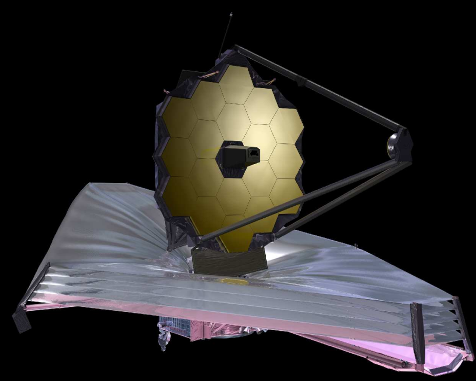
LyC studies from space in the next decades

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

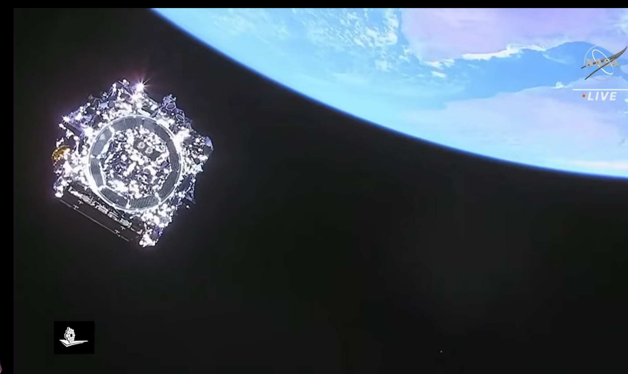
Hubble

1973∼2034^{+}?



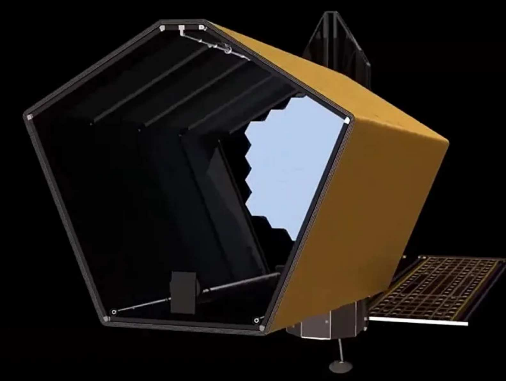
Webb (designed)

1996∼2031



Webb (launched 2021)

1996∼2046^{+}?



Habitable Worlds

2040∼2070^{+}?

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.pdf`

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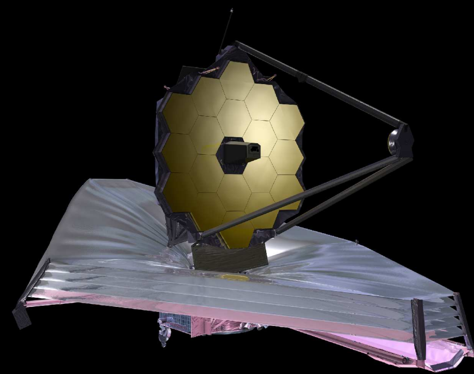
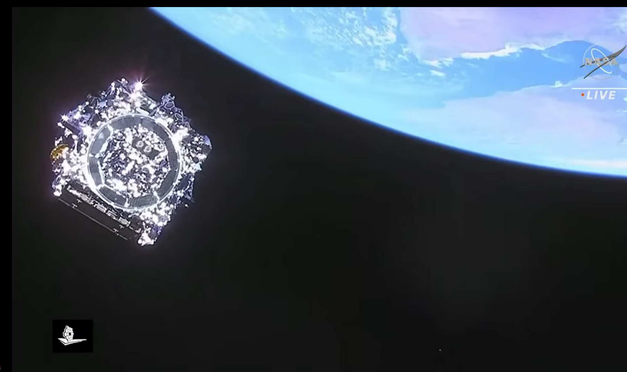
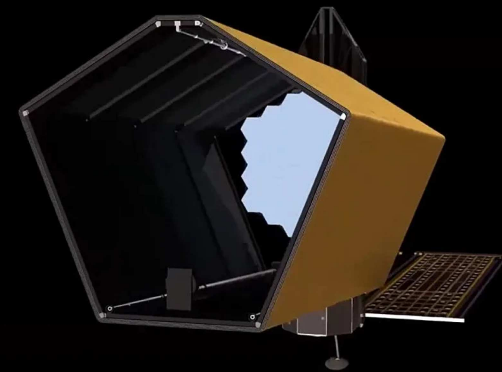




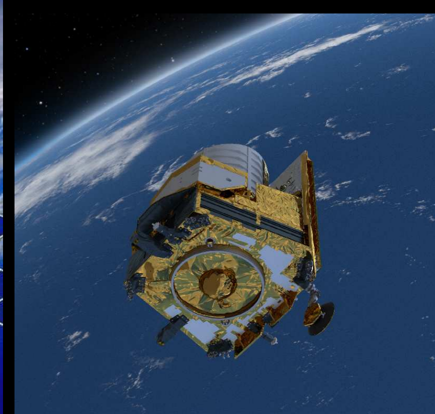
Hubble 1973∼2034$^+$?

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?

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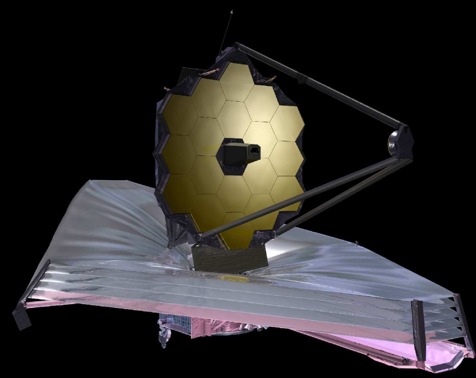

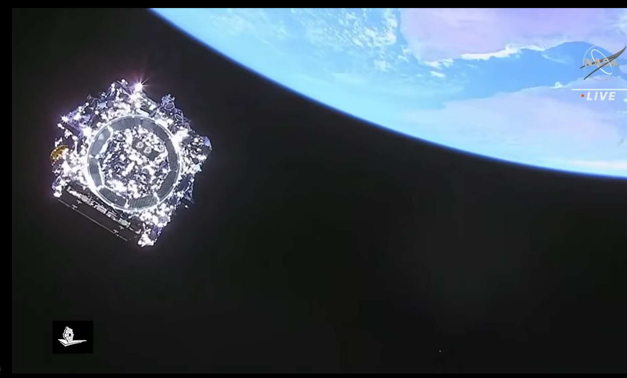

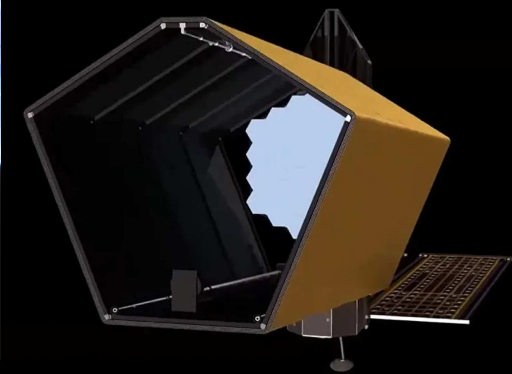

Hubble	Webb (designed)	Webb (launched 2021)	Habitable Worlds
1973$\sim$2034^{+}?	1996$\sim$2031	1996$\sim$2046^{+}?	2040$\sim$2070^{+}?

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

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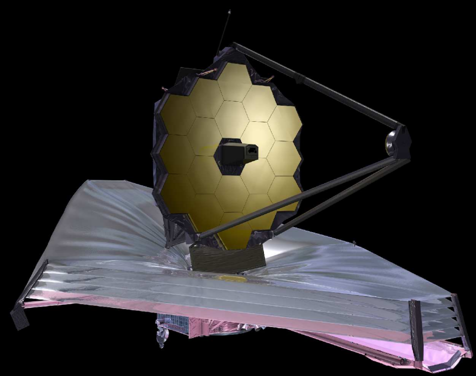
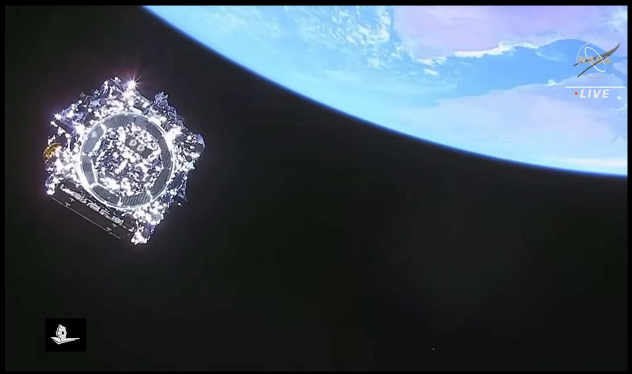
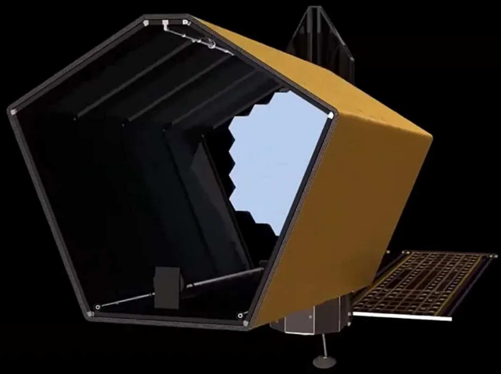
Hubble
$1973{\sim}2034^{+}$?



Webb (designed)
$1996{\sim}2031$



Webb (launched 2021)
$1996{\sim}2046^{+}$?

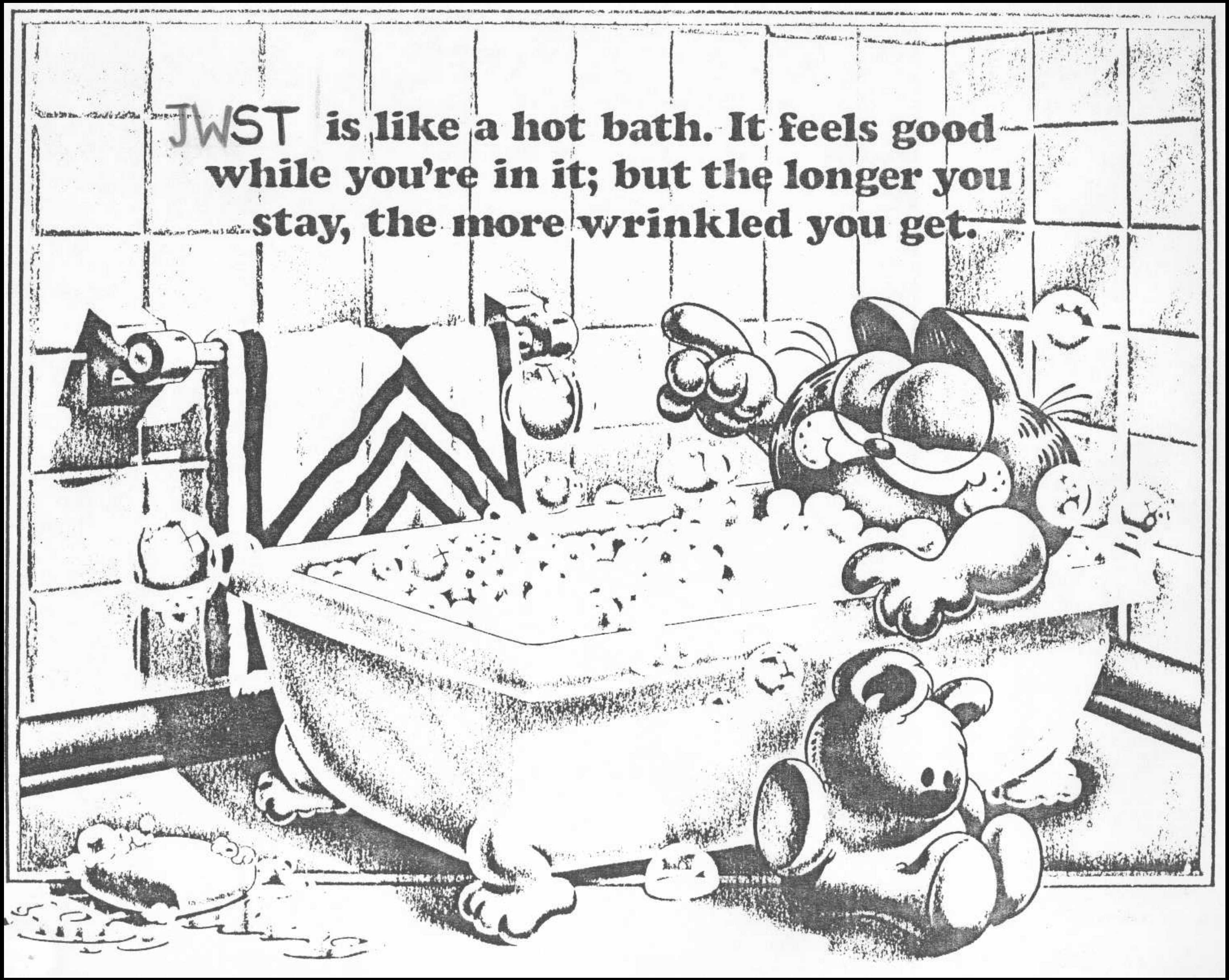


Habitable Worlds
$2040{\sim}2070^{+}$?

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.

$\Longrightarrow$ Maintain the long-term vision to do LyC work 30 years from now!



