Cosmic Acceleration: From Today To WFIRST

David Weinberg, Ohio State University
Dept. of Astronomy and CCAPP
WFIRST-AFTA Science Definition Team

1. Is cosmic expansion accelerating because of a breakdown of GR on cosmological scales or because of a new energy component that exerts repulsive gravity within GR?
2. If the latter, is the energy density of this component constant in space and time, consistent with fundamental vacuum energy?

General approach: Measure the expansion history and structure growth history with the highest achievable precision over a wide range of redshifts. Stay open to anomalies and surprises.

Priors: What should we expect when our theories are lousy?

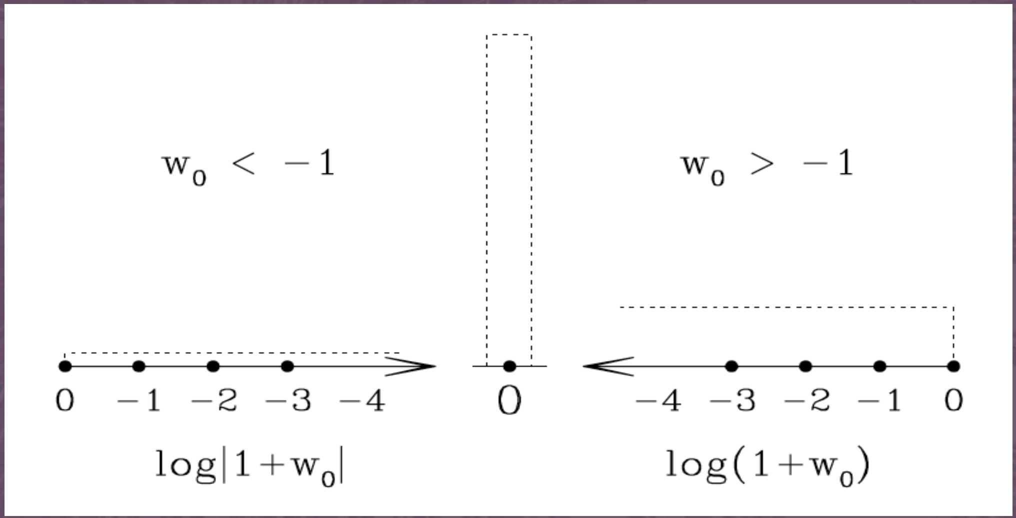
Dark energy vs. modified gravity vs. other: Equal priors?

Modified gravity would be (even) more interesting.

But consistently modifying GR is hard.

Could have DE phenomenology but different interpretation.

Prior on effective value of $1+w_0$



A big discovery could come any time … Or never …

The Figure of Merit: Aggregate Precision

In absence of theoretical guidance, most important FoM of an experiment is the aggregate precision with which it measures its basic observable, including correlations and systematics.

E.g.,	overall multiplication of $D_A(z)$ or $H(z)$	(BAO)
	tilt of $D_L(z)$	(SN)
	multiplication of $\sigma_8(z)$	(WL, CL, RSD)

For *uncorrelated* errors in N bins, $(\Delta \ln O)_{agg} = [\ \Sigma_N (\Delta \ln O_i)^{-2}\ ]^{-1/2}$
At comparable aggregate precision, wider range of redshift and diversity of measures is better.

	Expansion History Measures	Structure Growth Measures
Today	1 – 2 %	5 – 10 %
To	0.2 – 0.5 %	1 – 2 %
WFIRST	~ 0.1%	~ 0.1%

