Galaxy Quenching in FIRE-3 by AGN Cosmic Ray Feedback

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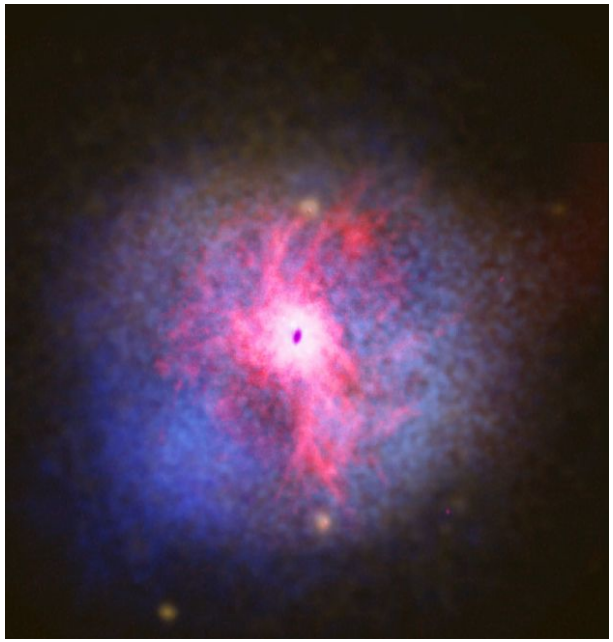
Galaxy Evolution

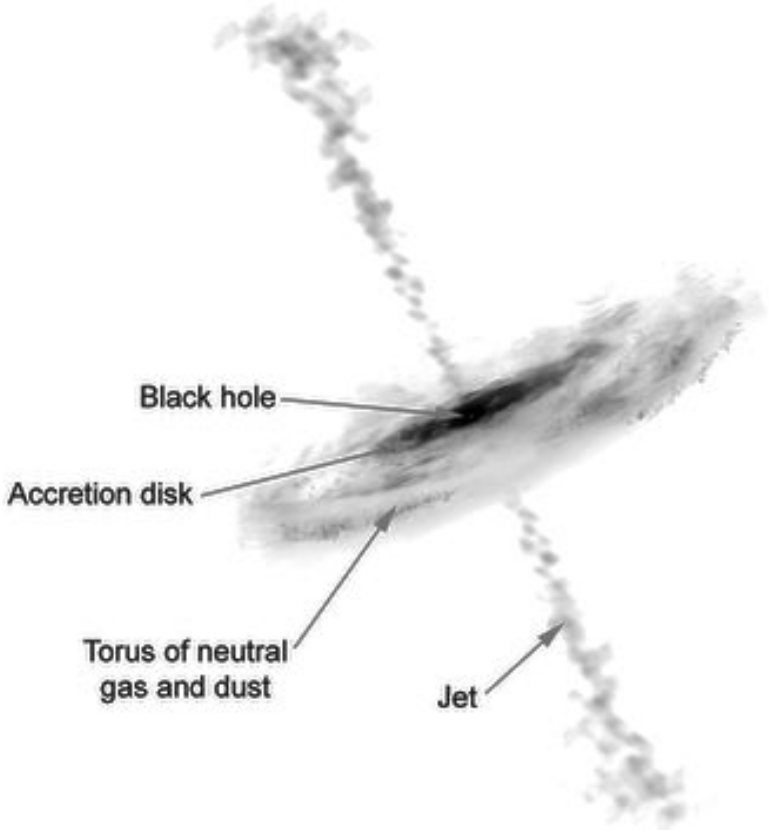
- **Galaxy**: Gravitationally-bound structure of stars, gas, dust, black holes, and dark matter
- How do galaxies form and evolve?
- The **quenching** problem: too many red and dead massive galaxies



