

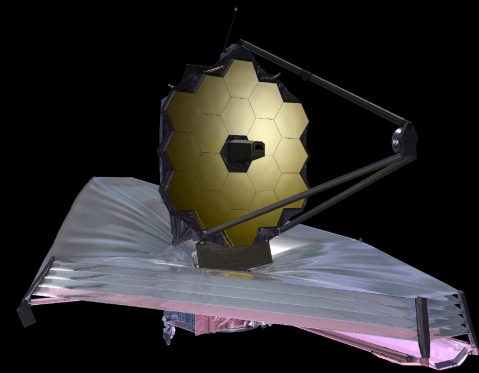
The tale of two telescopes: Hubble and Webb: Essential complementarity of a UV-optical and an IR facility

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

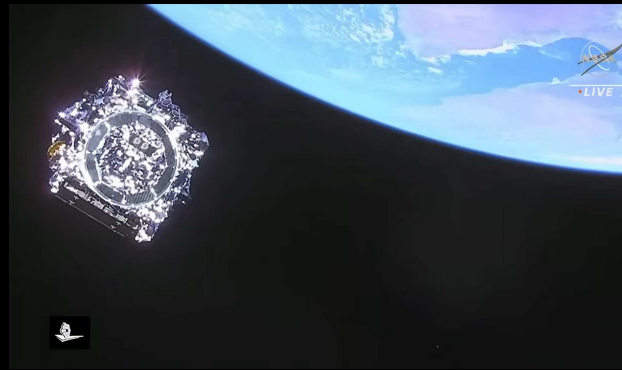
+ HST SKYSURF and JWST PEARLS & SKYSURFIR teams: T. Carleton, S. Cohen, R. Jansen, J. Berkheimer, D. Carter, I. McIntyre, D. Kramer, T. McCabe, R. O'Brien, R. Ortiz, T. Acharya, H. Archer, P. Bahtia, C. Cain, L. Conrad, K. Croker, Z. Goisman, N. Foo, B. Frye, R. Honor, H. Ingram, P. Kamienieski, A. Koekemoer, M. Miller, P. Porto, C. Redshaw, B. Smith, J. Summers, S. Tompkins, H. Yan,
+ 100 more scientists over 18 time-zones



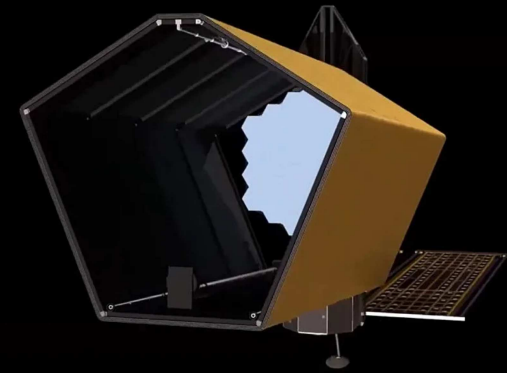
Hubble
1973~2033⁺?



Webb (designed)
1996~2031



Webb (launched 2021)
1996~2046⁺?



Habitable Worlds
2040~2070⁺?

Review Talk; Hubble, Webb, and Beyond session, AAAS Annual Meeting;

Hynes Convention Center, Boston, MA; Friday Feb. 14, 2025

PDF on: http://www.asu.edu/clas/hst/www/aaas25_windhorst_hstjwst_v3.pdf

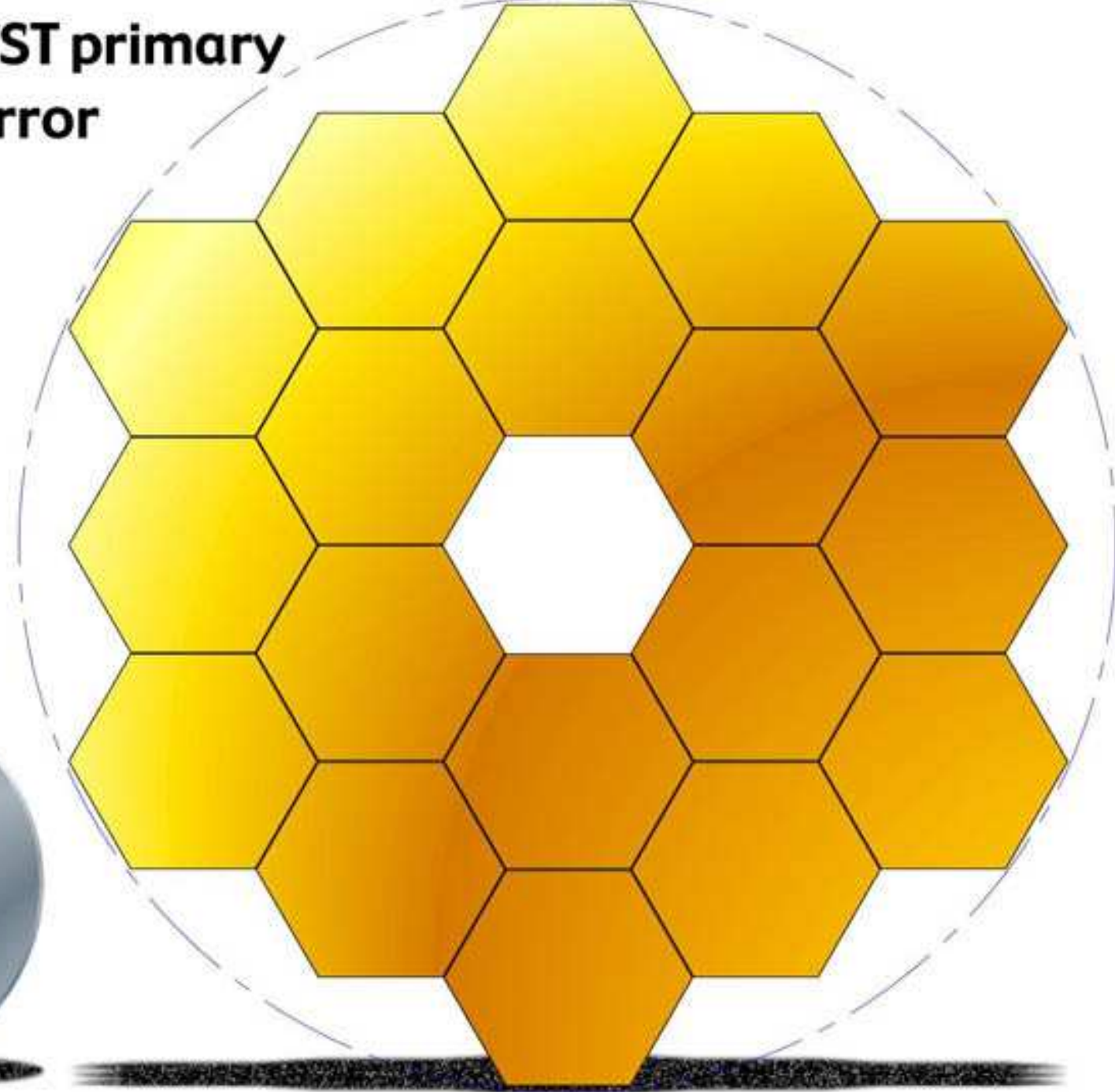
Outline

- (1) Uniquely complementary roles of Hubble and Webb:
414–500 hr combined HST+JWST images \Rightarrow keep HST alive!
- (2) Viewing the Universe through the “Eyes of Einstein”
- (3) Summary and Conclusions
- (4) Spare science charts

