UltraVISTA

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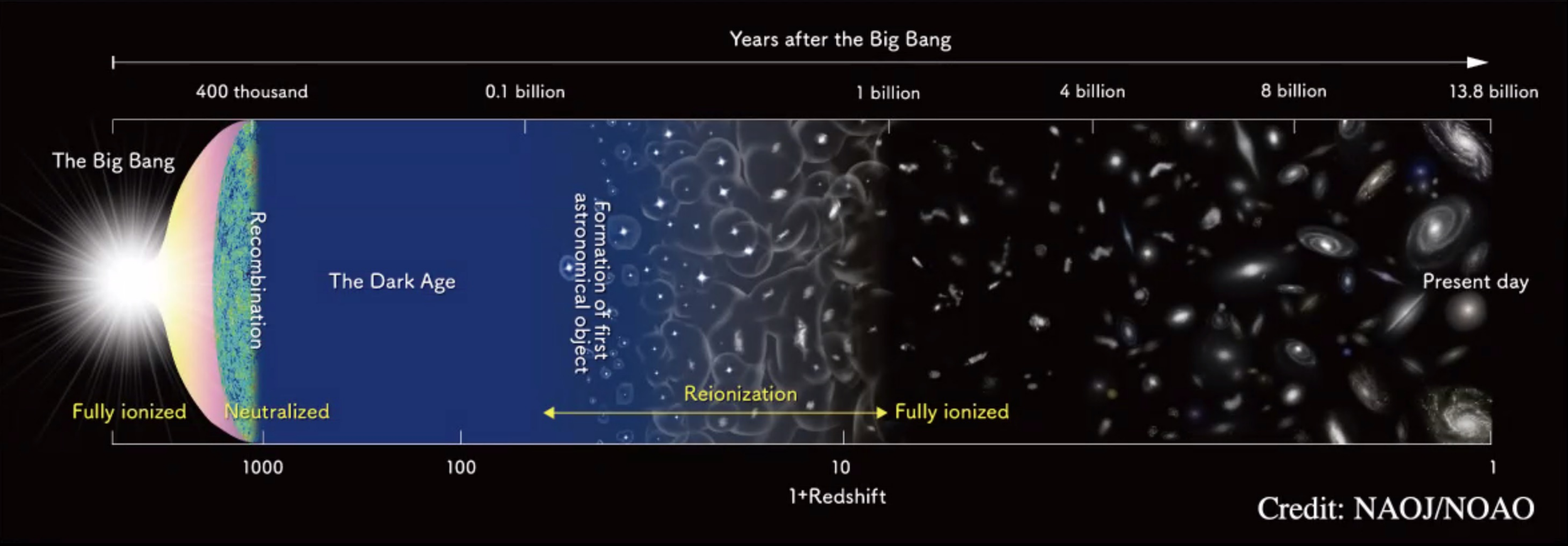
ESO Garching

Oct 2023

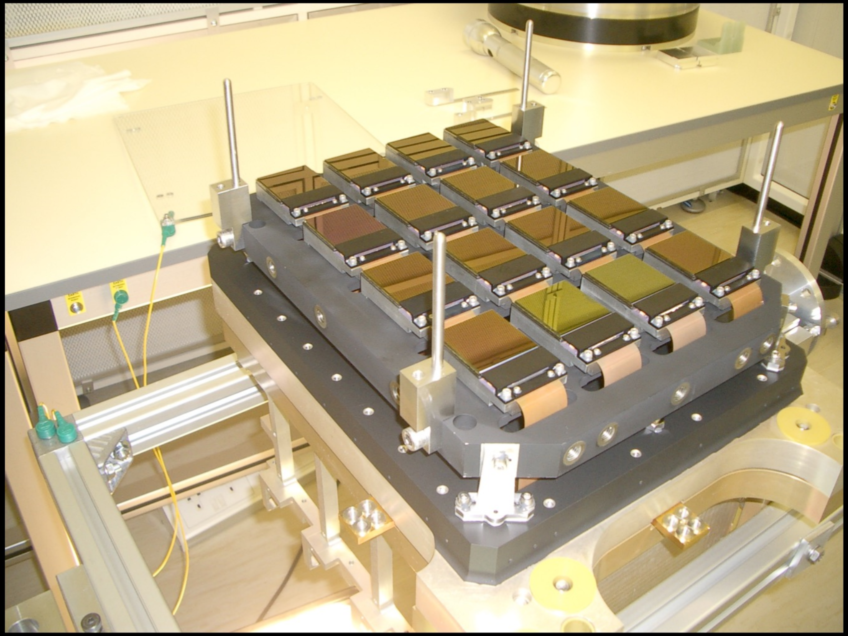
Key facilities for study of early galaxy evolution

Cosmic History



UltraVISTA

VISTA: Paranal, Chile



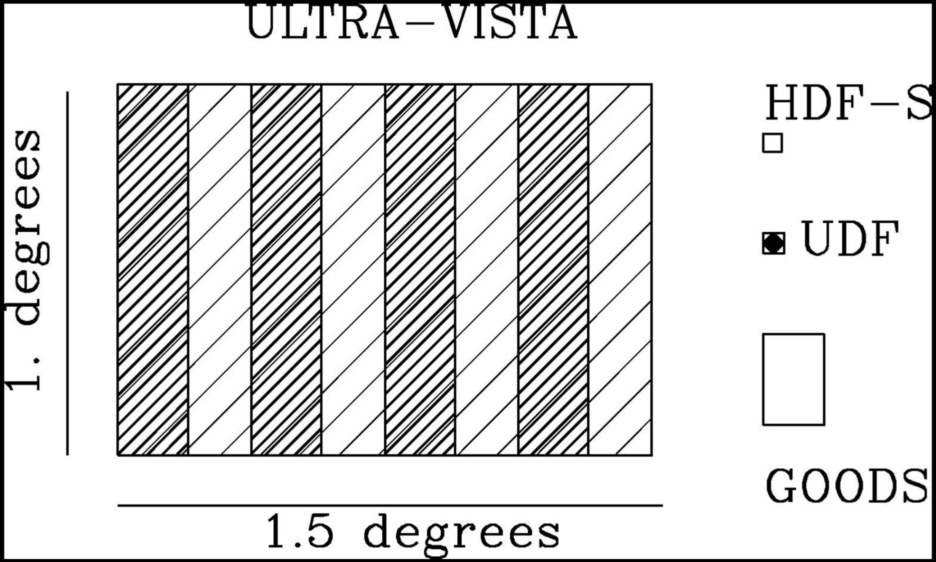
VIRCAM: 67 Mega pixels (1.5 deg^2)

~ 3-4 x most efficient near-IR camera

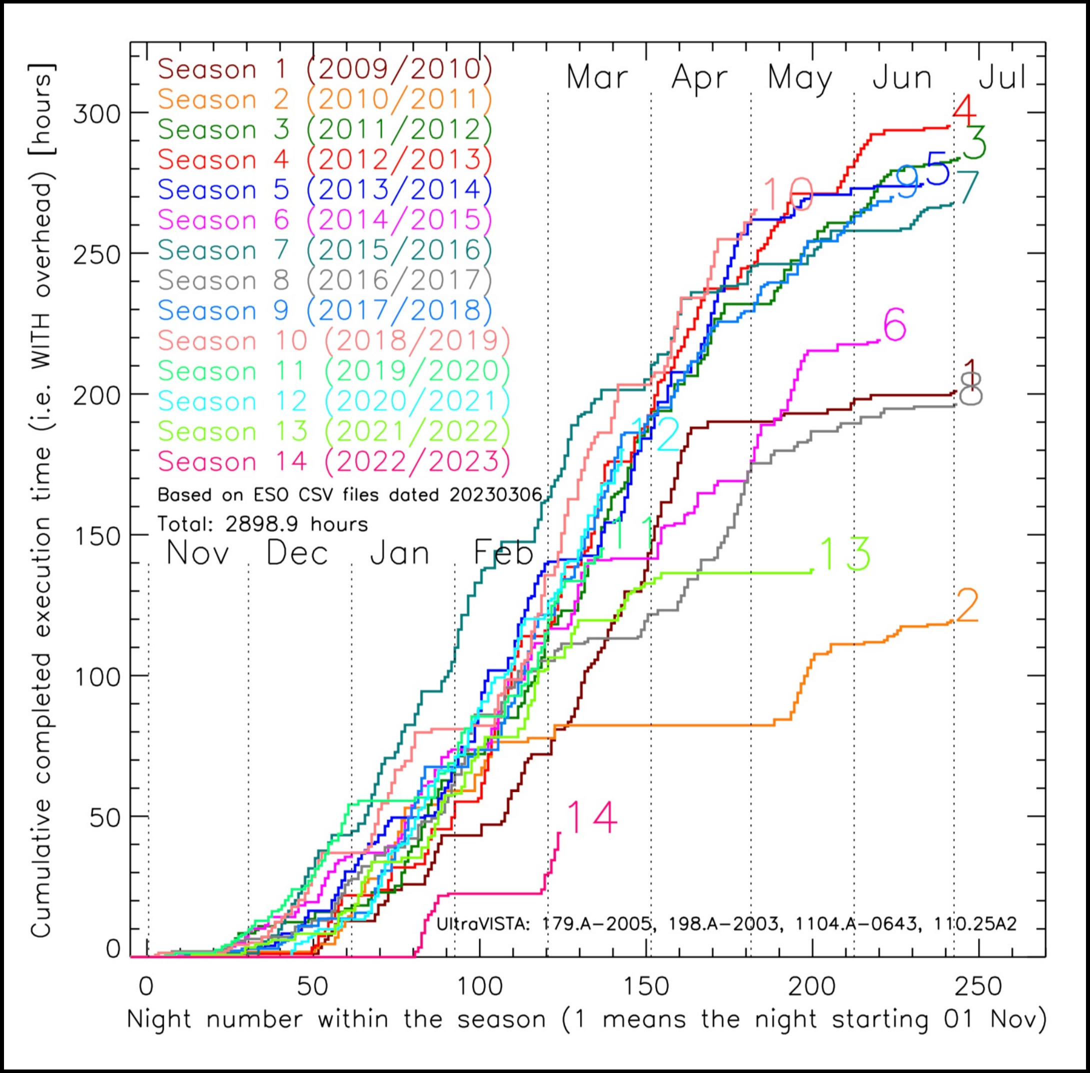
UltraVISTA

UltraVISTA – planned as deepest public survey with VISTA

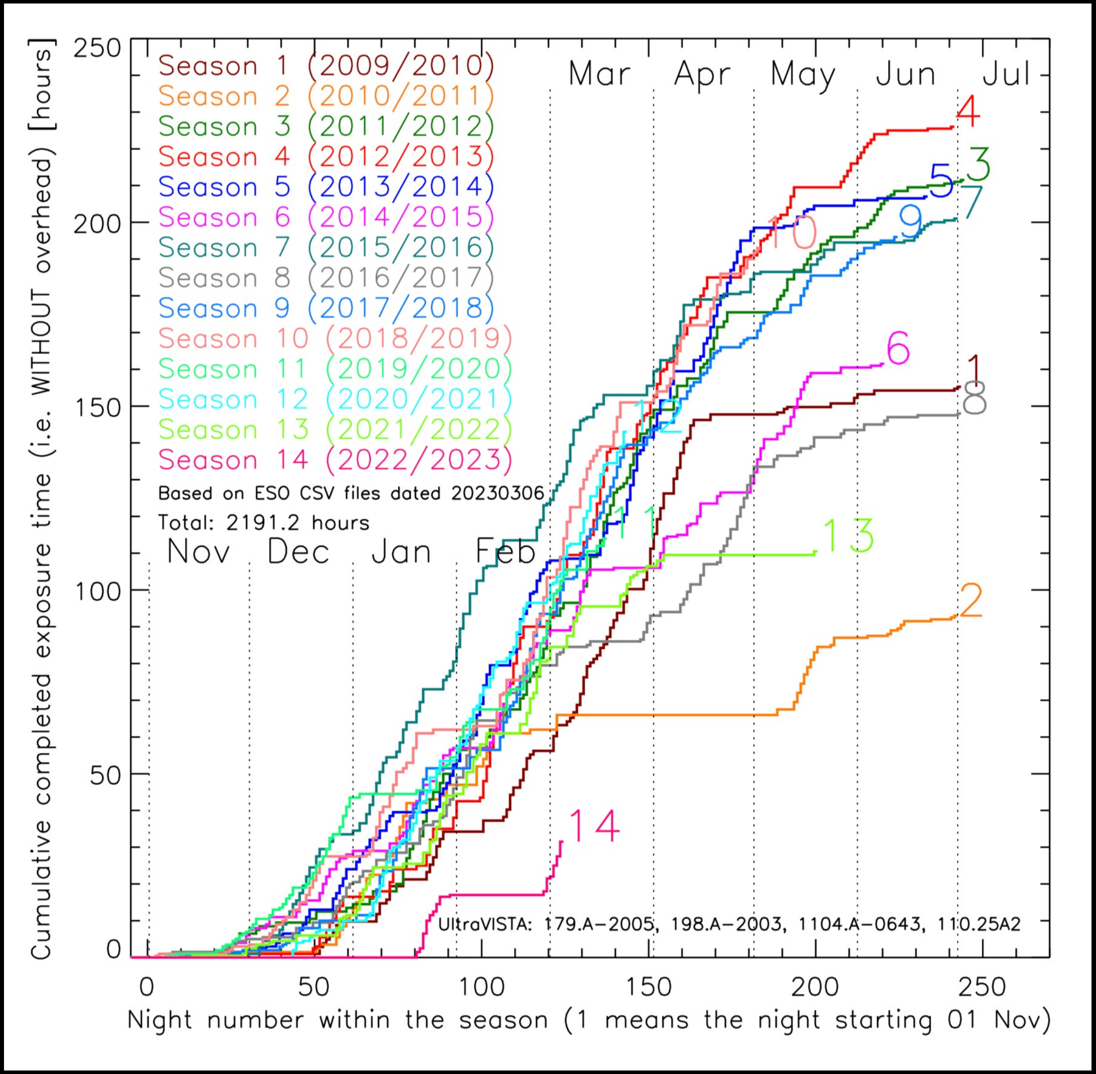
- PIs Dunlop, Franx, Le Fevre, Fynbo
- DEEP - 0.73 sq. deg., Y=26.7, J=26.6, H=26.1, K=25.6 (1408 hr)
- WIDE – 1.50 sq. deg., Y=25.3, J=25.2, H=24.7, K=24.2 (212 hr)
- Narrow-band survey, at 1.185 microns (z = 8.8 for Lyman-alpha) (180 hr)
- Originally allocated 1800 hours over 5 years – started Jan 2010