Elliptical galaxy NGC 5044, image courtesy of ESA/Dunn et al. 2010

AGN Feedback

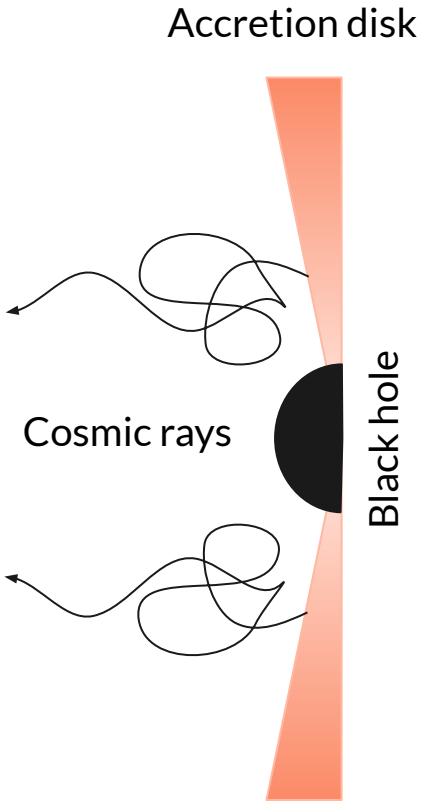
- Active Galactic Nucleus (**AGN**): Highly energetic center of galaxy
- AGN **feedback** is vital to produce quenching in simulations
- Exact mode and mechanics of feedback are unknown
    - Possibilities: radiative, mechanical, and cosmic rays



Adapted from Fermi Gamma-ray Space Telescope, NASA

Cosmic Ray Feedback Mode

- **Cosmic rays**: charged particles that get accelerated to relativistic speeds
- Could be critical mode of feedback for quenching (Su et al. 2018, Wellons et al. 2022)
  - More efficient than other modes
- Physics of CR feedback is uncertain



Heuristic inspired by Tjus (2018)

How does varying the CR feedback prescriptions change massive galaxy properties?

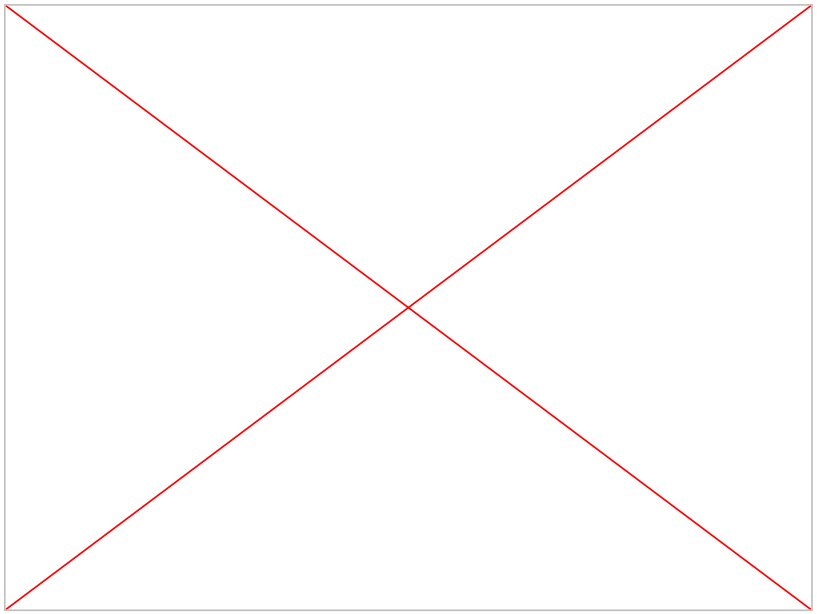
This project aims to…

- find **plausible CR feedback models** by checking which models produce reasonable, quenched massive ($\geq 10^{12.5}\ M_{\odot}$) galaxies
- identify potential observable differences between models

Exploring CR Feedback with FIRE-3 Simulation

- Feedback in Realistic Environments (FIRE), a cosmological **zoom-in** simulation
- FIRE-3: has supermassive black holes and CR feedback
  - Can change **how much** feedback is produced and **how it diffuses** through the galaxy

$$\dot{E}_{\rm cr}^{\rm BH} \equiv \epsilon_{\rm cr}^{\rm BH} \dot{M}_{\rm BH} c^2$$



