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

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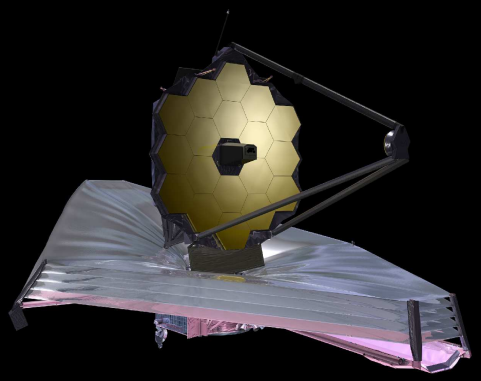
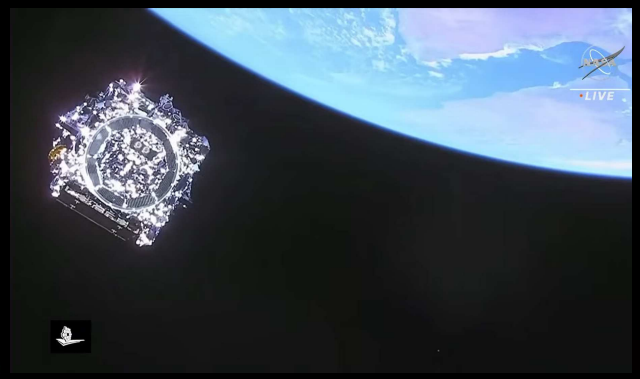
+ HST SKYSURF and JWST PEARLS & SKYSURFIR teams: T. Carleton, S. Cohen, R. Jansen, J. Berkheimer, D. Carter, I. McIntyre, D. Kramer, T. McCabe, R. O'Brien, R. Ortiz, T. Acharya, H. Archer, P. Bahtia, C. Cain, L. Conrad, K. Croker, Z. Goisman, N. Foo, B. Frye, R. Honor, H. Ingram, P. Kamieneski, A. Koekemoer,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

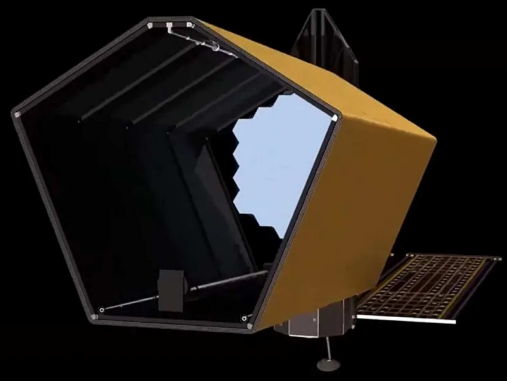
Hubble
1973∼2033^{+}?



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_v4.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"

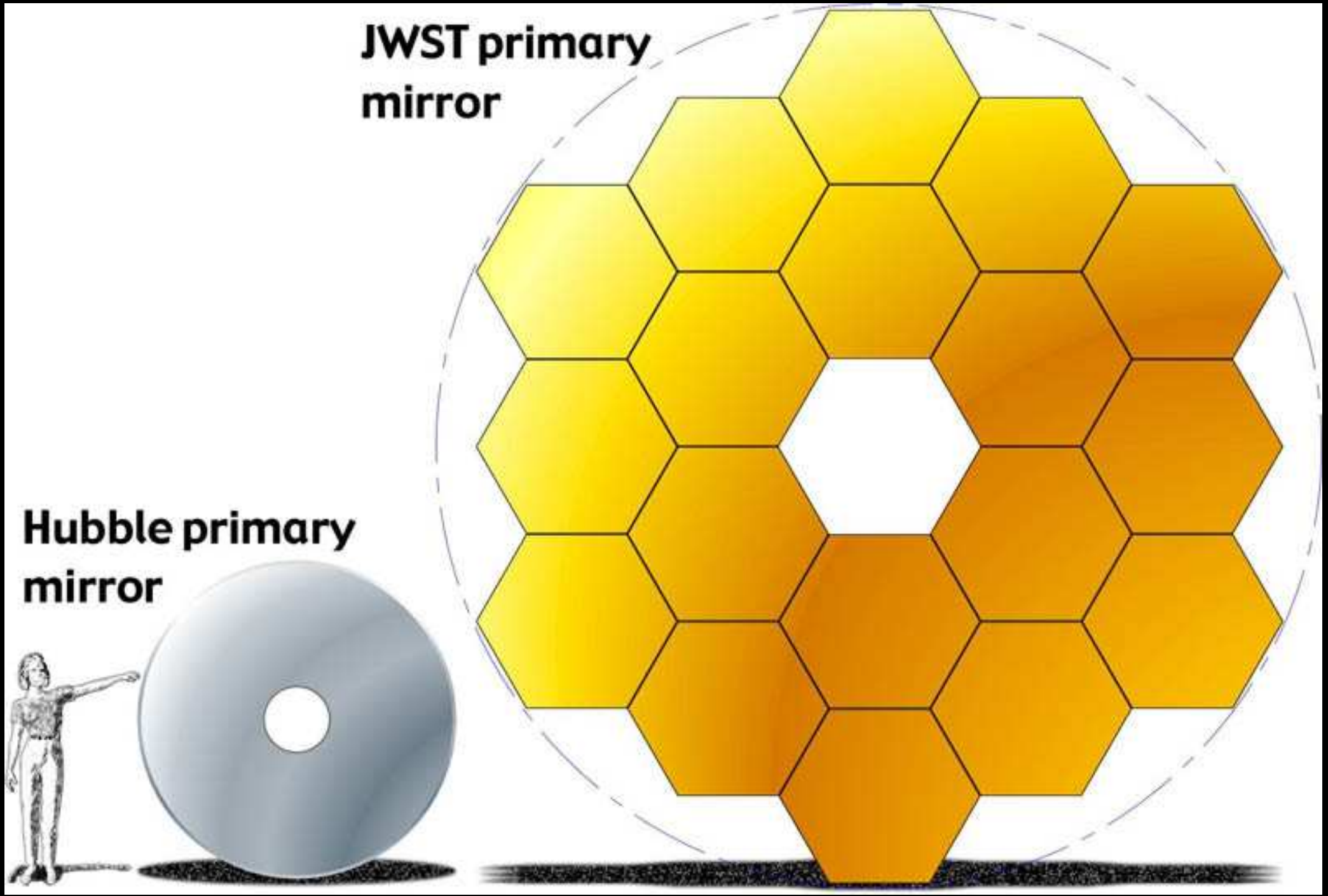
- (3) Summary and Conclusions

- (4) Spare science charts

Sponsored by NASA/HST & JWST

ASU Arizona State University

AAAS now has a Collaborative with ASU (see here and here).

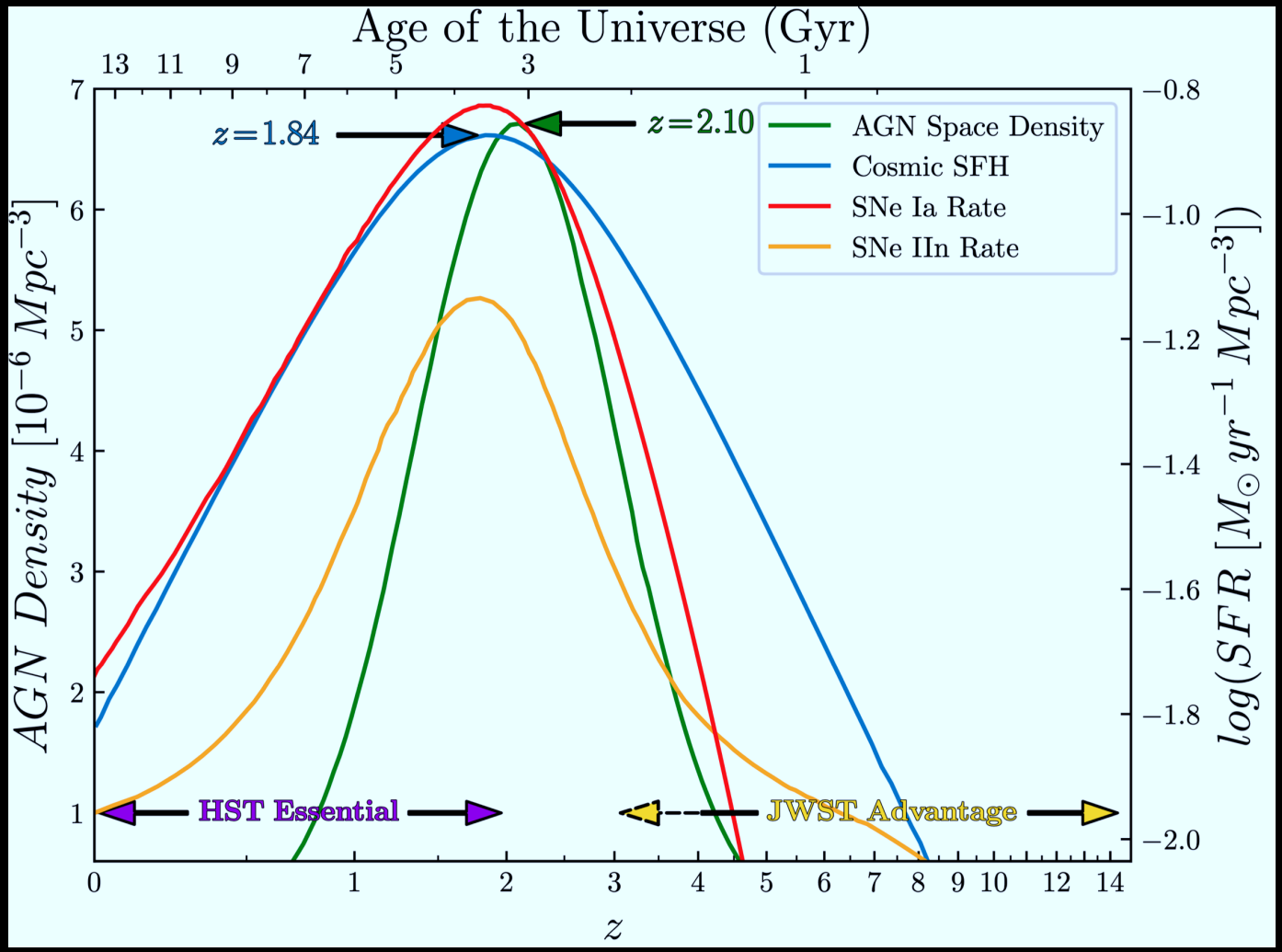


JWST $\simeq 2.5\times$ larger than Hubble, so at $\sim 2.5\times$ larger wavelengths:

JWST has the same resolution in the near-IR as Hubble in the optical.

