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Exploring Early Galaxy Formation with JWST and SPHINX

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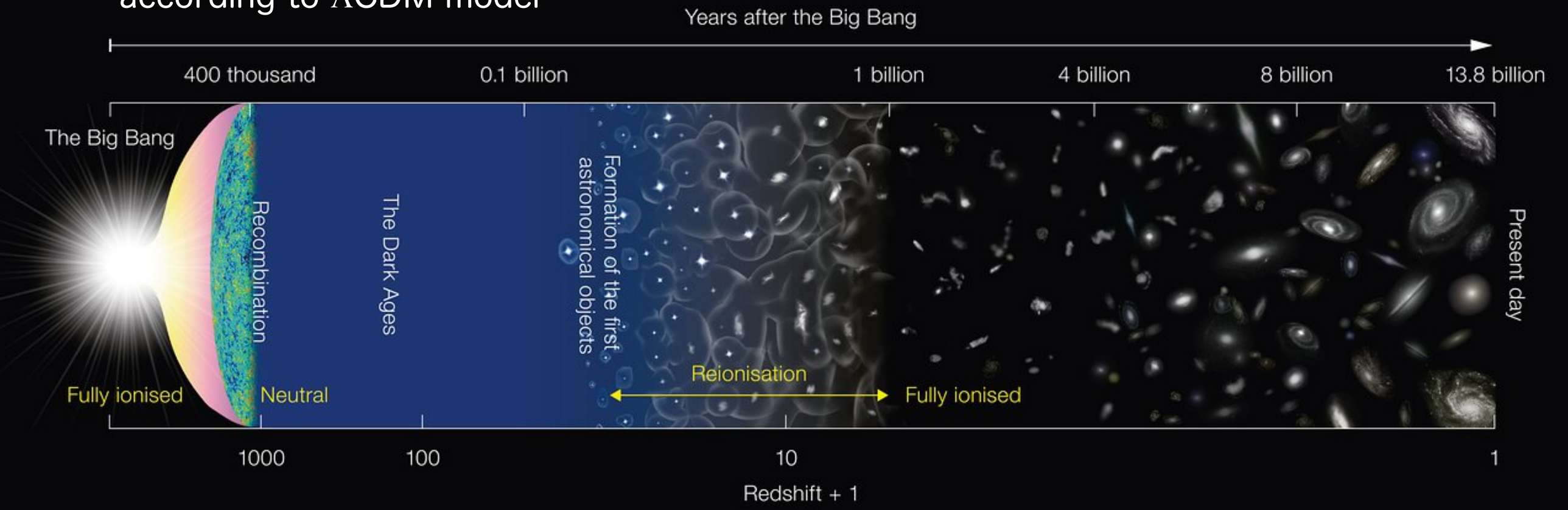
Lyon 1

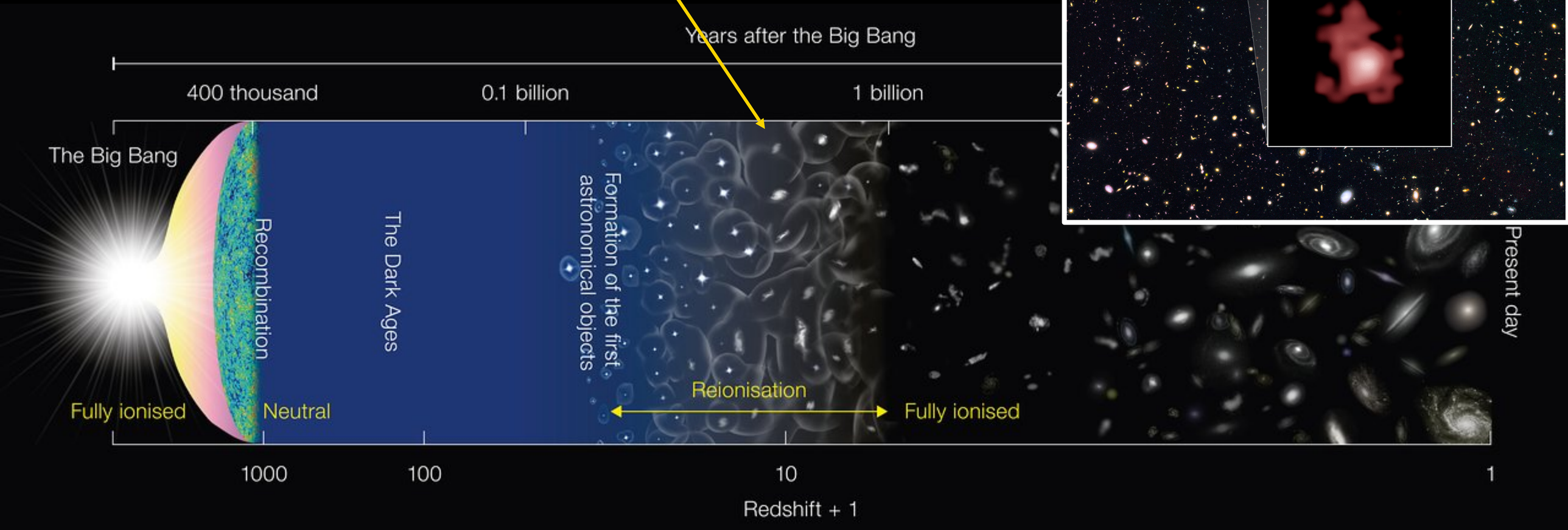
CRAL

Part I: History of the Universe

according to ΛCDM model



Earliest galaxy discovered by Hubble:
z=11, universe~400 million years old!



