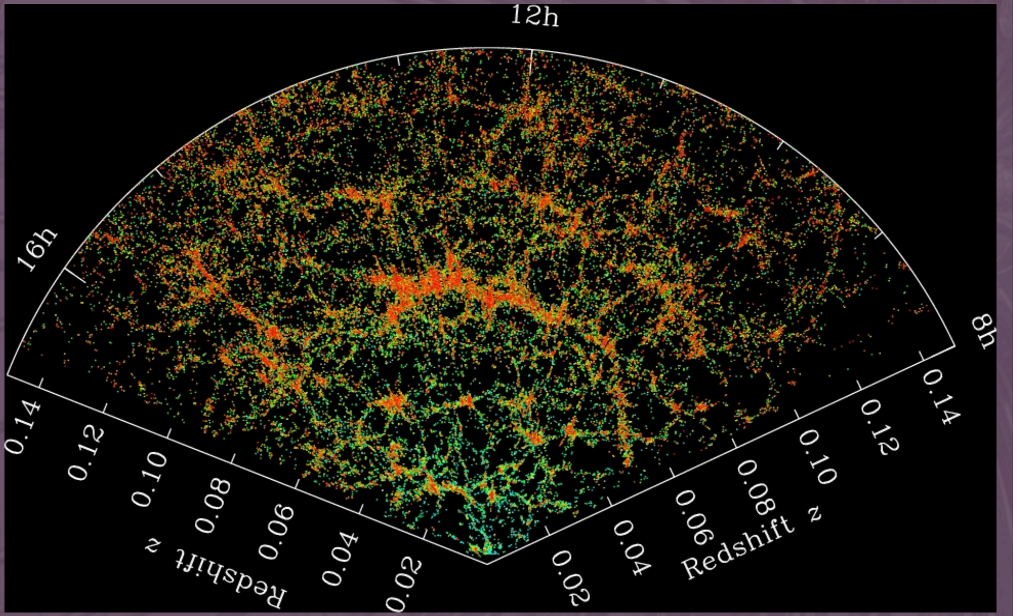
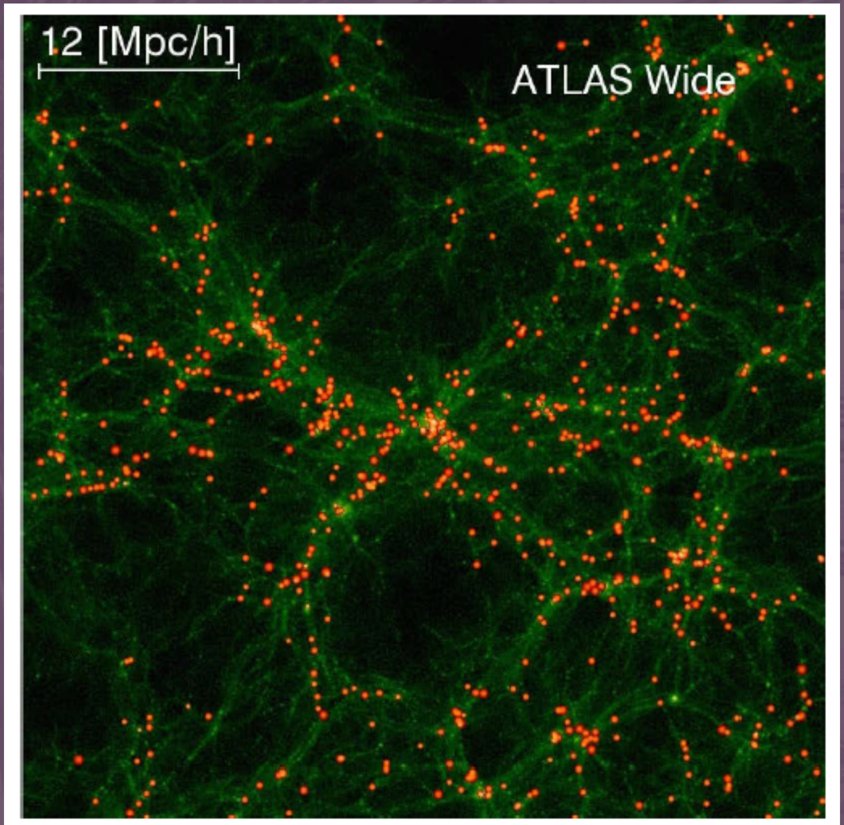
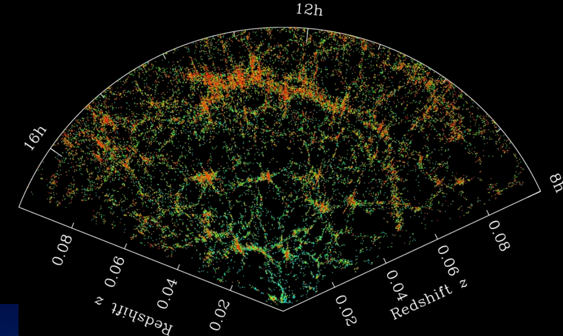
Massively Parallel Large Area Spectroscopy from Space: Cosmology Theory Review

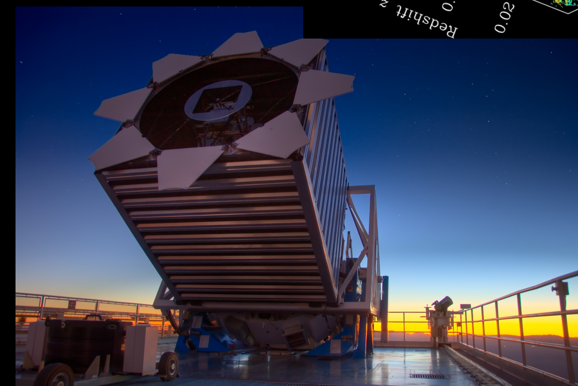
David Weinberg, Ohio State University







Hubble + SDSS



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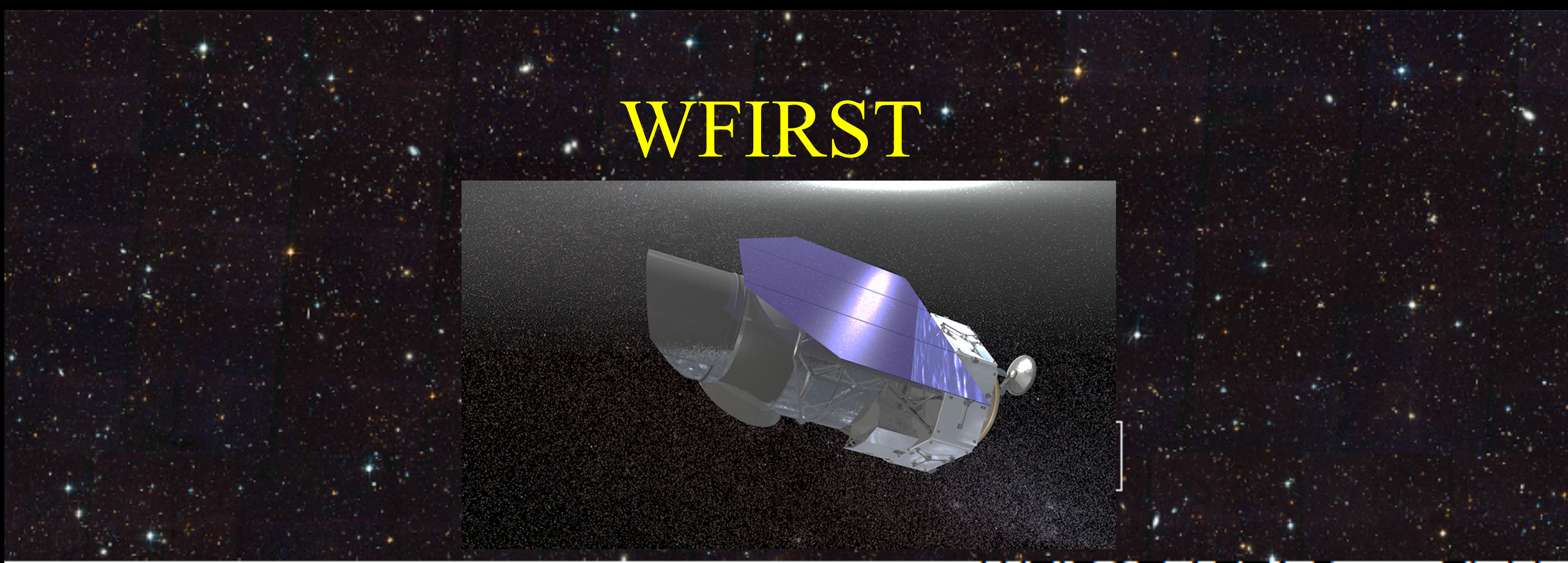
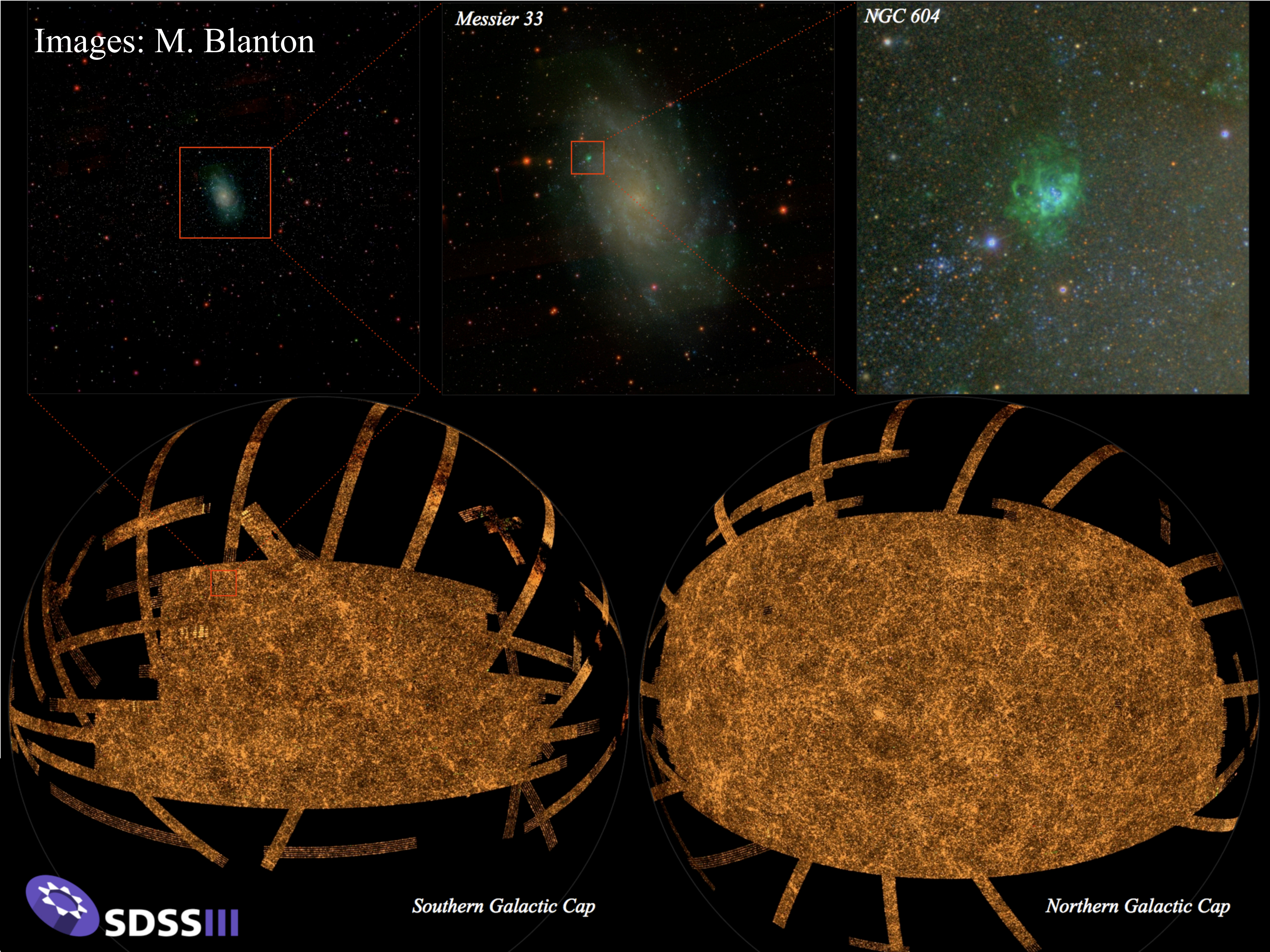
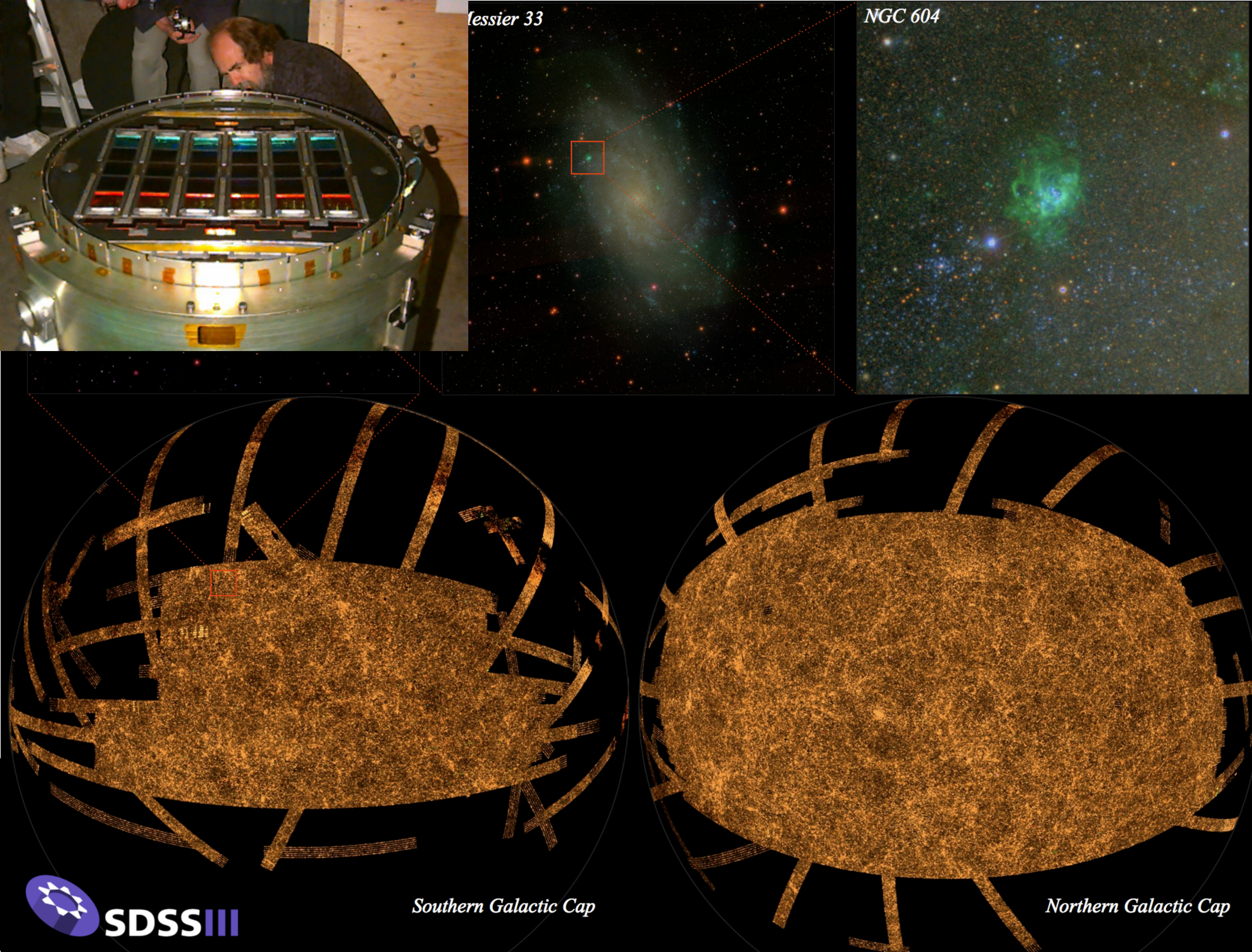


