Lessons in Galaxy Evolution from the First Year of JWST Observations

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Rochester Institute of Technology

+ the CEERS and COSMOS-Web Teams

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ELT Science in Light of JWST: UCLA

CEERS COSMOS-Web

Cosmic Evolution Early Release Science Survey

CEERS

COSMOS WEB

PIs

Steve Finkelstein | Jeyhan Kartaltepe & Caitlin Casey

Data Releases

https://ceers.github.io/dr06.html

https://cosmos.astro.caltech.edu/page/cosmosweb-dr

Social Media

@ceers_jwst

@cosmosastro

CEERS NIRCam and MIRI Data Papers:

Bagley et al. 2023

Yang et al. 2023

COSMOS-Web Overview paper:

Casey / Kartaltepe et al. 2023

Evolution of Galaxy Structure

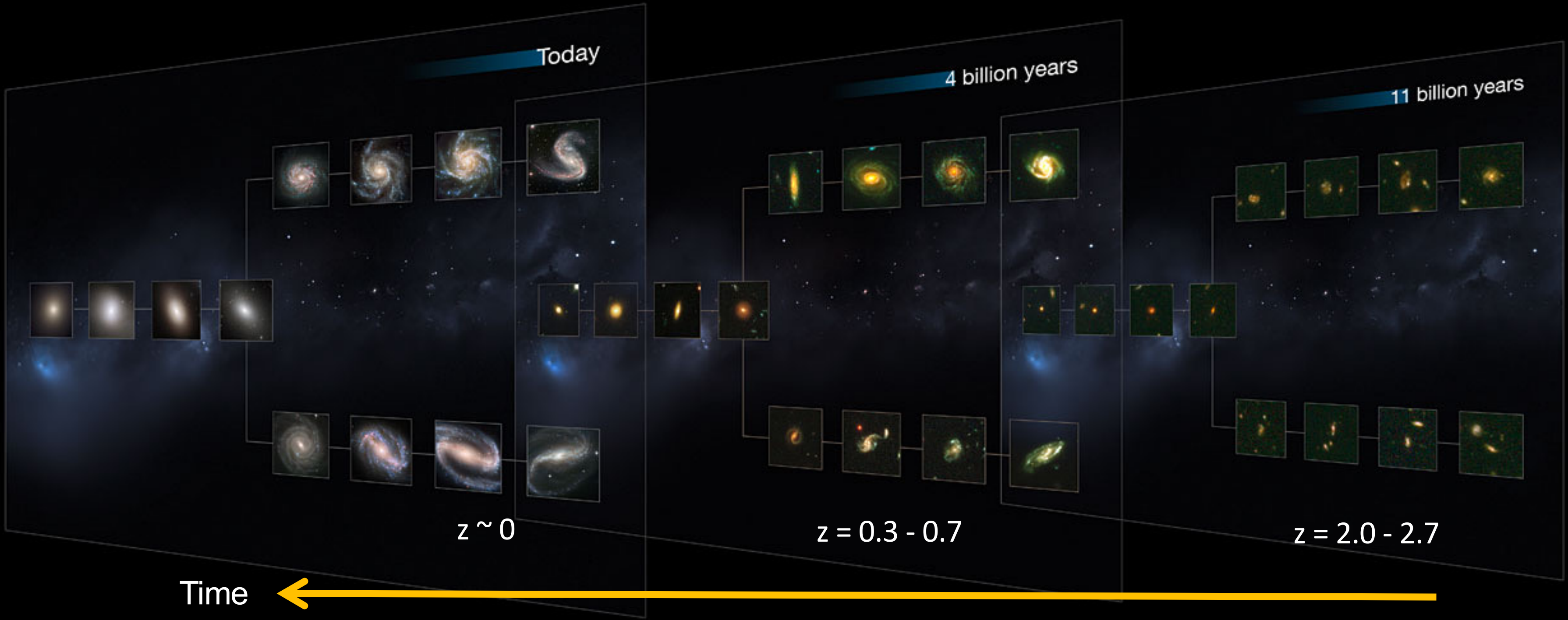


Image Credit: ESA Press Release on Lee et al. (incl. Kartaltepe) 2013

What can we Learn about/from Galaxy Structure?

- When was the Hubble Sequence put into place?
  - When did the first disks and bulges form?
  - What was the role of mergers in the very early universe?

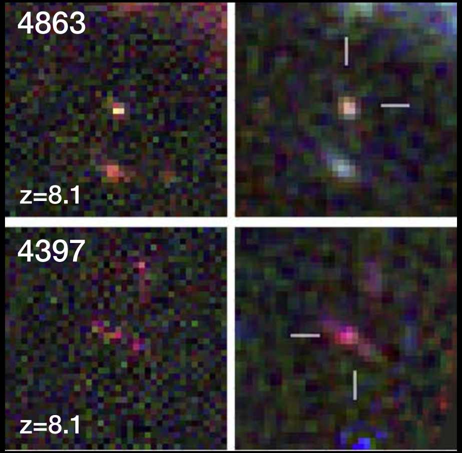
- What can the relationship between galaxy structure and other properties tell us about…
  - Mass assembly?
  - Supermassive black hole growth?
  - Star formation in galaxies?
  - Accretion of gas from the IGM?

