The World of Webb, the Cosmic Circle of Life, and seeing through the Eyes of Einstein

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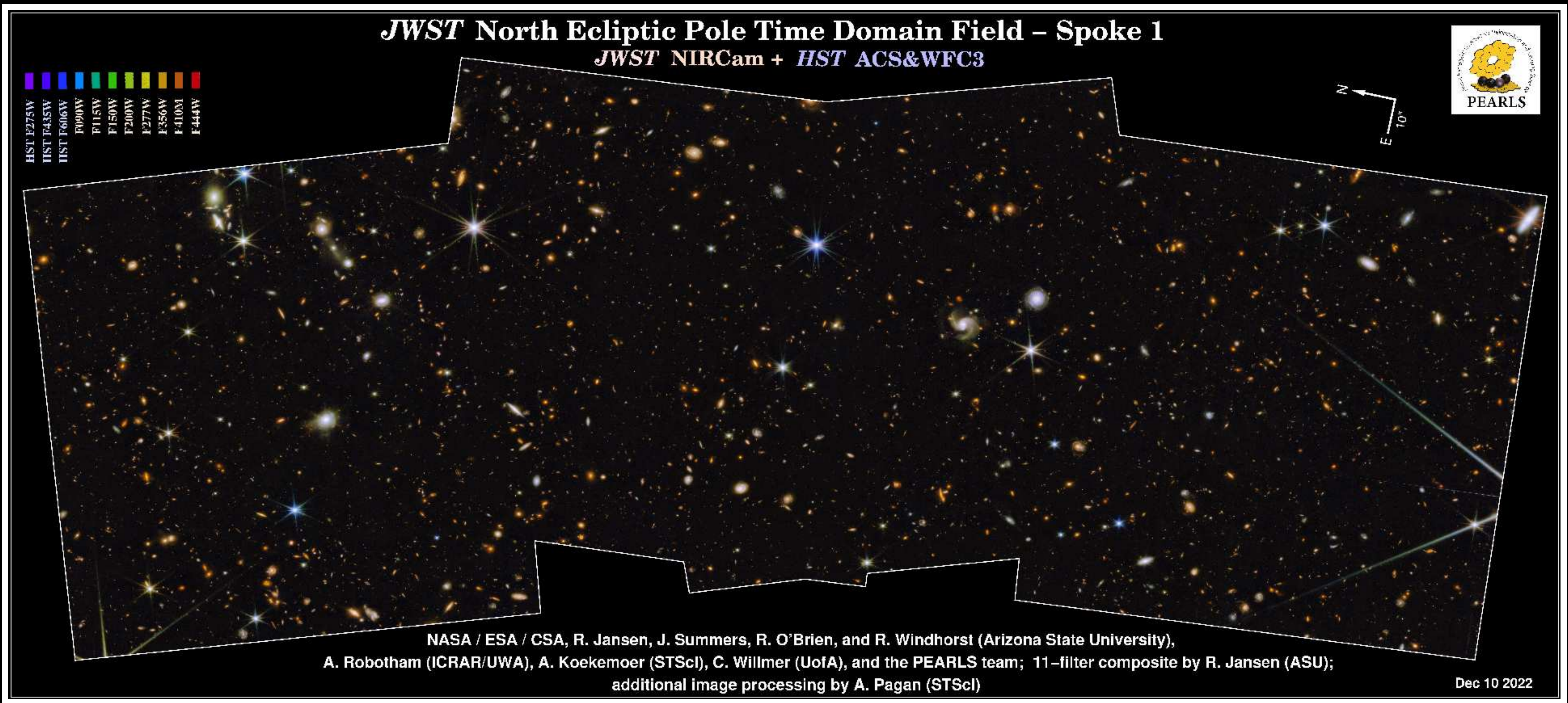

Talk at the SES 502 class, ASU, Tempe, Arizona; Wednesday November 19, 2025.

All presented materials are ITAR-cleared. [FOV∼Dist/1000].

Outline

- (1) Webb in orbit as of 2021
- (2) Webb's first images: the "Cosmic Circle of Life"
- (3) Viewing the Universe through the "Eyes of Einstein"
- (4) Summary and Conclusions

SPARE CHARTS:

- (5) Spare Science Charts
- (6) Uniquely complementary roles of Hubble and Webb

Sponsored by NASA/HST & JWST

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Talk is on: http://lambda.la.asu.edu/raw/jwst/talks/asuSES502grads_jwst25.pdf

WARNING: asking NASA for Hubble images is like drinking from a fire-hydrant;

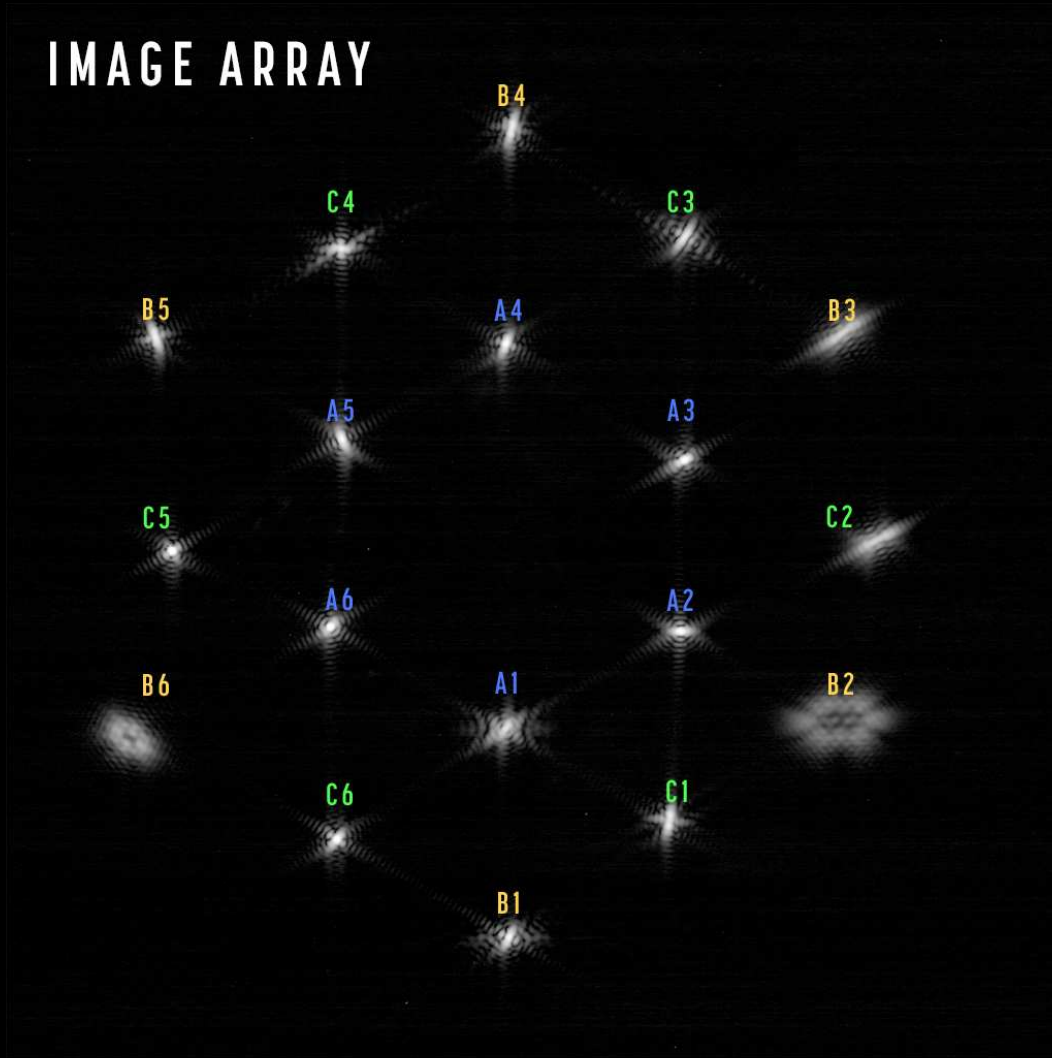
WARNING: asking NASA for Hubble images is like drinking from a fire-hydrant;

asking NASA for Webb images is like taking a sip from Niagara Falls!

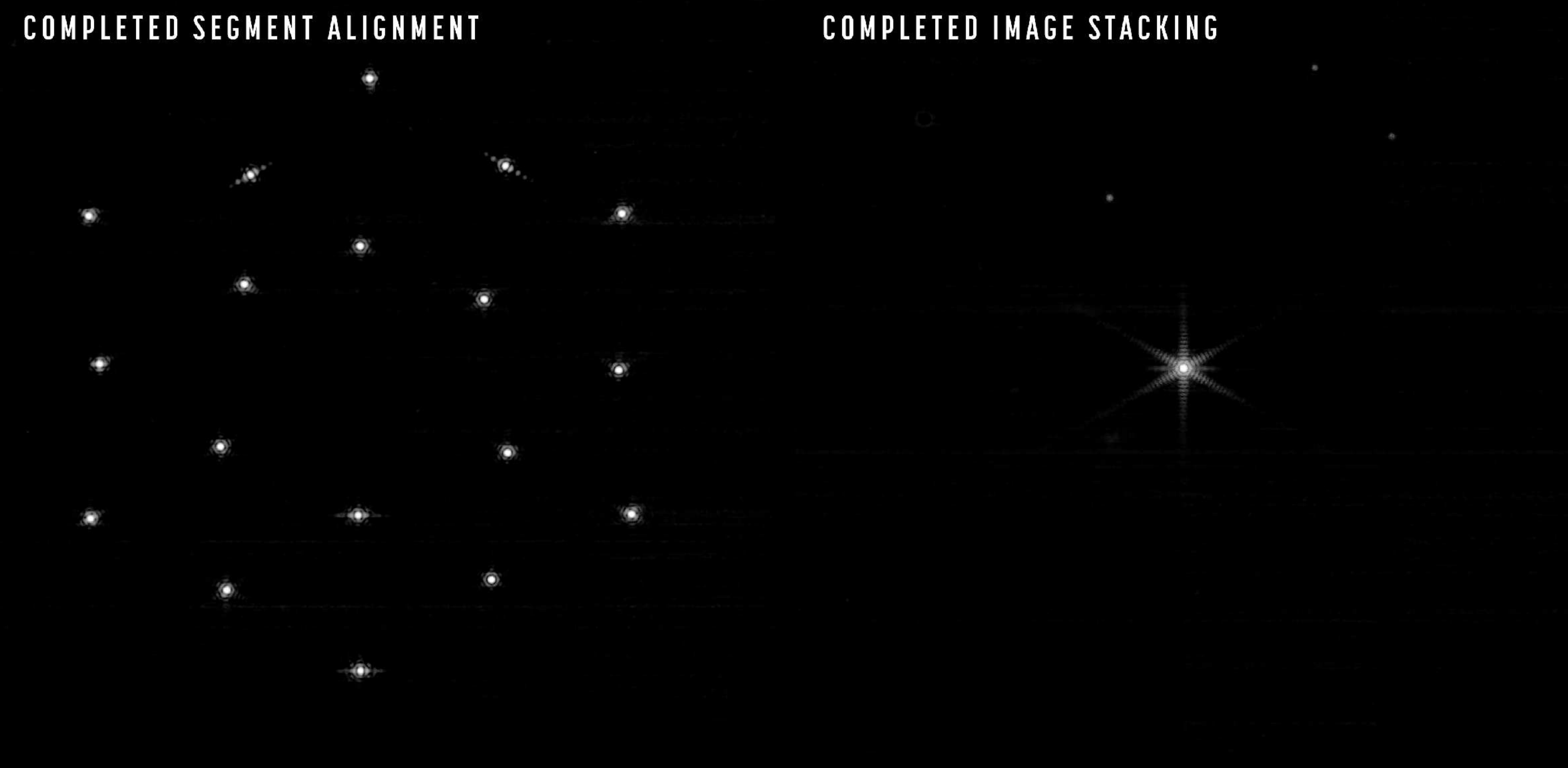
Children: Please don't do this at home!! :)

Webb is finally launched from Kourou on December 25, 2021!

Dec. 25, 2021: Webb seen shortly after launch over Africa using the Ariane V on-board camera.



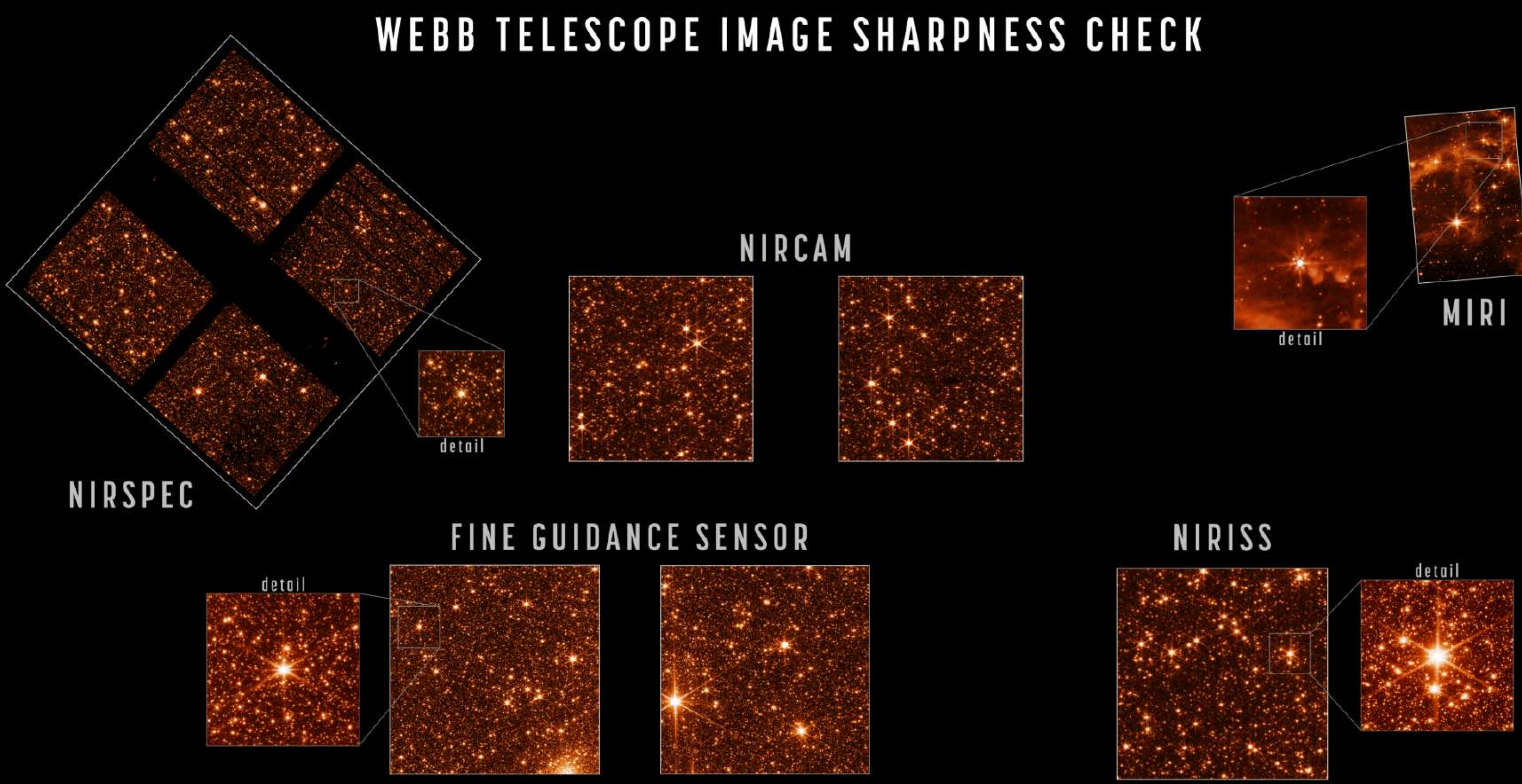
Feb. 2022: Webb's first selfie (left) and First Light raw image (right).



Webb's first segment alignment (left) and first image stack (right).

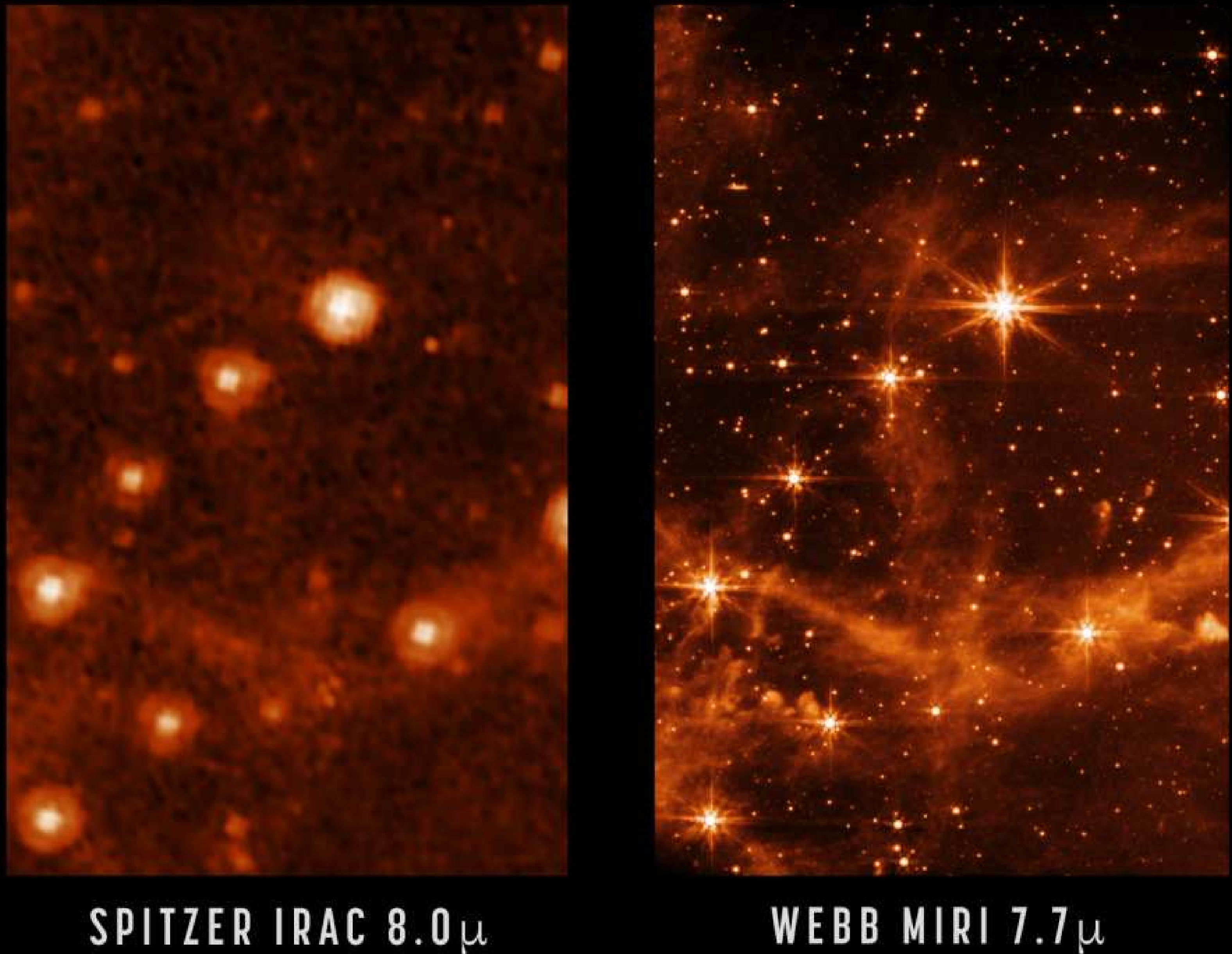
March 16, 2022: Webb's first fully focused image publicly released !!
Note the plethora of faint galaxies — Webb's looking back in time!

https://www.nasa.gov/press-release/nasa-s-webb-reaches-alignment-milestone-optics-working-successfully



April 28, 2022: Webb's first fully focused images in all four instruments: A dense star field in the Large Magellanic Cloud in the South Ecliptic Pole! (NIRSpec: 1.1 μm; NIRISS: 1.5 μm; NIRCam: 2.0 μm; MIRI 7.7 μm).

https://blogs.nasa.gov/webb/2022/04/28/nasas-webb-in-full-focus-ready-for-instrument-commissioning/

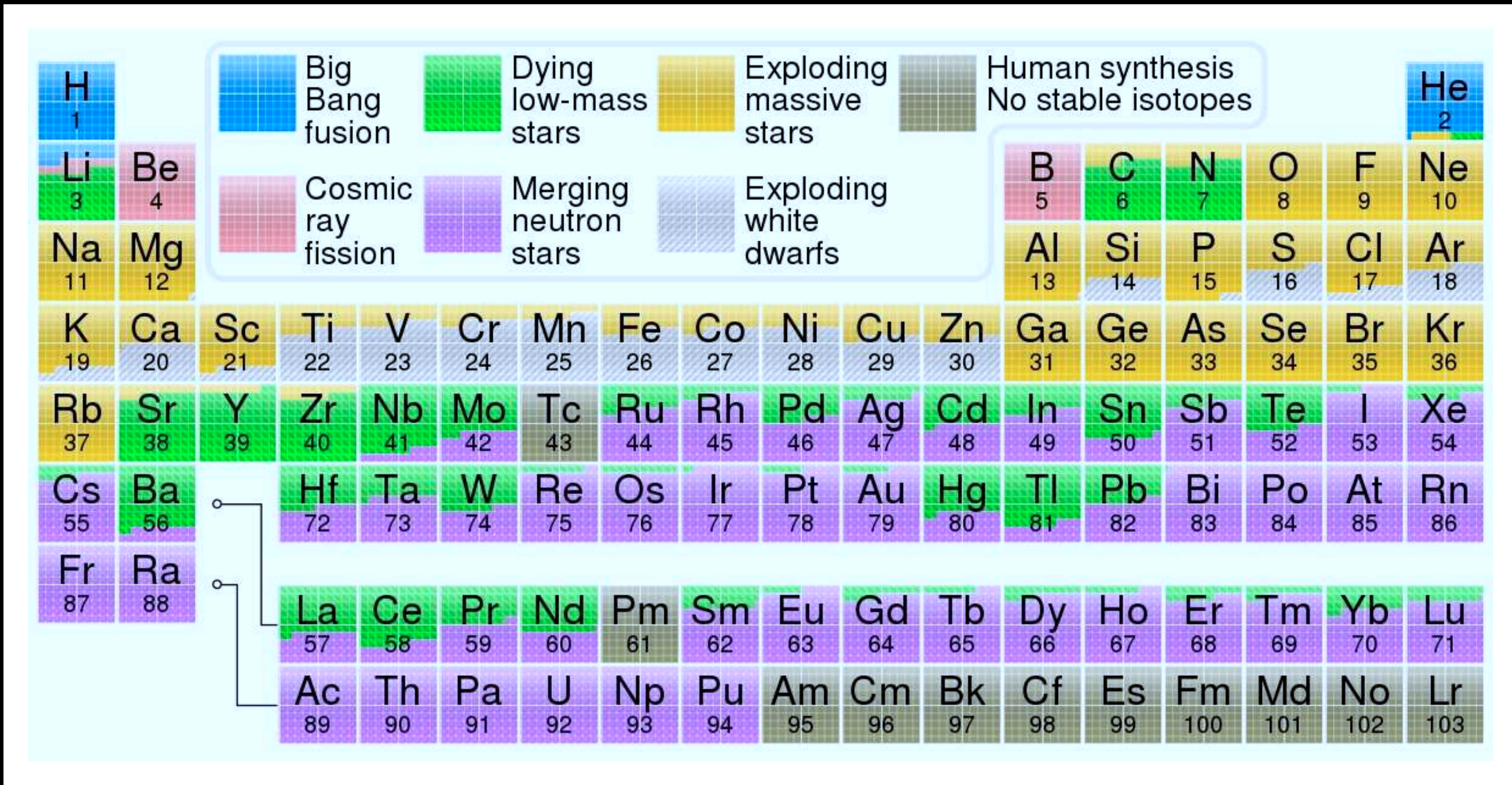


May 9, 2022: Webb's 7.7. μm MIRI image compared to Spitzer 8.0 μm: Same dense star field in the Large Magellanic Cloud in the South Ecliptic Pole

https://blogs.nasa.gov/webb/2022/05/09/miris-sharper-view-hints-at-new-possibilities-for-science/

Before we get to the cosmic circle of life, let's get this straight:

- This Periodic Table you learned in highschool is **NOT** the real one!:



(1) Hydrogen & Helium: the *only* chemical elements made in the Big Bang!

(2) All heavier elements made by (dying) stars: • Low mass stars ejecting their outer shells; • Supernova explosions/WD's; & • neutron star mergers.

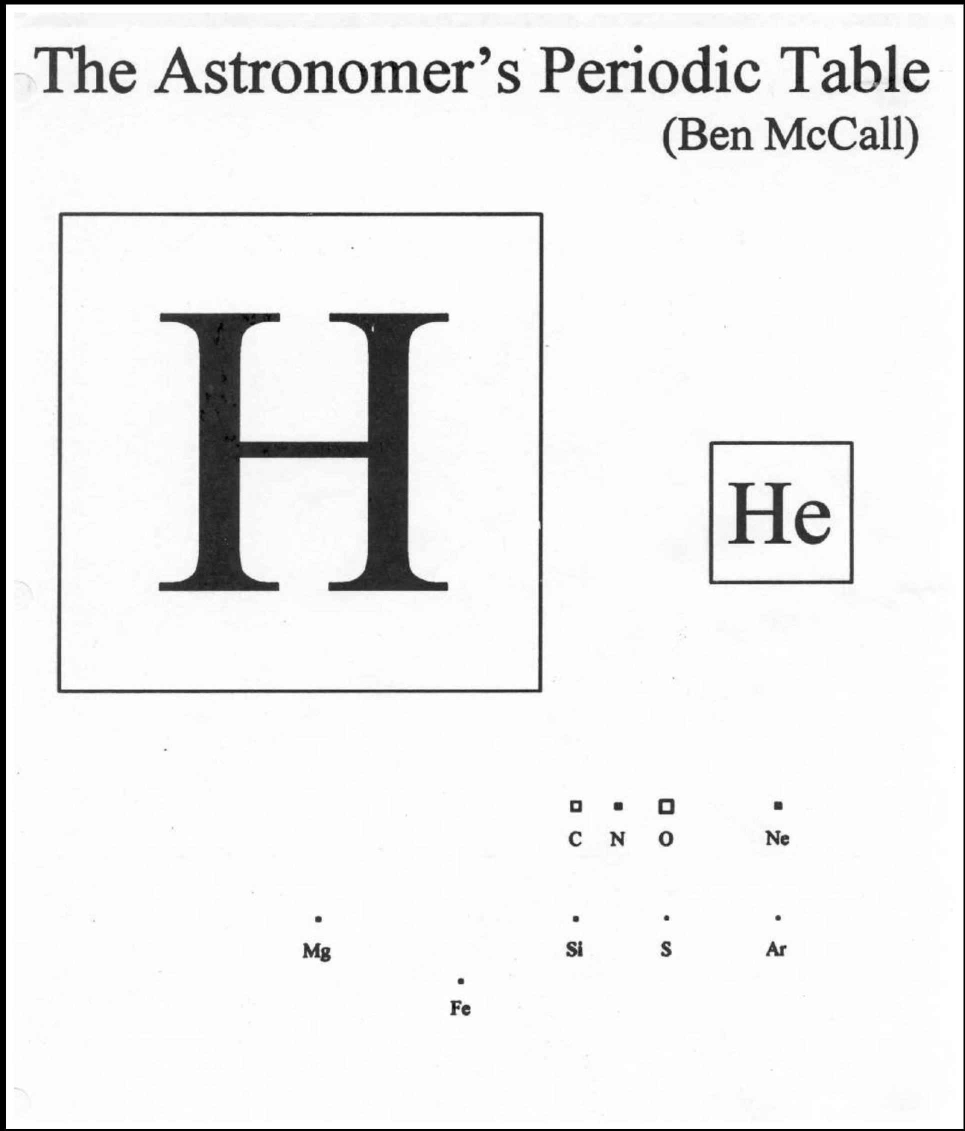
Here is the correct Astronomical Periodic Table:

(1) Hydrogen (76%) & Helium (24%) are the only chemical elements made in the Big Bang.

(2) Heavier chemical elements ($\lesssim$1%; "dust") made by (dying) stars:

- Late stages of stellar evolution, Supernova explosions & white dwarfs, and neutron star mergers distribute these throughout the universe.

$\Longrightarrow$ Planets and people are literally made from stardust!

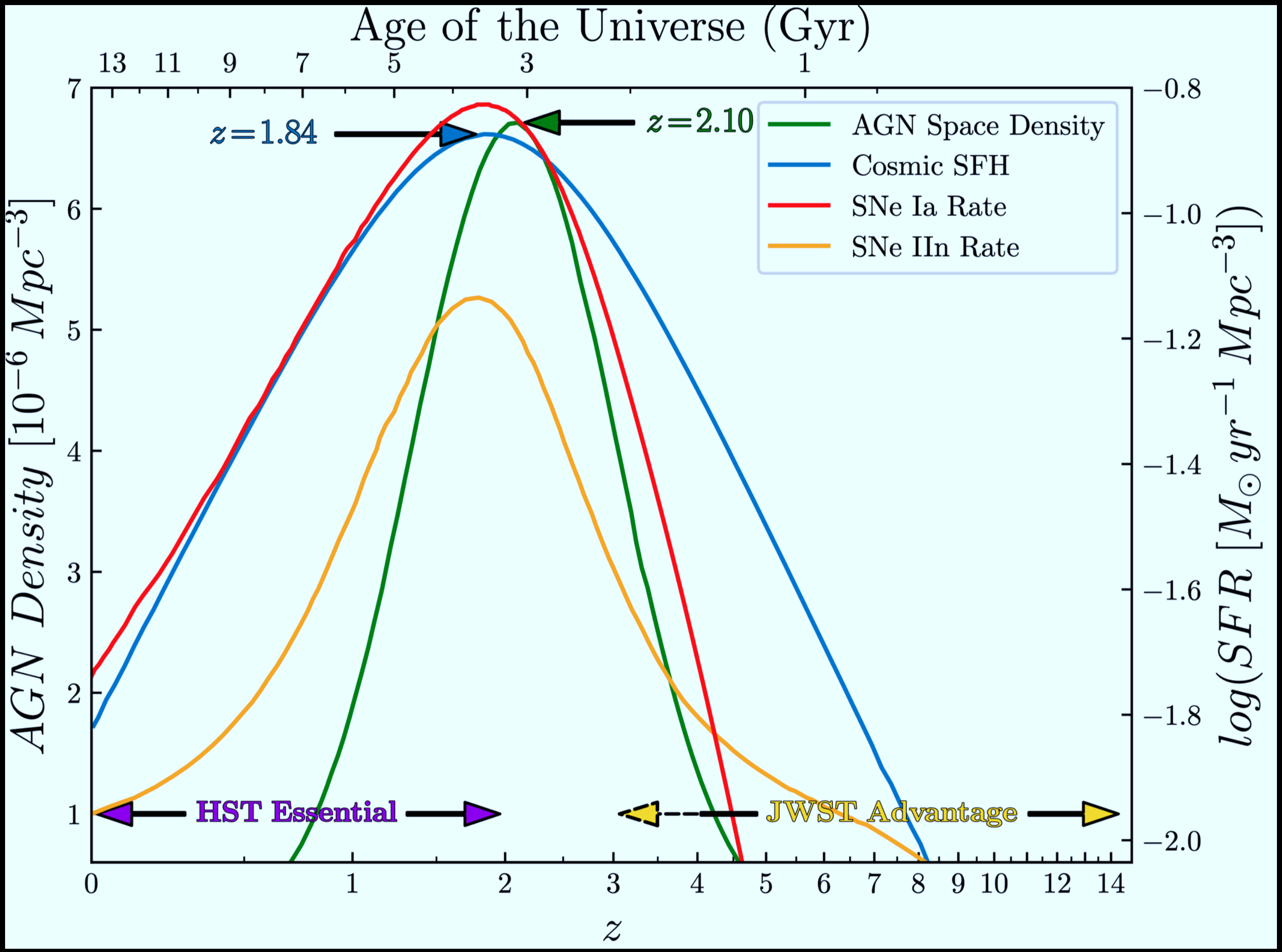


- This is the real Periodic Table with cosmic abundance included.
- This has significant consequences for Hubble and Webb complementarity!