WFIRST


Images: M. Blanton
Messier 33
NGC 604
Southern Galactic Cap
Northern Galactic Cap
SDSS III


essier 33
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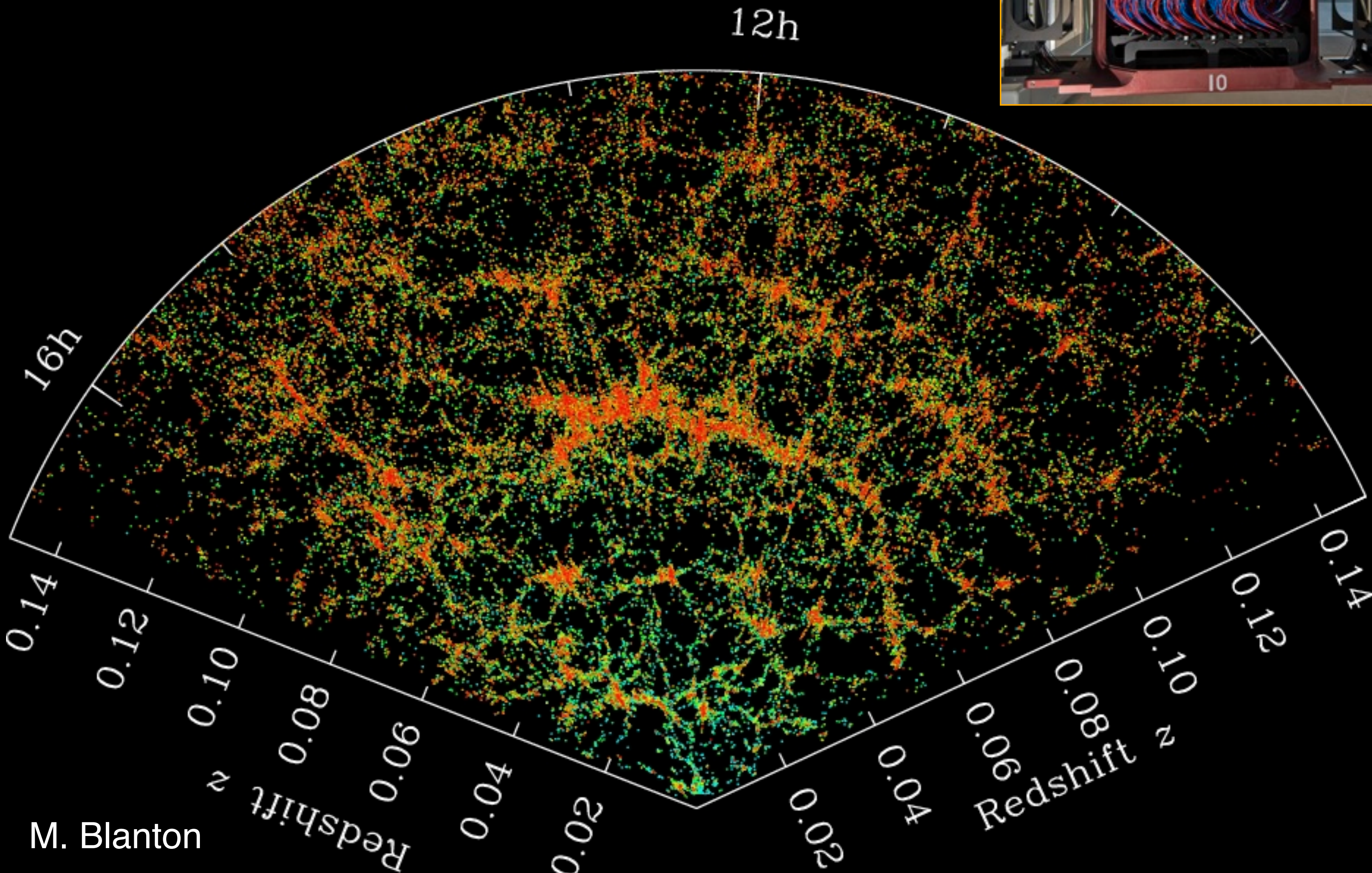
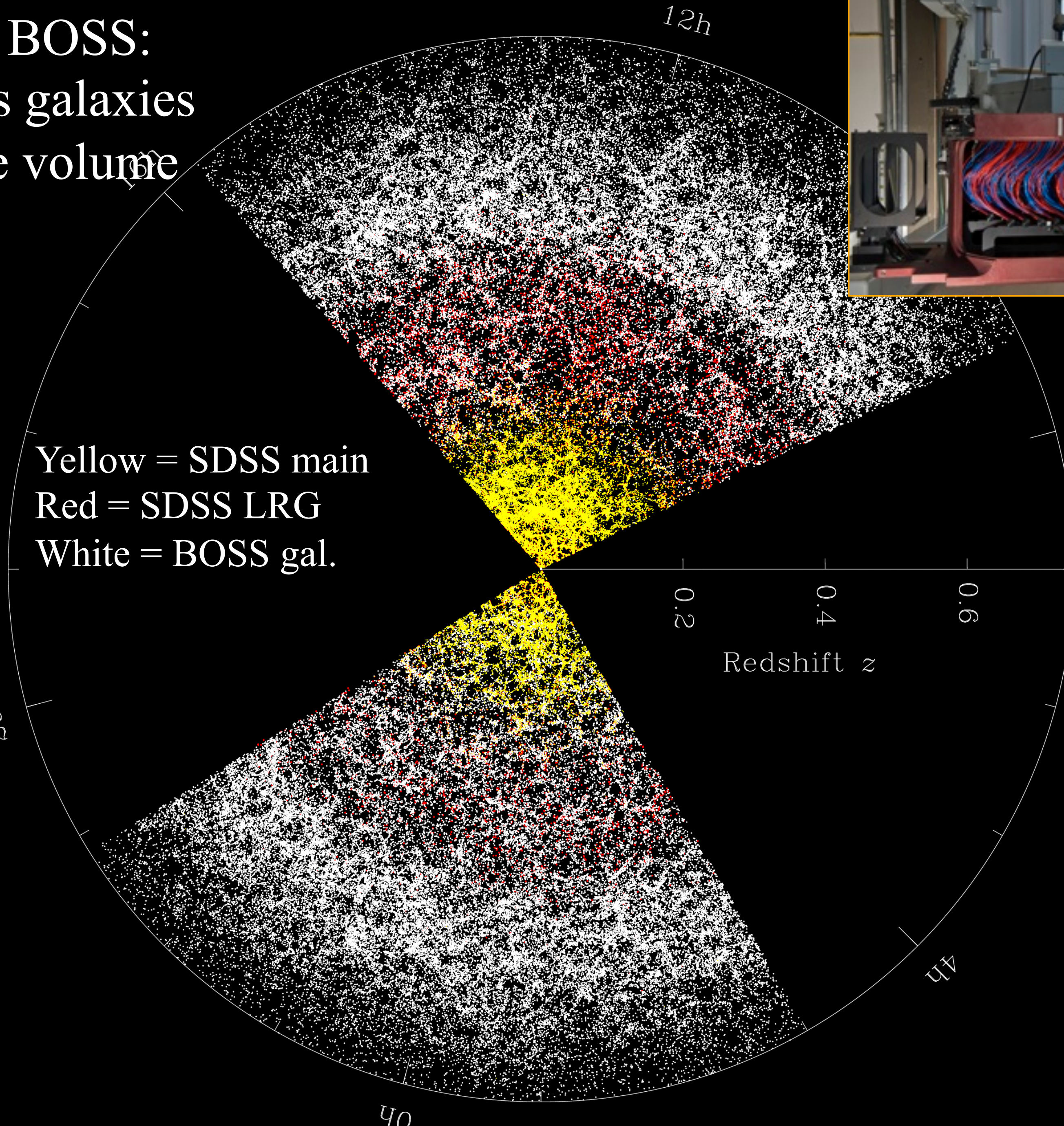
SDSSIII

