Star-by-star Feedback and Chemical Evolution in Low Metallicity Dwarf Galaxies

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Emerick + 18a (1807.07182) - Emerick + 18b (1808.00468) - Emerick + 18c (1809.01167)

Open Questions in Galaxy Evolution

Feedback

Chemical Evolution

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Can self-consistent models of feedback explain galaxy properties?

How does multi-channel stellar feedback couple to ISM and winds?

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How does multi-channel stellar feedback couple to ISM and winds?

Chemical Evolution

What physics drives abundance evolution at all scales (gas+stars)?

How are metals distributed across phases in the ISM and CGM?

“Star Particles” = Stellar Populations in Simulations

Issues with “simple stellar populations” at high res. **(Revas + 16):**

- IMF sampling at $M_* < 10^4 M_\odot$
- Smoothing over stellar properties

Individual star simulations are logical "next step"

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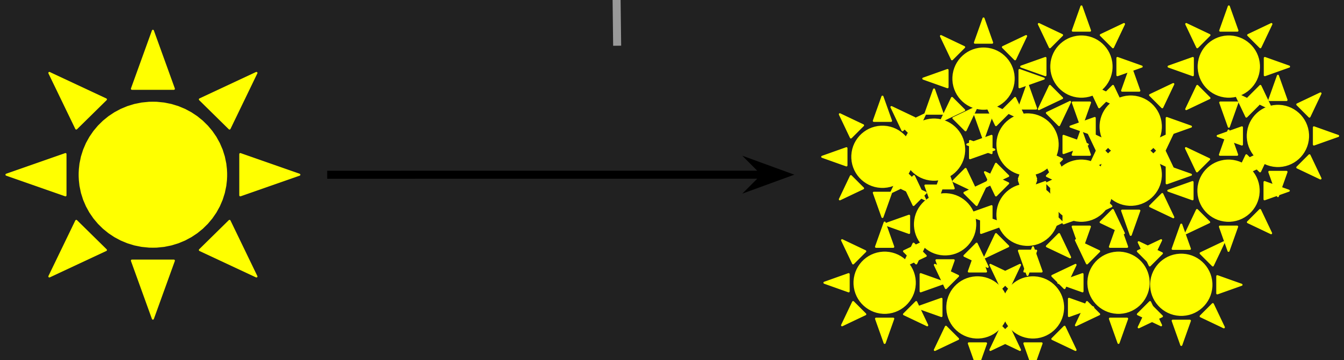
- Smoothing over stellar properties

Detailed accounting of:

- Feedback (winds + radiation)
- Chemical Enrichment

Caveat: Expensive



Galactic Chemical Evolution Using Enzo [Emerick+2018a]

Isolated, idealized dwarf galaxy simulations ($M_{vir} \sim 10^9\, M_{sun}$)

~ 1 pc physical grid resolution

Individual stars from 1 to 100 M_{sun} with multi-channel stellar feedback:

- Stellar winds + AGB winds
- Photoelectric Heating
- Lyman-Werner radiation
- Ionizing radiation using adaptive ray-tracing RT w/ radiation pressure
- Core collapse SNe
- Type Ia SNe

Stellar yields with 15 individual metals

[1]https://www.enzo-project.org . **This work @ Bitbucket: aemerick/enzo-emerick**

Click here to see movie shown during talk

First Results: Feedback Driven Metal Evolution

1) Stellar radiation feedback regulates star formation and helps drive outflows [Emerick + 2018b]

2) Metal Mixing and Ejection Depends upon Nucleosynthetic Source (AGB winds vs. supernovae) [Emerick + 2018c, submitted]

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First Results: Feedback Driven Metal Evolution

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    I) Localized ionization / heating regulates star formation

    II) Long-range ionization is key for driving outflows

2) Metal Mixing and Ejection Depends upon Nucleosynthetic Source (AGB winds vs. supernovae) [Emerick + 2018c, submitted]

Role of Ionizing Radiation in Low Mass Dwarfs

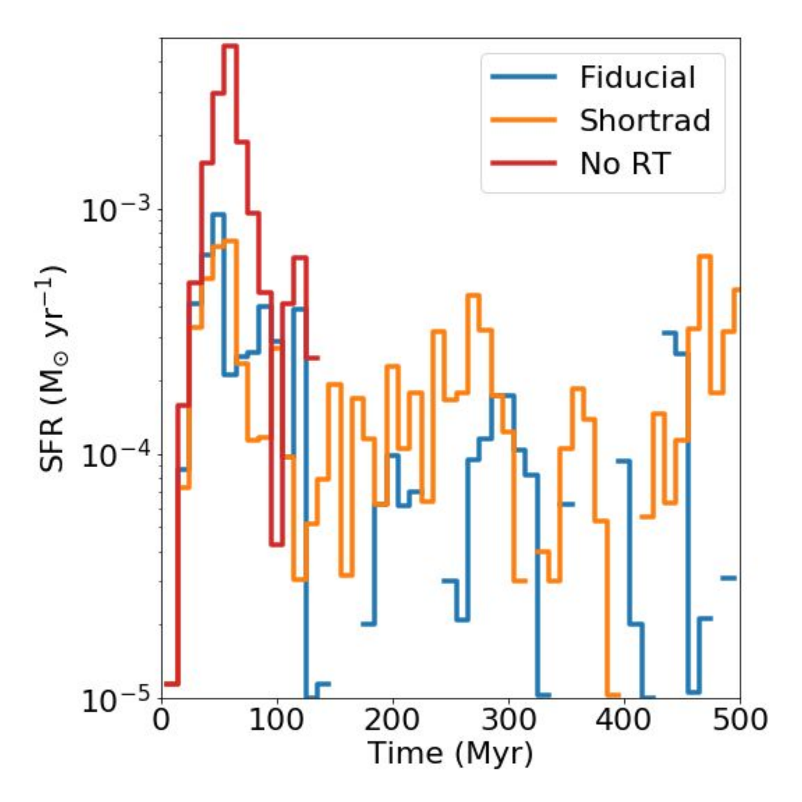
Three Simulations:

1) **Fiducial:** Full Physics (radiative transfer for stellar ionizing radiation)

2) **No RT:** No stellar ionizing radiation feedback

3) **Shortrad:** Localized stellar ionizing radiation only (< 20 pc from source)

Long-Range Ionizing Radiation is Important



1) Significantly higher SFR without radiation feedback

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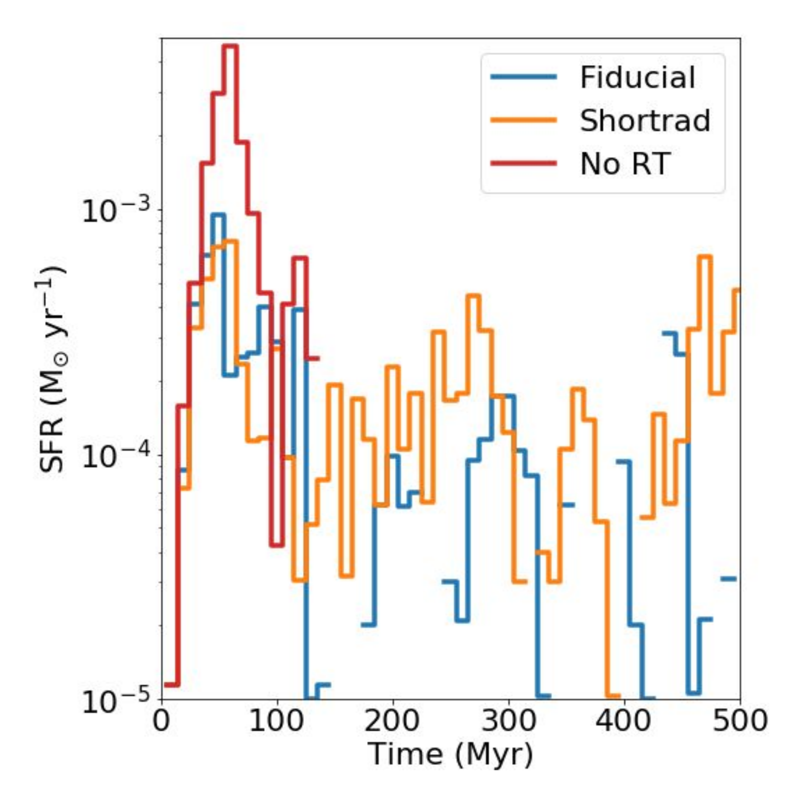

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2) Localized radiation feedback sufficient to regulate SFR….

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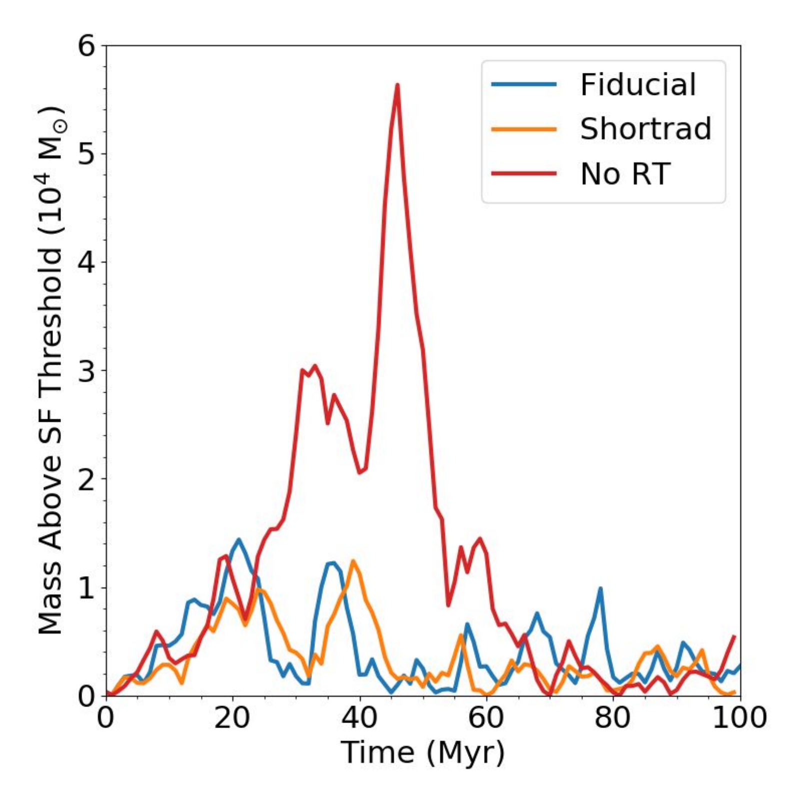

