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S. Toft, I. Davidson (Copenhagen), P. Capak (Caltech), B. Mobasher (UCRiverside)



The Evolution of Massive Galaxies at $3 < z < 7$ (The Hawaii 20 deg² Survey – H2O)

Dave Sanders
Institute for Astronomy
University of Hawaii

Hawaii Two-0

A 20 deg² deep Subaru Hyper-SuprimeCam imaging and Keck LRIS + MOSFIRE spectroscopic survey of the two primary Euclid Deep Calibration Fields (NEP and CDFS).

[Read the abstract](#)

Keck LRIS+MOSFIRE



Subaru HSC



University of Hawaii • Institute for Astronomy
Research Proposal—Observing Time Request

Name: Sanders, D. B.

Proposal Number:

E-mail: sanders@ifa.hawaii.edu

Semester: A Year: 2018

Institution/Dept (if not IfA): IfA

PROGRAM TITLE(S) (*one line per program*)

A. Hawaii Two-0 (H20)

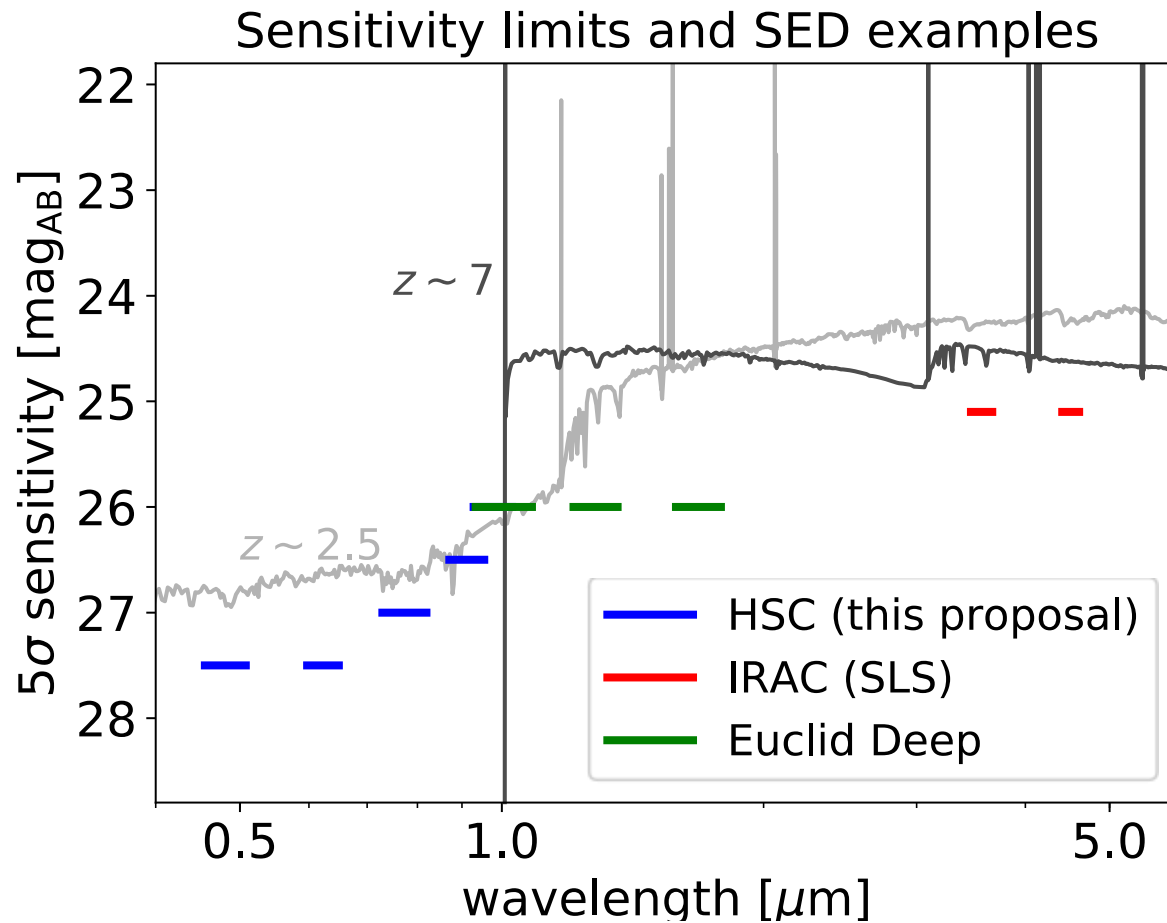
B.

C.

ABSTRACT(S) (*one single abstract or one abstract per program*)

A. We propose the Hawaii Two-0 (H20) survey, which will help to put Hawaii at the forefront of galaxy evolution studies for the next decade or more. This will be achieved by carrying out a 20 deg² deep Subaru Hyper-SuprimeCam (HSC) imaging and Keck LRIS + MOSFIRE spectroscopic survey of the two primary *Euclid* Deep Calibration Fields (NEP and CDFS). These two 10 deg² fields are the targets of the largest allocation of *Spitzer* time ever granted (~ 5300 h) and will be the targets of ultra-deep 1–2 μ m photometry and spectroscopy by the *Euclid* mission scheduled to launch in early 2021. The H20 data will permit immediate science investigations at $z < 7$ using the HSC+*Spitzer* data and will give Hawaii priority for $z > 7$ science once *Euclid* launches.

The proposed program spans 3 years (6 semesters). The first two years consists of 30 nights of HSC (*grizy*) imaging to cover both fields. In the final year of the program we request 5 nights of Keck-LRIS and 5 nights of Keck-MOSFIRE time to obtain spectroscopy of high-redshift sources selected from the Imaging Survey. The spectroscopy will be critical for verifying the photometric redshifts, for characterizing rare and interesting sources, and for selecting targets for follow-up with ALMA and JWST.



Sensitivity limits in the HSC filters of H2O (blue), along with the IRAC ch. 1 and 2 from our ongoing SLS program (red) and the designed NIR filters of Euclid (green). Light and dark grey lines show spectral energy distributions (SEDs) of two galaxies at $z=2.5$ and 7 respectively, which the deep H2O imaging will be able to disentangle. To confirm and characterize this differentiation the proposed Keck follow-up is essential.

H2O website: <https://project.ifa.hawaii.edu/h20/>

H2O SCIENCE

Goals

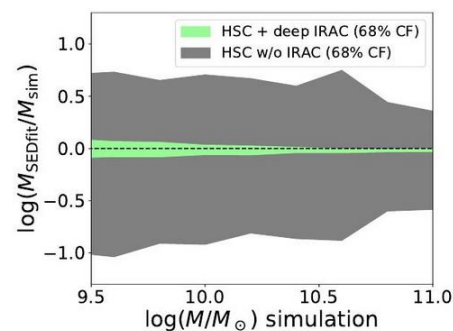
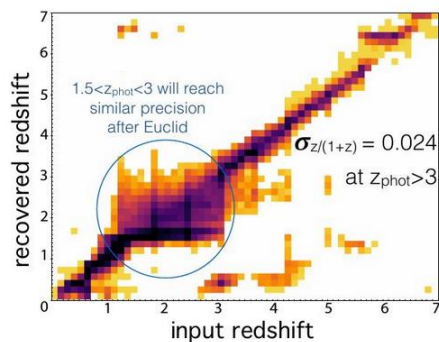
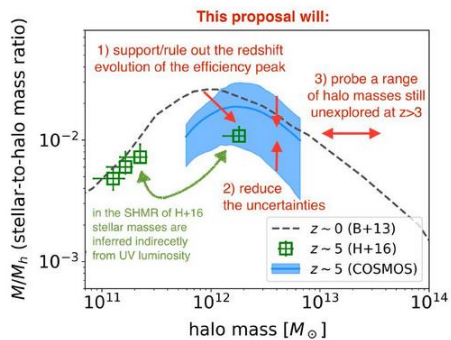
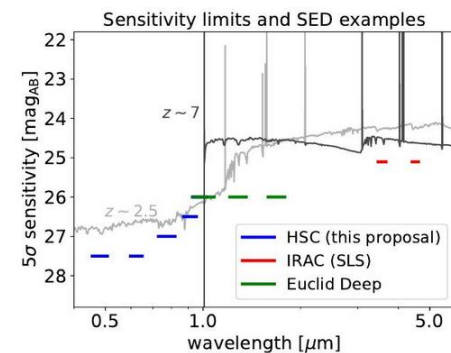
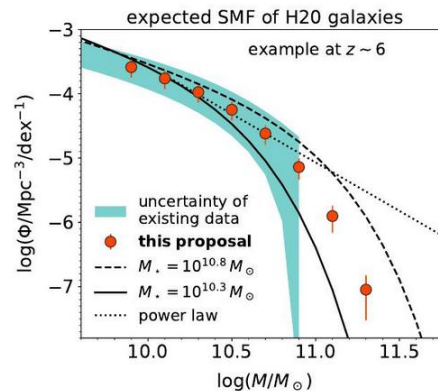
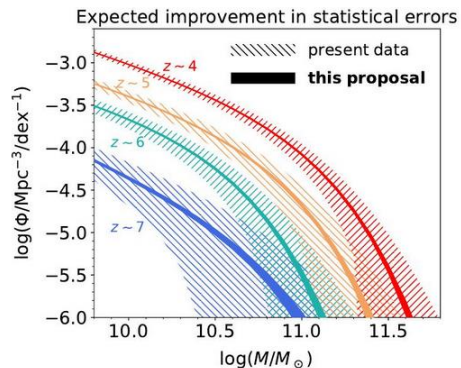
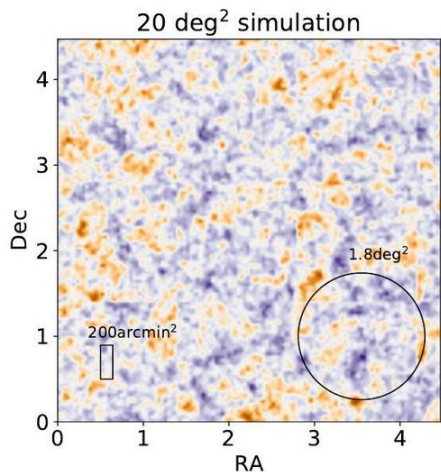
- Probe the assembly of massive galaxies by tracing the evolution of their stellar mass function with $>500,000$ galaxies at $3 < z < 6$ and including several thousand at $z > 6$.
- Link the stellar mass of galaxies to their dark matter halos via clustering, for testing of cosmological models.
- Constrain the properties of dark energy using the non-linear power spectrum at high-redshift.
- Identify the earliest sites of galaxy formation and reionization, and spectroscopically confirm high-escape fraction candidates.
- Identify and confirm the first galaxies to quench their star formation.