SDSS Main Galaxy Sample



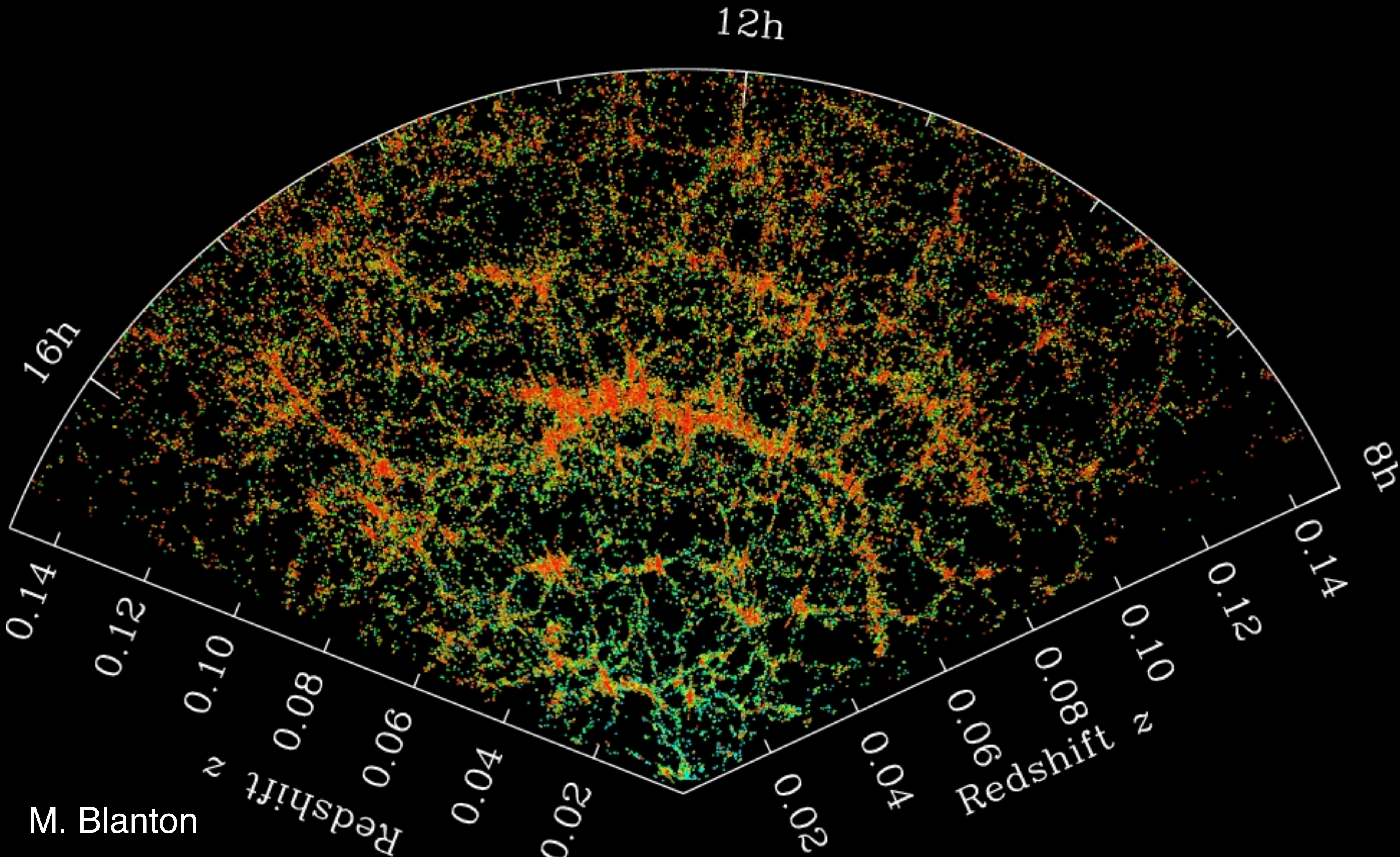
M. Blanton

SDSS-III BOSS: Luminous galaxies over large volume



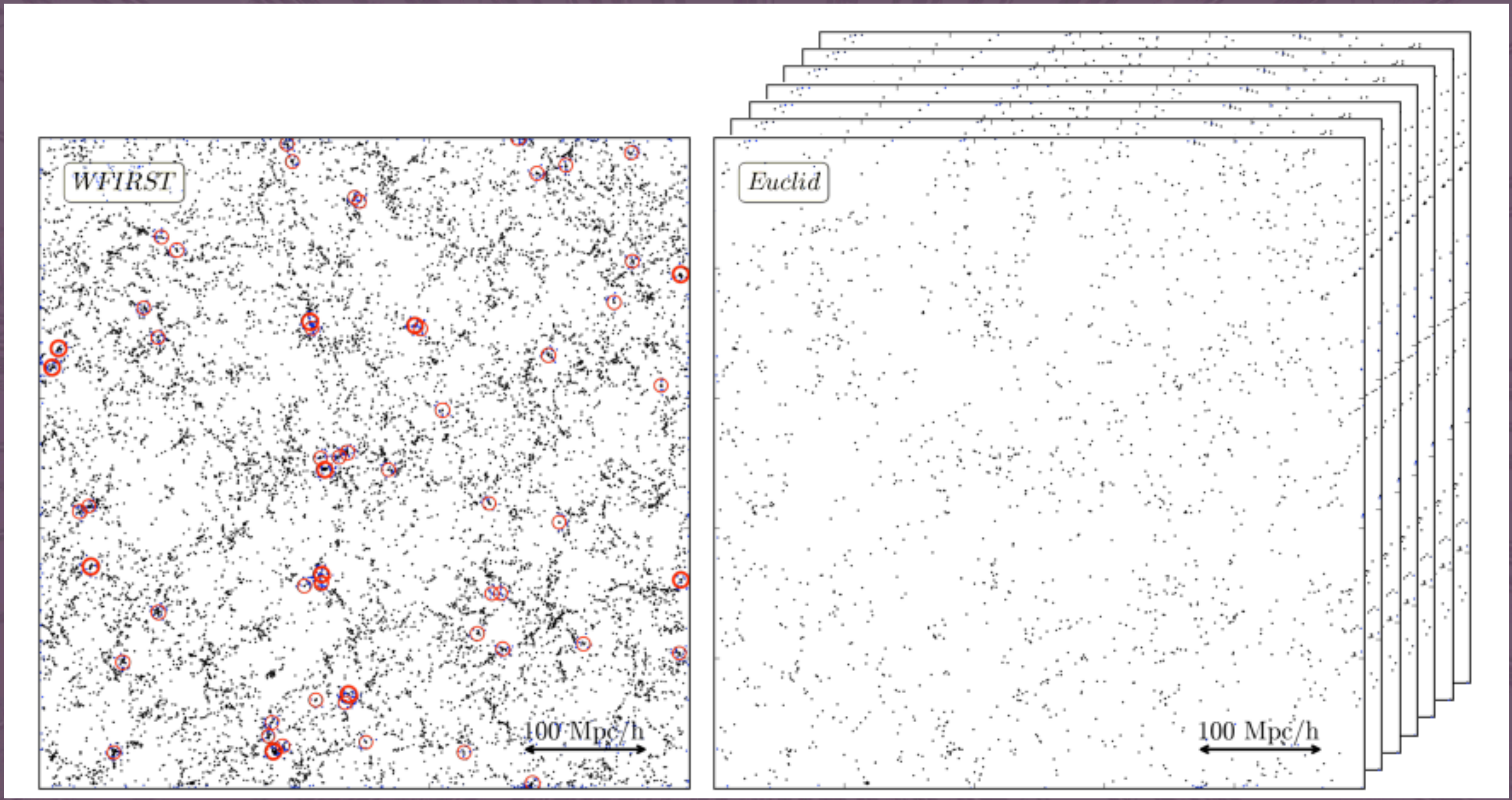
M. Blanton

SDSS Main Galaxy Sample



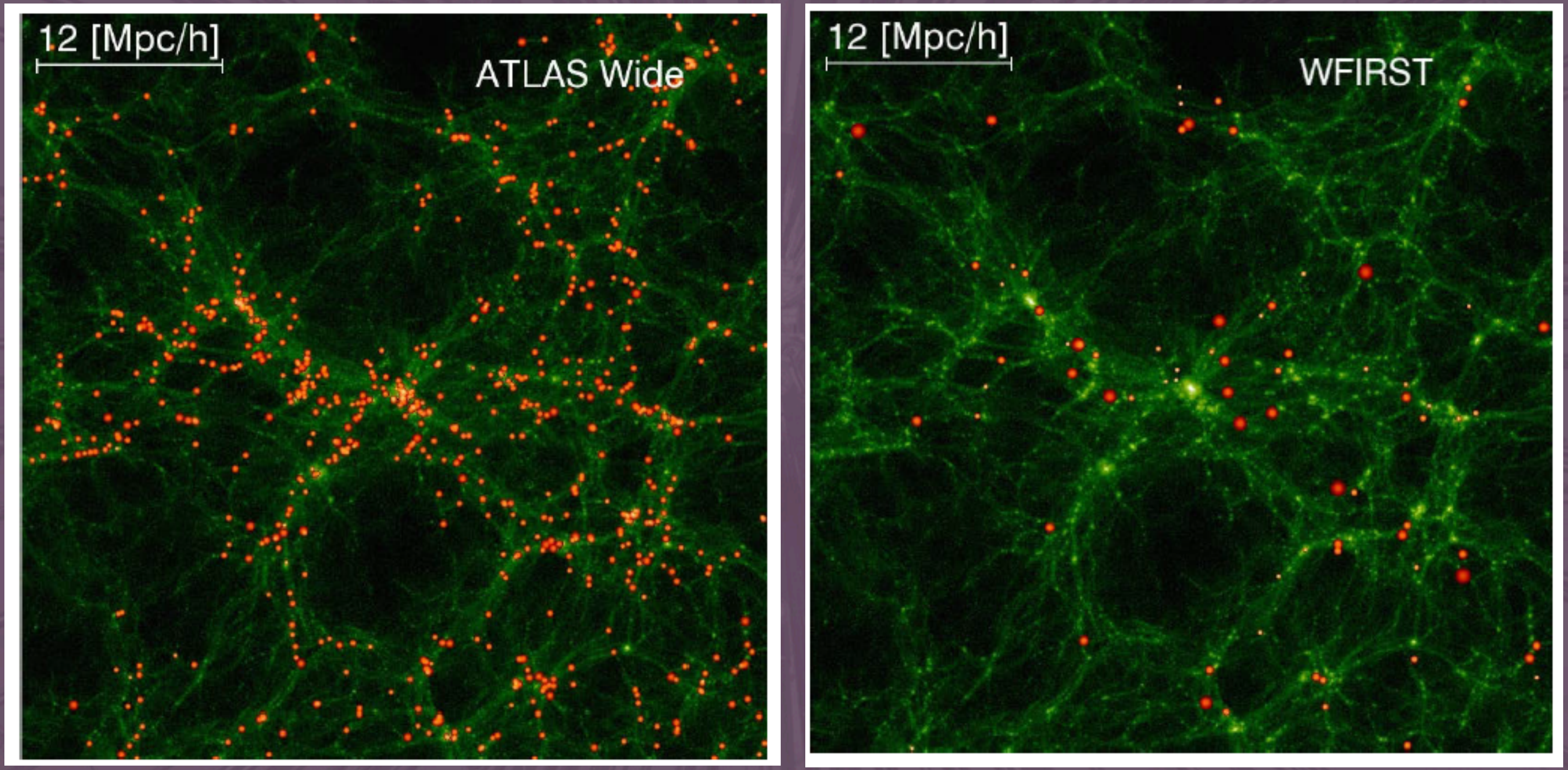
M. Blanton

WFIRST vs. Euclid: Dense sampling vs. large area.