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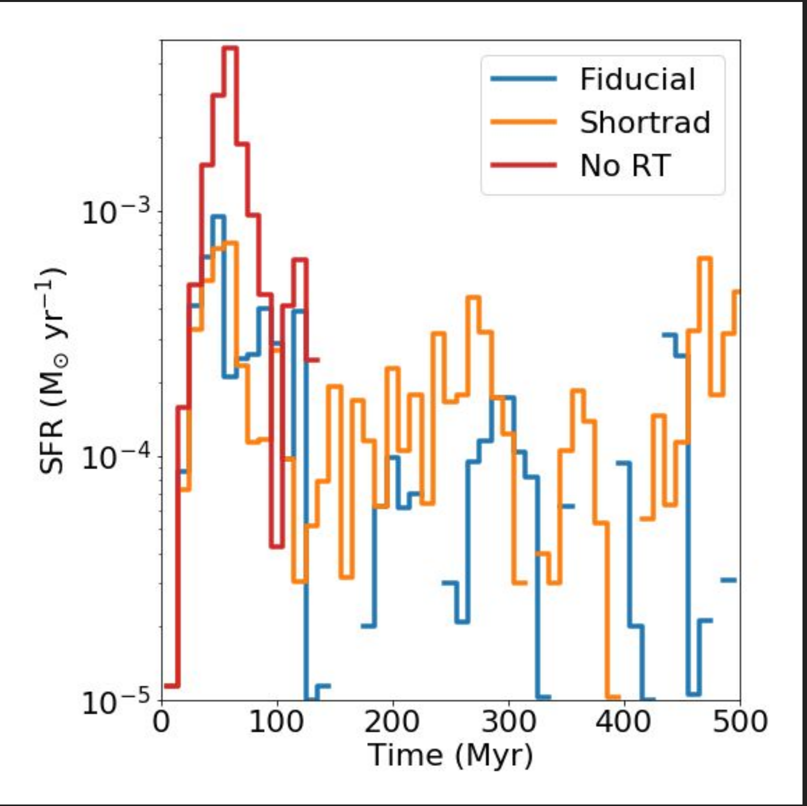

1) Significantly higher SFR without radiation feedback

2) Localized radiation feedback sufficient to regulate SFR….

3) … however, there are long-term differences in evolution

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Radiation-assisted outflows:

Mass Loading Factor ($\eta = \dot{M}_{out}$ / SFR)

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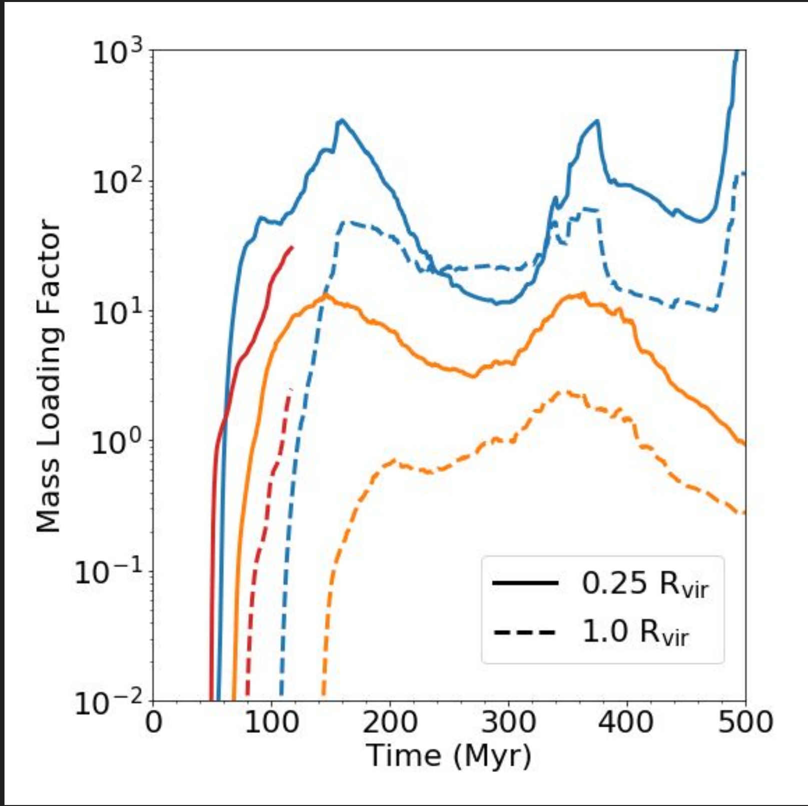

