HOW GALAXIES ARE MADE, FROM Z=0 TO Z=8

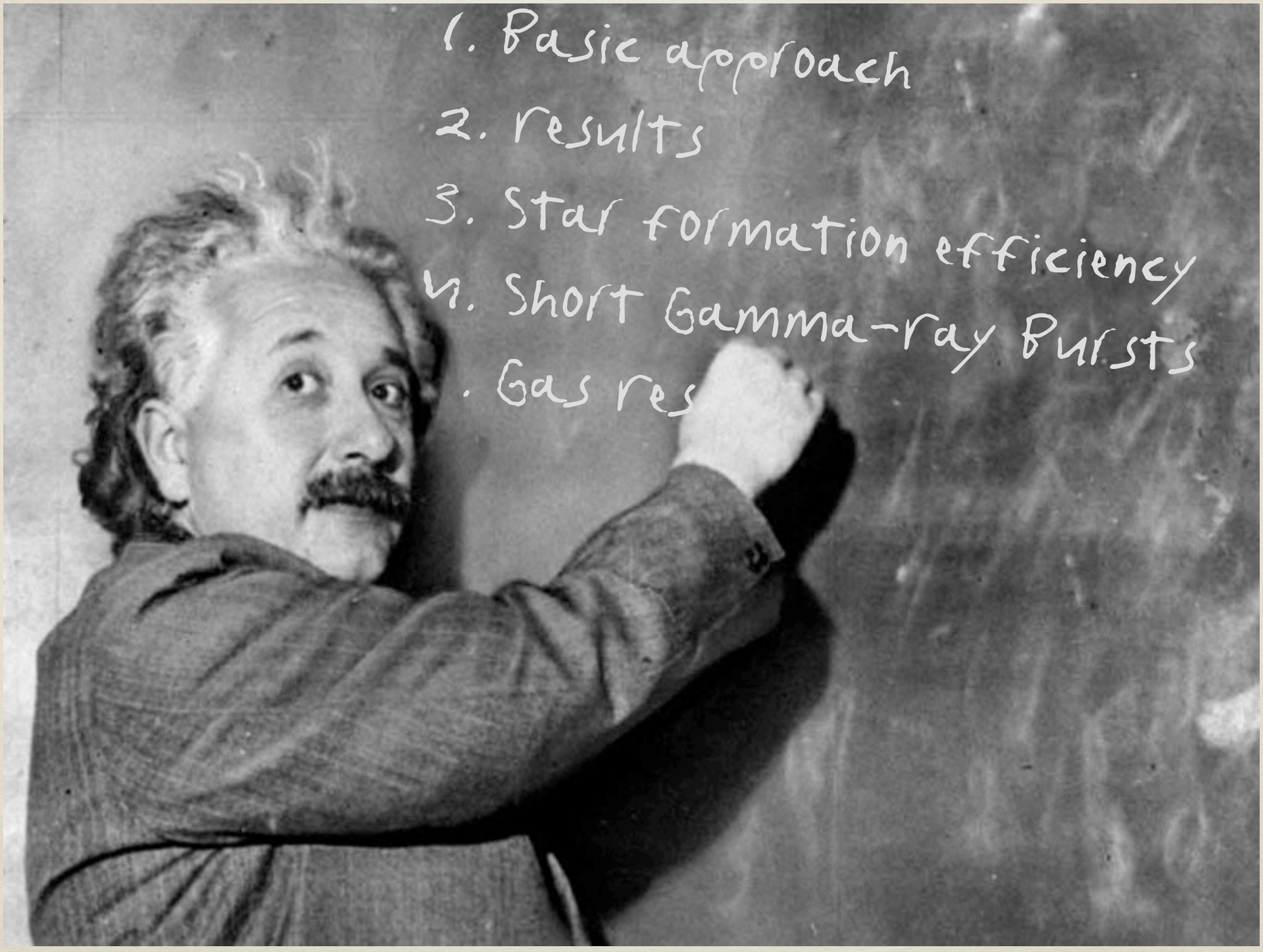
...and a little about what makes them unique.

Picture Credit: John MacKenty, NASA, Hubble Heritage Team

Peter Behroozi, Stanford University / KIPAC

IPMU - 7/18/13

Outline


1. Basic approach
2. results
3. Star formation efficiency
4. Short Gamma-ray Bursts
5. Gas res

Basic Approach

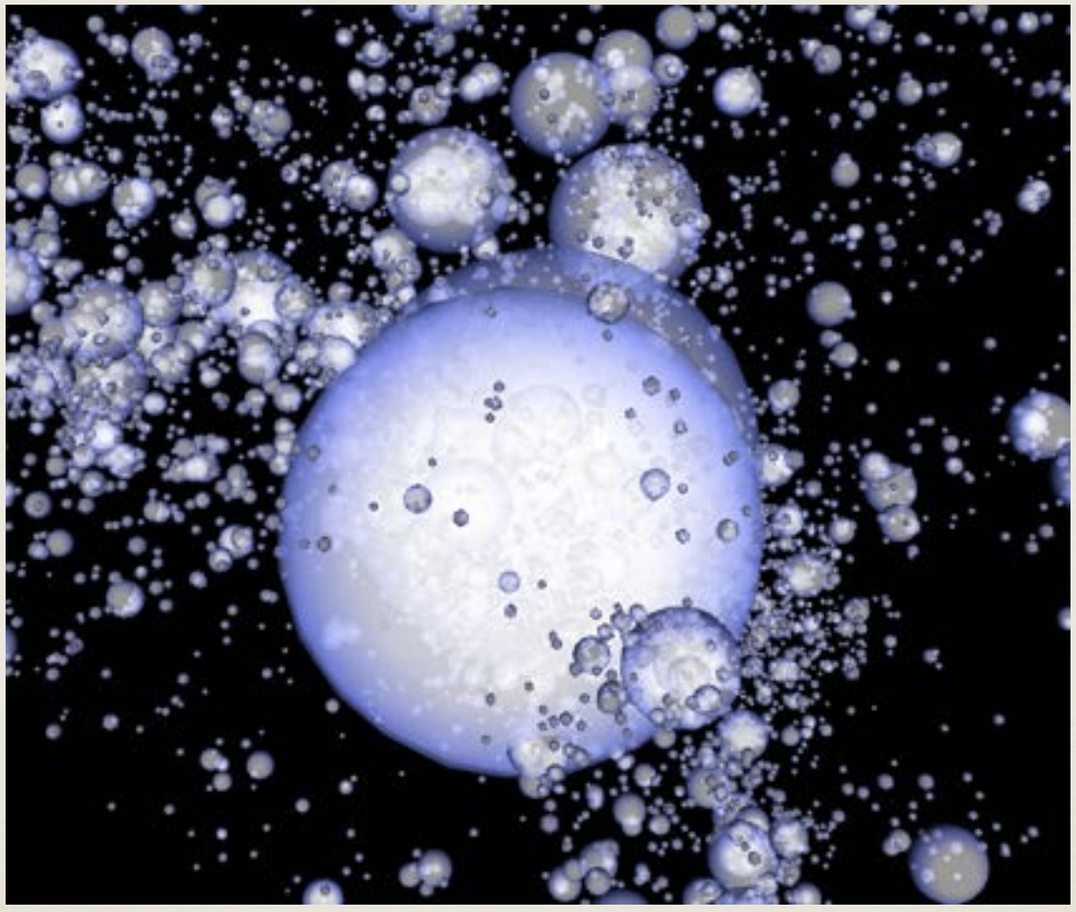
We can observe galaxies at many different redshifts

What we cannot see, nor ever hope to, is a movie of how a real galaxy evolves with time.

(Real galaxies take hundreds of millions of years to change)

Basic Approach

Yet, this is a basic feature of simulations



But currently, the only precise results of simulations are the clustering and motion of matter on large scales.

Basic Approach

So, we combine the two:

Observations tell us how many galaxies there are;

Simulations tell us how often they merge together and what happens when they do---as well as how to *connect* galaxies observed at different times.

So, we ought to be able to reconstruct what happens to stars (on average) in individual galaxies.

Basic Approach

How do we match observed galaxies to halos in simulations?

No-one knows ahead of time.

So, we adopt a very flexible parametrization of the matching and let computers search for the answer.

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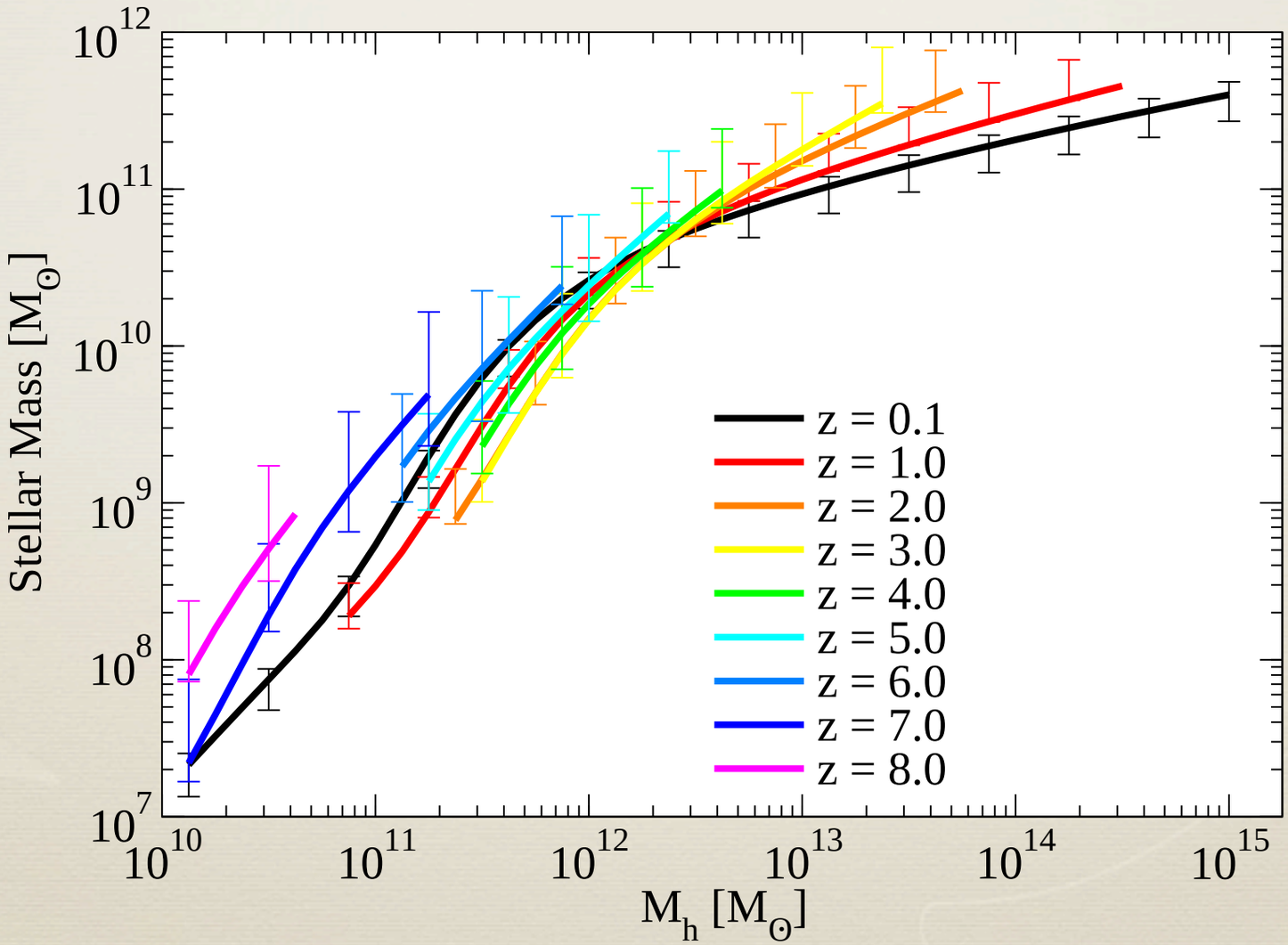
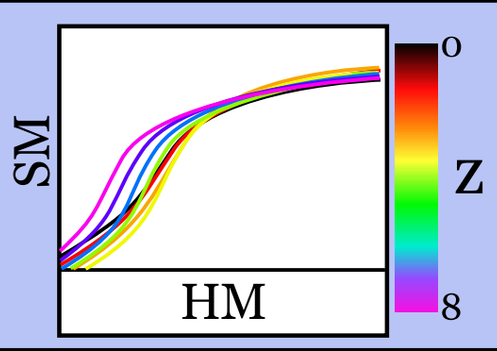
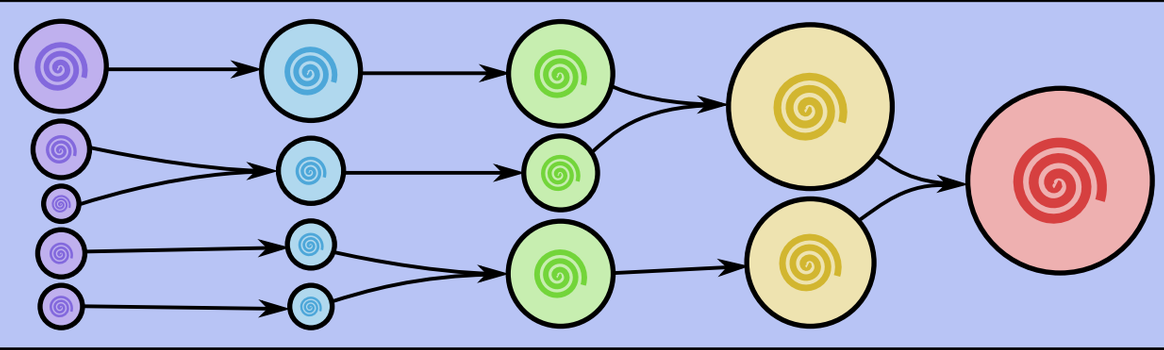