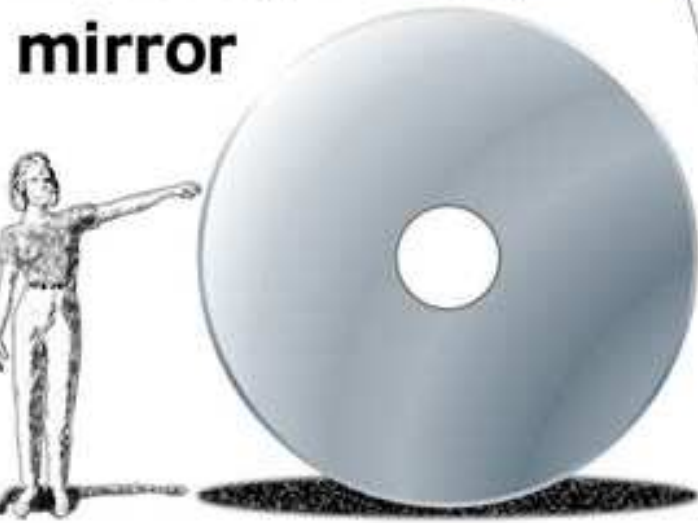


Sponsored by NASA/HST & JWST

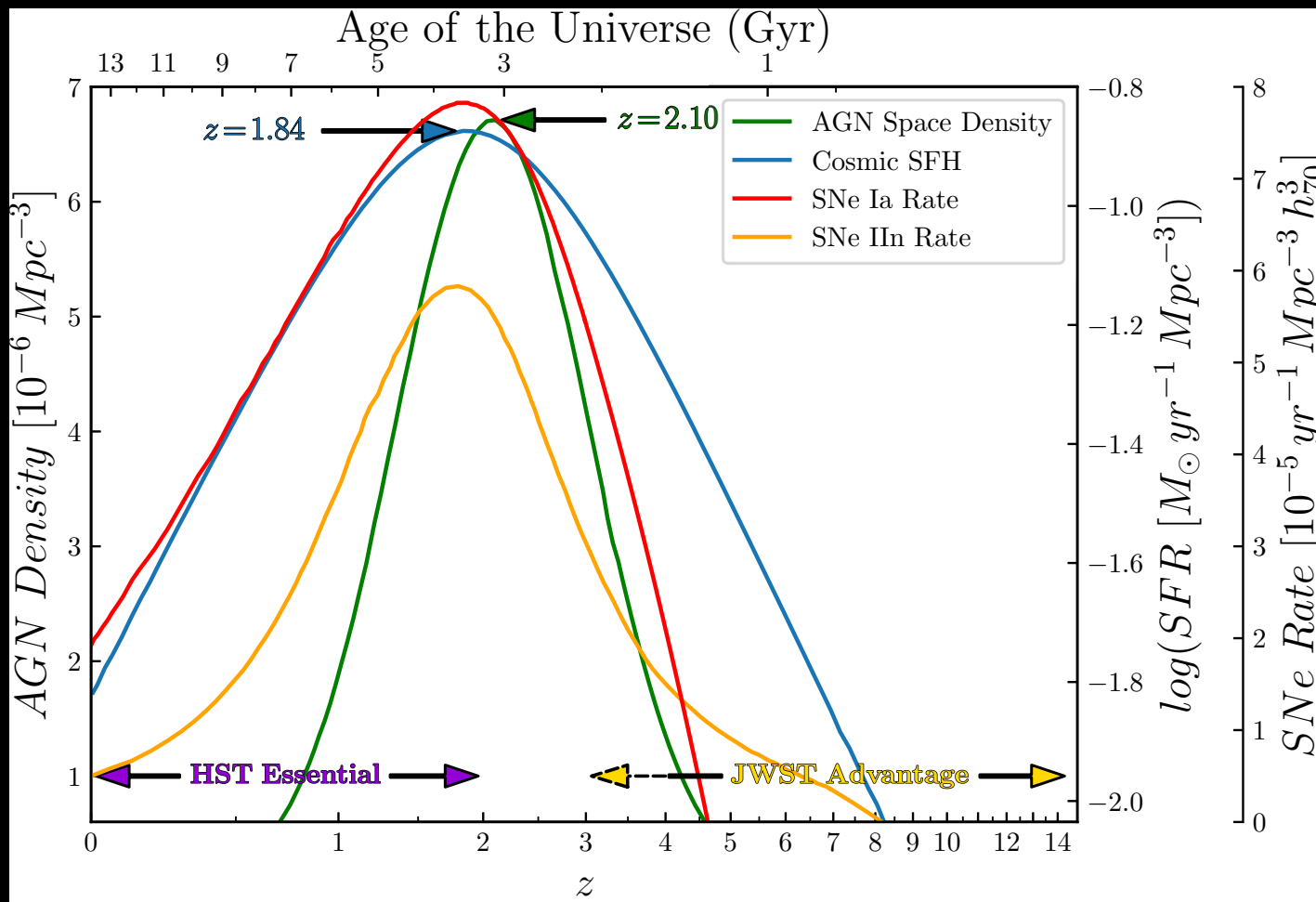
**JWST primary
mirror**



**Hubble primary
mirror**

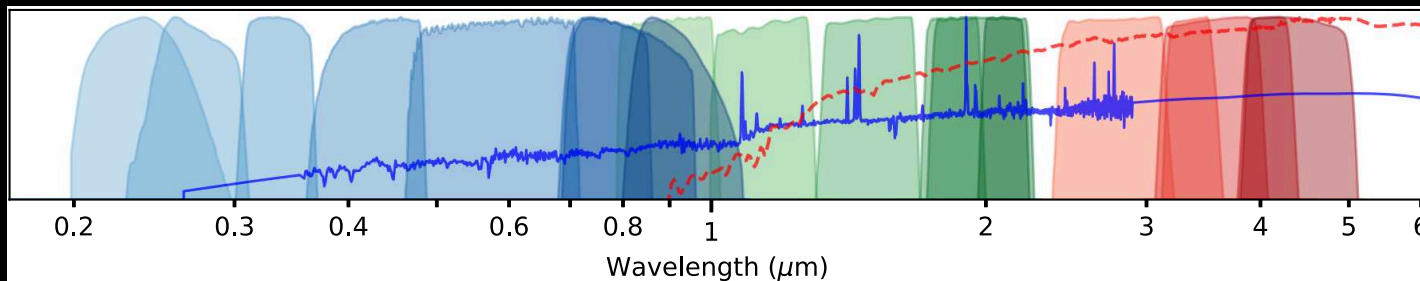


JWST $\simeq 2.5\times$ larger than Hubble, so at $\sim 2.5\times$ larger wavelengths:
JWST has the same resolution in the near-IR as Hubble in the optical.



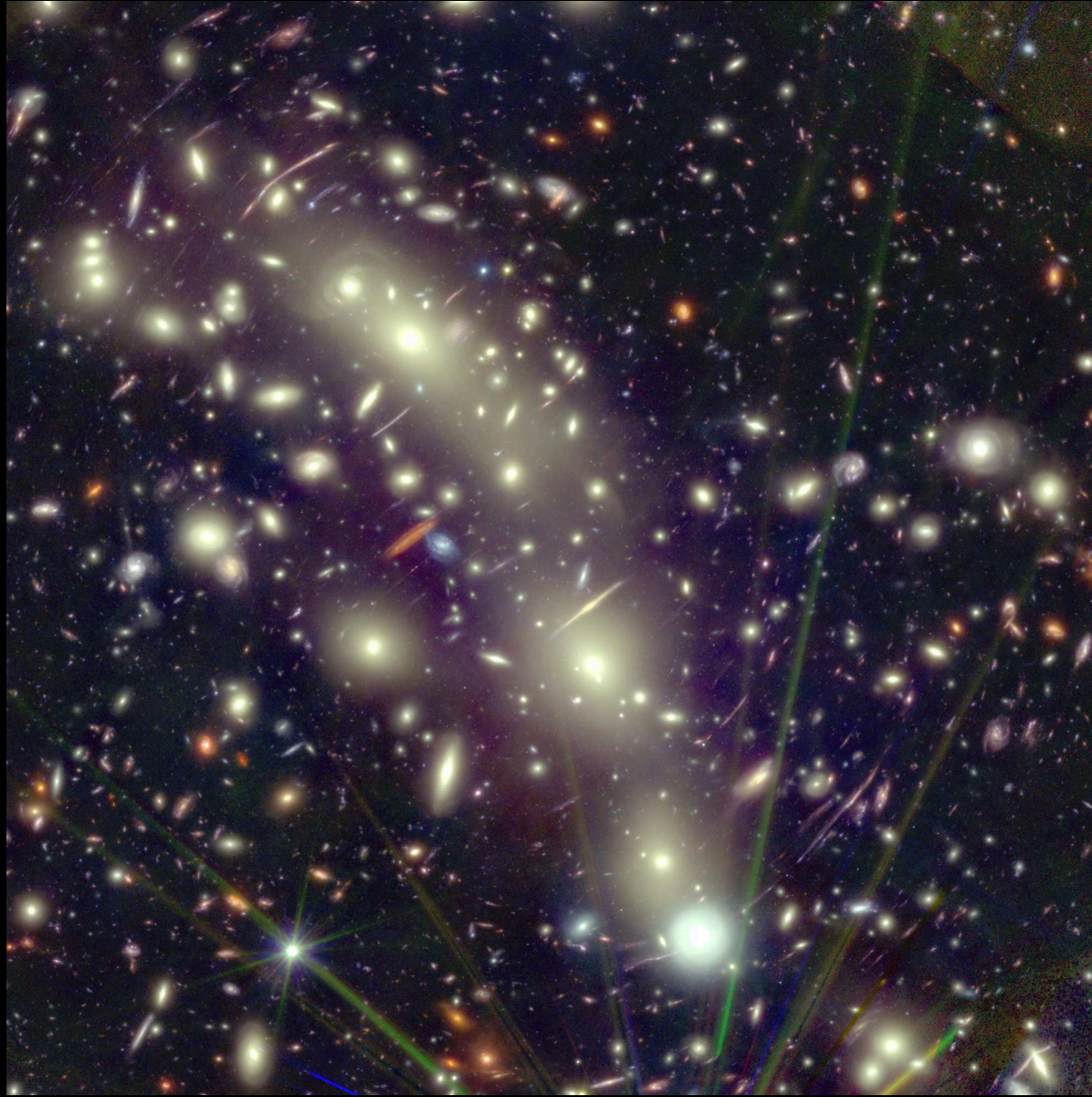
$$\text{Age} \sim \frac{13.8}{(1+z)} \text{ Gyr}$$

