Element abundance ratios and star formation quenching: satellite versus central galaxies

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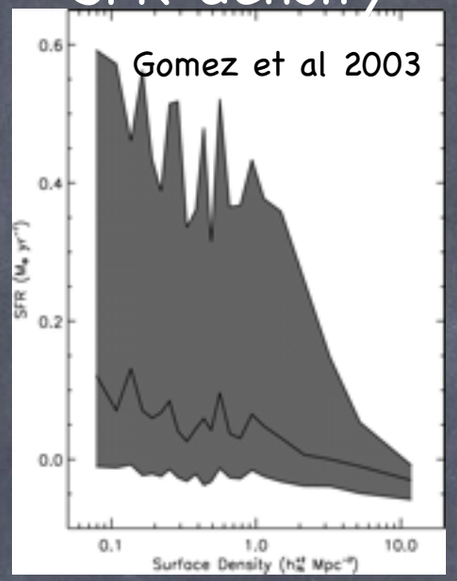
Mass and environment shape galaxies' SFHs

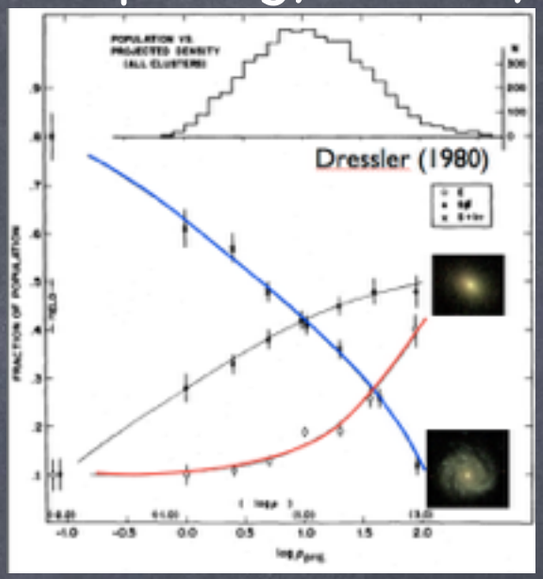
- Several galaxy properties (morphology, SFR, color, quiescent fraction) correlate both with environment and with galaxy mass

- Disentangle a causal environmental dependence from that induced by the dominant dependence on galaxy mass

SFR-density

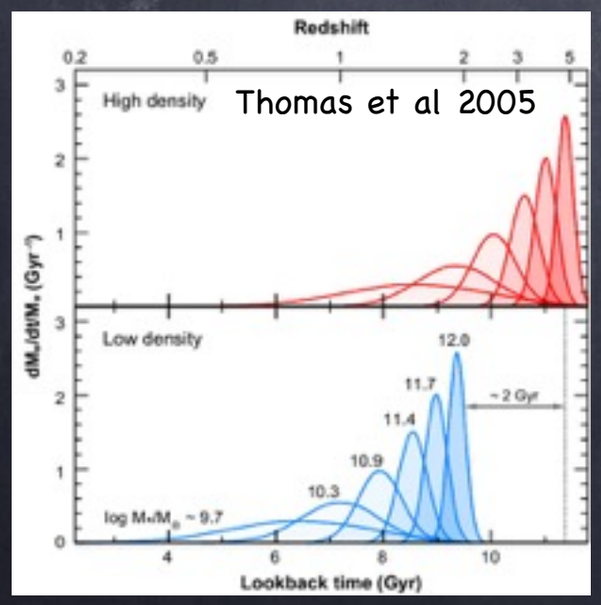


morphology-density



Age-mass

→ "satellite" galaxies vs equally-massive "central/isolated" galaxies



Stellar population properties as tracers of past star formation history and chemical enrichment

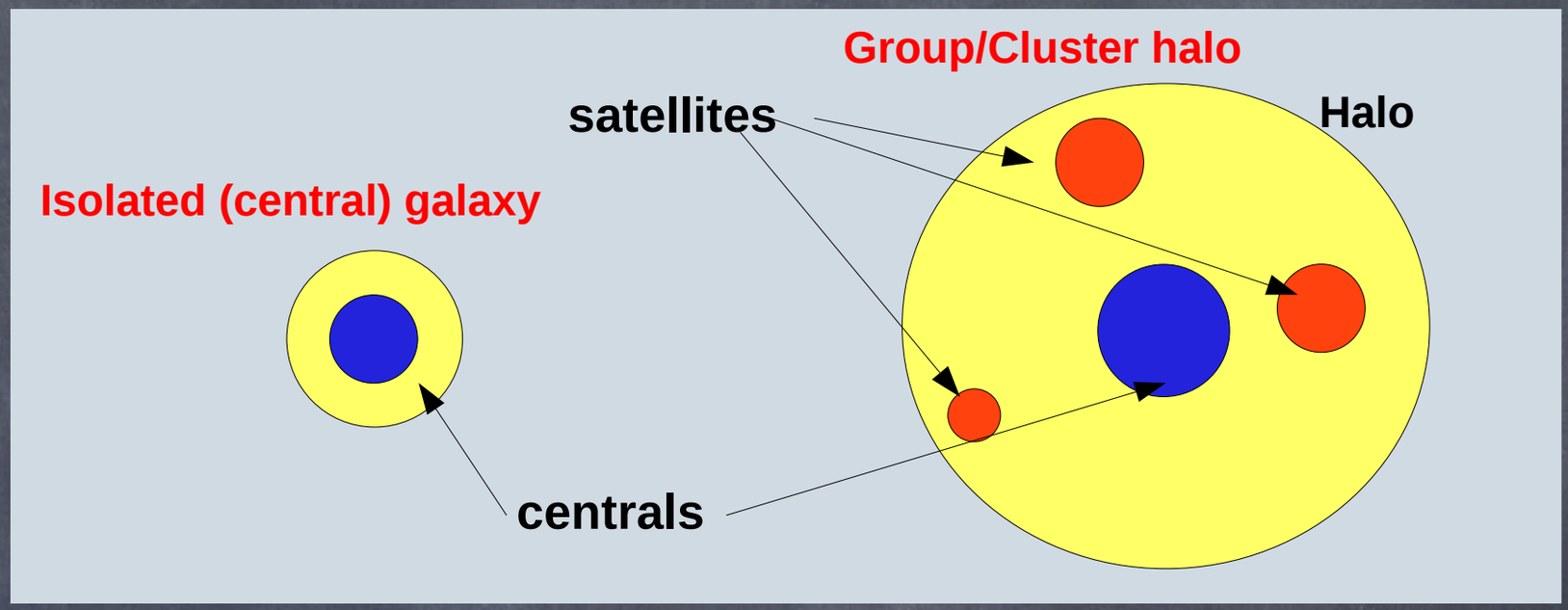
- METALLICITY -> degree of chemical enrichment
- LIGHT-WEIGHTED AGE -> epoch of main SF
- ELEMENT ABUNDANCE RATIO -> timescale of SF