Synergy with other surveys

- Spitzer — Spitzer Legacy Survey
- Euclid — Deep Calibration Fields
- WFIRST — Likely to be target of WFIRST deep surveys.

H2O website: <https://project.ifa.hawaii.edu/h2o/>

Research



Subaru HSC Imaging Depths

g	r	i	z	y	J,H,K [☆]	ch.1 [†]	ch.2 [†]
27.5	27.5	27	26.5	26	26	24.8	24.7

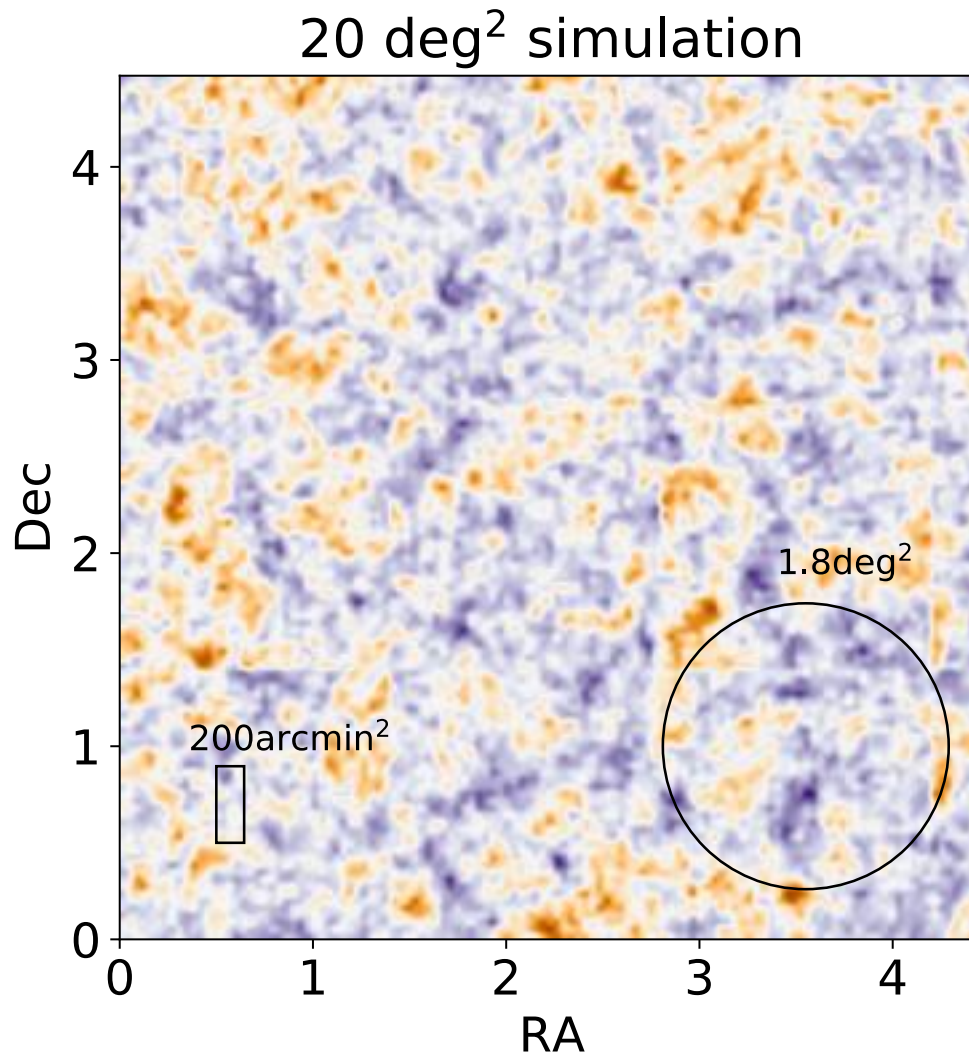
☆ From Euclid Deep (operations start in 2021). WFIRST will also cover this area at 26 mag 10σ (operations start mid-2020s).

† From the Euclid/WFIRST Spitzer Legacy Survey ([ADS](#))

Subaru-HSC
***grizy* mag_{AB} (5 σ)**

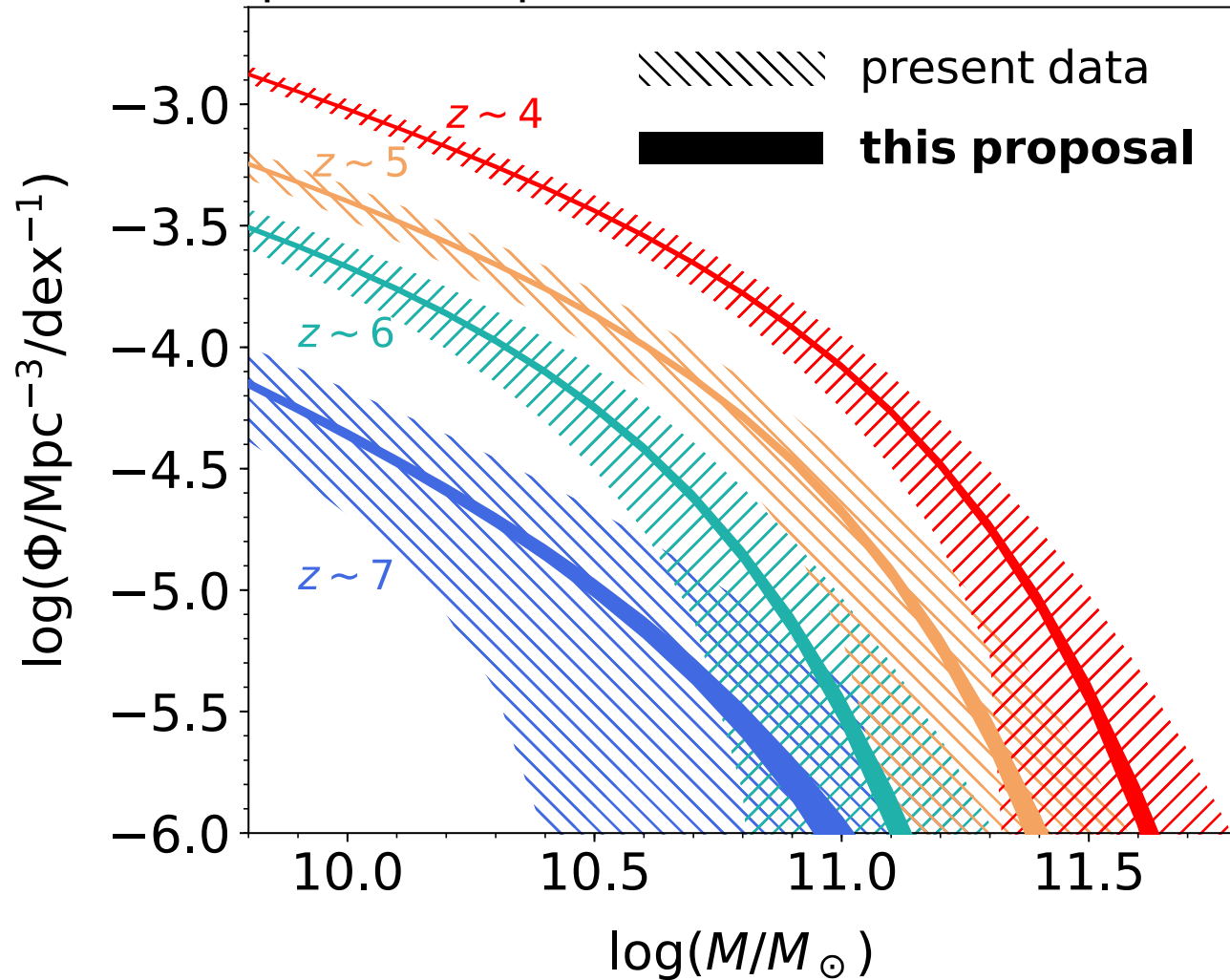
	<i>g</i>	<i>r</i>	<i>i</i>	<i>z</i>	<i>y</i>
	27.5	27.5	27.0	26.5	26.0
Hrs	1.1	2.5	4.1	4.8	9.0

