MIT KAVLI INSTITUTE

Suggested live twitter feed:

Remco van den Bosch @remcovdbosch · Apr 13

Torrey is scripting his own twitter feed at #galaxies2016. Either very strange or brilliant. Not sure yet.

Galaxy Mass Evolution

Two Fundamentally Distinct Approaches

Population Statistics

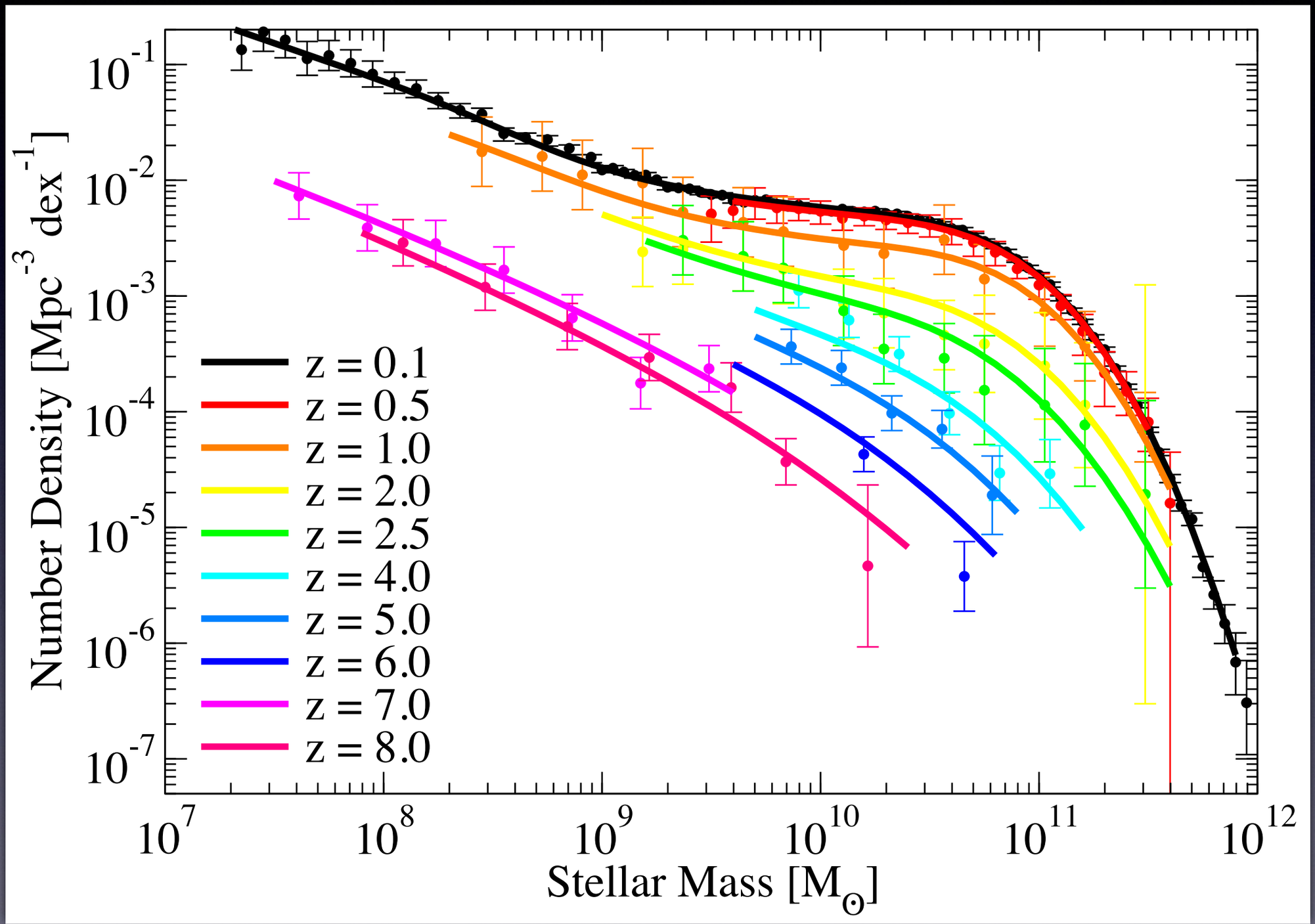
- Stellar Mass Functions
- Cosmic Star Formation Rate Density
- Mass-Size Relation
- Mass-Metallicity Relation
- …

Physical Evolution

- Stellar Mass Growth
- Gas inflow/outflow
- Metal enrichment
- Feedback
- …

Meaningful Link?

Stellar Mass Function Evolution



Data from:
Baldry+ (2008)
Moustakas+ (2013)
Pérez-González+ (2008)
Mortlock+ (2011)
Marchesini+ (2009)
Marchesini+ (2010)
Lee+ (2012)
Start+ (2009)
Bouwens+ (2011)
Bradley+ (2012)

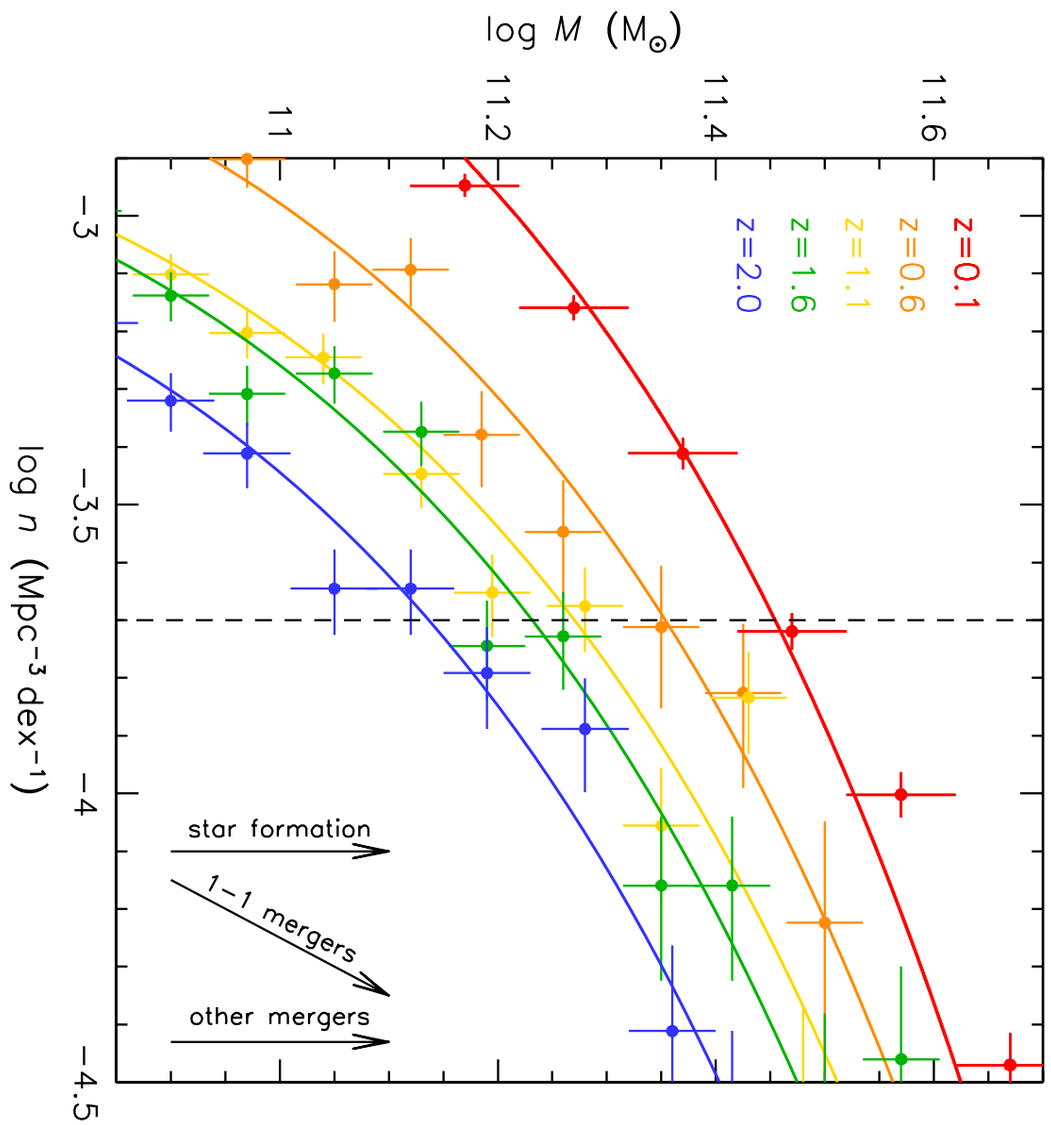
Behroozi+ (2013)

