

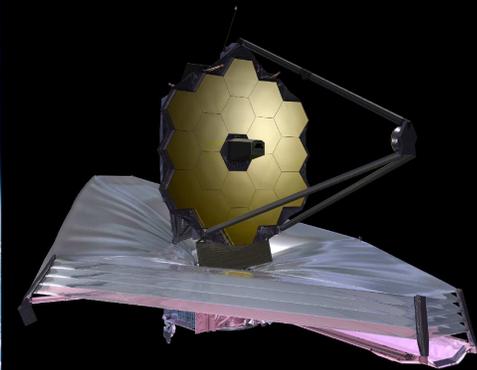
# LyC studies from space in the next decades

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

+ HST SKYSURF, UVCANDELS and JWST PEARLS & SKYSURFIR teams: incl B. Smith, S. Cohen, R. Jansen + 130 scientists over 18 time-zones



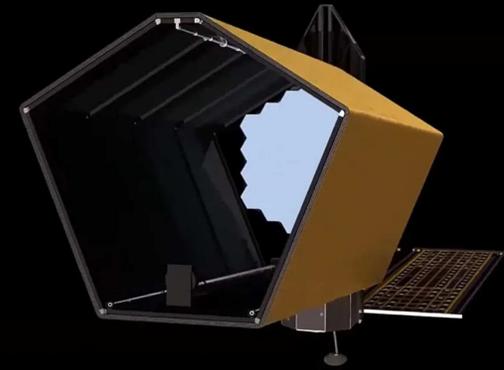
Hubble  
1973~2034<sup>+</sup>?



Webb (designed)  
1996~2031



Webb (launched 2021)  
1996~2046<sup>+</sup>?



Habitable Worlds  
2040~2070<sup>+</sup>?

*Review at the “Escape of Lyman radiation from Galactic Labyrinths” Conference*

*Friday April 11, 2025; OAC, Kolymbari, Crete, Greece*

PDF on: [http://www.asu.edu/clas/hst/www/crete25\\_futureLyC\\_fromspace\\_v3.pdf](http://www.asu.edu/clas/hst/www/crete25_futureLyC_fromspace_v3.pdf)

*This talk is dedicated to our friend and PEARLS colleague Dr. Mario Nonino ( 07/2023).*

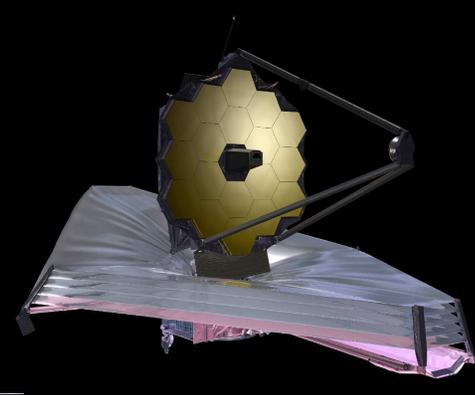
# LyC studies from space in the next decades

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

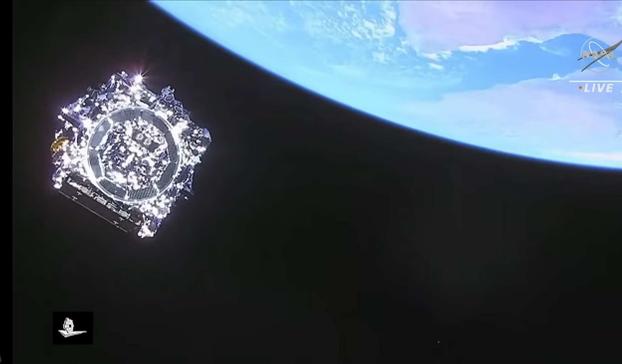
+ HST SKYSURF, UVCANDELS and JWST PEARLS & SKYSURFIR teams: incl B. Smith, S. Cohen, R. Jansen + 130 scientists over 18 time-zones



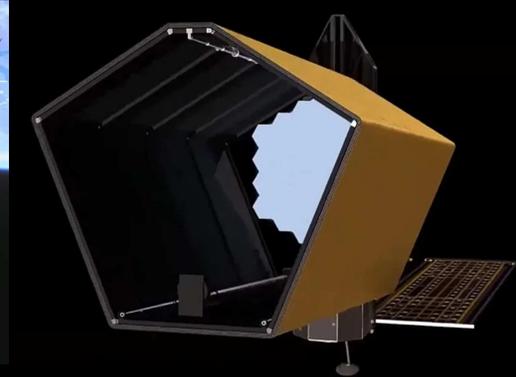
Hubble  
1973~2034+?



Webb (designed)  
1996~2031



Webb (launched 2021)  
1996~2046+?



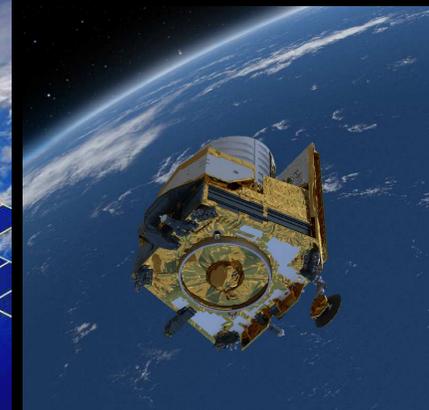
Habitable Worlds  
2040~2070+?



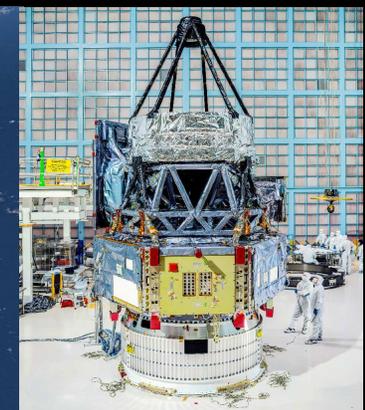
India Astrosat (2015)  
2004~2030+?



China Xuntian (2027?)  
2012~2037+?



Euclid (2023)  
2009~2035?



Roman (2027)  
2011~2037?

# LyC studies from space in the next decades

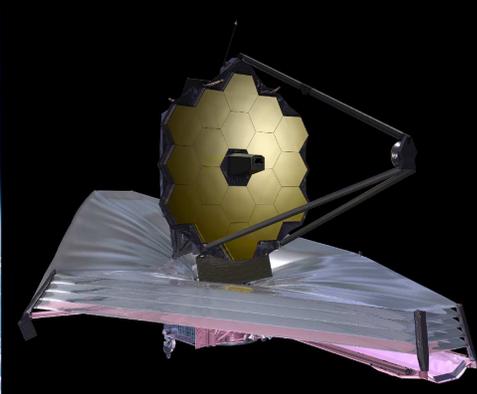
Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

+ HST SKYSURF, UVCANDELS and JWST PEARLS & SKYSURFIR teams: incl B. Smith, S. Cohen, R. Jansen + 130 scientists over 18 time-zones



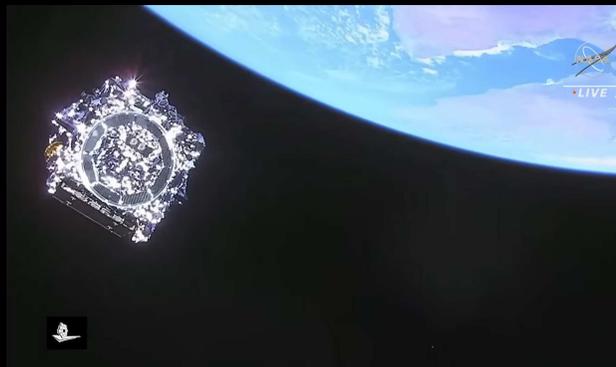
Hubble

1973~2034<sup>+</sup>?



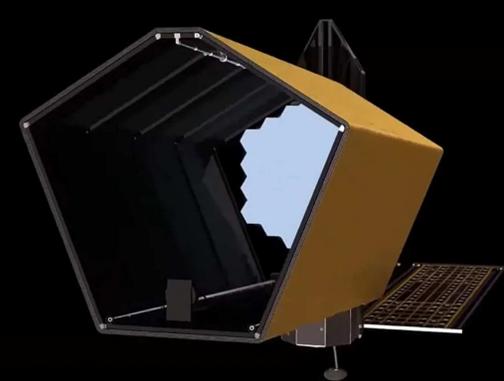
Webb (designed)

1996~2031



Webb (launched 2021)

1996~2046<sup>+</sup>?



Habitable Worlds

2040~2070<sup>+</sup>?

To those (understandably) concerned about events in the world today:

- HST survived 15 presidential, 30 congressional elections, 3 cancellations.
- JWST survived 8 presidential, 16 congressional elections, 2 cancellations.

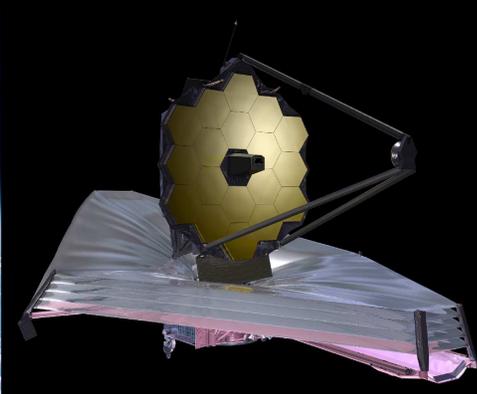
# LyC studies from space in the next decades

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

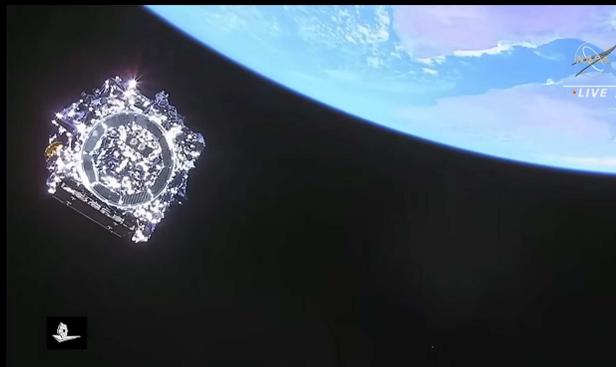
+ HST SKYSURF, UVCANDELS and JWST PEARLS & SKYSURFIR teams: incl B. Smith, S. Cohen, R. Jansen + 130 scientists over 18 time-zones



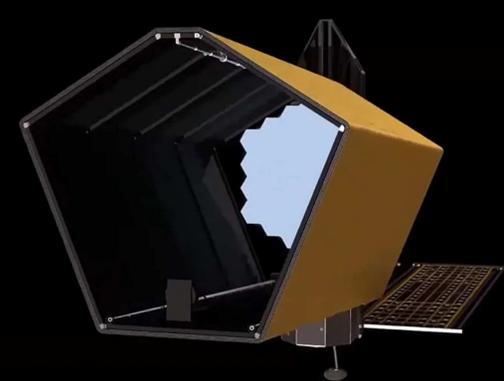
Hubble  
1973~2034<sup>+</sup>?



Webb (designed)  
1996~2031



Webb (launched 2021)  
1996~2046<sup>+</sup>?



Habitable Worlds  
2040~2070<sup>+</sup>?

To those (understandably) concerned about events in the world today:

- HST survived 15 presidential, 30 congressional elections, 3 cancellations.
  - JWST survived 8 presidential, 16 congressional elections, 2 cancellations.
  - HST–HWO will span ~25 US presidential & 50 congressional elections.
- ⇒ Maintain the long-term vision to do LyC work 30 years from now!

**JWST is like a hot bath. It feels good while you're in it; but the longer you stay, the more wrinkled you get.**



**WARNING:** Both Hubble and James Webb are 50–60<sup>+</sup> year projects:

⇒ Maintain the long-term vision to do LyC work 30 years from now!

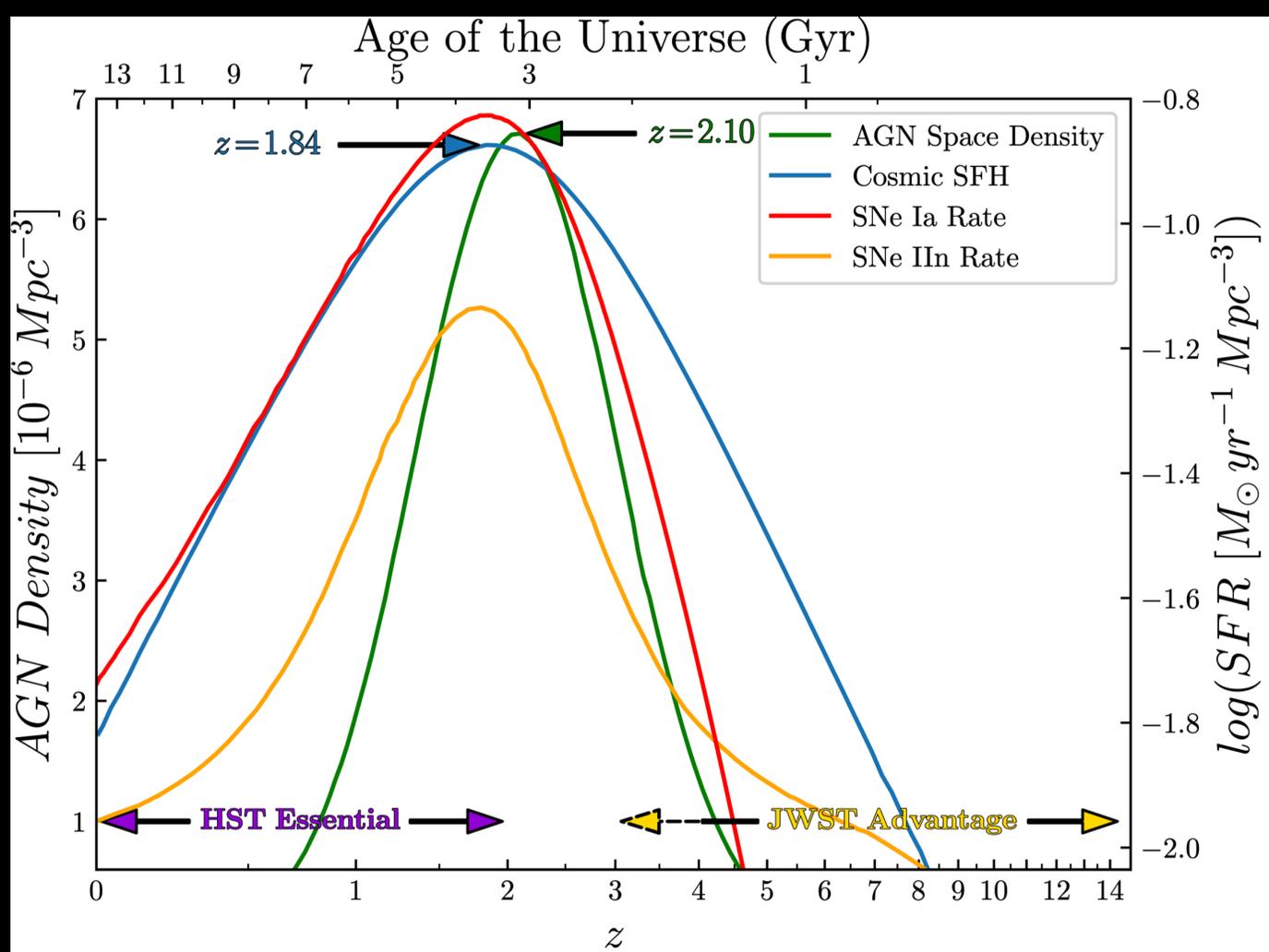
# Outline

---

- (1) Uniquely complementary roles of Hubble and Webb:  
414–500 hr combined HST+JWST images  $\Rightarrow$  keep HST alive!
- (2) Need space-based resolution for contamination-free LyC work
- (3) Habitable World Observatory requirements for LyC work
- (4) Summary and Conclusions



Sponsored by NASA/HST & JWST



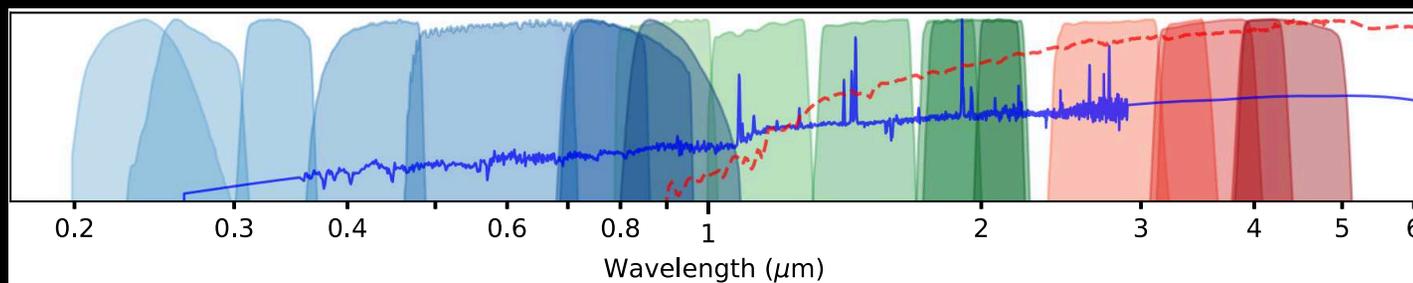
$$\text{Age} \sim \frac{13.8}{(1+z)} + \dots \text{ Gyr}$$

Active galactic nuclei (AGN)

↔ BH accretion disks

↔ Chandra X-ray sources

Star Formation, **Supernova Rate**, & **Black Hole growth peak**  $\sim 10$  Gyr ago!



$\Rightarrow$  HST best samples *unobscured* SFH & BH growth in last 10 Gyr ( $z \lesssim 2$ ),  
 while JWST best samples *obscured* parts, especially in first 3 Gyr ( $z \gtrsim 3$ ).

