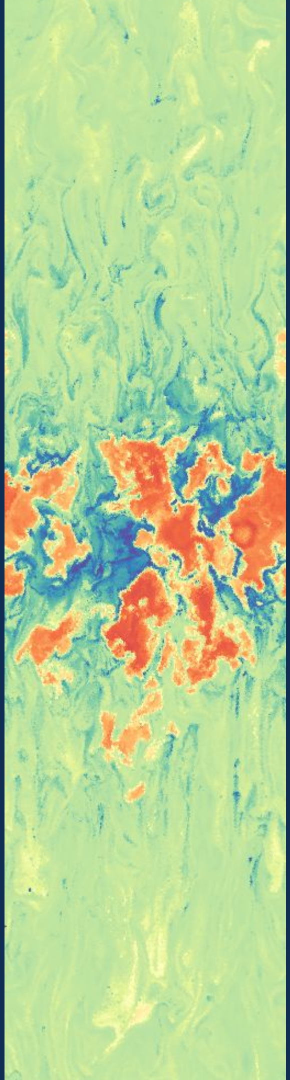
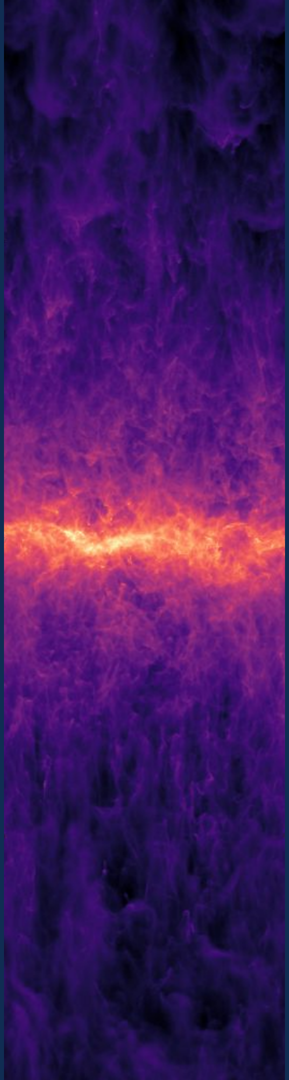
Too Hot, Too Cold, or Just Right? Simulating Cosmic Ray-Driven Galactic Winds with Resolved ISM and Ion-Neutral Damping





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Cosmic Rays in Galaxies

- Relativistic, charged particles which behave as a fluid over galactic scales.
- Equipartition with other energy densities in the ISM.
- Provide a source of **pressure**, contribute to heating, drive molecular chemistry, trace magnetic field topology.
- Notably, **cosmic rays can exchange momentum and energy with the gas over long time and distance scales.**

Table 1.3 Energy densities in the local ISM[a]

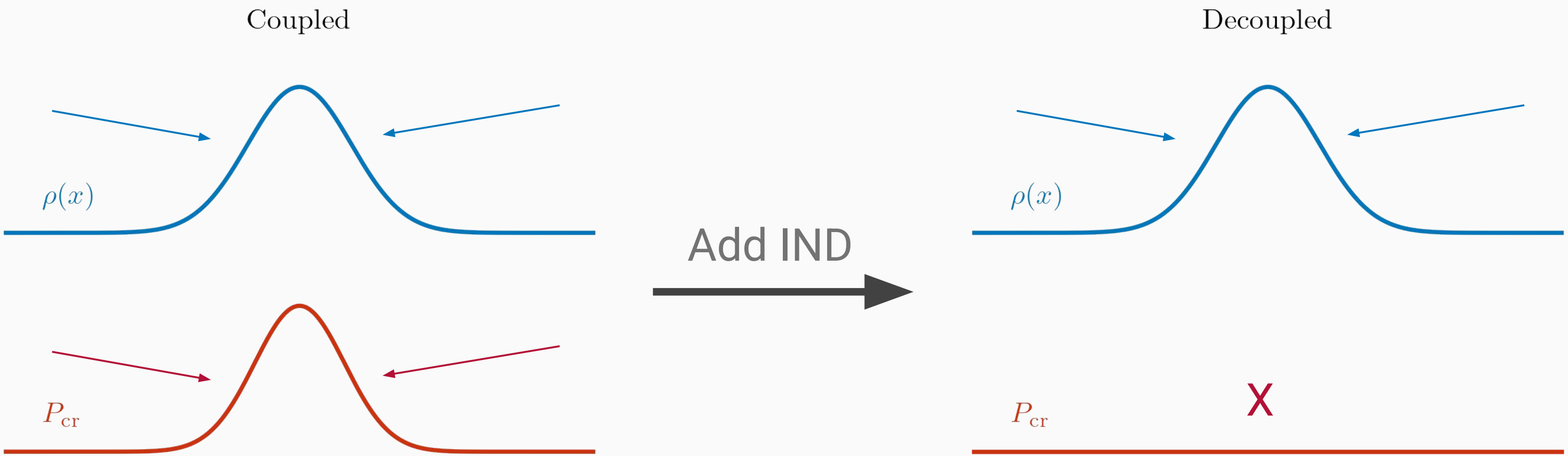
Type	Energy density ($eV\ cm^{-3}$)
Cosmic microwave background	0.2606
Thermal energy	0.4
Turbulent kinetic energy	0.2
Far-infrared from dust	0.3
Starlight	0.6
Magnetic energy	0.9
Cosmic rays	1.4