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

Windhorst et al.

astro-ph/2410.01187

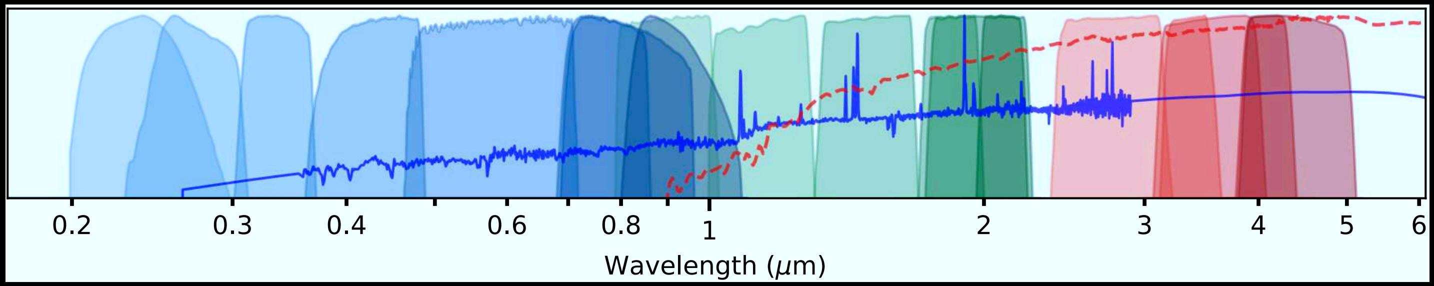


$Age \sim \frac{13.8}{(1+z)} + ...$ Gyr

Active galactic nuclei (AGN)

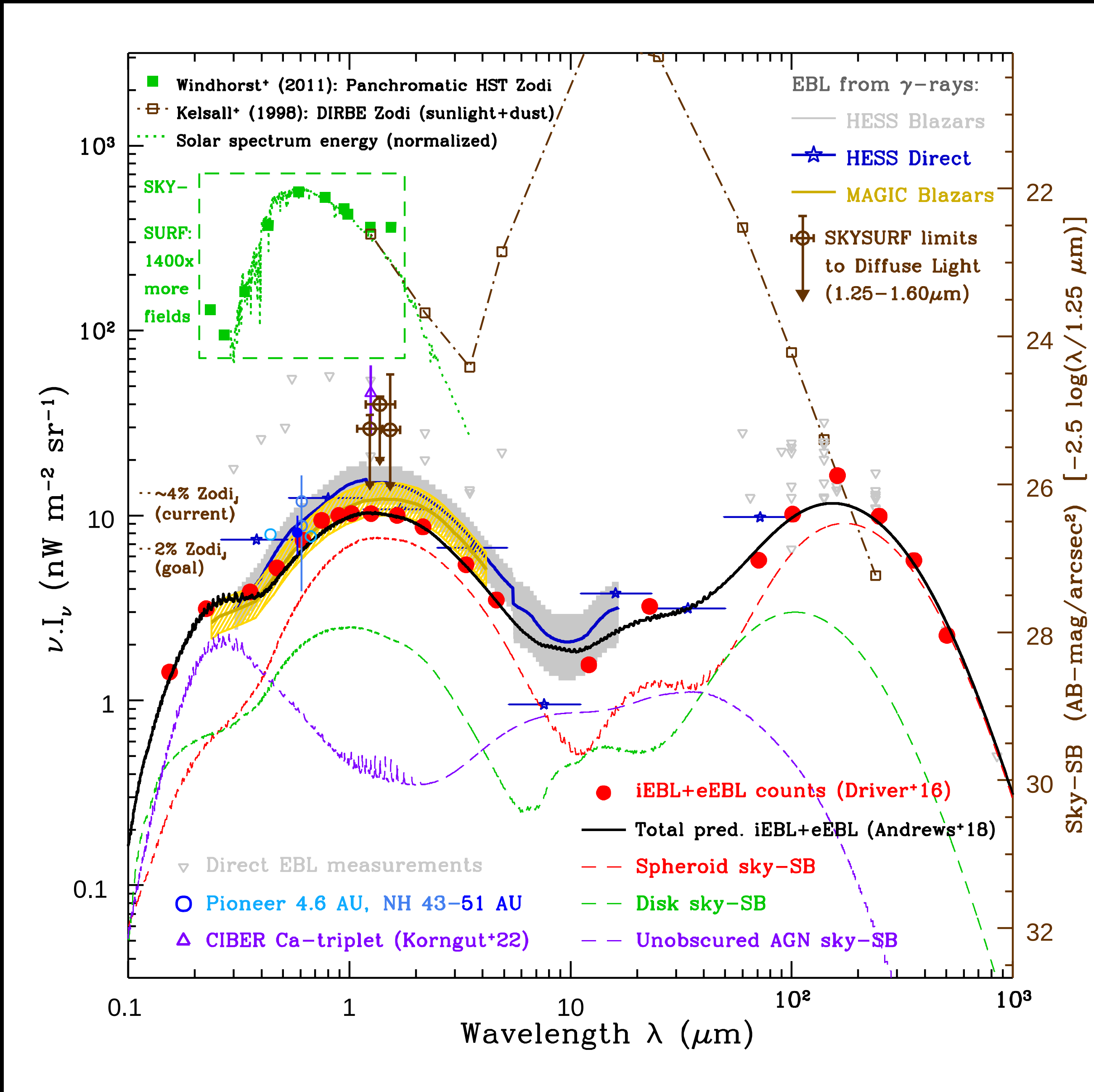
⟺ BH accretion disks

⟺ Chandra X-ray sources



⇒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 ($z \gtrsim 3$).

Fly's-eye energy in Universe vs. λ: (Driver[+] 2016; Windhorst[+] 2018, 2022):



Sunlight scattered off the Zodiacal dust.

Thermal radiation from $\gtrsim$240 K Zodiacal dust.

● integrated light from galaxy counts (+models).

New Horizon diffuse light (Lauer[+] 2021, 2022; 43-51 AU).

SKYSURF 1.25–1.6 μm diffuse light (Carleton[+] 2022; O'Brien[+] 2023, 2025; McIntyre[+] 2024).

- Energy(cosmic SF+AGN) $\simeq$ 48%; Energy(dust) $\simeq$ 52% $\Rightarrow$ Dust wins !
- $\Rightarrow$ 1% of the baryons ("dust") produce $\sim$52% of Energy (except CMB)!

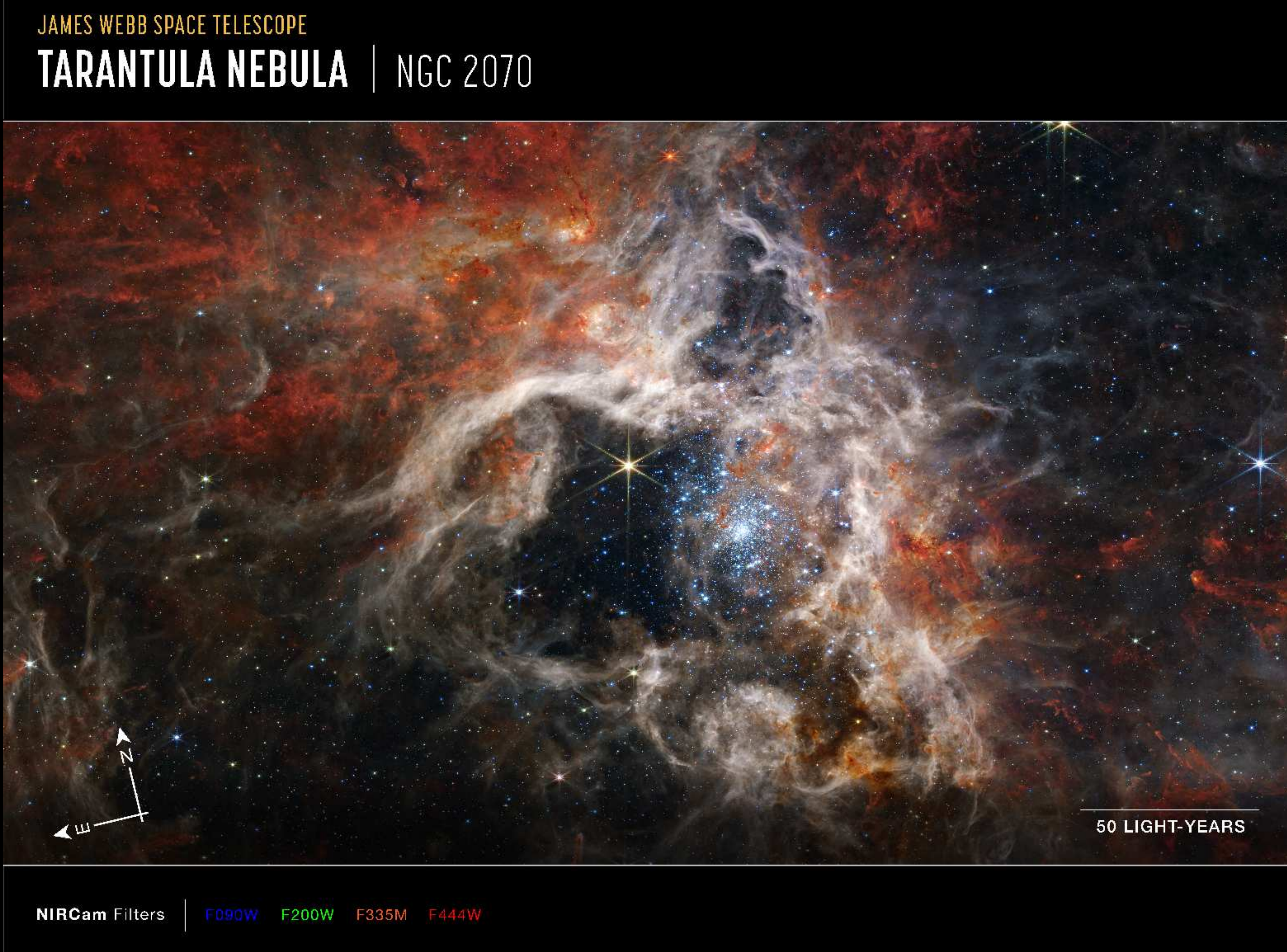
• (2) Webb's first images: the "Cosmic Circle of Life"

Hubble WFPC2 Eagle Nebula (1995) compared to JWST NIRCam (2022):

• The cradle of cosmic star-formation: NIRCam peers through the dust!

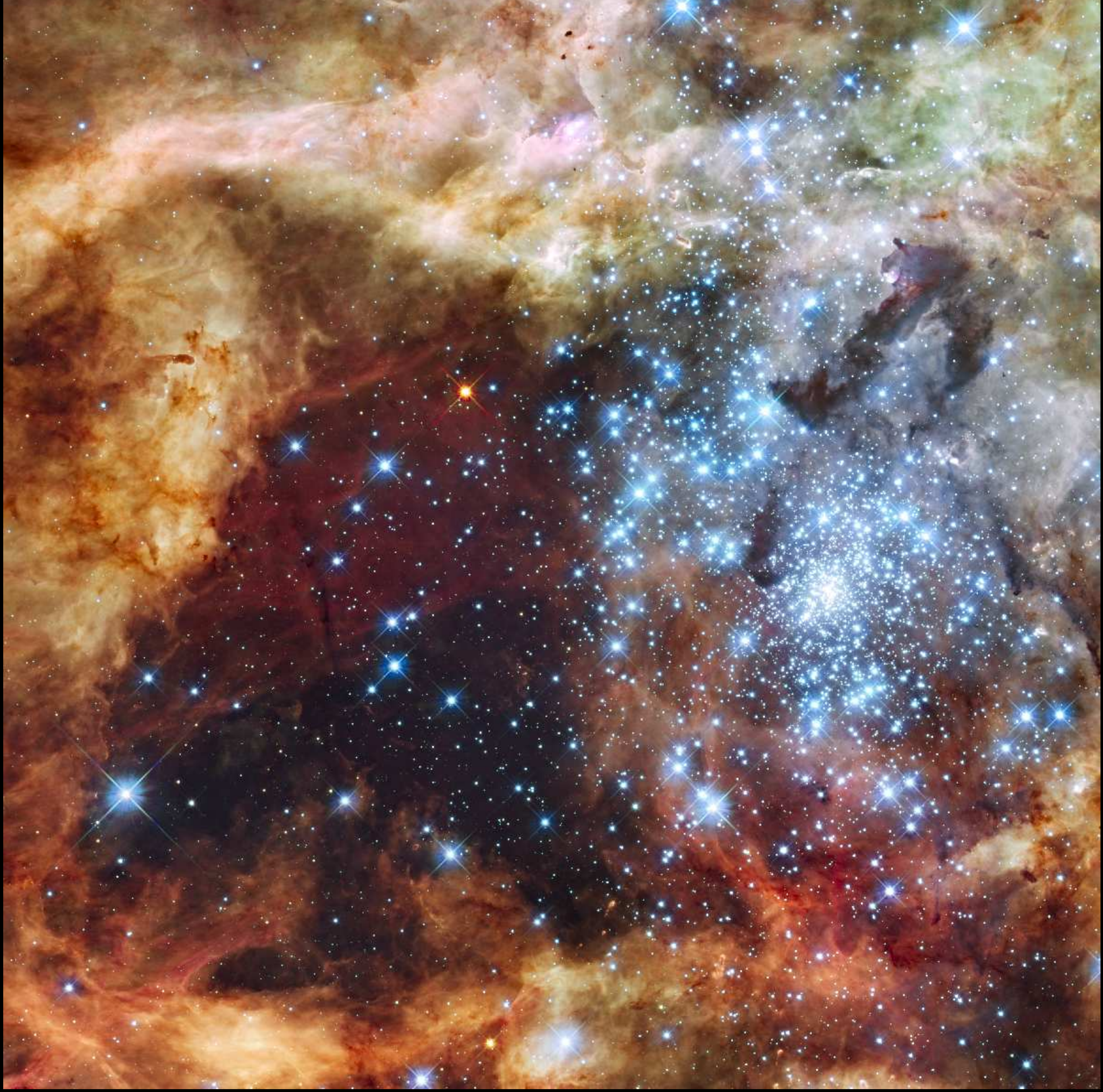
• The 1995 Hubble WFPC2 image (left) was made by Prof. Jeff Hester and Paul Scowen at ASU. It made it onto a US postage stamp!

Webb's MIRI shows the hauntingly beautiful cosmic dust pillars (8–15 μm)

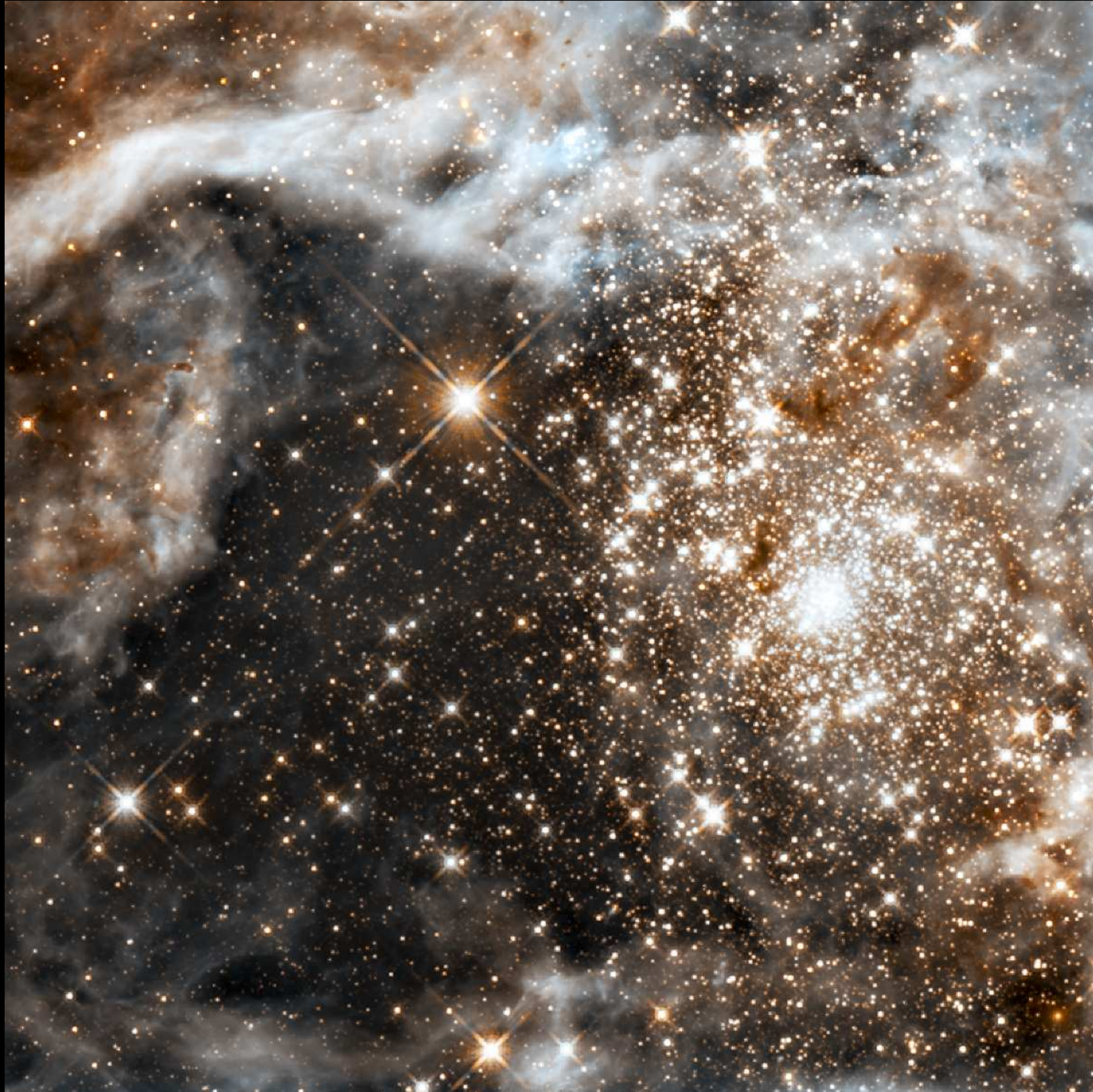


Tarantula Nebula “30 Doradus” in Large Magellanic Cloud (163,000 lyrs away)

Cradle of cosmic star-formation: massive stars trigger formation of sun-like stars



HST Wide Field Camera 3 UV–optical image of 30 Dor: hot massive stars.



HST WFC3 near-IR image of 30-Dor: massive and low-mass stars.

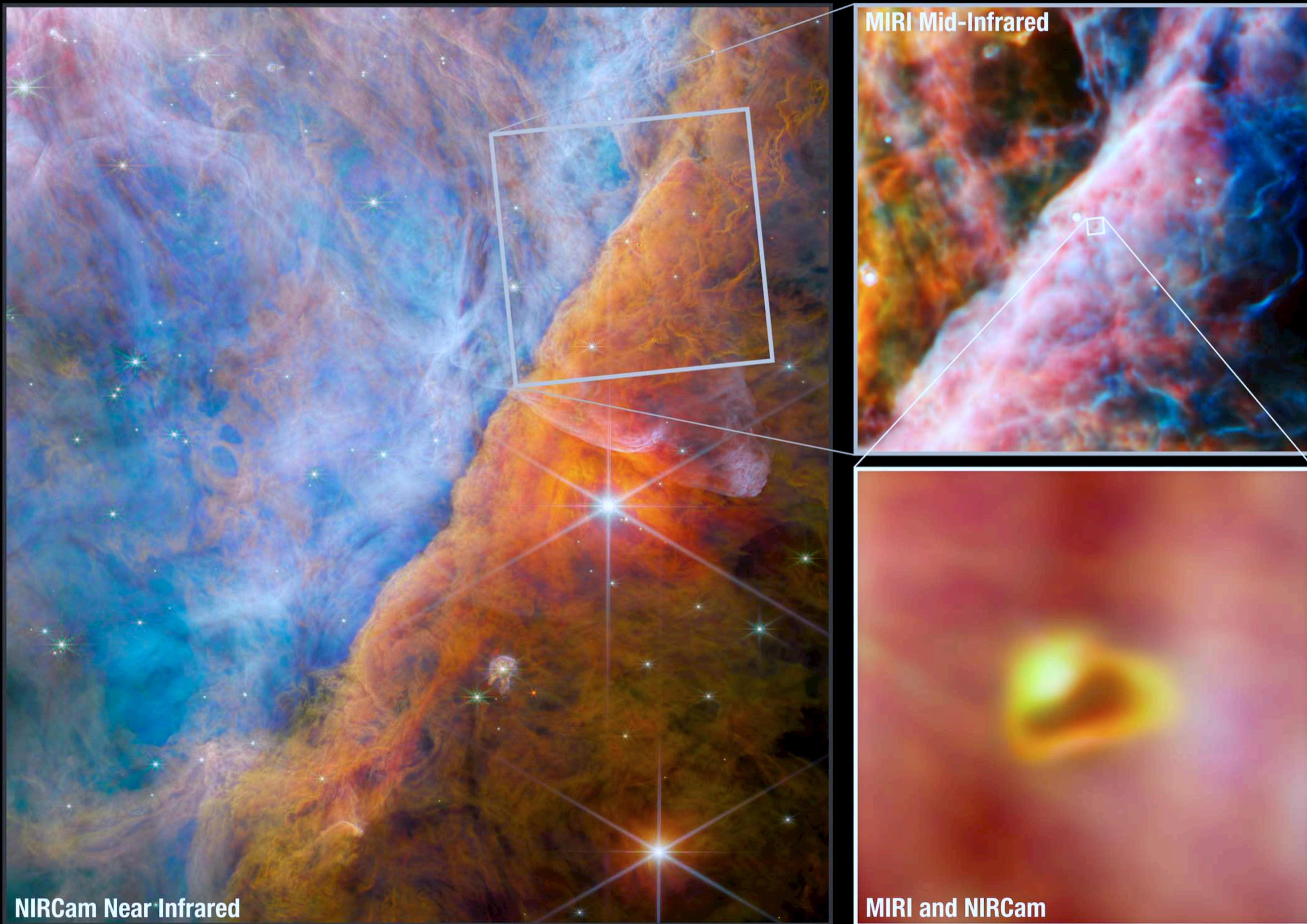
“Cosmic Cliffs” of star-formation in the Carina Nebula (NIR; 7600 light-years).

You will be witnessing the “Cosmic Circle of Life” ...

Cosmic Cliffs of Star-formation in Carina Nebula (NIR+MIR).

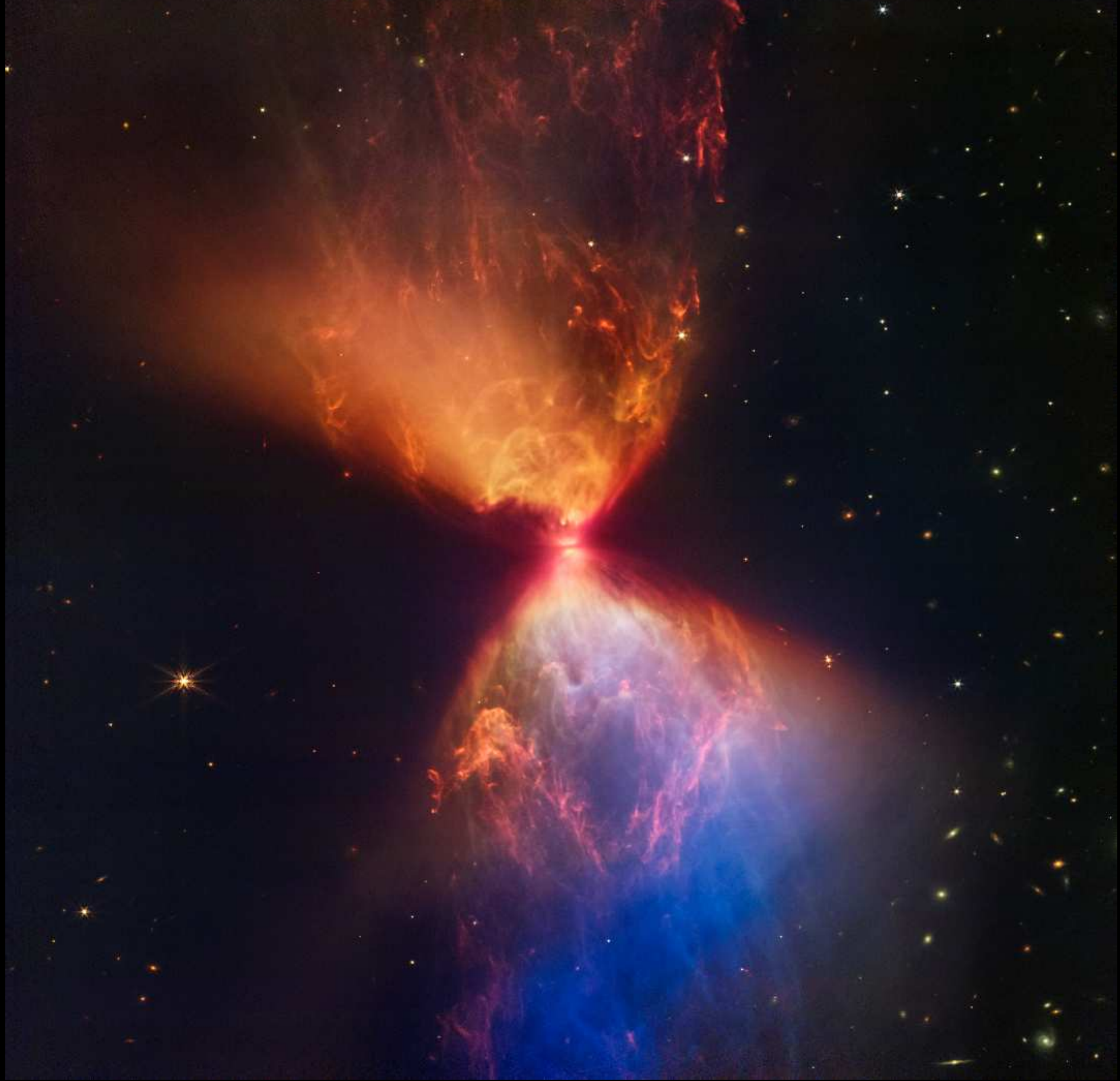
Compared to optical+near-IR, mid-IR sees "Cradle of Cosmic Star-formation"

Deep inside the gas and dust, mid-IR reveals birth of young Sun-like stars.



JWST NIRCam+MIRI: Cosmic Cliff-like in Orion's Trapezium (1344 lyrs):

- New stars are forming containing the carbon chain "Methyl Cation"

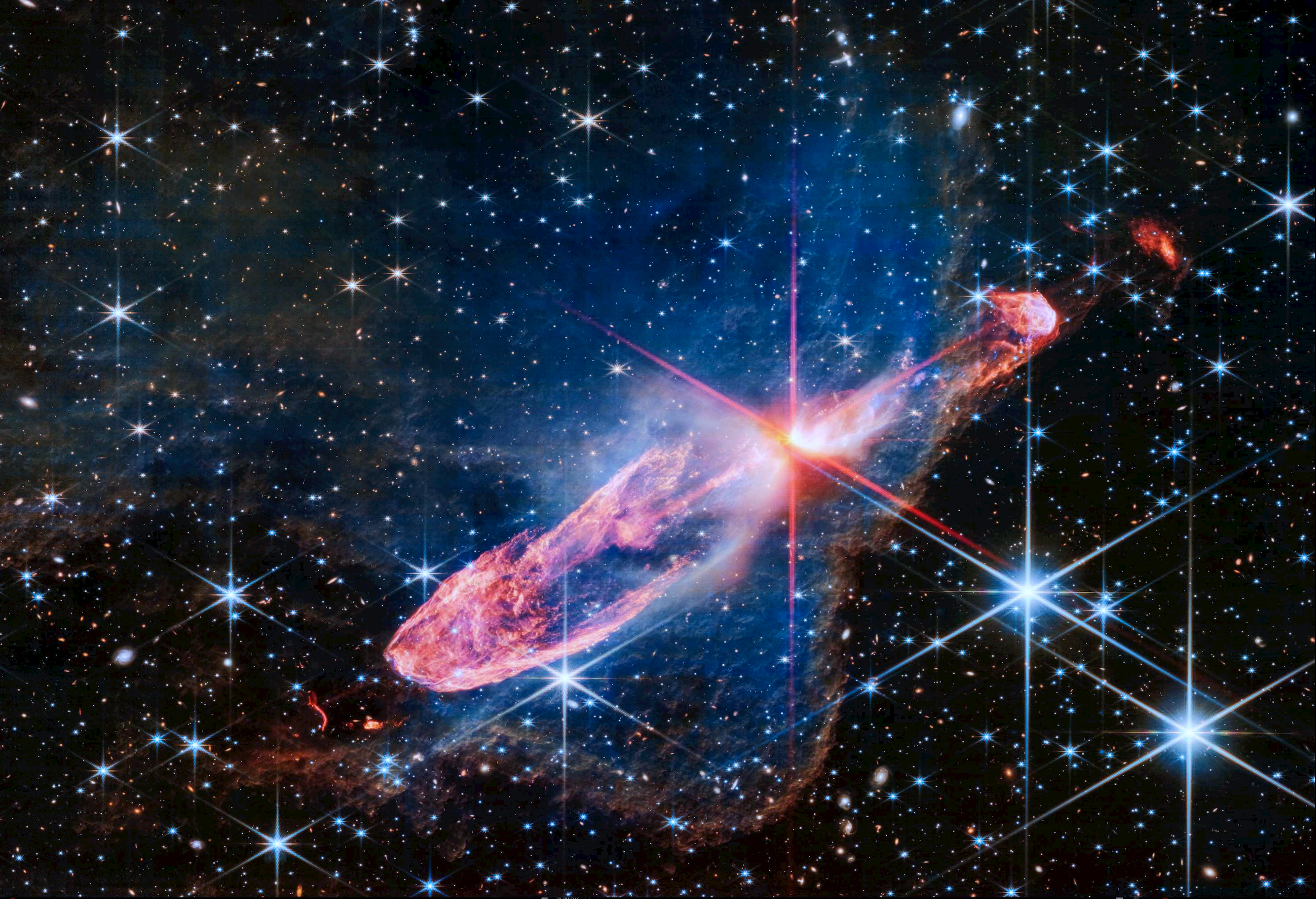


Our birth, $e.g.$, : Protoplanetary "Hourglass Nebula" L1527 at 460 lyrs.

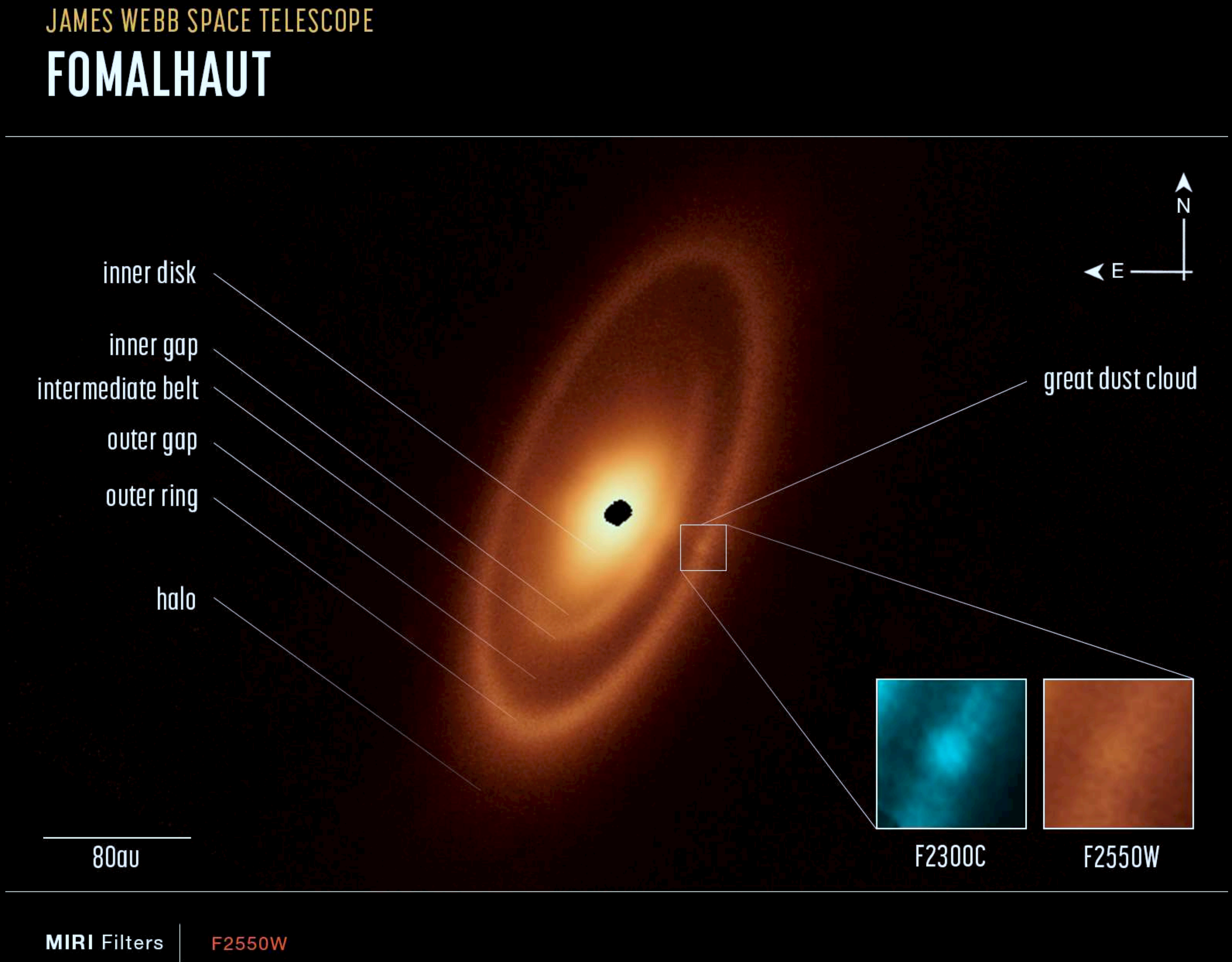
- A forming protostar with ∼30% of Sun's mass only 100,000 year old!
- The protostar has surrounding accreting gas, and a circumstellar disk.
- Eventually, L1527 will start shining as a star, and have its own planets.

NIRCam+MIRI: ρ Ophiuchi dark cloud (closest stellar nursery at 456 lyrs):

- Cradle of star-formation contains Polycyclic Aromatic Hydrocarbons!

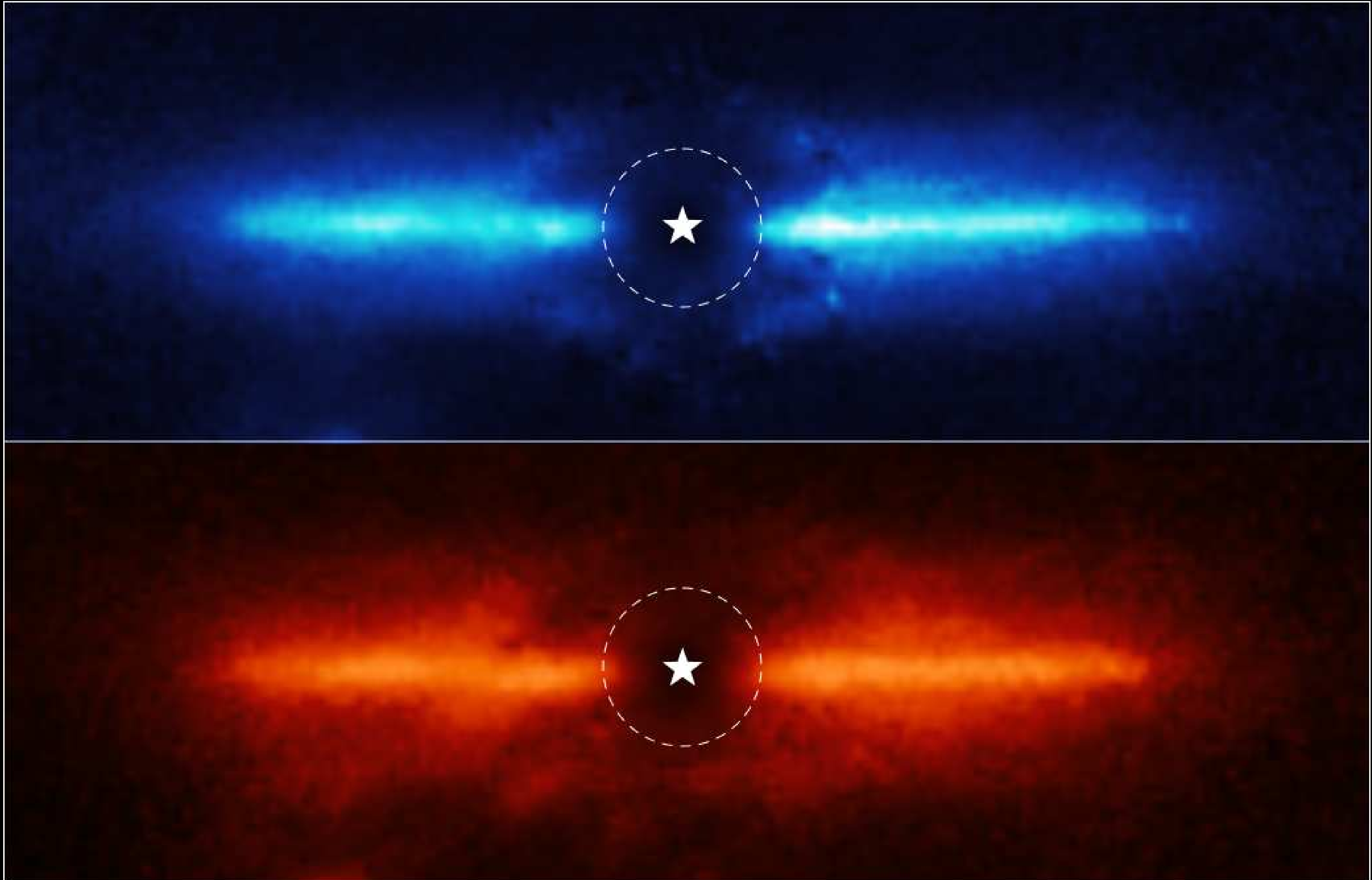


Newly forming stars Herbig-Haro 46/47 with jet-expelled material (1470 lyrs):
Formation of Sun-like stars is messy: inflow and outflow of gas & dust!



