A JWST investigation into barred galaxies at high redshifts z > 1

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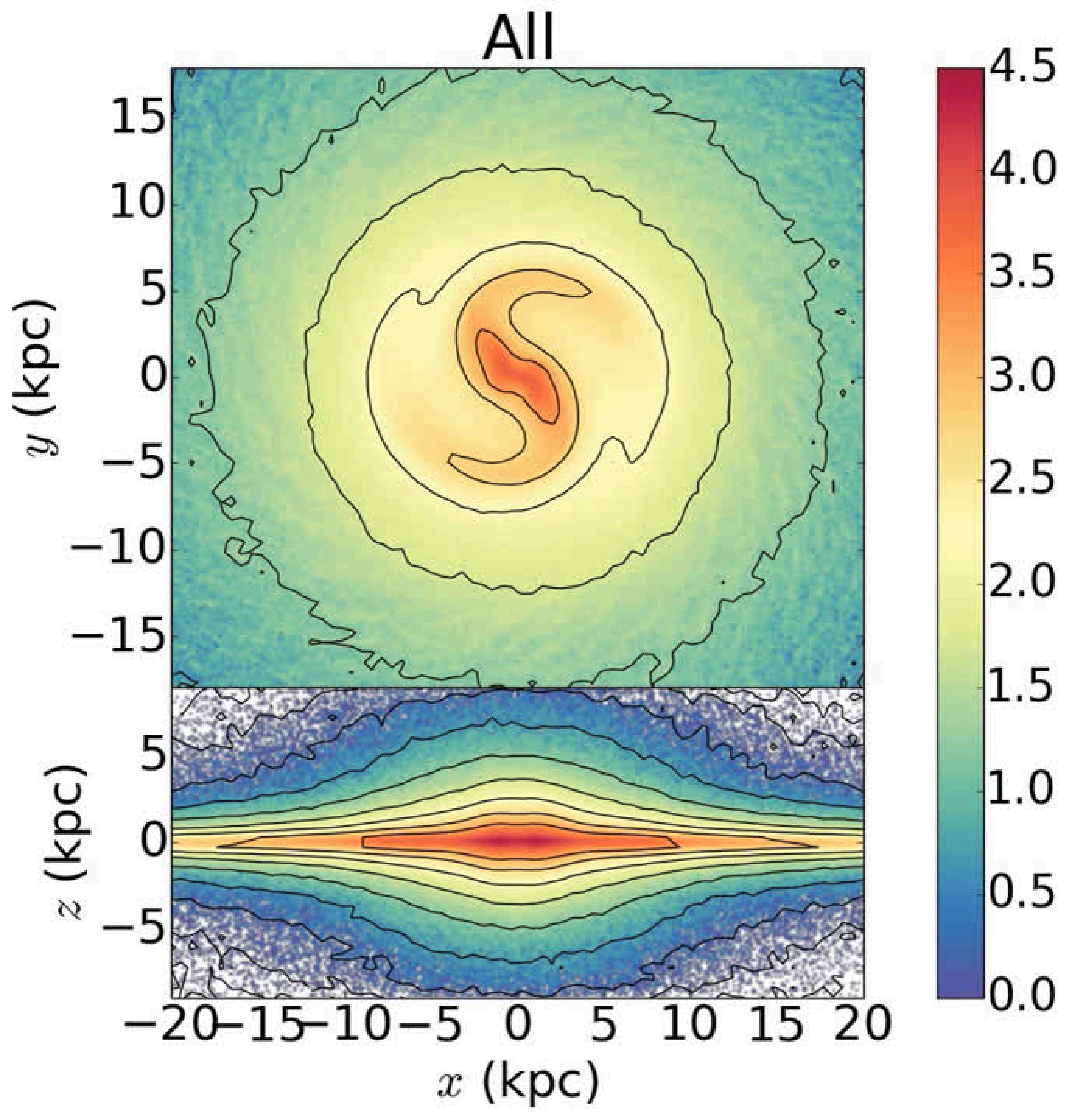
1 HISTORY OF THE BAR FRACTION

2 THE BAR FRACTION

3 BAR PROPERTIES

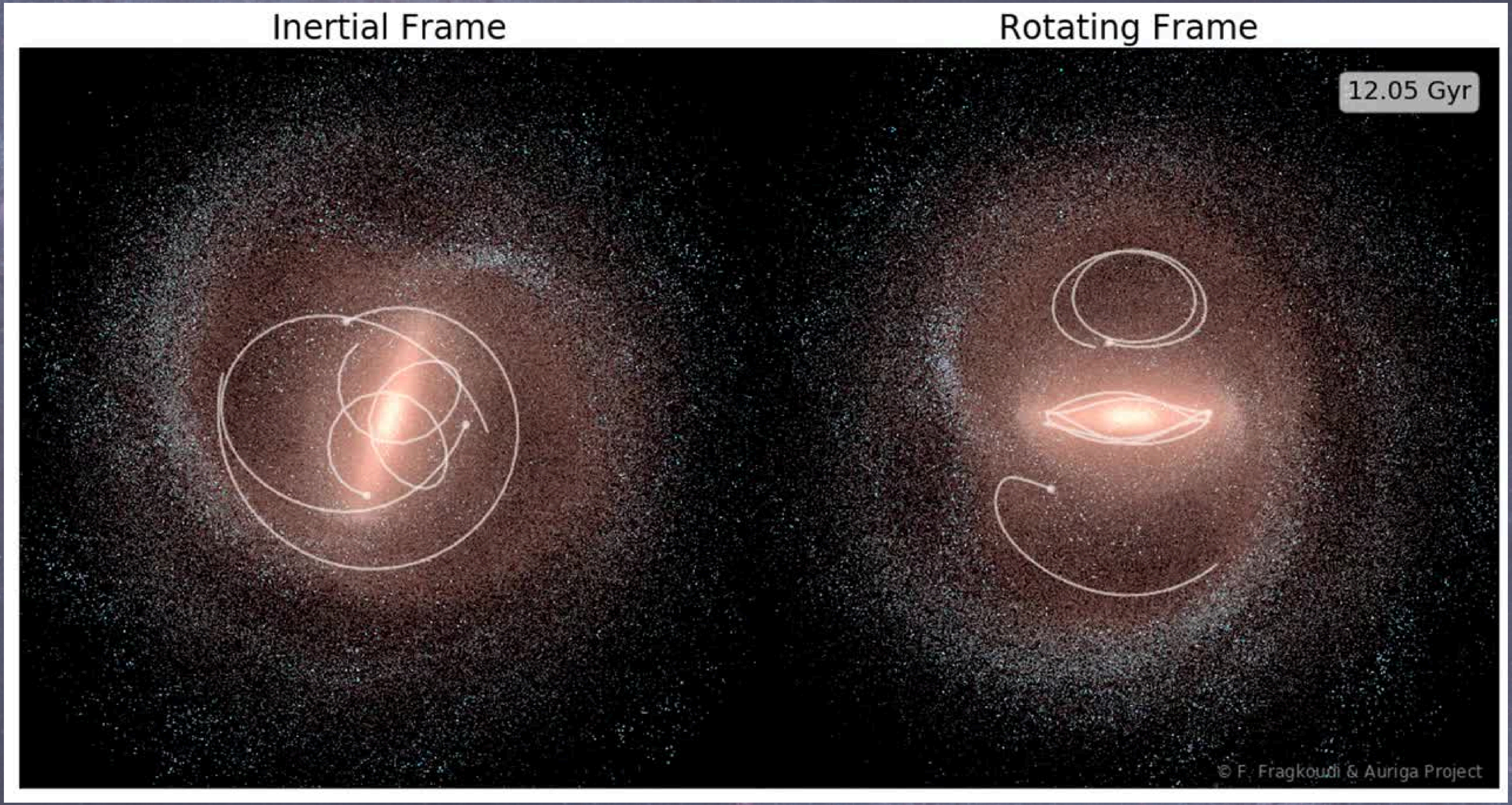


Credit: Fragkoudi

BAR FORMATION

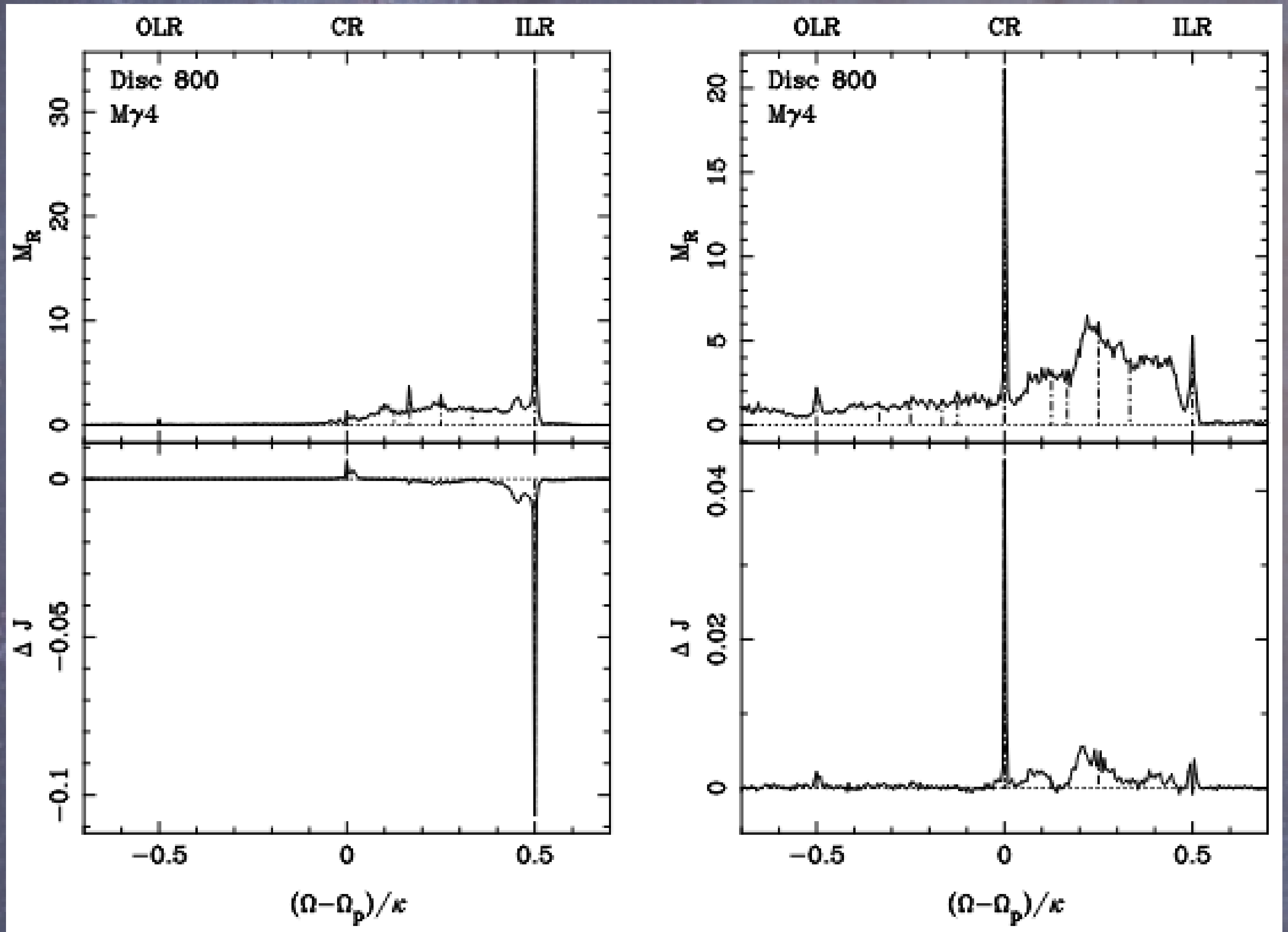
- Bars form in thin and kinematically cold disc galaxies.
- The disc galaxy is unstable to small non-axisymmetric instabilities.
- Instabilities can occur from interactions or local density variations.

BAR RESONANCES



Credit: Fragkoudi

BAR-DRIVEN EVOLUTION: REDISTRIBUTION OF ANGULAR MOMENTUM



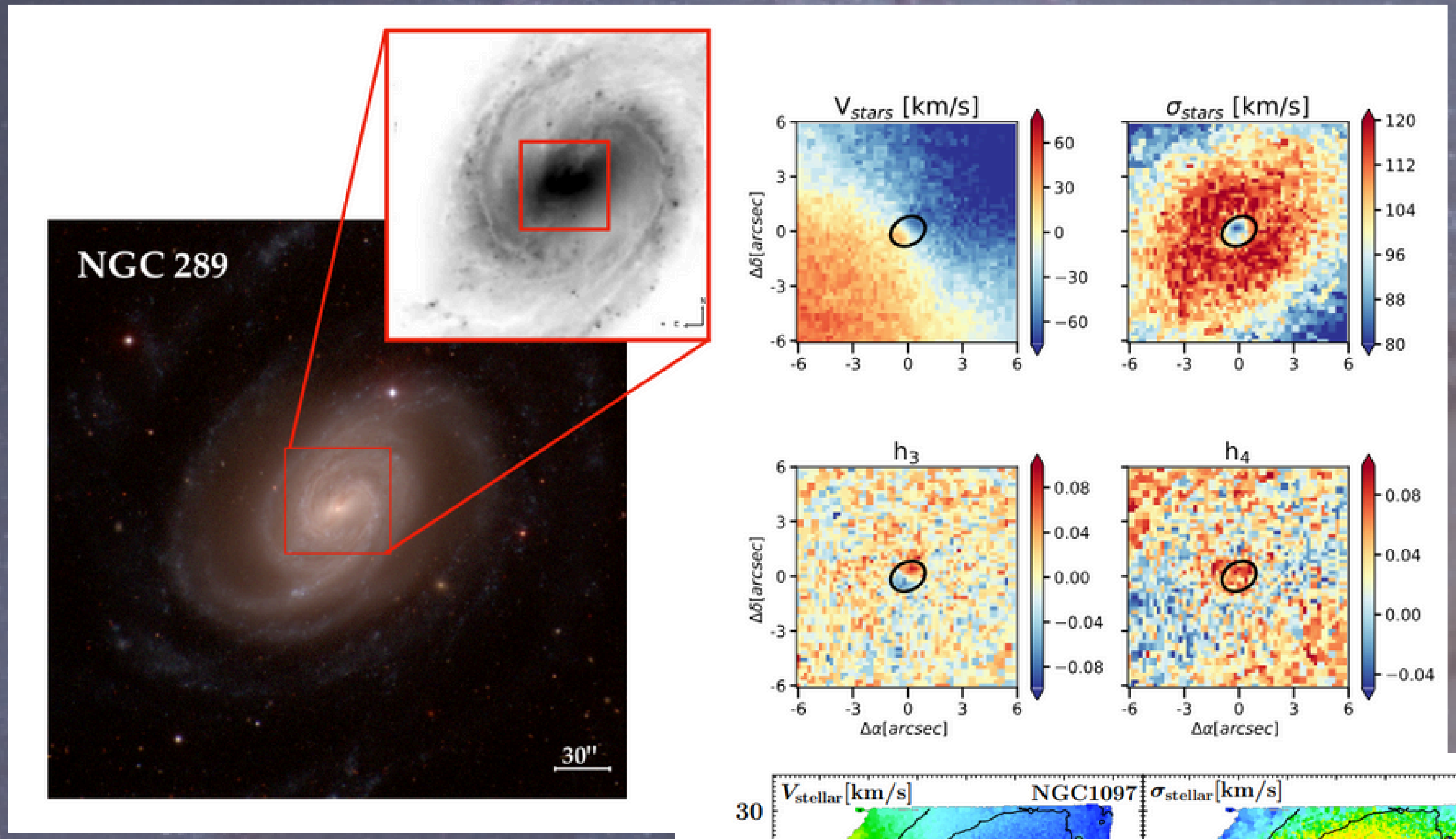
Athanassoula (2005)

- Bars primarily redistribute angular momentum, baryonic and dark matter within a disc galaxy.

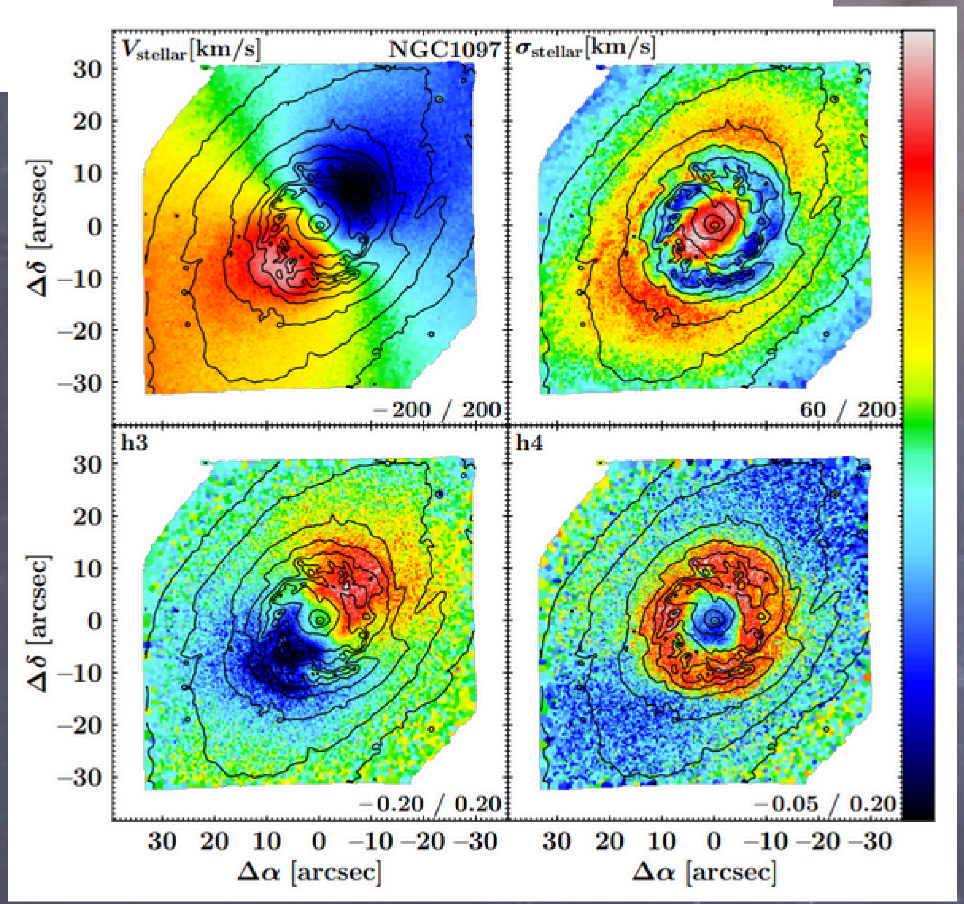
(e.g., Menéndez-Delmestre et al. 2007; Regan et al. 2006; Di Matteo et al. 2013)

- J moves outwards: stars at the ILR emit angular momentum while those at the OLR and CR absorb it.

BAR-DRIVEN EVOLUTION: CENTRAL REGIONS



de Sá-Freitas et al. (2023)



Gadotti et al. (2020)

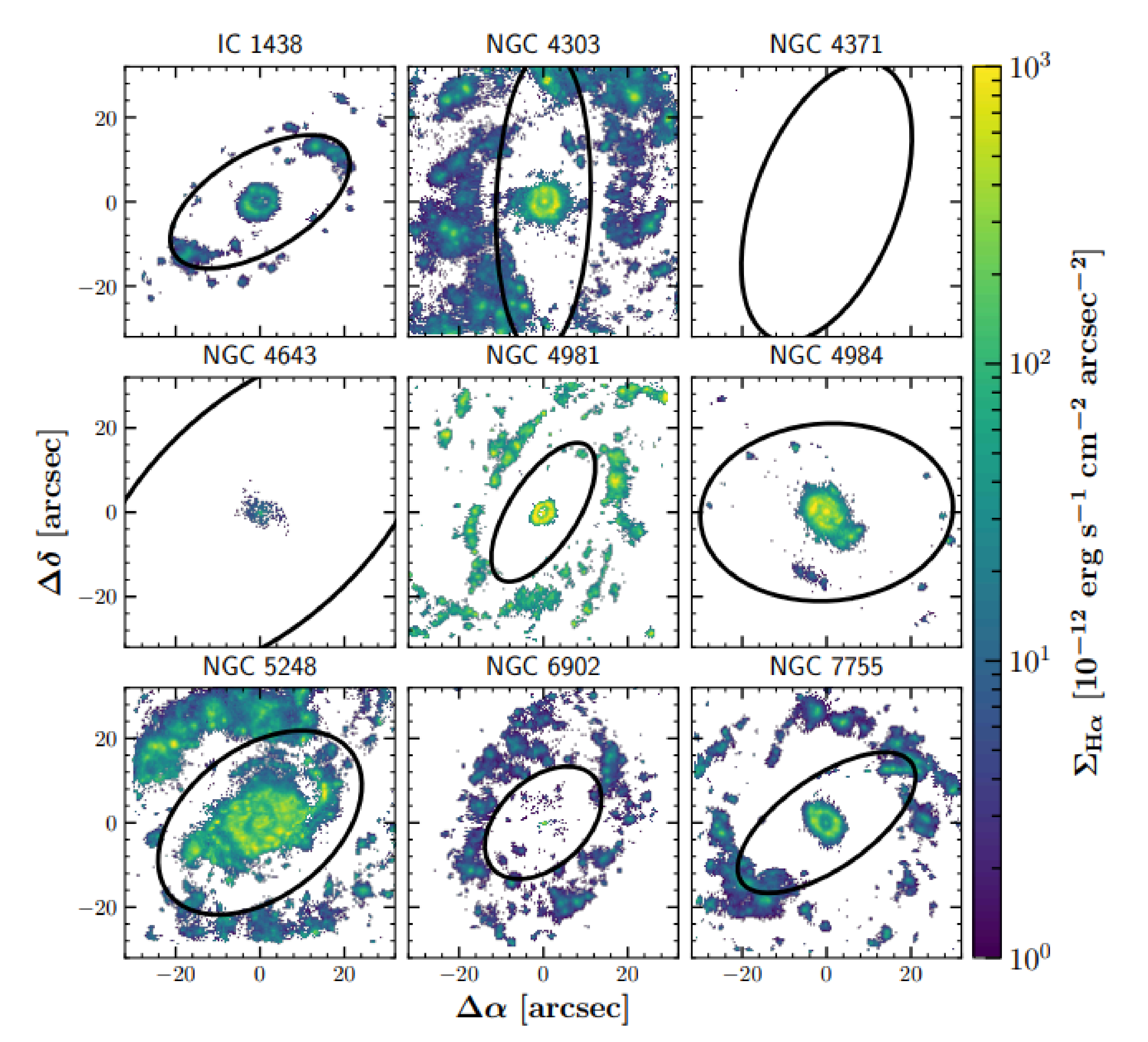
- Gas loses angular momentum from shocks due to the non-axisymmetric potential.
- Provoke gas inflow to the inner regions of the galaxy.

(e.g., Athanassoula 1992; Quillen et al. 1995; Athanassoula & Bosma 2016; Laine & Gottesman 1998; Newnham et al. 2020)

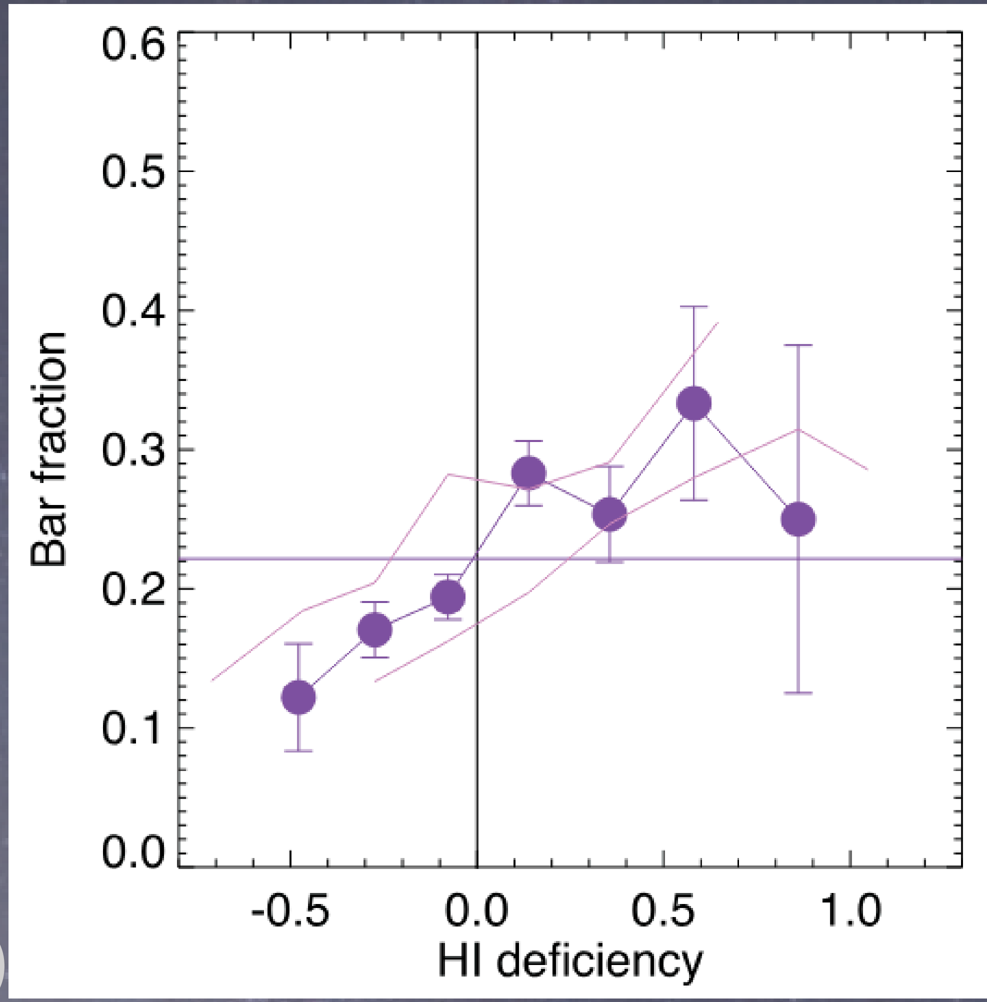
- High velocities halt inflow and begin the formation of central structures - nuclear discs.

