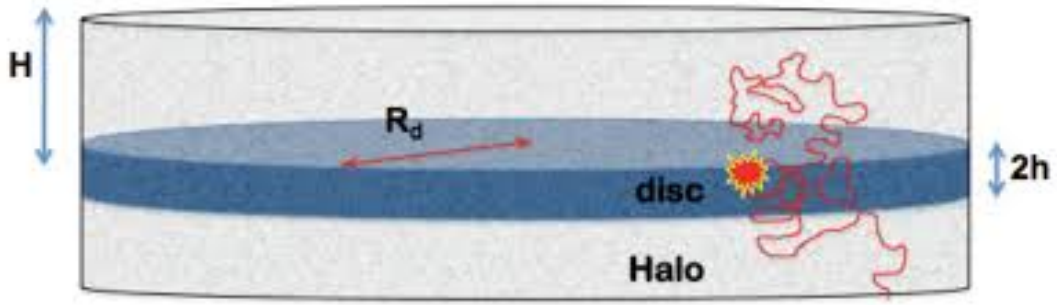
[Abeysekara et al. 2017; Aharonian et al. 2008]



- Hints for strongly reduced diffusion coefficient observed near SNRs [Fujita et al. 2009; Gabici et al. 2010] and pulsars [Abeysekara et al. 2017]

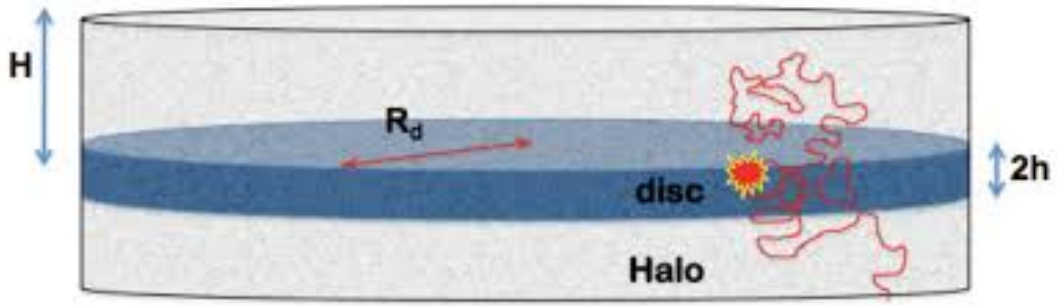
Model of Galactic CR Transport

Standard Picture of Galactic CR Transport



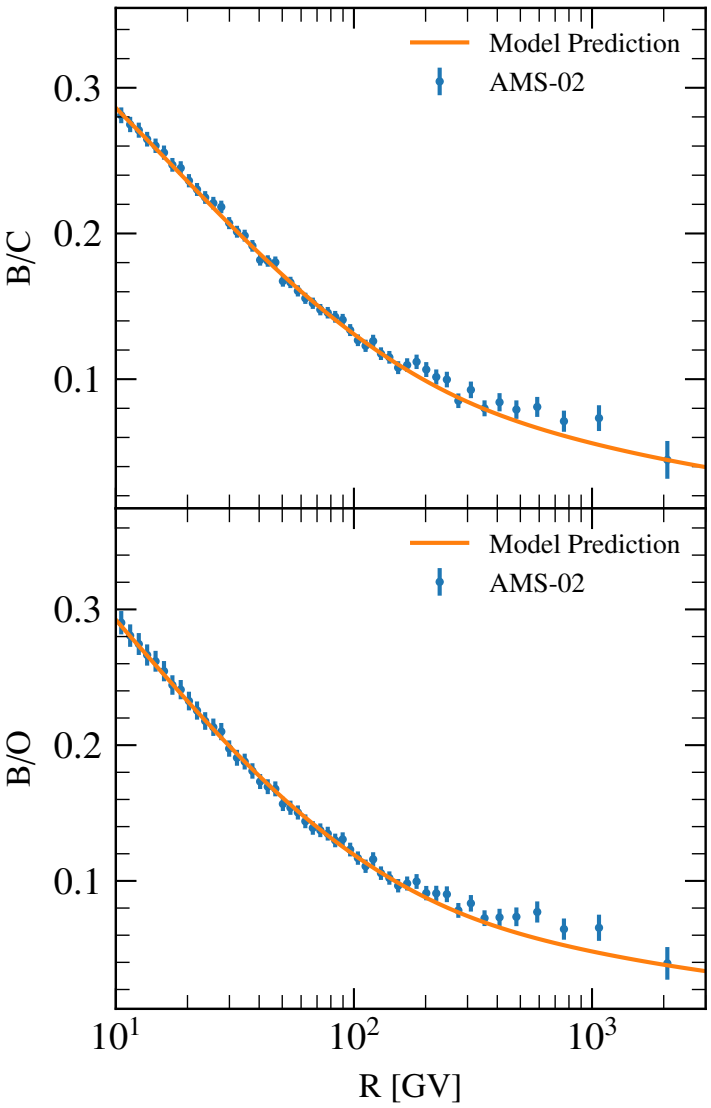
- Standard Model very successful in describing measurements of light nuclei
- Increasing amount of data especially of different nuclei allows us to put the model to the test
- Constantly new anomalies are discovered (e.g. hardening at 300 GV, softening at $\sim$ 10 TV, different slopes of intermediate-mass primary nuclei)
- Each could provide clues of the shortcoming of our model and possible need to extend the theory
- However some are rather consequences of the model itself than new physical findings

