Prime Extragalactic Areas for Reionization and Lensing Science

PEARLS

PEARLS Observations in the North Ecliptic Pole Time Domain Field

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PEARLS Team:

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Incomplete list

PEARLS Fields

- Lensing Clusters
  - MACS J0416.1−2403 at $z \simeq 0.397$ (Diego+ 2023a, Yan+2023a)
  - Abell 2744 at $z \simeq 0.31$
  - MACS J1149.5+2223
  - El Gordo at $z \simeq 0.87$ (Diego+ 2023b; Frye+ 2023a; Carleton+ 2023)
  - PLCK G165.7+67.0 (G165) double cluster at $z \simeq 0.35$ (Frye+ 2023b)
  - Clio cluster at $z \simeq 0.42$
  - XC J1212+27 = A1489 at $z \simeq 0.35$
- Protocluster candidates
  - PHz G191.24+62.04 (G191) is a protocluster candidate at $z = 2.55$
  - TNJ1338−1942 is a protocluster at $z = 4.1$ (Duncan+ 2023)

- QSOs
  - QSO 1425+3254 (or NDWFS J142516.3+325409) at z = 5.85
  - QSO J0005−0006 (or SDSS J000552.35−000655.6) at z = 5.86
- Deep fields
  - GOODS-S ERS
  - NEP IRAC deep field (Yan+ 2023b.
  - NEP time domain field
- VV191 - pair of galaxies with a foreground spiral galaxy and an unassociated elliptical galaxy behind (Keel+ 2013; 2023)

PEARLS Observations in the NEP

- The Ecliptic Poles are fields that fall in the continuous viewing zone (CVZ) of several (if not all) space observatories.
- The CVZs can be observed any time of the year and are ideal for the search of transients and variable sources.
- The South Ecliptic Pole has a major contribution of sources coming from the Large Magellanic Cloud, which impairs somewhat studies of the very distant universe.
- Jansen & Windhorst (2018) identified a region in the North Ecliptic Pole with no bright stars and low galactic absorption that could be used for the search of transients. This is the NEP Time Domain Field (TDF).
- An additional deep field is being monitored for transients within the NEP – the IRAC Deep Field (IDF) which also has deep coverage from other missions – notably Spitzer and AKARI (which was discussed yesterday by Matt Malkan).

PEARLS

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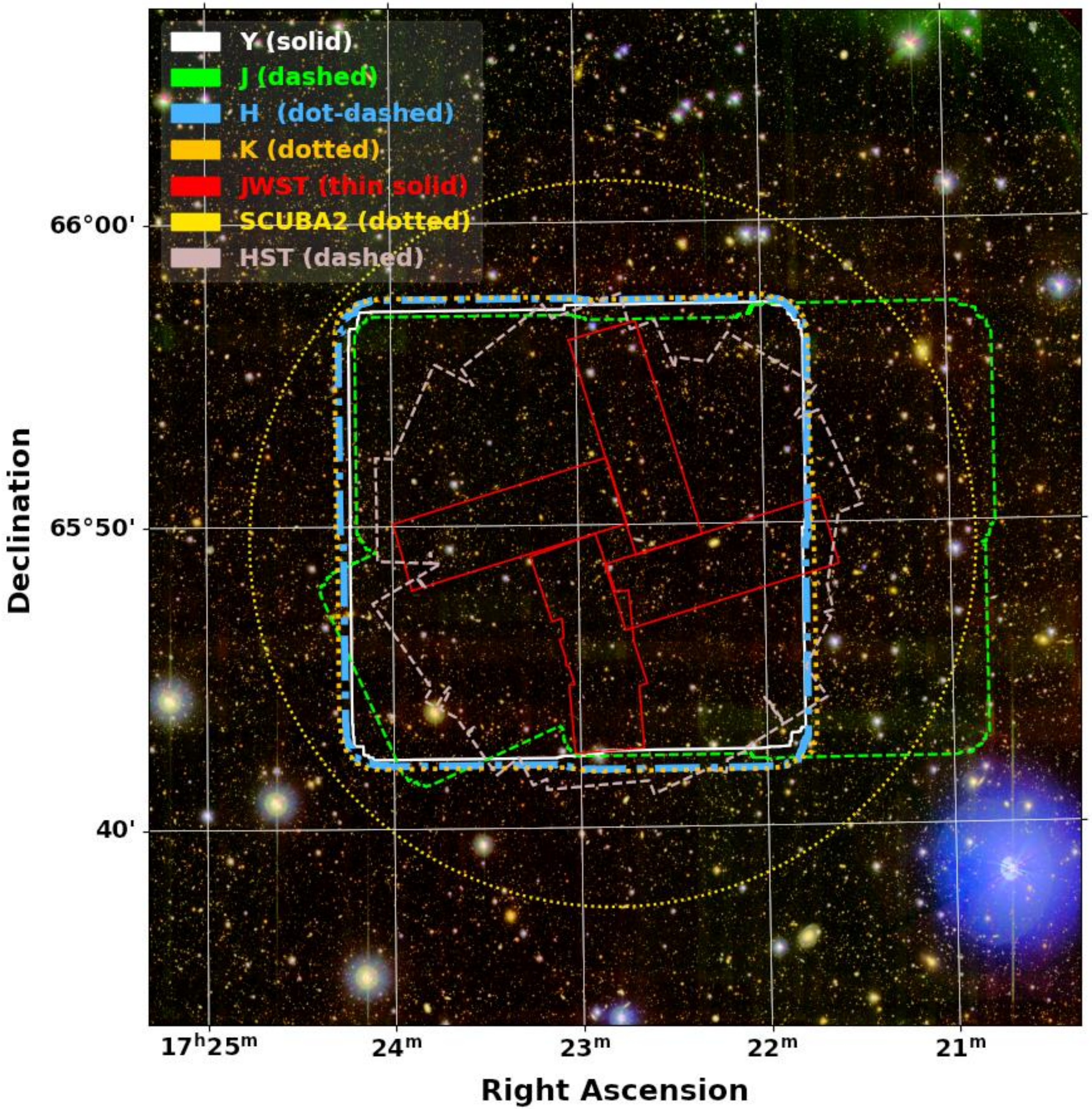
Table 1: *JWST* NEP Time-Domain Field multiwavelength community investment

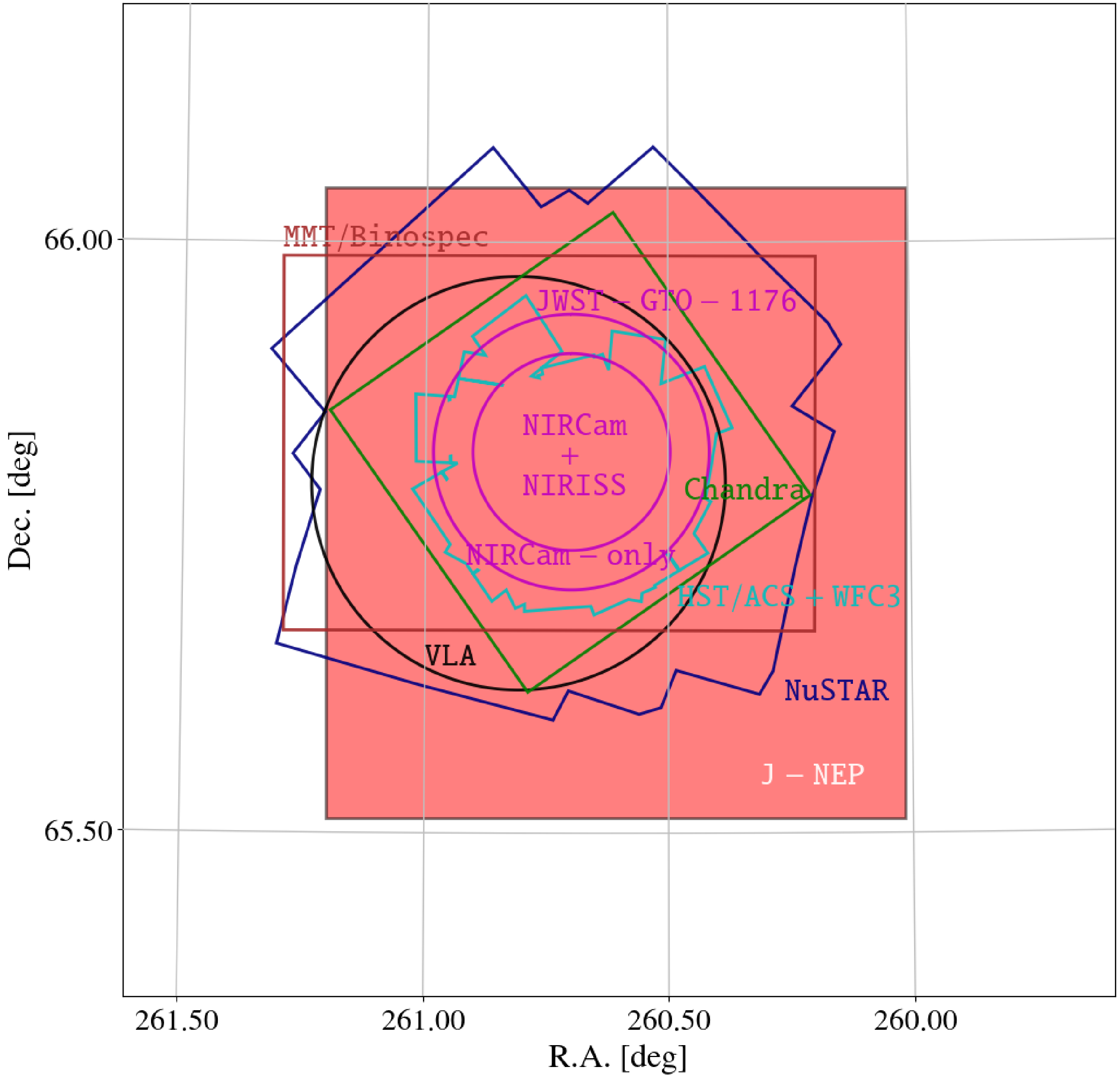
Telescope	PI	Status	Depth
NuSTAR 3–24 keV	F. Civano	extant (33 sources)	1467 ks; $>$50 cts
″	″	approved	855 ks ; ″
Chandra/ACIS-I 0.2–10 keV	W.P. Maksym	extant; 238 sources	1300 ks; $\sim$1$\times$10^{-16} cgs
″	″	in progress	500 ks; ″
XMM-Newton 0.5–2.0 keV	F. Civano	extant / approved	40 ks / 30 ks; 1$\times$10^{-15} cgs
AstroSat/UVIT F154W,F172M	K. Saha	approved	97.78 hrs; $m\sim$27 mag
GALEX NUV+FUV	MIS+AIS	extant	2$\times$2.8 ks; $m\sim$24.1 mag
HST/WFC3+ACS	R. Jansen / R. Jansen & N. Grogin	extant	96 CVZ orbits; $r\lesssim 7\farcm5$
F275W,F435W,F606W		GO 15278, GO 16252, GO 16793	$m\sim$27.3, 28.2, 29 mag
LBT/LBC $U_{\rm sp}$*griz*	R.A. Jansen	extant; wide-field (2 epochs)	11 hrs; $m\sim$26.8–26.0 mag
Subaru/HSC *giz*,nb816,nb921	G. Hasinger / E. Hu	extant; wide-field	5 hrs; $m\sim$25.5–25.1 mag
GTC/HiPERCAM *ugriz*	V. Dhillon	extant; $r<5'$	16$\times$1 hr; $m\sim$27 mag
TESS (0.6–1.0μm bandpass)	G. Berriman & B. Holwerda	in progress; ultra wide-field	357 days; low-SB xtd
MMT/MMIRS *YJHK*$_{\rm s}$	C.N.A. Willmer	extant	68 hrs; $m\sim$24.5–23.5 mag
JWST/NIRCam+NIRISS	R.A. Windhorst / H.B. Hammel	*guaranteed time*	$\sim$49 hrs; 54.7 arcmin^2
0.8–5 μm + 1.75–2.23 μm		GTO #2738	$m<$29–28.5 mag
JCMT/SCUBA-2 850μm	I. Smail / M. Im	extant; 113 sources (82 at $>4\sigma$)	43.4 hrs; rms$\sim$0.8 mJy
″	″	approved	20.0 hrs; rms$\sim$0.7 mJy
SMA 0.87 mm	G. Fazio	extant; 11 sources	66 hrs; rms$\sim$0.85 mJy/beam
IRAM/Nika2 1.2, 2 mm	S.H. Cohen	extant (pilot)	30 hrs; rms$\sim$2 mJy
VLA 3(2–4) GHz	R.A. Windhorst / W. Cotton	extant; $\sim$2500 sources	47 hrs; rms$\sim$0.9 μJy
VLBA 4.7 GHz	W. Brisken	extant; $\sim$128 targets	147 hrs; rms$\sim$3 μJy
eMERLIN 1.5 GHz	A. Thomson	extant	40 hrs
″	″	in progress	100 hrs; rms$\sim$3 μJy/beam
LOFAR 150 MHz	R. van Weeren	extant; ultra-wide field	72 hrs; rms$\sim$0.12 mJy
mini-JPAS (56 narrow-bands)	S. Bonoli / R. Dupke	extant; ultra-wide field	48 hrs; $m\sim$21.5–22.5 mag
MMT/Binospec (mos)	C.N.A. Willmer	extant; 1378 spectra/1000 redshifts	26 hrs; $m\sim$22.5–24 mag
MMT/MMIRS (mos)	C.N.A. Willmer	approved	$m<22$, $z>0.4$

