JWST Time-Domain Science through a Community Field

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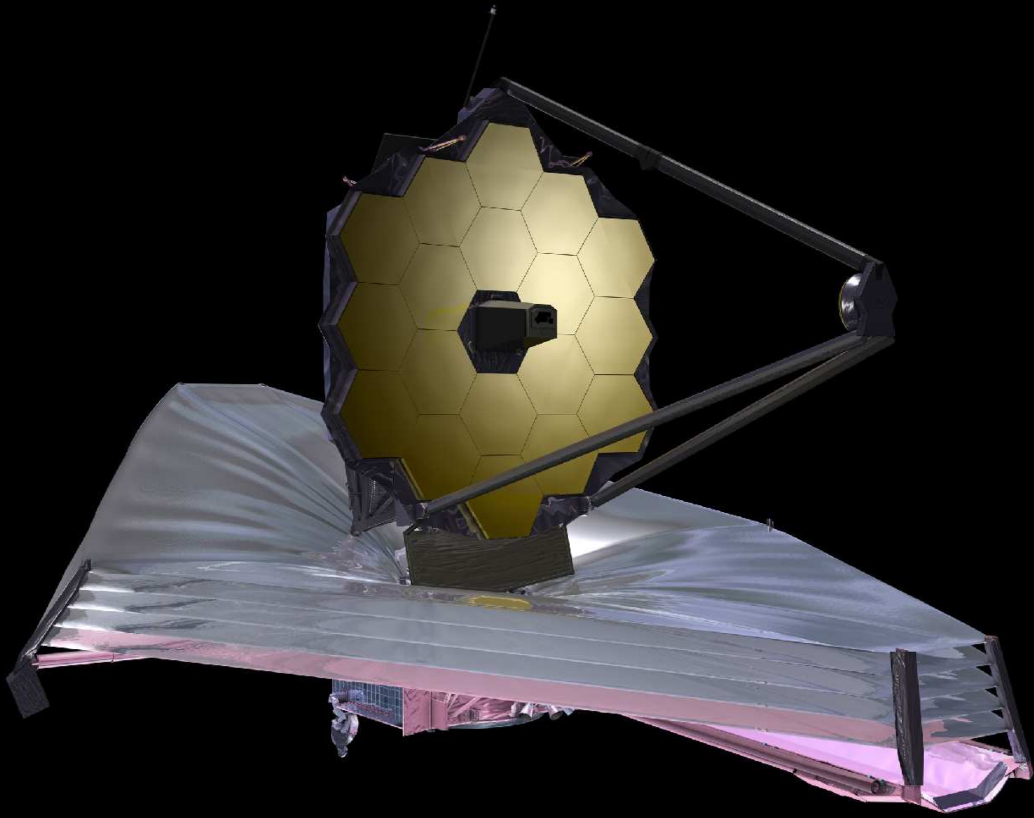
With strong support and/or GTO time contributions from other JWST IDS GTO's:

H. Hammel (AURA), J. Lunine (Cornell), & M. Stiavelli (STScI).



Presentation to the STScI Director; Tuesday August 2nd, 2016; Baltimore (MD)

Talk is on: `http://www.asu.edu/clas/hst/www/jwst/jwsttalks/JWST_NEP_communityfield16.pdf`

Outline & Conclusions

(1) JWST CVZ at the North (NEP) & South Ecliptic Pole (SEP).

(2) NIRCam + NIRISS-parallels can optimally cover the best NEP field.

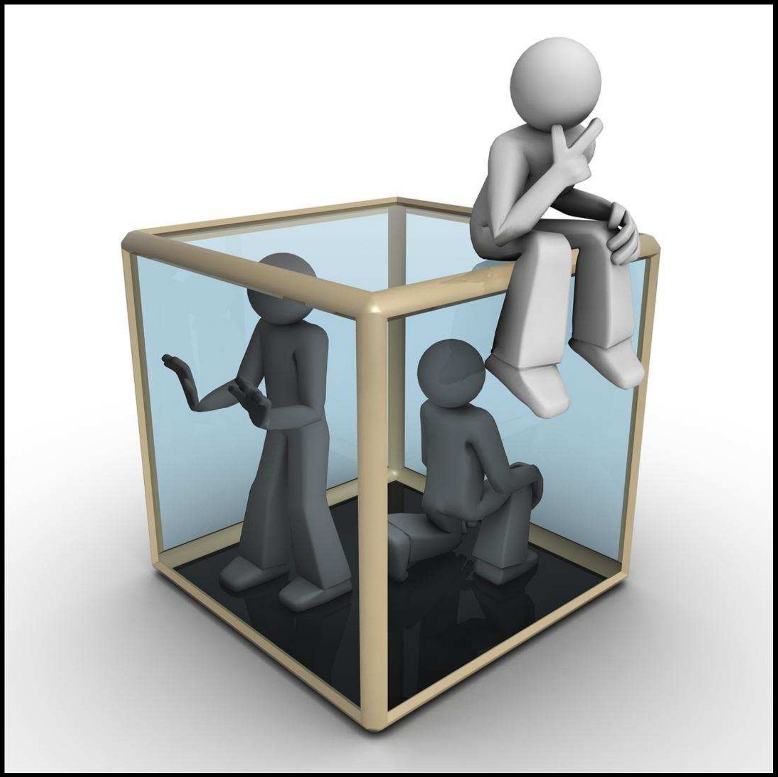
(3) Unique new JWST Time-Domain Science possible in the NEP CVZ:

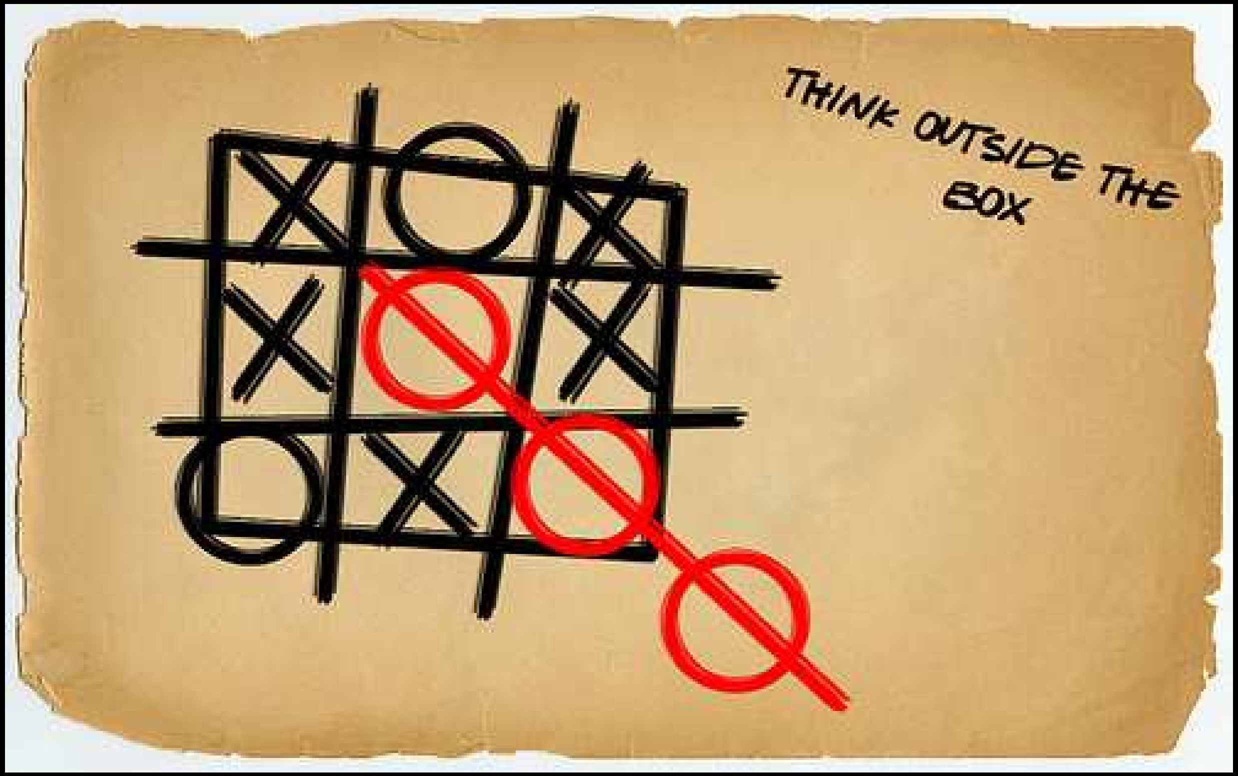
- Parallaxes (Oort Cloud Objects at high Ecliptic Latitude);
- Proper Motions (Brown Dwarfs: Galactic structure, variability);
- Weak AGN Variability (*e.g.*, for escaping LyC studies), and:
- Very high redshift supernovae incl Pair Instability Supernovae (PISN).
- (Dark-sky benefit of the NEP CVZ): CIB-fluctuations constrain First Light sources: Primordial & Direct-Collapse Black-Holes.

- We propose to make the best NEP field a JWST Community Field for Time-Domain Science over 5–14 years (max JWST propellant life).

- If there is enough community interest, we will invest up to half my GTO time in 4 epochs over 1–2 years, and make it (plus all its data products) public immediately, *triggering significant GO community efforts*.

(1) JWST Continuous Viewing Zones (CVZs): North & South Ecliptic Poles.





This JWST Community Project will require Out-of-the-Box thinking — Nothing about it is standard!

The JWST North Ecliptic Pole (NEP) CVZ Community Field will provide:

- Unique Time-Domain science throughout the JWST mission.
- Get critical JWST pilot data *very early* to the GO community.
- Calibration ground-truth for WFIRST & Euclid's NEP fields (incl ZPs$\lesssim$1%).

What we are asking:

(1) The JWST NEP CVZ field is not a viable community field without the essential HST data: Please advise how to best assure that these will exist.

- No-one has targeted this best JWST CVZ field in the NEP from space.

- We already asked for Spitzer time, and have collaborators keen to propose for Chandra, XMM and VLA+LOFAR time.

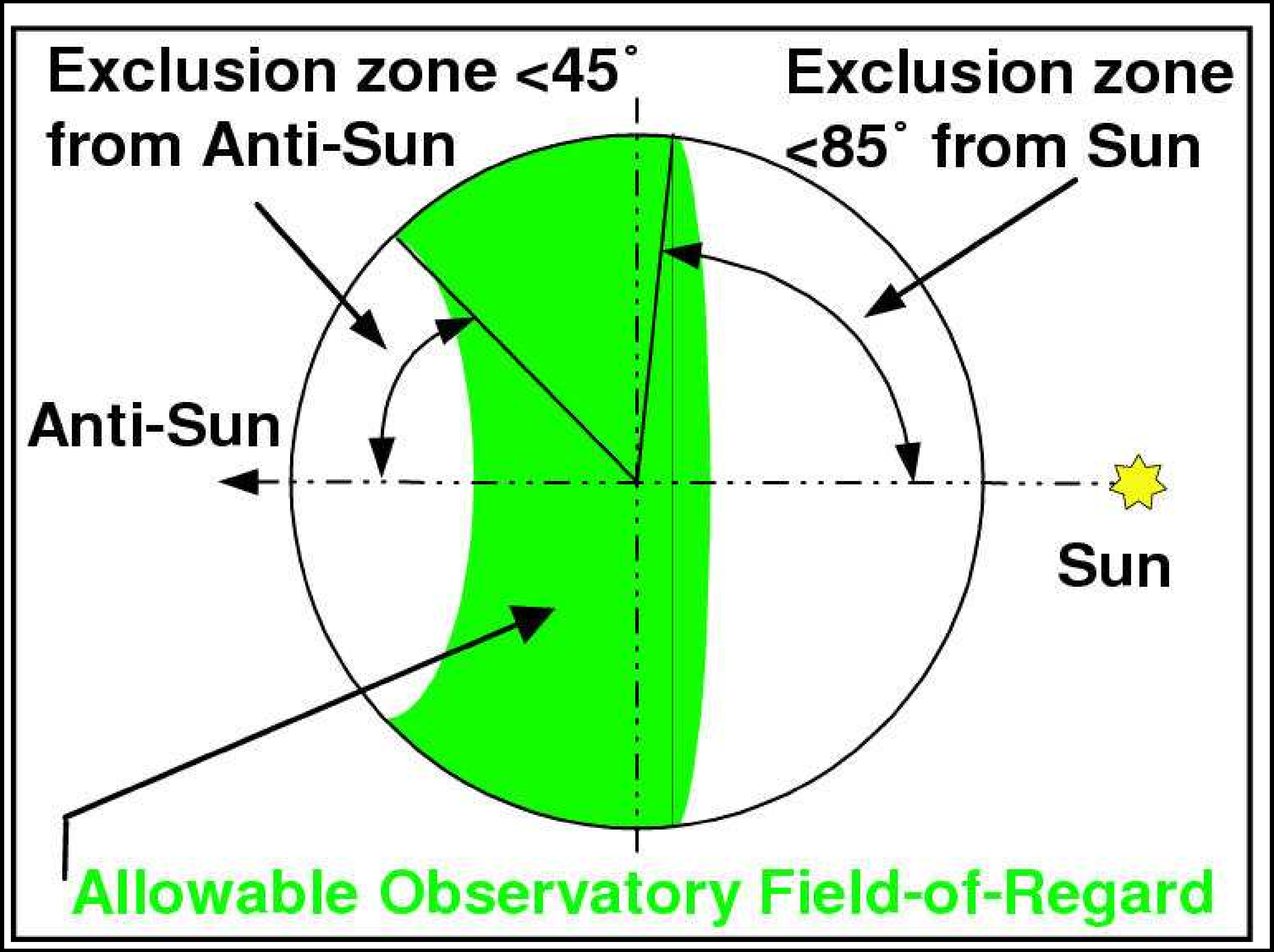
- We will ask for SOFIA/HAWC time, which from 50–250 μm is about as sensitive as Herschel.

- Plateau de Bure/NOEMA can do mm-wavelengths in the North. NRAO plans to upgrade JVLA with an ALMA-like inner-core this next decade.

- A JWST Community Field must use JWST unique strengths!

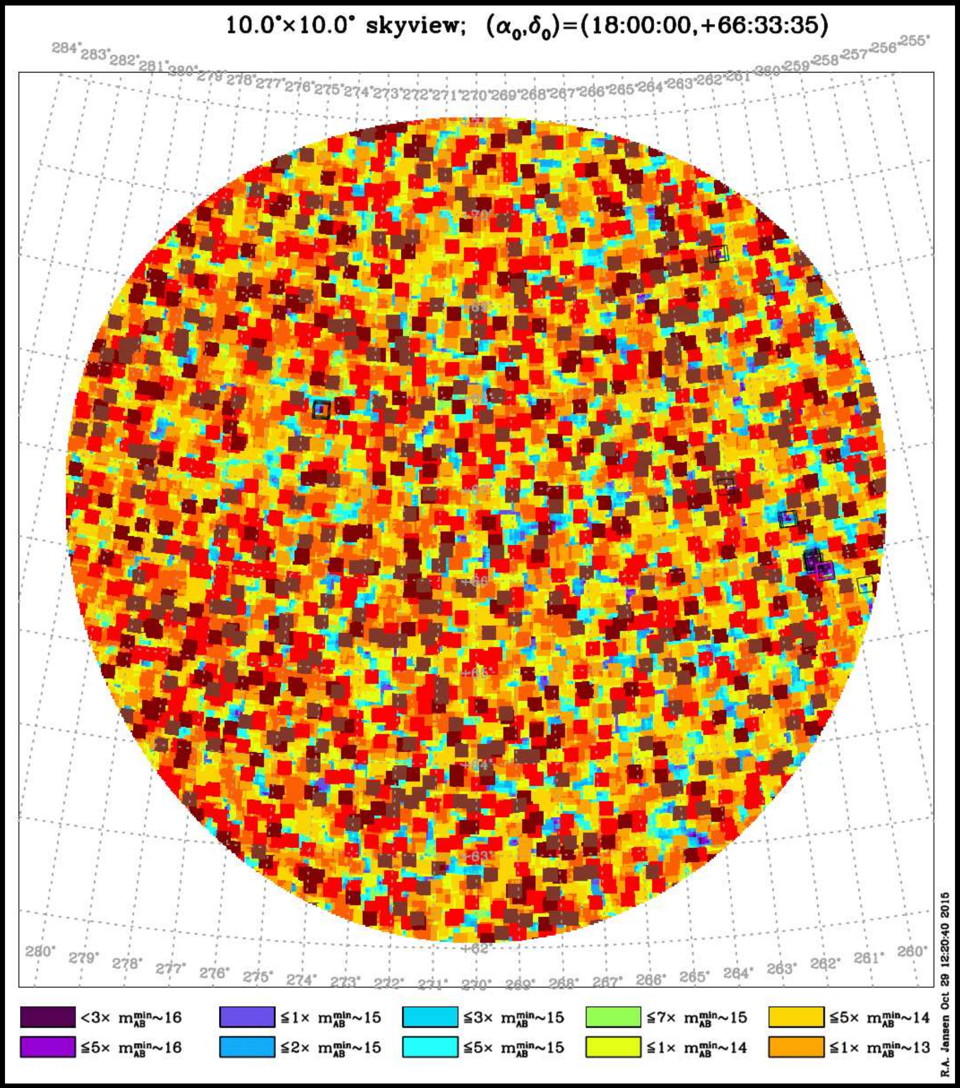
(2) If the JWST NEP CVZ becomes a community field, please allow GOs explicitly to build on it through ERS & GO proposals starting in Cycle 1!

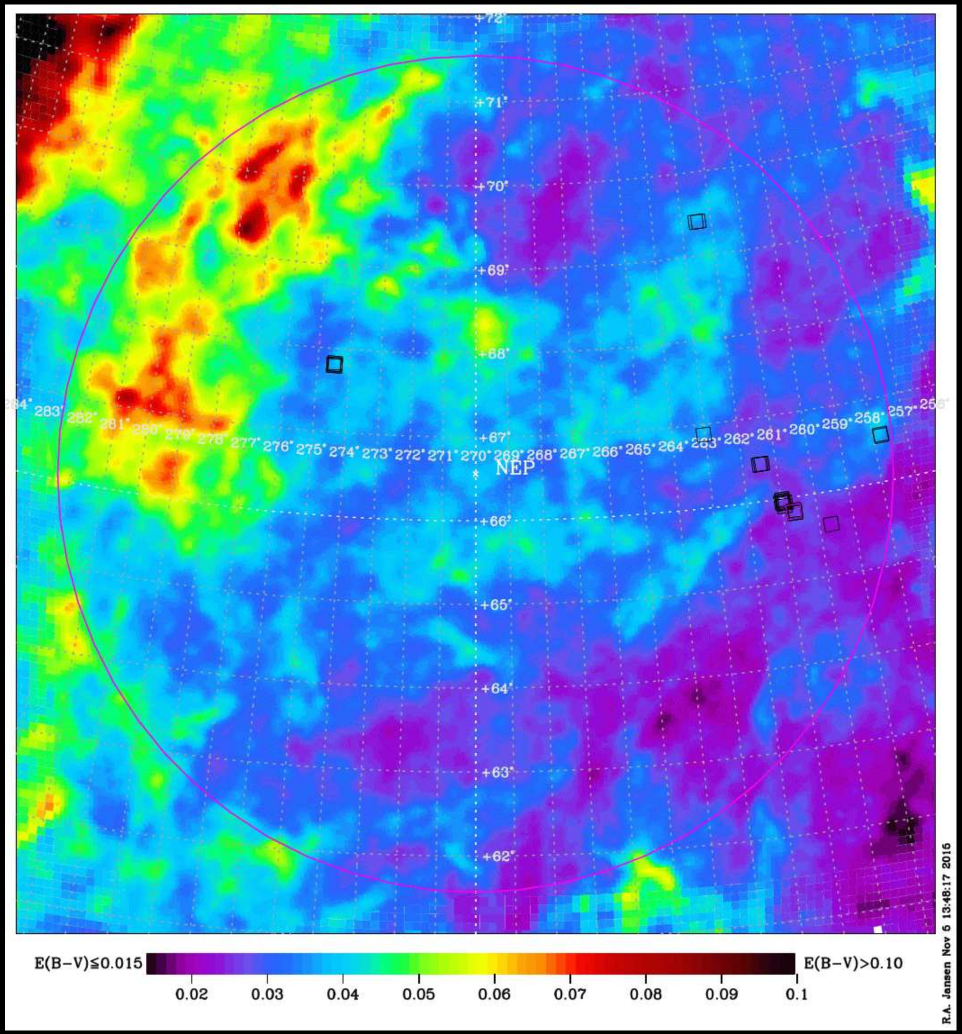
(1) JWST Continuous Viewing Zones (CVZs): North & South Ecliptic Poles.



