Euclid & WFIRST:

Dark Energy & Cosmic Acceleration

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1. **Euclid is a dark energy mission.**
2. **WFIRST is** *not* **a dark energy mission.**
3. **WFIRST is nonetheless a better dark energy mission than Euclid.**
4. **WFIRST will also do many other things.**

Euclid main scientific objectives

- Understand the origin of the Universe's accelerating expansion and
- Probe the properties and nature of dark energy, dark matter, gravity
  - from the measurement of the cosmic expansion history and the growth rate of structures.

- Distinguish their effects decisively by:
  - Using at least 2 independent but complementary probes
  - Tracking their observational signatures on the
    - geometry of the universe: Weak Lensing (WL) and Galaxy Clustering (GC)
    - cosmic history of structure formation: WL, Redshift-Space Distortion, clusters of galaxies
  - Controling systematic residuals to an unprecedented level of accuracy.

The Euclid Mission: imaging, photometry, spectroscopy

Euclid Consortium

SURVEYS

	Area (deg2)	Description
Wide Survey	**15,000 deg^2**	Step and stare with 4 dither pointings per step.
Deep Survey	40	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey

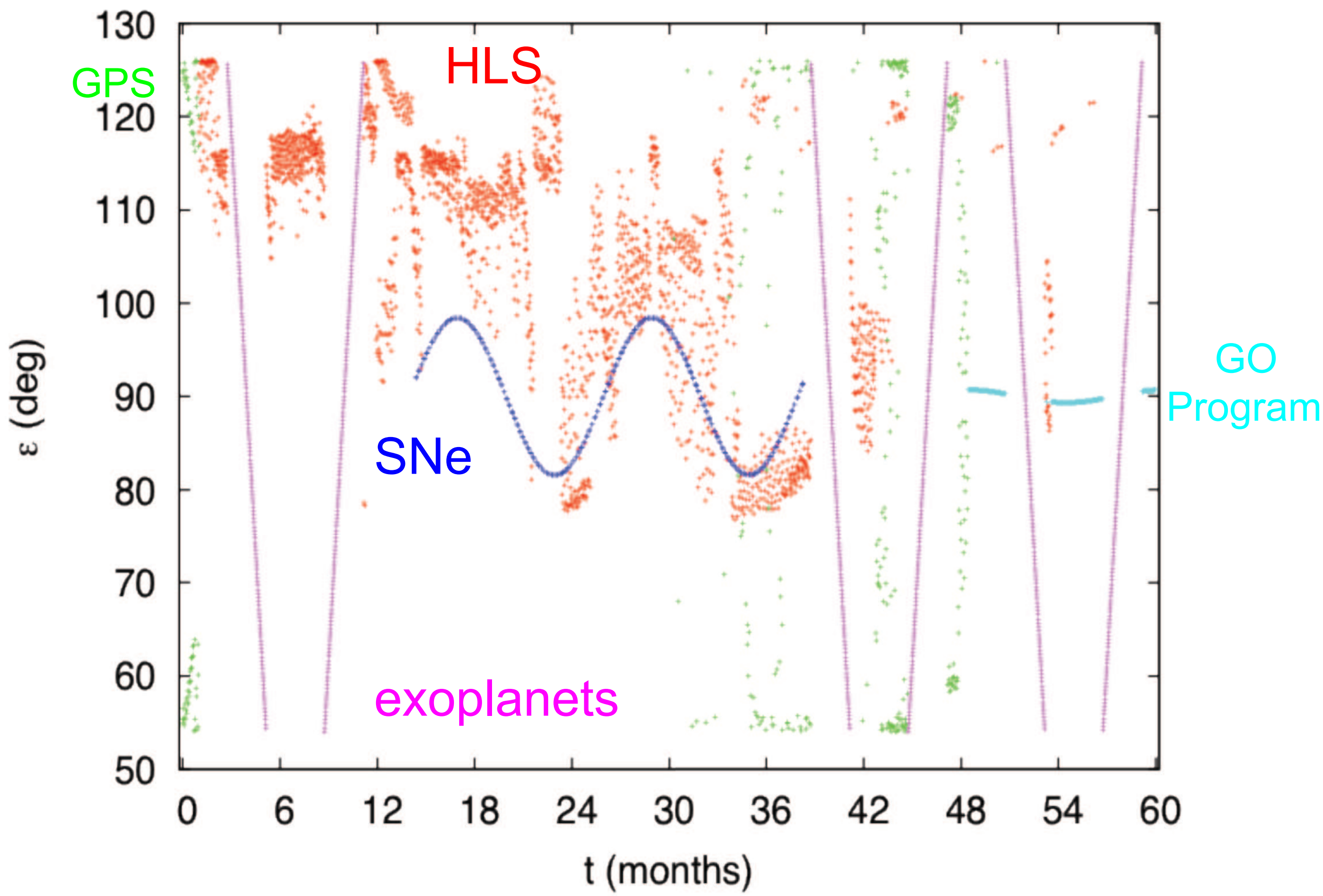
PAYLOAD

Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of $2x10^9$ galaxies			**z of $5x10^7$ galaxies**	
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

Survey Strategies

Example DRM1 Observing Plan

The horizontal axis shows time *t* from the start of observations, and the vertical axis shows the angle between the line of sight and the Sun



WFIRST Science Program

Complete the statistical census of planetary systems in the Galaxy
Determine the expansion history of the Universe and the growth history its largest structures
Perform a deep NIR survey of the Galactic and extra-Galactic sky
Execute a General Observer Program

Baseline Survey Characteristics[1]

Survey	Bandpass	Area (deg^2)	Depth[2]	Duration	Cadence
Exoplanet Microlensing	Y,W	3.38	n/a	1.2 years (72 days x 6)	W:15 min Y:12 hrs
Galactic Plane	Y,J,H,K	1240	25.1	0.45 years	n/a
High Latitude Survey (HLS)[3]	Y,J,H,K	3400	26.0	2.4 years	n/a
	GRS Prism	3400	1.0×10^{-16}		n/a
Supernova (SN) Survey	J,H,K	6.5 / 1.8 (wide/deep)	28.1 / 29.6	0.45 years (in 1.8 year interval)	5 days
	SNe Prism		27.6 / 28.5		

Payload

Telescope	Aperture	Form	Focal Ratio	Plate Scale
	1.3m	Unobstructed TMA	15.9	0.18”/pixel

