# NASA's WFIRST–2.4m Mission

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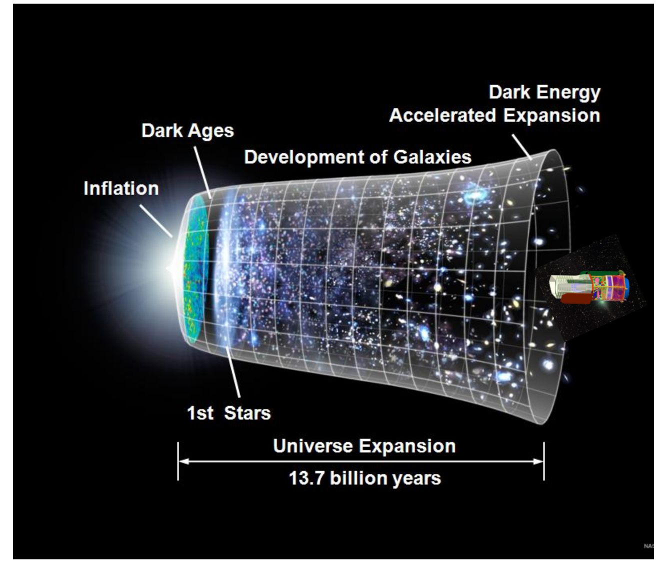
Cosmic Frontiers Workshop
March 7, 2013

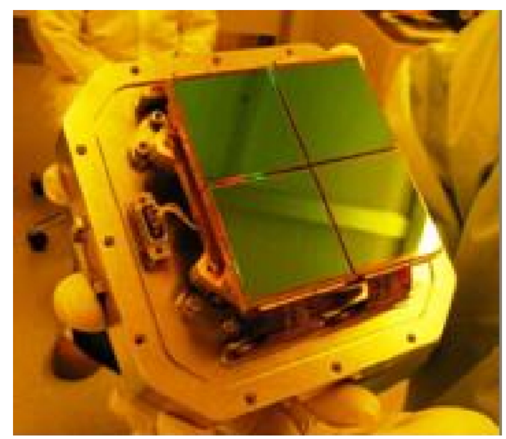
# WFIRST Summary

- WFIRST is the highest ranked large space mission in 2010 US Decadal Survey
  - dark energy
  - exoplanet microlensing and coronagraphy
  - galactic and extragalactic astronomy from the dark energy surveys
  - Guest Investigator program




- Measurements:
  - NIR sky surveys for BAO & weak lensing
  - NIR monitoring for SNe & microlensing

- Enabled by US-developed large format HgCdTe detectors



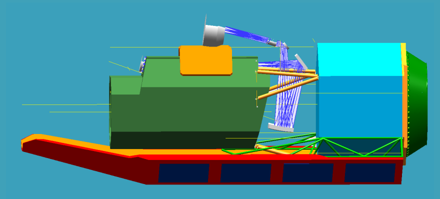
JWST HgCdTe Detector

# WFIRST Status

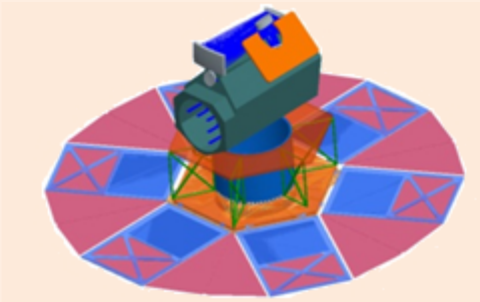
- WFIRST design specified by Astro2010 based JDEM and SNAP, with 1.5m telescope.
- 2012:  NRO makes available two 2.4m telescope to NASA; one under consideration for WFIRST
- Science Definition Team formed to study WFIRST-2.4m
- Provided the JWST funding wedge returns to astrophysics, WFIRST will happen, and the key decision is "which design?"
- There is enthusiasm in NASA and the community for WFIRST-2.4 with launch in 2020-2022
- There is good hope for overlap of LSST, Euclid, WFIRST (& JWST). Great win for science due to complementarity of capabilities.

# Design Concepts

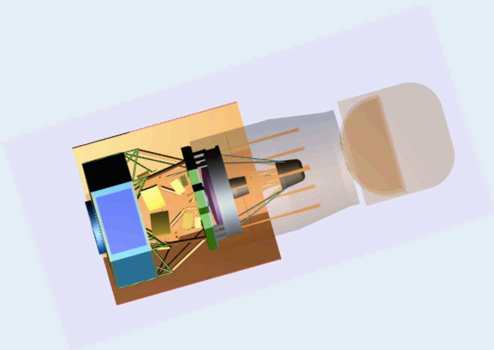
- **DRM1**
  - **1.3 meter off-axis telescope**
  - **150 Mpixels, 0.4 $deg^2$**
  - **5 year mission (2.5 yr Dark Energy)**
  - **Atlas V Launch Vehicle**



- **DRM2**
  - **1.1 meter off-axis telescope**
  - **234 Mpixels, 0.6 $deg^2$**
  - **3 year mission (1.5 yr Dark Energy)**
  - **Falcon9 Launch Vehicle**