# (1) Uniquely complementary roles of Hubble and Webb:

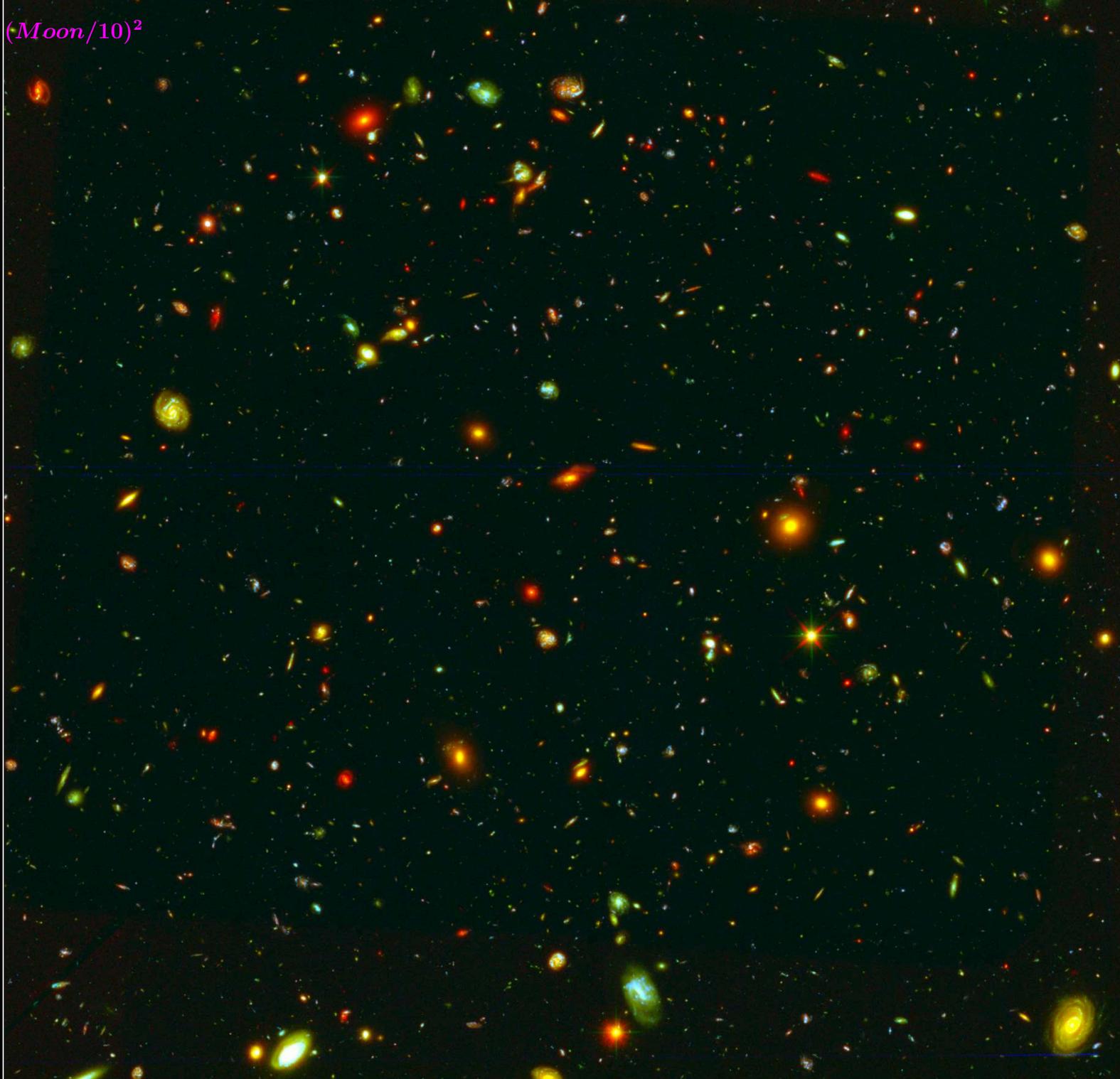


500 hrs HST+JWST: 45 filters ( $0.2\text{--}5.0\mu\text{m}$ ), lensing cluster MACS0416:

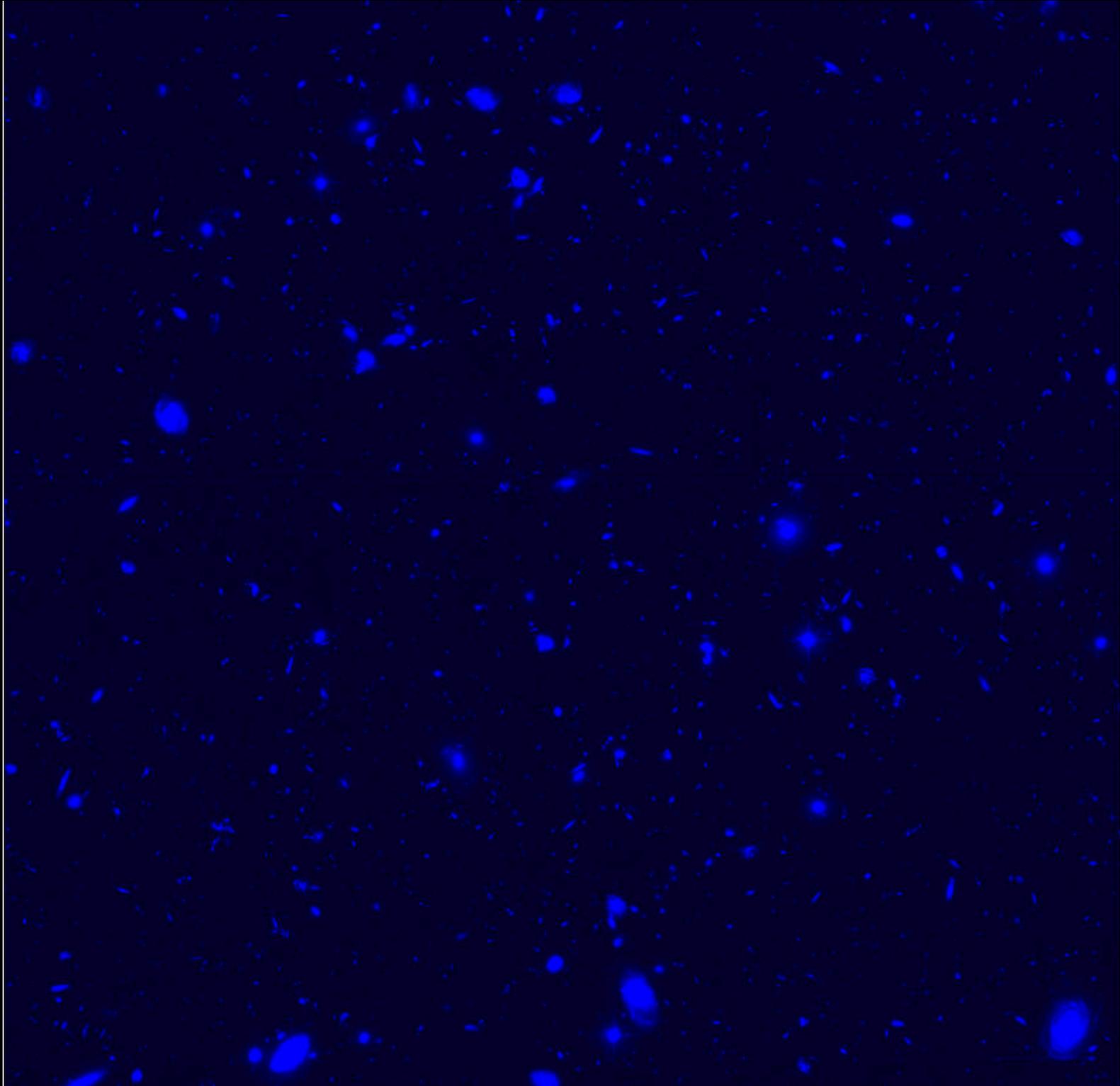
- HST darkest skies ( $10\text{--}10^3\times$  darker) + JWST's dark skies ( $10^3\text{--}10^5\times$  darker than ground based):

$\implies$  HST & JWST reach 30–31 mag ( $\simeq 1\text{ nJy} \simeq 1$  firefly from Moon).

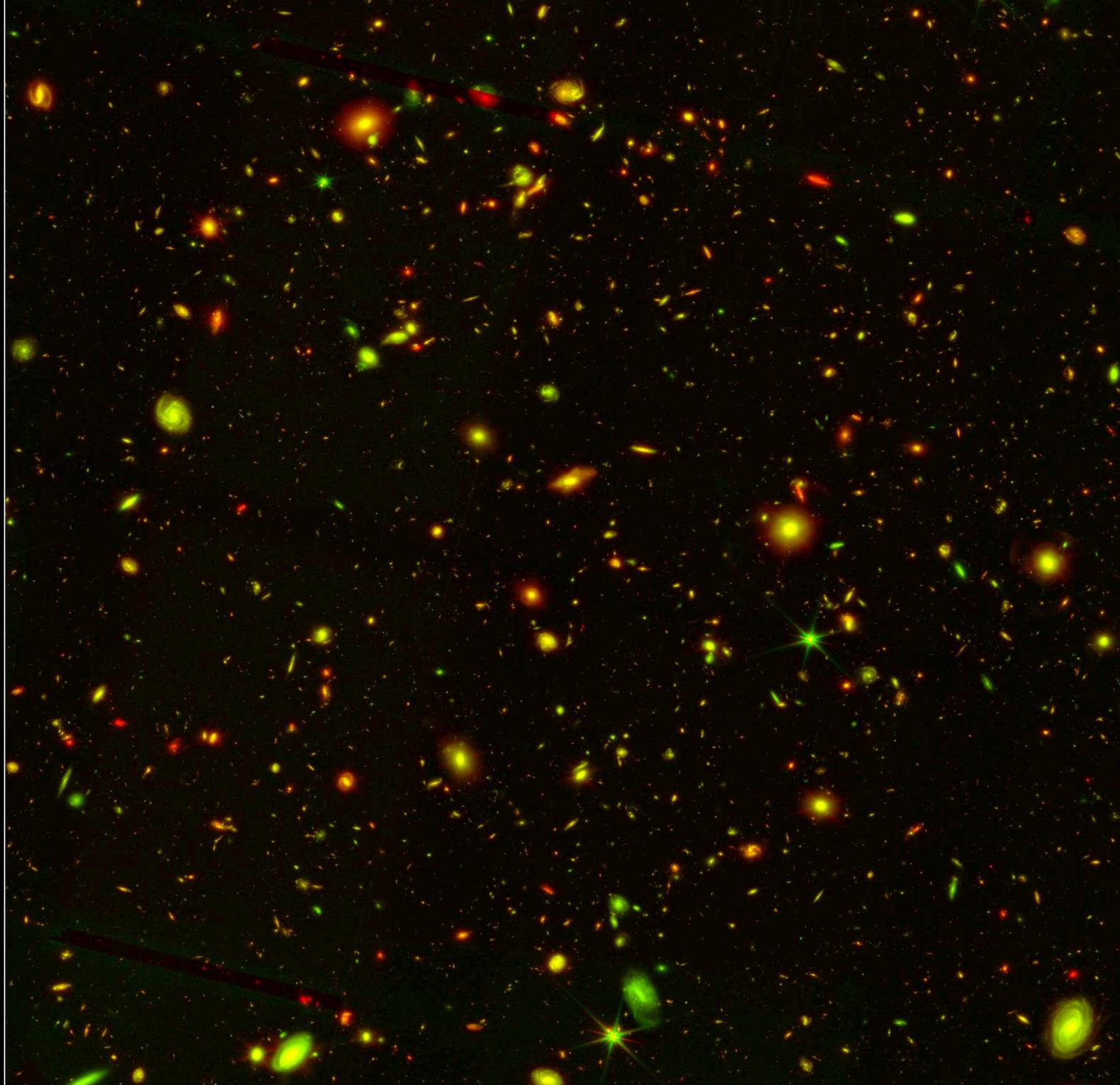
Field-of-View  $\sim (Moon/10)^2$



556 hr HST Hubble UltraDeep Field: 12 filters at 0.2–1.6  $\mu\text{m}$  ( $AB \lesssim 31$  mag;  $\sim 1$  nJy; full BGR).

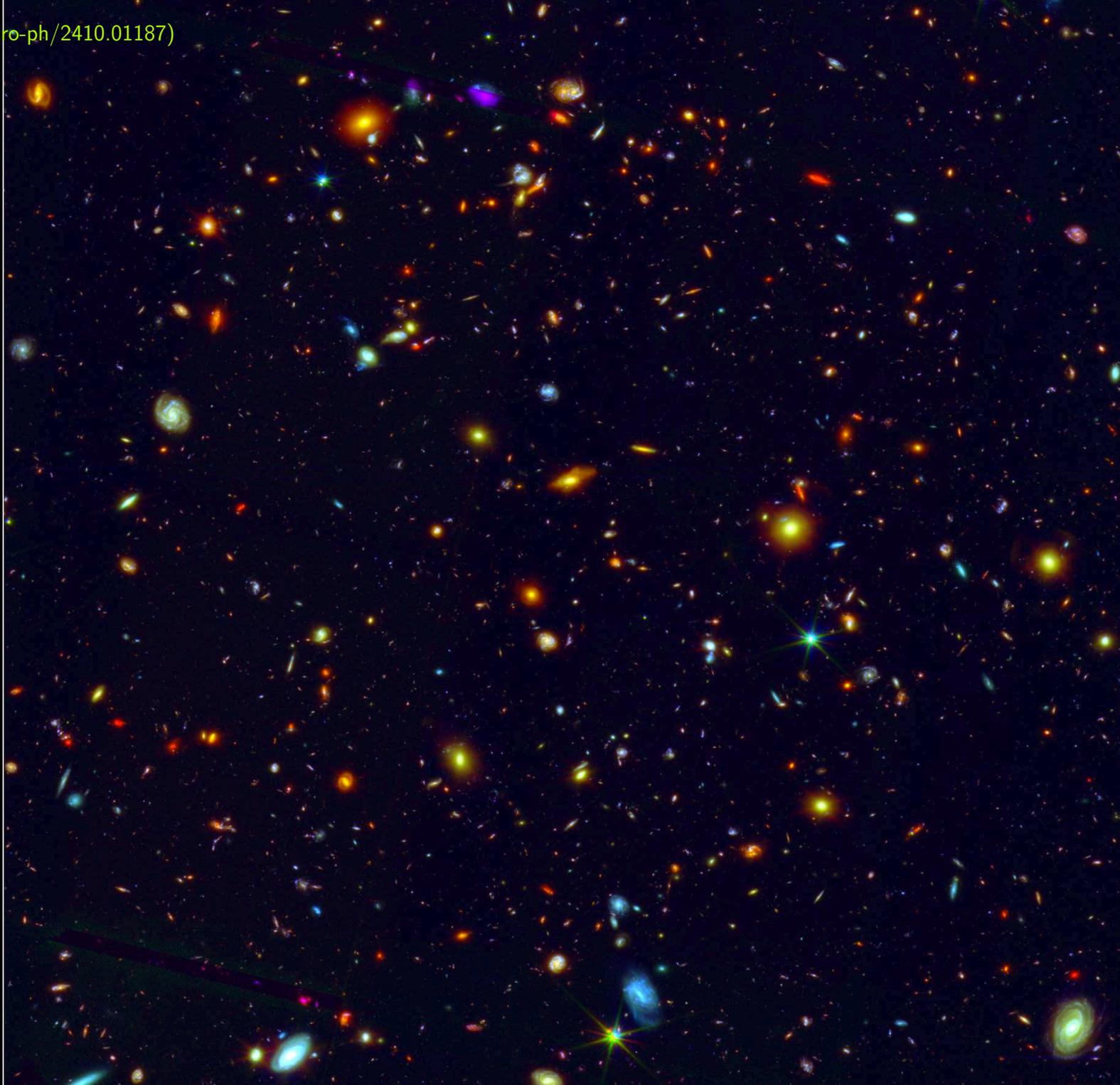


361 hr HST Hubble UltraDeep Field: 8 HST-unique filters 0.2–0.9  $\mu\text{m}$  (in false color blue).



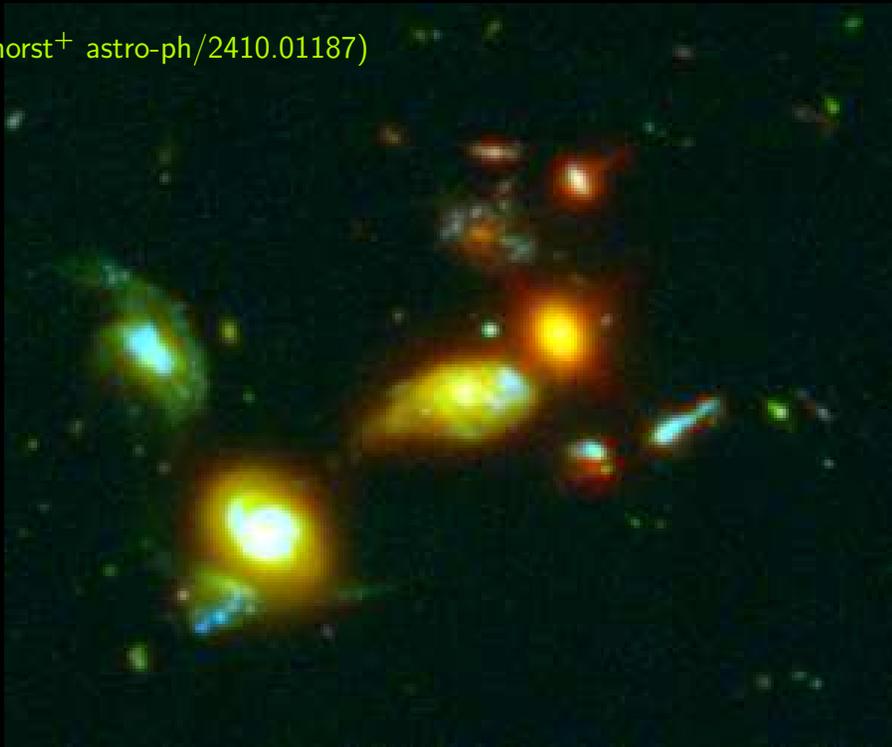
53 hr JWST/NIRCam Hubble UltraDeep Field: 12 filters at 0.9–5.0  $\mu\text{m}$  ( $AB \lesssim 31$  mag; in green + red).

(Windhorst+ astro-ph/2410.01187)

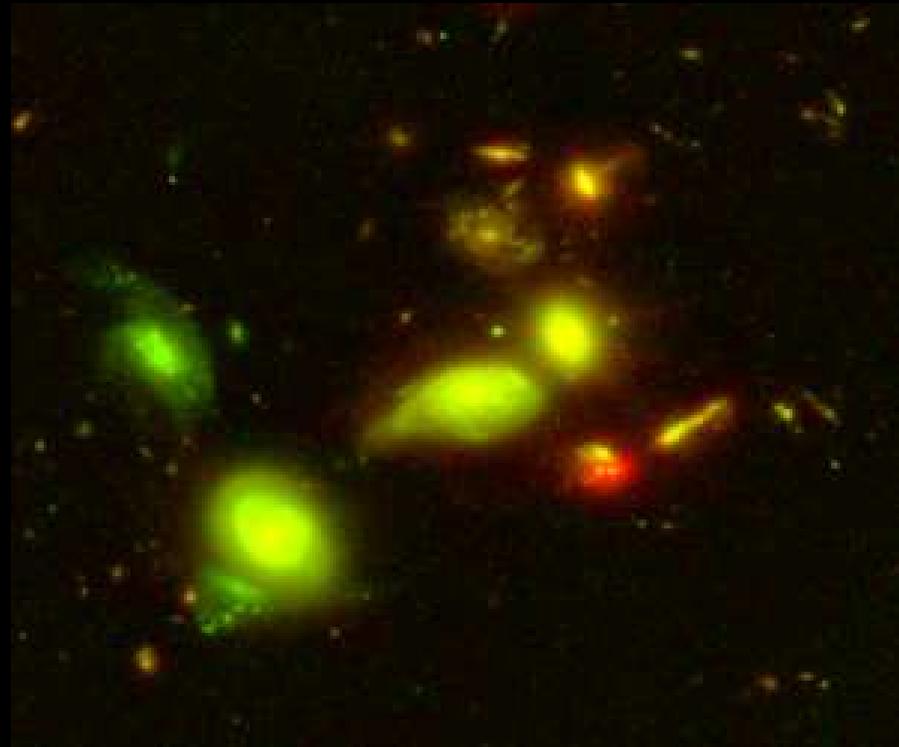


414 hr HST+JWST Hubble UltraDeep Field: 20 filters at 0.2–5.0  $\mu\text{m}$  ( $AB \lesssim 31.5$  mag; full BGR).

