

The Primordial Universe SWG

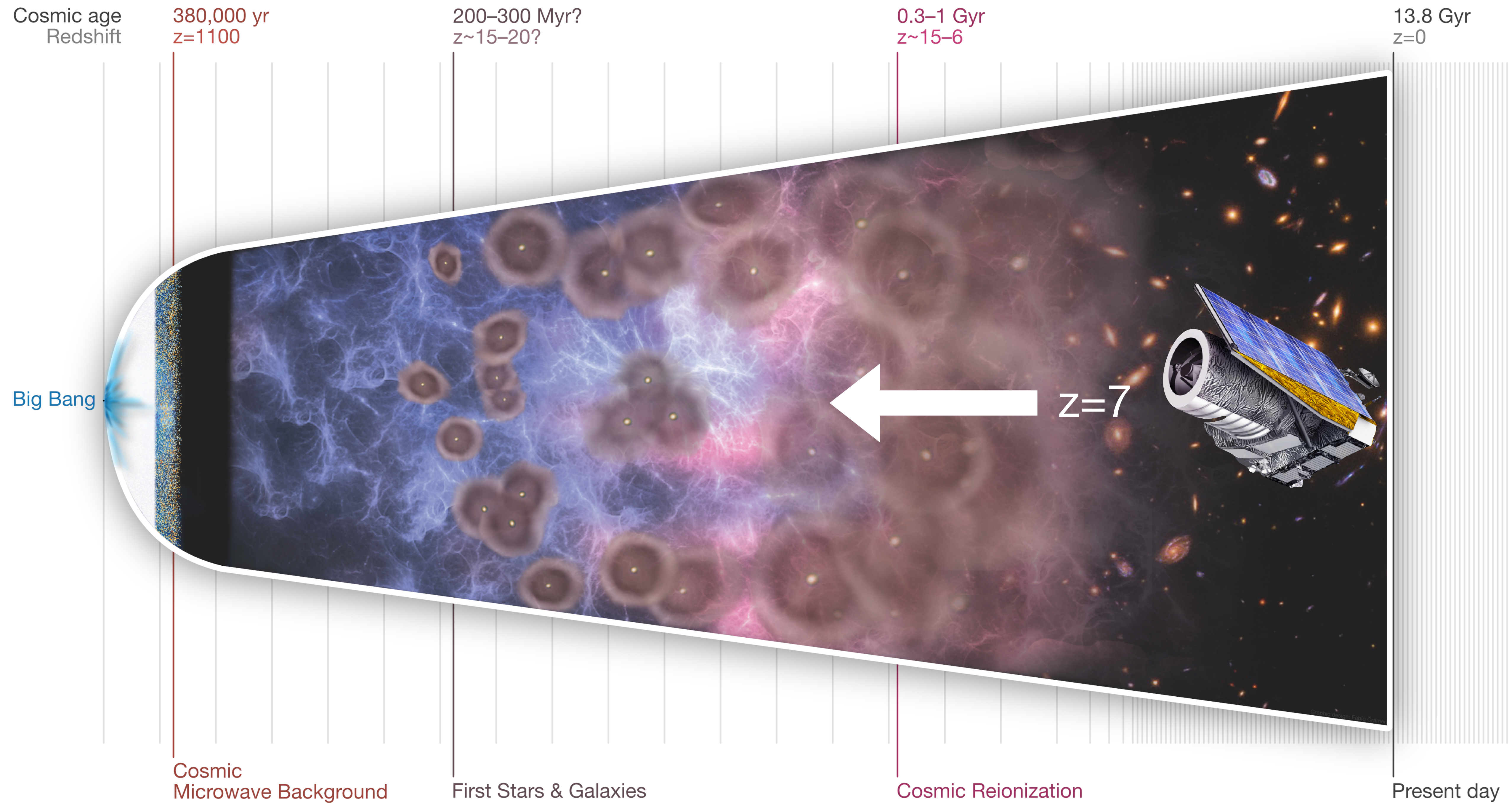
Marco Castellano

INAF - Osservatorio Astronomico di Roma

on behalf of PU-SWG

Slides courtesy of PU-SWG members:

R. Bowler, H. Atek, E. Bañados, J. Weaver and many others



The Primordial Universe SWG

Leads: *Eduardo Bañados, Marco Castellano, Rebecca Bowler*



Work Packages:

○ Quasars (WIDE/DEEP high-z)

Leads: Schindler, Mortlock

○ Galaxies (DEEP, LAE & LBG)

Leads: Oesch, Weaver

○ Theory (re-ionization)

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○ Cosmic Infrared Background

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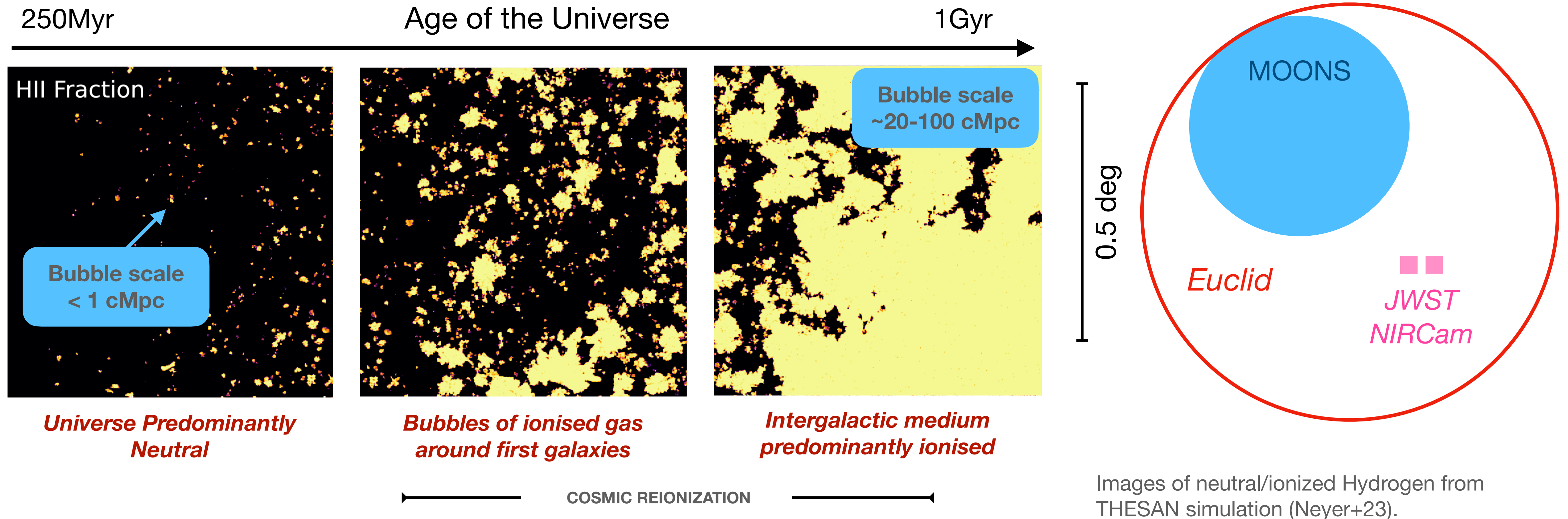
Leads: Cooray, Serjeant

Viola,Allevato
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Richard,Arendt
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Eduardo,Banados
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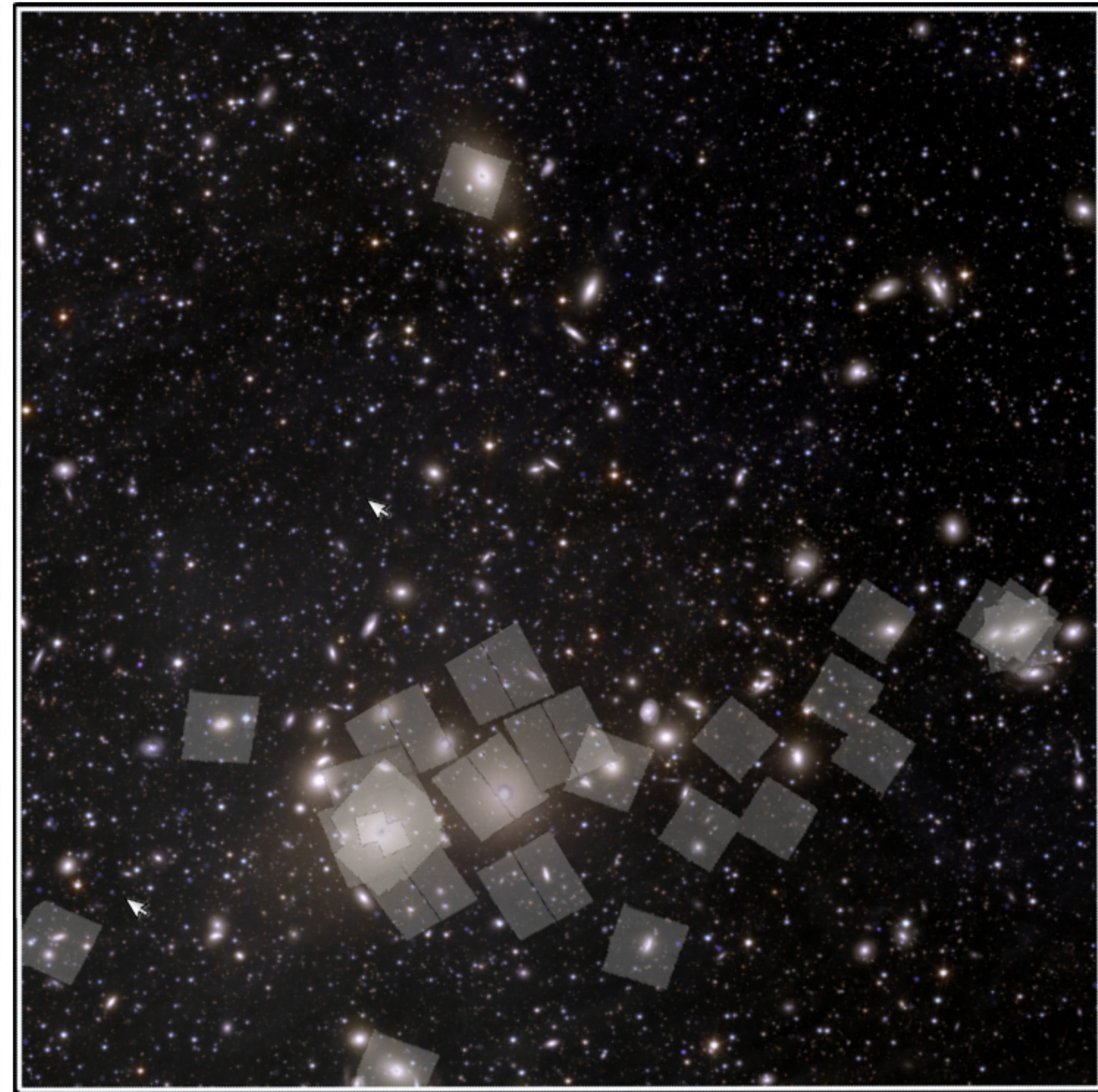
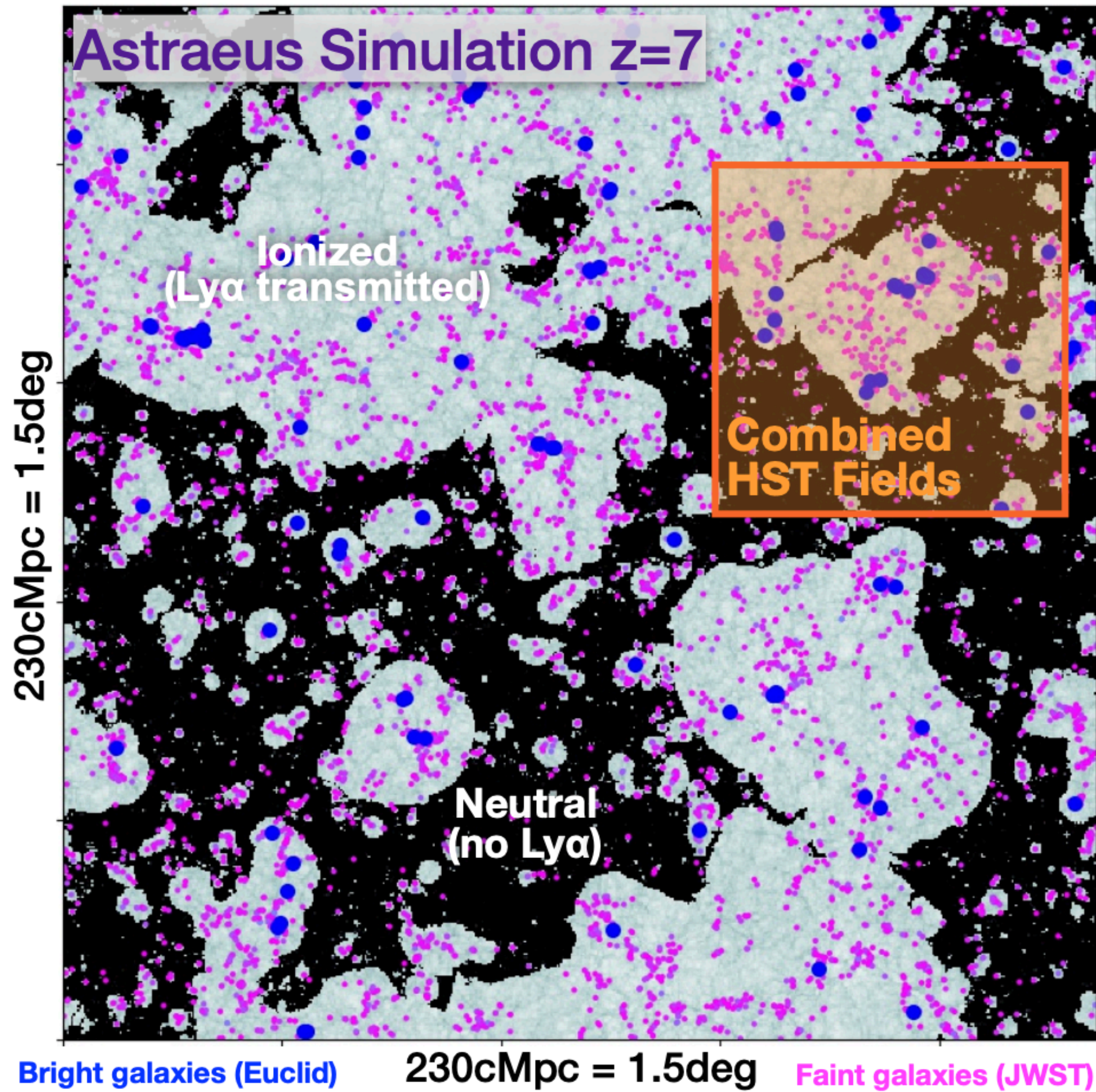
Francesco,Guarneri
Melanie,Habouzit
Yuichi,Harikane
Joseph,Hennawi
Arvind,Hughes
Andrew,Humphrey
Pascale,Jablonka
Knud,Jahnke
Alexander,Kashlinsky
Leon,Koopmans
Jussi,Kuusisto
Vincent, Le Brun
Lena,Lenz
Manuela,Magliocchetti
Sabino,Matarrese
Yoshiki,Matsuoka
Ross,McLure
Conor,McPartland
Simona,Mei
Thiago,Mergulhão
Bo,Milvang-Jensen
Andrew,Mizener
Daniel,Mortlock
David,Mota
Grey,Murphree
Ahmadreza,Nourizonoz
Pascal,Oesch
Masafusa,Onoue
James,Pearson
Roser,Pello
Laura,Pentericci
Lucia,Pozzetti
Thomas,Reiprich
Giulia,Rodighiero
Martin,Sahlen

