Dark Energy Progress Report

Shirley Ho

Carnegie Mellon University

WFIRS2014 conference, Pasedena, 2014

Outline

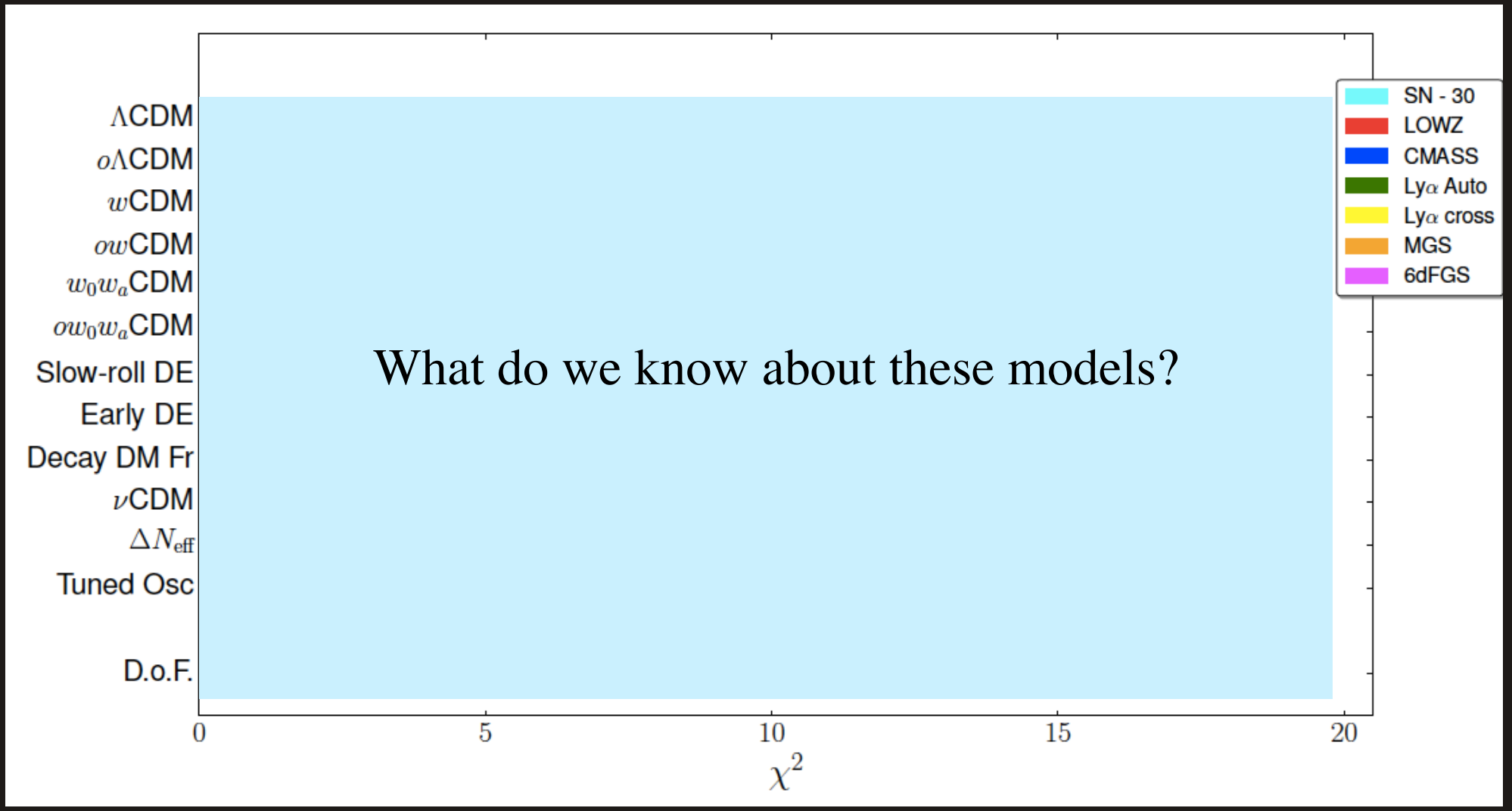
- Brief revisit to Models of Dark Energy
- What each of the following probe have told us:
  - Lensing
  - Cluster
  - CMB
  - SN
  - BAO

Image: Robert Lupton & SDSS

Dark Energy Models

- LCDM
- Equation of State
- Dark Energy density
- Dark Energy interacting with Dark Matter
- Decaying Dark Energy

Dark Energy Models



BOSS collaboration 2014

WFIRST-AFTA
Wide-Field Infrared Survey Telescope

Outline

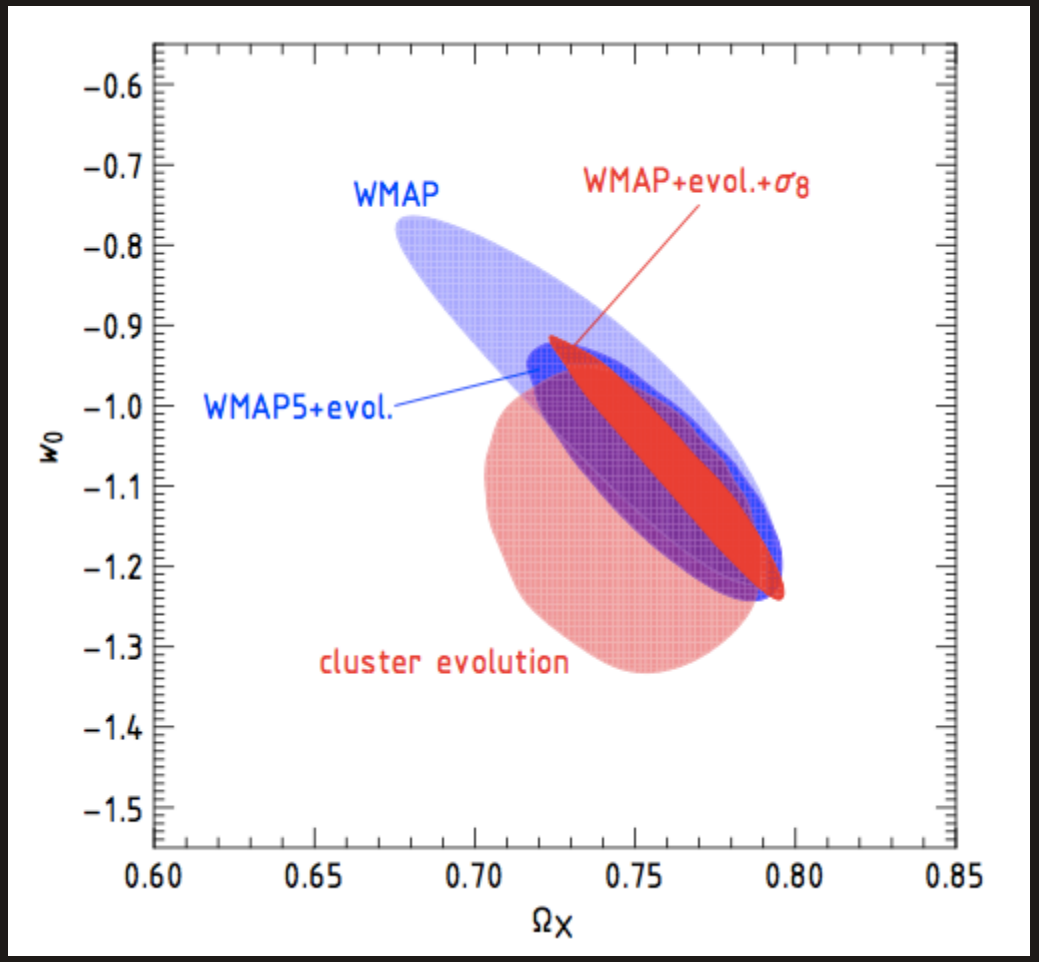
- Brief revisit to Models of Dark Energy
- What each of the following probe have told us:
  - Cluster
  - Lensing
  - CMB
  - SN
  - BAO

