Next Generation (Semi-)Empirical galaxy formation models
-
Matching individual galaxies

Benjamin Moster (IoA/KICC)

Simon White, Thorsten Naab (MPA),
Rachel Somerville (Rutgers), Frank van den Bosch (Yale), Andrea Macciò (MPIA)

Rob Crain @rcrain_astro 27 Apr

Just occurred to me that this summer's #qnq2014 conference starts the morning after the World Cup final. Monday morning might be difficult.

Expand


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Why (semi-)empirical models?

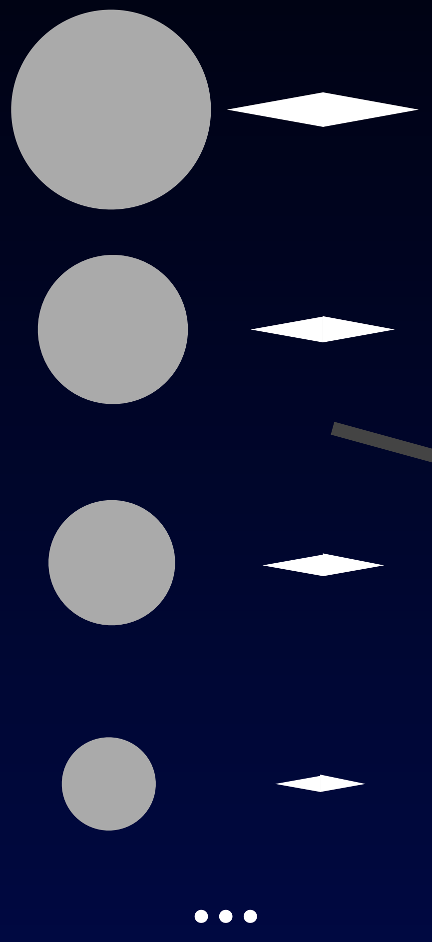
- Model observations in self-consistent cosmological framework
  - Build-up of stellar mass over time and relation to DM haloes
  - What determines galaxy mass and clustering properties
  - What sets the SFR? When/how is it triggered/quenched?
  - What does the stochastisity in GF depend on?

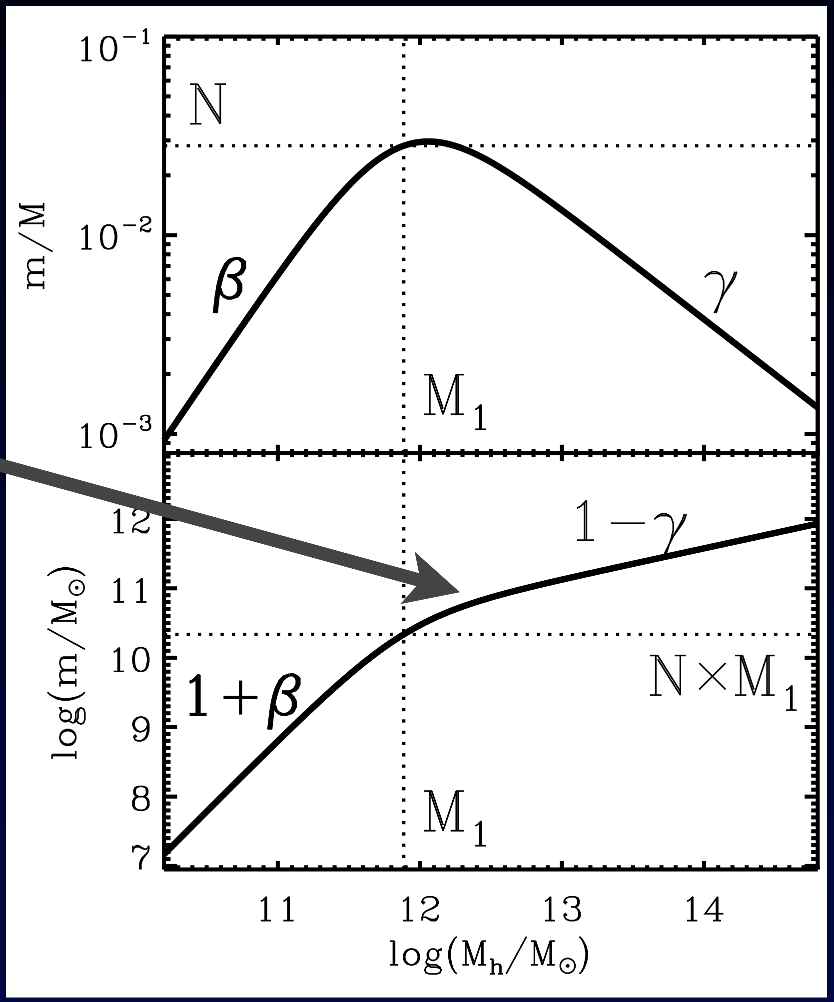
- Ab initio models: motivated by baryonic physics
  → try to predict statistical galaxy properties (e.g. SMF, CF, SSFR)
  - Hydro Sims: uncertain, unresolved physics, comp. expensive
  - SAMs: large parameter space, may not include all rel. physics

- Empirical Models: link stellar mass and halo mass statistically
  → put constraints on physical processes involved (SF, FB, ...)

Abundance matching & parameterized linking

- Produce galaxy catalogue from observed SMF in same volume as halo catalogue
- Match galaxies-haloes by mass
- Optional: Use fitting-function to get $m_*(M_h)$





$$m_*(M_h) = 2\ R\ M_h \left[\left(\frac{M_h}{M_1} \right)^{-\beta} + \left(\frac{M_h}{M_1} \right)^{\gamma} \right]$$

Abundance matching & parameterized linking

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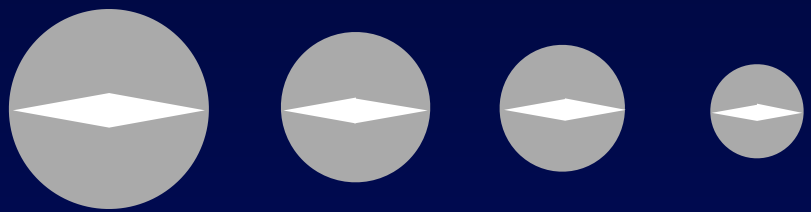
- Optional: Use fitting-function to get $m_*(M_h)$

- Assume function for $m_*(M_h)$
- Populate haloes with galaxies
- Compute model SMF
- Fit parameters to observed SMF

$$m_*(M_h) = 2\ R\ M_h \left[\left(\frac{M_h}{M_1} \right)^{-\beta} + \left(\frac{M_h}{M_1} \right)^{\gamma} \right]$$



...

