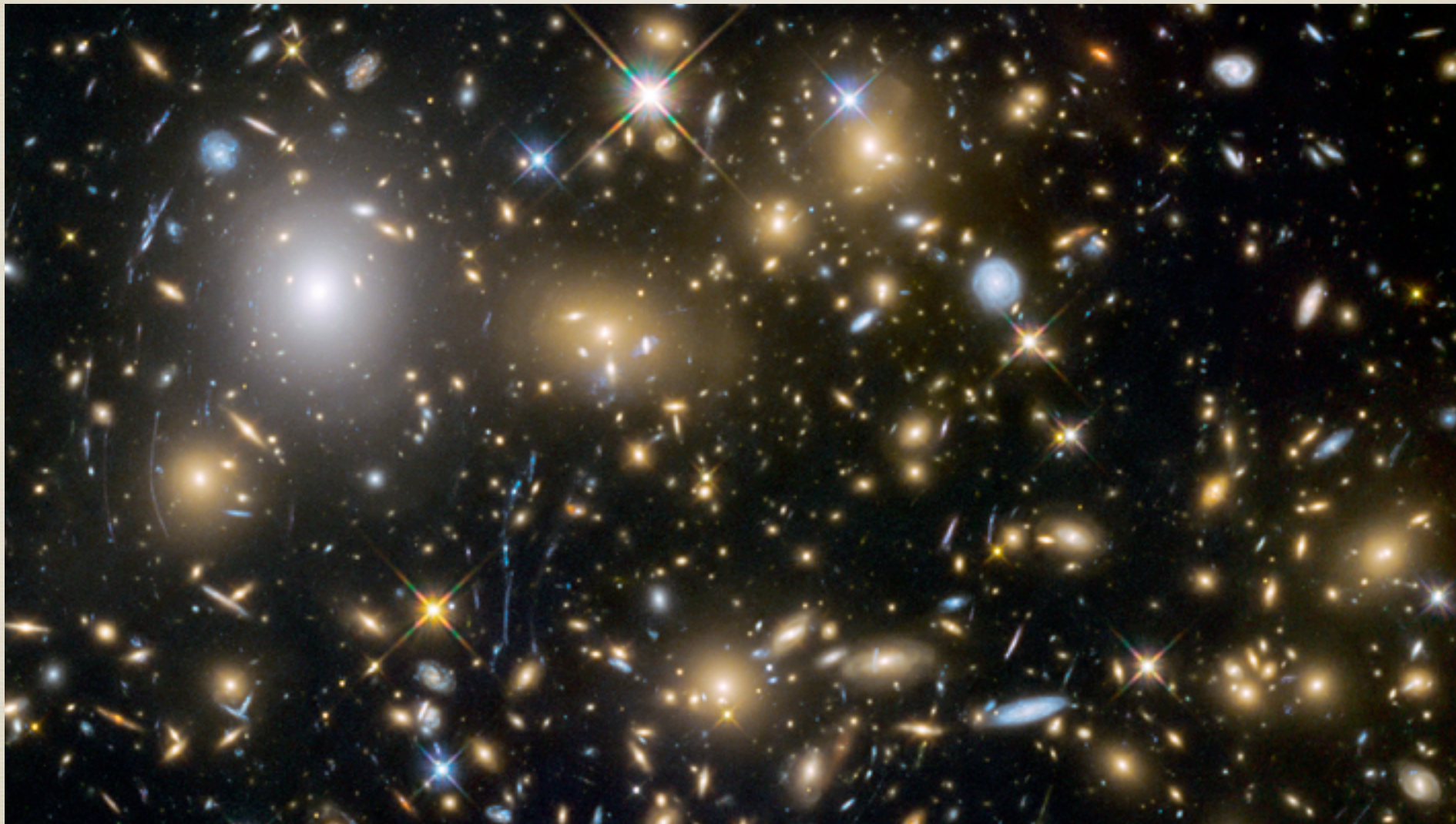


THE FUTURE OF EMPIRICAL MODELING

a.k.a. The UniverseMachine (Behroozi) & EMERGE (Moster)



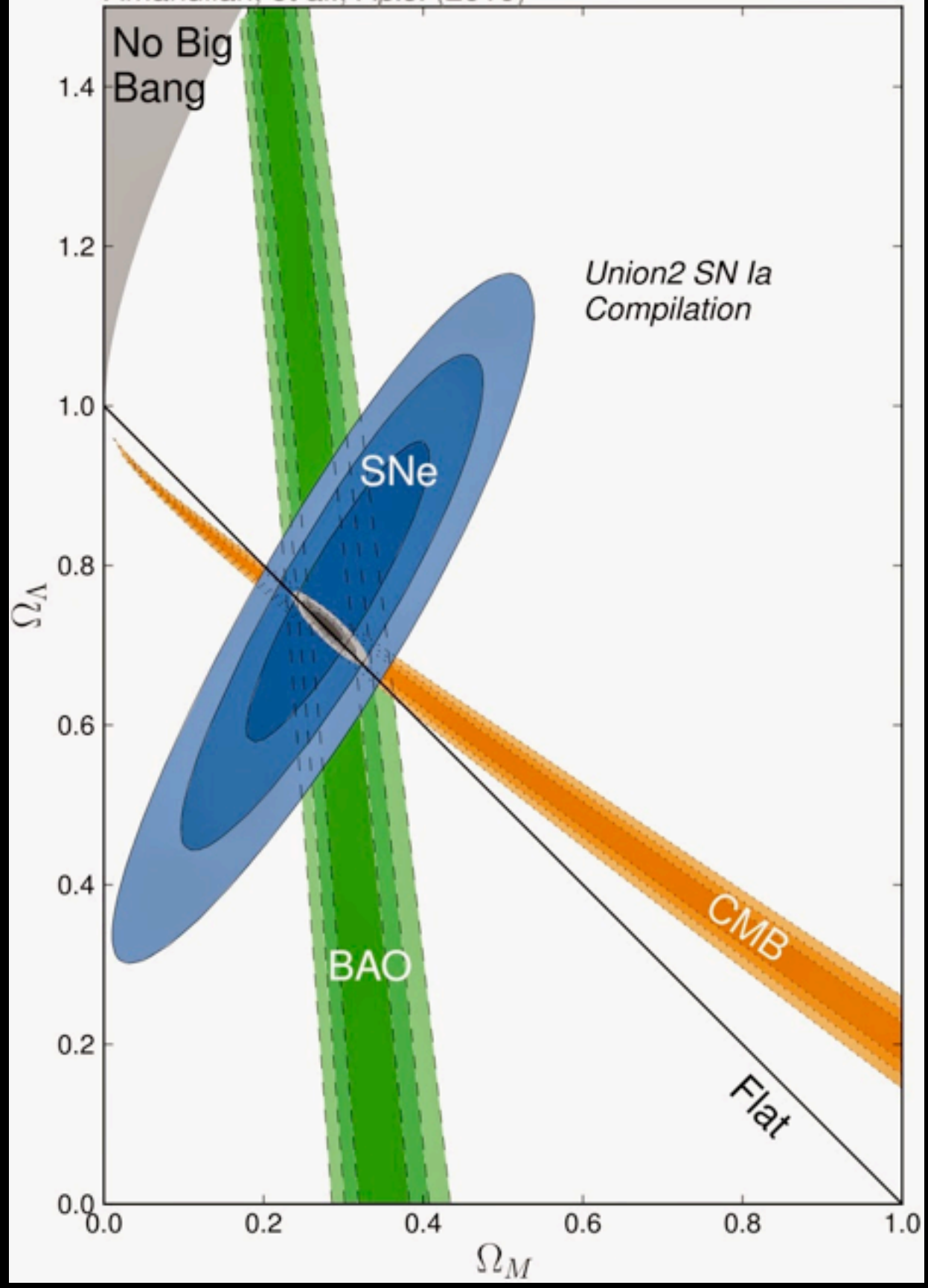
Credit: MACS J0717, NASA, ESA, HST FF Team (STScI)

Peter Behroozi, UC Berkeley
with R. Wechsler, A. Hearin, C. Conroy

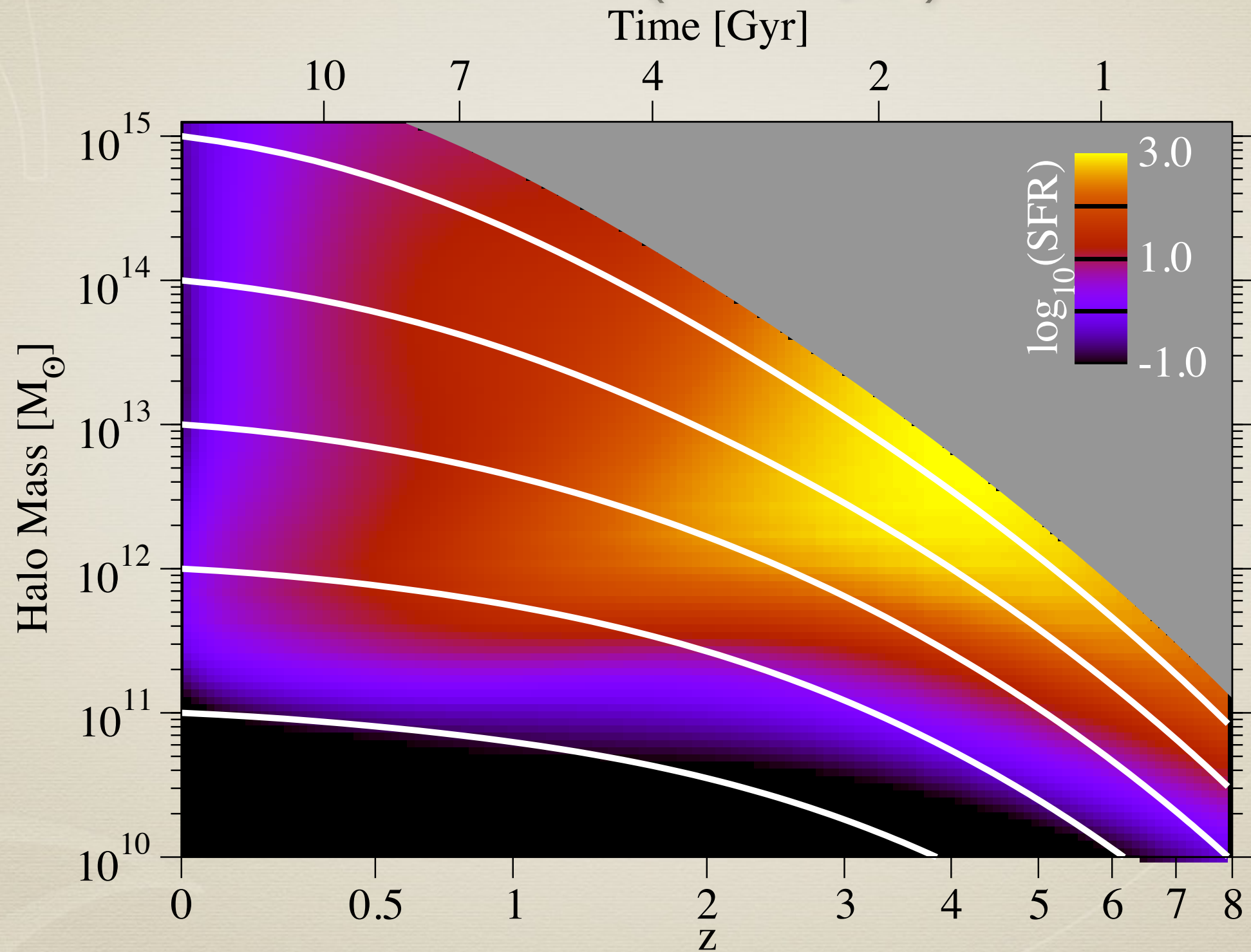
Benjamin Moster, LMU

with T. Naab, S. White, A. Obreja, U. Steinwandel, R. Somerville, F. van den Bosch, A. Maccio

KITP 5/17/17



SFR(M_h, z)



PB et al. (2013)