Ruben,Salvaterra
Dave,Sanders
Riku,Sato
Claudia,Scarlata
Jan-Torge,Schindler
Raffaella,Schneider
Stephen,Serjeant
Francesco,Shankar
Robert,Smith
Daniel,Stern
Yuma,Sugahara
Lidia,Tasca
Gianmassimo,Tasinato
TRAN,"Thi Thai"
Sune,Toft
Laurence,Tresse
Isabella,Valdes
Sophie,van Mierlo
Rohan,Varadaraj
Aprajita,Verma
Fabian,Walter
Stephen,Warren
John,Weaver
Stephen,Wilkins
Chris,Willott
Lukas,Zalesky
Gianni,Zamorani

The power of *Euclid* data at $z > 7$



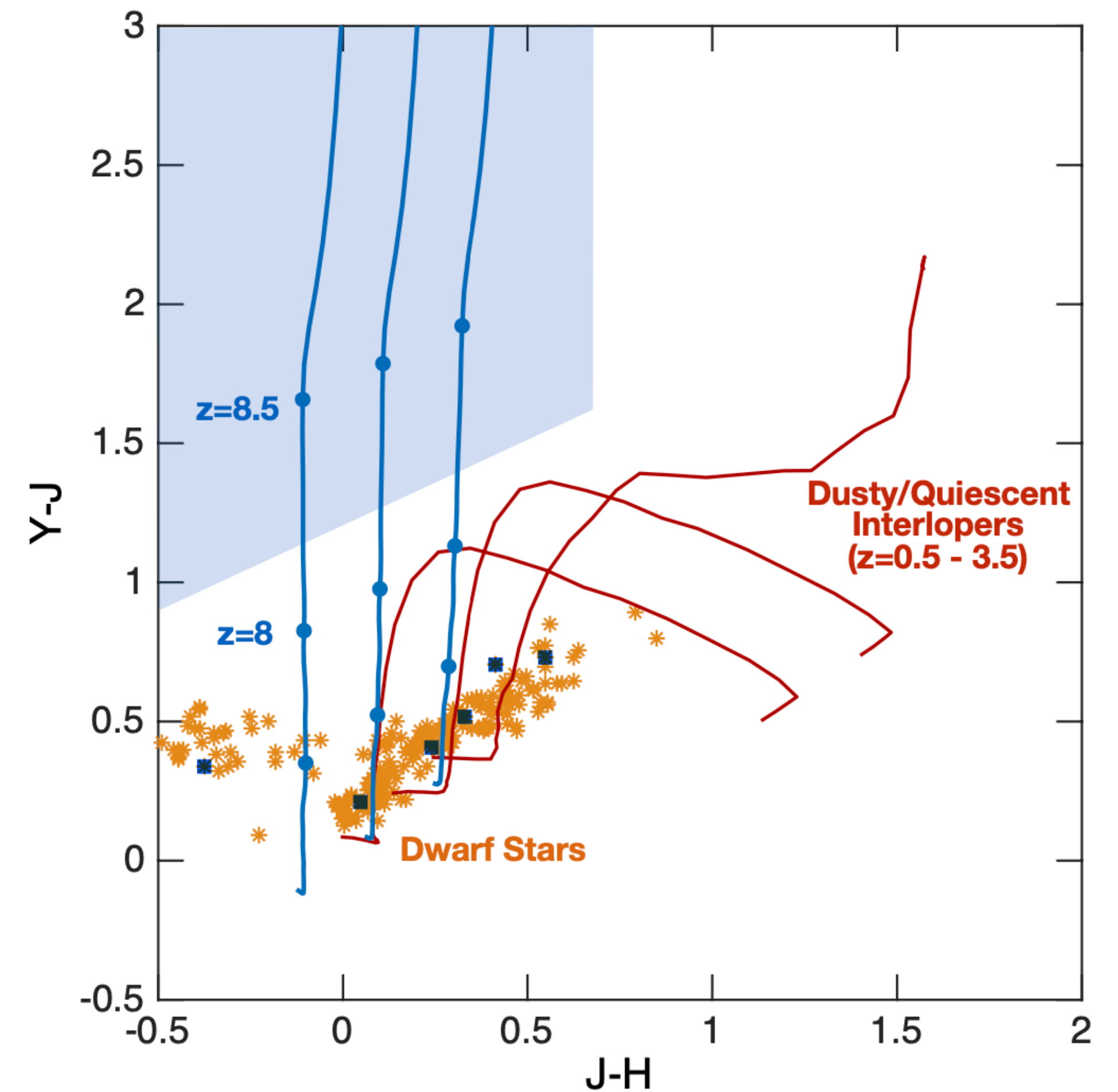
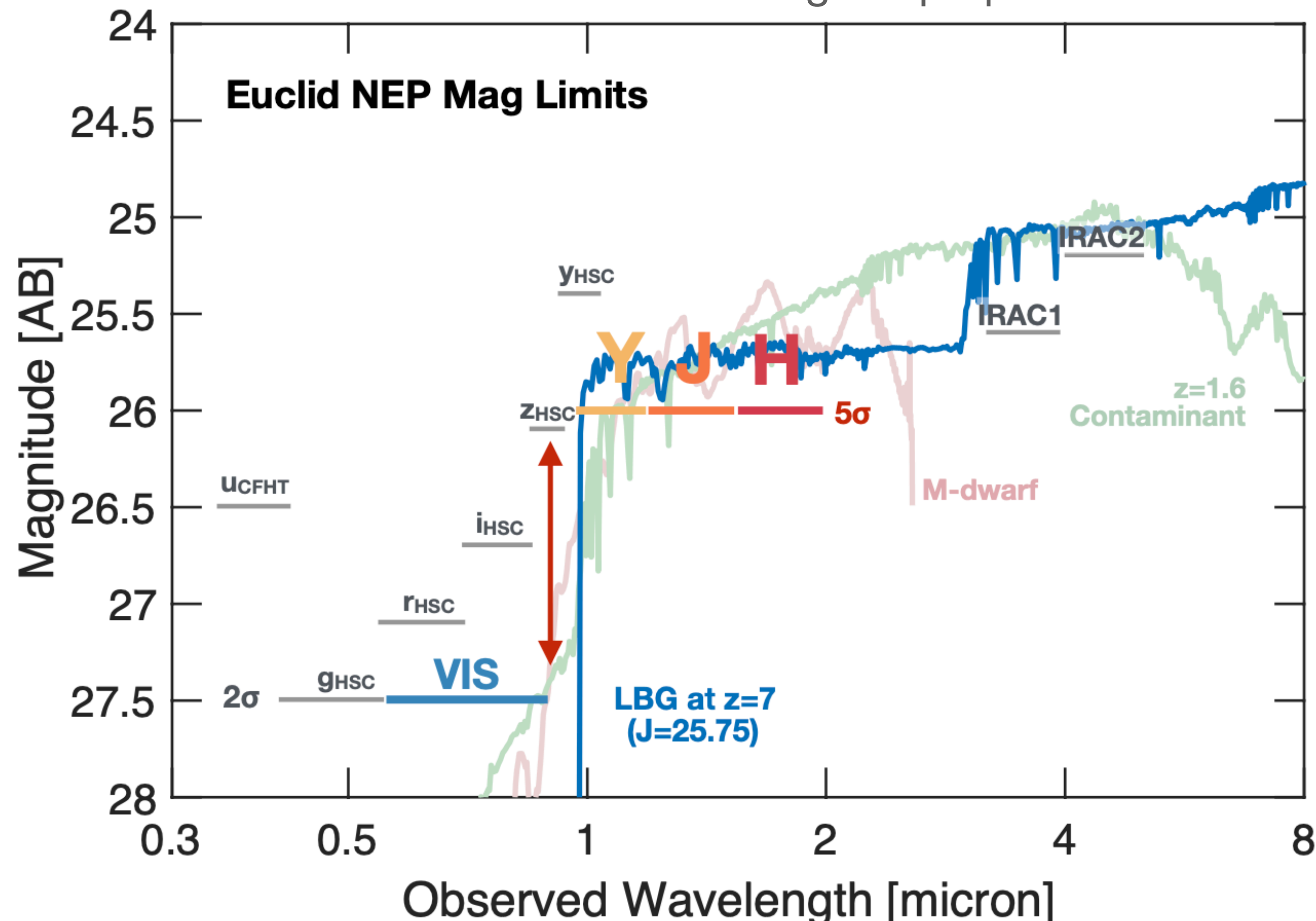
- Euclid will provide the first statistical samples of galaxies within cosmic reionization on the expected (evolving) scale of ionised bubbles



Lyman break selection of $z > 7$ galaxies and quasars

See van Mierlo et al. 2022, Allen et al. 2025 in prep.

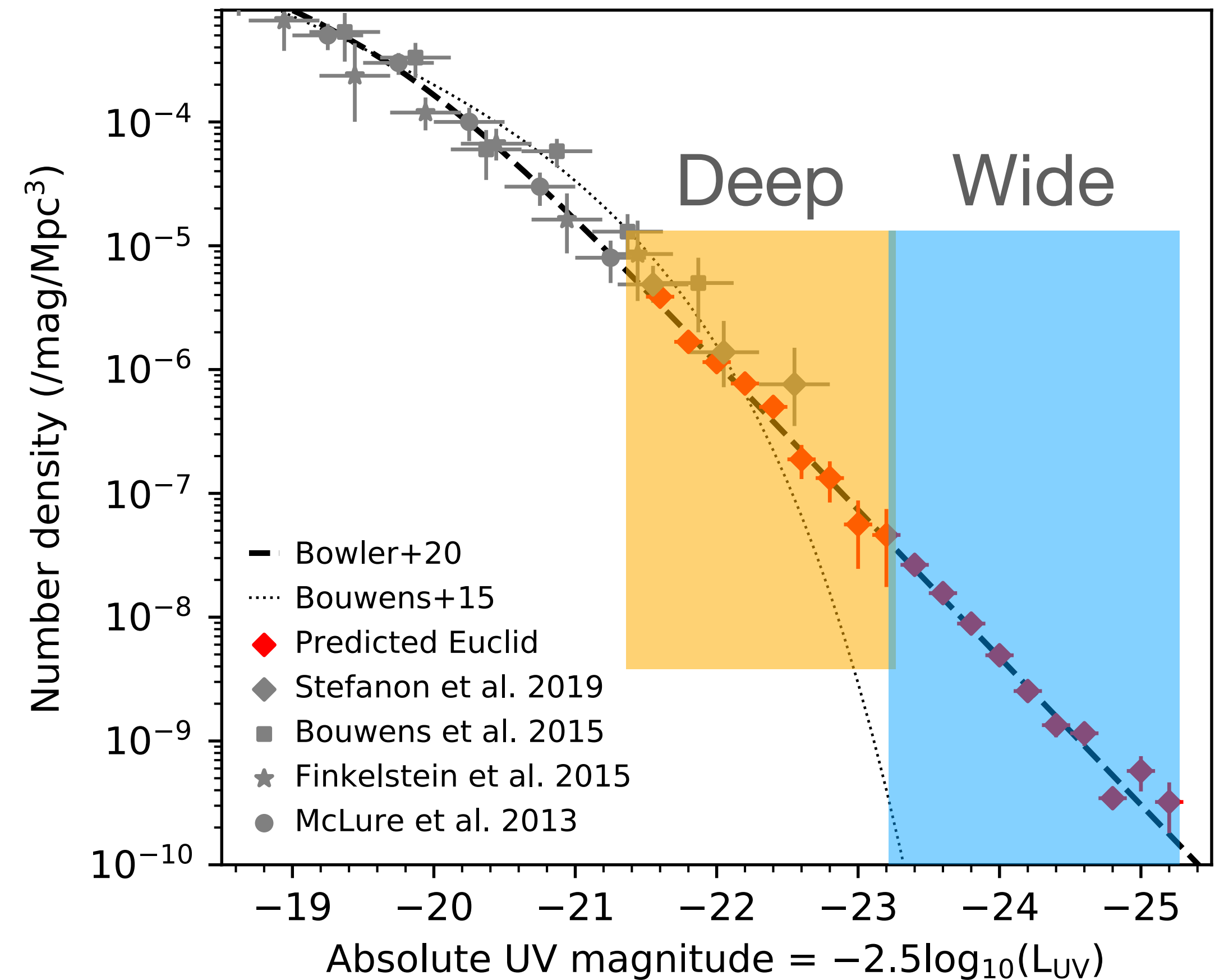
Selection including deep optical data H20