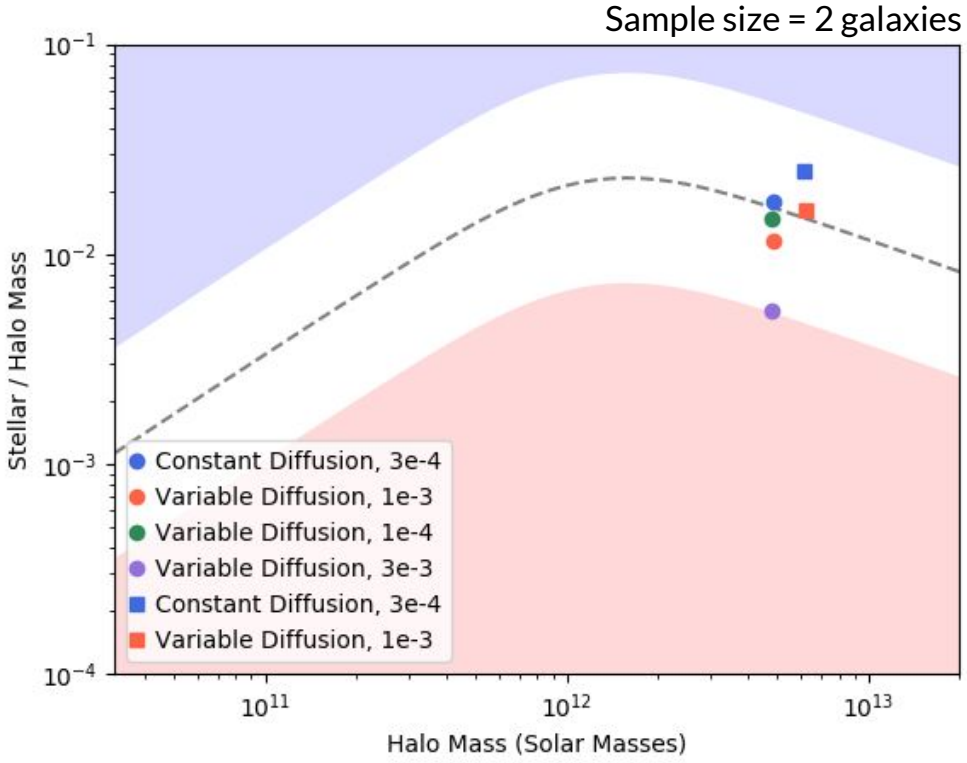
Cosmic rays in a simulated galaxy in FIRE

Analysis & Methods

- Dataset: 2 galaxies with variations in CR prescriptions (6 runs total with 4 models for first galaxy and 2 for second)
- Developed pipeline for FIRE data to calculate:
  - Halo mass
  - Stellar mass
  - Star formation rate
  - Velocity dispersion
  - CR and magnetic energy densities
  - Gas number density
- Compared bulk properties to observed constraints
- Compared radial profiles of different physical quantities

Different CR feedback prescriptions produce galaxies with reasonable bulk properties

Sample size = 2 galaxies



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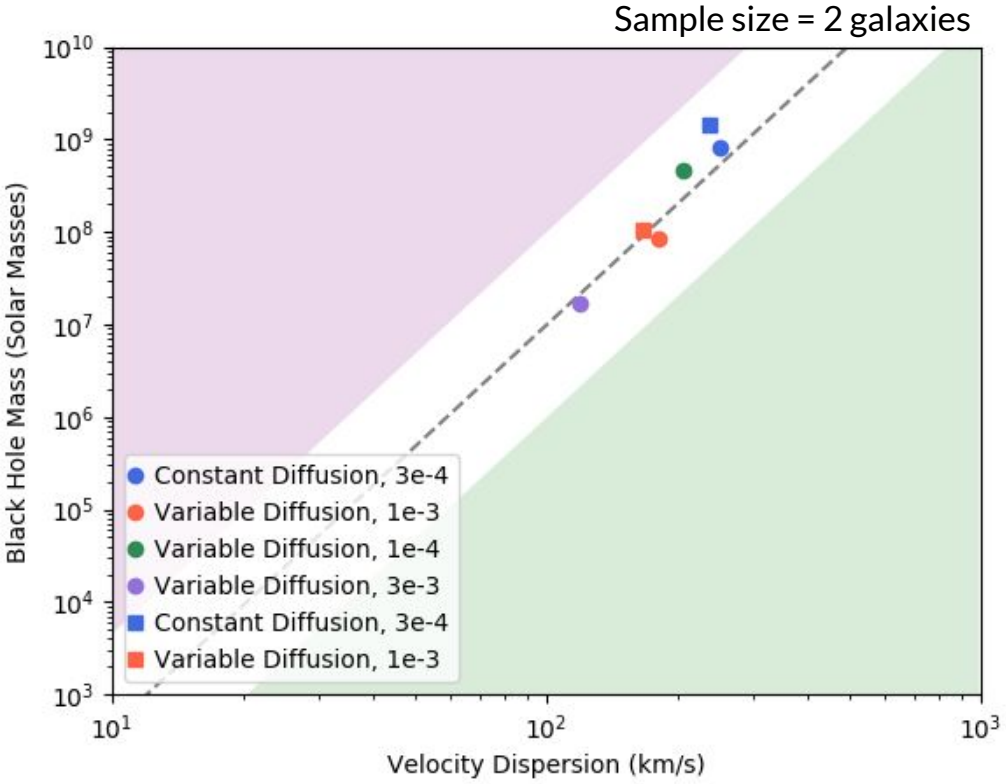