Today: A Report from BOSS

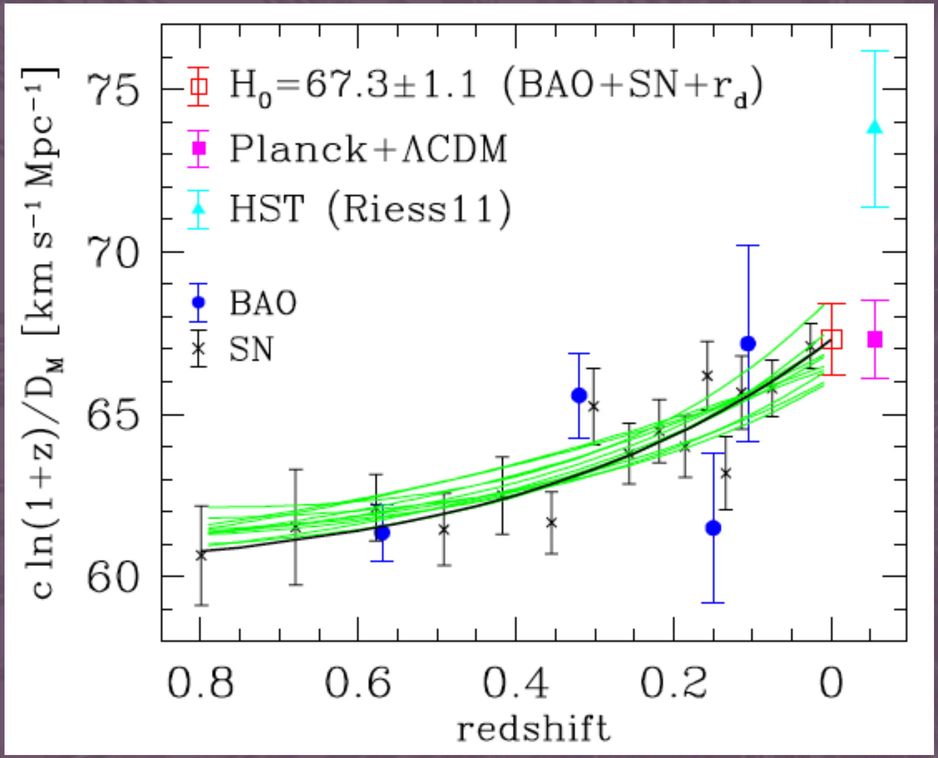
arXiv:1411.1074

Cosmological implications of baryon acoustic oscillation (BAO) measurements

Éric Aubourg[1], Stephen Bailey[2], Julian E. Bautista[1], Florian Beutler[2], Vaishali Bhardwaj[3,2], Dmitry Bizyaev[4], Michael Blanton[5], Michael Blomqvist[6], Adam S. Bolton[7], Jo Bovy[8], Howard Brewington[4], J. Brinkmann[4], Joel R. Brownstein[7], Angela Burden[9], Nicolás G. Busca[1,10,11], William Carithers[2], Chia-Hsun Chuang[12], Johan Comparat[12], Antonio J. Cuesta[13,14], Kyle S. Dawson[7], Timothée Delubac[15], Daniel J. Eisenstein[16], Andreu Font-Ribera[2], Jian Ge[17], J.-M. Le Goff[18], Satya Gontcho A Gontcho[14], J. Richard Gott, III[19], James E. Gunn[19], Hong Guo[7], Julien Guy[20,2], Jean-Christophe Hamilton[1], Shirley Ho[21], Klaus Honscheid[22,23], Cullan Howlett[9], David Kirkby[6], Francisco S. Kitaura[24], Jean-Paul Kneib[15,25], Khee-Gan Lee[26], Dan Long[4], Robert H. Lupton[21], Mariana Vargas Magaña[1], Viktor Malanushenko[4], Elena Malanushenko[4], Marc Manera[9,27], Claudia Maraston[9], Daniel Margala[6], Cameron K. McBride[16], Jordi Miralda-Escudé[28,14], Adam D. Myers[29], Robert C. Nichol[9], Pasquier Noterdaeme[30], Sebastián E. Nuza[24], Matthew D. Olmstead[7], Daniel Oravetz[4], Isabelle Pâris[31], Nikhil Padmanabhan[13], Nathalie Palanque-Delabrouille[2,18], Kaike Pan[4], Marcos Pellejero-Ibanez[32,33], Will J. Percival[9], Patrick Petitjean[30], Matthew M. Pieri[9], Francisco Prada[12,34,35], Beth Reid[2,36], Natalie A. Roe[2], Ashley J. Ross[9,23], Nicholas P. Ross[37], Graziano Rossi[38,18], Jose Alberto Rubiño-Martín[32,33], Ariel G. Sánchez[39], Lado Samushia[40,41], Ricardo Tanausú Génova Santos[32], Claudia G. Scóccola[12,32,42], David J. Schlegel[2], Donald P. Schneider[43,44], Hee-Jong Seo[23,45], Erin Sheldon[26], Audrey Simmons[4], Ramin A. Skibba[46], Anže Slosar[47], Michael A. Strauss[19], Daniel Thomas[9], Jeremy L. Tinker[5], Rita Tojeiro[9], Jose Alberto Vazquez[47], Matteo Viel[31,48], David A. Wake[49,50], Benjamin A. Weaver[5], David H. Weinberg[23,51], W. M. Wood-Vasey[52], Christophe Yèche[18], Idit Zehavi[53], and Gong-Bo Zhao[54,9]

(Dated: November 6, 2014. Authors' institutions can be found in Appendix A.)

