JWST-ER1: An Einstein Ring

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https://www.nature.com/articles/s41550-023-02103-9

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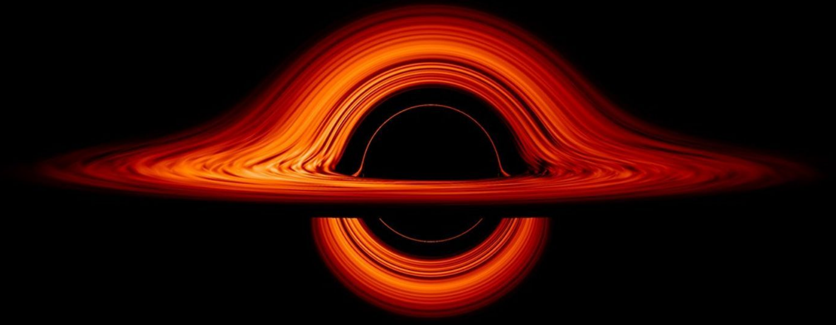
Einstein Rings

[1]

Gravitational Lensing

- **Definition:** the bending of light due to spacetime curvature around a mass, causing background objects to appear magnified, distorted, or multiplied.



https://science.nasa.gov/universe/black-hole-week/

$\hat{\alpha}$ = deflection angle (rad)

G = Gravitational Constant ($m^3 kg^{-1} s^{-2}$)

M = Mass of object (kg)

c = Speed of light (m/s)

b = Impact parameter (m, pc, or AU)

β = True angular position (rad)

θ = Apparent angular position (rad)

$\alpha(\theta)$ = Reduced deflection angle (rad)

θ_E = Ring angular size (Einstein Radius)

D_L = Distance from lens and object/source (m)

D_L = Distance from lens to observer (m)

D_S = Distance form source to observer (m)

$$\hat{\alpha} = \frac{4GM}{c^2 b}$$

Deflection Angle

$$\beta = \theta - \alpha(\theta)$$

Lens Equation

$$\theta_E = \sqrt{\frac{4GM}{c^2}\frac{D_{LS}}{D_L D_S}}$$

Einstein Radius

$$\theta_E = \sqrt{\frac{4GM}{c^2}\frac{D_{LS}}{D_L D_S}}$$

$\theta_E =$ *Ring angular size (Einstein Radius)*

$D_{LS} =$ *Distance from lens and object/source (m)*

$D_L =$ *Distance from lens to observer (m)*

$D_S =$ *Distance form source to observer (m)*

Some History (Proving GR)

Eddington Experiment:

- **Goal:** test Einstein's General Relativity by measuring how much starlight bends near the Sun.
- **Method:** photograph stars during a total solar eclipse, when the Sun's light is blocked.
- **Eddington led two expeditions to observe the eclipse:**

    Principe Island (off Africa)

    Sobral, Brazil

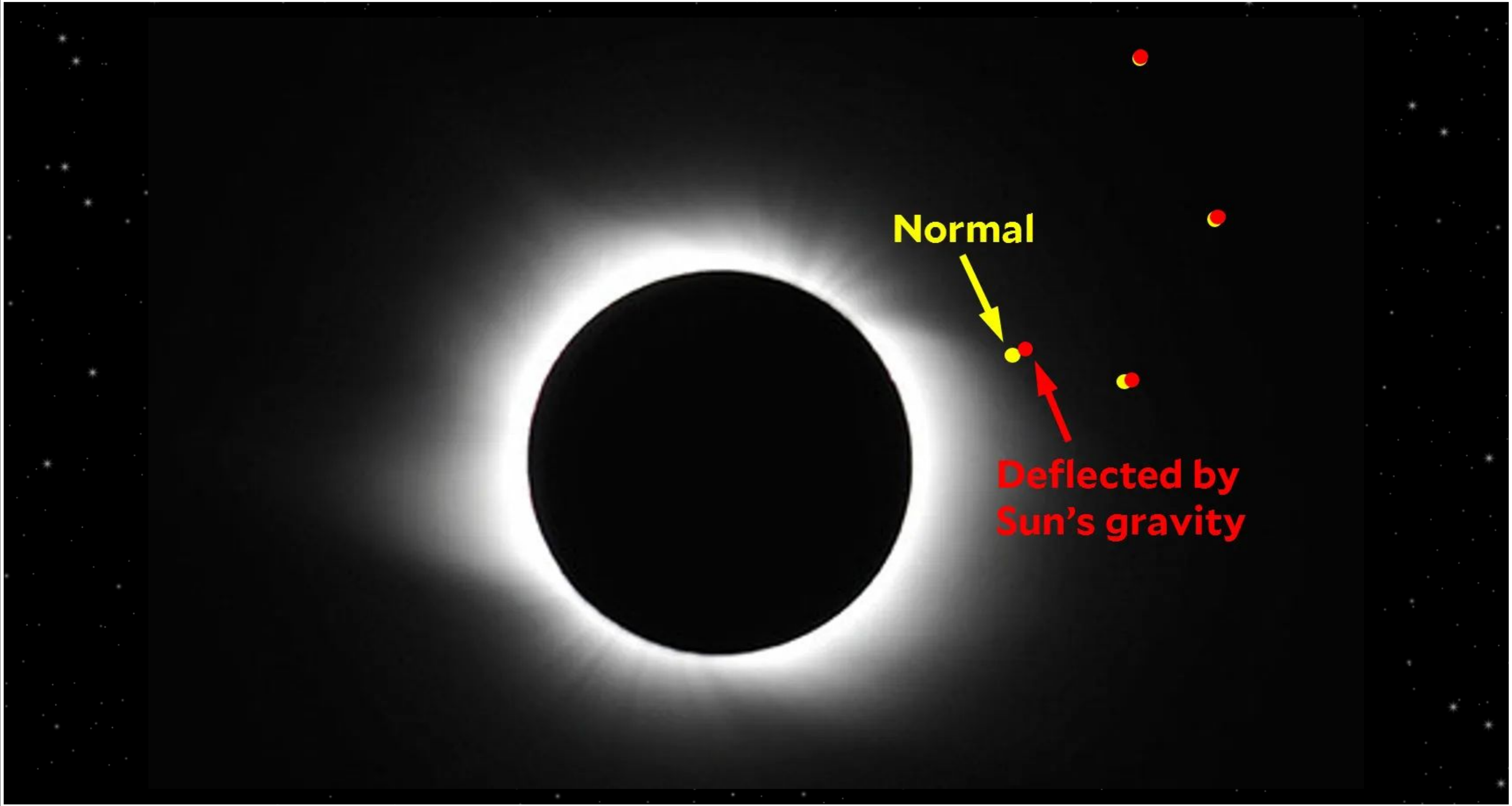
- During the eclipse, starlight passing near the Sun's edge was measured and compared to their normal positions at night.

