Satellite Galaxy Evolution in Groups & Clusters

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Using galaxy group/cluster catalogs created from the Sloan Digital Sky Survey (SDSS) Data Release 7, we examine the specific star formation rate (SSFR) distribution of satellite galaxies and its dependence on stellar mass, halo mass, and halo-centric radius. We show that the fraction of quenched satellites depends sensitively on halo mass and halo-centric radius, but beyond this the bimodal SSFR distribution of satellites is nearly identical to that of centrals. Using a high-resolution cosmological simulation to track satellite orbits, we test the mechanisms and timescales for satellite star formation quenching that best fit these observed dependencies. Satellites that are active at infall must evolve in the same manner as active central galaxies, regardless of their environment, for 2-5 Gyr after infall, after which star formation quenching occurs on a rapid (<1 Gyr) timescale. Satellite quenching is responsible for the majority of galaxies on the 'red sequence' at $M_{star} < 10^{10}\,M_\odot$.

Galaxy Group Catalog

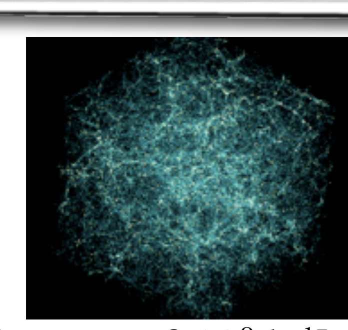
SDSS Data Release 7, NYU value-added catalog (Blanton et al. 2005)

Spectroscopically derived specific star formation rates (Brinchmann et al. 2004)

