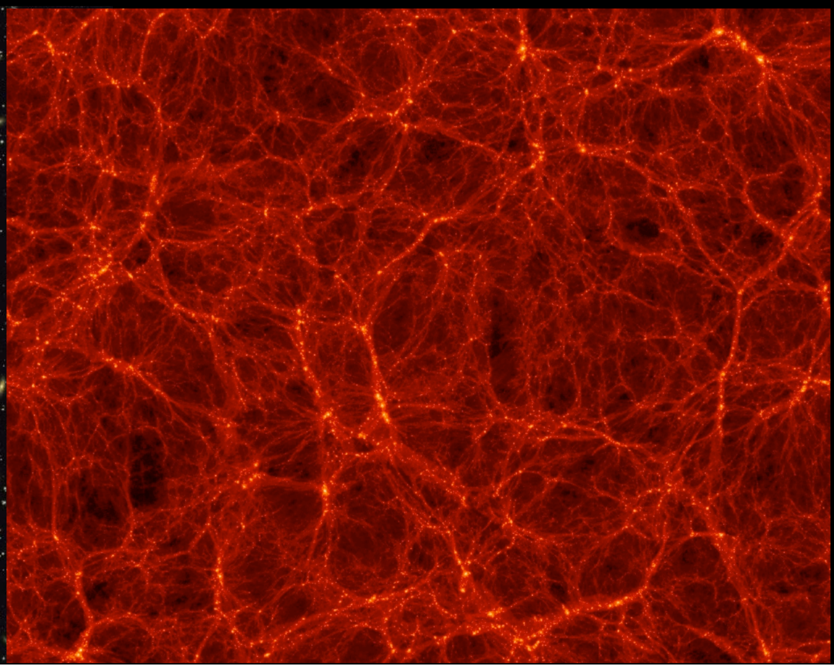
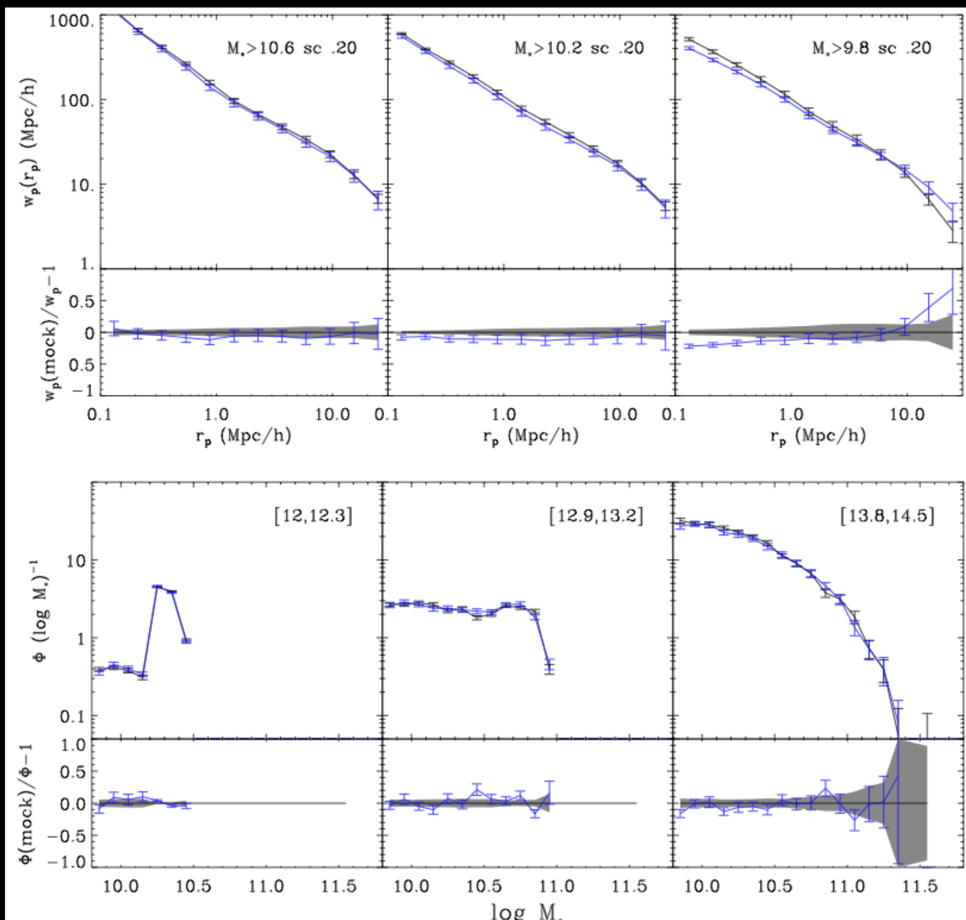
Simulating the Sky, Lecture2

Creating, Testing, and Using
Simulations of the Galaxy Population
in the era of surveys of 10 billion galaxies

Risa Wechsler
KIPAC @ Stanford & SLAC



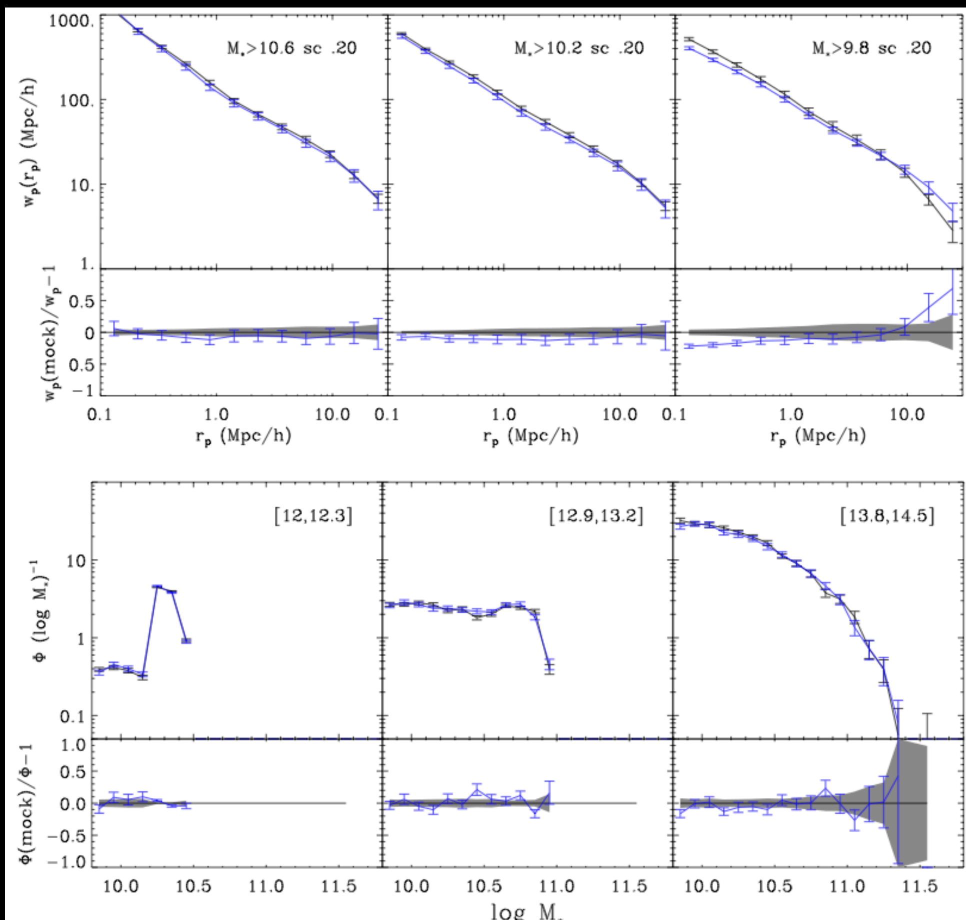
models with abundance matching



- 3 parameters
  - choice of halo property (or: difference between M*-Mh relation for satellites vs centrals)
  - scatter in galaxy properties at a given halo property
  - parameter describing halo stripping: how much can halos be stripped before they fall below the mass limit of the sample

Reddick et al 2012 (arxiv/1207.2160)

models with abundance matching



- with these 3 parameters, can match clustering, group abundance, conditional stellar mass function (+stellar mass function, which is input) within current very tight error bars.
- also (previous studies):
  - galaxy-galaxy lensing
  - 3-pt statistics
  - Tully-Fisher relation

Reddick et al 2012 (arxiv/1207.2160)

this is the simplest case:
one galaxy parameter
(stellar mass or L),
high resolution
simulations.

- extension to other galaxy properties
- evolution?
- can this be modeled without high resolution simulations?
- cosmology dependence?

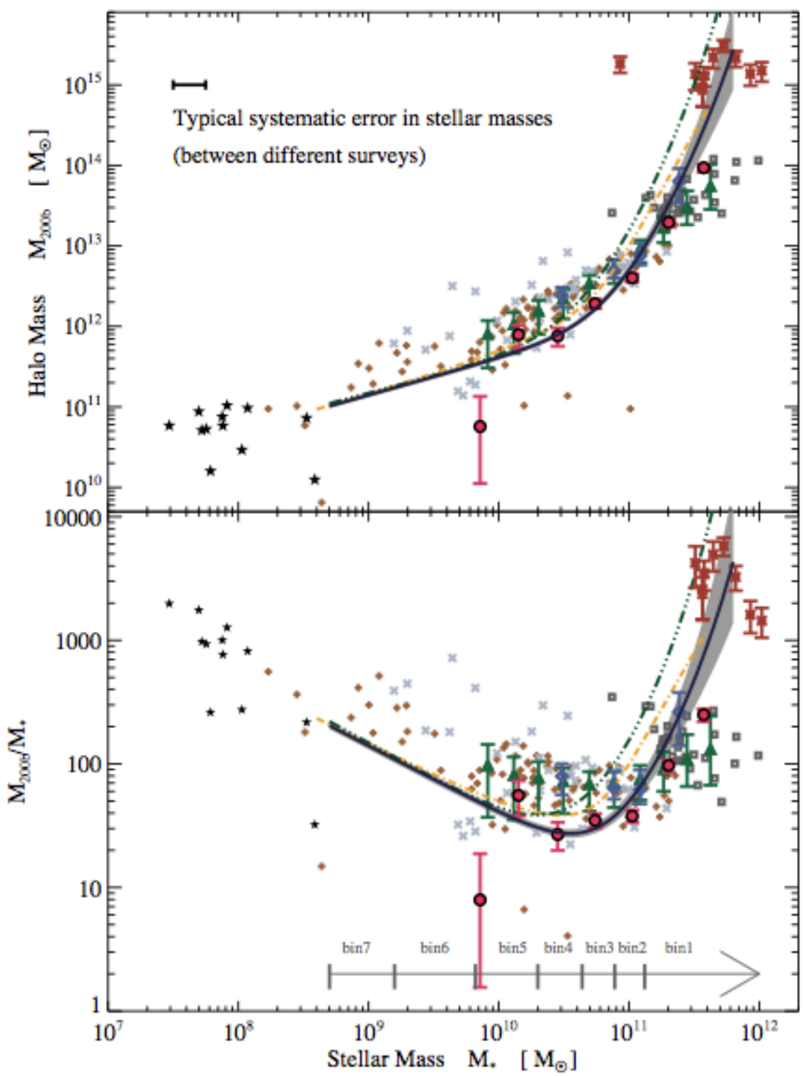
statistics of the galaxy distribution

- two-point correlation function + higher order
- conditional luminosity function
  - central galaxies in groups and clusters
  - satellite galaxies in groups and clusters
- galaxy-galaxy lensing
- galaxy-cluster cross correlation
- etc...

