The metal enrichment of passive galaxies in cosmological simulations of galaxy formation

Okamoto et al.

https://arxiv.org/pdf/1610.06578v2.pdf

Presentation by Lucas deHart

Background

- Metallicity(Z) – The mass fraction of an astronomical object that is not composed of Hydrogen(X) or Helium(Y)
- α elements – Elements formed in the α-process of nuclear fusion.
  - C, O, Ne, Mg, Si, S, Ar, Ca
- Abundance of α elements given by α/Fe

Metallicity and Galaxies

- Metallicity can constrain formation theory

From observations, we know:

  - Z generally increases with luminosity and velocity dispersion
  - α/Fe ratio also increases with luminosity and velocity dispersion

- Theoretical models and galaxy formation simulations have had trouble reconstructing these relations

The Paper – Introduction

The Goal:

- Perform a cosmological and hydrodynamic simulation of hierarchical galaxy formation including quenching from radio-mode Active Galactic Nuclei (AGN)
- Analyze other large simulations of this kind
- Track metallicity and α/Fe via chemical evolution, looking to recreate observed trends

Lit Review

Semi-Analytic Model – Pipino et al. (2009)

- Looked at [α/Fe]-σ relation for elliptical galaxies
- Included chemical enrichment from both supernovae and low mass stars. Included Radio Mode AGN.
- Good [α/Fe]-σ, but inverse Z-σ correlation

Calura and Menci (2011)

- Chemical evolution of individual star formation histories for all progenitors for a galaxy and Quasar Mode AGN.
- Did not show mass-metallicity relation

Lit Review Continued

Other Simulations -

- Taylor & Kobayashi (2015)
  - Showed that quasar-mode AGN feedback increases α/Fe in high mass galaxies
- Segers et al. (2016b)
  - Included AGN feedback and found that α/Fe increases in massive galaxies without changing the IMF. Also showed α/Fe is roughly constant without feedback

The Simulation

- Cosmological simulation based on Lamda-CDM
- Star formation rate

$$\dot{\rho}_* = c_* \frac{\rho_{\rm gas}}{t_{\rm dyn}},$$

- Smoothed Particle Hydrodynamics from Gadget 3
- Large SPH particles can spawn new star particles
- Small SPH particles convert into star particles
- Each new particle or star inherits the chemical history of its progenitor

The Simulation Ctd.

- Each star particle is a simple stellar population (SSP)
- Stellar lifetime and chemical yield depend on Z
- Includes both type Ia and type II supernovae with rates from Portinari et al. (1998)
- Track abundance of H, He, C, N, O, Ne, Mg, Si, and Fe and assume that S and Ca are ~ to Si
- Stellar feedback calculated as radiative winds
- Type II supernovae modeled as energy-driven winds

The Simulation Ctd.

- Radio-Mode AGN
  - Implemented as a reduction of radiative cooling for gas particles
  - Happens when velocity dispersion is greater than

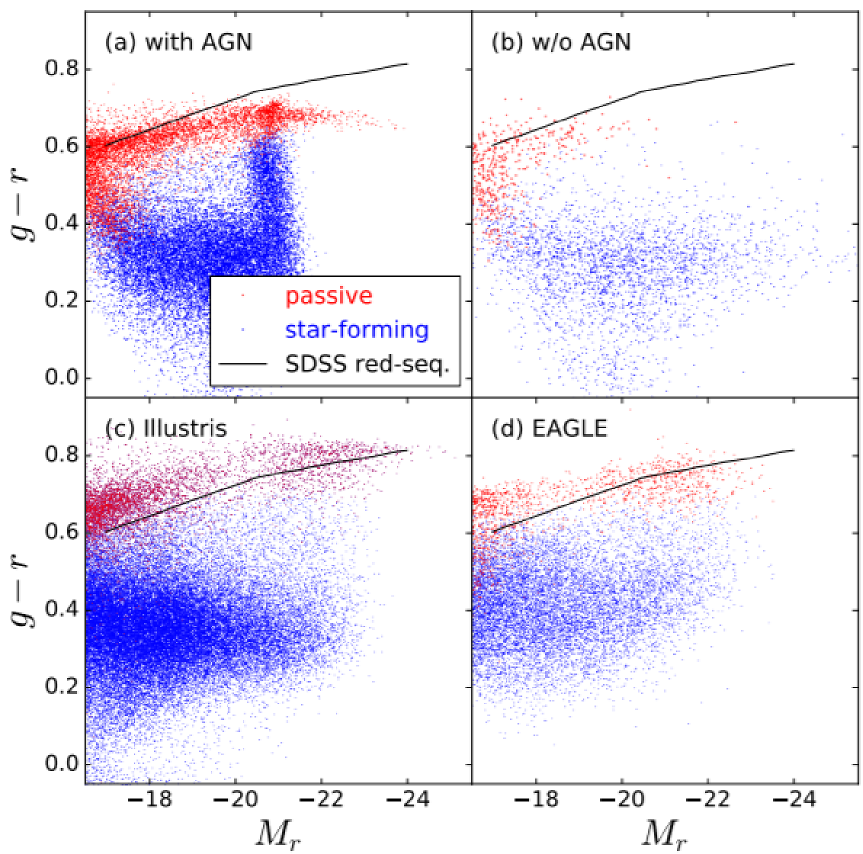
$$\sigma_{\rm th}(z) = \sigma_0(1+z)^{\alpha}.$$