1. Measuring H_0 from the outside in



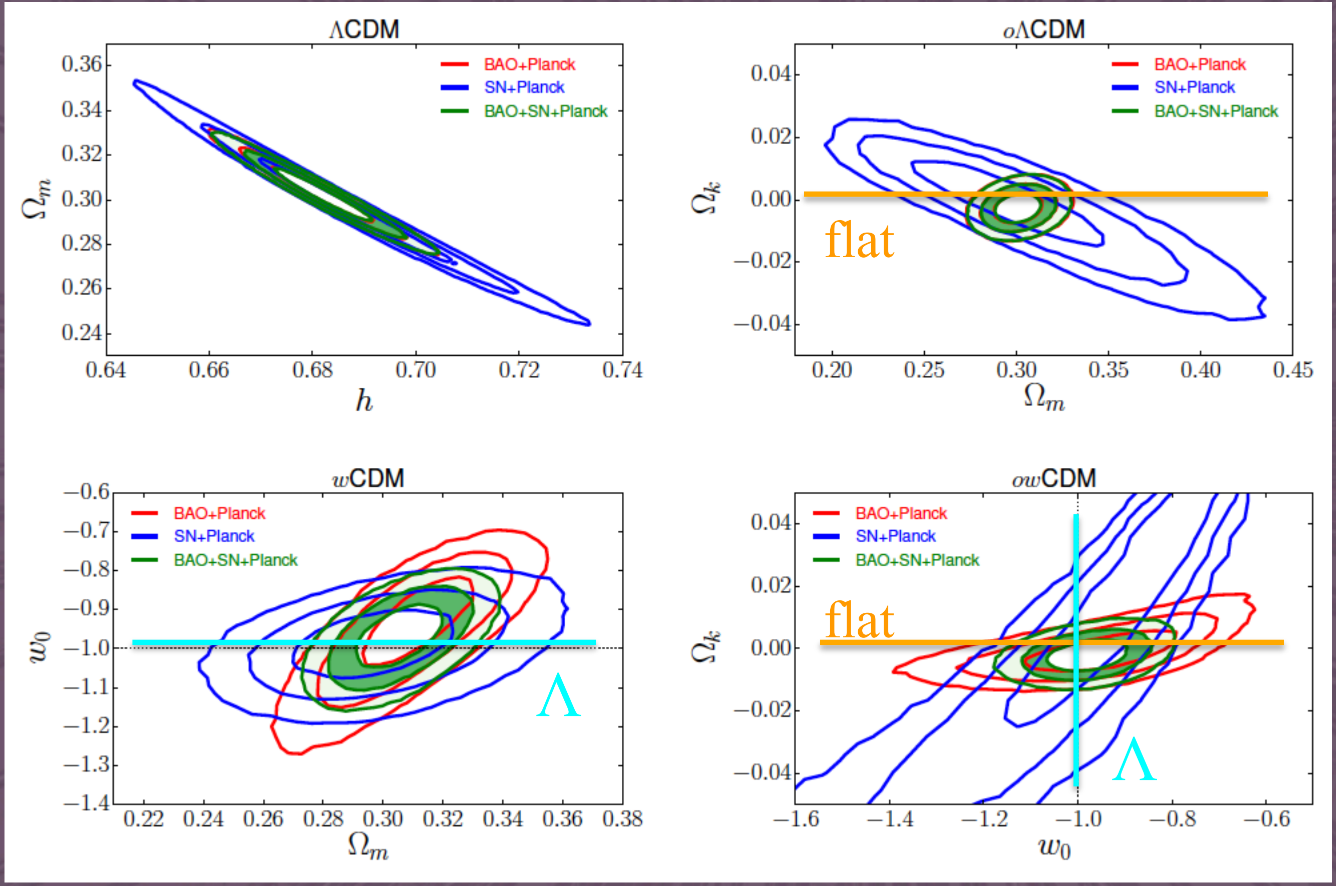
In effect: Calibrate SNIa absolute magnitude using BAO absolute distances.

End result:
$H_0 = 67.3 \pm 1.1$ km s^{-1} Mpc^{-1}

Perfect agreement with Planck+ΛCDM.
Impressive success of the standard model.