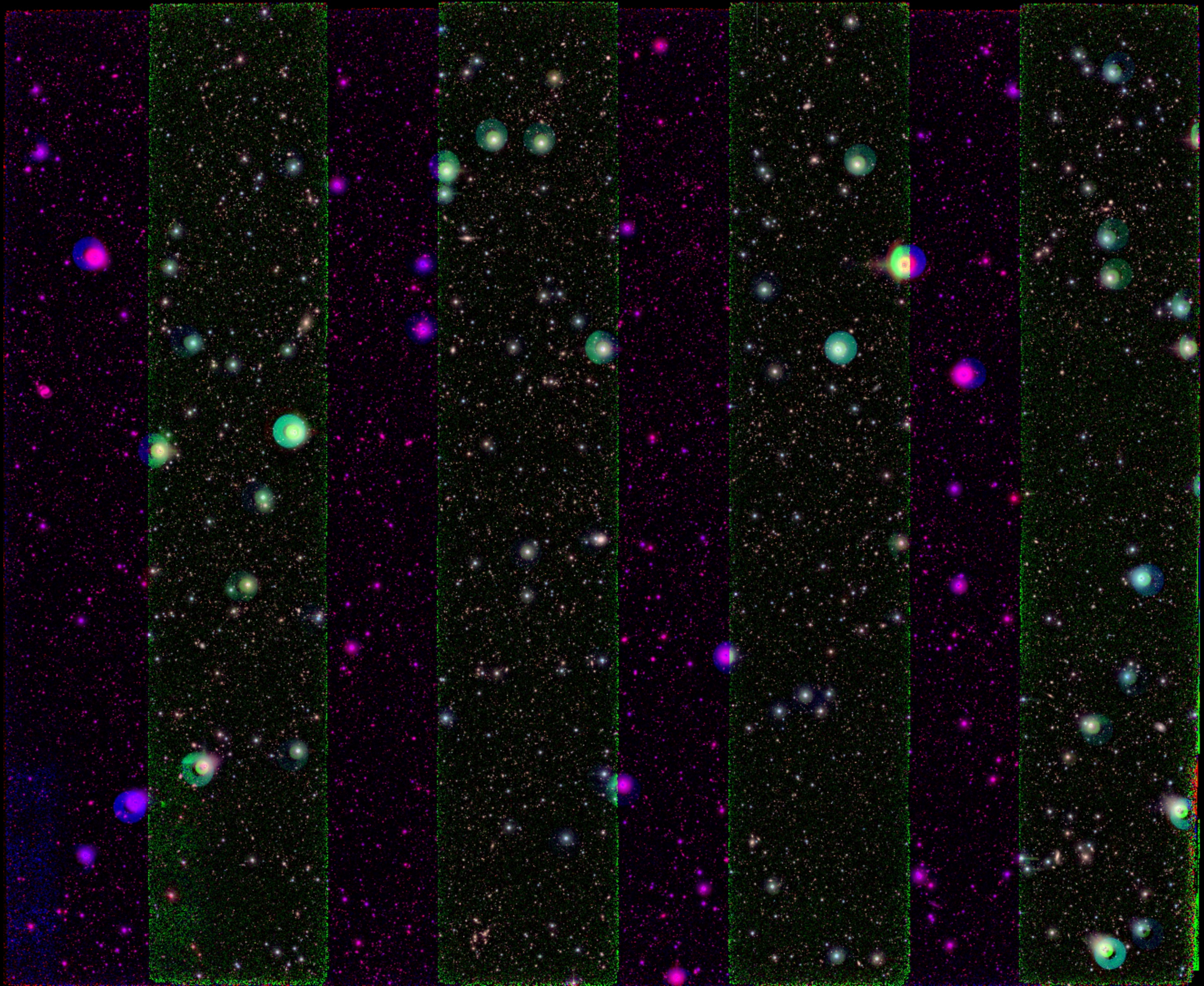


14 seasons of UltraVISTA observing



14 seasons of UltraVISTA integration





UltraVISTA proposal history

179.A-2005 “UltraVISTA”
- original 1800 hr Public Survey proposal (2009)

198.A-2003 “Completing the legacy of UltraVISTA”
- 750 hr Public Survey proposal to flatten J, H, K_S imaging (2016)

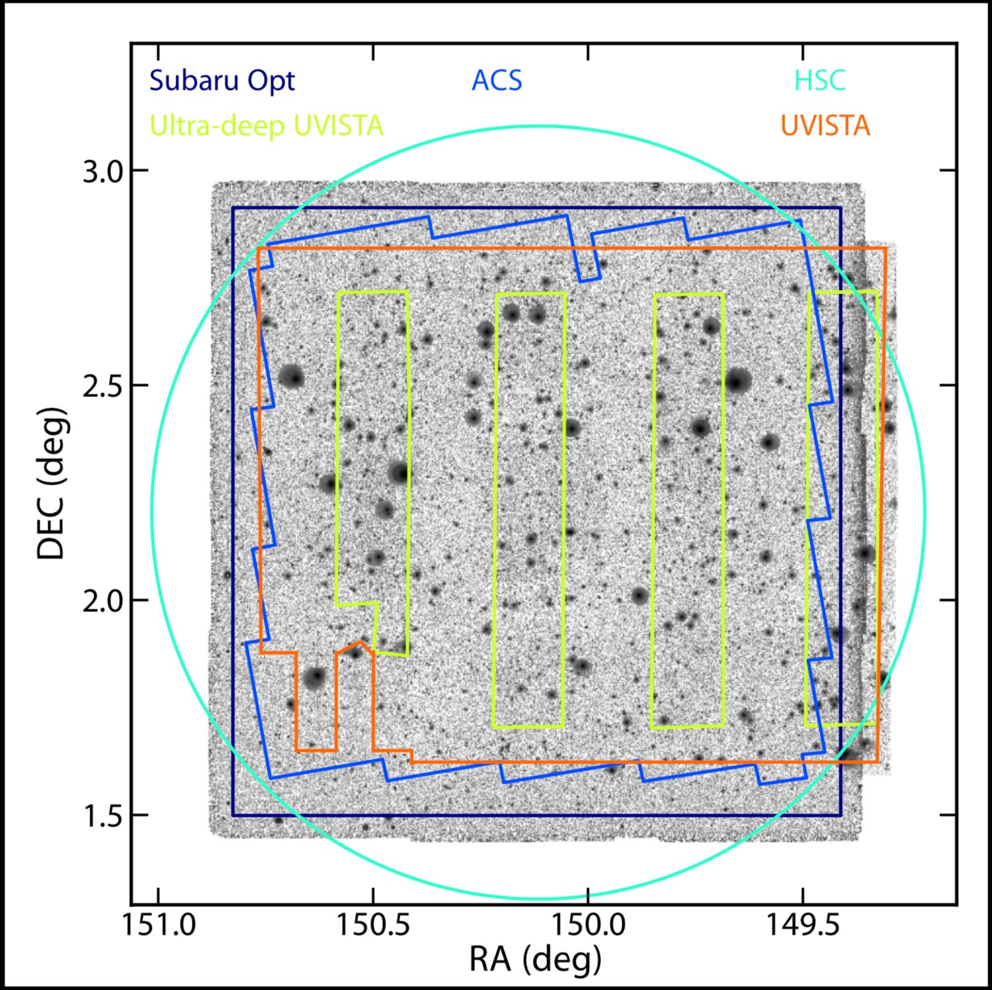
LP 1104.A-0643 “Completing UltraVISTA: charting cosmic reionization & preparing for *EUCLID*”
- 272 hr Large Programme to flatten Y (2019)

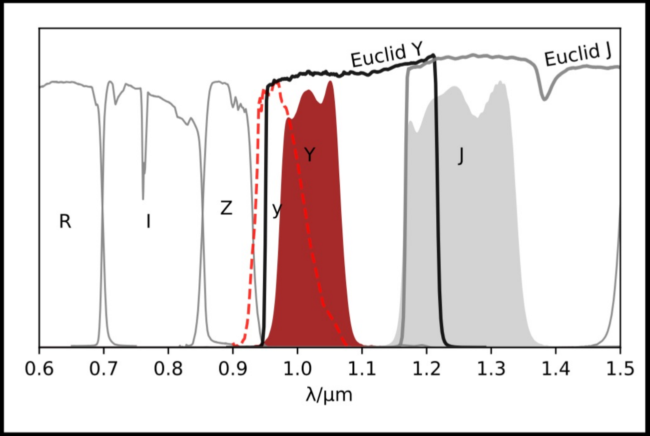
DDT 110.25A2 “Completing UltraVISTA”
- 99.5 hr DDT request to refine homogenization of J, H, K_S imaging (2022)

Final allocation was curtailed due to VIRCAM observations ceasing on 5/6 March 2023

UltraVISTA proposal history

Complementing Subaru - boosting the legacy value of UltraVISTA





VISTA Y-band and Subaru Hyper Suprime-Cam y-band are different, and different again from the broad Euclid Y filter.

Prospects for improved selection of high-z galaxies, + quantifying the strength of Ly-α emission in the reionization epoch.

UltraVISTA data releases

DR1: 179.A-2005
DR2: 179.A-2005
DR3: 179.A-2005
DR4: 179.A-2005
DR5: 179.A-2005, 198.A-2003
DR6: 179.A-2005, 198.A-2003, 1104.A-0643, 110.25A2, maybe also 284.A-5026

Andrea Moneti & Henry-Joy McCracken, IAP

Bo Milvang-Jensen, DAWN

UltraVISTA DR5 – May 2023

Fifth Release of UltraVISTA Public Survey Data

Published: 05 May 2023

UltraVISTA is an ultra-deep near-infrared survey of the central region of the COSMOS field. The fifth UltraVISTA data release comprises stacked images in YJHKs and NB118 narrow-band filters, as well as single-band and dual-mode source lists. The data release also contains a five-band merged catalogue, created from the individual Ks-selected source lists. The release is based on the observations carried out from December 2009 to mid 2019, corresponding to 81125 individual images. This is three years more than DR4. The additional data have almost homogenised the exposure time in the “deep” and “ultra-deep” stripes in the J, H and Ks filters, which now reach the same depths to ~0.15 mag.

The total exposure time contributing to this release is 1786 hours, and the total survey area is close to 1.9 square degrees. The seeing in the five stacks is in the range 0.75"-0.77".

The data products are available from the ESO Archive Science Portal or the Programmatic Access service. More details about the release content can be found in the associated data release description. Moreover the band-merged catalogue data, containing 475286 records, can be queried programmatically or via the dedicated Catalogue Interface.

By accessing the UltraVISTA DR5, the ESO community benefits from joint efforts by ESO, the Principal Investigators of the VISTA public survey projects and their collaborators, including the CALET data centres (France) and CASU (UK).

The DOI assigned to the data collection is 10.18727/archive/52

UltraVISTA DR5 – May 2023

5-sigma limiting magnitude (AB) in 2-arcsec diameters apertures (as measured on Ultra-deep columns of DR5)

Y	J	H	K
25.7	25.8	25.5	25.2

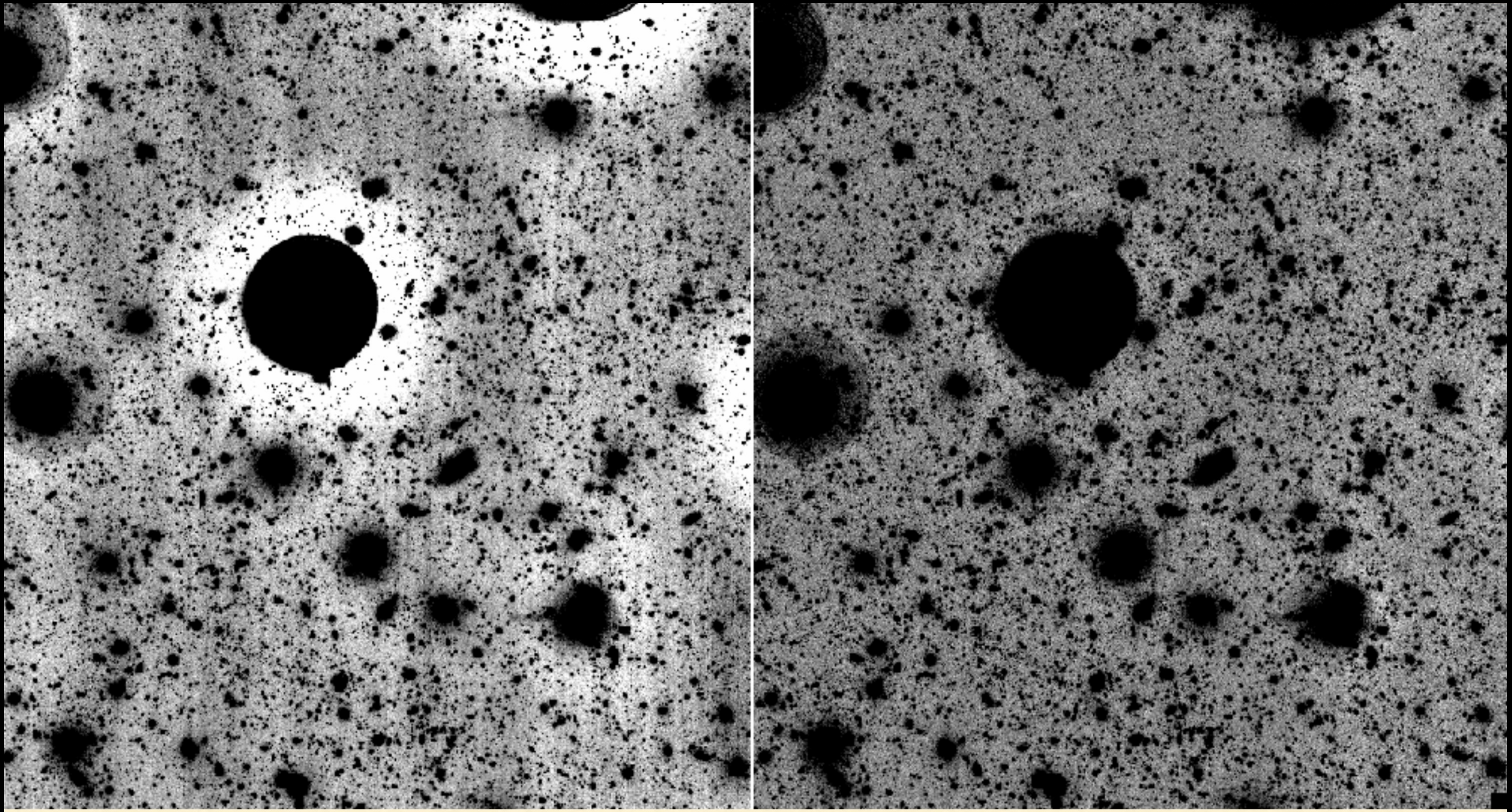
Deep columns ~0.2 mag shallower in DR5

Extra observations included in DR6 have removed this difference and have increased homogeneous Y-band depth to 26.0.

UltraVISTA DR6 – March 2024

- Will include all UltraVISTA observations from Dec 2009 to Mar 2023 (when VIRCAM was retired)
- 110,433 images and 2,467 hours of exposure time
- ~10% of frames rejected: FWHM > 1 arcsec and/or star ellipticity > 0.1 (peak of ellipticity distribution is at ~0.01)
- Final stacks contain ~175 hr of integration per pixel
- Improved sky subtraction via a proper time-localized sky for each image
- Improved astrometry using GAIA catalogue shifted to observation time
- Full stacks for all 5 filters and a 5-band catalogue

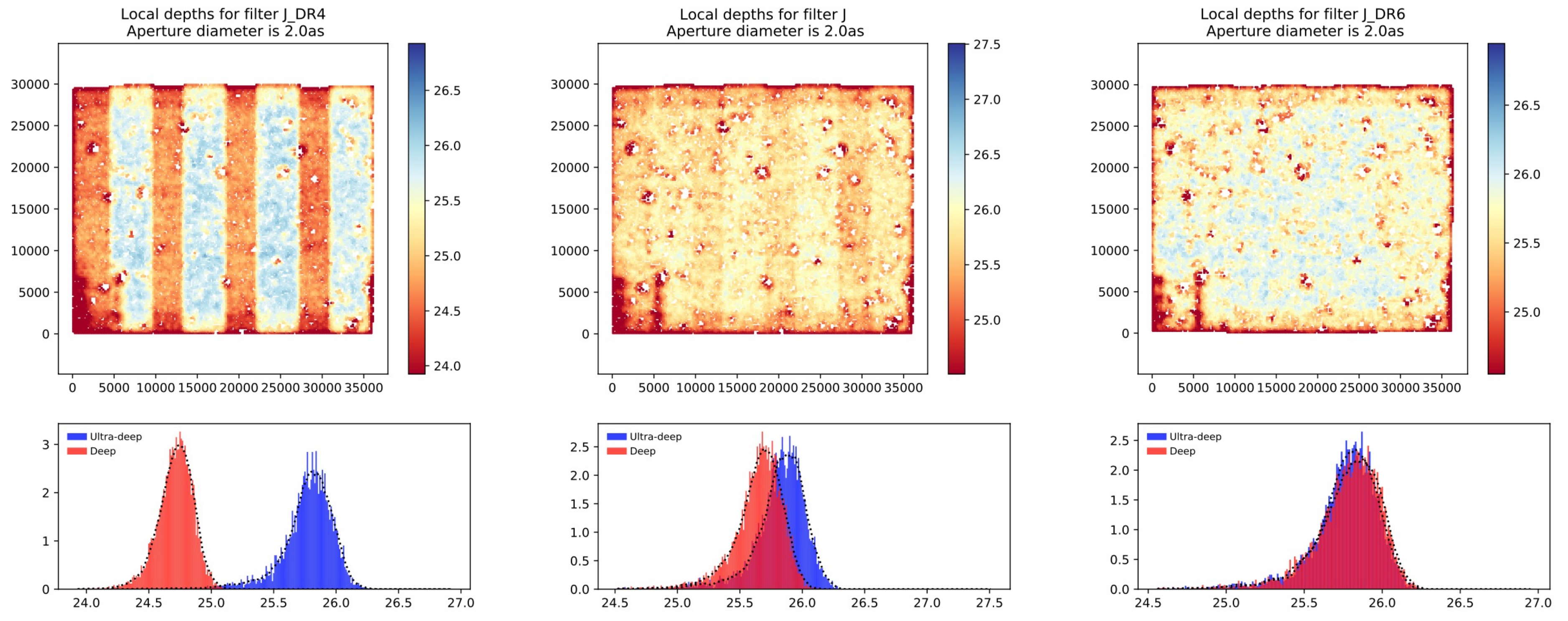
The power of full re-reduction



Stack of CASU files (left) vs stack of DR6 (beta) files (right)