Basic Approach

1. Choose a stellar mass - halo mass (SMHM) relation from parameter space.

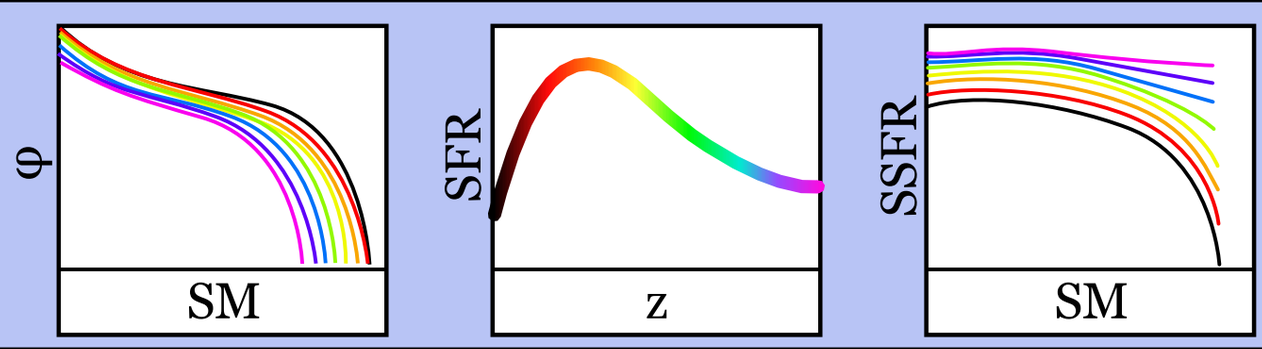


2. Find galaxy growth histories by applying the SMHM relation to dark matter merger trees.

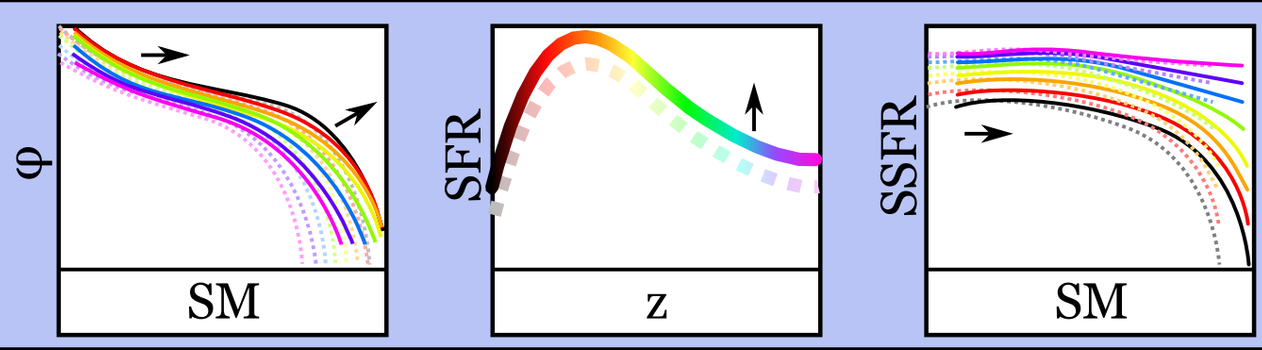


Basic Approach

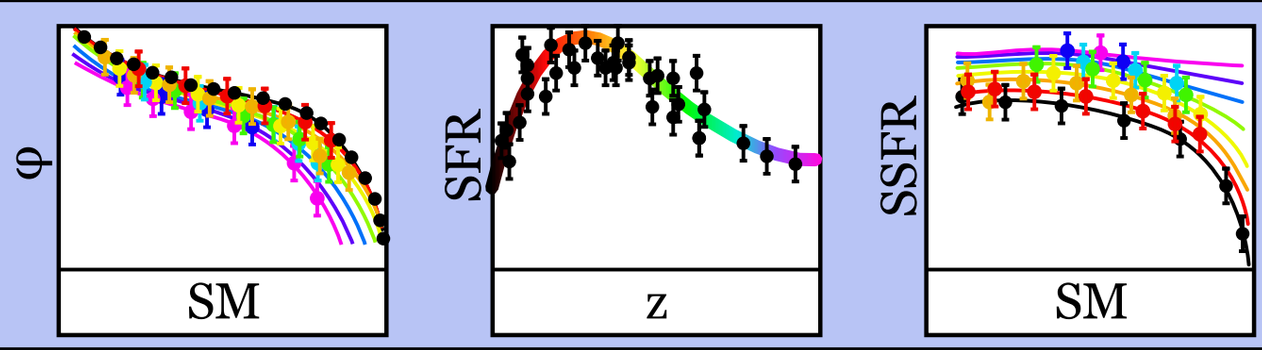
3. Derive the inferred stellar mass functions and star formation rates.



4. Apply effects to simulate observational errors and biases.



5. Compare to data and calculate likelihood of the chosen SMHM relation.



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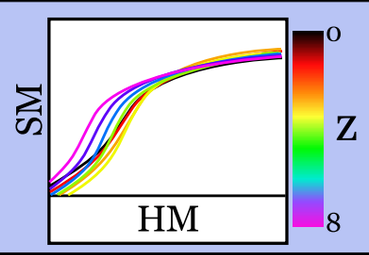

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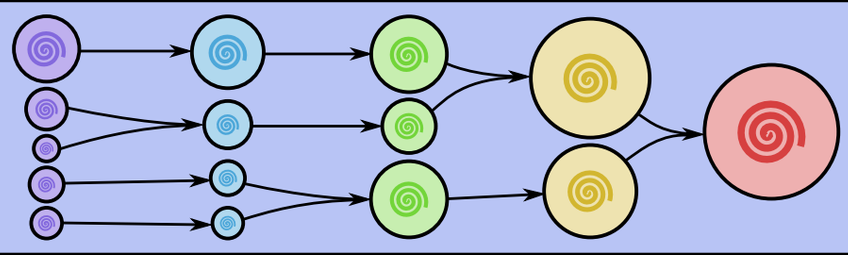

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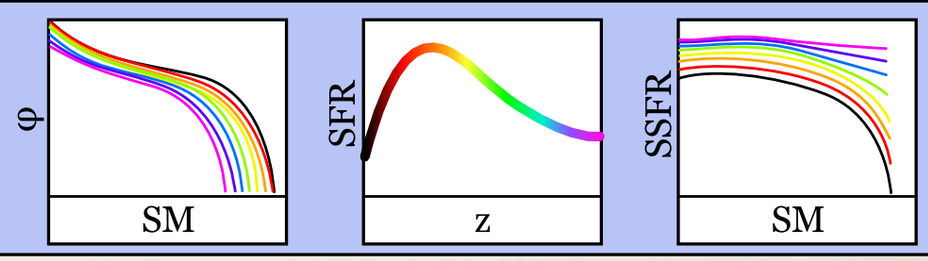

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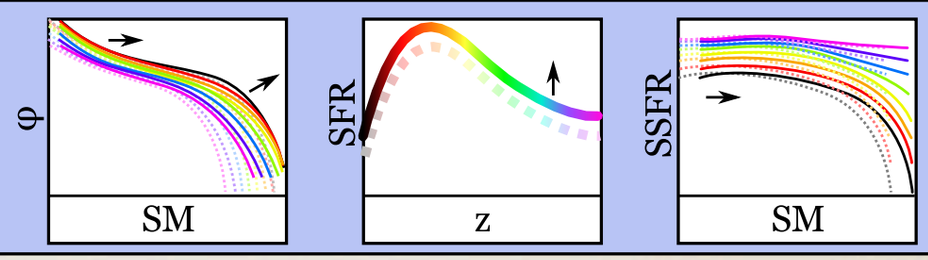

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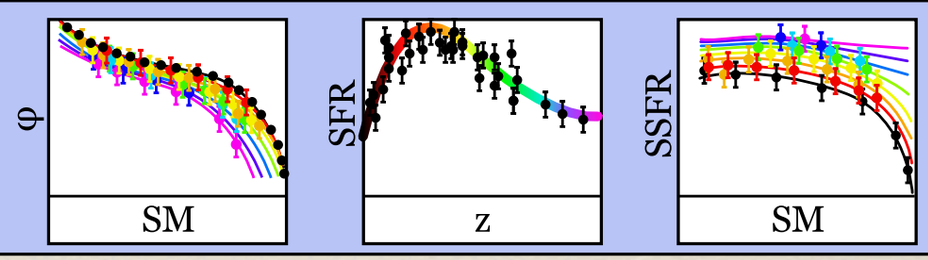
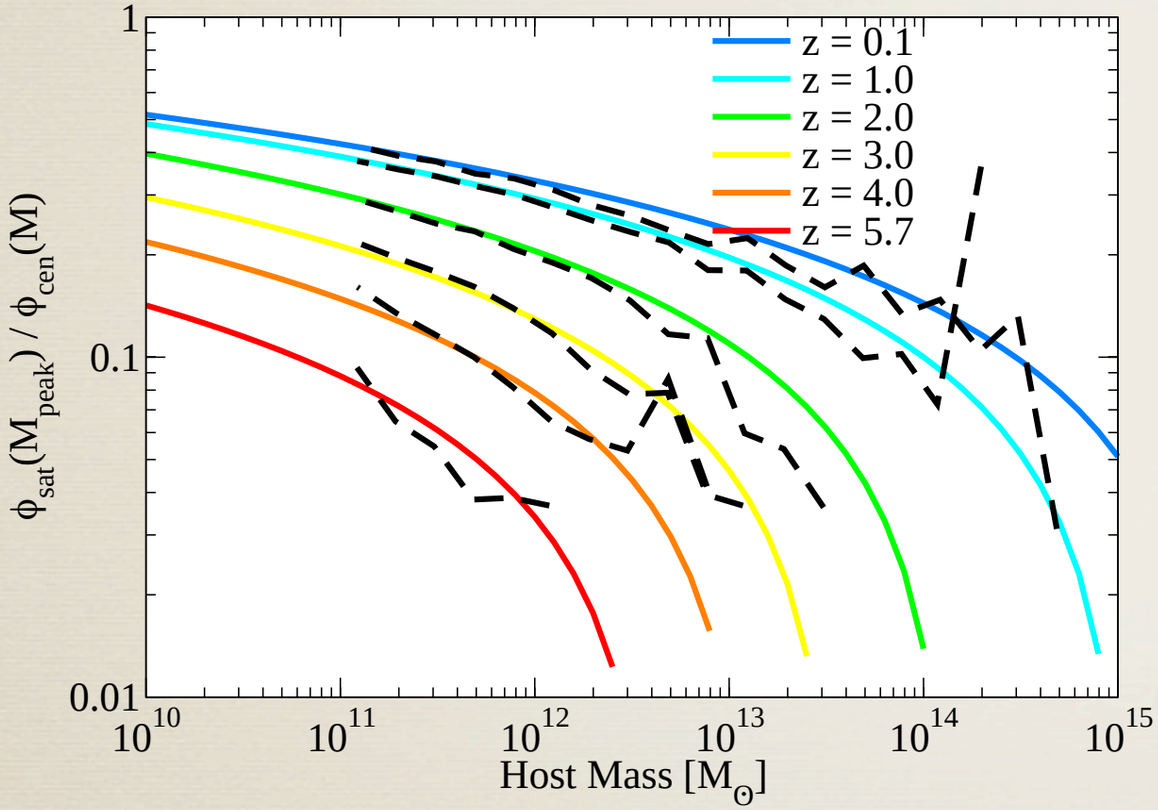
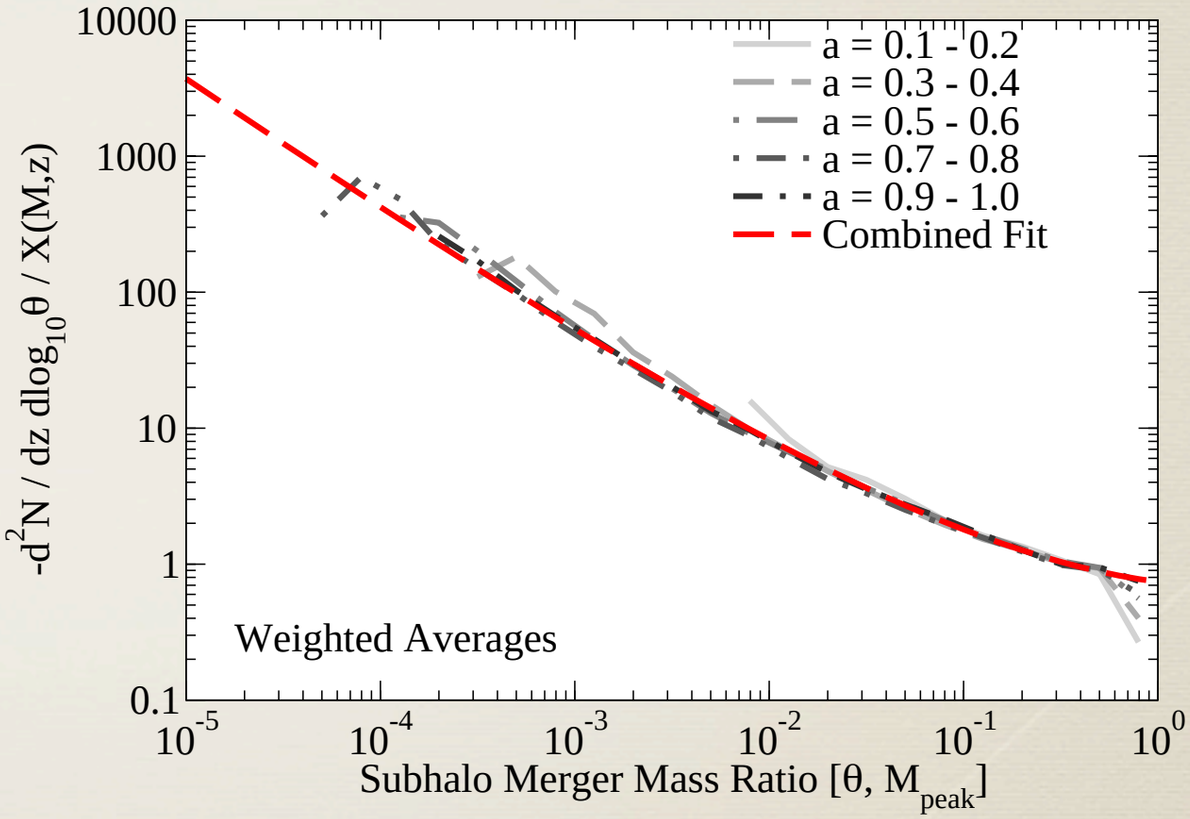


Repeat as often as necessary to explore allowable solutions.

Basic Approach

Data Sets:





New calibrations of halo mass functions,
satellite fractions, and merger rates to z=8 from Bolshoi.

