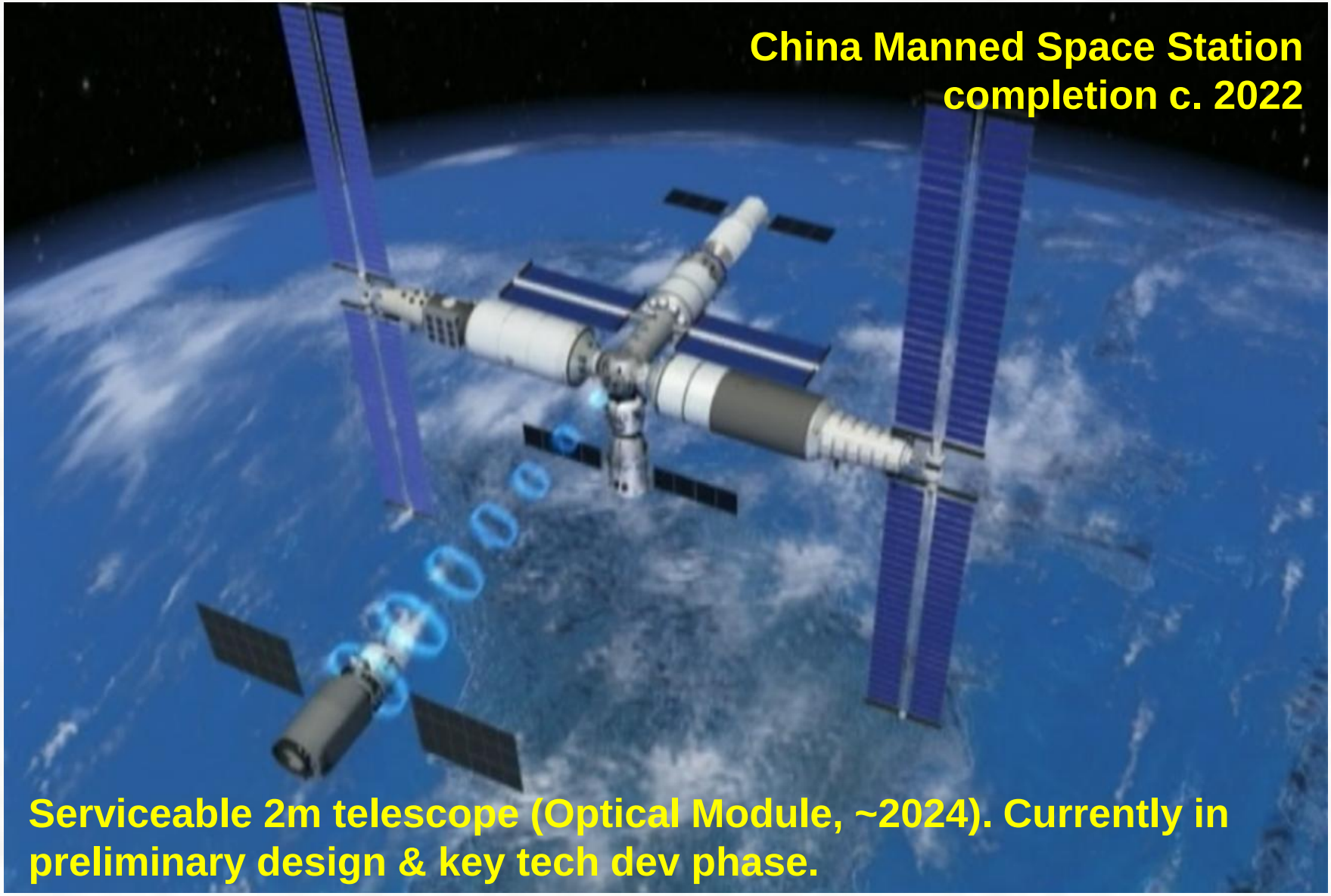
An Overview of the Chinese Space Station Optical Survey

Hu Zhan
National Astronomical Observatories of China
& Peking University

ISSI Program: Weak Gravitational Lensing Studies from Space Missions
Bern, Dec 18, 2018

Optical Module for Survey



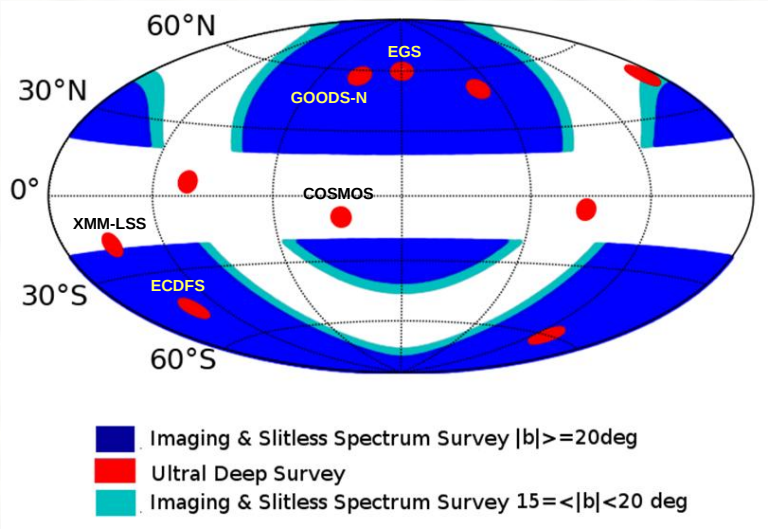
Serviceable 2m telescope (Optical Module, ~2024). Currently in preliminary design & key tech dev phase.

Milestones

- **Science case:** 2009, suggestion of a telescope for astronomy on the Chinese space station (CSS); 4/2010, 1st meeting about astronomy with a large-aperture telescope on the CSS; 12/2010, 1st version of science goals; concept of a large-scale multiband imaging & slitless spectroscopy survey was well received by the CSS Space Application System and by China Manned Space Agency.
- **Telescope:** 2011, feasibility review; 2012, CSS applications selection; 2013, down-selection of design, budget review, & approval; 2014, man-tended free flyer concept; 2015-, preliminary design & technology development.
- **Camera:** 2015, NAOC & IOE design selected; preliminary design & technology development.

Survey Specs

- **17500□° imaging : 255-1000nm, ≥6 filters, avg ≥25.5^{m} (5σ, point source, AB mag);**
- **17500□° slitless spect: 255-1000nm, R≥200, ≥20-21^{m}/res;**
- **400□° deep imaging & spect: at least 1^{m} deeper.**



Ecliptic Coord.

Deep fields will be finalized later; sim results for demo only.

Science

Cosmology: dark energy, dark matter, gravity, large-scale structure, neutrinos, primordial non-Gaussianity…

AGNs: high-z AGNs, clustering, dual AGNs, variability, UV excess, host galaxies…

Galaxies: formation & evolution, mergers, high-zs, dwarfs, LSBs, near field, halos properties…

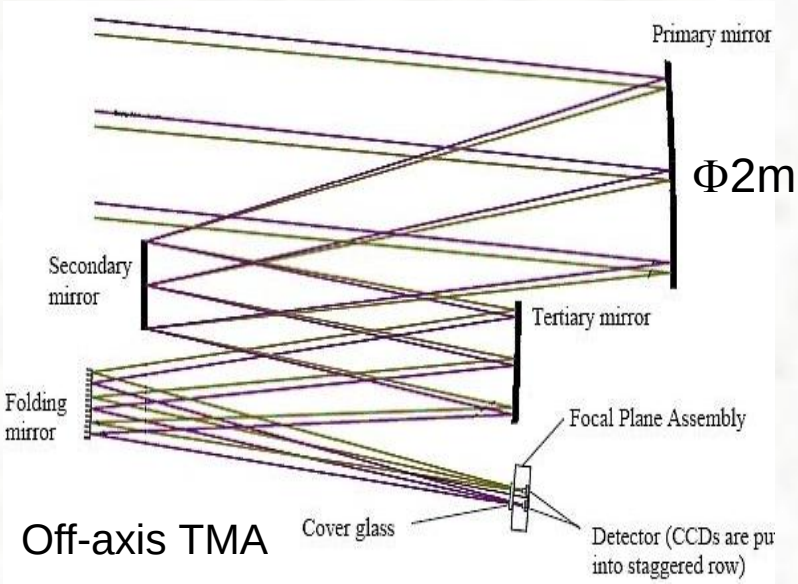
Milky Way: structure, satellites, dust, extinction…

Stellar science: formation, dwarfs, metal poor…

Solar system (high inclination): TNO、NEA…

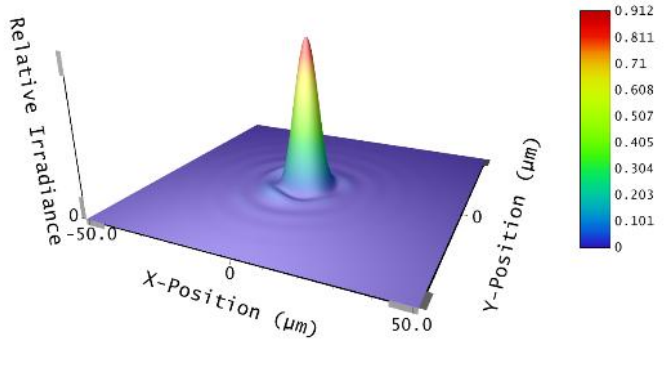
Astrometry: reference frame, star clusters…