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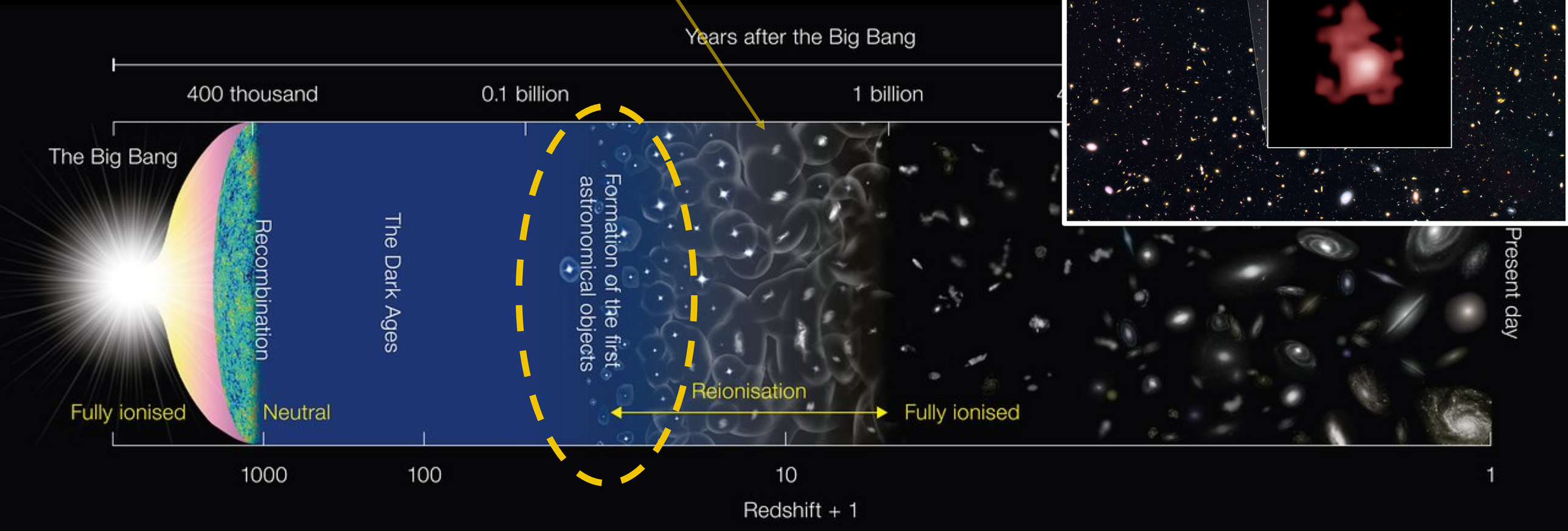
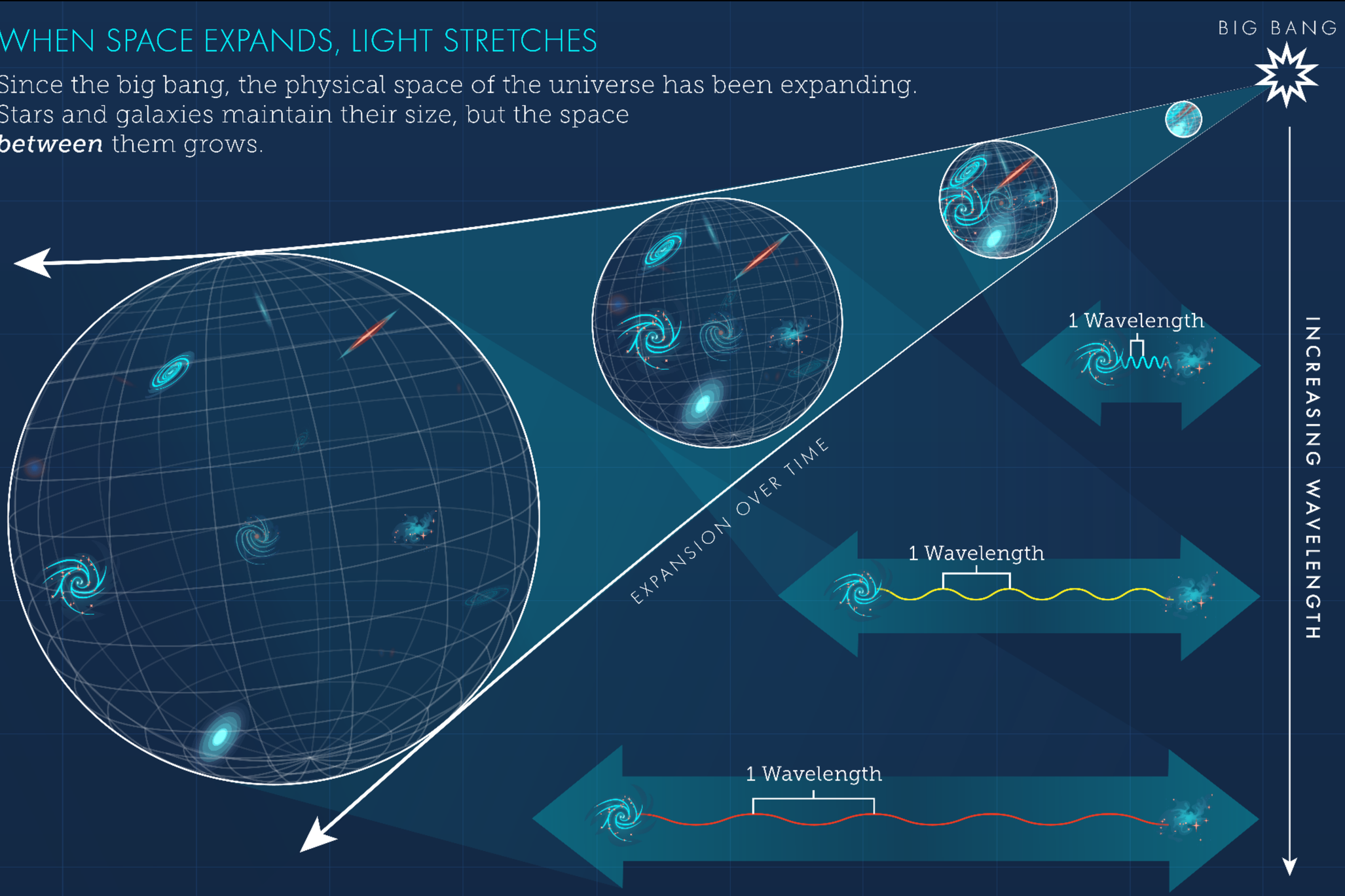


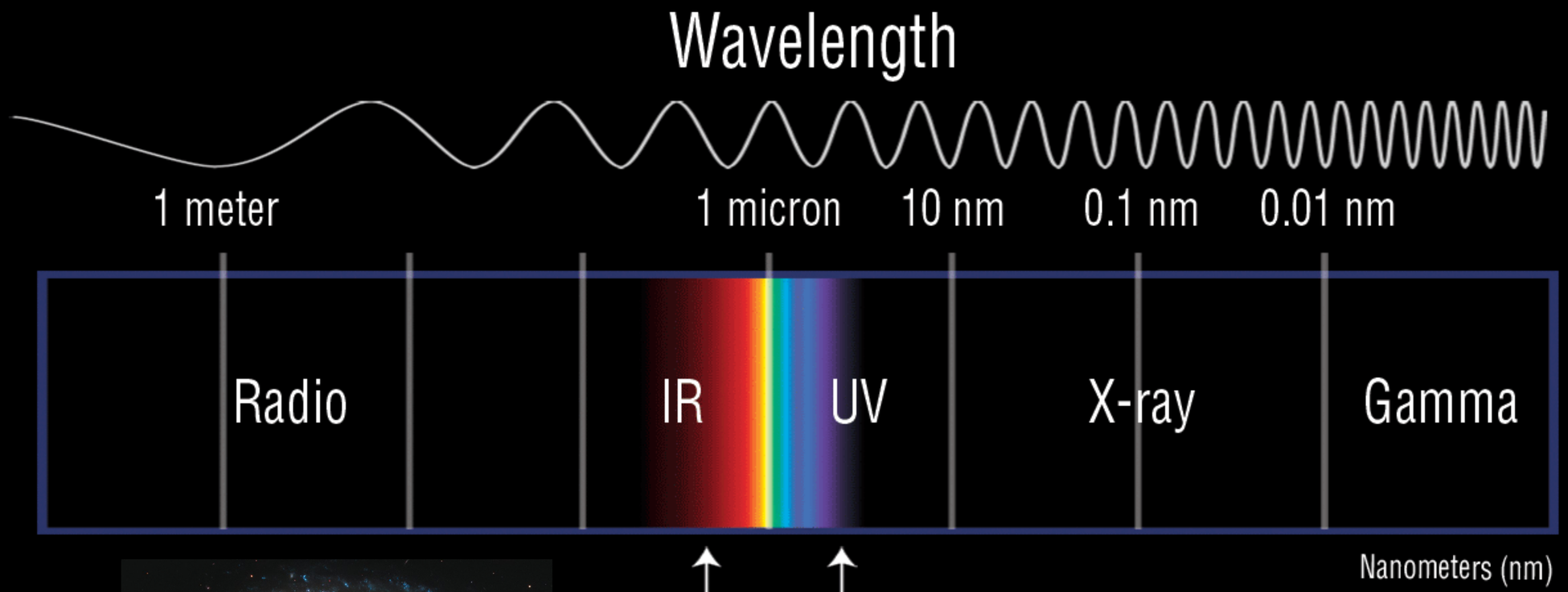
But can we go further?

WHEN SPACE EXPANDS, LIGHT STRETCHES

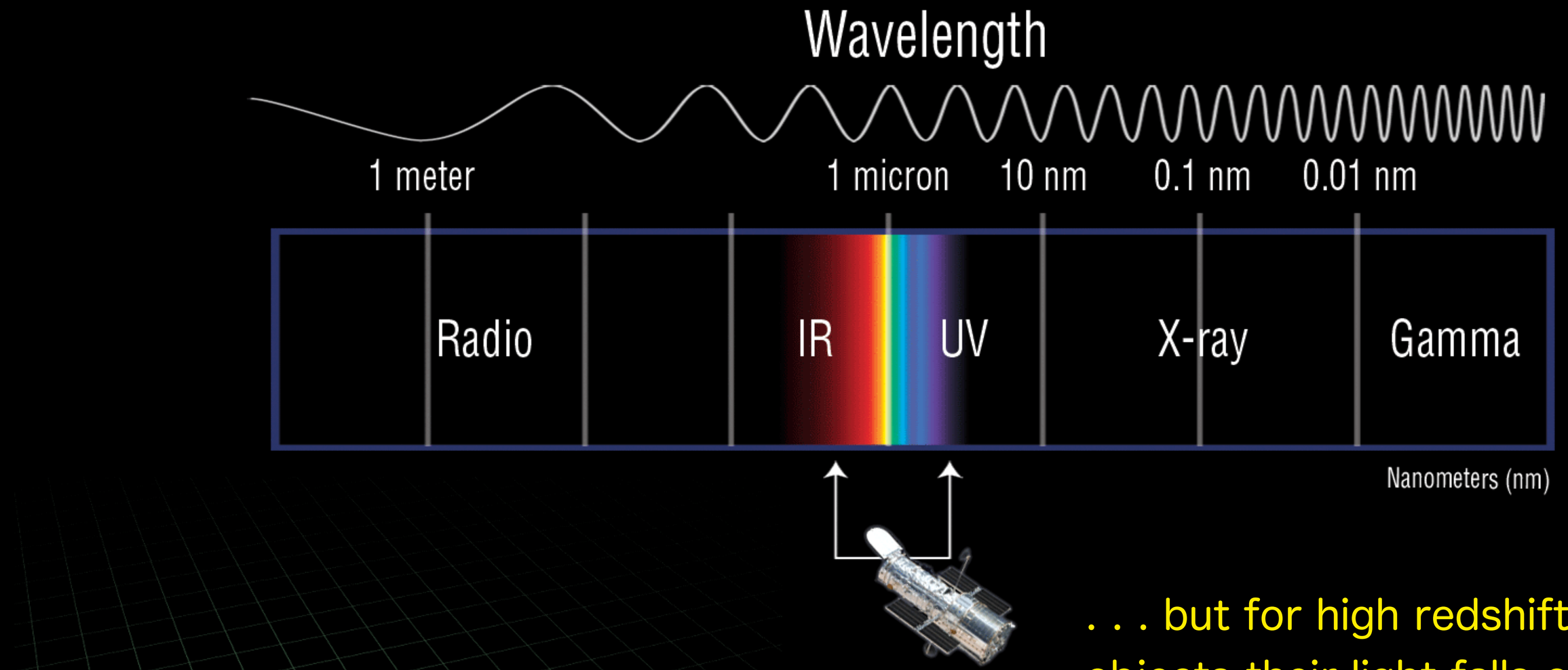
Since the big bang, the physical space of the universe has been expanding. Stars and galaxies maintain their size, but the space ***between*** them grows.

