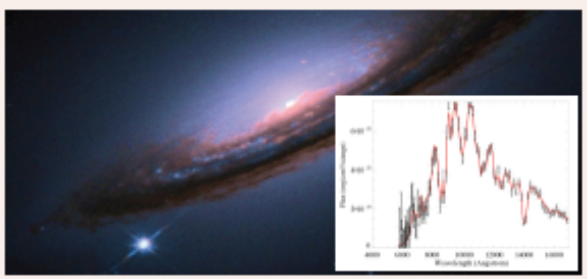
The WFIRST-2.4 Dark Energy Roadmap

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

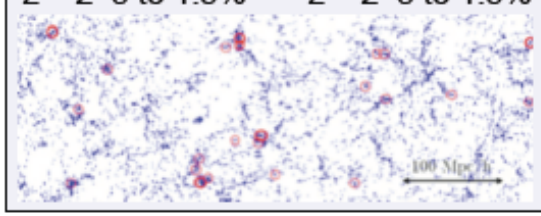
20 million Hα galaxies, z = 1–2
2 million [OIII] galaxies, z = 2–3

imaging: weak lensing shapes

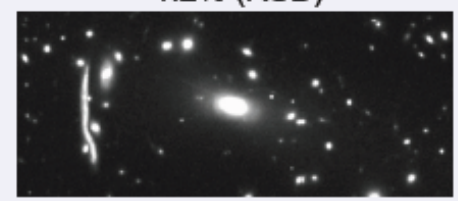
500 million lensed galaxies
40,000 massive clusters

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%

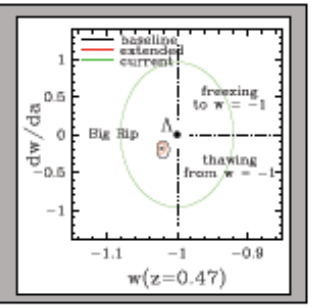


dark matter clustering
z < 1 to 0.16% (WL); 0.14% (CL)
z > 1 to 0.54% (WL); 0.28% (CL)
1.2% (RSD)



history of dark energy
+
deviations from GR

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



Comments on dark energy Figures of Merit

Widely used measure is FoM = $[\sigma(w_p) \times \sigma(w_a)]^{-1}$ for forecast errors on a model in which $w(a) = w_p + w_a(a_p - a)$, assuming standard matter and radiation content and GR, allowing non-zero curvature. Typically $a_p \approx 0.7$.

Useful standard of comparison and optimization, but doesn't account for sensitivity to GR deviations or early dark energy.

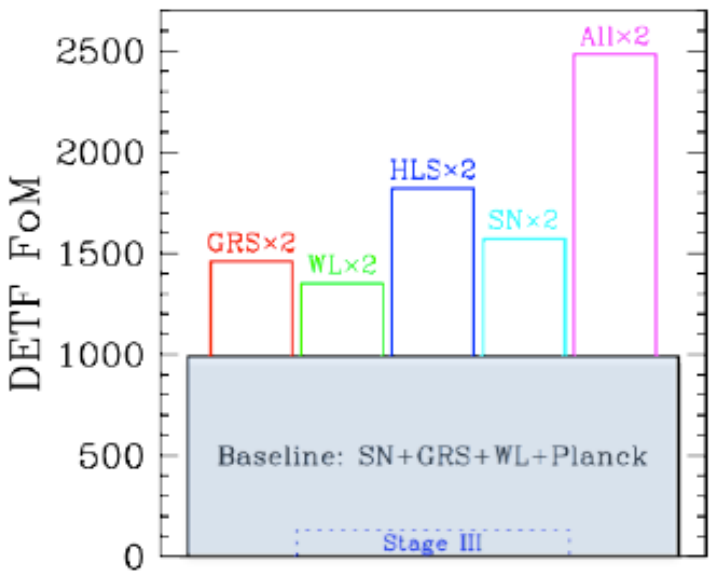
Assumptions about systematic uncertainties have big impact on FoM.