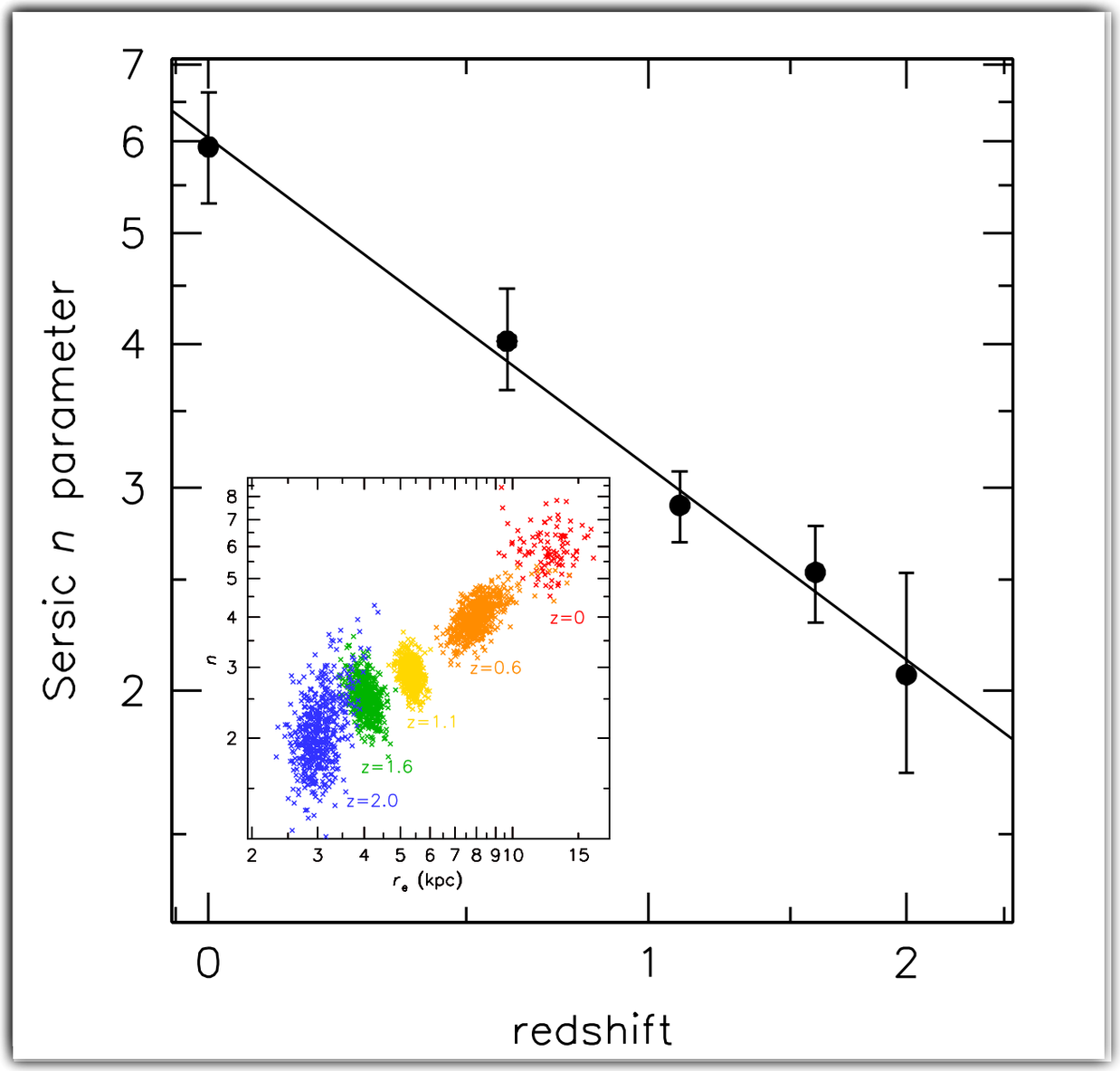
More on this in Kevin's talk

Rank Order Analysis

Link progenitors/descendants with their number density

“Constant Comoving Number Density”



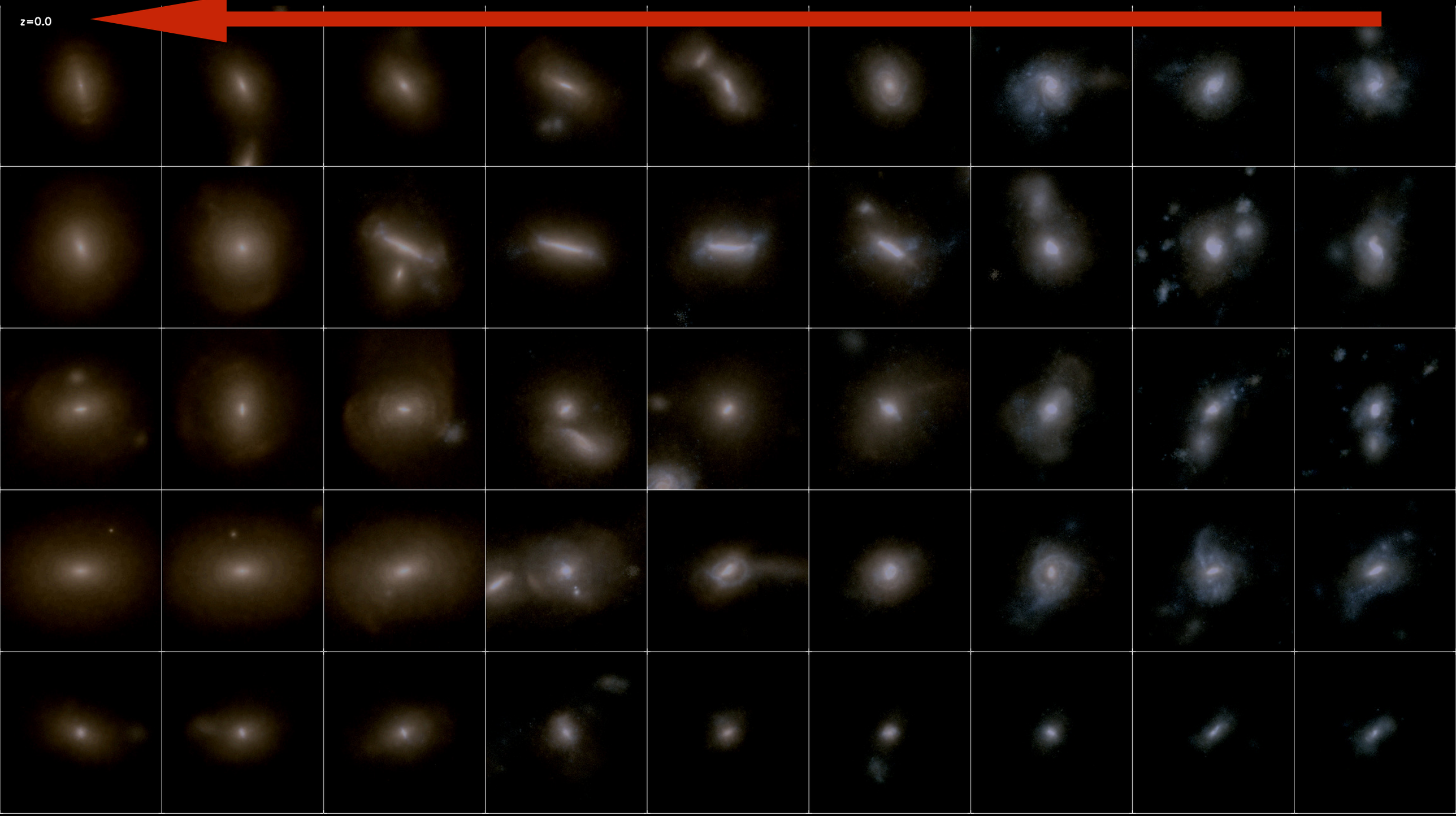


van Dokkum+ (2010)

Rank Order Analysis

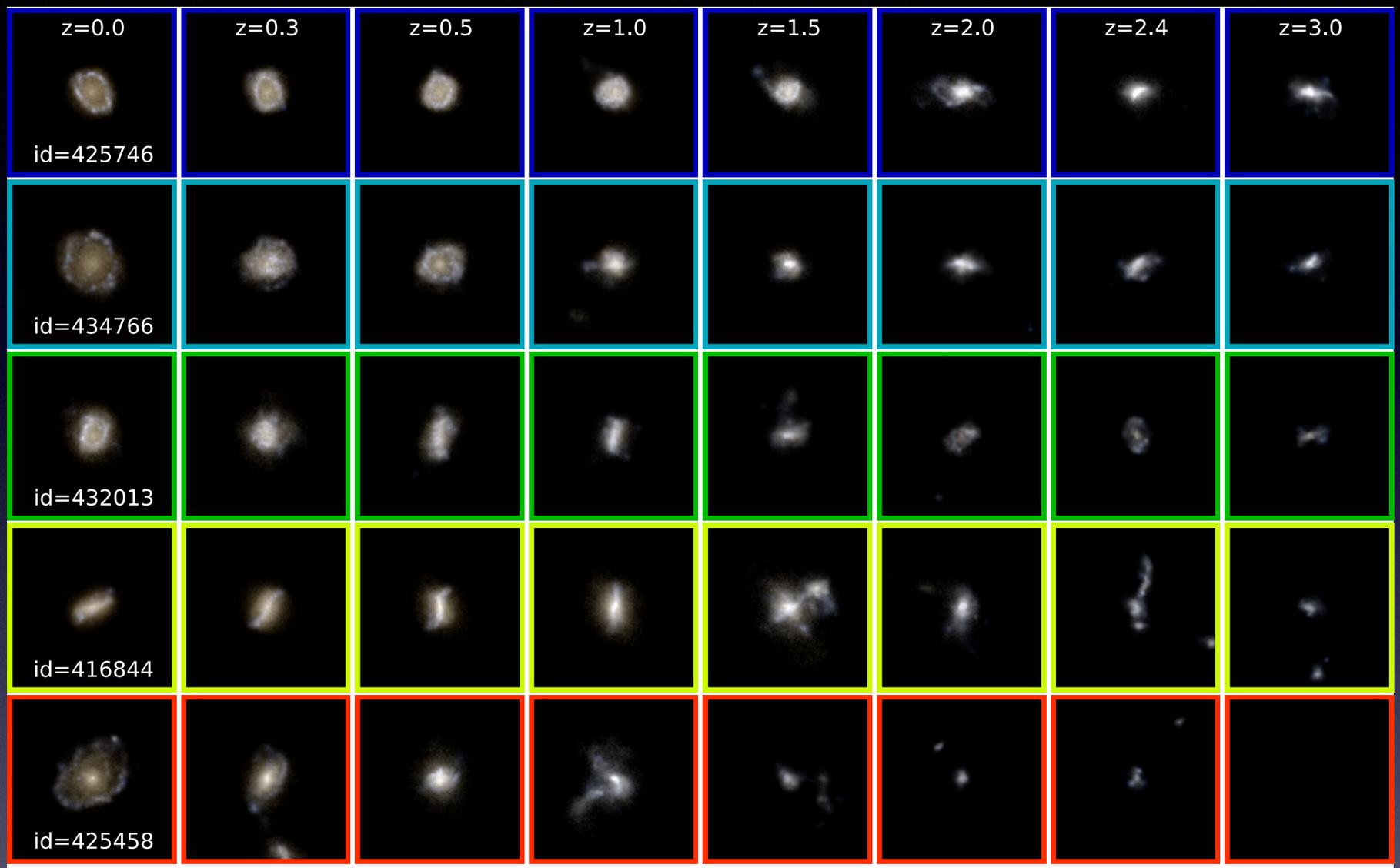
Check using “Tracked” Mass Evolution in Simulations

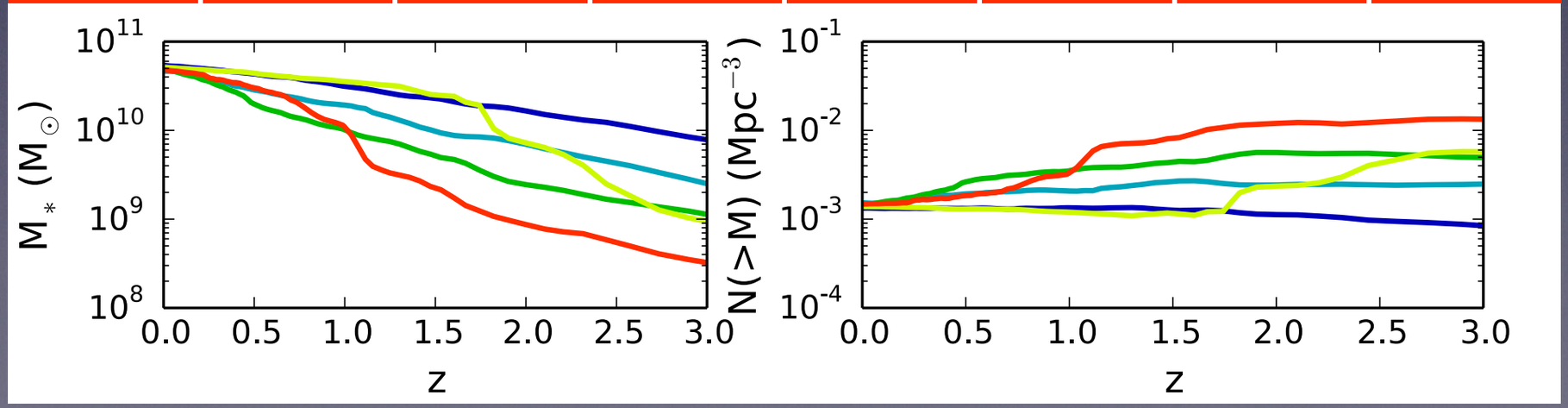
z=0 **z=2**



Torrey+ (2015a)

Rank Order Analysis





1) Constant number density evo rare.