$$\text{SFR}(\dot{M}_h)$$

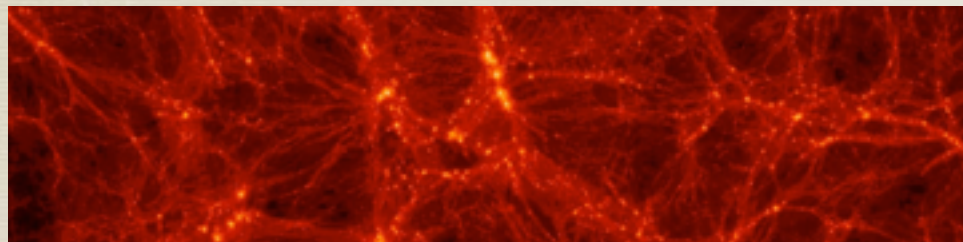


Credit: Abell 1689,
NASA, N. Benitez, T. Broadhurst, H. Ford, M. Clampin



NGC 5033, Adam Block, Mt. Lemmon SkyCenter, University of Arizona

EMERGE / UniverseMachine



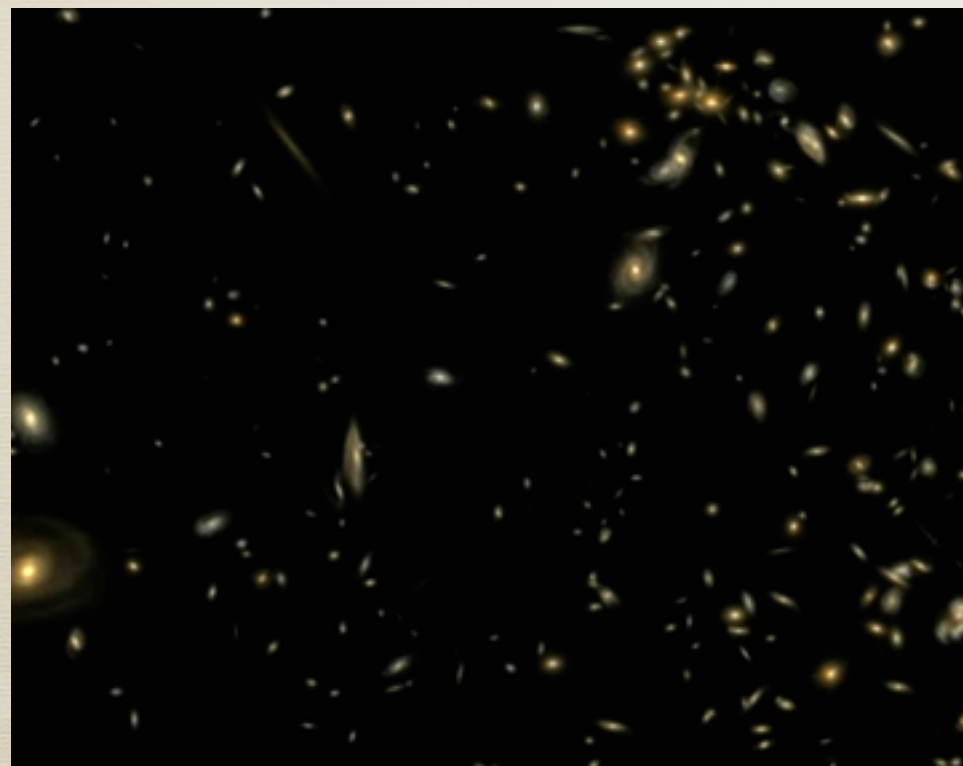
DM Simulation

+

$$\text{SFR} = f(M_h, \dot{M}_h, z)$$

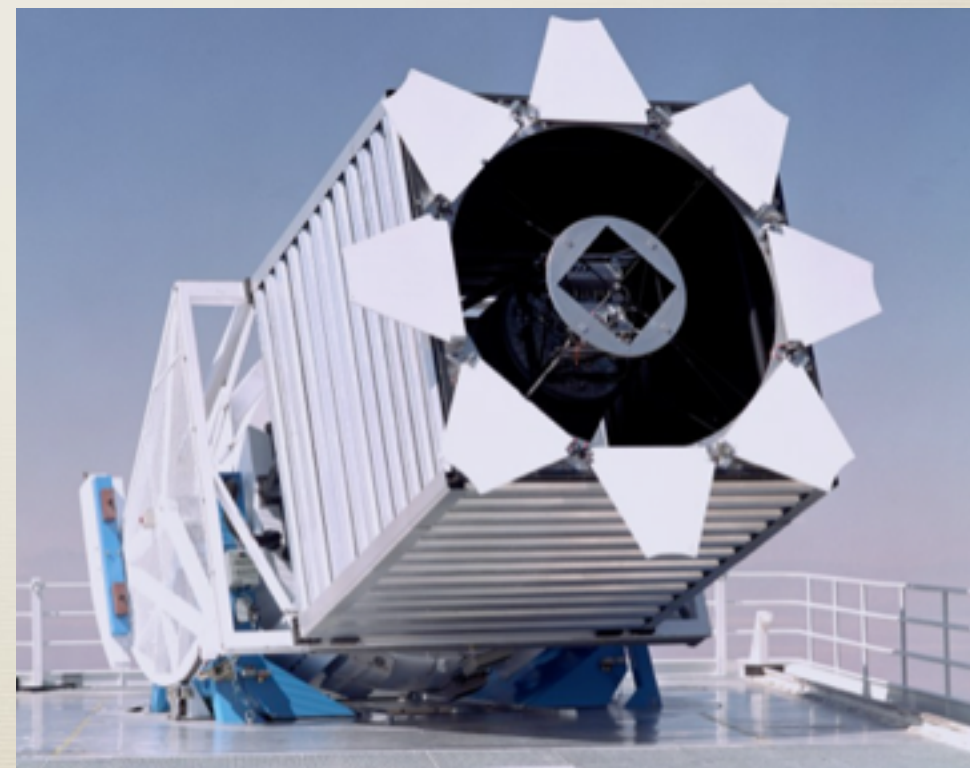
=

Minimal Galaxy Model



Mock Universe

||••||



MCMC

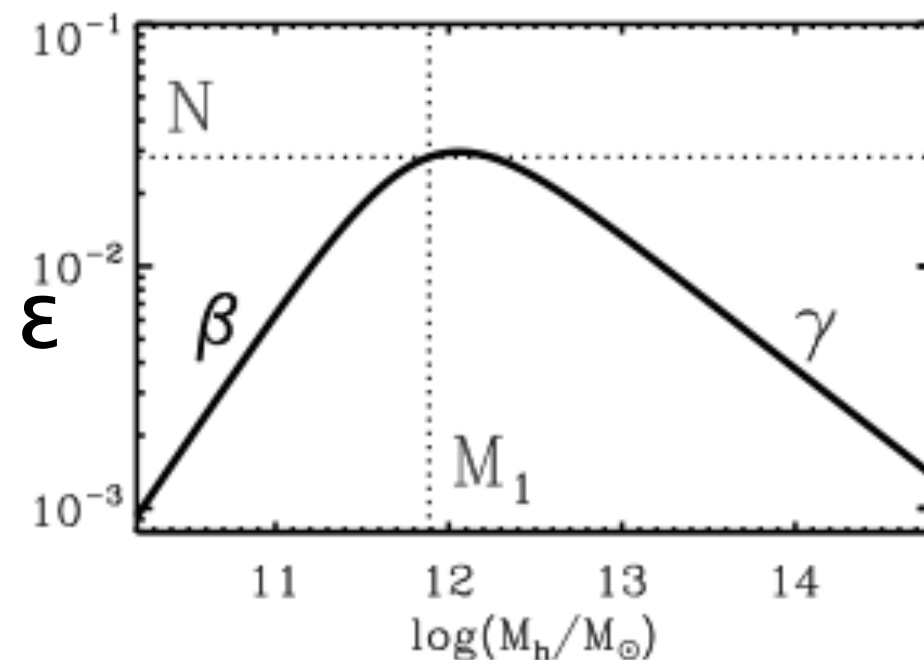
EMERGE: Models for individual haloes

- So far: average m_* - M_h relation
Now: individual growth histories
 $m_* / M_h = \epsilon_{\text{integr}} (M_h, z)$

EMERGE: Models for individual haloes

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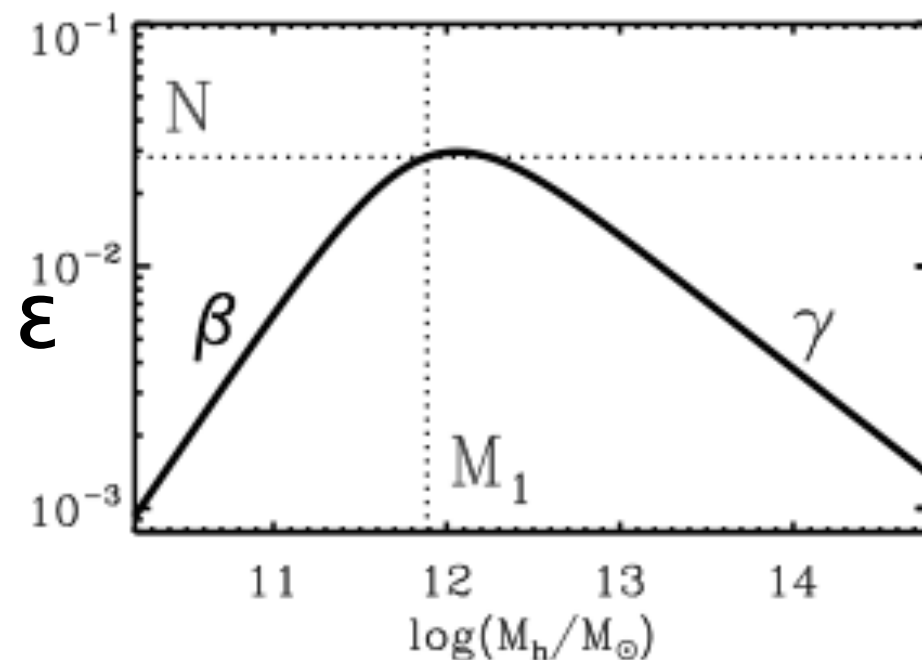
$$m_* / M_h = \epsilon_{\text{integr}} (M_h, z)$$



EMERGE: Models for individual haloes

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$$\dot{m}_* / \dot{M}_h = \epsilon_{\text{instant}}(M_h, z)$$



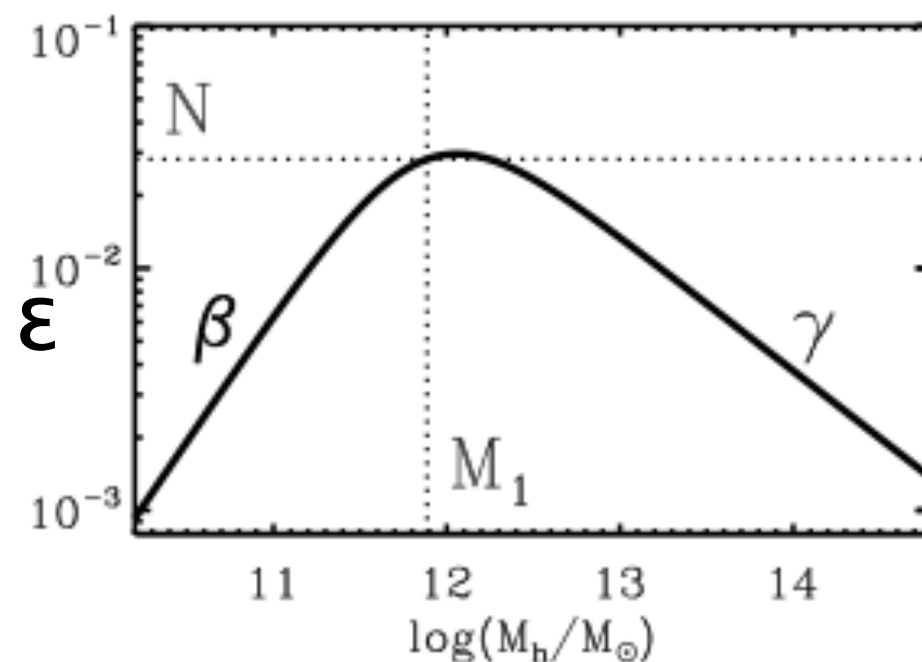
EMERGE: Models for individual haloes

- So far: average m_* - M_h relation
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$$\dot{m}_* / \dot{M}_h = \varepsilon_{\text{instant}}(M_h, z)$$

- Stellar mass increases as

$$\Delta m_* = \varepsilon \cdot \Delta M_h = \varepsilon \dot{M}_h \Delta t$$



EMERGE: Models for individual haloes

- So far: average m_* - M_h relation

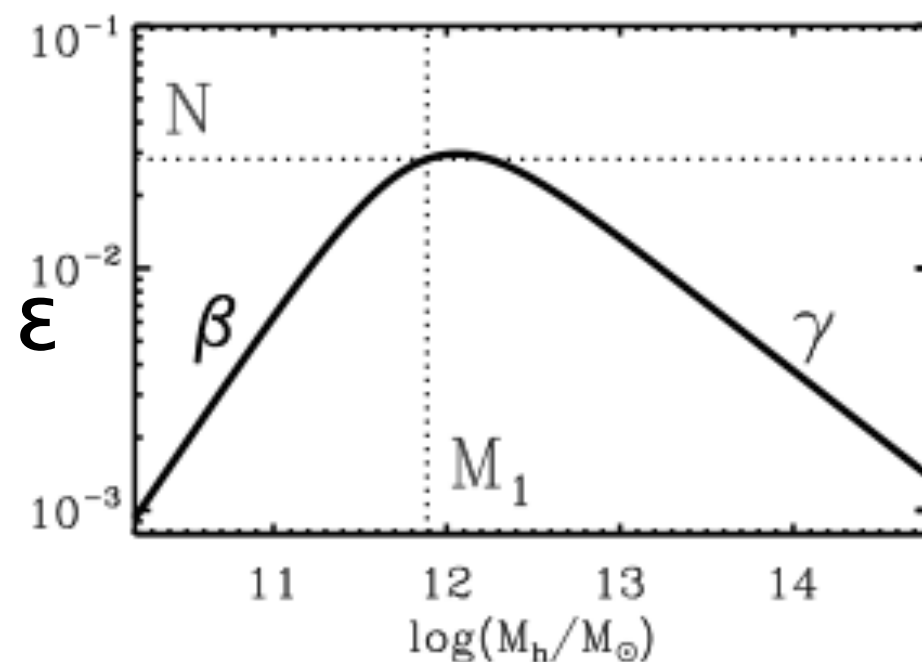
Now: individual growth histories

$$\dot{m}_* / \dot{M}_h = \varepsilon_{\text{instant}}(M_h, z)$$

Material becoming available

- Stellar mass increases as

$$\Delta m_* = \varepsilon \cdot \Delta M_h = \varepsilon \dot{M}_h \Delta t$$



EMERGE: Models for individual haloes

- So far: average m_* - M_h relation

Now: individual growth histories

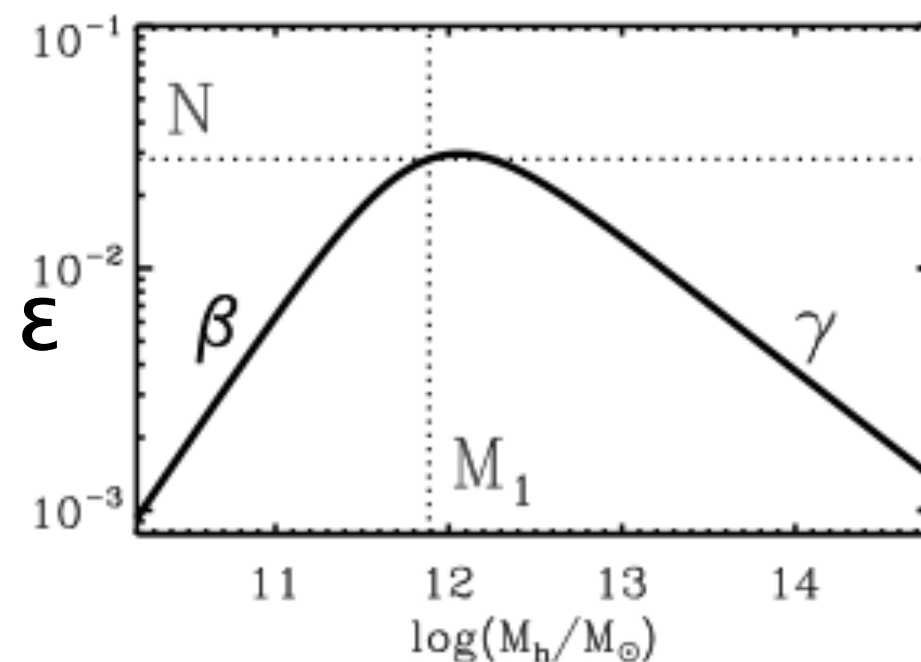
$$\dot{m}_* / \dot{M}_h = \epsilon_{\text{instant}}(M_h, z)$$

Material becoming available

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Conversion efficiency



EMERGE: Models for individual haloes

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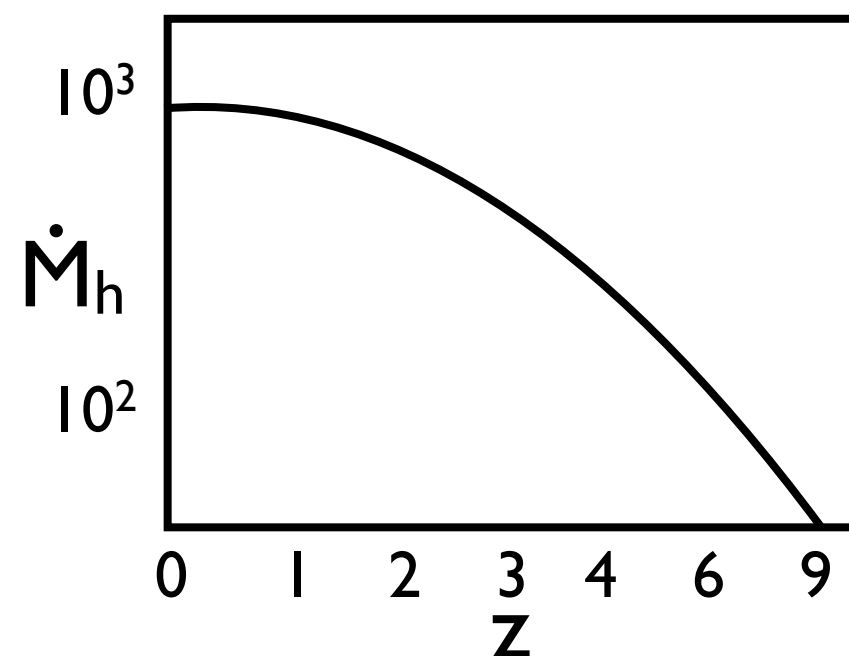
$$\dot{m}_* / \dot{M}_h = \epsilon_{\text{instant}}(M_h, z)$$

Material becoming available

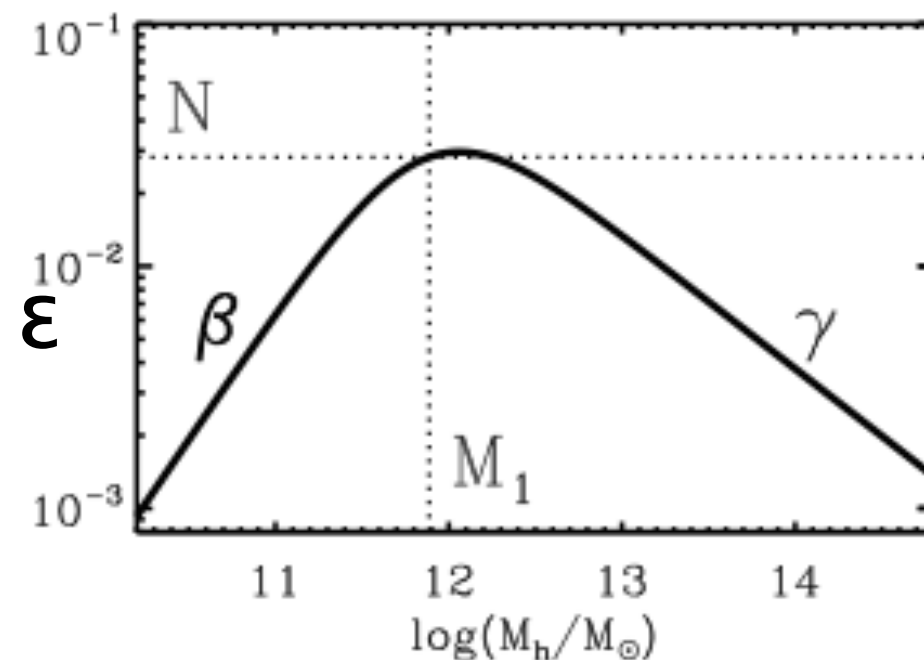
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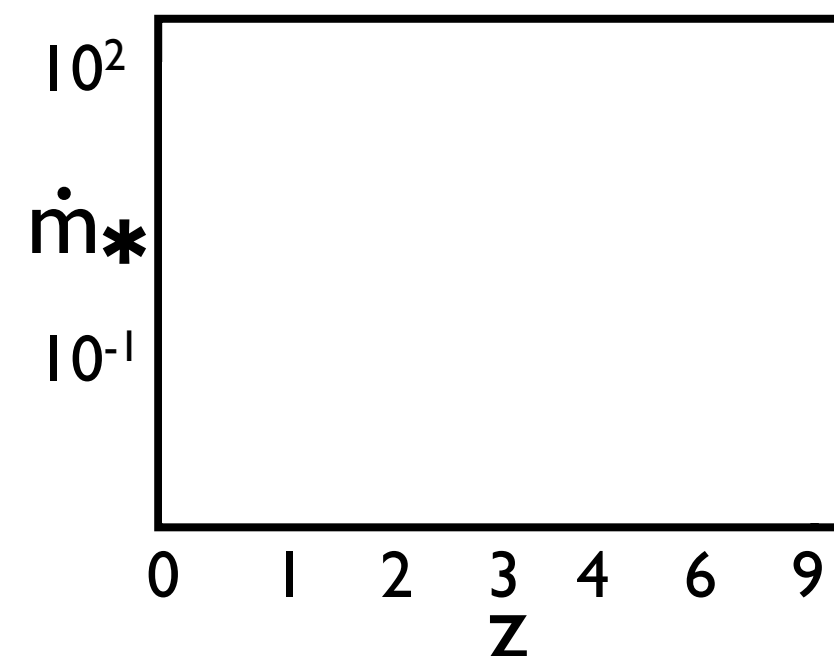
Conversion efficiency



