China Manned Space
Space Application System

The Chinese Survey Space Telescope

(a.k.a. the Chinese Space Station Telescope)

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NAOC & PKU

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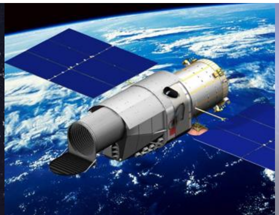
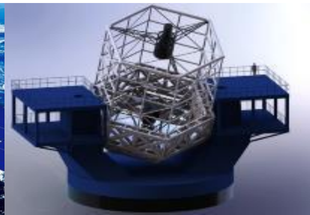
2021.09.22





Introduction

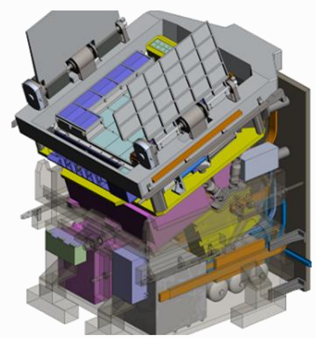
A 2m space telescope in the same orbit as the China Manned Space Station, serviceable while docking with the station.

Instruments: Survey Camera (SC), Terahertz Receiver (THz), Multichannel Imager (MCI), Integral Field Spectrograph (IFS), Cool-Planet Imaging Coronagraph (CPIC).

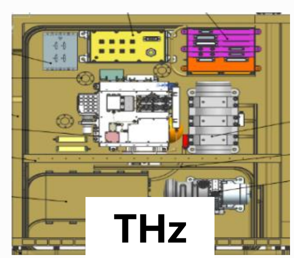
Mission: wide-area multiband imaging & slitless spectroscopic survey (7yr); other key programs & GO programs (2+yr).

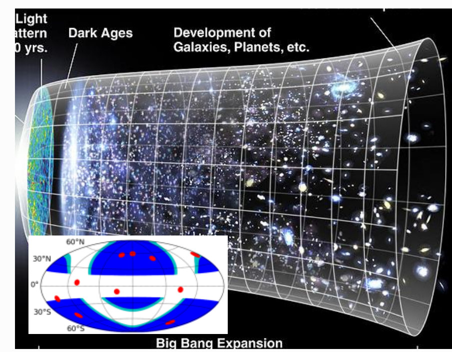
https://doi.org/10.1360/132011-961

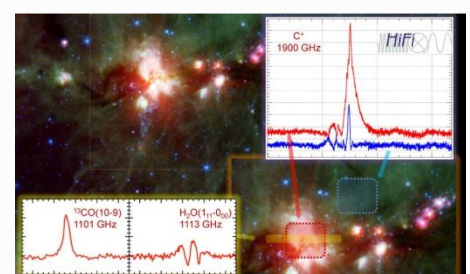
https://doi.org/10.1360/TB-2021-0016



Survey Cam







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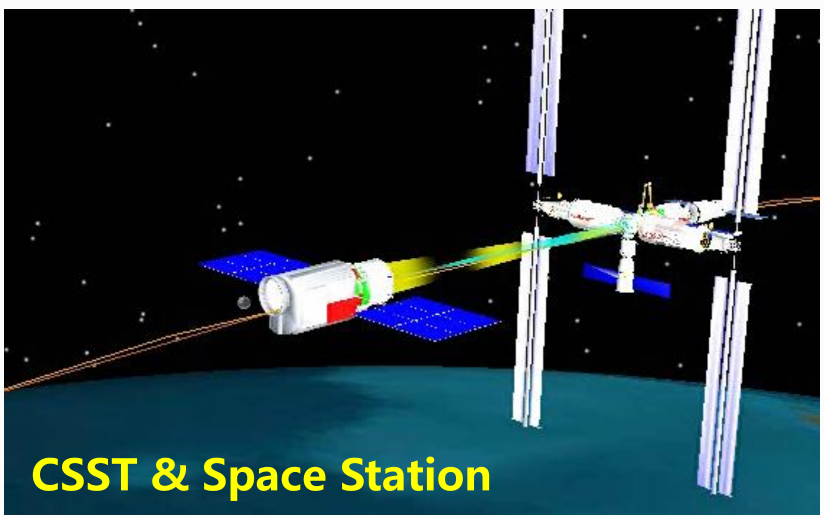

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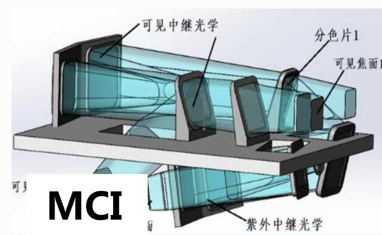
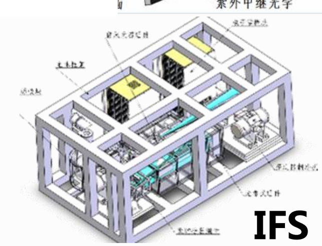
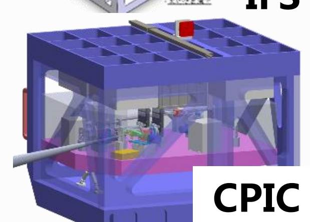
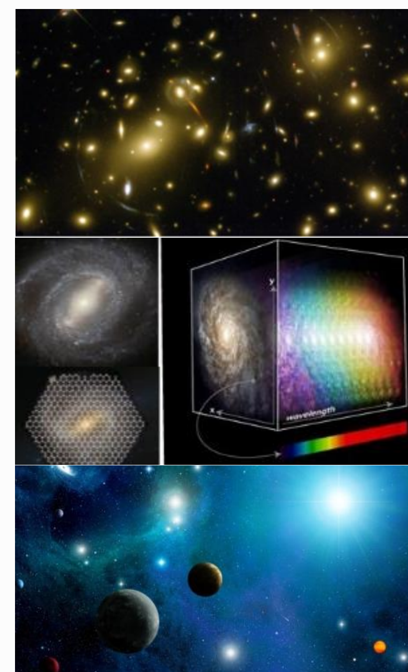








Project Timeline

2010 — Mission concept & def (SC & THz)

2013 — CoDR & mission approval

2014 — Free-flying design

2018 — New instr: MCI、IFS、CPIC

2019 — Data reduction system design; OA、SC、THz bgn final design

2020 — Sci Cmte, Sci Centers, DRS & res proj appd; MCI、IFS、CPIC bgn final design

2021-2023 — Qual model & flight model

Organizational Structure of Science Work

- Funded by China Manned Space
- Administrated by the Space Application System
- Decision making body: Science Committee
- Research management & organization: Joint Science Center & Science Centers (PKU, NAOC, Yangtze River Delta Region, & Guangdong-Hong Kong-Macao Greater Bay Area)

Science Committee

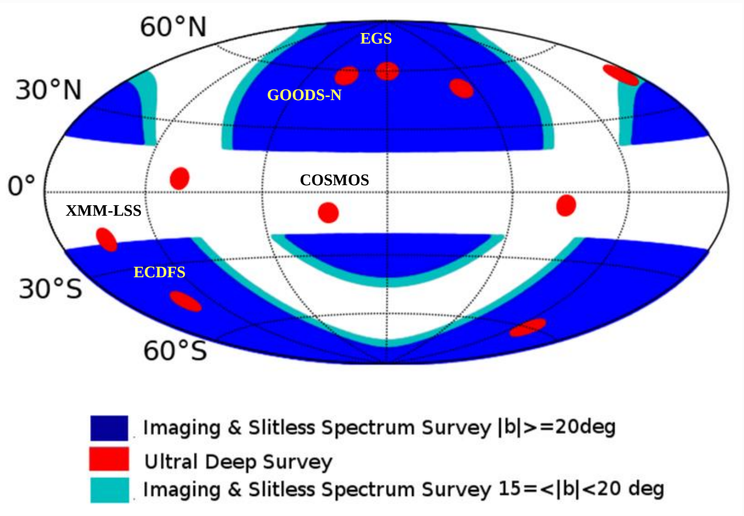
Advisor: Yidong GU (Chief Expert of Space Science, CMS)
Chair: Jin CHANG; Vice Chairs: Zhanwen HAN, Yipeng JING, Luis HO
Members: Xuebing WU, Shude MAO, Jianning FU, Xiaohu YANG,
Weipeng LIN, Yong SHI, Zuhui FAN, Taotao FANG, Junhui FAN,
Jianmin WANG, Gang ZHAO, Hu ZHAN, Zhiqiang SHEN,
Ji YANG, Jinming BAI, Xu KONG

Project Scientist Team

Hu ZHAN (CSST PS), Yiping AO, Zhenya ZHEN, Lei HAO, Jiangpei DOU, Ran LI,
Zhongwen HU, Wei WANG, Guotong SUN

Survey Specs

- **17500□° imaging :** 255-1000nm, ≥6 filters, avg ≥25.5^{m} (5σ, point source, AB mag)
- **17500□° slitless spect:** 255-1000nm, 3 bands, R≥200, ≥22-23^{m}
- **400□° deep imaging & spect:** at least 1^{m} deeper than above
- **300□′ SDF (MCI):** simultaneous observation in 3 bands, V ≥ 30^{m}



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…

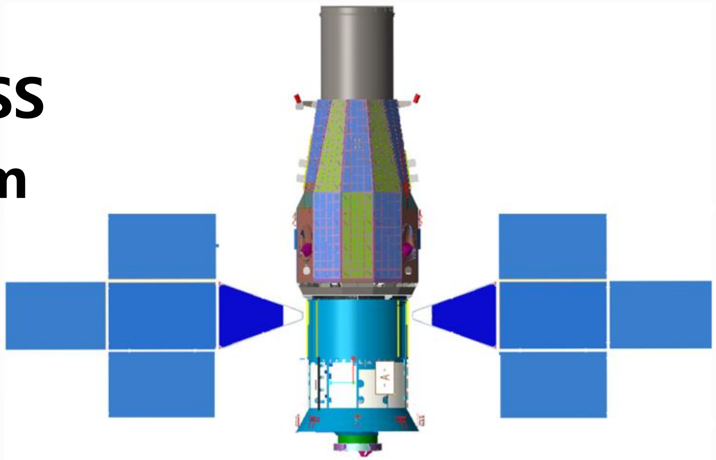
Astrometry: reference frame, star clusters…

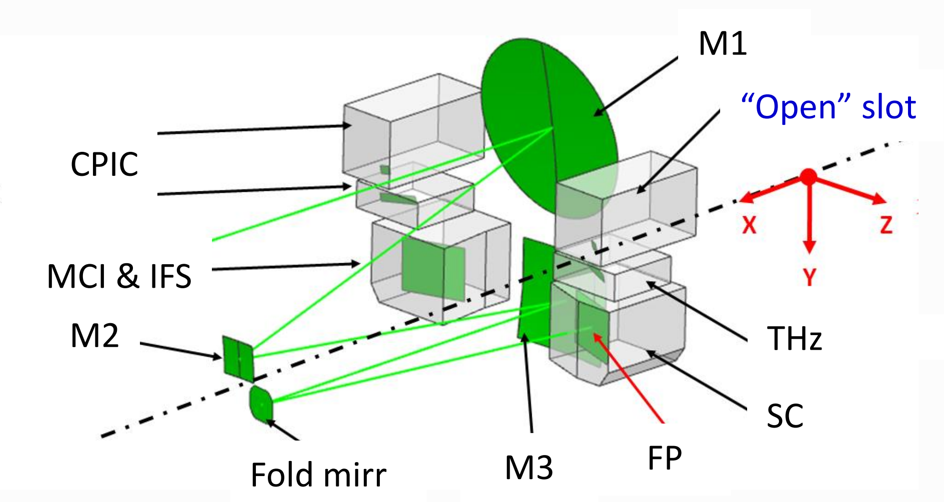
Telescope Specs

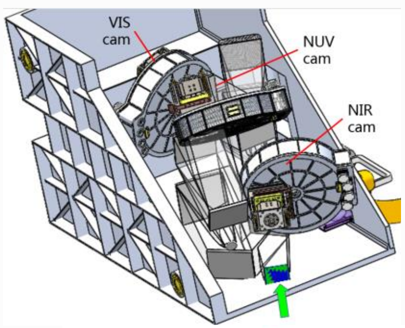
Aperture	2m
Focal length	28m
Field of view	1.7□° (≮1.1□° for survey)
Wavelength	0.255-1μm, 0.9-1.7μm, 0.41-0.51THz
Image quality	optics: R_{EE80}≯0.13", whole system R_{EE80}≯0.15" e_{avg}≤0.05, e_{max}≤0.15 (λ=0.6328μm, within 1.1□°)
Throughput	≮0.65 (NUV-Vis-NIR average, optics only)
Pointing accuracy	LOS: ≯5" (w/ guide star, goal 0.2"), 10" (w/o GS) Roll: ≯10" (w/o GS)
Stability (≮300s)	LOS: ≯0.05" (3σ, w/ GS), ≯0.85" (w/o GS) Roll: ≯1.5" (w/o GS)
Jitter	≯0.01" (3σ)
Slew	1°/50s, 20°/100s, 45°/150s; max 0.35°/s