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:

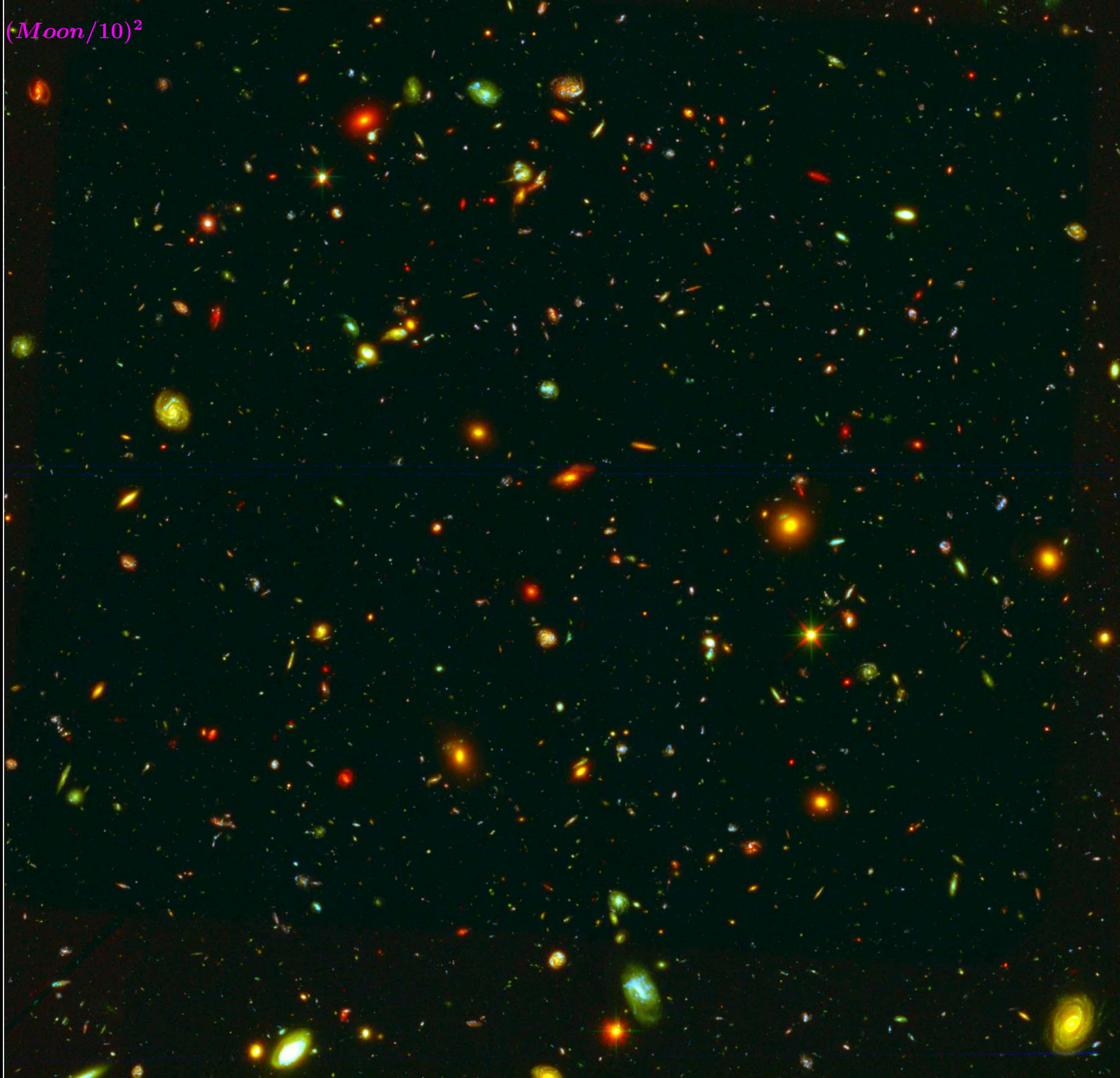


500 hrs HST+JWST: 45 filters ($0.2\text{--}5.0\mu\text{m}$), lensing cluster MACS0416:

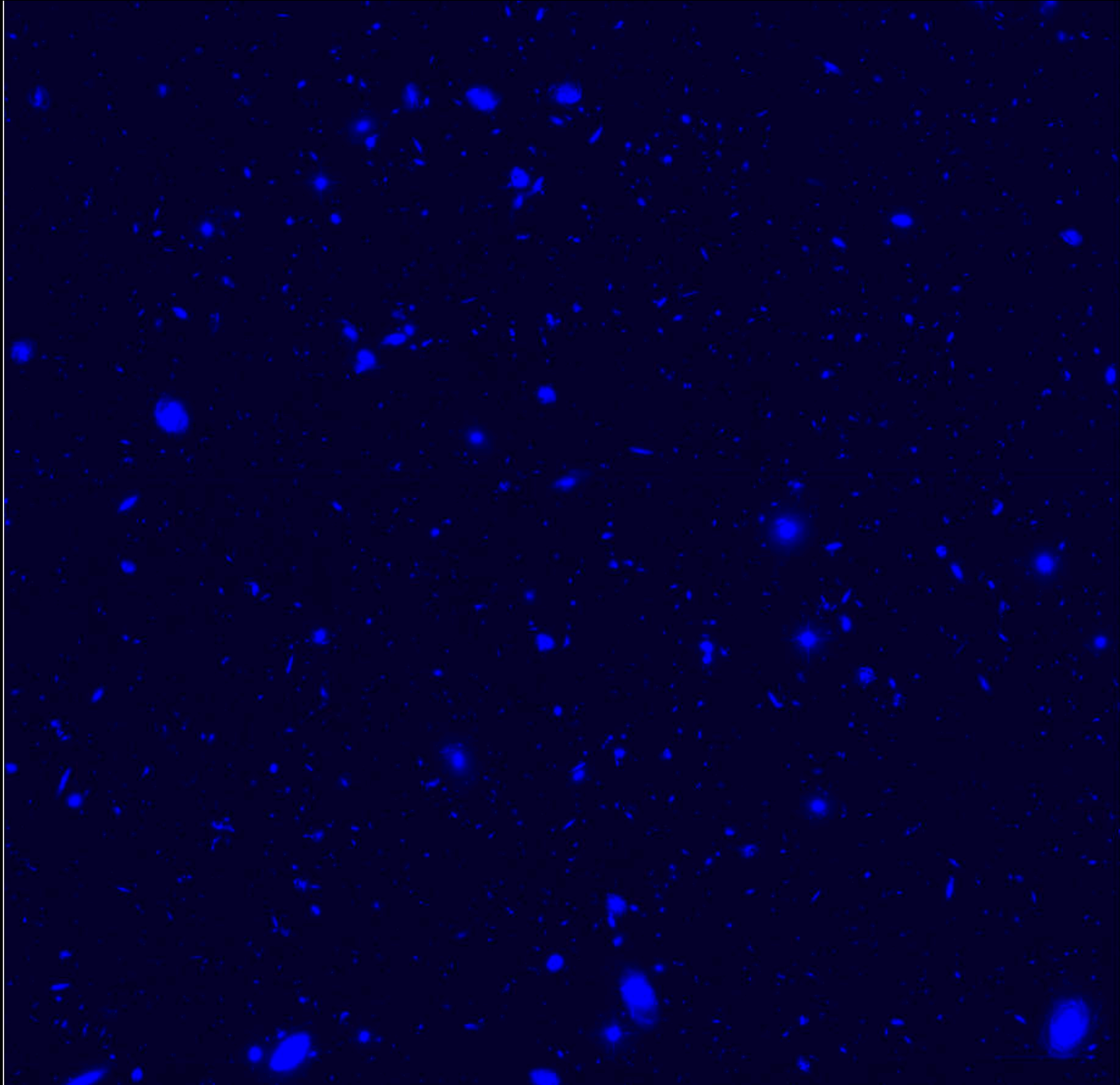
- HST darkest skies ($10\text{--}10^3\times$ darker) + JWST's dark skies ($10^3\text{--}10^5\times$ darker than ground based):

\implies HST & JWST reach 30–31 mag (~ 1 firefly from Moon).

