

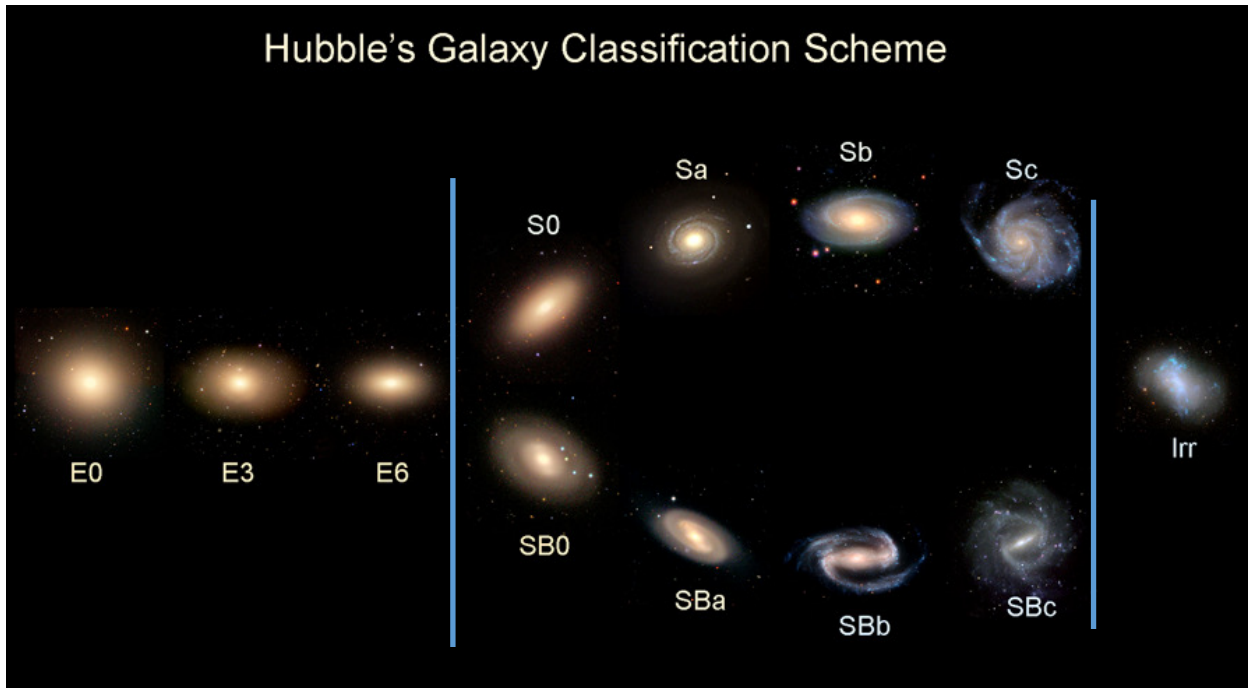
Morphology of High-Redshift Galaxies in the Horizon Run 5 Simulation and JWST Observation

10th East Asia Numerical Astrophysics Meeting, Jeju, Korea
September 15-19, 2025

Changbom Park (Korea Institute for Advanced Study)

HR5: Jaehyun Lee, Juhan Kim (KIAS), Yonghwi Kim (KISTI), & the HR5 collaboration
JWST: Jeong Hwan Lee, Ho Seong Hwang, Minseong Kwon

Hubble's Galaxy Classification Scheme



Spheroidal
morphology

Disk
morphology

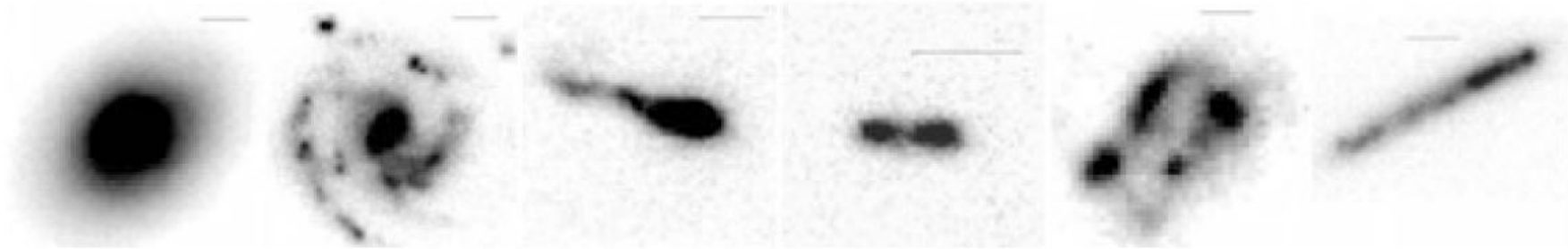
Irregular
morphology

1. Morphology of the galaxies in the cosmic morning?
The initial morphology distribution at $z=10^4$?
2. What determines the initial galaxy morphology?
3. How does the morphology evolve throughout the
lifetime of galaxies?

.....

Observations of galaxy morphology at high z [Marshall+19; Elmegreen 15]

- High- z galaxies more clumpy and irregular (Abraham 01; Papovich+05; Elmegreen 14)
- $z > 2$: **Irregulars** the most prominent type (HUDF09 & GOODS-S ; Cameron+11)
- The $z \sim 2.5-5$ population is dominated by extended **disc**-like galaxies and **irregulars** or merger-like systems. (Ravindranath+06)
- At high z larger fraction of **spheroids** (Bundy+05; Franceschini+06; Lotz+06; Ravindranath+06; Dahlen+07)



[UHDF. Elmegreen+07; Elmegreen 15]

Cons: Rest-frame optical bands not covered well for galaxies at $z > 2$.
Surface brightness limit not deep.

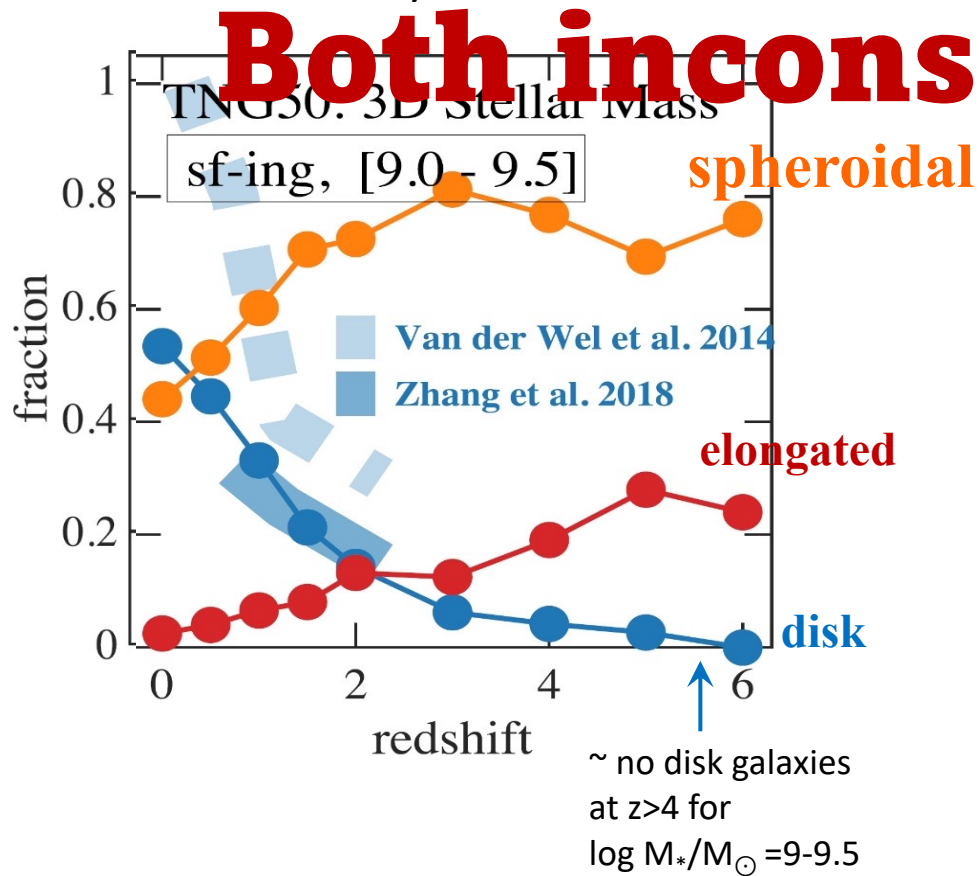
Cosmological gravity/hydrodynamics simulations