(e.g., Sumio et al. 1990; Kormendy & Kennicutt 2004; Coelho & Gadotti 2011; Carles et al. 2016; Gadotti et al. 2020)

BAR-DRIVEN EVOLUTION: STAR FORMATION



Neumann et al. (2020)

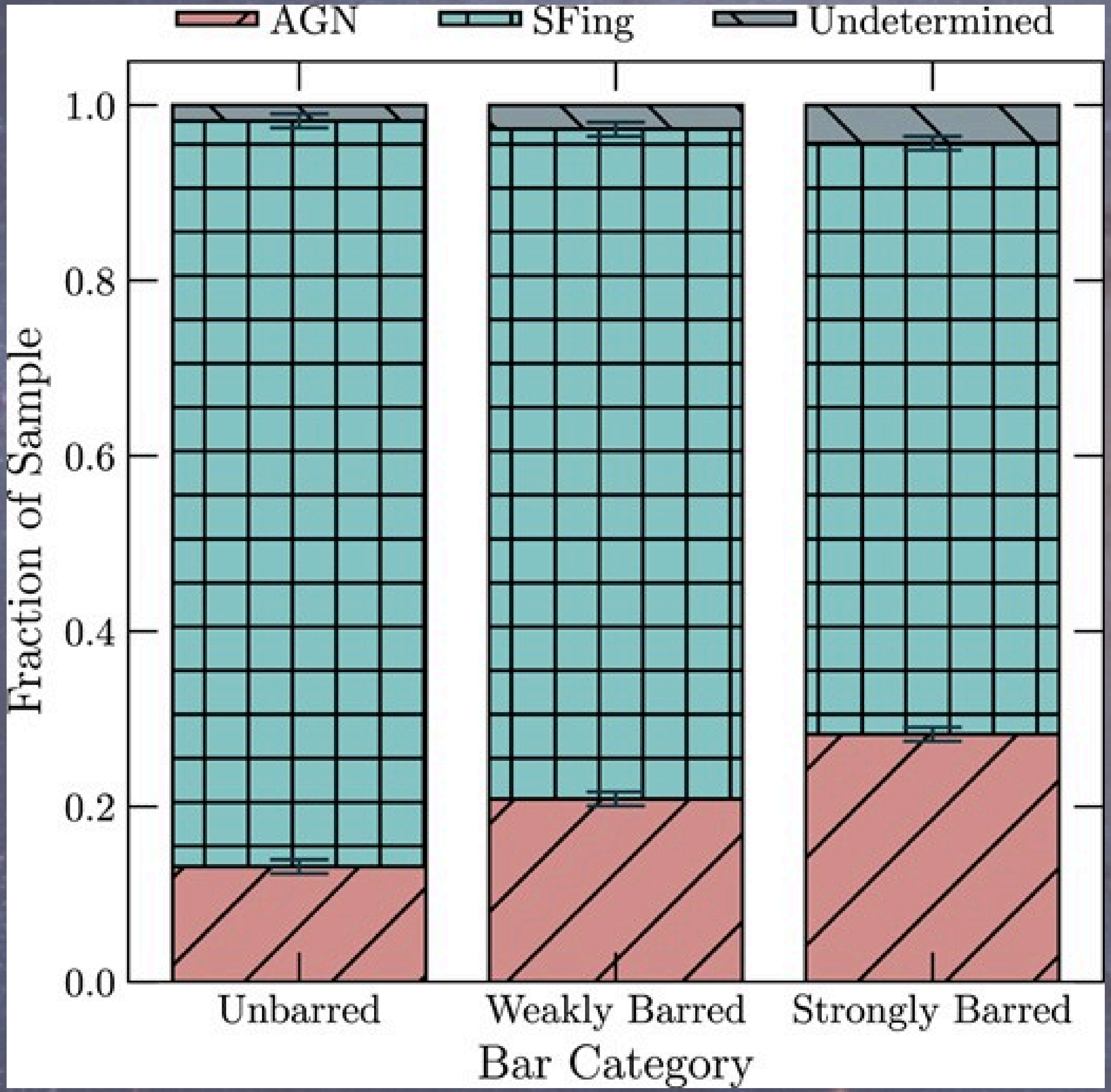


Masters et al. (2012)

- Bars quench star formation in the outer disc of massive galaxies.
- Concentrated molecular gas in the central regions ignite bursts of star formation.

(e.g., Ho et al. 1997; Sheth et al. 2005; Ellison et al. 2011; Lee et al. 2012)

BAR-DRIVEN EVOLUTION: AGN

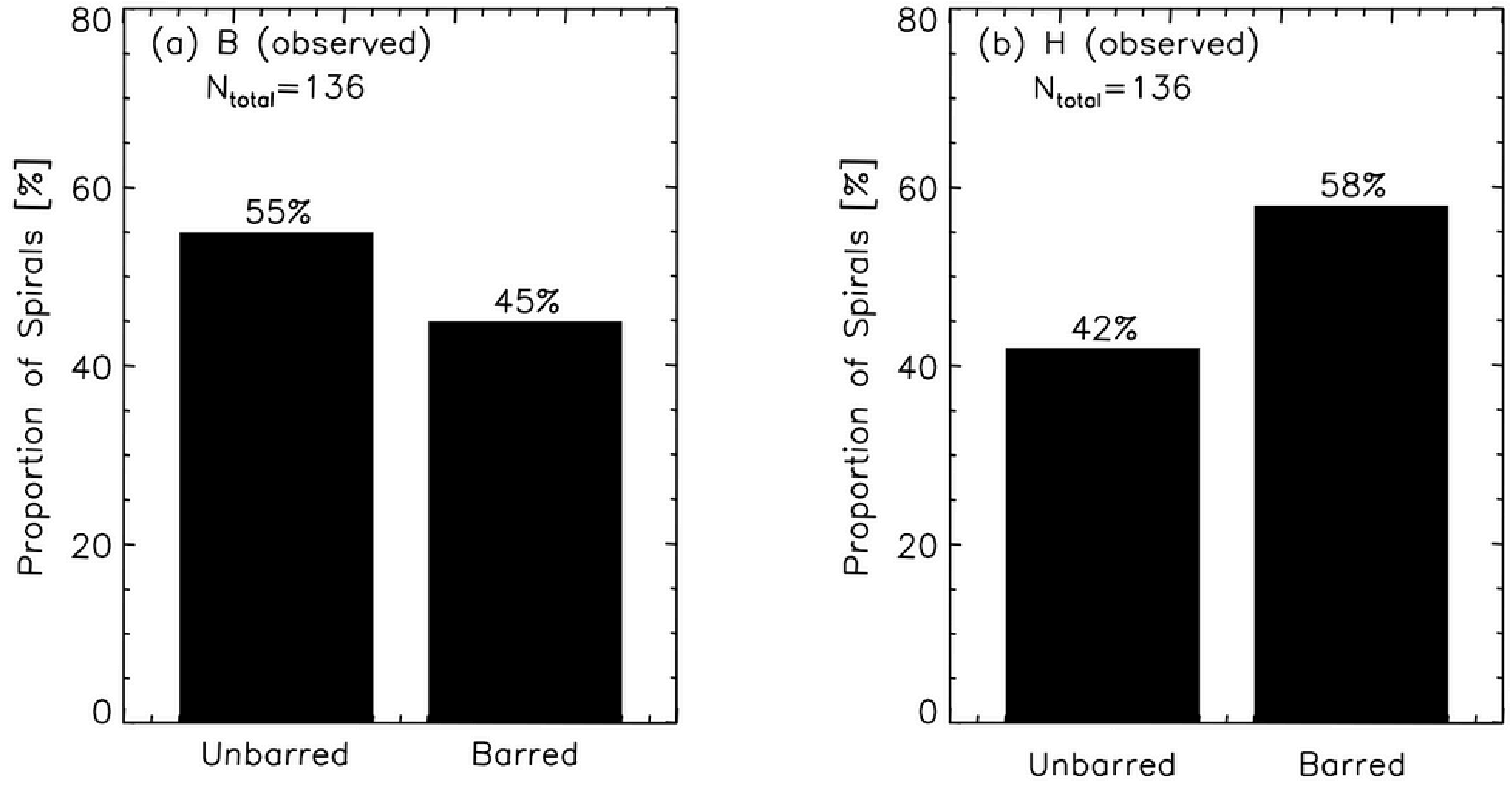


Garland et al. (2024)

- The fraction of AGN in strongly barred galaxies is greater than the AGN fraction in unbarred galaxies.
- The funnelling of gas towards the inner regions could create a fuel reservoir.
- Potential fuelling of AGN.

(e.g., Knapen et al. 1995; Alonso, M. S. et al. 2013; Cisternas et al. 2015; Silva-Lima et al. 2022).

WAVELENGTH DEPENDENCE



Marinova & Jogee (2007)

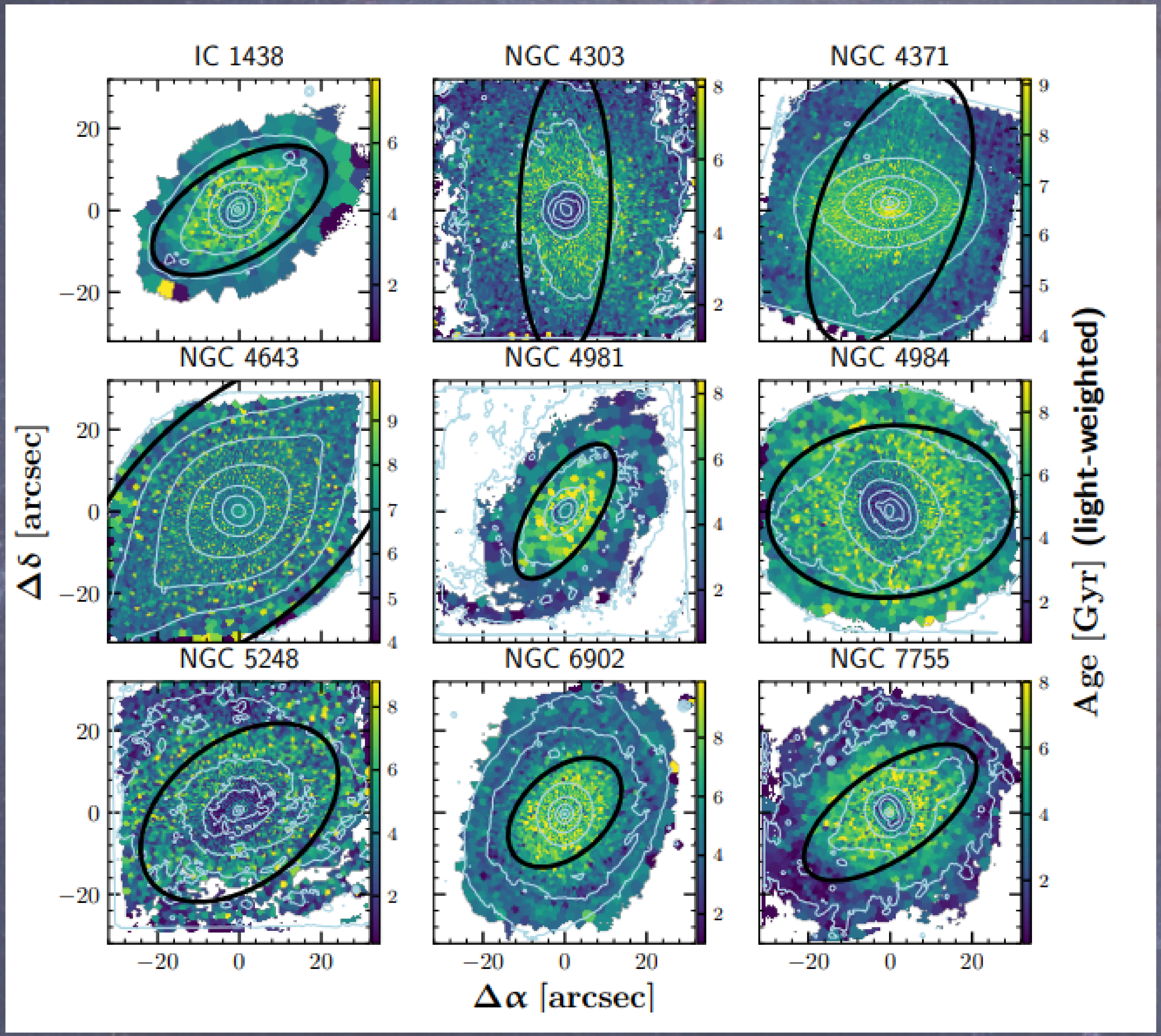
- The strong bar fraction increases in the NIR.
  (e.g., Marinova & Jogee 2007; Buta et al. 2015)
- The NIR traces the stellar mass distribution.
- Highly subjective as the fractions can be dependent on the identification method:
  - Visual

  (e.g., Cheung et al. 2013; Simmons et al. 2014; Buta et al. 2015)

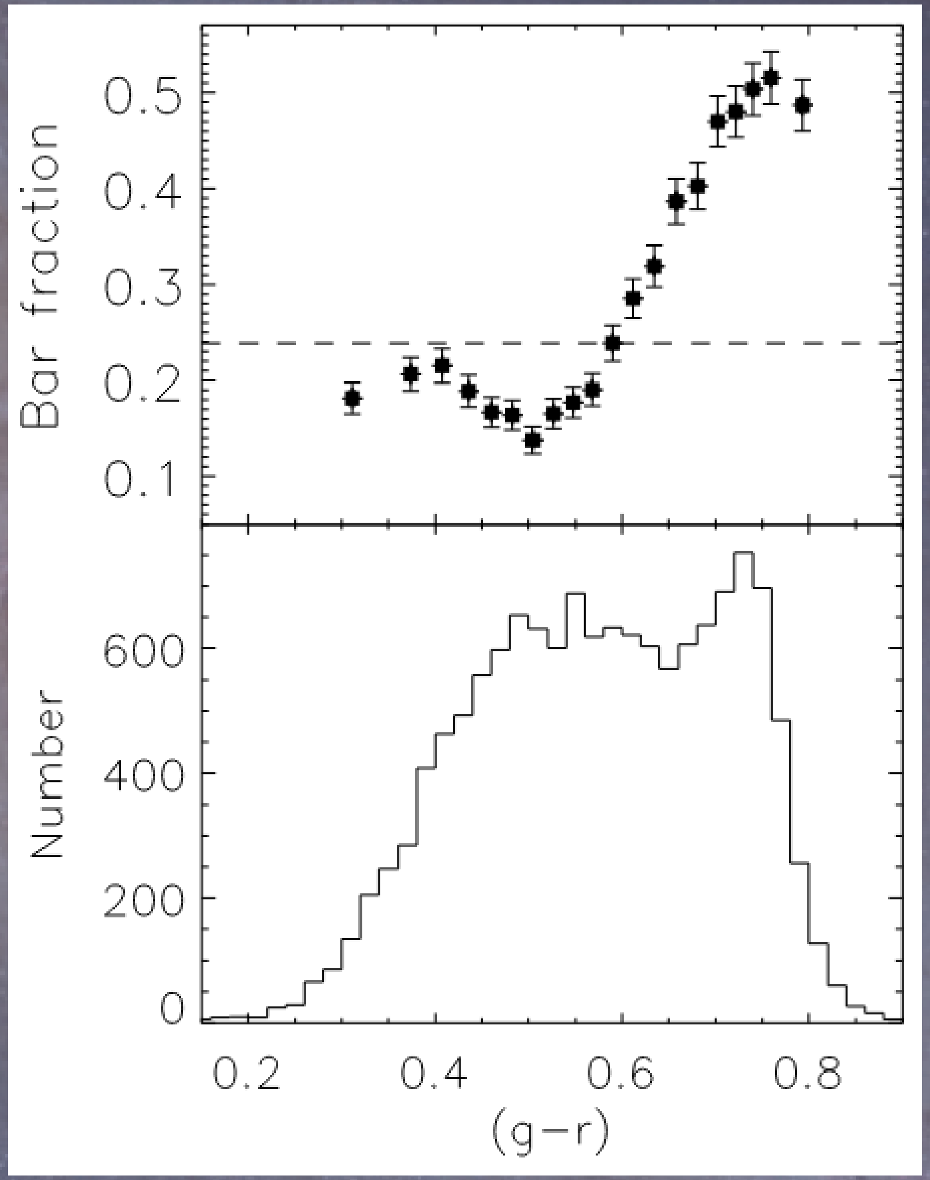
  - Automated

  (e.g., Wozniak et al. 1995; Elmegreen et al. 2004; Jogee et al. 2004; Marinova & Jogee 2007; Guo et al. 2022)

STELLAR POPULATION WITHIN THE BAR



Neumann et al. (2020)



Masters et al. (2011)

- Older stars dominate the bar's stellar population.

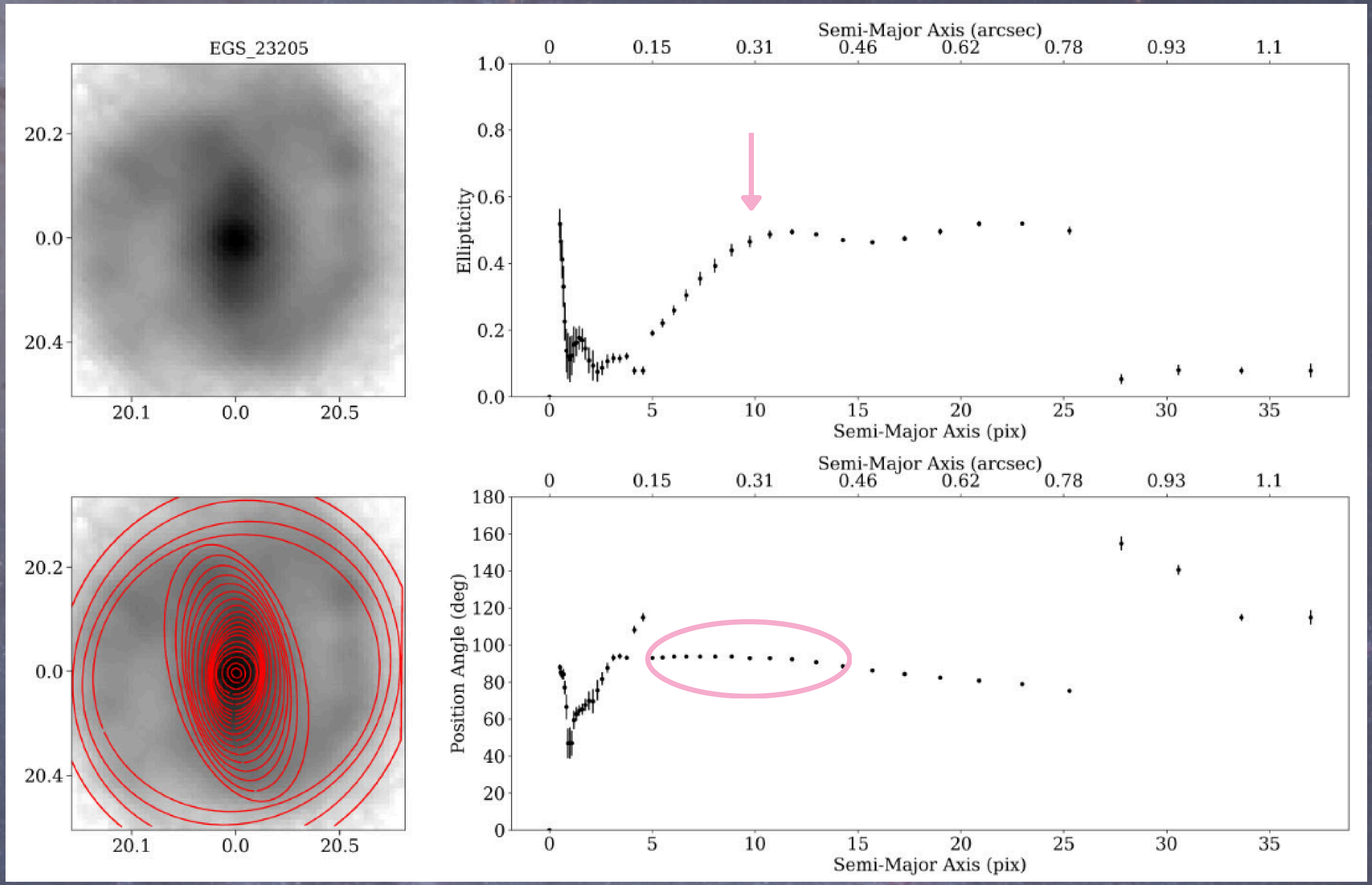
(e.g., Gadotti & de Souza 2006; Perez, Sanchez-Blazquez & Zurita 2007,2009; Neumann et al. 2020).

BAR IDENTIFICATION: ISOPHOTAL ANALYSIS

- Automated process.
- Favourable for large surveys.
- Can falsely identify the spiral arms as bars.

Example:

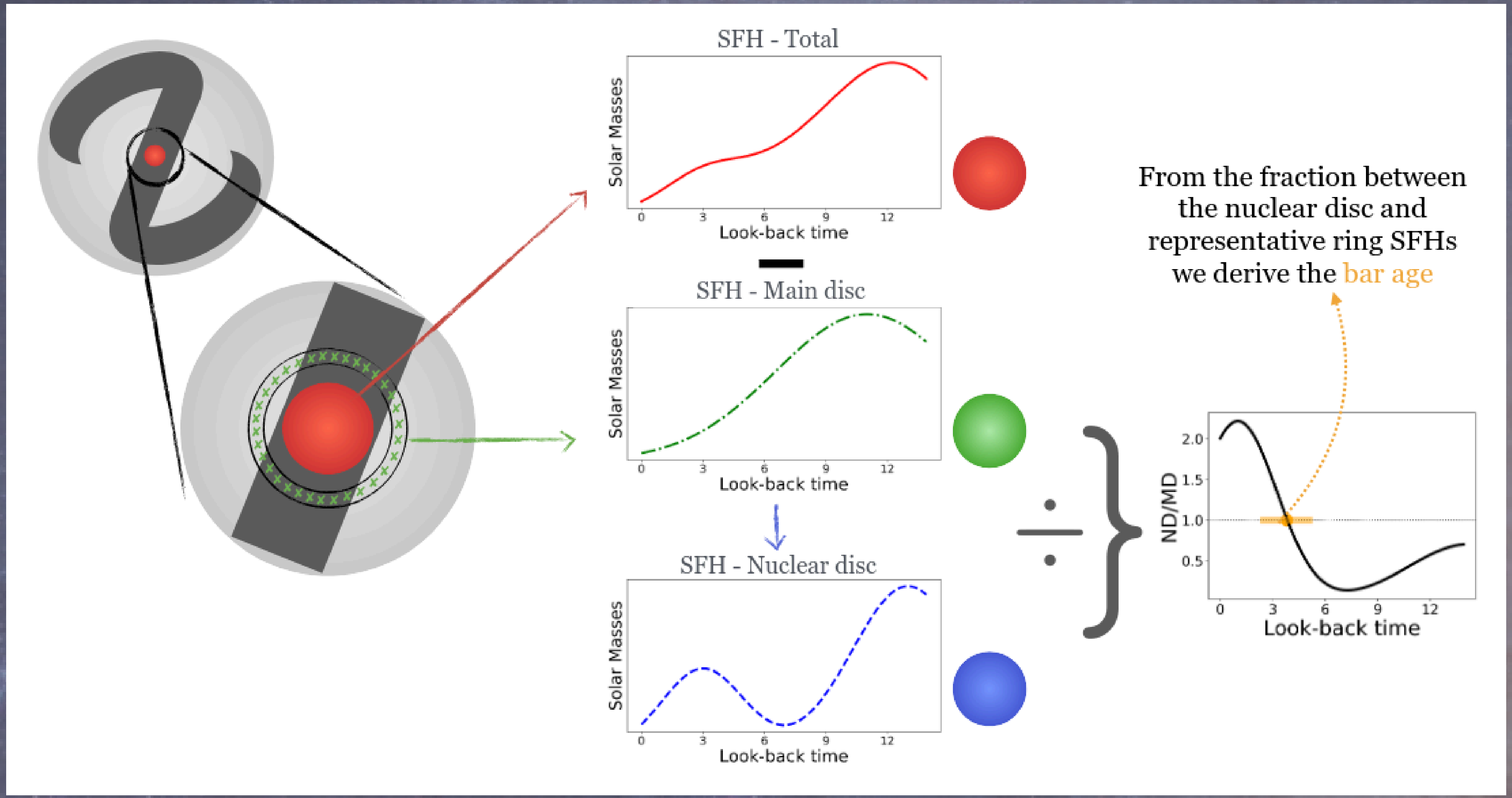
- Bar region: e rises smoothly to max $e > 0.25$, and PA stays consistent at < 20 degrees.
- Outer disc: drop in e by 0.1 and change in PA by 10 degrees.