2) Scattered growth rates are ubiquitous!

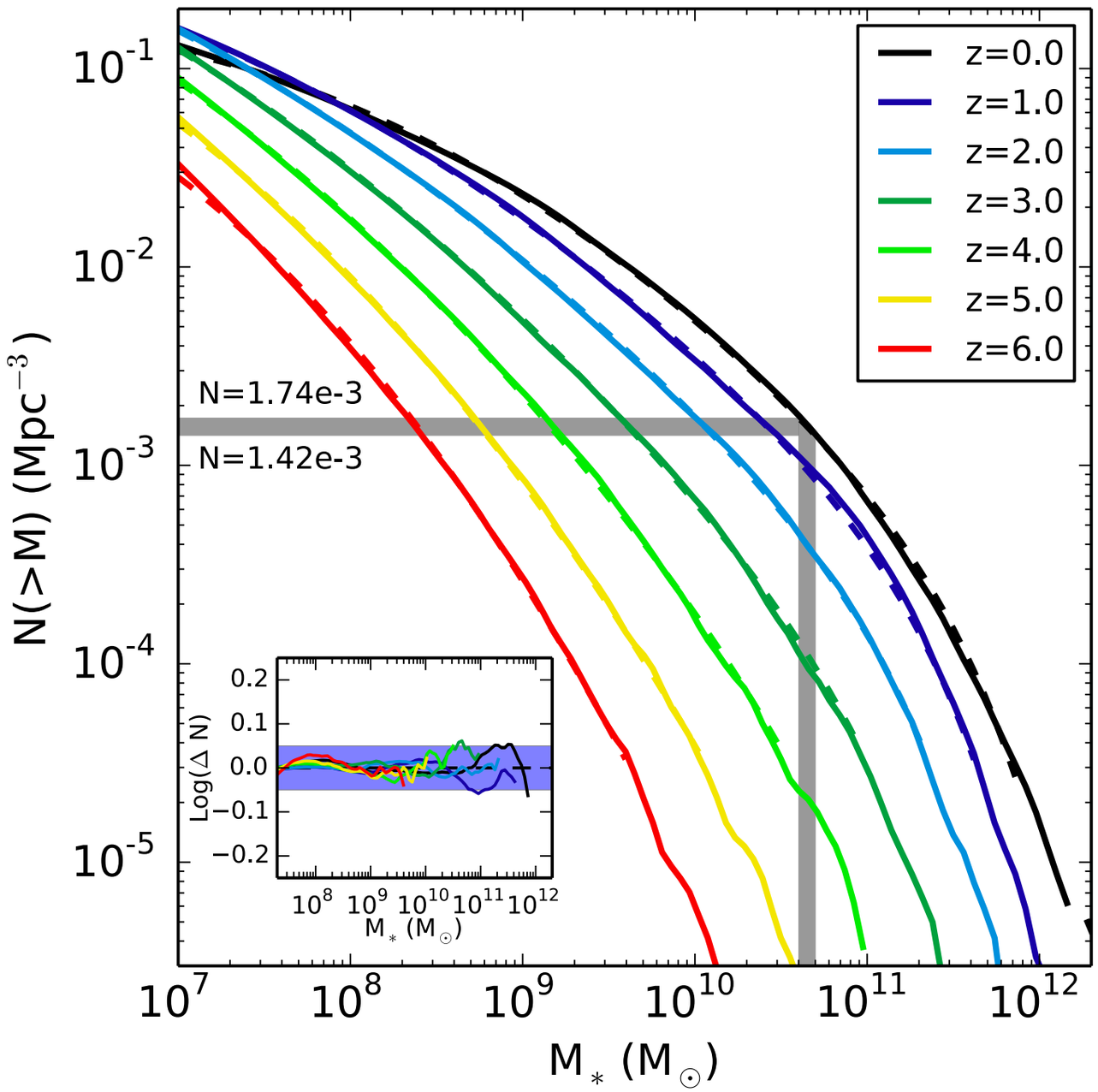
3) Spread in SFR-MS and mergers both contribute.

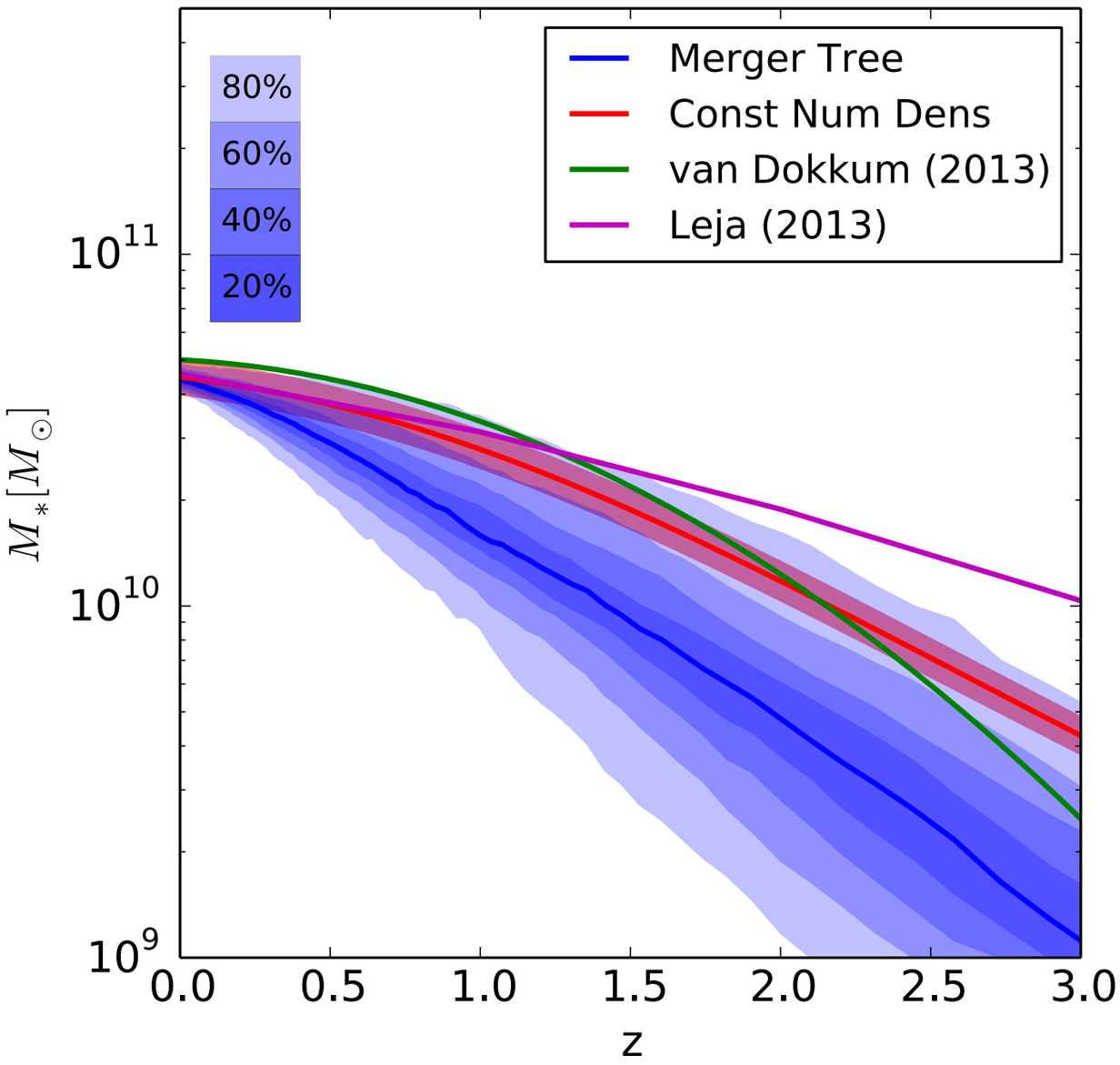
See Also:
Leja+ (2013)
Behroozi+ (2013)
Wellons+ (2015)
Jaacks+ (2016)
Terrazas+ (2016)

Torrey+ (2015b)