    Newtonian gravity → 0.87 arcseconds of deflection

    Einstein's GR → 1.75 arcseconds

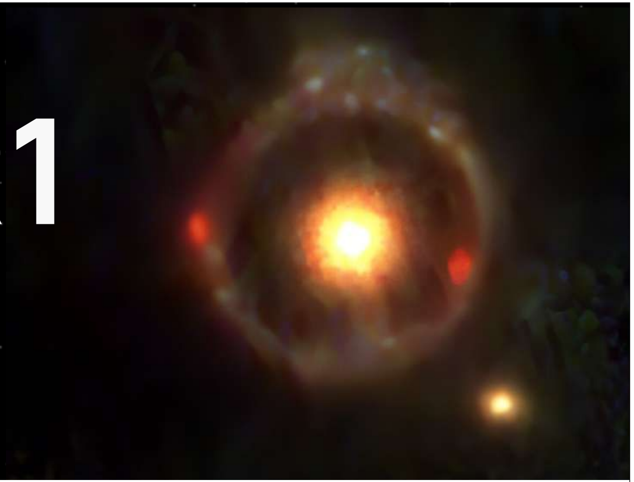
    Observed deflection matched Einstein's prediction, not Newton's.

- **Result:** first major experimental confirmation of General Relativity.


Normal
Deflected by
Sun's gravity

02

JWST-ER1



https://science.nasa.gov/mission/hubble/science/science-behind-the-discoveries/hubble-gravitational-lenses/

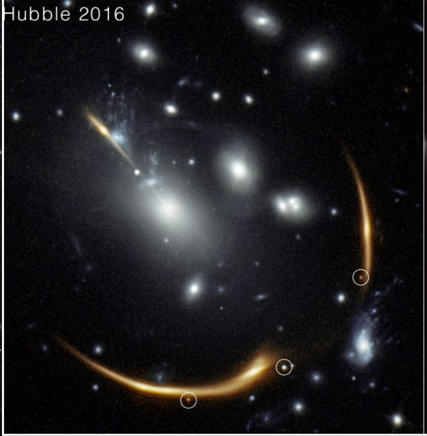
Known Features:

- Lens Galaxy **(JWST-ER1g):**
  Photometric redshift: z_l = 1.94 (+0.13 / −0.17)
  Effective radius: r_e ≈ 1.9 ± 0.2 kpc
  Sérsic index: n ≈ 5.0 ± 0.6
  Stellar mass (within Einstein radius): ~1.1 × 10^11 solar masses
  Total mass (within Einstein radius): ~6.5 × 10^11 solar masses
  Dark-matter mass (same region): ~2.6 × 10^11 solar masses
  Stellar population age: ~1.9 billion years
  Star-formation rate: ~4 solar masses per year (quiescent)
  Morphology: compact, round, early-type galaxy

- Einstein Ring **(JWST-ER1r):**
  Observed diameter: 1.54 arcsec ± 0.02
  Corresponding physical radius: ~6.6 kpc

- Background Source Galaxy:
  Photometric redshift: z_s = 2.98 (+0.42 / −0.47)

[3-8]



JWST is great at finding lenses

03
Research

Select a collection...

MAST Observations by Object Name or RA/Dec

About Collections...

and enter target:

Enter object name or RA and Dec to cone search

Search

Show Examples... Random Search Advanced Search

anonymous

Login...

Account Info...

Upload Target List

My Download Basket: 14208 files

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AstroView

MAST: Barbara A. Mikulski Archive for Space Telescopes

The MAST Portal lets you search multiple collections of astronomical datasets all in one place. Use this tool to find astronomical data, publications, and images.

Note: This site uses cookies in order to monitor feature usage, track user preferences, and provide authentication for some services. By using this site you consent to the use of cookies for such purposes.

