A JWST investigation into the bar fraction at redshifts $1 \leq z \leq 3$

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Barred galaxies and their importance

- Bars form over times of the order of a hundred million years, in massive disc galaxies which are dynamically cold and rotationally supported.
- Hence, the presence of a bar indicates a mature stage of galaxy evolution.
- Torques induced by the bar redistribute the angular momentum, causing bar-driven secular evolution.
- Stars on elongated orbits in the bar are typically older stellar populations.
- Simulations find higher bar fractions than observations but can replicate results when applying stellar mass limits or observational limits.
- Studies are using the improved sensitivity and longer wavelength range of JWST to find barred galaxies beyond $z = 1$.
- By observing the bar fraction at high redshifts, we can determine when disc settling occurs and bar-driven processes commence.

Sample Selection

- Redshift range between $1 \leq z \leq 3$.
- Applied a 95% stellar mass limit from Duncan et al. (2019).
- Sample optimisation:
  - Fit elliptical isophotes using photutils.isophote from Python's astropy package, then fix the isophote centres. Remove poorly resolved systems and disturbed systems.
  - Remove galaxies with an inclination $i > 60$.
- Disc sample:
  - JWST [HST] disc galaxies are visually classified and selected from Ferreira et al. (2023) [Kartlatepe et al. (2015)].

See Table 1 for sample selection results!

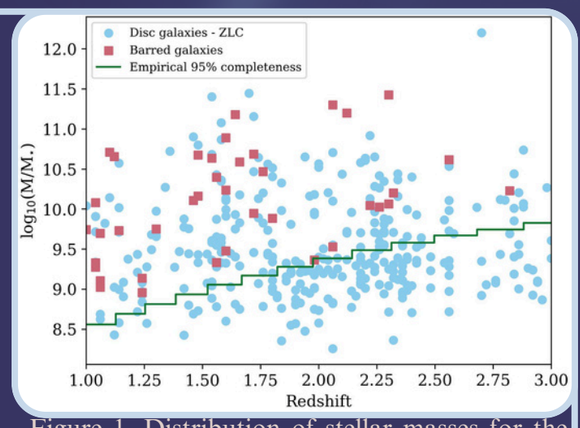

Figure 1. Distribution of stellar masses for the sample of disc galaxies as classified by ZLC in JWST CEERS between the redshifts $1 \leq z \leq 3$.

Observing galaxies with the James Webb Space Telescope (JWST)

- We use the initial four public NIRCam JWST observations from the Cosmic Evolution Early Release Science Survey (CEERS; Finkelstein et al. 2023).
- These pointings overlap with our HST sample.
- We use the JWST Near Infrared Camera (NIRCam) filter F444W to measure the bar fraction.
- Five co-authors visually classified the disc galaxy sample as *barred*, *maybe barred* or *unbarred*.
- 3+ barred votes means the galaxy is strongly barred.
- 3+ maybe barred votes means the galaxy is weakly barred.

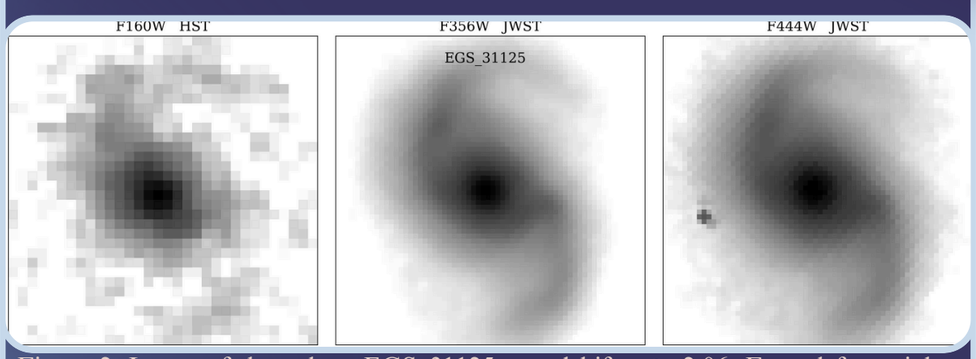

Figure 2. Image of the galaxy EGS_31125 at redshift $z \simeq 2.06$. From left to right: HST WFC3 F160W and JWST NIRCam F356W and F444W. This filter comparison demonstrates the effects of PSF, sensitivity and wavelength range on a galaxy image, particularly in the context of bars. The image shows EGS_31125 in rest frame 0.52, 1.16, and 1.45 μm, respectively.

Credit: NASA

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Bars in the Hubble Space Telescope (HST)

- In the local Universe, ~ 60% of disc galaxies have a stellar bar.
  - The fraction of bars in disc galaxies decreases to ~10% at z=1 (Simmons et al. 2015).
    - Higher bar fractions are found in the Near Infrared (NIR) compared to the optical.
      - We use the HST Wide Field Camera 3 (WFC3) filter F160W from the Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey (CANDELS).

Table 1. Progression of the galaxy sample sizes after the different selection and classification criteria are applied. The bar fractions derived before and after applying the 95% mass completeness limit are given for the two redshift bins at the bottom of the table.