Rank Order Analysis

Inferred vs. Tracked Mass Evolution in Simulations

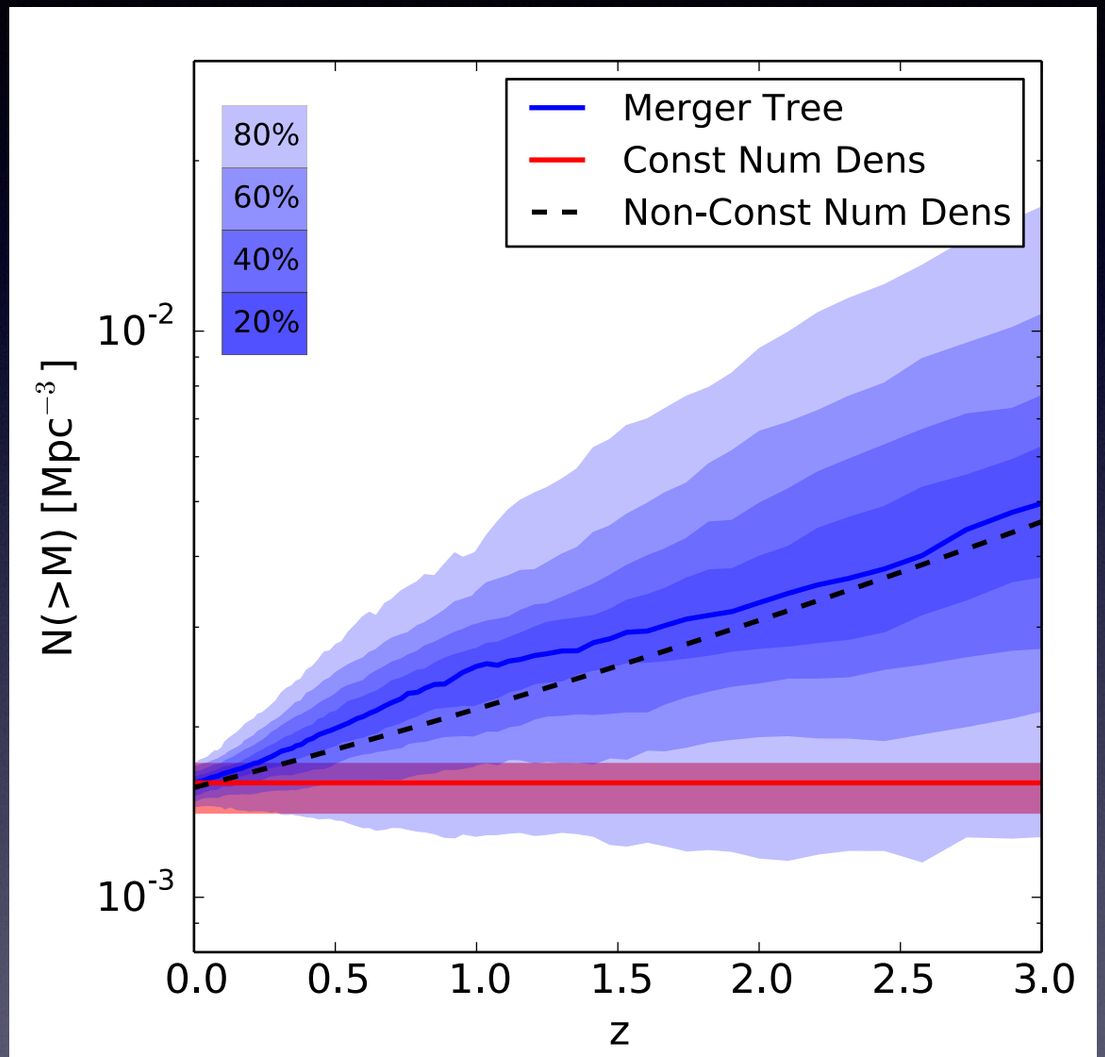


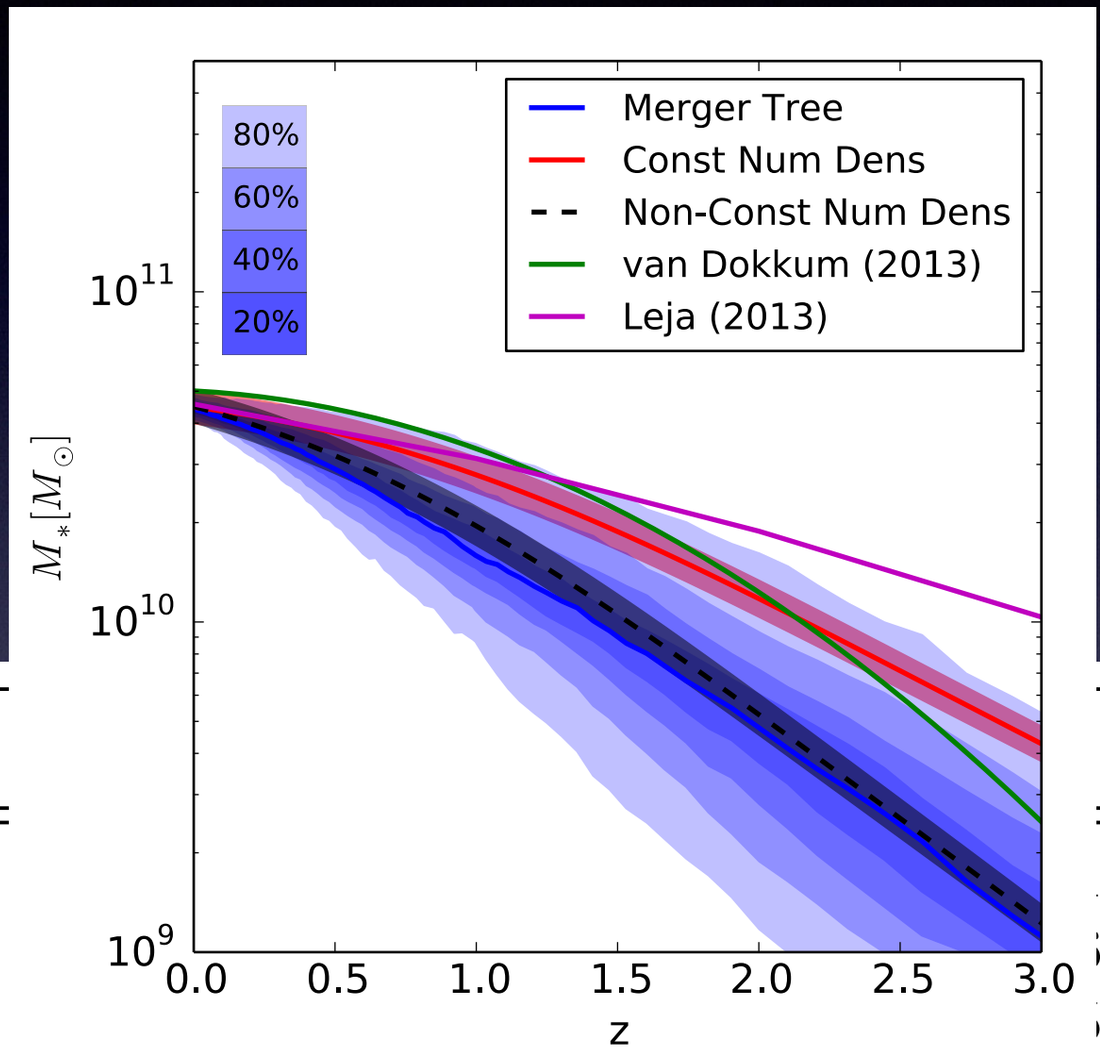


Torrey+ (2015b)

Rank Order Analysis

Number Density Evolution





- Apply General Regression

$$N = A\ \tilde{M}_*^{\alpha+\beta \mathrm{Log}\tilde{M}_*}\ \exp(-\tilde{M}_*)$$