WARNING: Both Hubble and James Webb are 50–60$^+$ year projects:

$\Longrightarrow$ 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

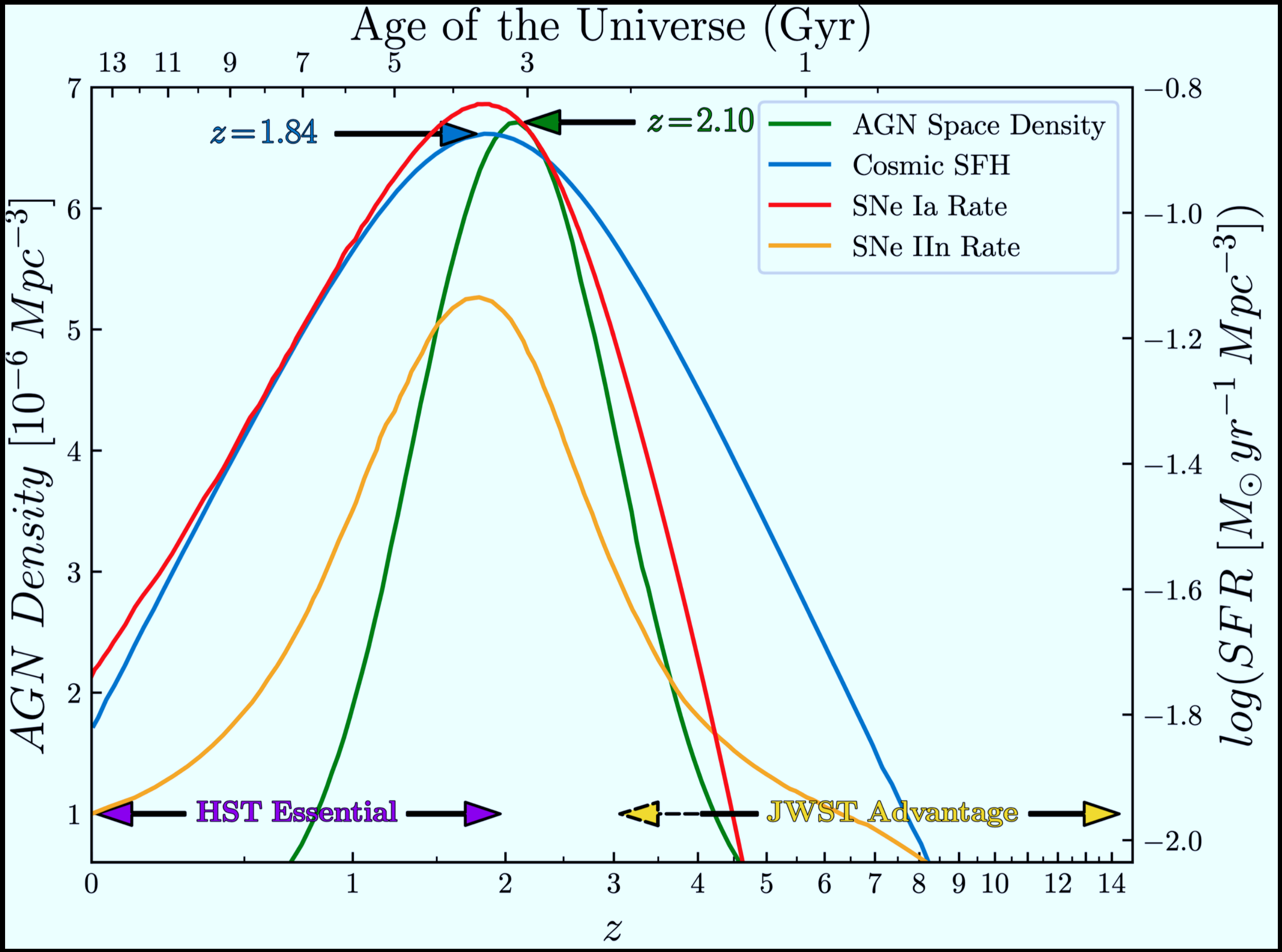
ARIZONA STATE UNIVERSITY

Sponsored by NASA/HST & JWST

PDF on: `http://www.asu.edu/clas/hst/www/crete25_futureLyC_fromspace.pdf`

Windhorst et al.

astro-ph/2410.01187



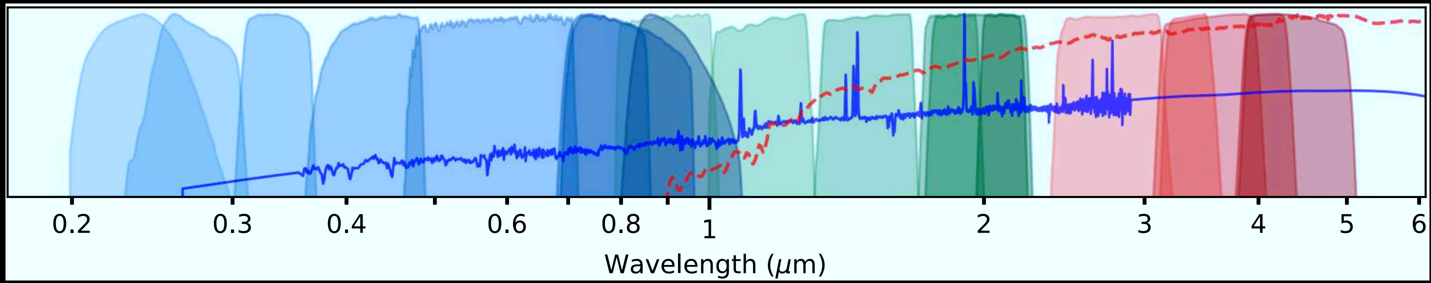
Age$\sim\frac{13.8}{(1+z)}+\ldots$ Gyr

Active galactic nuclei (AGN)

$\Longleftrightarrow$ BH accretion disks

$\Longleftrightarrow$ Chandra X-ray sources

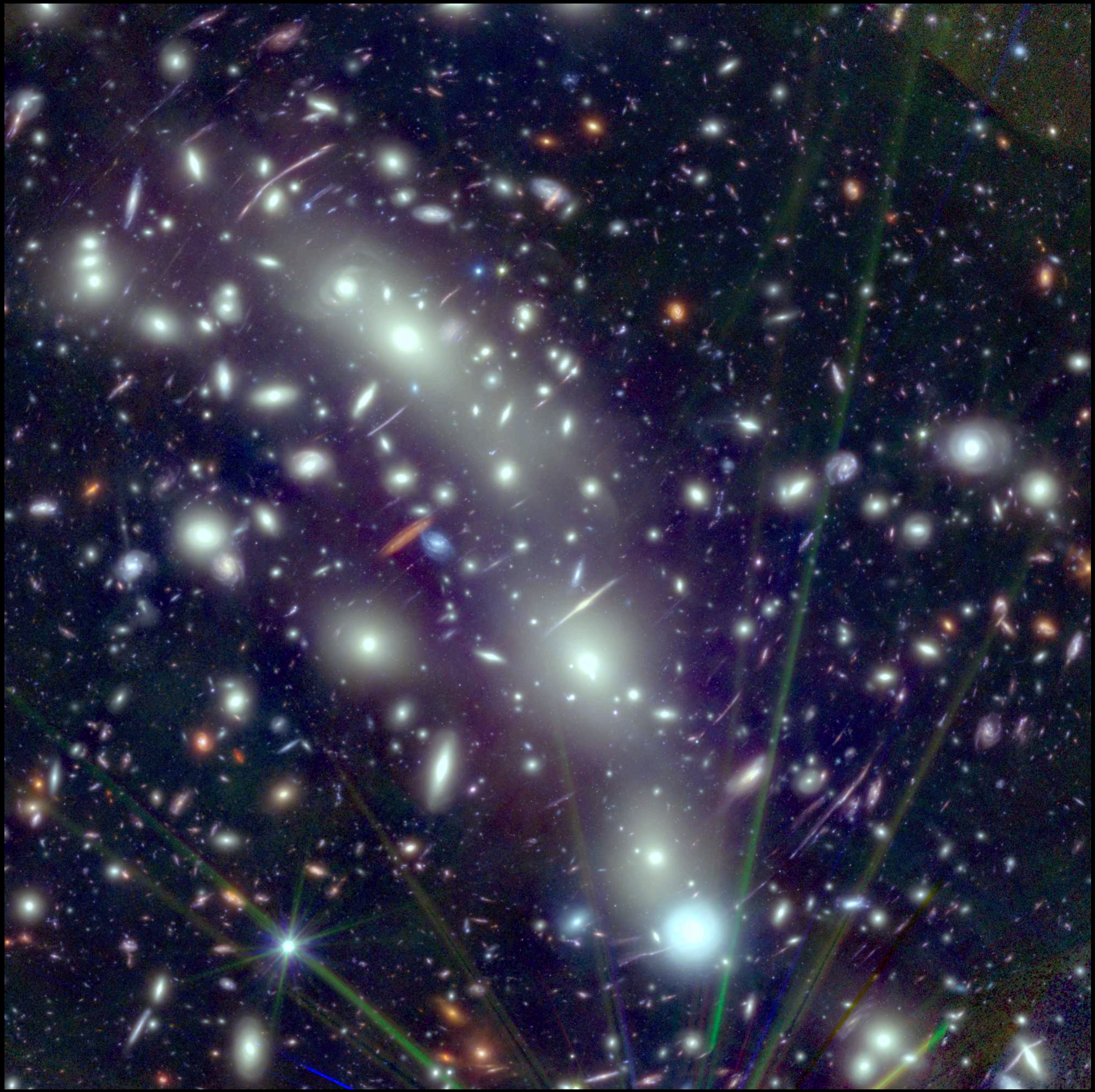
Star Formation, Supernova Rate, & Black Hole growth peak ~10 Gyr ago!



$\Rightarrow$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:

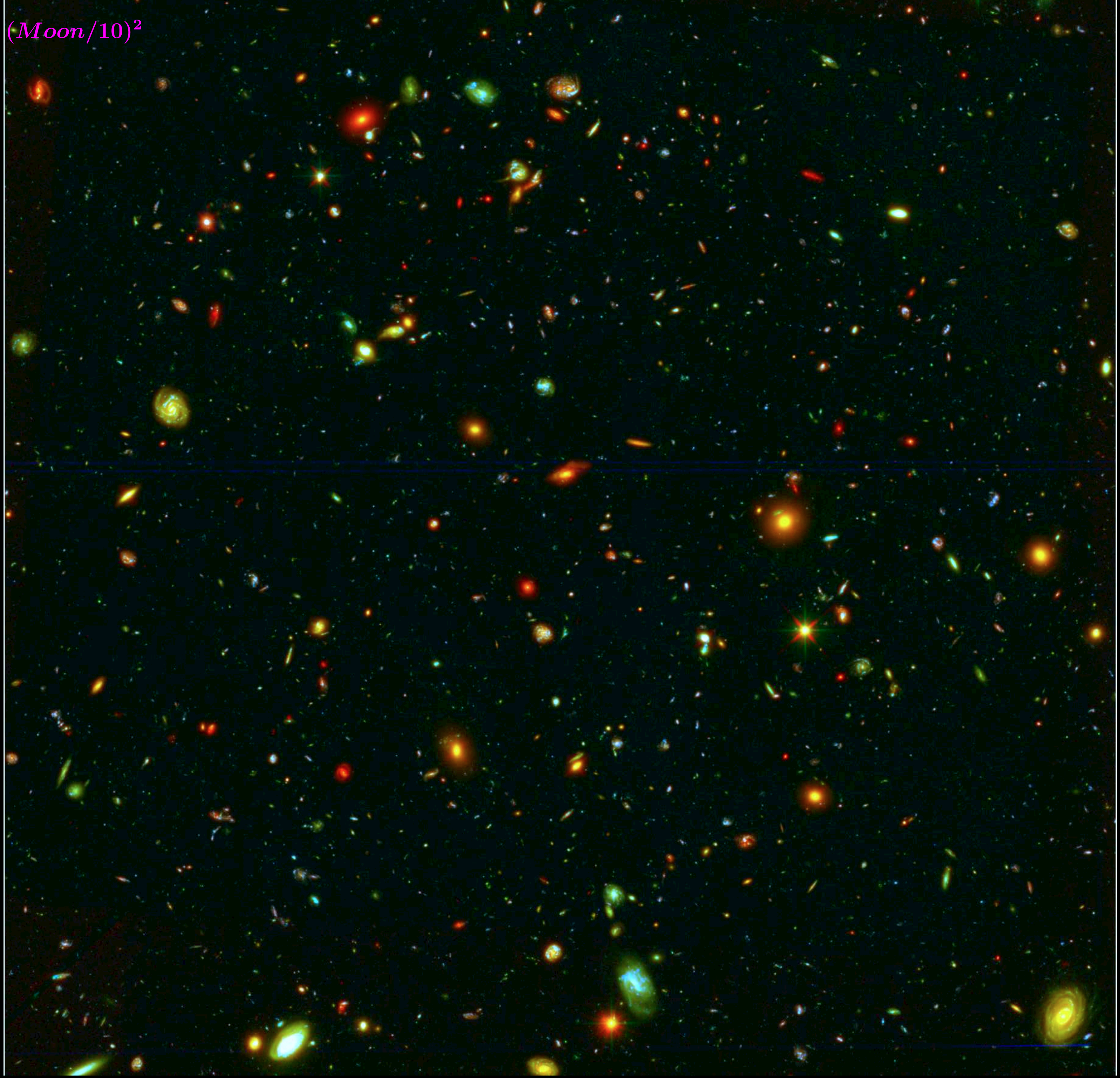


500 hrs HST+JWST: 45 filters (0.2–5.0μm), lensing cluster MACS0416:

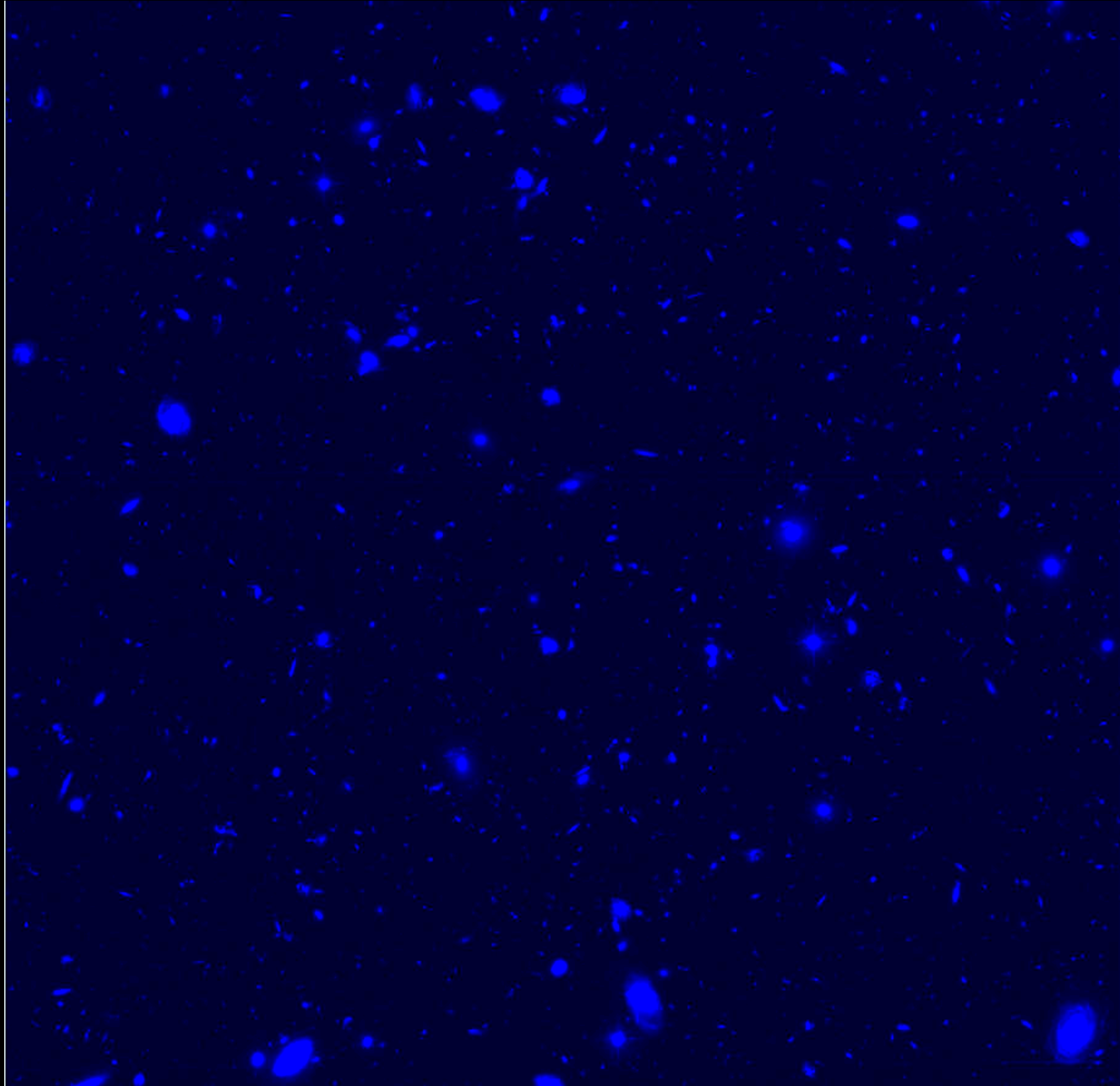
- HST darkest skies (10-$10^3\times$ darker) + JWST's dark skies (10^3–$10^5\times$ darker than ground based):

$\Longrightarrow$ HST & JWST reach 30–31 mag ($\simeq$1 nJy $\simeq$1 firefly from Moon).

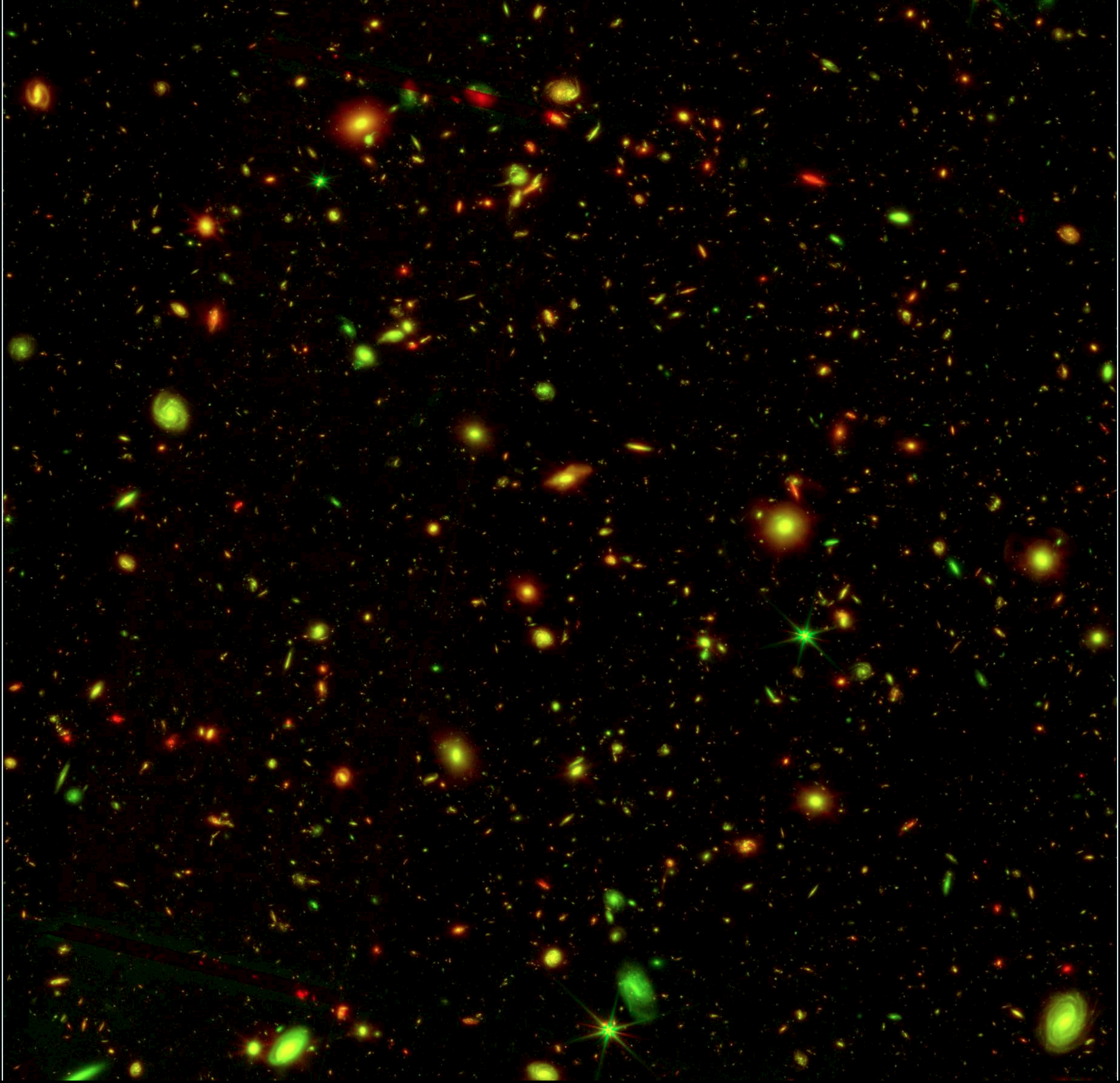
Field-of-View $\sim (Moon/10)^2$



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

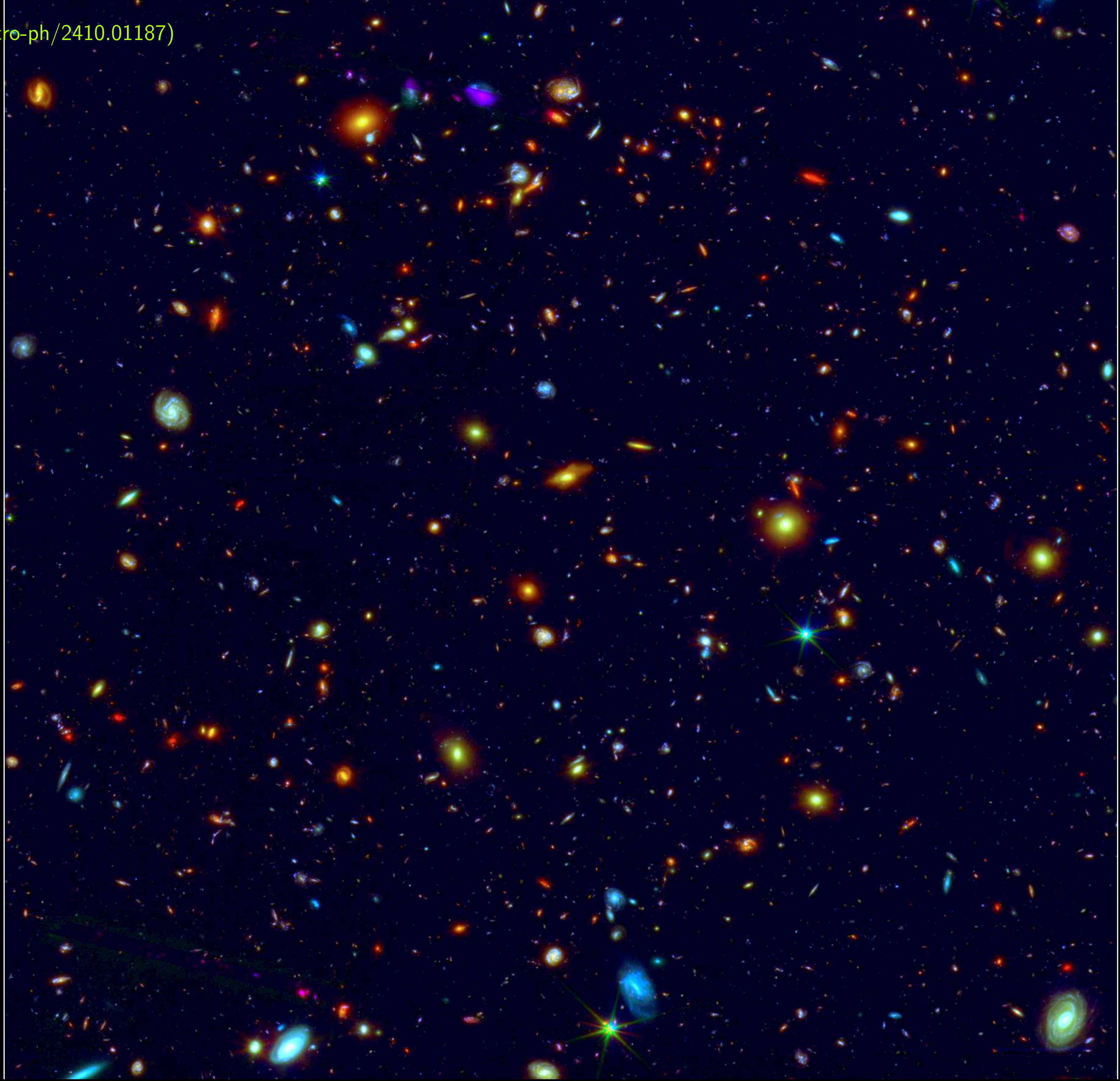


361 hr HST Hubble UltraDeep Field: 8 HST-unique filters 0.2–0.9 μm (in false color blue).



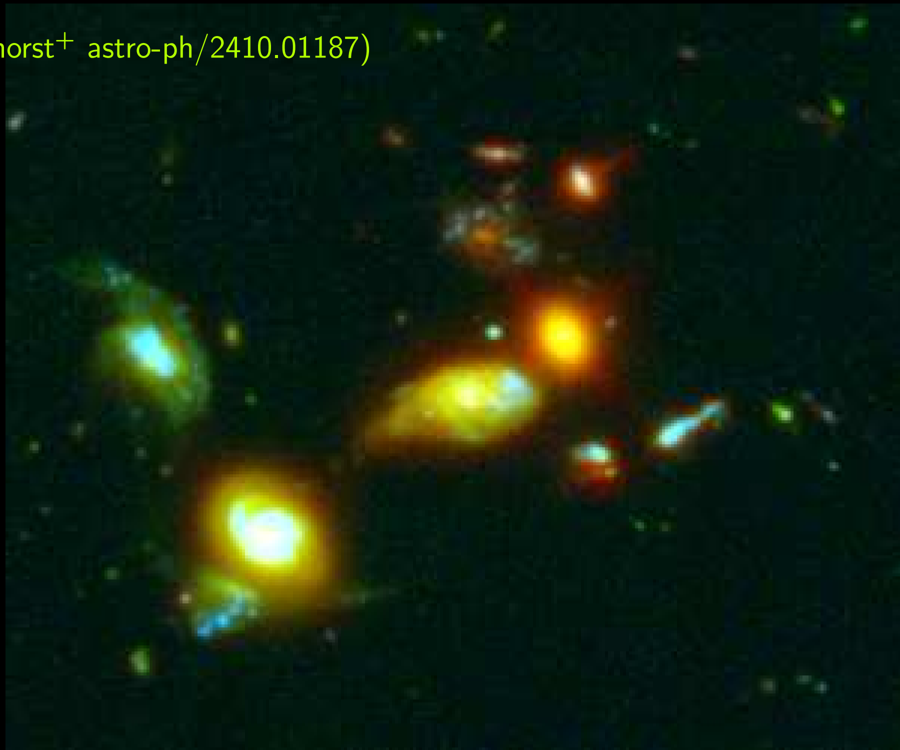
53 hr JWST/NIRCam Hubble UltraDeep Field: 12 filters at 0.9–5.0 μm (AB$\lesssim$31 mag; in green + red).