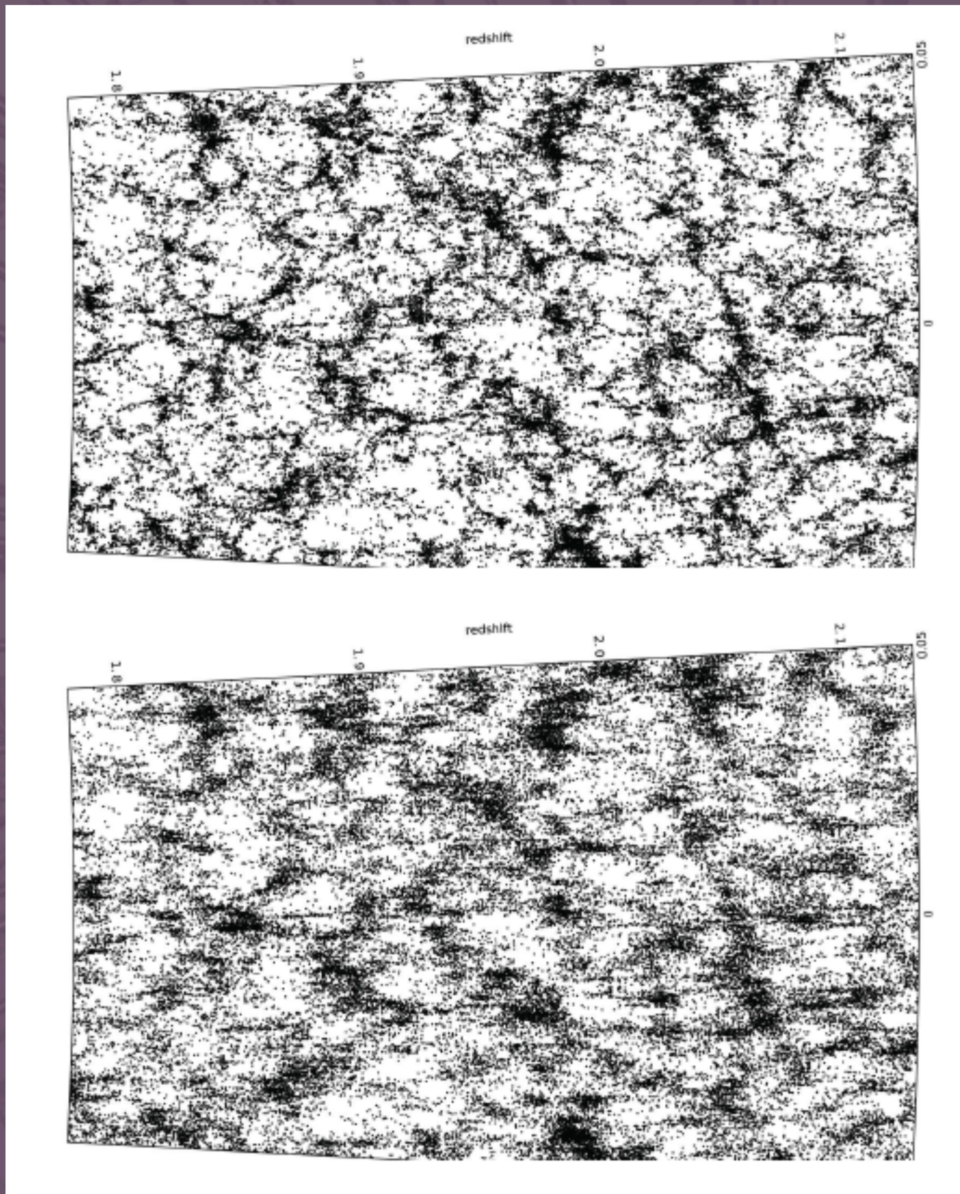


Spergel++ 2015, figure by Ying Zu from Millenium simulation

ATLAS-Wide vs. WFIRST: Denser sampling, more complete sampling of galaxy population, more informative spectra.



Wang, Robberto, Dickinson++, 1802.01539



$\sigma_z / (1+z) = 10^{-4}$

$\sigma_z / (1+z) = 10^{-3}$

Wang, Robberto, Dickinson++, 1802.01539

Questions from Astro2010

Cosmology & Fundamental Physics

How did the universe begin?

Why is the universe accelerating?

What is dark matter?

What are the properties of neutrinos?

Galaxies Across Cosmic Time

How do cosmic structures form and evolve?

How do baryons cycle in and out of galaxies, and what do they do while they are there?

How do black holes grow, radiate, and influence their surroundings?

What were the first objects to light up the universe, and how did they do it?

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Why is the universe accelerating?

A breakdown of General Relativity on cosmological scales?

A cosmological constant, with a very surprising magnitude?

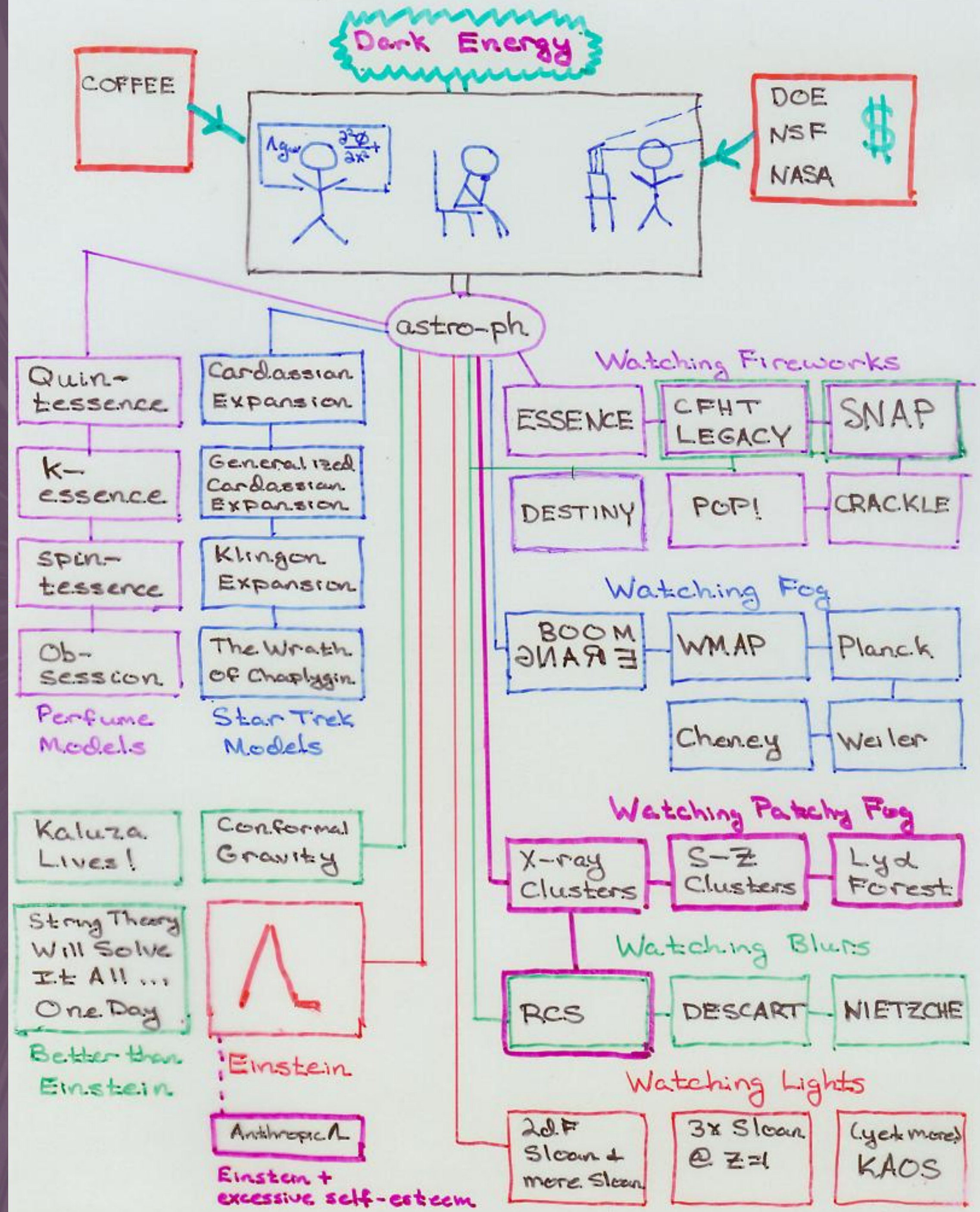
Dynamical dark energy that varies in space and time?

Relic signature of: Extra dimensions? String theory?
Inflation? The Multiverse?

To address these questions, measure the history of cosmic expansion and growth of structure with the highest achievable precision over a wide range of redshift.

Grand Unified Model of Dark Energy

c. 2004



Dark energy experiments: precision goals

Current

Expansion history measurements 1-3%

Structure growth measurements 5-10%

Ongoing

Expansion history measurements 0.3-0.5%

Structure growth measurements 1-2%

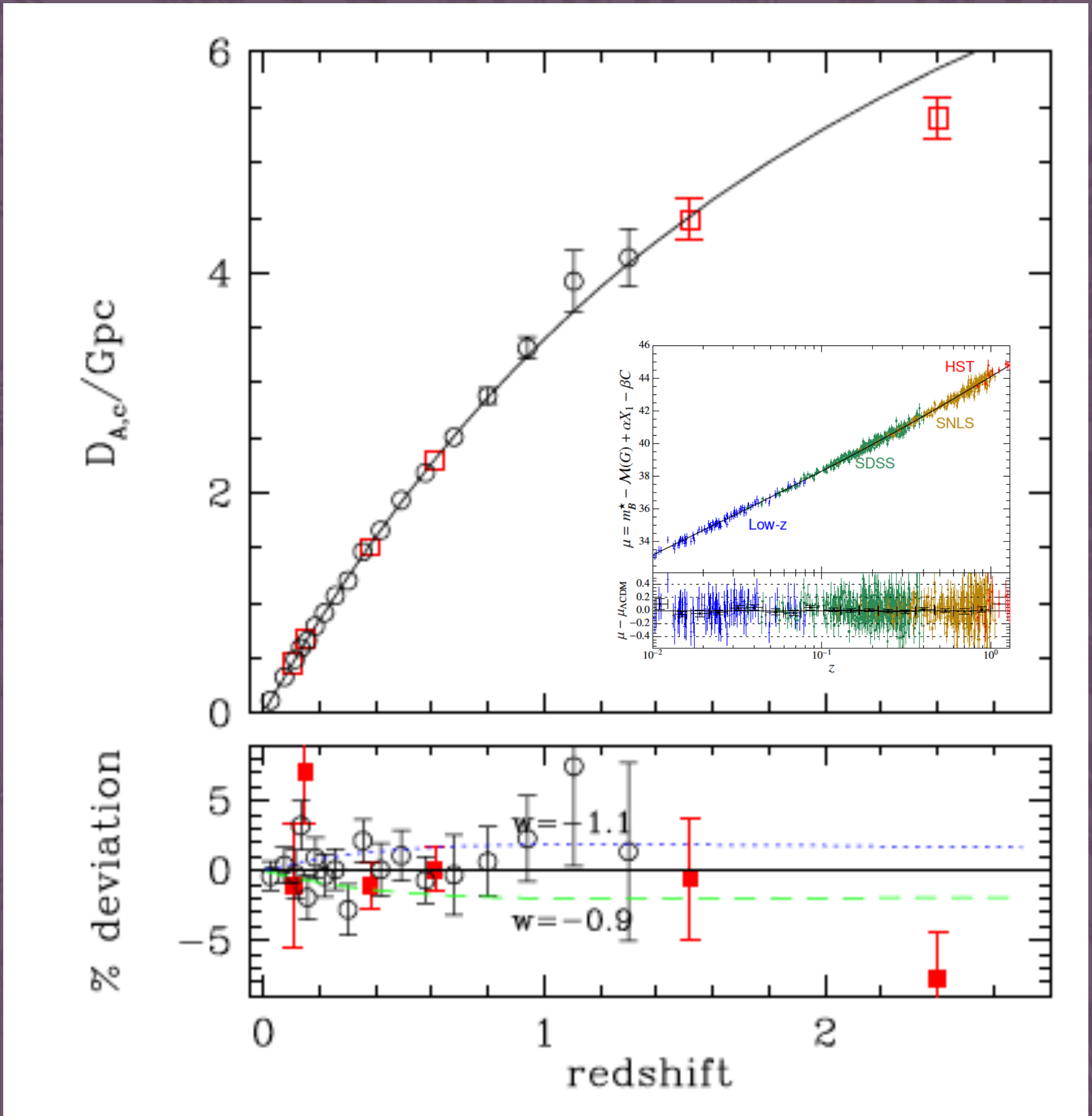
Future

Expansion history measurements ~ 0.1%

Structure growth measurements ~ 0.1%

Lots of discovery space. Big challenge to control systematics.