- **WFIRST-2.4m**
  - **2.4 meter on-axis telescope**
  - **288 Mpixels, 0.3 $deg^2$**
  - **Additional IFU for SN slit spectroscopy**
  - **5 year mission (2.5 yr Dark Energy)**
  - **Falcon9 or Atlas V Launch Vehicle**

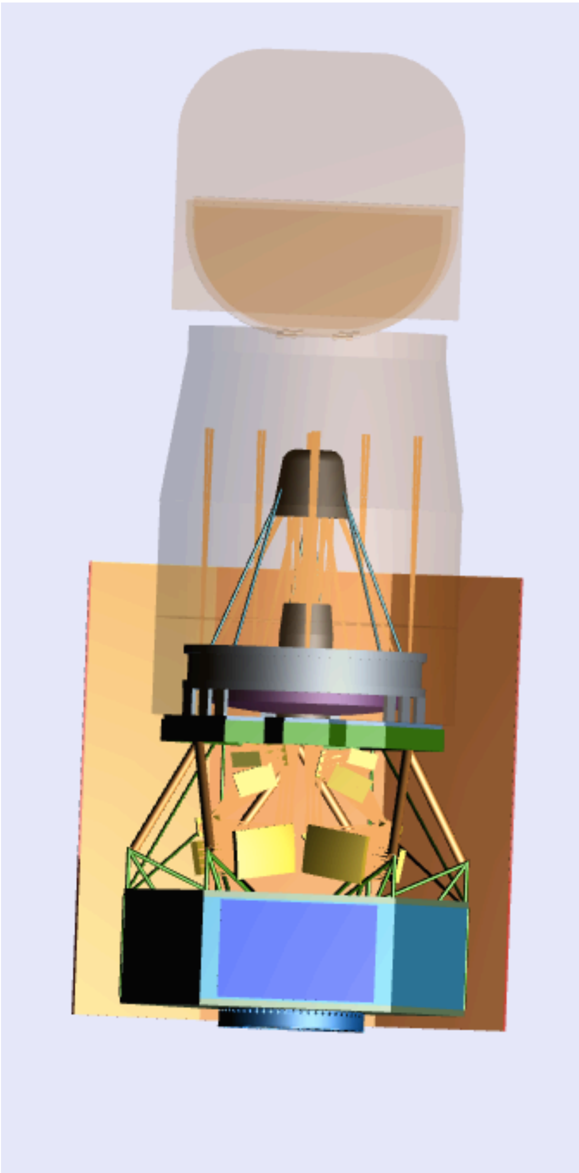


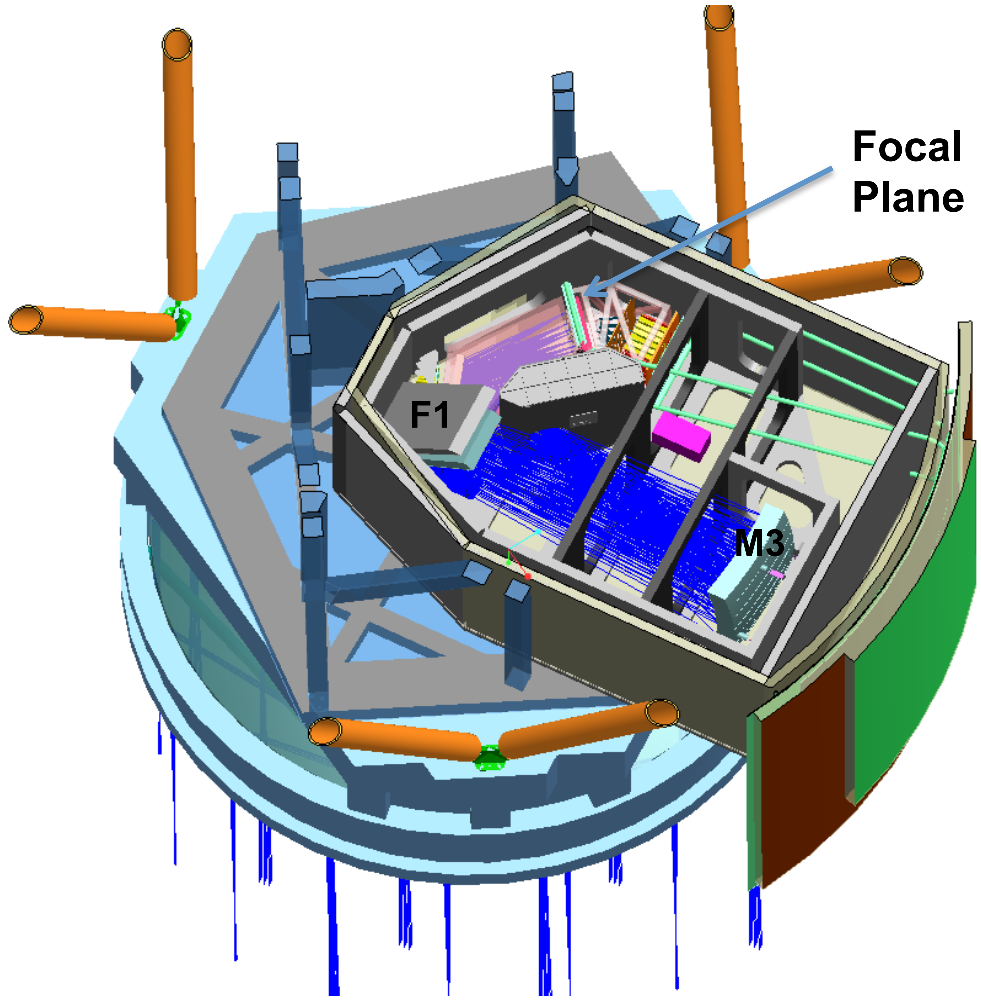
* WFIRST-2.4m also known as Astrophysics Focusing Telescope Asset (AFTA)