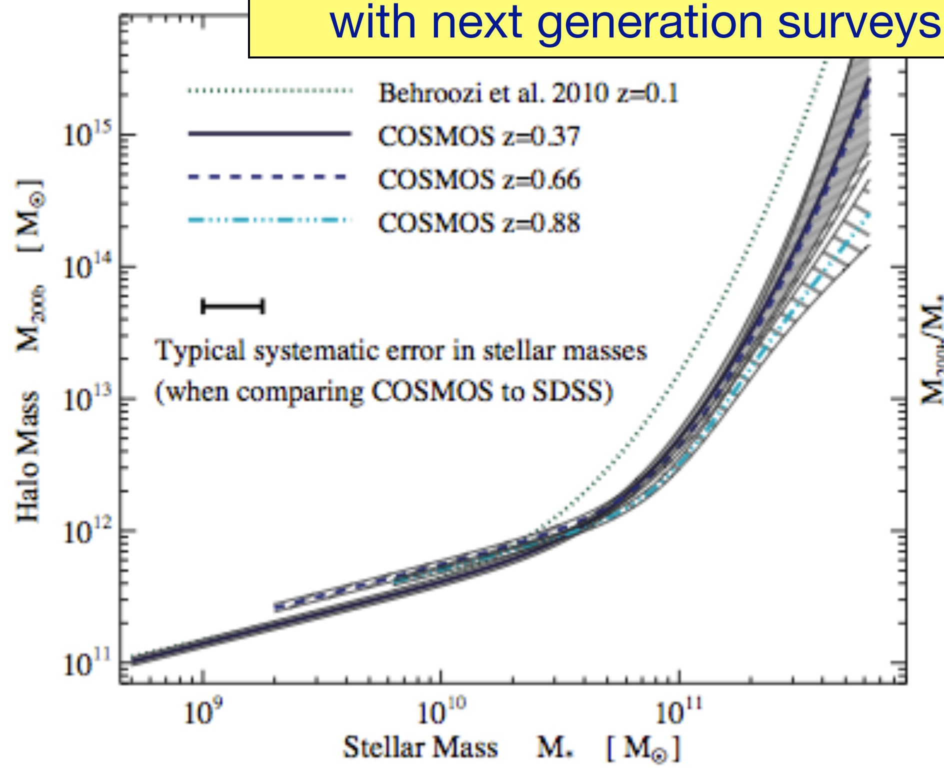
can be used to compare observed and simulated data sets

Joint constraints on M*/M from stellar mass function, galaxy clustering, and galaxy-galaxy lensing from z=0.2-0.9

Leauthaud et al 2012
using data from COSMOS survey



this analysis is for 2 sq. degrees! will be able to make very precise with next generation surveys.

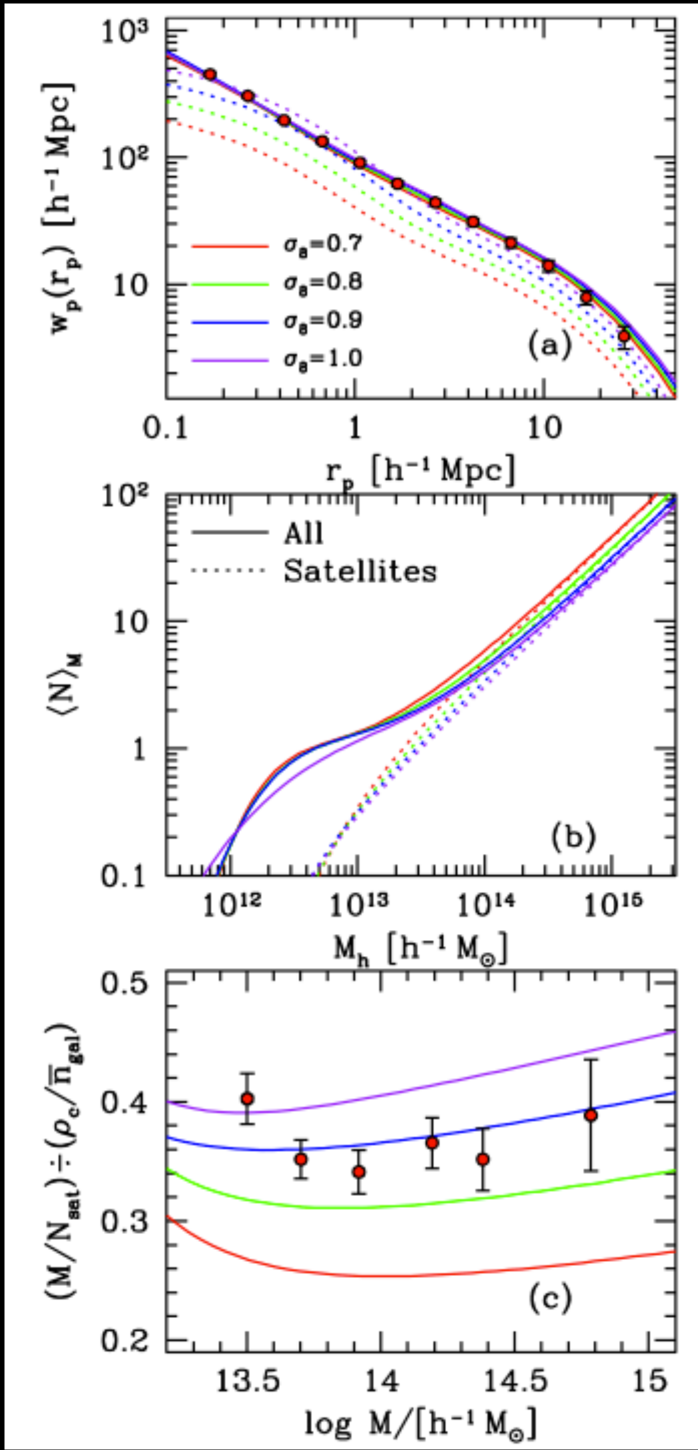


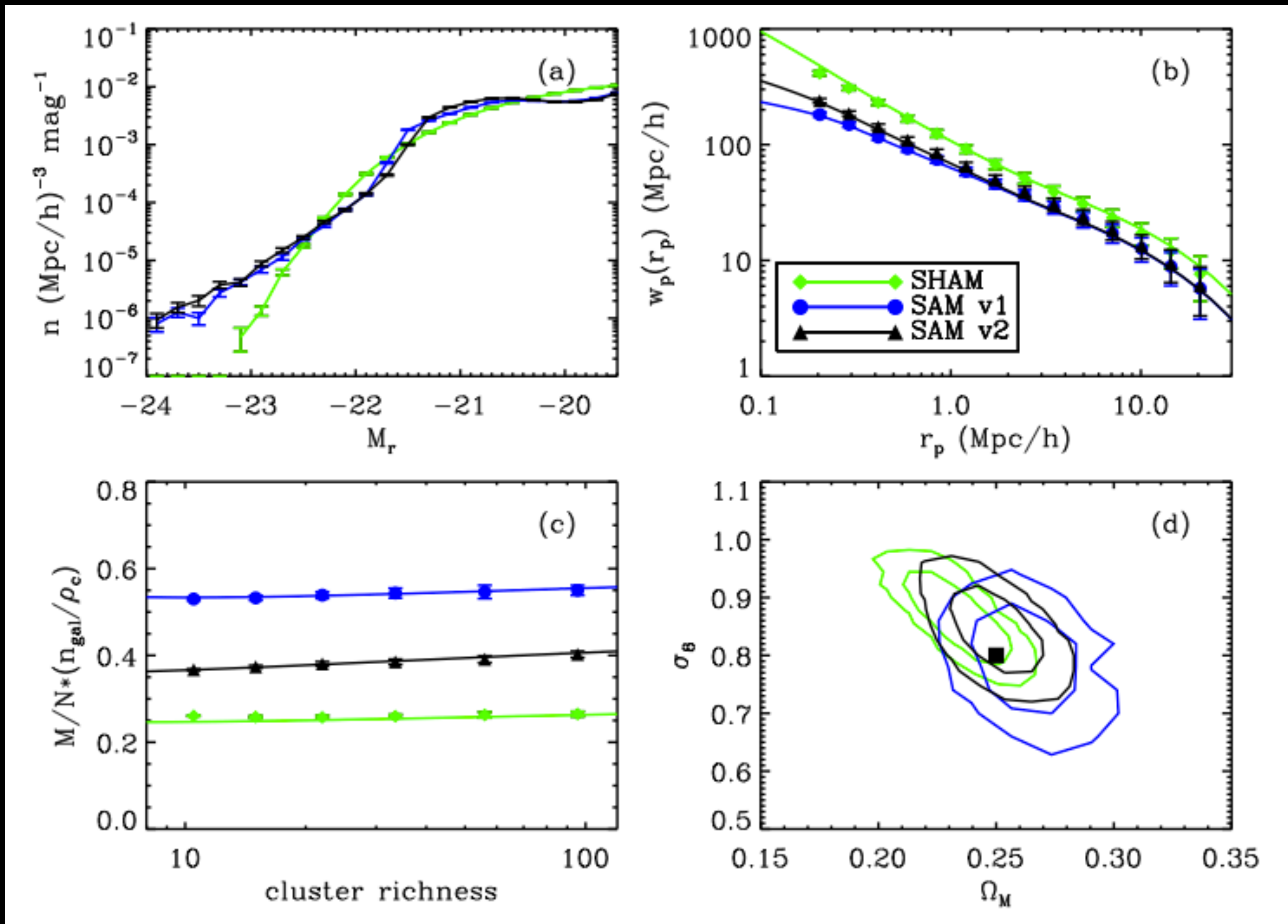
very good agreement with abundance matching -- differences dominated by differences in stellar mass functions

joint constraints on HOD/CLF and cosmology

- basic idea: clustering and cosmology are degenerate with galaxy bias (HOD)
- several observables can break that degeneracy
- e.g. M/N in clusters, galaxy-galaxy lensing