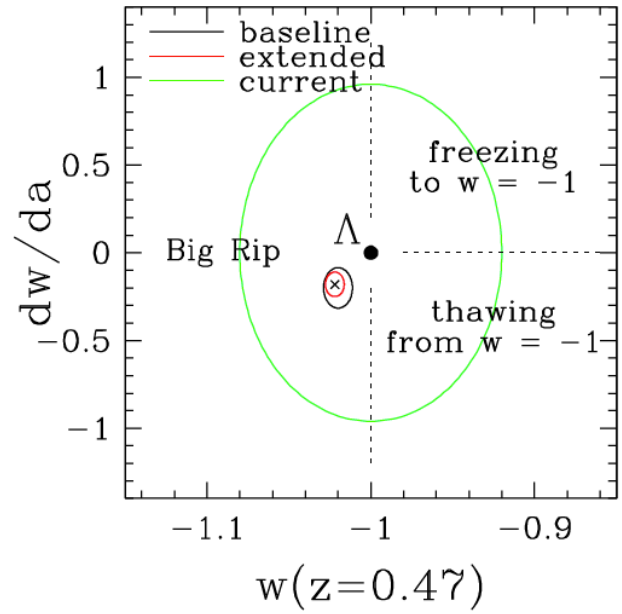
We focus on FoM of combined program and variants around it; much less sensitive to external assumptions than "single-probe" FoM.

We also characterize probes by the aggregate fractional precision with which they measure their primary observable, including estimate of systematic error contribution.

More model-independent than FoM.

Contribution to FoM generally scales as $(\sigma_{agg})^{-2}$.





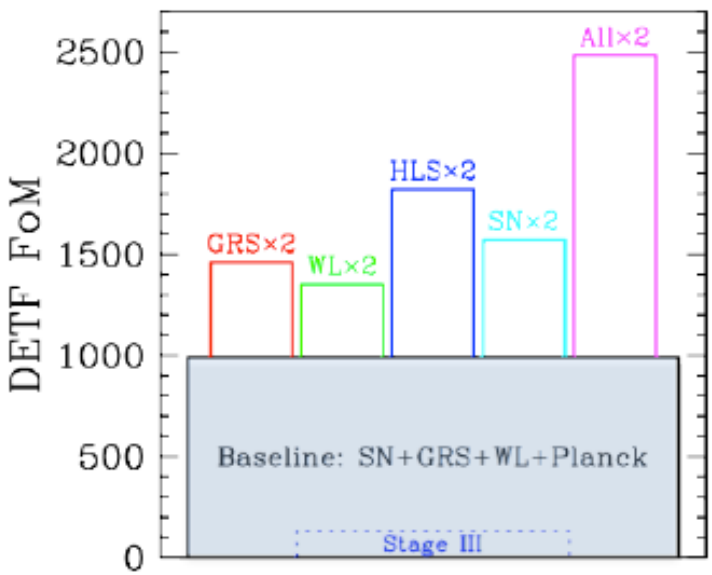
FoM = $[\sigma(w_p) \times \sigma(w_a)]^{-1}$ for baseline case is 7.5× increase over "Stage III" forecast.

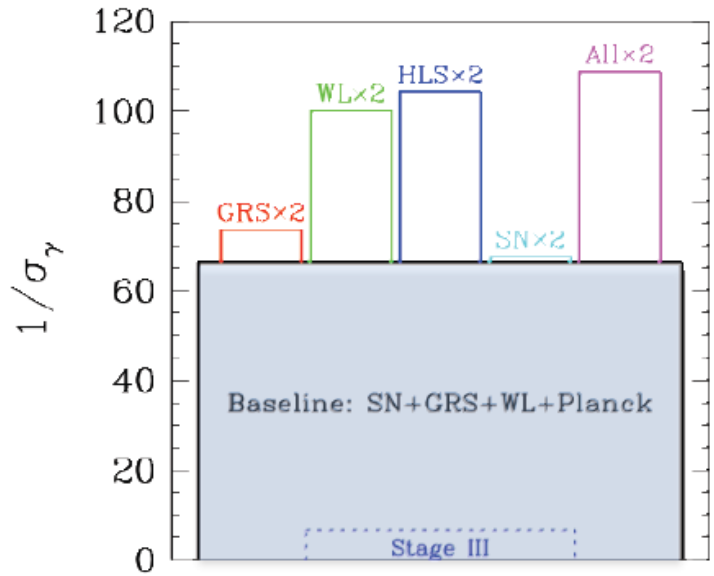
This represents big advance in ability to distinguish physically interesting models.