Basic Approach

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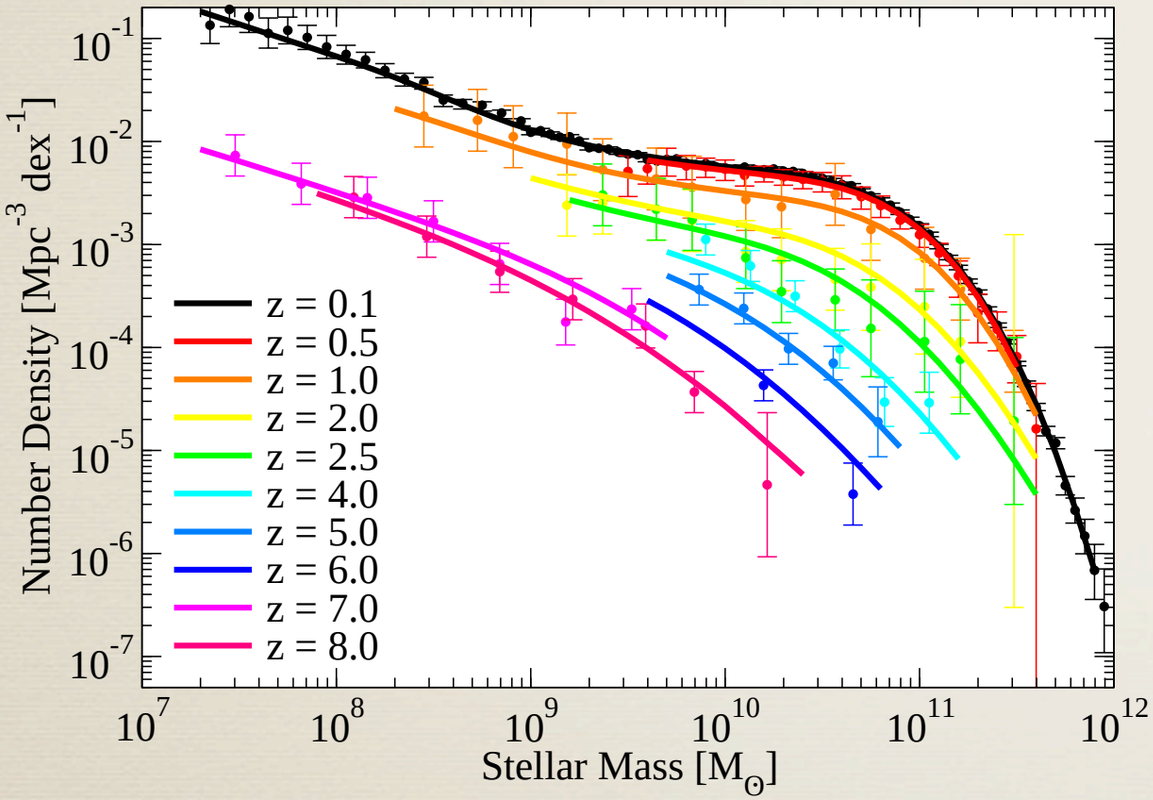
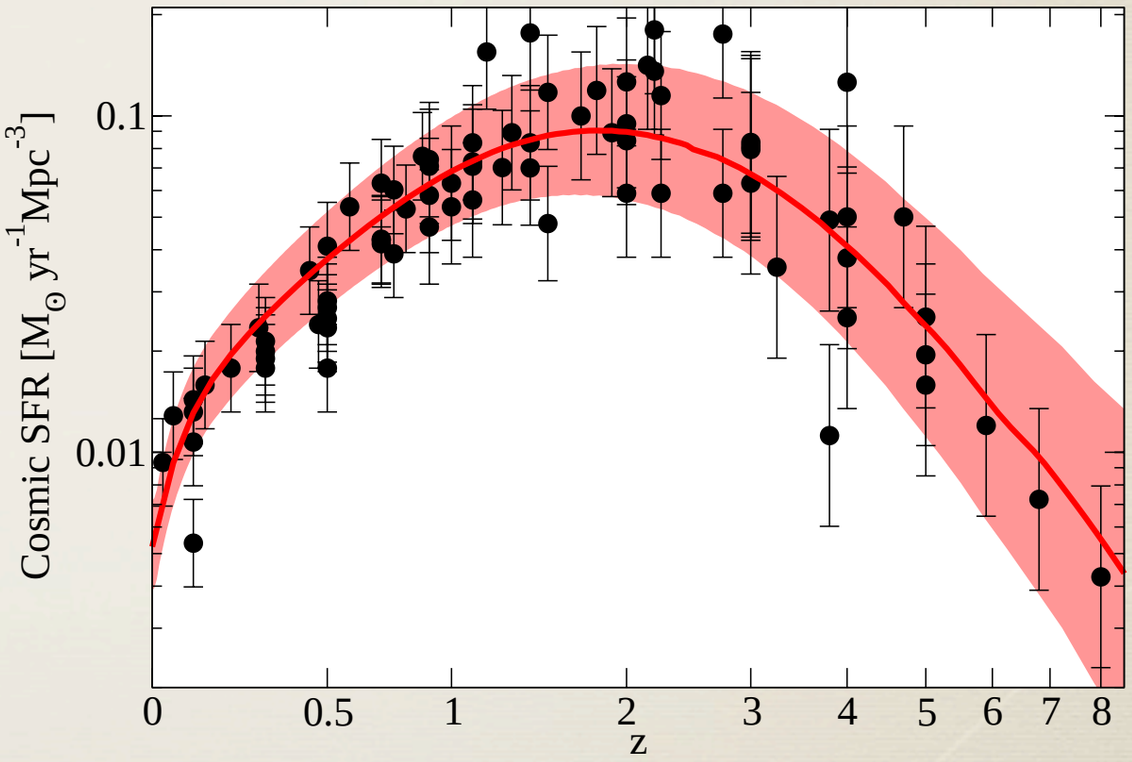


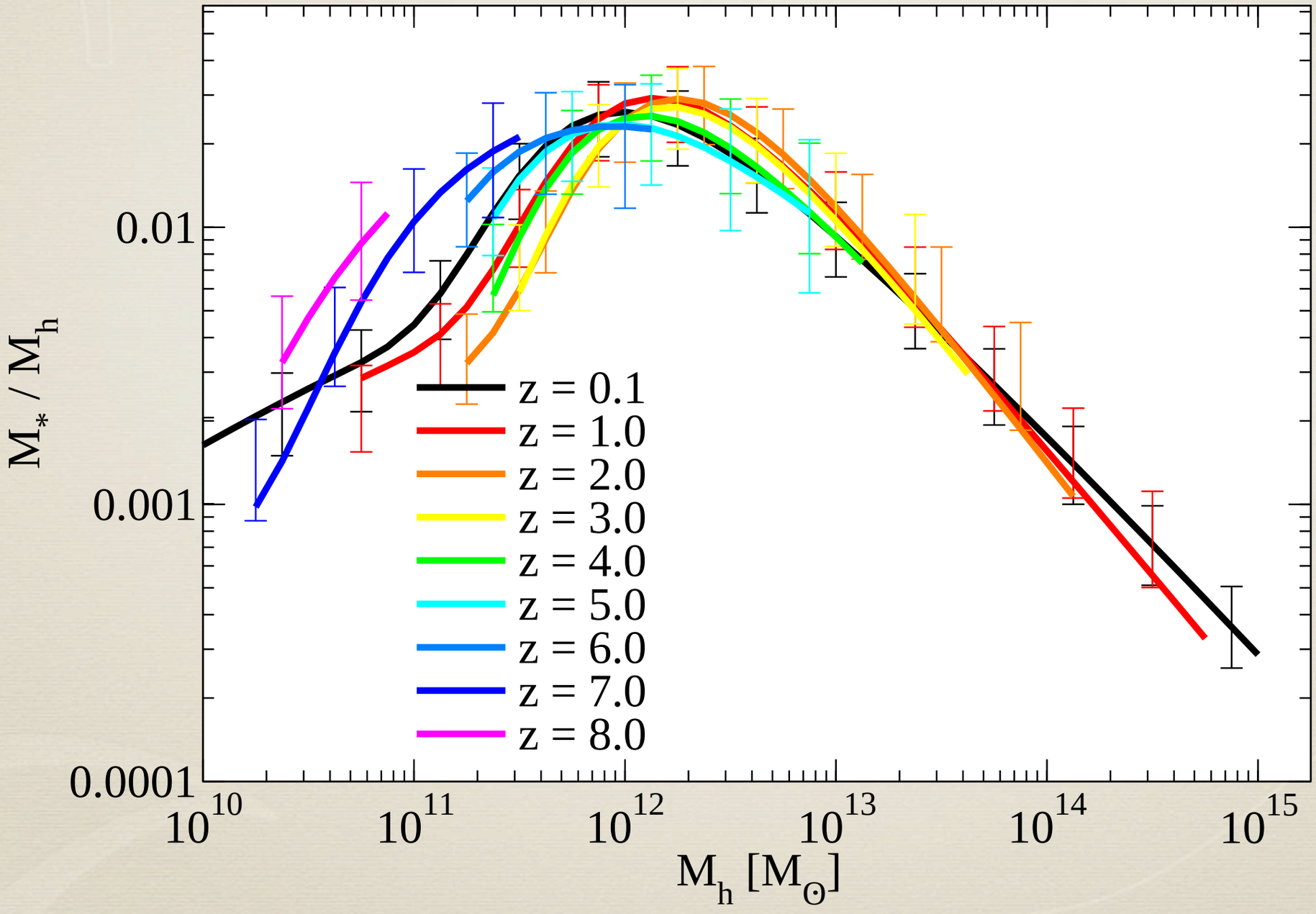
New Stellar Mass Functions from PRIMUS, others up to z=8



New compilation of cSFRs to z=8

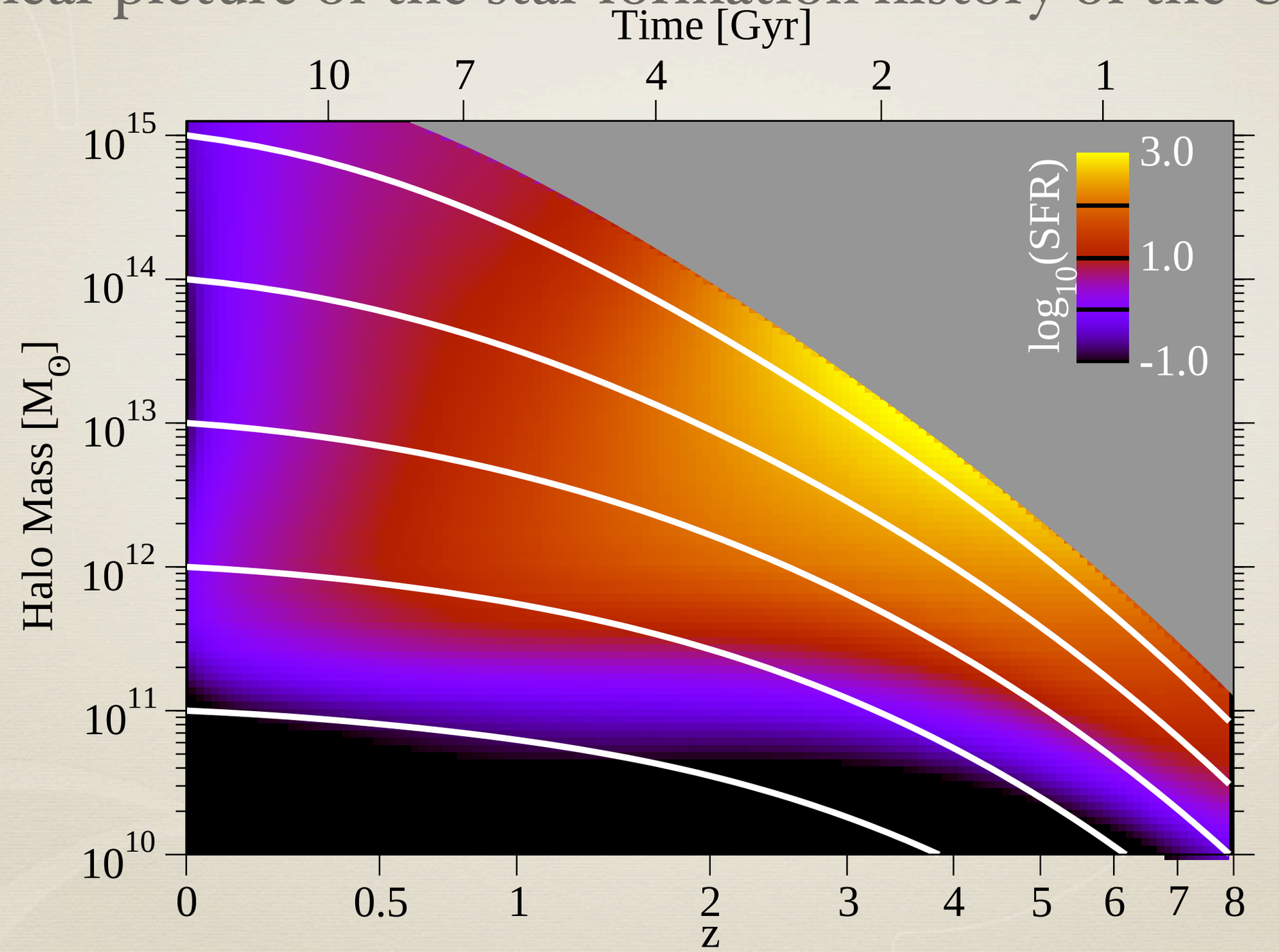
Results

Constraints on Mh(M*), M*(Mh), useful for theory and observers:



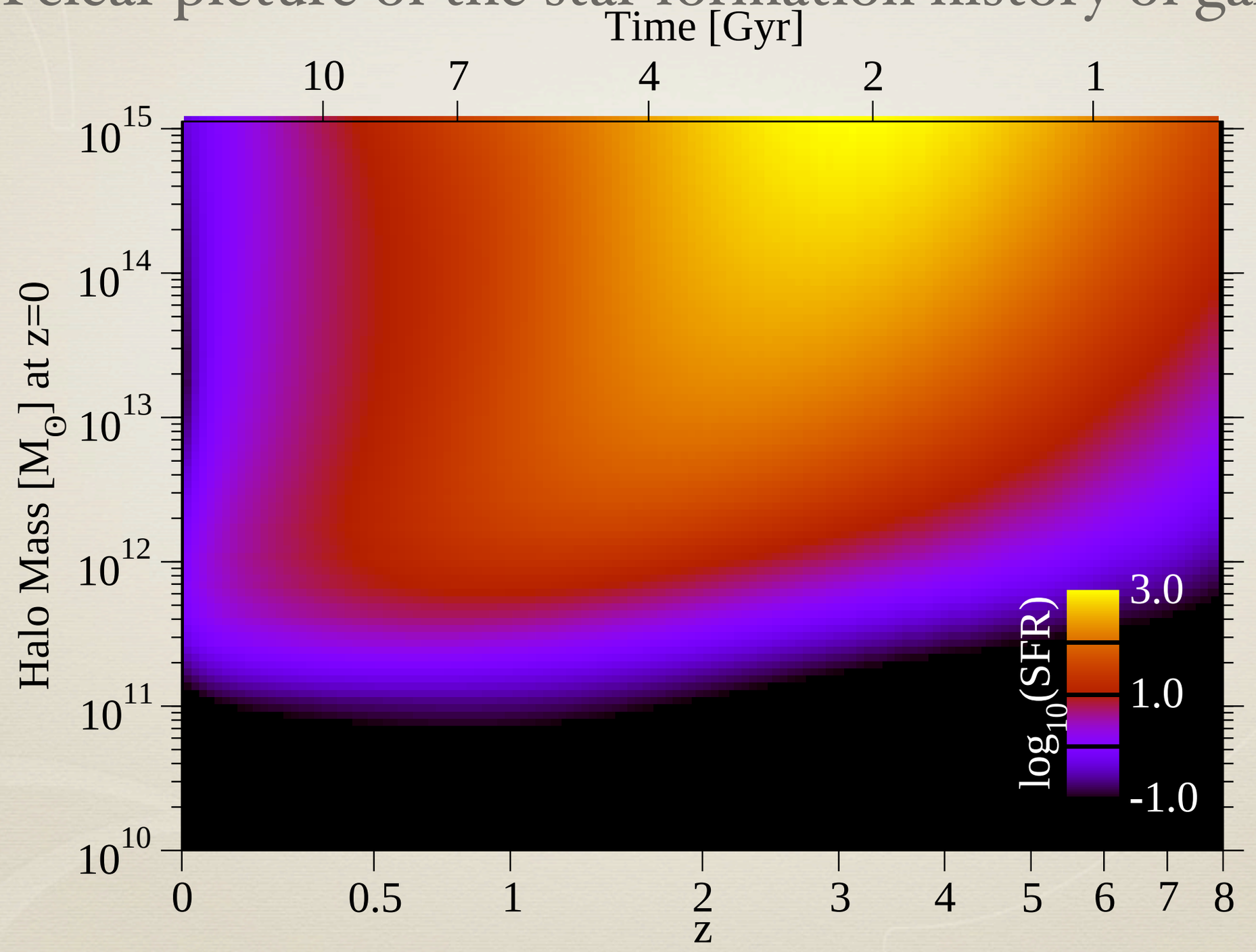
Results

A clear picture of the star formation history of the Universe:



Results

A clear picture of the star formation history of galaxies:



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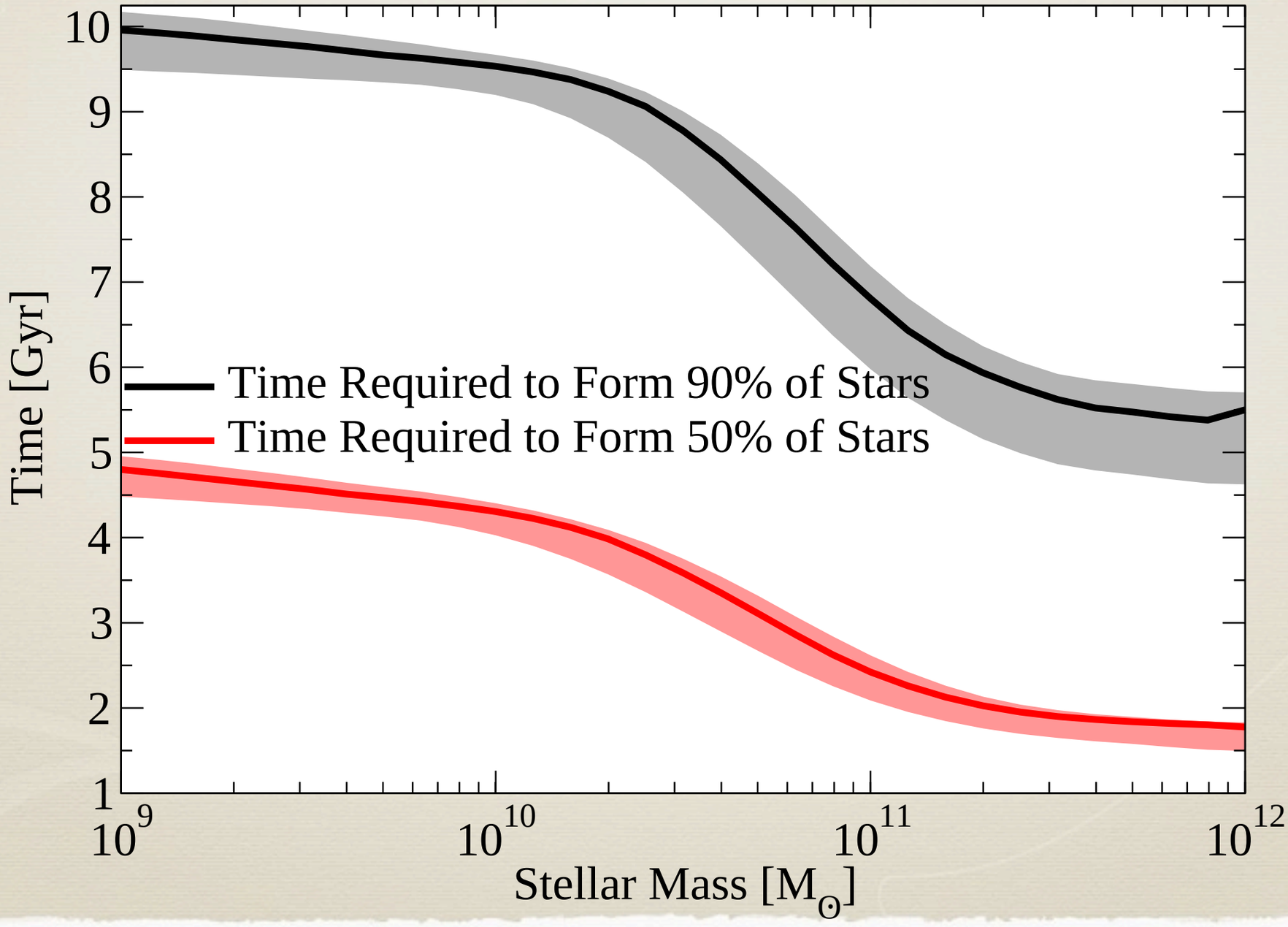
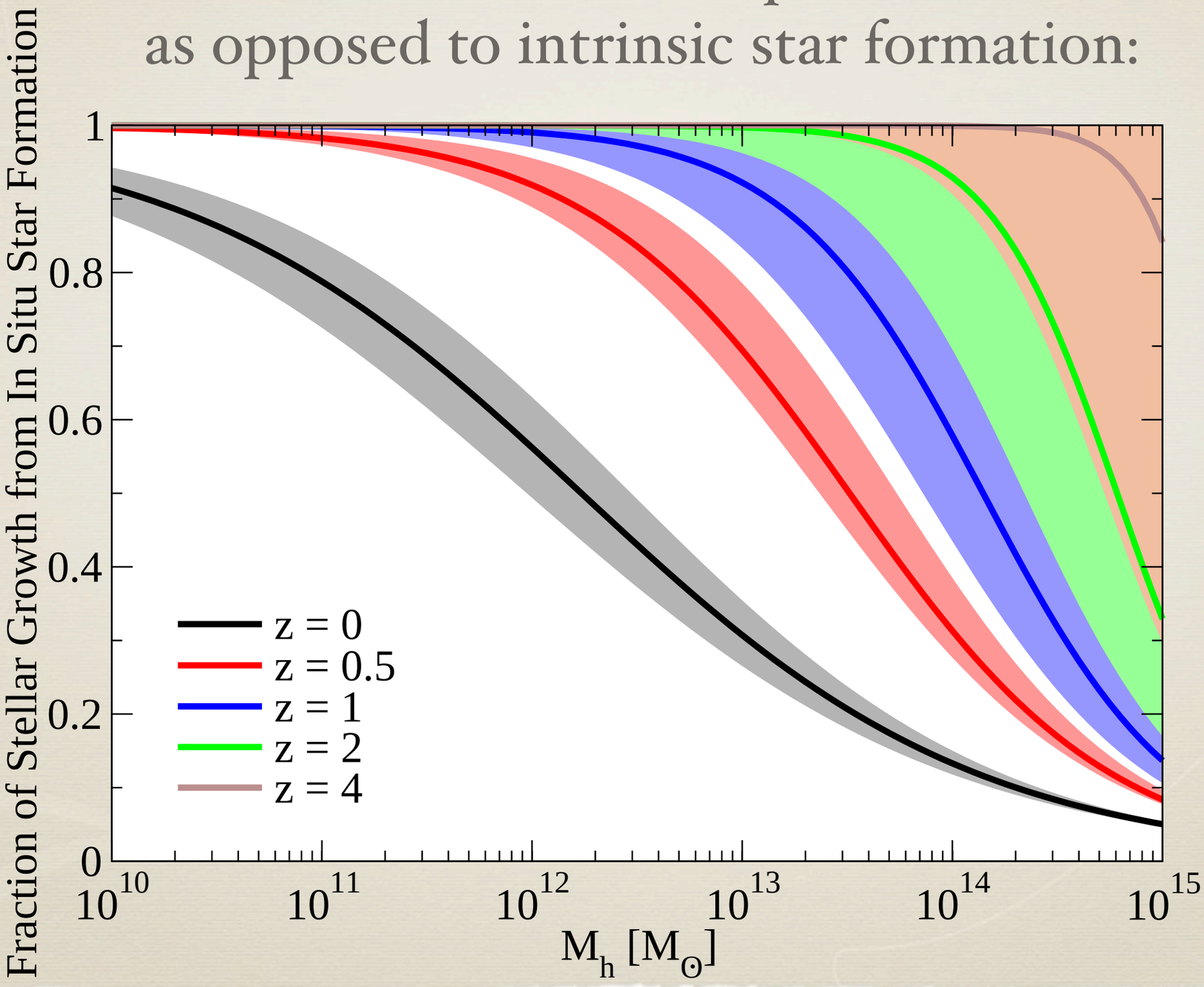


Results

We can also constrain the buildup of stars from mergers as opposed to intrinsic star formation:



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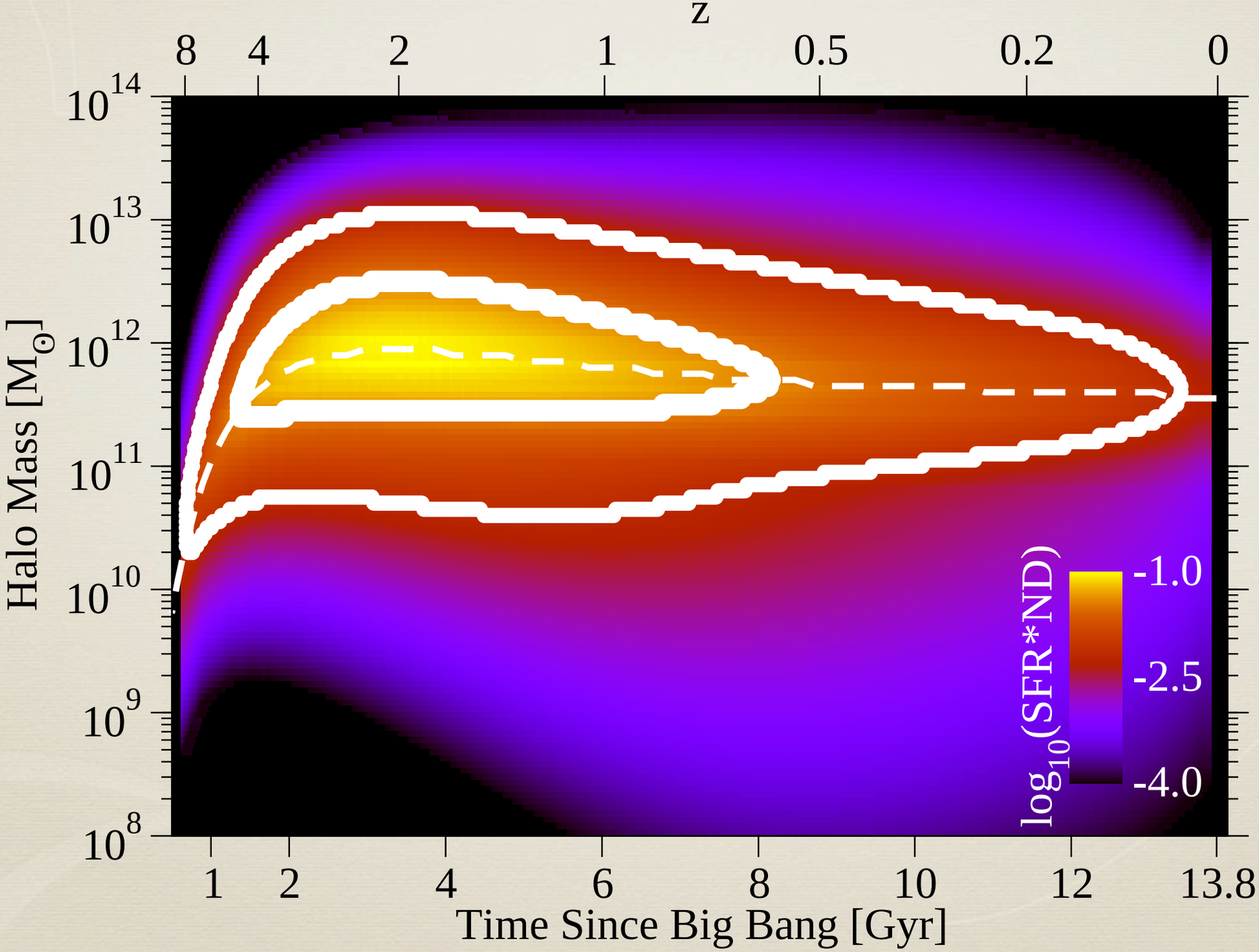