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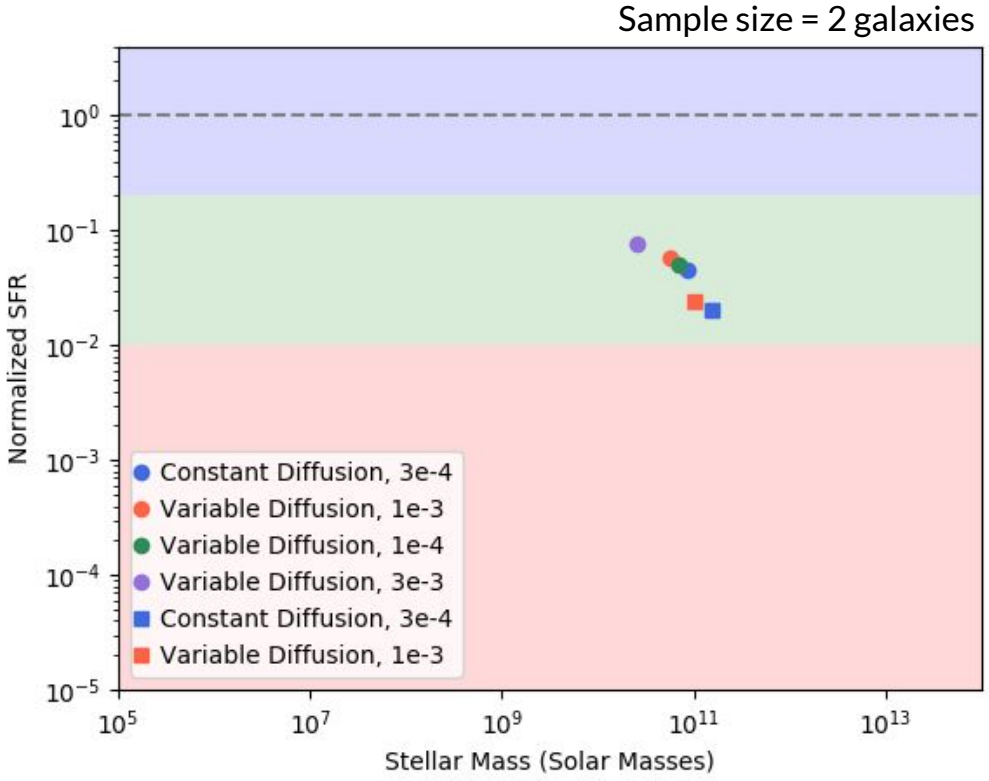
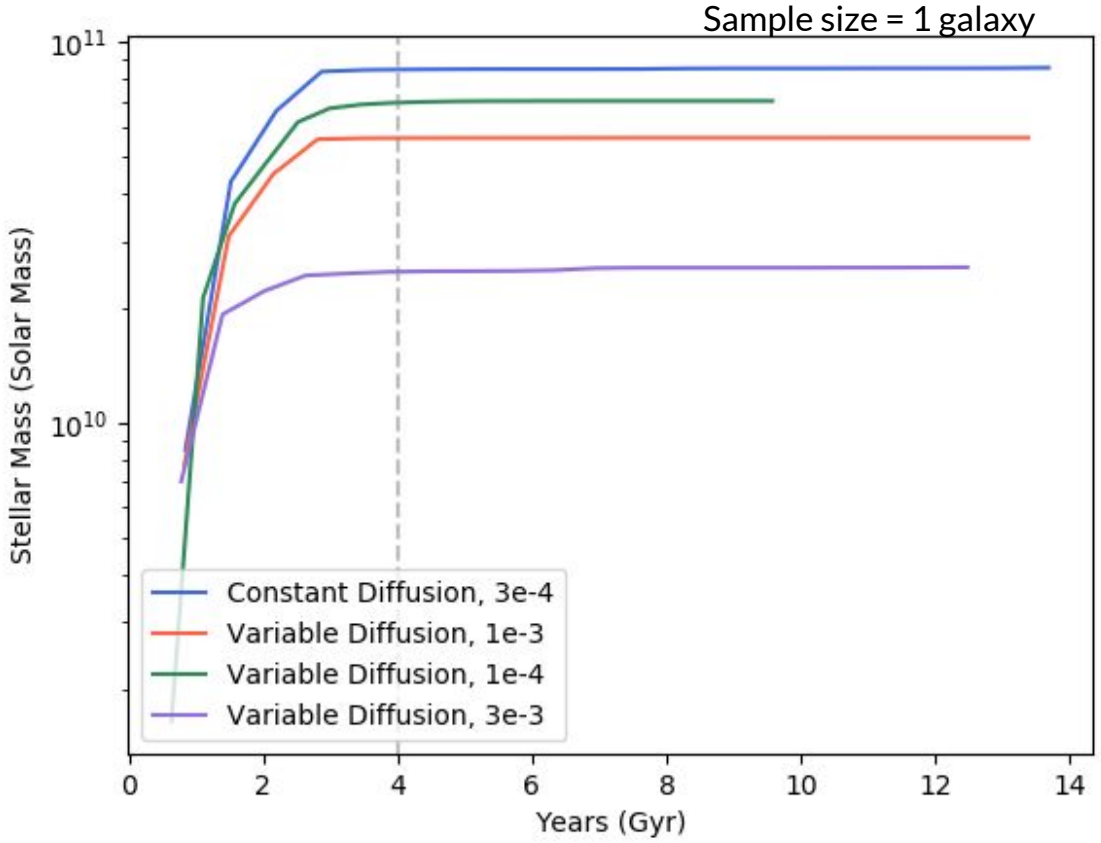