(Windhorst+ astro-ph/2410.01187)

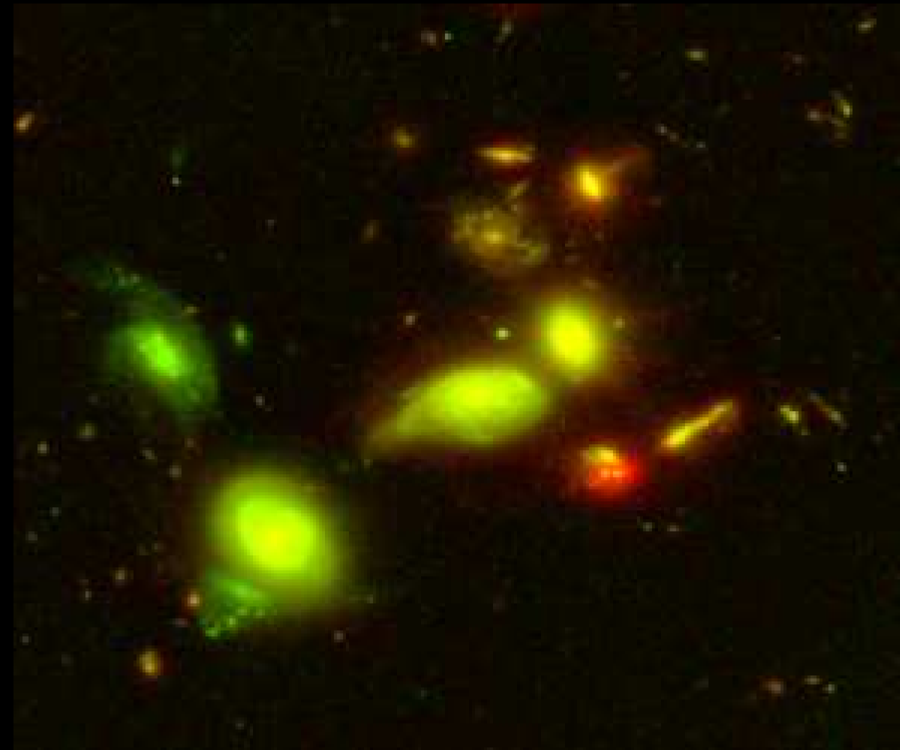


414 hr HST+JWST Hubble UltraDeep Field: 20 filters at 0.2–5.0 μm (AB$\lesssim$31.5 mag; full BGR).

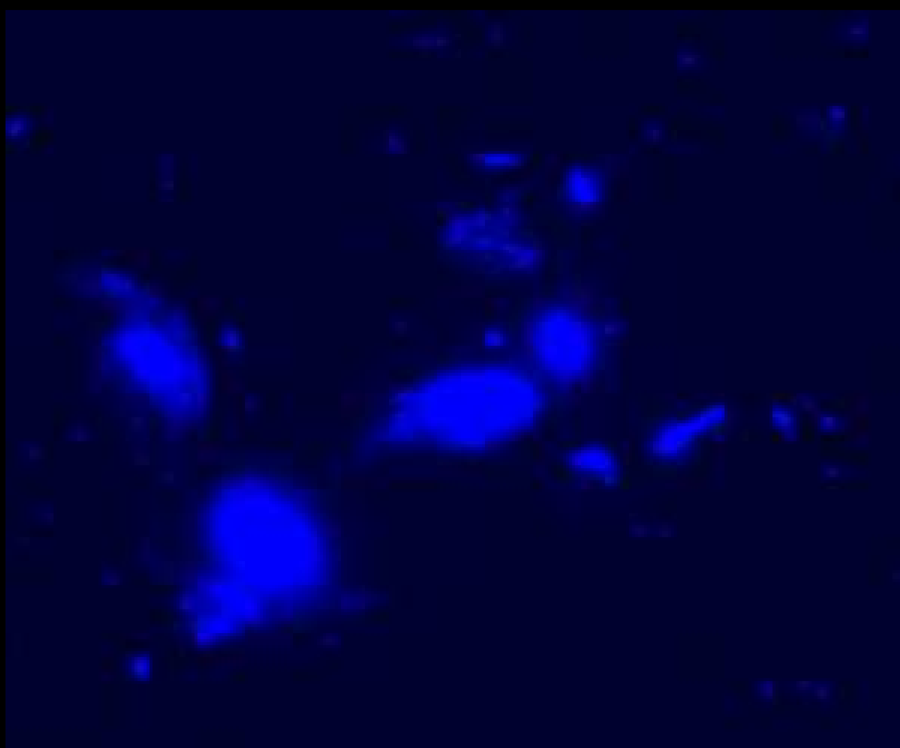
(Windhorst+ astro-ph/2410.01187)



556 hr HST HUDF 12 filters



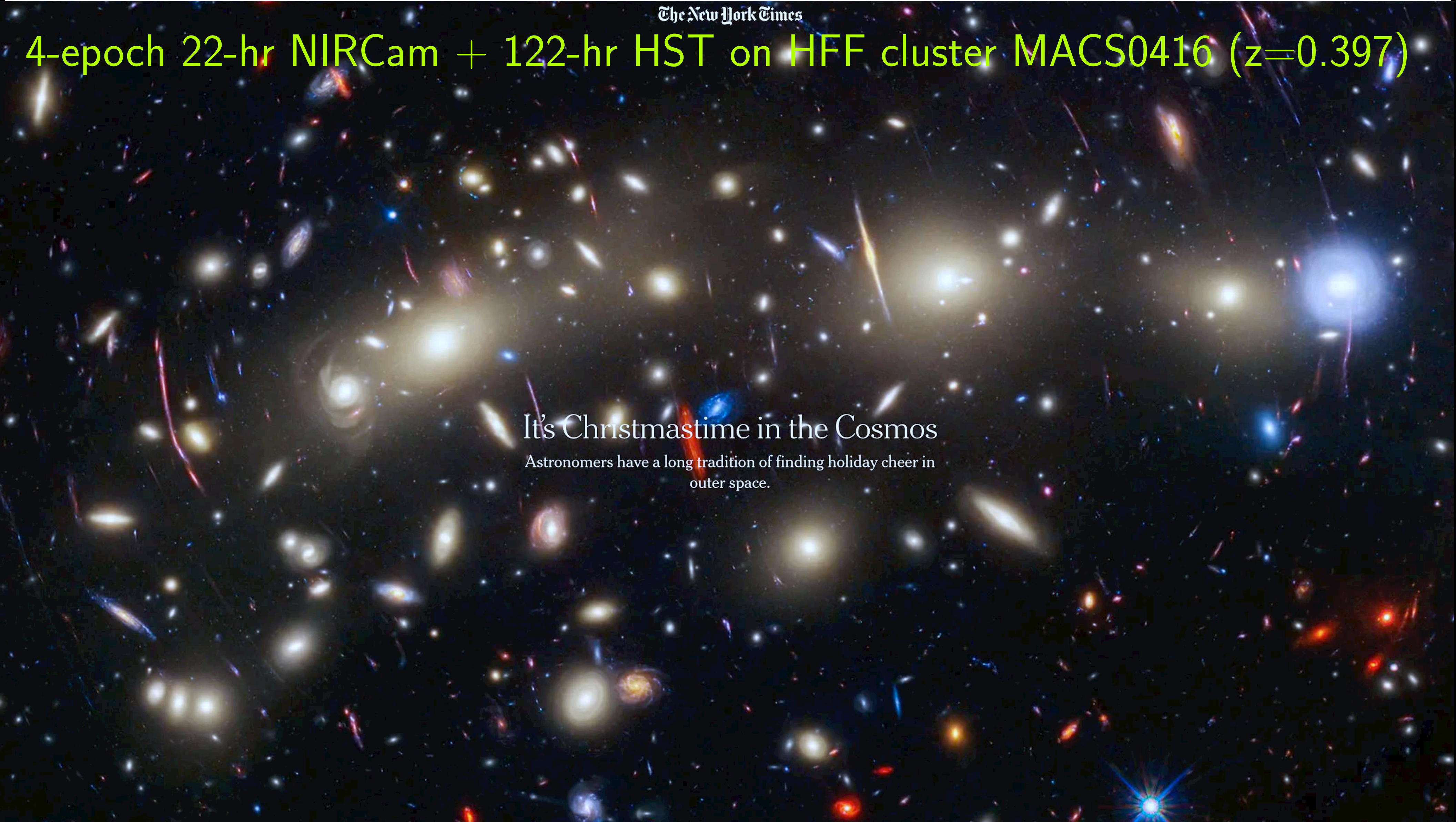
53 hr JWST/NIRCam 12 filters



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)

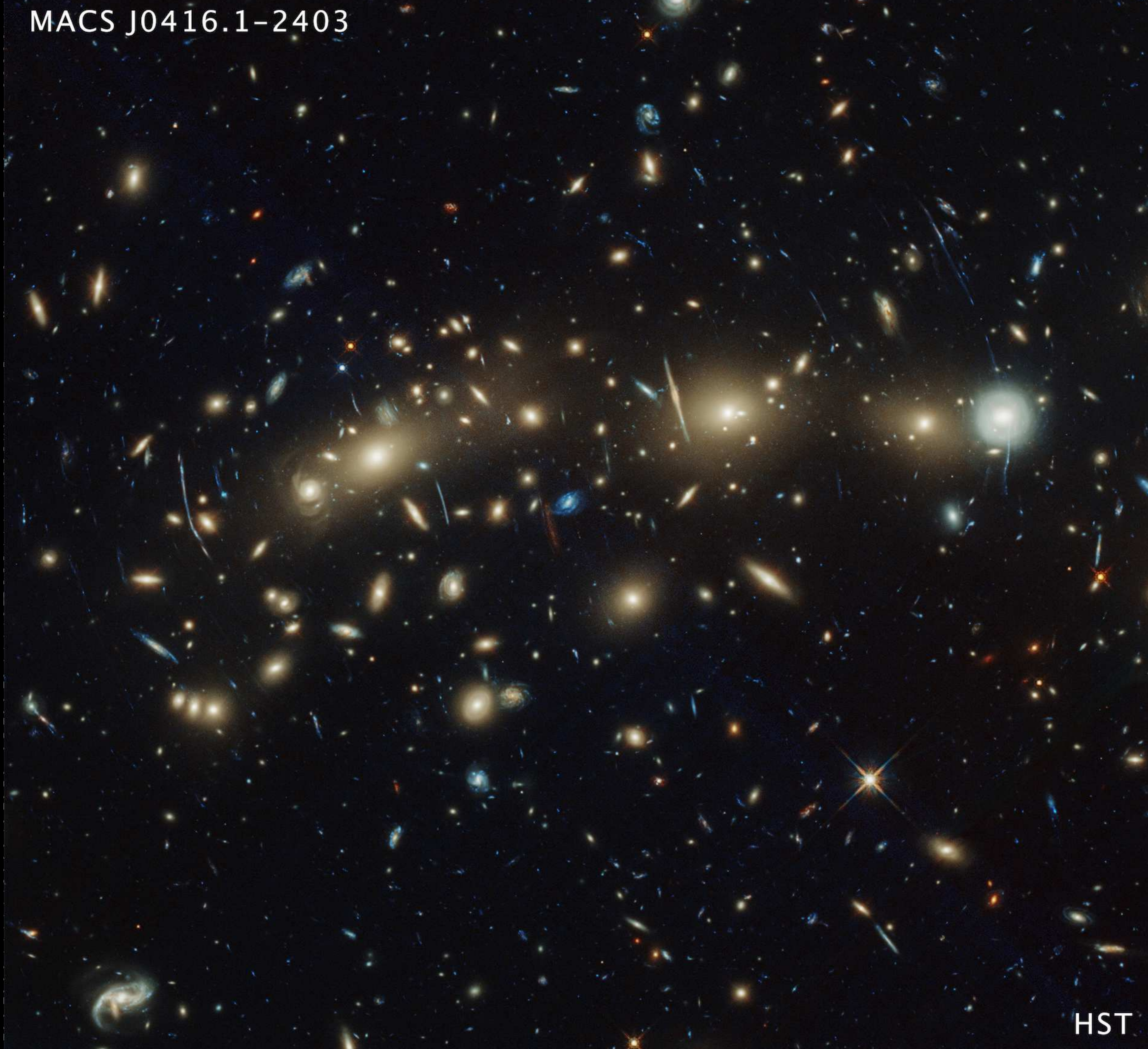


12 new caustic transits at $z \simeq 1$–2 from 4 epochs! (Yan, H.[+], 2023, ApJS, 269, 42)

