MOVIES OF ALL THE GALAXIES IN THE UNIVERSE

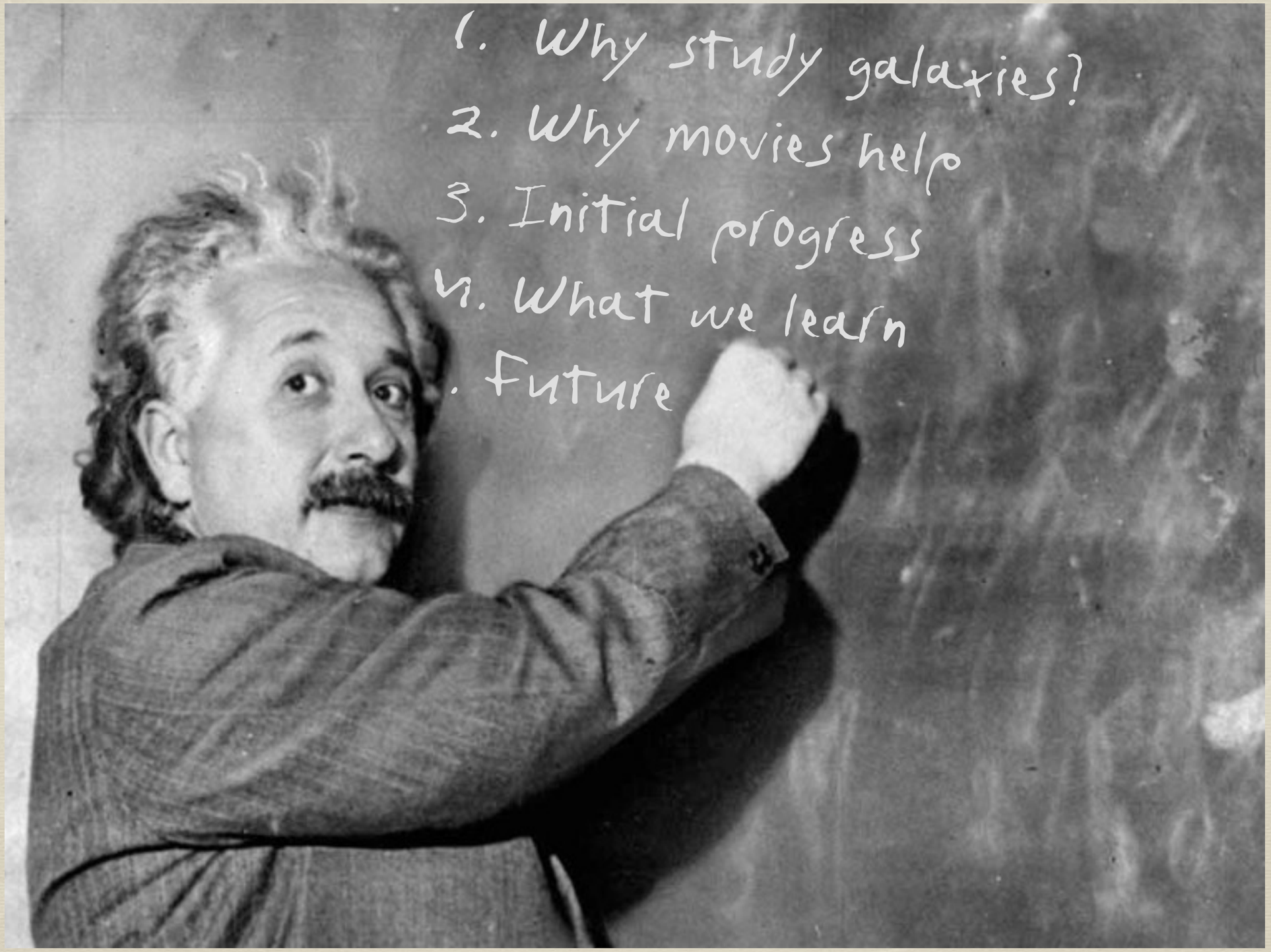
a.k.a. “Making Movies of Real Galaxies and their Dark Matter Halos”

Credit: M31, NASA

Peter Behroozi, Hubble Fellow, UC Berkeley

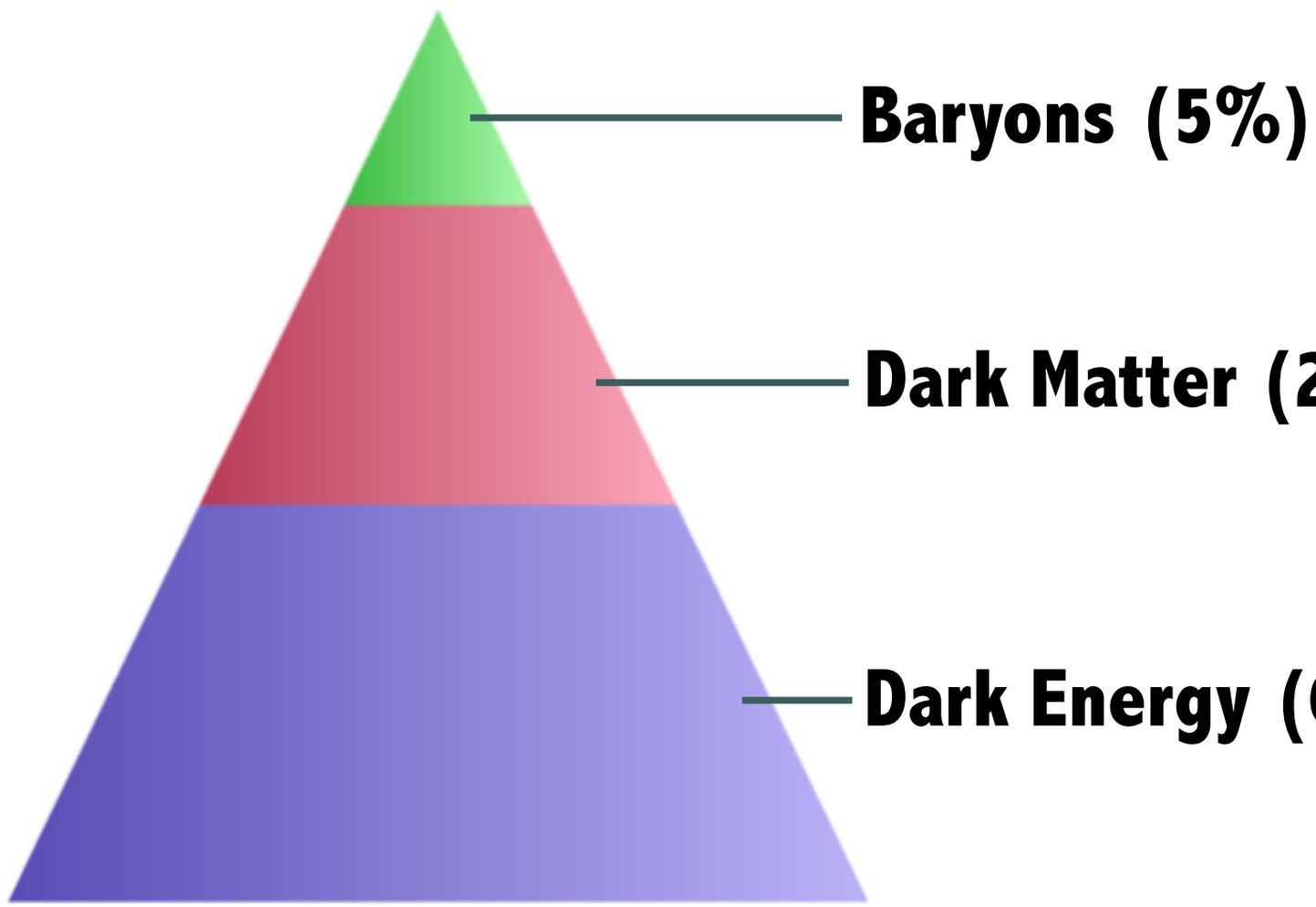
LBNL, 4/22/16

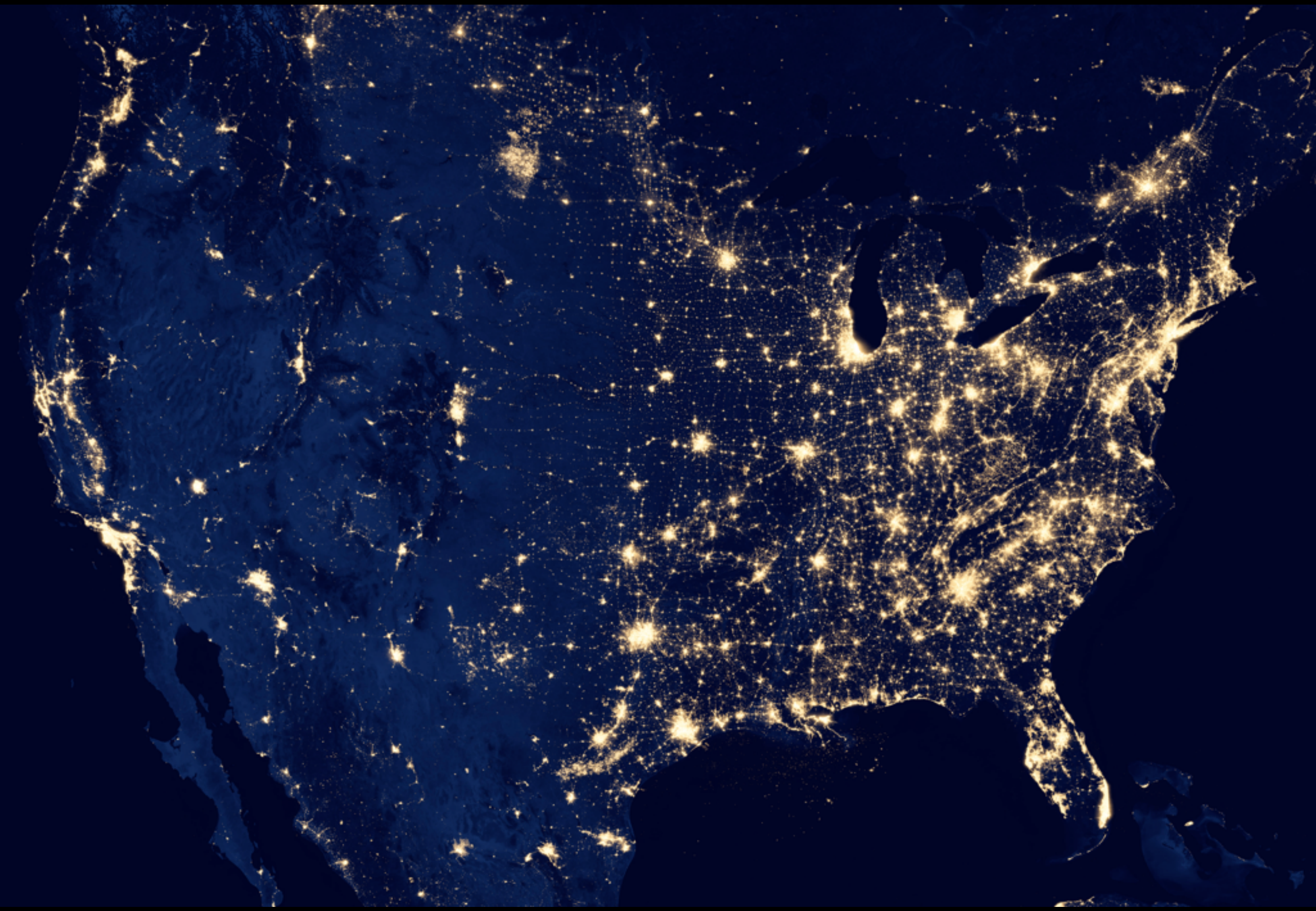
Outline


1. Why study galaxies?
2. Why movies help
3. Initial progress
4. What we learn
. Future

Why Study Galaxies?

Cosmology Review

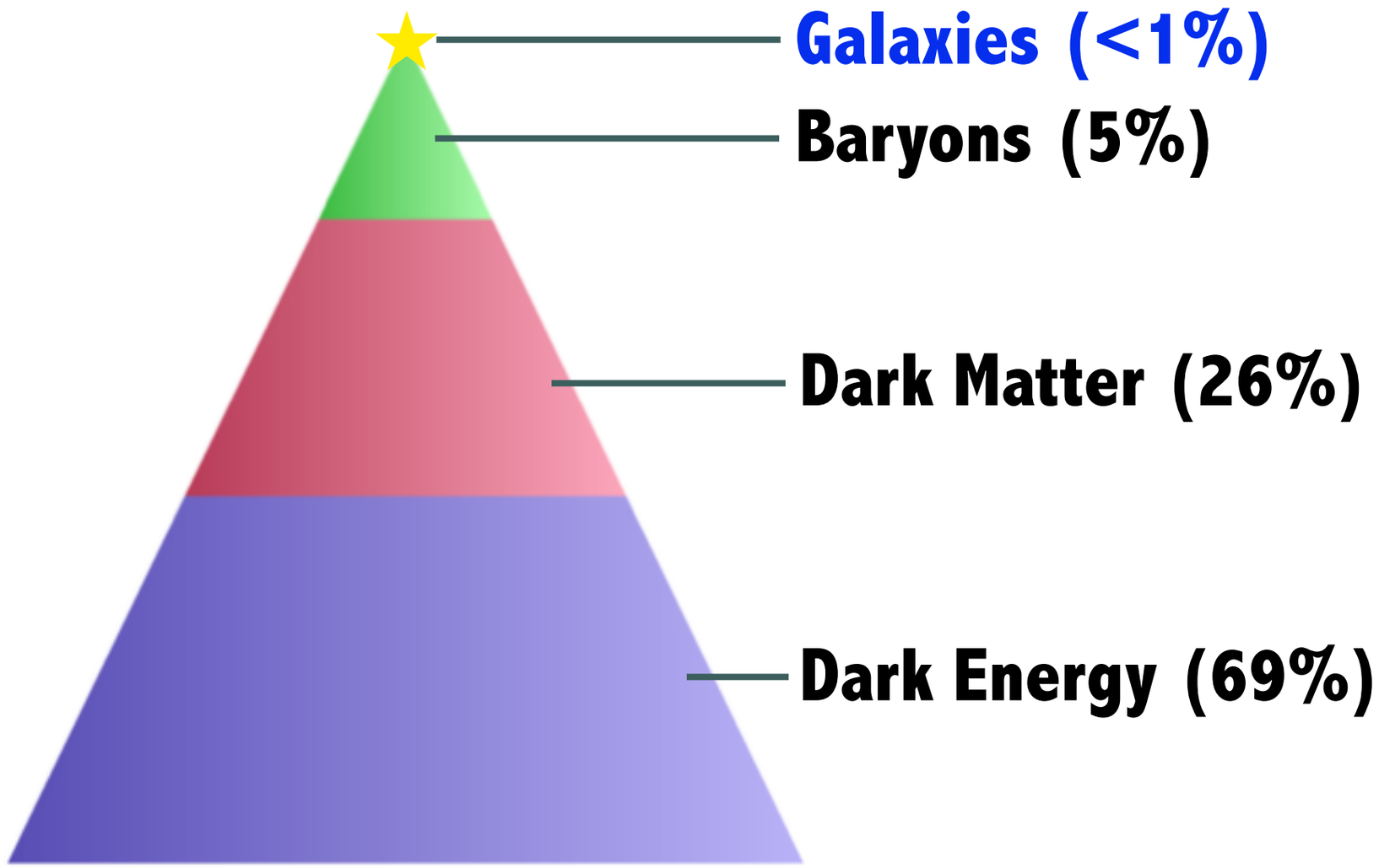




Credit: NASA Earth Observatory/NOAA NGDC

Why Study Galaxies?

Cosmology Review



Why Study Galaxies?

Goal:

What physics affects galaxy formation?

Info Source: Observations

We can observe galaxies at many different redshifts

Credit: Hubble UDF; NASA, ESA, S. Beckwith (STScI) and the HUDF Team

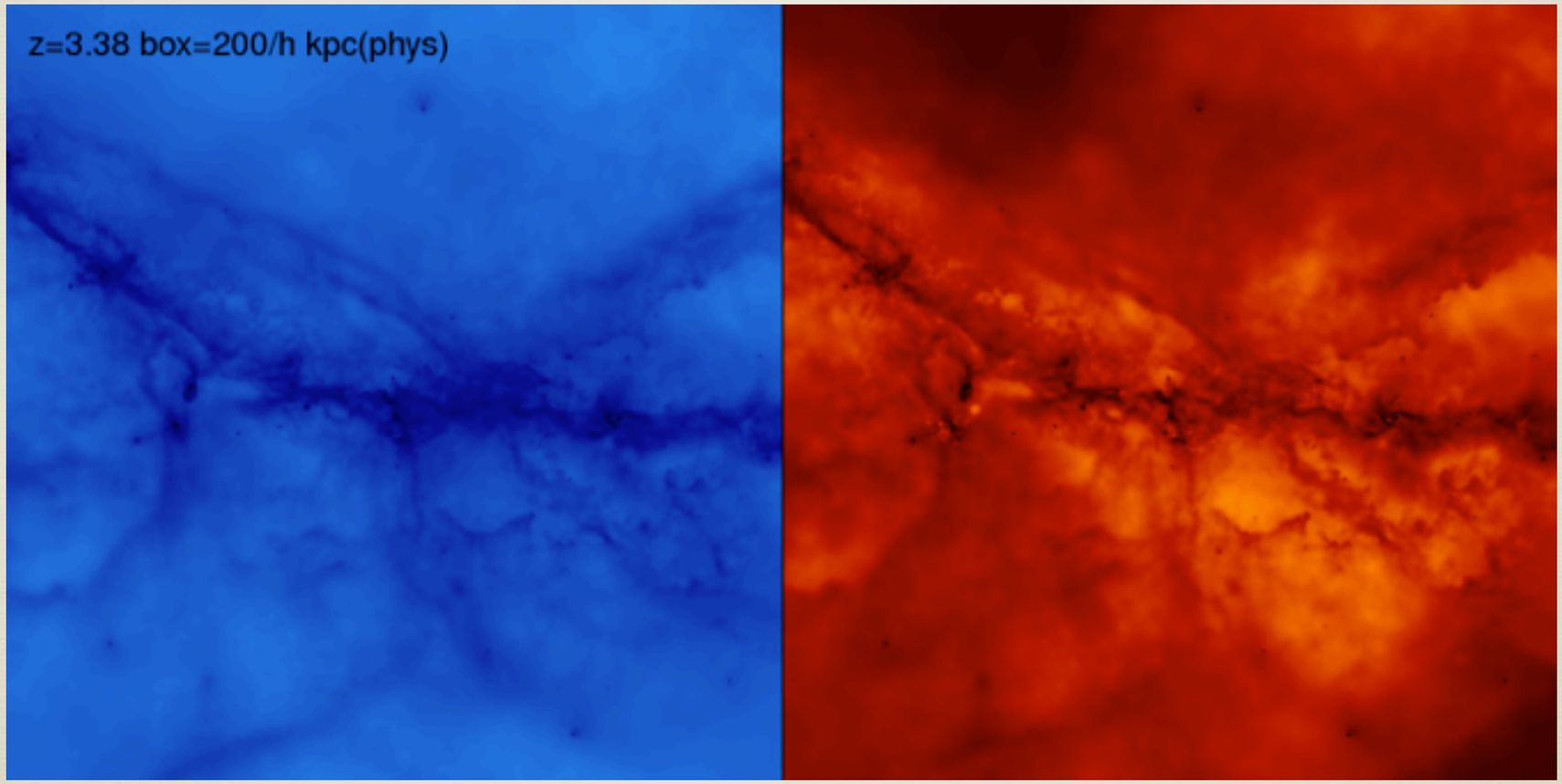
Credit: M101; Adam Block

But these are only snapshots!

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

Info Source: Simulations*

We can get fantastic movies

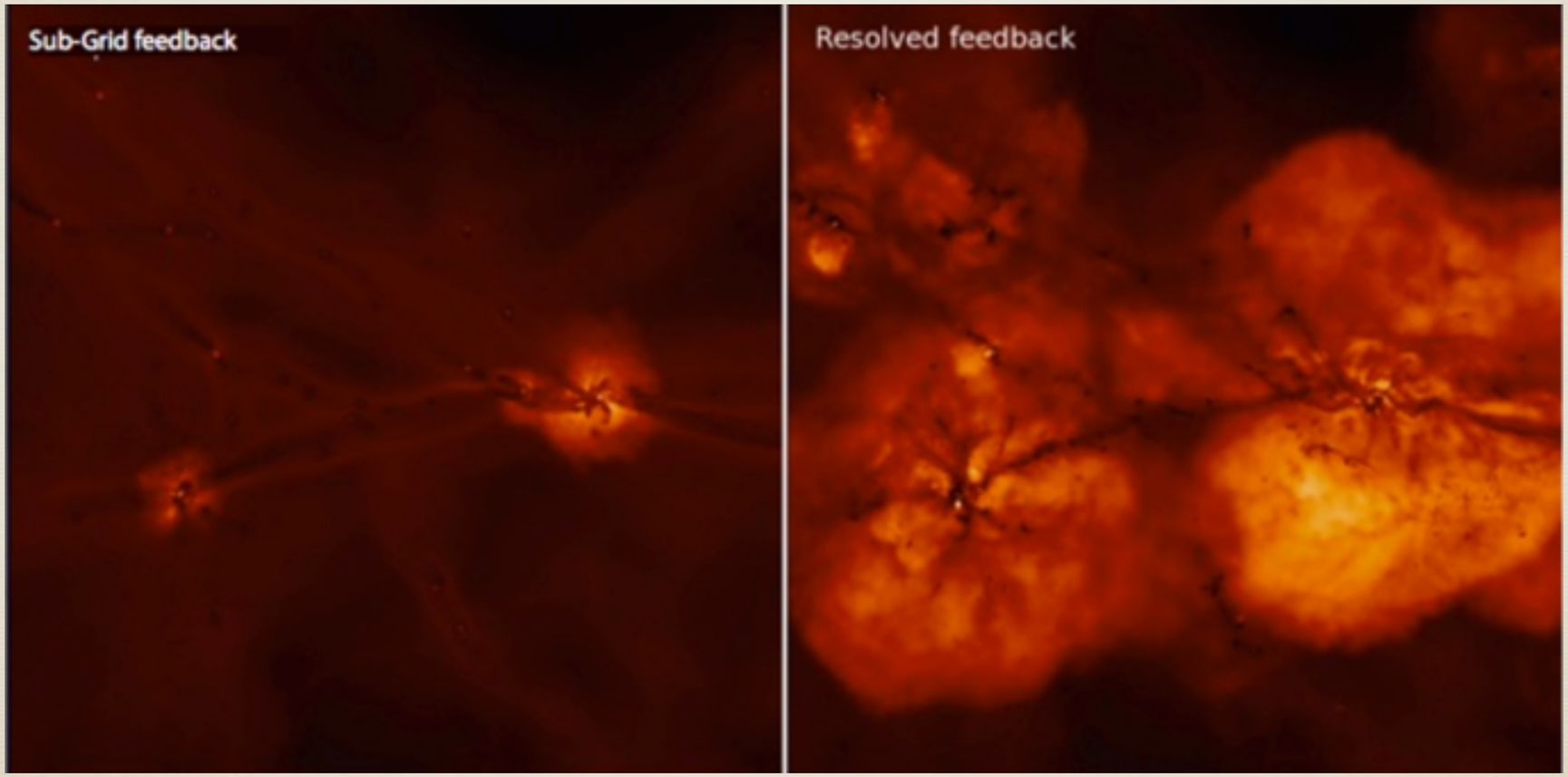


Credit: FIRE Project, Phil Hopkins

*Including semi-analytic models.