(Total = ~21 Hrs per pointing)



Dark matter density map at $4:3 < z < 5:3$ over 20 deg², from the Millennium Simulation (Springel+05), while small rectangle and circle are comparable to CANDELS and COSMOS respectively. Only H2O has the statistical power to study the rare overdensity peaks (dark orange) and cosmic voids (dark purple) as well as characterizing the overall density field needed for cosmology.

Expected improvement in statistical errors



Galaxy stellar mass functions with 1σ statistical errors from existing (hatched) and proposed (solid) data. H20 will improve the constraints by a factor of > 10 , thus allowing us to make a more definitive measurement of the overall mass function, link it to the dark matter via clustering, and characterize differences as a function of local environment.

The H20 and Spitzer Legacy Survey

- Spitzer Legacy Survey (**SLS**) designed to complement
WFIRST and Euclid (PI: P. Capak)
- 20 deg² in NEP and CDFS (Fornax)
- Can see $10^{9.5}$ solar mass galaxies to $z \sim 8$ (3σ)
- **Spitzer Data 100% complete**
- Approved Hawaii Large program (**H20**) (PI: D. Sanders)
 - 30 N of Subaru-HSC imaging to complement SLS
 - 10 Nights of Keck-DEIMOS for high- z galaxies
 - **H20 Data ~60% complete**

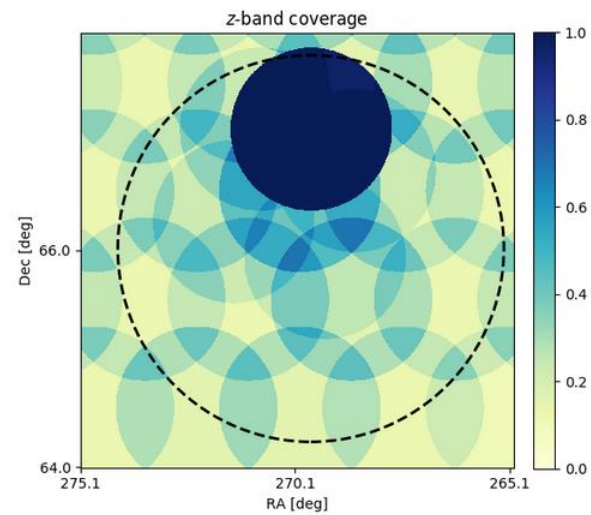
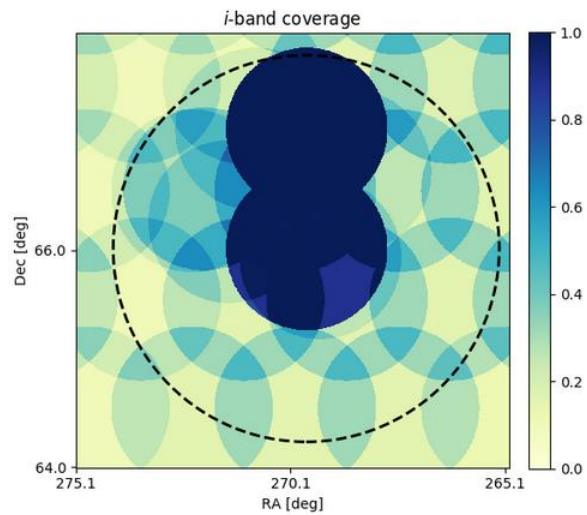
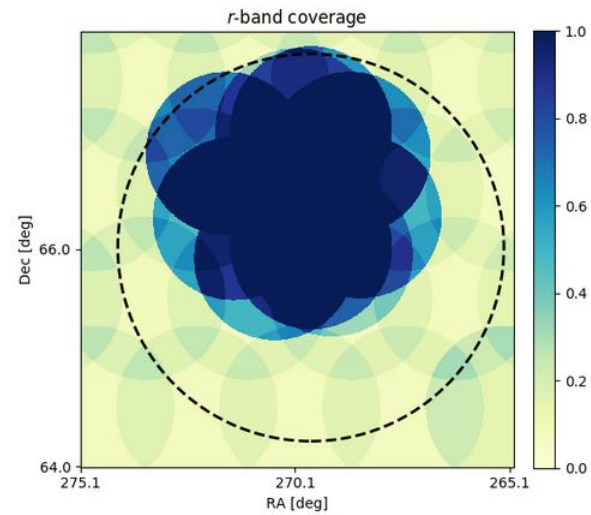
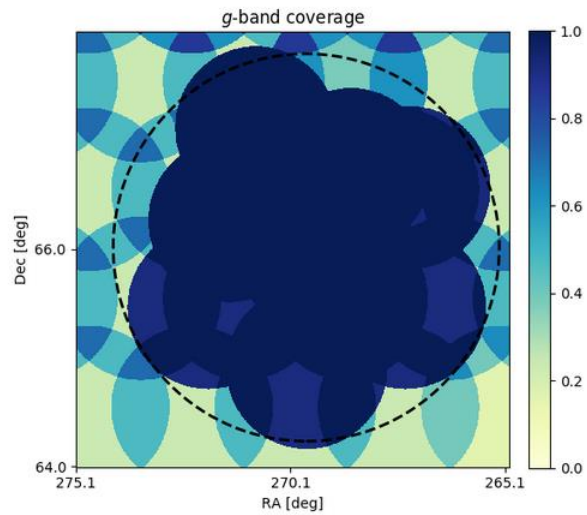
Hawaii Two-0 Progress Report

Current status of Hawaii Two-0 data collection including NEP archival data (AKARI & HEREOS) and CDFS archival data (miscellaneous). Note these percentages reflect completion of H2O in the *griz*-bands (i.e. after descopring by removing Y-band).



NEP HSC Coverage

The dashed white circle indicates the boundary of the NEP H20 coverage. Total enclosed area is ~ 10 square degrees.

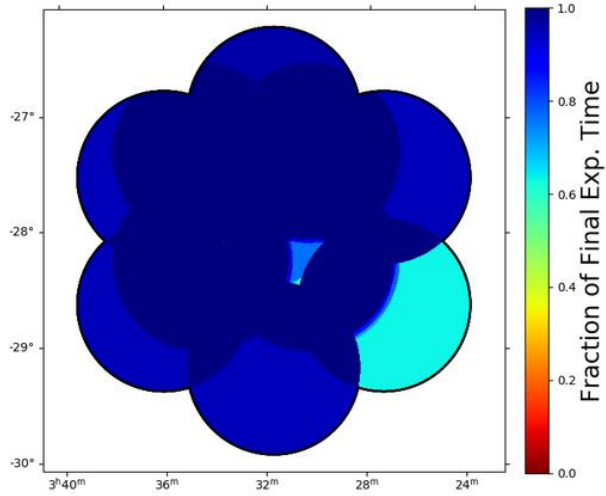


HSC Coverage Maps

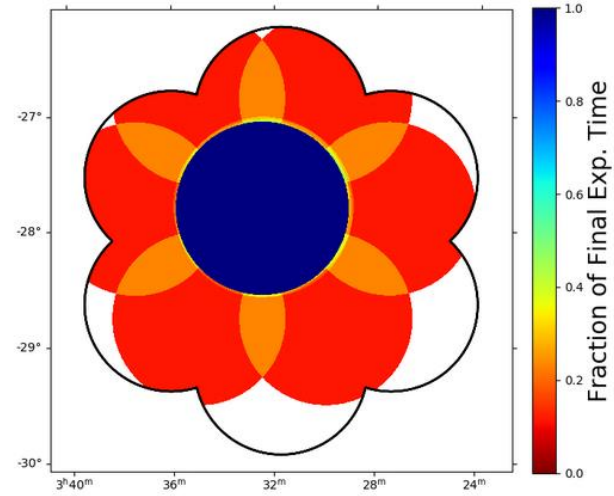
CDFS HSC Coverage

The solid black line indicates the boundary of the CDFS H20 coverage. Total enclosed area is ~ 10 square degrees.