Group finding based on the Yang et al. 2007 algorithm

High purity & low contamination (~15%) as calibrated against mock catalogs

High-resolution N-body Simulation

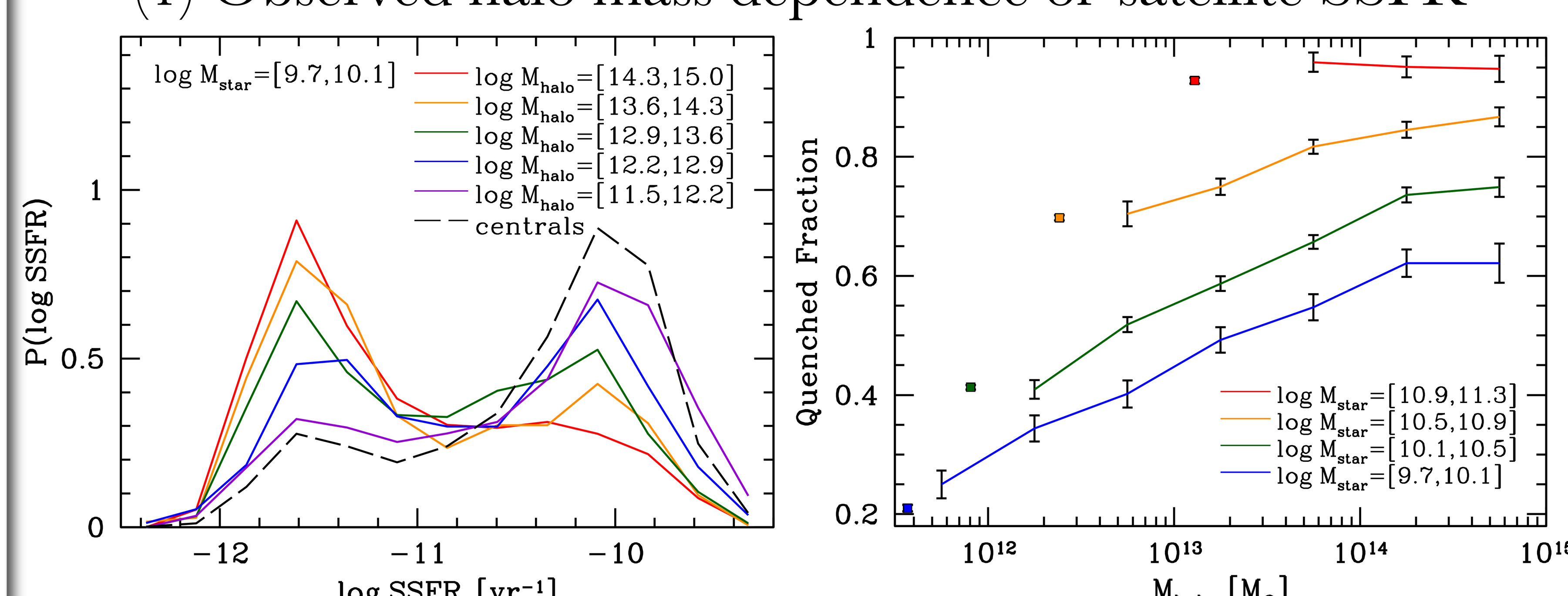


250 h^{-1}Mpc box, particle mass of $10^8\,h^{-1}M_\odot$

Stellar mass assigned to subhalos via abundance matching

We apply our group finder to the simulation to robustly compare against SDSS

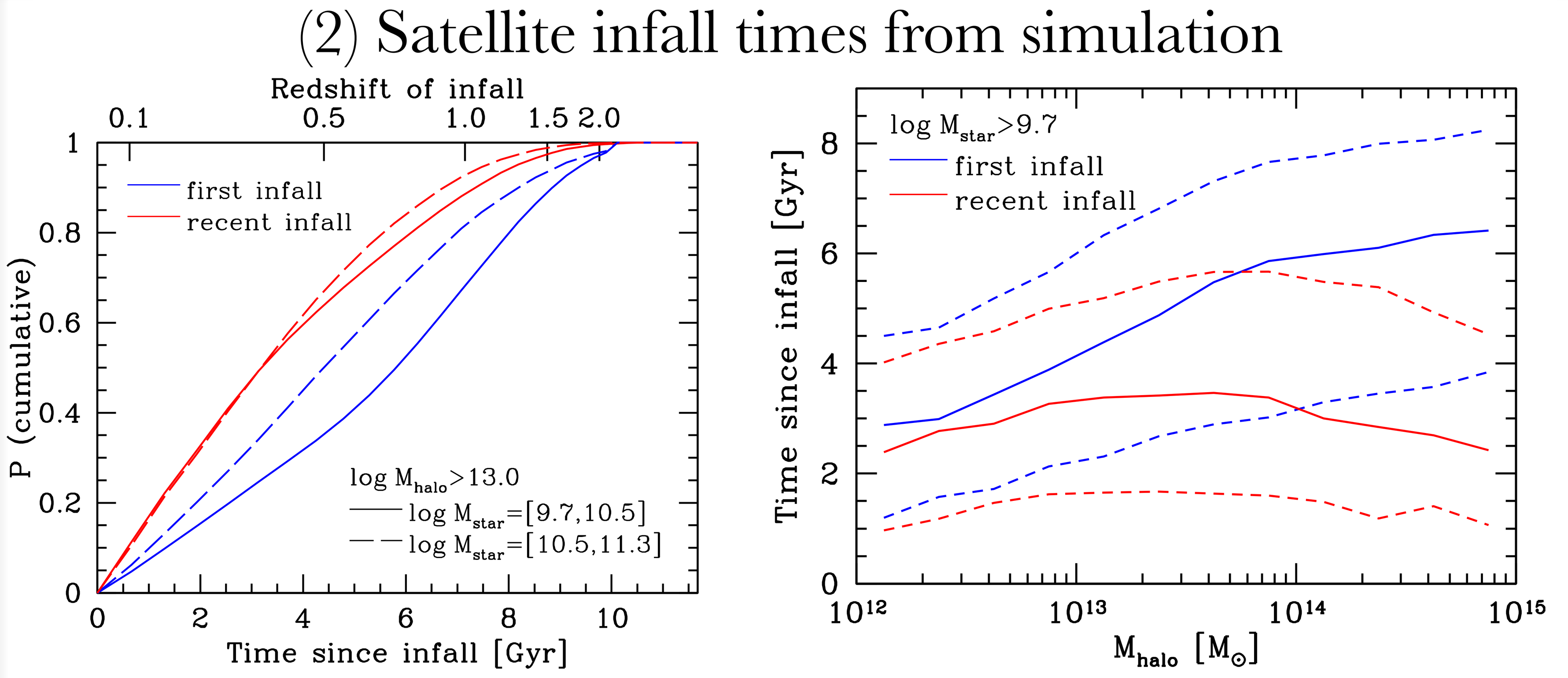
(1) Observed halo mass dependence of satellite SSFR



