The chemical evolution of galaxies: Insights from the Munich model

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DEEP15: Back at the edge of the Universe

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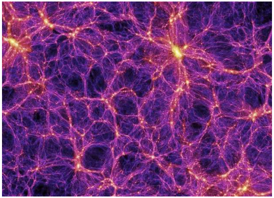
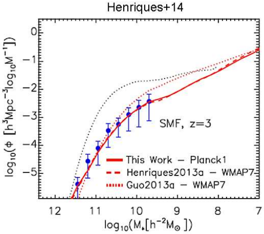
Outline

- **Ellipticals:** SFHs and the M_*-[α/Fe] relation
- **Clusters:** Iron in the ICM around galaxy clusters
- **SF galaxies:** Evolution of the MZR

The Munich SAM: L-Galaxies

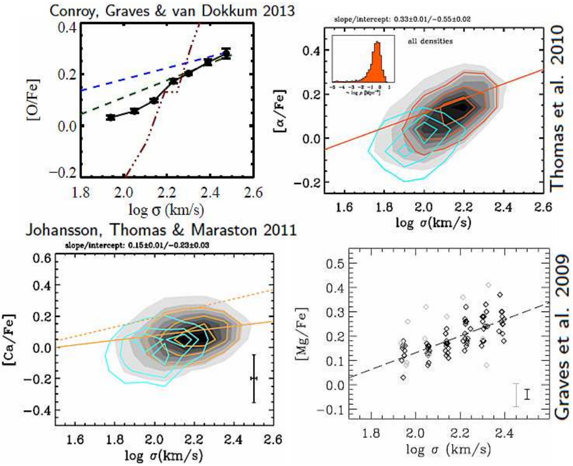
- DM haloes from DM N-body simulations, such as **Millennium** *(Springel+05)*, used to make merger trees
- Baryonic physics is implemented on top **analytically**, following laws motivated by observations and simulations, for over 25 million galaxies (by $z = 0$)
- Base model: *(Guo+11)*
    - **Includes:** Infall; gas cooling; SF; BH & bulge growth; SN & AGN feedback; chemical enrichment; merging; starbursts; reincorporation; ...
    - **Reproduces:** Low-z SMF, LFs & MZR; large-scale clustering; Tully-Fisher relation; ...
- New model: *(Henriques+, in prep.)*
    - **Will include:** delayed reincorporation; H_2 formation; Σ_{H_2}-Σ_{SFR} law, radial gradients; Planck cosmology; MCMC; **delayed chemical enrichment**





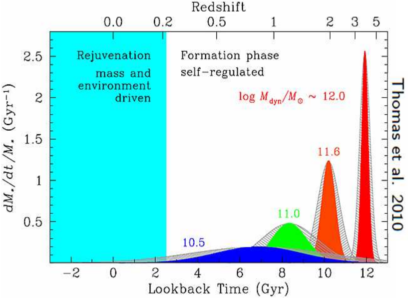
Elliptical galaxies

Observed M_*-[α/Fe] relations

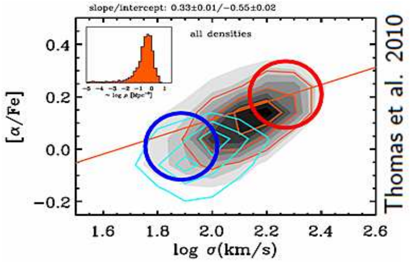


A **positive correlation** between σ (i.e. M_*) and α enhancement is found in local ellipticals.

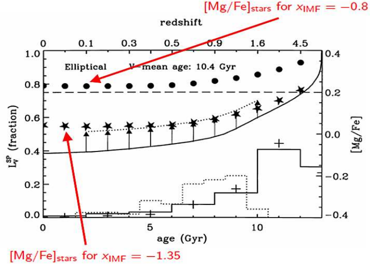
1) Shorter τ_{SF} in massive ellipticals?



- **Massive ellipticals:**
  Form stars over shorter timescales
  $\Rightarrow$ high [α/Fe]
- **Low-mass ellipticals:**
  Form stars over longer timescales
  $\Rightarrow$ low [α/Fe]

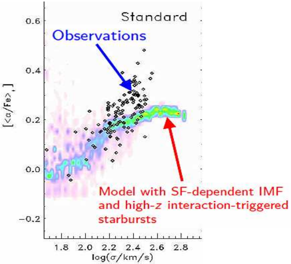


Top-heavy IMF in massive ellipticals?



Thomas (1999)

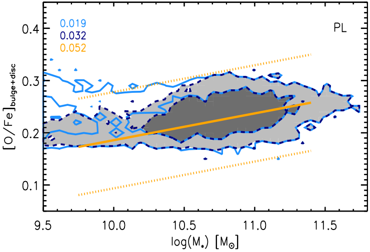
"Only under the assumption that **the IMF is significantly flattened** with respect to the Salpeter value during the [major-merger-induced] starburst, can a Mg/Fe overabundant population be obtained."