What's New

JWST Instrument metadata have changed. Now, the complete configuration is specified; for example, an Observation previously labeled "MIRI" might now be labeled "MIRI/IMAGE." This update brings JWST metadata in line with HST and allows for greater specificity in your search. See the JWST Instrument Names page for a full list of configurations.

Data from FIMS-SPEAR, a joint Korean-US UV satellite, are now available in MAST. In addition to its invaluable spectral maps of the UV sky, FIMS-SPEAR has paved the way for us to ingest new cubesat, balloon, and small-rocket missions. Stay tuned as we add more of these missions to our collection!

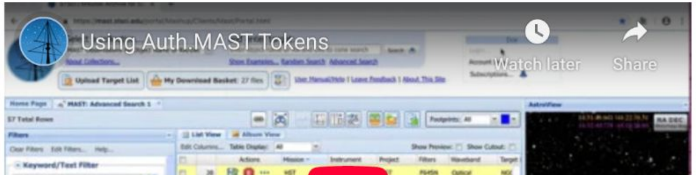
You can now access the PLATO MAST Catalog using the API or catalog search form.

Data Retrieval Notes

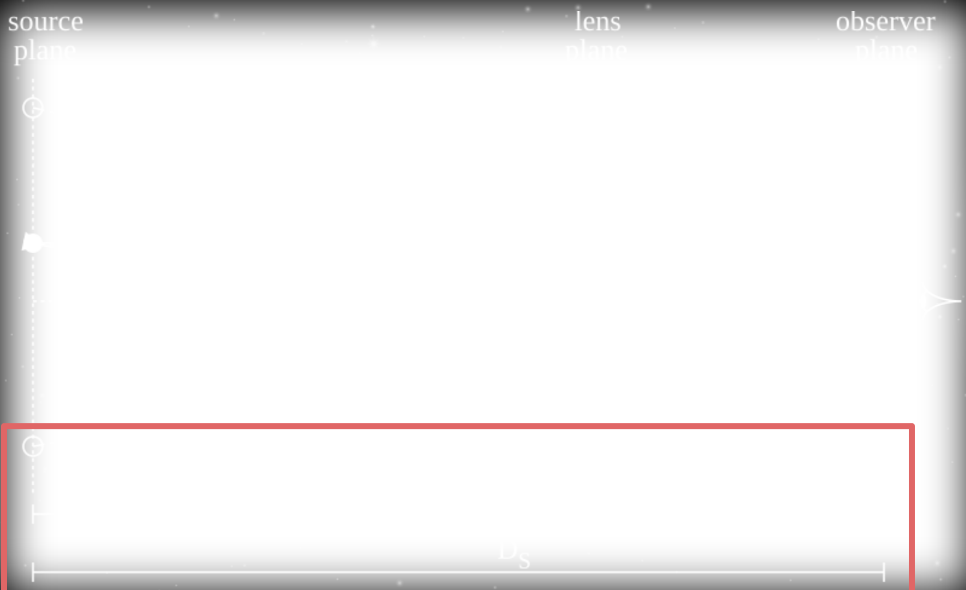
Currently available data collections:

- MAST Observations: Millions of observations from JWST, Hubble, Kepler, GALEX, IUE, FUSE, and more.
- Virtual Observatory: Search thousands of astronomical data archives from around the world for images, spectra, and catalogs.
- Hubble Source Catalog: A master catalog with a hundred million measurements of objects in Hubble images.
- MAST Catalogs: Access to catalog data such as Gaia and TESS Input Catalog, with more coming soon.

Featured tutorial: Using Auth.MAST, MAST's authorization token system.