SSFR distribution of satellites exhibits strong halo mass dependence, but the mechanism that quenches satellite star formation preserves the strong bimodality.

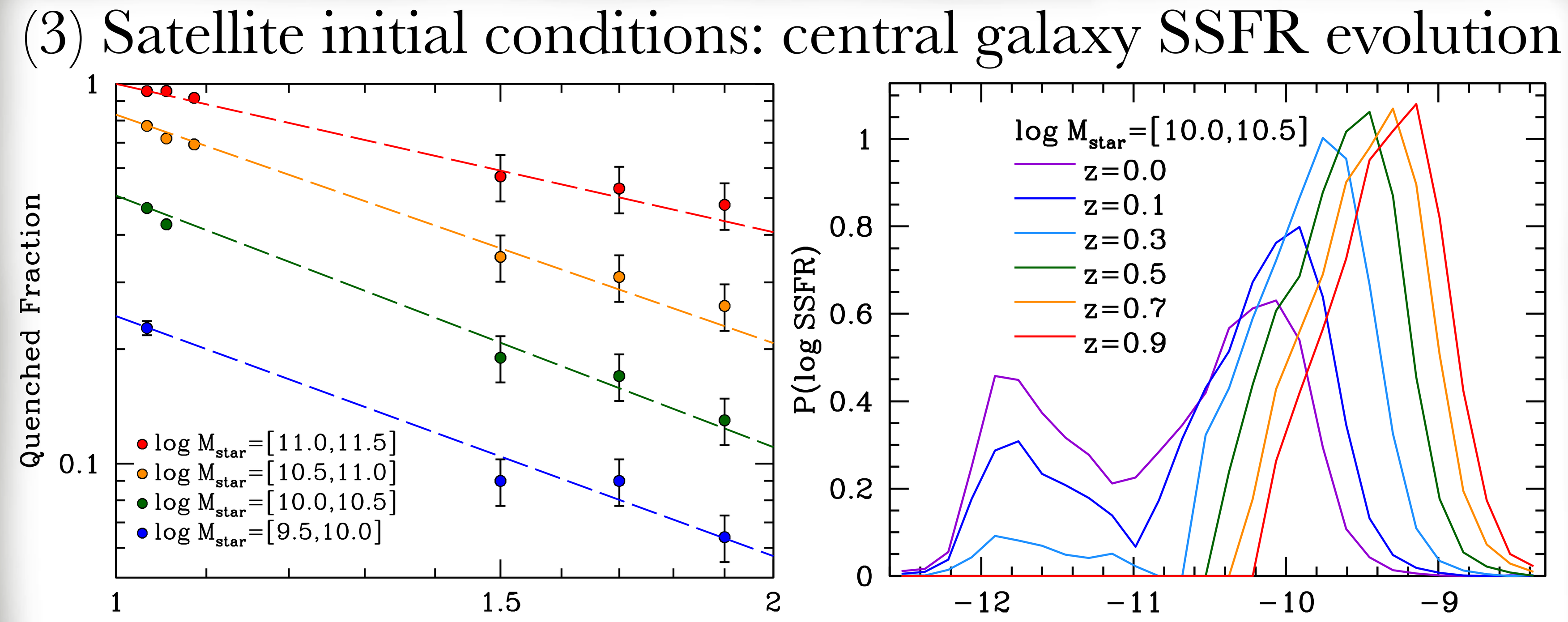
Satellite quenched fraction (SSFR < 10^{-11}yr^{-1}) increases with both galaxy stellar mass and halo mass. The quenched fraction also increases toward halo center [see (5), right].

