UCSC Physics Colloquium
October 20, 2022

Cosmology, Galaxies, and Planets with JWST

Joel Primack
Distinguished Professor of Physics Emeritus
University of California Santa Cruz

11 December 2020

New Challenges in Cosmology

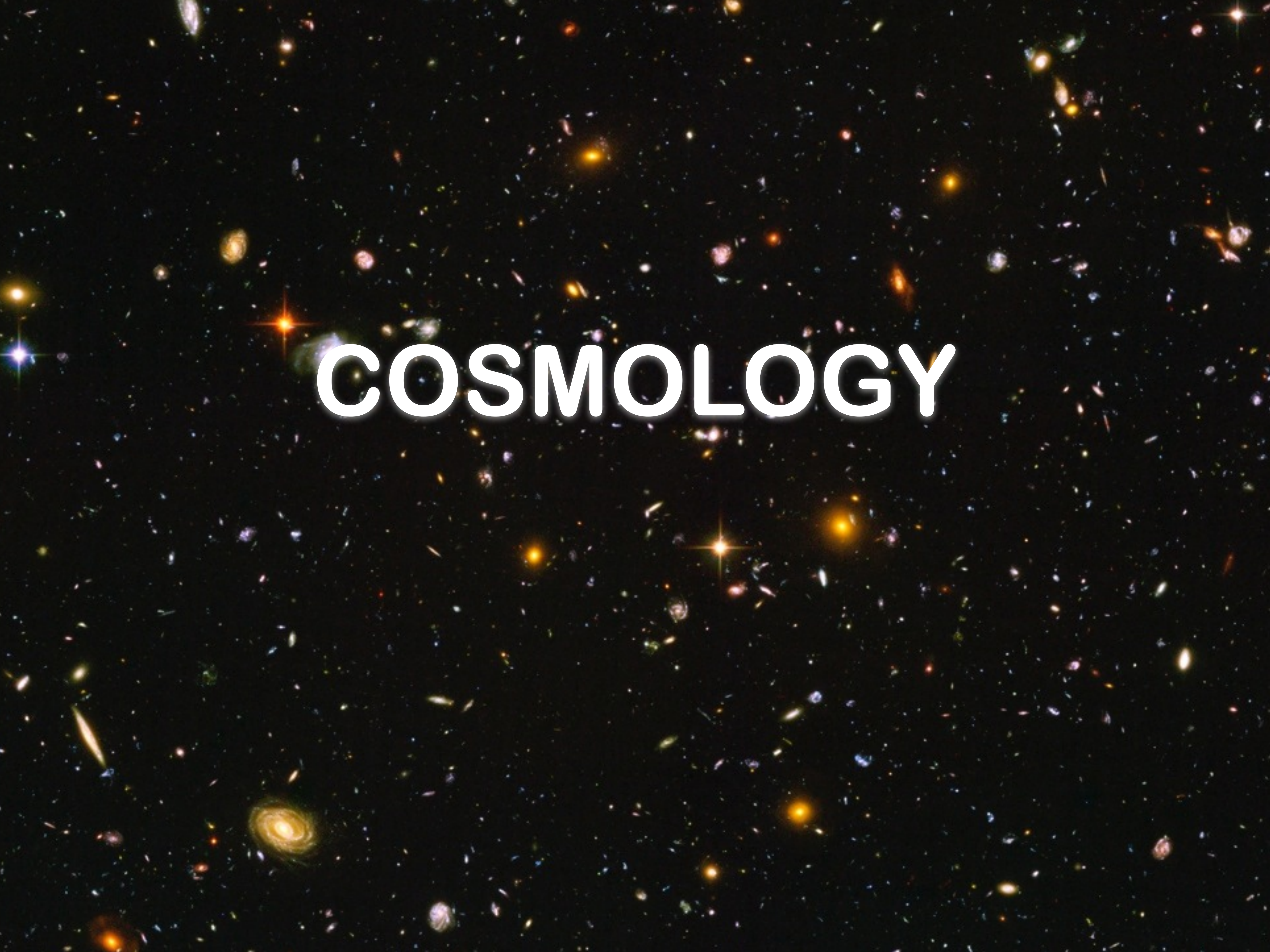
There is persuasive cosmological evidence that most of the density of the universe is invisible dark matter and dark energy, with atomic matter making up only about five percent of cosmic density. But the latest high-precision measurements of the expansion rate of the universe have revealed potential discrepancies that may require new physics.

