Cosmology from the WFIRST High Lattitude Survey

Yun Wang

IPAC/Caltech

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Outline

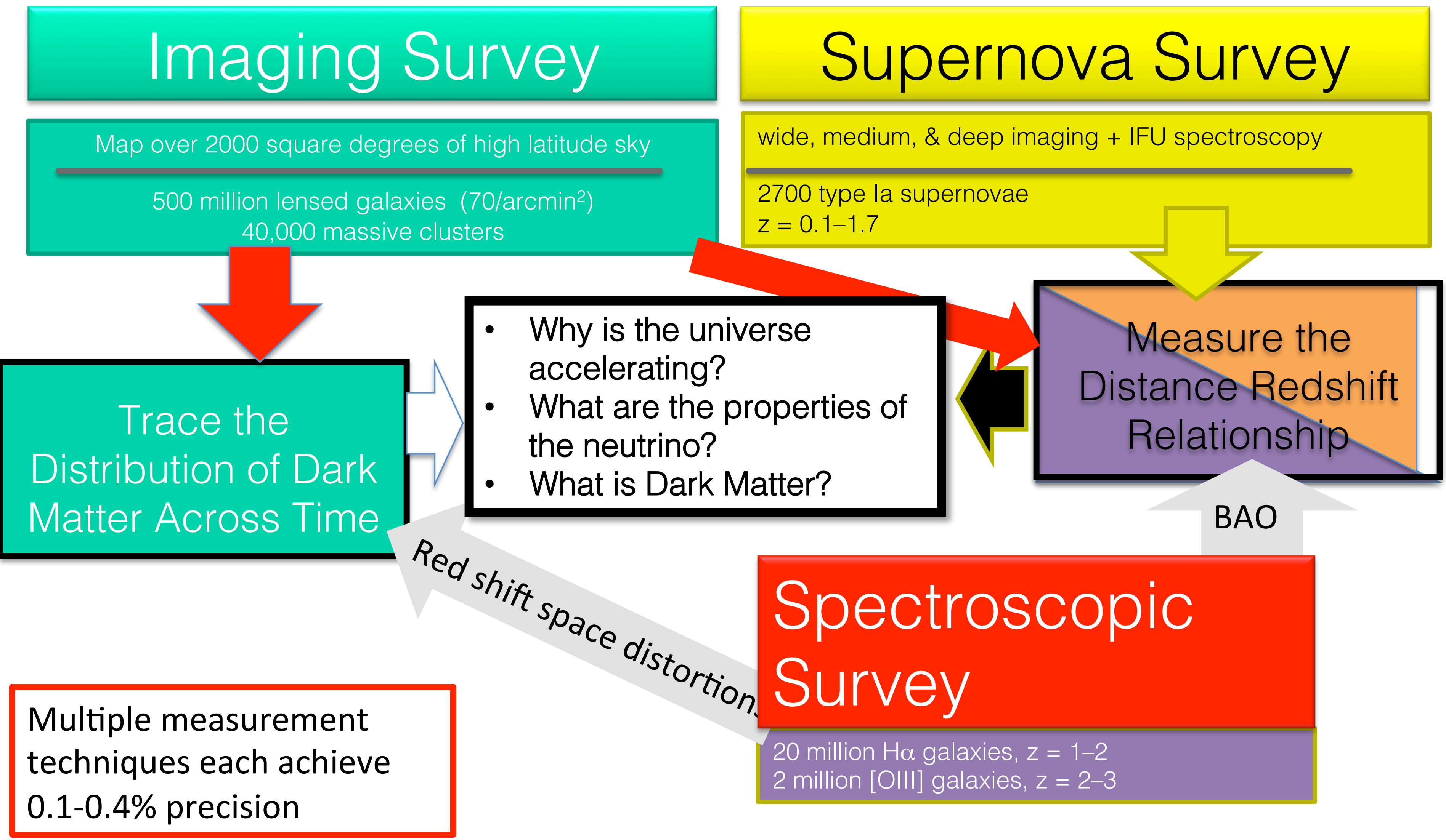
- Probing dark energy with the High Latitude Survey (HLS): WFIRST Science Investigation Team (SIT) on GRS/WL (PI: Doré)
- Other cosmology from the HLS
- Link to guest observers and archival science