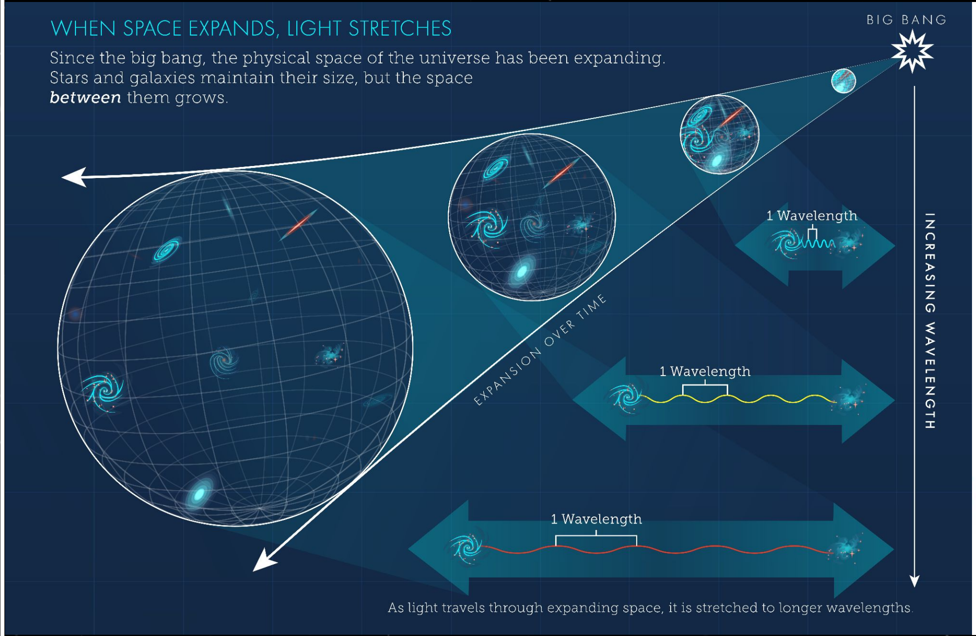
Einstein Radius

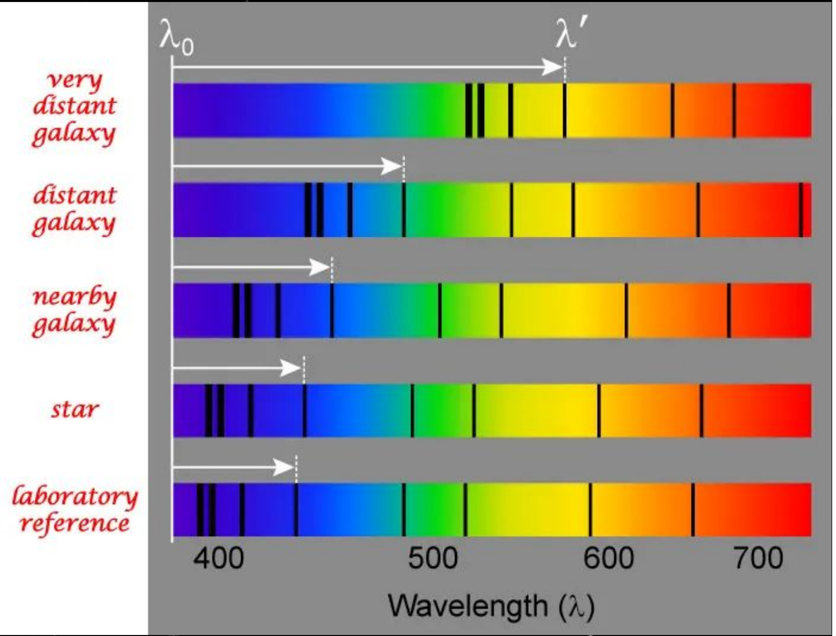


$$M(<\theta_E) = \frac{c^2}{4G}\boxed{\frac{D_\mathrm{l}\, D_\mathrm{s}}{D_\mathrm{ls}}}\theta_E^2$$

https://en.wikipedia.org/wiki/Einstein_radius#/media/File:Gravitational_lens_geometry.svg

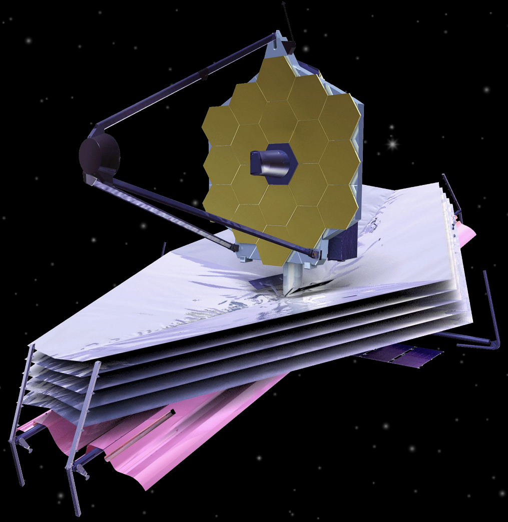
Spectroscopy!