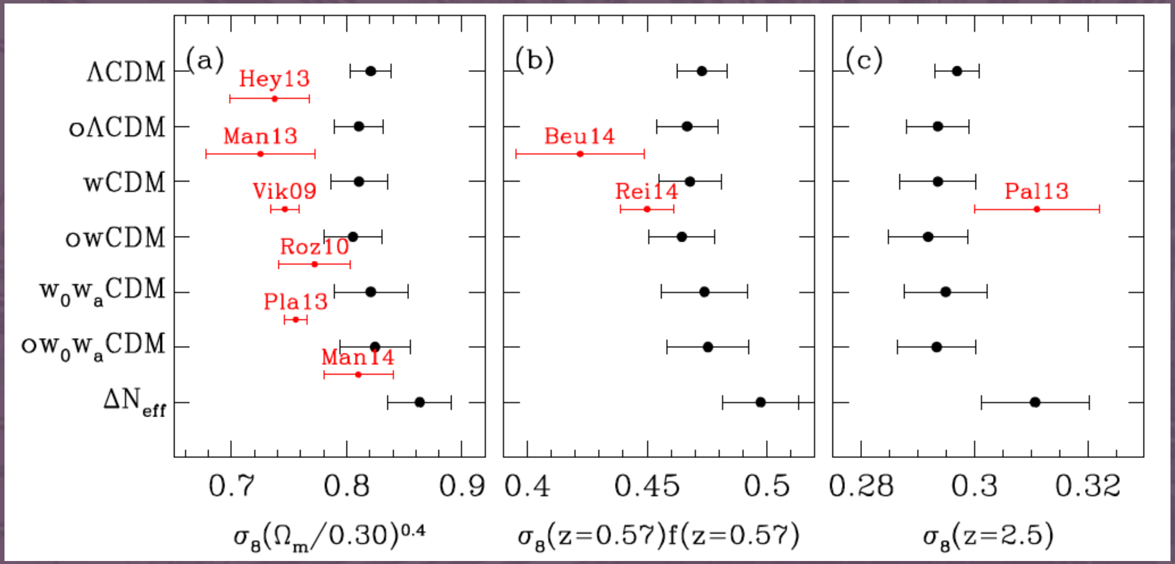
"Outside-in" and "inside-out" measurements could be reconciled if there was extra energy present in the early universe, which would change the size of the standard ruler.

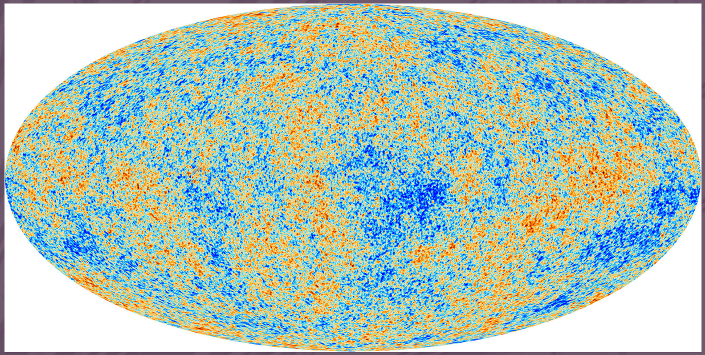
2. Continued success of the standard model

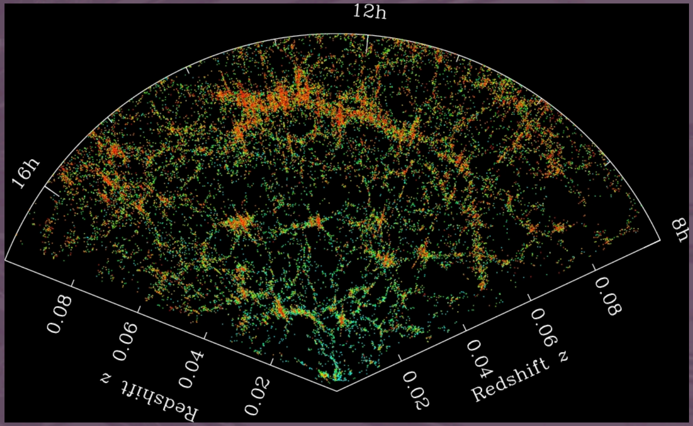


When fitting flexible models to the observed cosmic expansion history, a cosmological constant and a flat universe are always close to the best fit.

3. Trouble with gravity?







Extrapolating growth of cosmic structure from the CMB to today overpredicts most, but not all, local measurements of dark matter clustering.

To: What's on the near horizon?