All elements of program contribute, as one sees by doubling precision of any one of them.

Calculation includes AFTA-WFIRST, Planck, local SN calibrators, BOSS.

Includes cluster-galaxy lensing but not galaxy-galaxy lensing or higher order lensing statistics. Forecasts for these are more uncertain, but could improve constraints significantly.



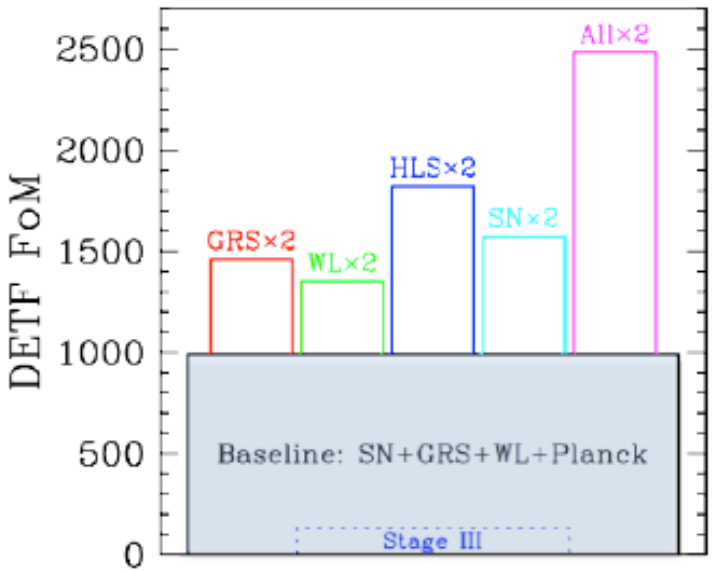


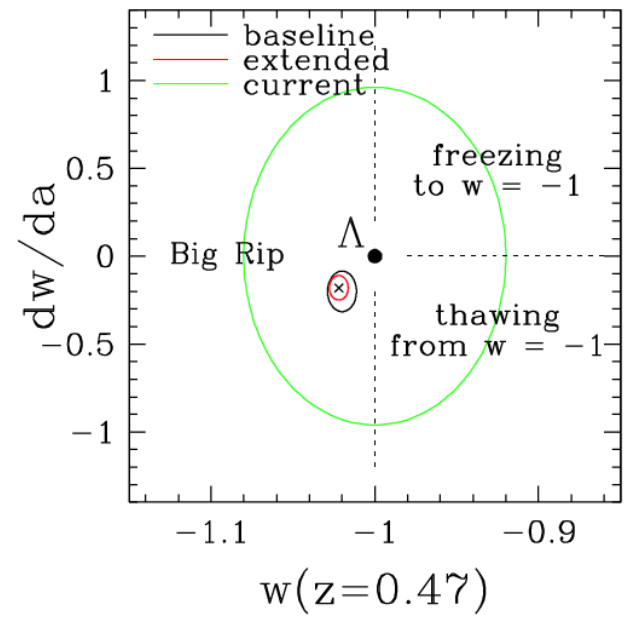
Major advance in testing modified gravity explanations of cosmic acceleration, here parameterized by deviation of growth index γ.

With baseline assumptions, WL dominates these constraints. Galaxy-galaxy lensing and higher order statistics might improve them by significant factor.

Comparison of WL and RSD is itself an important test of modified gravity models; affected by different gravitational potentials that are equal in GR.

AFTA-WFIRST RSD also probes higher redshift than WL and clusters.





Doubling (or at least increasing) precision can be achieved by combination of systematics control and additional observations in extended mission.

SN: Evolutionary and calibration systematics may be lower than assumed, spectral diagnostics could reduce statistical error. Quadrupling survey would take additional 1.5 years.