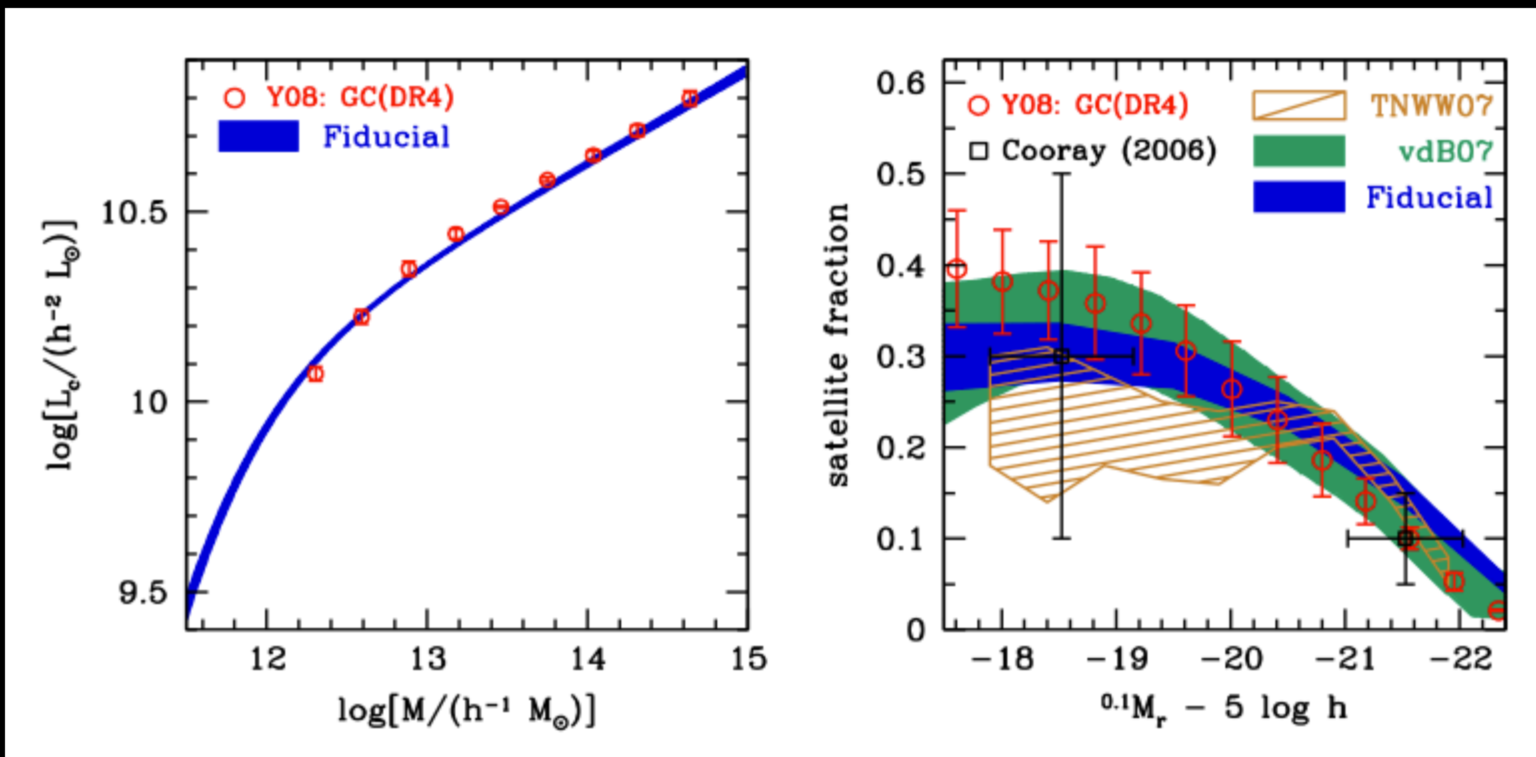
Tinker et al 2012





Reddick et al in prep

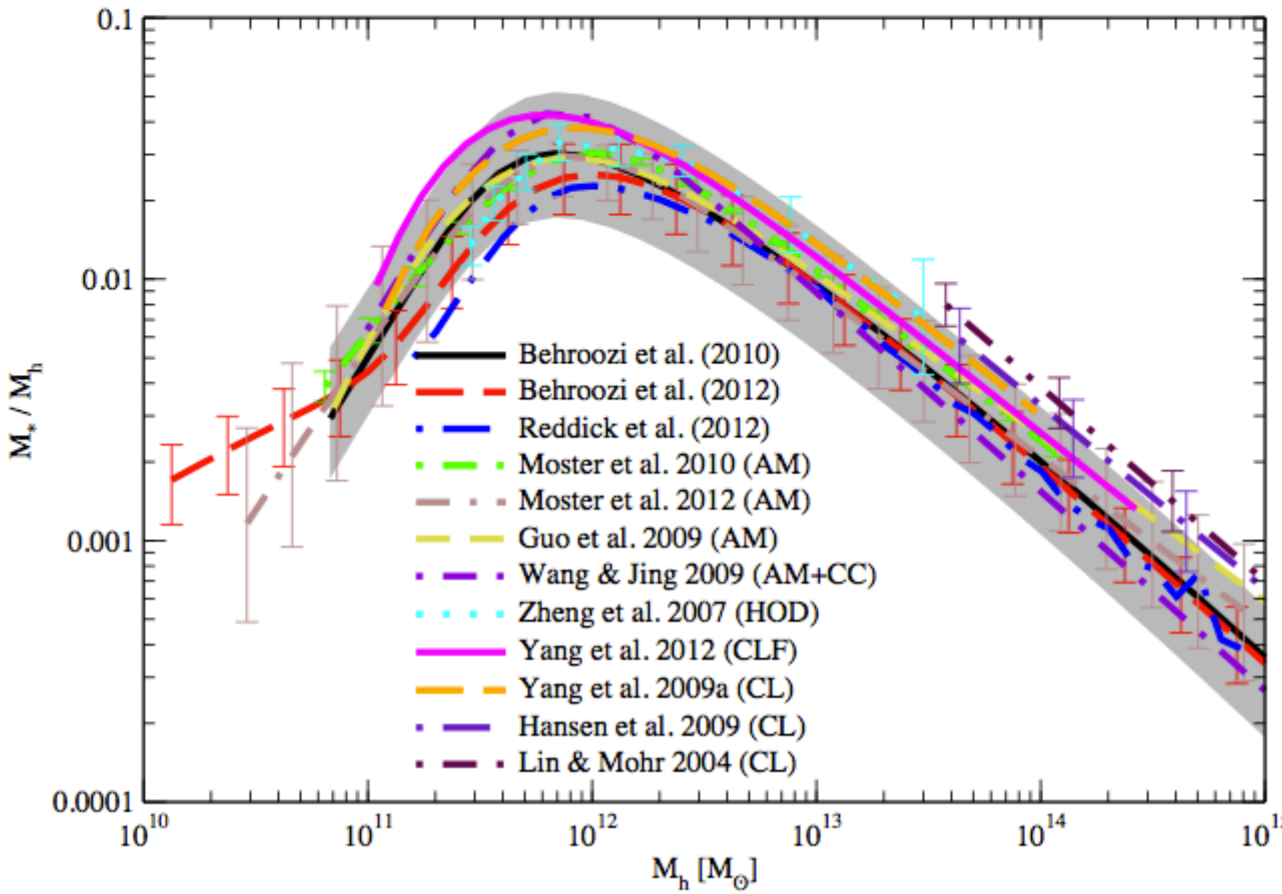
results from abundance matching agree with analysis that jointly constrains CLF and cosmological parameters using galaxy clustering and galaxy-galaxy lensing