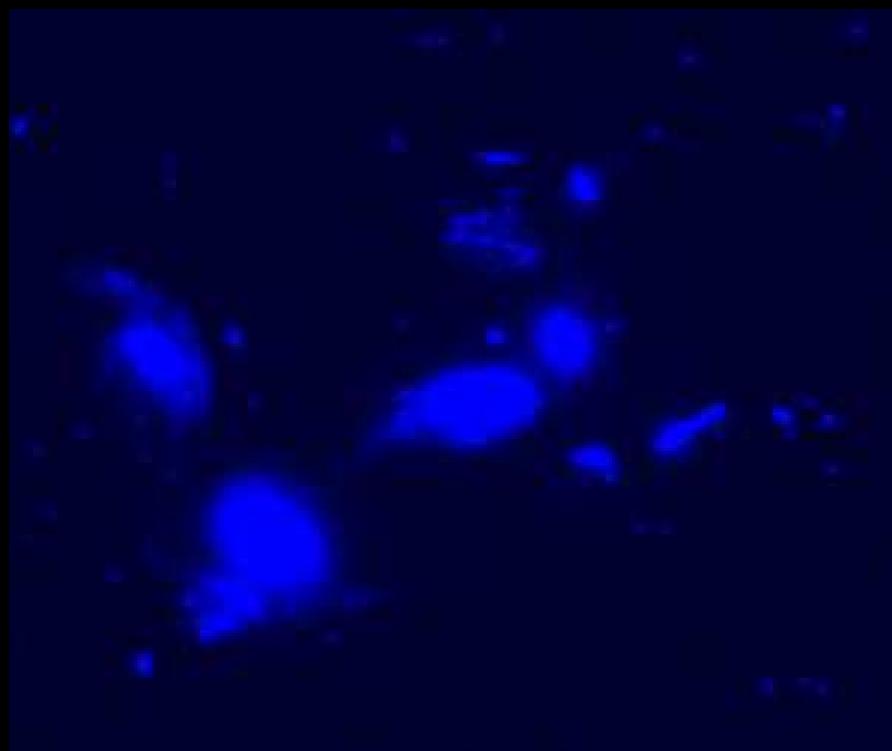
(Windhorst<sup>+</sup> astro-ph/2410.01187)



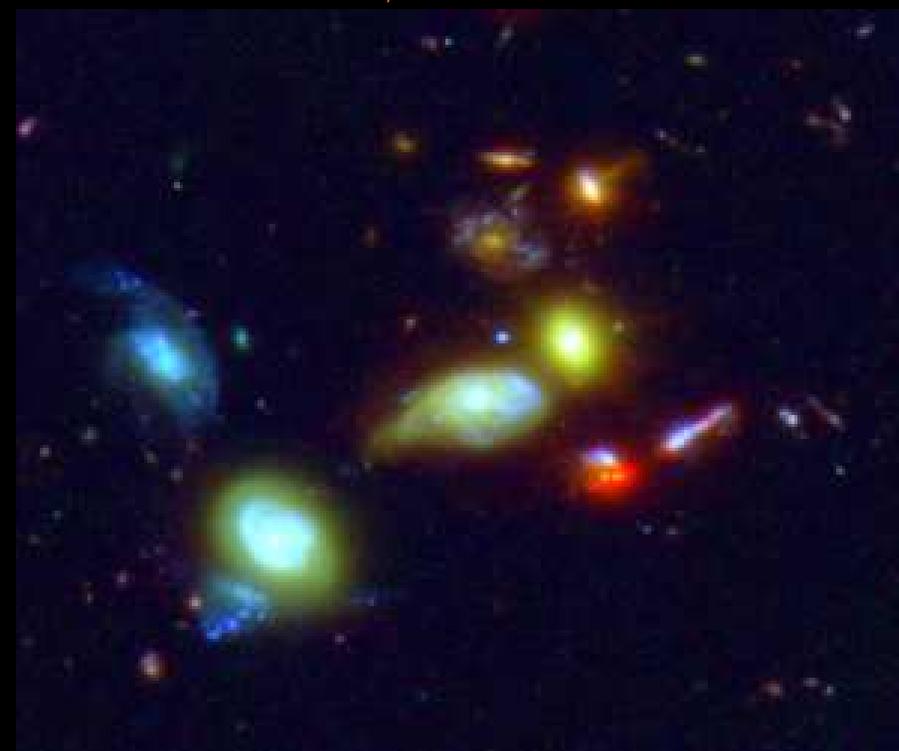
556 hr HST HUDF 12 filters



53 hr JWST/NIRCam 12 filters



361 hr 8 HST-unique filters (false-blue)



414 hr HST+JWST 20 filters

# 4-epoch 22-hr NIRCam + 122-hr HST on HFF cluster MACS0416 ( $z=0.397$ )

## It's Christmastime in the Cosmos

Astronomers have a long tradition of finding holiday cheer in outer space.

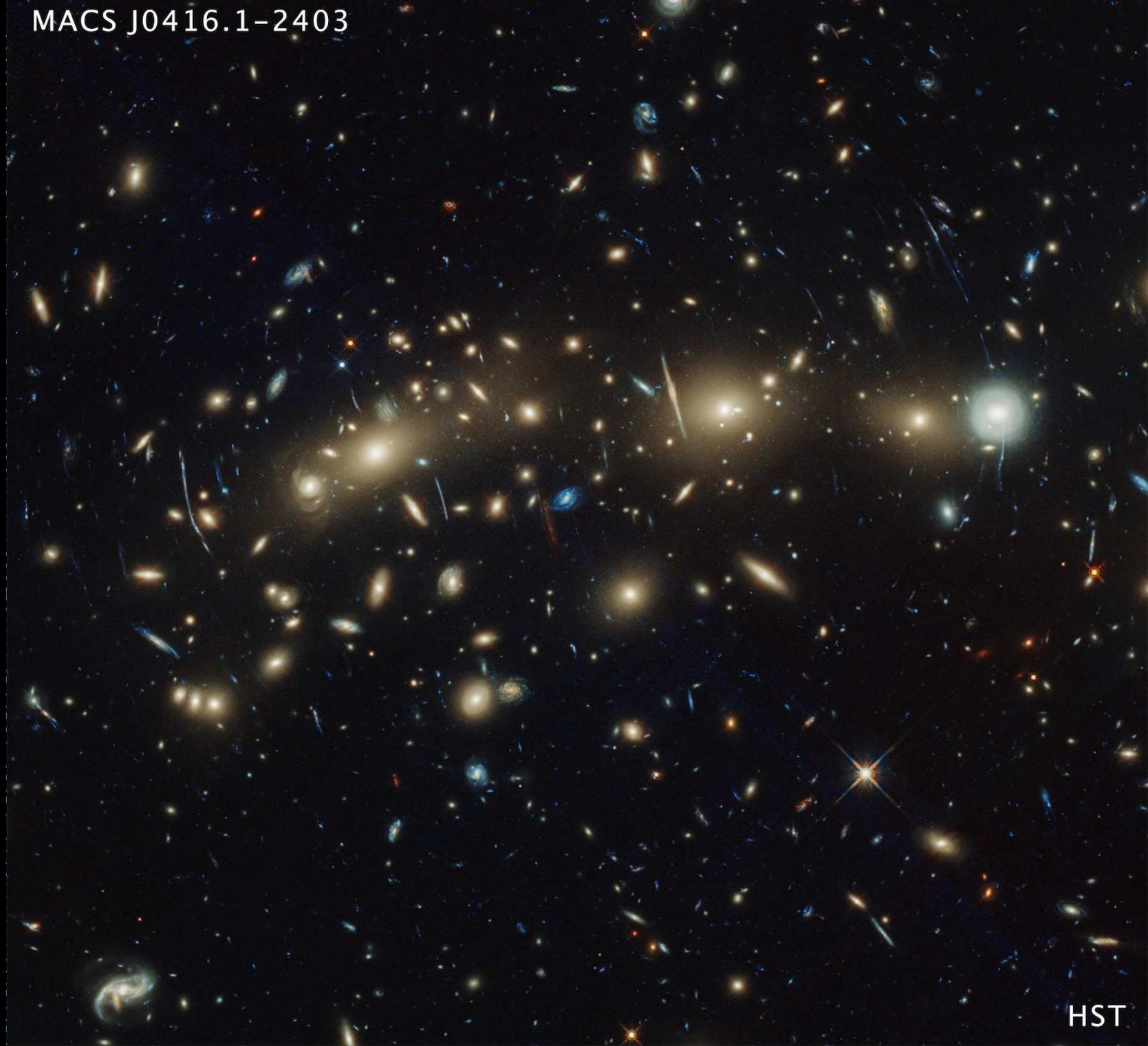
12 new caustic transits at  $z \simeq 1-2$  from 4 epochs! (Yan, H.<sup>+</sup>, 2023, ApJS, 269, 42)

Extremely magnified binary star at  $z=2.091$ ! (Diego, J.<sup>+</sup>, 2023, A&A 679, A31)

<https://www.cnn.com/2023/11/09/world/webb-hubble-colorful-galaxy-cluster-scen/index.html>

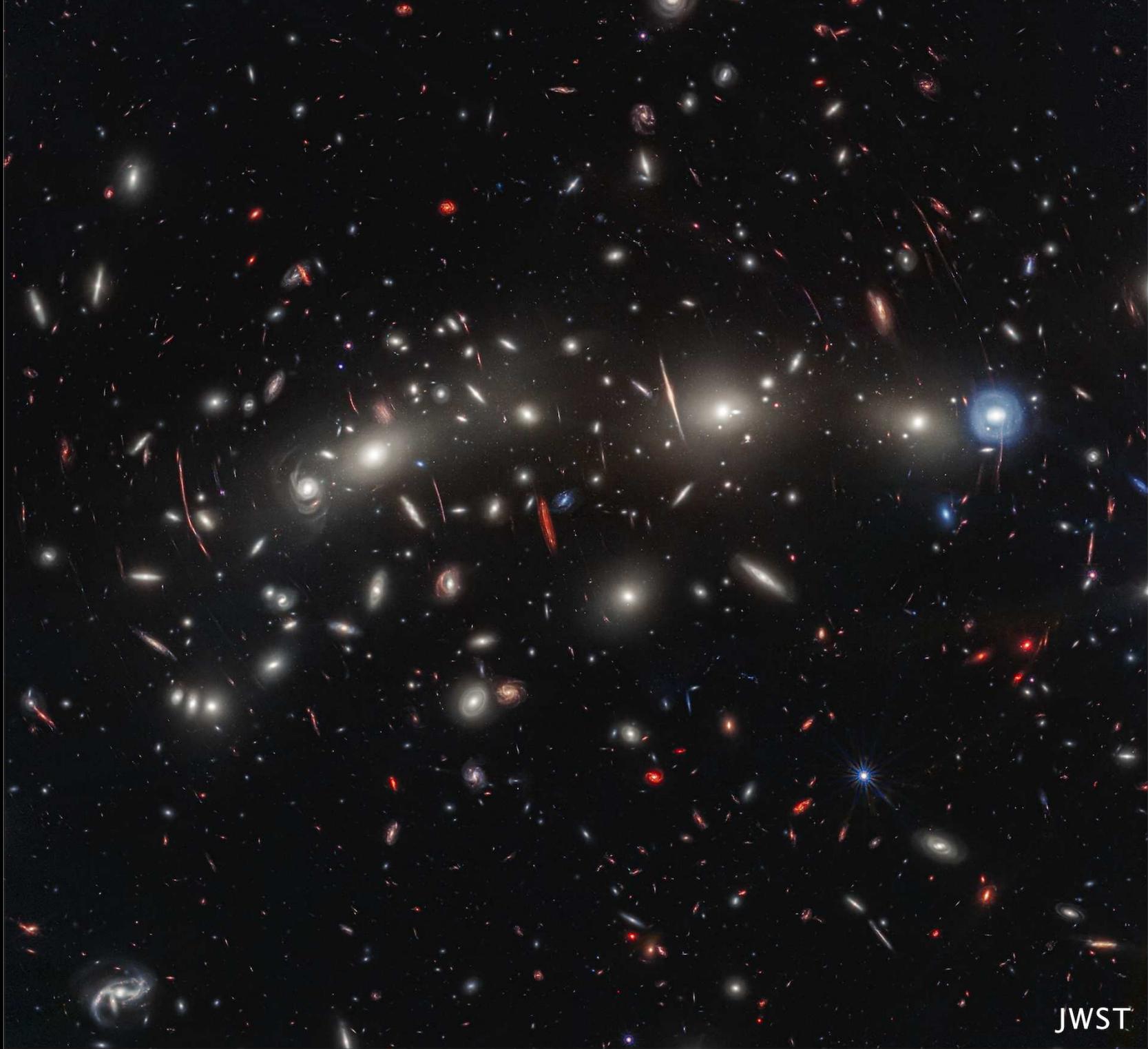
<https://www.nytimes.com/2023/12/19/science/christmas-stars-galaxies-webb-nasa.html?>

MACS J0416.1-2403



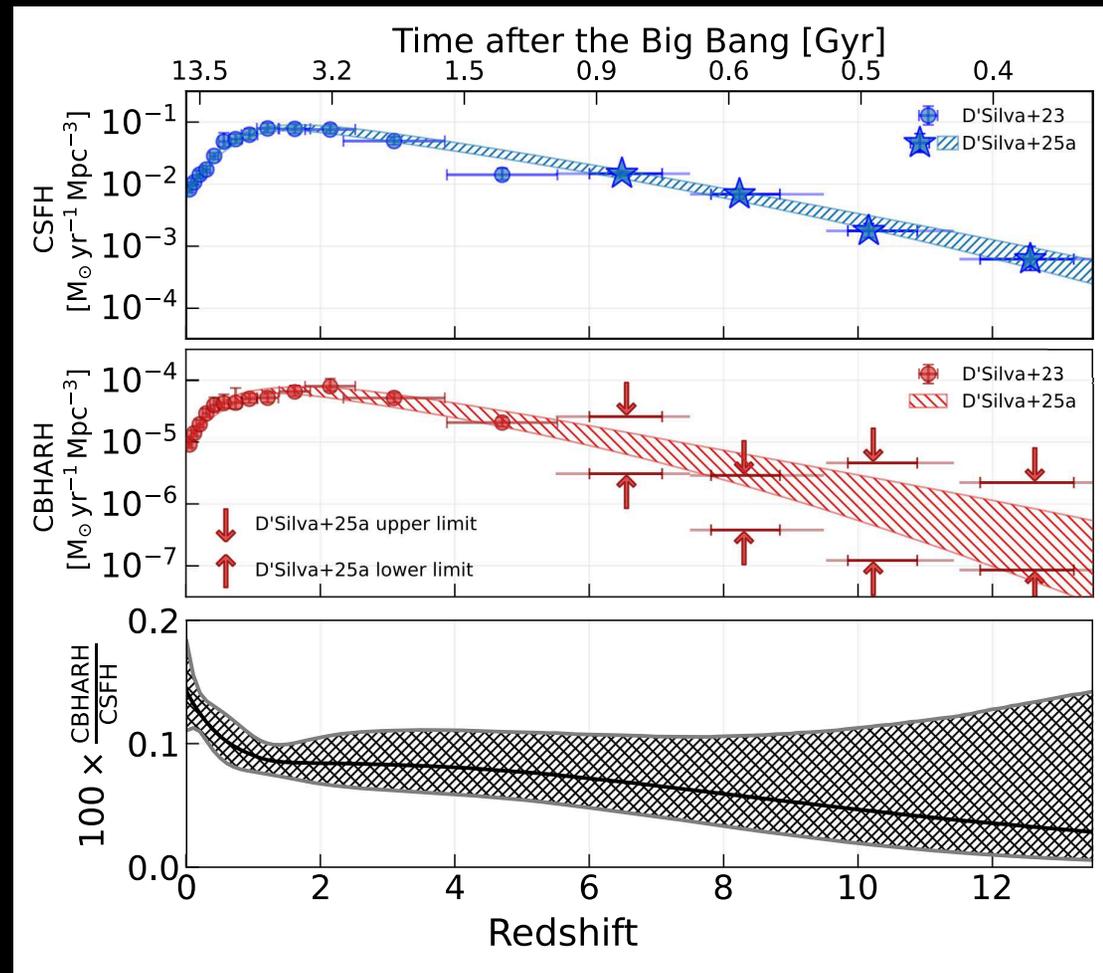
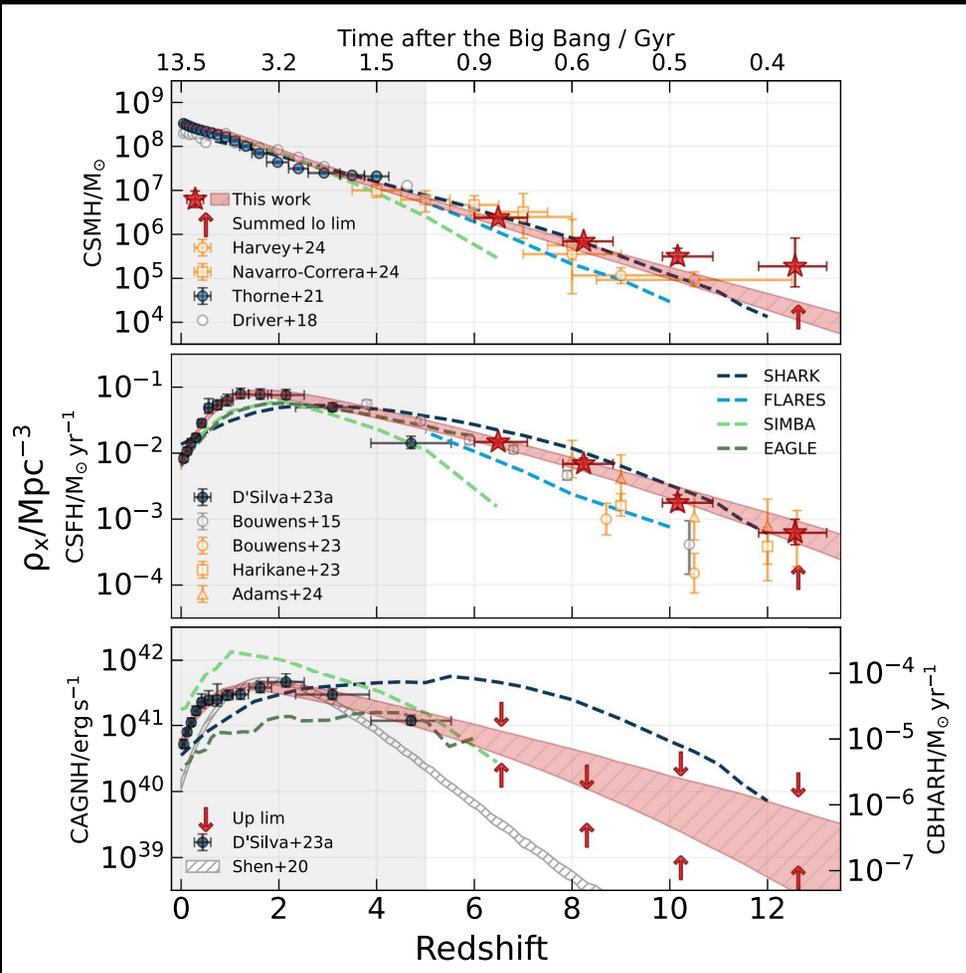
HST

122 hr HST on Hubble Frontier Field cluster MACS0416 ( $z=0.397$ ; 4.3 Blyr)



22 hrs JWST on Hubble Frontier Field cluster MACS0416 ( $z=0.397$ ; 4.3 Blyr)