Long-Range Ionizing Radiation is Important

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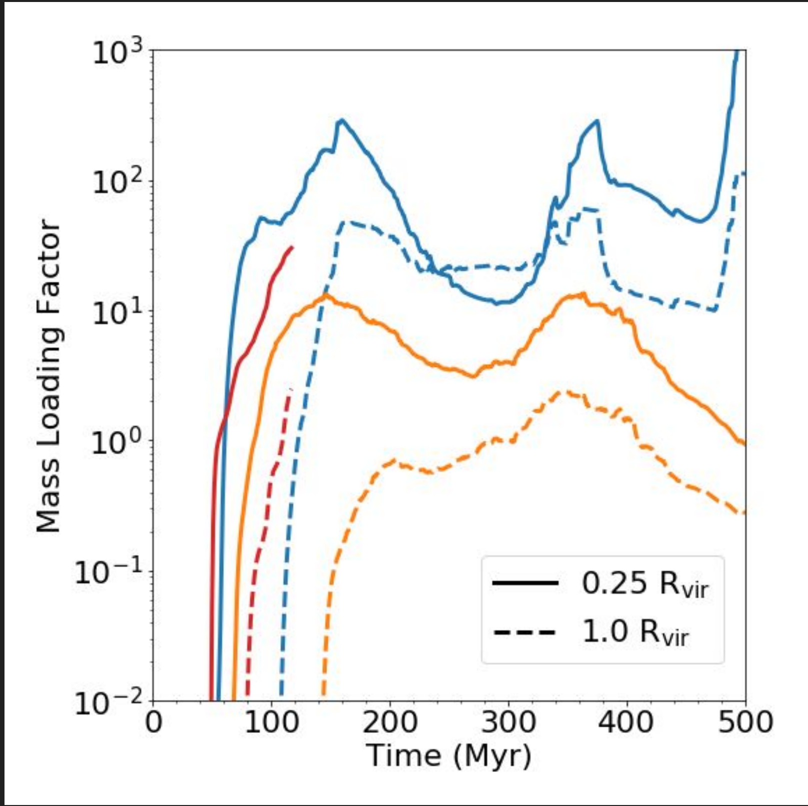
1) Fiducial drives significant outflows (η ~ 20 - 300 at 0.25 R_{vir})

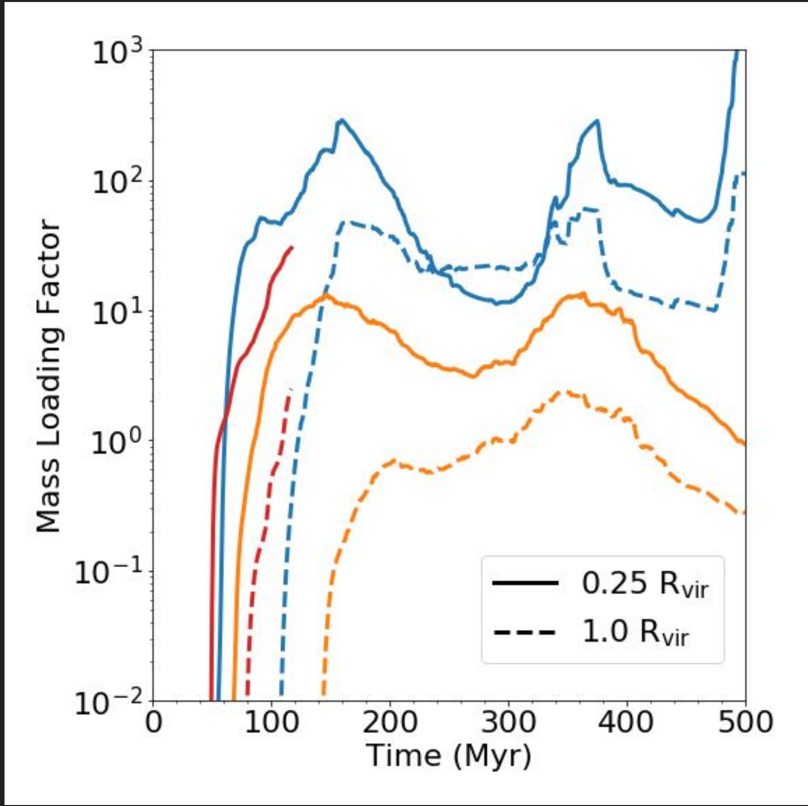


Long-Range Ionizing Radiation is Important

Mass Loading Factor ($\eta = \dot{M}_{out}$ / SFR)

1) Fiducial drives significant outflows ($\eta \sim 20 - 300$ at 0.25 R_{vir})

2) Localized radiation <u>much less</u> efficient ($\eta \sim 3 - 10$)



How do these differences in feedback drive chemical evolution?

Dwarf Galaxies Lose Most of Their Metals

MW dSph’s only have few percent of metals in stars (Kirby + 2011)

Leo P retains ~5% of its metals in gas + stars (McQuinn+2015)