IllustrisTNG -- Pillepich+2019

Morphology ← axis ratios

~no disk galaxies (M_* based) at high redshifts

Disk formation only after $z \sim 2$

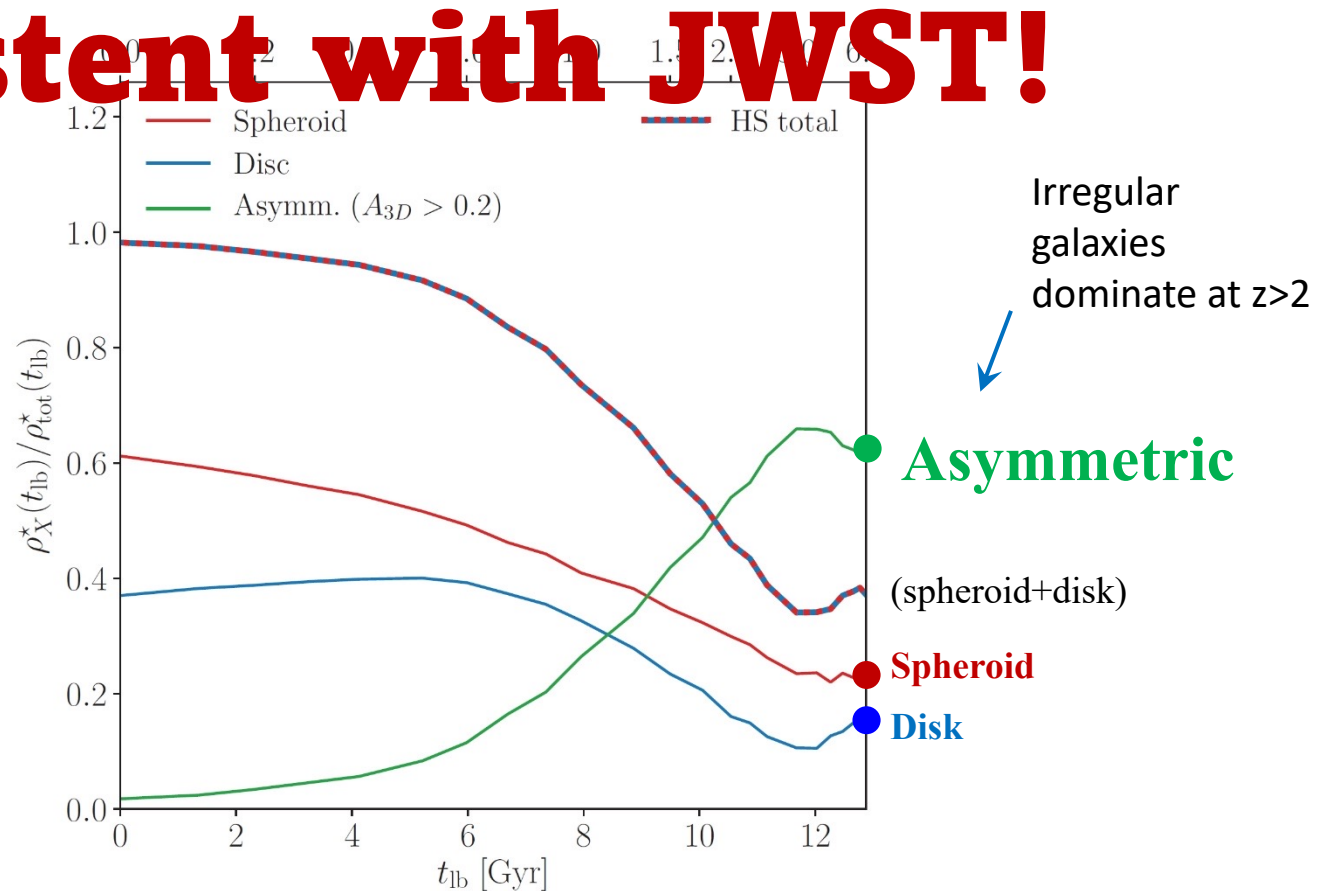


EAGLE (Trayford+19) : $M_* > 10^9 M_\odot$

Morphology ← disc stellar mass fraction, Asymmetry

Asymmetric galaxies & spheroids dominate,

and only 10~15% are disc type @ high z



Horizon Run 5 Cosmological Simulation [JH Lee+ 2021, ApJ, 908, 11]

Simulation code: Hybrid MPI-OpenMP RAMSES

Initial conditions: generated by the MUSIC package
using the second-order Lagrangian perturbation theory

Cosmological parameters: $\Omega_m=0.3$, $\Omega_\Lambda=0.7$, $\Omega_b=0.047$, $h_0=0.684$
(flat Λ CDM)

Simulation box size: $(1049 \text{ Mpc})^3$

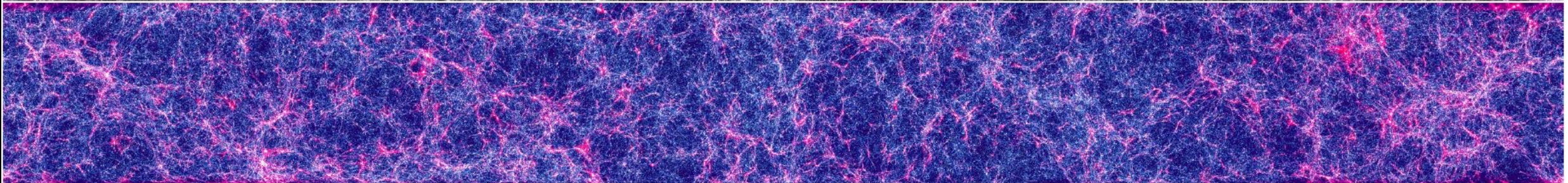
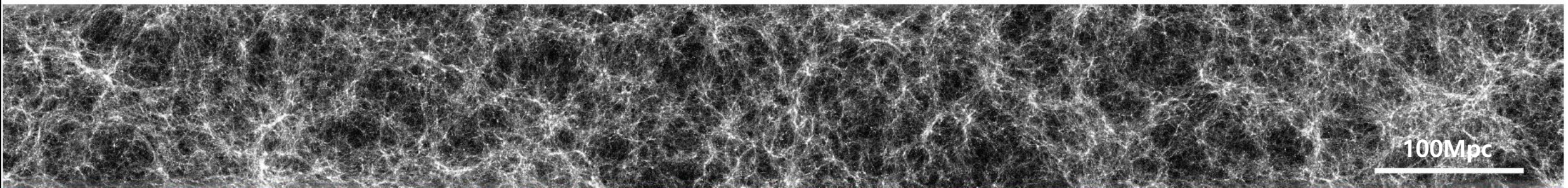
Zoomed-in region $(1049 \times 119 \times 127) \text{ Mpc}^3$