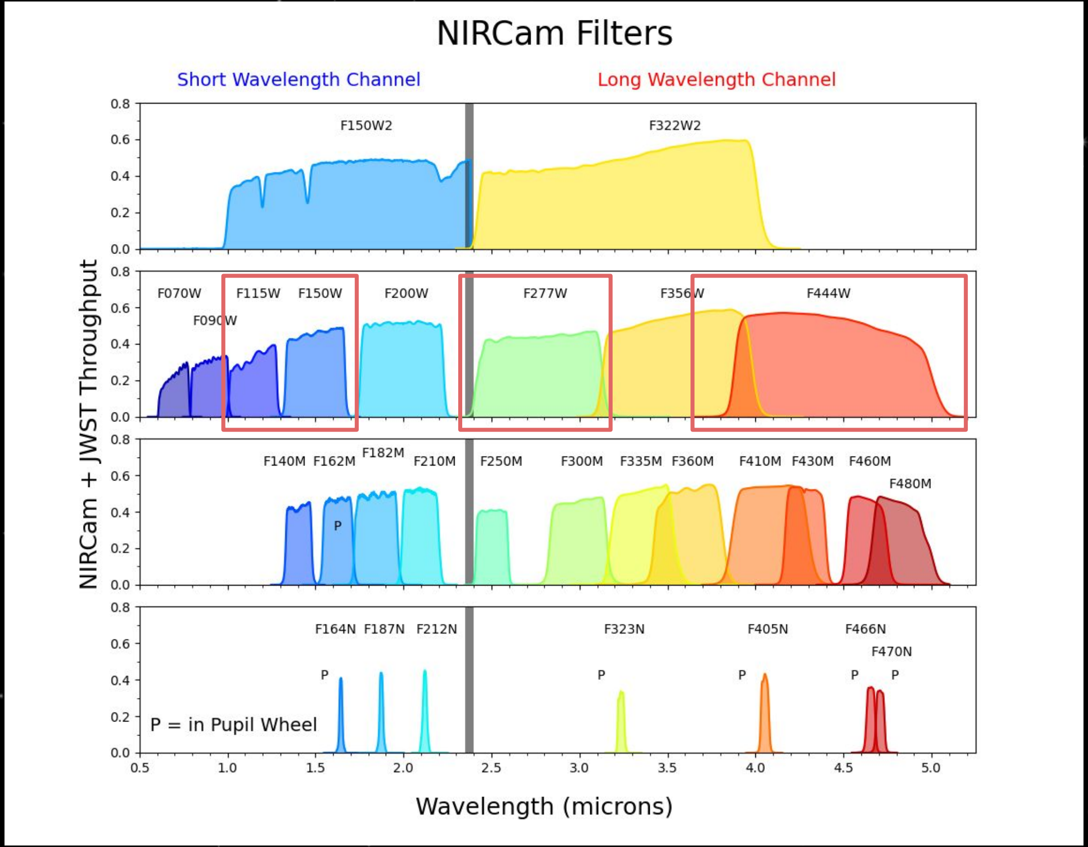




https://science.nasa.gov/mission/hubble/science/science-behind-the-discoveries/hubble-cosmological-redshift/
https://www.universetoday.com/articles/a-new-way-to-measure-the-expansion-rate-of-the-universe-redshift-drift

*NOT ACCURATE COLORS





https://jwst-docs.stsci.edu/jwst-near-infrared-camera/nircam-instrumentation/nircam-filters#gsc.tab=0

The following datasets were analyzed (nomenclature explanation):

Program ID **01727**, Observation ID **o140**, Target **t104** (the region where JWST-ER1 is located in the JWST data map). Focused on **nircam** data (0.6 - 5.0 µm | 2.07 - 0.248 eV), using no additional filters (**clear**).

jw01727-o140_t104_nircam_clear-f115w

jw01727-o140_t104_nircam_clear-f150w

jw01727-o140_t104_nircam_clear-f277w

jw01727-o140_t104_nircam_clear-f444w

Link

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James Webb Space Telescope JWST NASA • ESA • CSA

Extraction, Calibration, and Cleaning

- Utilized the filters previously mentioned:
  - **f115W**: 1.013 - 1.282 μm | 1.225 - 0.968 eV
  - **f150W**: 1.331 - 1.668 μm | 0.932 eV - 0.744 eV
  - **f227W**: 2.422 - 3.131 μm | 0.512 - 0.396 eV
  - **f444W**: 3.881 - 4.982 μm | 0.319 - 0.249 eV

- **Stage 0**: Produces uncalibrated raw data products from single exposures in units of total DN (e.g., "uncal.fits")
- **Stage 1:** Produces data products that have been corrected for certain detector effects and converted to units of DN/s (e.g., "rate.fits")
- **Stage 2:** Produces calibrated data products from single or multiple exposures with world coordinates and photometric information (e.g., "cal.fits")
- **Stage 3**: Produces calibrated data products resulting from the combination of multiple exposures into a single integrated product (e.g., "i2d.fits", "s3d.fits", "x1d.fits")

