Cosmic Acceleration: WFIRST and Beyond

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Thanks to the WFIRST SDT Dark Energy Crew:
Charlie Baltay, Rachel Bean, Chris Hirata, Nikhil Padmanabhan, Saul Perlmutter, Jason Rhodes, Yun Wang, DW

For (much) further reference:
Observational Probes of Cosmic Acceleration, arXiv:1201.2434 by D. Weinberg, M. Mortonson, D. Eisenstein, C. Hirata, A. Riess, and E. Rozo

The big cosmological questions when I was in grad school:

- Did structure form by gravitational instability?
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  Non-baryonic. Probably weakly interacting and cold (CDM).
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Cosmology makes progress. Big questions can be answered.

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Critical contributions from many directions:
COBE, large-scale structure surveys, supernova surveys,
CMB balloon experiments & WMAP, HST and big telescopes.
Theory crucial in developing unified interpretation of disparate observations.

Astro2010 CFP #2: Why is the universe accelerating?

1. Is this acceleration caused by a breakdown of general relativity or by a new form of energy?
2. If dark energy is causing the acceleration, is its energy density constant in space and time?

The main line of attack:

- Is the cosmic expansion history consistent with Λ?
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Other possible signatures:

- Scale-dependent structure growth.
- Inconsistency of lensing and non-relativistic dynamics.
- Different strength of gravity in different environments.
- Small- or mid-scale deviations from GR.
- Imprint of clustered dark energy on CMB.
- Time- or space-variation of fundamental “constants”.

The WFIRST DRM1 dark energy program

Supernova Survey: 0.45 years of imaging and spectroscopy, spread over 1.8 years, 5-day cadence.
About 2000 Type Ia SNe, $0.2 < z < 1.7$.

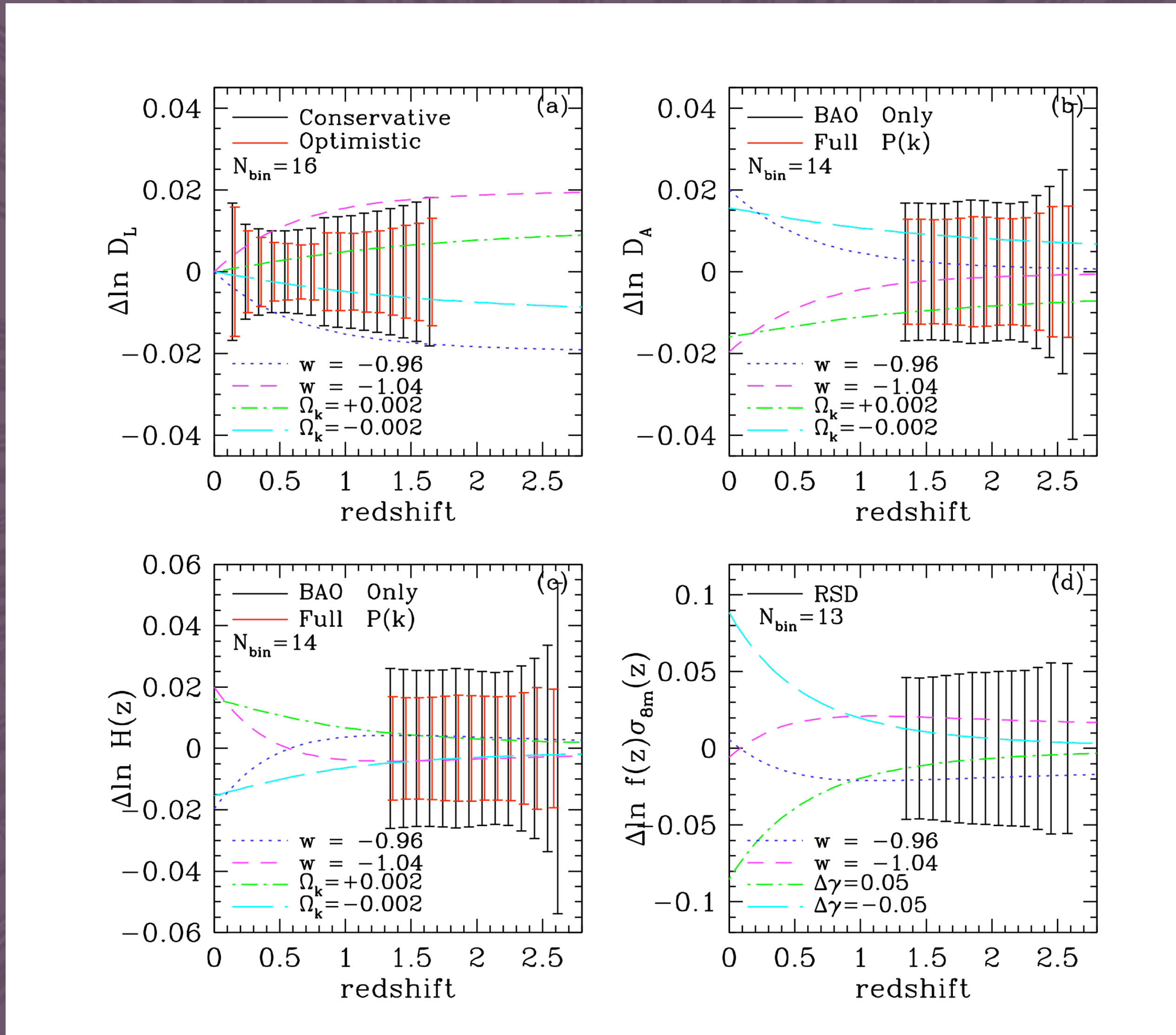
High-Latitude Survey: 2.4 years of Y, J, H, K imaging and R=600 slitless spectroscopy, covering 3400 deg^2