Windhorst et al.

astro-ph/2410.01187



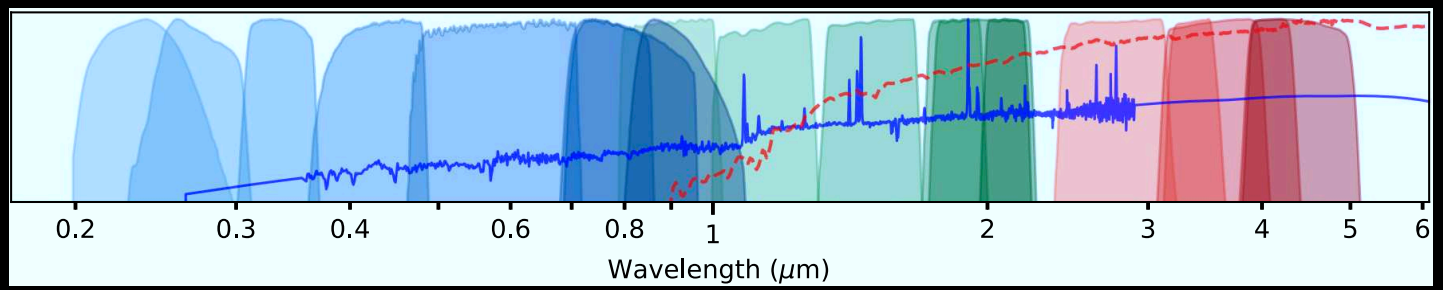
$\mathbf{Age} \sim \frac{13.8}{(1+z)} + \ldots\ \mathbf{Gyr}$

Active galactic nuclei (AGN)

$\Longleftrightarrow$ BH accretion disks

$\Longleftrightarrow$ Chandra X-ray sources

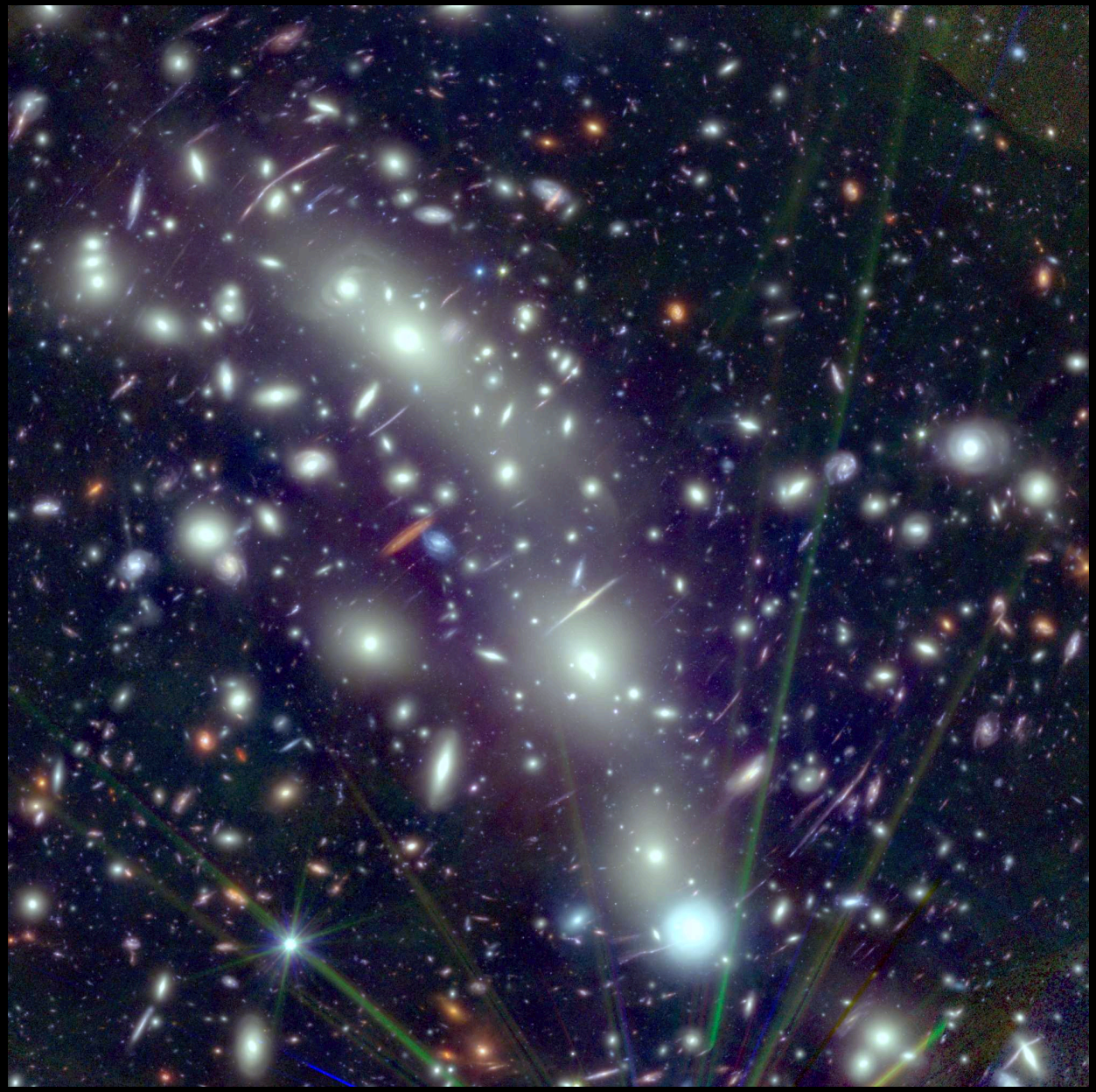
Star Formation, Supernova Rate, & Black Hole growth peak $\sim$10 Gyr ago!



$\Rightarrow$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 ($z \gtrsim 3$).

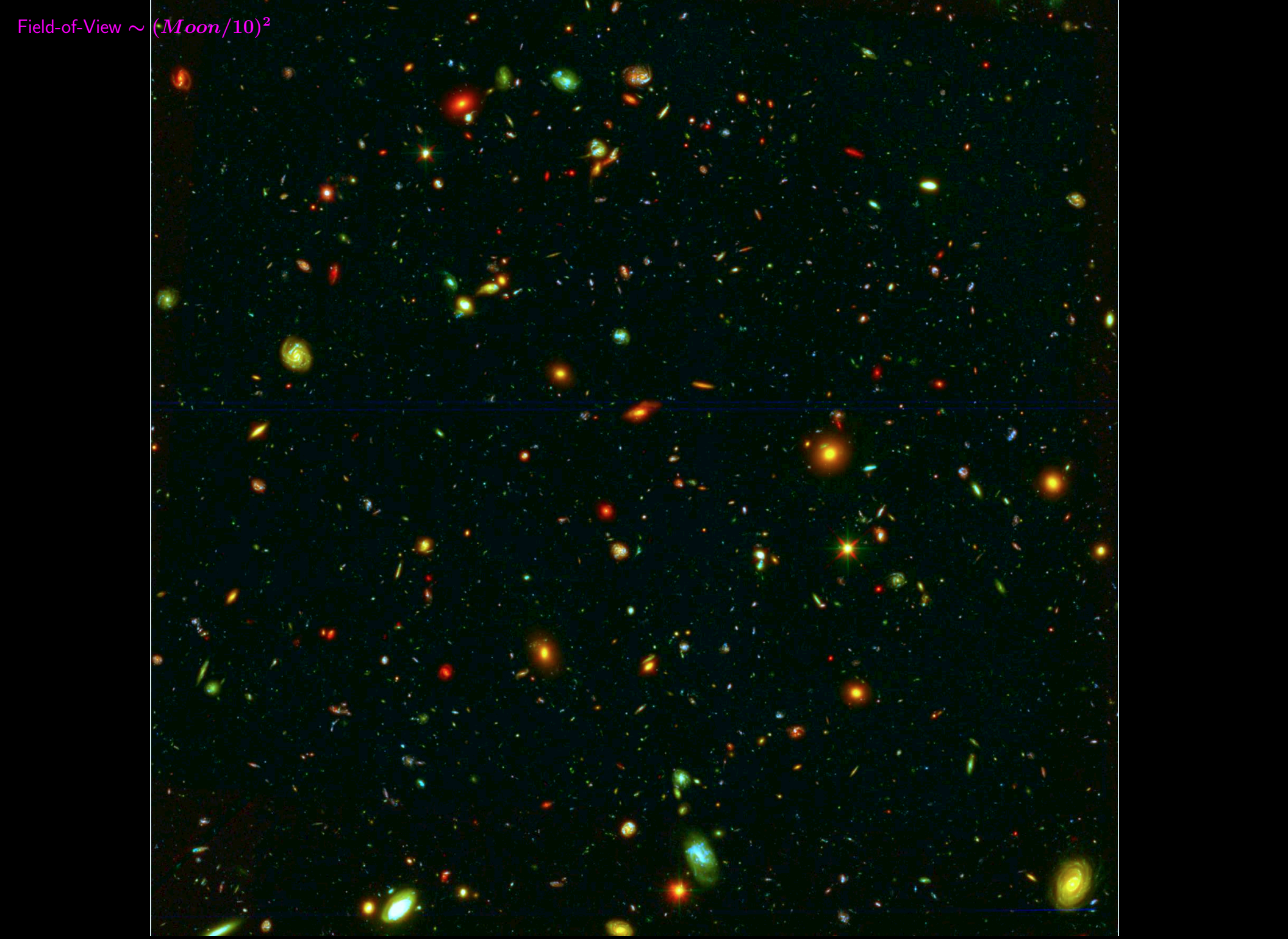
(1) Uniquely complementary roles of Hubble and Webb:



