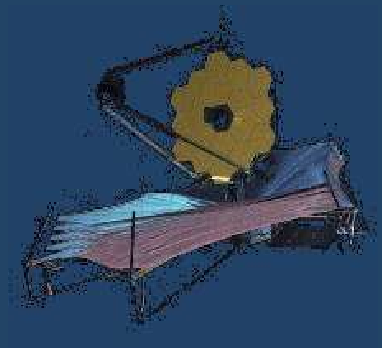


JWST as a Time-Domain Science Facility

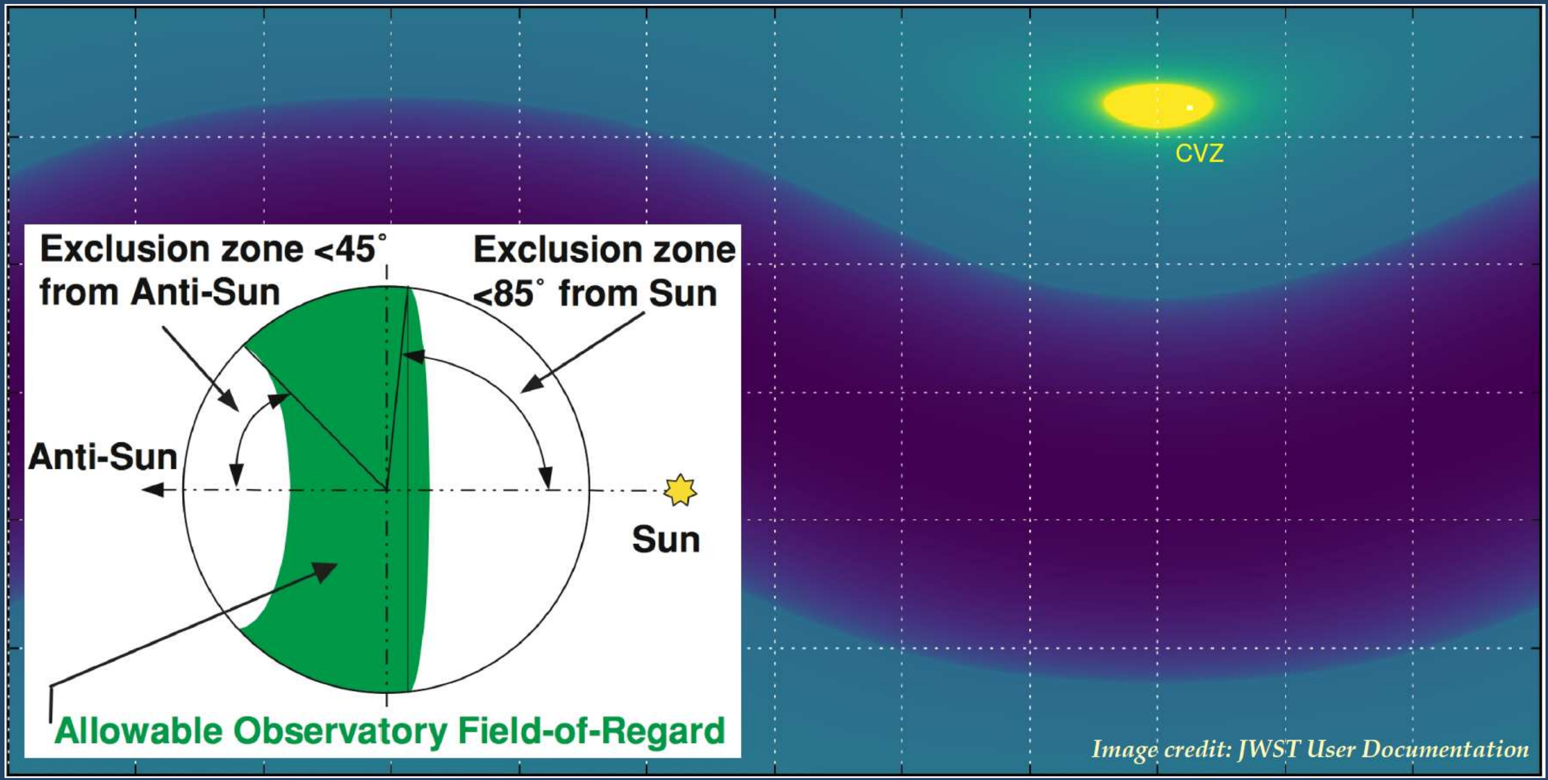
- **Advent of the era of deep, large area (survey) time-domain science (relatively faint objects with, e.g., PanSTARRS, *Rubin*/LSST, *Roman*)**
  - **Solar System**
  - **Galactic neighborhood (and beyond)**
  - **Objects at cosmological distances / large look-back times**

- **Question: can *JWST* do time-domain survey science? What would it add?**
  - ***Rubin* / LSST: $m_{\rm AB} \lesssim$ 23.8 mag (10σ per 2$\times$15 s visit; $\sim$15 min – 1 hr time-scales over large fraction of the sky)**
  - ***JWST*/NIRCam: $m_{\rm AB} \sim$ 26.8–28.3 mag (10σ per epoch; $\sim$15 min – 1 hr time-scales in a suitable survey field):**

▷ **Unexplored magnitude regime for variability studies: $m_{\rm AB} \gtrsim$ 24 mag**
  - **Supernovae (Type Ia SNe to $z \sim 5$, Core Collapse SNe to $z \sim 1.5$, Pair Instability SNe to the Epoch of Reionization); AGN; brown dwarf atmospheres**

▷ **Unexplored regime for proper motion detections: $m_{\rm AB} \gtrsim$ 24 mag, $p \gtrsim$ 0.5 mas/yr**
  - **Extreme outer Solar System objects; interstellar asteroids and comets (such as 1I/'Oumuamua or 2I/Borisov); nearby Galactic brown dwarfs and low-mass stars, and ultra-cool white dwarfs.**

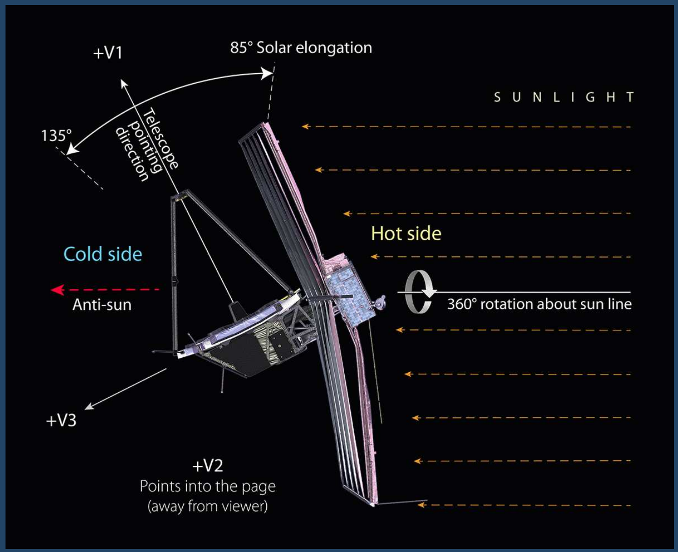
JWST Operational Restrictions = Orientation Restrictions