  - σ0 = 50 km/s, α = 0.75, and β = 0.3

Other Simulations Analyzed

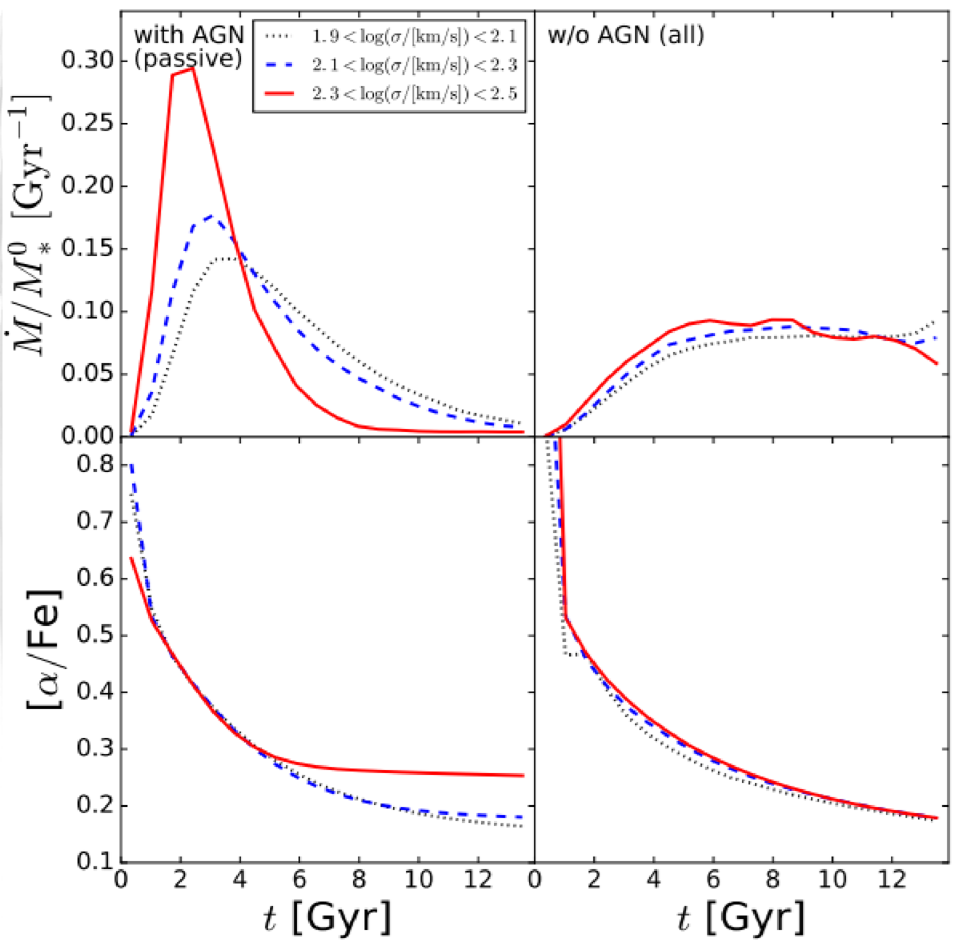
- Also analyzed Illustris (Nelson et al. 2015) and EAGLE (McAlpine et al. 2016) simulations