Probing Dark Energy With the High Latitude Survey

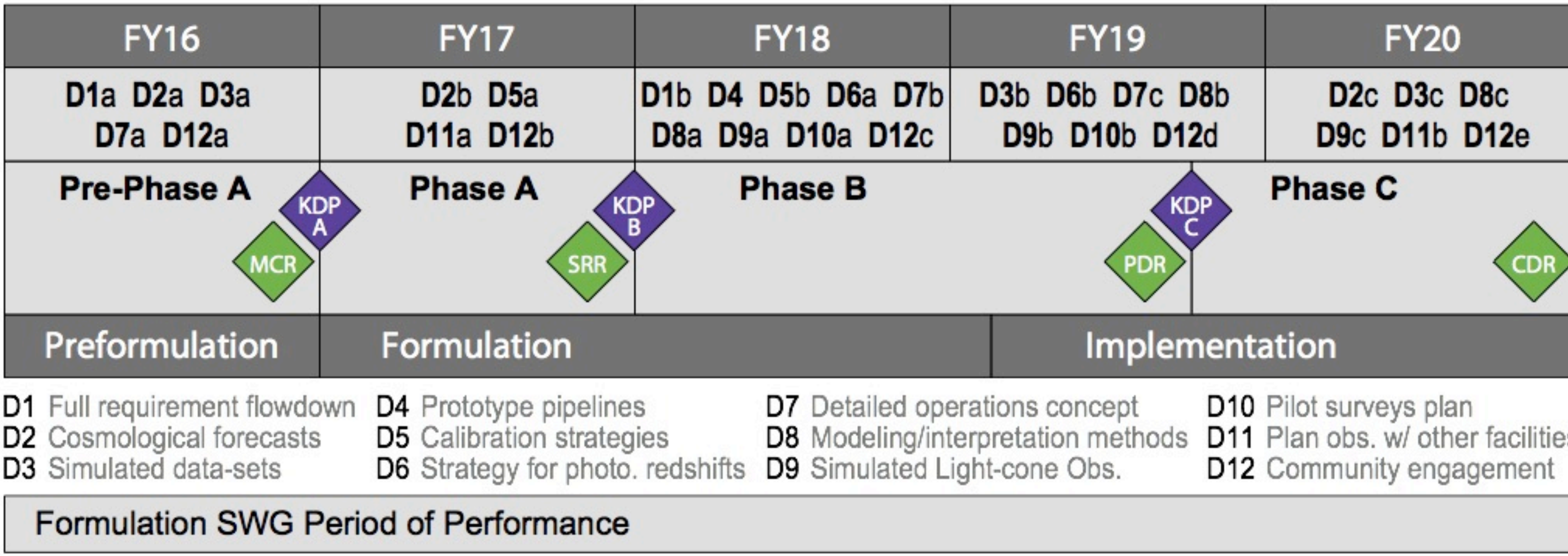
- Imaging survey for weak gravitational lensing (WL) measurements
- Spectroscopic galaxy redshift survey (GRS) for baryon acoustic oscillation (BAO) and redshift space distortion (RSD) measurements

Frontiers of Knowledge

As envisioned in NWNH, WFIRST uses multiple approaches to measure the growth rate of structure and the geometry of the universe to exquisite precision. These measurements will address the central questions of cosmology



Our SIT work plan maps the six SIT tasks to twelve deliverables.



Deliverables	Co-Investigators	Collaborators	Full requirement flowdown	Cosmological forecasts	Simulated data-sets	Prototype pipelines	Calibration strategies	Strategy for photo. redshifts	Detailed operations concept	Modeling/interpretation methods	Simulated Light-cone Obs.	Pilot surveys plan	Plan obs. w/ other facilities	Community engagement
	Co-I	Coll	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Oliver Doré (PI)	●		●	●					●	✓		●	✓	●
Chris Hirata (WL lead)	◆		◆	◆	✓				◆	✓		◆		✓
Yun Wang (GRS lead)	★		★	★					★	✓		★		✓
David Weinberg (CL sub-lead)	▲		▲	▲					✓	✓		✓	✓	✓
Rachel Bean	✓		✓	✓						✓			✓	✓
Andrew Benson		✓								✓	✓			✓
Peter Capak	✓						✓	●					●	✓
Tim Eifler	✓			●					✓	✓				✓
Katrin Heitmann		✓								✓	✓			✓
George Helou		✓			✓	✓								✓
Shirley Ho	✓			✓				✓		✓	●		✓	✓
Michael Hudson		✓						✓		✓			✓	✓
Bhuvnesh Jain	✓			✓						✓			✓	✓
Mike Jarvis	✓				✓	✓								✓
Alina Kiessling	✓									✓	✓			✓
Elisabeth Krause		✓		✓						✓			✓	✓
Robert Lupton	✓					◆								✓
Rachel Mandelbaum	✓		✓	✓	◆	✓				◆	✓			✓
Hironao Miyatake		✓	✓	✓	✓	✓				✓				✓
Nikhil Padmanabhan	✓				✓	✓	●			★		✓		✓
Eduardo Rozo		✓		✓						✓				✓
Lado Samushia	✓			✓	✓	✓				✓				✓
Mike Seiffert		✓			✓	✓								✓
Charles Shapiro		✓	✓		✓	✓								✓
Kendrick Smith		✓		✓						✓				✓
David Spergel	✓			✓						✓		✓	✓	●
Masahiro Takada		✓		✓						✓			✓	✓
Harry Teplitz	✓		✓		★	★		✓						✓
Anja von der Linden		✓		✓						✓	✓		✓	✓
Naoki Yoshida		✓								✓	✓			✓

Matrix of team responsibilities.