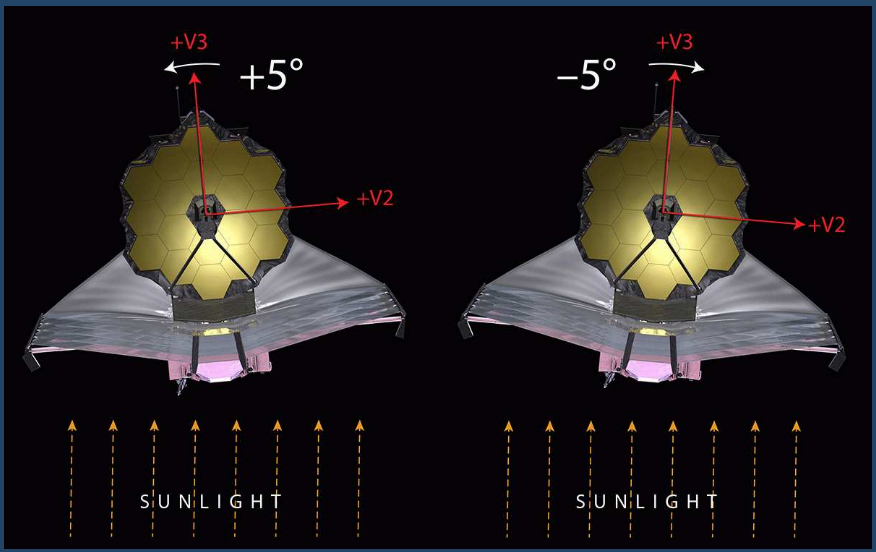


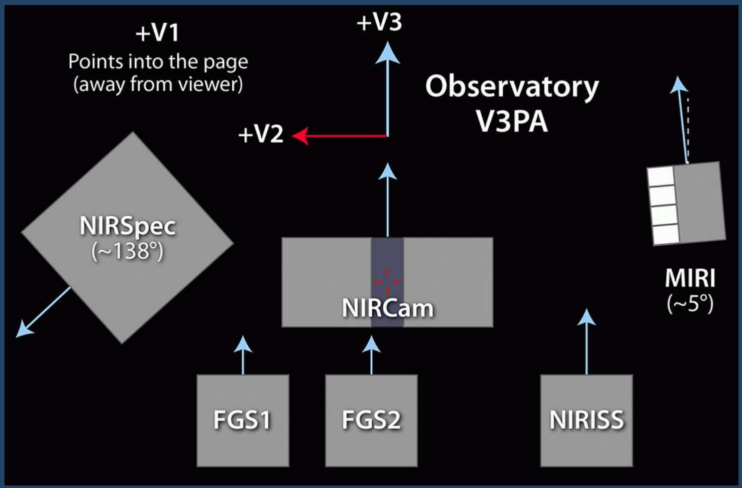
- **Sun avoidance, power generation, and shielding requirements of the cryogenic telescope restricts object visibility to two time intervals per year**

▷ **Except for objects within two small ($r < 5°$) continuous viewing zones (CVZs) centered on the North Ecliptic Pole (NEP) and the South Ecliptic Pole (SEP).**

JWST Operational Restrictions = Orientation Restrictions



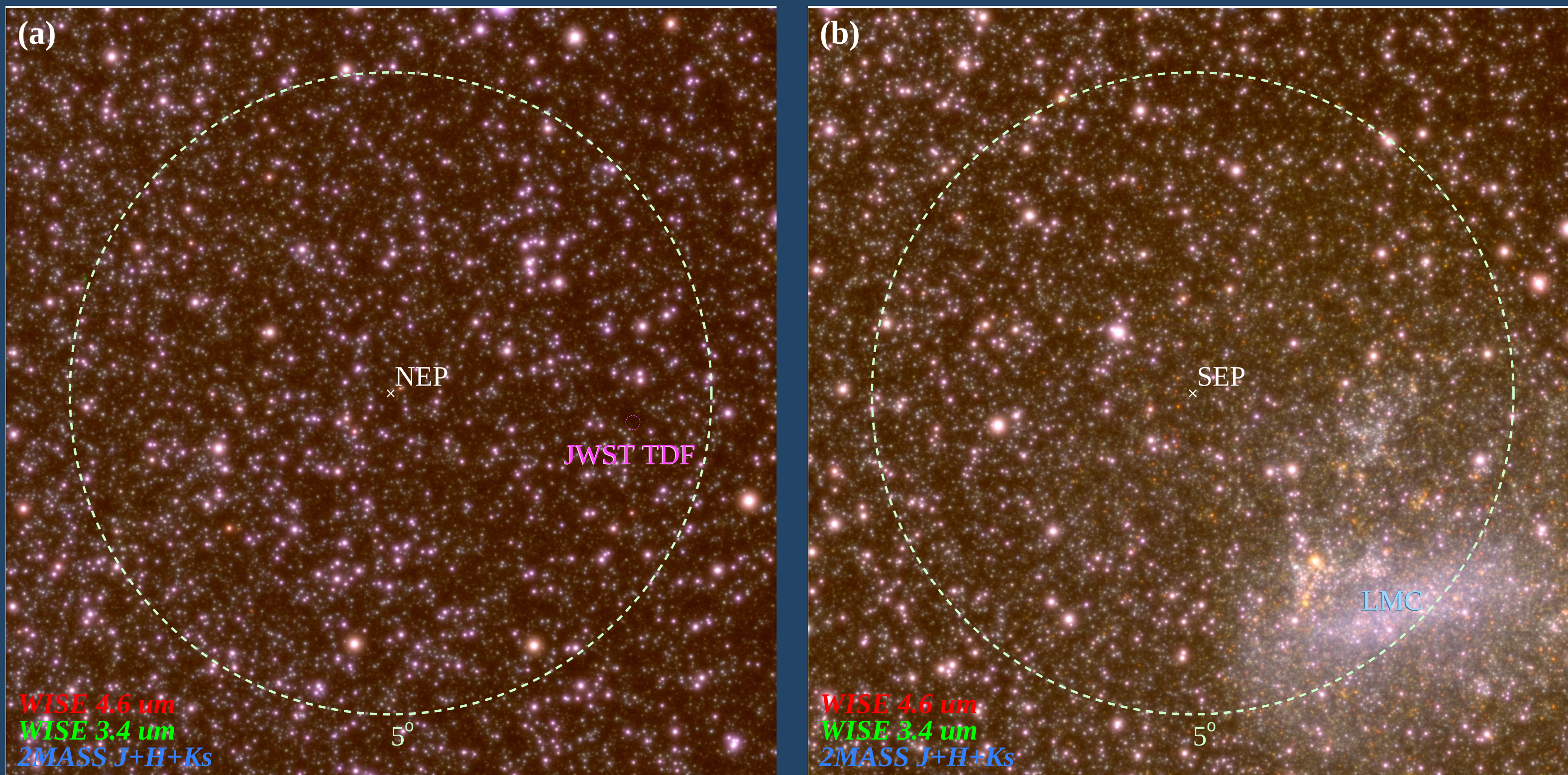




- **The date of observation dictates the orientation of the instrument foot-prints on the sky, limiting the range of possible orientations for a given object.**
  - ▷ **Except for objects located within *JWST*'s CVZs.**