- 480 million WL shape measurements (J,H,K) + IR photo-z
- 17 million galaxy redshifts, $1.3 < z < 2.7$
  $D_A(z)$ and $H(z)$ from baryon acoustic oscillations (BAO)
  Growth rate from redshift-space distortions (RSD)
  Other consistency checks (e.g., scale-independent growth)

WFIRST DRM1: Forecast errors on basic observables, SN survey and galaxy redshift survey

Aggregate precision ~ 0.3%

Aggregate precision ~0.5%

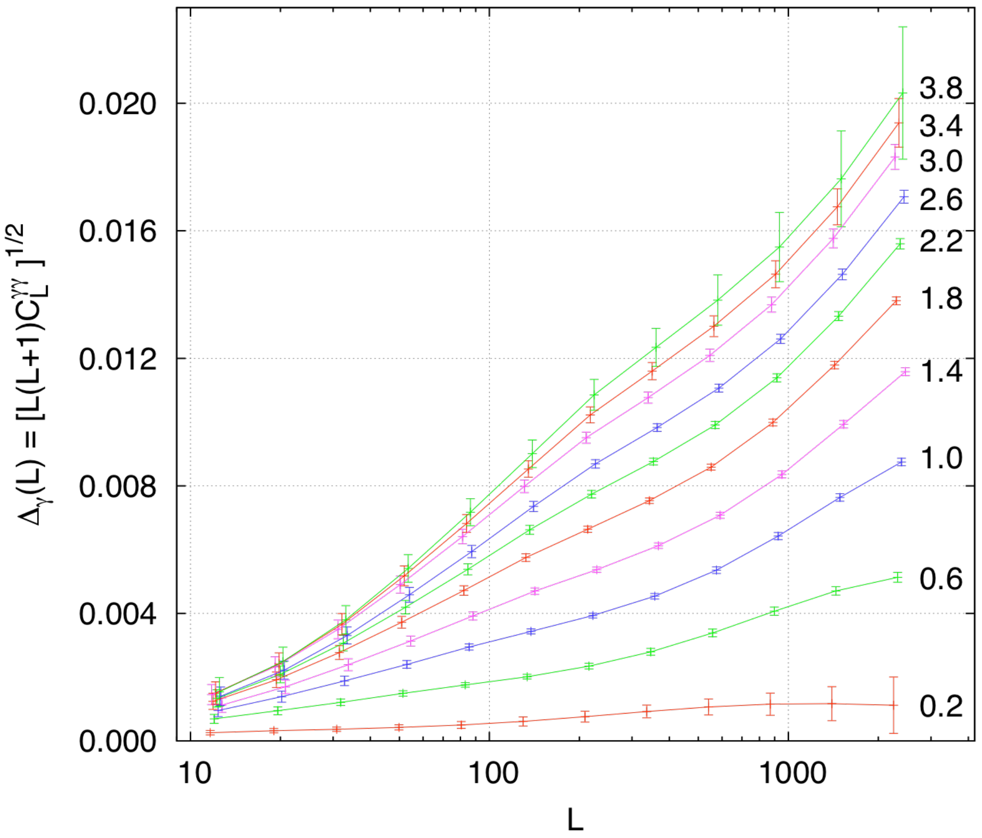


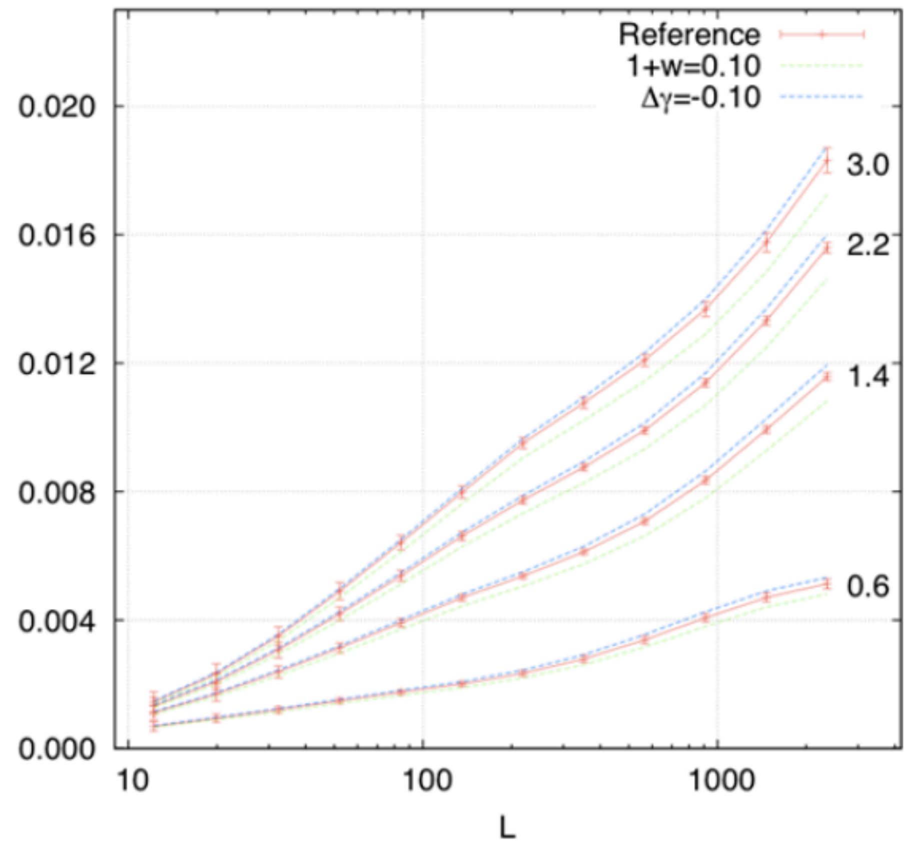
Aggregate precision ~0.7%

Aggregate precision ~1.4%

WFIRST SDT Report

WFIRST DRM1: Forecast errors on WL shear power spectrum in 10 photo-z bins





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WFIRST SDT Report

Where might we be near the end of DRM1?

(Including DES, Subaru HSC/PFS, BigBOSS, Euclid, LSST)

• Errors 10× smaller, still consistent with ΛCDM
$1+w = 0 \pm 0.01$ instead of 0 ± 0.1, more robust conclusion

• Hints of significant departure from ΛCDM, in expansion history or structure growth or both.