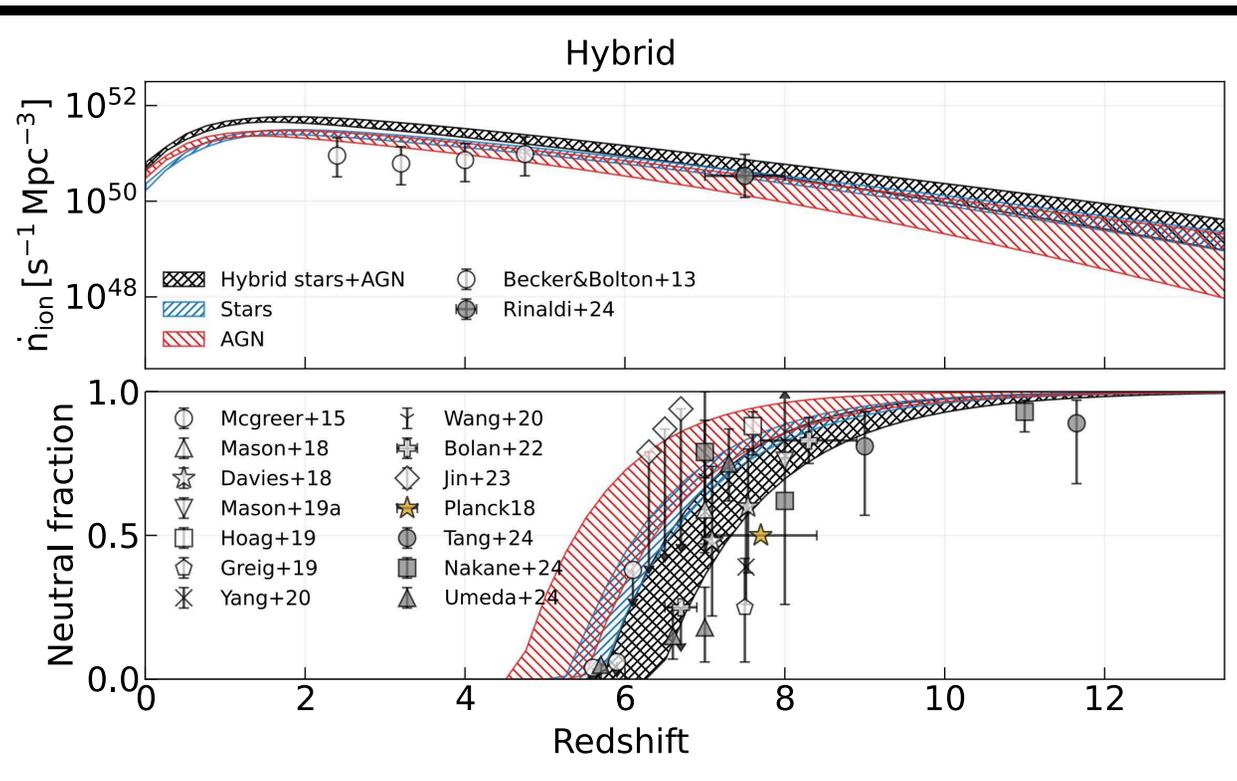
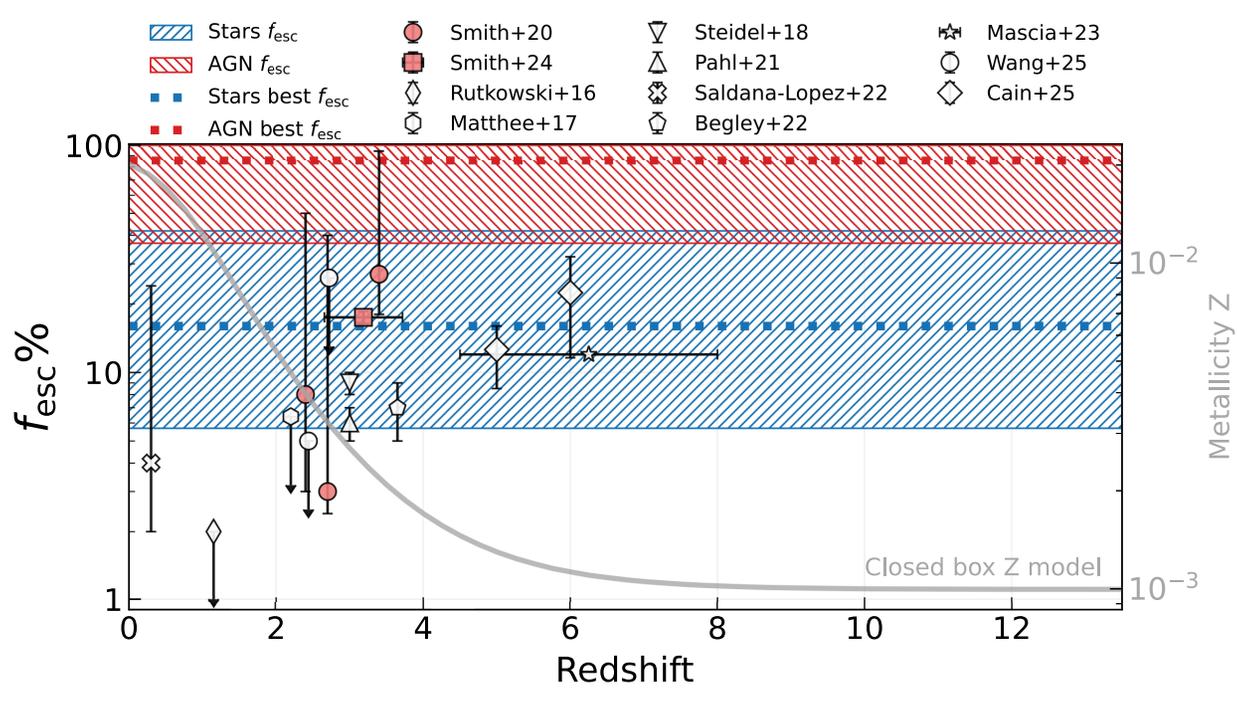
# Summary of Cosmic SFH & AGN-FH from HST+JWST:



- Cosmic SFH & AGN-FH derived from multi-band HST+JWST data:
- Use ProSpect to decompose into galaxy & AGN SEDs.

(J. D'Silva<sup>+</sup> 2023, MNRAS, 524, 1448; — 2024, ApJL, 959, L18; — 2025, A&A, astro-ph/2503.03431).

⇒ Within errors, AGN-FH/SFH  $\simeq$  constant at  $z \gtrsim 2$ , but increases at  $z \lesssim 1$ .



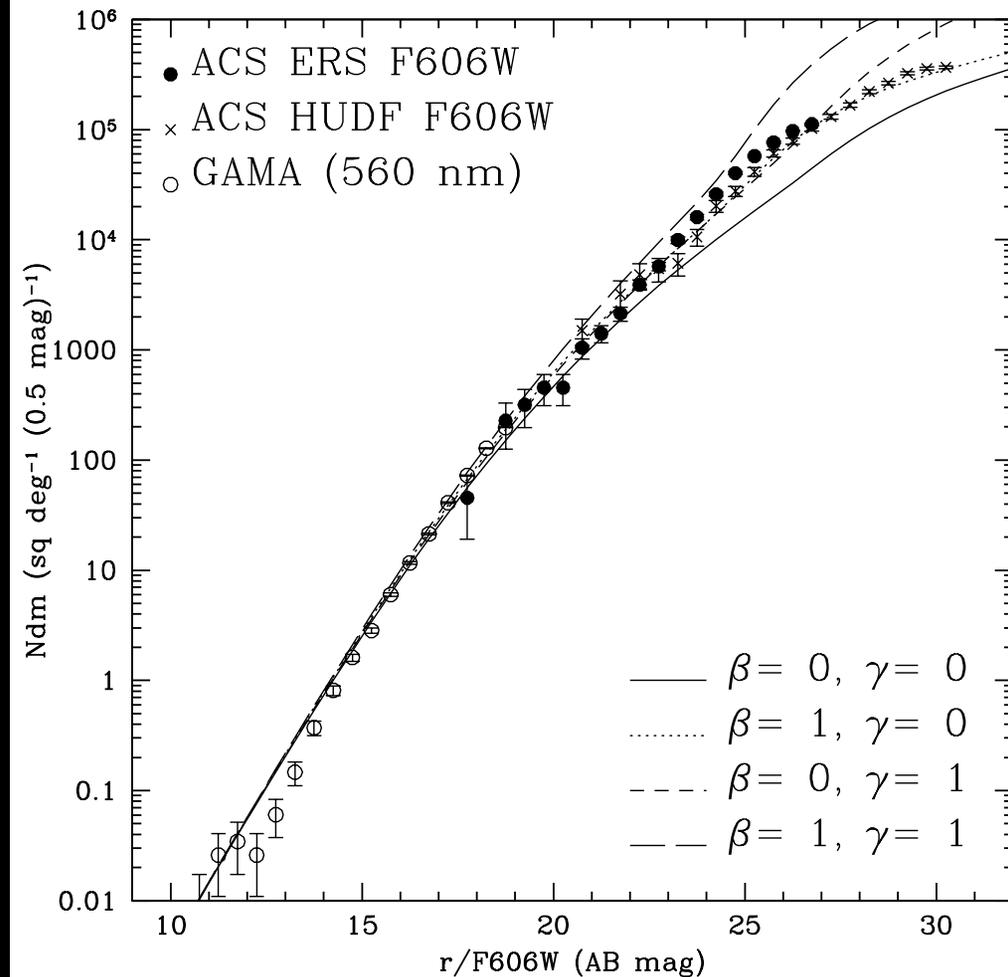
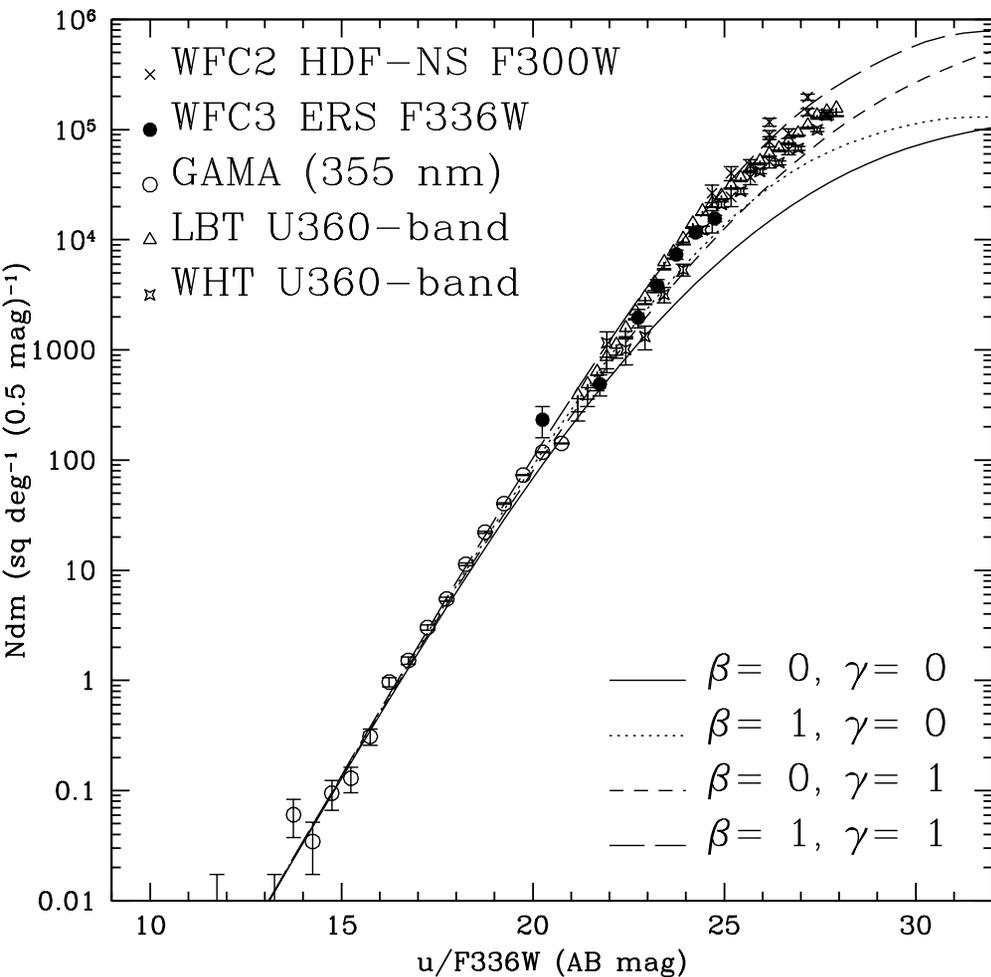
J. D'Silva+ 2025a, A&A

(astro-ph/2503.03431)

& — 2025b, in prep.

● HST+JWST's SFH & AGN-FH consistent with  $f_{esc}$ ,  $\dot{n}_{ion}$ ,  $X_{HI}(z)$ .

## (2) Need space-based imaging for contamination-free LyC work !

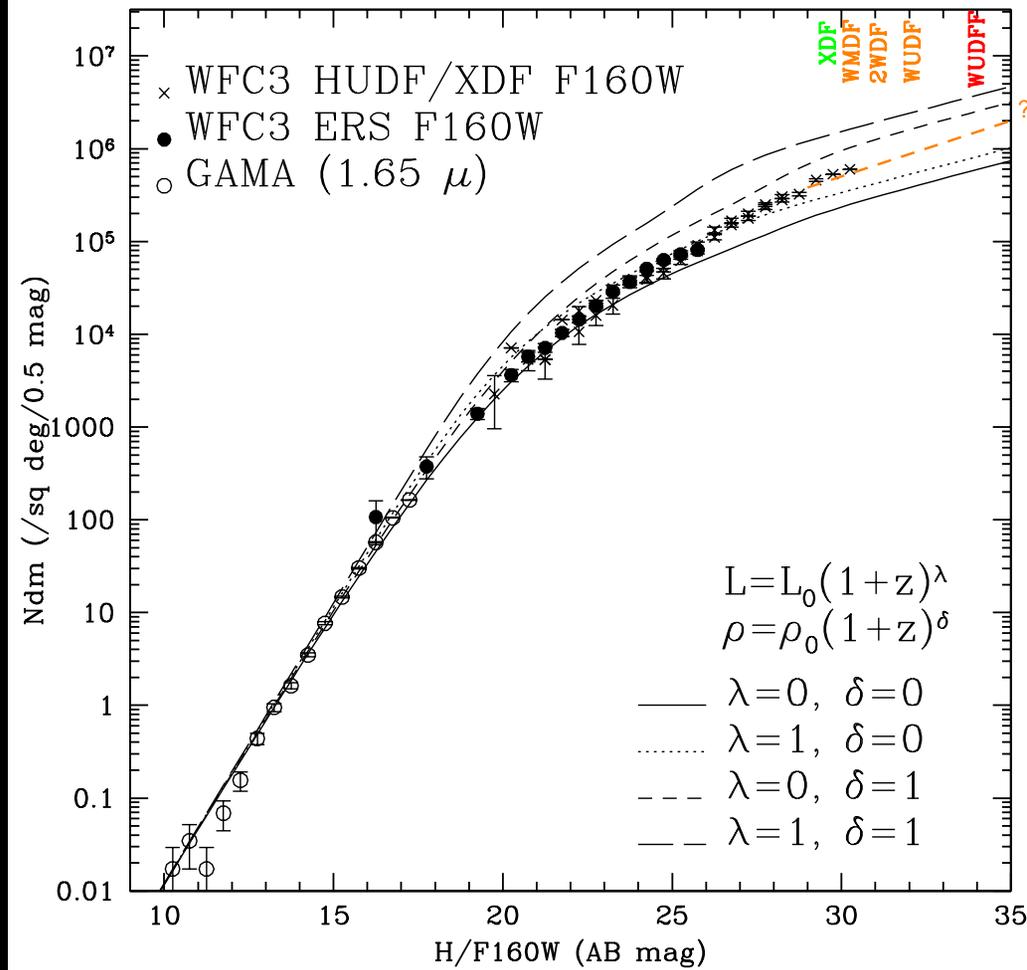
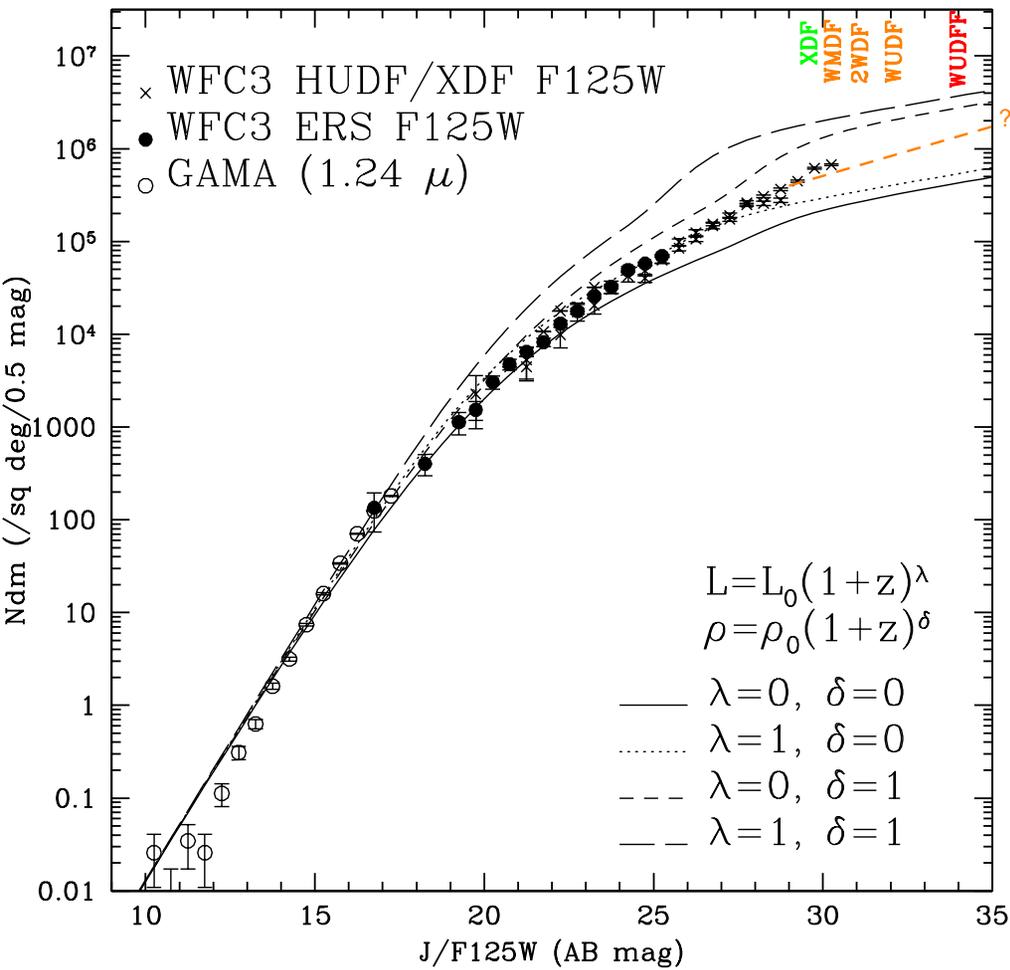


U-band and V-band galaxy counts (Windhorst<sup>+</sup>2011, ApJS, 193, 27).

Faint-end blue count-slope  $\simeq 0.30-0.40$  dex/mag.

Integrated surface density at  $AB \lesssim 31$  mag:  $3 \times 10^6 \text{ deg}^{-2}$ .

## (2) Need space-based imaging for contamination-free LyC work !



J-band and H-band galaxy counts (Windhorst<sup>+</sup>2011, ApJS, 193, 27).

Faint-end near-IR count-slope  $\simeq 0.12 \pm 0.02$  dex/mag.

Integrated surface density at  $AB \lesssim 31$  mag:  $4.2 \times 10^6 \text{ deg}^{-2}$ .

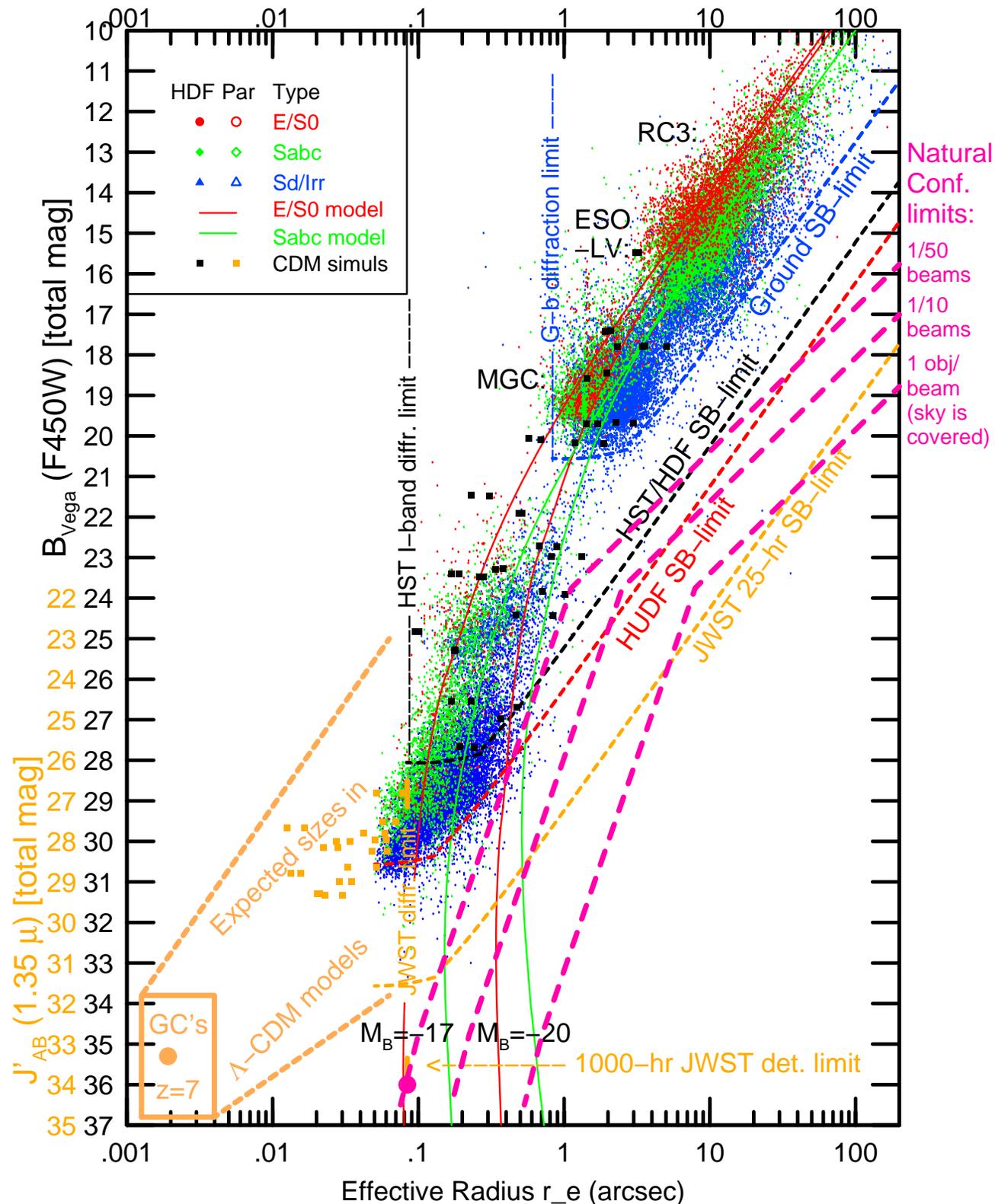
B, I, J AB-mag vs. half-light radii  $r_e$  from RC3 to HUDF.