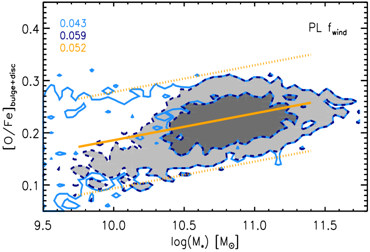


Calura & Menci (2009)

"By **assuming a SF-dependent IMF**,. . . the observed correlation between $[\alpha/\mathrm{Fe}]$ and σ can be accounted for."

Shorter τ_{SF} in massive ellipticals



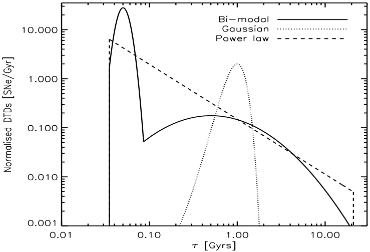


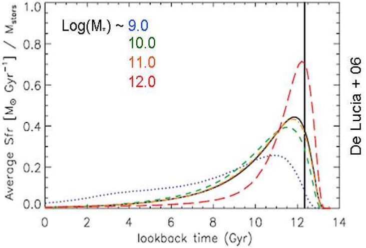
Positive slope obtained without needing variable IMF

$$f_{\rm wind} = \min\left[1.0, \left(\frac{\Sigma_{\rm cold}}{10\ {\rm M_\odot pc^{-2}}}\right)^{-1}\right]$$

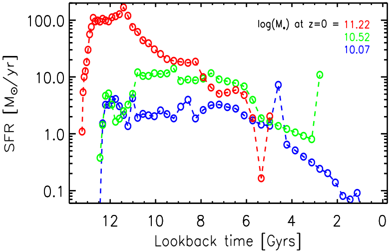
Oxygen rich, α enhanced, and shortly after SF. *(e.g. Martin et al. 2002; Tumlinson et al. 2011)*

Shorter τ_{SF} in massive ellipticals





Some delayed Fe enrichment (<50% of SNe-Ia exploding within 400 Myr) plus mass-dependent SFHs is enough

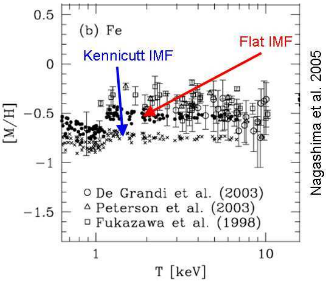


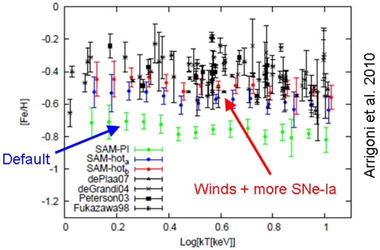
Galaxy clusters

Enrichment of the ICM

A significant amount of iron is found in the hot gas around local clusters ([Fe/H]~ -0.5).

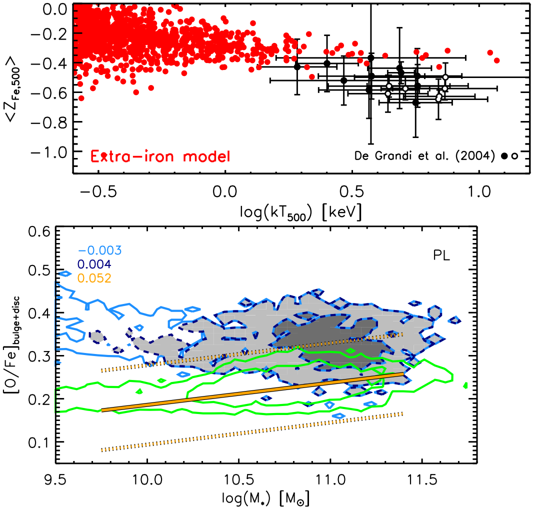
Are variations to the IMF or SN-Ia production efficiency required to explain this?



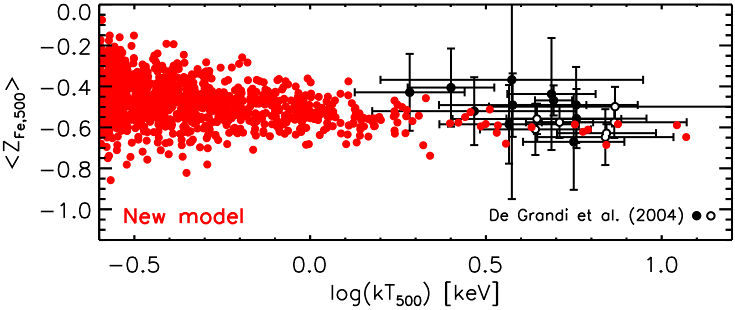


Consider the whole galaxy population

Increasing the production/ejection of Fe from galaxies affects the chemistry of the whole galaxy population.