Resolution of the initial conditions: 128 kpc

Highest simulation resolution: 1 kpc

Simulation from $z_i=200$ to $z_{\text{final}}=0.625$

[dark matter]



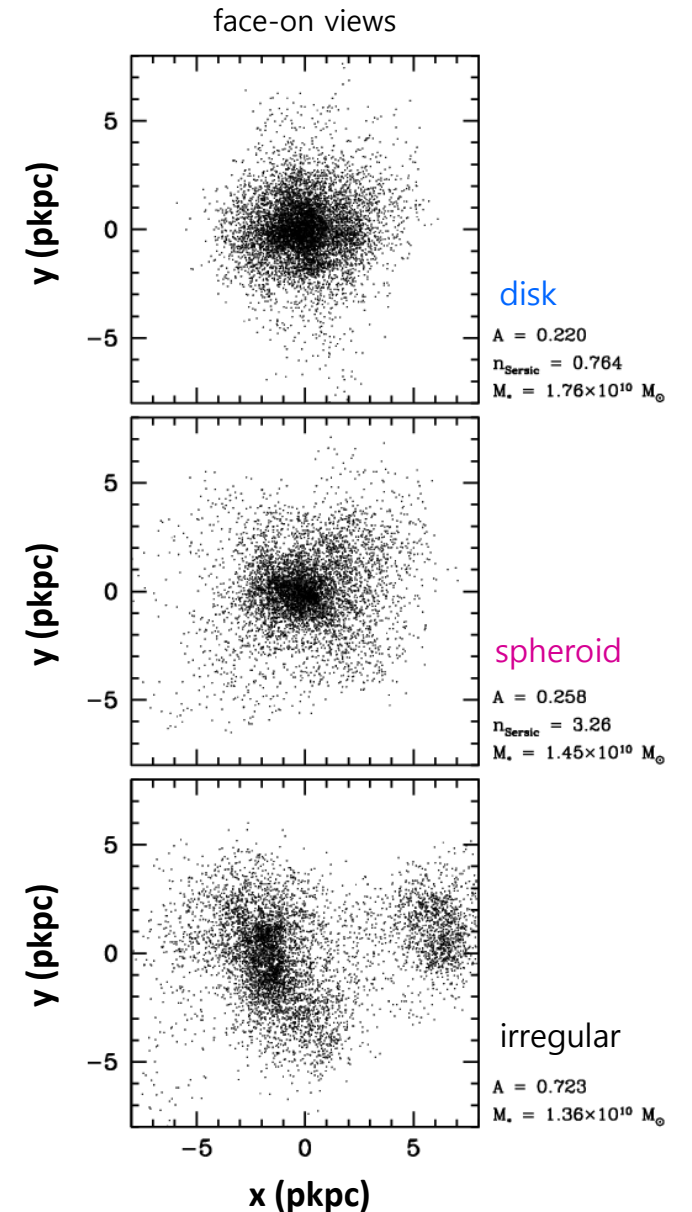
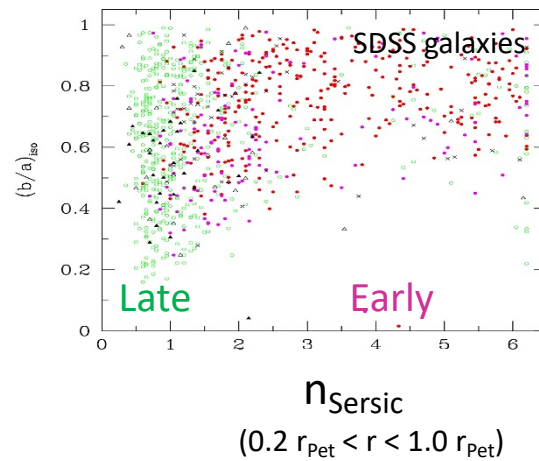
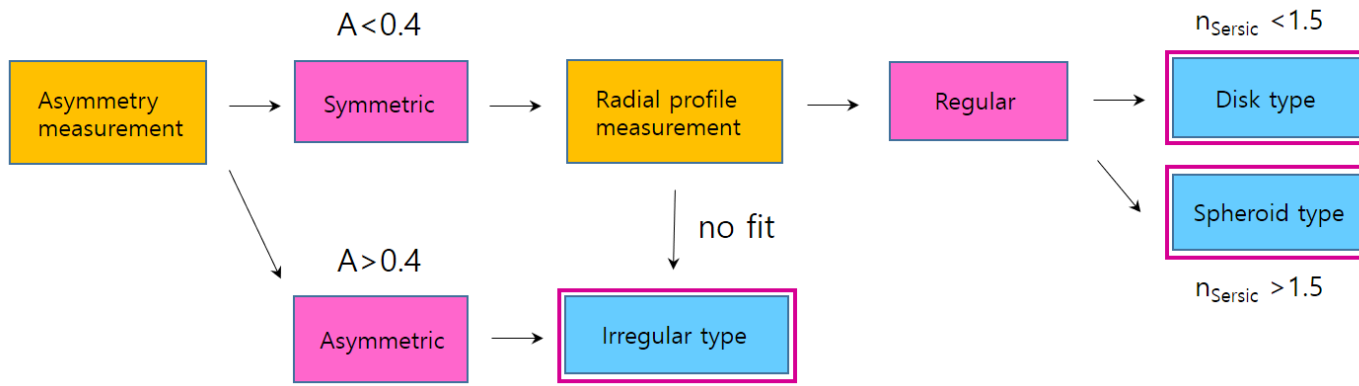
[baryon]