Models are quenching

Sample size = 1 galaxy



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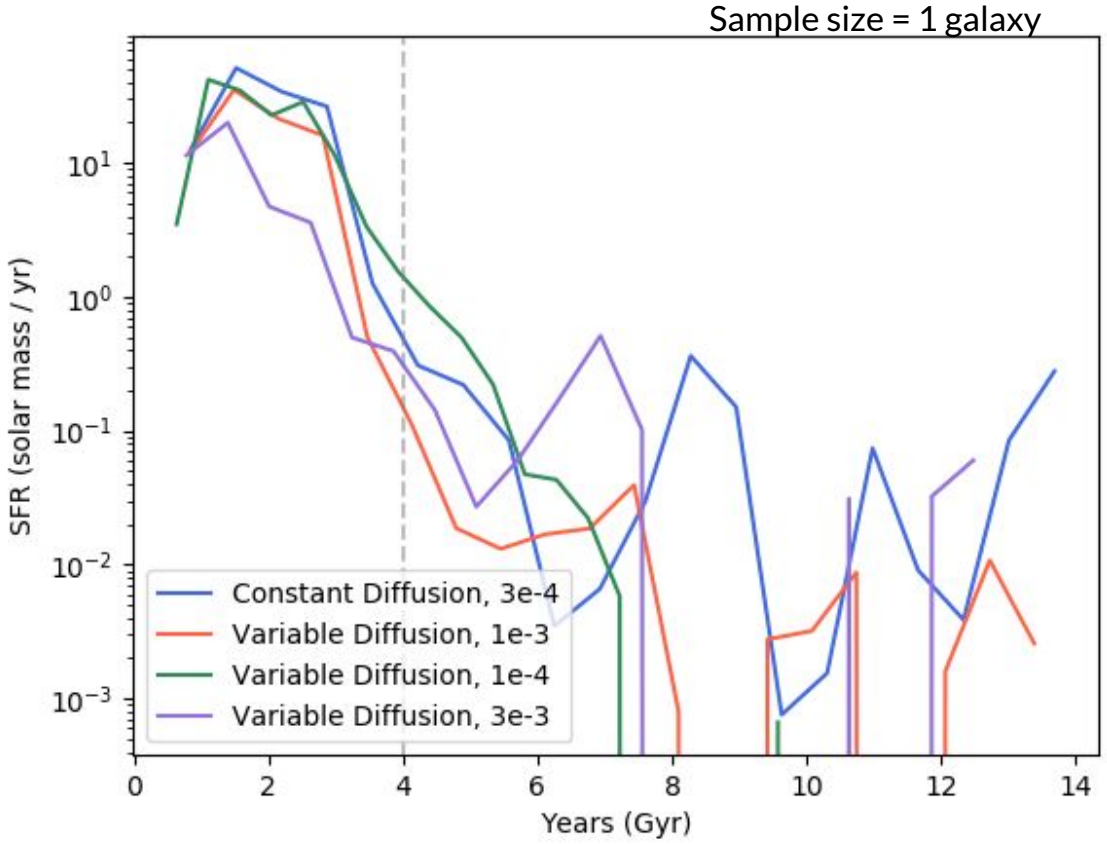
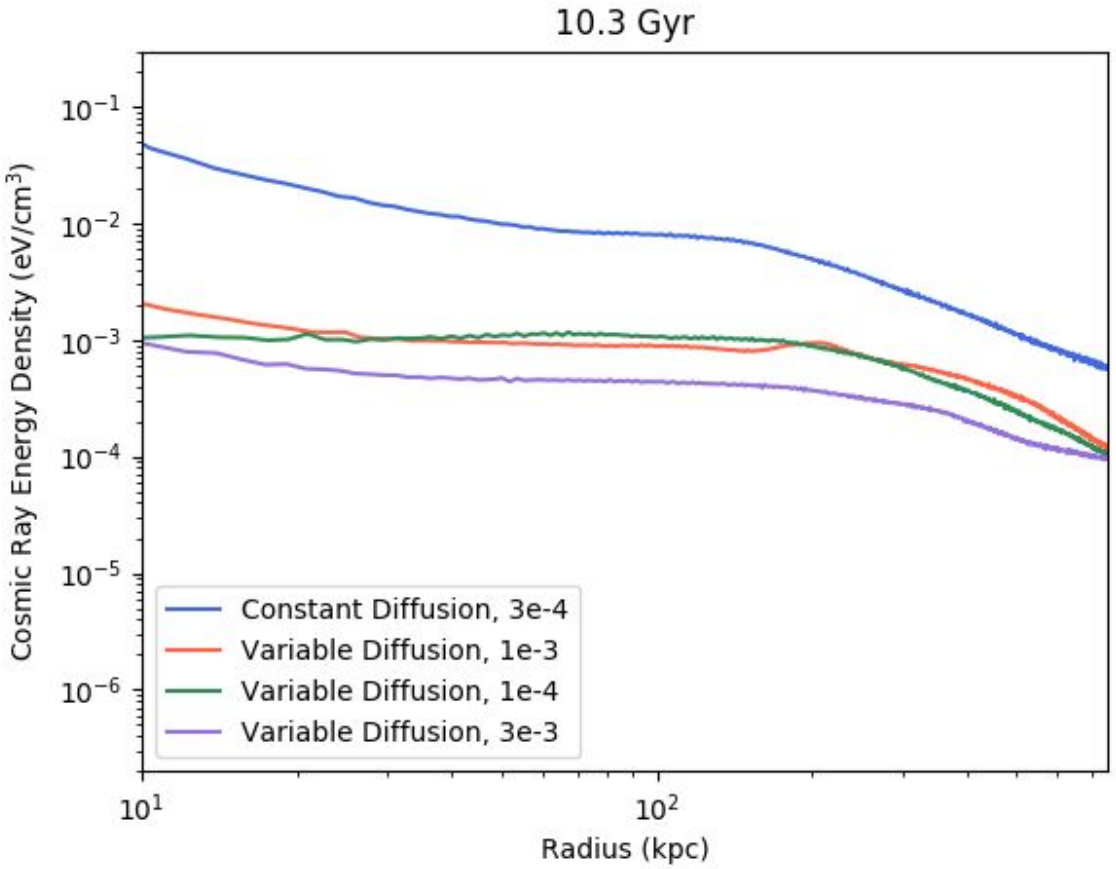