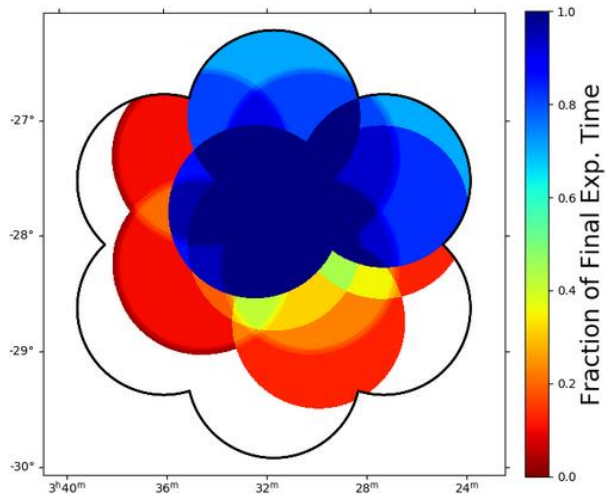
CDFS g-band



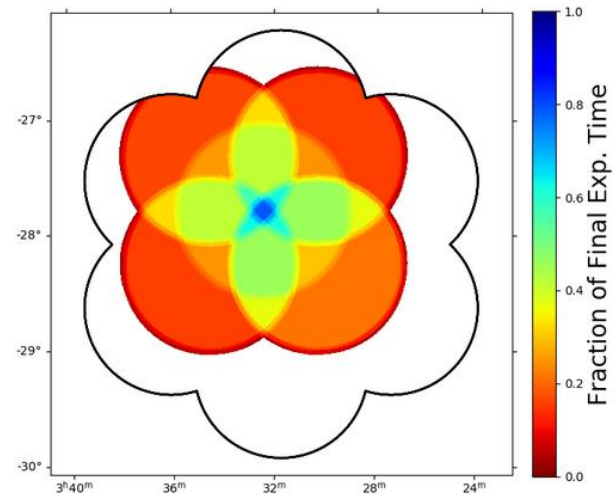
CDFS r-band



CDFS i-band



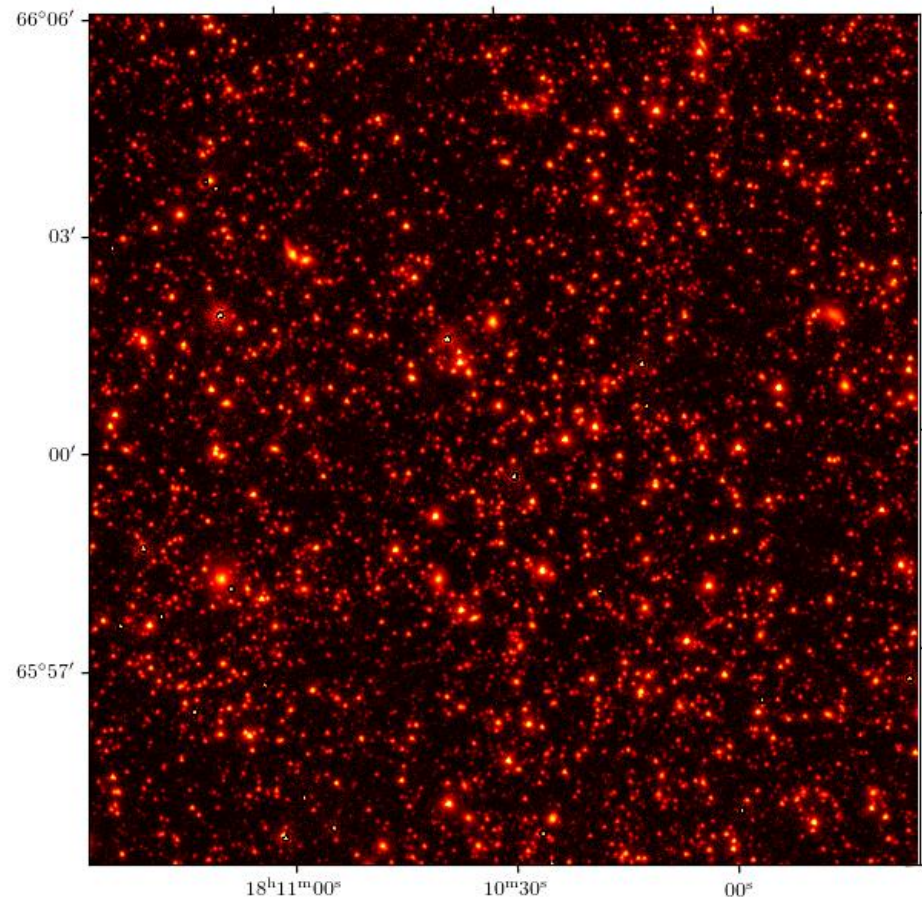
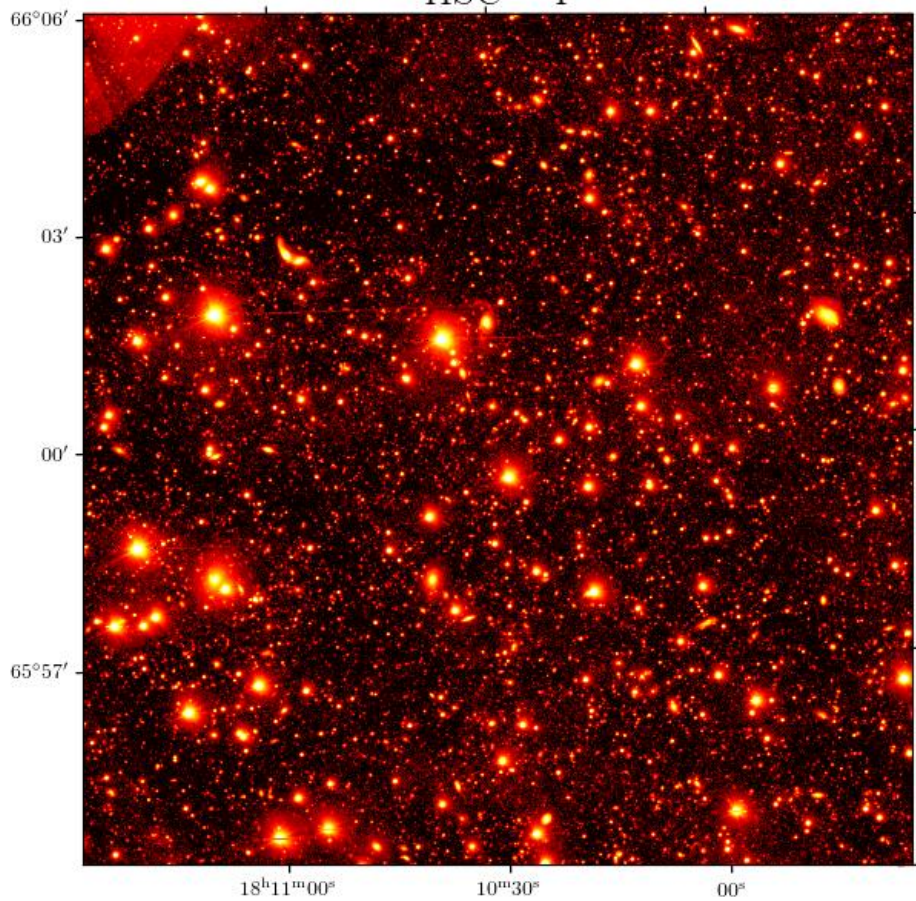
CDFS z-band