Info Source: Simulations

We can get fantastic movies



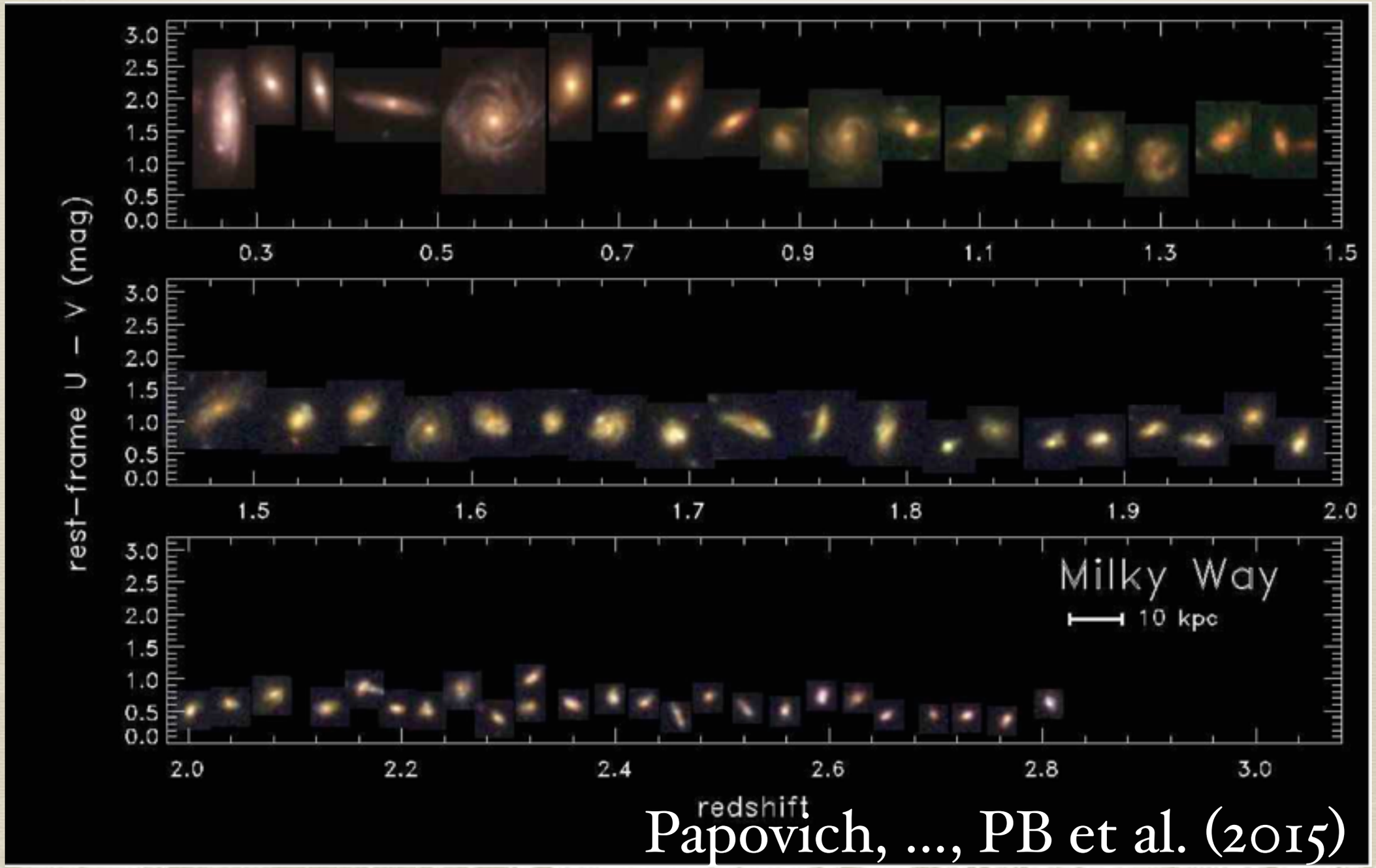
Credit: FIRE Project, Phil Hopkins

We just don't know if they are right!

(Small scales influence large scales)

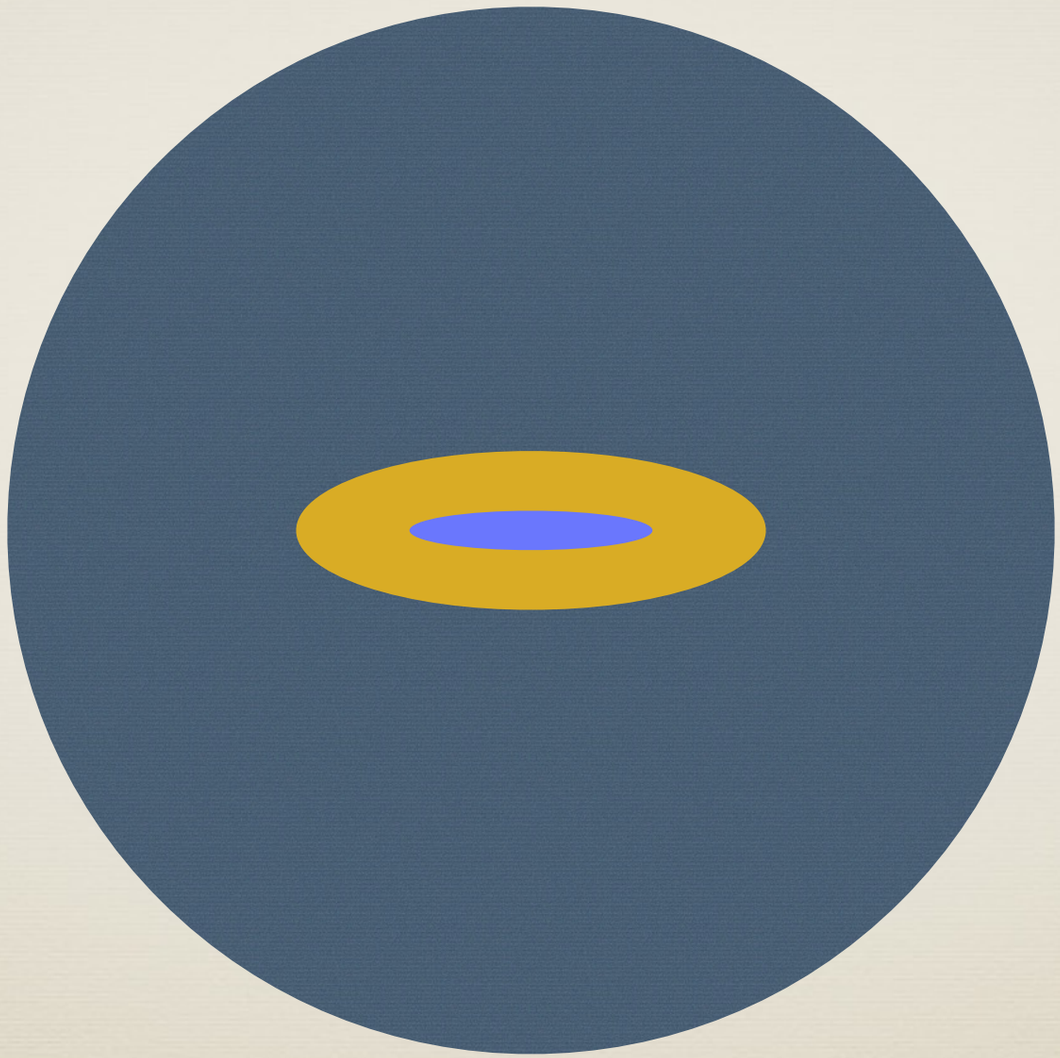
Info Source: Ideal

We'd like movies for real galaxies!



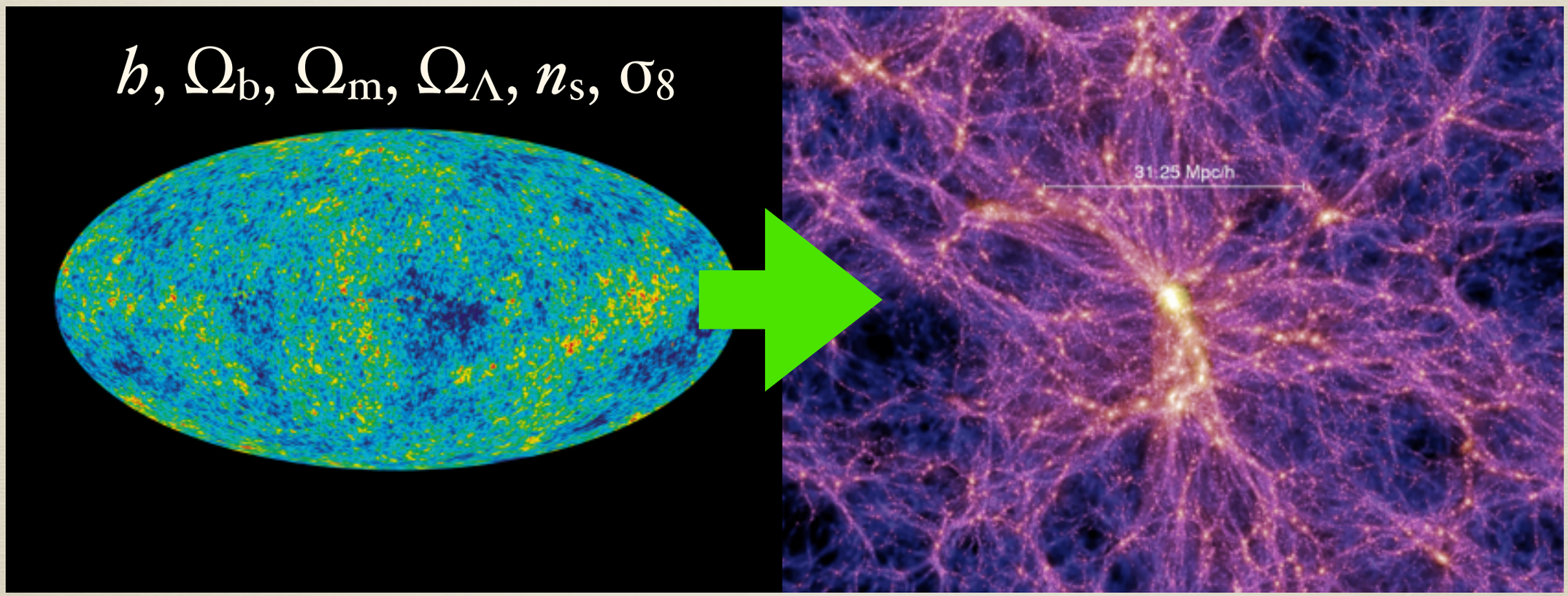
Papovich, ..., PB et al. (2015)

Getting There



Binney, Efstathiou, Ostriker, Rees, Silk, White, ... (1977-1983)

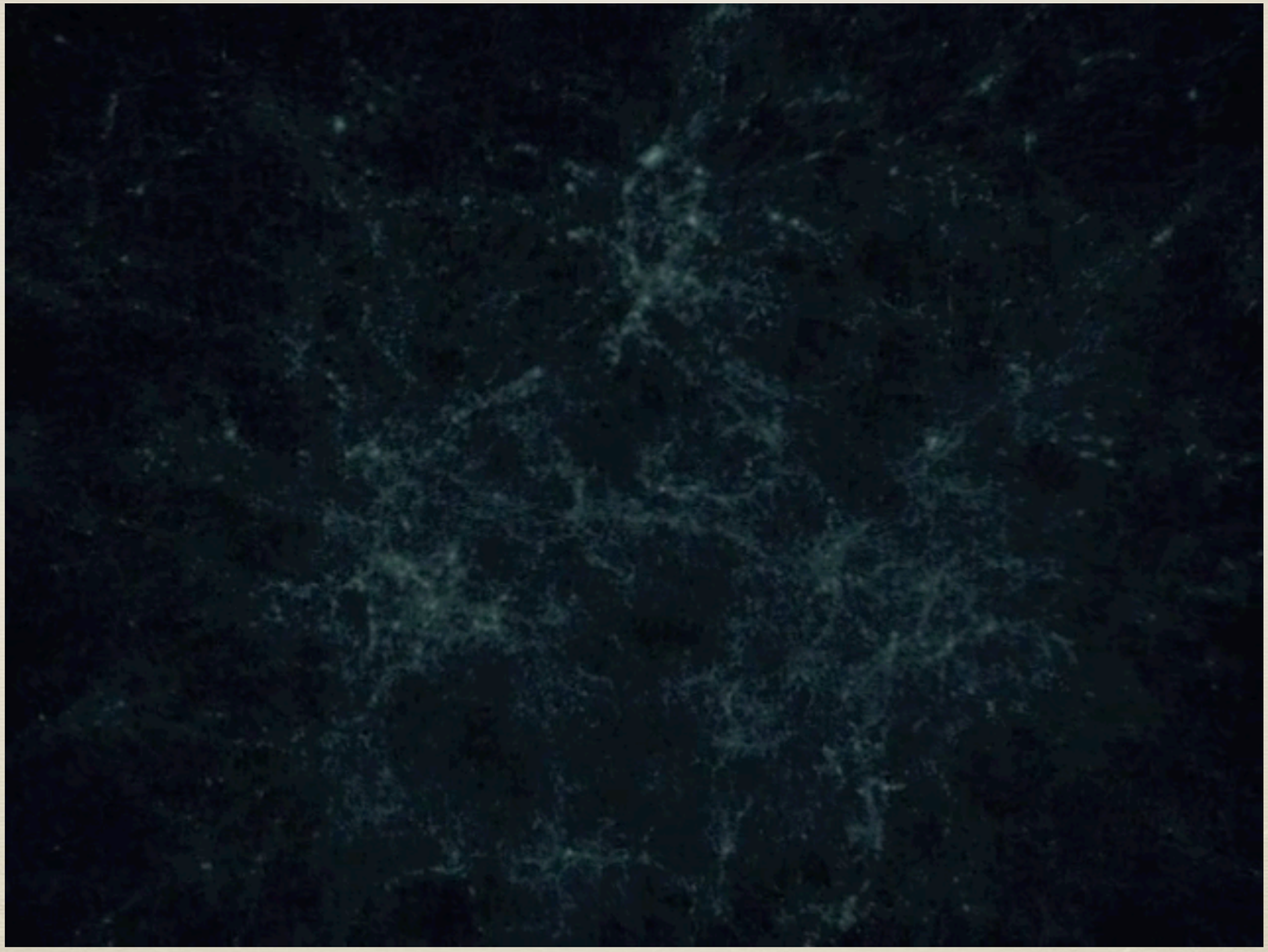
DM Simulations Review



Credit: WMAP Team

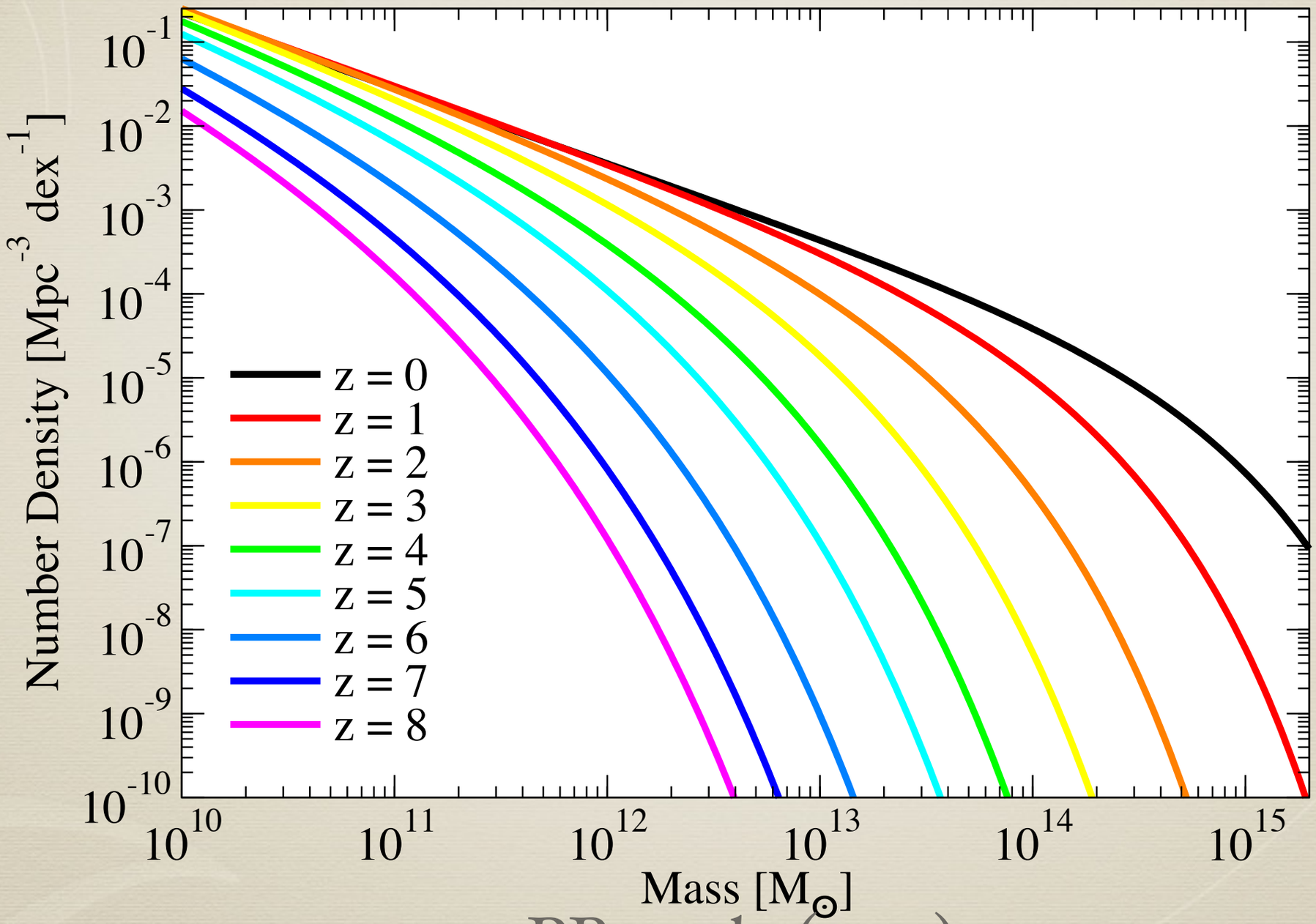
Credit: V. Springel, Millennium Simulation Project

DM Simulations Review



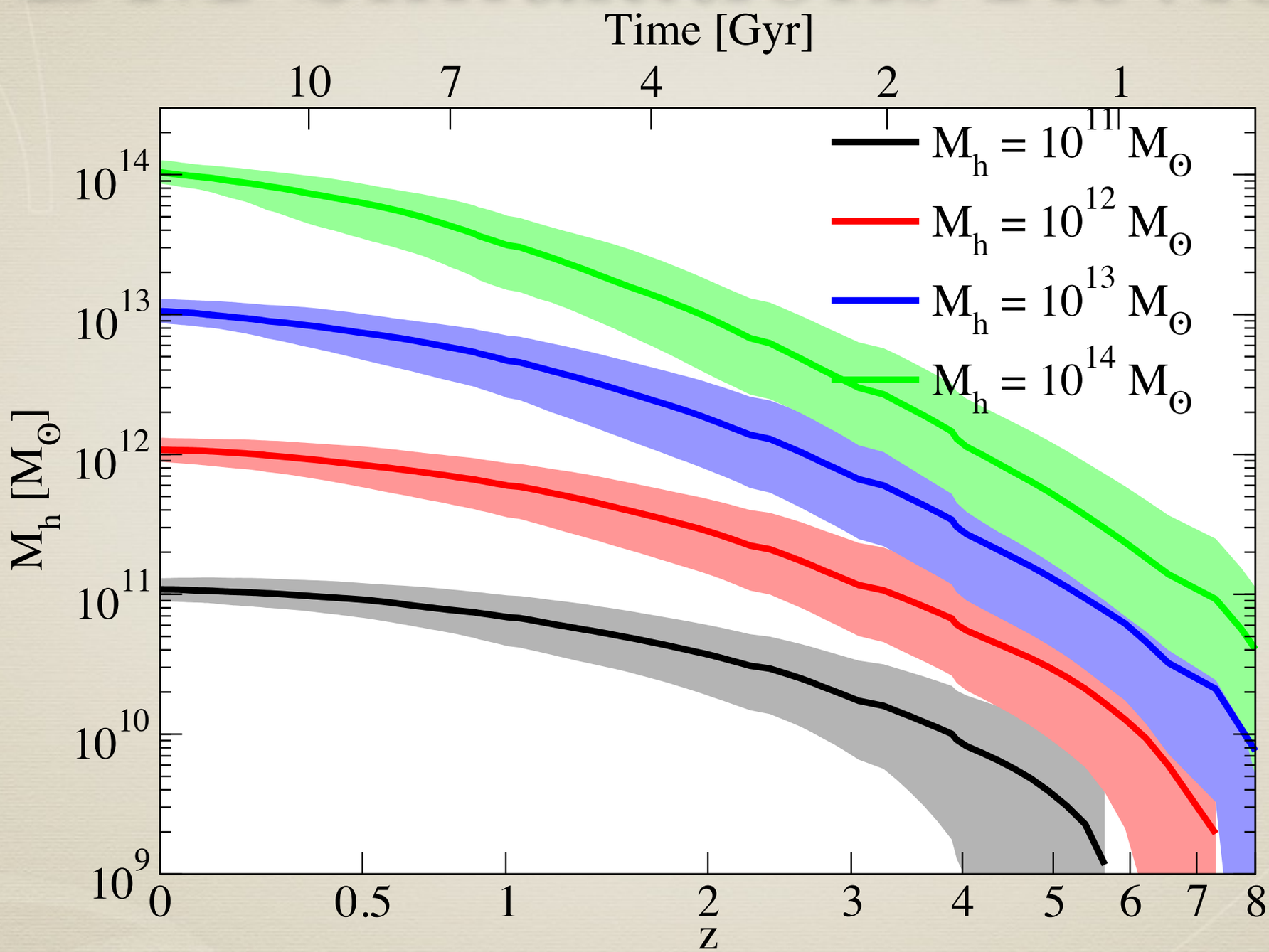
Credit: Wu, Wechsler, Hahn, Kaehler

DM Simulations Review



PB et al., (2013)

DM Simulations Review



PB et al. (2013)

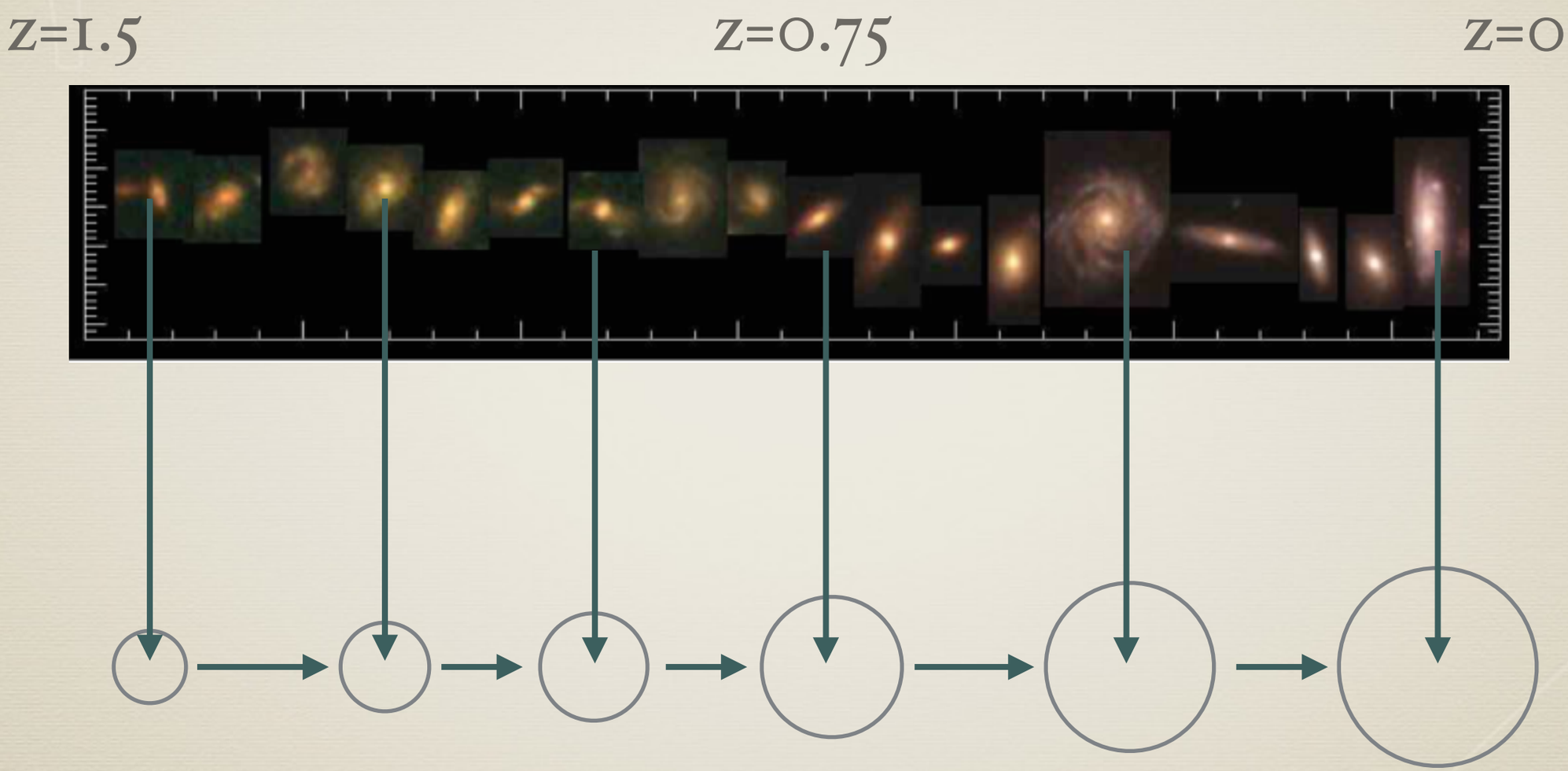
Concept

Credit: Wu, Wechsler, Hahn, Kaehler

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

Connecting Observed Galaxies to DM Halos
= Movies of Galaxies

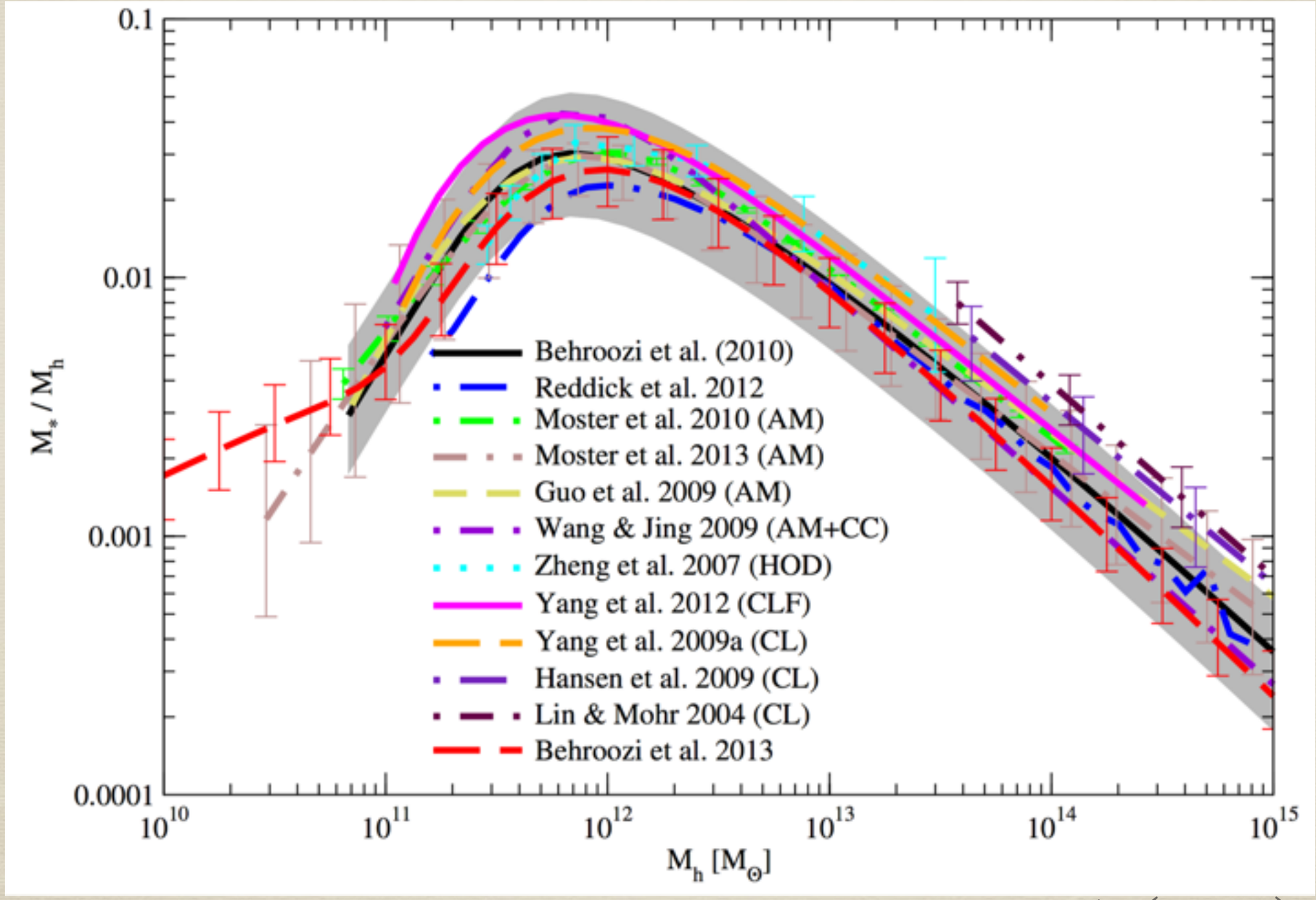
Concept



Connecting Observed Galaxies to DM Halos
= Movies of Galaxies

Getting There

Stellar Mass is tightly correlated with Halo Mass



PB et al. (2013)