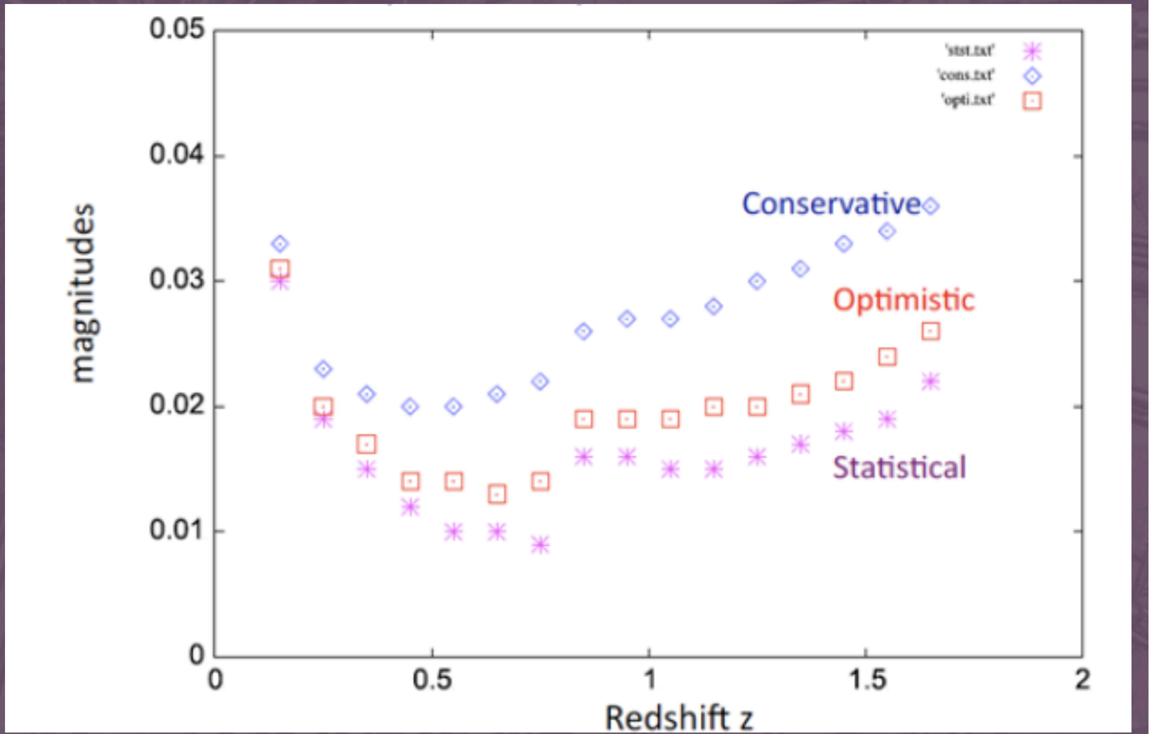
• Clear discrepancy with ΛCDM, more and better data needed to understand it.

At least in the second or third scenario, we will want to do more, and the details of what we will want to do will depend on what has been found.

WFIRST Extended Mission

At the end of DRM1, we would have a satellite, already in orbit, that is a powerful tool for further investigation.

SN: Value of extended mission depends on systematics. For optimistic case, 0.01 mag systematic error per Δz=0.1, uncorrelated bin-to-bin, it would be worth doubling the DRM1 (0.45-yr) survey.