CLF generally ~ 5 parameters per mass bins or 10 parameters total

Cacciato et al 1207.0503

Consistency between studies



constraints from abundance & clustering

mass measurements from lensing/dynamics

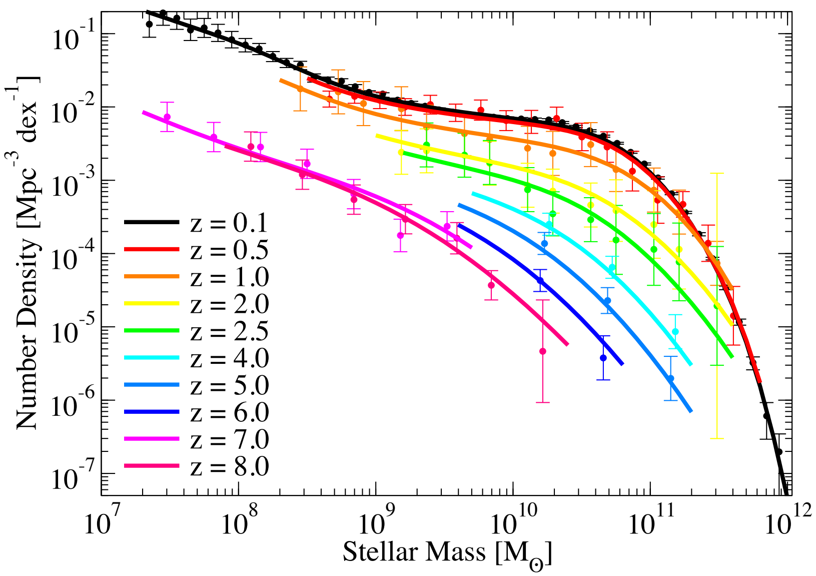
galaxy content of clusters

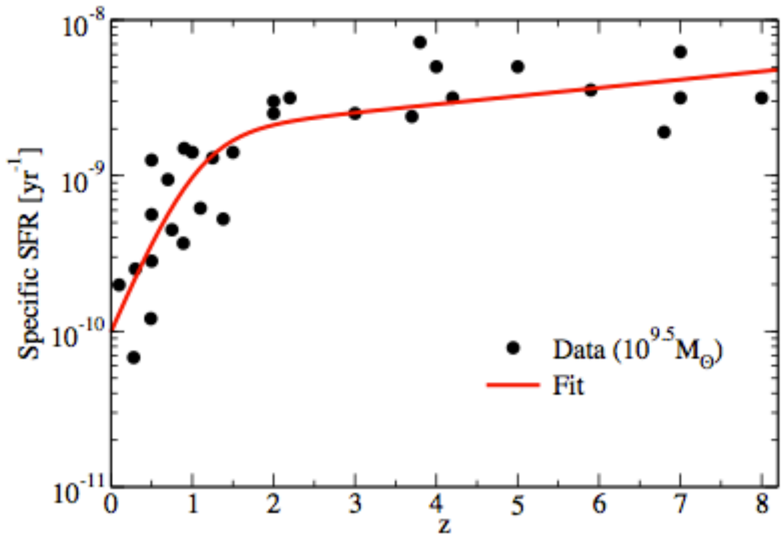
Behroozi, RW, Conroy 2012

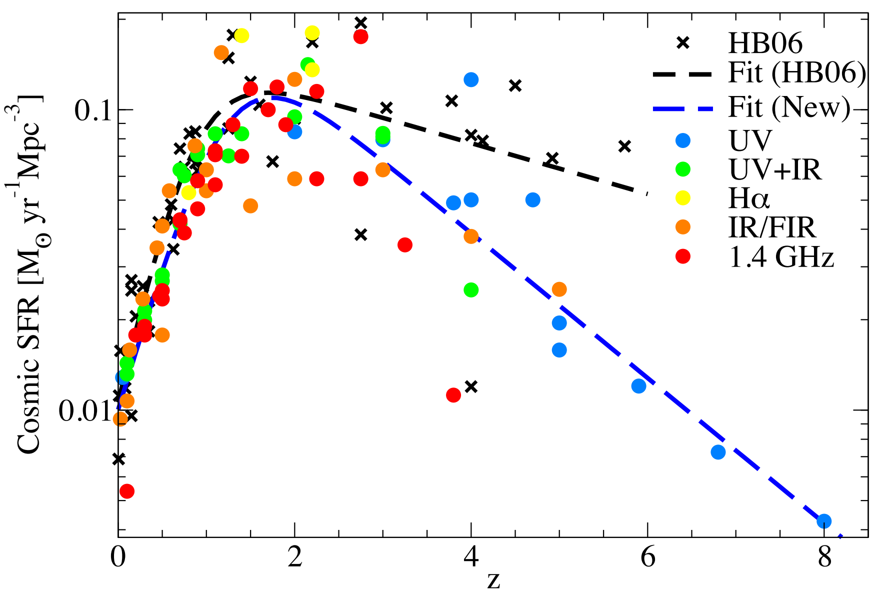
would like to use what we learn from this approach to infer the evolution of the full population of galaxies over all time...

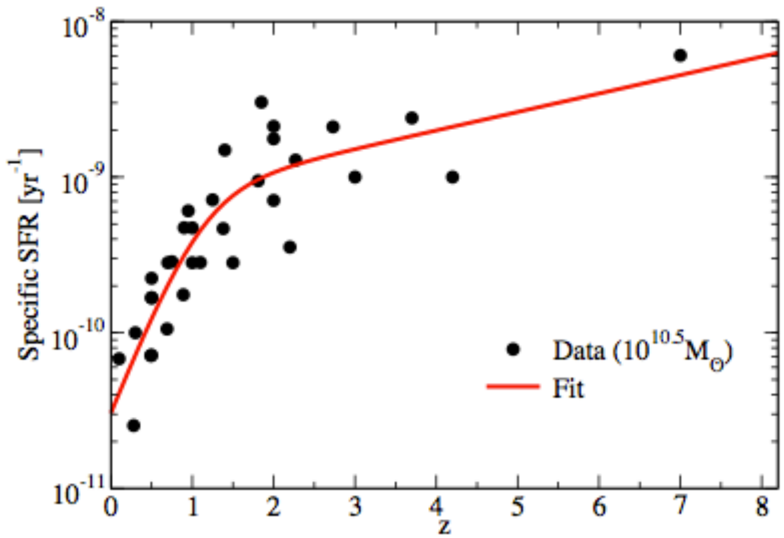
Observed evolution of galaxy stellar masses and star formation rates

Behroozi, Wechsler & Conroy 2012
compiling most recent data in the literature

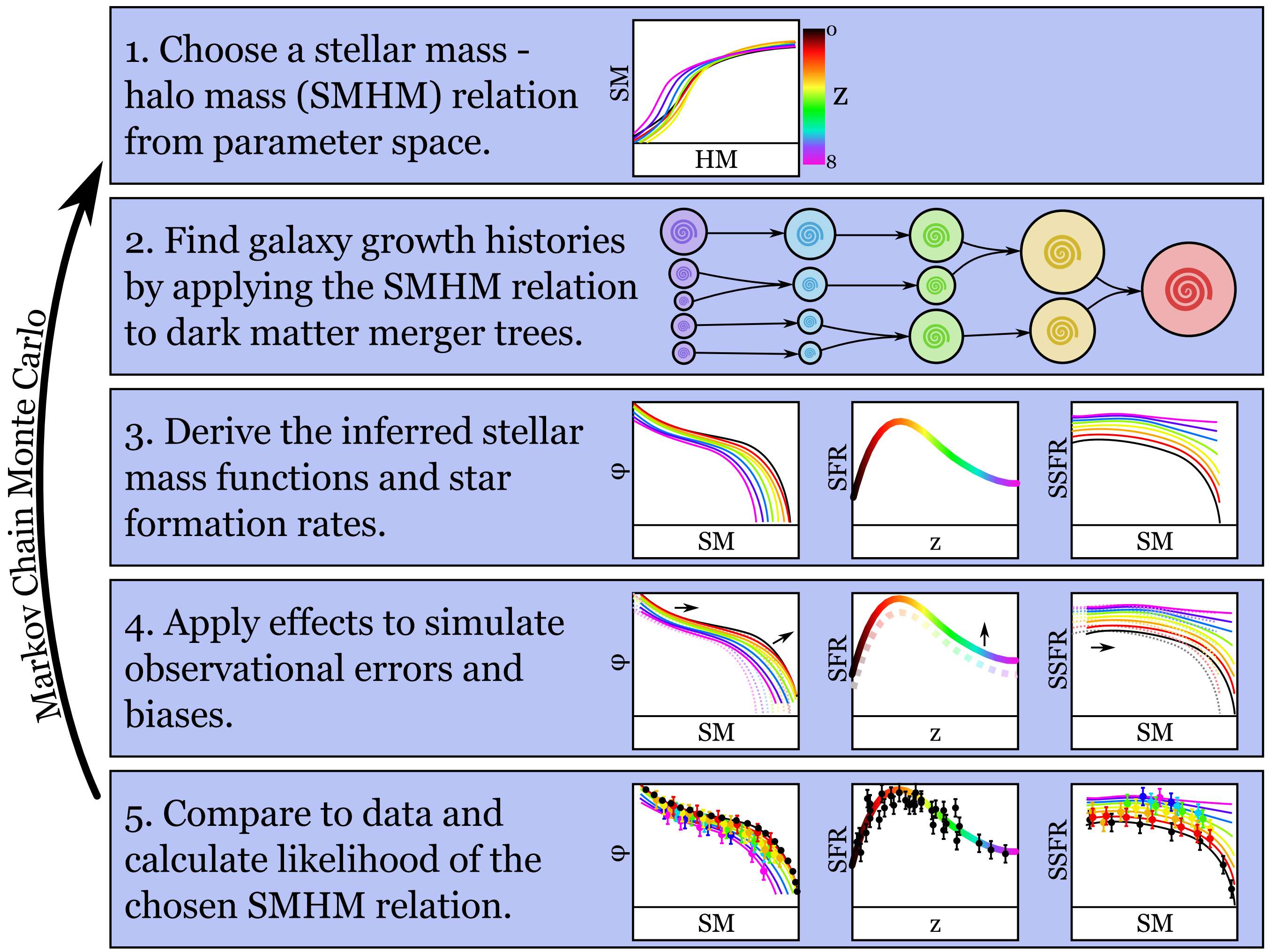








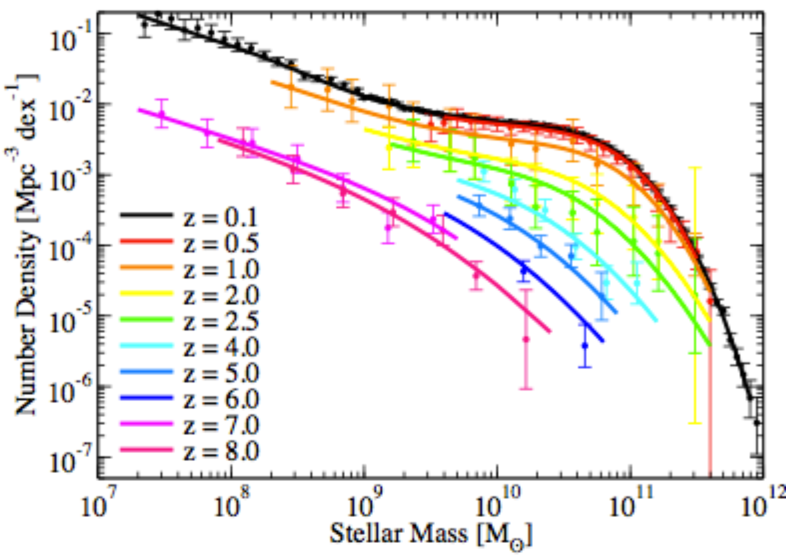
method: combine observations with halo statistics and growth