Focal Plane	Detectors	Layout	Detector Cutoff	Active area
	HgCdTe H2RG	9x4 [150 Mpix]	2.5 μm	0.375 deg^2

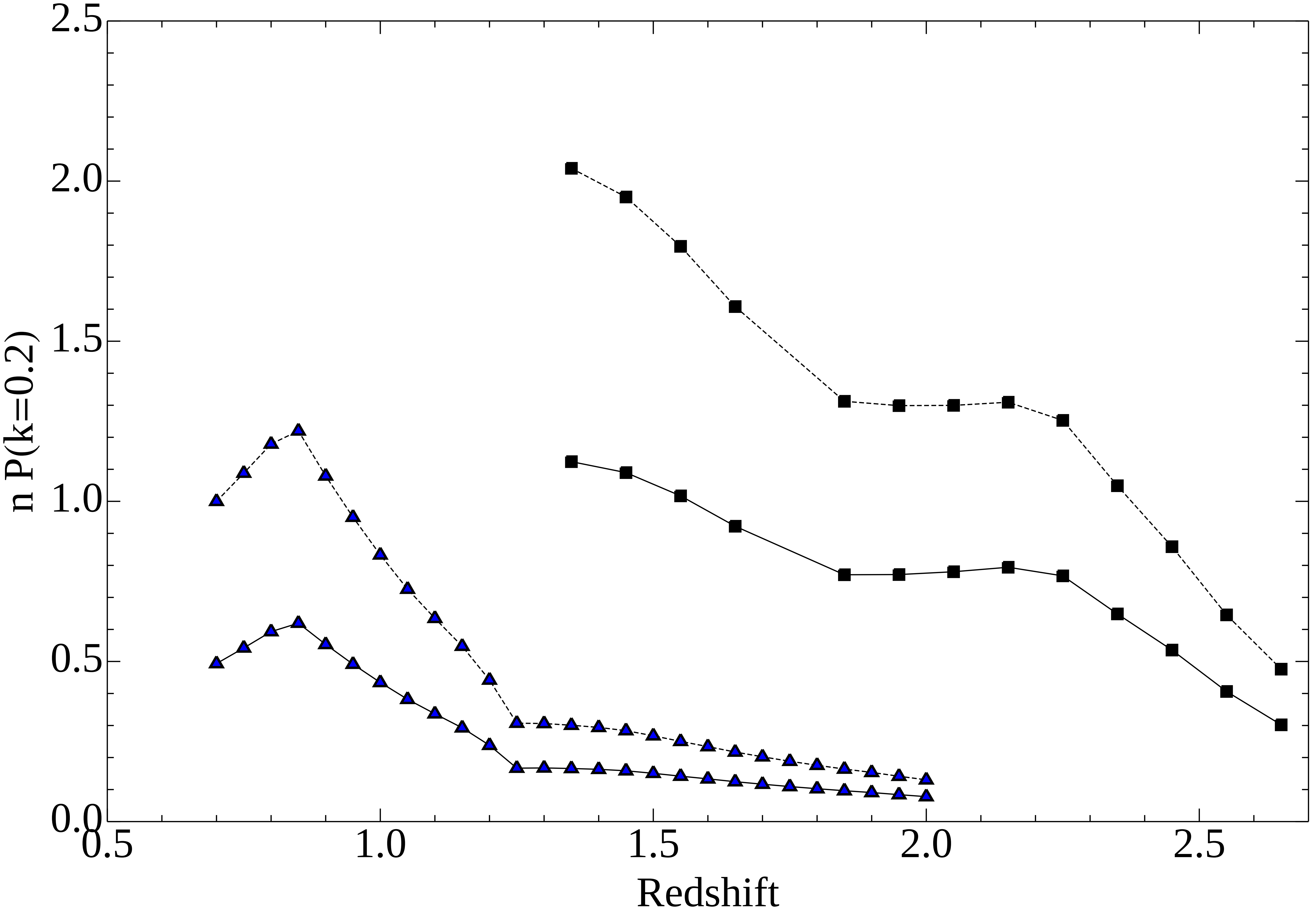
Filters (μm)	Z	Y	J	H	K	W
	0.73-0.962	0.92-1.21	1.156-1.52	1.453-1.91	1.826-2.4	0.92-2.40