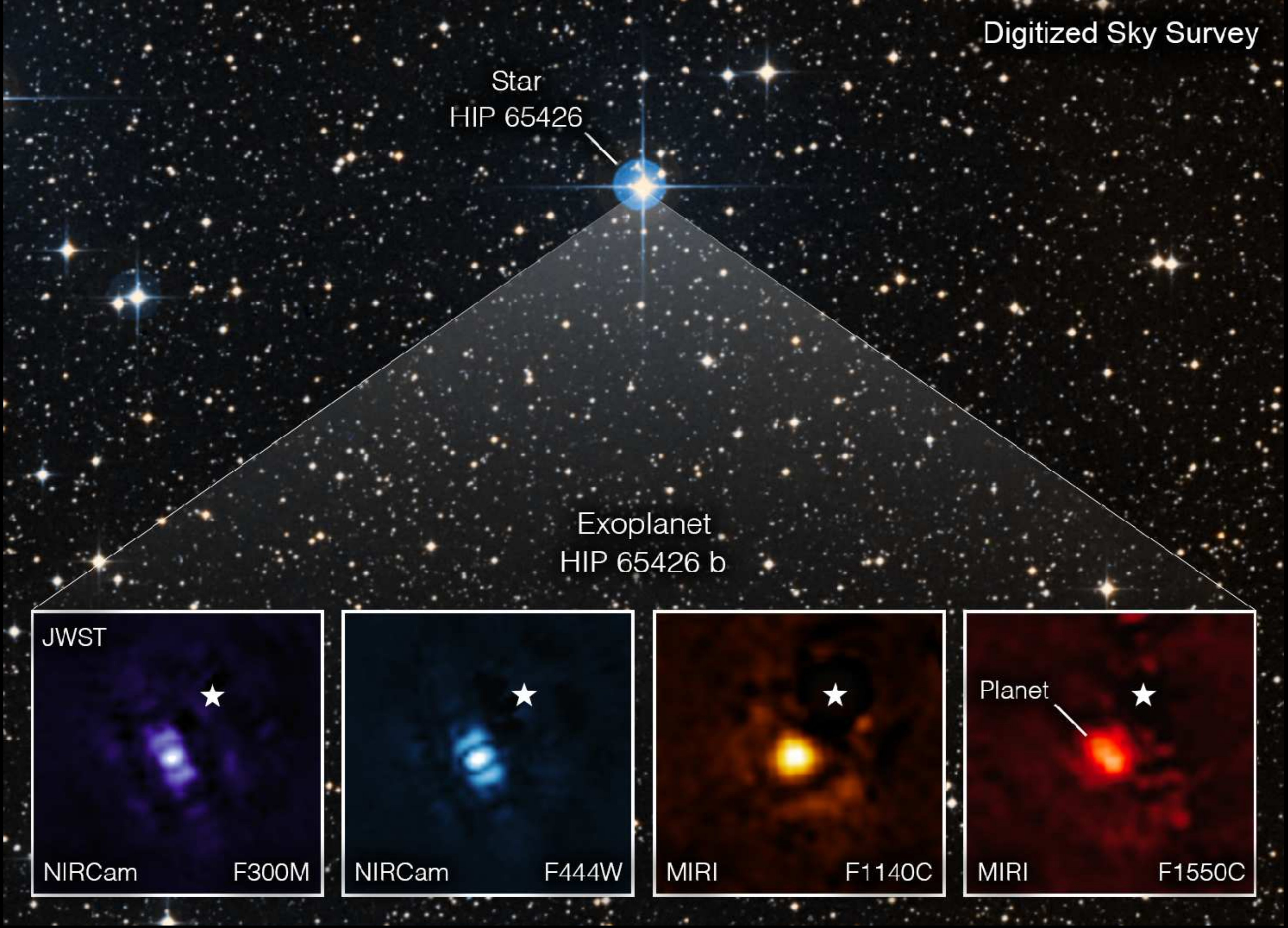
JWST MIRI Coronagraph: Debris disk around nearby star Fomalhaut:

- This is how the giant planets and terrestrial planets formed around our Sun

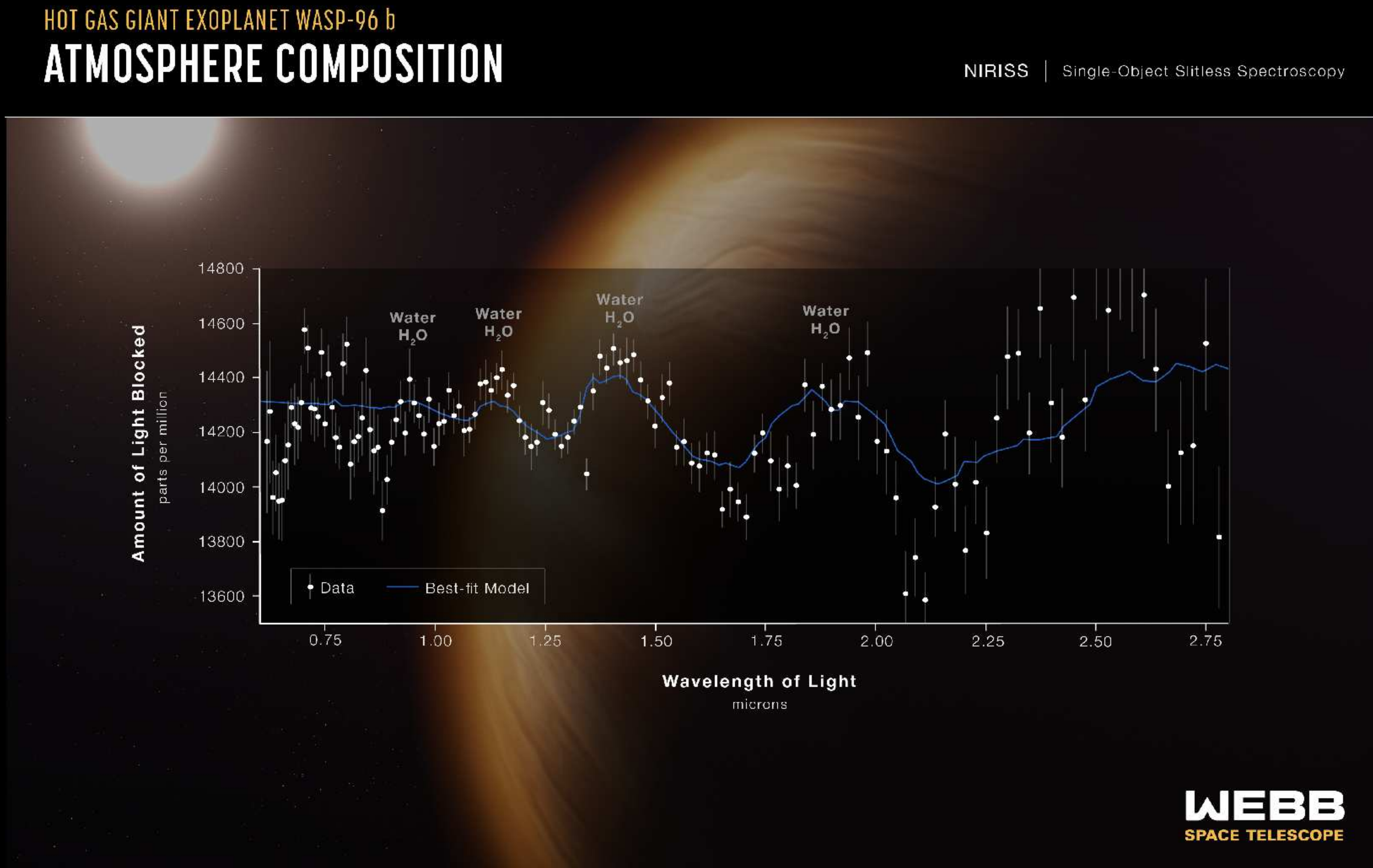


Dusty debris disk around red dwarf star AU Mic at 32 light-years:

- NIRCam's Coronagraph blocks the central star-light.
- Debris disk visible at 5–60 AU, *i.e.*, slightly larger than Solar System.

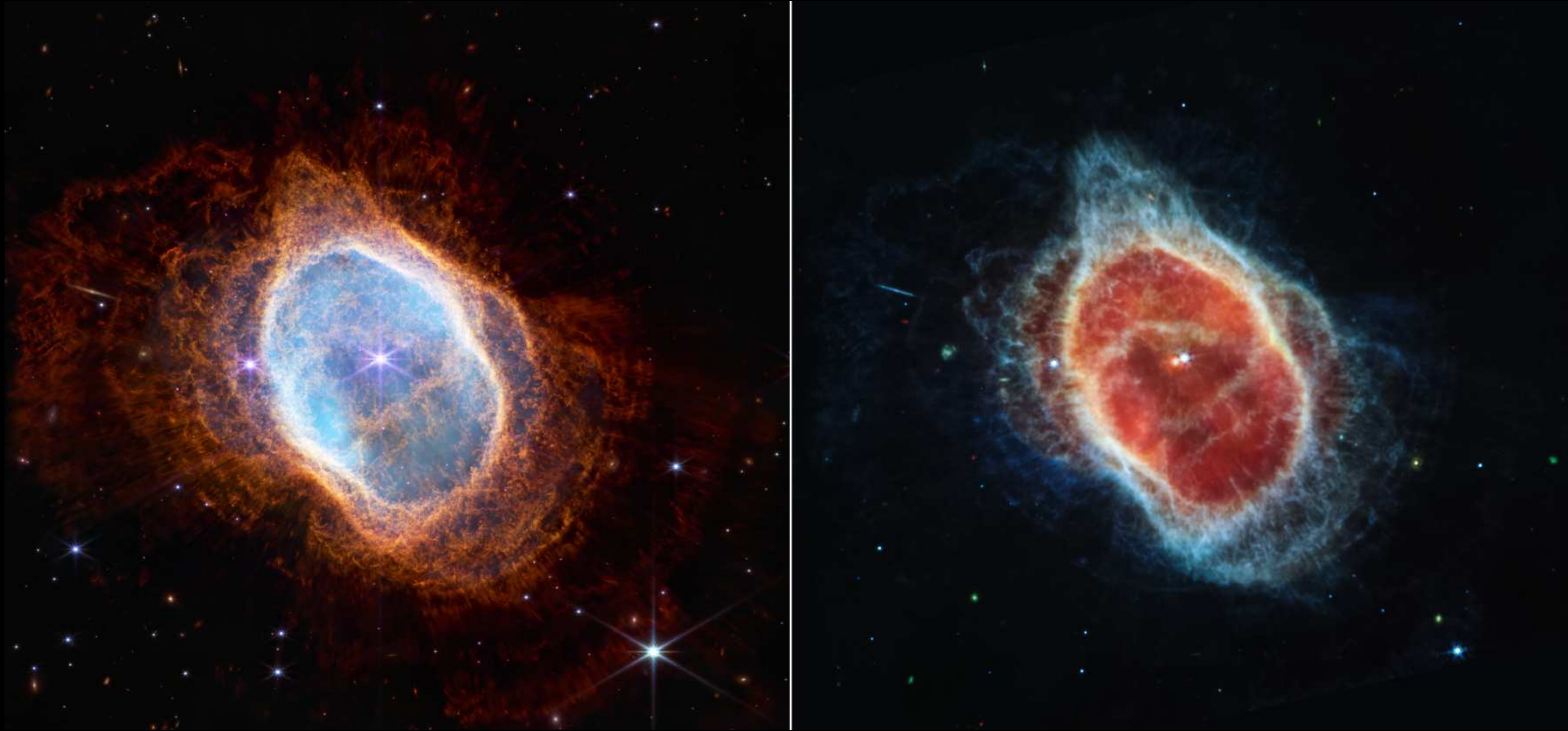


Webb 3–15 micron exoplanet images (10 Jupiter masses; 15 Myr young!)



Hot exoplanet WASP-96b orbiting a Sun-like star (1150 light-years):

- Near-IR spectrum shows characteristic features of water (steam !).
- It has a temperature of 1000 F and is half Jupiter in mass.
- Webb will scan Earth-like exoplanets for building blocks of life.



Southern Ring Nebula (Near-IR+Mid-IR; 2500 light-years):

- You $*are*$ witnessing the "Cosmic Circle of Life" here ...
- This is a Sun-like star expelling its outer layers in retirement ...
- It has exhausted its hydrogen and helium as nuclear fuel ...

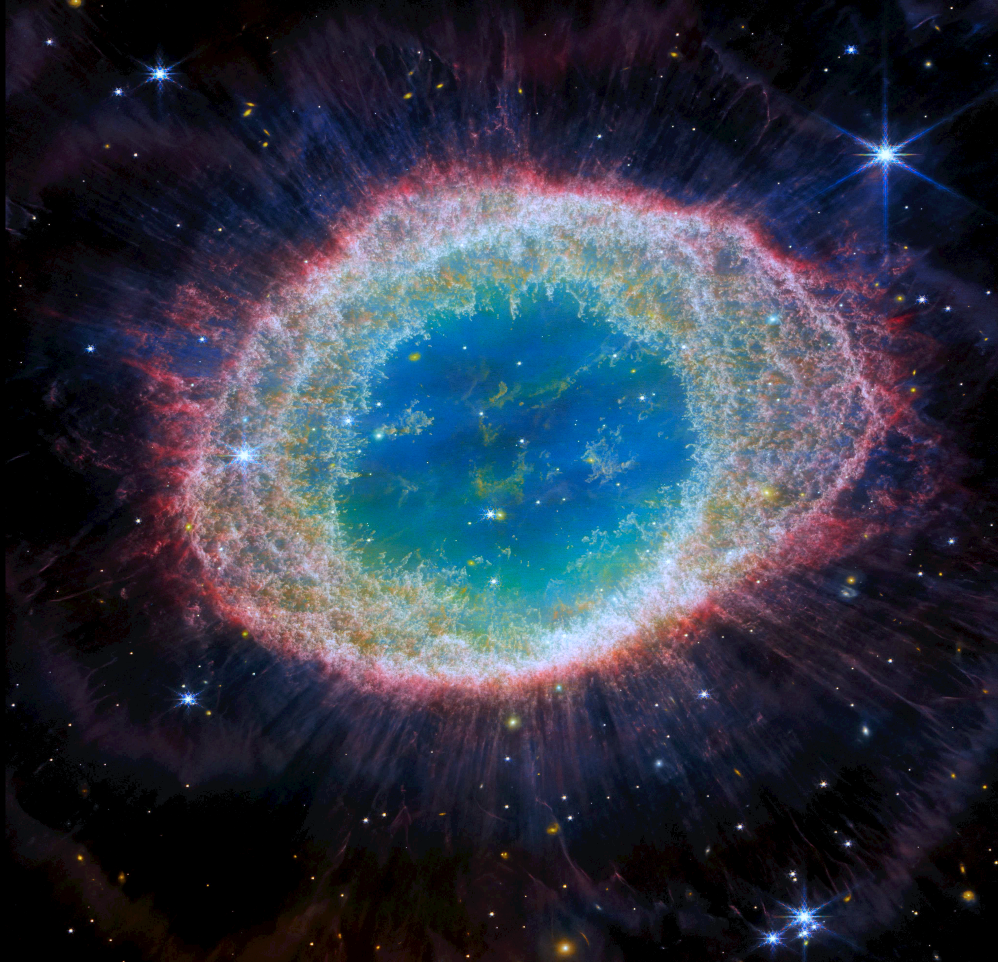
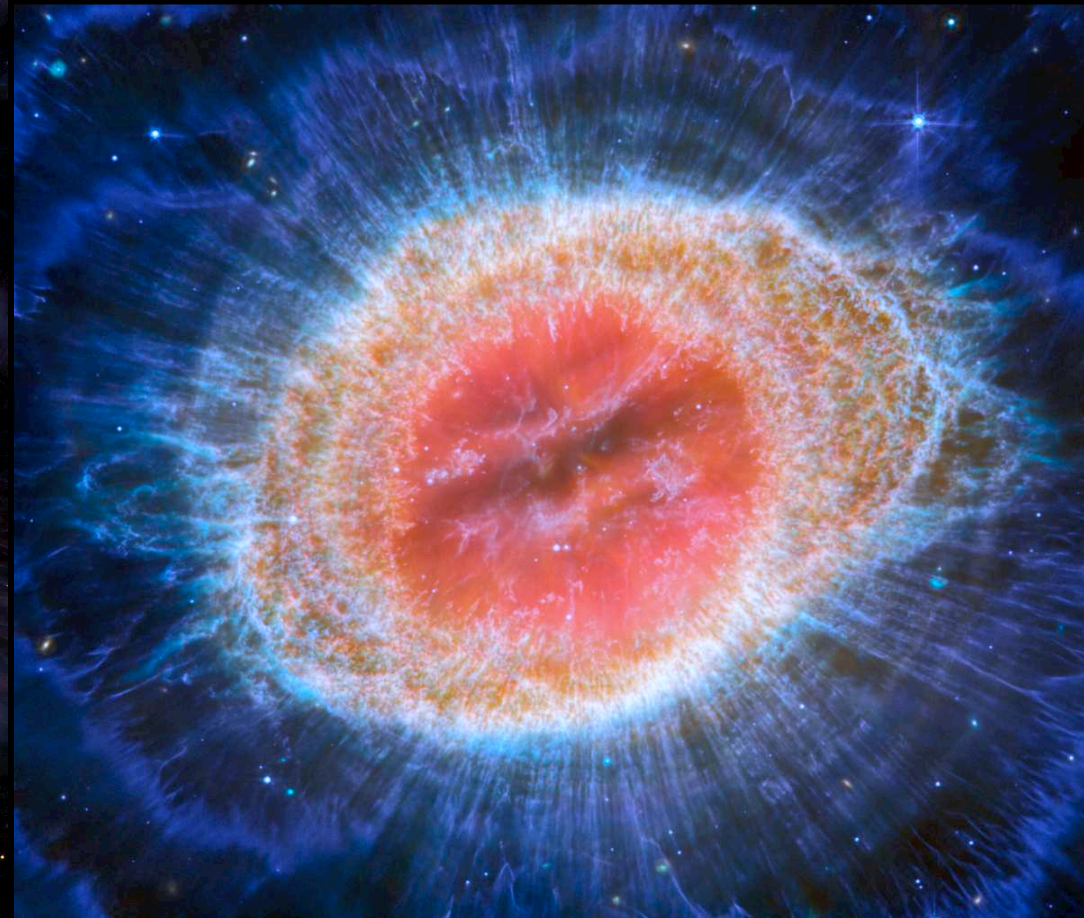
and expanded to $>>100\times$ its current size, engulfing the Earth.

This is how our Sun *will* come to an end in 5 Billion years (near-IR).

Genesis 3:19: "... for dust thou art, and unto dust shalt thou return".

From gas expelled by previous sun-like stars, new stars are born (mid-IR).

And thanks to the dust they expelled, new stars will form with planets ...

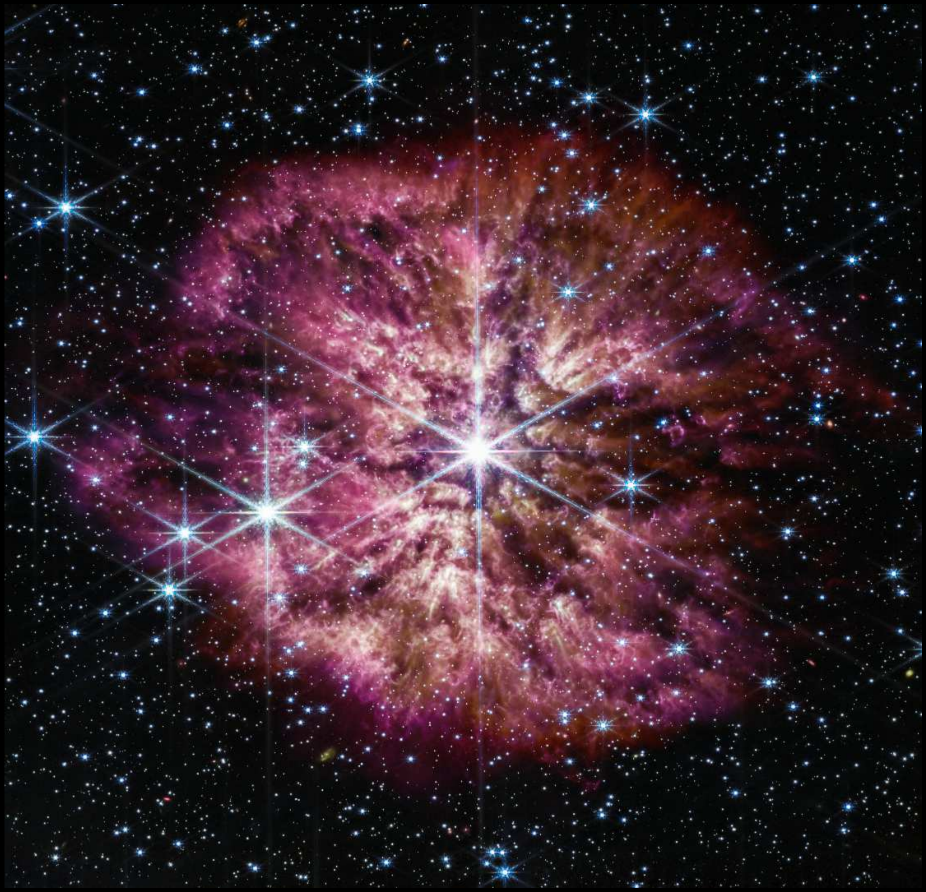
Webb images of THE Northern Ring Nebula in Lyra:

[Left] NIRCam & [Right] MIRI: mass loss in Asymptotic Giant Branch stage.

• This is how our Sun *will* come to an end in 5 Billion years ...

and leave an ultra hot dim white dwarf star behind in the center.

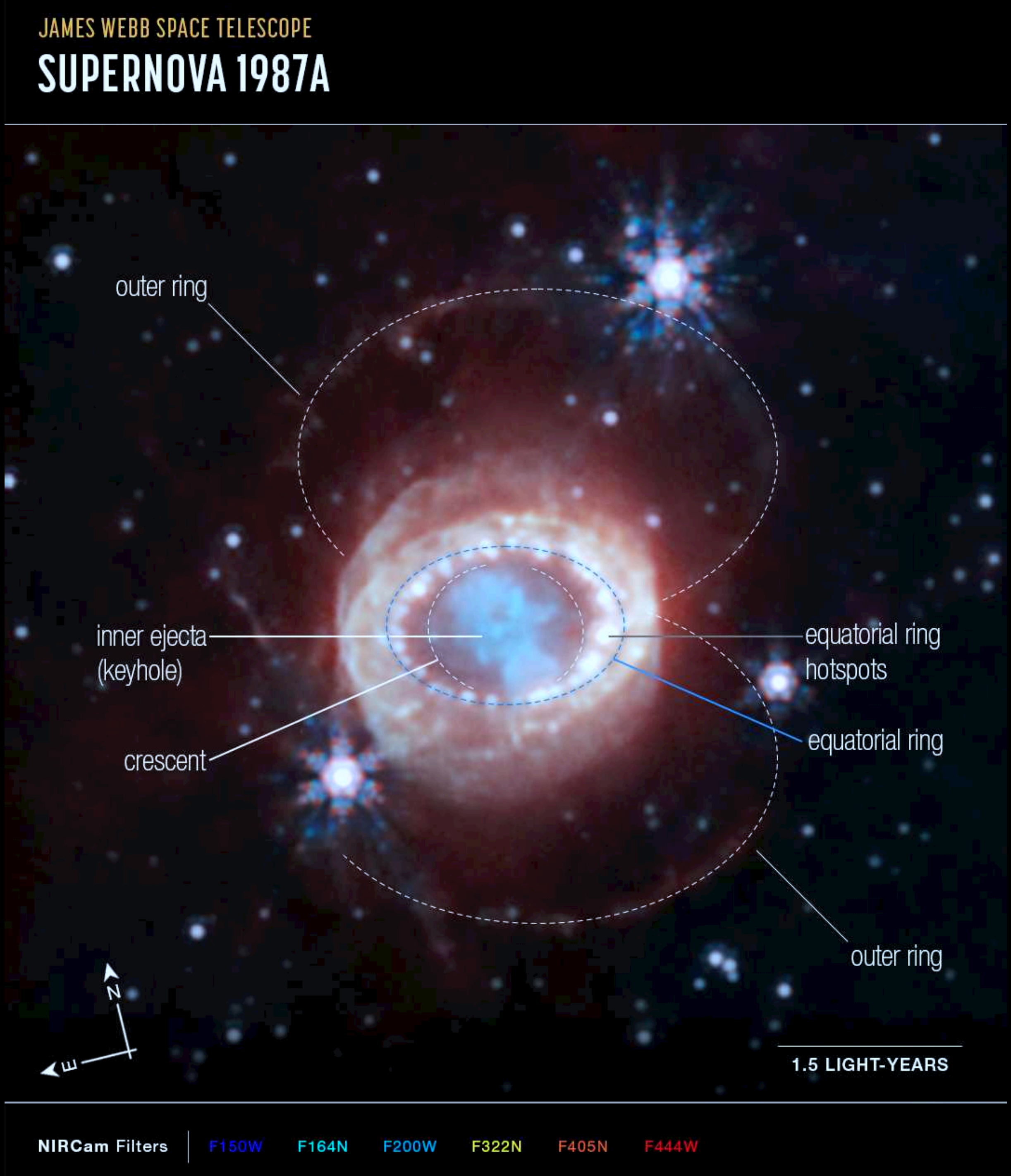
Genesis 3:19: "... for dust thou art, and unto dust shalt thou return".



30 solar mass Wolf Rayet star WR124 shortly before it turns Supernova ...

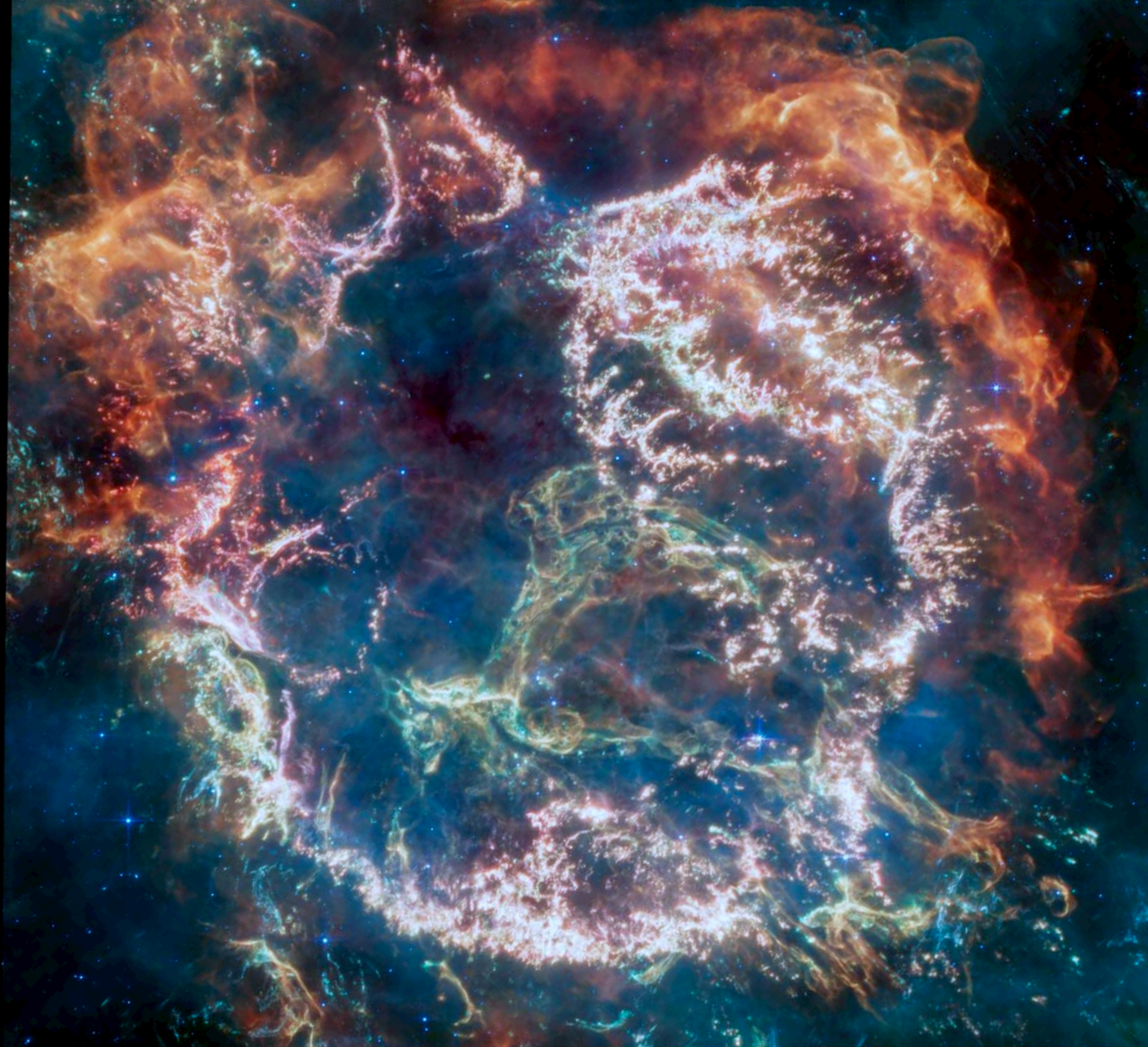
- [Left] NIRCam and [Right] MIRI — both showing recent mass loss.
- Prelude stage to Supernova also releases a lot of (dusty) mass!

Genesis 3:19: "... for dust thou art, and unto dust shalt thou return".