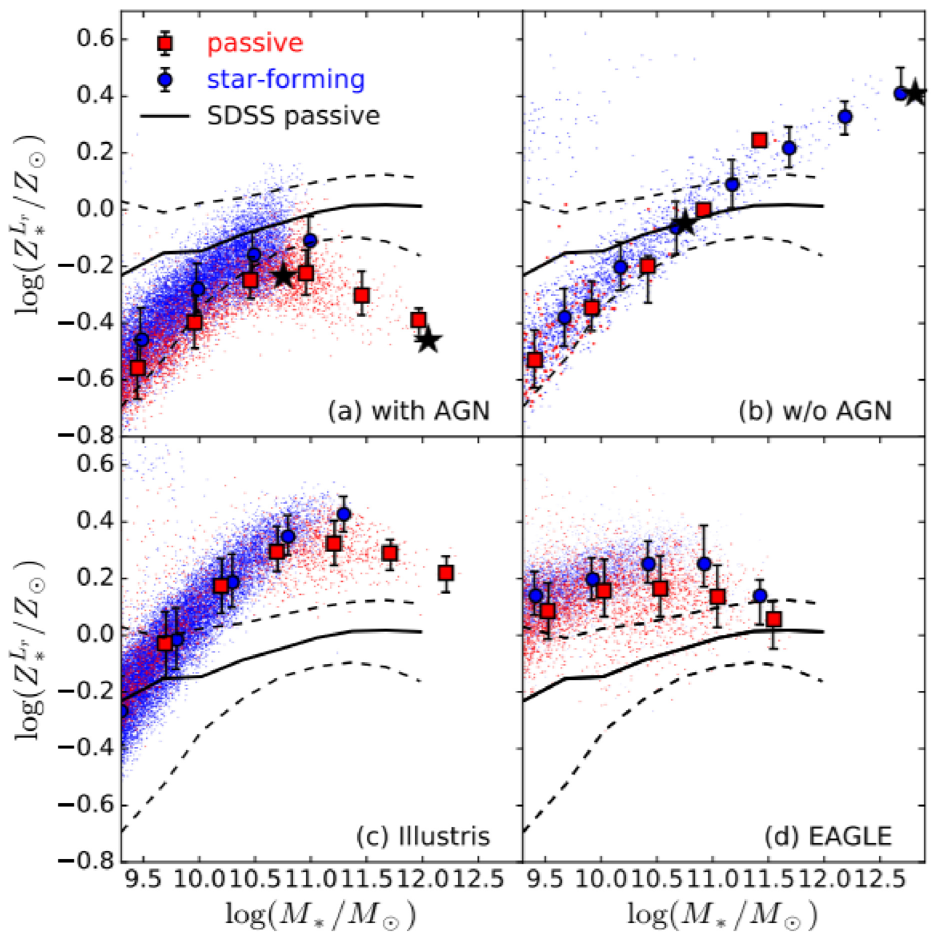
There are some important differences between the reference, Illustris, and EAGLE simulations. While stellar feedback in the reference and Illustris simulations are implemented as winds, feedback energy is deposited locally as thermal energy in the EAGLE simulation. For AGN feedback, the reference simulation only has the radio-mode feedback. AGN feedback in the Illustris simulation has two modes: quasar and radio modes, while the EAGLE simulation only has the quasar-mode feedback.



Results

- Star formation histories, α/Fe, and mass-Z relations





Findings

- The simulation showed α/Fe increasing with mass
- However, the mass-Z corellation was again inverted passed a certain turning point (M ~ 5 * 10^10 SM)
- This is explained by examining progenitors
  - The most massive galaxies have the most massive progenitors
  - In massive progenitors, the AGN model feedback occurs much earlier, decreasing cooling rates and stunting later star formation
  - This leads to lower overall metallicity

Conclusions

- Correctly retrieving both the α/Fe ratio trend and the mass-Z relation from simulations remains a difficult challenge
  - Variable IMF suggested by Calura and Menci (2009) as we as Gargiulo et al. (2015)
- Simulations show passive galaxies with lower Z than SF, but observations (Peng et al. 2015) show that they should be much higher
  - Need a preferential enrichment of passive galaxies

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