UV–Visible observations with *HST* in the *JWST* North Ecliptic Pole Time-Domain Field

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ABSTRACT

We report on a UV–Visible *HST* imaging survey of the *JWST* North Ecliptic Pole (NEP) Time-Domain Field (TDF) (Jansen & Windhorst 2018). To date, using CVZ and pseudo-CVZ opportunities, we observed seven out of nine tiles with WFC3/UVIS in F275W and with ACS/WFC in both F435W and F606W. This survey is designed to provide near-contiguous 3-filter coverage of the central $r \lesssim 5'$ of this new *community field* for time-domain science with *JWST*. The *JWST* NEP TDF is located within *JWST*'s northern Continuous Viewing Zone, will span $\sim 14'$ in diameter (of which $\sim 10'$ with NIRISS coverage), is devoid of sources bright enough to saturate the NIRCam detectors, has low Galactic foreground extinction, and will be roughly circular in shape (initially sampled during Cycle 1 at four distinct orientations with *JWST*/NIRCam — the JWST "windmill"). NIRISS slitless grism spectroscopy will be taken in parallel, overlapping an alternate NIRCam orientation. This is the *only* region in the sky where *JWST* can observe a clean extragalactic deep survey field of this size at *arbitrary cadence* or at *arbitrary orientation*. This will crucially enable a wide range of new and exciting time-domain science, including high redshift transient searches and monitoring (e.g., SNe), variability studies from Active Galactic Nuclei to brown dwarf atmospheres, as well as proper motions of extreme scattered Kuiper Belt and comets beyond the distance of Neptune, and of nearby Galactic brown dwarfs, low-mass stars, and ultracool white dwarfs. Ancillary data across the electromagnetic spectrum will exist for this field when *JWST* science operations commence in 2021. This includes deep ($m_{\rm AB} \gtrsim 26$ mag) wide-field ($\sim 23' \times 25'$) *Ugriz* photometry of the JWST NEP TDF and surrounding area from LBT/LBC, Subaru/HSC, and GTC/HiPERCAM, *YJHK* from MMT/MMIRS, JVLA 3 GHz and VLBA 5 GHz radio observations to sub-μJy sensitivity, and deep (600 ks) *Chandra*/ACIS X-ray images. Observations at long-wave radio (LOFAR) and (sub)mm (IRAM 30m, JCMT, SMA) wavelengths, optical narrow-band spectrophotometry (J-PAS), and multi-object spectroscopy (MMT) are in progress, scheduled, or proposed, ensuring a rich legacy of the UV–Visible *HST* observations.

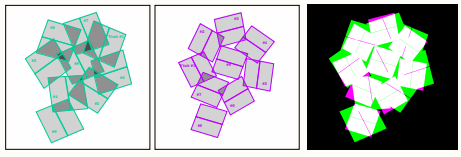

Fig. 1 — Exposure maps for [*a*] the ACS/WFC F435W and F606W images, showing the near-contiguous coverage of the *JWST* NEP TDF in these filters, as well as areas of 2- or 3-epoch overlap for cross-calibration and time-domain science, and [*b*] the WFC3/UVIS F275W images, where the smaller footprint of WFC3/UVIS results in larger gaps in coverage and smaller areas of 2-epoch overlap. Each tile is labeled with its visit number. Remaining visits #3 and #9 are scheduled for Feb 2019. [*c*] Color composite image of the combined exposure maps, with ACS/WFC F435W+F606W coverage in green and WFC3/UVIS in magenta, highlighting the area with 3-filter UV–visible coverage, which appears here as white. (*Adapted from Jansen, Grogin, et al. 2019, in prep.*)

