arXiv:1207.6105

THE STORY OF ALL THE STARS IN THE UNIVERSE

a.k.a. "Galaxy Star Formation Efficiency from Redshift 8 to the Present Day"

Picture Credit: John Davis

Peter Behroozi, Stanford University / KIPAC

Berkeley, 10/23/12

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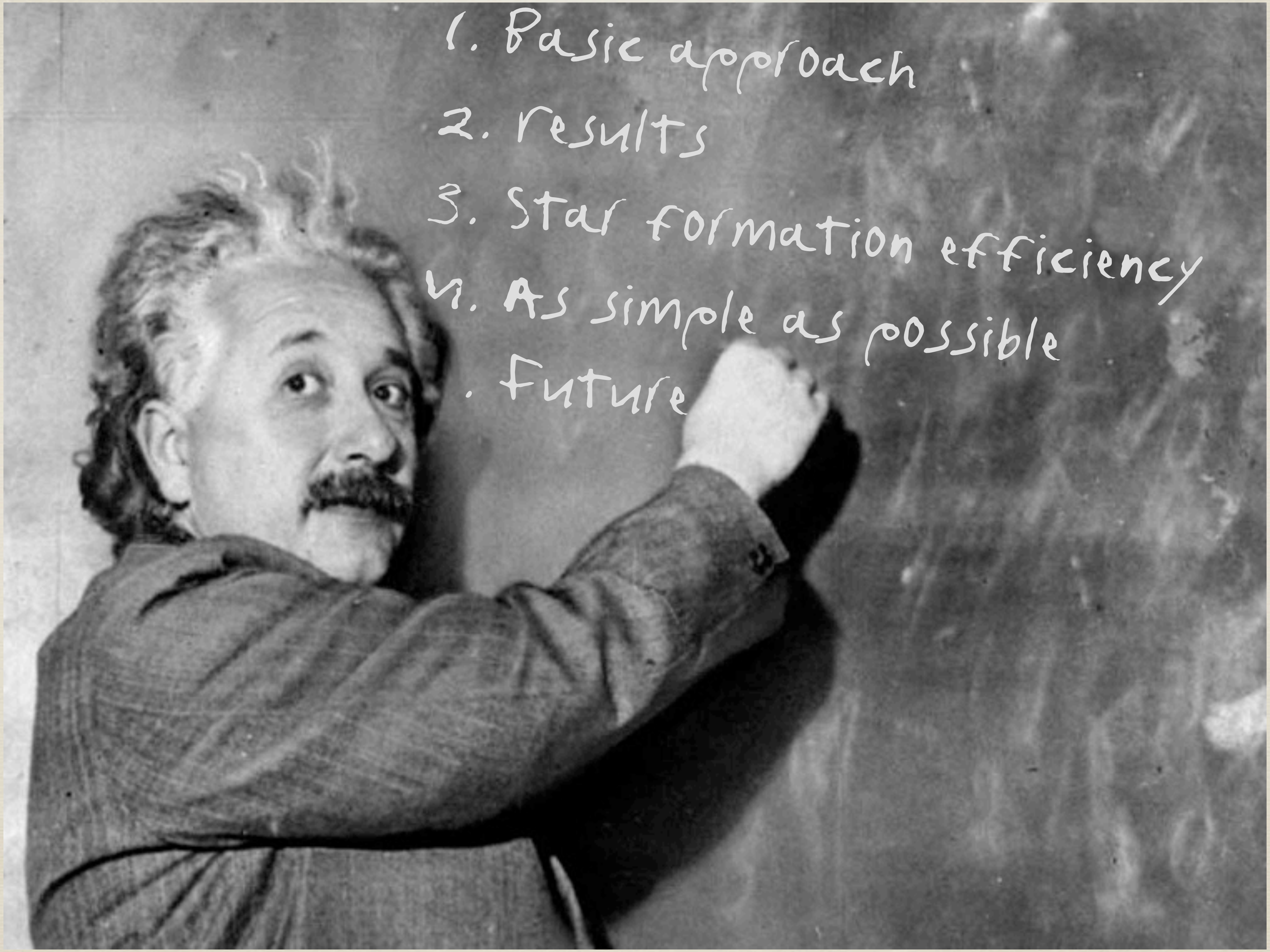
Outline



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)

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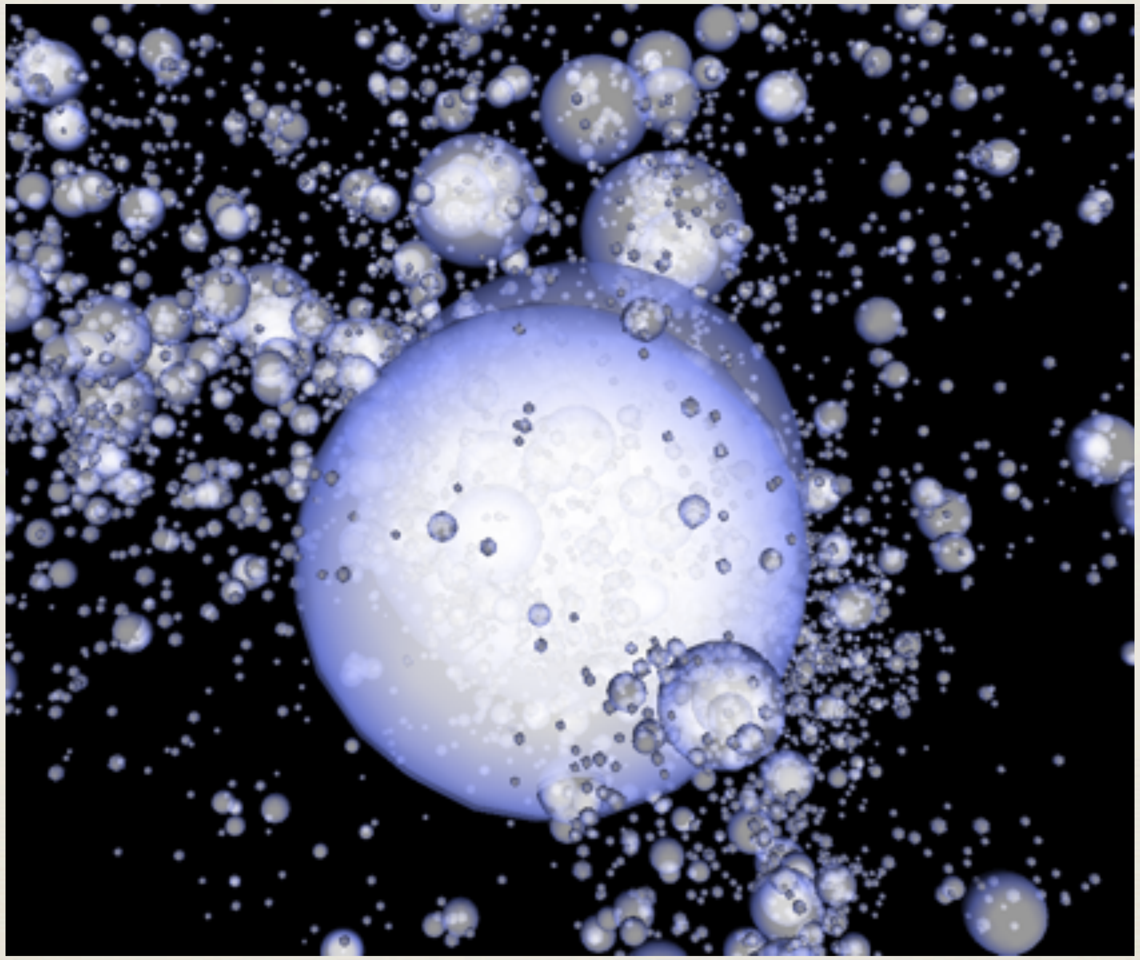
Basic Approach

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.

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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

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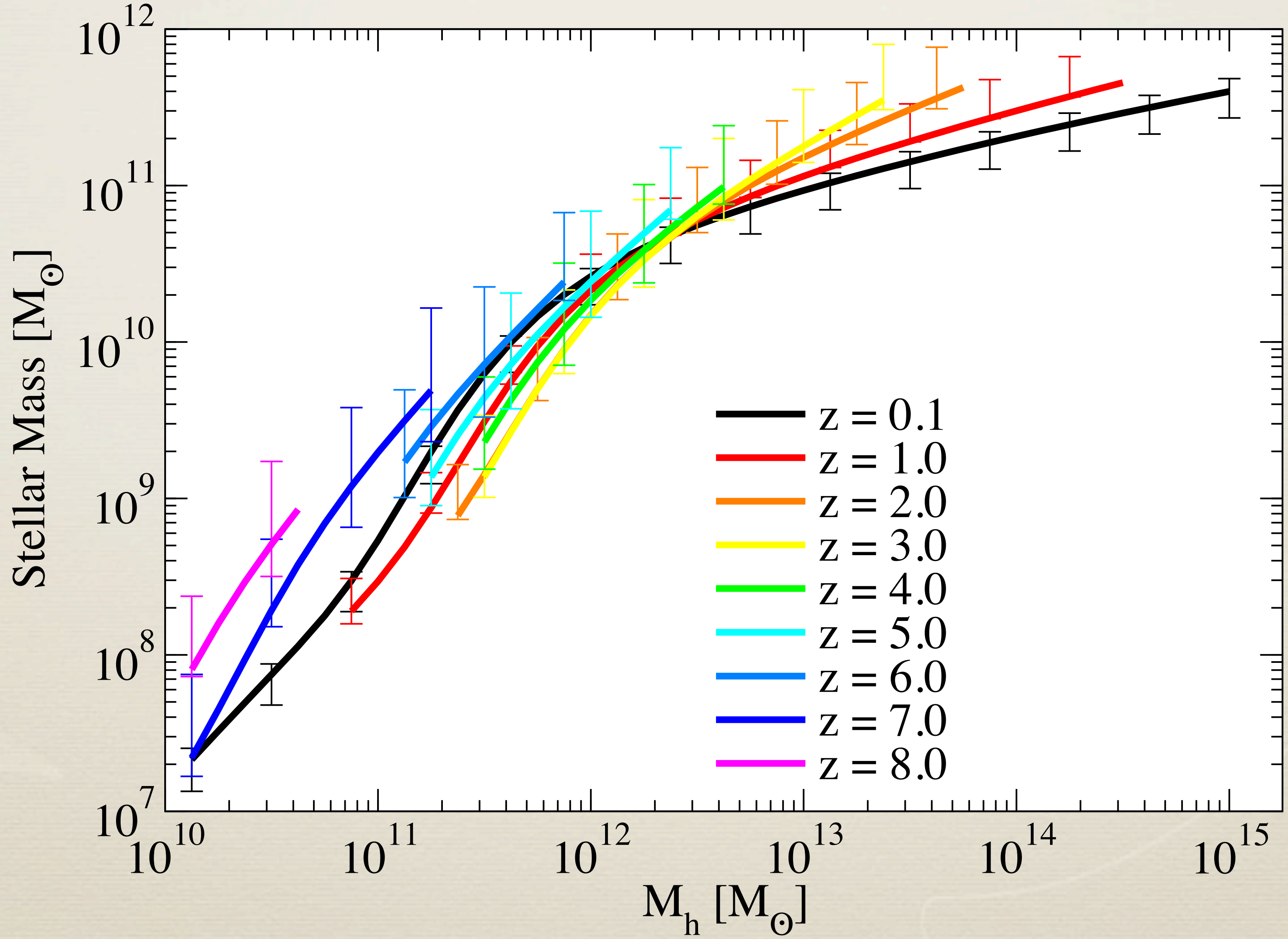
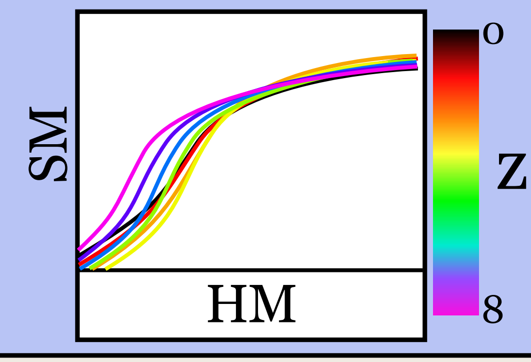
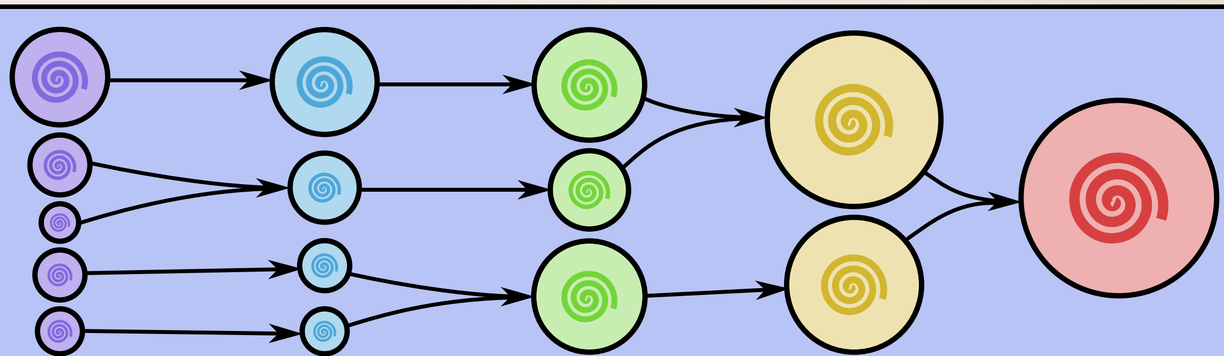


Basic Approach

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.



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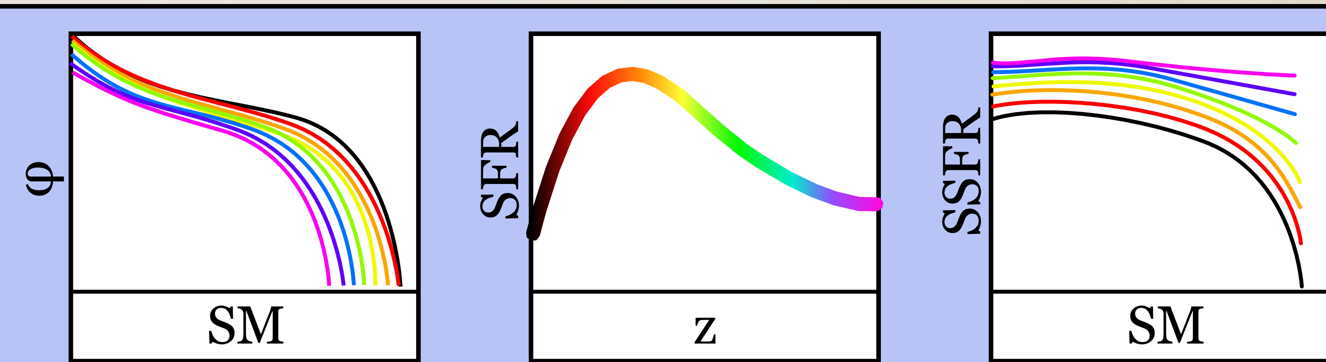
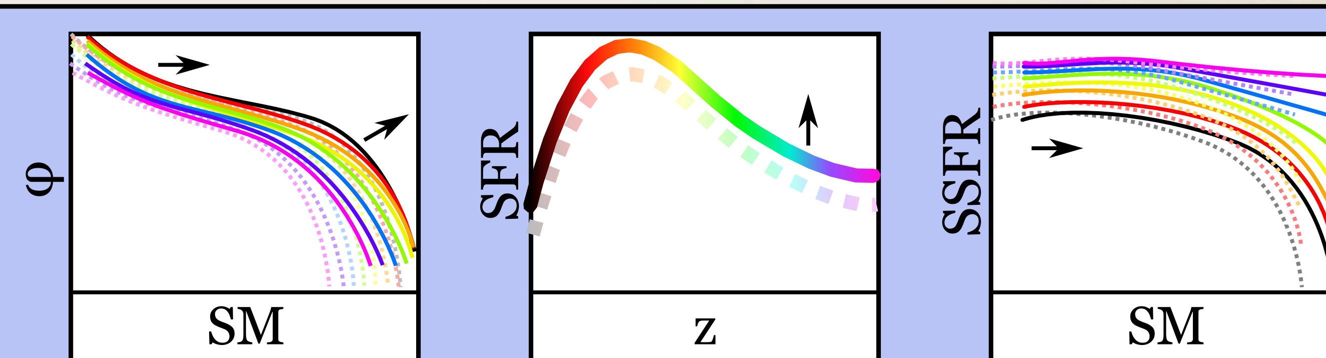
Basic Approach

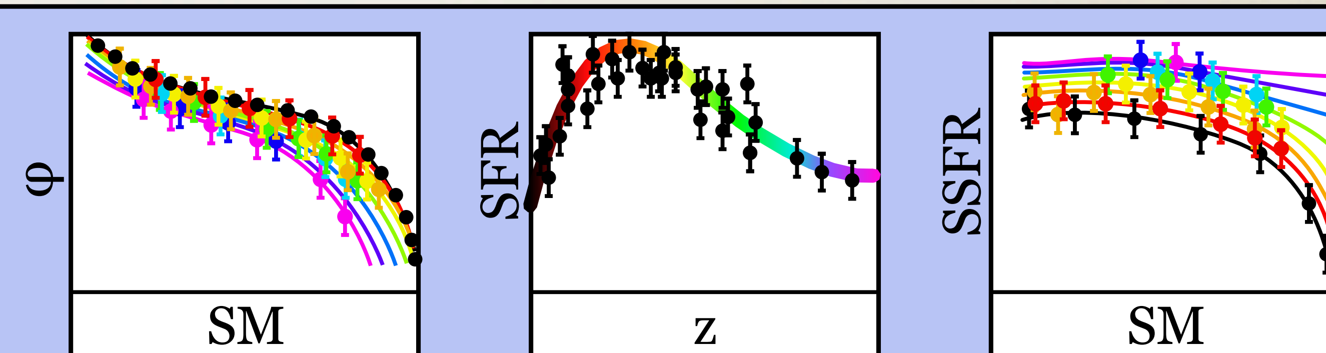
3. Derive the inferred stellar mass functions and star formation rates.