Lyman-break Galaxy Work Package

Credits R. Bowler

- Survey of high-redshift ($z > 7$) galaxies identified from *Euclid* VIS+YJH data in combination with deep auxiliary data
- Focus on the Deep survey
- Predict ~3000-4000 galaxies at $z = 8$ and ~80-500 galaxies at $z = 10$ (for Schechter vs. double-power law function)
- Samples probe bubble scale and high-density regions in cosmic reionization

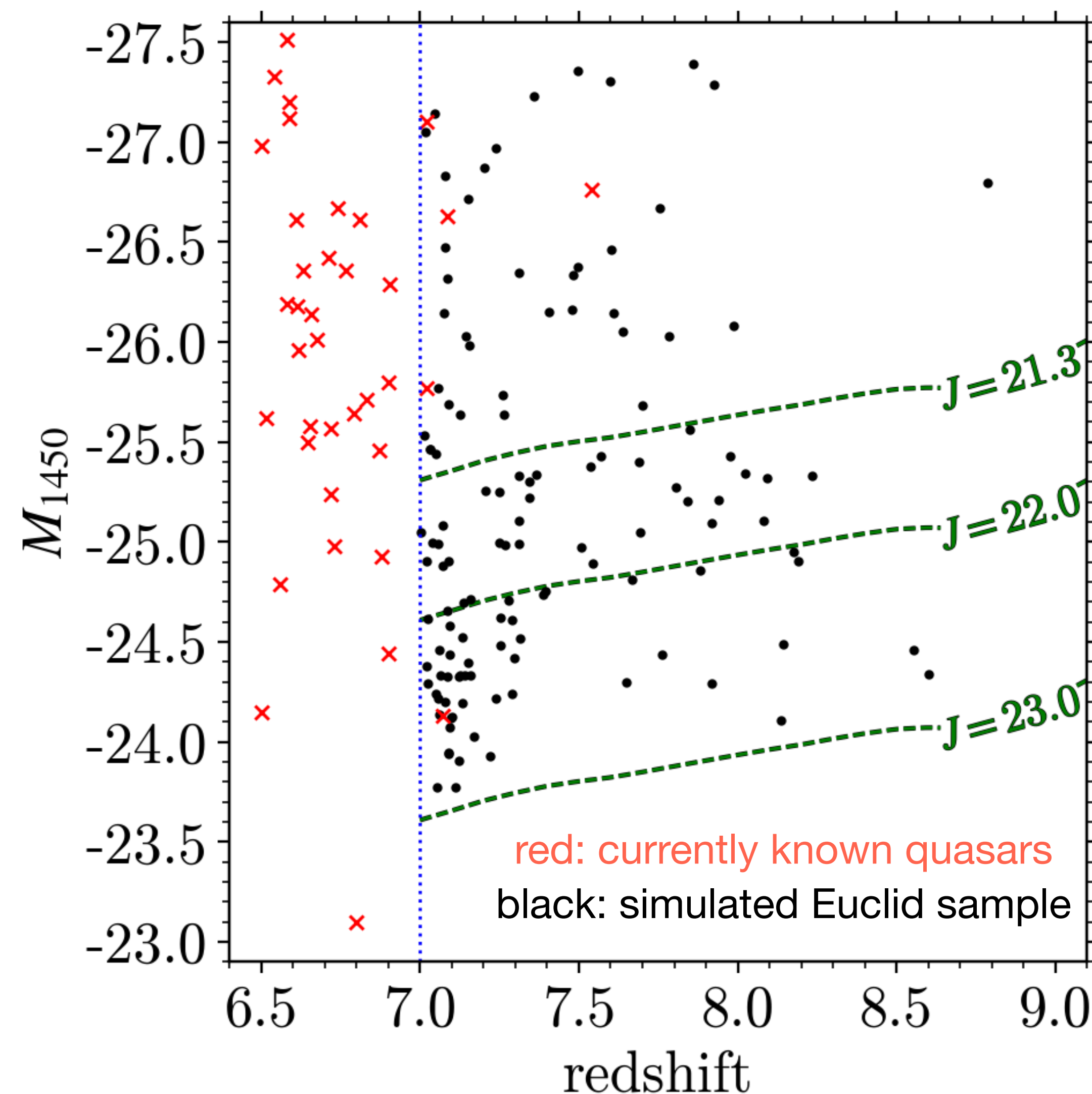


Simulated luminosity function at $z = 8$ (630 Myr) that will be derived from the EDF + EWF (R. Bowler)

Quasars Work Package

- Survey of high-redshift ($z > 7$) quasars identified from Euclid VIS+YJH photometry and red grism spectra
- Predominantly in the Wide survey
- Predict ~100 quasars with $z > 7$ and ~20 with $z > 8$ (EC, Barnett et al. 2019)
- Likely to break the current redshift record of $z = 7.6$ in DR1

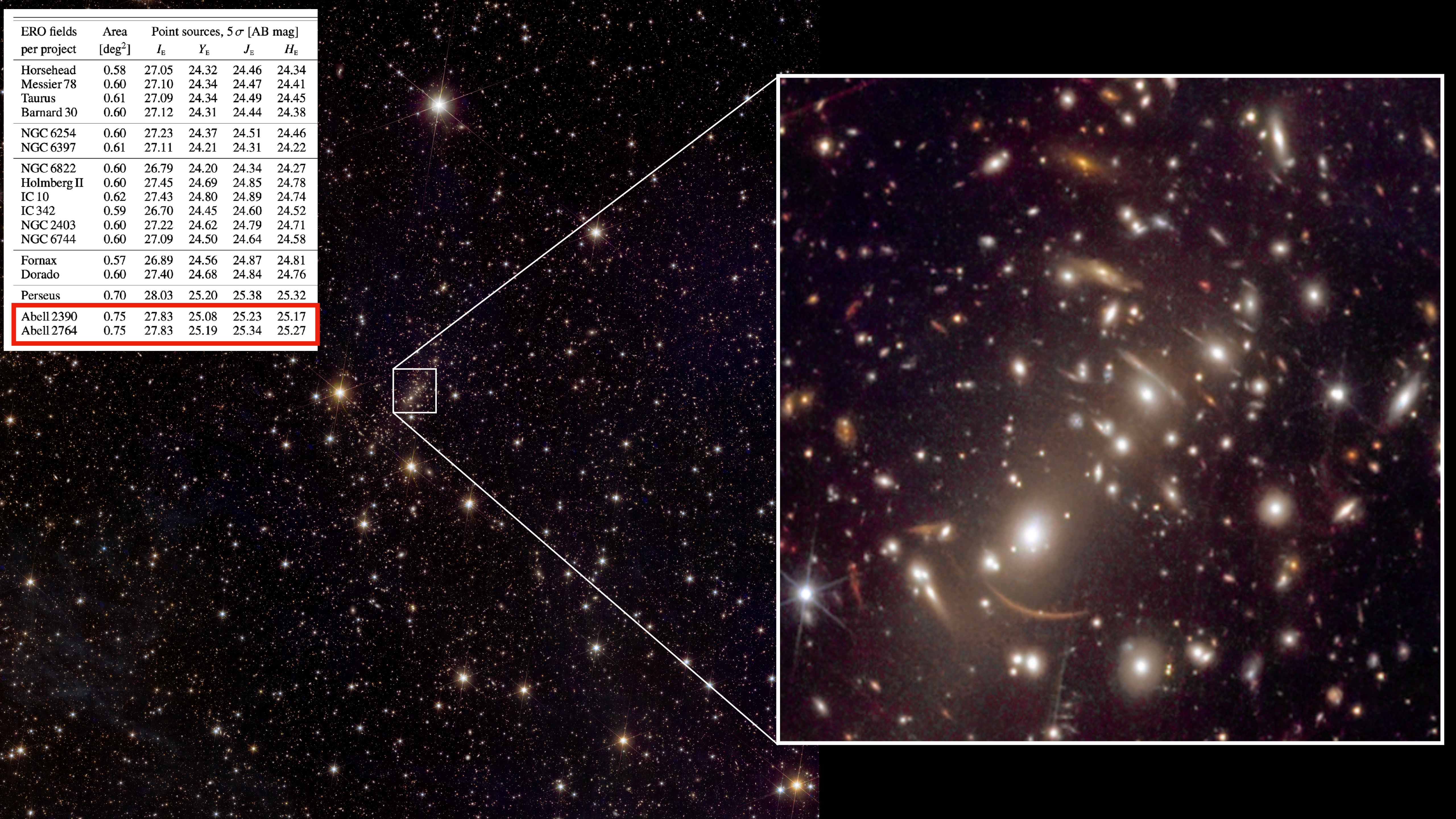
Figure of absolute UV magnitude vs. redshift
Euclid Collaboration: Barnett et al. 2019



First results using :

- Early Release Observations (ERO)
- On the Fly (OTF) data
- Quick release Q1

ERO fields per project	Area [deg ²]	Point sources, 5σ [AB mag]			
		I_E	Y_E	J_E	H_E
Horsehead	0.58	27.05	24.32	24.46	24.34
Messier 78	0.60	27.10	24.34	24.47	24.41
Taurus	0.61	27.09	24.34	24.49	24.45
Barnard 30	0.60	27.12	24.31	24.44	24.38
NGC 6254	0.60	27.23	24.37	24.51	24.46
NGC 6397	0.61	27.11	24.21	24.31	24.22
NGC 6822	0.60	26.79	24.20	24.34	24.27
Holmberg II	0.60	27.45	24.69	24.85	24.78
IC 10	0.62	27.43	24.80	24.89	24.74
IC 342	0.59	26.70	24.45	24.60	24.52
NGC 2403	0.60	27.22	24.62	24.79	24.71
NGC 6744	0.60	27.09	24.50	24.64	24.58
Fornax	0.57	26.89	24.56	24.87	24.81
Dorado	0.60	27.40	24.68	24.84	24.76
Perseus	0.70	28.03	25.20	25.38	25.32
Abell 2390	0.75	27.83	25.08	25.23	25.17
Abell 2764	0.75	27.83	25.19	25.34	25.27

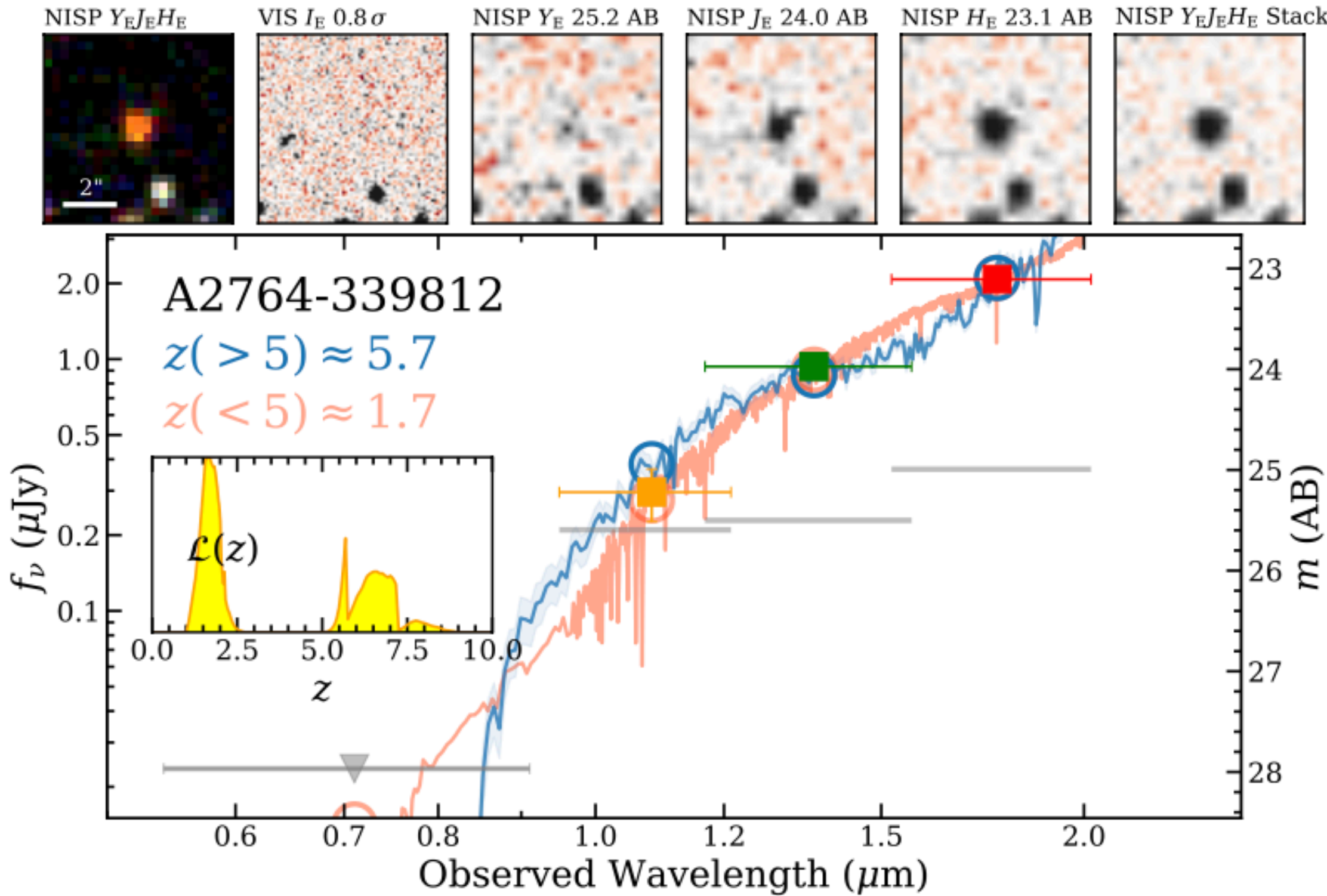
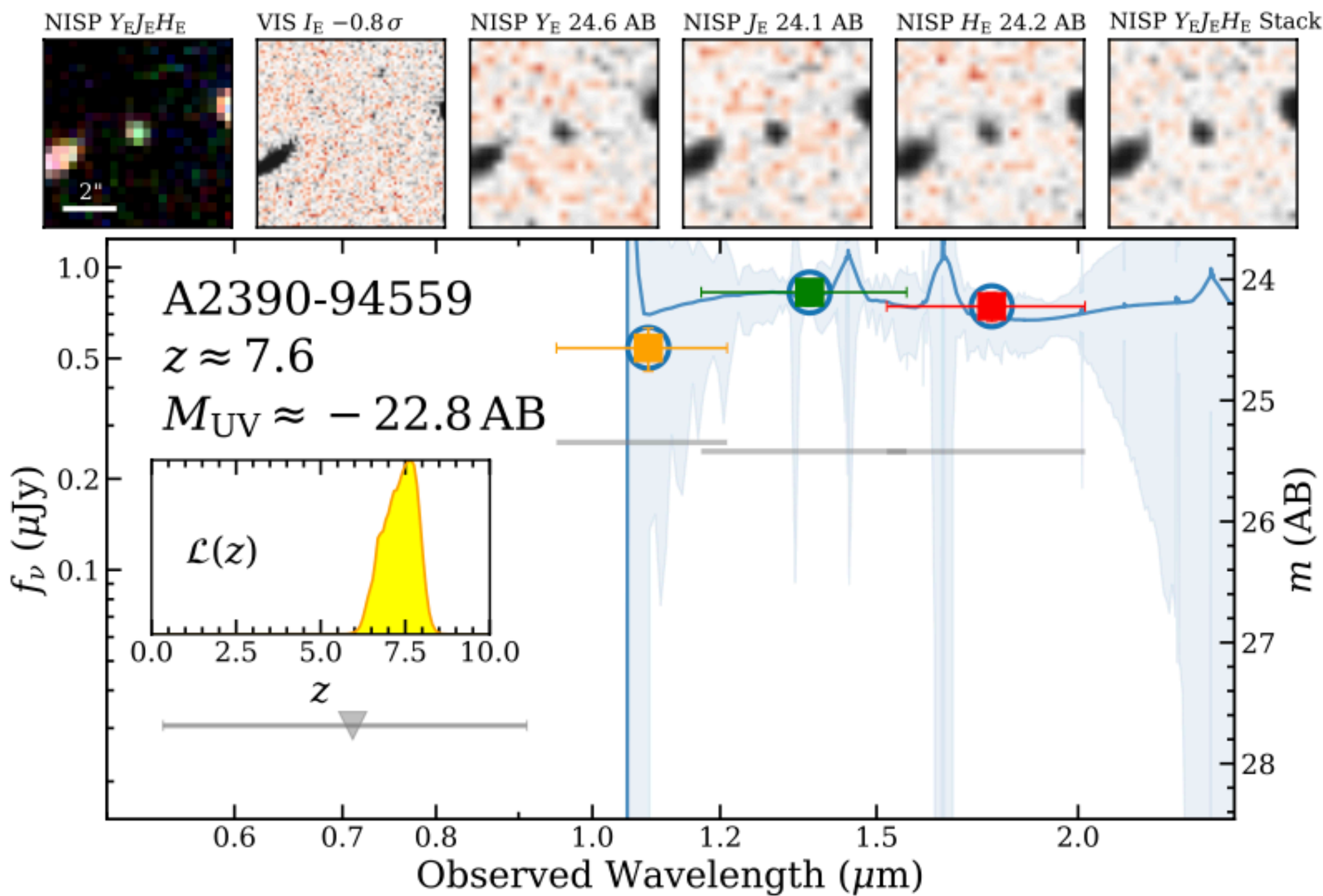