CR energy density profiles of models differ



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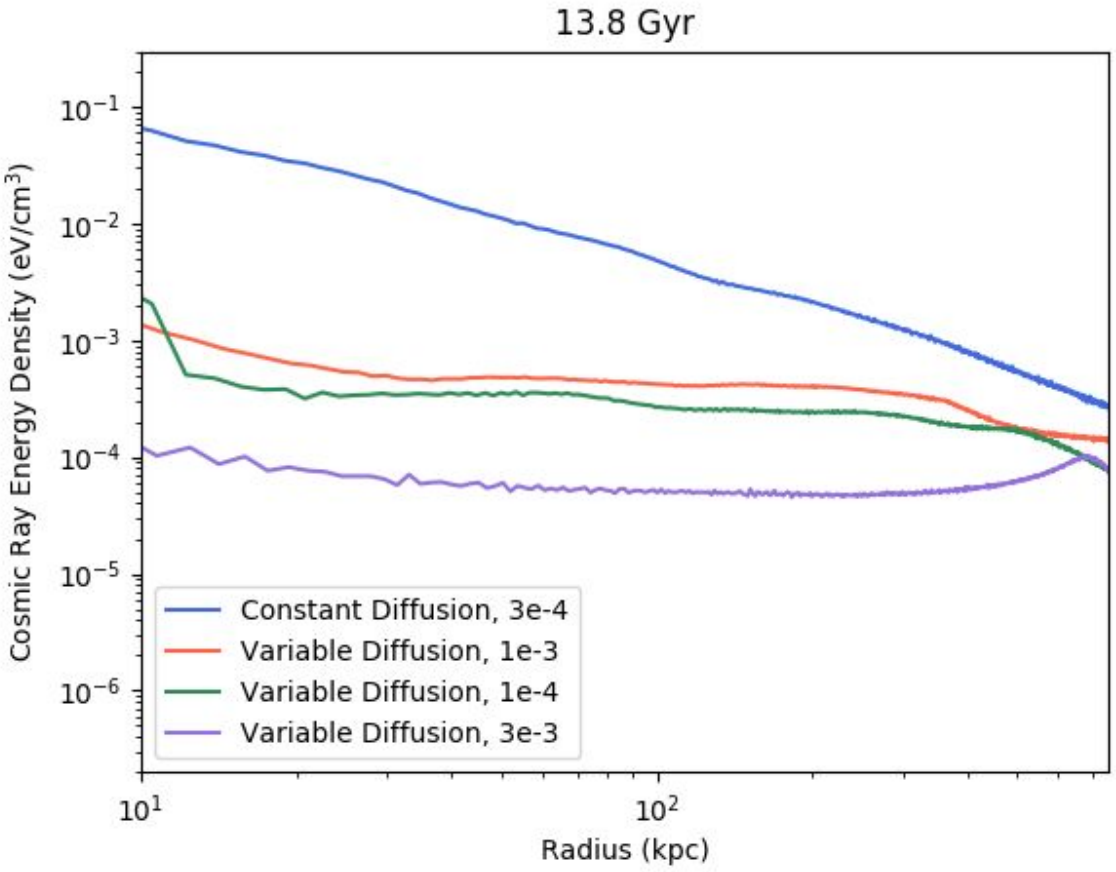