Galaxy Formation

James Webb Space Telescope's infrared capabilities allow its cameras to see starlight from even the highest-redshift galaxies. JWST's better resolution than Hubble Space Telescope is also revealing new aspects of galaxy formation.

Planet Habitability

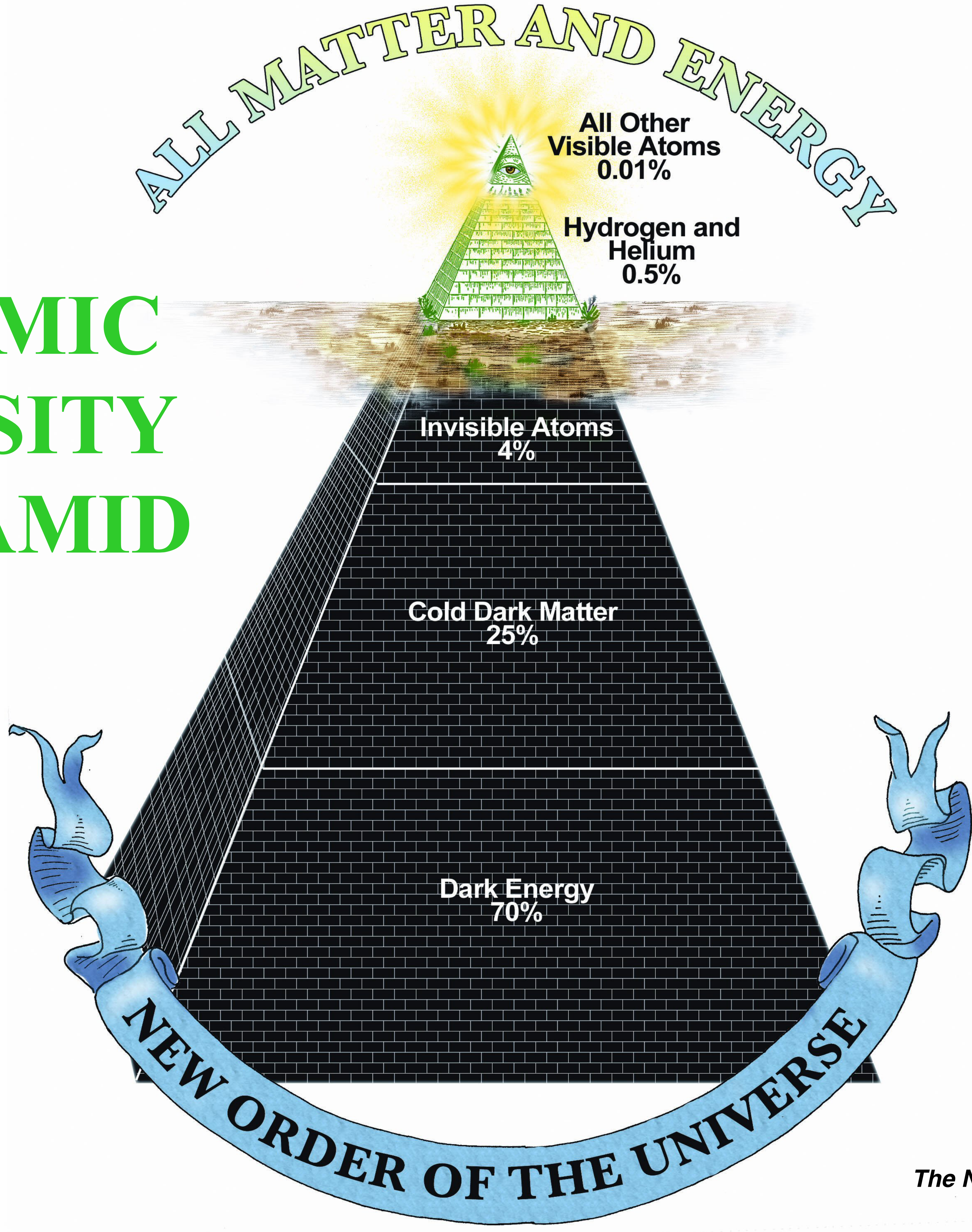
Earth may be a radioactively Goldilocks planet, with just the right amount of radiogenic heating by Th and U for a magnetic field and plate tectonics, both of which may be necessary for the evolution of complex life.