NASA / JWST User Documentation

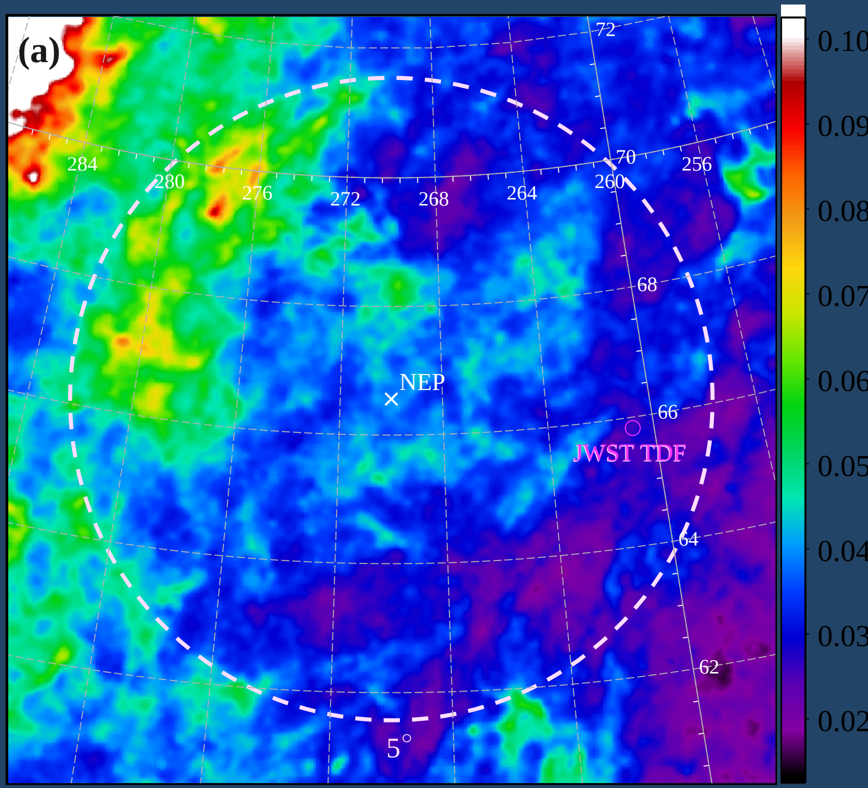
JWST's Northern and Southern CVZs

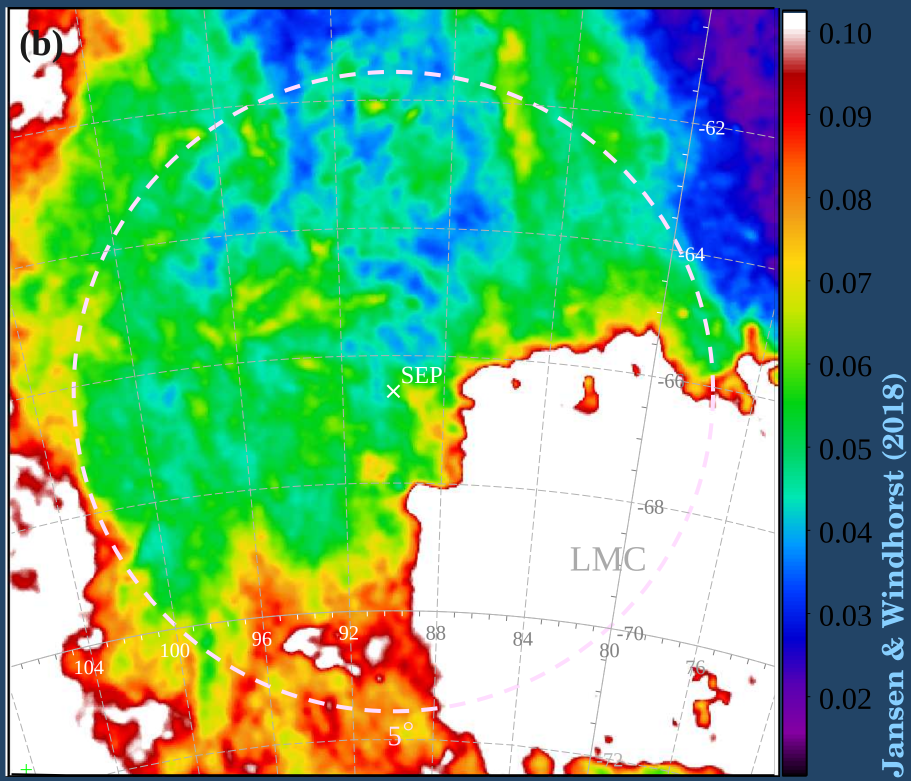


Jansen & Windhorst (2018)

- ***JWST* Time-Domain Science on time-scales of minutes to years implies a survey field that *must* be located within *JWST*'s CVZs.**
  - ▷ **Existing, well-established, fields (e.g., from *HST*, *Chandra*, *XMM*, VLA) won't do.**
  - ▷ **Northern CVZ emptier sky than Southern CVZ (LMC and Galactic structures)**

JWST's Northern and Southern CVZs





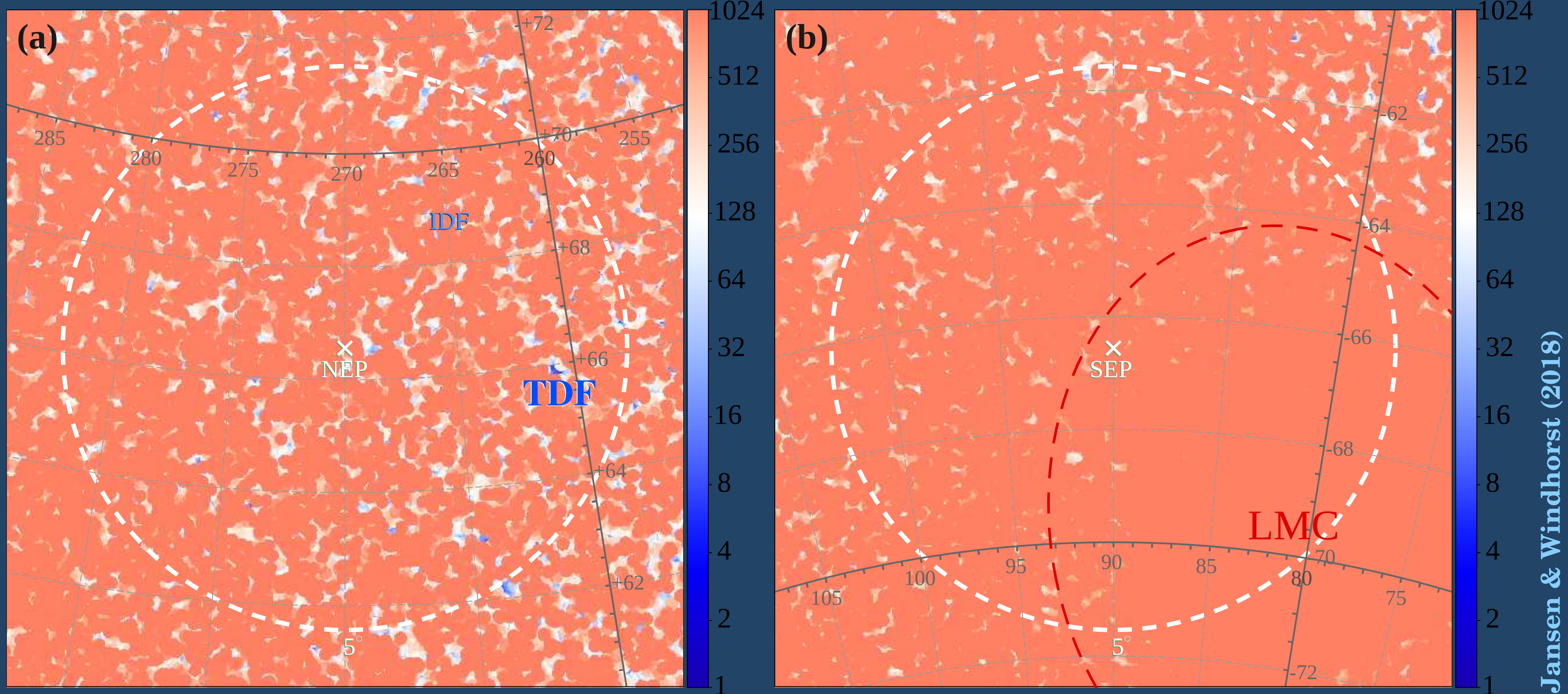
- **Maps of $E(B-V)$ values (Schlegel et al. 1998; Schlafly & Finkbeiner 2011) in the $12^\circ \times 12^\circ$ area around (a) the NEP, and (b) the SEP.**
  - ▷ **Northern CVZ has less foreground extinction by dust than Southern CVZ (LMC and Galactic structures)**

Selection of a new *JWST* field for Time-Domain Surveys

- **Field size and shape: $\sim 14'$ diameter, circular**
  - accommodates the imaging instruments (NIRCam, NIRISS, and MIRI) in *JWST*'s focal plane *at any orientation*, and allows contiguous survey coverage for various dithering strategies

- **Bright Object concerns: no 2–4 μm-bright stars ($m_{\rm AB} \lesssim 15.5$ mag) within field of view**
  - Persistence acts as localized reductions in sensitivity and increases in image noise
  - Persistence forms a record of observations that may have taken place hours earlier $\longrightarrow$ source of sample contamination
  - Persistence no longer modelable and correctable for $m_{\rm AB} \lesssim$ 15.5,mag.