CR energy is driven out to large scales



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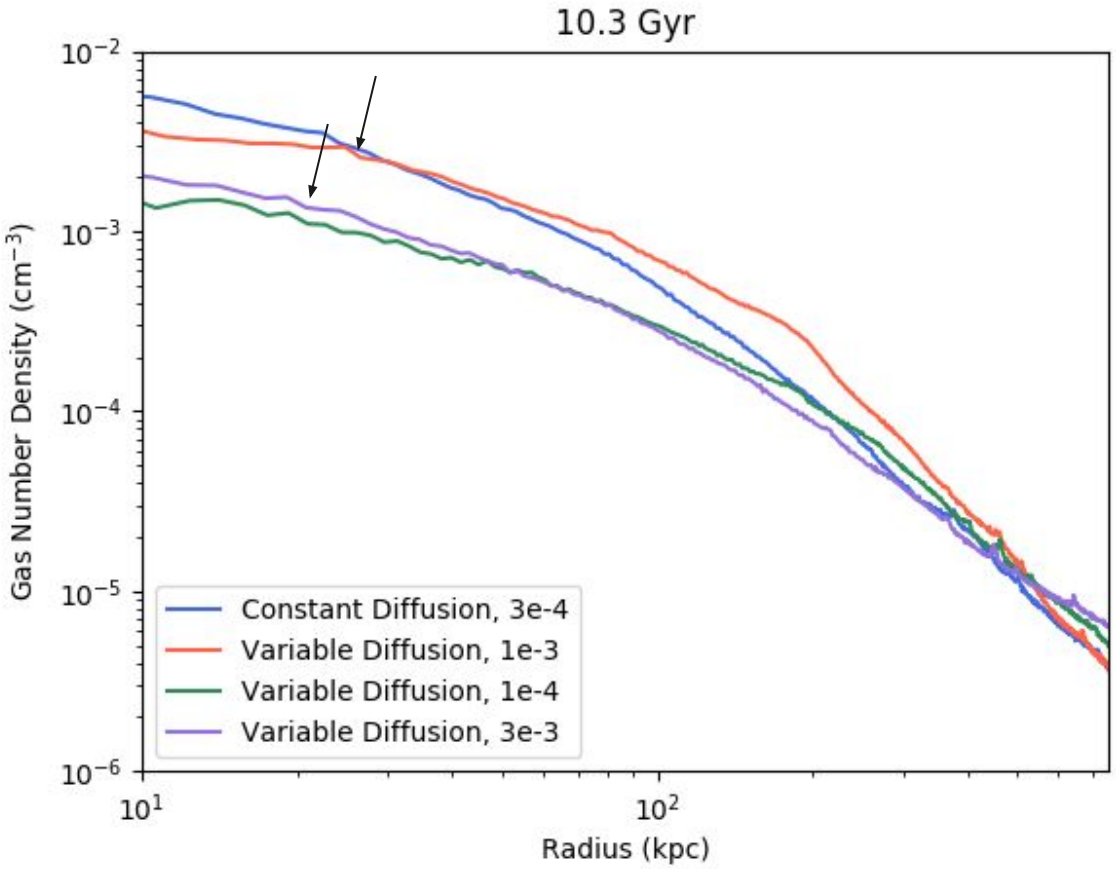
Gas is being pushed out, may be due to CR