# NRO Telescopes for NASA and Astrophysics

- 2.4 meter telescope
  - High quality mirror and optical system
  - Easily used in a TMA design
    - Wide field of view
  - Well suited towards WFIRST mission concept
    - Higher spatial resolution enhances science capability
    - Larger collecting area enables more science in fixed time

# Optics



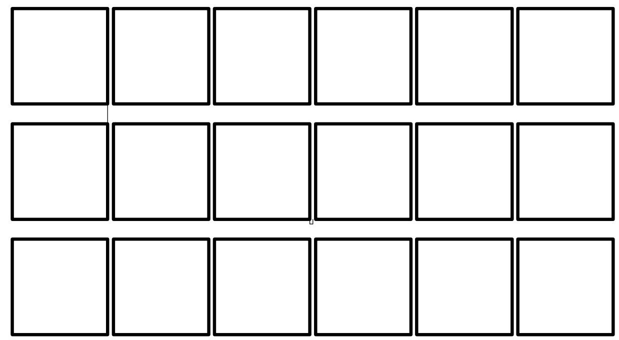



looking up
from bottom

# Detector Layout on Sky

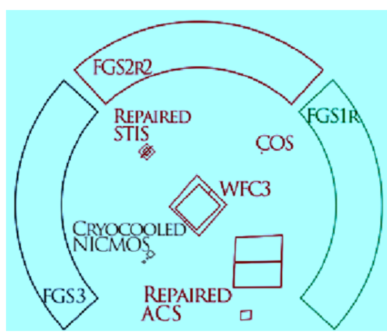
0.11 arcsec/pixel     0.33 $deg^2$

24 x H4RG
Detectors
(10 $\mu$m pitch)
288 Mpixels

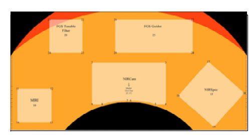


IFU

coronagraph




HST [all instruments]