NEP 12' x 12' H20+SLS full depth

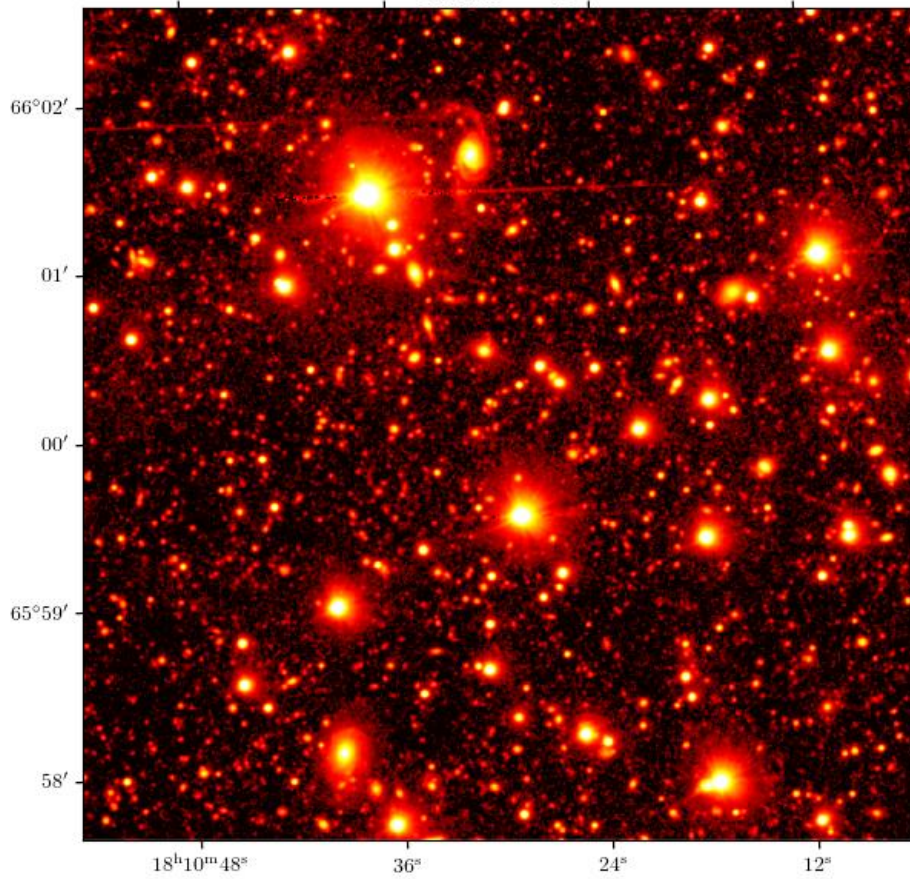
HSC - I

IRAC ch1

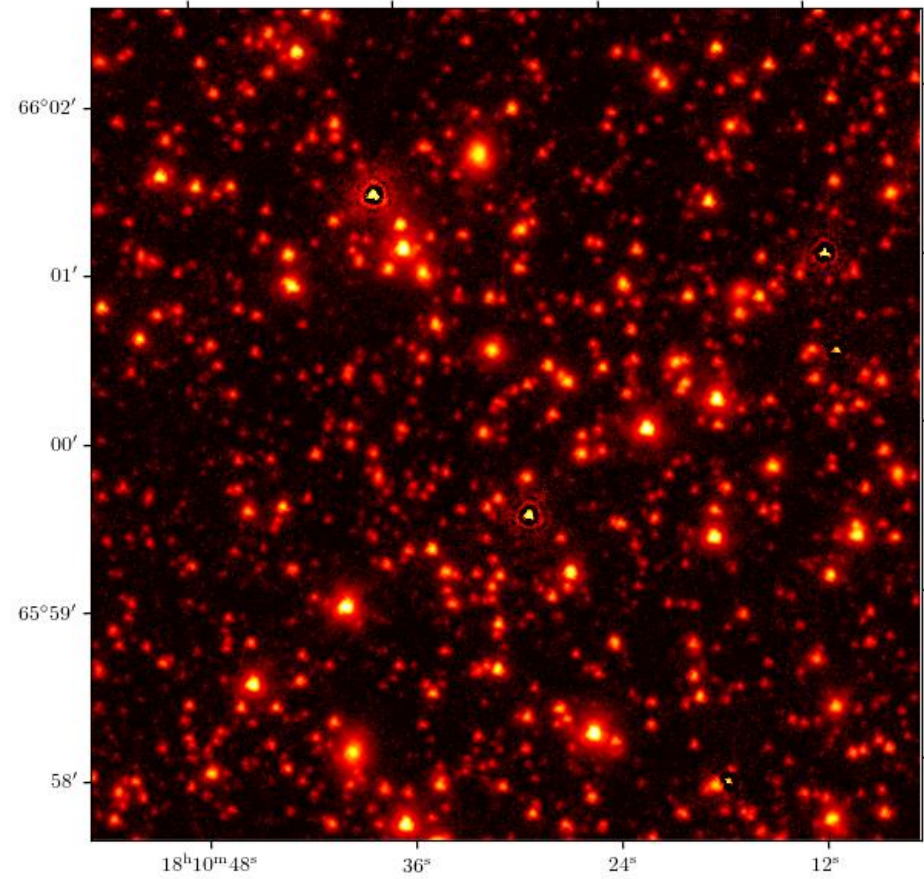


NEP 5' x 5' H2O+SLS full depth

HSC - I



IRAC ch1



Test plan

- > **Combine existing HSC (*grizy*) imaging of the COSMOS Field to simulate the H2O depths:**

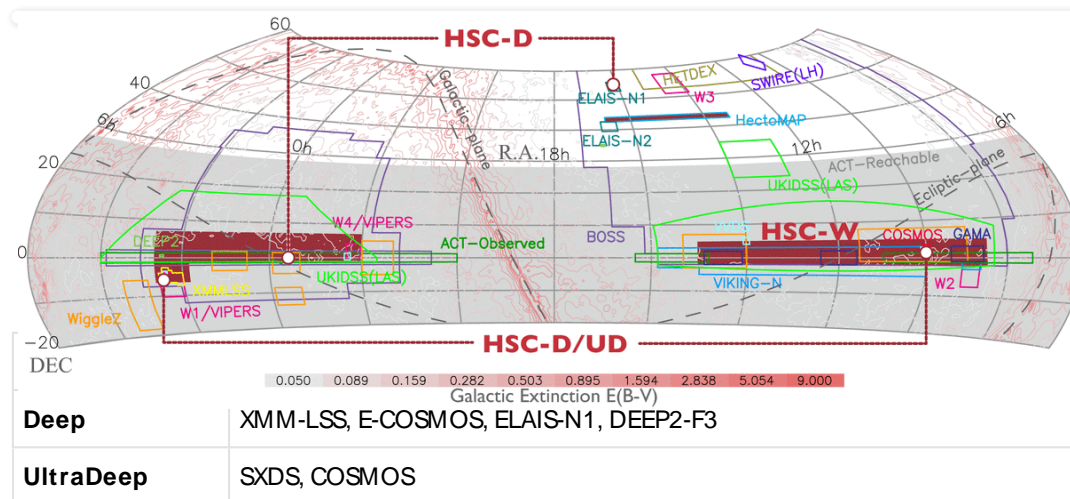
1. Subaru Strategic Survey Program (SSP-COSMOS)
- +
2. IfA-Hawaii COSMOS-HSC imaging

Hyper Suprime-Cam Subaru Strategic Survey in a Nutshell

The HSC-SSP is a three-layered, multi-band (*grizy* plus 4 narrow-band filters) imaging survey with the Hyper Suprime-Cam (HSC) on the 8.2m Subaru Telescope. HSC has 104 science CCDs covering a 1.5 degree diameter field of view with a 0.168 arcsec pixel scale. The delivered image quality is excellent across the field of view; the median seeing in the i-band is about 0.6 arcsec. Each of the Wide, Deep, and UltraDeep layer covers 1400 deg² (*r*~26), 27 deg² (*r*~27), and 3.5 deg² (*r*~28), respectively. By combining data from these layers, we address some of the most pressing problems in modern cosmology and astrophysics with a particular focus on gravitational weak lensing, galaxy evolution, supernovae, and galactic structure. The survey is uniquely designed to enable various science cases, with particular attention to controlling systematic errors. The survey is awarded 300 nights over 5-6 years and it started in March 2014.

Layer	Area (deg ²)	# of 1.8deg ² HSC fields	Filters & Depth
Wide	1400	916	<i>grizy</i> (<i>r</i> ~ 26)
Deep	27	15	<i>grizy</i> +3NBs (<i>r</i> ~ 27)

Survey Fields



Subaru-HSC COSMOS **Test stack**
g r i z y mag_{AB} (5 σ)

H2O:	27.5	27.5	27.0	26.5	26.0
IfA+SSP:	27.8	27.7	27.6	26.8	26.2
SSP-Ono+18:	27.13	26.84	26.46	26.10	25.28



COSMOS (SSP+IfA)

FOV = 5' x 5'

H2O depth

Subaru-HSC

grizy-band

~ 21Hrs



COSMOS (SSP+IfA)

FOV = 5' x 5'

H2O depth

Subaru-HSC

g-band

27.8 mag (5 σ)



COSMOS (SSP+IfA)


FOV = 5' x 5'


H2O depth

Subaru-HSC

g-band

27.8 mag (5 σ)

 *r*-dropout
($z \sim 5$)

 *i*-dropout
($z \sim 6$)



COSMOS (SSP+IfA)

FOV = 5' x 5'

H2O depth

Subaru-HSC

r-band

27.7 mag (5 σ)



HSC COSMOS


H20 Depth


FOV = 5' x 5'

Subaru-HSC

r-band

27.7 mag (5 σ)

 *r*-dropout
($z \sim 5$)

 *i*-dropout
($z \sim 6$)



COSMOS (SSP+IfA)

FOV = 5' x 5'

H2O depth

Subaru-HSC

i-band

27.6 mag (5 σ)



COSMOS (SSP+IfA)


FOV = 5' x 5'


H2O depth

Subaru-HSC

***i*-band**

27.6 mag (5 σ)

 *r*-dropout
($z \sim 5$)

 *i*-dropout
($z \sim 6$)