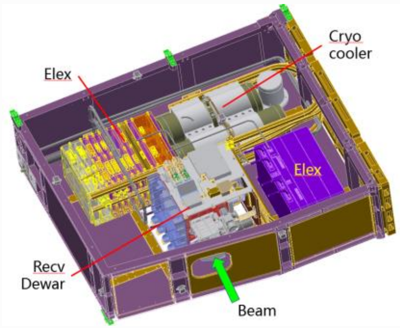
System Design

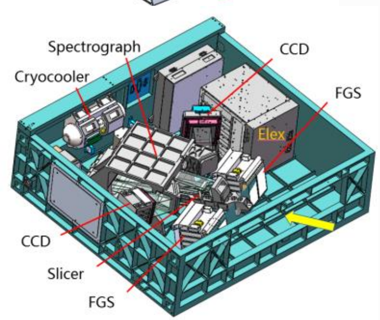
- Cook-type Off-axis TMA
- Serviceable while docking w/ the CSS
- Slew & LOS/roll: control-momentum gyro + Stewart platform + fast steering mirror (fold mirr) + vib control
- MCI, IFS & CPIC can observe in parallel (limited by power)

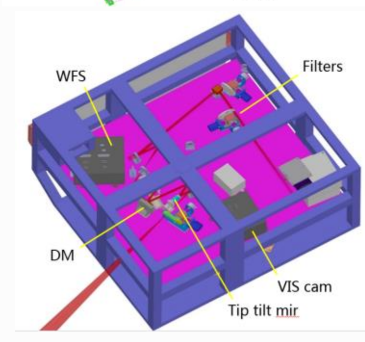




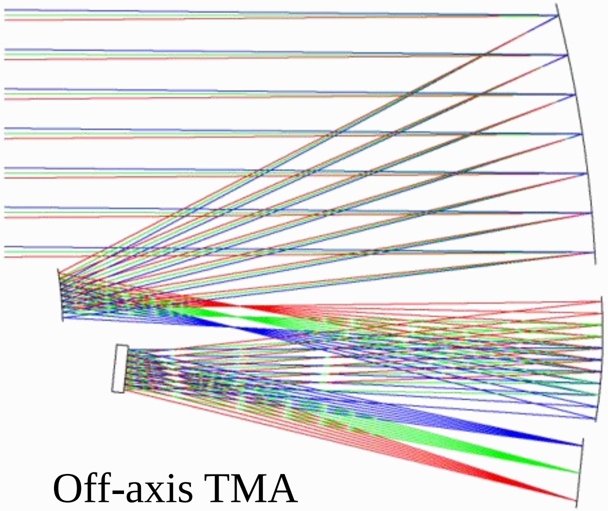








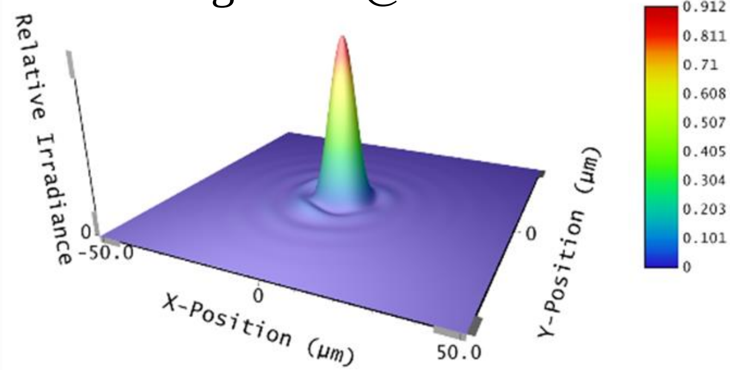
Optical Design



Φ2m
SiC mirror

Off-axis TMA

Design PSF @ corner



Requirements

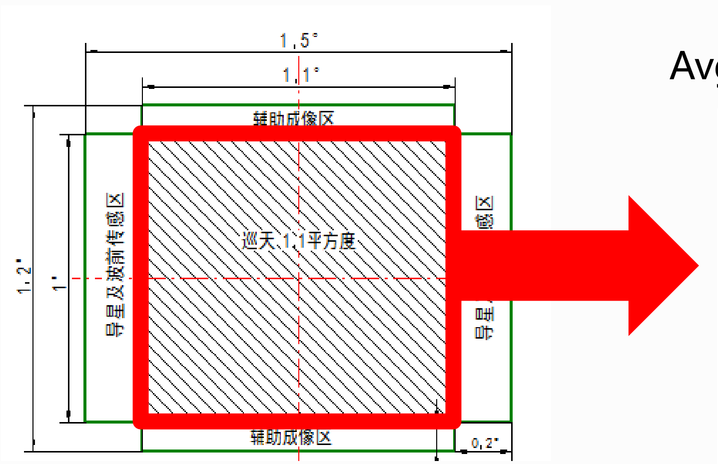
R_{EE80}≤0.15” @ 632.8nm

e_{avg}≤0.05, e_{max}≤0.15

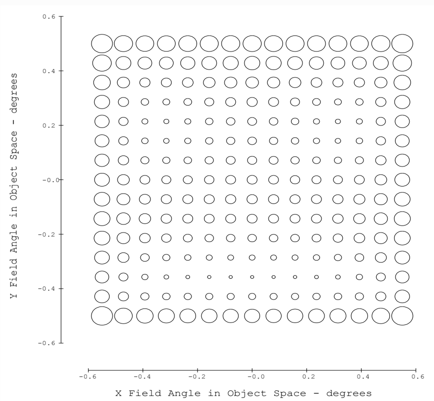
PSF + jitter sim

R_{EE80}<0.13”

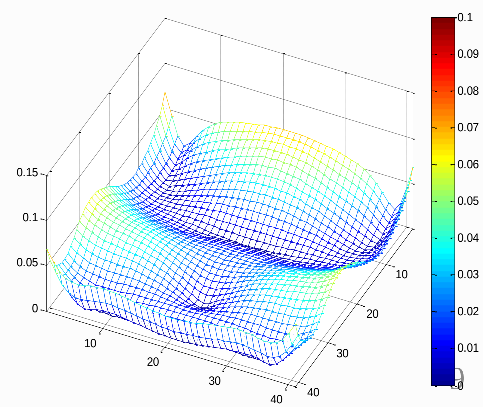
SC pix size 0.074”