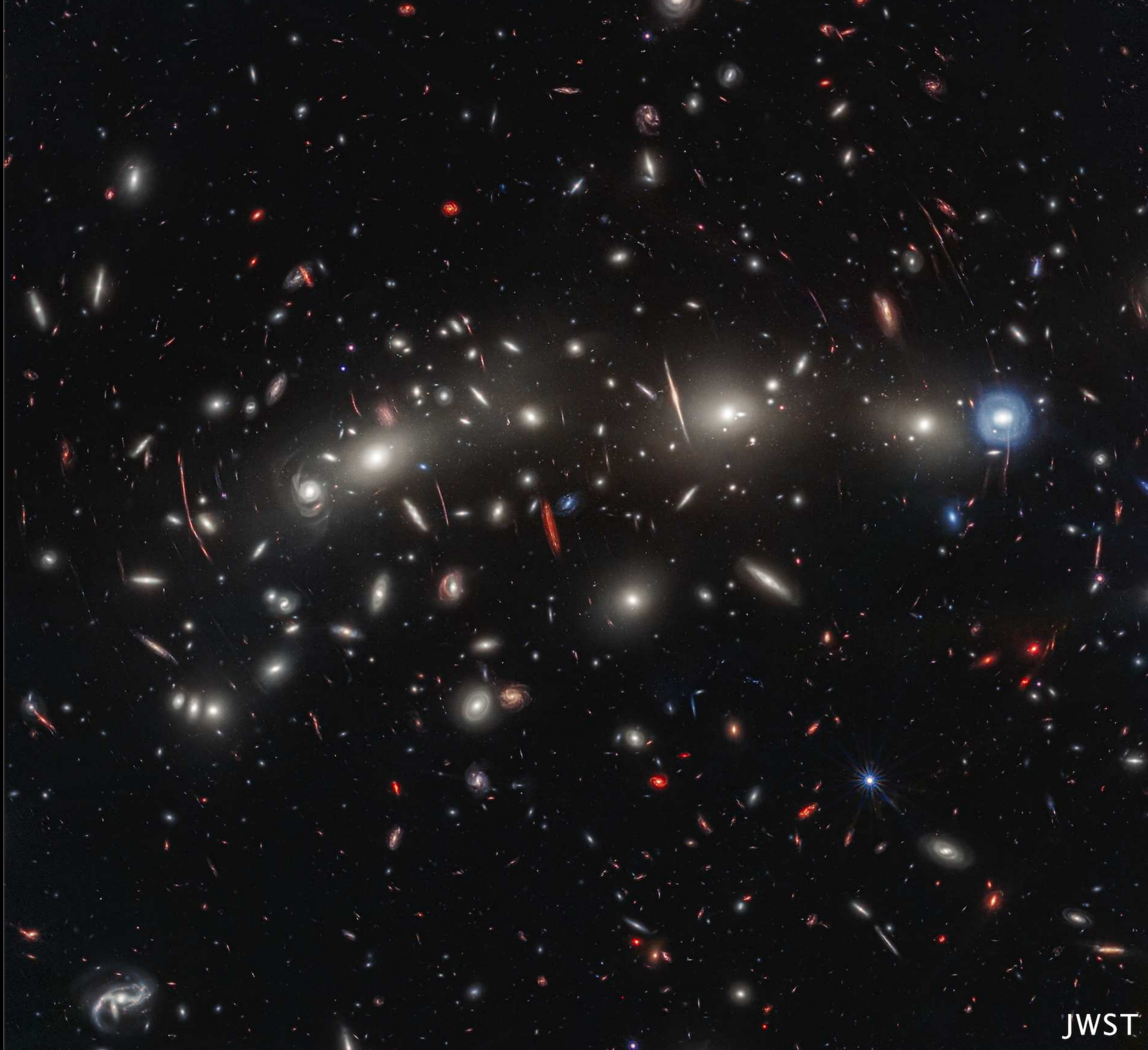
Extremely magnified binary star at z=2.091! (Diego, J.[+], 2023, A&A 679, A31)

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

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

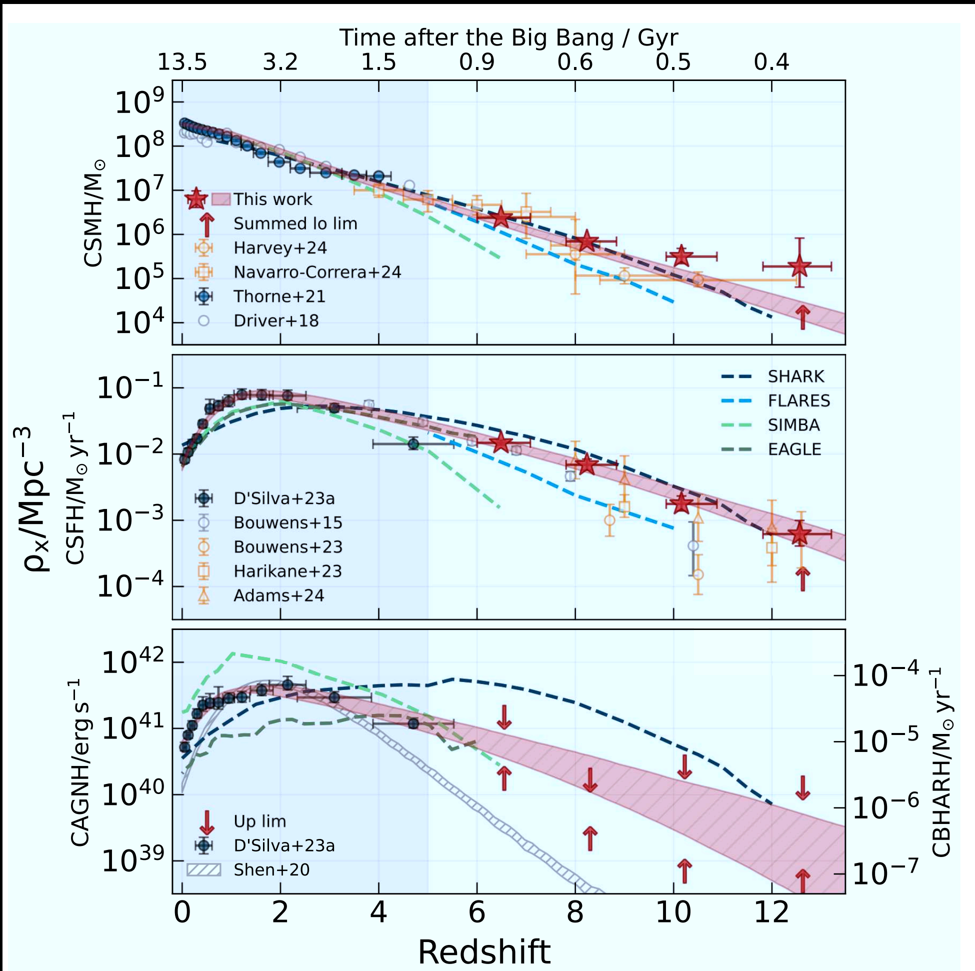


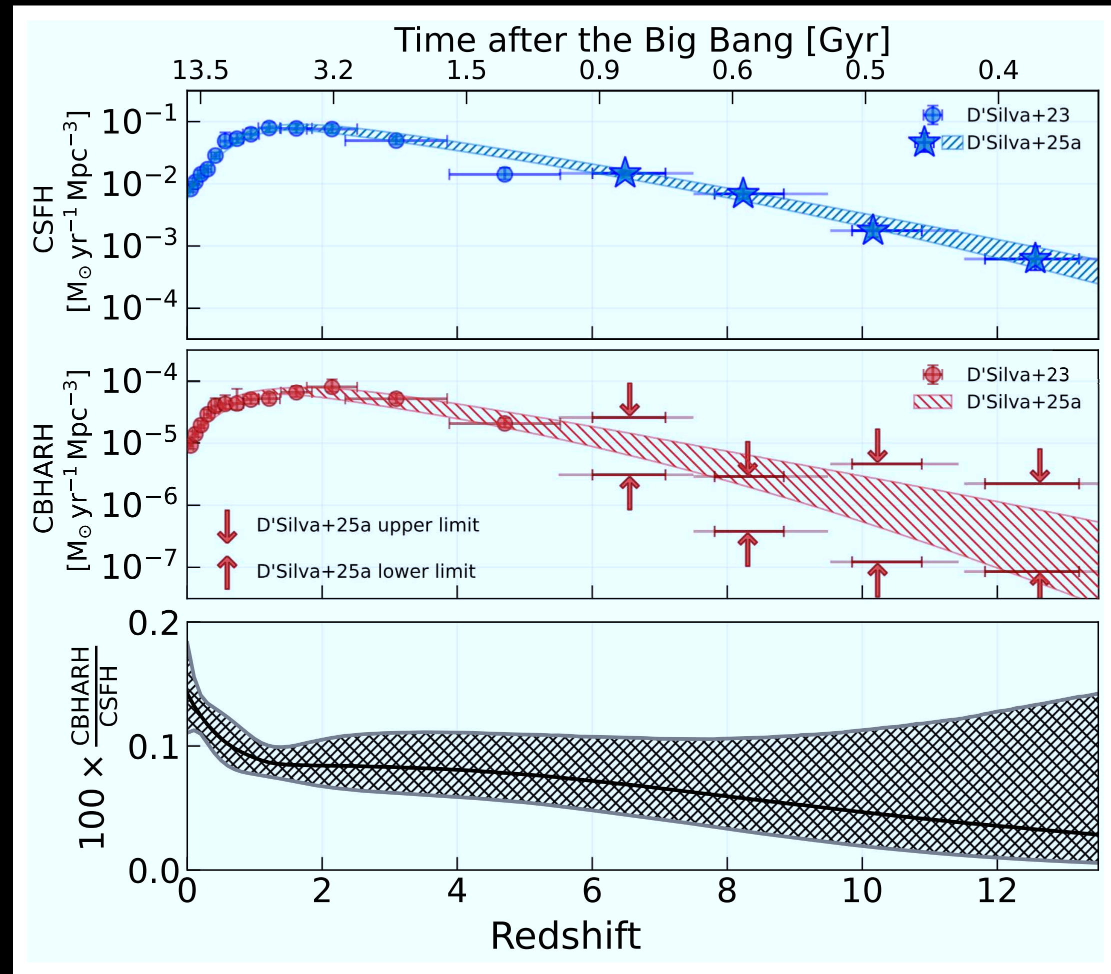
122 hr HST on Hubble Frontier Field cluster MACS0416 (z=0.397; 4.3 Blyr)



