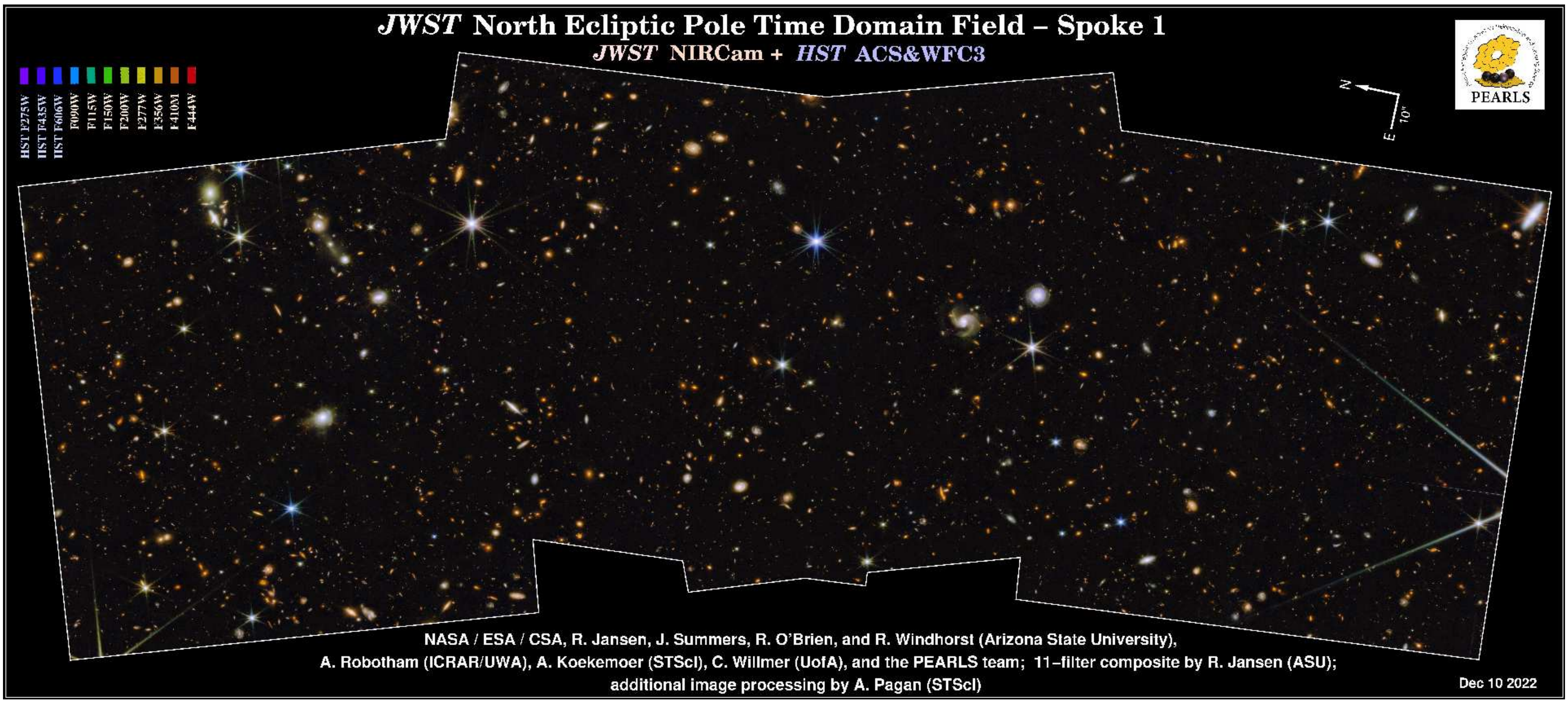
The Crown Jewels of the JWST PEARLS Project

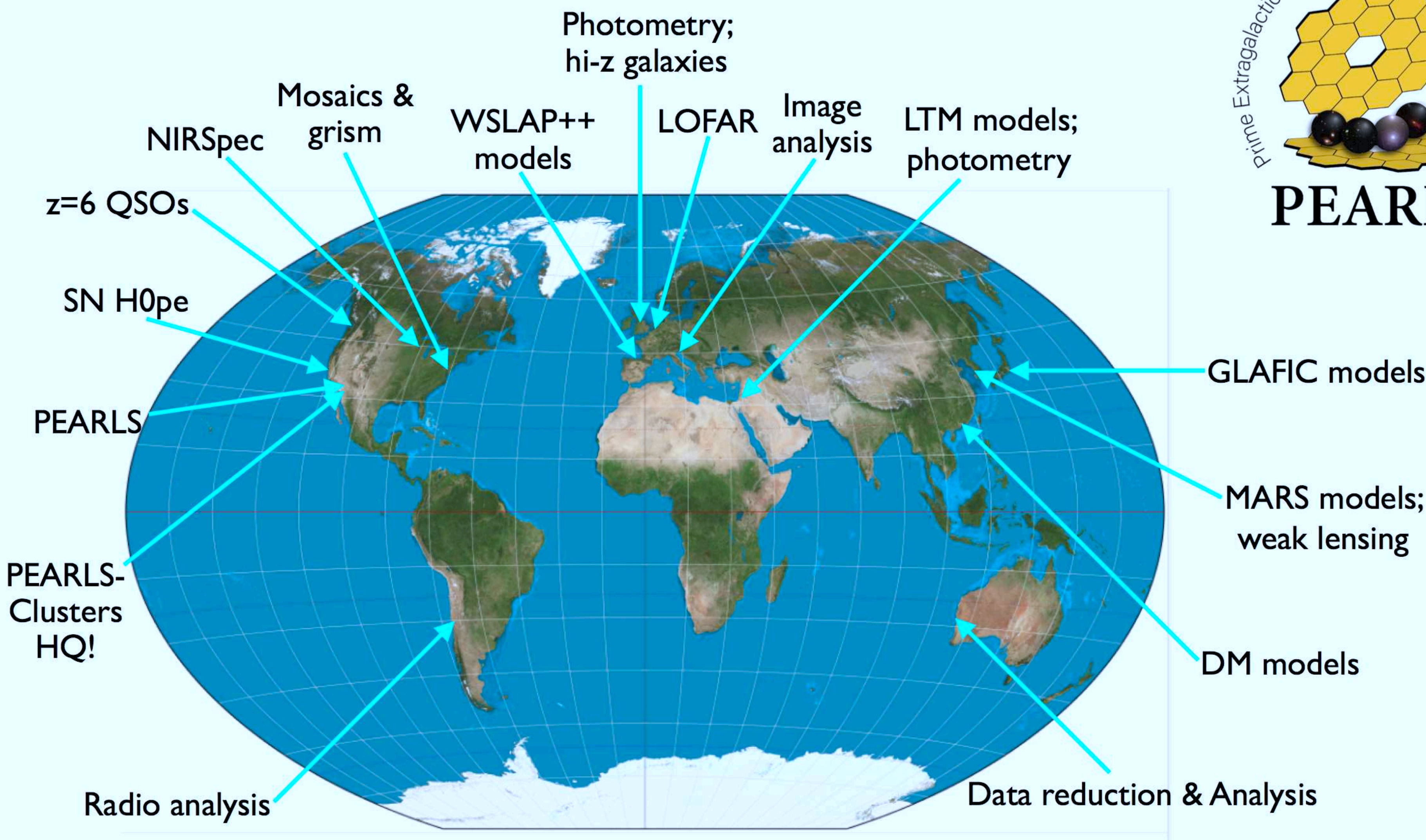
Rogier Windhorst (ASU) — Regents' Professor & JWST Interdisciplinary Scientist

+JWST PEARLS team: T. Carleton, S. Cohen, R. Jansen, P. Kamieneski, T. Acharya, J. Berkheimer, N. Foo, R. Honor, D. Kramer, T. McCabe, I. McIntyre, R. O'Brien, R. Ortiz, J. Summers, C. Conselice, J. Diego, S. Driver, J. D'Silva, B. Frye, A. Koekemoer, M. Marshall, M. Nonino, A. Robotham, S. Tompkins, C. Willmer, H. Yan, N. Adams, D. Austin, D. Carter, D. Coe, K. Duncan, H. Hammel, N. Grogin, W. Keel, N. Pirzkal, M. Polletta, R. Ryan Jr., I. Smail, S. Willner, R. Arendt, J. Beacom, R. Bhatawdekar, L. Bradley, T. Broadhurst, C. Cheng, F. Civano, L. Dai, H. Dole, G. Fazio, G. Ferrami, L. Ferreira, S. Finkelstein, L. Furtak, H. Gim, A. Griffiths, K. Harrington, N. Hathi, B. Holwerda, J. Huang, M. Hyun, M. Im, B. Joshi, I. Juodzbalis, P. Kelly, R. Larson, J. Li, J. Lim, Z. Ma, P. Maksym, G. Manzoni, A. Meena, S. Milam, M. Pascale, A. Petric, A. Pozo Larocha, P. Porto, C. Redshaw, C. Robertson, H. Rottgering, M. Rutkowski, S. Scheller, B. Smith, B. Sun, F. Sun, A. Straughn, L. Strolger, J. Trussler, L. Wang, B. Welch, S. Wilkins, S. Wyithe, M. Yun, E. Zackrisson, J. Zhang & X. Zhao et al. (120 scientists over 18 time-zones)



Hubble and James Webb Space Telescopes VII Conference; Thursday May 02, 2024 (Porto, Portugal)