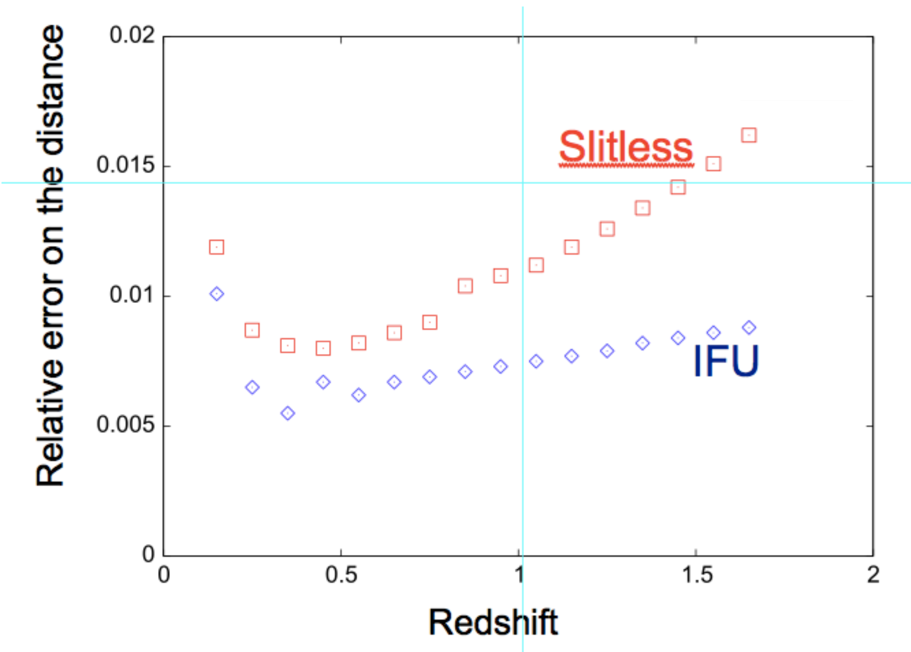


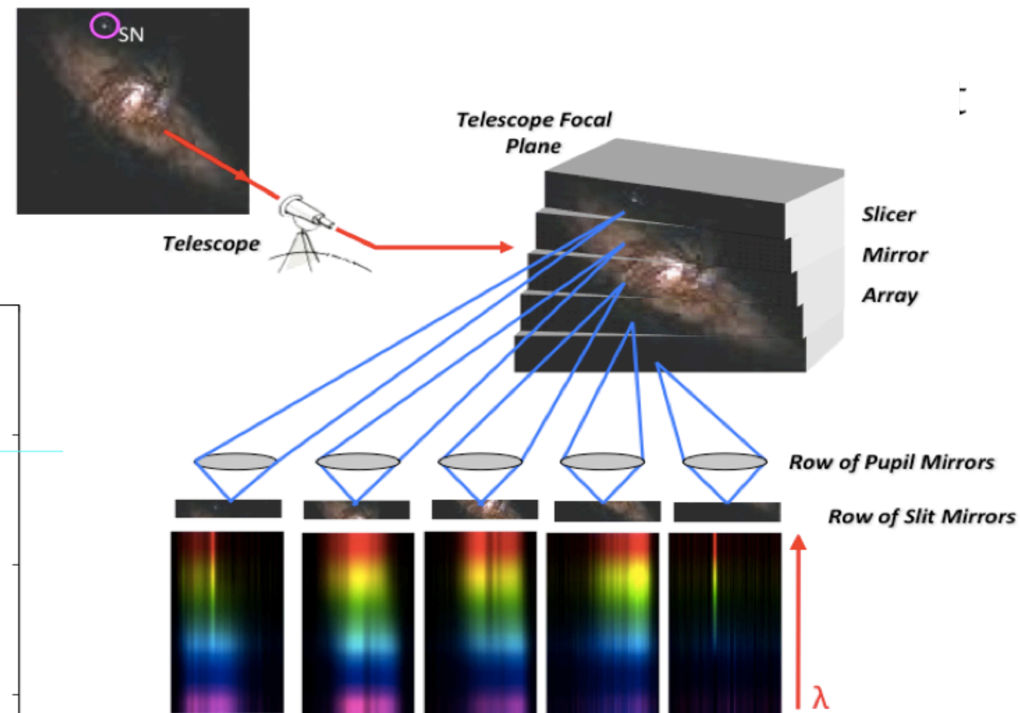
JWST [all instruments]

Moon (average size seen from Earth)

Slitless spectroscopy with grism in filter wheel
R_θ ~ 100 arcsec/micron

# IFU Spectrometer



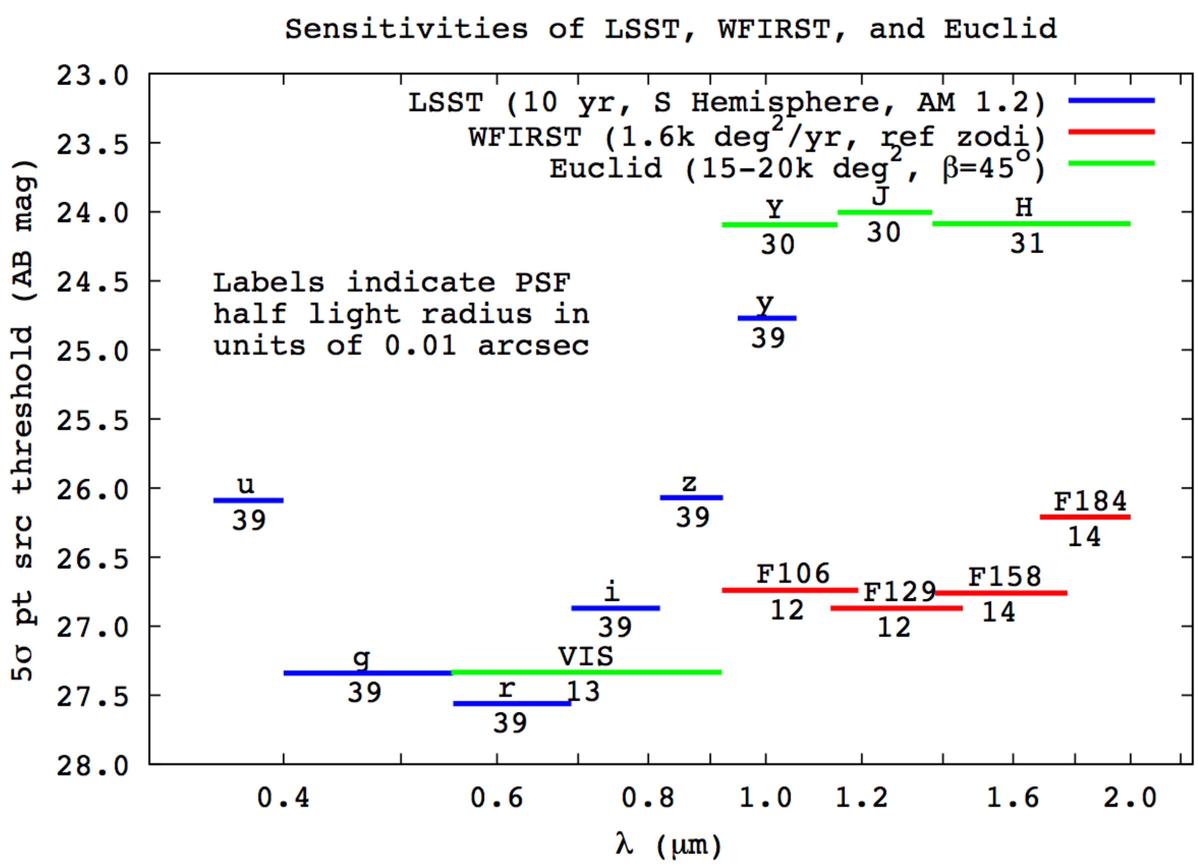

R ~ 75 spectral resolution

Background zodi is 100X less than with slitless grism spectroscopy

# WFIRST-2.4m Philosophy for DE

- Do exquisite observations in multiple techniques: SNe, BAO, RSD, WL
- Push SN lightcurves and spectroscopy to z=1.7 with controlled systematics
- Perform deep, narrow surveys compared to shallow, wide for Euclid & LSST. Survey size 2k $deg^2$ in prime mission, possibly expanding to ~10k $deg^2$ in extended mission.
- Aim is complementarity, optimum joint data set & precision measurements
- High nP for BAO
- High $n_{eff}$ for WL
- WL shape measurement in IR.