Image: Robert Lupton & SDSS

Dark Energy Progress

- **Cluster**

Vikhlinin et al. 2008

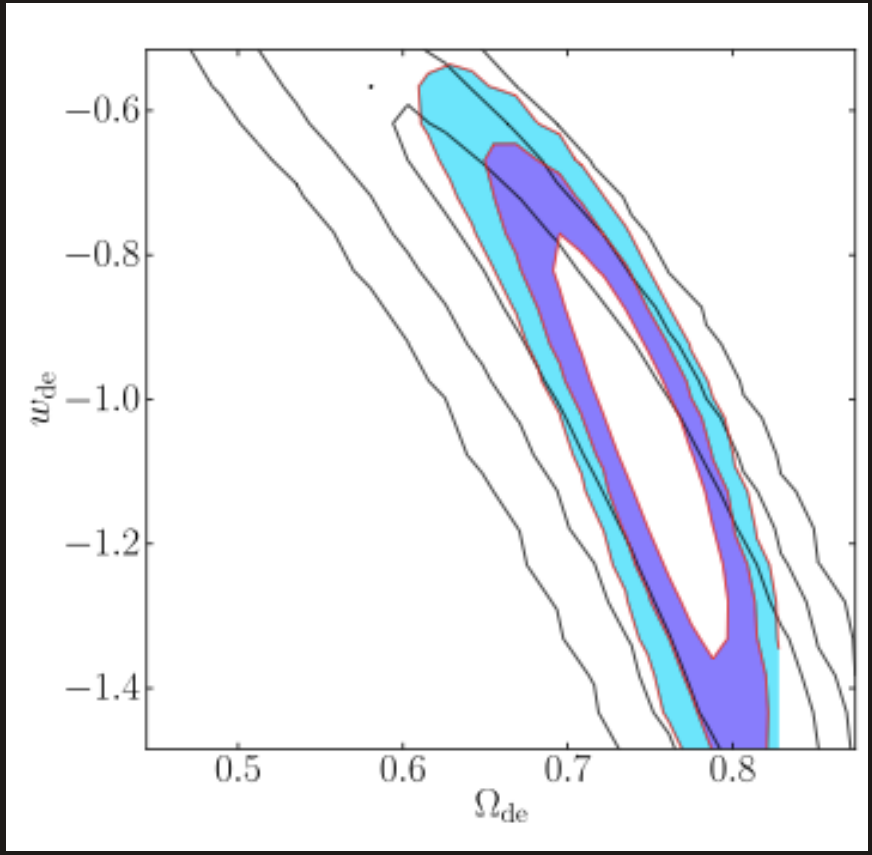


36 clusters from Chandra

WFIRST-AFTA
Wide-Field Infrared Survey Telescope

Dark Energy Progress

- **Gravitational Lensing**



SDSS-DR7 lensing
+ WMAP7
+ SDSS clustering

Mandelbaum et al. 2012

Dark Energy Progress

- **Supernova**

Suzuki et al. 2012

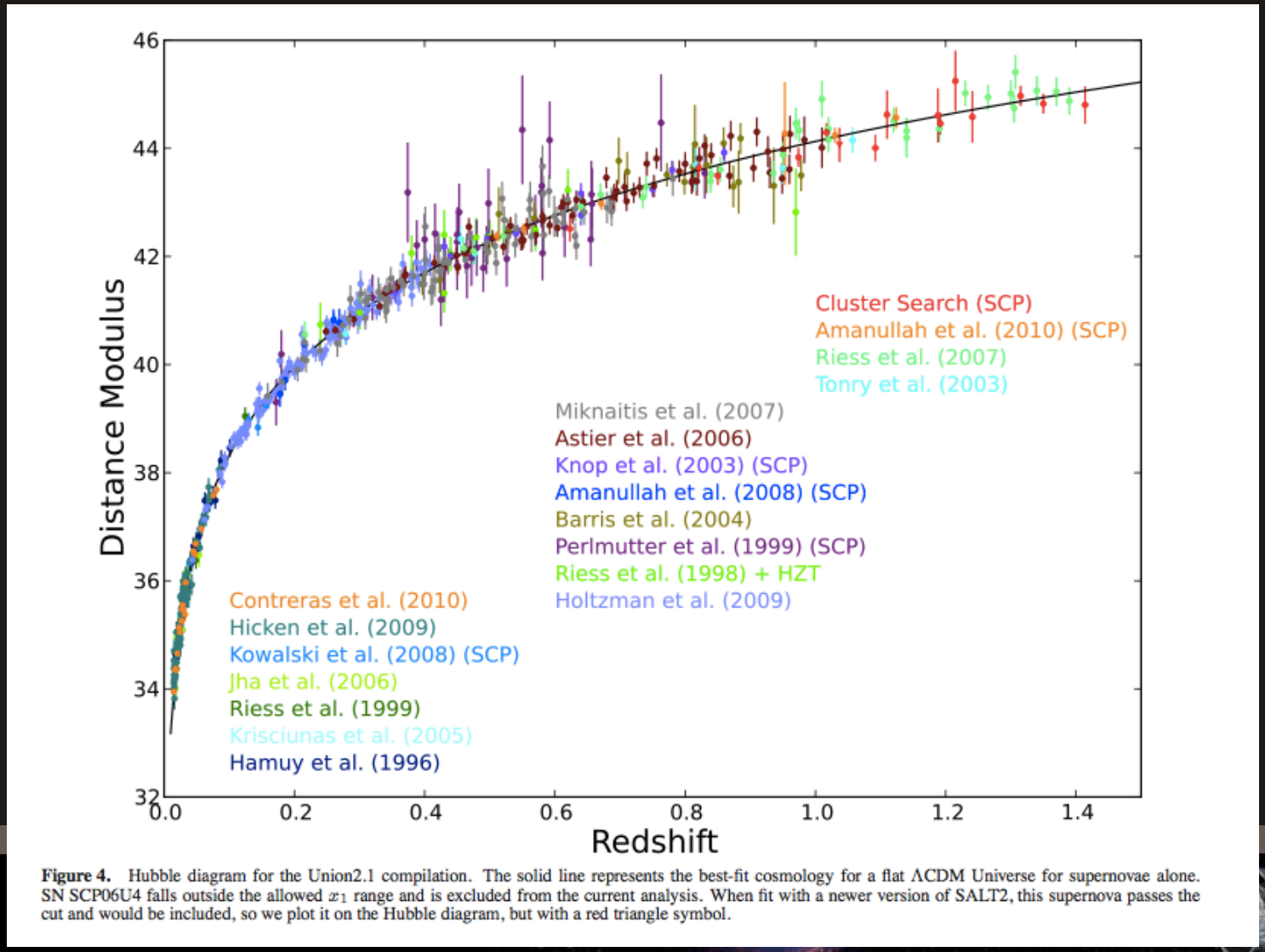
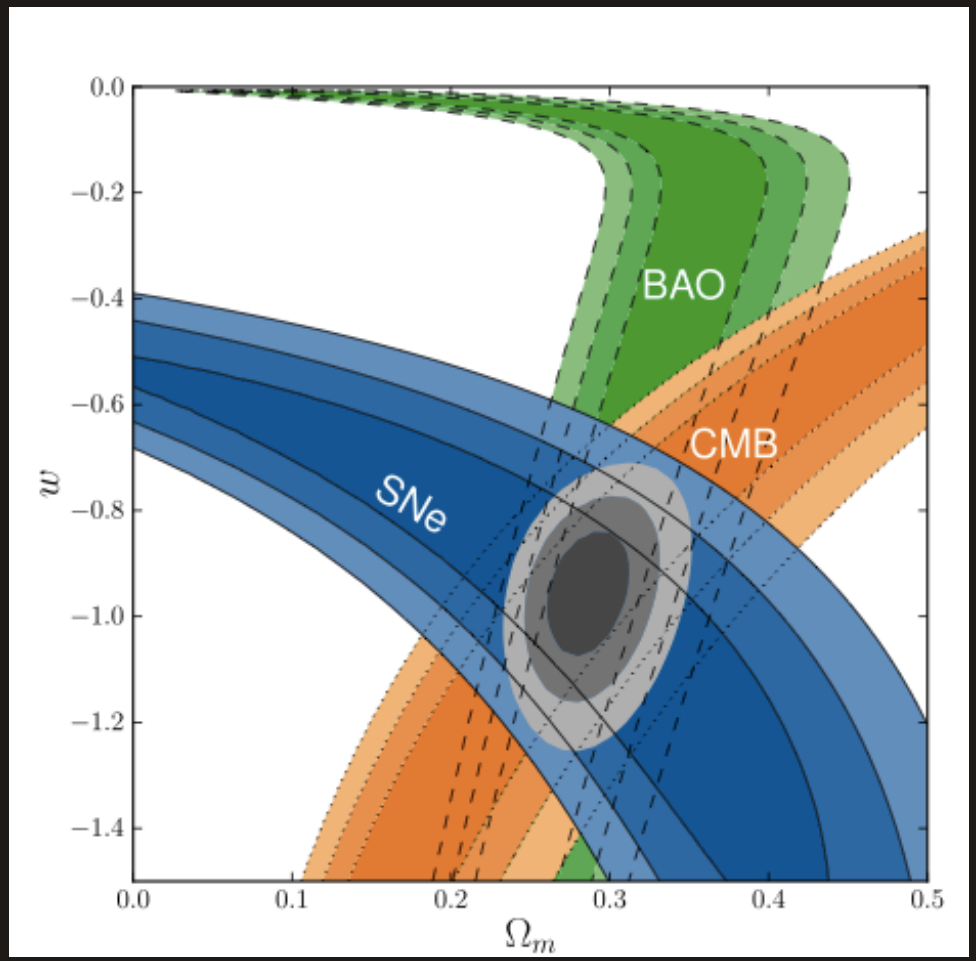


Figure 4. Hubble diagram for the Union2.1 compilation. The solid line represents the best-fit cosmology for a flat ΛCDM Universe for supernovae alone. SN SCP06U4 falls outside the allowed x_1 range and is excluded from the current analysis. When fit with a newer version of SALT2, this supernova passes the cut and would be included, so we plot it on the Hubble diagram, but with a red triangle symbol.

Dark Energy Progress

- **Supernova**

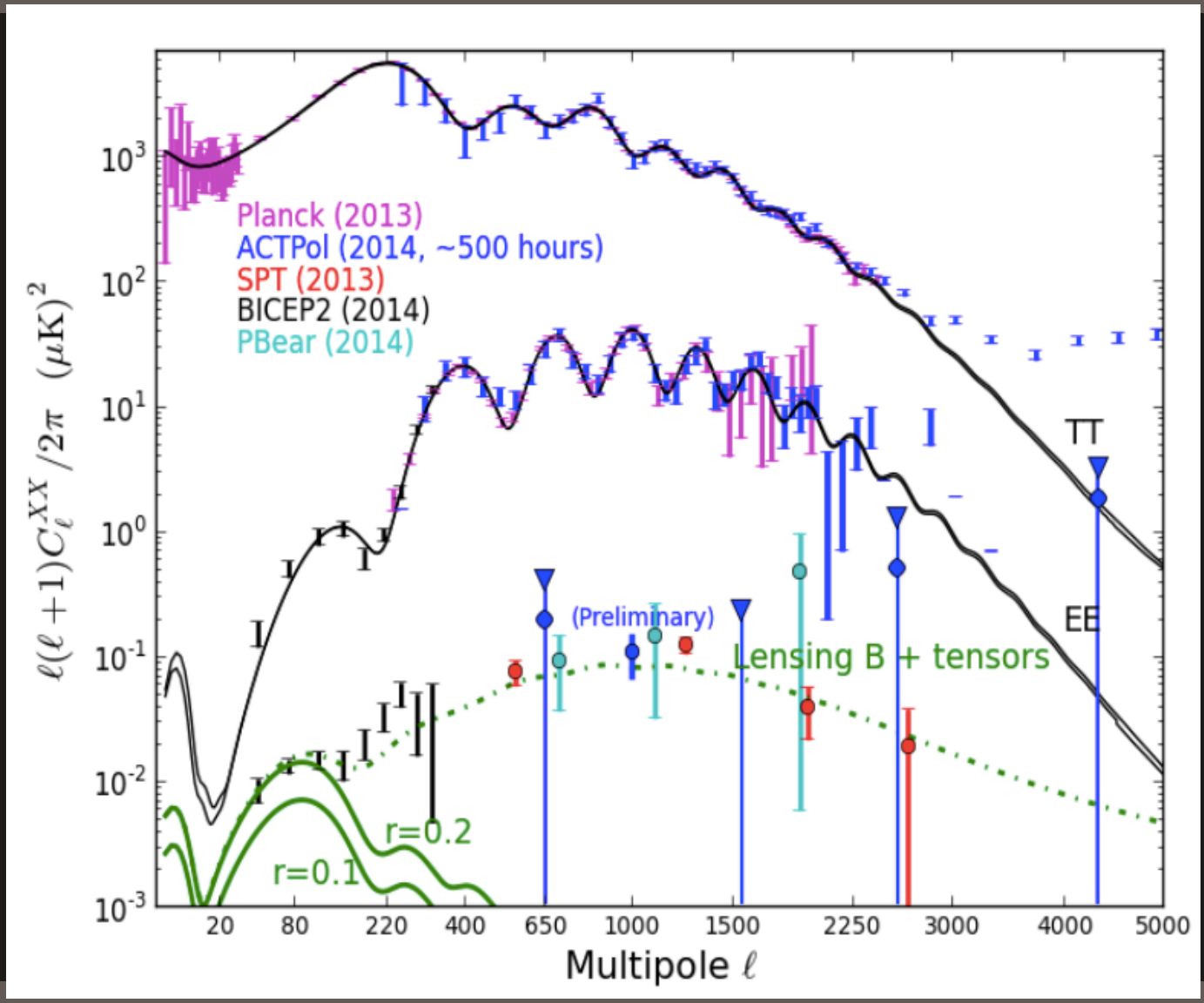
Suzuki et al. 2012



SN+
WMAP7+
BAO (SDSSI/II+2dF)