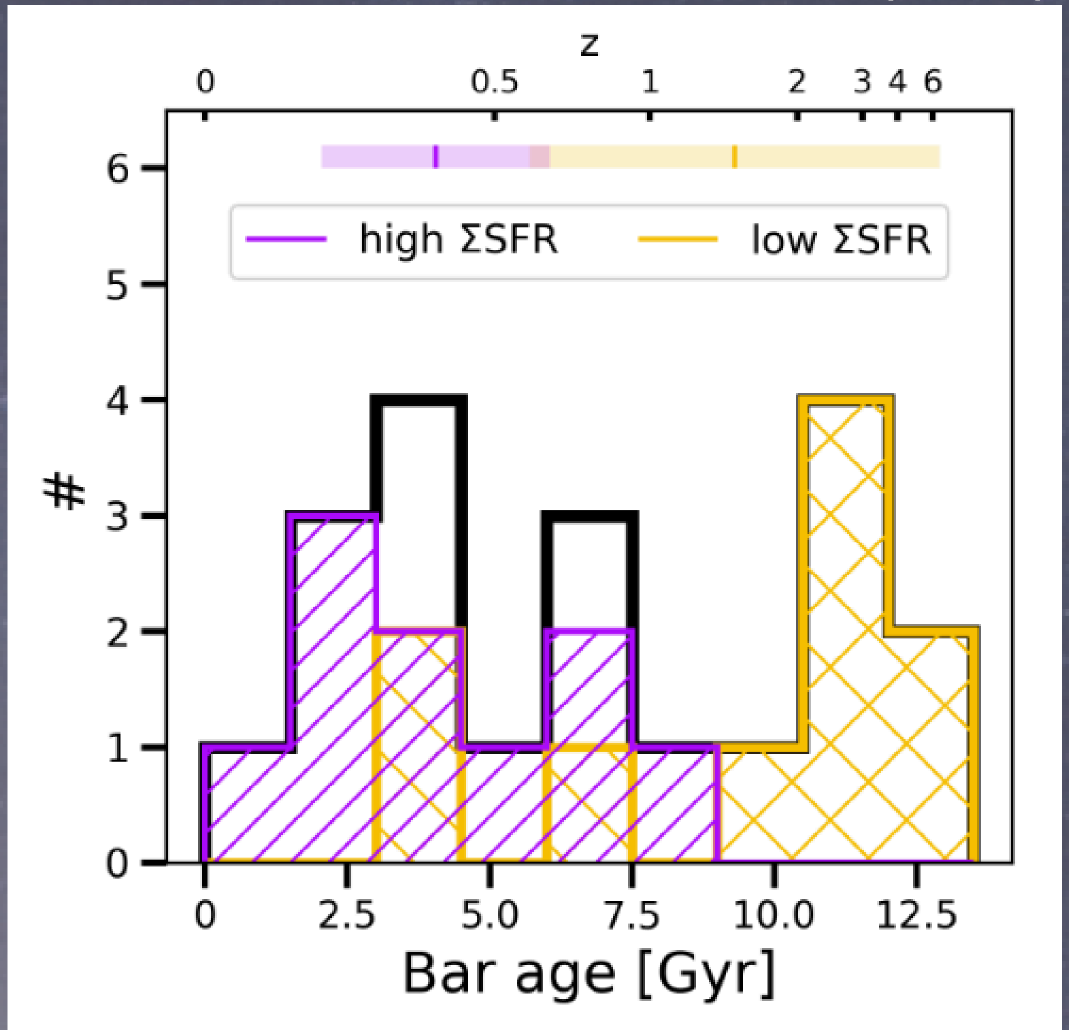


Le Conte et al. (2024)

BAR AGE

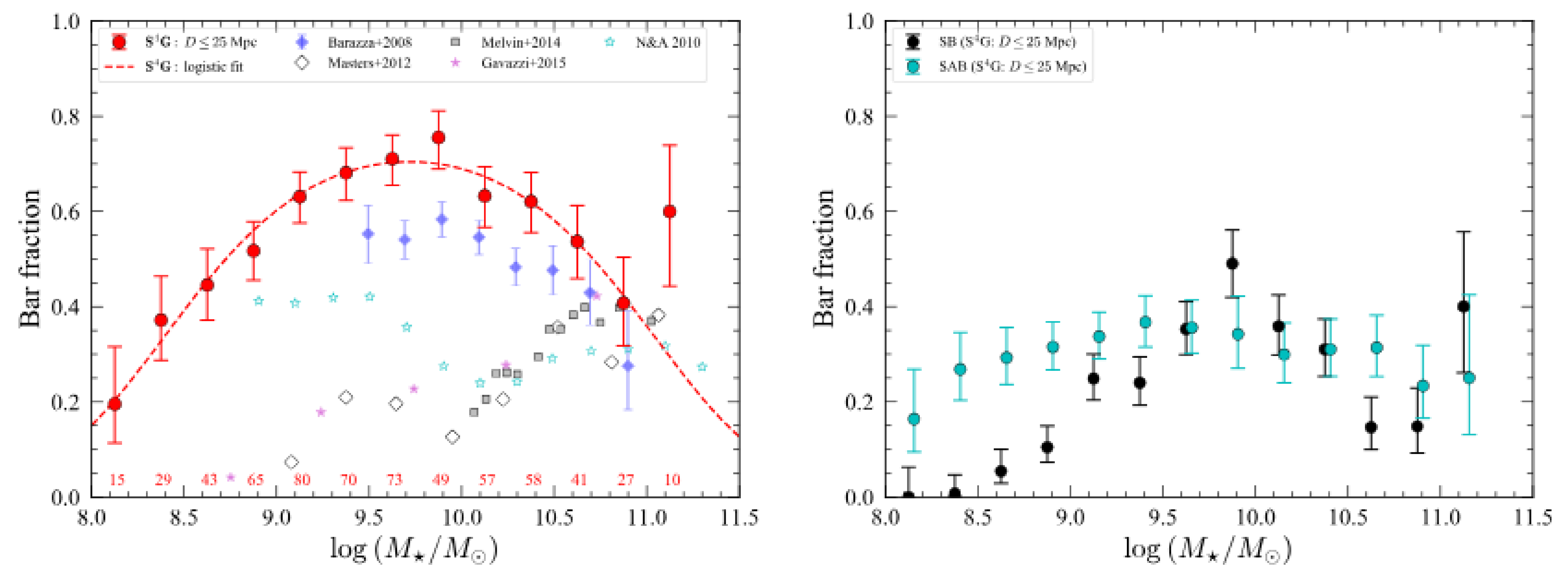
de Sá-Freitas et al. (2024)





- In simulations, bars form relatively quickly - within the order of a few hundred million years.
  (Athanassoula & Sellwood 1986; Athanassoula 2013; Ghosh et al. 2023; Fragkoudiet al. 2024)
- Bar ages can be dated by the point at which SF ignites in the nuclear disc using novel techniques and IFU data.
- Bars are found to develop at z > 1.

THE LOCAL BAR FRACTION



Erwin (2018)

- There is agreement that the local Universe bar fraction is up to 60-80%, including weak bars.

(e.g., de Vaucouleurs 1963; Eskridge et al. 2000; Menéndez-Delmestre et al. 2007; Sheth et al. 2008; Erwin 2017)

- The bar fraction peaks for galaxies with log stellar mass = 9.7.

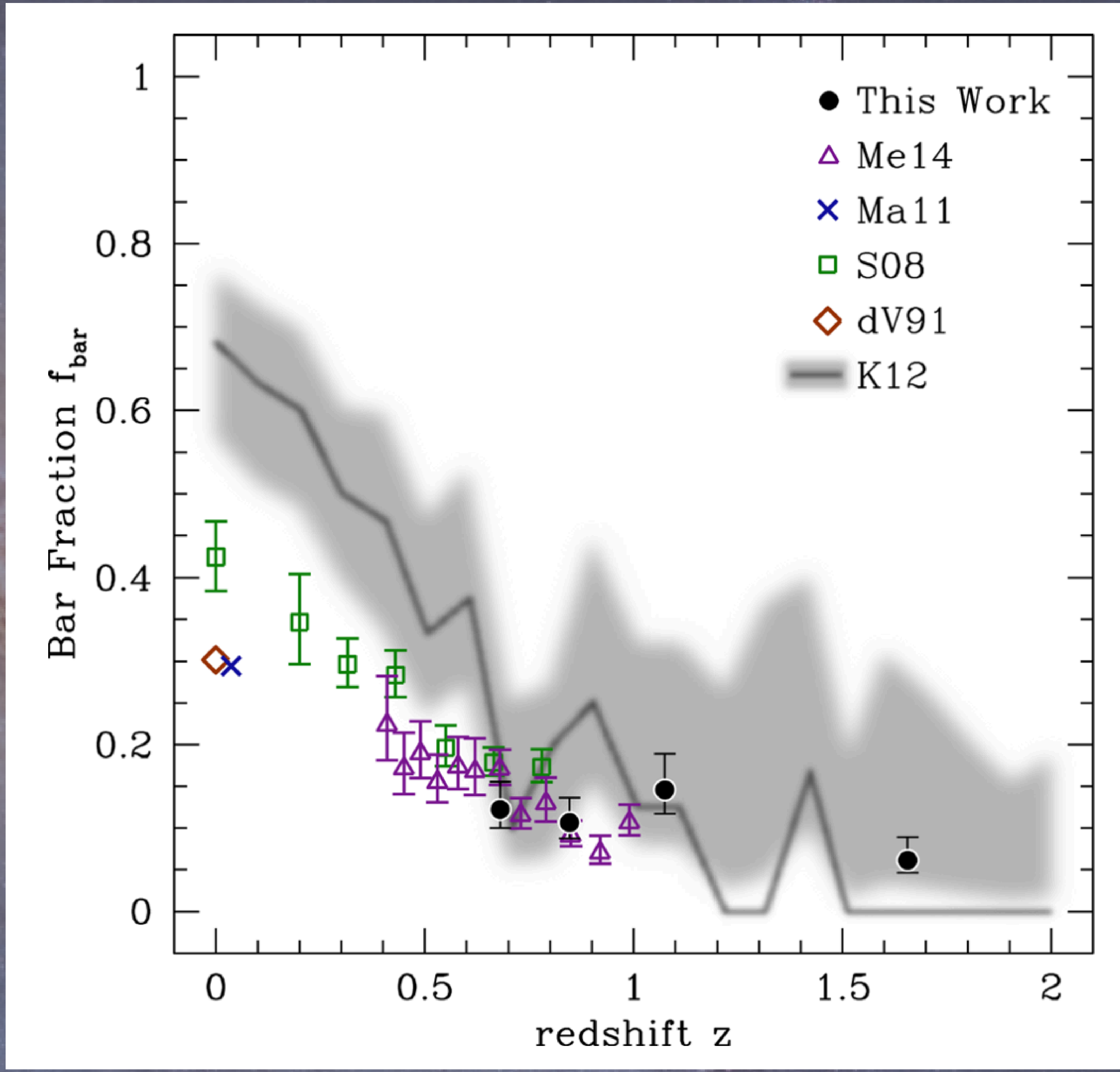
THE EVOLUTION OF THE BAR FRACTION

- Bar fraction studies using HST are limited to z < 1.8.
- The bar fraction steadily decreases to 10% at z = 1.

(e.g., Abraham et al. 1999; Sheth et al. 2003; Jogee et al. 2004; Sheth et al. 2008; Melvin et al. 2014).

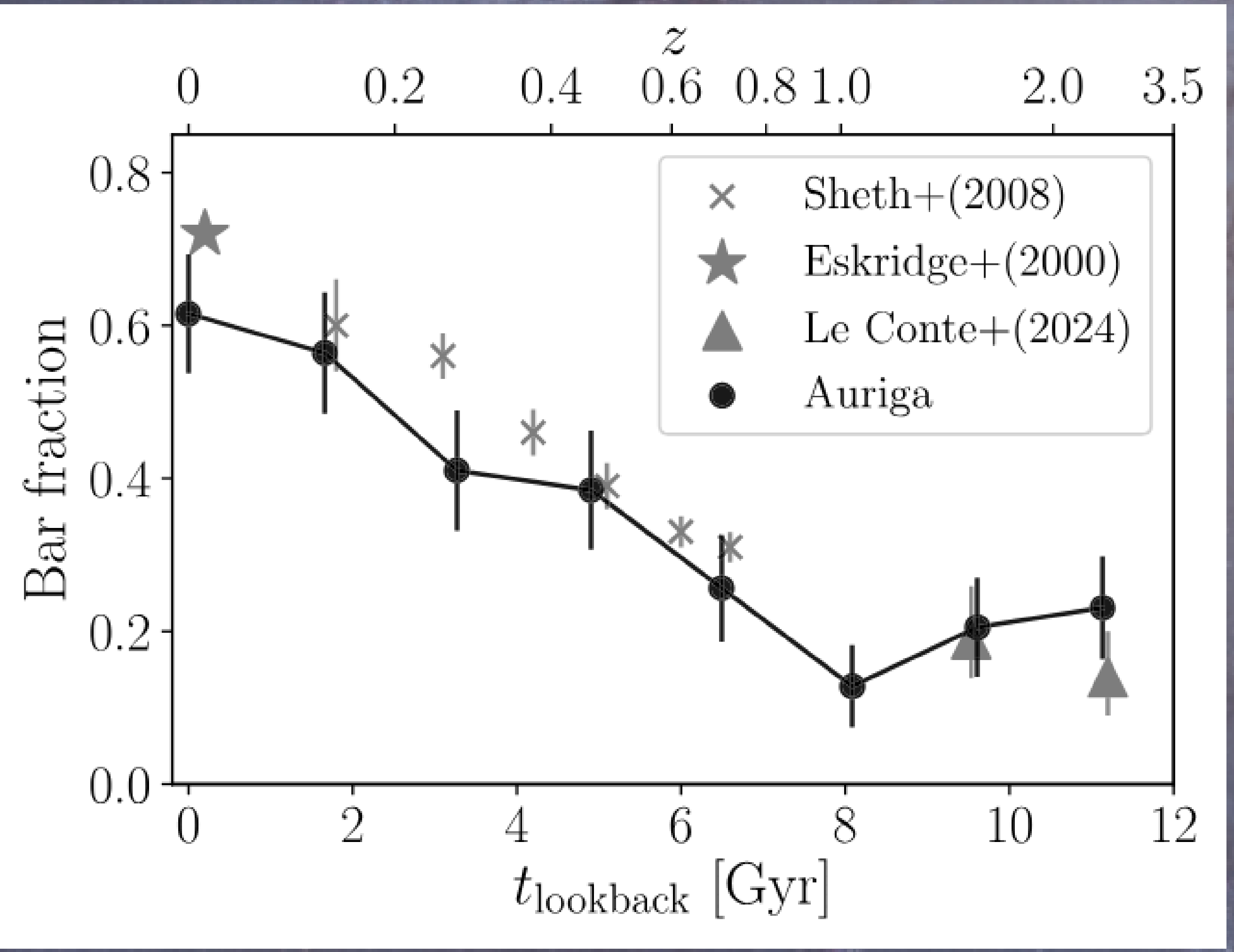
- A constant bar fraction of 10% has been found between redshifts 1 to 1.8.

(Simmons et al. 2014)



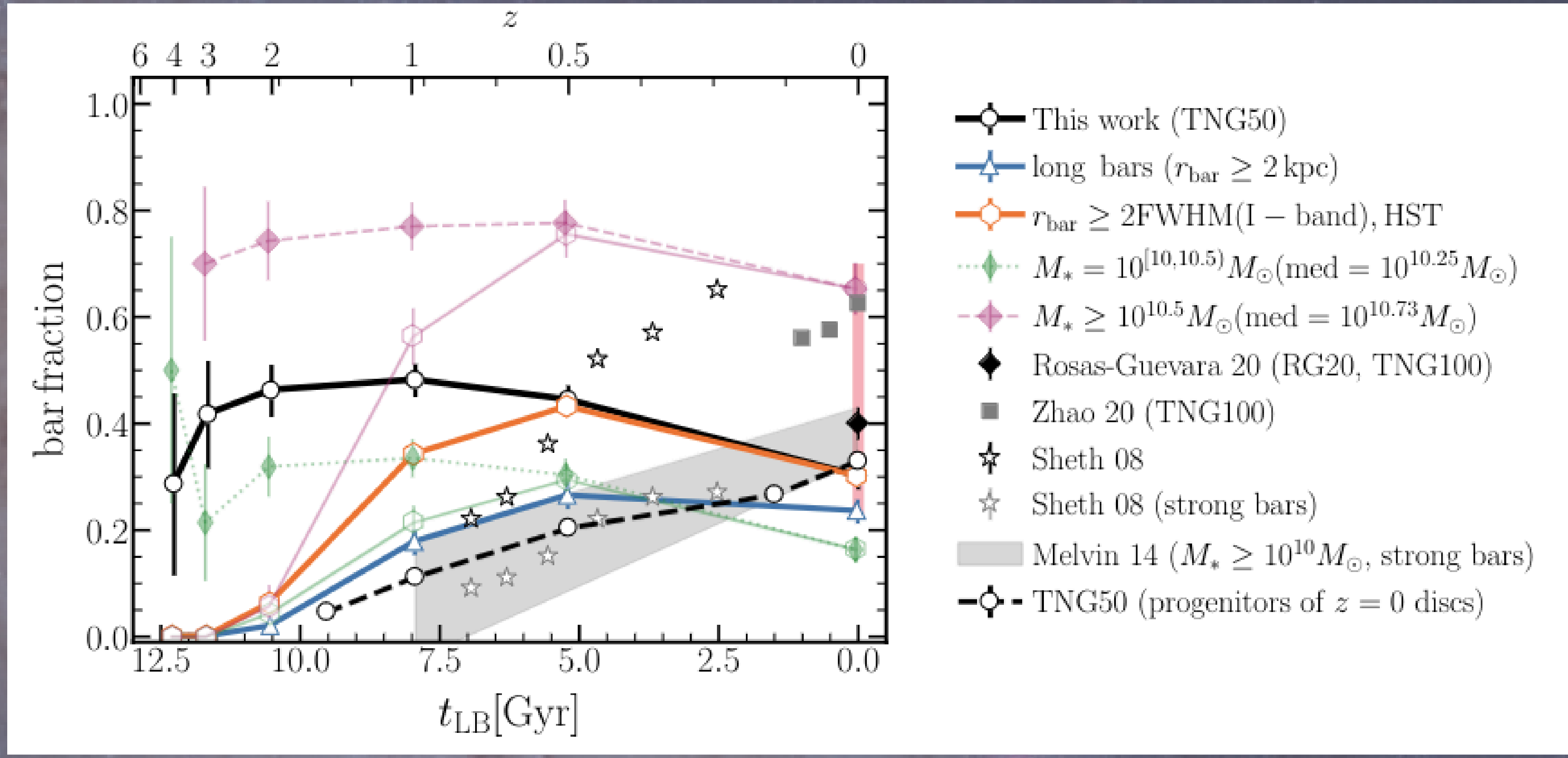
Simmons et al. (2014)

THE EVOLUTION OF THE BAR FRACTION IN SIMULATIONS



Fragkoudi et al. (2025)

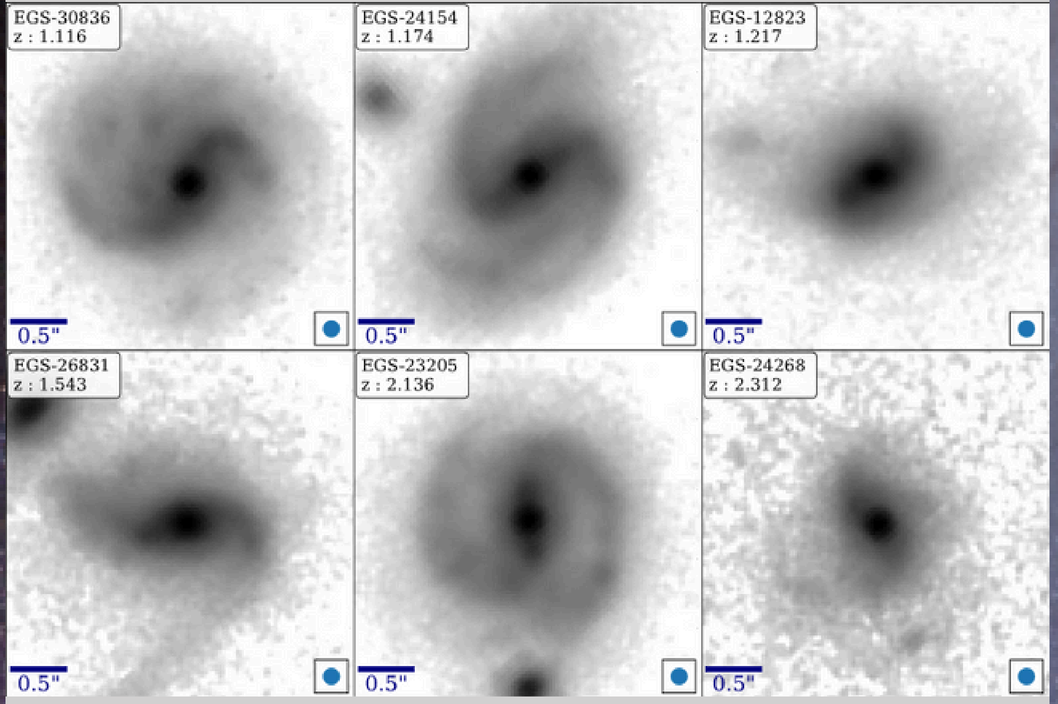
- Some simulations find a decrease in the bar fraction up to z = 3.5.
- In agreement with observations.



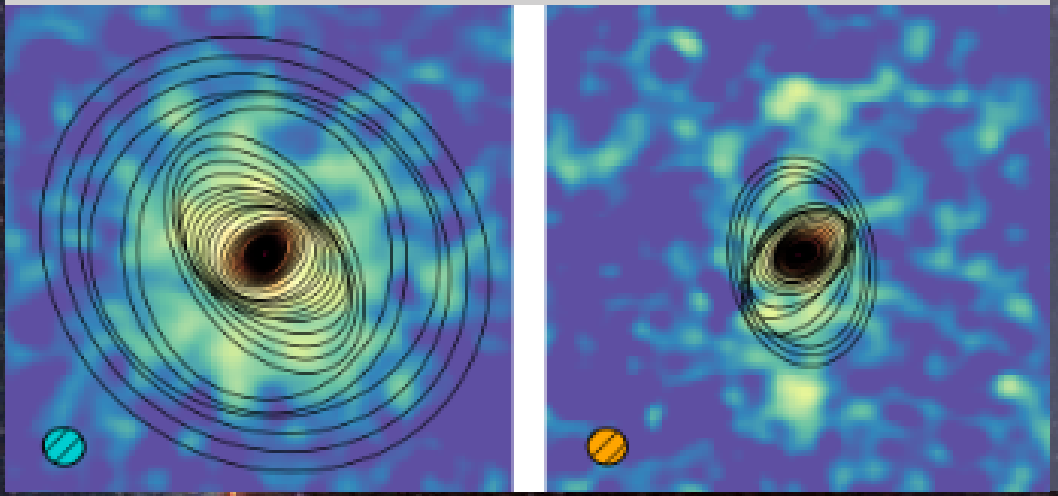
Rosas-Guevara et al. (2022)

- Some simulations find an increase in the bar fraction up to z = 1.
- By z = 3, the bar fraction is still 40%.

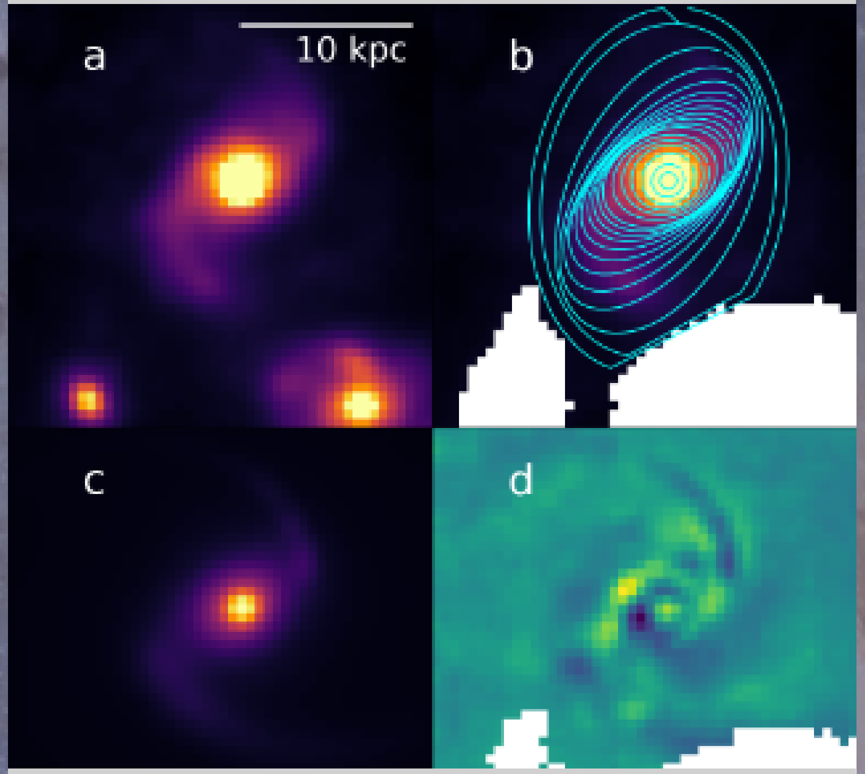
Guo et al. (2023) found six barred galaxies using JWST with the highest being $z \sim$ 2.136 and 2.312.



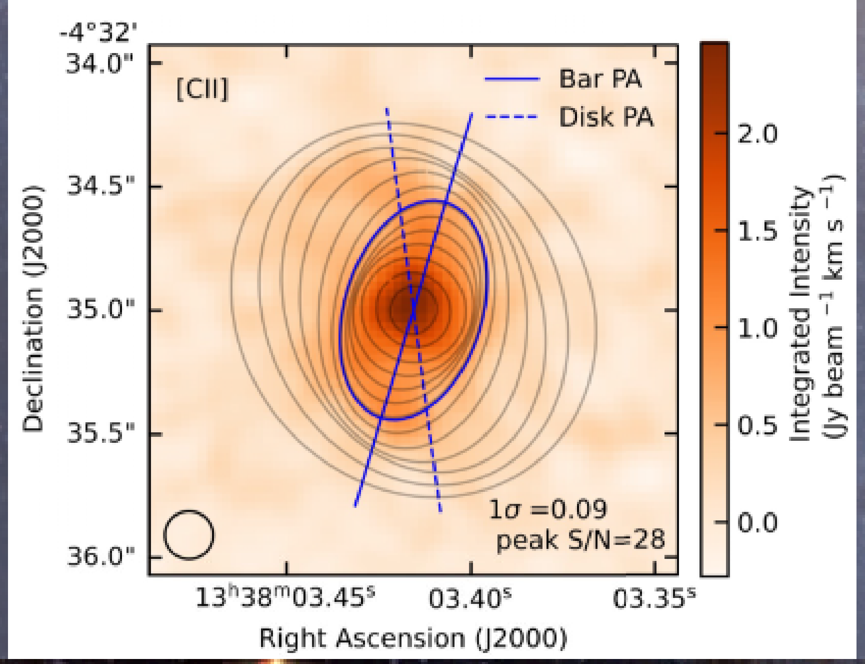
Rowland et al. (2024) found a barred galaxy using ALMA [CII] at z = 7.3065.