- Derive $m_*(M_h)$ individually for a set of redshifts

Abundance matching & parameterized linking

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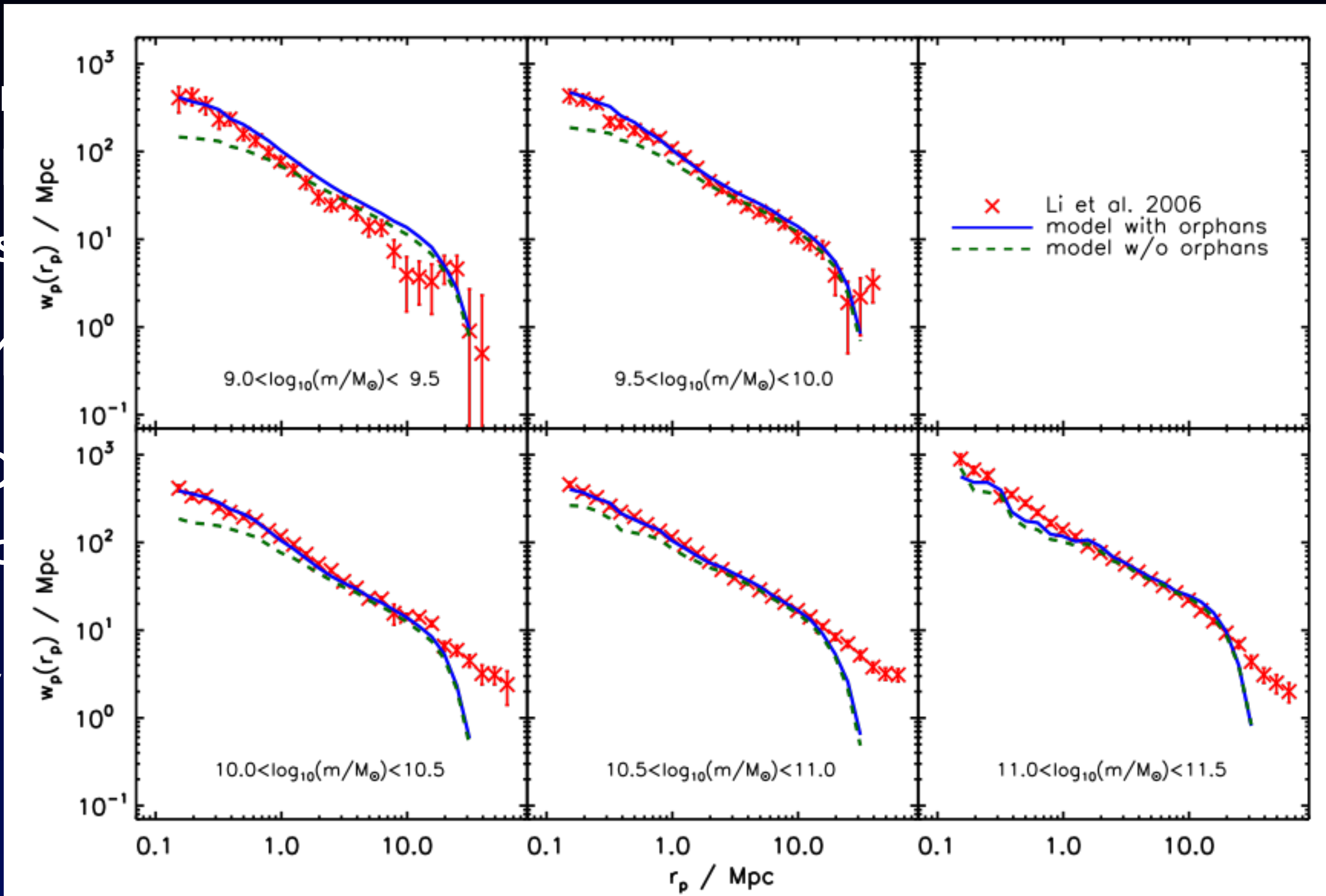
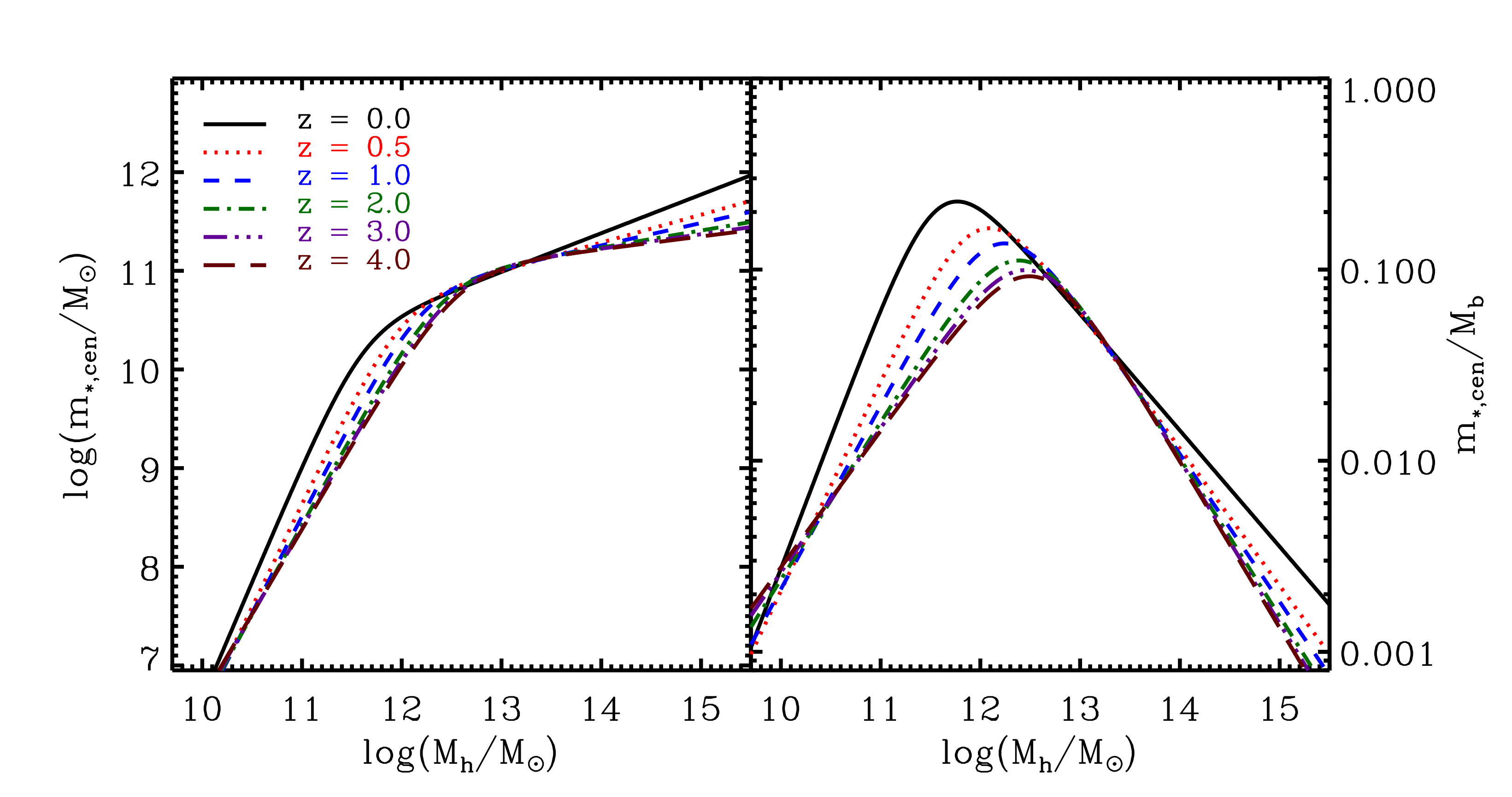


m ... ...