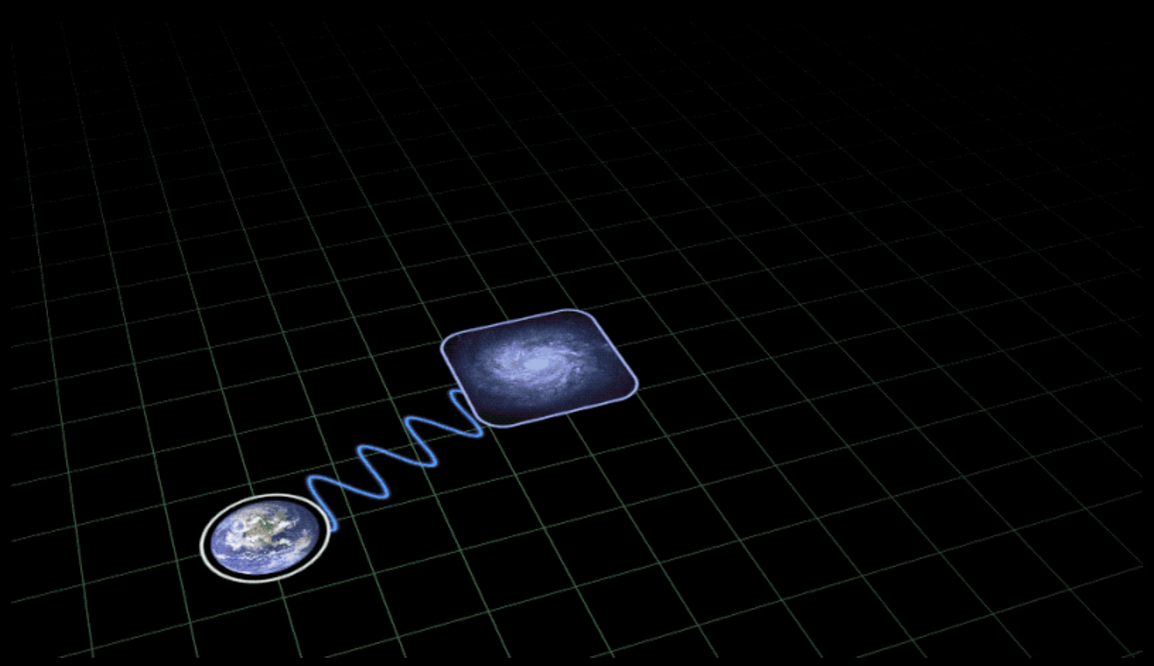


As light travels through expanding space, it is stretched to longer wavelengths.



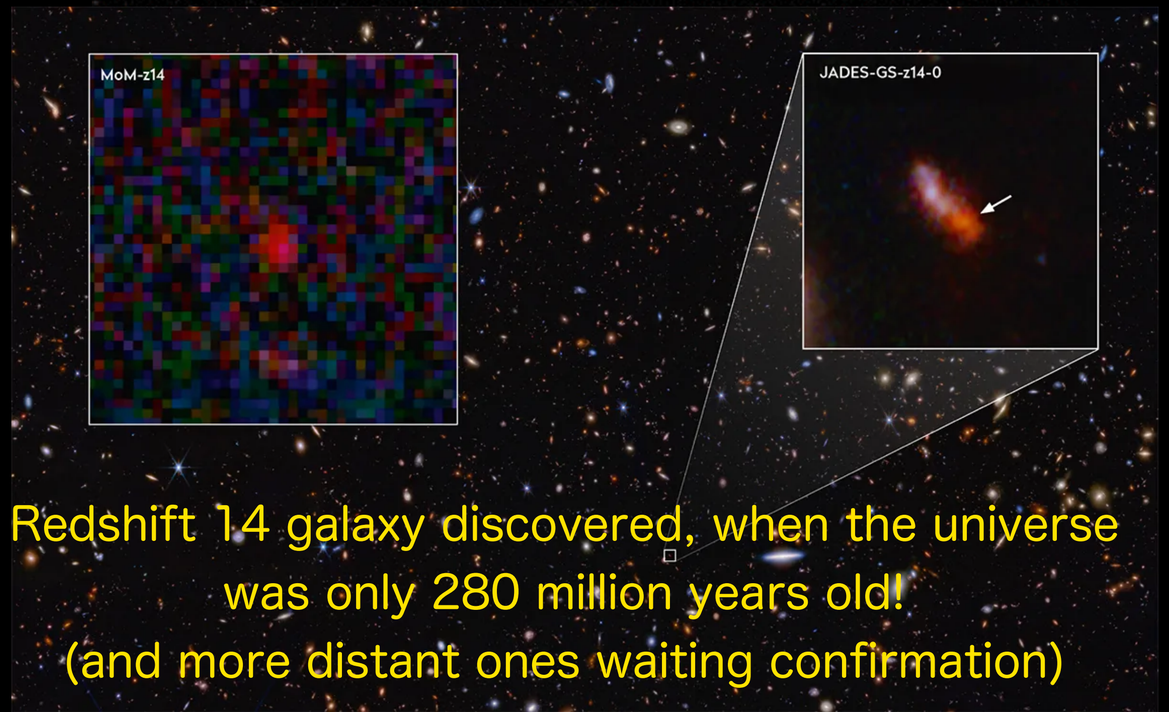
Hubble observes around the visible, which makes it great for making beautiful images of nearby galaxies!