All surveys limited by SB (+5 mag dash)

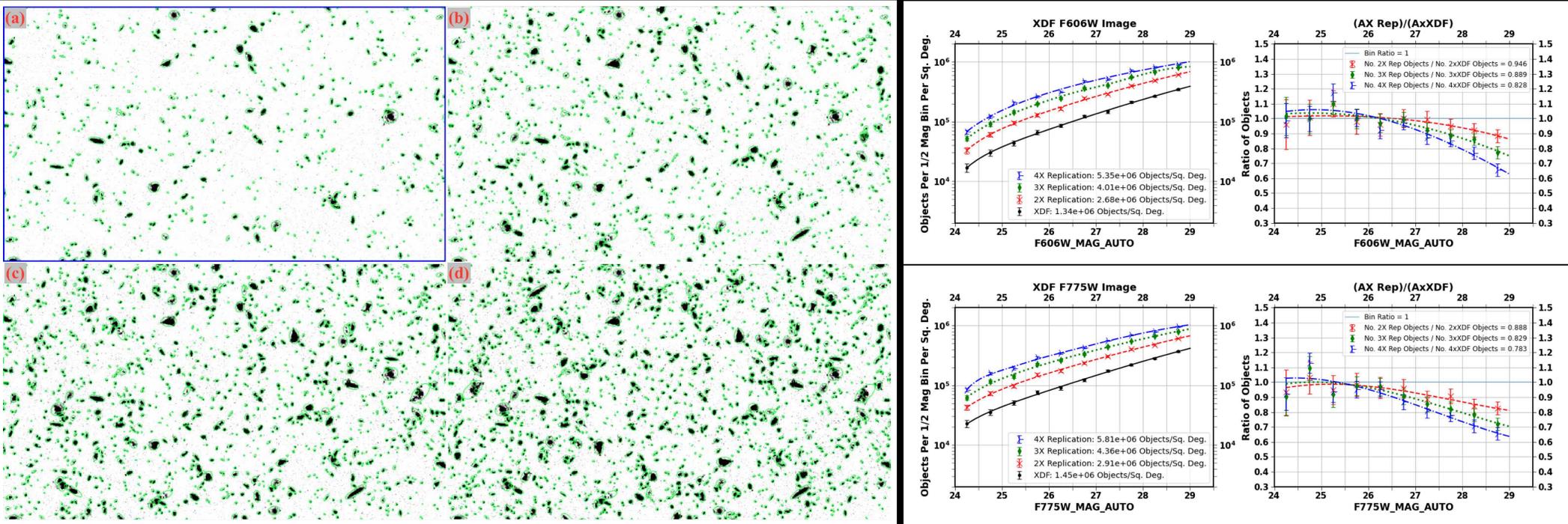
Deep surveys bounded also by object density:

violet lines are gxy counts converted to natural conf limits.

Since  $UVC/LyC \lesssim -3.7$  mag, LyC imaging must avoid contaminants at all costs!



# How much does deep-field object-overlap affect reliable LyC detections?



[Left]: Add HUDF image to itself  $2\times$ ,  $3\times$ ,  $4\times$  after  $n\times 90^\circ$  rotation:

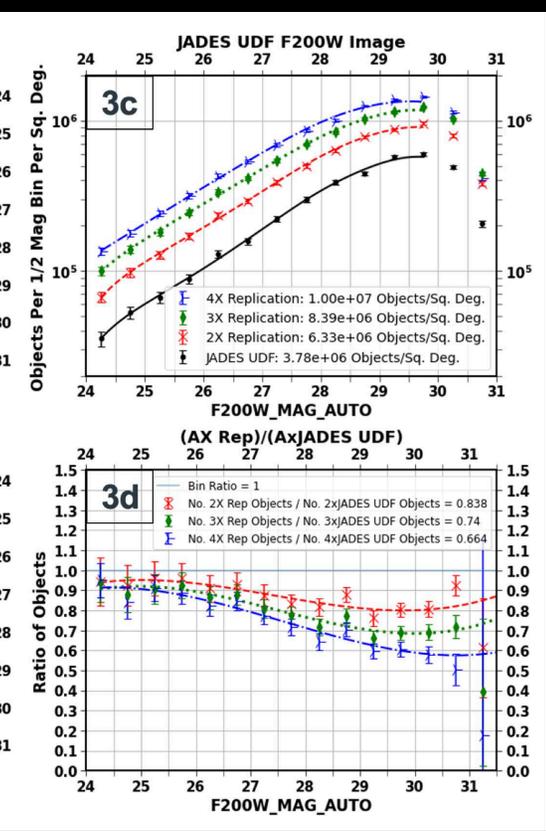
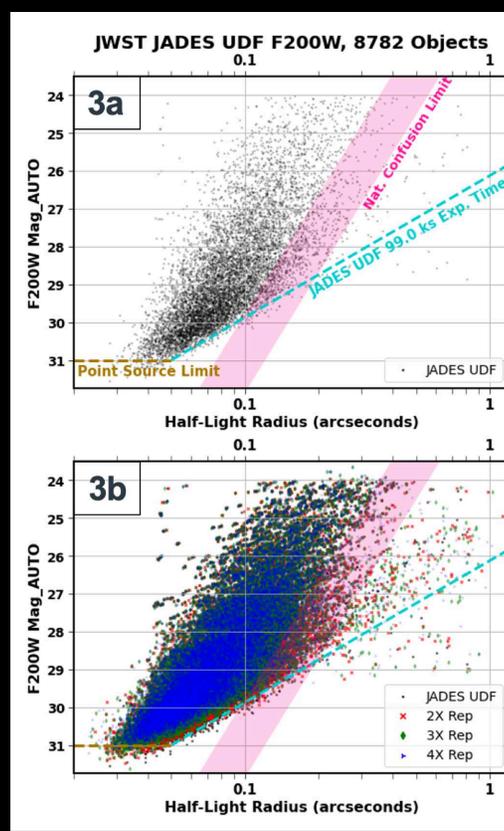
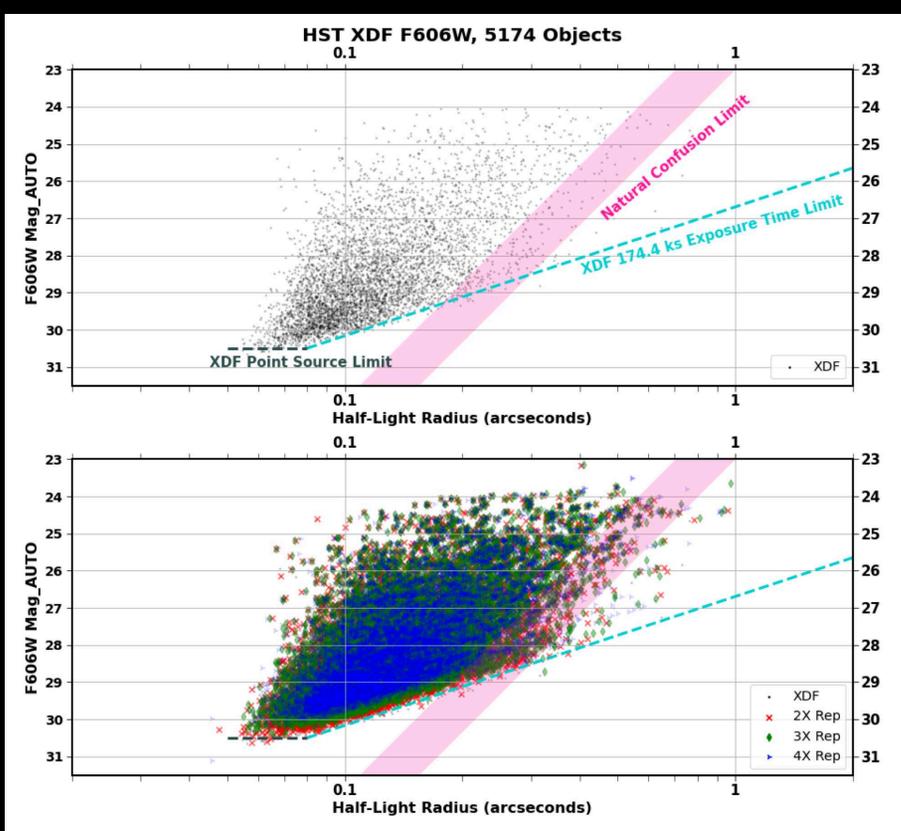
[Right]:  $4\times$  HUDF counts still  $\gtrsim 65\%$  complete for  $AB \gtrsim 28.5-29$  mag.

(Kramer, D.<sup>+</sup>, 2022, ApJL, 940, L15; astro-ph/2208.07218v2).

- Natural confusion ( $\neq$  instrumental confusion): increasing inability of object detection algorithms to deblend extended galaxies at  $AB \gtrsim 24$  mag.

- $3-4 \times 10^6$  galaxies/deg<sup>2</sup> at  $AB \lesssim 31$  mag with  $r_{hl} \lesssim 0''.1-0''.2$  FWHM.

(Windhorst<sup>+</sup> 2008, Adv. in Space Res., 41, 1965 (astro-ph/0703171); — 2011, ApJS, 193, 27; — 2022, AJ, 164, 141; — 2023, AJ, 165, 13; see also Fernando Buitrago's talk).



Top: mag vs  $r_e$  for 174 ksec XDF (left) & 99 ksec JADES (middle) galaxies.  
 Bottom: Same for XDF & JADES rotated+replicated onto itself 2x, 3x, 4x.

Right: Counts and completeness functions for 2x, 3x, 4x rotated images.

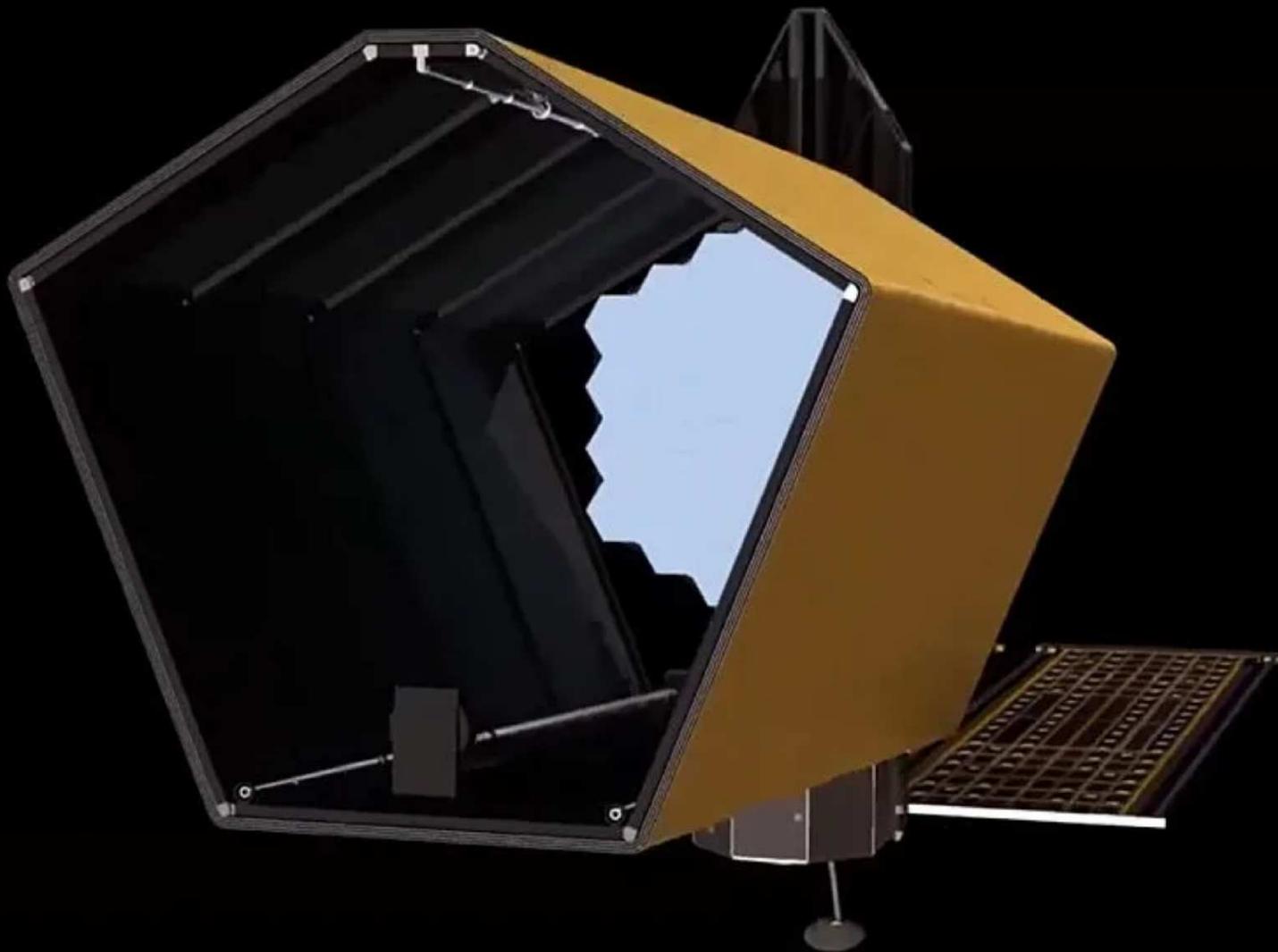
•  $\lesssim 35\%$  of faintest galaxies lost due to statistical object overlap.

(Kramer, D.<sup>+</sup>, 2022, ApJL, 940, L15; astro-ph/2208.07218v2).

$\Rightarrow$  LyC work at UVC  $\sim 24-27$  must avoid contaminants with AB  $\lesssim 28-31$  mag!

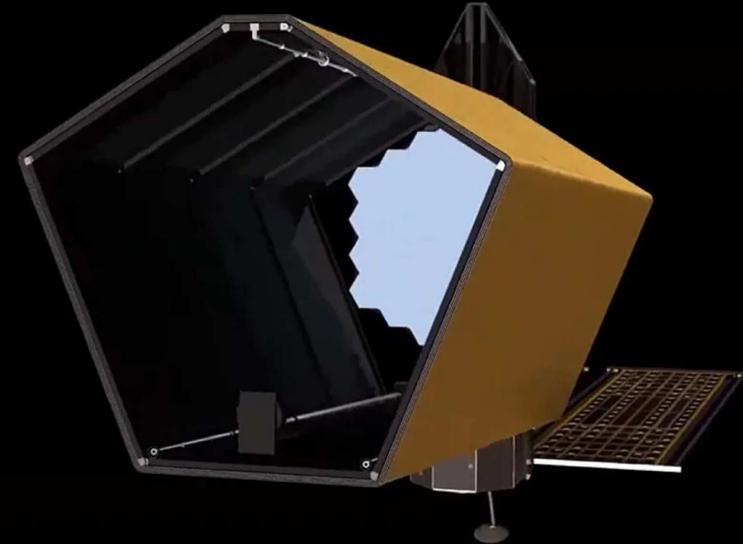
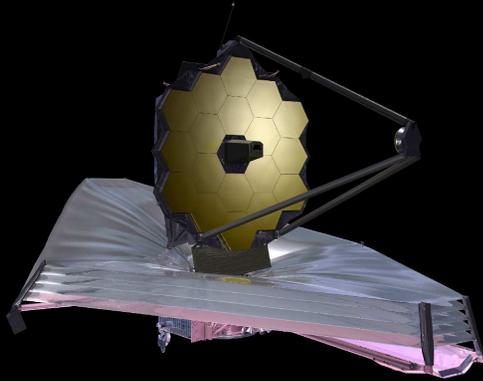
JWST: 1" LyC apert  $\lesssim 30\%$  contaminated by foreground UVC  $\lesssim 31$  mag!

### (3) Habitable World Observatory requirements for LyC work



- Next generation  $\gtrsim 6\text{--}8$  meter UV-optical space telescope (HWO) essential for  $AB \lesssim 30$  detections and  $AB \sim 32$  mag for LyC stacks ( $N \gtrsim 10^4$ ).
- Need: L2 servicing, periodic CCD replacement, & wide-field UV IFU/MSA.

Past, Present and Future: Can and will the dream continue?  
 True relative size: Hubble, James Webb, Roman, & HWO



1973–2034+(!)

1996–2046+

2012–2037?

2025–2070+?

Launch: 1990

2021

≥2027

≥2040?