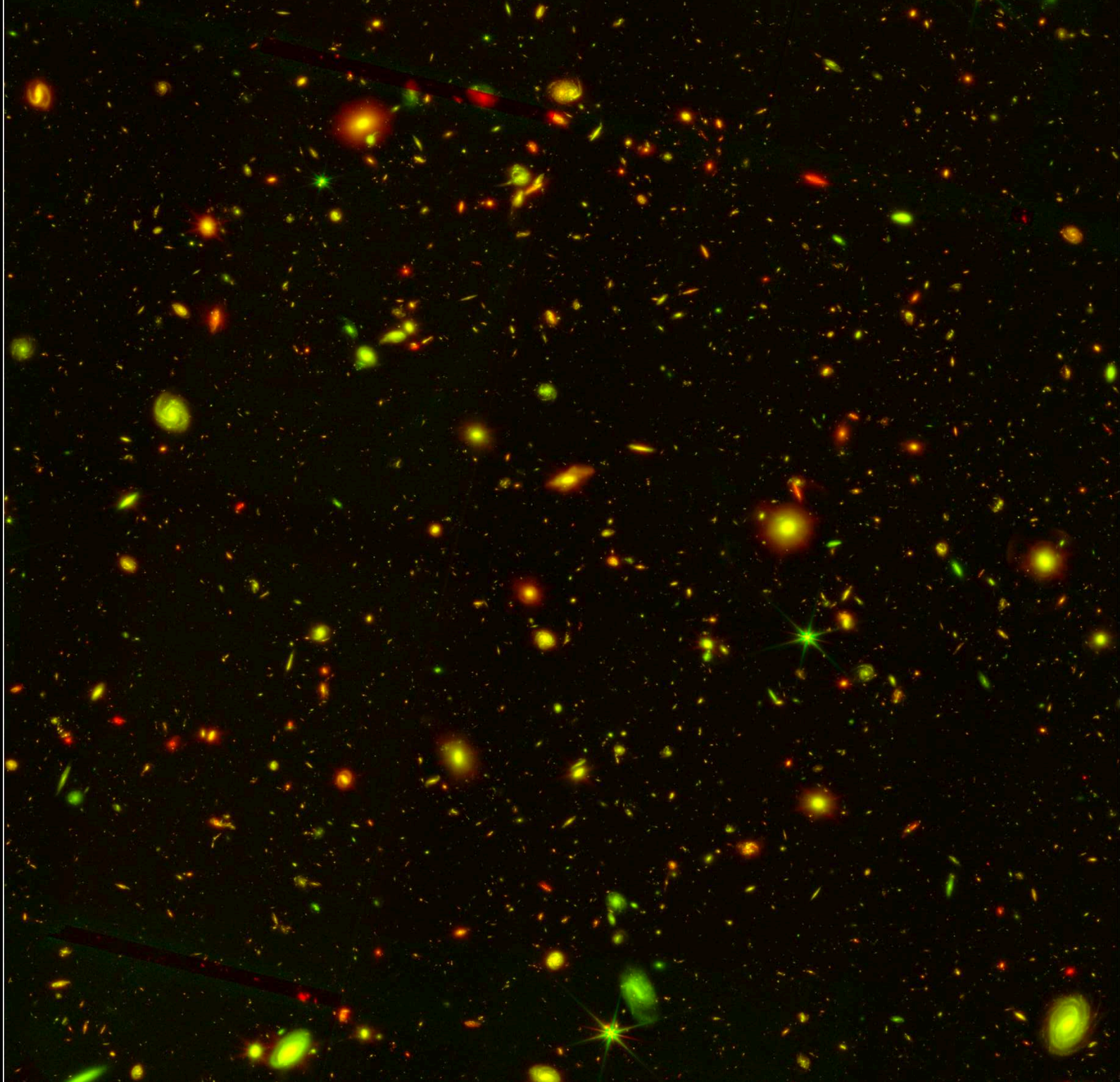
Field-of-View $\sim (Moon/10)^2$



556 hr HST Hubble UltraDeep Field: 12 filters at 0.2–1.6 μm ($AB \lesssim 31$ mag; 1 FF(Moon); full B GR).



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



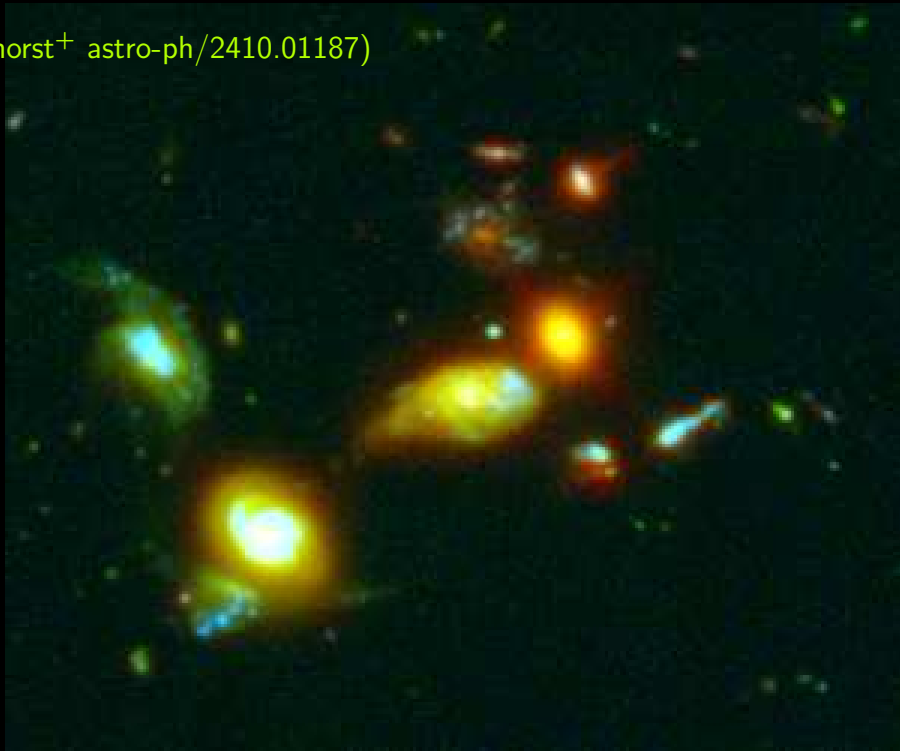
53 hr JWST/NIRCam Hubble UltraDeep Field: 12 filters at 0.9–5.0 μm ($AB \lesssim 31$ mag; in green + red).

(Windhorst⁺ astro-ph/2410.01187)

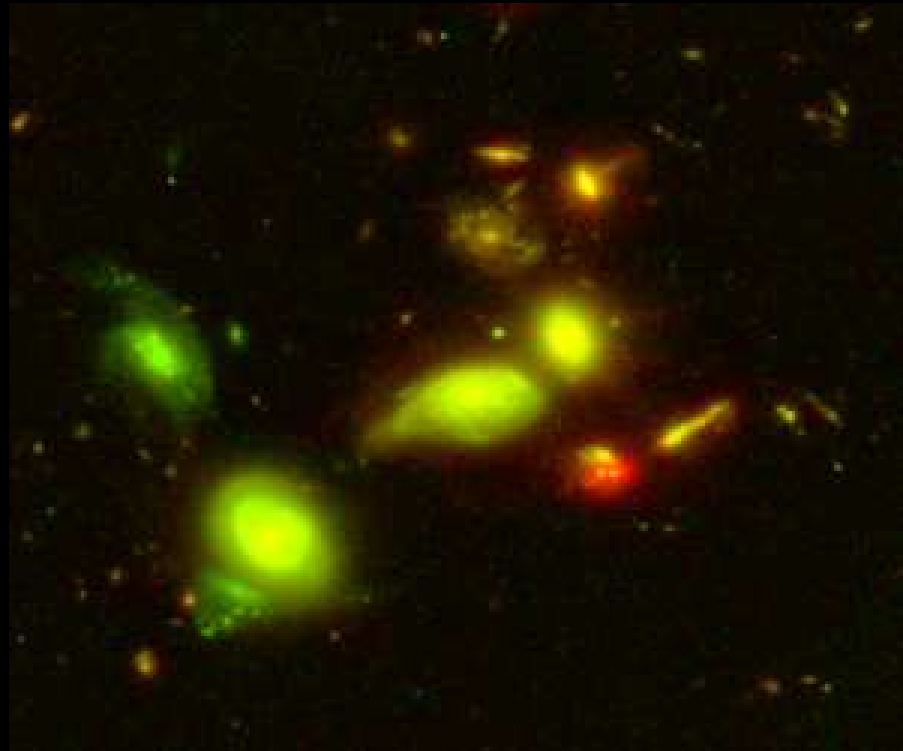


414 hr HST+JWST Hubble UltraDeep Field: 20 filters at 0.2–5.0 μm ($\text{AB} \lesssim 31.5$ mag; full BGR).