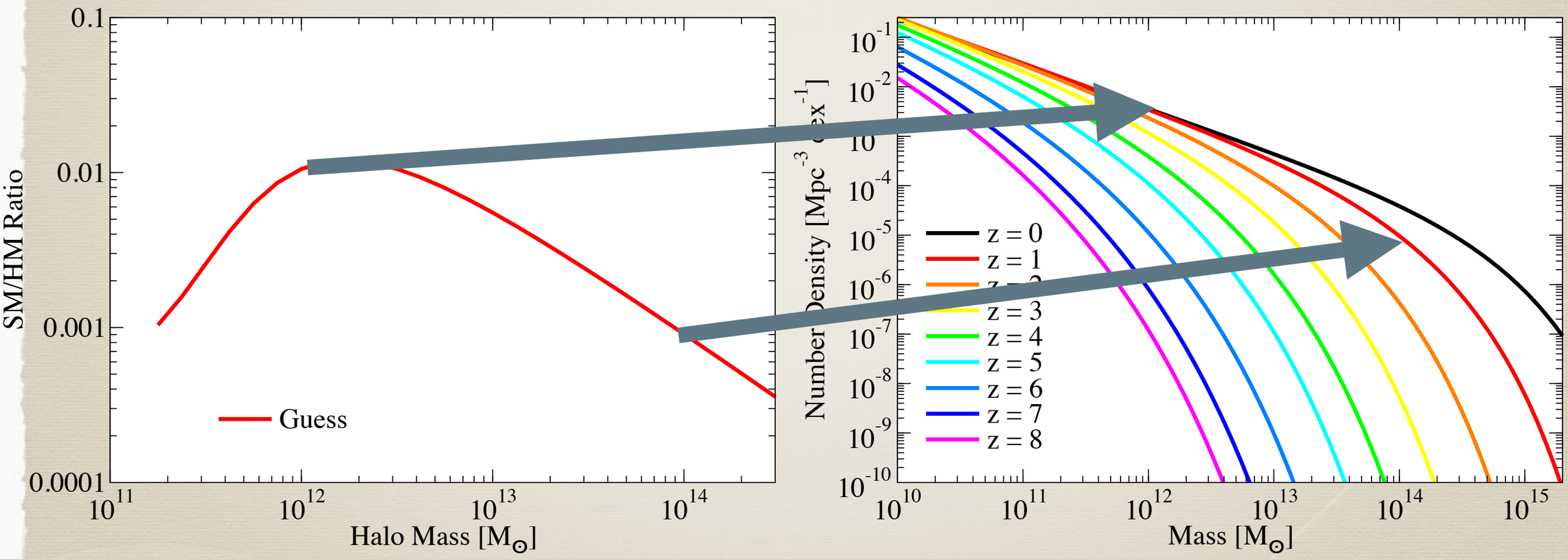
Getting There

How do we measure the SM/HM relation at higher redshifts?

No-one knows ahead of time.

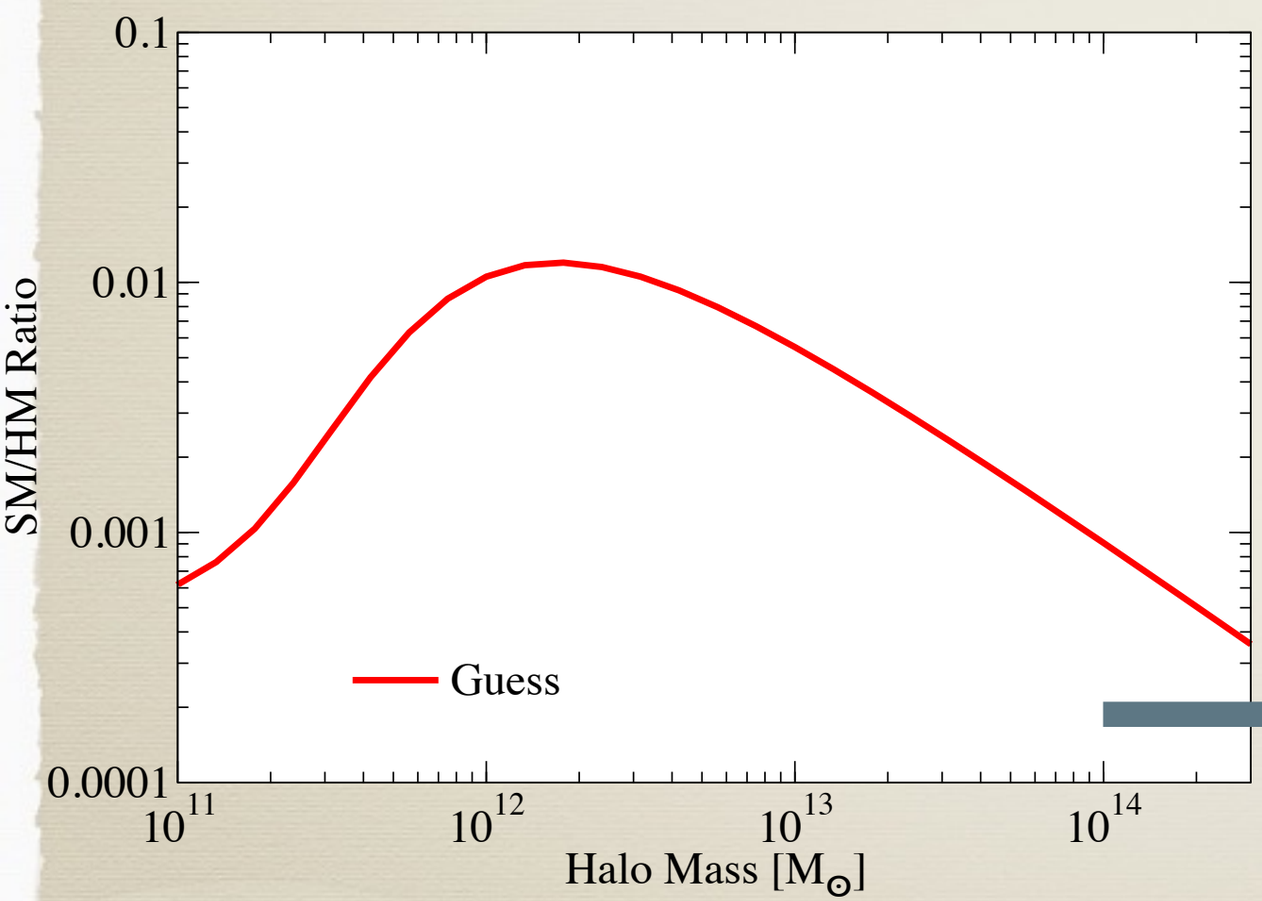
Getting There

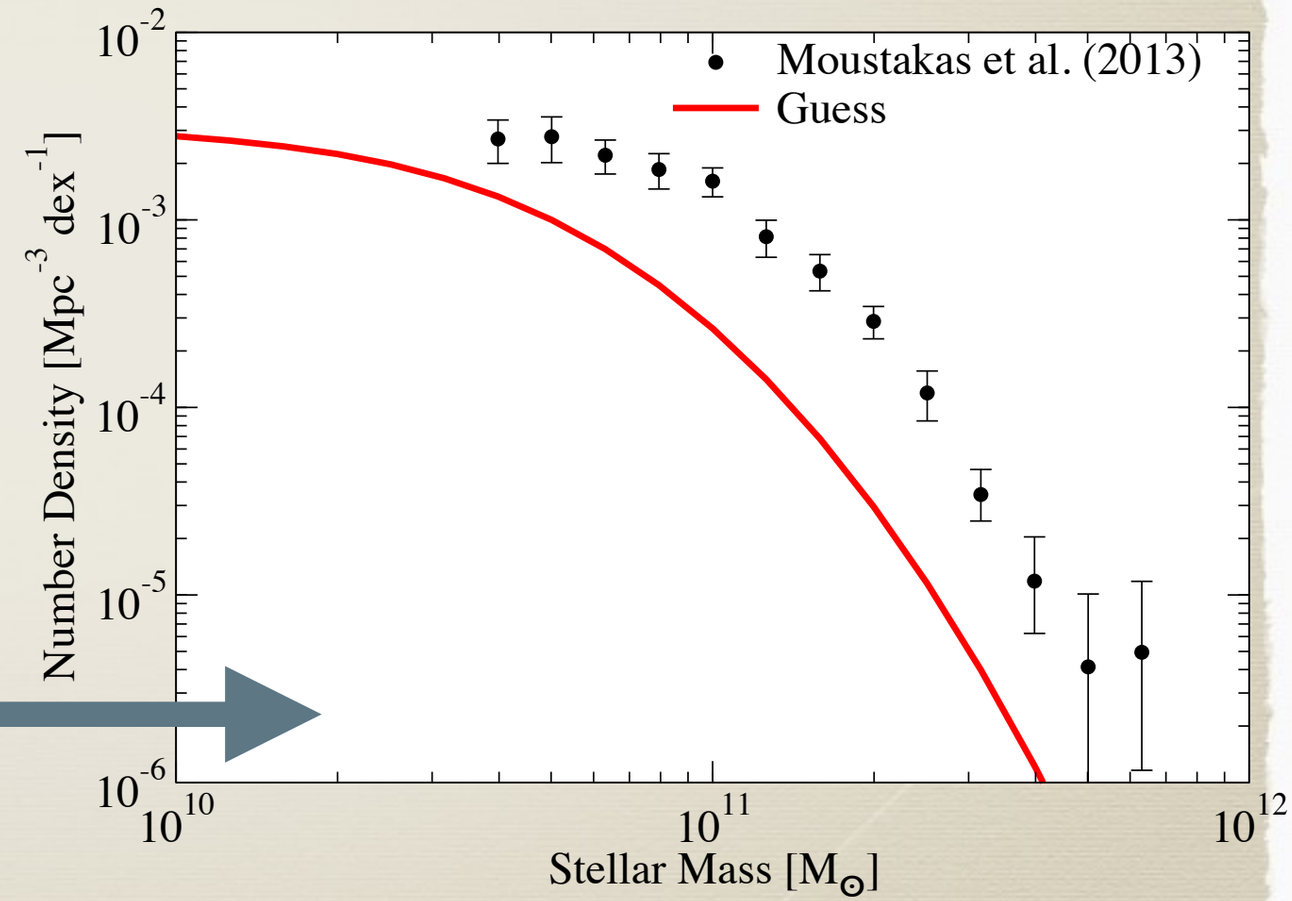
Start with a guess, and check it.



Getting There

Start with a guess, and check it.

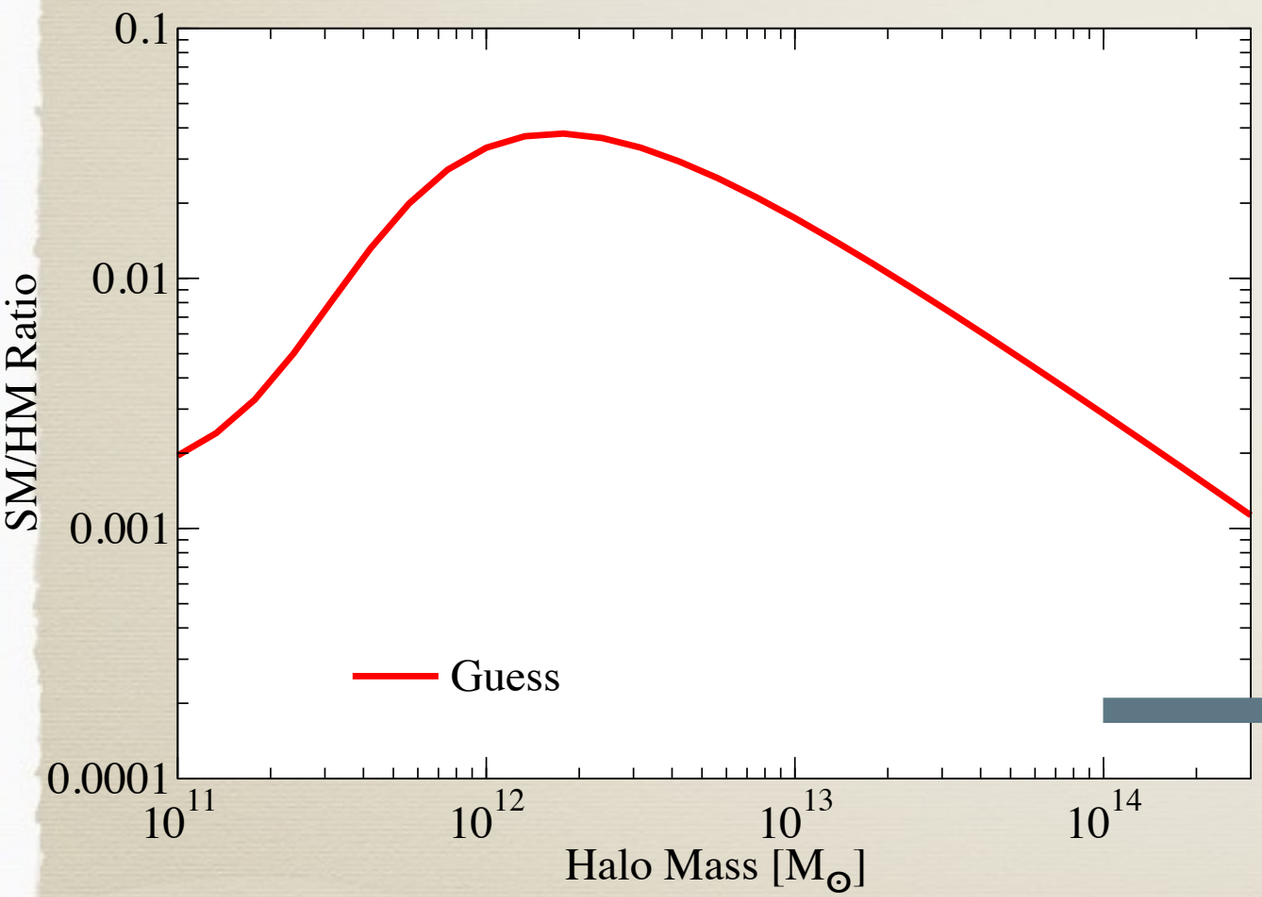


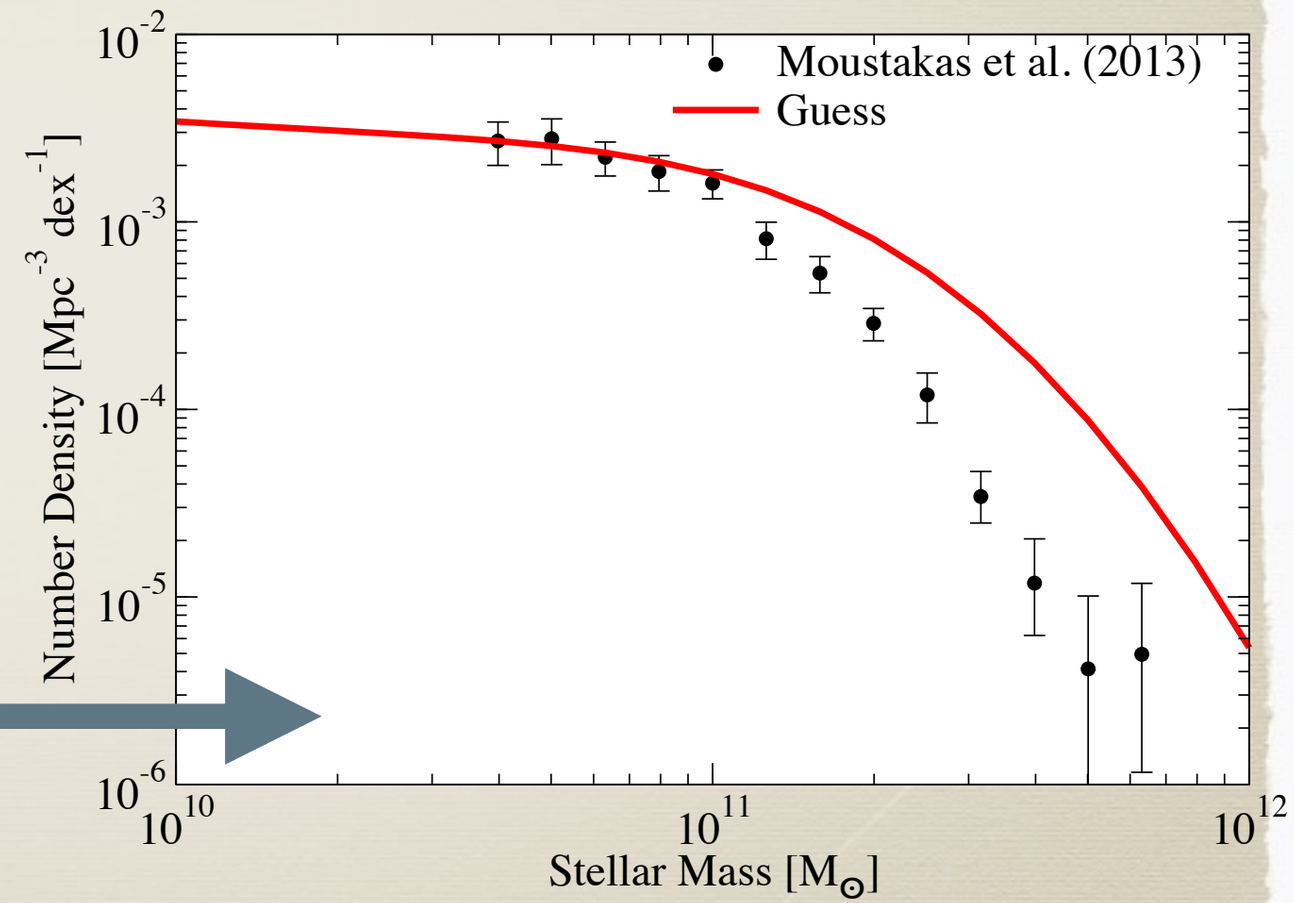


Z=1

Getting There

Start with a guess, and check it.

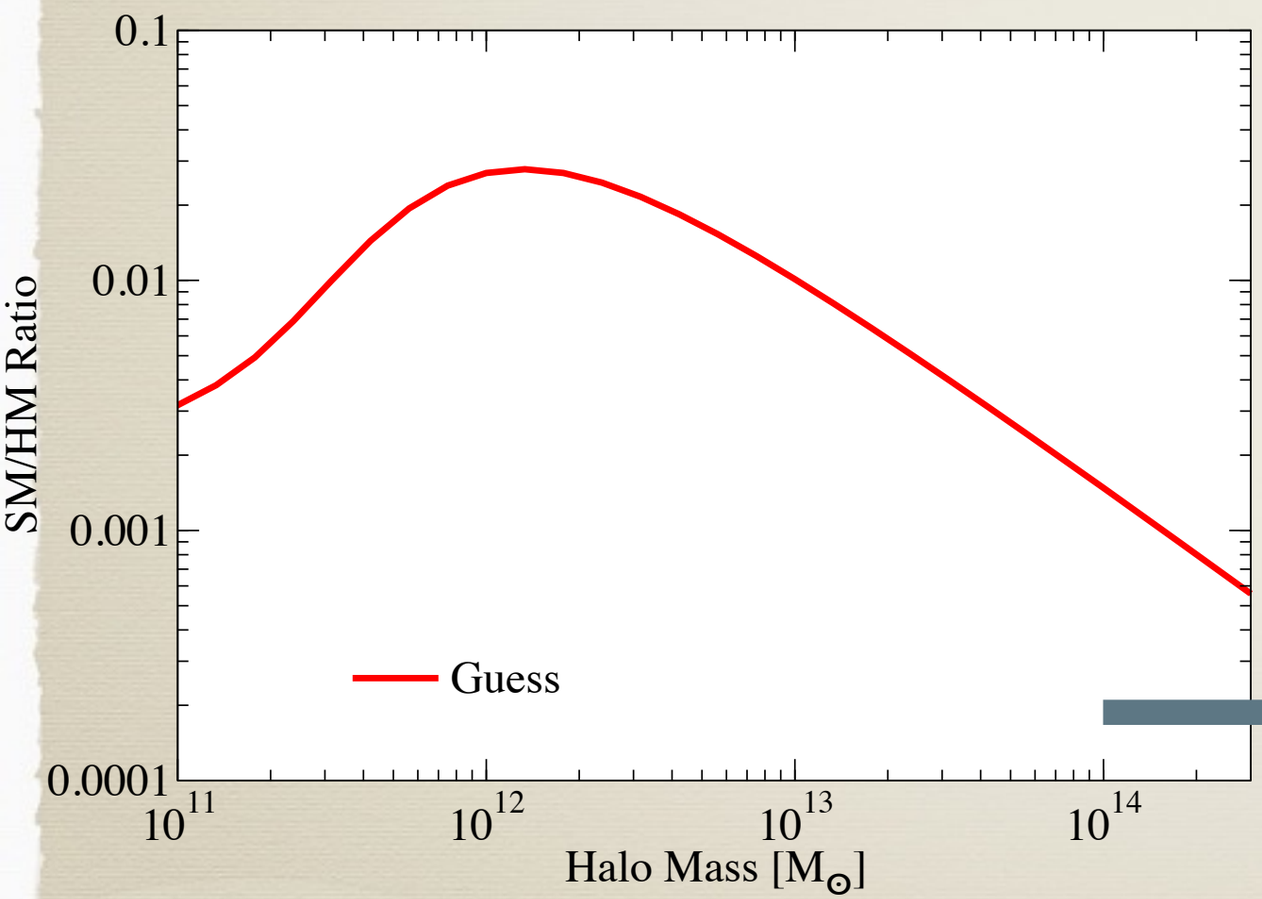


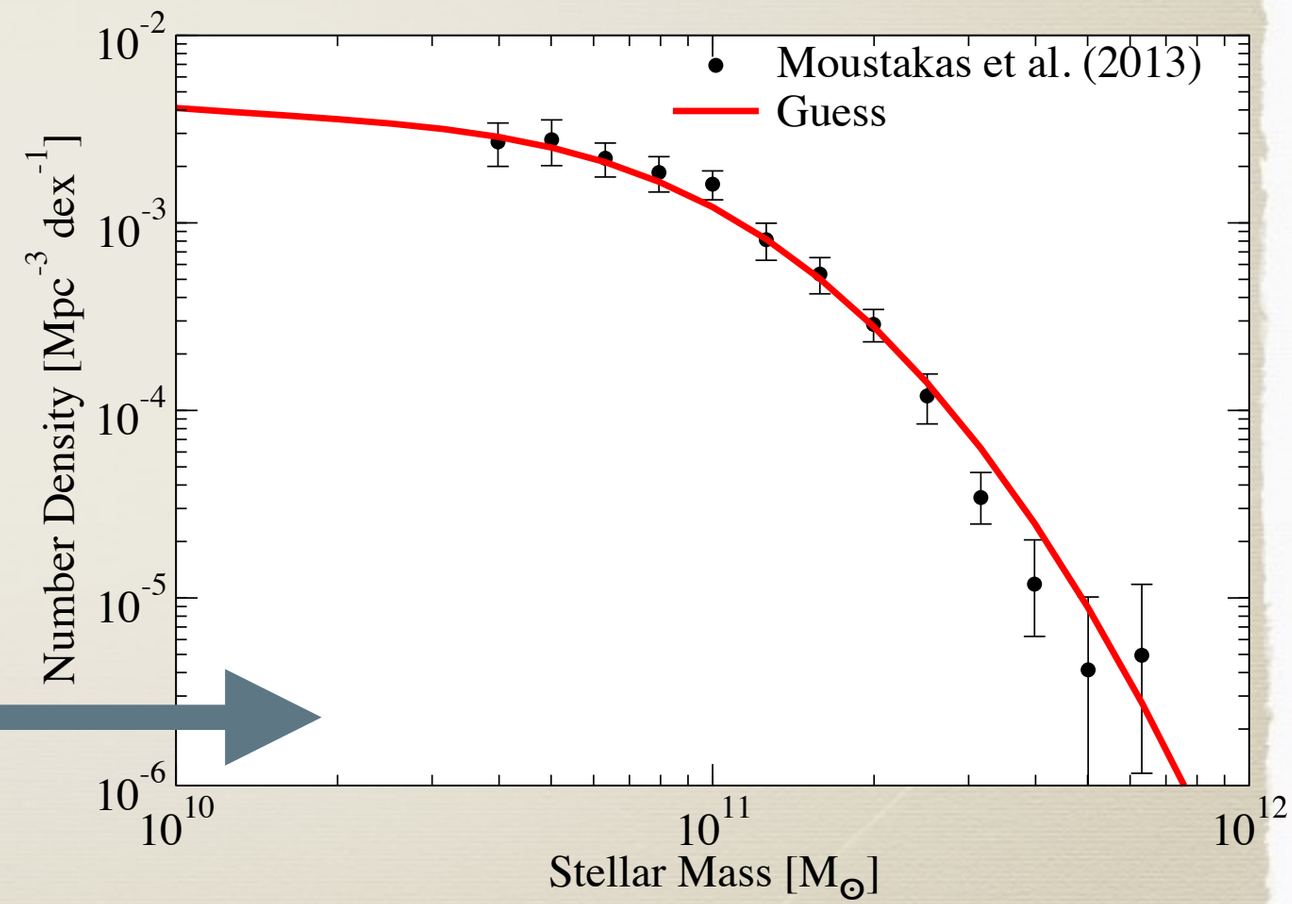


z=1

Getting There

Start with a guess, and check it.