grey: stellar mass. red: gas temperature. blue: gas density

Galaxy morphology classification in HR5

using stellar mass density distribution

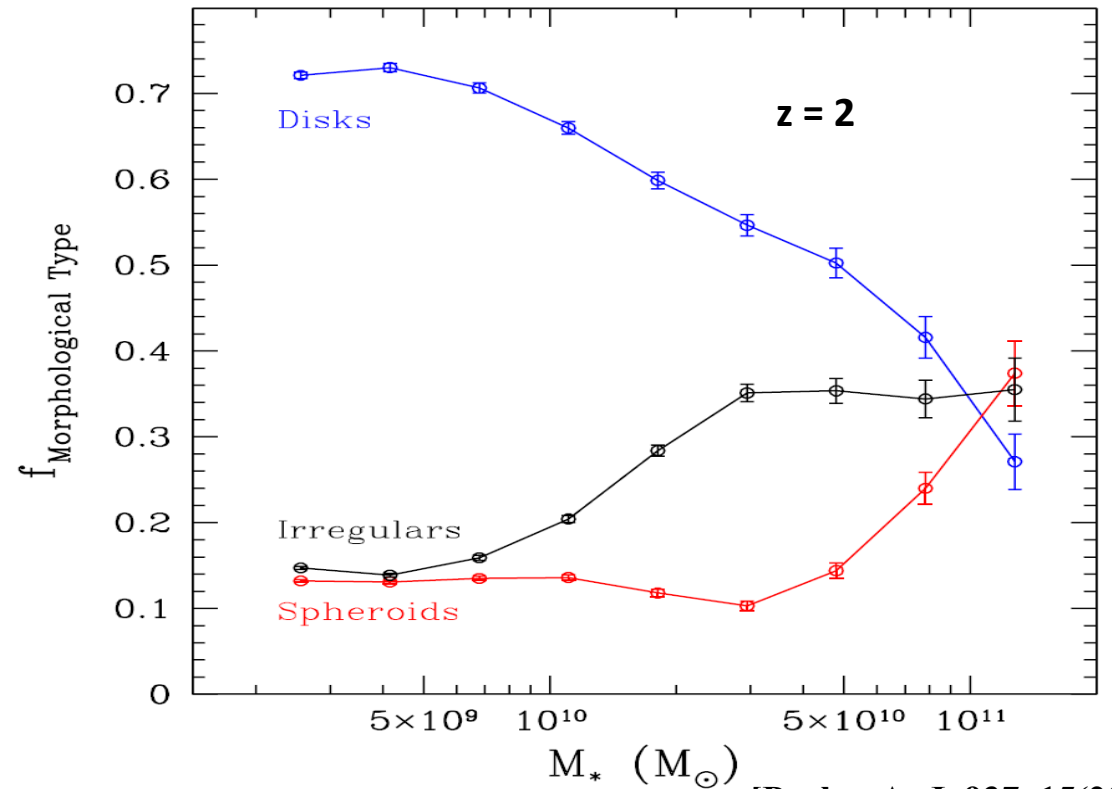
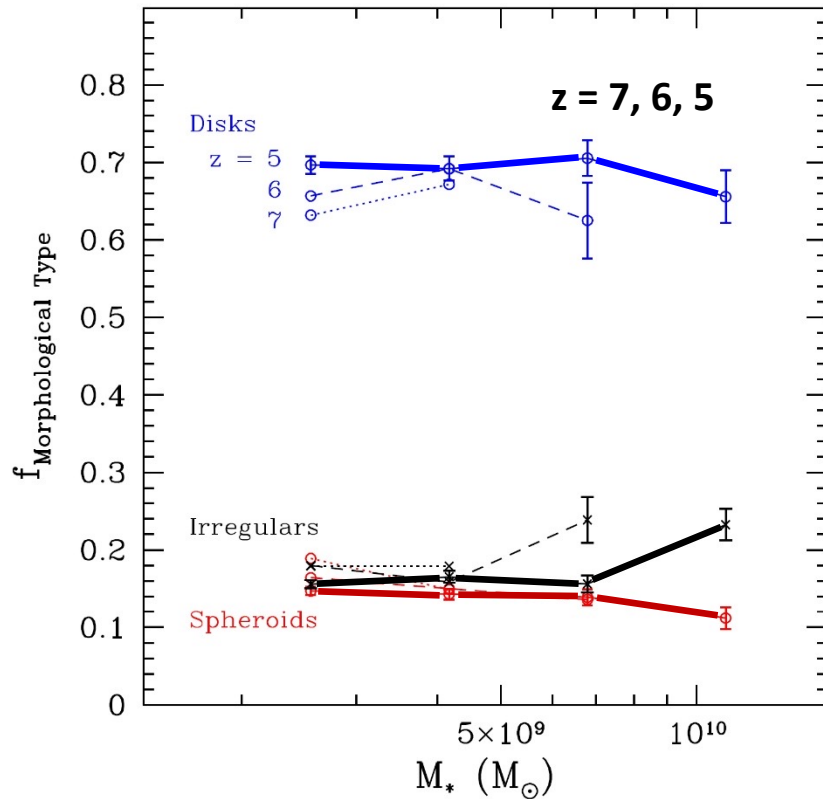
1. **Asymmetry parameter**
2. **Sersic index** of the radial profile of projected stellar mass density



Horizon Run 5 Simulation

Morphology of high-z low- M_* galaxies: **disk** types!!

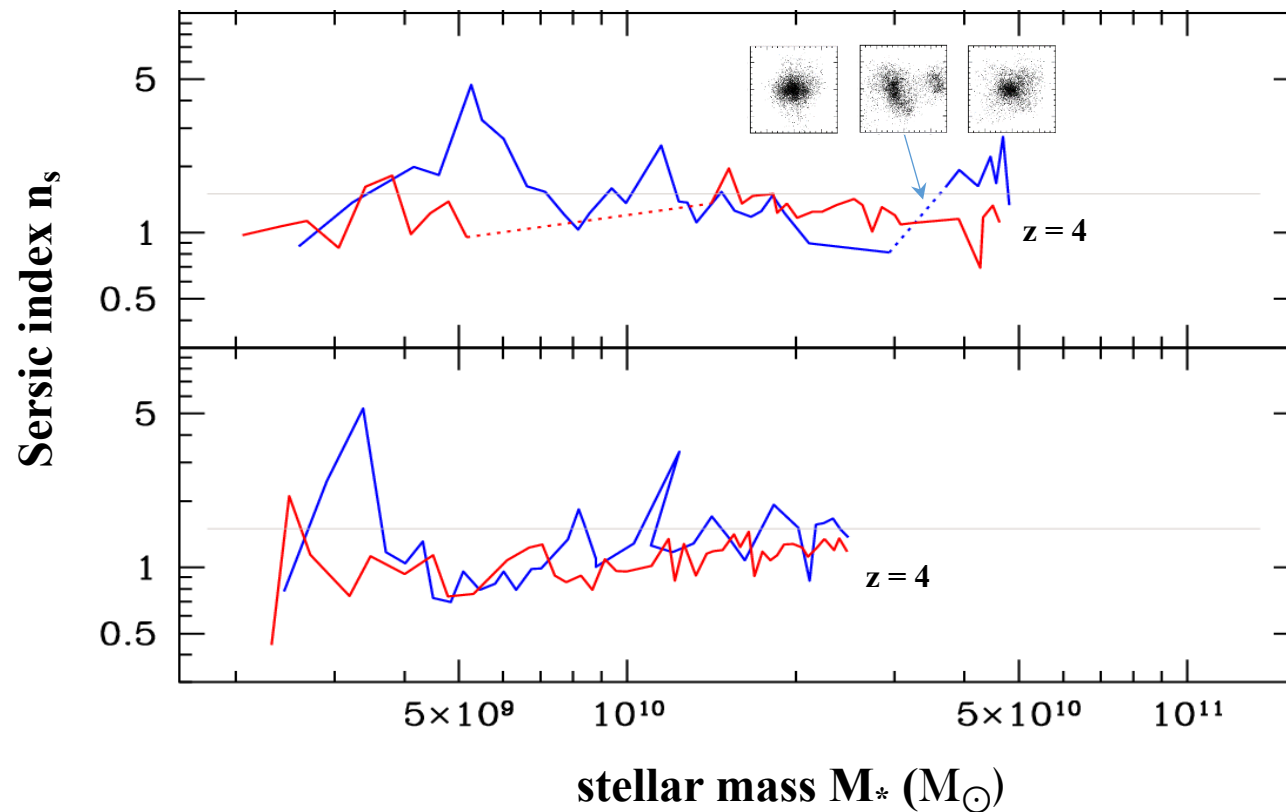
Morphology distribution: Disks : Spheroids : Irregulars = $\sim 70 : 14 : 16$ at all mass up to $\sim 10^{10} M_\odot$
 $f_{\text{Disk}} \sim 70\%$ for $M_* < \sim 10^{10} M_\odot$ at all z . Strong mass dependence of morphology above $\sim 10^{10} M_\odot$.