Selection of a new *JWST* field for Time-Domain Surveys



- **$12^\circ \times 12^\circ$ maps of $\sim$4 μm source penalties for (a) the NEP, and (b) the SEP. There are *very* few regions 14′ diameter or larger devoid of sources brighter than $m_{\rm AB} = 15.5$ mag in *JWST*'s Northern CVZ (appearing in dark blue hues; the biggest one marked "TDF") and *none* within the Southern CVZ.**

Selection of a new *JWST* field for Time-Domain Surveys

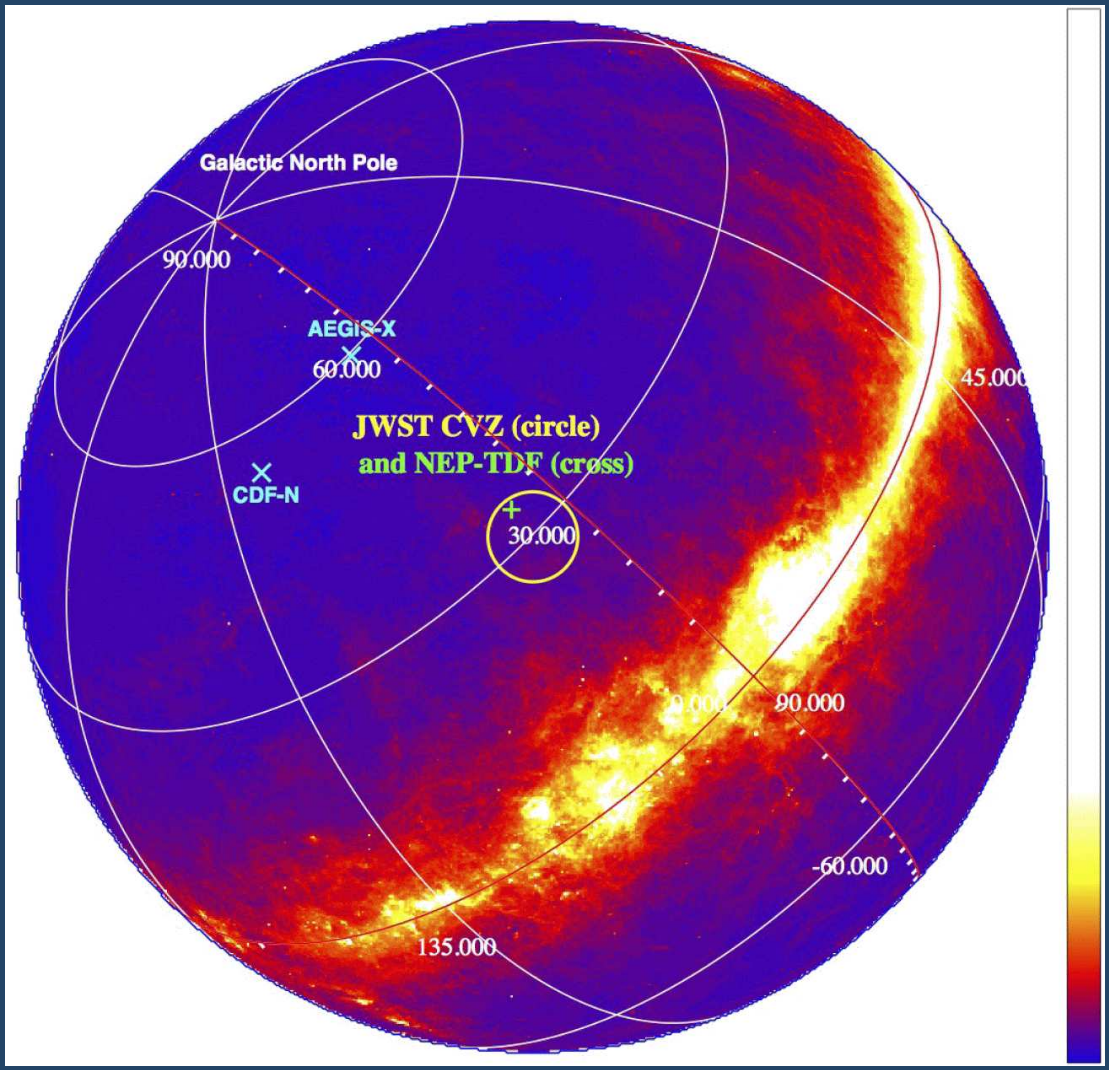
▷ **No solutions found in the SEP CVZ**

- **The very best region also has guide star solutions for *Hubble*, a bright quasar that can serve as a phase calibrator for radio interferometric observations, and has low Galaxy foreground extinction $E(B-V) \lesssim$ 0.03 for extragalactic surveys.**

▷ ***JWST NEP Time-Domain Field* centered at (RA, Dec)$_{\mathrm{J2000}}$ = (17:22:47.896, +65:49:21.54)**

- **Low Zodiacal foreground emission: NEP and SEP always have lowest foreground**

Selection of a new *JWST* field for Time-Domain Surveys



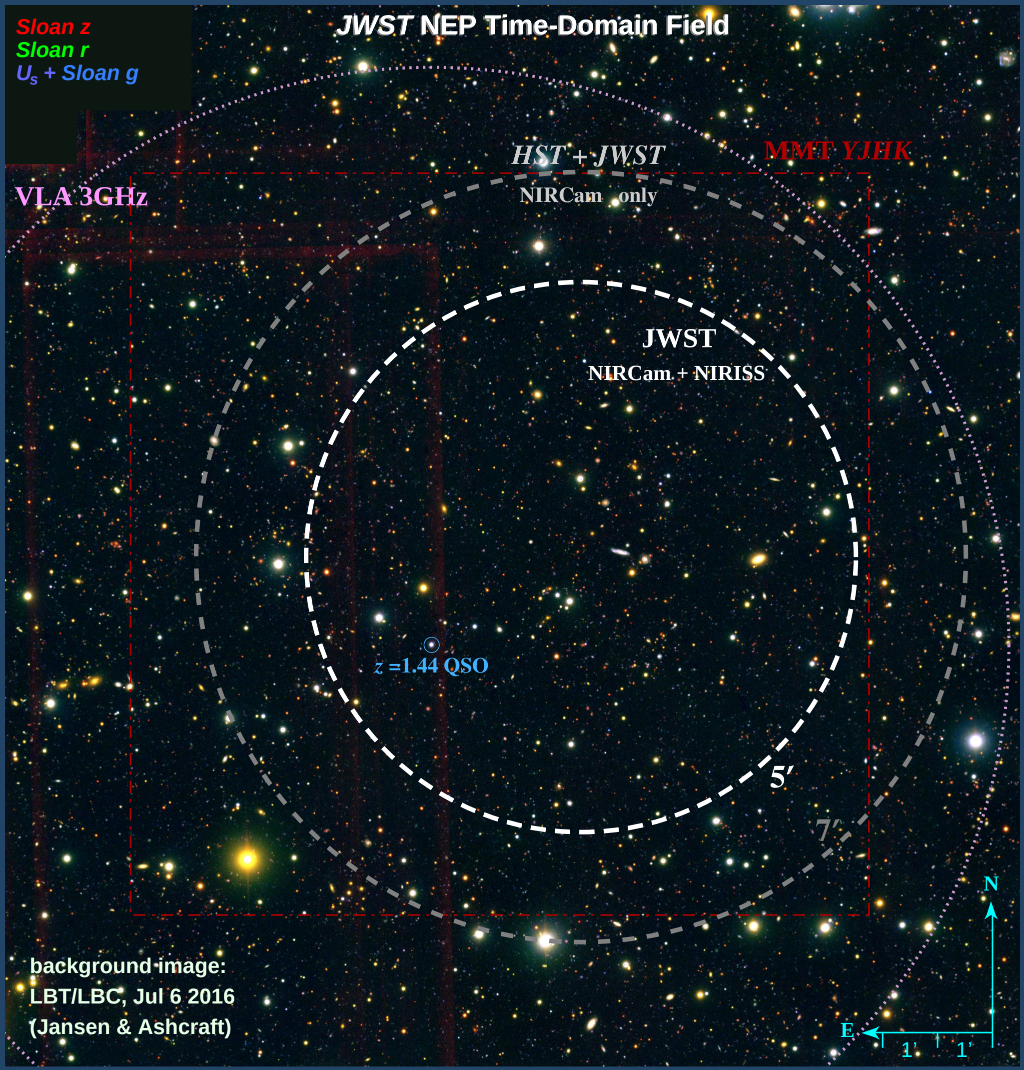
Maksym et al. (2019)