Dark Energy Progress

- **CMB**

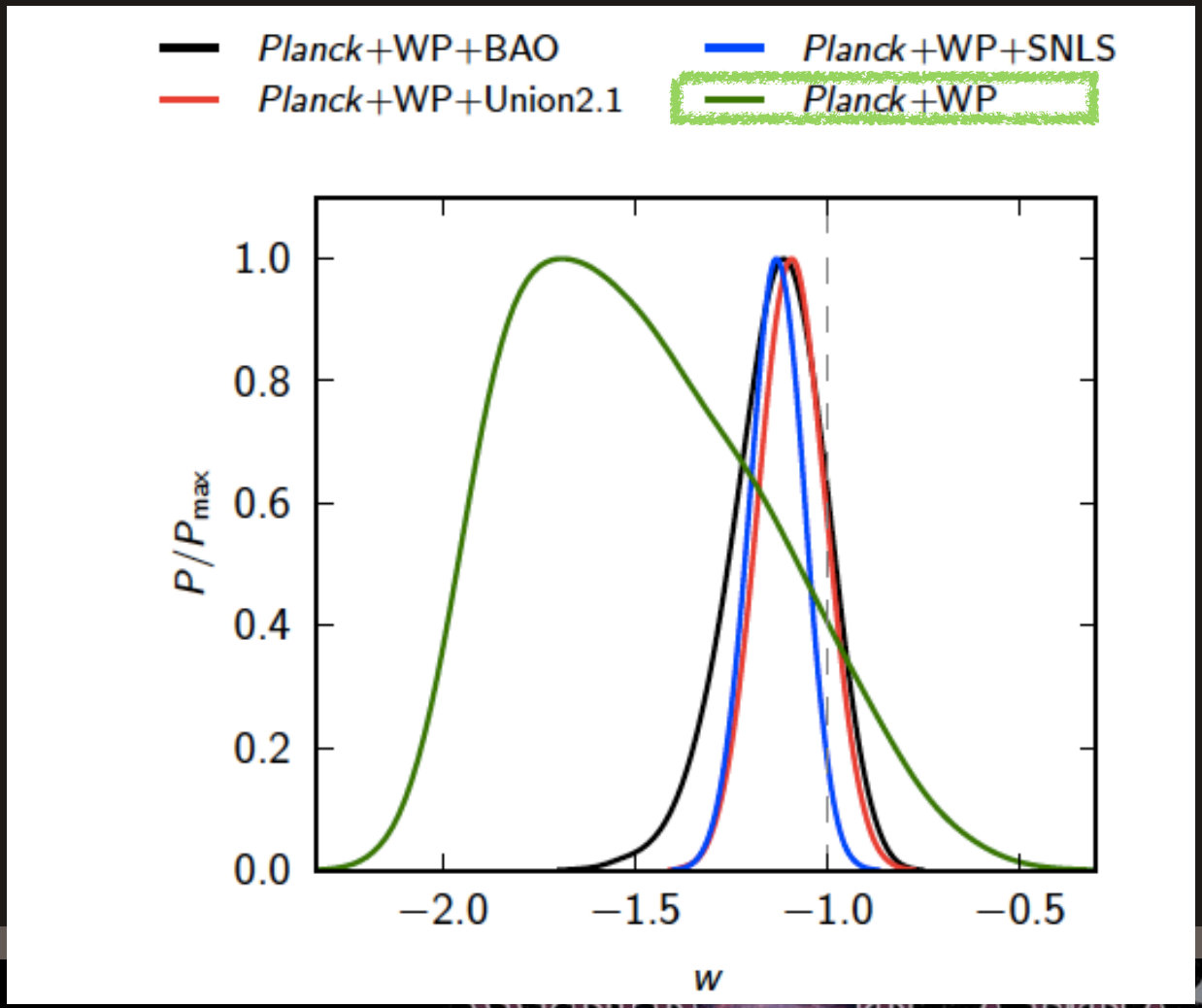


Naess et al. 2014

Dark Energy Progress

- **CMB**

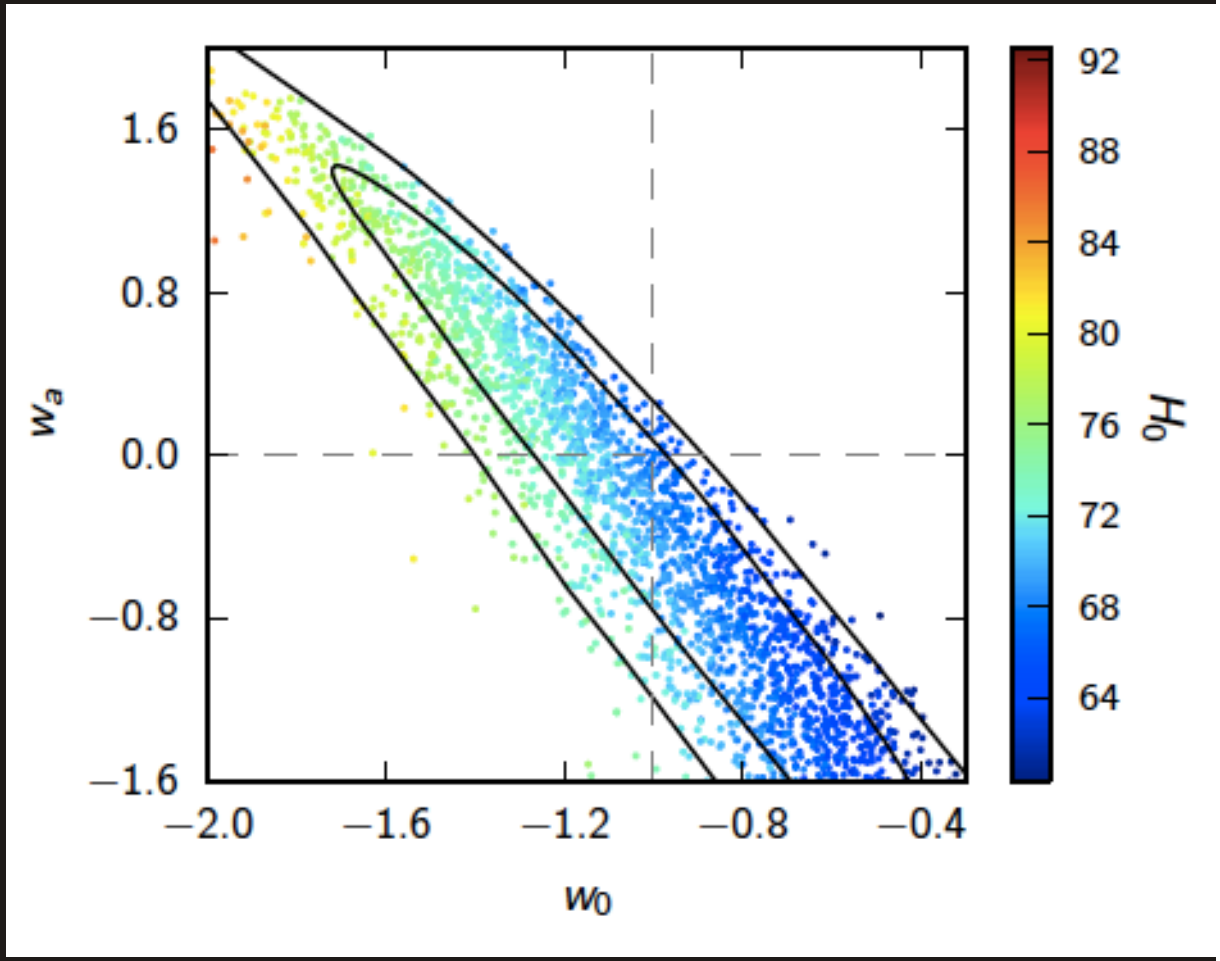
Planck Collaboration 2013



Dark Energy Progress

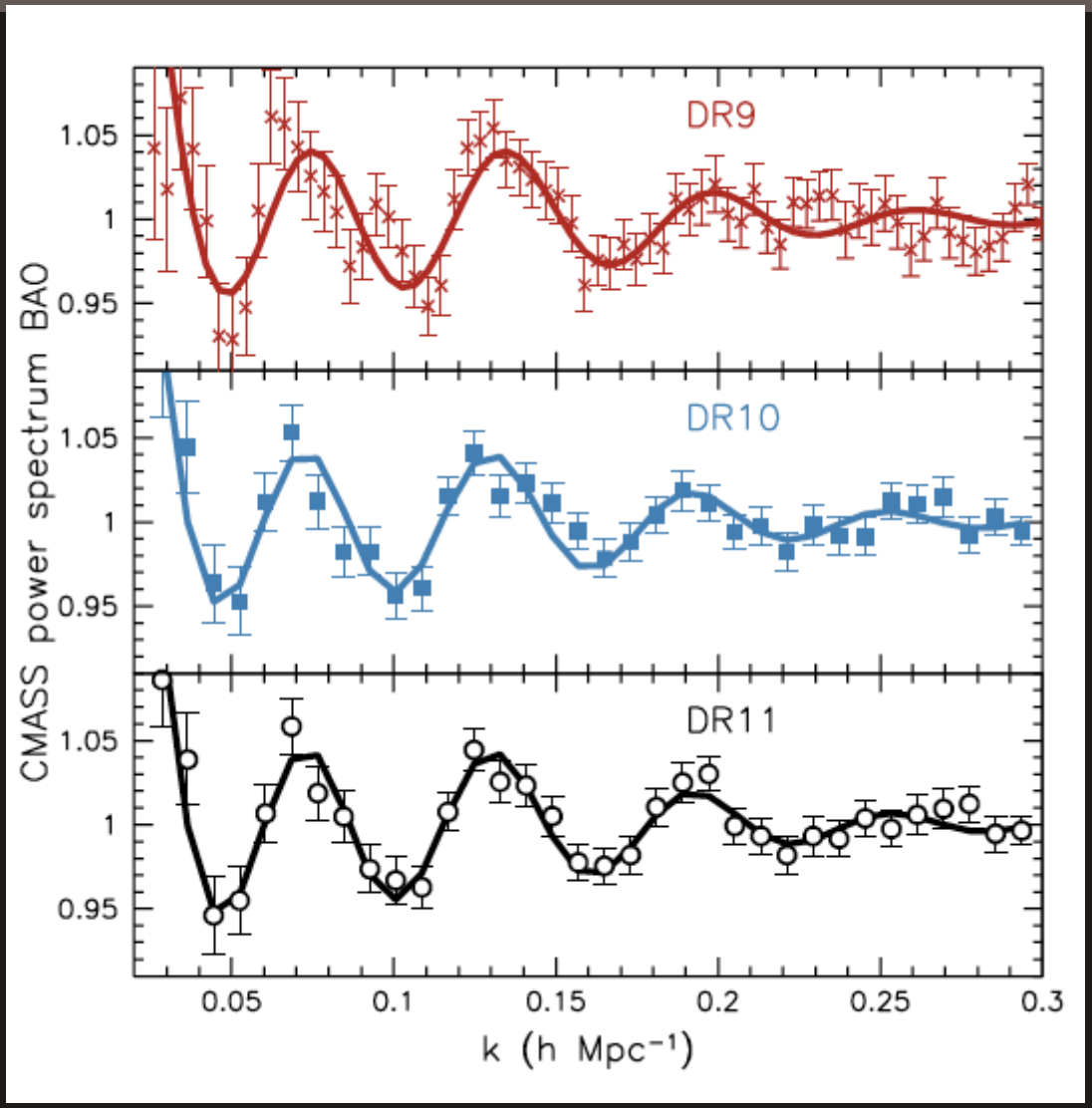
Planck Collaboration 2013

- Planck +
- WMAP polarization+
- BOSS 1st year data



Dark Energy Progress

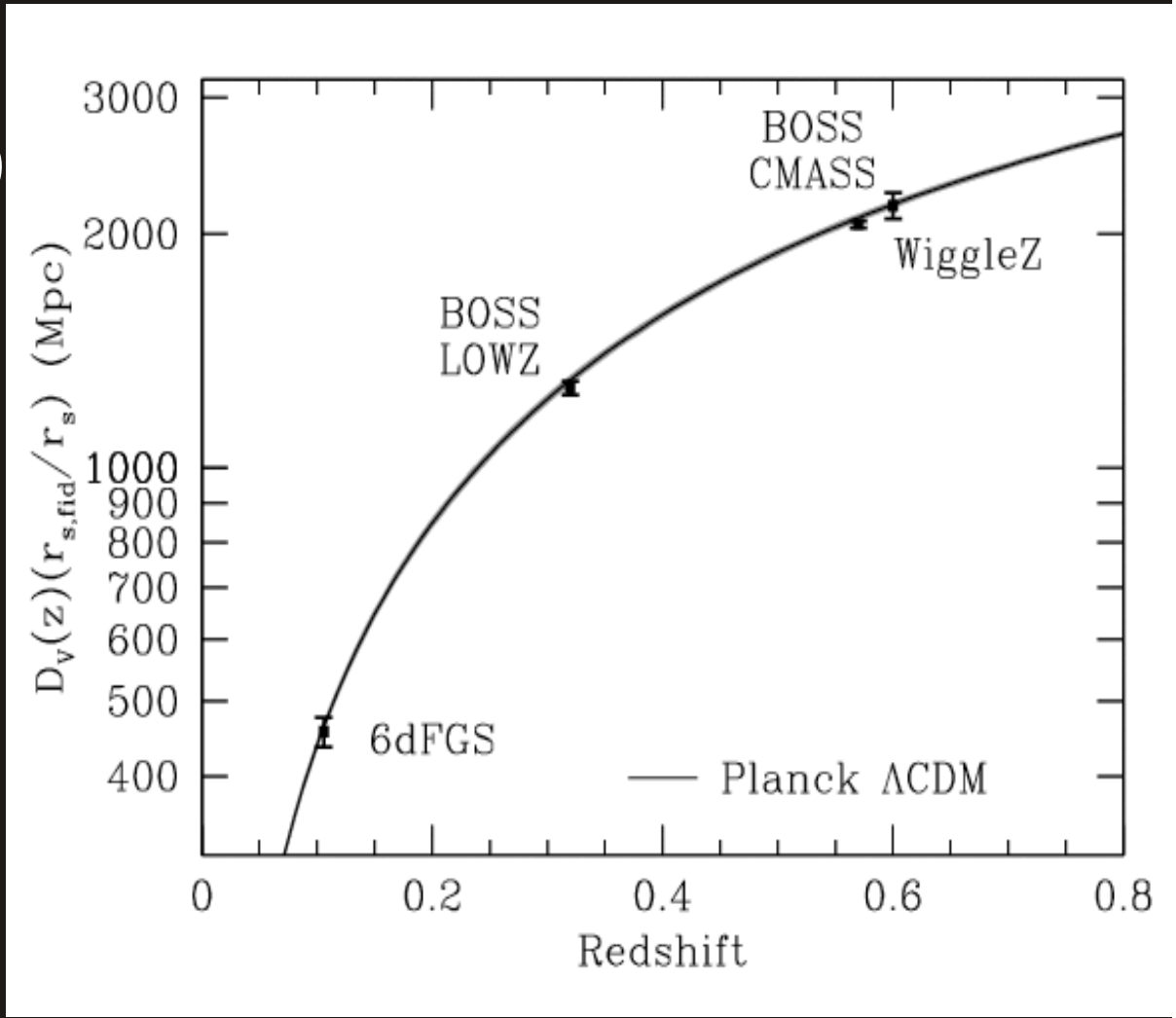
- **BAO**
- BOSS DR11 (near final)
- Same Acoustic Oscillations as in CMB