Definition of environment

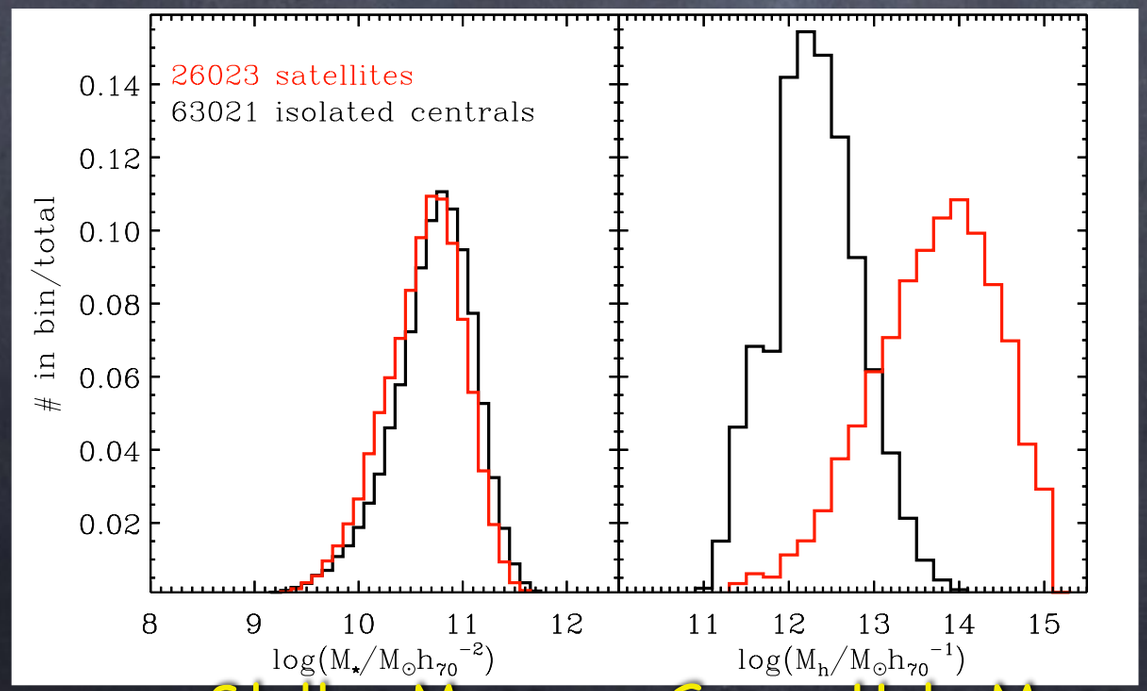
SDSS DR7 group catalog (Yang+07) ➜ Total Mass of hosting halo (group/cluster) and group hierarchy

CENTRALS: sitting at the center of a dark matter halo either as dominant galaxy in a group or as ISOLATED galaxy

SATELLITES: accreted into a larger halo and orbiting as a satellite



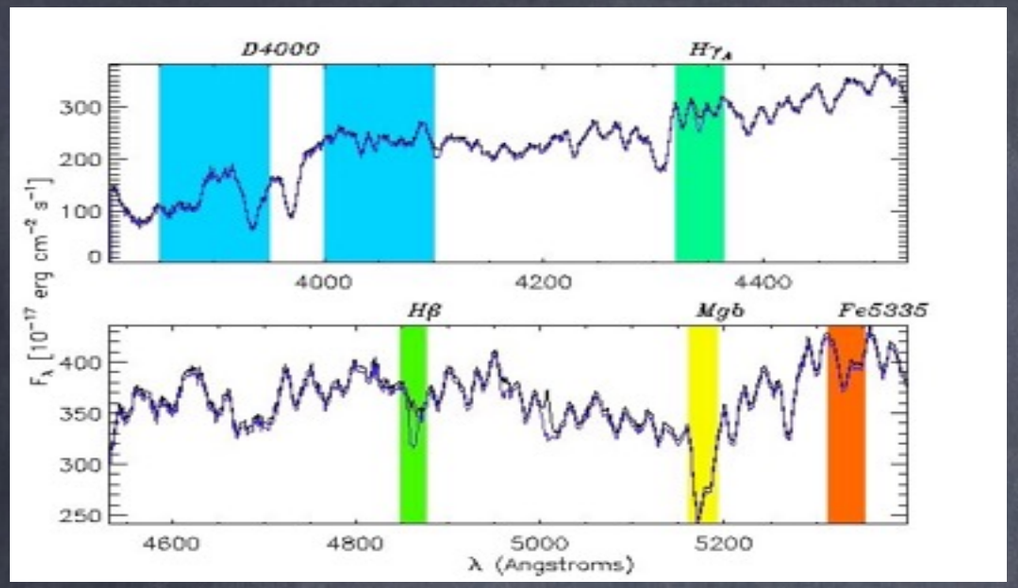
SDSS DR7 group catalog + stellar populations catalog; 0.01<z<0.2, r<17.77, S/N>20



Stellar Mass Group Halo Mass

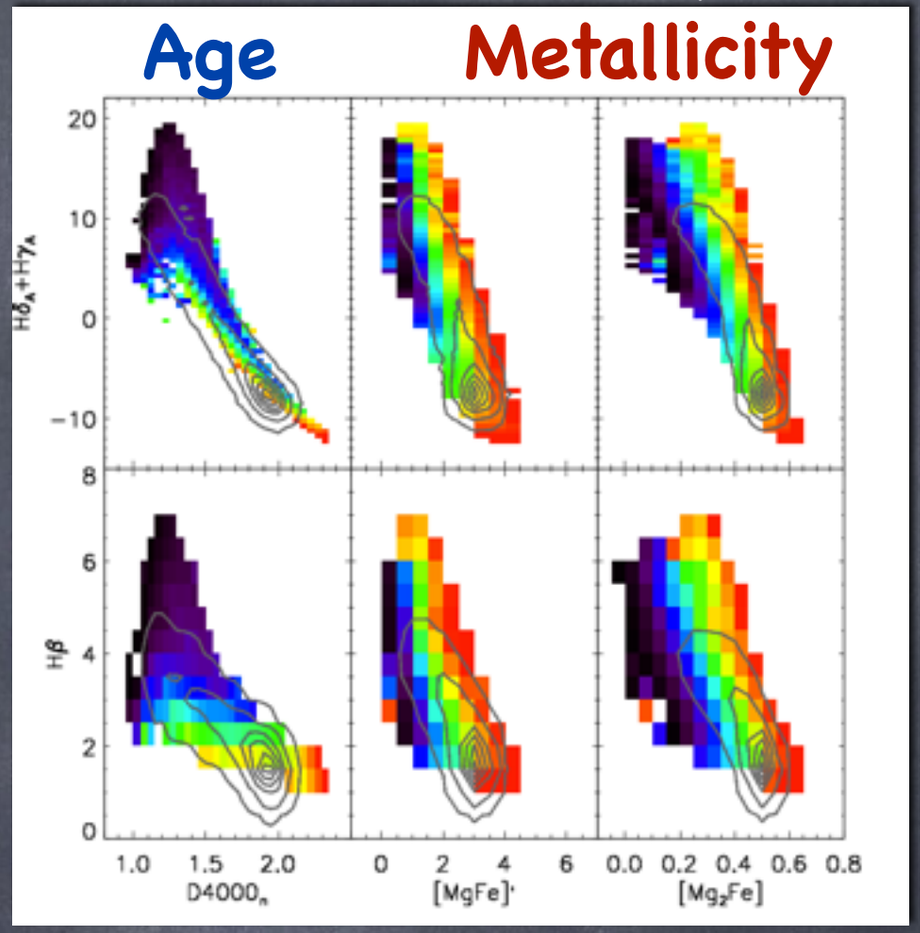
- **Strangulation**: slow removal of hot gas (Larson et al 1980)
- **Ram-pressure stripping**: fast removal of cold gas (Gunn & Gott 1972)
- Tidal stripping of stars
- Harassment: fast encounters (Moore et al 1998)
- Mergers with central galaxy