# Complementarity to LSST & Euclid




WFIRST-2.4 IR depth well matched to LSST optical.

Compared to Euclid IR,

- WFIRST-2.4 is ~10x deeper
- 2.3 higher angular resolution
- Less time spent in prime mission on DE survey (2.5 vs 6.25 years)

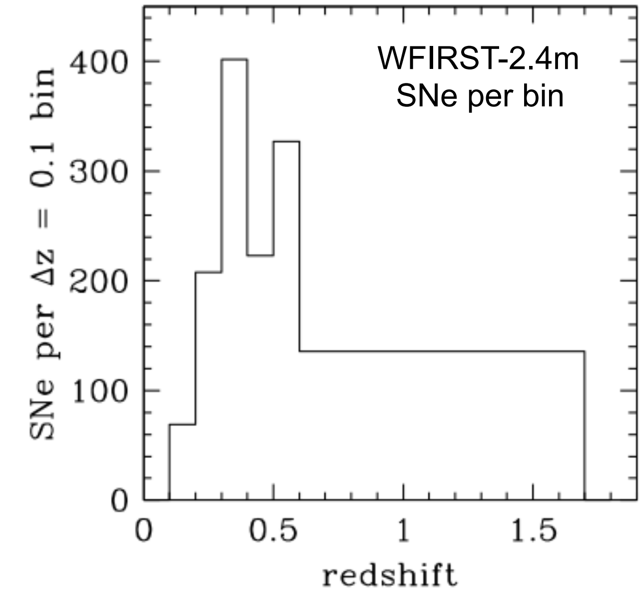
# Dark Energy: Supernovae

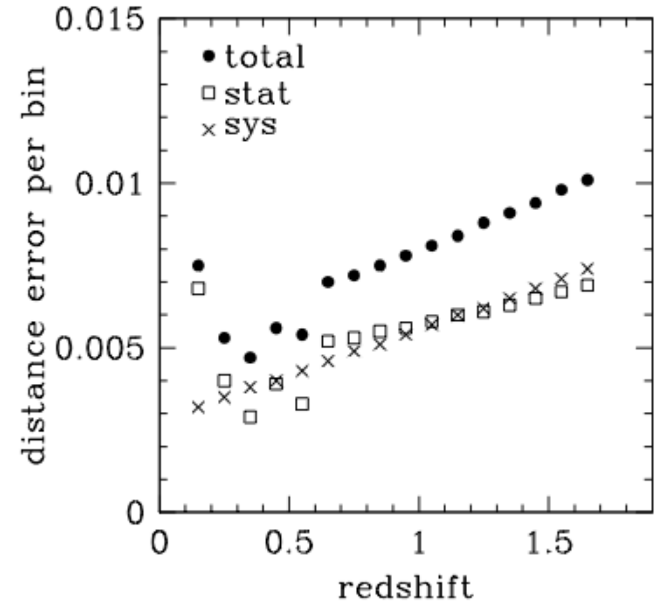
Observing program:

- 6 months of observations spread over 2 years
- 5-day cadence of 3 hrs of imaging & spectroscopy
- 3 tiers: shallow 27 $deg^2$ $z<0.4$, medium 9 $deg^2$ $z<0.8$, deep 5 $deg^2$ $z<1.7$
- SNe discovered with wide-field imager and observed with IFU
- 7 IFU spectra at 5 days (restframe) cadence
- Deep IFU spectrum at peak (S/N = 10 per pixel)

WFIRST-2.4m strengths

- SNe are core part of WFIRST program
- IFU included for spectroscopy
  - No K corrections
  - Ability to separate SN & galaxy
  - Spectral diagnostics to reduce evolutionary effects