[a] *Data from Draine 2011, Table 1.5 and Table 12.1*

Ryden & Pogge: Interstellar and Intergalactic Medium (2021) with data adapted from Draine (2011), with cosmic ray data from Voyager measurements (Webber & Yushak 1983).

CR Transport: Ion-neutral damping

Ion neutral damping (IND) is ~frictional loss from self-confining Alfvén waves by ion/neutral collisions. The loss of these self-confining Alfvén waves **decouples CRs from neutral regions**.

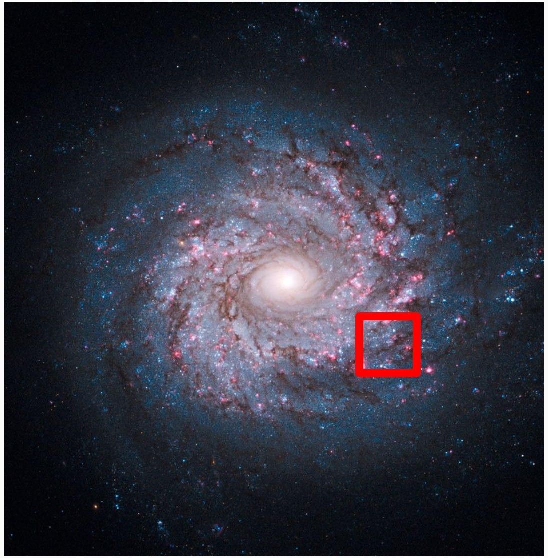


The Questions:

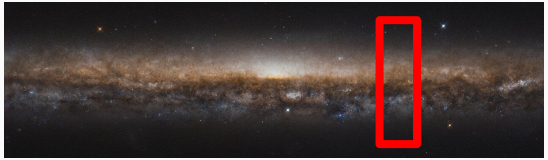
- How does CR feedback affect the steady-state SFR and galactic outflow?
- How do CRs interact with multiphase gas in the wind?
- **Does ion-neutral damping prevent CRs from providing effective feedback?**

Simulation Model: ISM Tallbox

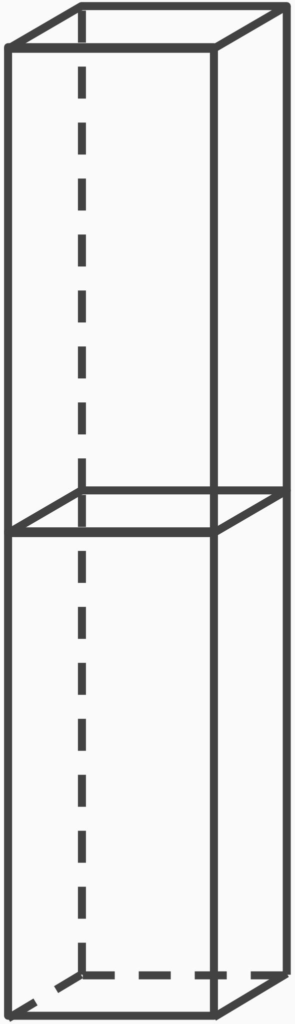
- Use AREPO (Springel 2010).
- 1 kpc * 1 kpc * 8 kpc.
- Σgas = 10 Msun / pc^2.
- 10 Msun resolution in the ISM.
- ~3 pc resolution in the wind.
- Live MHD, stellar feedback.
- Nonequilibrium ionization model CRISP.
- Two-moment CR transport model following self-confined behavior.



Face-on spiral galaxy NGC 3982, NASA, ESA, and the Hubble Heritage Team (STScI/AURA)



Edge-on spiral galaxy NGC 5907, ESA/Hubble & NASA, R. de Jong. Acknowledgement: Judy Schmidt (Geckzilla)



3 Cases

- ("MHD"): No CRs.
- ("CRMHD"): Add CRs with **uniform coupling of CRs to gas.**
- ("CRMHD+IND"): Add ion-neutral damping; **CRs decouple from neutral gas.**
  - "Full physics," expected to be most realistic.