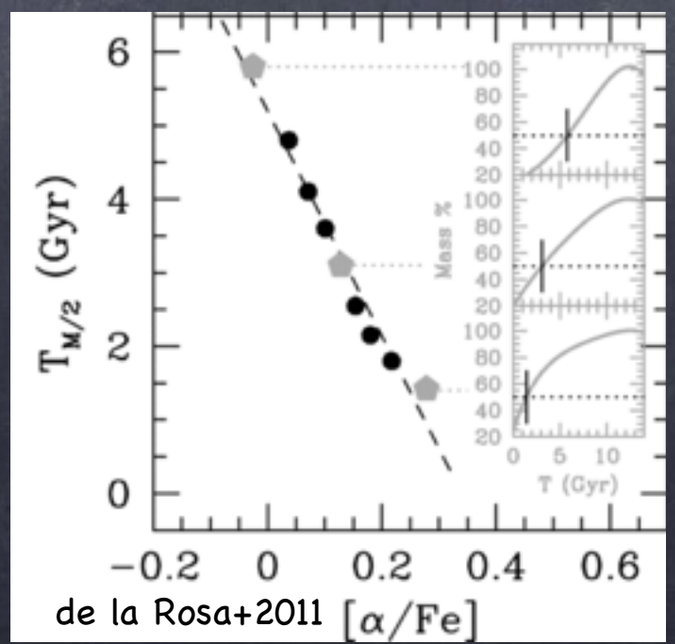
Physical properties of stellar populations encoded in galaxy spectra

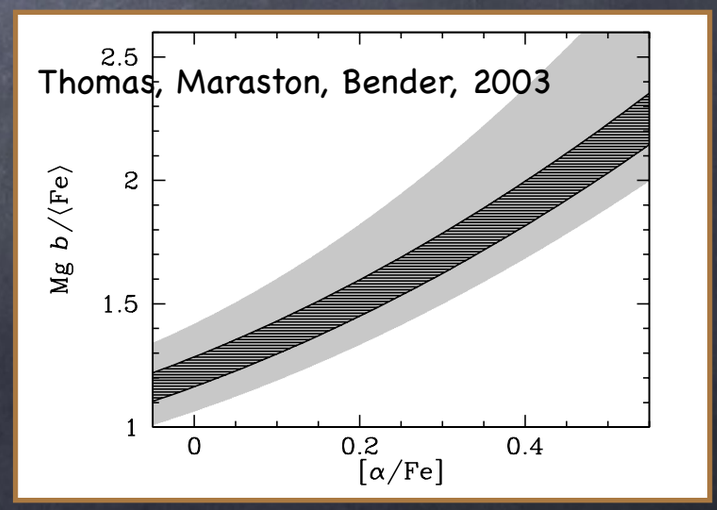


- **D4000, Hβ, Hγ+Hδ : Age indicators**
- **[Mg₂Fe], [MgFe]' : Metallicity indicators**
- **Mgb/<Fe> : [α/Fe]** : relative effective yields of SNII and SNIa products -> **galaxy SF timescale** (de la Rosa+11, Graves+10, Gallazzi+06)
  - Excess Mgb/<Fe> wrt to solar-scale model that best fits [α/Fe]-insensitive features
  - Δ(Mgb/<Fe>) → [α/Fe] calibrated with TMB+03/TMK+04 models (largely independent of age and metallicity)

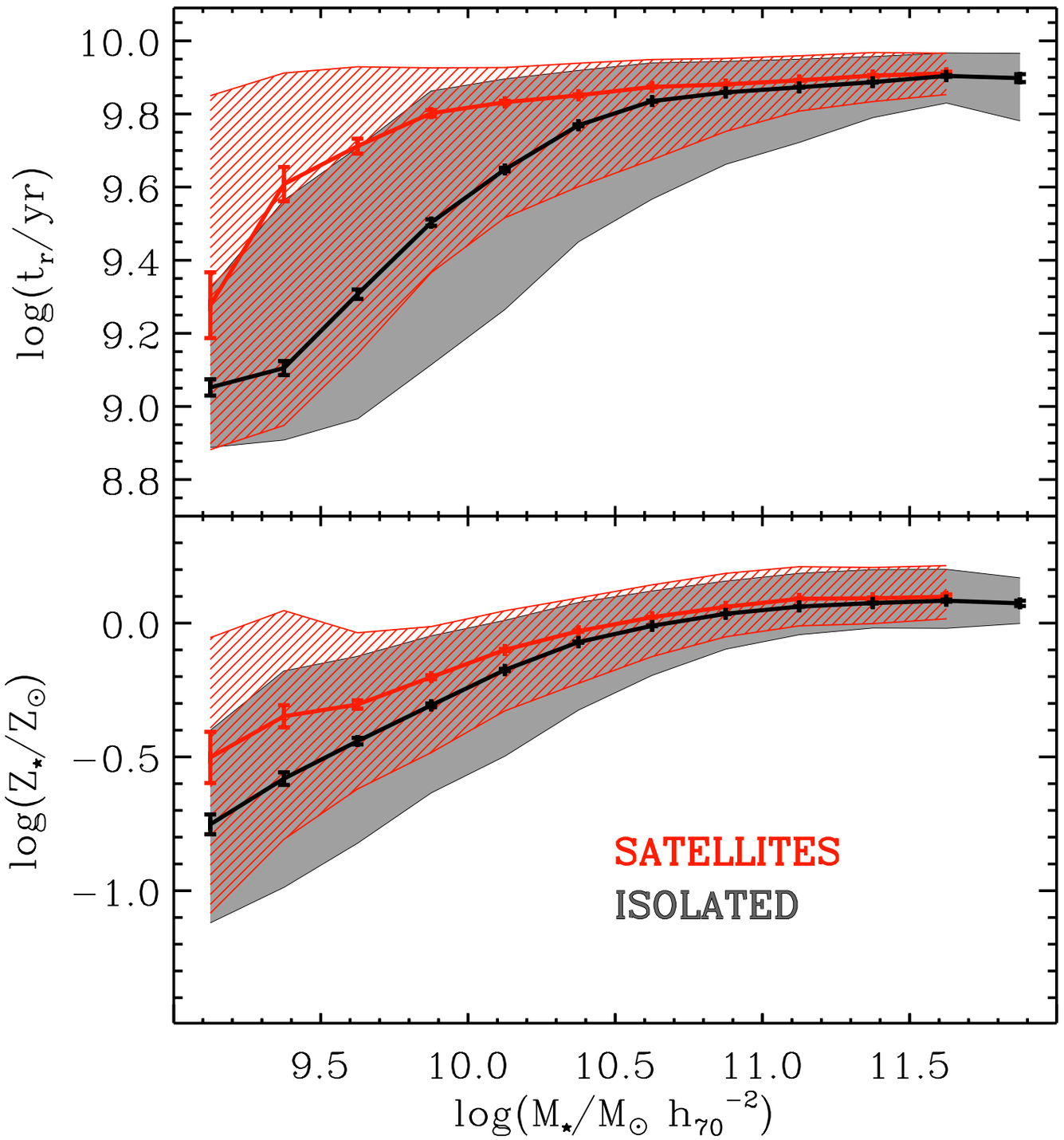
Population synthesis models with complex SFHs