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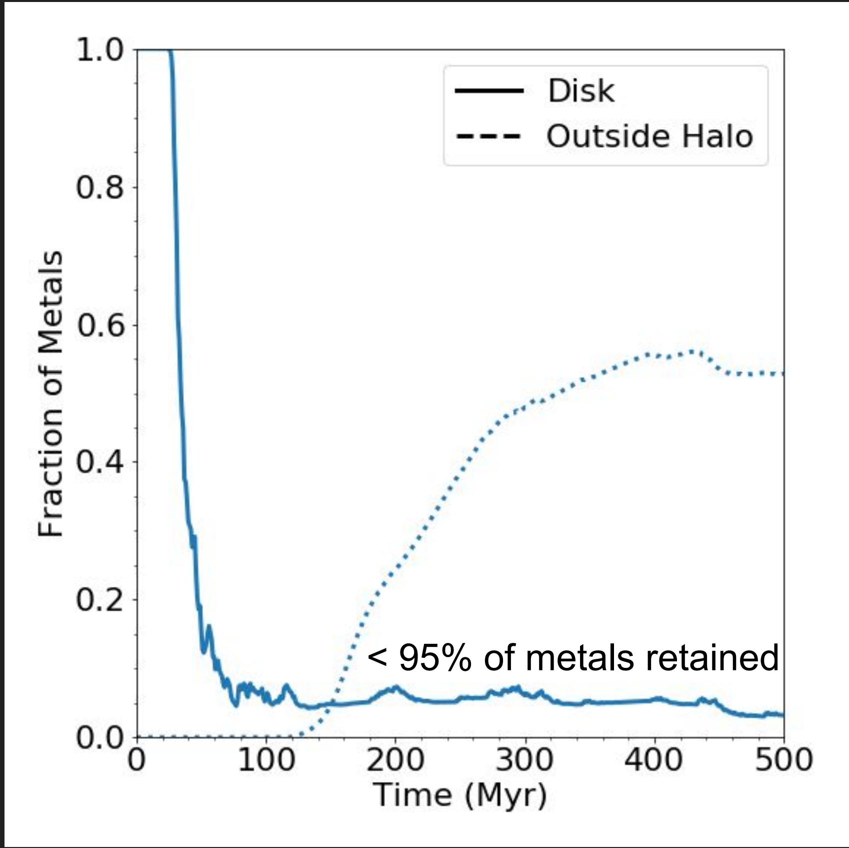
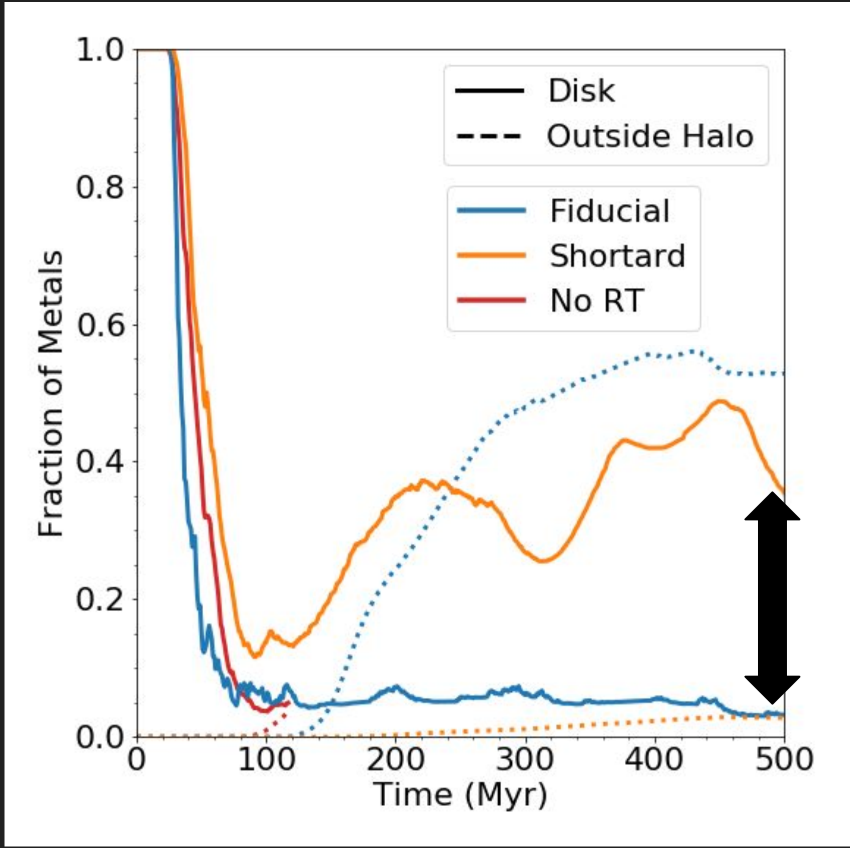
(See also Christensen + 2016, 2018)