[Park+, ApJ, 937, 15(2022)]

Mechanism for spheroidal & irregular morphology?

Irregular or spheroidal morphology is incidental and transient! : disk (\rightarrow Irr) \rightarrow Sph \rightarrow disk



2 random galaxies reaching
 $M_*(z=4) \sim 5 \times 10^{10} M_\odot$

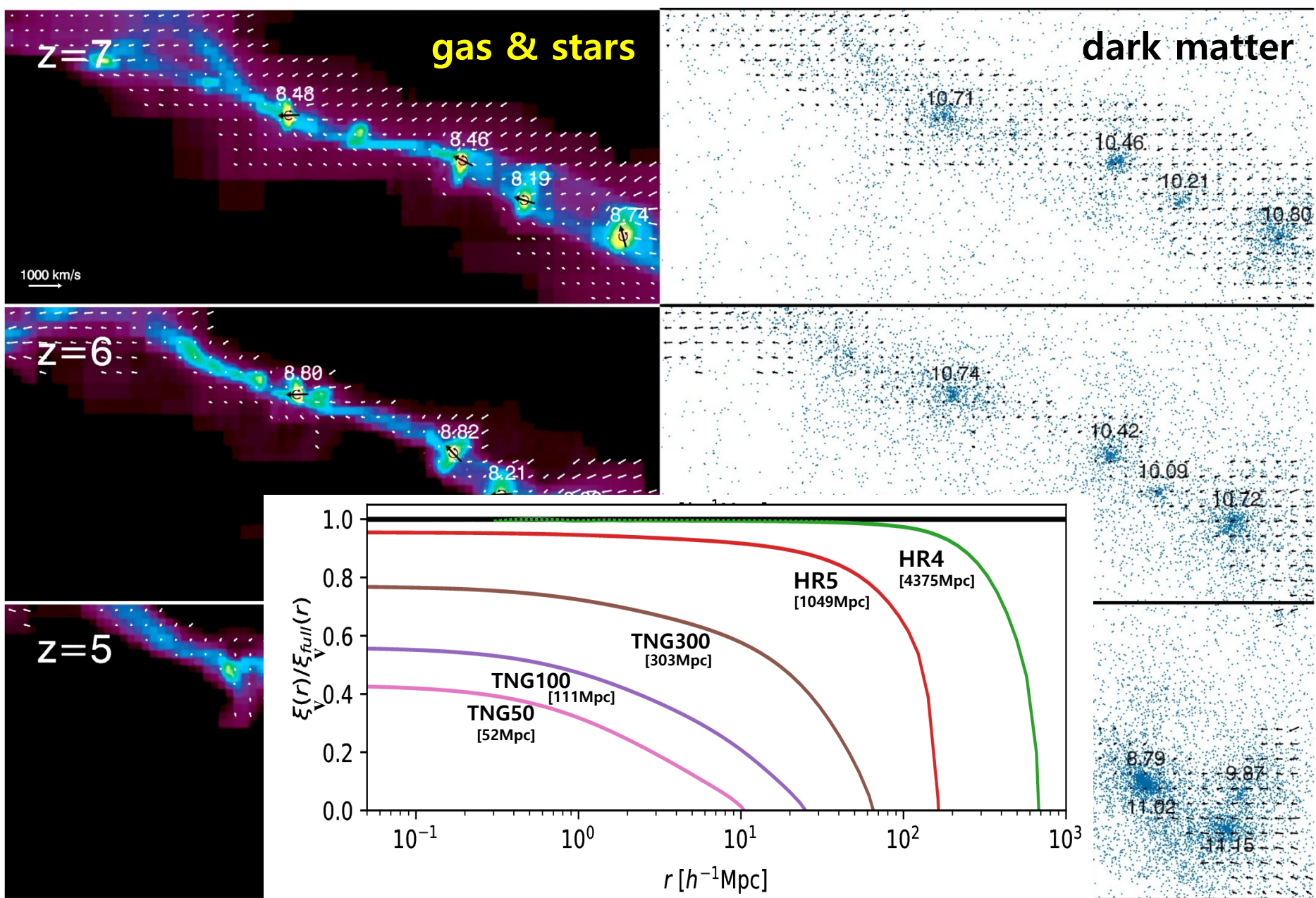
2 random galaxies reaching
 $M_*(z=4) \sim 2.5 \times 10^{10} M_\odot$

Memory of the initial flow pattern stored in the DM component

→ Importance of large-scale flow!

HR5 has

- 1 Gpc physical scale
- Large-scale velocity field correctly simulated!
- &
- 1kpc resolution
- Galaxy formation directly simulated!



HR5 [Park et al. 2022]

Morphology of Galaxies in JWST Fields: Initial Distribution and Evolution of Galaxy Morphology

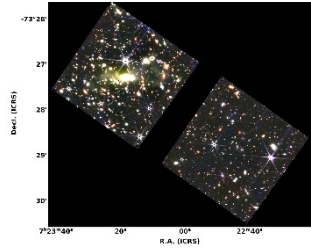
Jeong Hwan Lee^{1,2,4,6} , Changbom Park³ , Ho Seong Hwang^{4,5} , and Minseong Kwon⁴ 

Abstract

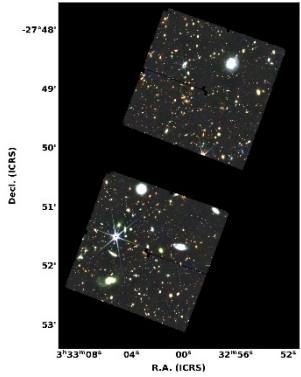
A recent study from the Horizon Run 5 (HR5) cosmological simulation has predicted that galaxies with $\log M_*/M_\odot \lesssim 10$ in the cosmic morning ($10 \gtrsim z \gtrsim 4$) dominantly have disk-like morphology in the Λ CDM universe, which is driven by the tidal torque in the initial fluctuations of matter. For a direct comparison with observation we identify a total of about 19,000 James Webb Space Telescope (JWST) galaxies with $\log M_*/M_\odot > 9$ at $z = 0.6\text{--}8.0$ utilizing deep JWST/NIRCam images of publicly released fields, including North Ecliptic Pole Time-Domain Fields, Next Generation Deep Extragalactic Exploratory Public survey, Cosmic Evolution Early Release Science Survey, Cosmic Evolution Survey, UltraDeep Survey, and SMACS J0723-7327. We estimate their stellar masses and photometric redshifts with the redshift dispersion of $\sigma_{\text{NMAD}} = 0.009$ and an outlier fraction of only about 6%. We classify galaxies into three morphological types, *disks*, *spheroids*, and *irregulars*, applying the same criteria used in the HR5 study. The morphological distribution of the JWST galaxies shows that disk galaxies account for 60%–70% at all redshift ranges. However, in the high-mass regime ($\log M_*/M_\odot \gtrsim 11$), spheroidal morphology becomes the dominant type. This implies that the mass growth of galaxies is accompanied by a morphological transition from disks to spheroids. The fraction of irregulars is about 20% or less at all masses and redshifts. All the trends in the morphology distribution are consistently found in the six JWST fields. These results are in close agreement with the results from the HR5 simulation, particularly confirmin

The morphological distribution of the JWST galaxies shows that disk galaxies account for 60 – 75% at $z=0.6\text{-}8$ and $\log M_*/M_\odot < 10$.