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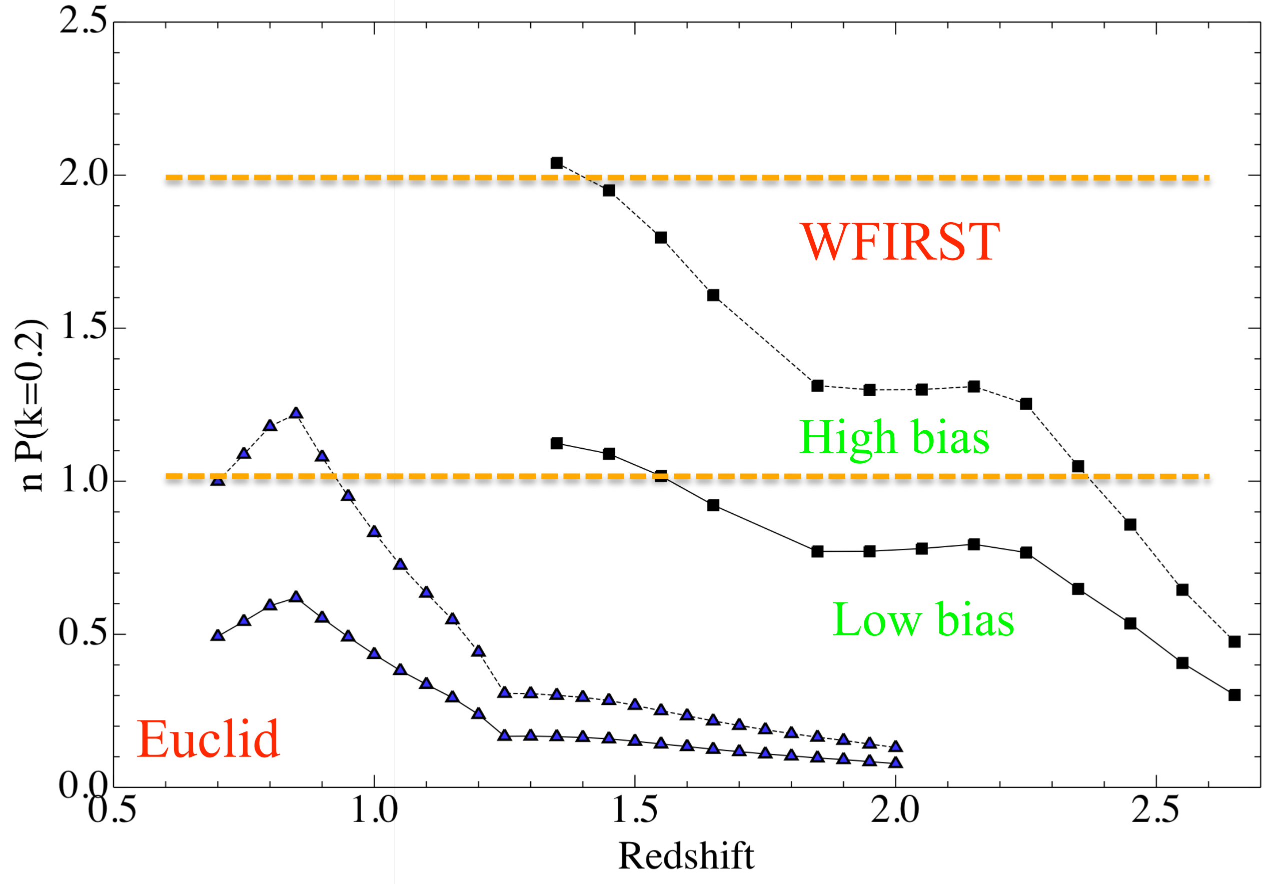
WL: If WFIRST systematic error budget is achieved, worth extending the WL survey to 10^4 deg^2. Survey rate could perhaps be sped up with focus on H-band.

BAO/RSD: DRM1 is far below the fundamental limit for BAO – marginal sampling, 8.5% of the sky. Easy to extend with more survey time.



WFIRST
High bias
Low bias
Euclid
n P(k=0.2)
Redshift
2.5
2.0
1.5
1.0
0.5
0.0
0.5
1.0
1.5
2.0
2.5

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An extended WFIRST dark energy program

- 1-1.5 yrs of SN (4000-6000 Sne),
- 5-7.5 years of HLS (~10^4 deg^2 of WL and spectroscopy)

would probably come close to the fundamental limits of SN and optical WL.

Still a significant gap relative to fundamental limit of BAO.