WL: Galaxy-galaxy lensing and higher order statistics may yield higher precision. Extended survey might use fewer bands or faster scan strategy if systematics demonstrated to be low.

GRS: Theoretical modeling may improve return from full P(k) shape, redshift-space distortions. Extended survey might cover larger area at shallower depth.

AFTA-WFIRST Supernova Program

Forecast aggregate precision: 0.20% (z<1), 0.34% (z>1), 0.18% (all z)

Comparison to DRM1 or IDRM

Larger aperture and IFU allow *major* improvements:

- More SNe (2750 vs. 1500)
- More even redshift distribution
- *Lower systematics*: Better photometry and calibration, no K-corrections, spectral diagnostics to compare similar high- and low-z SNe

Observing strategy can be tailored to match statistical and systematic uncertainties in each redshift bin.

Comparison to Euclid

Euclid has no planned SN program

In AFTA-WFIRST, SN makes a large contribution to combined FoM (for fiducial assumptions, it has the highest FoM leverage of any single probe)

Why did the IFU become baseline in AFTA-WFIRST?

Lower systematics

Better calibration:

- Each pixel on detector illuminated by light of fixed wavelength for both source and backgrounds
- Total # of pixels to calibrate is small; feasible to scan standard star along length of each slice in IFU

No K-corrections; compare SNe at fixed rest-frame wavelength (slitless spectra have much higher background noise)

Spectral diagnostics for sub-typing SNe; reduce evolutionary systematics and add cross-checks by comparing like-to-like across redshift.

Better statistics

More efficient than wide-field slitless spectroscopy because exposure time tailored to each individual SN. More SNe measured.

Redshift distribution can be tailored to be optimal.

This gain is much larger for the 2.4m than 1.3m aperture.

Major improvement to SN program at moderate cost

May reduce net cost by simplifying calibration and prism requirements.

AFTA-WFIRST Weak Lensing Program

Forecast aggregate precision: 0.16% (z<1), 0.54% (z>1), from cosmic shear

0.14% (z<1), 0.28% (z>1) from cluster-galaxy

Comparison to DRM1

Smaller survey area (2000 deg^2 vs. 3400 deg^2) but higher n_{eff} (68 $arcmin^{-2}$ vs. 40 $arcmin^{-2}$) leads to same number of shape measurements (0.5 billion), similar statistical power

Higher n_{eff} allows detailed dark matter maps, greater gains in extended survey

Obstructed pupil, GEO orbit add complications, but surmountable

Comparison to Euclid

Euclid has lower n_{eff} (20-35 $arcmin^{-2}$) but larger area 15,000 deg^2), with more shape measurements and thus higher statistical precision

AFTA-WFIRST has much tighter control and cross-checks of systematics: 8-9 passes in 3 shape measurement filters (6 auto/cross correlations) vs. 3 passes in a single wide optical filter

AFTA-WFIRST much more likely to achieve statistics-limited accuracy, could confirm (or challenge) accuracy of Euclid and LSST shape measurements

AFTA-WFIRST Galaxy Redshift Survey Program

Forecast aggregate precision: 0.40% in D_A, 0.72% in H, at z=1-2

1.3% in D_A, 1.8% in H, at z=2-3 ([OIII] emitters)

1.2% in $\sigma_m(z)f(z)$ at z=1-2 (from RSD)

Comparison to DRM1

Hα redshift range z = 1-2 instead of z=1.35-2.65

Smaller survey area (2000 deg^2 vs. 3400 deg^2) but much higher galaxy space density (by a factor ~4 at peak redshift)