jw01727-o138_t096_nircam_clear-f115w
jw01727-o138_t096_nircam_clear-f150w
jw01727-o138_t096_nircam_clear-f277w
jw01727-o138_t096_nircam_clear-f444w
jw01727-o140_t104_nircam_clear-f115w
jw01727-o140_t104_nircam_clear-f150w
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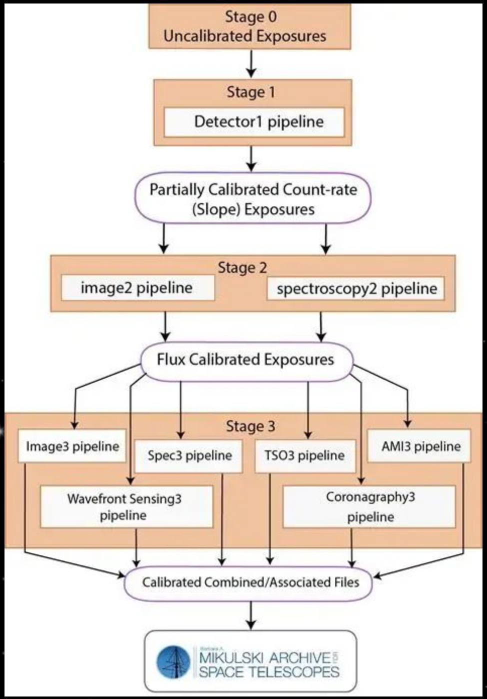
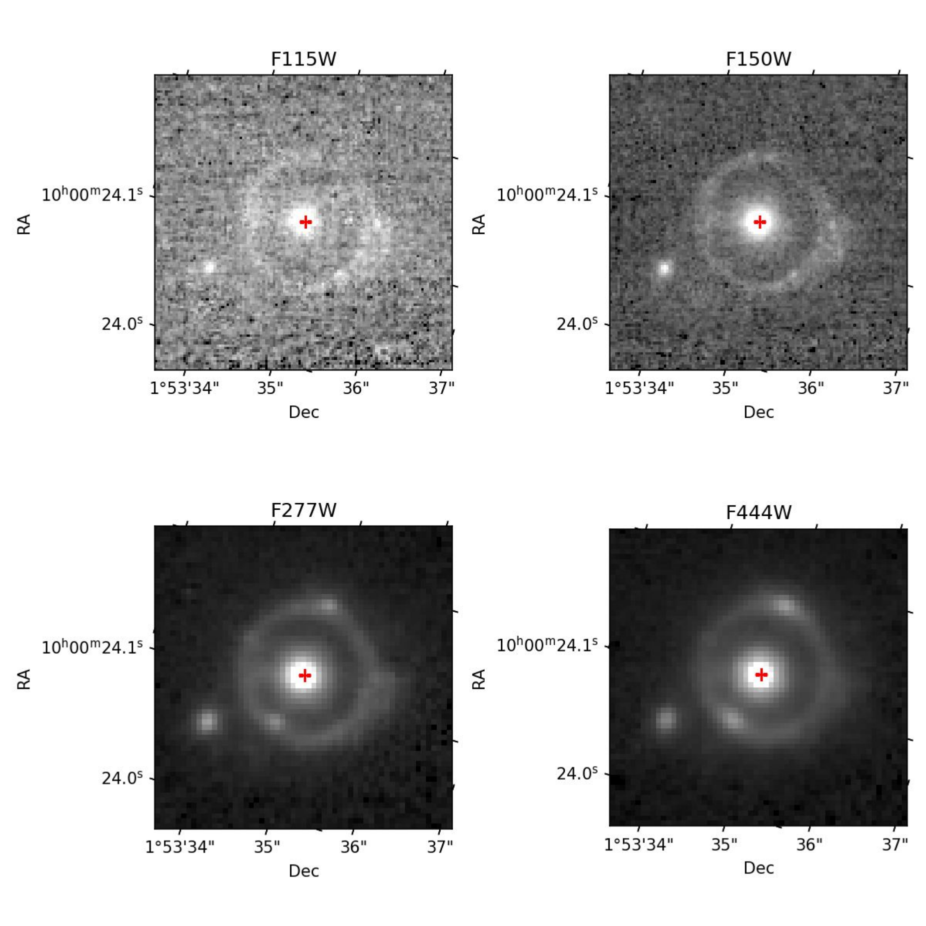
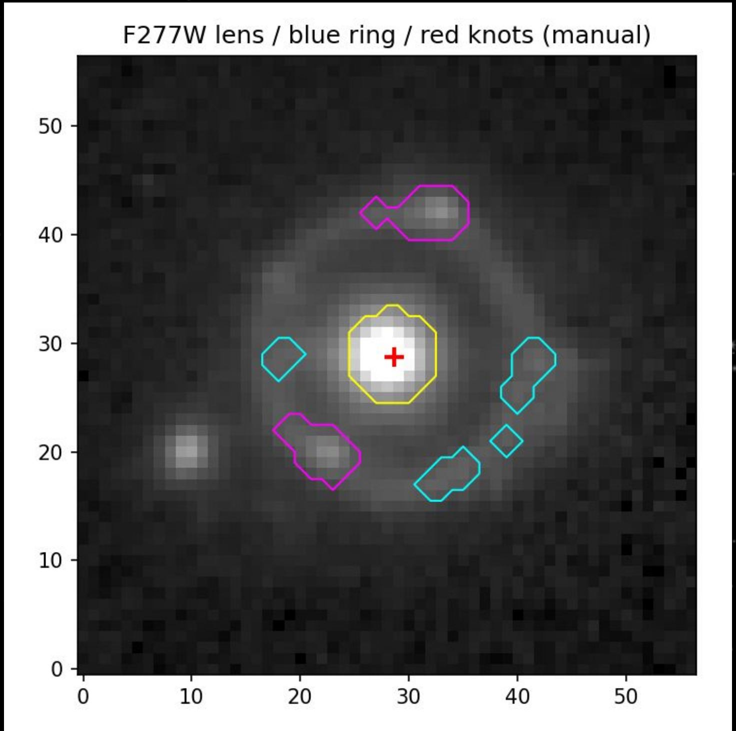
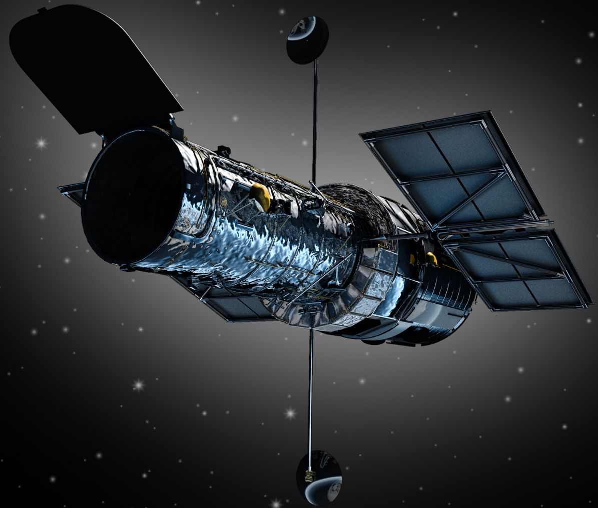
jw01727-o140_t104_nircam_clear-f444w