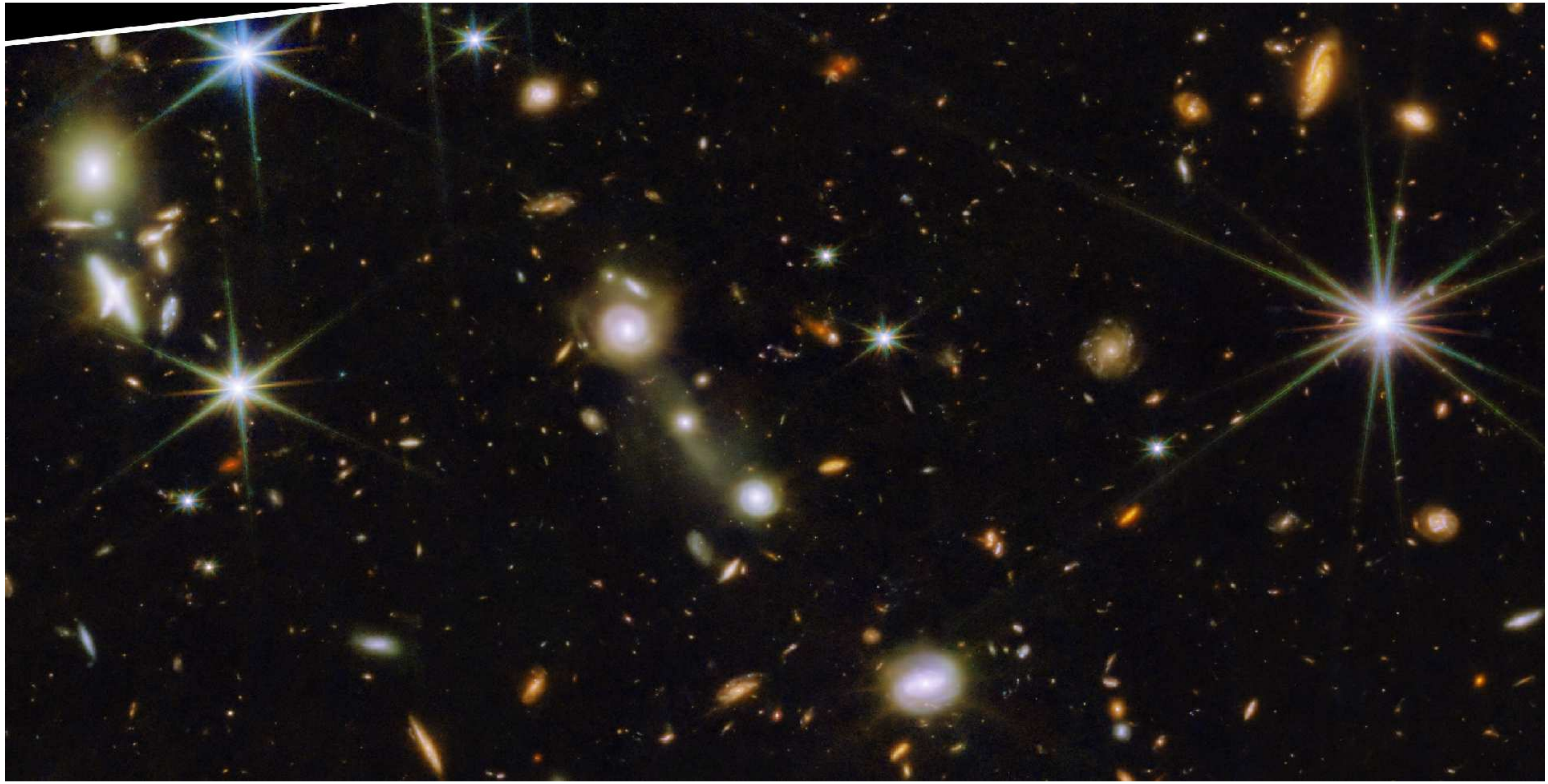
PEARLS Program



PEARLS = Prime Extragalactic Areas for Reionization and Lensing Science (Windhorst^{+} 2023, AJ, 165, 13):

- A mix of medium-deep NIRCam fields (GTO-2738; PIs Windhorst & Hammel), best lensing clusters (GTO-1176 Windhorst & DD-4446 PI Frye), and high-zs QSOs (GTO-1176 & GO-1813 PI Marshall).

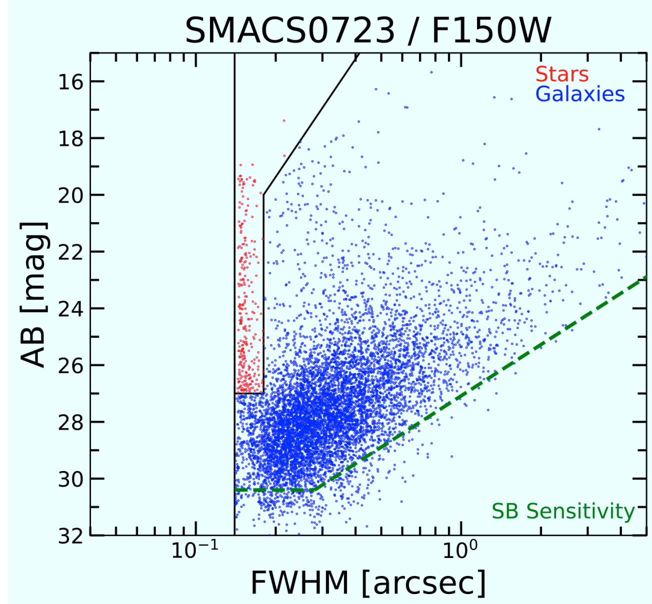
- PEARLS crown jewels today: Extremes in Cosmic SF (low$\longrightarrow$high $\sim 10^6\times$)!

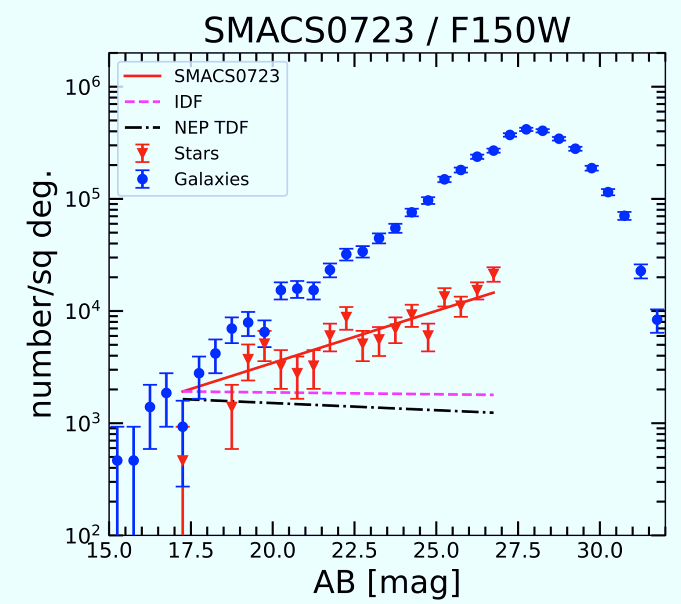


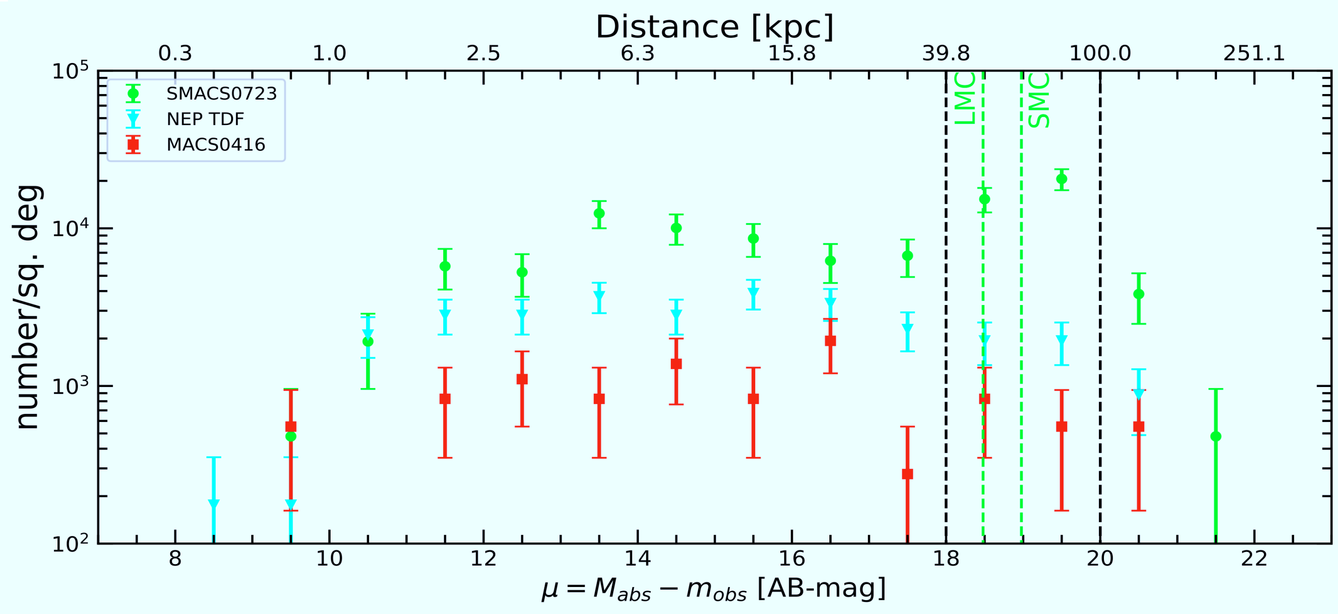
North Ecliptic Pole (NEP) Time Domain Field (TDF) from PEARLS project

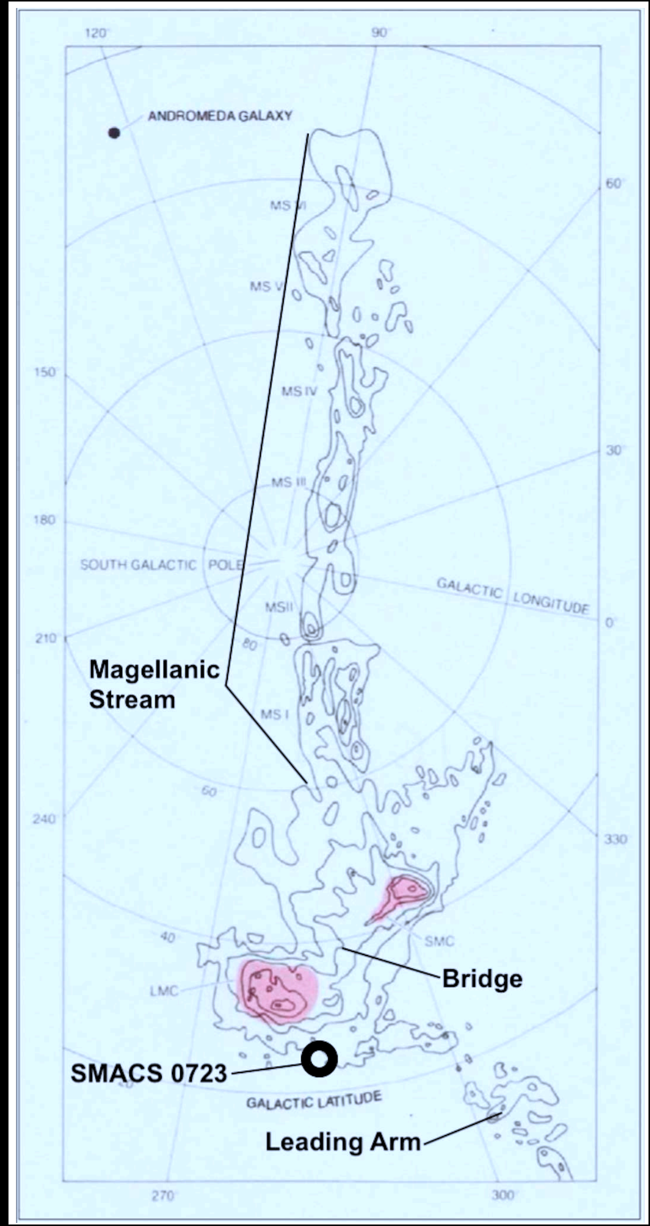
— some remarkable results in PEARLS and other JWST projects:

- (Old star) tidal tails everywhere (J. Summers$^+$ 2023, ApJ, 958, 108);
- $\lesssim$1% of objects variable: AGN & SNe (O'Brien$^+$ arXiv/2401.04944);
- Gravitational (galaxy-galaxy) lensing common (Keel$^+$ 23, AJ, 165, 166).