Prisms[4]	SN Ia		Galaxy Redshift Survey (GRS)	
	R=75	0.6-2.0 μm	R=600	1.5-2.4 μm

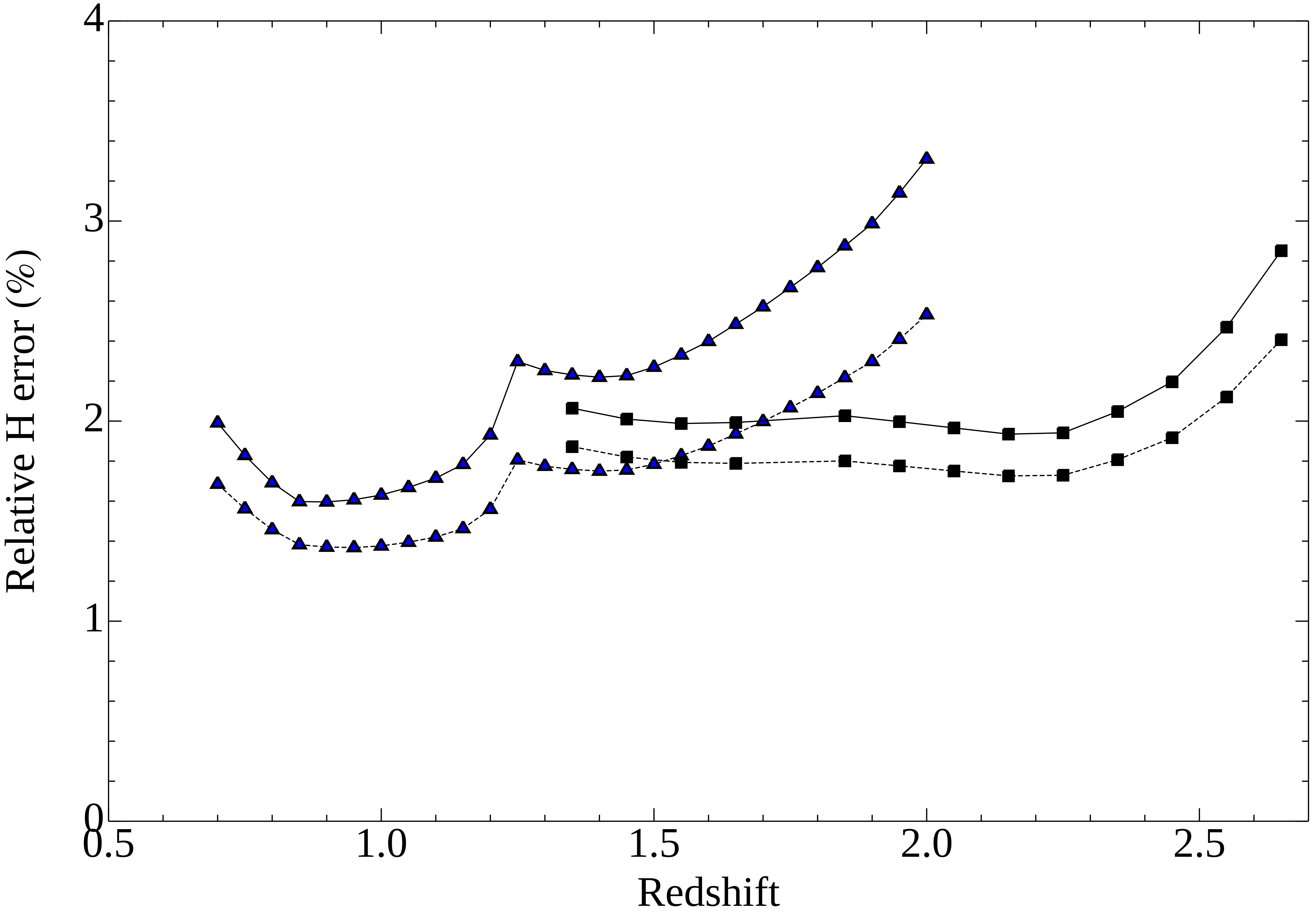
WFIRST: WHAT IT *IS*

A Wide-Field Infrared Survey Telescope

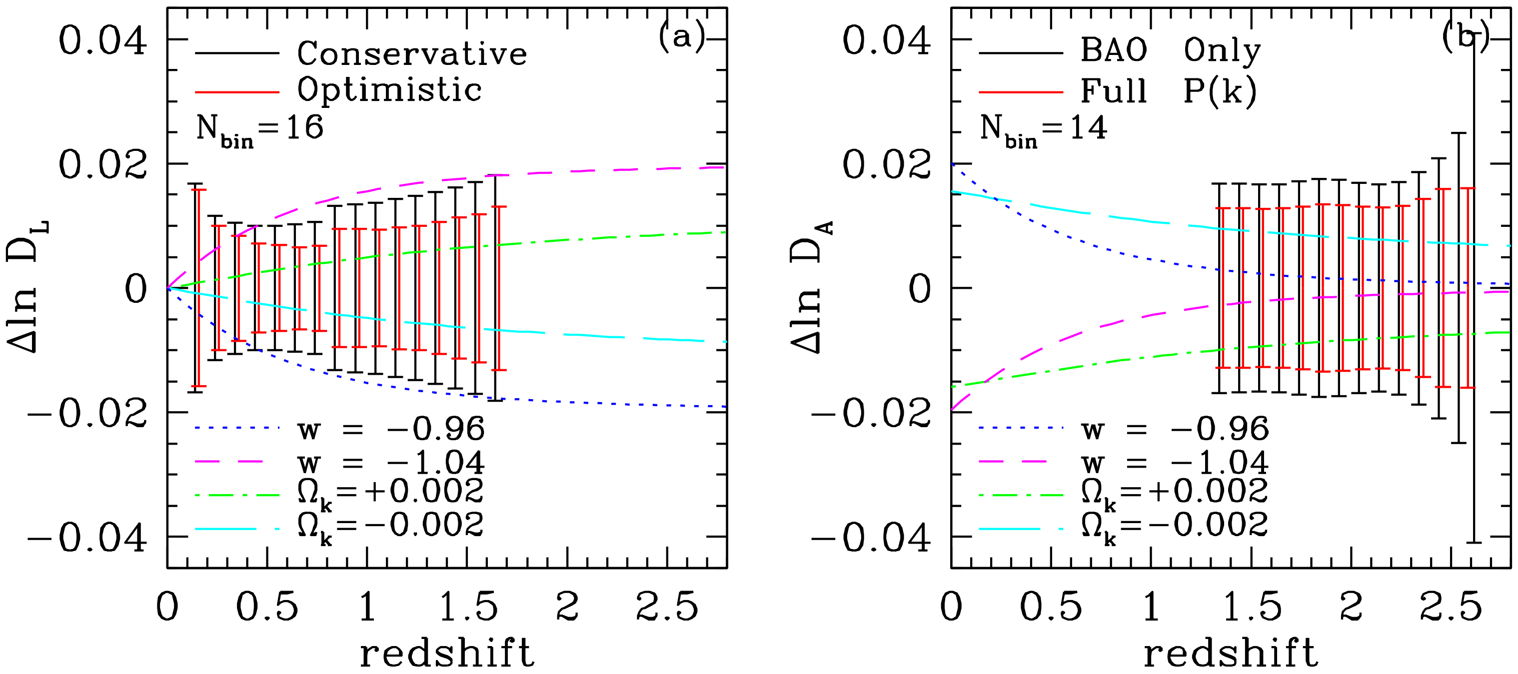
imager to 2.4 μm with 2×10^8 HgCdTe pixels
a 205K unobstructed *three* mirror anastigmat
slitless spectrometer: $R = 75$ & $R = \frac{200''}{\theta_{FWHM}}$



2.5
2.0
1.5
1.0
0.5
0.0
n P(k=0.2)
0.5
1.0
1.5
2.0
2.5
Redshift



0
1
2
3
4
Relative H error (%)
0.5
1.0
1.5
2.0
2.5
Redshift



(a)
Conservative
Optimistic
$N_{bin}=16$
w = −0.96
w = −1.04
Ω_k=+0.002
Ω_k=−0.002
$\Delta \ln D_L$
redshift
(b)
BAO Only
Full P(k)
$N_{bin}=14$
w = −0.96
w = −1.04
Ω_k=+0.002
Ω_k=−0.002
$\Delta \ln D_A$
redshift

$$\left(\begin{array}{c} \textbf{uncertainty in local} \\ \textbf{mean image ellipticity} \end{array} \right) < \mathbf{0.0005}$$

This is really hard.