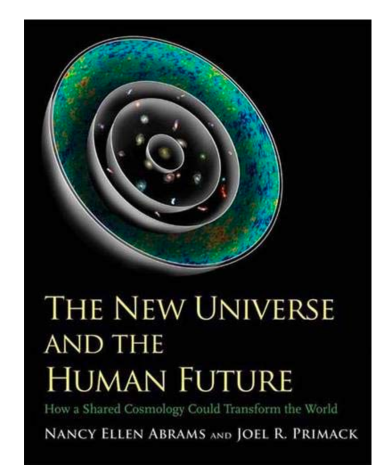

COSMOLOGY

This picture is beautiful but misleading, since it only shows about 0.5% of the cosmic density.

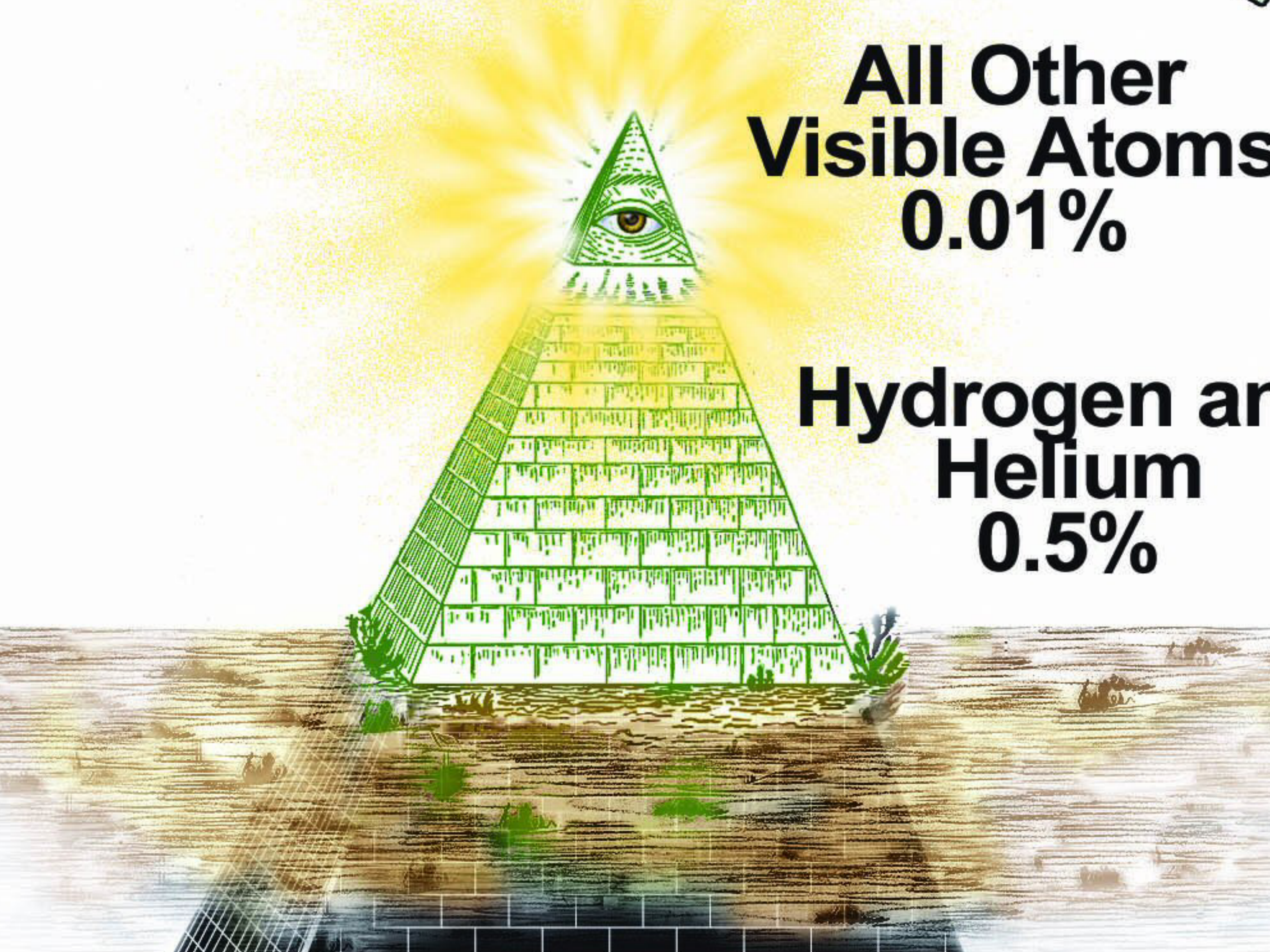
The other 99.5% of the universe is dark.