Results

arXiv:2410.06988 (astro-ph)

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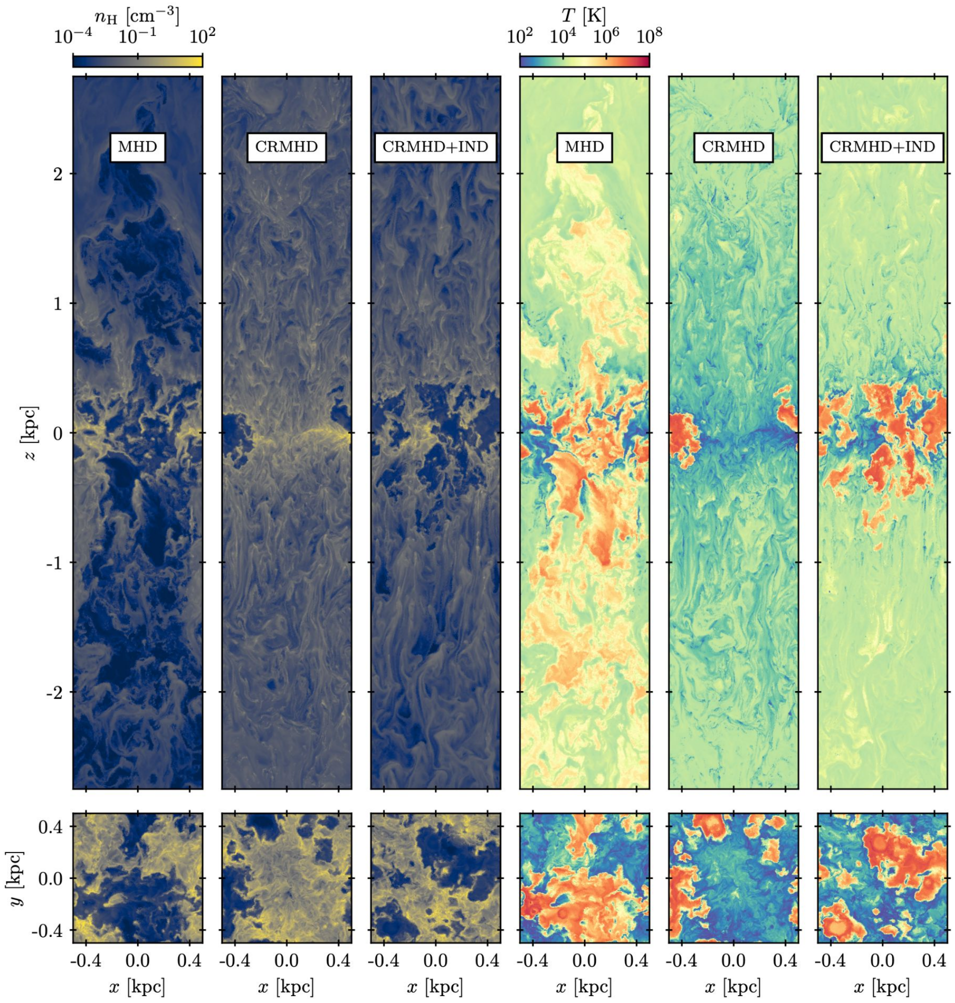
Comments: 27 pages, 13 figures. Submitted to ApJ