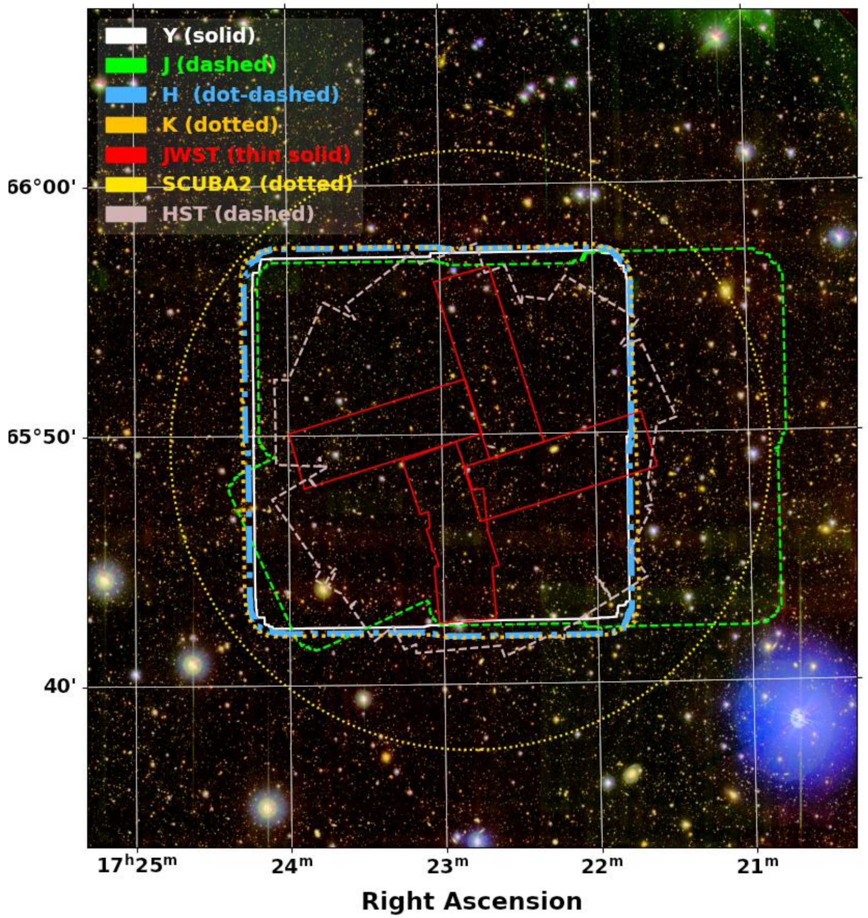
http://lambda.la.asu.edu/jwst/neptdf/table1.png

NEP TDF

Footprints of some of the ground-based observations and HST and JWST. Subaru HSC *g*, *i2* and *z* form the background.







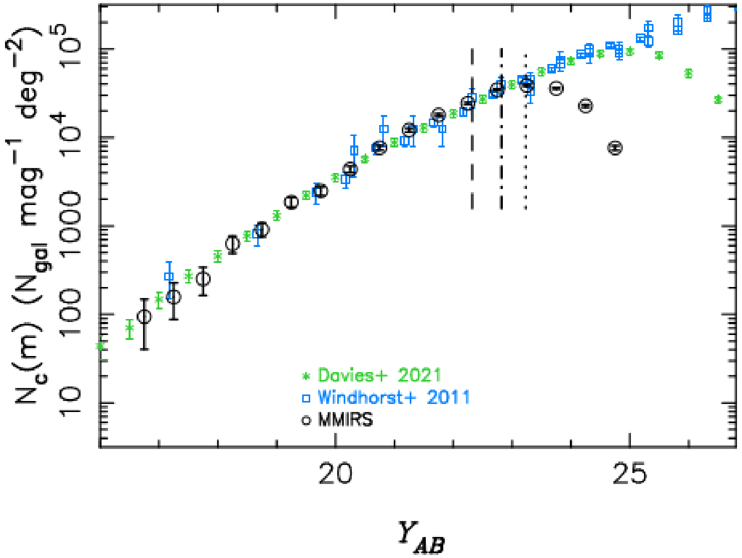
JNEP and PEARLS_HSC

TDF Milestones since last JPAS meeting

- HST imaging is complete (WFC3 F275W, ACS F435W, F606W).
- JWST imaging is complete.
- AstroSat/UVIT observations are complete (F154W, F172M) .
- PEARLS NIR and Subaru PEARLS-HSC data.
- Two MMT/Hectospec runs targeting NuSTAR and XMM sources (PI X. Zhao)

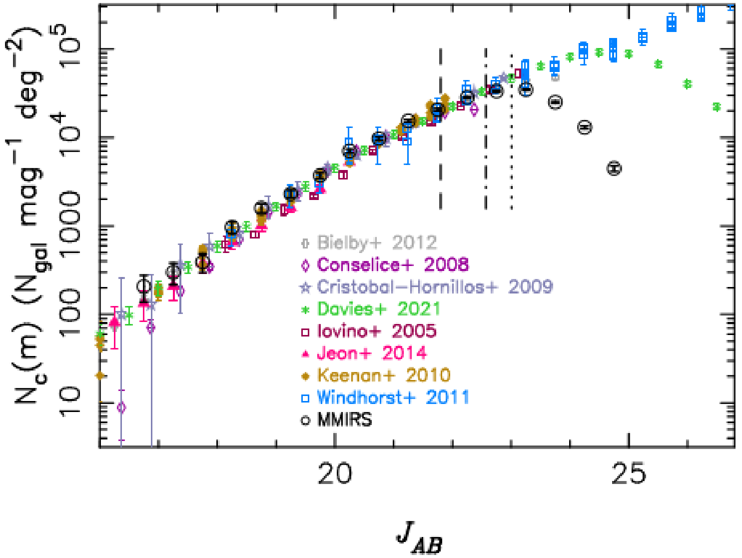
Near Infrared imaging

- MMT/MMIRS NIR imaging
  - Observations taken in *Y, J, H* and *K.*
  - observations taken over 37 nights between 2017 and 2019
  - Astrometric calibration used GAIA DR3 and produce RMS residuals of ~ 70 mas.
- The number counts in the NIR bands show good agreement with published results.



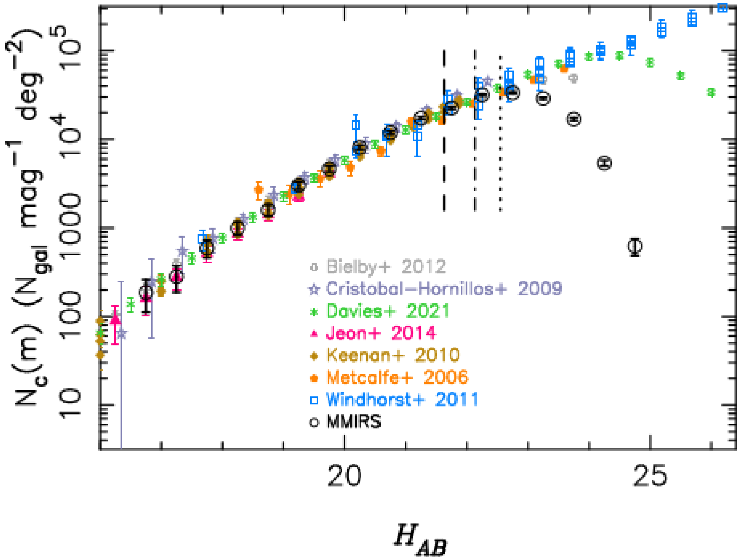
$N_c(m)$ (N_{gal} mag^{-1} deg^{-2})
10
100
1000
10^4
10^5
20
25
Y_{AB}
Davies+ 2021
Windhorst+ 2011
MMIRS

(a)