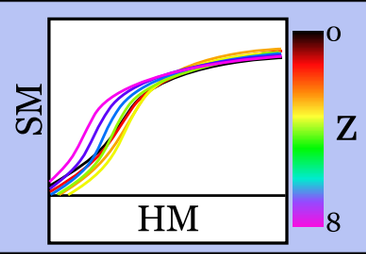




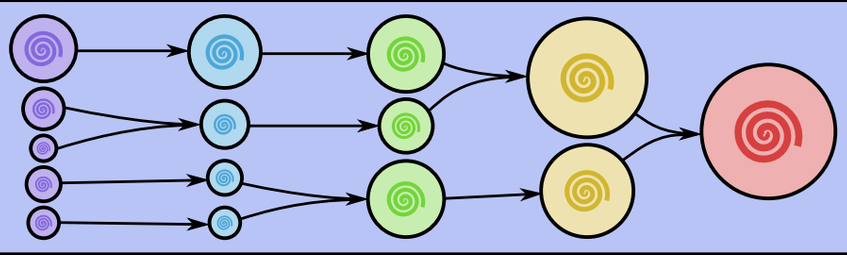
Z=1

Getting There

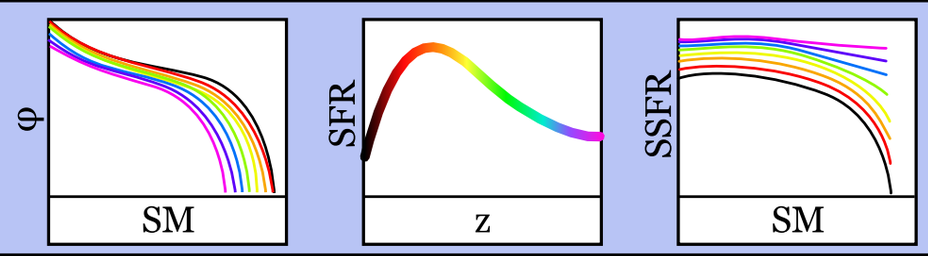
1. Choose a stellar mass - halo mass (SMHM) relation from parameter space.



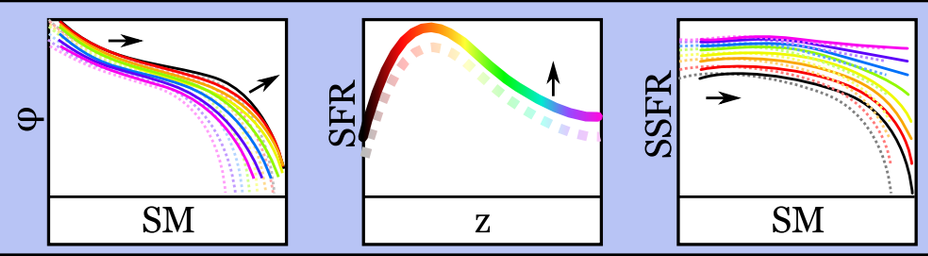
2. Find galaxy growth histories by applying the SMHM relation to dark matter merger trees.



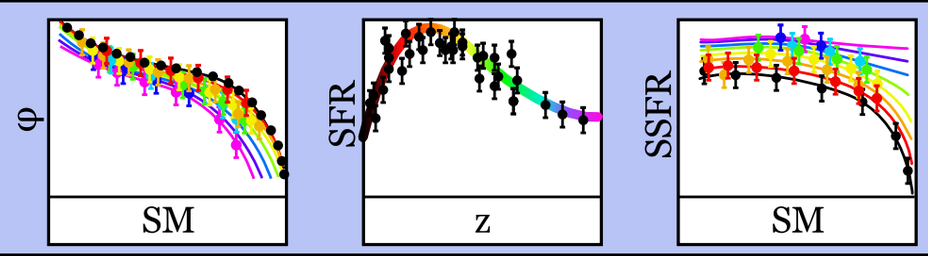
3. Derive the inferred stellar mass functions and star formation rates.



4. Apply effects to simulate observational errors and biases.



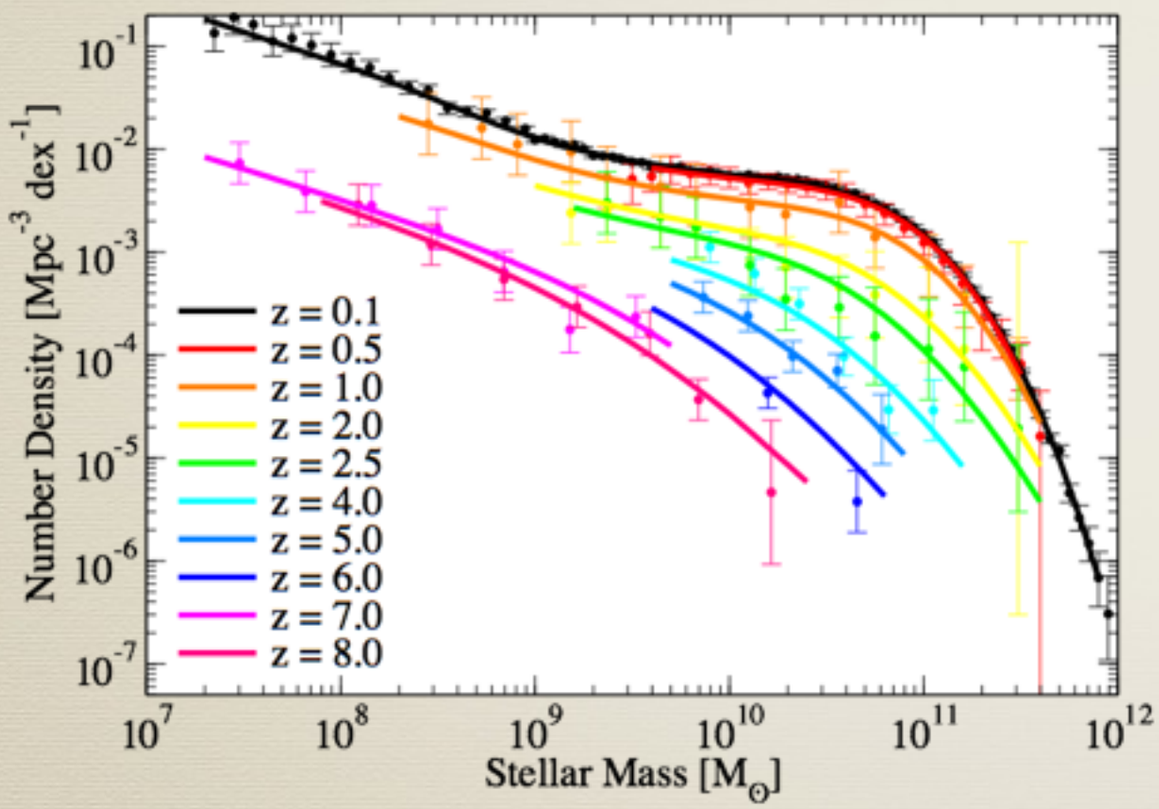
5. Compare to data and calculate likelihood of the chosen SMHM relation.



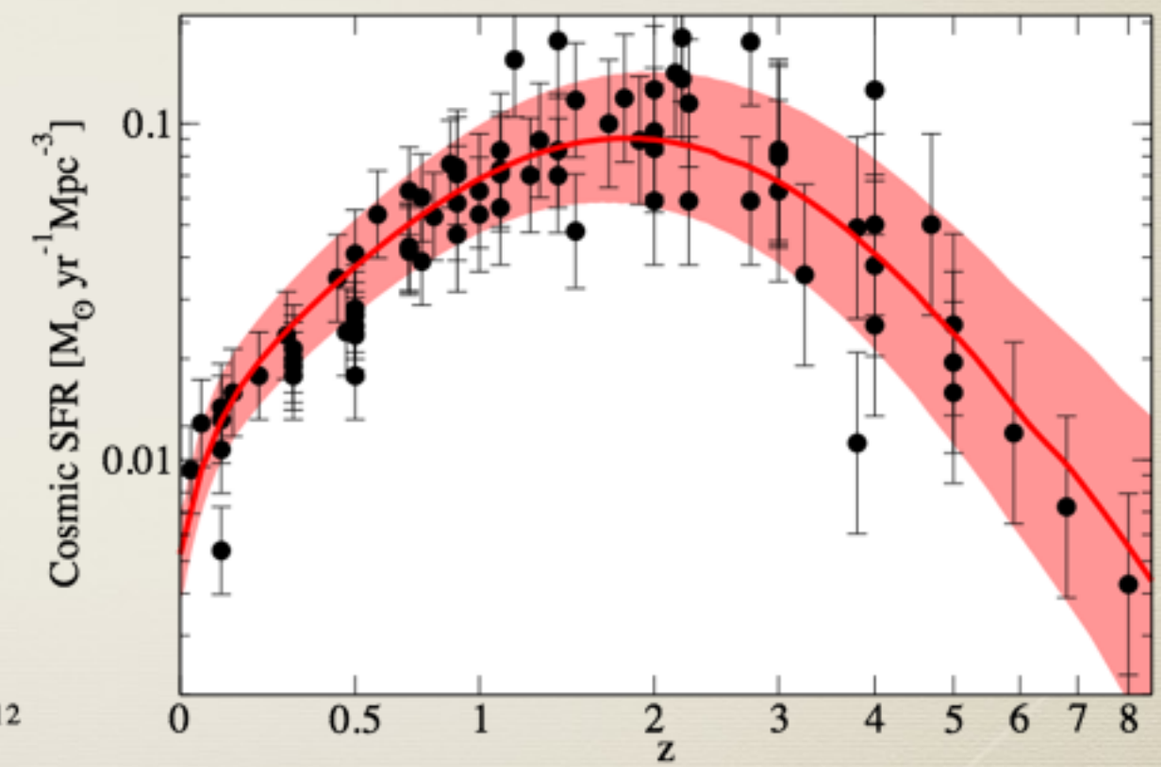
Repeat as often as necessary to explore allowable solutions.

Getting There

Data Sets:



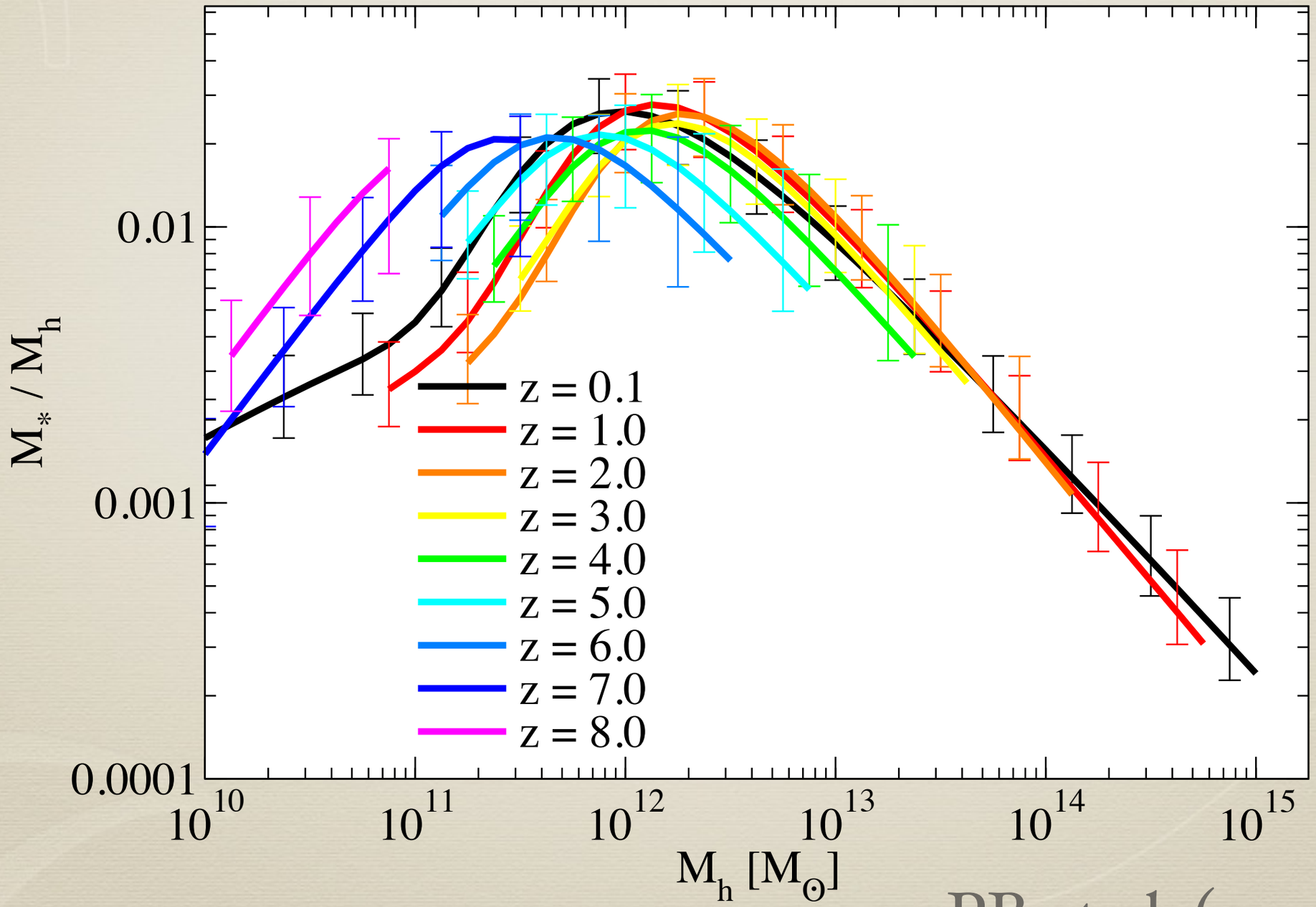
Stellar Mass Functions
from PRIMUS, others up to z=8



Compilation of cSFRs
to z=8
PB et al. (2013)

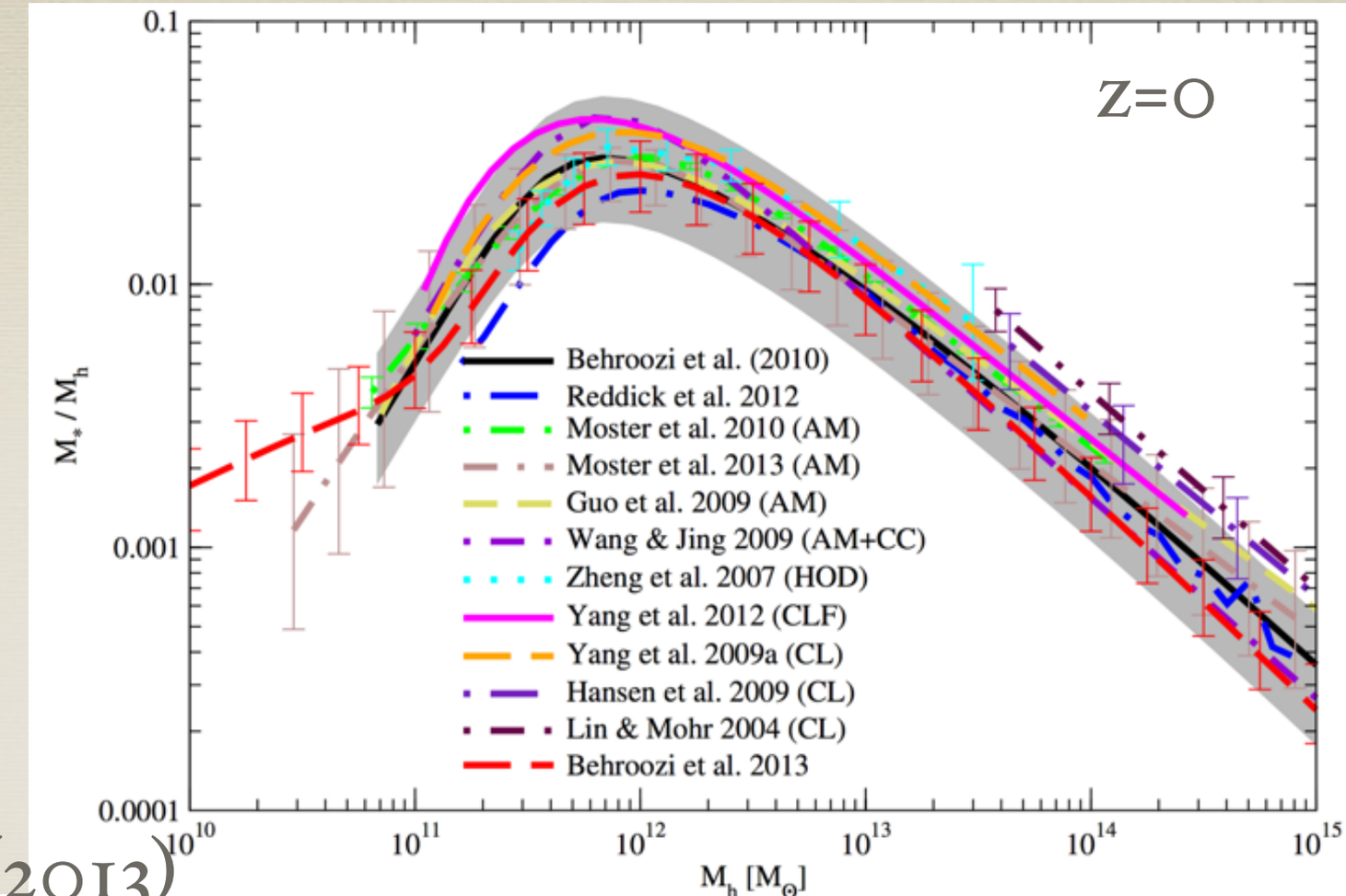
Results

Constraints on the fundamentals of galaxy formation:

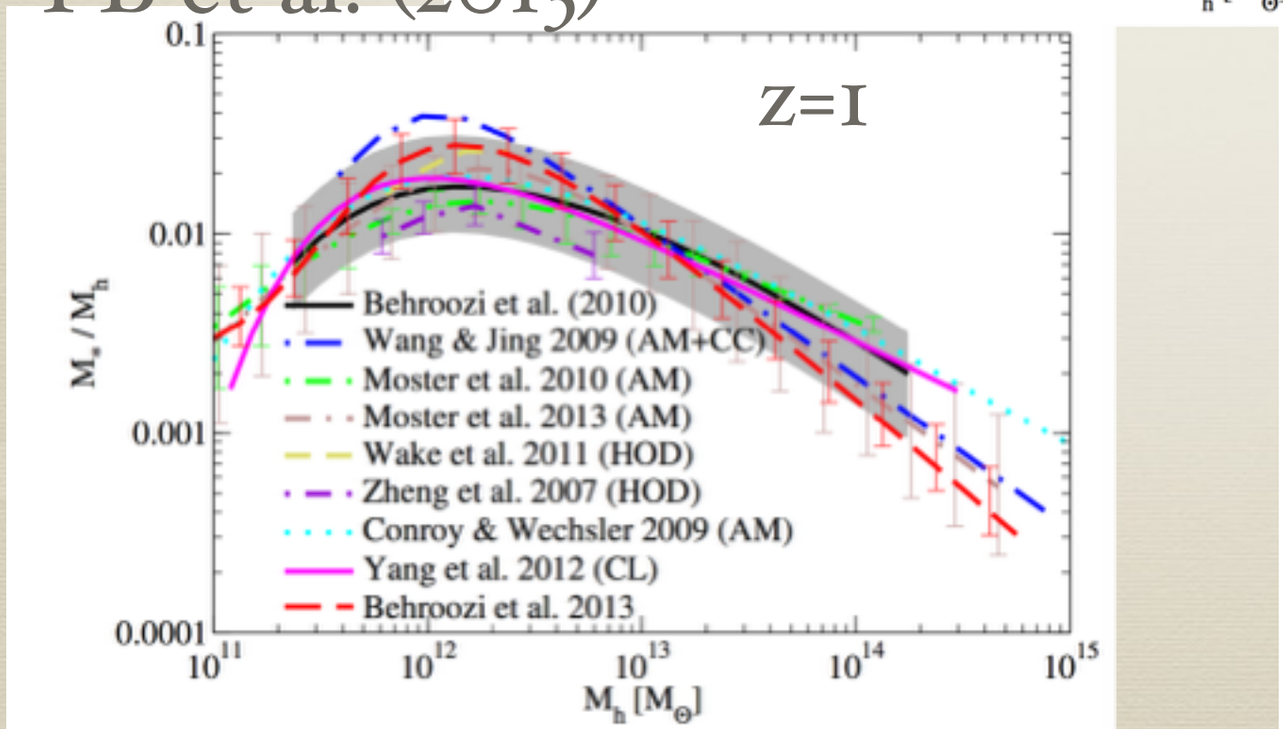


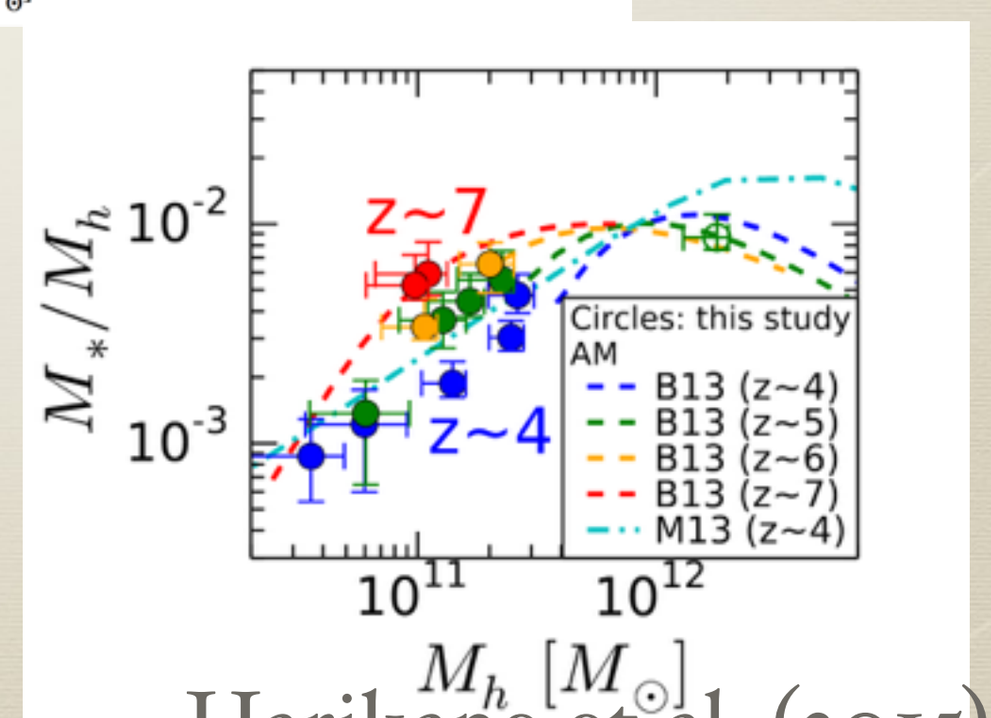
PB et al. (2013)