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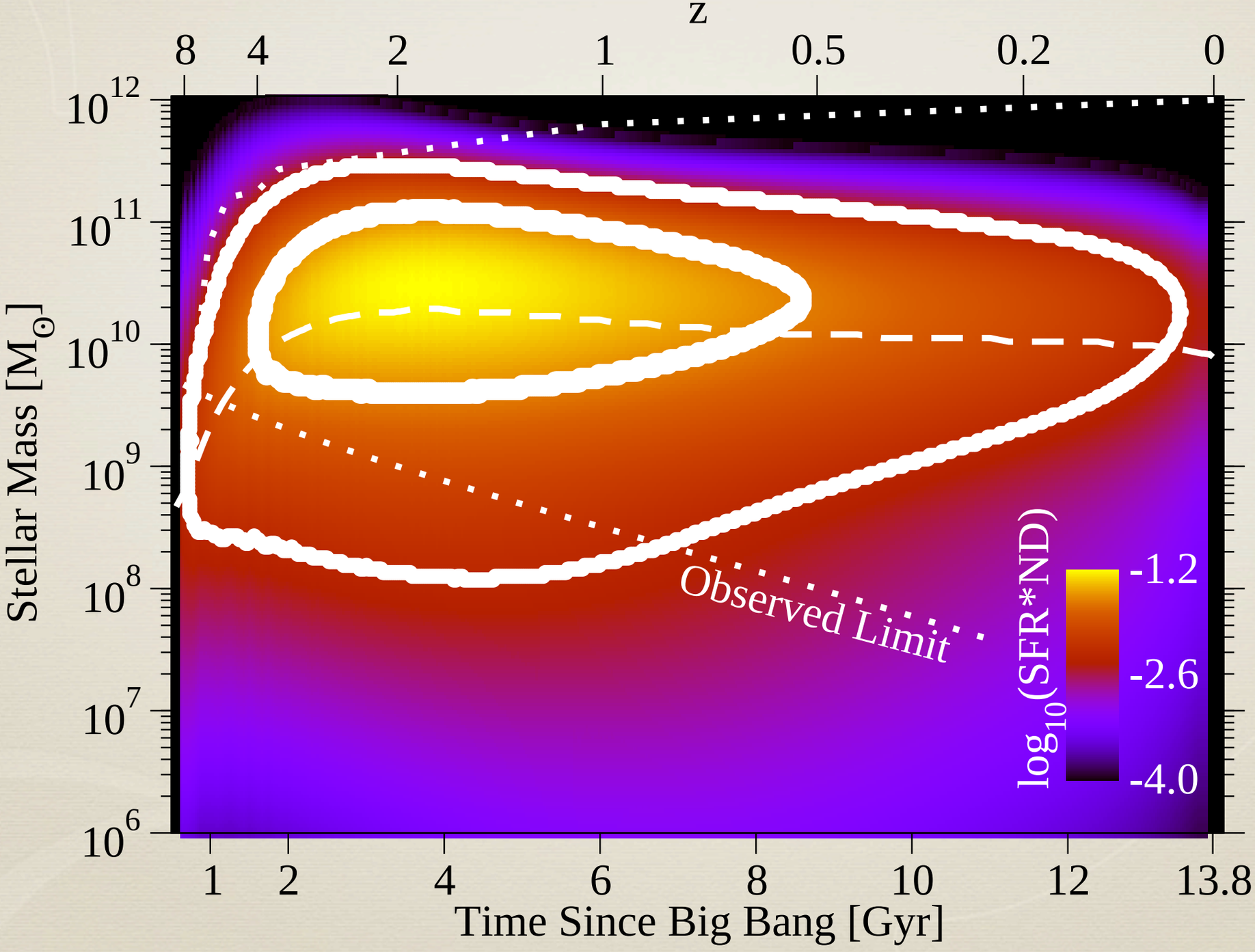
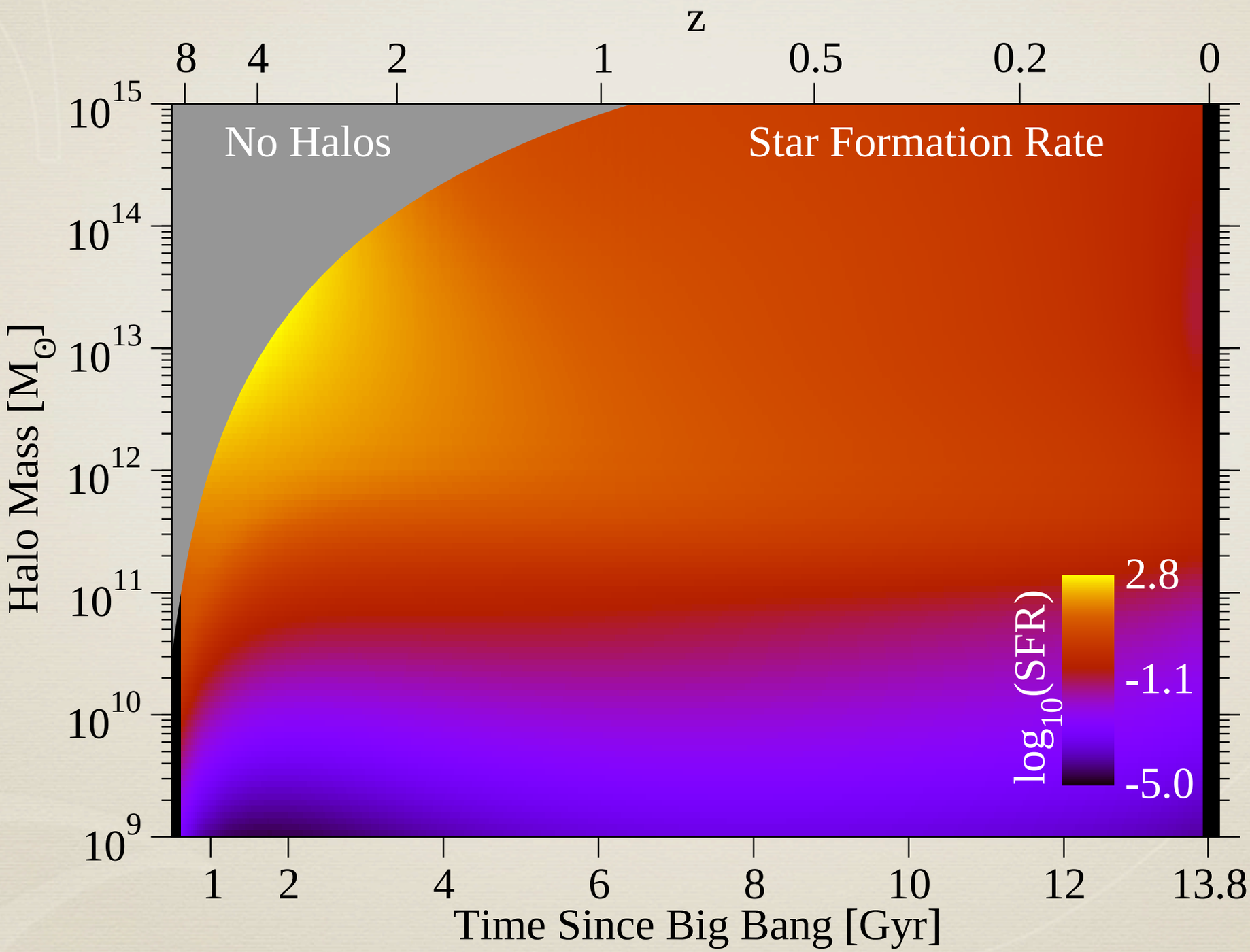


Star Formation Efficiency



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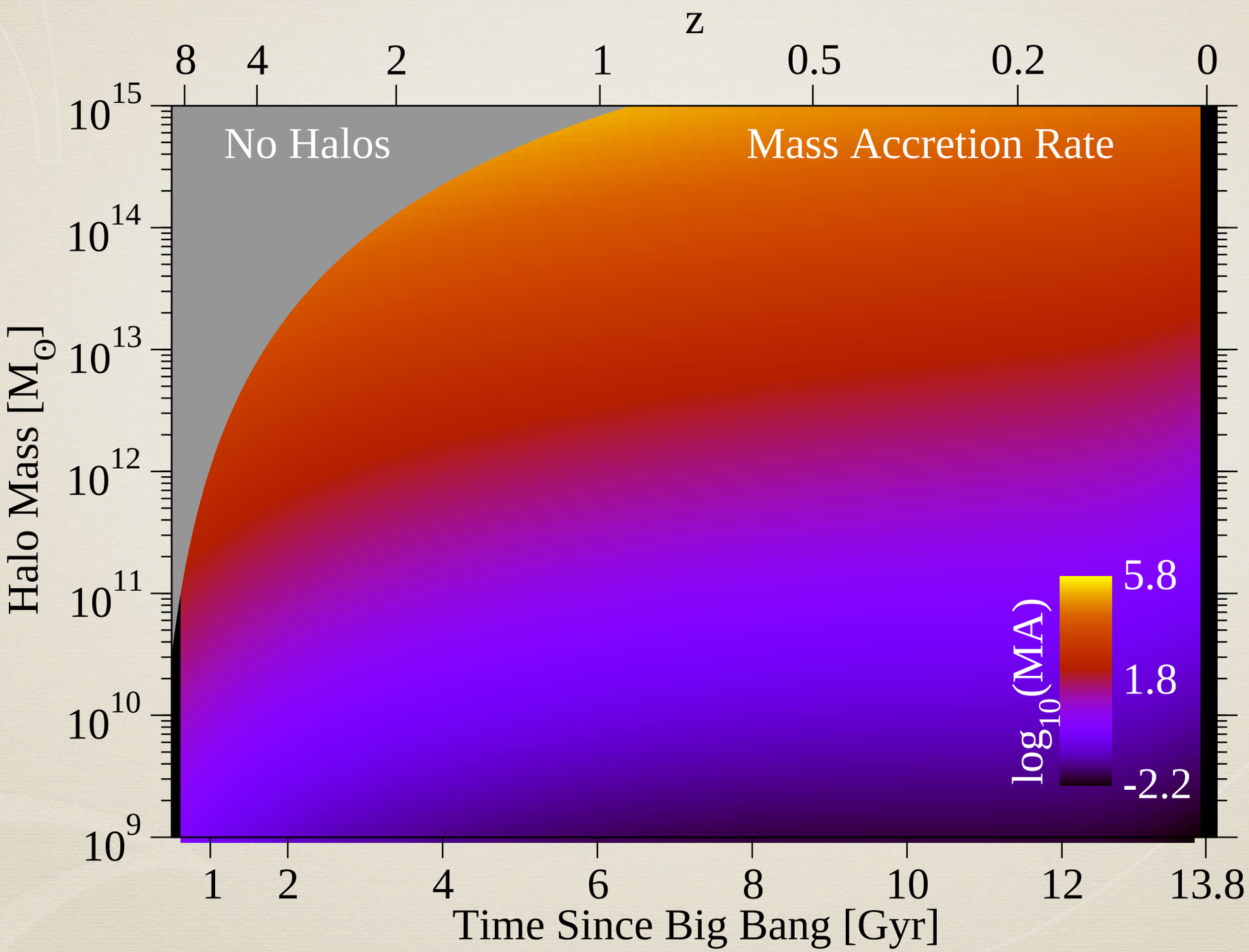

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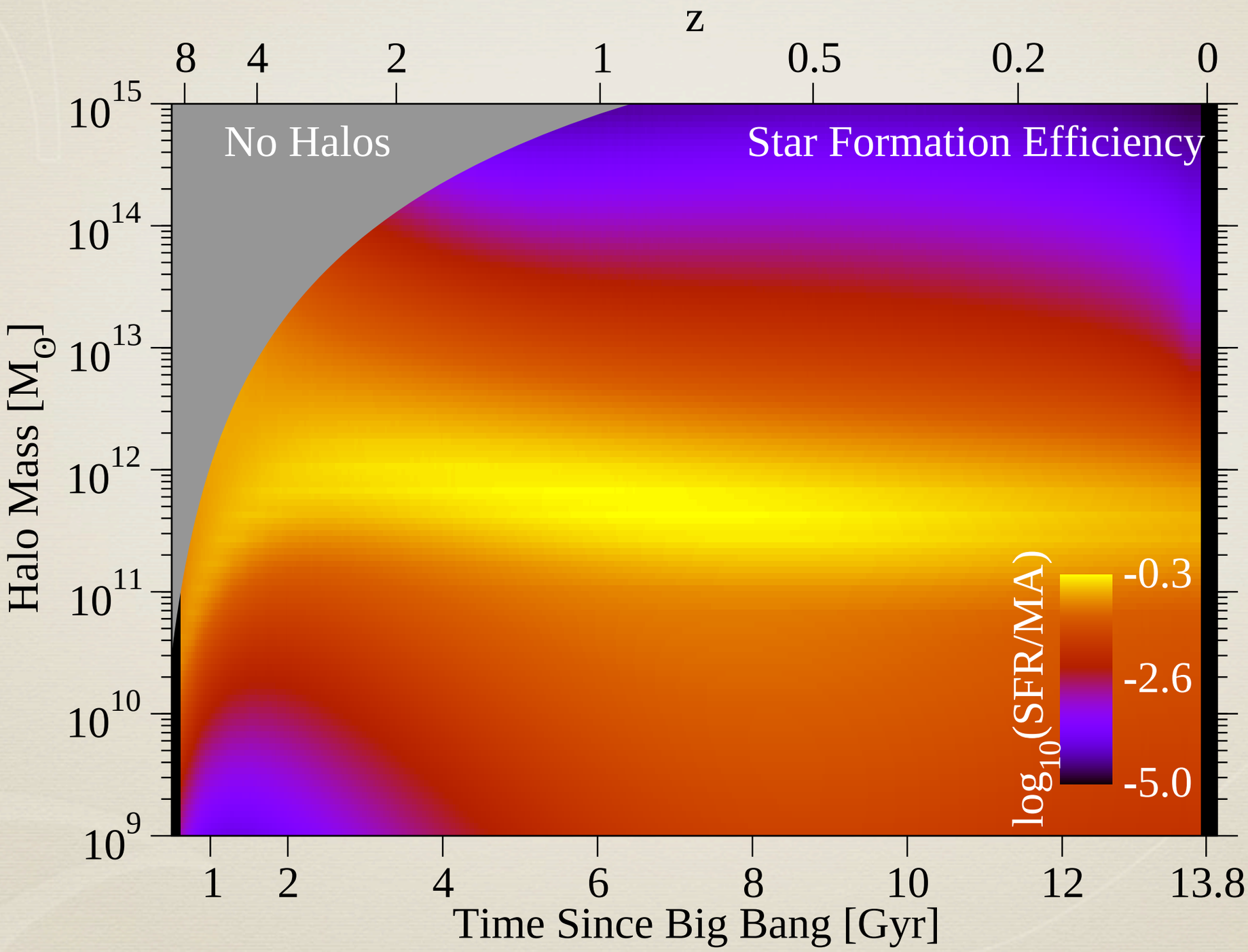
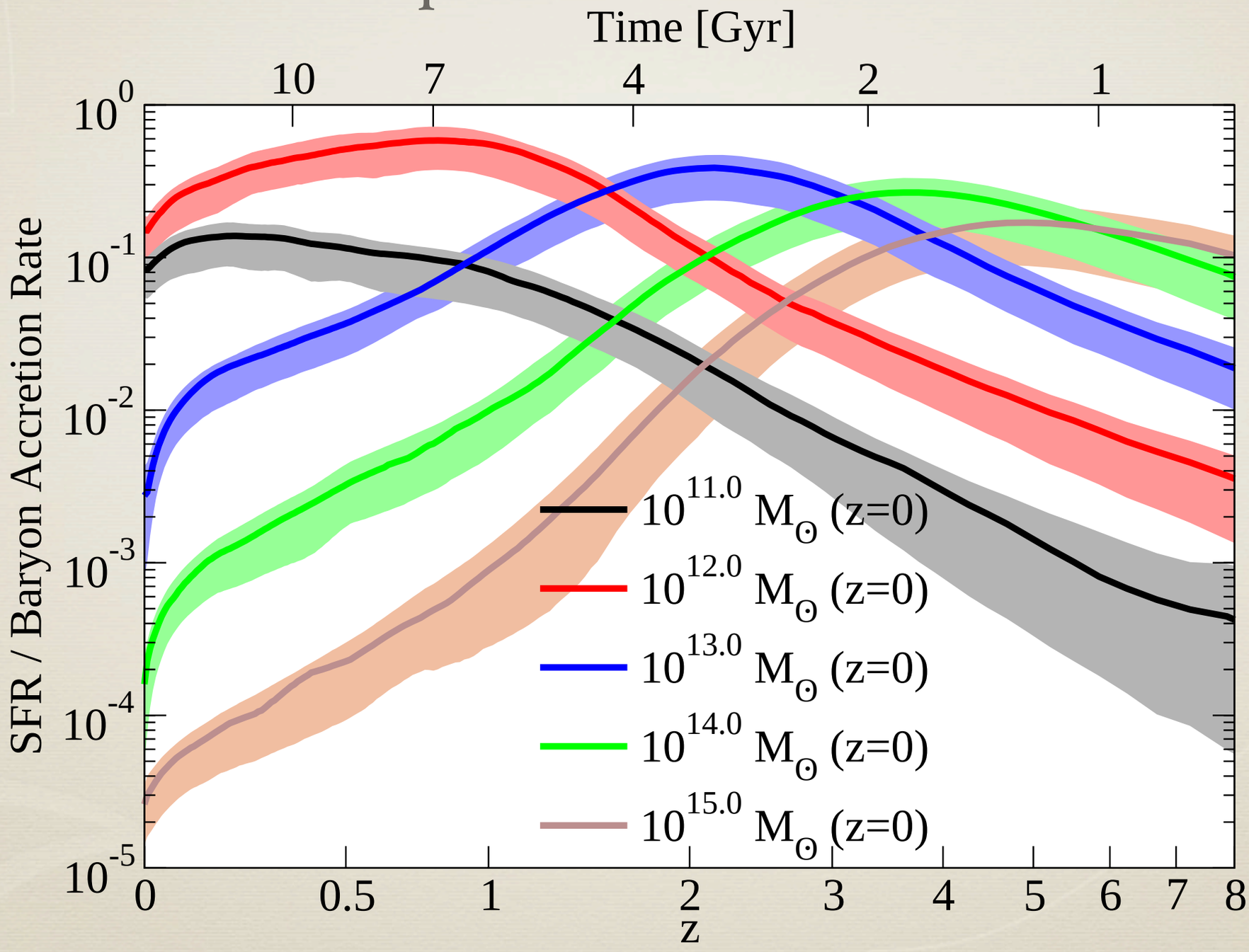