Accessible by JWST 365 days/yr: *only* the NEP & SEP CVZ (r$\lesssim$5°):

- LMC covers the SEP; NEP has good regions for far-extragalactic science.
- NEP great for parallax, proper motions, high redshift variability, etc.

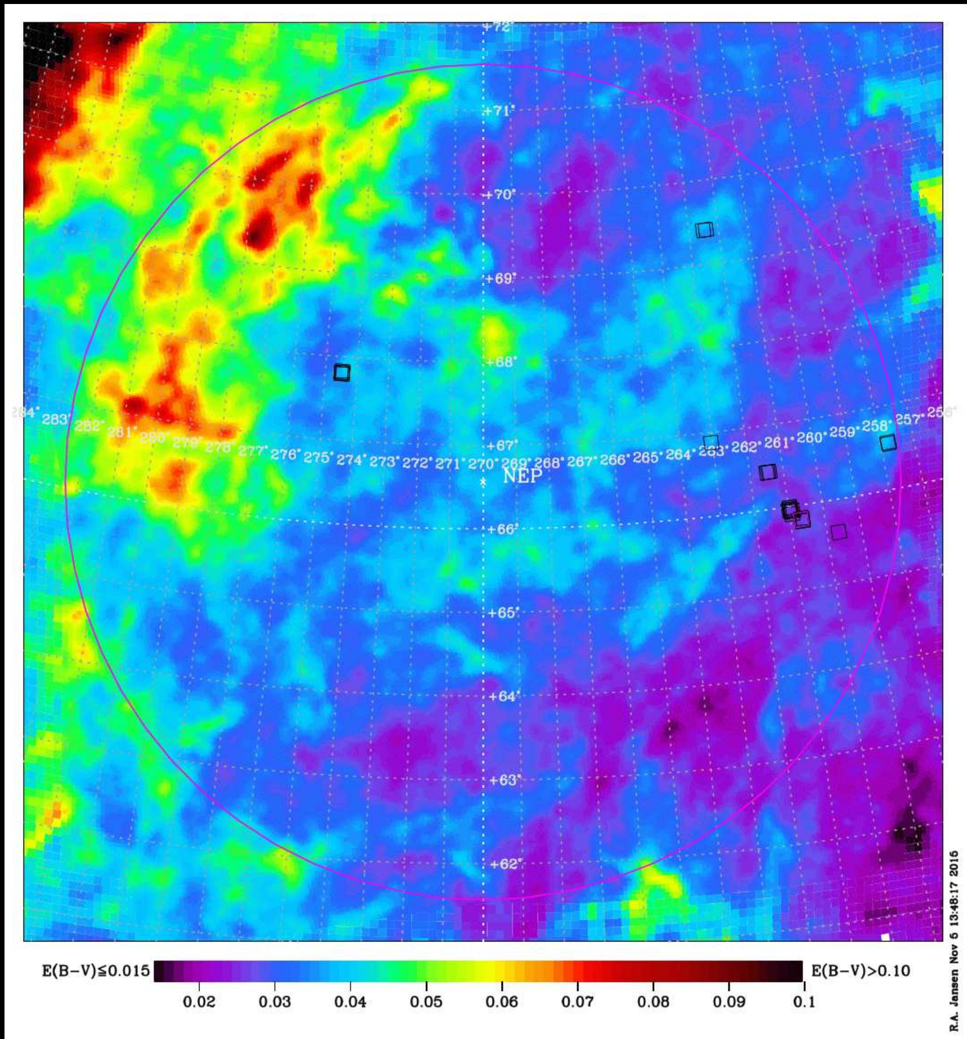


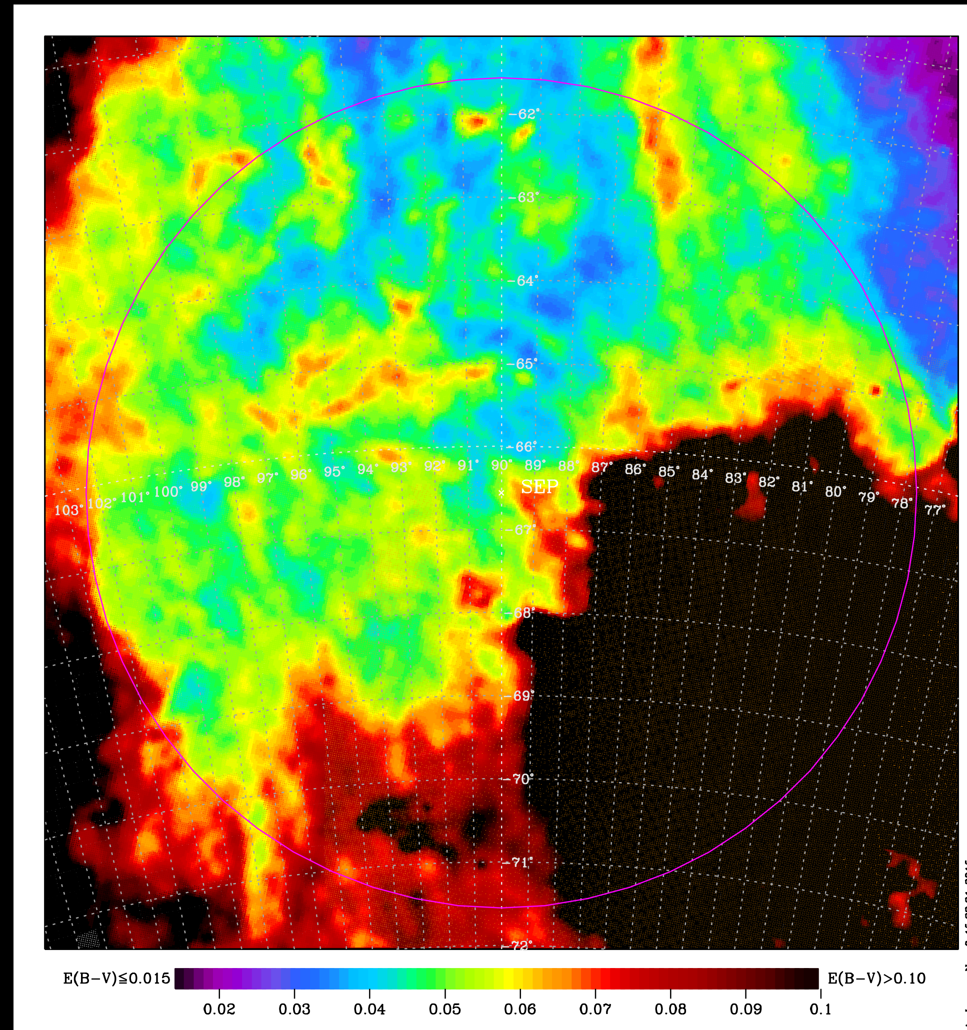


[LEFT]: *WISE* 4μm bright-object penalties in 10′ grid: Very few regions (purple) exist *without bright stars* (AB$\lesssim$16) to minimize persistence.

[RIGHT]: *E(B−V)* map (Schlegel et al. 1998) in same NEP-region.

Cleanest 10×10′ region for JWST has modest extinction: *E(B−V)*$\lesssim 0.028^m$.

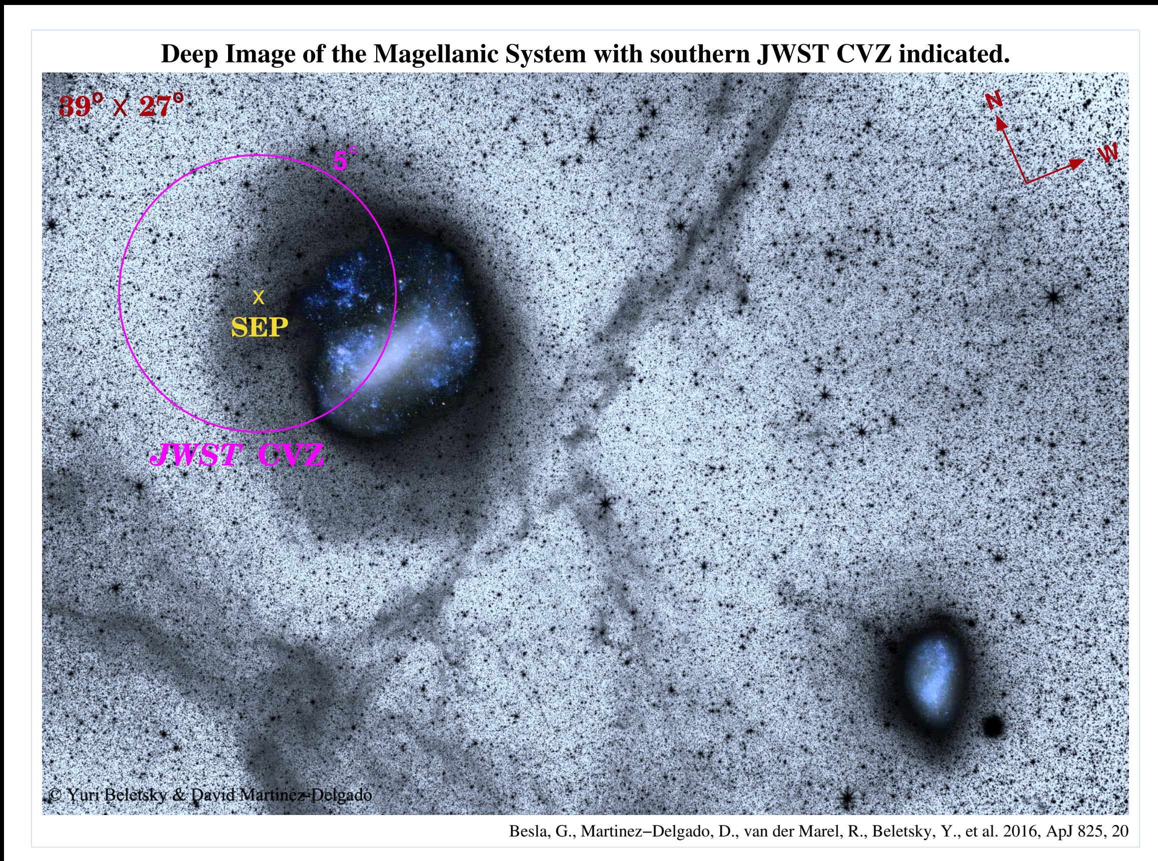


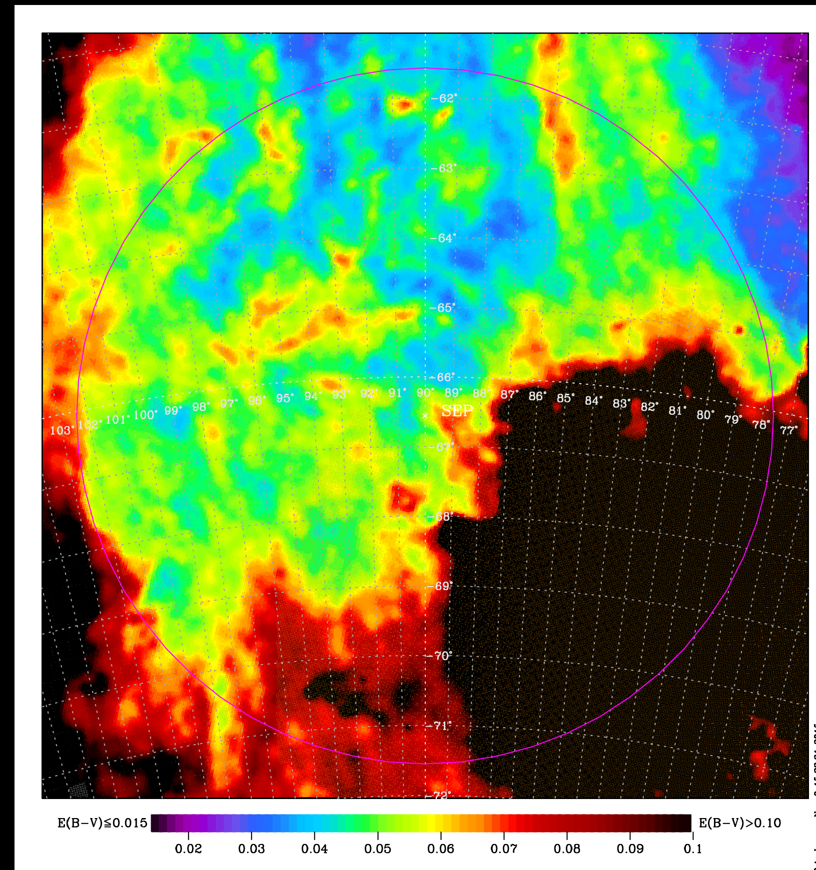


Comparison of *E(B−V)*-maps of NEP [Left] and SEP [Right].

- NEP contains clean $10 \times 10'$ region: no AB$\lesssim$16 stars, *E(B−V)*$\lesssim 0.028^m$.
- SEP contains no clean, bright-star free regions with r$\lesssim 5^\circ$ due to LMC.

Only NEP CVZ can be used for (far-extragalactic) time-domain science.



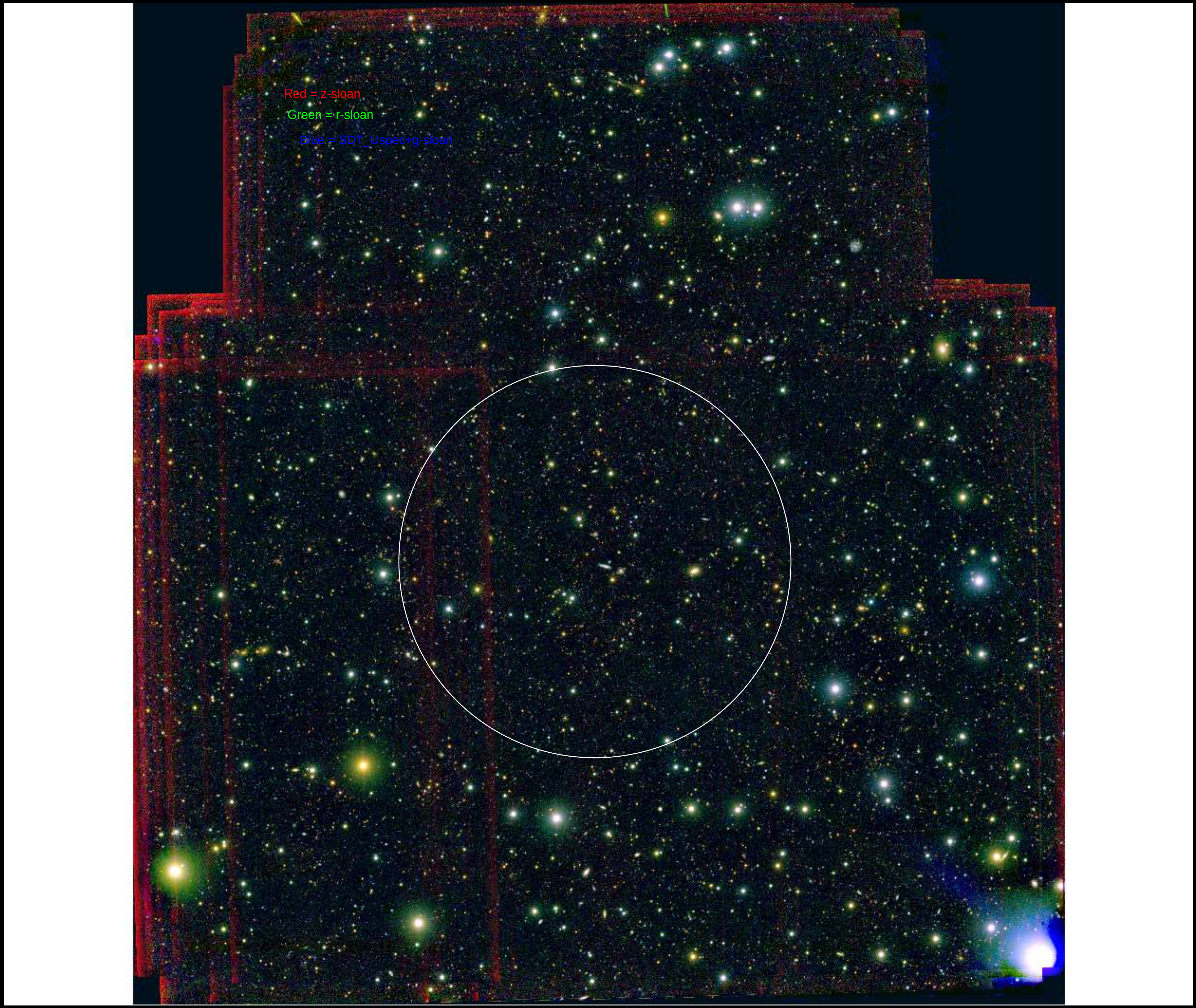


[LEFT] Map of LMC+SMC and spurs (Besla et al. 2016, ApJ, 825, 20).

[RIGHT]: *E(B−V)* map (Schlegel et al. 1998) in SEP-region.

- SEP will be perfect for CVZ studies of LMC+outskirts (bottom of IMF!).

- SEP/LMC can serve as counter-target for NEP surveys: offsets accumulated angular momentum, and so help save JWST propellant/lifetime!

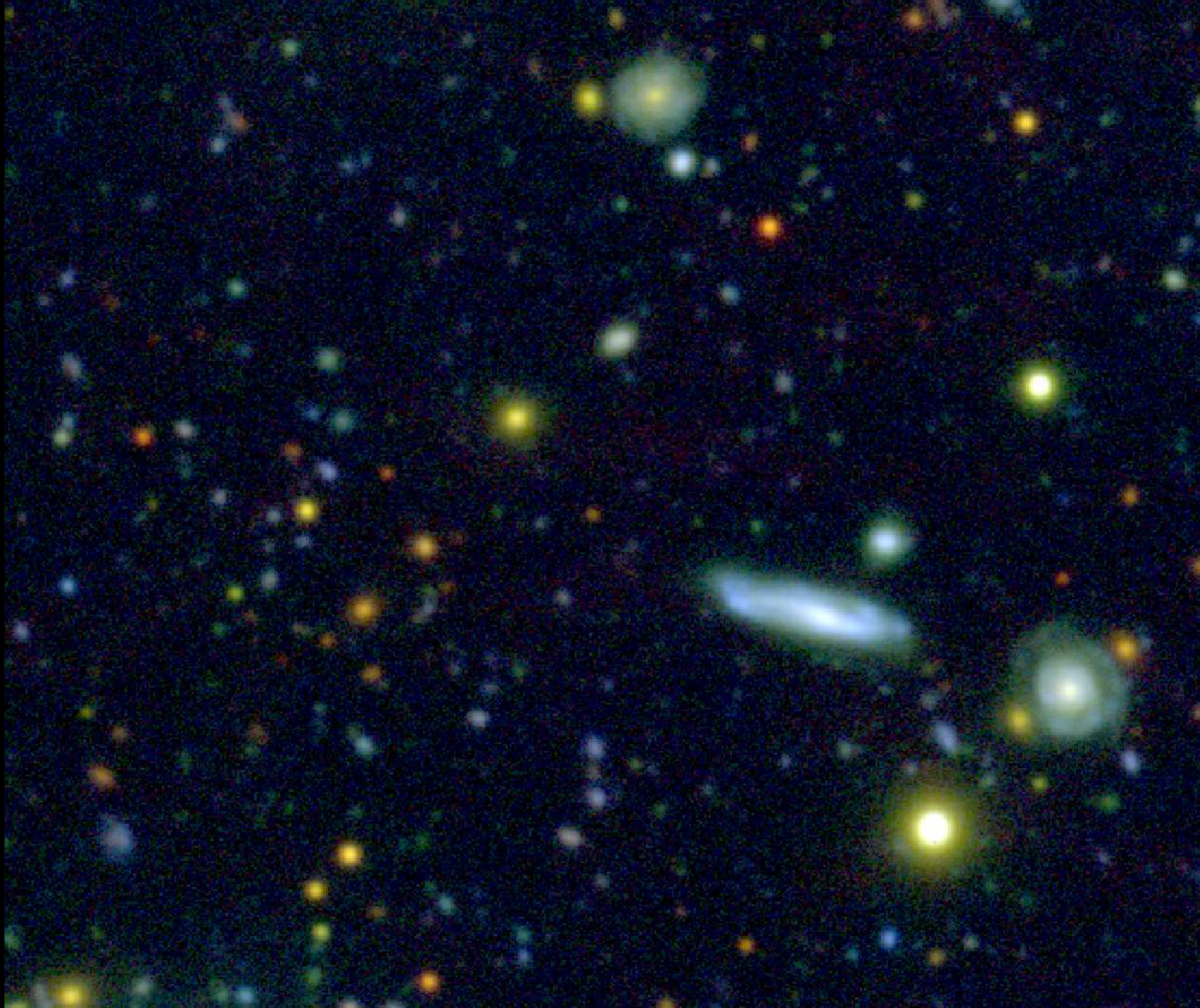


$23' \times 27'$ 3-hr $\boldsymbol{Ugrz}$ mosaic with twin-8m LBT/LBC (July 6, 2016):

- Intended r=$5'$ JWST NEP CVZ field indeed free of bright (AB$\lesssim$16) stars.

r=5′ JWST NEP CVZ field is a normal, clean extragalactic survey field!