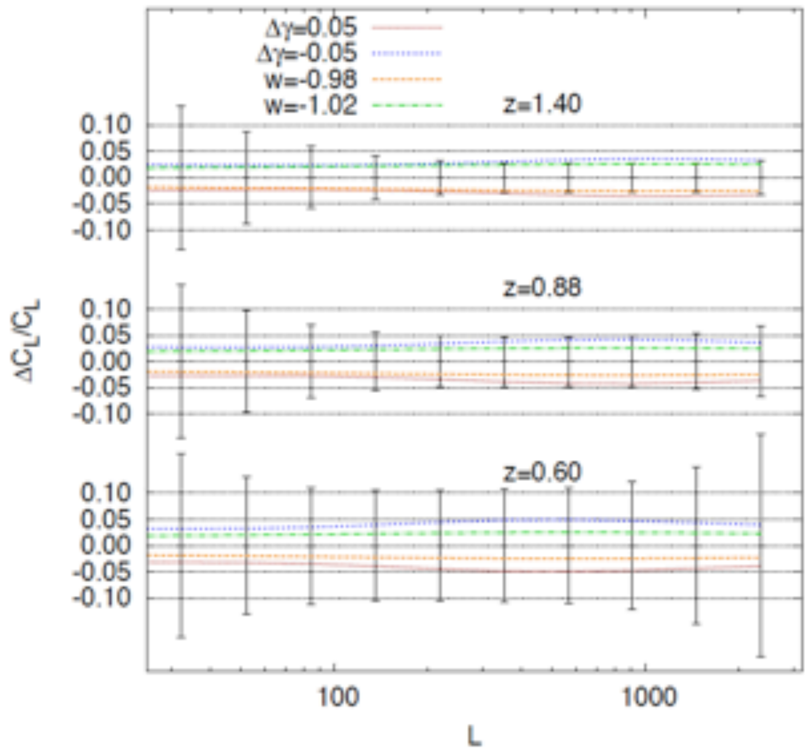
# Dark Energy: Weak Lensing

Observing program:

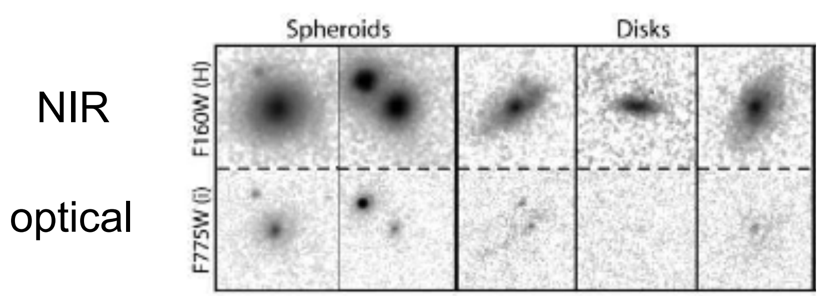
- Deep galaxy imaging survey over 2000 $deg^2$
- Redshifts obtained from photo-z's

WFIRST-2.4m strengths

- High surface density of galaxies
- 0.5 billion galaxies total
- Stable space platform with small PSF
- Shape measurement in IR
- 3 shape measurement filters enabling color-dependent PSF corrections
- Multiple passes to reduce cosmic ray effects




Cross-correlation of WFIRST shapes against LSST/Euclid should be powerful for all three.

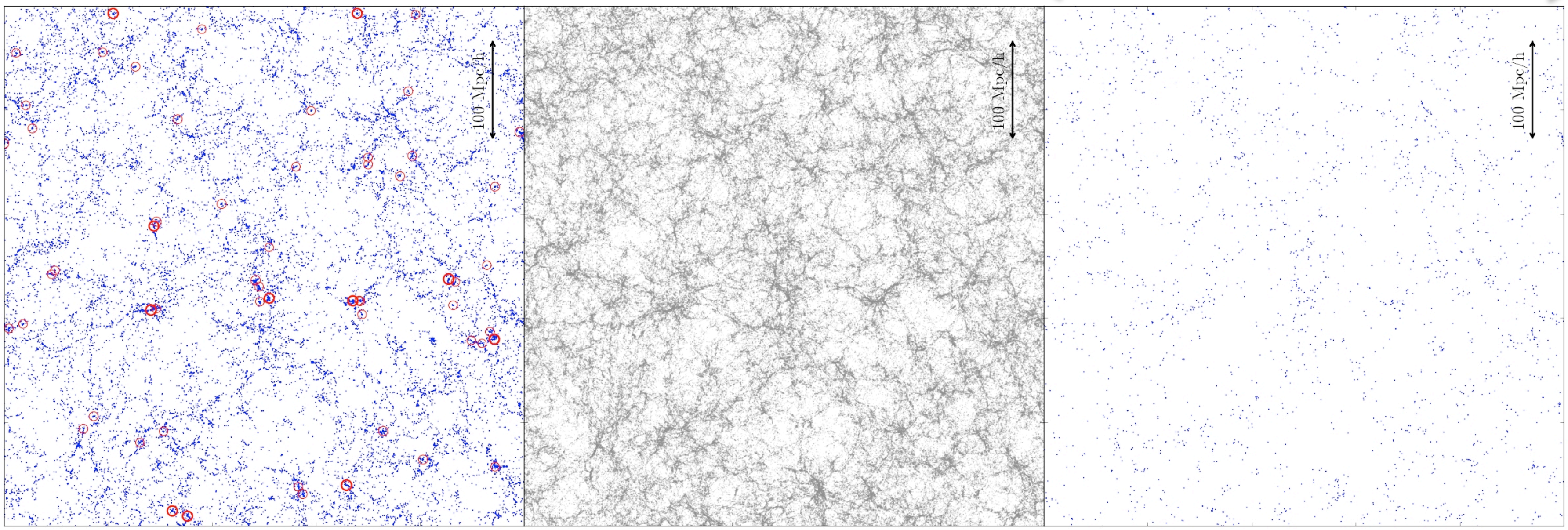



| Observatory | $n_{eff}$ (galaxies $arcmin^{-1}$) |
|---|---|
| WFIRST-2.4m | 70 (250 deep field) |
| Euclid | 30-35 |
| LSST | 30-35 |