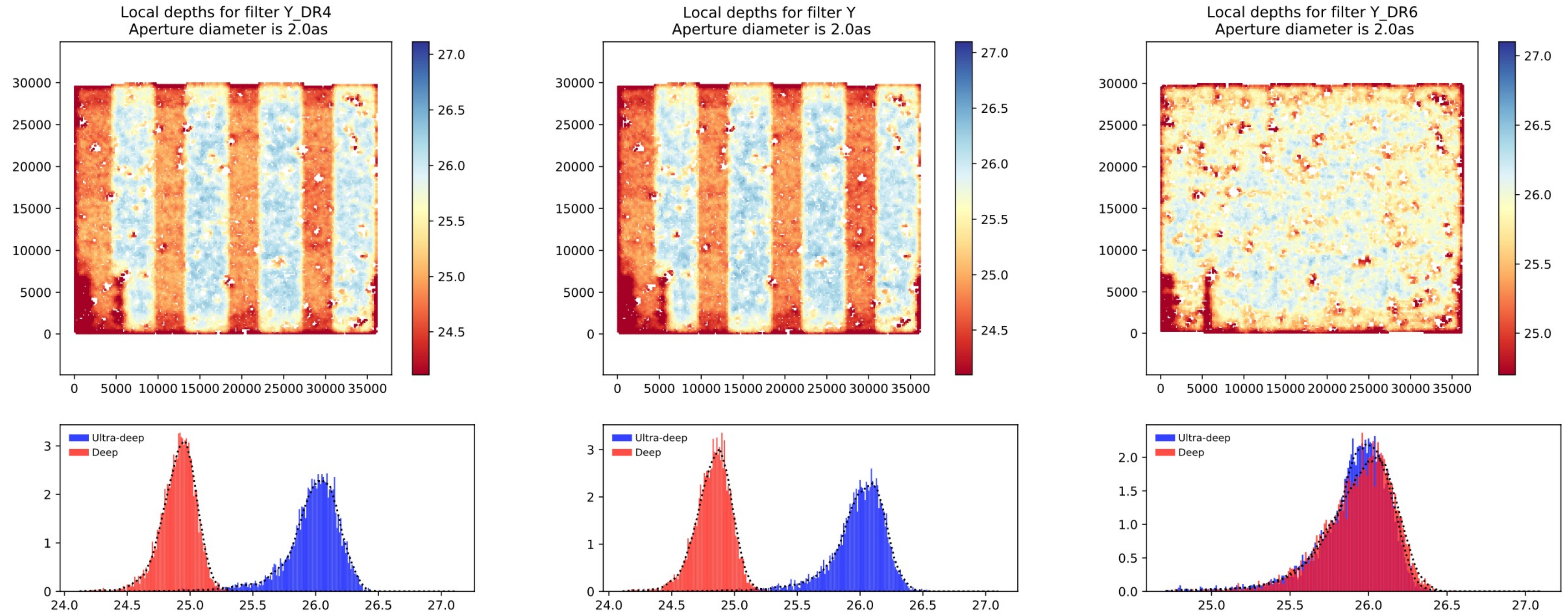
Demonstrates importance of individual skies

DR4 versus DR5 versus DR6



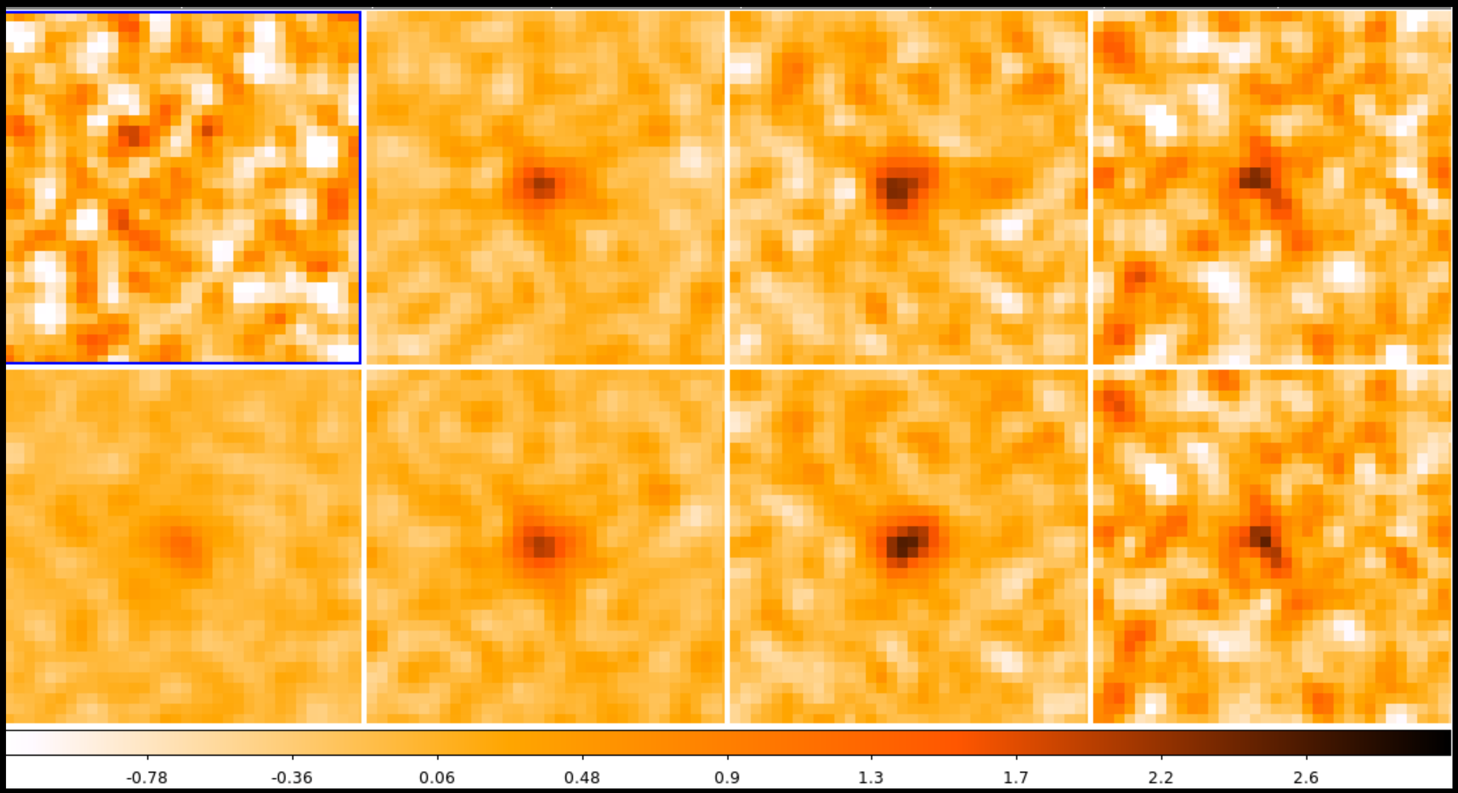
J band

DR4 versus DR5 versus DR6



Y band

DR5 versus DR6



Y	J	H	K_S
26.0	25.8	25.5	25.1

5-sigma, 2-arcsec diameter apertures

The impact of UltraVISTA

According to https://telbib.eso.org 270 papers have utilized UltraVISTA data

The original survey definition paper (McCracken et al. 2012) has been cited 616 times

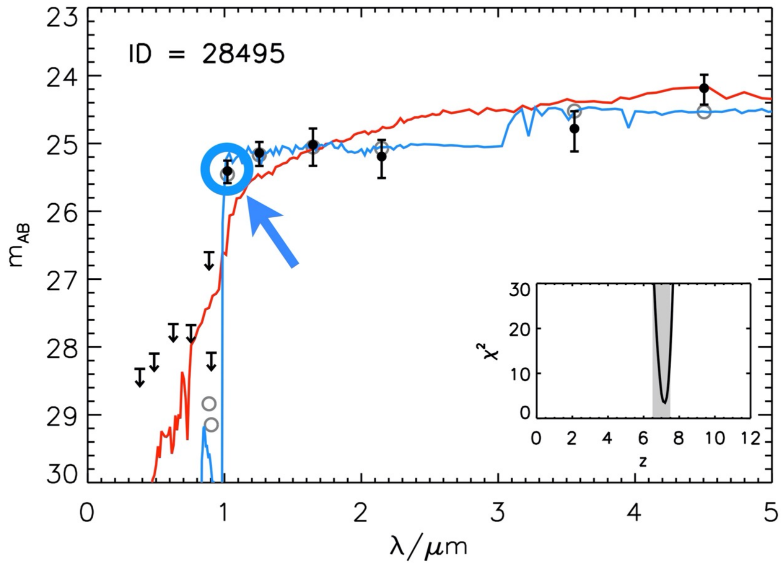
The COSMOS 2015 (Laigle et al. 2016) and COSMOS 2020 (Weaver et al. 2022) catalogue papers have been cited 813 and 138 times respectively

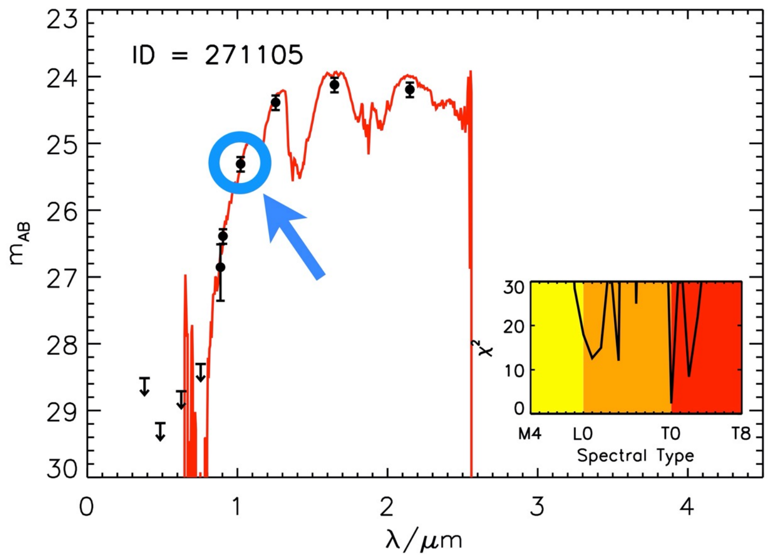
Papers based on UltraVISTA data have now garnered ~17000 citations in total

Key Science 1: UV-selected Galaxies at high z

Major challenge is distinguishing z = 7 galaxies from T dwarfs

Big problem for ground-based surveys at J ~ 25

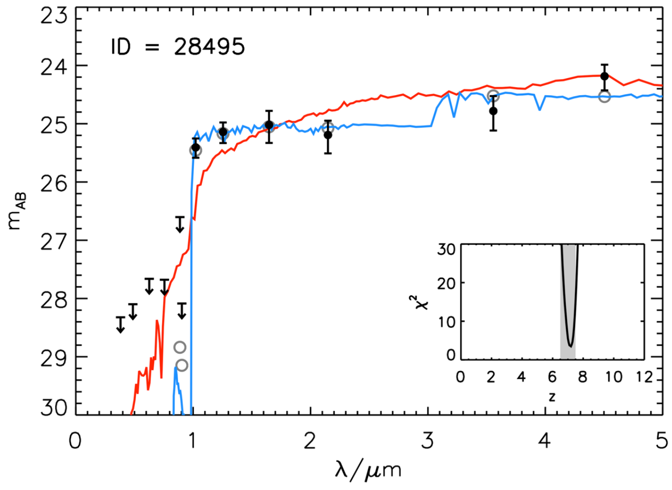


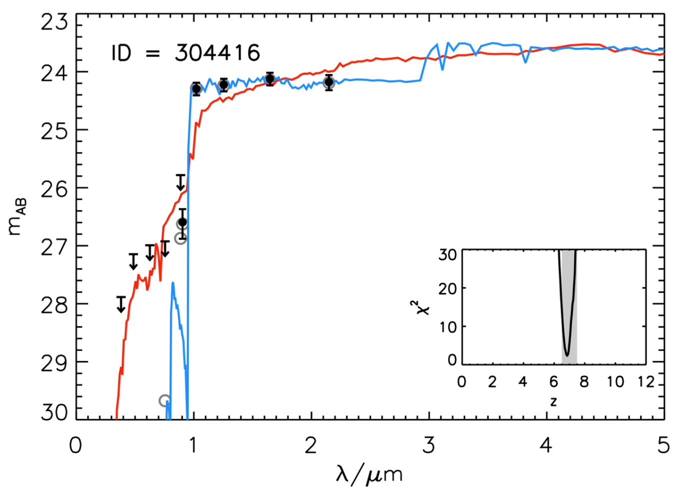


Crucial importance of deep Y-band, and deep z-band

UltraVISTA robust z ~ 7 galaxies

Bowler et al. (2012, 2014)





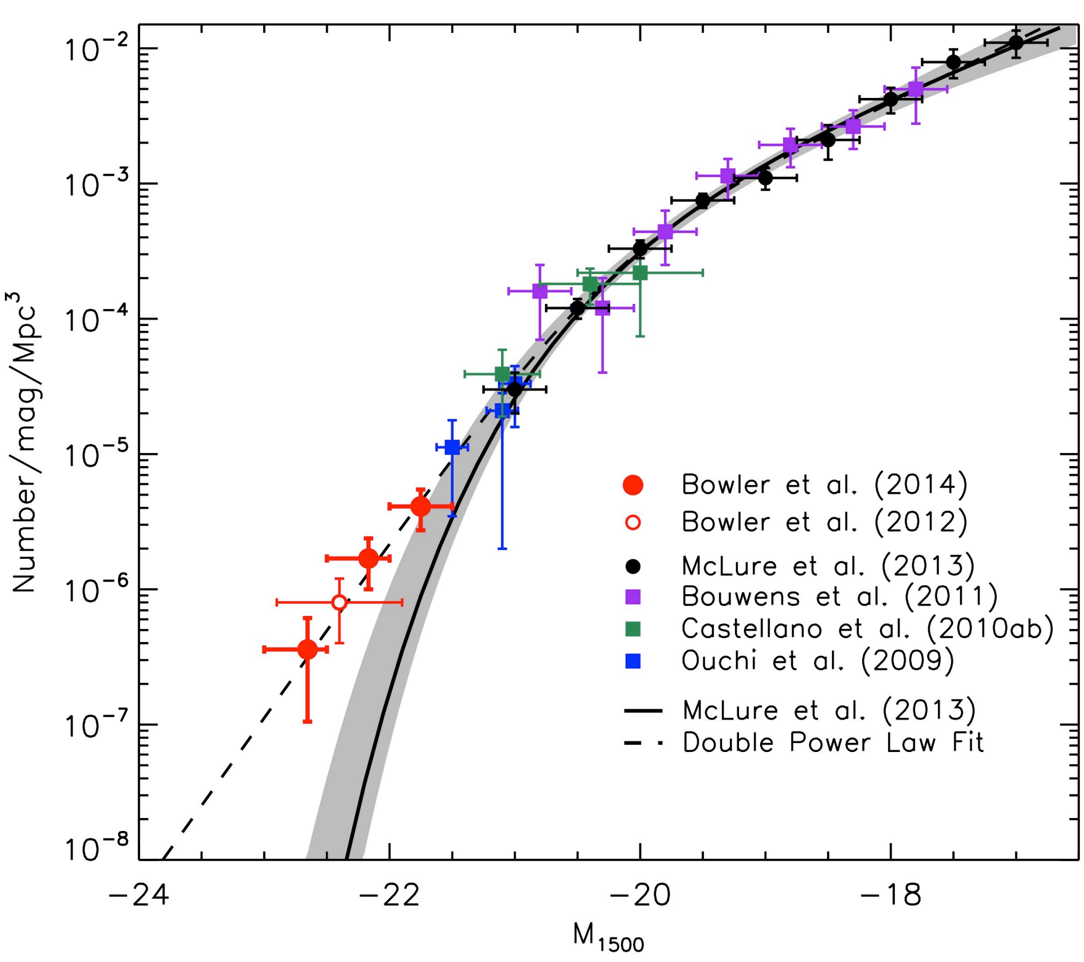
Sample includes most massive z = 7 galaxies with $M^* = \sim 10^{10}$ M_{sun}