Benjamin Moster



Empirical galaxy formation models



EMERGE: Models for individual haloes

- So far: average m_* - M_h relation

Now: individual growth histories

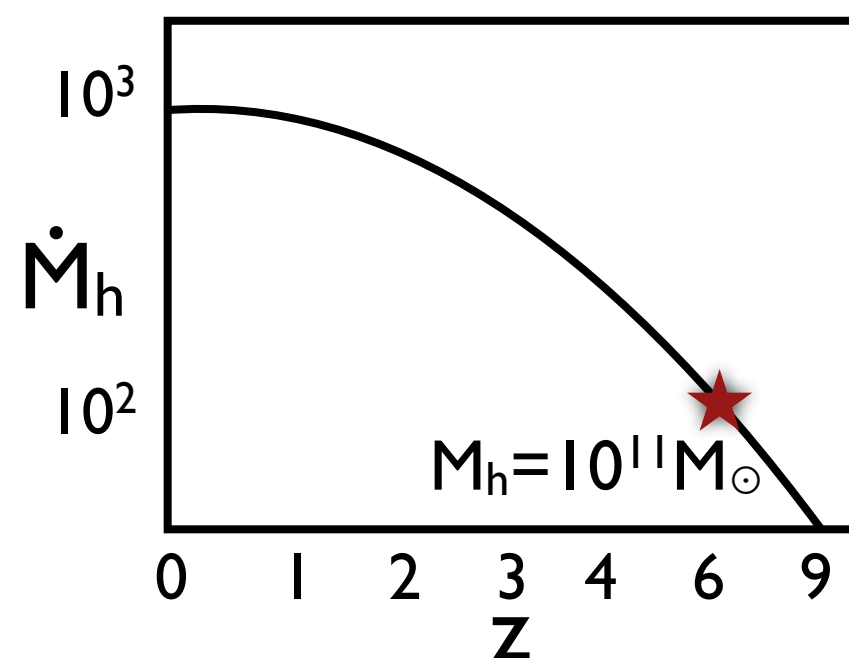
$$\dot{m}_* / \dot{M}_h = \epsilon_{\text{instant}}(M_h, z)$$

Material becoming available

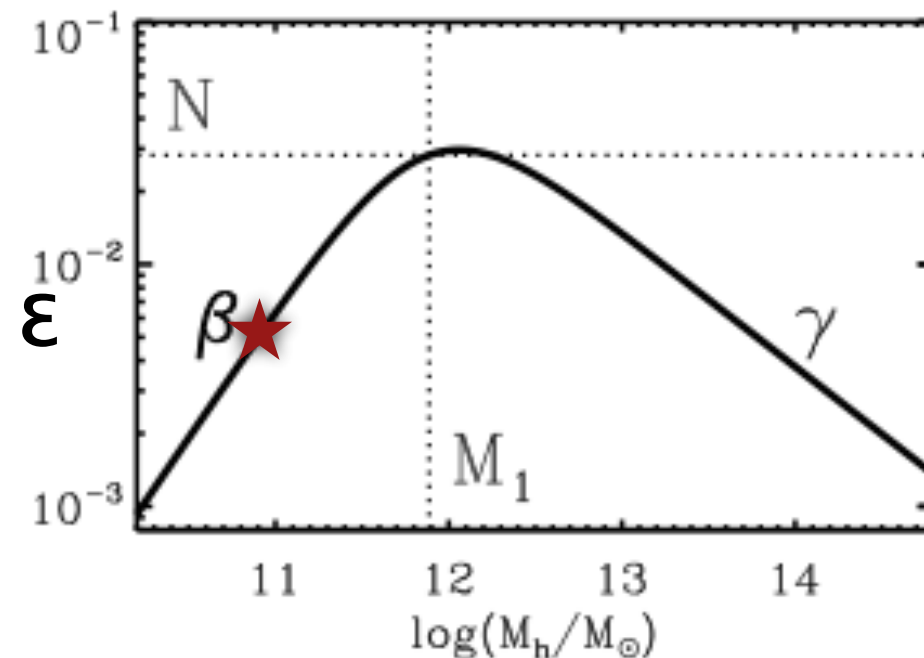
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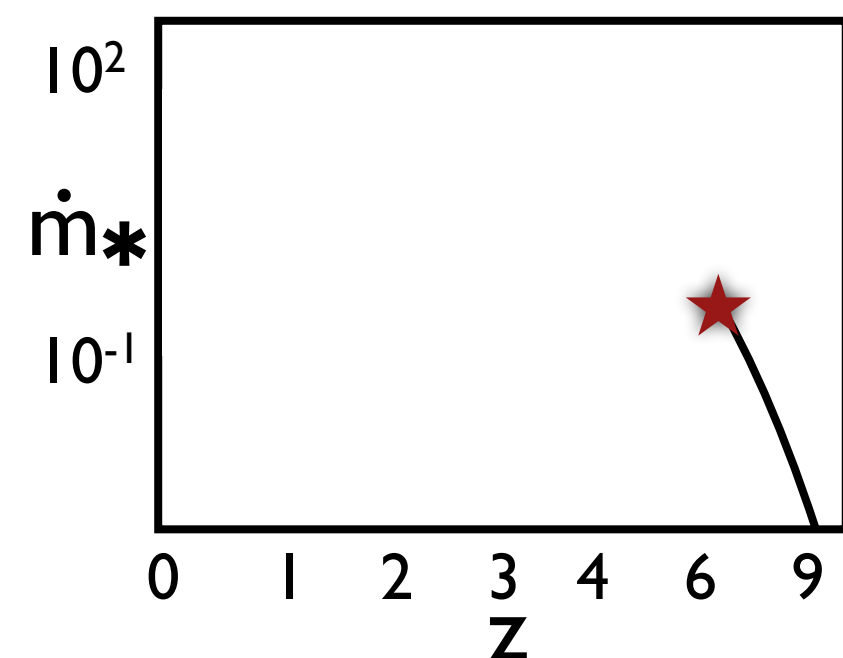
Conversion efficiency



Benjamin Moster



Empirical galaxy formation models



EMERGE: Models for individual haloes

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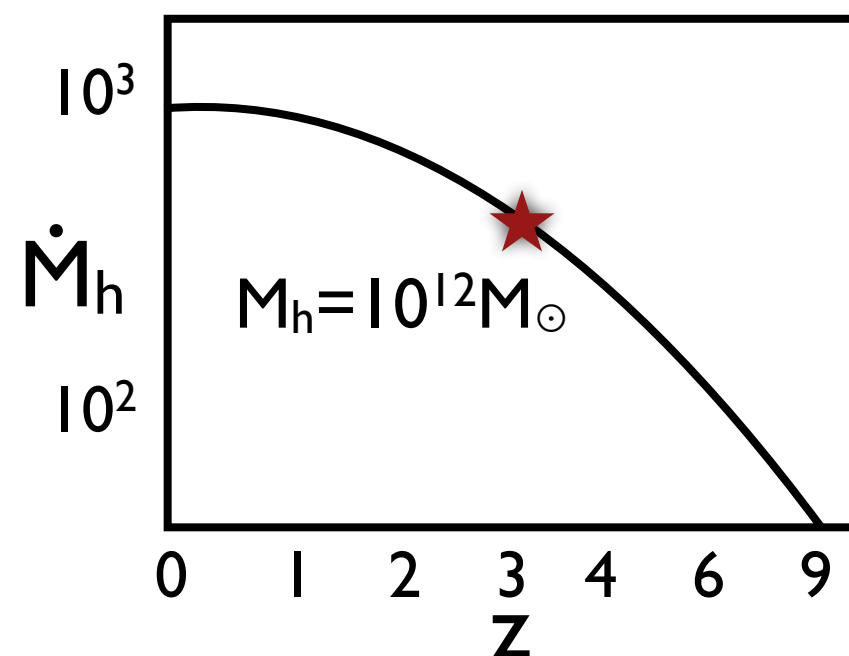
$$\dot{m}_* / \dot{M}_h = \epsilon_{\text{instant}}(M_h, z)$$

Material becoming available

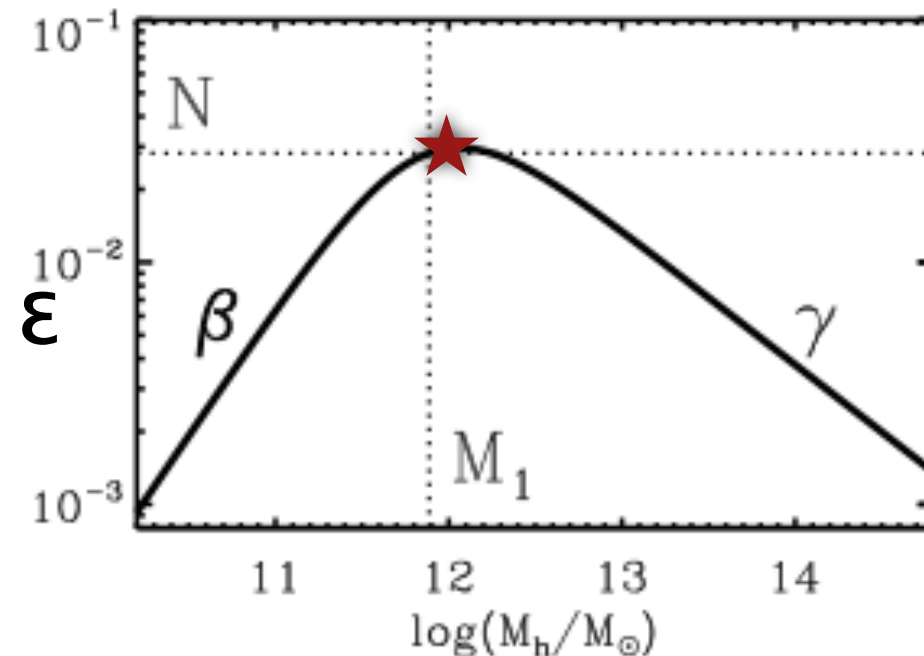
- Stellar mass increases as

$$\Delta m_* = \epsilon \cdot \Delta M_h = \epsilon \dot{M}_h \Delta t$$

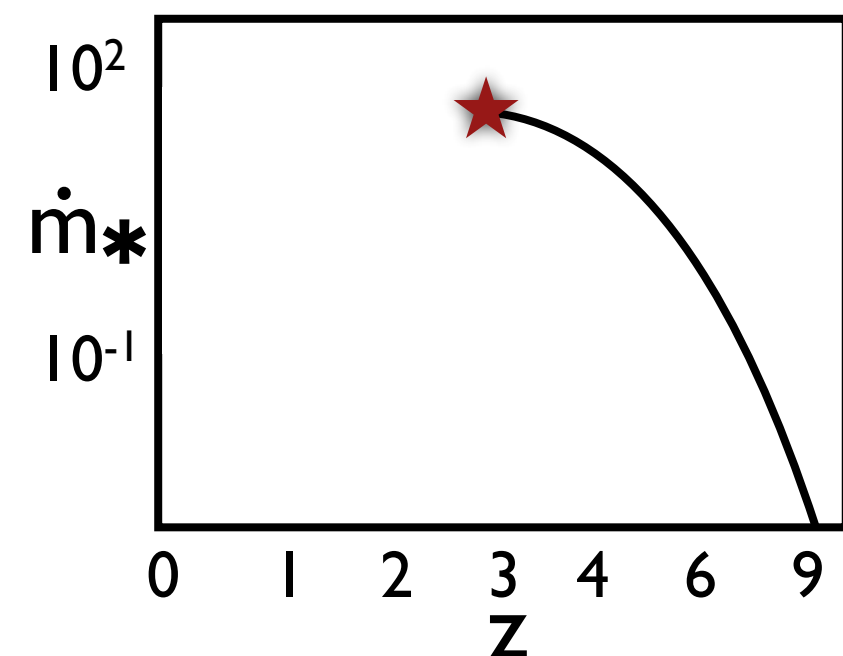
Conversion efficiency



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Empirical galaxy formation models



EMERGE: Models for individual haloes

- So far: average m_* - M_h relation
Now: individual growth histories

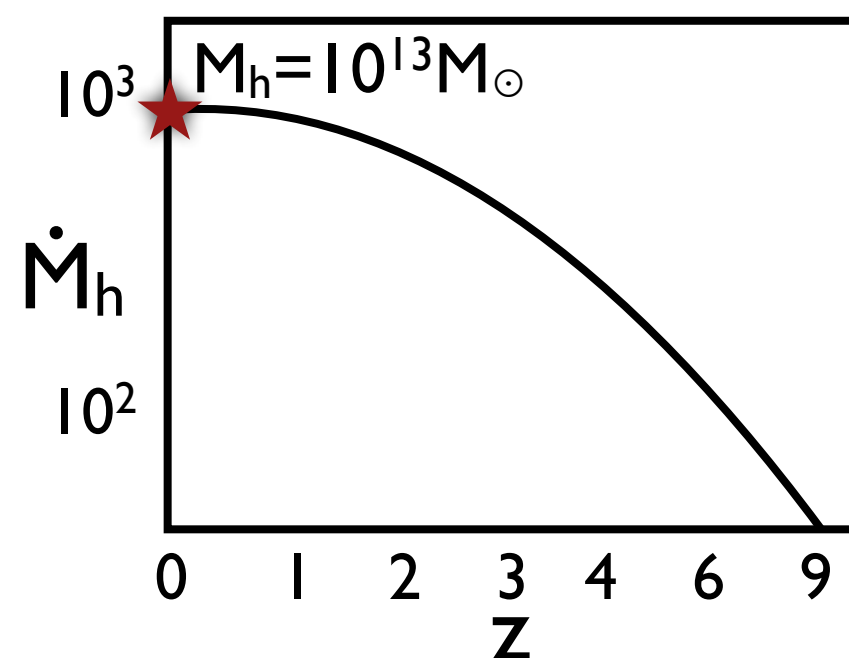
$$\dot{m}_* / \dot{M}_h = \epsilon_{\text{instant}}(M_h, z)$$