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

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

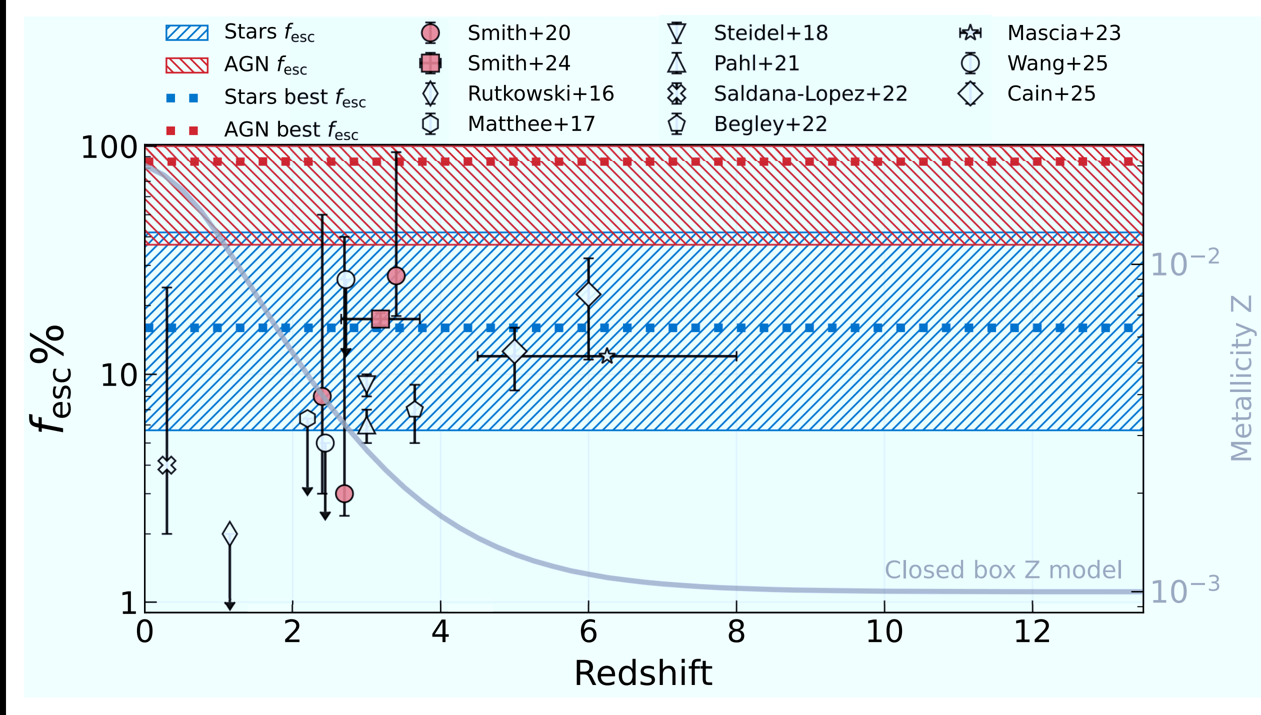


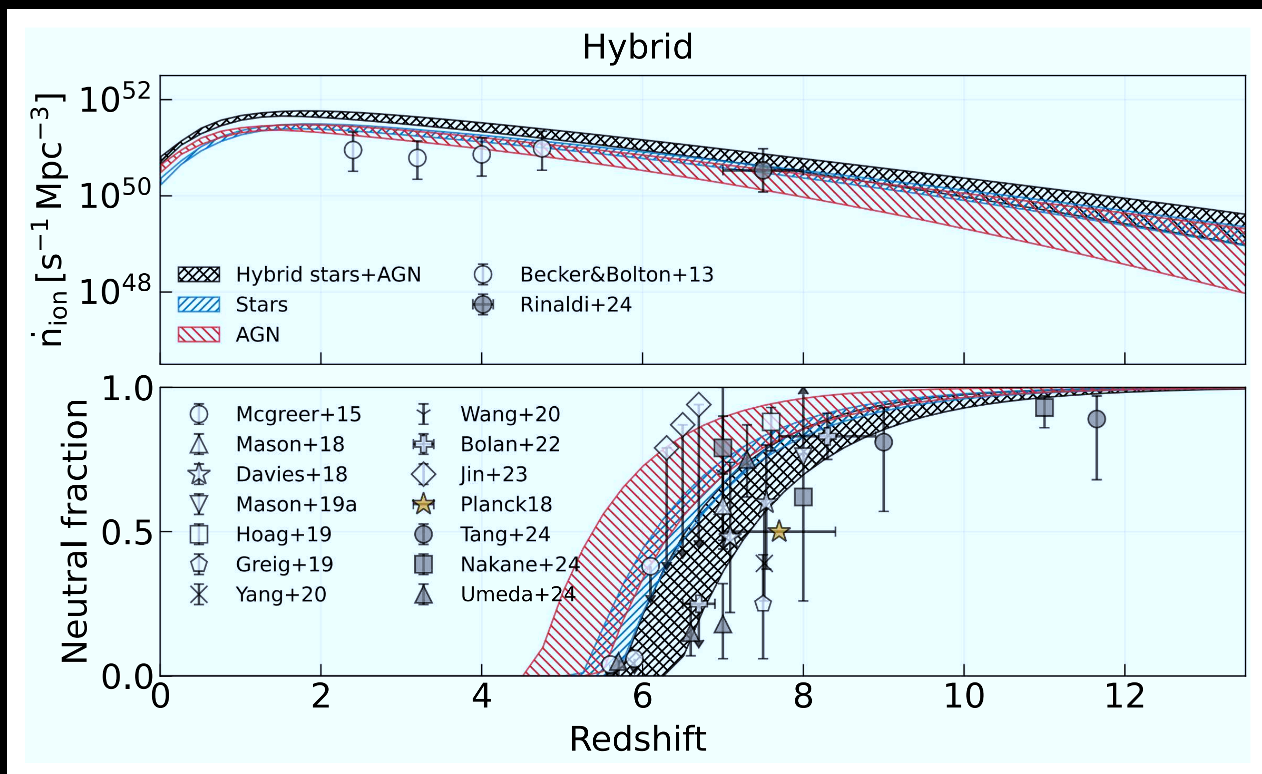


- Cosmic SFH & AGN-FH derived from multi-band HST+JWST data:
- Use ProSpect to decompose into galaxy & AGN SEDs.

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

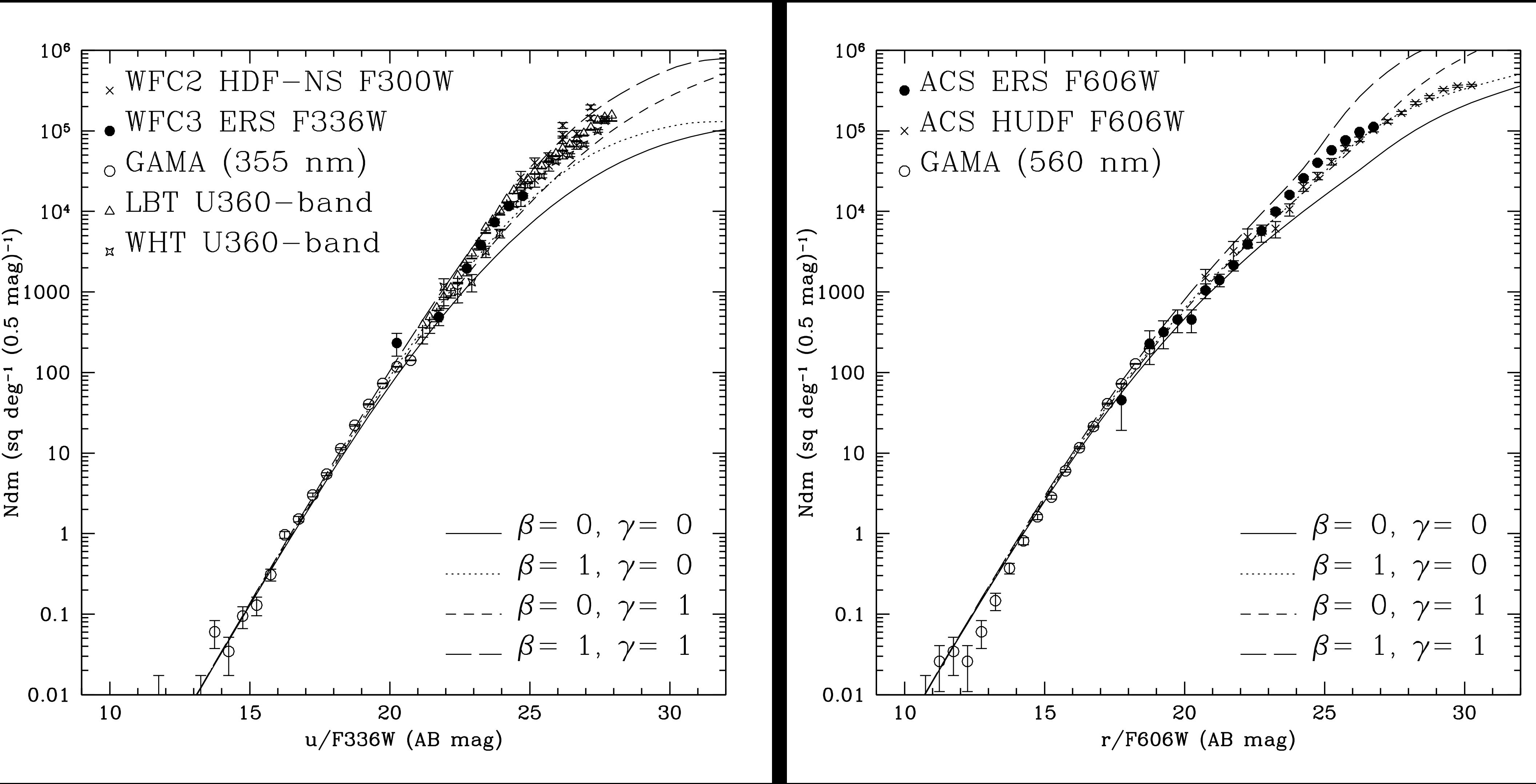
$\Longrightarrow$Within errors, AGN-FH/SFH $\simeq$ constant at $z \gtrsim 2$, but increases at $z \lesssim 1$.





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

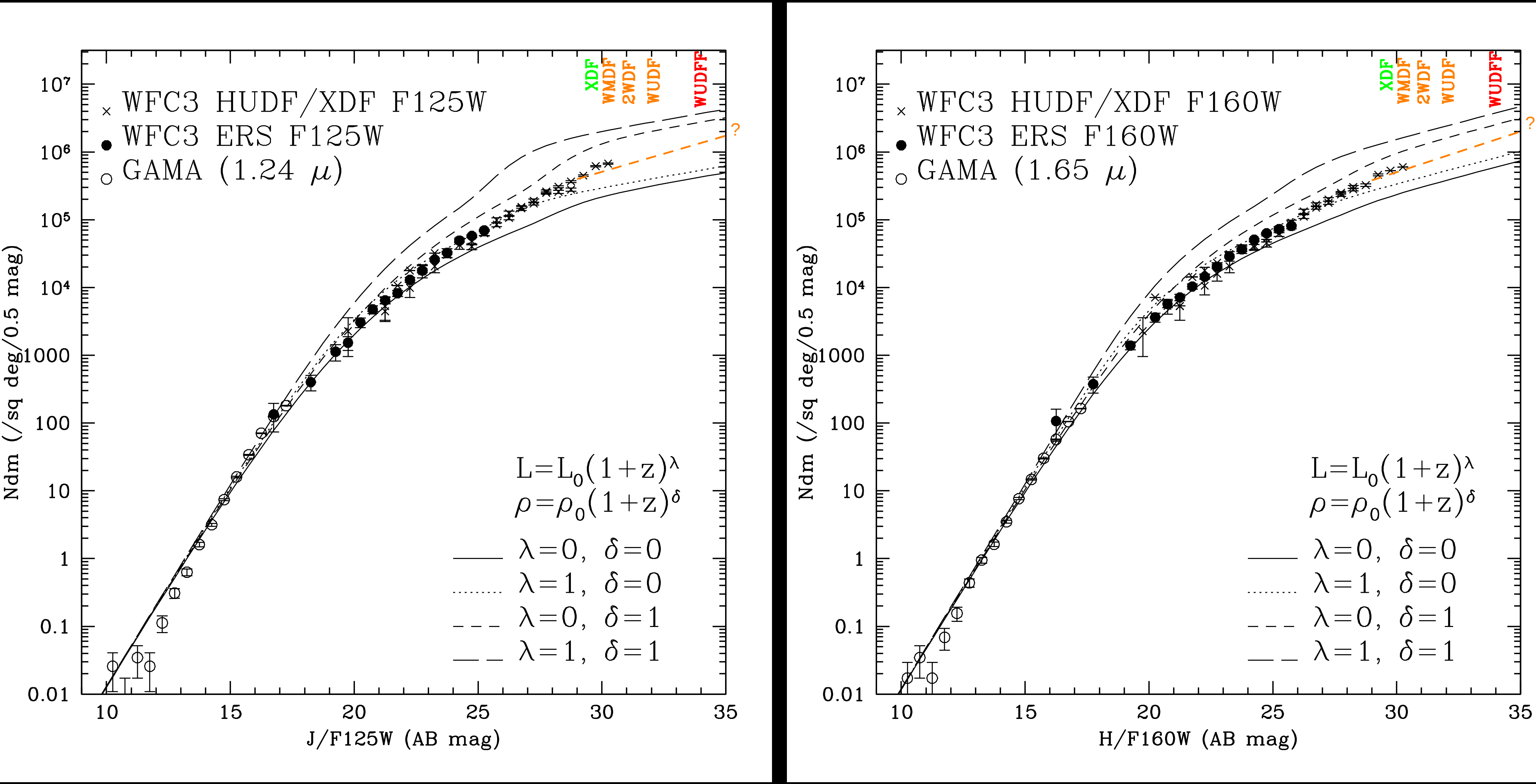
(2) Need space-based imaging for contamination-free LyC work !



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

Faint-end blue count-slope≃0.30–0.40 dex/mag.

Integrated surface density at AB≲31 mag: 3×10^6 deg^{-2} .



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

Faint-end near-IR count-slope≃0.12±0.02 dex/mag.

Integrated surface density at AB≲31 mag: 4.2×10^6 deg^{-2} .

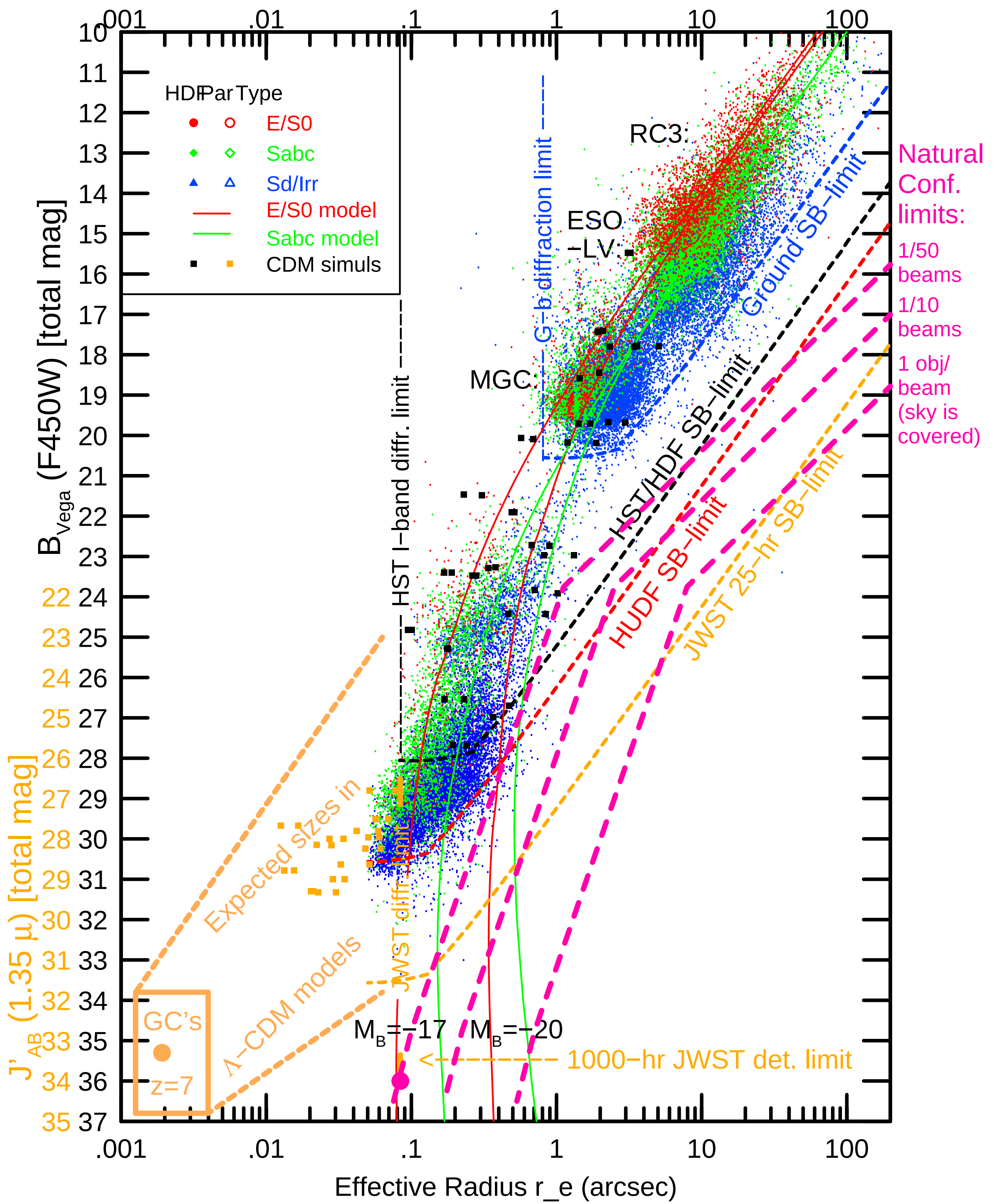
B, I, J AB-mag vs. half-light radii r_e from RC3 to HUDF.