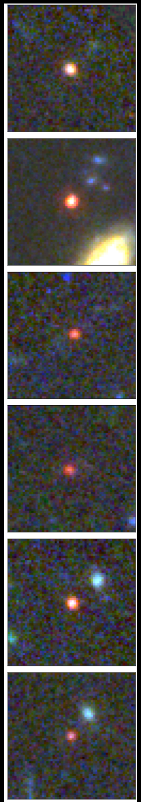
Surprises/Discoveries from JWST

- High Redshift Galaxies are *compact*

Ferreira et al. 2022

Treu et al. 2023





Labbe et al. 2023

Kartaltepe et al. 2023

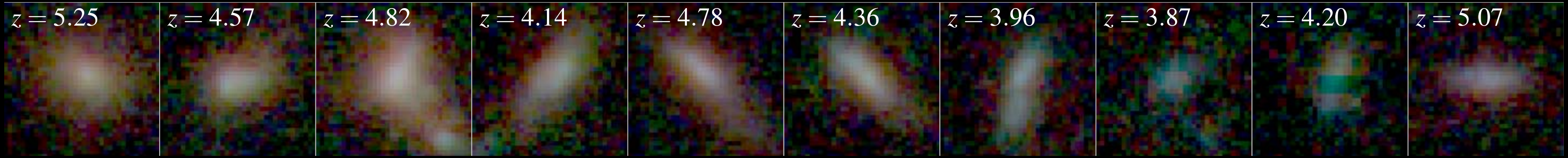
Surprises/Discoveries from JWST

- High Redshift Galaxies are *compact*
- High Redshift Galaxies are *extended*

Ferreira et al. 2022

Kartaltepe et al. 2023

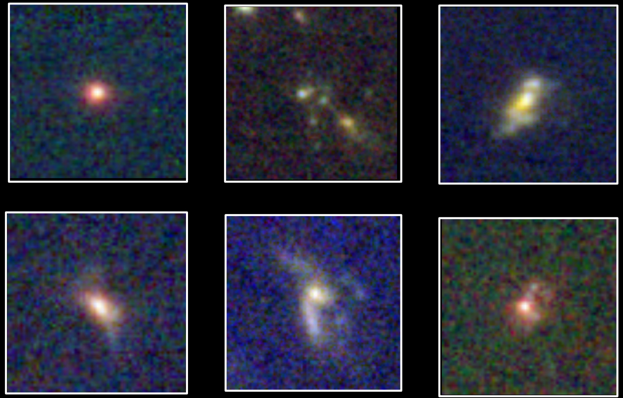
Robertson et al. 2023



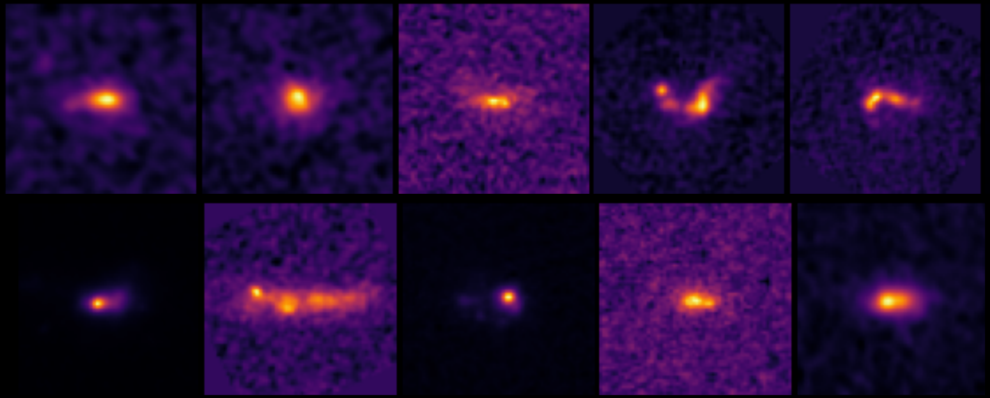
Surprises/Discoveries from JWST

Larson et al. 2023

- High Redshift Galaxies are *compact*
- High Redshift Galaxies are *extended*
- High Redshift Galaxies are *diverse*



Kartaltepe et al. 2023

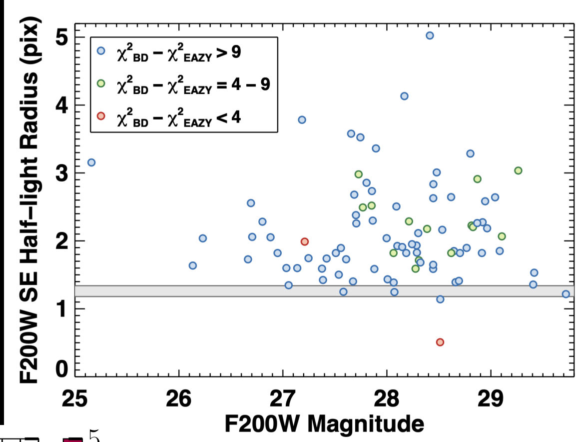


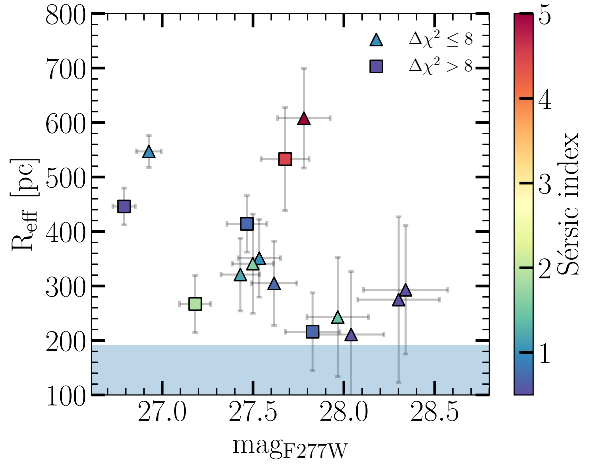
Tohill et al. 2023

Surprises/Discoveries from JWST

Finkelstein et al. 2023b

- High Redshift Galaxies are *compact*
- High Redshift Galaxies are *extended*
- High Redshift Galaxies are *diverse*
- High Redshift Galaxies are *resolved*