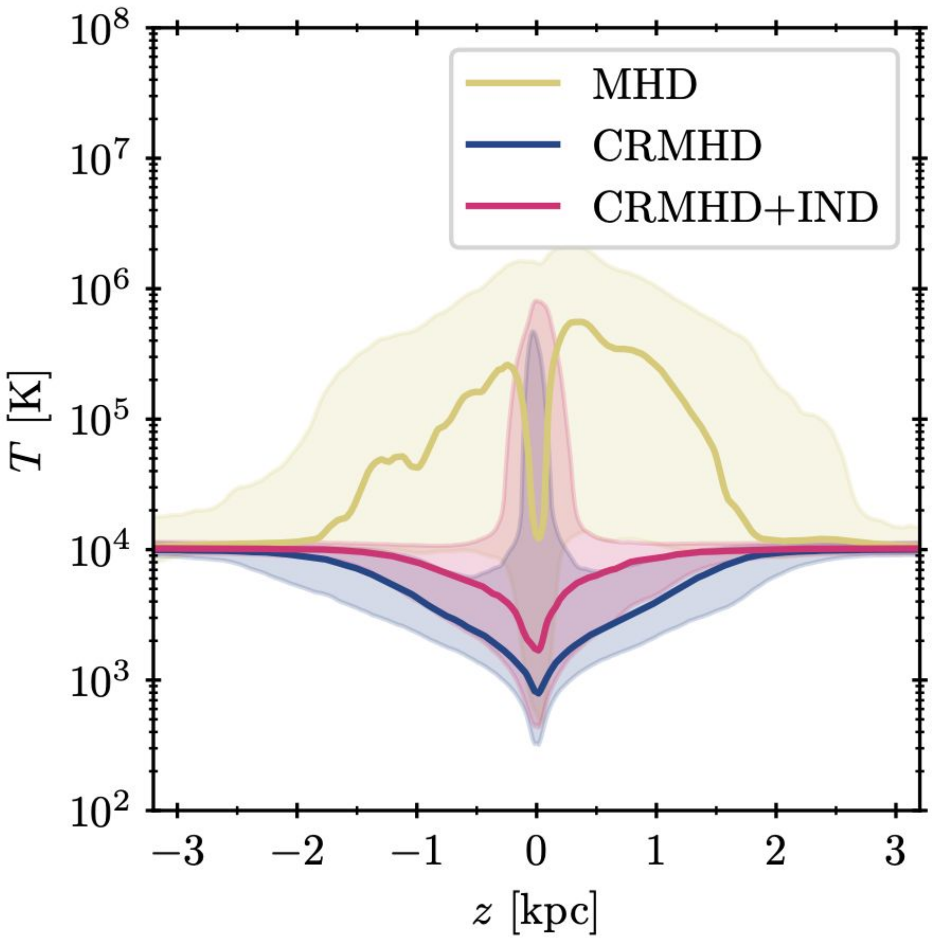
Slices

- Produce a variety of multiphase galactic winds and ISMs.
- Immediate visual differences between the three cases, primarily in the wind but also in the ISM.