Optical Design & Camera



Off-axis TMA

Design PSF @ one corner

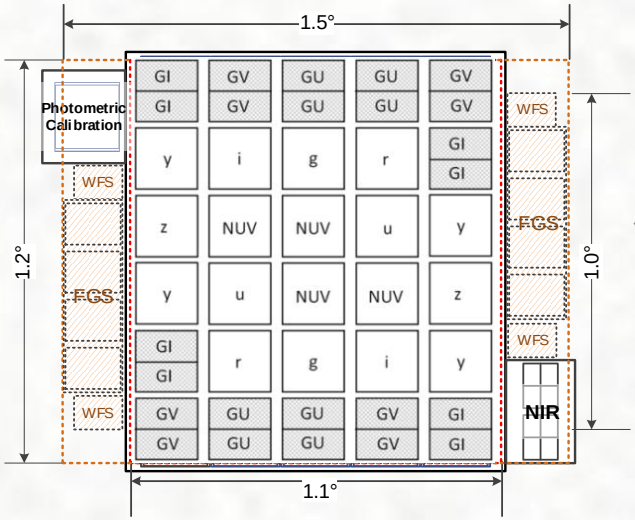


R_{EE80}≤0.15" @ 632.8nm

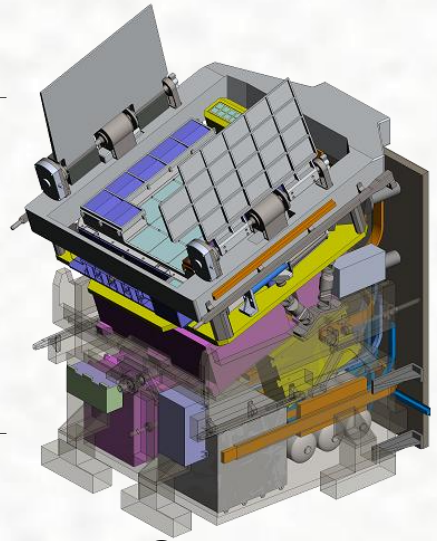
e_{avg}≤0.05, e_{max}≤0.15

Designed PSF

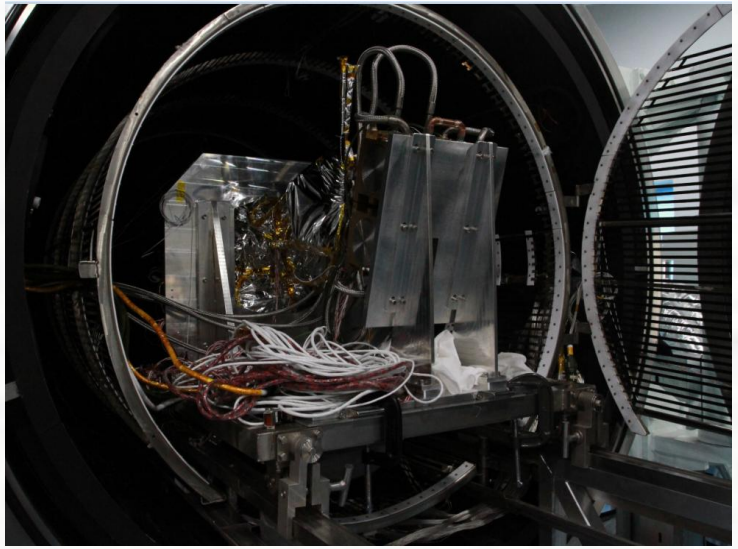
R_{EE80}<0.11" @ 620nm



Central FoV >1.1 sq deg

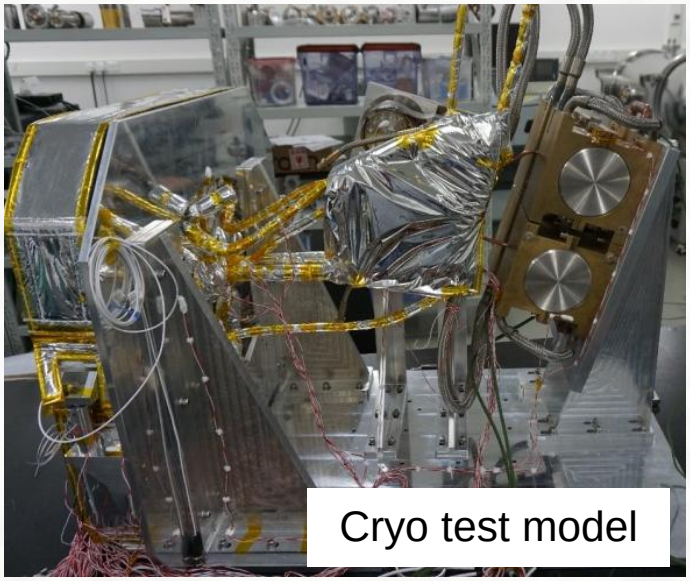


Camera

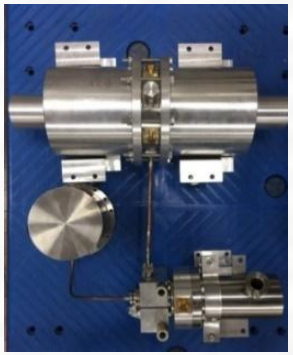


Cryo cooling test

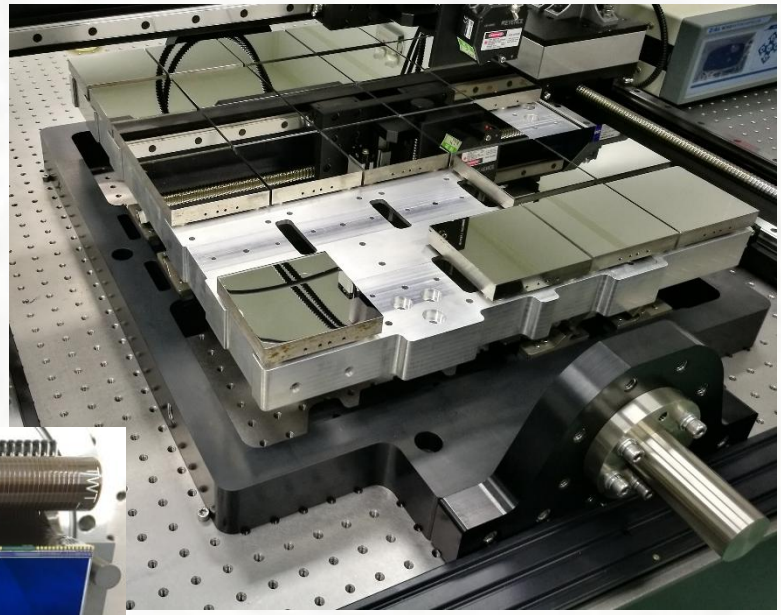
Camera Technology Demonstration



Cryo test model



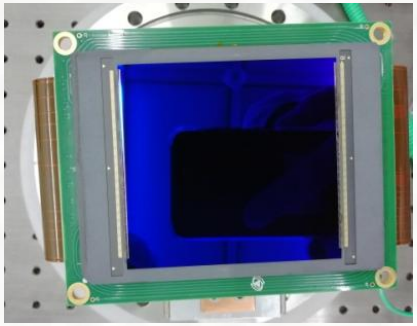
cryocooler



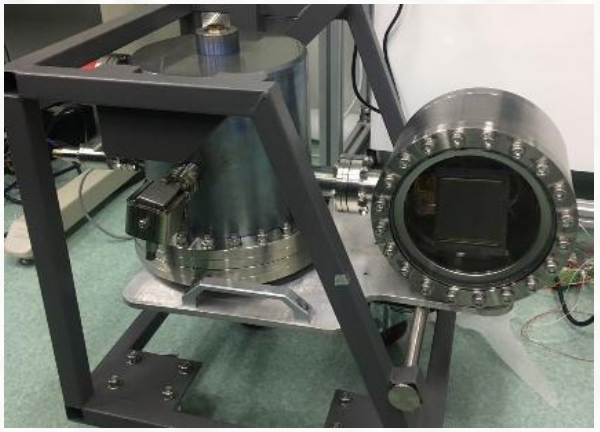
Mock focal plane

4.6k×11k CCD

Shutter (1.5M+ ops)



6k×6k CMOS



Test Dewar

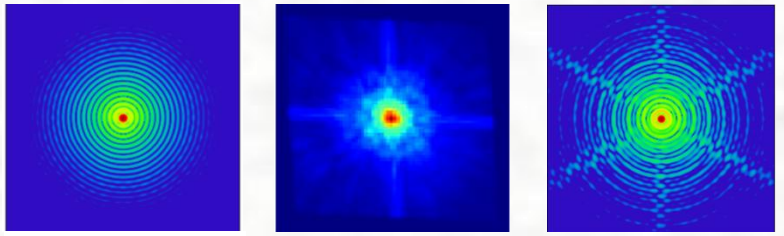
Comparison with Other Surveys

Project	Site/ orbit	Launch /op	FoV	R_{EE80}	Num pixels	Area	Wavelength	Num Filters	Spect
			deg^2	″	10^9	deg^2	nm		
CSS-OS	LEO	~2024	1.1	0.15 0.074/pix	2.5	17500	255—1000	≥6	yes
Euclid	L2	2022	0.56 0.55	>0.2 pix lmt	0.6 0.07	15000	550—920 1000—2000	1 3	no yes
WFIRST	L2	>2025	0.28	>0.2	0.3	~2000	927—2000	4	yes
LSST	Chile	2022	9.6	~0.5	3.2	18000	320—1050	6	no

R_{EE80}: radius encircling 80% energy

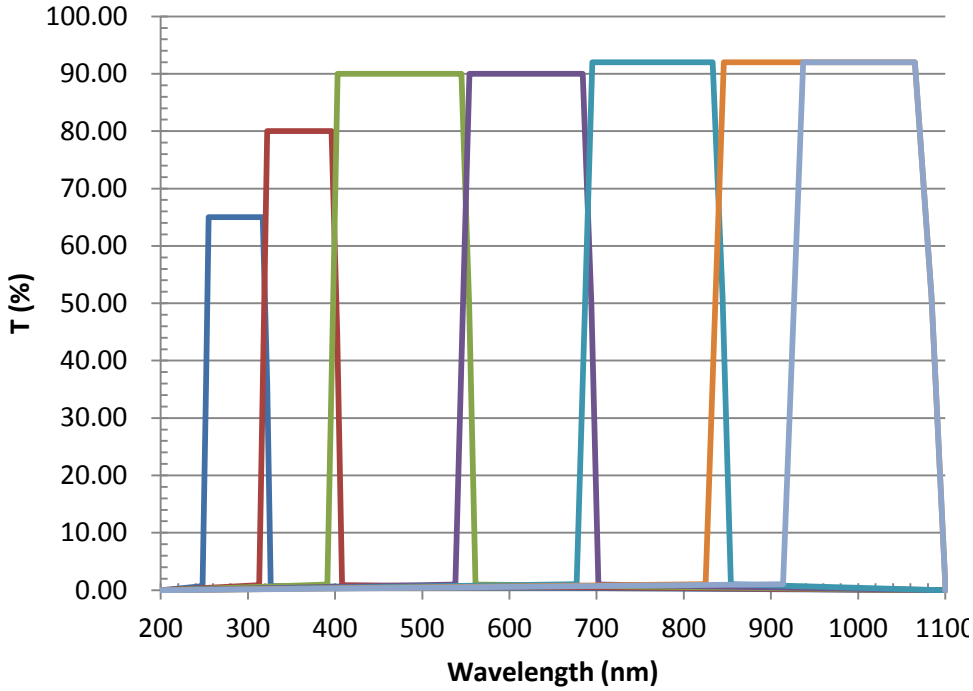
	CSS-OS	HST/ACS WFC	Euclid	WFIRST
R_{EE50}	0.1"	0.06"	0.13"	0.12"
R_{EE80}	0.15"	0.12"	~0.23"	~0.24"

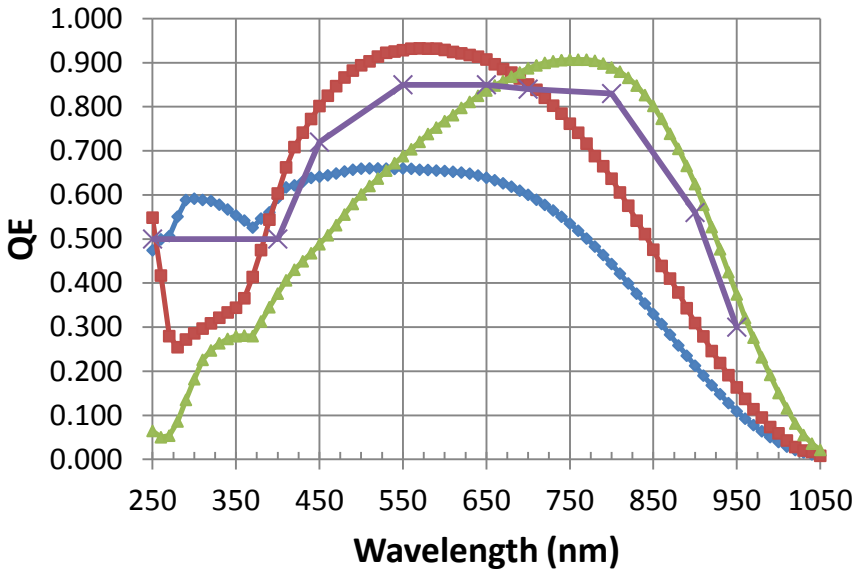
Dynamic sims: R_{EE80} ~0.13”