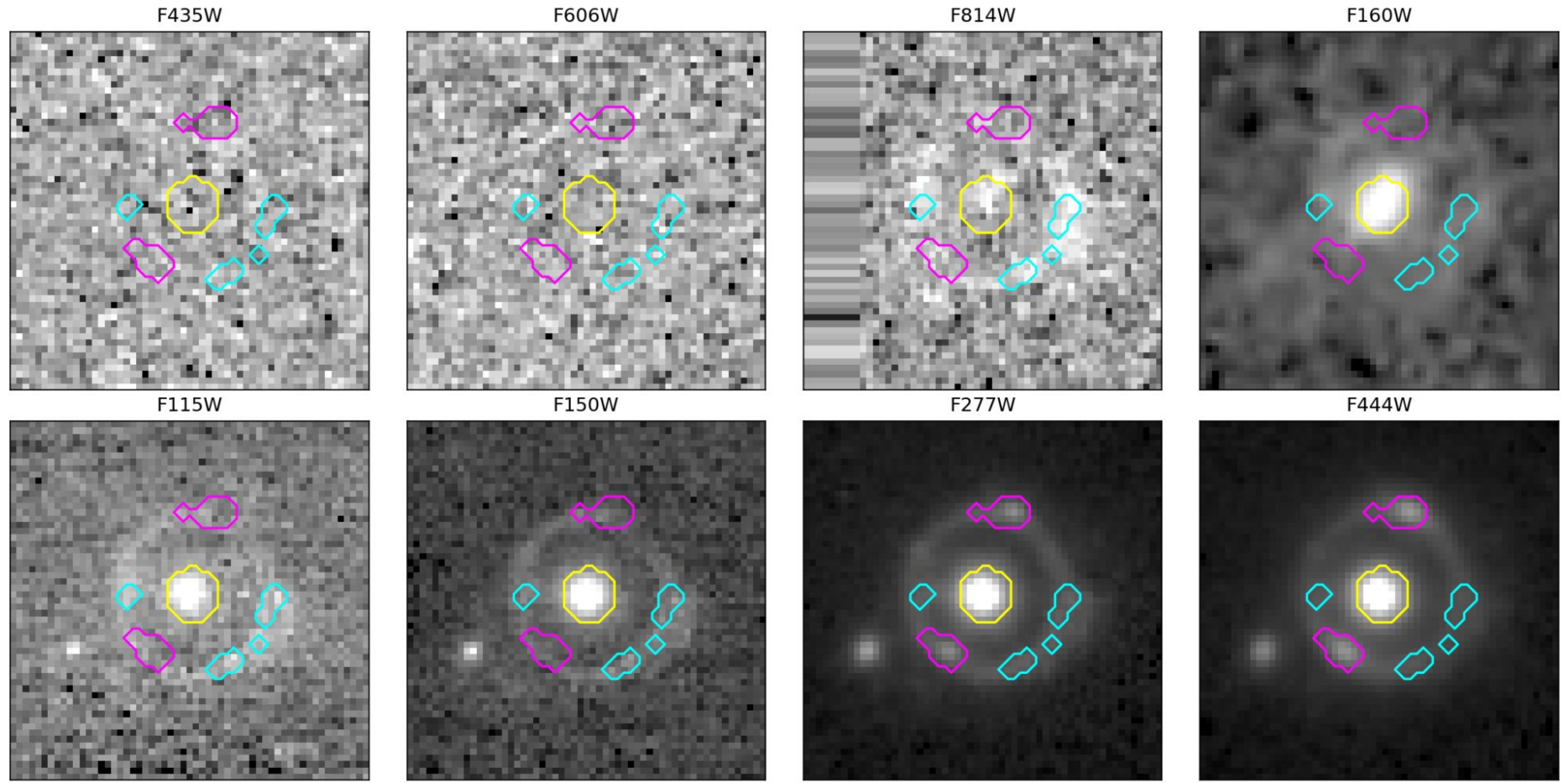
https://jwst-docs.stsci.edu/jwst-science-calibration-pipeline#gsc.tab=0