Sample	Redshift	$N_{gal,HST}$	$N_{gal,JWST}$	$N_{gal,HST}$ Mass Complete	$N_{gal,JWST}$ Mass Complete	Criteria applied
Sample Sizes						
Parent sample	$1 \leq z \leq 3$	5445	5218	1299	1180	Redshift
Optimised sample	$1 \leq z \leq 3$	133	768	126	368	ellipse fitting, $i \leq 60°$
	$1 \leq z \leq 2$	108	404	105	237	
	$2 < z \leq 3$	25	364	21	131	
Disc sample	$1 \leq z \leq 3$	100	339	98	229	HST discs from Kartaltepe et al. (2015) and JWST discs from Ferreira et al. (2023)
	$1 \leq z \leq 2$	81	196	81	157	
	$2 < z \leq 3$	19	143	17	72	
Weakly Barred	$1 \leq z \leq 3$	9	26	9	25	Visually classified bars
	$1 \leq z \leq 2$	8	21	8	20	
	$2 < z \leq 3$	1	5	1	5	
Strongly Barred	$1 \leq z \leq 3$	1	13	1	13	Visually classified bars
	$1 \leq z \leq 2$	1	8	1	8	
	$2 < z \leq 3$	0	5	0	5	
The Bar Fraction						
Bar Fraction	$1 \leq z \leq 2$	$0.11^{+0.05}_{-0.04}$	$0.15^{+0.05}_{-0.05}$	$0.11^{+0.05}_{-0.04}$	$0.18^{+0.05}_{-0.05}$	$\frac{N_{weakly\_barred}+N_{strongly\_barred}}{N_{disc}}$
	$2 < z \leq 3$	$0.05^{+0.08}_{-0.04}$	$0.07^{+0.07}_{-0.06}$	$0.06^{+0.08}_{-0.04}$	$0.14^{+0.07}_{-0.06}$	

Finding barred galaxies 11 billion years ago

- For the first time, we have extended the bar fraction in disc galaxies to z=3 using the JWST.
- We found the bar fraction to be 18% between $1 \leq z \leq 2$ which drops to 14% at $2 < z \leq 3$.
- The bar fraction from JWST images is approx. twice that found with HST images.
- The bar fraction depends on the instrumental setup's sensitivity and wavelength.
- Smaller blue disc galaxies will be missed by JWST and bars shorter than 3 kpc are unresolved.
- Our results are presented as the lower limit to the true bar fraction.
- Bar-driven galaxy evolution could commence at a lookback time ~11 Gyrs,

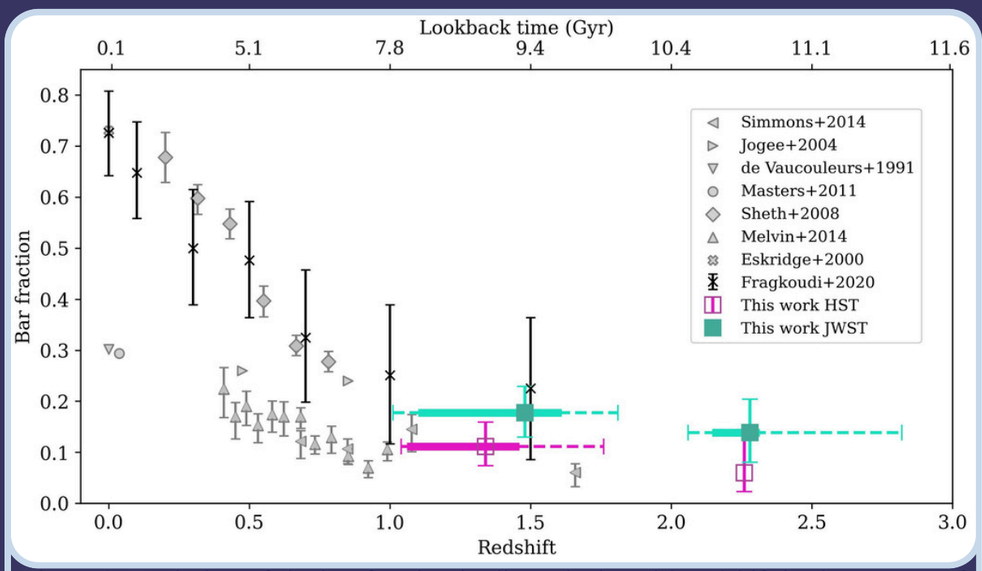

Figure 3. Evolution of the bar fraction in disc galaxies with redshift in the context of other bar assessment work using HST. The fractions of barred disc galaxies found in JWST NIRCam images are shown as filled squares, and the fractions of barred disc galaxies found in this study in HST WFC3 images are shown as empty squares. The bar fraction was found for two redshift bins, $1 \leq z \leq 2$ and $2 < z \leq 3$, where the marker indicates the median redshift of the barred galaxies. The bar fraction errors are the sum in quadrature of the systematic and statistical errors. A dashed line indicates the redshift range of barred galaxies. A thick solid line indicates the redshift range of the quartiles 25%-75% of the barred galaxies distribution.

References

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