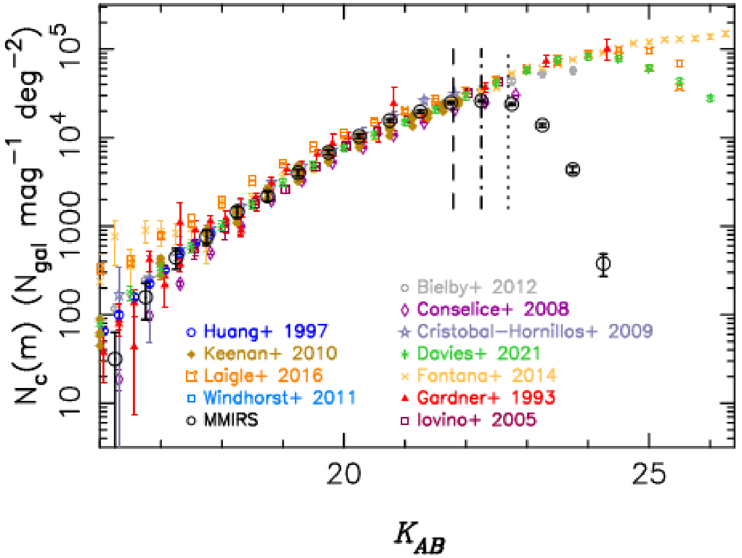
$N_c(m)$ (N_{gal} mag^{-1} deg^{-2})
10
100
1000
10^4
10^5
20
25
J_{AB}
Bielby+ 2012
Conselice+ 2008
Cristobal−Hornillos+ 2009
Davies+ 2021
Iovino+ 2005
Jeon+ 2014
Keenan+ 2010
Windhorst+ 2011
MMIRS

(b)



$N_c(m)$ (N_{gal} mag^{-1} deg^{-2})
10
100
1000
10^4
10^5
20
25
H_{AB}
Bielby+ 2012
Cristobal−Hornillos+ 2009
Davies+ 2021
Jeon+ 2014
Keenan+ 2010
Metcalfe+ 2006
Windhorst+ 2011
MMIRS

(c)



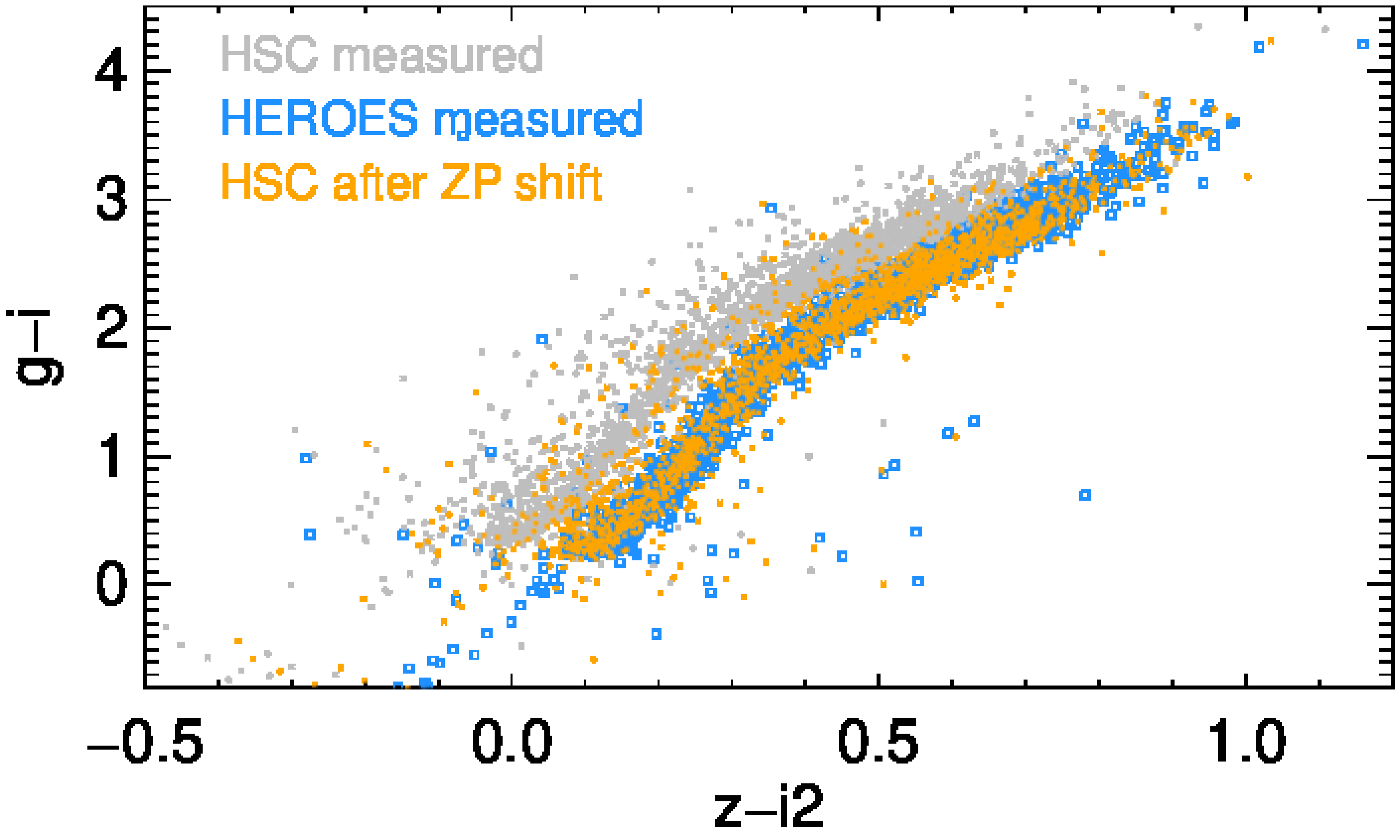
$N_c(m)$ (N_{gal} mag^{-1} deg^{-2})
10
100
1000
10^4
10^5
20
25
K_{AB}
Huang+ 1997
Keenan+ 2010
Laigle+ 2016
Windhorst+ 2011
MMIRS
Bielby+ 2012
Conselice+ 2008
Cristobal−Hornillos+ 2009
Davies+ 2021
Fontana+ 2014
Gardner+ 1993
Iovino+ 2005

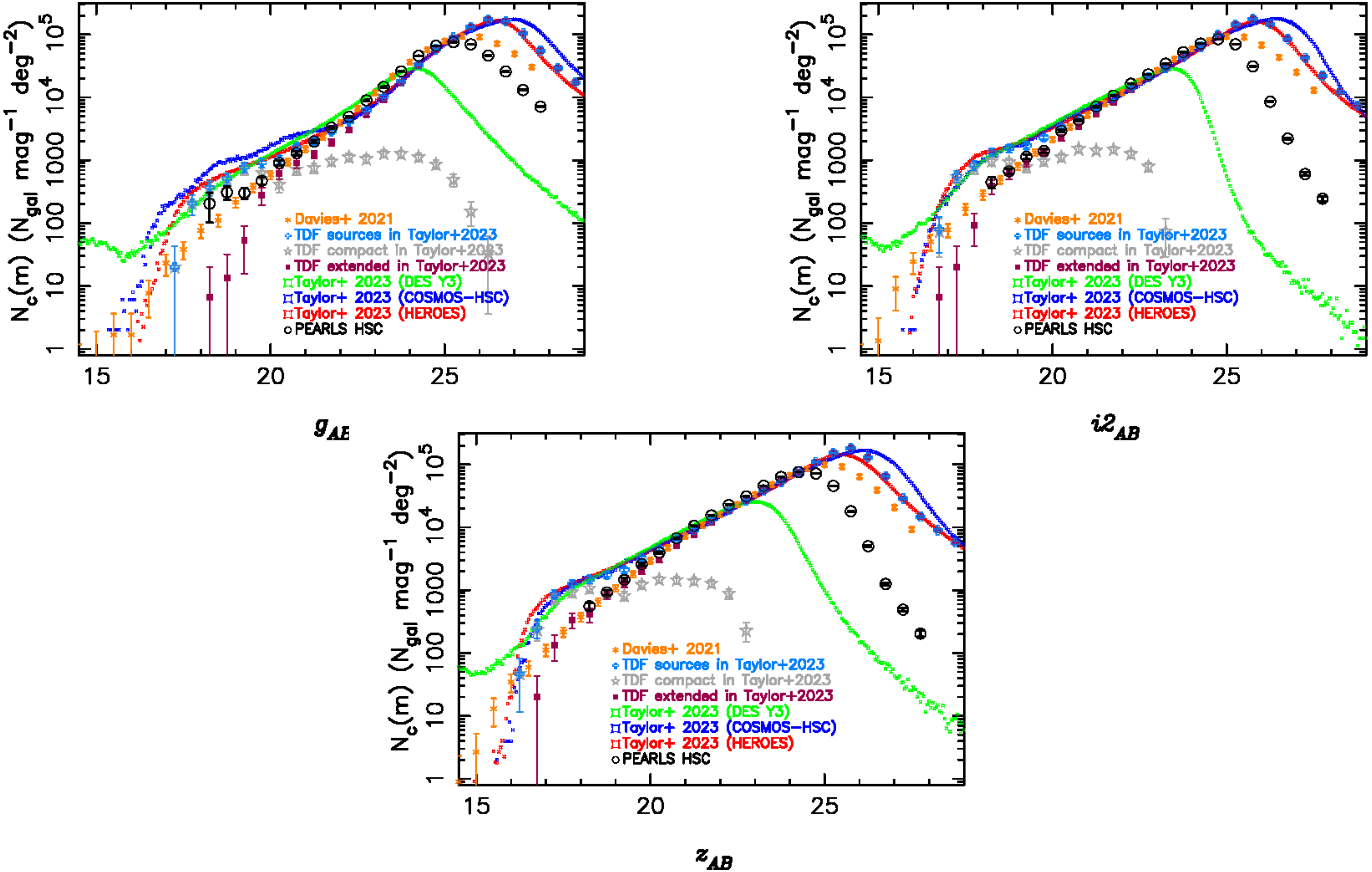
(d)

HSC Archival Imaging

- Subaru HSC imaging available in the NAOJ archive early 2020 from HEROES (Hawai'i Erosita Ecliptic Pole Survey) was used to create catalogues in the visible.
- The PEARLS-HSC catalogues were matched to sources identified in the MMT MMIRS observations in *Y, J, H* and *K*
- Astrometric quality has an rms of 20 mas relative to GAIA DR3 and was used to calibrate the JWST astrometry in the NEP-TDF.
- In early 2023 a catalogue of the HEROES was published by Taylor+ (2023) and the comparison with PEARLS-HSC showed the latter had small photometric offsets.
- The number counts from both reductions show good agreement.