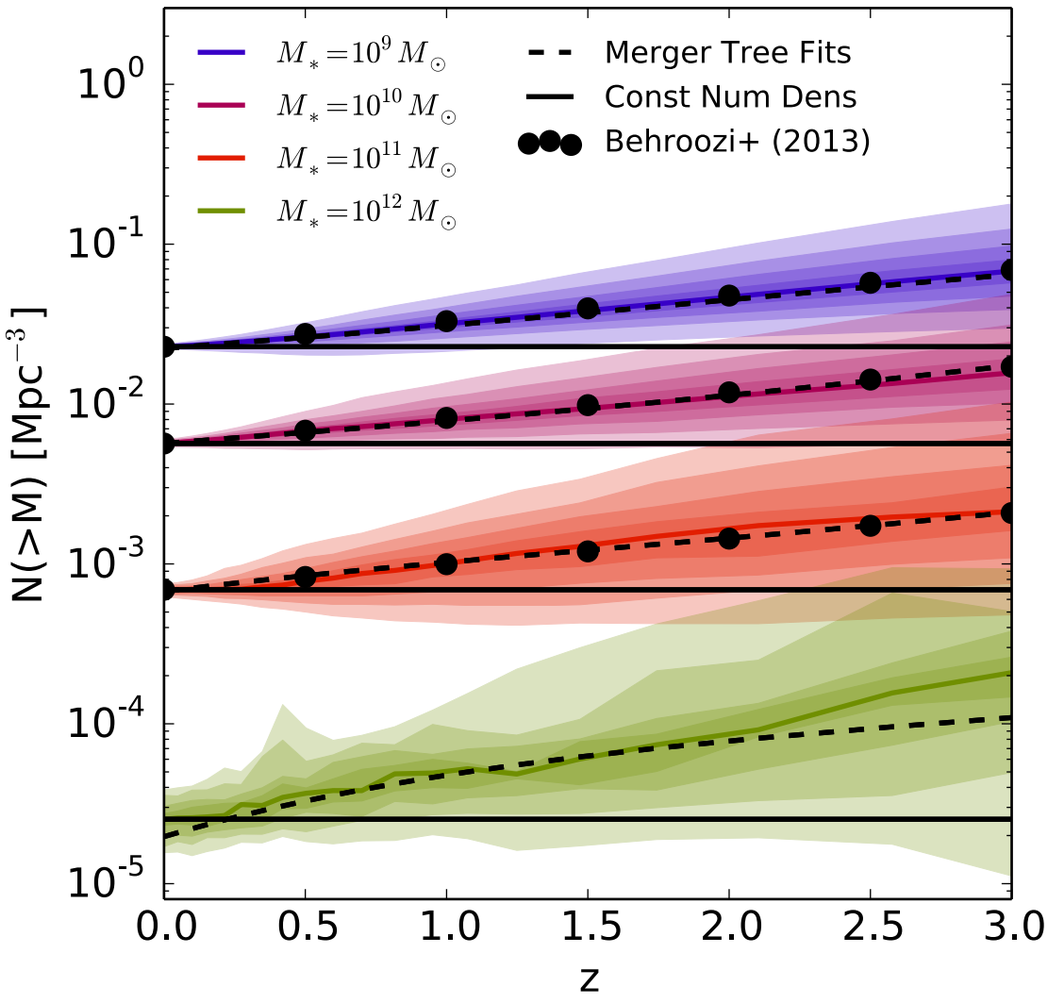
- Invert for Corrected Mass Evo

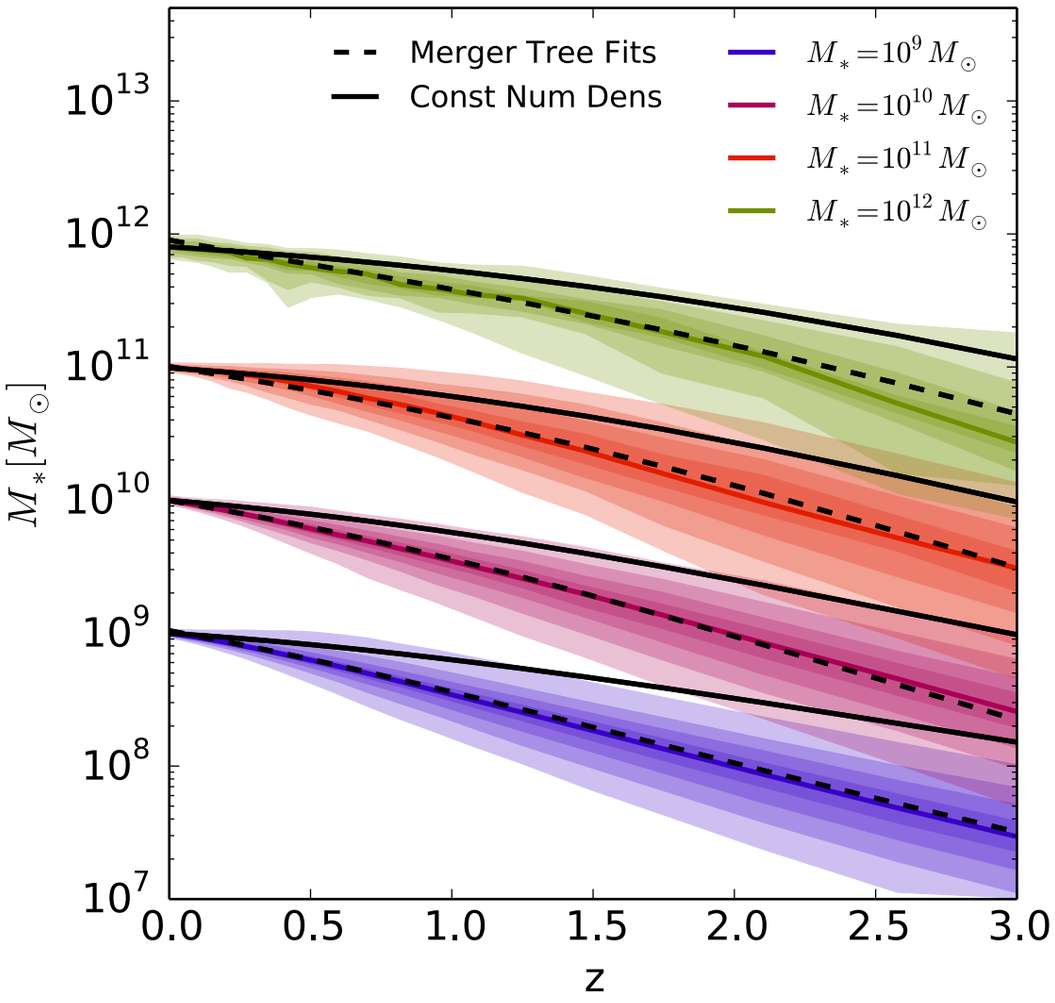
$$m_{10}(z) = m_{10}(z, N_{z=0})$$

Torrey+ (2015b)

Rank Order Analysis

Number Density Evolution





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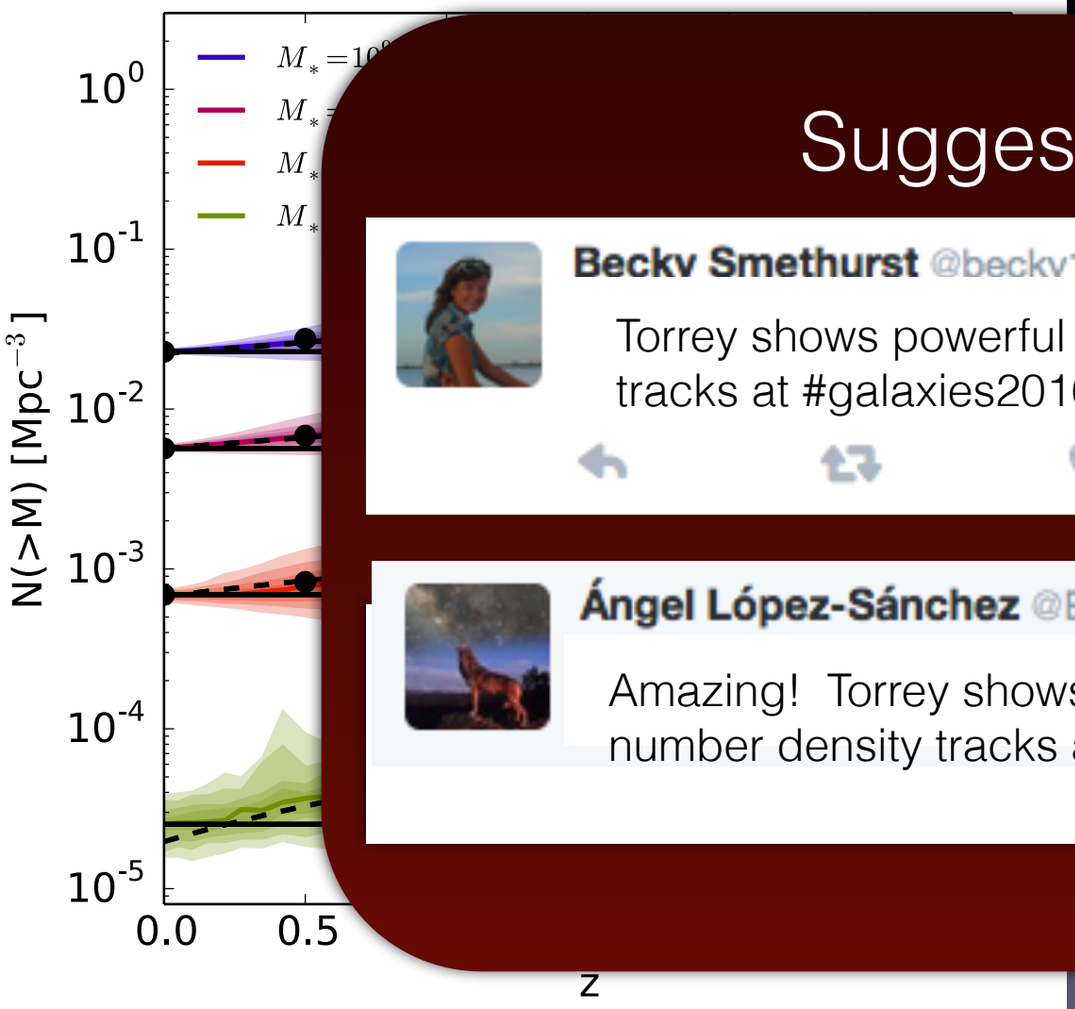
$$m_{10}(z) = m_{10}(z, N_{z=0})$$

Torrey+ (2015b)

Rank Order Analysis

Number Density Evolution



Suggested Twitter Posts:

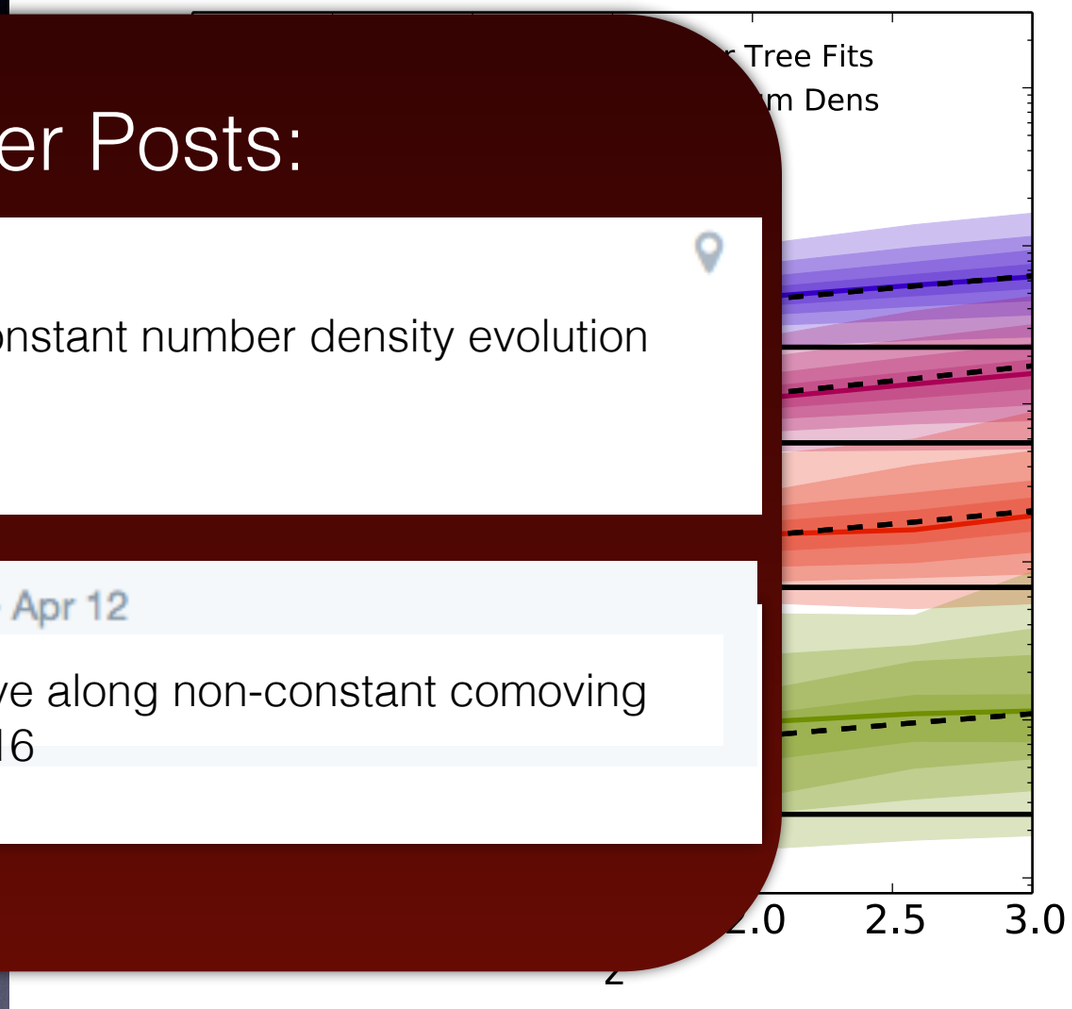
Becky Smethurst @beckv1505 · 2h

Torrey shows powerful derived non-constant number density evolution tracks at #galaxies2016

2

Ángel López-Sánchez @El_Lobo_Rayado · Apr 12

Amazing! Torrey shows galaxies evolve along non-constant comoving number density tracks at #galaxies2016



- Apply General Regression

$$N = A\ \tilde{M}_*^{\alpha+\beta \mathrm{Log}\tilde{M}_*}\ \exp(-\tilde{M}_*)$$