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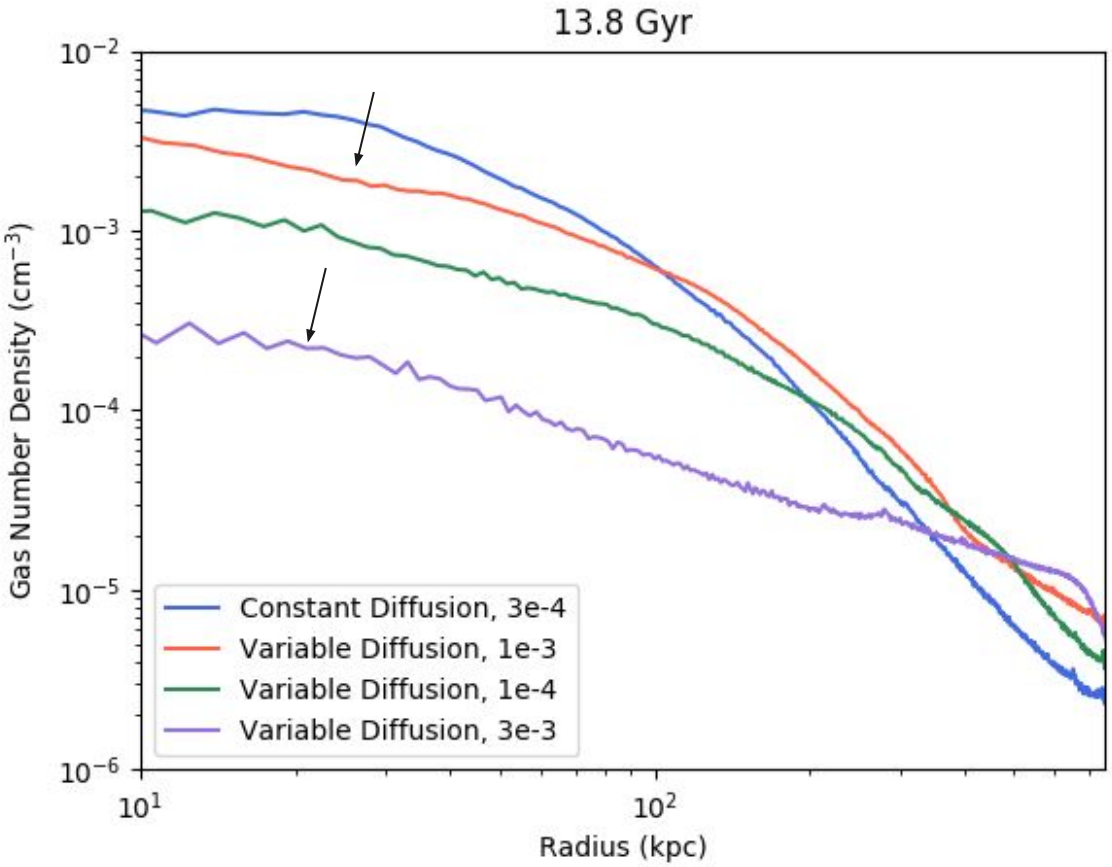

Sample size = 1 galaxy

Conclusions

- Bulk galaxy properties are not sensitive to CR physics
- CR physics may affect gas properties
- Different CR transport and efficiency prescriptions may produce differing observables

Future Work

- Analyze more simulations to expand sample size
- Further exploration of gas properties to constrain parameter space
- Production of synchrotron emission images for comparison to current and future observations

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