PI: Olivier Doré
WL Lead: Chris Hirata
GRS Lead: Yun Wang
CL Sub-Lead: David Weinberg

Green = WL deliverable leads
Blue = GRS deliverable leads
Red = general deliverable leads

Weak Lensing

- Slight (~1%) distortion of the image of a galaxy due to matter along the line of sight.
  - **Shear** = l.o.s. integral of tidal field
    - Manifest in the ellipticity of a galaxy.
    - Since shear << intrinsic ellipticity, must do statistics.

  - **Magnification** = l.o.s. integral of density
    - Less mature; not a formal WFIRST requirement.

Slide from Chris Hirata

Thanks to B. Jain for the cartoon.

Major Uses

WL serves both cosmology and galaxy evolution

1. The growth of large scale structure via the statistics of weak lensing.
   – **The weak lensing power spectrum is a "Key Project" for WFIRST, one of the science cases called out in Astro2010, and the source of most of our demanding requirements.**
2. The connection between galaxies and their host dark matter haloes.
3. Galaxy biasing – the relation between galaxies and their large-scale environment.

Slide from Chris Hirata

Cosmic Shear

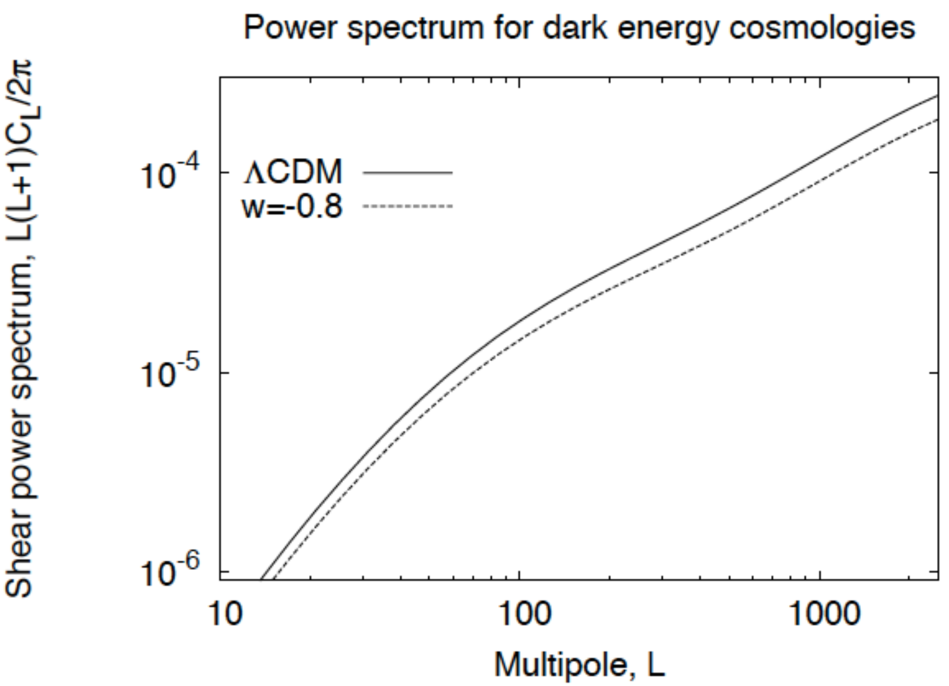
- Use the power spectrum or correlation function of galaxy ellipticities.
- This depends directly on the matter (and background cosmology) – no more messy galaxy biasing uncertainties!

$$W_{\rm flat}(D_{C1}, D_C) = \frac{3}{2}\Omega_m H_0^2 (1+z_1) \frac{D_{C1}(D_C - D_{C1})}{D_C} \Theta(D_C - D_{C1})$$

$$C_{EE}(l) = \int_0^{D_C} [W(D_{C1}, D_C)]^2 \frac{P_\delta(k = l/D_{A1})}{D_{A1}^2} dD_{C1}$$

But is very hard!

- Needs lots of time to resolve shapes of distant (small/faint) galaxies!
- Systematic errors in measuring a <1% signal.



Slide from Chris Hirata

SDT plan

- 3 shape filters (J/H/F184) – J and H are “primary”, but F184 provides capability for multiple internal cross-spectra
  - Two “passes” in each filter, with small-step dithers.
- Additional Y filter for photo-z’s
  - Y is heavily undersampled, pixels > λ/D; we’re not imposing a requirement to reach shape systematics targets in Y.
- Overlap with LSST for comparison of shapes, optical+NIR photo-z solutions
- Covered 2200 deg^2 (in 2 years, imaging + spectroscopy)

- Details subject to change

Slide from Chris Hirata

Major Challenges/ Systematics

1. The point spread function
   – including optics, but also detector effects
2. Shear measurement algorithms
   – complex morphologies, blending, sampling, …
3. Intrinsic alignments
   – both their auto-correlation, and correlation with lensing
4. Photometric redshifts
   – with LSST + WFIRST, still need other data to calibrate
5. The nonlinear matter power spectrum
   – including the effects of baryons