Confirmation from other studies



PB et al. (2013)

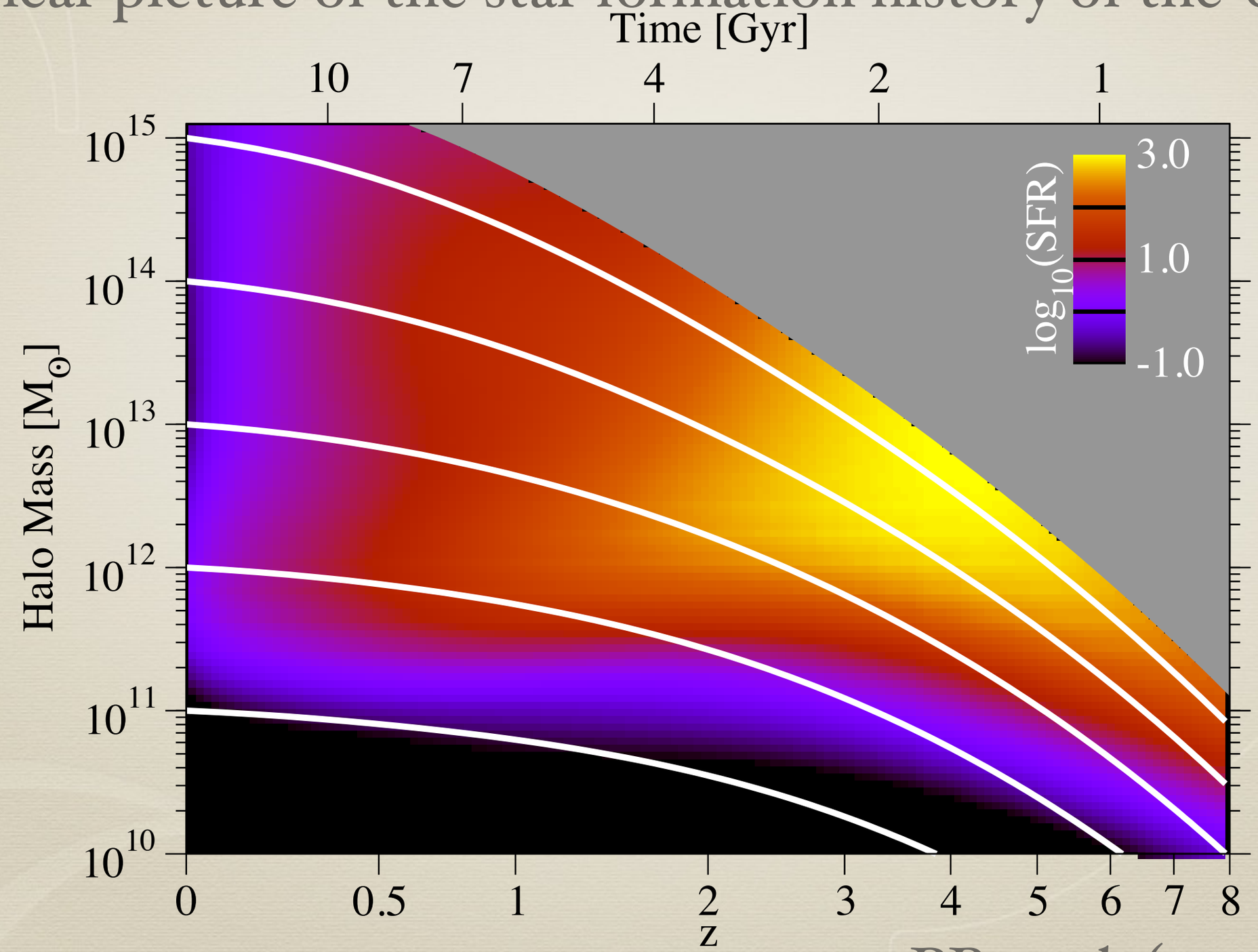




Harikane et al. (2015)

Results

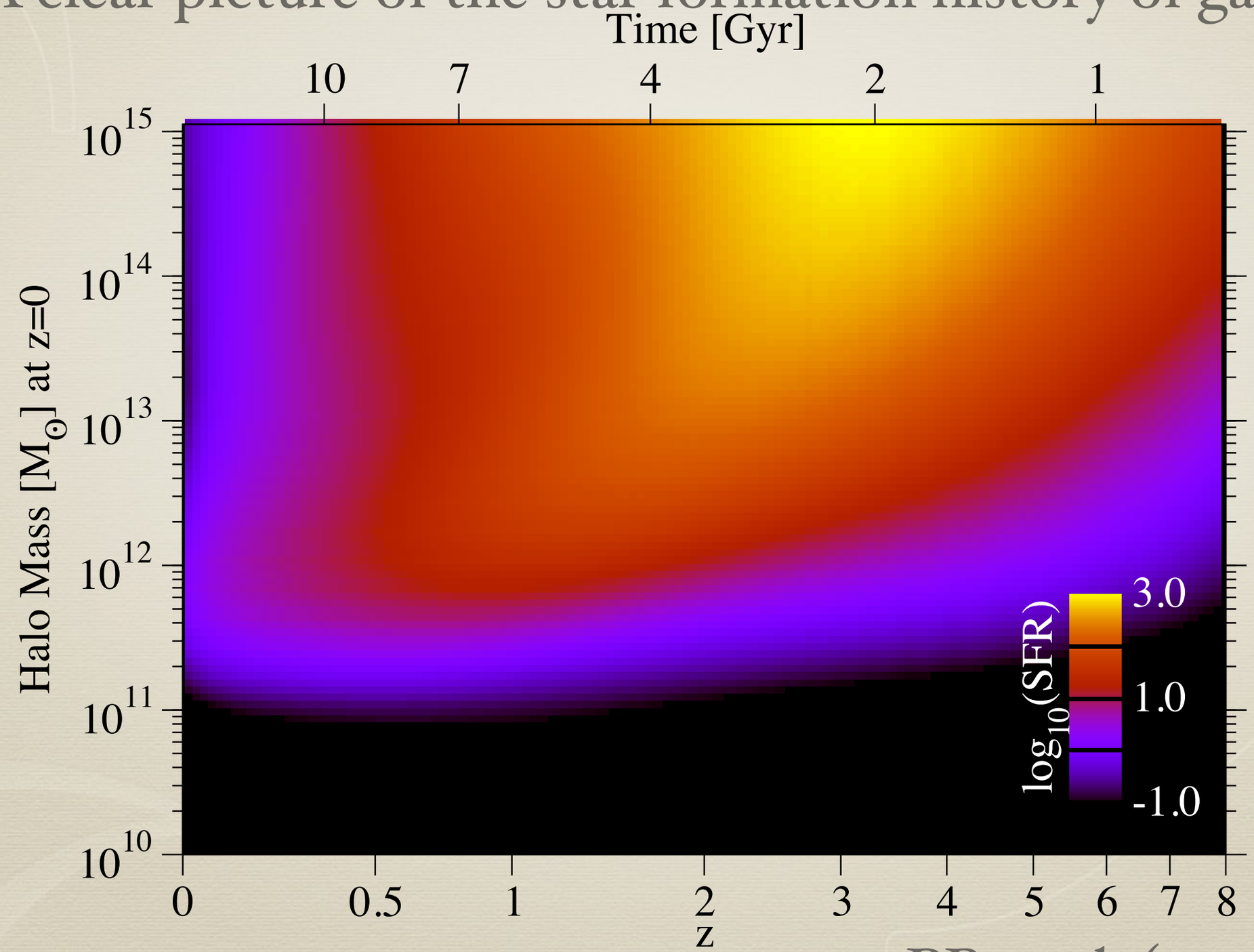
A clear picture of the star formation history of the Universe:



PB et al. (2013)

Results

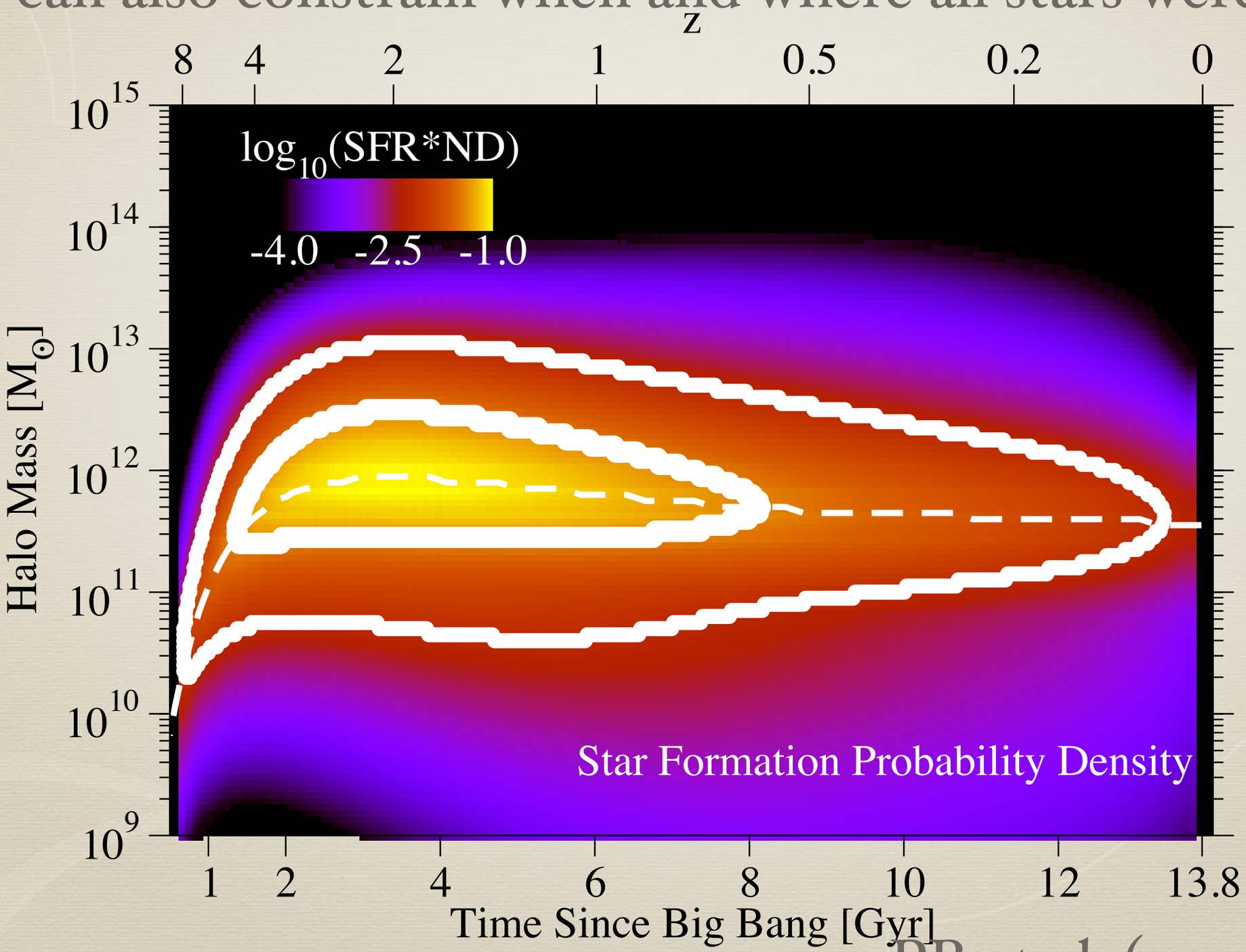
A clear picture of the star formation history of galaxies:



PB et al. (2013)

Results

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



PB et al. (2013b)

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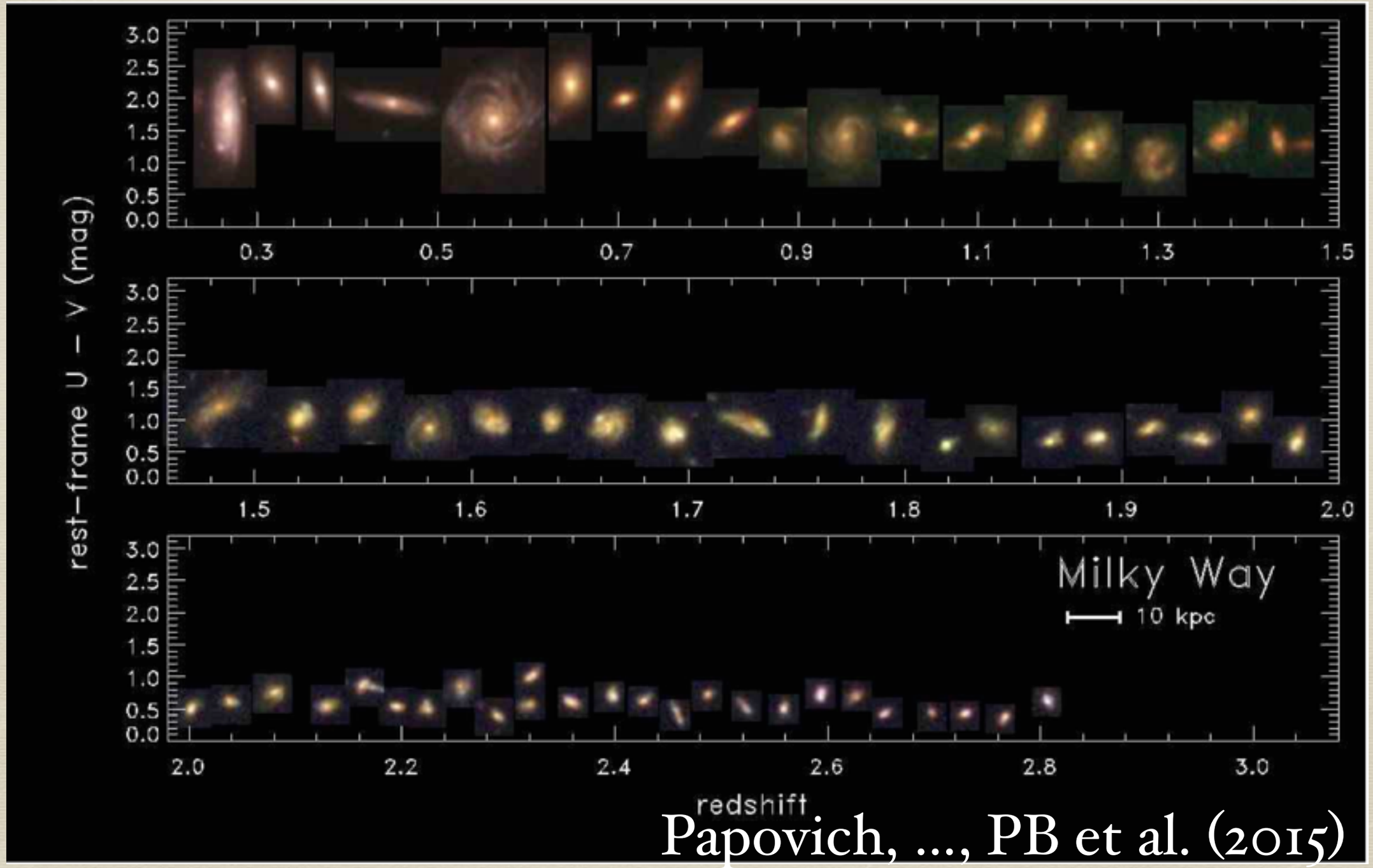
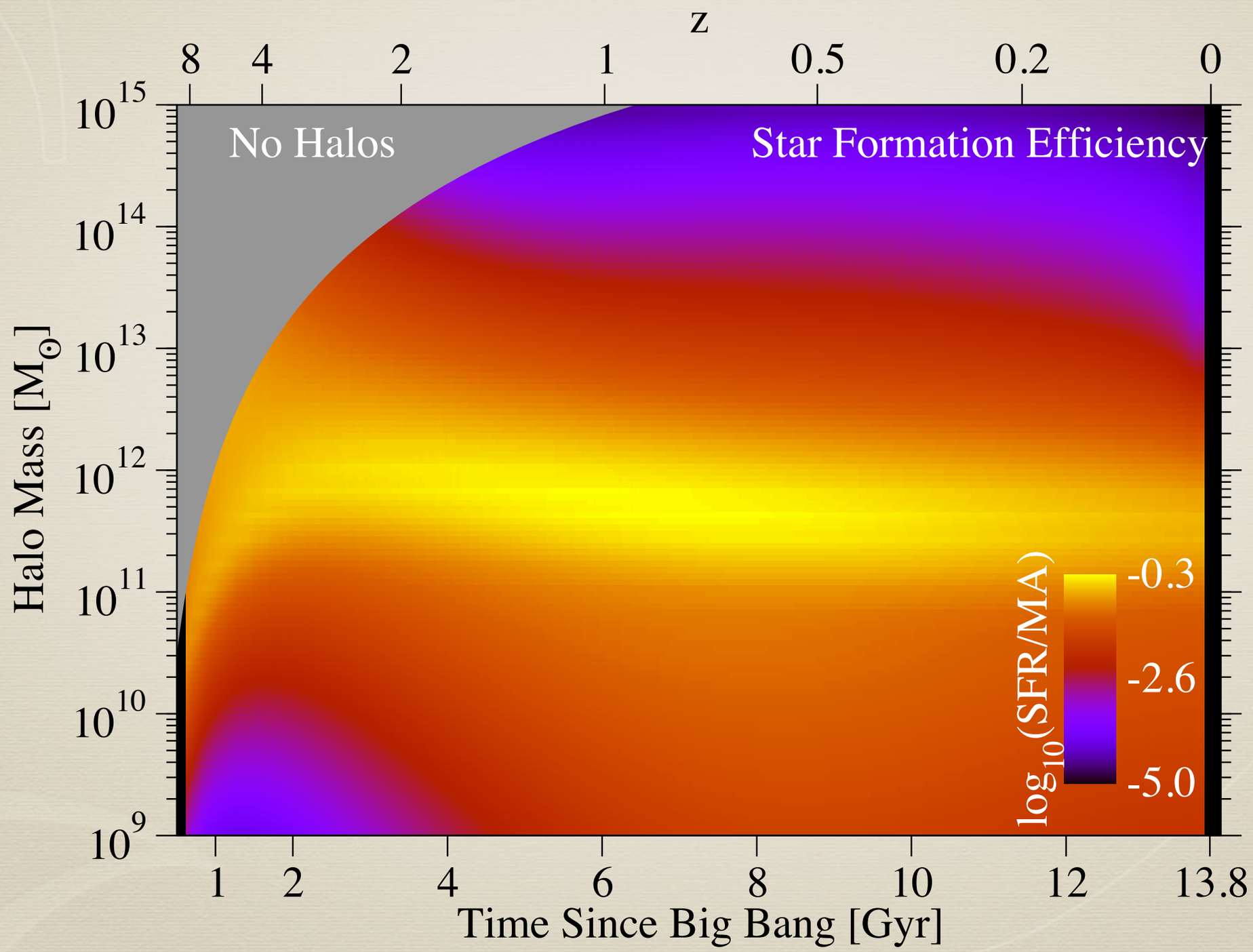


Papovich, ..., PB et al. (2015)

As Simple As Possible



PB et al. (2013b)

Ongoing/Future Projects

Galaxy Formation / Cosmology:

Determining when/where/why do galaxies quench (AH,RW,CC)
Using metallicity to learn about gas flows and feedback (MP, GP)
Using JWST to learn about dwarfs and reionization (SF)
Making mock catalogs to study BAO and WL systematics (PP)
Using LSST to learn about extreme galaxies (TBD)

Using Galaxy Formation for Intragalactic Physics:

Making movies of black holes (EQ, PH, JS, MV)
Supernova / GRB time delays and metallicity dependences (ER^2)
Planet formation history of the Milky Way (MP)

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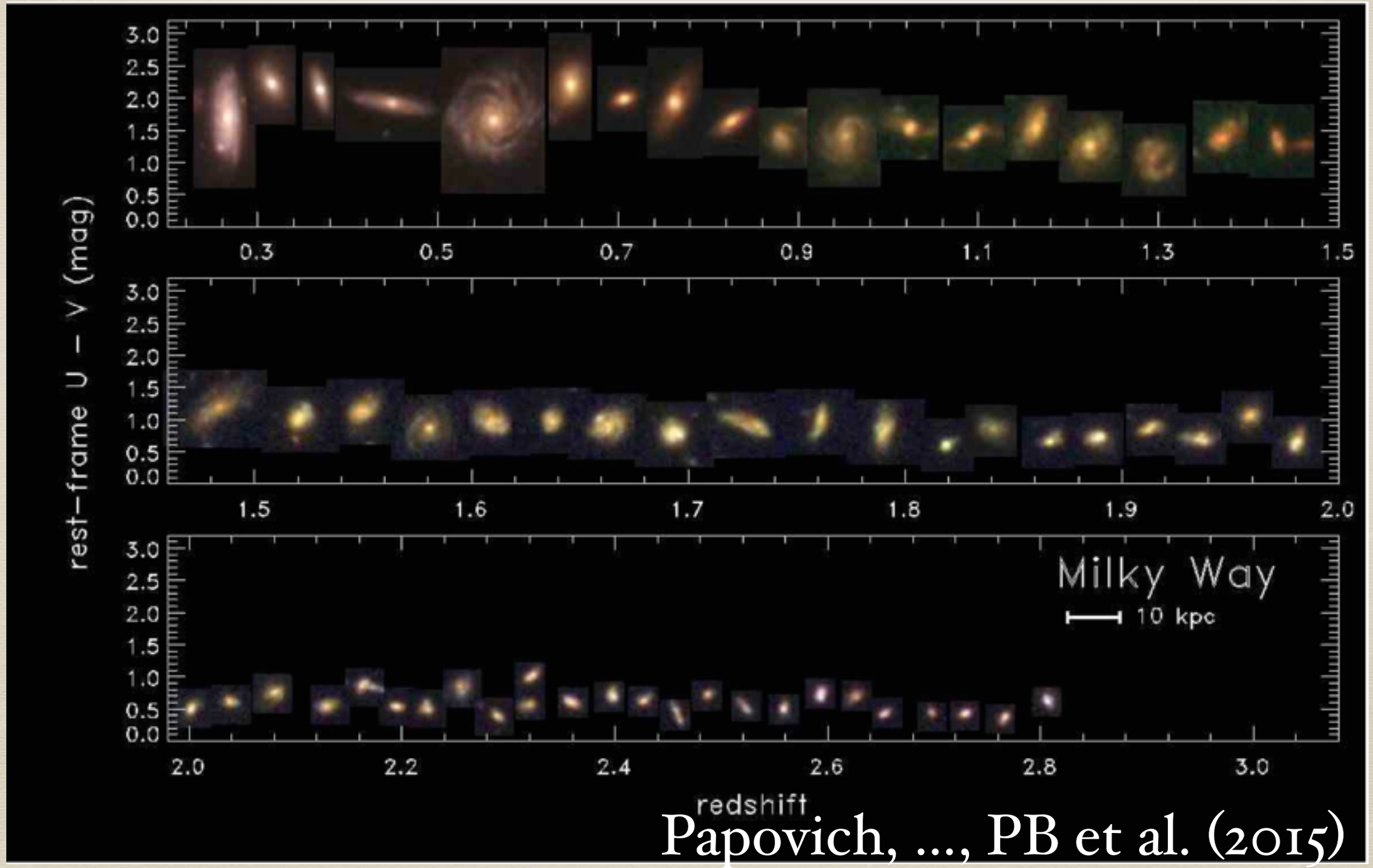
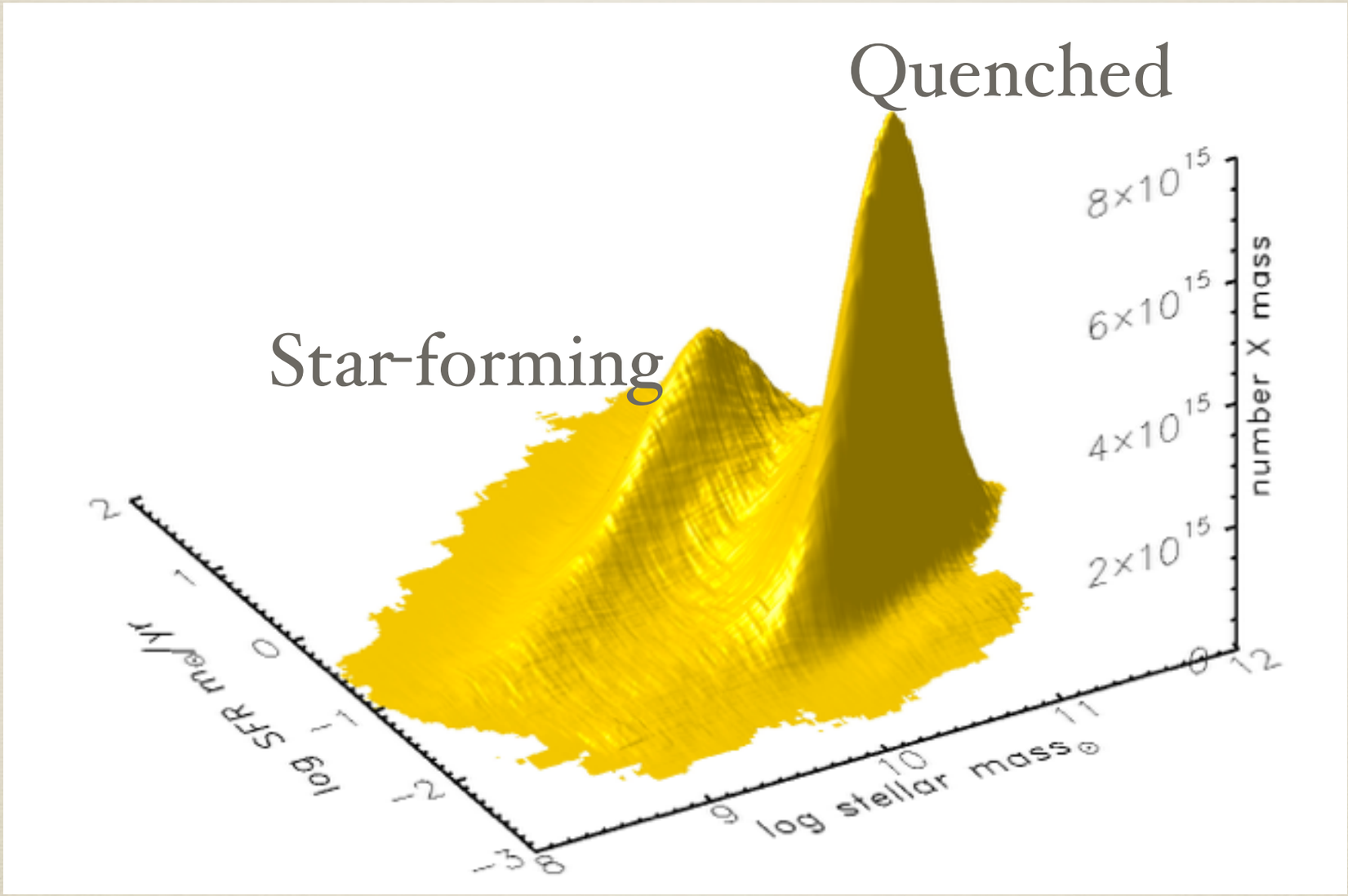