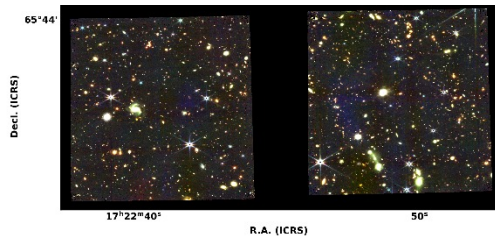
SMACS J0723.3-7327 cluster
(SMACS0723)



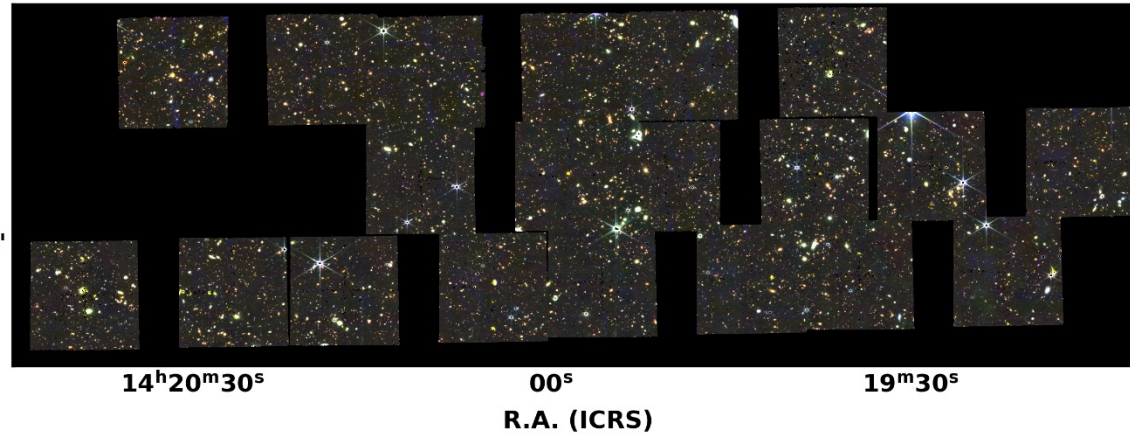
Next Generation Deep Extragalactic
Exploratory Public **(NGDEEP)** Survey



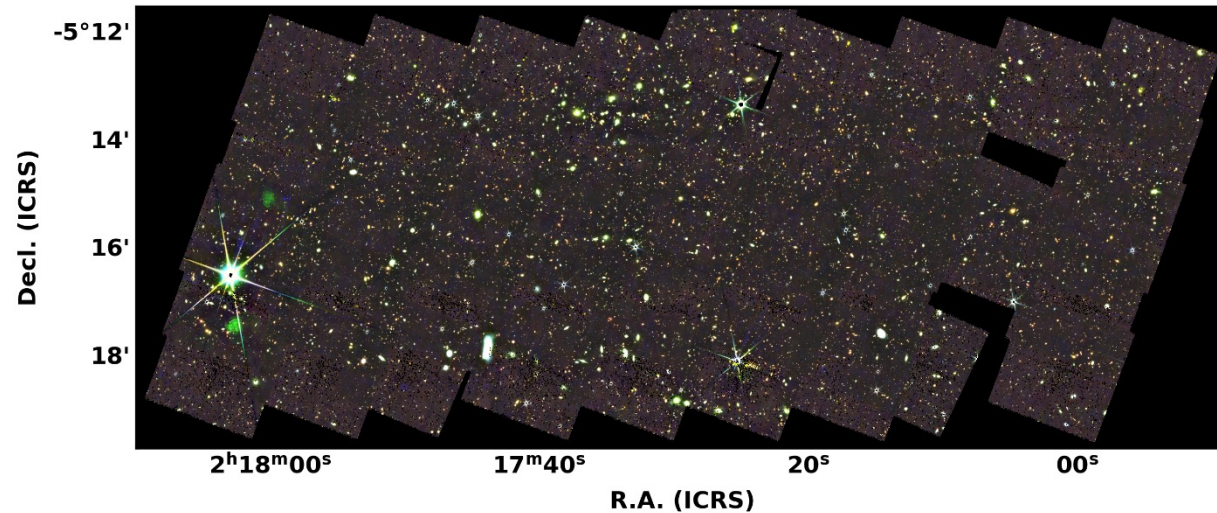
North Ecliptic Pole-
Time-Domain Fields **(NEP-TDF)**



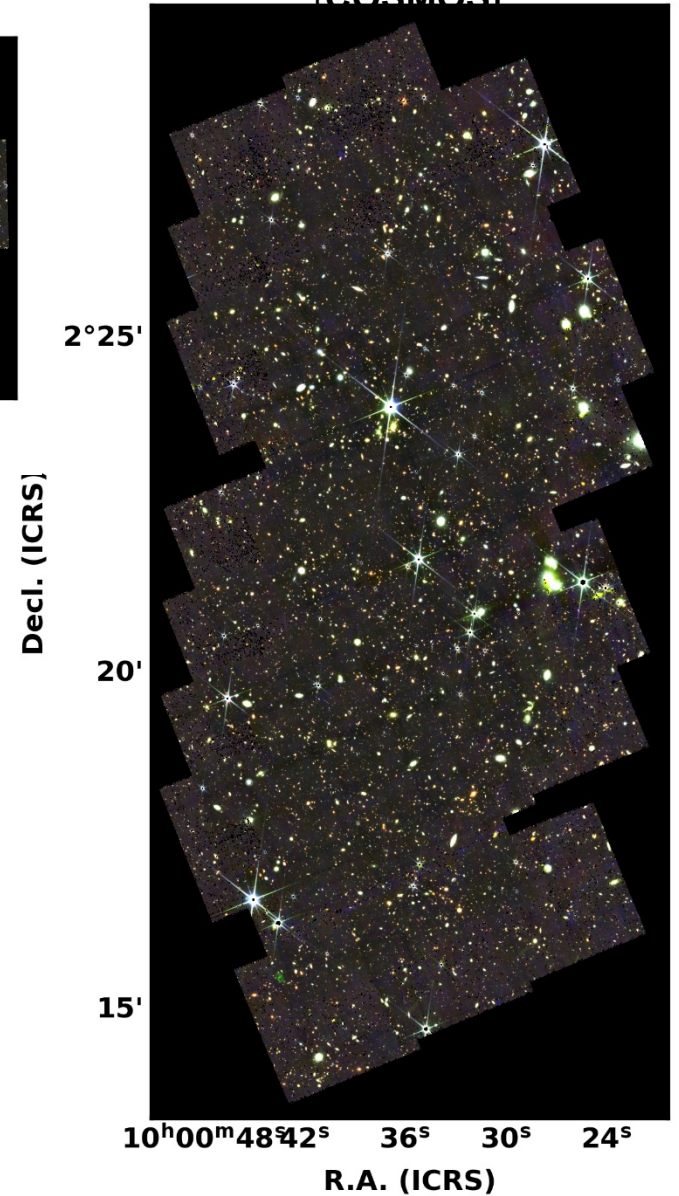
Cosmic Evolution Early Release Science Survey **(CEERS)**