Slide from Chris Hirata

WFIRST Cluster Cosmology

- For dark energy investigations, think of “cluster cosmology” as a specialized subset of weak lensing.
- Measure tangential shear profiles around clusters in bins of “mass-correlated observable” (richness, X-ray or SZ properties).
- At ~ Mpc scale, WL calibrates the mean of the mass-observable relation P(M|O), combined with cluster counts yields high end of halo mass function.
- Large scale (many Mpc) shear has additional information.
- Compared to cosmic shear, uses subset of WL shapes but adds “baryonic” information about locations/redshifts of massive halos.
- Generic forecasts (Oguri & Takada 2011; Weinberg++ 2013; SDT 2015) indicate comparable constraining power to cosmic shear, complementary information and response to systematics.

Slide from David Weinberg

Requirements & Opportunities

What are cluster-specific requirements, beyond cosmic shear?

- Likely no additional instrument requirements
- Software requirements for photometry in cluster regions
- Survey strategy requirements for contiguity and uniformity, overlap with other cluster data sets
- Need detailed simulations of cluster identification and measurement in HLS data set

Opportunities:

- Clusters may *mitigate* other WL systematics: photo-z biases, intrinsic alignments, shear measurement biases
- GO or extended mission observations could provide WL profiles for hundreds of clusters outside HLS: high mass and/or high-z
- Lots of great galaxy evolution and dark matter science from the cluster data set, highly magnified background objects