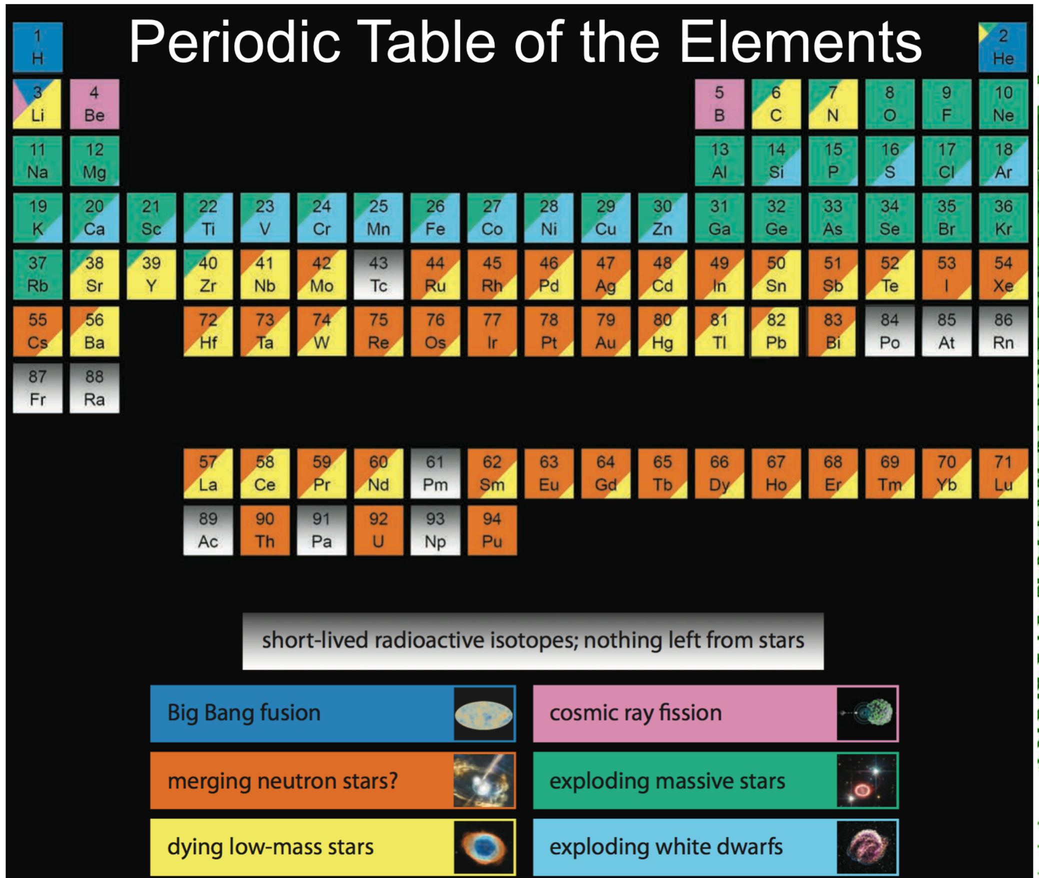
COSMIC DENSITY PYRAMID

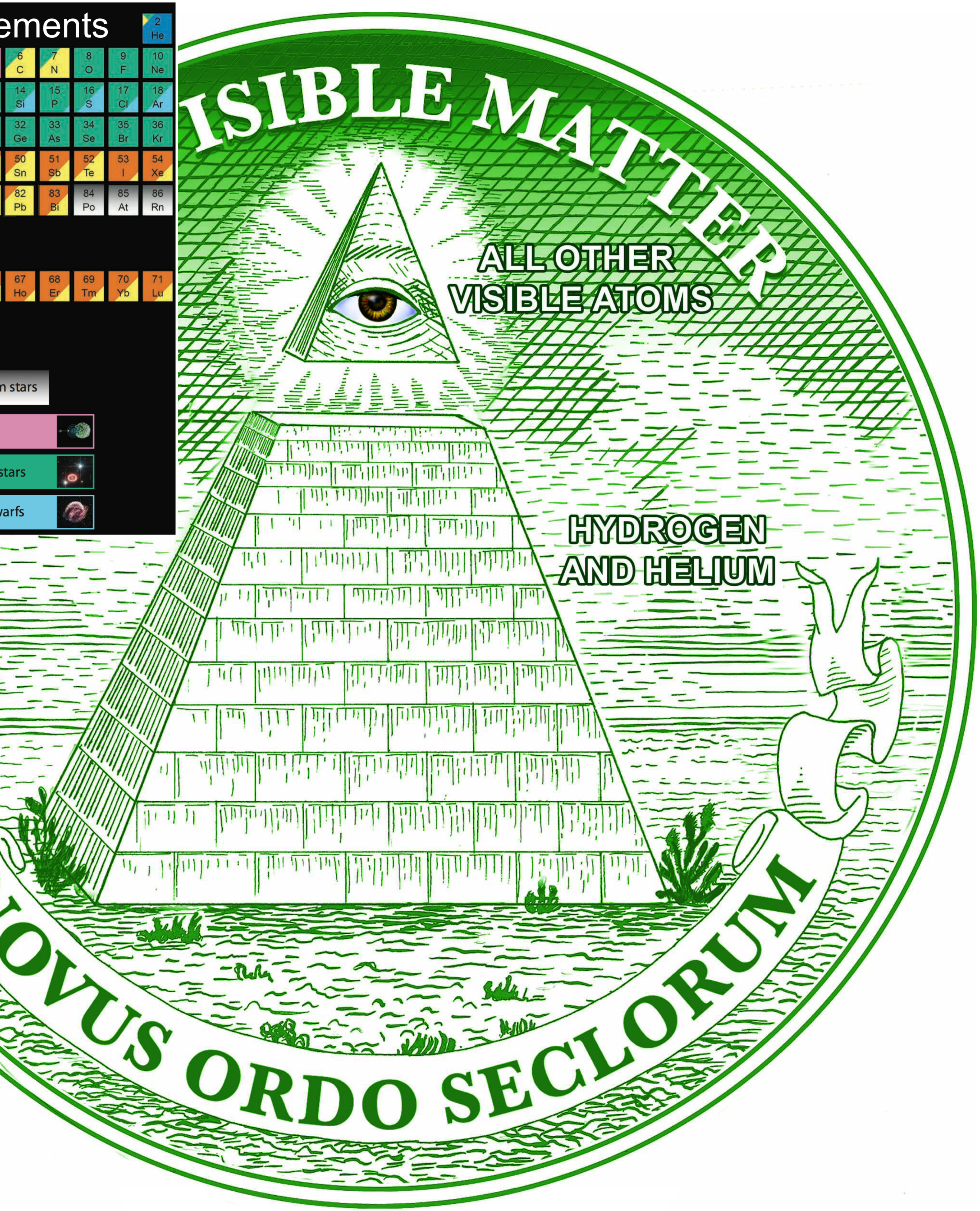




Nancy Abrams & Joel Primack,
The New Universe and the Human Future
http://new-universe.org