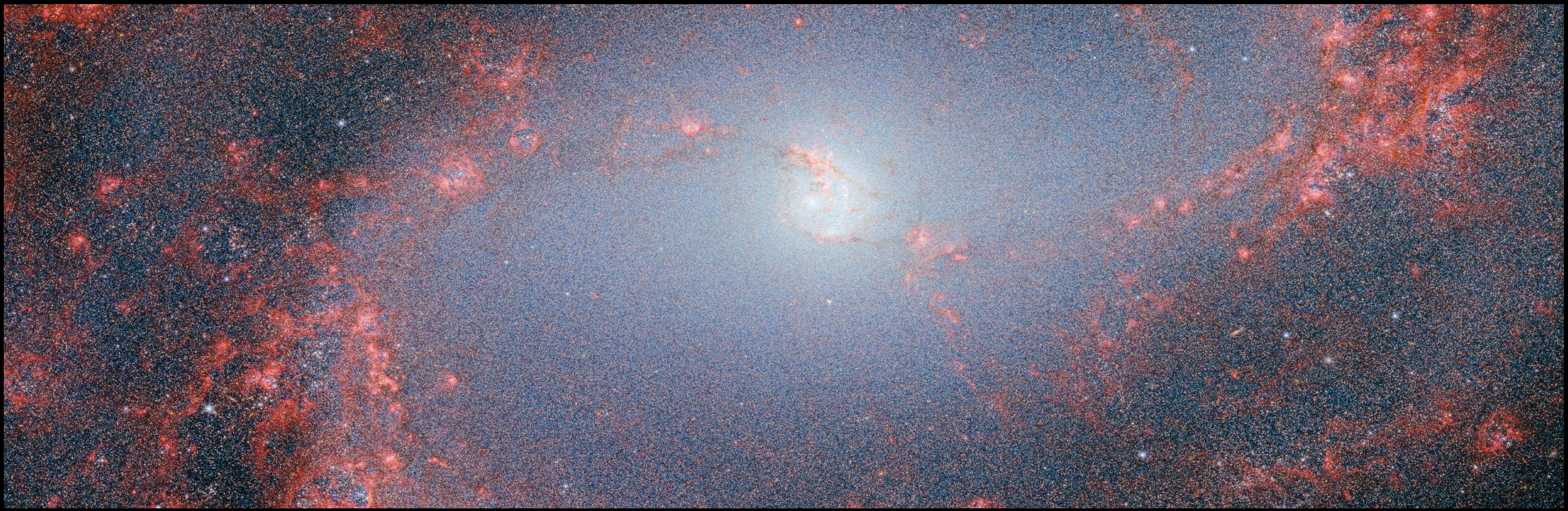


NIRCam: Remnants of Supernova 1987A seen in Large Magellanic Cloud

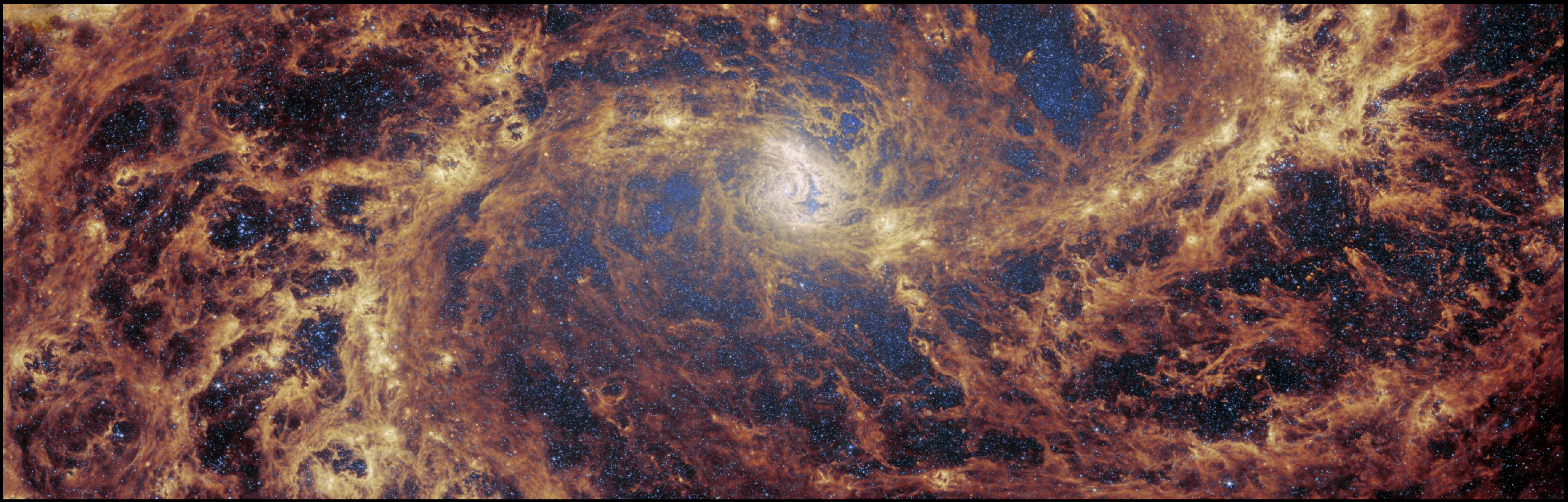
- Shells outflowing over the decades caused hour-glass shaped bubbles



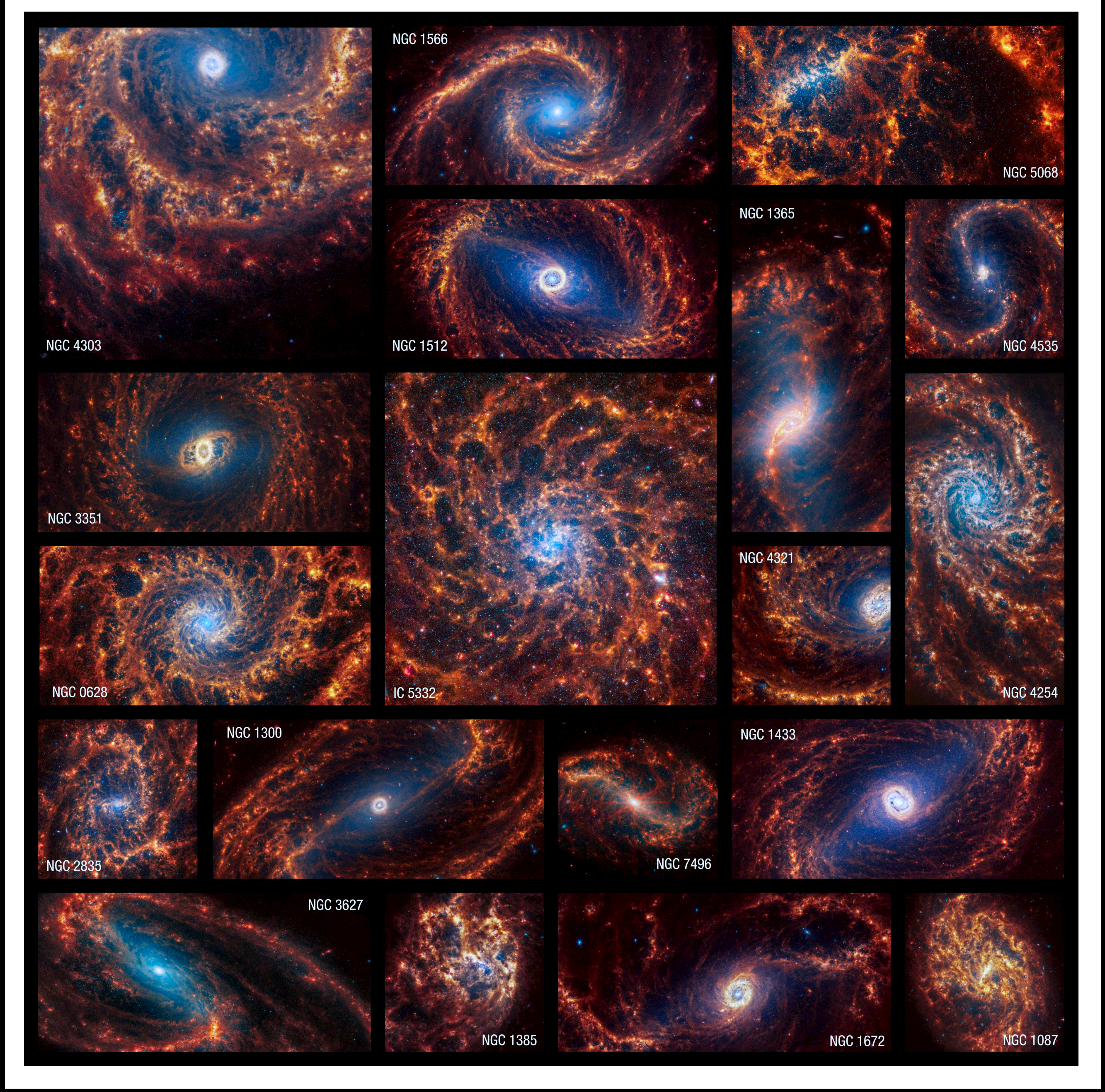
JWST MIRI: Supernova Remnant Cassiopeia-A expelling dust



M83 spiral galaxy NIRCam (near-IR): Through dust thou art made, stars!

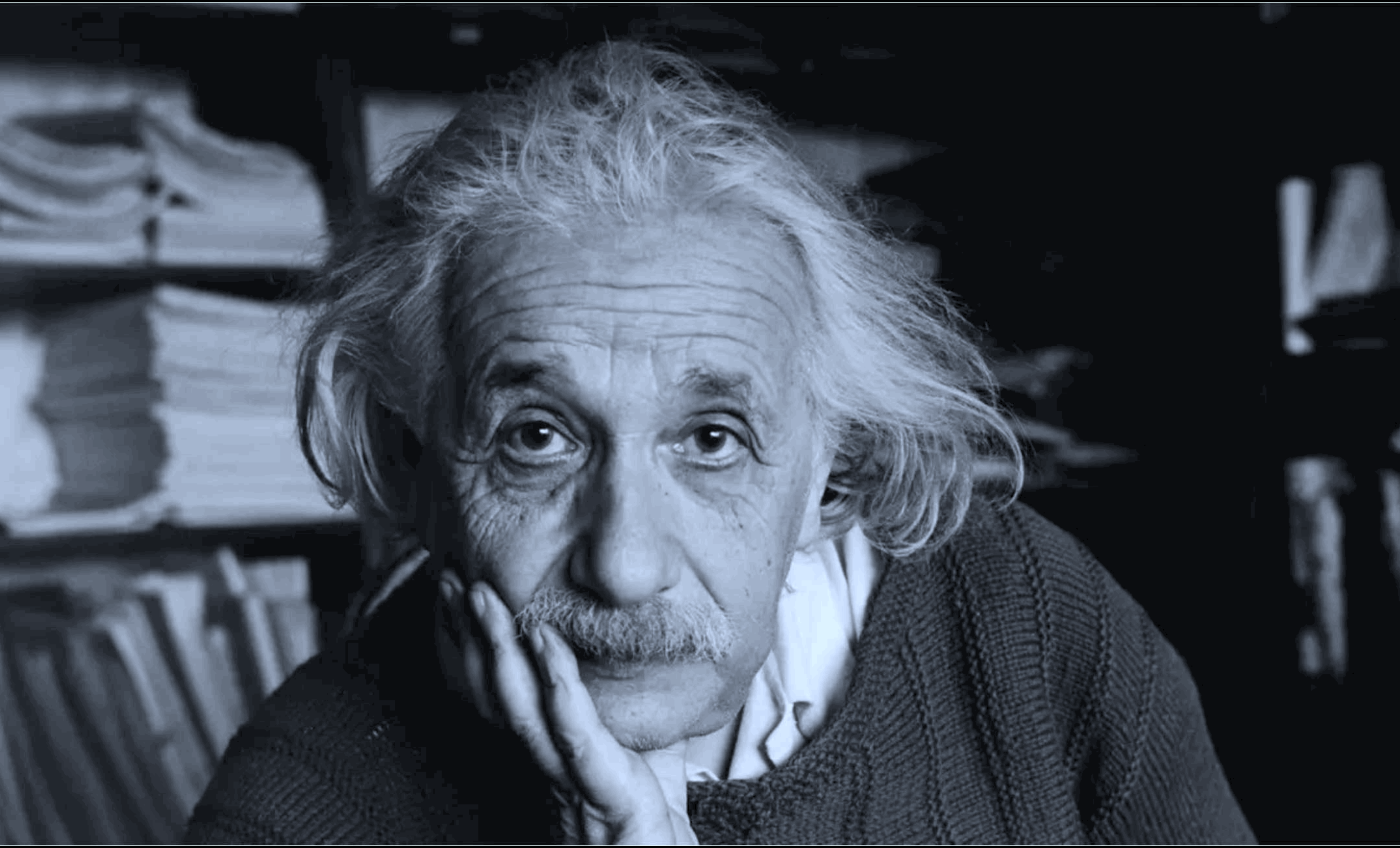


M83 spiral galaxy MIRI (mid-IR): ... and dust thou shalt return, stars!



Webb NIRCam and MIRI images of nearby galaxies:
Cosmic star-formation and dust production ubiquitous throughout the universe!
The "Cosmic Circle of Life" rules throughout the universe!

• (3) 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, Λ ...

Stephan's Quintet: 4 colliding galaxies (290 M-lyr; left spiral is foreground).

- These major "Cosmic Trainwrecks" are much more common in the past.
- Sun-like stars formed in aftermath of minor "Cosmic Fender-benders".

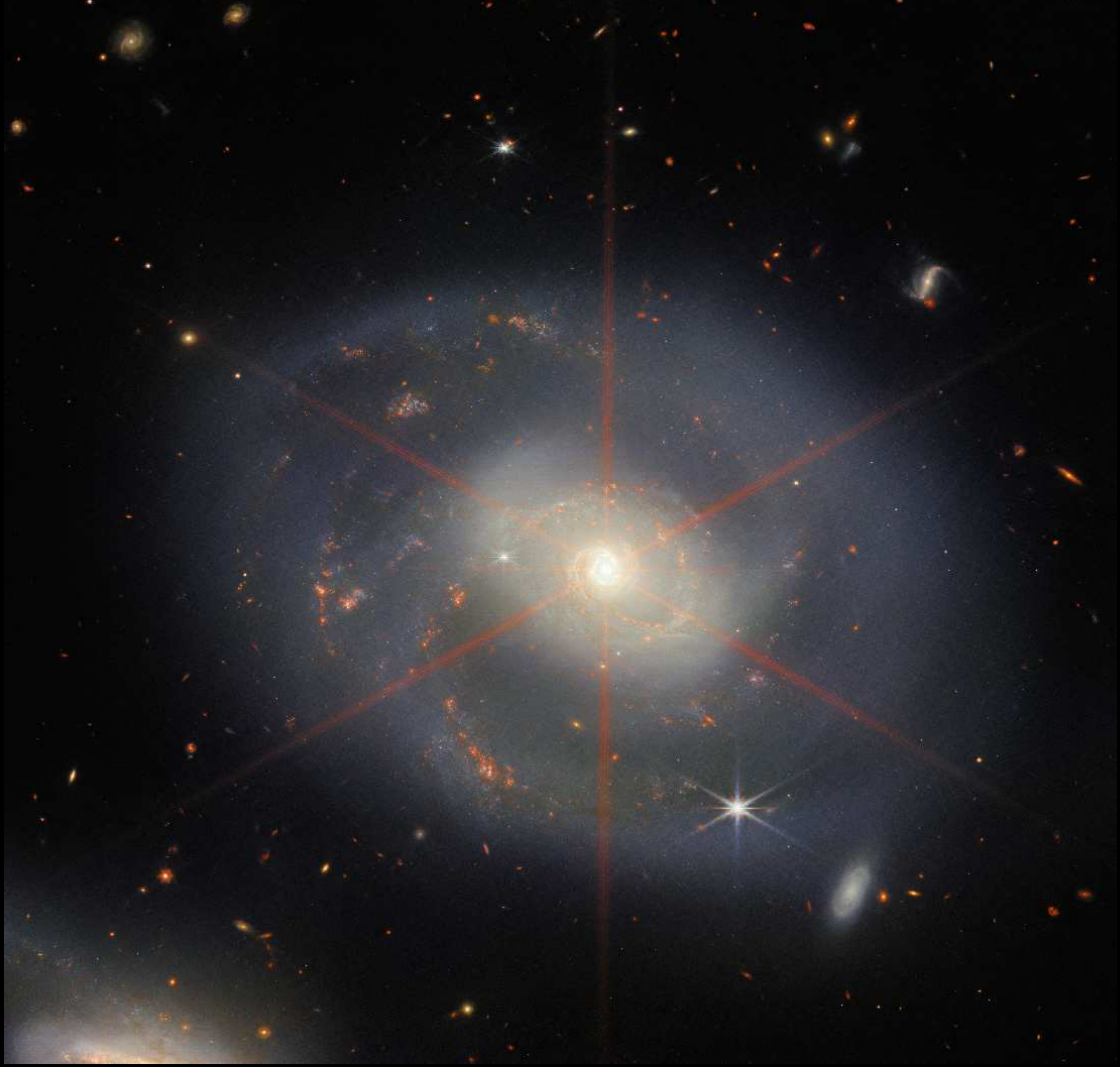
Stephan's Quintet: 4 colliding galaxies at 290 million light-years (Mid-IR):

- Mid-IR shows molecular gas being pulled out during collision.
- Gravity from collision in top galaxy feeds the Beast: central black hole!

NGC1433 a galaxy with dusty spiral arms at 48 million light-years

NGC7496 a galaxy with dusty spiral arms at 24 million light-years:

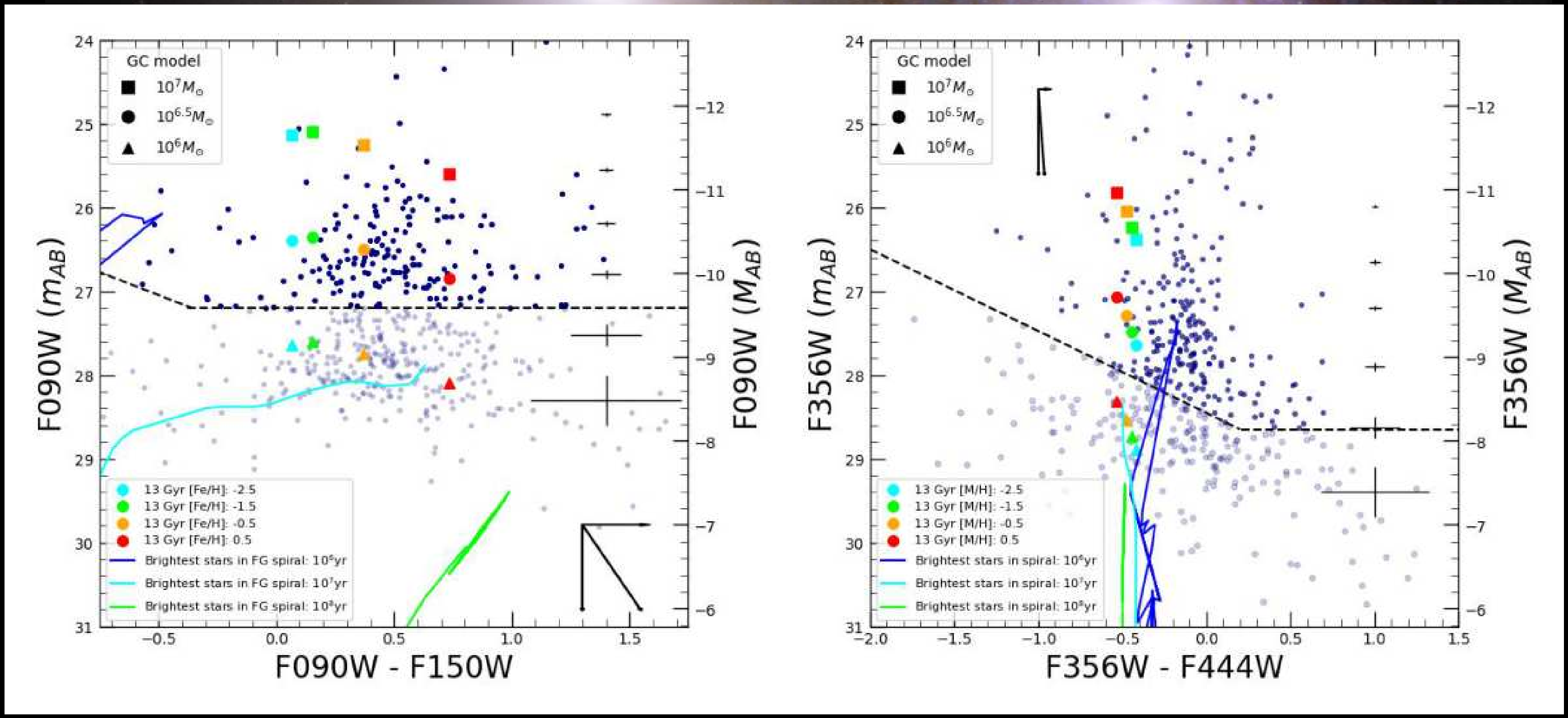
- Inner spiral arms feed the central monster (supermassive black hole!)



Don't feed the animals: NGC7469, a spiral galaxy at 220 million light-years:

- It has a supermassive black hole (SMBH) feasting on the in-falling gas!
- In area surrounding the SMBH, gas is expelled at very high speeds.

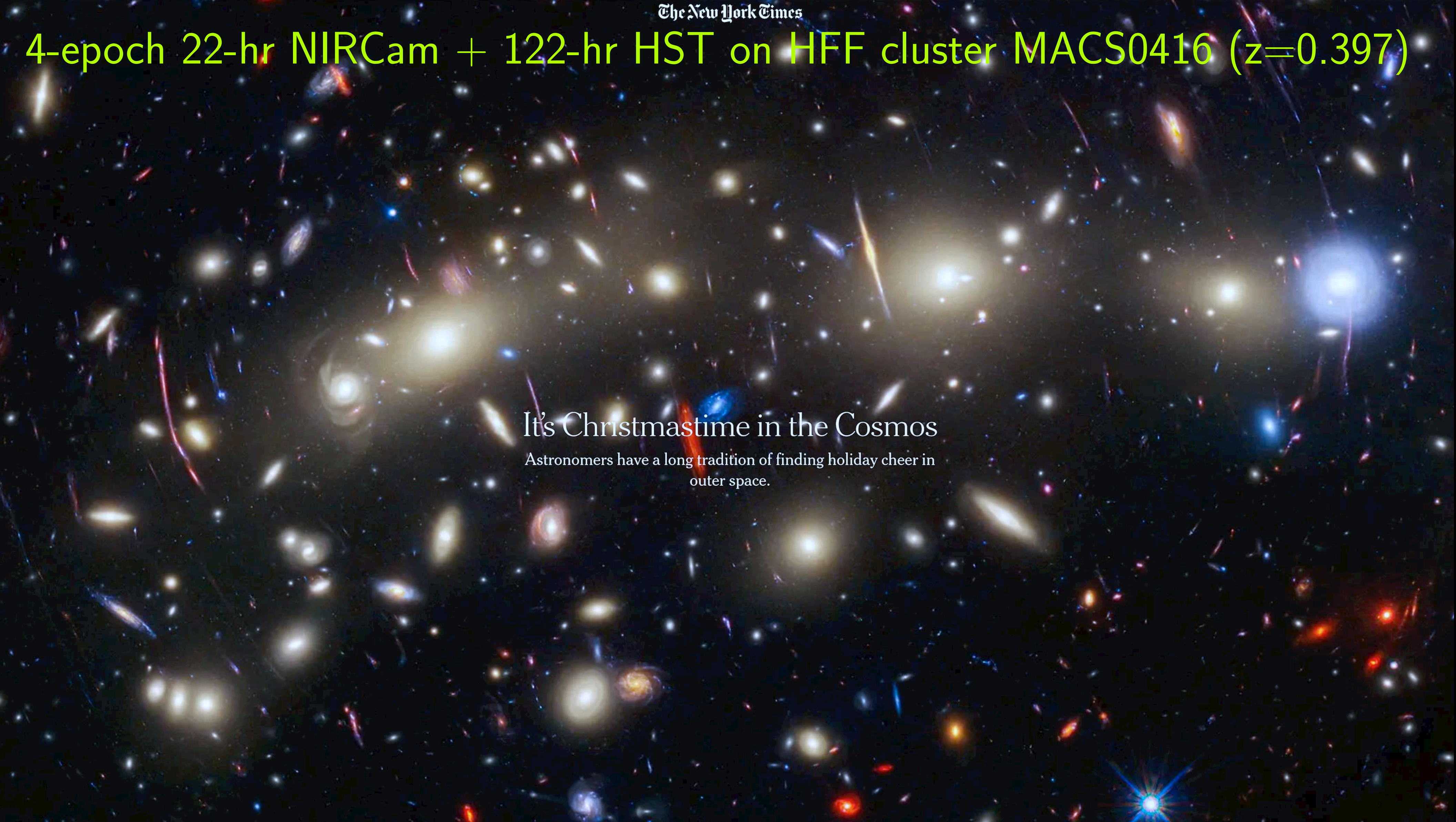
- Spiral overlapping Elliptical VV191: Tracing dust: small grains! (Keel$^+$ 23).
  - 150 Globular Clusters in z=0.0513 Elliptical (Berkheimer$^+$ 2024, ApJ, 964, L29).



- Spiral overlapping Elliptical VV191: Tracing dust: small grains! (Keel$^+$ 23).
- Webb measures GC masses/ages at large distances! (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)!

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

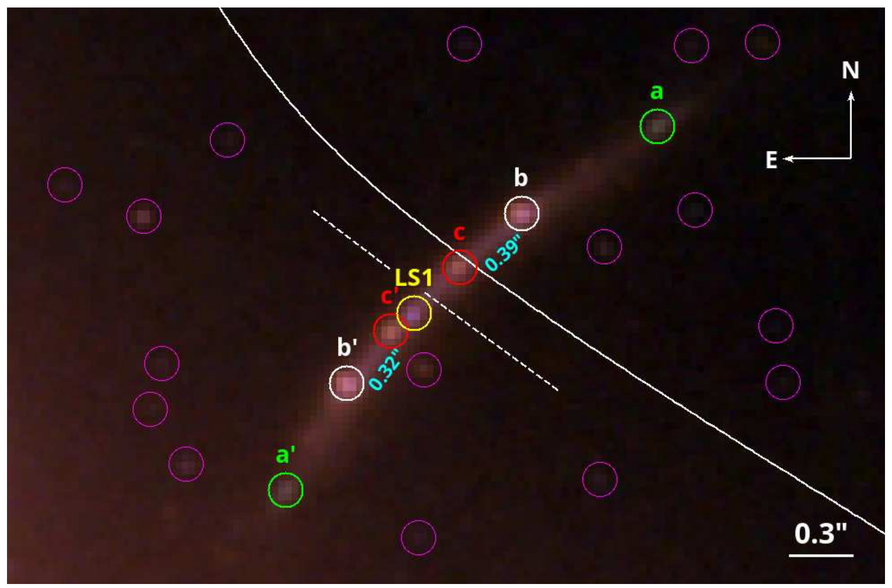


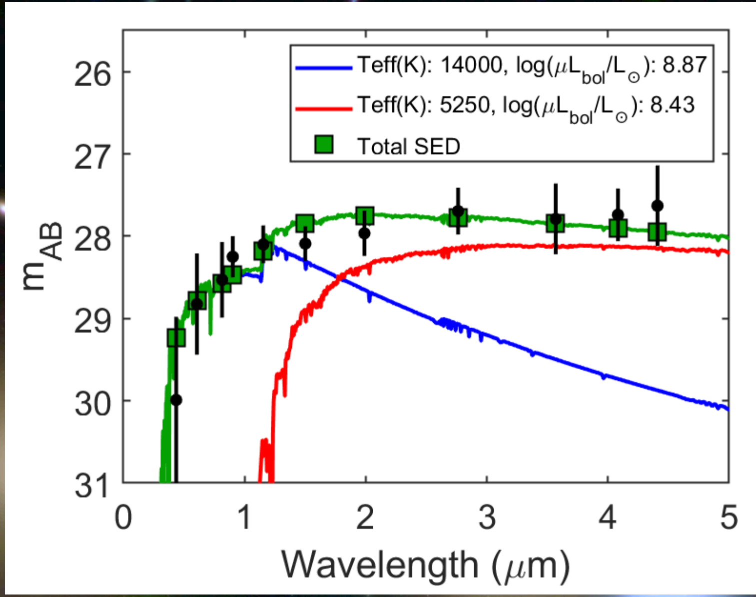
12 new caustic transits at $z \simeq 1$–2 from 4 epochs! (Yan, H.+, 2023, ApJS, 269, 42)

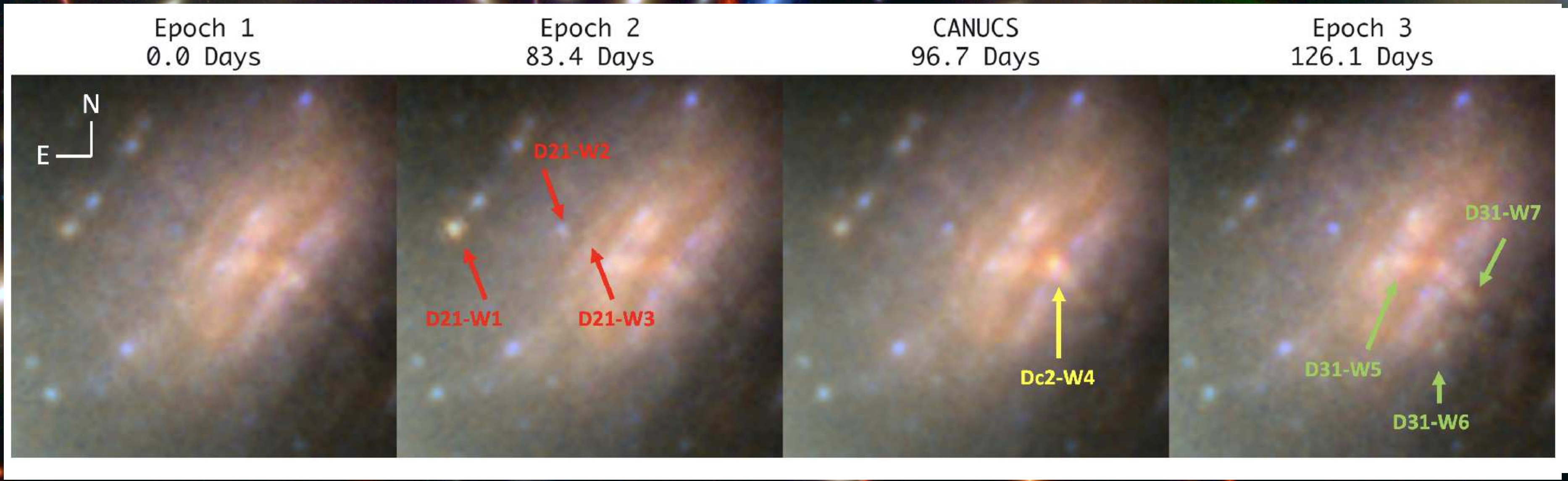
Extremely magnified binary star at $z=2.091$! (Diego, J.+, 2023, A&A 679, A31)

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?





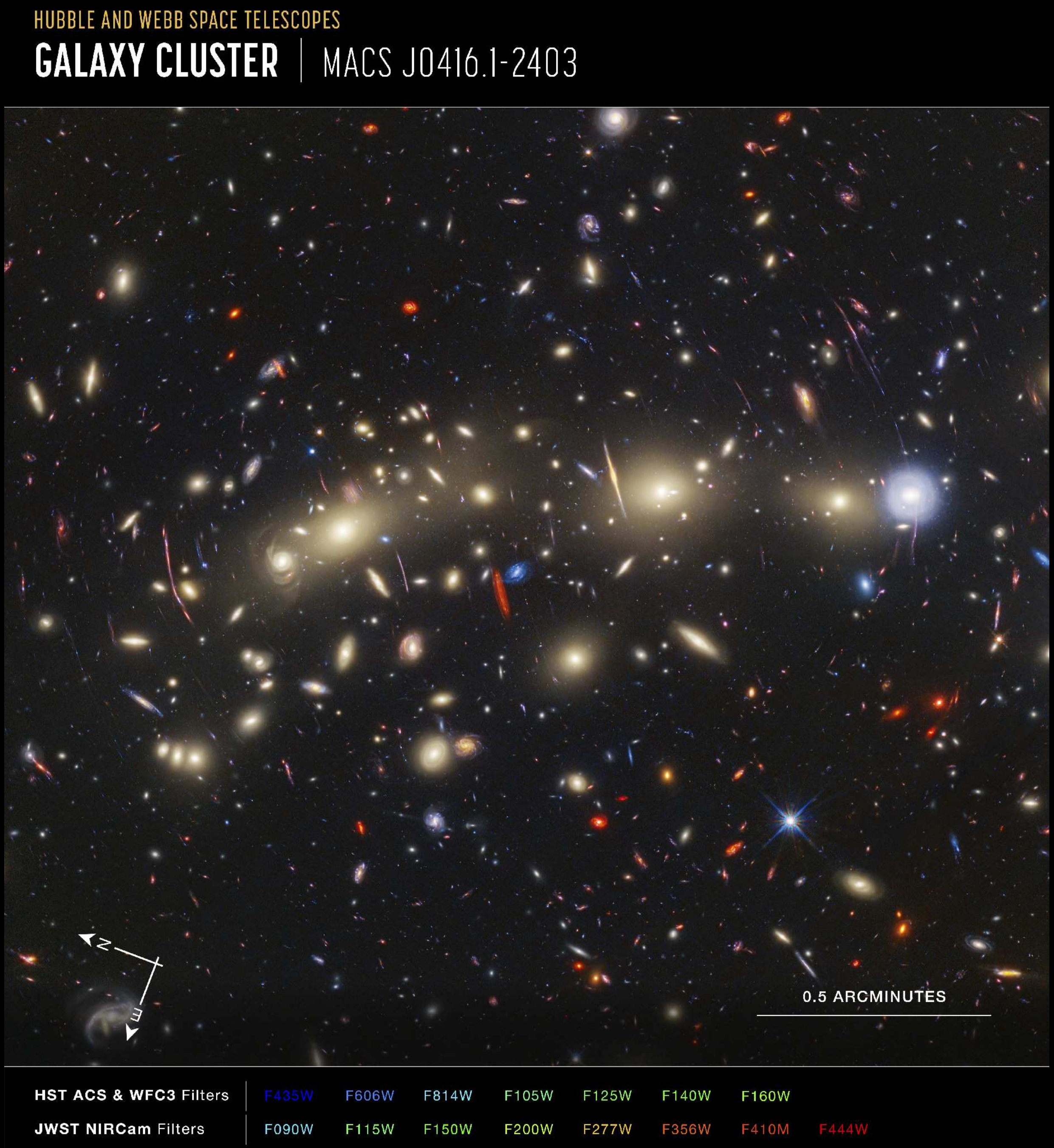


Yan, H.$^+$ (2023, ApJS, 269, 42): 12 new caustic transits at z$\simeq$1–2 from 4 epochs!

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

$\Longrightarrow$ Regular monitoring of several clusters can see stars at z$\gtrsim$1 directly!

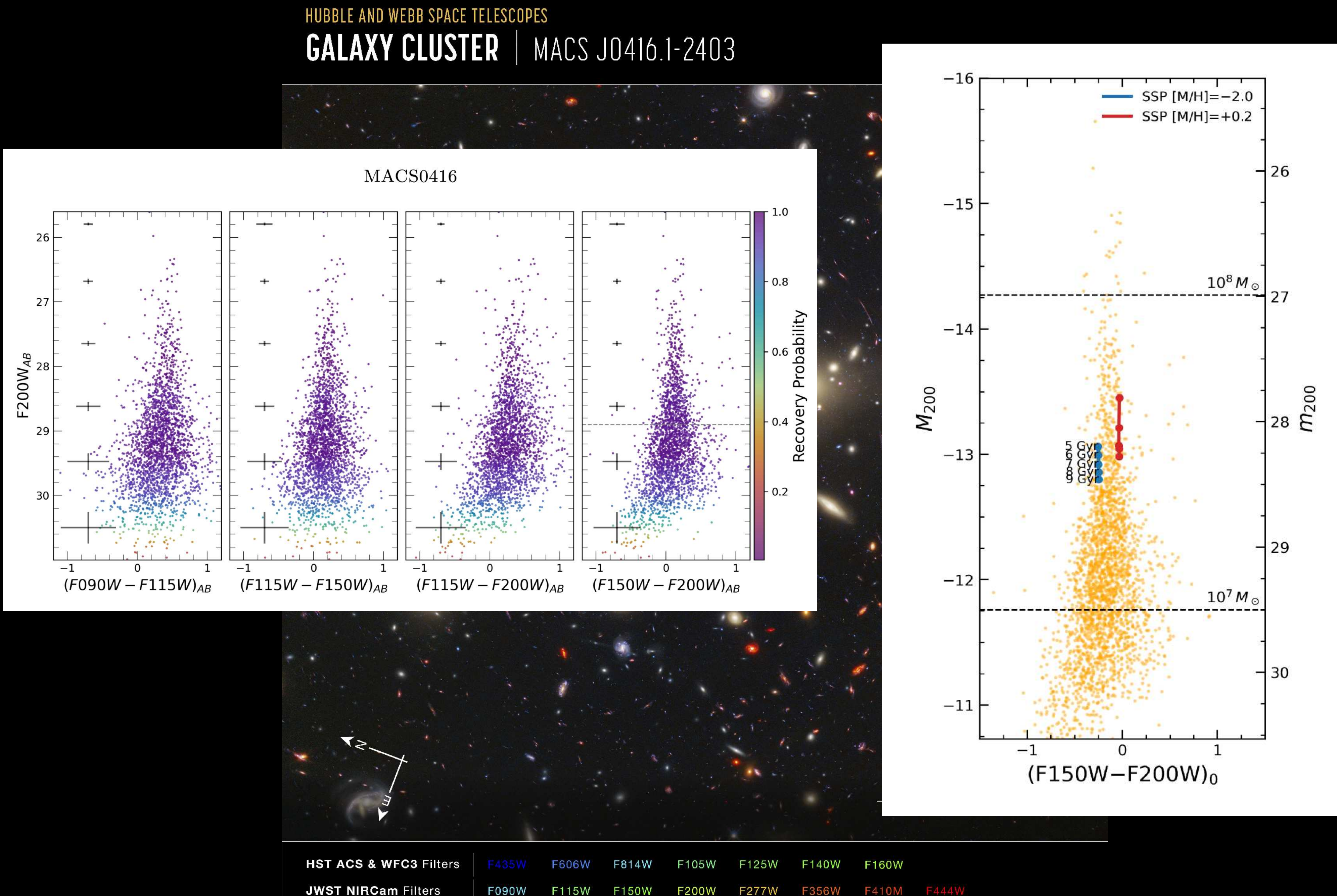
- With magn$\simeq$1000-4000, many have spectra of binary stars at z$\simeq$1–2!