Material becoming available

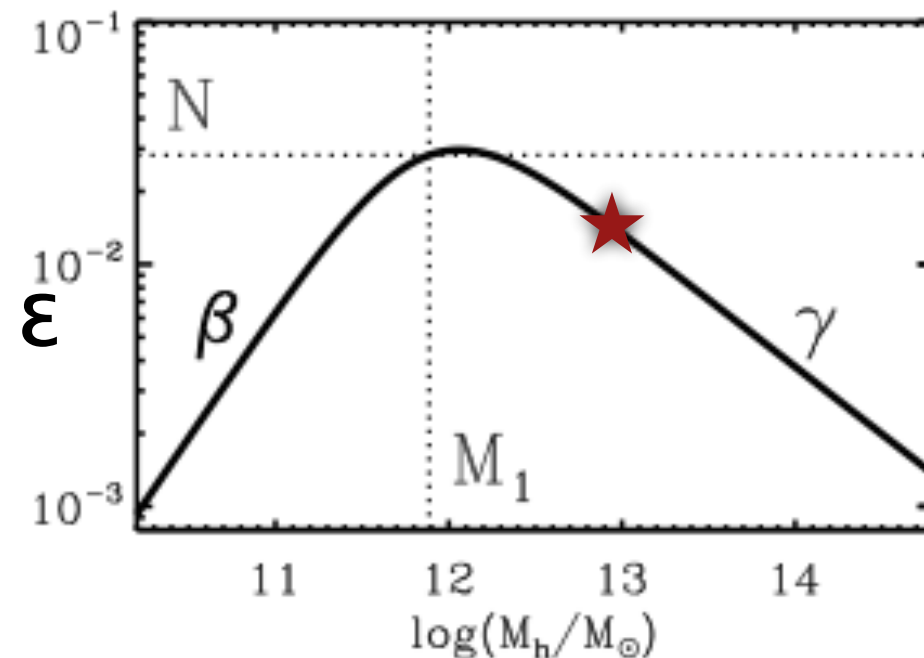
- Stellar mass increases as

$$\Delta m_* = \epsilon \cdot \Delta M_h = \epsilon \dot{M}_h \Delta t$$

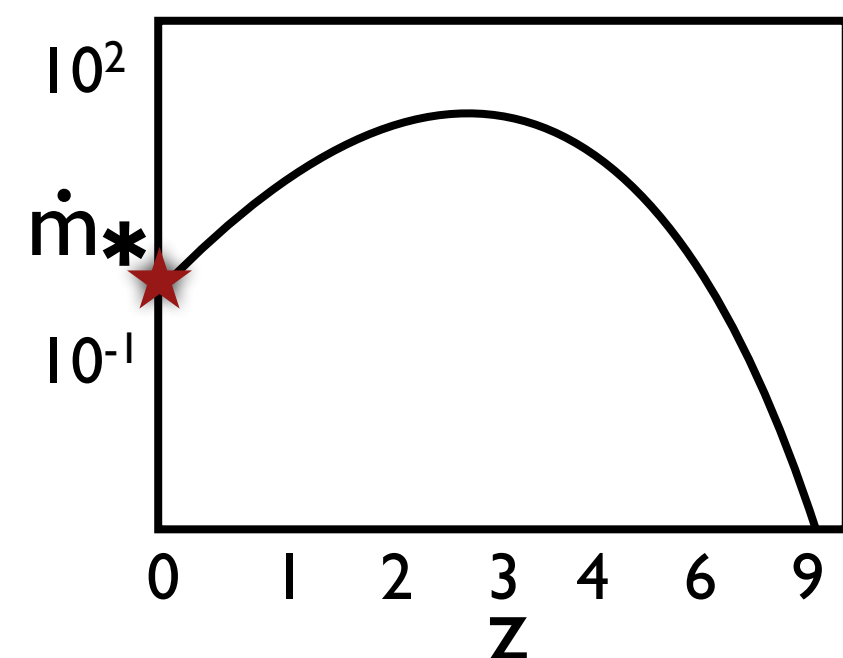
Conversion efficiency



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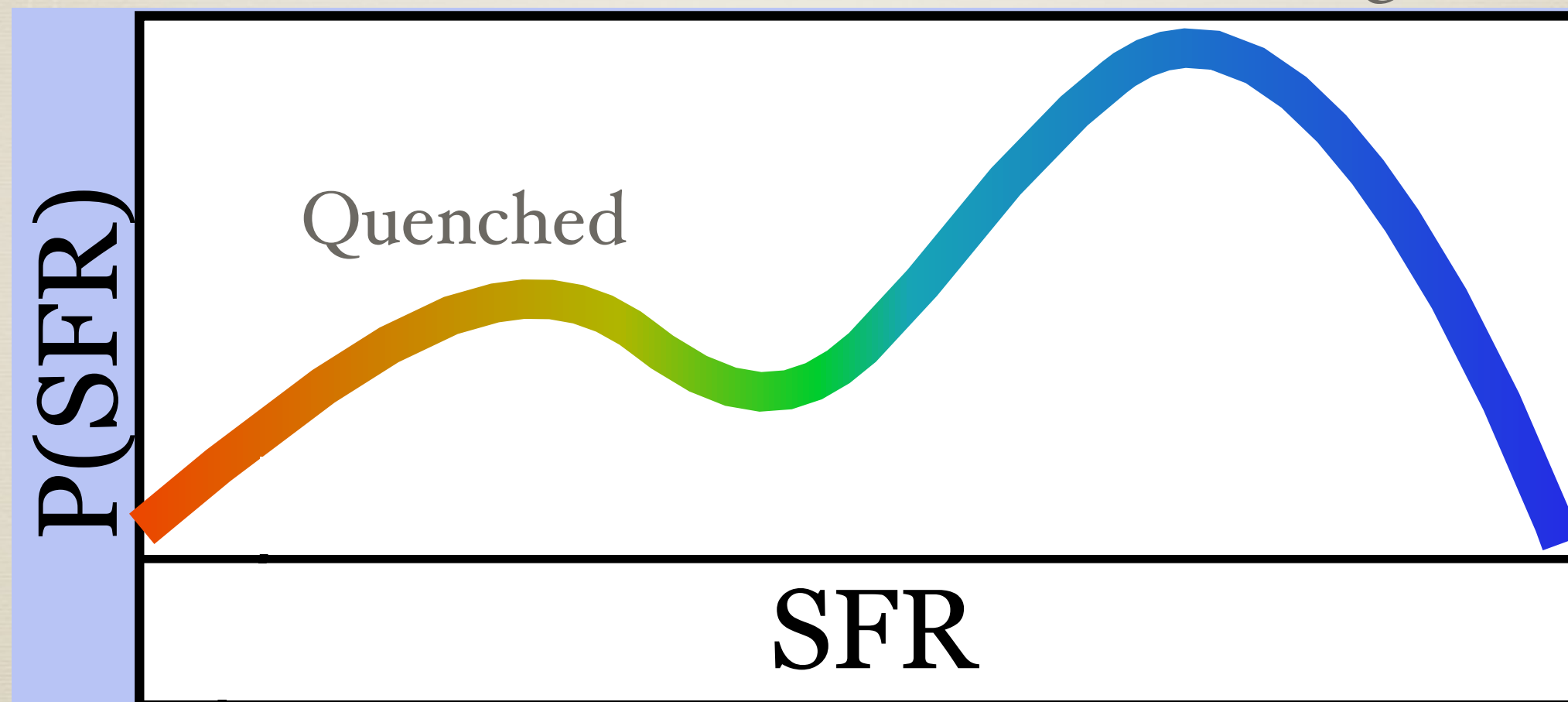
Empirical galaxy formation models



UniverseMachine: Parametrization

$$SFR(Mh, z, dMh/dt)^*$$

Star-Forming



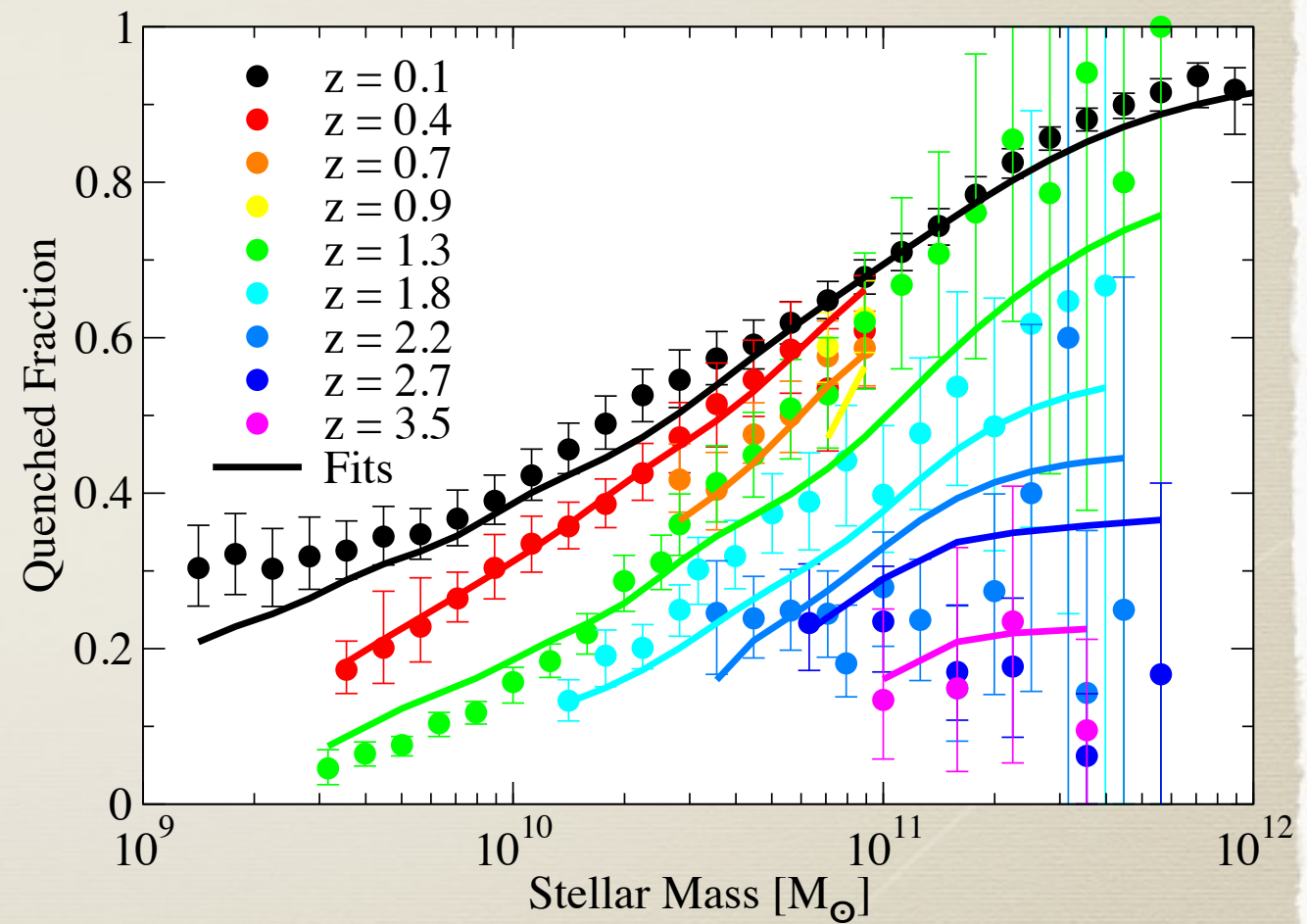
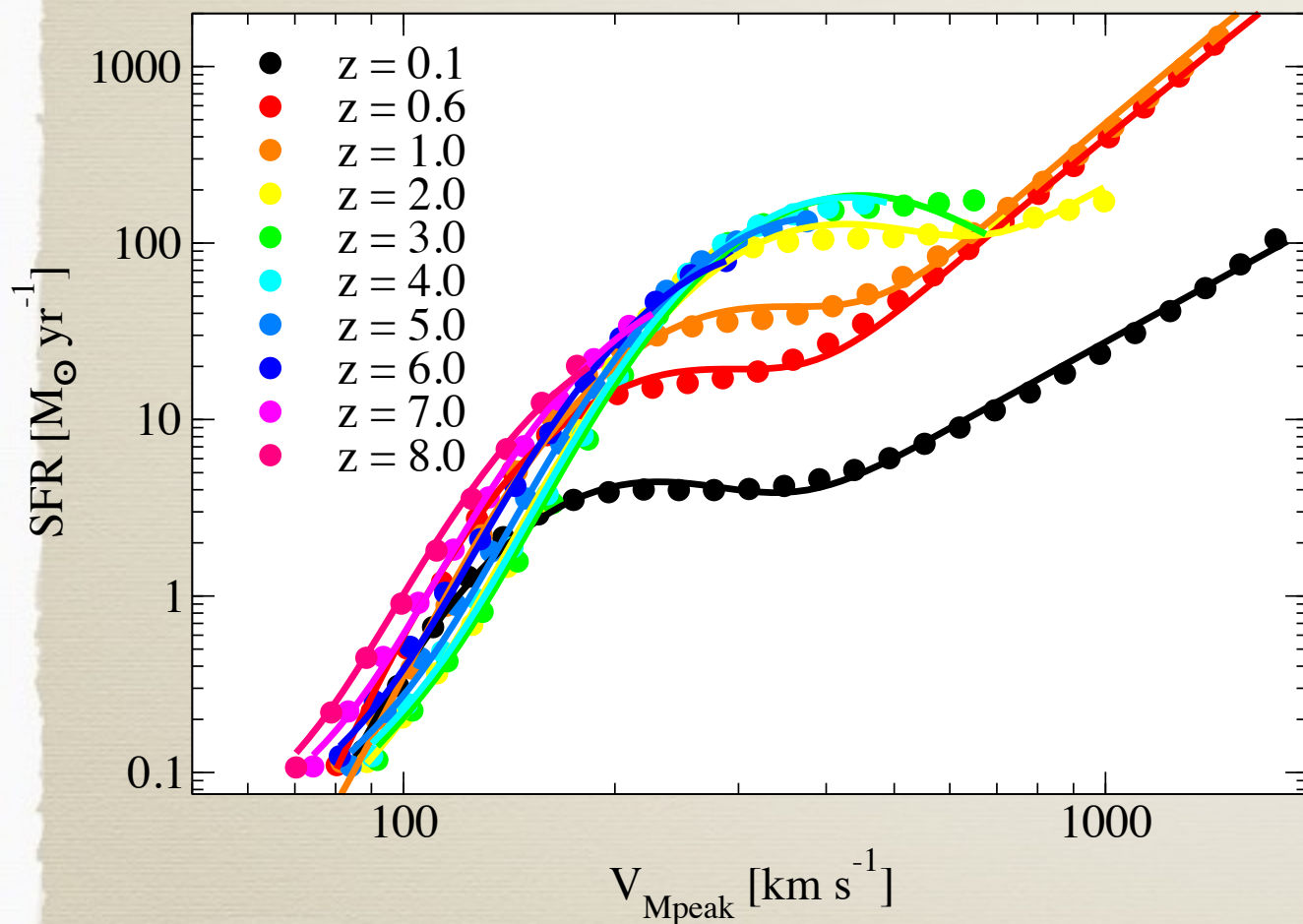
Rapidly Losing Mass