All Other
Visible Atoms
0.01%
Hydrogen ar
Helium
0.5%

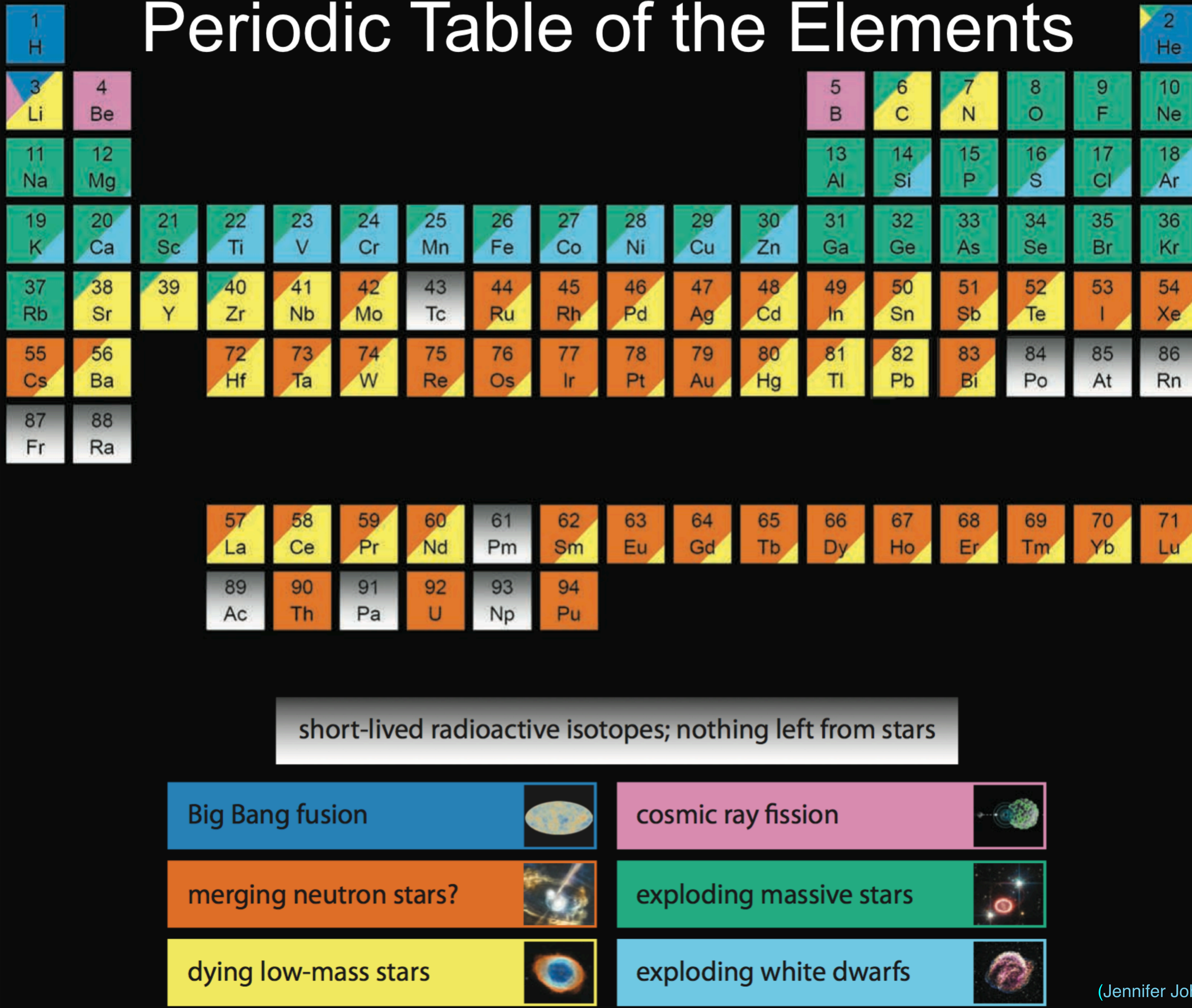




stardust

first stars

Periodic Table of the Elements



(Jennifer Johnson)