ALL GALAXY TYPES

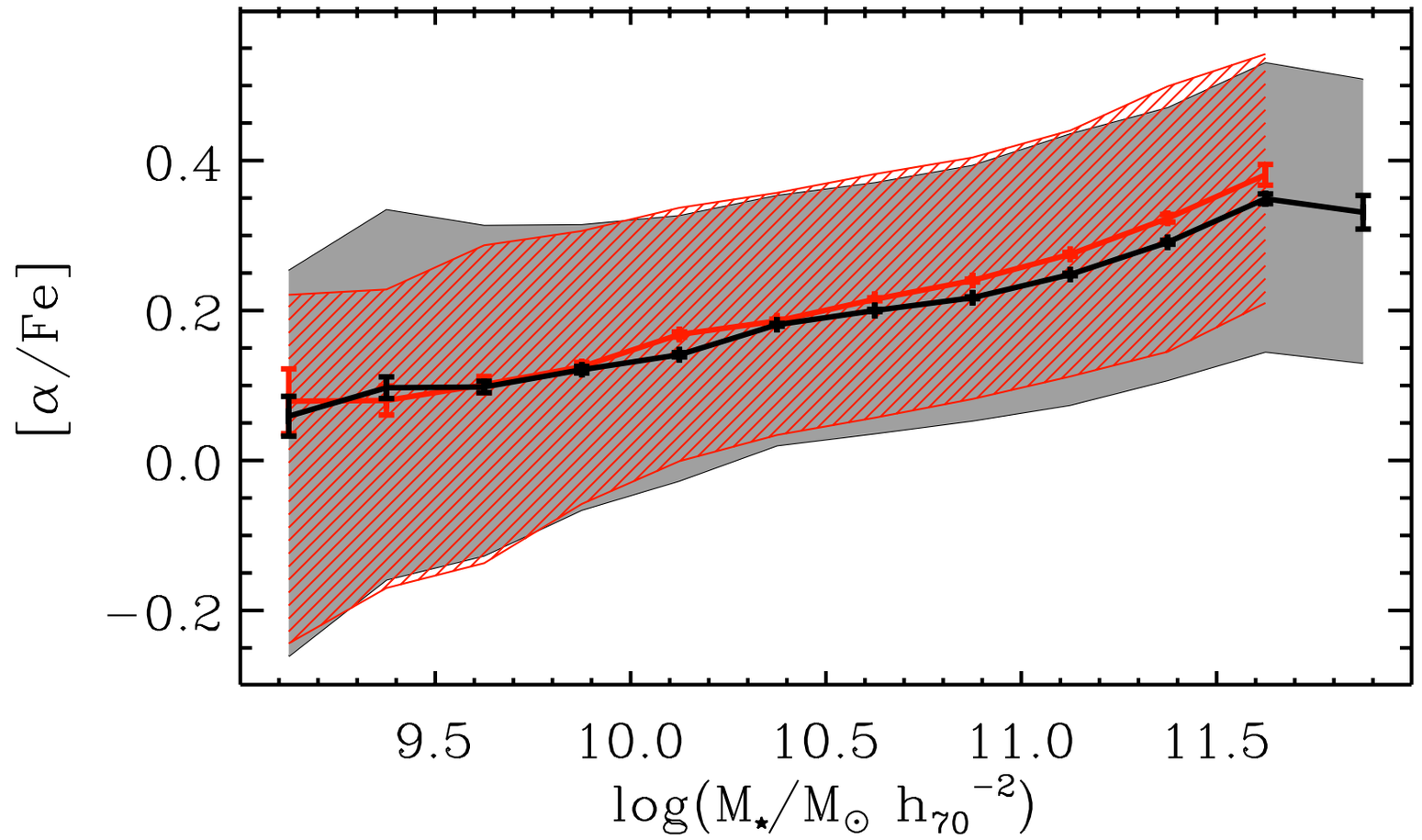


Stellar Mass

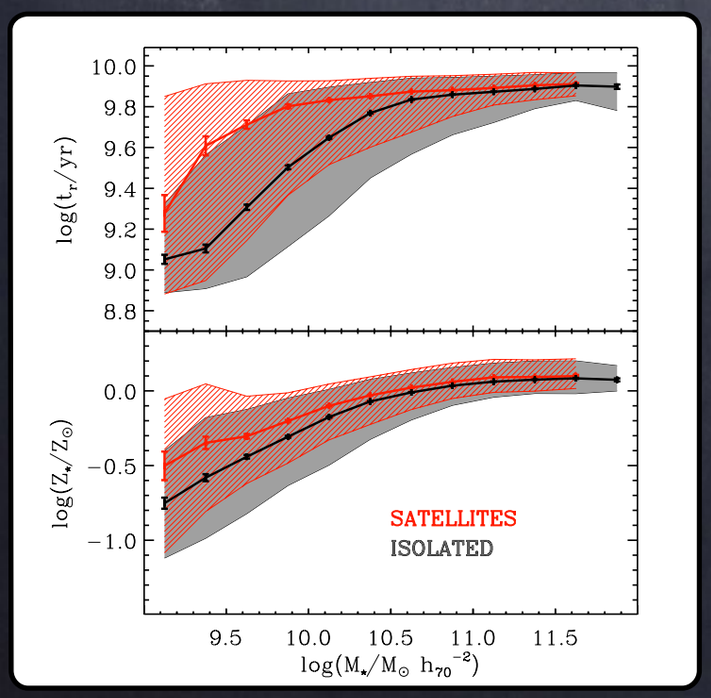
- At a given stellar mass, satellites are older and more metal-rich than isolated central galaxies, with increasing difference below $3 \times 10^{10} M_\odot$
- At nearly all mass lack of young, metal-poor galaxies among satellites; at masses $< 6 \times 10^{10} M_\odot$ excess of old, metal-rich galaxies among satellites