122 hr HST + 22 hr JWST on Frontier Field cluster MACS0416 (4.3 Blyr)

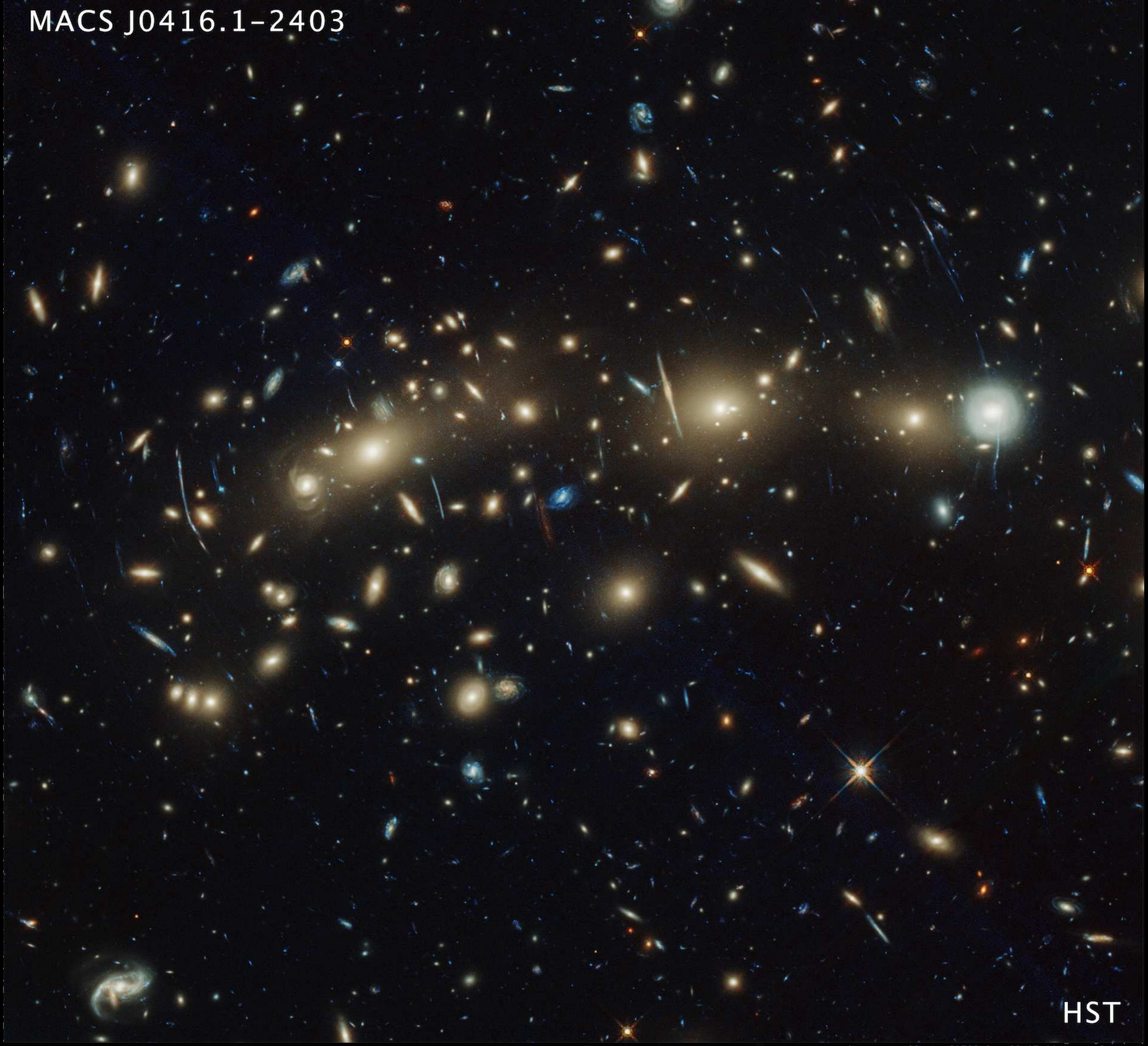
- The power of Two Telescopes: Webb collects 6× more light than Hubble!

NASA press release for Nov. 9, 2023: https://webbtelescope.org/contents/news-releases/2023/news-2023-146

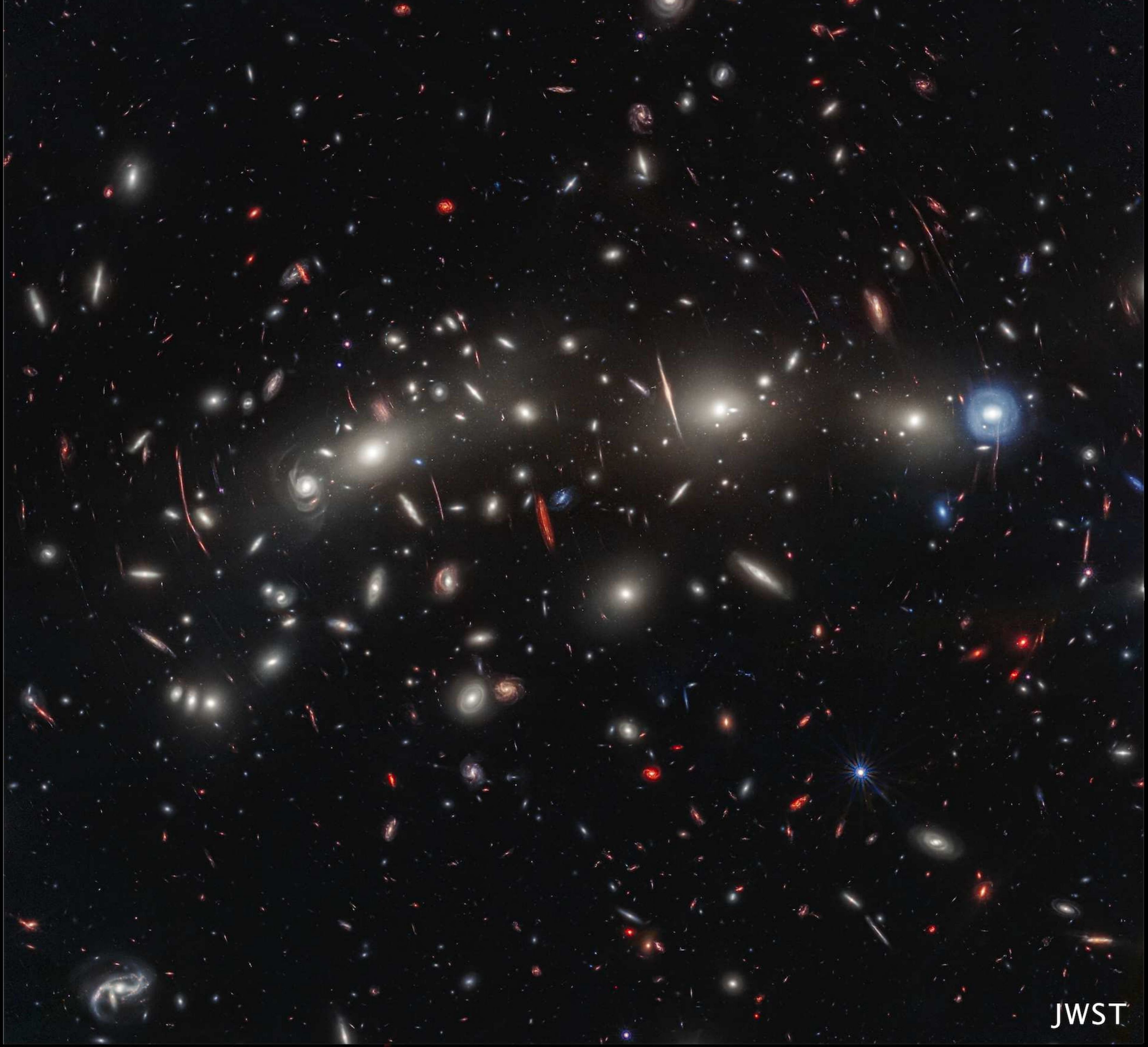


122 hr HST + 22 hr JWST on Frontier Field cluster MACS0416 (4.3 Blyr)

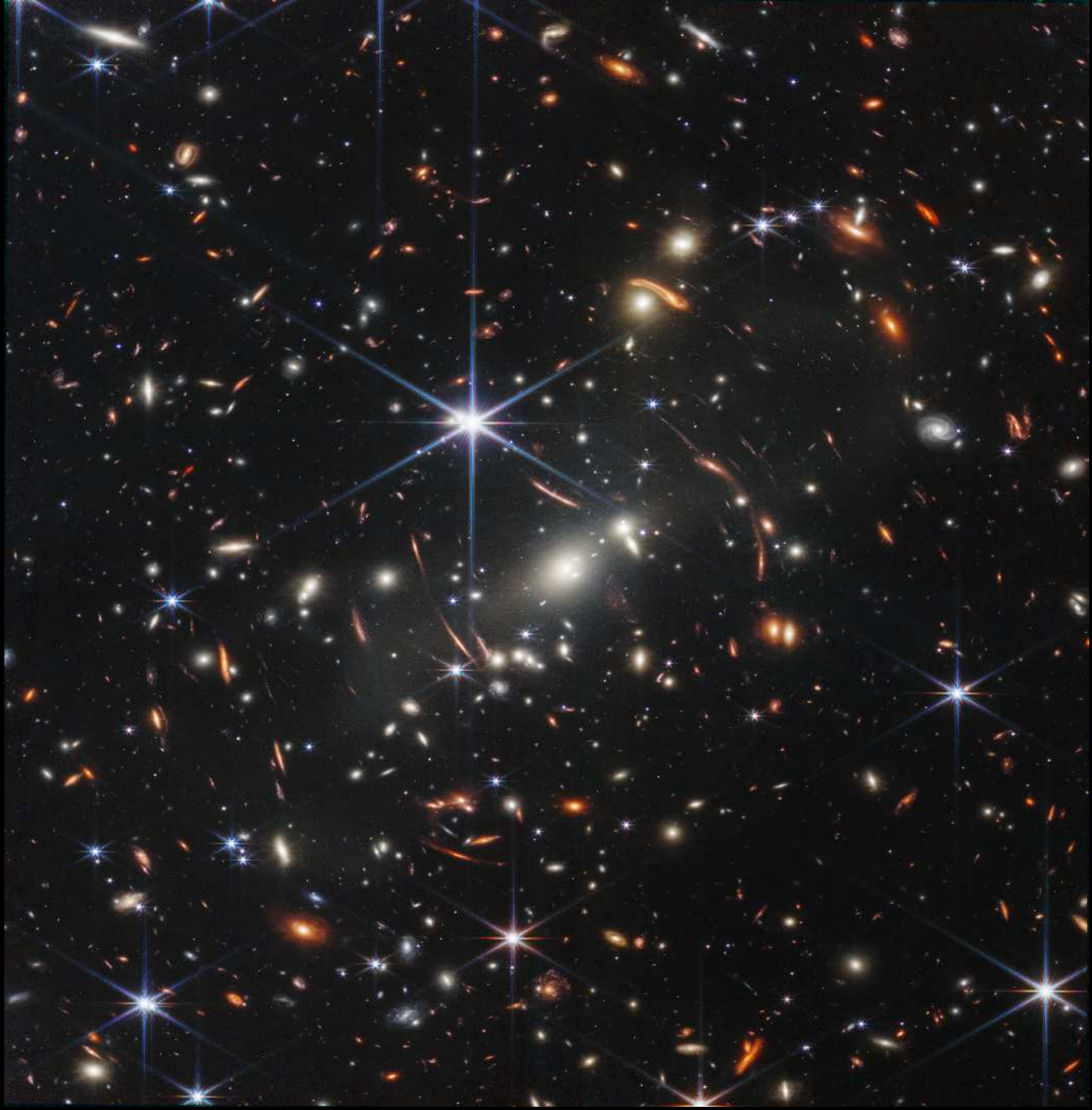
- 2900 Globular clusters in z=0.397 cluster MACS0416 (Berkheimer+ astro-ph/2508.03883)
  - Webb is measuring GC masses/ages at cosmological distances!



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

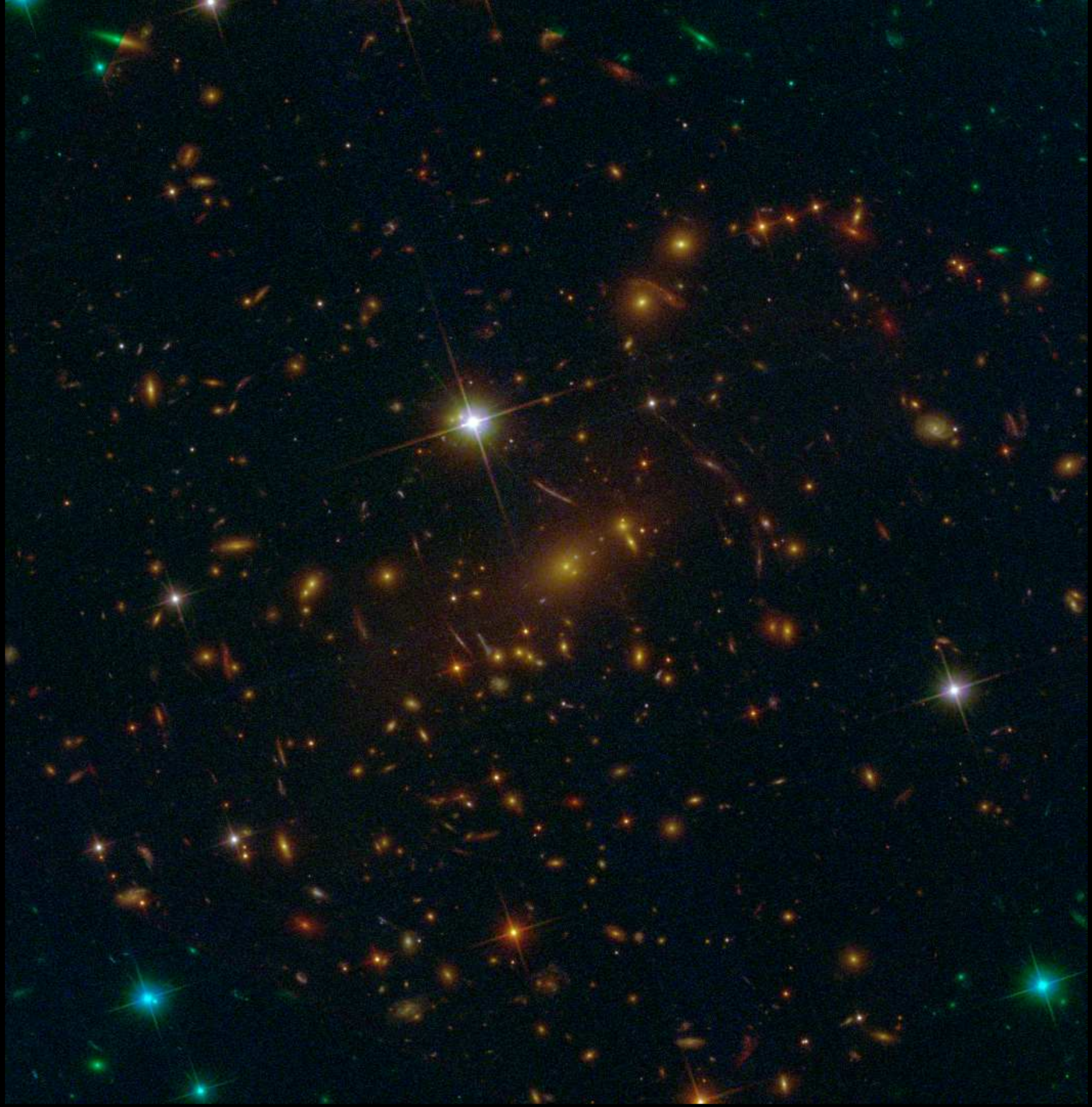


22 hrs JWST on Hubble Frontier Field cluster MACS0416 (z=0.397; 4.3 Blyr)



July 11, 2022: 12-hr Webb Deep Field on galaxy cluster SMACS 0723

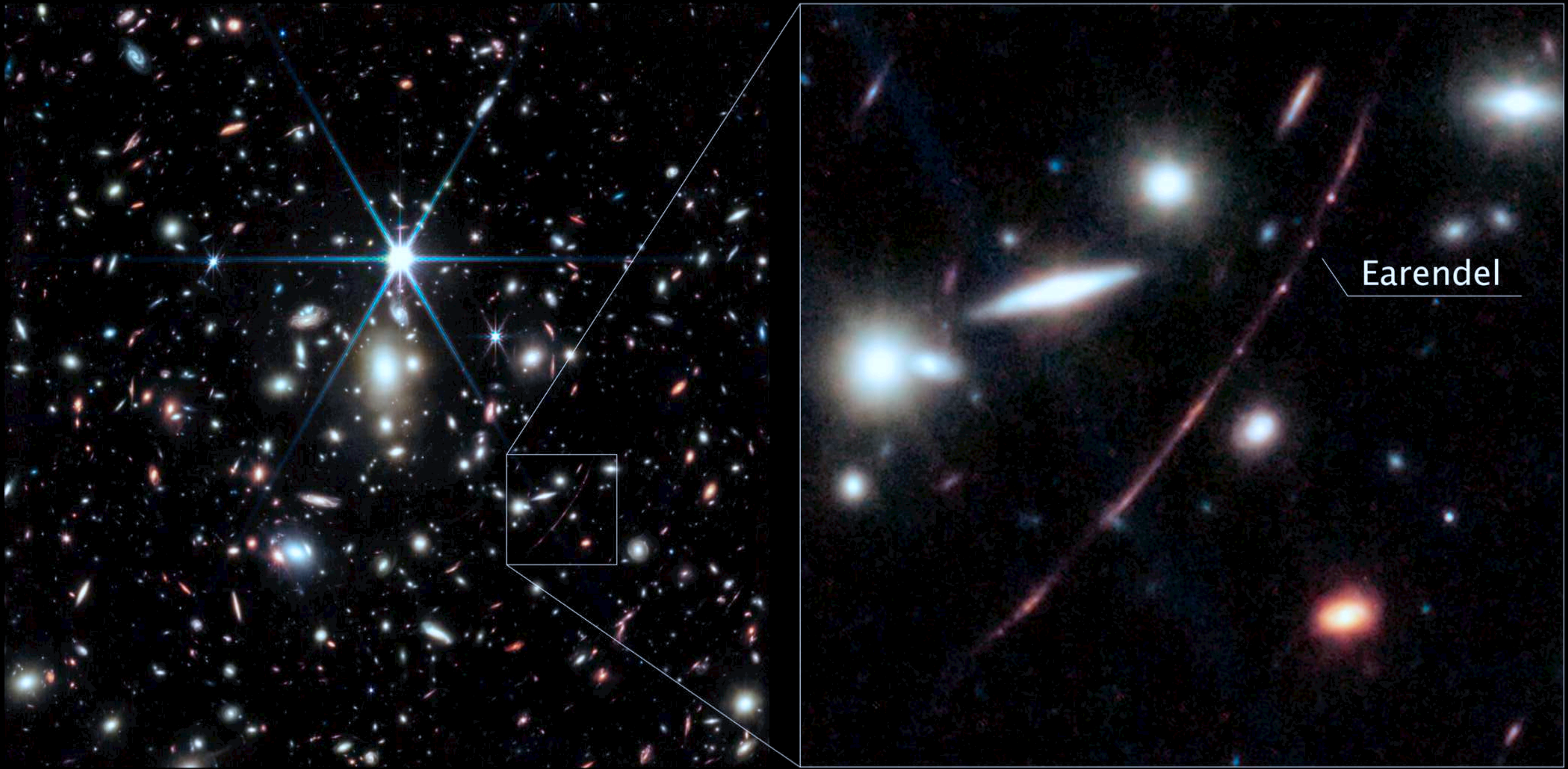
- Cluster galaxies already are $\sim$9 Byrs old, seen at 4.5 Blyr distance!



Hubble image of SMACS 0723: not the same depth and breadth as Webb!

- Cluster 3×older than the Earth today: we are cosmic late bloomers!

Cluster MACS0647 triply lensed a galaxy 0.4 Byrs after BB! (Hsiao, Coe^{+} 22)



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

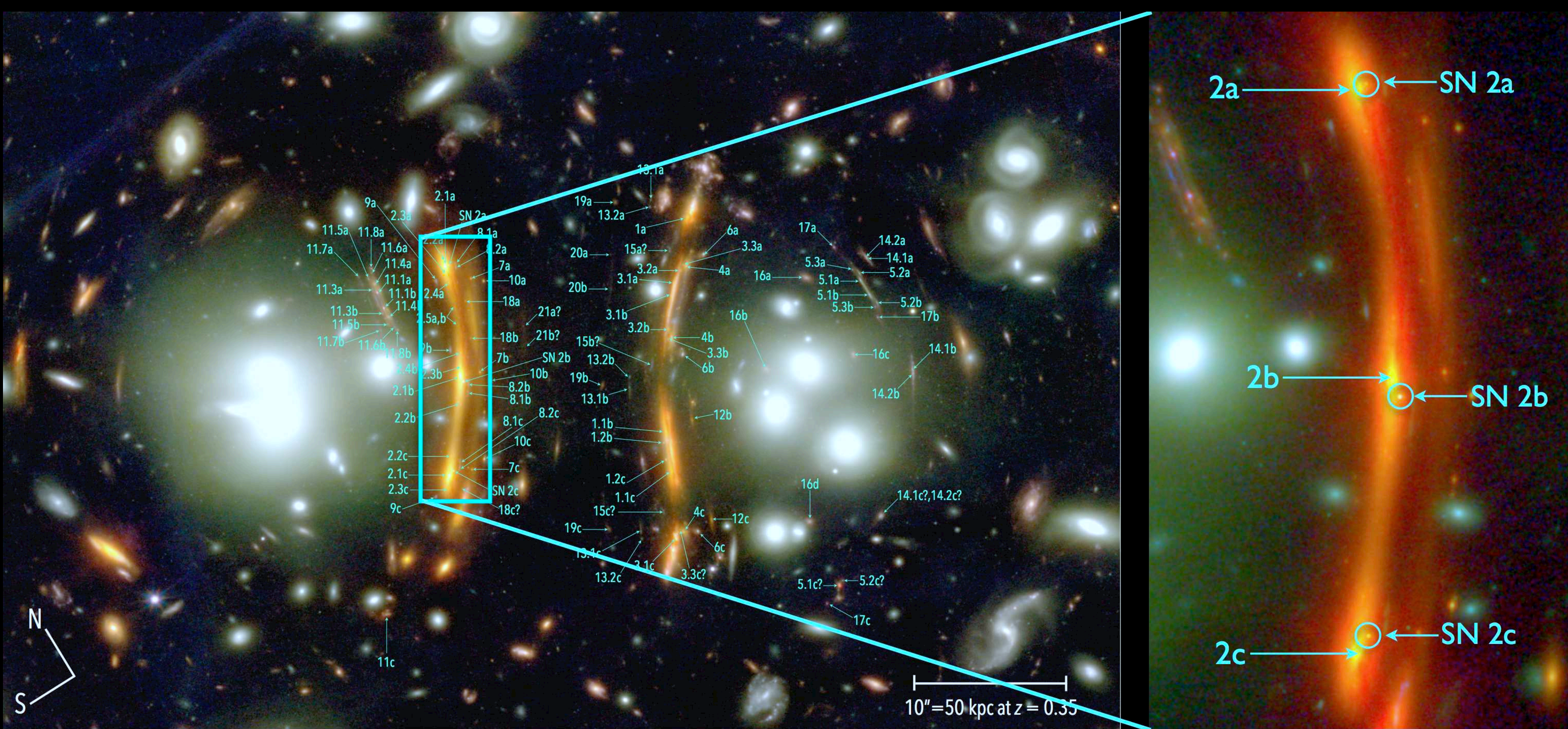
• Earendel: a highly magnified $\mu \sim 9000$ (double-)star seen in the first billion years after the Big Bang: the most distant star ever observed directly!

Light-paths are straight in 4D-curved space-time !

(Welch, B., Coe, D., et al. 2022, ApJ, 940, L1; astro-ph/2208.09007; — 2022, *Nature*, 603, 815; astro-ph/2209.14866).

JWST image of most luminous far-IR Planck cluster G165 at z=0.35 found: Lensed Supernova Ia at z=1.78 $\longrightarrow$ 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, Agrawal+2025).



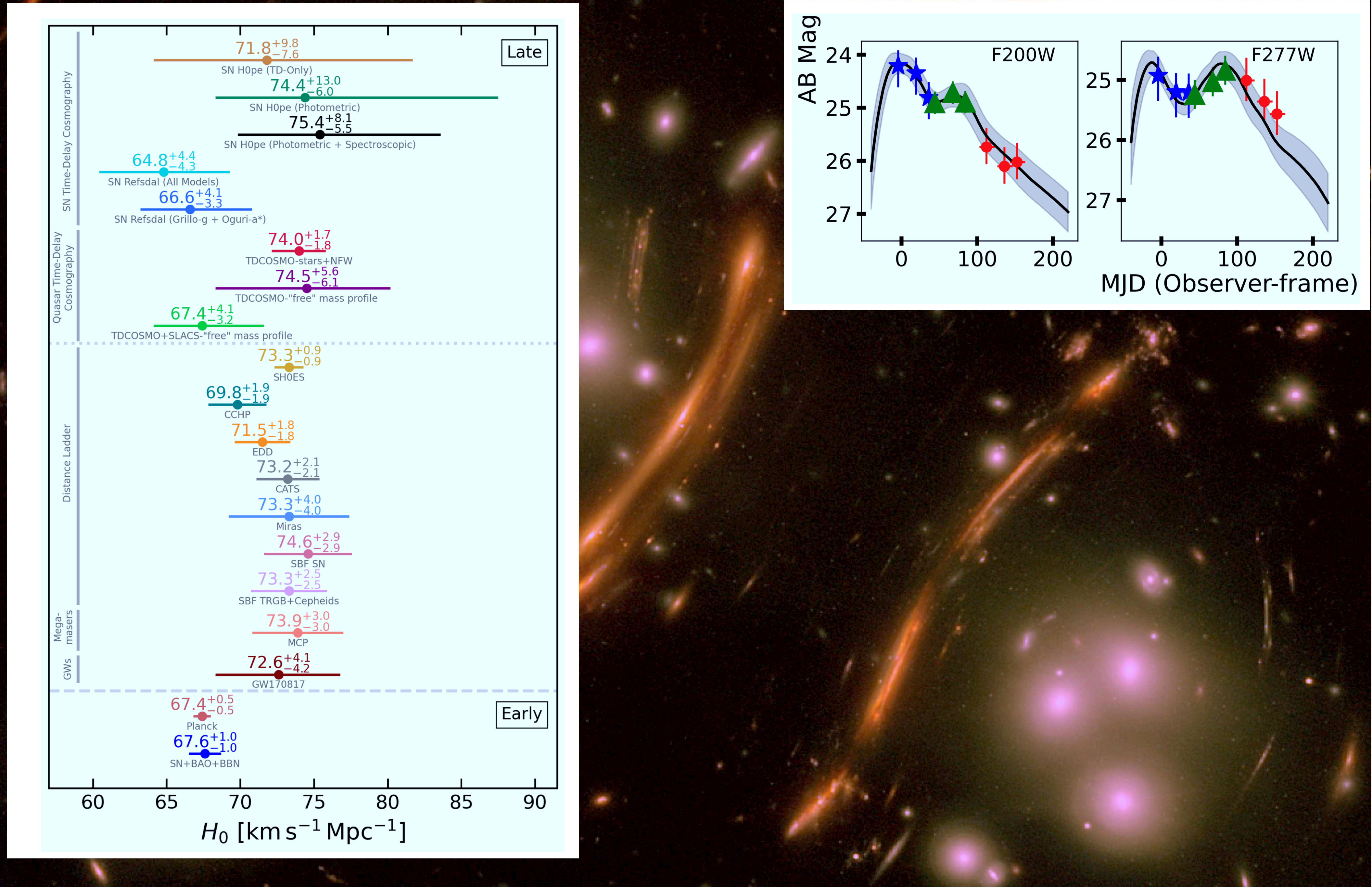
NIRCam in G165 shows: 3 bright point sources parity-flipped w.r.t. Arc-2:

- Clearly a lensed SN Type Ia at z=1.783, seen only 3.6 Byrs after BB!
- 3-epoch 9-point light curve! $\Longrightarrow$ measure $\boldsymbol{H_0}$ constant directly !

(Polletta$^+$ 2023, Frye$^+$ 2024, Chen$^+$ 2024, Kamieneski$^+$ 2024, Pierel$^+$ 2024, Pascale$^+$ 2025).

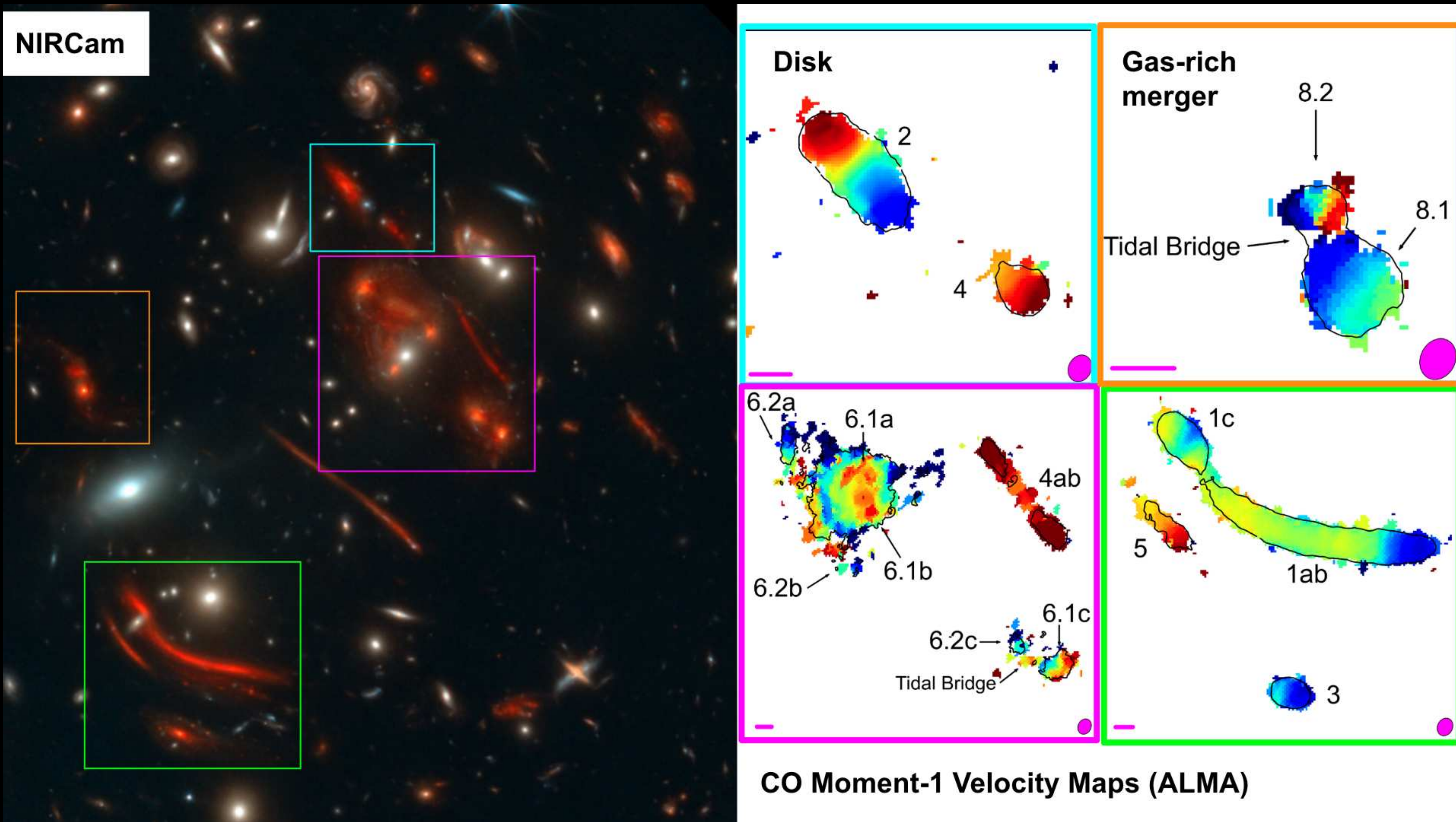
$\longrightarrow$ Regular monitoring of clusters with extreme SF to yield more lensed SNe!

- Total SFR$\simeq$200–350 $M_\odot$/yr predicts $\gtrsim$1 lensed SN/yr (Kamieneski$^+$ arXiv/2404.08058)



Pascale+ (2025, ApJ, 979, 13): Photo & spectro time delay: $H_o = 75.4^{+8.1}_{-5.5}$ (at z=0.35).