Papovich, ..., PB et al. (2015)

Galaxy Quenching

Context



Renzini & Peng (2015)

Galaxy Quenching

Context

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

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

Galaxy Quenching

Context

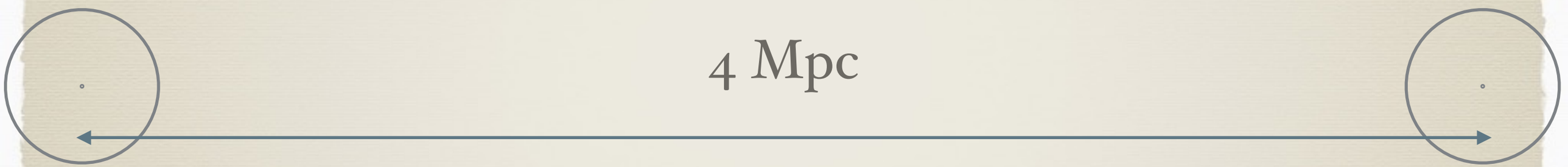
4 Mpc

1000 x galaxies' half-light radii

Kauffmann et al. (2013)

Galaxy Quenching

Context

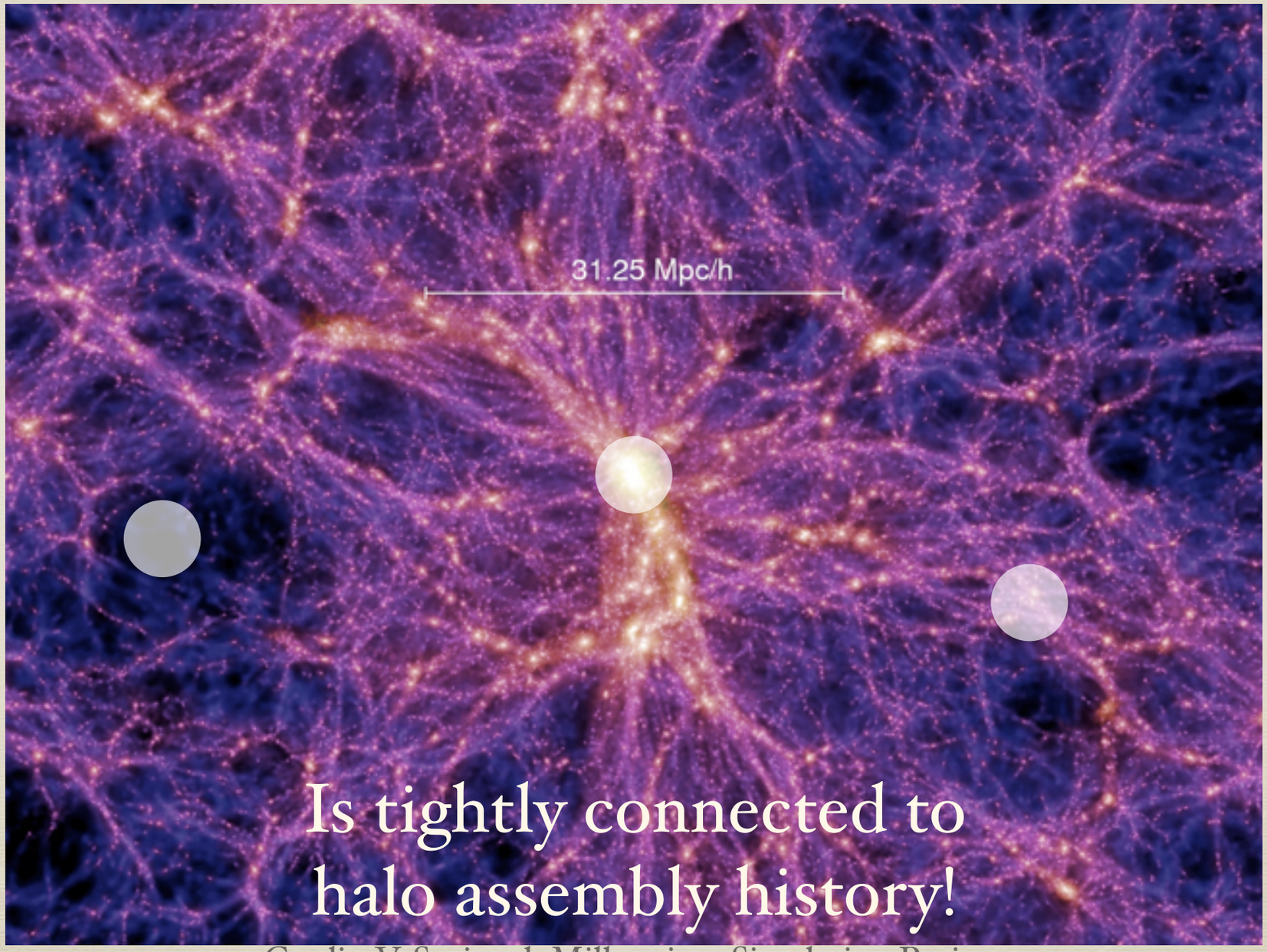


>10 x host halos' virial radii

Kauffmann et al. (2013)

Galaxy Quenching

Context

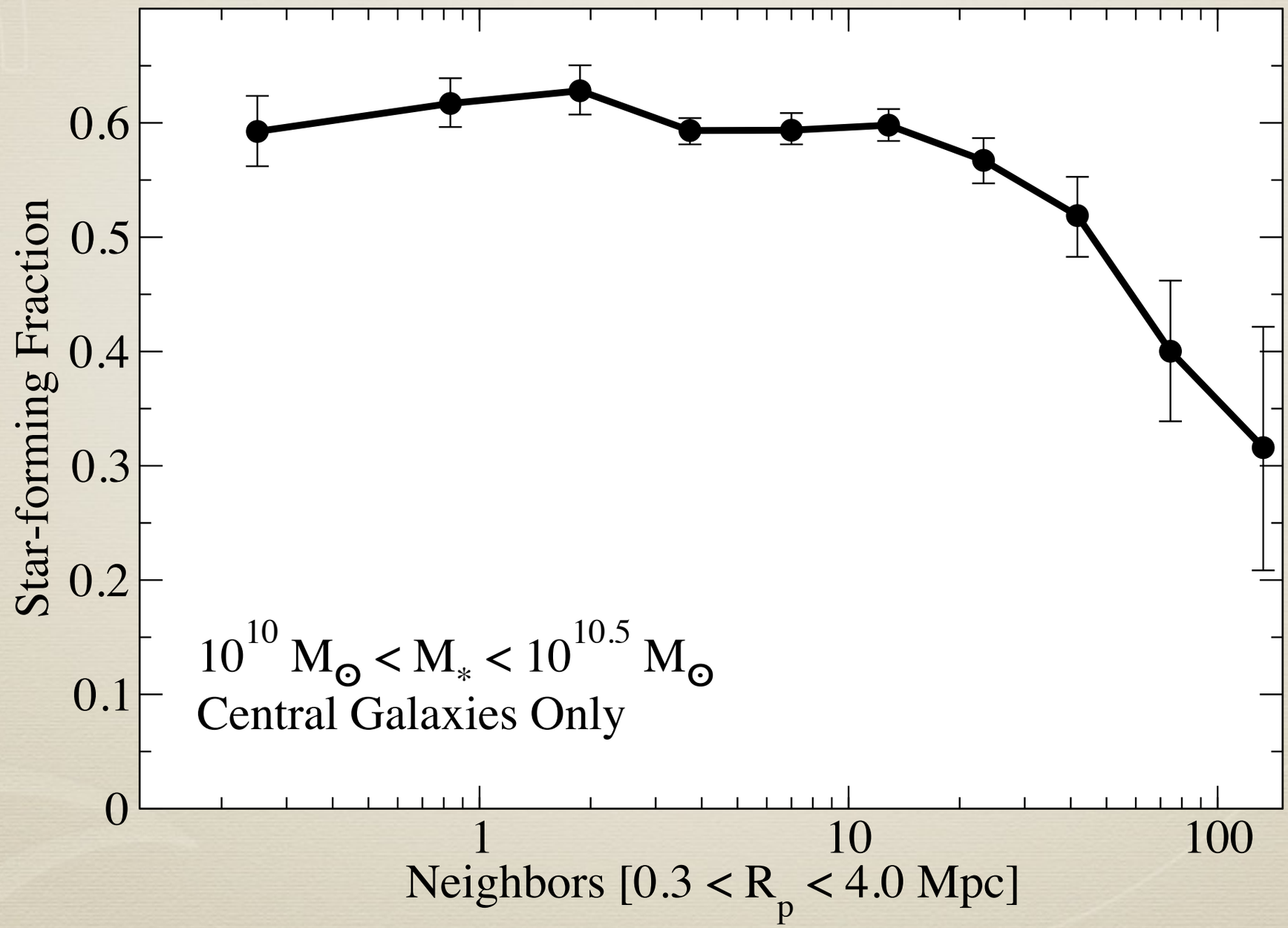


Credit: V. Springel, Millennium Simulation Project

Hearin, PB, van den Bosch (2015)

Galaxy Quenching

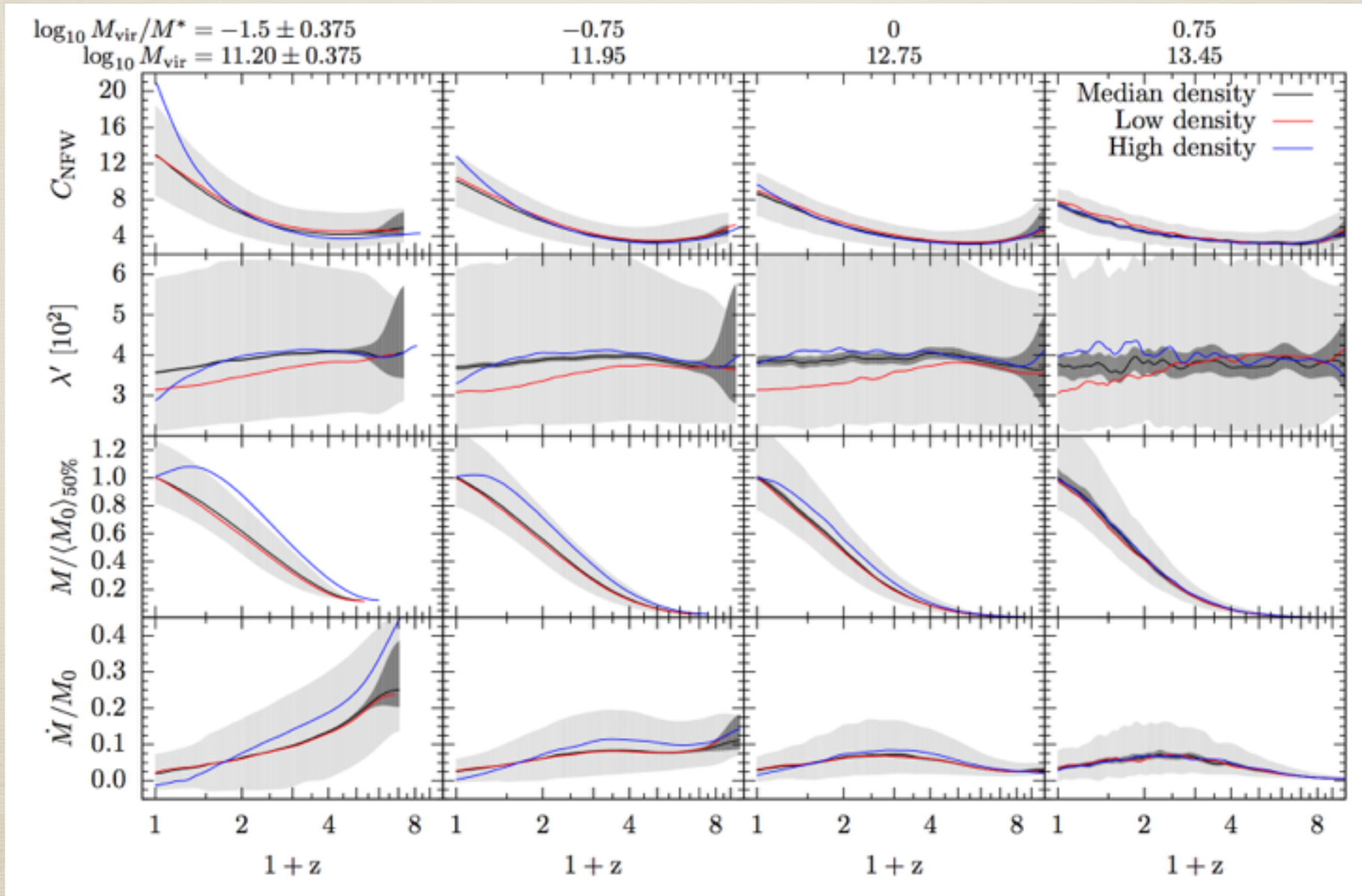
Context



PB, et al. in prep.

Galaxy Quenching

Context

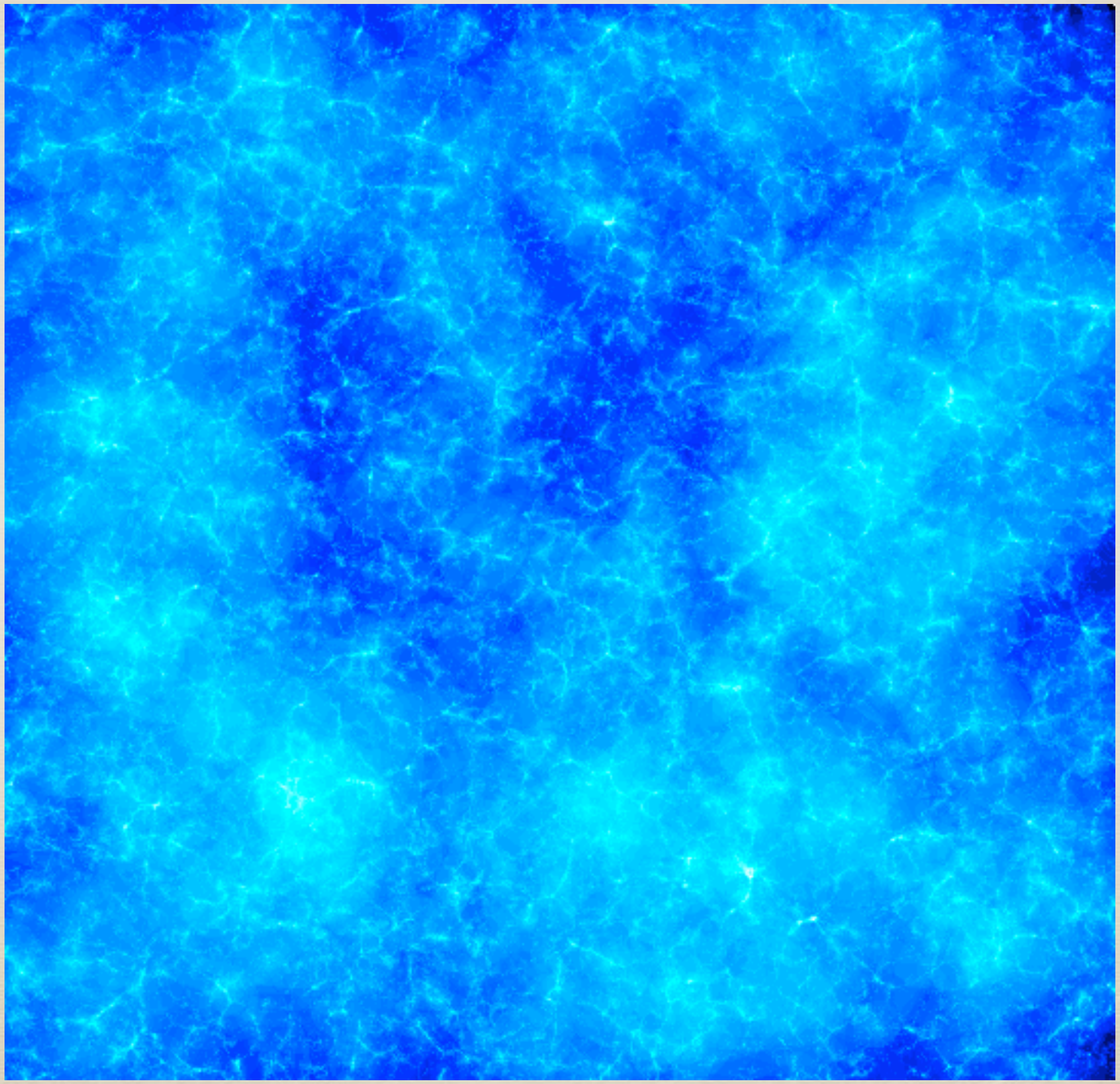


Lee, et al. in prep.