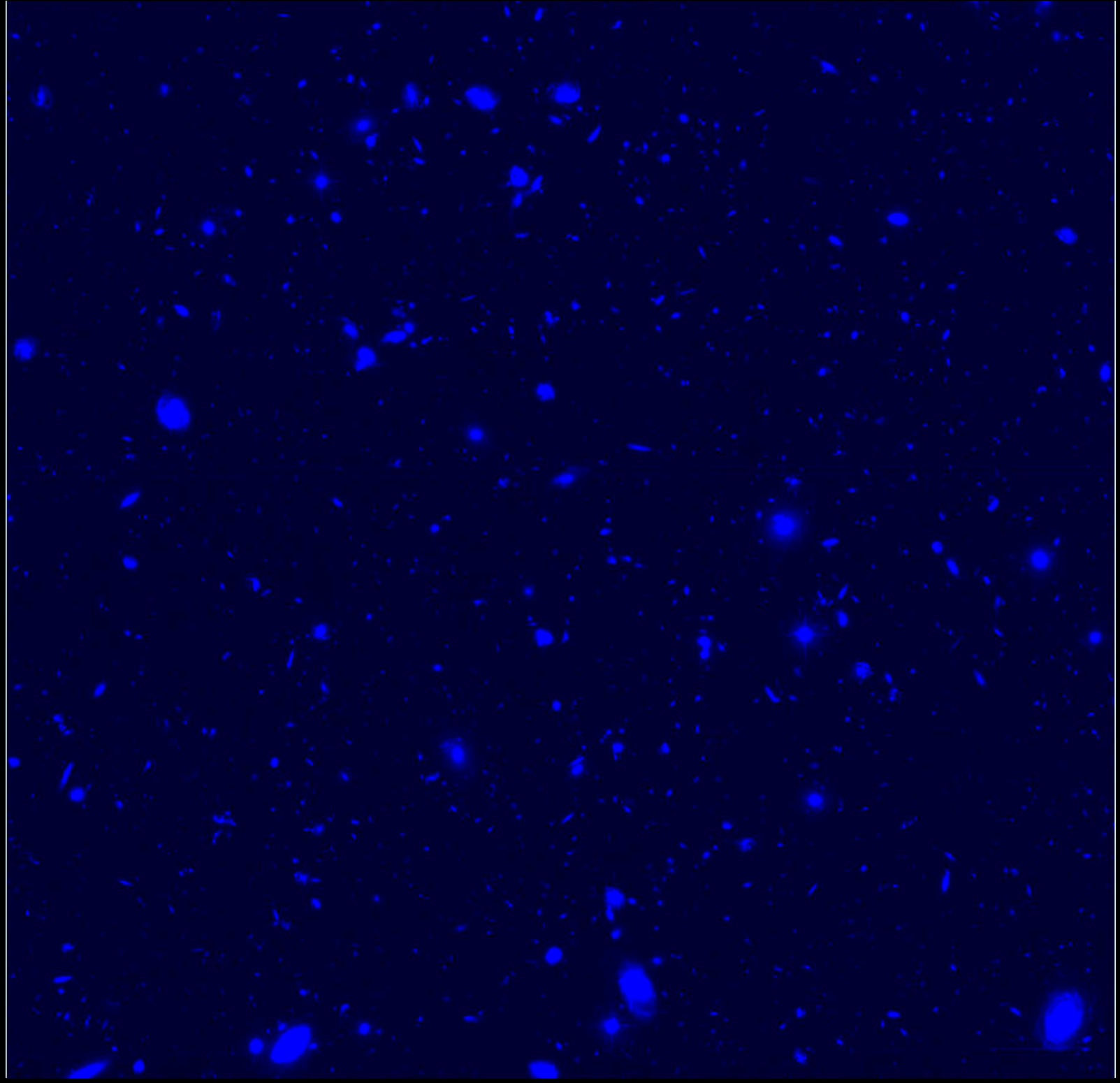
500 hrs HST+JWST: 45 filters (0.2–5.0μm), lensing cluster MACS0416:

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

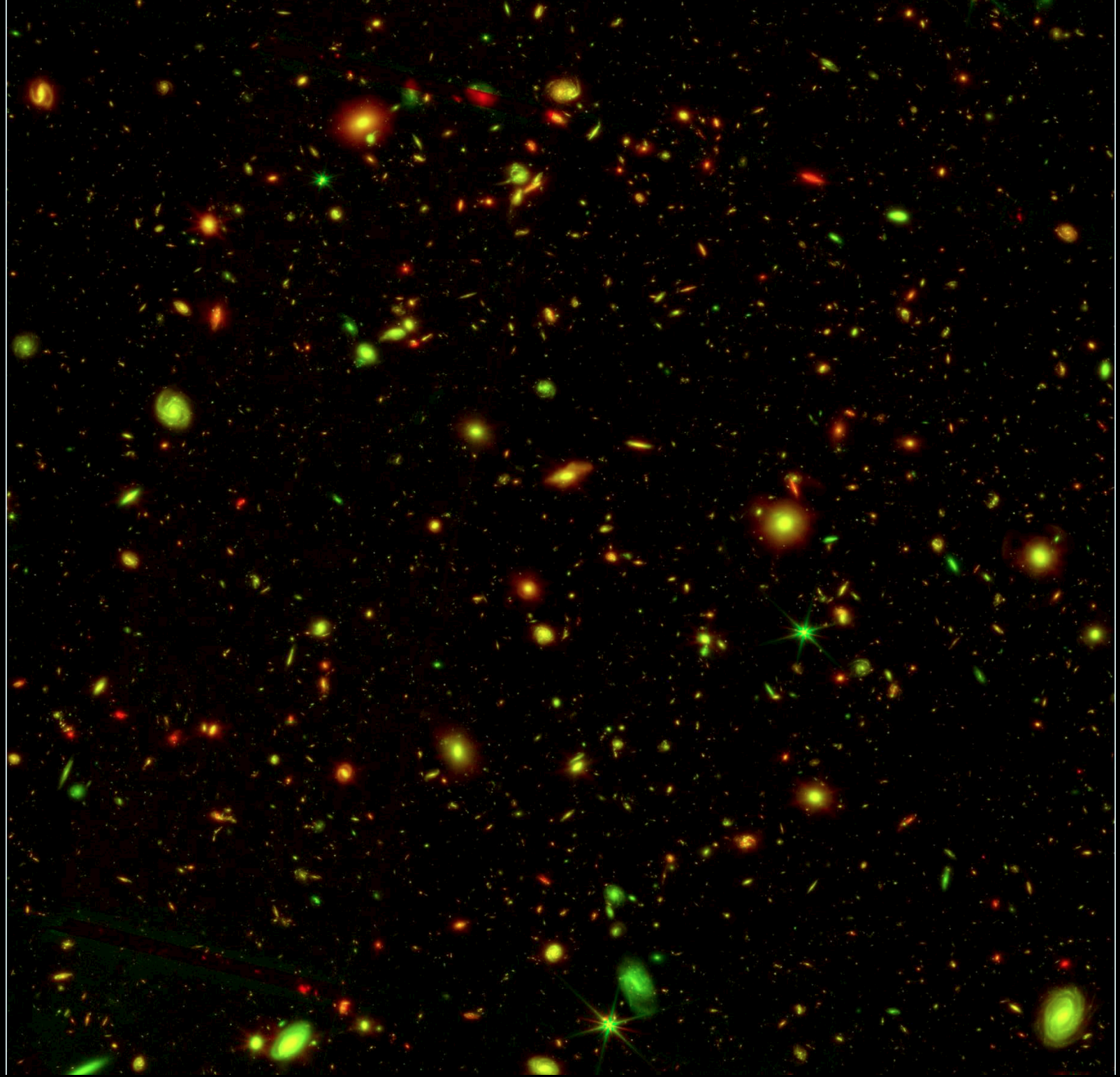
$\Longrightarrow$ HST & JWST reach 30–31 mag ($\sim$1 firefly from Moon).