Slide from David Weinberg

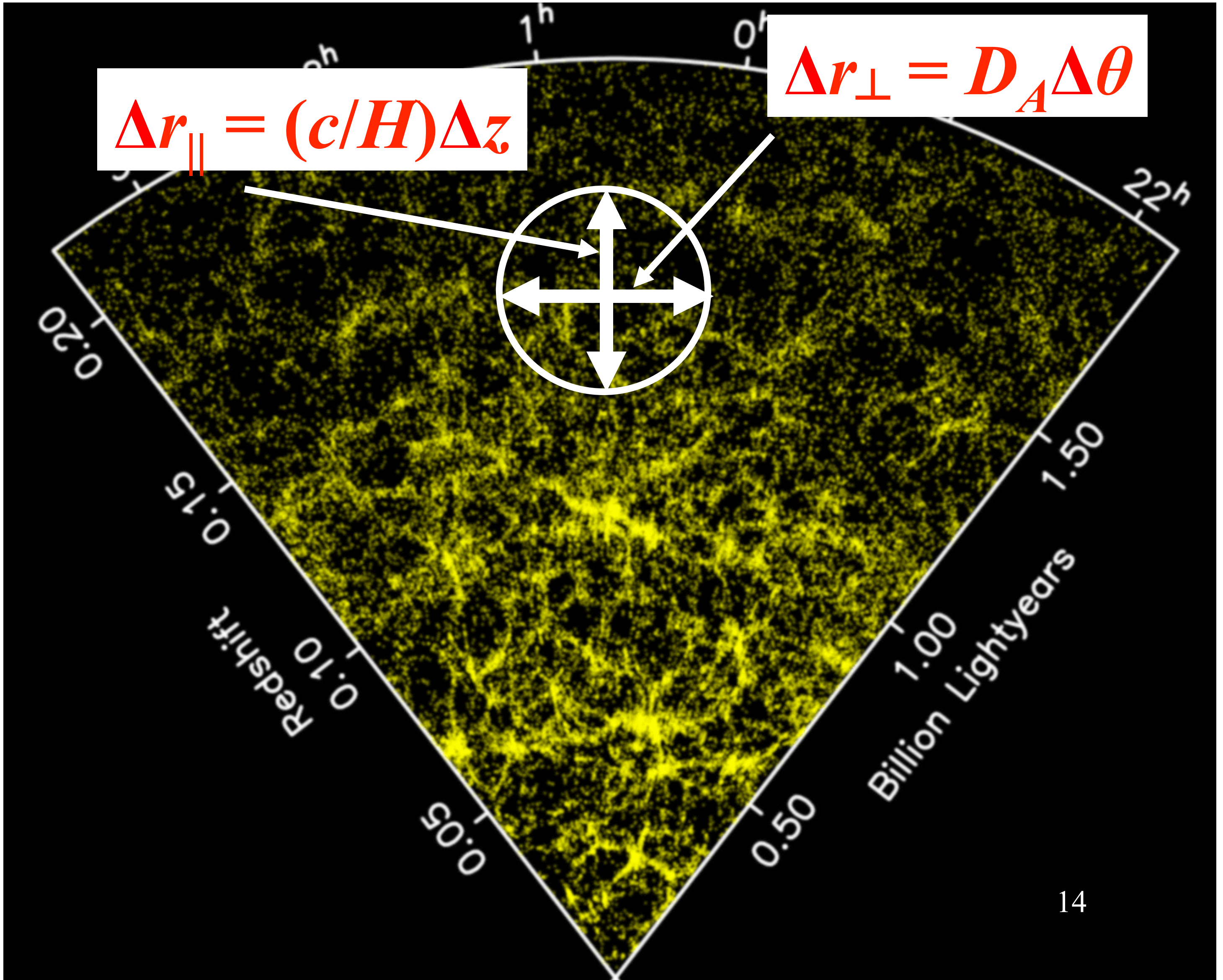
BAO as a Standard Ruler

Blake & Glazebrook 2003
Seo & Eisenstein 2003

BAO"wavelength" in radial direction in slices of z : $H(z)$

BAO "wavelength" in transverse direction in slices of z : $D_A(z)$

BAO systematics:
➔Bias
➔Redshift-space distortions
➔Nonlinear effects



The Use of Galaxy Clustering to Differentiate Dark Energy & Modified Gravity

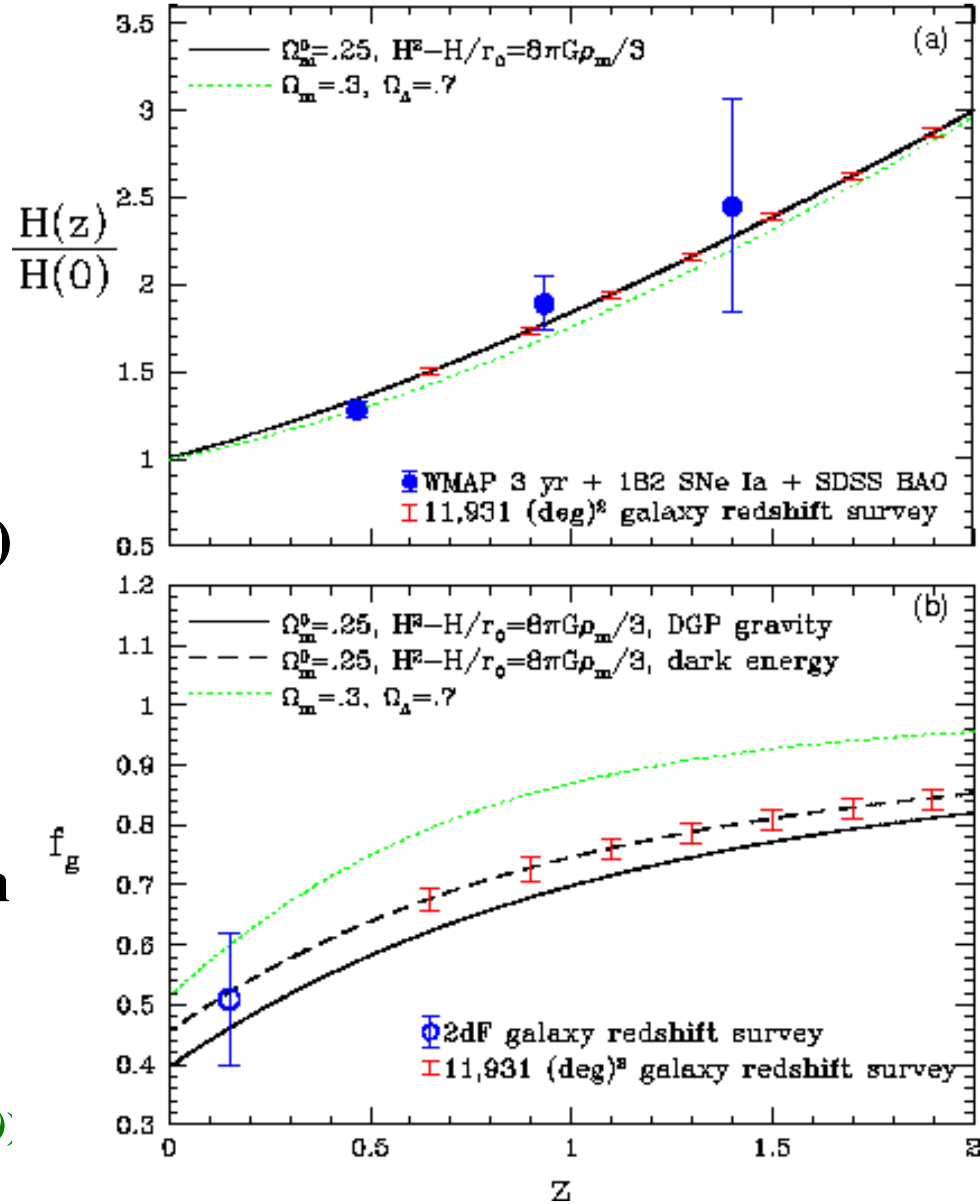
Measuring redshift-space distortions $\beta(z)$ and bias $b(z)$ allows us to measure $f_g(z)=\beta(z)b(z)$