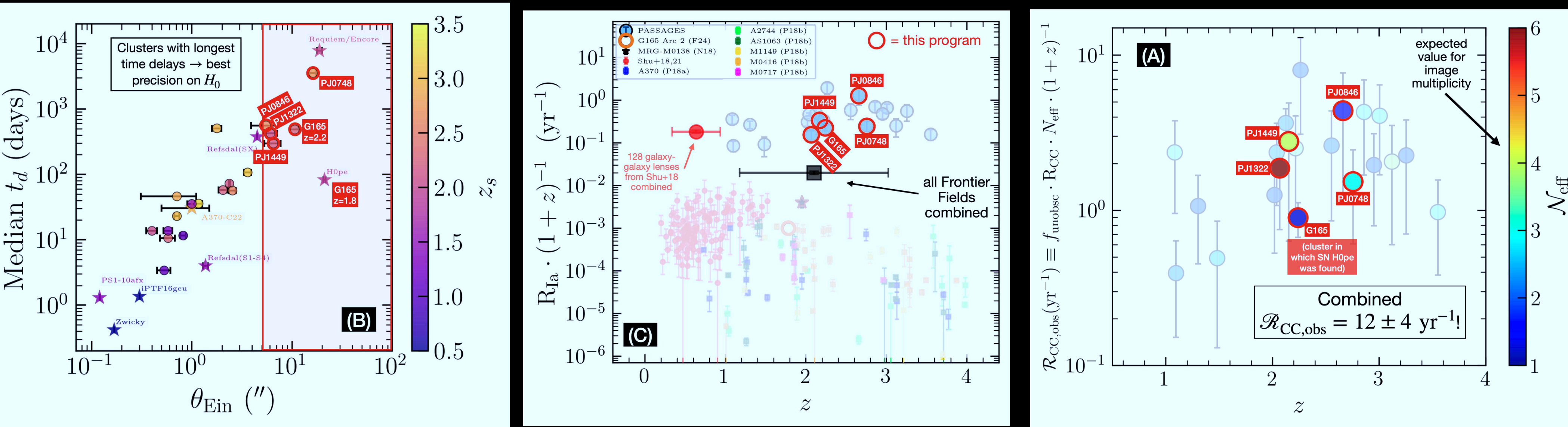
• Monitoring G165 predicts $\gtrsim$1 lensed SN-Ia/yr ! (Kamieneski+ 2024, ApJ, 973, 25)



How to find clusters with highest lensed Supernova rate to improve H_0 ?:

- Use the brightest Planck clusters with regular, merger-driven & chaotic star-formation, as seen by JWST (left) and ALMA velocity maps (right);

(Foo, N. et al. 2025, ApJ, in press, astro-ph/2504.05617; Kamieneski, P. et al. ApJ, submitted, astro-ph/2510.00923)



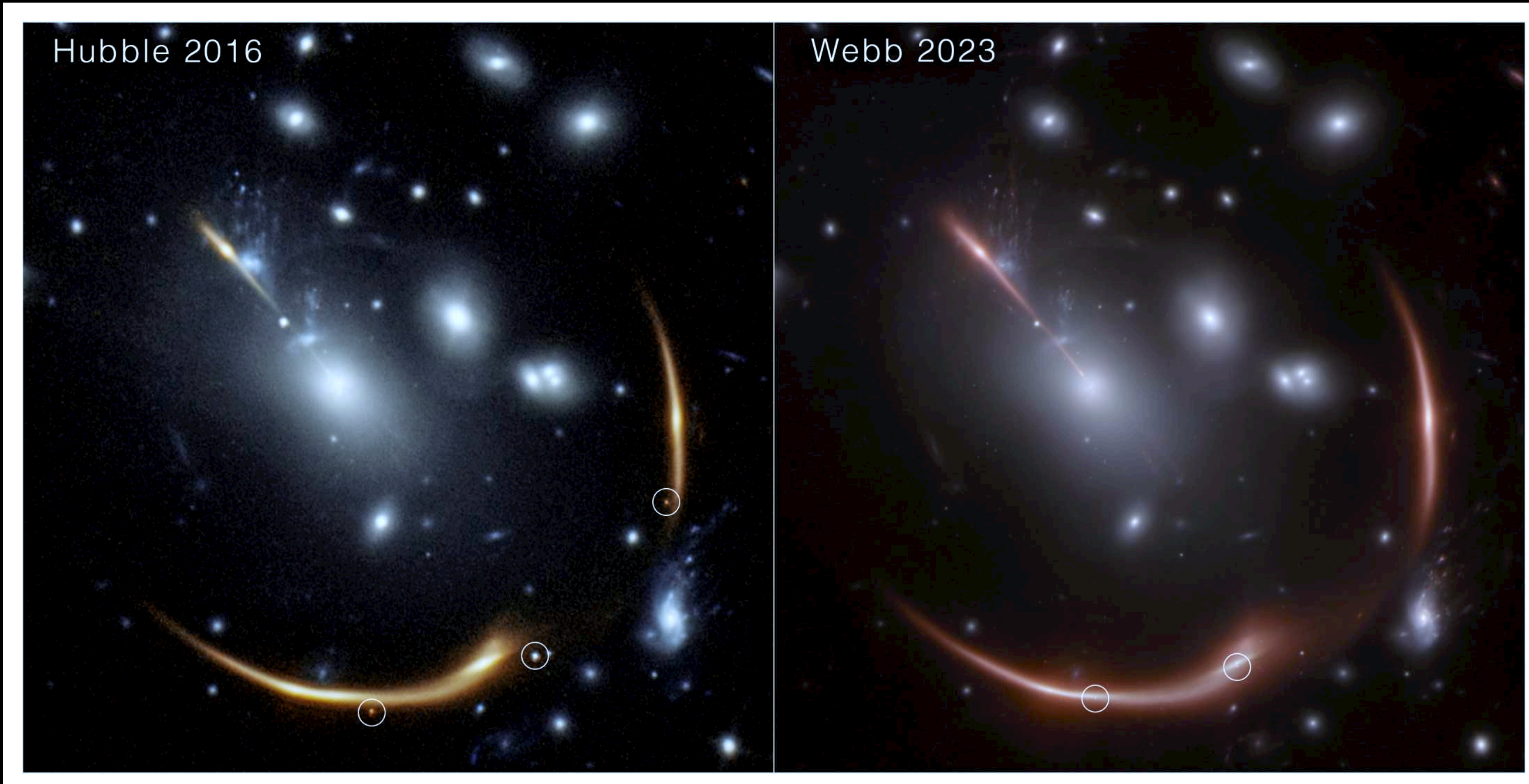
How to find clusters with highest lensed Supernova rate to improve $\boldsymbol{H_0}$?:

• Select the most massive clusters to get the largest Einstein angles and largest relativistic time-delays (within reason);

• Select the brightest Planck clusters with highest SFR at z$\simeq$2–3;

• Observe a few times yearly with JWST to find gravitationally lensed SNe (SN rate ∼0.3–3/year for Type Ia SNe to Core Collapse SNe);

• Measure relativistic time-delays from multiple images, & improve on $\boldsymbol{H_0}$

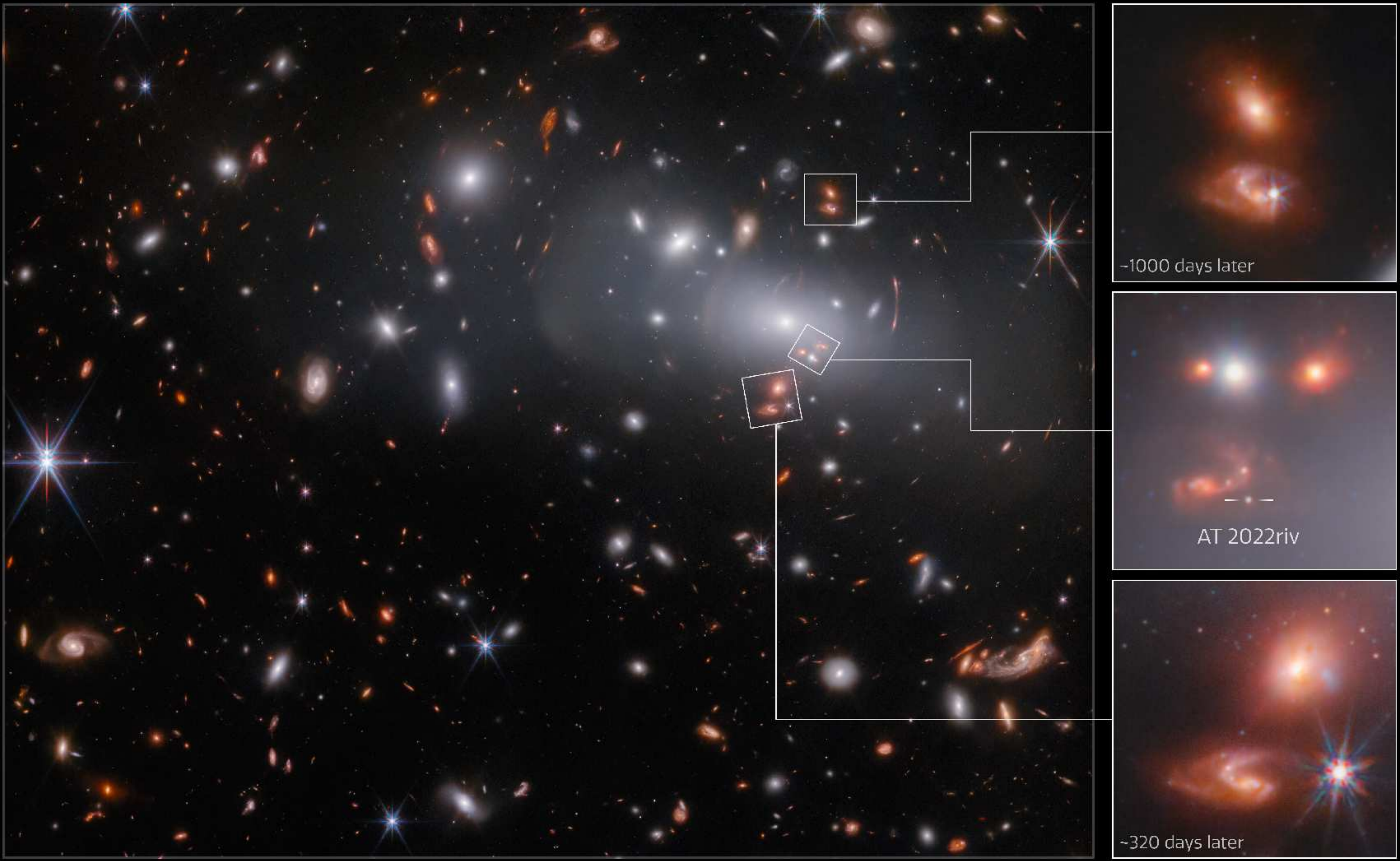


Hubble saw a lensed Supernova Ia behind this galaxy cluster in 2016:

Webb saw more distant lensed Supernova at z=1.9 (age 3.5 Byrs) in 2023!

$\Longrightarrow$ "SN Encore": Lensing is the gift that keeps on giving!

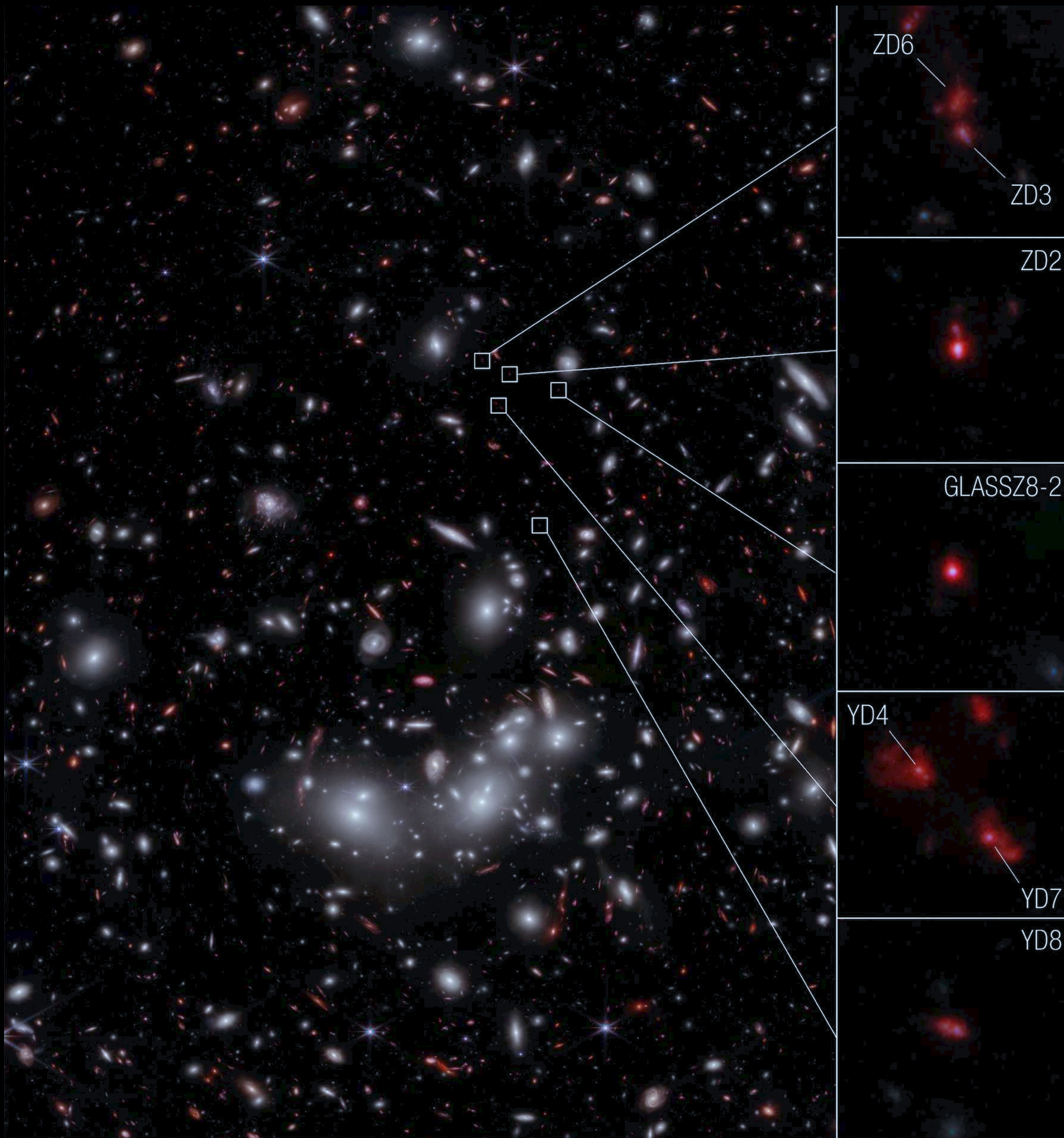
(Dhawan, S., Pierel, J., et al. 2024, MNRAS, 535, 2939; astro-ph/2407.16492).



Cluster RXJ2129 with triply lensed Supernova at 2.9 billion lyrs distance

- SN only seen in middle panel sampling the earliest observation

https://esawebb.org/images/potm2302a/



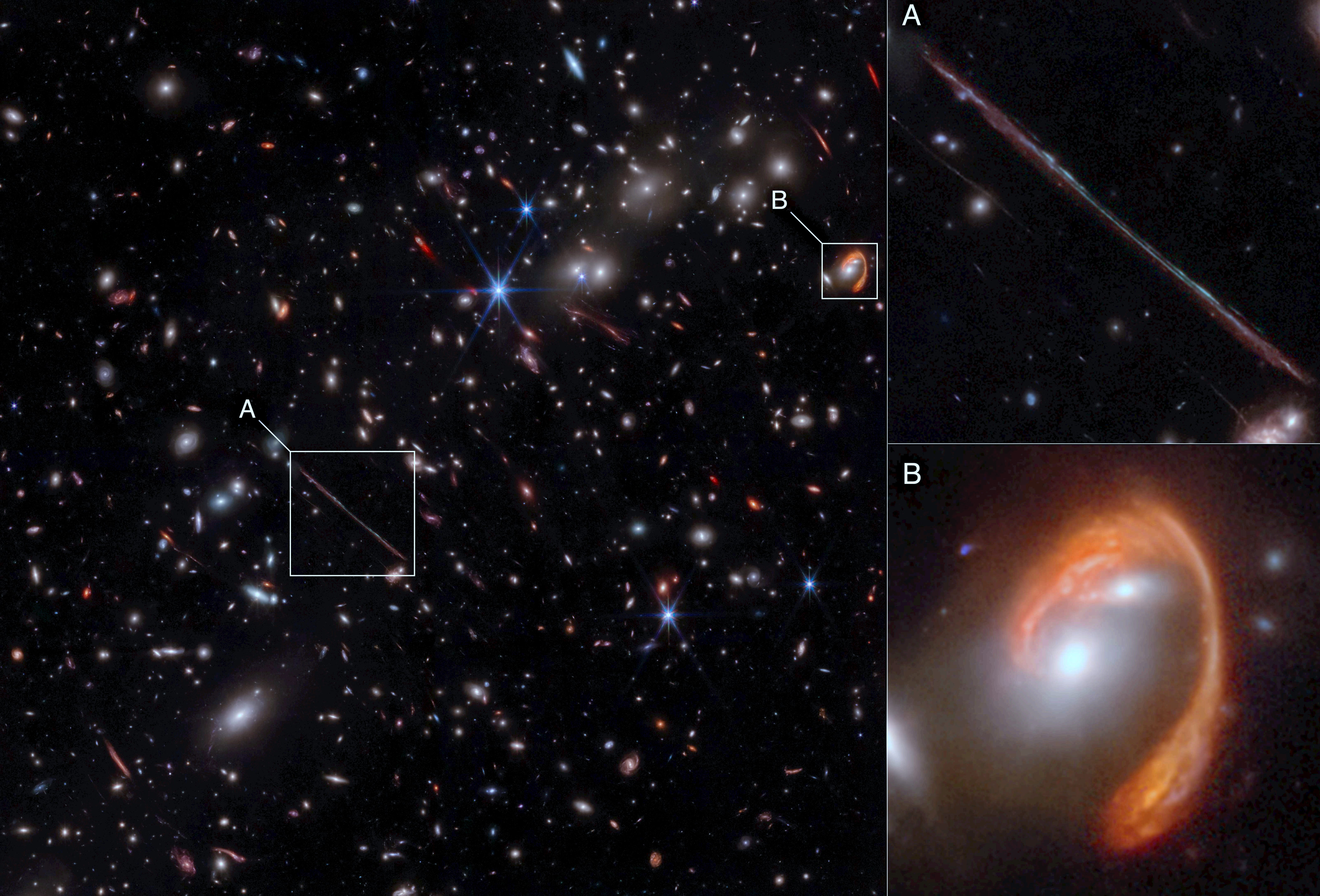
Massive lensing cluster Abell 2744:

Over $\mathbf{10^{15}}$ solar masses seen 4 billion years ago:

its gravity lenses 5 young galaxies at redshift z≃7.88,

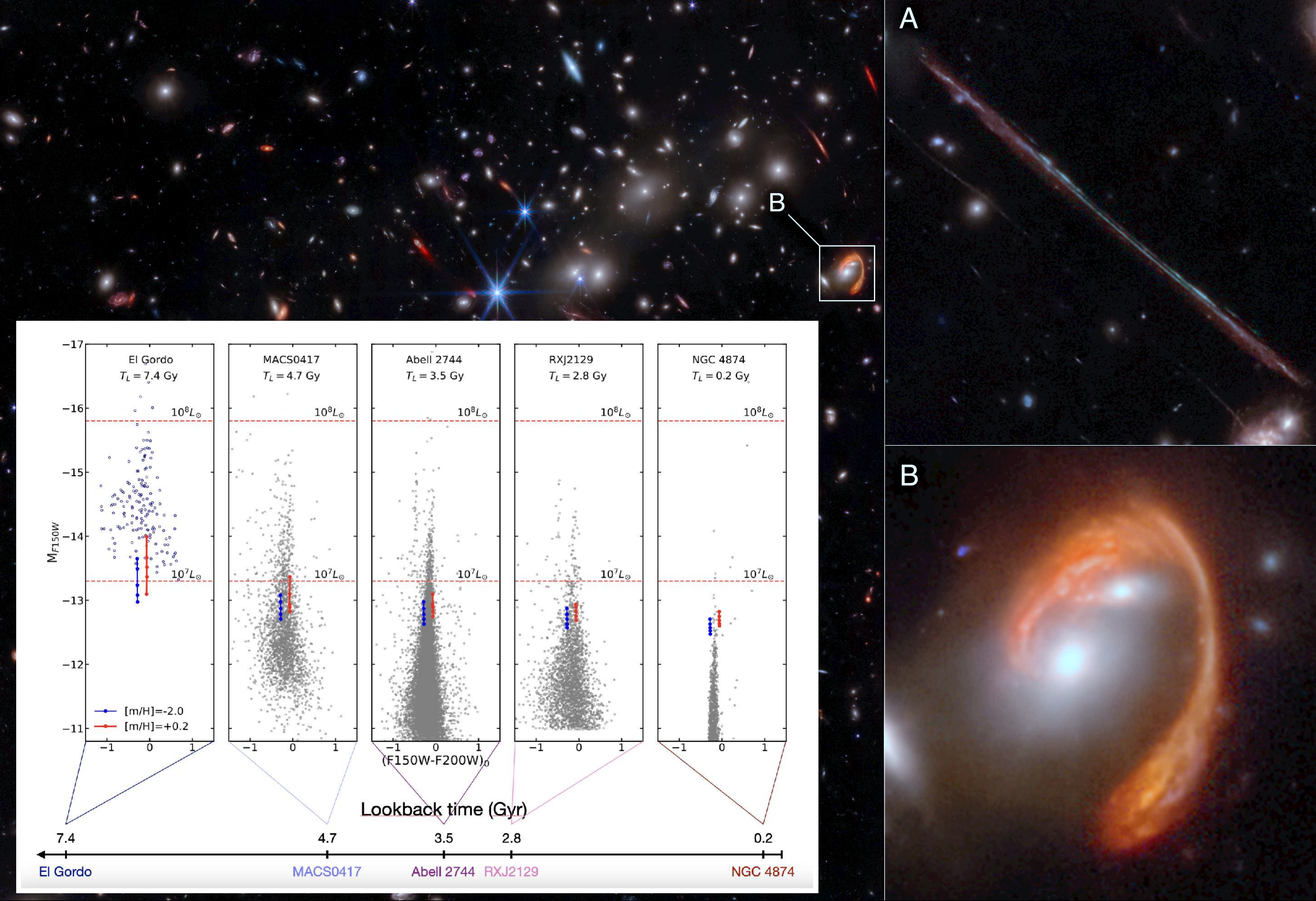
i.e., magnifying objects seen 13 billion years ago.

Webb is looking back to 650 million years after Big Bang!



Monster cluster El Gordo distorts distant galaxies into “pencils” (Diego^{+}22)

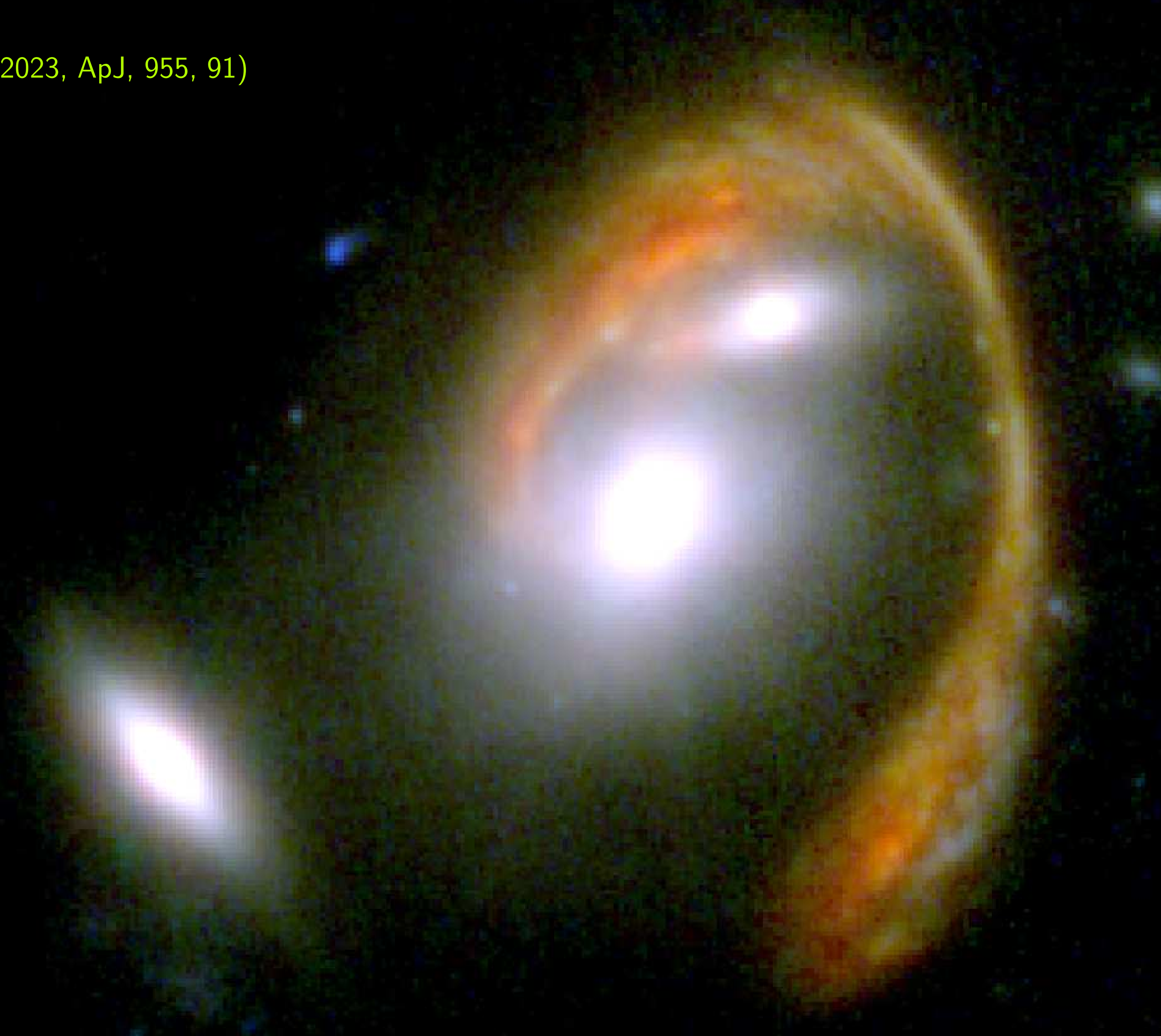
https://news.asu.edu/20230801-jwsts-gravitational-lens-reveals-distant-objects-behind-el-gordo-galaxy-cluster



- Webb yields direct Globular Cluster ages/masses over half the Hubble time!

(Harris, W., Reina-Campos, M., et al. 2025, ApJ, 991, 7; astro-ph/2508.12862)

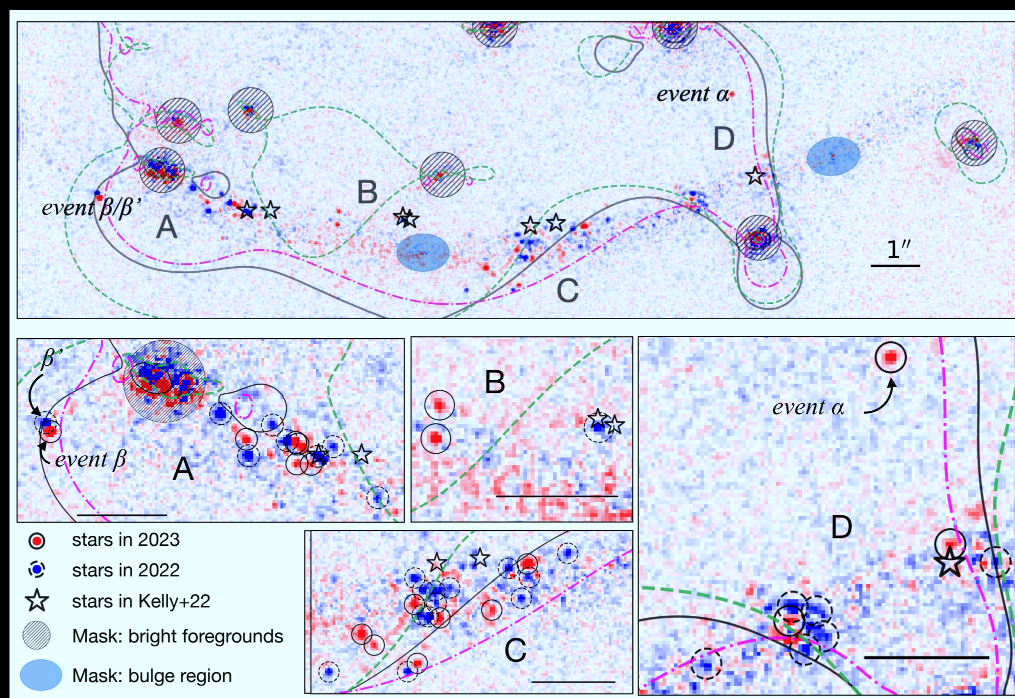
(Kamieneski[+] 2023, ApJ, 955, 91)



and El Gordo makes a super-lens “El Anzuelo” — Einstein’s fishhook!

https://webbtelescope.org/contents/news-releases/2023/news-2023-119

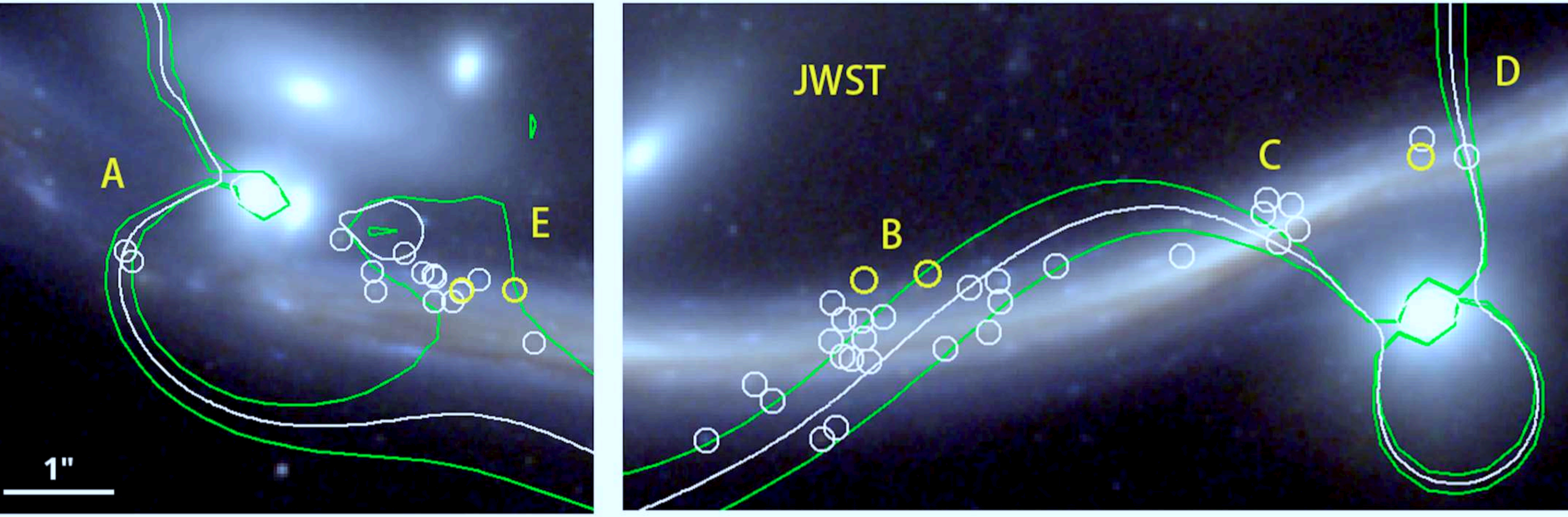
https://news.asu.edu/20230802-global-engagement-asu-webb-telescope-einstein-werner-salinger-holocaust

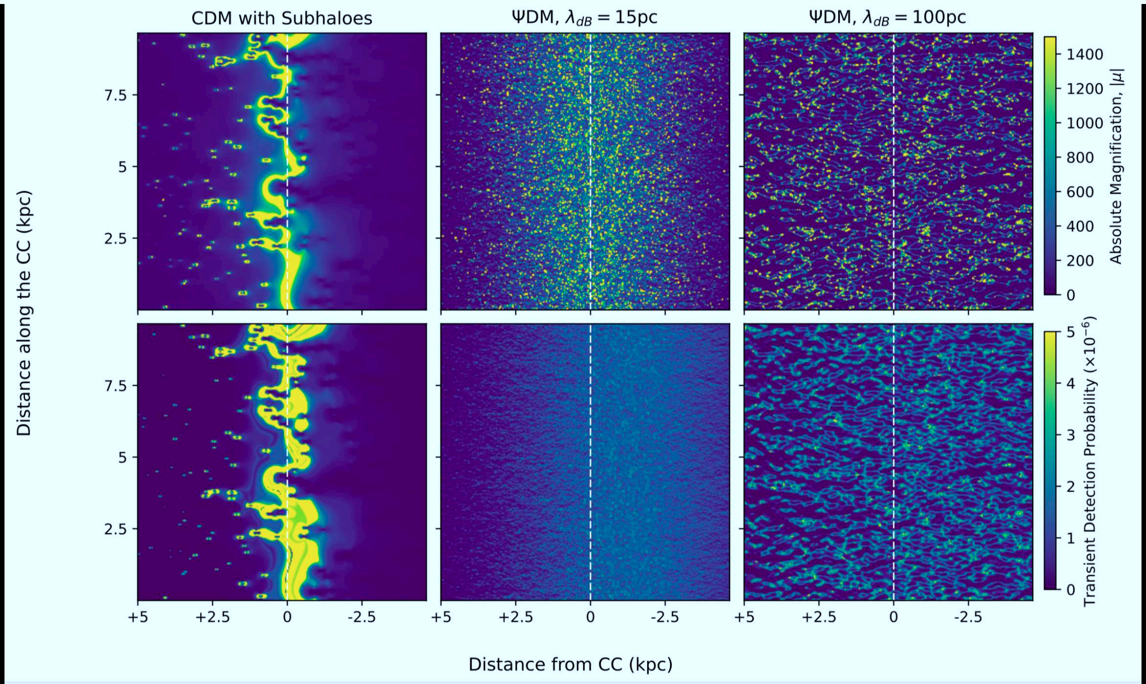


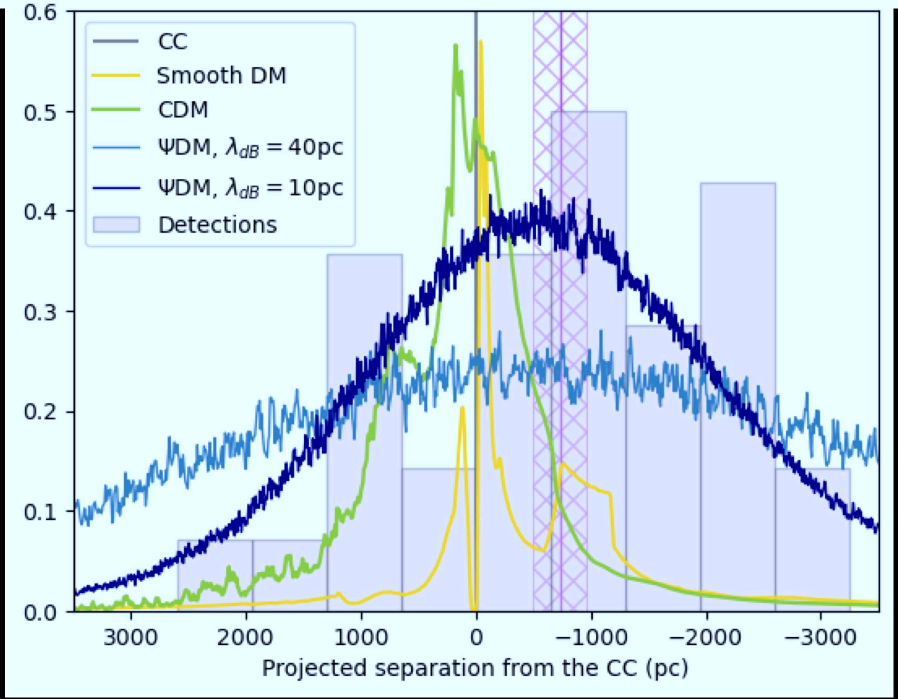
Abell 370 Dragon's arc: 44 individual caustic-transiting stars at z=0.73!