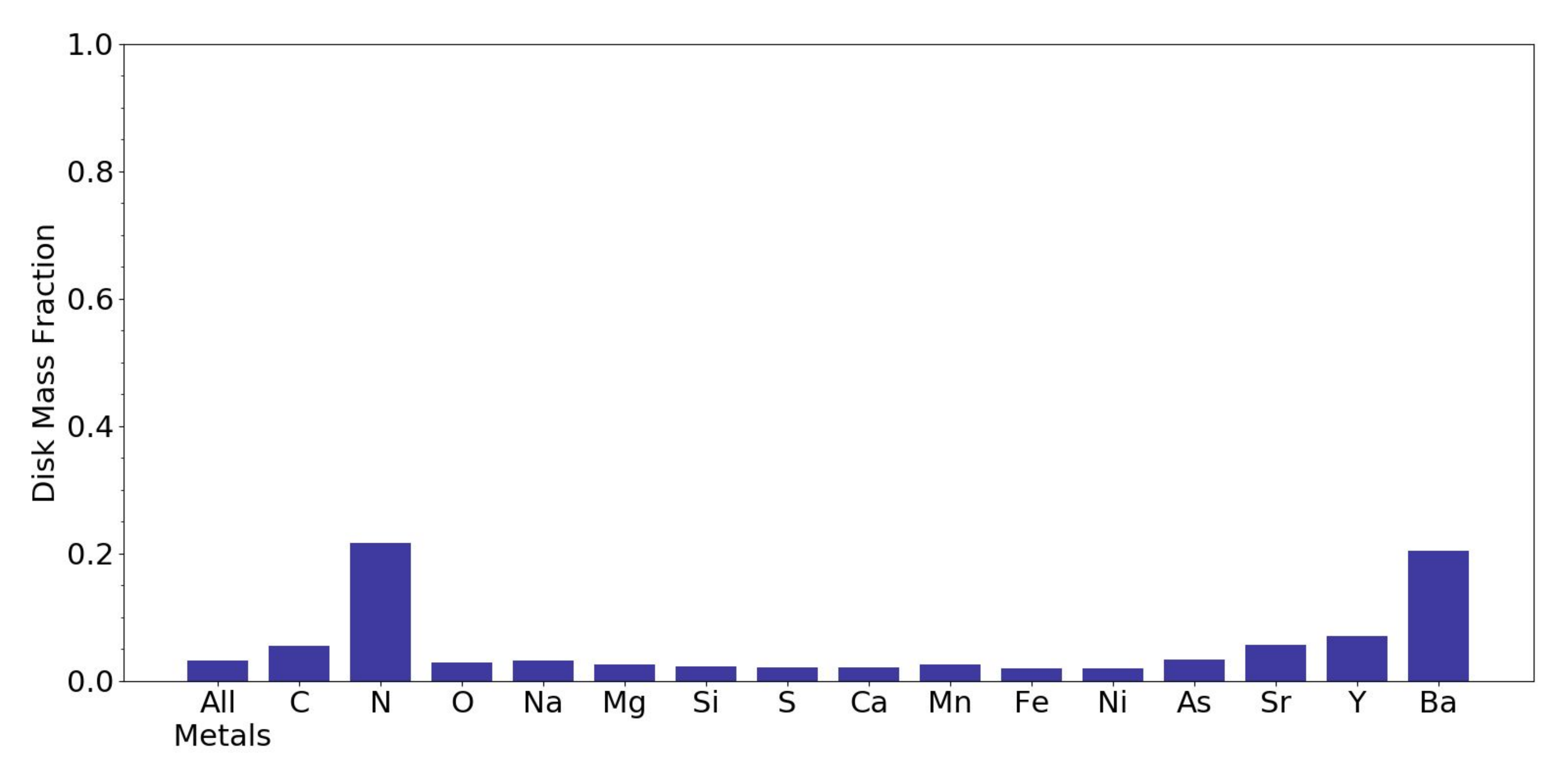


Dwarf Galaxies Lose Most of Their Metals

Long-range radiation creates conditions needed for significant outflows and metal loss.



Retention Fraction at 500 Myr (Fiducial Simulation)



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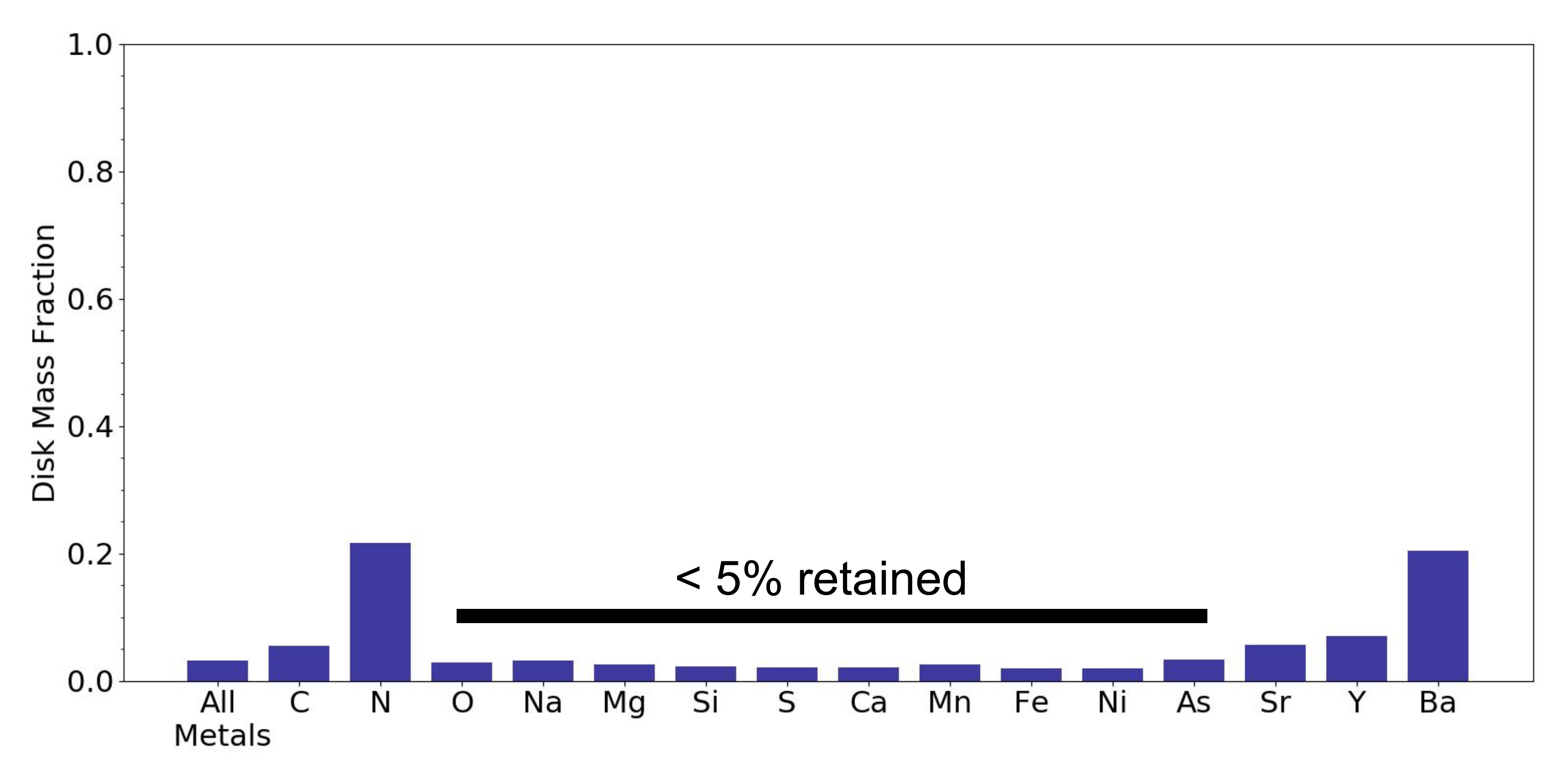

