Some Issues in Cosmic Ray Feedback

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The *Where* of Cosmic Ray Feedback

- Gas cycle in galaxies:
  - Outflows: winds, fountains
  - Heating, pressurizing, & structuring the CGM

- Formation of dense, star forming gas:
  - Thermal instability
  - Nature of interstellar turbulence

What are the appropriate theoretical models for describing these processes and what are their observational signatures?

A Multiscale Problem

- Characterize the interaction between cosmic rays and ~ AU scale (gyroscale) magnetic field fluctuations.
  - Huge progress since the last Thinkshop in simulating the interaction of cosmic rays with magnetic waves & turbulence.
    - Goal is characterizing energy & momentum exchange
    - Inextricably intertwined with structure of magnetic field & nature of turbulent cascade
    - Very dependent on the state of the thermal gas (ionization level, β).
- Mesoscale processes:
    - Bottlenecks
    - Energy exchange with large scale turbulence.

The Classical Picture of Cosmic Ray Transport

- Propagation model:
  - Self confinement: scattering by waves amplified by cosmic ray driven instabilities?

    Or

  - Scattering by waves generated through a turbulent cascade?

  - 2017PhPl...24e5402Z

Extrinsic Turbulence

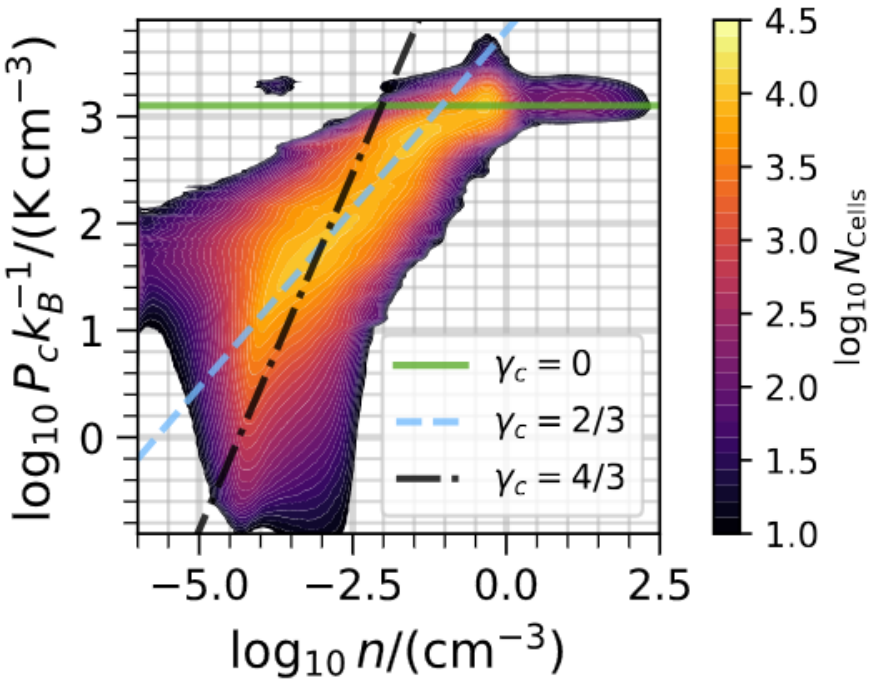
- Advection by the thermal gas, diffusion, & possibly stochastic acceleration.
- CR transfer momentum to the gas through their pressure gradient.
- Exact B need not actually be modeled
- Empirically chosen diffusivity & acceleration rates are somewhat a*d hoc*.

Self Confinement

- Stream relative to the gas at a rate determined by marginal stability criterion for waves (thermal damping balances cosmic ray driving).
- Transfer momentum through pressure gradient and heat through wave excitation.
- Demands understanding of wave damping & an accurate magnetic field model.
- Theory of self confinement near sources still needed. *TeV Halos, Nonresonant instabilities*

Boil Transport Down to a Cosmic Ray Equation of State?