UKIRT Infrared Deep Sky Survey Ultra-deep Survey field **(UDS)**

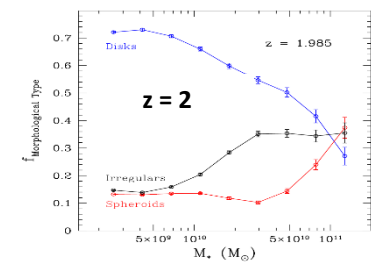
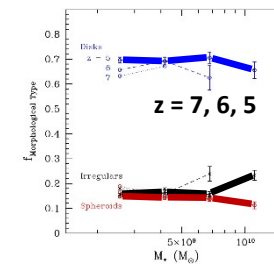
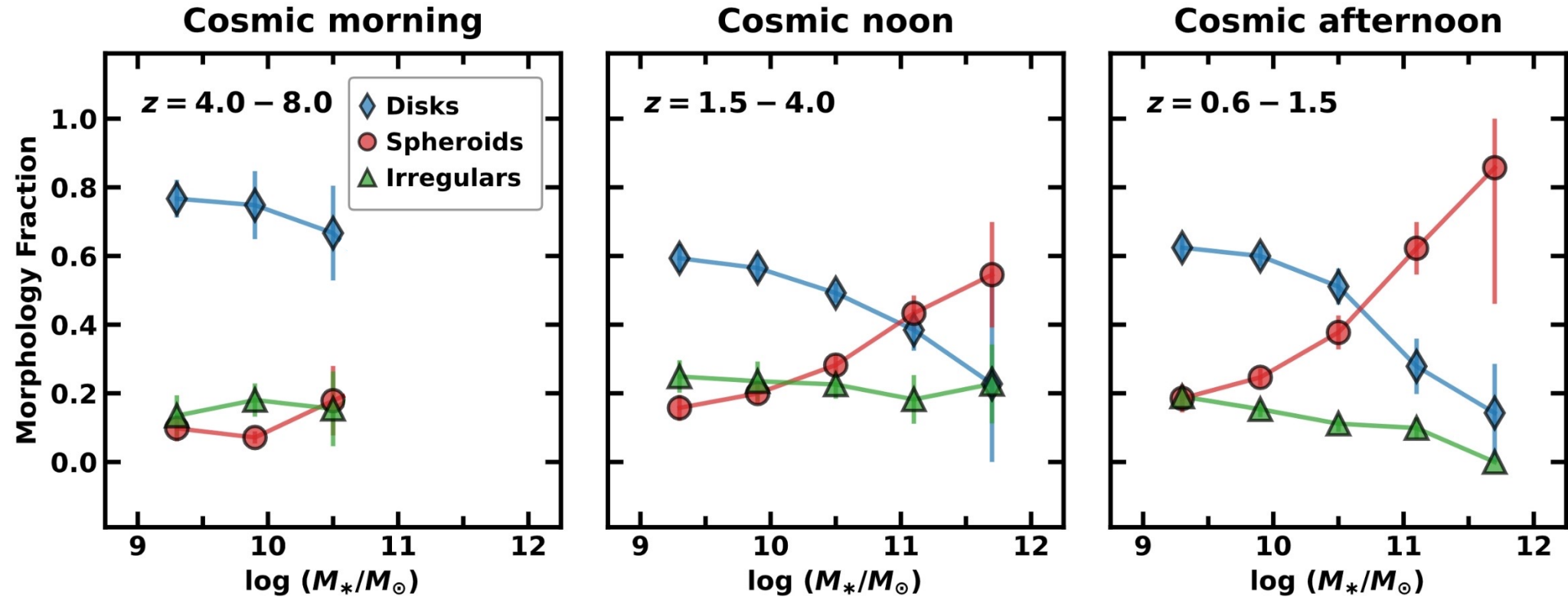


Cosmic Evolution Survey
(COSMOS)

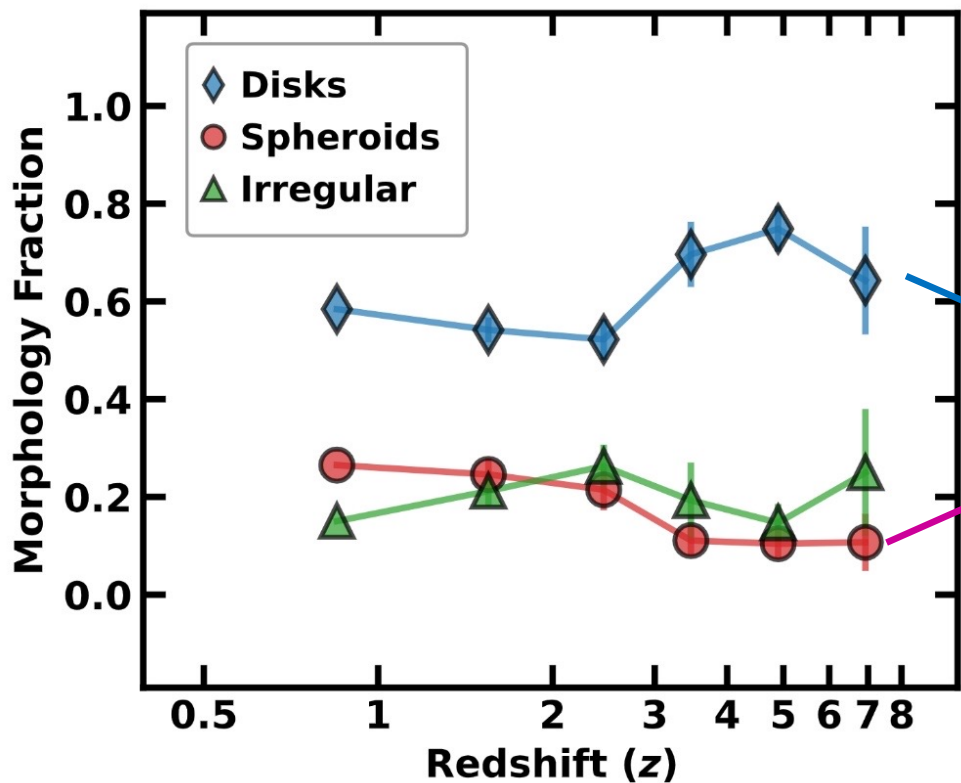


M*-dependence: ~19,000 JWST galaxies [Lee+ 2024]