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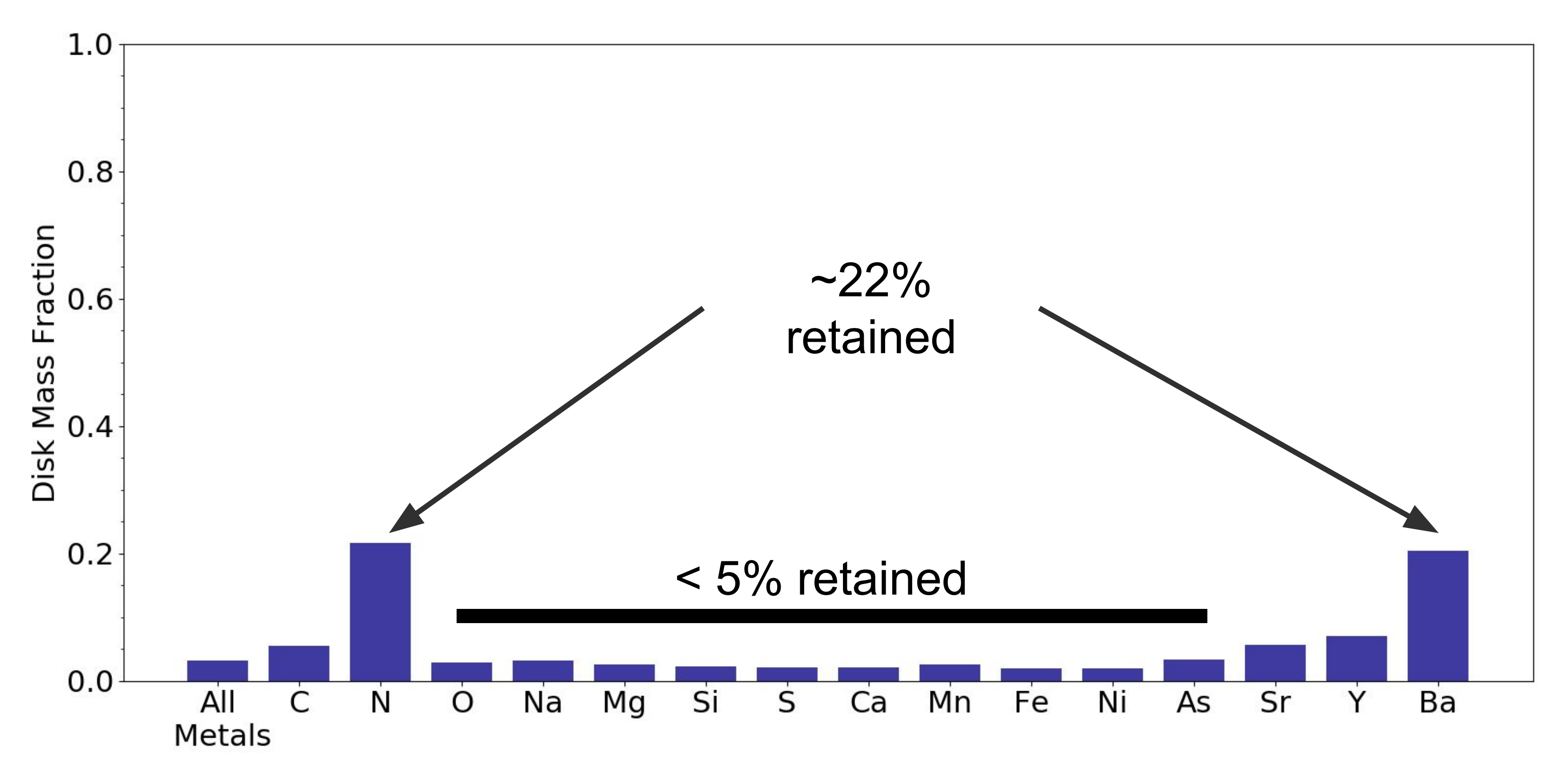
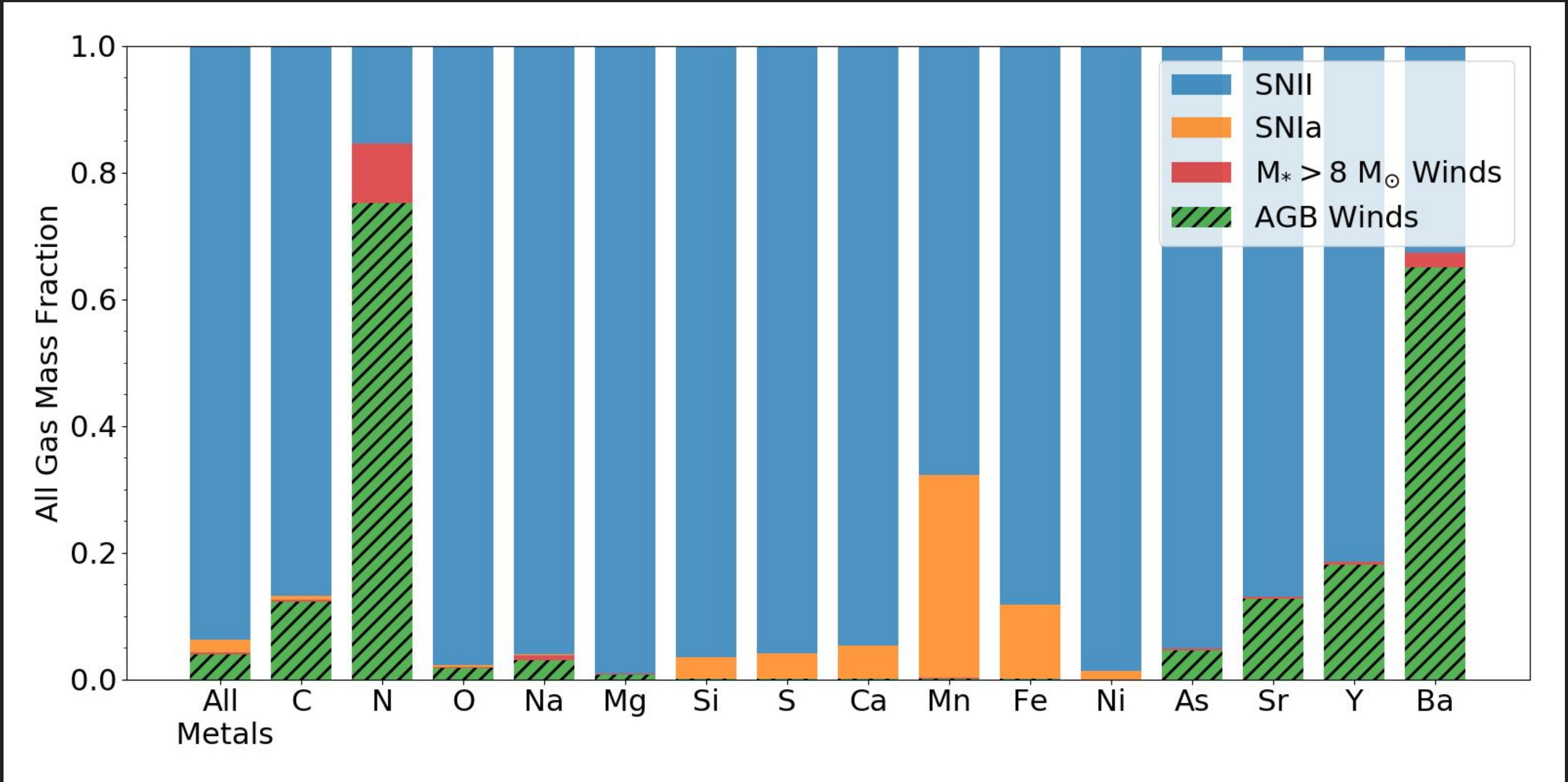


Production Fraction at 500 Myr



Summary:

1) Developed new method for chemical evolution and feedback in Enzo following **individual stars** [Emerick + 2018a (1807.07182)]
2) Long-range ionizing radiation effects are important in low mass, low metallicity dwarf galaxies [Emerick + 2018b (1808.00468)]
3) Metals released in AGB winds are retained more easily than metals from SNe [Emerick + 2018c (1808.00468)]

And also in Emerick + 2018c:

a) Metal mixing in the ISM less efficient for AGB elements
b) Metal mass fraction distributions in ISM can be described analytically