Pasquali et al 2010
Gallazzi et al 2015, in prep.

ALL GALAXY TYPES



Stellar Mass

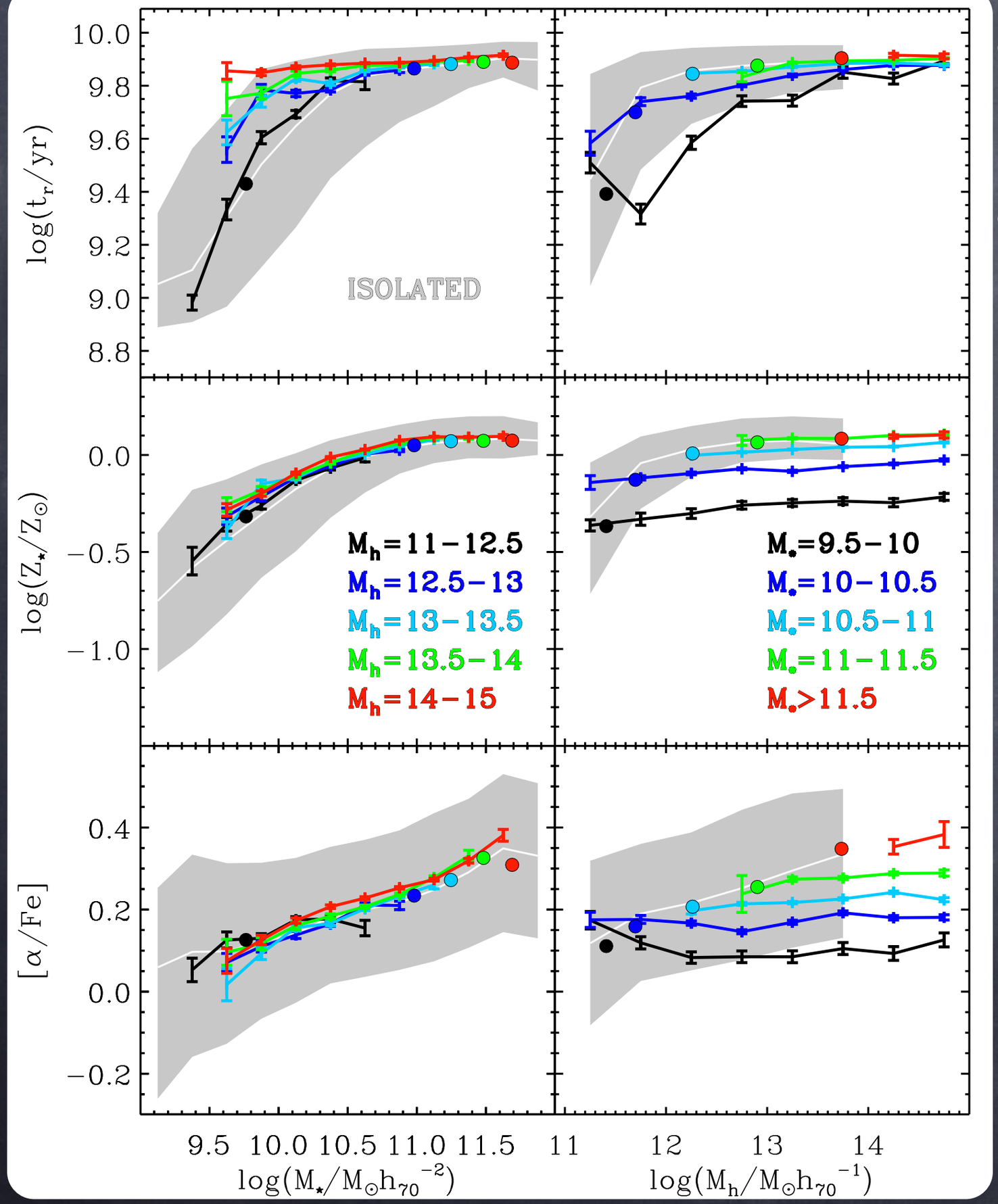


At fixed stellar mass SATELLITE galaxies are only slightly more α-enhanced than ISOLATED galaxies

not more than ~500Myr difference in "half-mass time" (using de la Rosa et al 2011 relation)

qualitatively consistent with Thomas et al 2010

Gallazzi et al 2015, in prep.