The Stellar Locus as measured by PEARLS-HSC and HEROES

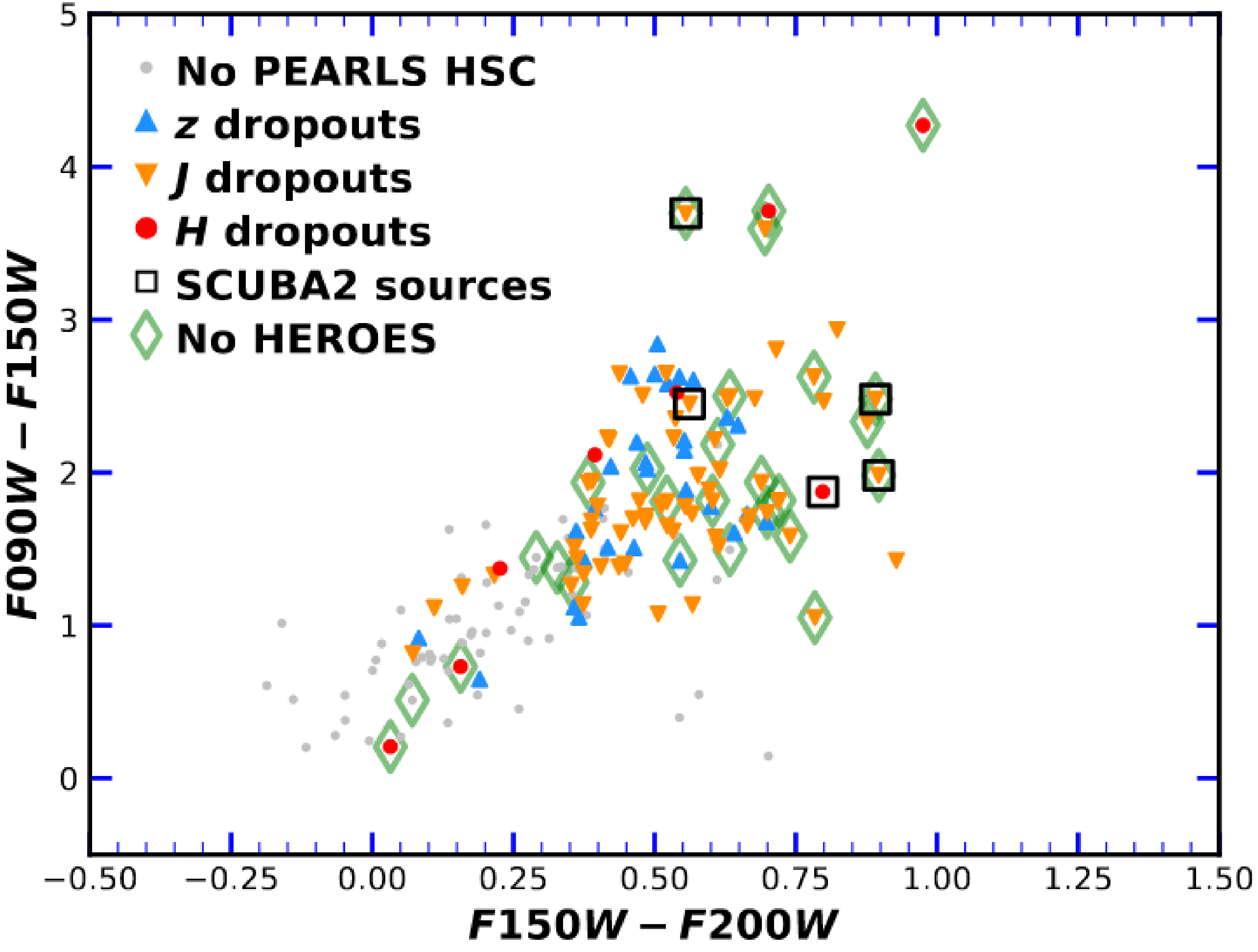




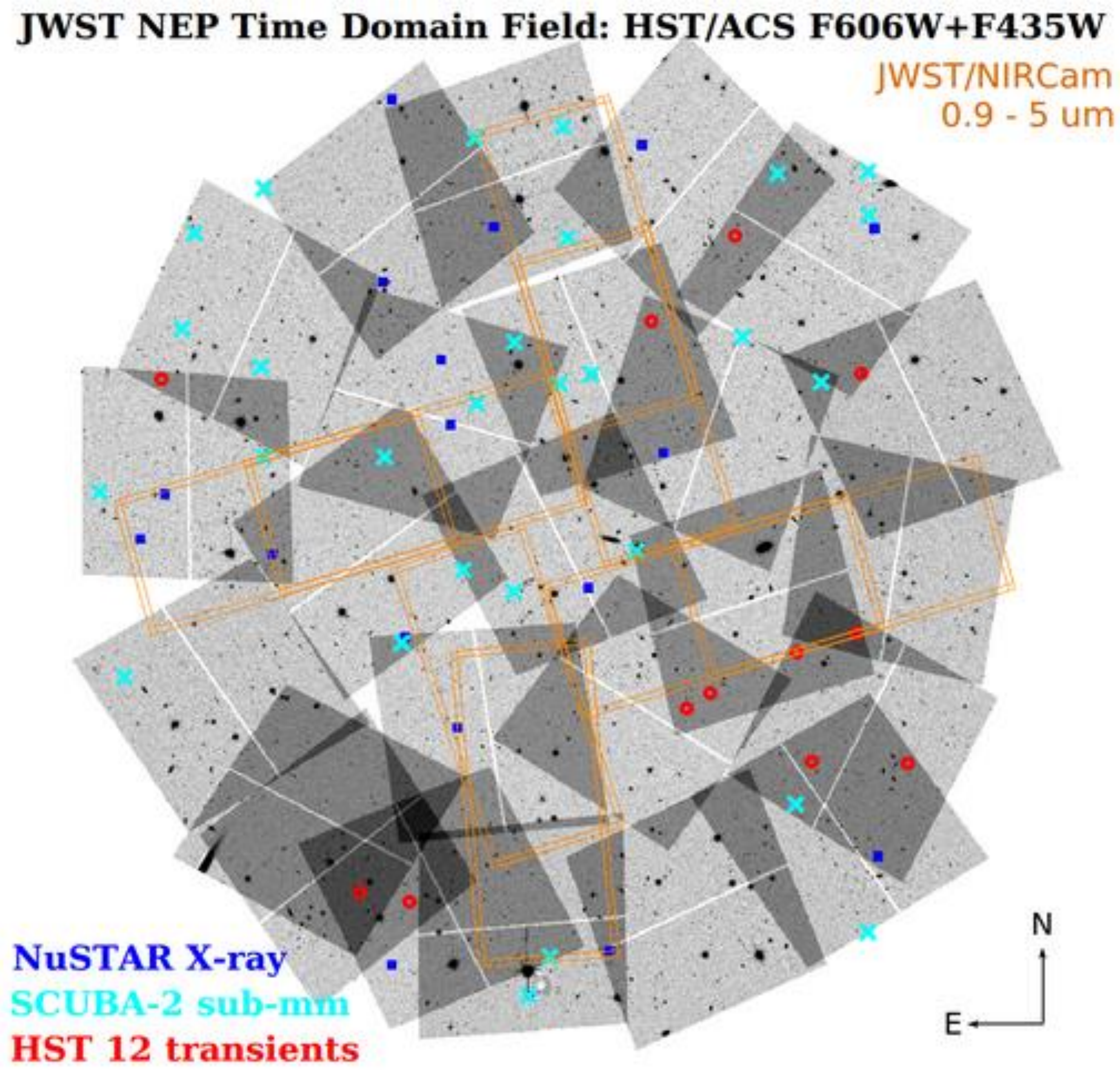
Davies+ 2021
TDF sources in Taylor+2023
TDF compact in Taylor+2023
TDF extended in Taylor+2023
Taylor+ 2023 (DES Y3)
Taylor+ 2023 (COSMOS-HSC)
Taylor+ 2023 (HEROES)
PEARLS HSC
$N_c(m)$ (N_{gal} mag^{-1} deg^{-2})
1
10
100
1000
10^4
10^5
15
20
25
g_{AB}
$i2_{AB}$
z_{AB}

Summary of ground-based imaging

- Limiting magnitudes at a 95% completeness level for point sources: (*g, i2, z, Y, J, H, K*) ≤ (25.68, 24.50, 24.09, 23.80, 23.53, 23.13, 23.28)
- Merged catalogue with 57,467 sources, of which 56,752 are PEARLS-HSC detections and 715 are NIR only-detections.
- Some of these are spurious detections, many are real sources but below the PEARLS-HSC detection limit. A second match was made with the HEROES catalogue and 174 sources had no match.
- A few sources are dusty galaxies detected by SCUBA2.

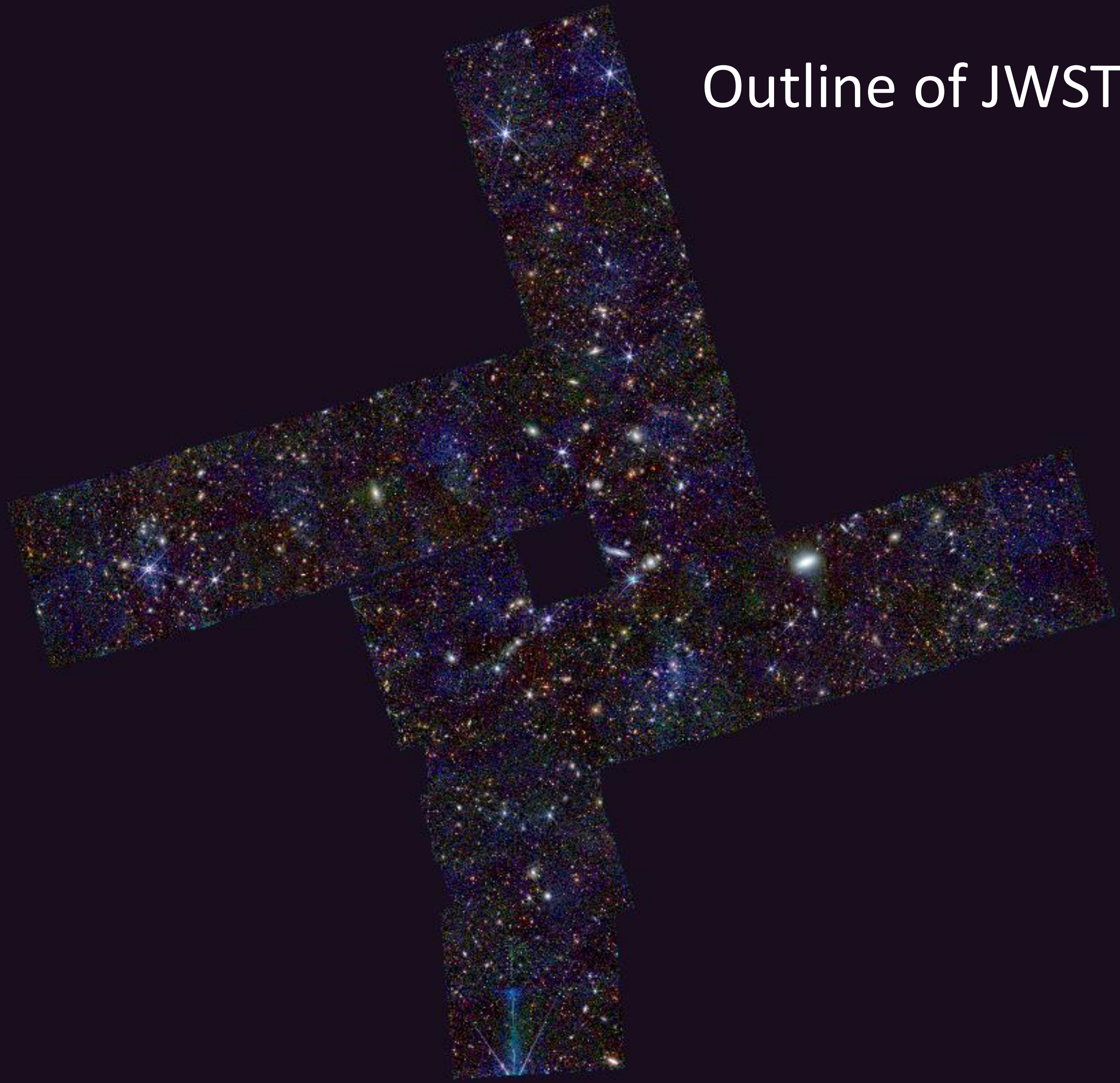


No PEARLS HSC
z dropouts
J dropouts
H dropouts
SCUBA2 sources
No HEROES
F090W − F150W
F150W − F200W
0
1
2
3
4
5
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50