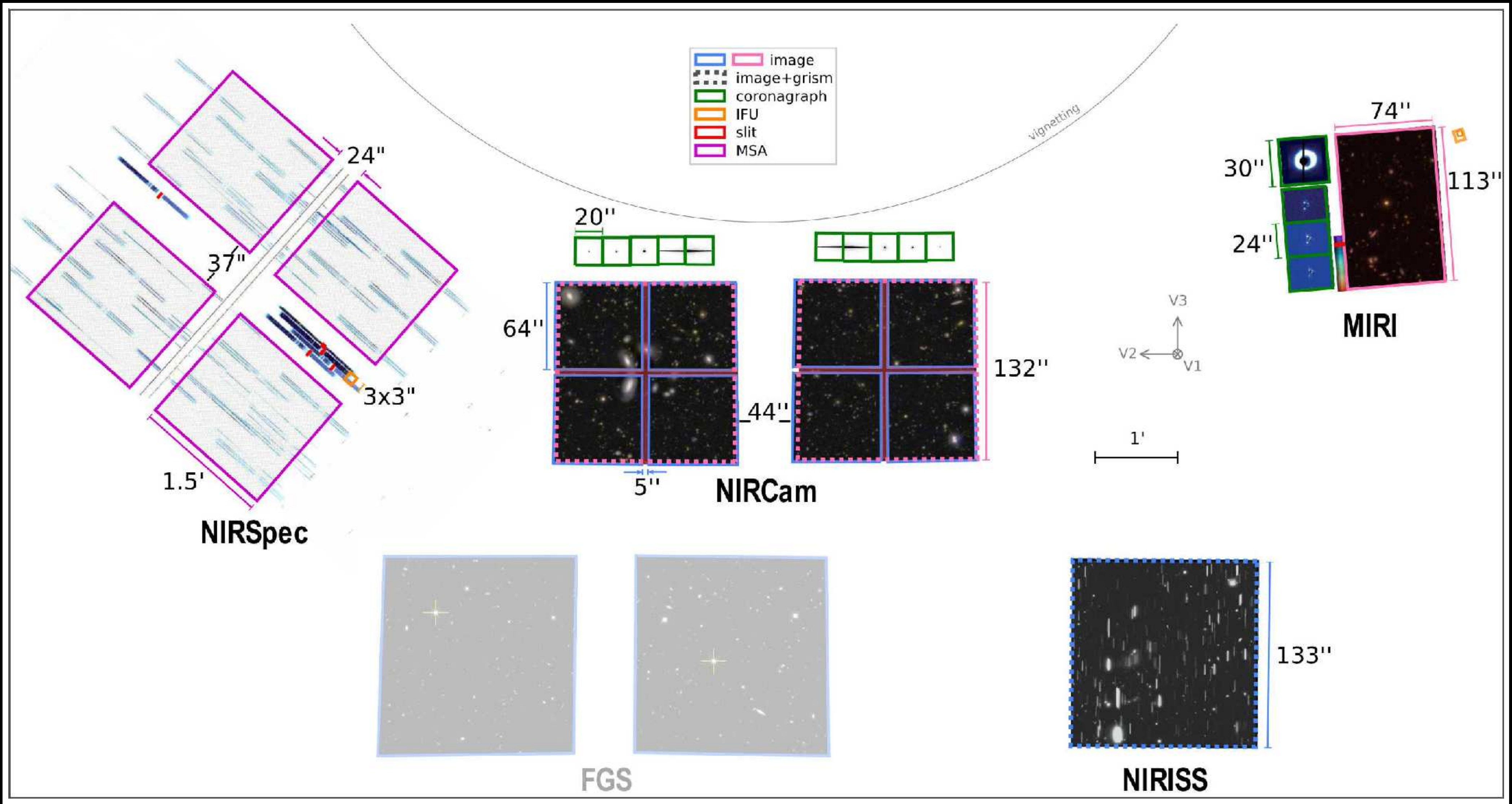
JWST NEP CVZ has plenty of faint blue galaxies and foreground ellipticals.



To AB$\lesssim$26 mag, see also faint Galactic brown dwarfs and high-z dropouts.

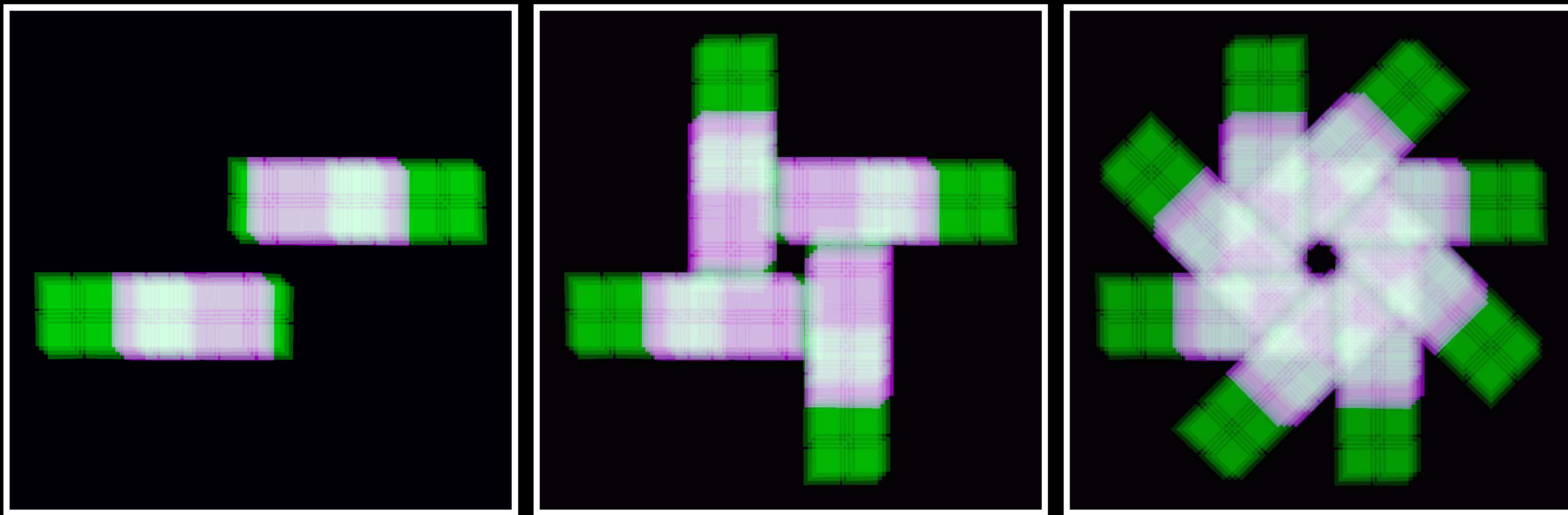
Best LBT U-band PSF has $0''.8$ FWHM: Can never replace HST resolution!

(2) NIRCam + NIRISS-parallels optimally cover the best NEP CVZ field.



- As of FY16, JWST instruments can be used for science parallels.
- Currently being implemented for most-used JWST instrument pairs.
- CVZ enables well-overlapping *dark-sky* NIRCam+NIRISS-parallel mosaics.

Exposure Maps of NEP JWST-Windmill & GO-Extensions:



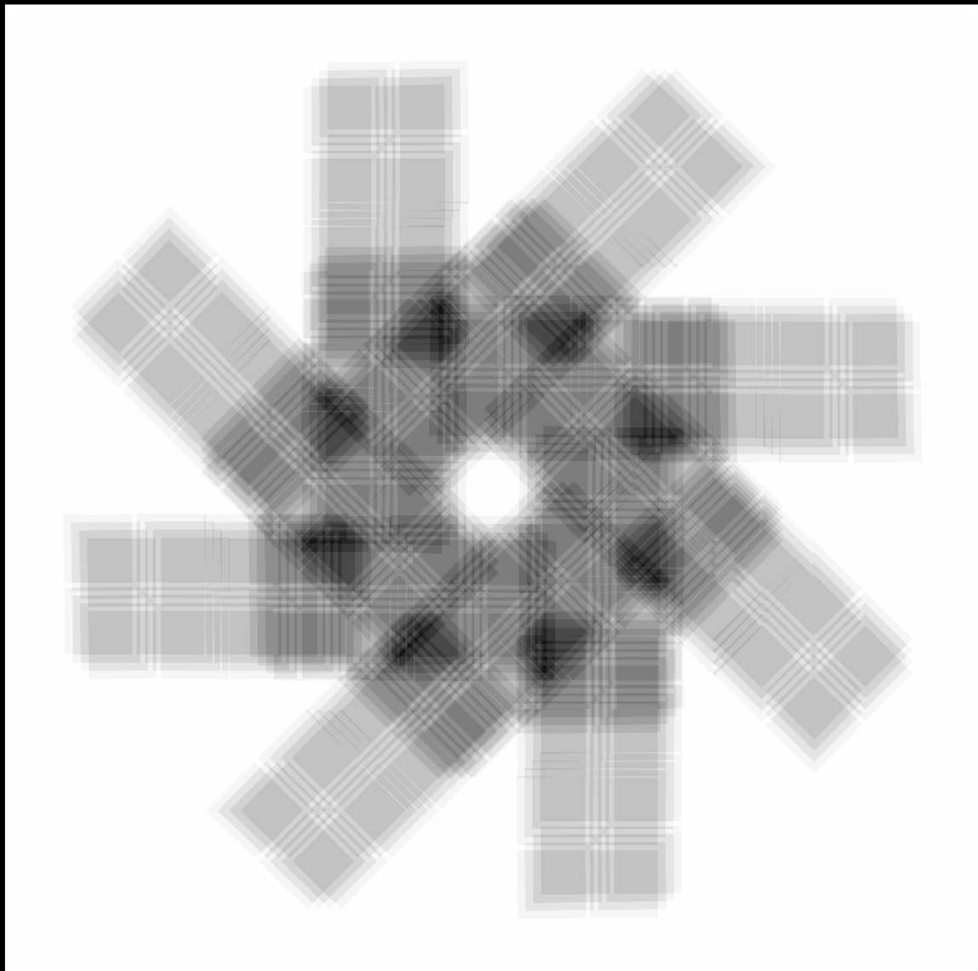
[LEFT]: Parallel NIRISS R150C+R150R grism spectra (purple) observed at ΔPA=0+180°, overlayed on primary NIRCam images (green).

[MIDDLE]: Same with ΔPA=90+270° added: This is our 50-hr GTO plan.

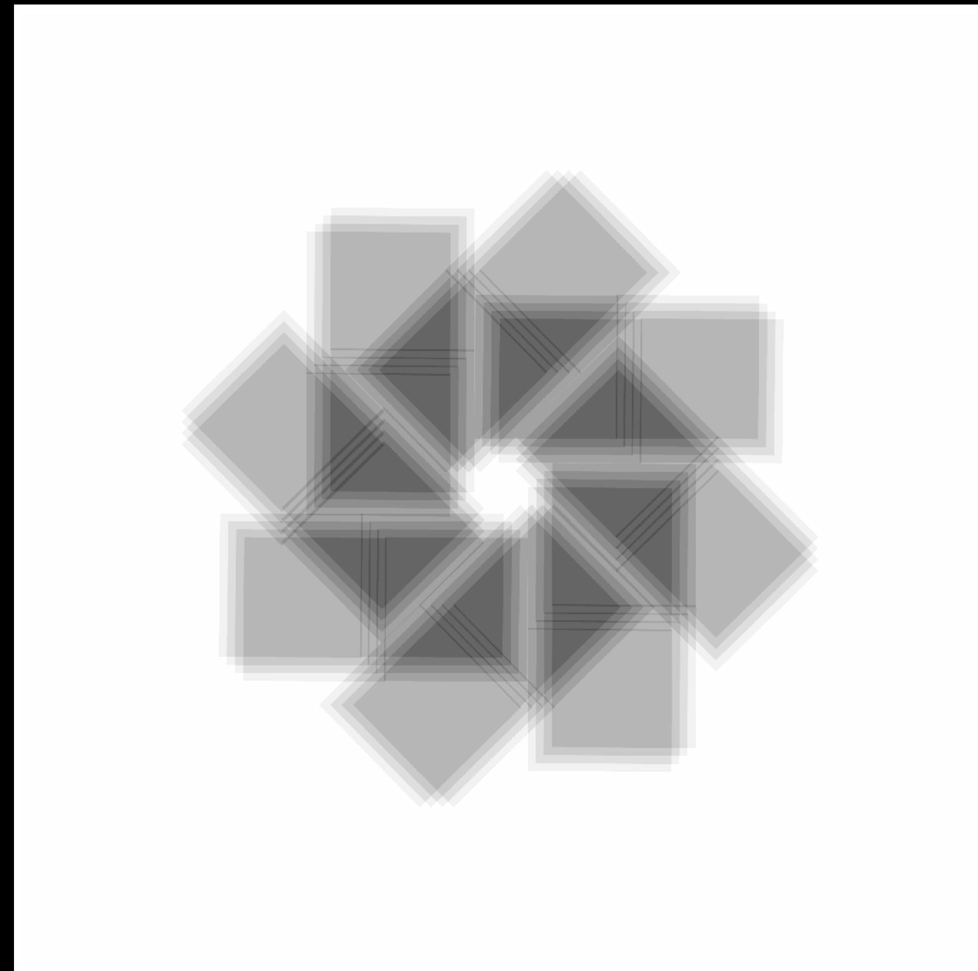
[RIGHT]: Anticipated GO-Community extensions in JWST Cycle $\gtrsim$1.

White regions: NIRCam exposures overlap, reaching $\lesssim$0.75 mag deeper.

- GO's can repeat NIRCam primaries+NIRISS parallels as often as needed during JWST's 5–14 year lifetime at ANY PA!



NIRCam+NIRISS Windmills combined



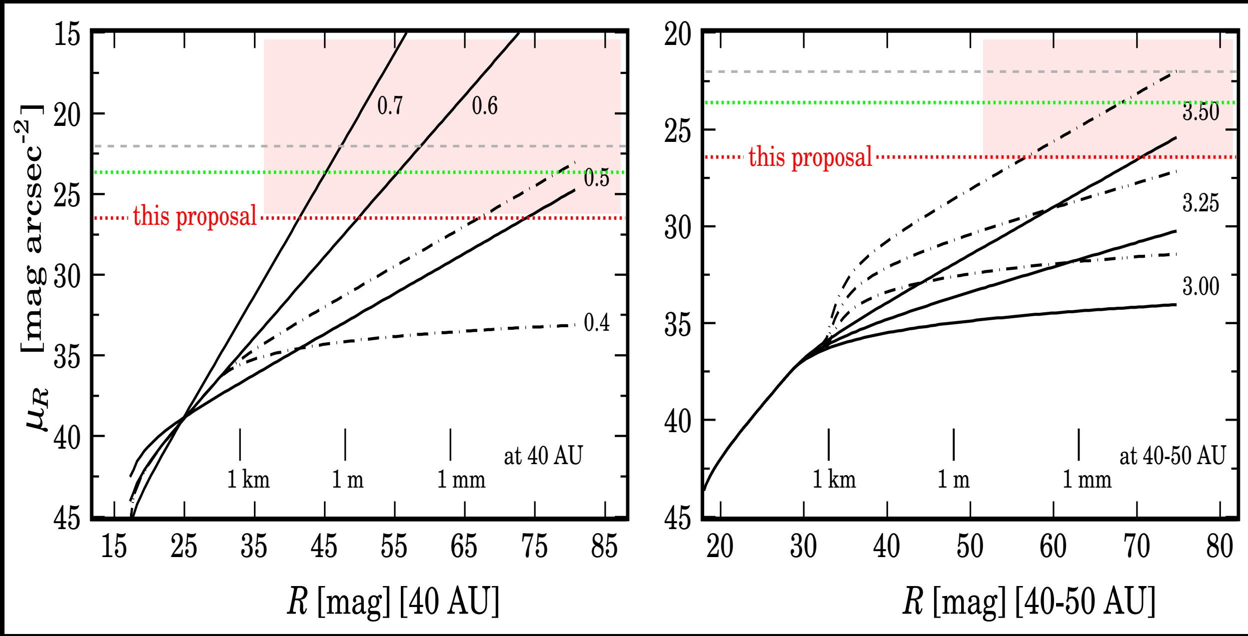
NIRISS-parallel Windmill alone

Exposure map of a community-driven GO extension of the JWST-Windmill adds, e.g., relative position angles ΔPA=45, 135, 225, and 315°.

Increases area by $\sim$60%, provides new epochs, and go $\lesssim$0.75 mag deeper.

- NIRISS parallel grism spectra increase the number of PA's grism angles to robustly disentangle overlapping object spectra to AB$\lesssim$27.5–28 mag.

(3) Unique new JWST Parallax Science possible in the NEP CVZ:



Integrated sky-SB vs. R-mag for KBO's at 40–50 AU (Kenyon & Windhorst 2001).

Models with count-slopes $\alpha \gtrsim 0.55$ (size slopes $\gtrsim \mathrm{D}^{-3.5}$) are ruled out.

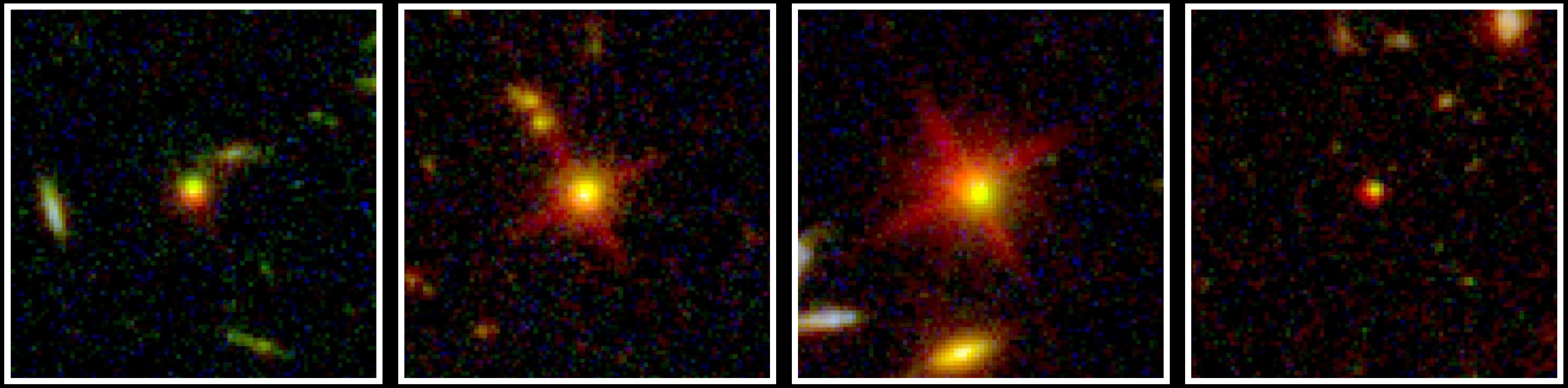
Tick-marks are KBO-sizes at ∼45 AU, assuming Albedo∼0.04.