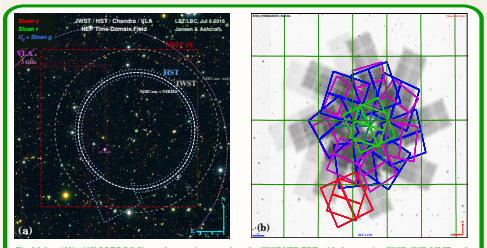

Fig. 2 [*a*] — 18′.4×19′.2 LBT/LBC *Ugrz* color mosaic centered on the *JWST* NEP TDF, with the tentative *JWST*, *HST*, MMT, and VLA survey areas indicated. *Chandra* X-ray observations cover the entire field shown. The white and grey dashed circles indicate the core *JWST* NEP TDF survey area with both NIRCam 0.8–5 μm imaging *and* 1.7–2.3 μm NIRISS slitless grism spectroscopy (5′ radius), and the larger area with only NIRCam coverage ($\sim 7'$ radius). Very few bright stars are seen inside the $r = 5'$ radius in this ground-based image, which reaches $m_{\rm AB} \sim 26.5$ mag. (*Jansen & Windhorst 2018; Jansen, Ashcraft, et al. 2019, in prep.*) [*b*] — Layout of our *HST* ACS/WFC F435W + F606W and WFC3/UVIS F275W exposures, overlayed on a tentative *JWST*/NIRCam exposure map that includes the core 4-spoke GTO survey, as well as an anticipated community-driven GO extension at a notional ΔPA of 45°.

Acknowledgements

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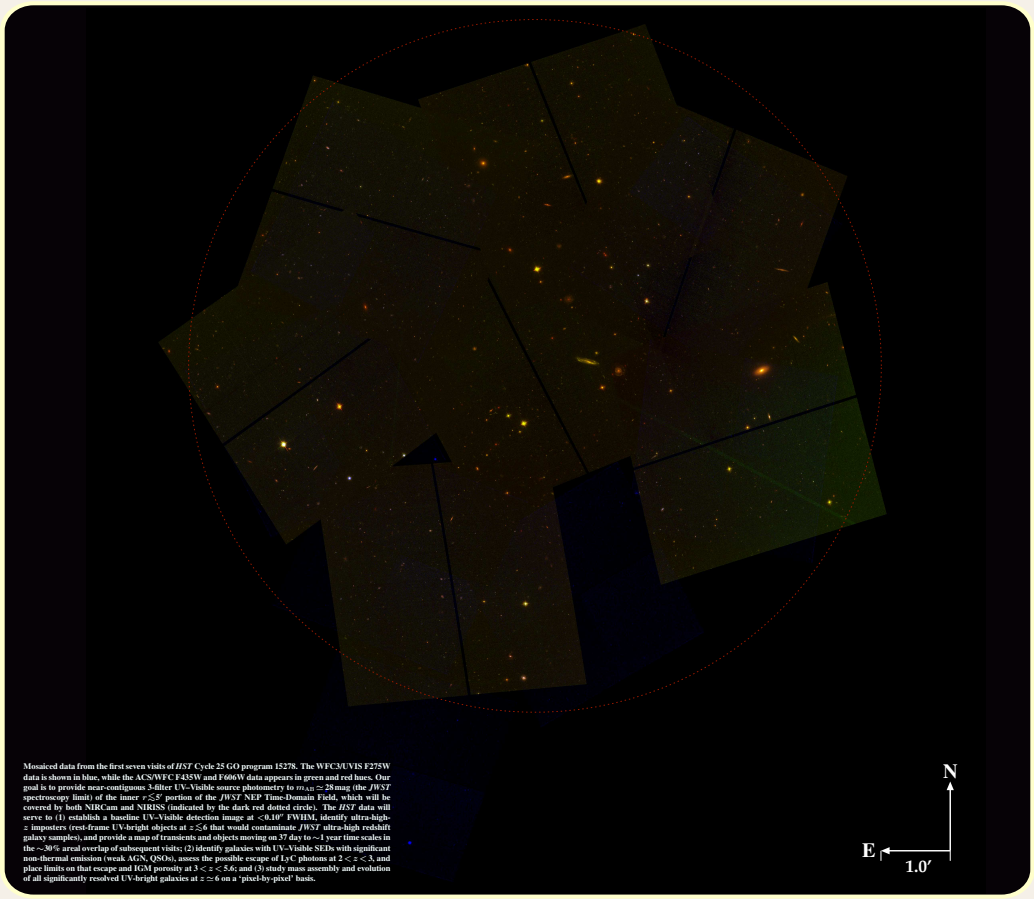
We used the `Montage` (v5.0) toolkit (Jacob et al. 2009), funded by NASA's ESTO/CTP under Cooperative Agreement NCC5-626 between NASA and Caltech. That code was developed at the Infrared Processing and Analysis Center (IPAC) and the Jet Propulsion Laboratory (JPL) by Bruce Berriman, John Good, Joseph Jacob, Daniel Katz, and Anastacia Laity, and is maintained by the NASA/IPAC InfraRed Science Archive.