Firefox



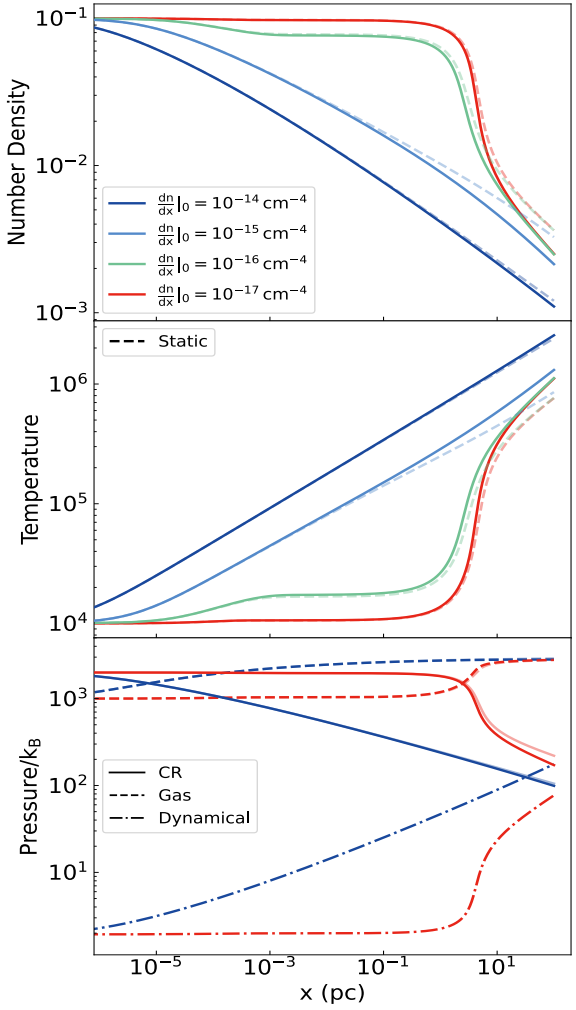
γ_c = 0: Large diffusion

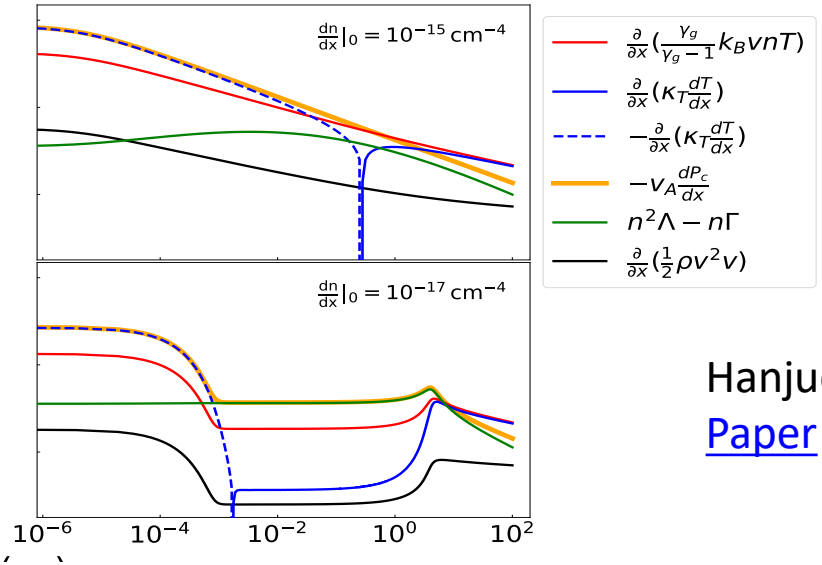
γ_c = 2/3: Alfvenic streaming

γ_c = 4/3: Small diffusion; advection dominated.

Roark Habegger: Simulations of a stratified ISM patch with supernova injections (RH & EZ Preprint)

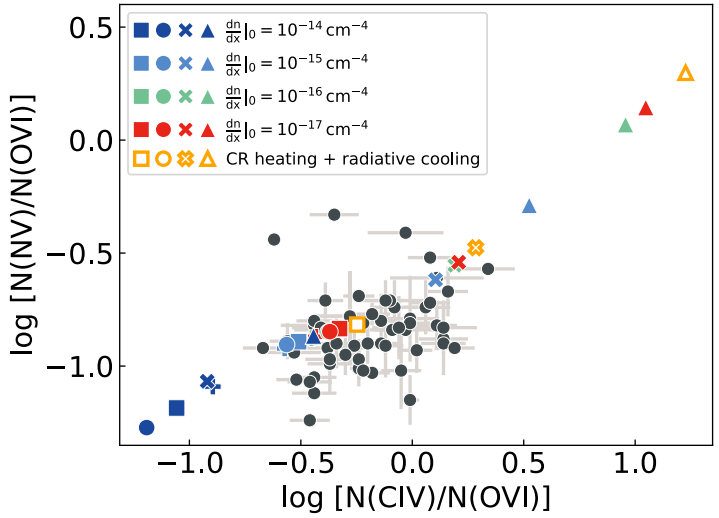
Observational Diagnostic? Cosmic Ray Mediated Cloud/Intercloud Transitions