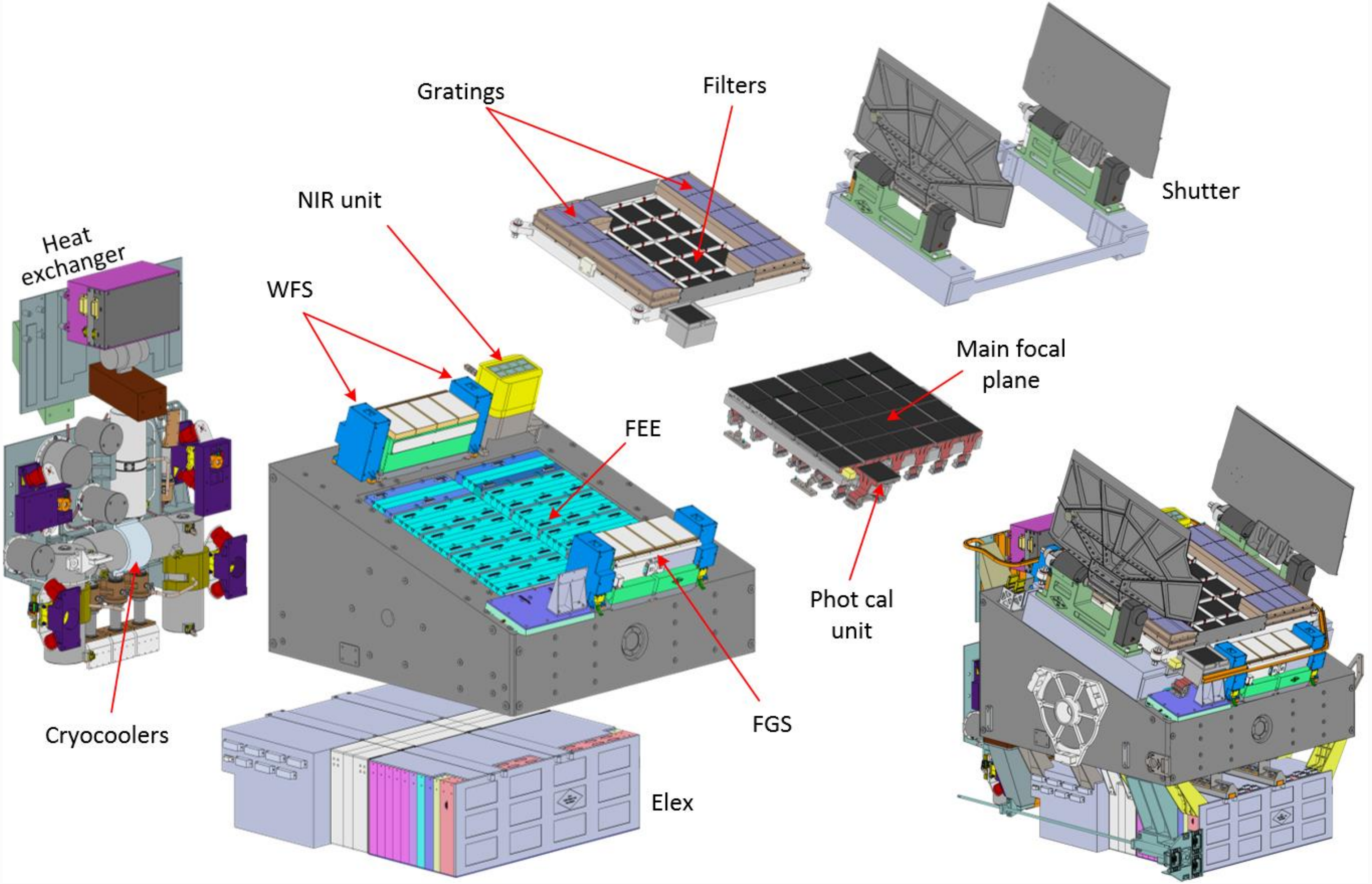
WFE
Avg 0.027λ(18nm), max 0.052λ



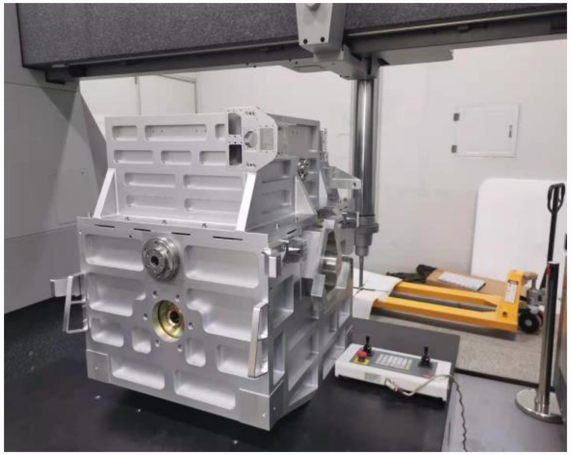
Ellipticity
Avg 0.0263, max 0.087



Survey Camera



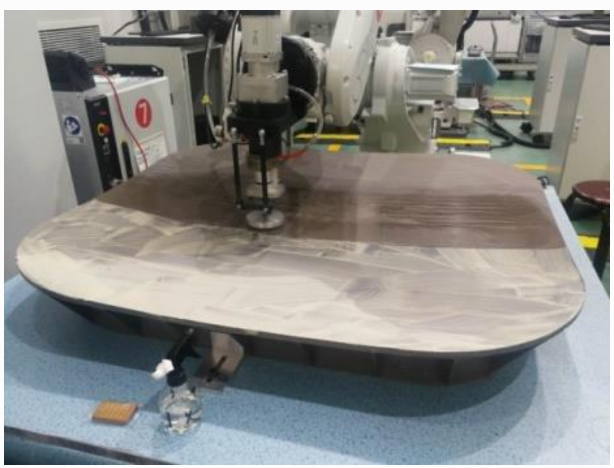
Fabrication in Progress



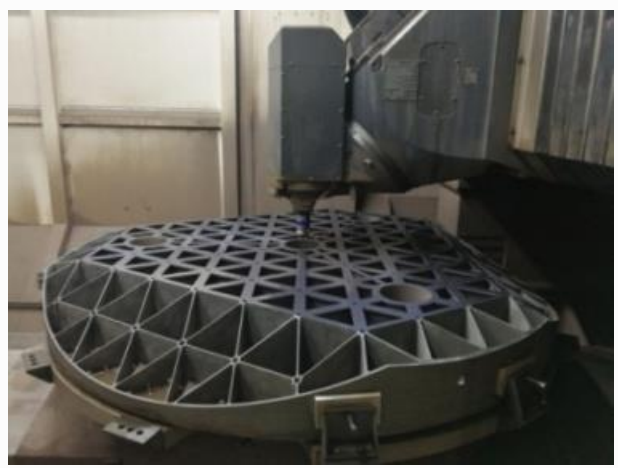
SC mech model

SC table-top elex

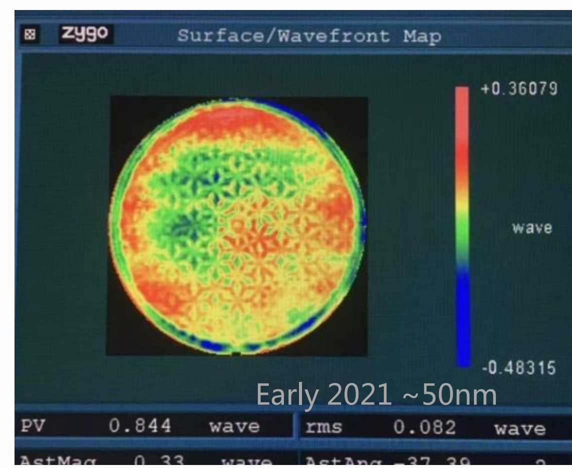
CF composite Truss



Tertiary mirror



Primary mirror



PM WFE currently ~20nm

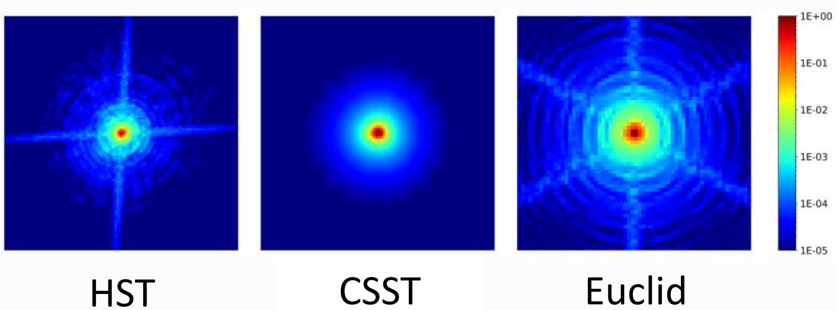
Comparison with Other Projects

Project	Site/ orbit	Launch /op	FoV	R_{EE80}	Num pixels	Area	Wavelength	Num Filters	Spect
			deg^2	″	10^9	deg^2	nm		
CSST	LEO	2023/ 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
Roman	L2	~2025	0.28	>0.2	0.3	~2000	927—2000	4	yes
Rubin	Chile	2023	9.6	~0.54	3.2	18000	320—1050	6	no

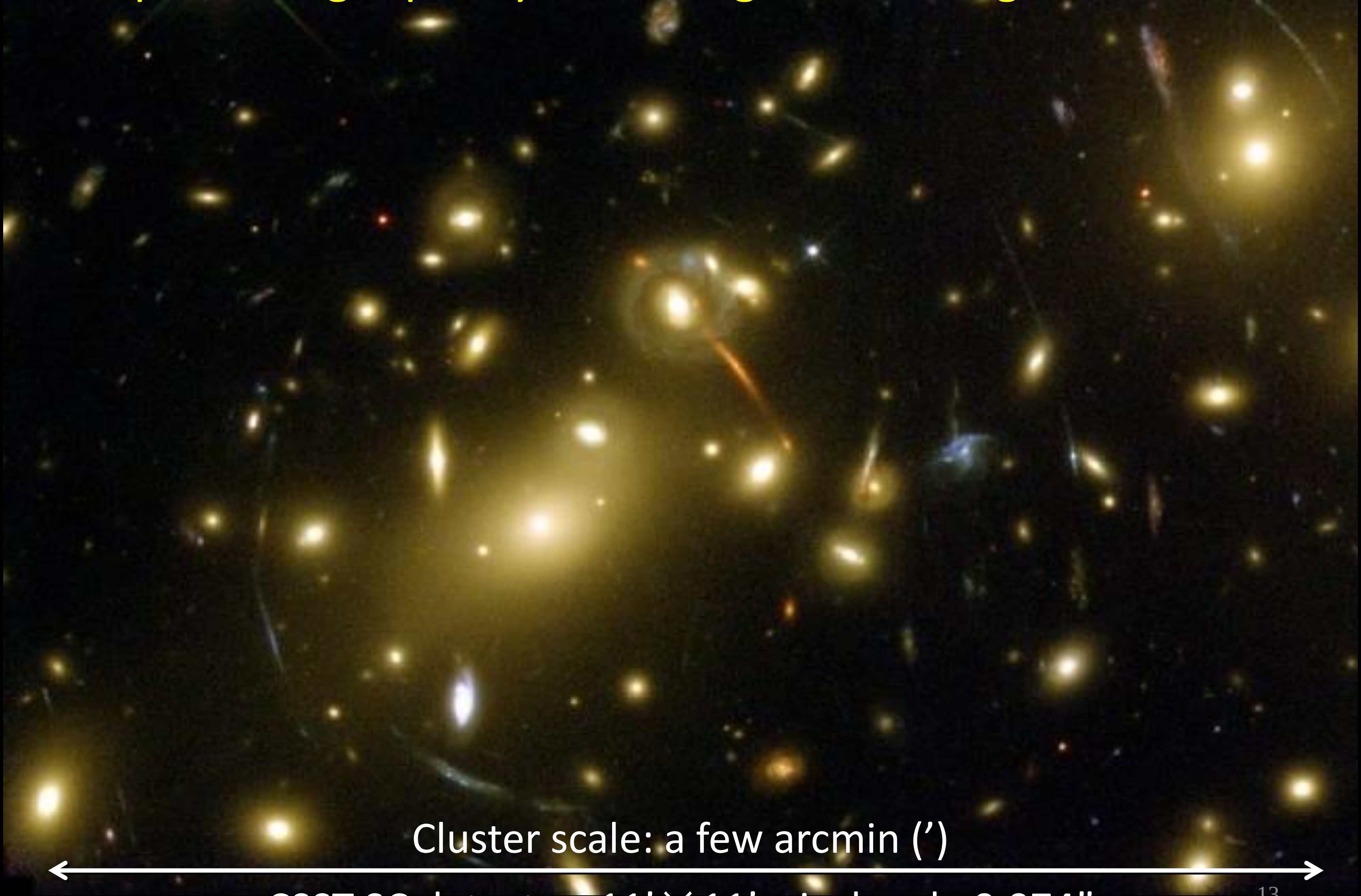
R_{EE80}: radius encircling 80% energy

	CSST	HST/ACS WFC	Euclid VIS	WFIRST J
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”

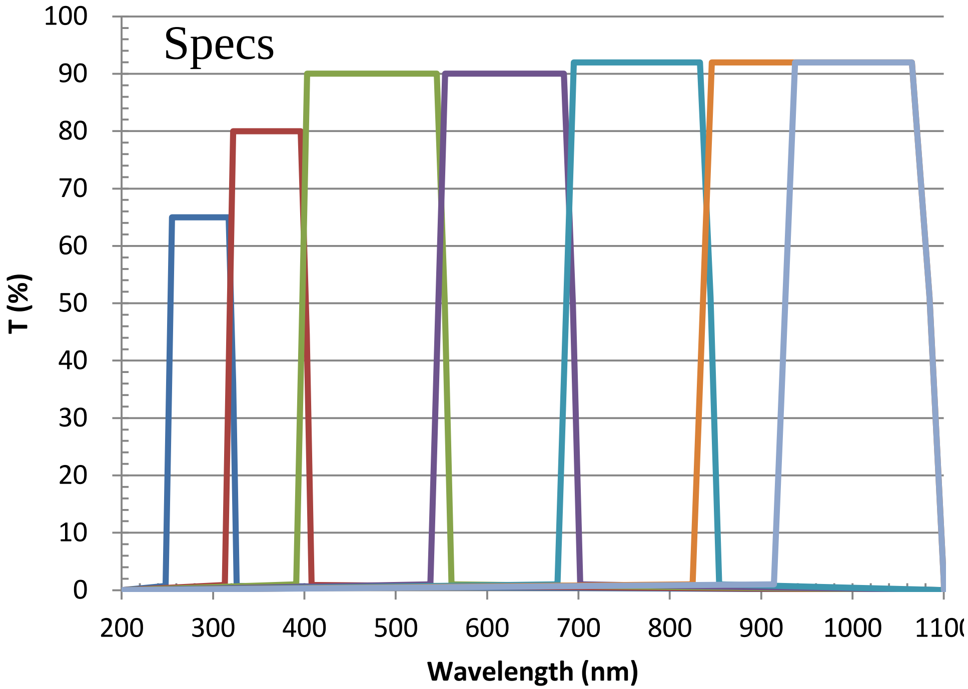


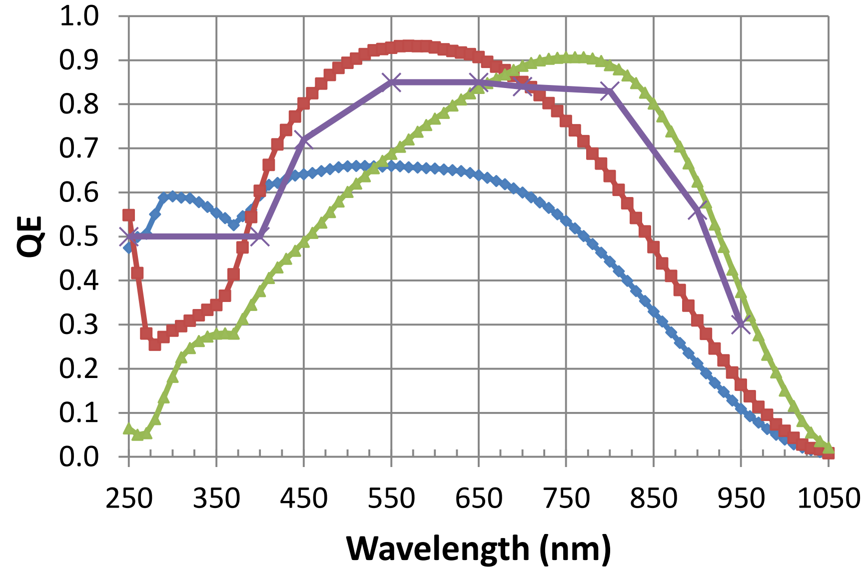
Superb image quality: advantage for lensing studies



CSST SC detector: 11’ × 11’, pixel scale 0.074”