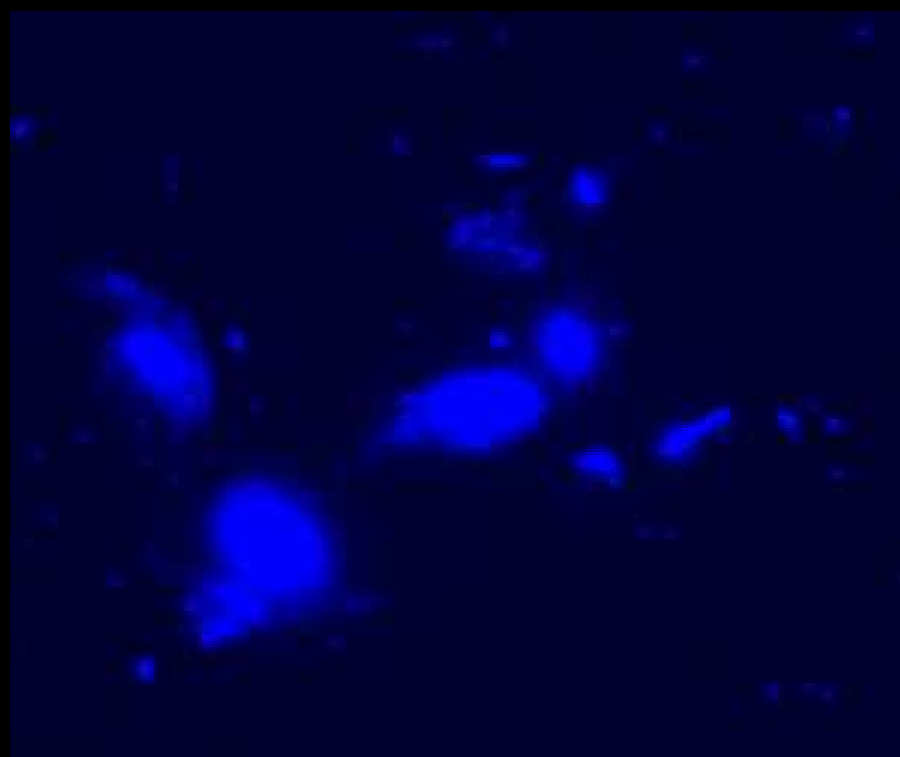
(Windhorst⁺ astro-ph/2410.01187)



556 hr HST HUDF 12 filters



53 hr JWST/NIRCam 12 filters

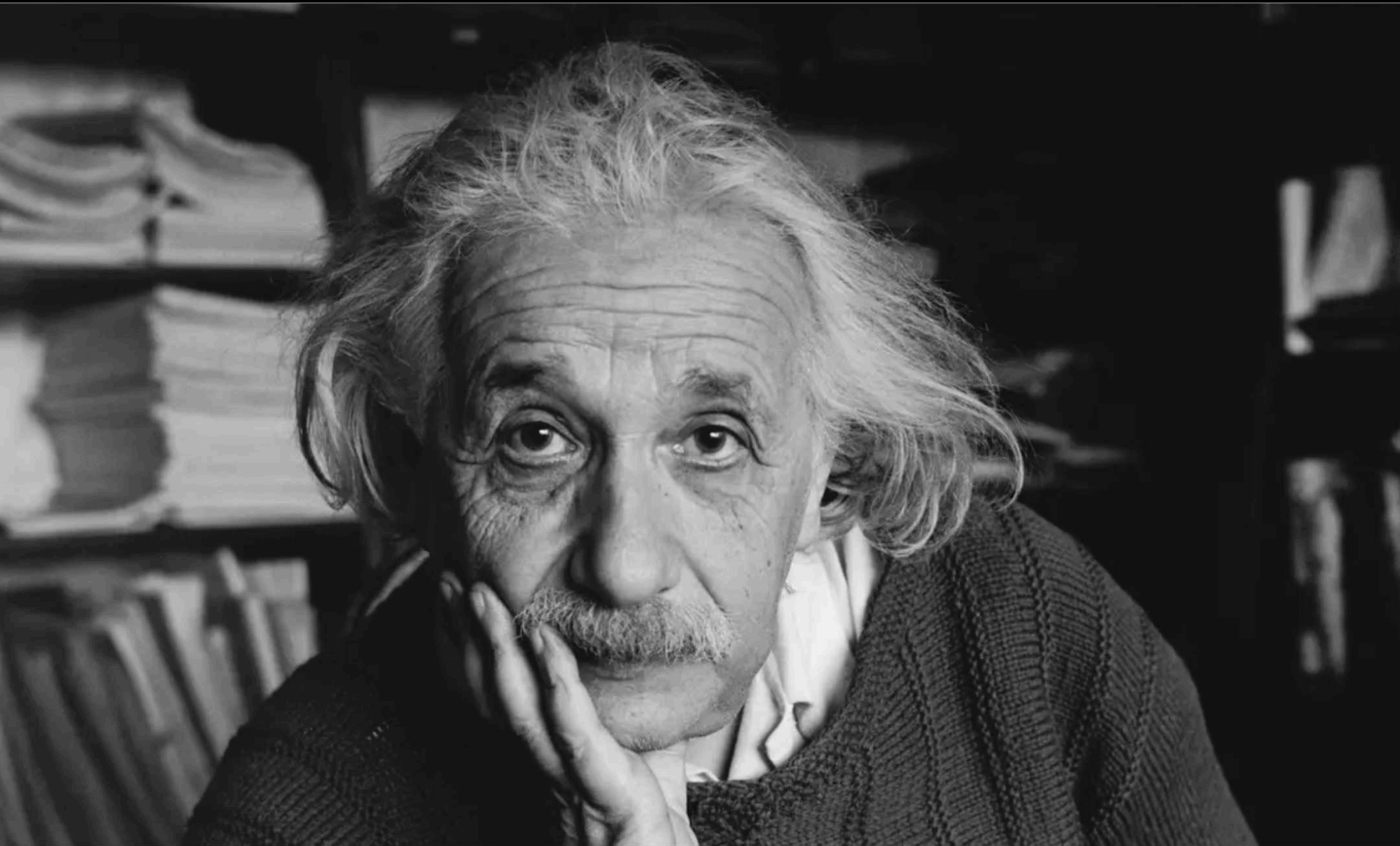


361 hr 8 HST-unique filters (false-blue)