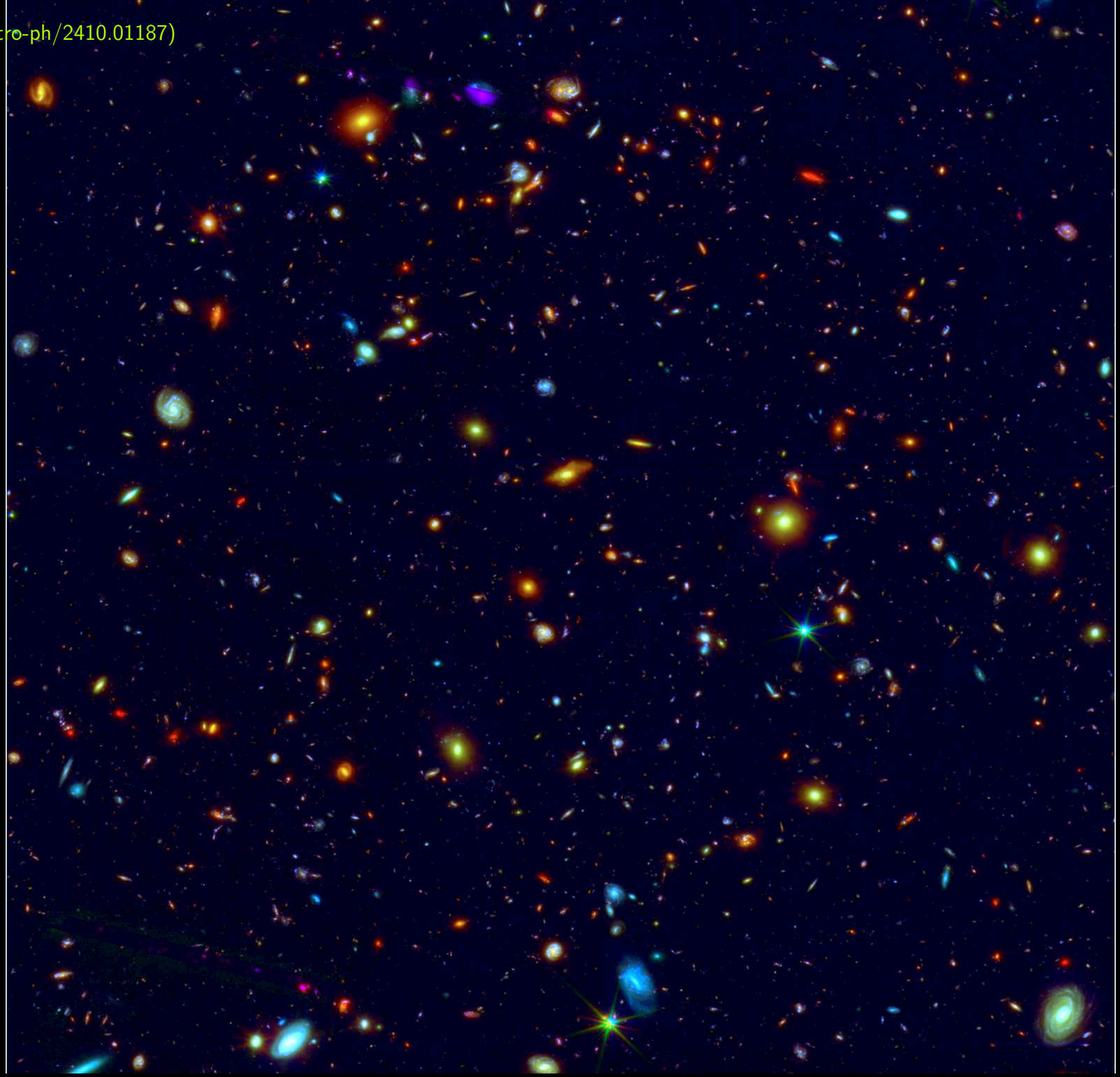
556 hr HST Hubble UltraDeep Field: 12 filters at 0.2–1.6 μm (AB$\lesssim$31 mag; 1 FF at Moon; full BGR).



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

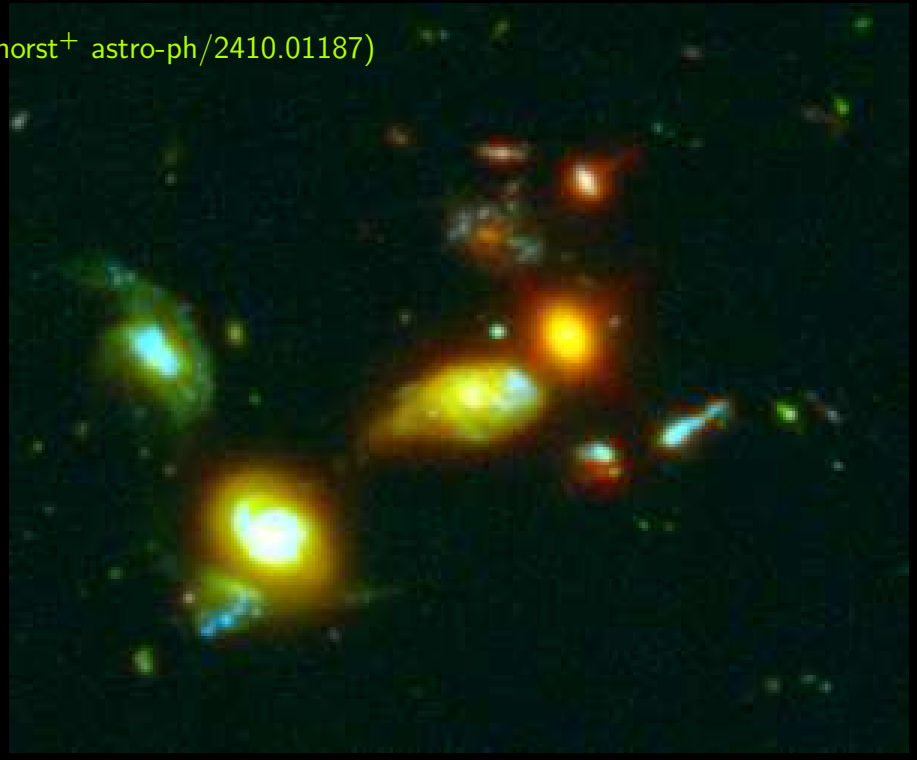


53 hr JWST/NIRCam Hubble UltraDeep Field: 12 filters at 0.9–5.0 μm (AB$\lesssim$31 mag; in green + red).

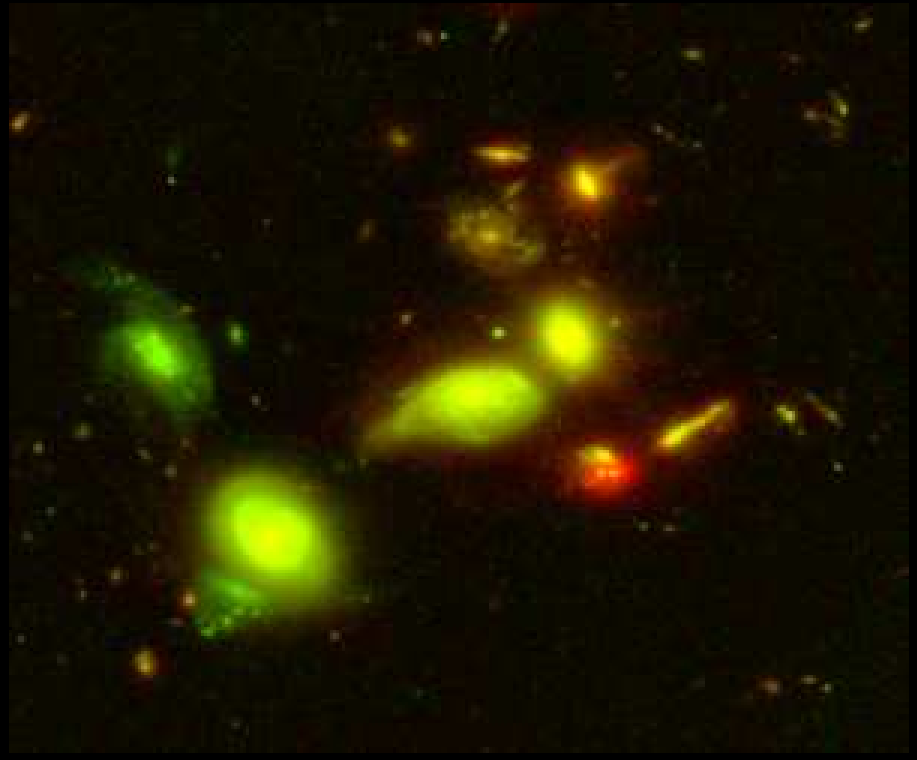


414 hr HST+JWST Hubble UltraDeep Field: 20 filters at 0.2–5.0 μm (AB$\lesssim$31.5 mag; full BGR).