$[f_g=\mathrm{dln}\delta/\mathrm{dln}a]$

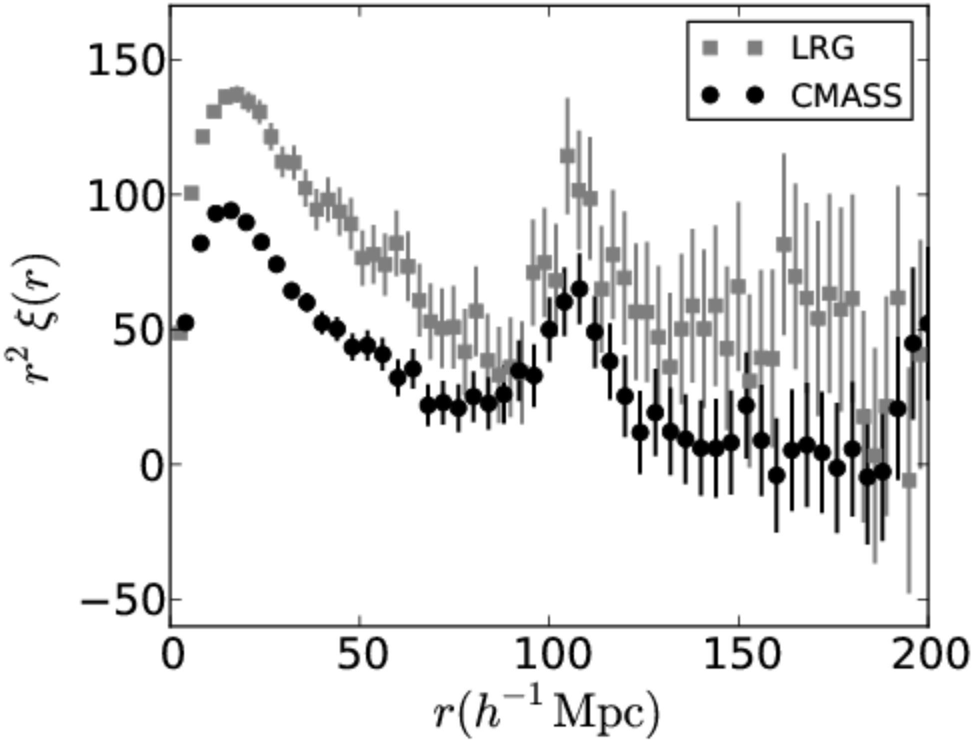
$H(z)$ and $f_g(z)$ allow us to differentiate dark energy an modified gravity.

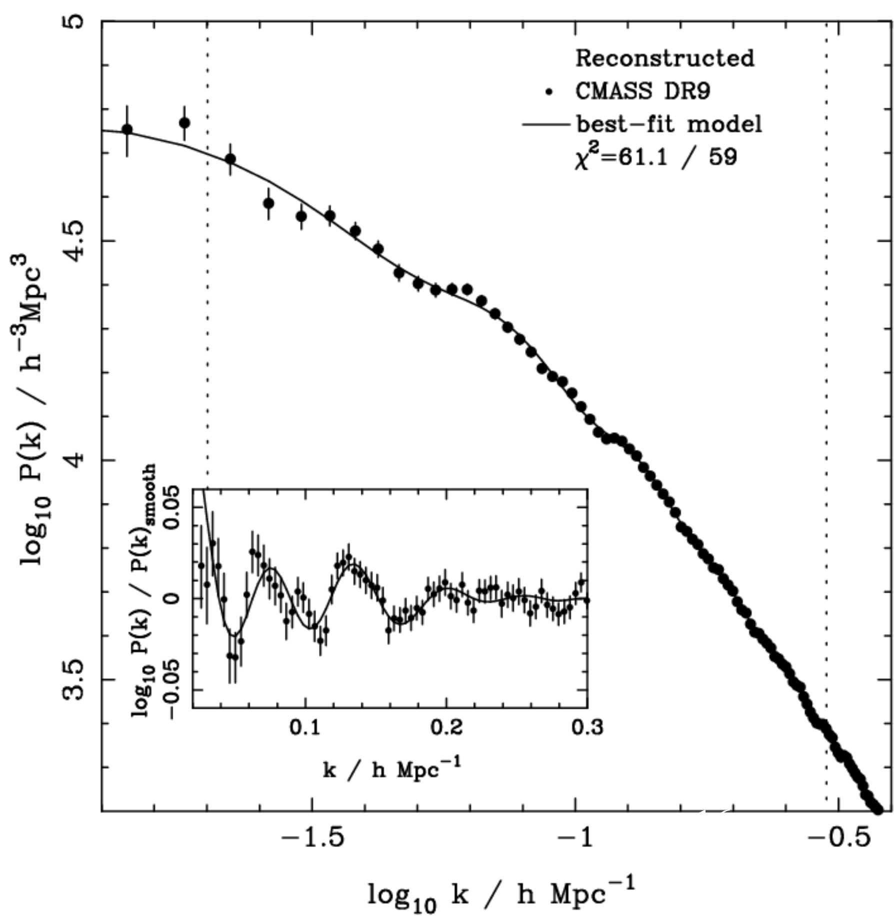
Wang (2008)