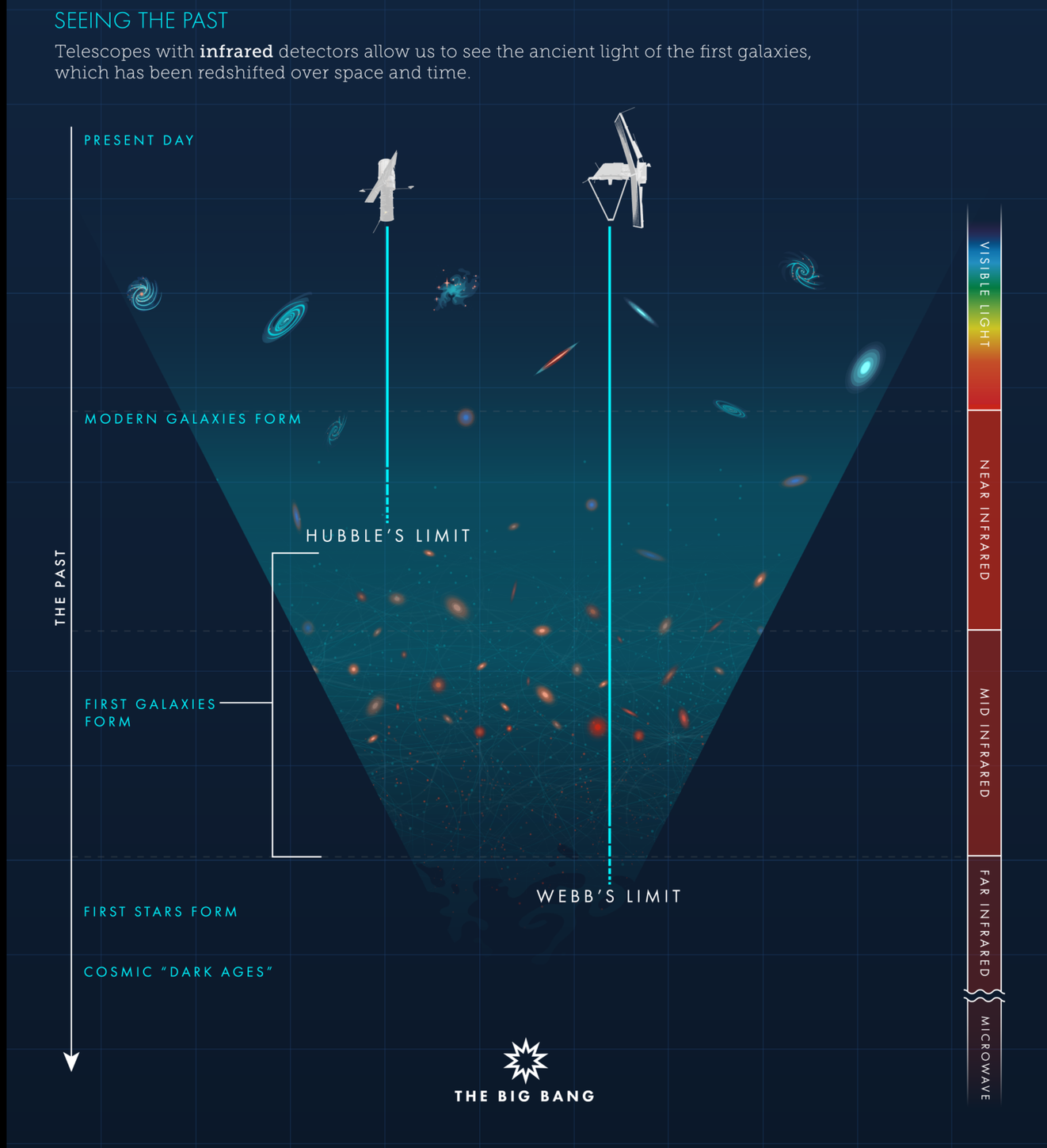


. . . but for high redshift objects their light falls out of Hubble's range :(

JWST to the rescue!



Redshift 14 galaxy discovered, when the universe was only 280 million years old!
(and more distant ones waiting confirmation)



Part II: Galaxies in the New Frontier

- First observations with JWST in 2022
- Unexpected results: galaxies seemed **brighter**, more **massive** and more **structured** than expected in this young universe
- The universe seemed too young to produce these galaxies. . . was this the beginning of the end of ΛCDM?

***JWST* early Universe observations and ΛCDM cosmology**

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ABSTRACT

Deep space observations of the *JWST* have revealed that the structure and masses of very early Universe galaxies at high redshifts ($z \sim 15$), existing at ~0.3 Gyr after the Big Bang, may be as evolved as the galaxies in existence for ~ 10 Gyr. The *JWST* findings are thus in strong tension with the ΛCDM cosmological model. While tired light (TL) models have been shown to

Not so fast!

Initial papers like these were found to have errors in their redshift measurements

ΛCDM not dead yet: massive high-z Balmer break galaxies are less common than previously reported

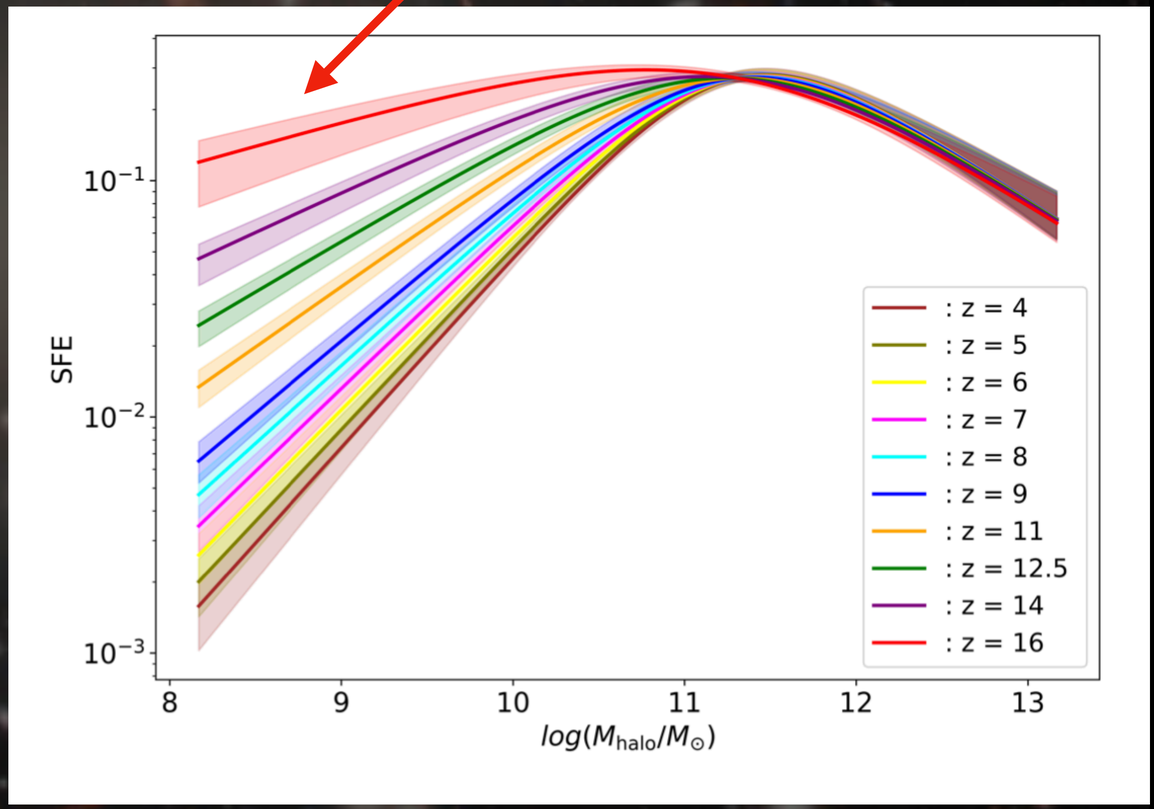
Guillaume Desprez, Nicholas S. Martis, Yoshihisa Asada, Marcin Sawicki, Chris J. Willott, Adam Muzzin, Roberto G. Abraham, Maruša Bradač, Gabe Brammer, Vicente Estrada-Carpenter, Kartheik G. Iyer, Jasleen Matharu, Lamiya Mowla, Gaël Noirot, Ghassan T. E. Sarrouh, Victoria Strait, Rachel Gledhill, Gregor Rihtaršič

Early JWST observations that targeted so-called double-break sources (attributed to Lyman and Balmer breaks at $z > 7$), reported a previously unknown population of very massive, evolved high-redshift galaxies. This surprising discovery led to a flurry of attempts to explain these objects' unexpected existence including invoking alternatives to the standard ΛCDM cosmological paradigm. To test these early results, we adopted the same double-break candidate galaxy selection criteria to search for such objects in the JWST images of the CAnadian NIRISS Unbiased Cluster Survey (CANUCS), and found a sample of 19 sources over five independent CANUCS fields that cover a total effective area of ~ 60 arcmin^2 at $z \sim 8$. However, (1) our SED fits do not yield exceptionally high stellar masses for our candidates, while (2)

Not so fast!