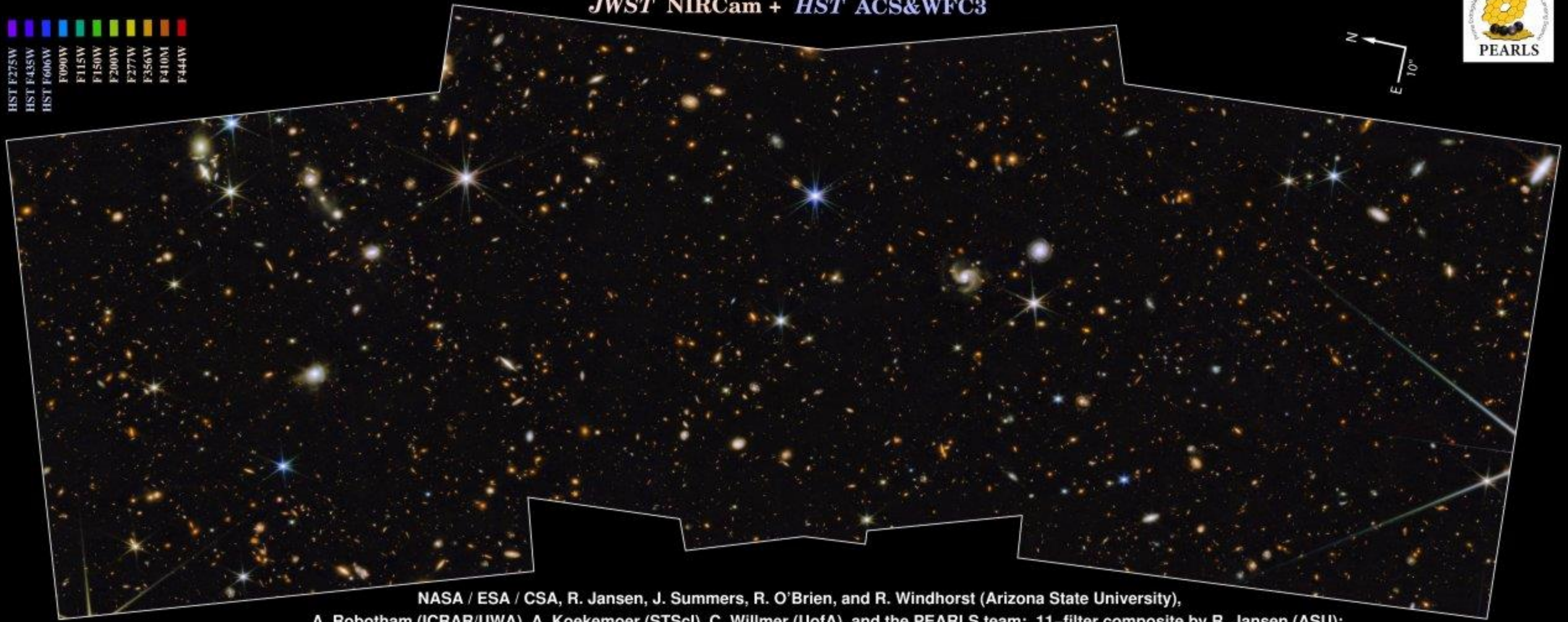
Jansen & O’Brien
2023 Jun 19

Outline of JWST observations



JWST North Ecliptic Pole Time Domain Field – Spoke 1

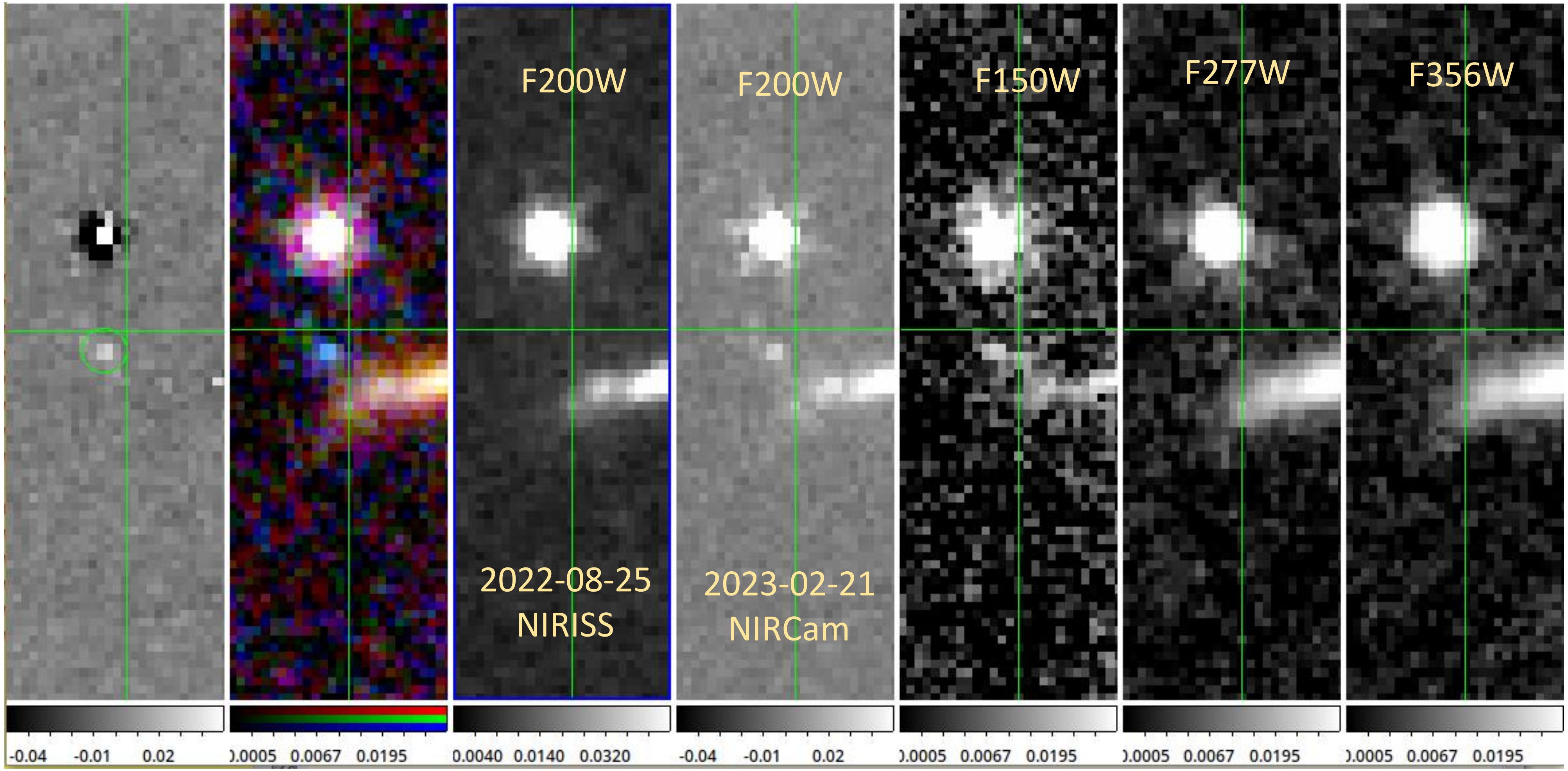
JWST NIRCam + *HST* ACS&WFC3



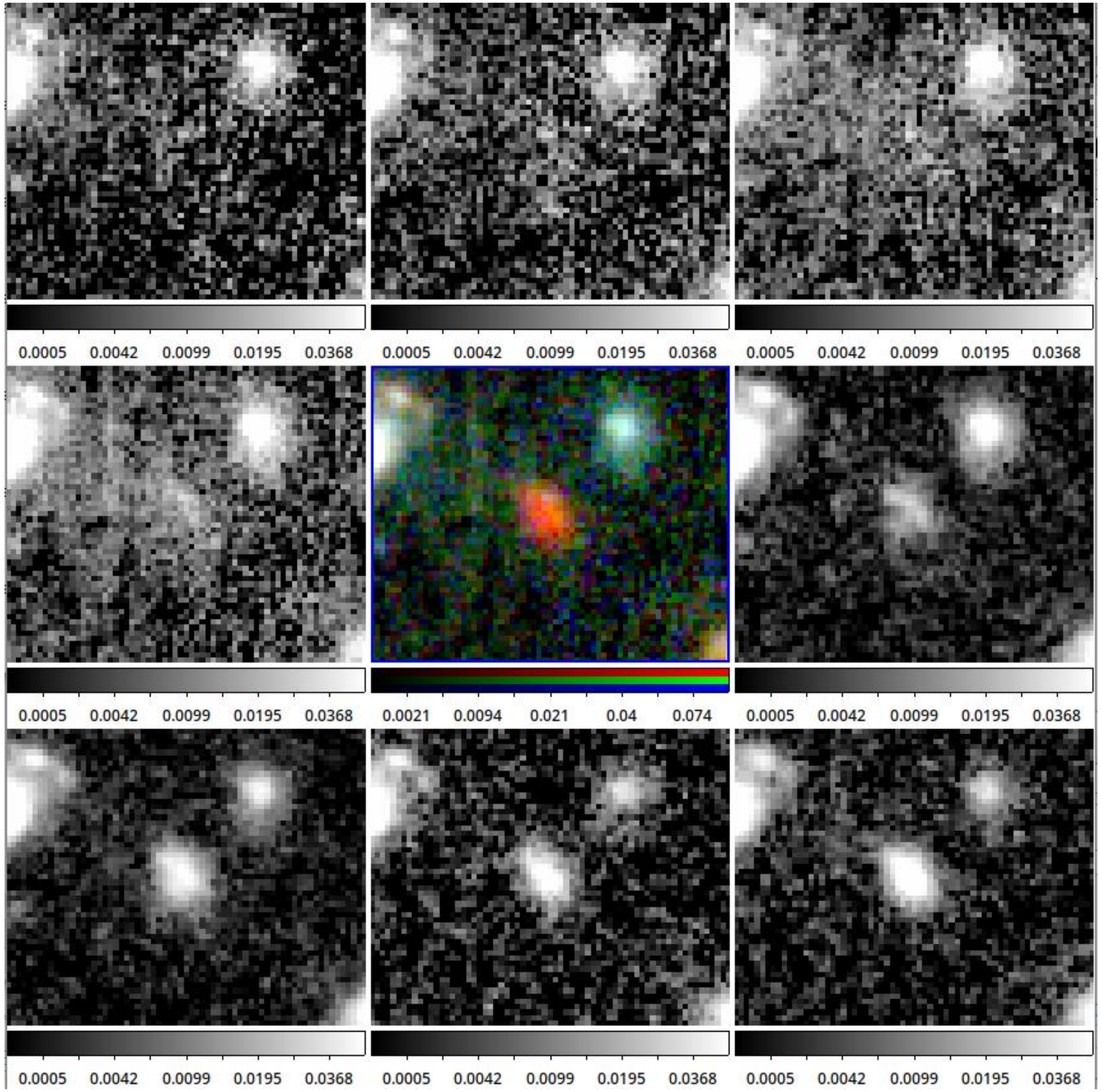
NASA / ESA / CSA, R. Jansen, J. Summers, R. O'Brien, and R. Windhorst (Arizona State University), A. Robotham (ICRAR/UWA), A. Koekemoer (STScI), C. Willmer (UofA), and the PEARLS team; 11–filter composite by R. Jansen (ASU); additional image processing by A. Pagan (STScI)