SC: Filters & Limiting Mags



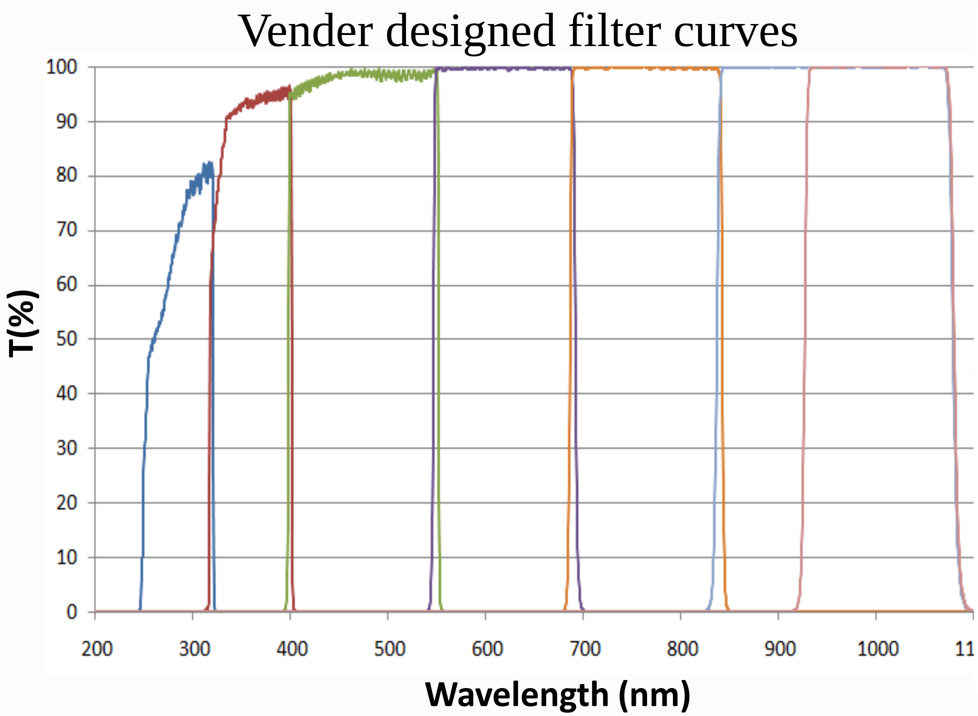


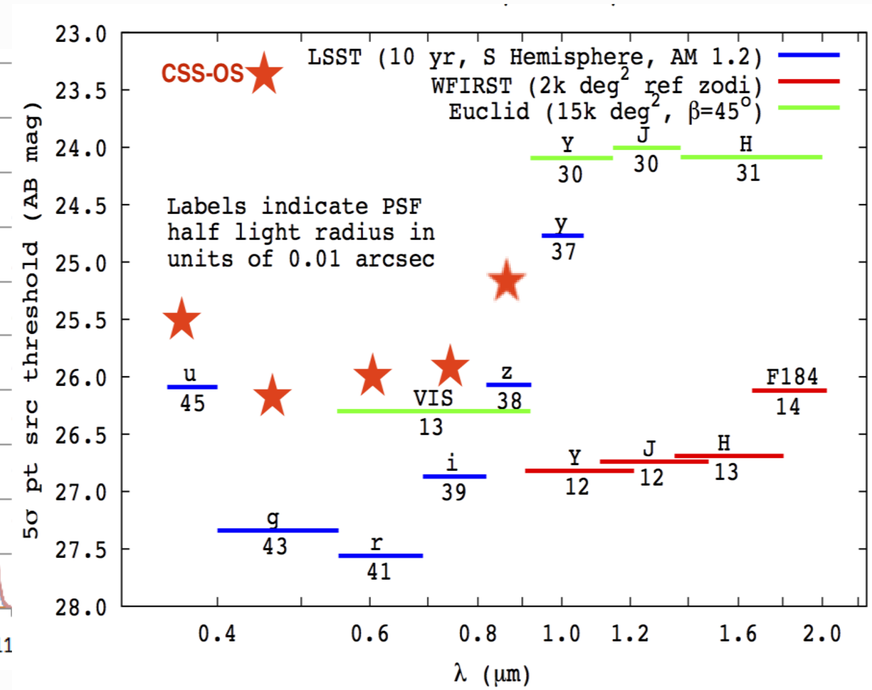
	t_{exp}	NUV*	u	g	r	i	z	y*
17500□°	2×150s	25.4	25.4	26.2	25.9	25.8	25.2	24.5
400□°	8×250s	26.7	26.7	27.4	27.1	26.9	26.4	25.7

*NUV & y: 4×150s

w/ ~0.2^{m} margin from design

SC: Filters & Limiting Mags





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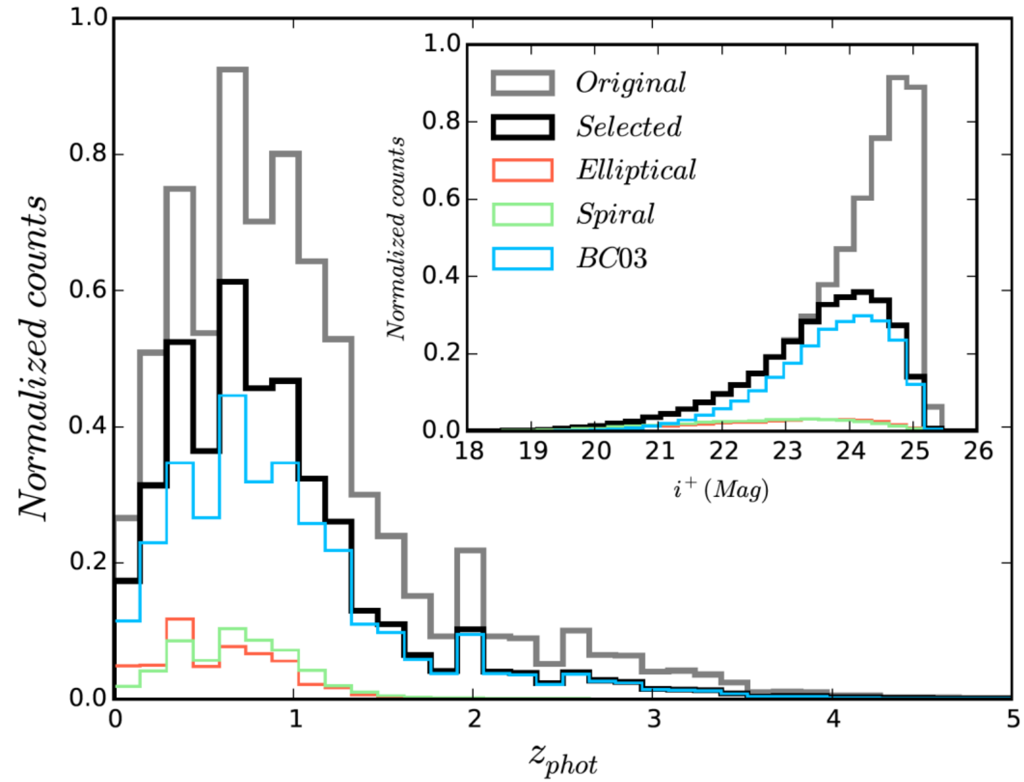
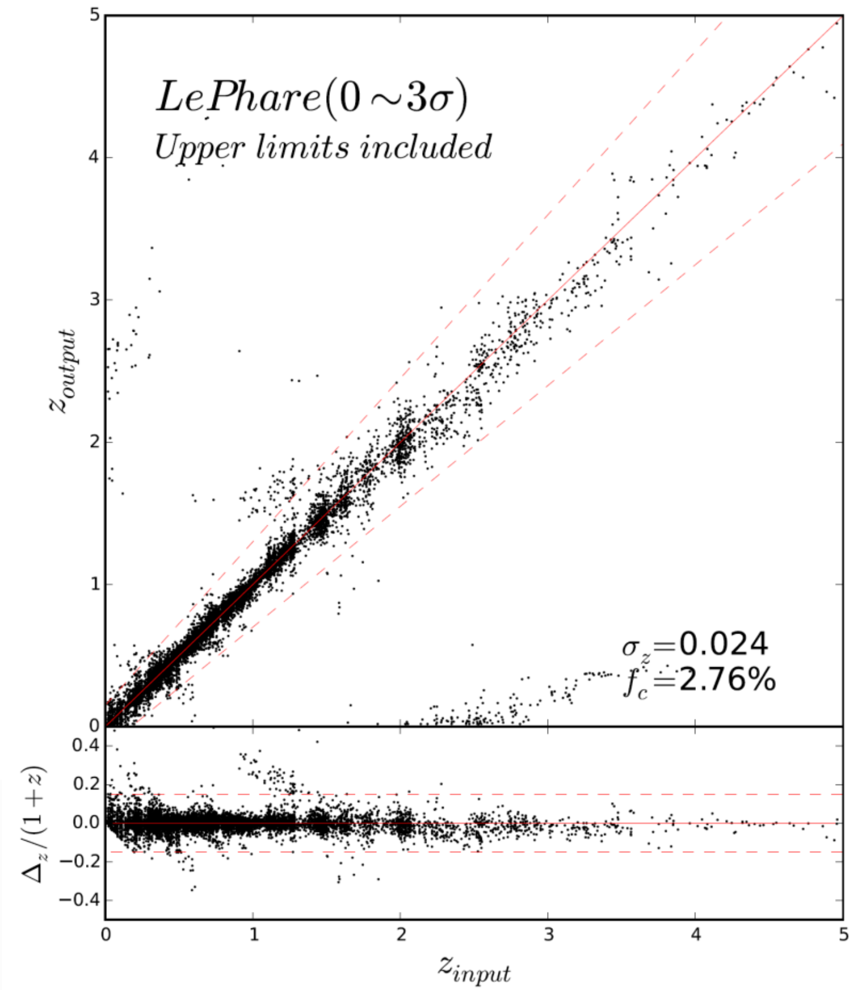
*NUV & y: 4×150s

w/ ~0.2^{m} margin from design

SC: Photo-z Estimates

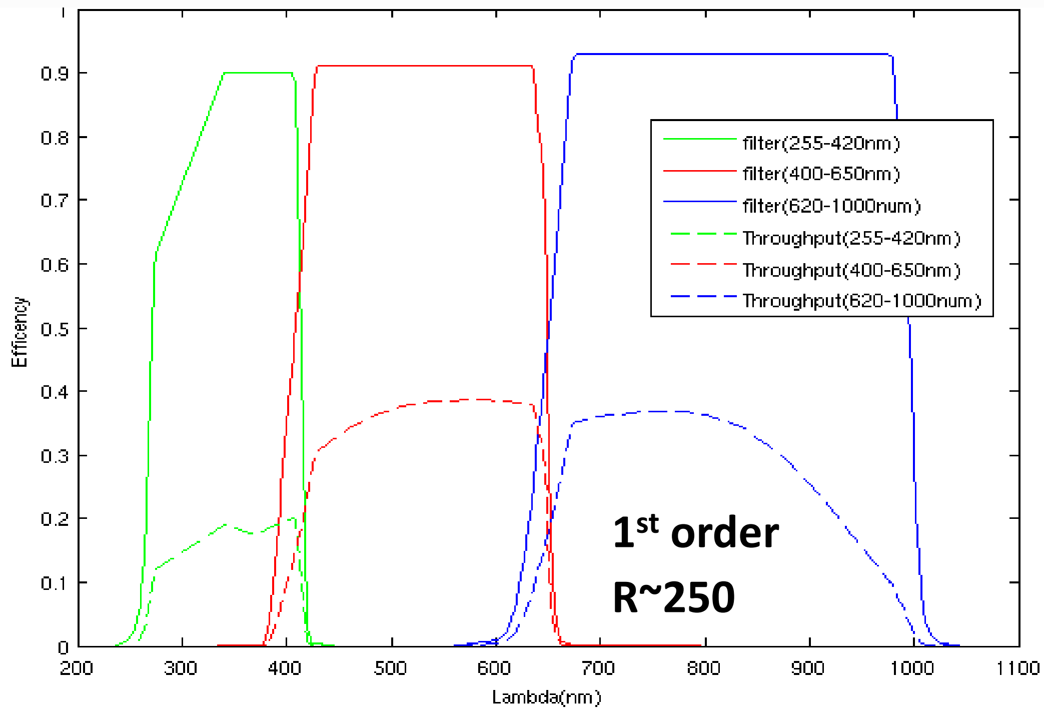


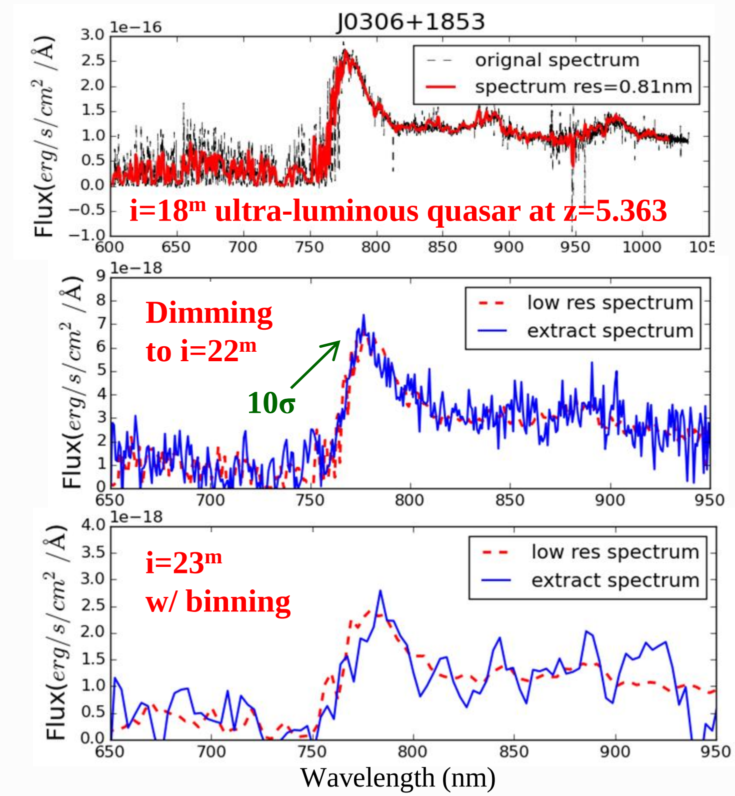


Galaxy dN/dz of a high-S/N mock sample (17.5/□′, σ_{z0}=0.024) for the CSST wide survey based on COSMOS. If σ_{z0} is relaxed to 0.05, galaxy density ~ 29/□′.