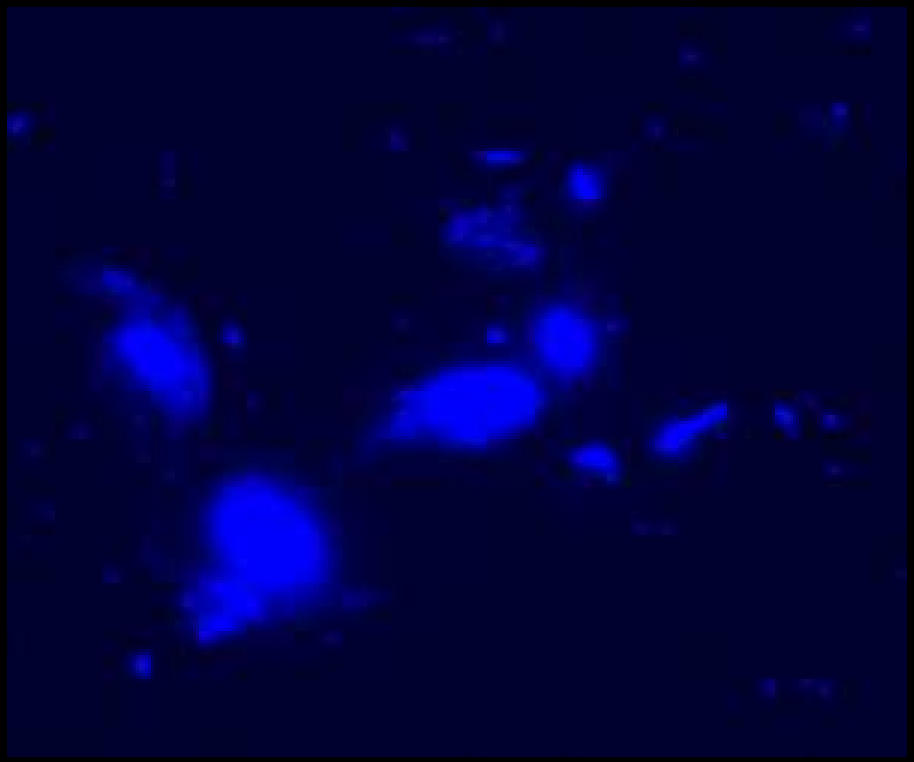
(Windhorst+ astro-ph/2410.01187)



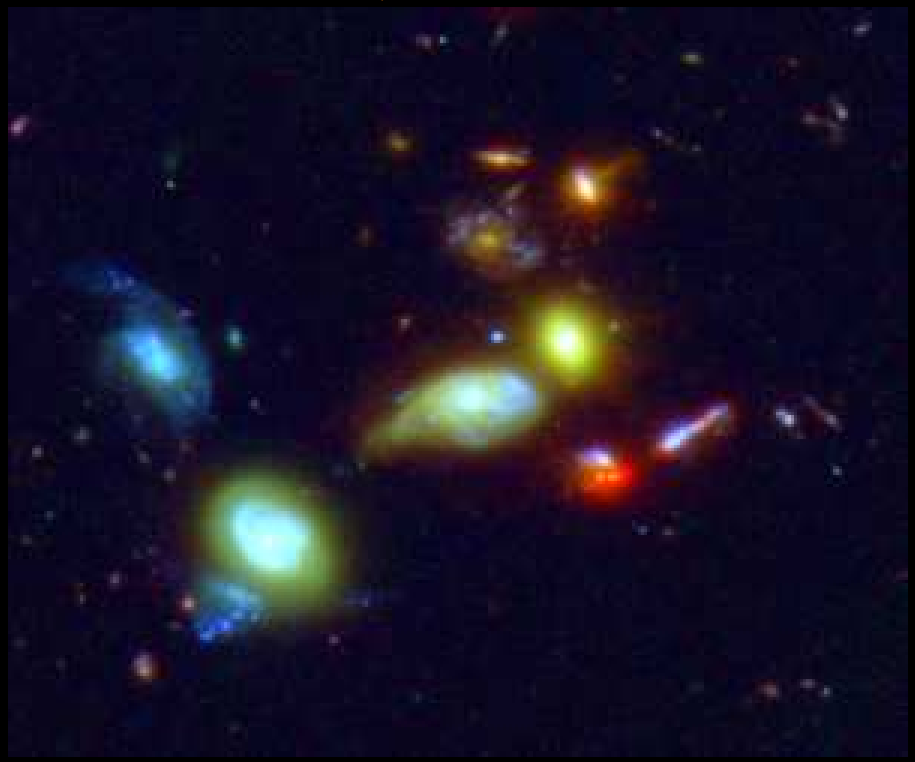
556 hr HST HUDF 12 filters



53 hr JWST/NIRCam 12 filters

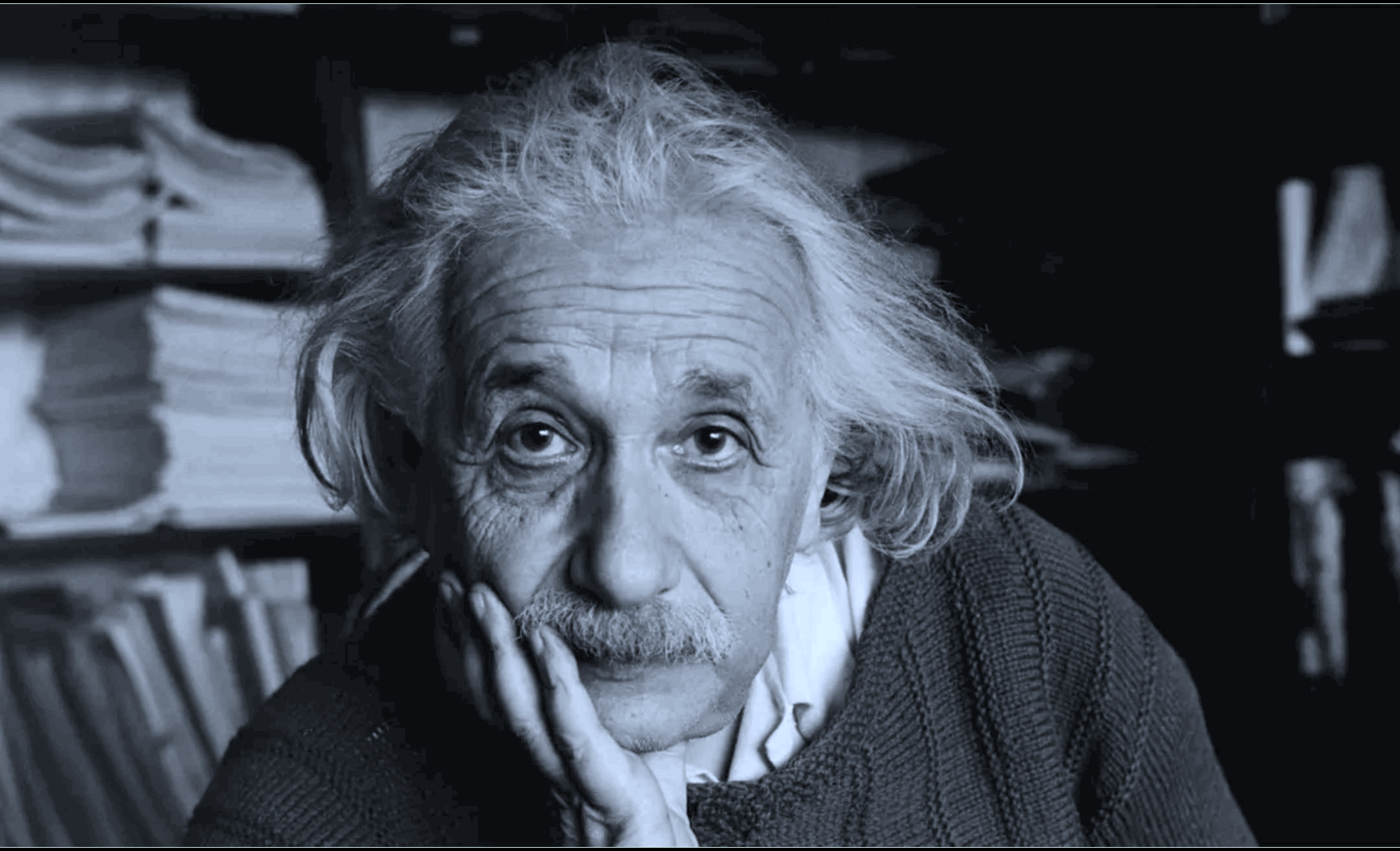


361 hr 8 HST-unique filters (false-blue)