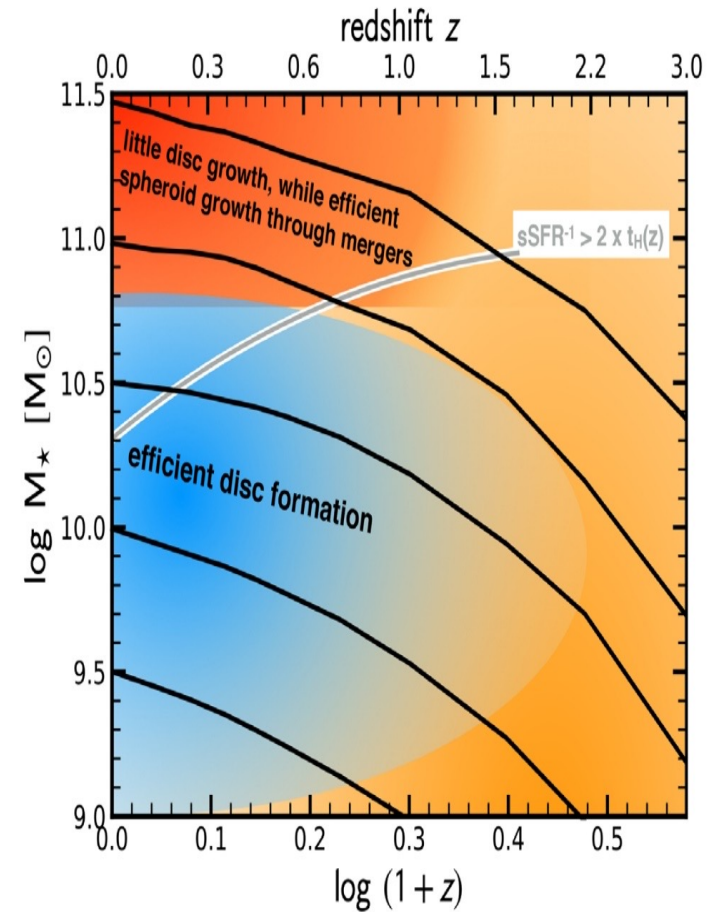
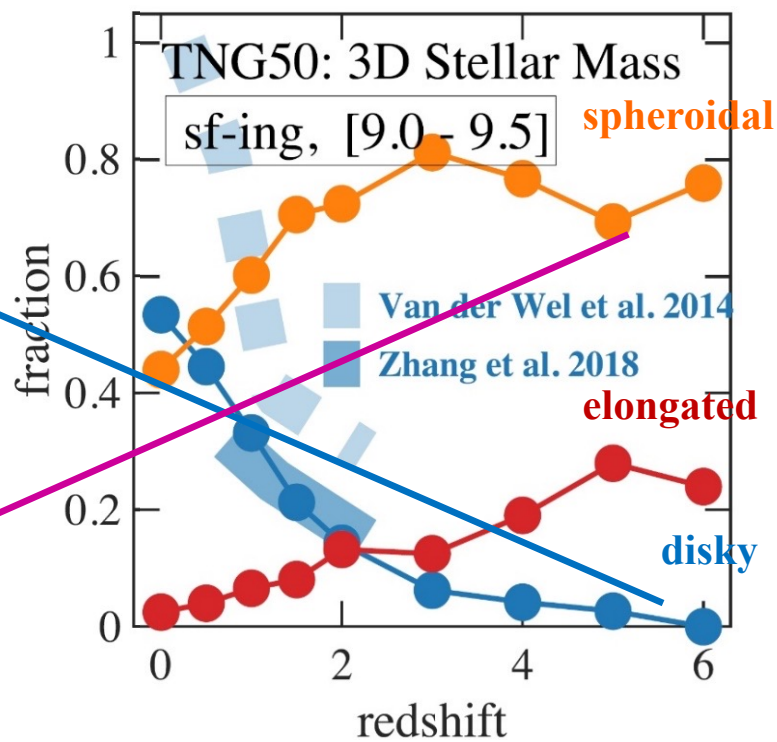
: Majority of high-z low-M* galaxies are disk types! Spheroids dominate for M* > 10¹¹ M_⊙



JWST galaxies with $M_* > 10^9 M_\odot$



IllustrisTNG with $M_* = 10^{9-9.5} M_\odot$



Summary

1. Galaxy morphology at $z > 4$

- 2/3 are **disks** at $M_* < 10^{10} M_\odot$!!
- Disk formation driven by the **tidal torque** imprinted in the initial conditions
- Spheroidal and irregular morphologies are incidental and transient.

2. Galaxy morphology in the cosmic noon and afternoon

- Disk morphology still dominates at $M_* < 10^{10} M_\odot$
- Spheroids dominate at high mass $M_* > 10^{11} M_\odot$

3. Morphology of 19,115 JWST galaxies at $z=0.6-8$

- 60 – 70% of galaxies with $M_* < 10^{10} M_\odot$ are disks at all redshifts!
- Strong mass dependence of morphology: Spheroids dominate for $M_* > 10^{11} M_\odot$
- The fraction of irregulars is about 20% or less at all mass and redshifts.
- **Quantitative agreement with the HR5 study!**

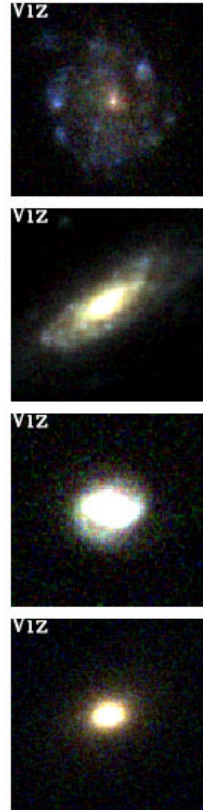
Recent evolution of galaxy morphology at $z <$

~ 1

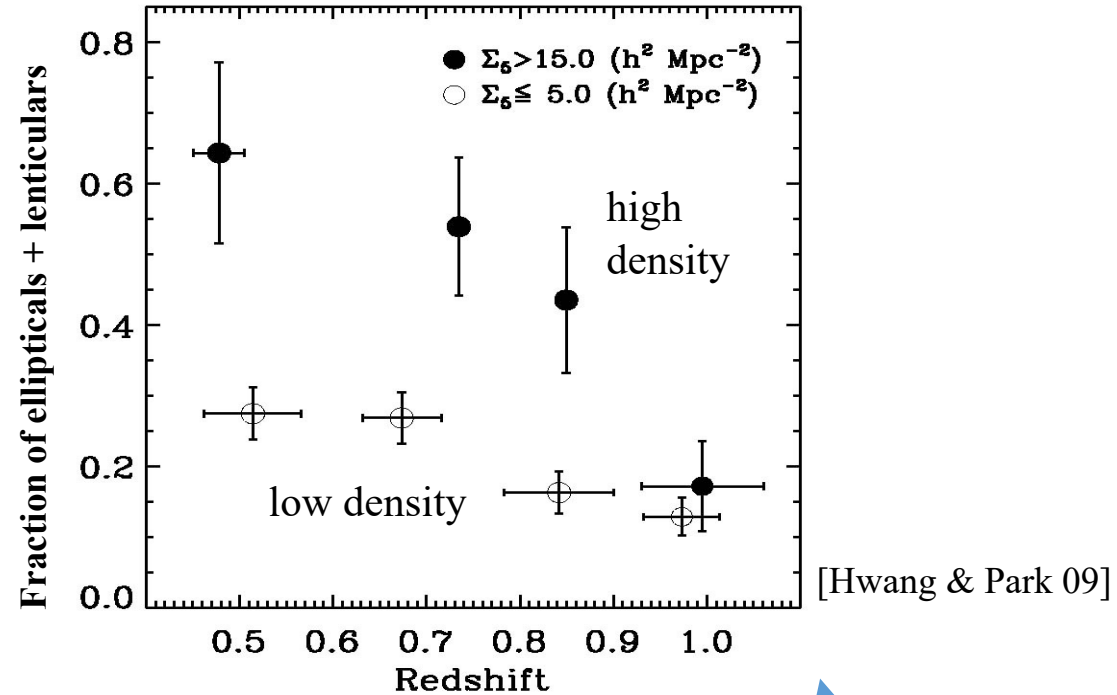
Evolution of early-type galaxy fraction f_E

Rapid evolution of f_E in high-density regions at $z \sim 0.8 \pm 0.2$

[HS Hwang & CB Park 2009]



~ 4400 Galaxies with $M_B < -18$ in GOODS-North & South



[Hwang & Park 09]

Are the galaxies at $z > 1$ all late types?

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Highest simulation resolution: 1 kpc