414 hr HST+JWST 20 filters

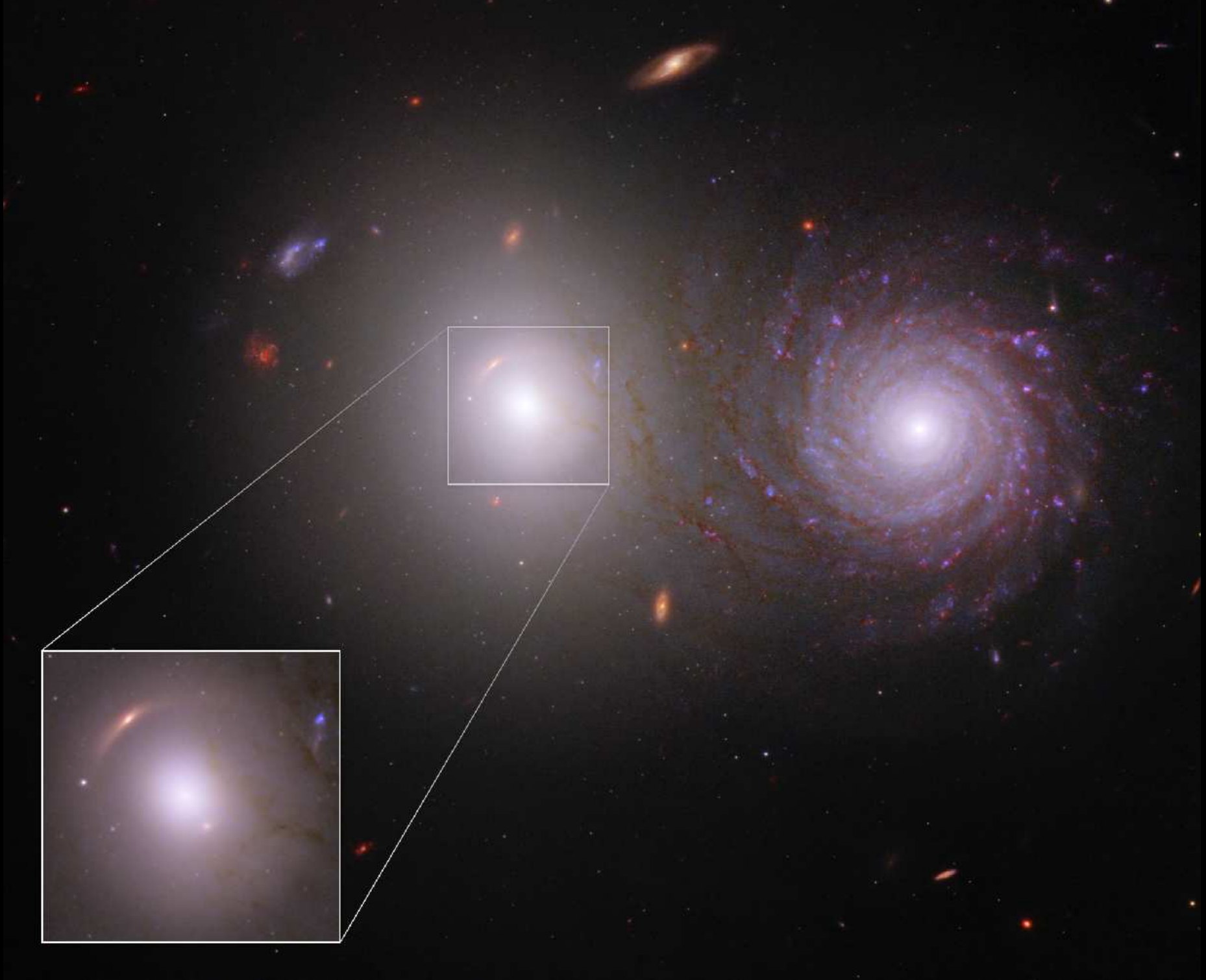
- (2) Viewing the Universe through the “Eyes of Einstein”



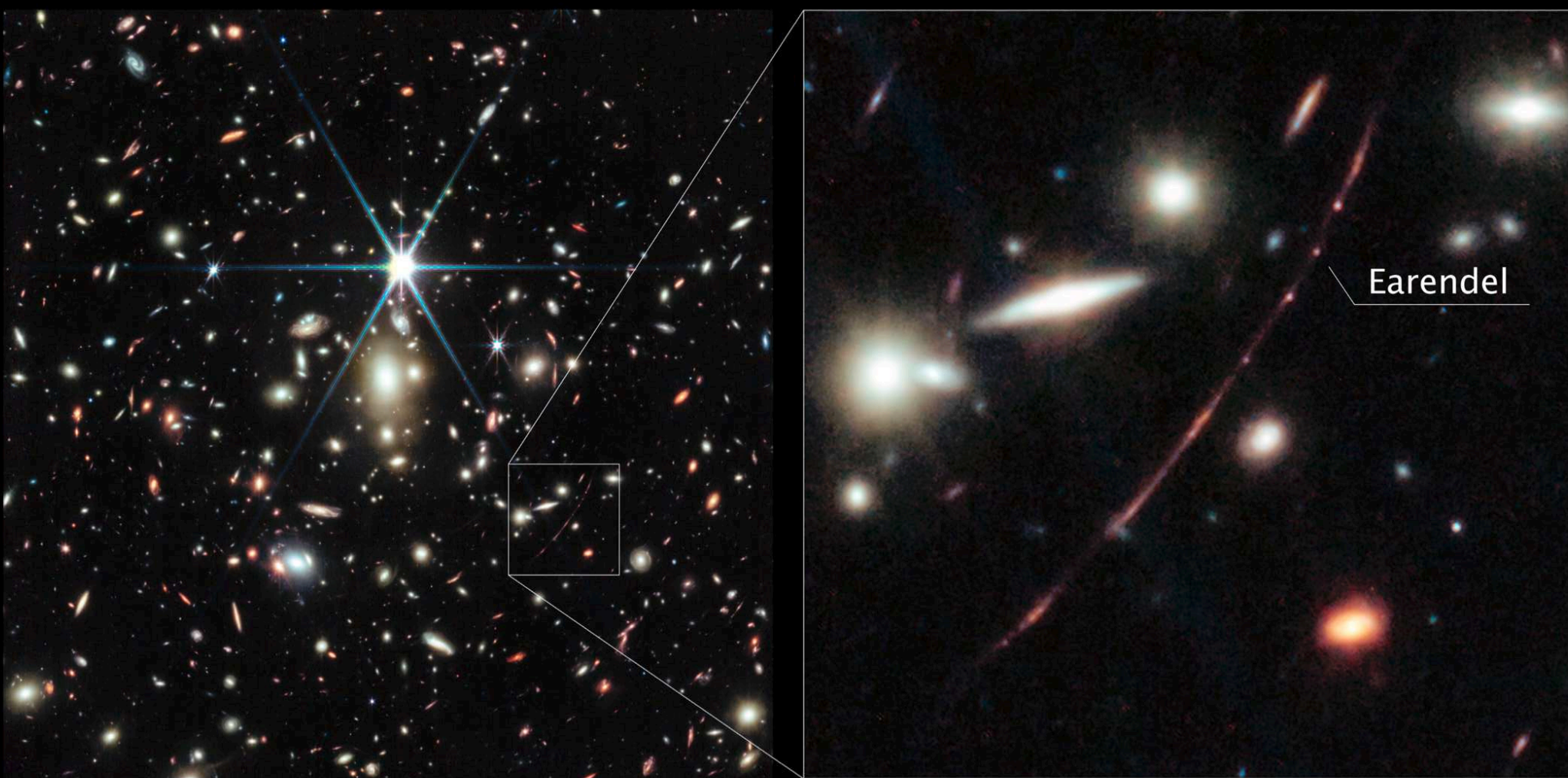
Webb is observing many things Einstein correctly predicted, yet doubted:
Gravitational lensing, Black Holes, the Hubble Expansion, ...



- Spiral overlapping Elliptical VV191: Tracing dust: small grains! (Keel⁺ 23).
 - 150 Globular Clusters in $z=0.0513$ Elliptical (Berkheimer⁺ 2024, ApJ, 964, L29).



... and the $z=0.0513$ Elliptical also lenses a background galaxy at $z\sim 1$ (Keel⁺ 2023, AJ, 165, 16)!



NIRCam: Cluster WHL0137-08 with highly lensed arc at $z=6.2$ (0.9 Byr).

- Earendel: a highly magnified (double-)star seen in the first billion years after the Big Bang — the most distant star ever observed directly!
- Gravitational magnification $\mu \simeq 9000$ due to “caustic crossing”.

(Welch, B., Coe, D., incl. Timmes, F. X. & Windhorst R. et al. 2022, ApJ, 940, L1 and — 2022, *Nature*, 603, 815).



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/>

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.