Evolving stellar-halo mass relation

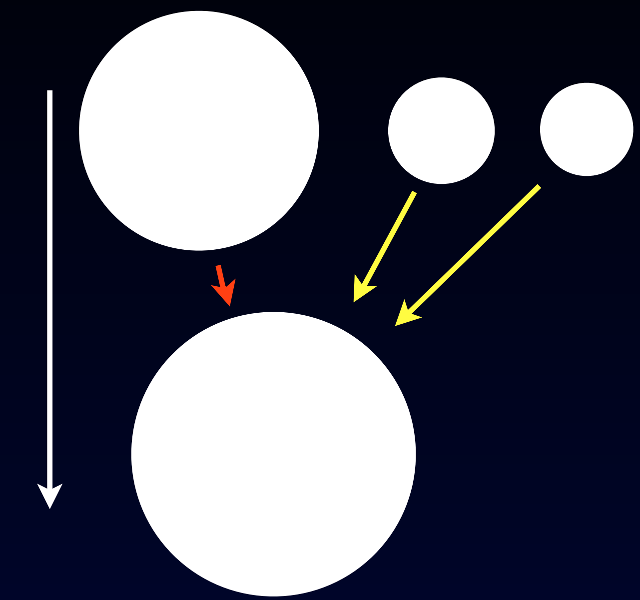
- Evolving relation, but satellites are forced to follow the local one
- Inconsistency between different redshifts
- Assume redshift dependent parameters M1(z), N(z), β(z), γ(z)
- Stellar-to-halo mass relation now depends on M_{infall} and z_{infall}

- Fit $m_s(M_h,z)$ using all SMFs simultaneously using a MCMC
- SMFs can be fitted to high redshift

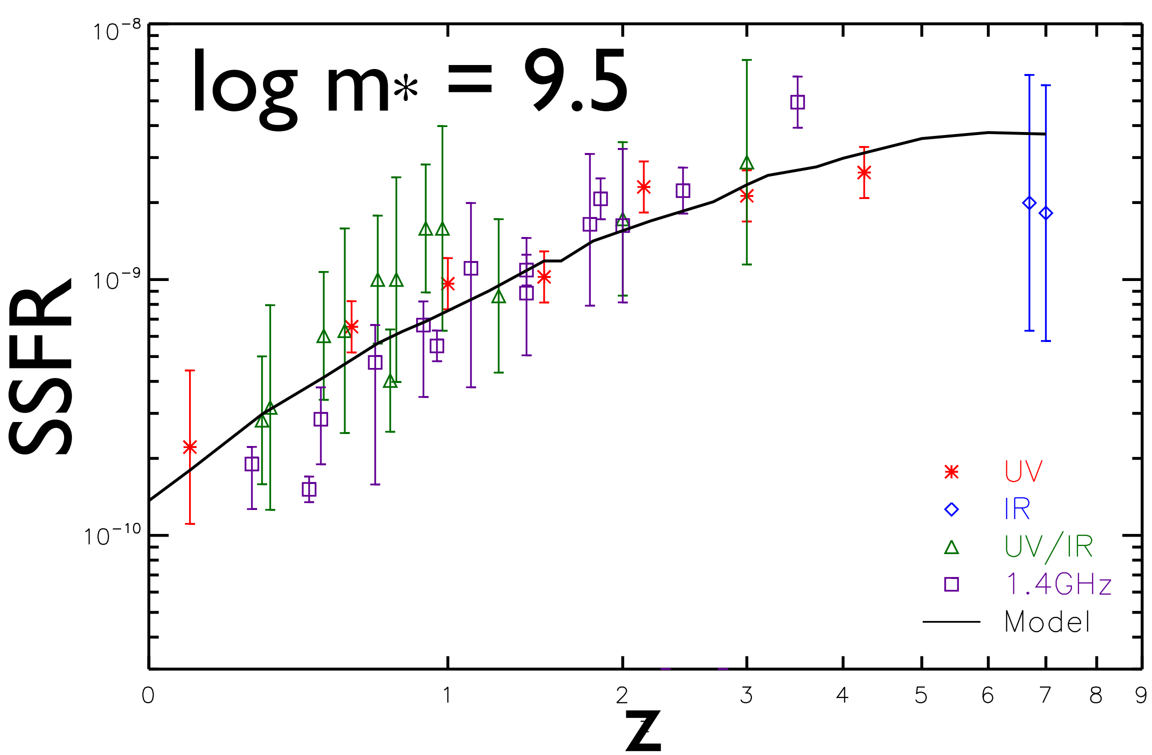


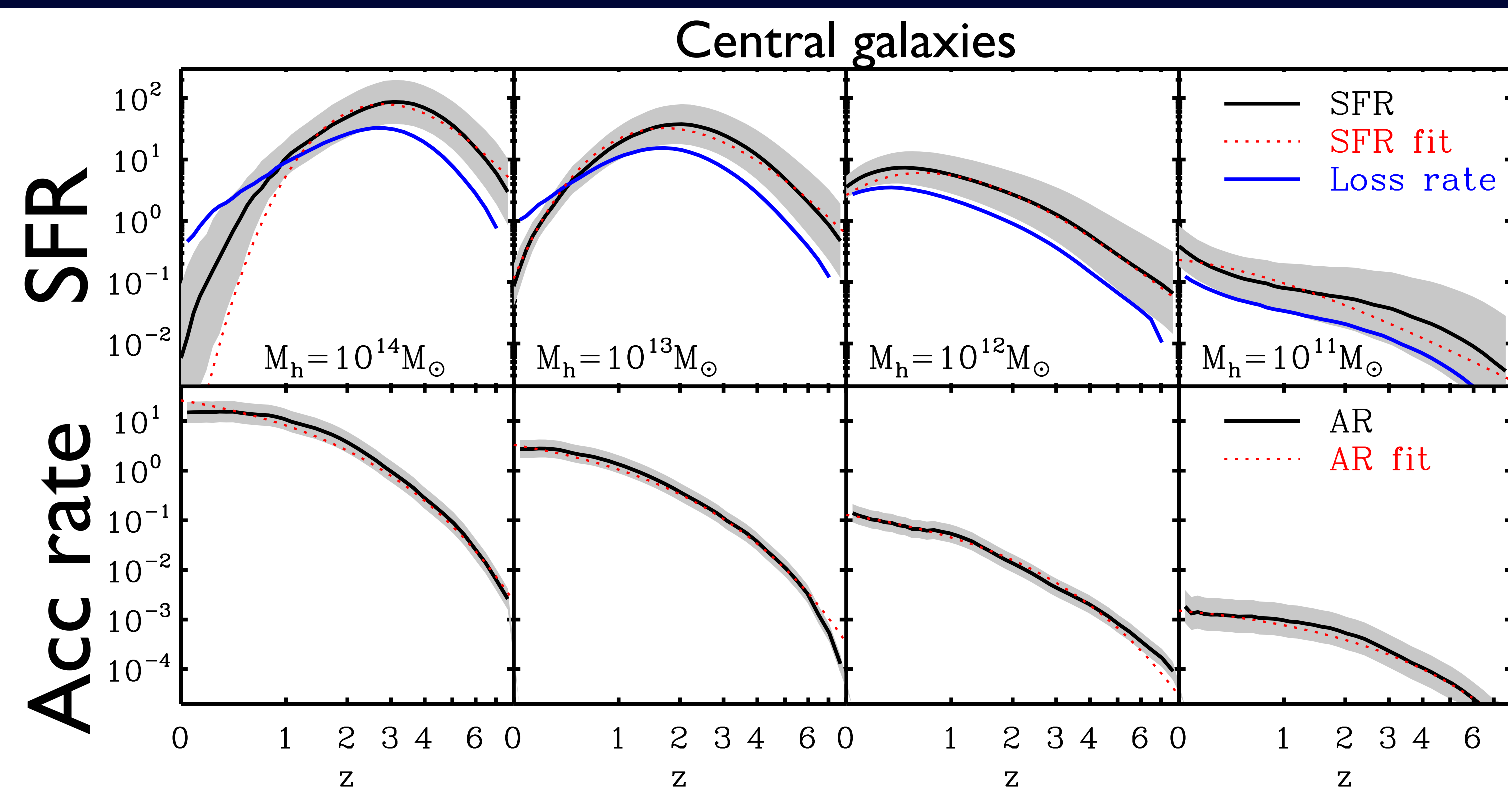
Inferred SFRs and accretion rates

- Identify all progenitors at previous snapshot
- SFR = total growth rate - accretion rate
- SFR peaks at some redshift and declines again
- Use derived SFR relation to predict SSFRs
- Model predictions are in excellent agreement