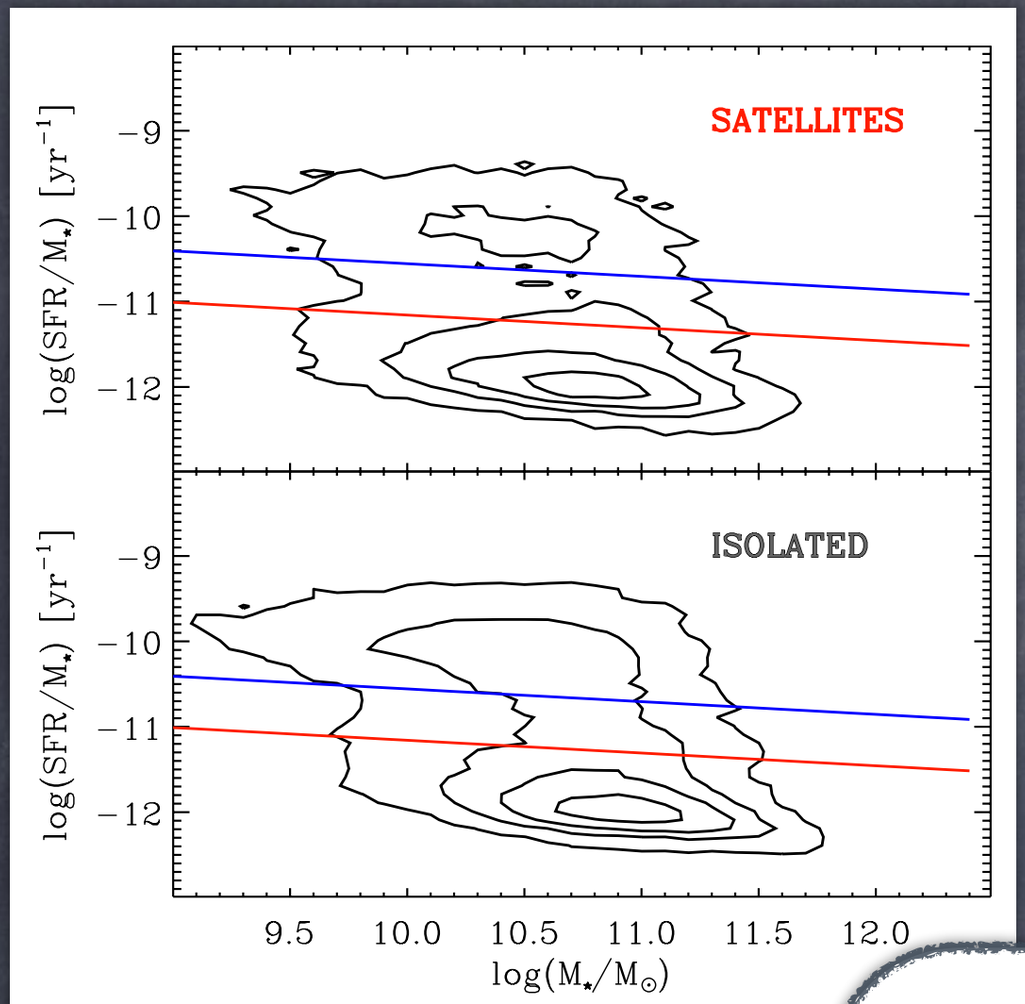
- $M_* > 3x10^{10}M_\odot$: satellites are coeval to centrals, nearly independent of halo mass
- $M_* < 3x10^{10}M_\odot$:
  - ages of satellites increase with the mass of the halo in which they reside
  - quenching of SF at infall; galaxies in more massive groups were accreted earlier

See also Pasquali et al 2010

- [α/Fe] of satellites is set by the galaxy stellar mass, almost independently of halo mass
- environmental quenching happens significantly after bulk of SF occurs

Gallazzi et al 2015, in prep.