- Currently, can barely control systematics with smaller datasets.
  - Some of the big recent surveys are statistics-limited at N_{gal} ~ few M … with years of effort.
- Need to measure shear with really small biases:
  - Typical specification is on c,m where: $\boldsymbol{\gamma_{meas} = (1+m)\gamma_{true} + c}$
- For Stage IV: need $c \sim 2\times10^{-4}$, $m \sim 10^{-3}$.
  - So far the community's big problem has been additive bias (c)
  - But as we go to larger area, m is just as hard
    - Has to be calibrated from simulations
  - Requirement[c] ~ $\mathbf{Area}^{-1/4}$ but Requirement[m] ~ $\mathbf{Area}^{-1/2}$
- Cross correlations of data sets: A×B
  - If the systematics are independent, can suppress additive systematics
    - A **very** powerful technique!
    - But beware of subtle correlations (used same PSF stars, photo-z's, etc.)
  - The multiplicative systematics remain
    - The "effective" m is $(m_A+m_B)/2$.

Euclid

- Advantages
  - Large sky coverage
  - Lots of galaxies – $N_{gal,eff} = 1.8\times10^9$
    - Past Fisher studies found total $N_{gal,eff}$ ($=n_{eff}A$) as the most important term
  - Highest resolution
  - PSF from space platform with small number of dynamic DOFs
- Disadvantages
  - Constructs only 1 shear map
    - No cross correlations, or comparison of auto correlations
    - Euclid × (anything else) does not provide check of multiplicative biases
    - Color corrections are large and have to be treated statistically
  - Low redundancy in observing strategy
    - Expect ~40% of galaxies to be “lost” to cosmic rays (get ≤2 clean exposures)
    - Lack of roll, small step dither are not ideal for internal calibration
  - Charge transfer inefficiency (generic space CCD issue)

WFIRST

- Advantages
  - 3 high resolution shape filters
    - Enables a suite of cross checks (auto vs cross, etc)
    - Color corrections implementable on every galaxy
  - Redundant passes within each filter
    - Enable internal null tests and embed relative calibration measurements in the science data itself
  - Unobstructed telescope
    - Simpler, more compact, less chromatic PSF – e.g. no diffraction spikes
    - Enables small PSF in NIR where galaxies are bright
  - PSF from space platform with small number of dynamic DOFs
- Disadvantages
  - Small area – only 3400 deg^2 (DRM1) or 2400 deg^2 (DRM2)
    - Extended missions could mitigate this
  - HgCdTe detectors exhibit unique effects
    - e.g. persistence, interpixel capacitance, rate dependent nonlinearity

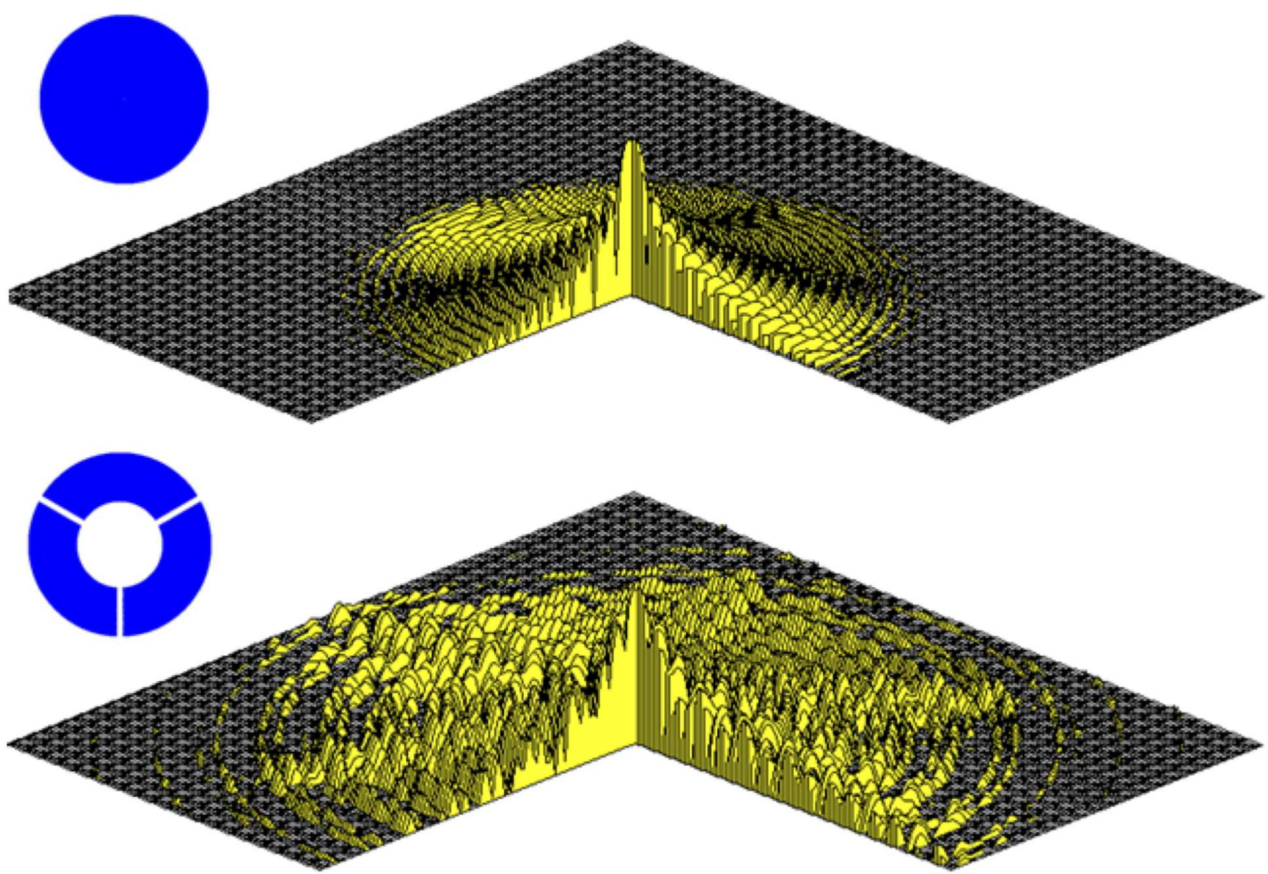


Figure 7: Monochromatic diffraction for unaberrated pupils. Top: an unobscured pupil. Bottom: pupil obscured by a centered 50% linear disk and three spider legs. Pupils are shown at the upper left. Logarithmic vertical scale spans four decades. Fresnel-Kirchoff diffraction assumed.