CSS-OS HST Euclid

Filters & Limiting Mags

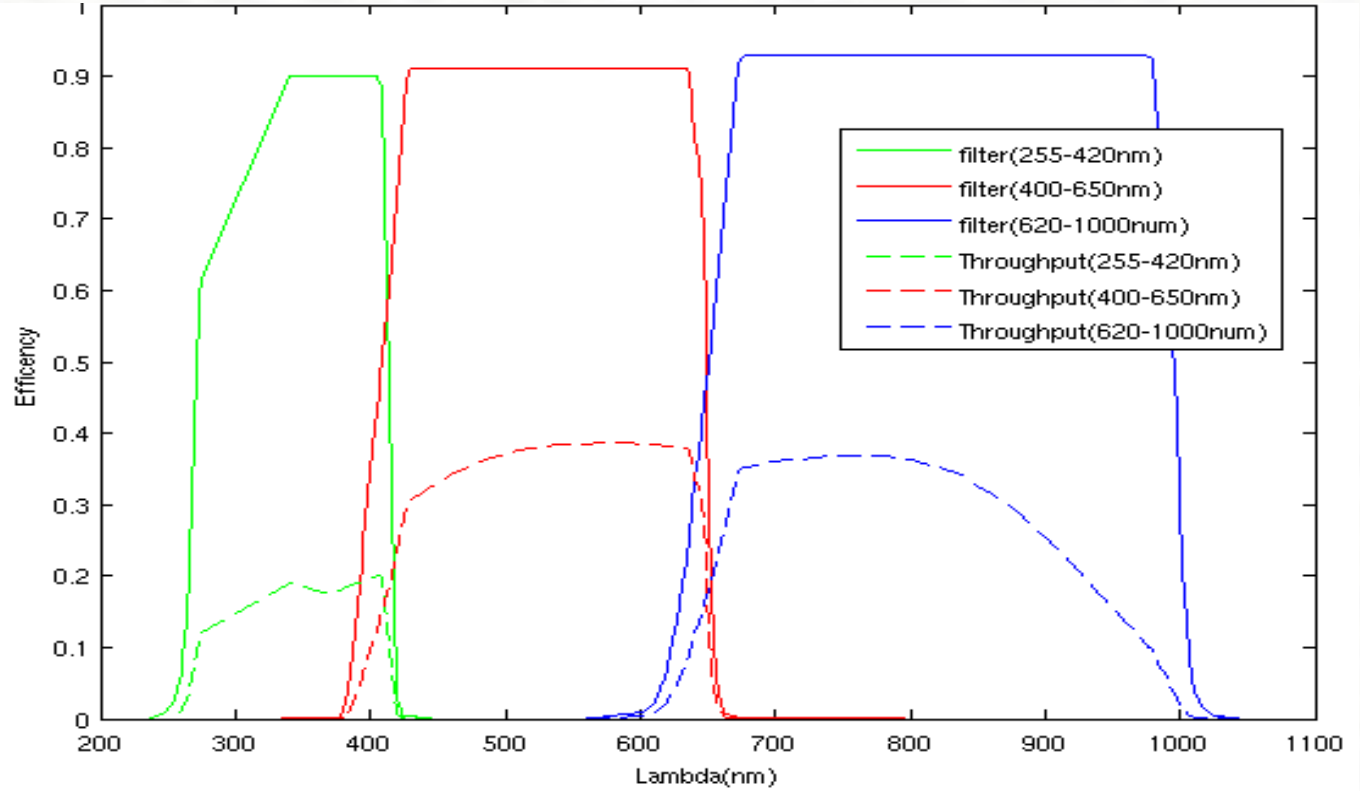




	Exp.	NUV	u	g	r	i	z	y
17500□°	2×150s	25.4	25.4	26.3	26.0	25.9	25.2	24.4
400□°	8×250s	26.7	26.7	27.5	27.2	27.0	26.4	25.7

NUV:u:g:r:i:z:y=2:1:1:1:1:1:2

Gratings & Limiting Mags

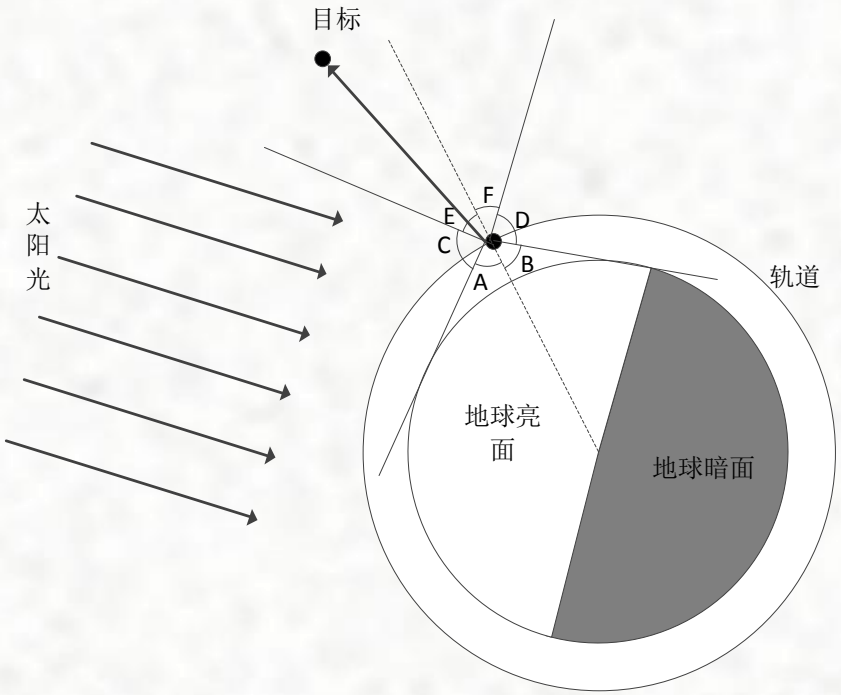


1st order

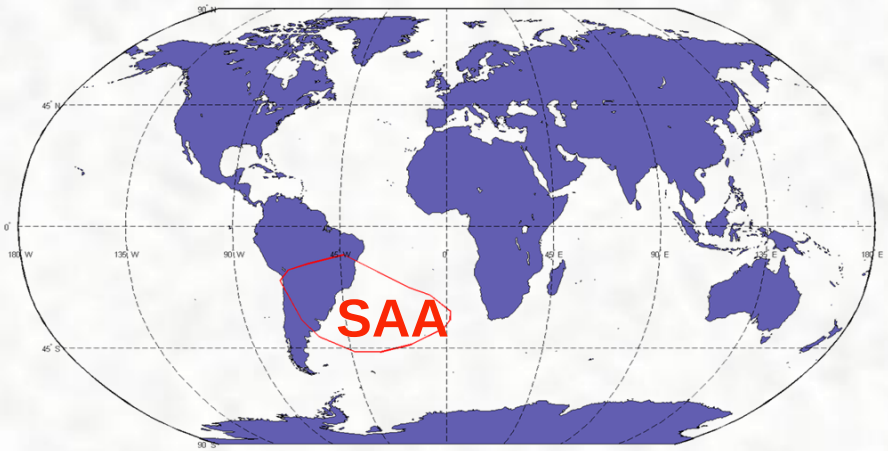
R~250

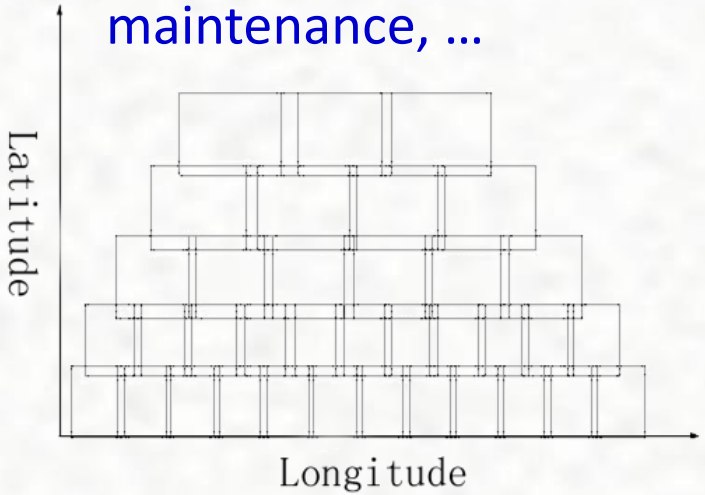
	Exp.	GU (per res)	GV (per res)	GI (per res)
17500□°	4×150s	20.5	21.0	21.0
400□°	16×250s	21.8	22.2	22.1

Operations Conditions

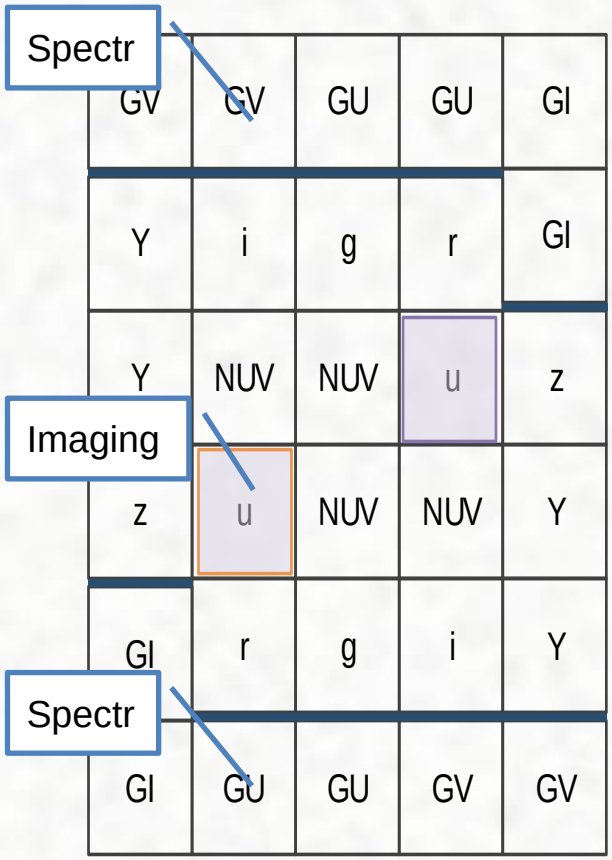


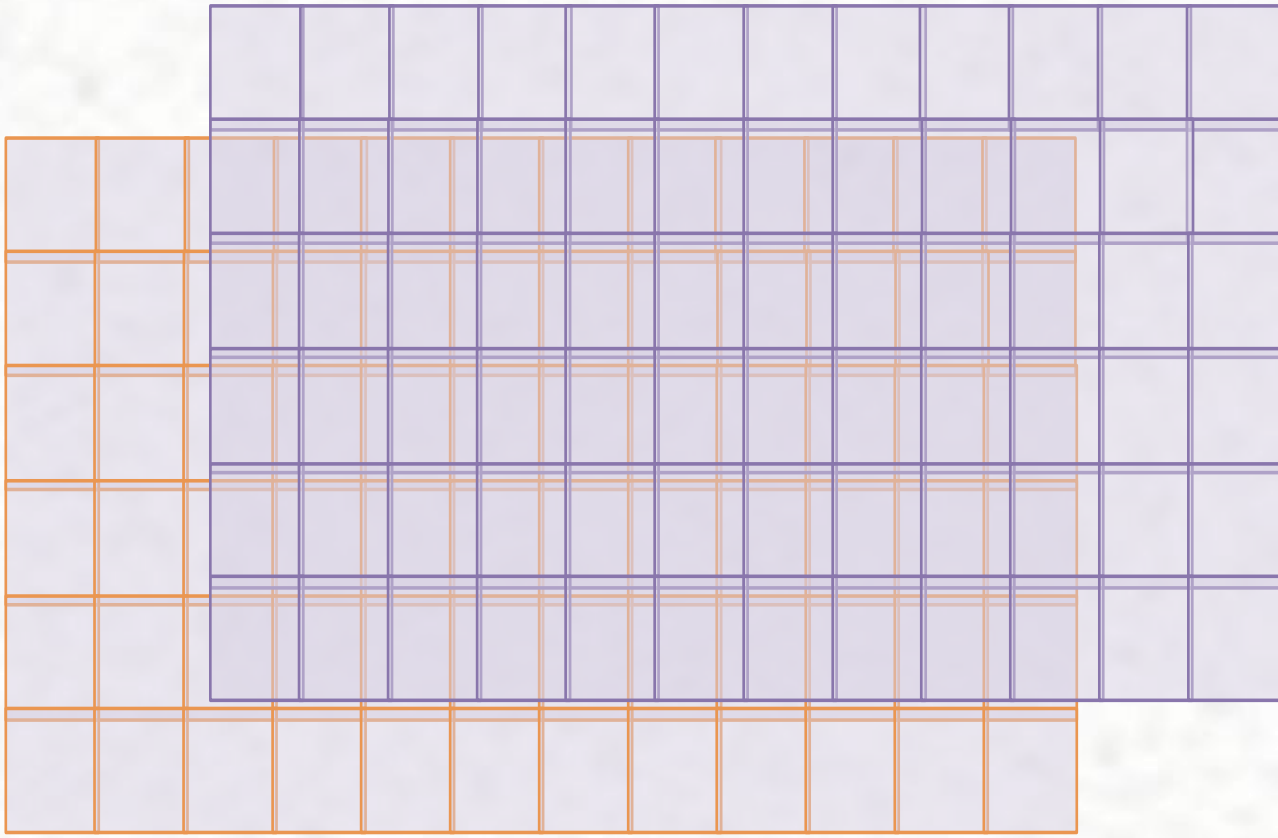
- LOS to Sun ≥50°
- LOS to Moon ≥40°
- LOS to Earth limbs ≥70°/30°
- Field stitching
- Electricity balance
- Slew rate & settling time
- SAA standby, relay tracking, engineering down time, orbital adjust., docking for maintenance, …