Cao et al. MNRAS, 480, 2178 (2018)
1706.09586

SC: Gratings & Limiting Mags



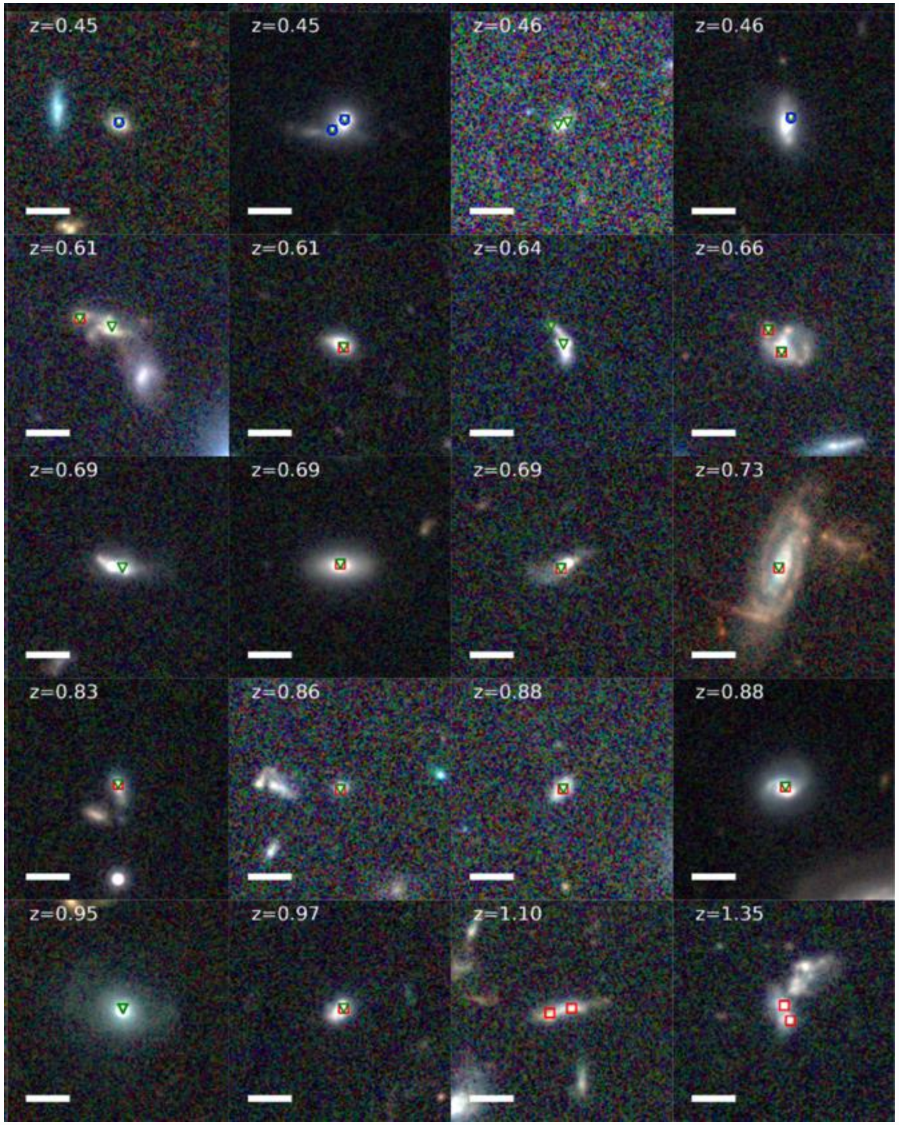


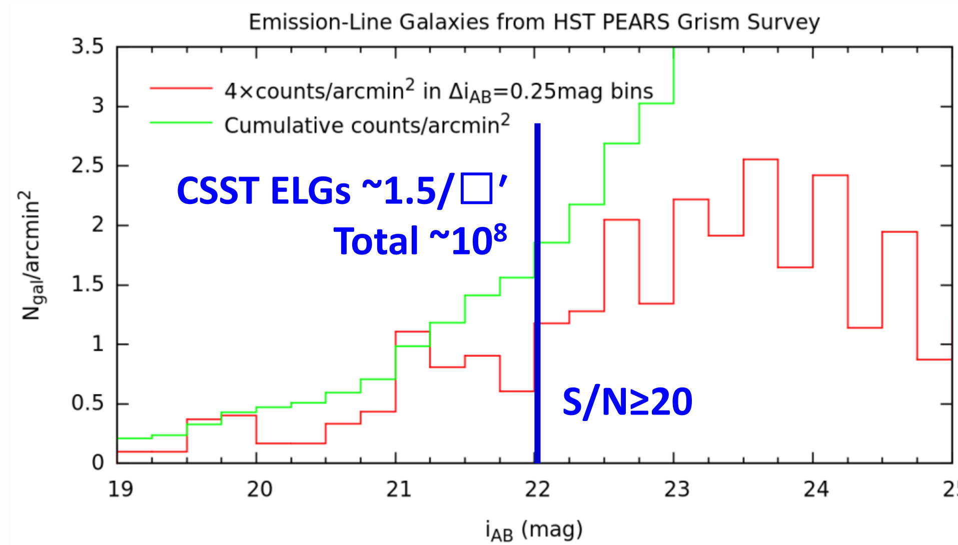
	t_{exp}	GU	GV	GI
17500□°	4×150s	22.5	23.4	23.4
400□°	16×250s	23.7	24.6	24.5

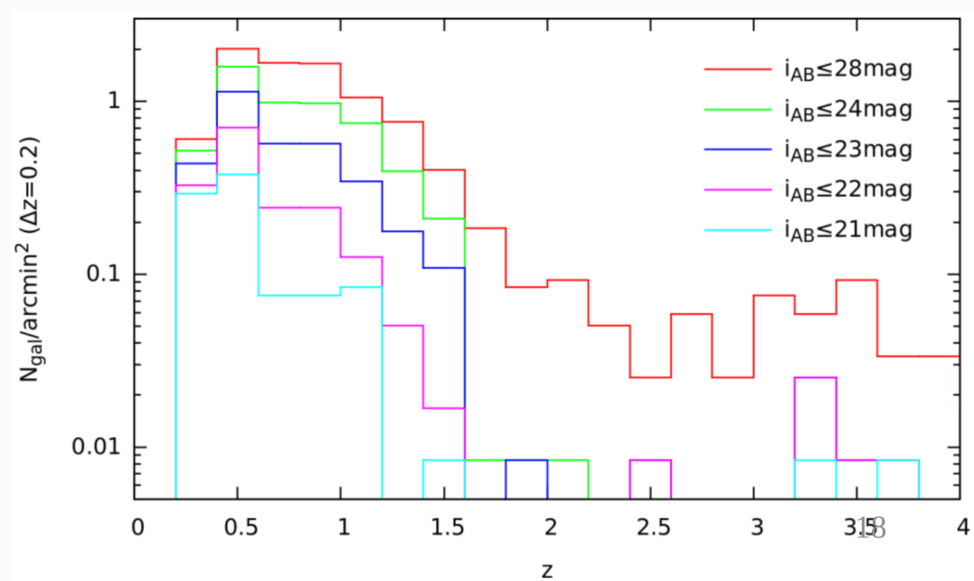
Broadband limiting mag w/ ~0.2^m margin

SC: Galaxies from Slitless Spectroscopy

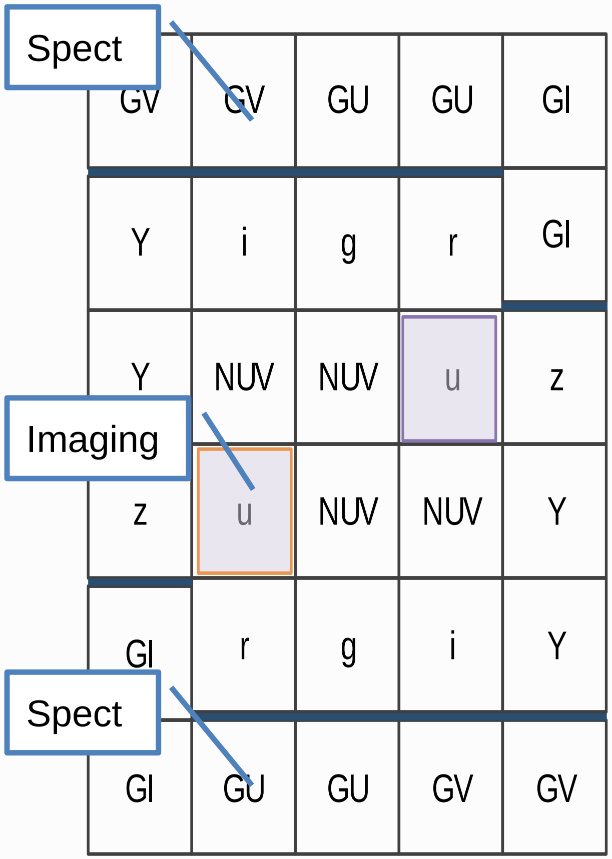
Checking against HST PEARS Survey: 120/□′，550-1050nm，R≃69-131，$i_{AB} \lesssim 28^m$