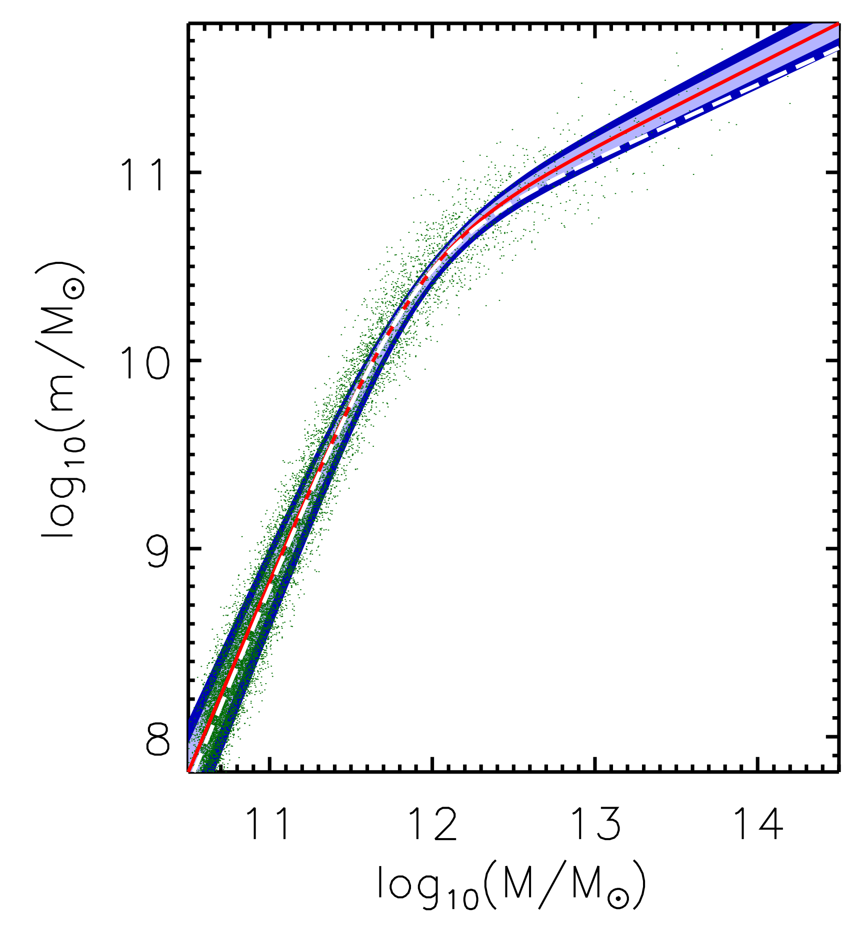
star formation
accretion
total growth





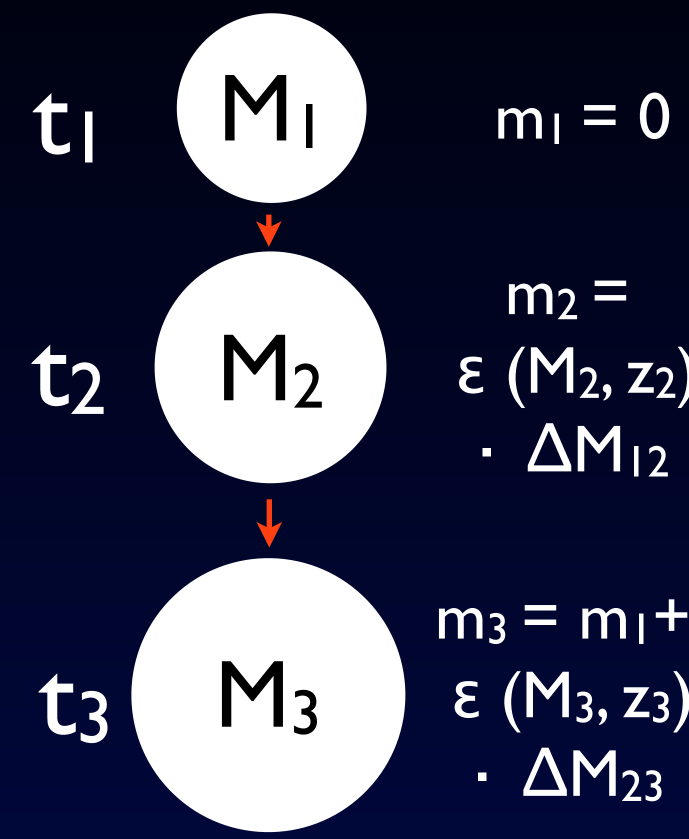
Scatter / Colour

- Expect haloes of same mass M to have galaxies with different stellar masses (due to different formation history)
- To include that, scatter drawn from lognormal distribution (0.15-0.2 dex) is added to average m_s-M_h relation
- SFR prediction only for average halo mass
  → no SSFR / colour information for individual galaxies
- Difficult to include individual SSFRs in average models (but cf Hearin & Watson)
- Simple models cannot predict colour-dependence, e.g. for clustering…