Specific SFR

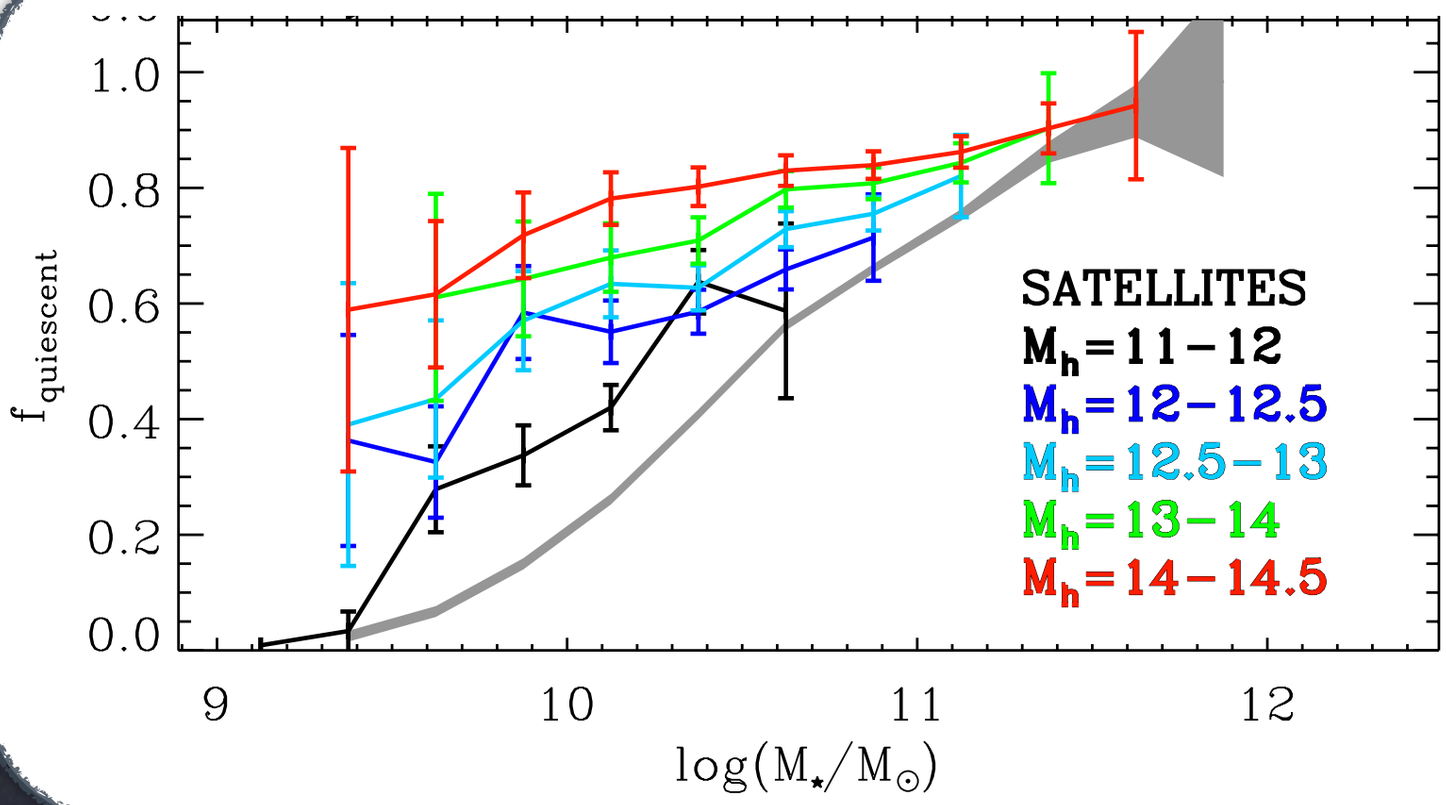


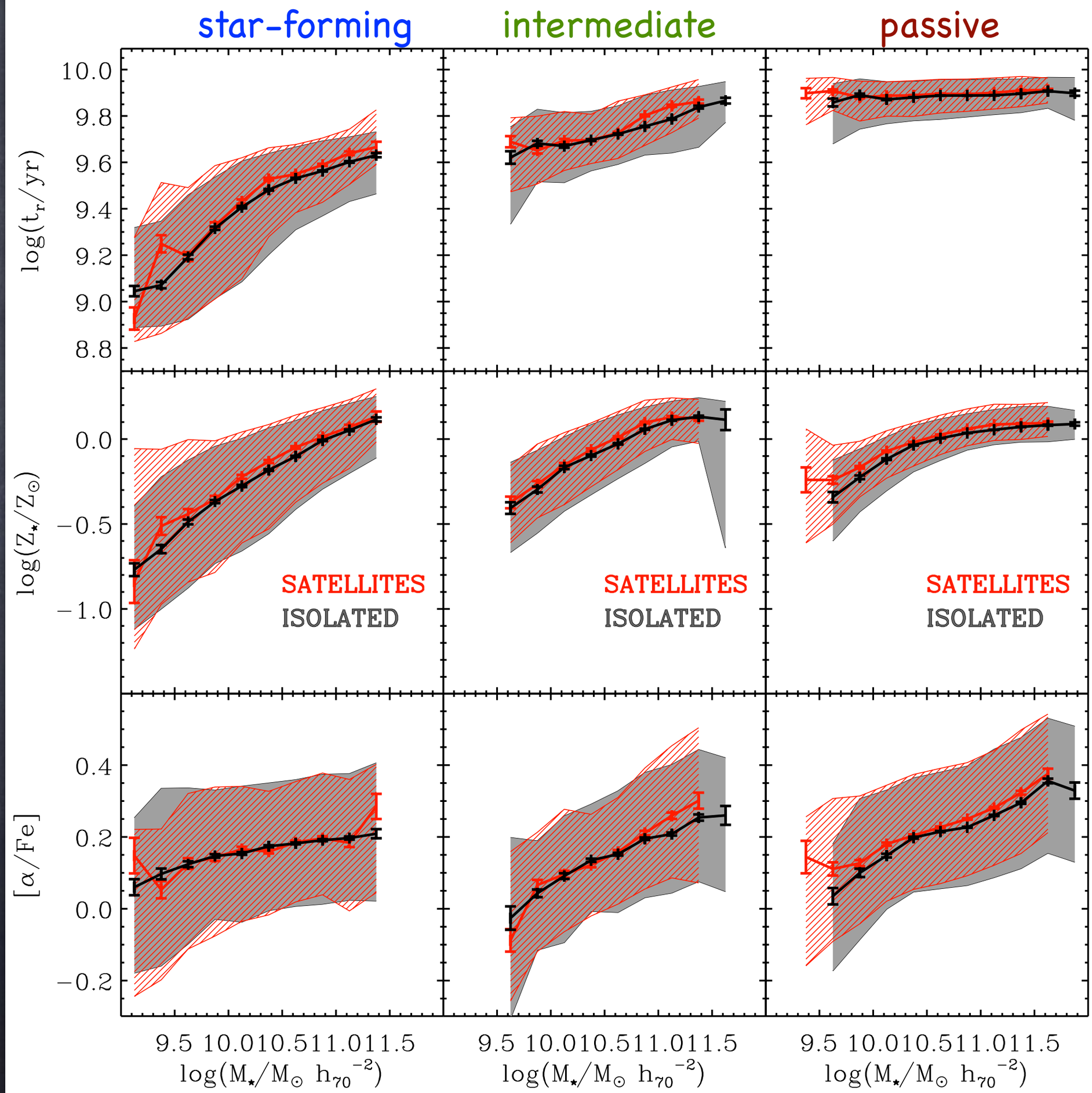
Stellar Mass

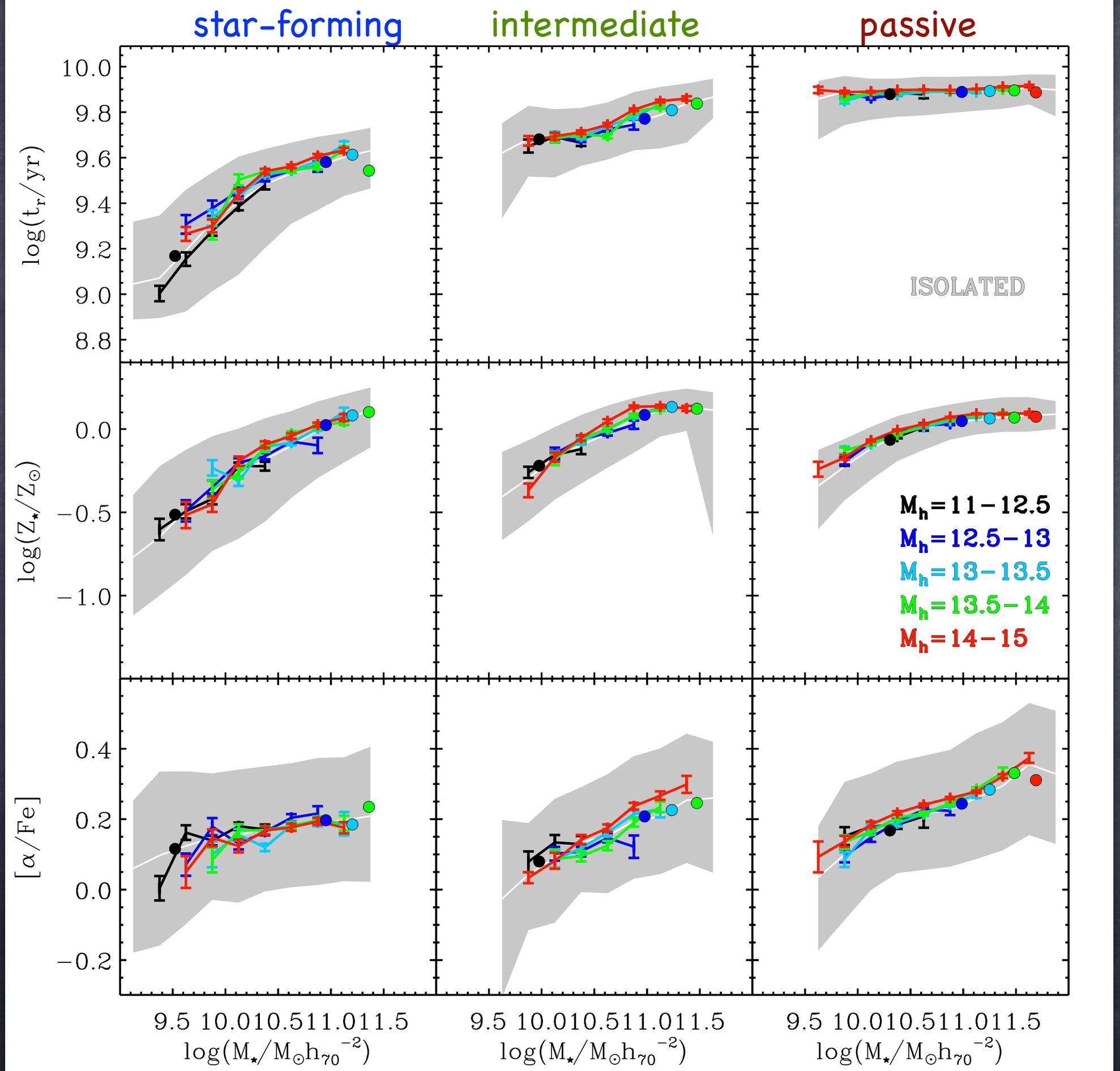
(e.g. Balogh+2000, Baldry +2008,van den Bosch+2008, Peng+2011, Wetzel+2013)