BOSS galaxy clustering WG + BOSS collaboration 2013

Dark Energy Progress

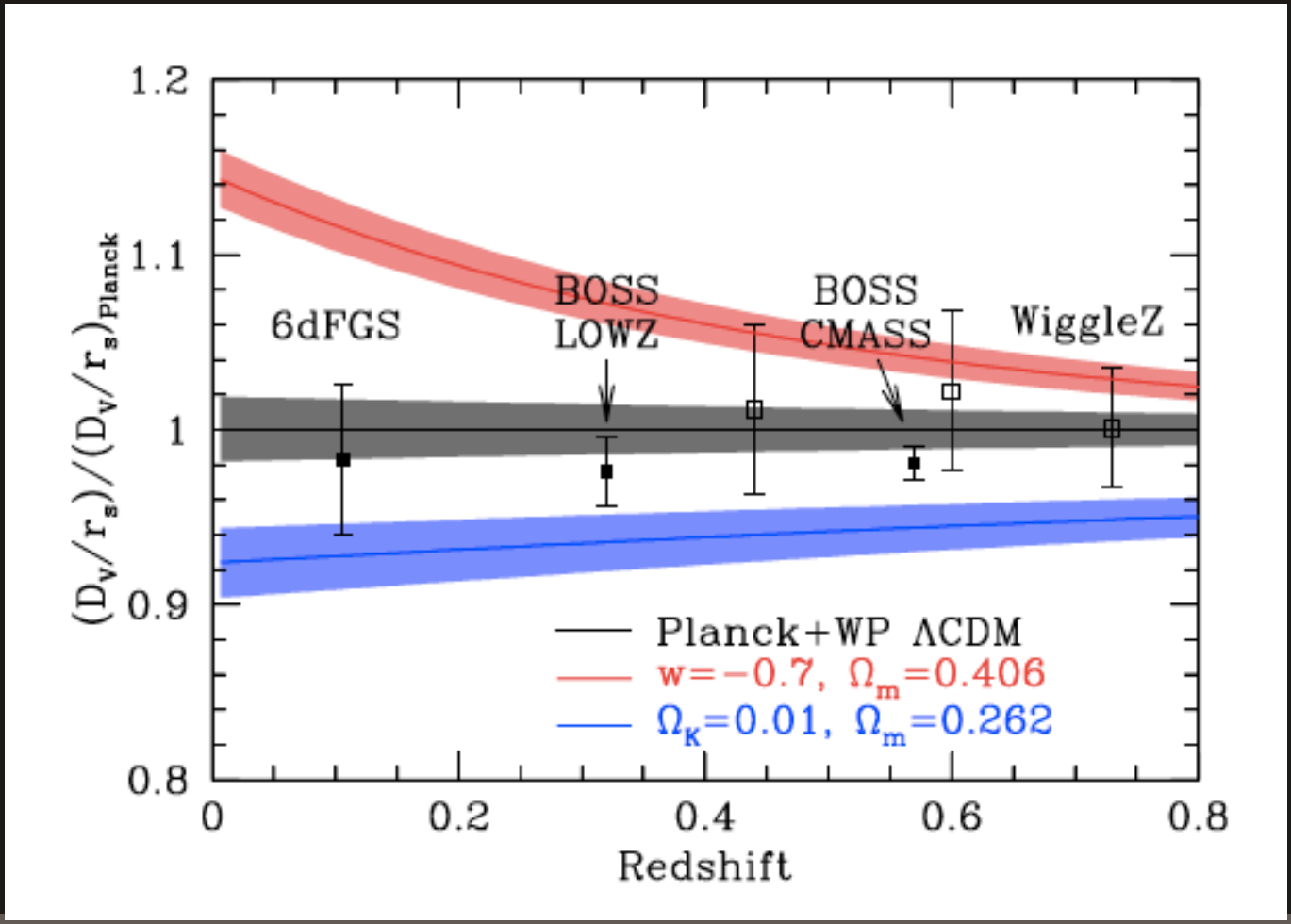
- **BAO**
- BOSS DR11 (near final)
- Distance measurement at of 1% at z=0.57 and 2.1% at z=0.32