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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Basic Approach

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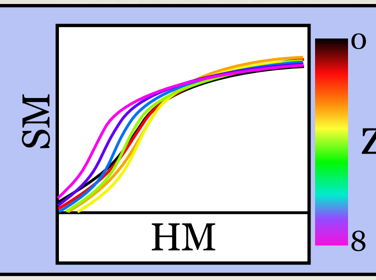

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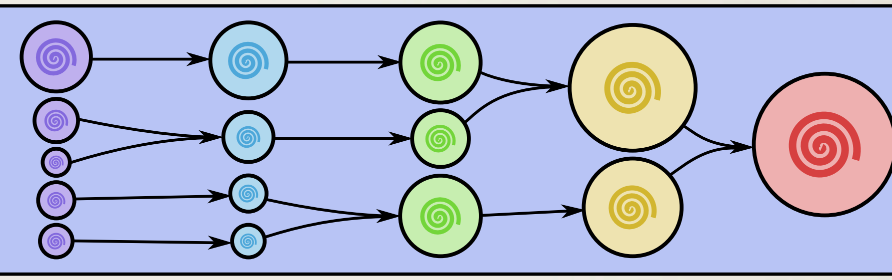

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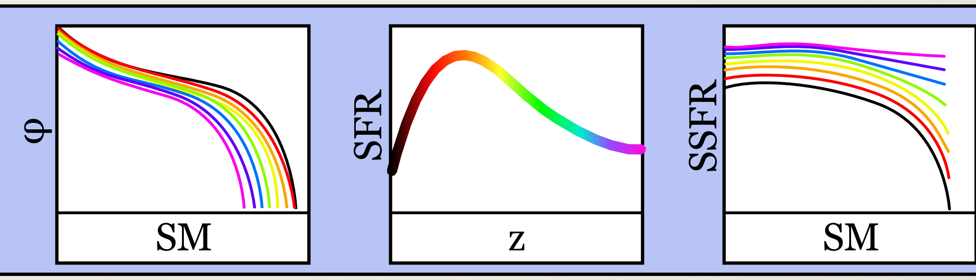

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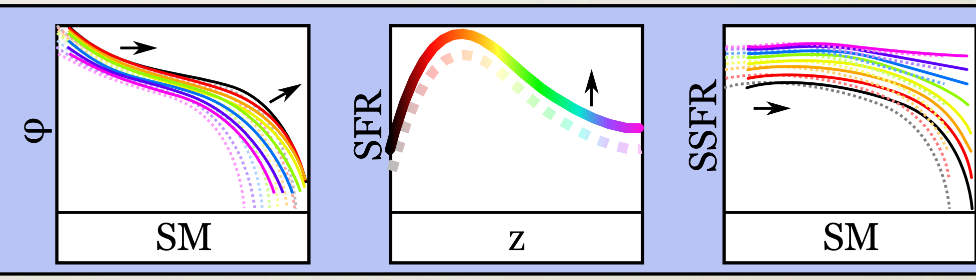

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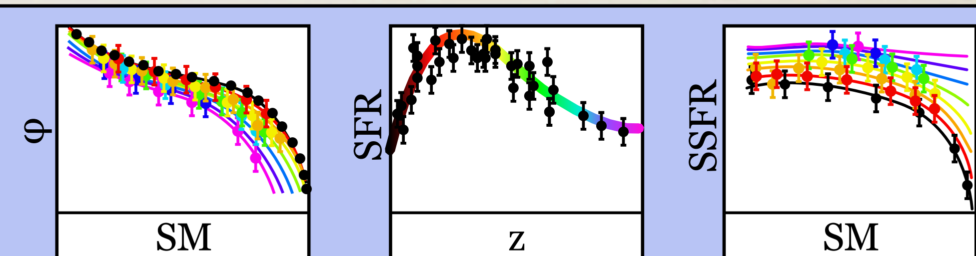
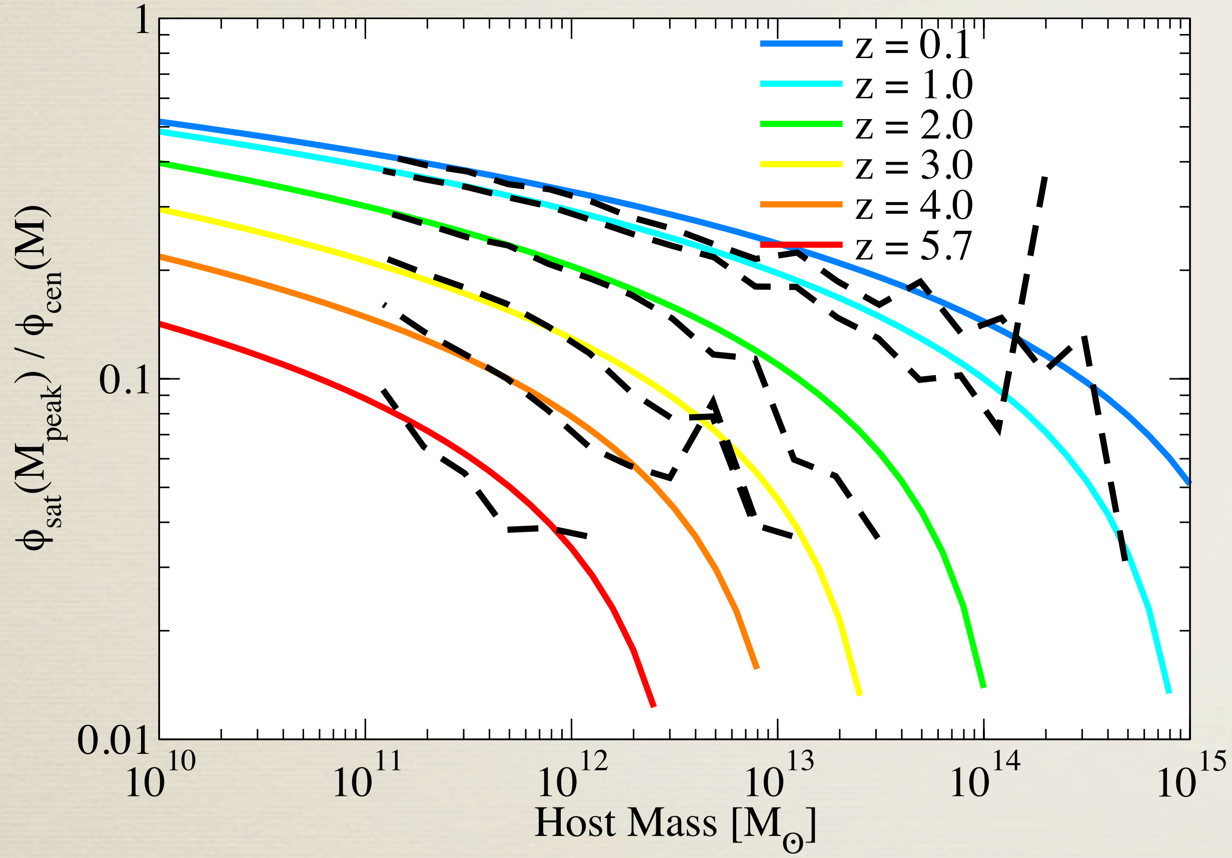
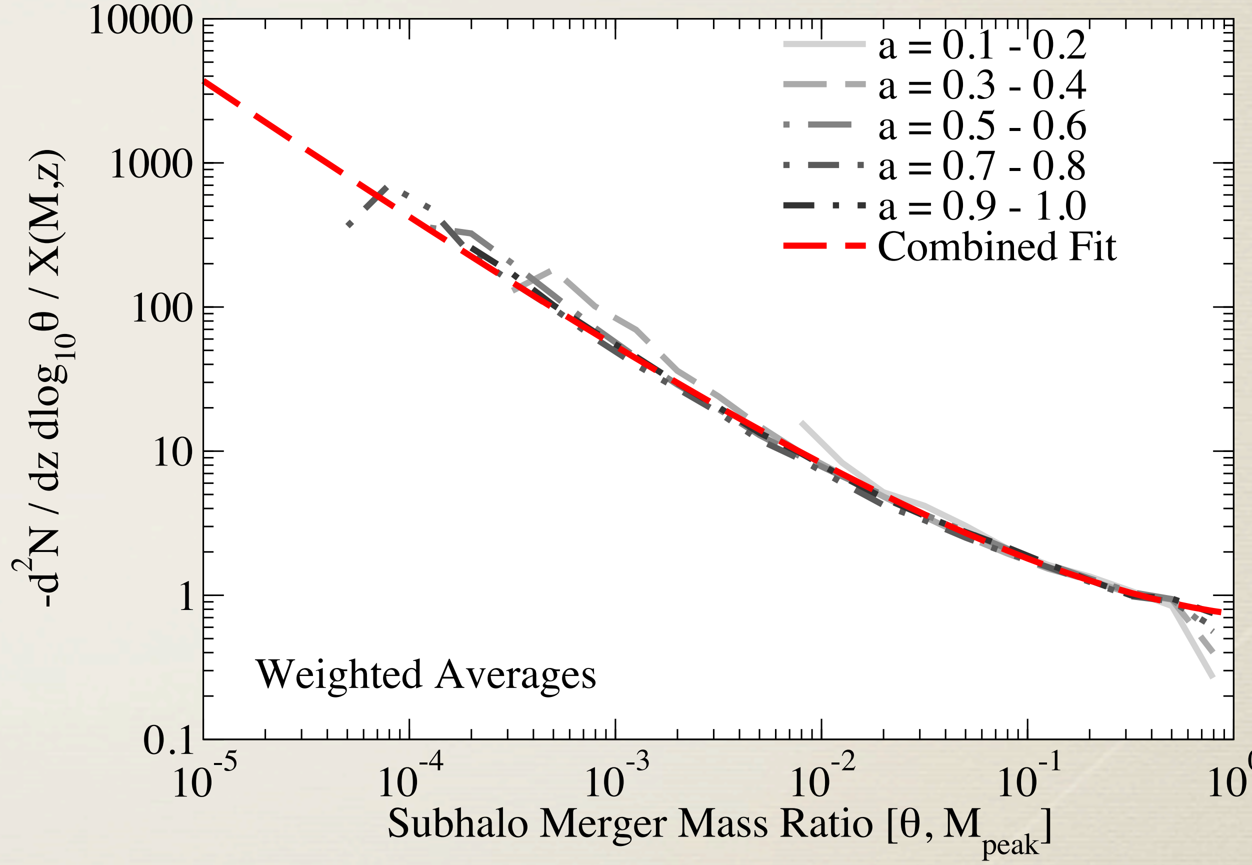


Repeat as often as necessary to explore allowable solutions.

Basic Approach

Data Sets:





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

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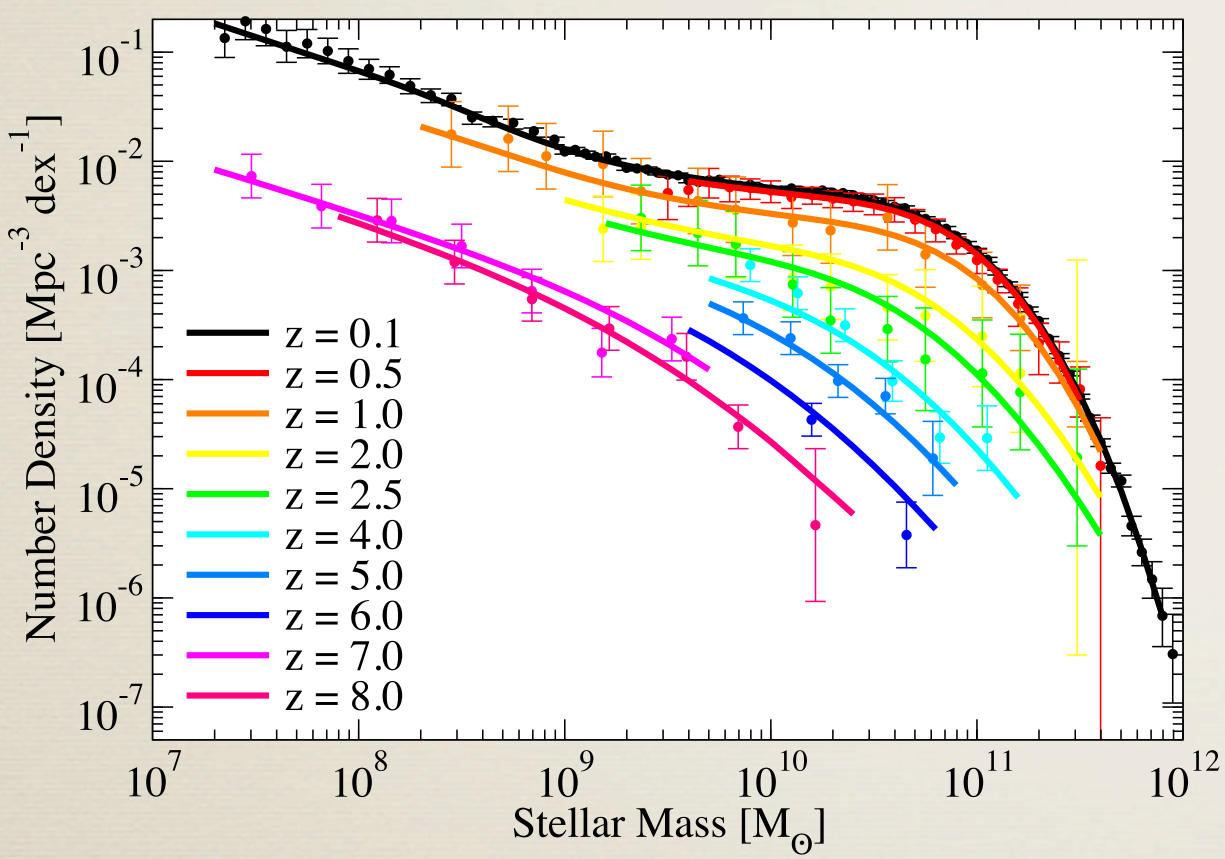
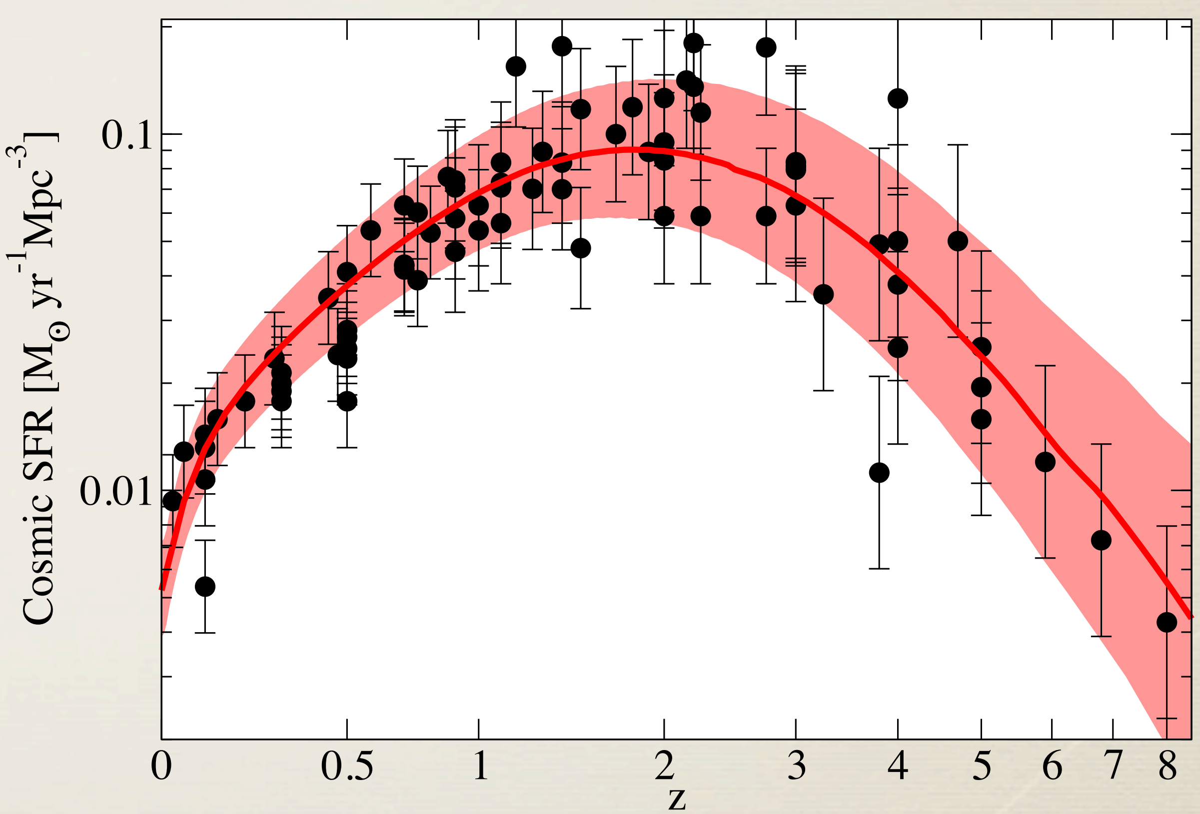
Basic Approach