# Millennium Simulation

z = 1.5

500 $h^{-1}$ Mpc
9 degrees




galaxies at luminosity threshold to match WFIRST-2.4m space density

dark matter

galaxies at luminosity threshold to match Euclid space density

Figure by Y. Zu

Springel et al. 2005

# Dark Energy: BAO & RSD

Observing program

- Galaxy redshift survey with grism
- 2000 $deg^2$ baseline

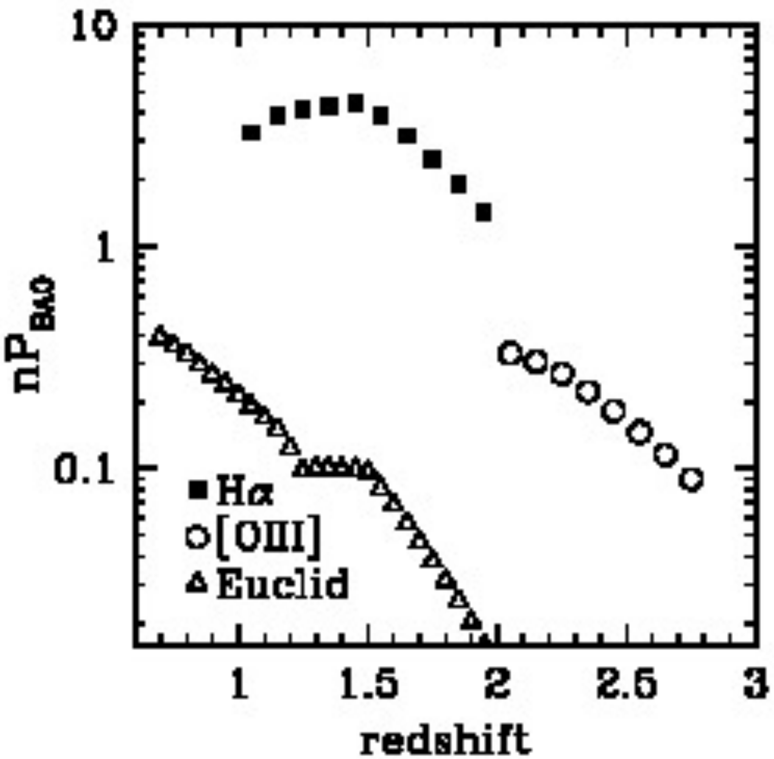
WFIRST-2.4 strengths

- High nP above cosmic variance limit for $1 < z < 2$
- Large redshift range

  H$\alpha$ line z = 1.1 – 2.0

  OIII line z = 1.7 – 2.9

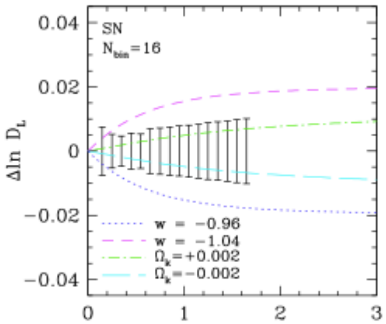
- 25M galaxies at 7$\sigma$



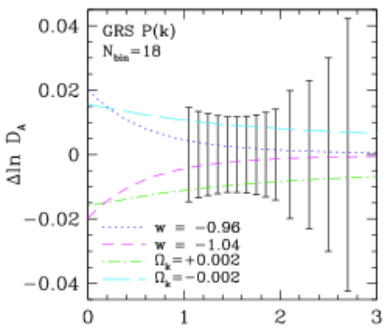

- H-alpha LF and OIII LF from Colbert et al. (in prep.)
- Galaxy bias b = 0.9 + 0.4z, from Orsi et al. (2010)
- P_BAO is linear galaxy power spectrum at k = 0.2 h/Mpc