- Overabundance of bright galaxies:
  - Initial analysis used models of star formation valid in the local universe
  - . . . but the young universe was denser with less metals, meaning star formation was more efficient!
  - Testing these models has shown that these bright galaxies fit well within the ΛCDM framework

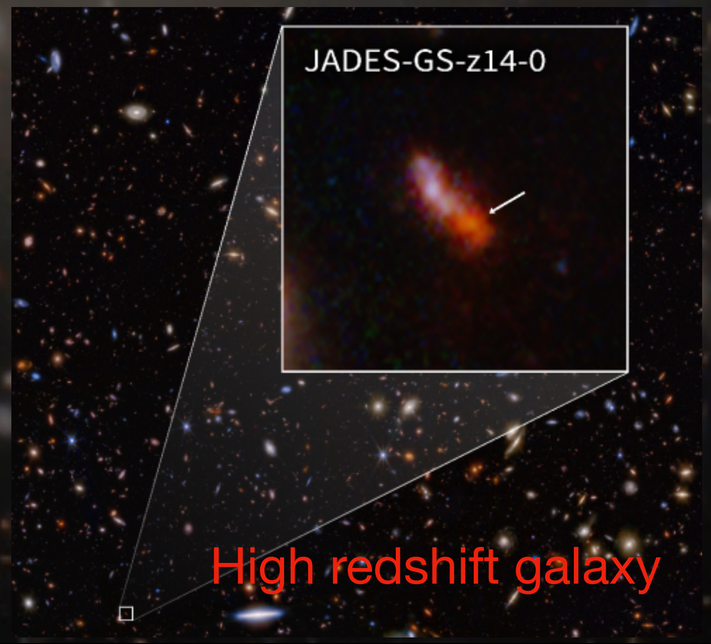
Star formation efficiency is higher at higher redshift!



. . . So what is galaxy formation like in the early universe?

- JWST has clearly shown that early galaxies are very different than those in the local universe
- Studying them is harder because of limited resolution

Local galaxy



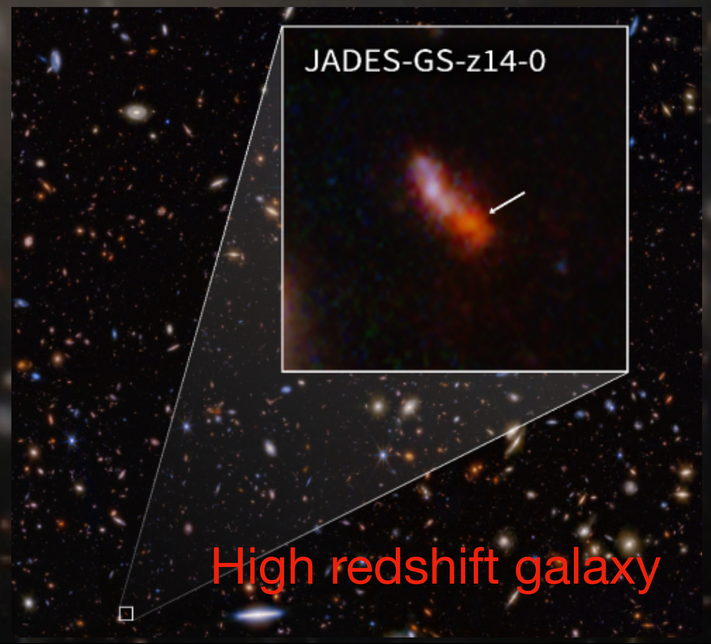
High redshift galaxy

. . . So what is galaxy formation like in the early universe?

How can we connect what we observe to physical processes?

What are the observational biases affecting our results?

Local galaxy

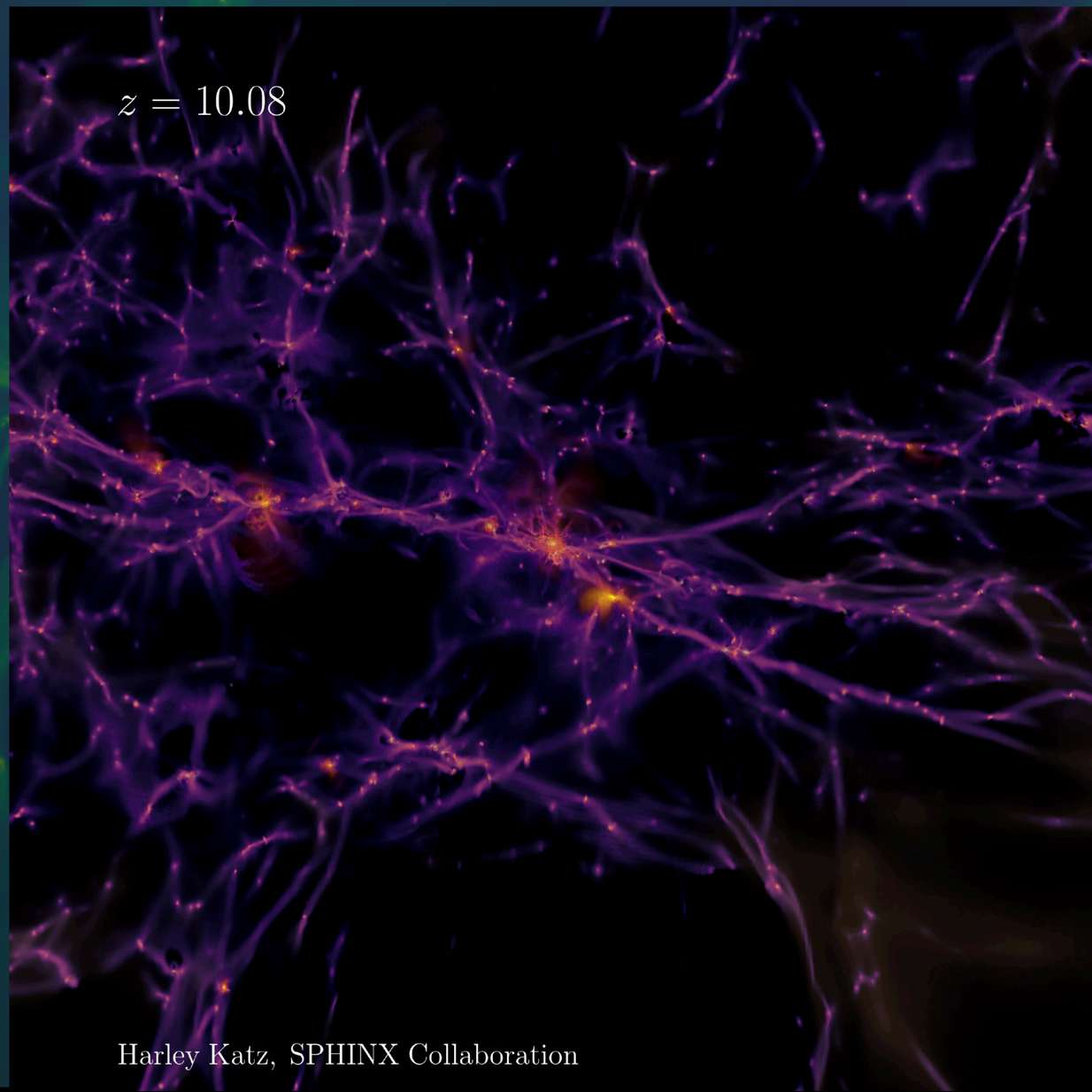


High redshift galaxy

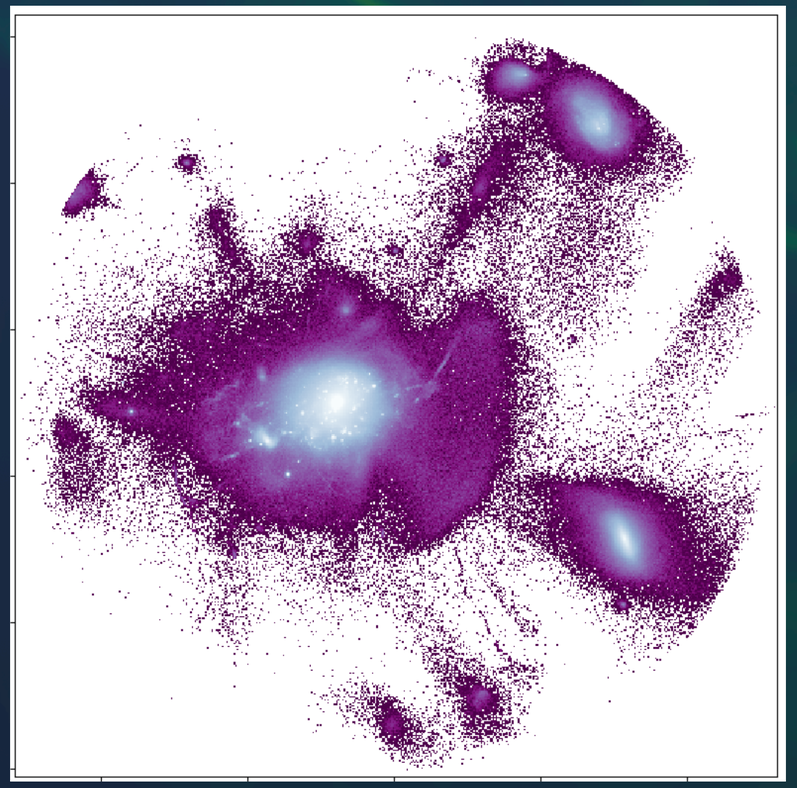
Part III: Cosmological Simulations

What I'm actually doing in my PhD ;)