Data Sets:





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

New compilation of cSFRs to z=8

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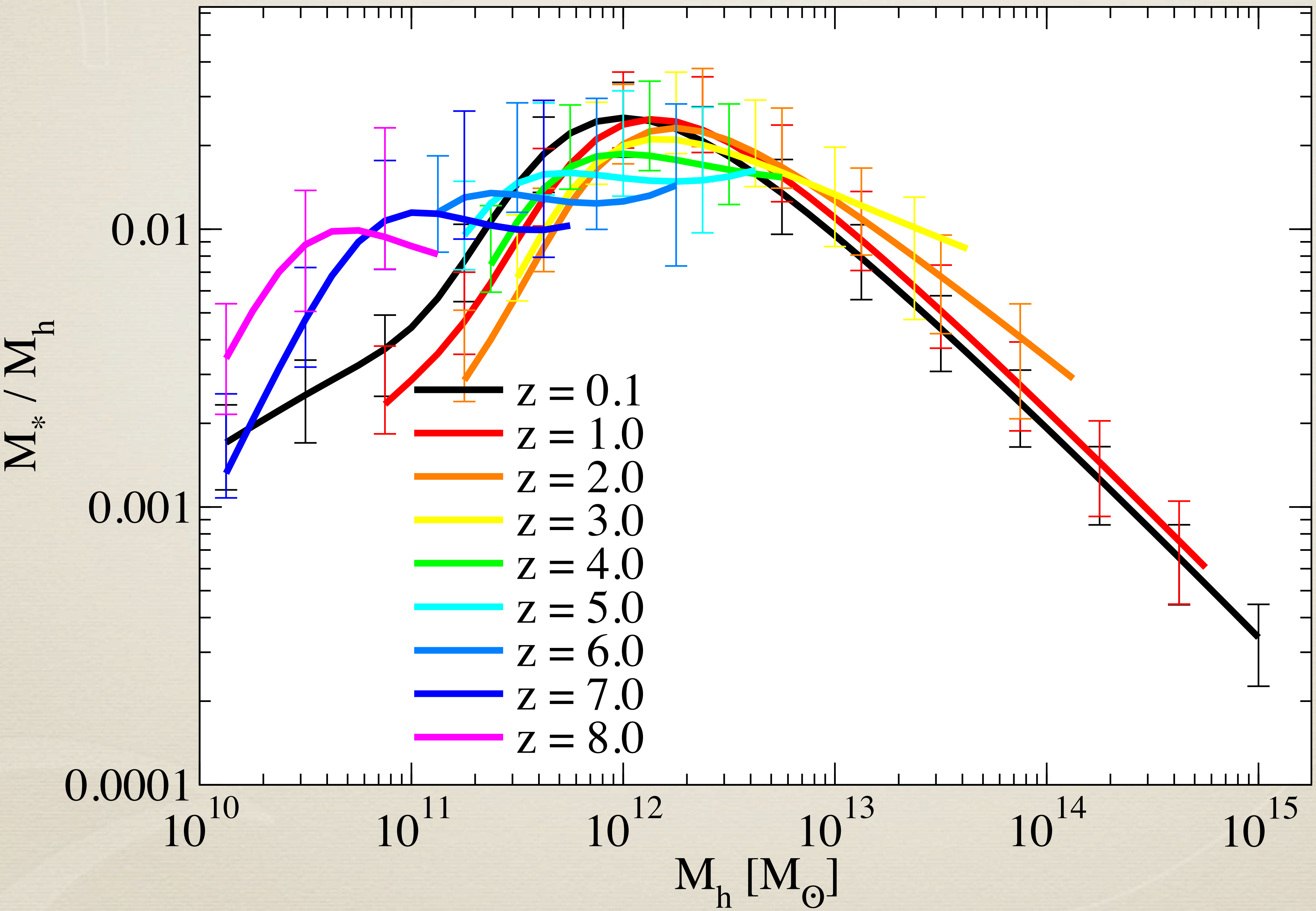
Results

Constraints on the M*/Mh ratio, useful for SAMs and hydro:



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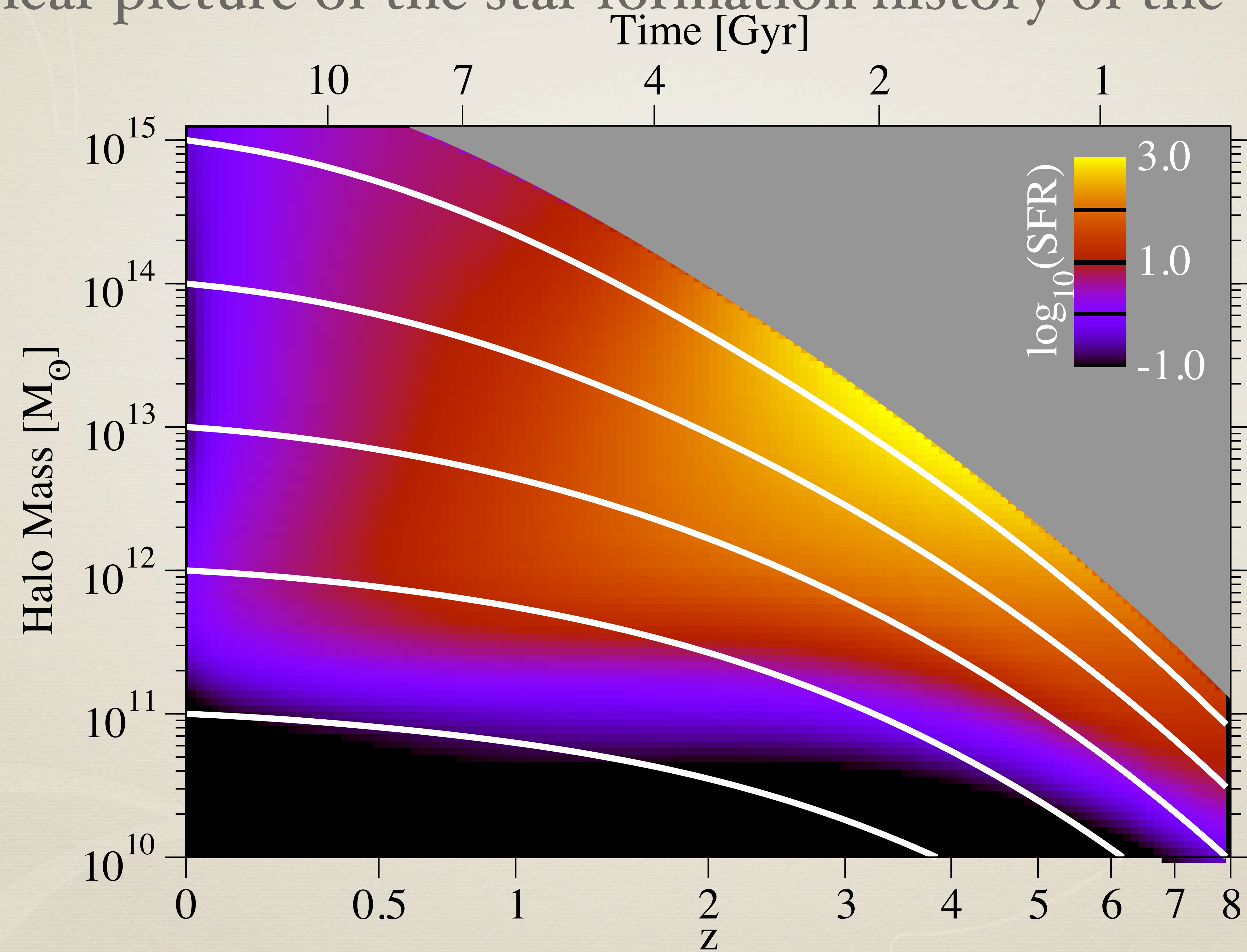
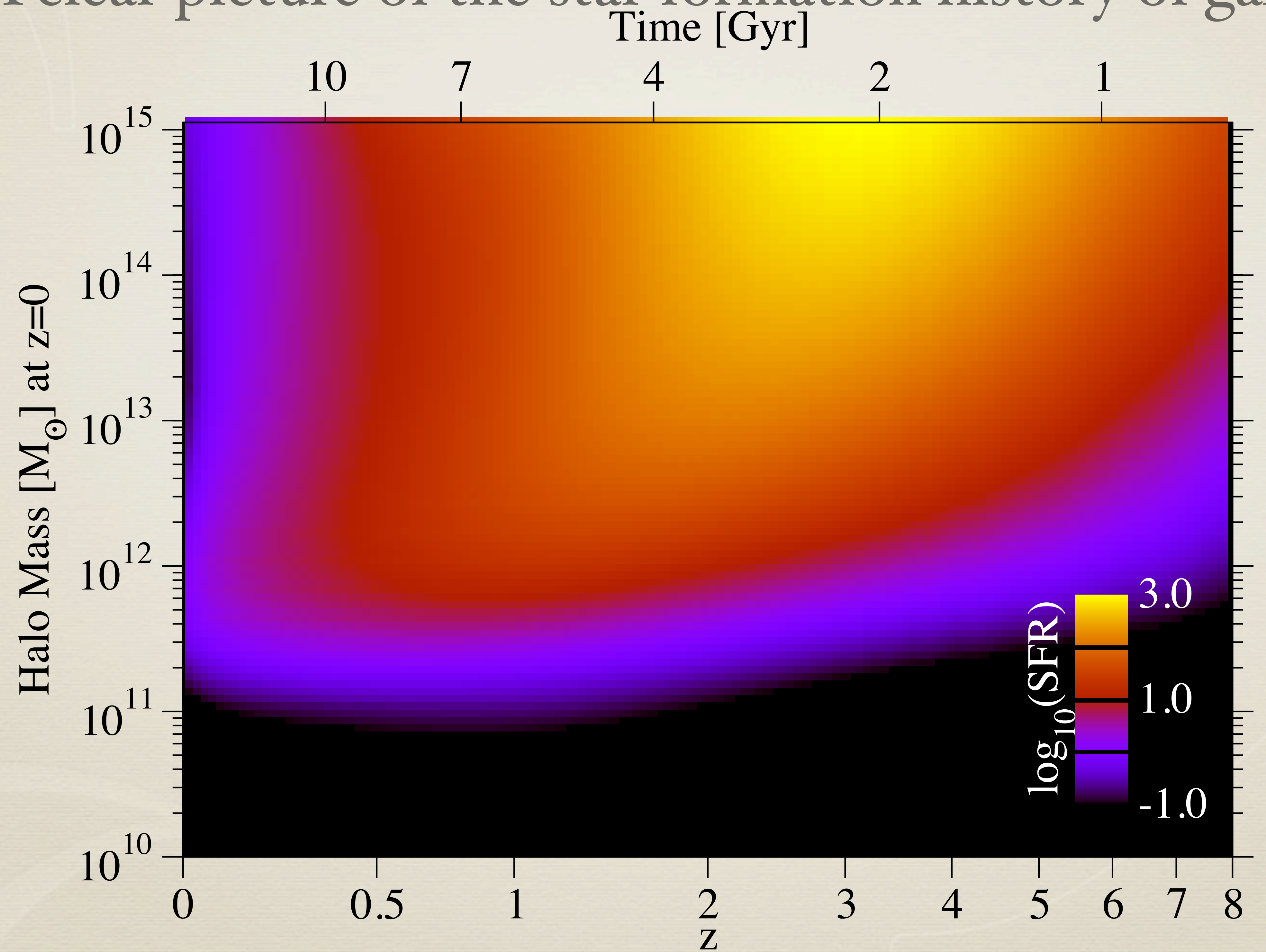
Results

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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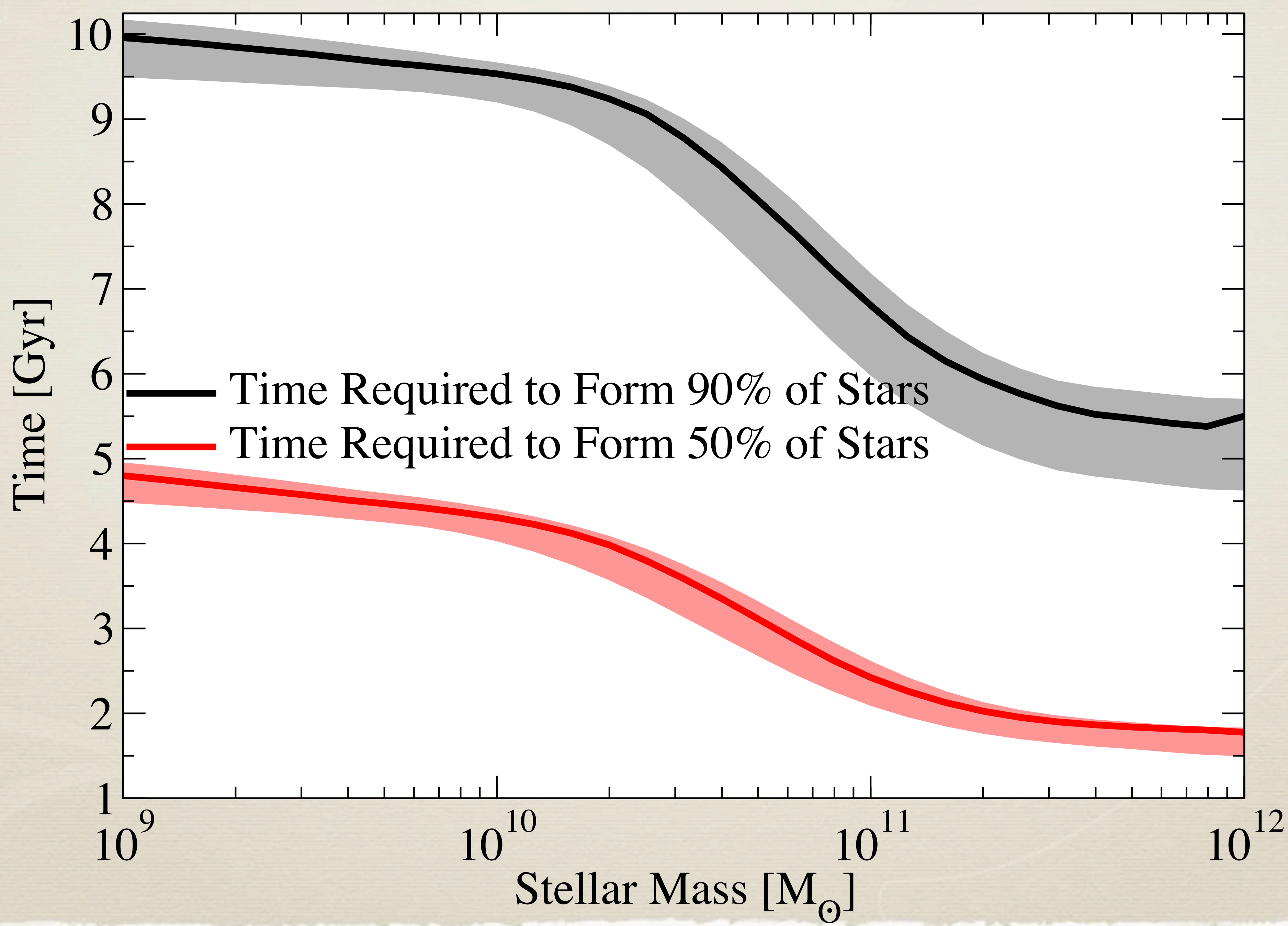