# Parameter Measurement Accuracy

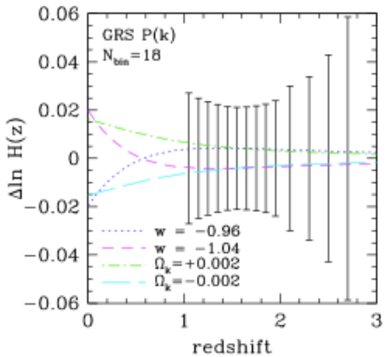
## Expansion History




SNe
0.2%



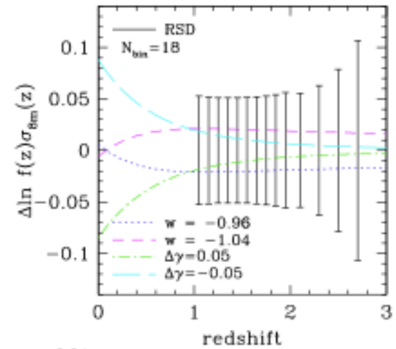

BAO
0.4%



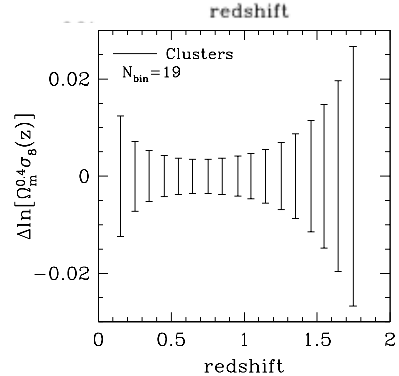

BAO
0.7%

## Growth of Structure

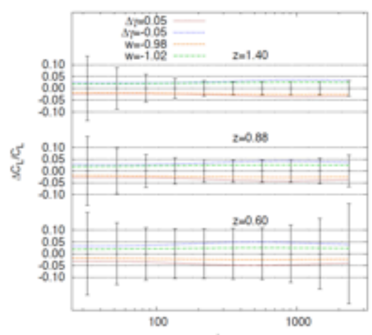
RSD
1.7%




WL
Cluster
Mass Function
0.1%




WL
Shear
~0.1%



# Improving Precision

- WFIRST-2.4m measures several different observables much more precisely than known today, goes into new redshift ranges
- Systematics control is key
- The BAO and RSD precision limited by survey area and could be reduced in an extended mission
- The RSD precision based on kmax = 0.2, so it could be improved if modeling of smaller scales is sufficiently accurate
- The SN, cluster, and WL precision improved by extended observations provided not already hitting a systematic floor.

Question 1

*What are the opportunities afforded by combining results from different probes or directly cross-correlating measurements from overlapping data sets?*
*(1) calibrating nuisance parameters or mitigating systematic uncertainties,*
*(2) improving parameter constraints and Figures of Merit,*
*(3) providing the chance to make "surprising" discoveries that lie outside the conventional parameter space.*

- LSST, Euclid and WFIRST will all benefit from combining filters for galaxy photo-z redshifts.

- WFIRST will provide superb SN measurements with unequalled precision and low systematic errors to anchor DE measurements at low redshift.

- WFIRST, Euclid and JWST will provide a multichromatic view of galaxies at ~0.1" resolution
  - Euclid at 0.6 microns
  - WFIRST at 1.2 microns
  - JWST at 3 microns

Question 2

*What theoretical development and simulations are needed to assess these opportunities and exploit them?*

- WFIRST lensing survey will have a higher galaxy number density of lensed galaxies than previous studies. How can we make better use of this information on smaller scales?
- Can we use the more detailed morphology information to improve our DE measurements?
- How can we best use cluster number counts to constrain DE?
- More work needed on using redshift space distortions to constrain DE
- The WFIRST IFU should provide significantly improved SN spectra. How do we best exploit this to minimize systematics?

## Question 3

*What are the implications of cross-correlation techniques for the design of surveys or experiments?*

- We need to explore how to optimally combine data from Euclid, LSST and WFIRST to identify systematics in each experiment
- We need to explore combining measurements based on other techniques (X-ray clusters, SZ clusters, CMB lensing) with optical weak lensing to identify ways of maximizing S/N

## Question 4

*What do we gain from carrying out "the same" measurement using different instruments or different tracers --- e.g., weak lensing with LSST, Euclid, and WFIRST, or BAO/RSD with red galaxies and blue galaxies? What is the right balance between reaching into new redshift ranges and sky areas vs. repeating measurements to test for systematic errors or improve precision?*

- WL galaxy shapes measured in different wavelength bands
  - WFIRST in NIR
  - LSST and Euclid in optical

- Systematic controls is difficult and will benefit from complementary measurement

- Detector systematics is different for three projects

- WL photo-z redshift measured in different filters
  - LSST in 6 filters 300 – 1000 nm
  - WFIRST in 4 filters 700 – 2000 nm
  - Euclid in 3 filters 700 – 2000 nm

- Redshifts best constrained by combining measurements

- Deep Euclid and WFIRST fields can provide photo-z calibration sets.

# Summary

- 2.4m telescope has expanded WFIRST capabilities & increased interest in community and NASA
- WFIRST-2.4m strength is in deep galaxy surveys with high $n_{eff}$ and nP, and a robust supernova program
- WFIRST weak lensing galaxy shape measurement is uniquely in NIR.
- Dark Energy program is allocated 2.5 years in prime mission with 2000 $deg^2$ surveys. Extended mission could greatly increase survey area.
- WFIRST, Euclid and LSST are highly complementary
- Overlapping operations promises great advance in DE understanding

# “Stage IV” – 2020+

| | LSST | Euclid | WFIRST |
|---|---|---|---|
| Area [$deg^2$] | ~12,000 (S Hemisphere) | ~15,000 | 2,000 (in 440 days) |
| Source density $n_{eff}$ [gal $am^{-2}$] | ~30? [15 at Res>0.4] | 33 [Res>0.4, S/N>18, $\sigma_e$<0.2] | 75 [Res>0.4, S/N>18, $\sigma_e$<0.2] |
| Median z | 0.8 | 0.8 | 1.3 |
| Shape measurement filter | r + i | VIS (550—920 nm) | J + H + F184 |
| Detectors | CCD | CCD (e2v) | HgCdTe (H4RG-10) |
| Photo-z filters | 6 (ugrizy) | 4 (VIS + YJH) | 4 (YJH+F184) |
| Location | Ground | Space (L2) | Space (GEO) |
| PSF half light radius | ~0.39” (median) | 0.13” | 0.12” |
| Exposures in filled shape survey | ~700× 15 s (r+i) | 3× 600 s | 16× 184 s (6+5+5) |

*Number densities based on the COSMOS Mock Catalog – S. Jouvel et al (2009)*