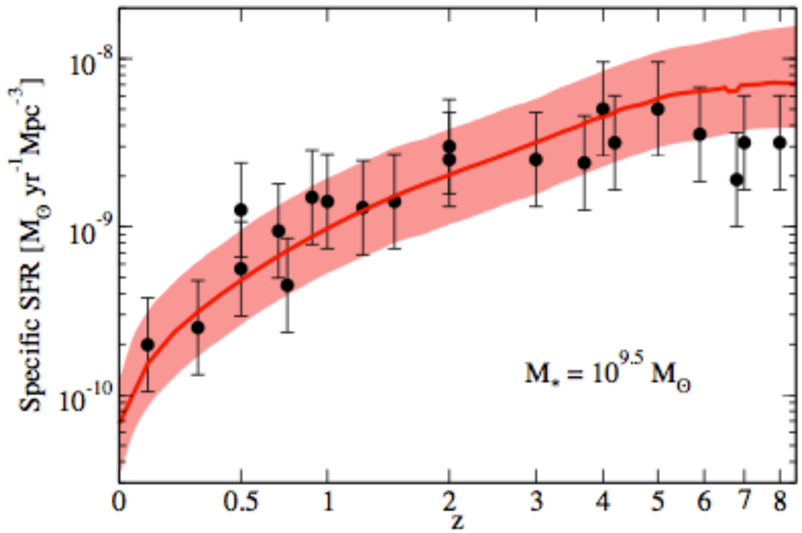


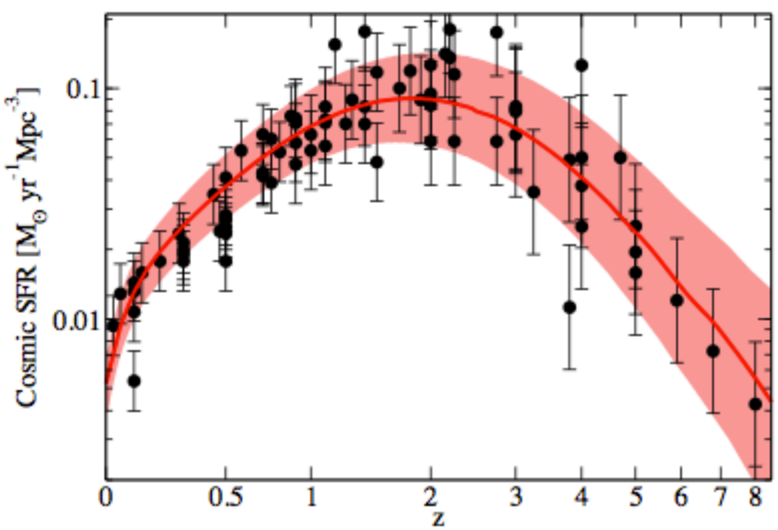
Behroozi, Wechsler & Conroy 2012 extension of approach in Conroy & Wechsler 2009, with better data, more realistic and detailed halo statistics, full accounting for errors and parameter degeneracies.