VIS Dropouts

Atek et al. 2024, Weaver et al. 2024

- 29 Lyman-break galaxy candidates selected, plus 139 “extremely red sources” likely at lower redshift

Field	RA [deg]	Dec [deg]	I_E	Y_E	J_E	H_E
A2390	328.397	+17.709	27.01	25.18	25.22	25.12
A2764	5.713	-49.249	27.26	25.30	25.41	25.21



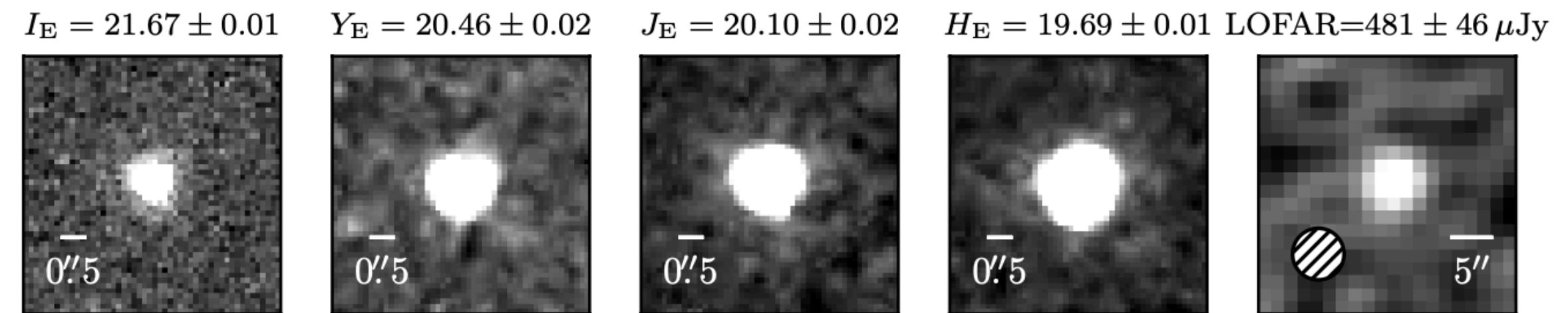
On-the-fly data

Includes Euclid + ground-based z-band + WISE W1/W2

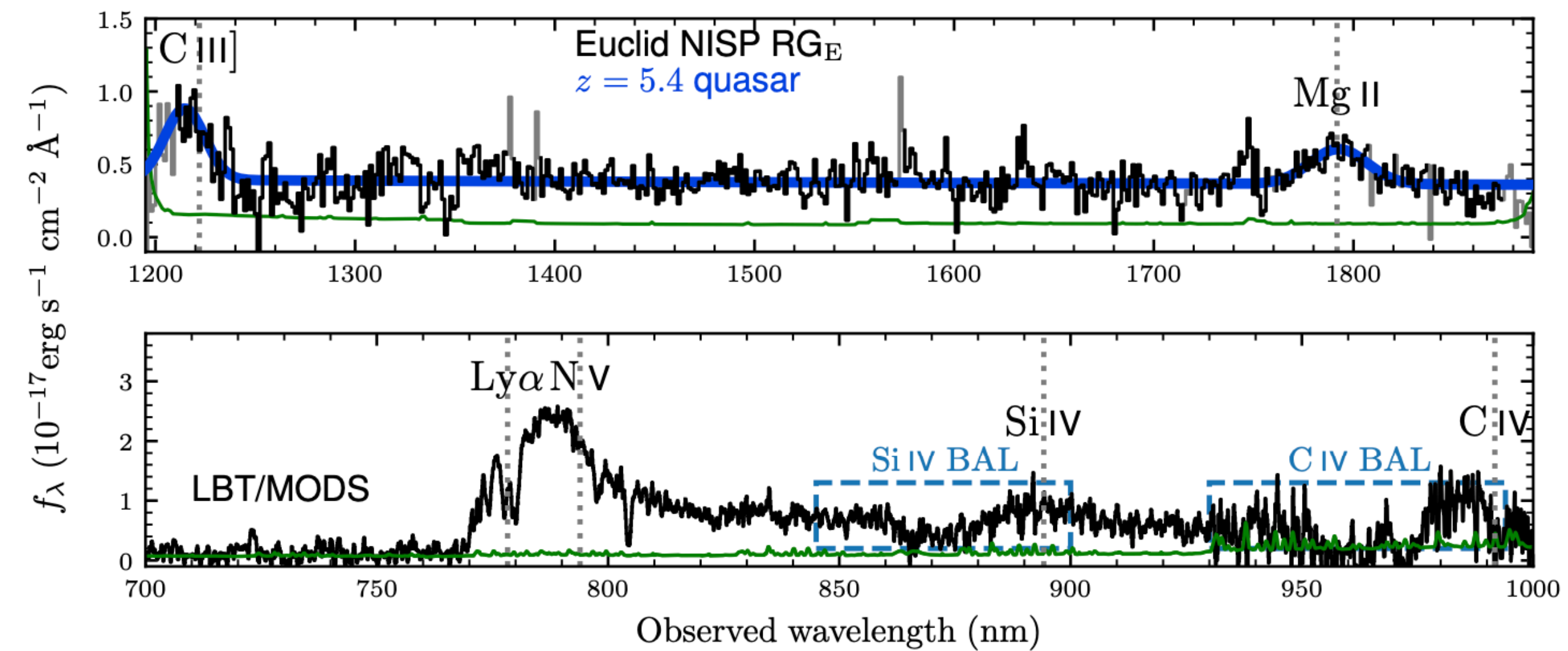
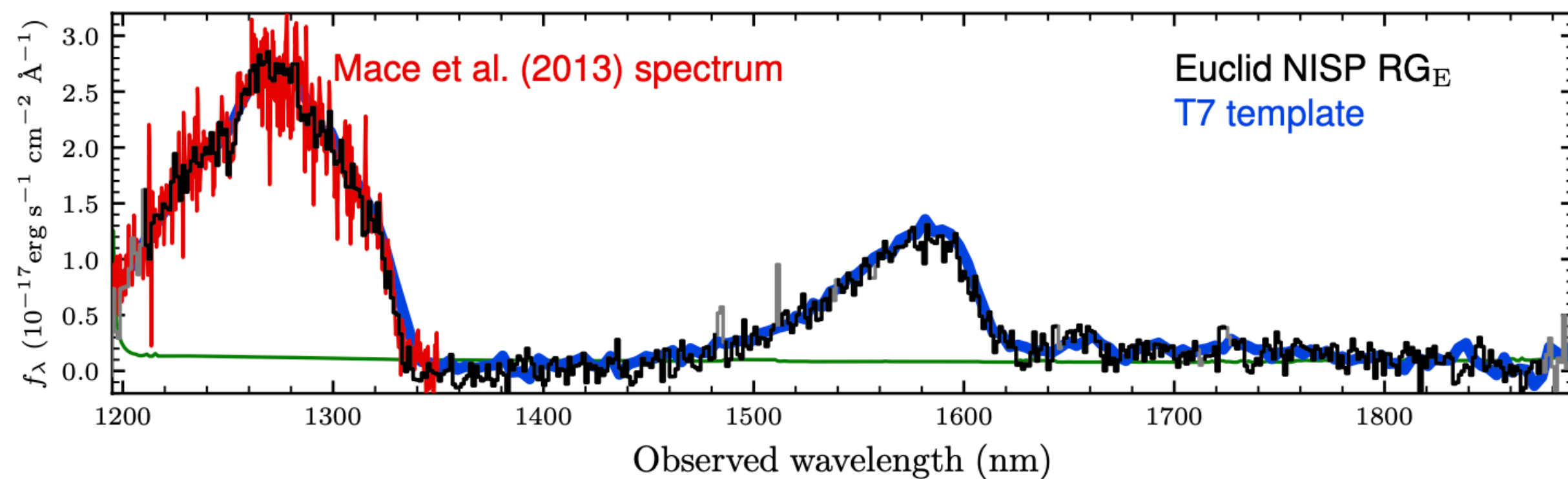
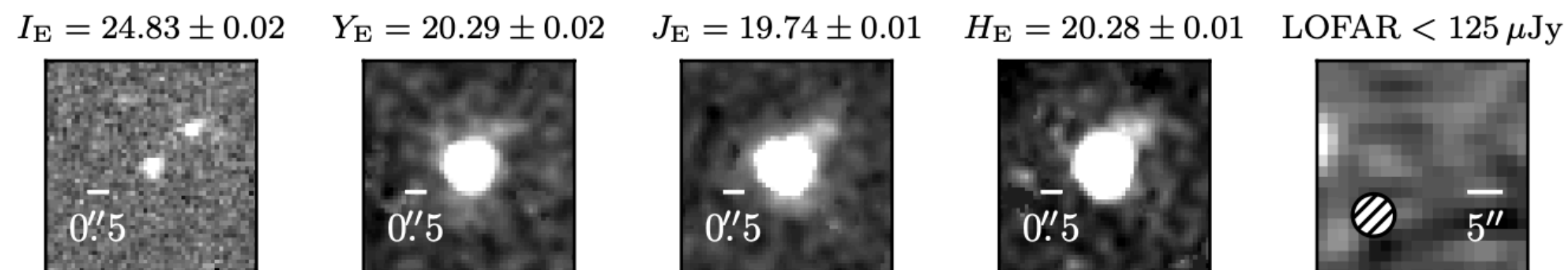
- ~8 follow-up proposals written, with 6 successful
- Magellan observations (PI: J. Yang) have recently identified five quasars with $z = 6.6$ -7.2

Banados et al. submitted to A&A

A bright quasar at $z=5.4$ with NISP Grism and ground-based follow-up spectroscopy