414 hr HST+JWST 20 filters

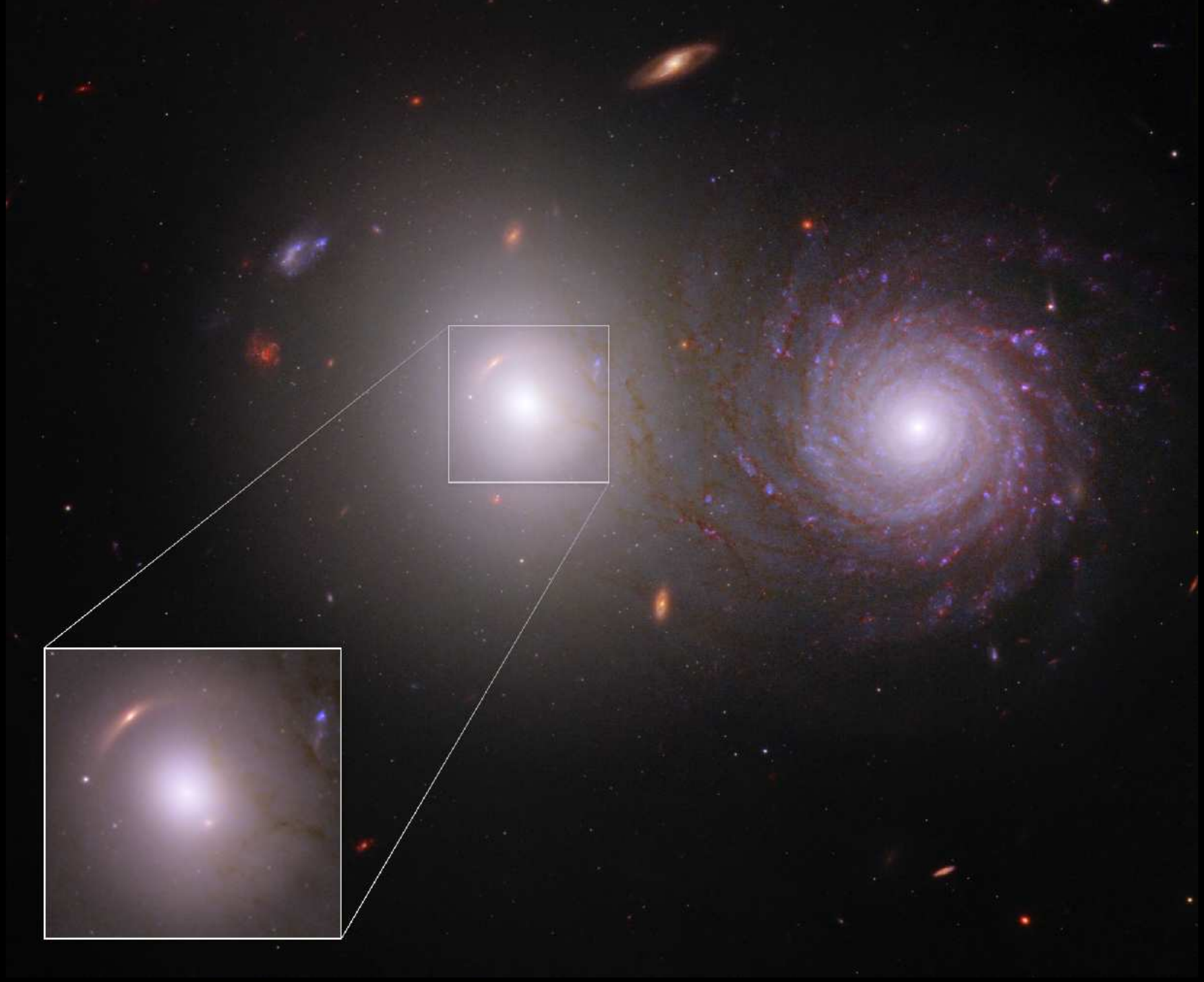
• (2) Viewing the Universe through the "Eyes of Einstein"



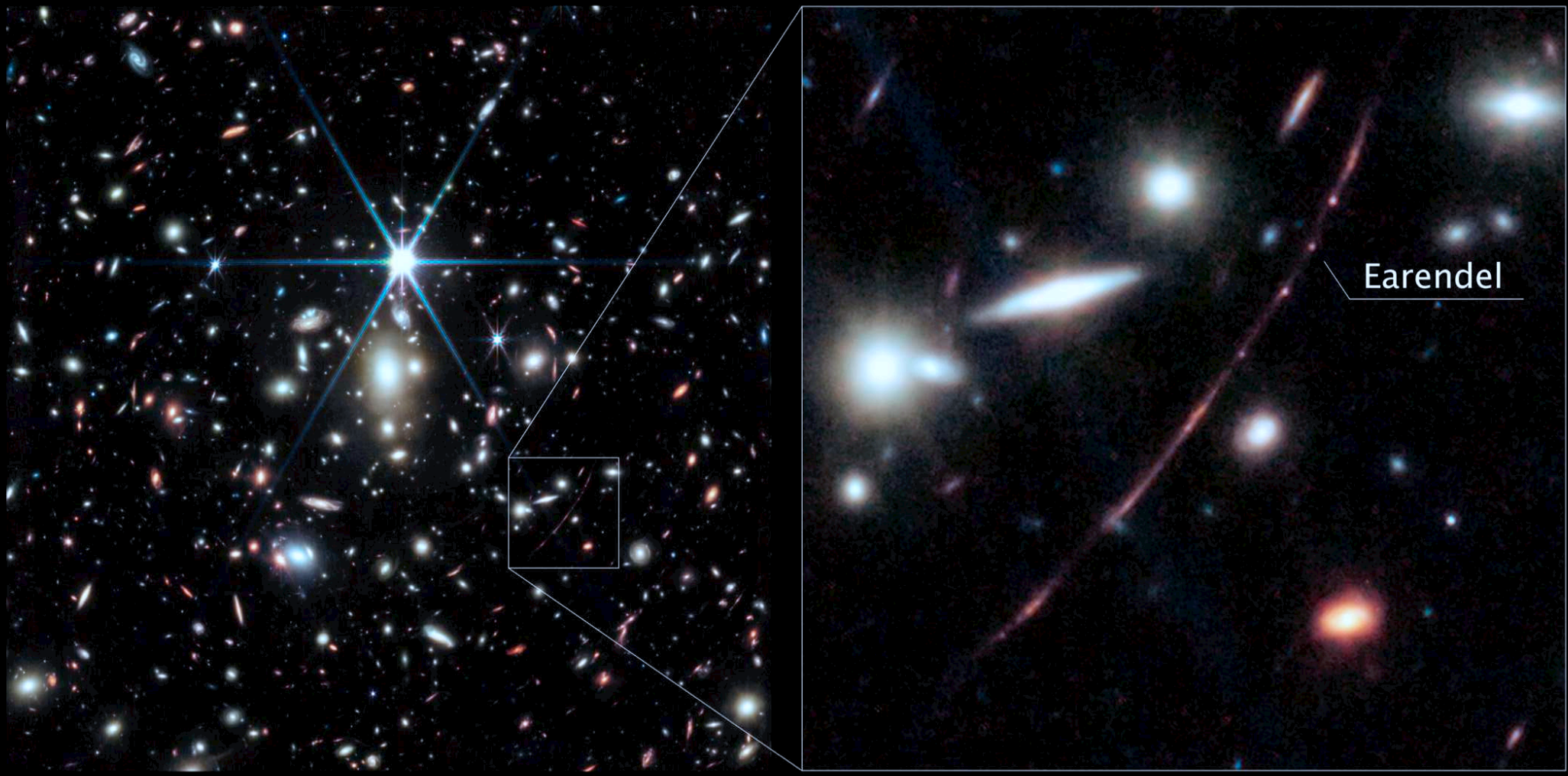
Webb is observing many things Einstein correctly predicted, yet doubted:

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∼1 (Keel^{+} 2023, AJ, 165, 16)!



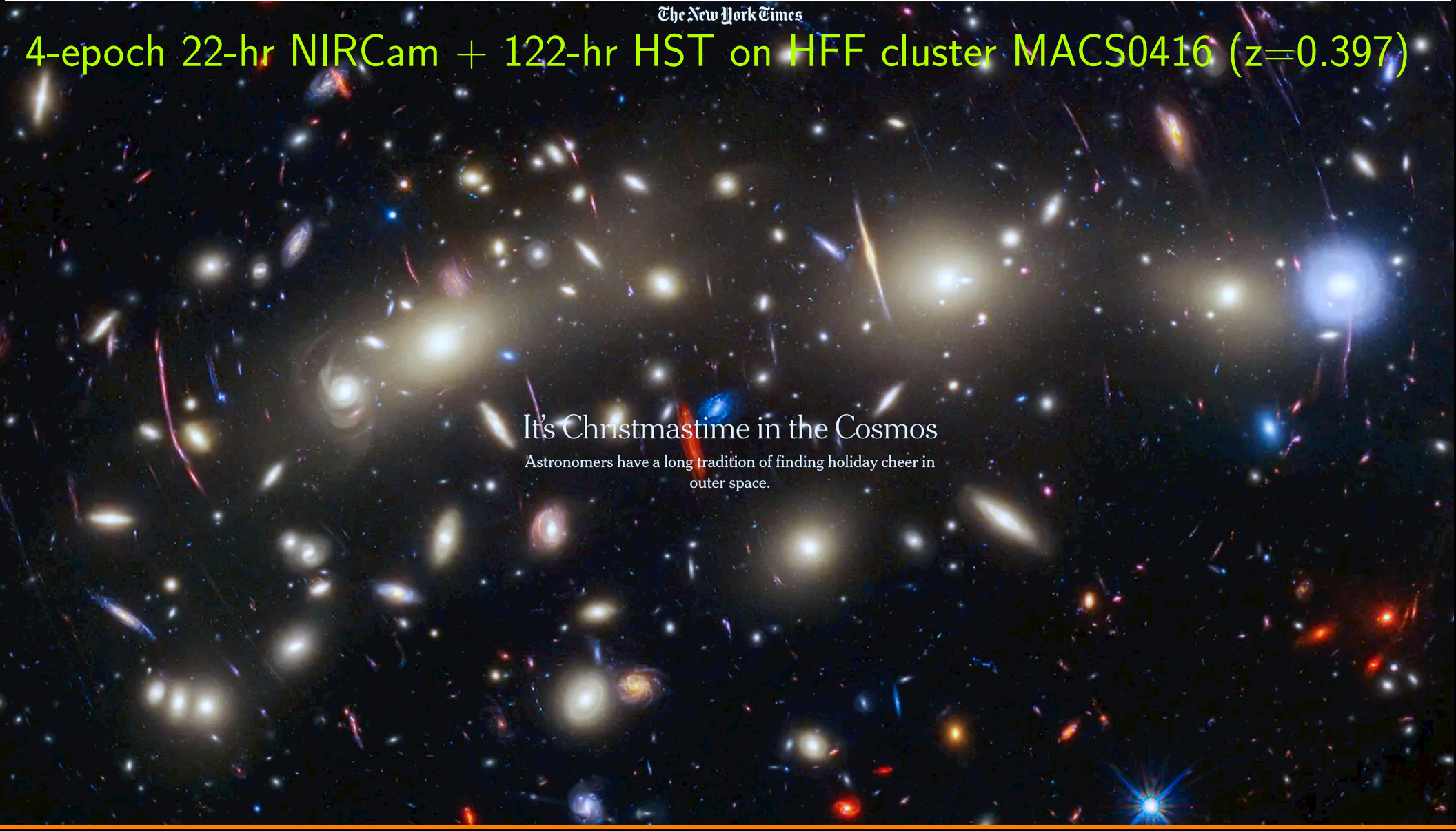
NIRCam: Cluster WHL0137-08 with highly lensed arc at z=6.2 (0.9 Byr).