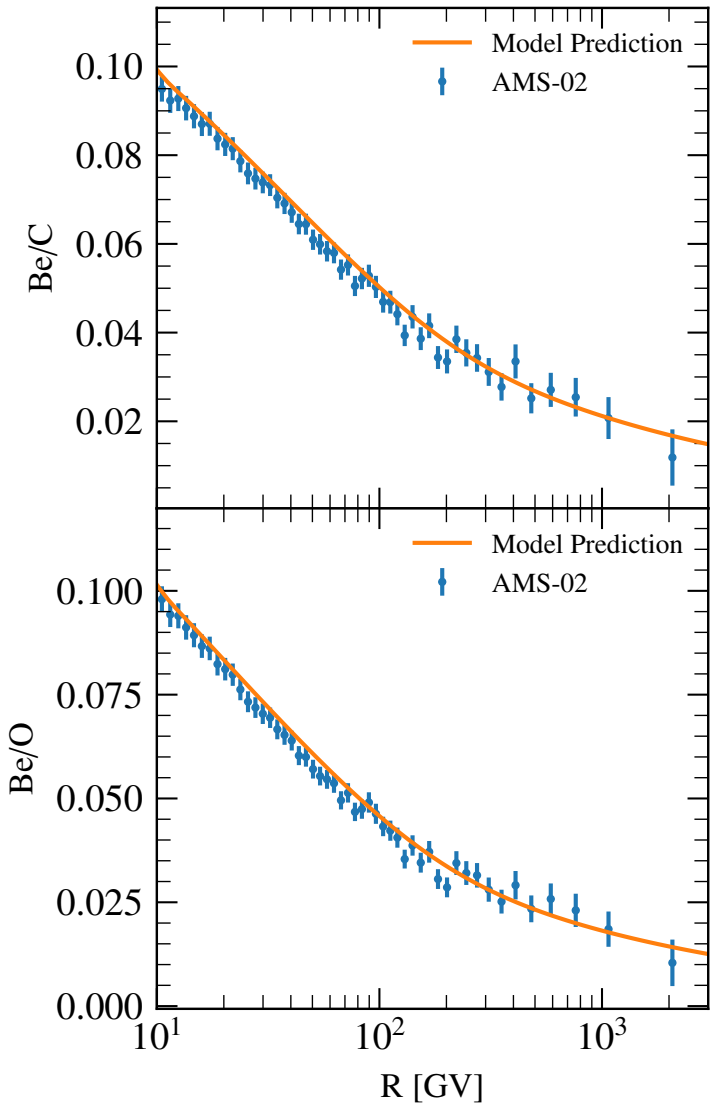
Standard Picture of Galactic CR Transport



- In our work we solve the transport equation for all ~ 90 different CR isotopes
- Underlying assumption: All nuclei are injected with the same power-law slope in rigidity
- By fitting model parameters like the diffusion coefficient we are able to reproduce all AMS-02 measurements (over 10 different nuclei fluxes at % level between 10 and 1000 GV)
- Findings are summarized in the following