Key Point

Galaxy Star Formation Rate = Proxy for Halo Assembly

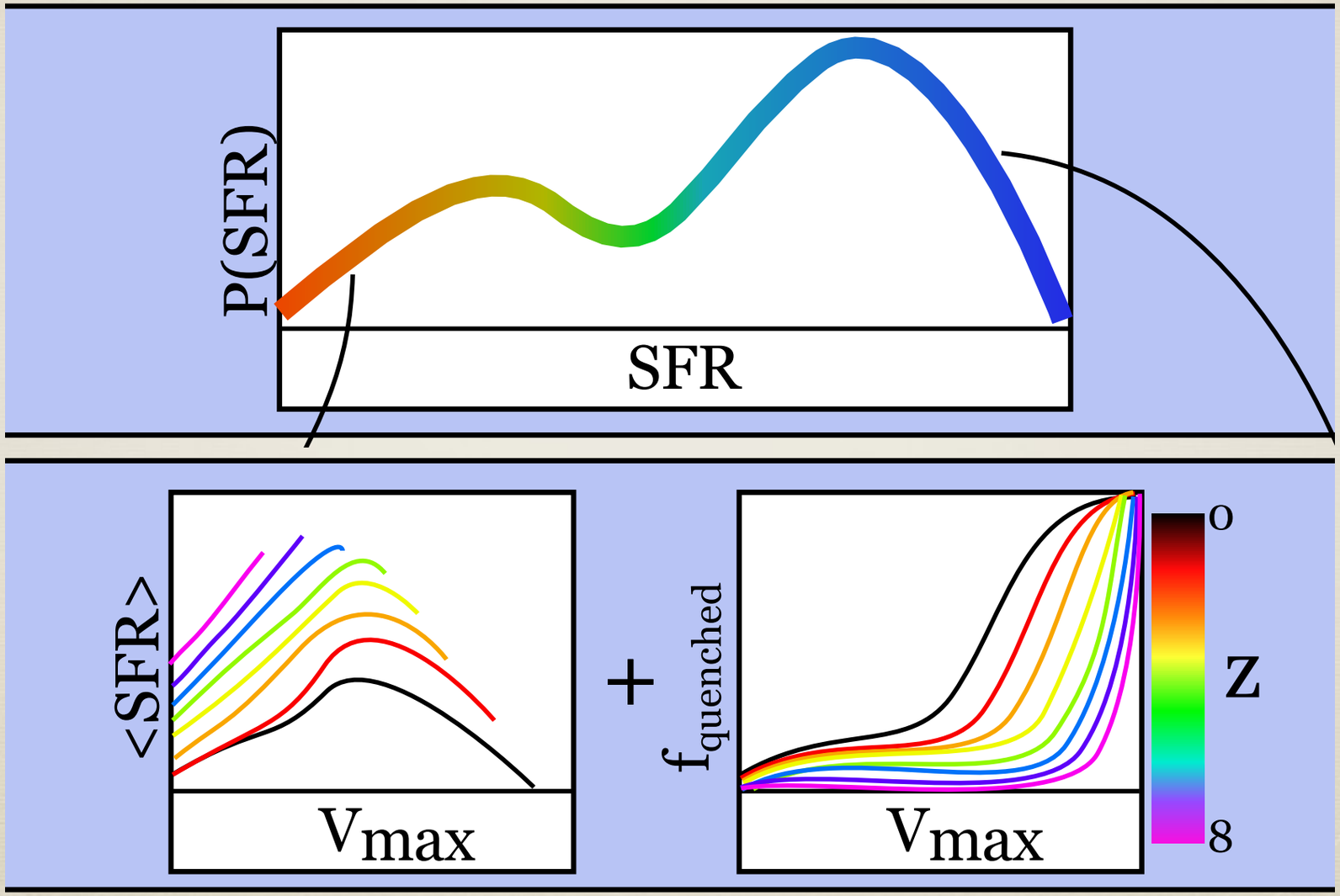
Galaxy Quenching



Credit: K. Riebe, Gustavo Yepes, Stefan Gottloeber

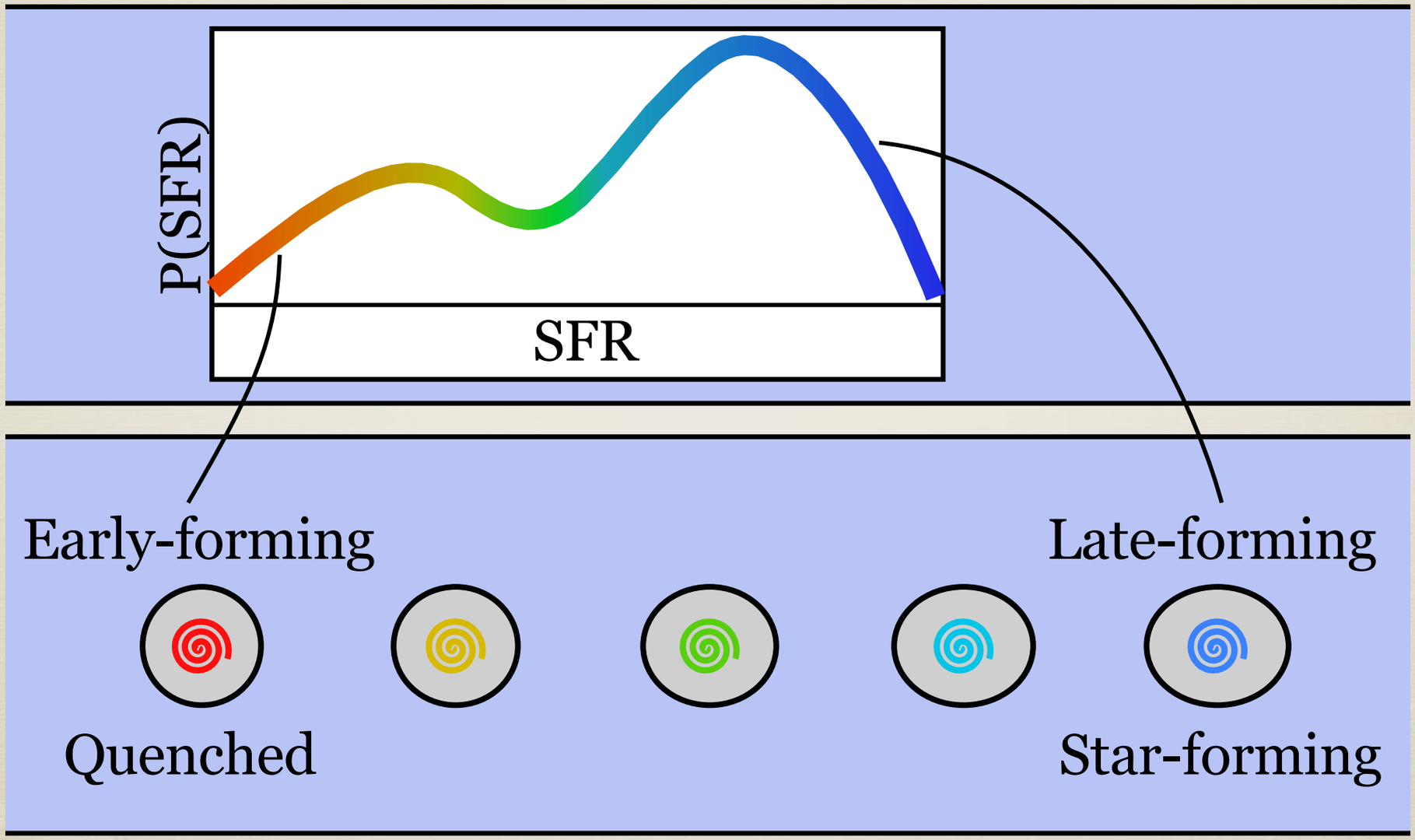
PB et al., in prep

Galaxy Quenching



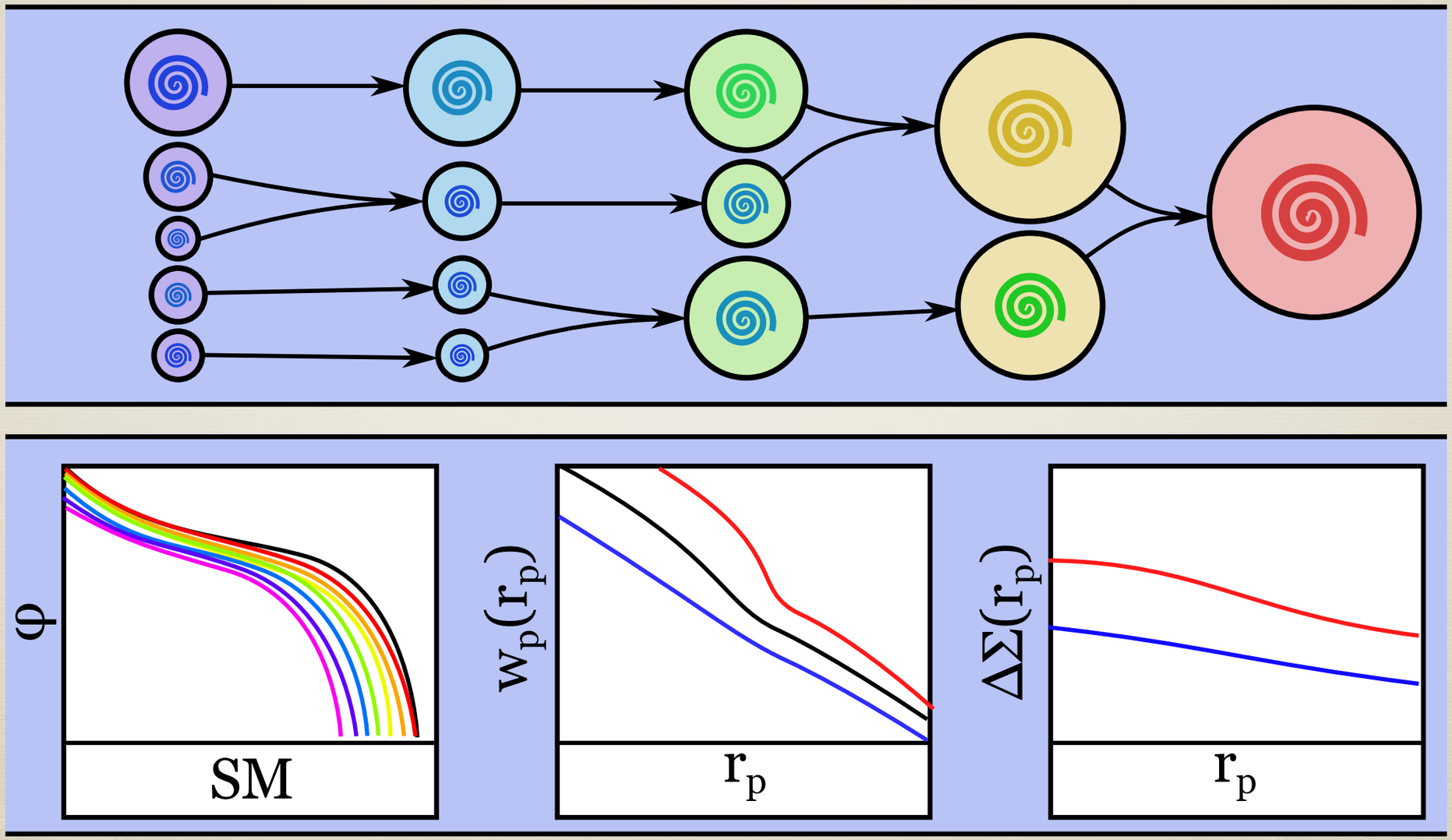
PB et al., in prep

Galaxy Quenching



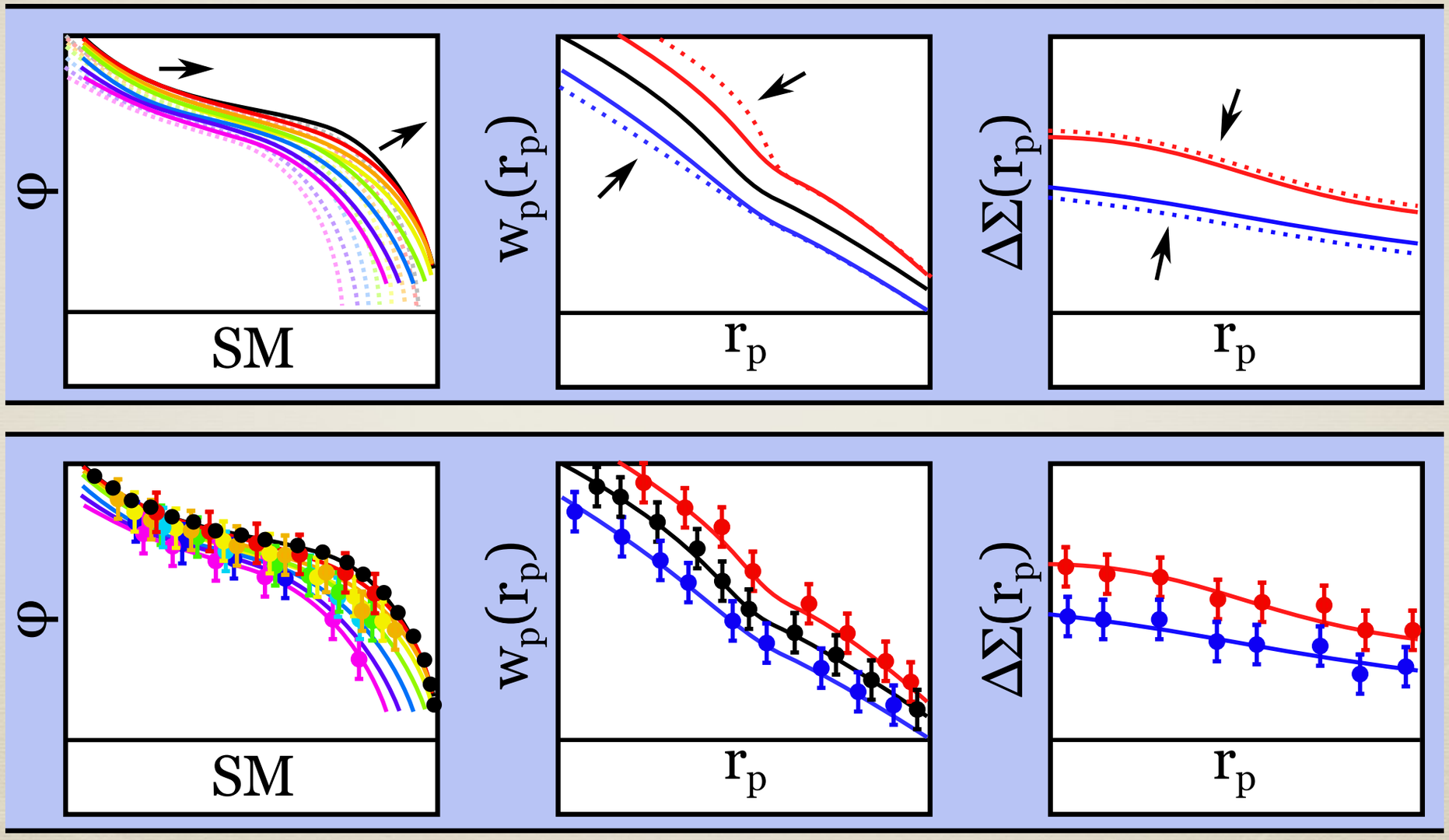
PB et al., in prep

Galaxy Quenching



PB et al., in prep

Galaxy Quenching

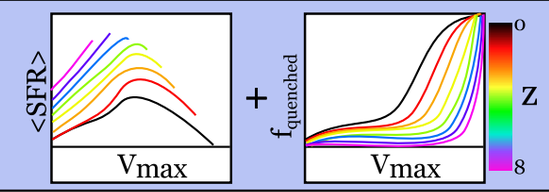


PB et al., in prep

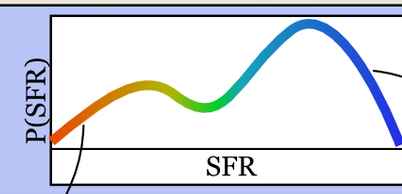
Galaxy Quenching

Markov Chain Monte Carlo

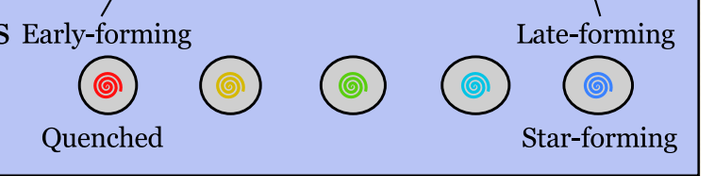
1. Choose a SFR - v_{max} (SFRVM) relation from parameter space.



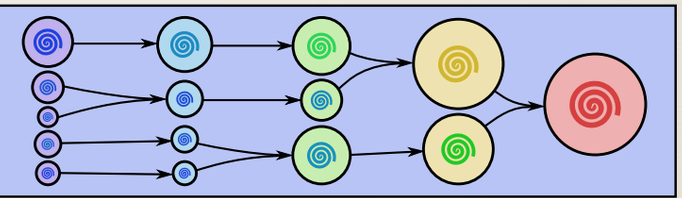
2. This gives the probability distribution of SFRs for any chosen halo v_{max} and redshift.



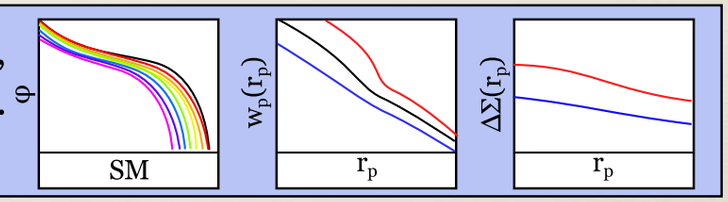
3. Map these SFR distributions to halos such that earlier-forming halos get lower SFRs.



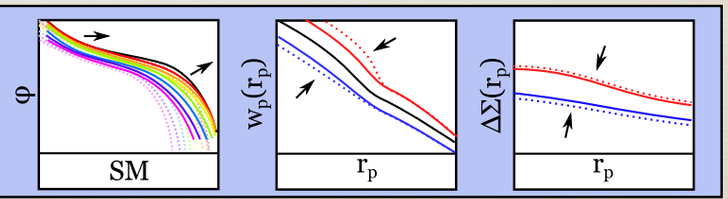
4. Integrate SFRs along halo merger trees to infer galaxy growth.



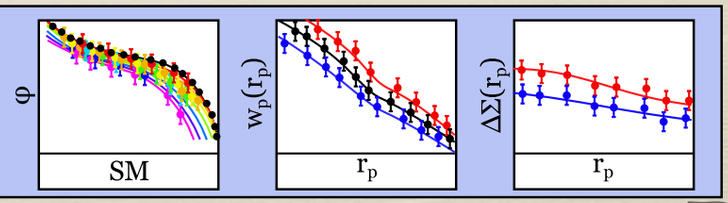
5. Predict observables: SMFs, correl. functions, lensing, etc. for SF, quenched galaxies.



6. Apply effects to simulate observational errors and biases.



7. Compare to data and calculate likelihood of the chosen SFRVM relation.



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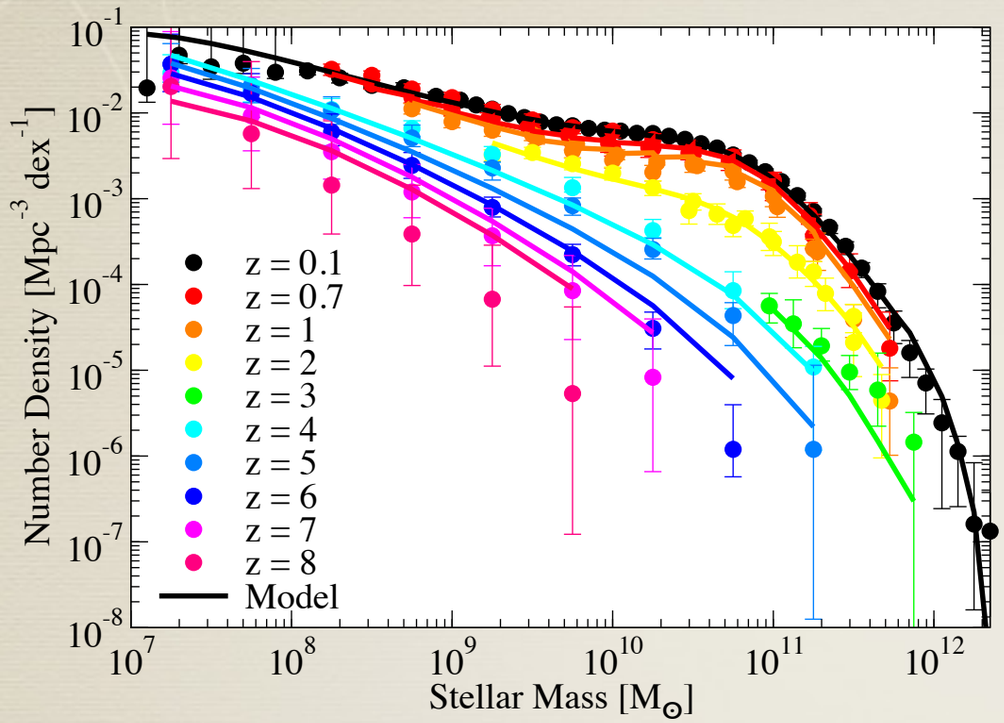
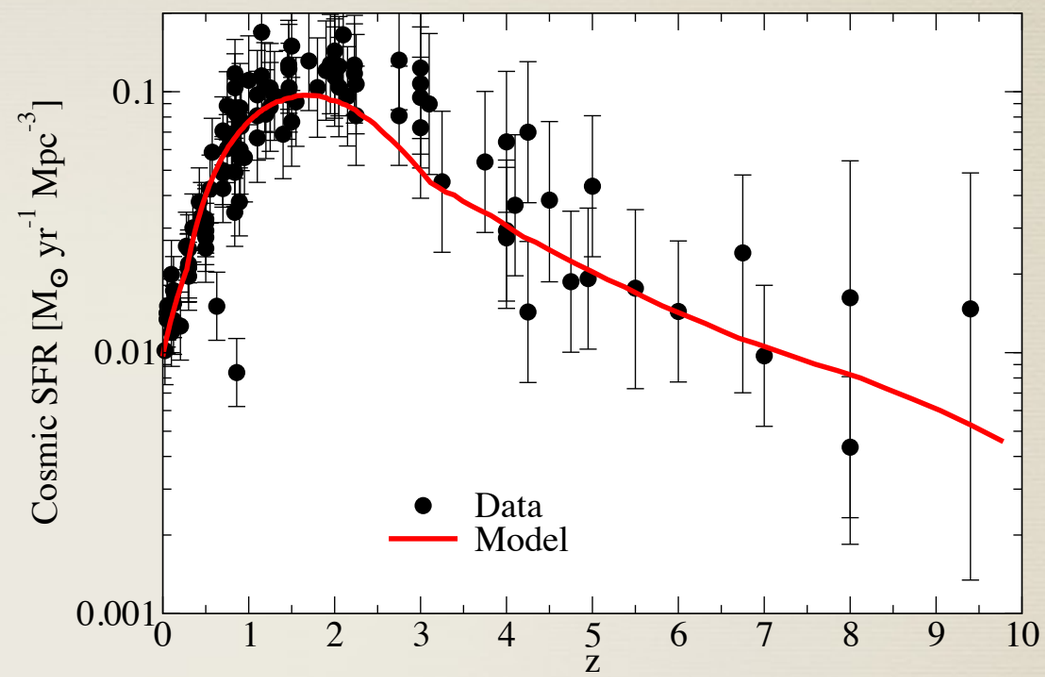
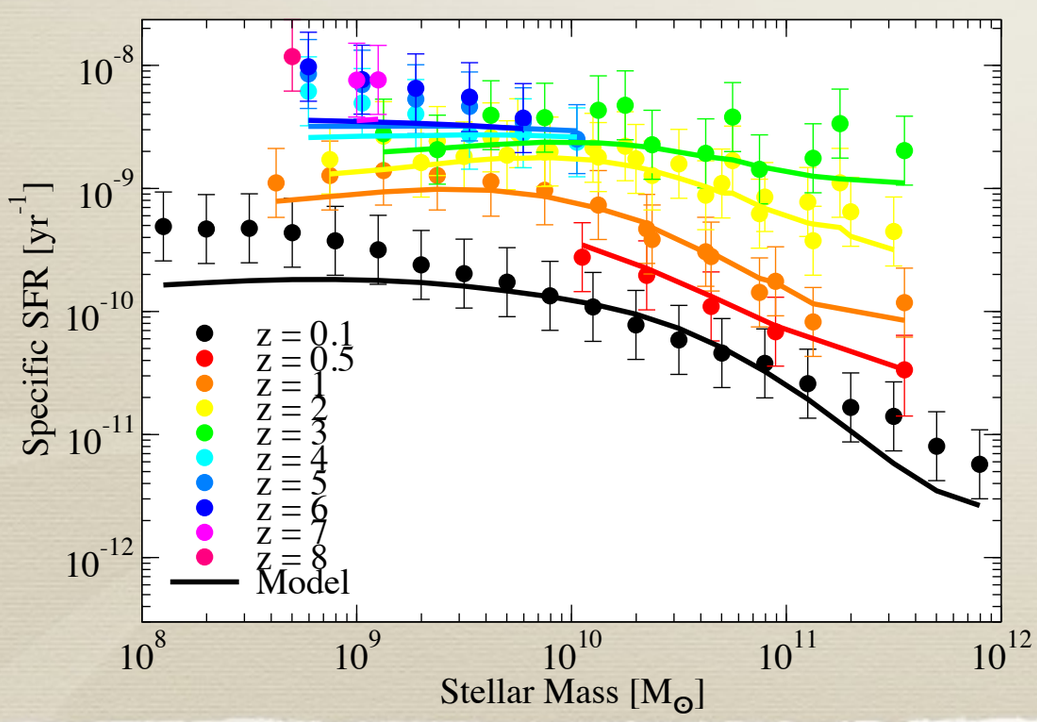
Universe Machine