LT Cool dwarves from NISP grism spectroscopy



Q1: Predicted numbers of high-*z* galaxies

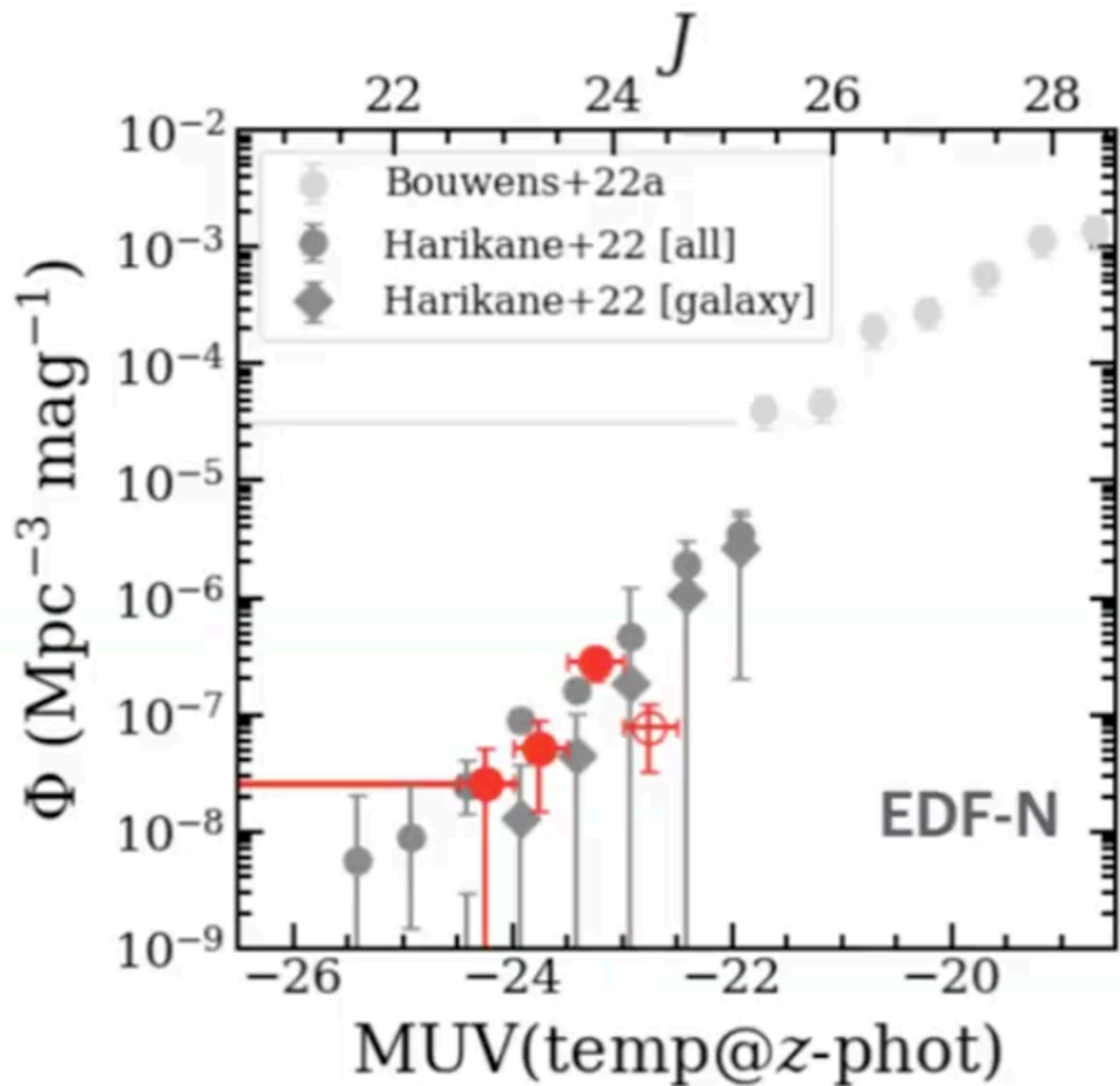
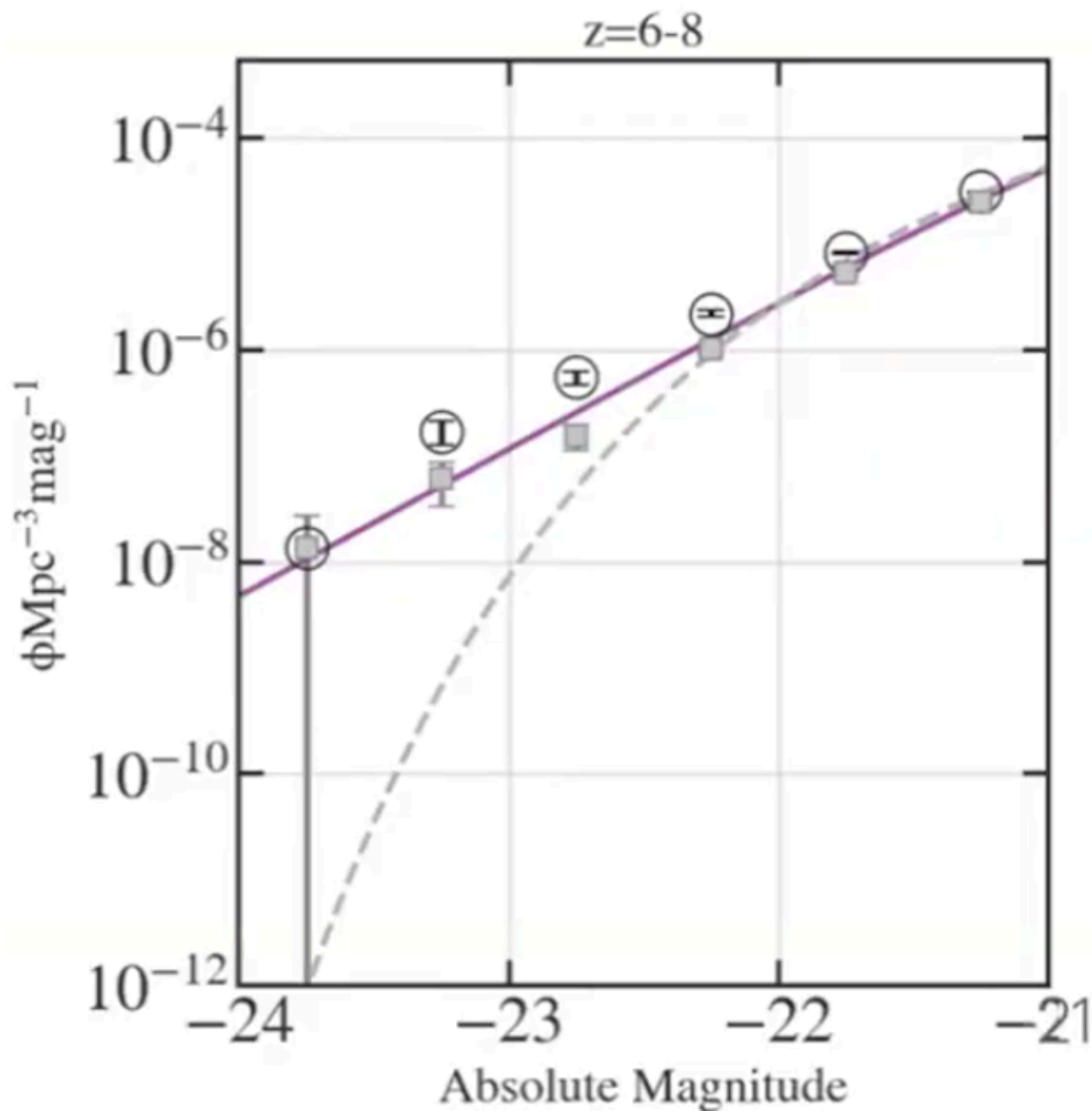
Allen et al. Q1 paper

Mock catalogs of $z>5$ galaxies and contaminants, at the full survey depth, EDF-N, EDF-S, EDF-F

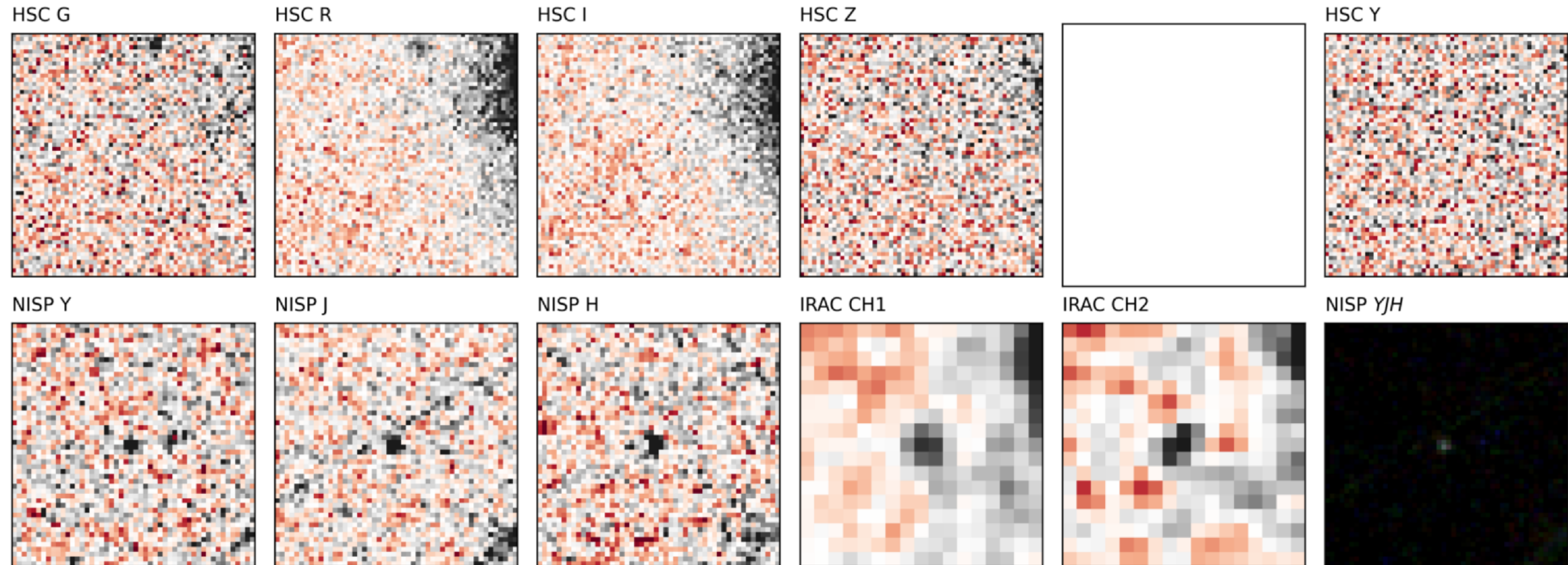
Photometric redshifts using Eazy. Better constraints on the bright-end of the UVLF

First robust candidates from Q1 data

<i>z</i>	EDF-N	EDF-S	EDF-F
6	58575	67361	29287
7	11621	13365	5811
8	2633	3028	1316
9	960	1104	480
10	391	449	195
11	176	203	88
12	87	101	44
13	47	54	24
14	28	32	14
15	17	20	9



Q1: search for high- z galaxies in EDFN



- Q1 analysis (led by John Weaver) has focused on the Euclid Deep Field North where there exists Spitzer/HSC data from the Cosmic Dawn Survey

DR1 Key Projects



- **DR1-KP-PU-1: The statistical and physical properties of $z > 7$ galaxies from Euclid**

Christopher Conselice

Marko Shuntov

- **DR1-KP-PU-2: Properties of Lyman alpha emitters at $z > 6.5$ and constraints on the reionisation history**

POSITIONS OPENED

- **DR1-KP-PU-3: Discovery of high redshift Euclid quasars**

Daniel Morlock

Jan Torge Schindler

Daming Yang

- **DR1-KP-PU-4: Characterising the quasar population with Euclid**

MERGED WITH PU-3

- **DR1-KP-PU-5: Multi-wavelength follow-up of Euclid quasars**

Silvia Belladitta

Eduardo Banados

- **DR1-KP-PU-6: Euclid constraints on reionisation and galaxy formation models**

IDLE

- **DR1-KP-PU-7: Euclid observations of the Cosmic Infrared Background**

Asantha Cooray, POSITION FOR 2nd COORDINATOR OPENED

Ongoing application/selection process for DR1 papers:

coordination between WP and KP leads to select 1st wave of paper leads by the end of September

29 papers proposed so far for DR1

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Pascal, Oesch
Masafusa, Onoue
James, Pearson
Roser, Pello

Laura, Pentericci

Lucia, Pozzetti

Thomas, Reiprich

Giulia, Rodighiero

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Ruben, Salvaterra

Dave, Sanders
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Raffaella, Schneider
Stephen, Serjeant
Francesco, Shankar
Robert, Smith
Daniel, Stern
Yuma, Sugahara
Lidia, Tasca
Gianmassimo, Tasinato
TRAN, "Thi Thai"

Sune, Toft

Laurence, Tresse
Isabella, Valdes
Sophie, van Mierlo
Rohan, Varadaraj
Aprajita, Verma
Fabian, Walter
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Stephen, Wilkins
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Lukas, Zalesky