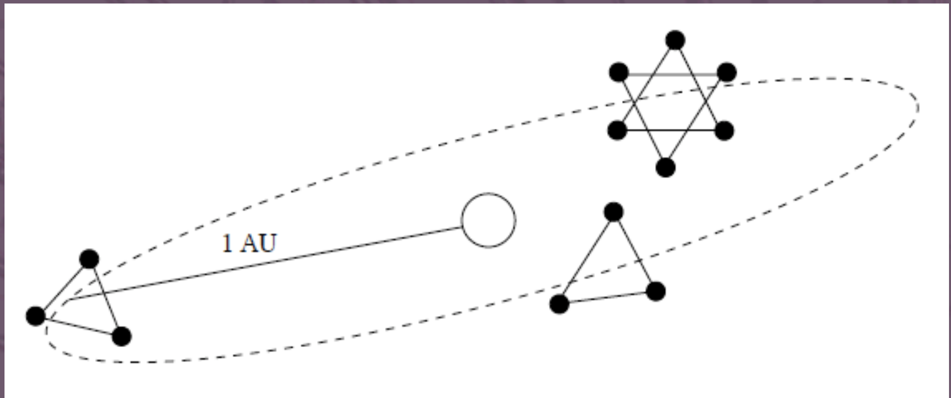
And Beyond

If we're still interested in cosmic acceleration after LSST, Euclid, and WFIRST, what might we contemplate?

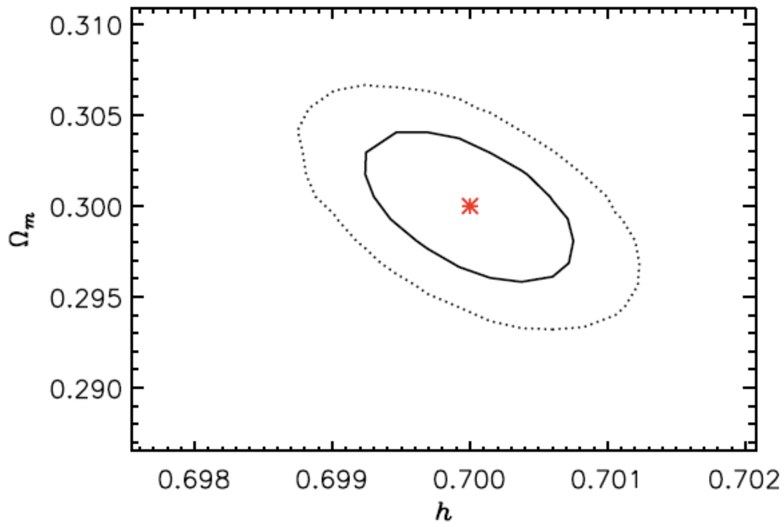
• A galaxy redshift survey mission that would approach the BAO cosmic variance limit out to $z \geq 3$. With larger IR detectors, might be relatively inexpensive. Micro-shutters might make it more powerful for general applications.

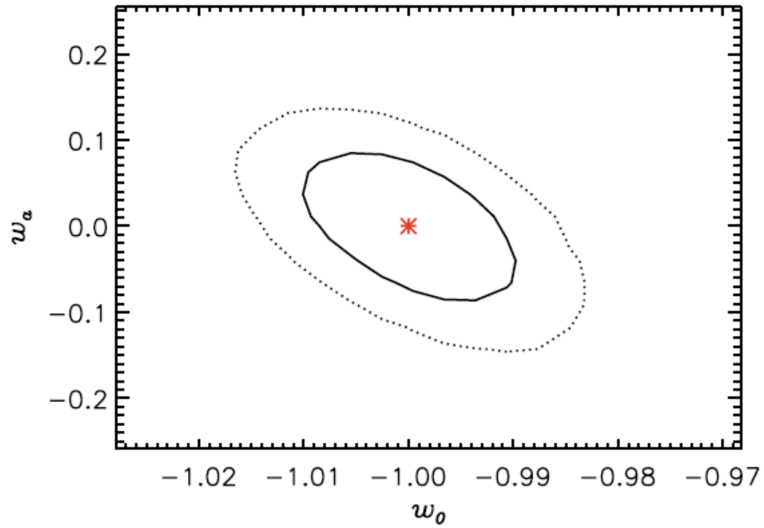
• A gravity wave observatory like Big Bang Observer (BBO) or Decigo, which would measure "standard siren" distances to $> 10^5$ merging compact binaries (Cutler & Holz 2009). For BBO they forecast 0.1% error on H_0, 0.01 error on w_0.