- 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_o=$75.4^{+8.1}_{-5.5}$, 10 Byrs ago!

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

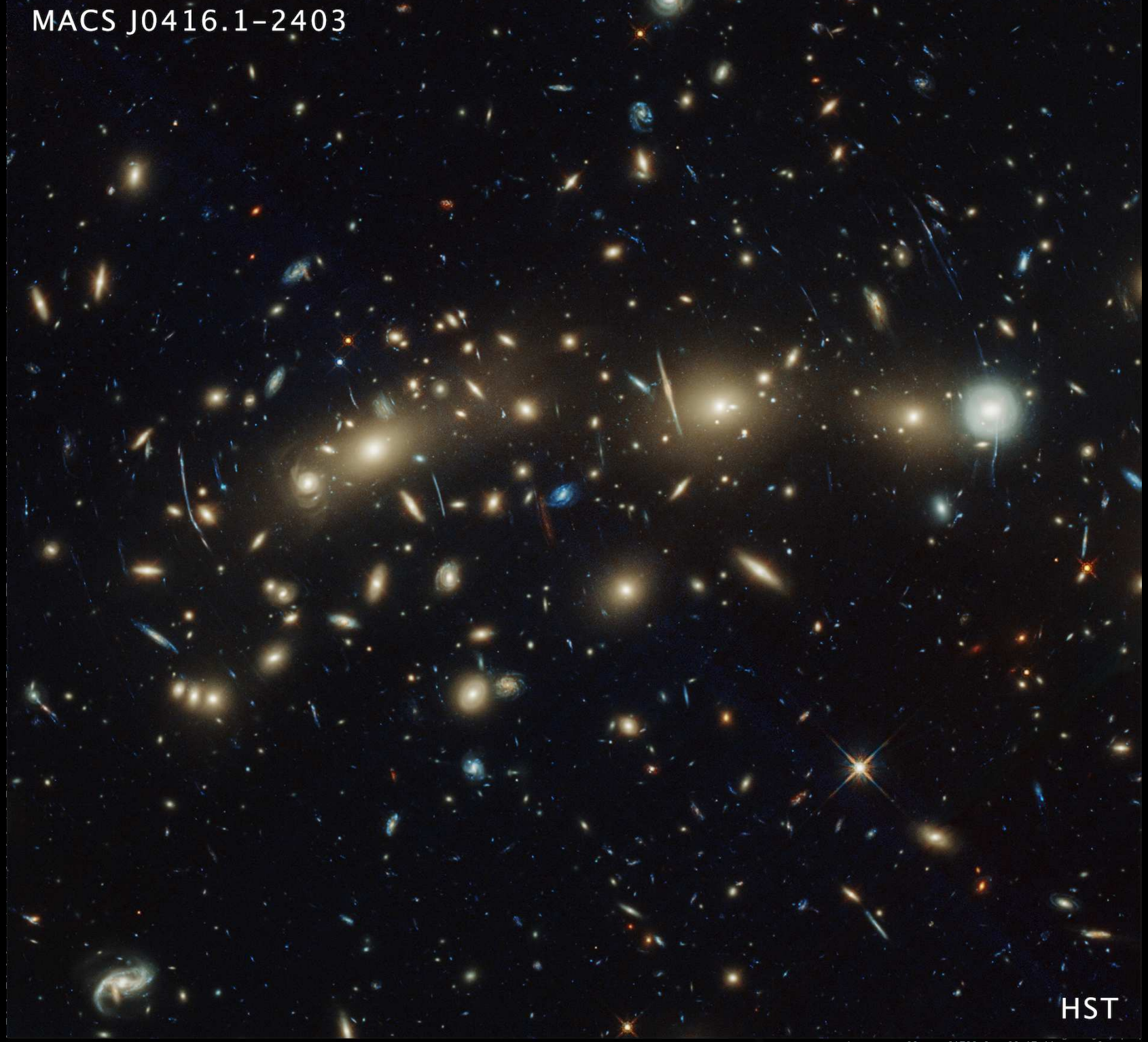


12 new caustic transits at z≃1–2 from 4 epochs! (Yan, H.+, 2023, ApJS, 269, 42)

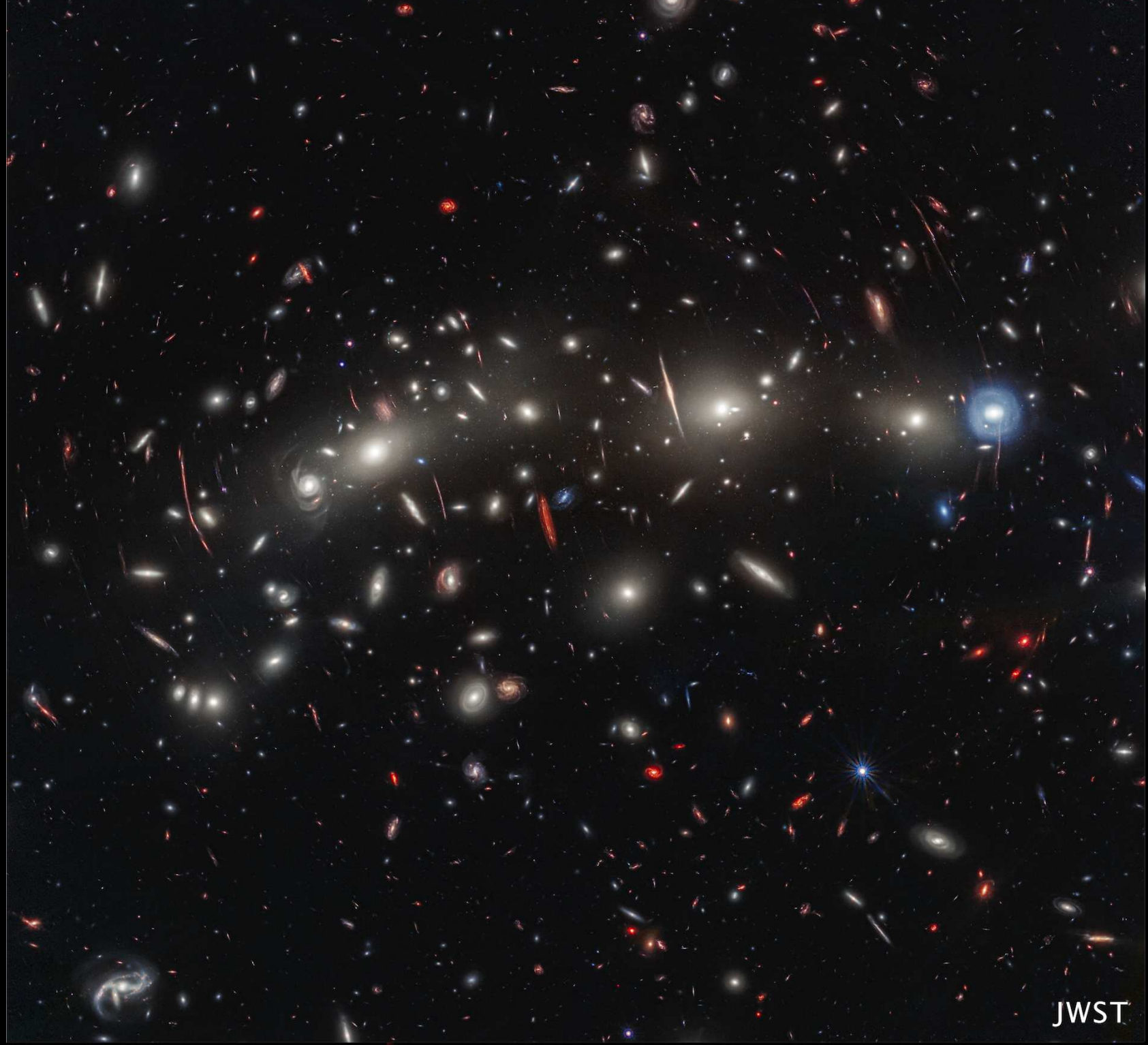
Extremely magnified binary star at z=2.091! (Diego, J.+, 2023, A&A 679, A31)

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)

(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.