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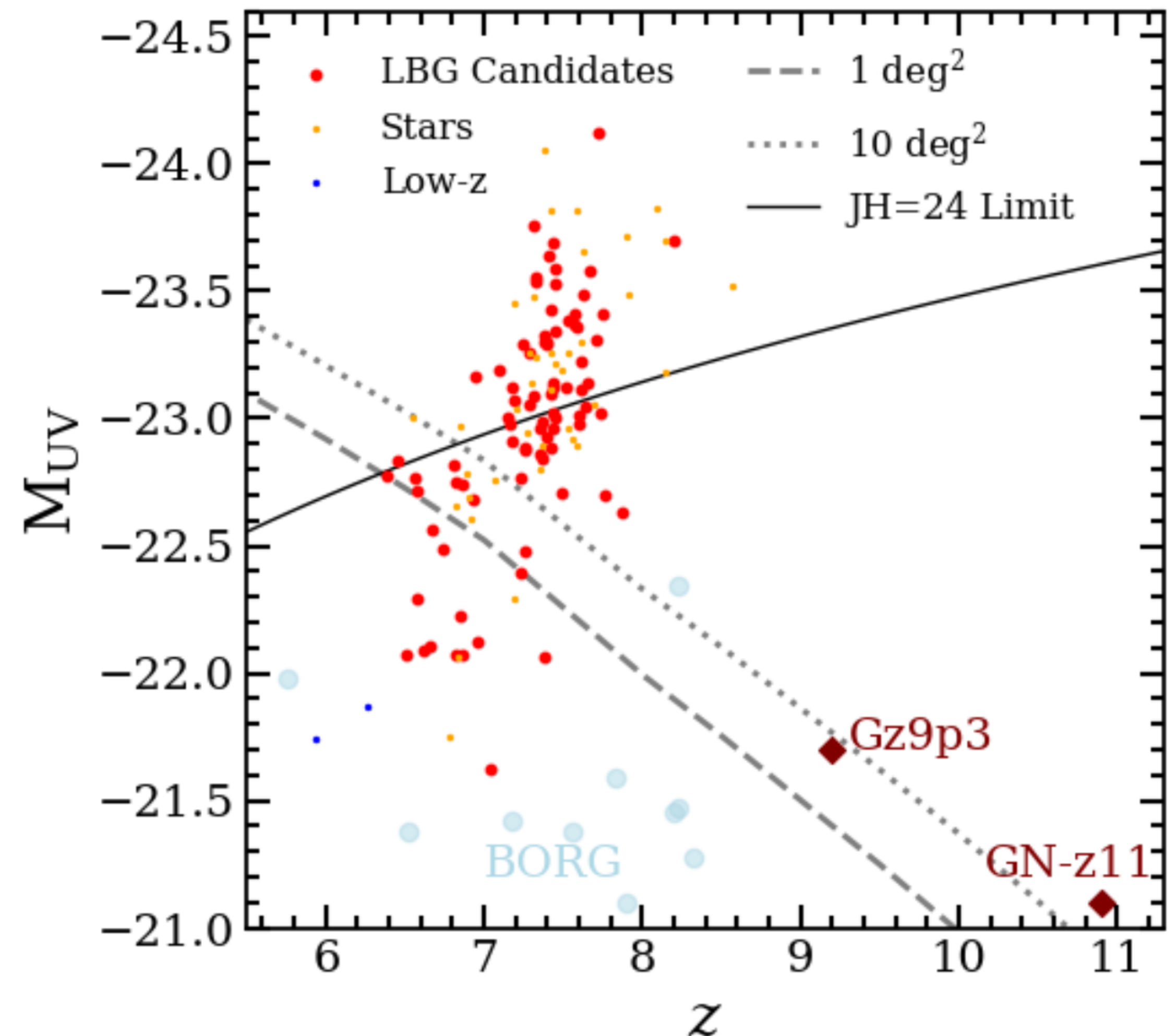
- Euclid is a goldmine for the very high-redshift universe: more efficient than any other instrument to find bright Lyman-break galaxies and NIR-selected QSOs at $z \sim 7-12$.
- Synergy with other instruments, in particular ground-based spectroscopy and JWST.
- Mostly proof-of-concept papers and preparatory studies from ERO and OTF data, but we expect a huge impact on high- z science from forthcoming works:
- Three papers in progress for the second Q1 wave; two OTF SP in progress (LBGs and QSO spectroscopic confirmations at $z > 7$); we expect many DR1 papers.
- Issues: delay in the ingestion of data in the OTF archive (important for QSO searches and follow-up proposals); coordination with other SWGs needs to be strengthened.
- Italian point of view: several researchers involved but few leadership roles (community still more focused on JWST? lack of dedicated funding?)

BACKUP SLIDES

Q1: search for high- z galaxies in EDFN

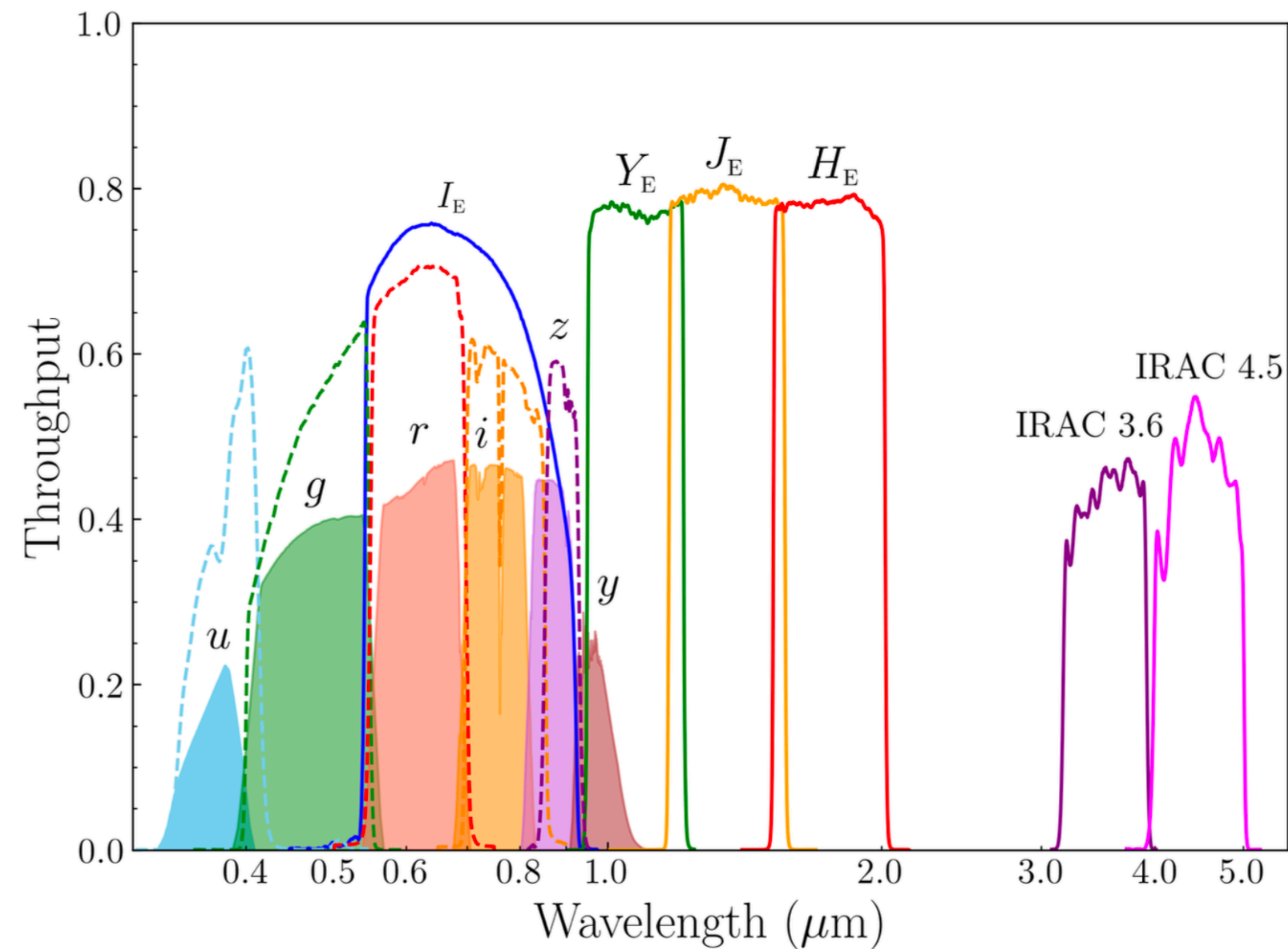
- Lyman-break galaxy selection has uncovered 73 candidates over 10 square degrees
- These sources are selected with photometric redshifts
- If confirmed, they would be the brightest galaxies known at $z > 7$
- At these magnitudes, faint $z > 7$ quasars could “contaminate” the galaxy samples - TBC!

Weaver et al. in prep

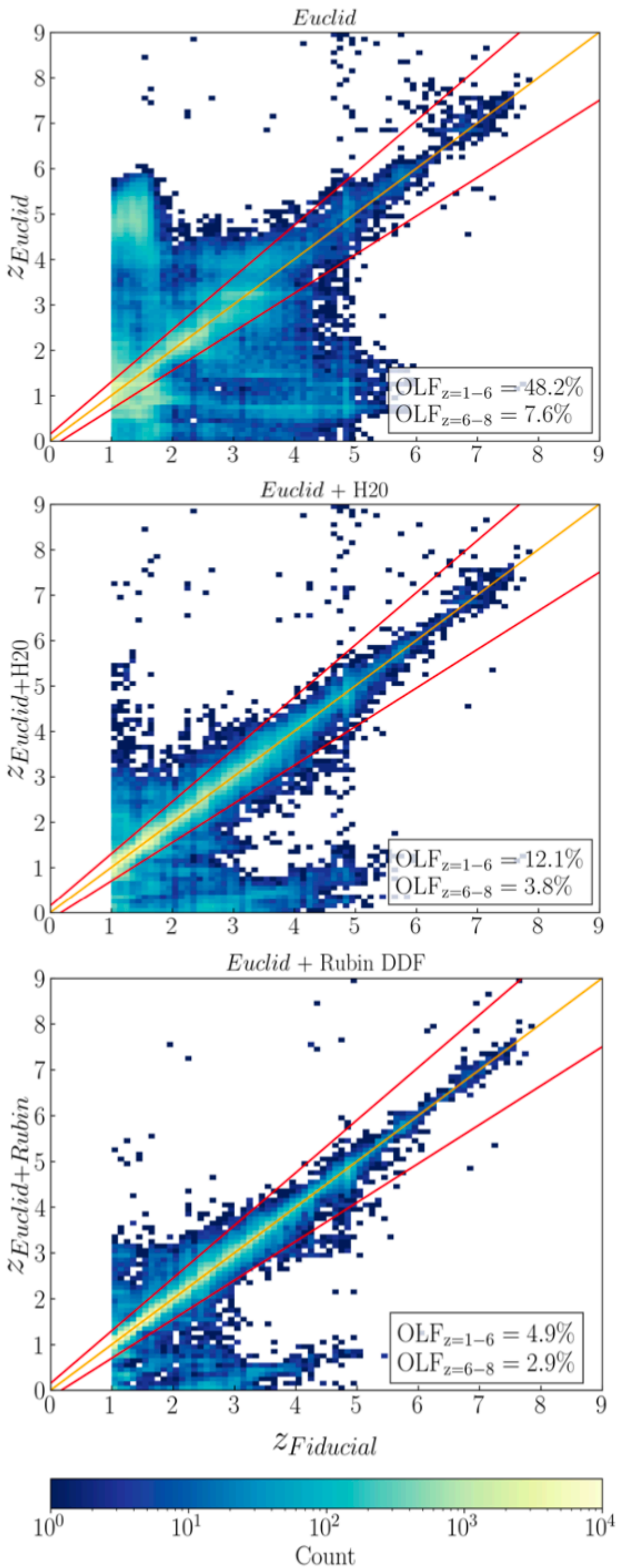


Euclid + Ancillary Data

Van Mierlo et al. 2022



Band	5σ depth [AB]	λ_{mean} [$\text{\AA}$]
I_E	28.2	7140
Y_E	26.3	10 829
J_E	26.5	13 696
H_E	26.4	17 762
Rubin/ u	26.1 (26.8) ^a	3685
Rubin/ g	27.4 (28.4)	4802
Rubin/ r	27.5 (28.5)	6231
Rubin/ i	26.8 (28.3)	7542
Rubin/ z	26.1 (28.0)	8690
Rubin/ y	24.9 (26.2)	9736
CFHT/ u	26.2	3832
HSC/ g	27.5	4816
HSC/ r	27.5	6234
HSC/ i	27.0	7741
HSC/ z	26.5	8911
IRAC/3.6 μm	24.8	35 634
IRAC/4.5 μm	24.7	45 110



Strong Lensing Work Package

- Search for bright strongly-lensed $z > 7$ galaxies in *Euclid* imaging and in blue and red grism spectroscopy
- Very rare sources that will be the brightest known ultra-high-redshift galaxies on the sky
- Contamination a key issue, including by a new numerous population of lensed red sub-mm galaxies*
- Current algorithms not sufficient, visual selection still required