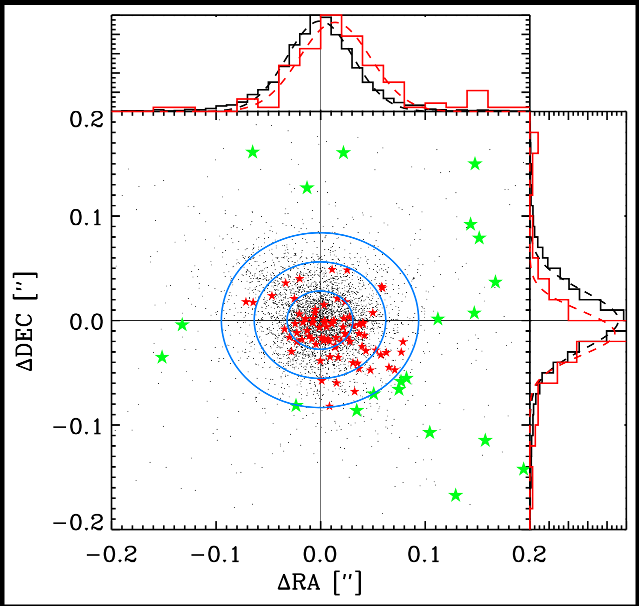
The JWST NEP CVZ field will detect & monitor:

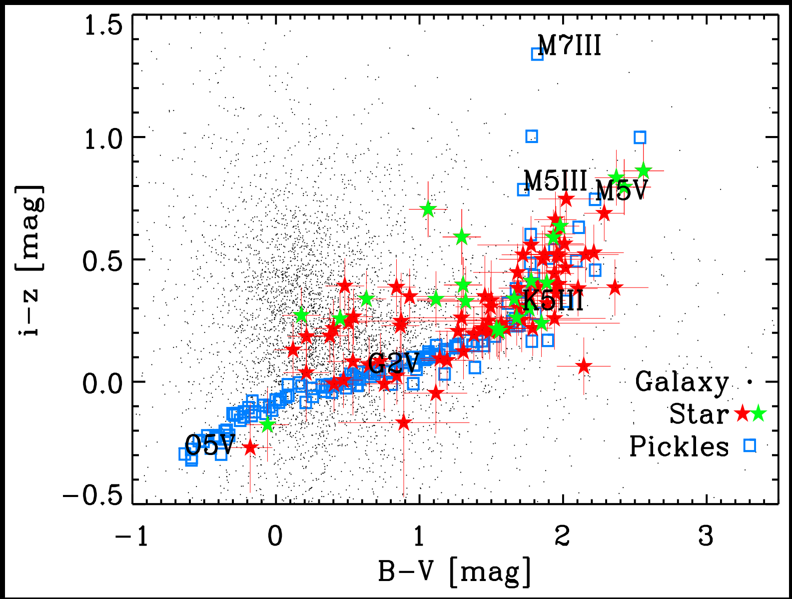
- Scattered KBO's/Oort Cloud Objects (OCO's) to AB$\lesssim$29–30 mag.
- KBO's/OCO's with parallaxes $\pi \lesssim 300''$ /yr (distances $\gtrsim$700 AU).
- D$\simeq$3 km diameter objects to 40 AU, D$\simeq$30 km to 400 AU, etc.

- It will require non-standard processing to detect all moving OCO's!

(3) Unique new JWST Proper-Motion Science possible in the NEP CVZ:



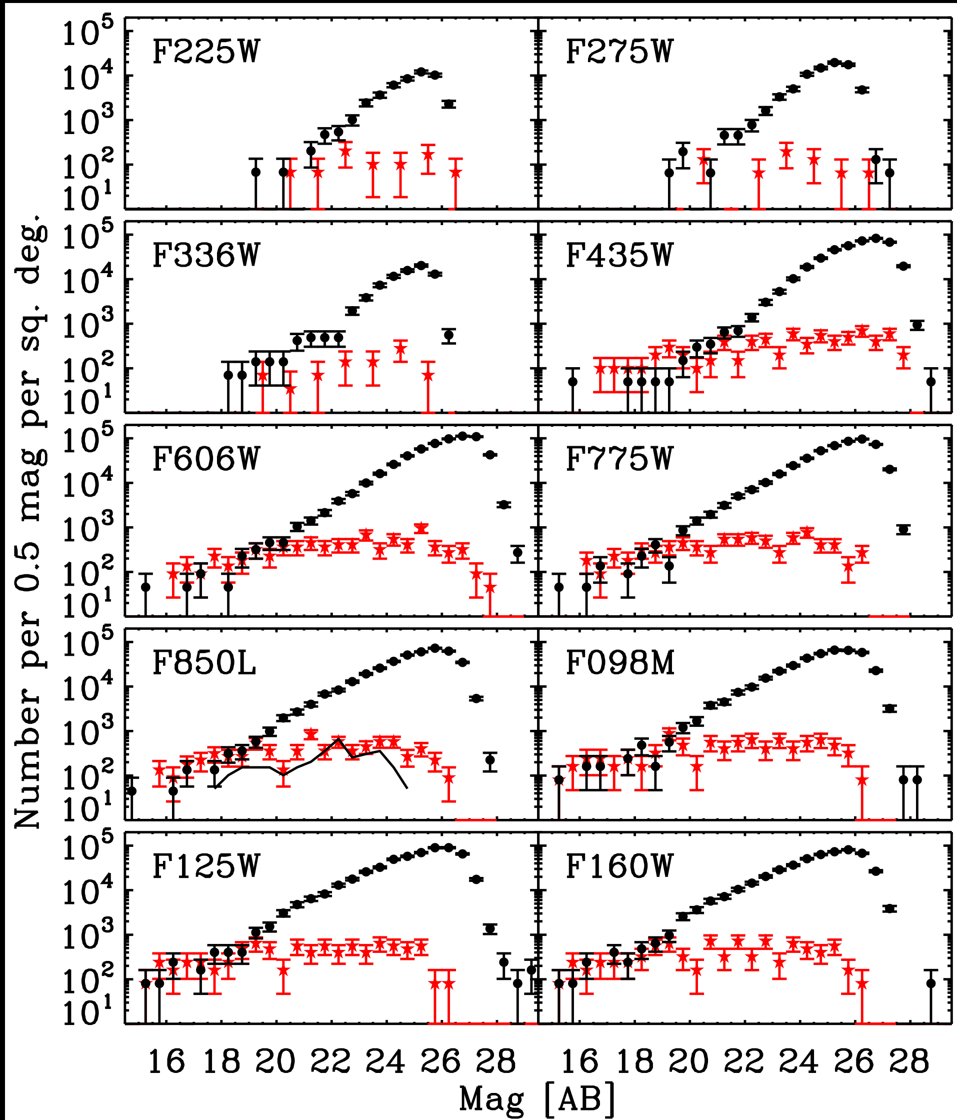


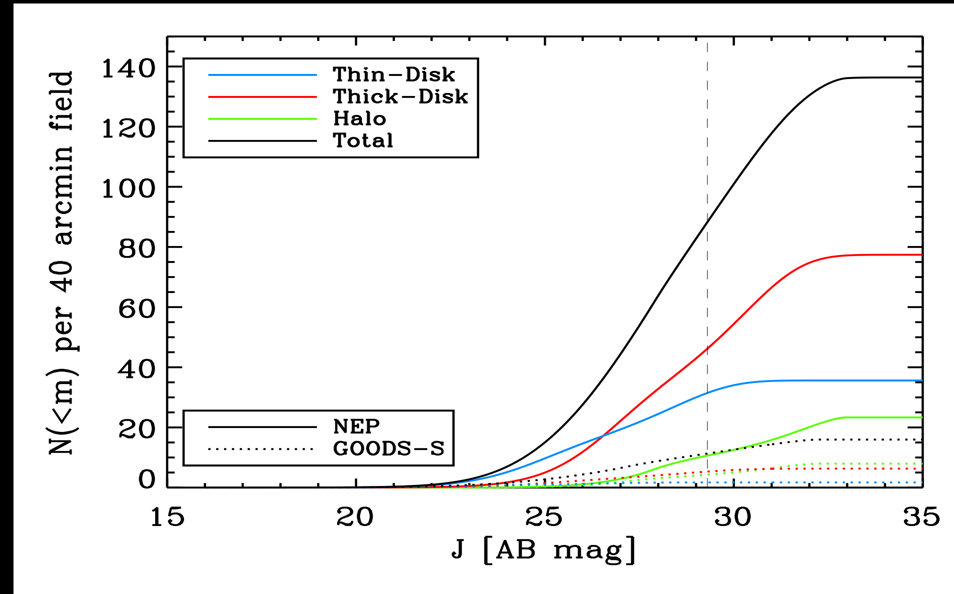


6-year WFC3-ACS high Proper-Motion (PM) stars in the WFC3 ERS (W11):

PM$\simeq$3.06 m.a.s./yr (4.6$\boldsymbol{\sigma}$; AB$\lesssim$27), constraining Galactic structure models.

- **JWST NEP will yield m.a.s. PM to AB$\lesssim$29-30 in $\lesssim$3 years.**





From WFC3/ERS (Windhorst et al. 2011; W11):

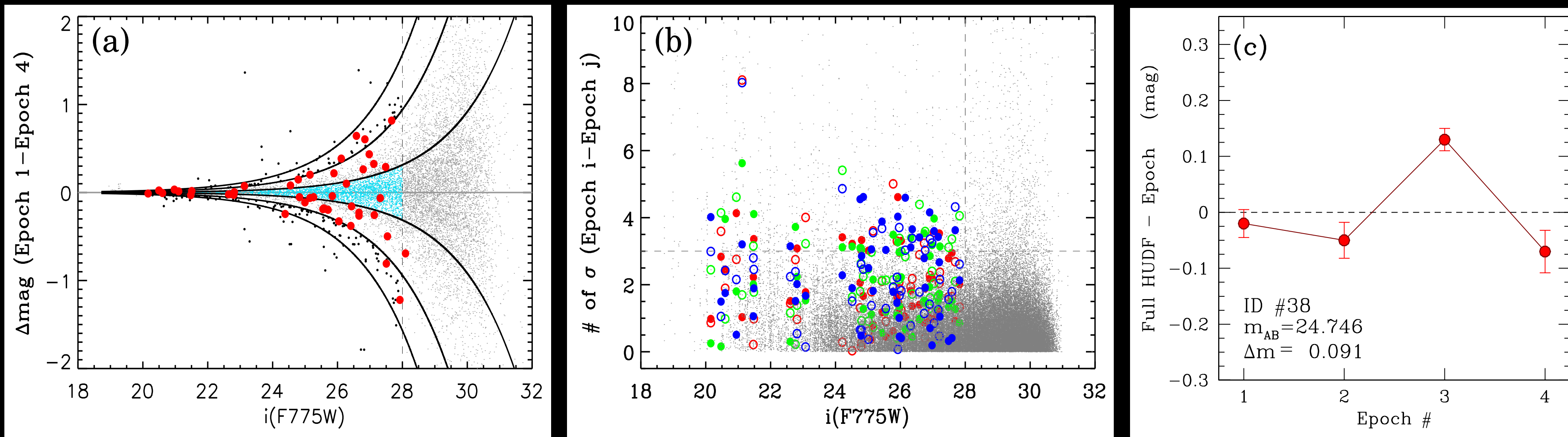
[LEFT] Panchromatic galaxy counts vs. star-counts in WFC3 ERS.

Galaxy count slope steeper than stars, so gals outnumber stars at AB$\gtrsim$21.

[RIGHT] Ryan & Reid (2015) model: 6–9$\times$ more brown dwarfs in NEP.

JWST NEP will have $\lesssim 10^{-5}$–10^{-4} of pixels covered by stars to AB$\lesssim$29.

(3) Unique new JWST Variability Science possible in the NEP CVZ:



[LEFT] Flux diff. between 2 HUDF epochs vs. $\boldsymbol{i}$-mag (Cohen et al. 2006).

● Red points mark $\gtrsim 3\boldsymbol{\sigma}$ variables between 6 epoch pairs to AB$\lesssim$28 mag.

[MIDDLE] Same for all-epoch flux differences in number-of-$\boldsymbol{\sigma}$.

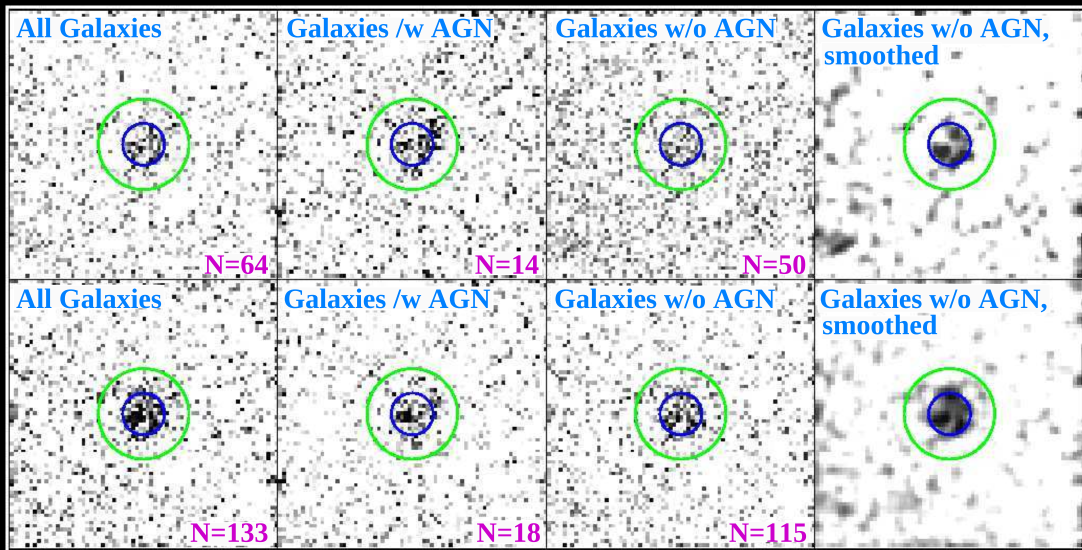
[RIGHT] Weak AGN point-source with 20% flux variation on timescales of months ($\simeq$weeks in restframe).

● JWST NEP will show a few % of all objects to have variable weak AGN on timescales of months–years to AB$\lesssim$29–30 mag.

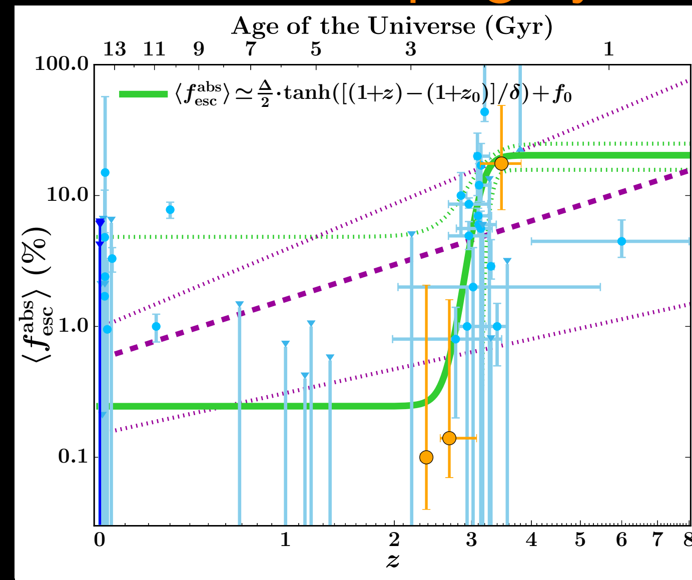
● JWST NEP will provide a *robust, independent* way to select weak AGN, complementing NIRCam colors+NIRISS grism emission lines.

● [Galactic microlensing: An 8 $M_\odot$ BH has $t_{rise/fall} \simeq$ 6 mo, $r_E \simeq 0\farcs06$.]

(3) Galaxy & Variable Weak AGN Contributions to Escaping LyC:



All Objects Weak AGN w/o AGN (Smoothed)

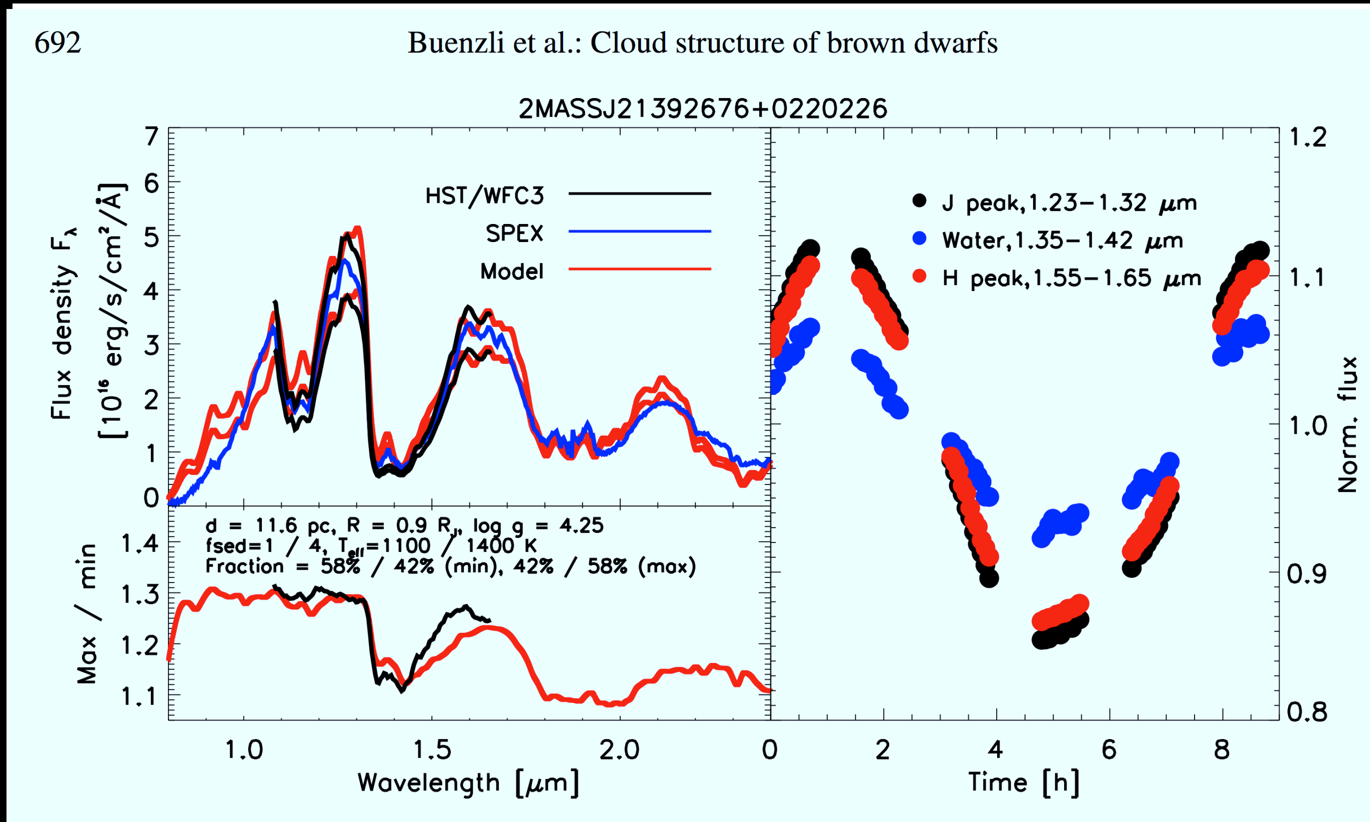


[LEFT] WFC3/ERS galaxies & weak AGN in UV (Smith+; astro-ph/1602.01555):

- The stacked LyC emission has a *very flat* SB-distribution with radius!

[RIGHT] Absolute f_{esc} of galaxies increases (suddenly?) with redshift:

- Galaxies dominated and completed reionization at 3≲z≲6.
- Weak AGN may dominate and maintain reionization at z≲3.
- JWST NEP will provide ≳500-1000 NIRISS redshifts to AB≲27.5 mag.
- If they are also observed with HST UV, this will 10-fold LyC statistics.