Kocevski et al. http://www.arxiv.org/pdf/1109.2588

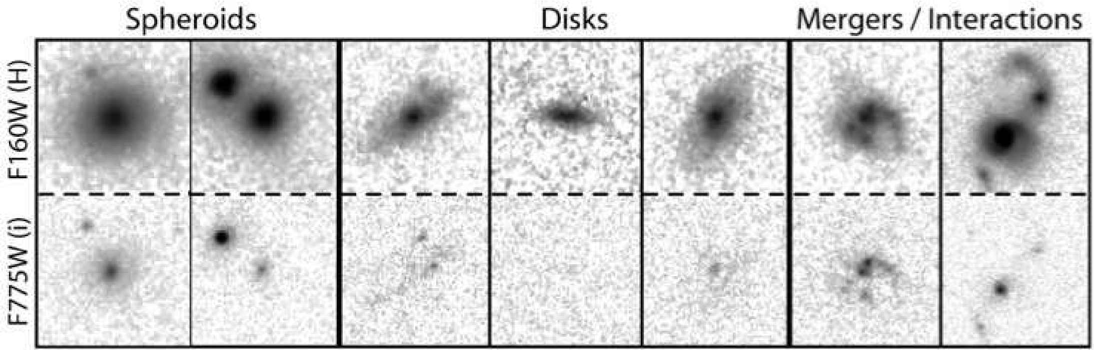
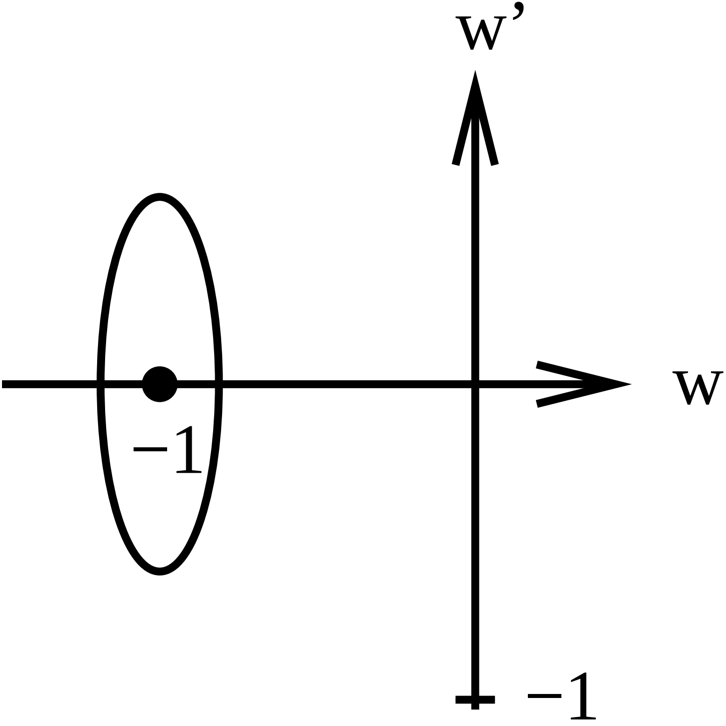


FIG. 3.— Examples of AGN host galaxies that were classified as having spheroid and disk morphologies, as well as two galaxies experiencing disruptive interactions. Thumbnails on the top row are WFC3/IR images taken in the F160W (H) band (rest-frame optical), while those on the bottom row are from ACS/WFC in the F775W (i) band (rest-frame ultraviolet). These images demonstrate that accurately classifying the morphology of these galaxies at $z \sim 2$ requires H-band imaging.

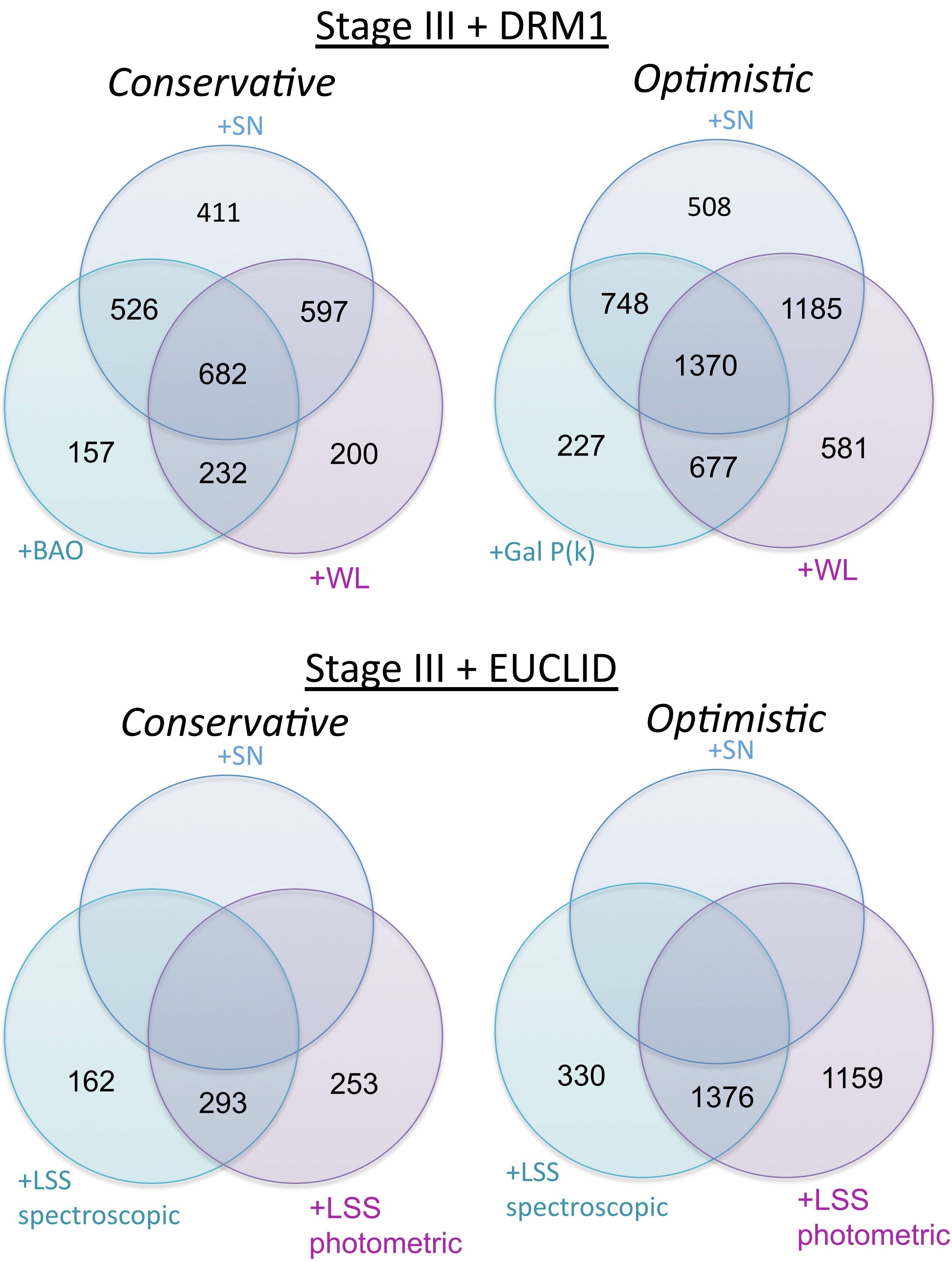
IF general relativity is correct then:

$$H(z)^2 = H_0^2[\underbrace{\Omega_m(1+z)^3}_{\text{matter}} + \underbrace{\Omega_r(1+z)^4}_{\text{radiation}} + \underbrace{\Omega_w(1+z)^{3(1+w)}}_{\text{dark energy}} + \underbrace{\Omega_k(1+z)^2}_{\text{curvature}}],$$

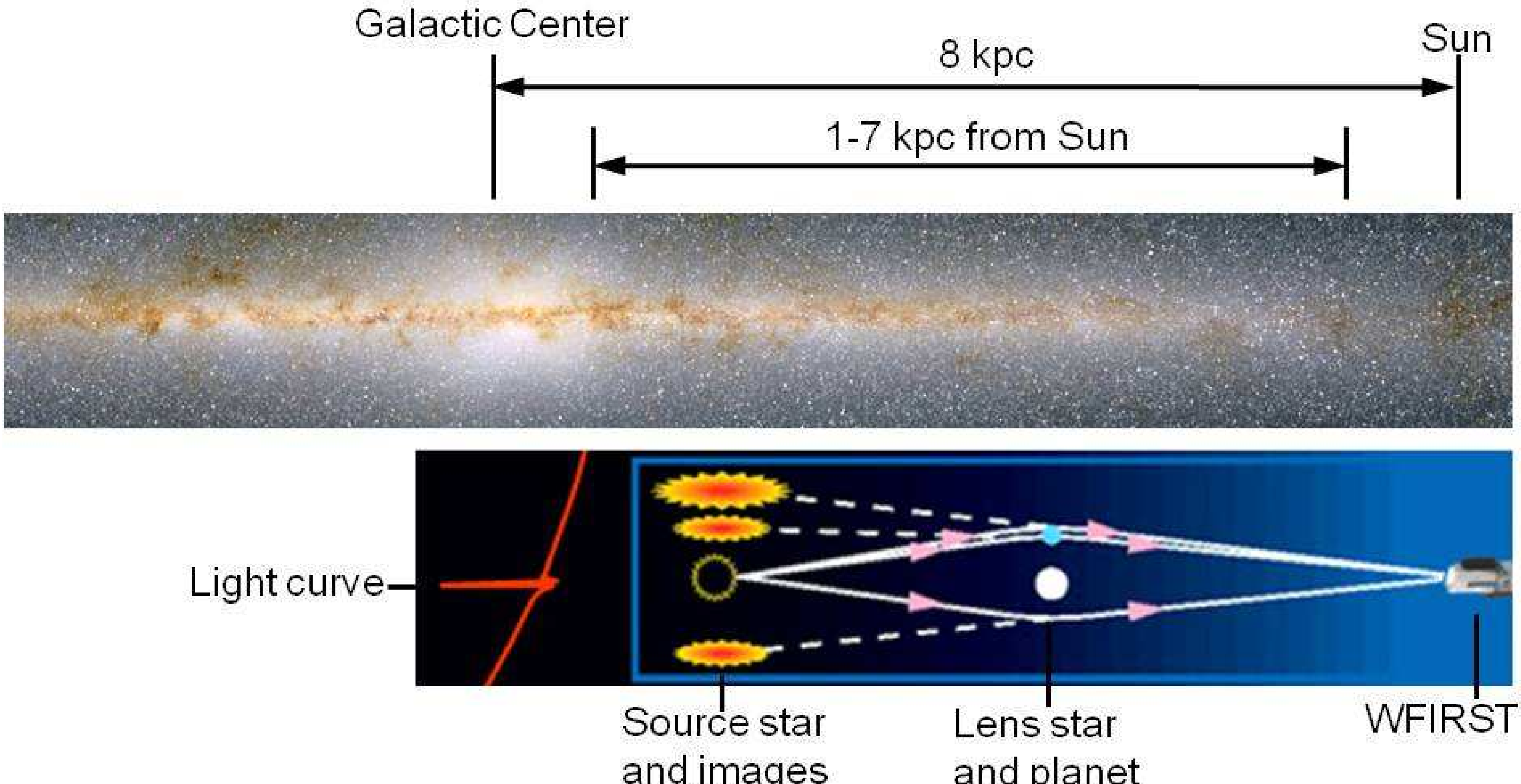
where $w = -1 \Leftrightarrow$ cosmological constant Λ.

