Dark Energy From Space: Euclid and WFIRST

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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.

Main reference: WFIRST-AFTA SDT Report, arXiv:1503.03757

Timeline

(It's hard to make predictions, especially about the future.)

BOSS: 2008 – 2014

DES: 2013 – 2018

eBOSS: 2014 – 2020

DESI: 2019 – 2024

LSST: 2020 – 2030

Euclid: 2020 – 2026

WFIRST: 2024 – 2030

Forecast vs. Forecast

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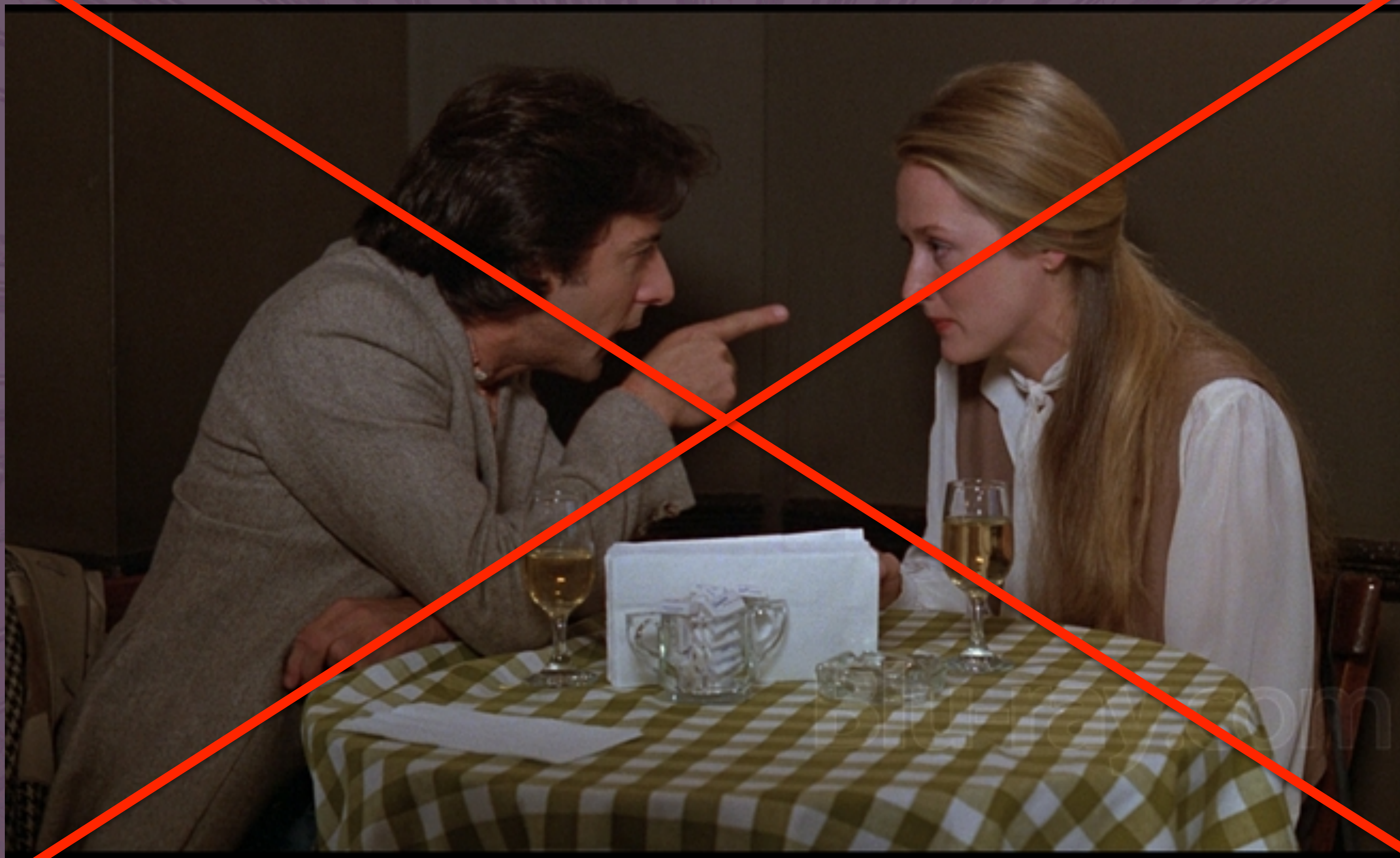