Expansion history data

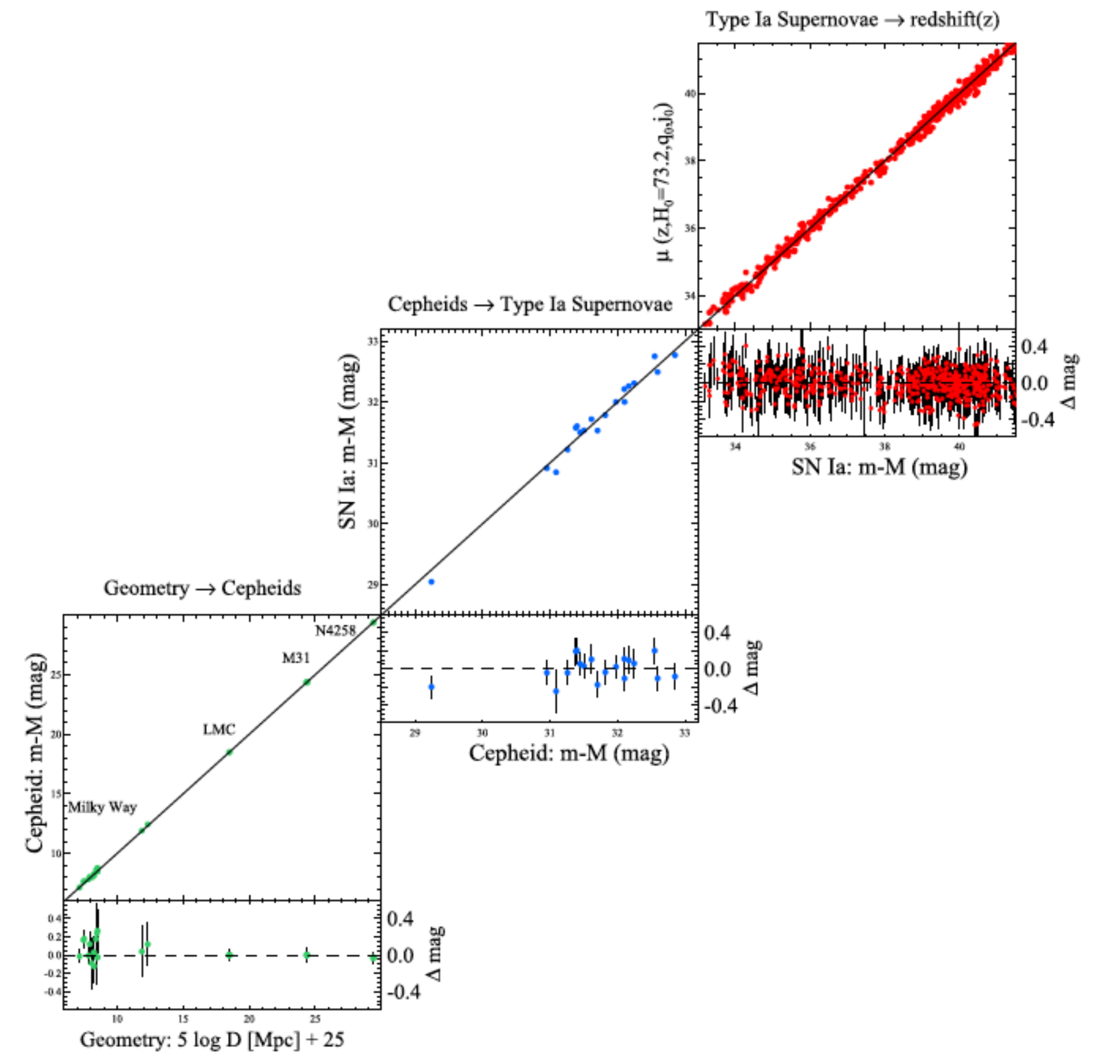


Mostly in excellent agreement with CMB-normalized ΛCDM

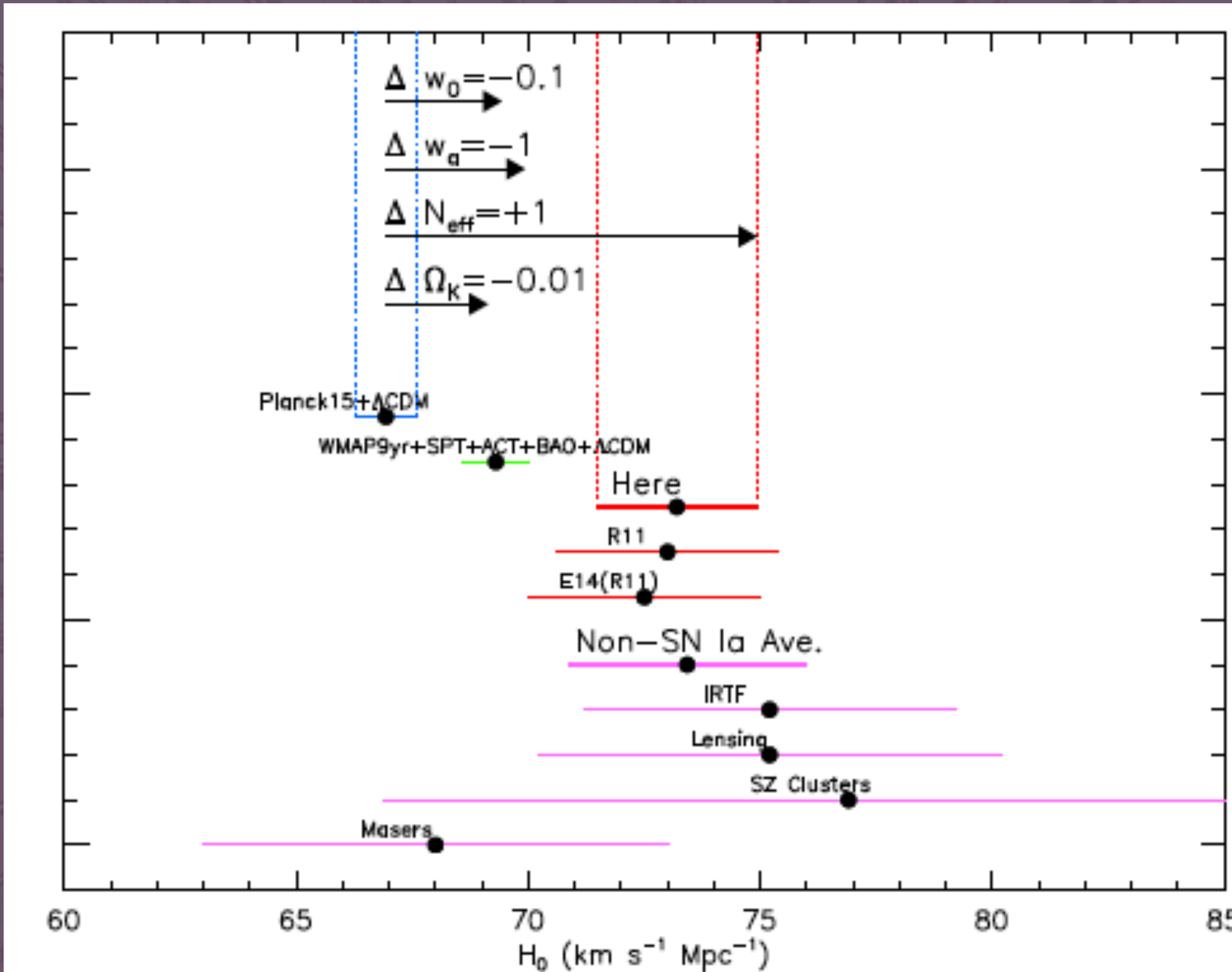
Weinberg & White 2018 Particle Data Group review of Dark Energy

Except for H_0

Best (?) local measurements yield $H_0 = 73 \pm 2$ km/s/Mpc vs. 67 ± 0.6 km/s/Mpc for Planck + ΛCDM



Riess et al. 2016

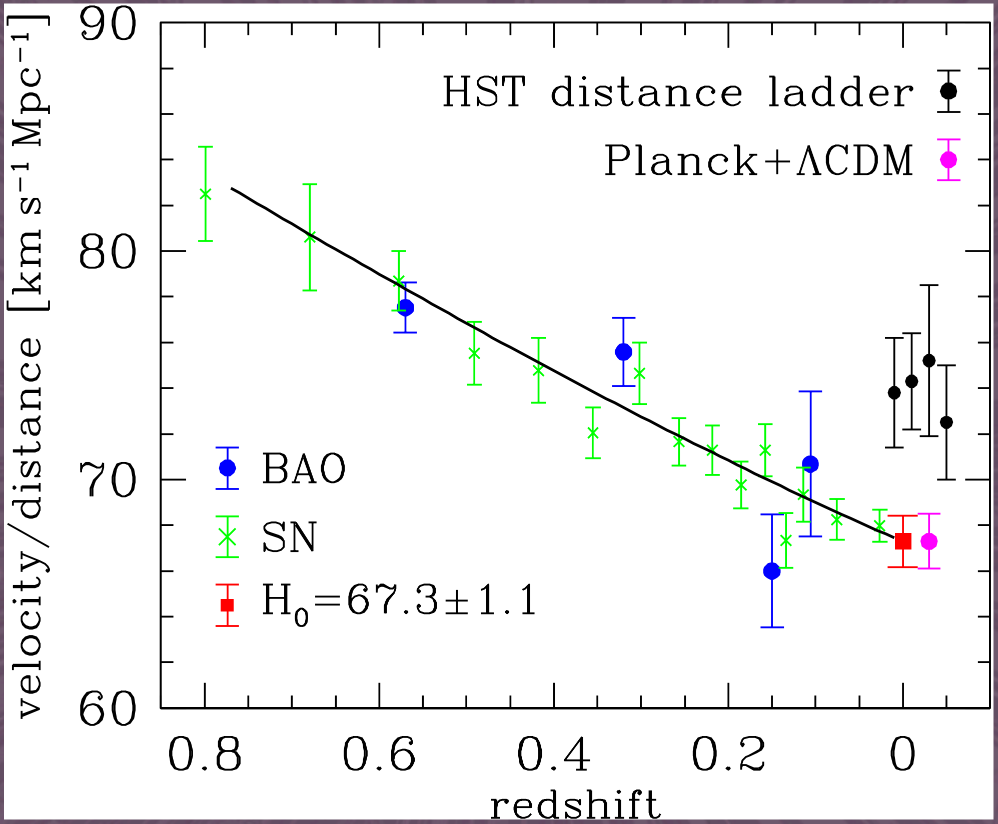


Riess et al. 2016

An "inverse distance ladder" measurement of H_0.