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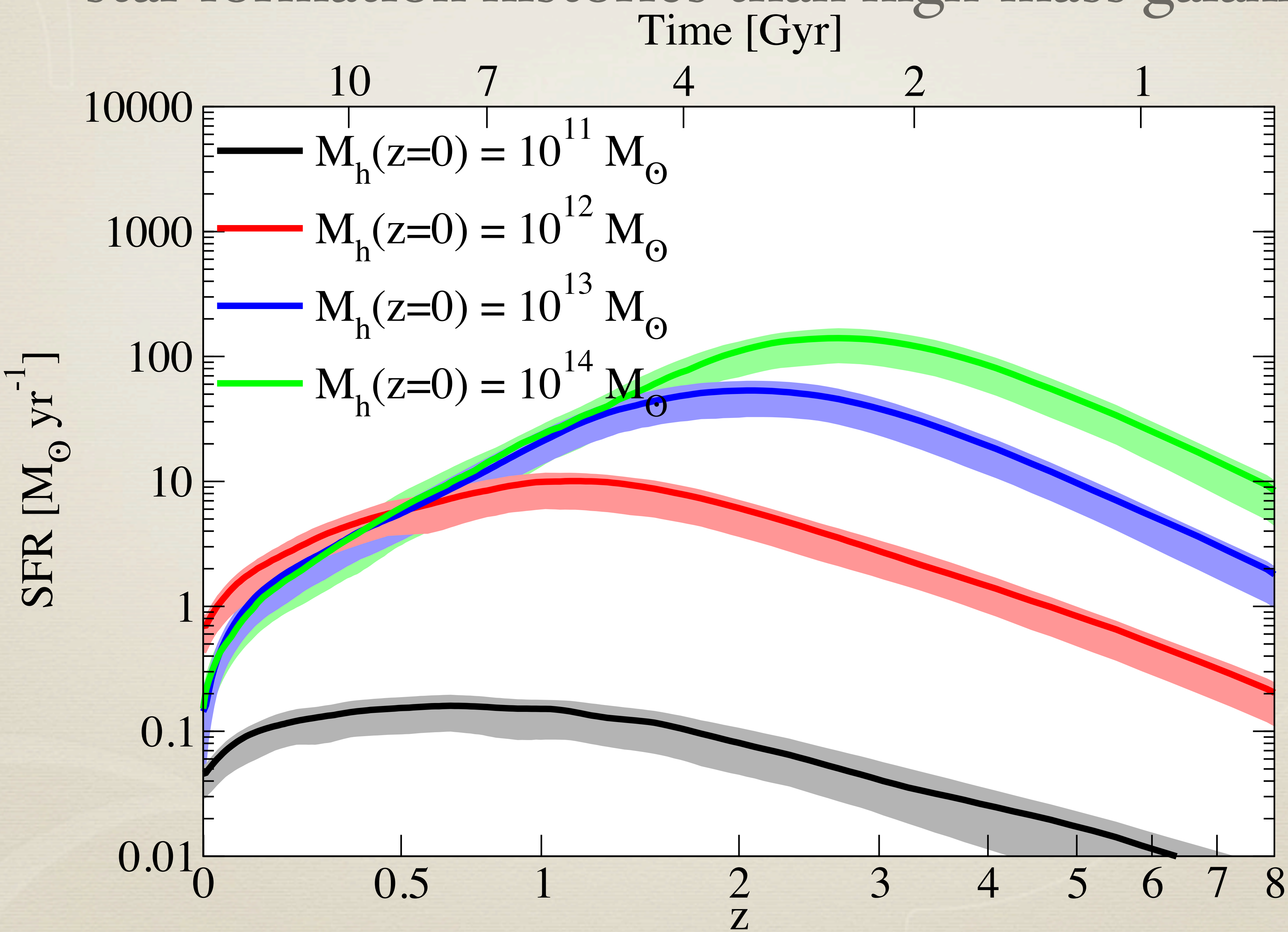
Results

Low-mass galaxies have had significantly different star formation histories than high-mass galaxies



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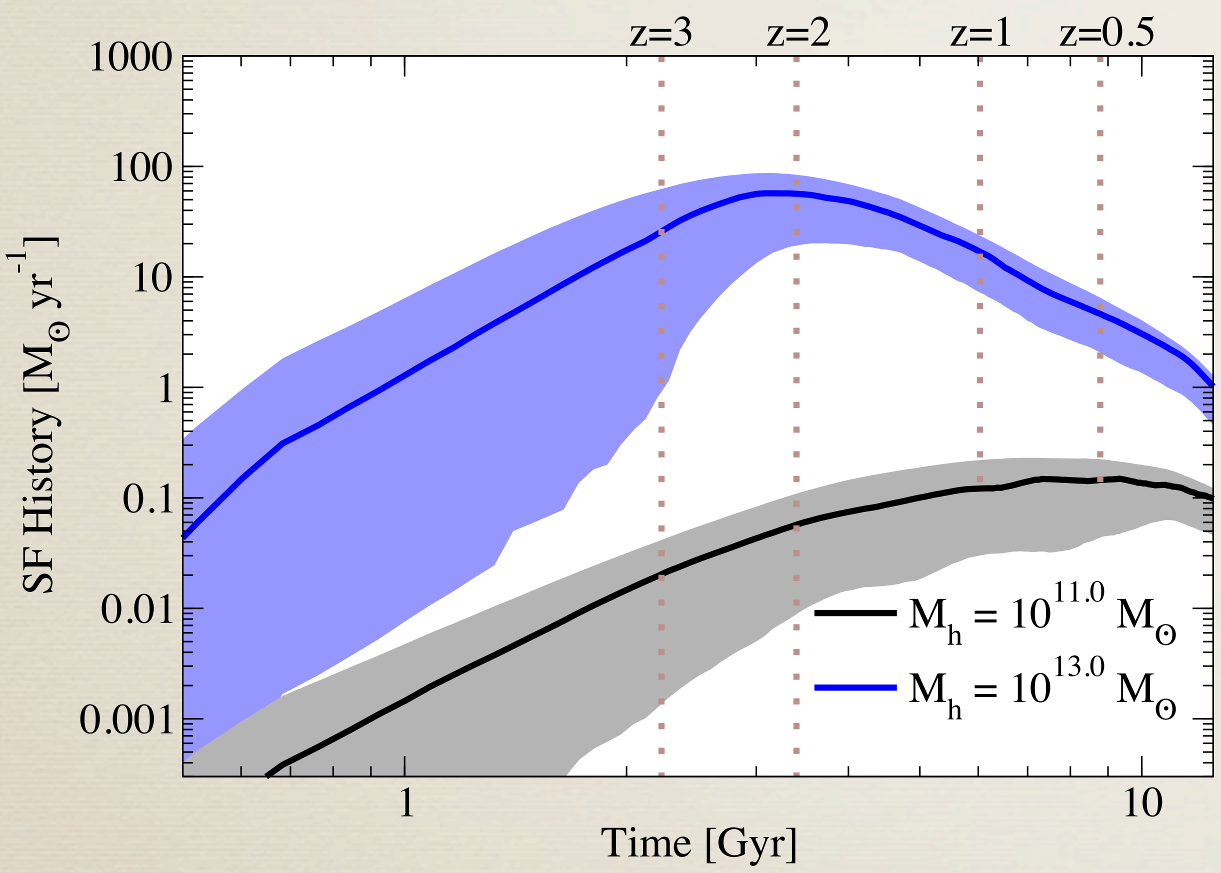
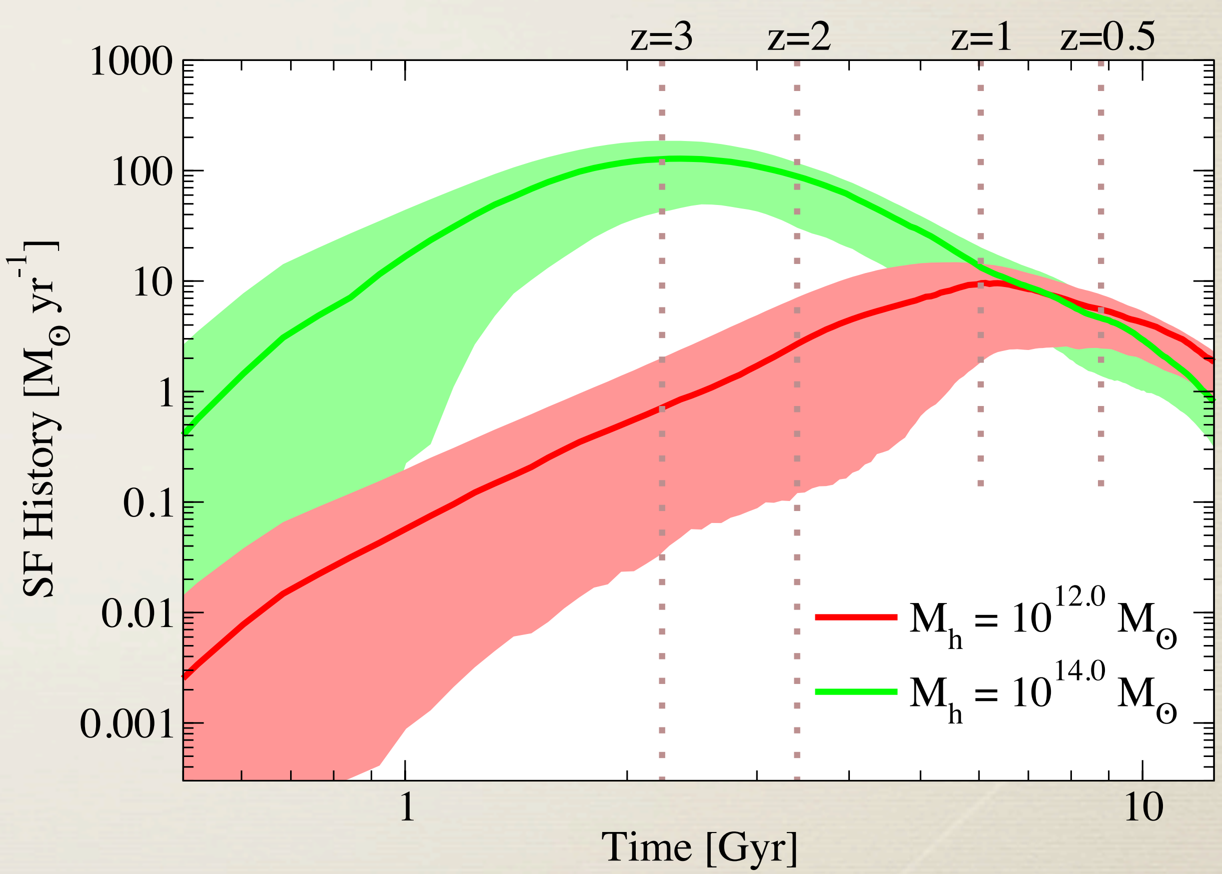
Results

Constraints on Individual Star Formation Histories





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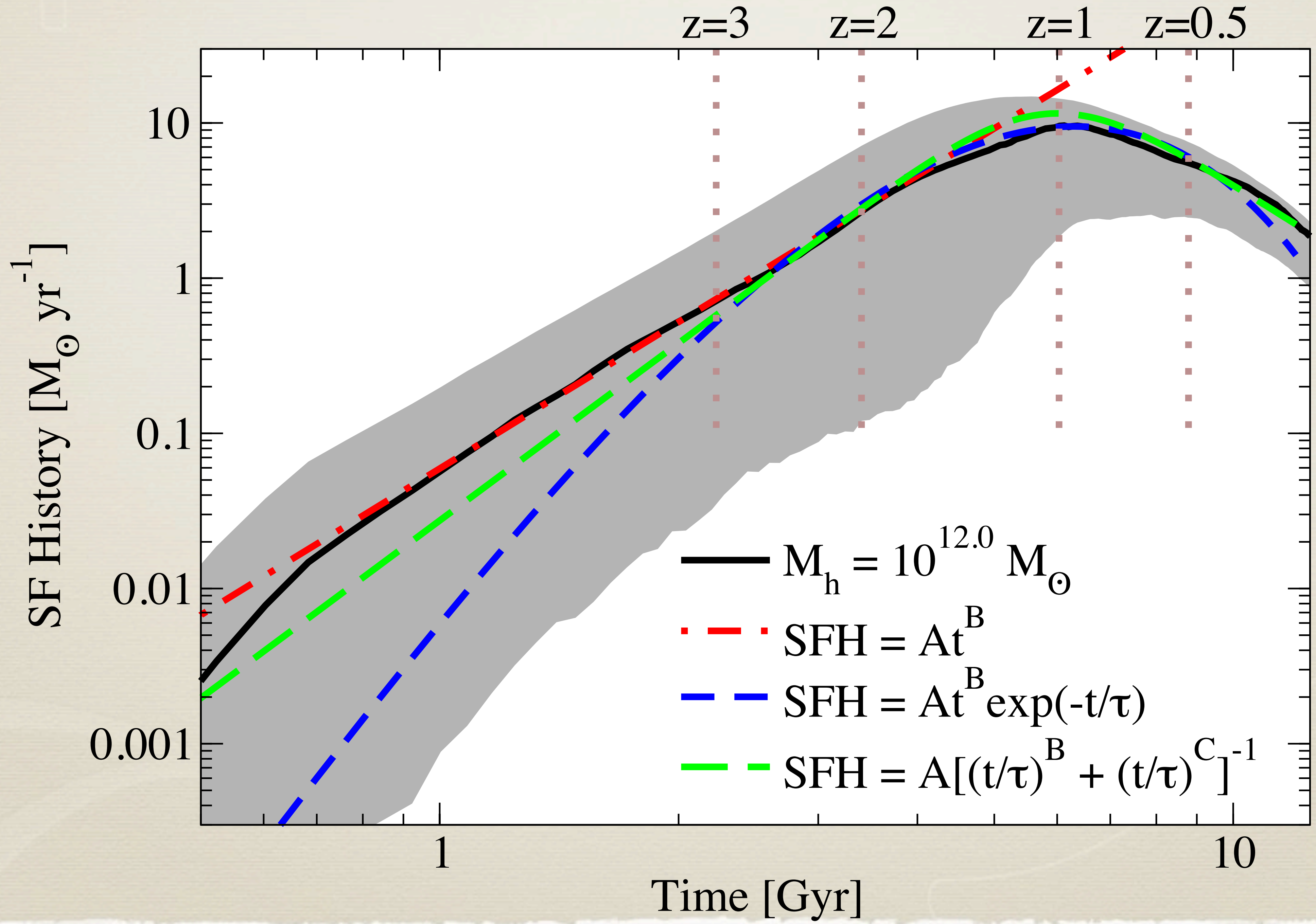