SFR ~ 10 – 40 M_{sun}/yr

Median rest-frame UV slope β = – 2.0

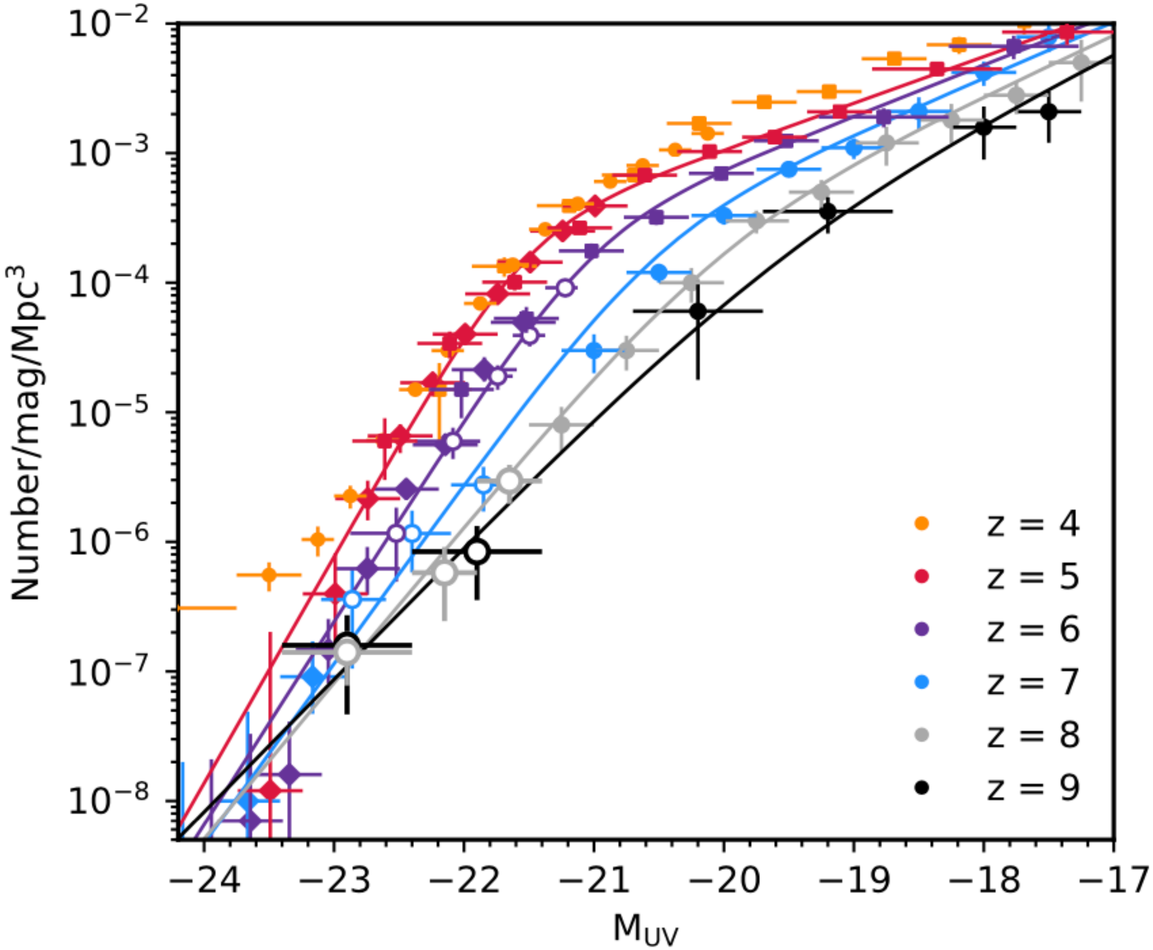
Bright end of z = 7 Luminosity Function (LF)

Bowler et al. (2012, 2014)



Evolving high-redshift UV galaxy luminosity function

Combining space-based and ground-based data – Bowler et al. (2020)

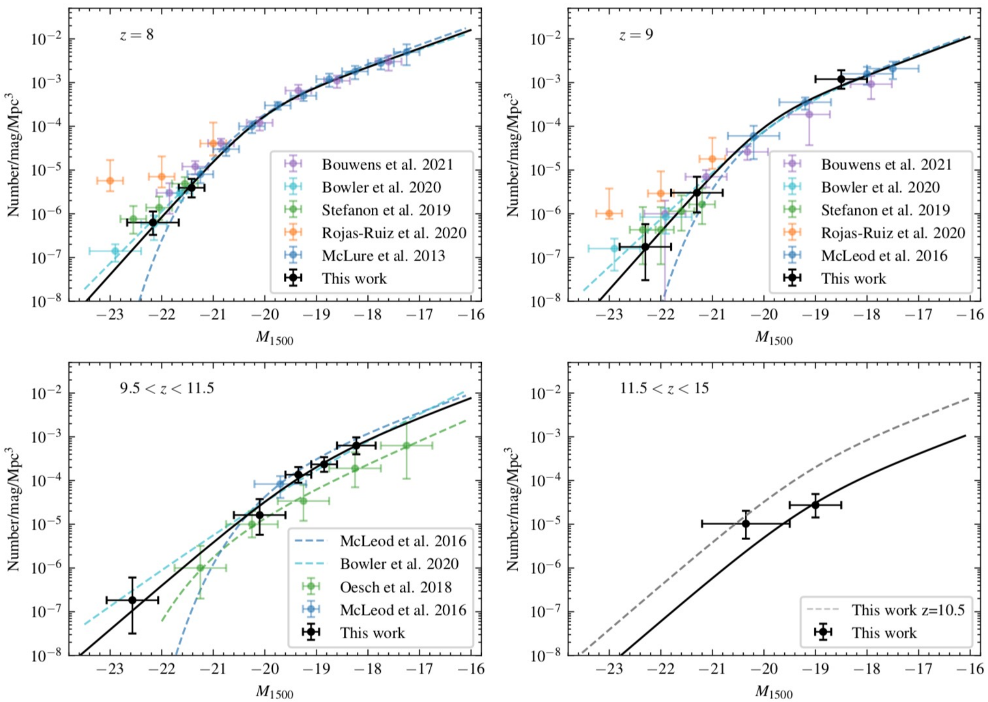


Evolution in shape towards CDM mass function at very high z?

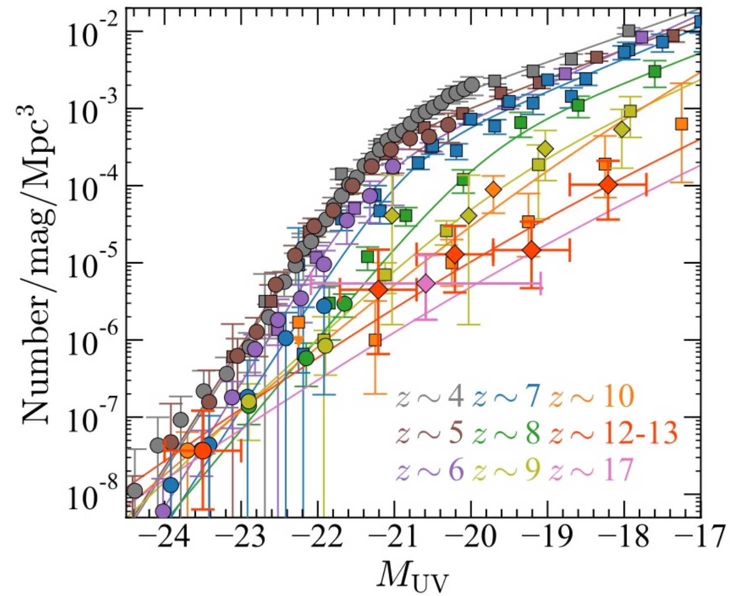
The latest high-redshift UV galaxy luminosity functions

Results from JWST and UltraVISTA – support shape change at very high z

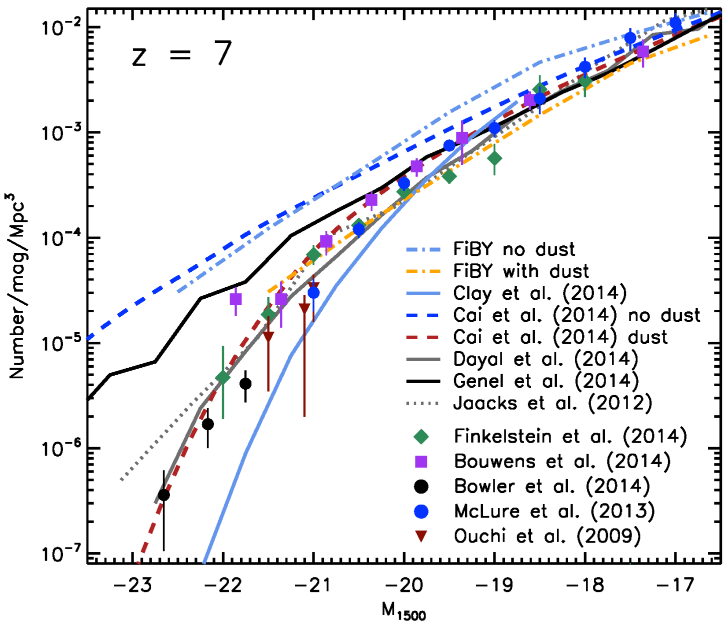
Donnan et al. (2023a) MNRAS, 518, 6011



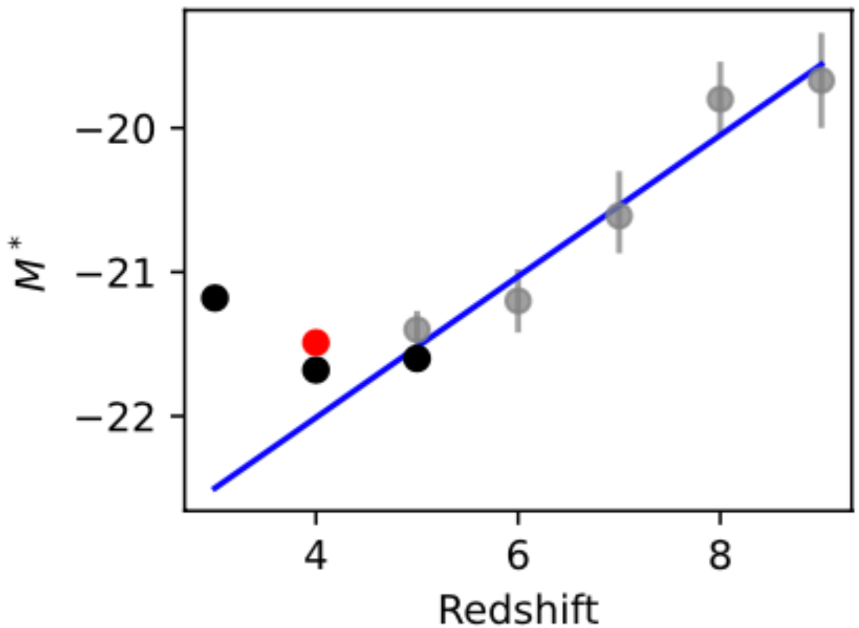
Harikane et al. (2023)



Physical reasons for change of LF shape – dust and/or quenching?



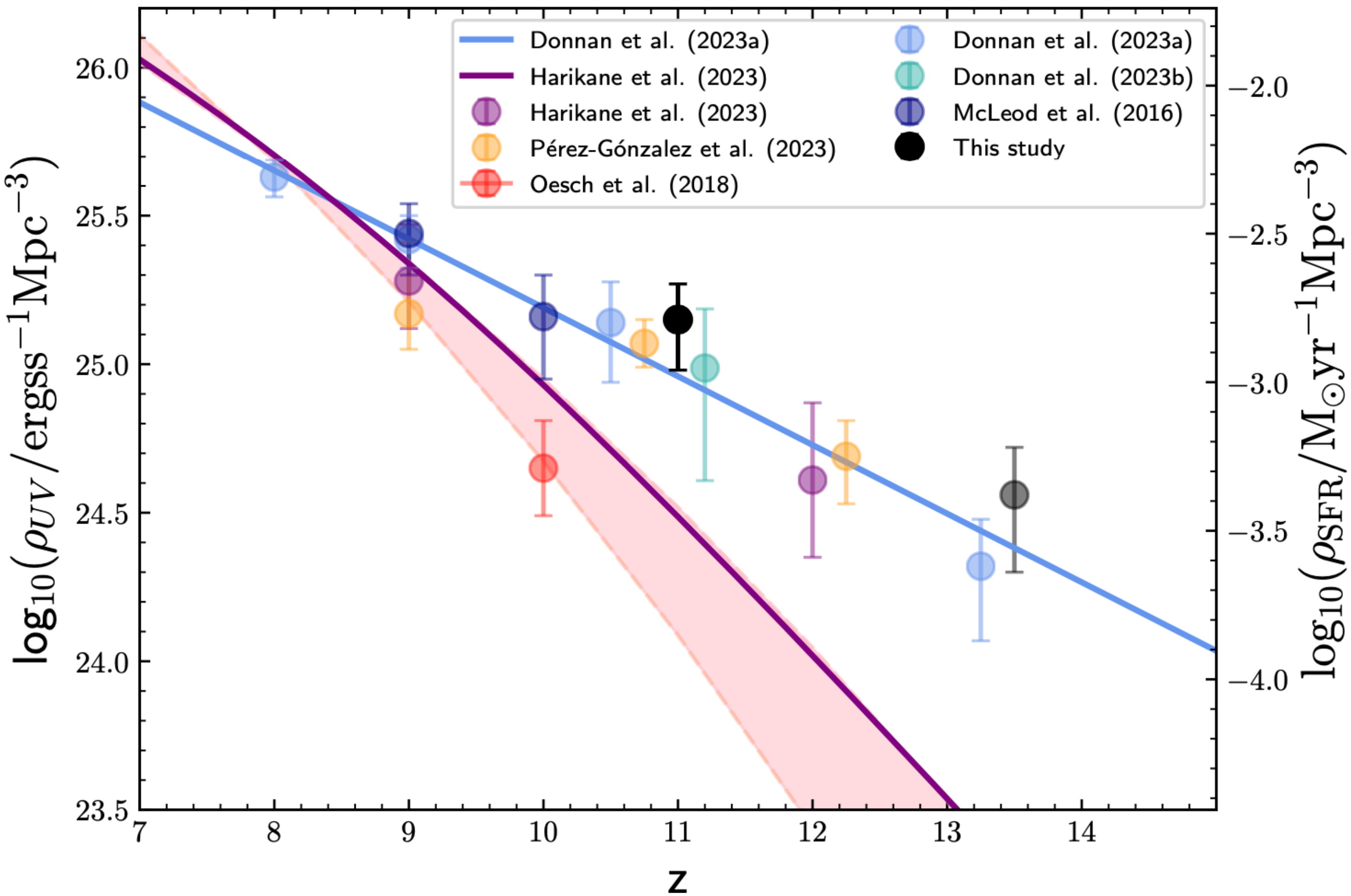
Dust needed to match models at z = 7
(e.g., Bowler et al. 2015)