Rapidly Accreting

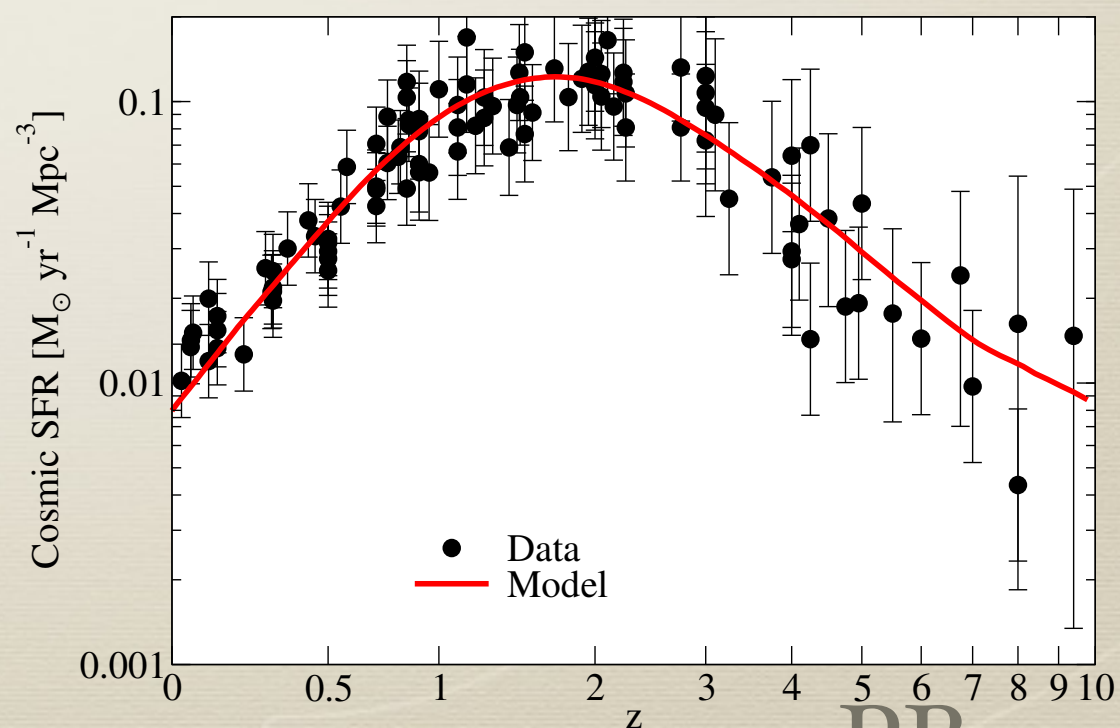
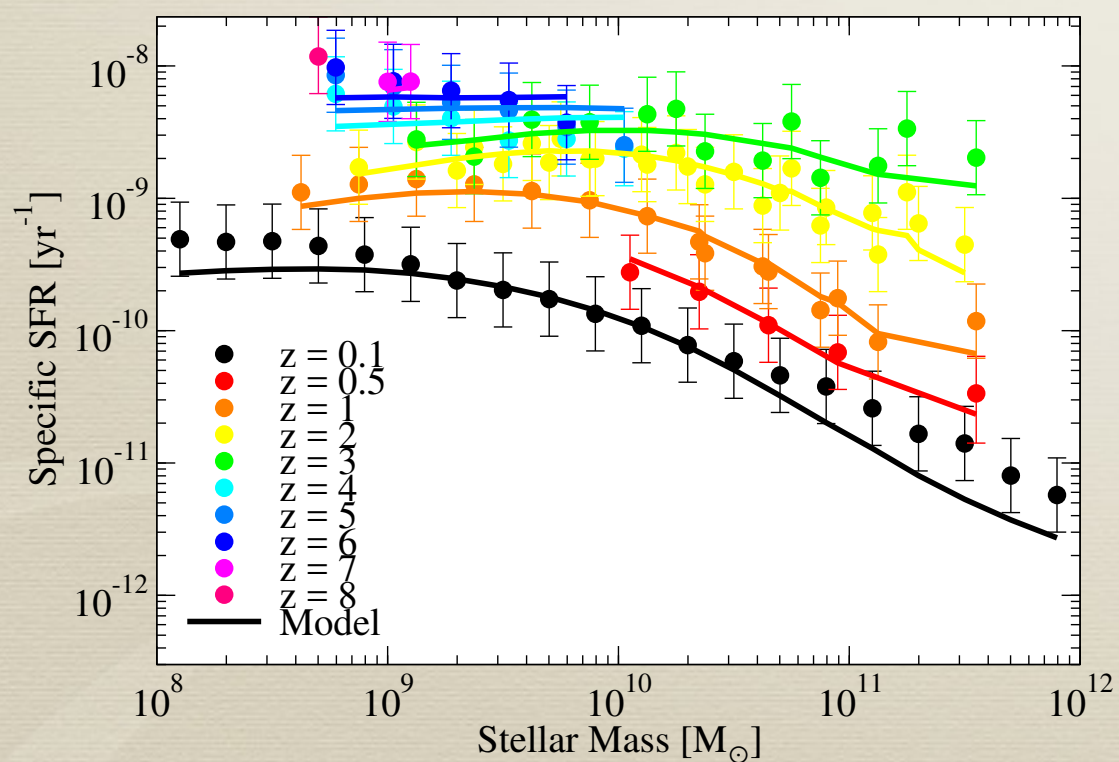
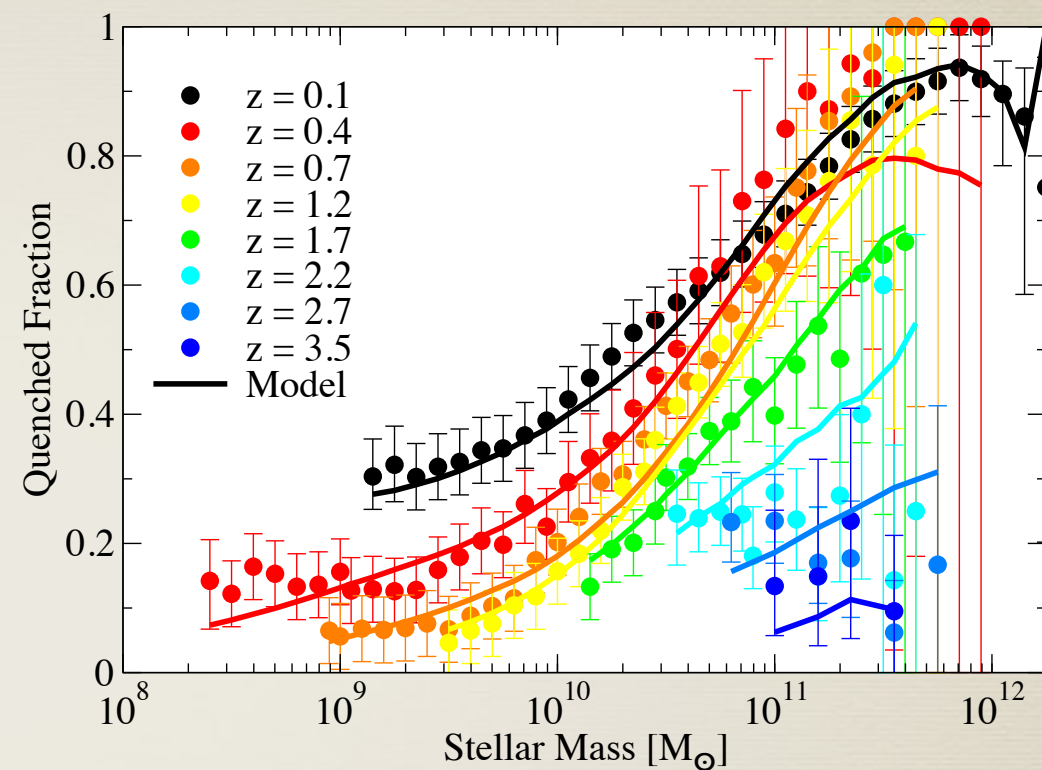
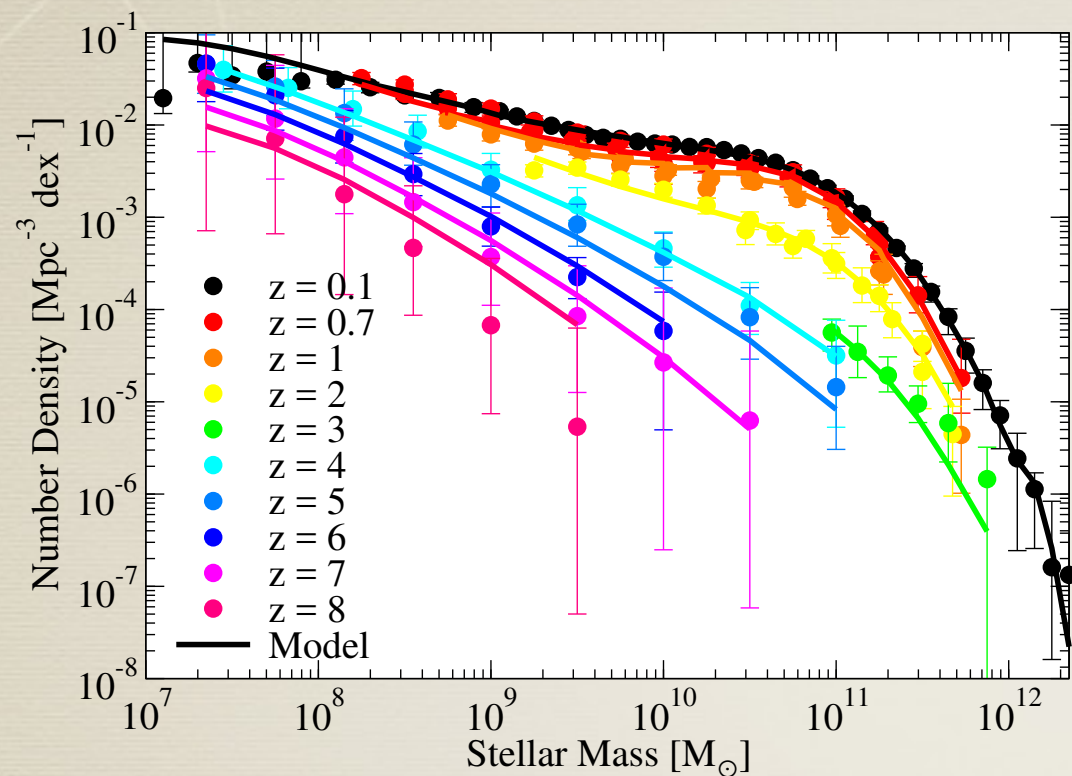
*In practice, we use $SFR(v_{M_{\text{peak}}}, z, \Delta v_{\text{max}})$, with $\Delta v_{\text{max}} \equiv \frac{v_{\text{max}}(t_{\text{now}})}{v_{\text{max}}(\min(t_{\text{now}} - t_{\text{dyn}}, t_{M_{\text{peak}}}))}$

UniverseMachine: Parametrization

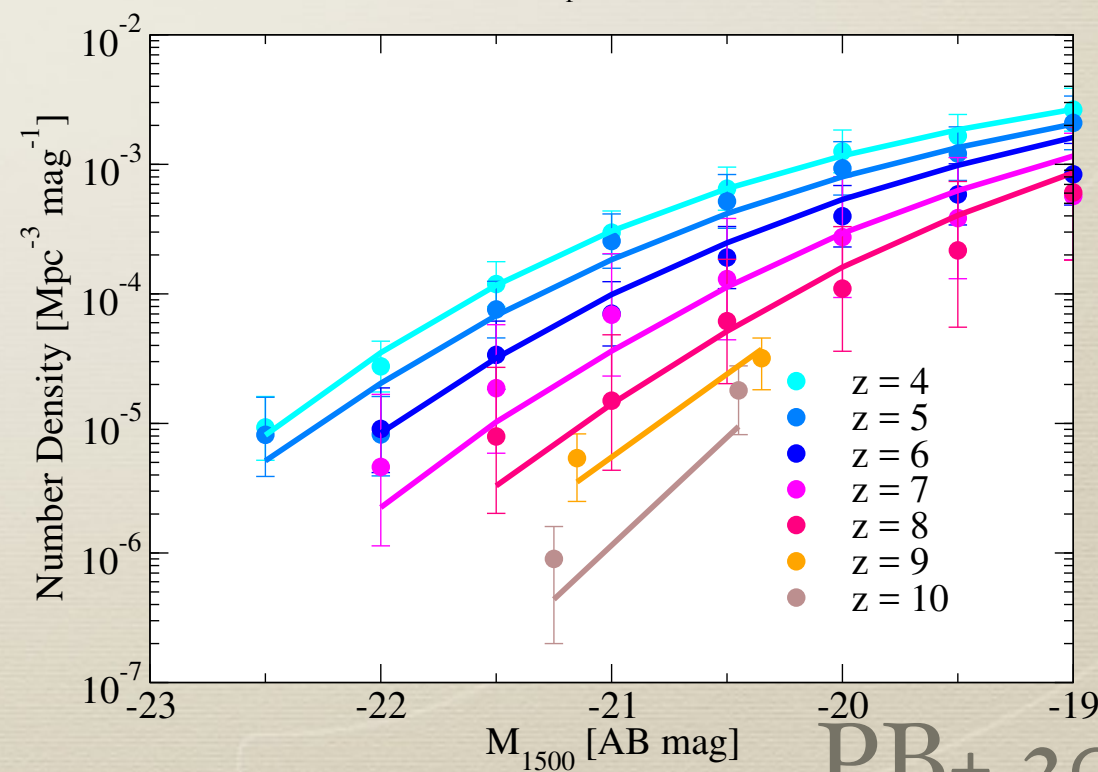
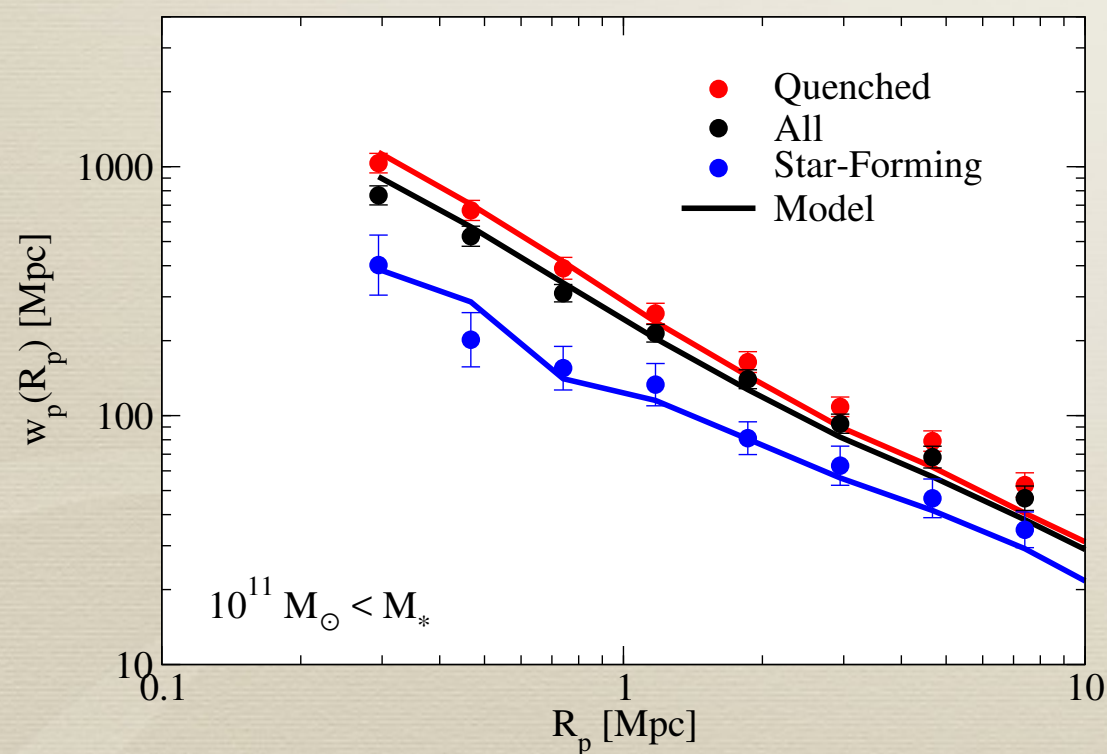
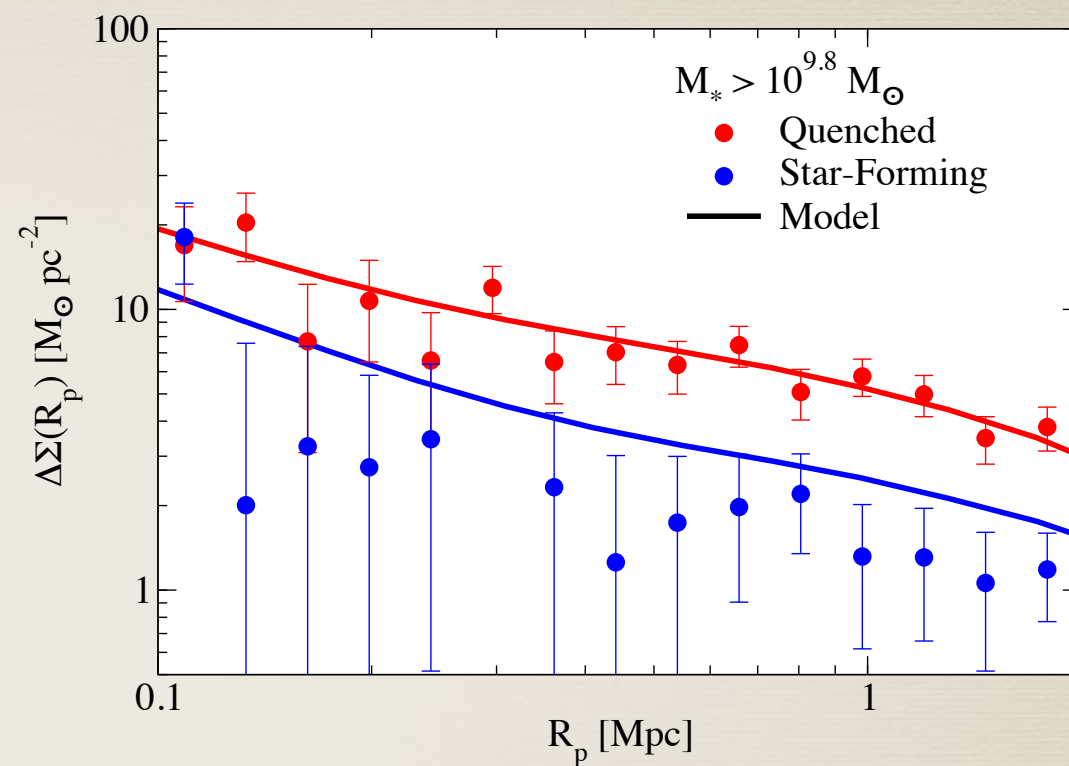
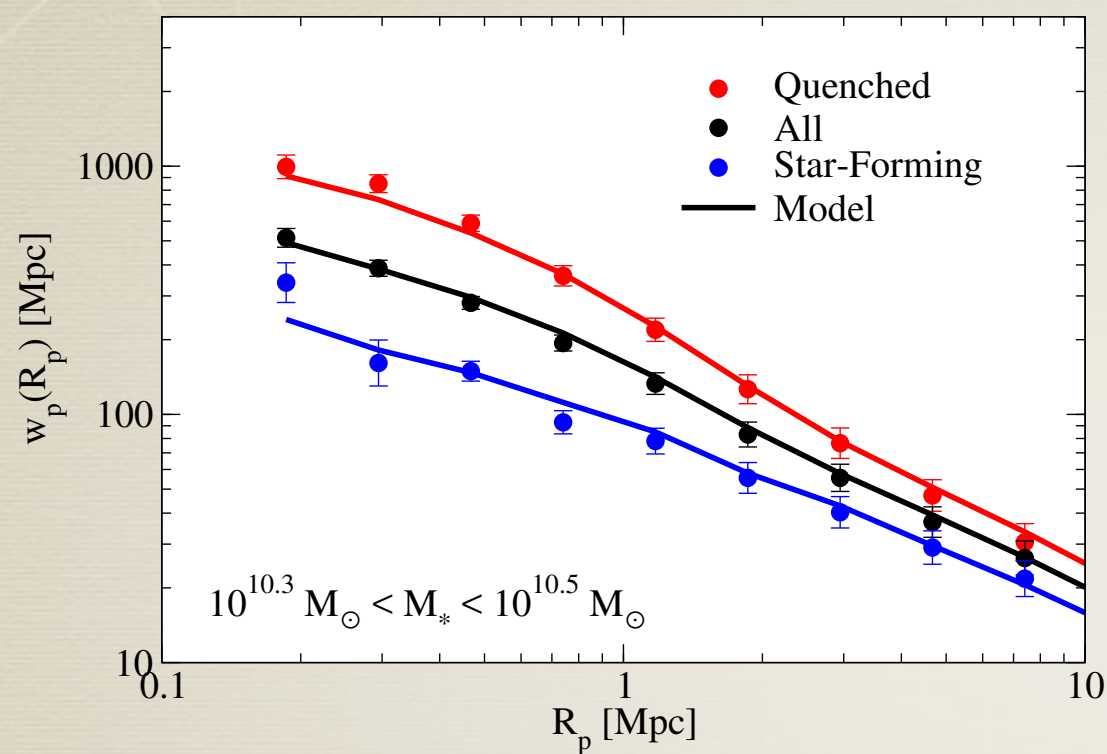
SFR($M_h, z, dM_h/dt$)