$\Sigma_{FC}$ : ≥20 B\$

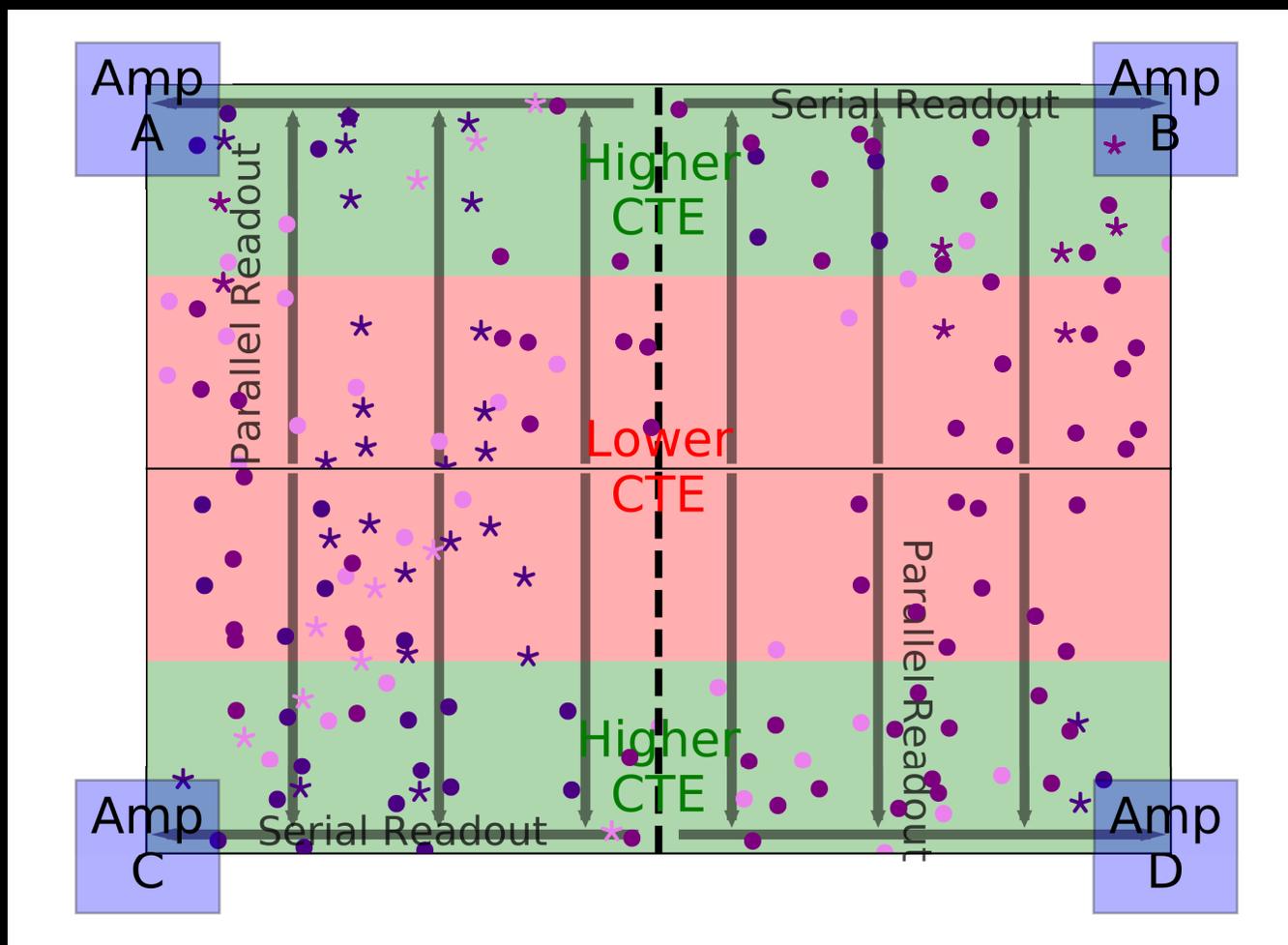
≥10 B\$

~3 B\$

15–20 B\$?

- My goal today: Inspire the younger folks in the audience to successfully build the Habitable Worlds Observatory (HWO).

Many speakers this conference already talked about future prospects, amongst others: Pratika Dayal, Andrea Grazian, Sara Mascia, Ivan Nikolić, Allison Strom, Ana Sofia Uzsoy, Alessandra Venditti, and others.



B. Smith+ (2018  
& ApJ, 853, 191)

Main CCD LyC limitation: Charge-Transfer Efficiency (CTE) degradation.  
 “Higher-CTE” & “Lower-CTE” sub-samples for WFC3/UV filters.

- Green regions are closest to parallel read-out amplifier. Red regions are furthest from amplifiers, and suffer more from CTE-degradation.
- CTE-degradation may be mitigated by s/w corrections (Anderson 2016, 2021).
- CTE-loss linear with time/CR-flux: need CCD replacement every 10 yrs!

# Summary of lessons learned from JWST:

## What is required to make Mega-Science projects succeed?

---

- JWST Lessons: Mega-project lessons also apply to HST & HWO. Key is that scale of efforts goes beyond what people are used to.
- Mega-projects demand new rules, in particular regarding building and keeping together a *strong Coalition* of project supporters and advocates.

Consumers Report: Very Good  $\Rightarrow$  Good  $\Rightarrow$  Neutral  $\Rightarrow$  Fair  $\Rightarrow$  Poor.

- (A) Scientific/Astro-Community Lessons
- (B) Technical Lessons
- (C) Management/Budget/Schedule Lessons
- (D) Political/Outreach Lessons

*I thank Drs. S. Cohen, G. Illingworth, R. Jansen, J. Mather, E. Smith, R. Smith & H. Thronson for comments.*

Full 1-hr talk is on: [http://www.asu.edu/clas/hst/www/jwst/jwsttalks/fall2020\\_jwstlessons.pdf](http://www.asu.edu/clas/hst/www/jwst/jwsttalks/fall2020_jwstlessons.pdf)



- Infighting killed the 1988 Superconducting Supercollider in Texas (left).
- Canceled project funds never returns: CERN didn't make that mistake (right).
  - ⇒ Avoid infighting with other (exoplanet) HWO stake-holders.
- Design HWO for exoplanets, reionization, and everything in between.

## Summary: Main Lessons from the JWST Project:

(1) Mega-projects demand new rules, in particular regarding building and keeping together a *strong Coalition* of project supporters and advocates:

### (A) JWST Scientific/Astro-Community Lessons:

- 1) Project is a must-do scientifically and cannot be done any other way.
- 2) Keep advocating Mega-project to community until launch/first light.
- 3) Don't ignore importance of communication with patrons: Scientists, international partners, contractors, tax-payers, Congress, White House.
- 4) Don't have community infighting ("My mission is better than yours"  
— One key reason for Supercollider (SSC) demise).

### (B) JWST Technical Lessons:

- 1) Use advanced technologies being developed elsewhere, if possible.
- 2) Know when not to select the most risky technologies.
- 3) Do your hardest technology development upfront. Have all critical components at TRL-6 before Mission Preliminary Design Review (PDR).

### (C) JWST Management/Budget/Schedule Lessons:

- 1) Make conservative full end-to-end budget before Mission CDR.
- 2) Make sure budgets are externally reviewed, and at  $\gtrsim 80\%$  joint cost+schedule confidence level. (Could not do  $\lesssim 2010$ ; Did so early 2011).
- 3) Plan & effectively use 25–30% (\$+schedule!) contingency each FY.

### (D) JWST Political/Outreach Lessons:

- 1) Assemble, maintain and fully use a broad Coalition of supporters and advocates who will fight for the project (SSC did so too late).
- 2) Have strong multi-partisan & multi-national support for project.
- 3) Strong technology benefits/lessons *TO* other parts of government.
- Today, JWST *is* the telescope that the community asked for almost 30 years ago, and has become an amazing reality. JWST has become the most-in-demand NASA Astrophysics mission ever (see spare charts).

OVERALL CONCLUSION: JWST was built and launched right, but we had to learn our lessons over 25 years.

## (4) Summary and Conclusions

- (1) HST and JWST uniquely complement each other to trace cosmic star-formation and (supermassive) black-hole formation over 13.5 Gyr.
- (2) Need space-based resolution for contamination-free LyC at  $z \simeq 2.3\text{--}3.5$ 
  - Design HWO filters with low-enough redleak to enable this.
  - Deepest multi-band images to mask foreground  $AB \lesssim 31$  mag interlopers.
- (3) Habitable World Observatory requirements for LyC work:
  - L2 servicing every 5–10 years or so — is feasible to L2.
  - Wide-field UV sensitized CCDs with periodic replacement in L2.
  - Wide-field UV IFU, & UV MSA Spectrograph — needs development.
- (4) Coherent team: design HWO for science from exoplanets to reionization.

# Spare charts — Conference Summary: Smoking Guns of Cosmic Reionization



Bronze “Falcon” gun in Heraklion’s Historical Museum ...

- LyC from (weak) AGN with outflows !



Venetian fortress Spinalonga in Elounda, Crete ...

- LyC from galaxies with (small holes !

- Reionization by LyC escaping from Galactic fortresses with small holes!

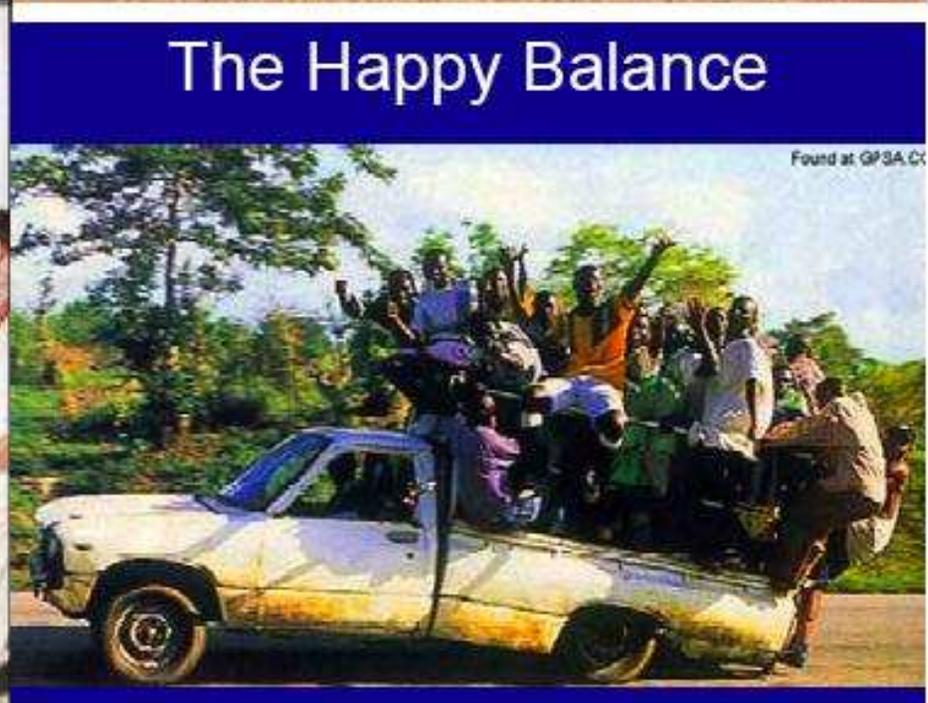
What the Scientists See:



What the Project Manager Sees:

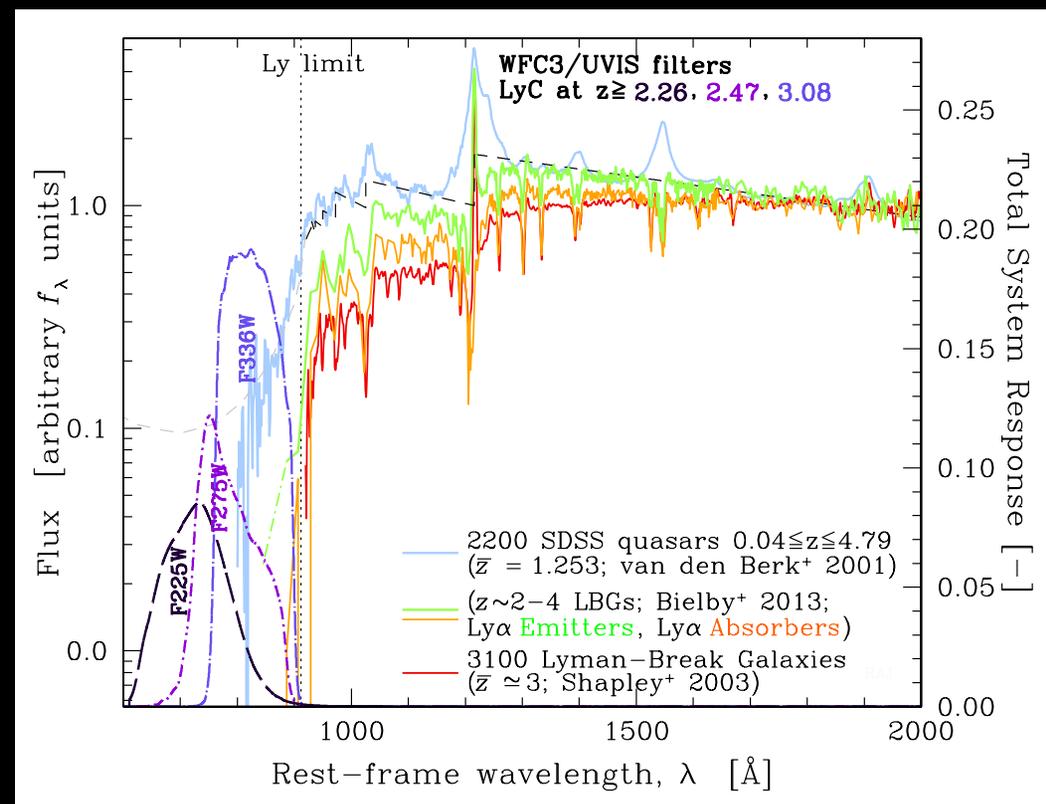
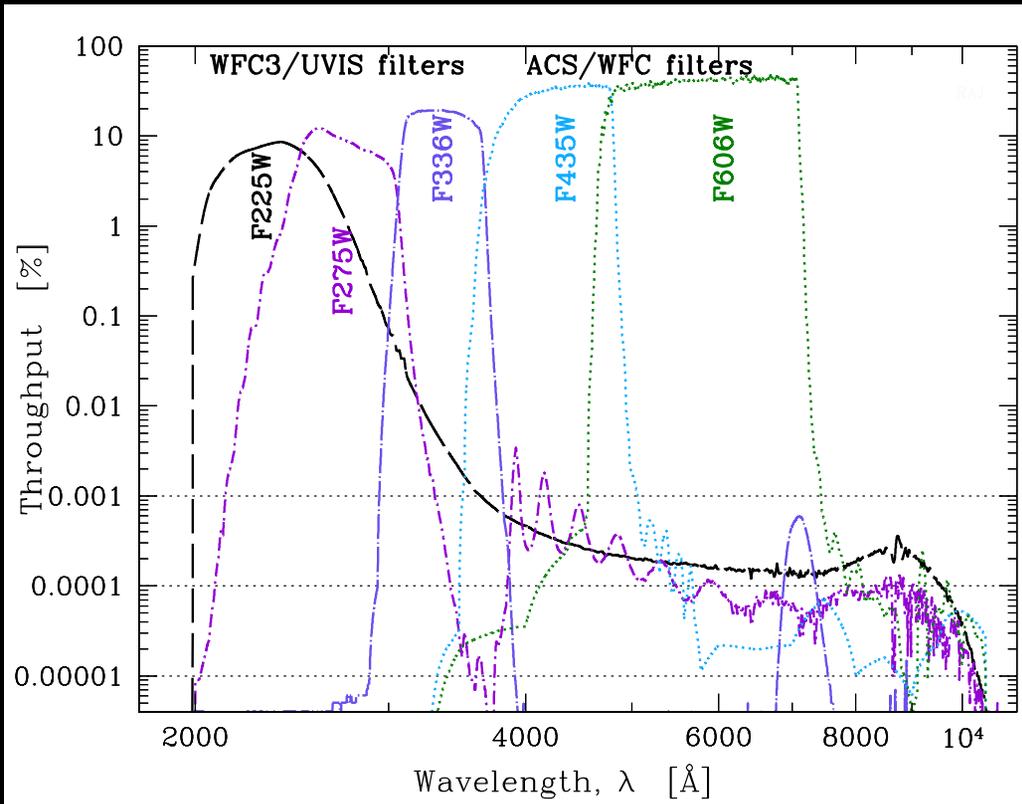


The Happy Balance



Any (space) mission is a balance between what science demands, what technology can do, and what budget & schedule allows ... (courtesy Prof. R. Ellis).

● HST WFC3/UVIS Constraints of LyC at  $z \sim 2.2-3.5$  (Smith<sup>+</sup> 2018).

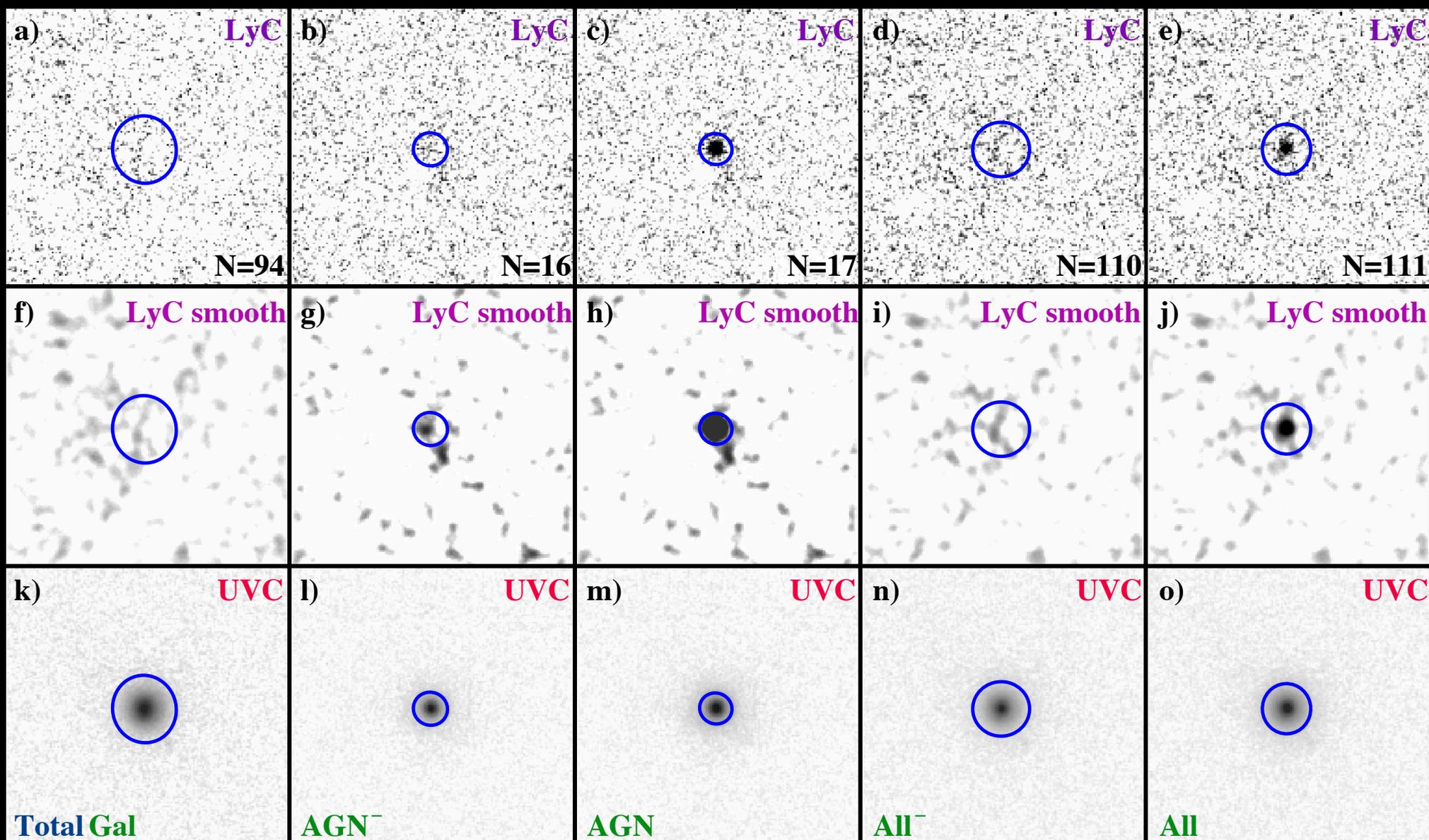


[Left] WFC3 designed to maximize throughput and minimize red-leak:

- Red-leaks  $\lesssim 3 \times 10^{-5}$  of peak transmission, or  $\lesssim 0.6\%$  of LyC signals.

[Right] Composite rest-frame far-UV spectra of: SDSS QSOs at  $z \simeq 1.3$ ; LBGs at  $z \simeq 2-4$ : Ly $\alpha$  emitters, & absorbers; & LBGs at  $z \simeq 3$ .