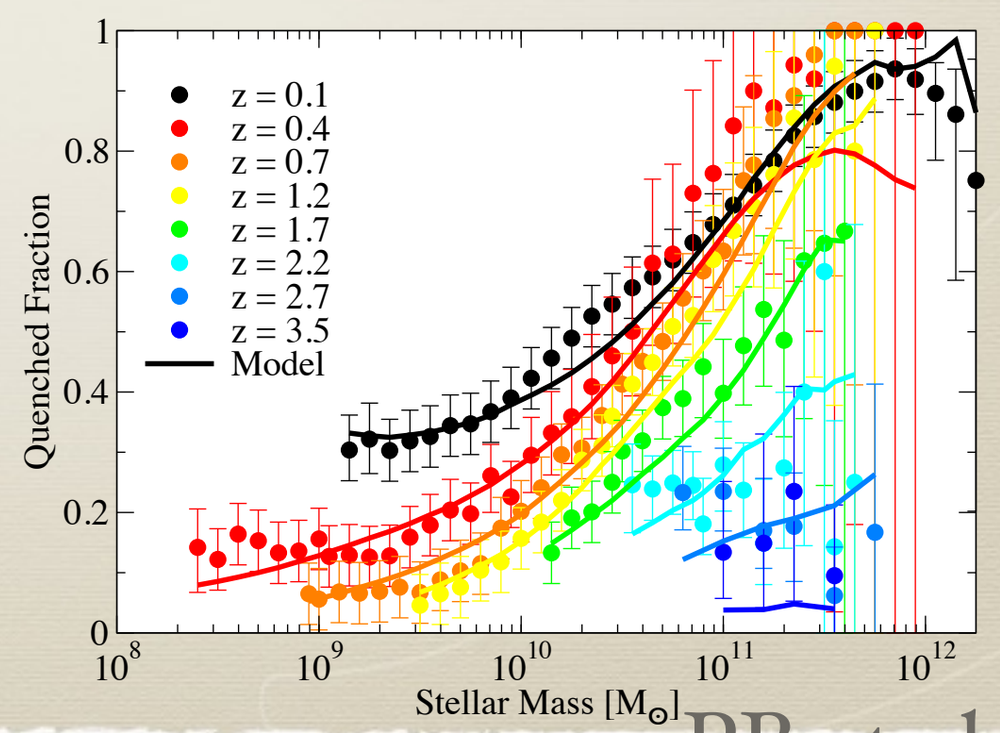
Credit: US DOE

Galaxy Quenching









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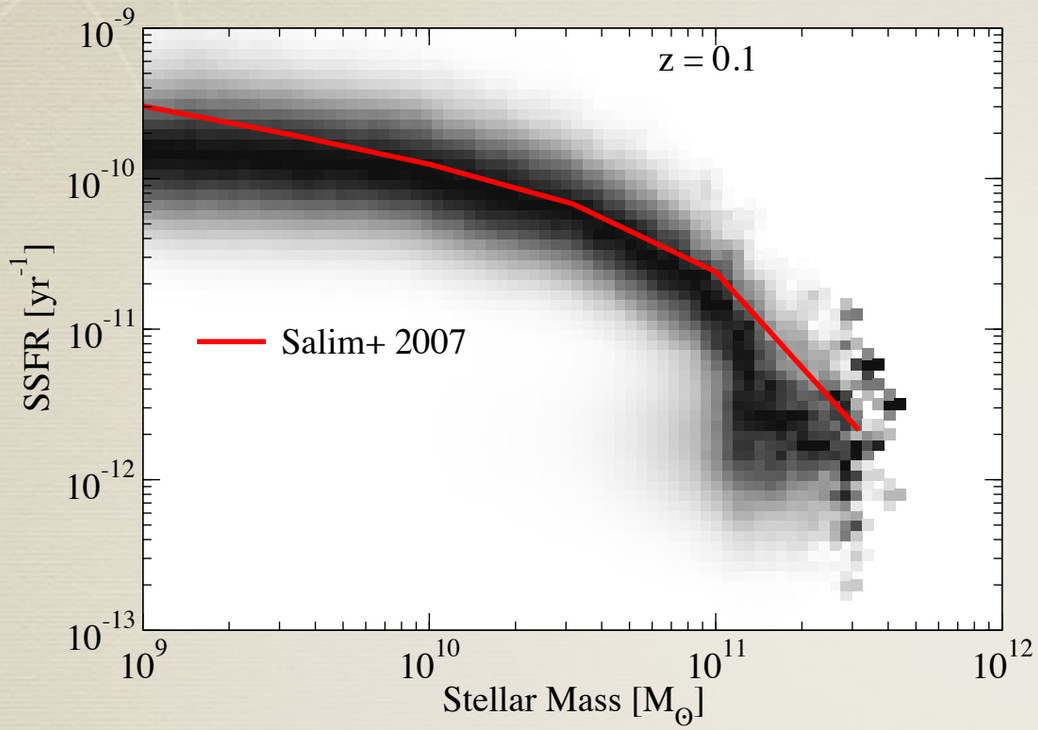
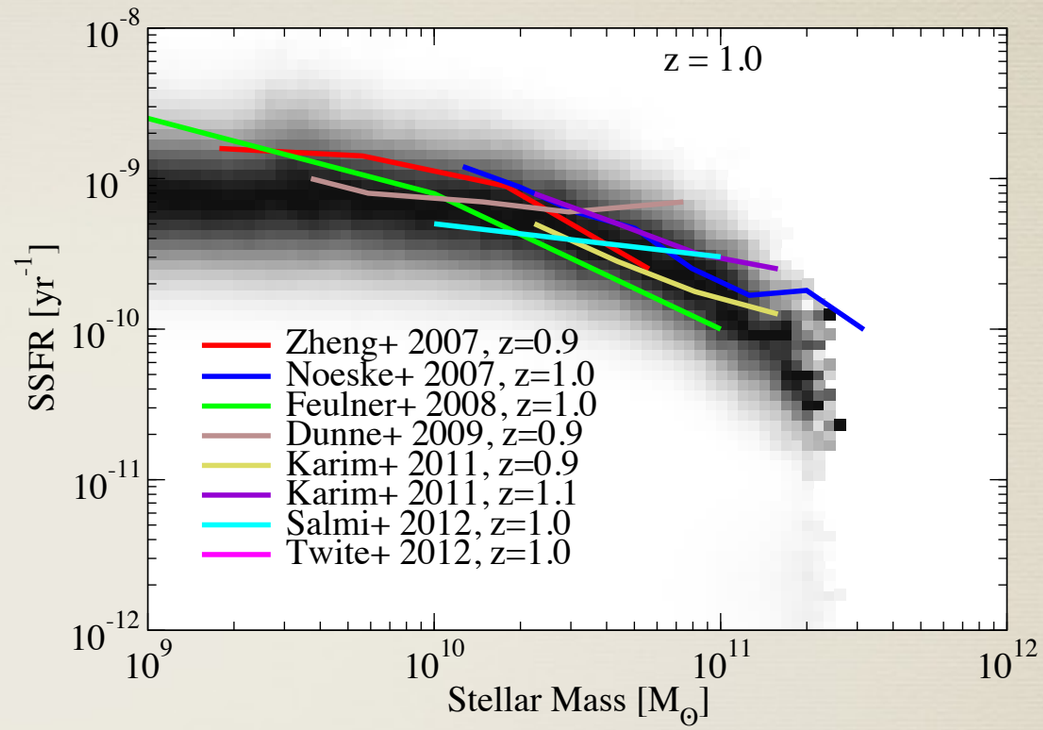
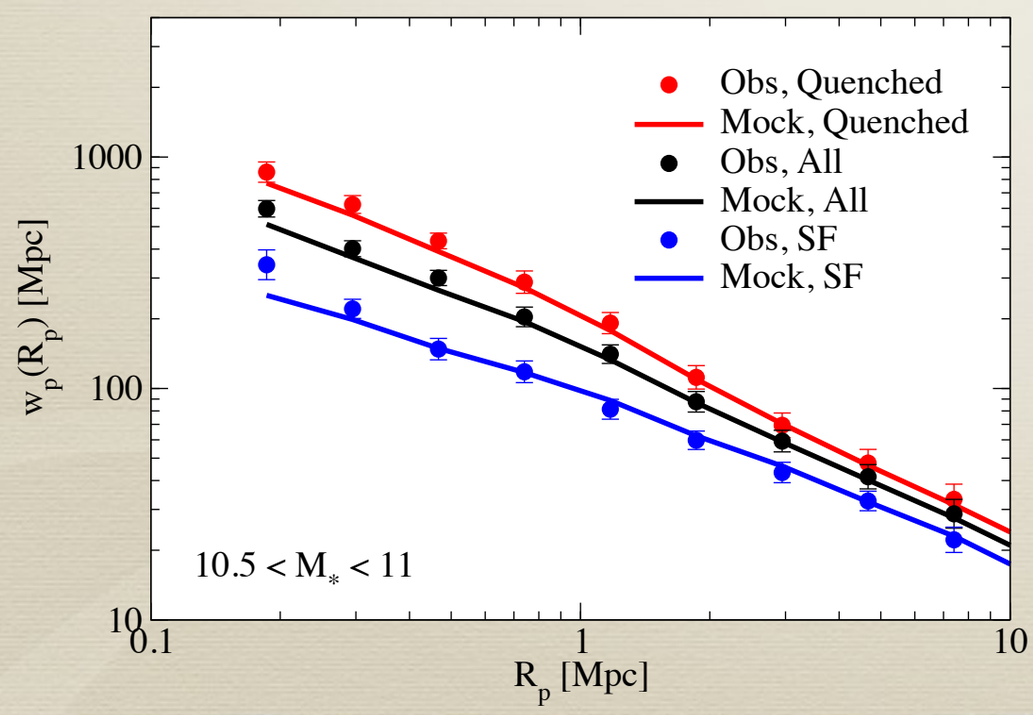
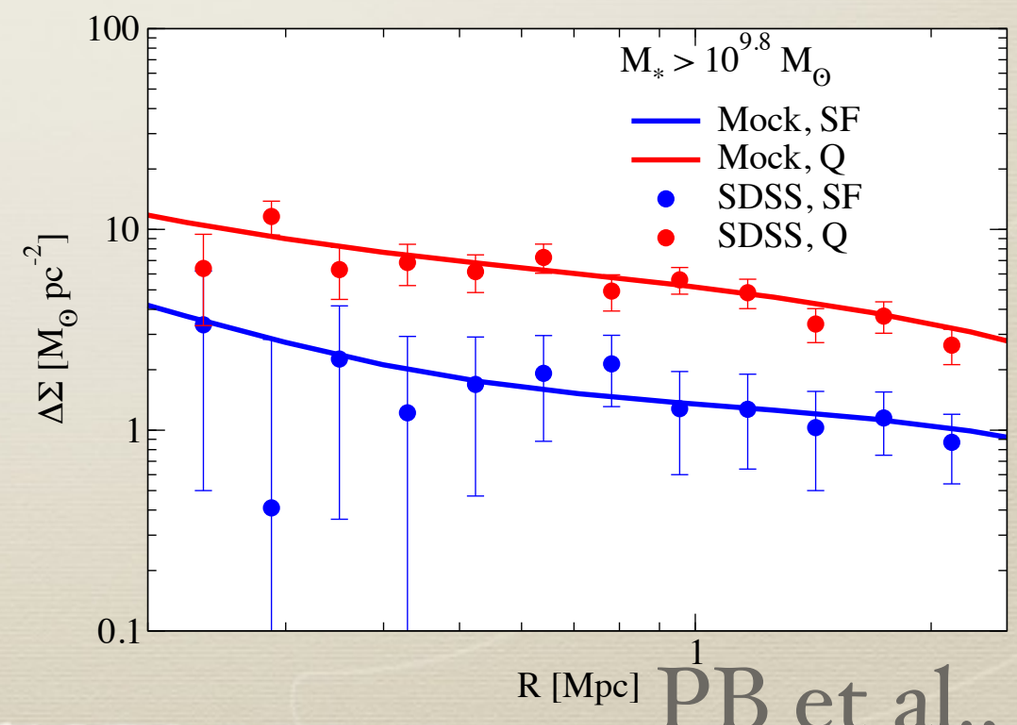
Galaxy Quenching









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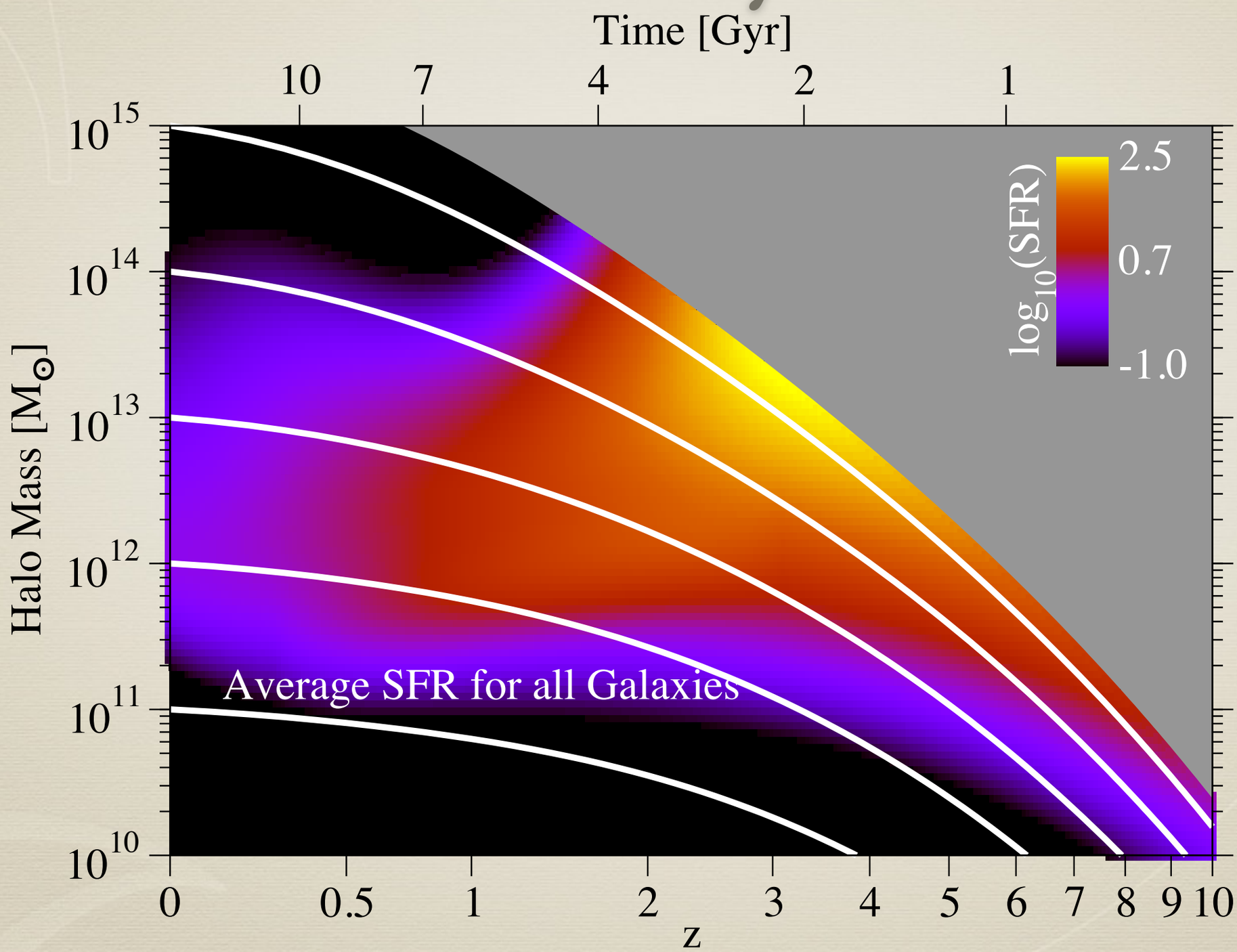
Preliminary Results



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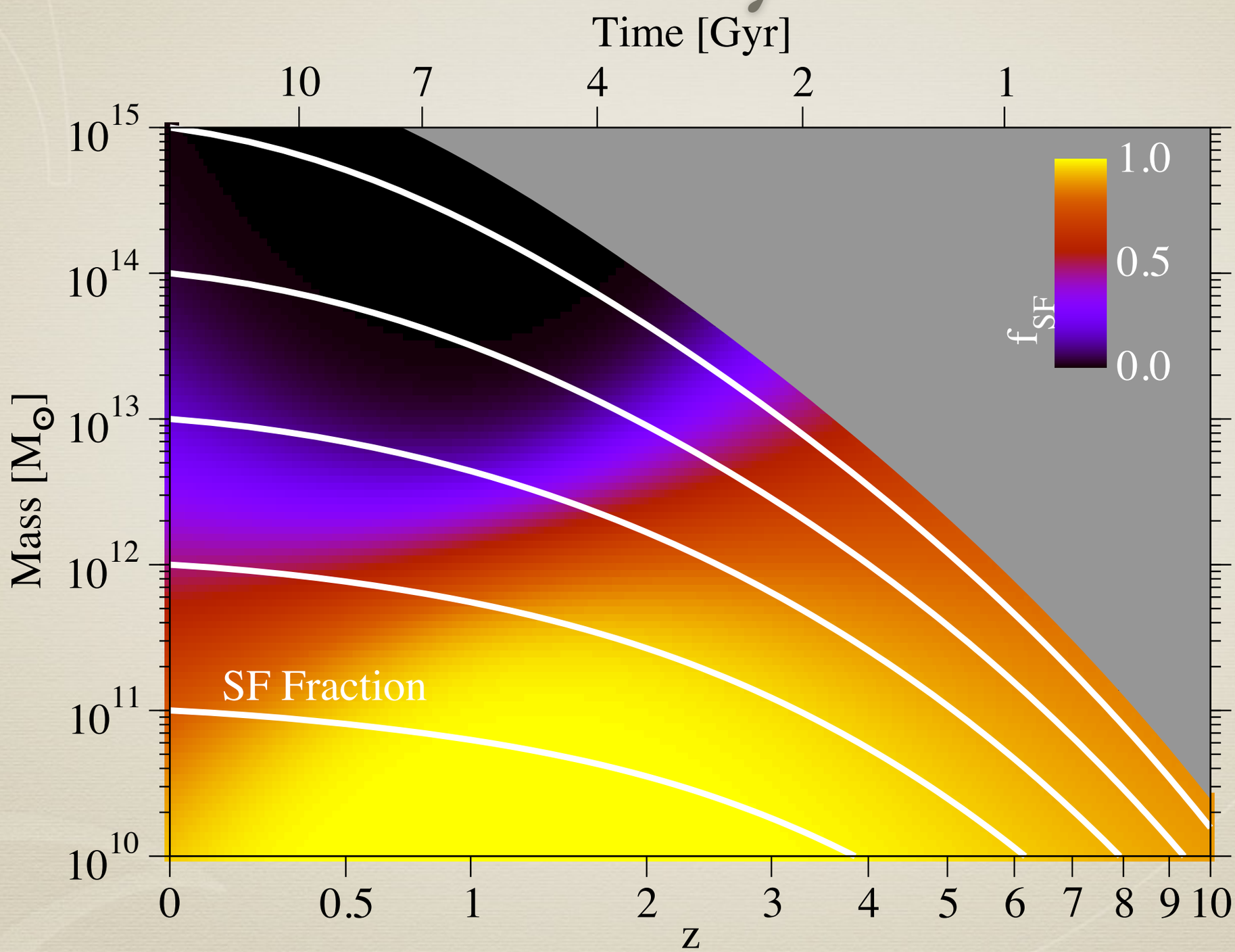
Preliminary Results



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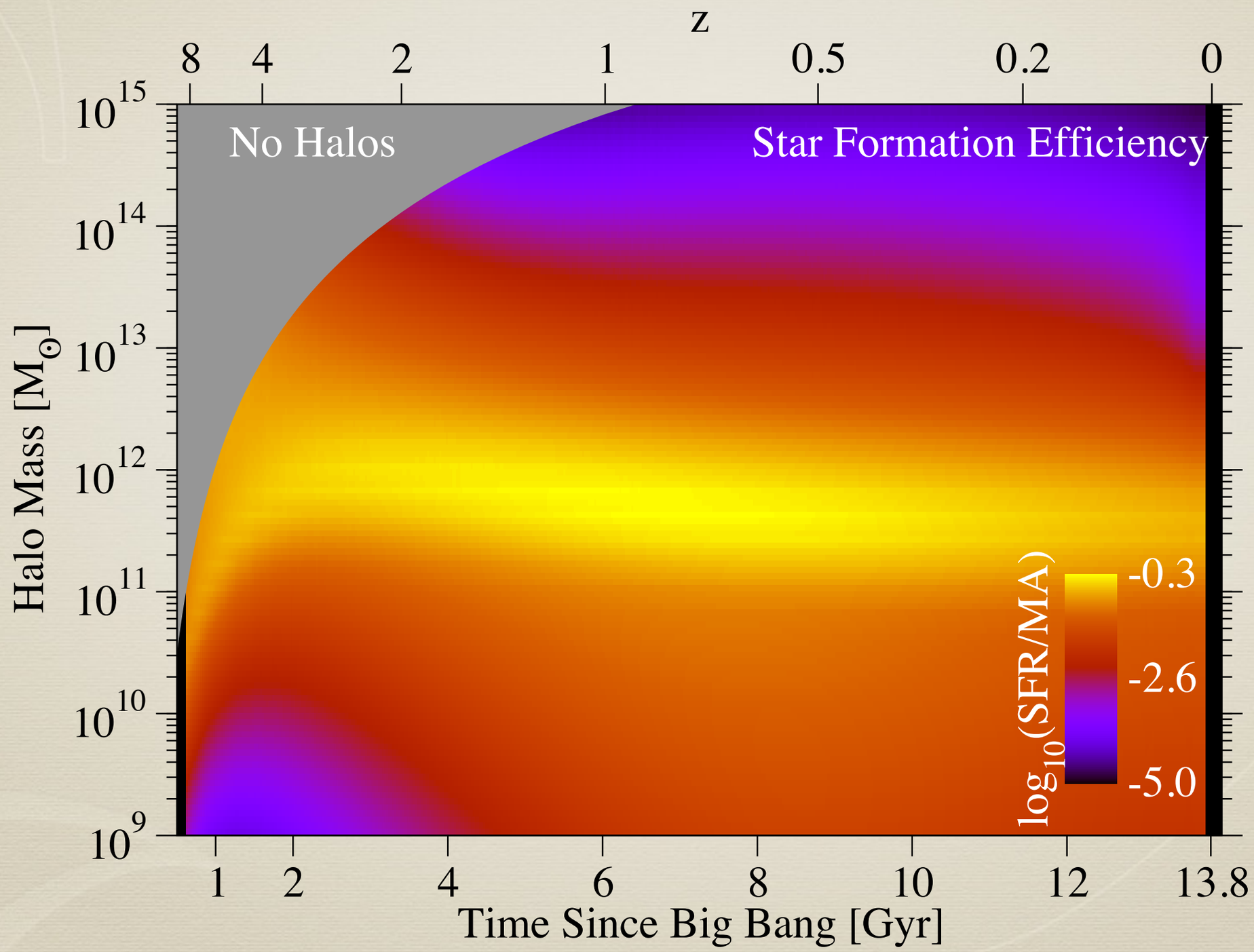
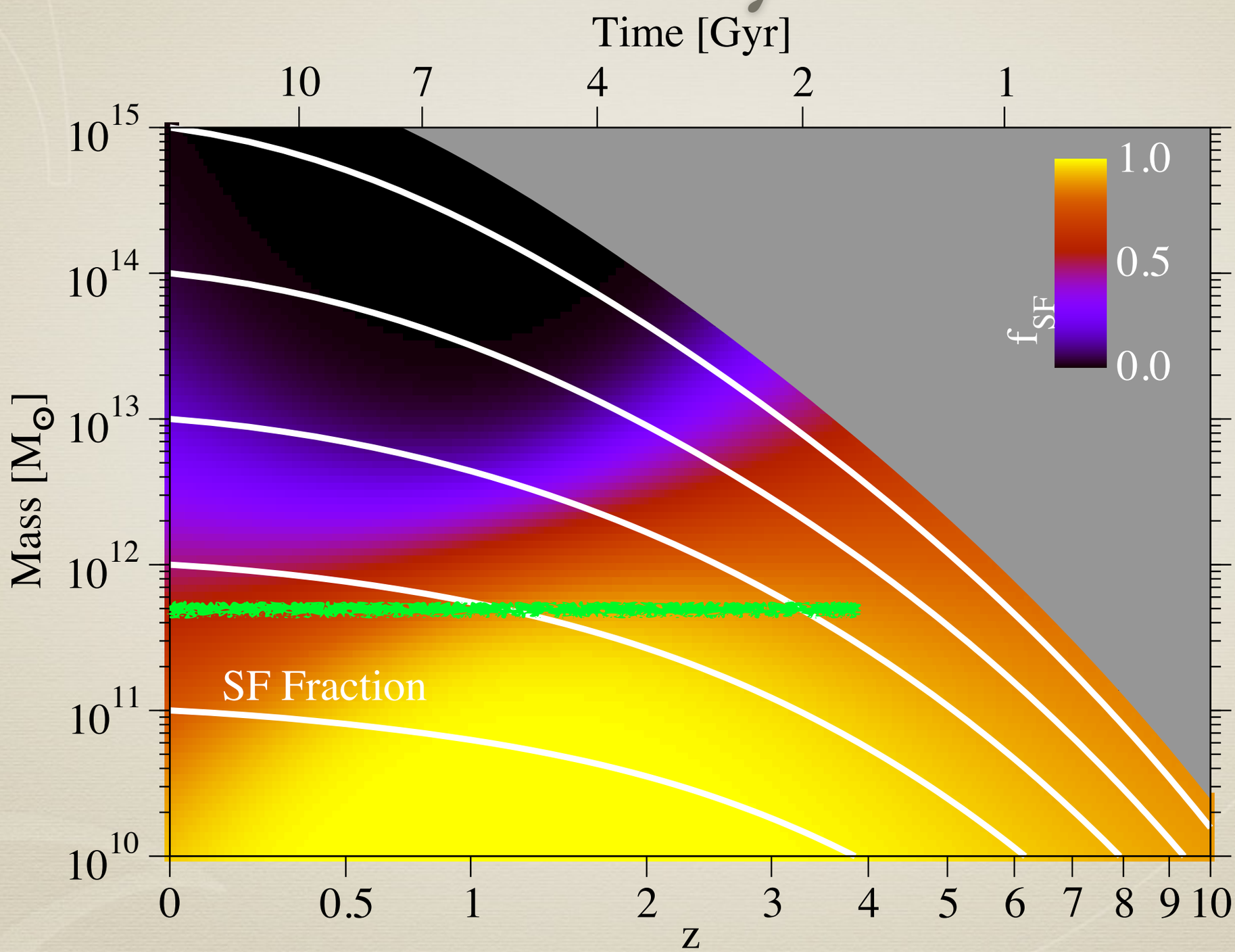
Preliminary Results



Preliminary Results



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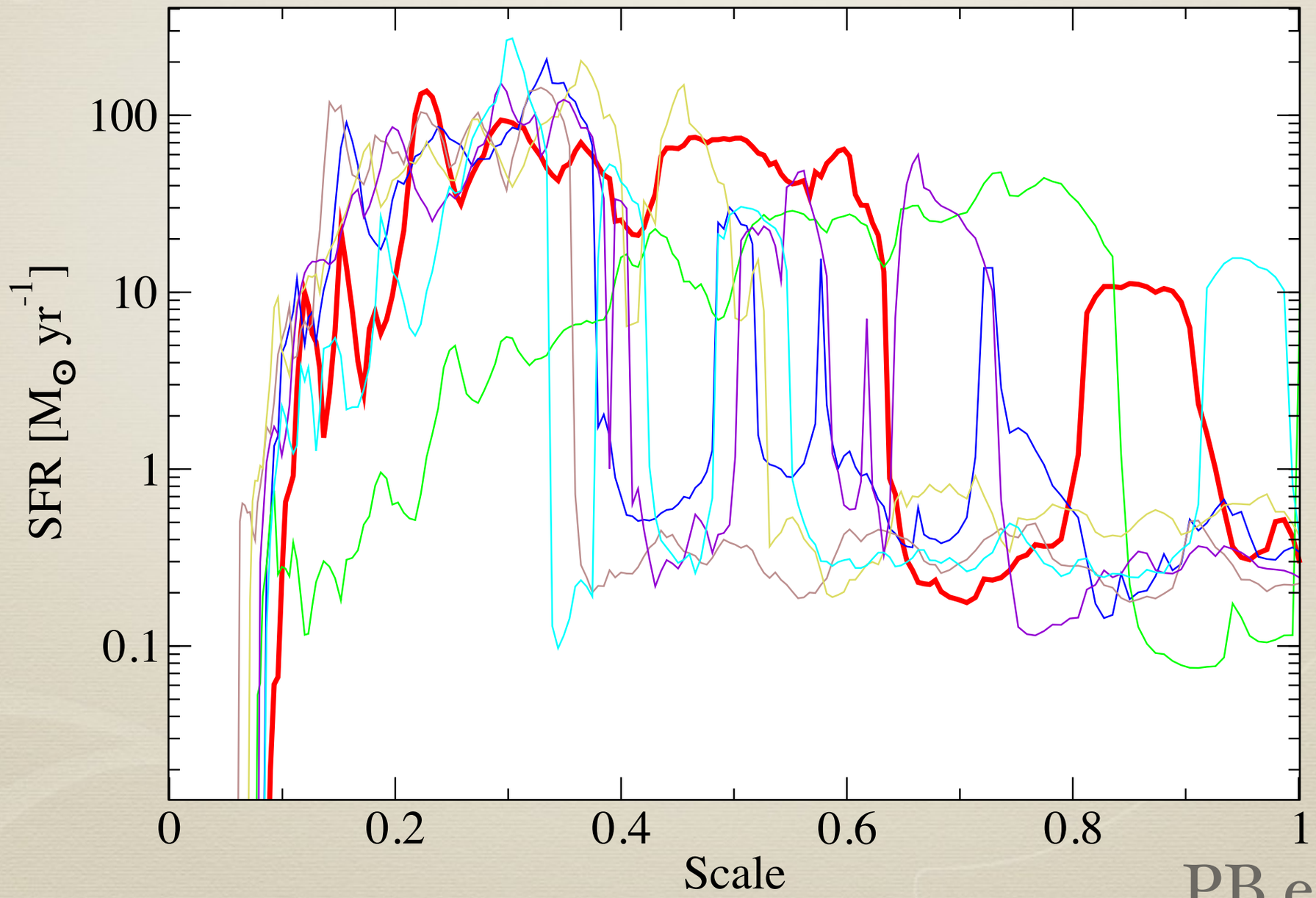
Preliminary Results

Quenching is **generically not permanent**.



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Galaxy Quenching

Galaxy Star Formation Rate = Proxy for Halo Assembly

Determining when/where/why do galaxies quench

New tool to infer halo assembly histories from observations

Credit: M31; NASA/Hubble

Thanks!

to YOU for listening

and also to

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Charlie Conroy
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