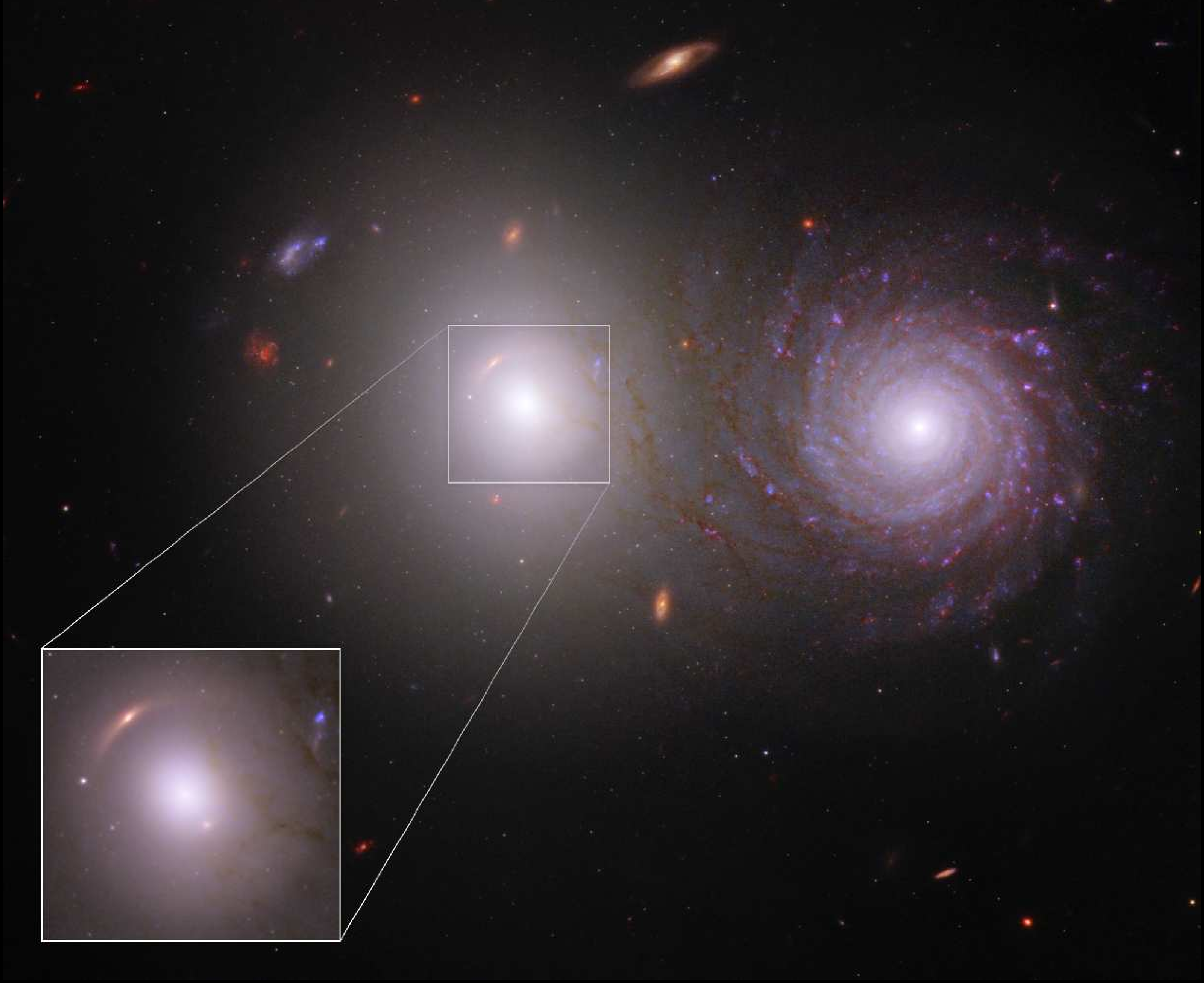




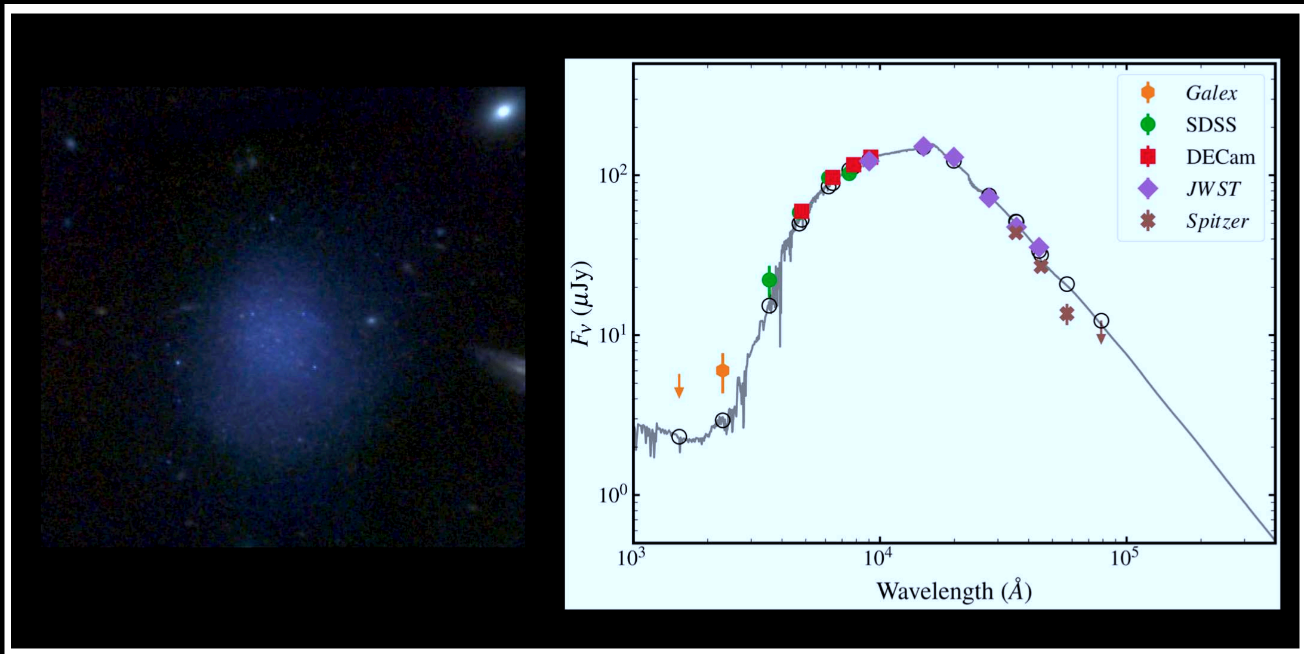
Summers, J.+ (2023, ApJ, 958, 108; astro-ph/2306.13037):

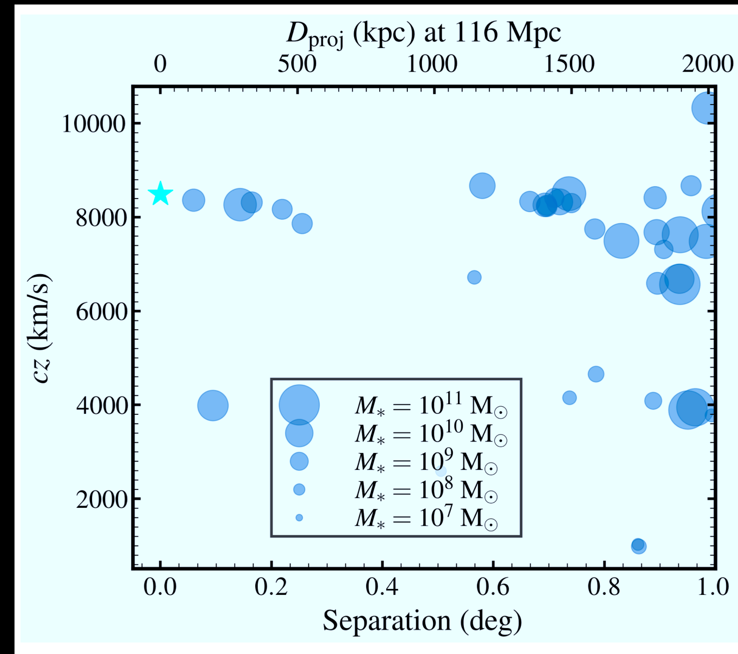
- SMACS0723 star counts show excess near LMC/SMC compared to NEP;
- 71 stars (AB$\lesssim$27) with $D_{SpecType}$$\simeq$40–100 kpc about 10° from LMC;
- Part of Leading Arm between LMC and MW: 10 mag fainter than Gaia!

- 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)!



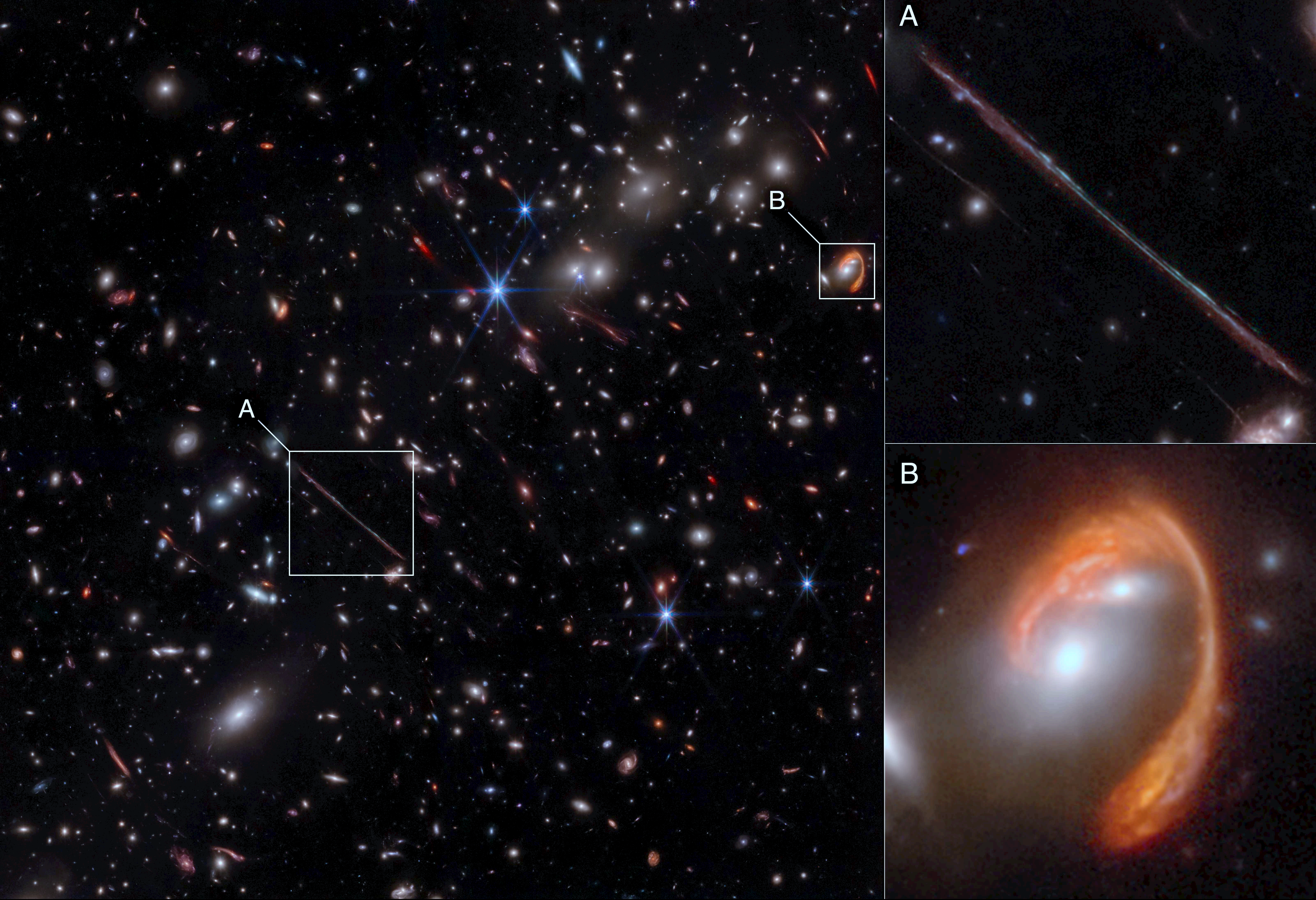


PEARLSDG: A distant old quiescent dwarf galaxy:

NIRCam image of Abell 1489 (LTM cluster CLG1212) reveals (Carleton$^+$ 2024, ApJL, 961, L37):

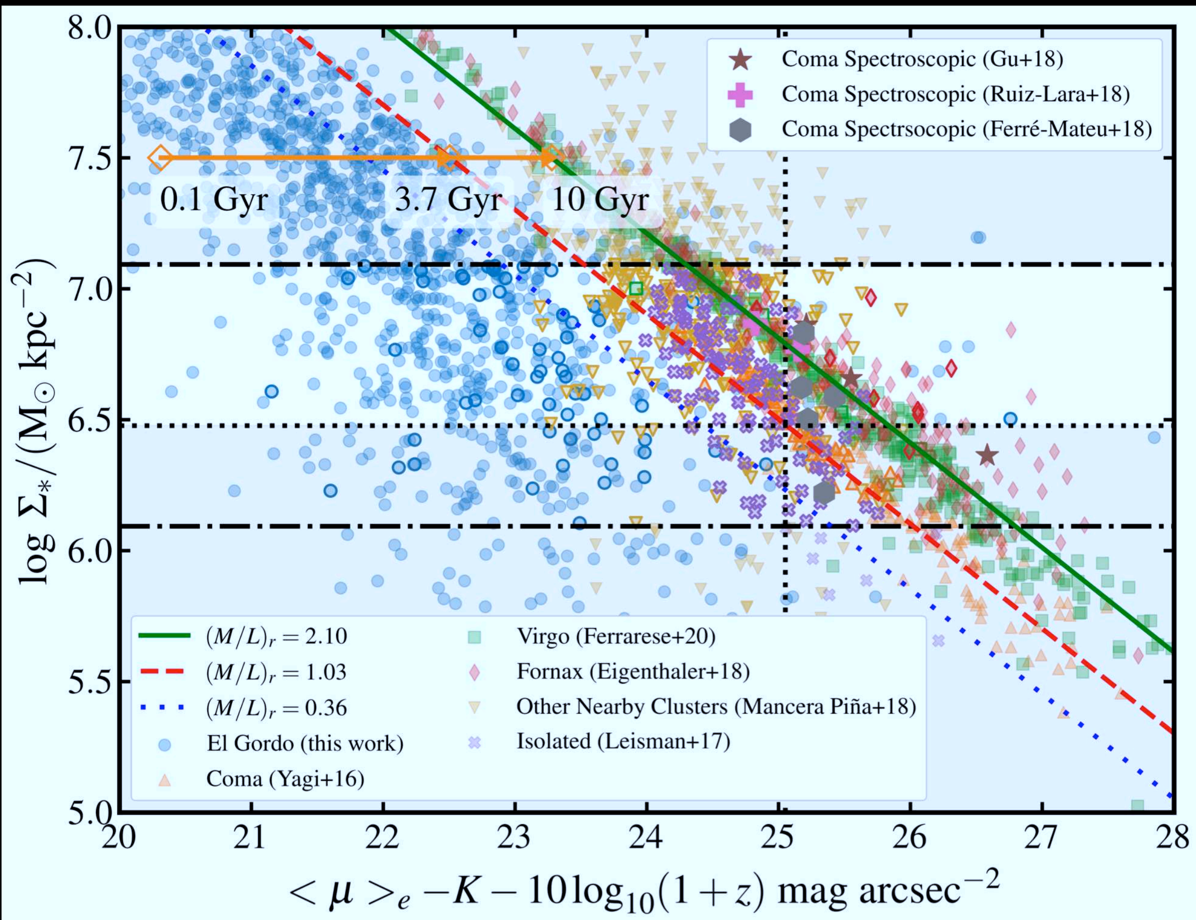
- Low-SB dwarf beyond Coma/Great Wall resolved into individual stars (cz$\sim$8500 km/s; $\gtrsim$200 kpc from nearest neighbor).

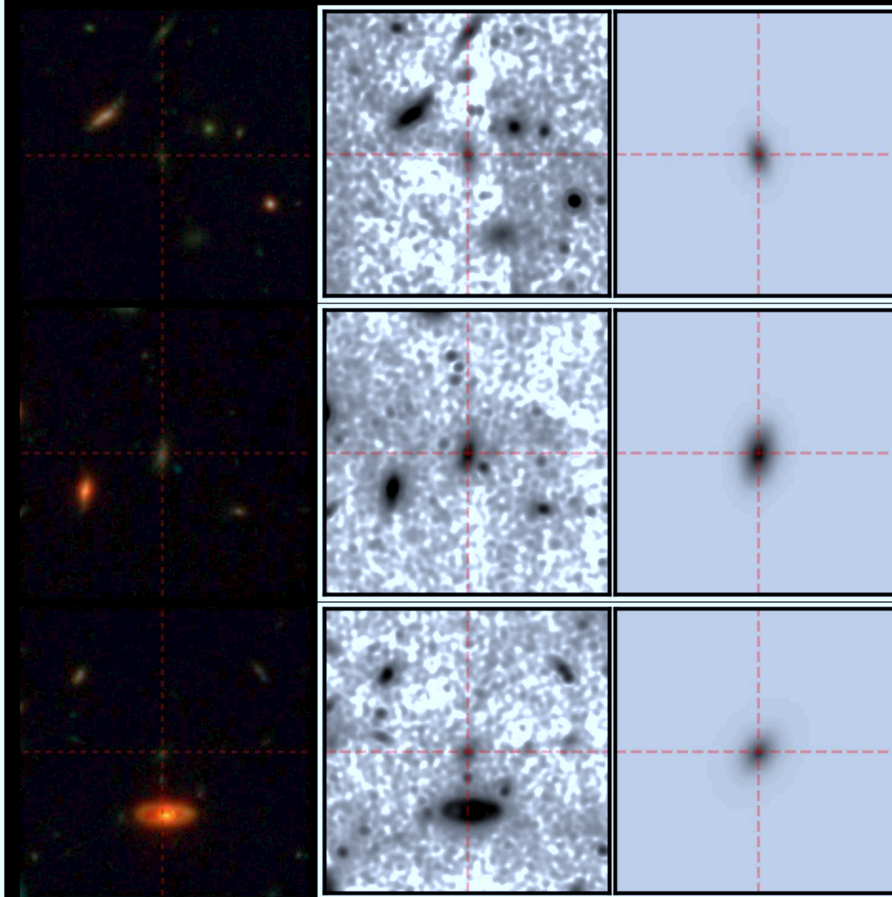
- 10 Gyr old, and very low SFR$\sim 5\times10^{-3}$ $M_\odot$/yr (sSFR$\sim10^{-11}$/yr)!



8-filter JWST/NIRCam of massive El Gordo cluster at redshift z≃0.87

T. Carleton+ (2023, ApJ, 953, 83); P. Kamieneski+ (2023, ApJ, 955, 91); J. Diego+ (2023; A&A, 672, A3); B. Frye, N. Foo+ (2023, ApJ, 952, 81).





We find low stellar density galaxies in imaging of the El-Gordo cluster.
These objects are younger than local UDGs, suggesting that they were more recently accreted onto the cluster.

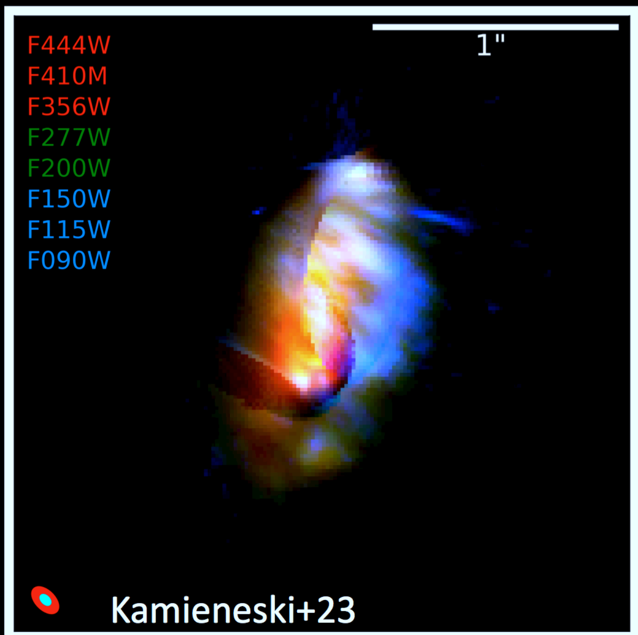
Carleton^{+} (2023, ApJ, 953, 83; astro-ph/2205.06347) NIRCam:

- El Gordo's Low Density Galaxies at z=0.87 have SFR≃0.1 $M_\odot$/yr.
- *i.e.*, SFR higher than Local Dwarfs, but much lower than the upcoming higher-z extremes ...

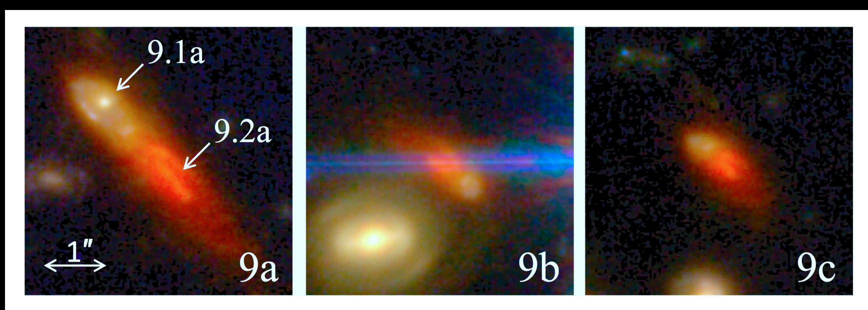
El Anzuelo

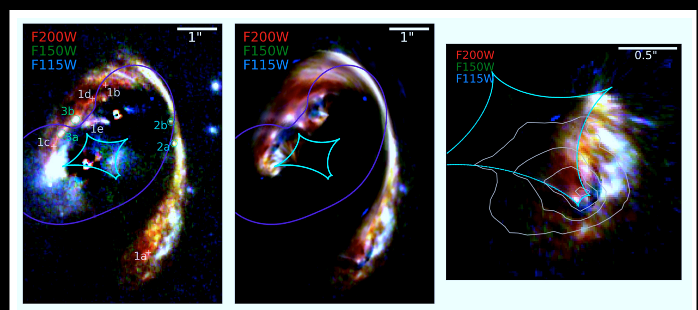
"The Fish Hook"