- **Relatively long but clear sight-line through our Galaxy**

$$(l^{II}, b^{II}) \simeq (96°, +33°)$$

▷ **also good for Galactic time-domain science!**

Verification of the *JWST* NEP Time-Domain Field

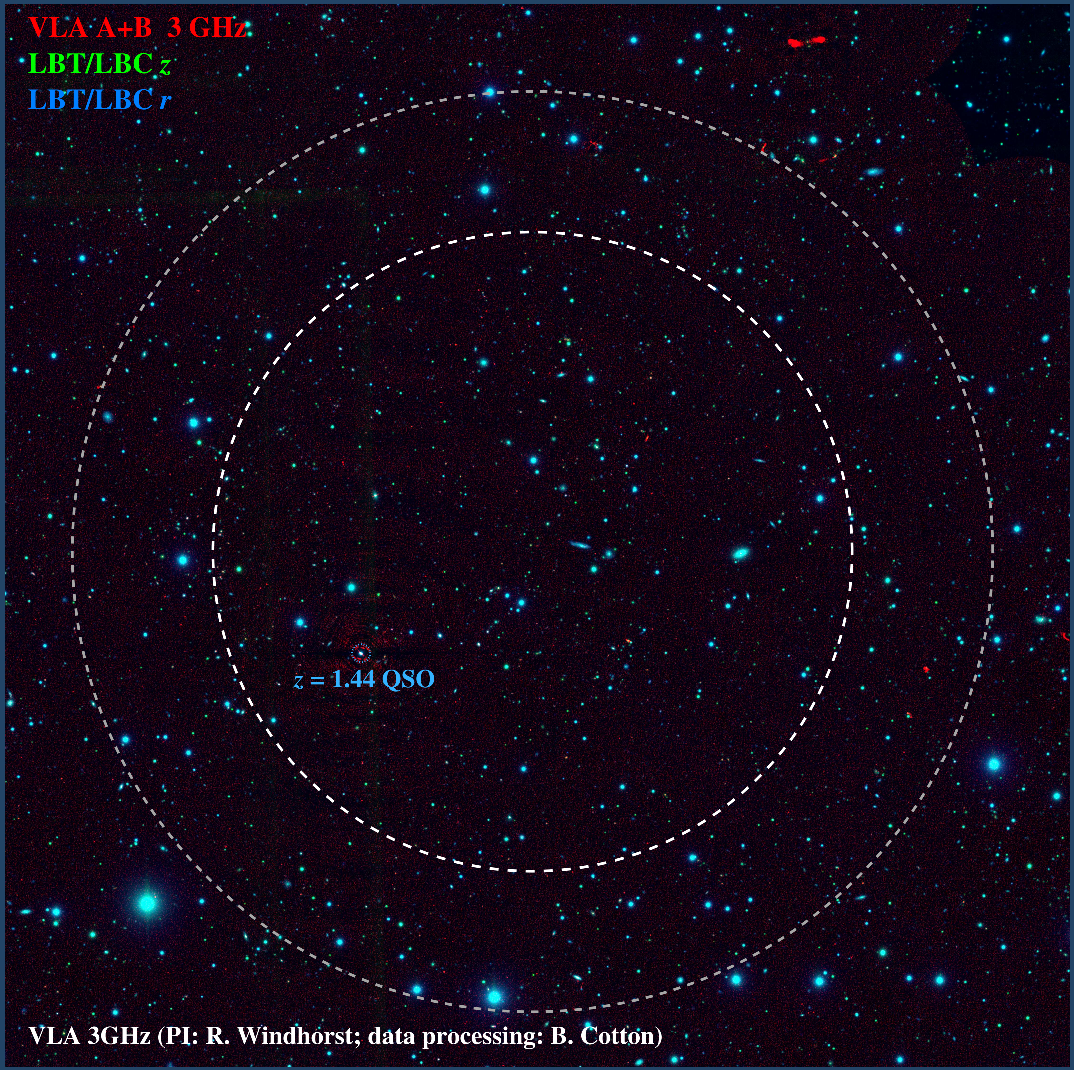


Jansen & Windhorst (2018)

- Verified using 2×8.4 m Large Binocular Telescope / LBC *Ugriz* imaging to $m_{\rm AB} \sim 26.5$ mag at $\sim$0.″95 FWHM (PI: R. Jansen)
- Verified using 6.5 m MMT/-MMIRS *YJHK* imaging to $m_{\rm AB} \sim$ 24–22 mag (PI: C. Willmer)

▷ Best region selected is indeed devoid of bright *red* stars & excellent for deep extragalactic science

Verification of the *JWST* NEP Time-Domain Field



- **Verified using VLA A+B configuration 3 GHz ($\lambda \sim 10$ cm) observations to 0.9 μJy** **(PI: R. Windhorst)**

▷ **Most of the faint radio sources detected have faint visible–near-IR counterparts.**

▷ **Nature of these μJy radio sources is being studied: most appear powered by *star formation* rather than by AGN.**

Development as a *JWST Community Field*: Ancillary X-ray through Radio Observations in the *JWST* NEP TDF

- **Field selection & Verification:**
  - **Field selection (Jansen & Windhorst 2018)**
  - **Large Binocular Telescope/LBC *Ugriz* (Jansen)**
  - **MMT/MMIRS *YJHK* & spectroscopy (Willmer), and**
  - **VLA 3 GHz observations (Windhorst)**

- **Imaging with *Hubble* at wavelengths inaccessible to *Webb*:**
  - ***HST* Cycle 25 + Cycle 28+29 UV–Visible imaging ($m_{\mathrm{AB}} \sim$ 27.3–29 mag) of central $r \lesssim 5'$ area (completed), and of the annulus to $r \lesssim 7.5'$ (in progress) (PI: R. Jansen; PI: R. Jansen & N. Grogin)**

- **IDS GTO *JWST*/NIRCam imaging ($m_{\mathrm{AB}} \lesssim$ 29 mag) + NIRISS slitless grism spectroscopy ($m_{\mathrm{AB}} \lesssim$ 28 mag) (PI: R. Windhorst)**
  - **After the Dec 18 2021 launch & 6-month on-orbit verification, we expect the first observations of the field with *Webb* in June 2022!**

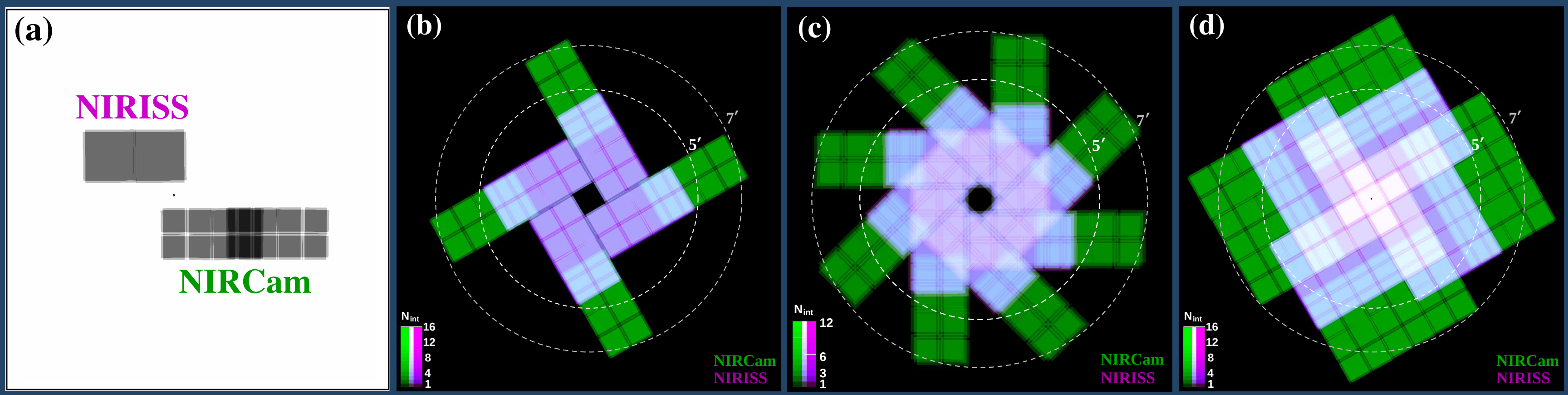
- **Coverage across the electromagnetic spectrum secured by the community:**