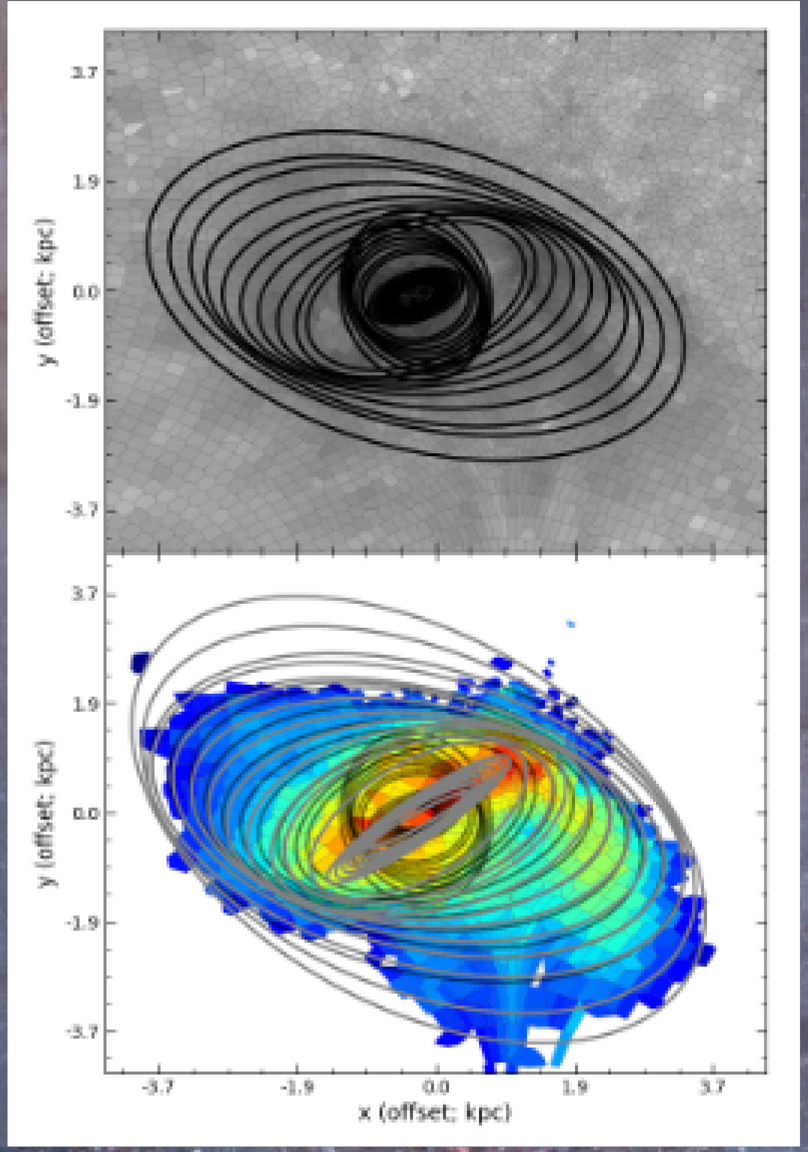
Huang et al. 2023 found a barred galaxy at z = 2.467 with JWST.



Tsukui et al. (2023) found a barred galaxy at $z \approx$ 4.4 with ALMA.

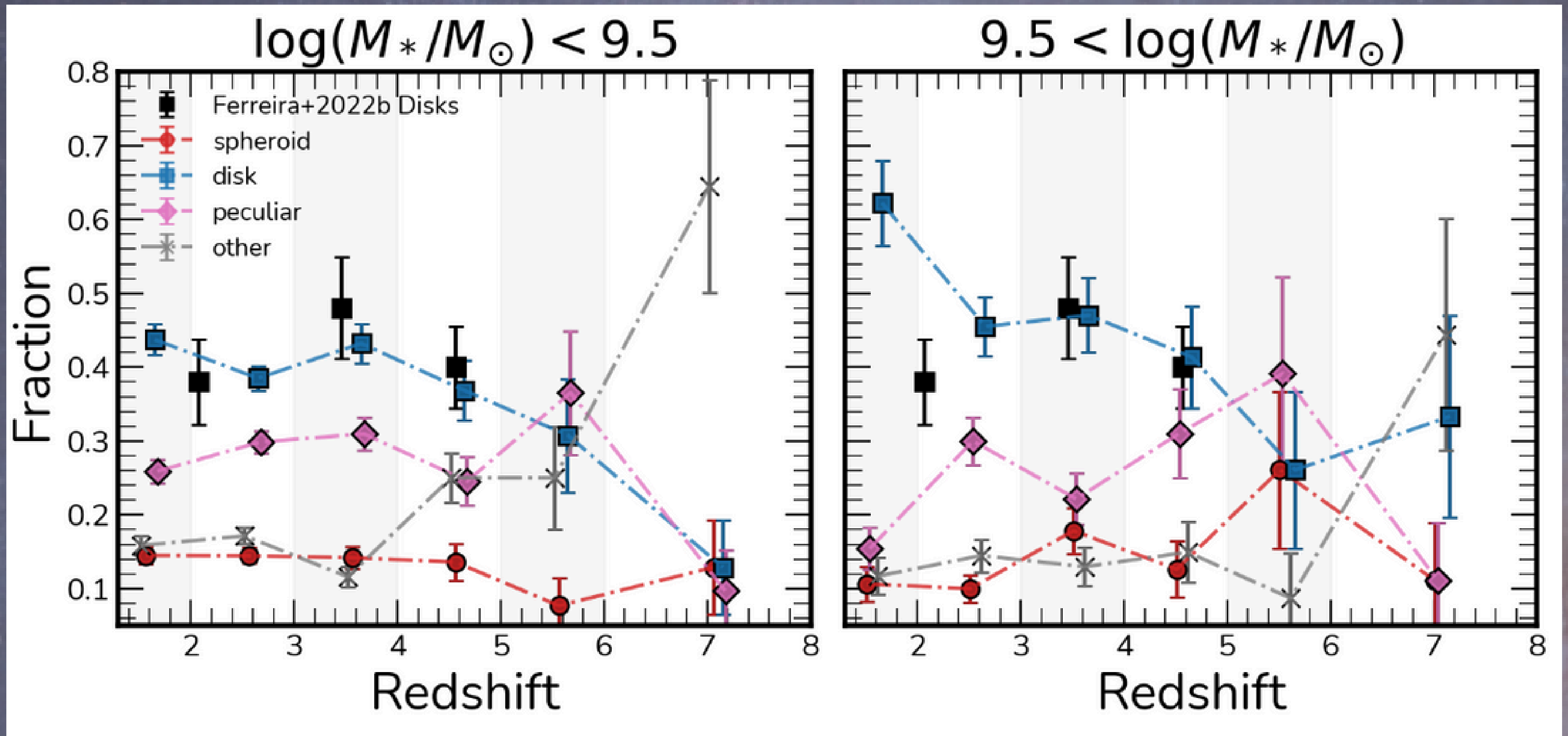


Amvrosiadis et al. (2024) found a barred galaxy at z = 3.762 by strong lensing.



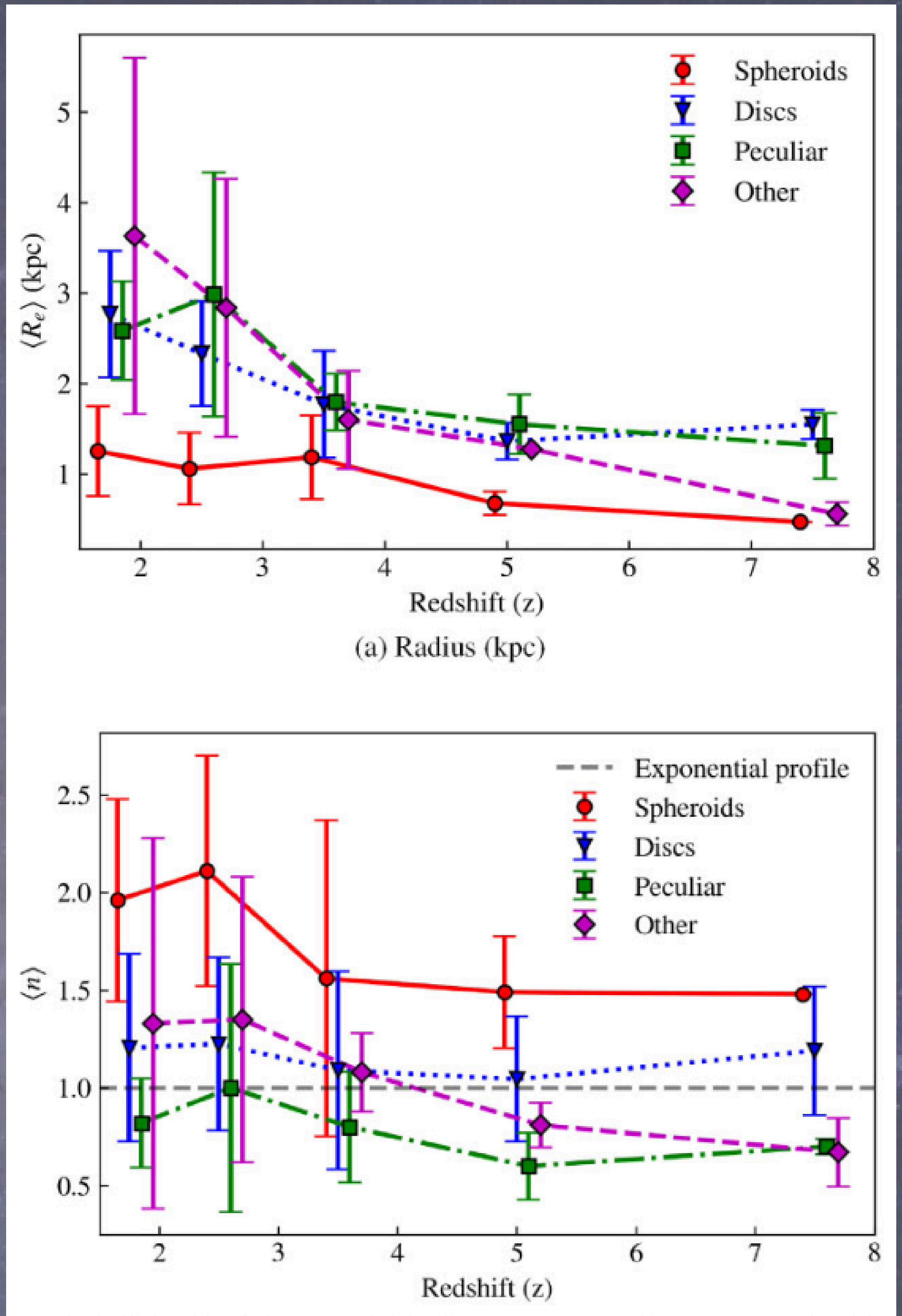
HIGH REDSHIFT BARS

GALAXY EVOLUTION WITH JWST

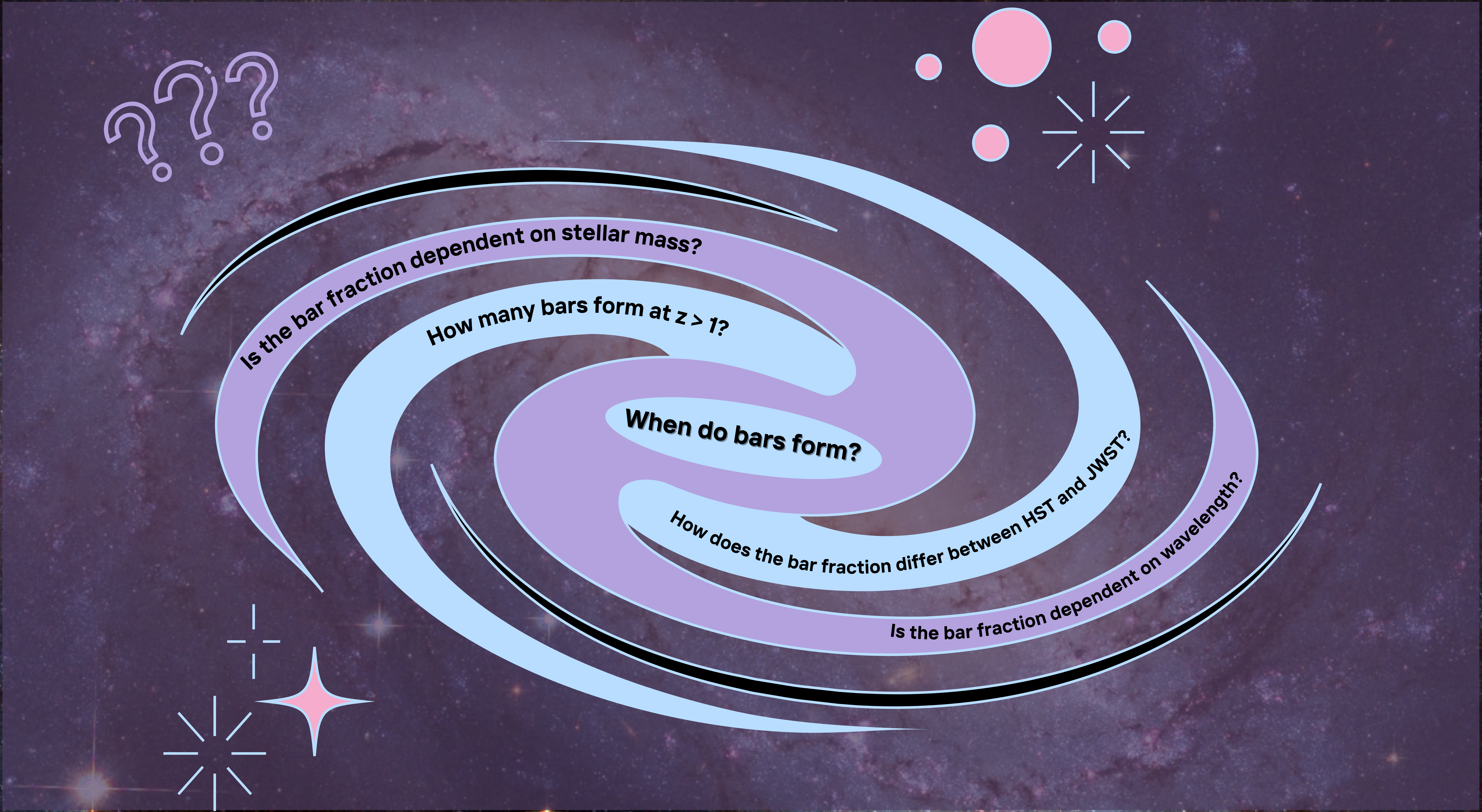


Ferreira et al. (2023)

- The disc fraction dominates one billion years after the Big Bang.
- Stellar mass and star formation rate densities are dominated by disk galaxies z < 6; most stars in the universe were likely formed in a disk galaxy.
- The vast majority of massive galaxies at high redshifts have low Sérsic indices.



Ormerod et al. (2024)


Is the bar fraction dependent on stellar mass?
How many bars form at z > 1?
When do bars form?
How does the bar fraction differ between HST and JWST?
Is the bar fraction dependent on wavelength?

SAMPLE SELECTION

Parent sample

JWST data:
- 4 CEERS pointings.
- Used NIRCam F444W and F356W filters.
- F444W PSF is 0.145" or 2 kpc.

HST data:
- CANDELS on the EGS and the UDS fields.
- Used HST infrared channel WFC3/IR F160W.

5,241 galaxies for $1 < z < 3$.
Same galaxies in HST and JWST.

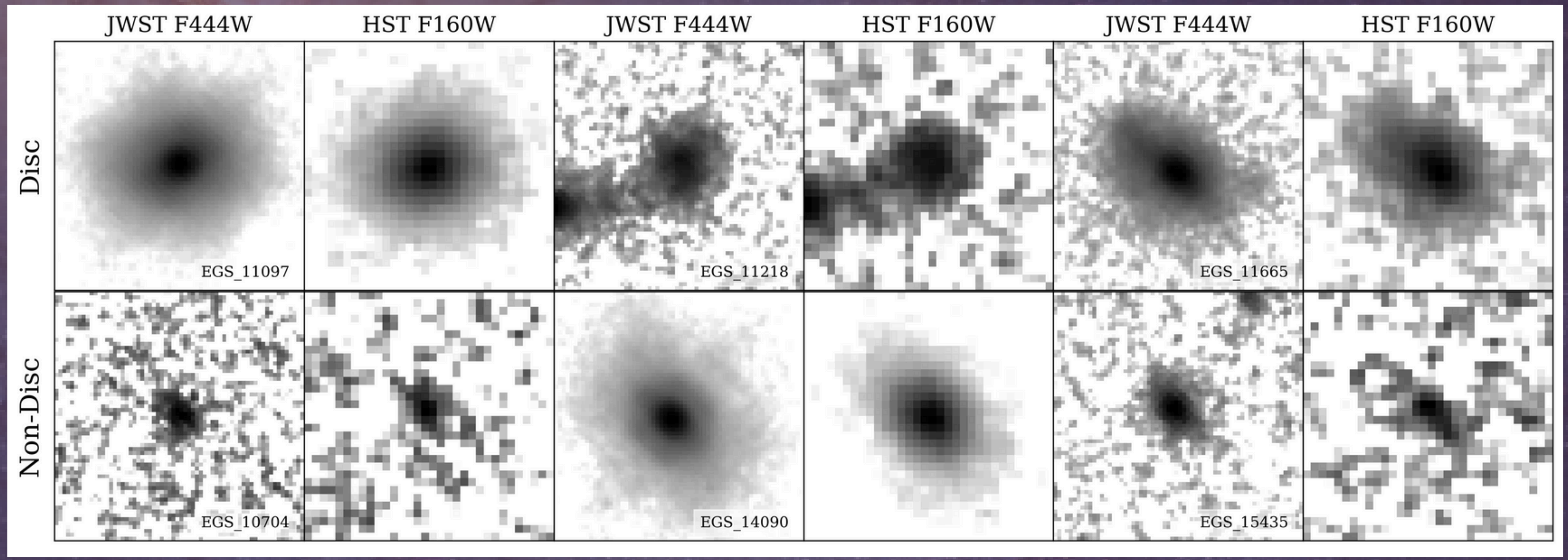
Disc sample

- JWST disc fractions from Ferreira et al. (2023). Their disc fraction is approx. 45%.
- HST disc fractions from Kartaltepe at al. (2015). Their disc fractions is approx. 76%.

Bars are easier to identify in near face-on galaxies

- Fit elliptical isophotes to the galaxies.
- Fix the galactic centre.
- Apply a 60-degree inclination limit to outer elliptical isophotes.

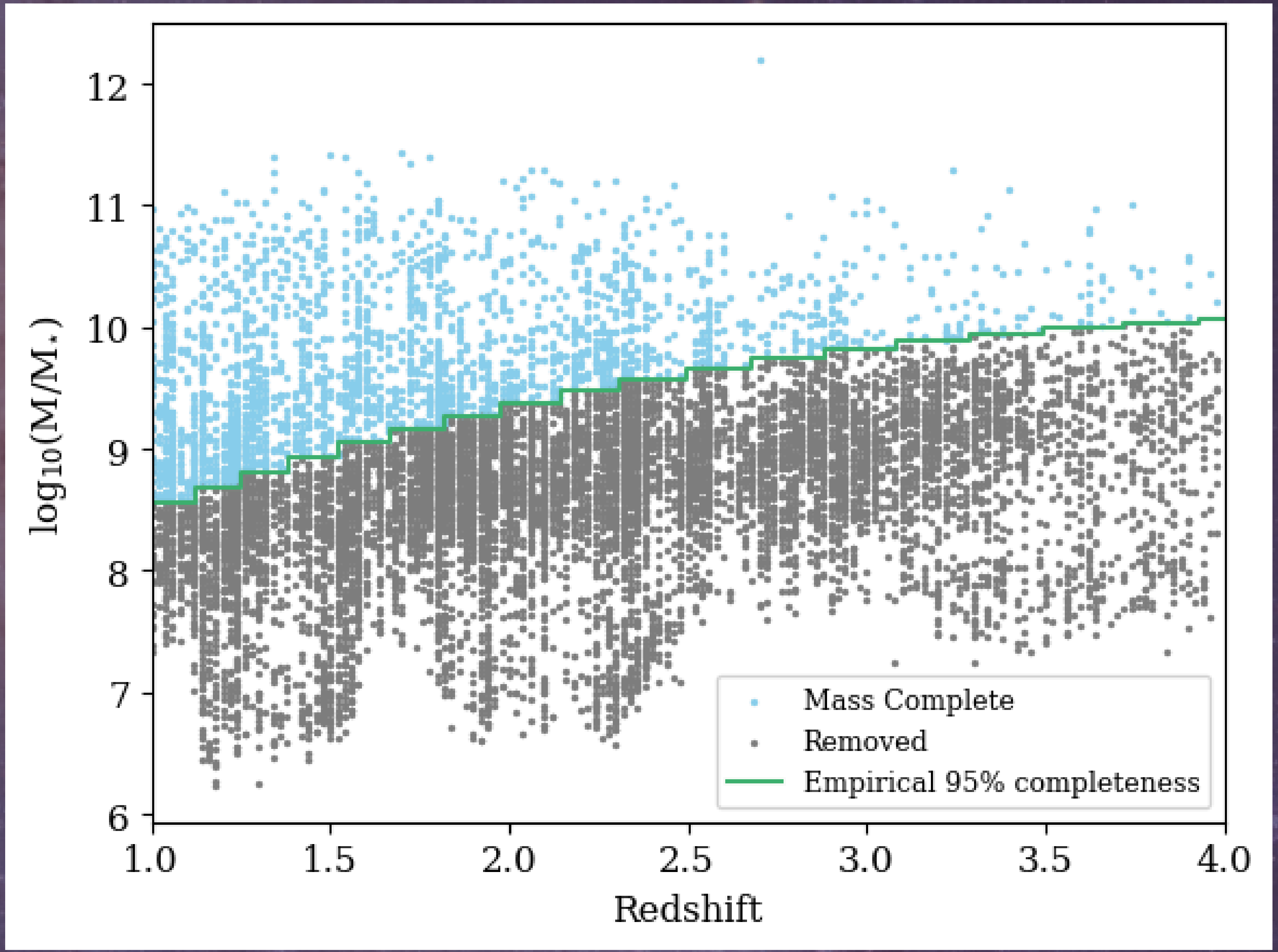
Optimised sample



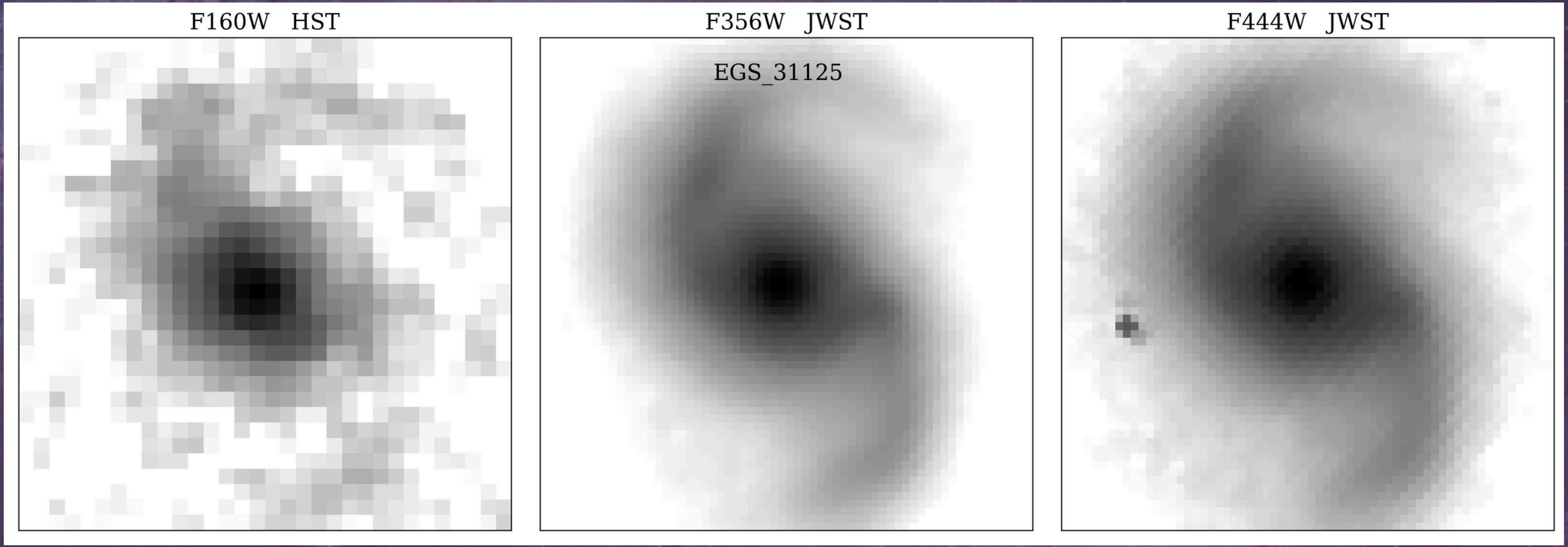
Le Conte et al. (2024)

MASS COMPLETENESS

- The mass complete sample is above the Duncan et al. (2019) green line.
- The parameter space below the step function corresponds to a completeness fraction of ≈ 85 – 95%.