$cz / D_M(z)$

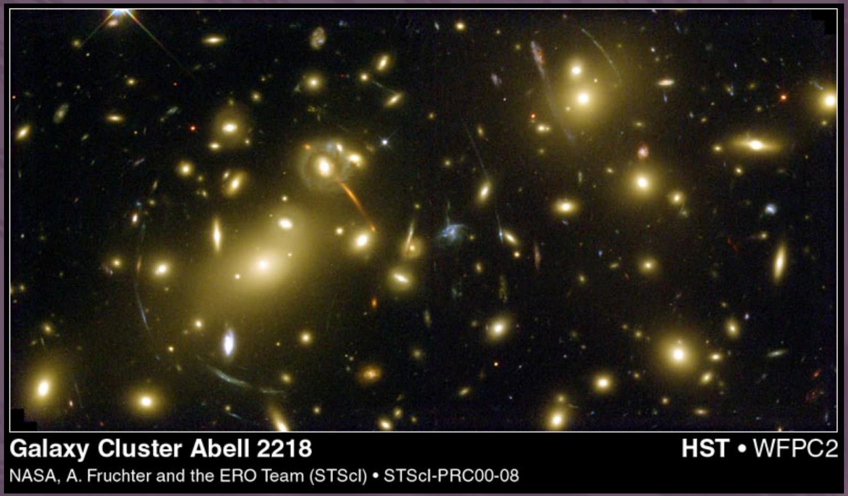
converges to H_0 at $z = 0$



Aubourg++ 2015
BOSS + JLA SNe

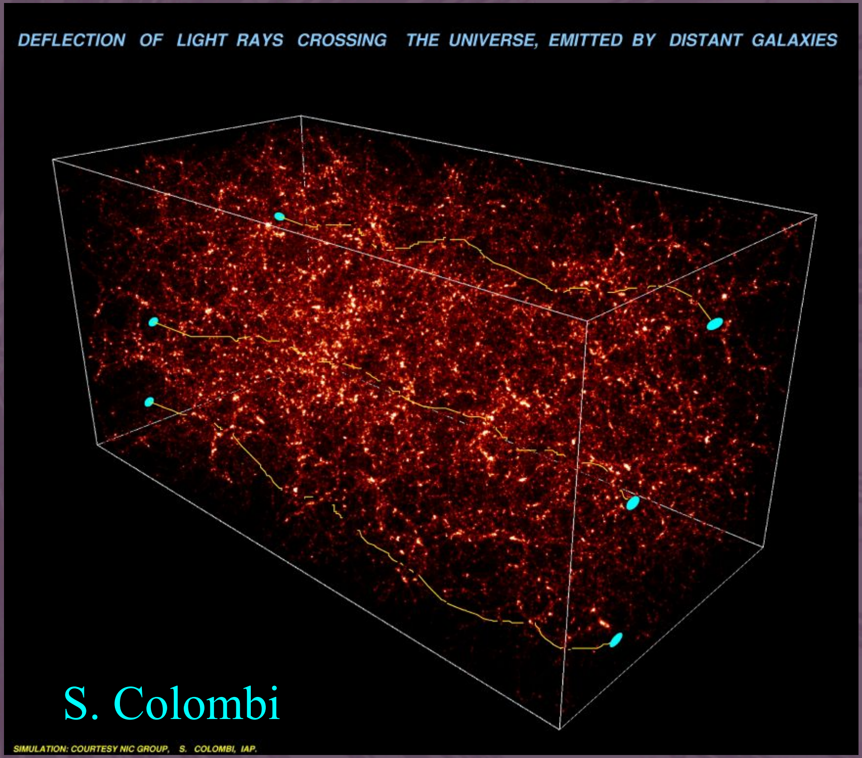
Joint BAO + SN fit with extremely flexible dark energy model yields $H_0 = 67.3 \pm 1.1$ km s^{-1} Mpc^{-1}.
Higher H_0 requires changing r_d, hence pre-recombination physics.

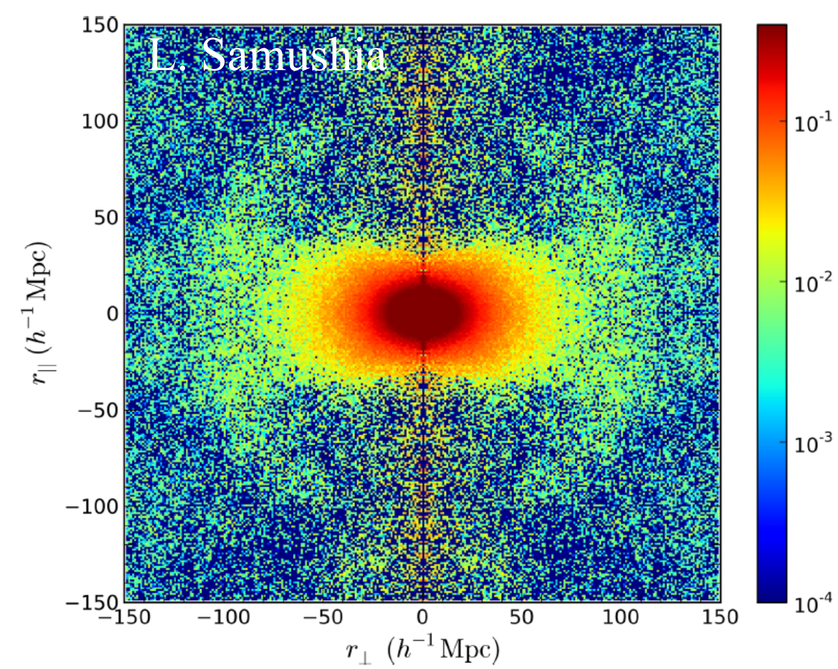
Measuring dark matter clustering



Masses of galaxy clusters

Weak lensing cosmic shear



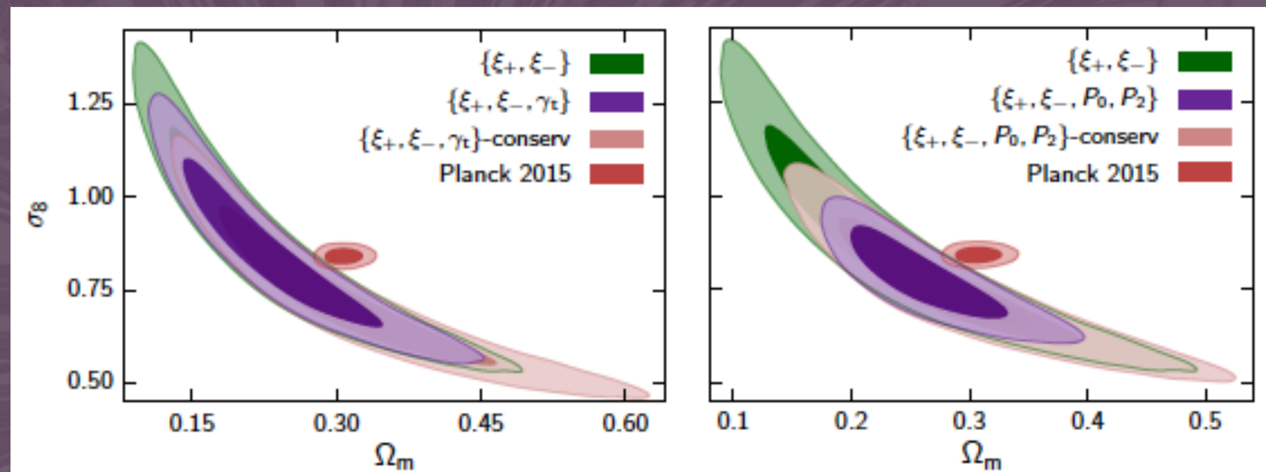


Redshift-space distortions

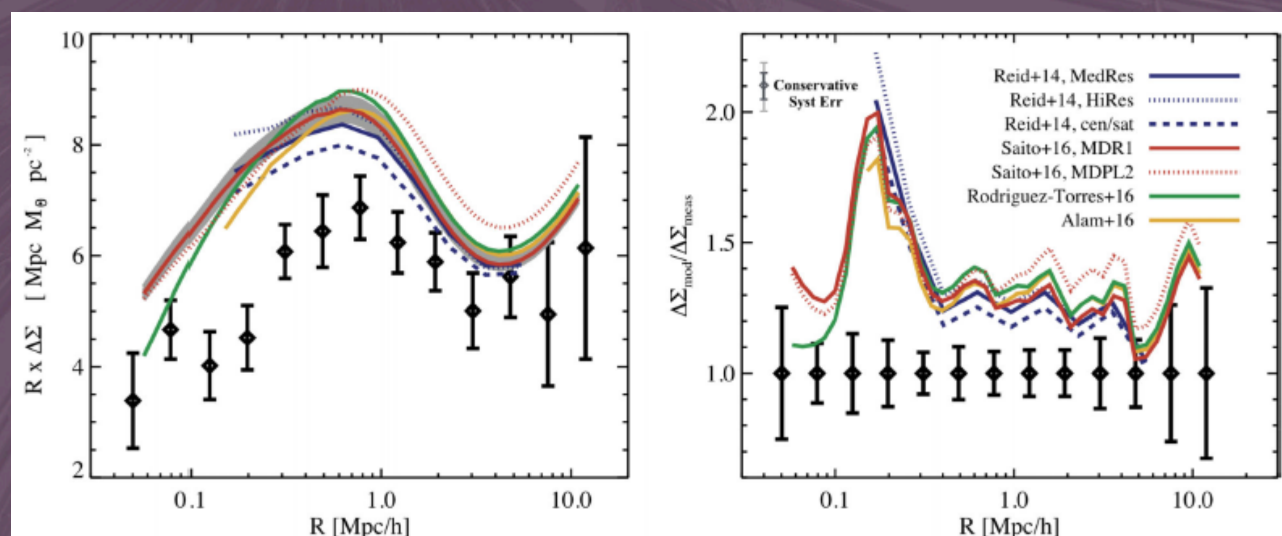
Cosmic shear and galaxy-galaxy lensing

Still some unexpectedly low measurements

Joudaki++ 2018
KiDS-450 + 2dFlens

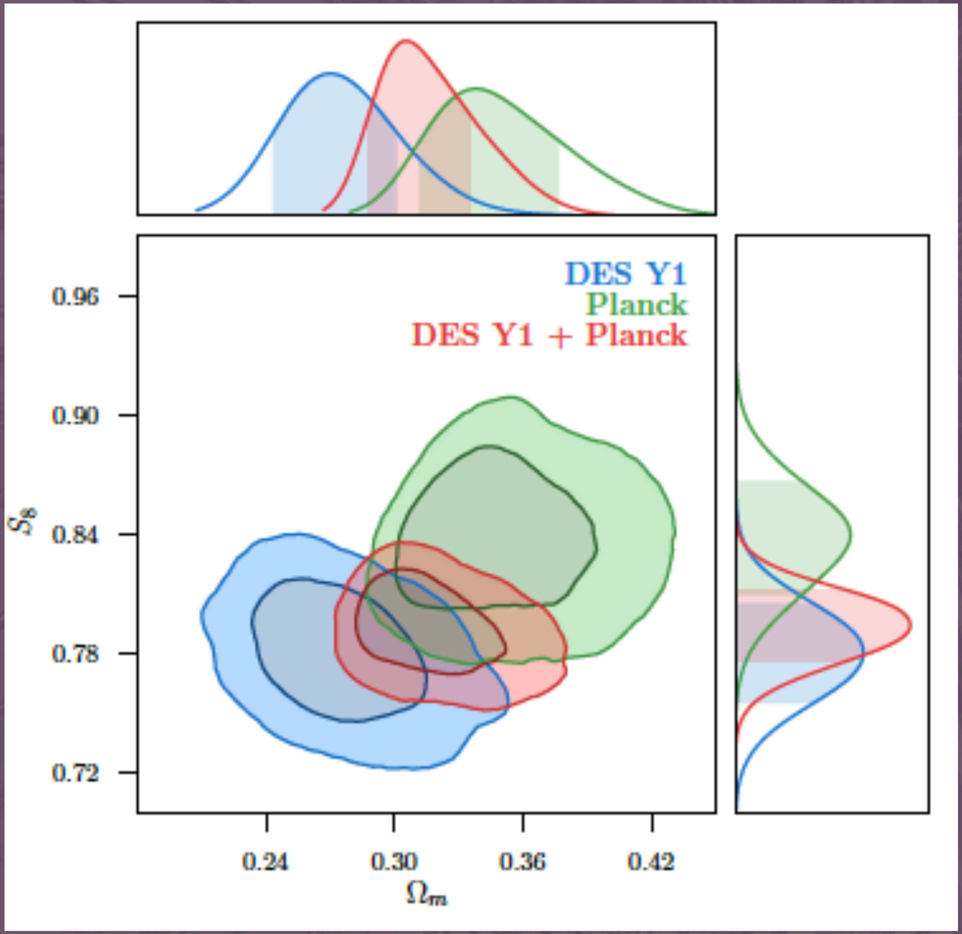


Leauthaud++ 2017
CS82 + BOSS



Cosmic shear and galaxy-galaxy lensing

Dark energy survey Year 1 intermediate between low measurements and CMB + ΛCDM.
Consistent with either.