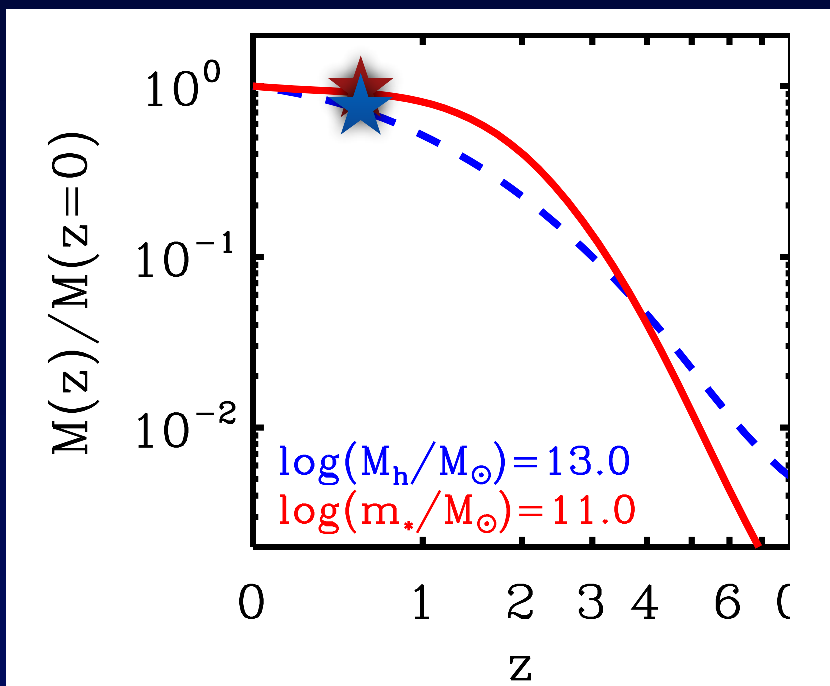


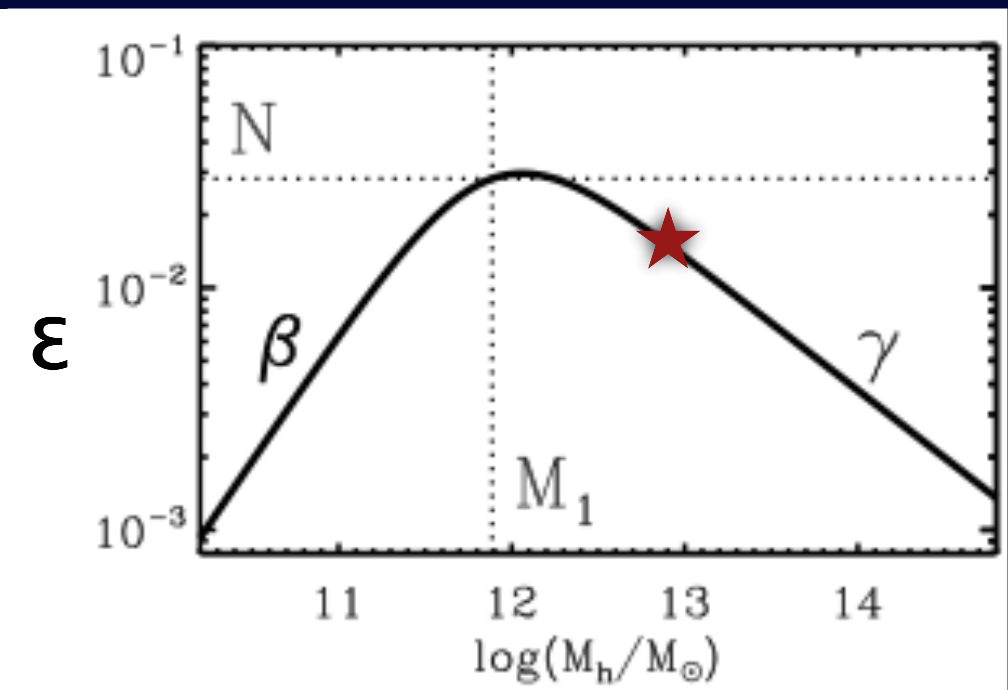
Models for individual haloes

- So far: stellar masses from average m_*-M_h relation (no growth history)
- Now: parameterize SF efficiency as function of halo mass: $\dot{m}_* / \dot{M}_h = \varepsilon\,(M_h, z)$
- Stellar mass increases in one time-step as $\Delta m_* = \varepsilon \cdot \Delta M_h = \varepsilon\,\dot{M}_h\,\Delta t$



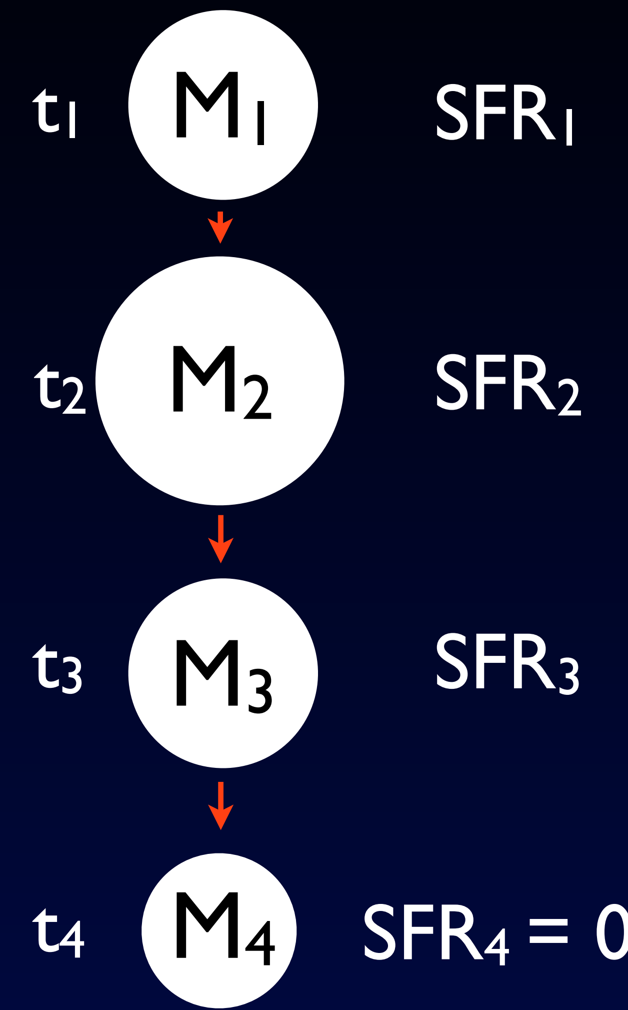
- Maximum SFR reached when $M_h \sim 10^{12}\,M_{sun}$
- Afterwards SFR declines again

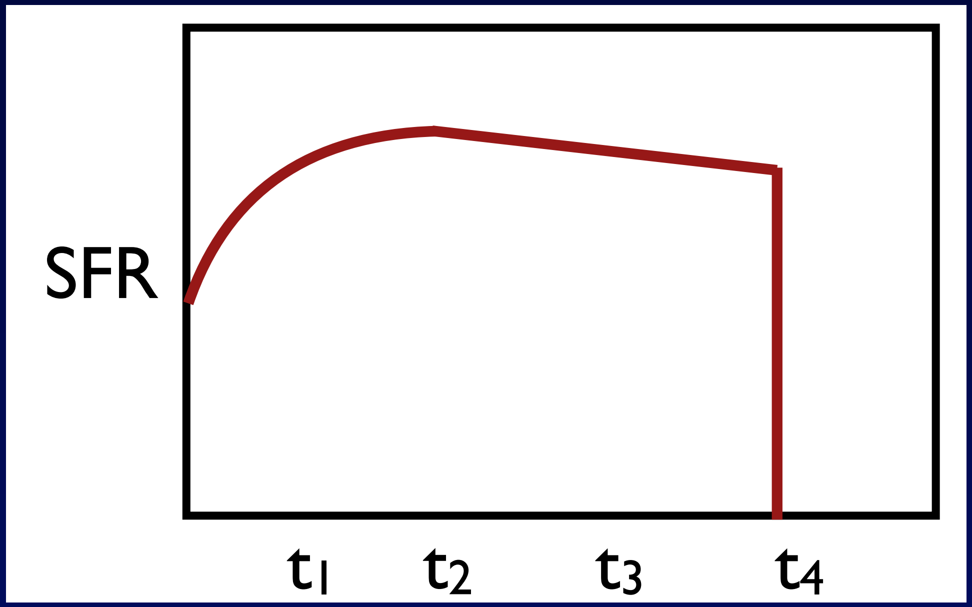




Satellite galaxies in individual haloes

- While host halo grows → galaxy forms stars
- When host stops growing mass (loses mass) → galaxy continues forming stars at current SFR with exponential decline on time-scale τ_1
- After time-scale τ_2 has passed → SF is completely quenched (cf. Wetzel et al.)
- Time-scales can be constrained by fitting to quenched fractions vs stellar mass