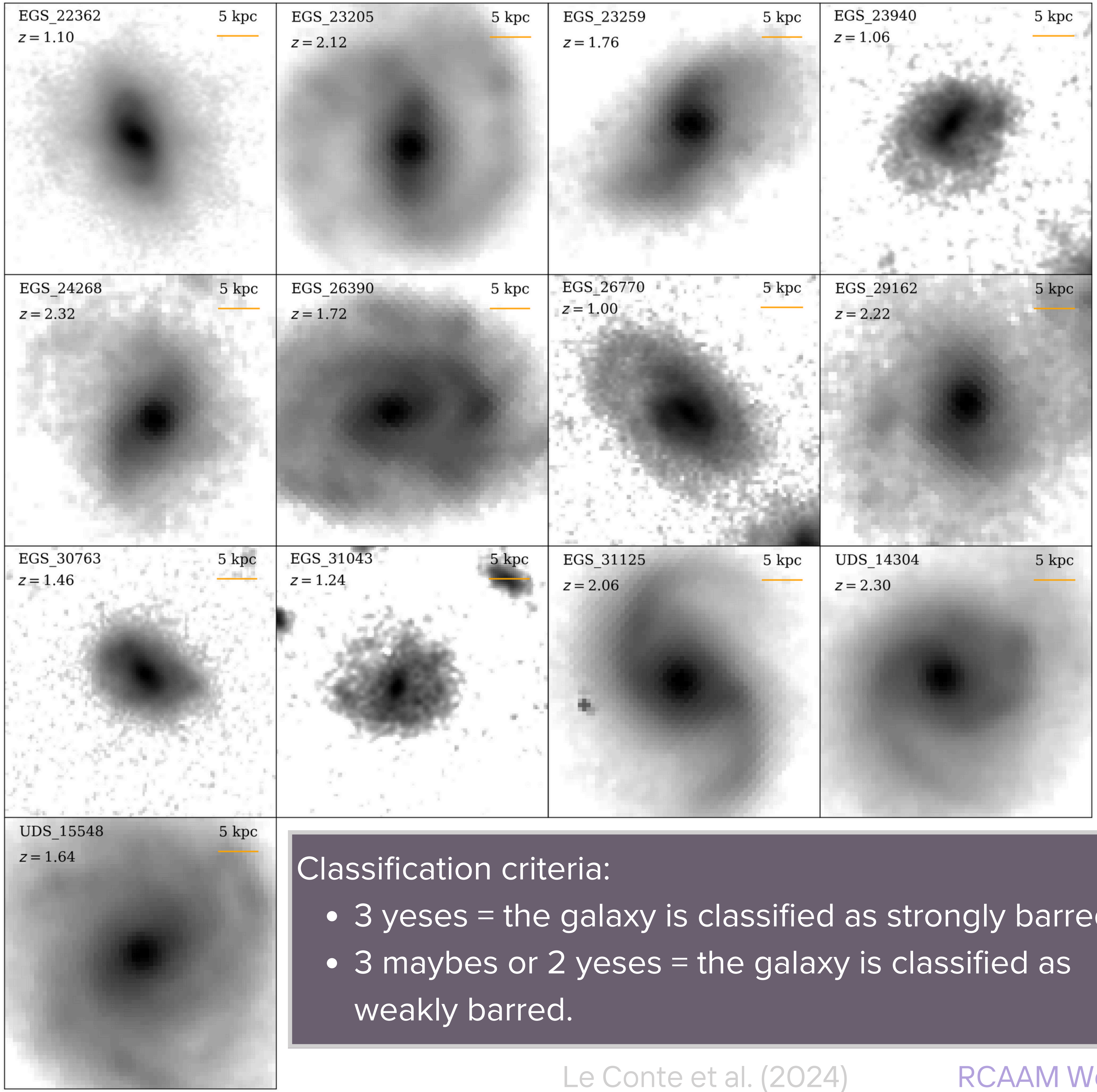


FILTER COMPARISON



Le Conte et al. (2024)

wavelength



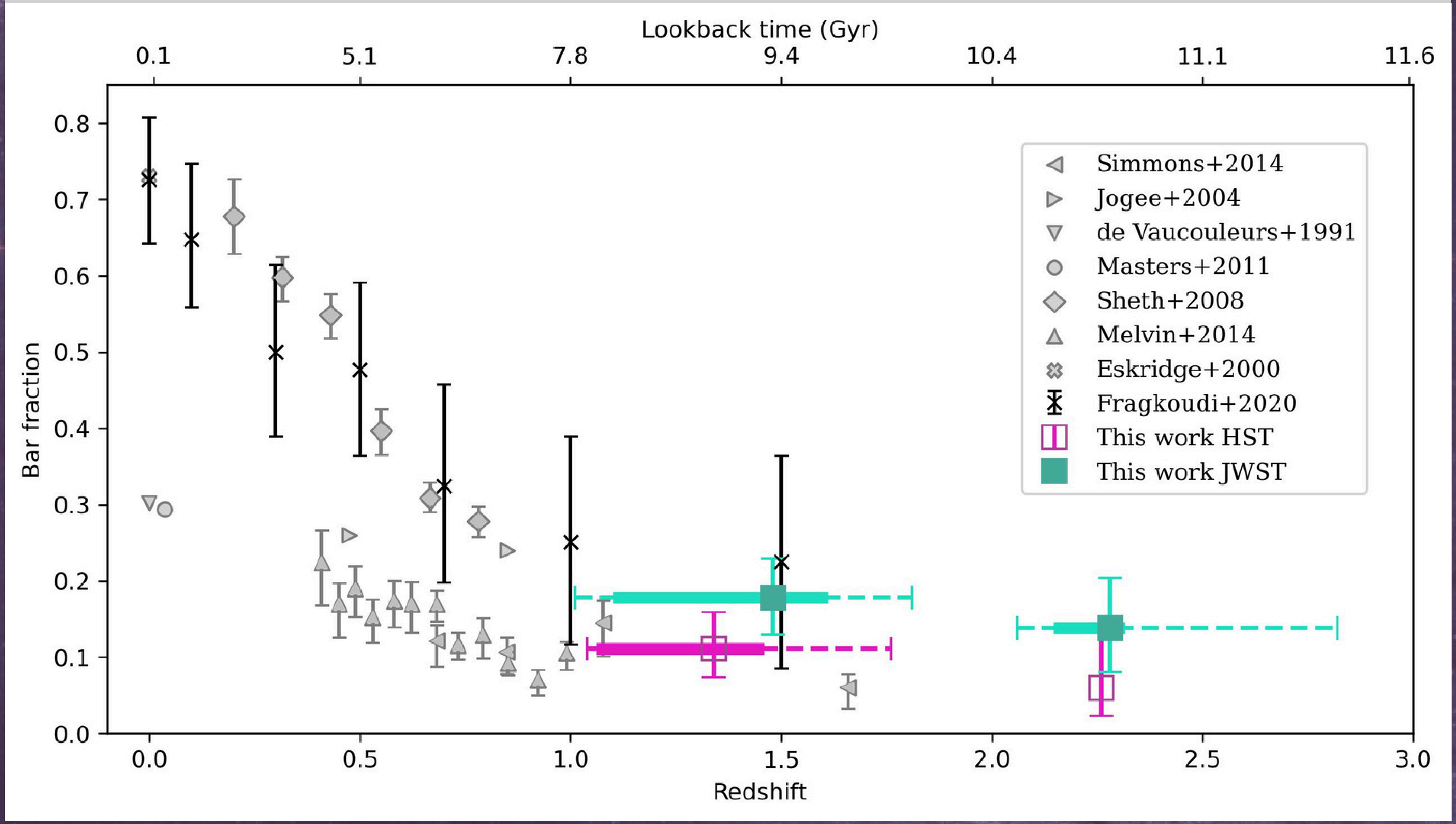
Classification criteria:

- 3 yeses = the galaxy is classified as strongly barred.
- 3 maybes or 2 yeses = the galaxy is classified as weakly barred.

Le Conte et al. (2024)

THE EVOLUTION OF THE BAR FRACTION

	z = 1 - 2	z = 2 - 3	Total bars z = 1 - 3
JWST	0.18	0.12	39
HST	0.11	0.06	10

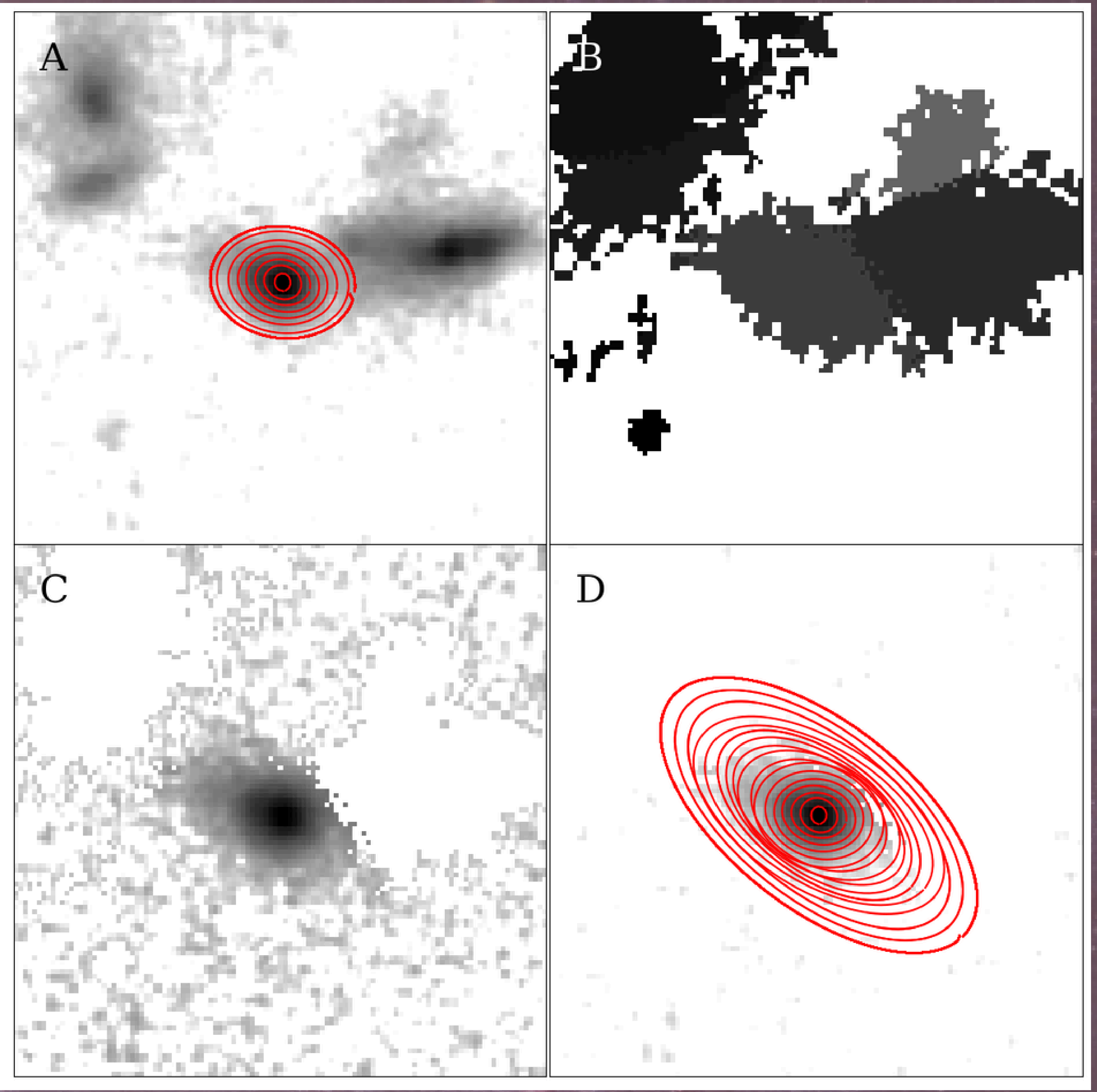


Le Conte et al. (2024)

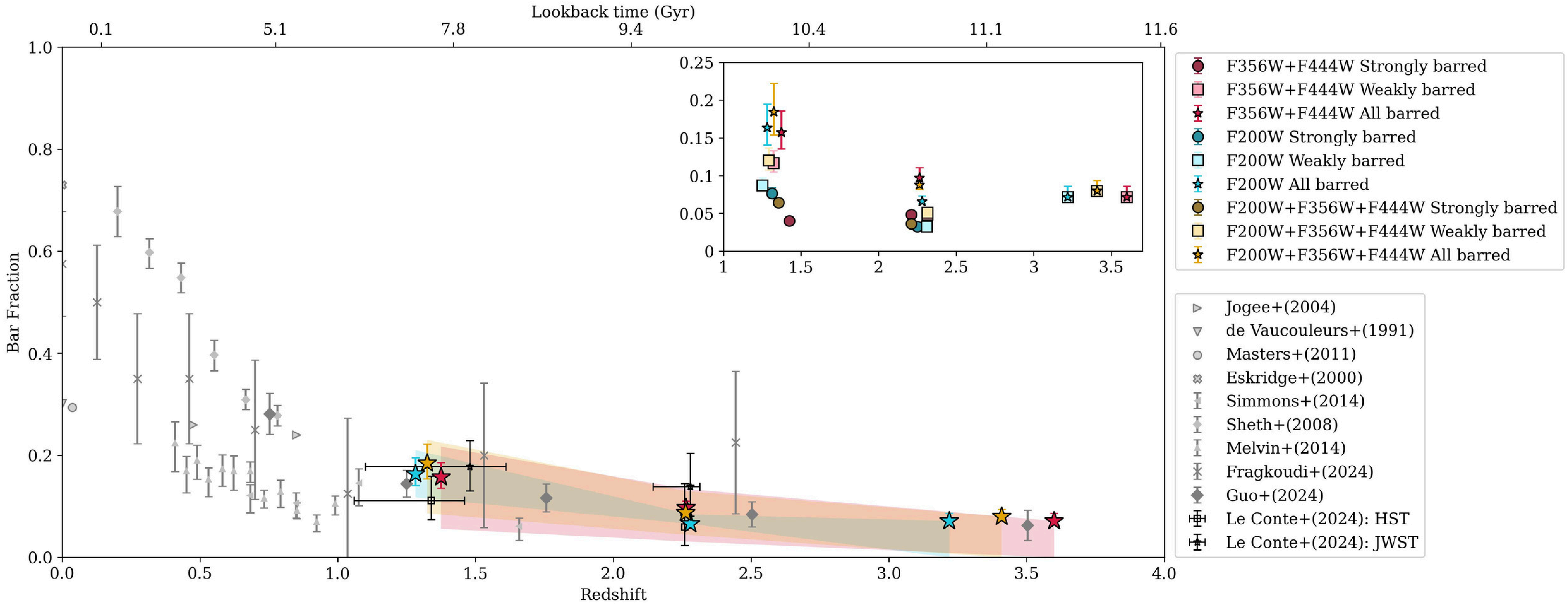
HOW PAPER II DIFFERS FROM PAPER I

- 10 CEERS pointing between $1 < z < 4$.
- F356W for $1 < z < 2$; F444W for $2 < z < 4$.

- Select mass complete sample.
- Remove neighbouring objects with SExtractor.
- Remove edge-on galaxies in optimisation.
- Remove unresolved objects using 2D fits with Imfit.
- Visually classify barred and unbarred disc galaxies.
- Repeat for F200W filter.



THE EVOLUTION OF THE BAR FRACTION



Le Conte et al. (in prep)

THE EVOLUTION OF THE BAR FRACTION

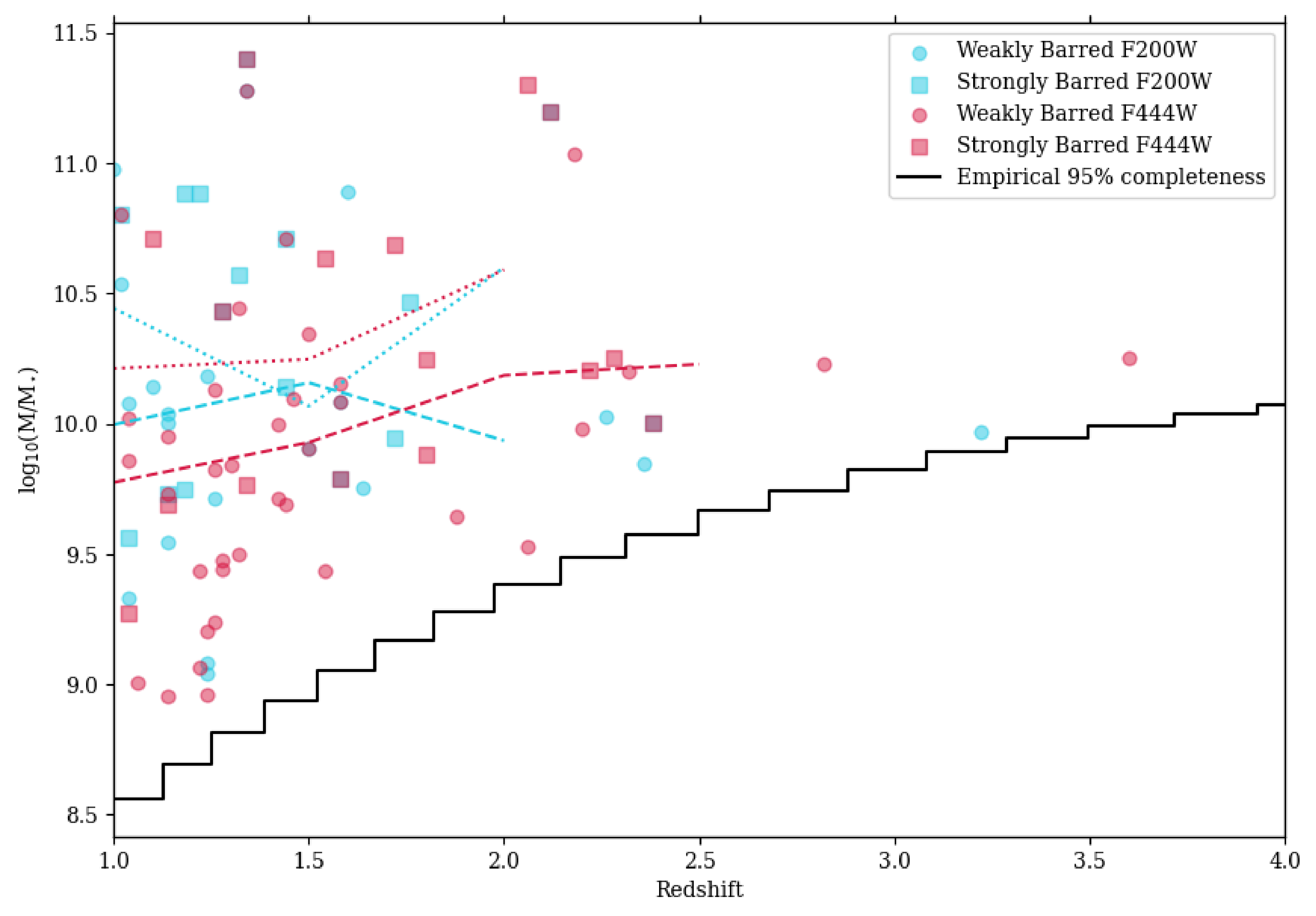
Paper I conclusions:

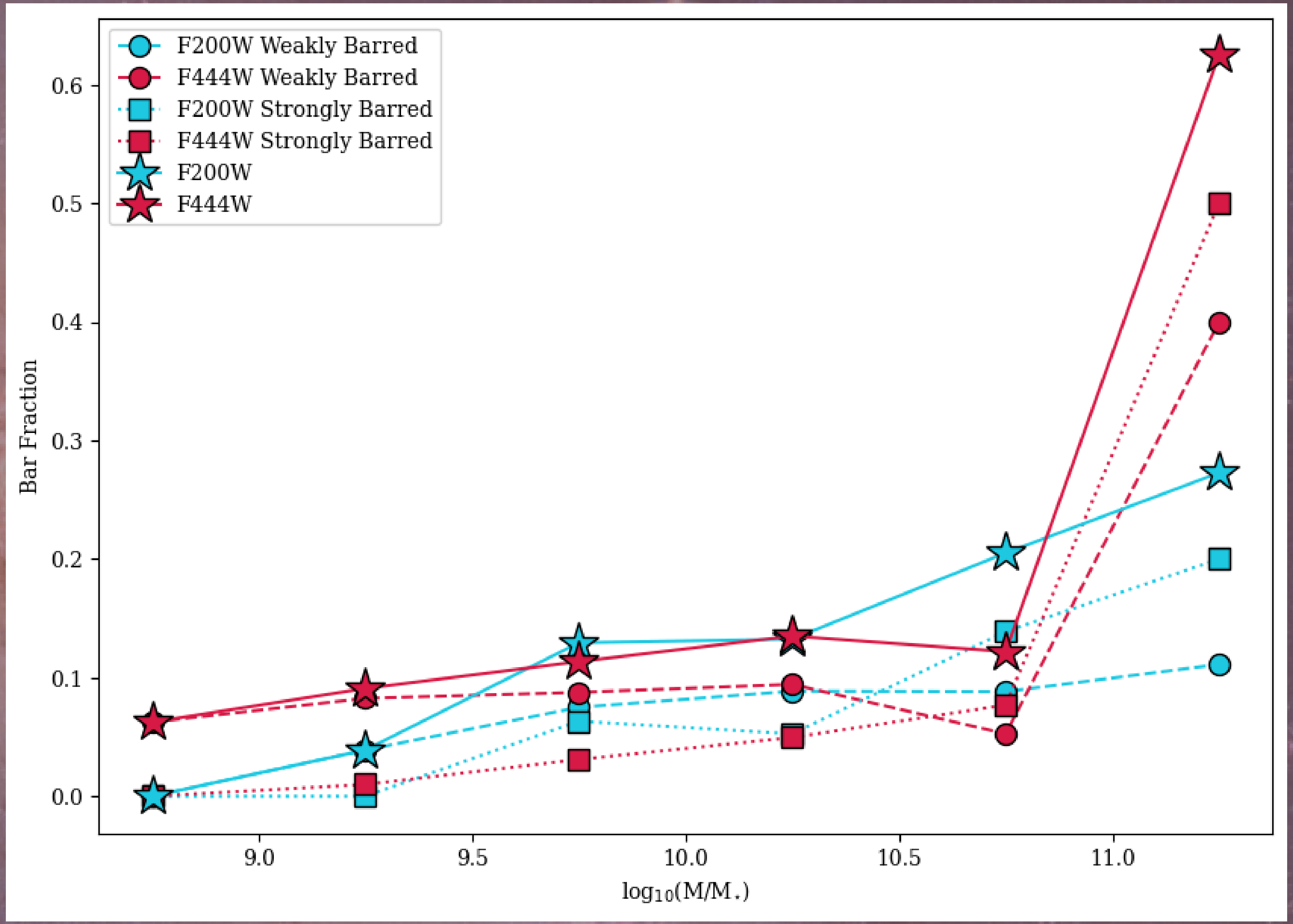
- The fraction of bars in disc galaxies at redshifts 1 - 2 is ~ 18%.
- The fraction of bars in disc galaxies at redshifts 2 - 3 is ~ 12%.
- The JWST bar fraction is twice the HST bar fraction.

Paper II conclusions:

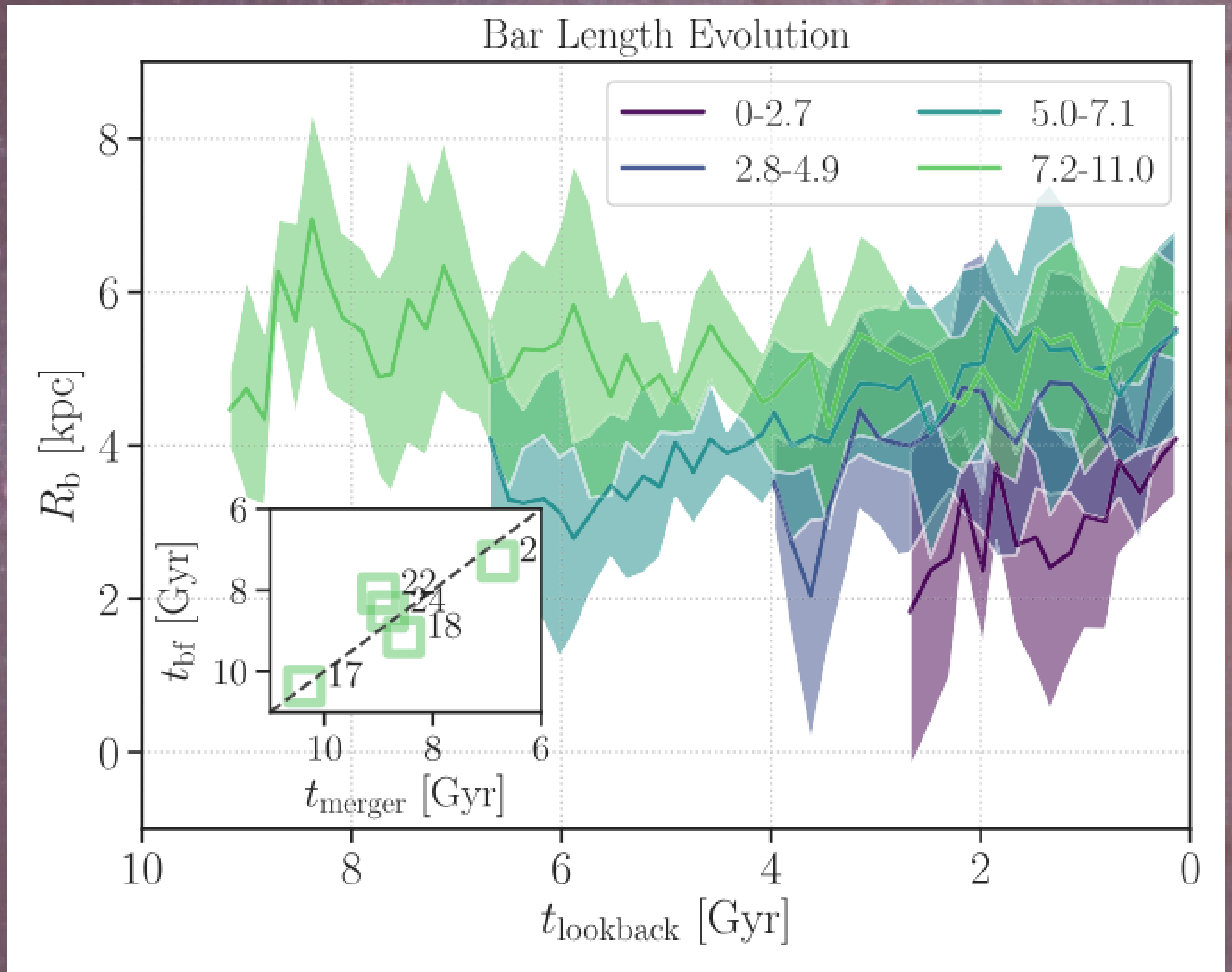
- Weakly barred galaxies seen at $z > 3$.
- The bar fractionis consistent with Paper I within the uncertainties.
- At all redshifts, the bar fraction is similar in short- and long-wavelength NIRCam filters.