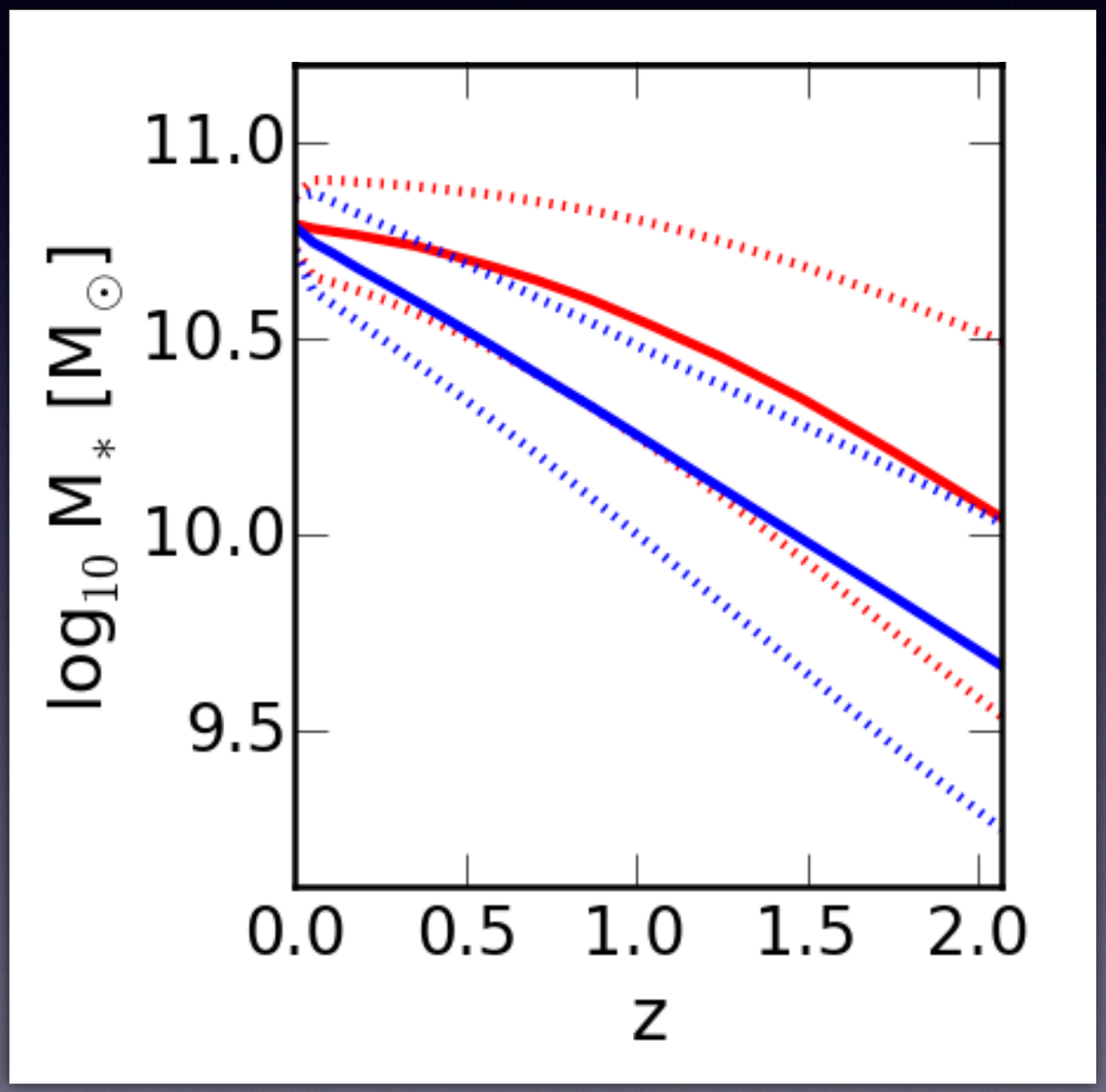
- Same Fit Applies to DM halo mass rank order evolution

Torrey+ (2015b)

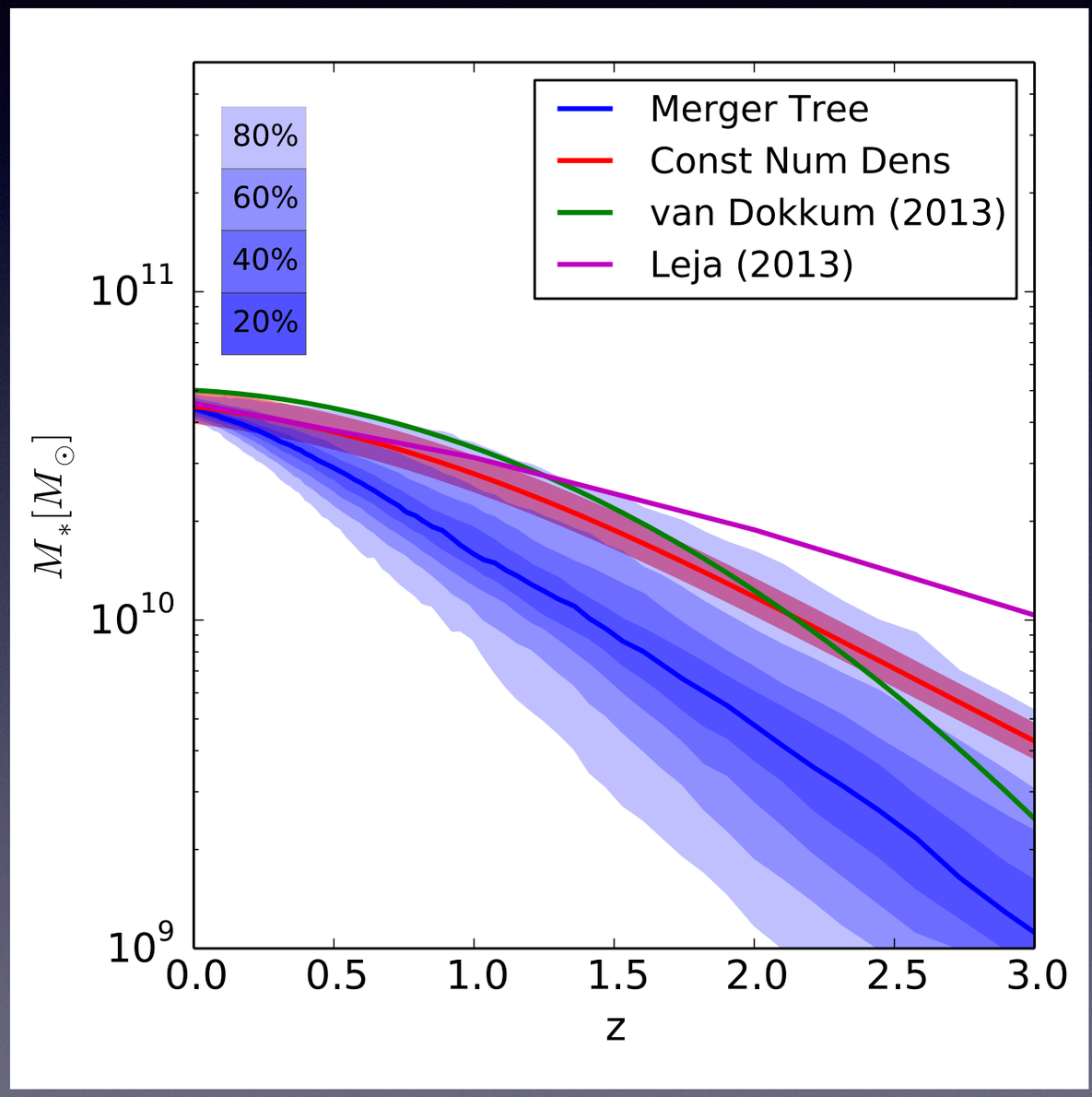
MW Galaxy Progenitors

Consistency of Results: General Prediction of LCDM

Similar mass evolution found in SAMs and Abundance Matching



Terrazas+ (2016 arXiv:1603.09746)

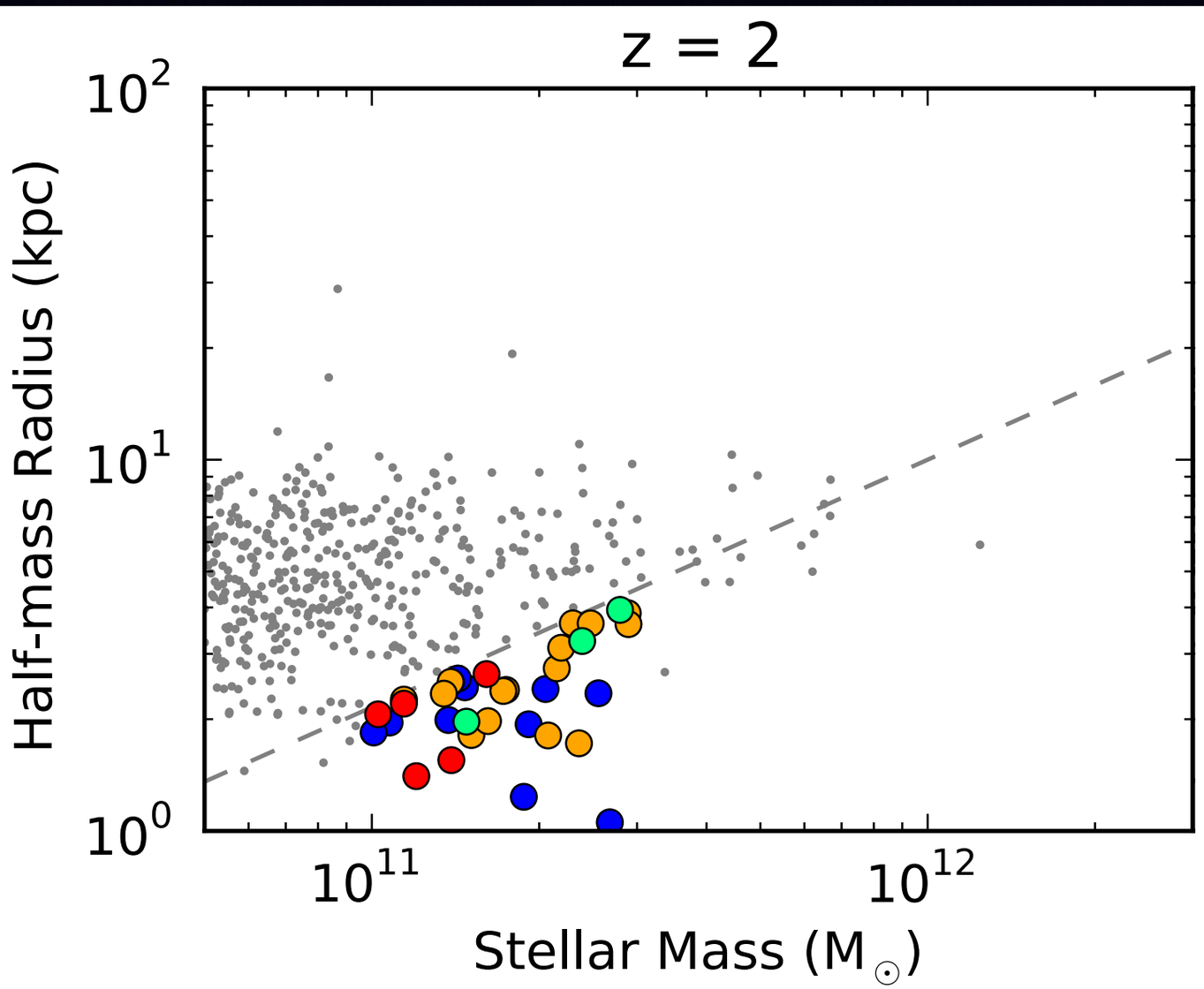


Torrey+ (2015b)

See Also: Leja+ (2013), Behroozi+ (2013), Jaacks+ (2016)