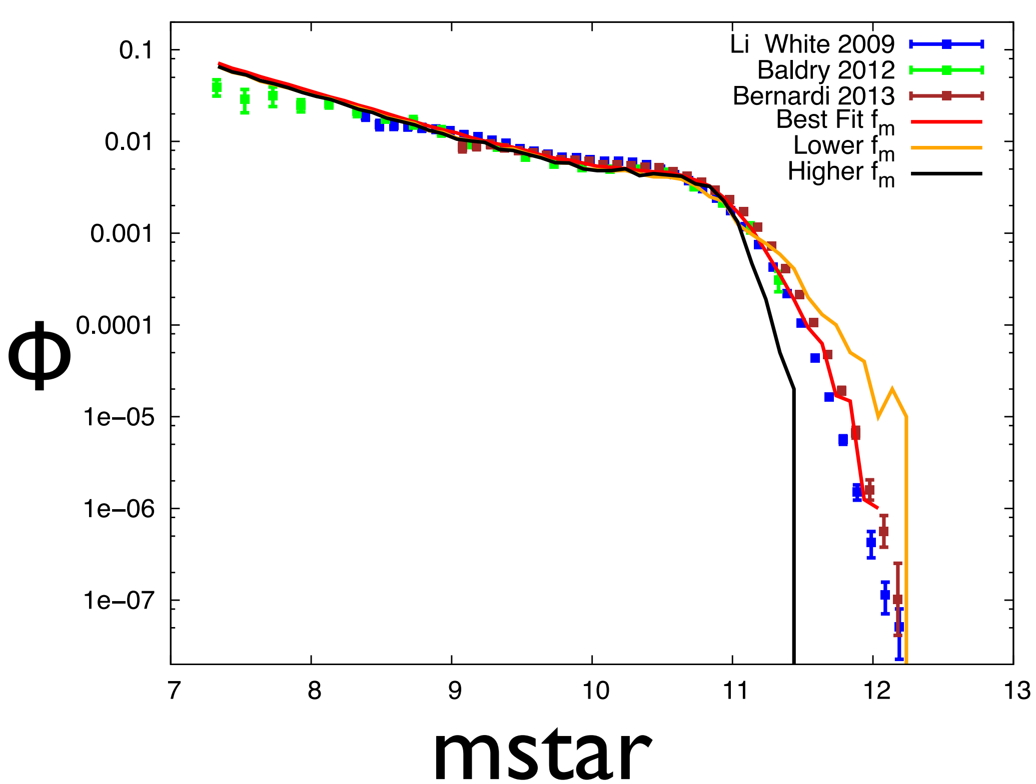
Satellite stripping and merging

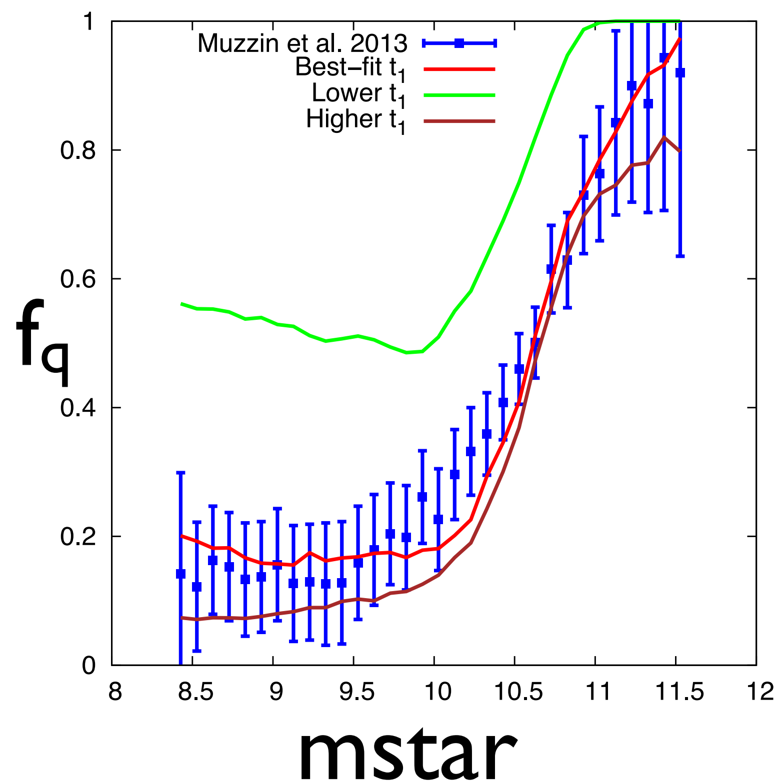
- While satellite orbits in a larger halo its subhalo loses mass
- When subhalo mass has decreased sufficiently, satellite stars become unbound and galaxy is stripped
- Model this effect by assuming satellite is stripped to ICM when halo mass is a fraction f_s of its peak mass: $M_h = f_s M_{peak}$
- Can be constrained with the 1-halo term of the galaxy CF

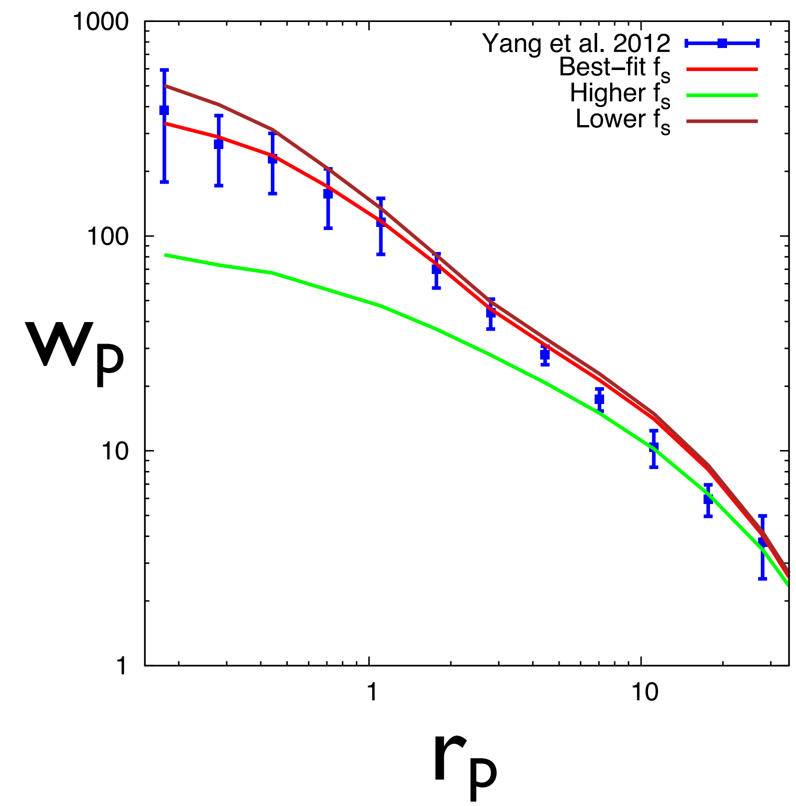
- When subhalo finally merges (i.e. after dynamical friction time)
  ➝ fraction f_m of the satellite mass is ejected to the ICM
  ➝ the rest $(1-f_m) \cdot m_s$ is added to the central galaxy
- Is constrained by low z stellar mass function (massive end)

Constraints on the model

- Stellar Mass Functions to z~8 → Constraints on ε (M_1), f_m
- Cosmic SFR density to z~9 → Constraints on ε's normalization
- SSFRs to z~8 → Constraints on ε's slopes (β,γ)
- Quenched Fractions → Constraints on sat. quenching (τ_1, τ_2)
- 1-halo term of galaxy CF → Constraints on sat. stripping (f_s)