Tiling of the Sky

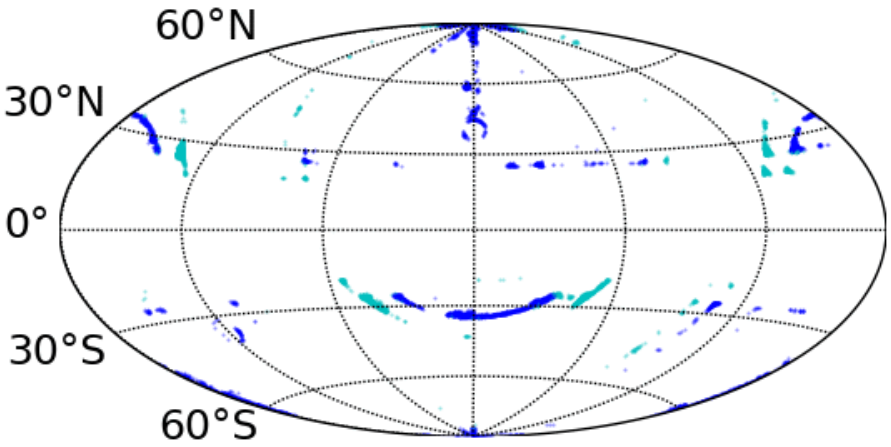


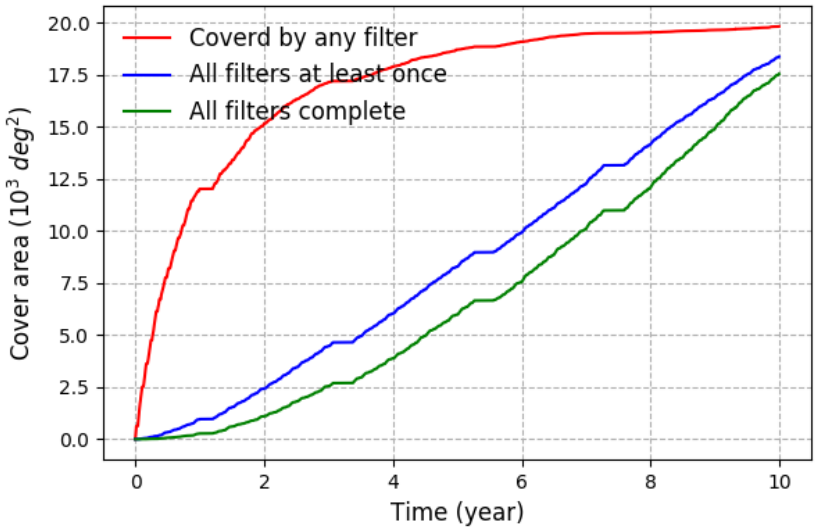


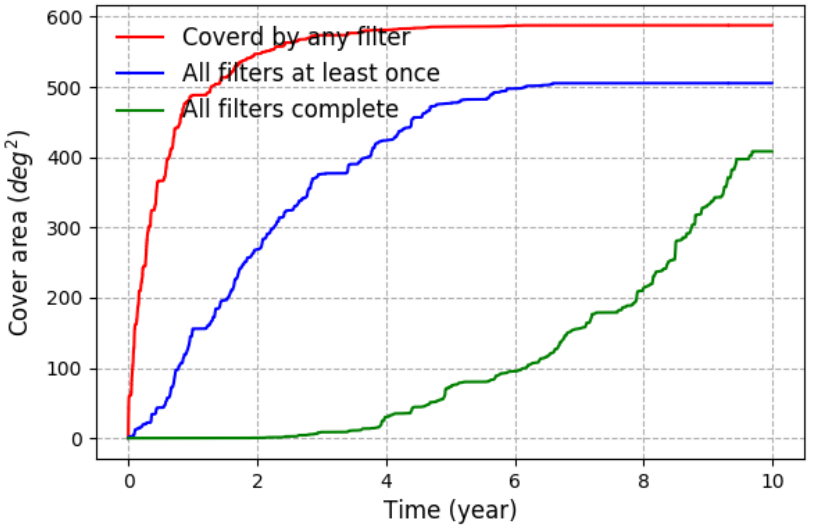
- 10” overlap b/w fields of each chip
- If one chip covers the whole sky, all other chips will also cover the whole sky.
- # of pieces of each type of filters = # of visits

Operations Simulations

Baseline: 63% orbital time for survey





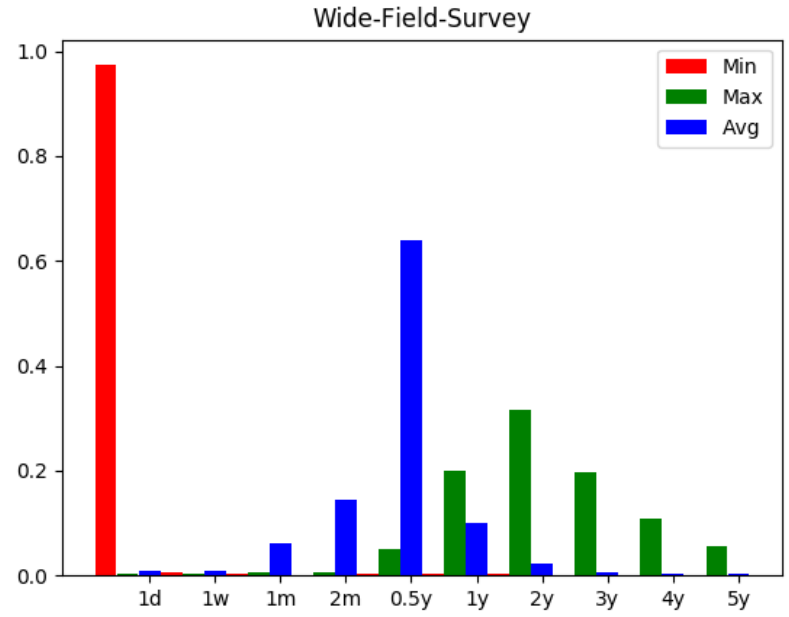


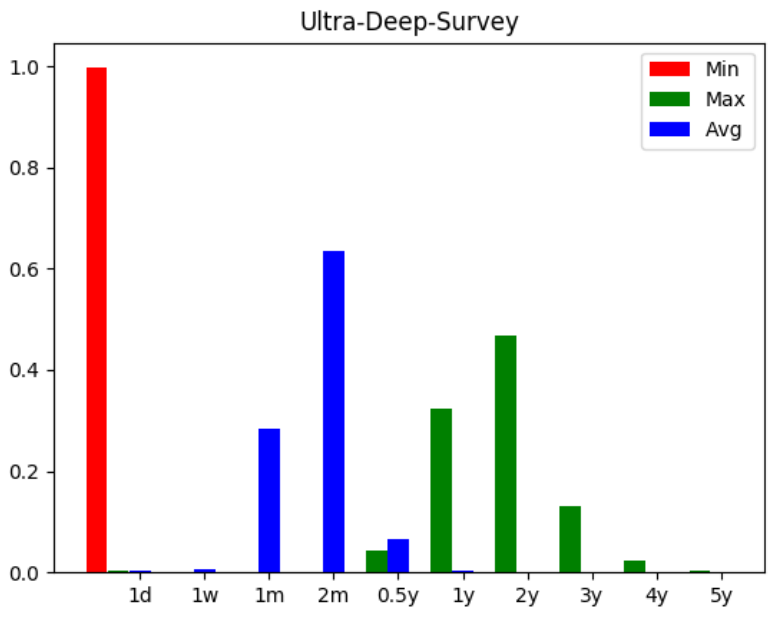
The Galactic plane & ecliptic plane can be observed!

Wide-Field: 17540 deg^2

Ultra-Deep: 408 deg^2

Operations Simulations



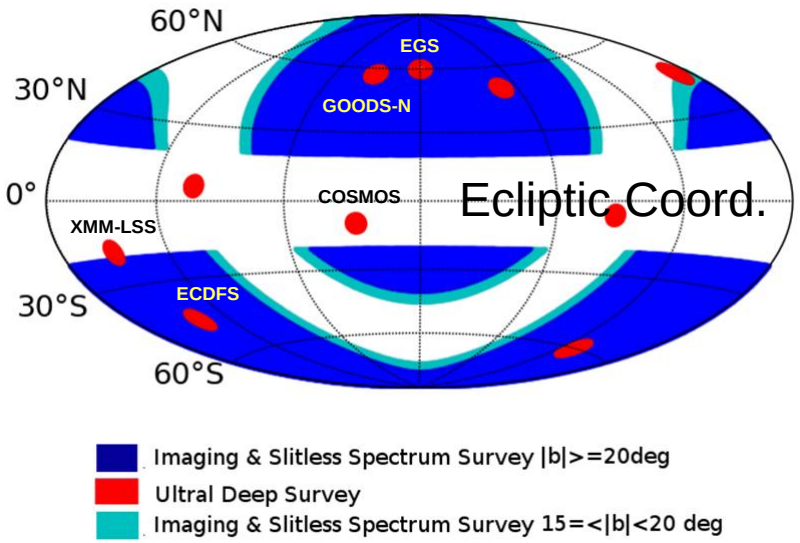


Time between two visits, regardless the filter.

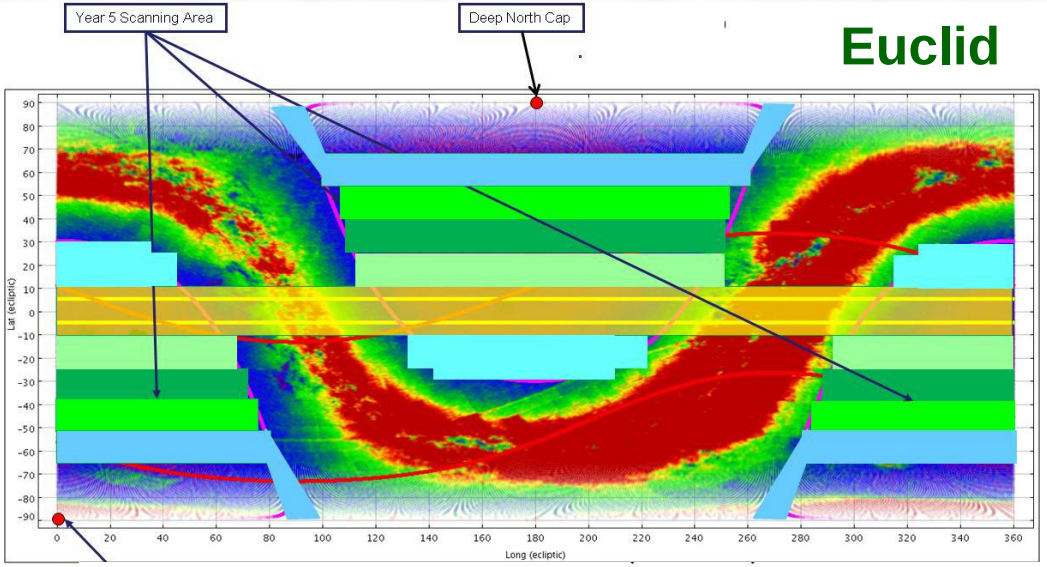
Given that the CSS-OS is an LEO mission for large-area survey, it is difficult to schedule visits at a fixed cadence without impacting the survey efficiency. However, it has some time-domain capability, especially for investigations that are insensitive to color.