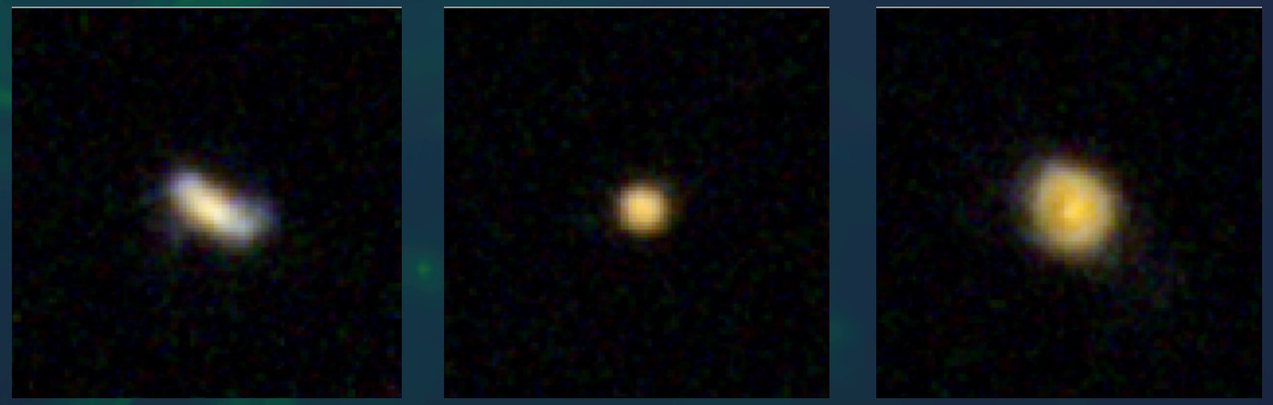
- SPHINX cosmological simulation developed at CRAL
  - Relatively small volume -> high resolution!
- Can study star formation and feedback mechanisms in the early universe