BOSS galaxy clustering WG + BOSS collaboration 2013

Dark Energy Progress

- BAO constraints on Dark Energy

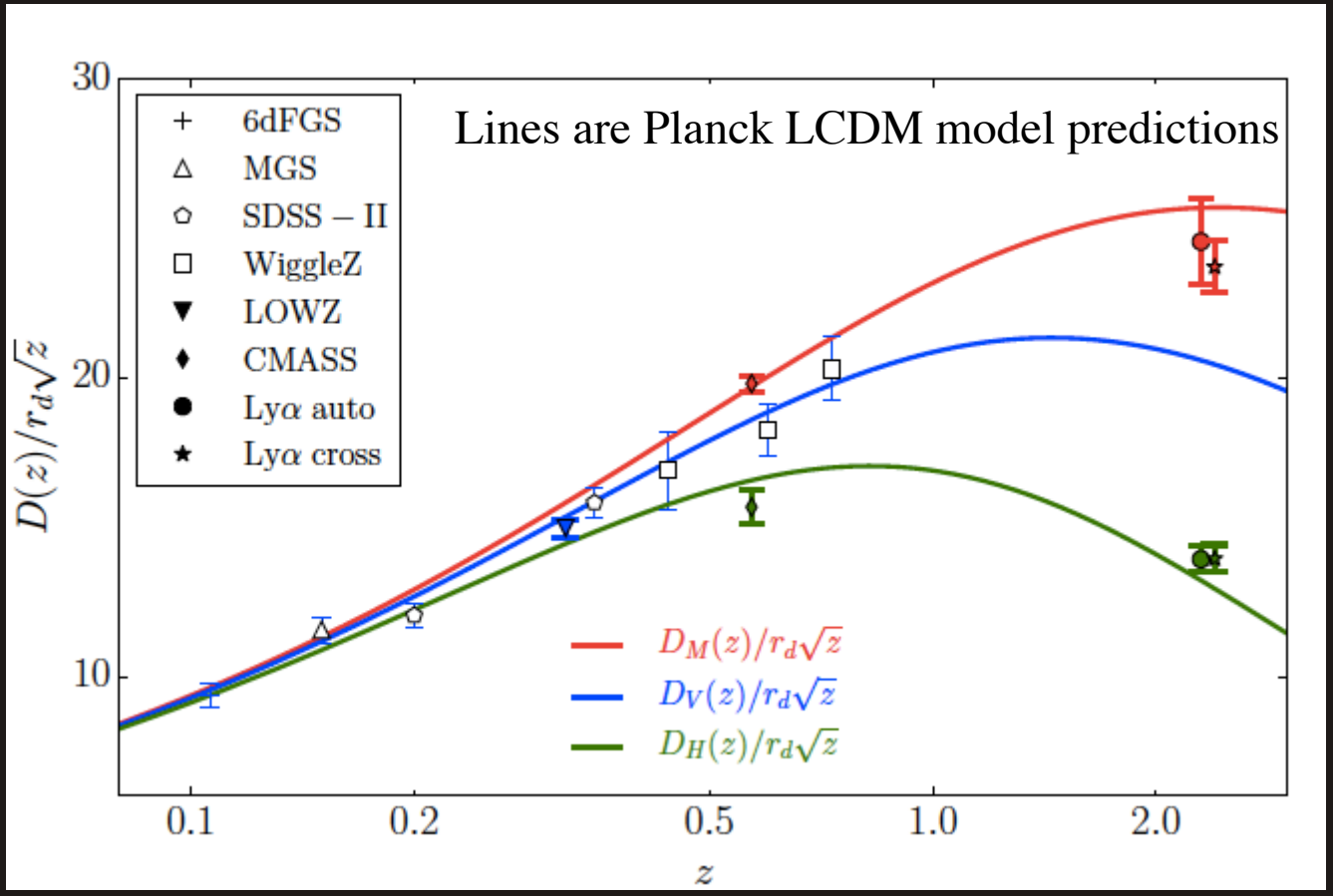


BOSS galaxy clustering WG+
BOSS collaboration 2013

WFIRST-AFTA
Wide-Field Infrared Survey Telescope

Dark Energy Progress

- Combining all BAO measurements

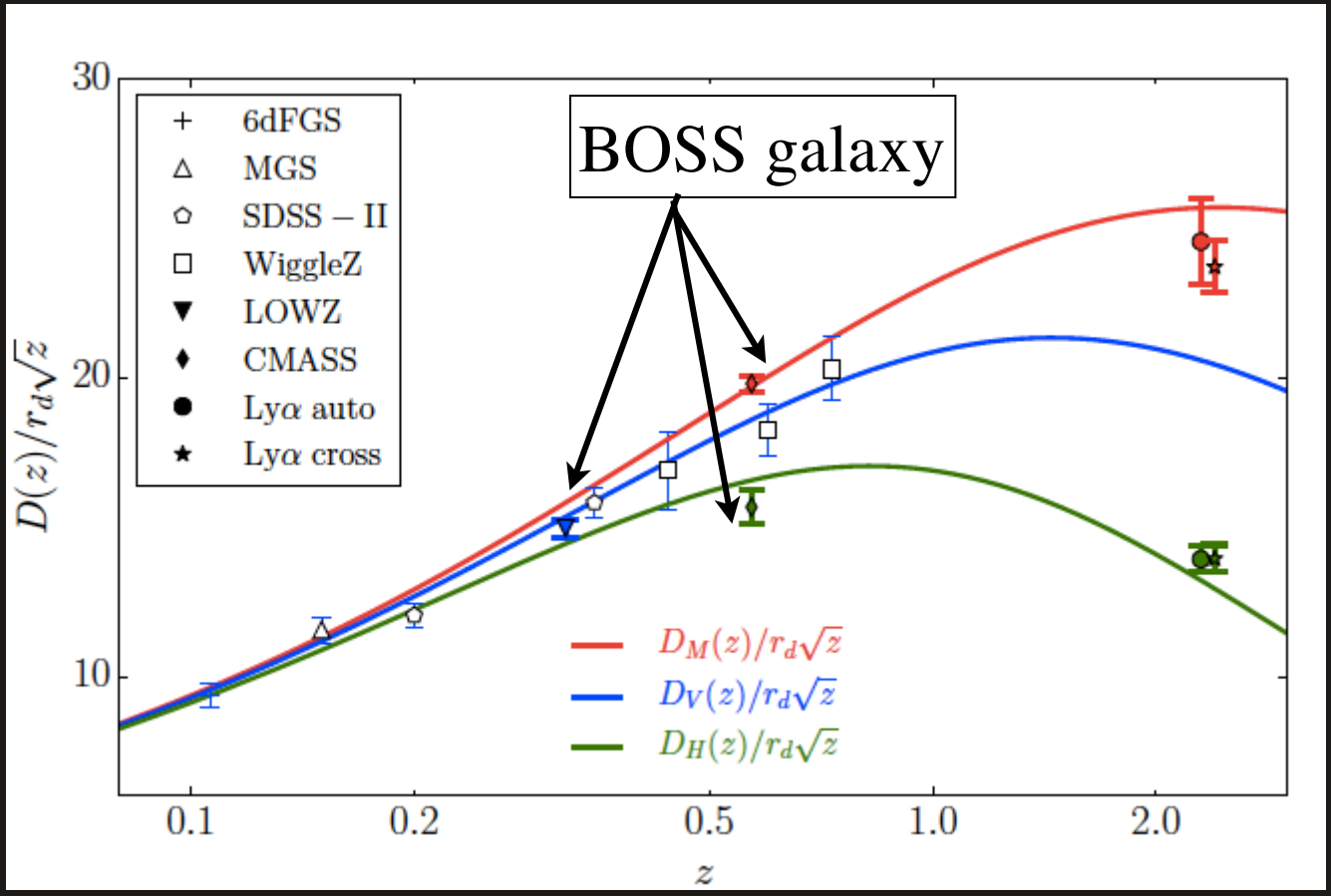


BOSS collaboration 2014

Dark Energy Progress

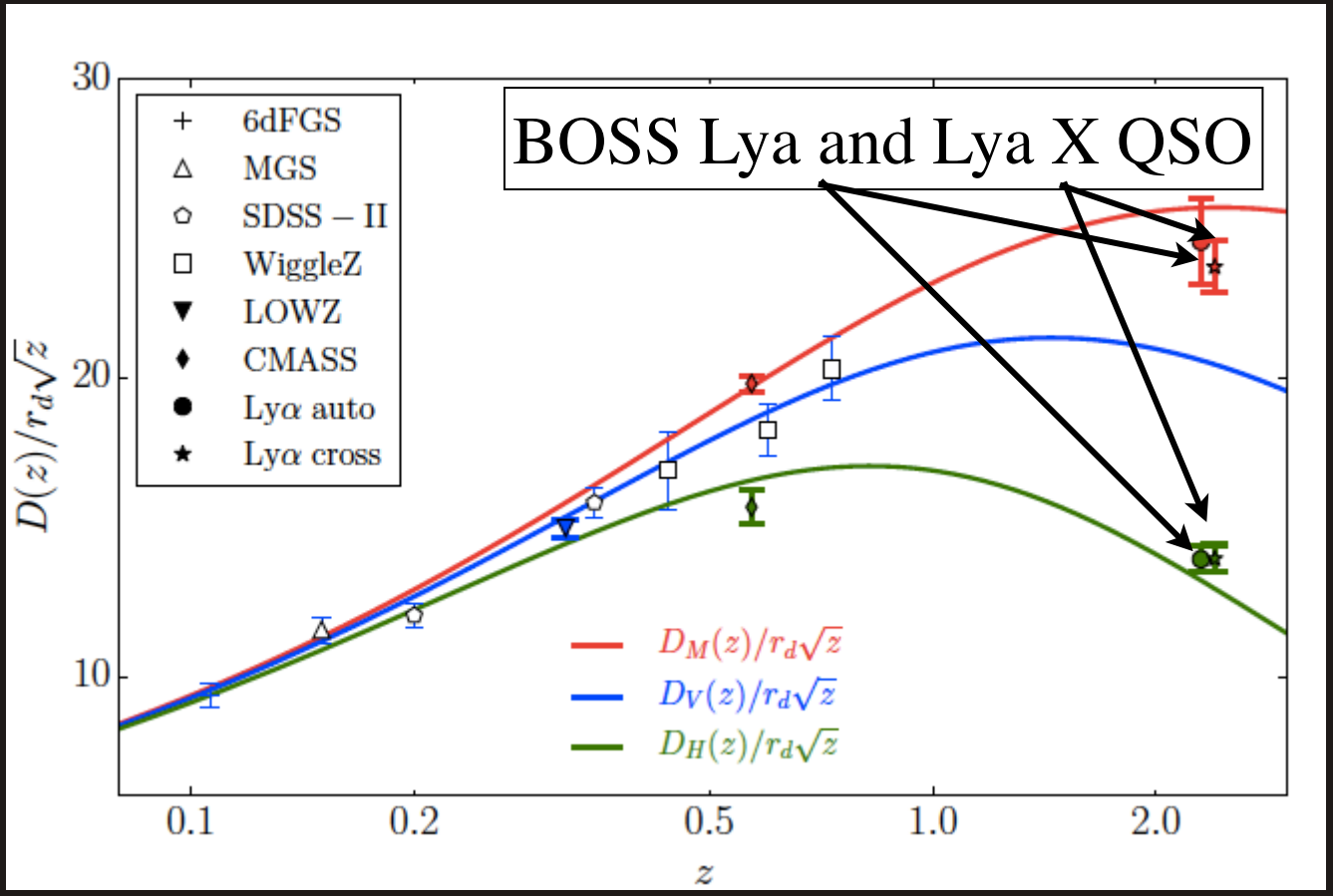
- BOSS galaxy BAO

BOSS collaboration 2014



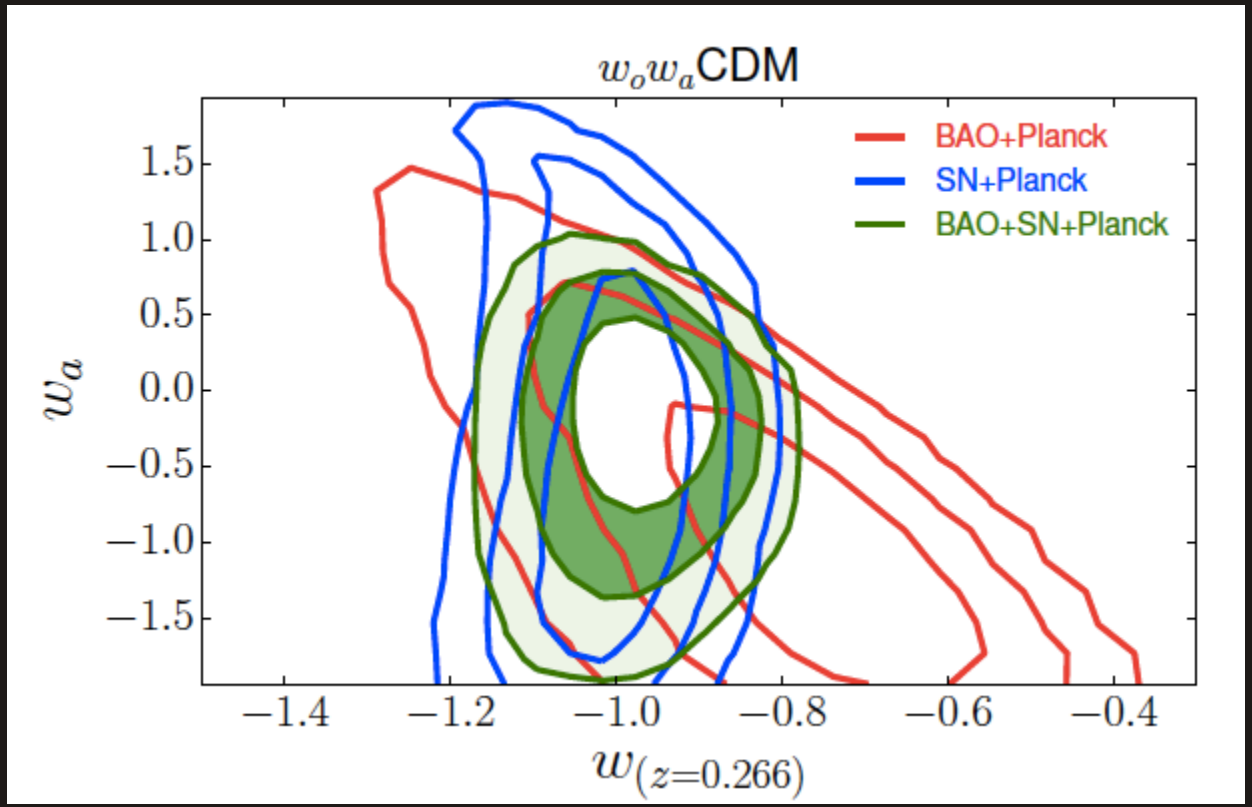
Dark Energy Progress

- Other BAO results: including Lyman-alpha forest



Dark Energy Progress

- Combined constraints:

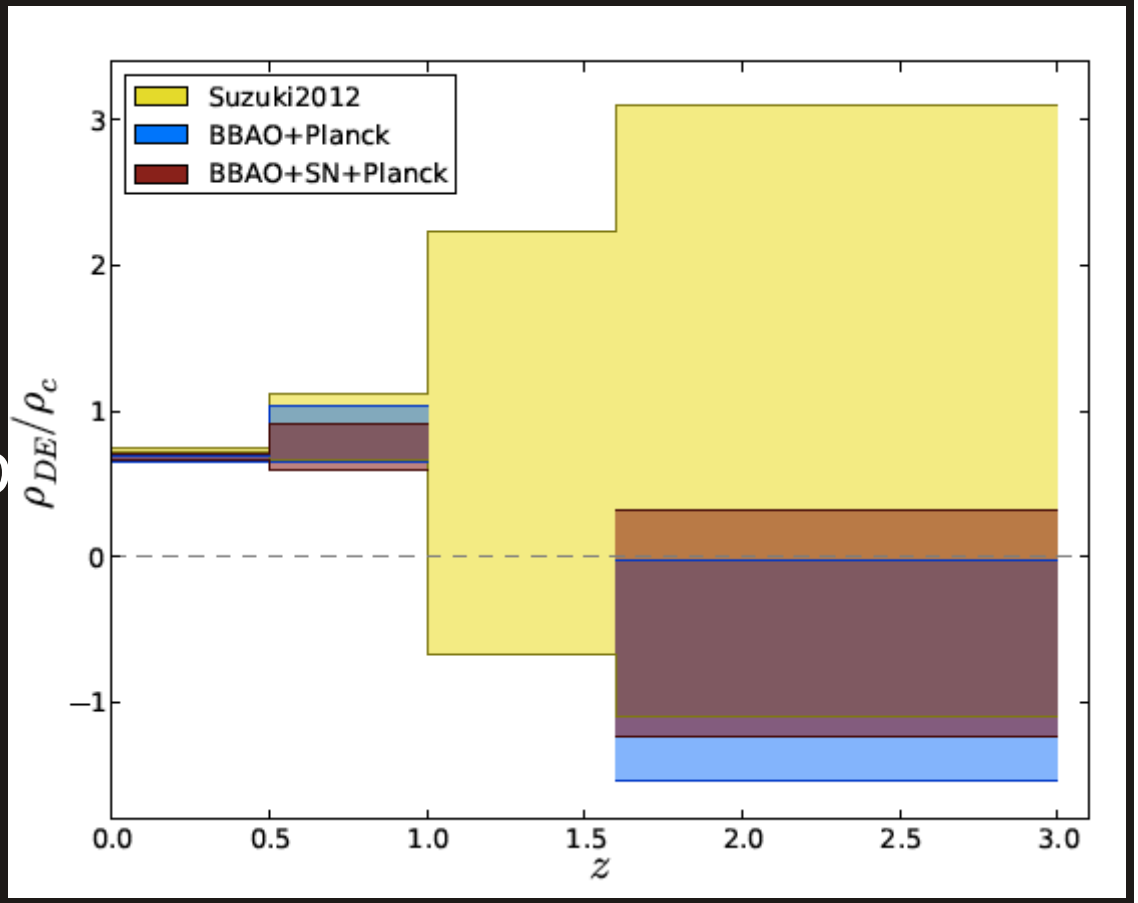


BOSS collaboration 2014

WFIRST-AFTA
Wide-Field Infrared Survey Telescope

Dark Energy Progress

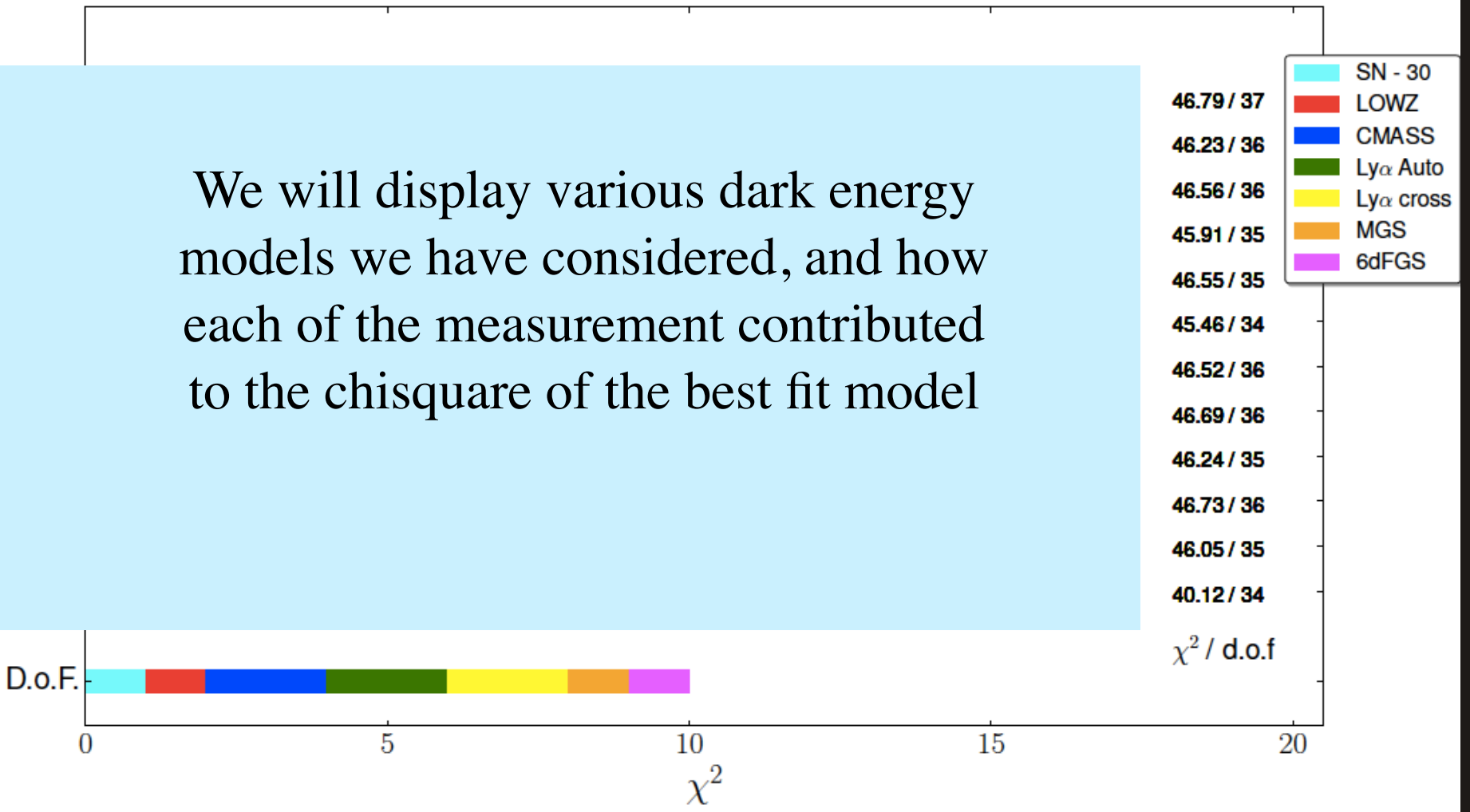
- Dark Energy Density as a function of z:
  Positive Dark Energy component at z<1.
  Slightly negative ones at z>1.6, due to Lya data.



Dark Energy Progress

BOSS collaboration 2014

We will display various dark energy models we have considered, and how each of the measurement contributed to the chisquare of the best fit model

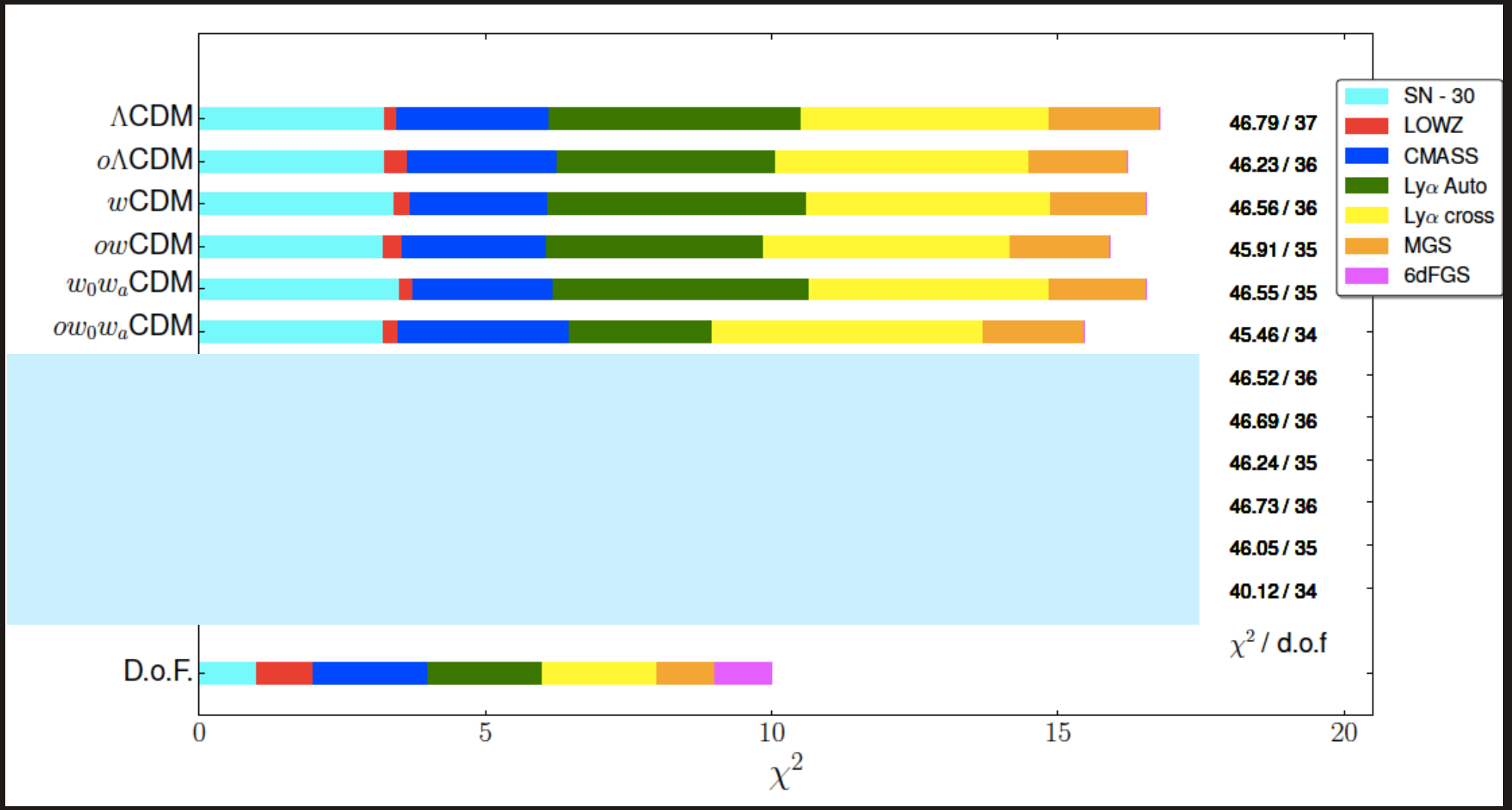


CMB chisq contributions are not shown

WFIRST-AFTA
Wide-Field Infrared Survey Telescope

Dark Energy Progress

BOSS collaboration 2014



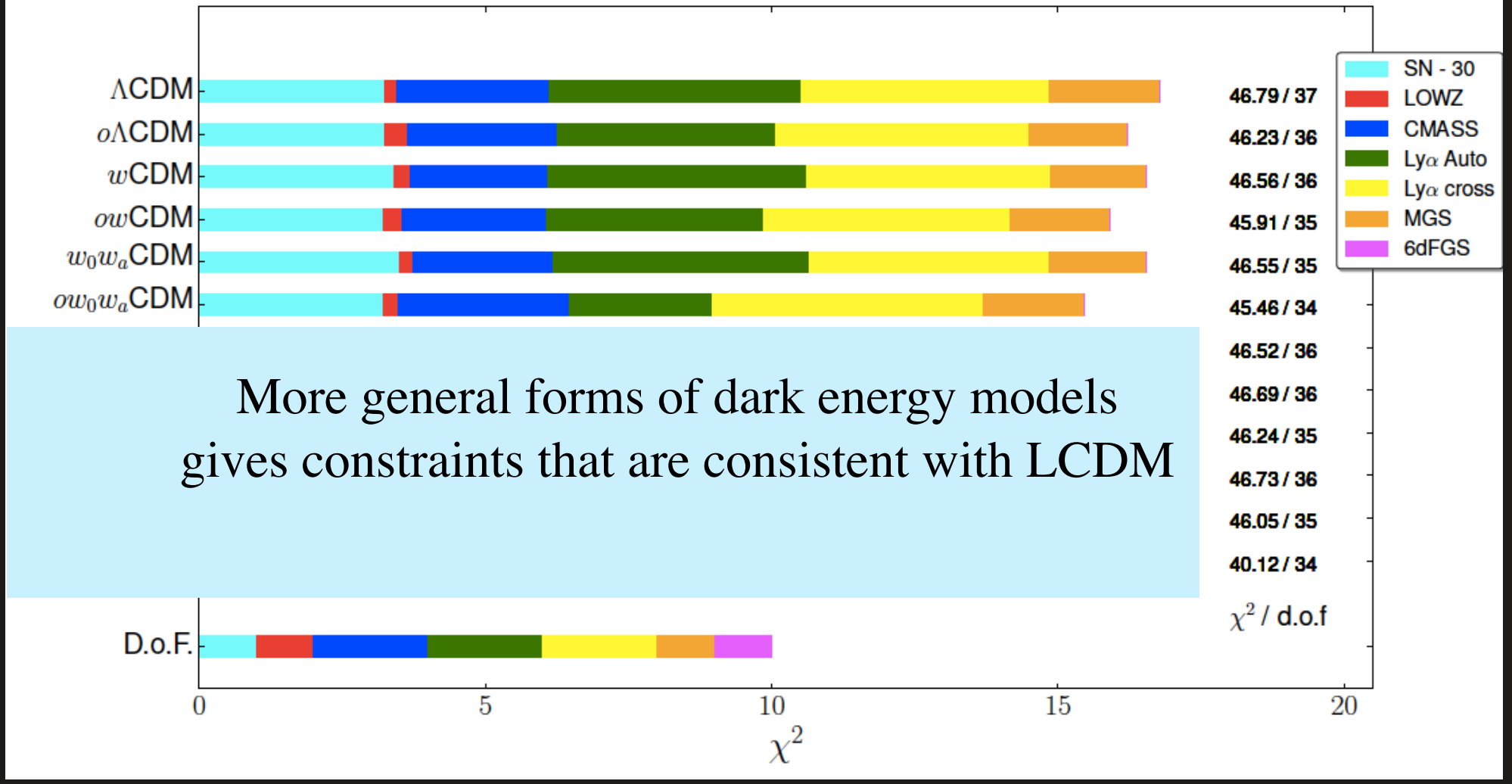
CMB contributions are not shown

WFIRST-AFTA

Wide-Field Infrared Survey Telescope

Dark Energy Progress

BOSS collaboration 2014



More general forms of dark energy models gives constraints that are consistent with LCDM