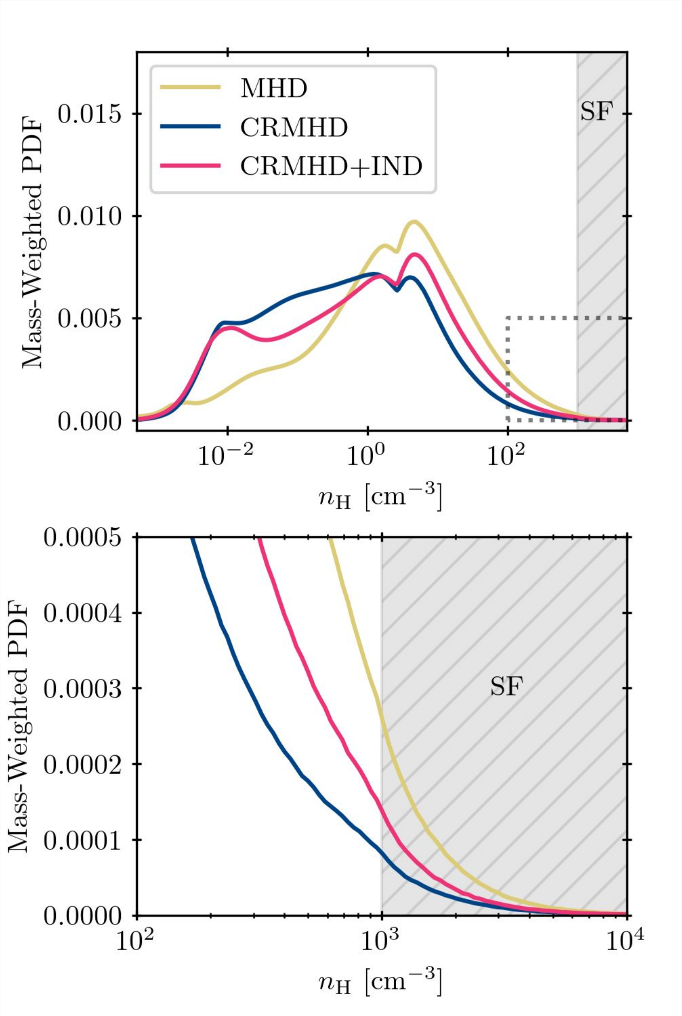
Temperature Profiles

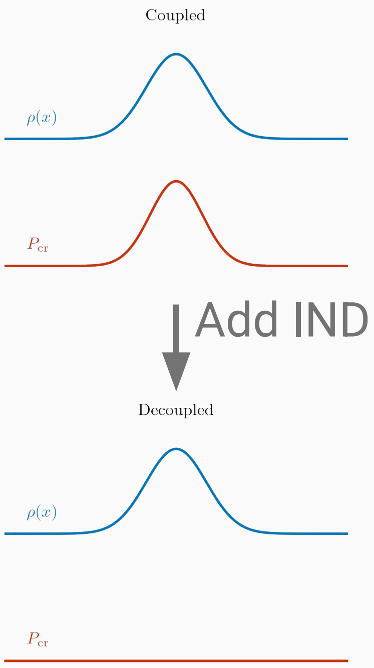
- MHD is the hottest; supernovae-driven.
- CRs in CRMHD can couple to cold gas in the wind, CRs in CRMHD+IND cannot.
- **CRs make the wind colder, IND makes the wind moderately warmer**.



Star Forming Conditions

- Amount of mass above the star formation threshold is directly linked to the SFR.
- CRs reduce the amount of star-forming gas.
- **IND decouples CRs from dense, neutral gas, allowing gas to reach star-forming densities with less resistance.**

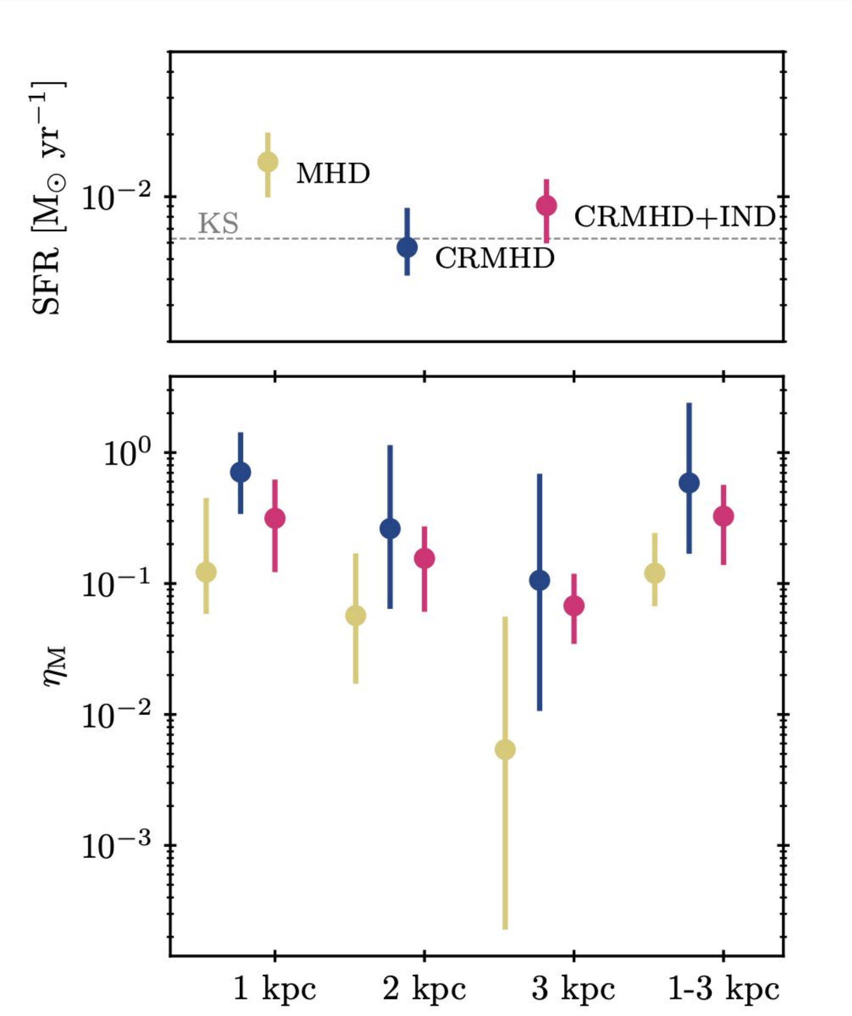




Mass Loading Factors

- MHD case has the lowest mass-loading factors, and the outflow becomes very weak by |z|=3kpc.
- SFRs are not different enough to explain the differences in mass loading factors.
- **Ion-neutral damping does not prevent CRs from expelling mass in the outflow.**

$$\eta_M = \frac{\dot{M}_{out}}{SFR}$$



Summary

- **Ion-neutral damping does not prevent CRs from providing effective feedback.**
- Ion-neutral damping reduces the effect of CRs on the SFR.
- Full-physics CR-driven wind is primarily warm with moderate mass loading.

See astro.brsike.com/aas2025 for slides and contact information