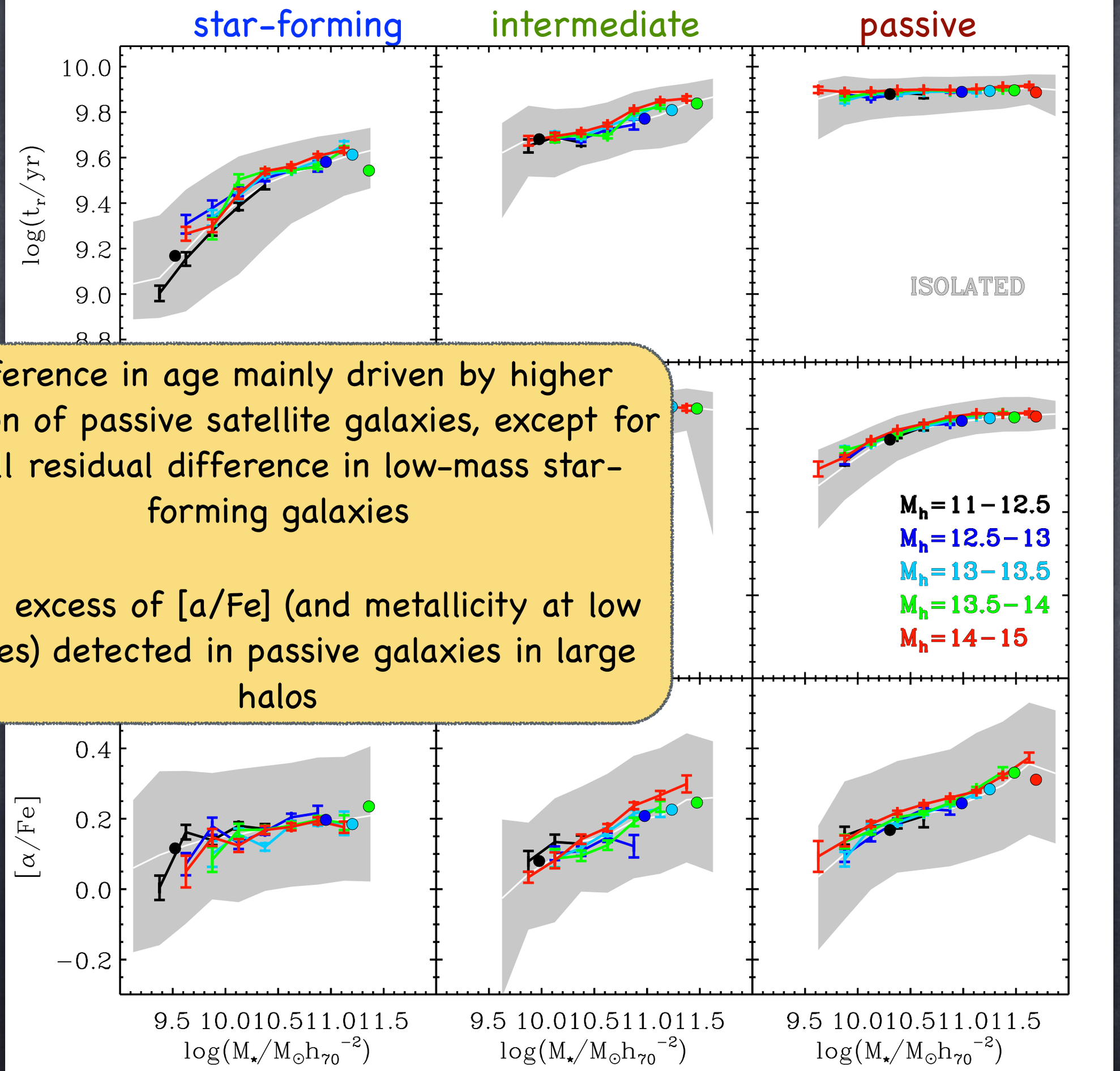
Do the differences reflect just a different fraction of quiescent and star-forming galaxies?

Do quiescent and star-forming satellites separately differ from their isolated analogs?




star-forming
intermediate
passive
log(t_r/yr)
10.0
9.8
9.6
9.4
9.2
9.0
8.8
log(Z_*/Z_⊙)
0.0
−0.5
−1.0
SATELLITES
ISOLATED
[α/Fe]
0.4
0.2
0.0
−0.2
9.5 10.010.511.011.5
log(M_*/M_⊙ h_70^-2)


star-forming
intermediate
passive
ISOLATED
$M_h = 11 - 12.5$
$M_h = 12.5 - 13$
$M_h = 13 - 13.5$
$M_h = 13.5 - 14$
$M_h = 14 - 15$
$\log(t_r/yr)$
$\log(Z_\star/Z_\odot)$
$[\alpha/Fe]$
$\log(M_\star/M_\odot h_{70}^{-2})$



Difference in age mainly driven by higher fraction of passive satellite galaxies, except for small residual difference in low-mass star-forming galaxies

Small excess of [a/Fe] (and metallicity at low masses) detected in passive galaxies in large halos

Summary and thoughts

- **Massive ($M^* > 3\times10^{10}M_\odot$) or passive galaxies**: **early formation epoch** (as isolated galaxies); [α/Fe] primarily driven by galaxy mass (internal efficiency); influence of environment seen in the slightly higher [α/Fe] in the most massive halos **-> quenching timescales shorter by at most ~500Myr** ...quenched before being accreted? (see also Wetzel et al 2013)

- **Low-mass satellites older and slightly more metal-rich than equally massive isolated centrals** → gas strangulation and/or stripping that quenches supply of cold gas for star-formation; also explains the higher gas metallicities by preventing inflows of metal-poor gas from the outskirts

- Differences in age reflect to first order the increasing fraction of passive galaxies among satellites in increasingly massive haloes

- **Timescale of SF, as traced by [α/Fe], depends only on stellar mass, equally for isolated and satellites:** The overall timescale of quenching is long enough for SF to continue and process SN products according to internal efficiency

- consistent with a **delayed-then-rapid quenching scenario** (Wetzel et al 2013): star-formation continues for 2-4Gyr before quenching on <1Gyr timescale; timescale only dependent on galaxy mass (shorter at higher masses) -> two-phase quenching: "strangulation" + ram-pressure stripping (see also Pasquali et al 2012)