• "Look to the side" and hope for clues, from, e.g., a CMB polarization mission (link to inflation, clustered dark energy), or high-precision tests of GR or fundamental constants.

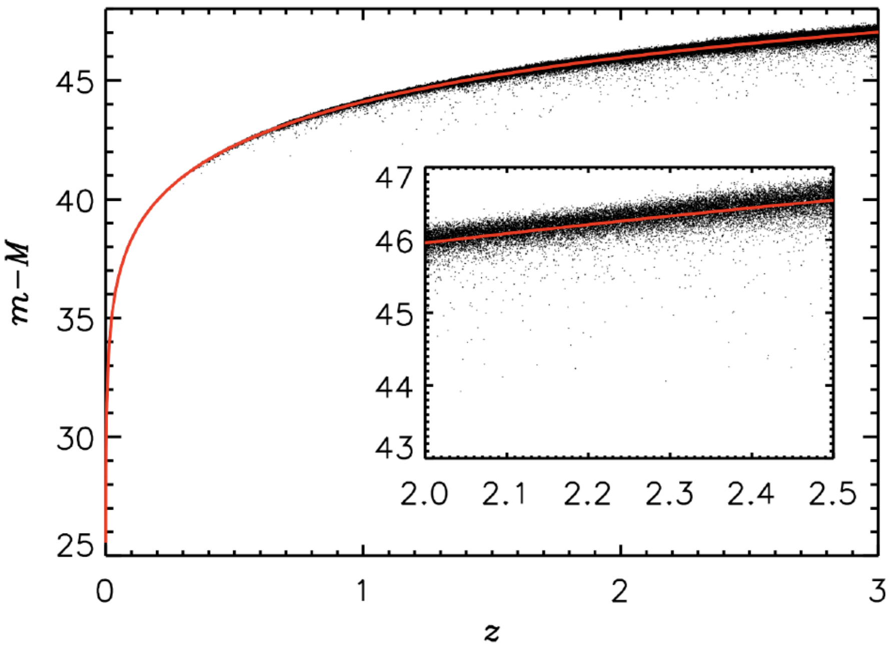


BBO Configuration: frequency range 0.03 – 3 Hz, typical Δθ ~ few arcsec





Constraint forecast w/ Planck prior.



Noise dominated by weak lensing

All figs from Cutler & Holz 2009

Stray thoughts on NRO as WFIRST

Relative to the SDT designs, an NRO 2.4-m implementation of WFIRST would likely have:

- Larger aperture and étendue
- Higher angular resolution
- Bluer wavelength cutoff
- Uglier PSF

WL: Better statistics. Key issue is PSF control/correction.

BAO/RSD: Should be more efficient at covering large volume; loses the high redshift range of SDT DRMs, so less complementary to Euclid, but much better sampling. Net win.

SN: Probably less good because systematics get better in rest-frame IR. Might regain this ground with IFU spectroscopy and spectrophotometry, better matching of spectroscopic cohorts.

My view: Whichever implementation is more likely to happen, or to happen sooner, is the better one.

If we know $w = -1 \pm 0.1$, why not just live with Λ?

Many physicists consider a cosmological constant "natural," but the measured value is definitely not.

There is a range of opinion on whether $w = -1$ is a "spike" in the space of theoretical priors.

The implications of even tiny departures from Λ would be profound. Maybe very profound.

But gaining a decade of precision is hard, and deviations in $|1+w|$ could be in any decade.

Why might the next decade be an interesting one?

Many theories predict $w = -1$ as an asymptotic state, at either early or late times. But with $\Omega_m \sim 1-\Omega_m \sim 0.5$, we are not in an asymptotic state. Might plausibly expect $|1+w| \sim \Omega_m$.

Manifest destiny

The solution to the cosmic acceleration puzzle could be around the corner, or it could be decades away, or more.

A crucial part of the rationale for studying cosmic acceleration is that the data sets needed to do so are rich, supporting a wide range of astronomical discovery.

These data sets fall within the "manifest destiny" of astronomy: to map the observable universe with the greatest achievable sensitivity and resolution.

When a major next step on this path is feasible (technologically, financially), it makes sense to take it.