Bridging simulations and observations

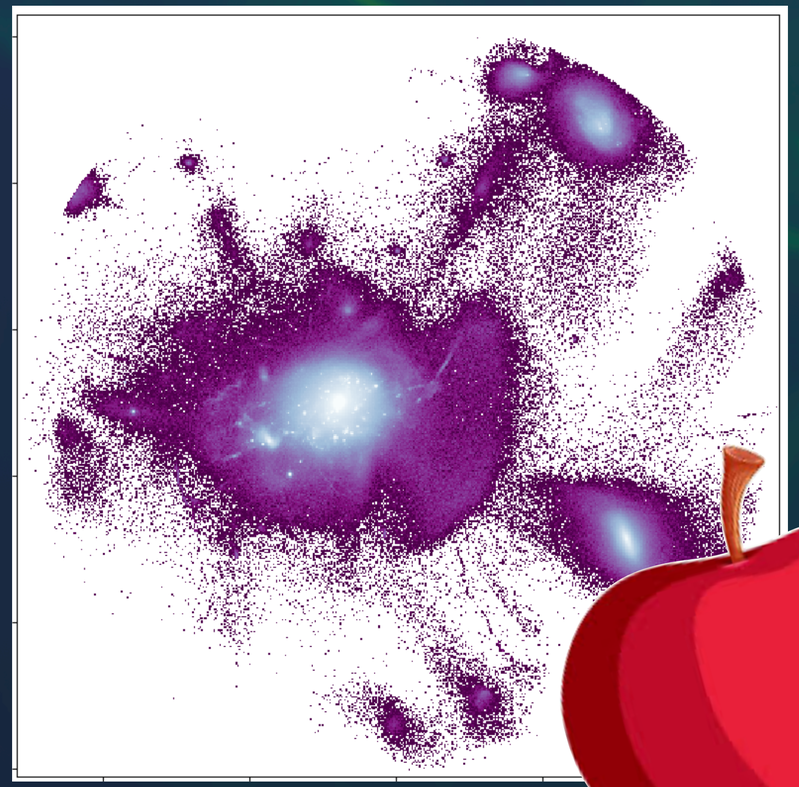


Simulated galaxy



JWST observed galaxies

Bridging simulations and observations

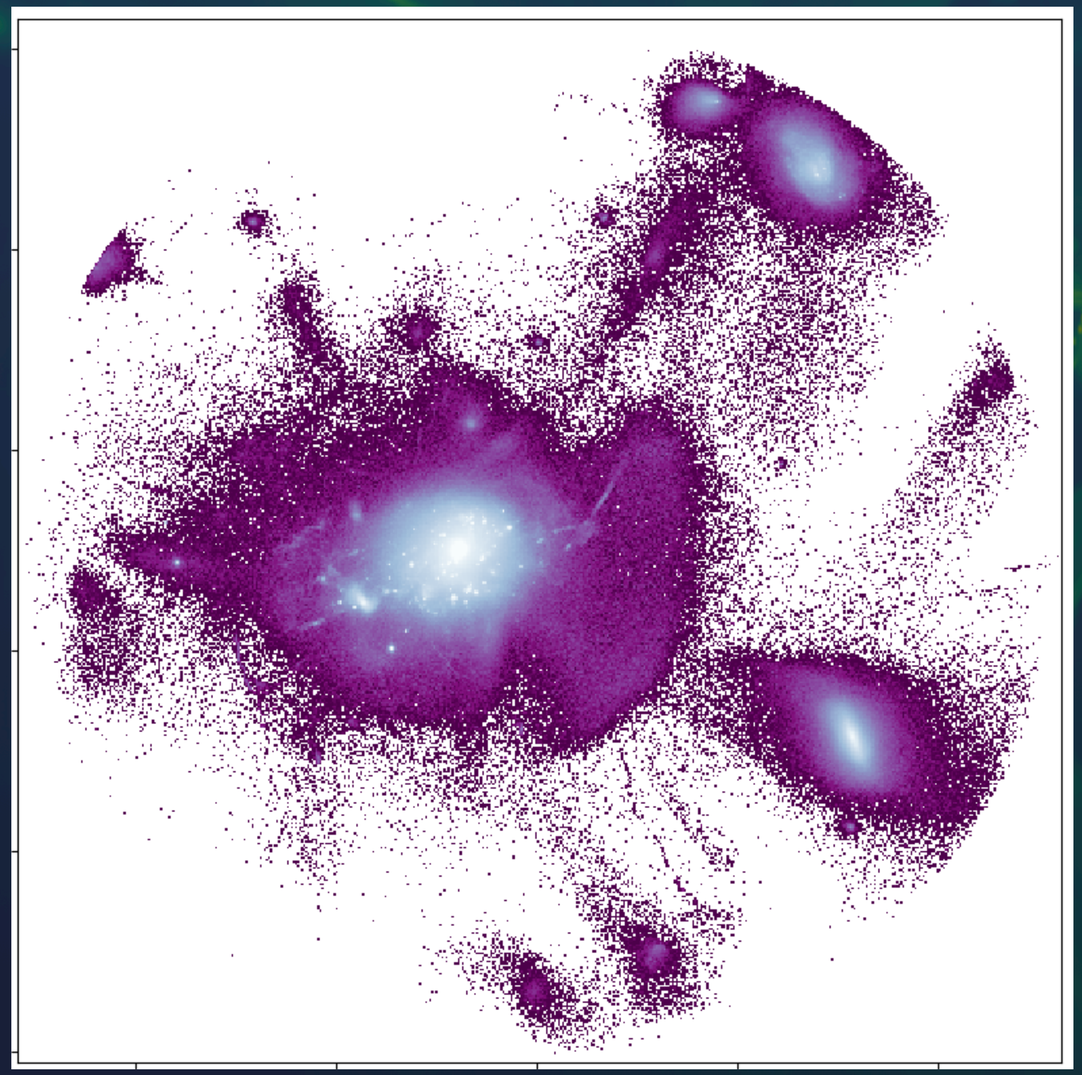


Simulated galaxy

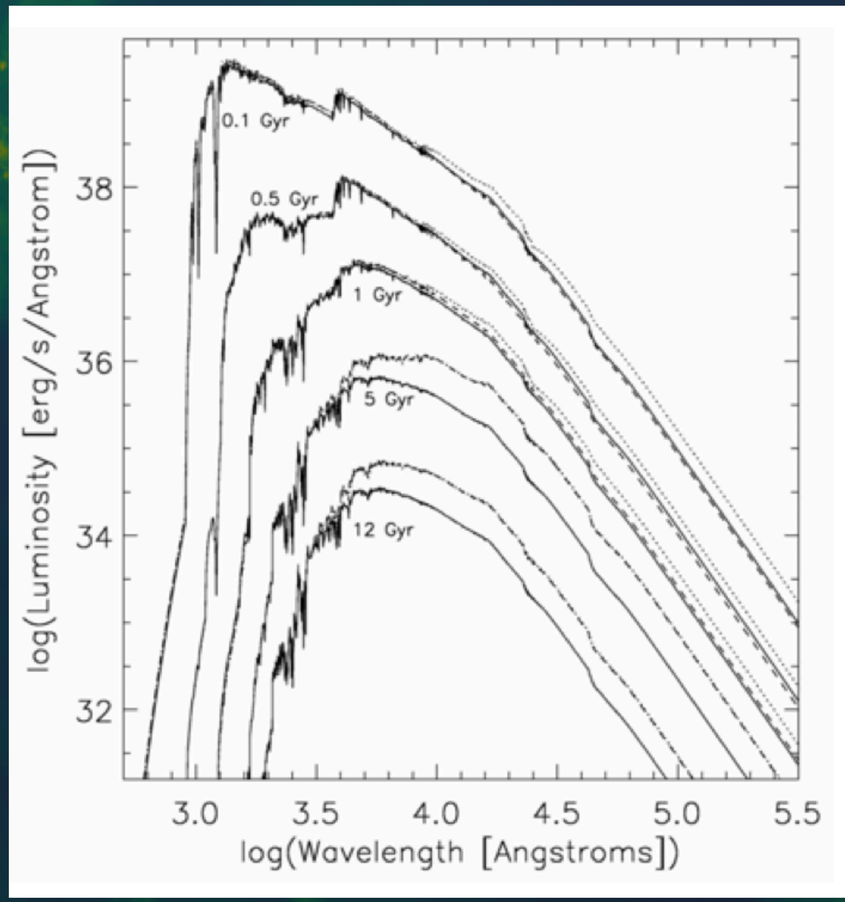
JWST observed galaxies

Creating ‘Mock’ Observations

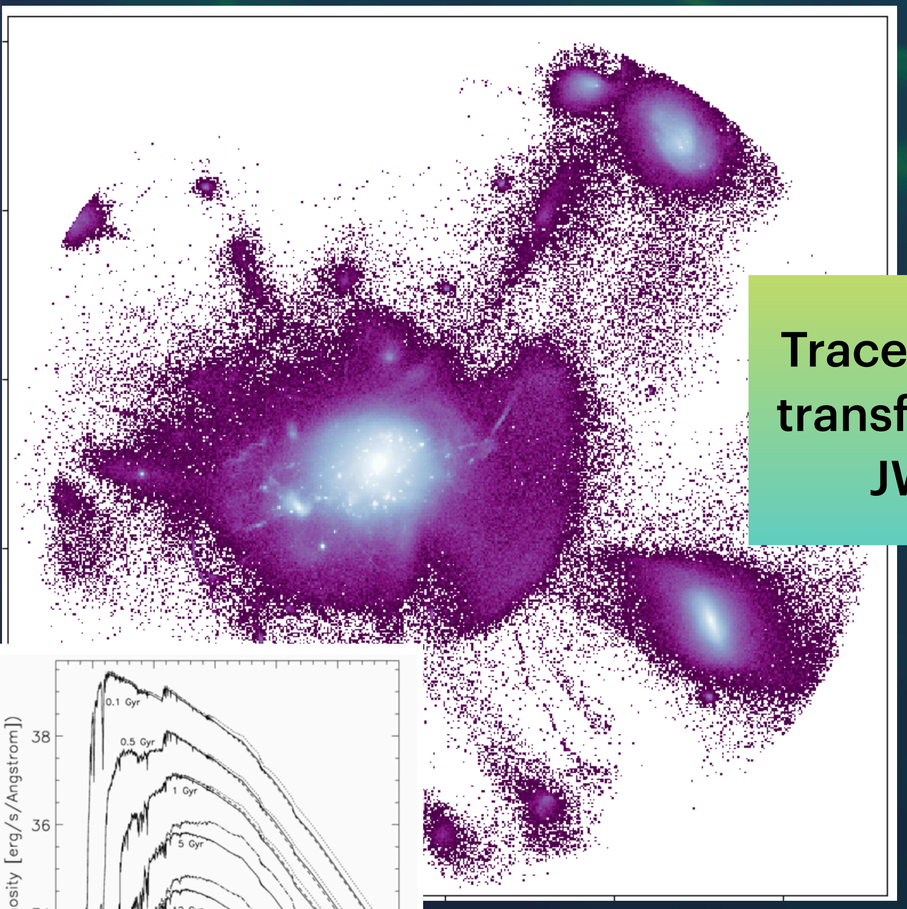
Galaxy star particles from simulation



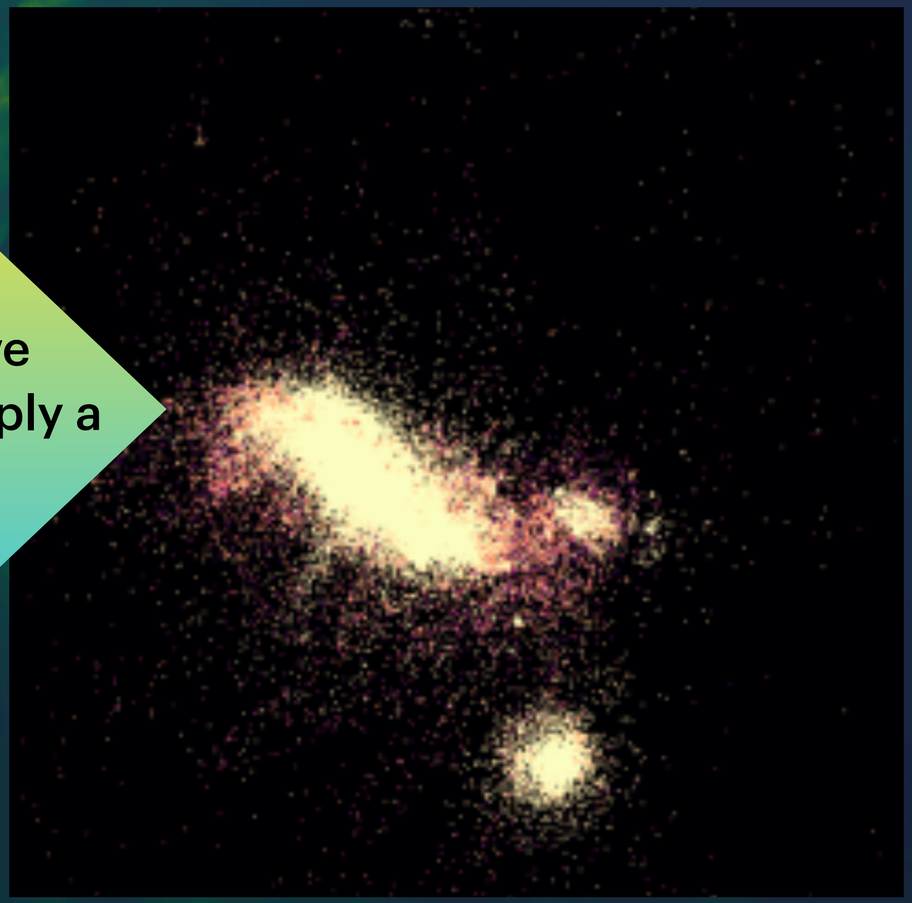
Each star emits light, following a spectrum that depends on their age



Creating ‘Mock’ Observations



Trace light emission in radiative transfer code RASCAS, and apply a JWST filter transmission