STELLAR MASS BAR FRACTION





MEASURING THE BAR LENGTH



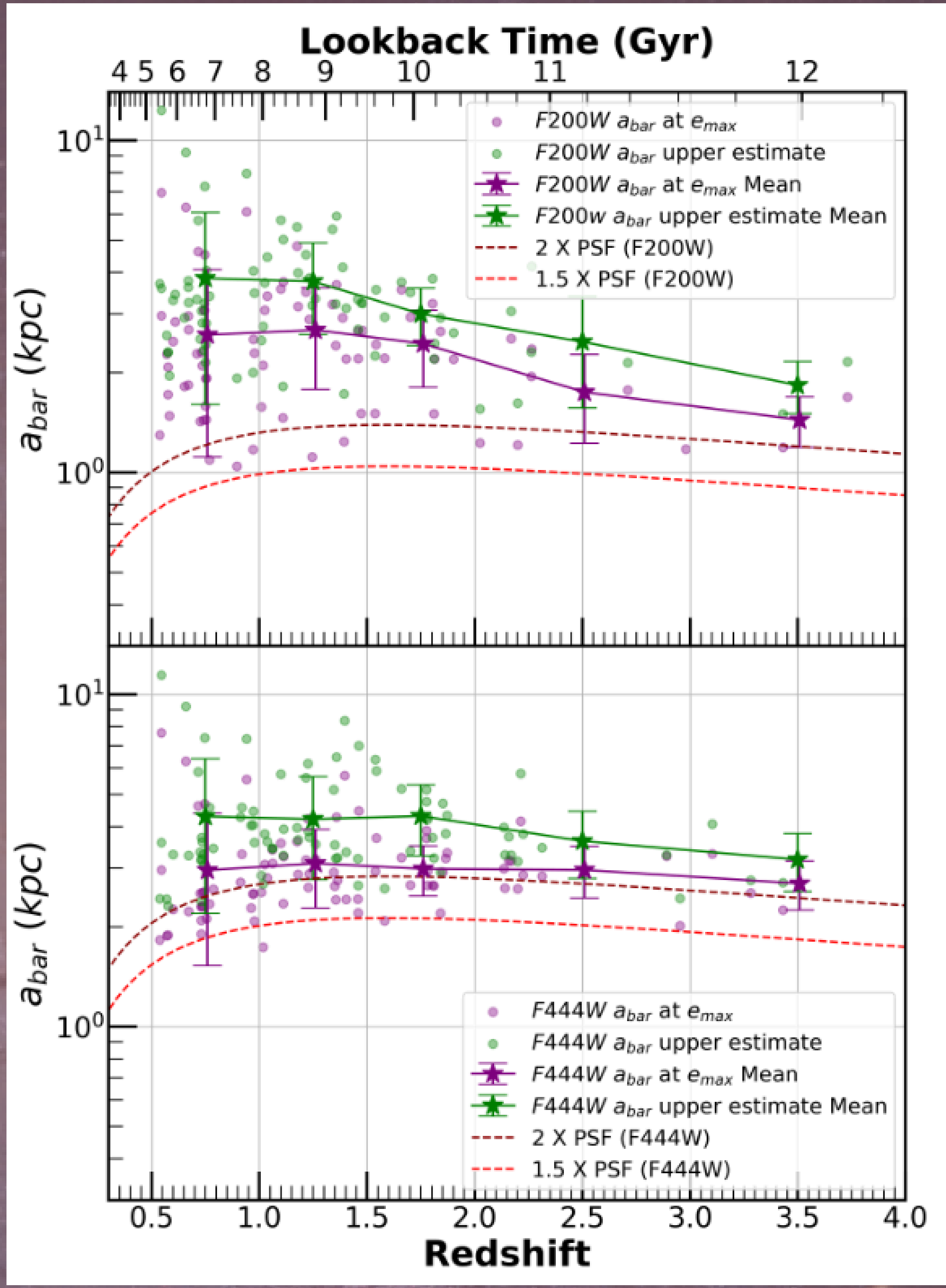
Fragkoudi et al. (2025)

- Bar length grows from high- to low-z.

(e.g., Hohl 1971; Athanassoula & Misiriotis 2002; O'Neil & Dubinski 2003; Debattista et al. 2006; Dubinski et al. 2009; Minchev et al. 2011)

- Bars do not grow in length across the redshift range.

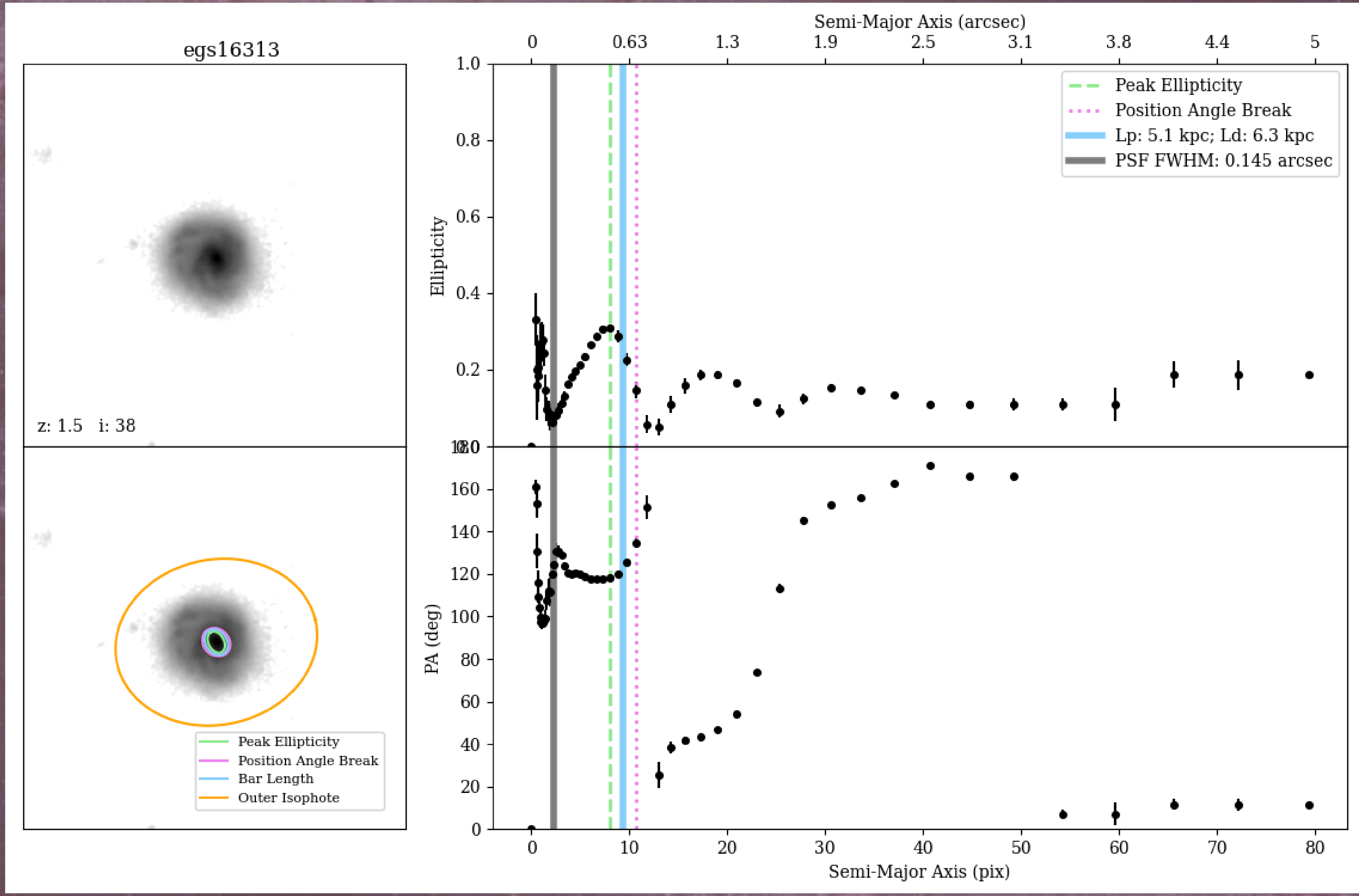
(e.g., Kim et al. 2021; Guo et al. 2024)



Guo et al. (2024)

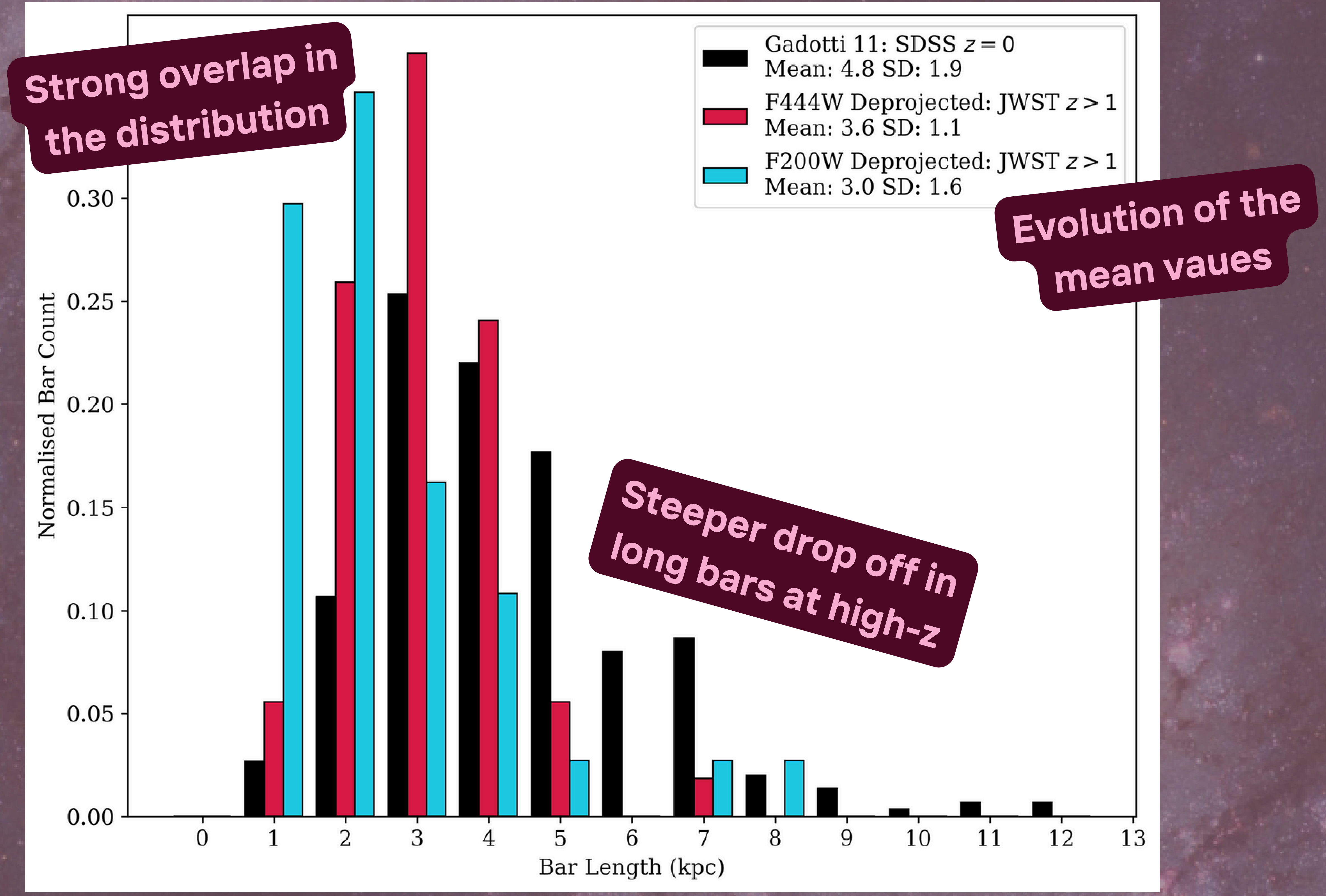
Deprojected bar length

$$L_{\mathrm{bar}} = L_{\mathrm{p}}(\sin^2\alpha\ \sec^2 i + \cos^2\alpha)^{1/2}$$



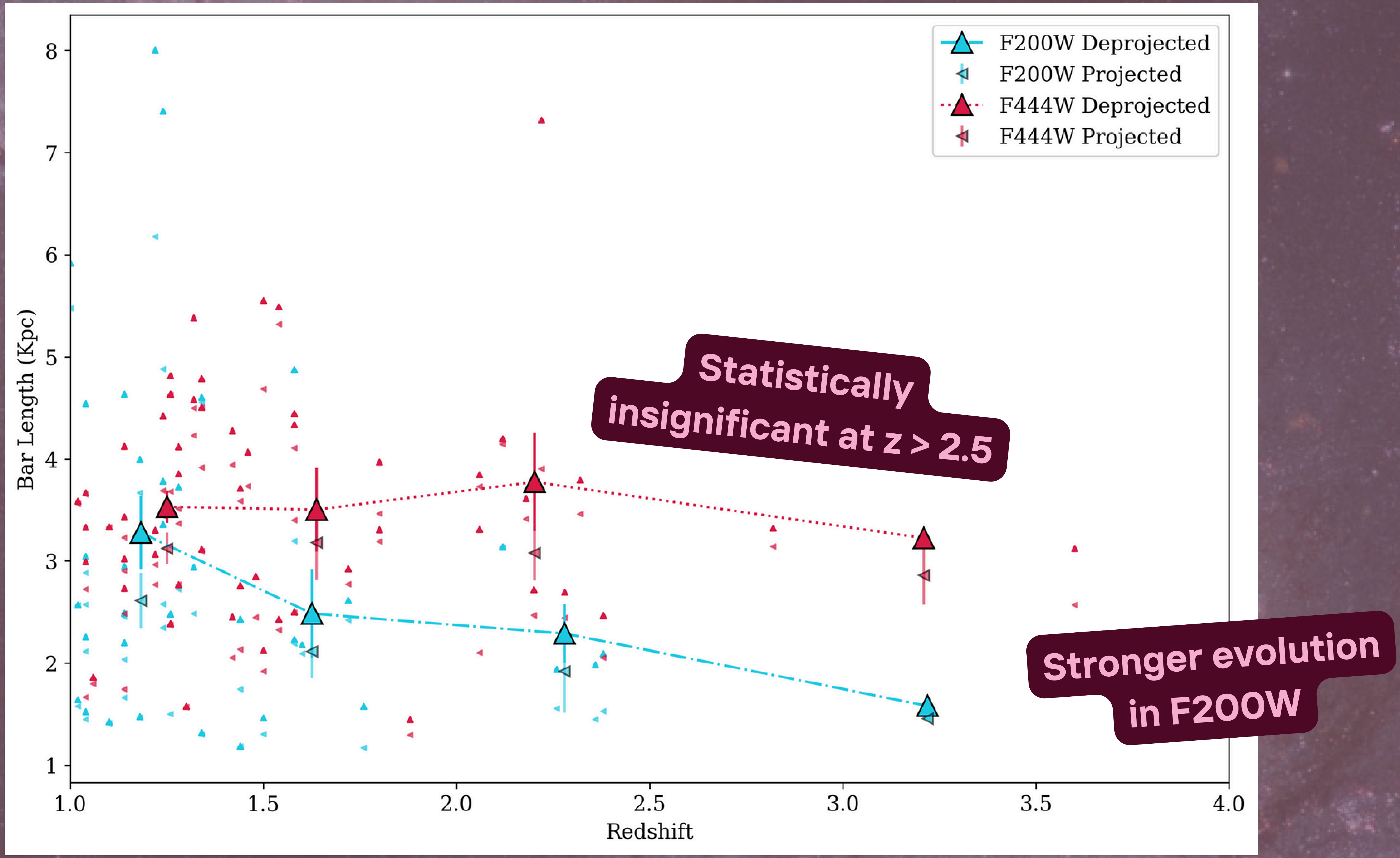
Le Conte et al. (in prep)

THE BAR LENGTH



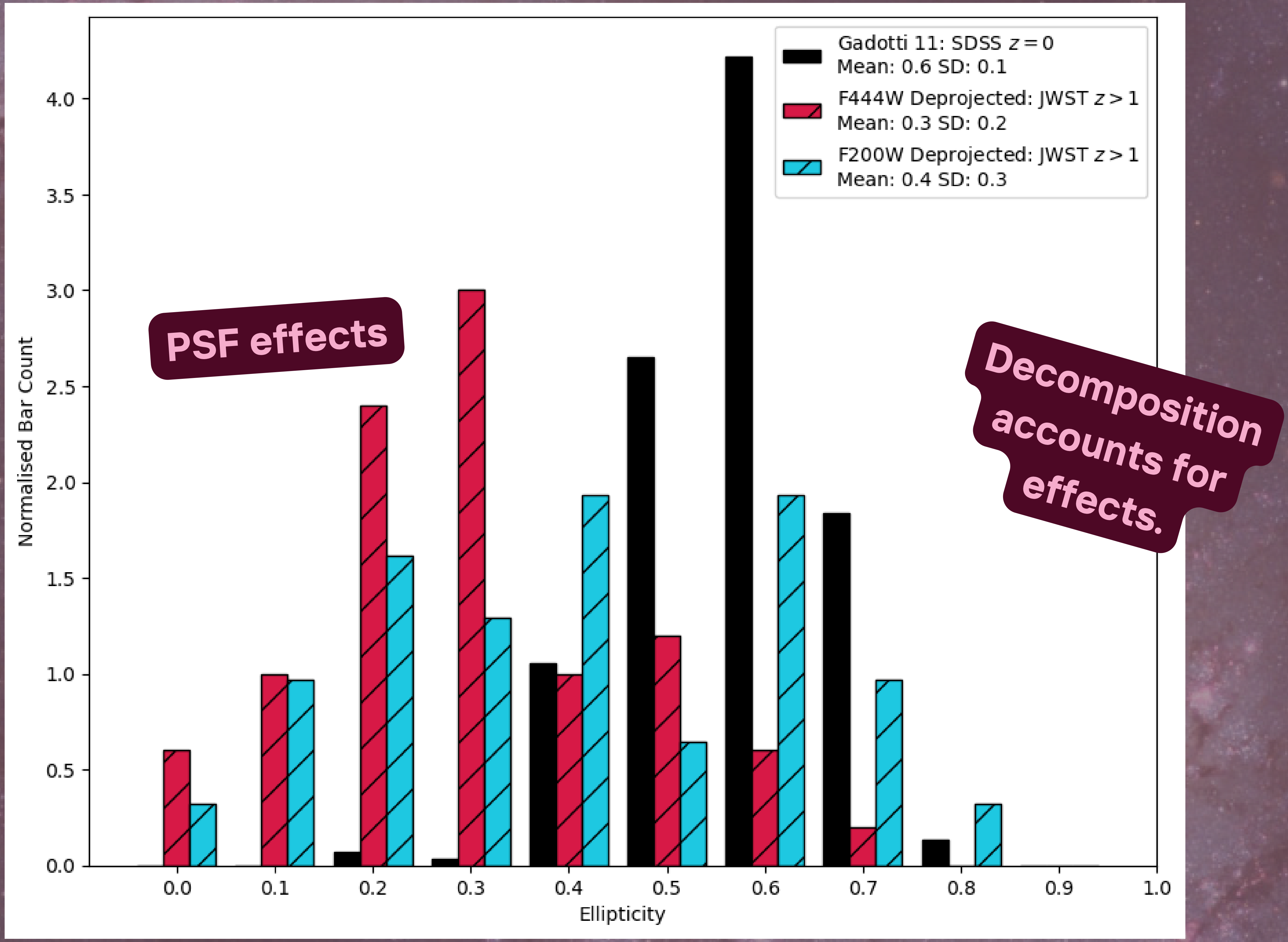
Le Conte et al. (in prep)

THE EVOLUTION OF THE BAR LENGTH



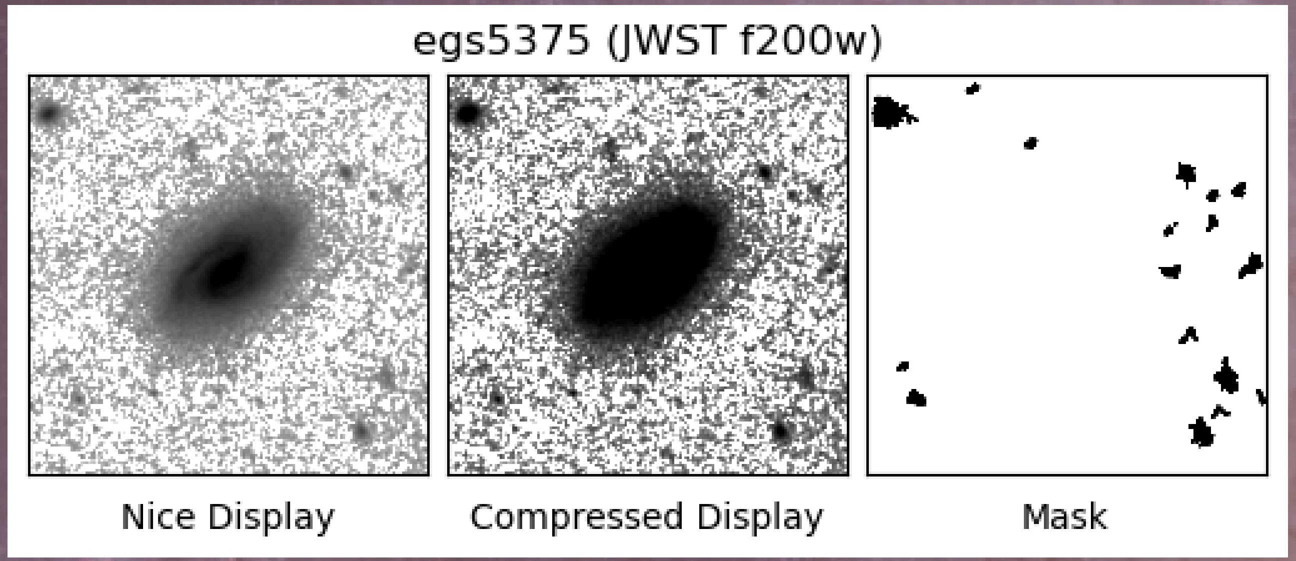
Le Conte et al. (in prep)

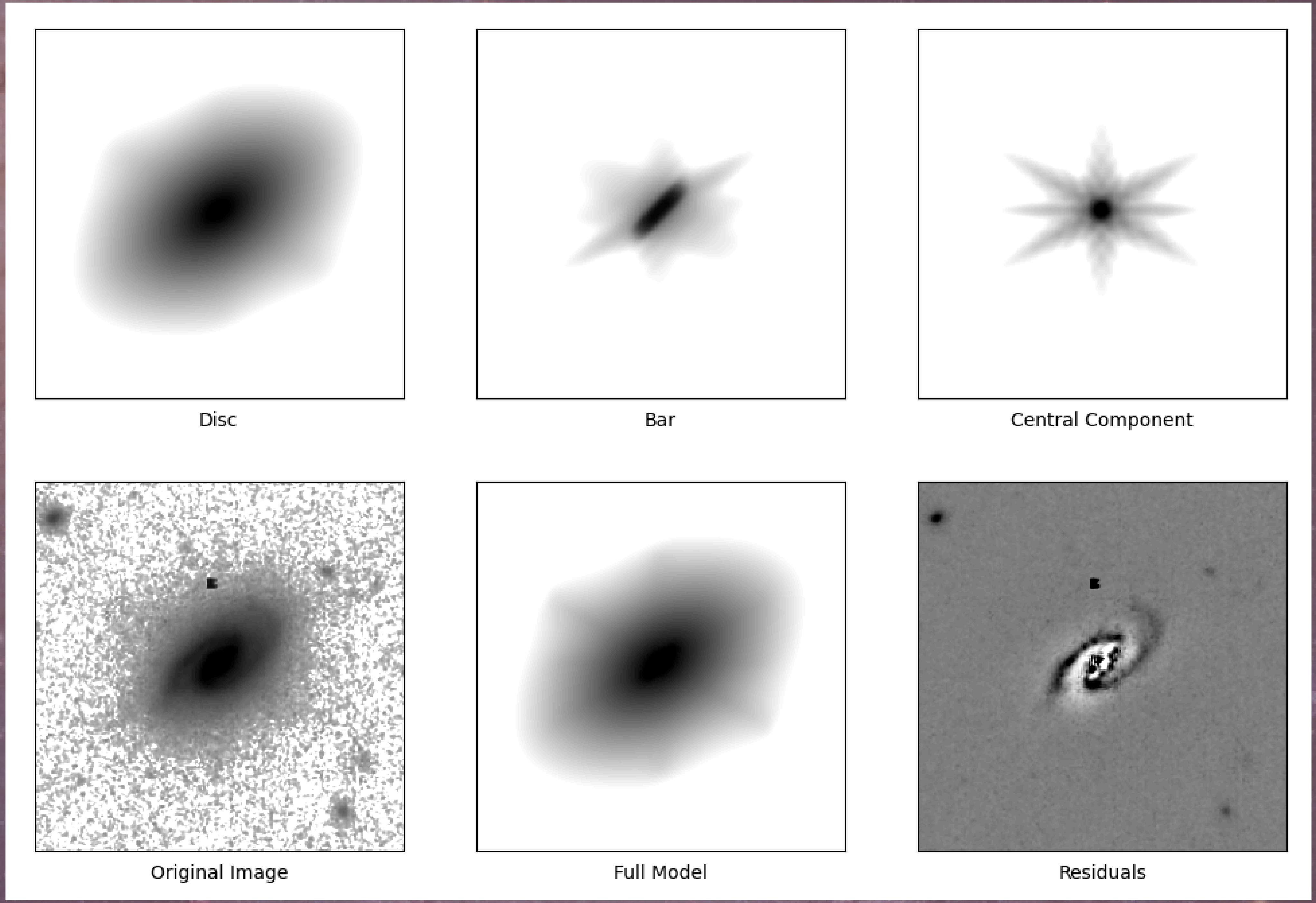
THE BAR ELLIPTICITY



Le Conte et al. (in prep)

BAR DECOMPOSITION





- Imfit: 2D functions fit to high-z bars. Erwin 2019
- Up to 3 components modelled.
- A technique for bar length, ellipticity and bar/total mass ratio measurements.

CONCLUSIONS - LE CONTE ET AL. (2024)

- The fraction of bars in disc galaxies at redshifts 1 - 2 is ~ 18%.
- The fraction of bars in disc galaxies at redshifts 2 - 3 is ~ 12%.
- The JWST bar fraction is twice the HST bar fraction.
- We miss bars shorter than 3 kpc.

CONCLUSIONS - LE CONTE ET AL. (2025, IN PREP)

- At bluer wavelengths, we may encounter dust obscuration and observe shorter bars.
- High-z bars have a similar length to bars at z = 0.
- High-z bars are rounder in the lower resolution filters due to a PSF effect.
- Evolution in average bar length no greater than 1 kpc, and observed stronger in F200W NIRCam filter.
- Internal secular evolutionary processes begin earlier than once thought.