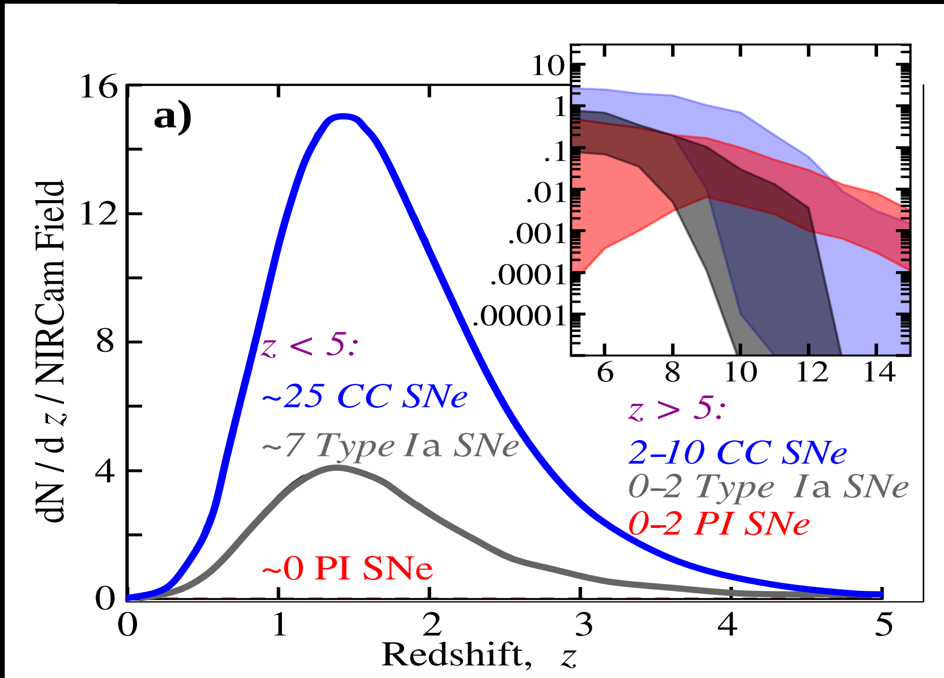


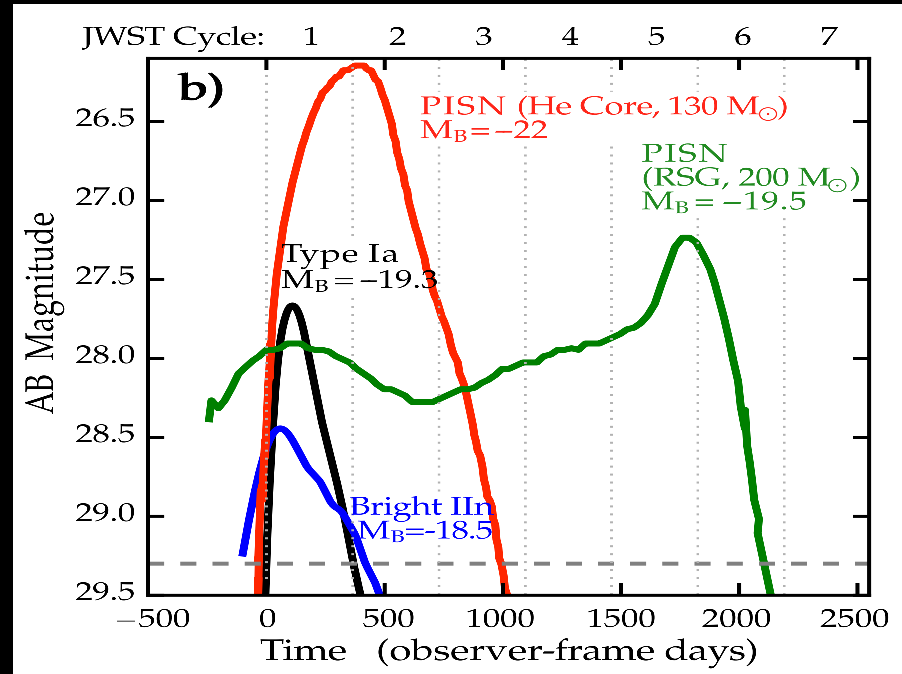
[Top]: Varying HST/WFC3 spectrum (black) compared to average BD spectrum from SPEX library (blue), Burgasser et al. 2006).

Red over-plots the best patchy cloud model of Buenzli et al. (2014).

[Bottom]: Max/Min ratio of data (black) & model (red) for indicated physical parameters; [Right]: Measured broad-band light curves over 6 orbits.

- JWST NEP CVZ will monitor 100's of faint BD's to AB$\lesssim$29-30 mag.
- Hours-weeks timescales will constrain rotation curves & cloud coverage.





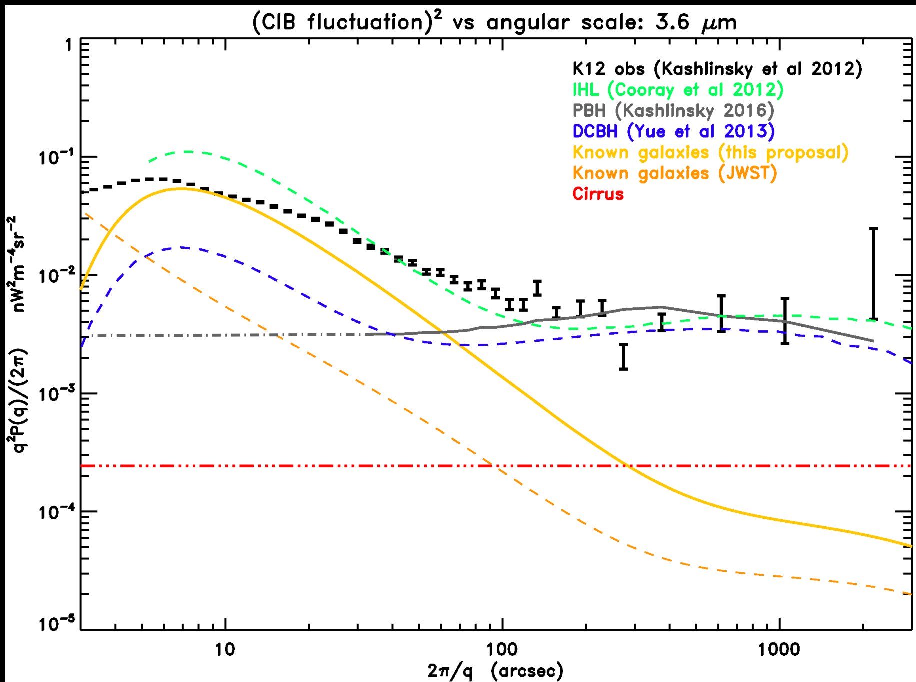
[LEFT] Projected Supernova yield for a single JWST/NIRCam field:

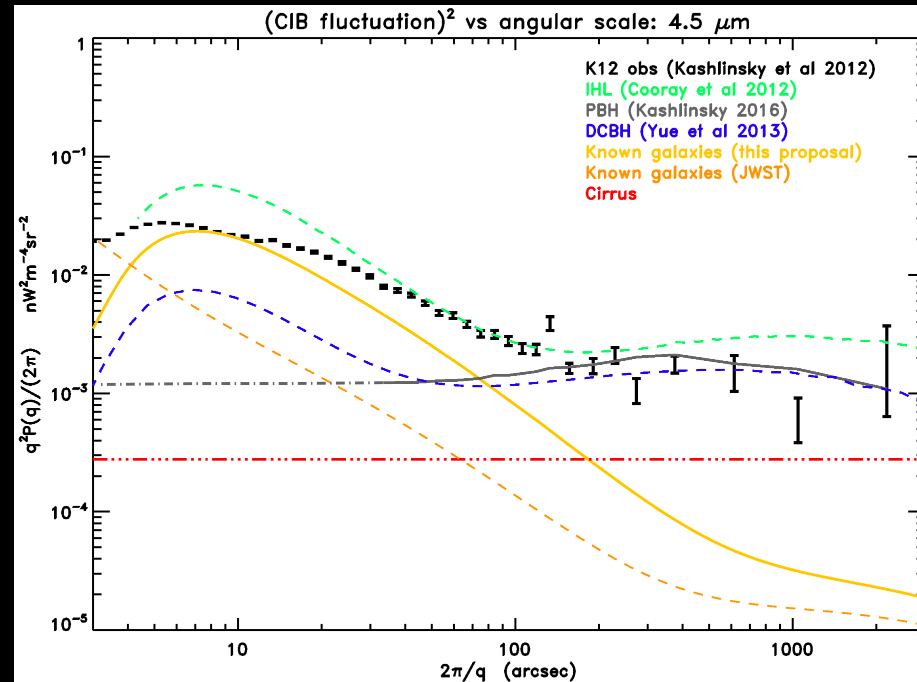
- The $10' \times 10'$ JWST NEP field will provide $10\times$ more high-z SNe.
- JWST NEP will detect *every* Type Ia SN to z$\lesssim$5, and 90% of all Core Collapse (CC) SNe to z$\lesssim$1.5 (Rodney et al. 2015; Strolger et al. 2015).

[RIGHT] Simulated light curves for various SN types at z=7. JWST can detect some (rare) Pair Instability SuperNovae (PISN; Kasen et al. 2011).

- The JWST NEP Time-Domain field is critical for high-z SN work:
- 7-yr timescale of massive PISN: Must start NEP field in JWST Cycle 1.
- And start HST-unique UV/blue observations as soon as possible.

(3) Other Science Enabled by the Darkest Possible JWST NEP sky:





Darkest possible Zodi sky in JWST NEP field enables fluctuation studies in Cosmic Infrared Background (CIB; Kashlinsky et al. 2012, 2015).

- Current Spitzer CIB power-spectrum at 3.6 (left) and 4.5 μm (right) begin to constrain various CIB fluctuation models:

Orange+red dashed lines shows ($\gtrsim$50 hr, $10\times10'$) JWST NEP CIB-limits.

The darkest JWST NEP sky-data will clearly constrain First Light models:

- Primordial black hole models (PBHs; Kashlinsky et al. 2016).
- Direct-collapse black hole models models (DCBHs; Yue et al. 2015).

SPARE CHARTS

References and other sources of material shown:

http://www.asu.edu/clas/hst/www/jwst/ [Talk, Movie, Java-tool]

http://www.jwst.nasa.gov/ & http://www.stsci.edu/jwst/

http://ircamera.as.arizona.edu/nircam/

http://www.stsci.edu/jwst/instruments/fgs

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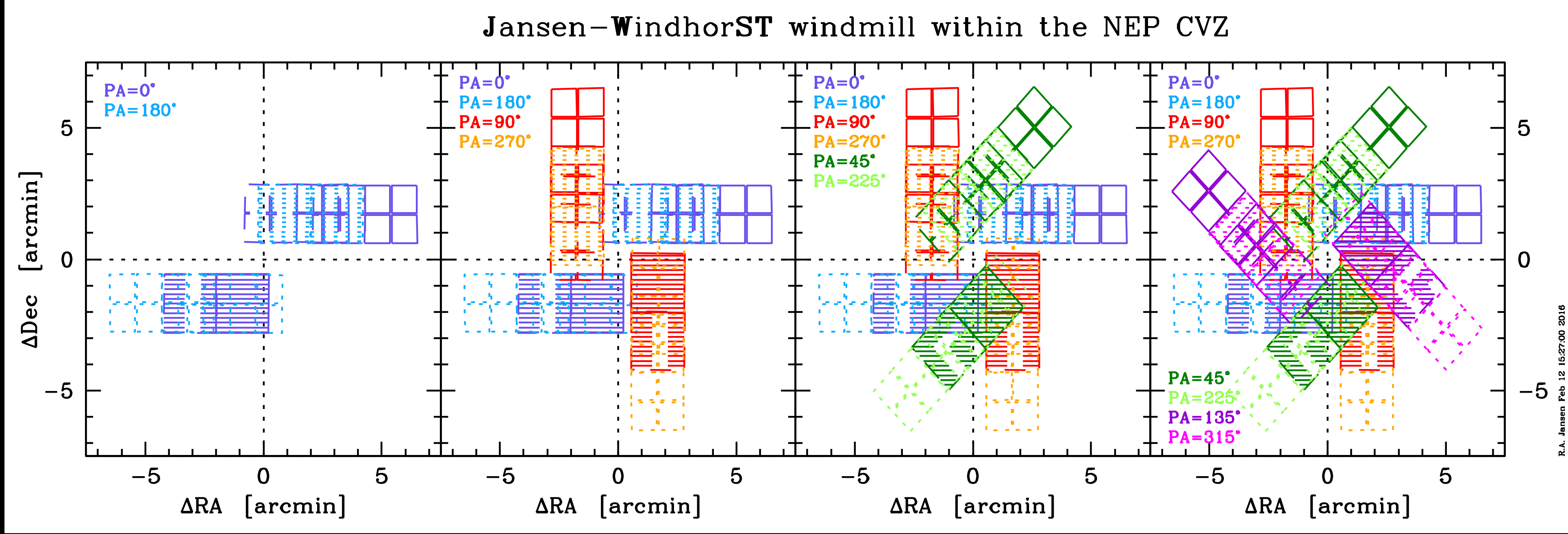


[LEFT]: 2-epoch JWST-"Windmill" that takes maximum advantage of JWST CVZ for time-domain (lines: NIRCam; shaded: NIRISS-parallels).

[MIDDLE LEFT]: JWST-Windmill with 4 epochs ∼3 months (90°) apart (our planned GTO Medium-Deep NEP survey):

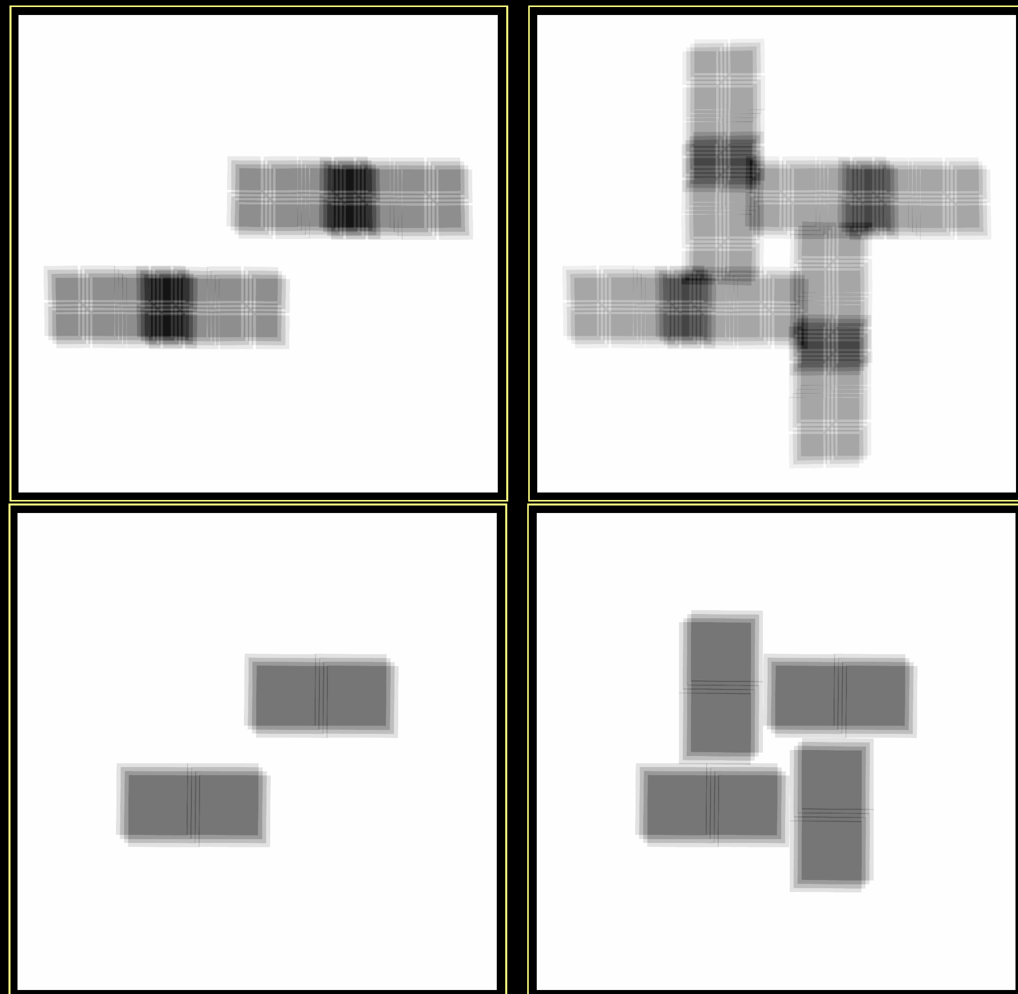
Area: ∼66 arcmin^2 NIRCam (AB$\lesssim$29) with ∼46 arcmin^2 NIRISS (AB$\lesssim$28).

On timescales of months–years, we expect GO's to add many spokes:

[MIDDLE RIGHT]: with 6 epochs 1.5–2 months (45–90°) apart.

[RIGHT]: 8 epochs ∼1.5 months (45°) apart (increases area by ∼60%).

... Can repeat above as needed during JWST's life at ANY PA!



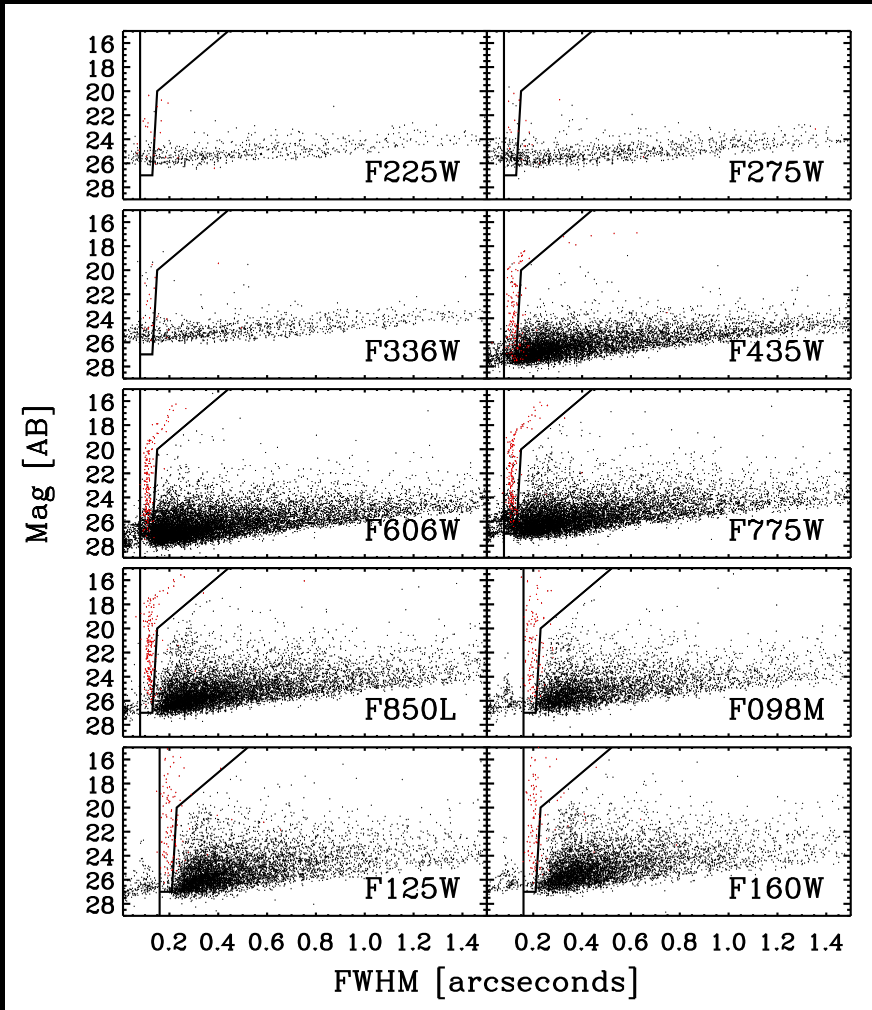
[TOP] Primary NIRCam JWST-Windmill at ΔPA=0° & 180°.

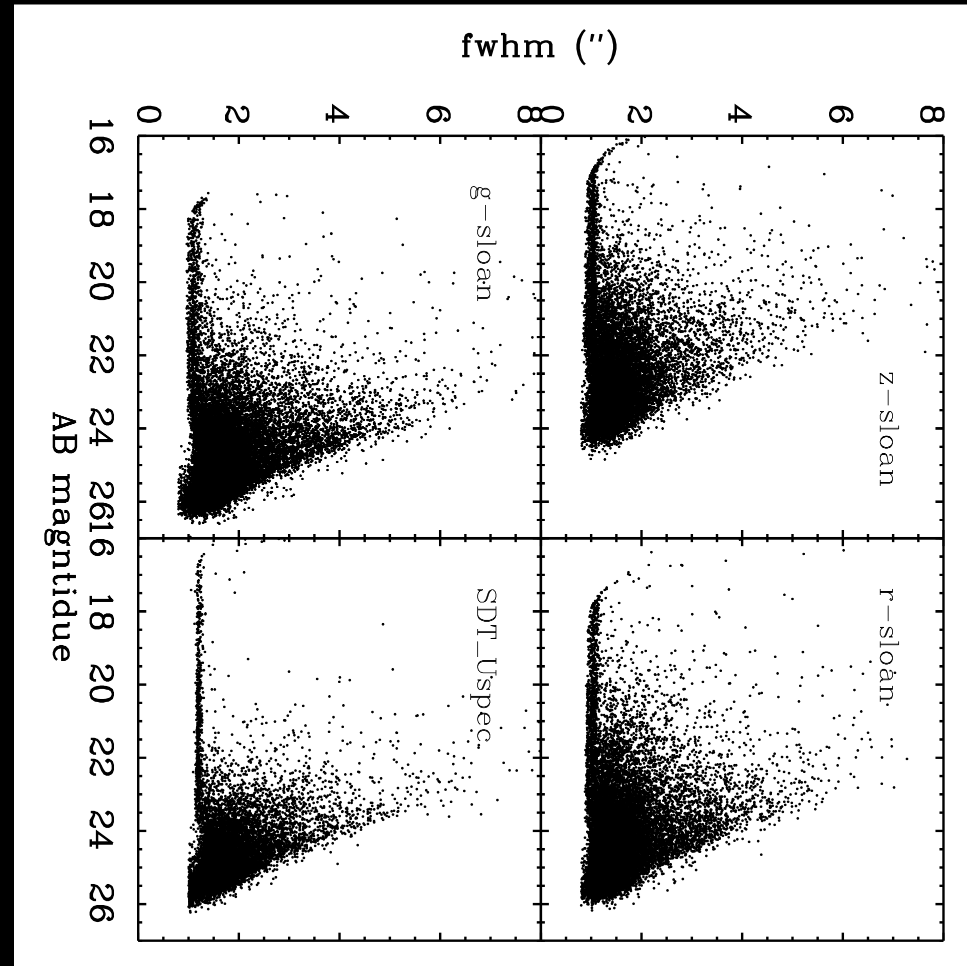
[BOTTOM] Parallel NIRISS grisms at the same relative PA's.