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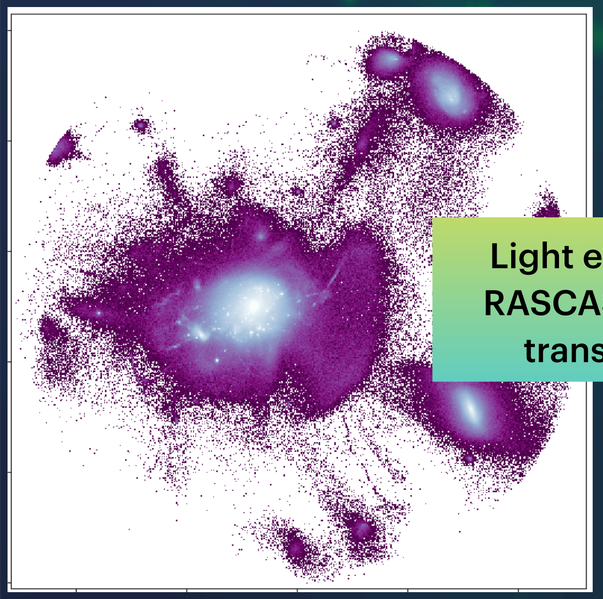
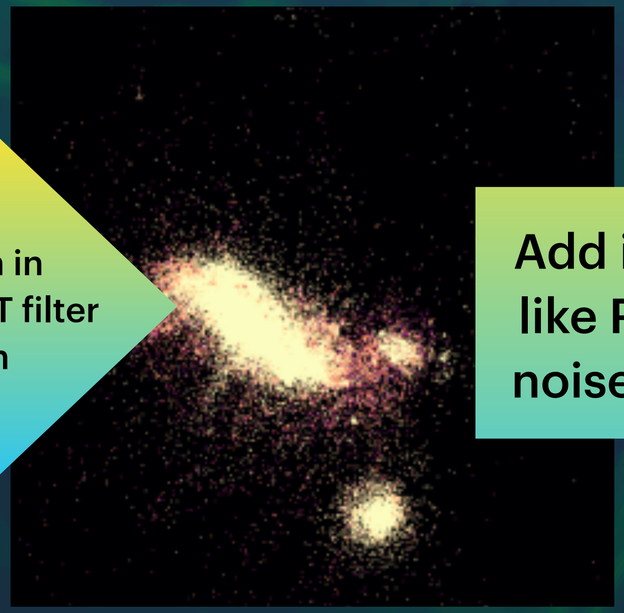
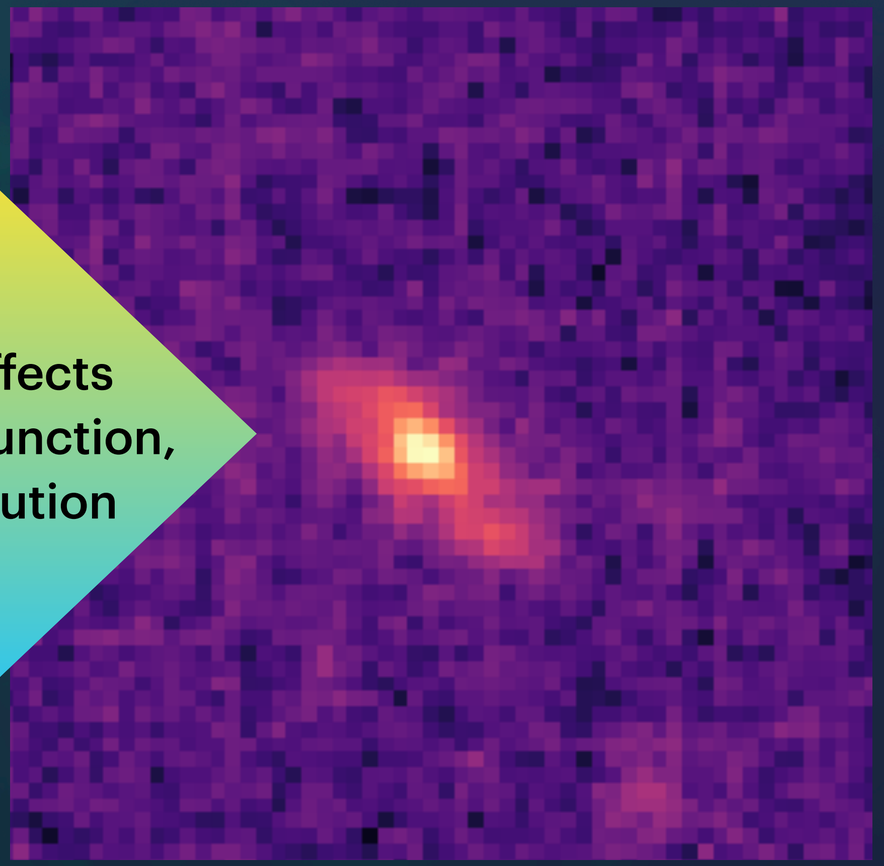


Light emission in RASCAS, JWST filter transmission



Add instrumental effects like Point-Spread-Function, noise, and low resolution



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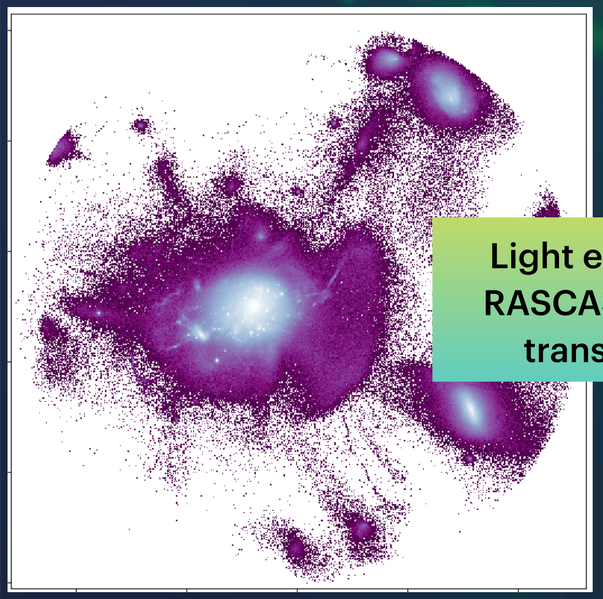
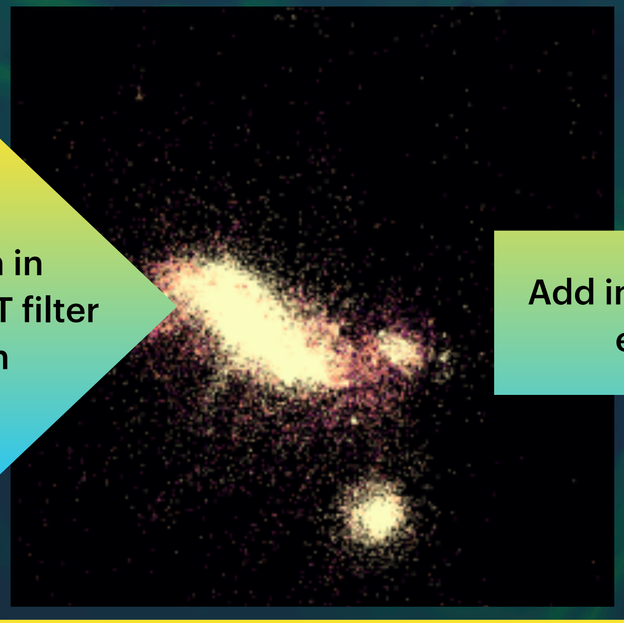
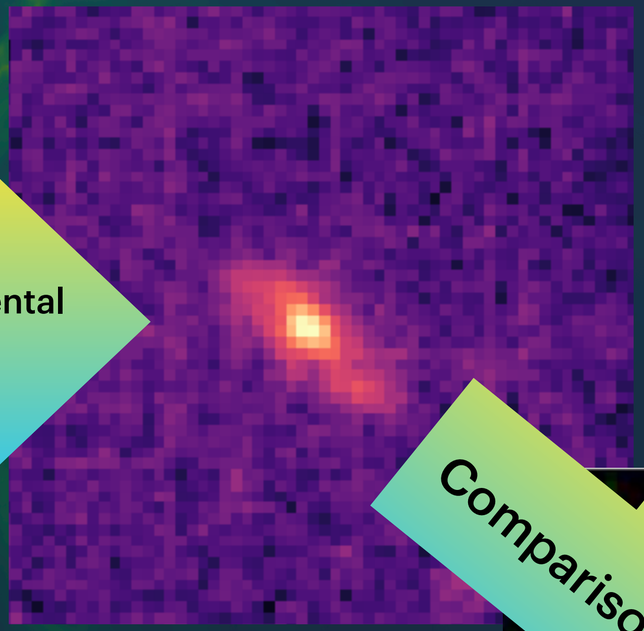


Light emission in RASCAS, JWST filter transmission



Add instrumental effects



Comparison!

I now have a framework to make meaningful connections between observations and simulations!

Thesis goals

- What modes of star formation dominated the early universe? (Bursty and intense?)
- How do star formation and feedback mechanisms shape galaxy morphology?
- How does dust attenuation affect the observed features of galaxies?
- How accurate are our current methods at recovering physical properties?