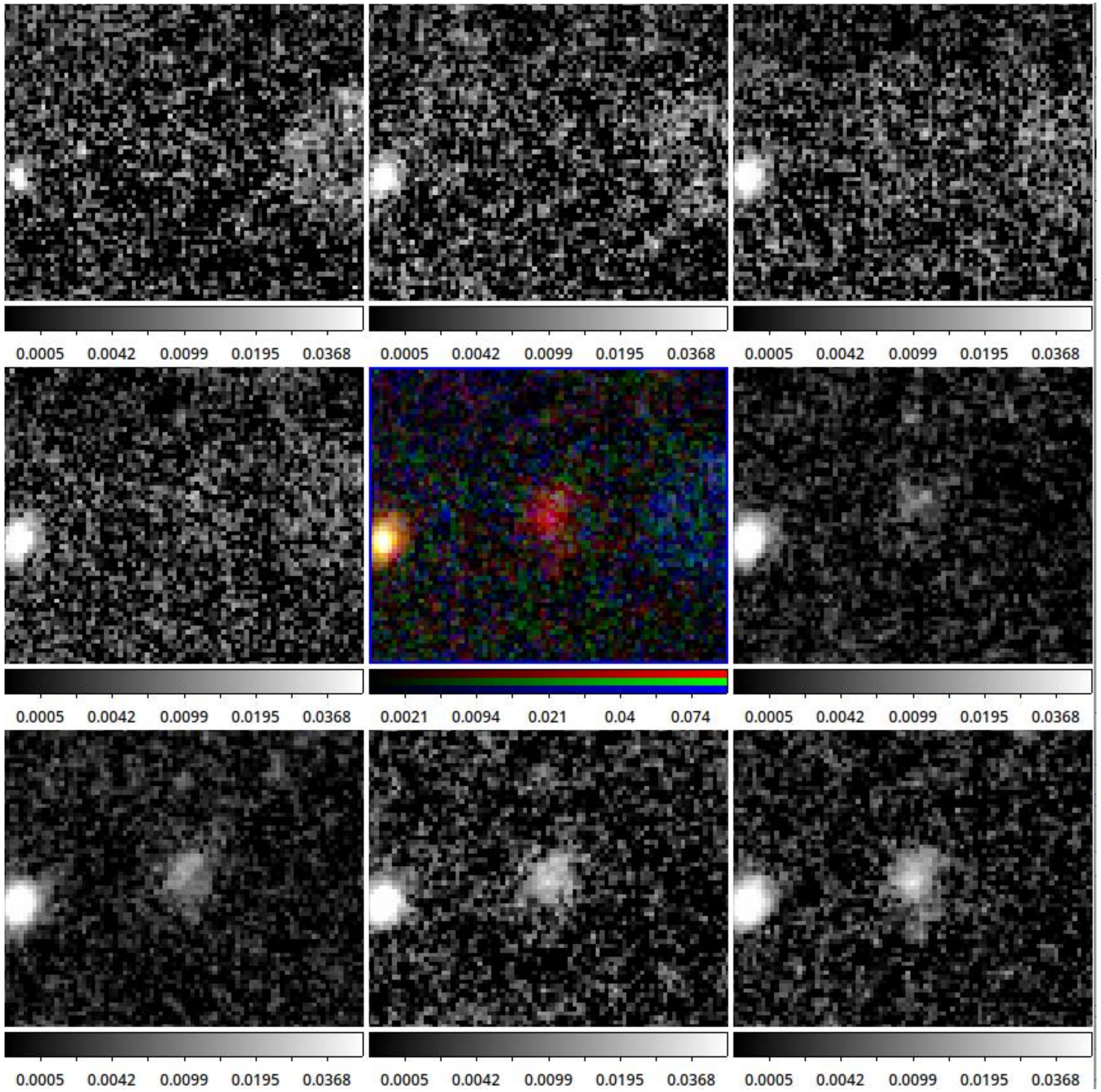
Dec 10 2022

JWST-discovered transient in the TDF

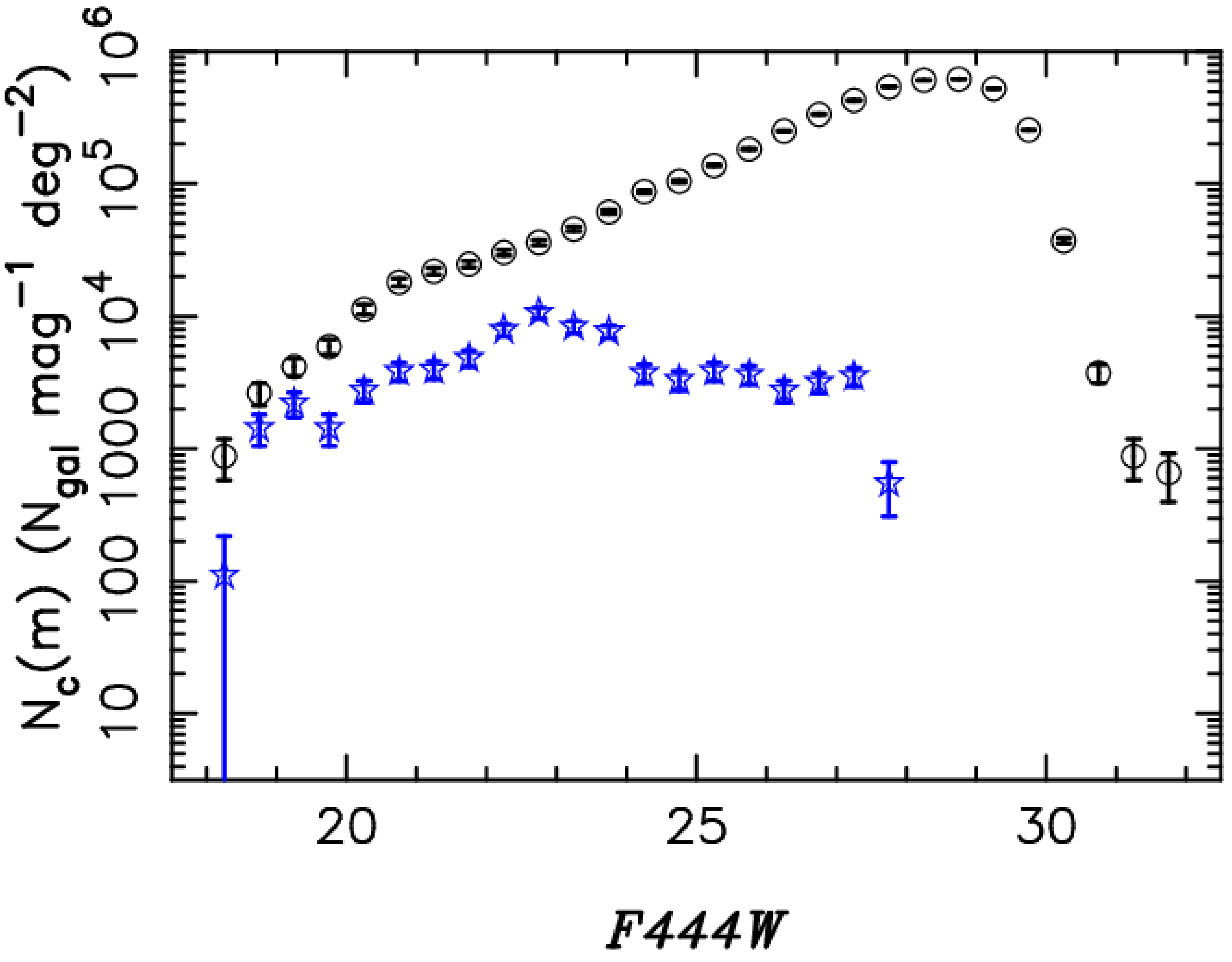


Dusty Galaxies (almost) invisible shortward of 2 μm





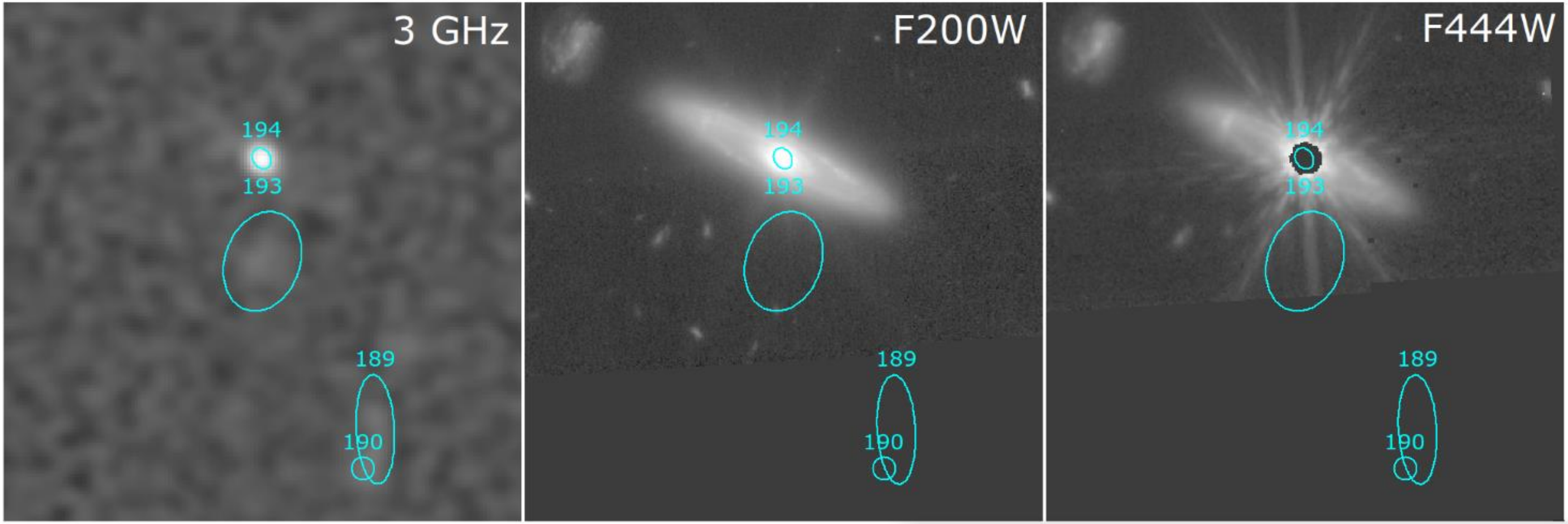
Number counts for full TDF using a preliminary catalogue by Seth Cohen (ASU)