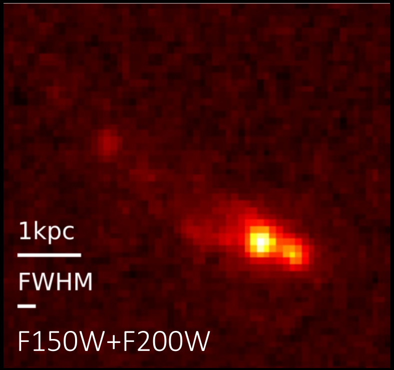


z>9 samples

Franco et al. 2023

Surprises/Discoveries from JWST

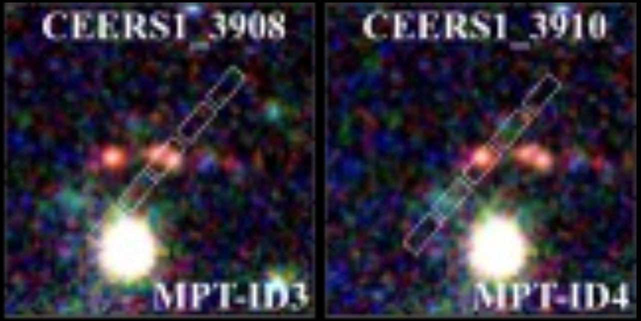
- High Redshift Galaxies are *compact*
- High Redshift Galaxies are *extended*
- High Redshift Galaxies are *diverse*
- High Redshift Galaxies are *resolved*
- Finding example galaxy mergers



Boyett et al. 2023, z=9.3

Ferreira et al. 2022

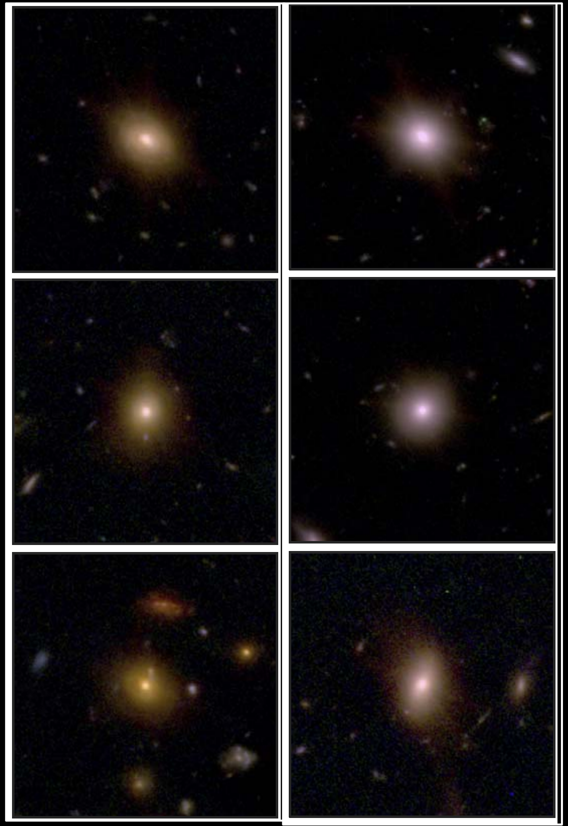
Kartaltepe et al. 2023



Fujimoto et al. 2023, z=8.0

Surprises/Discoveries from JWST

- High Redshift Galaxies are *compact*
- High Redshift Galaxies are *extended*
- High Redshift Galaxies are *diverse*
- High Redshift Galaxies are *resolved*
- Finding example galaxy mergers
- Finding example *minor* mergers

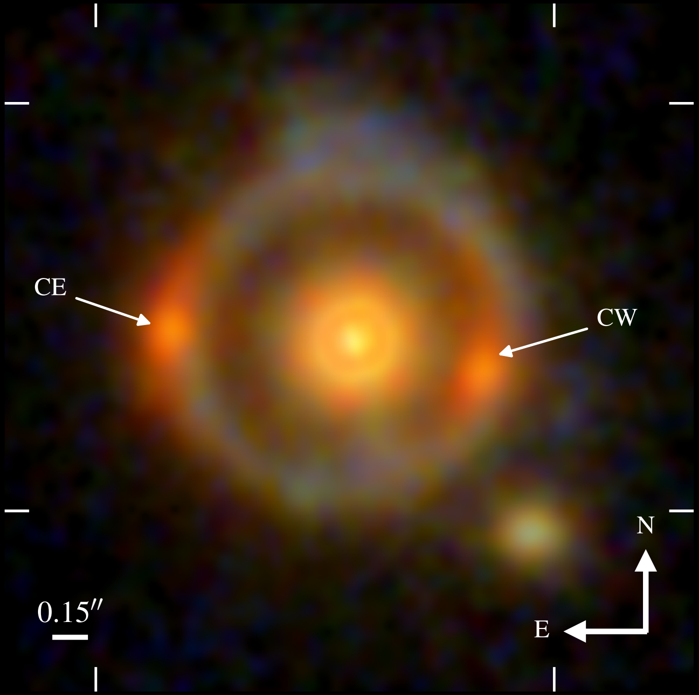


Suess et al. 2023

Surprises/Discoveries from JWST

- High Redshift Galaxies are *compact*
- High Redshift Galaxies are *extended*
- High Redshift Galaxies are *diverse*
- High Redshift Galaxies are *resolved*
- Finding example galaxy mergers
- Finding example *minor* mergers
- Finding exquisite gravitational lenses