The Current State of Play

Expansion history measurements

Relative distance scale (SNIa), 1-2% accuracy

currently limited by observational systematics

Absolute distance scale (BAO), 1% accuracy

currently limited by statistics

Structure growth measurements

Weak lensing and clusters, 5-10% accuracy

currently limited by observational systematics and statistics

Redshift-space distortions, 10% accuracy

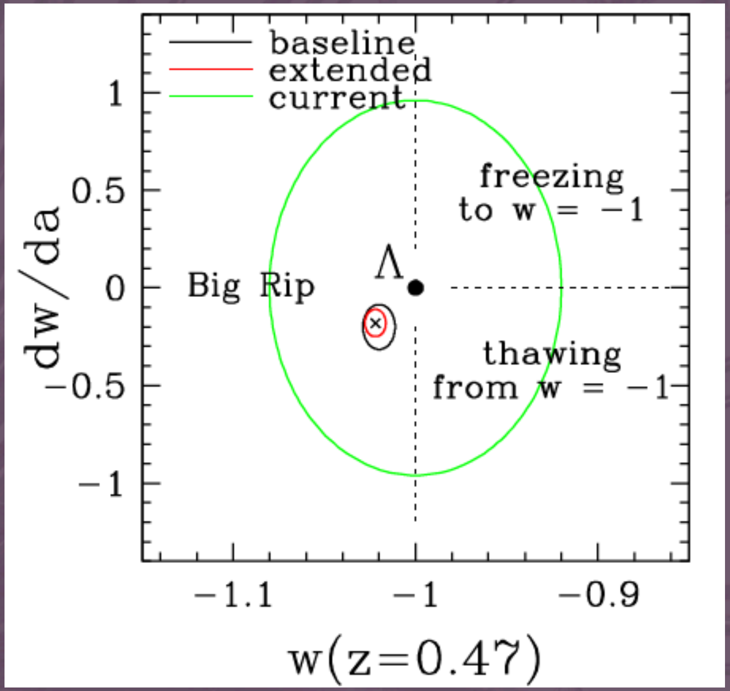
currently limited by statistics and theoretical systematics

Most measurement power at $z <= 1$

Most expansion history measurements agree well with CMB-normalized ΛCDM

Many but not all growth measurements in mild tension w/ ΛCDM

Goals for Stage IV



In measurement terms, goals of DESI/LSST/Euclid/WFIRST are ~ 0.1 – 0.3% aggregate precision in both expansion history and structure growth.

Expand redshift reach to z ~ 2-3.

Multiple consistency checks across experiments and across methods (SNe, BAO, WL, RSD, Clusters, …).

Factors of 5-50 gain over current data.

- The discovery potential is large
  Many models consistent with today's data can be easily distinguished
- Control of systematics is a critical challenge
  We only benefit from improved precision if we believe the accuracy of the measurements.

Dark Energy From Space

Primary methods for probing cosmic acceleration are:

- Supernovae: relative distance scale, precision highest at low z
- Baryon Acoustic Oscillations: absolute distance scale and expansion rate, precision highest at high z
- Weak gravitational lensing: amplitude of matter clustering, also sensitive to distance scale.
- Clusters and cluster lensing: amplitude of matter clustering
- Redshift-space galaxy clustering: amplitude and growth rate of matter clustering. Non-relativistic tracer (distinct from lensing).

Unique opportunities from space:

- Near-IR sensitivity over wide fields (valuable for all methods)
- High stability observing (SN photometry, WL shape measurement)
- High angular resolution (WL shape precision, accuracy)