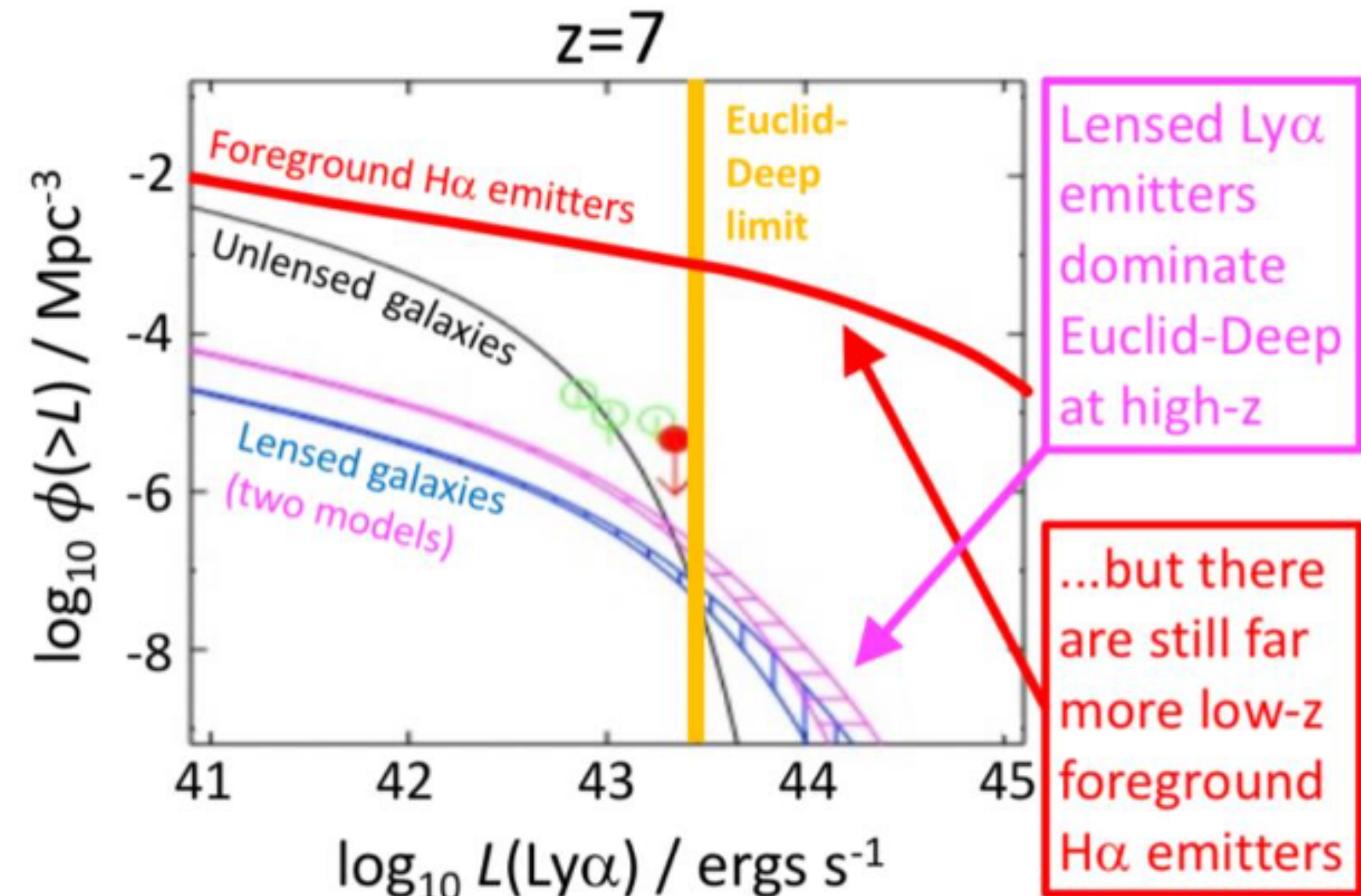
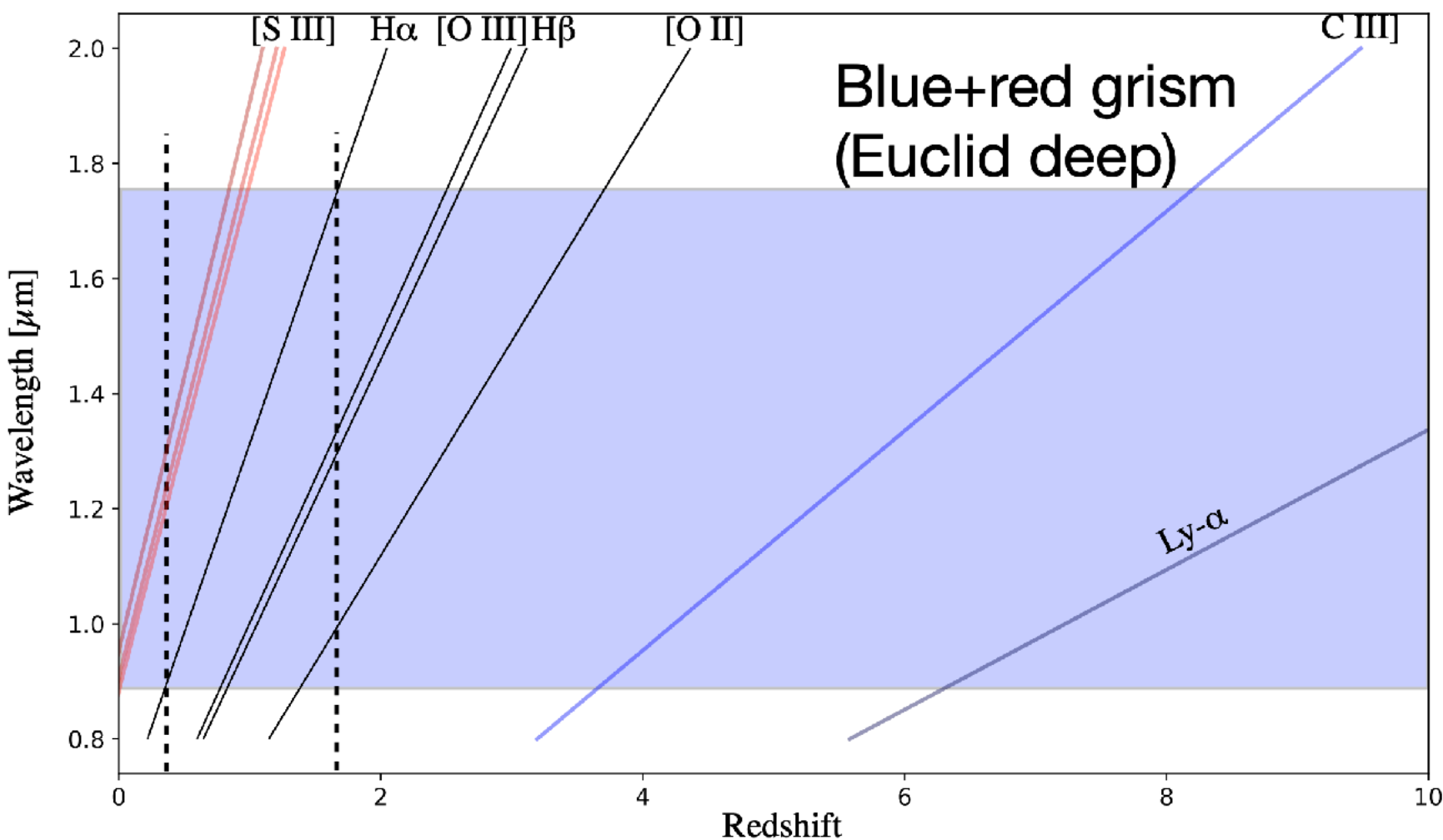
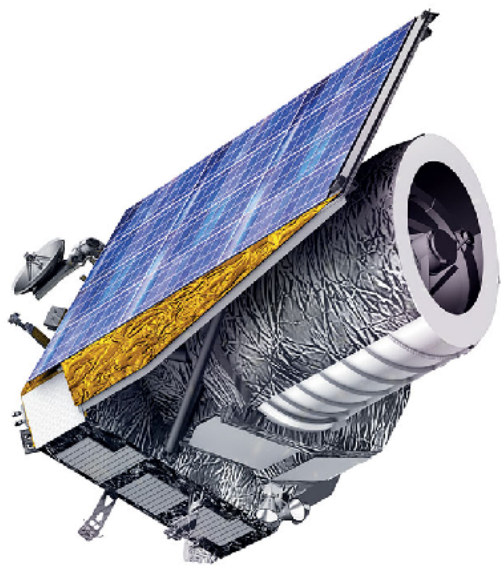
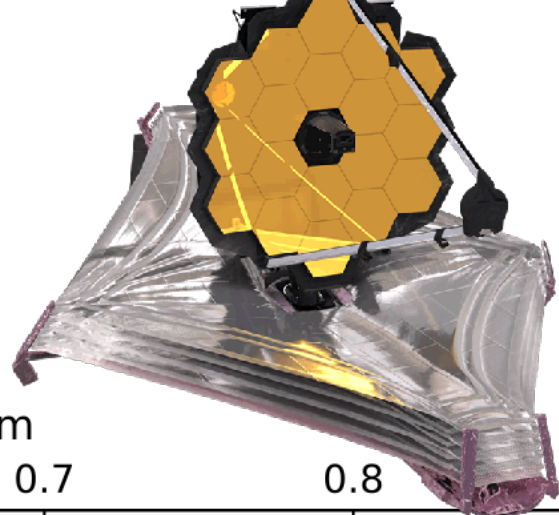


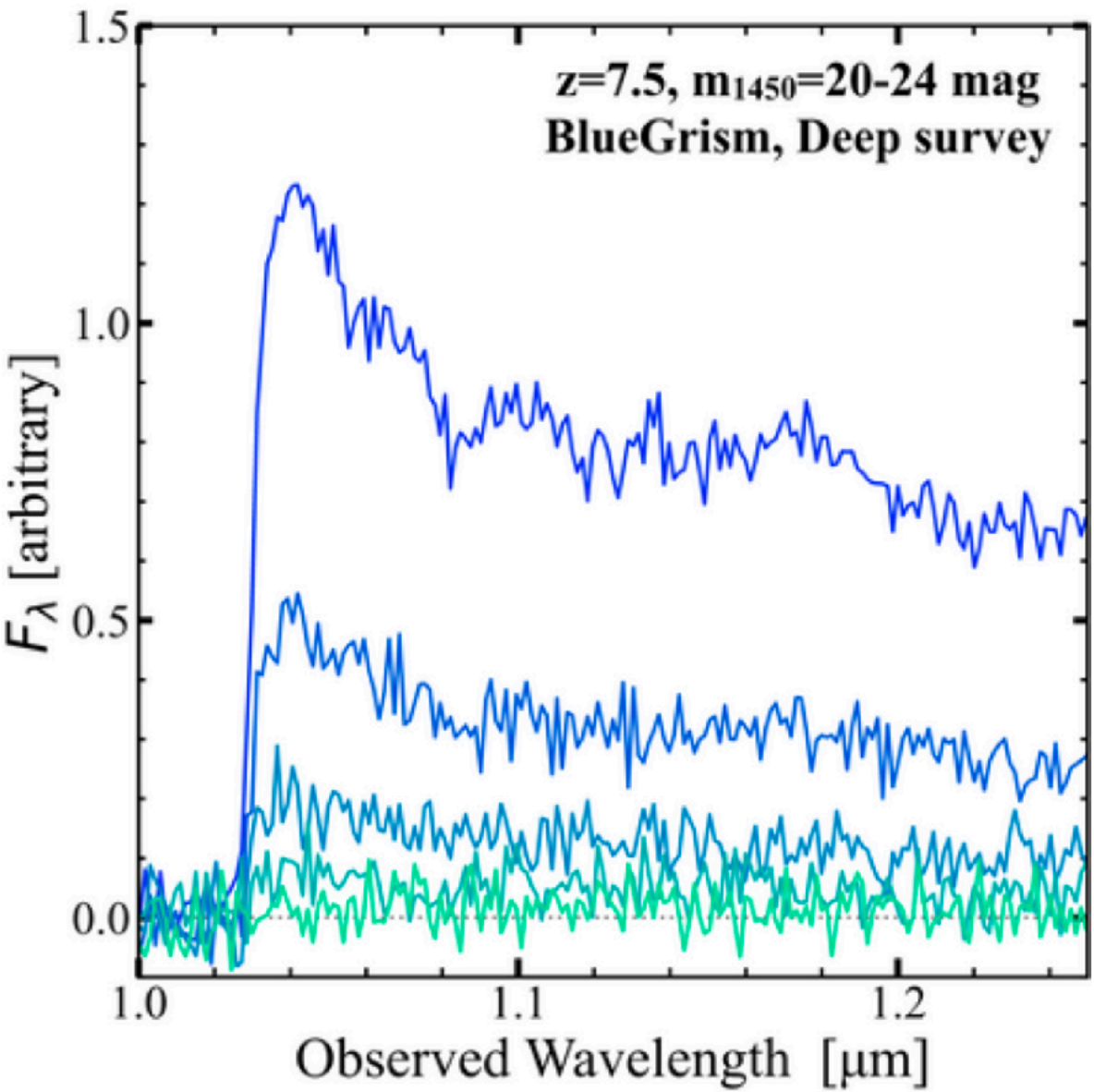
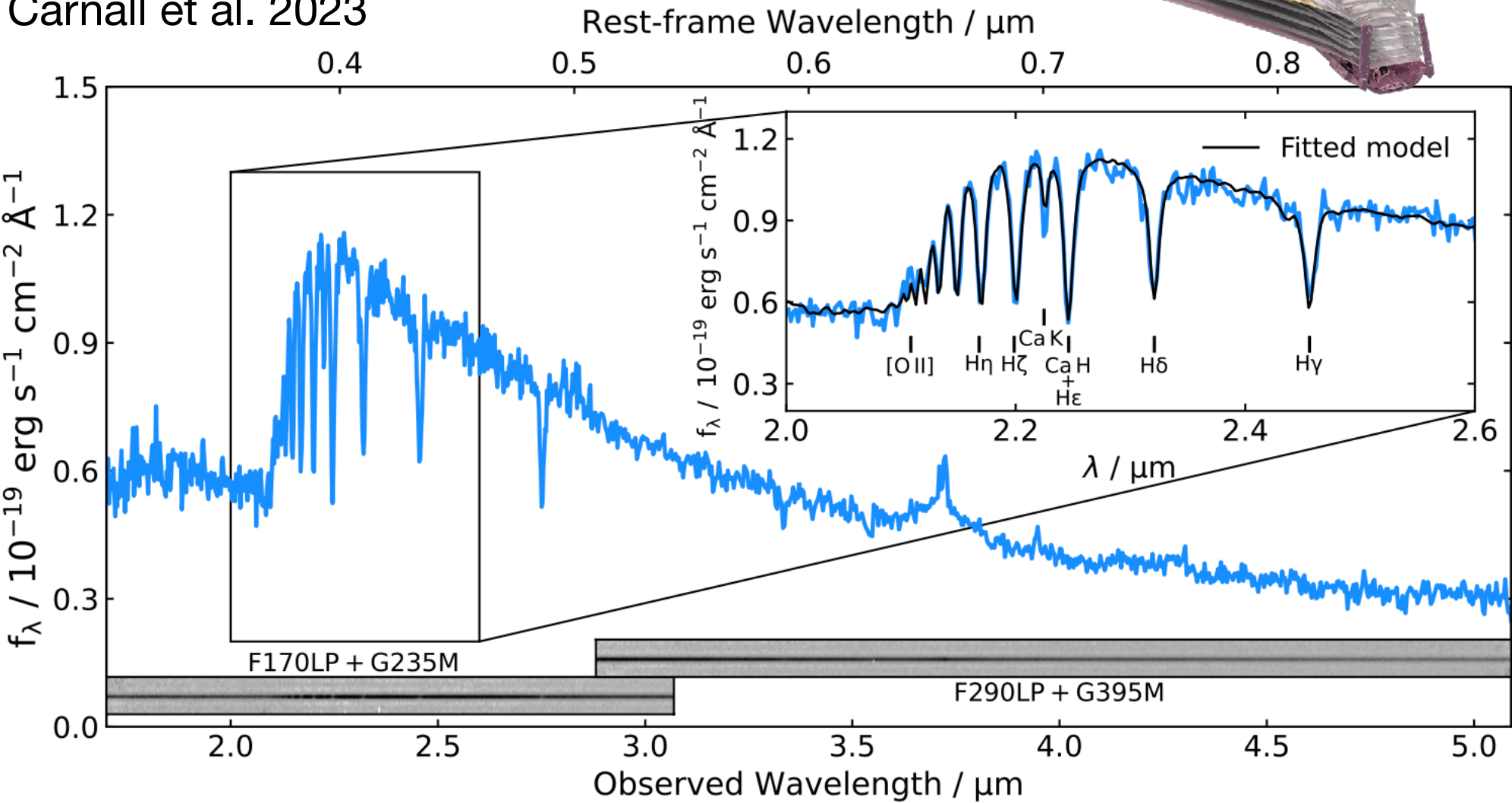
Figure from Marchetti et al. 2017 showing the expected number of $z = 7$ lensed galaxies in the Euclid deep field grism data, in comparison to low-redshift galaxy contaminants