COSMOS (SSP+IfA)

FOV = 5' x 5'

H2O depth

Subaru-HSC

z-band

26.8 mag (5 σ)



COSMOS (SSP+IfA)


FOV = 5' x 5'


H2O depth

Subaru-HSC

z-band

26.8 mag (5 σ)

 *r*-dropout
($z \sim 5$)

 *i*-dropout
($z \sim 6$)



COSMOS (SSP+IfA)

FOV = $5' \times 5'$

H2O depth

Subaru-HSC

y-band

26.2 mag (5σ)



COSMOS (SSP+IfA)


FOV = 5' x 5'


H2O depth

Subaru-HSC

y-band

26.2 mag (5 σ)

 *r*-dropout
($z \sim 5$)

 *i*-dropout
($z \sim 6$)

HSC-COSMOS (H20 Depth)

r-band dropouts ($z \sim 5$)

g

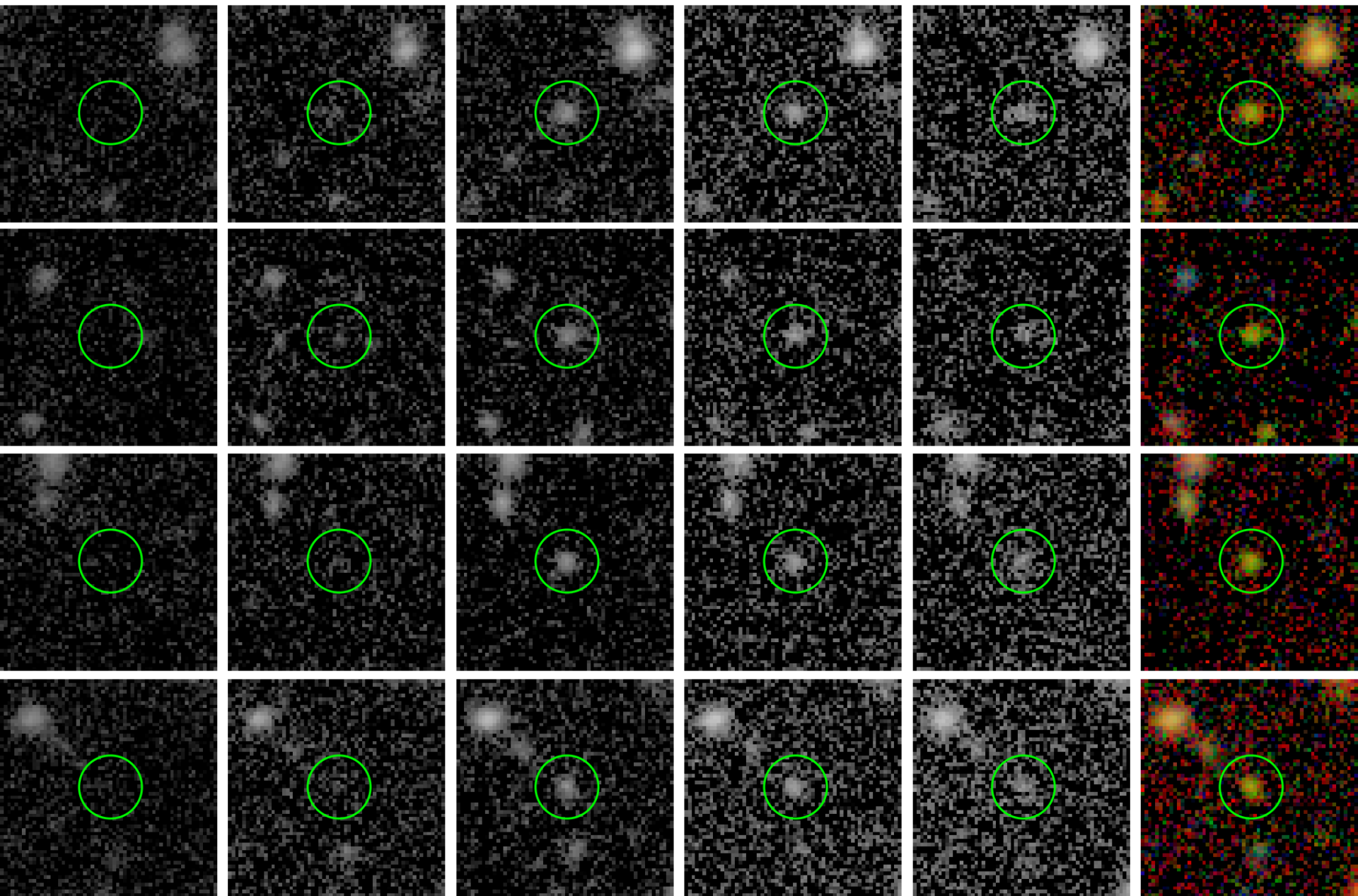
r

i

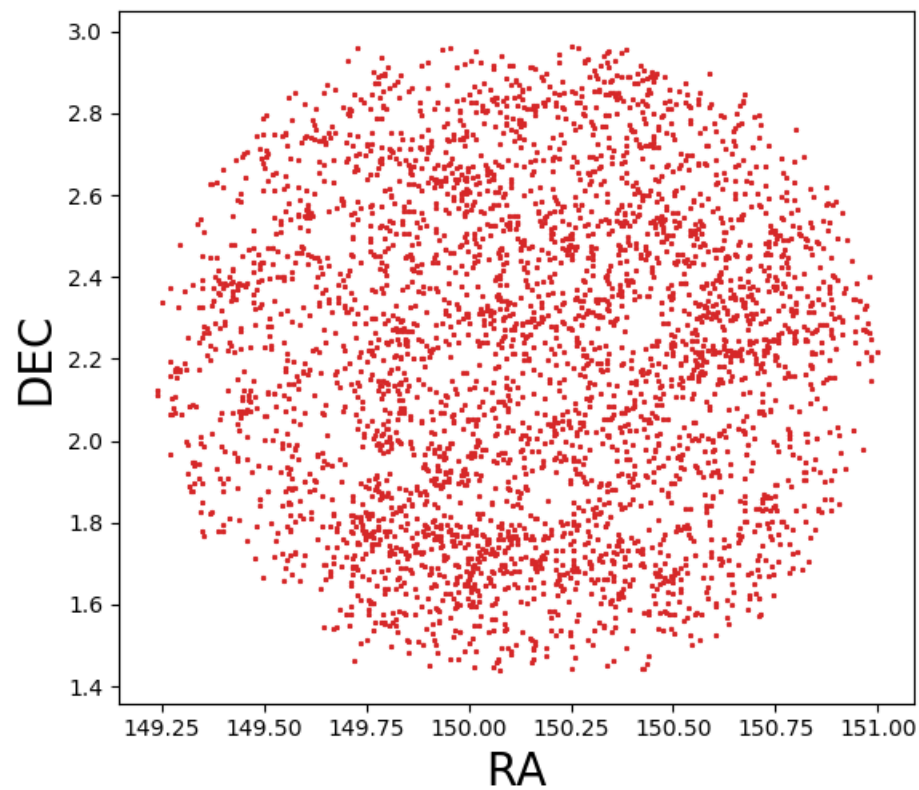
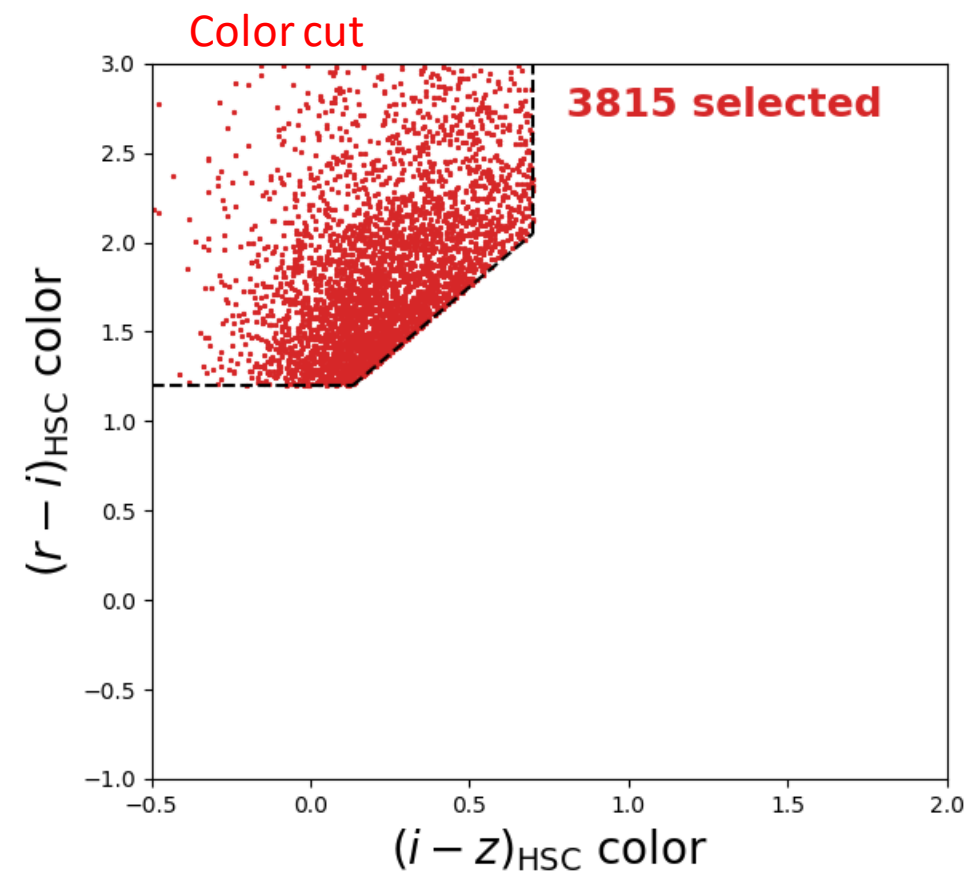
z