The COSMOS-Web Ring

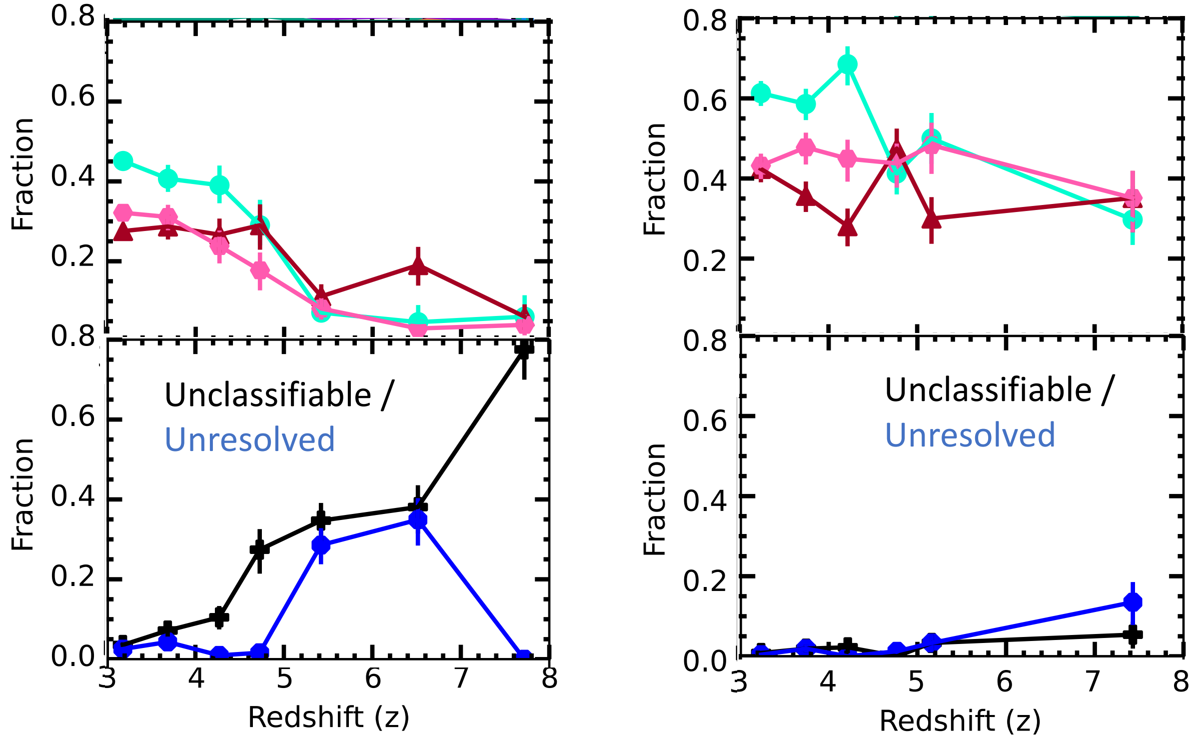


Mercier et al. 2023, see also van Dokkum et al. 2023

Morphological Evolution

HST CANDELS

JWST CEERS



See also: Ferreira et al. 2023, Robertson et al. 2023

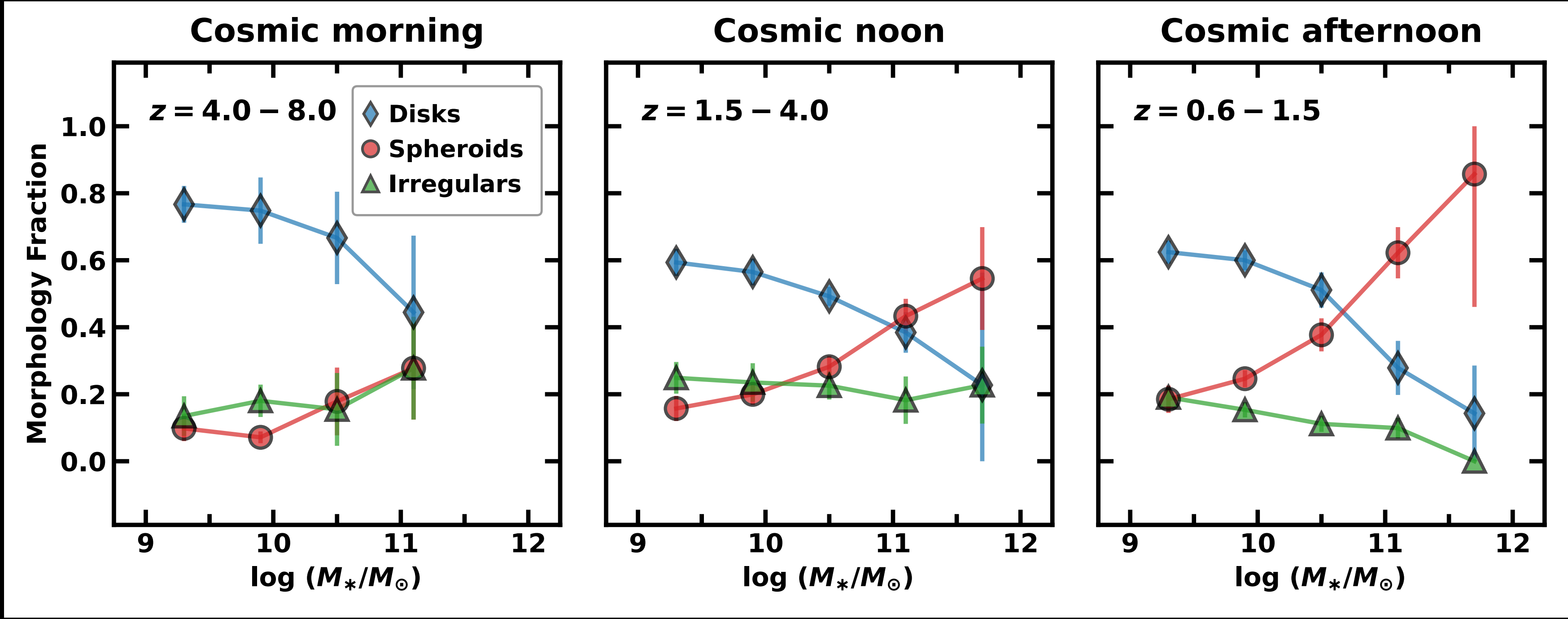
Galaxies with Disks

Galaxies with Spheroids

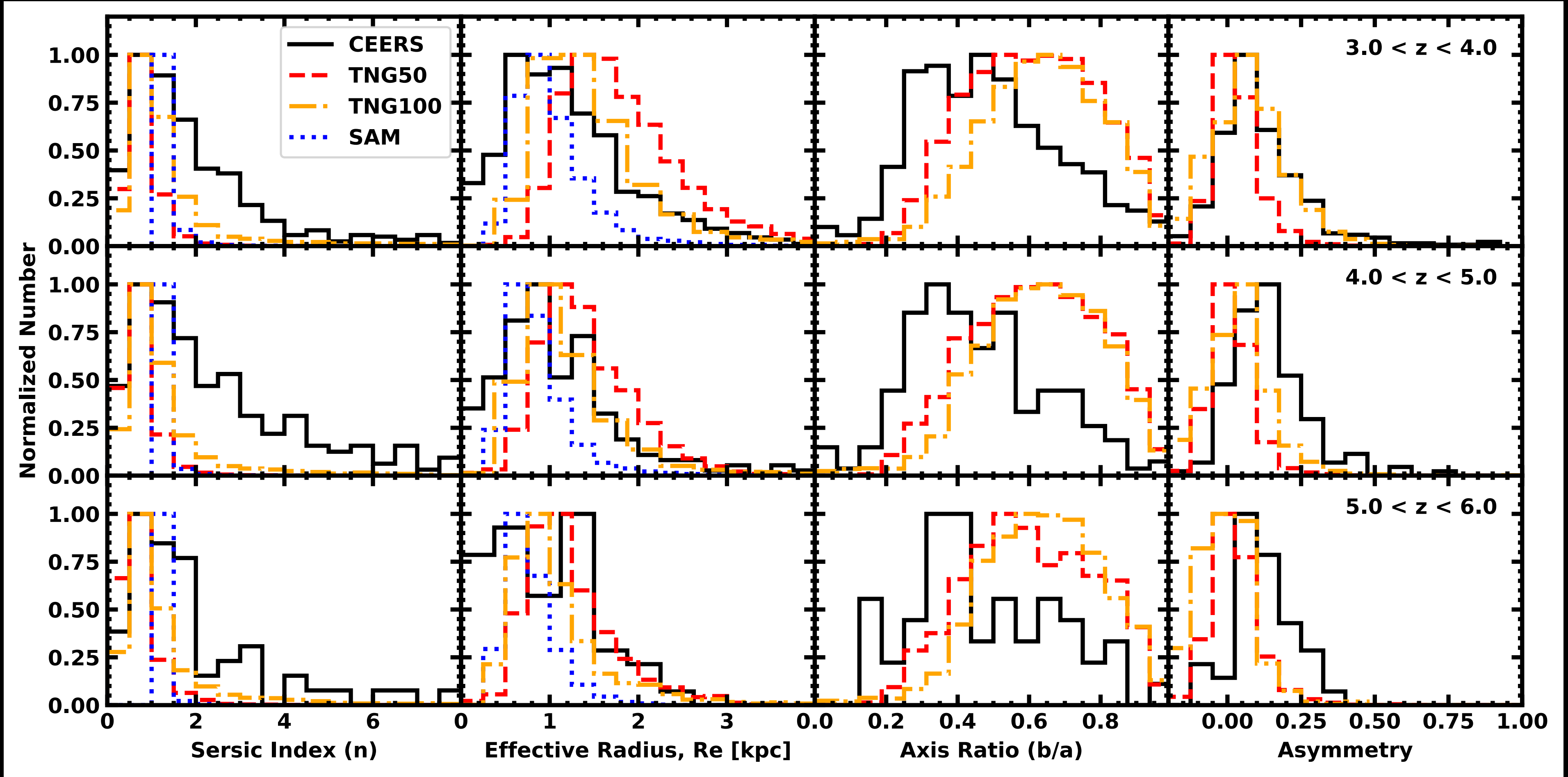
Galaxies with Irregular Features

Kartaltepe et al. 2023