*** Using $f_g(z)\sigma_8(z)$ can avoid needing to measure bias.** ***Song & Percival (2009)***



Results from BOSS (SDSS III)





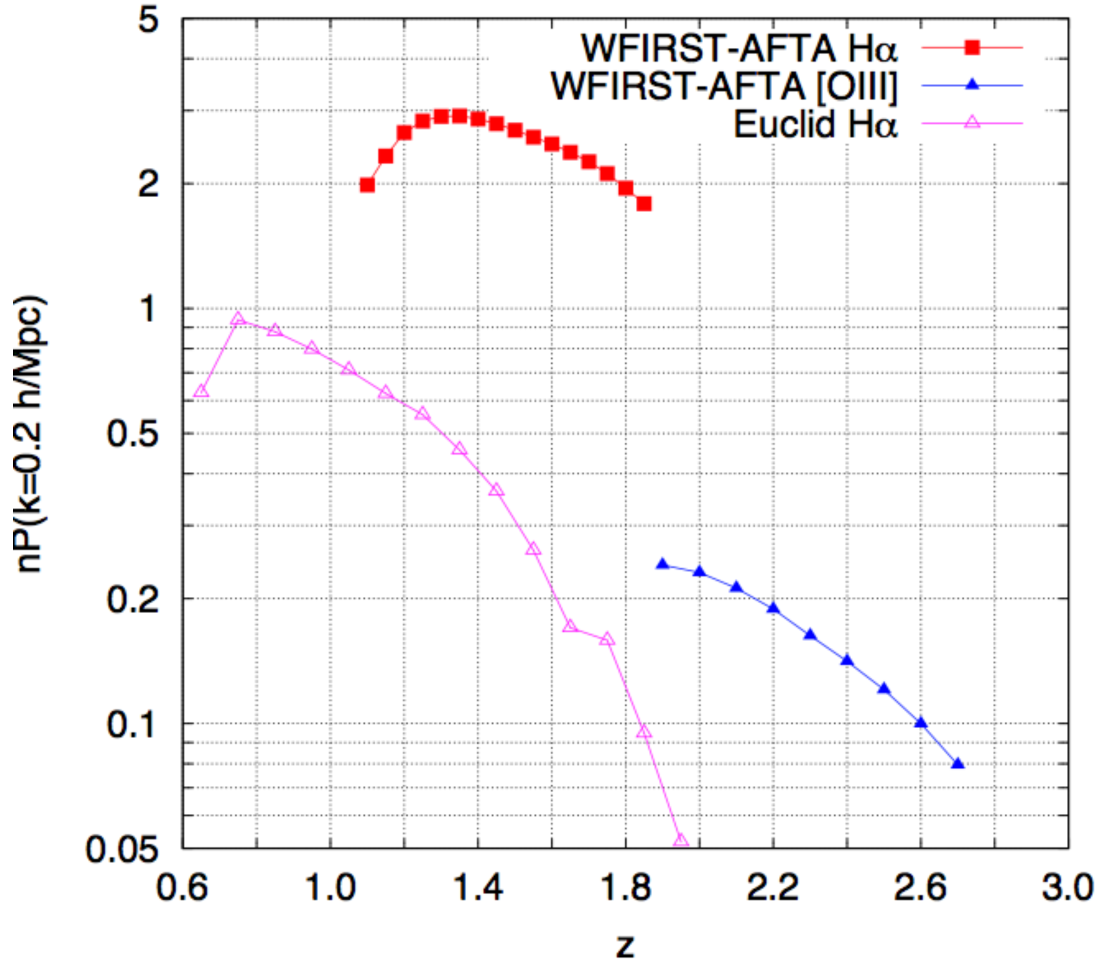
Spherically-averaged galaxy correlation function (top) and Galaxy power spectrum (right) from BOSS CMASS sample (DR9).

Anderson et al. (2012)

WFIRST GRS

Starting point:
SDT Final report baseline

- **2200 sq deg**
- **16.4 million Hα emission line galaxies**
- **1.4 million [OIII] emission line galaxies**
- **Complementary to Euclid GRS**