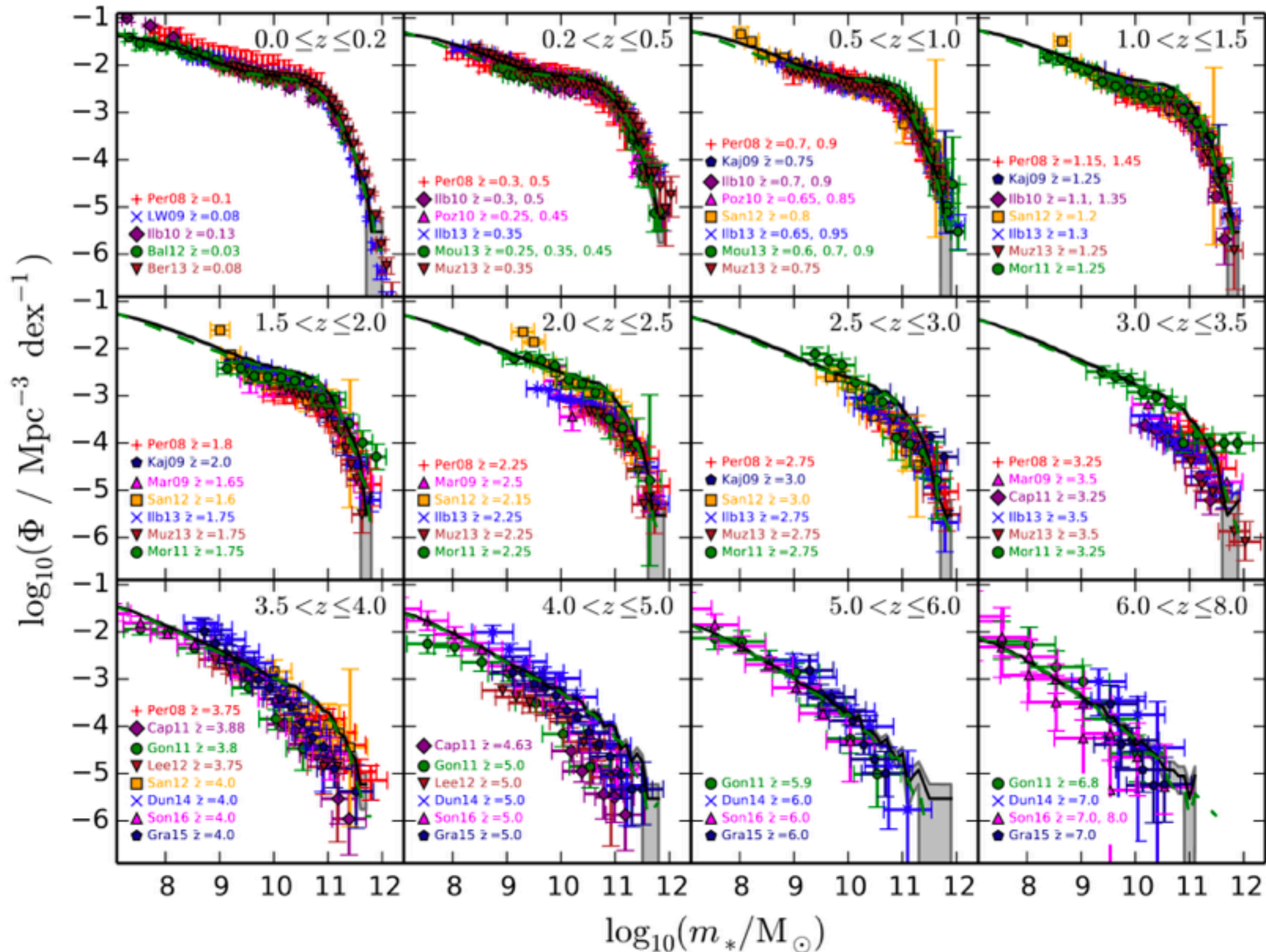
UniverseMachine: It Works



UniverseMachine: It Works



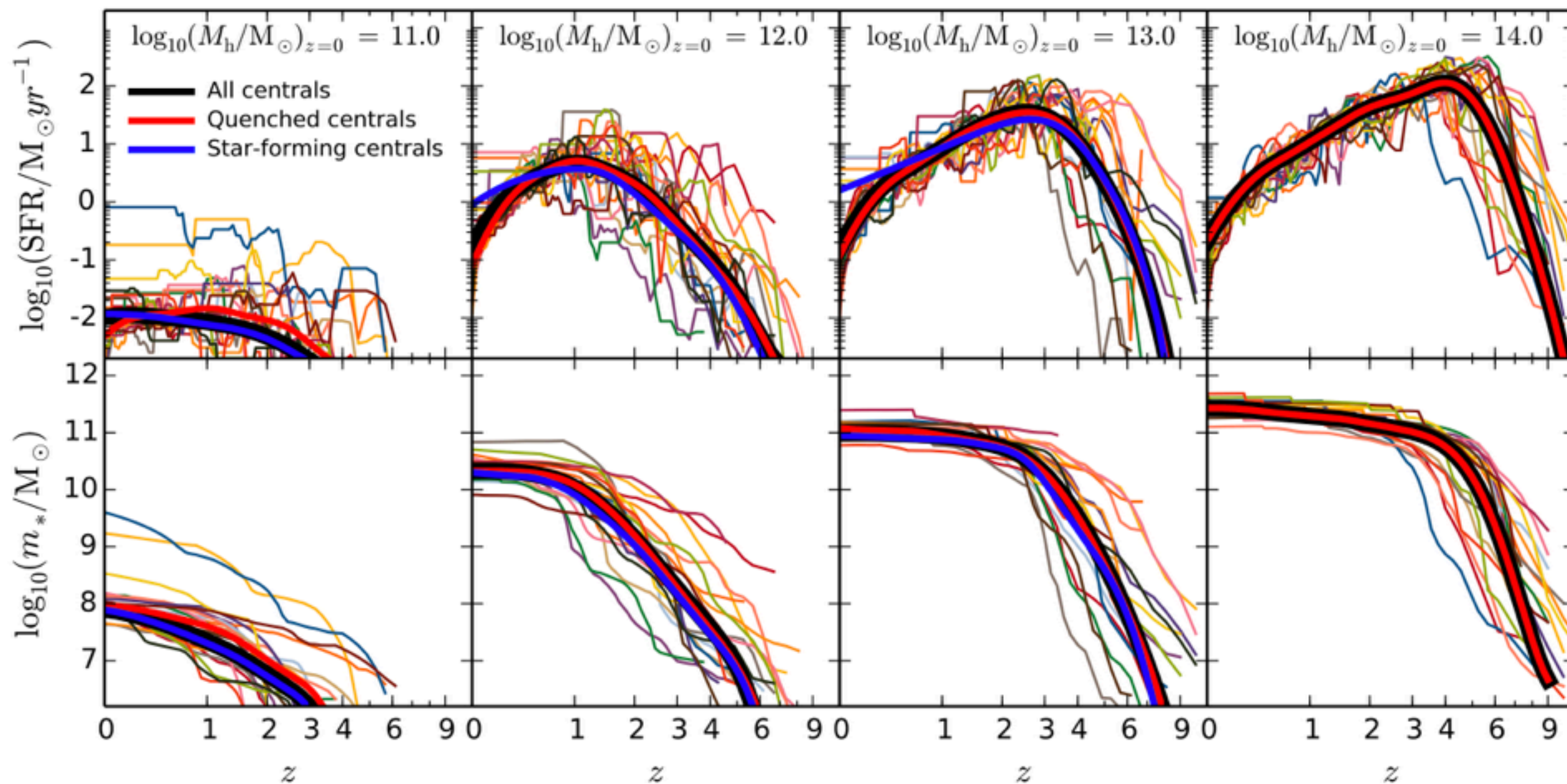
EMERGE: It Works



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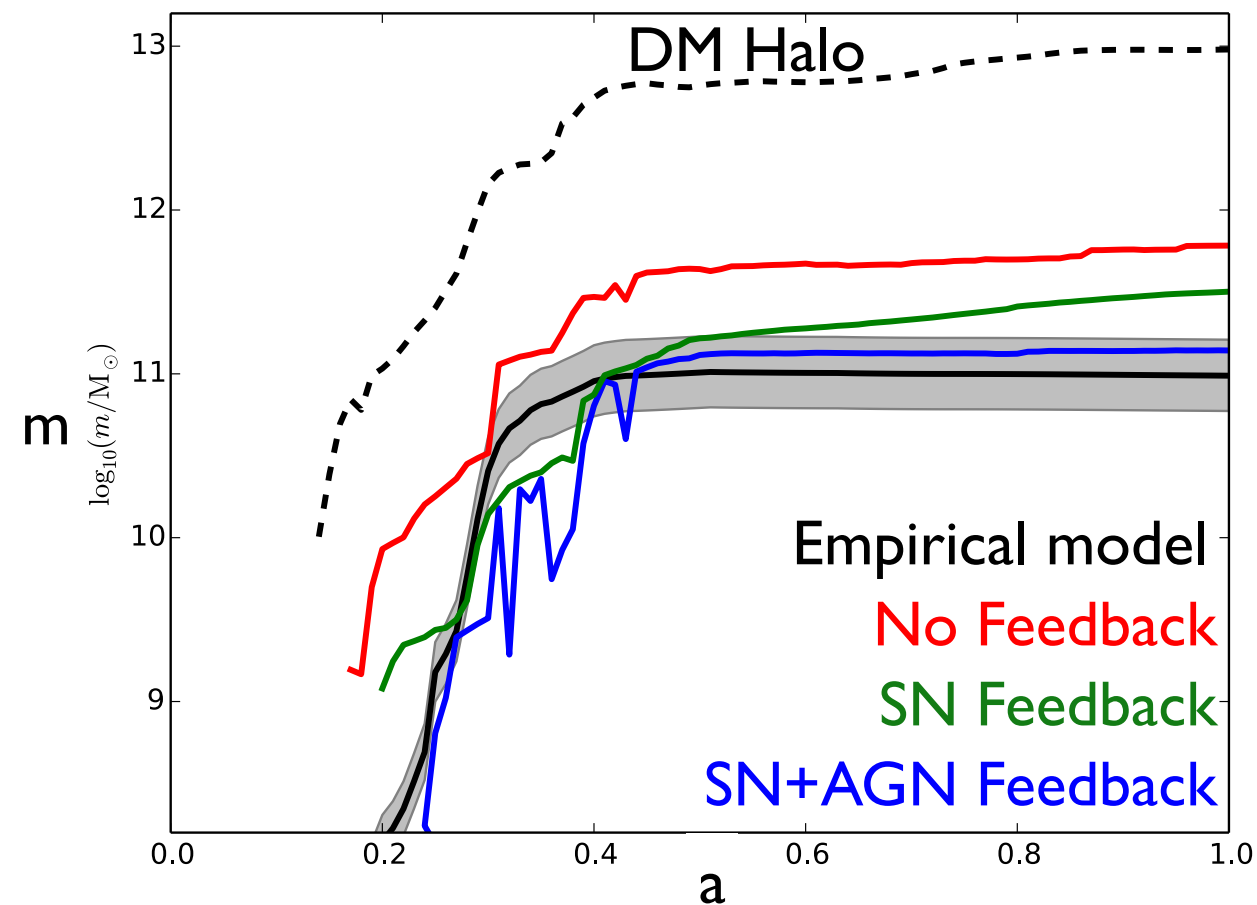
Empirical galaxy formation models

EMERGE: Results

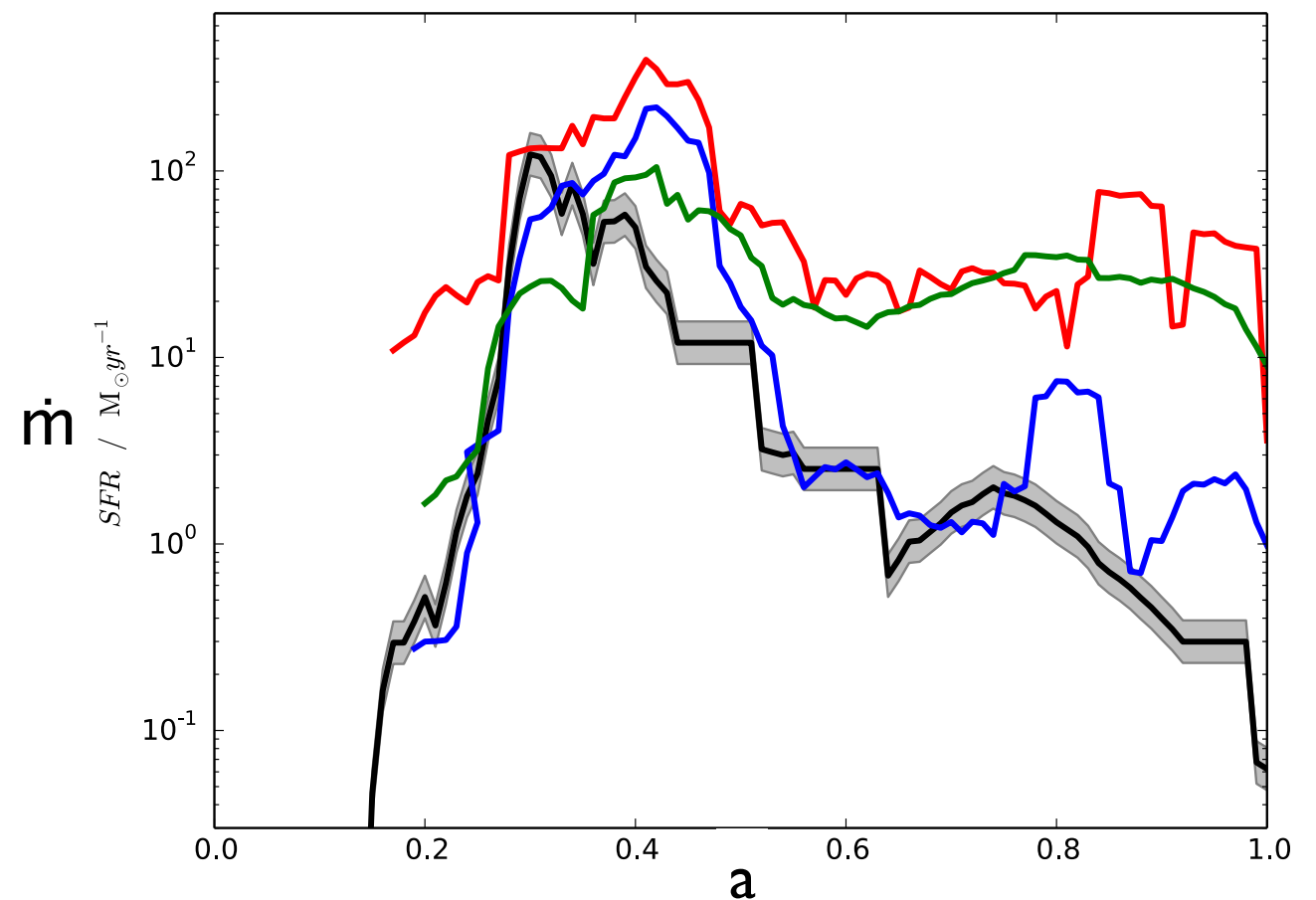


EMERGE: Comparison to zoom simulations

- Can now compare empirical prediction for each individual halo
- Run empirical model on DM-only run
- Compare SFR, m_* , etc directly to runs with different physics