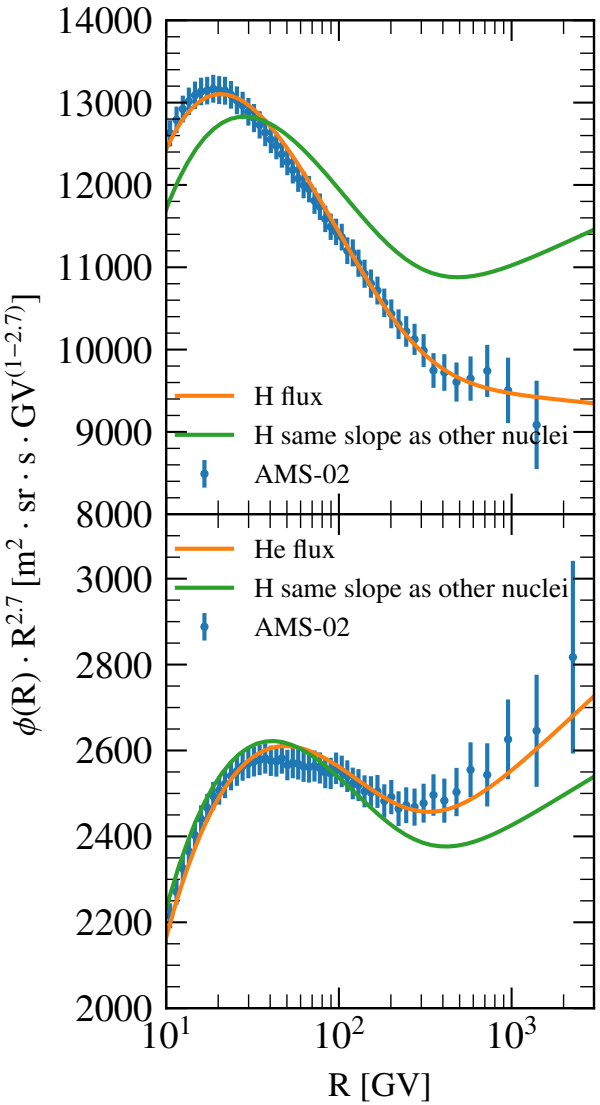
Light nuclei





[Schroer et al. 2021]