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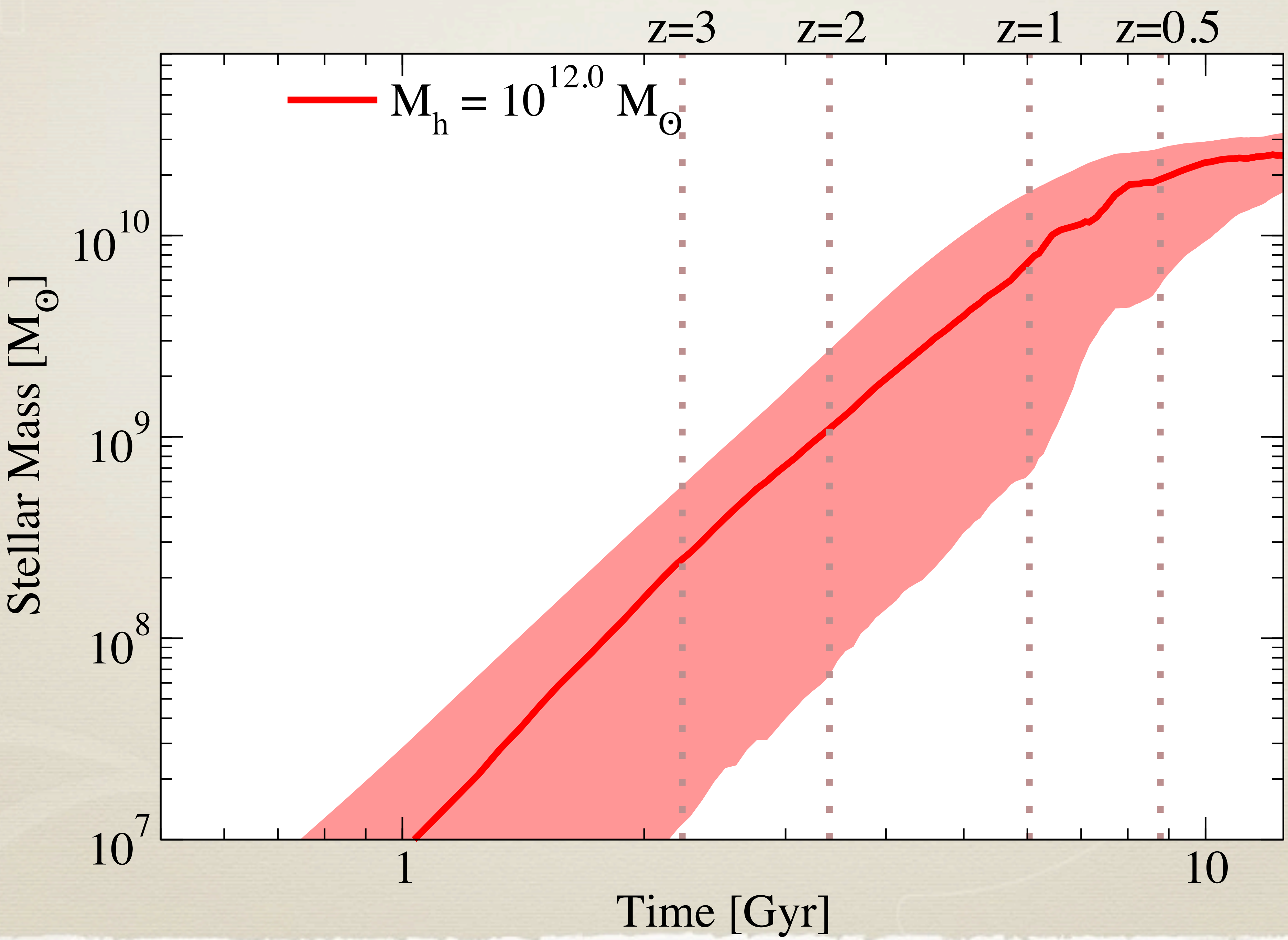
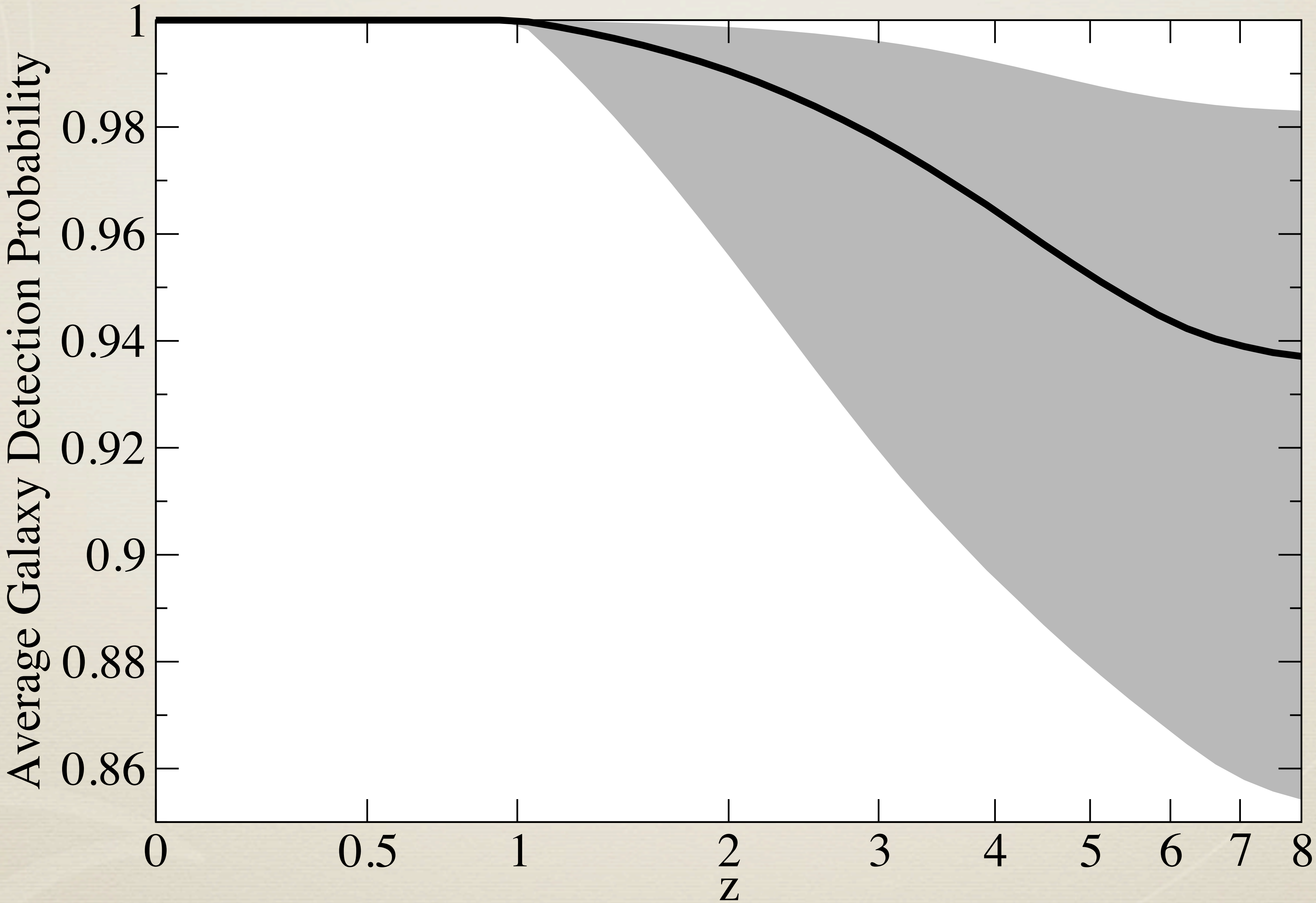


Results

Suggestions that incompleteness is not an enormous problem:



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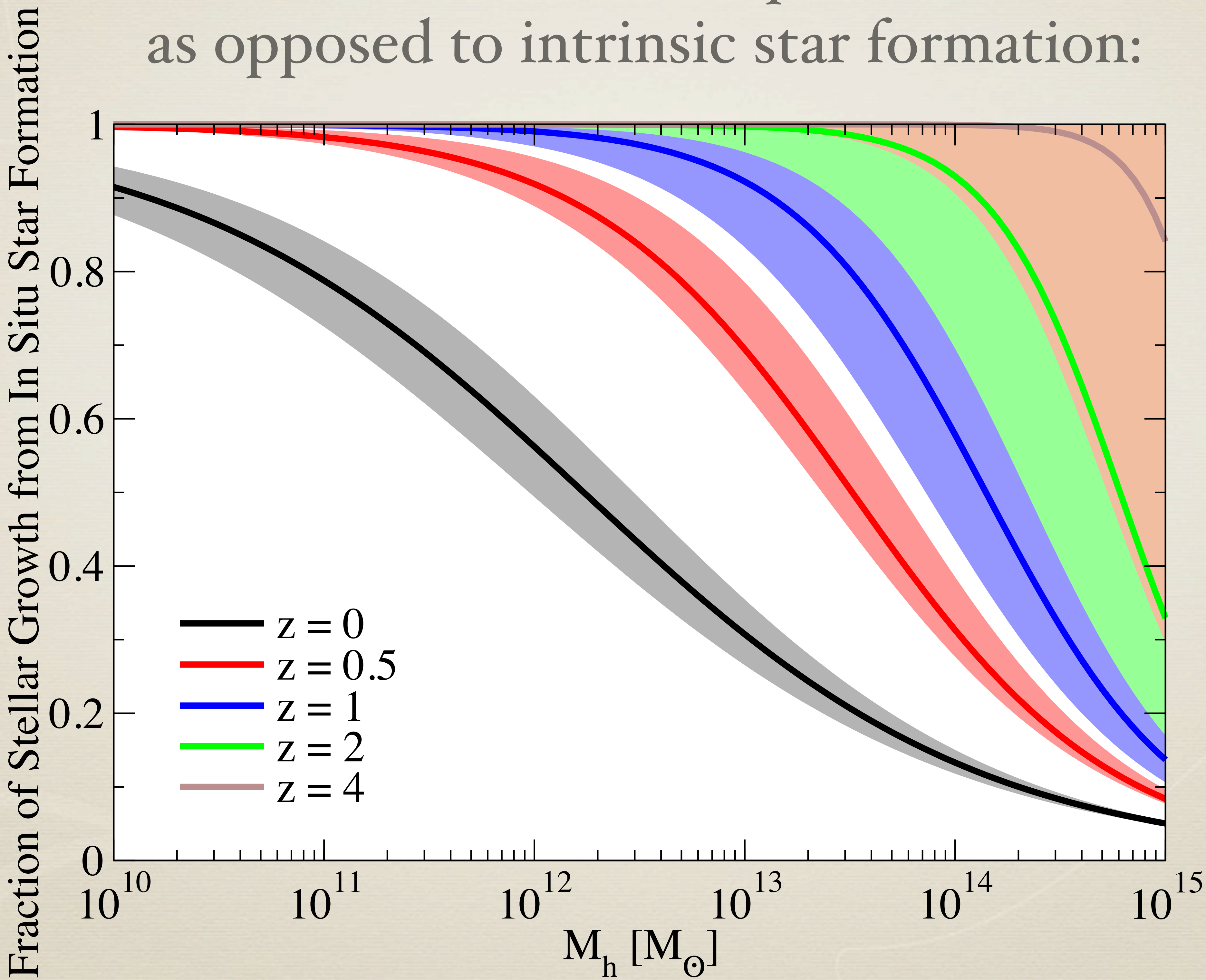
Results

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



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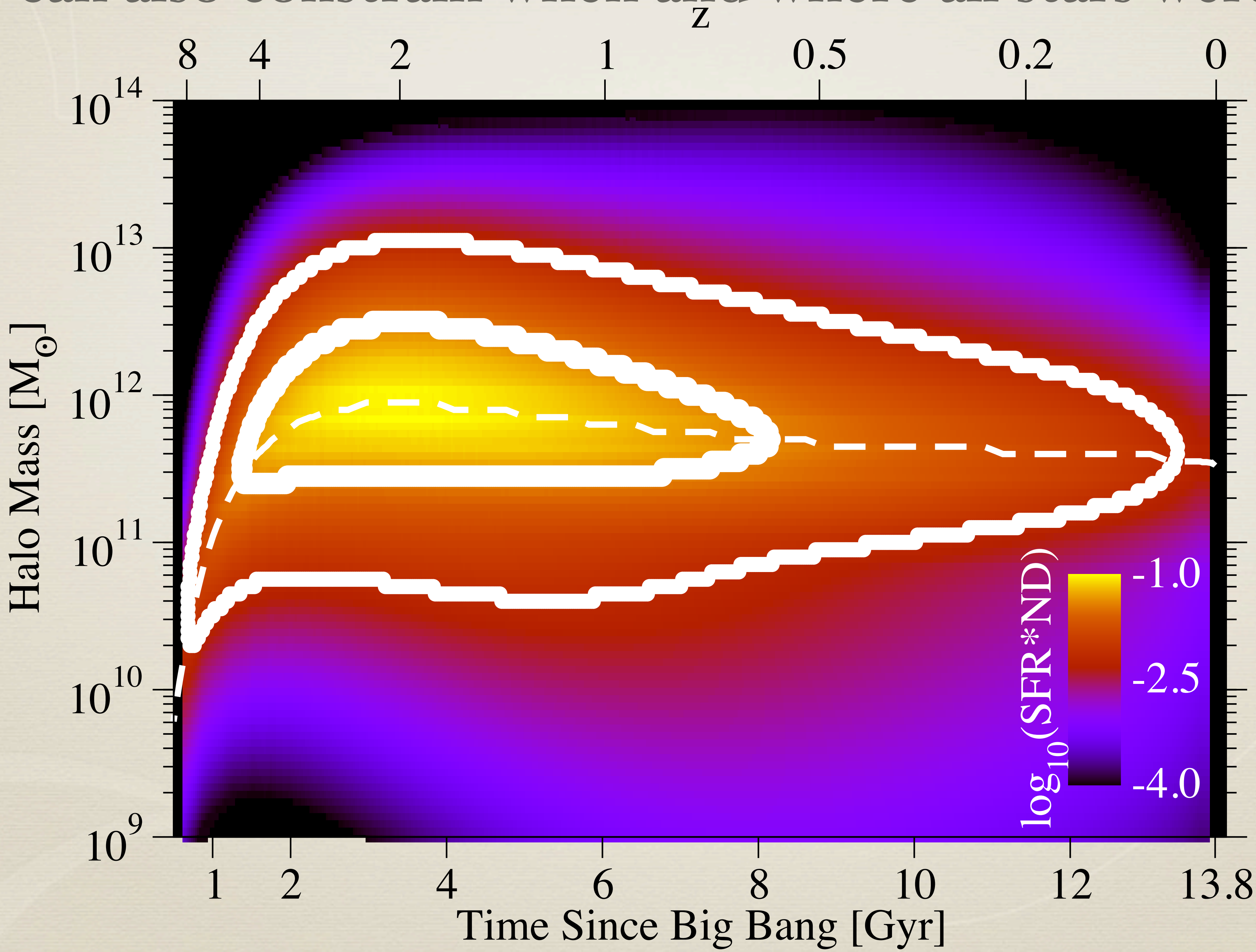
We can also constrain when and where all stars were formed:



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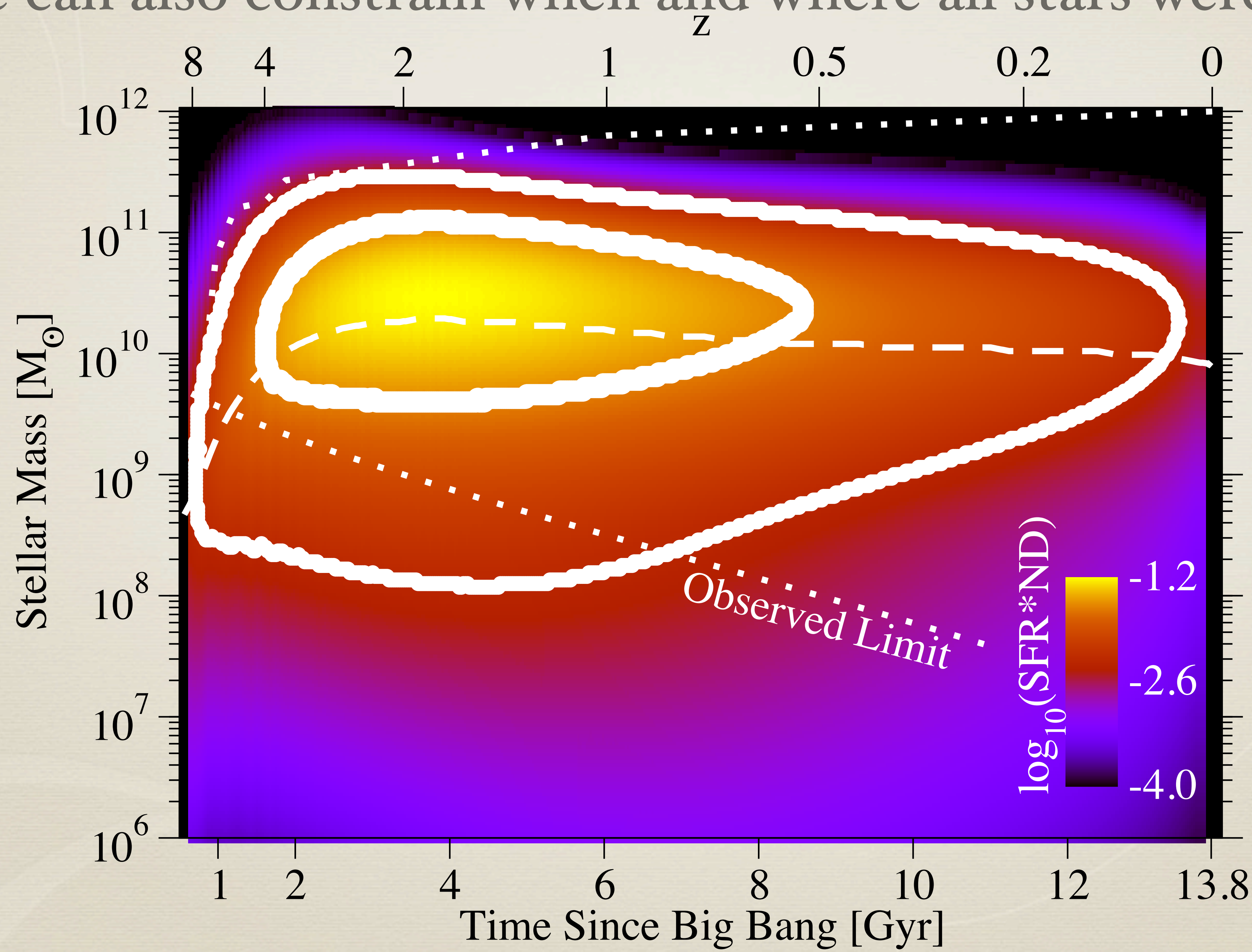
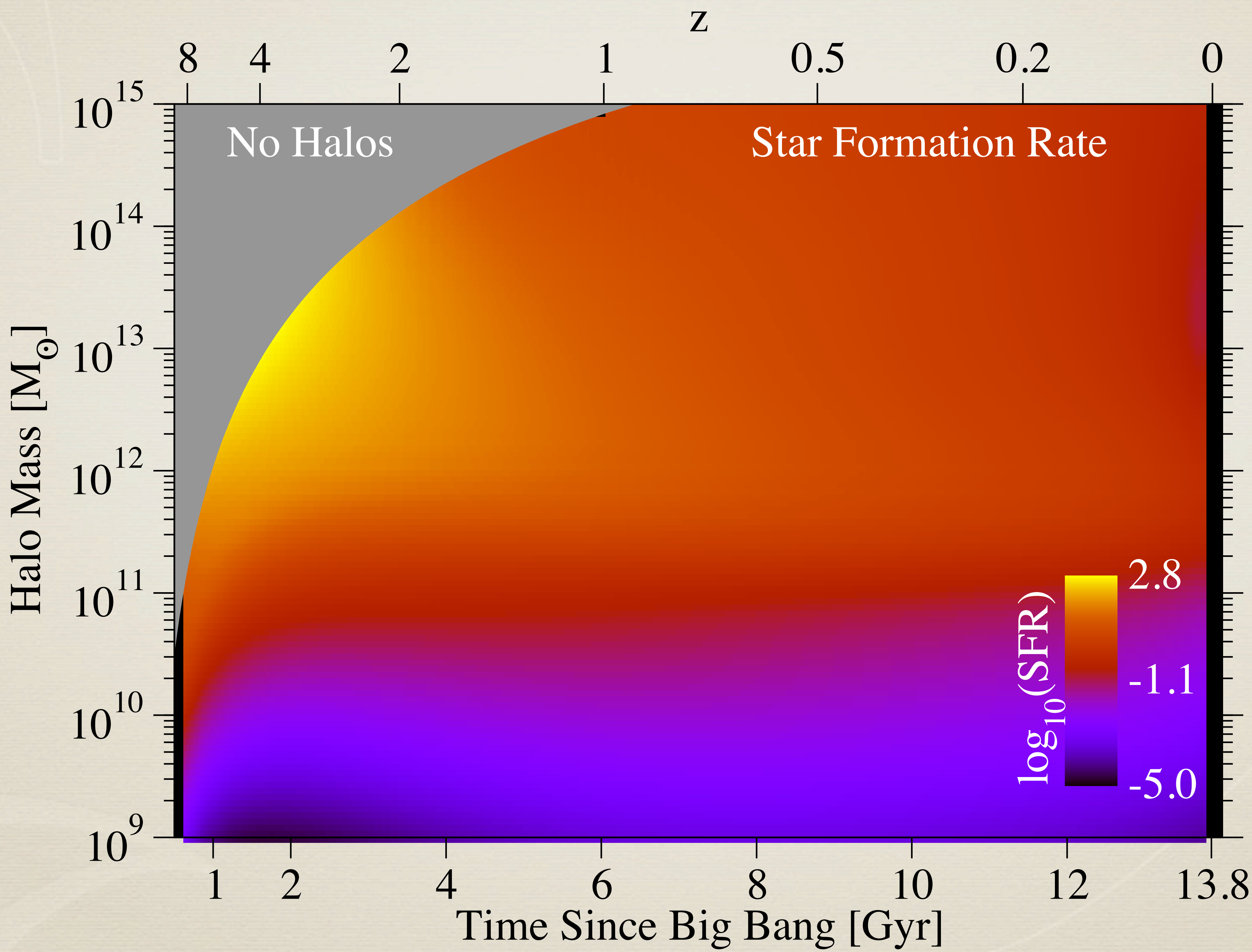


Star Formation Efficiency



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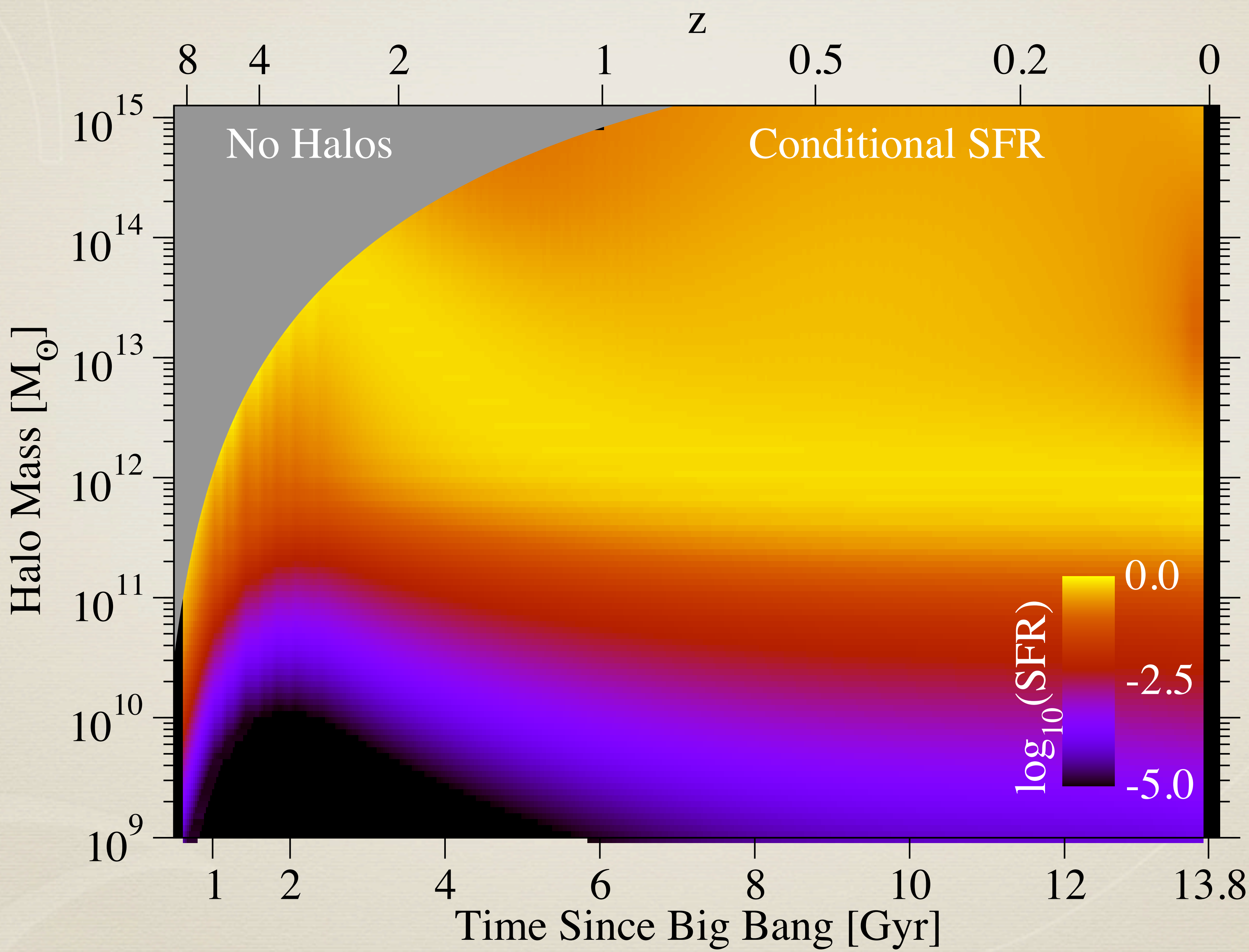

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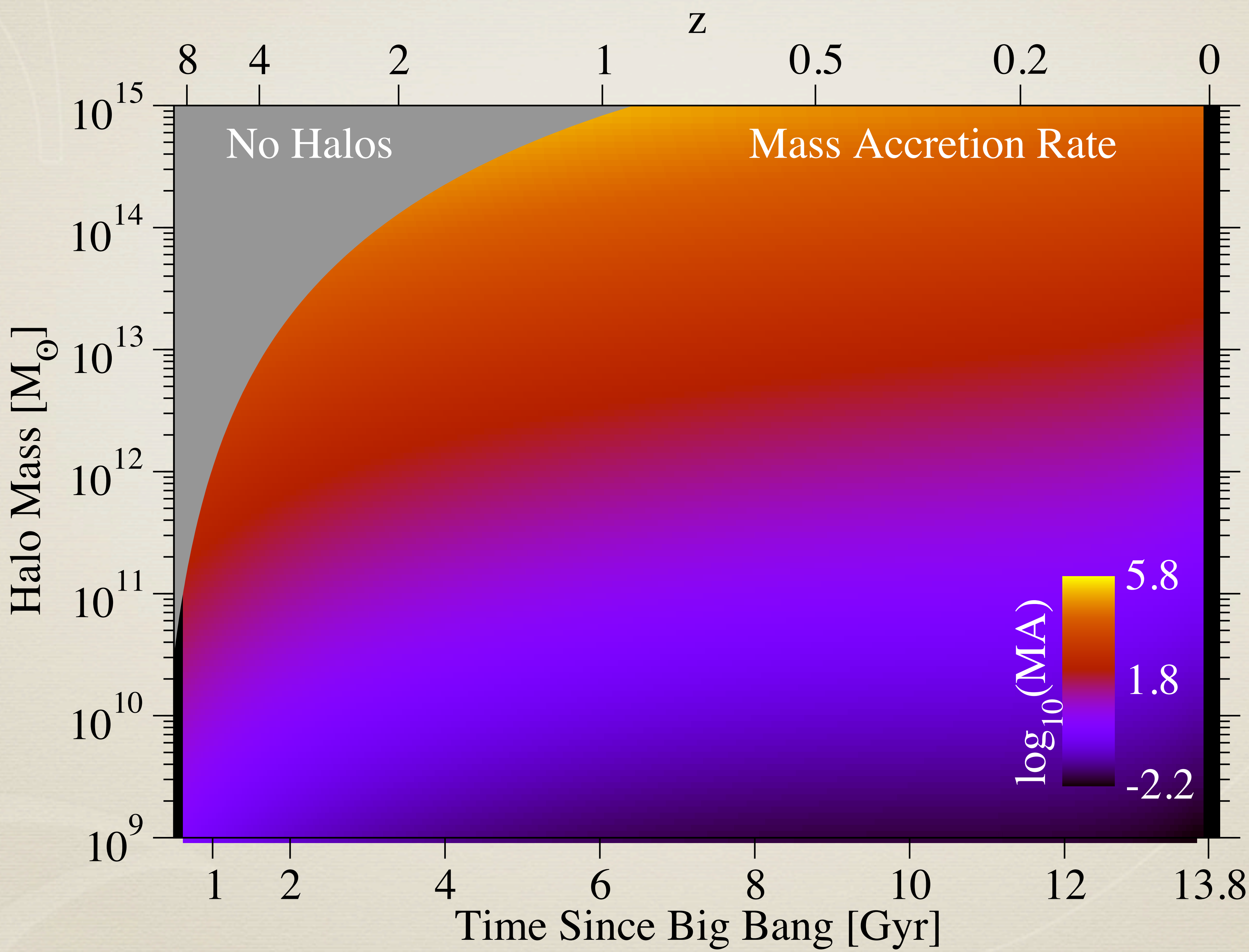

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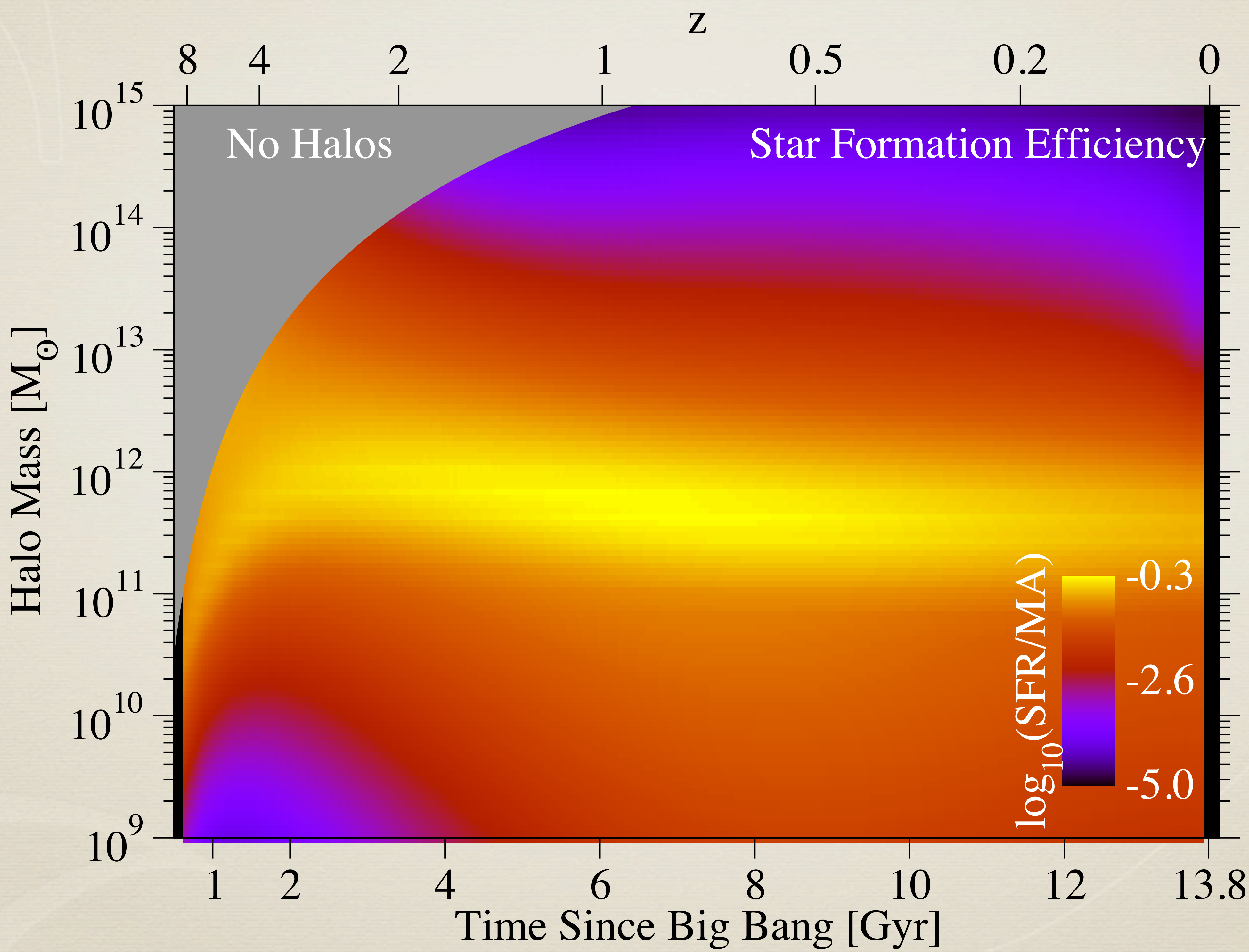