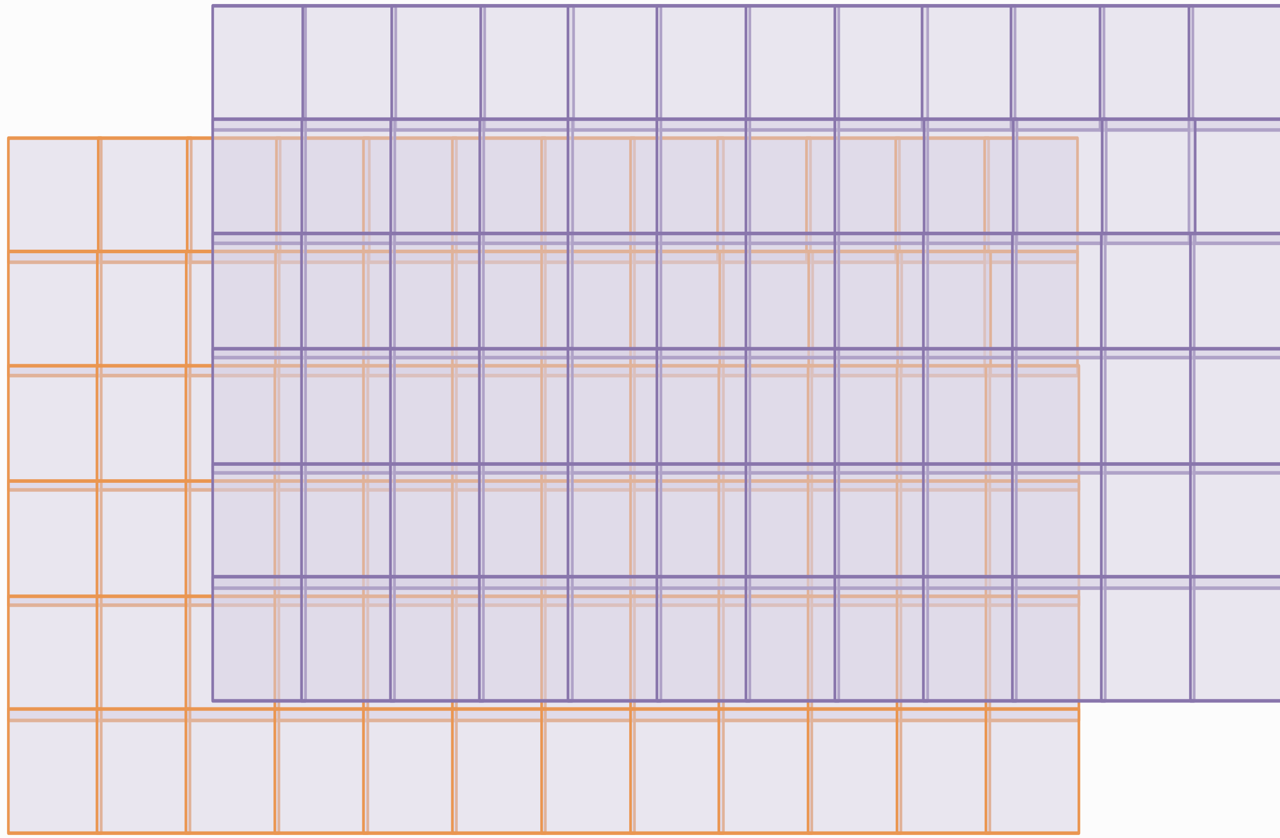






SC: Tiling of the Sky

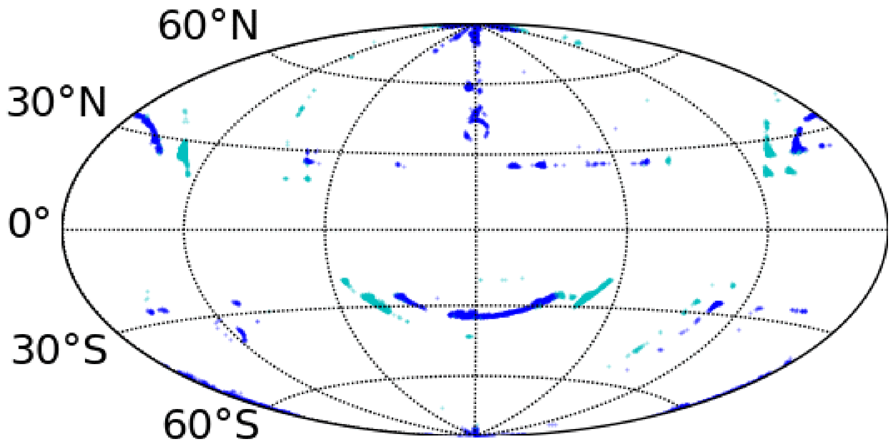


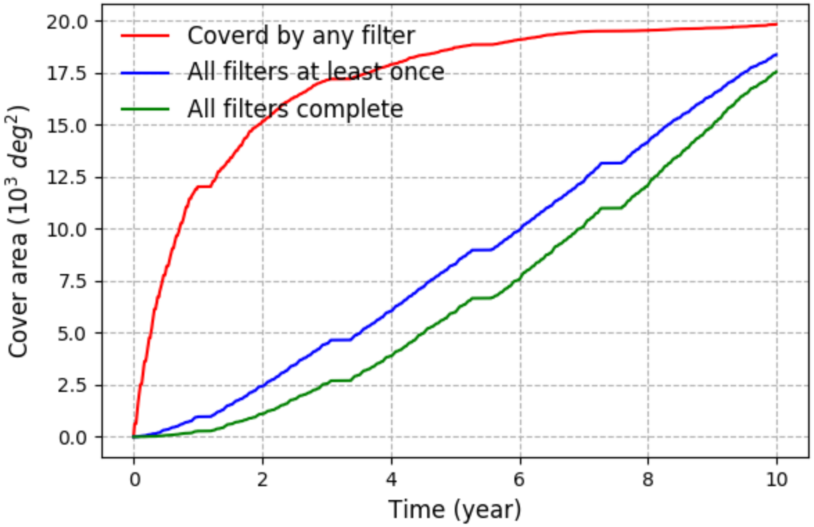


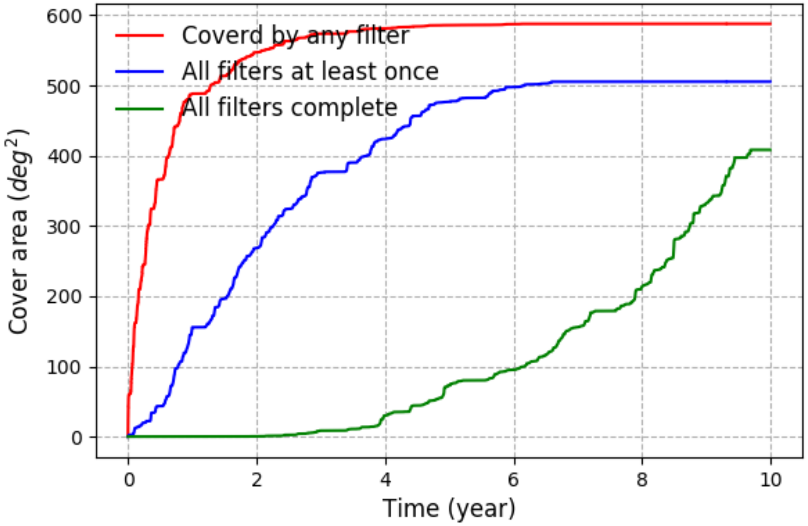
- 10” overlap b/w fields of each chip
- If one chip covers the whole sky, all other chips will also cover the whole sky.
- # of same-type filters = # of visits

SC: Operations Simulations

Baseline 64% orbital time for survey (requesting 70%)

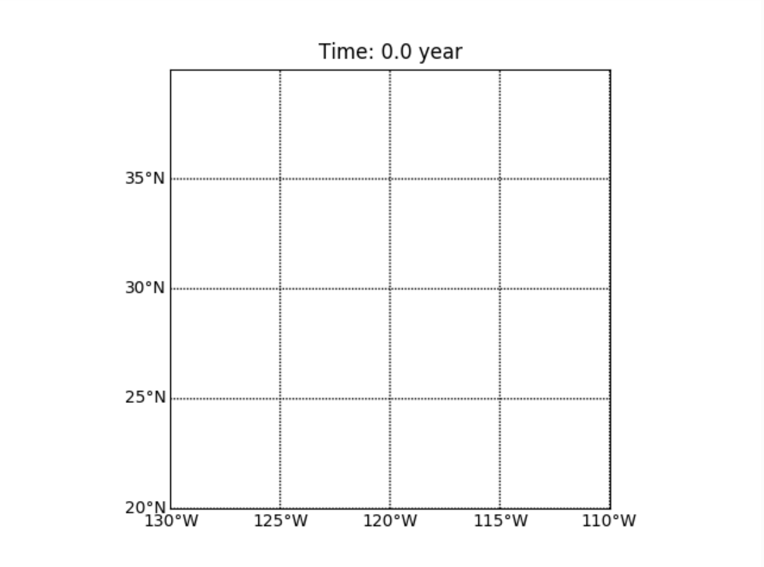


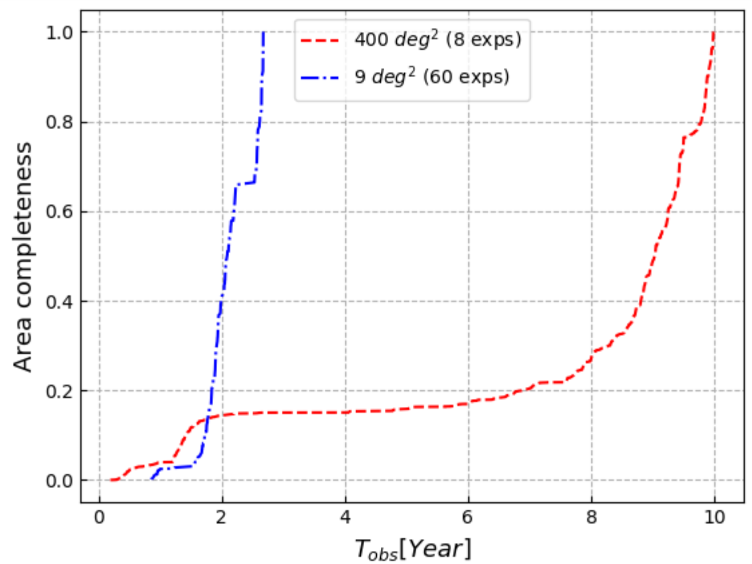


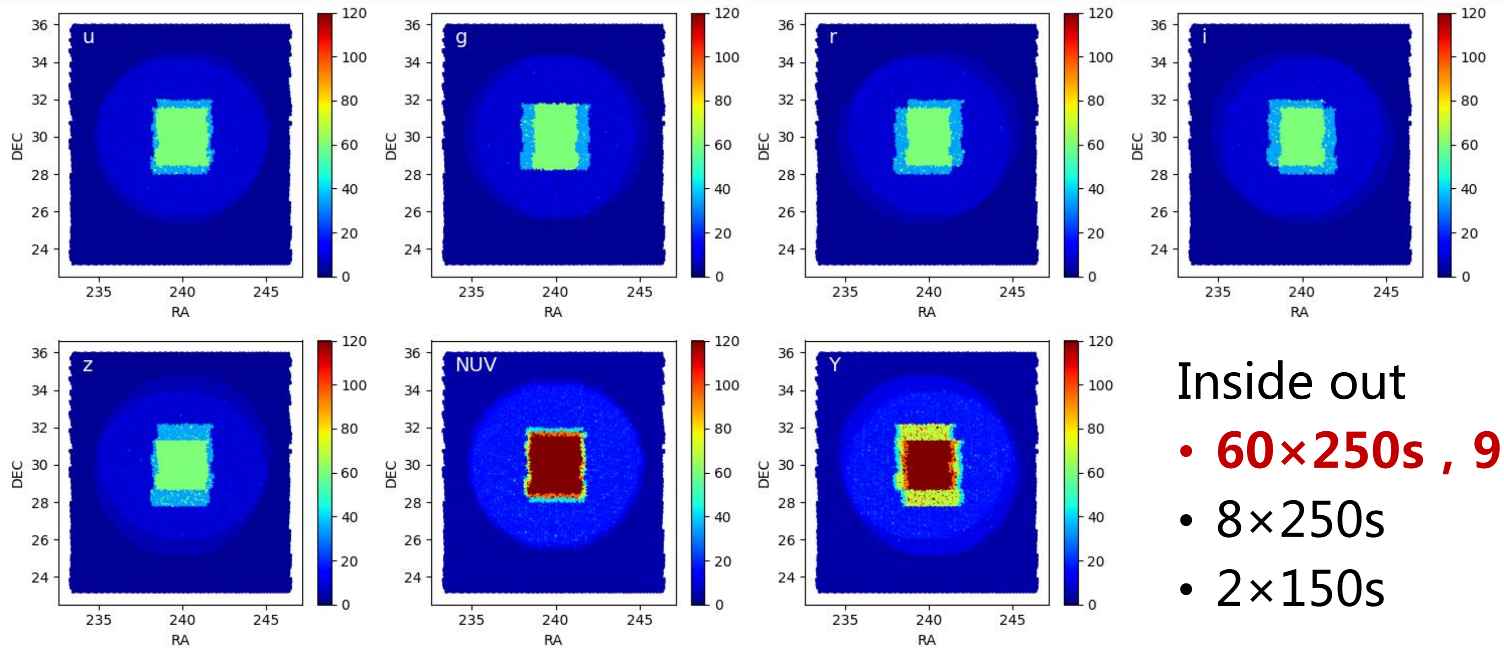


- 10-year coverage in simulation
  - Wide field: 17540 deg^2
  - Deep fields: 408 deg^2
- Most constraining factors: Sun & Earth
- Galactic plane & ecliptic plane can be observed

SC: Ultradeep Field (Demo)