$\rightarrow$ Detect stars at z$\gtrsim$0.7 directly, going across infinity lines! (Y. Fudamoto^{+}, *Nat. Astr. 9, 428*).

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







A370 z=0.73 caustic transits asymmetric around critical curve (2405.19422)

Explained better by ΨDM than CDM: $\sim 10^{-22}$ eV particle with $\lambda_{dB} \sim 10$ pc

A smooth filament origin for distant prolate galaxies seen by JWST and Hubble.

Alvaro Pozo[1,*], Tom Broadhurst[1,2,3], Razieh Emami[4], Philip Mocz[5], Mark Vogelsberger[6], Lars Hernquist[4], Christopher J. Conselice[7], Hoang Nhan Luu[1], George F. Smoot[1,8,9,10], and Rogier Windhorst[11]

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[*]alvaro.pozolarrocha@bizkaia.eu

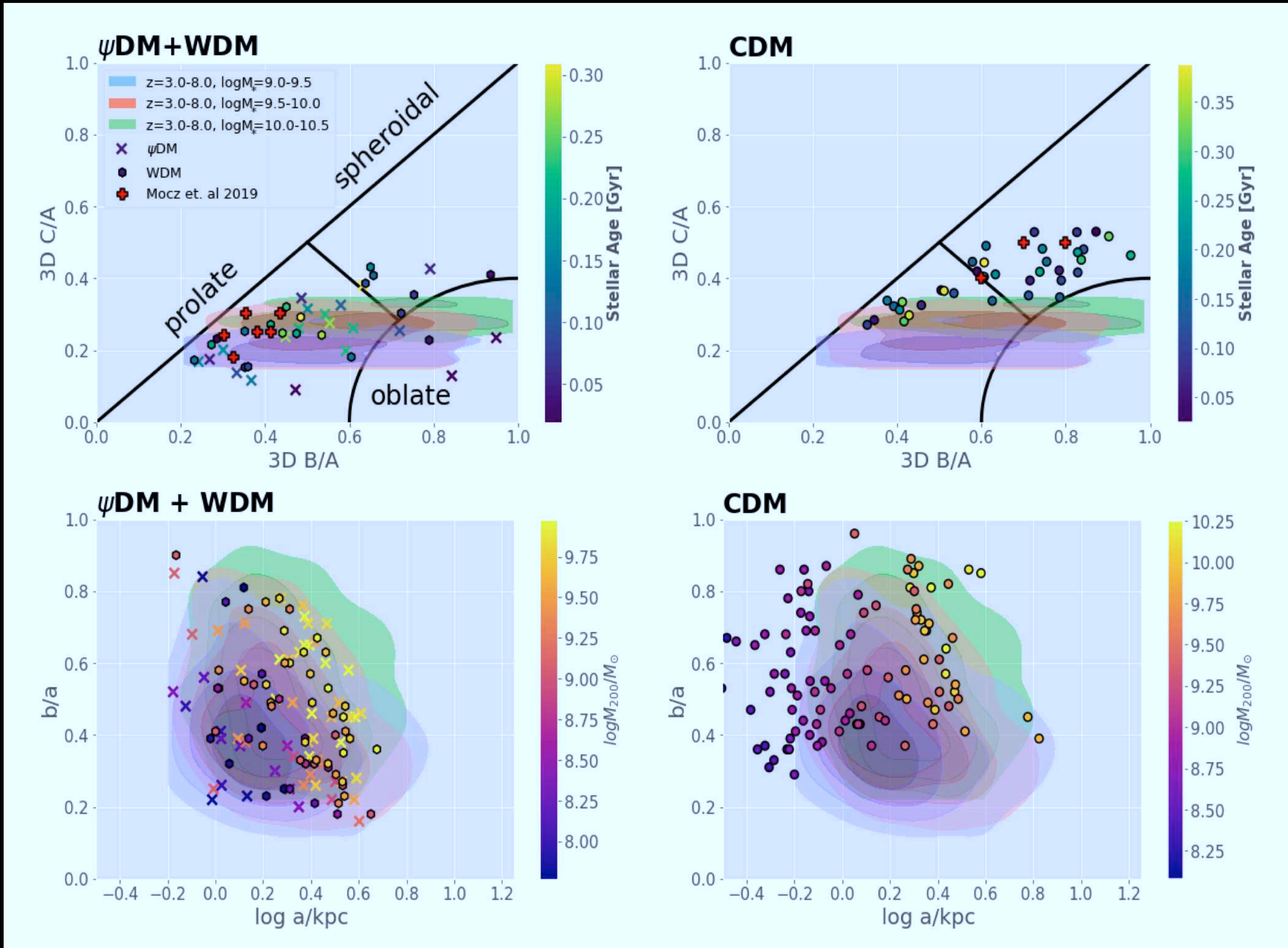
ABSTRACT

We compare the abundance of prolate-shaped galaxies reported in deep surveys with the predicted stellar morphology of young galaxies in high resolution hydrodynamical simulations of Cold Dark Matter (CDM), Warm Dark Matter (WDM) and Wave/Fuzzy Dark Matter, ψDM. For both CDM and WDM we have sufficient volume, $10^3 Mpc^3$, to yield galaxies with stellar masses over $> 10^9 M_\odot$ at $z > 2$, allowing comparison with the CEERS and CANDELS surveys. We find the observed elongation of young galaxies is well matched by WDM, during the first $\simeq$ 500Myr when material steadily accretes along smooth filaments, with little dependence on stellar mass over the range $10^{8-10} M_\odot$ in our simulations. The dark matter halos of WDM and ψDM both show prolate elongation, similar to that of the stars, indicating a shared, triaxial equilibrium. This contrasts with CDM where the early stellar morphology is mainly spheroidal, formed from fragmented filaments with frequent merging, resulting in modest triaxiality. For CDM, several visible subhalos are typically predicted to orbit within the virial radius of each galaxy, whereas sub-halos are absent for WDM and ψDM, as early merging is rare. Long, smooth filaments may be traced with JWST by alignment of neighbouring elongated galaxies on a predicted scale of $\simeq$ 150 kpc, set by the DM particle mass.

A. Pozo et al. 2025, Nature Astronomy, in press:
JWST & HST galaxies often elongated (prolate) $\Longleftarrow$ smooth WDM filaments

A. Pozo et al. 2025, Nature Astronomy, in press:

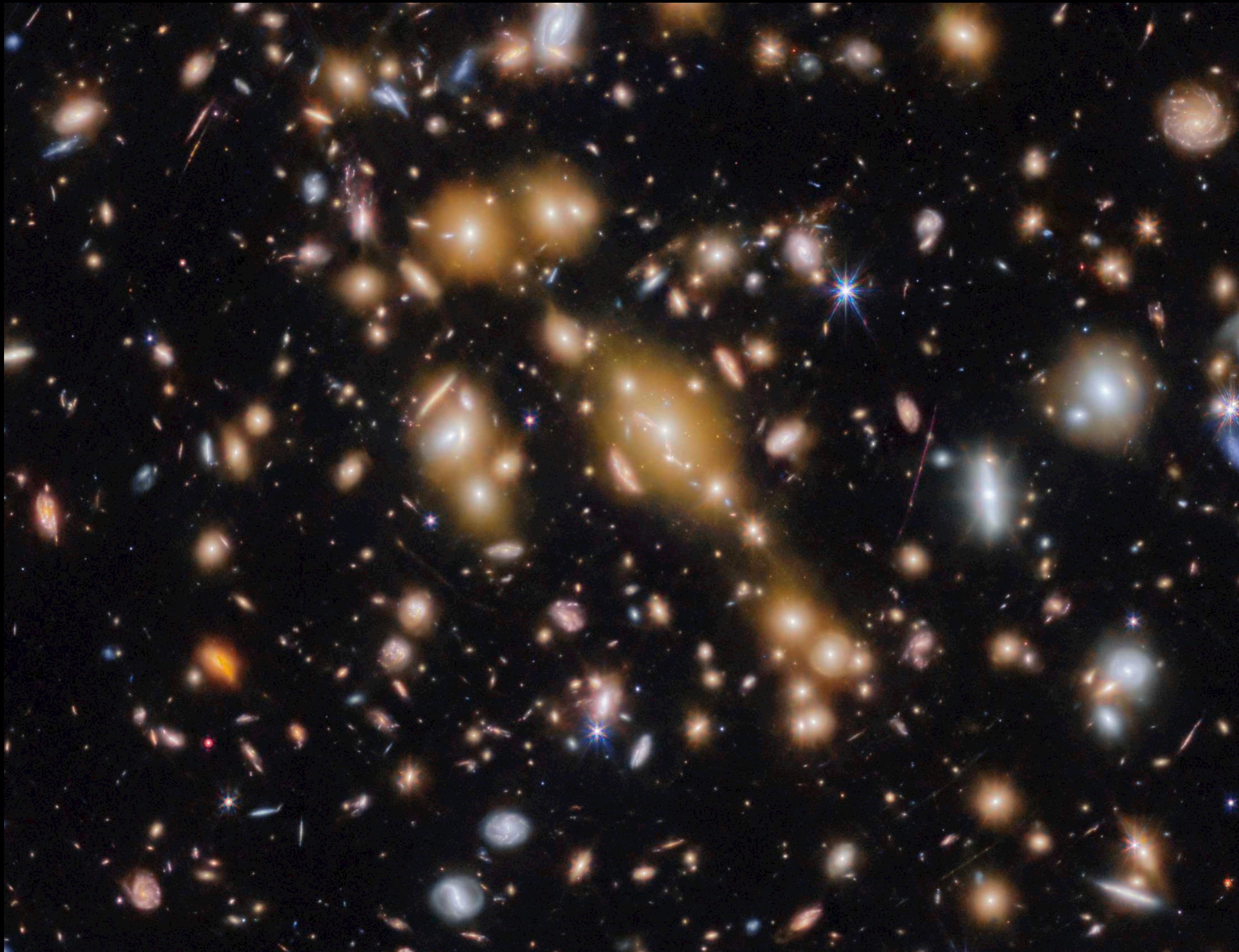
Prolate JWST and HST morphology better explained by WDM than CDM !



A. Pozo et al. 2025, Nature Astronomy, in press:

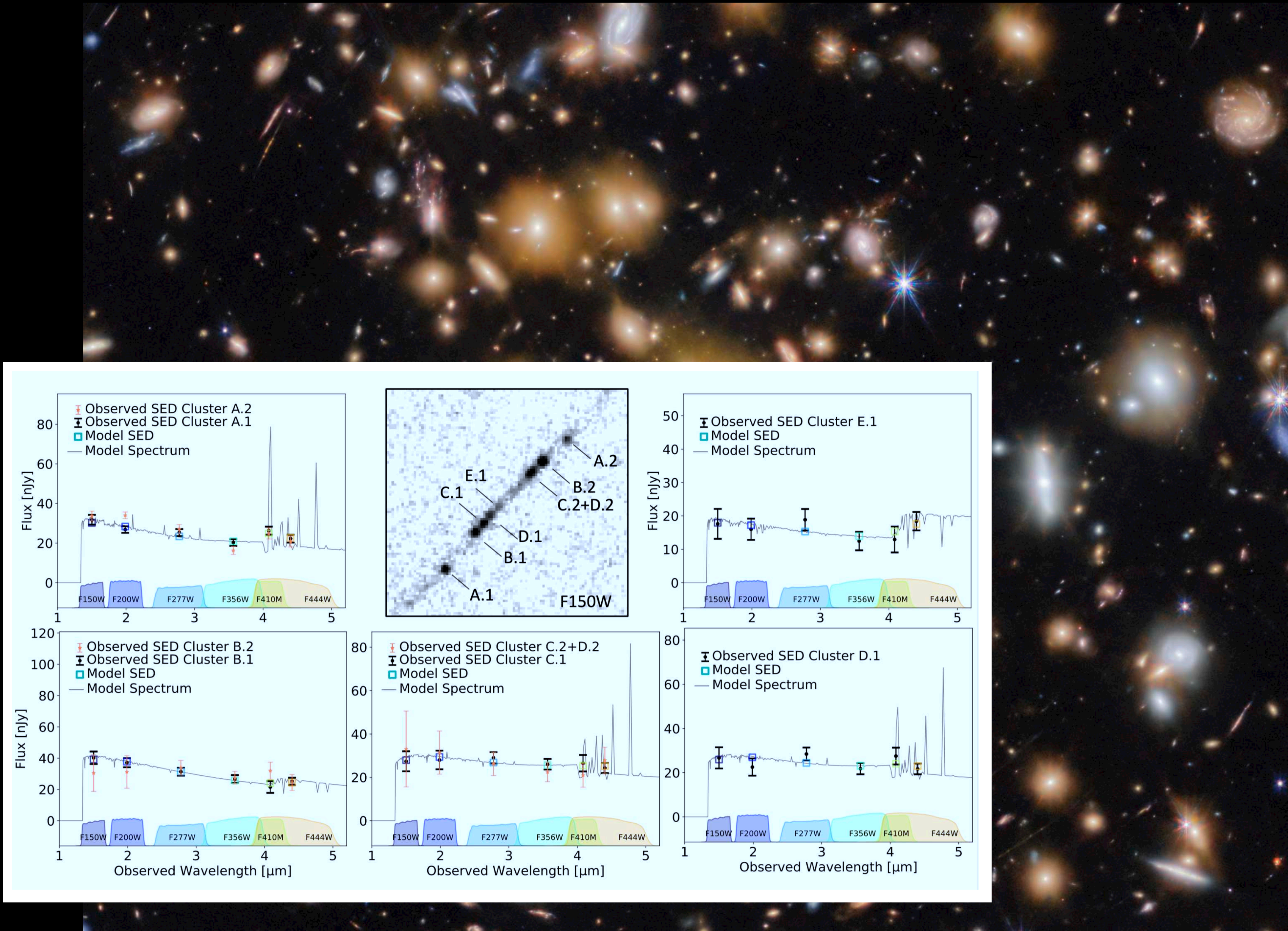
CDM predictions too round & too small; ΨDM+WDM model follows the data

Contours trace the JWST & HST data (CANDELS & CEERS); Dots are the model predictions.



z=0.97 cluster SPT0615: lenses young globular clusters at z=10.2 !

Adamo^{+} (Nature; astro-ph/2401.03224): $\sim$50 Myr old, formed at z$\sim$11!   `https://esawebb.org/news/weic2418/`



z=0.97 cluster SPT0615: lenses young globular clusters at z=10.2 !

- Webb yields Globular Cluster ages/masses at z=10.2 → $z_{form} \lesssim 11$!

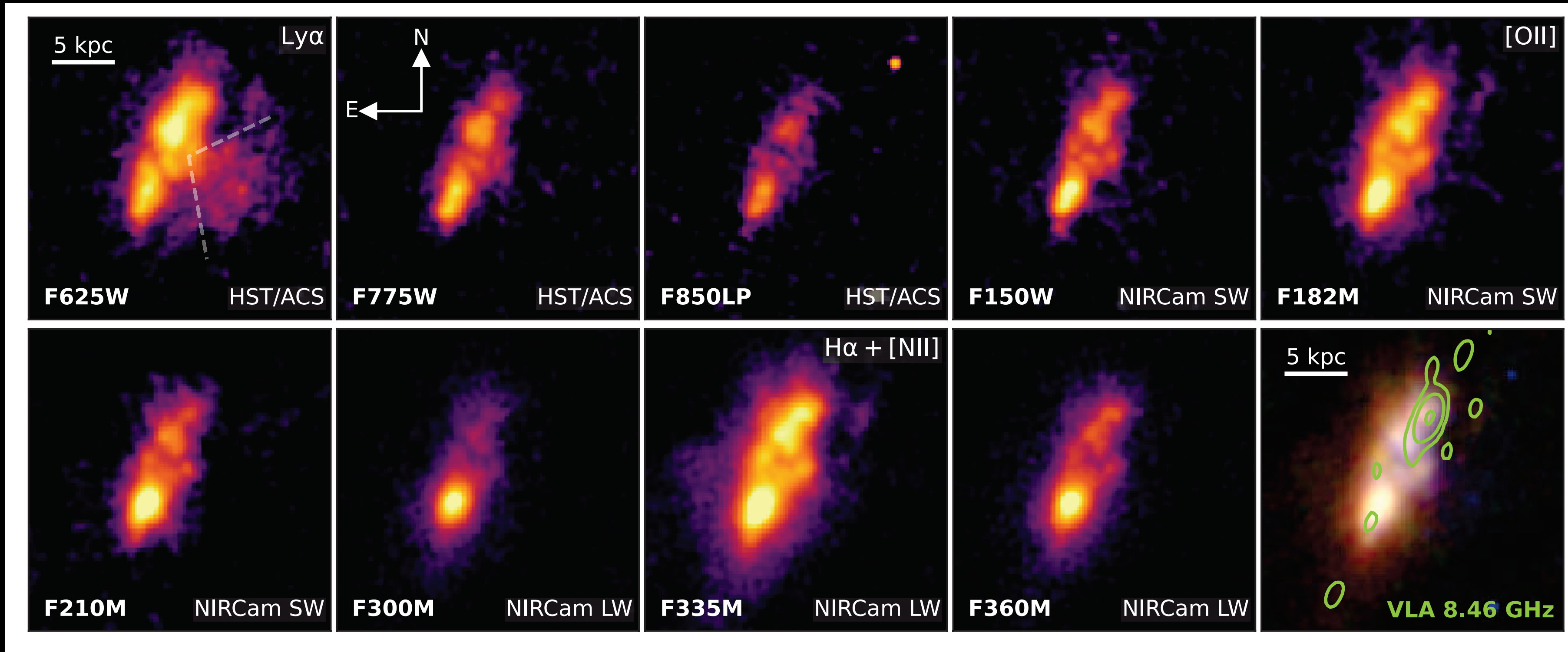
• z$\gtrsim$1 universe is littered with galaxy mergers and supermassive black holes!

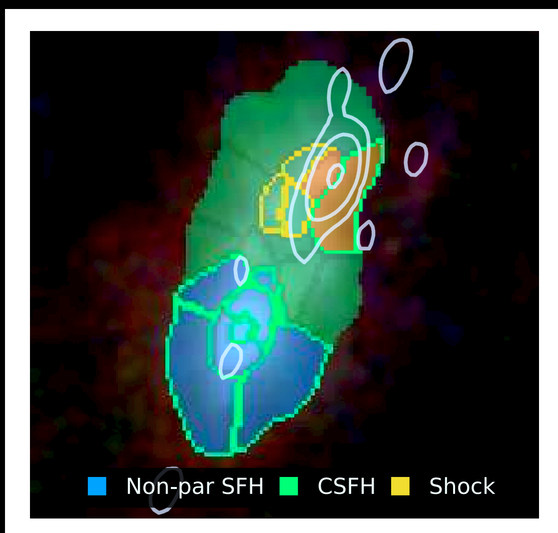
We live in a $boring$ galaxy far away from major mergers & SMBHs!

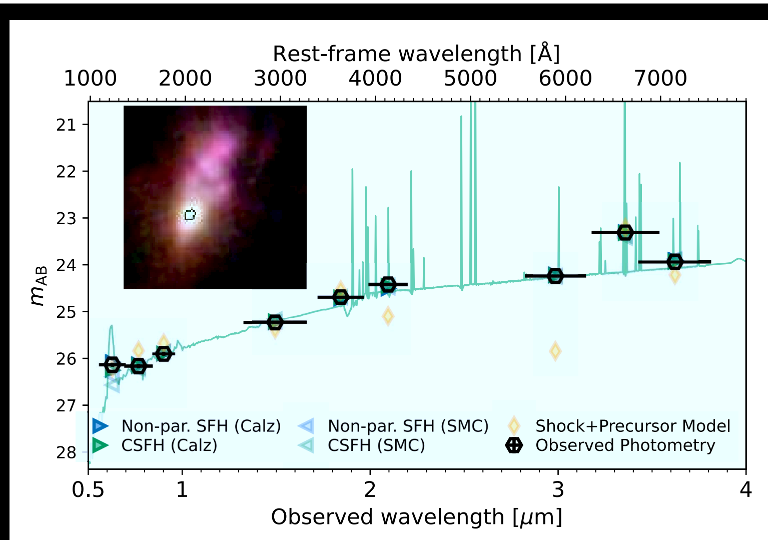
May 27, 2025: Deepest 120 hr JWST cluster image of Abell S1063 ($z=0.351$)!

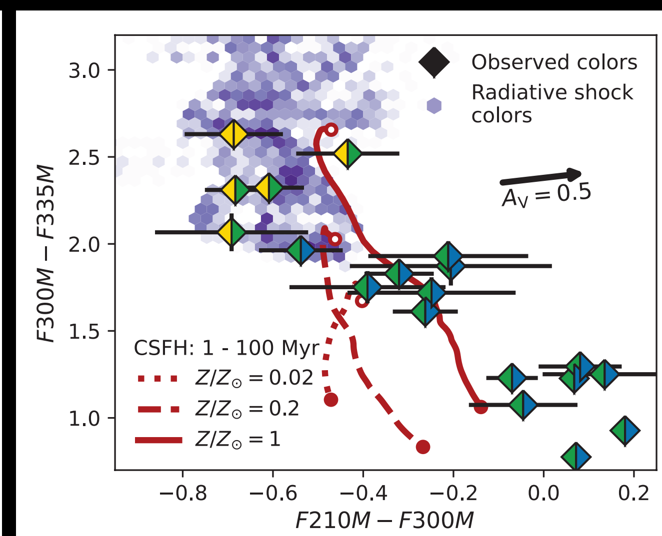
Einstein's cosmic house of mirrors: many galaxies with supermassive black holes!

Atek$^+$ (2025): `https://www.esa.int/ESA_Multimedia/Images/2025/05/Webb_glimpses_the_distant_past`



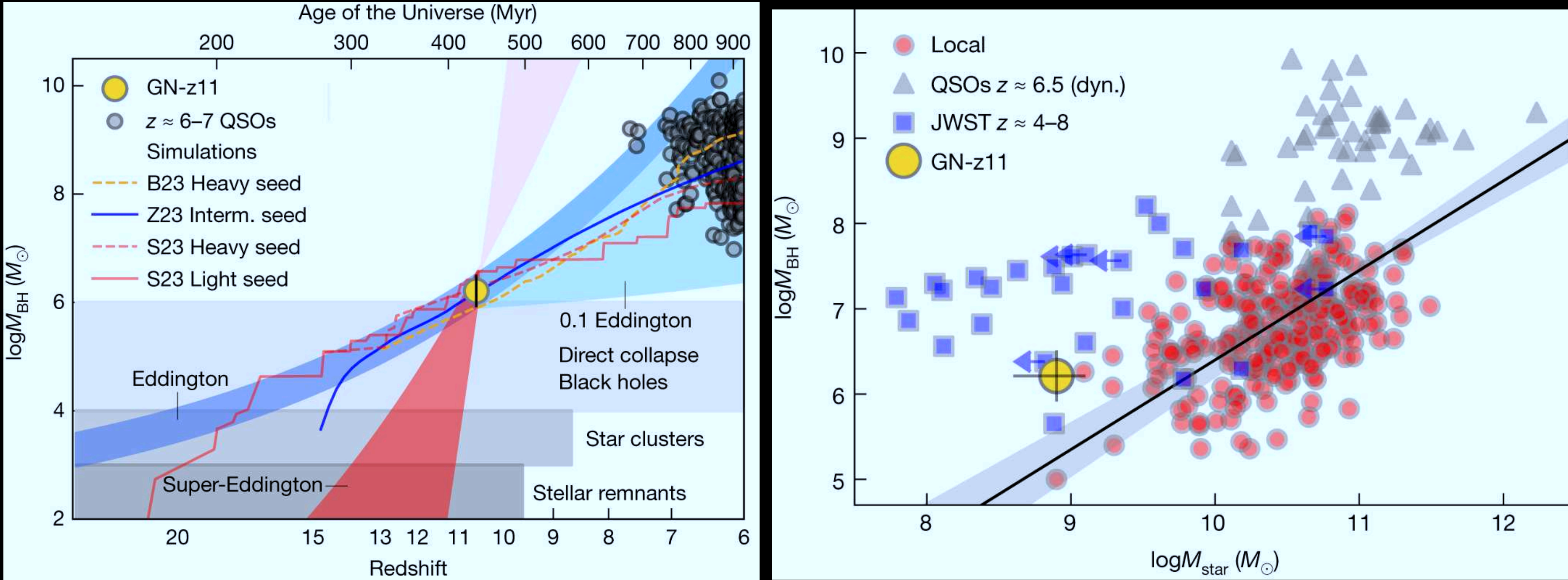






A massive ($10^{10.9}$ $M_\odot$) high-z radio galaxy at z=4.11 (Duncan+ 2023, MNRAS, 522, 4548):

- TNJ1338: NIRCam medium-band SFR∼1800 $M_\odot$/yr; extreme jet-induced SFR≳500 $M_\odot$/yr, t_{SFR}≃44 Myr.
- The ∼10^9 $M_\odot$ SMBH in this beast triggered its galaxy growth at z≳4.2!

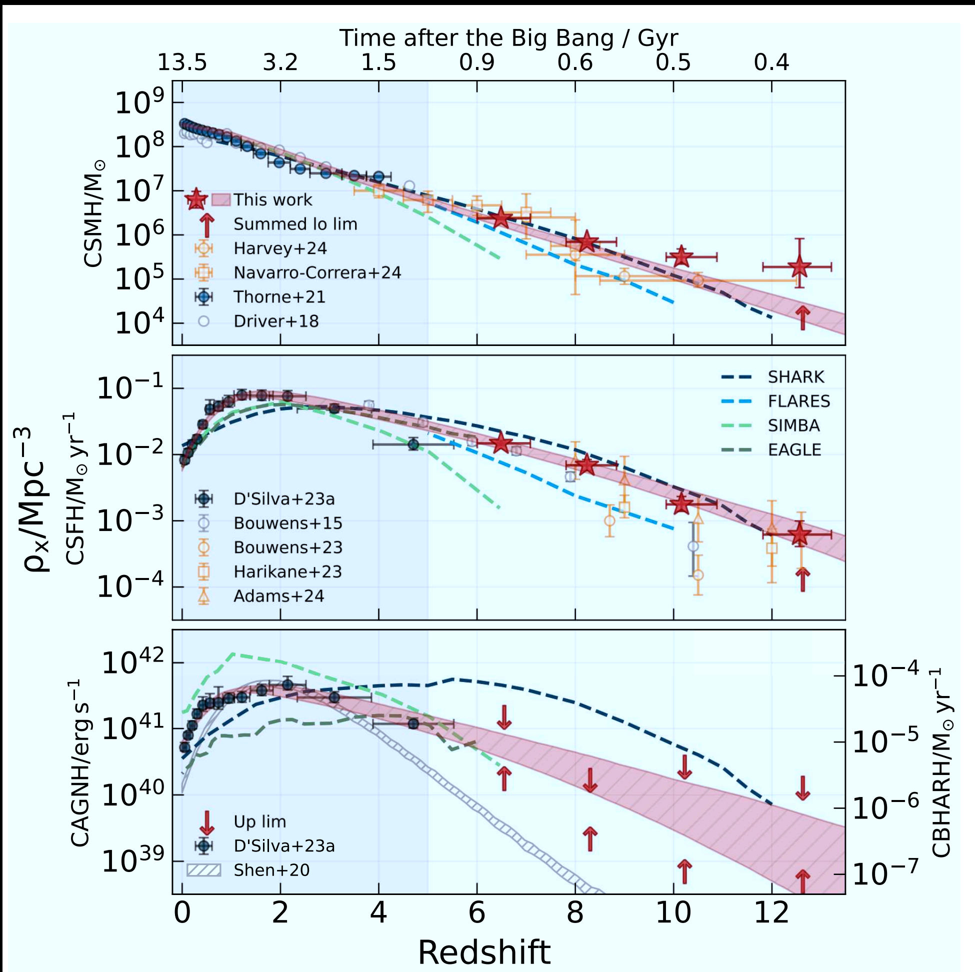


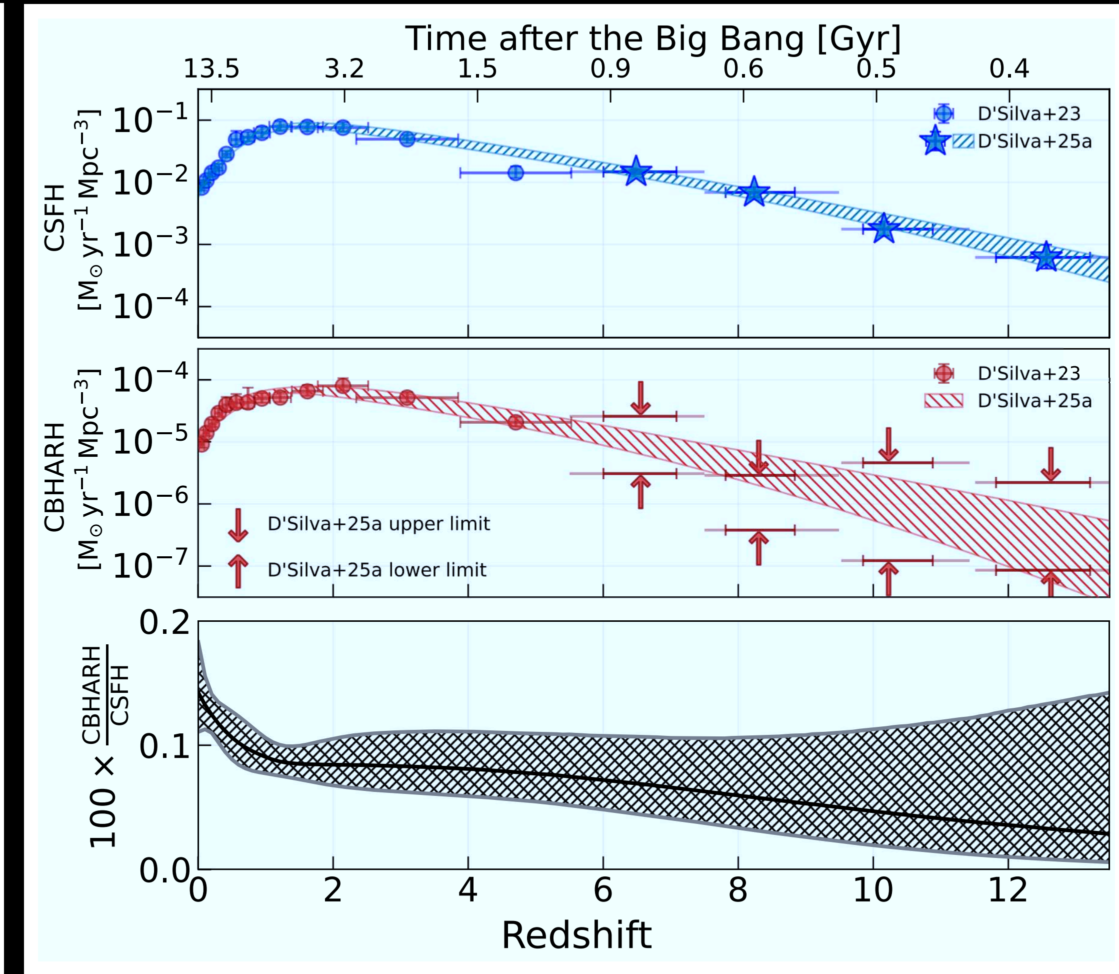
[Left] (Super Massive) Black Hole growth may start before z≃20 (175 Myr).

[Right] This results in overweight SMBHs compared to their host galaxies at z≃4–8 (*i.e.*, in the first 0.6–1.5 Byr)! (Maiolino^{+}2024, Nature, 627, 59)

Who came first: chicken (Galaxy) or egg (SMBH)?: Most likely the egg!

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





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

(J. D'Silva[+] 2023, MNRAS, 524, 1448; — 2024, ApJL, 959, L18; — 2025, A&A, 990, 44; astro-ph/2503.03431).

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

However, the large number of red, dusty AGN that JWST now sees at z$\gtrsim$4 suggests that SMBH's started growing fast, before the first galaxies.

(4) Summary and Conclusions

(1) Webb was successfully built, tested and finally launched in Dec. 2021.