Tidying up: Final Planck, Final BOSS

The Blobs: CMB Polarization Comes of Age
SPTPol, ACTPol, AdvACT, BICEP, TRICEP, QUADRICEP

The Smears: Weak Lensing Reaches High Precision
Dark Energy Survey, Hyper-SuPrime Camera

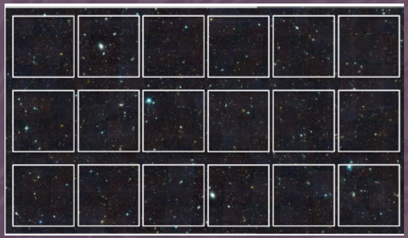
The Bangs: Advances in Supernova Cosmology?
Comprehensive surveys of local SN. Large samples from DES.

The Dots: BAO, Redshift-Space Distortion, Alcock-Paczynski, etc.
eBOSS, HETDEX, DESI, Subaru PFS, WEAVE, 4MOST

WFIRST

If all goes well, the 2020s are the decade of LSST, Euclid, and WFIRST, all pushing each other forward and cross-checking.

Distinctive strengths of WFIRST:



- The ultimate supernova cosmology experiment (space + 2.4m + IFU – sensitivity, calibration, spectrophotometry, diagnostics)
- Best control of systematics for WL (space, many passes, three filters = six correlations)
- Best sampling for galaxy clustering at z = 1.3 – 2 (high density, range of luminosity, good for high order statistics, non-linear scales, multi-tracer methods)

The WFIRST-2.4 Dark Energy Roadmap

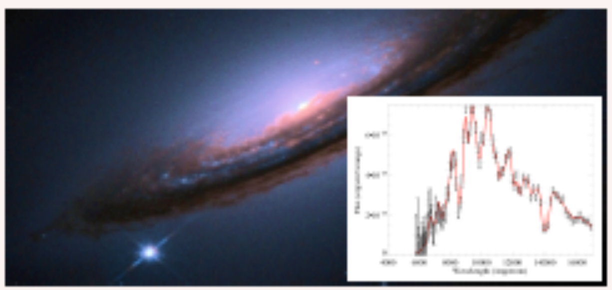
Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

↓

standard candle distances
z < 1 to 0.20% and z > 1 to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

20 million Hα galaxies, z = 1–2
2 million [OIII] galaxies, z = 2–3

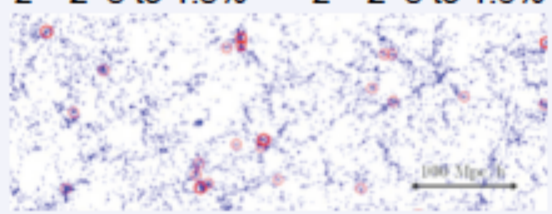
imaging: weak lensing shapes

500 million lensed galaxies
40,000 massive clusters

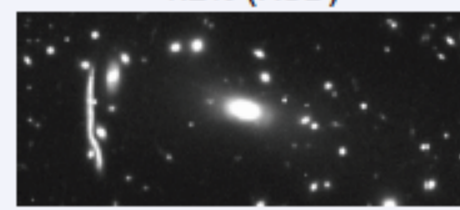
↓

standard ruler

distances	expansion rate
z = 1–2 to 0.4%	z = 1–2 to 0.72%
z = 2–3 to 1.3%	z = 2–3 to 1.8%



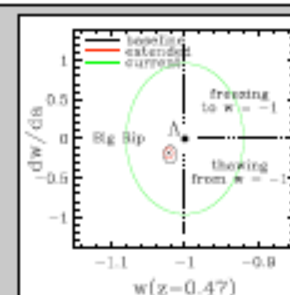
dark matter clustering
z < 1 to 0.16% (WL); 0.14% (CL)
z > 1 to 0.54% (WL); 0.28% (CL)
1.2% (RSD)



↓

history of dark energy
+
deviations from GR

$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}



Luck Favors the Prepared

What do we need to get the full benefit from the Bangs, the Smears, and the Dots?

Supernovae: Thorough understanding of and mitigation strategies for calibration, extinction, and evolution systematics.

Weak Lensing: Thorough understanding of and mitigation strategies for shear measurement biases, intrinsic alignments, photometric redshift uncertainties.
Accurate models and well characterized modeling uncertainties for cosmic shear, CGL, GGL, including baryonic effects.

Galaxy Clustering: Accurate models and well characterized modeling uncertainties of redshift-space clustering.