Results

This leaves a clear imprint on the historical conversion ratio:



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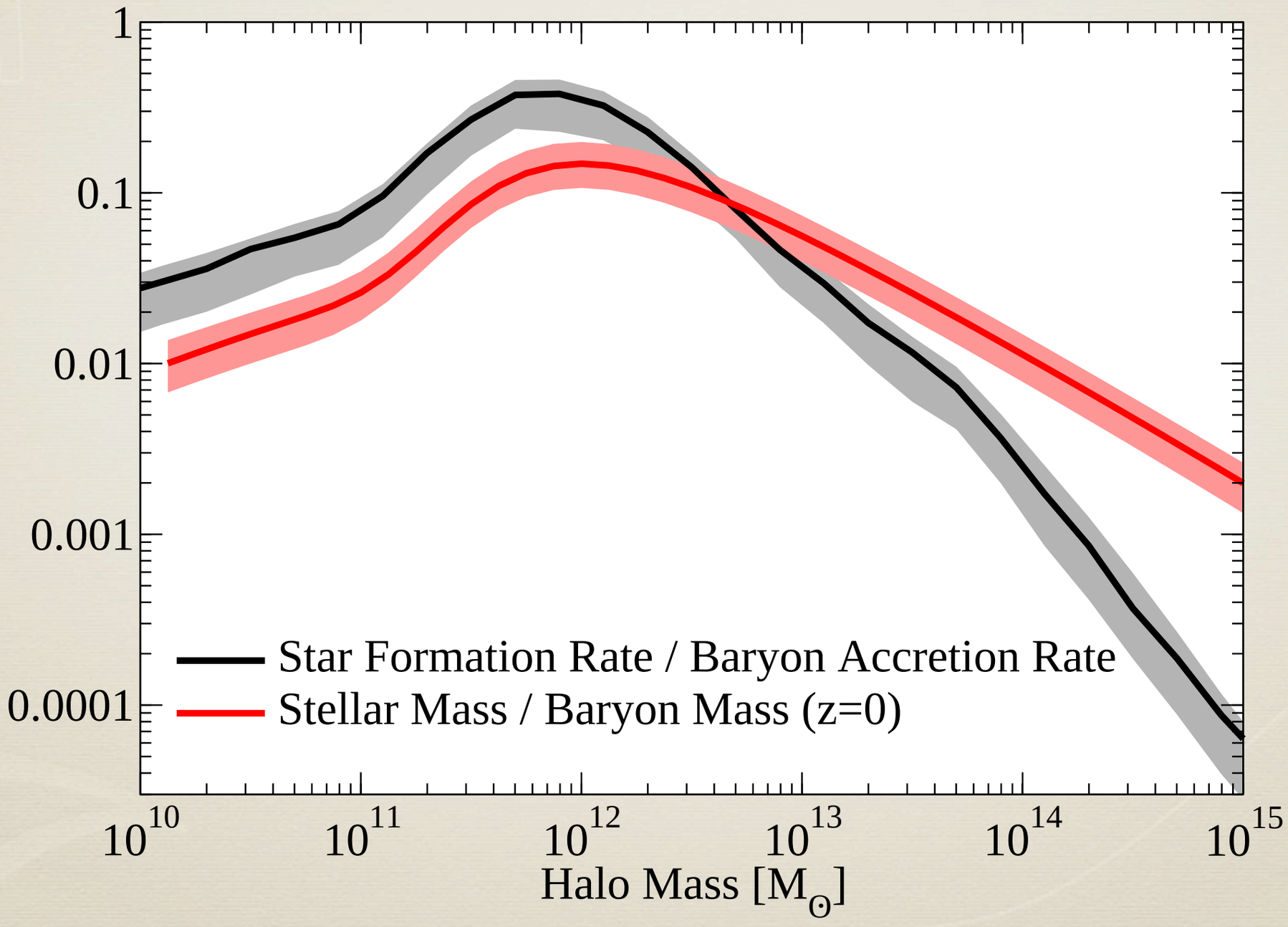
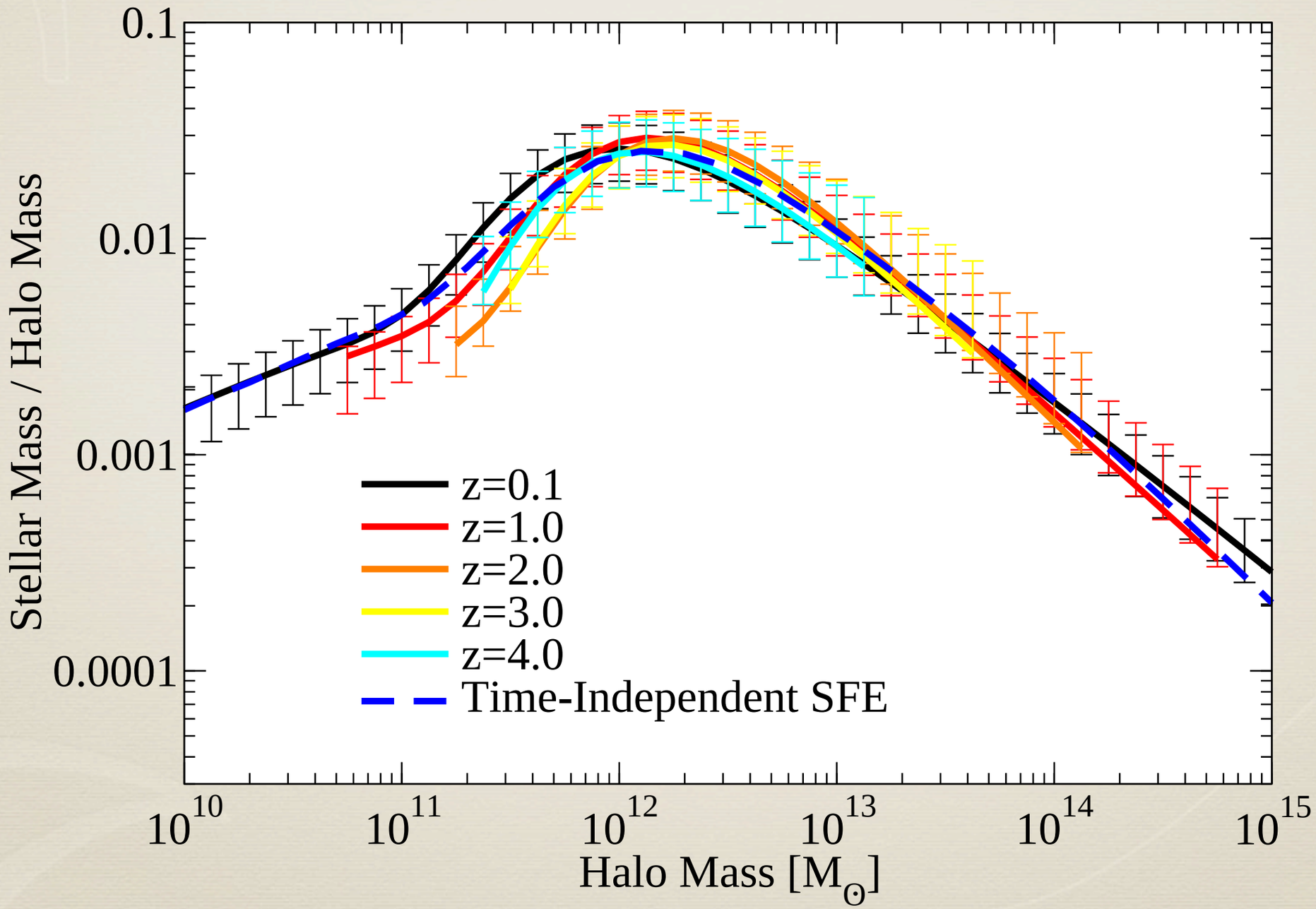


As Simple as Possible



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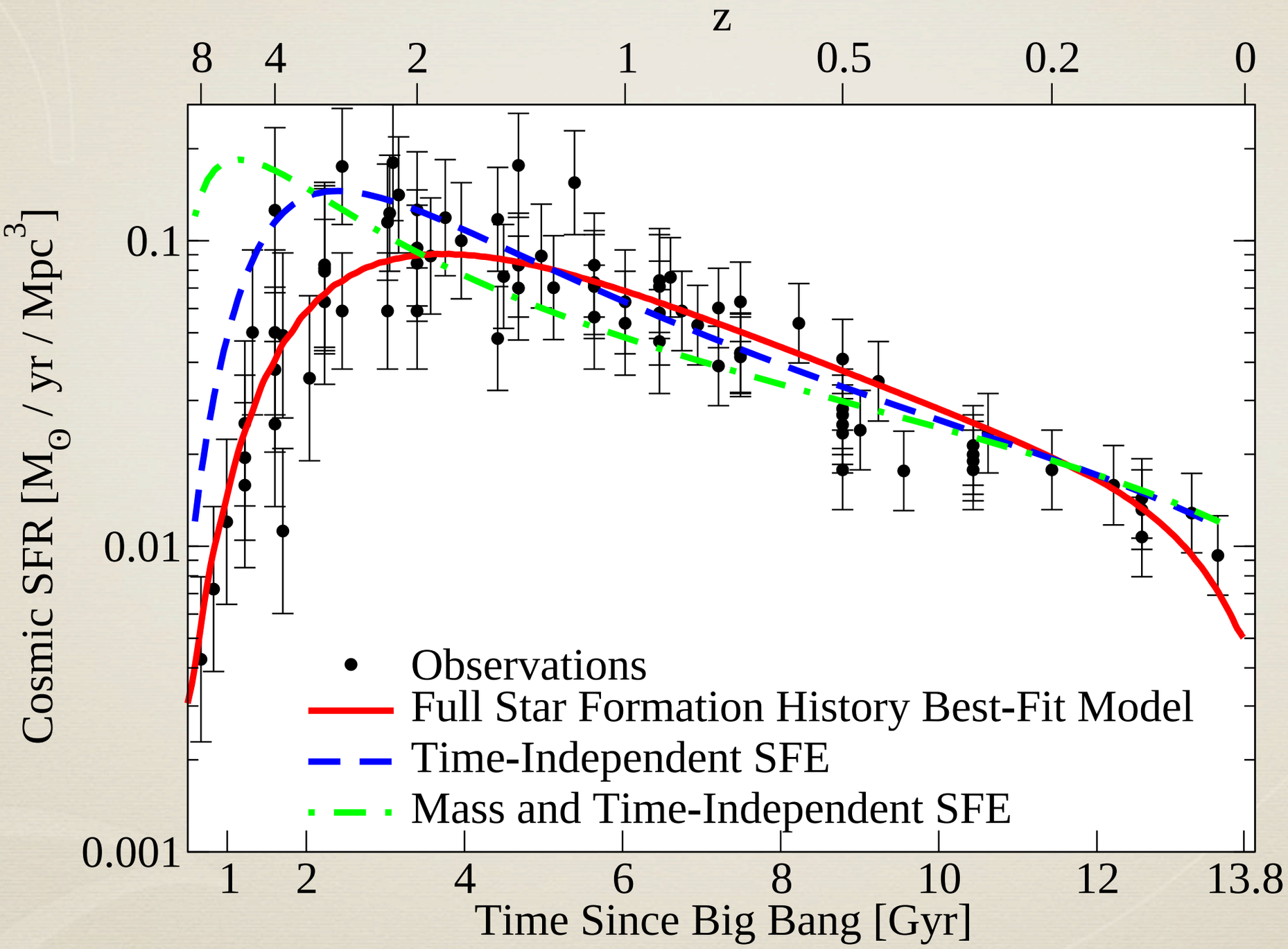
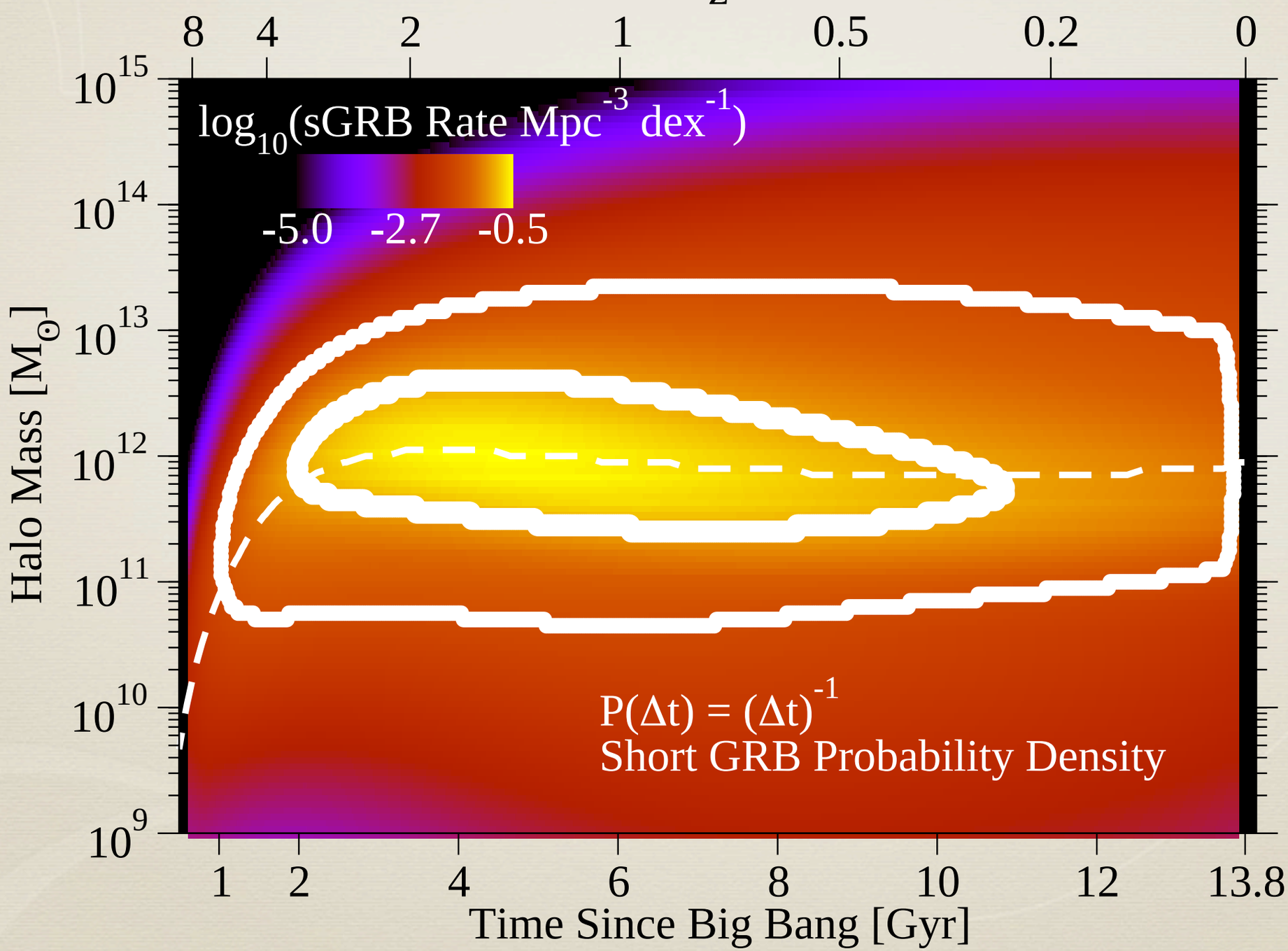