Mosaiced data from the first seven visits of *HST* Cycle 25 GO program 15278. The WFC3/UVIS F275W data is shown in blue, while the ACS/WFC F435W and F606W data appears in green and red hues. Our goal is to provide near-contiguous 3-filter UV–Visible source photometry to $m_{\rm AB} \simeq 28$ mag (the *JWST* spectroscopy limit) of the inner $r \lesssim 5'$ portion of the *JWST* NEP Time-Domain Field, which will be covered by both NIRCam and NIRISS (indicated by the dark red dotted circle). The *HST* data will serve to (1) establish a baseline UV–Visible detection image at $< 0.10''$ FWHM, identify ultra-high-z imposters (rest-frame UV-bright objects at $z \lesssim 6$ that would contaminate *JWST* ultra-high redshift galaxy samples), and provide a map of transients and objects moving on 37 day to $\sim$1 year time scales in the $\sim$30% areal overlap of subsequent visits; (2) identify galaxies with UV–Visible SEDs with significant non-thermal emission (weak AGN, QSOs), assess the possible escape of LyC photons at $2 < z < 3$, and place limits on that escape and IGM porosity at $3 < z < 5.6$; and (3) study mass assembly and evolution of all significantly resolved UV-bright galaxies at $z \simeq 6$ on a 'pixel-by-pixel' basis.

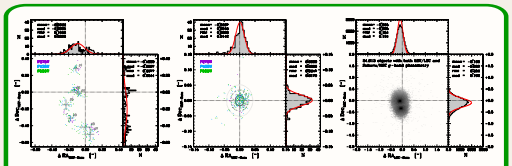


Fig. 2 — Measured astrometric offsets between the *HST* and *Gaia* DR2 astrometric reference frame as defined by 281 detected sources in common for [*a*] the initial pipeline-reduced drizzled and CTI-corrected mosaics, as reported by the WCS keyword values in the FITS headers, and [*b*] the same mosaics after correcting for systematic mean rotation and offsets resulting from the uncertainties in the absolute positions of the guide stars used in a particular visit. Residual offsets in the sense (*HST*–*Gaia*) for individual sources tend to be smaller than half a pixel on average, although a few outliers are evident. (*Adapted from Jansen, Grogin, et al. 2019, in prep.*), [*c*] Measured astrometric residuals with respect to the *Gaia* DR2 astrometric reference frame from a preliminary analysis of 24,013 objects observed in Sloan-*g* with both LBT/LBC and Subaru/HSC within the $\sim 23' \times 25'$ area surrounding the *JWST* NEP TDF proper. Residual offsets tend to be smaller than the $\sim 0\farcs2$ pixel size. (*Adapted from Jones 2019, in prep.*)

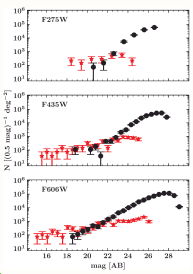


Fig. 4 — Preliminary differential number counts of stars (red) and galaxies (black) in each of the three *HST* filters (see companion poster #243.06 by White et al.). In the ACS/WFC filters, the number counts are presented in units of number per 0.5 mag per deg^2, while for the WFC3/UVIS F275W filter the number counts are plotted in units of number per mag per deg^2 due to the much lower source densities at ultraviolet wavelengths. The galaxy number counts follow a power law to $m_{\rm AB} \simeq 26$–28 mag, before turning over due to incompleteness, while the stellar counts follow a much shallower trend.

Work on source characterization has started using morphological information from these *HST* observations, and multi-wavelength source photometry using both *HST* and ground- and space-based ancillary observations.