Freezing/reversal of M* at z < 4 indicative of quenching?
(Adams et al. 2022)

Implications for high-z SFR density

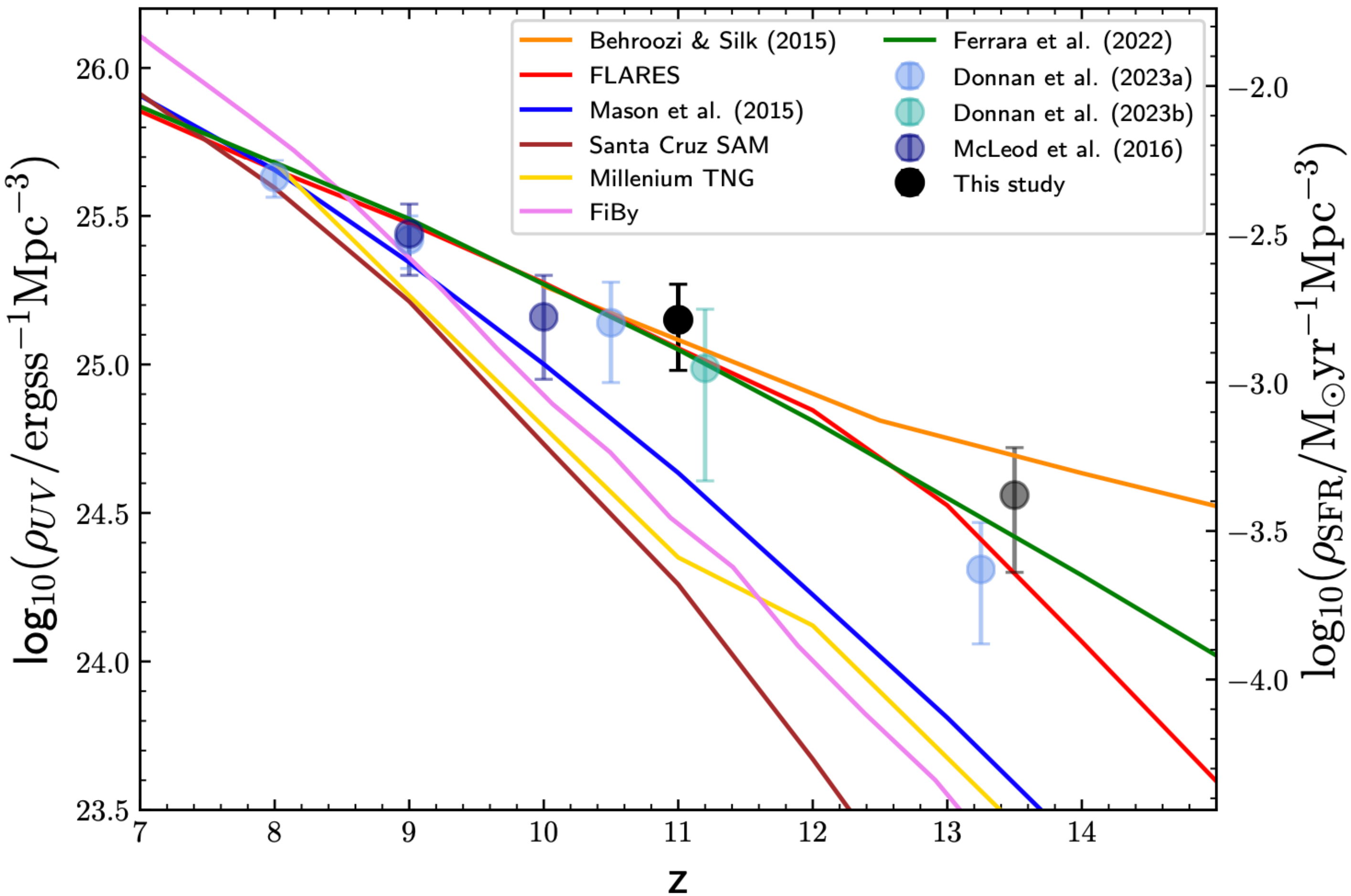
(and hence cosmic hydrogen reionization)



McLeod et al. (2023)

Implications for high-z SFR density

(and hence cosmic hydrogen reionization)

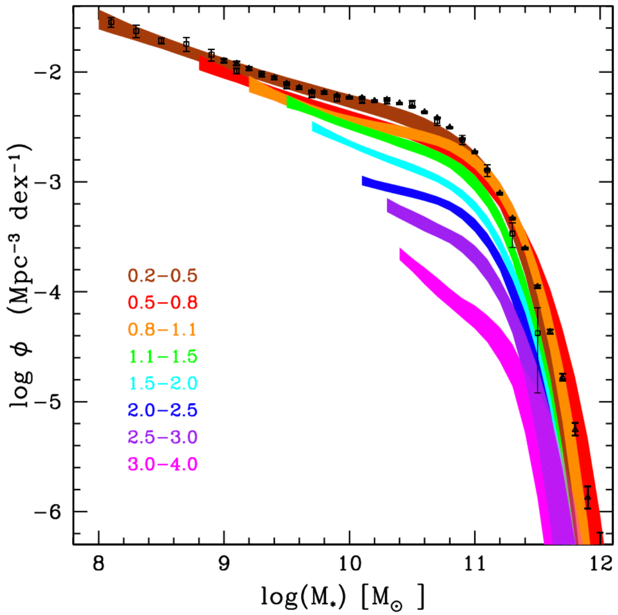


McLeod et al. (2023)

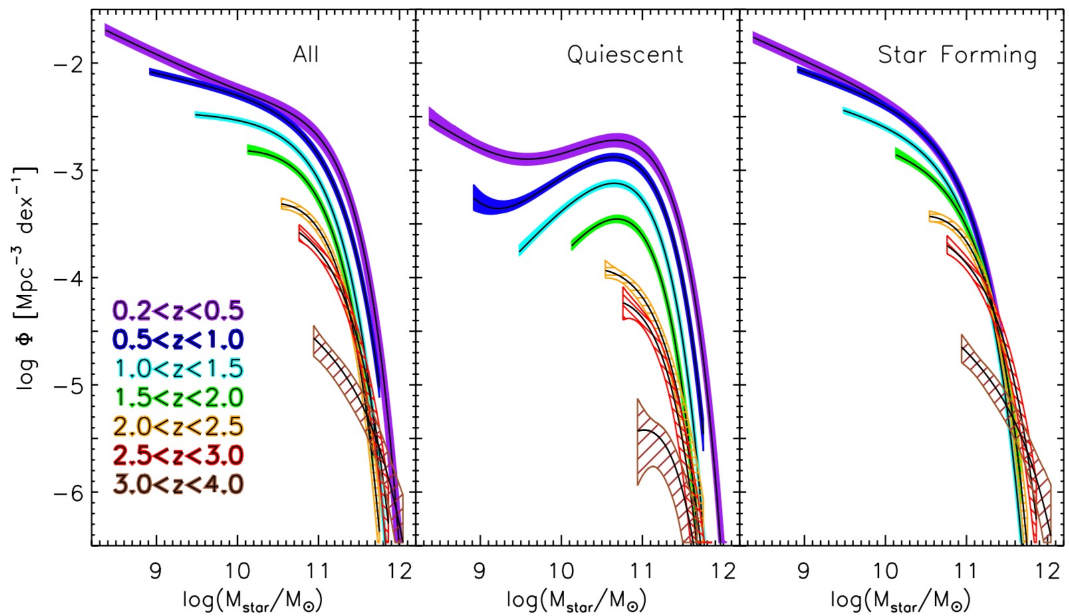
Key Science 2: The evolving galaxy mass function

Evolving galaxy (stellar) mass function

Major early impact with UltraVISTA DR1



Ilbert et al. (2013) – 826 citations



Muzzin et al. (2013) – 756 citations

Evolving galaxy (stellar) mass function

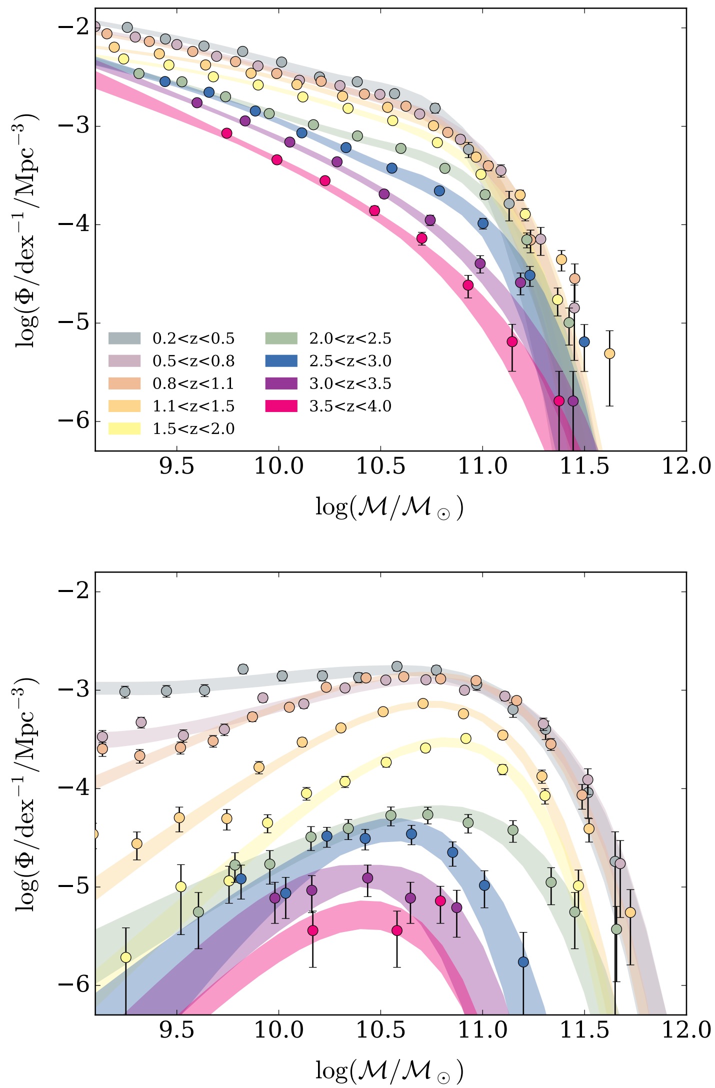
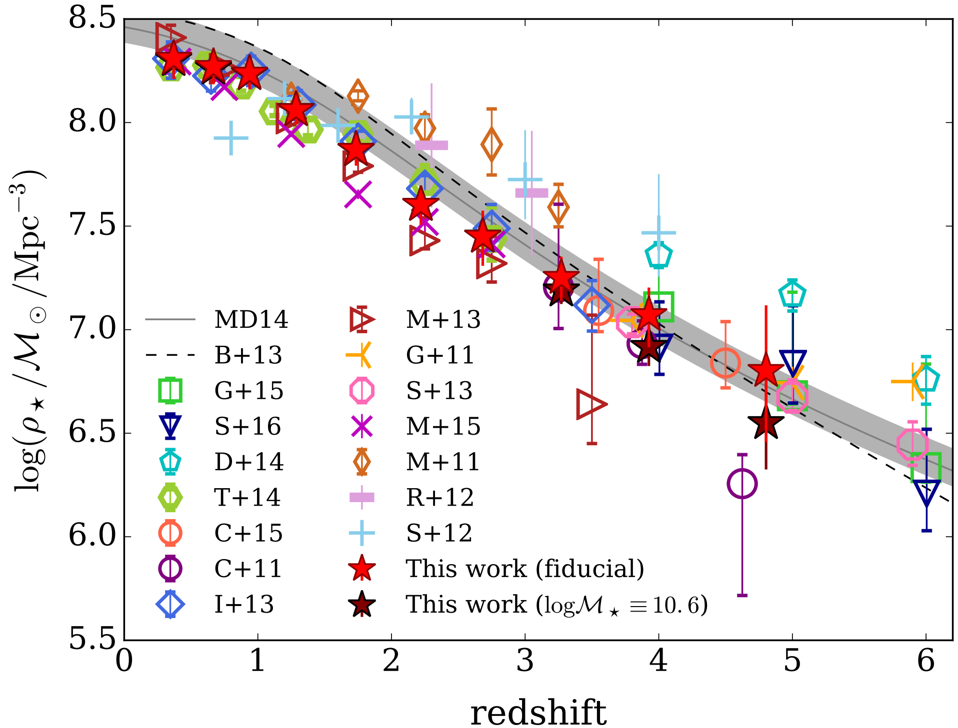


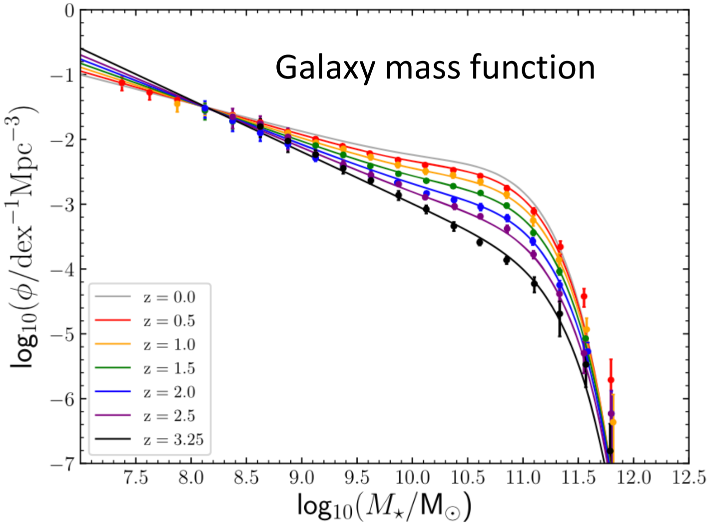
Fig. 16. Evolution of the SMF between z = 0.2 and 4, for active (*upper panel*) and passive (*lower panel*) galaxies. Same symbols as in Fig. 15.