Morphological Evolution

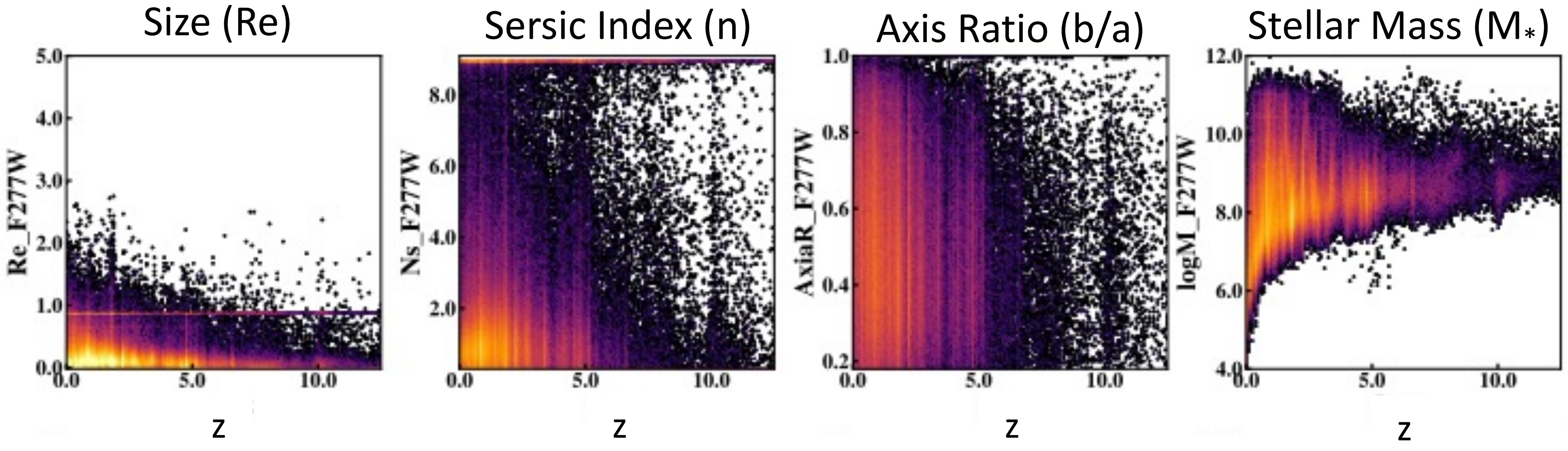


Lee et al. 2023



Kartaltepe et al. 2023

Galaxy Morphologies with Large Samples

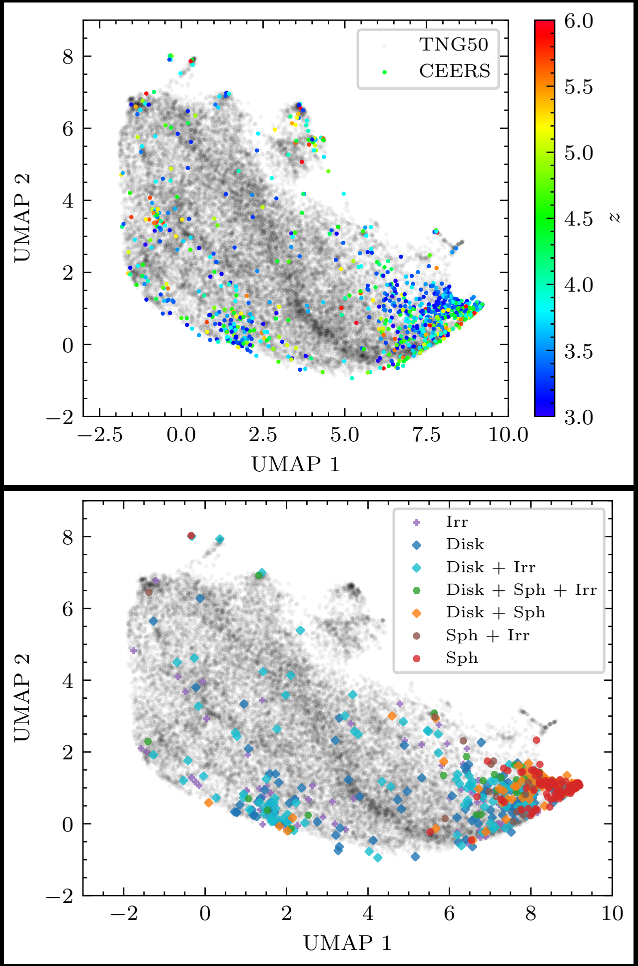


<u>Preliminary</u> measurements for *355,000* galaxies in COSMOS-Web

Yang et al. (incl. Kartaltepe), in prep

Morphologies with Contrastive Learning

- Trained on IllustrisTNG mock images