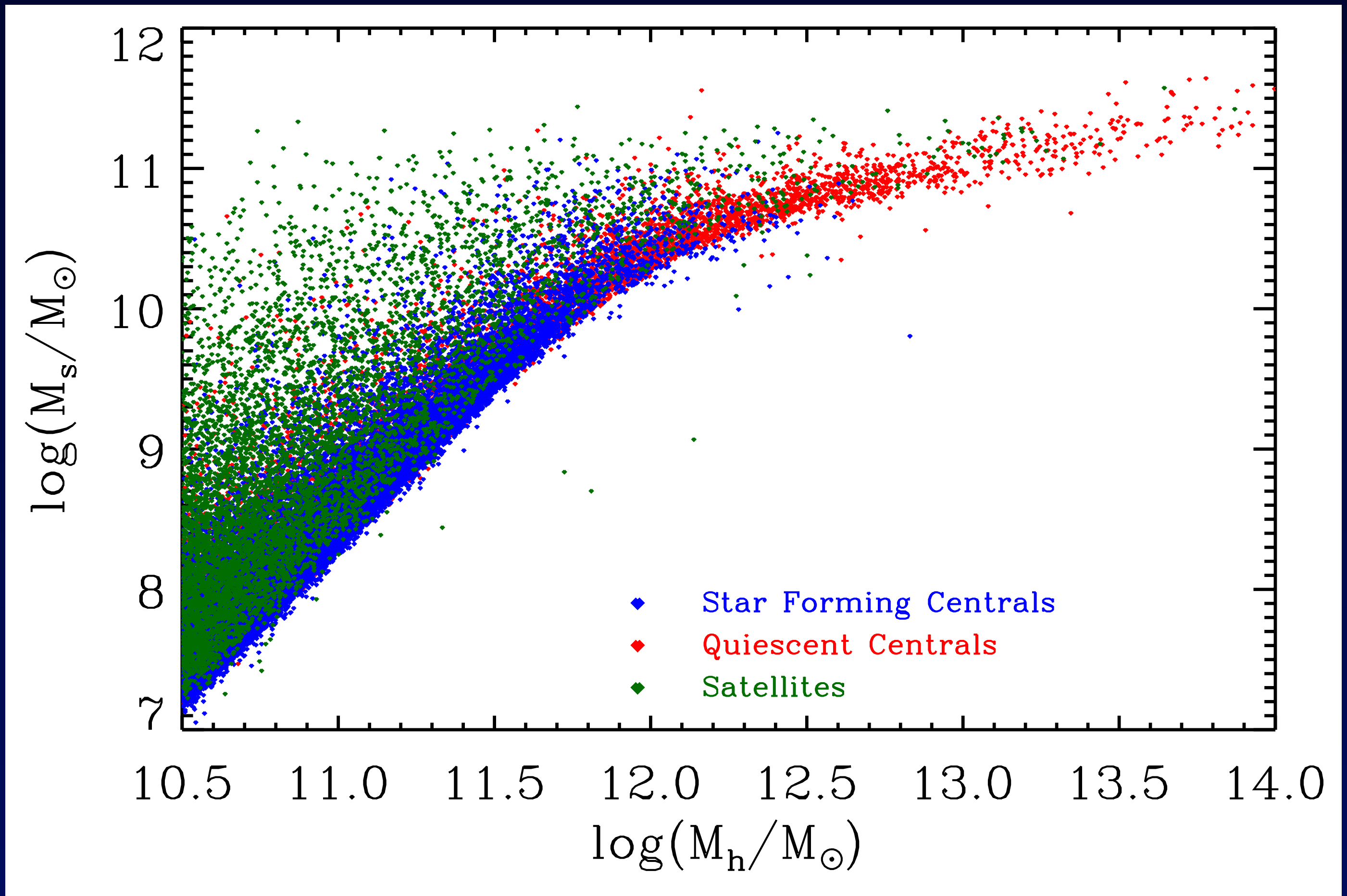






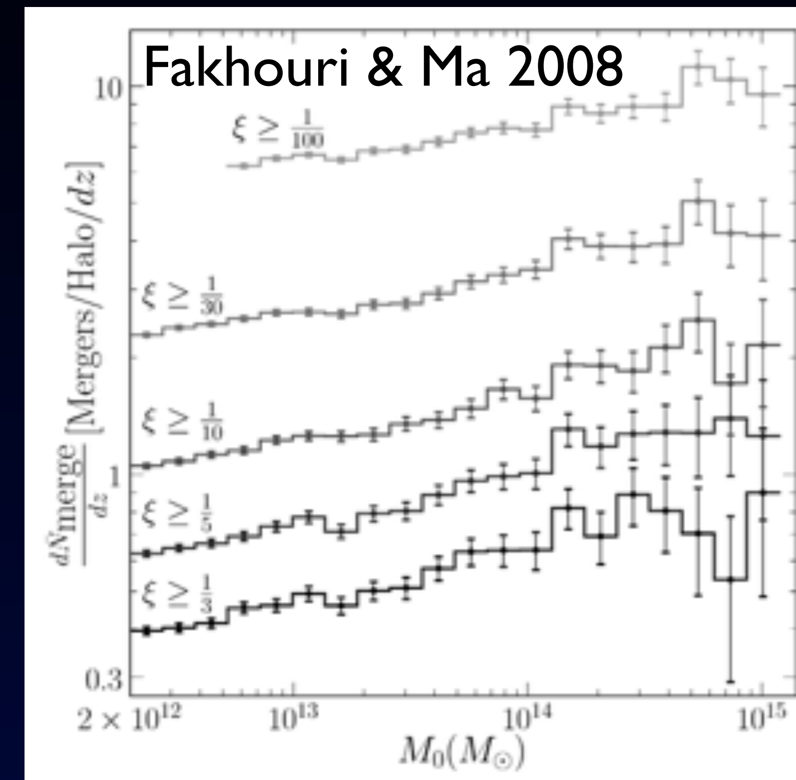
Constraints and Predictions

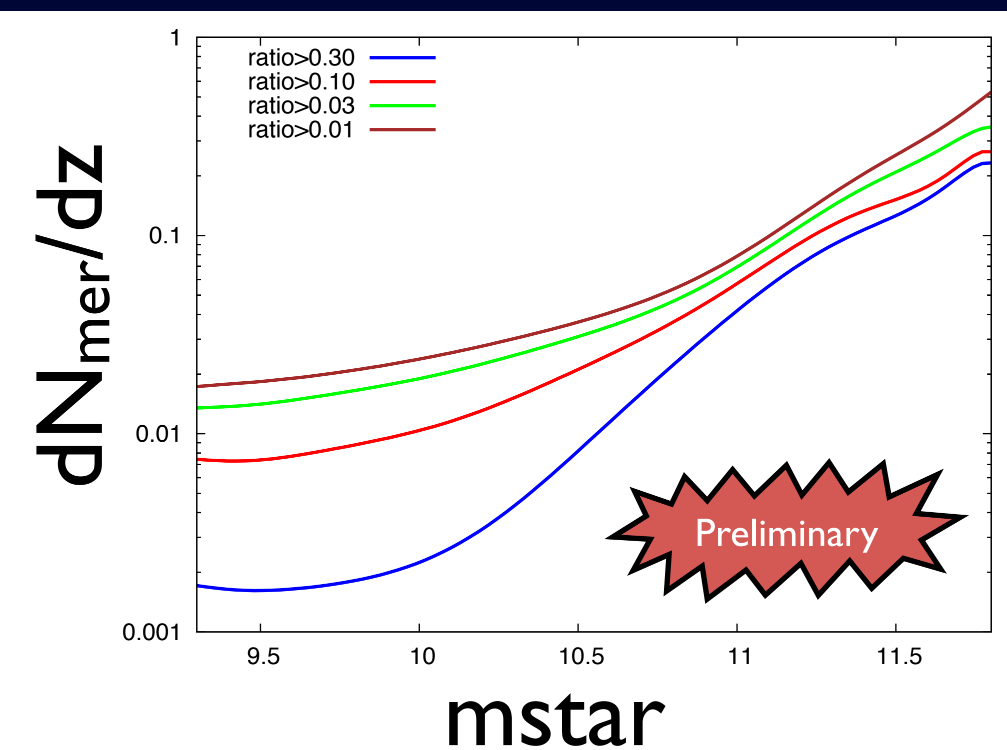
- Empirical models can be particularly helpful for:
  - Constrain models with more detailed baryonic physics
    e.g. cooling, star formation, feedback…
    Now we can also compare to individual zoom-simulations
  - Making predictions without many uncertain assumptions on baryonic physics:
    e.g.
    - high z clustering
    - GRB delay times
    - galaxy merger rates