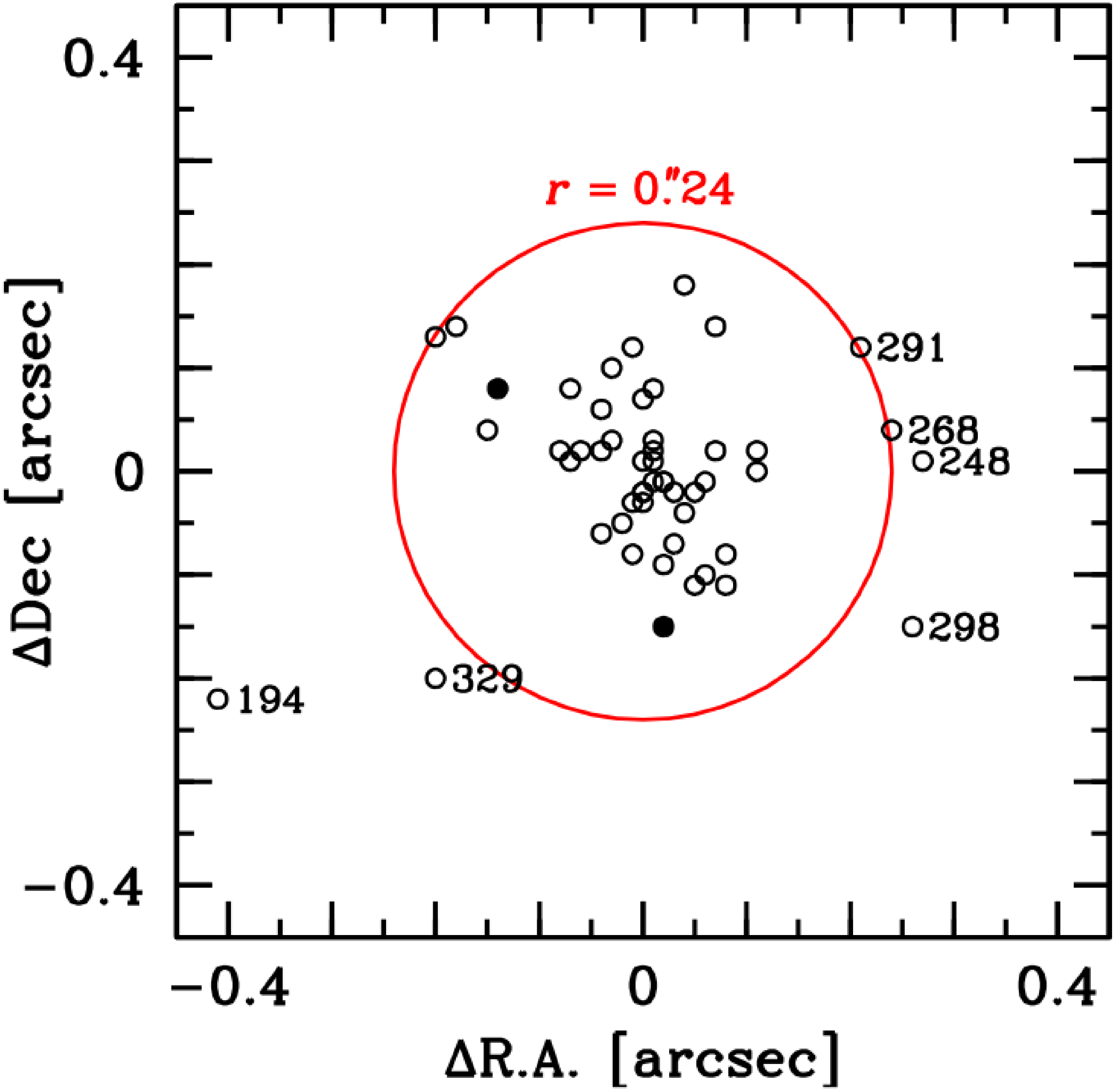


VLA sources in Spoke 1 (S. Willner+ 2023)

- Matched VLA sources from Hyun+2023 with a Spoke 1 catalogue by S. Cohen. A total of 62 out of 63 VLA sources that fall within the JWST footprint have JWST counterparts.
- The one VLA object without a counterpart could be a secondary lobe of the radio source associated to an AGN or an IR-faint radio source.
- The majority of sources fall within 0.24” from their counterparts.
- However, positional matching alone would produce mis-matches.
- About 11% of sample only have counterparts thanks to the imaging beyond 2 μm.

VLA source without counterpart

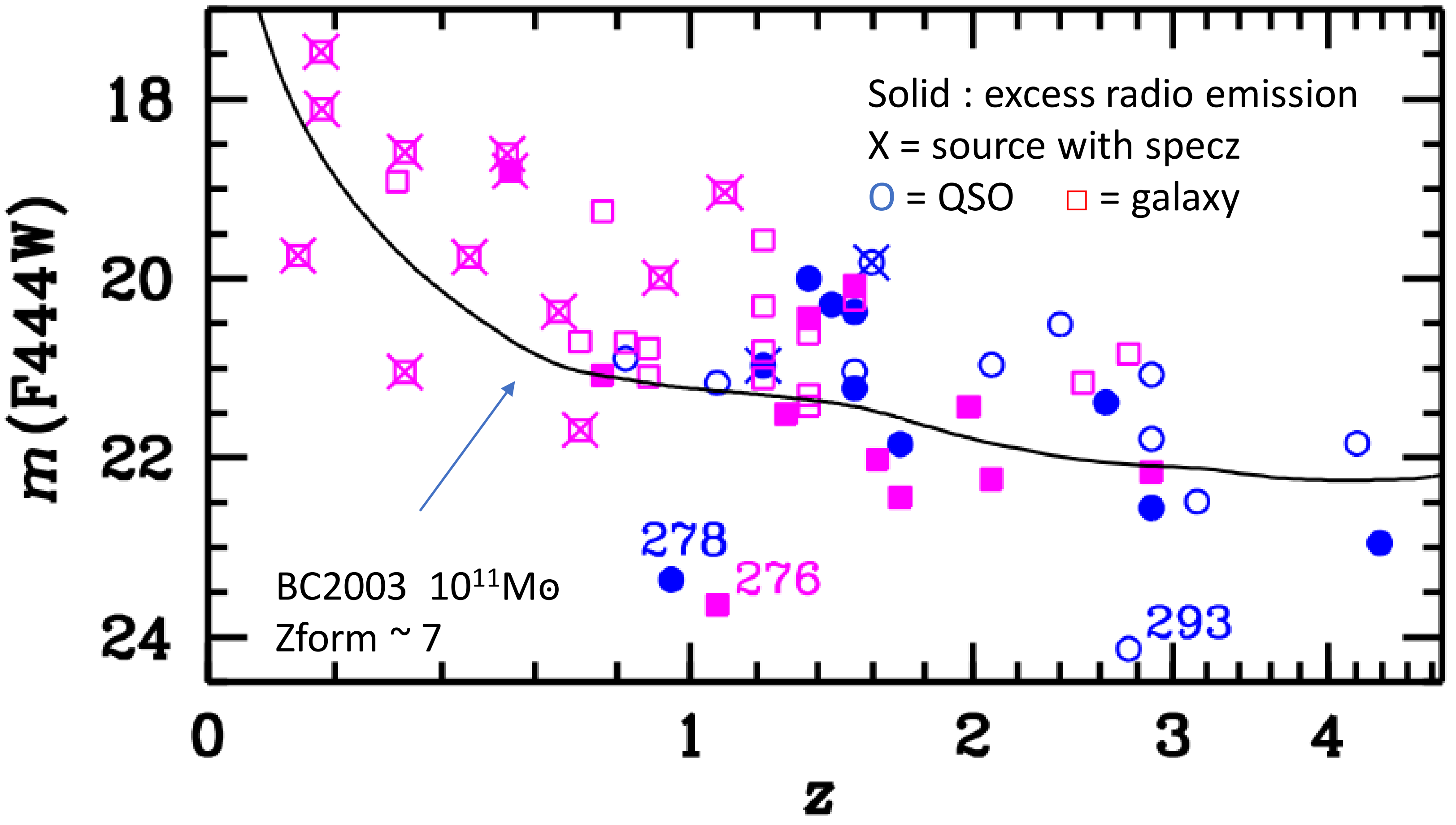




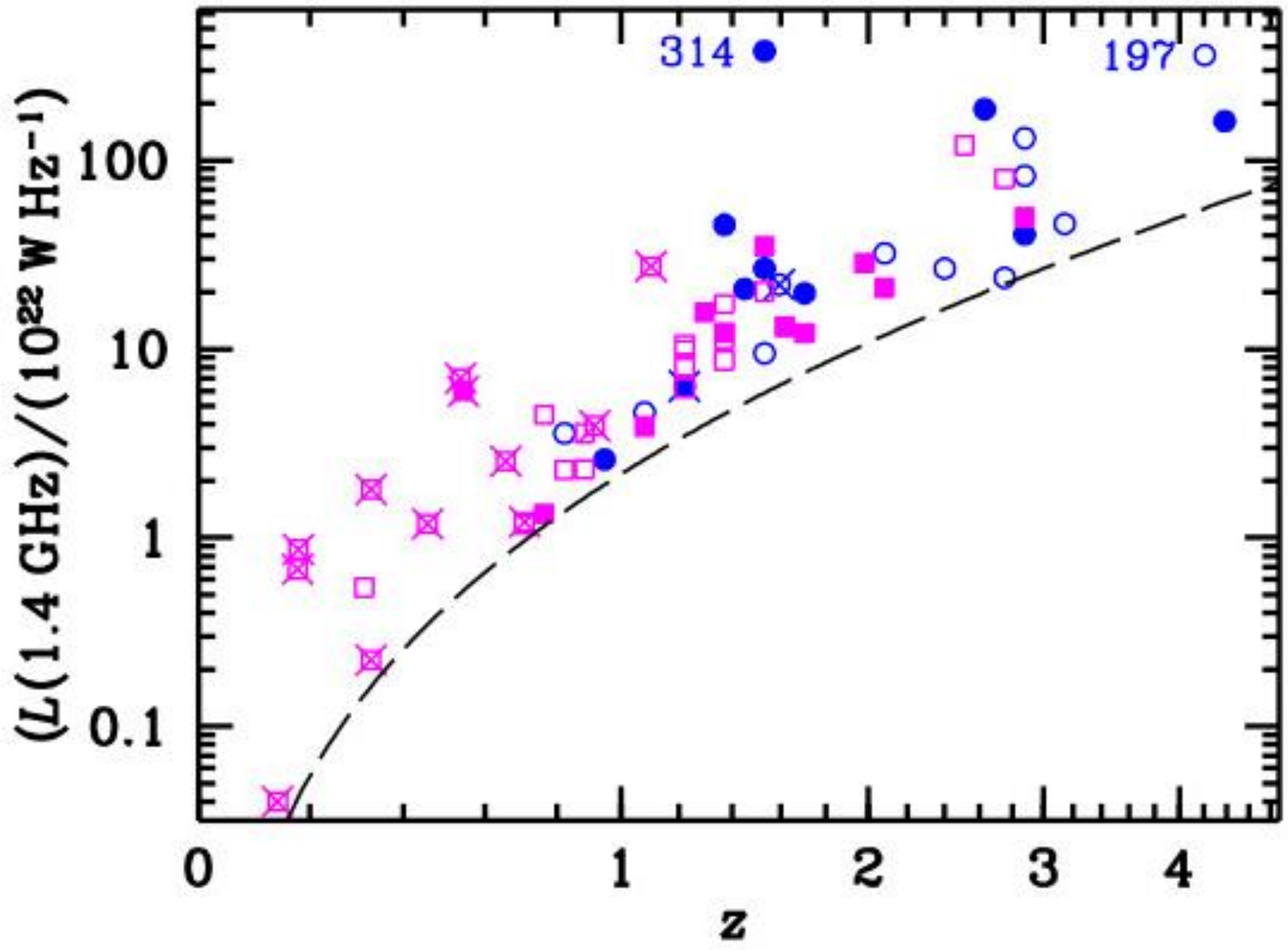
r = 0."24
291
268
248
298
329
194
0.4
0
−0.4
ΔDec [arcsec]
ΔR.A. [arcsec]