WFIRST-AFTA Design Reference Mission

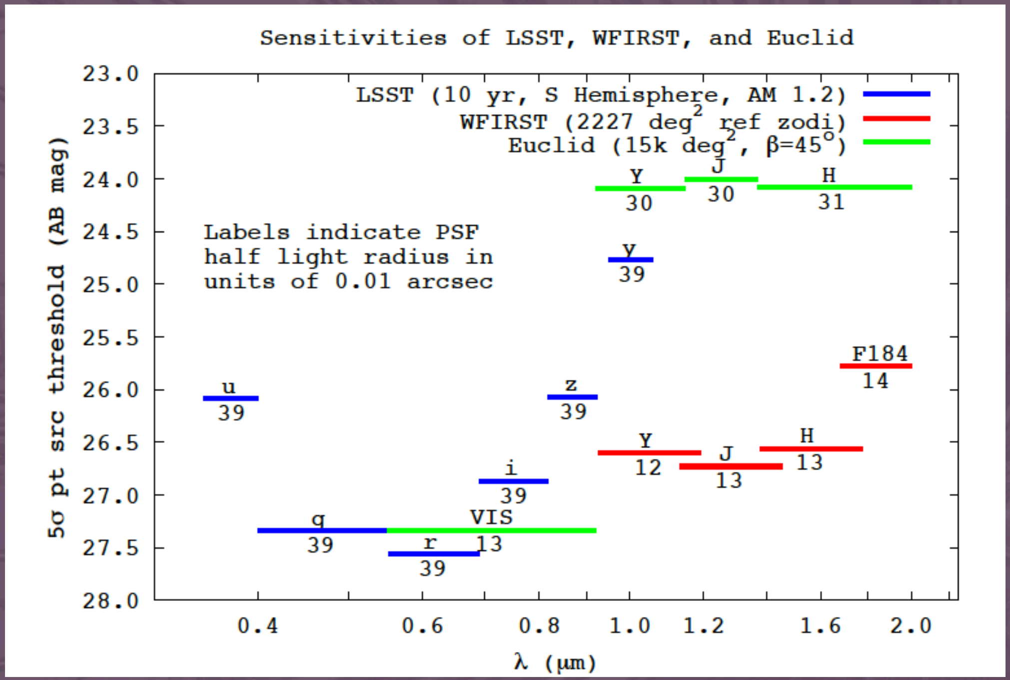
(arXiv:1503.03757)

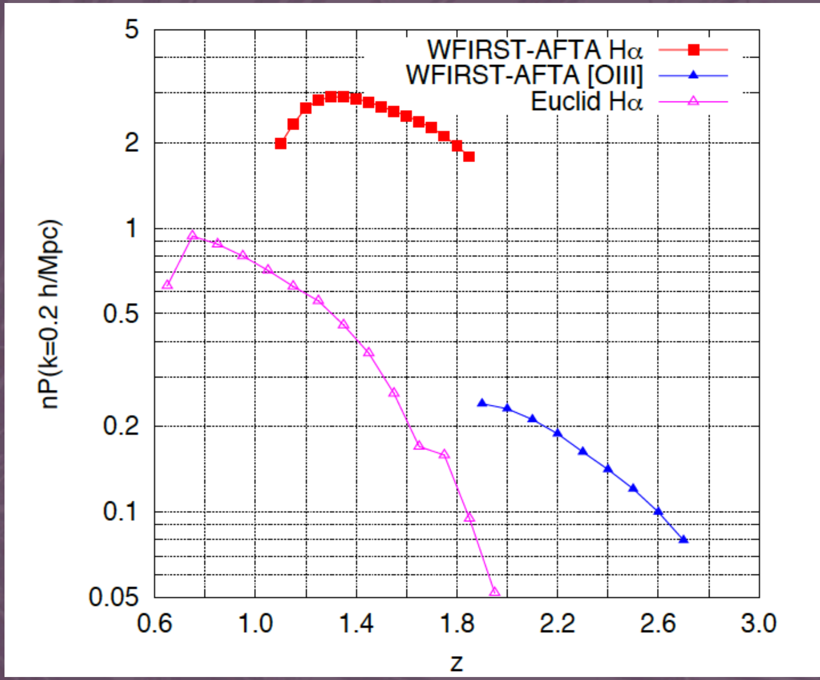
2.4-m telescope, geosynchronous or L2 orbit.
290 megapixel near-IR camera, 0.28 deg^2 FoV, 0.11 arcsec/pixel
IFU for supernova spectrophotometry
6 year prime mission --- could probably be extended to 10-15 yrs
In DRM, 0.5 years SNe, 2 years high-latitude survey

2700 well observed SNIa, $z = 0.1 – 1.7$, tiered area vs. depth
2200 deg^2 HLS:
Y, J, H, F184 imaging, $n_{eff} = 45\ deg^{-2}$ in J+H
380 million galaxies, $\Delta\sigma_8 = 0.12\%$
16 million Hα galaxies, $z = 1 – 2$
1.4 million [OIII] galaxies, $z = 2 – 3$

30% time for Guest Observers
Can include DE programs, e.g., 1000 massive galaxy clusters