Rank Order Application

Scattered Growth Rates of Compact Massive Galaxies

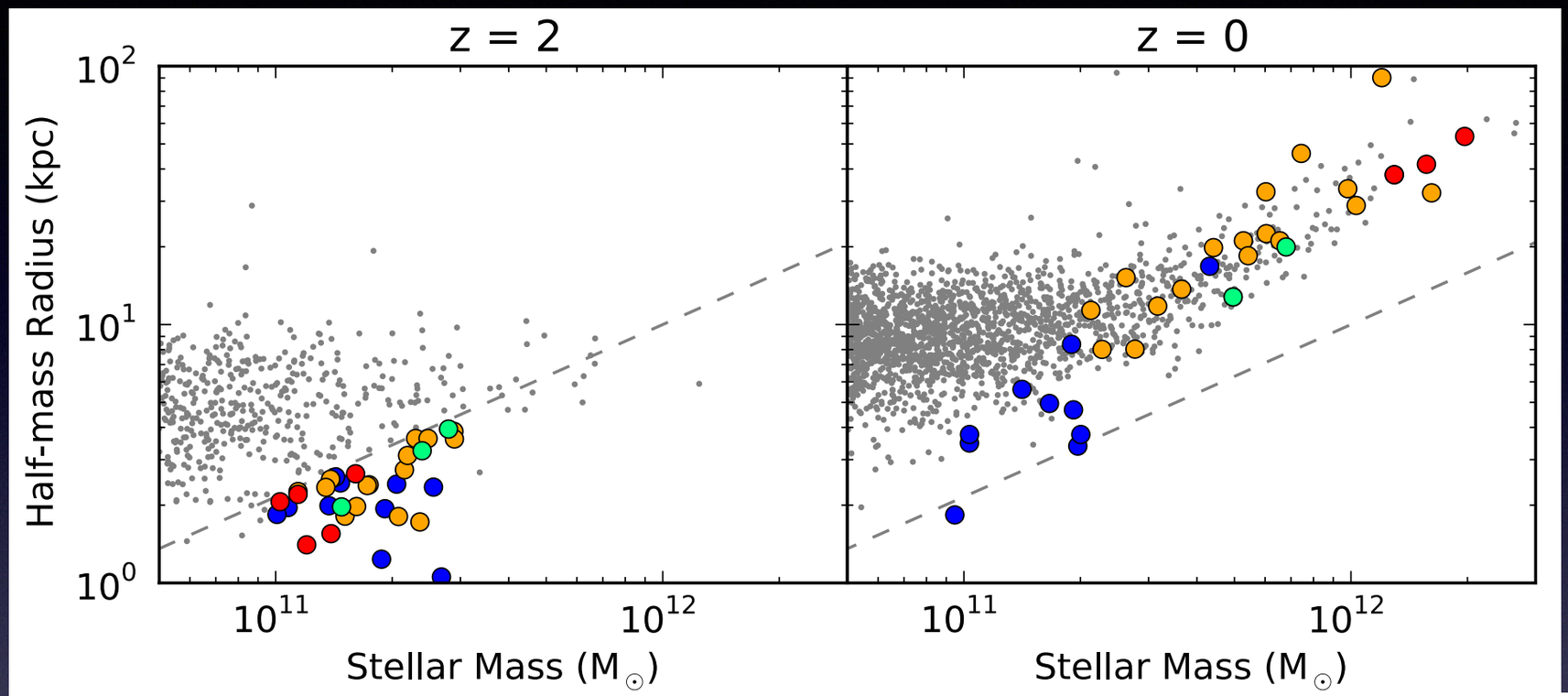


Evolution is **very** dispersive! Why?!

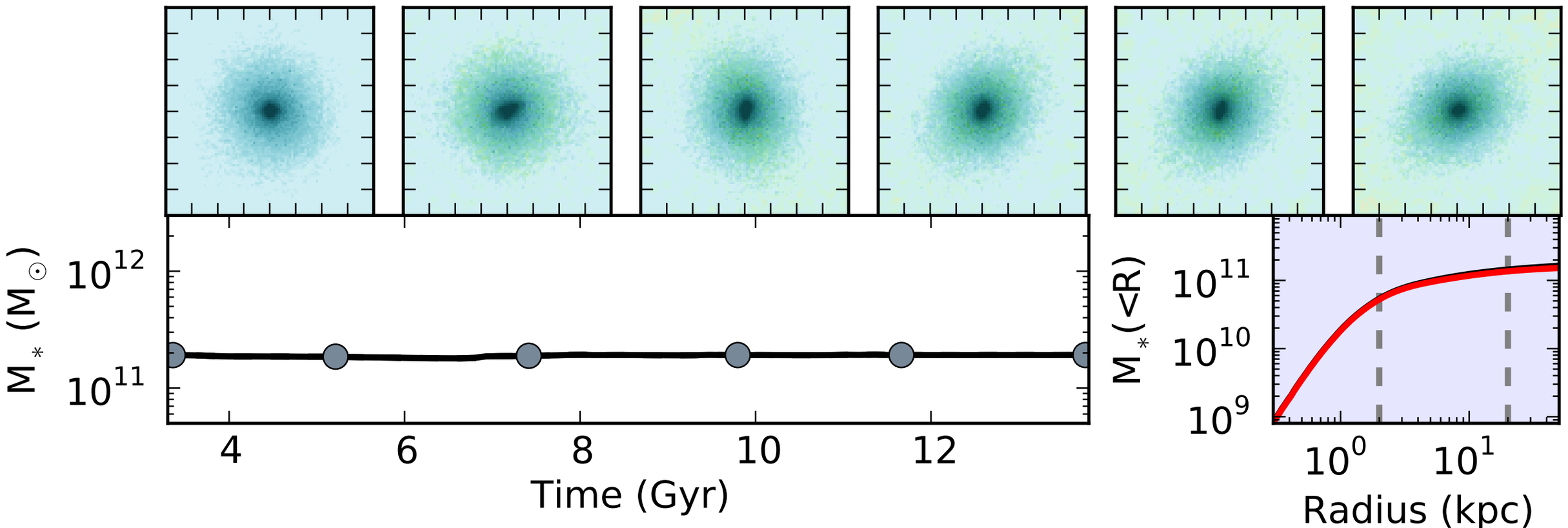
Wellons, Torrey+ (2016)

Rank Order Application

Scattered Growth Rates of Compact Massive Galaxies



Wellons, Torrey+ (2016)



Rank Order Application

Scattered Growth Rates of Compact Massive Galaxies

- About
- About
- About
- About

Twitter live feed:

Brad Gibson @profbradgibson · Apr 13

Torrey: only 50% of massive compact galaxies evolve into the cores of present day Ellipticals #galaxies2016

4

CALIFA Survey @CALIFAsurvey · 2h

It seems Torrey doesn't know how to use my data. #galaxies2016

of low

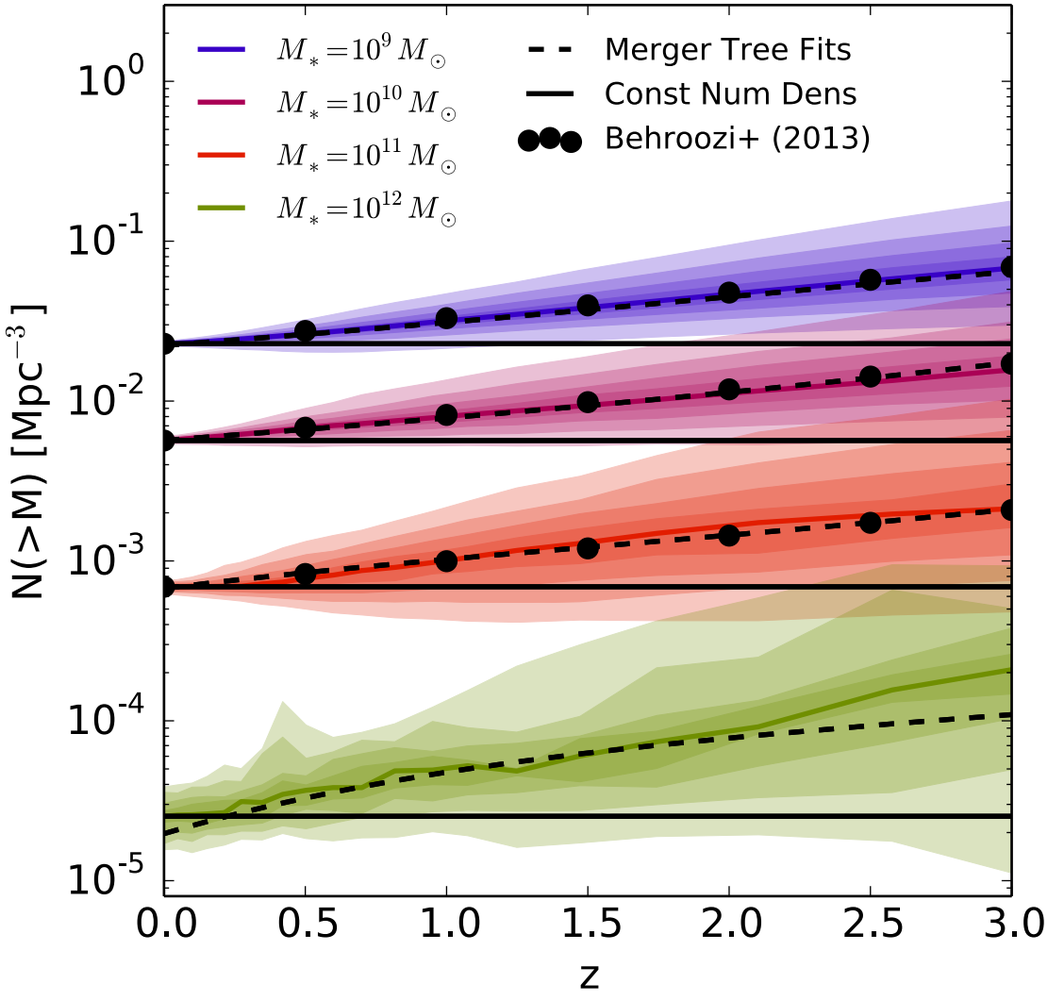
s, and

remai

- About **15%** undergo a **major merger**, and are well mixed by z=0

Rank Order Analysis

Accounting for the Scatter



- Can also measure “scatter”

- Scatter can be measured and fit
- Can *statistically* link progenitors/ descendants while including scatter
- Suggestion: Abandon phrase “typical MW progenitor”
- Replace: “Median mass MW progenitor” ***and*** don’t ignore scatter

MW Galaxy Progenitors

Implications for Observations

Twitter live feed:

Jeffrey Rich @astrojrich · Apr 11

Not accounting for scatter results in a secondary form of progenitor bias! My legs hurt from dancing. #galaxies2016

Oliver Elbert @astronoliver · Apr 11

Accounting for scatter: galaxies evolve along diverse paths, which can be folded into our understanding of galaxy evolution #galaxies2016

3

Torrey, Wellons+ (2016b)
Wellons, Torrey+ (2016)

Illustris: Data Release

- Full dataset publicly released through www.illustris-project.org
  - ~300 TB data — But smaller “chunks” of data are available through web API
  - Relational database (e.g., SDSS, Millennium)
  - Processing and analysis tools
  - All results from today reproducible and extendable…