All surveys limited by by SB (+5 mag dash)

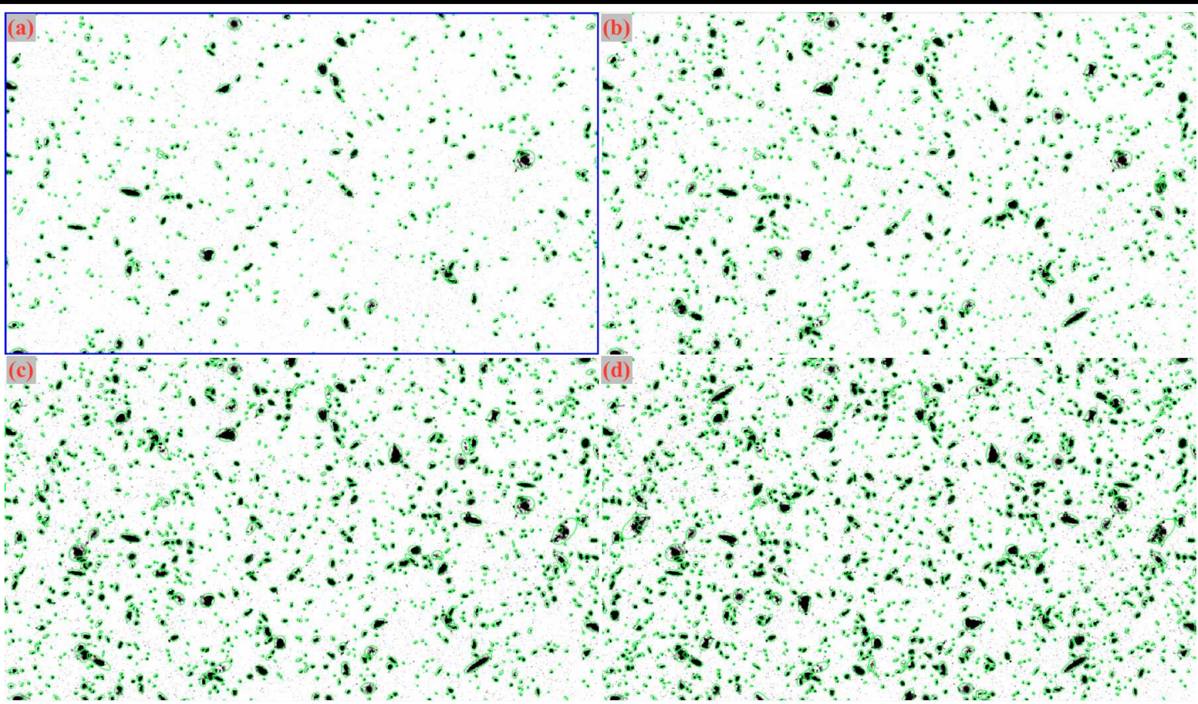
Deep surveys bounded also by object density:

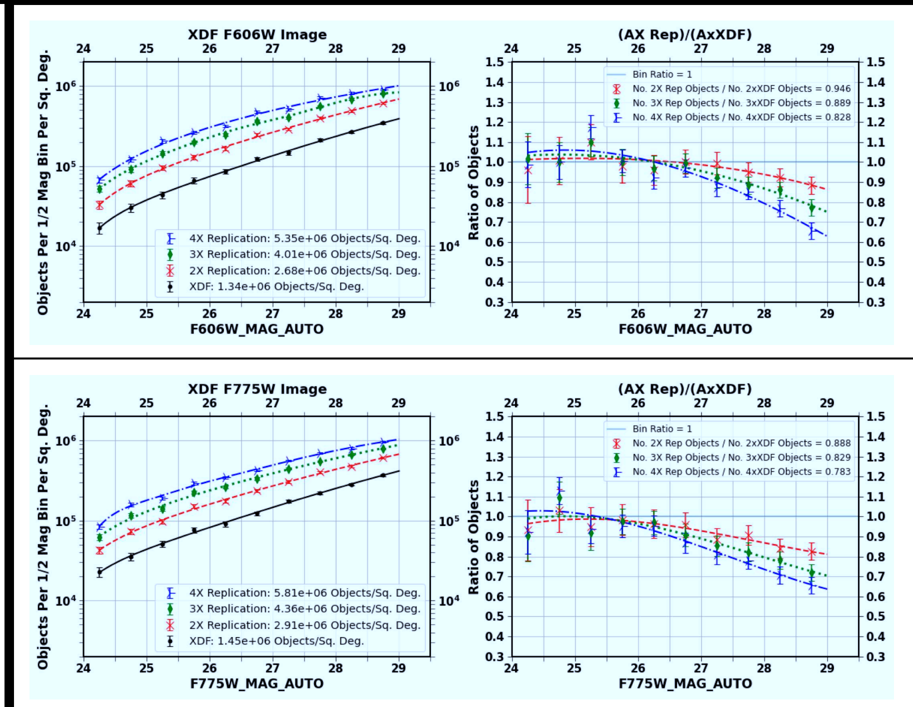
violet lines are gxy counts converted to to natural conf limits.

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° rotation:

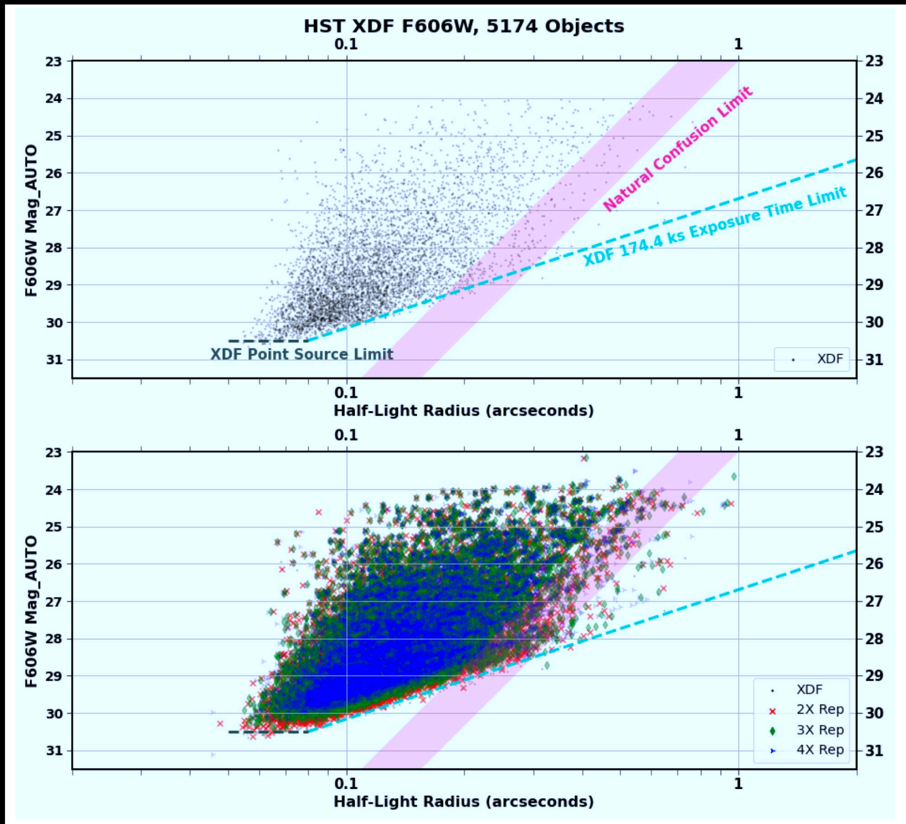
[Right]: 4$\times$HUDF counts still $\gtrsim$65% complete for AB$\gtrsim$28.5–29 mag.

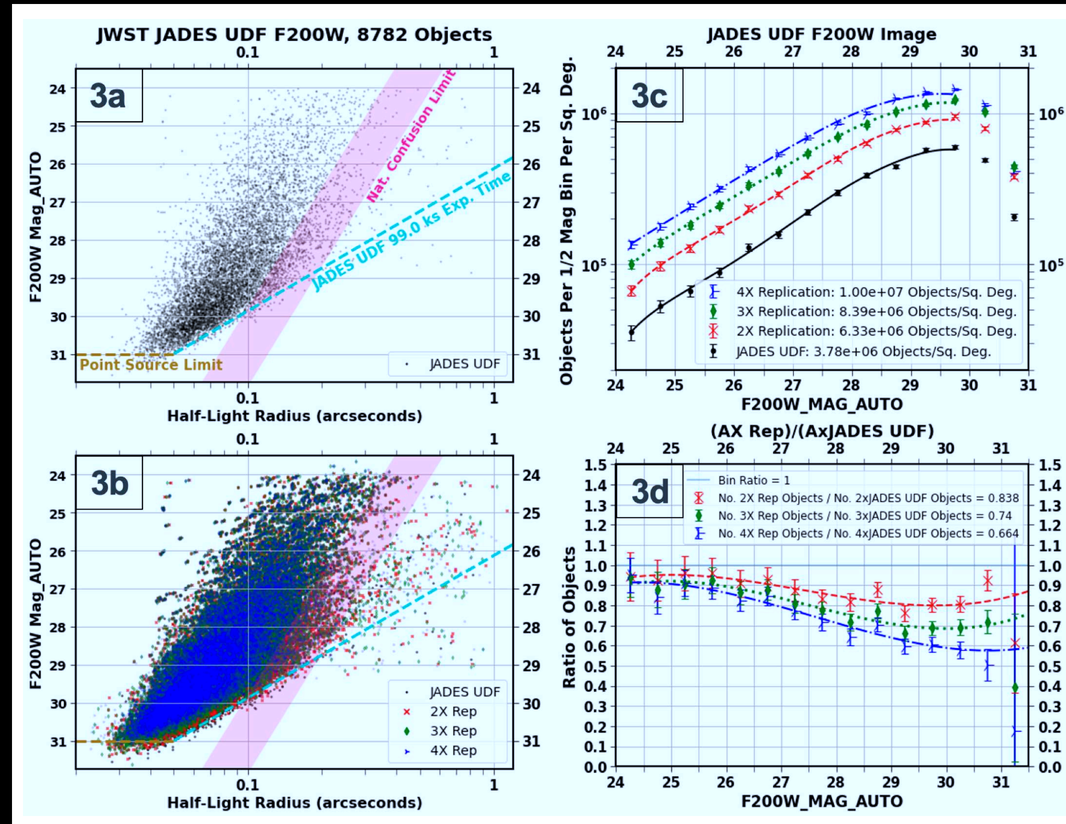
(Kramer$^+$, 2022, ApJL, 940, L15; astro-ph/2208.07218v2).

- 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^2 at AB$\lesssim$31 mag with $r_{hl} \lesssim 0\farcs1$–$0\farcs2$ FWHM.

(Windhorst$^+$ 2008, Adv. in Space Res., 41, 1965 (astro-ph/0703171); — 2011, ApJS, 193, 27; — 2022, AJ, 164, 141; — 2023, AJ, 165, 13).





Top: mag vs r_e for 174 ksec XDF (left) & 99 ksec JADES (middle) galaxies.

Bottom: Same for XDF & JADES rotated+replicated onto itself $2\times$, $3\times$, $4\times$.

Right: Counts and completeness functions for $2\times$, $3\times$, $4\times$ rotated images.

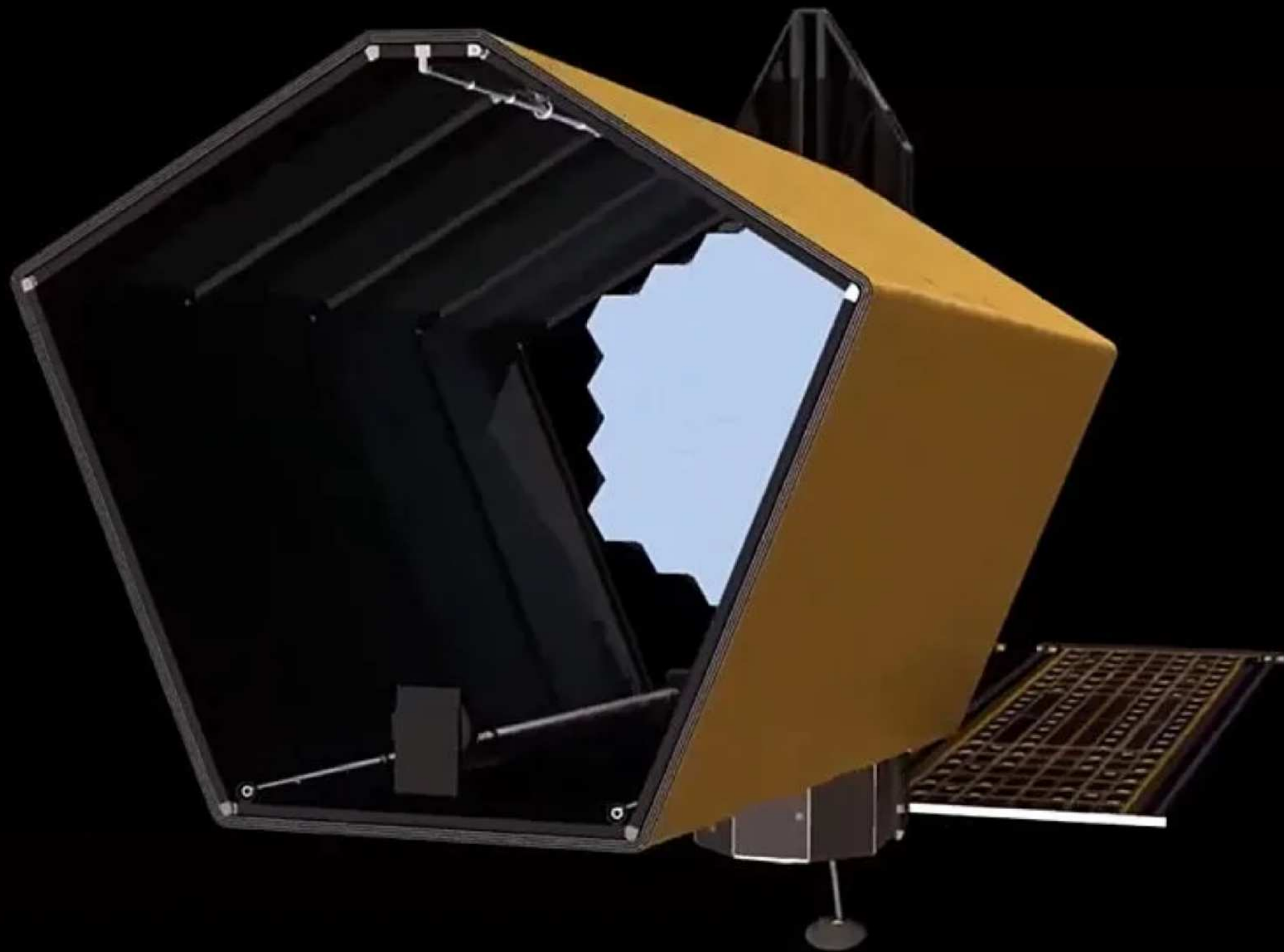
- $\lesssim$35% of faintest galaxies lost due to statistical object overlap.