- Observed galaxies tend to be more compact and more elongated than IllustrisTNG
- Some visual disks may be prolate/elongated ellipsoids



Vega-Ferrero (incl. Kartaltepe) et al. 2023

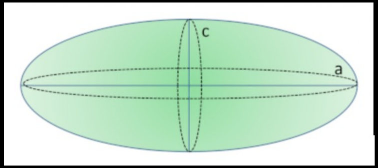
Inferring the 3D Shapes of Distant Galaxies

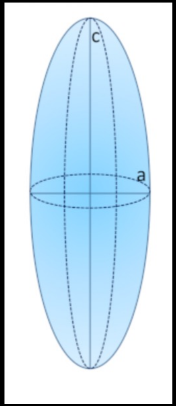
Viraj Pandya
(Columbia)

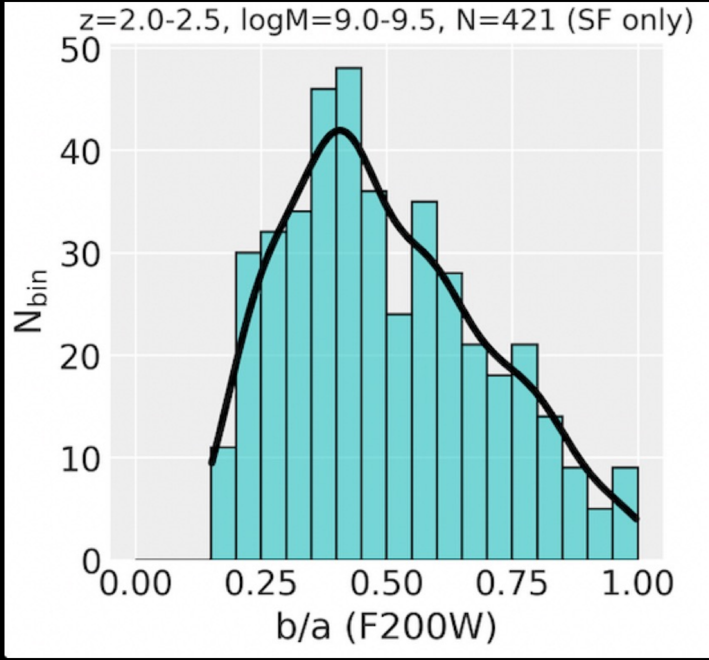
- Are galaxies that look like disks at high-z truly disks?