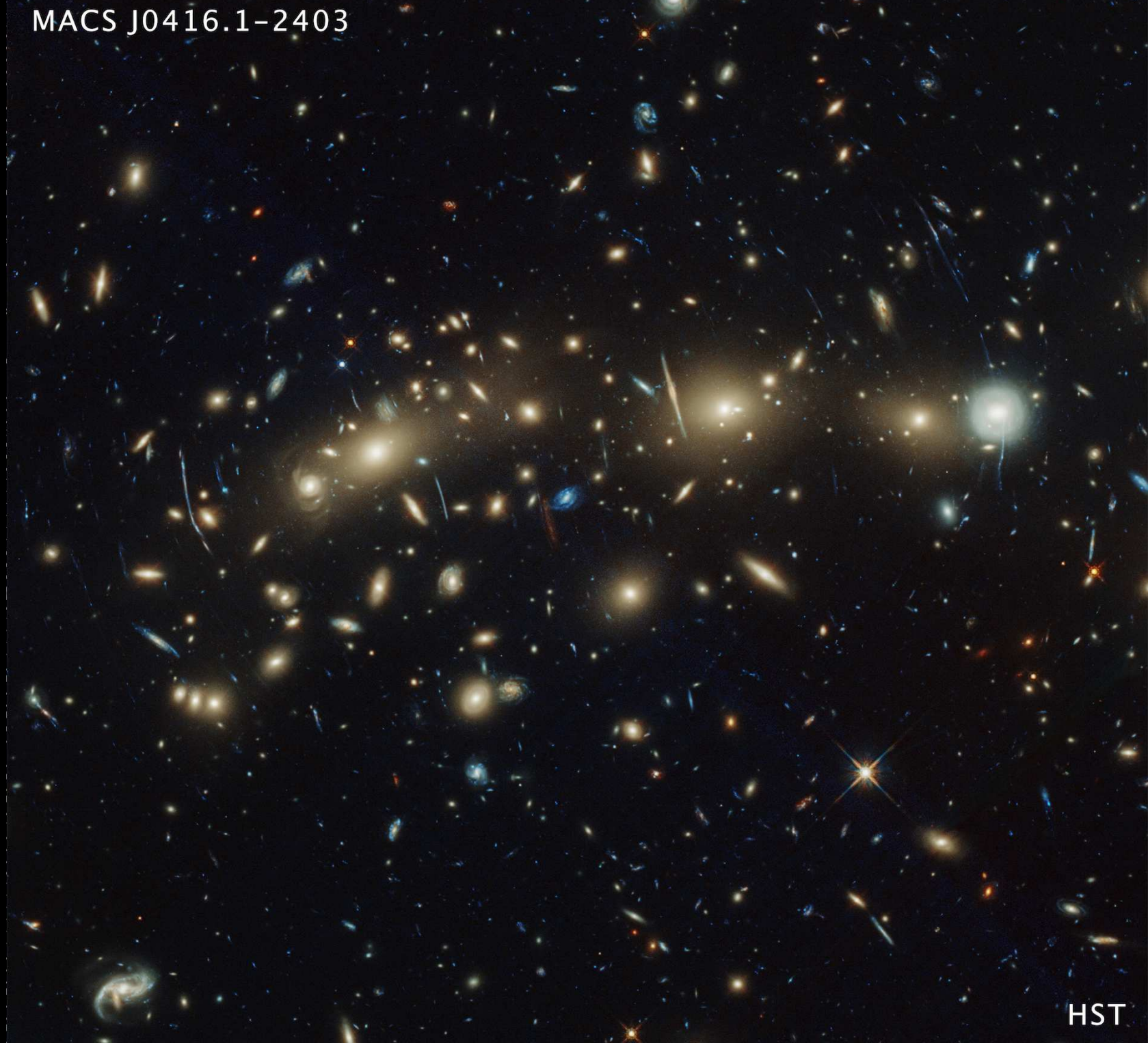
Yan, H.⁺ (2023, ApJS, 269, 42): 12 new caustic transits at $z \simeq 1-2$ from 4 epochs!

Diego, J.⁺ (2023, A&A 679, A31): extremely magnified binary star at $z=2.091$!

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

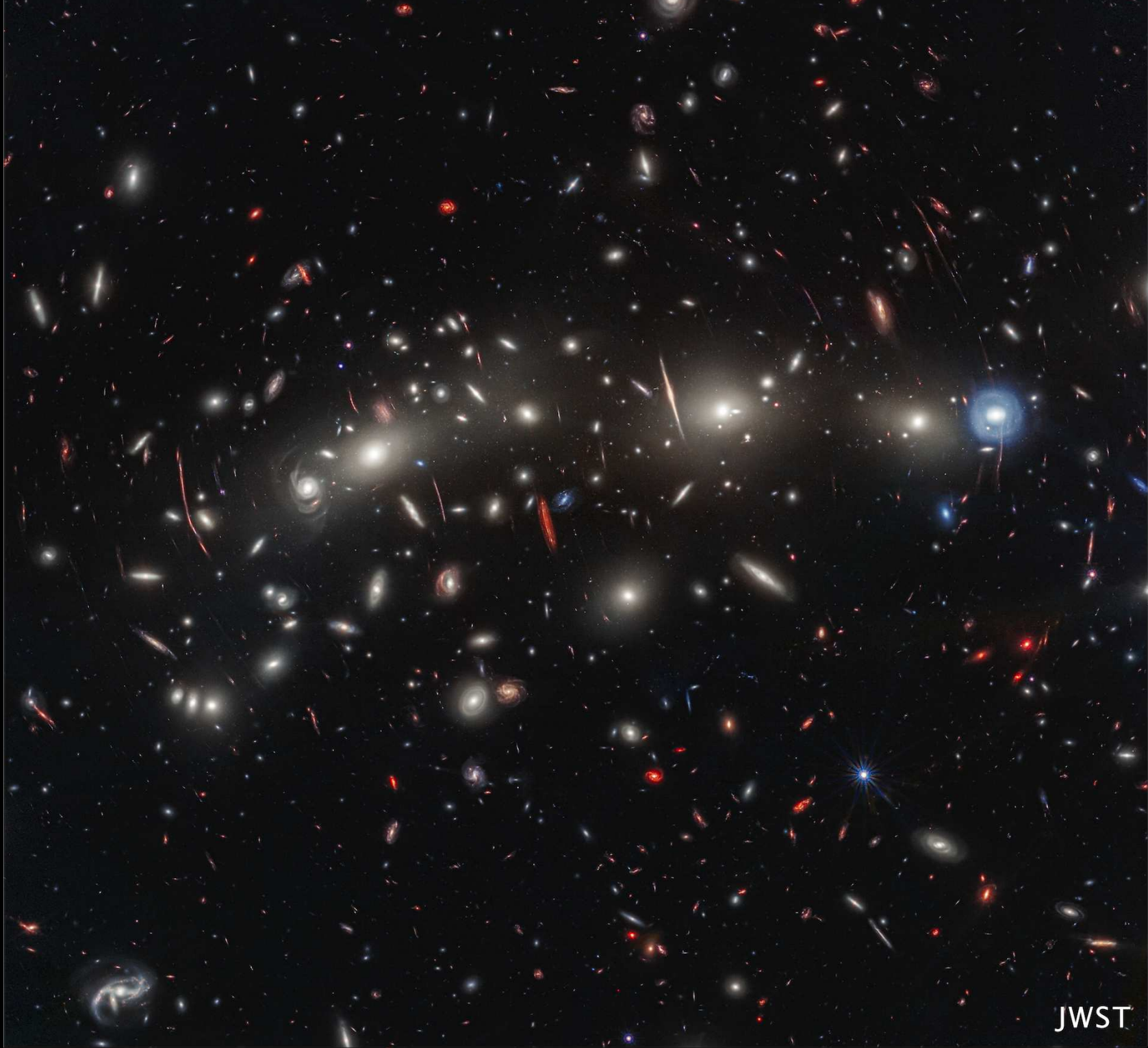
<https://www.nytimes.com/2023/12/19/science/christmas-stars-galaxies-webb-nasa.html?>

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)

(3) 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) Webb's images trace the "Cosmic Circle of Life" (see Julia Roman-Devil's talk):

- Formation and evolution of stars and dust over cosmic time.
- This dust helped form exoplanets and building blocks for life.