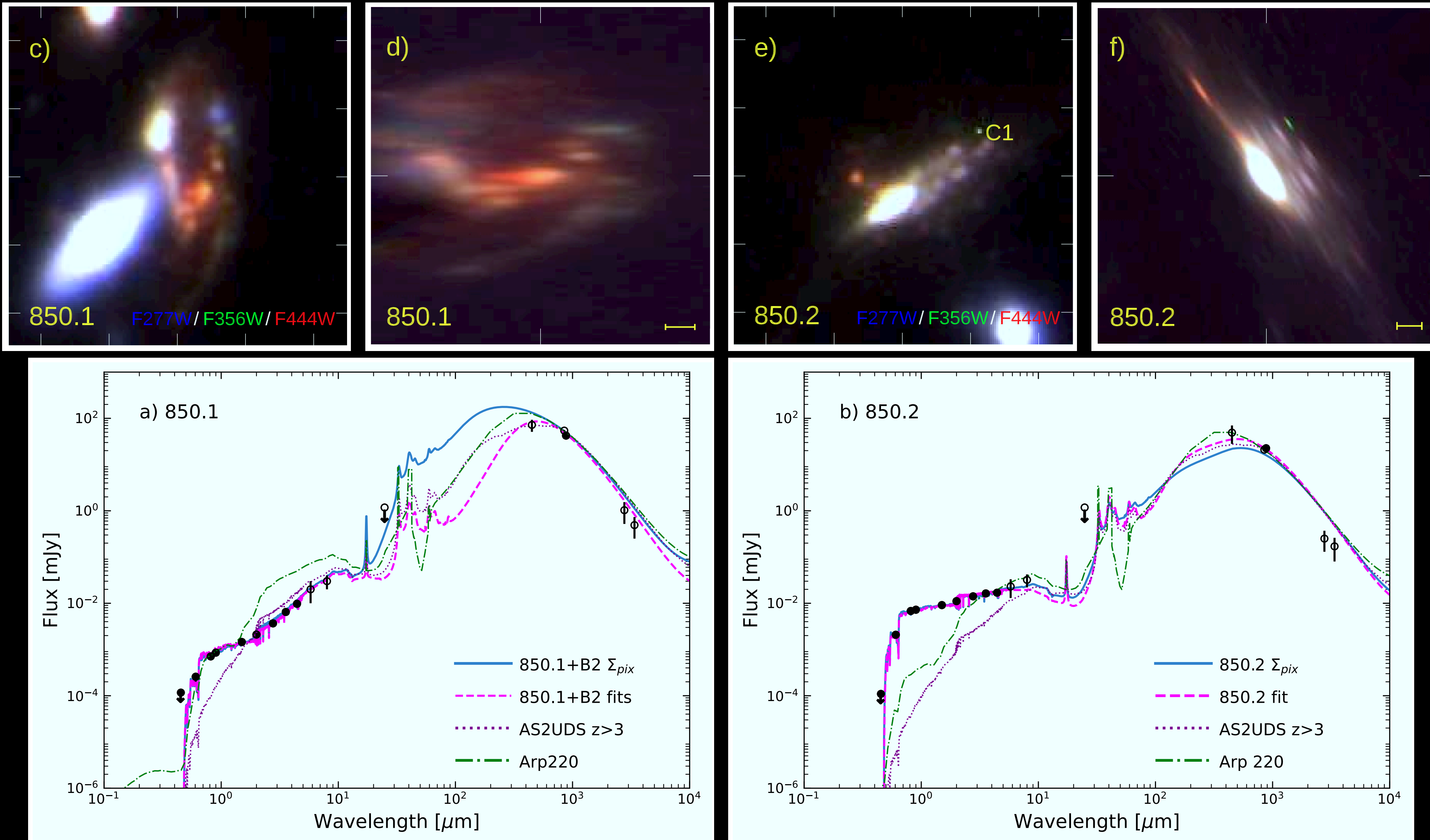
- SFR ~ 80 Msun/yr
- A_V ~ 2
- Source plane:



Dusty "El Anzuelo" has a high de-magnified total SFR≃80 $M_{\odot}$/yr (Kamieneski+ 2023, ApJ, 955, 91):

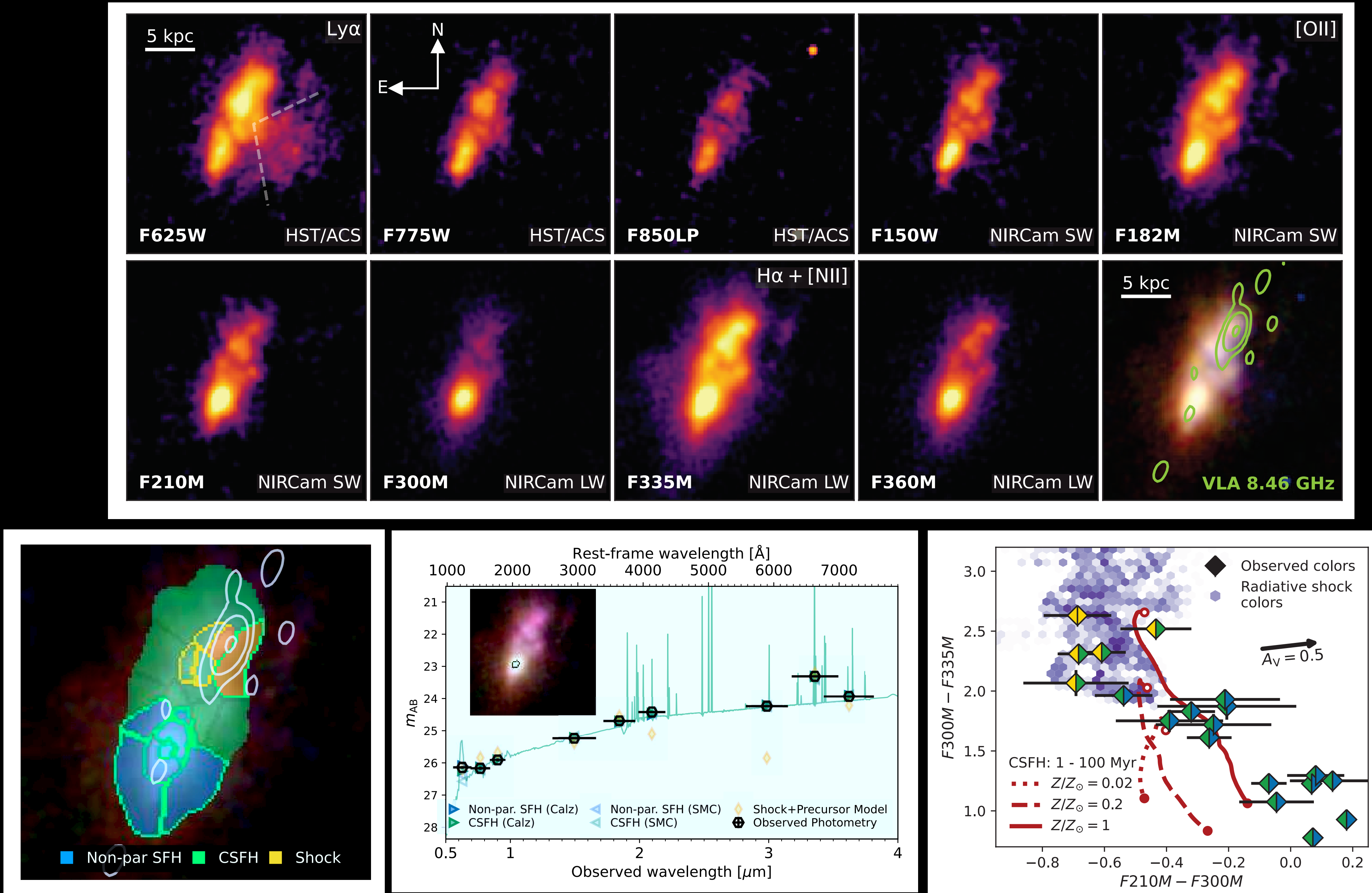






Smail^{+} (2023, ApJ, 958, 36): Two bright lensed sub-mm galaxies at z$\simeq$4.26 behind A1489 could not be more different:

- 850.1: $\sim 10^{11.8}$ $M_\odot$, $\tau \sim 450$ Myr, 1400 $M_\odot$/yr, $A_V \sim 5$ mag!
- 850.2: $\sim 10^{10.3}$ $M_\odot$, $\tau \sim 50$ Myr, 400 $M_\odot$/yr, $A_V \sim 1.2$ mag.



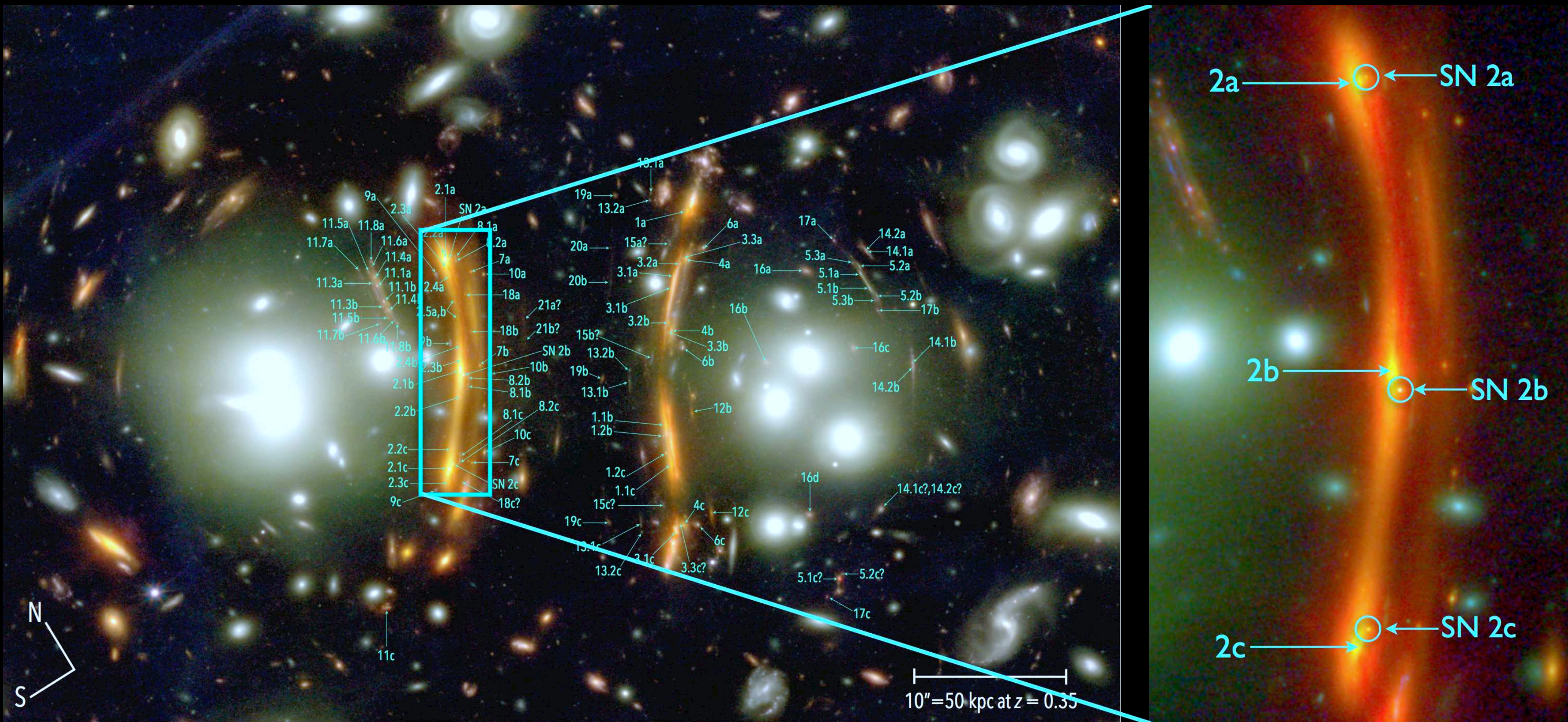
The most massive ($10^{10.9}$ $M_\odot$) high-z radio galaxy TNJ1338 at z=4.11:

Total medium-band SFR≃1600 $M_\odot$/yr (Duncan^{+}23, MNRAS, 522, 4548)

- Extreme radio jet-induced SFR≳500 $M_\odot$/yr and t_{SFR}≃4 Myr.

NIRCam images of most luminous far-IR Planck cluster G165 at z=0.35:

- Frye+ (2024, ApJ, 961, 171): very high *de-magnified total* SFR≃200–350 $M_{\odot}$/yr.