F115W
F150W
F277W
F444W
10^h00^m24.1^s
24.0^s
RA
1°53'34"
35"
36"
37"
Dec

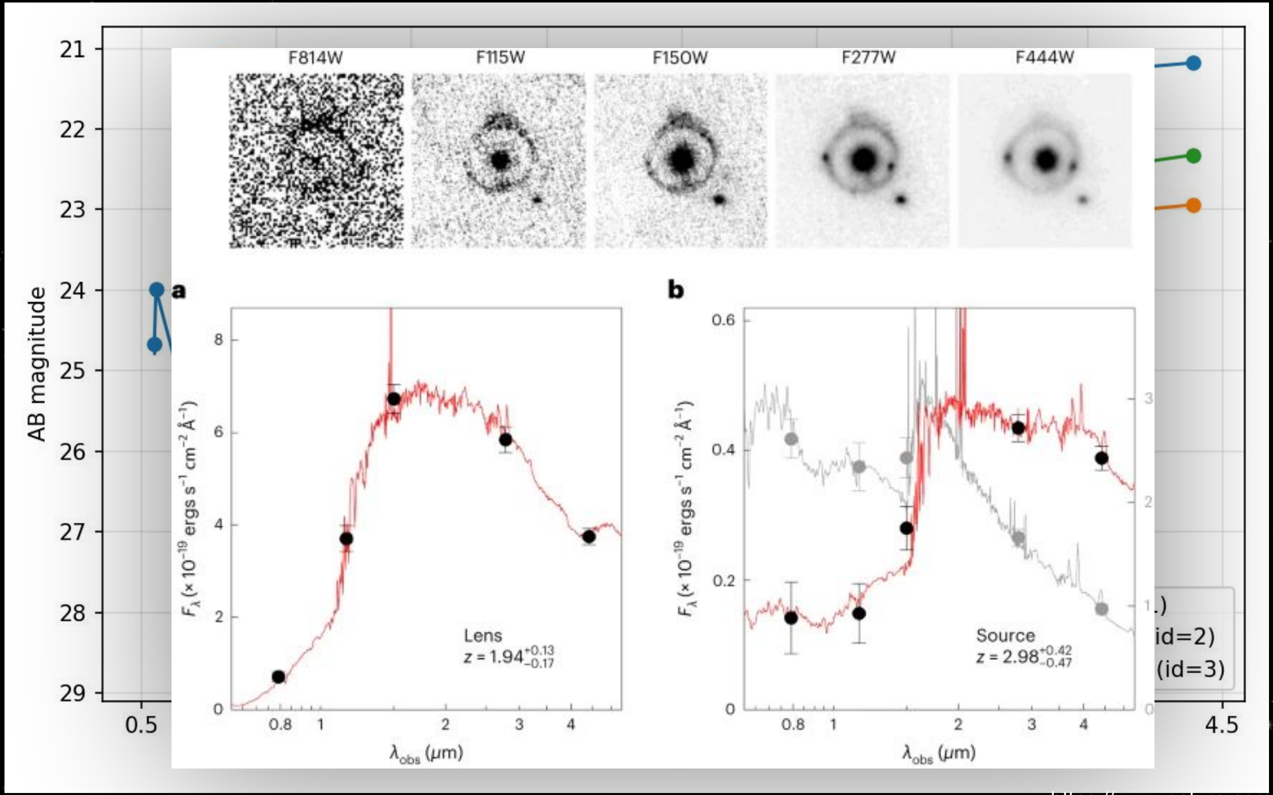

F277W lens / blue ring / red knots (manual)
0
10
20
30
40
50



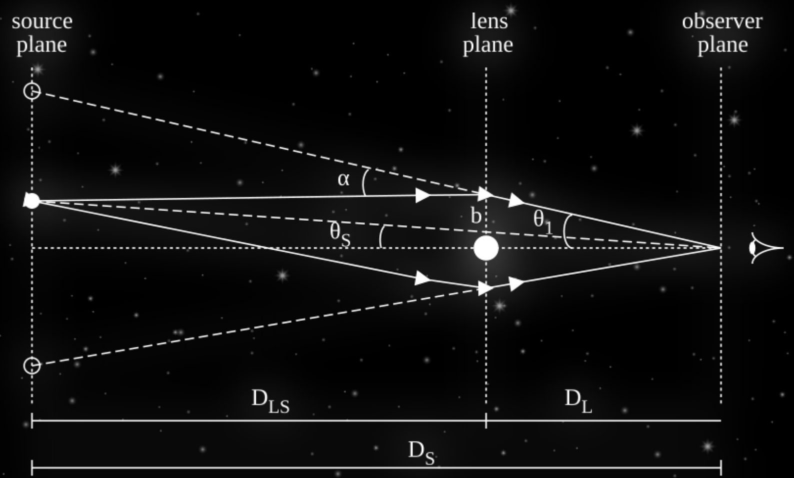

F435W
F606W
F814W
F105W
F125W
F160W
3.00
0.4
0.6
1.0
1.5
Wavelength (microns)


F435W
F606W
F814W
F160W
F115W
F150W
F277W
F444W

EAZY: A Fast, Public Photometric Redshift Code



https://www.nature.com/articles/s41550-023-02103-9



D_L = 1602.057 Mpc
D_s = 1179.631 Mpc
D_{LS} = 259.446 Mpc

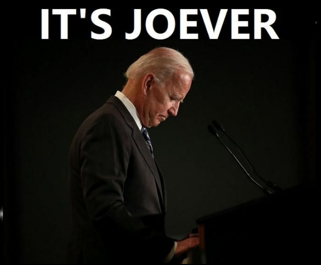
$M(<\theta_E) = 3.220 * 10^{11}\ M_{Sun}$
R_E (physical) = 4.66 kpc

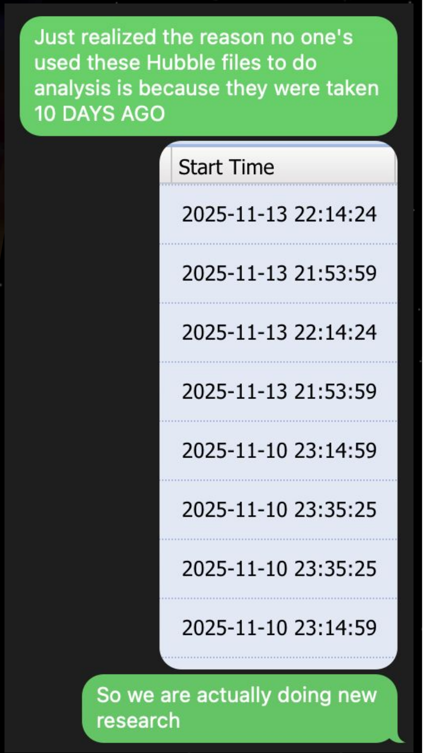
population during the 10 Gyr of galaxy evolution between $z = 2$ and $z = 0$. We find a mass for the lens $M_{\rm lens} = 6.5^{+3.7}_{-1.5} \times 10^{11}\ M_\odot$ within a radius of 6.6 kpc. The stellar mass within the close enough!

03
Conclusions

Conclusions

- Photometric Redshift fitting is HARD.
- Science can be overturned
- Gravitational lensing is cool
- This may have been overkill and we should have asked for more time





Check out the project code here:

Link

Citations Page:

Link

Thank you!

Questions?