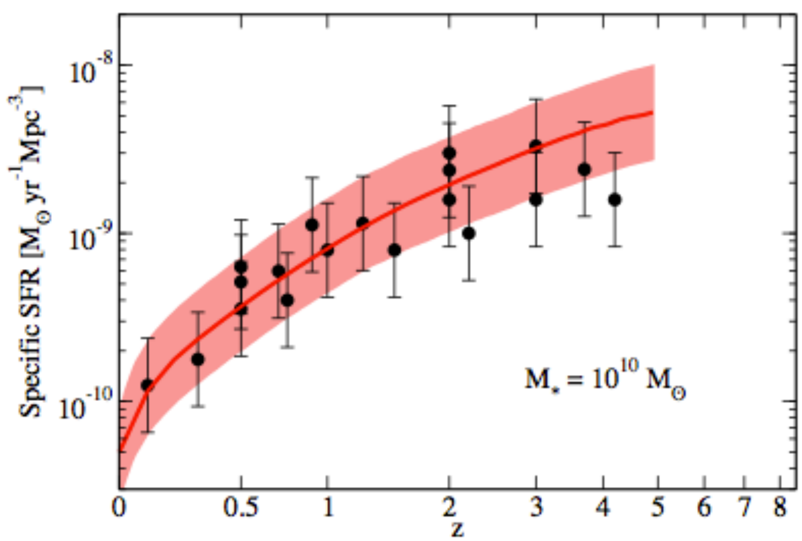
Results for best fit model

Behroozi, Wechsler & Conroy 2012

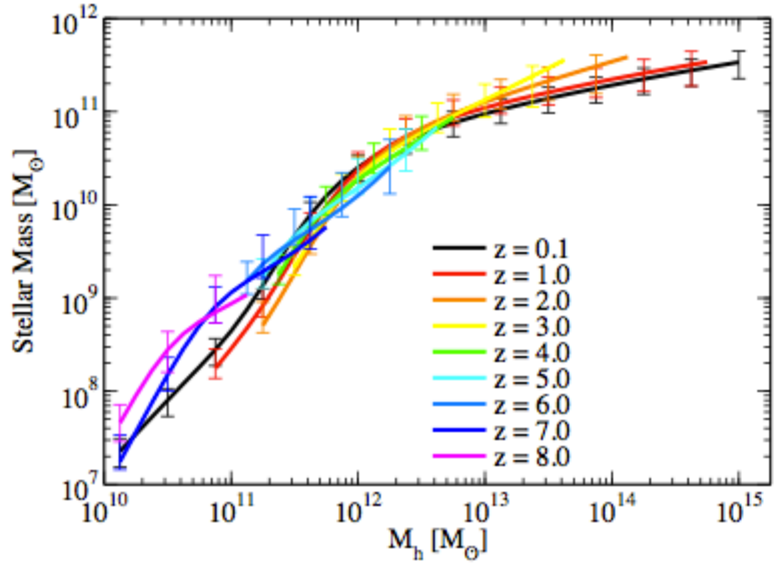


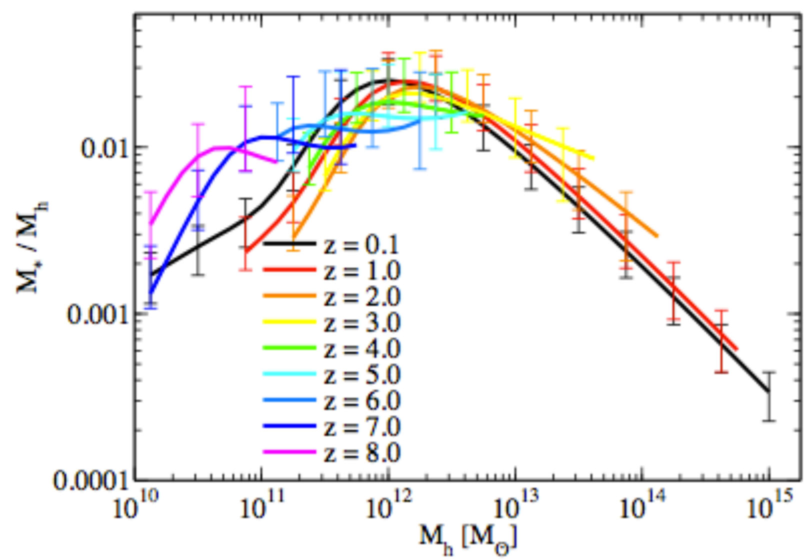


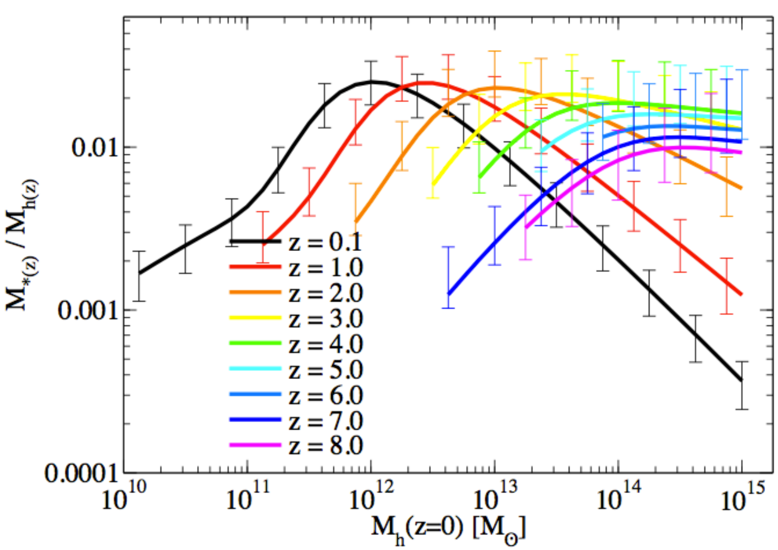




Evolution of the galaxy-halo relation from z=8-0



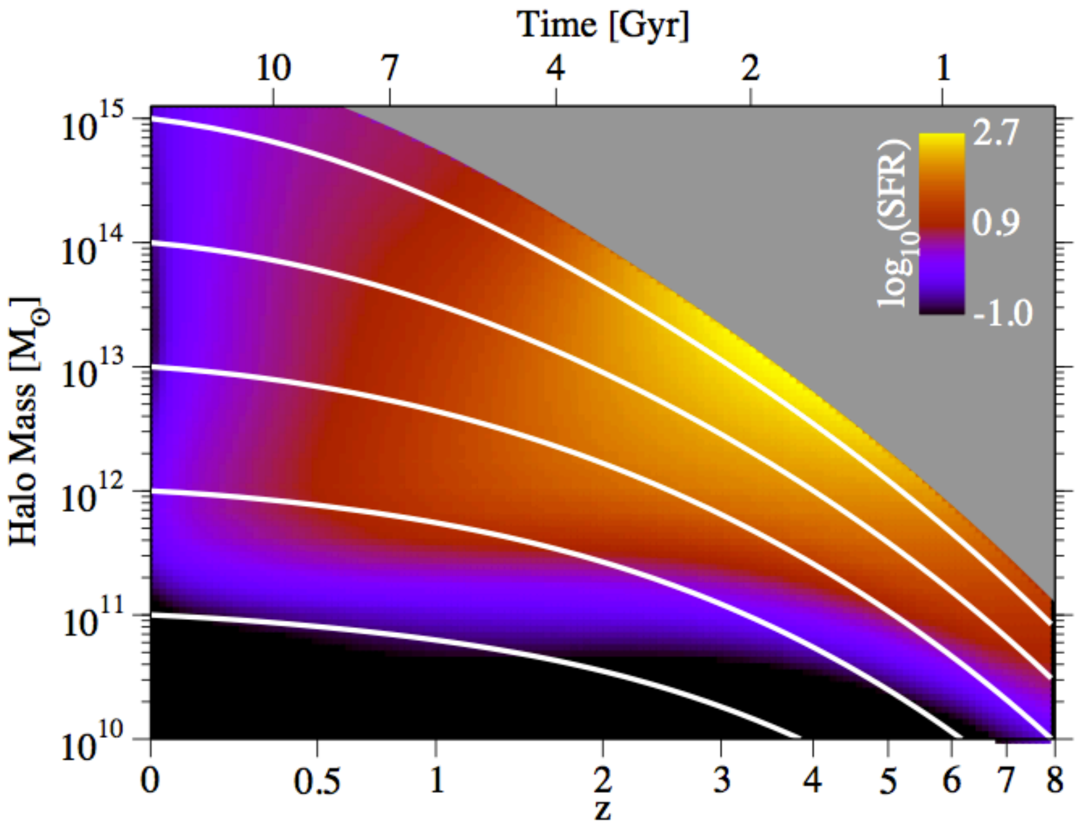




Behroozi, Wechsler & Conroy 2012
see also Conroy & Wechsler 2009,
Behroozi, Conroy & Wechsler 2010

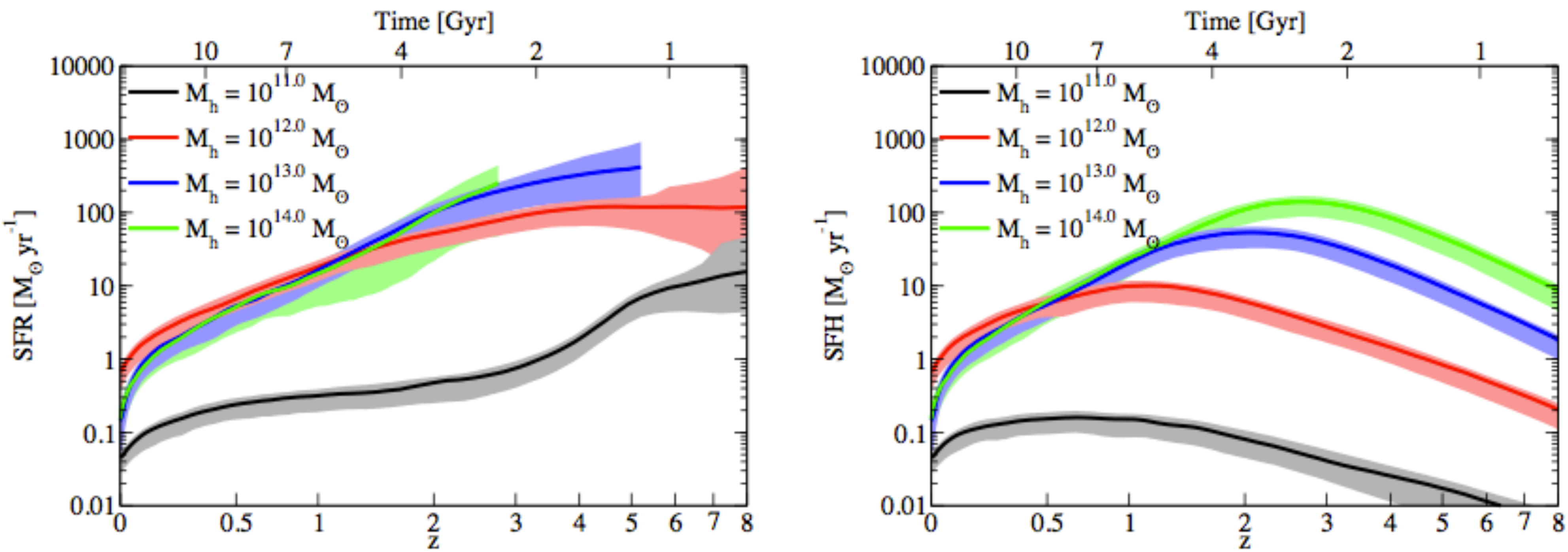
Star Formation Rates

Behroozi, Wechsler & Conroy 2012



typical galaxies evolve along white lines (halo accretion histories). star formation threshold at low halo mass; quenching at high mass.

provides a schematic way to understand many basic features in galaxy formation.
massive galaxies: start forming early, peaked at z ~2-4, then quenched. halo growth continues after galaxy growth. **low mass galaxies:** extended star formation histories, start later and continue longer at a low rate.


Time [Gyr]
10
7
4
2
1
10000
1000
100
10
1
0.1
0.01
$M_h = 10^{11.0}\ M_\odot$
$M_h = 10^{12.0}\ M_\odot$
$M_h = 10^{13.0}\ M_\odot$
$M_h = 10^{14.0}\ M_\odot$
SFR [$M_\odot\ yr^{-1}$]
0
0.5
1
2
3
4
5
6
7
8
z
Time [Gyr]
10
7
4
2
1
10000
1000
100
10
1
0.1
0.01
$M_h = 10^{11.0}\ M_\odot$
$M_h = 10^{12.0}\ M_\odot$
$M_h = 10^{13.0}\ M_\odot$
$M_h = 10^{14.0}\ M_\odot$
SFH [$M_\odot\ yr^{-1}$]
0
0.5
1
2
3
4
5
6
7
8
z

basic message: the cosmological framework of halo growth provides the context for a self-consistent model of the star formation histories, merging histories, and consequent stellar mass growth of galaxies.

currently just constrained to match global statistics,
just average properties.

next steps: model individual histories around this average, model additional observables

future data will allow more detailed tests:
galaxy clustering, galaxy-galaxy lensing, centrals and satellites in groups at high redshift.

DES simulation pipeline

basic idea: need to understand in gory detail how to go from cosmological parameters to observables, so that we can use data to infer cosmological parameters.

DES basics

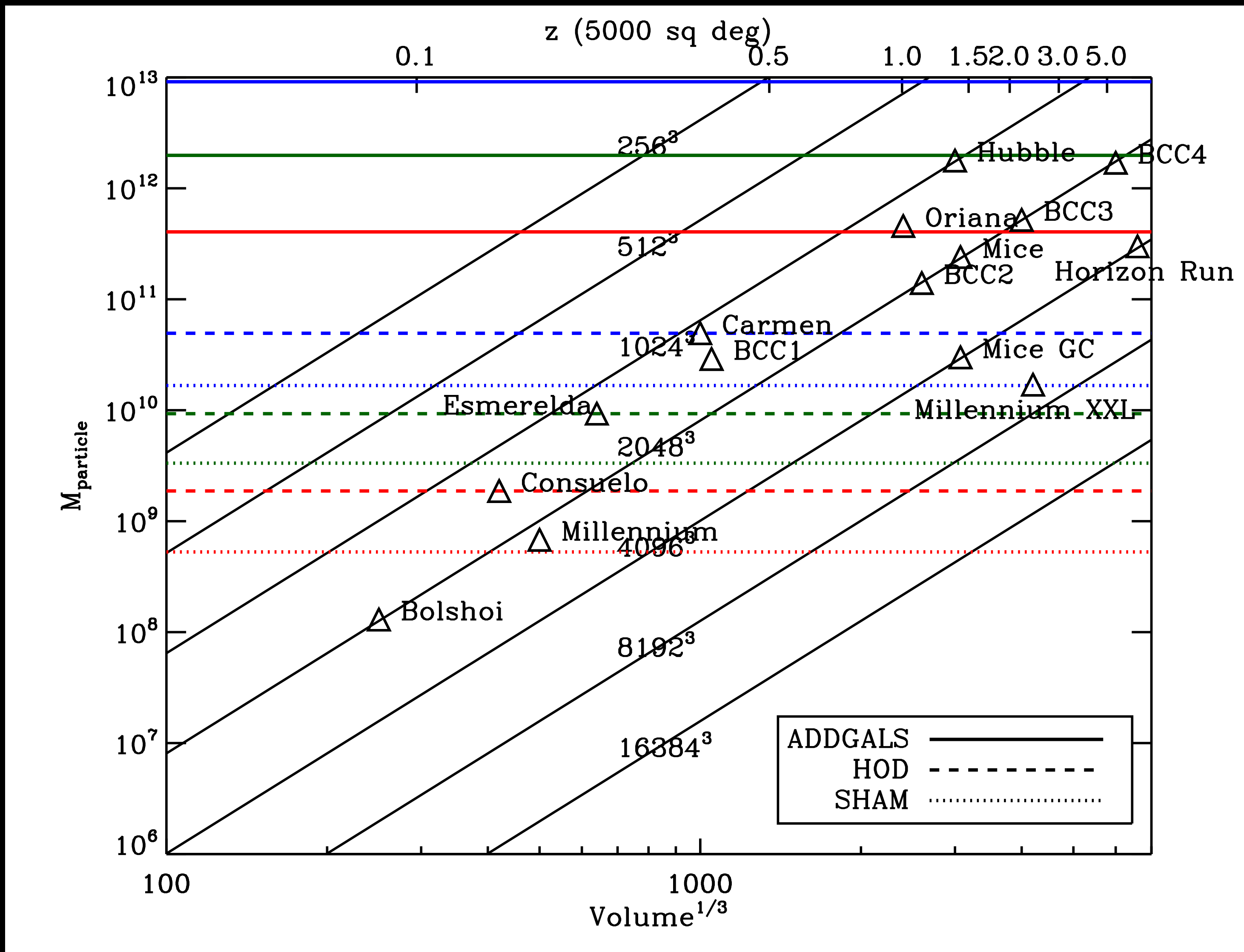
- photometric galaxy survey of 300 million galaxies
- "Stage III" dark energy experiment
  - lensing, galaxy clusters, galaxy clustering/BAO, SN in one survey!
- + lots of additional science! massive high z galaxies, low mass dwarf galaxies, strong lenses, quasars + things we haven't thought of yet.
- starting observations in Dec 2012
- baseline: 5000 deg^2 g, r, i, z, Y = 24.6, 24.1, 24.4, 23.8, 21.3
  - overlap with SPT (1200-2000 sq. degrees)
  - overlap with VISTA J, H, K VHS, VIKING
    [VHS: 20000 deg^2: 21.6, 20.6, 20.0;
    VIKING: 1500 deg^2: 22.1, 21.5, 21.2]
- deep and wide SN survey, 30 deg^2
  JHK from VIDEO: 15 deg^2: [24.5, 24.0, 23.5]