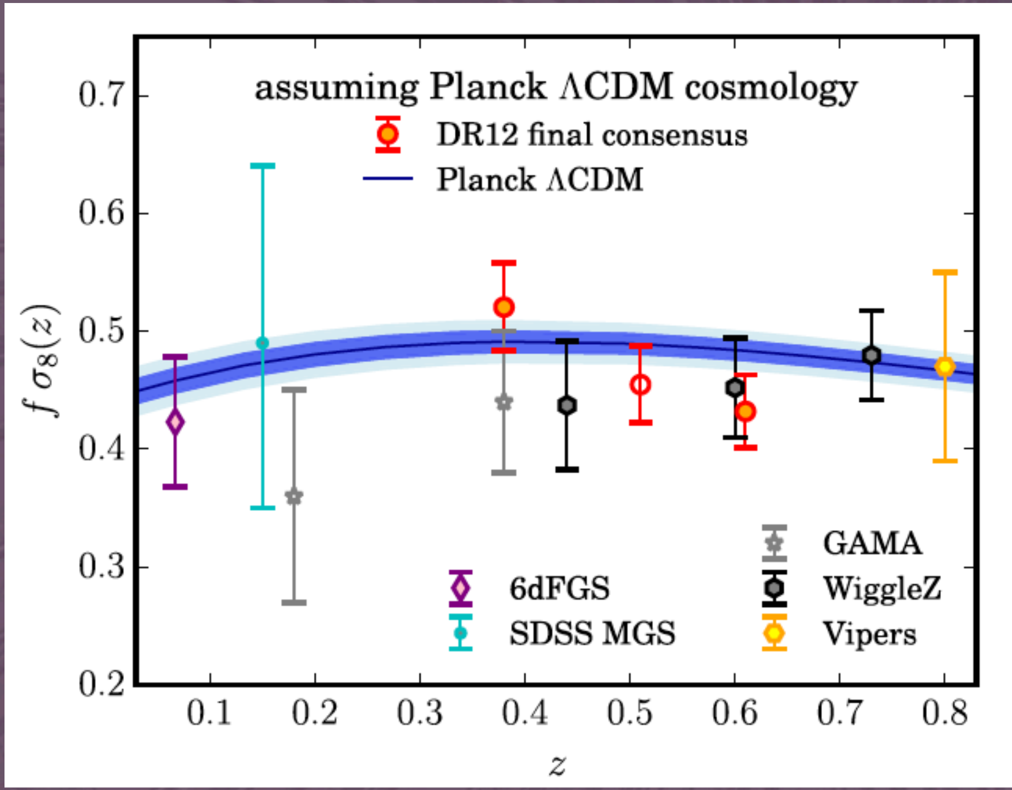


Year 3 coming soon!

DES Collaboration, Abbott++ 2018

Redshift-space distortions

Consistent with CMB + ΛCDM.
But not very constraining because errors are large (~10%).
Need: Larger volume, better modeling of non-linear clustering