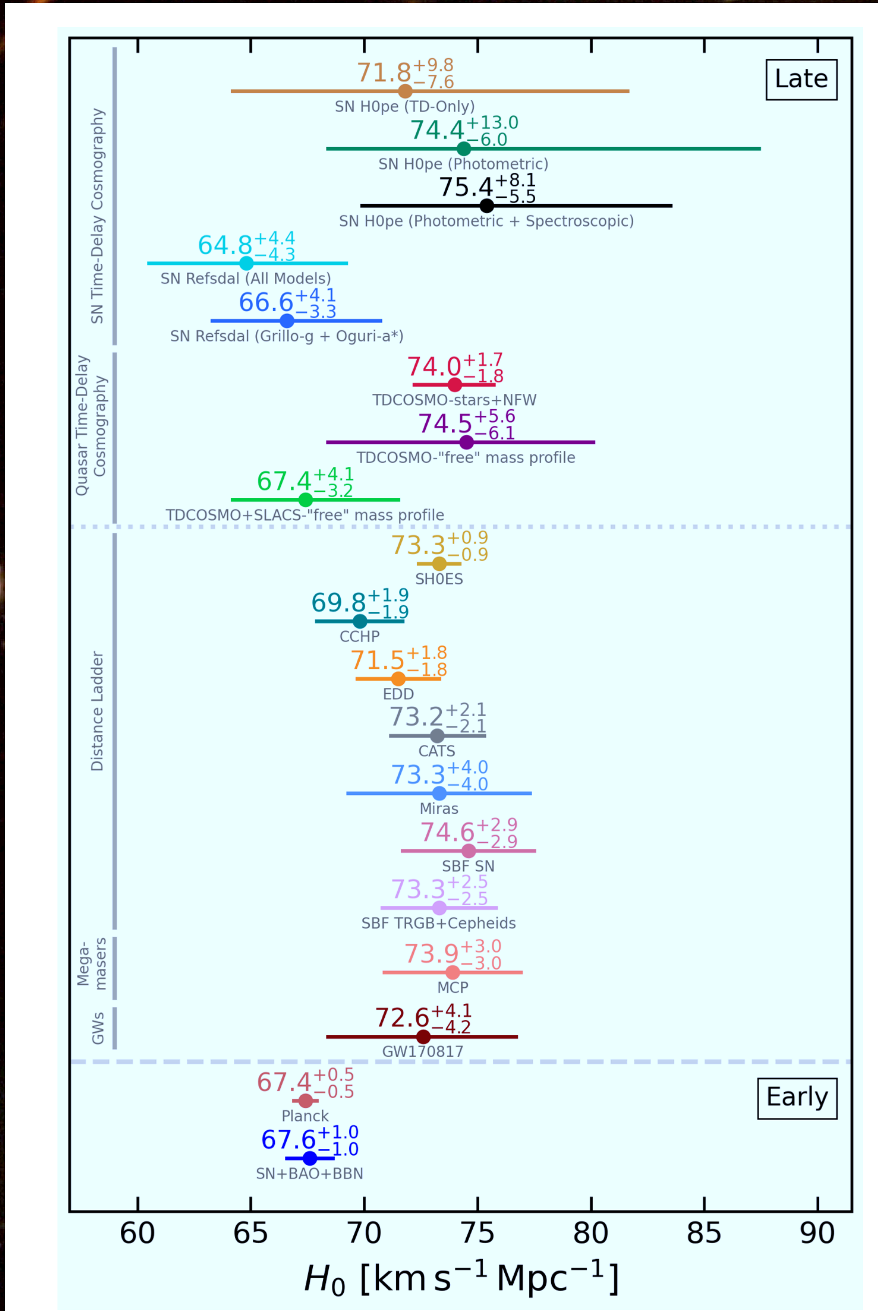


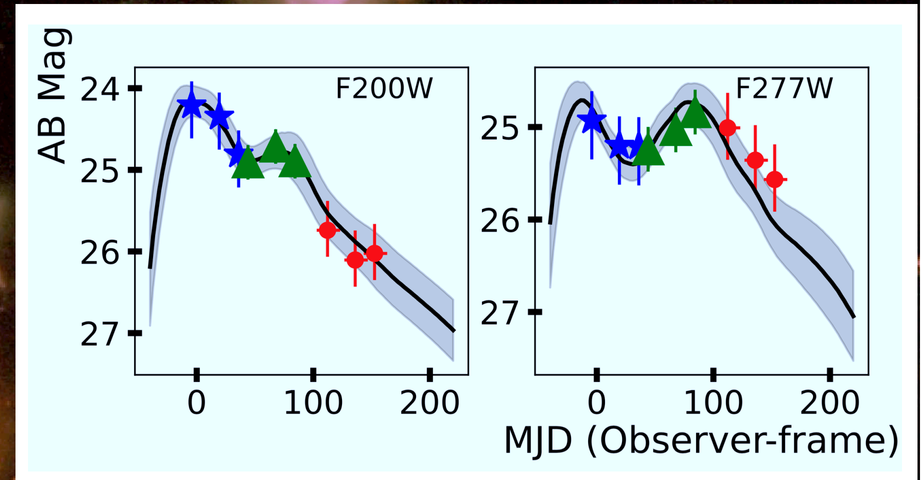
NIRCam in G165 shows: 3 bright point sources parity-flipped w.r.t. Arc-2:

- Clear SN-Ia at z = 1.783! (Frye, Pascale, Pierel, Chen$^+$ 2024, ApJ, 961, 171).
- 3-epoch G165: 9-point light curve (Pierel$^+$24)! $\longrightarrow$ measure H_0 (Polletta$^+$23, Frye$^+$24, Chen$^+$24, Kamieneski$^+$24, Pierel$^+$24, Pascale$^+$24);

$\rightarrow$ Regular monitoring of clusters with extreme SF can yield more lensed SNe!

- Total SFR$\simeq$200–350 $M_\odot$/yr predicts $\gtrsim$1 lensed SN/yr (Kamieneski$^+$ arXiv/2404.088058)

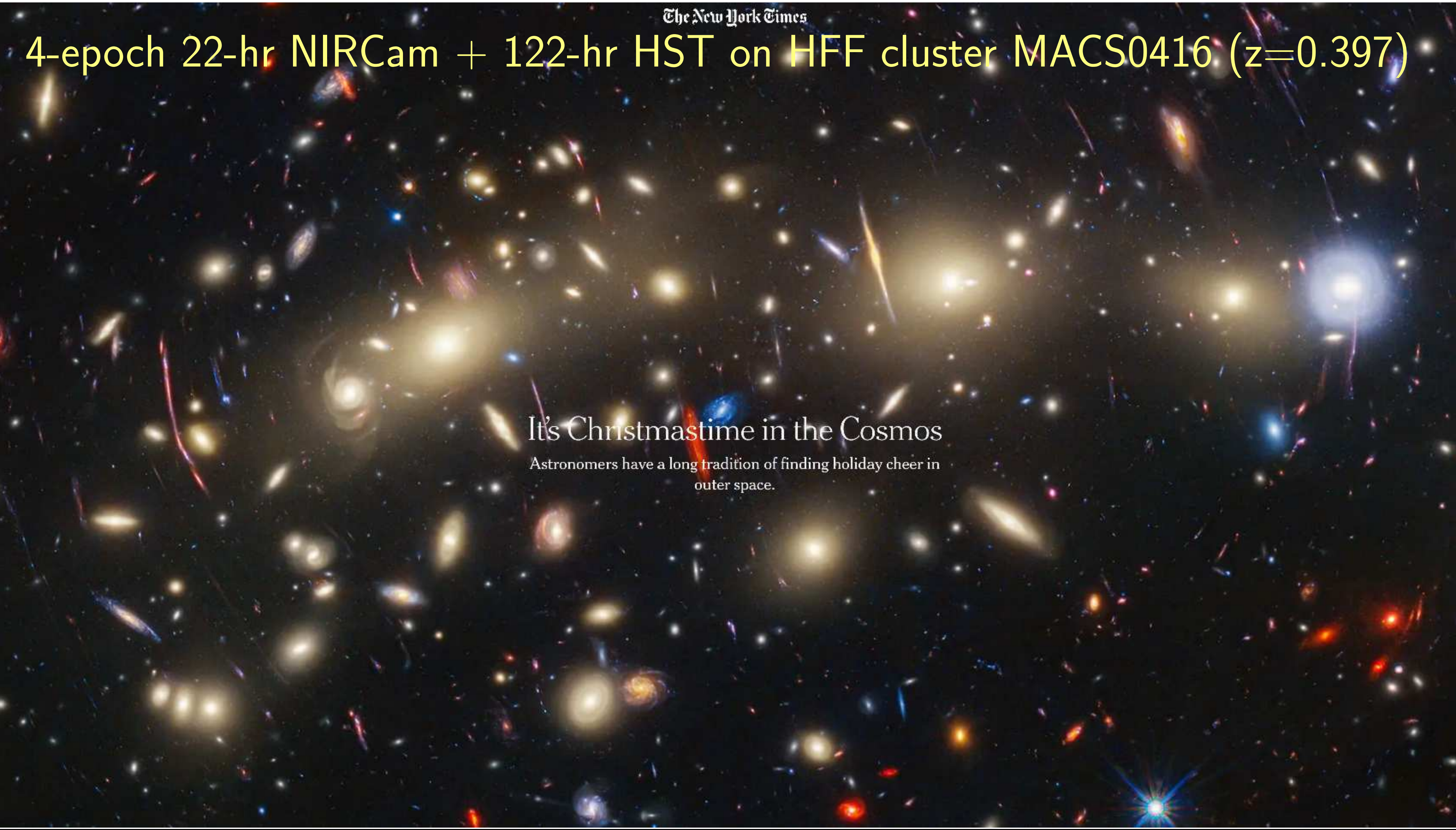




Pascale+ (arXiv/2402.18902): Photo & spectro time delay: $H_o = 75.4^{+8.1}_{-5.5}$ (at z=0.35).

• Monitoring G165 predicts ≳1 lensed SN-Ia/yr (Kamieneski+ arXiv/2404.088058)!