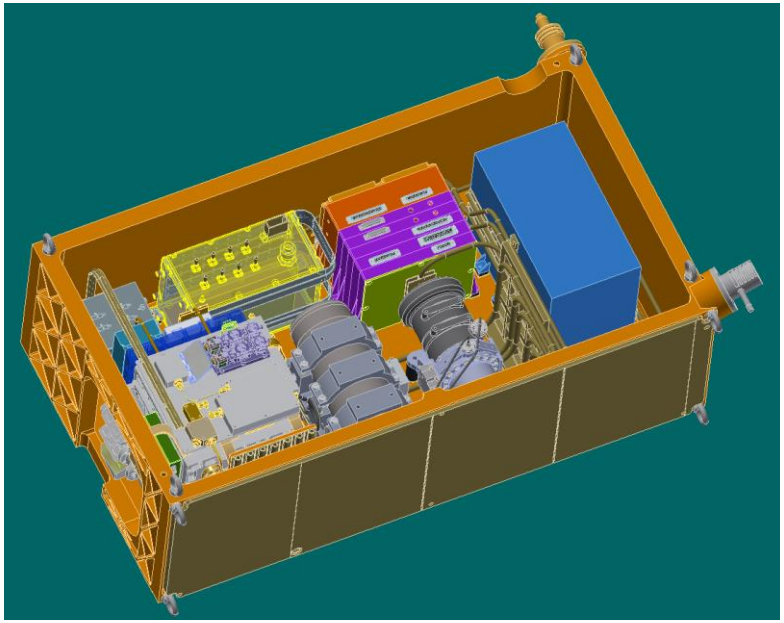


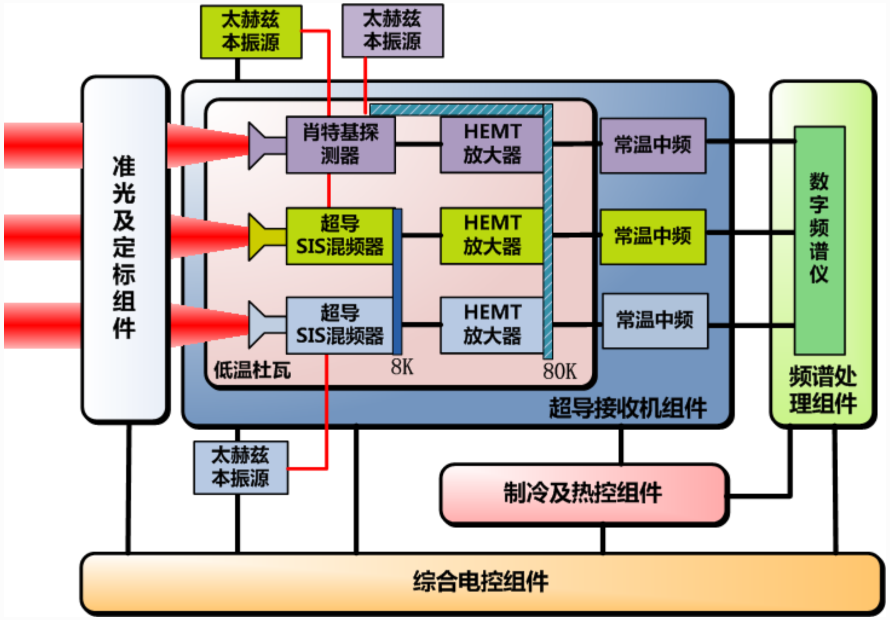


Inside out

- **60×250s , 9□°**
- 8×250s
- 2×150s

Terahertz Receiver

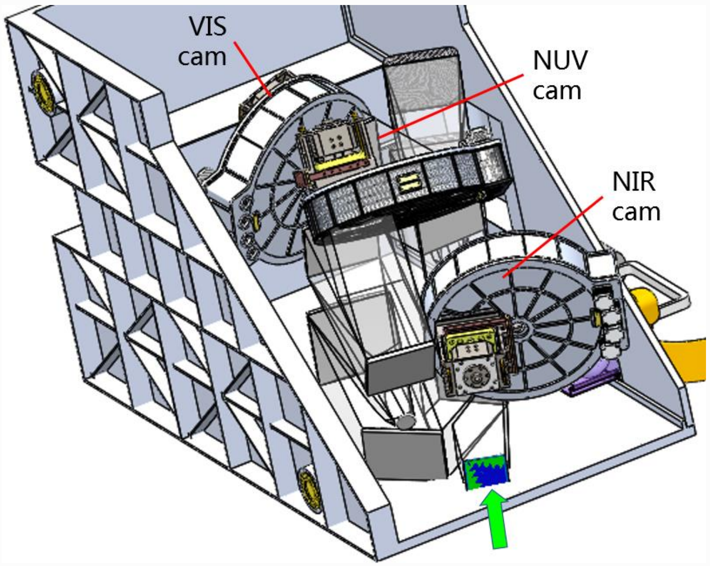




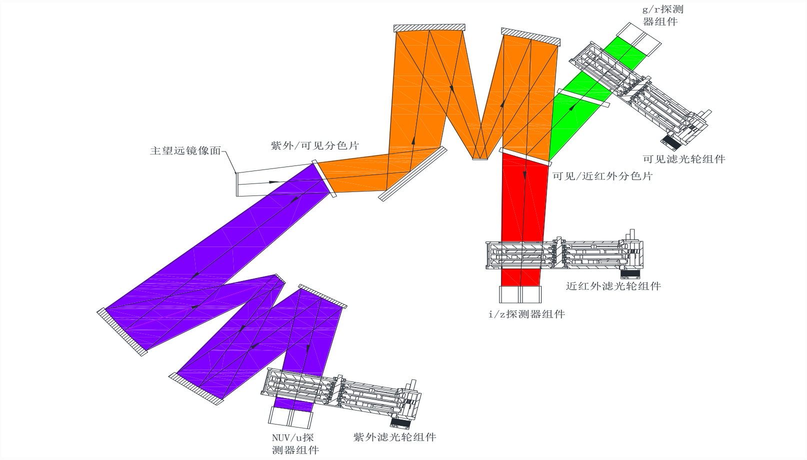
Specifications	
Frequency	0.41-0.51THz
Bandwidth	≥2GHz
Resolution	≥100kHz
Sensitivity	<150mK (200s)
Cryocooling	≥10mW@8K

- **410~510GHz spectral line survey**
  - Searching for new atomic and molecular species and physical & chemical processes
  - Complementary with Herschel (410~480GHz)
- **Carbon cycle (CI, 492GHz)**
  - Evolution of molecular clouds in early-stage
  - Filamentary structure in molecular clouds

Multi-Channel Imager

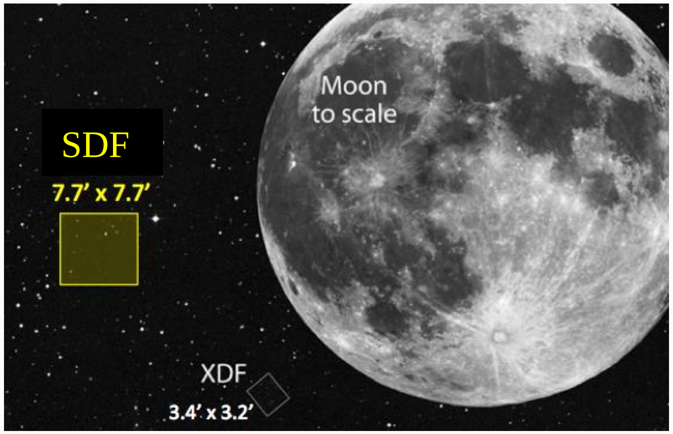


Now integrated with IFS.



- **3-channel simultaneous observation**
  - 0.25-0.43μm (CBU)
  - 0.43-0.7μm (CBV)
  - 0.7-1.0μm (CBI)
- 30 filters to select
- 9Kx9K detectors, 0.05”/pix, FOV ≥7.5’ x 7.5’
- High Precision Photometry (<0.5% , visible) with HST Standards, calibration for the survey camera.

Multi-Channel Imager



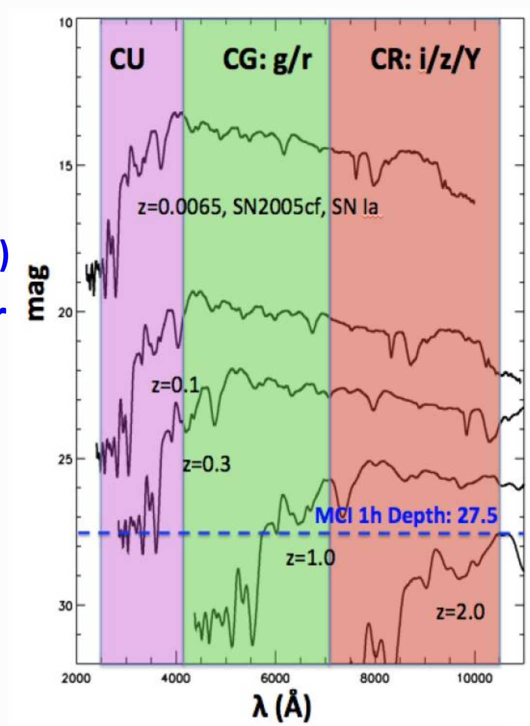
Sciences with (3-filter simultaneous) CSST Super Deep Fields

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

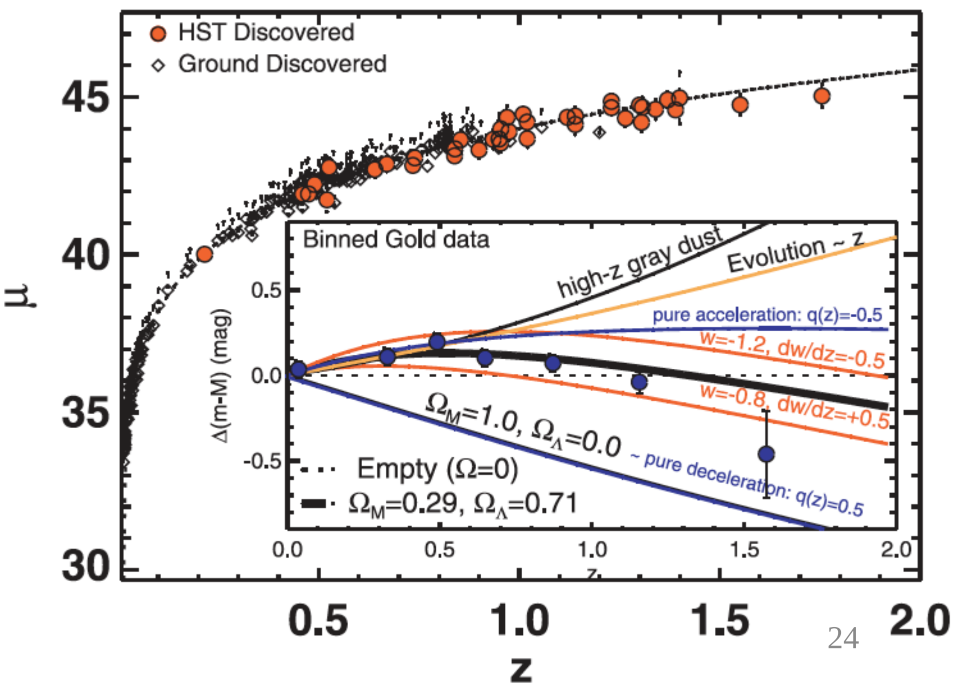
Potential SDFs:

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

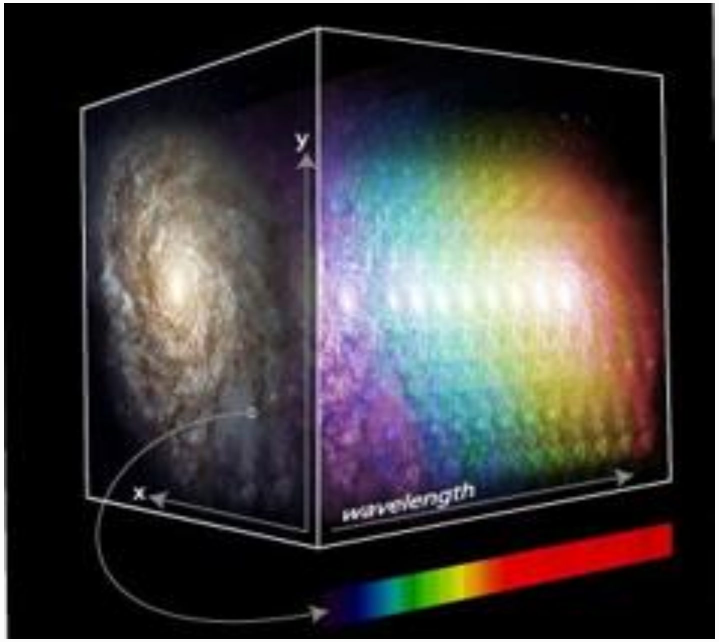
5 fields, 300 □′ tot, CBV ≥30^m (30× HST XDF)



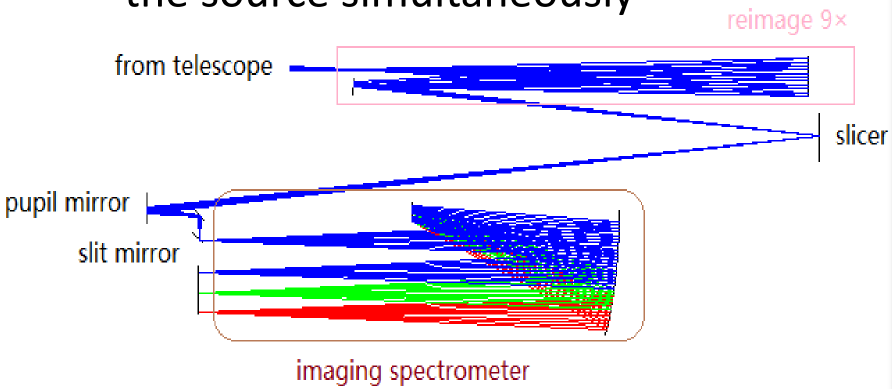
Credit: Adam Riess



Integral Field Spectrograph



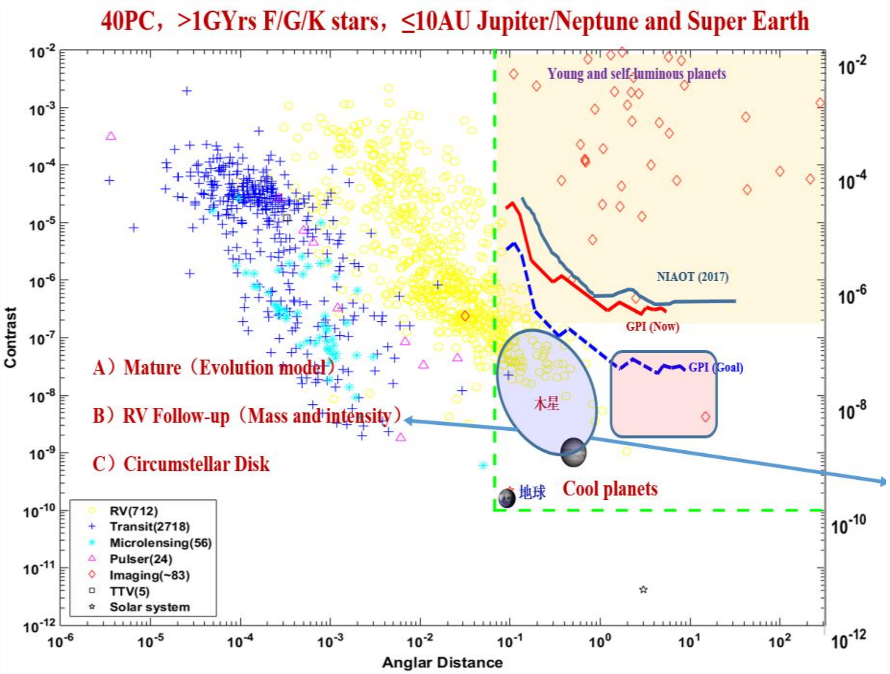
Taking spectra of different parts of the source simultaneously