- Spectral energy distributions (SEDs) were estimated combining JWST photometry with ground-based visible and NIR when extant using CIGALE (Boquien+ 2019; Yang+ 2020; 2022).
- CIGALE produced photometric redshifts, spectral classifications and stellar mass estimates.
- Photometric redshifts show good agreement with the spectroscopic ones.
- Distribution of magnitude versus redshift shows that majority of these VLA μJy sources are several magnitude brighter than the F444W detection limit

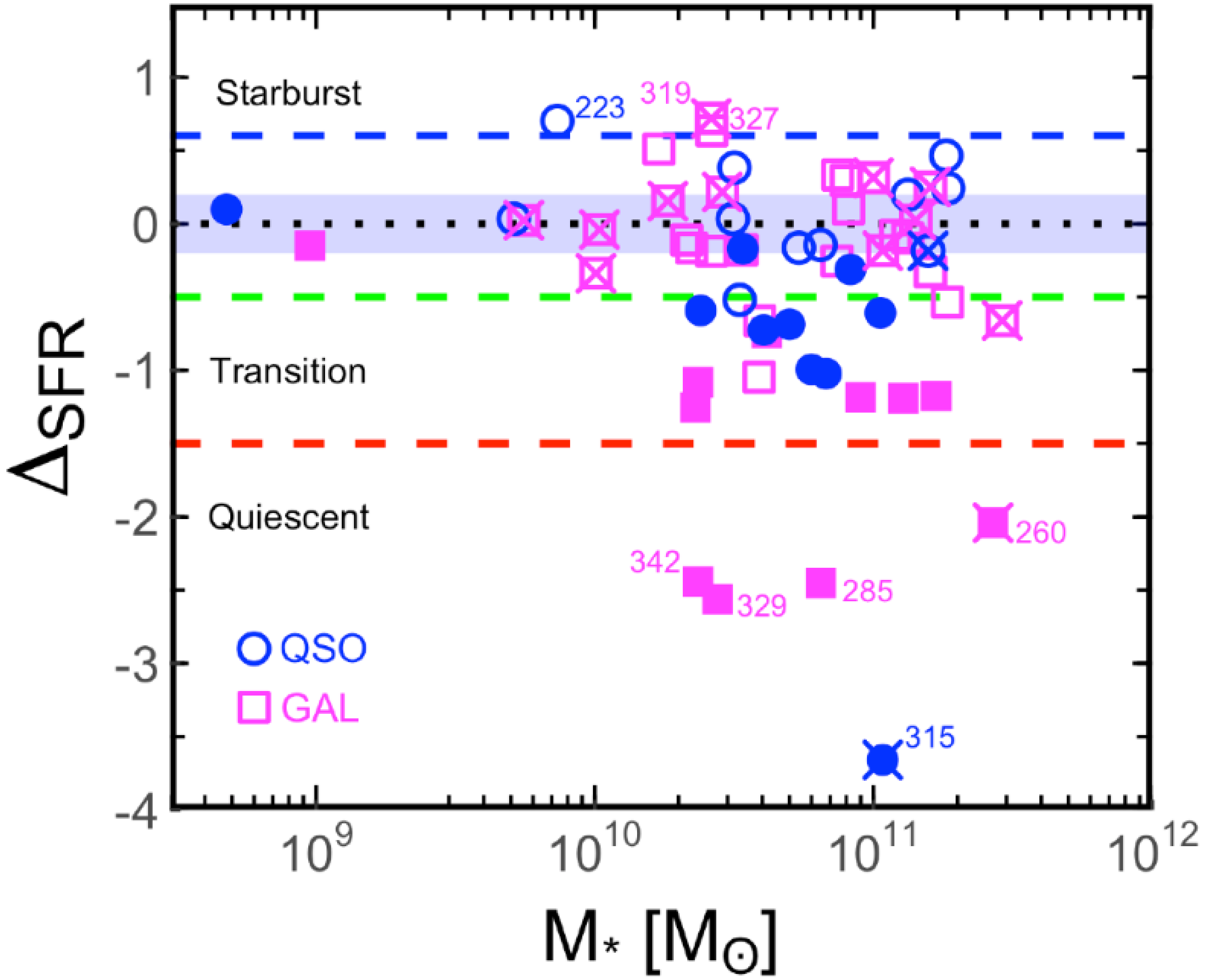
Redshift distribution



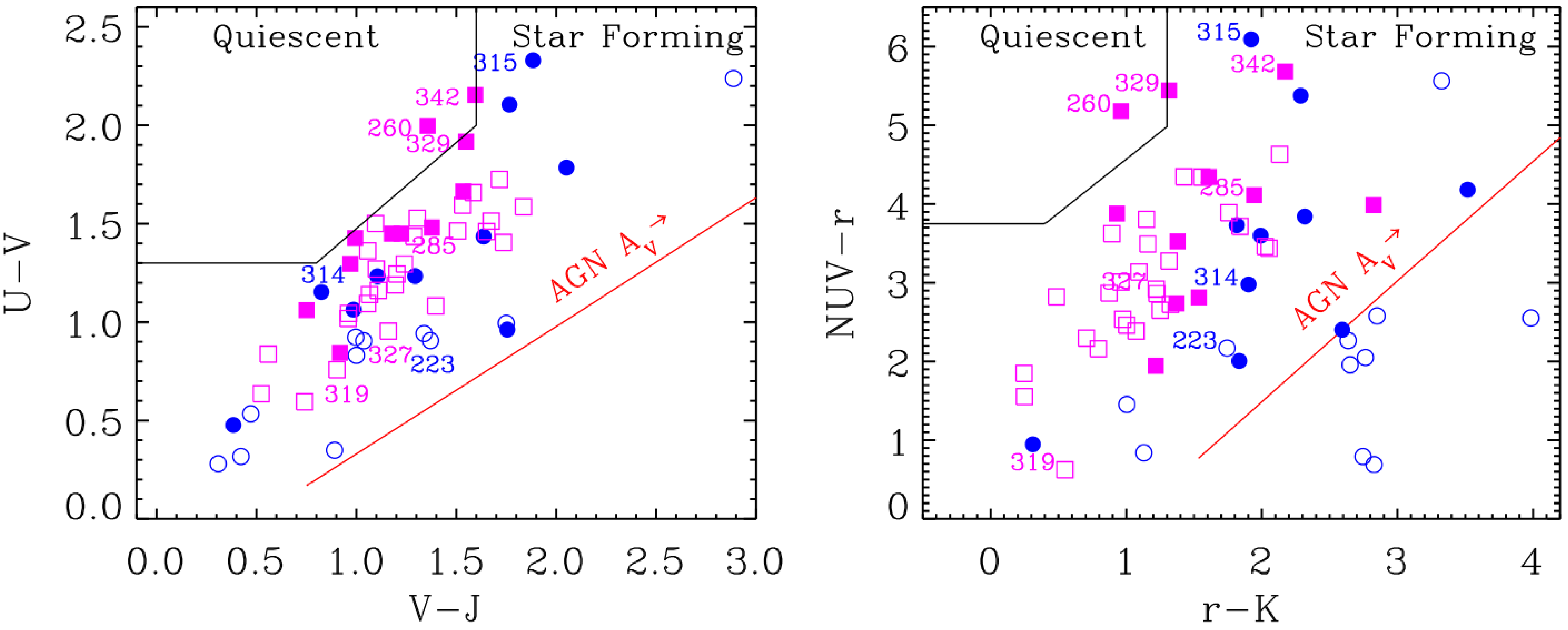
The source luminosity versus redshift plot shows that brightest sources are those with QSO spectral classification.



Object classification derived from the distance above or below the Main Sequence.



PEARLS


Quiescent
Star Forming
315
342
260
329
285
314
327
223
319
AGN A_V
U−V
V−J
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Quiescent
Star Forming
315
342
329
260
285
327
314
223
319
AGN A_V
NUV−r
r−K
6
5
4
3
2
1
0
0
1
2
3
4

- 50 min exposure with NIRCam detects 97% of the 5 µJy radio sources.
- No single match radius can give completeness and reliability.
- Radio emission comes mainly from star formation for 64% of the sample.
- The analysis using the full TDF sample is now under way (S. Willner in preparation).

PEARLS
Prime Extragalactic Areas for Reionization and Lensing Science

Synergies

- The JNEP data will be essential for the estimation of redshifts of brighter transients in the NEP, as spectroscopic full coverage is not feasible, enabling an efficient follow-up of interesting sources.
- The J-NEP provides additional “epoch 0” observations for the search of transients and variable sources.
- For sources in WEAVE, DESI and Binospec, J-NEP allows identifying redshifts of single emission-line sources, as well as explanations for the causes of failed spectroscopic redshifts.
- J-NEP photo-zs will enable many statistical studies of properties of individual galaxies as well as the clustering properties.

Concluding Remarks

- PEARLS has been successful in detecting transients through multiple observations
  - This is true both for the lensing clusters and the deep fields.
- The first analysis using the NEP TDF data emphasized the properties of radio sources
  - Almost all radio sources are detected by NIRCam imaging
  - In general all detected sources are at least 3 magnitude brighter than the nominal magnitude limit of the observations.
  - The radio sources show a mixture of star-forming and active galaxies, the latter being brighter because of the AGN
- The sparse spectroscopic coverage means that J-NEP will be a prime resource to characterise the statistical properties of galaxies in the NEP TDF.