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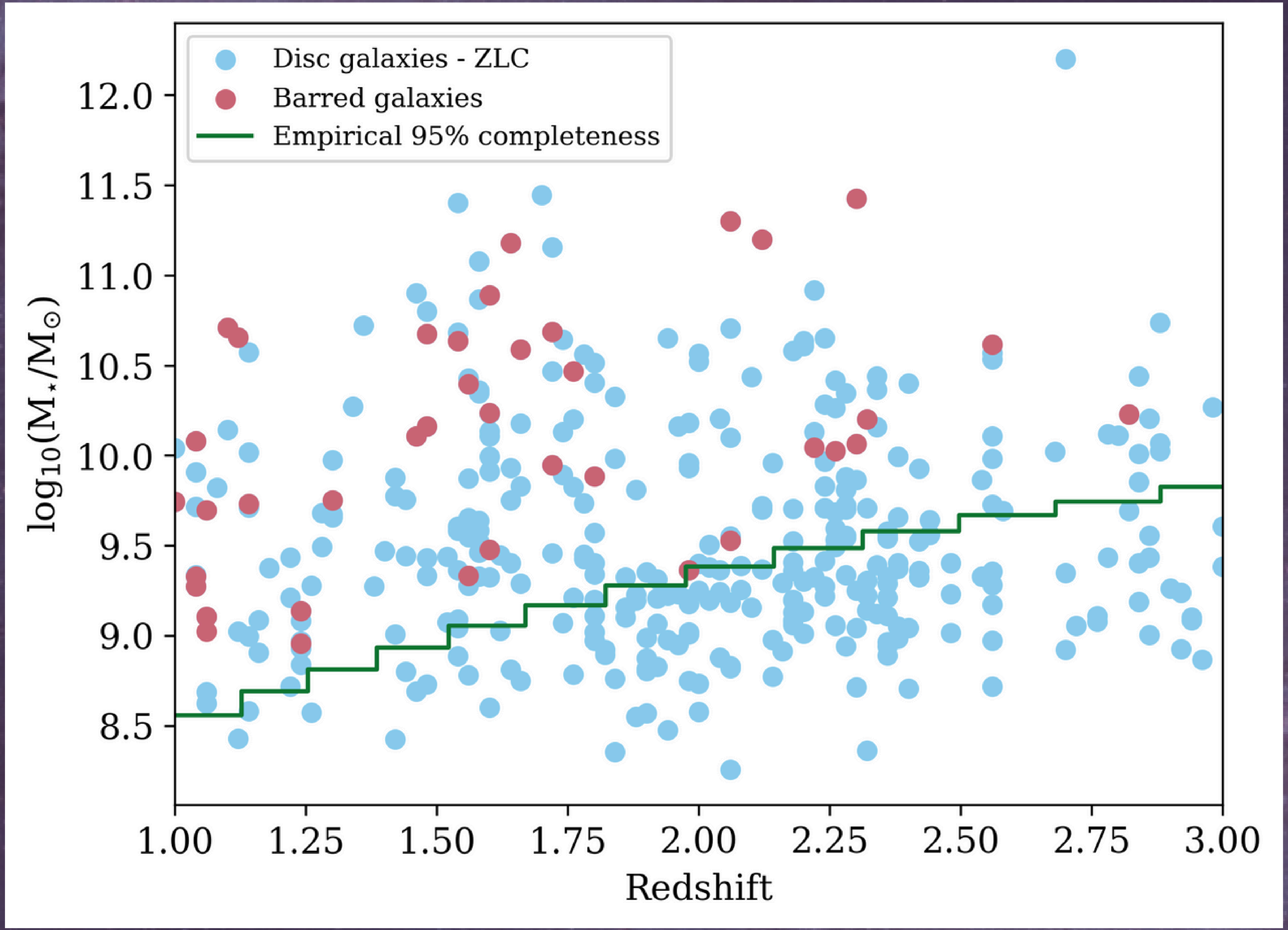
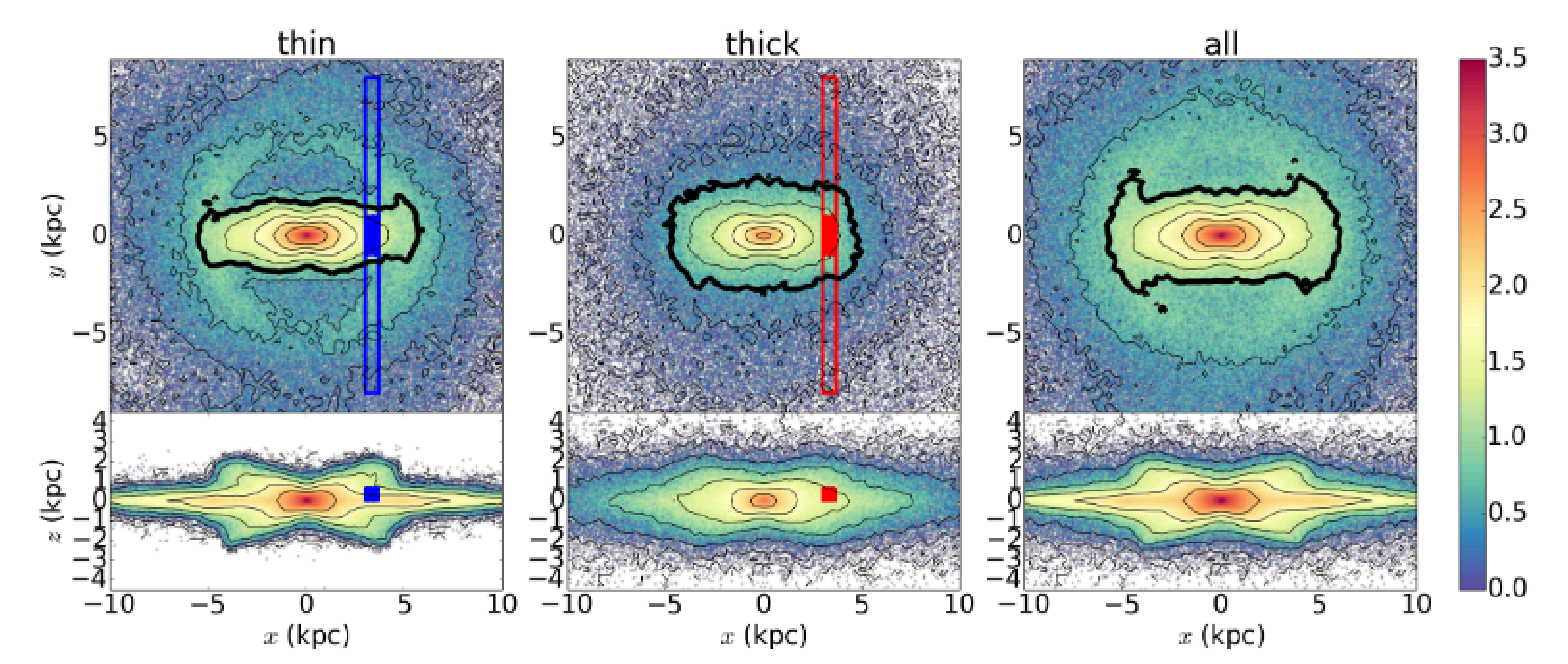
MASS DEPENDANCE



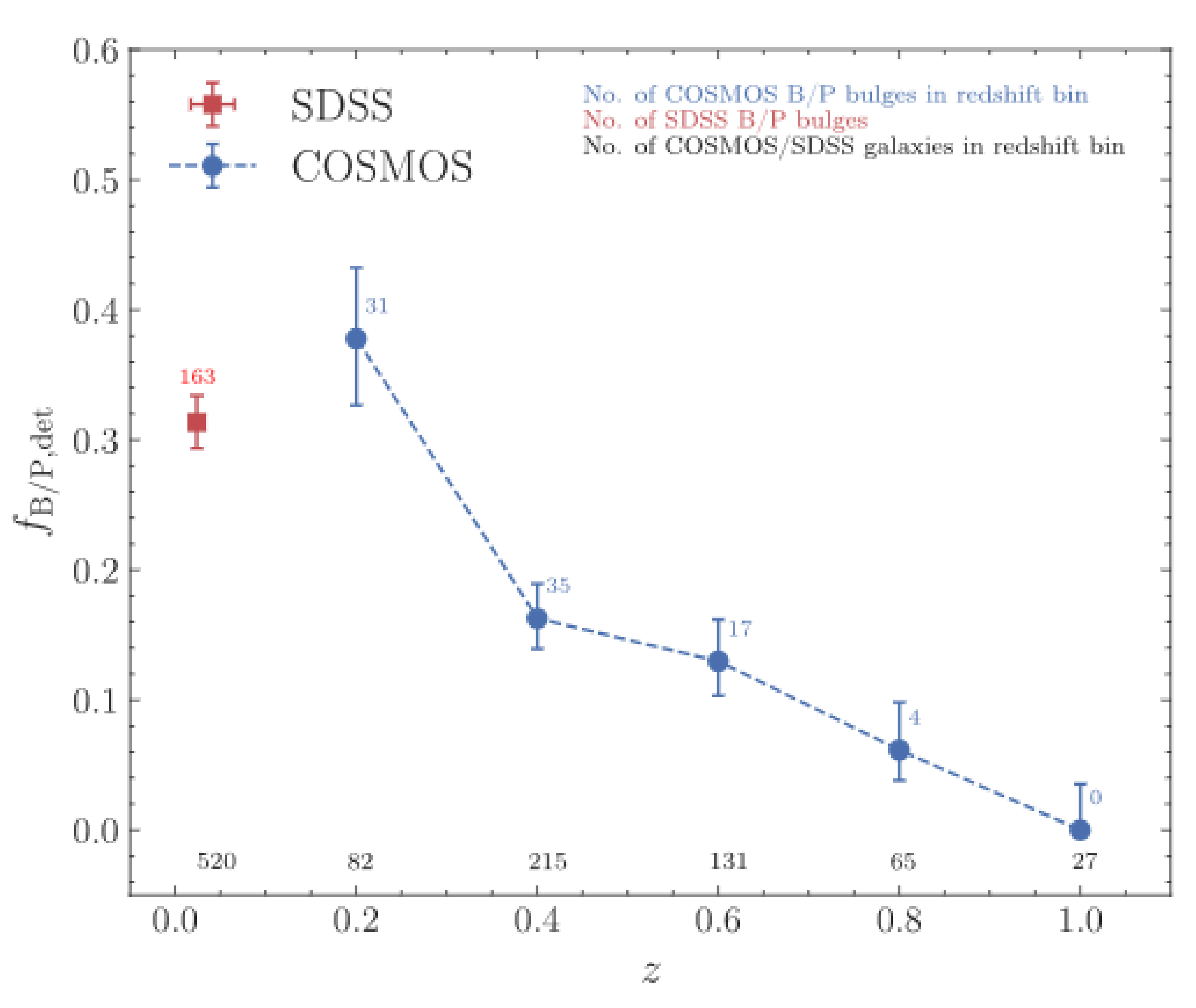
Le Conte et al. (2024)

BOXY/PEANUTS

- B/Ps are edge-on barred galaxies.
- Resolution challenges at high-z.
- Identification of B/Ps at early times will constrain theoretical models.
- Provide a measure of bar-driven evolution.



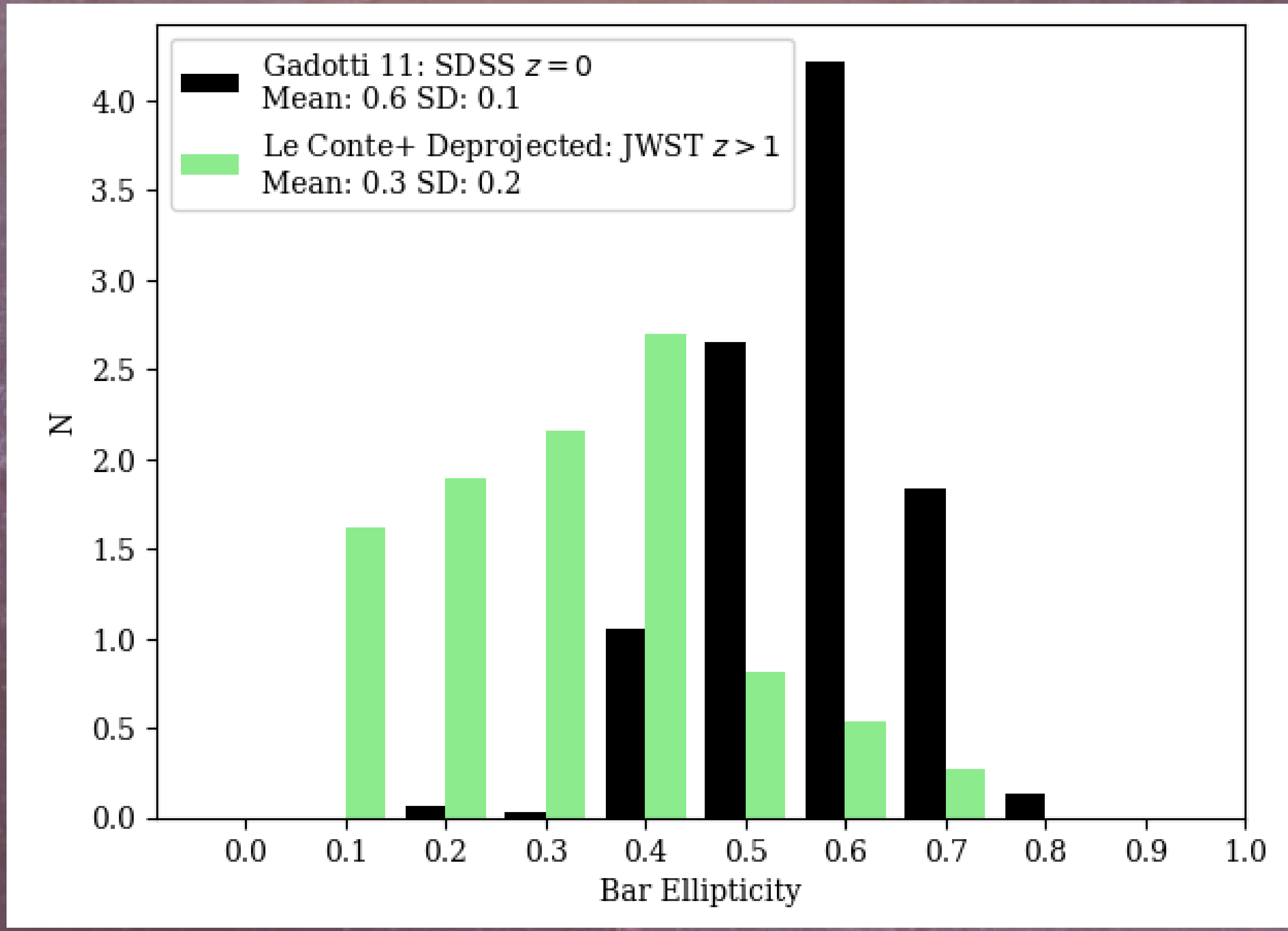
Fragkoudi et al. (2017)



Kruk et al. (2019)

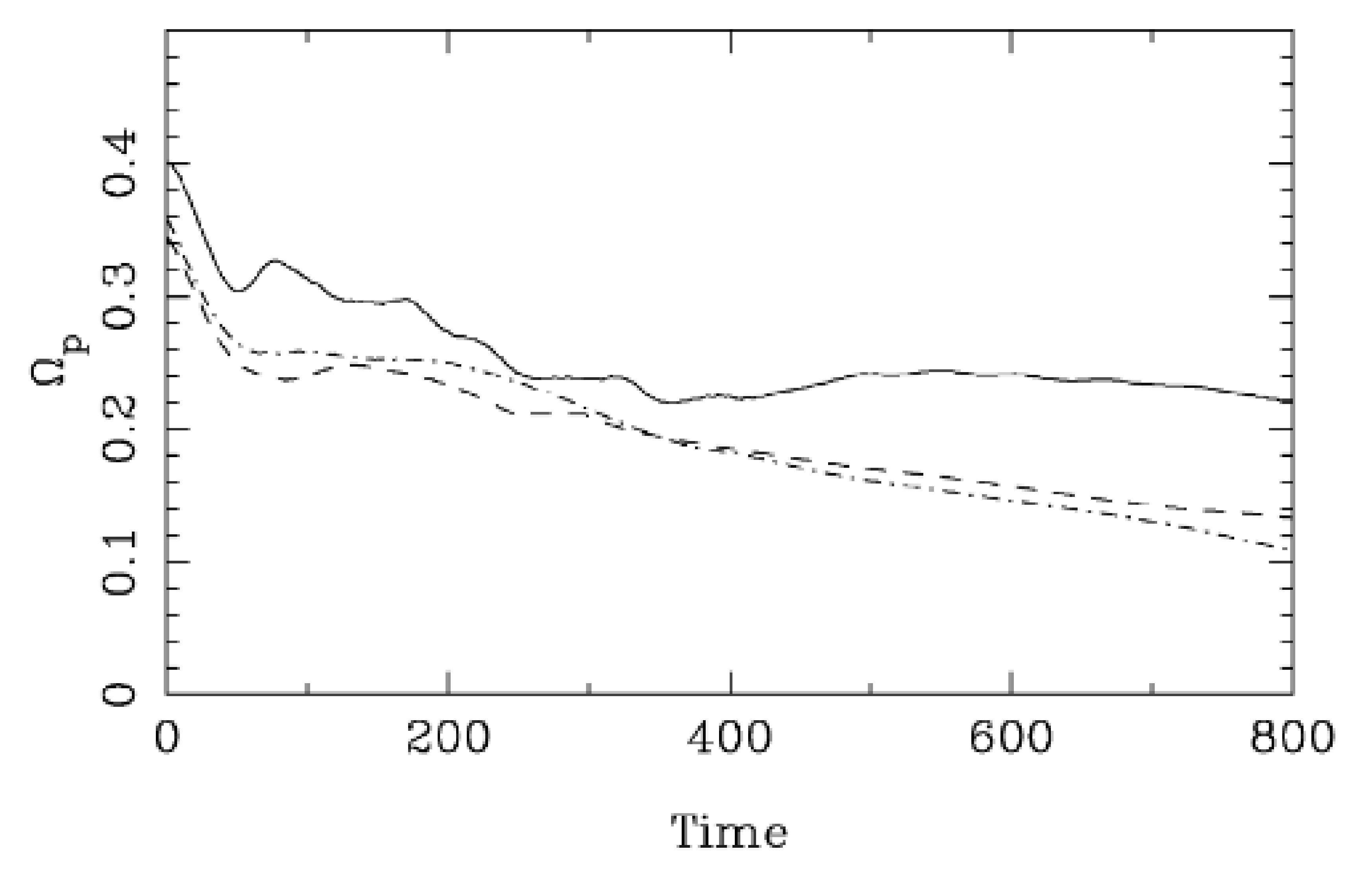
THE BAR STRENGTH

- Ellipticity is a measure of bar strength.
- Do bars grow in strength?
- Do bars form strongly at z > 1?



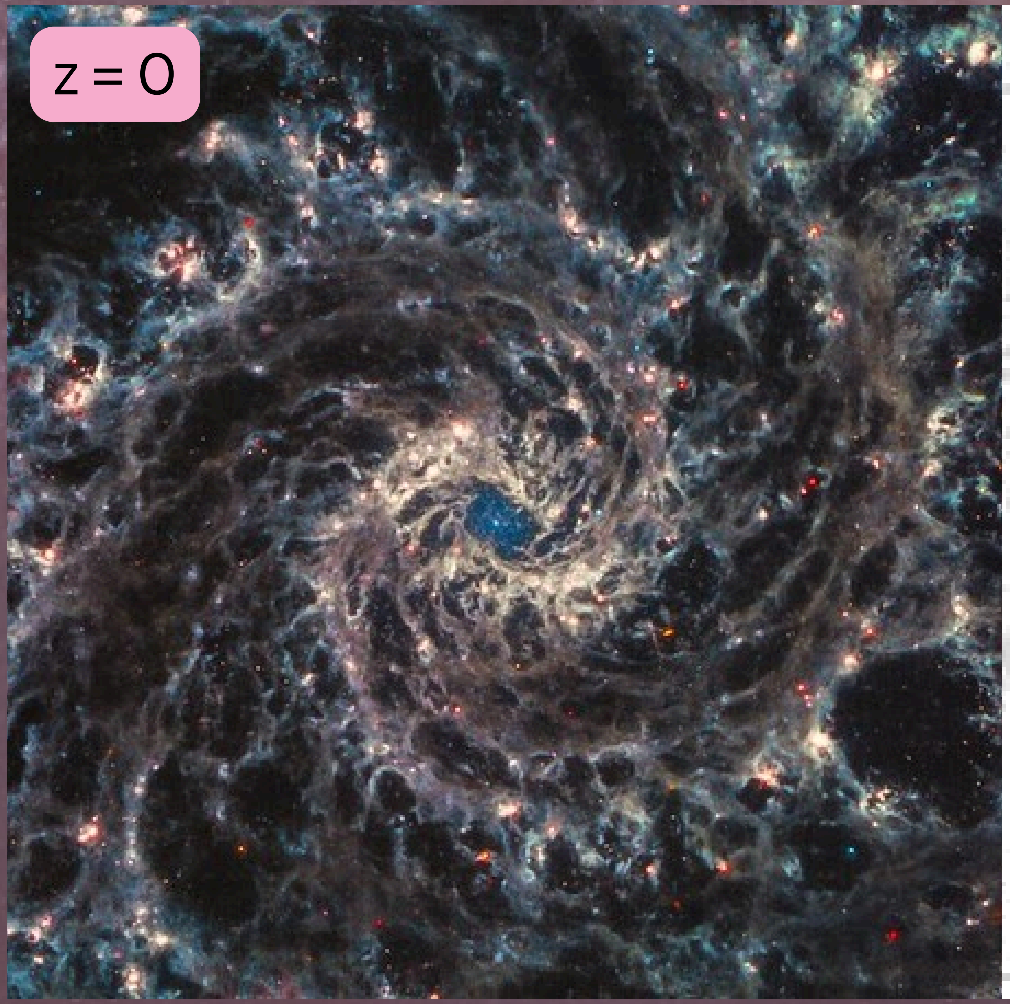
Le Conte et al. (in prep)

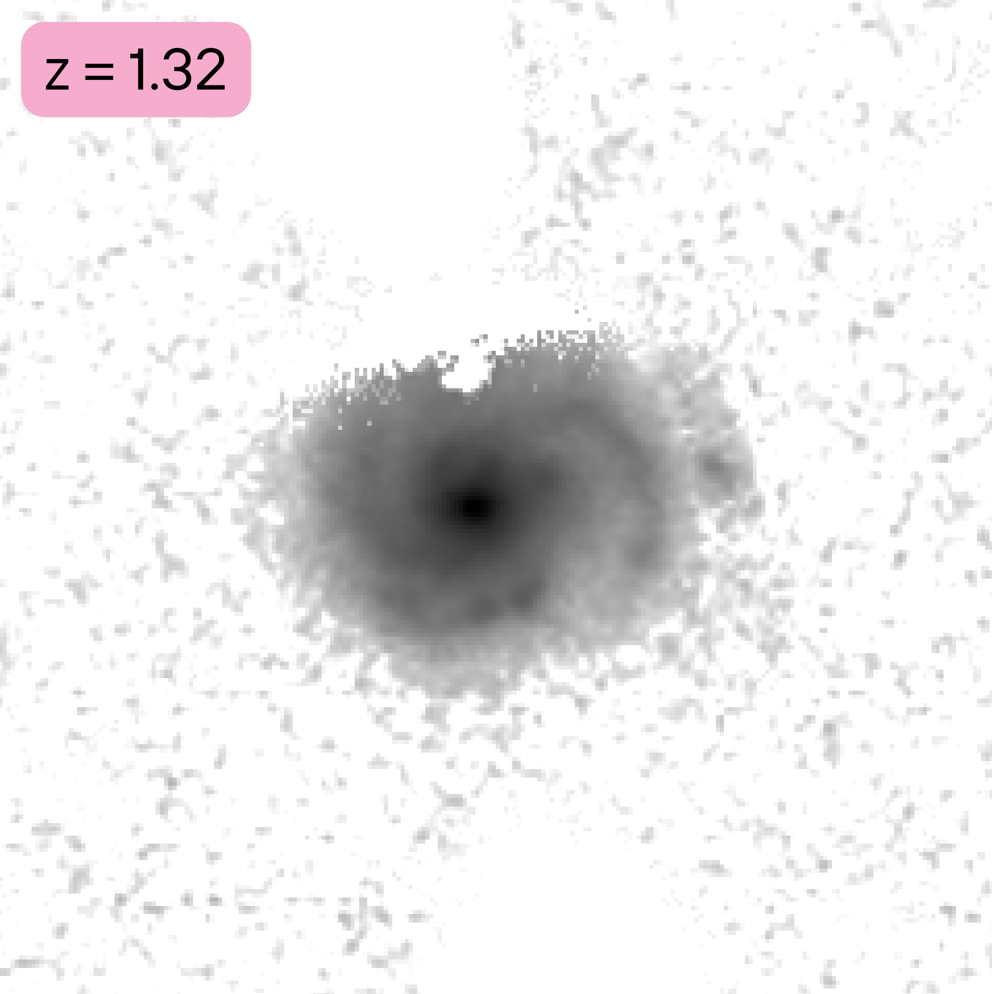
SLOWDOWN OF BAR PATTERN SPEED



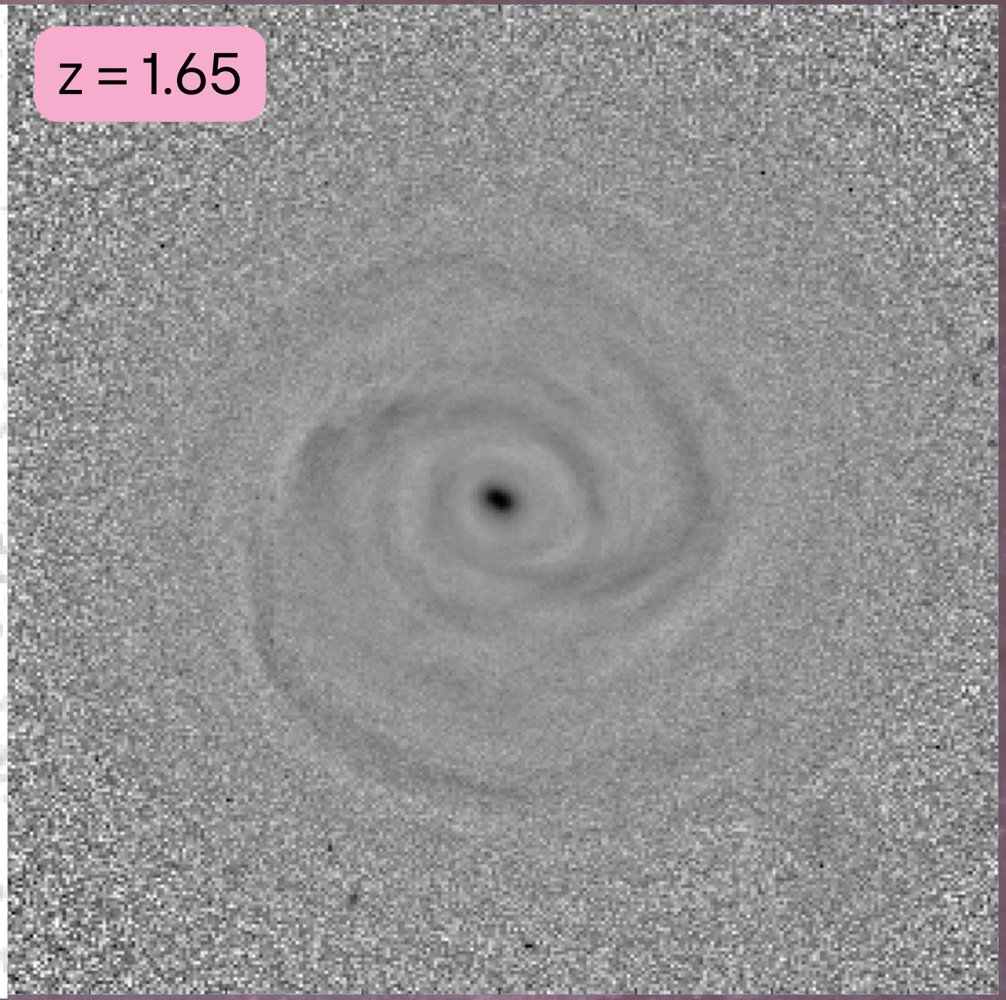
MATURE GALAXIES

- Grand design spirals exist at z > 1.
- Settled and mature galaxies were in place 11 billion years ago.
- Massive disc galaxies are seen in simulations.
- The high-z dis galaxies are similar to the local Universe.