Complementary Observations

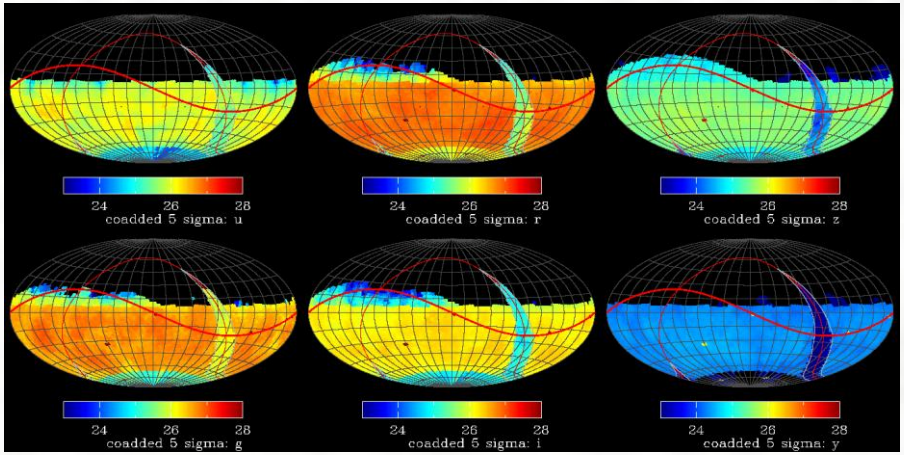
CSS-OS

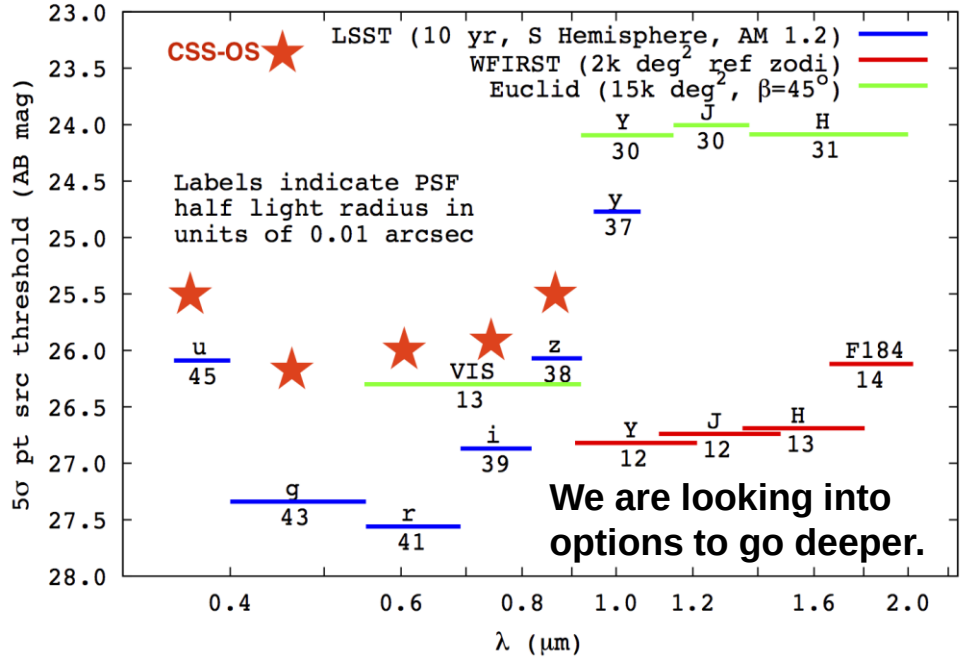


Euclid

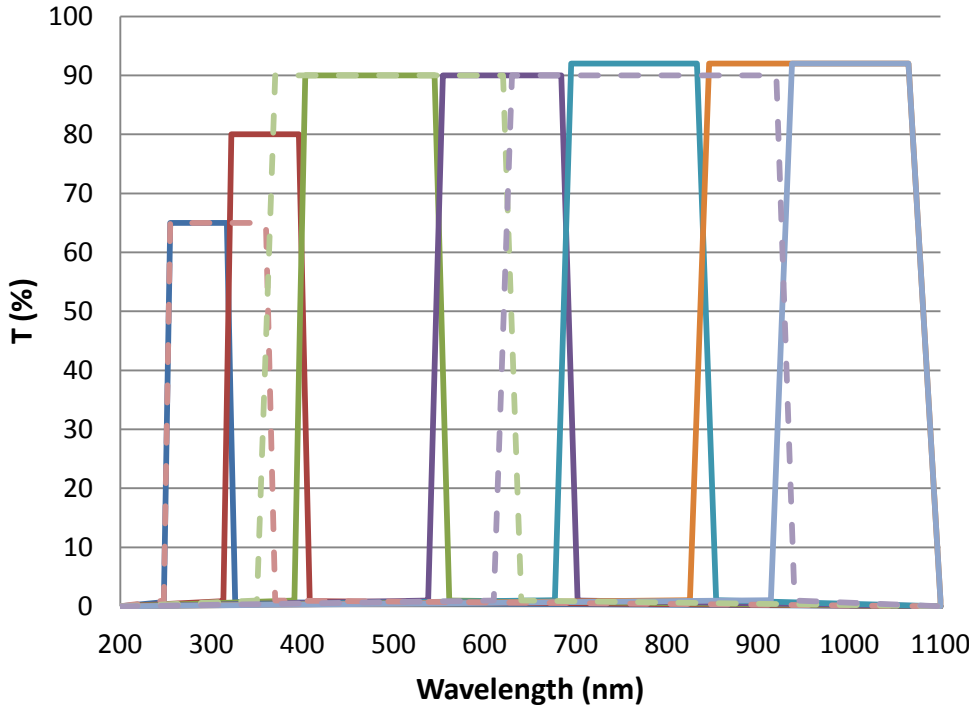


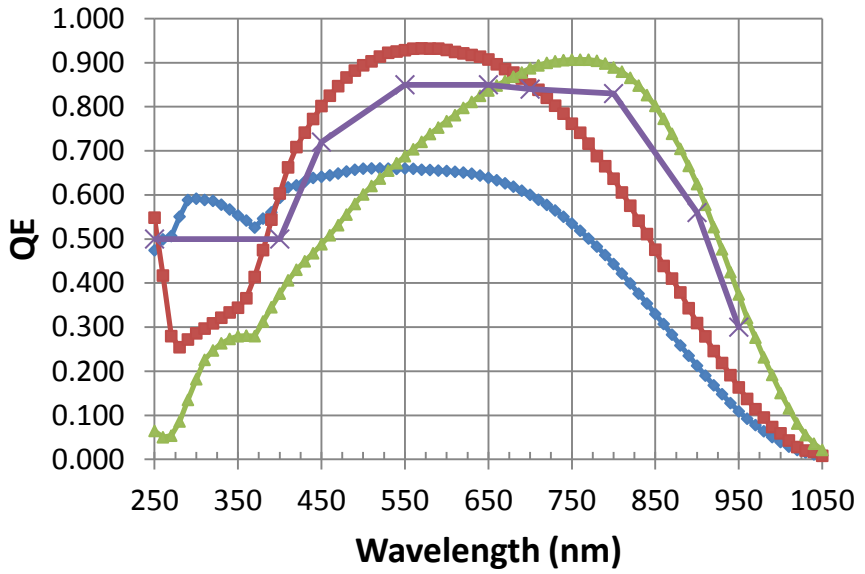
LSST





New Study of Filter Trade-offs

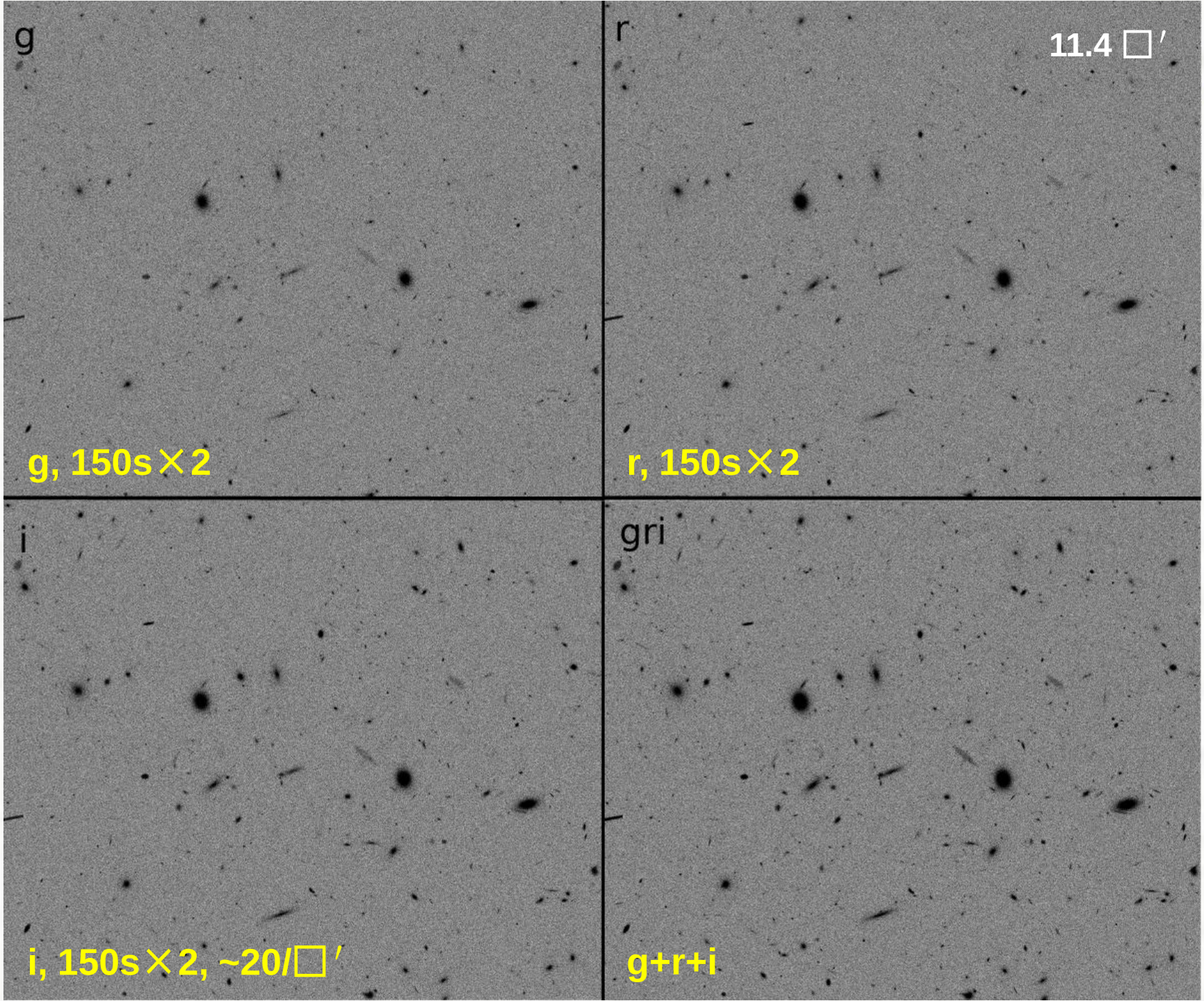




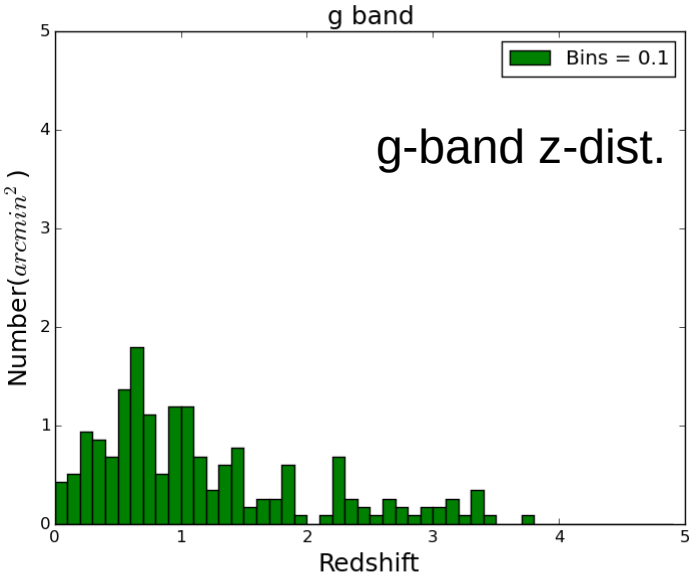
	Exp.	NUV	u	g	r	i	z	WU	WV	WI
17500□°	2×150s	25.1	25.4	26.3	26.0	25.9	25.2	25.6	26.8	26.5
400□°	8×250s	26.5	26.7	27.5	27.2	27.0	26.4	26.9	28.0	27.6

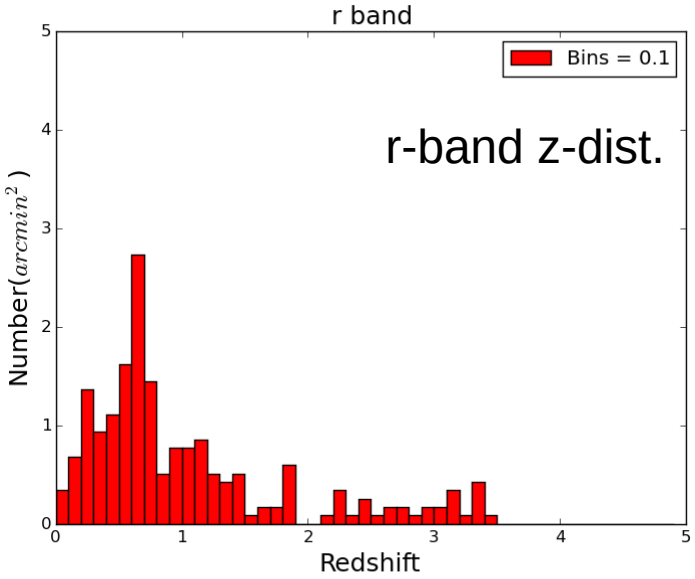
NUV, u, g, r, I, z, WU,WG, & WI, two pieces each. Deeper imaging, more galaxies, better photo-zs, potential improvement for stellar science, & redundancy.