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

- **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**
- **…**

Cool-Planet Imaging Coronagraph



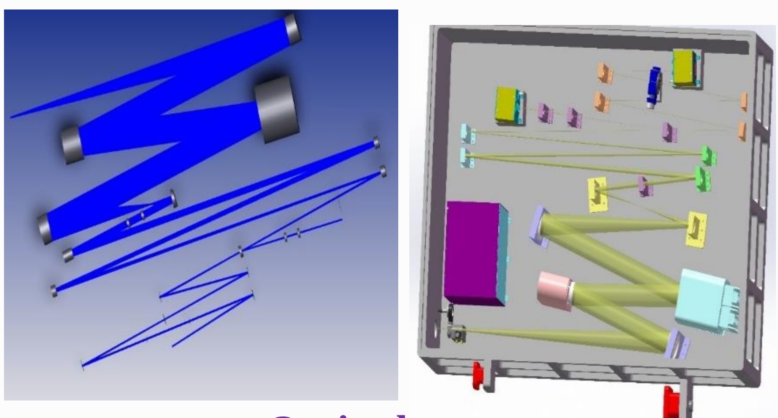
Contrast vs. angular separation

- **Wavelength**： 0.6-0.9μm (goal: 1.6μm)
- **Bandwidth**： 3~10%
- **FOV**： 2.5″×2.5″ obs, 20″×20″ targeting
- **IWA**： ≤0.55″@ 0.63μm
- **Contrast**： 10^{-8} (0.6-0.9μm) or better

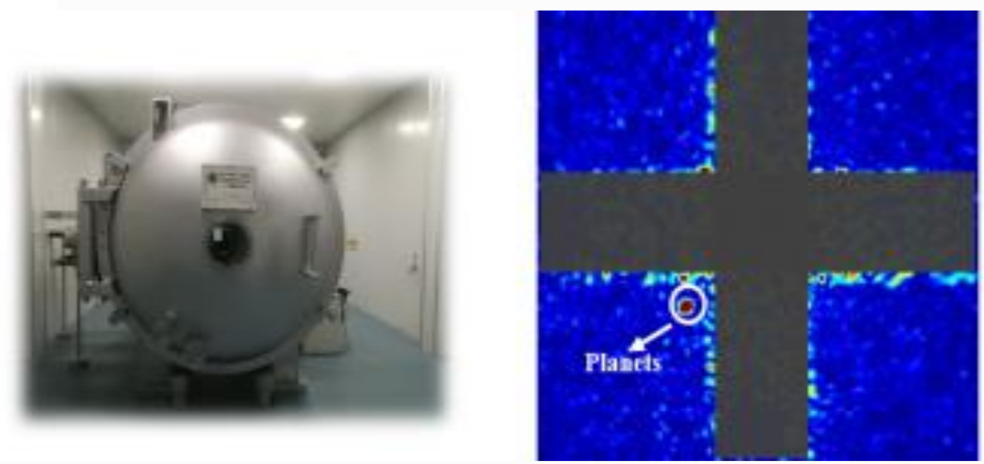
➢ **Searching for mature planets around solar-type stars**

➢ **RV follow up & planet formation & evolution**

➢ **Physics of circumstellar disk**



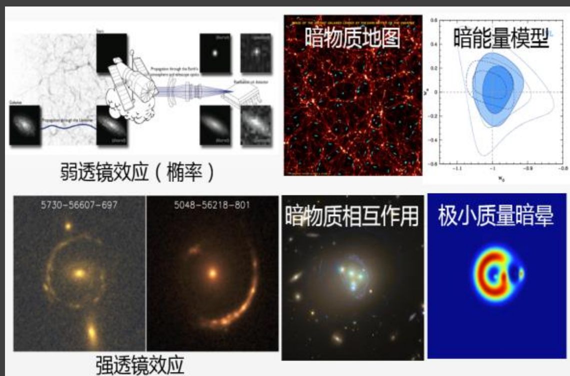
Optics layout



Vacuum chamber test reaching 10^{-9} contrast

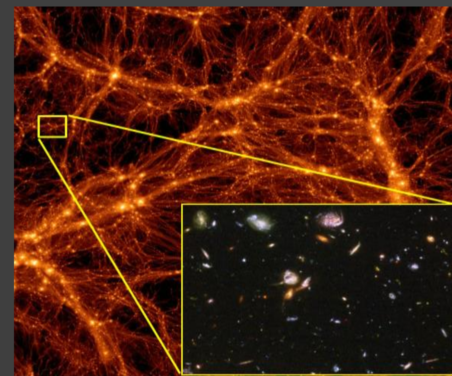
CSST Science

Cosmology：DE & DM



Exploring DM & DE; Testing GR; Measuring H0

Cosmology：LSS

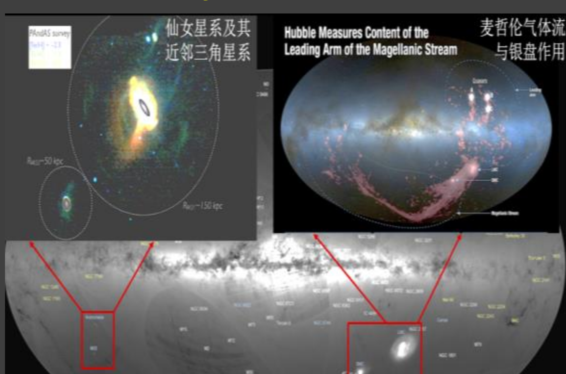


Mapping 3D galaxy distribution; Probe evolution of LSS

Galaxy & AGN

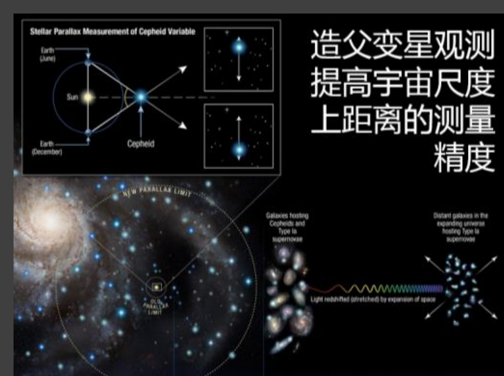
Constructing and studying high-z galaxy and AGN samples

Nearby Universe & Stars



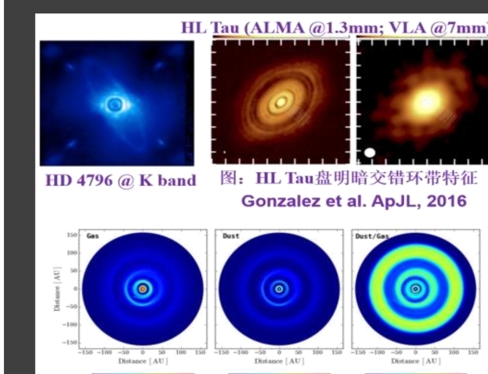
Illustrating str. and evo. of Milky way & nearby galaxies; Studying stellar physics

Astrometry, solar sys. & transient



Improving astrometry accuracy; Detecting SSSBs & transient objects

Exoplanet

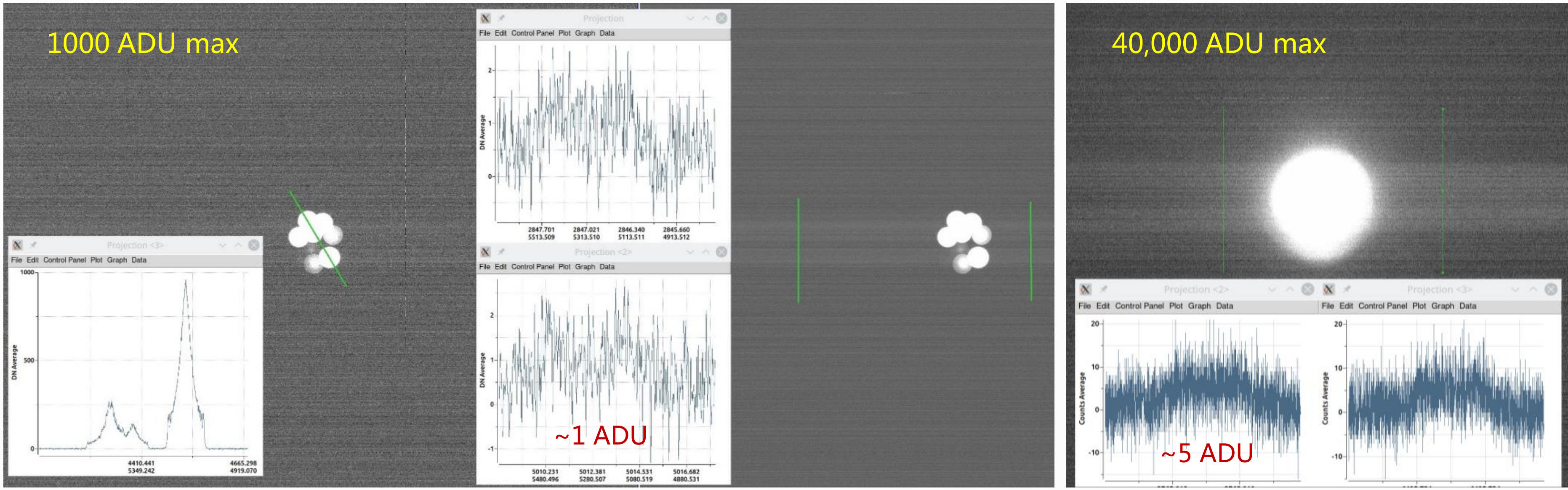


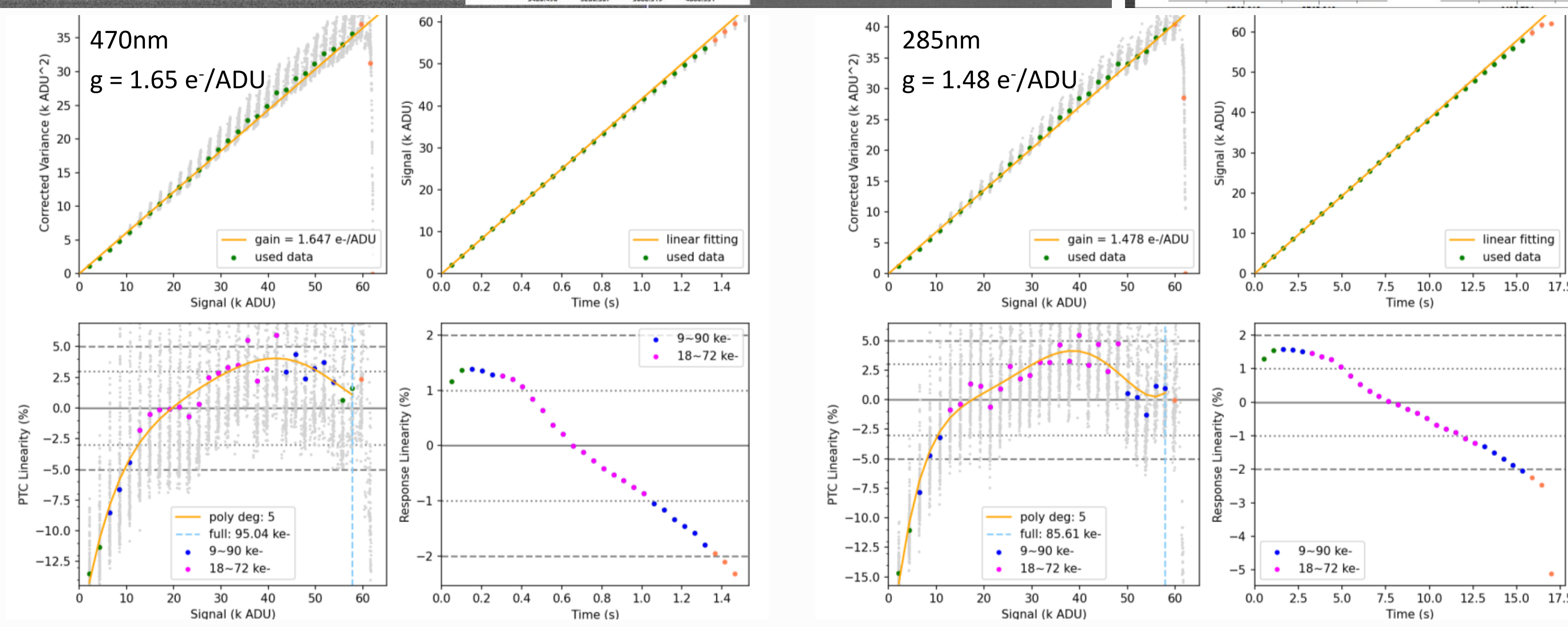
Probing and studying Exoplanets

Comments on CMOS Sensors for UV

- Fast readout: good for time domain studies
- RN ~ few e^-/pix: good for low background obs, i.e. UV
- UV photons convert into electrons in a very thin layer of Si, good match with CMOS processes.
- Potential issues
  - Image lag (maybe OK with more resets)
  - Intrapixel effects (depends on design and sampling)
  - Gain nonuniformity between pixels
  - Nonlinearity of photon transfer curve (signal-variance)
  - Apparent gain variation with wavelength derived from PTC
  - Interpixel coupling (optical & electrical)
  - Crosstalk over the whole row or column
  - Radiation (latch-up, dark current, …)

Examples of Sensor Effects






Thank you!