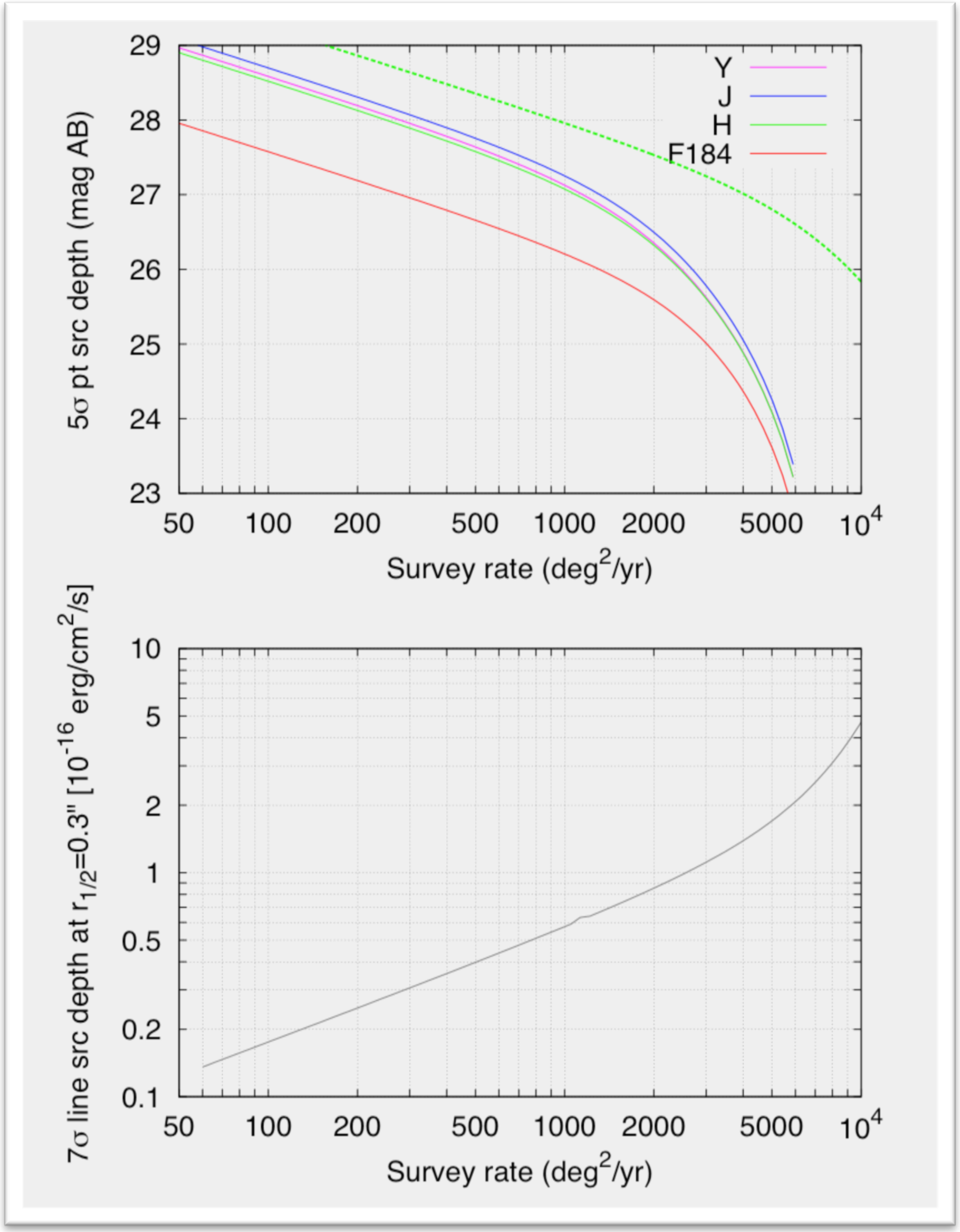
Key Part of D8 (Modeling/Interpretation): Systematics Testing & Mitigation

- To mitigate observational systematic effects, create pixel-level simulations based on galaxy mocks, and extract the simulated observed galaxy catalog, and produce the corresponding random catalogs.
- Test for systematics such as effects of stellar density, dependence on line luminosity & continuum luminosity, and varying exposure number. The last can lead to potential systematic effects caused by the complex structure of the completeness function as a function of redshift.
- Use template projection method and cross-correlation method in photometric clustering to mitigate observational systematics.

Flexibility and Power of WFIRST-AFTA

Weak lensing imaging survey

Spectroscopic galaxy redshift survey



Yun Wang, 2/29/16

Areas for Optimization Work

- Depth vs. area trades, multi-tier surveys, etc.
- Survey footprint location, links to other observatories
- Study pilot surveys
- Dithering strategies – relation to systematics req'ts and calibration techniques.
- Filter choices

- We will work with the other SITs on all of these.
- Tiling/scheduling simulation tools are already fairly advanced (down to individual pointings, slew times, observing constraints, incorporation of distortion

Slide from Chris Hirata

Other Cosmology

The High Latitude Survey will significantly tighten the constraints on

- The sum of neutrino mass
- Primordial non-Gaussianity
- Large scale distribution of dark matter
- Dark radiation (unknown massless particles)
- Initial conditions (inflation) in the Universe

GO & Archival Science

- HLS (WL/GRS) will provide targets for GO investigations and enable discoveries
- HLS will create an invaluable archive for a wide range of science areas (see other talks)
- The WL/GRS SIT will
  - Provide mock data products and simulation tools that enable simulations for GO science
  - Organize conferences to engage the broader cosmology community in WFIRST