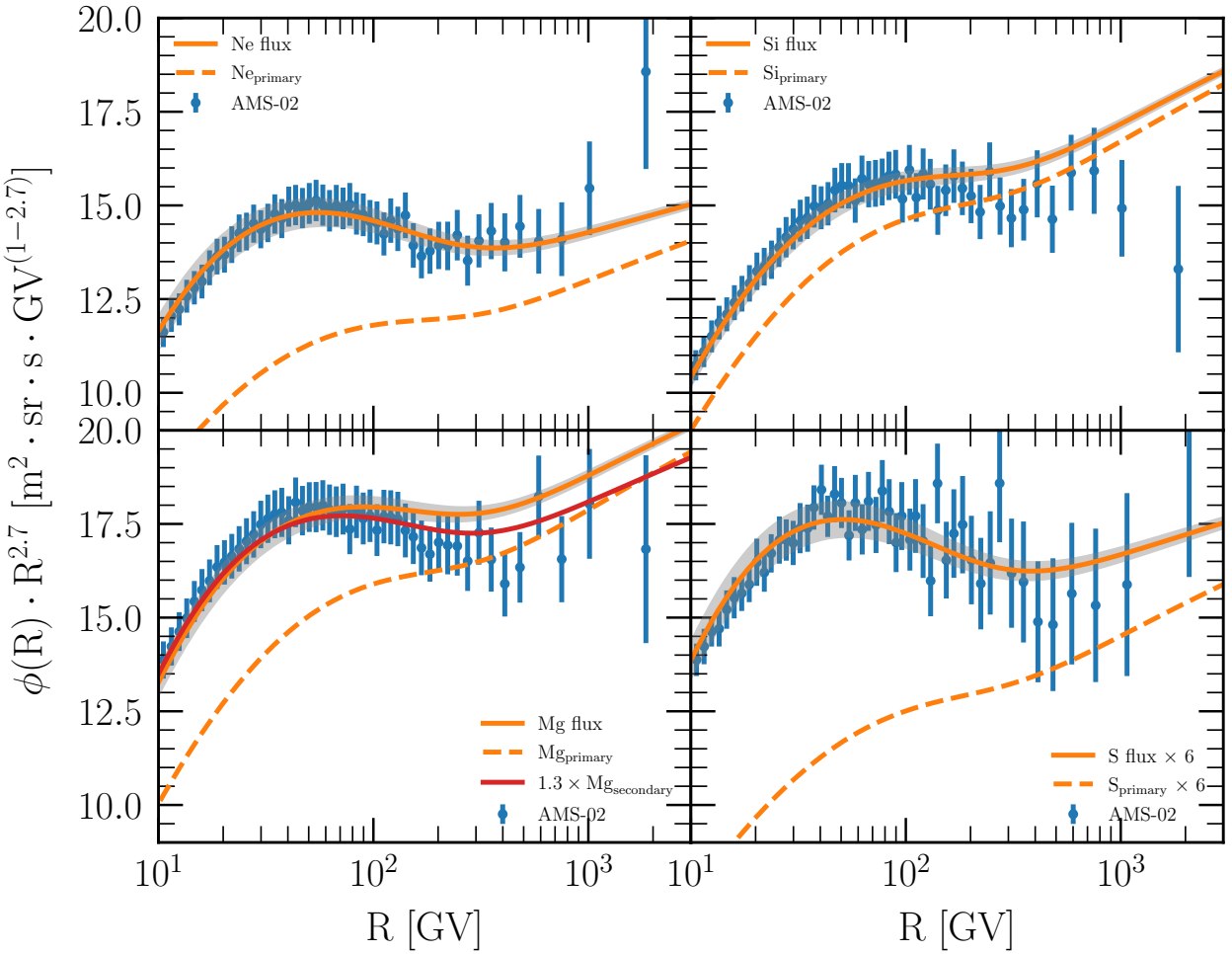
H and He



[Schroer et al. 2021]

- H and He require a different slope than other nuclei and each other, confirms result of previous study [Evoli et al. 2019] and independently confirmed by [Weinrich et al. 2020]
- Puzzling result as only theoretical explanation for different slopes is due to different A/Z but then He should have the same slope as other primaries like O

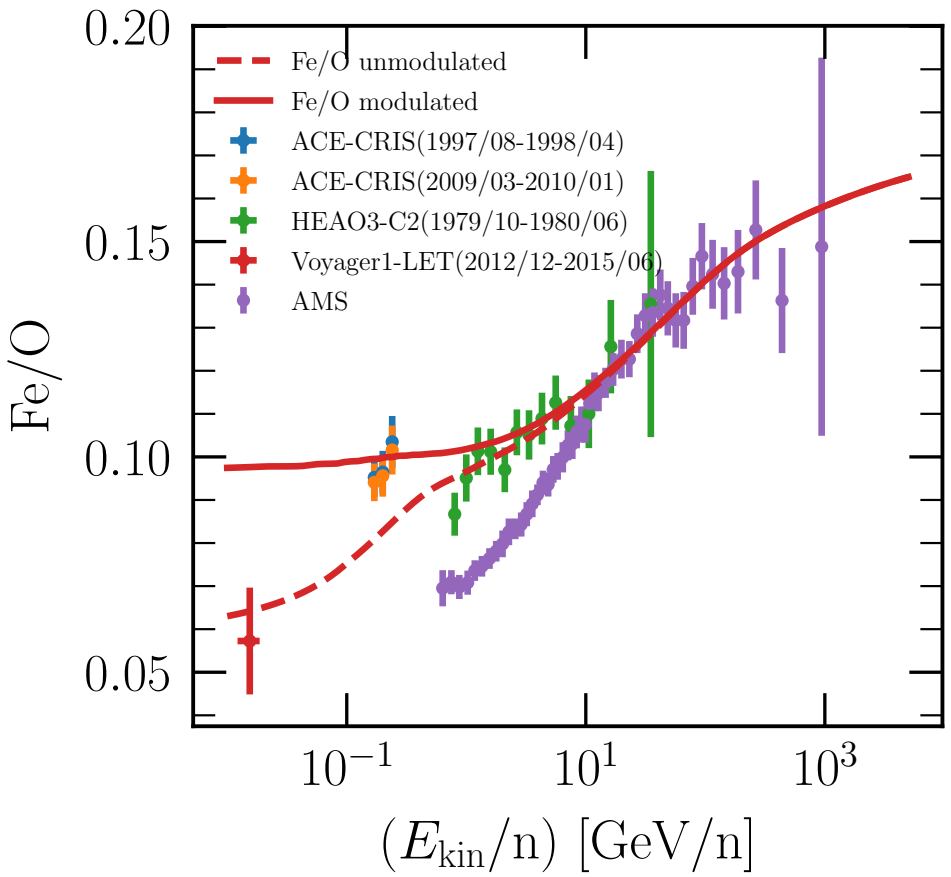
Intermediate-mass Nuclei



- Requiring the same slope leads to reasonably good fits
- Possible tensions can be lifted with cross-section uncertainties (see Mg) and possibly including the source grammage

[Schroer et al., 2021]

Iron



- Our model is compatible with all available data except AMS-02
- Fe data might require to incorporate a new or so far neglected effect into our model

[Schroer et al. 2021]

Conclusion

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- CR theory is like a big puzzle with many different pieces who are all connected
- As such working in this field can be very diverse ranging from analytical calculations over phenomenological studies to plasma simulations
- Many open questions remain and just wait for you to solve them