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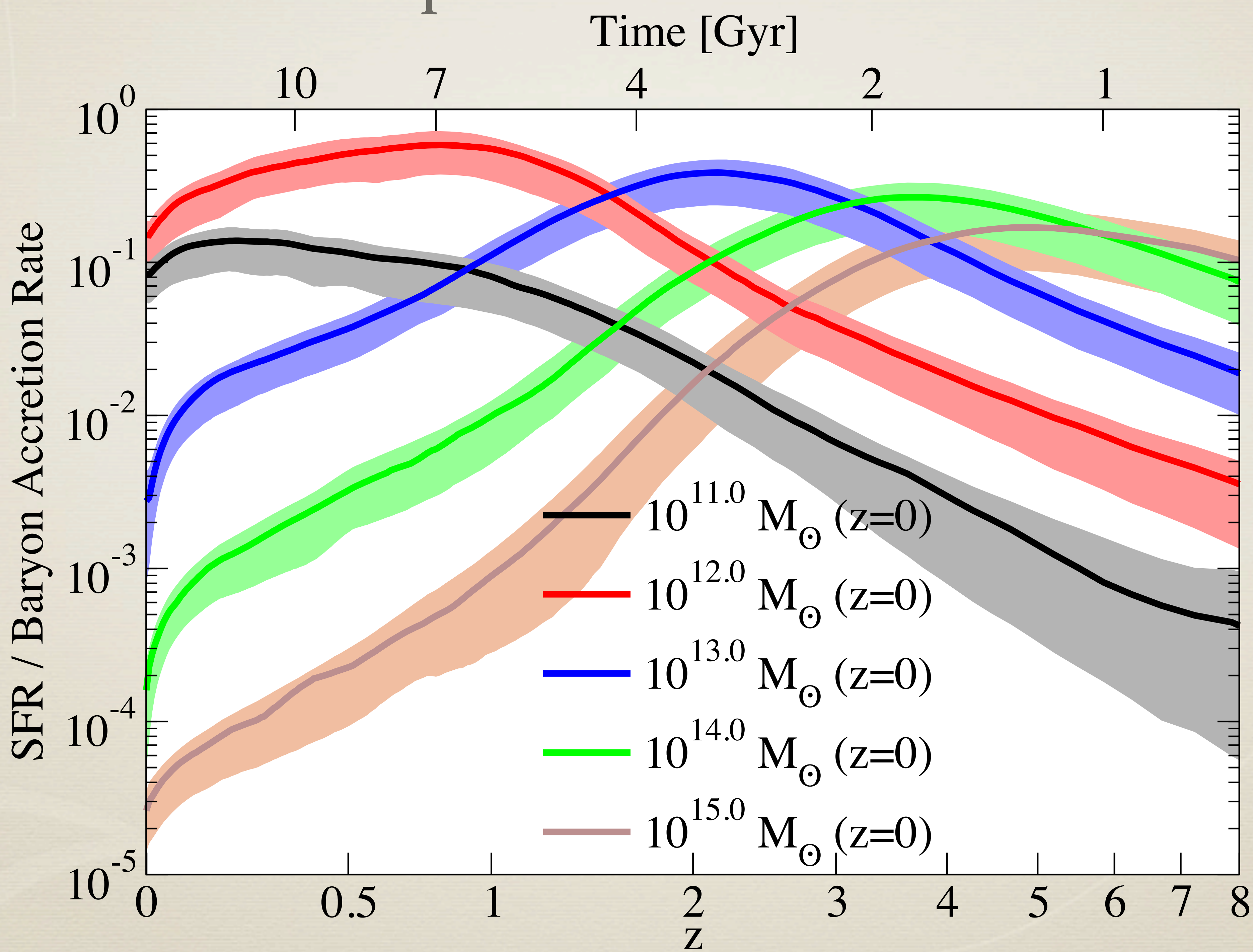
Results

This leaves a clear imprint on the historical conversion ratio:



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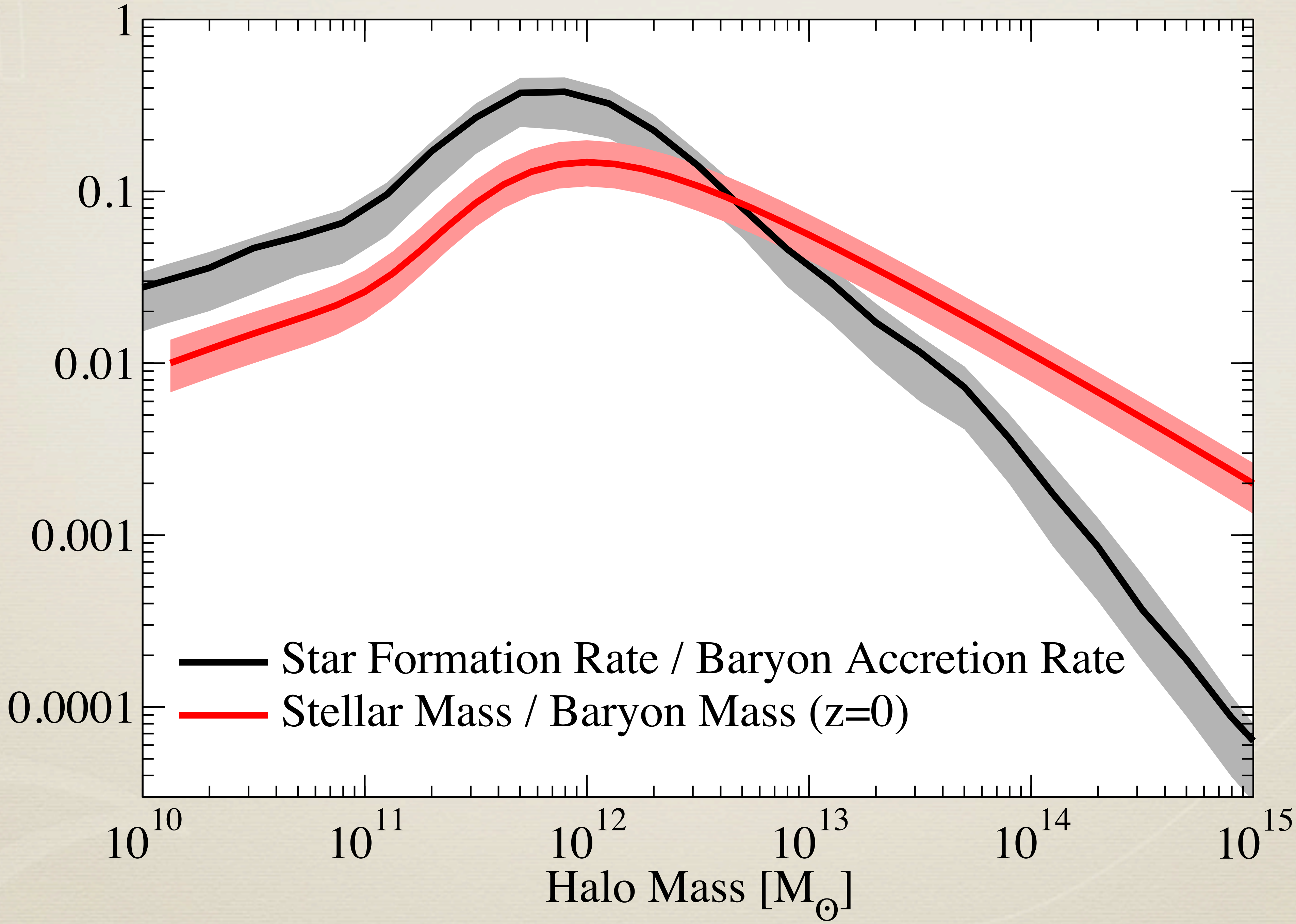

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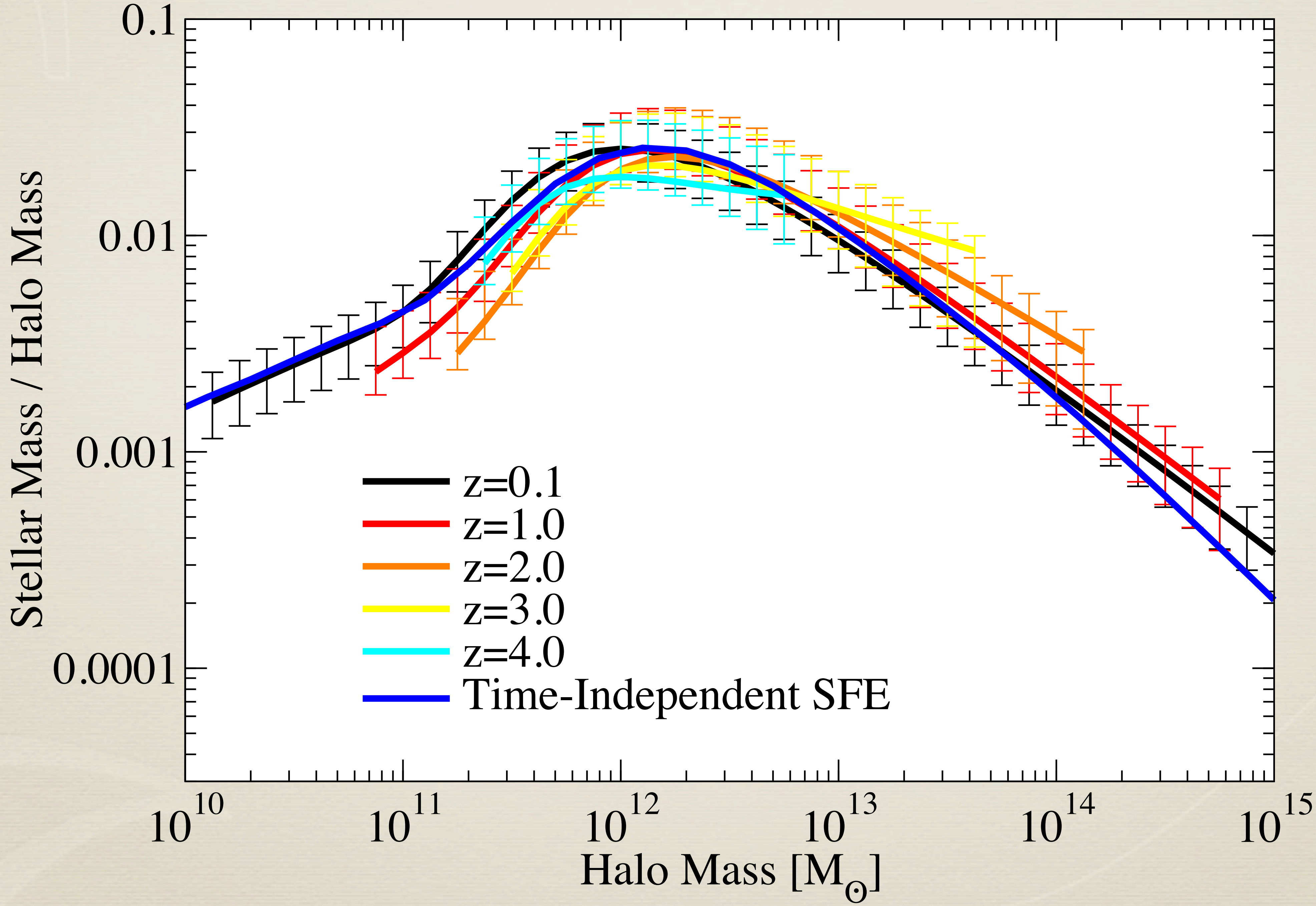
As Simple as Possible



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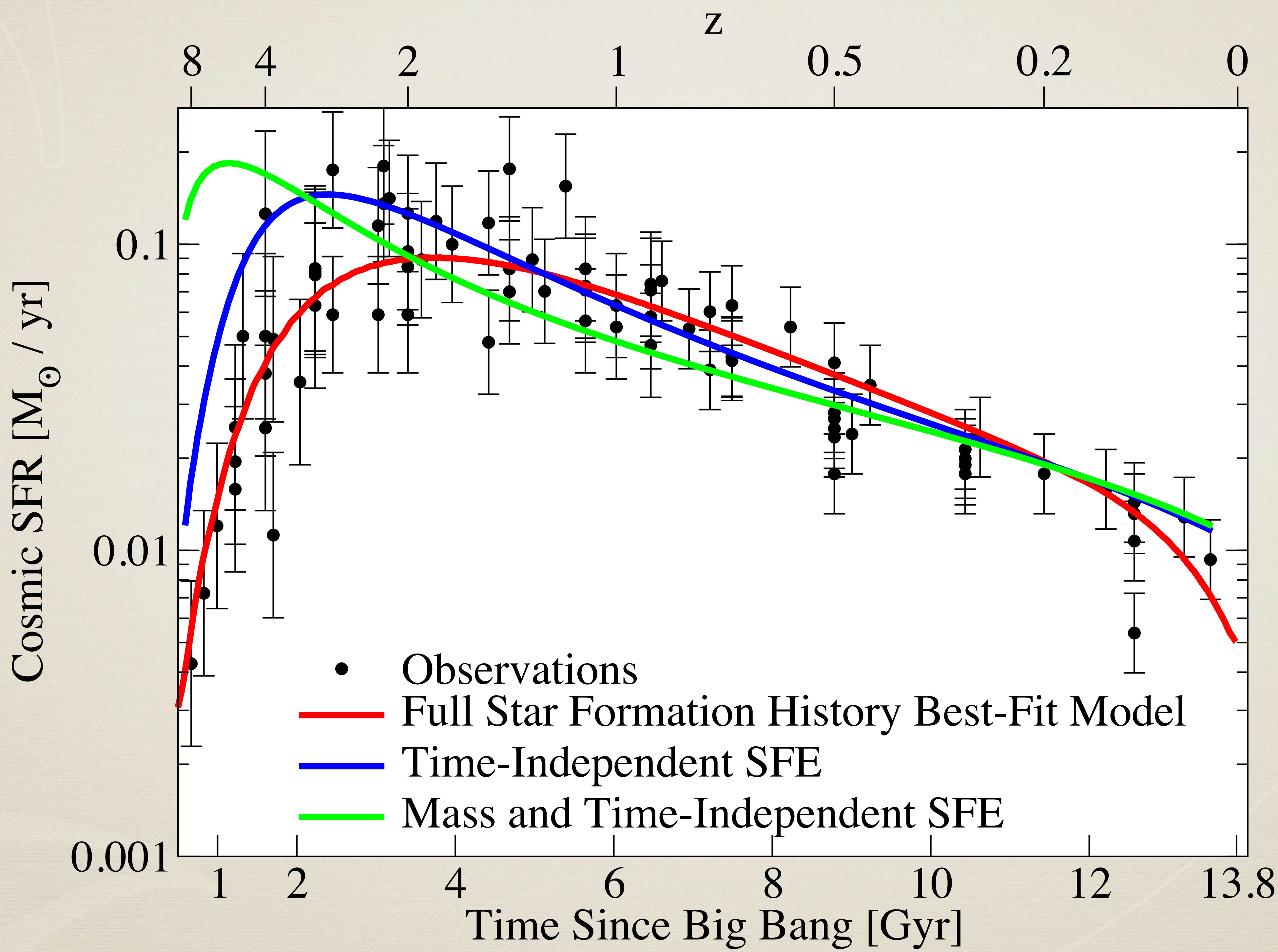
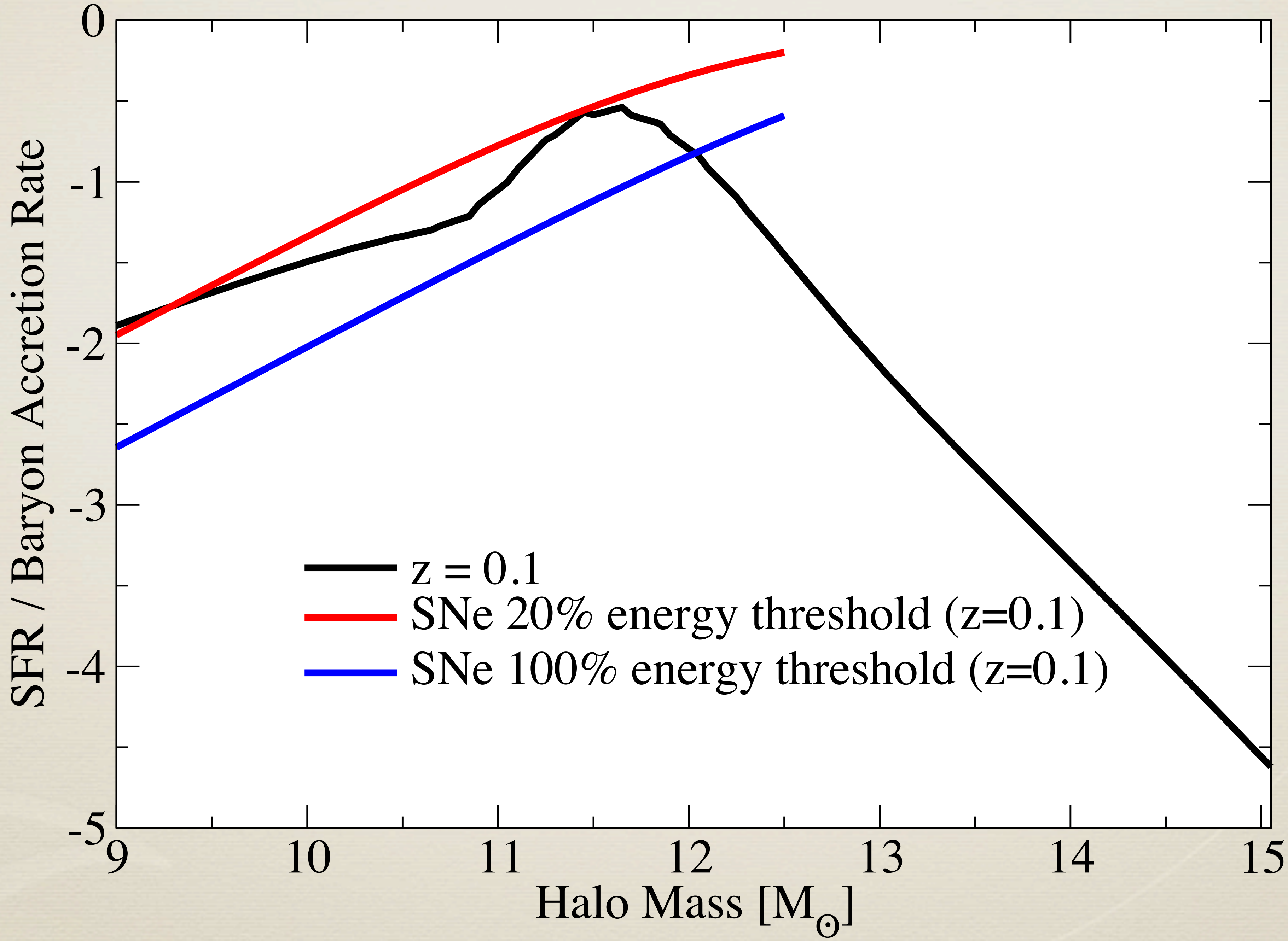