Development as a *JWST Community Field*: Ancillary X-ray through Radio Observations in the *JWST* NEP TDF

- ***JWST* NEP Time-Domain Field multiwavelength community investment**

Telescope	PI	Status	Depth
NuSTAR 3–24 keV	F. Civano	extant (33 sources) / in progress	687 ks / 780 ks; $>$50 cts
Chandra/ACIS-I 0.2–10 keV	W.P. Maksym	extant; 238 sources	540 ks; $\sim 1\times10^{-16}$ cgs
″	″	in progress	1260 ks; ″
XMM-Newton 0.5–2.0 keV	F. Civano/M. Ward/N. Cappelluti	approved / proposed	40 ks / 800 ks; 3×10^{-16} cgs
HST/WFC3+ACS	R.A. Jansen	extant / in progress	60 / 32 CVZ orbits; $r \lesssim 7'.5$
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 #1176, #1255	$m <$ 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	in progress (5 sources)	30 hrs; rms $\sim$ 0.9 mJy/beam
IRAM/Nika2 1.2, 2 mm	S.H. Cohen	in progress	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
LOFAR 150 MHz	R. van Weeren	extant; ultra-wide field	72 hrs; rms $\sim$ 0.12 mJy
J-PAS (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/799 redshifts	26 hrs; $m \sim$ 22.5–24 mag
MMT/MMIRS (mos)	C.N.A. Willmer	approved	$m <$ 22, $z >$ 0.4

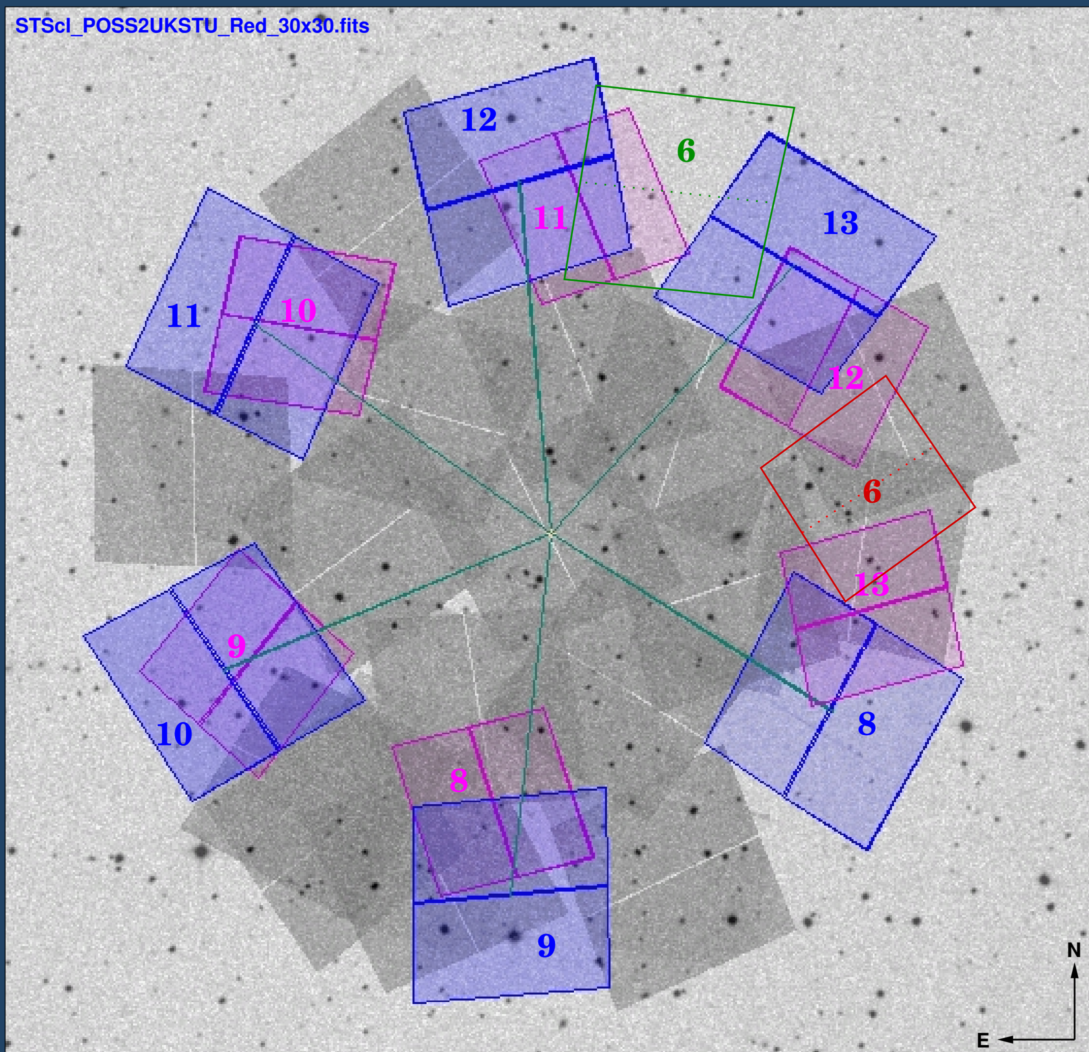
JWST IDS GTO and Possible GO implementations



Jansen & Windhorst (2018)

- [*a*] Footprint on the sky of a 2×1 mosaic of pointings with *JWST*/NIRCam (8-filter 0.8–5.0 μm imaging), and NIRISS 1.75–2.23 μm slitless spectroscopy taken in parallel. Upon 180° rotation, the footprints of NIRCam will almost fully overlap NIRISS coverage.
  [*b*] the 4-spoke design adopted in the Windhorst GTO program. [*c*] and [*d*] possible strategies to fully map the *JWST* NEP Time-Domain Field by replicating this 4-spoke pattern at either different orientations or different offset pointings.
- The actual orientation of these patterns on the sky will depend on the *JWST* launch date.