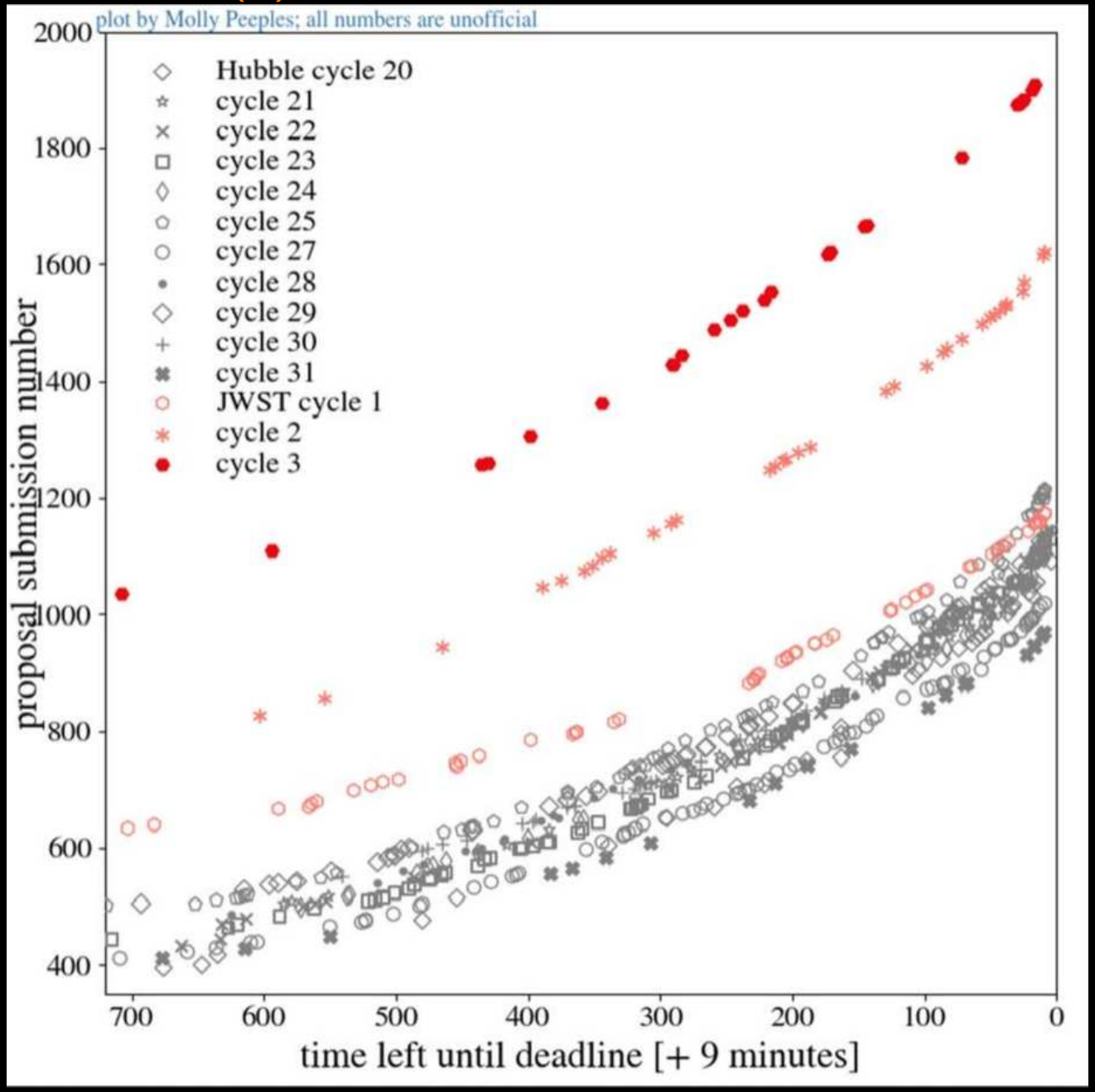
(2) Webb is observing the epochs of First Light, Galaxy Assembly & Super Massive Black Hole-growth in detail (much through grav. lensing):

- 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.

(3) 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!

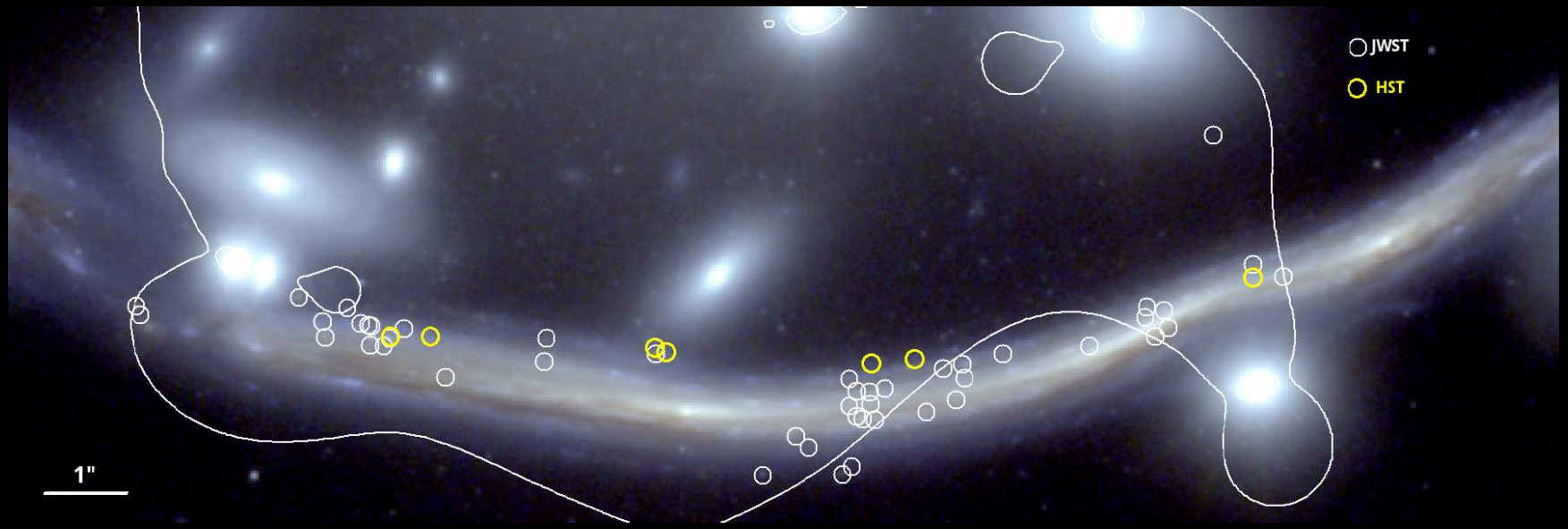
But Hubble remains in at least as high a demand as it was 30 years ago!

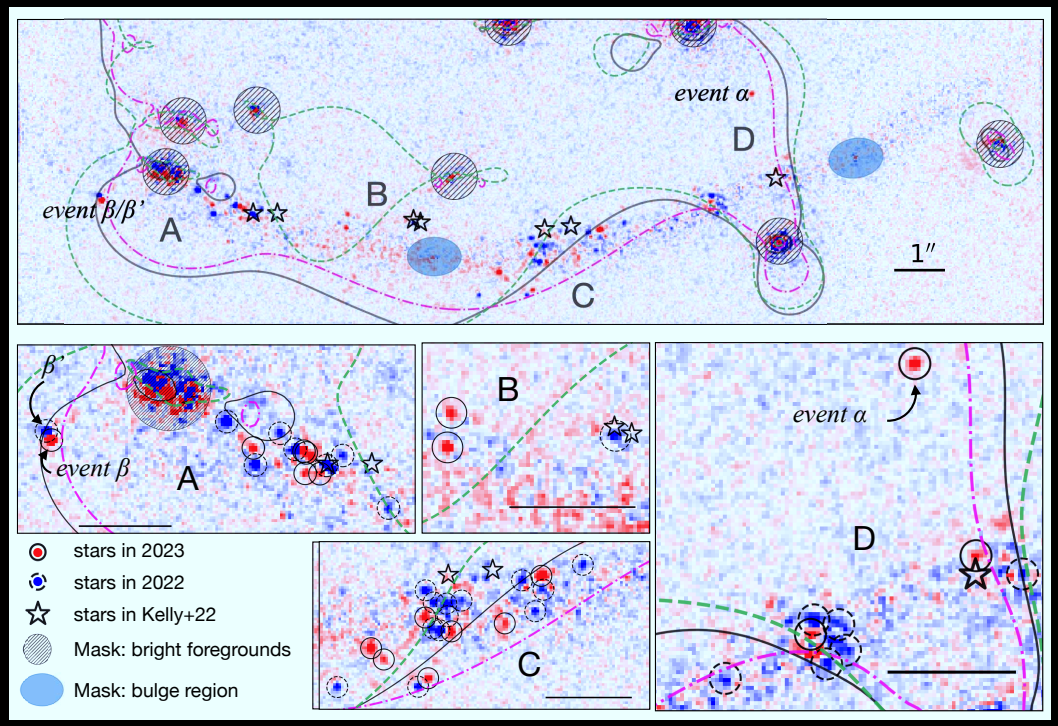
(1) SCIENCE IMPACT BY THE HST & JWST COMMUNITY (Feb. 2025):

- HST: $\gtrsim$500–1000 refereed papers/year by the community since 1990.
- 45,900 HST papers on ADS, 948,800 citations since 1990, h$_{\boldsymbol{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).





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).

$\Longrightarrow$ 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_v4.pdf Data: https://sites.google.com/view/jwstpearls

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