(Kramer$^+$, 2022, ApJL, 940, L15; astro-ph/2208.07218v2).

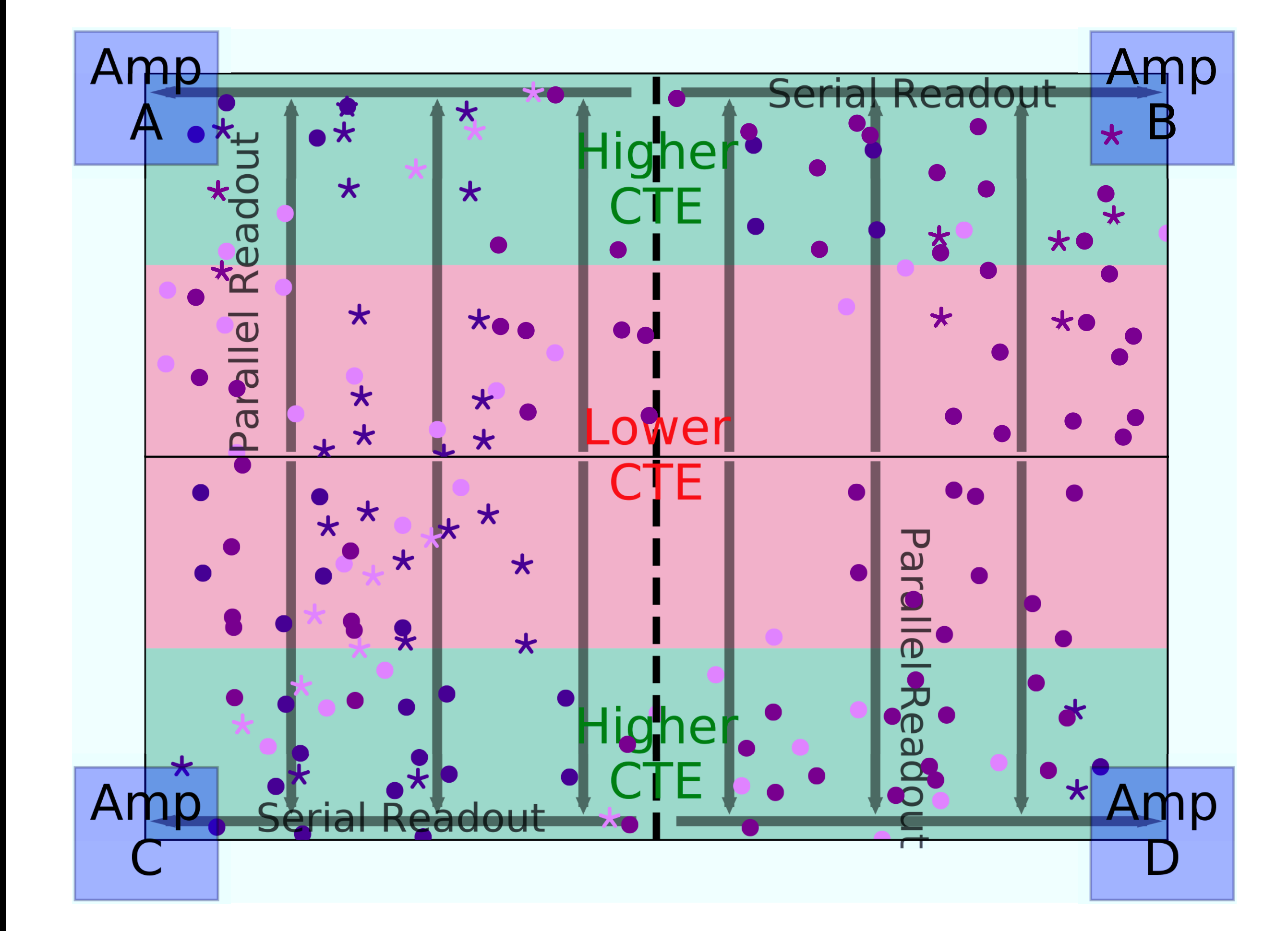
$\Rightarrow$ LyC work at UVC$\sim$24-27 must avoid contaminants with AB$\lesssim$28–31 mag!

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

(3) Habitable World Observatory requirements for LyC work



- Next generation $\gtrsim$6–8 meter UV-optical space telescope (HWO) essential for AB$\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.



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.

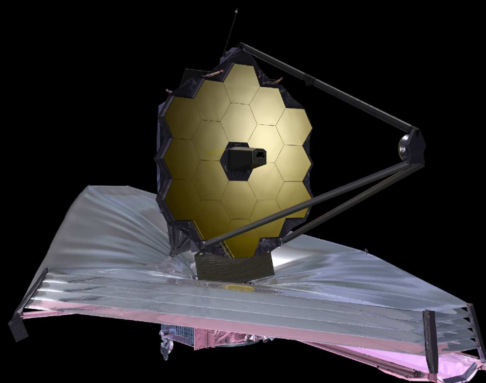
- (A) Scientific/Astro-Community Lessons
- (B) Technical Lessons
- (C) Management/Budget/Schedule Lessons
- (D) Political/Outreach Lessons

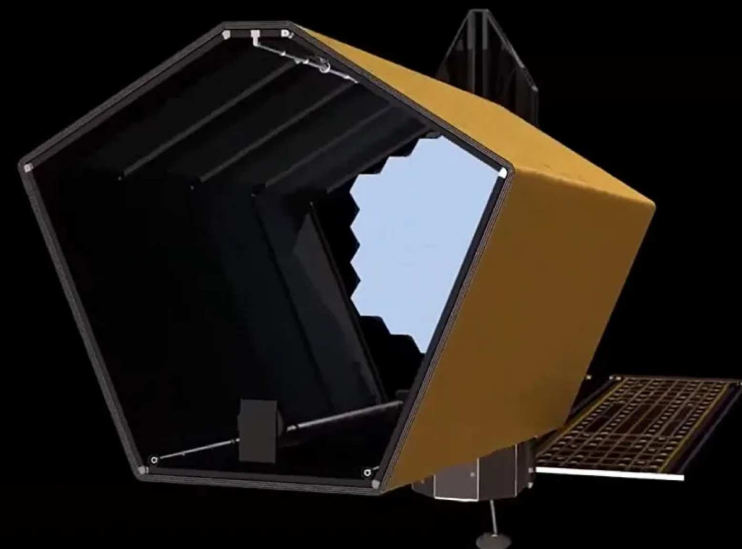
I thank Drs. S. Cohen, G. Illingworth, R. Jansen, J. Mather, E. Smith, R. Smith & H. Thronson for comments.

Full 1-hr talk is on: `http://www.asu.edu/clas/hst/www/jwst/jwsttalks/fall2020_jwstlessons.pdf`

Past, Present and Future: Can and will the dream continue?

True relative size: Hubble, James Webb, Roman, & HWO

	Hubble	James Webb	Roman	HWO
	1973–2034^{+}(!)	1996–2046^{+}	2012–2037?	2025–2070^{+}?
Launch:	1990	2021	$\gtrsim$2027	$\gtrsim$2040?
Σ_{FC}:	$\gtrsim$20 B$	$\gtrsim$10 B$	$\sim$3 B$	15–20 B$?

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

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.

• Infighting killed the 1988 Superconducting Supercollider in Texas (left).

• Canceled project funds never returns: CERN didn't make that mistake (right).

$\Longrightarrow$ Avoid infighting with other (exoplanet) HWO stake-holders.

• Design HWO for exoplanets, reionization, and everything in between.

(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 $z \simeq 2.3$–3.5

- Design HWO filters with low-enough redleak to enable this.
- Deepest multi-band images to mask foreground $AB \lesssim 30$ interlopers.

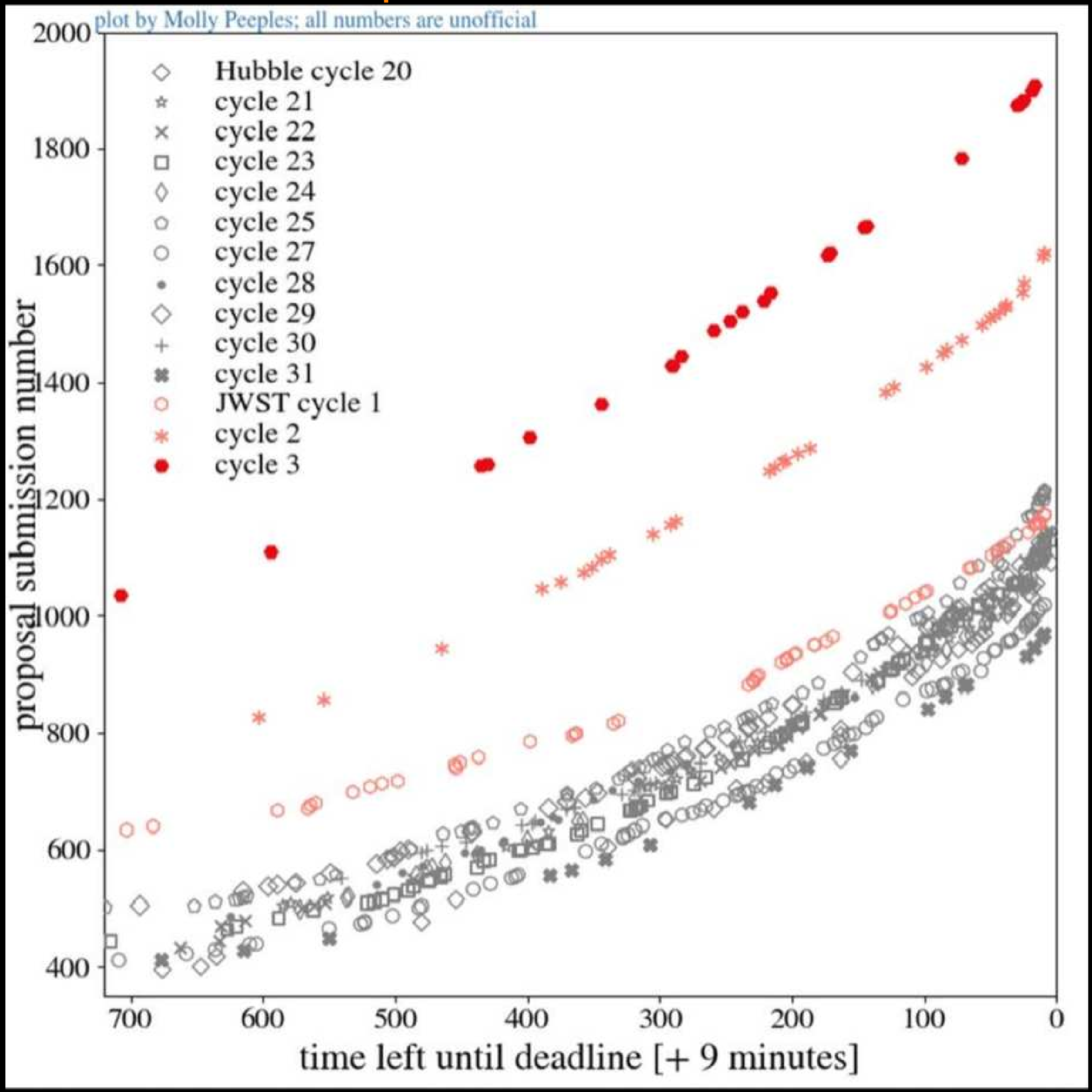
(3) Habitable World Observatory requirements for LyC work:

- L2 servicing every 5–10 years or so — is feasible to L2.
- Wide-field UV sensitized CCDs with periodic replacement.
- Wide-field UV IFU, & UV MSA Spectrograph — needs development.

(4) Coherent team: design HWO for science from exoplanets to reionization.

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

Spare charts



- 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).

PEARLS papers, press releases and other URLs

Talk: http://www.asu.edu/clas/hst/www/jwst/crete25_futureLyC_fromspace.pdf   Data: https://sites.google.com/view/jwstpearls

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