Two grisms (R150C+R150R) help disentangle overlapping spectra to AB$\lesssim$28.

[RIGHT] Adding NIRCam+NIRISS at ΔPA=90° & 270°to the left.

Total NIRCam Area$\simeq$66 arcmin^2, with $\sim$20% of the area $\sim$2$\times$ deeper.



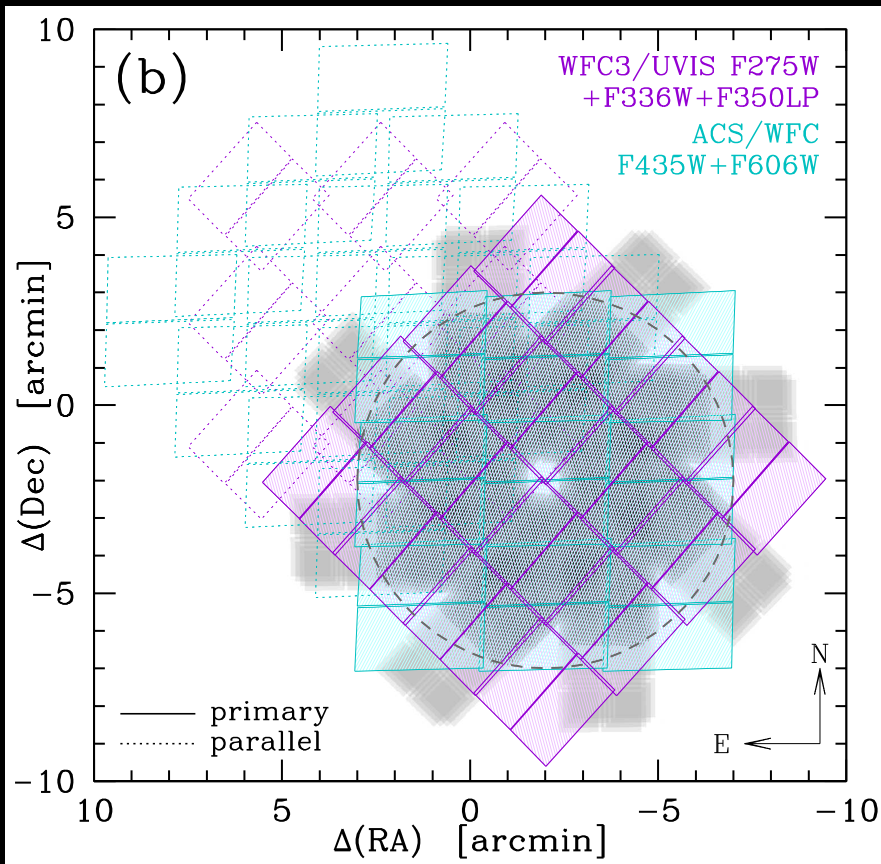


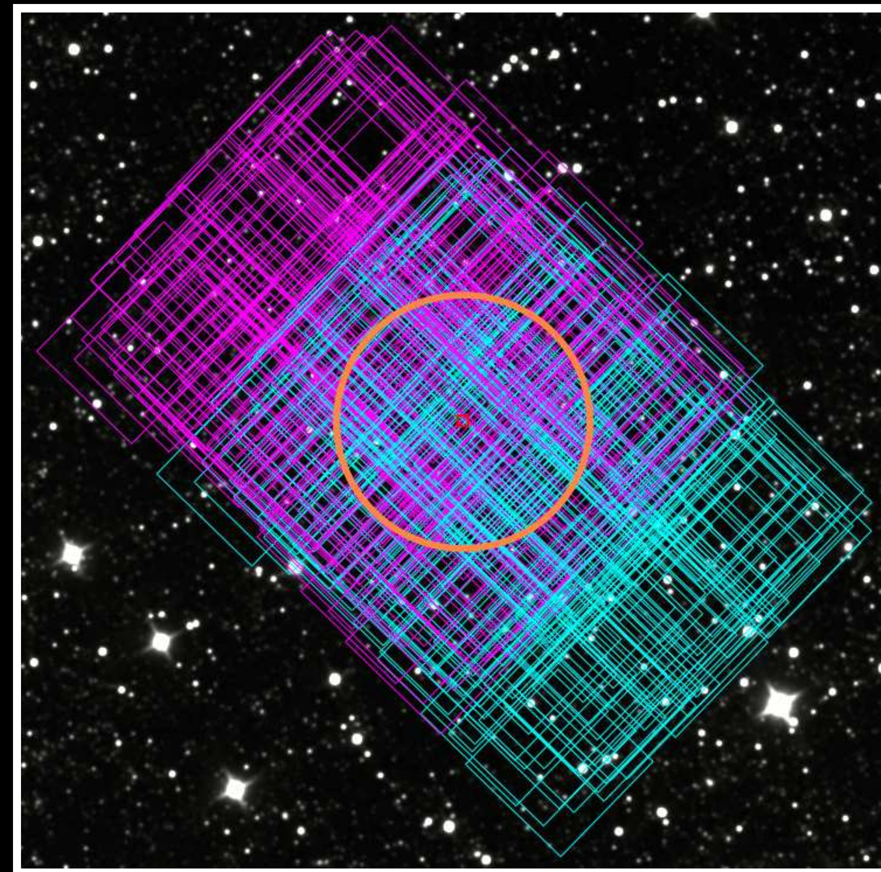
Feasibility of Star-Galaxy Separation in JWST NEP CVZ field:

[LEFT] 10-filter ERS stars + gals to AB$\lesssim$27 (Windhorst^{+} 2011; W11).

[RIGHT] July 2016 $\boldsymbol{Ugrz}$ LBT/LBC in JWST NEP field to AB$\lesssim$26 mag.

2.5$\times$ smaller drizzled JWST pixels provide very robust star-galaxy separation to AB$\lesssim$29, even in the denser NEP field.





[LEFT]: HST mosaics complement JWST NEP community field *(greyscale)*:

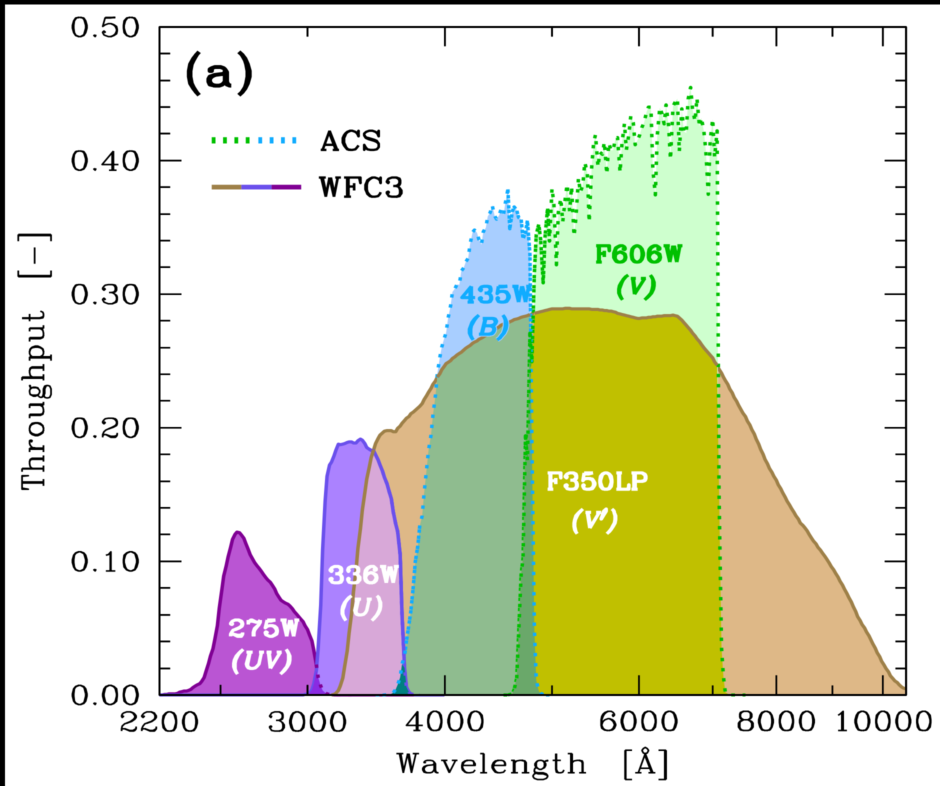
[Full]: Primary WFC3/UVIS *UV*, *U*, & F350LP, + ACS/WFC *B* & *V*.

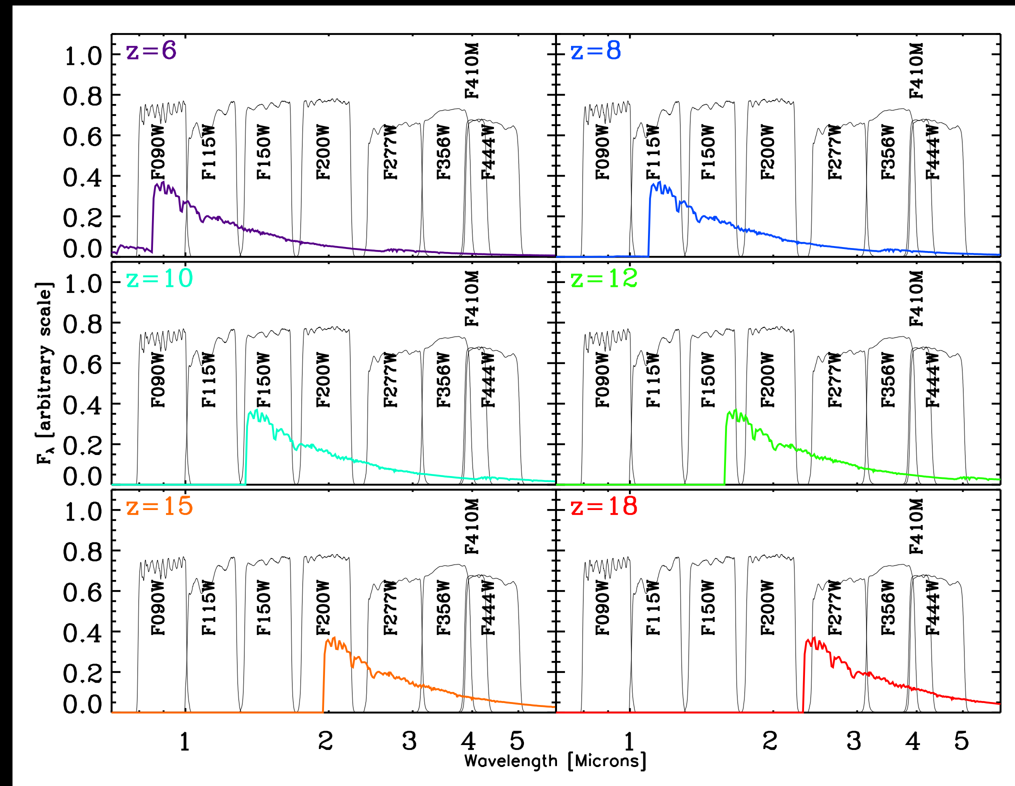
[Dotted]: Parallels in WFC3/UVIS F350LP, + ACS/WFC *B* & *V*.

[RIGHT]: Proposed Spitzer IRAC 3.6+4.5μm mosaics overlaid on a WISE image of the JWST-NEP field, using a 3×4 ($\sim$15′ ×20′) IRAC map.

IRAC will help calibrate rogue-path straylight gradients in JWST images.

HST+Spitzer: a lasting complement for the JWST NEP community field.



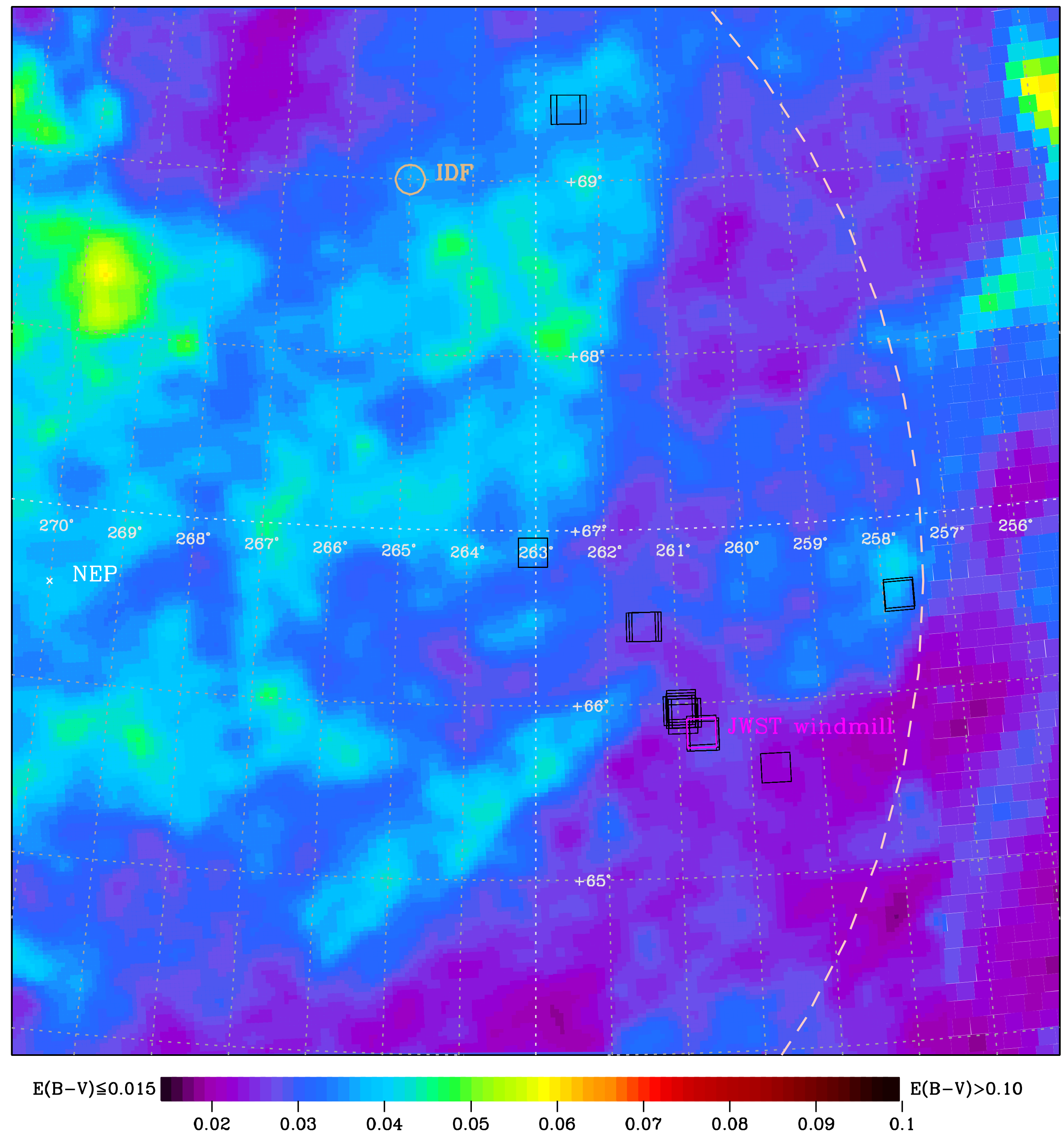


[LEFT] HST UV-vis filters complement the JWST NEP community field:

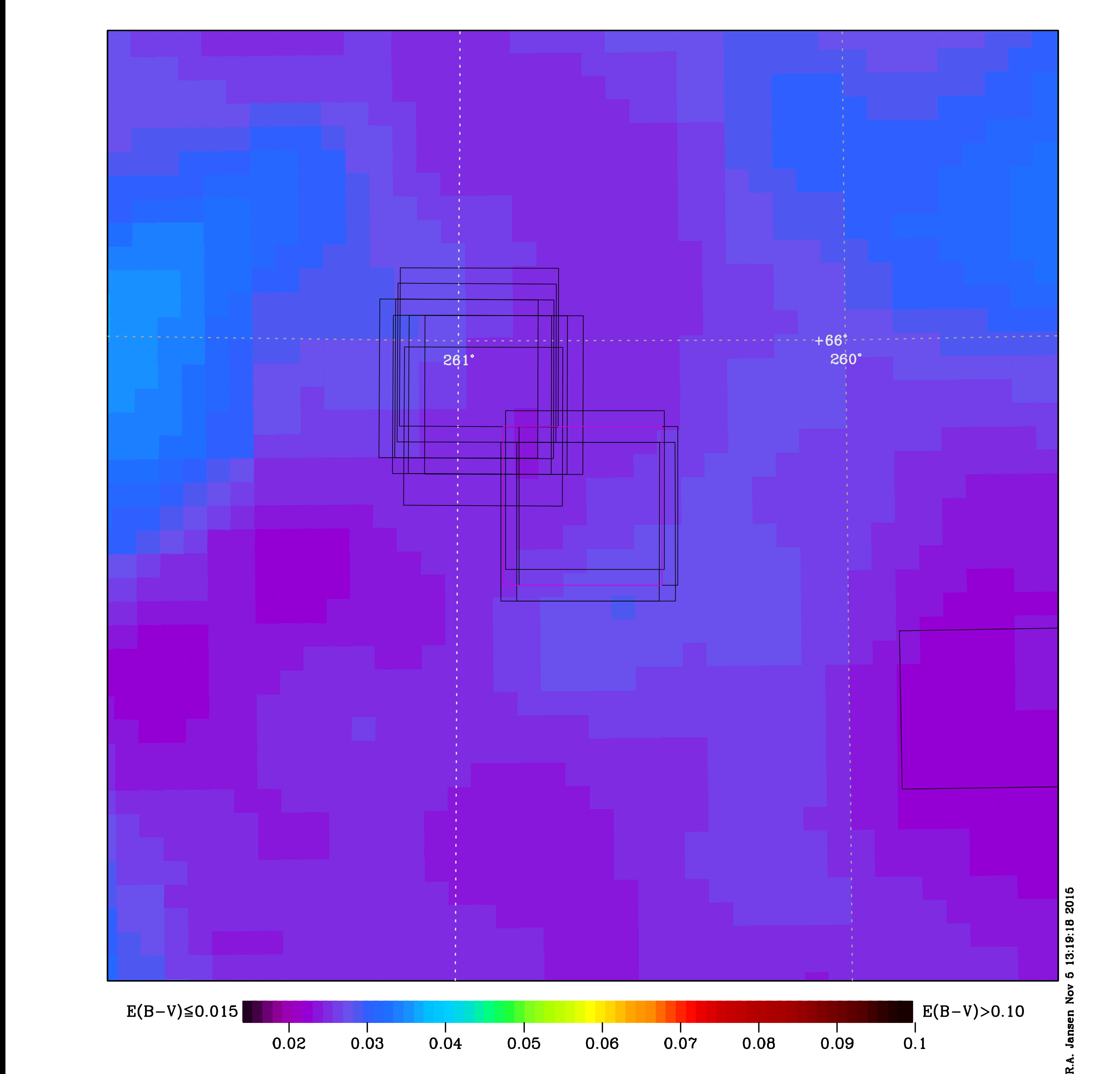
- HST adds λ's inaccessible to JWST, or where HST has better PSF.
- WFC3 F350LP is necessary as veto-filter for high-z SNe searches.