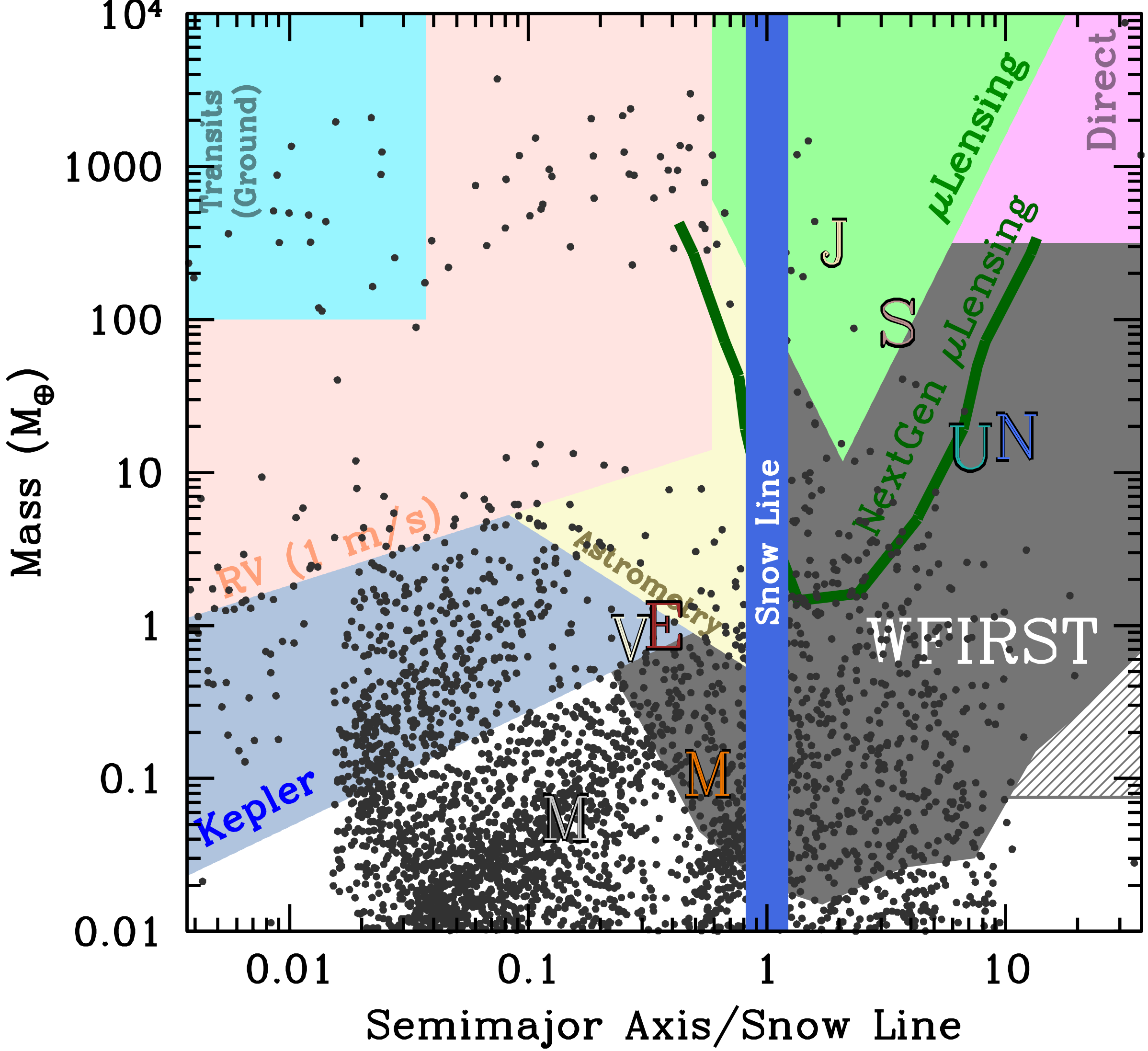


w'
w
−1
−1


Stage III + DRM1
Conservative
+SN
411
526
597
682
157
232
200
+BAO
+WL
Optimistic
+SN
508
748
1185
1370
227
677
581
+Gal P(k)
+WL
Stage III + EUCLID
Conservative
+SN
162
293
253
+LSS spectroscopic
+LSS photometric
Optimistic
+SN
330
1376
1159
+LSS spectroscopic
+LSS photometric