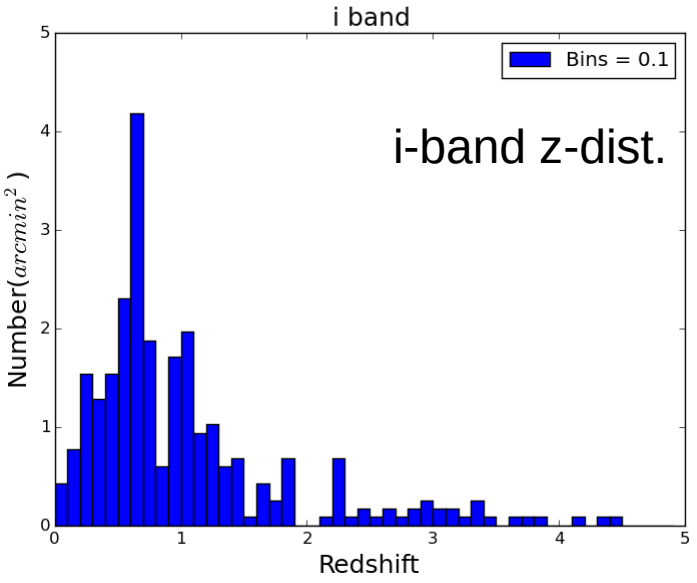
Image Simulations Using UDF



Galaxies from Imaging







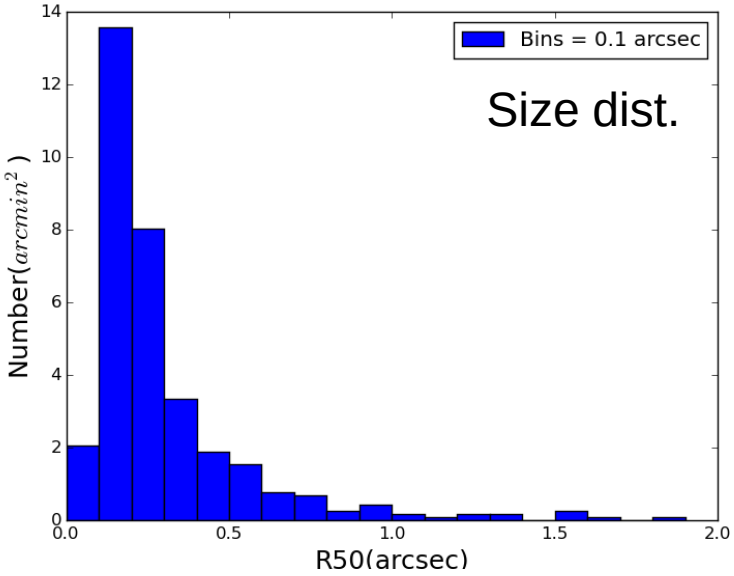
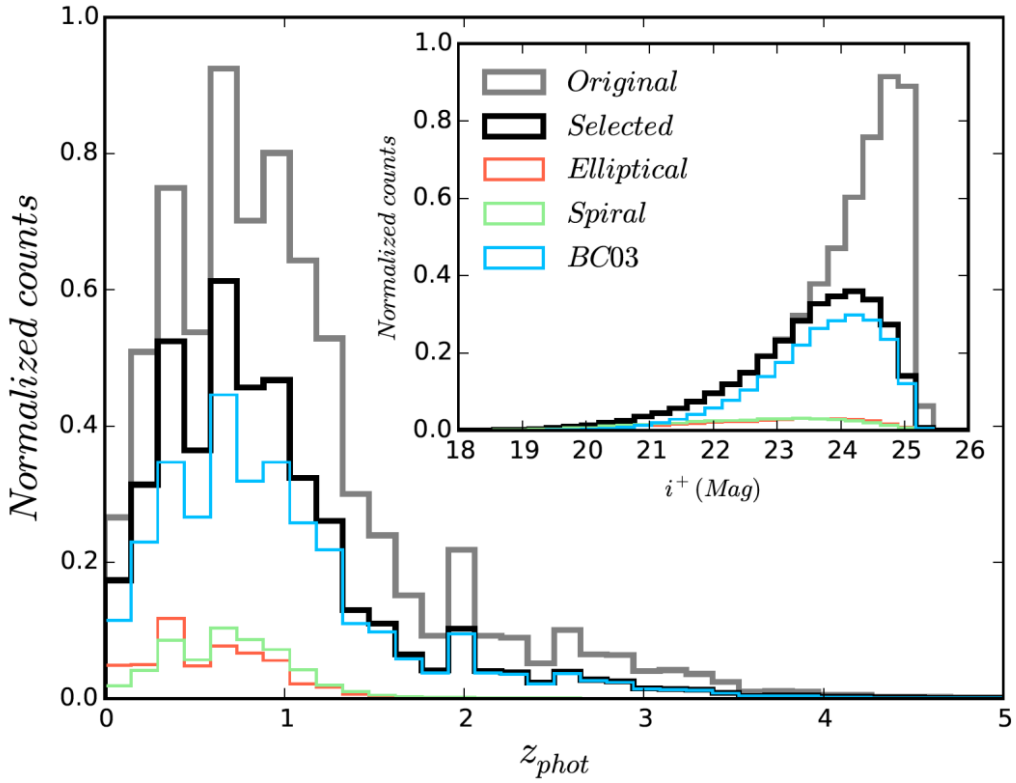
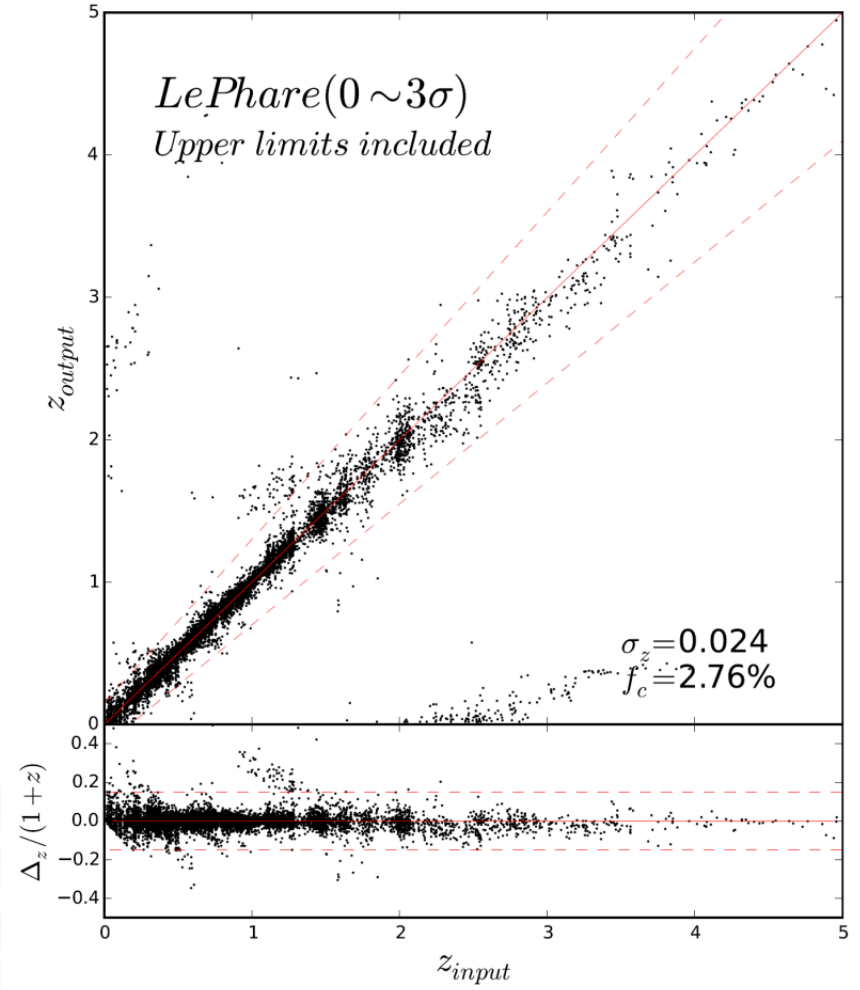


Photo-z Estimates





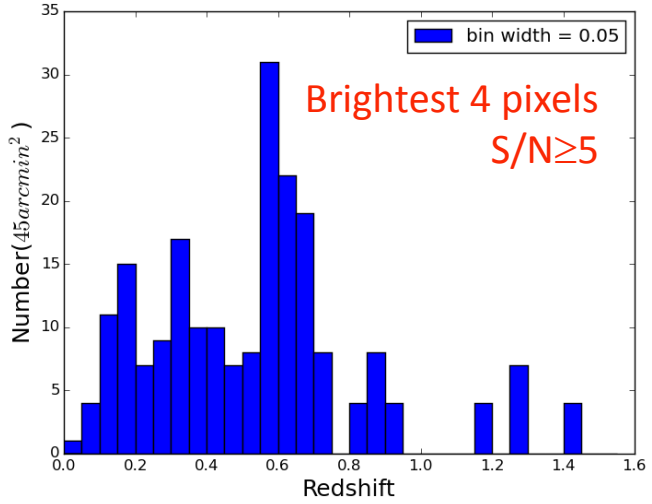
Galaxy dN/dz of a high-S/N mock sample (17.5/□′, σ_{z0}=0.024) for the CSS-OS based on COSMOS. If σ_{z0} is relaxed to 0.05, galaxy density ~ 29/□′.

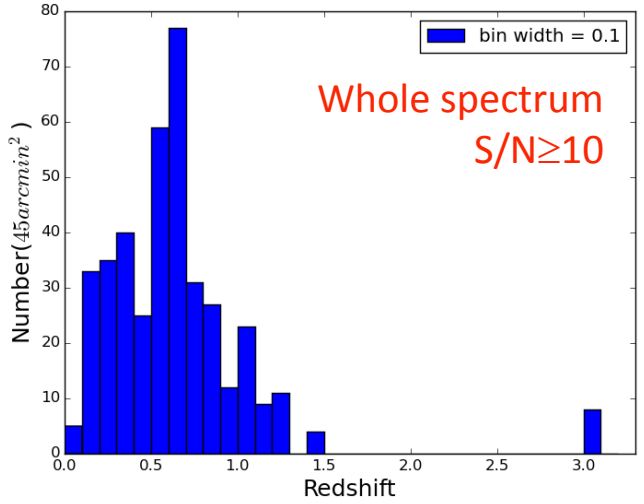
Y. Cao, Y. Gong et al. 2018
arXiv:1706.09586

Amounts to several hundred million low-resolution galaxy spectra!