(2) Webb's first images trace the "Cosmic Circle of Life":

- Formation and evolution of stars and dust over cosmic time.
- How 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 lensing):

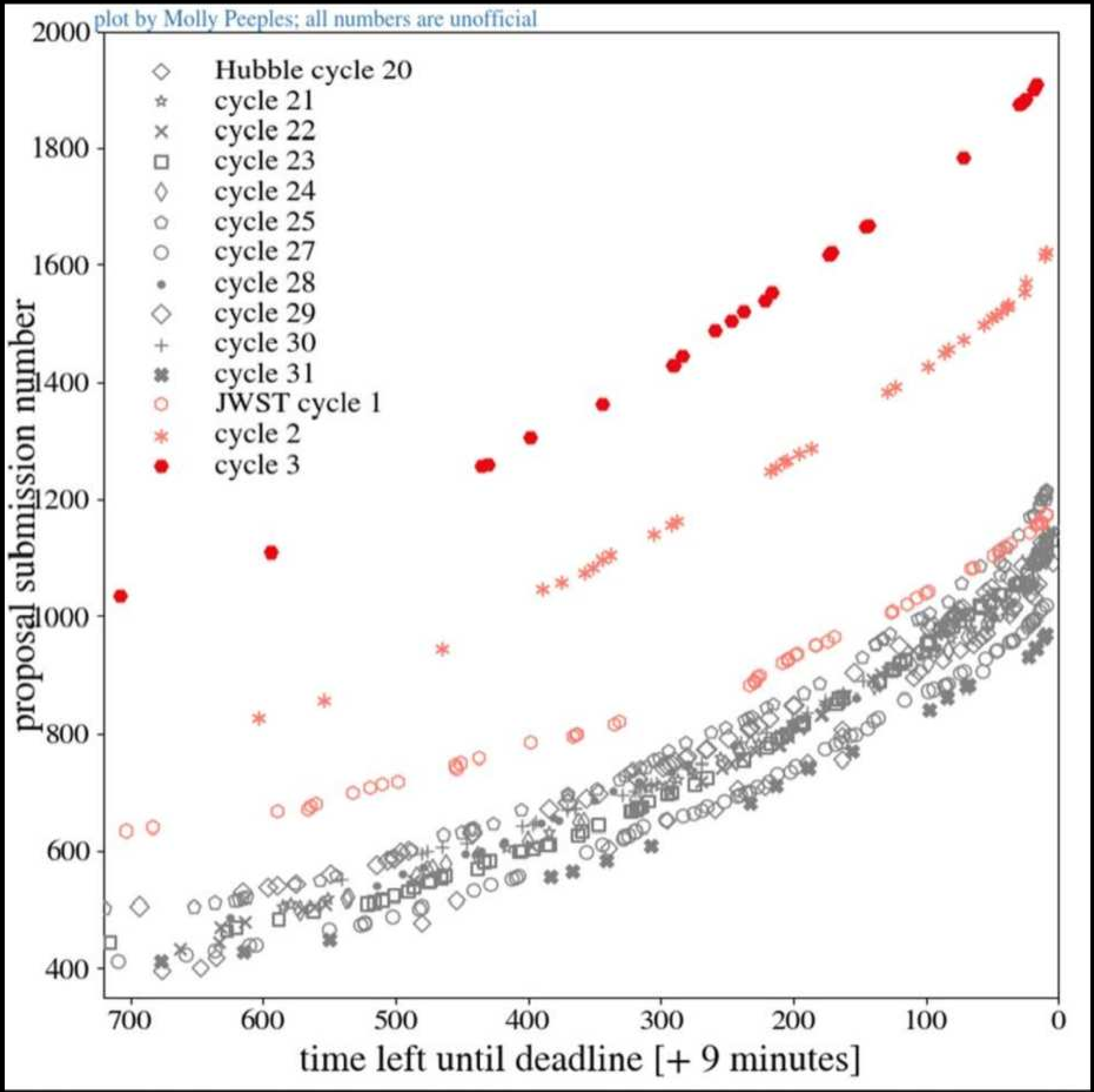
- Formation of the first stars, star-clusters, SMBH's after 0.2 Byr.
- How galaxies assembled over 13.6 Billion years (triggered by SMBHs?)

(4) Webb has shown us our place in the universe:

- From cosmic dust we were made, and to cosmic dust we shall return!
- Webb sees stellar populations (GCs) & lensed stars at cosmological distances!

(5) Spare Science Charts

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



• 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!

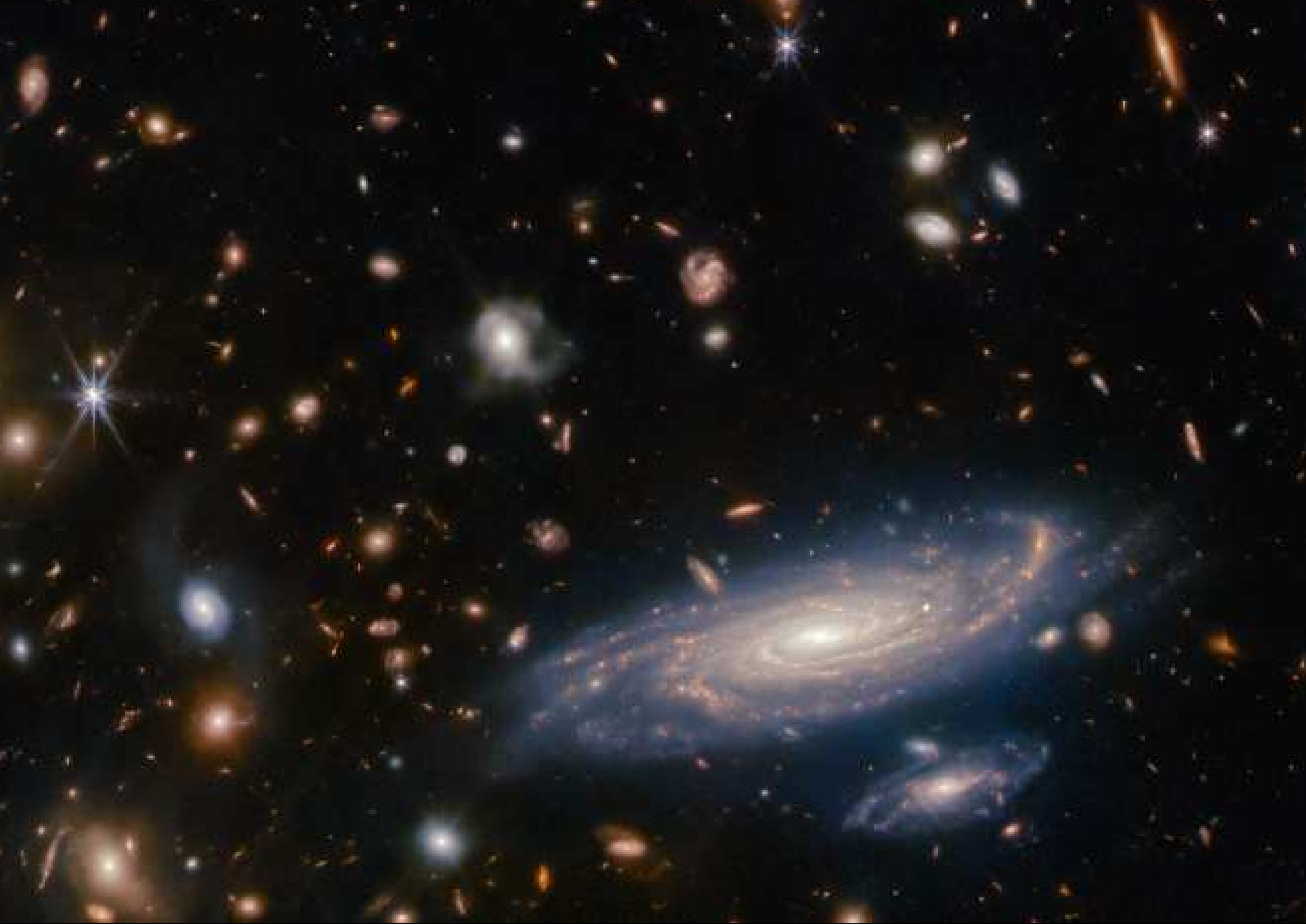
(1) SCIENCE IMPACT BY THE HST & JWST COMMUNITY (Feb. 2025):

- 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).

LEDA-2046648: a beautiful galaxy pair observed with NIRISS 1 Blyr away.



LEDA-2046648: Andromeda will collide with Milky Way like this in 4-5 Byrs.

Illustration Sequence of the Milky Way
and Andromeda Galaxy Colliding

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger ▪ STScI-PRC12-20b

Will this ever happen to our own Galaxy?

YES! Hubble showed no lateral motion of Andromeda:

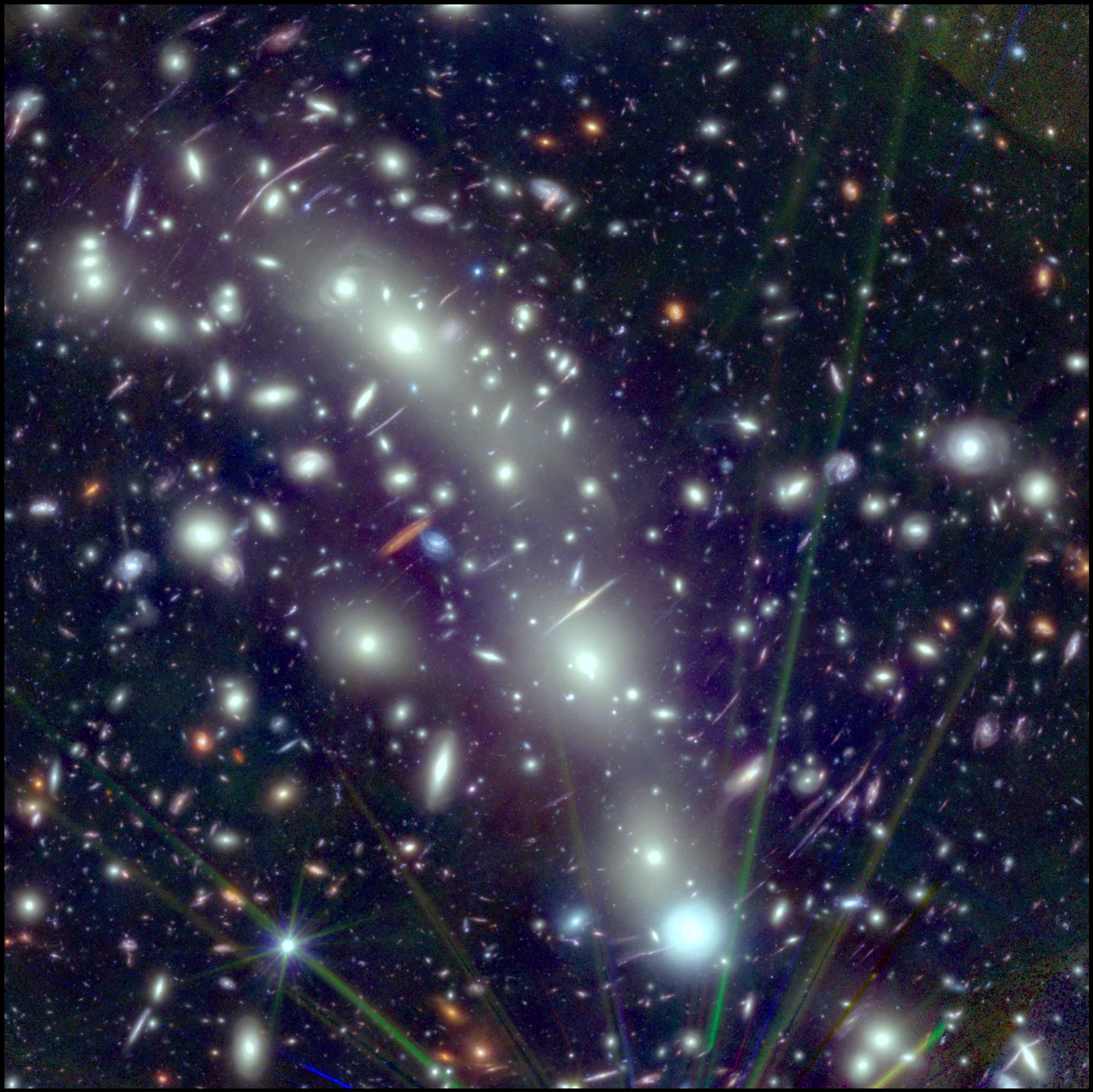
Approaches at –110 km/s.

Hence, Andromeda will merge with Milky Way!

The two blackholes (10^6–10^7 suns) will also merge!

Not to worry: only 4–5 Byr from today!

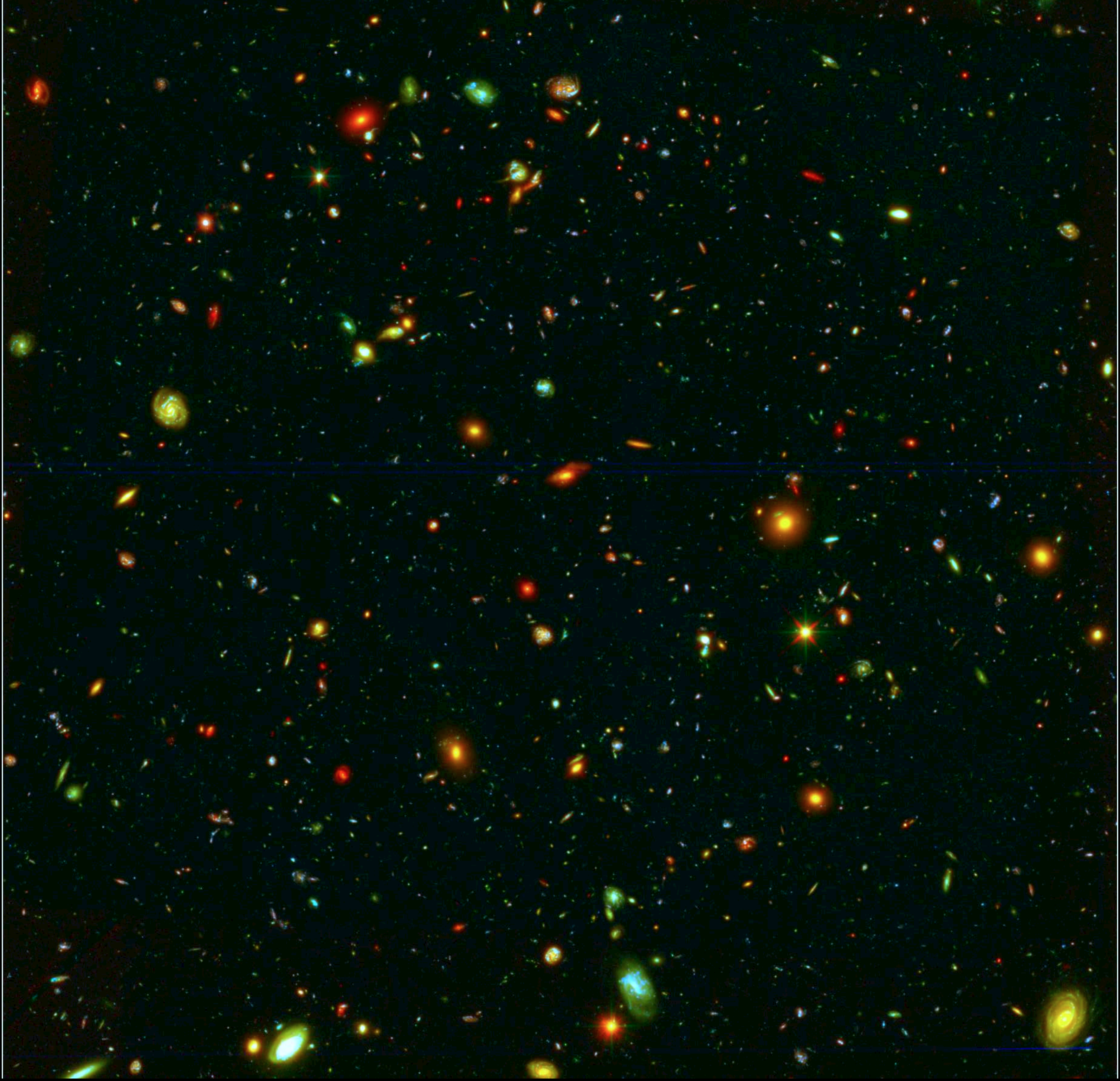
(6) Uniquely complementary roles of Hubble and Webb:



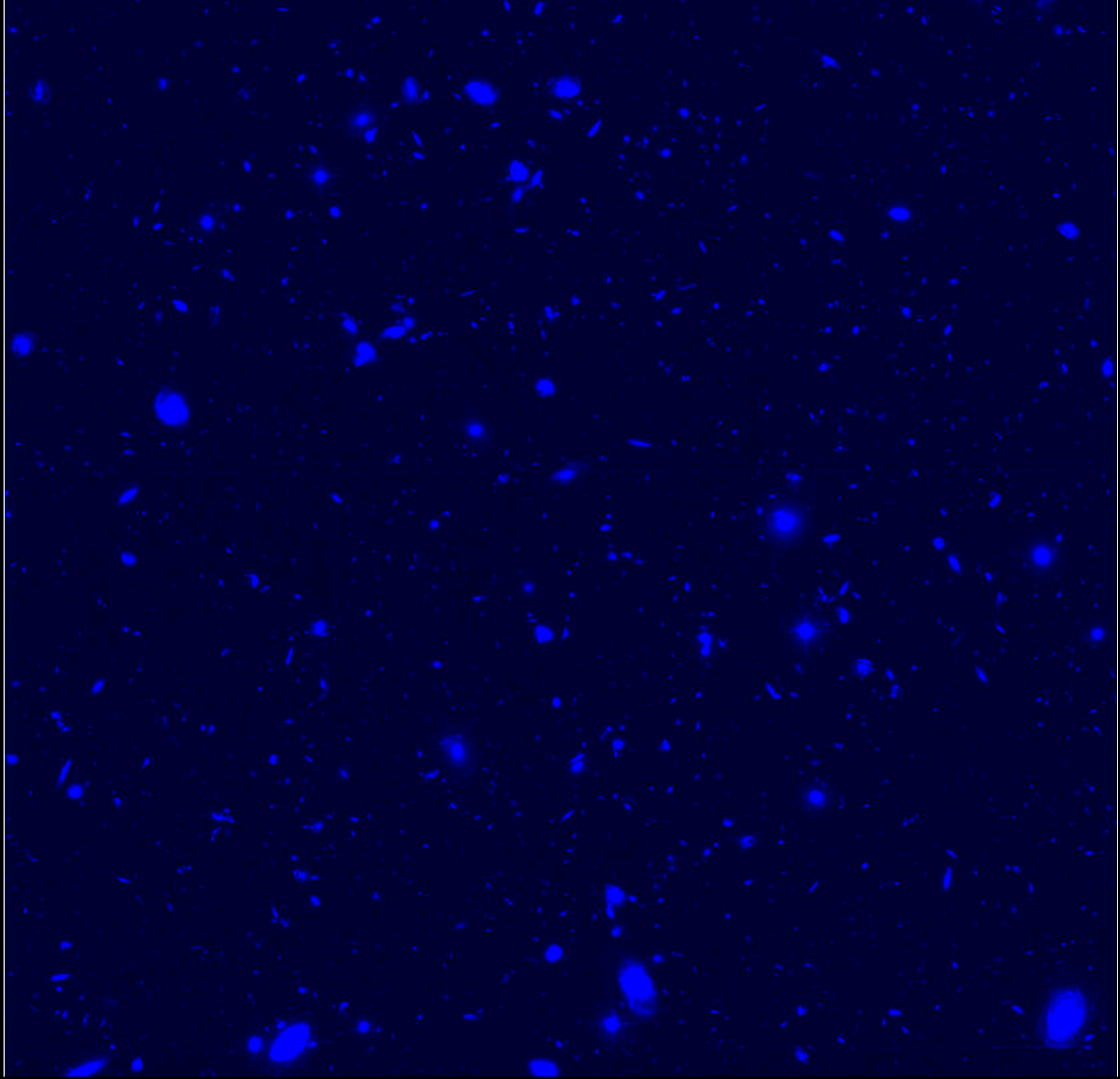
500 hrs HST+JWST: 45 filters (0.2–5.0μm), lensing cluster MACS0416:

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

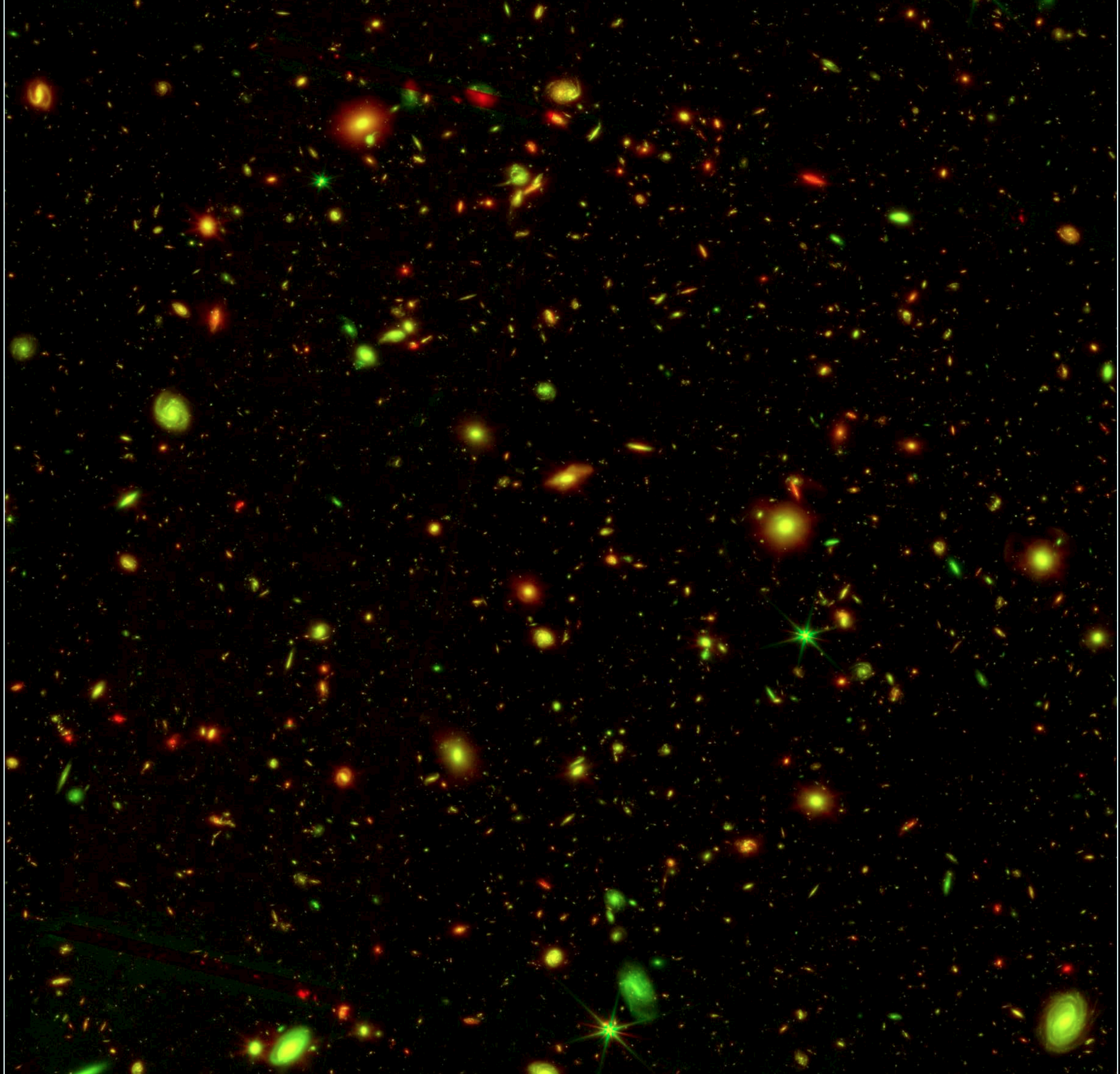
$\Longrightarrow$ HST & JWST reach 30–31 mag ($\simeq$1 nJy $\simeq$1 firefly from Moon).



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

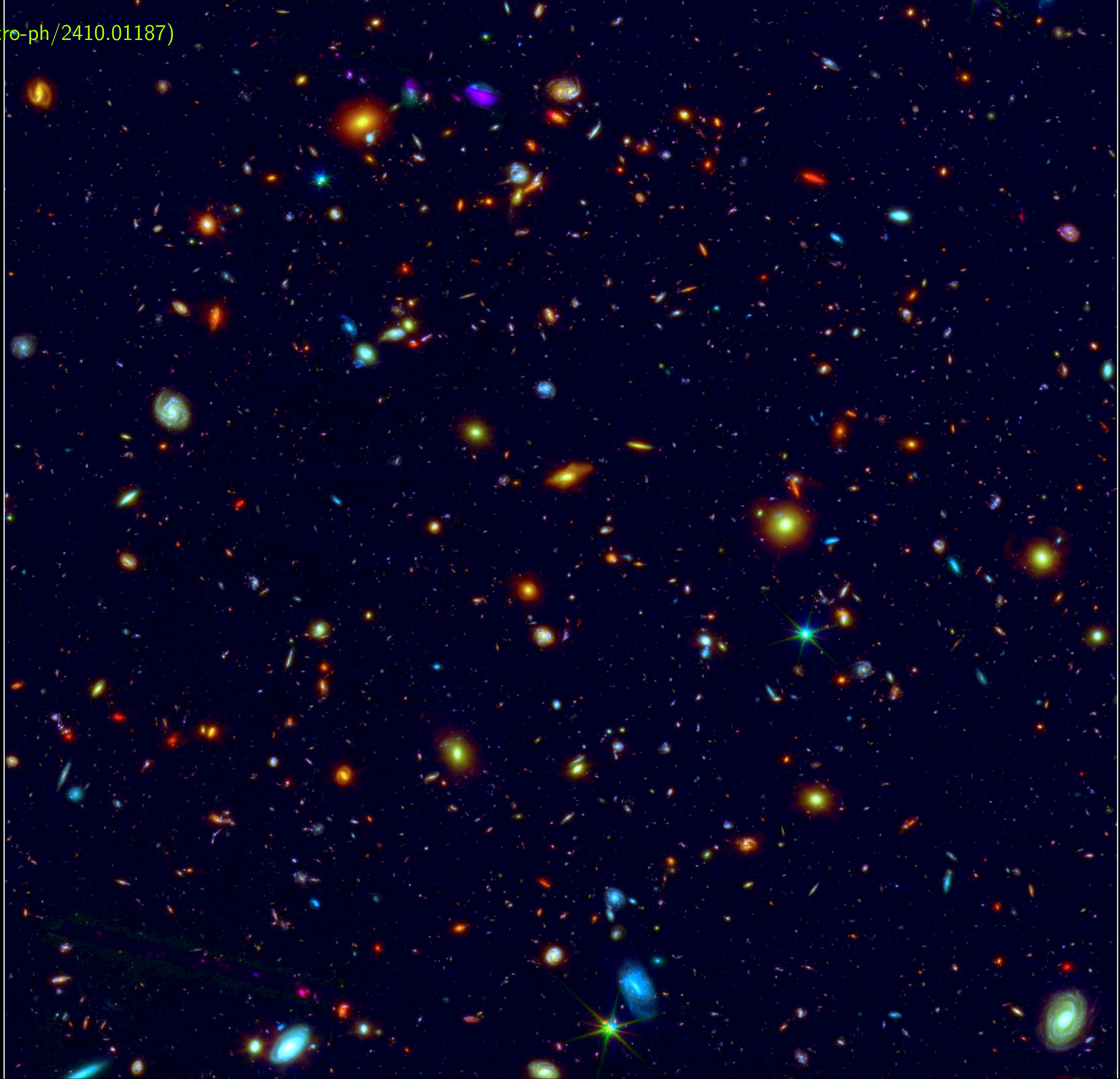


361 hr HST Hubble UltraDeep Field: 8 HST-unique filters 0.2–0.9 μm (in false color blue).



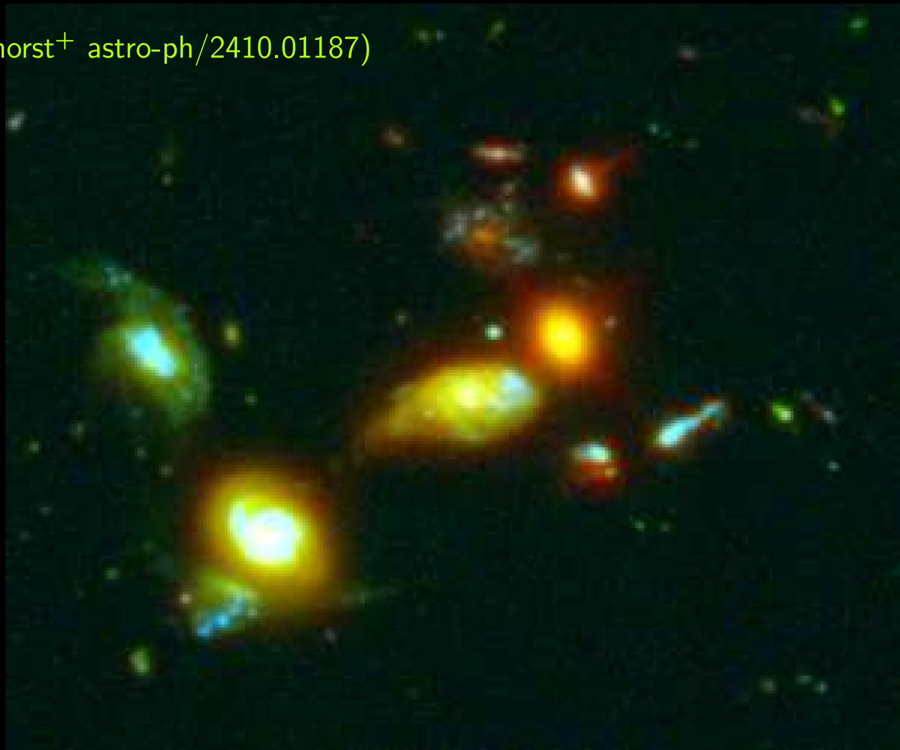
53 hr JWST/NIRCam Hubble UltraDeep Field: 12 filters at 0.9–5.0 μm (AB$\lesssim$31 mag; in green + red).

(Windhorst^{+} astro-ph/2410.01187)

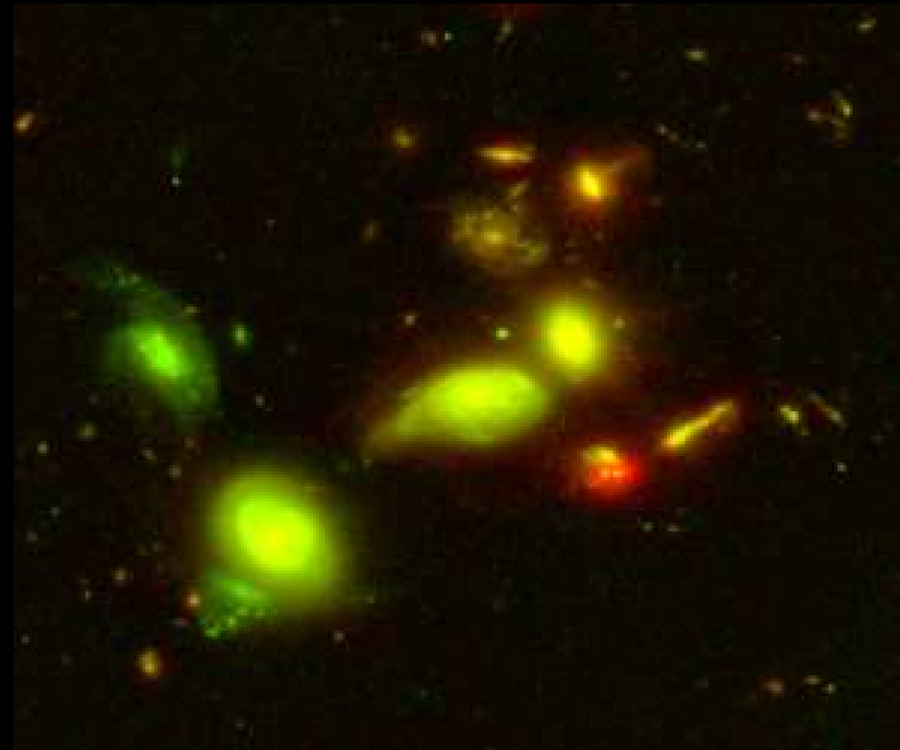


414 hr HST+JWST Hubble UltraDeep Field: 20 filters at 0.2–5.0 μm (AB$\lesssim$31.5 mag; full BGR).

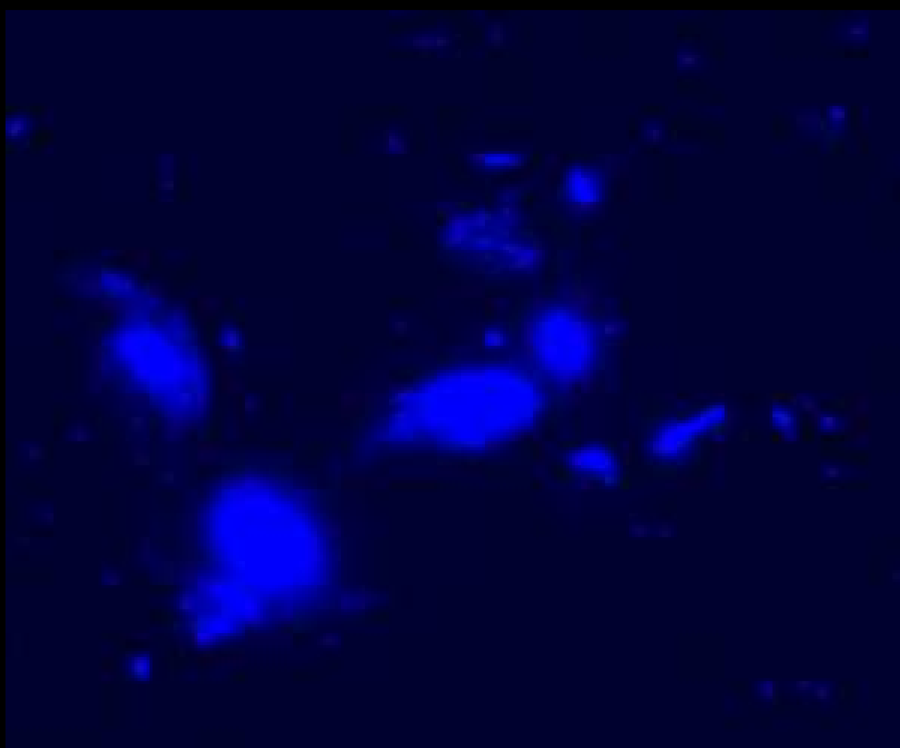
(Windhorst+ astro-ph/2410.01187)



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

Related papers, press releases and other URLs

Talk: http://lambda.la.asu.edu/raw/jwst/talks/asuSES502grads_jwst25.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/

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