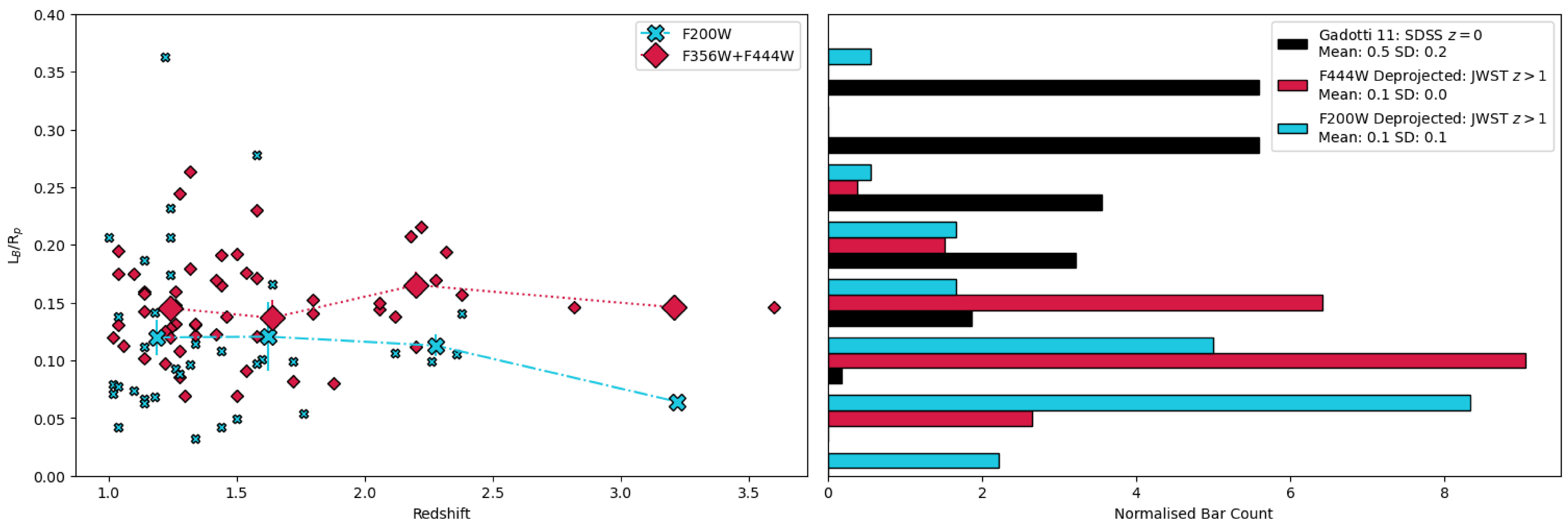


Credit: Judy Schmidt



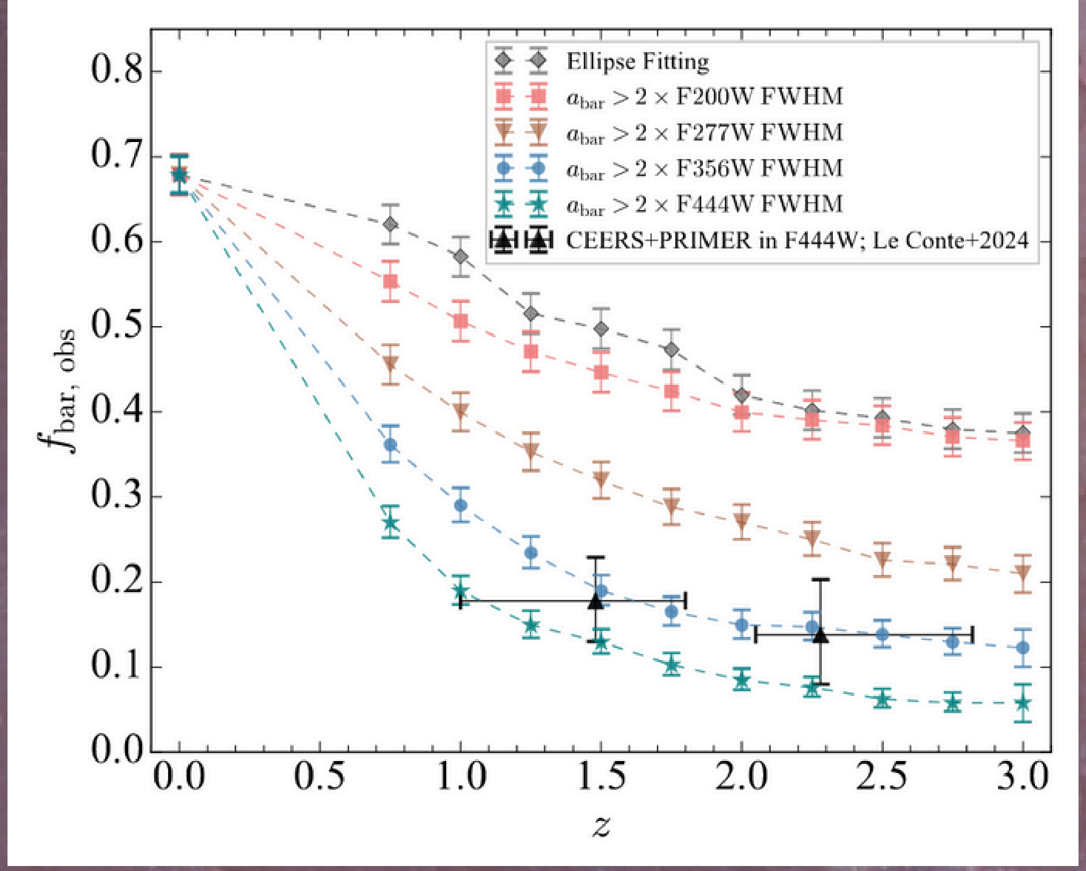
Credit: Thomas Tomlinson

THE EVOLUTION OF THE BAR LENGTH



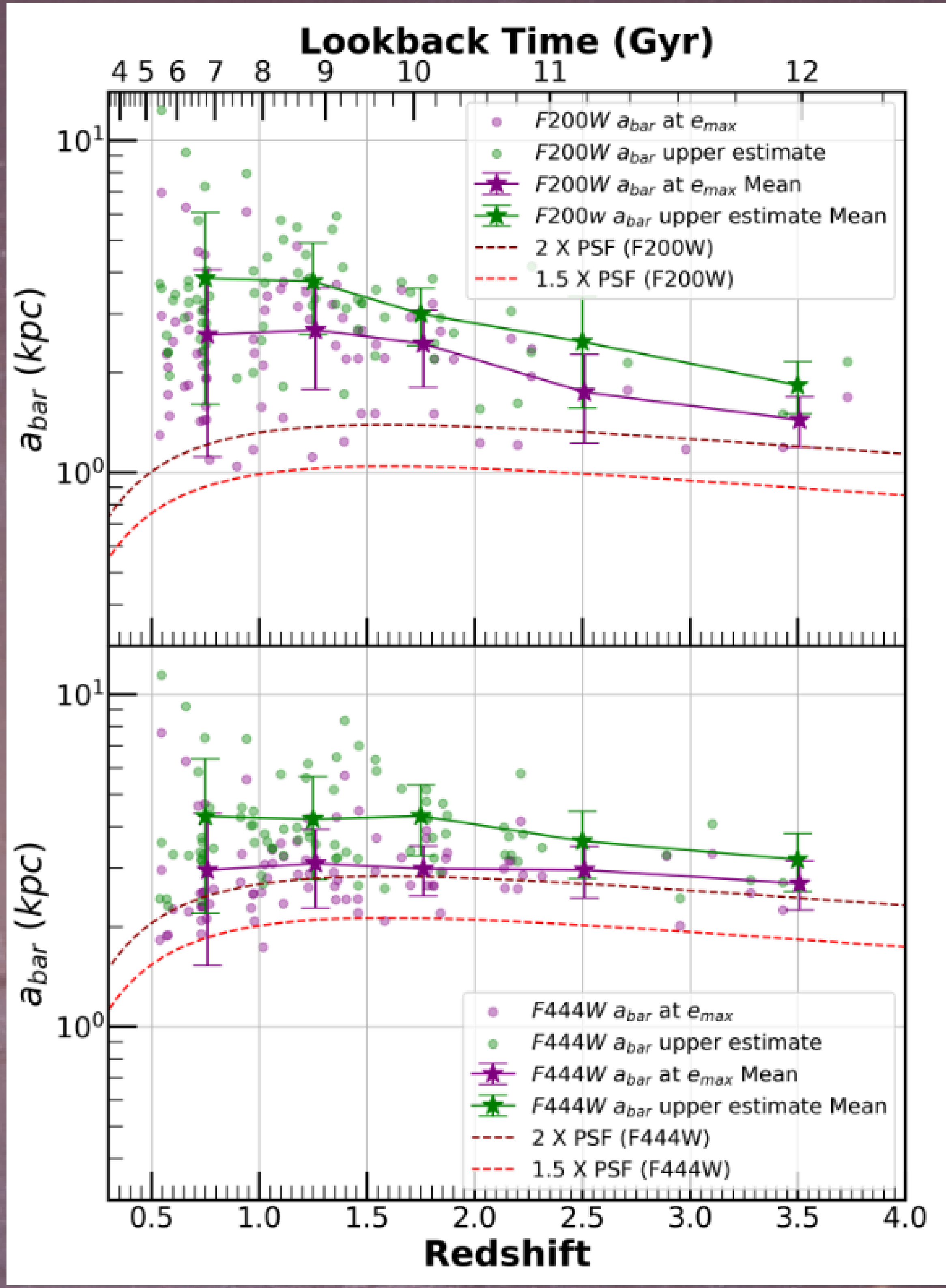
Le Conte et al. (in prep)

WAVELENGTH DEPENDENCE



Liang et al. (2024)

- 100% bar detection at bar length > 2 FWHM.
- Is the bar fraction higher in F200W?
- Bluer wavelengths have improved spatial resolution.
- At z = 0, a lower bar fraction at bluer wavelengths is found.
- Guo et al. (2024) found shorter bars and an evolution in bar length.



Guo et al. (2024)

MACHINE LEARNING

- The future of local morphological classifications is automated.
- Collaboration with Kolesnikov et al (in prep) to classify discs or spheroids using a hybrid method.
- Kolesnikov et al. (2024) achieved a 95% overall success rate on SDSS data and HST separately.

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Unveiling galaxy morphology through an unsupervised-supervised hybrid approach

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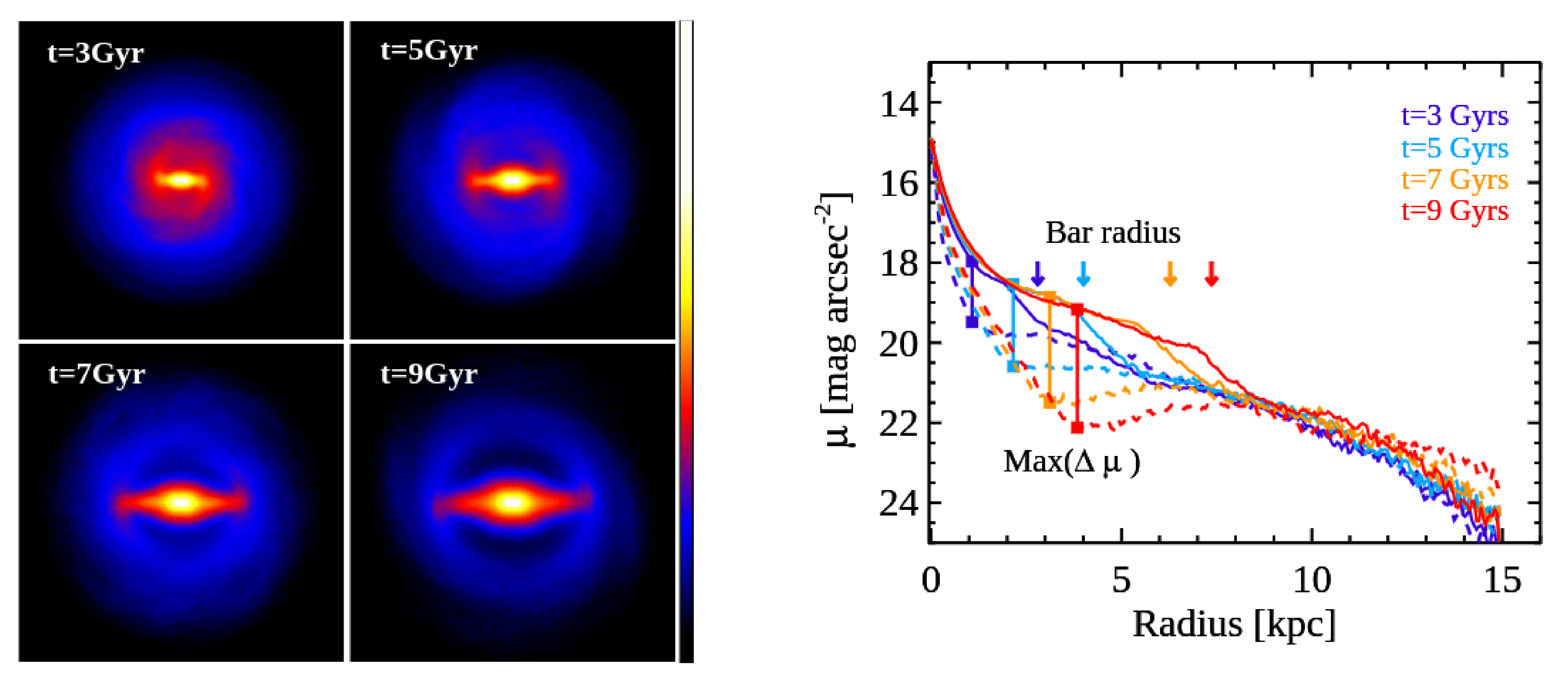
DARK GAPS

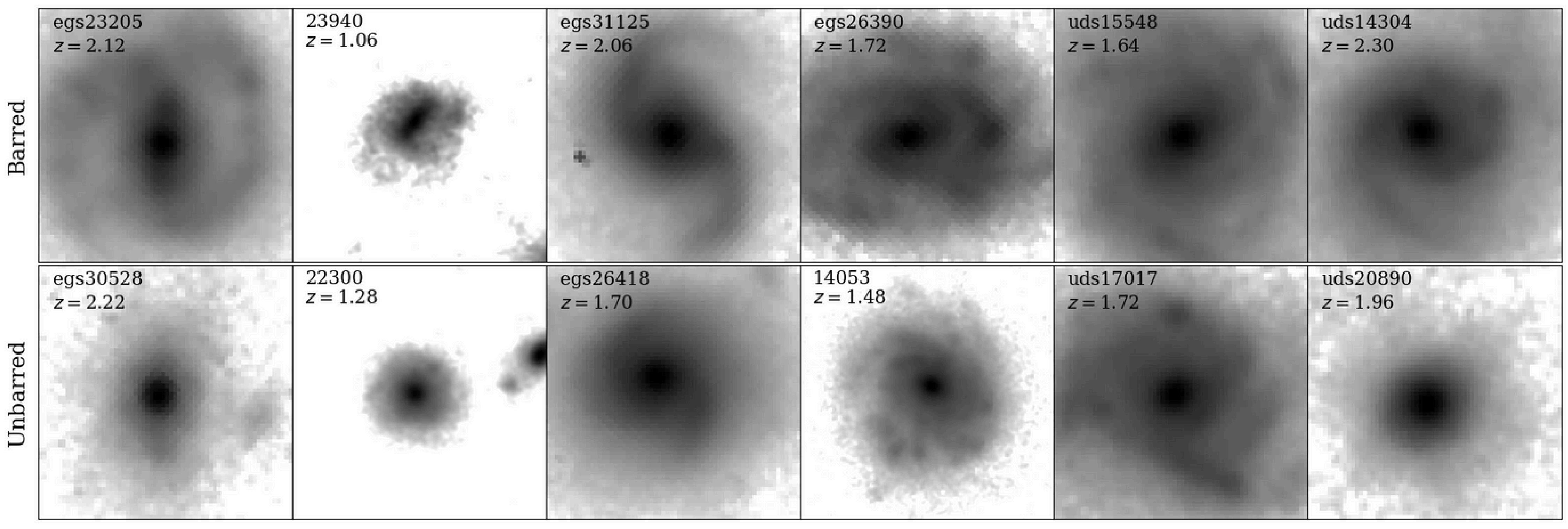


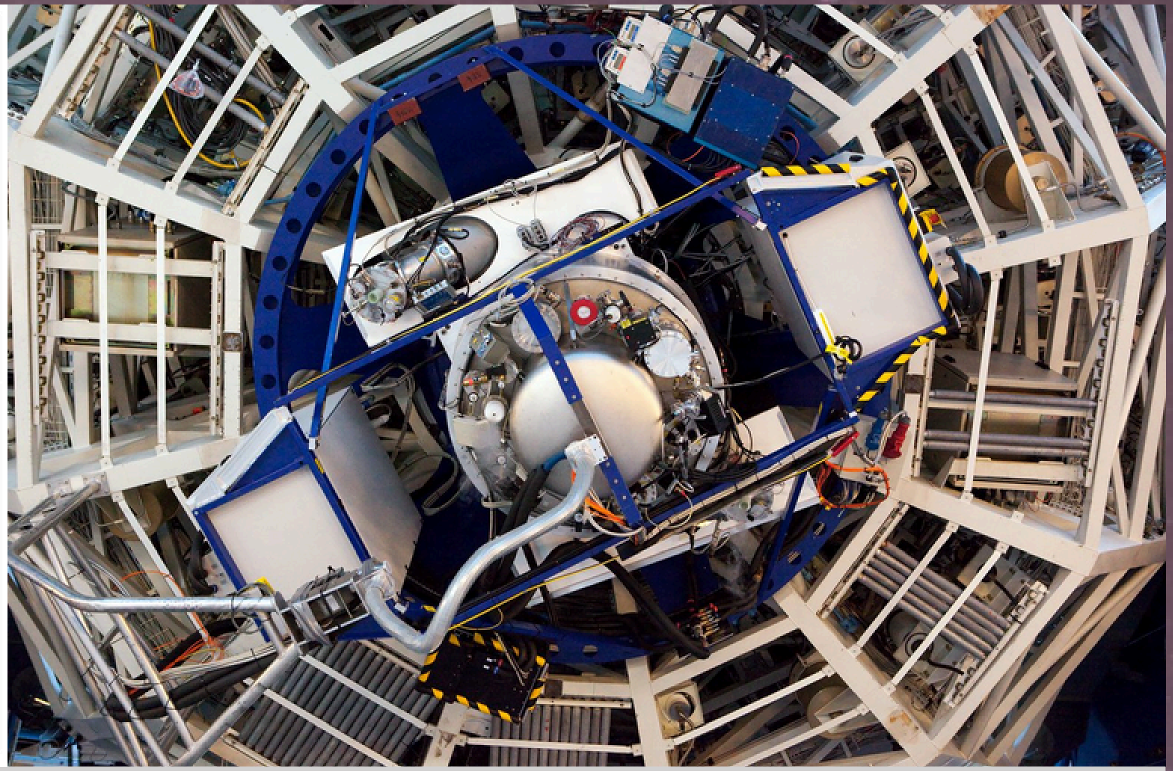
Kim et al. (2016)

- Long bars reside in inner discs and have flat radial profiles.
- Light deficit becomes more pronounced as a bar evolves.
- A measure of bar strength and length.
- A measure of bar-driven evolution.

BAR-DRIVEN STAR FORMATION PROCESSES AT Z > 1

Credit: ESO

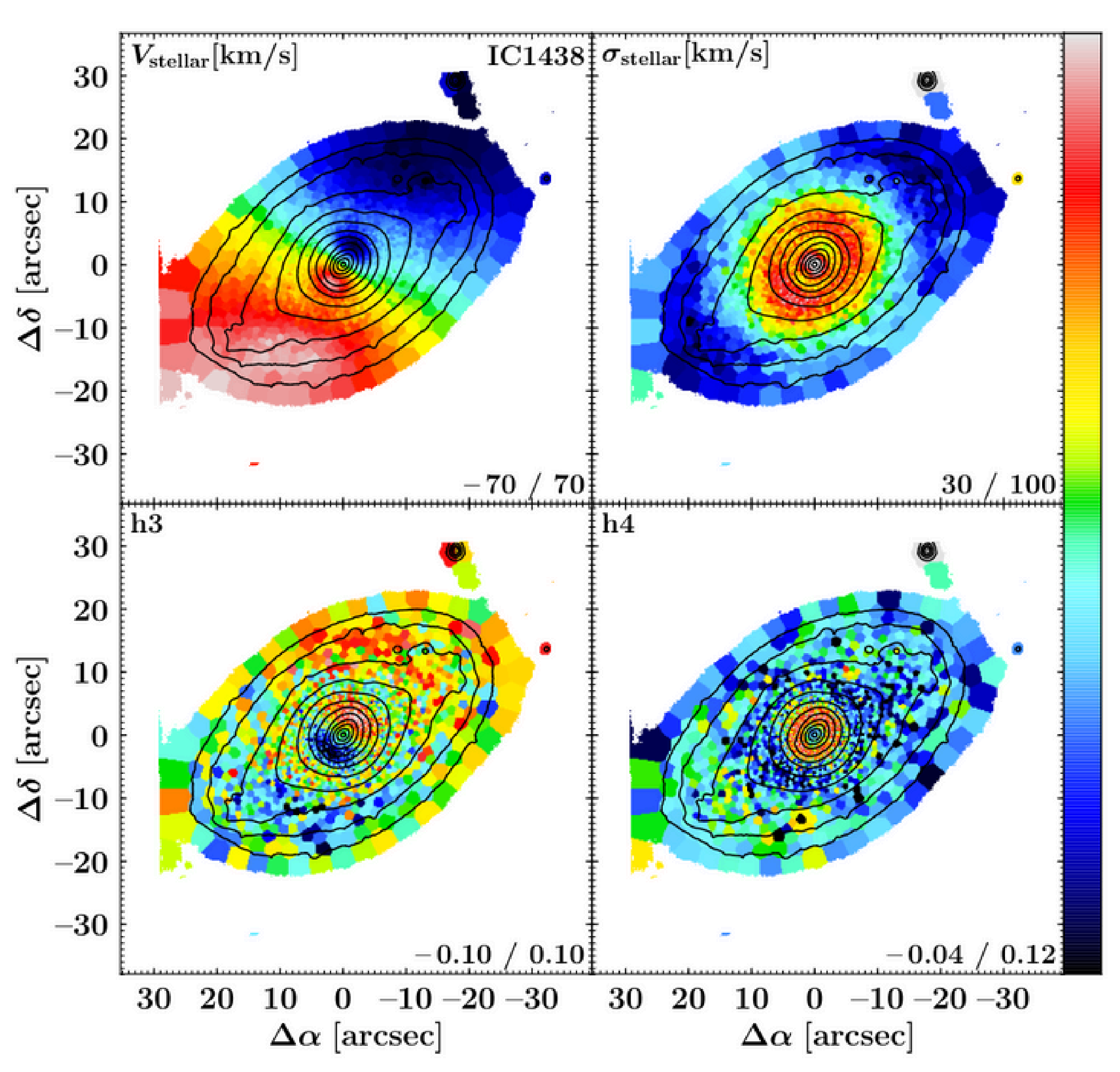




- Observe 6 barred and 6 unbarred galaxies between from Paper I.
- Matched in redshift and stellar mass.
- Measure integrated star formation rates from Hα and Hβ lines.
- Direct comparison of enhanced SFR in barred galaxies, due to gas inflow to central regions.
- Compare trends to Paper II.

WHAT INHIBITS BAR FORMATION?

- ESO studentship proposal.
- Use archival PHANGS data from the IFS MUSE on the VLT of 10 barred and unbarred galaxies.
- Analysis of the kinematics, stellar ages, and chemical compositions using the GIST pipeline.
- Measure the velocity dispersion at various radii and select locations across the bar and outer disc.
- Select young bars from the TIMER sample for insight into the properties which inhibit bar formation.



Gadotti et al. (2020)

The JWST bar fraction

JWST bar properties

JWST dark gaps

JWST boxy/peanuts

MUSE kinematic properties

JWST bar SFR

ROADMAP

Complete
Ongoing
Proposed

Paper I: The JWST bar fraction

Paper II: JWST bar properties; F200W; machine learning

Studentship: velocity dispersion of MUSE bars

Ghosh et al.: Dark gaps

XSHOOTER: SFR of JWST bars

The JWST B/P fraction