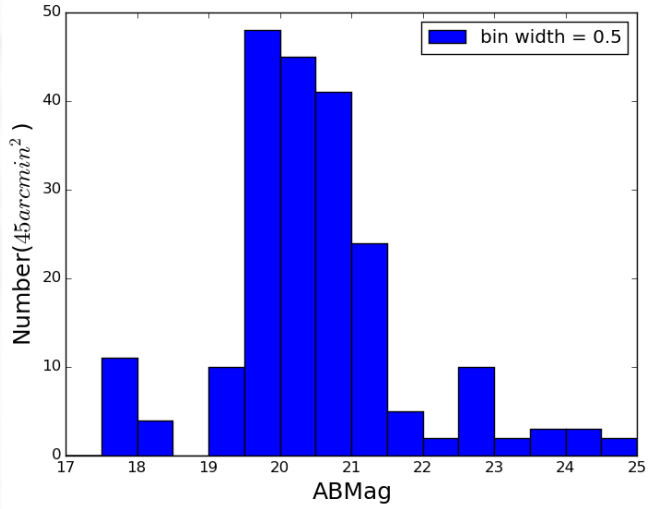
620-1000nm, 6000×4800pix (45 □′)
3.9/□′ with brightest 4 pixels S/N≥5
8.5/□′ with whole spectrum S/N≥10

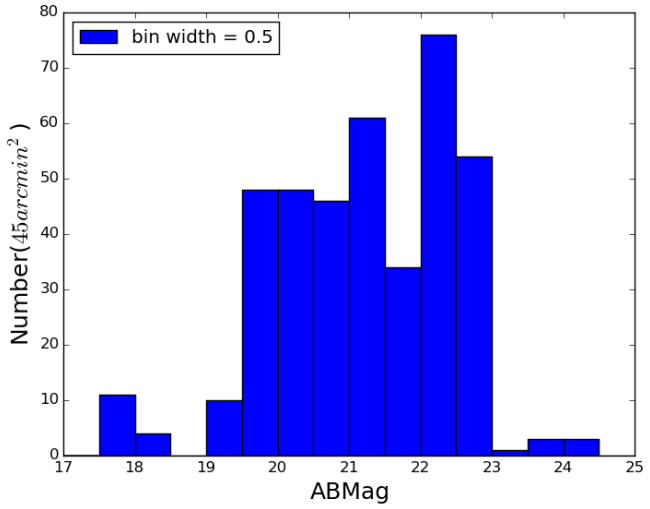
Galaxies from Spectroscopy





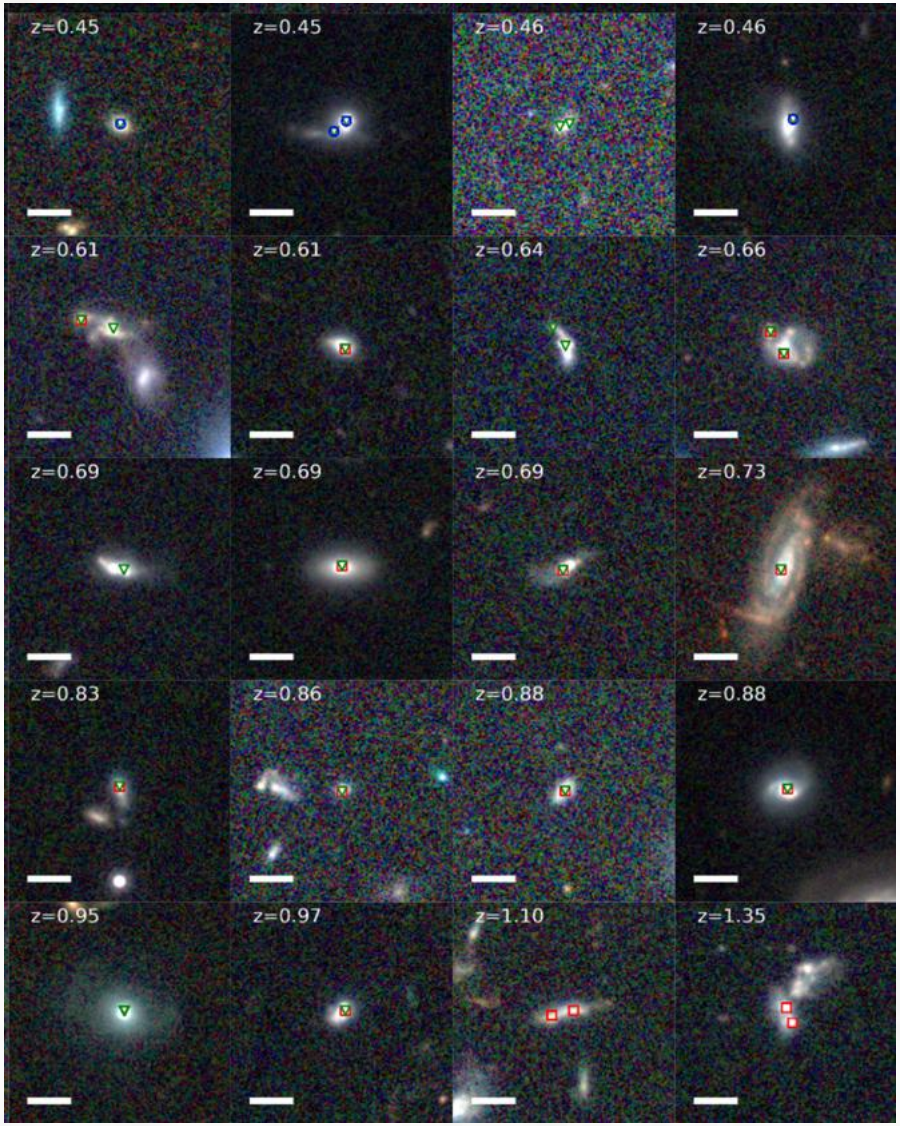
620-1000 nm

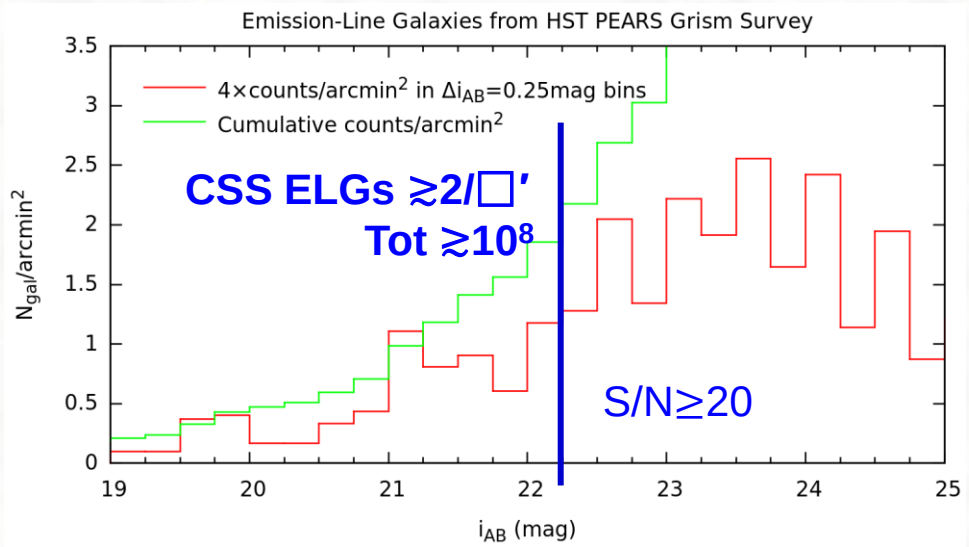


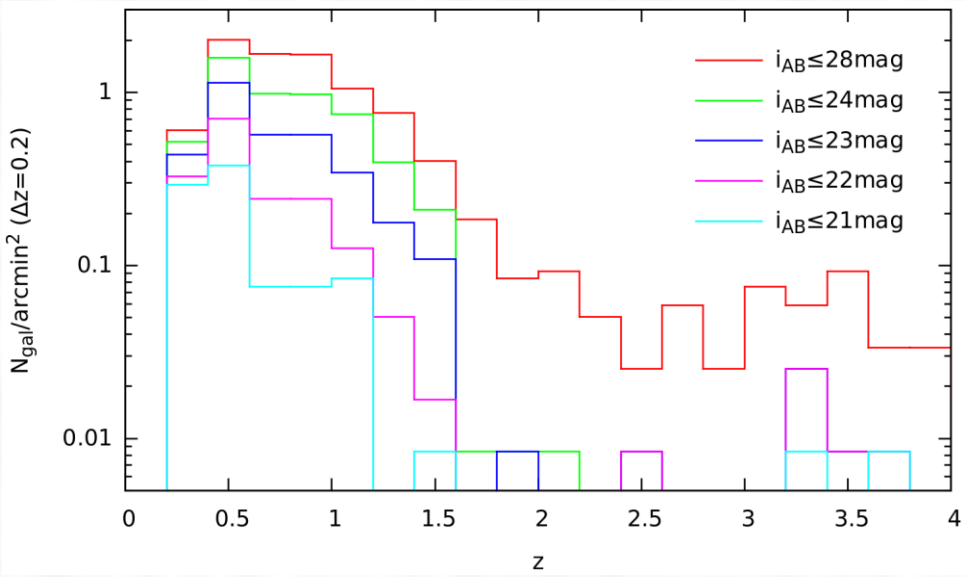


Checking against HST PEARS Survey

120/□′, 550-1050nm, R≃69-131, $i_{AB}\lesssim 28^{m}$







New instruments recommended

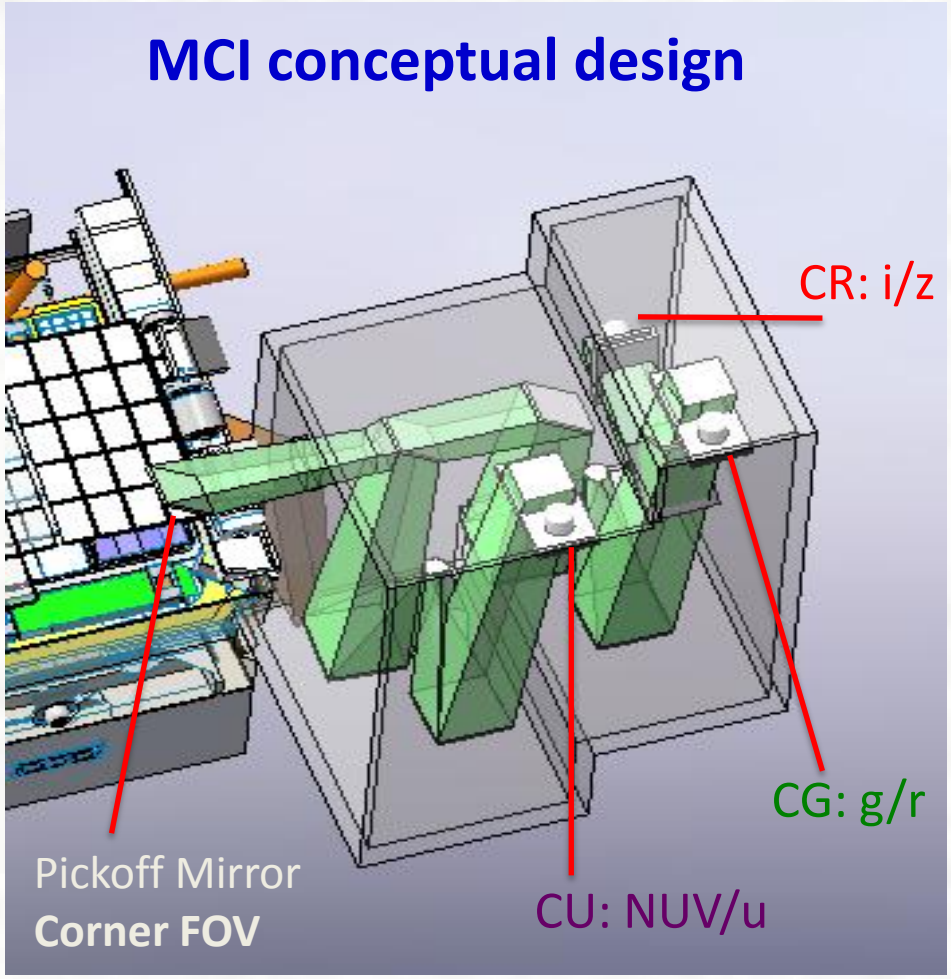
1. **Multi-channel imager (MCI)**
2. **Integral field spectrograph (IFS)**
3. **Exoplanet Imaging Coronagraph (EPIC)**

Time allocation for the first 10 years

- **Survey: ~70% (best case)**
- **Service: ~10%**
- **All others: ~20% unless able to observe in parallel with the survey camera**

Multi-Channel Imager

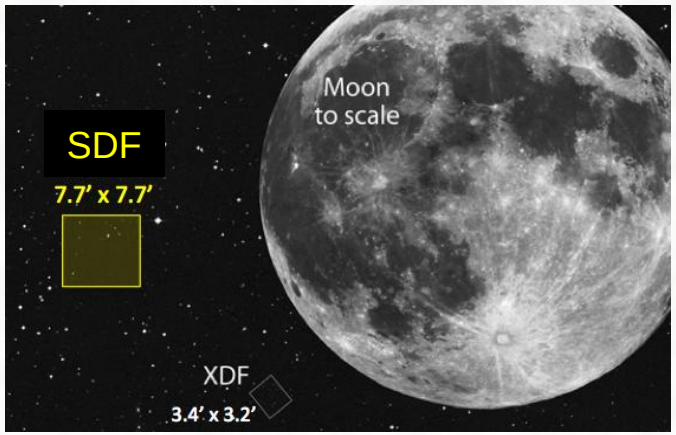
ZHENG Zhenya, JIANG Linhua, et al. (SHAO, SITP)



- NUV to optical 3-channel **simultaneous** observation:
  CU, CG, CR
  0.25-0.41, 0.43-0.70, 0.72-1.10 μm
- 20+ filters to select
- 9Kx9K e2v CCDs, 0.05”/pix, FOV 7.8’ x 7.8’
- Might use a corner of the survey FOV to work in parallel with the survey camera.
- High Precision Photometry (~0.1%) with HST Standards, calibration for the survey.