* Pearson et al. 23 (arXiv:2309.00888)

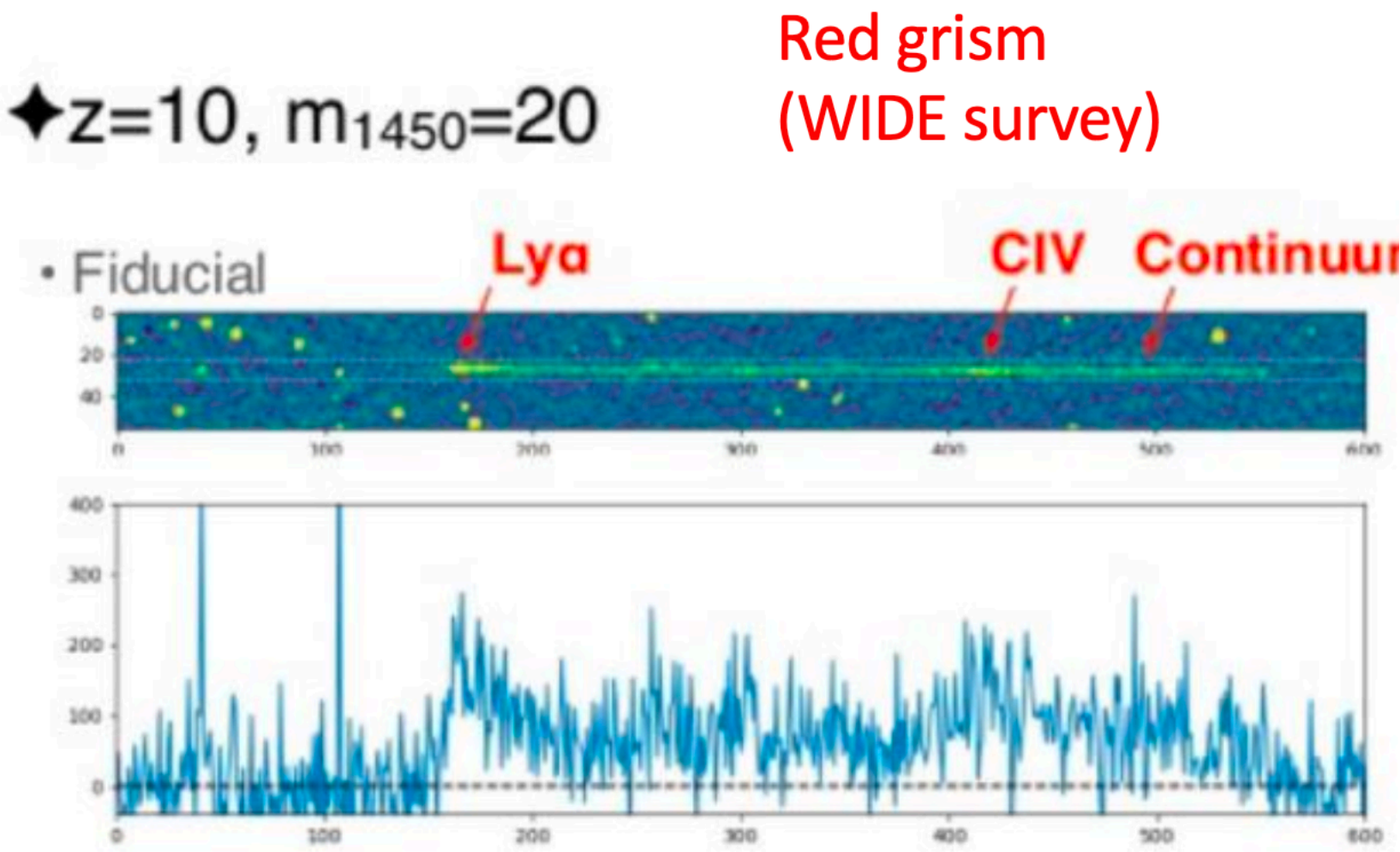
Spectroscopic follow-up will be crucial



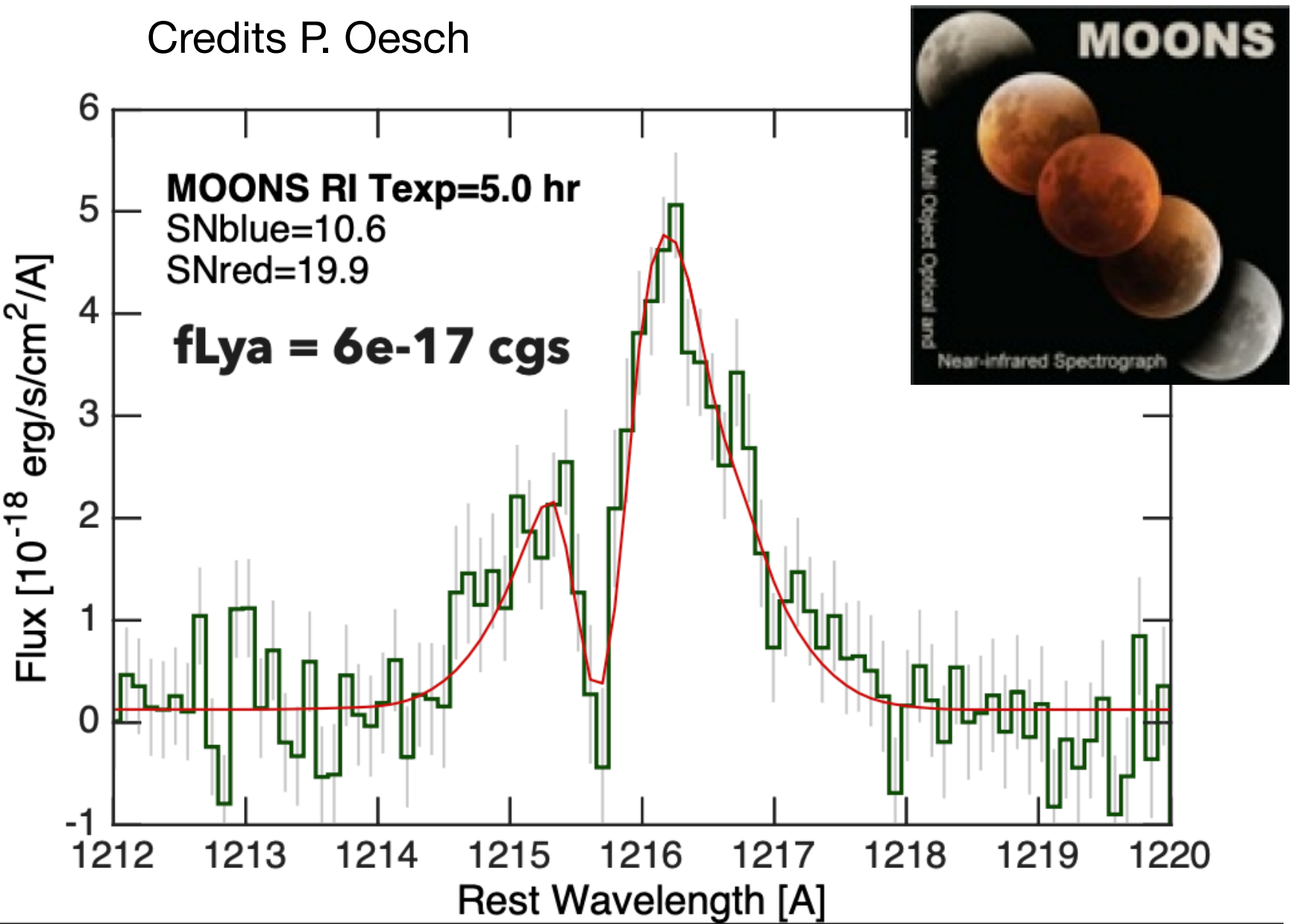
Carnall et al. 2023



Credits E. Banados. M. Onoue



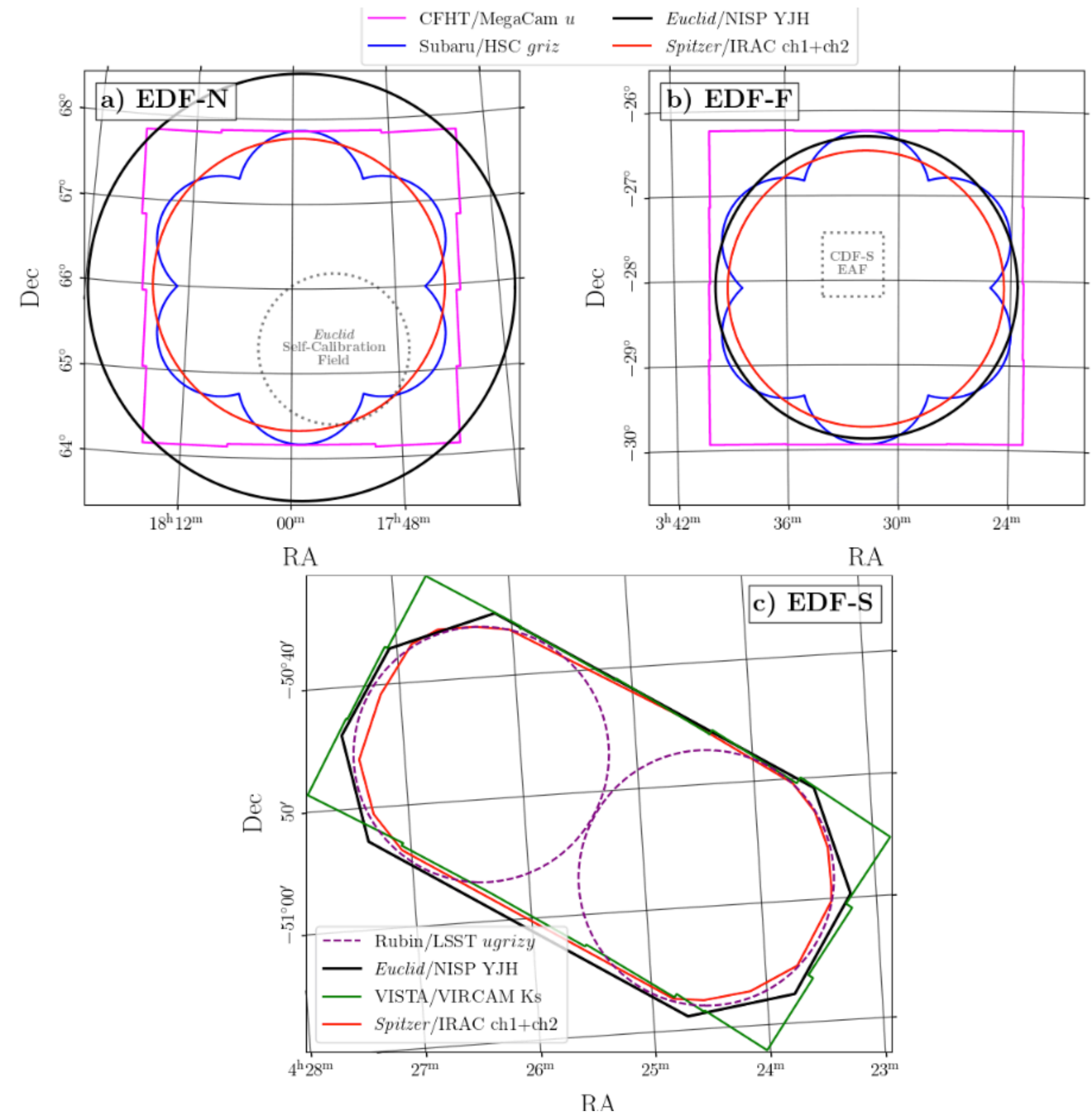
Credits P. Oesch



Cosmic DAWN Survey

- A unified value added catalog over $\sim 50 \text{ deg}^2$ in EDFs and EAFs
- Includes CFHT MegaCam, Subaru HSC, Rubin, Spitzer IRAC, and *Euclid*
- Consistent model-based photometry using The Farmer
- Follow-up spectroscopy of dropouts and protoclusters

Overlapping auxiliary data in the three Euclid Deep Fields (EC, McPartland et al. circulated)



The Early Release Observations Program

The chosen narrative of the ERO aimed at exploring the cosmos from our direct neighborhood out to the distant Universe, culminating with a plethora of galaxies

- A first glance at free-floating baby Jupiters with Euclid
Program Scientist : Eduardo Martín (Instituto de Astrofísica de Canarias)
- Euclid view of Milky Way globular clusters
Program Scientist : Davide Massari (INAF-OAS Bologna)
- A Euclid showcase of nearby galaxies
Program Scientist : Leslie Hunt (INAF-AO Arcetri, Firenze)
- The Fornax galaxy cluster & Dorado group of galaxies seen with Euclid
Program Scientist : Ariane Lançon (Observatoire de Strasbourg)
- The Perseus cluster of galaxies
Program Scientist : Jean-Charles Cuillandre (CEA Paris-Saclay)
- A Glimpse Into Euclid's Universe Through a Giant Magnifying Lens
Program Scientist : Hakim Atek (Institut d'Astrophysique de Paris)

Color-Color selection + Compactness

Weaver et al. 2024