[RIGHT] Standard 8-band 0.8–5 μm filter set for JWST NIRCam.

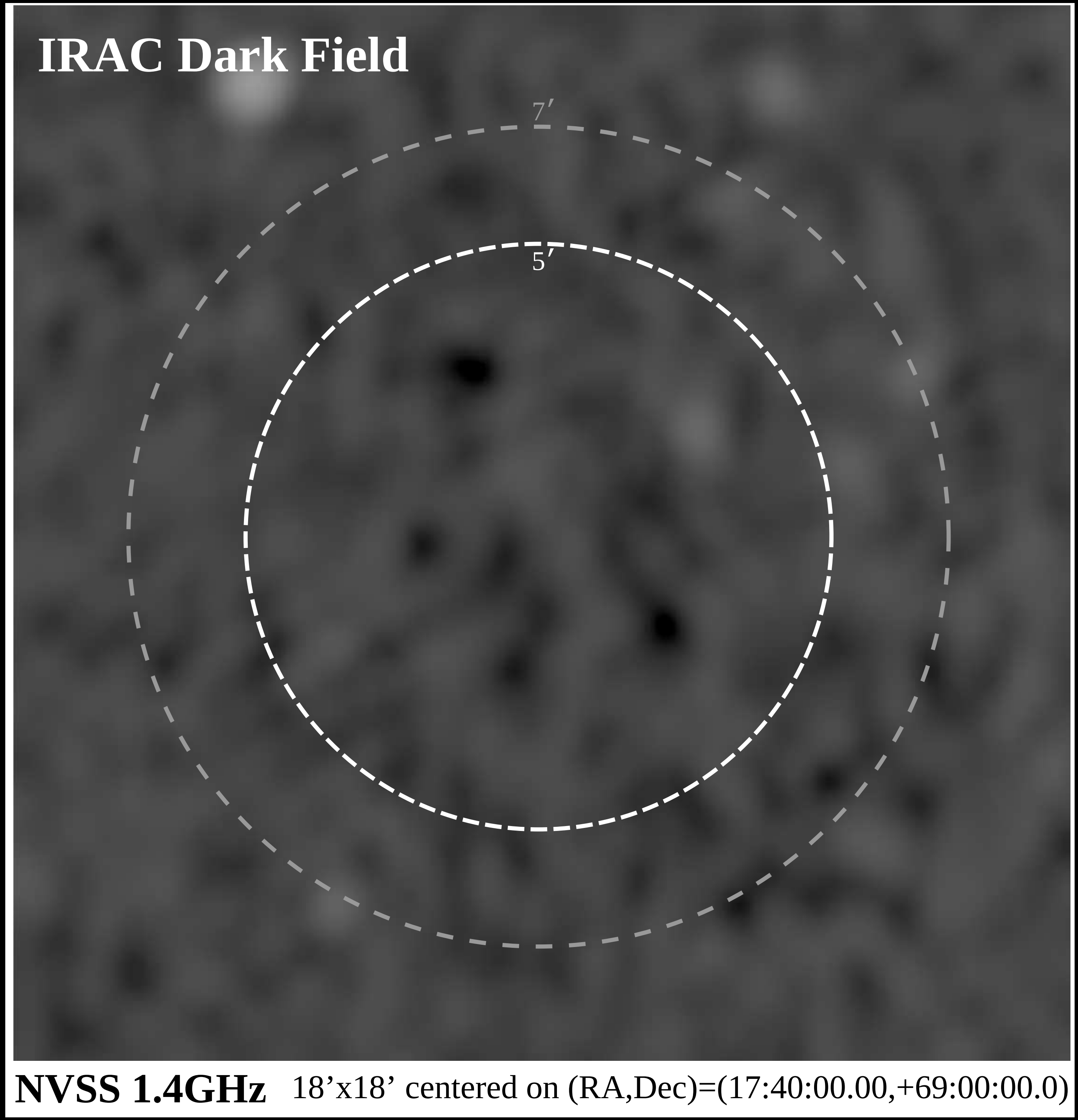
- These are what all GTO's will use as standard NIRCam filters.



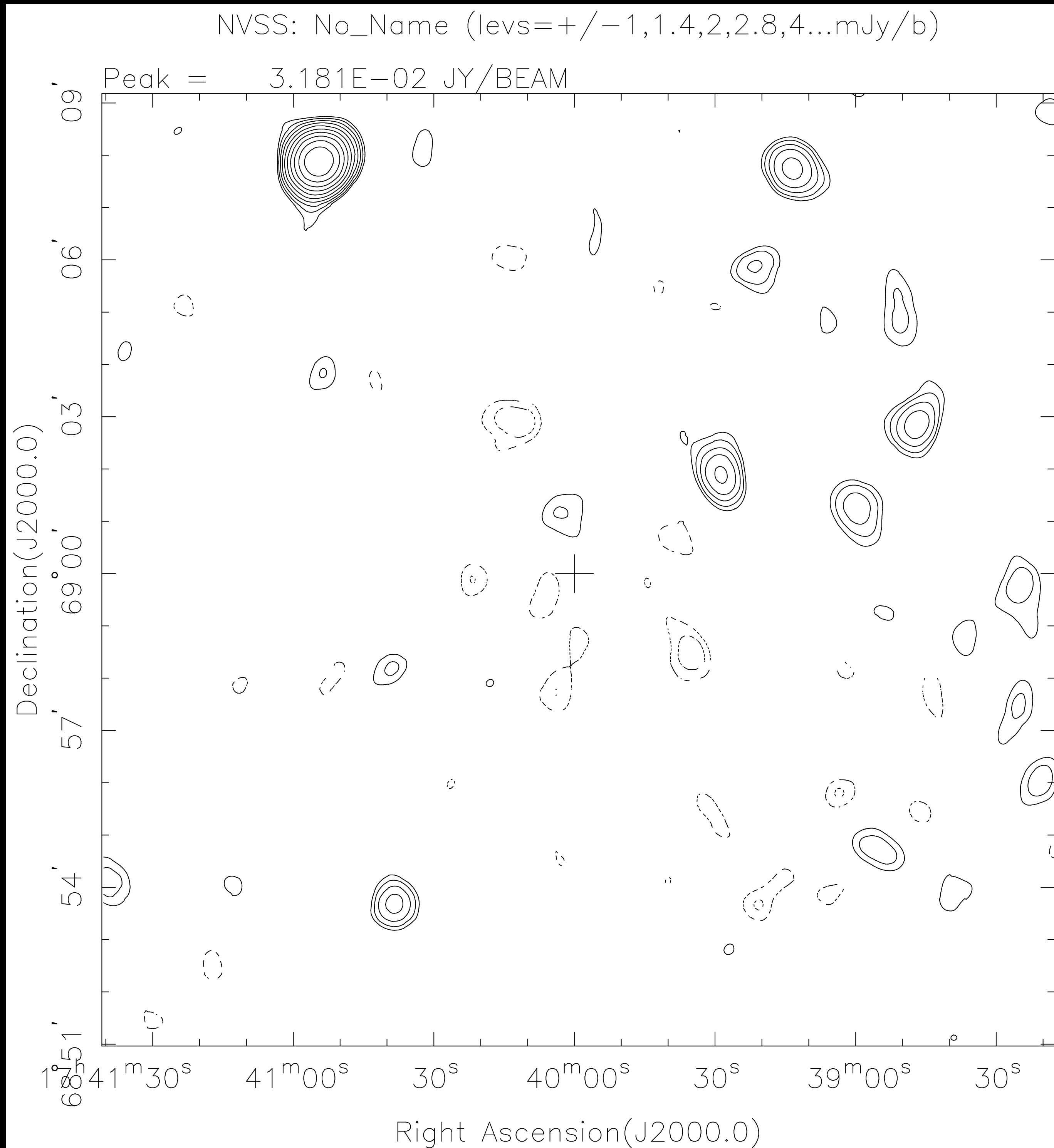
Enlargement of E(B–V) map of Spitzer IDF vs. JWST NEP region.



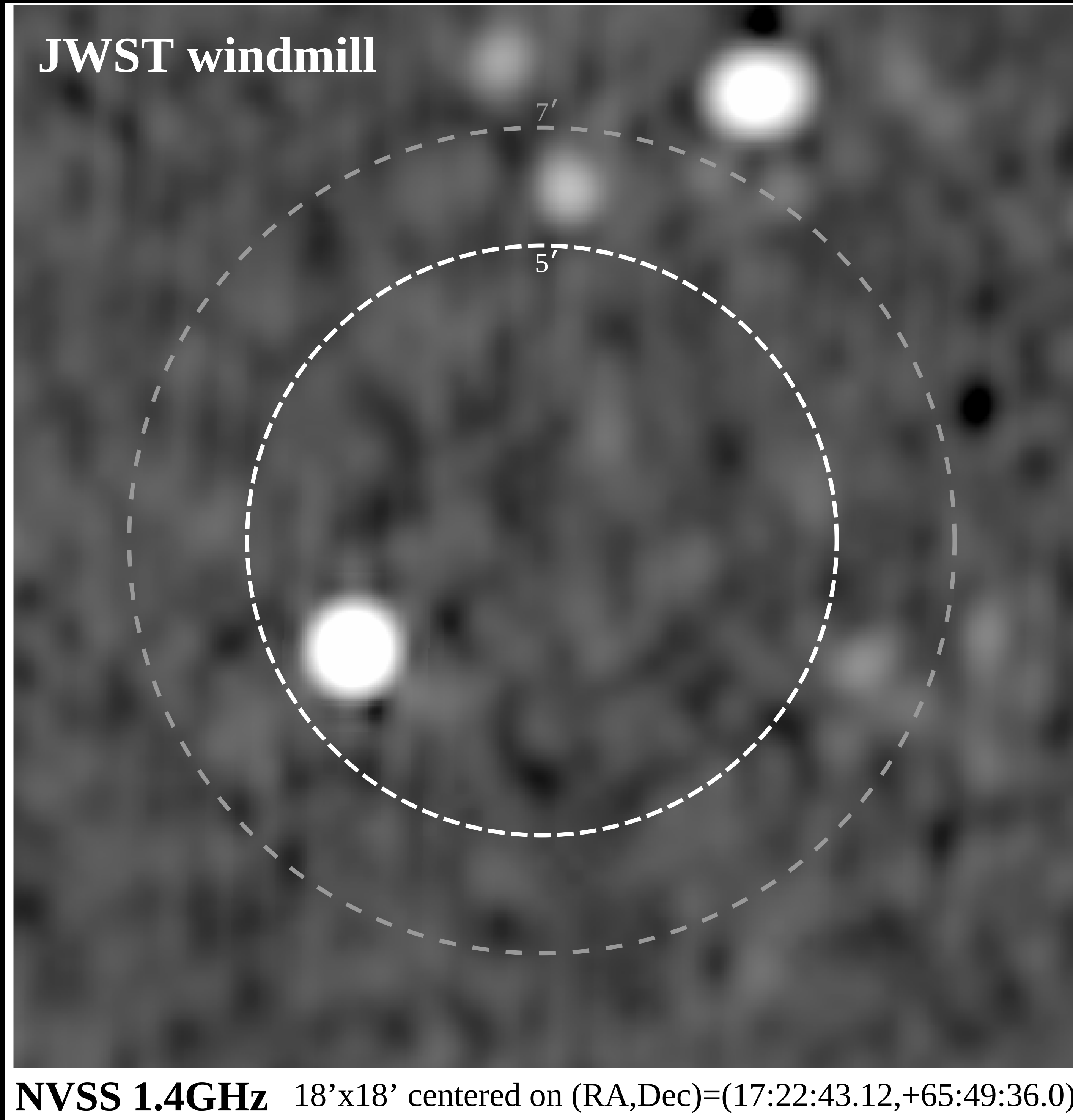
Enlargement of E(B–V) map of JWST NEP CVZ region.



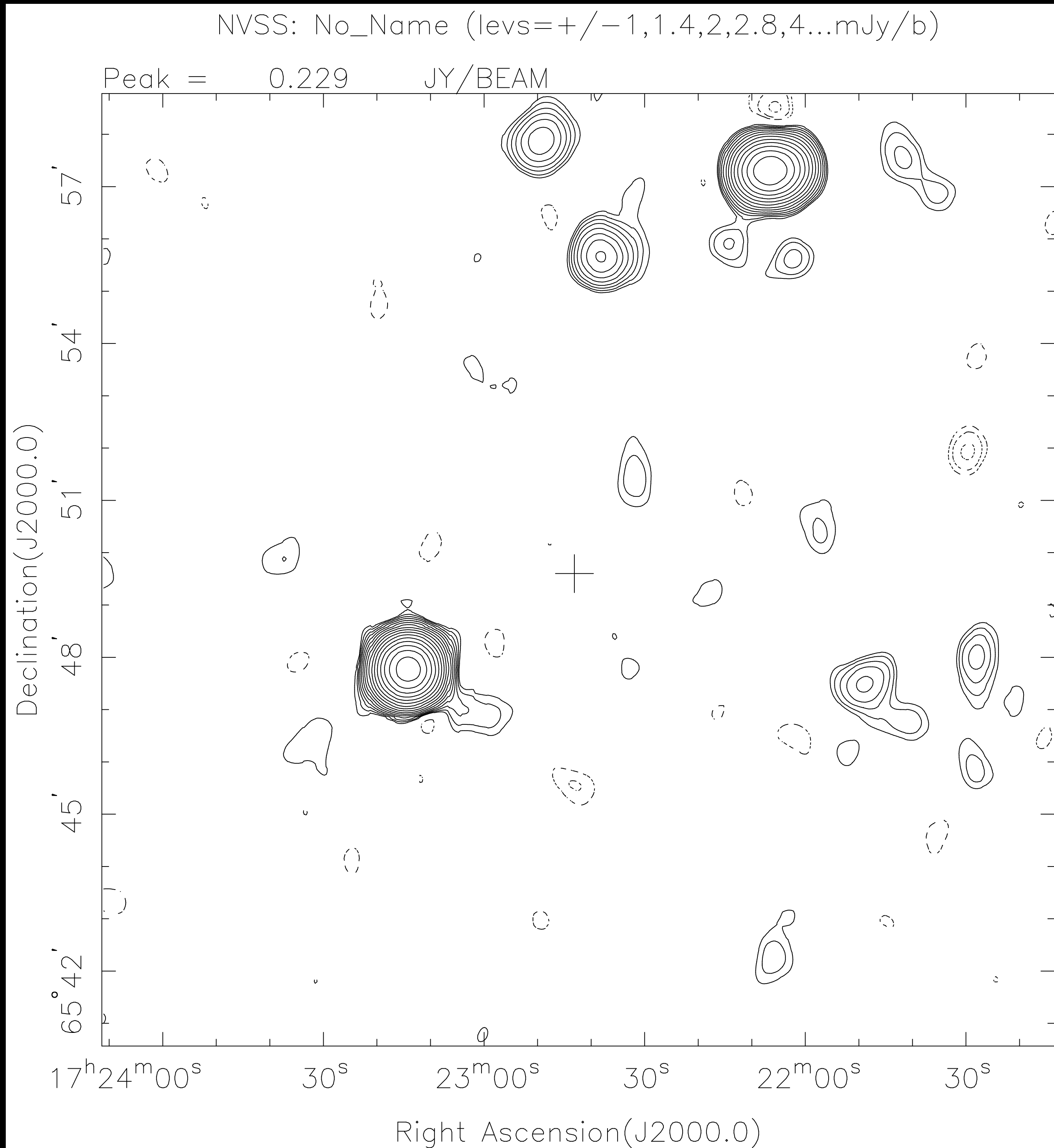
NVSS VLA 1.4 GHz map of Spitzer IRAC Dark Field (IDF) [to $\sim$2 mJy].



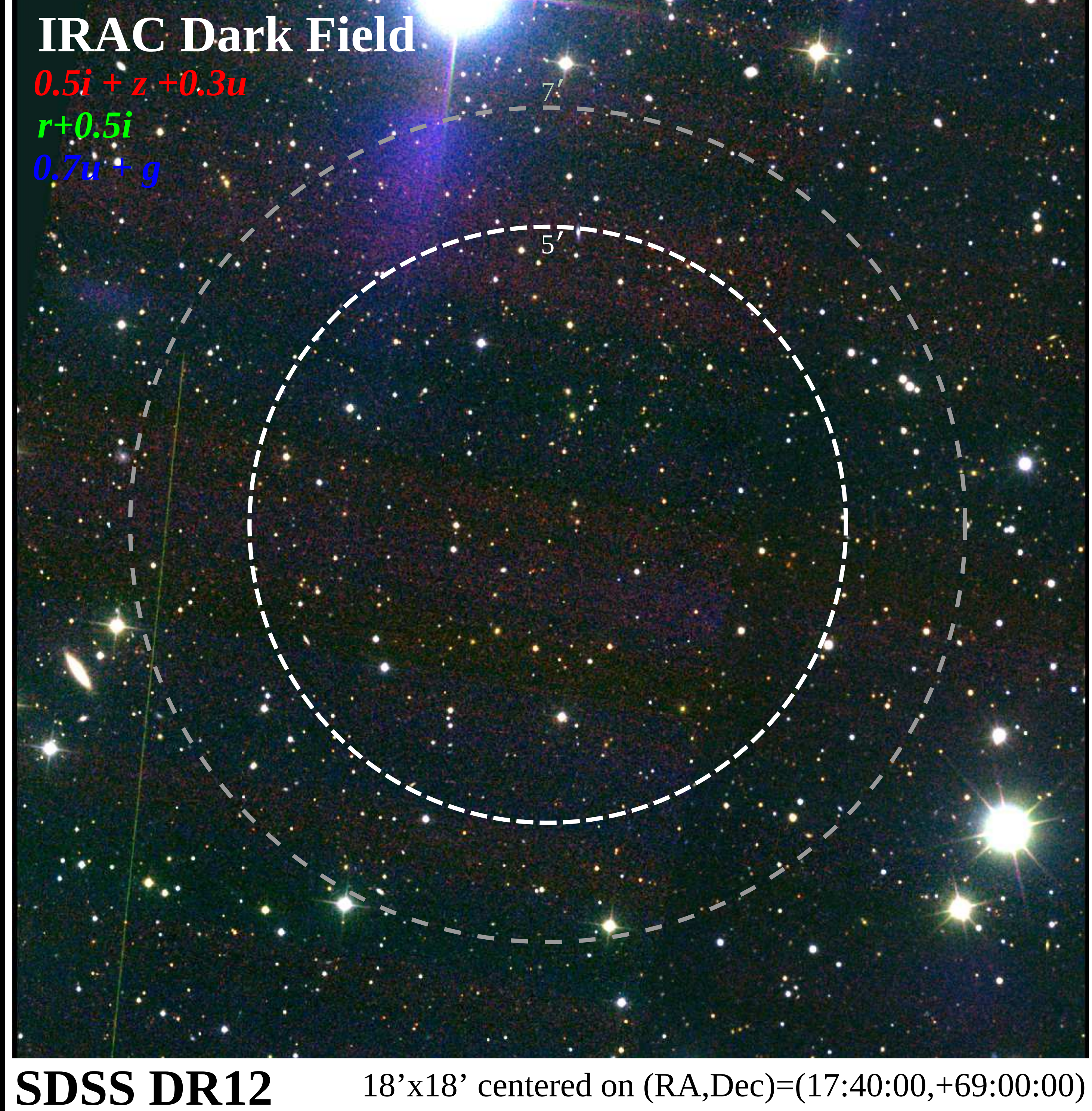
NVSS VLA 1.4 GHz map of Spitzer IRAC Dark Field (IDF) [to ∼2 mJy].