Euclid and WFIRST





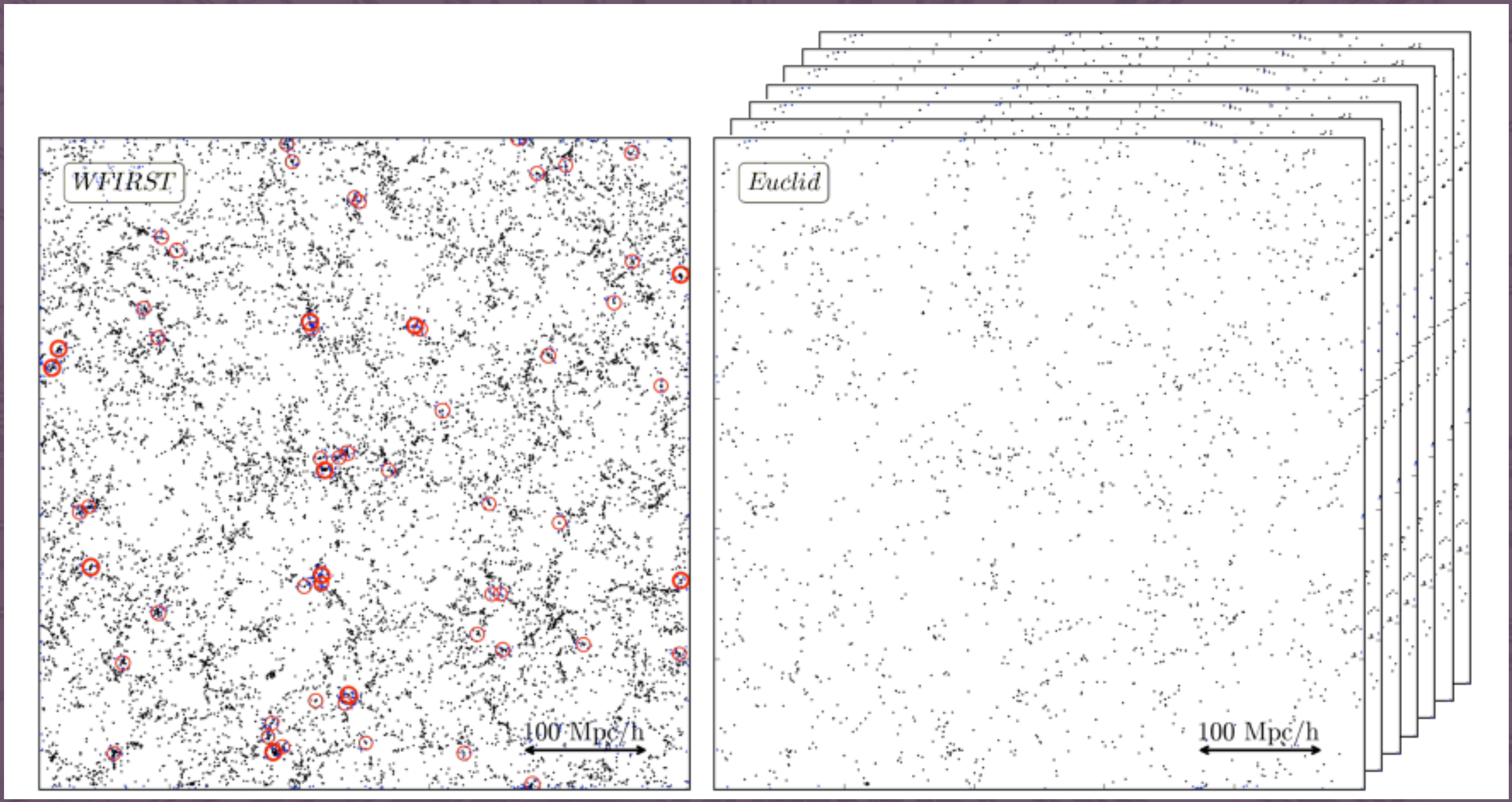
In near-IR, Euclid is wide, WFIRST deep.

Euclid does WL through wide optical filter, WFIRST through three near-IR filters (+1 more for photo-z).

WFIRST near-IR well matched to LSST optical.

Euclid built for statistics, WFIRST for systematics control.

SNe are a big part of WFIRST's dark energy program, not Euclid's.



Large scale structure at z ~ 1.5: Dense sampling vs. large area.