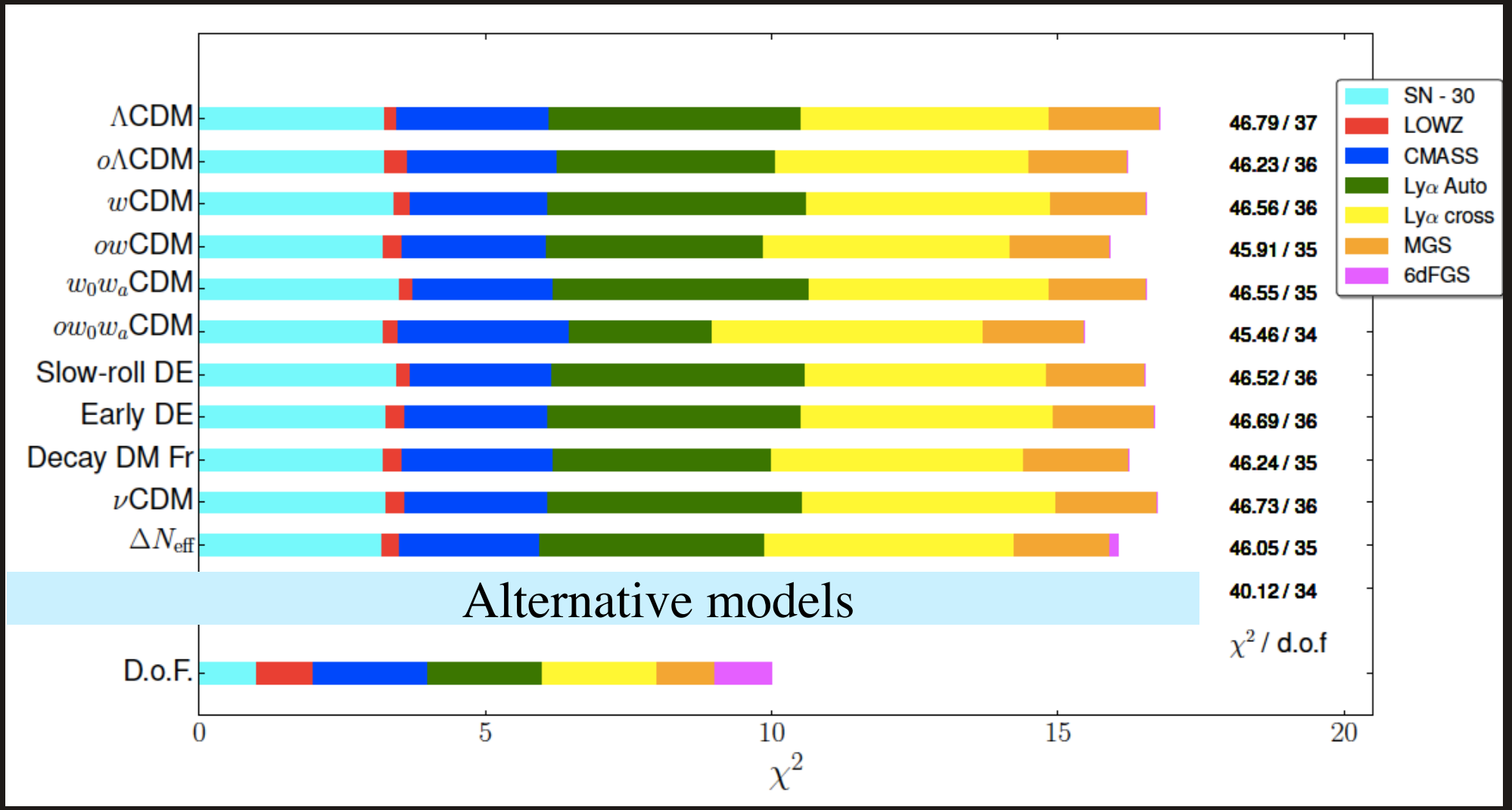
CMB contributions are not shown

WFIRST-AFTA

Wide-Field Infrared Survey Telescope

Dark Energy Progress

BOSS collaboration 2014



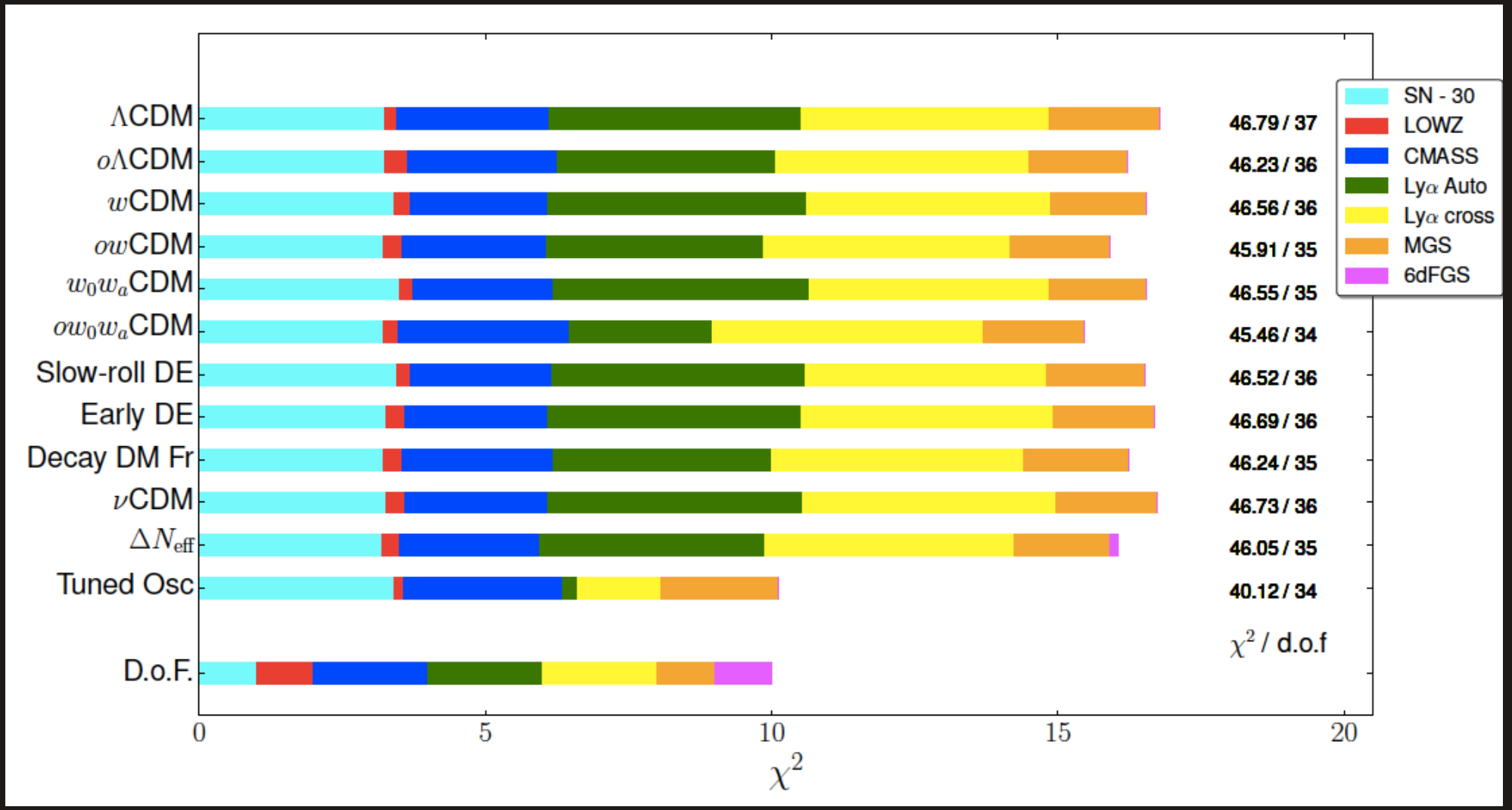
CMB contributions are not shown

WFIRST-AFTA

Wide-Field Infrared Survey Telescope

Dark Energy Progress

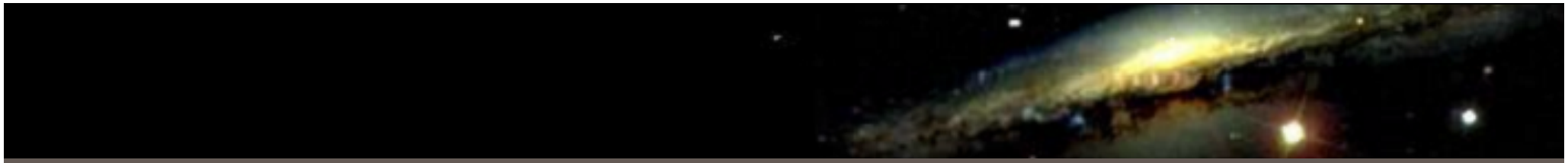
BOSS collaboration 2014



CMB contributions are not shown

WFIRST-AFTA

Wide-Field Infrared Survey Telescope



The End

Dark Energy Progress

- **CMB**

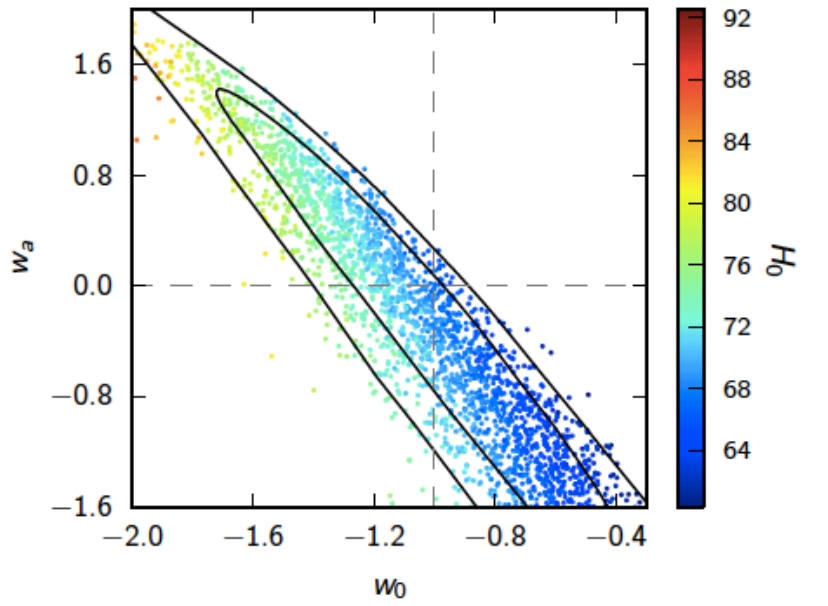
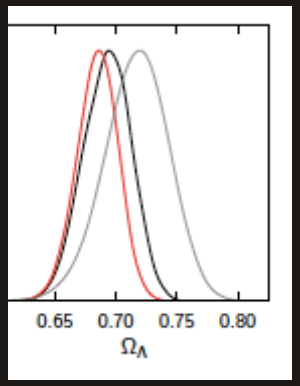


Fig. 35. 2D marginalized posterior distribution for w_0 and w_a for *Planck*+WP+BAO data. The contours are 68% and 95%, and the samples are colour-coded according to the value of H_0. Independent flat priors of $-3 < w_0 < -0.3$ and $-2 < w_a < 2$ are assumed. Dashed grey lines show the cosmological constant solution $w_0 = -1$ and $w_a = 0$.