Multi-Channel Imager

ZHENG Zhenya, JIANG Linhua, et al. (SHAO, PKU, SITP)



Sciences with (3-filter simultaneous)

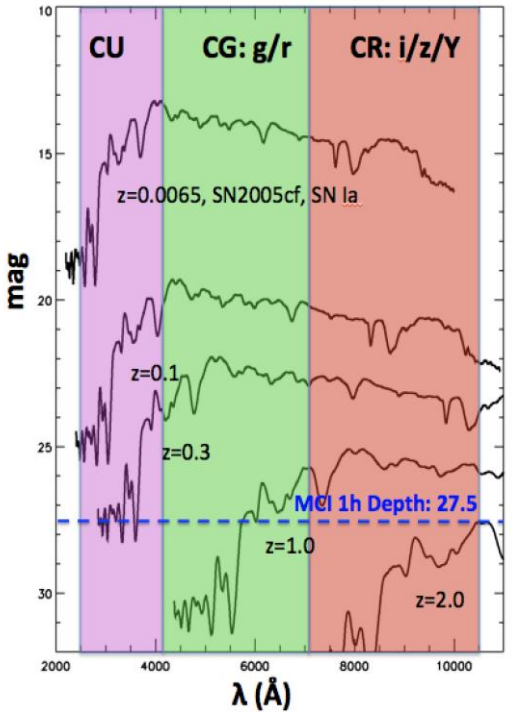
CSST Super Deep Fields:

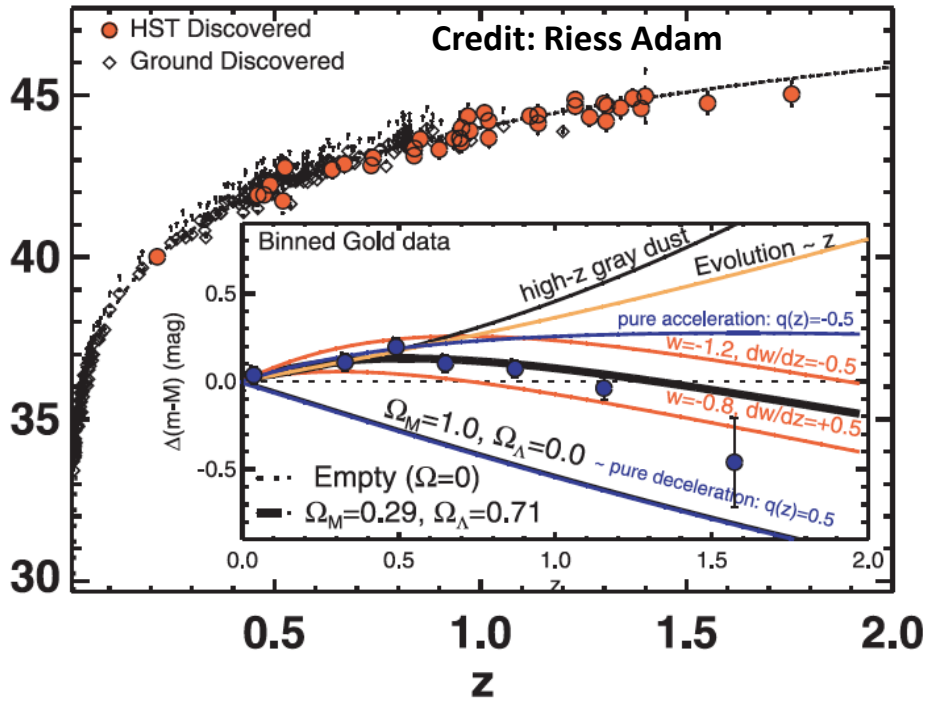
- SN Ia Cosmology and Highest-z SN
- Completeness of Galaxies used for WL, Clustering, etc.
- Galaxy & BH Co-Evolution
- ……

Potential SDFs:

- HST XDF (Illingworth+2013)
- Galaxy Cluster
- JWST UDF

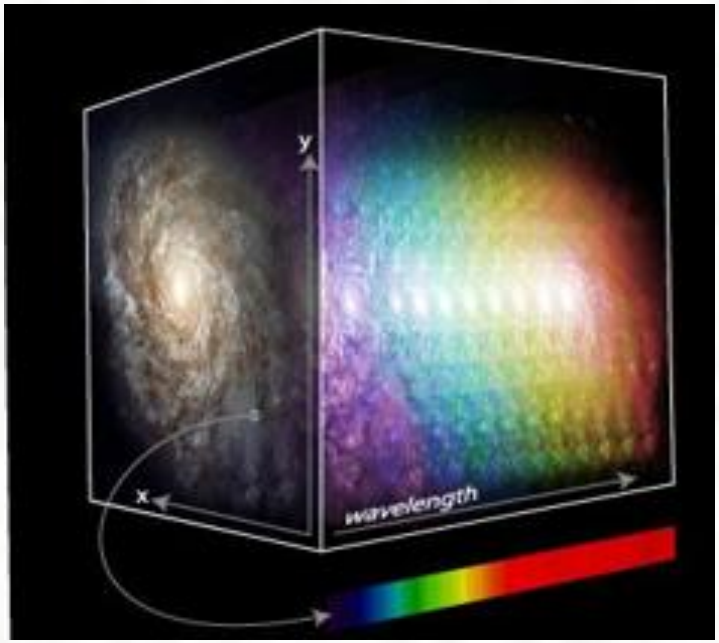
3 fields, ~240 orbits each



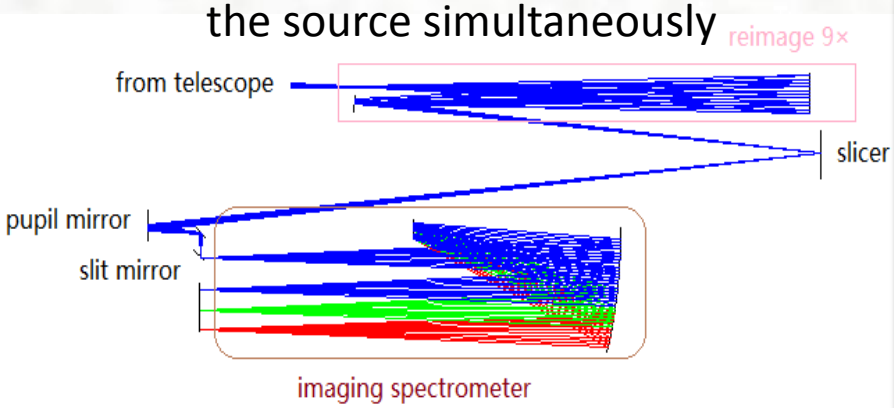


Integral Field Spectrograph

HAO Lei et al. (SHAO, SITP)



Taking spectra of different parts of the source simultaneously



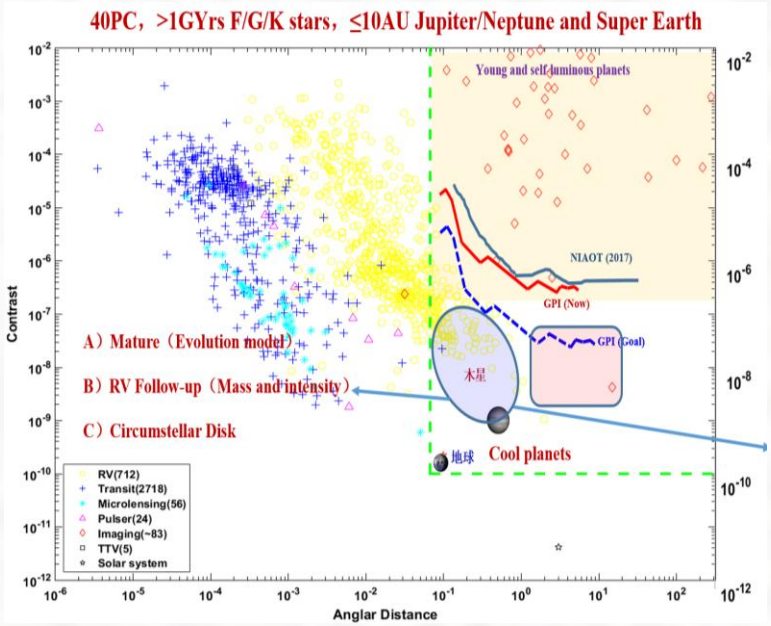
Specifications	
Spatial Resolution	0.2''
Spatial Elements	30x30
Field-of-view	6''x6''
Filling factors	100%
Wavelength Coverage	0.35-1.0um
Spectral resolution （△lambda）	0.175nm/pixel， R≥ 1000

Sciences

- Super-massive black holes and its surroundings
  - Measuring the BH masses
  - Feeding and feedback of BHs
  - Star clusters and star-formation around the BHs
  - Tidal-disruption events
- Star-formation of galaxies
  - Mergers, BCDs, Lyman-Break Analogs
- Many others

Exoplanet Imaging Coronagraph

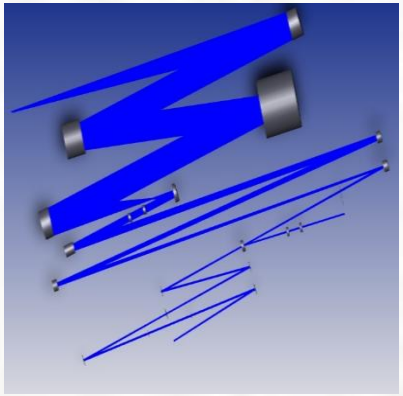
DOU Jiangpei et al. (NIAOT, XIOMP)

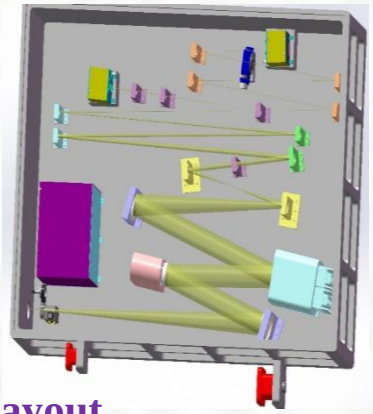


Contrast vs. angular separation

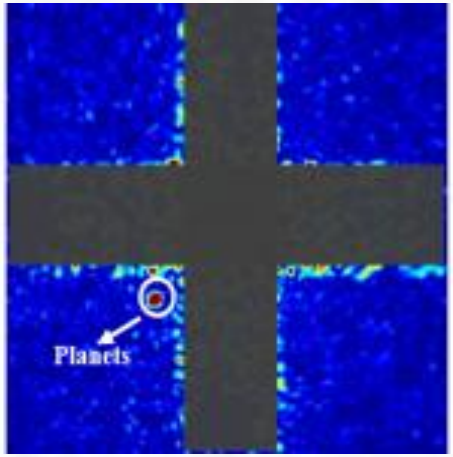
- **Wavelength**: 0.6μm-1.7μm
- **Bandwidth**: 5~20% (0.661, 0.883, 0.721, 0.94, 1.25, 1.65μm)
- **FOV**: 2.5″x2.5″ (working)
  12.5″x12.5″ (for targeting)
- **IWA**: **2~4 λ/D**（0.26″@ 0.6μm）
- **Contrast**: **10^{-9}**

Off-axis system: no central obstruction and spider, optimized for high-contrast imaging





Optics layout



Vacuum chamber test reaching 10^{-9} contrast

Thank you!