Are most high-z galaxies

oblate (disky) or **prolate** (elongated)







Pandya et al. (incl. Kartaltepe) 2023

Inferring the 3D Shapes of Distant Galaxies

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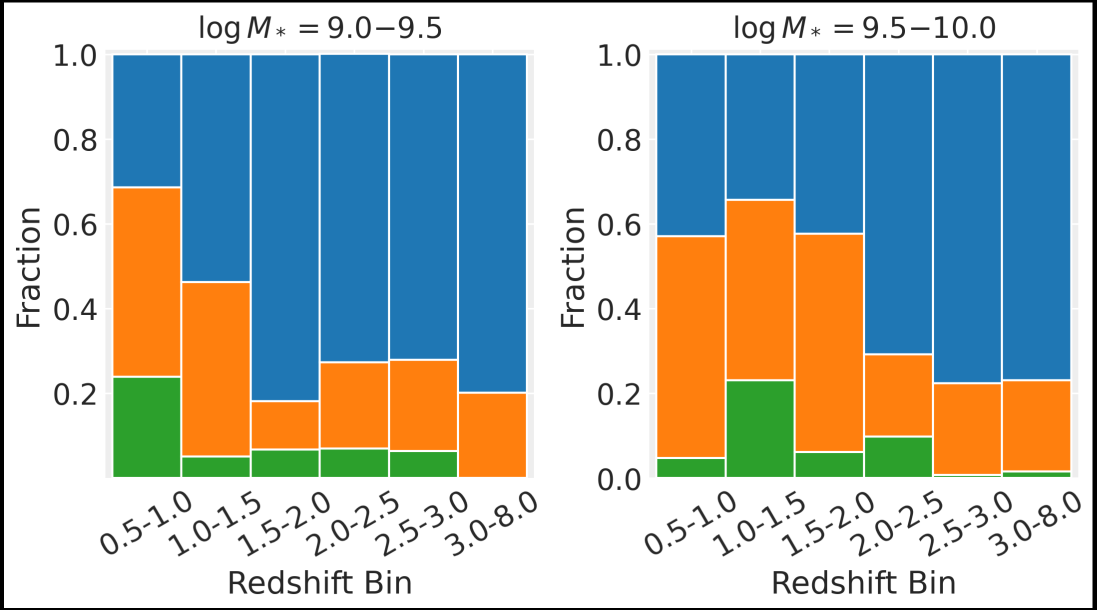


~50-80% of
$\log (M_*/M_\odot) = 9.0 – 9.5$
galaxies at z=2-8 are
intrinsically prolate

Oblate (disky)
spheroidal ellipsoids
are sub-dominant

significantly lower triaxialities for higher masses and lower redshifts indicating the emergence of disks

Pandya et al. (incl. Kartaltepe) 2023

Visual Mergers

z = 3 – 3.5 | z = 3.5 – 4 | z = 4 – 5

Merger

Interaction Class 1 (interaction within segmentation map)

Interaction Class 2 (interaction beyond segmentation map)

Non-interacting Companion

Rose et al. (incl. Kartaltepe), in prep

Identifying Mergers Using Machine Learning

- Using IllustrisTNG images with ‘CEERS-like’ noise as a training set (Rose et al. 2023)
- ‘Merger’ typically defined as +/- 250 Myr (with some experimentation), major and/or minor
- Testing Random Forests + Neural Network ‘DeepMerge’ (Ćiprijanović et al. 2020)

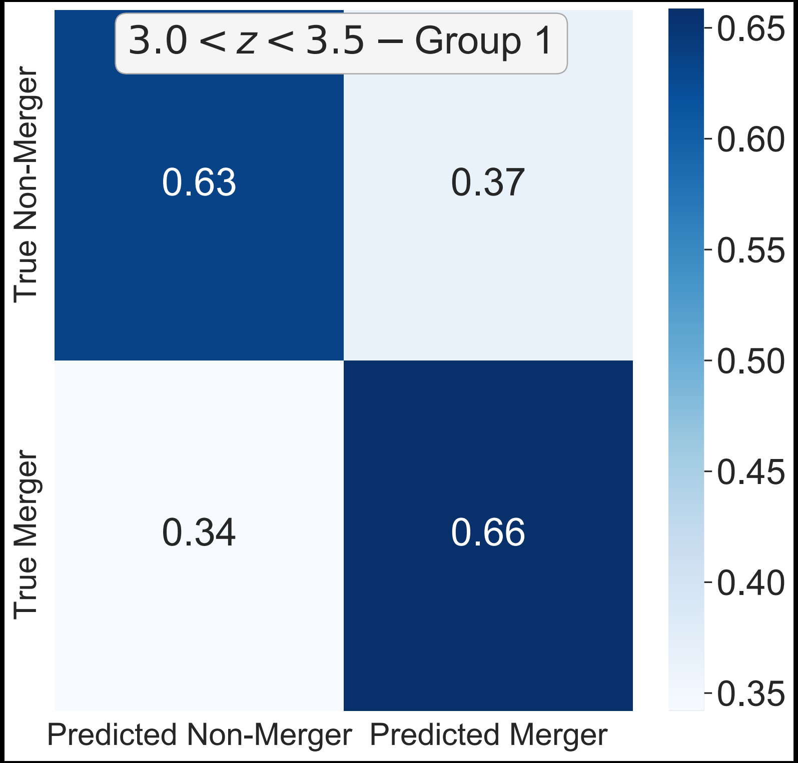
Rose et al. (incl. Kartaltepe), in prep

Preliminary Results

- Both Random Forests and DeepMerge can accurately classify **up to ~60-70%** of mergers