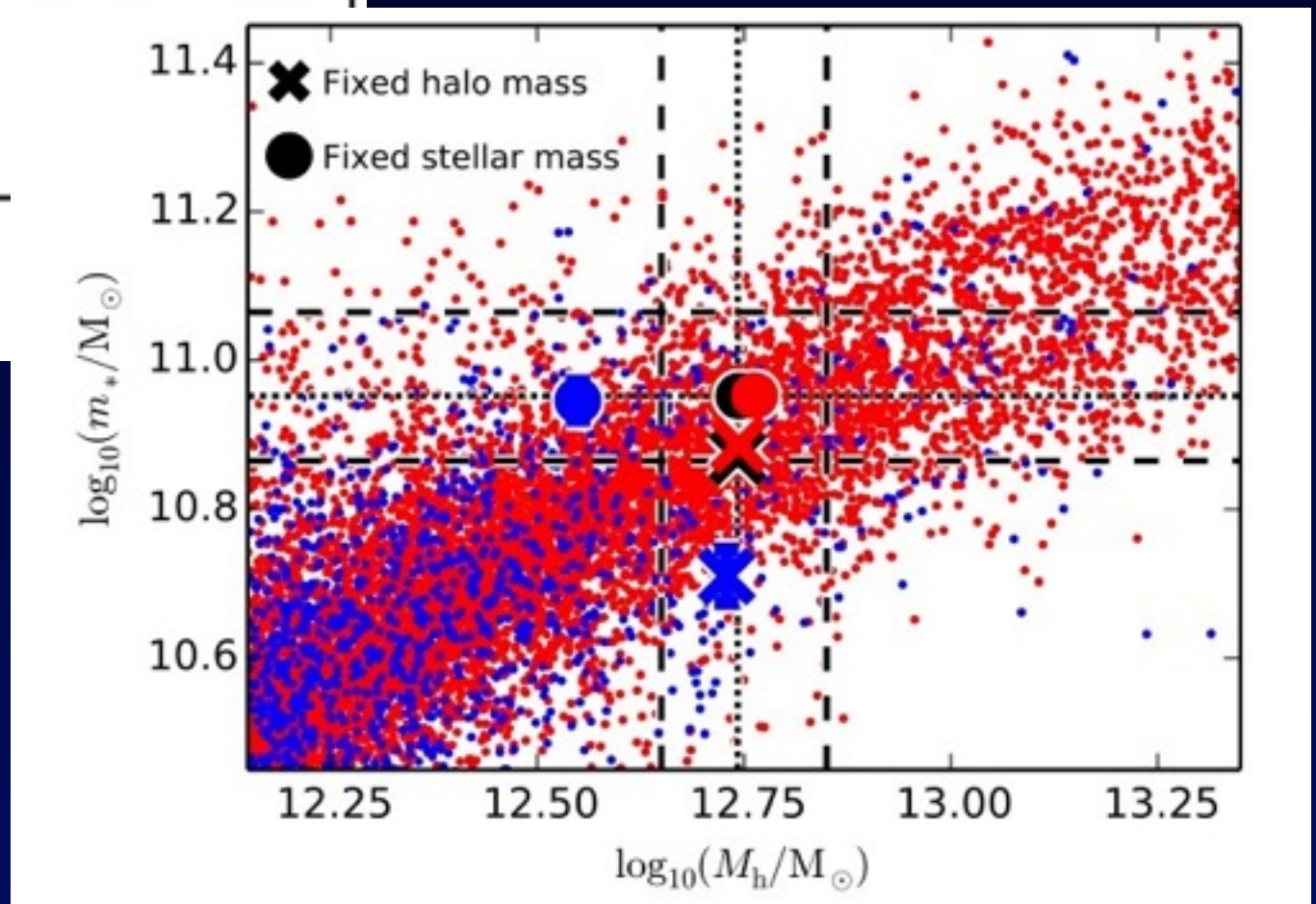
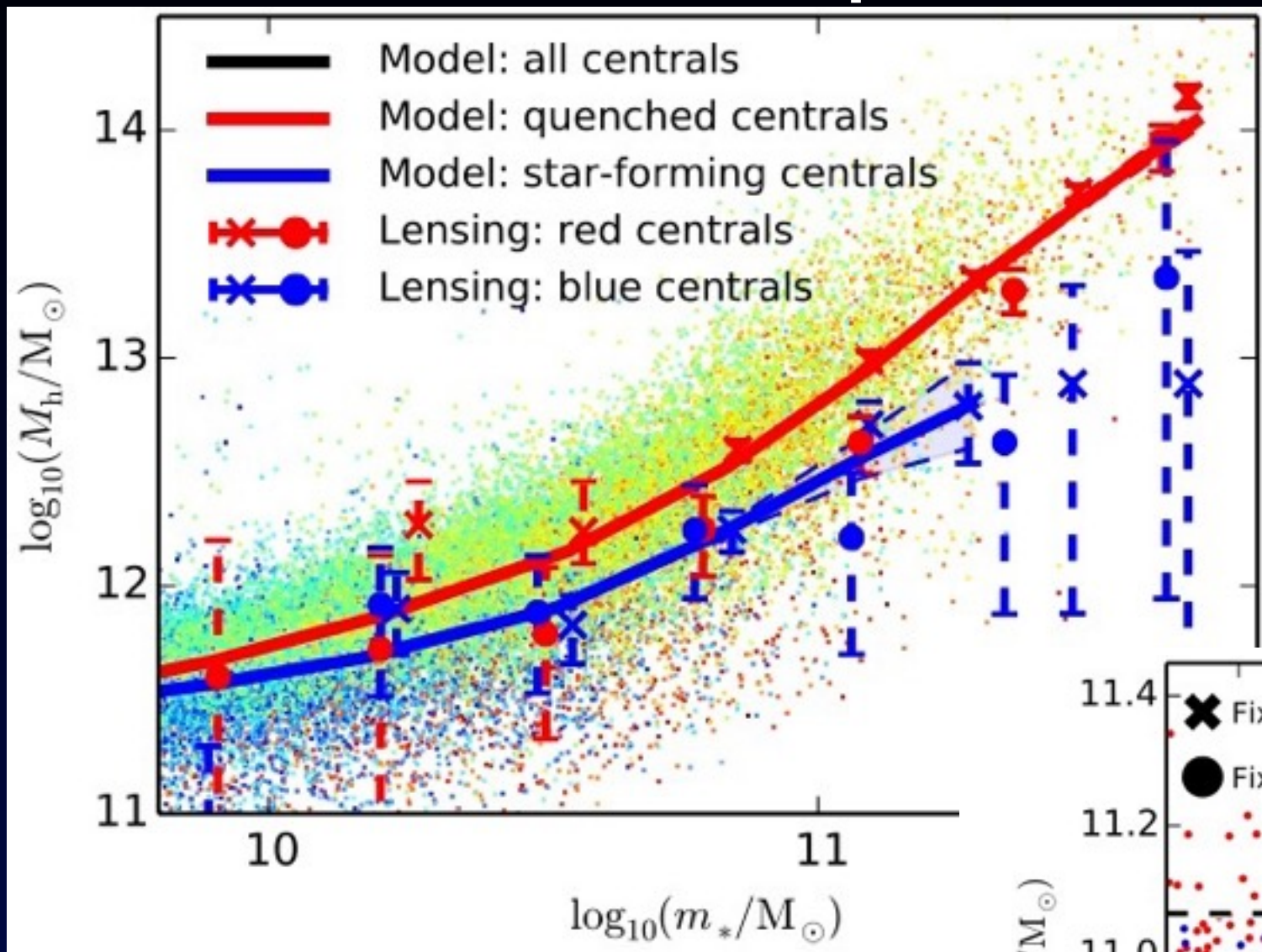


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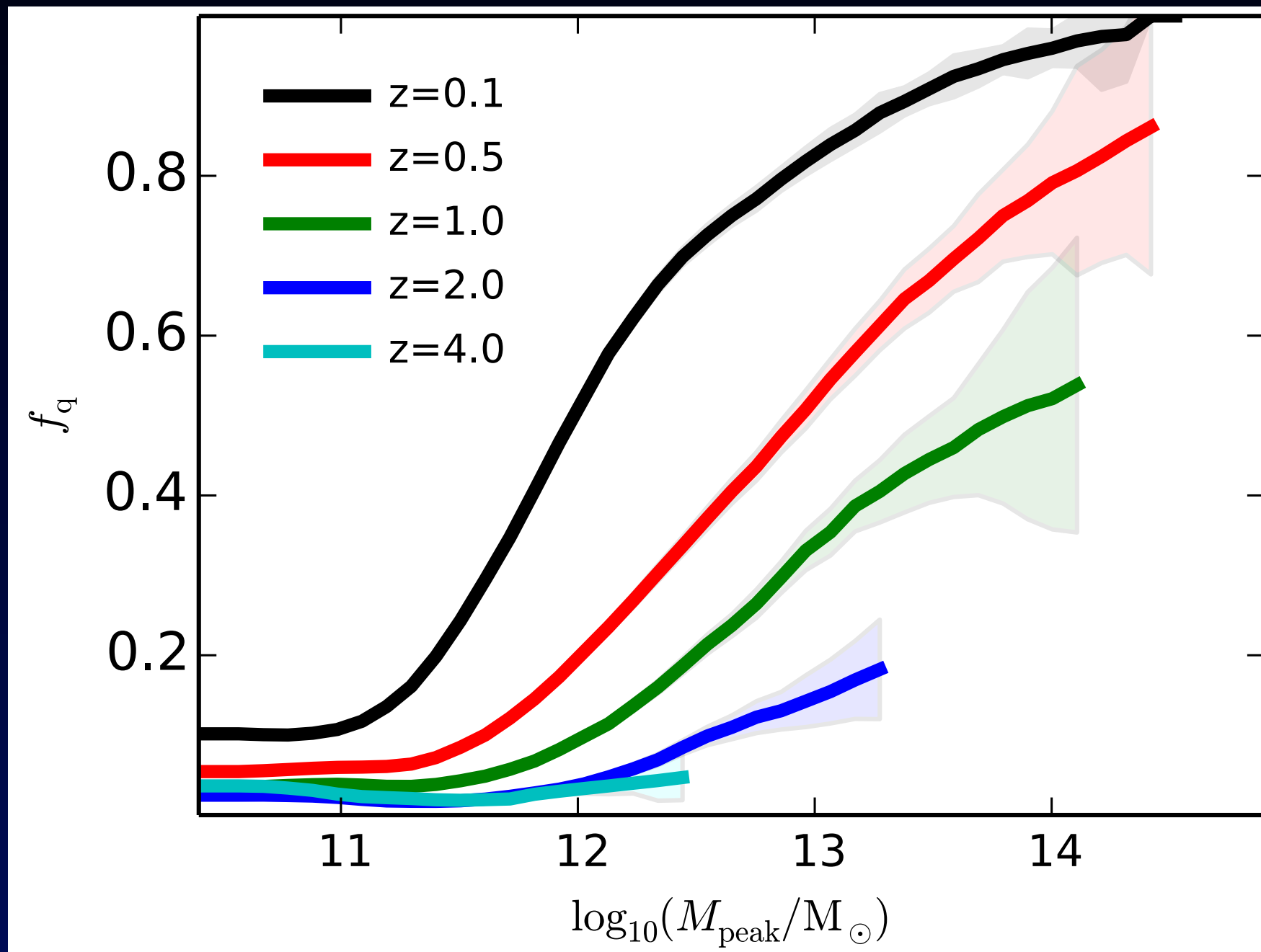
Empirical galaxy formation models

EMERGE: Comparison to weak lensing



See Ben's Poster!

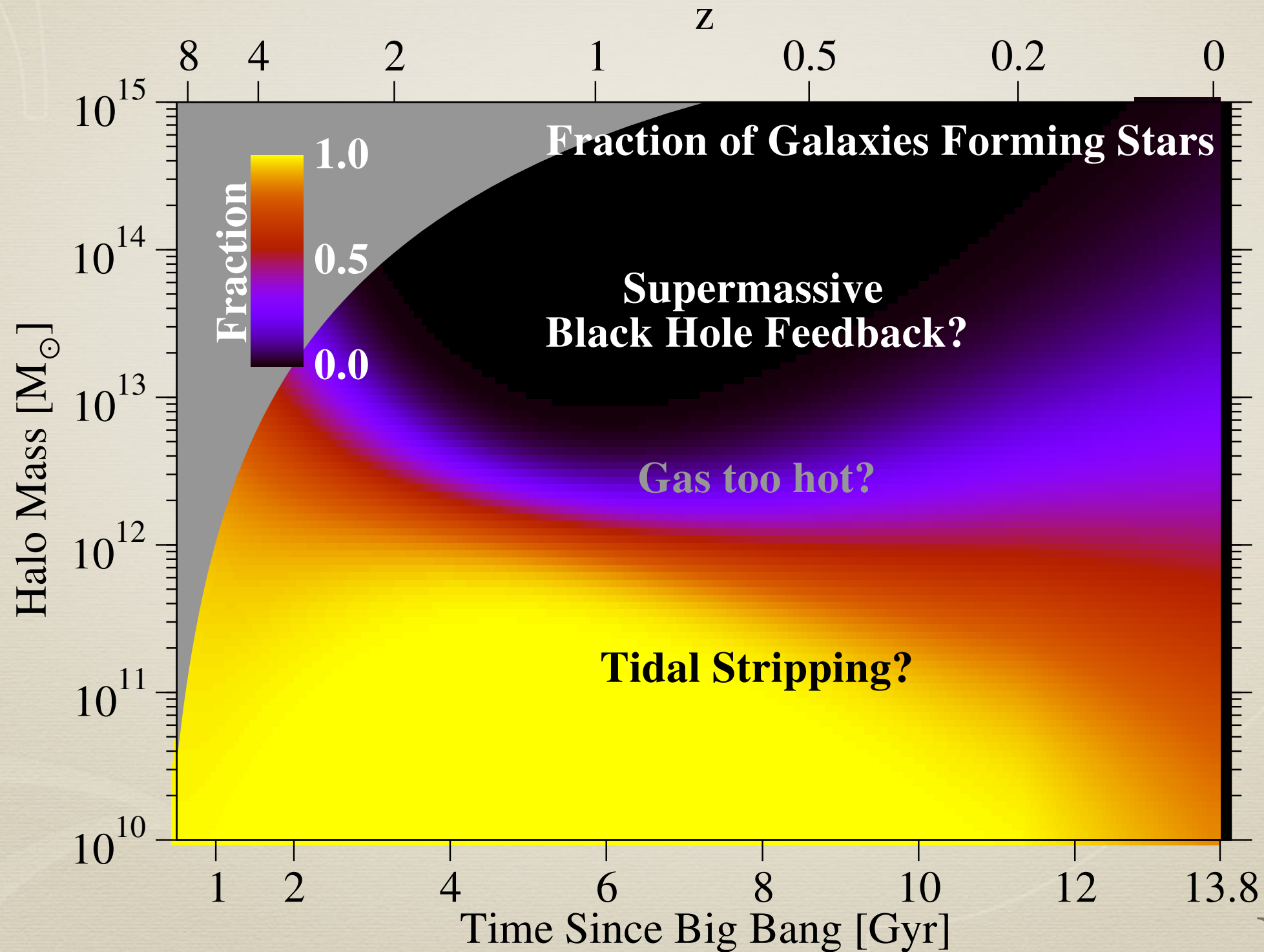
EMERGE: Results



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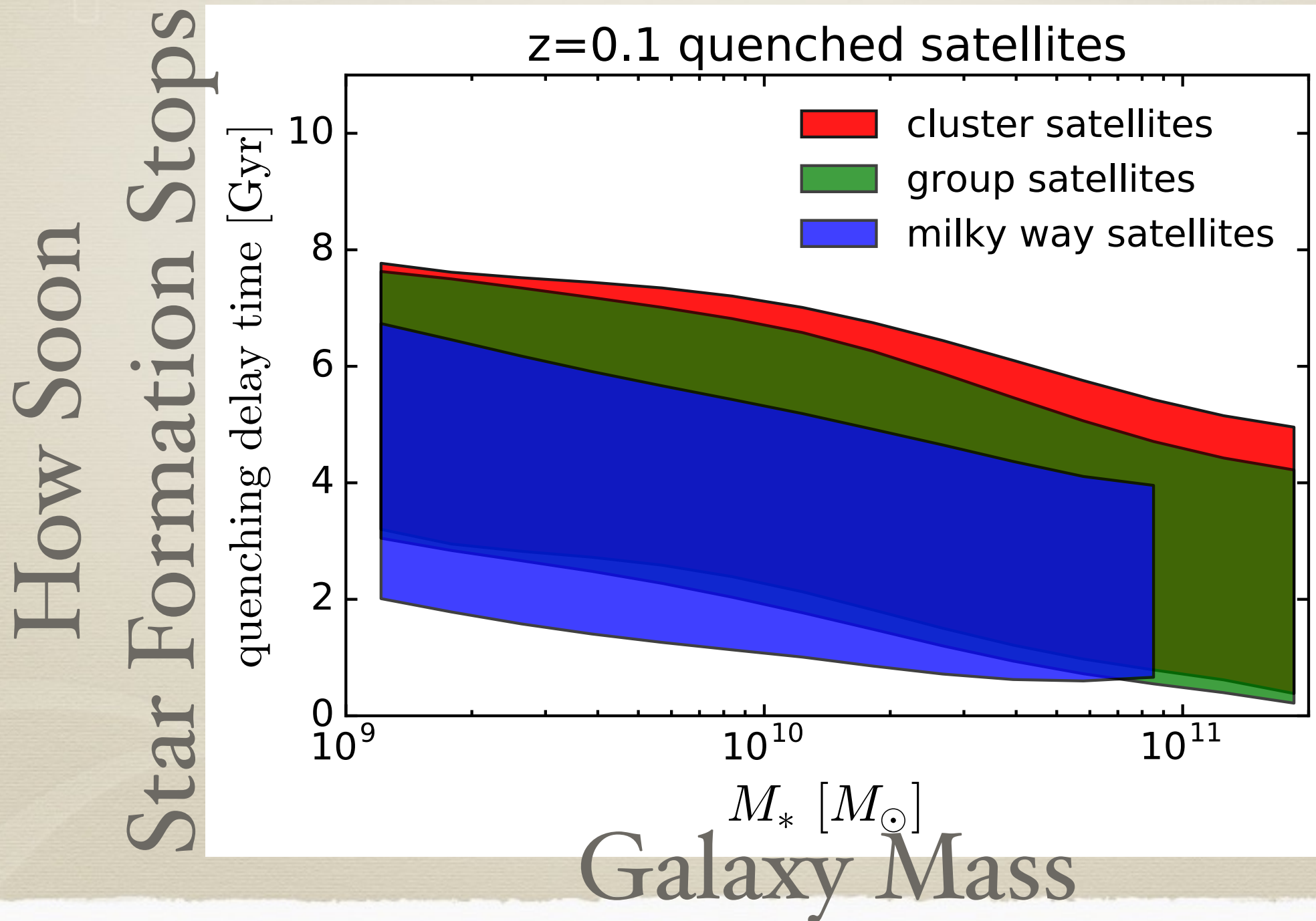
Empirical galaxy formation models