(2) Satellite infall times from simulation



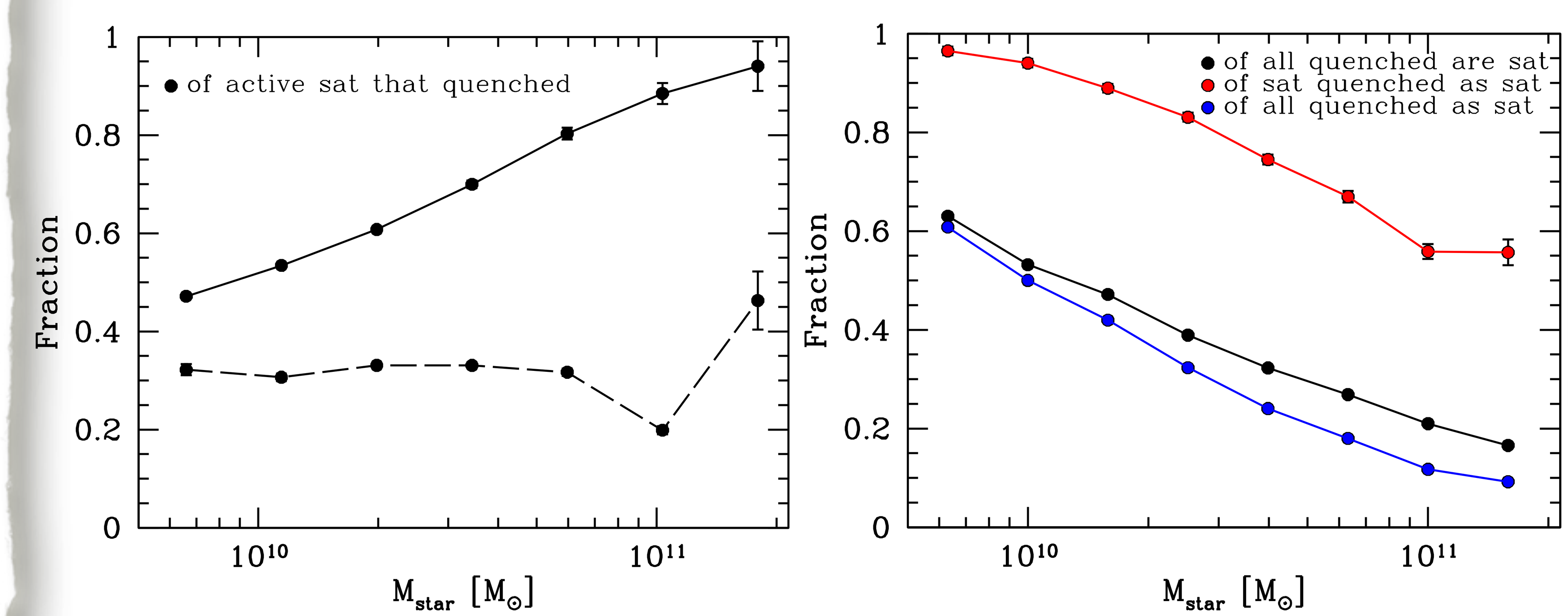
Left: Satellites at z = 0 experienced a broad distribution of infall times, with median first infall at z ~ 0.5. Modeling satellite quenching requires knowing central galaxy SSFRs up to z ~ 1.
Right: Satellite time since *first* infall increases with halo mass, while time since most *recent* infall does not, showing the importance of pre-processing in groups and ejection/re-infall.

(3) Satellite initial conditions: central galaxy SSFR evolution



To examine satellite star formation evolution, we first need their initial conditions at infall, given by the central SSFR distribution at higher z. Our empirical model uses the overall galaxy quenched fraction from SDSS and COSMOS (Drory et al. 2009) (left). We obtain the satellite fraction evolution from simulation and the satellite quenched fractions from Tinker & Wetzel 2010 to subtract the satellite contribution. We evolve the SSFR normalization of active galaxies with a τ-model consistent with DEEP2 (Noeske et al. 2007) (right).