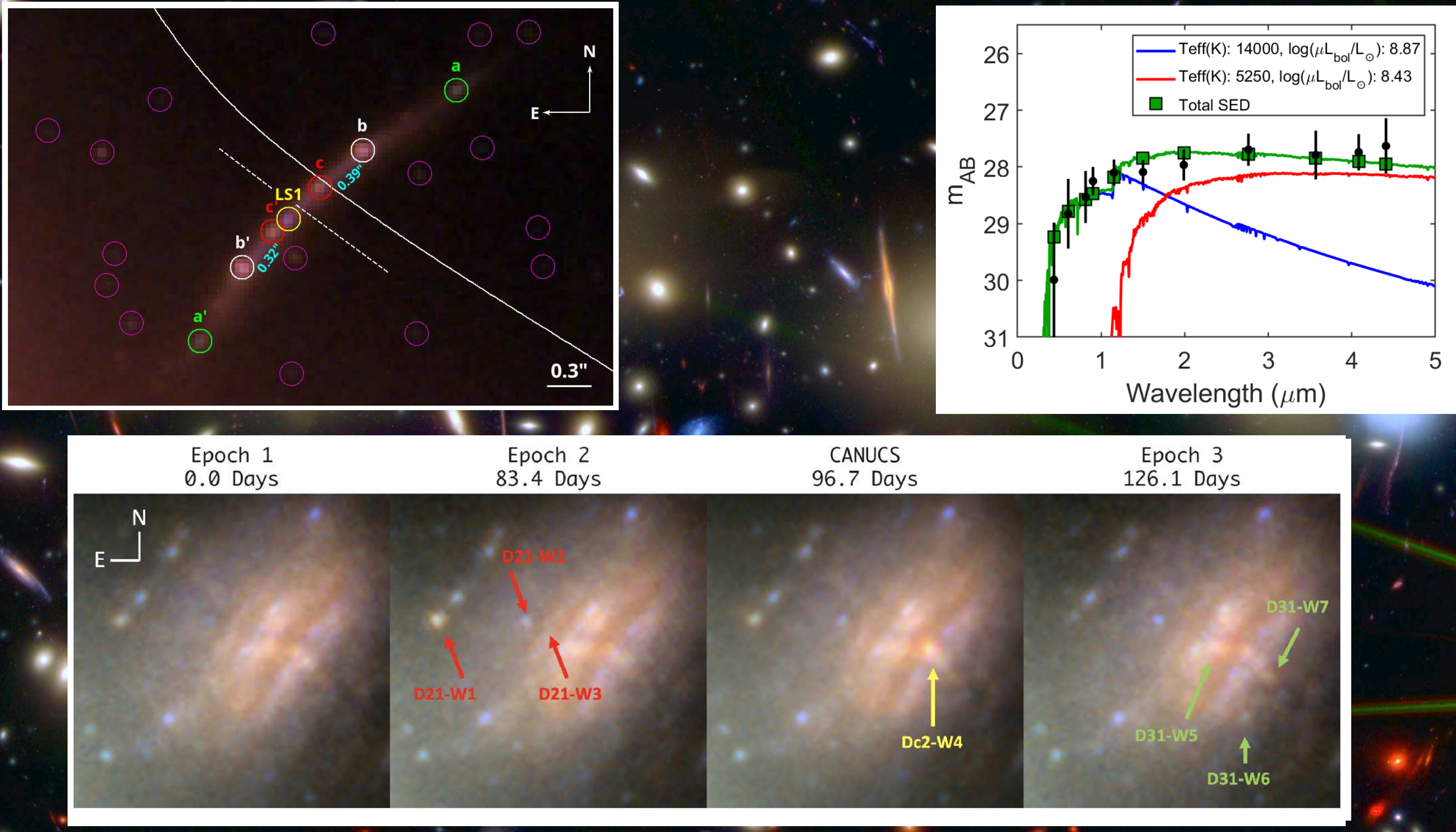
4-epoch 22-hr NIRCam + 122-hr HST on HFF cluster MACS0416 ($z=0.397$)



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 $z=2.091$!

$\Longrightarrow$ Regular monitoring of several clusters can yield IMF's at $z \gtrsim 1$ directly!

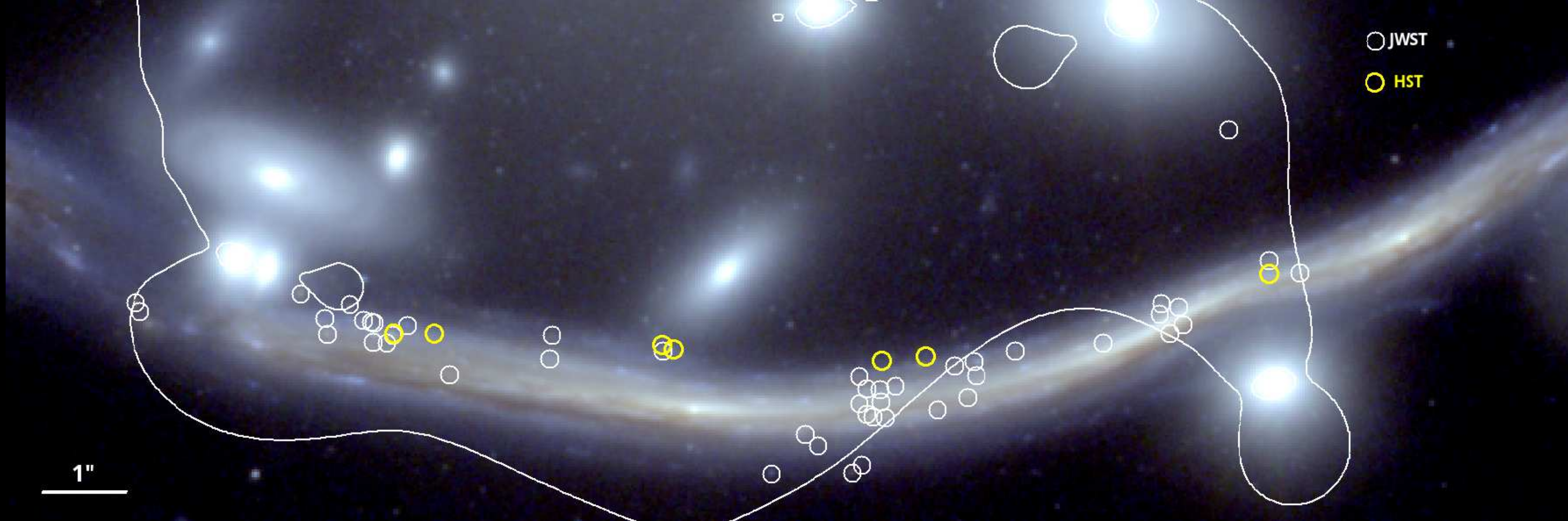


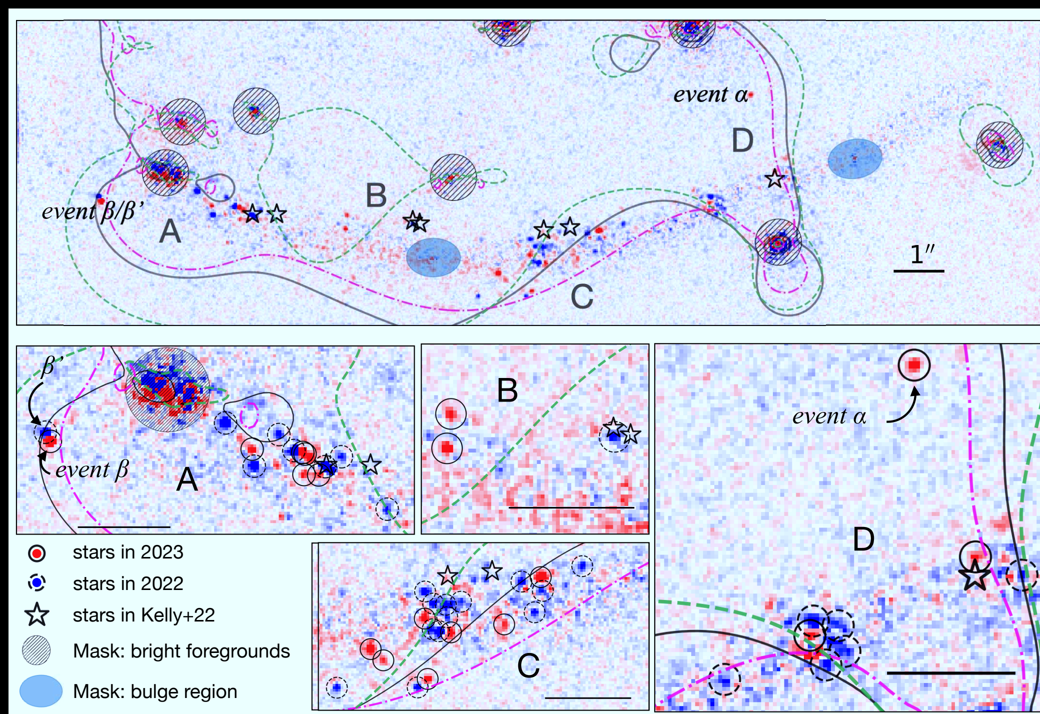
Yan, H.+ (2023, ApJS, 269, 42): 12 new caustic transits at z≃1–2 from 4 epochs!

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

$\Longrightarrow$ Regular monitoring of several clusters can yield IMF's at z$\gtrsim$1 directly!

- With $\mu\simeq$1000-4000, many have SEDs of binary stars at z≃1–2!





MAGNIF's A370 dragon's arc: 46 individual caustic-transiting stars at z=0.73!

(Y. Fudamoto^{+}, astro-ph/2404.08045; J. Diego^{+} astro-ph/2404.08033).

$\Longrightarrow$ JWST Time-Domain permits measuring the IMF at z$\gtrsim$0.7 directly!

PEARLS papers, press releases and other URLs

Talk: http://www.asu.edu/clas/hst/www/jwst/porto24_HST_JWST_VII_Windhorst.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://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, Duncan, 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)

Carleton, T., Ellsworth-Bowers, T., Windhorst, R. A., et al. 2024, ApJL, 961, L37 (astro-ph/2309.16028)

Chen, W., Kelly, P. L., Frye, B. L., et al. 2024, ApJ, submitted (astro-ph/2403.19029)

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, submitted (astro-ph/2312.11603)

Diego, J. M., Li, S. K., Amruth, A., et al. 2024, A&A, submitted (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)

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)

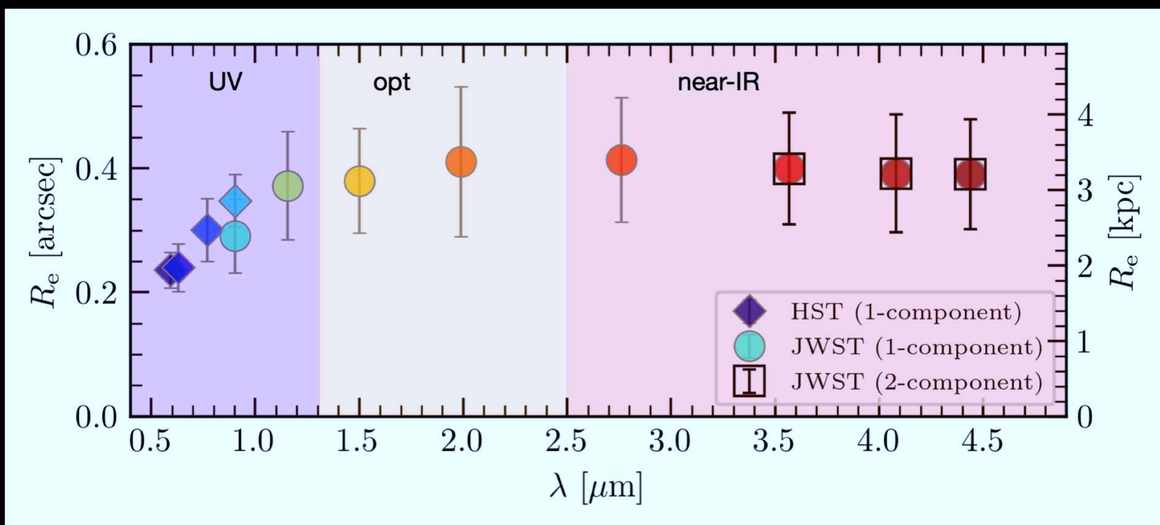
Frye, B. L., Pascale, M., Pierel, J., Chen, W., Foo, N., et al. 2024, ApJ, 961, 171 (astro-ph/2309.07326v1)