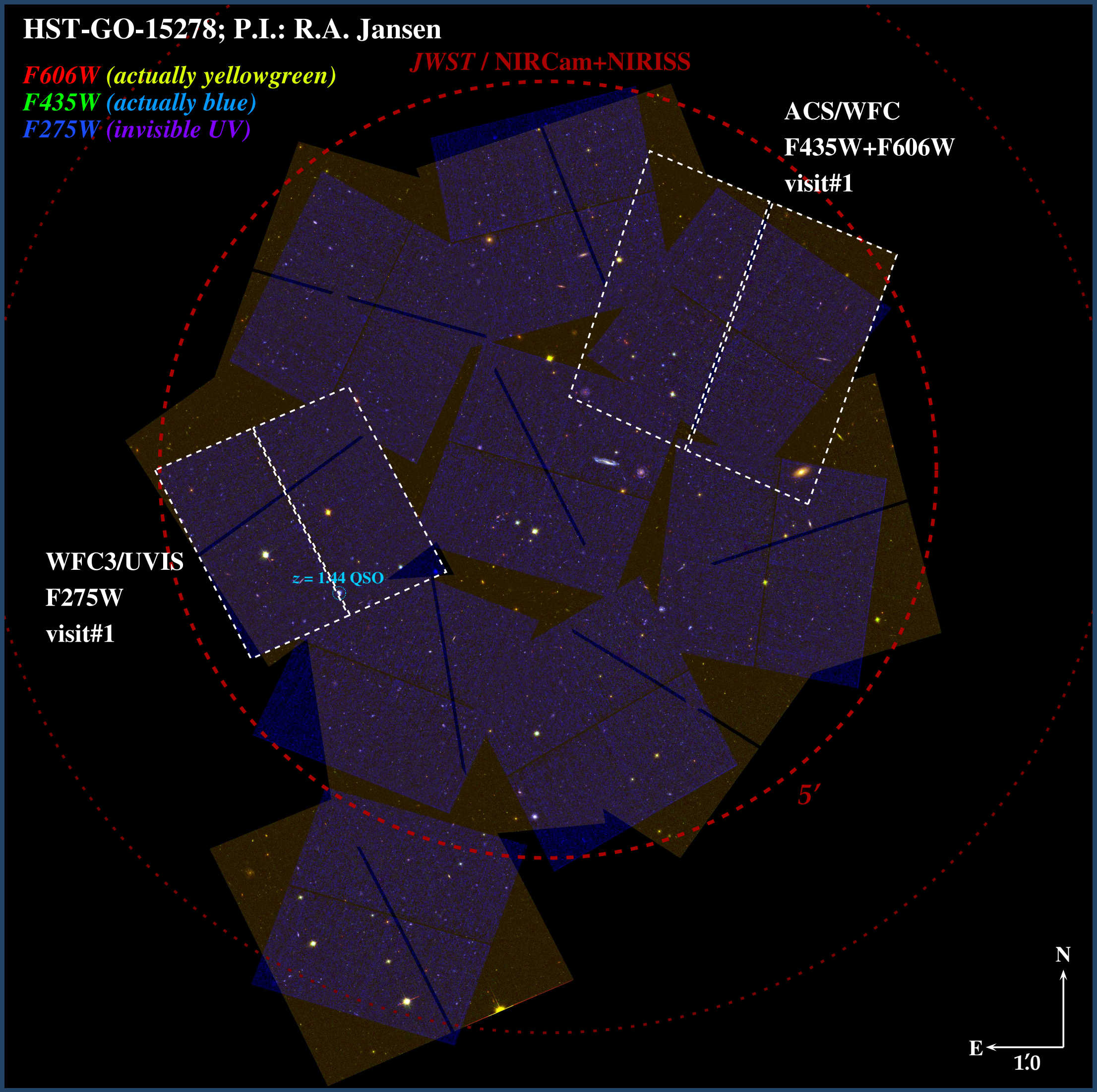
Ancillary Observations in the *JWST* NEP TDF: *Hubble*



- UV–Visible survey of the *JWST* NEP Time-Domain Field in 3 filters (WFC3/UVIS F275W [*UV*], ACS/WFC F435W [*blue*] and F606W [*yellowgreen light*]). The rosette of grey footprints indicates the extant coverage; colored ones are targeted in Cycle 29. The Cycle 25 (PI: Jansen) and Cycle 28+29 (PI: Jansen & Grogin) programs were awarded a total of 88 CVZ orbits, nominally spread over 22 separate visits.

R.A. Jansen

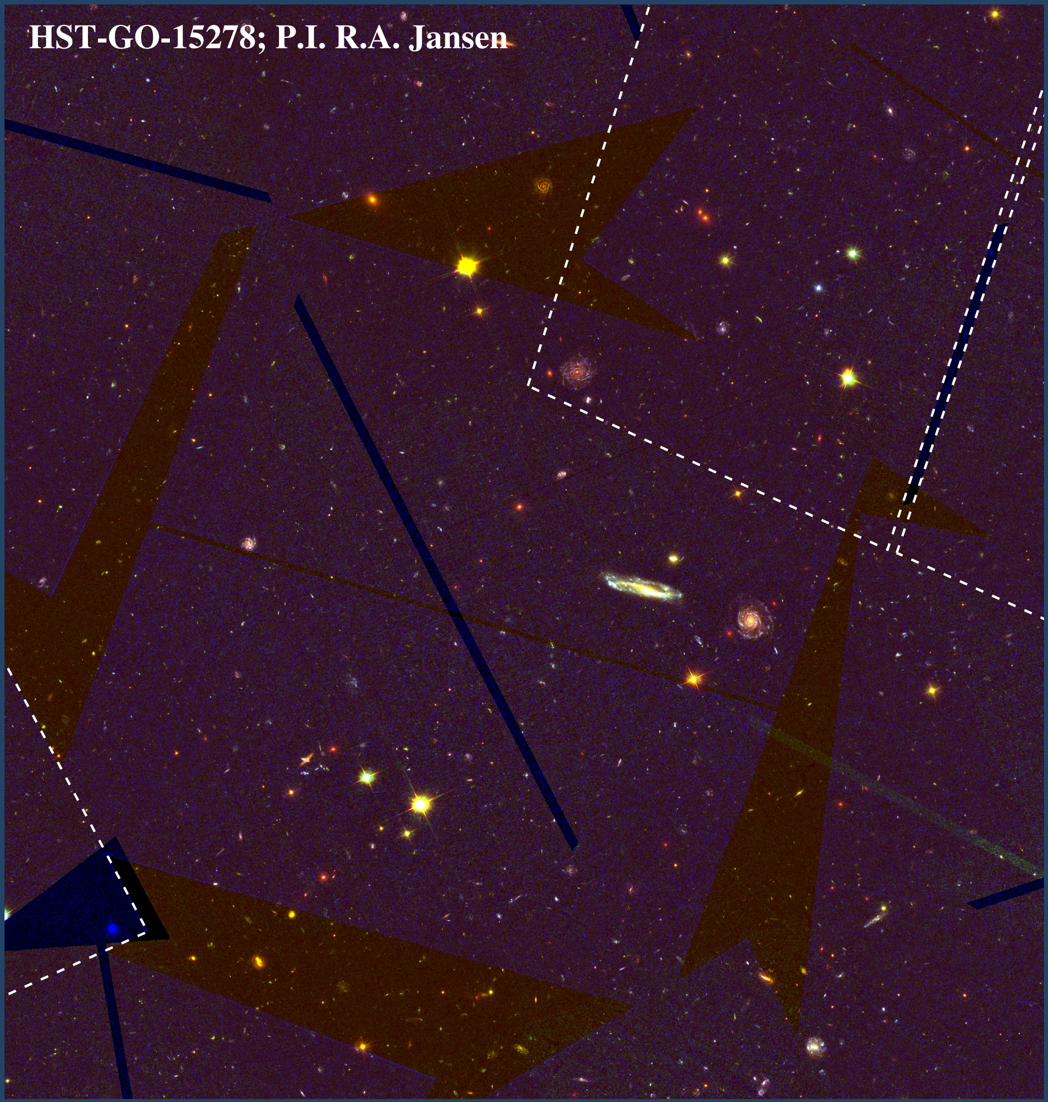
Ancillary Observations in the *JWST* NEP TDF: *Hubble*