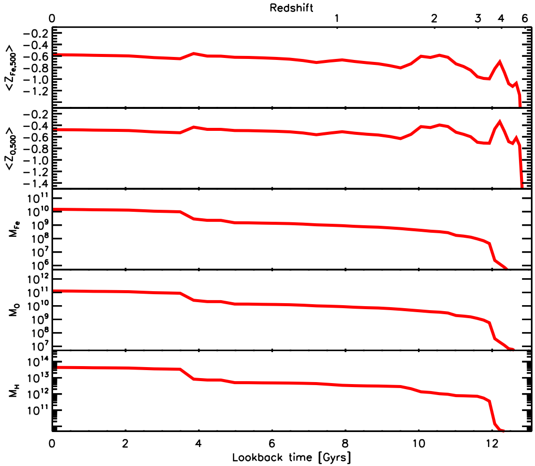


kT_{500}-$[Fe/H]_{ICM}$ relation in L-Galaxies



The same model that reproduces the chemical composition inside galaxies can also roughly **match [Fe/H] in the ICM**

Enrichment occurs at high redshift



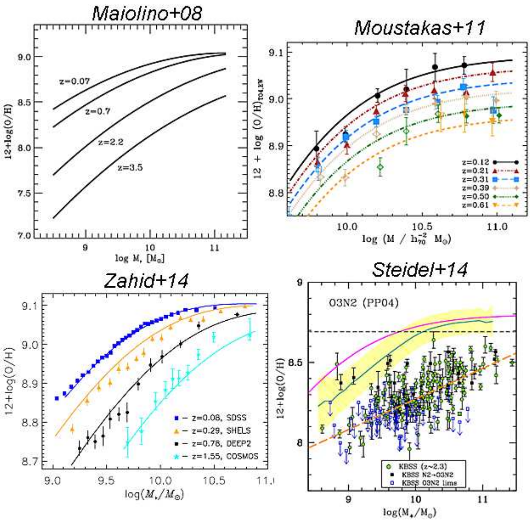
ICM reaches [Fe/H] seen at z = 0 by z ∼ 2.

A cluster in a DM halo of $M_{vir} \sim 10^{12.5}\,M_{\odot}$ will have ejected $\sim 10^{9}\,M_{\odot}$ of metal into the ICM by $z = 2$.

This is consistent with measurements of the metal mass in the cool CGM at $z = 2$ (*Prochaska+14*).

SF galaxies

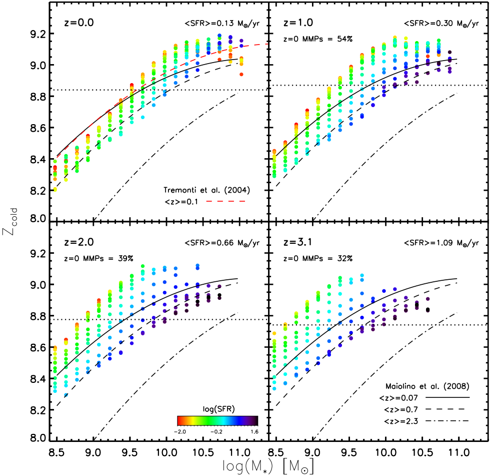
Evolution of the MZR in obs

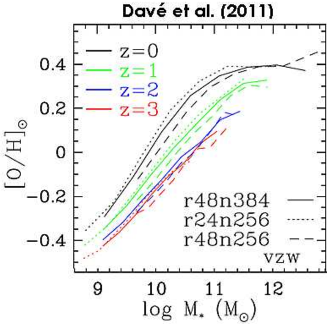


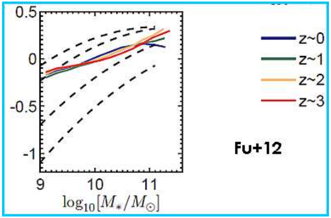
The rate of evolution of the MZR, and it's mass-dependence (i.e. chemical downsizing), is still uncertain

An increasing number of spectroscopic samples will be available soon, but **calibrating metallicities at high redshift is still a major challenge** (see e.g. *Steidel+14*).

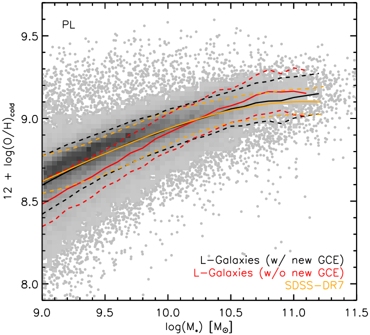
Evolution of the MZR in previous models

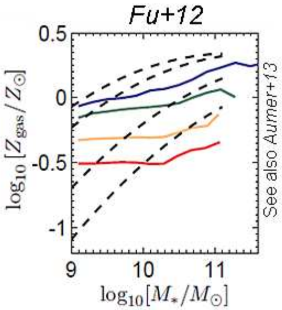






MZR evolution in L-Galaxies – future work. . .





The model MZR at $z = 0$ is in very good agreement with observations (*Yates+13*), and a form of evolution is obtainable when H_2 formation is modelled (*Fu+12*).

So what will our model predict in detail at higher redshift?. . .

Summary

- The Munich SAM has a detailed chemical enrichment scheme implemented.
- The chemical properties of local ellipticals are reproduced. This is due to mass-dependent-τ_{SF} and a small number of 'prompt' SNe-Ia.
- The iron observed in the ICM can also be modelled. Our model indicates that ICM enrichment has already occurred by $z \sim 2$.
- The evolution of the MZR for SF galaxies is the next big step. . .