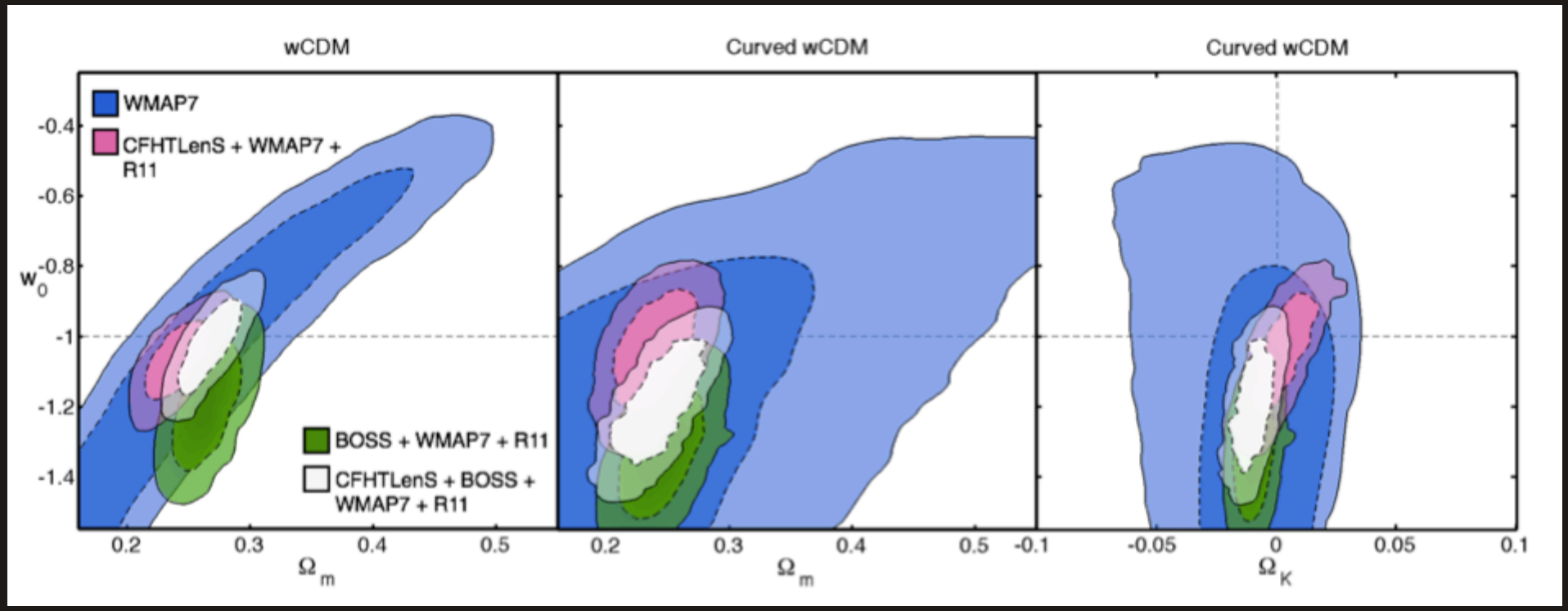


Ω_Λ	0.6817	$0.685^{+0.018}_{-0.016}$	0.6830	$0.685^{+0.017}_{-0.016}$	0.6939	0.693 ± 0.013	0.6914	0.692 ± 0.010
σ_8	0.8347	0.829 ± 0.012	0.8322	0.828 ± 0.012	0.8271	0.8233 ± 0.0097	0.8288	0.826 ± 0.012
z_{re}	11.37	11.1 ± 1.1	11.38	11.1 ± 1.1	11.42	11.1 ± 1.1	11.52	11.3 ± 1.1
H_0	67.04	67.3 ± 1.2	67.15	67.3 ± 1.2	67.94	67.9 ± 1.0	67.77	67.80 ± 0.77
Age/Gyr	13.8242	13.817 ± 0.048	13.8170	13.813 ± 0.047	13.7914	13.794 ± 0.044	13.7965	13.798 ± 0.037

Dark Energy Progress

- **Gravitational Lensing**

CFHTLS combined with other datasets

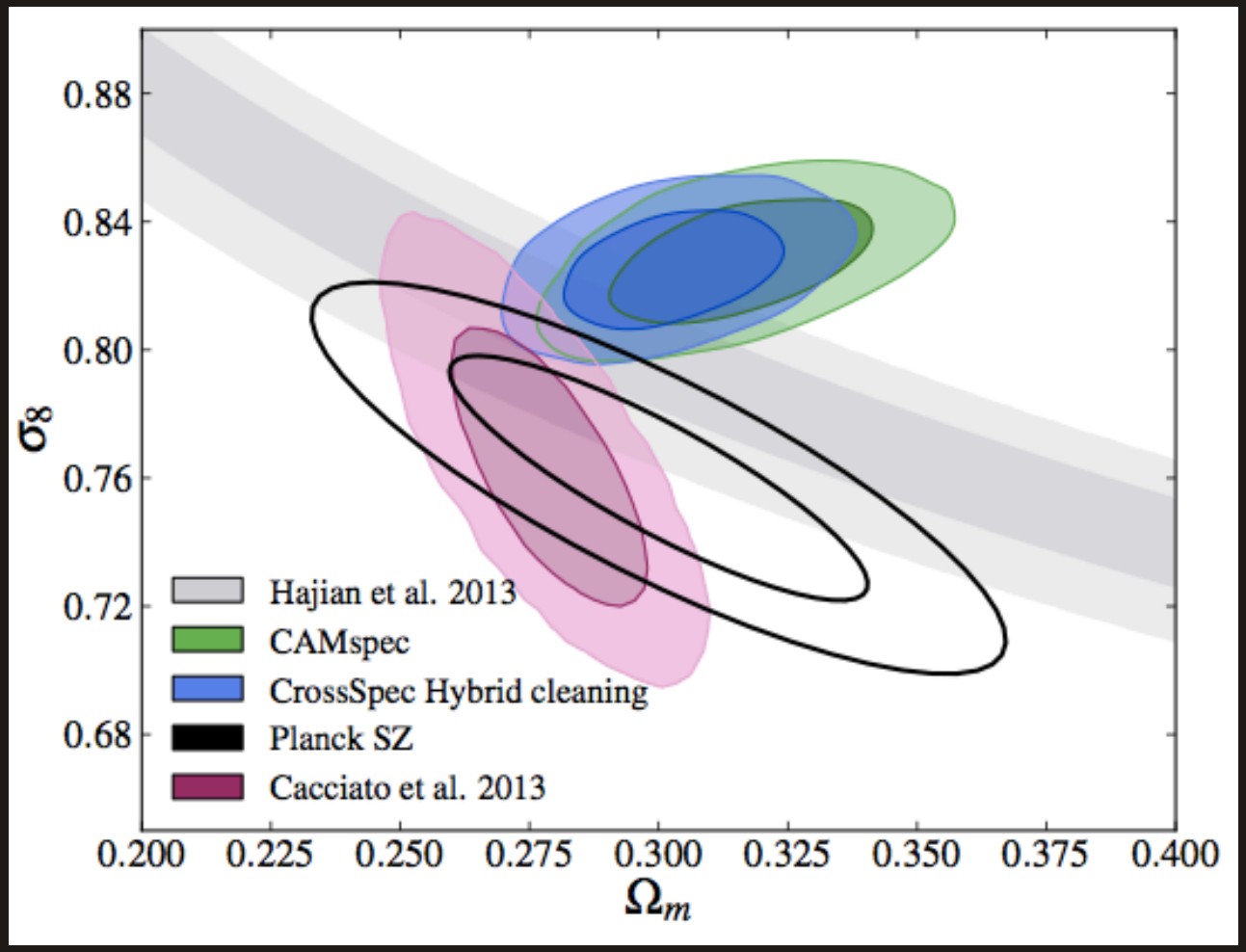


Heymans et al. 2013

Dark Energy Progress

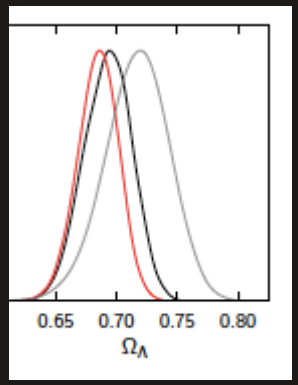
- **Cluster**

Spergel, Flauger & Hlozek 2013



Dark Energy Progress

- CMB



Ω_Λ	0.6817	$0.685^{+0.018}_{-0.016}$	0.6830	$0.685^{+0.017}_{-0.016}$	0.6939	0.693 ± 0.013	0.6914	0.692 ± 0.01
σ_8	0.8347	0.829 ± 0.012	0.8322	0.828 ± 0.012	0.8271	0.8233 ± 0.0097	0.8288	0.826 ± 0.01
z_{re}	11.37	11.1 ± 1.1	11.38	11.1 ± 1.1	11.42	11.1 ± 1.1	11.52	11.3 ± 1.1
H_0	67.04	67.3 ± 1.2	67.15	67.3 ± 1.2	67.94	67.9 ± 1.0	67.77	67.80 ± 0.77
Age/Gyr	13.8242	13.817 ± 0.048	13.8170	13.813 ± 0.047	13.7914	13.794 ± 0.044	13.7965	13.798 ± 0.03

Dark Energy Progress

- **SN or**
- **BAO (BOSS 1st year)**
- + Planck
- + WMAP Polarization

Planck Collaboration 2013

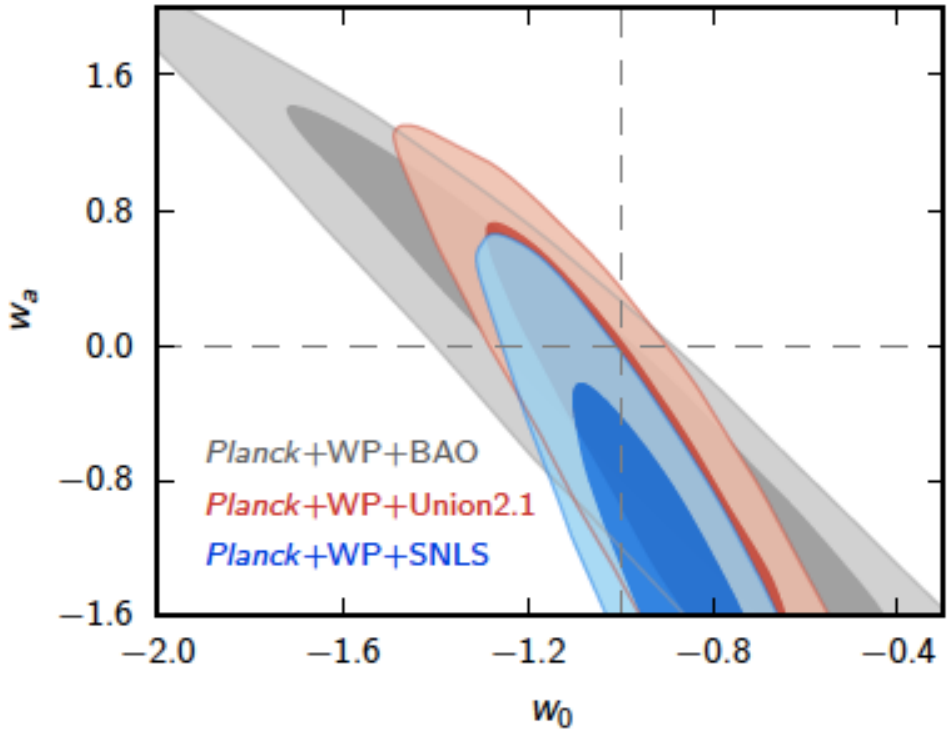


Fig. 36. 2D marginalized posterior distributions for w_0 and w_a, for the data combinations *Planck*+WP+BAO (grey), *Planck*+WP+Union2.1 (red) and *Planck*+WP+SNLS (blue). The contours are 68% and 95%, and dashed grey lines show the cosmological constant solution.