(4) Importance of satellite quenching



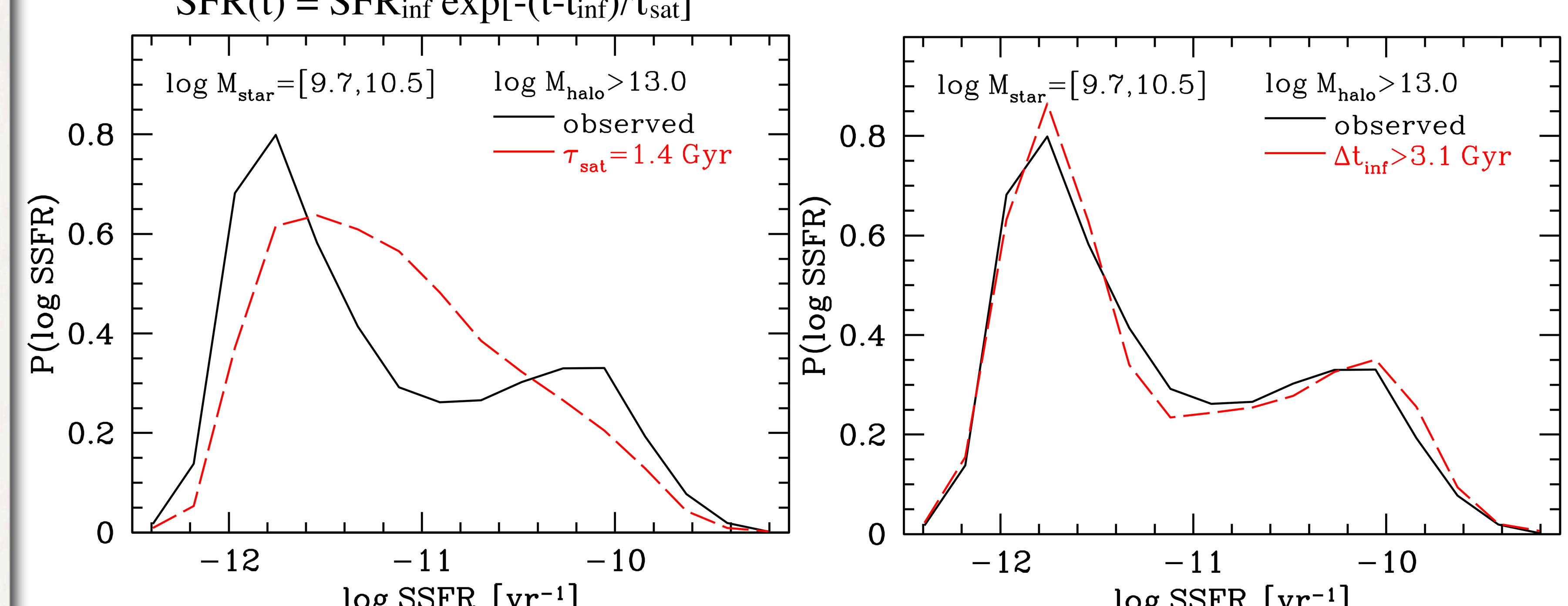
Left: Fraction of active satellites that quenched after infall, using our central SSFR evolution model (solid curve). Satellite quenching is more efficient/rapid in more massive satellites. Dashed curve shows simply assuming z = 0 central SSFR for satellite initial conditions, highlighting the importance of having accurate values for SSFRs at infall.

Right: Fraction of all quenched galaxies at z = 0 that are satellites (black), fraction of quenched satellites that quenched as satellites (red), and fraction of all quenched galaxies that quenched as satellites (blue). At $M_{star} < 10^{10}\,M_\odot$, the majority of quenched galaxies quenched as satellites.