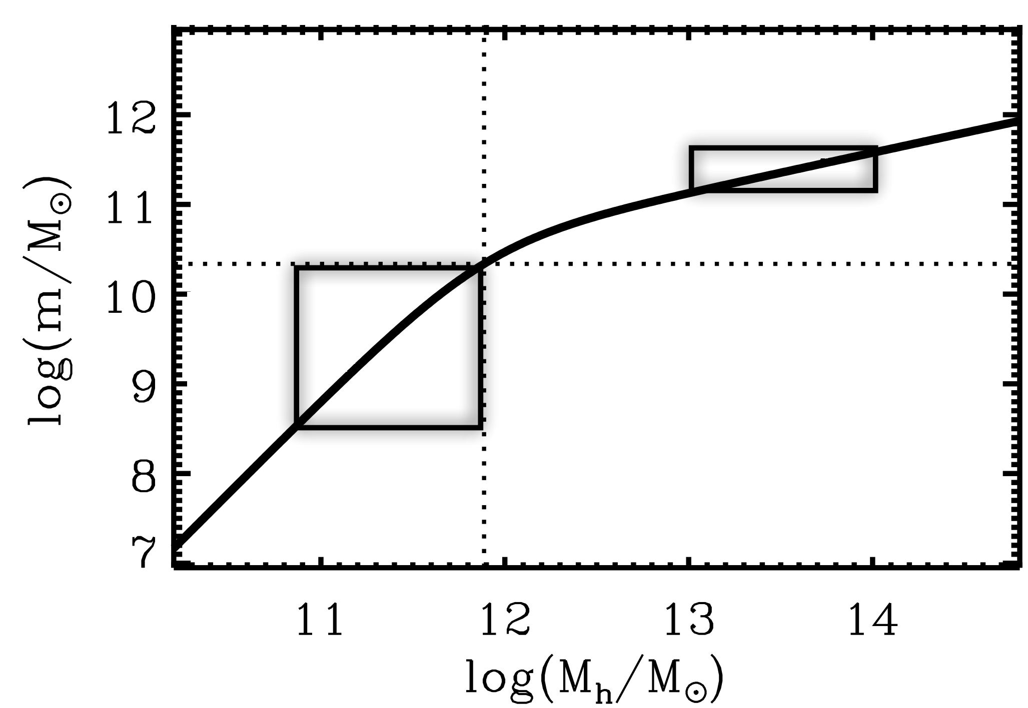


Galaxy merger rates

- Mean halo merger rates have a power-law dependence on mass
- Enhanced likelihood for major mergers for massive galaxies
- Low mass galaxies rarely experience major mergers

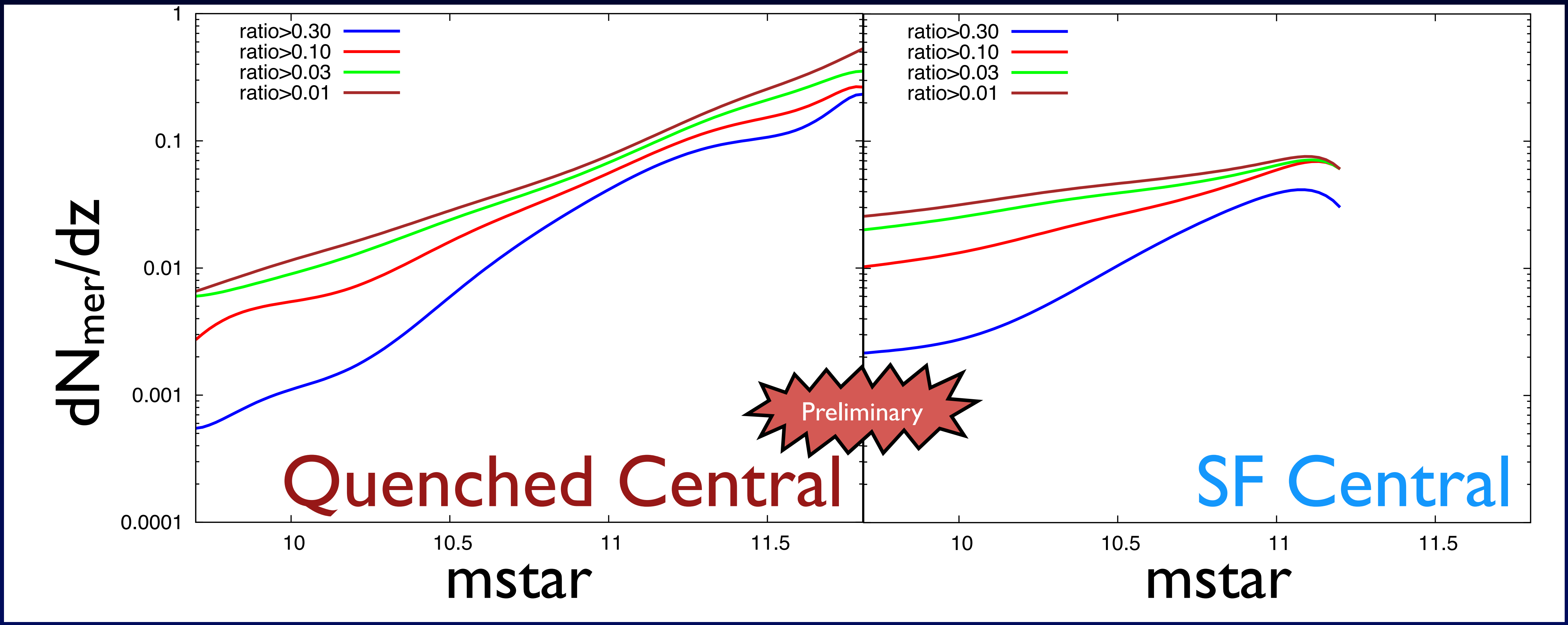






Merger rates for SF/quenched centrals

- Divide merger rates into two samples: SF/quenched central
- For low mass: SF galaxies are more likely to have a merger
- For high mass: Quenched and SF galaxies show similar merger rates



Conclusions

- Self-consistent cosmological framework using constraints from the observed SMFs to connect galaxies to dark matter haloes
- SFR of massive galaxies peaked at high redshift (z~2) and is quenched afterwards ➙ growth only through accretion
- Haloes can also be modelled individually by parameterizing the star formation efficiency
- Satellite quenching and stripping can be constrained with additional observations (quenched fractions, 1-halo term of CF)
- Possible to divide computed galaxy statistics into SF/non-SF
- Next steps: include colours, gas, metallicity, etc…