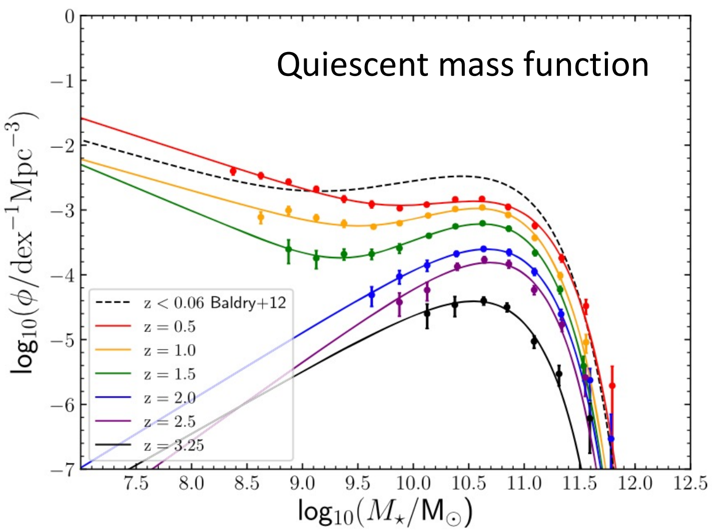


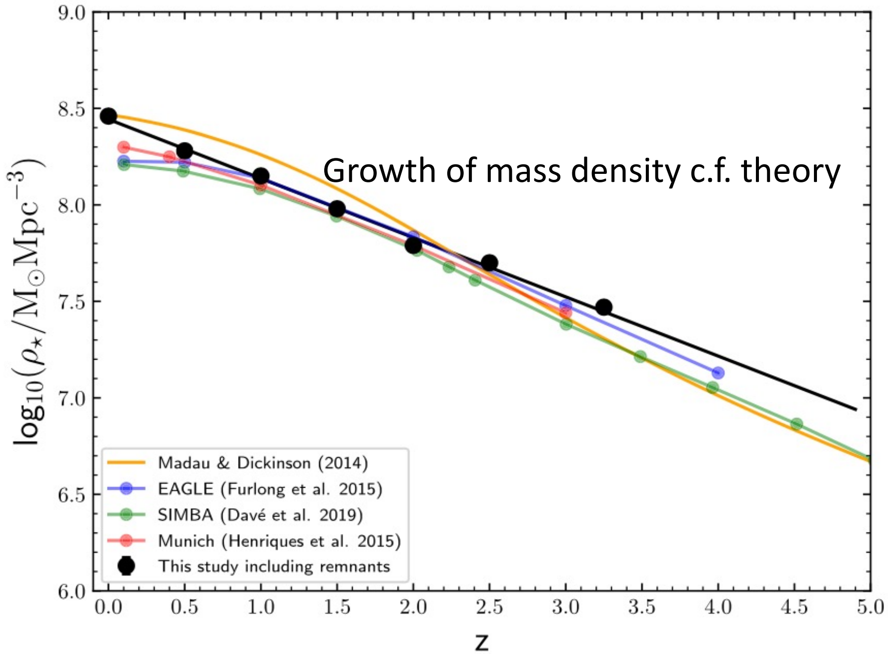
Davidzon et al. (2017)

Evolving galaxy (stellar) mass function

now well established out to z ~ 3.5





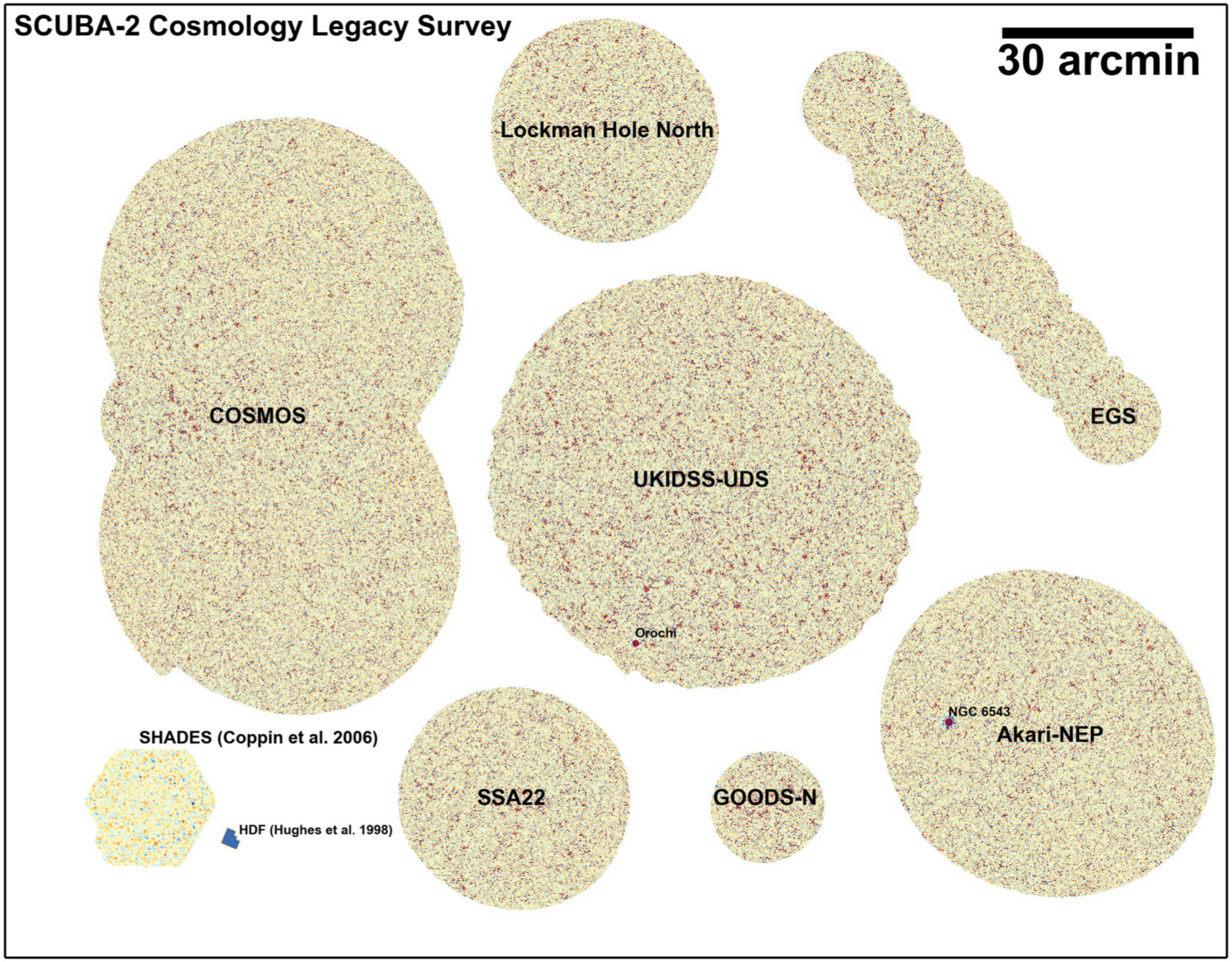


McLeod et al. (2021)

Mass quenching then environmental quenching? – e.g. Peng, Lilly, et al. (2010)

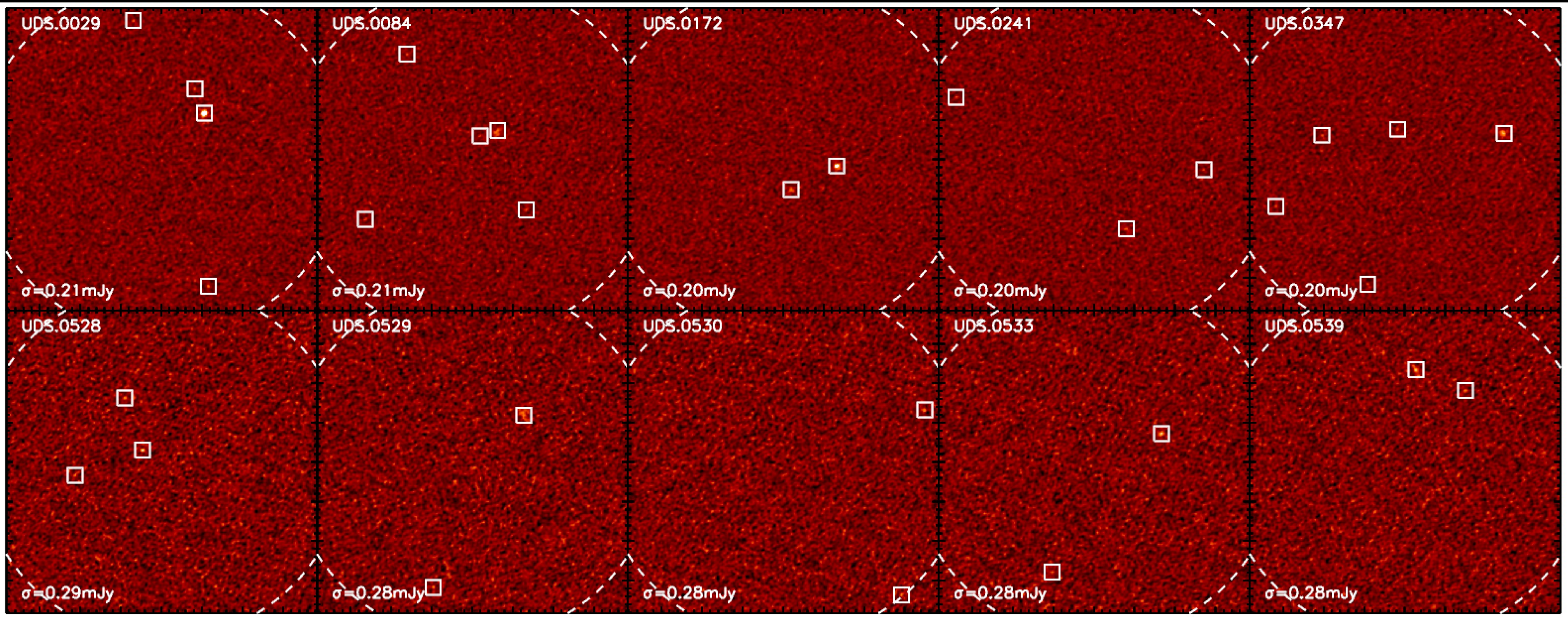
Key Science 3: Dust-enshrouded star formation

SCUBA2-CLS > A2COSMOS > A3COSMOS



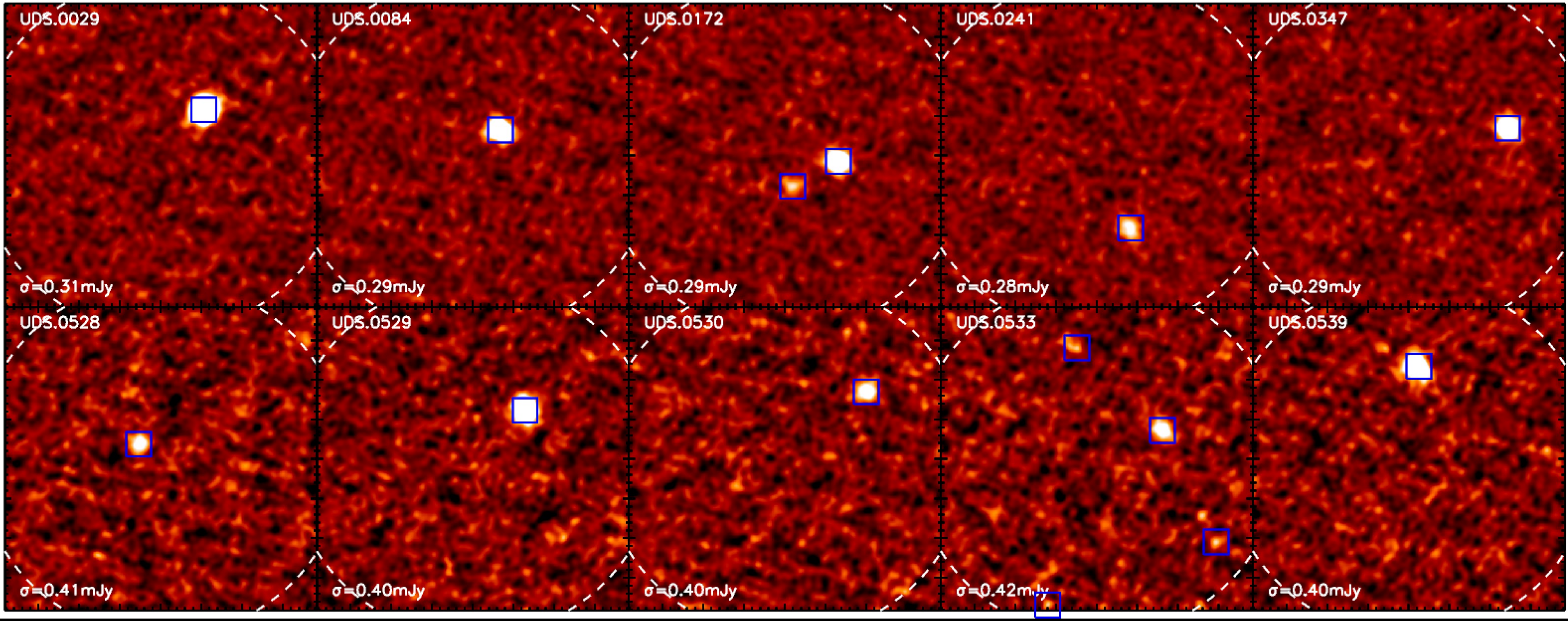
Geach, Dunlop et al. (2017), Simpson et al. (2020), Chen et al. (2022)