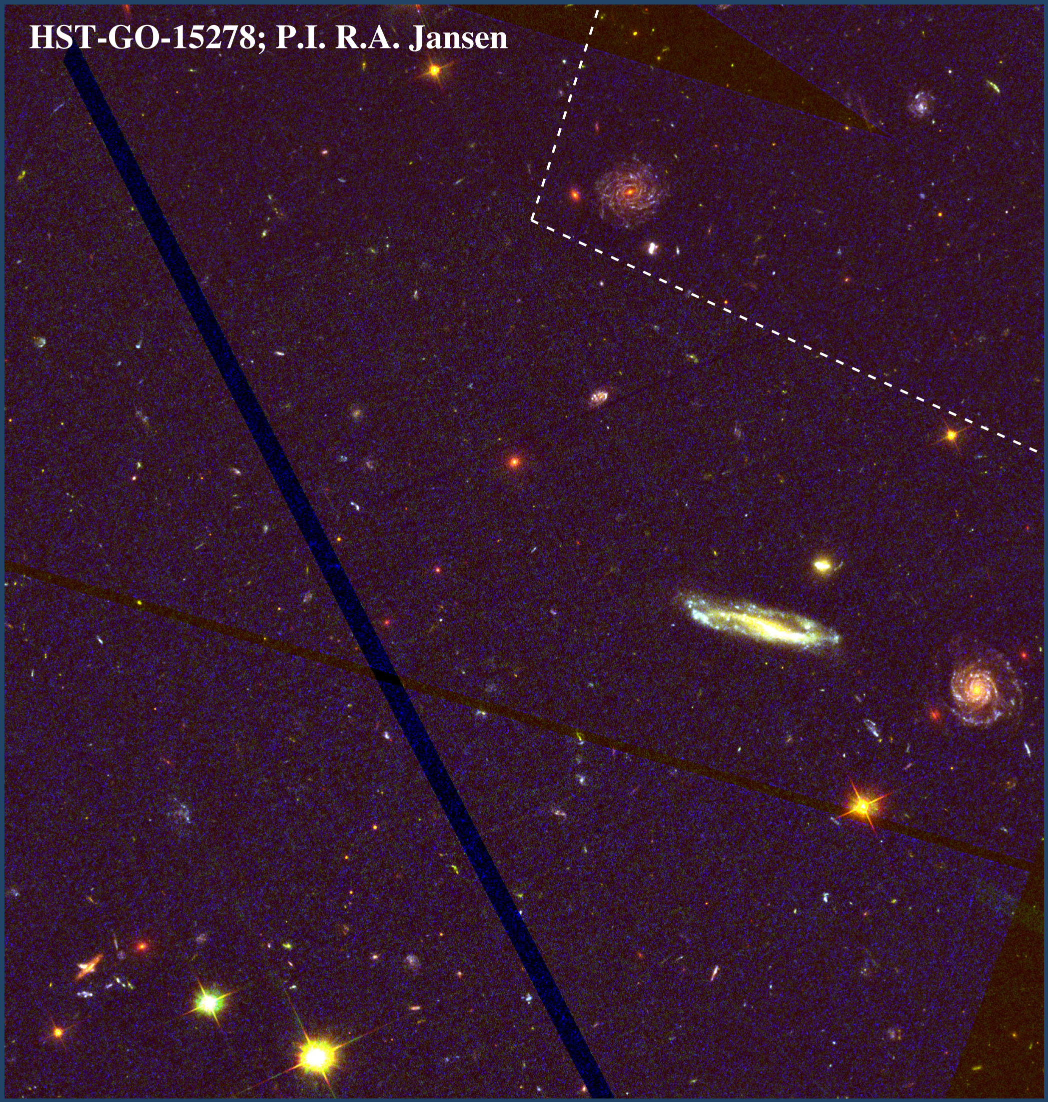
- Mosaic of the *Hubble* observations of Cycle 25. The dark red circle (radius = 5′) indicates where NIRCam and NIRISS GTO observations will overlap.
- Preliminary analyses resulted in Senior Theses by C. White (2019), V. Jones (2019), and S. Bechel (2020), and in ASU/NASA Space Grant presentations by T. Tyburczy (2019) and L. Nolan (2020, 2021).
- Detailed analysis by ASU graduate student R. O'Brien is in progress.

R.A. Jansen

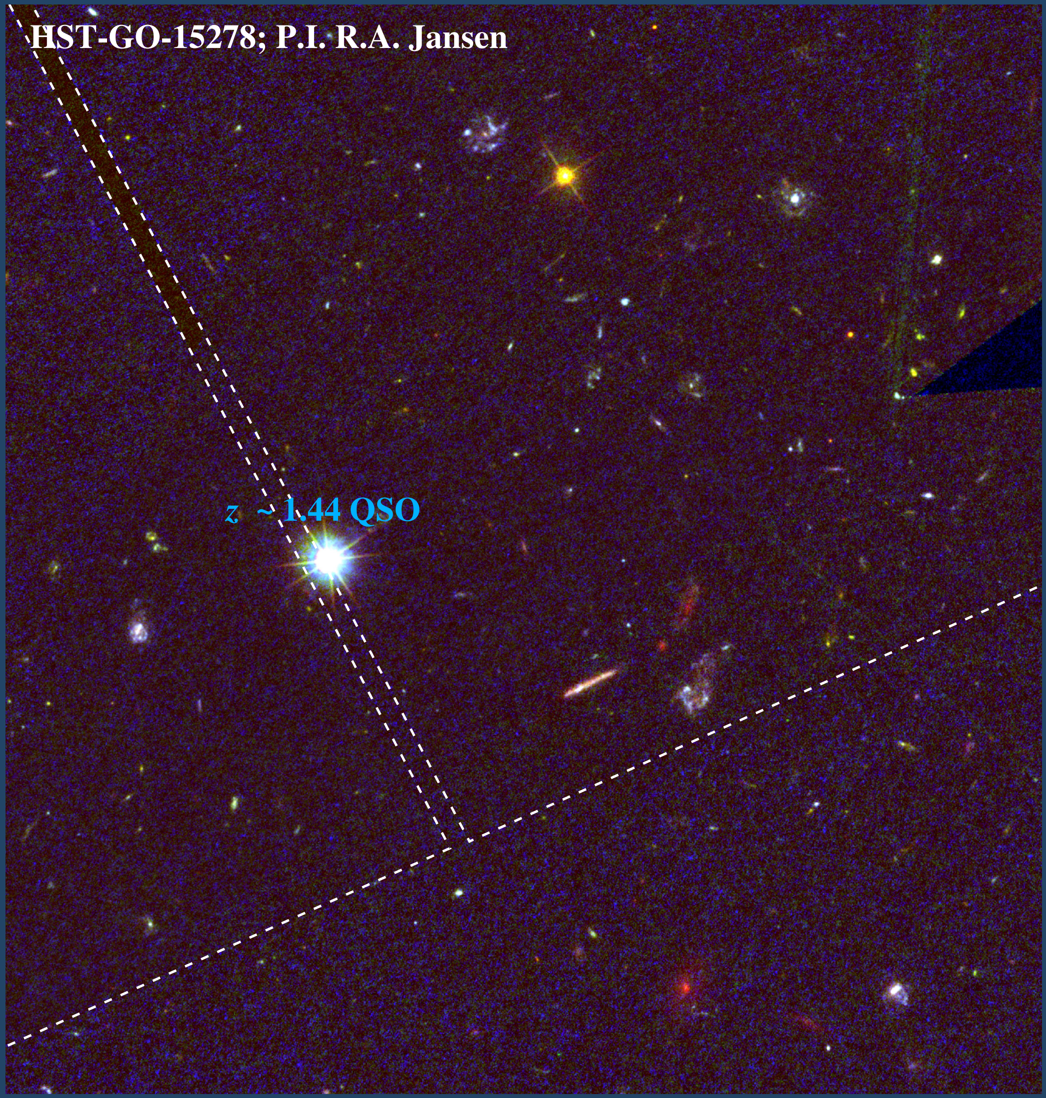
Ancillary Observations in the *JWST* NEP TDF: *Hubble*



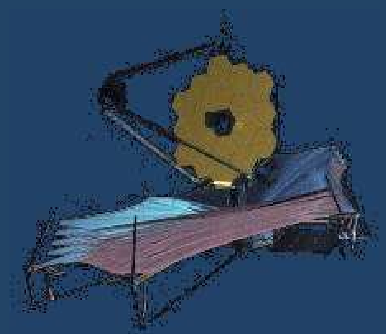
Ancillary Observations in the *JWST* NEP TDF: *Hubble*



Ancillary Observations in the *JWST* NEP TDF: *Hubble*



Take-home Message



- **Can *Webb* do ultra-deep time-domain survey science?**

  Yes... but only in a few very special locations in the sky.

- **The best field to do so is the *JWST* NEP Time-Domain Field**
  - ▷ **new *community field*, centered at: (RA, Dec)$_{J2000}$ = (17:22:47.896, +65:47:21.54)**
  - ▷ **field size: ∼14 arcmin diameter, or an area of 154 arcmin^2**
  - ▷ **ancillary data from radio through X-ray**
  - ▷ **first *Webb* observations at 4 orientations provided by IDS R. Windhorst in Year 1**

Are you moved by moving objects?
or are celestial beacons that vary in brightness more your style?

The JWST NEP Time-Domain Field is for you!