DES Simulated Sky Surveys

DARK ENERGY SURVEY

- Want simulations that allow us to do a realistic cosmology analysis for the main DE probes
    - cluster abundance and clustering
    - galaxy clustering / BAO
    - lensing / shear-shear; galaxy-galaxy lensing; cluster mass calibration
    - + galaxy, MW science, etc...
- Goal is to produce a full simulated sky that reproduces
    - observed properties of galaxies
    - large-scale structure of galaxies
    - realistic impact of shear on galaxies
    - as many relevant observational systematics as possible
- Want to produce *many* full DES area and depth sky surveys; need relatively lightweight simulations (not most heroic run ever)
    - many cosmological models
    - a variety of galaxy models / systematics for a given cosmology
    - multiple skies for covariance

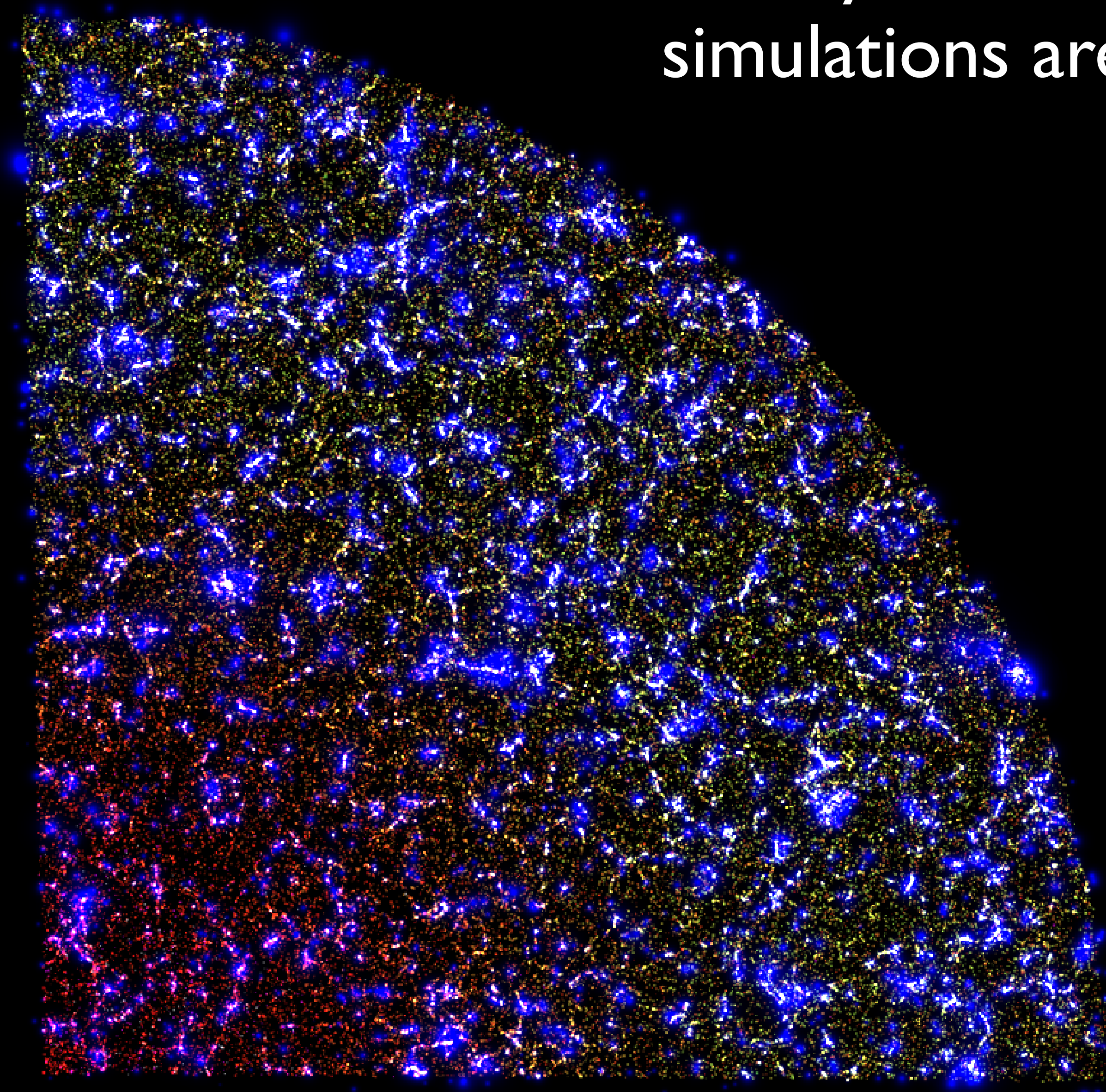
Simulation needs for galaxy catalogs



blue:-21
green:-20
red:-18

Busha & Wechsler

basic point:
surveys are magnitude limited
simulations are volume limited



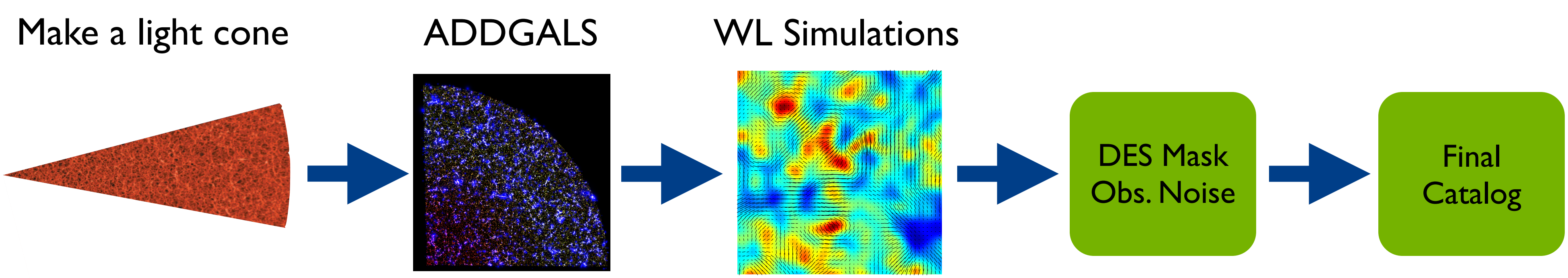
- in contrast to previous discussion, focused on
  - populating large volumes with galaxies
  - getting global statistics correct:
    - galaxy luminosity functions, color distributions
    - clustering statistics as a function of luminosity and color
- moving towards simulated skies that look like ours in detail

DES Simulated Sky Surveys

RW, Michael Busha, Matt Becker, Brandon Erickson, Andrey Kravtsov, Gus Evrard,,
Matthew Becker, Joerg Dietrich, and Molly Swanson

- full N-body light cones out to z~6 (M. Becker, M. Busha, B. Erickson, & A. Kravtsov)
- ADDGALS mock galaxy catalogs (Wechsler & Busha, in prep)
- weak lensing shear, magnification, and position shifts (Becker, in prep)
- realistic DES masks (M. Swanson)
- shape noise and sizes including the effects of seeing (J. Dietrich)
- additional observational effects (e.g., blended galaxies, star-galaxy confusion, etc.)

Designed to allow the DES collaboration to test for systematic errors and understand how precisely the DES can constrain the properties of Dark Energy. “Monte Carlos”



DARK ENERGY SURVEY

The Blind Cosmology Challenge

- Would like to assess the ability of the main DE probes to recover cosmological parameters in realistic sky surveys, including realistic systematic errors
- “VCC” Visible Cosmology Challenge
  - one simulated sky with a known cosmology
  - allows code testing with known results
  - this simulation will be updated as galaxy model and knowledge of galaxy population improves
- “BCC” Blind Cosmology Challenge
  - many simulated skies with cosmological parameters that are unknown to collaboration
  - design a coordinated analysis among LSS, lensing, cluster working groups, which determines the cosmological parameters for this suite of simulated skies.
  - will produce 10-20 simulated sky surveys with blind parameters in different cosmological models
  - additional simulations to test the impact of galaxy prescription, observational systematics + additional simulations for covariance ~ 100 surveys.
  - this work is starting now on the first simulation, plan to start analysis of first “blind” simulation with all working groups this fall.