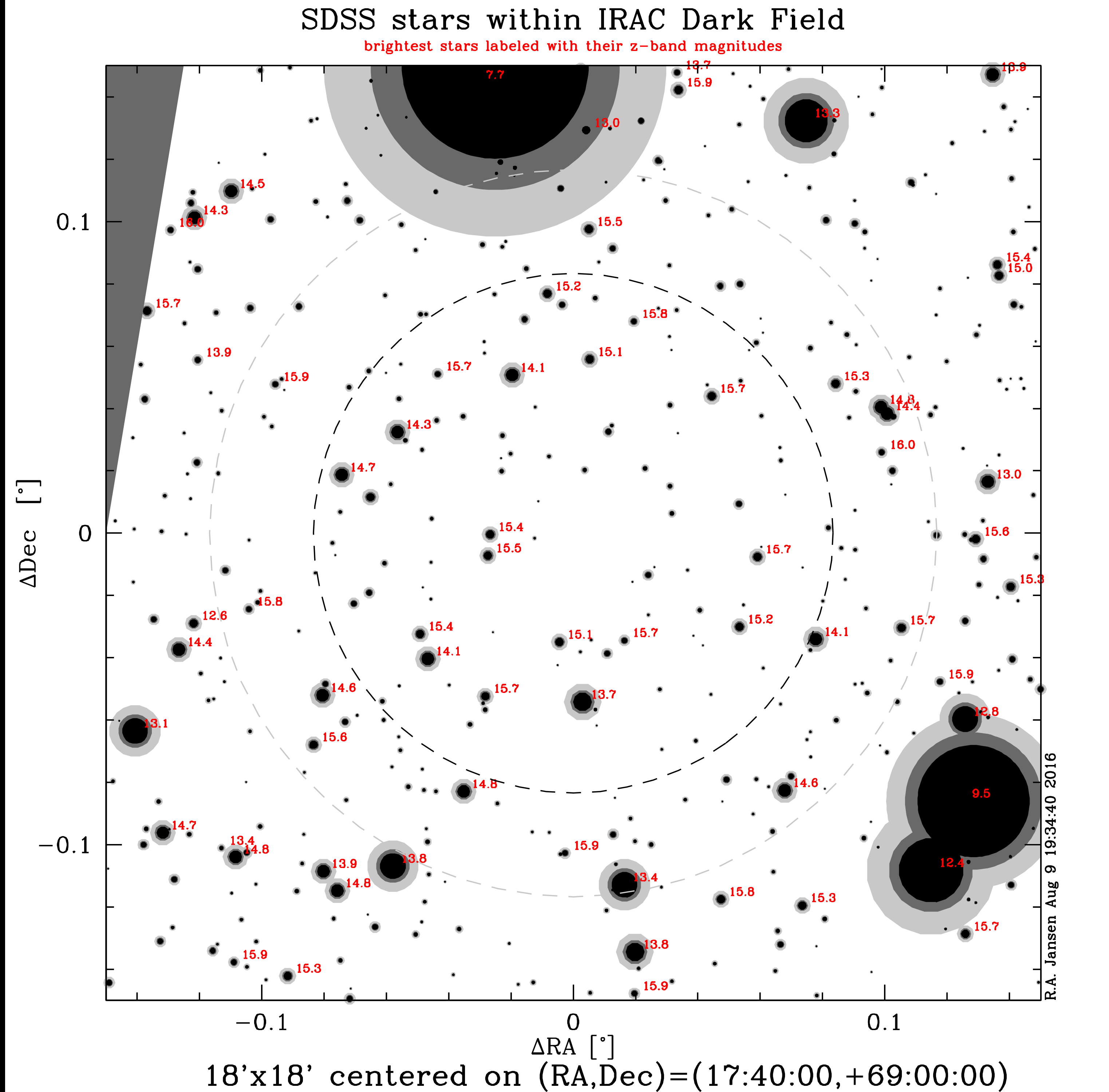
NVSS VLA 1.4 GHz map of best JWST NEP CVZ region [to ∼2 mJy].



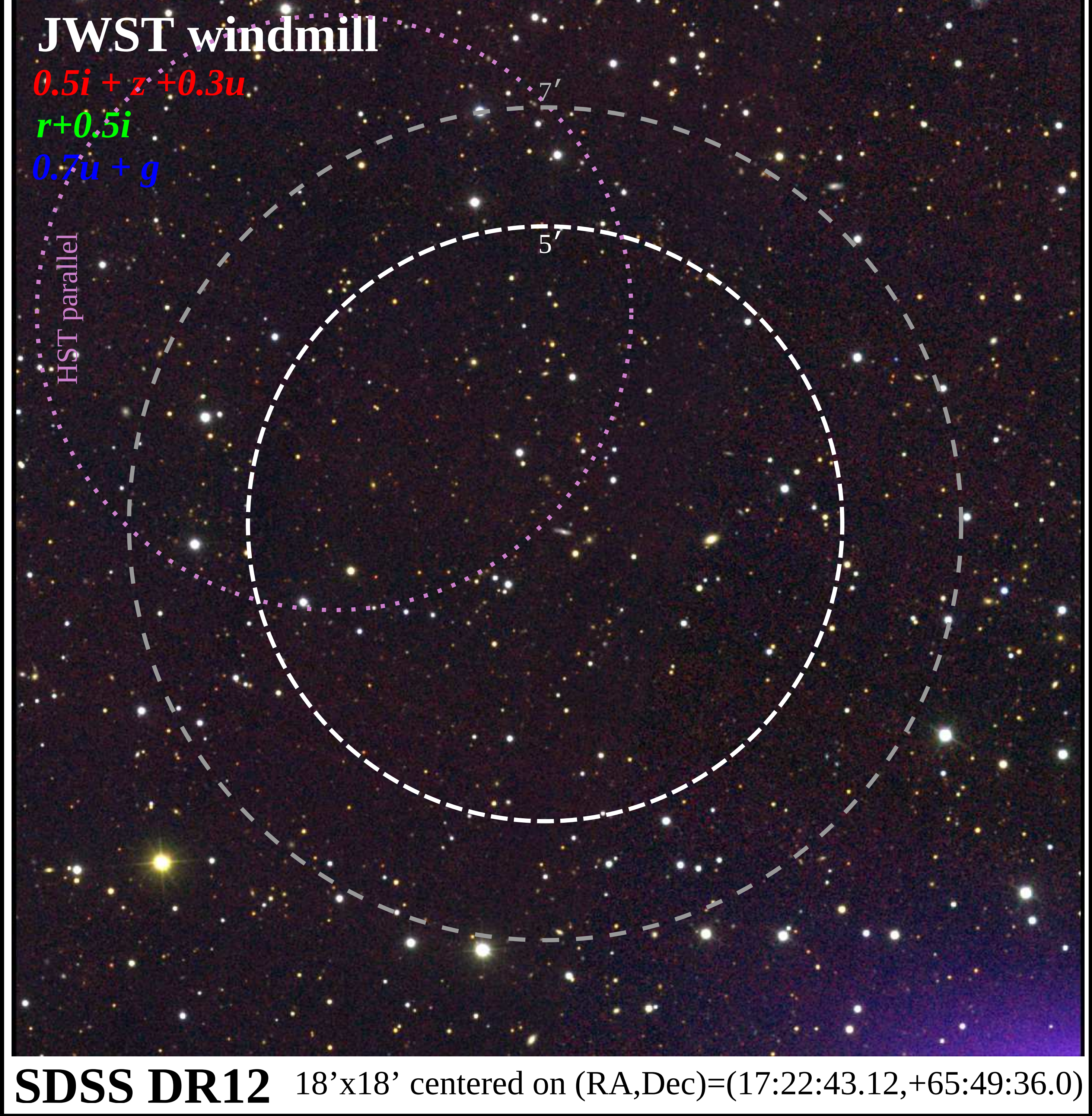
NVSS VLA 1.4 GHz map of best JWST NEP CVZ region [to ∼2 mJy].



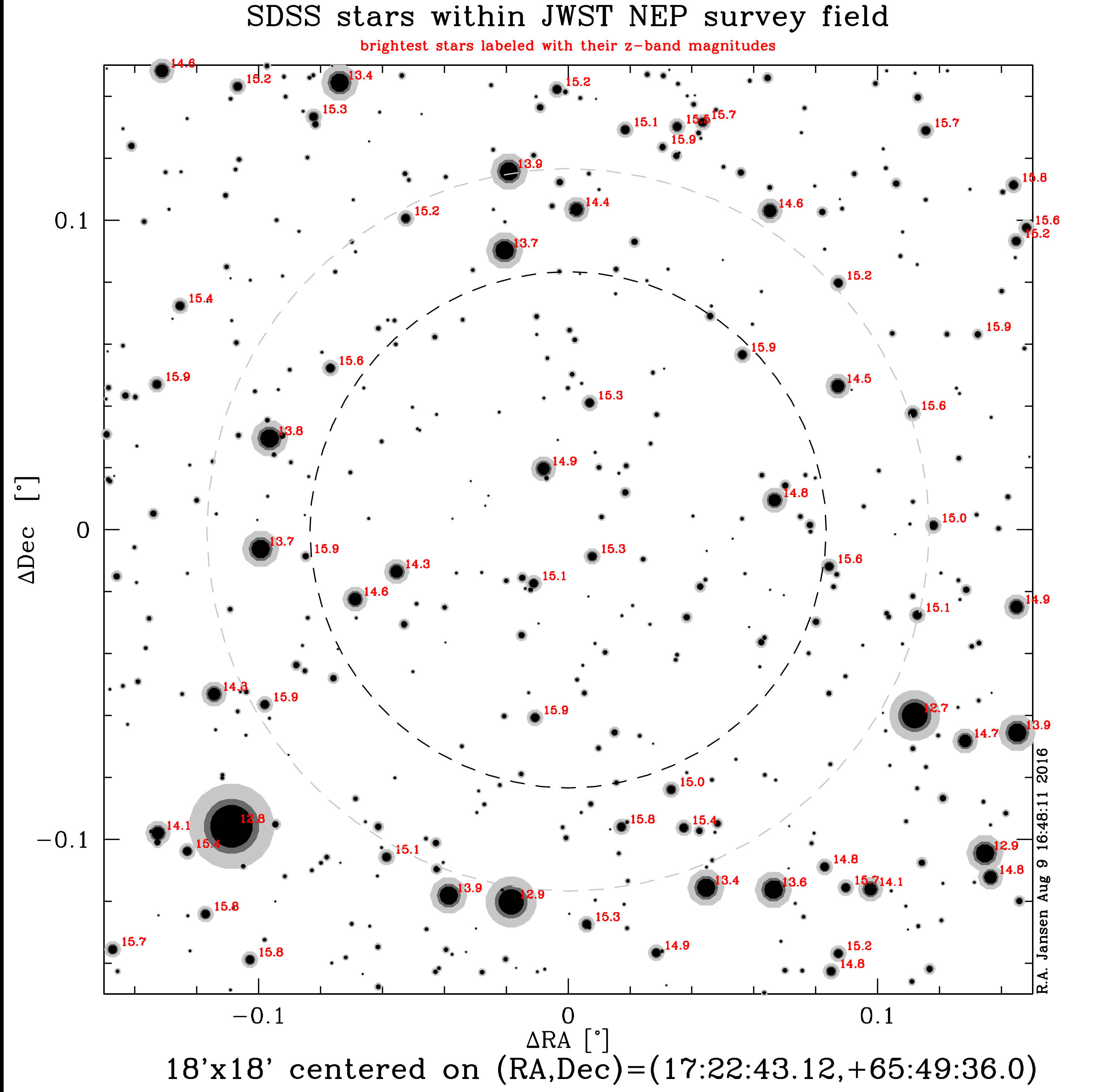
SDSS ugriz mosaic of Spitzer IRAC Dark Field to AB$\lesssim$23.5 mag.



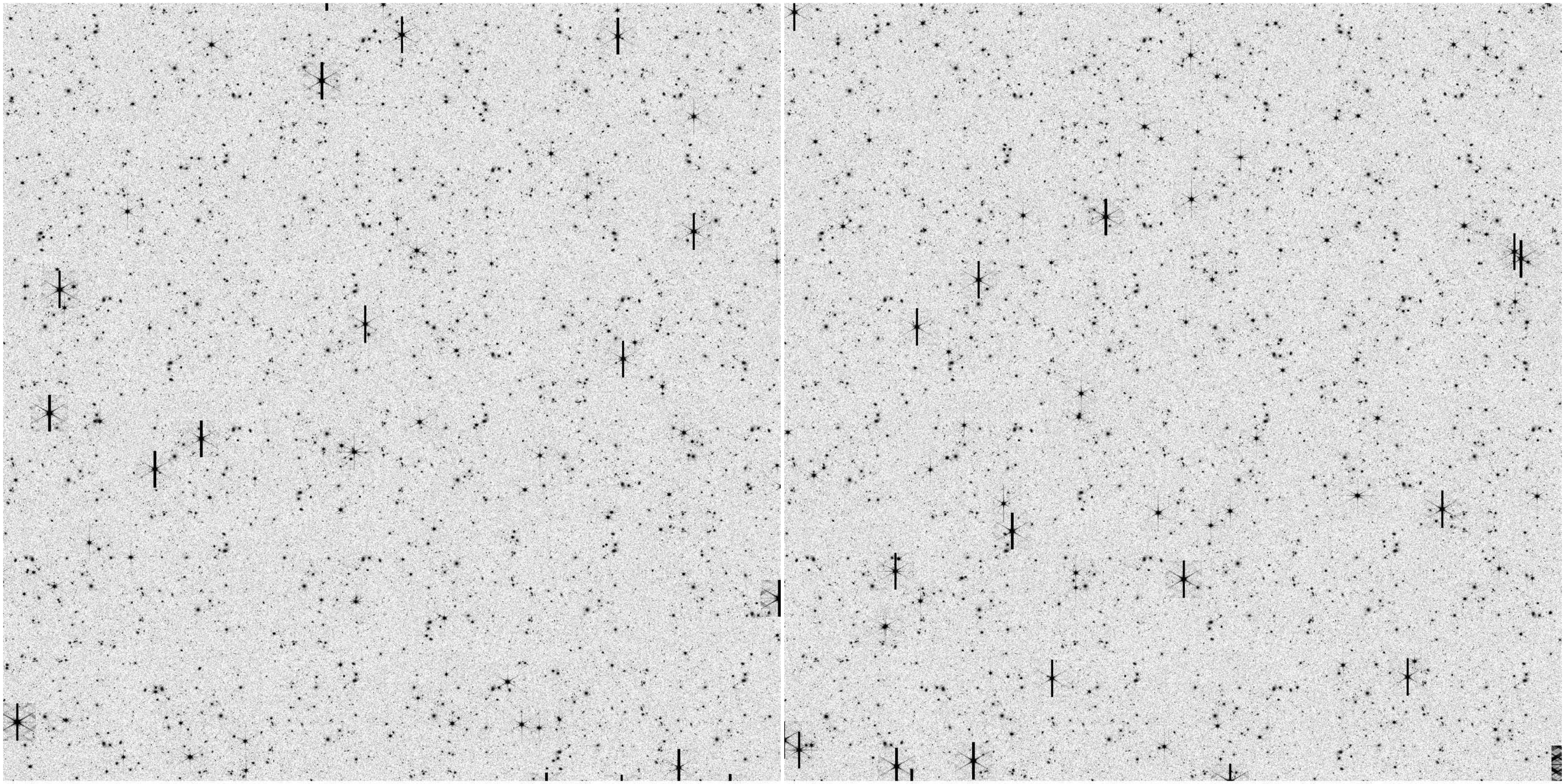
SDSS ugriz mosaic of Spitzer IDF with bright stars indicated.



SDSS ugriz mosaic of best JWST NEP CVZ region to AB≲23.5 mag.



SDSS ugriz mosaic of best JWST NEP CVZ region with bright stars.



Replicated HUDF ($z_{AB} \lesssim 30$) with F090W stars overlaid to AB$\lesssim$16 (NEP, IDF).

- Diffuse F090W halos from ultra-bright stars outside FOV included.
- Persistence and saturation streaks should be diffused, to be done.
- Out-of-field rogue-path JWST straylight from Galaxy to be included.

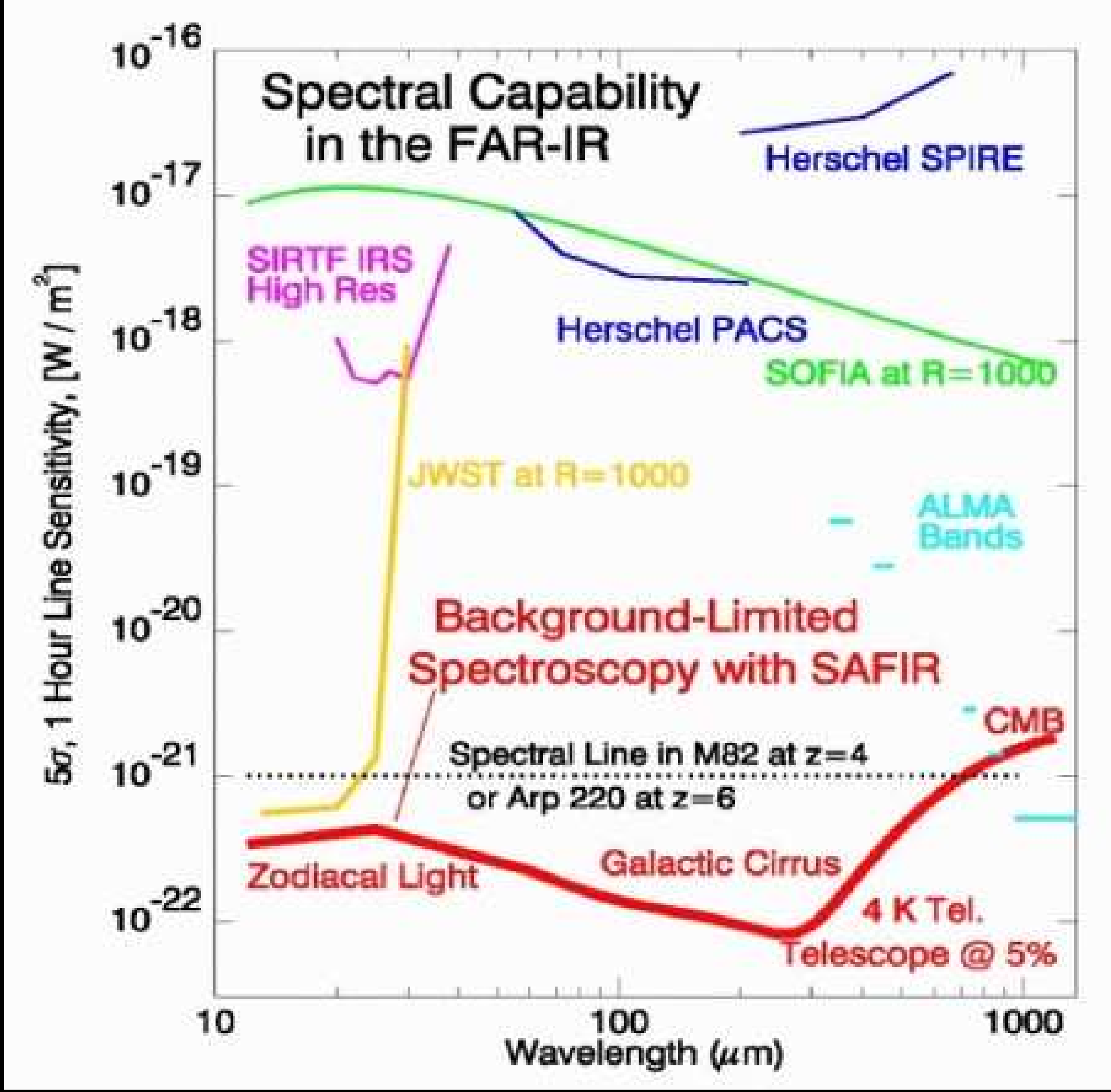
Summary Spitzer IRAC Dark Field (IDF) vs. best JWST NEP CVZ field:

Spitzer IDF has the following advantages/disadvantages:

- Higher bright-star density, especially just outside Windmill (straylight!).
- Higher E(B–V)$\simeq$0.04–0.05 mag. More visible cirrus structure.
- $\gtrsim$10 year epoch IRAC data (IDF!); one epoch MIPS 70μm data;
- HST ACS F814W mosaic ($\simeq$1 orbit per tile);
- 100 ksec of Chandra ACIS images.
- No bright NVSS radio sources (no obvious sources for self-cal either).

Best JWST NEP field has the following advantages/disadvantages:

- By selection, no prohibitive bright stars, also just outside Windmill FOV.
- By selection, the lowest possible E(B–V)$\simeq$0.02–0.03 mag (no cirrus?).
- Excellent-seeing LBT Ugrz-images to AB$\lesssim$26 (p. 28), more to come!
- No HST, Spitzer, or Chandra/XMM data (X-ray collabs eager to apply).
- 200 mJy NVSS radio source (z$\simeq$1.44 QSO), self-calibration point source!



SOFIA/HAWC+ is as sensitive as Herschel/PACS for far-IR spectroscopy.

Plateau de Bure/NOEMA can do mm-wavelengths in the North. NRAO plans to upgrade JVLA with an ALMA-like inner-core this next decade.

Hence, lack of Herschel or ALMA is not a reason to not monitor NEP.