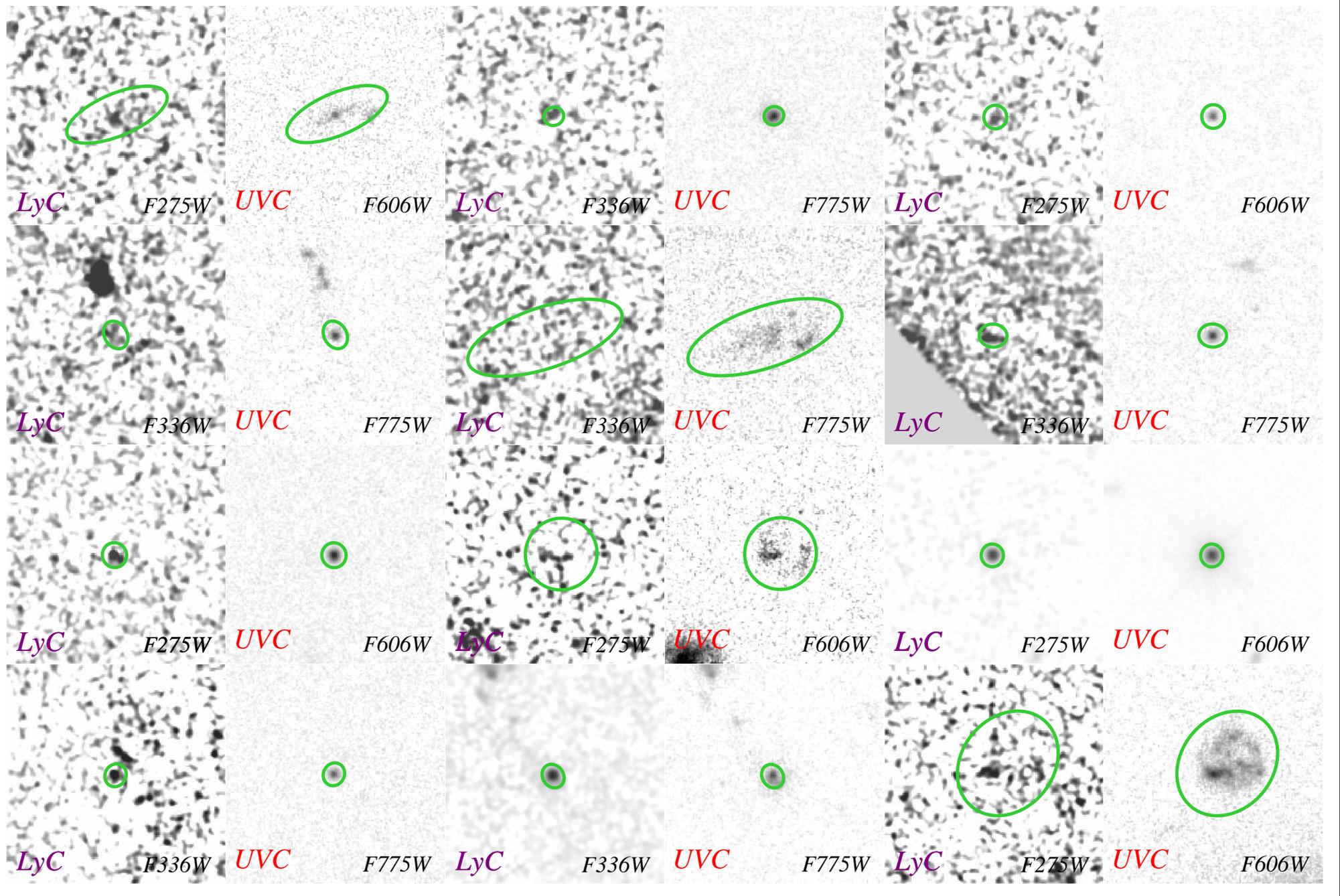
- WFC3/UVIS F225W, F275W, F336W filters sample LyC ( $\lambda < 912 \text{Å}$ ) at  $z \geq 2.26$ ,  $z \geq 2.47$ , and  $z \geq 3.08$  (best at low-end of each  $z$ -range).
- Lower  $z$ -bounds: *no*  $\lambda > 912 \text{Å}$  below filter's red-edge ( $\equiv 0.5\%$  of peak).



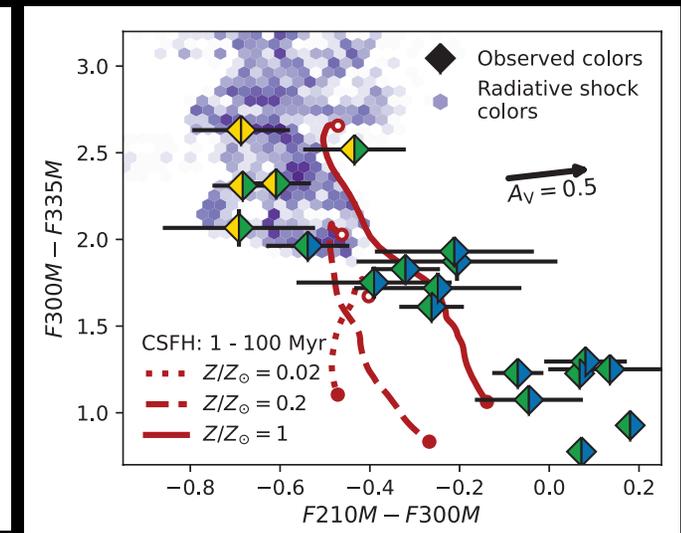
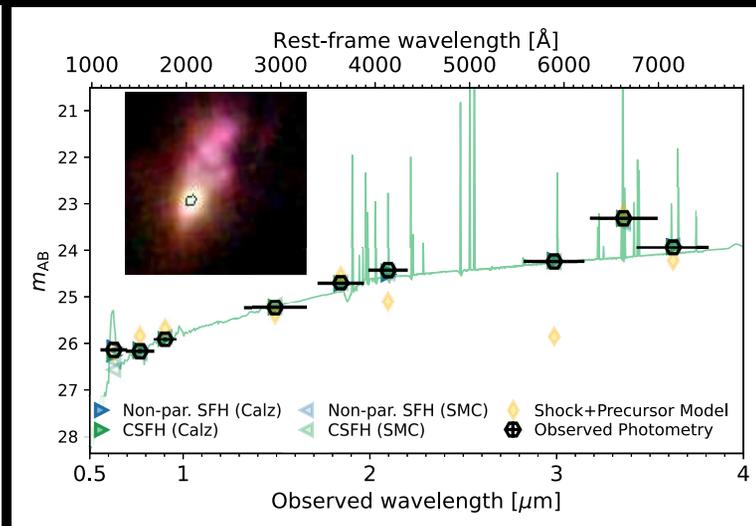
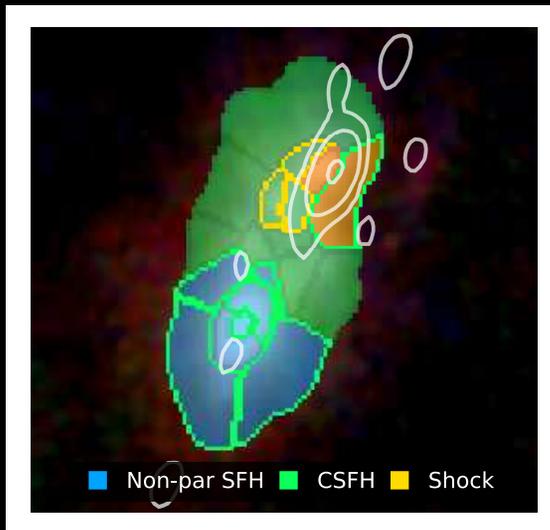
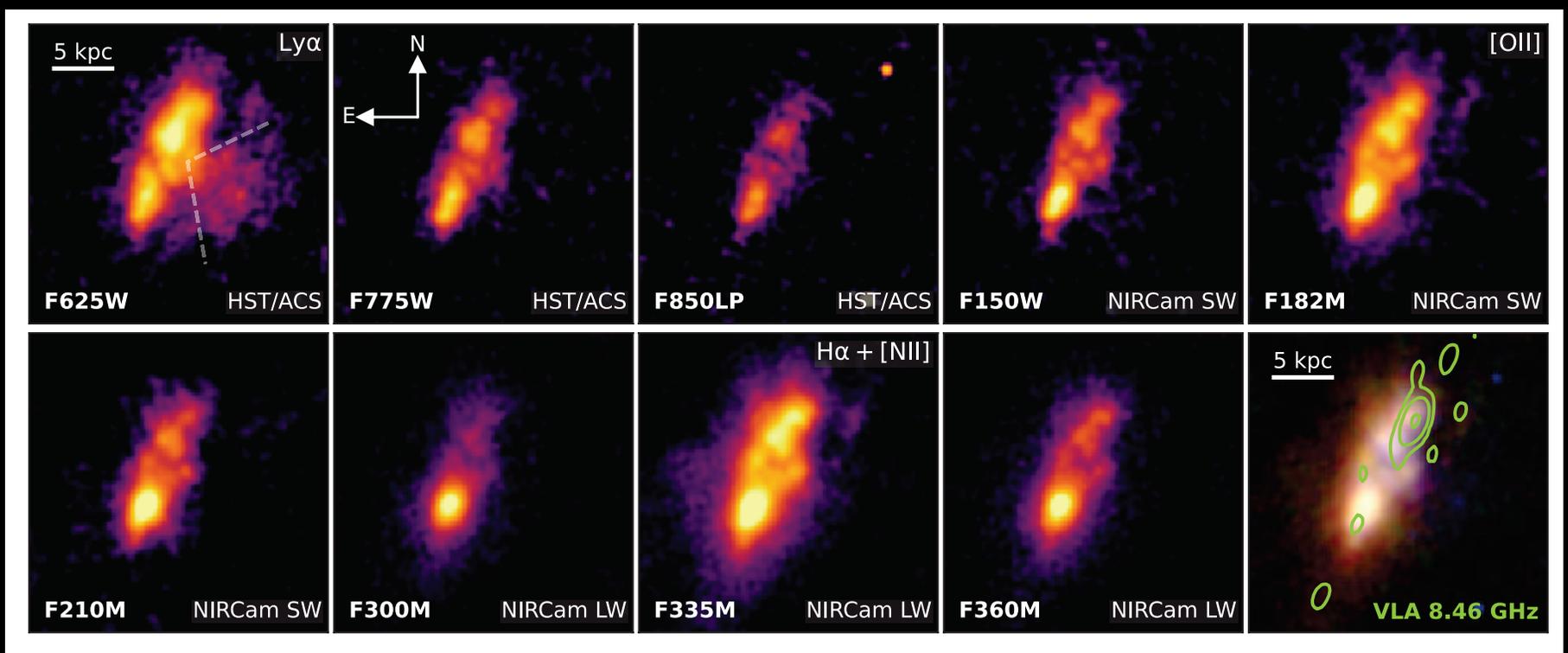
WFC3/ERS & HDUV AGN+Galaxy LyC stacking (Smith et al. 2018, ApJ, 853, 191; — 2020, ApJ, 897, 41).

- Rare (weak) AGN with robust spectroscopic redshifts at  $z \simeq 2.3-3.5$  dominate reionizing LyC flux in stacked WFC3/UVIS images ( $AB \lesssim 29$  mag).

- Need  $\simeq 0''.04$  WFC3 UV-PSF to remove all foreground interlopers at  $\gg 99\%$  confidence!



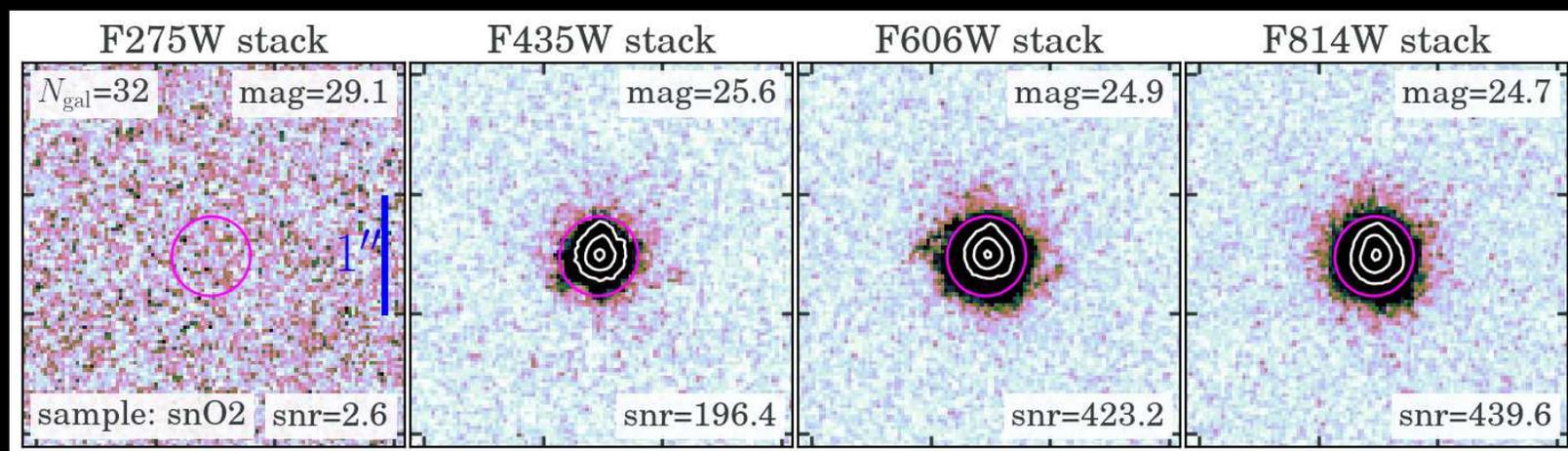
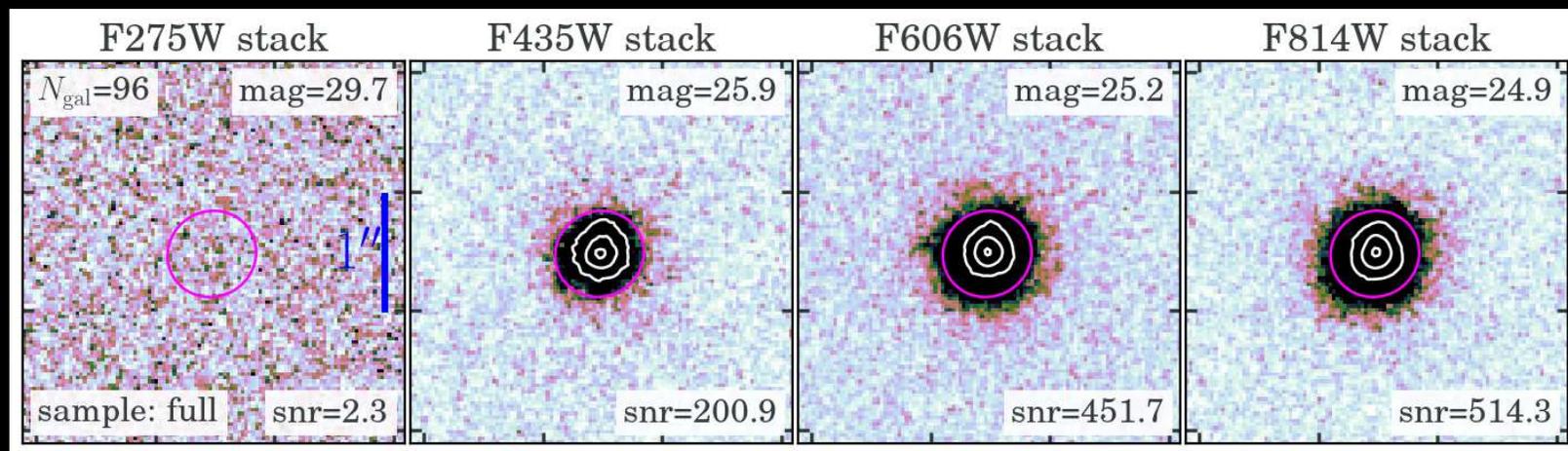
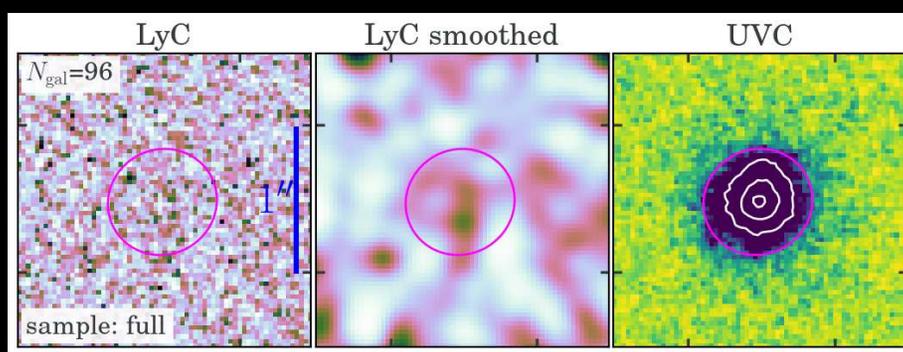
- UVCANDELS AGN LyC detections  $AB \simeq 23.4\text{--}28.5$  mag:  $f_{esc} \simeq 30 \pm 25\%$ .
- 12/58 detected (21%):  $\langle \text{LyC opening } \theta \rangle \lesssim 40^\circ$  (Smith<sup>+</sup> 2024, ApJ, 964, 73).



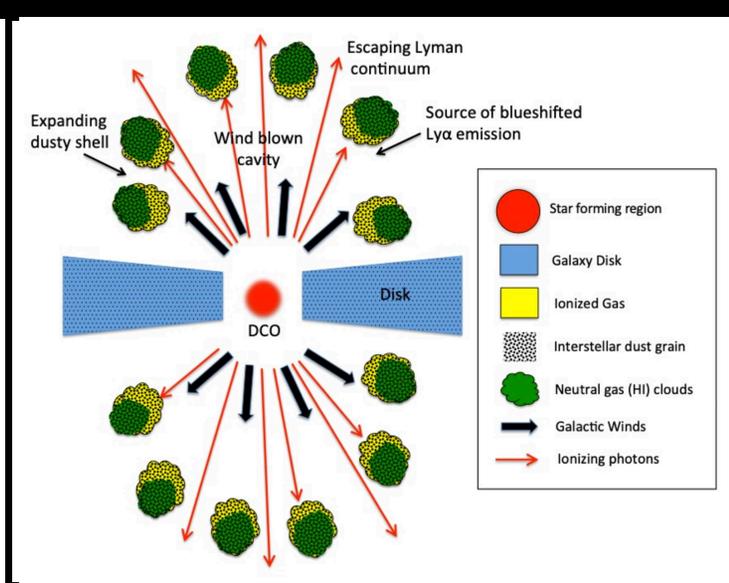
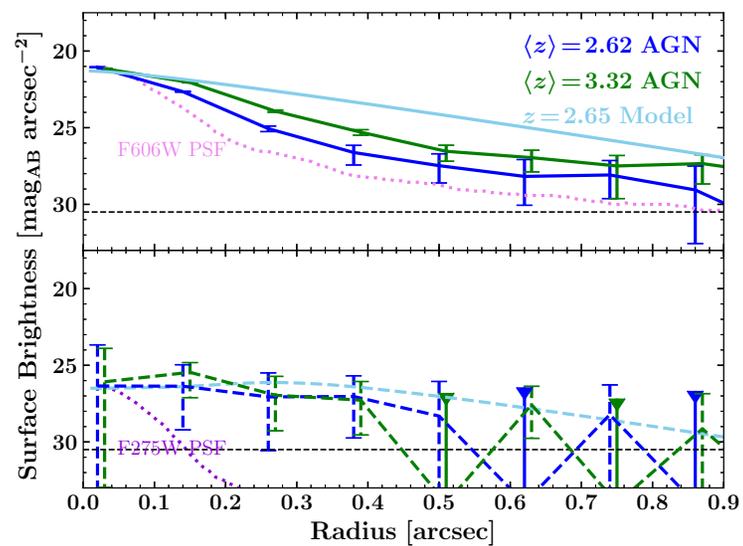
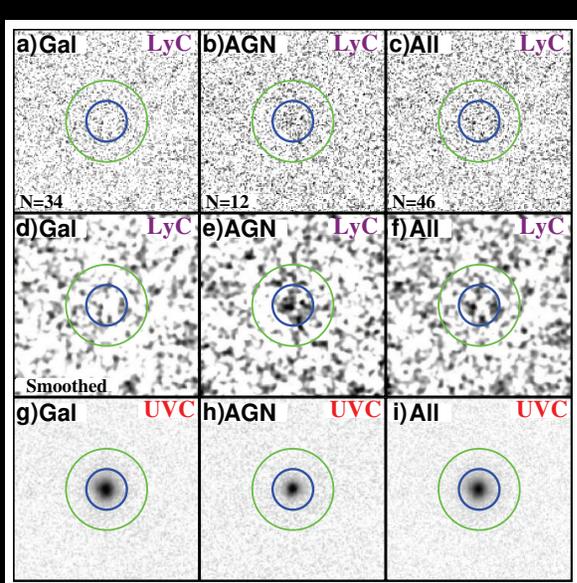
One of the most massive ( $10^{10.9} M_{\odot}$ ) high-z radio galaxies at  $z=4.11$ :

- TNJ1338: NIRCcam medium-band  $SFR \sim 1800 M_{\odot}/yr$ ; extreme jet-induced  $SFR \gtrsim 500 M_{\odot}/yr$ ,  $\tau_{SFR} \simeq 4$  Myr.