Short GRBs

The applications go **way** beyond galaxy formation:



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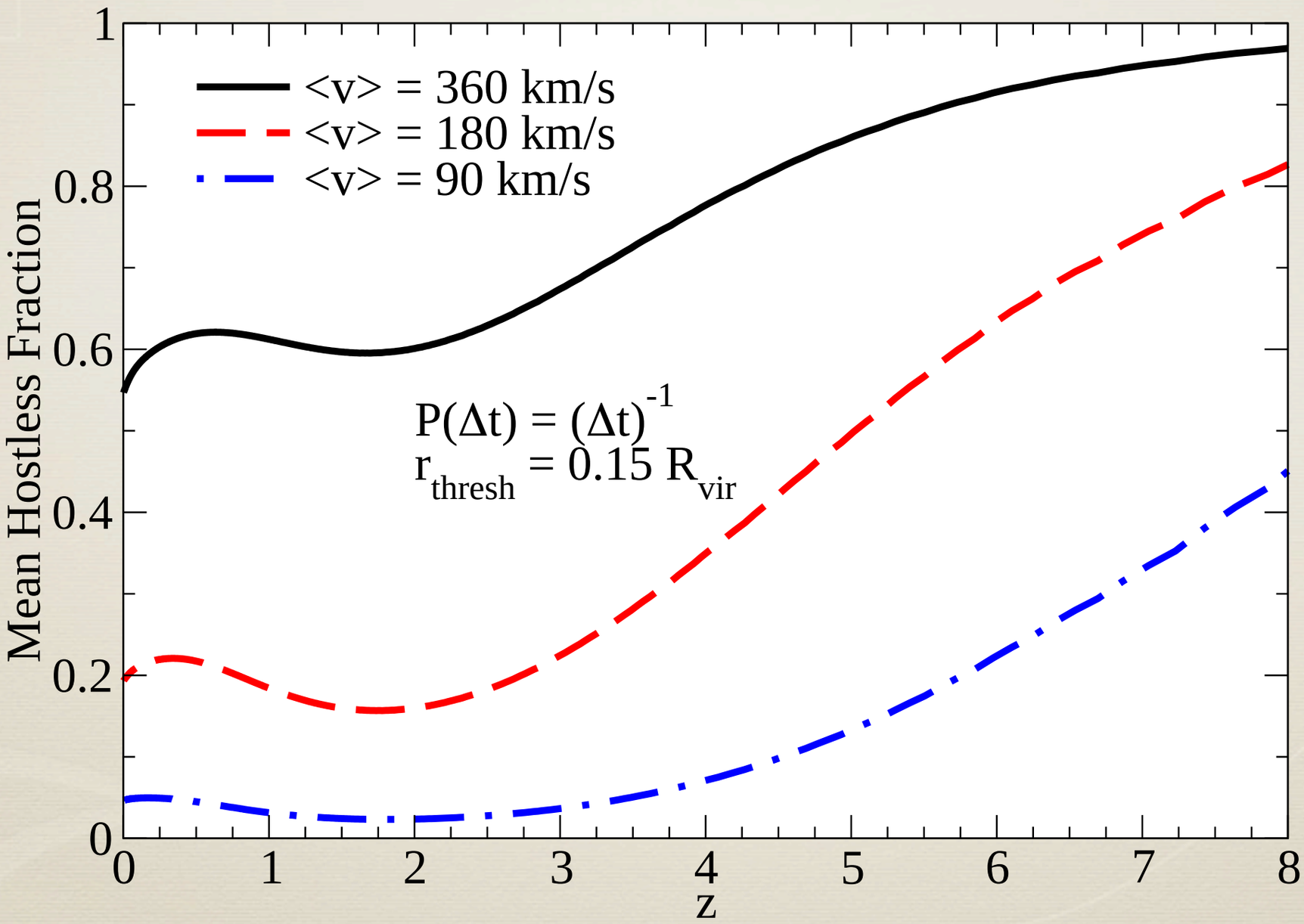

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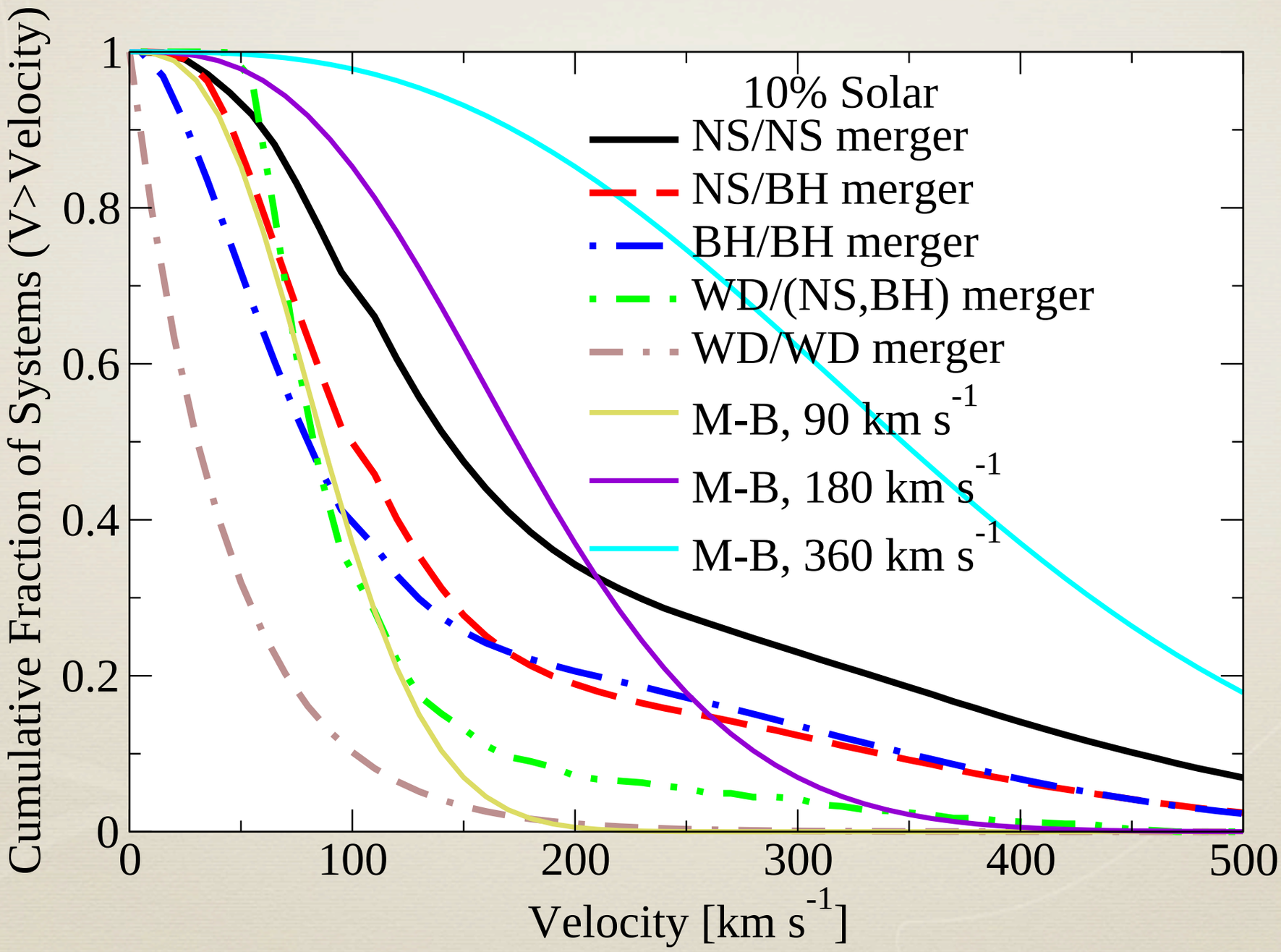


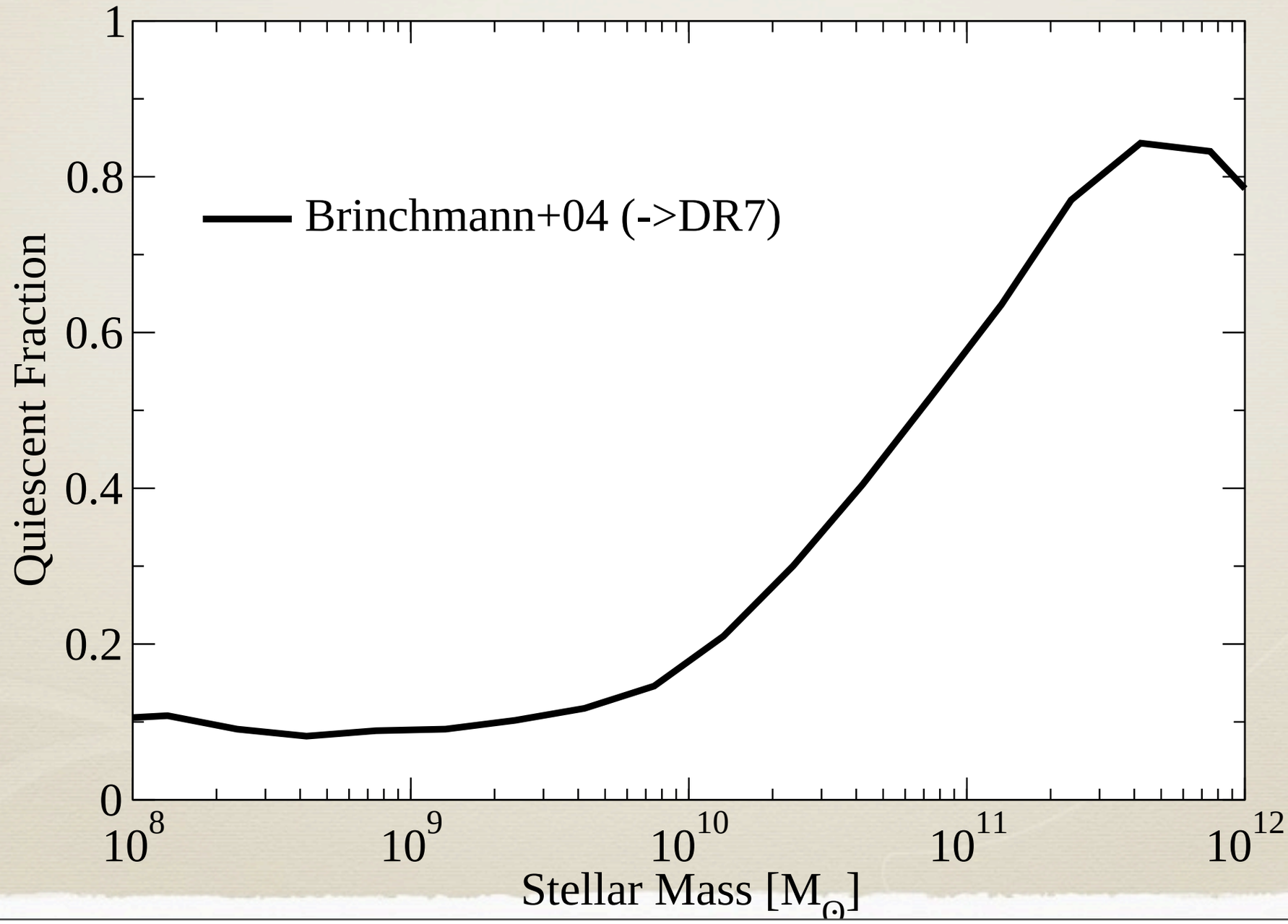
Gas Reservoir Lifetimes

How quickly do satellite galaxies quench?

Or, how long do galaxies keep forming stars after gas accretion onto the halo stops?

Gas Reservoir Lifetimes

Model: Halos quench *"t"* years after they reach peak mass.
Constraint: Quenched fraction of galaxies as a fn. of stellar mass.