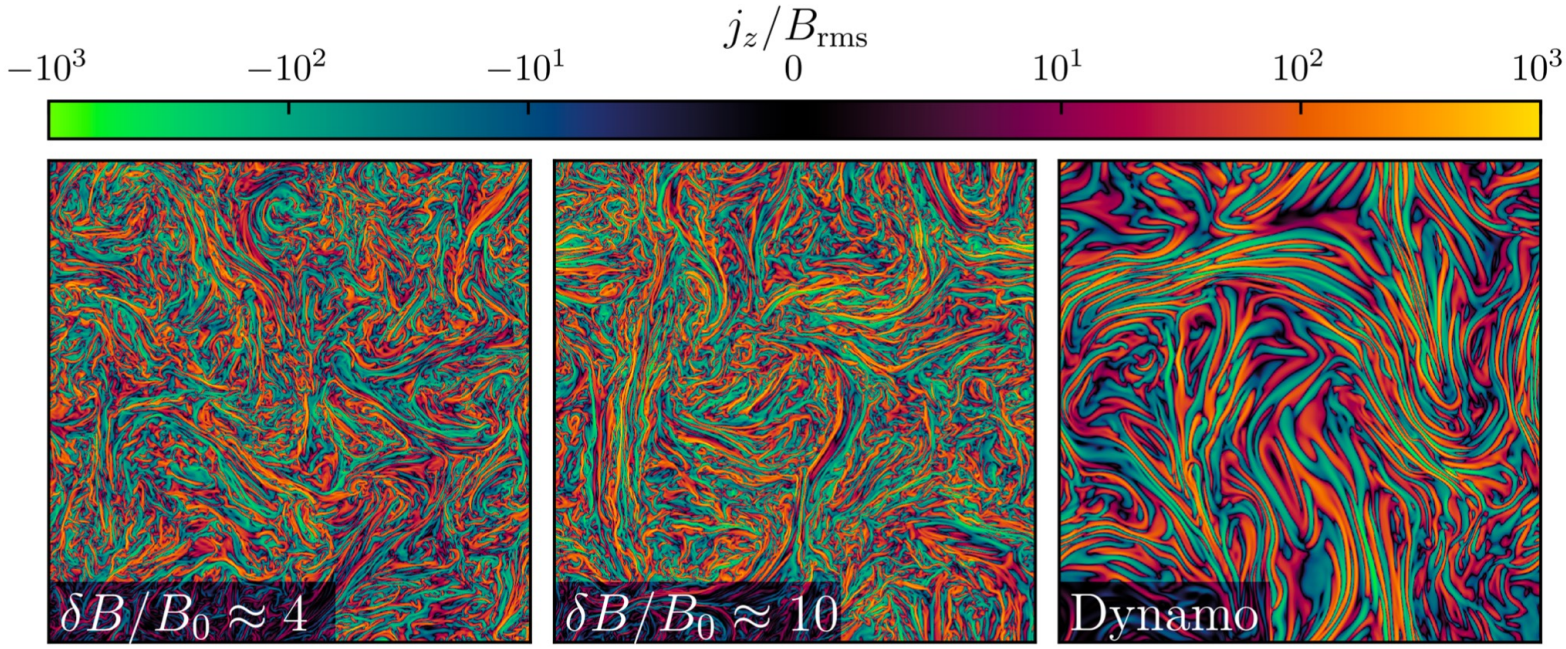


Hanjue Zhu+ 2025

Paper



Is Propagation Due for a Reset?



From Kempski 2023

How does the background magnetic field structure affect propagation?

- Growth and damping of instabilities in a turbulent background
- Interaction of cosmic rays with folded turbulence

Where does the ISM turbulent cascade end?