Opening angles: HST Ly $\alpha$   $\theta_h \lesssim 50^{\circ}$ ; NIRCcam+VLA jet  $\theta_h \sim 10^{\circ}$  (Duncan<sup>+</sup> 2023, MNRAS, 522, 4548)



- UVCANDELS galaxy LyC detections  $AB \simeq 25.5\text{--}26.6$  mag, LyC stacks  $\sim 29.1\text{--}29.7$  mag; resulting  $f_{esc} \sim 6\text{--}10\%$ . [ $1 - \cos(\theta_h) \equiv$  detected fraction]:
  - 5/96 detected (5%):  $\langle \text{LyC opening } \theta \rangle \lesssim 20^\circ$  (Wang<sup>+</sup> 2025, ApJ, 980, 74)



[Left]: WFC3 LyC stack of Gals, weak AGN and All, +non-ionizing UVC.

[Middle]: Radial SB-profiles of stacked UVC [Top]; LyC stack [Bottom]:

- LyC SB-profiles extended compared to PSFs, but very non-Sersic like!

Dashed: scattering model with ISM porosity+escaping LyC (Smith, B.<sup>+</sup> 2018).

[Right]: Patchy ISM model of escaping LyC (& Ly $\alpha$ ) (Borthakur<sup>+</sup>14).

- WFC3 Galaxy and AGN  $\langle \text{LyC opening angle} \rangle \lesssim 20\text{--}40^\circ$ , respectively.

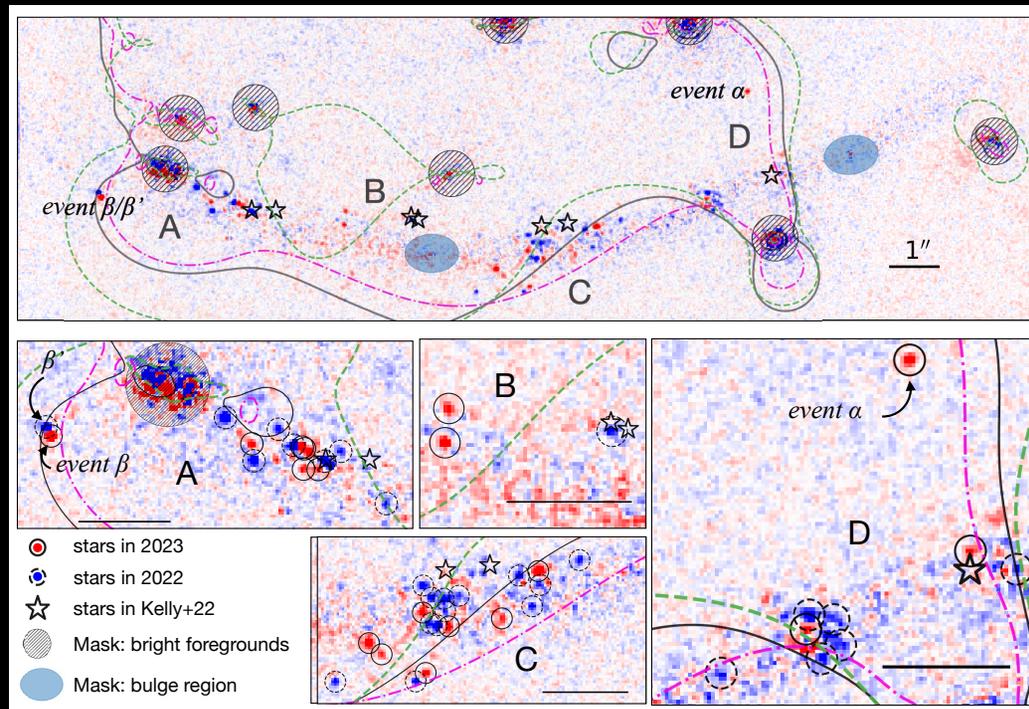
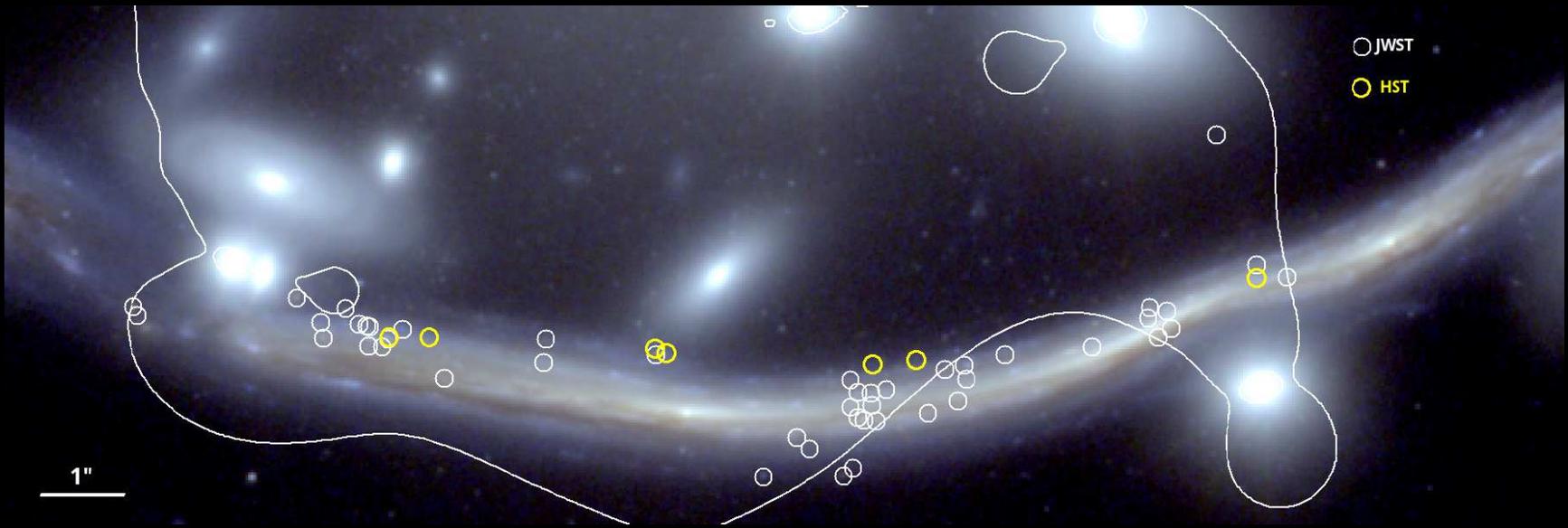
- Weak AGN more/bigger holes than Gals; LyC not always from accretion disk

(Smith, B.<sup>+</sup> 2018, ApJ, 853, 191; — 2020, ApJ, 897, 41; — 2024, ApJ, 964, 73; Wang<sup>+</sup> 2025, ApJ, 980, 74).



JWST image of most luminous far-IR Planck cluster G165 at  $z=0.35$  found:  
Lensed Supernova Ia at  $z=1.78 \rightarrow$  measured  $H_0=75.4^{+8.1}_{-5.5}$ , 10 Byrs ago!

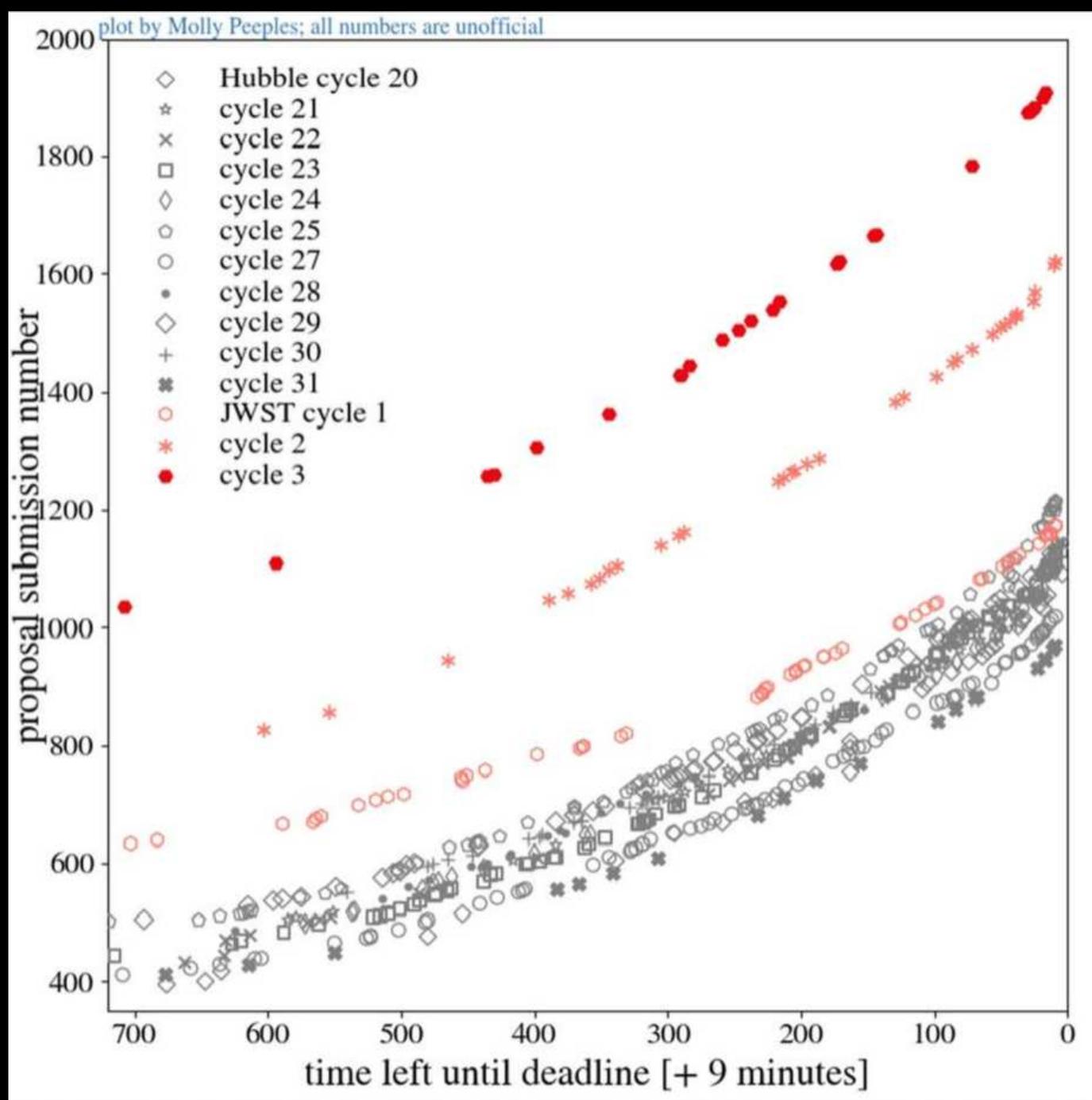
<https://bigthink.com/starts-with-a-bang/triple-lens-supernova-jwst/> (Frye<sup>+</sup> 2023, Pascale<sup>+</sup> 2025).



Abell 370 Dragon's arc: 44 individual caustic-transiting stars at  $z=0.73$ !

(Y. Fudamoto<sup>+</sup>, *Nat. Astron.*, astro-ph/2404.08045; J. Diego<sup>+</sup> 2024, *A&A*, 689, A167).

⇒ JWST Time-Domain detects luminous stars at  $z \gtrsim 0.7$  directly!



- Webb is now THE highest-in-demand NASA Flagship mission ever, but Hubble remains in at least as high a demand as it was 30 years ago!

## (1) SCIENCE IMPACT BY THE HST & JWST COMMUNITY (Feb. 2025):

- HST:  $\gtrsim 500$ – $1000$  refereed papers/year by the community since 1990.
- 45,900 HST papers on [ADS](#), 948,800 citations since 1990,  $h_{HST}=322!$
- JWST: over 2300 refereed papers ([57k cites](#)), since July 2022 alone!
- In year 1-3: JWST already outdoing HST's yearly production.

## (2) NEWS RELEASES BY THE HST & JWST COMMUNITY (Feb 2025):

- NASA's Hubble Space Telescope (HST) had 1,100 science press releases since 1990, each with  $\gtrsim 400$  million readers (or impressions) worldwide.
- $\sim 480 \times 10^9$  reads (or impressions) of Hubble press releases in total  $\Rightarrow$
- *On average* each human on Earth would have read  $\gtrsim 60$  Hubble stories during their lifetimes.
- HST is the most publicized space astrophysics mission in NASA history.
- JWST:  $\gtrsim 170$  press releases since 2022, each 0.5–1 billion readers.
- JWST is now the most-in-demand space mission in NASA history.
- ASU Cosmology: 10 billion [readers](#) from  $\gtrsim 10$  releases since 2022 ([URL](#)).

# Related papers, press releases and other URLs

Talk: [http://www.asu.edu/clas/hst/www/jwst/crete25\\_futureLyC\\_fromspace\\_v3.pdf](http://www.asu.edu/clas/hst/www/jwst/crete25_futureLyC_fromspace_v3.pdf) Data: <https://sites.google.com/view/jwstpearls>  
<https://hubblesite.org/contents/news-releases/2022/news-2022-050>  
<https://blogs.nasa.gov/webb/2022/10/05/webb-hubble-team-up-to-trace-interstellar-dust-within-a-galactic-pair/>  
<https://blogs.nasa.gov/webb/2022/12/14/webb-glimpses-field-of-extragalactic-pearls-studded-with-galactic-diamonds/>  
<https://esawebb.org/images/pearls1/zoomable/>  
<https://webbtelescope.org/contents/news-releases/2023/news-2023-119>  
<https://news.asu.edu/20230801-jwsts-gravitational-lens-reveals-distant-objects-behind-el-gordo-galaxy-cluster>  
<https://hubblesite.org/contents/news-releases/2023/news-2023-146>  
<https://www.nytimes.com/2023/12/19/science/christmas-stars-galaxies-webb-nasa.html?>  
<https://blogs.nasa.gov/webb/2024/10/01/> & <https://bigthink.com/starts-with-a-bang/triple-lens-supernova-jwst/>

Adams, N. J., Conselice, C. J., Austin, D., et al. 2024, ApJ, 965, 169 (astro-ph/2304.13721v1)  
Austin, D., Conselice, C. J., Adams, et al. 2024, ApJ, submitted (astro-ph/2404.10751)  
Berkheimer, J. M., Carleton, T., Windhorst, R. A., et al. 2024, ApJ, 964, L29 (astro-ph/2310.16923v2)  
Carleton, T., Windhorst, R. A., O'Brien, R., et al. 2022, AJ, 164, 170 (astro-ph/2205.06347)  
Carleton, T., Cohen, S. H., Frye, B., et al. 2023, ApJ, 953, 83 (astro-ph/2303.04726)  
Diego, J. M., Meena, A. K., Adams, N. J., et al. 2023, A&A, 672, A3 (astro-ph/2210.06514)  
Diego, J. M., Sun, B., Yan, H., et al. 2023, A&A, 679, A31 (astro-ph/2307.10363)  
Diego, J. M., Adams, N. J., Willner, S., et al. 2024, A&A, 690, 114 (astro-ph/2312.11603)  
Diego, J. M., Li, S. K., Amruth, A., et al. 2024, A&A, 690, A359 (astro-ph/2404.08033)  
D'Silva, J. C. J., Driver, S. P., Lagos, C. D. P., et al. 2024, ApJL, 959, L18 (astro-ph/2310.03081v1)  
D'Silva, J. C. J., Driver, S. P., Lagos, C. D. P., et al. 2025, A&A (astro-ph/2503.03431)  
Duncan, K. J., Windhorst, R. A., et al. 2023, MNRAS, 522, 4548–4564 (astro-ph/2212.09769)  
Frye, B. L., Pascale, M., Foo, N., et al. 2023, ApJ, 952, 81 (astro-ph/2303.03556)  
Frye, B. L., Pascale, M., Pierel, J., Chen, W., Foo, N., et al. 2024, ApJ, 961, 171 (astro-ph/2309.07326v1)  
Kamieneski, P. S., Frye, B. L., Pascale, M., et al. 2023, ApJ, 955, 91 (astro-ph/2303.05054)

Fudamoto, Y., Sun, F., Diego, J. M., et al. 2025, [Nature Astron.](#), 9, 428 (astro-ph/2404.08045)

Kamieneski, P. S., Frye, B. L., Windhorst, R. A., et al. 2024, *ApJ*, 973, 25 (astro-ph/2404.08058)

Keel, W. C., Windhorst, R. A., Jansen, R. A., et al. 2023, *AJ*, 165, 166 (astro-ph/2208.14475)

Kramer, D. M., Carleton, T., Cohen, S. H., et al. 2022, *ApJL*, 940, L15 (astro-ph/2208.07218v2)

O'Brien, R., Carleton, T., Windhorst, R. et al. 2023, *AJ*, 165, 237 (astro-ph/2210.08010)

O'Brien, R., Jansen, R. A., Grogin, N. A., et al. *ApJS*, 272, 19 (astro-ph/2401.04944)

Ortiz, III, R., Windhorst, R. A., Cohen, S. H., et al. 2024, *ApJ*, 974, 258 (astro-ph/2404.10709)

Pascale, M., Frye, B., Pierel, J., et al. 2025, *ApJ*, 979, 13 (astro-ph/2403.18902)

Polletta, M. del Carmen, Nonino, M., Frye, B., et al. 2023, *A&AL*, 675, L4 (astro-ph/2306.12385)

Robertson, C., Holwerda, B. W., Young, J., et al. 2024, *AJ*, 167, 263 (astro-ph/2403.15619)

Smail, I., Dudzeviciute, U., Gurwell, M., et al. 2023, *ApJ*, 958, 36 (astro-ph/2306.16039)

Smith, B. M., Windhorst, R. A., Jansen, R. A., et al. 2018, *ApJ*, 853, 191 (astro-ph/1602.01555v2)

Smith, B. M., Windhorst, R. A., Cohen, S. H., et al. 2020, *ApJ*, 897, 41 (astro-ph/2004.04360v2)

Smith, B. M., Windhorst, R. A., Teplitz, H., et al. 2024, *ApJ*, 964, 73 (astro-ph/2401.03094)

Summers, J., Windhorst, R. A., Cohen, S. H., et al. 2023, *ApJ*, 958, 108 (astro-ph/2306.13037)

Wang, X., Teplitz, H. I., Smith, B. M., et al. 2025, *ApJ*, 980, 74 (astro-ph/2308.9064v1)

Willner, S. P., Gim, H. B., Polletta, M. et al. 2023, *ApJ*, 958, 176 (astro-ph/2309.13008)

Windhorst, R. A., Timmes, F. X., Wyithe, J. S. B., et al. 2018, *ApJS*, 234, 41 (astro-ph/1801.03584)

Windhorst, R. A., Carleton, T., O'Brien, R., et al. 2022, *AJ*, 164, 141 (astro-ph/2205.06214)

Windhorst, R. A., Cohen, S. H., Jansen, R. A., et al. 2023, *AJ*, 165, 13 (astro-ph/2209.04119)

Windhorst, R. A., Summers, J., Carleton, T., et al. 2025, *J. BAAS*, 57, 1, in press ([astro-ph/2410.01187](#))

Yan, H., Cohen, S. H., Windhorst, R. A., et al. 2023, *ApJL*, 942, L8 (astro-ph/2209.04092)

Yan, H., Ma, Z., Sun, B., et al. 2023, *ApJS*, 269, 43 (astro-ph/2307.07579)