WFIRST-AFTA Dark Energy Roadmap

0.5 yr — **Supernova Survey**

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

High Latitude Survey — 2 yrs

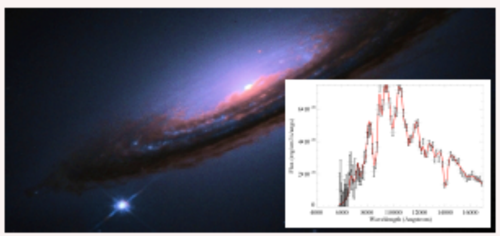
spectroscopic: galaxy redshifts

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

imaging: weak lensing shapes

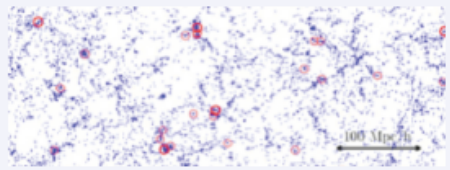
380 million lensed galaxies
40,000 massive clusters

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

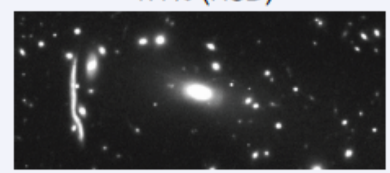


standard ruler

distances	expansion rate
z = 1–2 to 0.5%	z = 1–2 to 0.9%
z = 2–3 to 1.3%	z = 2–3 to 2.1%

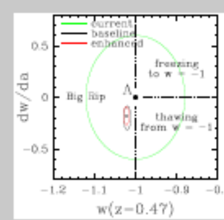


dark matter clustering
z < 1 to 0.21% (WL); 0.24% (CL)
z > 1 to 0.78% (WL); 0.88% (CL)
1.1% (RSD)



history of dark energy
+
deviations from GR

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



Potential synergies among Euclid, WFIRST, LSST, DESI

Some gains happen "automatically":

- Combination of constraints to get more stringent tests, more information about departures from standard model.
- Cross-checks of independently derived results from different experiments and methods.

Some gains come from combined data in area of overlap:

- Photo-z's using LSST+WFIRST fluxes
- Cross-correlation of shapes from different experiments to remove additive shear systematics
- Better shapes or magnifications from optical+near-IR?
- Multi-tracer RSD from galaxies with wide range of bias
- WFIRST galaxy-galaxy lensing of DESI galaxies
- Combined WFIRST + LSST SN light curves?

Potential synergies among Euclid, WFIRST, LSST, DESI

Biggest gains arise if deep WFIRST imaging/spectroscopy can be leveraged by large area of LSST, Euclid, DESI:

- Optical photo-z training using LSST+WFIRST fluxes
- Optical photo-z calibration by cross-correlation with the WFIRST+DESI redshift survey
- Improving (or demonstrating accuracy of) Euclid and LSST WL measurements, in a way extendable to full survey area.
- High source density cluster WL maps to improve cluster constraints from LSST

Big synergy in *theoretical and simulation work* to develop methods for extracting cosmological information from data, quantifying errors, controlling systematics, simulating data sets.

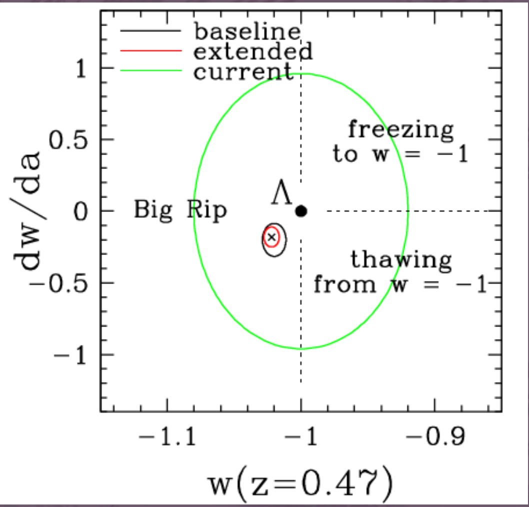
Where might we be in 2020, 2025, 2030?

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

• 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.

• Mystery of cosmic acceleration solved.



Depends on our ingenuity in reaching the objectives of the Stage IV projects and on what nature has behind the curtain.

And Beyond

If we're still interested in cosmic acceleration after these projects, what might we do?

• BAO surveys may still be well below cosmic variance limit at z > 1.2. WFIRST could cover large area to z=2 in an extended mission. Other routes to reach cosmic variance limit at z=3? Deeper Lya forest? Radio intensity mapping?

• Find some way to greatly reduce WL shape noise, e.g., with 21cm HI velocity fields or optical kinematic signatures.

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

• High redshift 21cm – many more modes in linear regime?

• Long run: A post-LISA gravity wave mission that can measure $\sim 10^5$ merging compact binaries as "standard sirens" could beat SNe and BAO by 1-2 orders of magnitude.