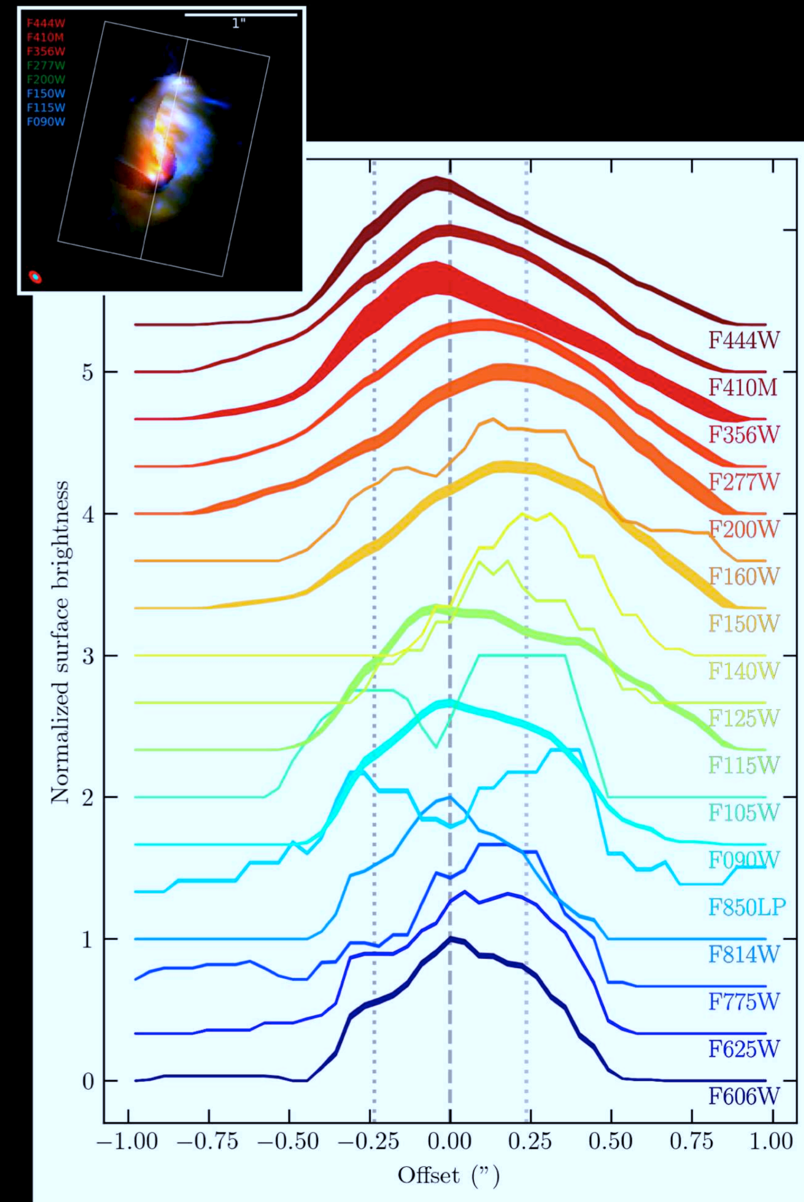
Fudamoto, Y., Sun, F., Diego, J. M., et al. 2024, Nat. Astron., submitted (astro-ph/2404.08045)
Juodzbalis, I., Conselice, C. J., Singh, M., et al. 2023, MNRAS, 525, 1353 (astro-ph/2307.07535)
Kamieneski, P. S., Frye, B. L., Pascale, M., et al. 2023, ApJ, 955, 91 (astro-ph/2303.05054)
Kamieneski, P. S., Frye, B. L., Windhorst, R. A., et al. 2024, ApJ, submitted (astro-ph/2404.08058)
Keel, W. C., Windhorst, R. A., Jansen, R. A., et al. 2023, AJ, 165, 166 (astro-ph/2208.14475)
Nabizadeh, A., Zackrisson, E., Pacucci, F., et al. 2024, A&A, 683-58 (astro-ph/2308.07260)
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, in press (astro-ph/2401.04944)
Ortiz, III, R., Windhorst, R. A., Cohen, S. H., et al. 2024, ApJ, submitted (astro-ph/2404.10709)
Pascale, M., Frye, B. L., Pierel, J. D. R., et al. ApJ, submitted (astro-ph/2403.18902)
Pierel, J. D. R., Frye, B. L., Pascale, M., et al. 2024, ApJ, in press (astro-ph/2404.02139)
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, in press (astro-ph/2403.15619)
Smail, I., Dudzeviciute, U., Gurwell, M., et al. 2023, ApJ, 958, 36 (astro-ph/2306.16039)
Summers, J., Windhorst, R. A., Cohen, S. H., et al. 2023, ApJ, 958, 108 (astro-ph/2306.13037)
Trussler, J. A. A., Conselice, C. J., Adams, N., et al. 2024, MNRAS, 527, 11627–11650 (astro-ph/2308.09665)
Willner, S. P., Gim, H. B., Polletta, M. et al. 2023, ApJ, 958, 176 (astro-ph/2309.13008)
Windhorst, R., 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)
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, ApJ, 2023, ApJS, 269, 43 (astro-ph/2307.07579)
Zhao, X., Civano, F., Willmer, C. N. A., et al. 2024, ApJ, 965, 188 (astro-ph/2402.13508)

SPARE CHARTS

How does its size vary from UV to IR?

- Effective radius is nearly *constant* from rest-frame blue optical through near-IR, despite a redder center
- Larger sSFR in galaxy outskirts --> Inside-out quenching?
- Both variations in sSFR and in dust attenuation are likely responsible for the complex color gradients

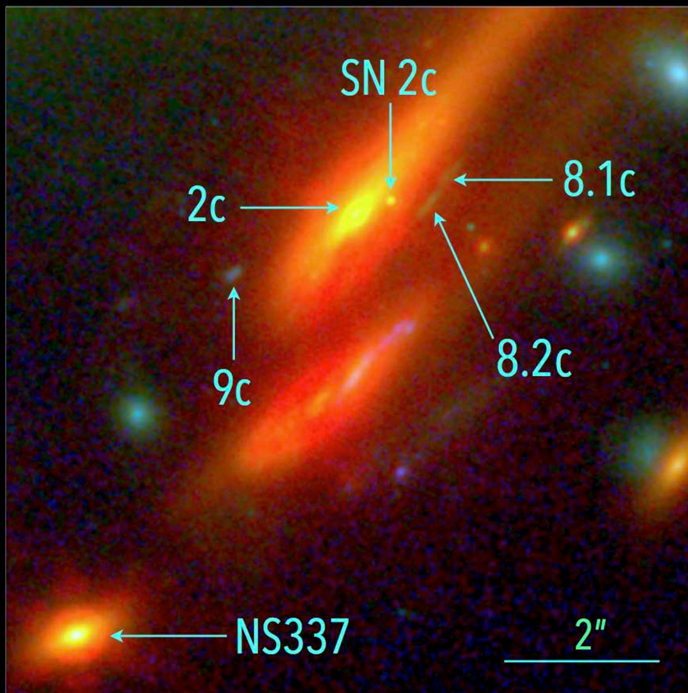


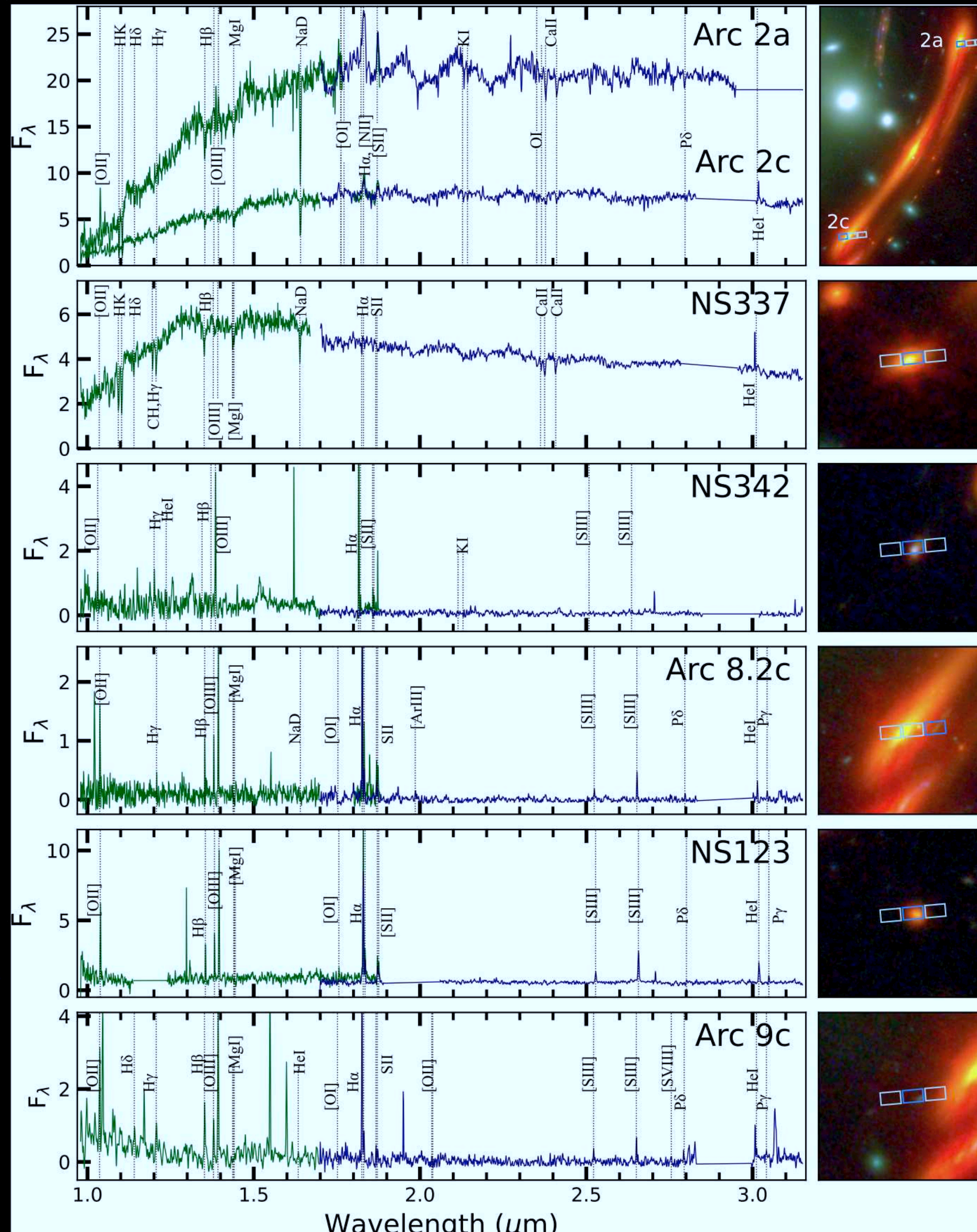


Kamieneski et al. (2023, ApJ, in press; astro-ph/2303.05054):

- Dusty “El Anzuelo” has a high de-magnified total SFR$\simeq$80 $M_\odot$/yr.
- Larger sSFR in delensed outskirts $\Longrightarrow$ inside–out quenching?

JWST/NIRSpec





- SN 2c and its host galaxy (2c) are depicted with 4 *close* galaxy neighbors (Δv<900 km/s, source plane separation <34 kpc)
- Spectroscopy/SED fits find Arc 2 to be quiescent & massive & its friends to be SFGs/SBGs
- This picture is potentially consistent with galaxy downsizing
- Look for upcoming papers **(Frye+23b; Pierel+23; Chen+23; Pascale+23b)**
-

- Frye$^+$ 23: Very high *de-magnified total* SFR$\simeq$200–350 $M_\odot$/yr.