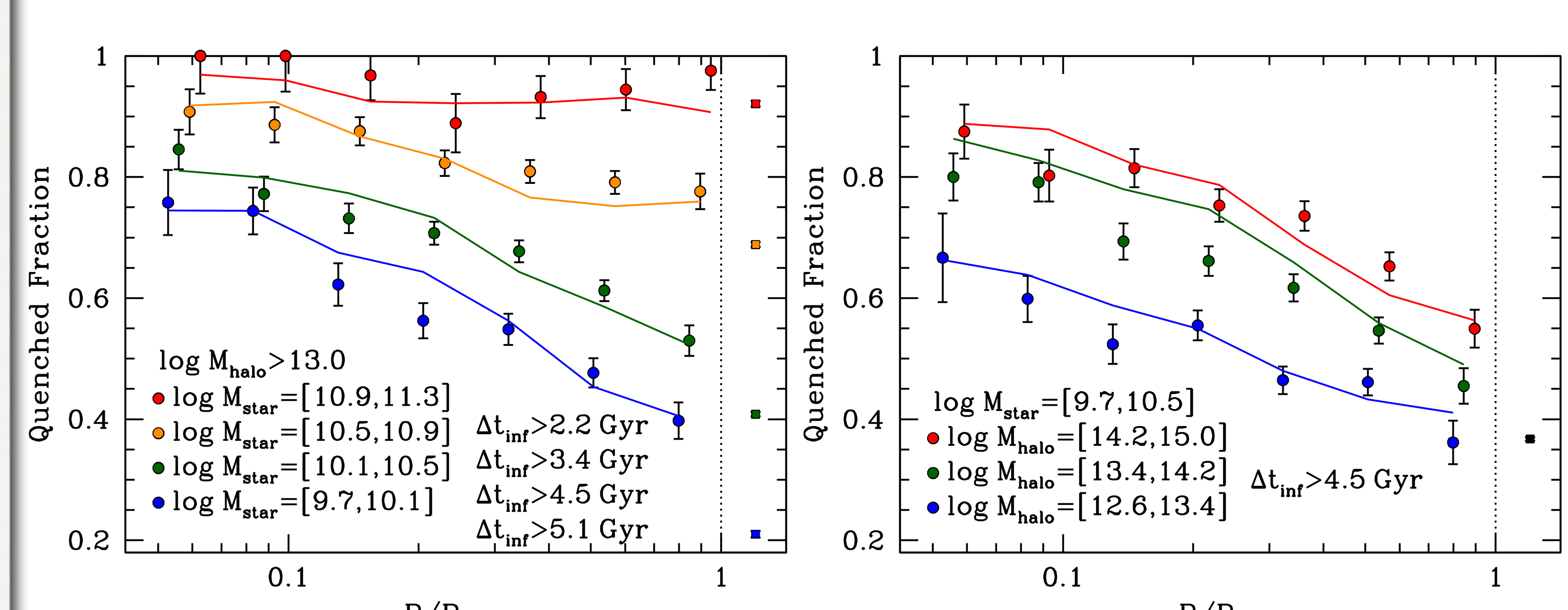
(5) Testing satellite quenching mechanisms & timescales

We develop simple models for satellite quenching, whose single parameter is constrained by matching the satellite quenched fraction at a given stellar mass. We then examine which models best match the satellite SSFR distribution and quenched fraction dependencies on halo mass, satellite mass, and halo-centric radius.

$SFR(t) = SFR_{inf}\exp[-(t-t_{inf})/\tau_{sat}]$



Left: A scenario in which satellite SFR fades gradually after infall, such as simple strangulation, puts too many satellites on the 'green valley'. **Right:** A scenario in which satellite SFR fades passively in the same manner as centrals for 2-5 Gyr after infall, followed by a rapid (~800 Myr) quenching phase, reproduces the SSFR bimodality well.



The above delayed-then-rapid satellite quenching model, which is based simply on time since infall, best matches the quenched fraction vs. radius as a function of both satellite mass (left) and halo mass (right). This implies that high-mass satellites quench much more quickly after infall than low-mass satellites (~2 Gyr for $M_{star} \sim 10^{11}M_\odot$ vs. ~5 Gyr for $M_{star} \sim 10^{10}M_\odot$).

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