Future Directions



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Future Directions

Uncertainties in Calculating Stellar Masses / SFRs

* Initial Mass Function
* Stellar Pop. Synthesis Model
* Metallicity, Dust Model
* Star Formation History
* Redshift
* Photometry Errors
* Source Separation

arXiv:1207.6105

Future Directions

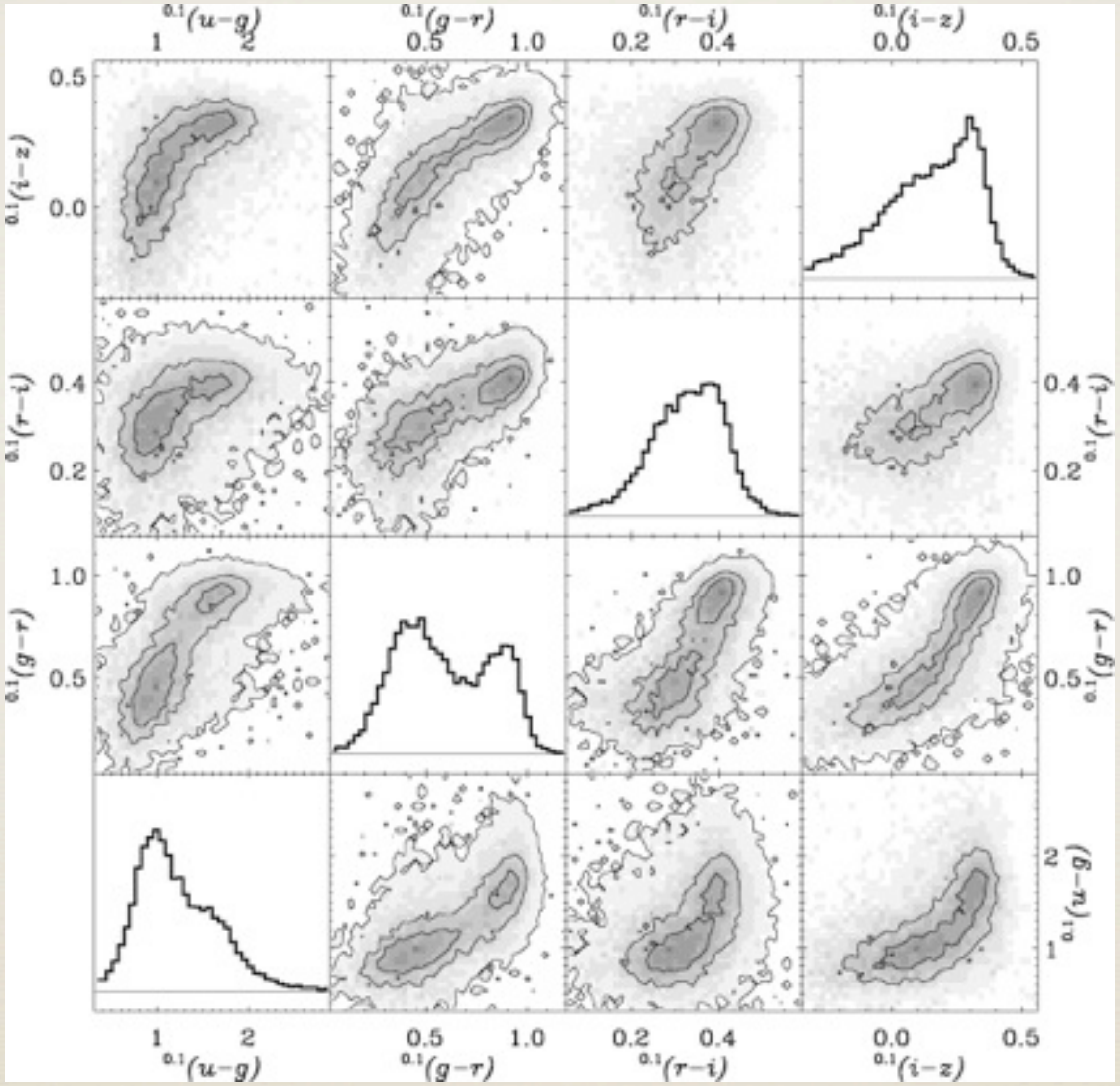
Uncertainties in Calculating Galaxy Apparent Magnitudes

* ~~Initial Mass Function~~
* ~~Stellar Pop. Synthesis Model~~
* ~~Metallicity, Dust Model~~
* ~~Star Formation History~~
* ~~Redshift~~
* Photometry Errors
* Source Separation

arXiv:1207.6105

Future Directions

Constraining directly to Galaxy Color-Magnitude Diagrams



Blanton et al. 2003

arXiv:1207.6105

Future Directions

Generating Mock Catalogs for Observers

Stellar Mass, SFR Catalogs already available

Catalogs with full galaxy colors planned.

Future Directions

Constraining Cosmology

A THEORETICAL FRAMEWORK FOR COMBINING TECHNIQUES THAT PROBE THE LINK BETWEEN GALAXIES AND DARK MATTER.

ALEXIE LEAUTHAUD[1,2], JEREMY TINKER[3], PETER S. BEHROOZI[4], MICHAEL T. BUSHA[4,5], RISA H. WECHSLER[4]

ABSTRACT

We develop a theoretical framework that combines measurements of galaxy-galaxy lensing, galaxy clustering, and the galaxy stellar mass function in a self-consistent manner. While considerable effort has been invested in exploring each of these probes individually, attempts to combine them are still in their infancy. These combinations have potential to elucidate the galaxy-dark matter connection and the galaxy formation physics that is responsible for it, as well as to constrain cosmological parameters, and to test the nature of gravity. In this paper, we focus on a theoretical model that describes the

NEW CONSTRAINTS ON THE EVOLUTION OF THE STELLAR-TO-DARK MATTER CONNECTION: A COMBINED ANALYSIS OF GALAXY-GALAXY LENSING, CLUSTERING, AND STELLAR MASS FUNCTIONS FROM Z=0.2 TO Z=1

ALEXIE LEAUTHAUD[1,2], JEREMY TINKER[3], KEVIN BUNDY[4], PETER S. BEHROOZI[5], RICHARD MASSEY[6], JASON RHODES[7,8], MATTHEW R. GEORGE[4], JEAN-PAUL KNEIB[9], ANDREW BENSON[7], RISA H. WECHSLER[5], MICHAEL T. BUSHA[5,10], PETER CAPAK[11], MARINA CORTÊS[1], OLIVIER ILBERT[9], ANTON M. KOEKEMOER[12], OLIVIER LE FÈVRE[9], SIMON LILLY[13], HENRY J. MCCRACKEN[14], MARA SALVATO[15], TIM SCHRABBACK[5,16], NICK SCOVILLE[7], TRISTAN SMITH[2], JAMES E. TAYLOR[17]

Submitted to ApJ

ABSTRACT

Using data from the COSMOS survey, we perform the first joint analysis of galaxy-galaxy weak lensing, galaxy spatial clustering, and galaxy number densities. Carefully accounting for sample variance and for scatter between stellar and halo mass, we model all three observables simultaneously using a novel and self-consistent theoretical framework. Our results provide strong constraints on the shape and redshift evolution of the stellar-to-halo mass relation (SHMR) from $z = 0.2$ to $z = 1$.

Future Directions

Constraining Cosmology

Cosmological Constraints from a Combination of Galaxy Clustering and Lensing – III. Application to SDSS Data

Marcello Cacciato[1★], Frank C. van den Bosch[2], Surhud More[3], Houjun Mo[4], Xiaohu Yang[5]

ABSTRACT
We simultaneously constrain cosmology and galaxy bias using measurements of galaxy abundances, galaxy clustering and galaxy-galaxy lensing taken from the Sloan Digital Sky Survey. We use the conditional luminosity function (which describes the halo occupation statistics as function of galaxy luminosity) combined with the halo model (which describes the non-linear matter field in terms of its halo building blocks) to describe the galaxy-dark matter connection. We explicitly account for residual redshift space distortions in the projected galaxy-galaxy correlation functions, and marginalize over uncertainties in the scale dependence of the halo bias and the detailed structure of dark matter haloes. Under the assumption of a spatially flat, vanilla ΛCDM cosmology, we focus on constraining the matter density, $\Omega_{\rm m}$, and the normalization of the matter power spectrum, σ_8, and we adopt WMAP7 priors for the spectral index, $n_{\rm s}$, the Hubble parameter, h, and the baryon density, $\Omega_{\rm b}$. We obtain that $\Omega_{\rm m} = 0.278^{+0.023}_{-0.026}$ and $\sigma_8 = 0.763^{+0.064}_{-0.049}$ (95% CL). These results are robust to uncertainties in the radial number density distribution of satellite galaxies, while allowing for non-Poisson

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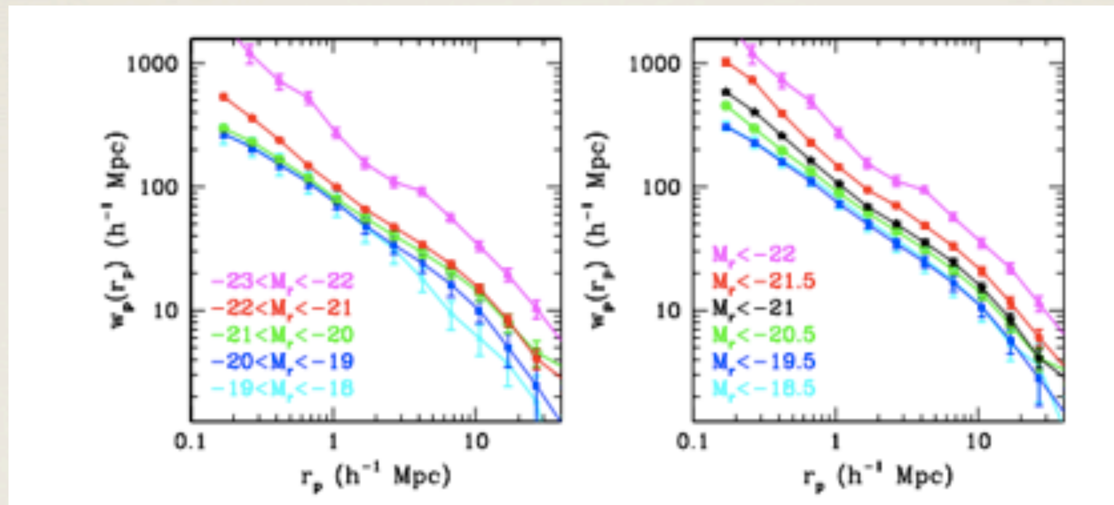
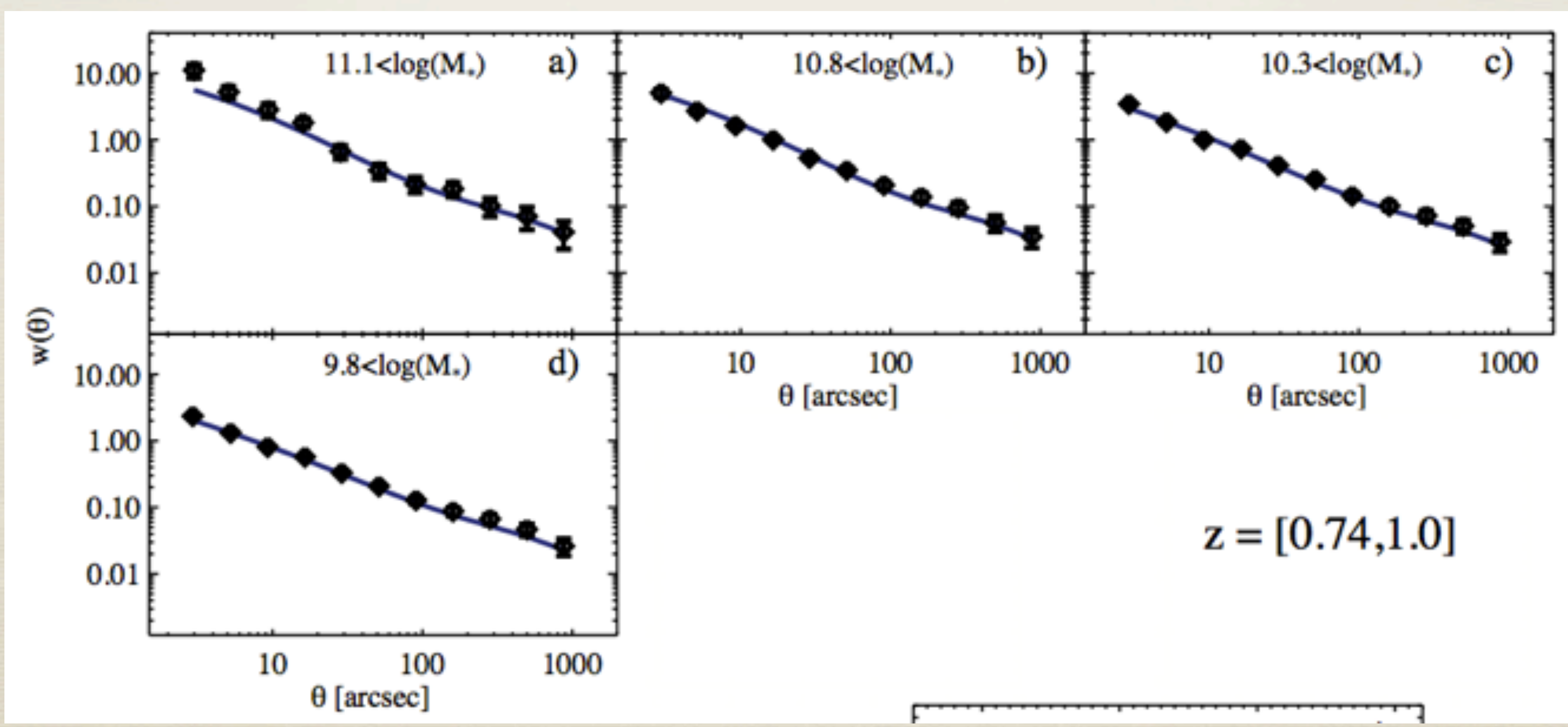
Future Directions

Constraining Cosmology



Zehavi et al. 2011



Leauthaud et al. 2012

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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

Declining Tau models are poor fits to galaxy star formation histories, except for massive galaxies at $z<1$.

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Summary

Declining Tau models are poor fits to galaxy star formation histories, except for massive galaxies at z<1.

Milky-way sized galaxies have gained a factor of a few in stellar mass since z~1, but a factor of ~20 since z=2.

High-redshift galaxies typically have rapidly rising star formation histories, SFR ~ t^3 or t^4

Summary

We're working to improve cosmological hydro simulations as well as semi-analytical models to better reproduce observed star formation.

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Summary

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Look forward to cosmology constraints in the future!

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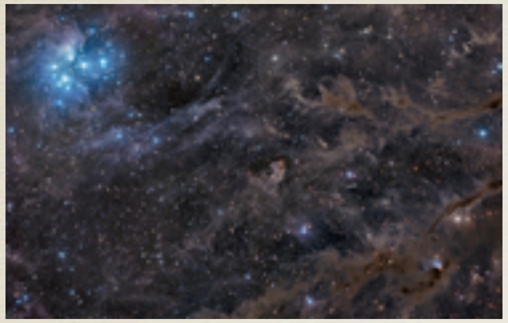
Thank you for listening!

Image Sources



John Davis; http://apod.nasa.gov/apod/ap101118.html

Adam Block: http://apod.nasa.gov/apod/ap090414.html

HUDF Working Group; http://apod.nasa.gov/apod/ap040309.html