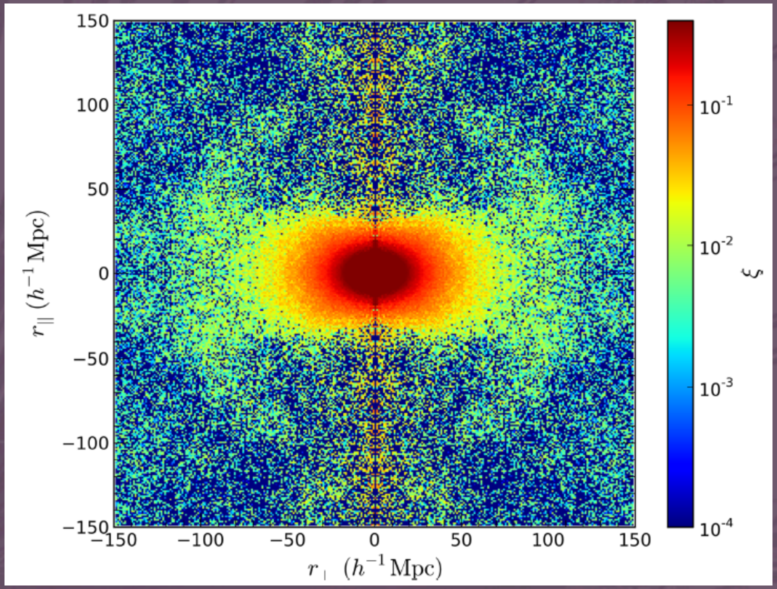


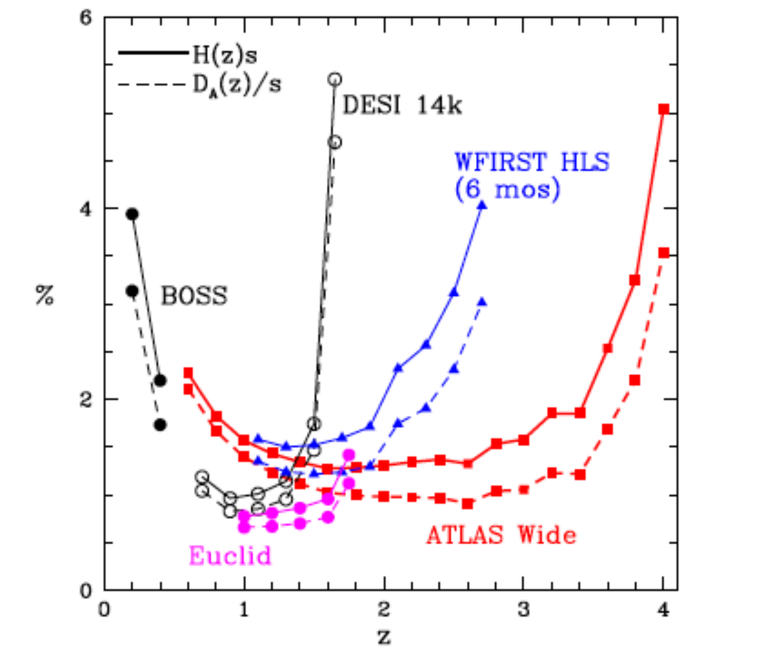
BOSS Collaboration, Alam et al. 2017

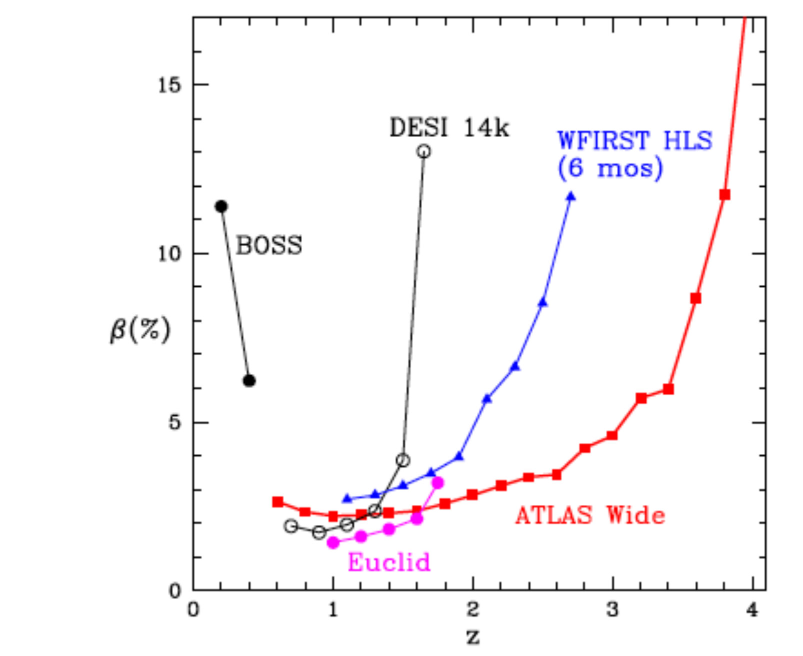
Samushia, Reid, White ++ 2014

Larger volumes coming from DESI, Euclid, WFIRST

Opportunity for ATLAS is BAO and RSD at z > 2, non-linear RSD at z = 0.5-2



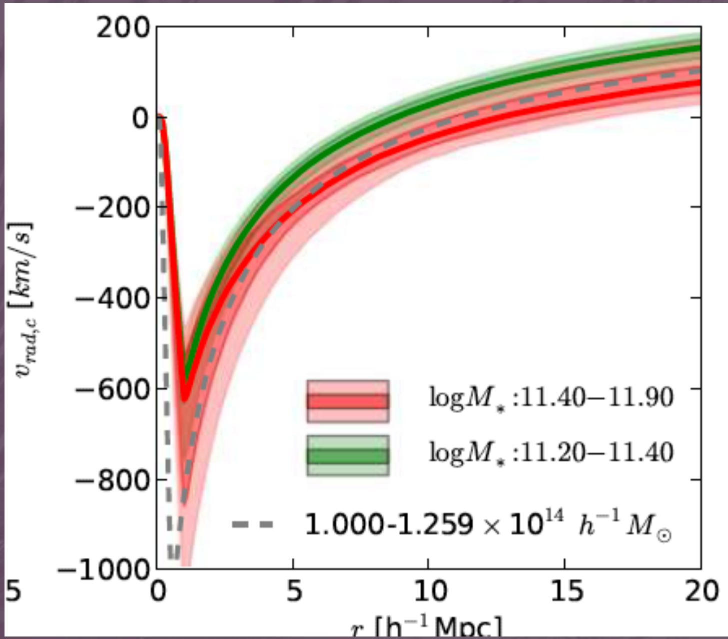


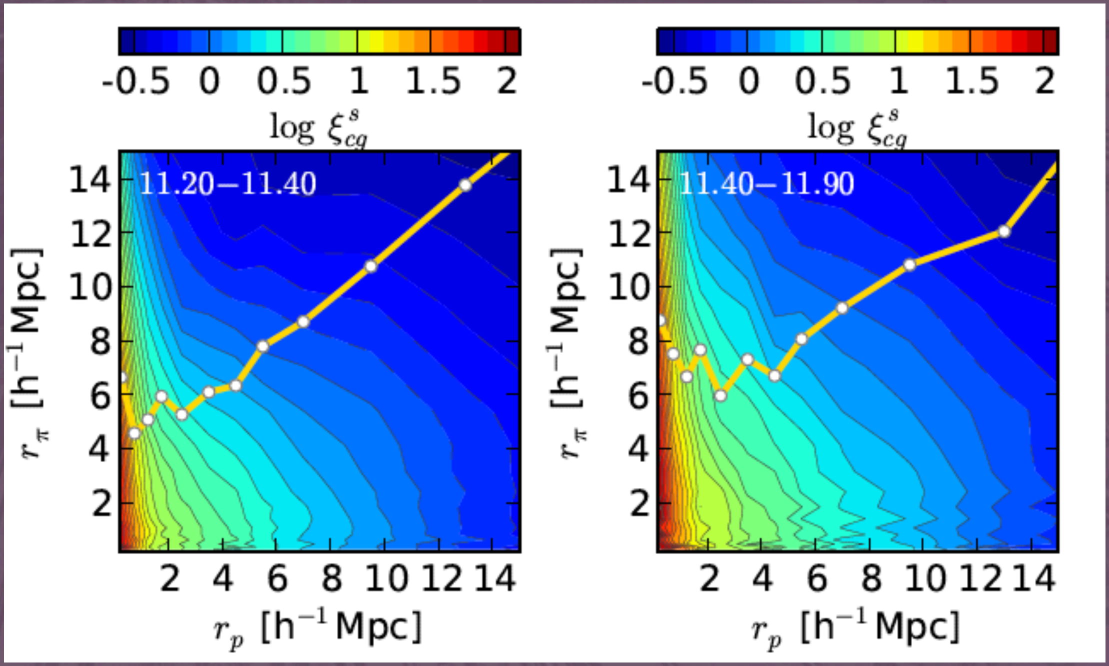


Wang, Robberto, Dickinson++, 1802.01539

Example of non-linear RSD modeling

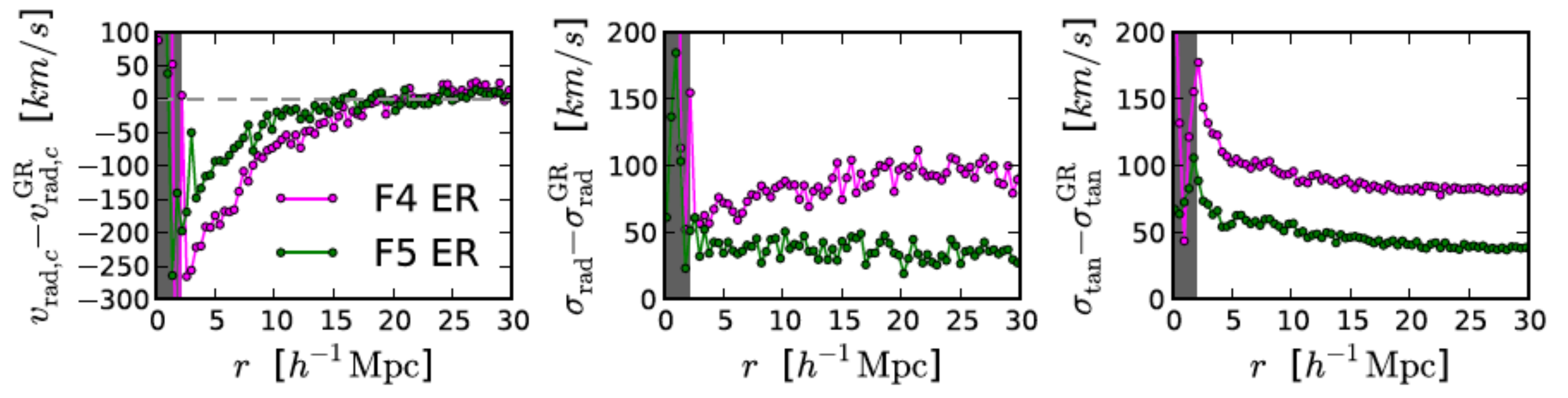
Inferring cluster infall velocity profiles from cluster-galaxy cross-correlation function





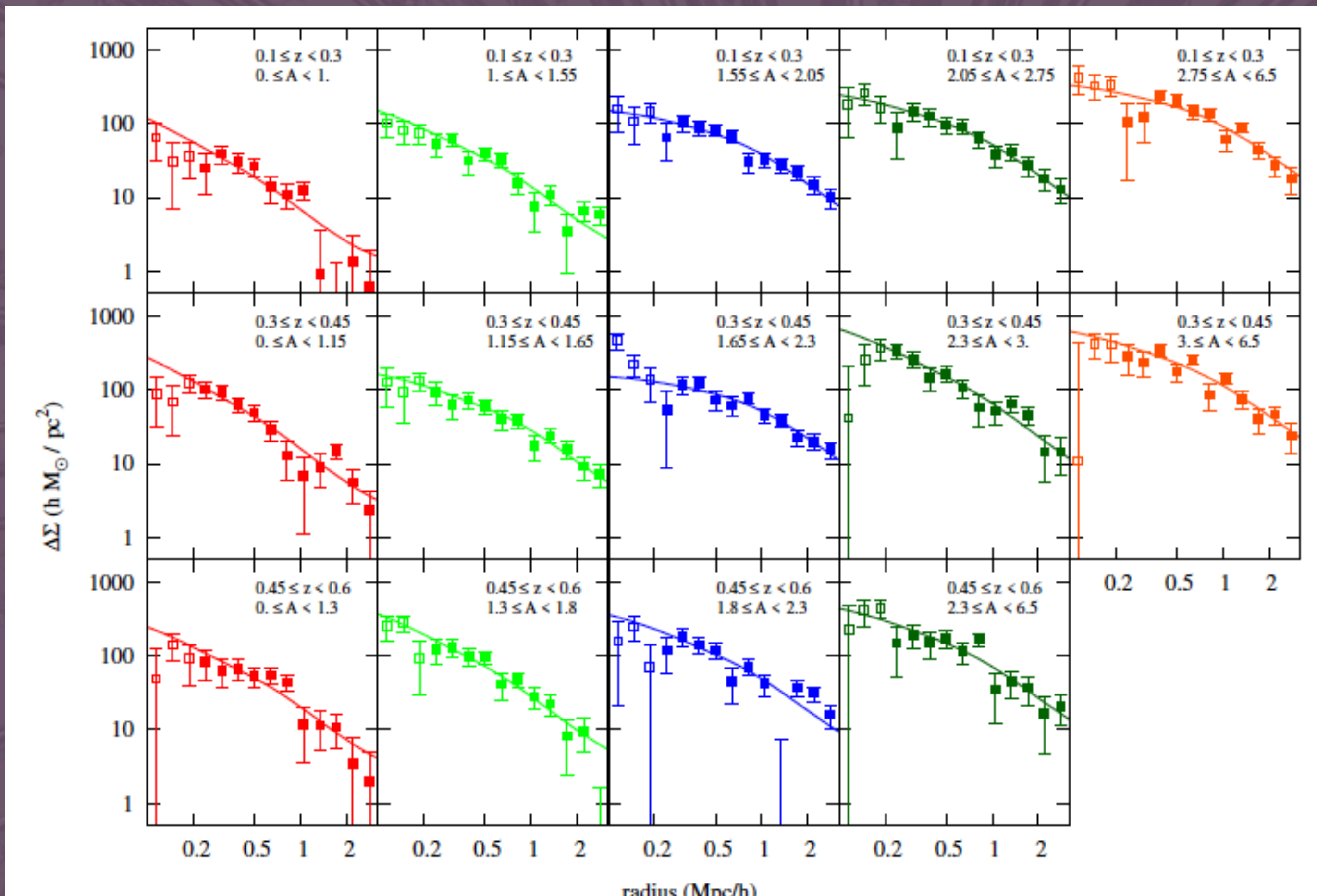
Zu & Weinberg 2013
Groups in SDSS main galaxy survey

Modified gravity predicts higher infall velocities, radial and tangential dispersions, because of stronger accelerations in "unscreened" regime.



Zu, Weinberg, Jennings, Li, Wyman 2014
Difference of velocity profiles between GR and f(R) gravity simulations.

Opportunity ahead: Precise comparison of extended cluster mass profiles inferred from weak lensing vs. galaxy kinematics.



Bellagamba, Sereno, Roncarelli++ 2018, KiDS cluster WL profiles

Will it matter by the late 2020s?

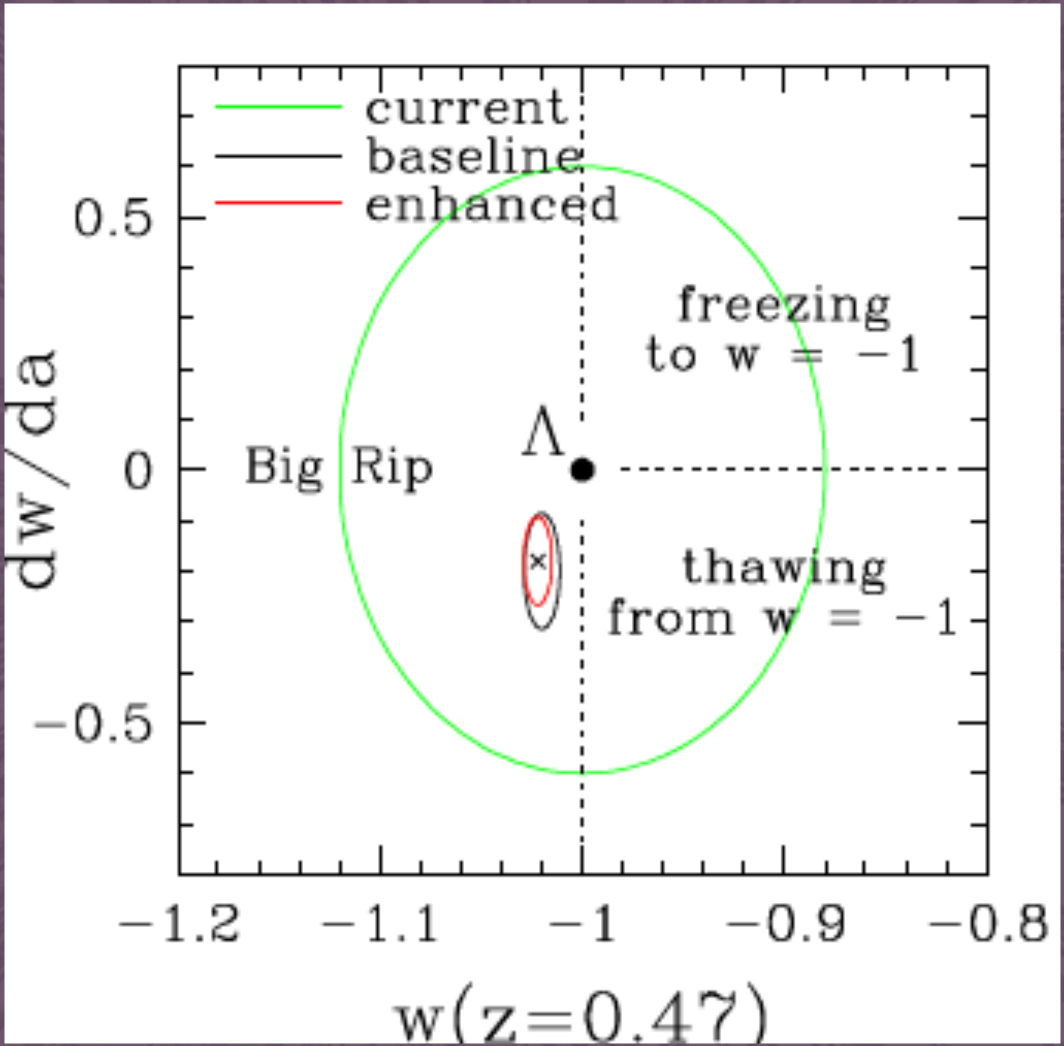
Three plausible scenarios

1. Current tensions confirmed by Stage III experiments + ACT/SPT CMB data.
   We are deep into trying to understand their origin.
2. Current tensions dissipate, but new ones have emerged at the 1% level. Confirmation and characterization are high priority.
3. Precision has improved to sub-percent level, all results consistent with ΛCDM.

DESI, Euclid, LSST, WFIRST all have important roles to play, partly overlapping, partly complementary.

For scenario 1 or 2, a more powerful spectroscopic survey could play a critical role.

Forecast errors on dark energy parameters, vs. current knowledge



2015 WFIRST SDT report

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The Biggest Cosmological Breakthroughs (last 200 years)

1859: Precession of Mercury

Newtonian gravity is incomplete.

1923: Distance to the Andromeda Nebula

The universe is big! Galaxies are basic unit.

1929: Hubble's law

The universe is expanding, as General Relativity naturally predicts.

1930s – 1970s: Dark matter

The dominant form of matter in the universe is invisible.

1960s: Cosmic microwave background and big bang nucleosynthesis

The universe began with a hot big bang.

1980s – 2000s: Large scale structure and CMB anisotropies

Cosmic structure formed by gravitational instability.

Dark matter is non-baryonic. Space is Euclidean.

Late 1990s: Cosmic acceleration

Gravity is repulsive over cosmological distances.

We seek the next great cosmological discovery.

Backup Slide

Cosmological tensions – historical templates?

Early 1990s: "Excess large scale power"

$\Omega = 1$? Theoretical elegance.

$\Omega = 0.3$? Simplest interpretation of observations.

New physics: $\Omega_m = 0.3$, $\Omega_{tot} = 1$

Mid 1990s: "The age crisis"

Systematic errors in H_0? Systematic errors in star cluster ages?

New physics: Cosmic acceleration implies $t_0 \approx 1/H_0$

Mid 2000s: WMAP1 σ_8 vs. cluster mass-to-light ratios

Systematics in M/L predictions? New physics?

Astrophysical systematics in CMB polarization foregrounds