y

grizy



COSMOS r -band dropouts



HSC-COSMOS Deep (16Hrs) (*i*-band dropouts $z \sim 6$)

g

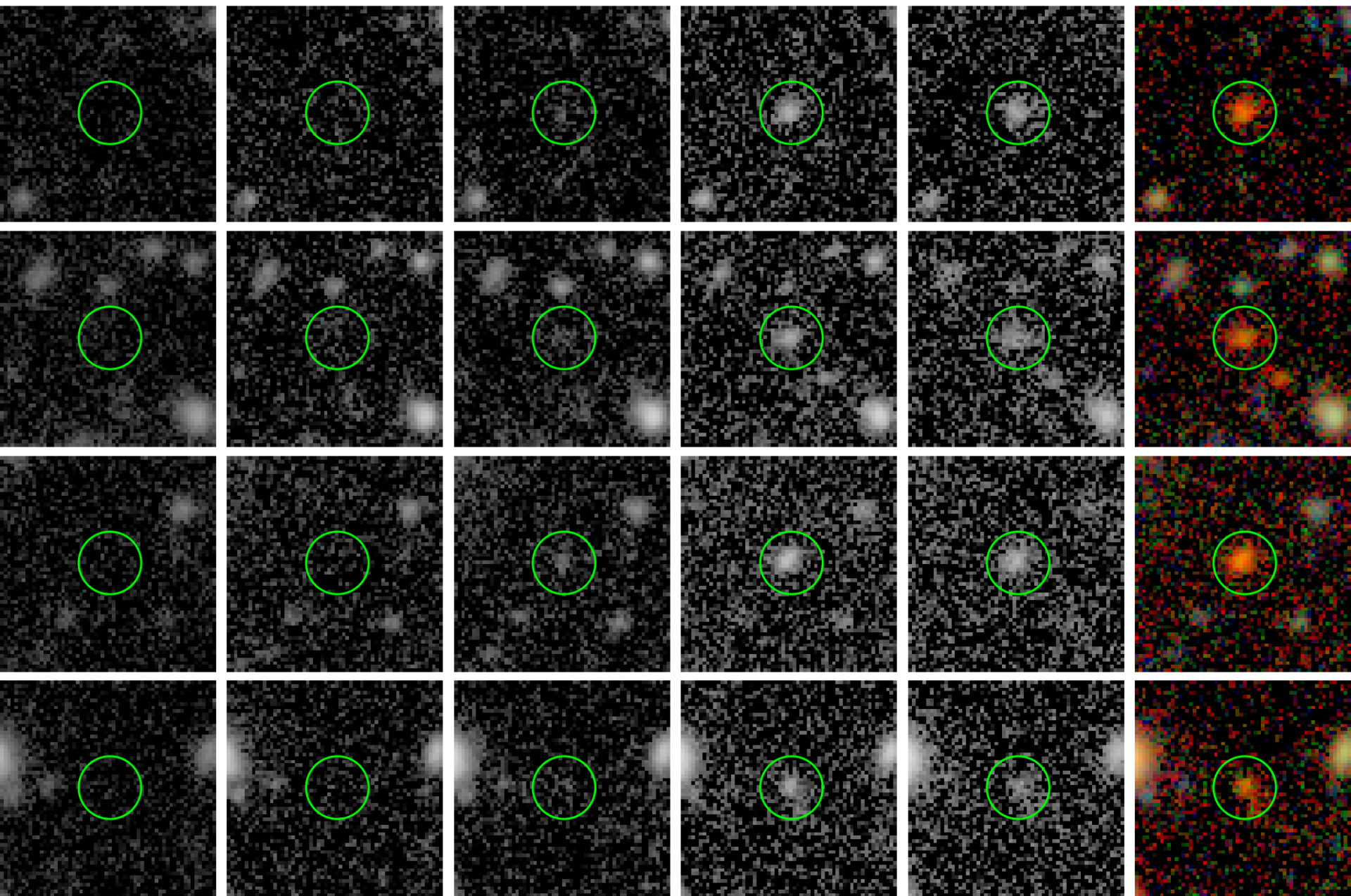
r

i

z

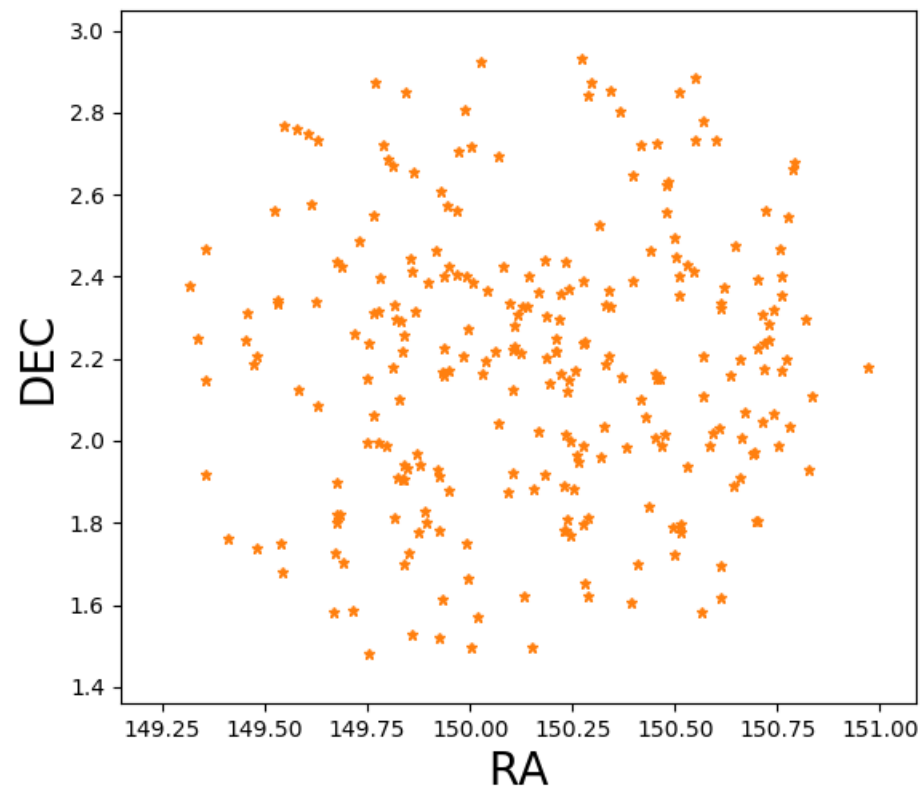
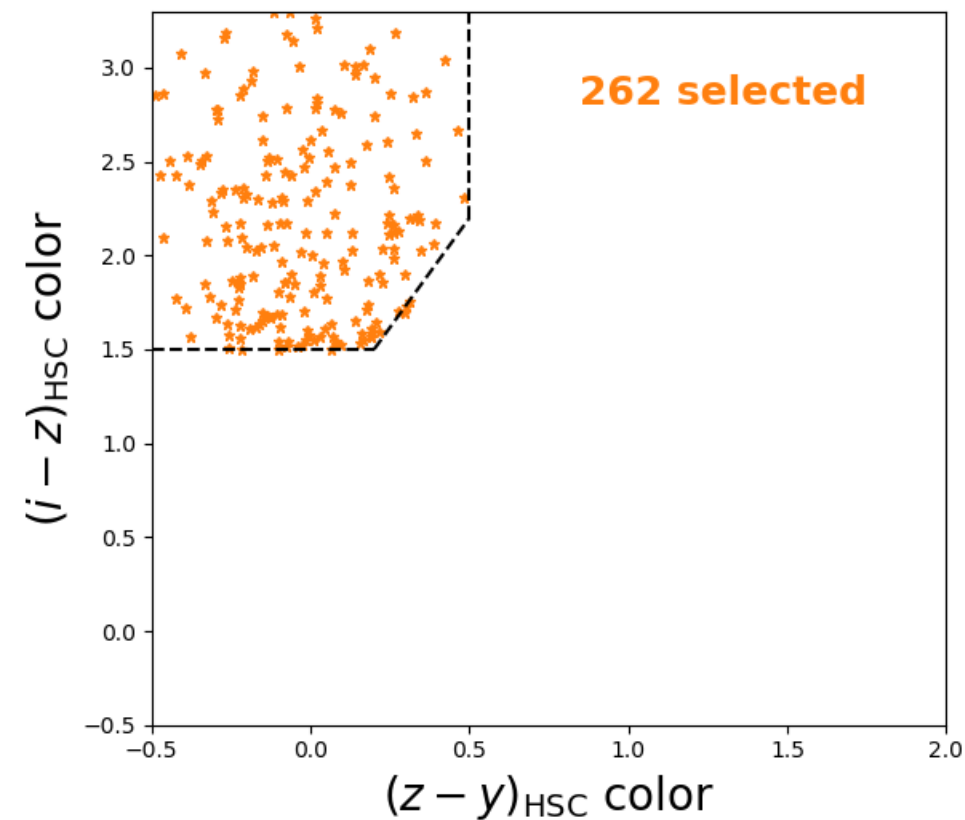
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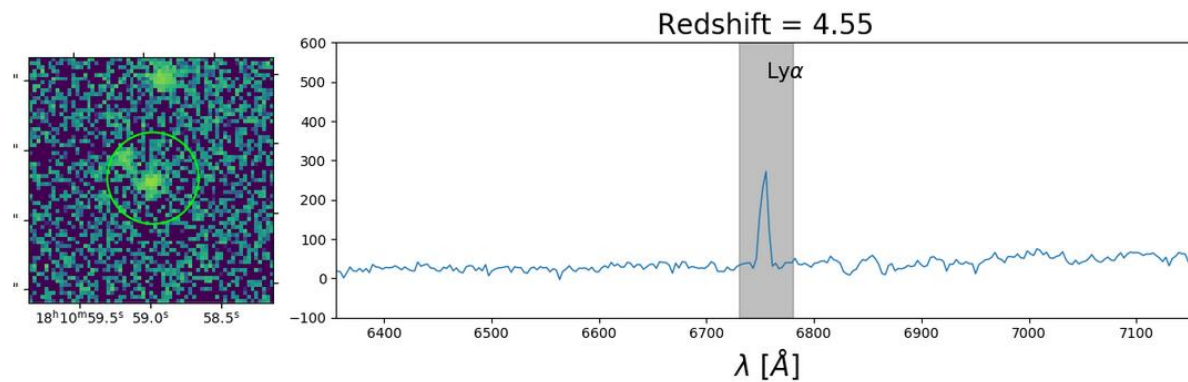
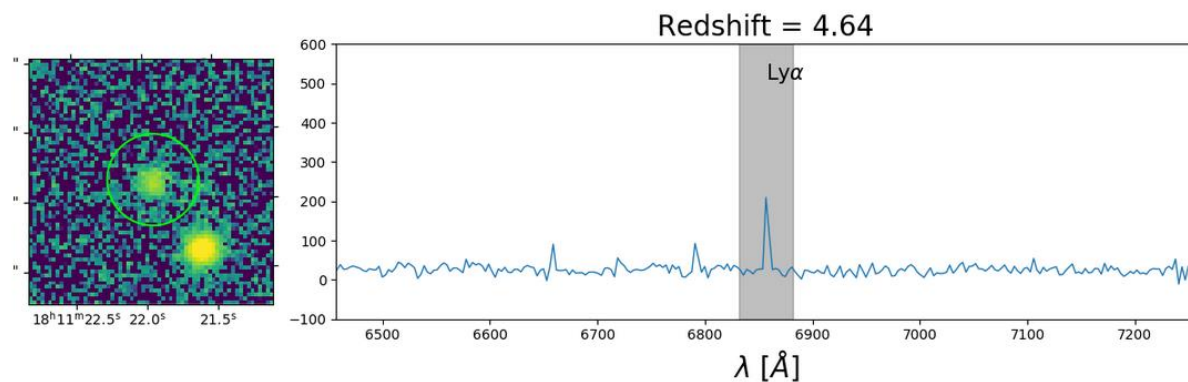
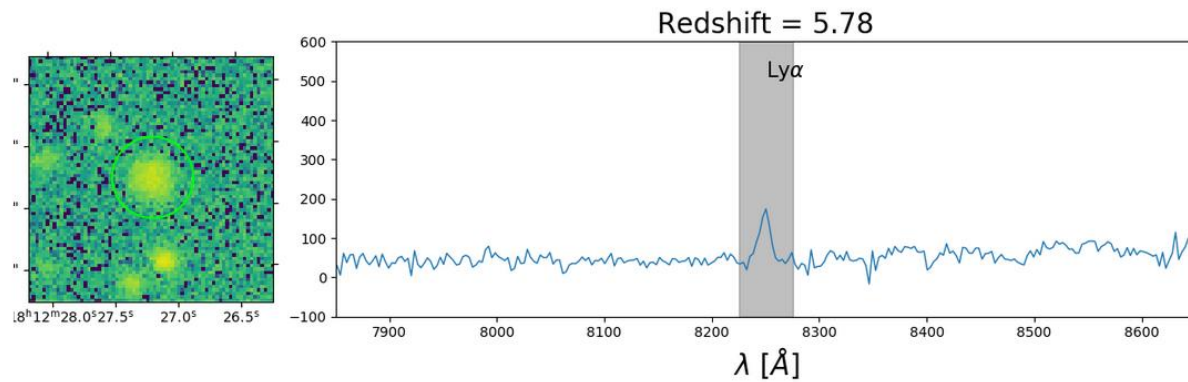
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COSMOS i -band dropouts

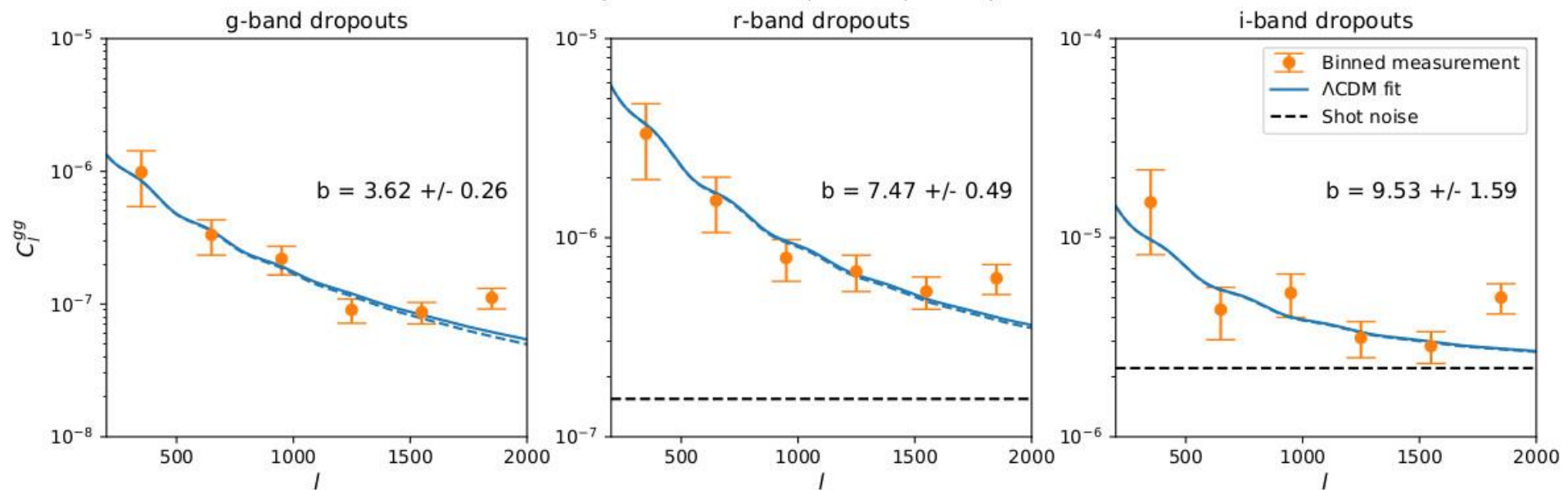
Color cut





Keck-DEIMOS 1st results (*g,r*-dropouts)

Galaxy autocorrelation spherical power spectra



Hawaii Two-0

A 20 deg² deep Subaru Hyper-SuprimeCam imaging and Keck LRIS + MOSFIRE spectroscopic survey of the two primary Euclid Deep Calibration Fields (NEP and CDFS).

[Read the abstract](#)

Keck LRIS+MOSFIRE

Subaru HSC

H2O Catalogs (NEP, CDFS):

~500,000 dropouts at $z > 3$

~3,000 dropouts at $z > 6$

Expected initial H2O release in late 2021

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[COSMOS Catalog ~ late 2020]

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