- Seems to be a ceiling: can increase, but at the expense of incorrectly classifying non-mergers

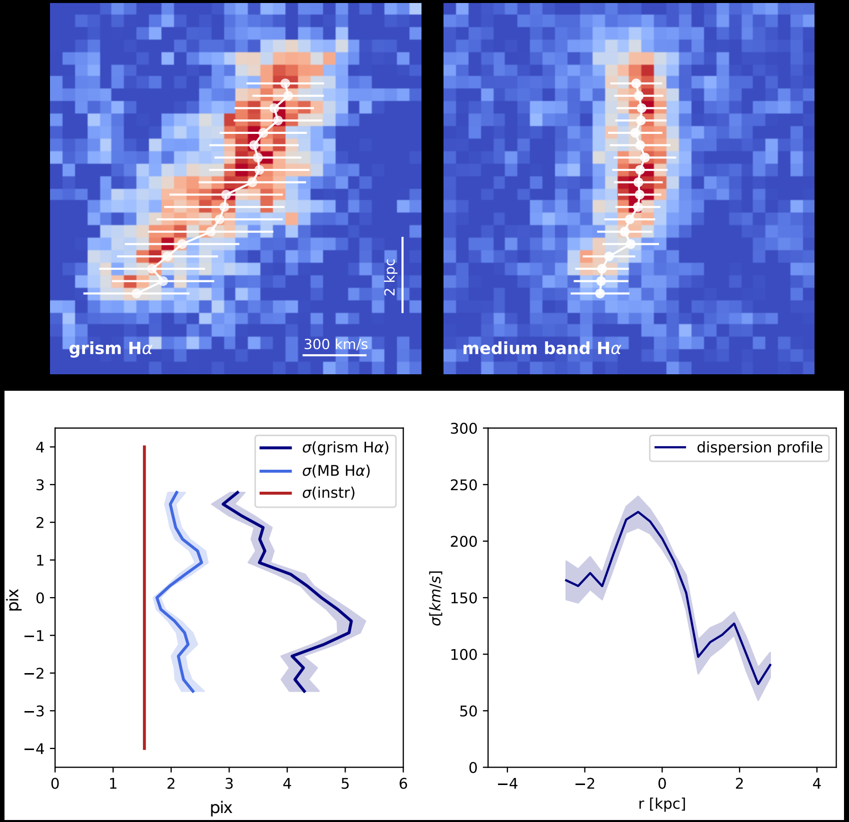
RF Comparison with Visual



Rose et al. (incl. Kartaltepe), in prep

Galaxy Kinematics

- Deep NIR spectroscopy with JWST will enable kinematic measurements of galaxies out to high-z
- Possible with high resolution mode on NIRSpec as well as NIRCam WFSS (for relatively bright sources)
- Kinematics will be essential for identifying true rotating disks and quantifying mergers



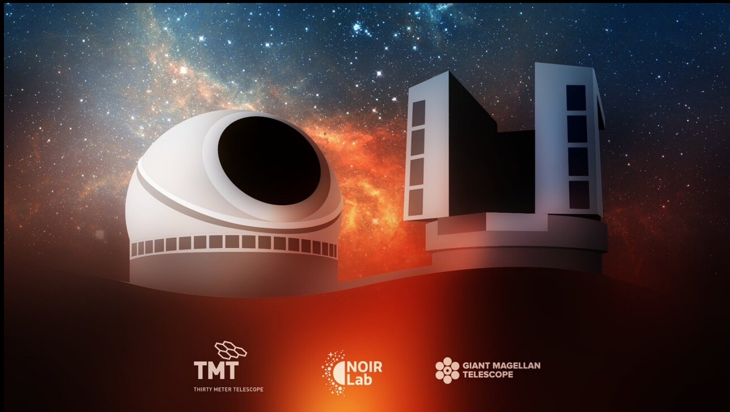
Nelson et al. 2023

Role of the ELTs

- Multiplexed moderate resolution spectroscopy (slit + IFU) will enable kinematic measurements (gas and stellar!) for large samples of galaxies, look for rotation/dispersion, mergers, rotation curves
  - TMT First light: IRIS, WFOS
  - TMT Second generation: IRMS, IRMOS
  - GMT: GMACS, GMTIFS

- High resolution imaging with AO will enable deep morphology studies for larger samples
  - Studies of low surface brightness features such as tidal tails, globular clusters, extended disks, etc.
  - Identification of minor companions

- Ability to follow-up sources identified with Euclid+Roman all over the sky



Summary

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- **Wide diversity of visual morphologies seen at z=3-9!**
  - Large fraction of galaxies with disks (~60% → ~30%)
  - Large fraction of galaxies with irregular features (~40-50%)
- Some evidence that the large numbers of high-z disks might not be true disks
  - Prolate/elongated systems (See Pandya et al. 2023, Vega-Ferrero et al. 2023)
- Identifying galaxy mergers, visually and through machine learning techniques
  - Testing on simulations, these techniques hit an upper limit of correctly identifying ~60-70% of mergers
- The ELTs will enable kinematic and deep imaging studies of large samples of galaxies