BCC simulation pipeline

1. Decide on a cosmological model
2. Initial conditions, run simulation, output light cone, run halo finder, validate (Busha, Erickson, Becker)
3. Add galaxies (Busha, Wechsler)
4. Run validation tests (Reddick, Rykoff, Hansen, Busha, Wechsler, others)
5. Calculate shear at all galaxy positions (Becker)
6. Add shapes, lens (magnify & distort) galaxies (Dietrich)
7. Add stars (Santiago) + quasars
8. Determine mask (Swanson), including varying photometric depth & seeing, foreground stars
9. Blend galaxies
10. Determine photometric errors, incorporating mask information
11. Misclassify stars and galaxies
12. Define “spectroscopic” training set for photo-z codes
13. Determine photometric redshifts
14. Provide a lensed galaxy catalog in the DESDM database with:

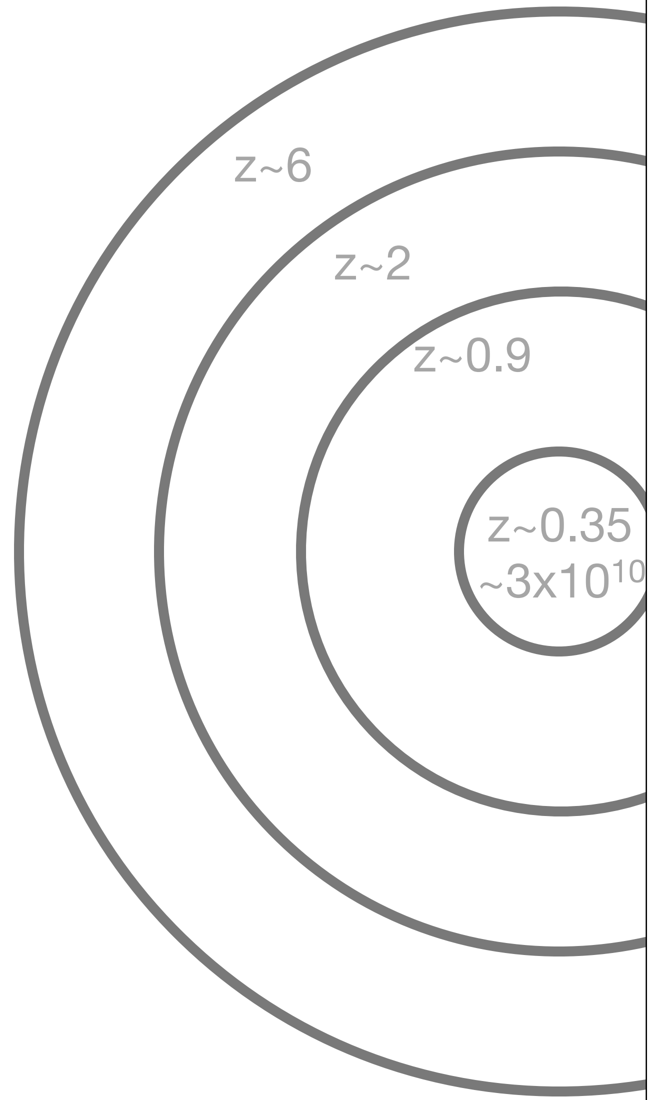
ra, dec, mags, magerrors, photoz’s, p(z), size, ellipticity, star/galaxy probability, seeing

☆ **Science working groups do analysis!**

DARK ENERGY SURVEY

BCC simulations

Lbox	Np	Mp	CPU	data
1.05 Gpc	1400	$\sim 3 \times 10^{10}$	43 kSU	2.7 TB
2.6 Gpc	2048	$\sim 1 \times 10^{11}$	125 kSU	8.4 TB
4.0 Gpc	2048	$\sim 5 \times 10^{11}$	115 kSU	8.4 TB
6.0 Gpc	2048	$\sim 1.6 \times 10^{12}$	115 kSU	8.4 TB
0.3 Gpc	2048	$\sim 6 \times 10^{8}$	230 kSU	28 TB

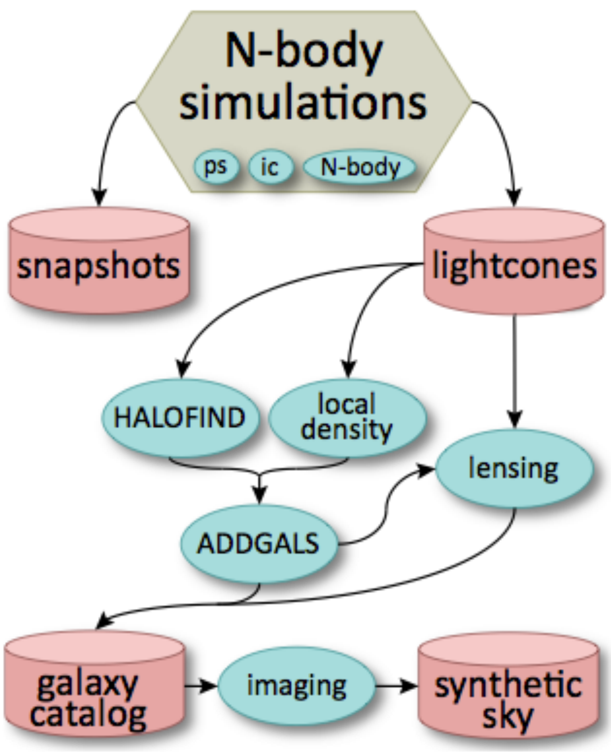


650K CPU hours per run
~100K for galaxies, lensing, photozs, etc.

A High Throughput Workflow Environment for Cosmological Simulations

DARK ENERGY SURVEY

paper with Brandon Erickson, Raminderjeet Singh, Gus Evrard, Matt Becker, Michael Busha, Andrey Kravtsov, Suresh Marru, Marlon Pierce, RW



with support from XSEDE Extended Collaborative Support Service:

code optimization, implemented workflow on XSEDE machines, based on Apache Airavata

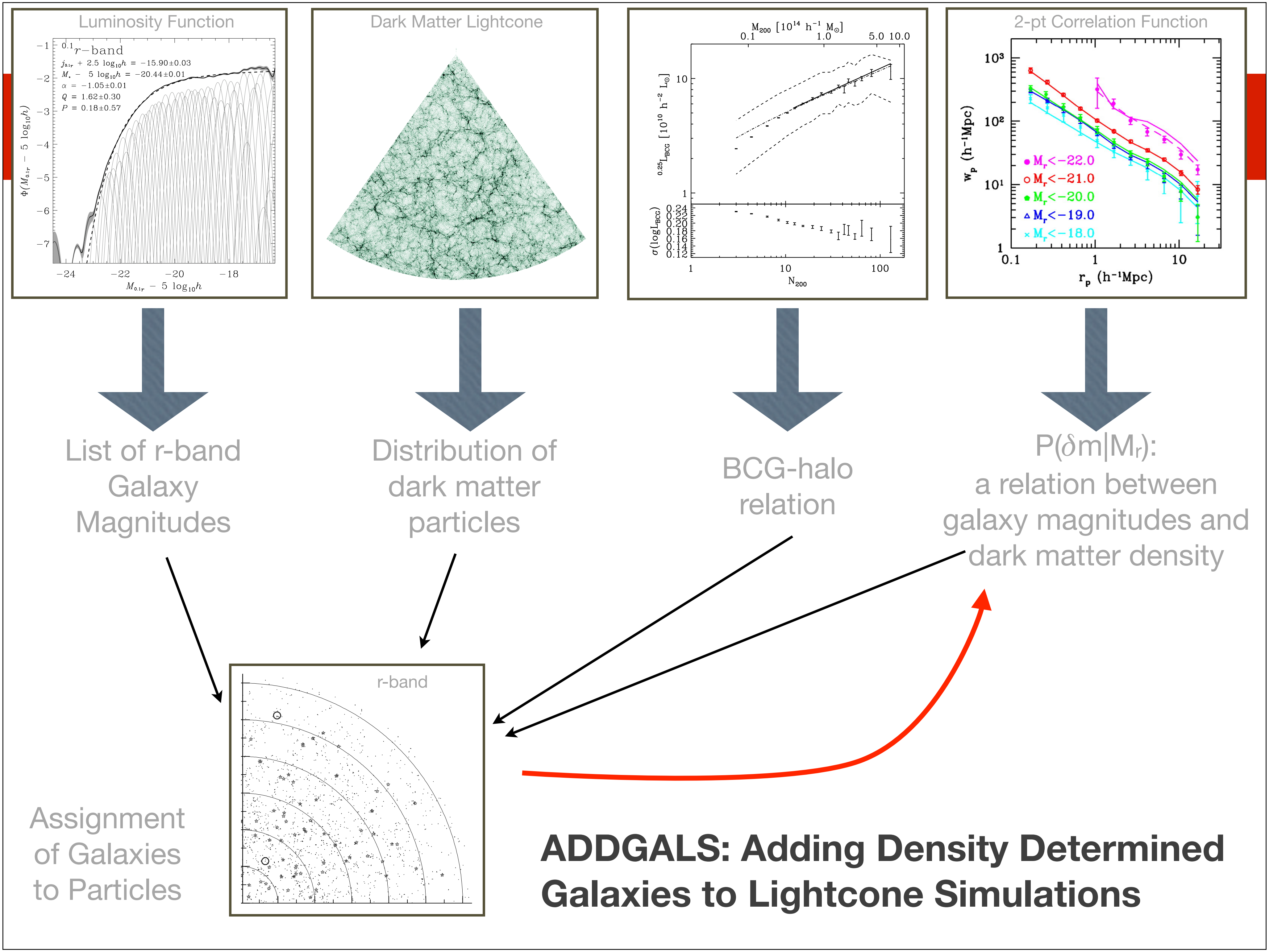
shorter total run time, less error prone

currently integrated:

initial conditions, simulations, lightcones

Table 2: Comparison of Manual and Workflow-enabled production times

Run	Total Time	CPU Time	Efficiency
Manual	8:15:33:05	4:07:24:10	50.0%
Manual	4:05:39:07	2:17:50:06	64.8%
Workflow	2:09:53:23	2:05:28:09	92.4%



Luminosity Function
$^{0.1}r$−band
$j_{0.1r}$ + 2.5 $\log_{10}h$ = −15.90±0.03
M_* − 5 $\log_{10}h$ = −20.44±0.01
α = −1.05±0.01
Q = 1.62±0.30
P = 0.18±0.57
$\Phi(M_{0.1r} - 5\log_{10}h)$
$M_{0.1r} - 5\log_{10}h$
Dark Matter Lightcone
M_{200} [10^{14} h^{-1} $M_\odot$]
$^{0.25}L_{BCG}$ [10^{10} h^{-2} $L_\odot$]
σ(logL_{BCG})
N_{200}
2-pt Correlation Function
w_p (h^{-1}Mpc)
r_p (h^{-1}Mpc)
M_r<−22.0
M_r<−21.0
M_r<−20.0
M_r<−19.0
M_r<−18.0
List of r-band Galaxy Magnitudes
Distribution of dark matter particles
BCG-halo relation
P(δm|M_r): a relation between galaxy magnitudes and dark matter density
r-band
Assignment of Galaxies to Particles
ADDGALS: Adding Density Determined Galaxies to Lightcone Simulations

DARK ENERGY
SURVEY

P(d_g | Mr) in high resolution simulations