UniverseMachine: Results



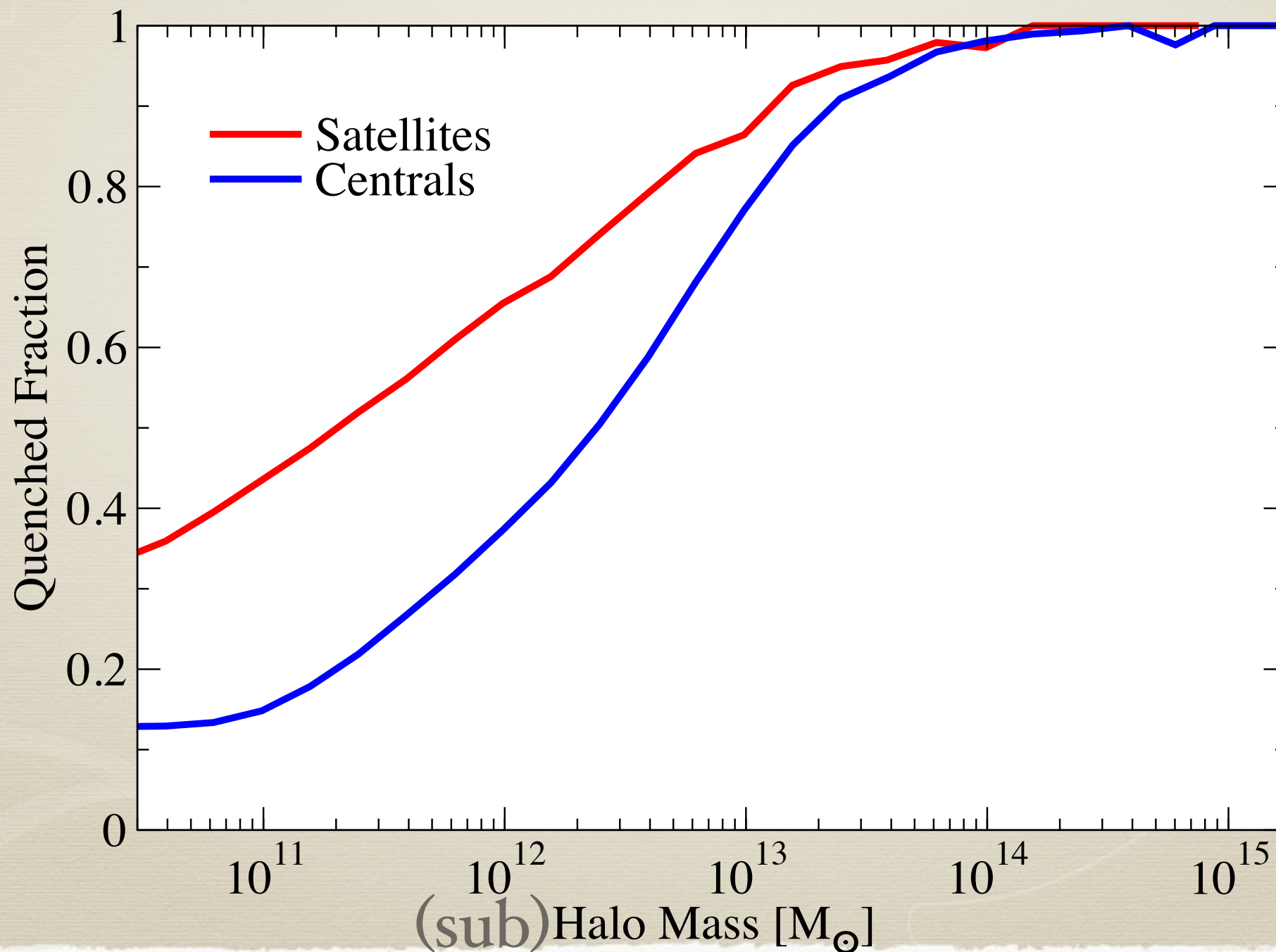
UniverseMachine: Results

Satellites **quench over a broad range of timescales**



UniverseMachine: Results

Being a satellite **only mildly increases quenching risk**



Most Satellites Quench Gently

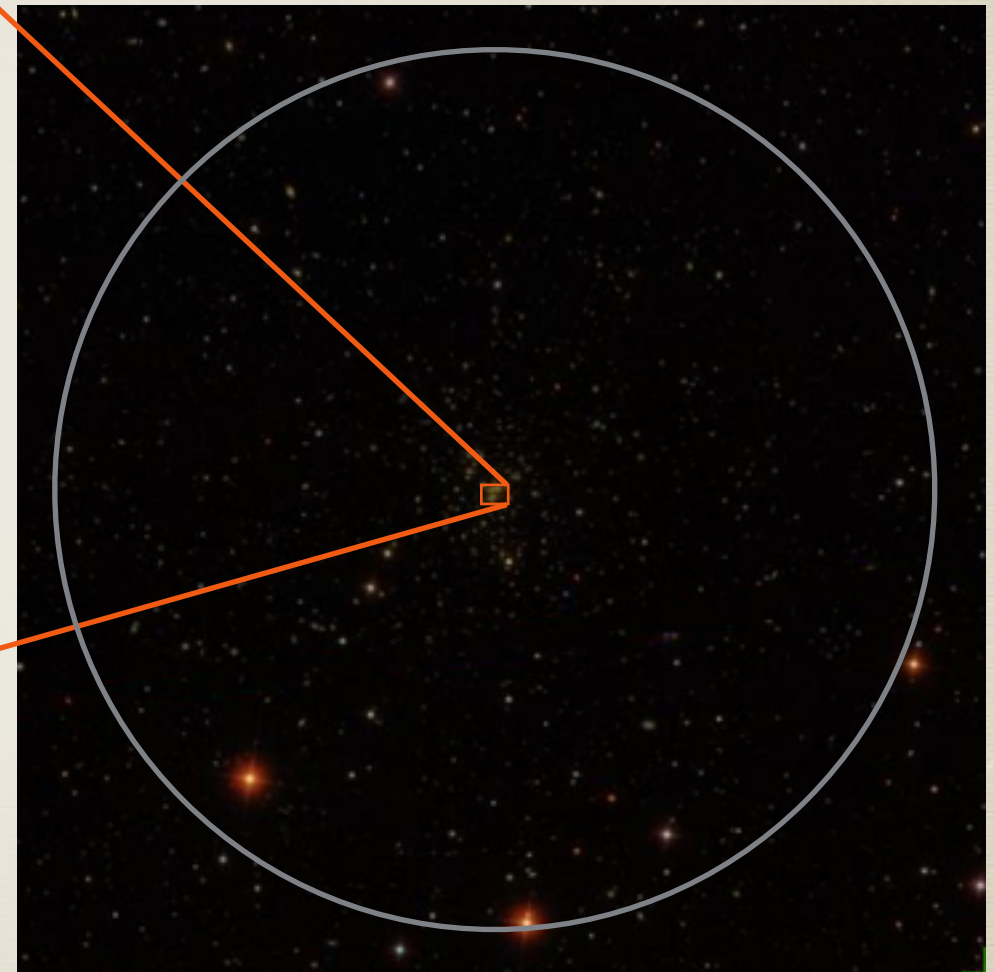


Abell 1689

Most Satellites Quench Gently

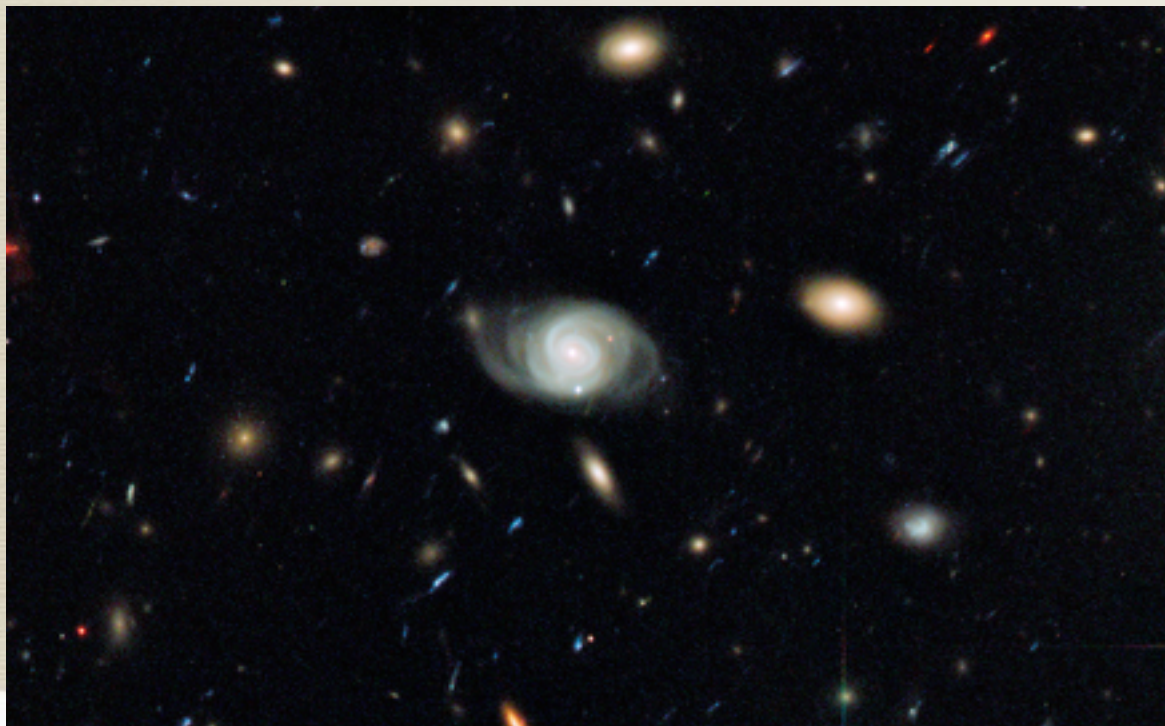


Halo Radius

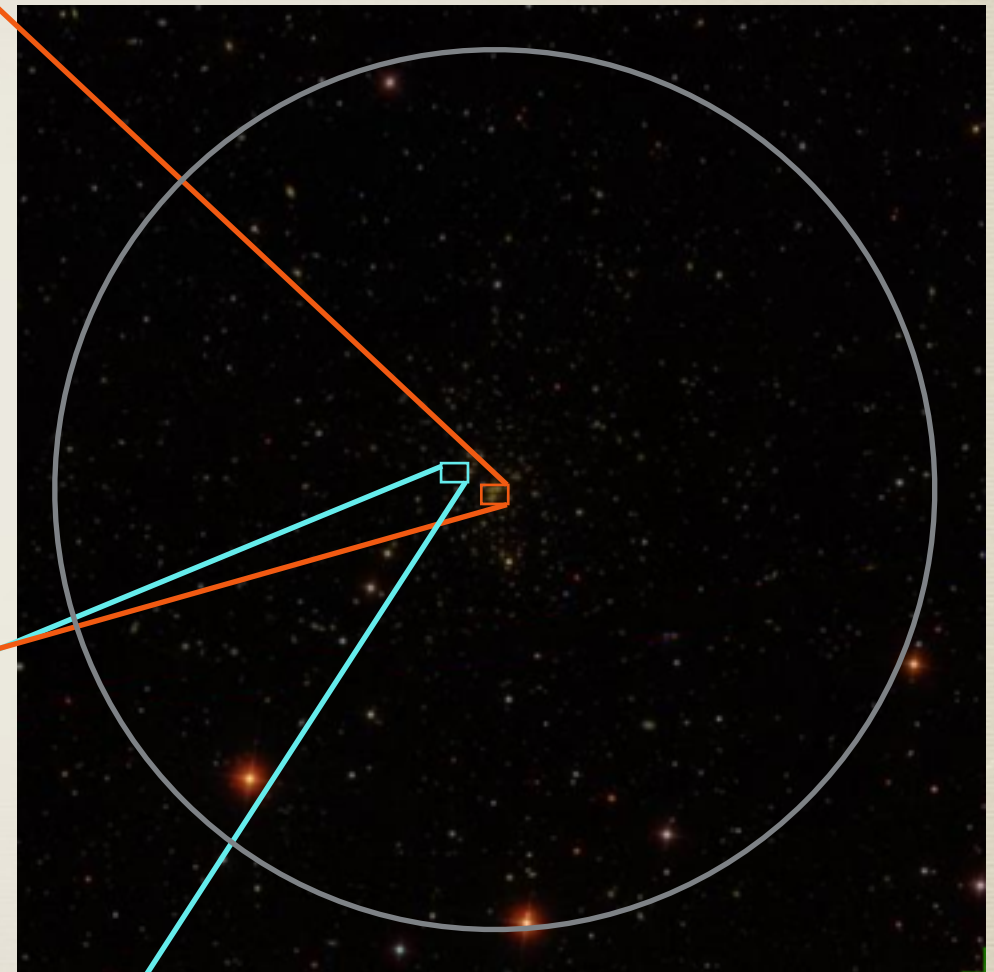


Abell 1689, SDSS

Most Satellites Quench Gently



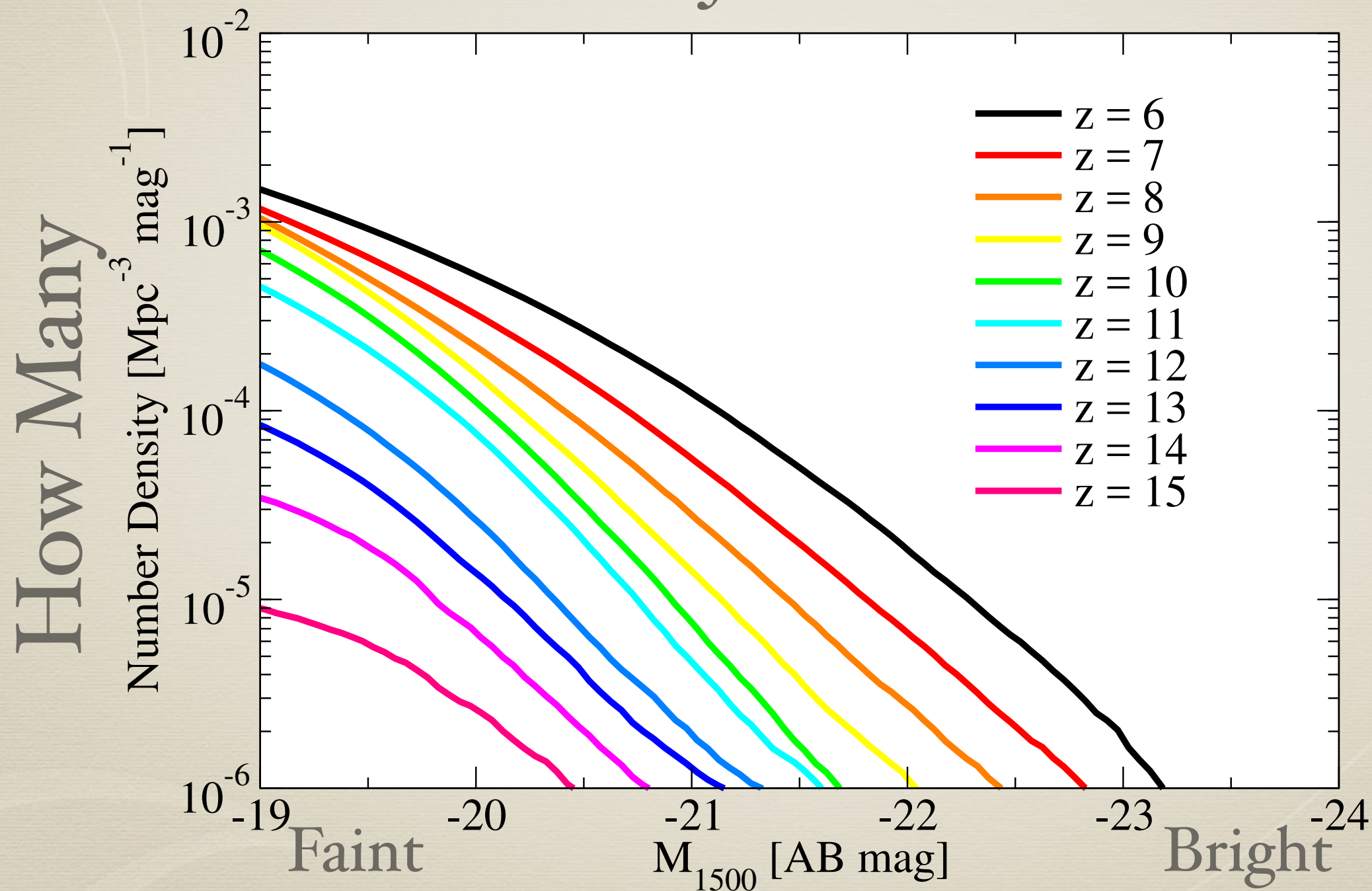
Halo Radius



Abell 1689, SDSS

UniverseMachine: Results

Predictions for JWST number counts



Rest-Frame UV Luminosity

Preliminary Results

What matters for quenching?

What will JWST likely see?

How do SFHs depend on current SSFR (& environment)?

What's the halo mass for a given galaxy (based on SM, SSFR, etc.)?

Is my hydro simulation right?