Nelson+ (2015)

www.illustris-project.org/data/ — Illustris

ILLUSTRIS | ABOUT | PEOPLE | RESULTS | PRESS | IMAGES/VIDEOS | DATA ACCESS | THE EXPLORER | GALAXY OBSERVATORY

There are three primary types of data for each simulation: snapshots, group catalogs, and merger trees. In addition, certain runs and/or snapshots may have additional data catalogs. Select a simulation to browse the available data files and get direct download links:

Parent Volumes | Subboxes | Other Runs

Simulation Name	$L_{\rm box}\,[Mpc]$	$N_{\rm DM}$	$m_{\rm DM}\,[M_\odot]$	$m_{\rm gas}\,[M_\odot]$	$N_{\rm snap}$	$N_{\rm Subfind}(z=0)$	Snaps	FoF	Subfind	SubLink	LHaloTree
Illustris-1	106.5	1820^3	6.3×10^6	1.3×10^6	134	4366546	✔	✔	✔	✔	✖
Illustris-1-Dark	106.5	1820^3	7.5×10^6	0	136	4872374	✔	✔	✔	✔	✔
Illustris-2	106.5	910^3	5.0×10^7	1.0×10^7	136	689785	✔	✔	✔	✔	✔
Illustris-2-Dark	106.5	910^3	6.0×10^7	0	136	735751	✔	✔	✔	✔	✖
Illustris-3	106.5	455^3	4.0×10^8	8.1×10^7	136	121209	✔	✔	✔	✔	✔
Illustris-3-Dark	106.5	455^3	4.8×10^8	0	136	111992	✔	✔	✔	✔	✖

Currently showing **6** runs with **814** total snapshots and **250.2 TB** total data volume,
including **1,259,309,875** FoF groups, **1,175,372,132** Subfind groups, and **2,765,286,583,516** particles.

Web-based Exploration

No need to write code to explore -- by drilling down on interesting objects within any of these browser-based tools you can: get properties, render and explore merger trees, extract particle data cutouts from the snapshots, and see available visualizations.

Community and Support

We welcome community involvement in this project. Have some (fast) python code that performs a specific analysis task on a galaxy, and want to add it to the API so that it can be run on-the-fly? Have some (slow, complex) code that you have developed on a single halo

Summary

1. Constant comoving number density is probably the best current method for observationally linking galaxy populations.

2. Galaxies do not evolve along constant comoving number density evolution tracks owing to galaxy mergers and scattered growth rates.

3. Non-constant comoving number density tracks can be identified and fit within simulations that recover the correct median ND evolution.

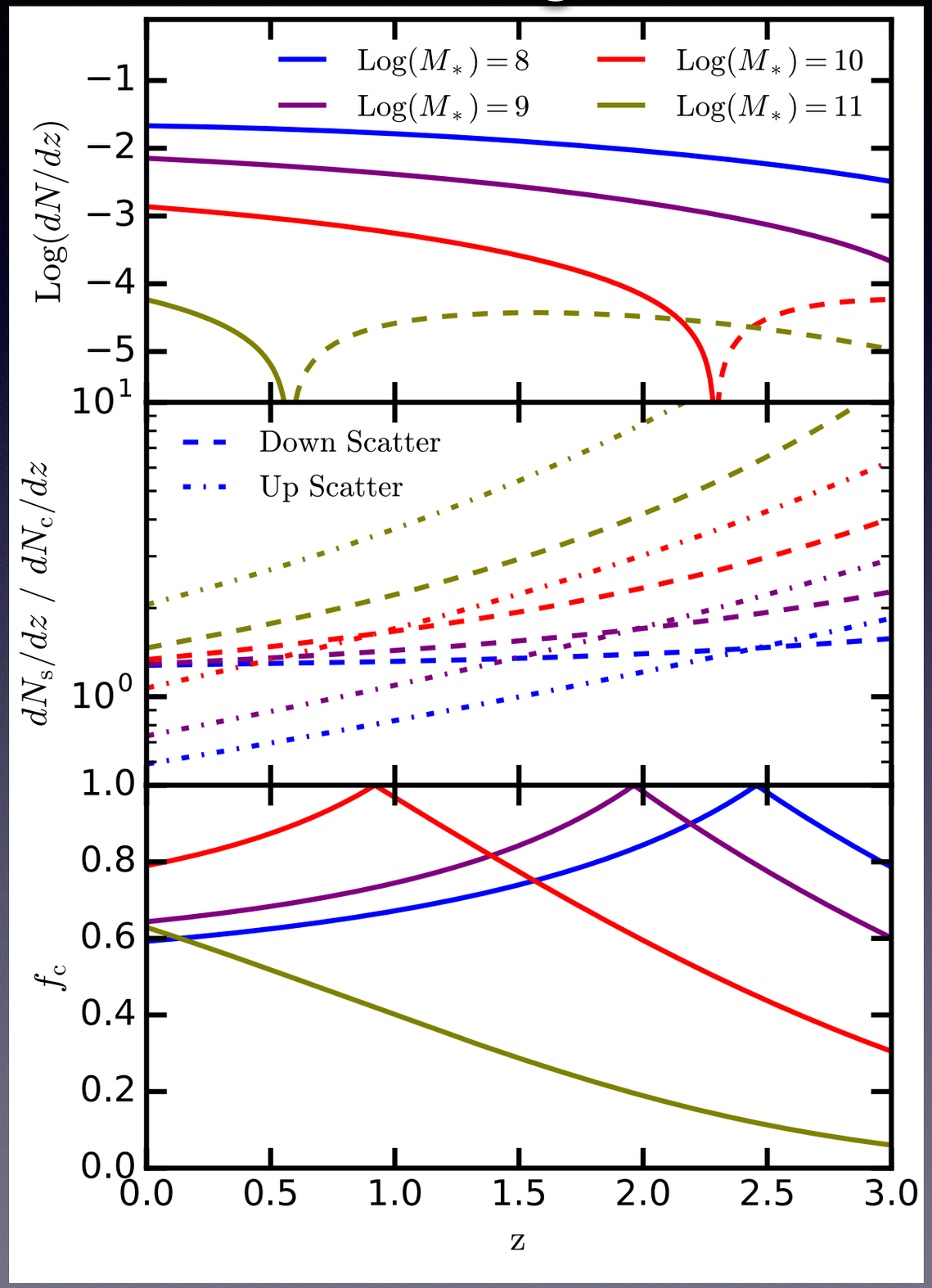
4. Intrinsic scatter in ND growth tracks can also be fit and apples to account for the scatter/diffusion in galaxy growth histories.

5. Using the ND evolution tracks prescribed in our work, improved methods for observationally linking galaxy populations can therefore be applied.

6. Data is public and available through www.illustris-project.org

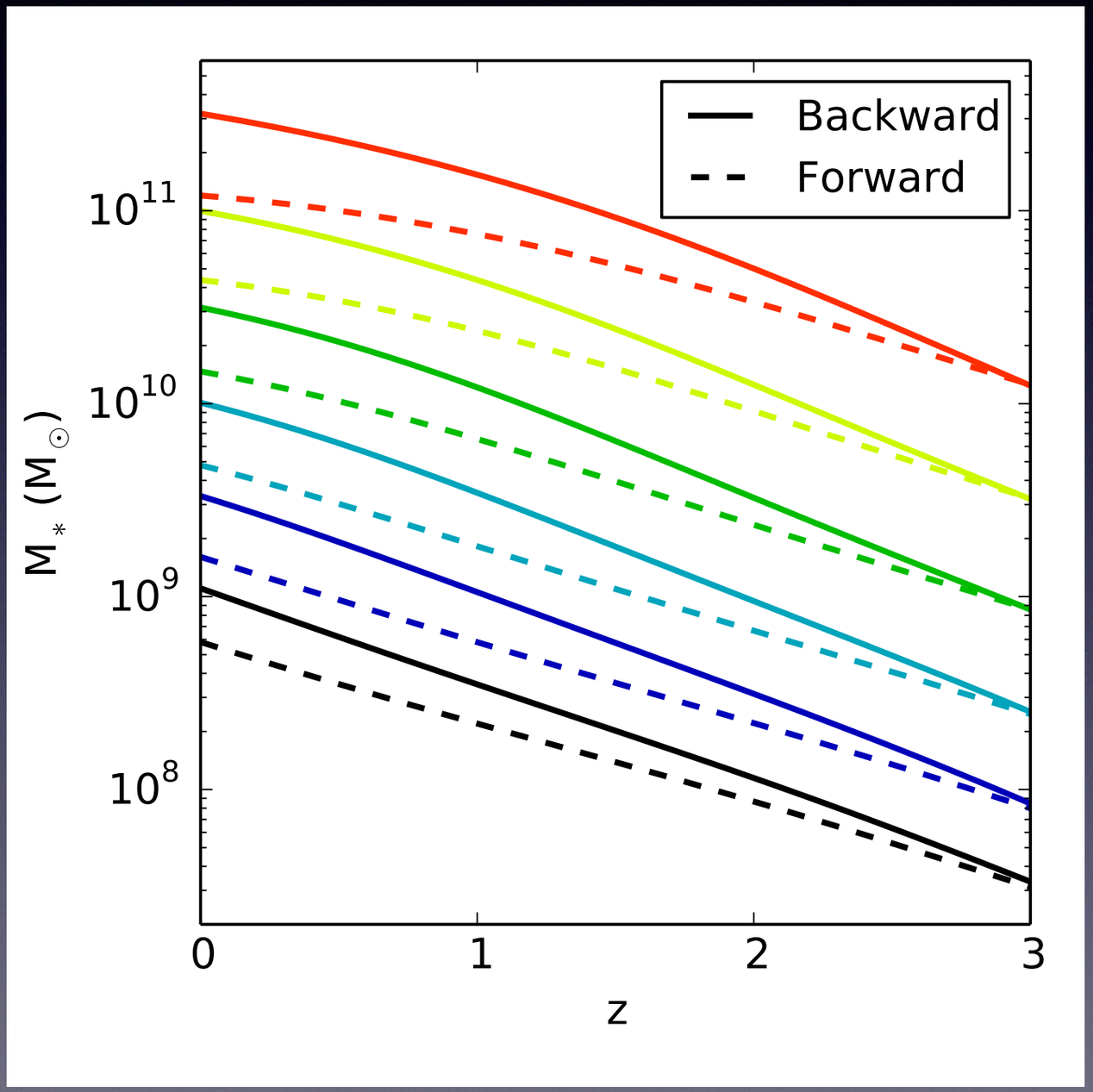
Rank Order Analysis

Caveat 2: Accounting for the Scatter



Rank Order Analysis

Progenitor/Descendant Mass Tracking is not symmetric!



- Descendant tracking is shallower; progenitor tracking is steeper.
- Driven by conditional probability of rapid growth based on shape of the mass function.
  - As me about this, if you're curious.
- Can be accounted for, without complication.