Similar forecast for aggregate precision

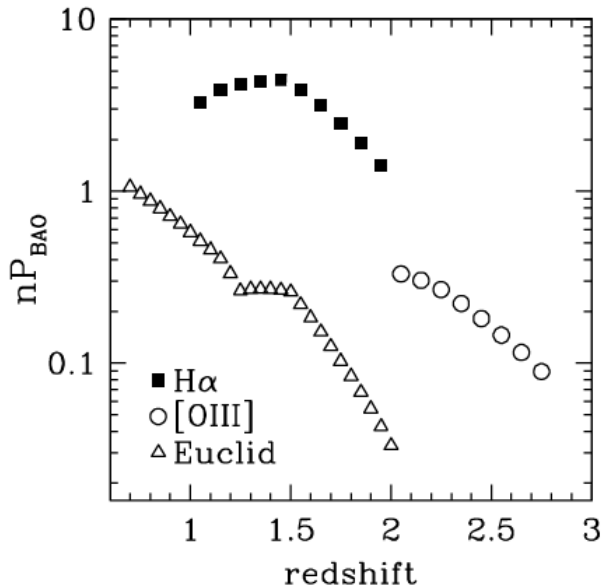
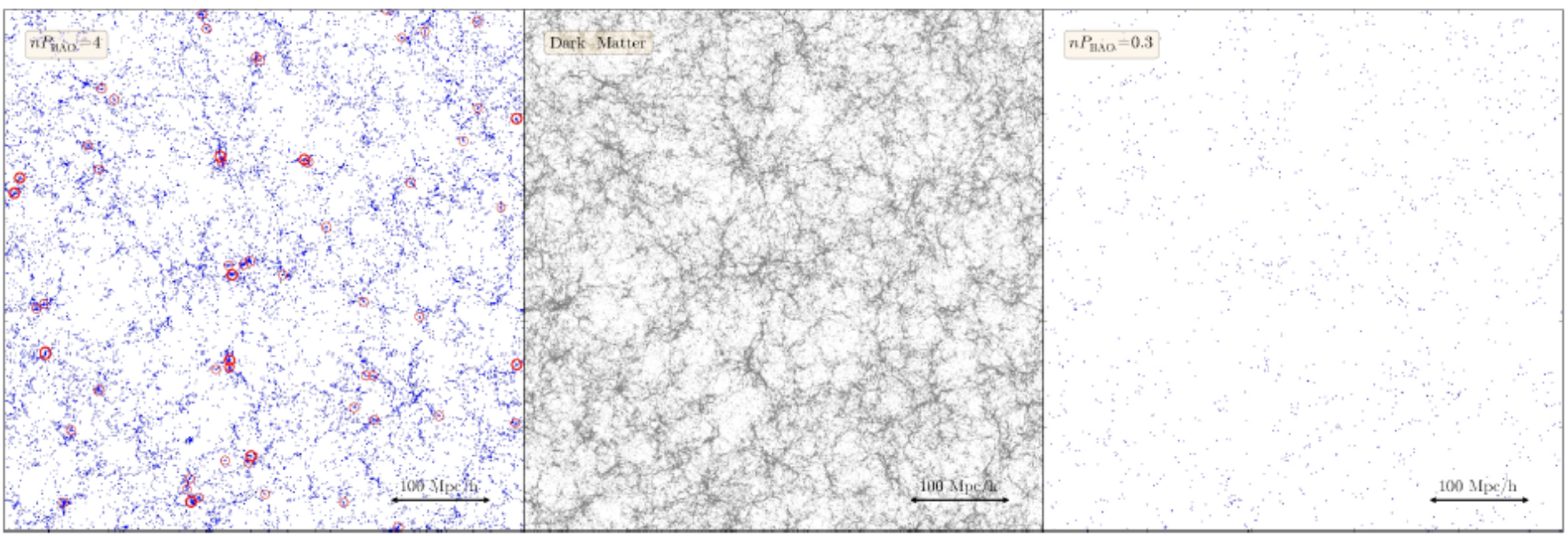
[OIII] emitters provide sparsely sampled tracers for BAO and RSD at z=2-3

Comparison to Euclid

Euclid has larger area but *much* lower space density (factor ~20)

Similar aggregate precision [???] and largely independent BAO/RSD, even in overlapping sky area

Greater depth of AFTA-WFIRST makes it much more robust to luminosity function uncertainty, allows large potential gains in extended survey.

Compared to Euclid, smaller survey area and much denser sampling.

Rough guess for DESI: Higher nP than Euclid out to z ~ 1.1, comparable or lower nP at higher redshift. ???