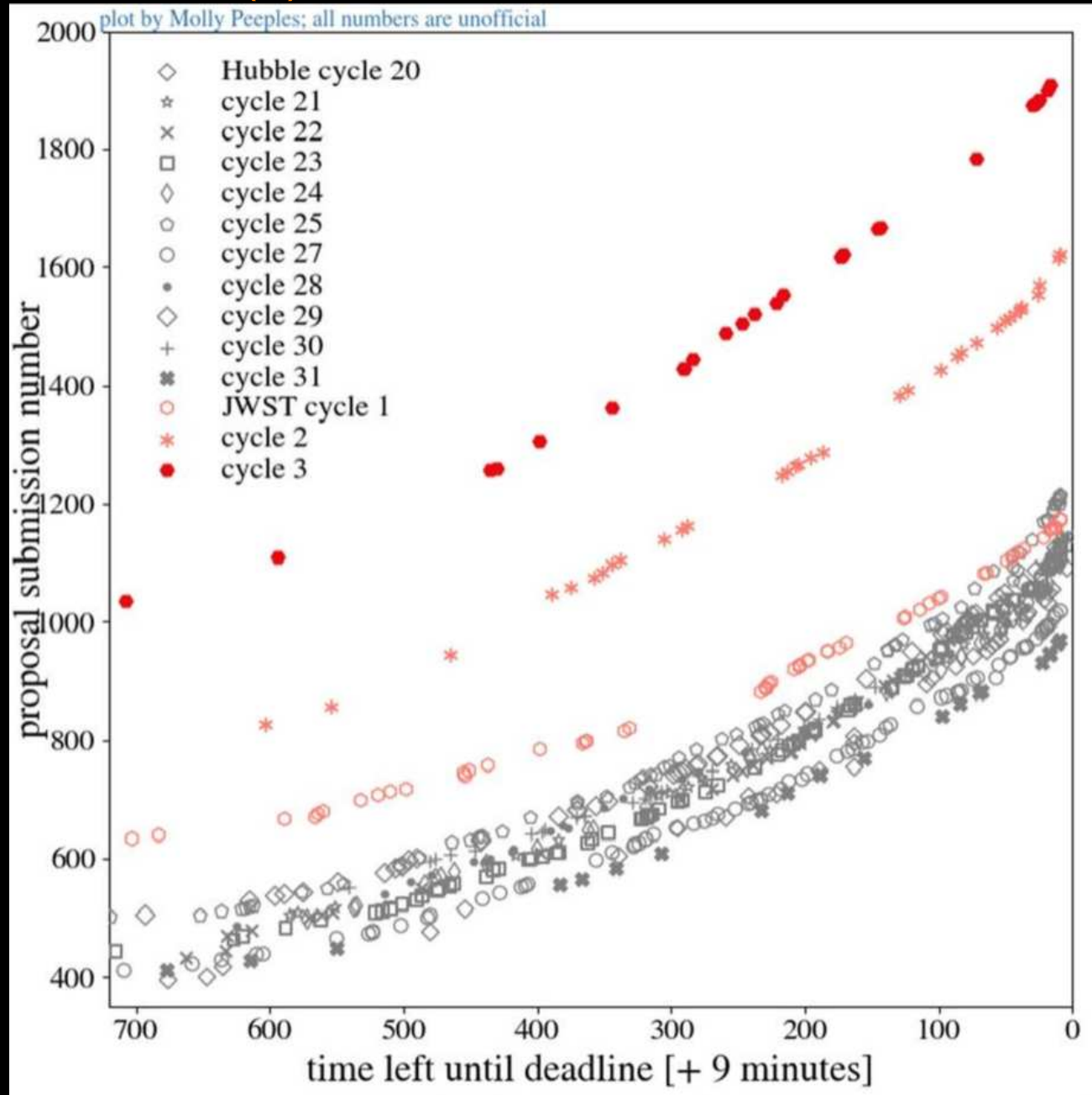
(3) Webb is observing the epochs of First Light, Galaxy Assembly & Super Massive Black Hole-growth in detail (much through grav. lensing):

- Formation of the first stars, star-clusters, SMBH's after 0.2 Byr.
- How galaxies form and produce their dust over 13.5 Billion years.

(4) HST maps (unobscured) SF in the last 10 Gyr, complementing Webb's advantage in the first 3-Gyr:

- Hubble must be kept operational to maximize Webb's science return!

(4) Spare science charts



Oct 2023: Webb is now THE highest-in-demand NASA Flagship mission ever!

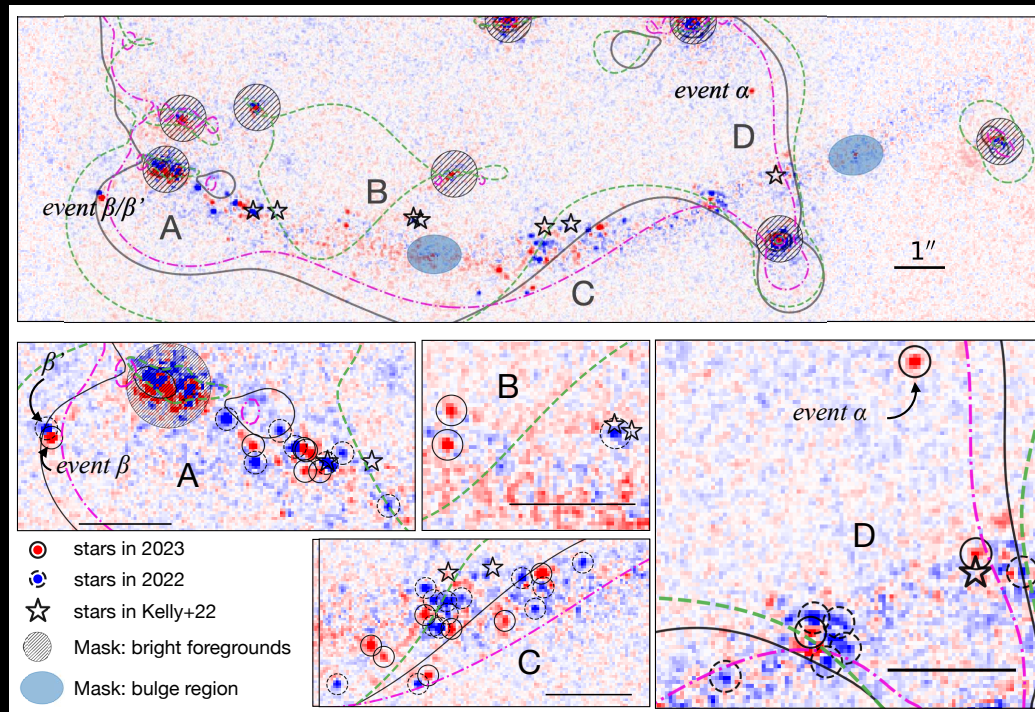
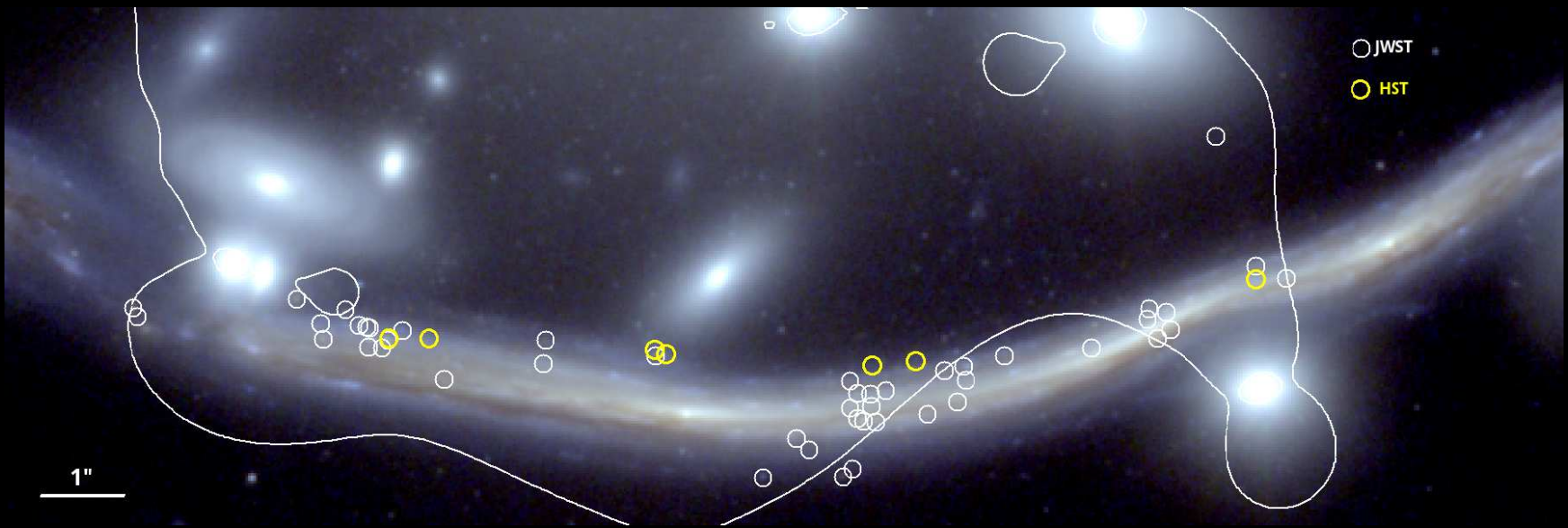
But Hubble remains in at least as high a demand as it was 30 years ago!

(1) SCIENCE IMPACT BY THE HST & JWST COMMUNITY (Dec. 2023):

- HST: $\gtrsim 500$ –1000 refereed papers/year by the community since 1990.
- 44,100 HST papers on ADS, 875,100 citations since 1990, $h_{HST}=308$!
- JWST: over 1000 refereed papers since July 2022 alone!
- In year 1, JWST already outdoing HST's yearly production significantly.

(2) NEWS RELEASES BY THE HST & JWST COMMUNITY (Dec 2023):

- 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: $\gtrsim 100$ 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 10 releases since 2022 ([URL](#)).



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

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

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

PEARLS papers, press releases and other URLs

Talk: http://www.asu.edu/clas/hst/www/jwst/aaas25_windhorst_hstjwst_v3.pdf Data: <https://sites.google.com/view/jwstpearls>

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