ALMA follow-up of SCUBA-2 sources



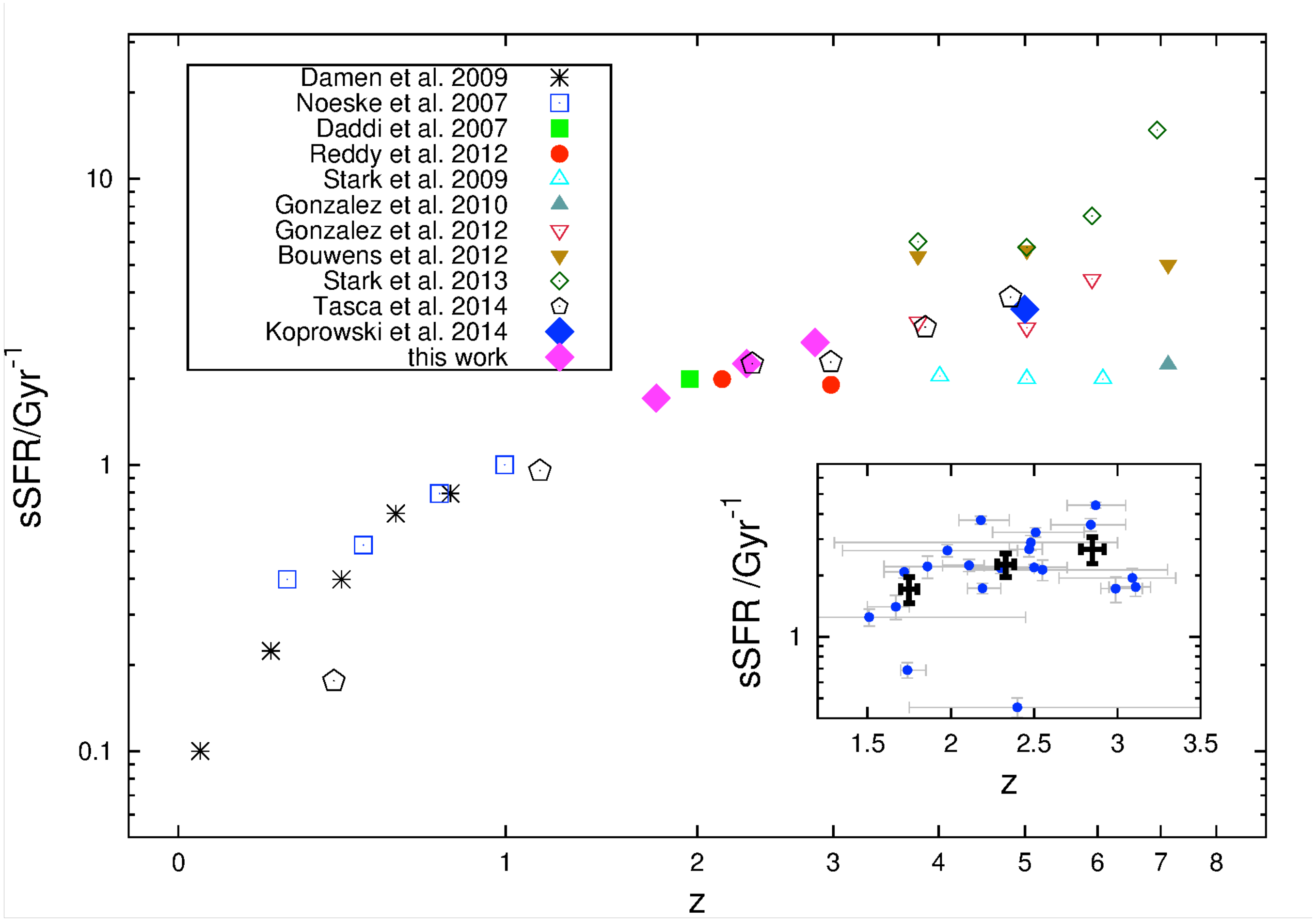
Untapered ~ 0.2 arcsec

ALMA follow-up of SCUBA-2 sources



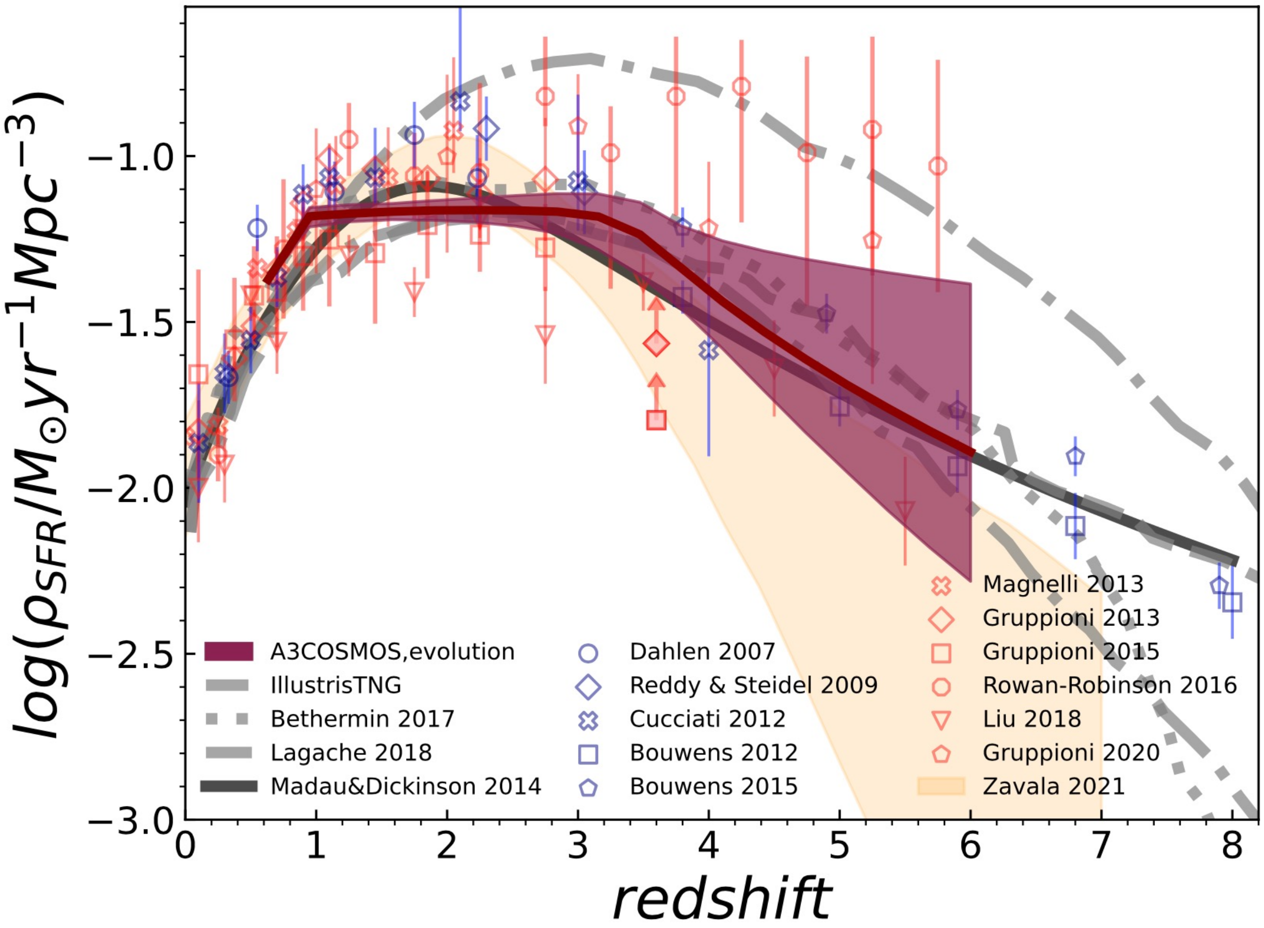
Tapered ~ 0.5 arcsec

Evolution of specific star-formation rate



Koprowski et al. (2016)

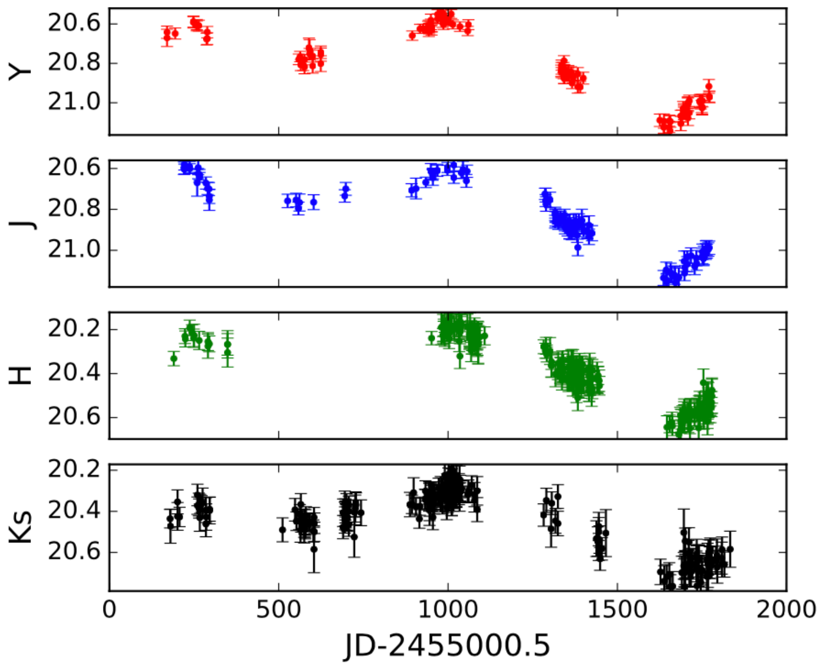
Evolution of dust-enshrouded cosmic star-formation rate density

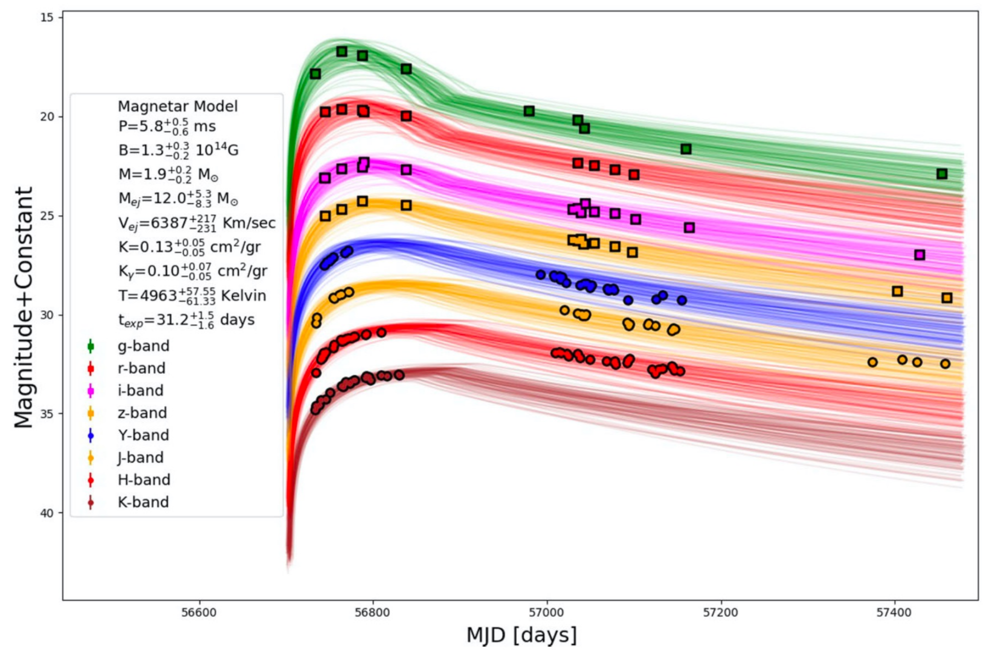


A3COSMOS – Traina et al. (2023) arXiv:2309.15150

Key Science 4: Time variability

Long time-base now enables variability studies





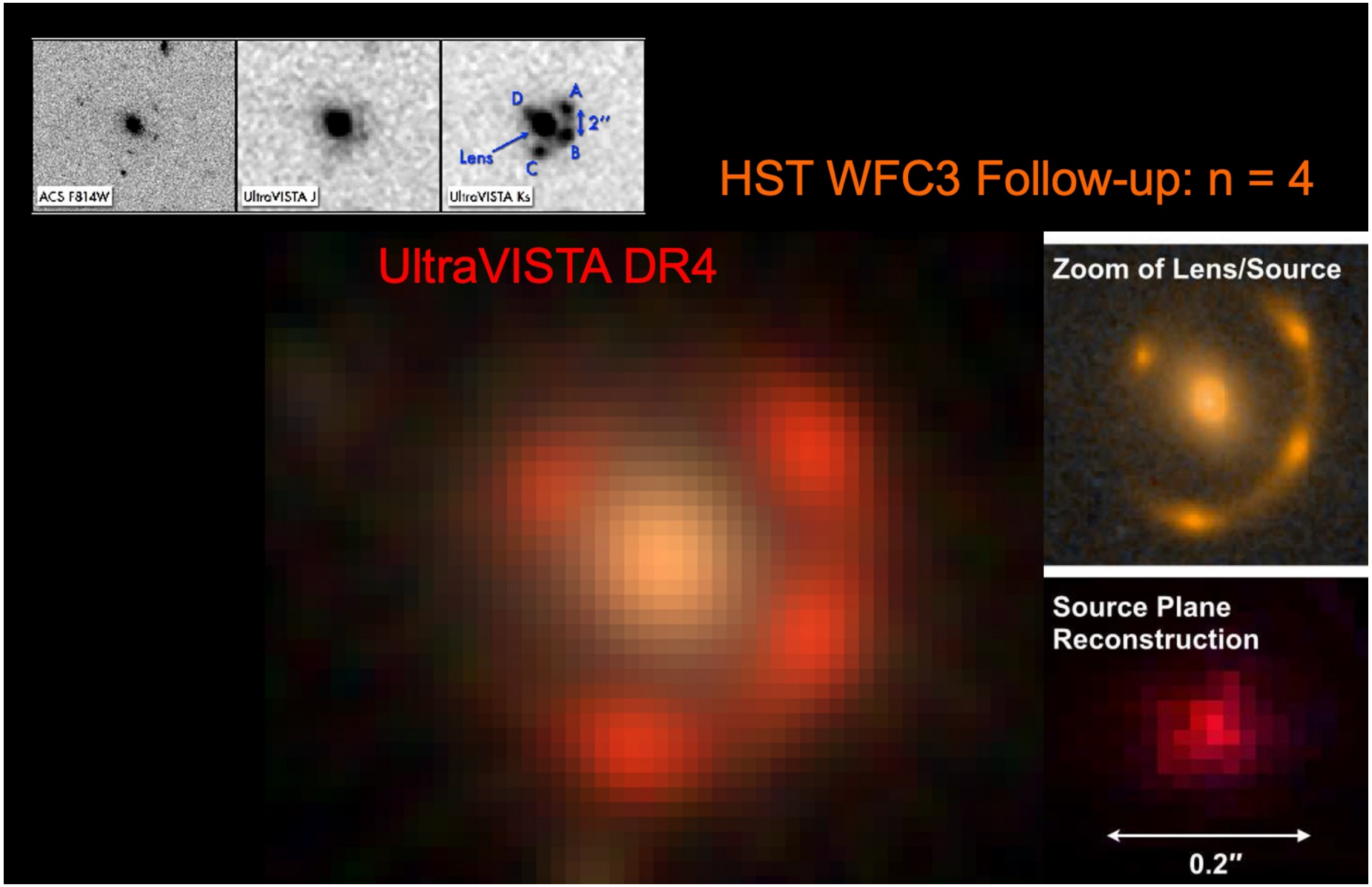
AGN: Sanchez et al. (2017)

Superluminous SN: Hueichapan et al. (2022)

Key Science 5: Rare objects

Large area enables discovery of unusual/extreme sources

Triply-lensed background z~2 galaxy, lensed by foreground elliptical galaxy
Muzzin et al. (2012)

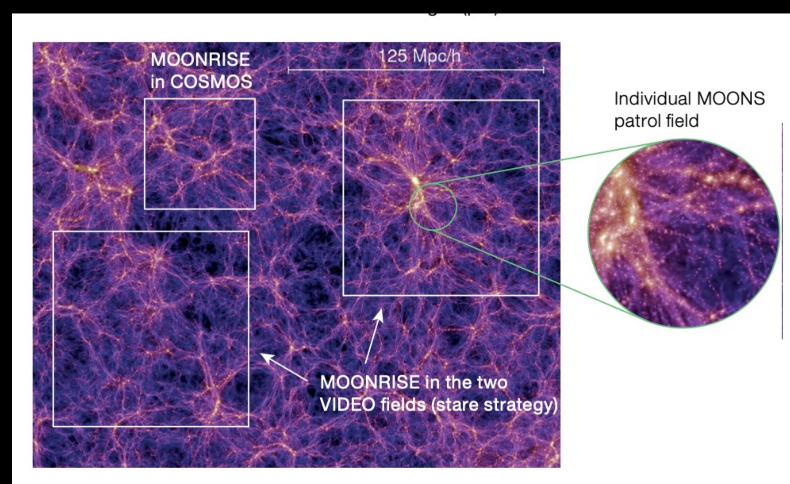


UltraVISTA – future relevance

Legacy 1

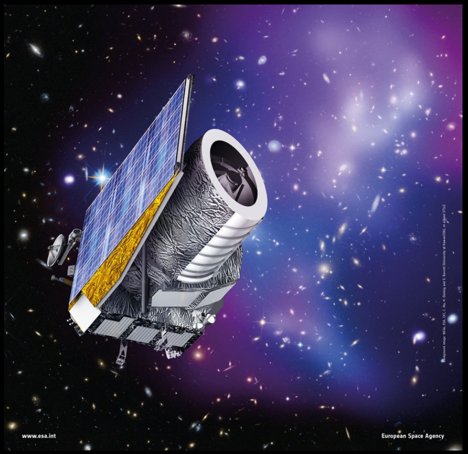
UltraVISTA underpins a whole series of ESO spectroscopic surveys

- z-Cosmos
- VUDS
- LEGA-C
- ALPINE — ALMA large programme exploiting VUDS
- MOONRISE

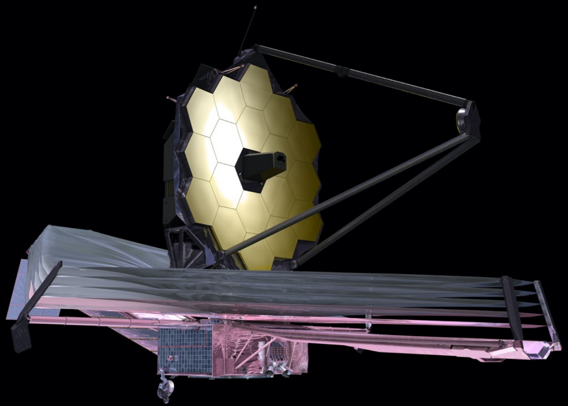


Legacy 2

UltraVISTA is vital for:



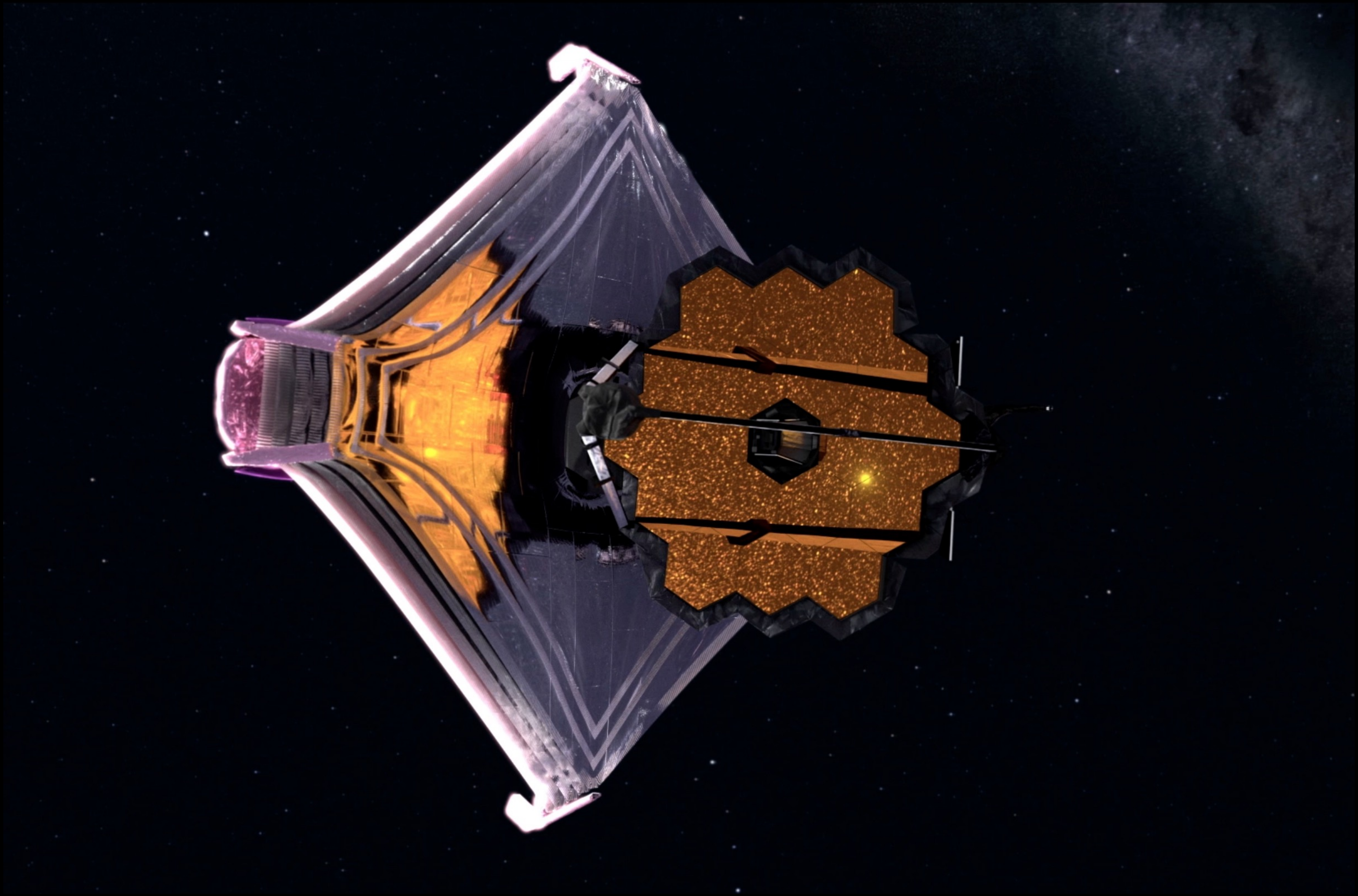
- Euclid – essential for photometric redshift work, indeed results on high-z galaxies drove the selection of the blue grism for Euclid



- JWST – high-z target selection, especially for NIRSpec follow-up

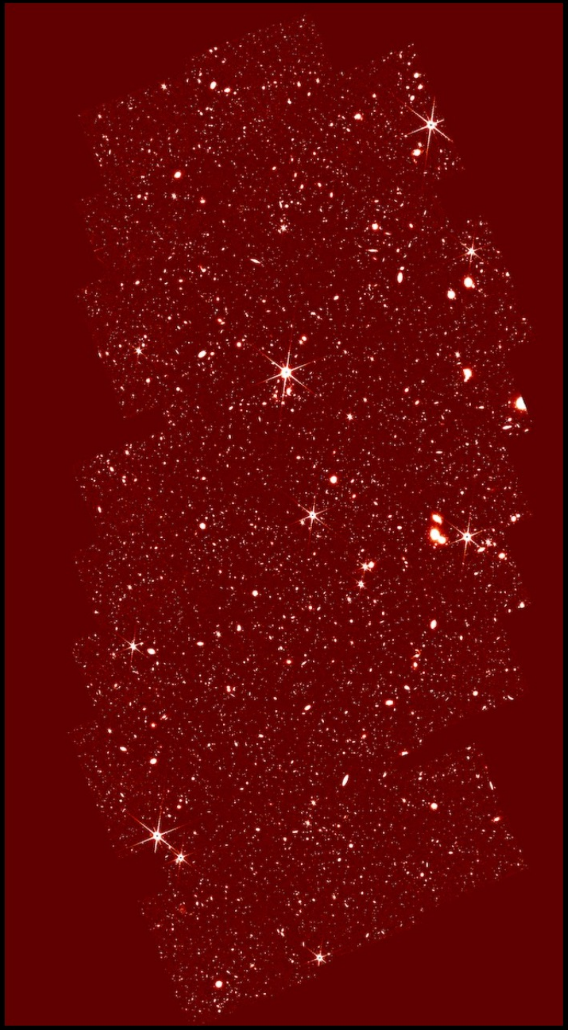
Extensive future data use and citations are assured

UltraVISTA and JWST



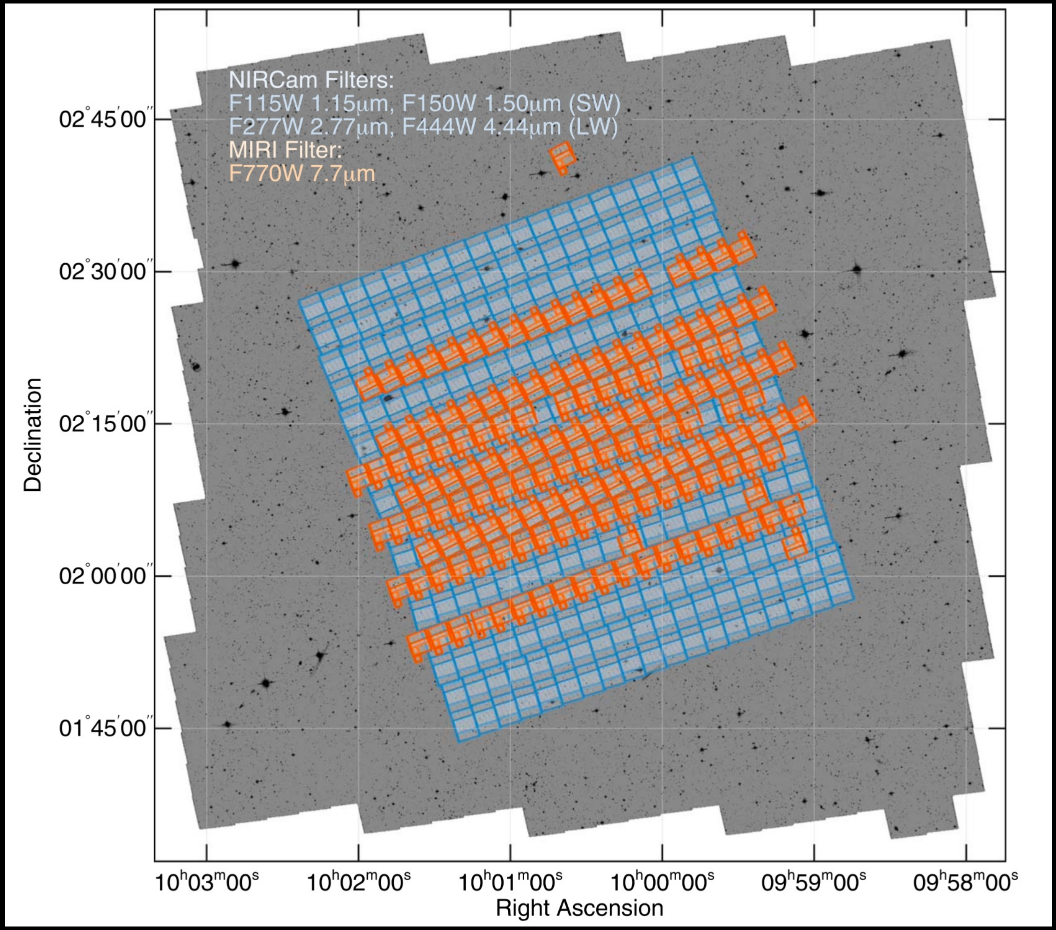
PRIMER (PI: J. Dunlop)

COSMOS ~86 sq. arcmin

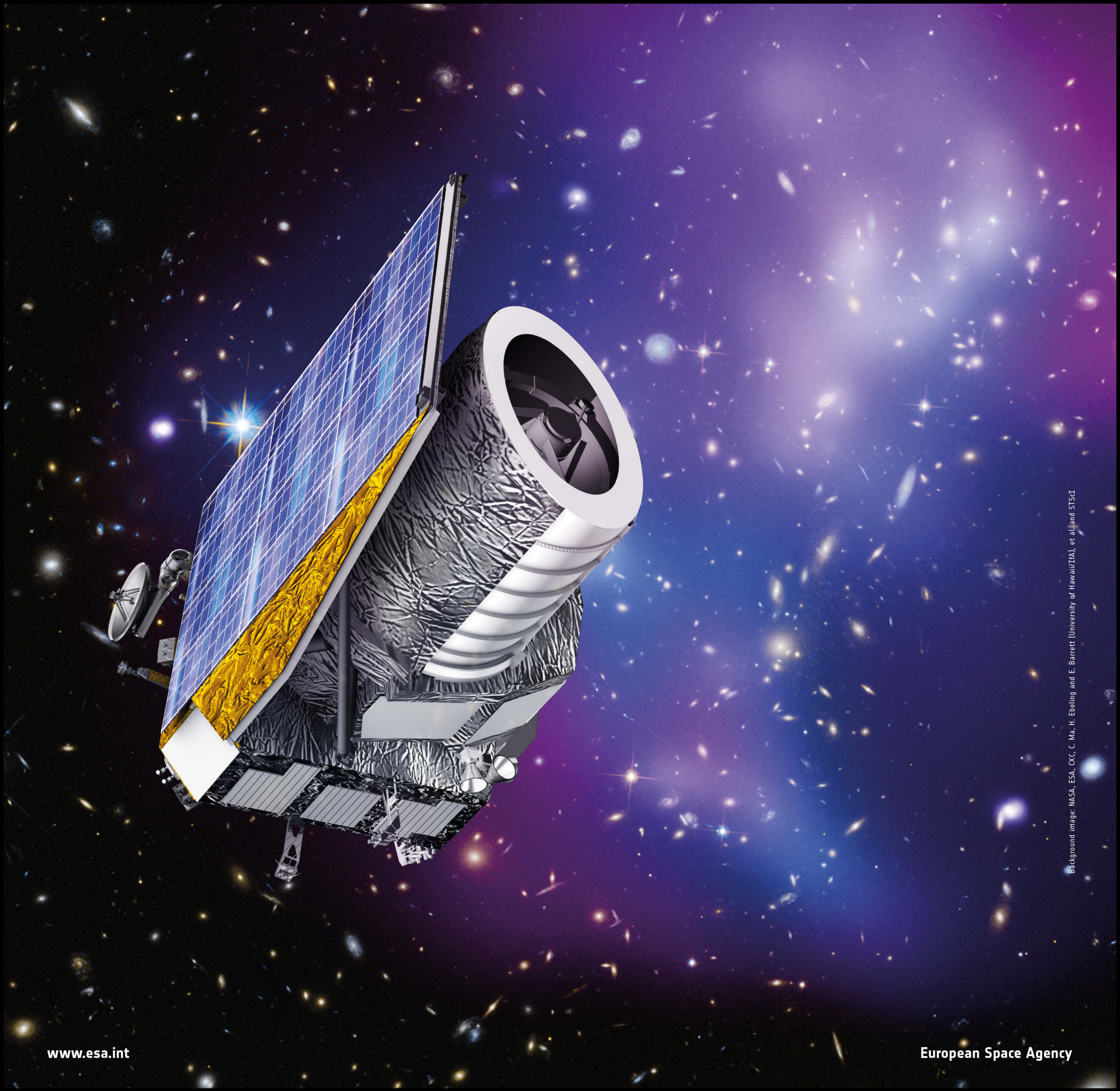


COSMOS-Web Casey et al. (2023)

~0.5 sq deg

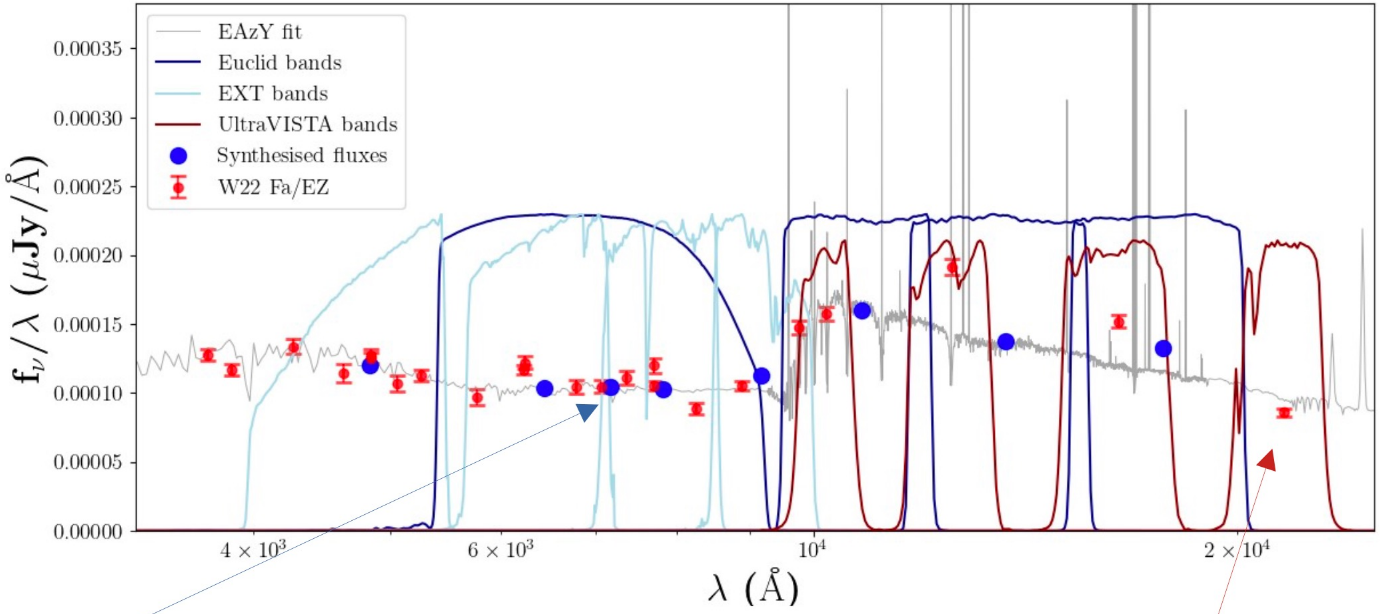


UltraVISTA and Euclid



UltraVISTA and Euclid

- COSMOS-UltraVISTA is the only field with the combination of area, depth and wavelength sampling that we can use to build reference data for the early stages of Euclid operations.
- We will rely on the COSMOS2020 catalogue for the first ~6 months of operations, until we can re-build the reference samples from real in-flight Euclid data.
- UltraVISTA will continue to be important throughout the mission due to the complementary Ks-band data – for stellar masses etc., and improved redshifts.



SED fits to the COSMOS-UltraVISTA photometry are used to construct synthetic Euclid photometry and the detailed SED through the VIS passband.

UltraVISTA bands extend the Euclid wavelength range and are narrower filters than NISP, which adds information in photo-z.

Conclusions

- UltraVISTA has been, and continues to be a powerful/productive public survey
- Now ultilised in essentially all studies of the COSMOS field

- Breakthrough results on bright high-redshift galaxies, into the reionization era at $z \sim 5 - 8$
- State-of-the-art galaxy stellar mass functions out to $z \sim 4$
- Key role in identifying and studying dusty star-forming galaxies

- Completes λ coverage with Chandra/XMM/CFHT/Subaru/Spitzer/Herschel/SCUBA-2/VLA
- Provides crucial boost in dynamic range when combined with HST and Hawk-I surveys
- Proving a powerful lever for HST, ALMA, VLT and now JWST follow-up
- With Subaru HSC, can study high-z evolution of Ly-α emission, tracing cosmic reionization

- UltraVISTA already played a key role in informing the design of the Euclid Deep Survey
- It is also playing a key role as a calibration field for Euclid photometric redshifts

In many ways UltraVISTA was a “no-brainer”: VISTA’s field-of-view was well matched to the COSMOS field, and all extragalactic studies need homogeneous deep near-IR imaging.

Consistent high data quality, sustained ESO observing support, rigorous data reduction, and ERC, STFC (CASU, WFAU) + ultimately Euclid funding have been key to its success.