Planetary Microlensing

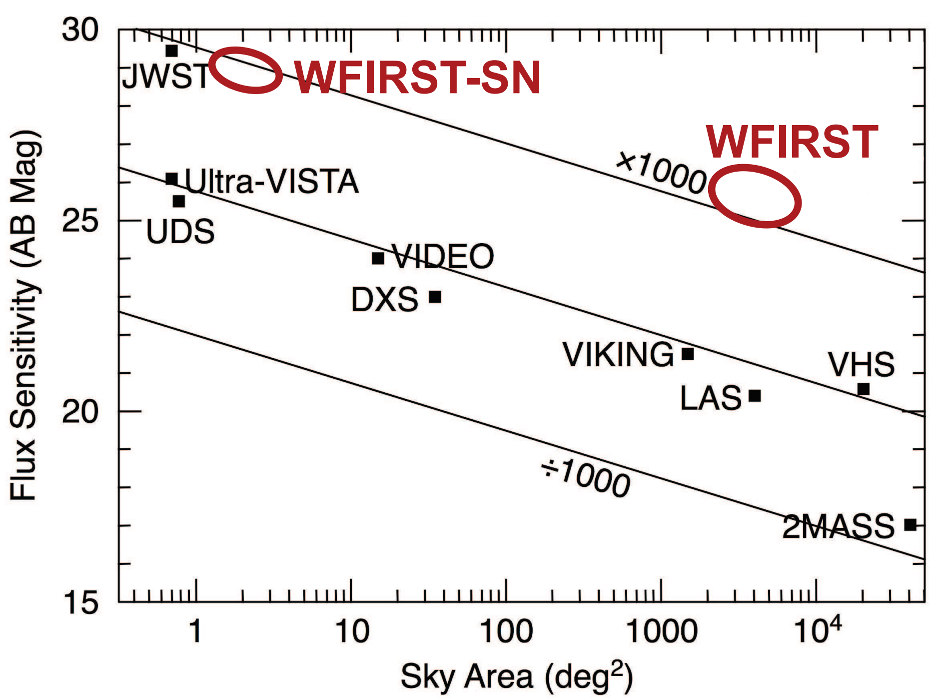




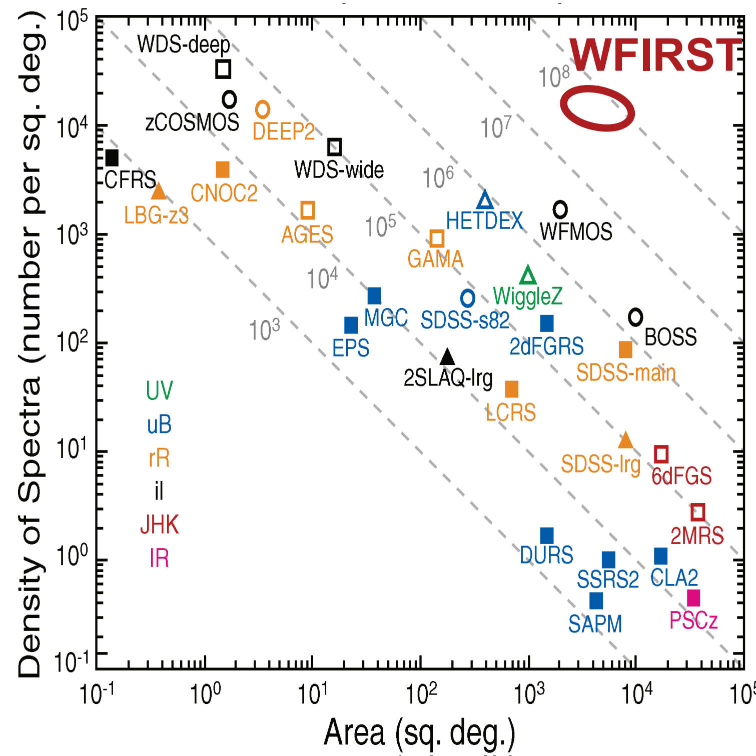
Transits (Ground)
RV (1 m/s)
Kepler
Astrometry
Snow Line
μLensing
NextGen μLensing
Direct
WFIRST
J
S
U
N
V
E
M
M
Mass (M⊕)
Semimajor Axis/Snow Line
10⁴
1000
100
10
1
0.1
0.01
0.01
0.1
1
10

WFIRST NIR Surveys

NIR Imaging Surveys



NIR Redshift Surveys



WFIRST provides a factor of 100 improvement in IR surveys

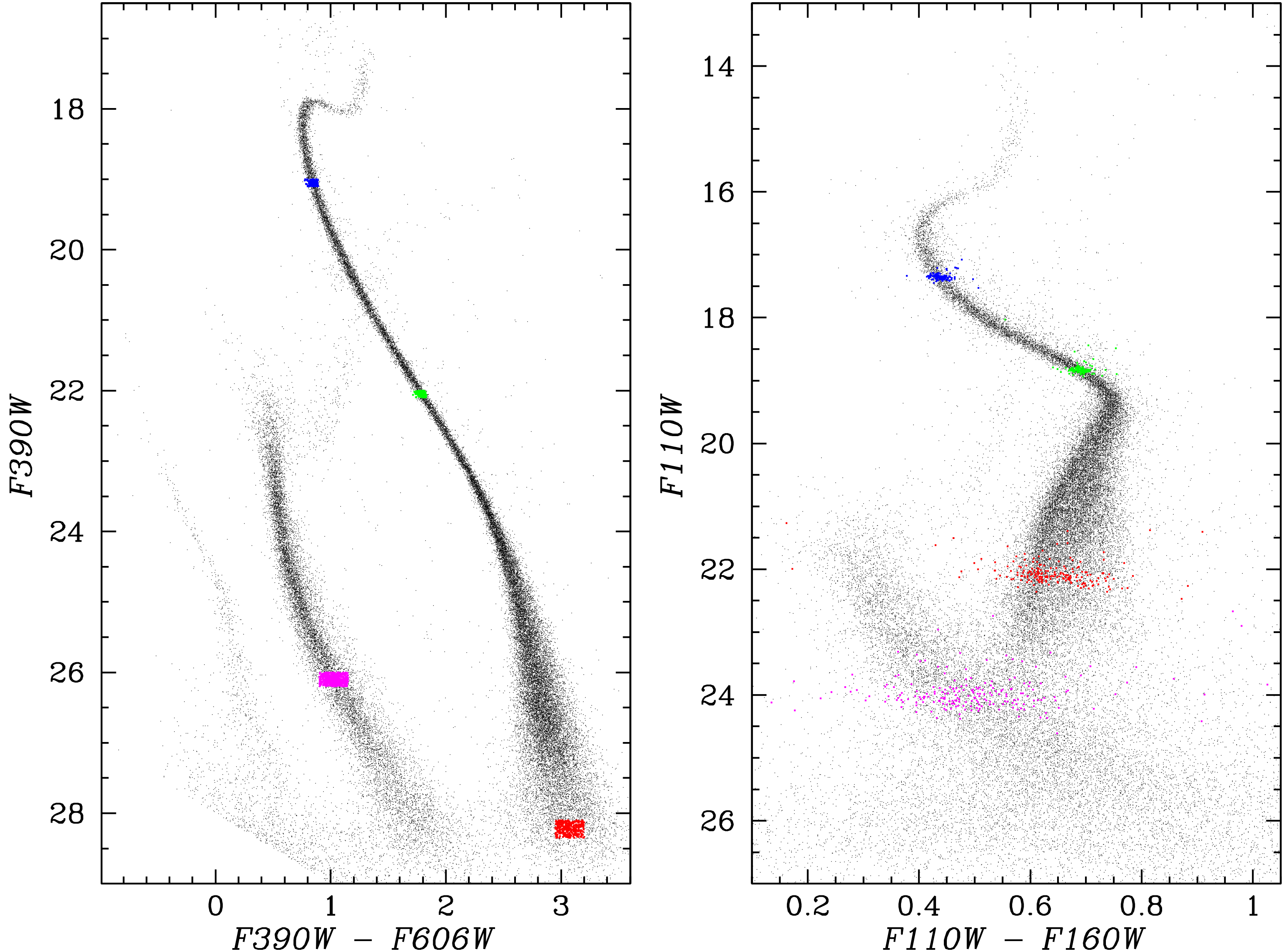
NOTIONAL GENERAL INVESTIGATOR PROGRAMS

Search for Kuiper Belt objects

Open cluster mass functions to $25 M_{Jup}$

Stellar populations in nearby galaxy halos

Lower main sequence in globular clusters


F390W
F390W − F606W
F110W
F110W − F160W
18
20
22
24
26
28
0
1
2
3
14
16
18
20
22
24
26
0.2
0.4
0.6
0.8
1

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