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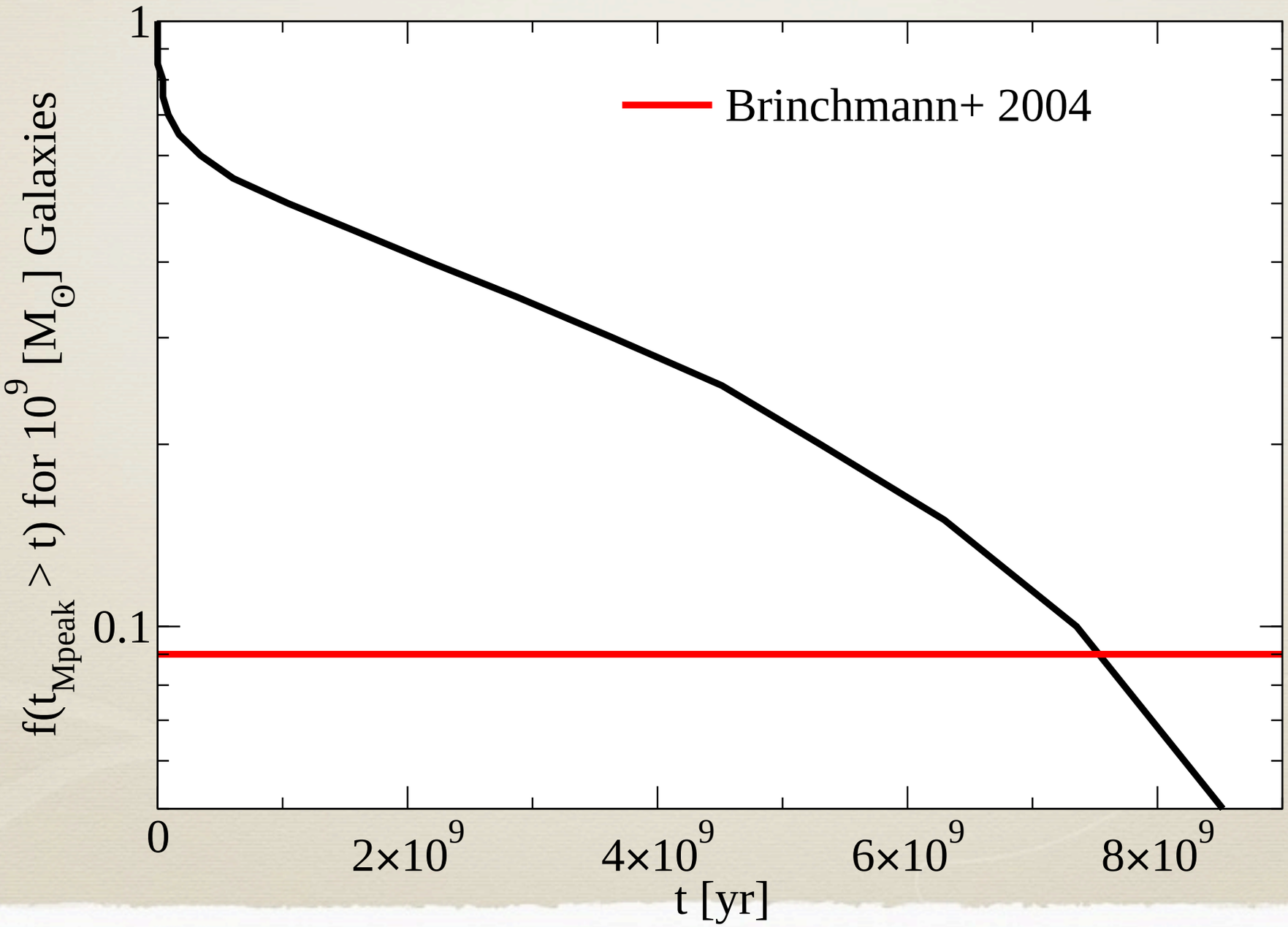

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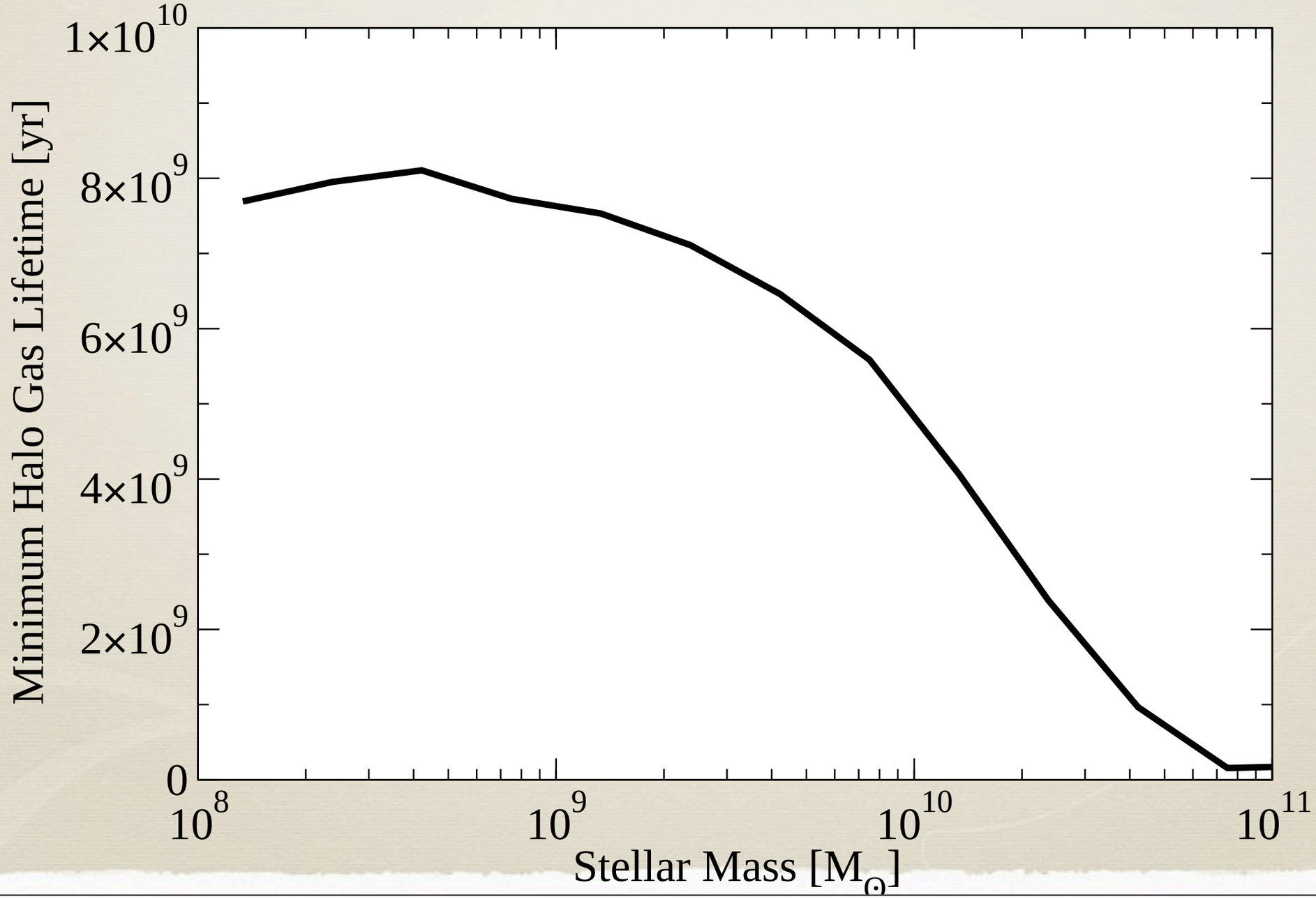

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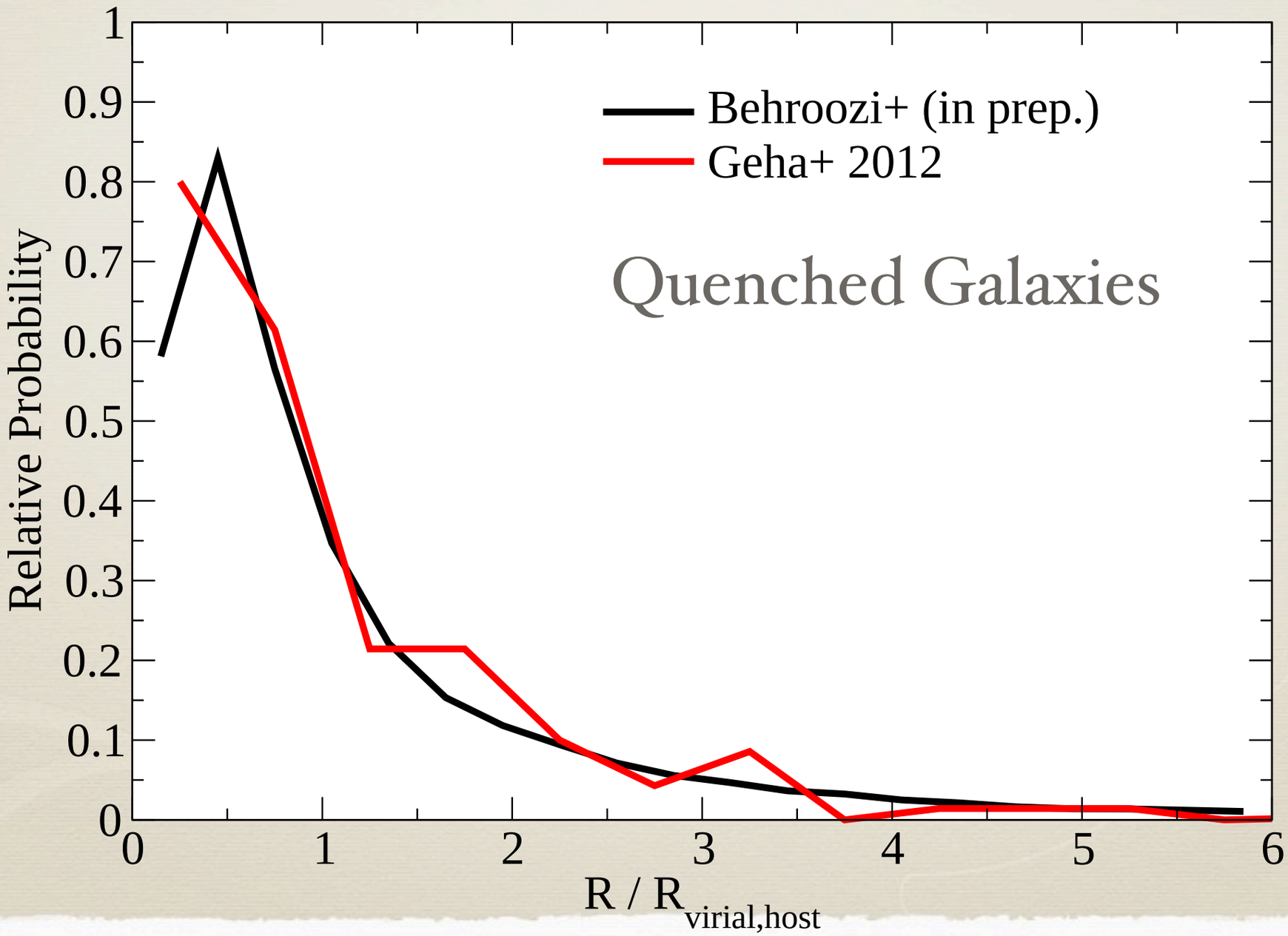

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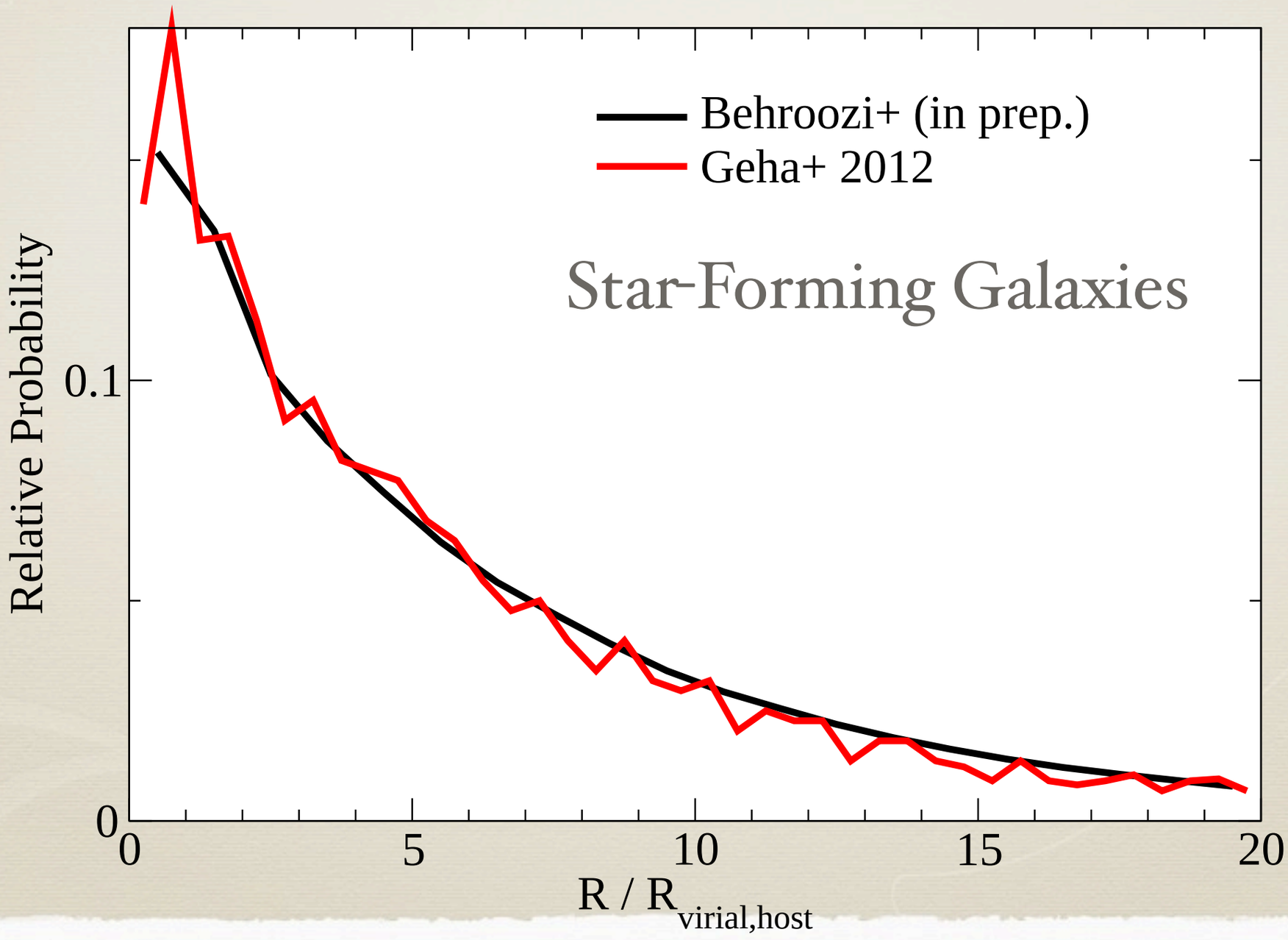

Summary

Most of the stars in the Universe were formed in halos similar in size to the Milky Way.

Unsurprisingly, this is where the gas to stars conversion efficiency also peaks, at about 20-40% of available hydrogen converted into stars.

It's more surprising that this efficiency has remained relatively constant over time!

Summary

Lots of data already available for you to use (http://www.peterbehroozi.com/data.html)

Lots of applications (short GRBs, halo gas lifetimes) already in progress...

Thank you for listening!

arXiv:1207.6105

Future Directions