Dark Matter Ships

on a

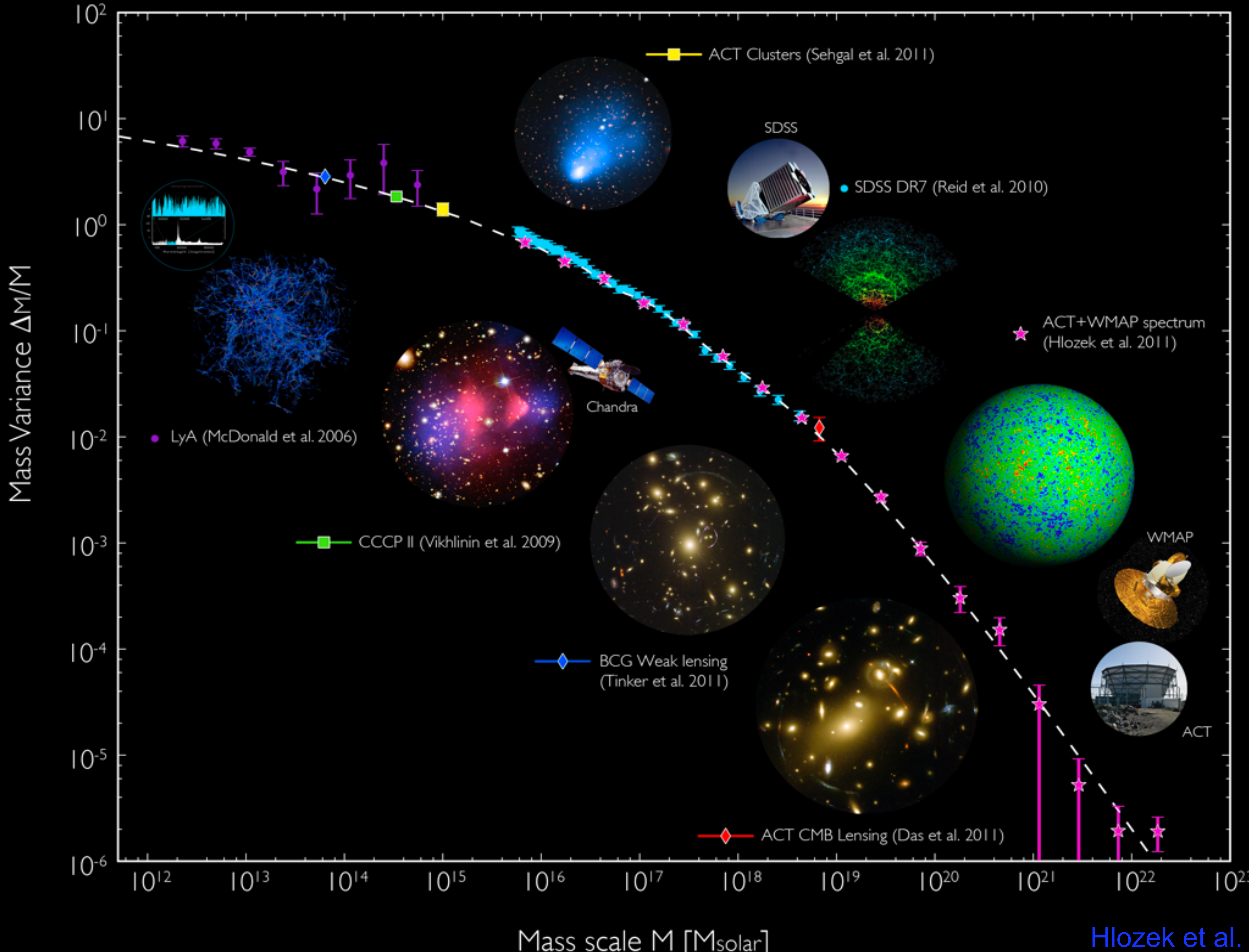
Dark Energy Ocean

Matter and Energy Content of the Universe

ΛCDM

Double Dark Theory

Matter Distribution Agrees with Double Dark Theory!

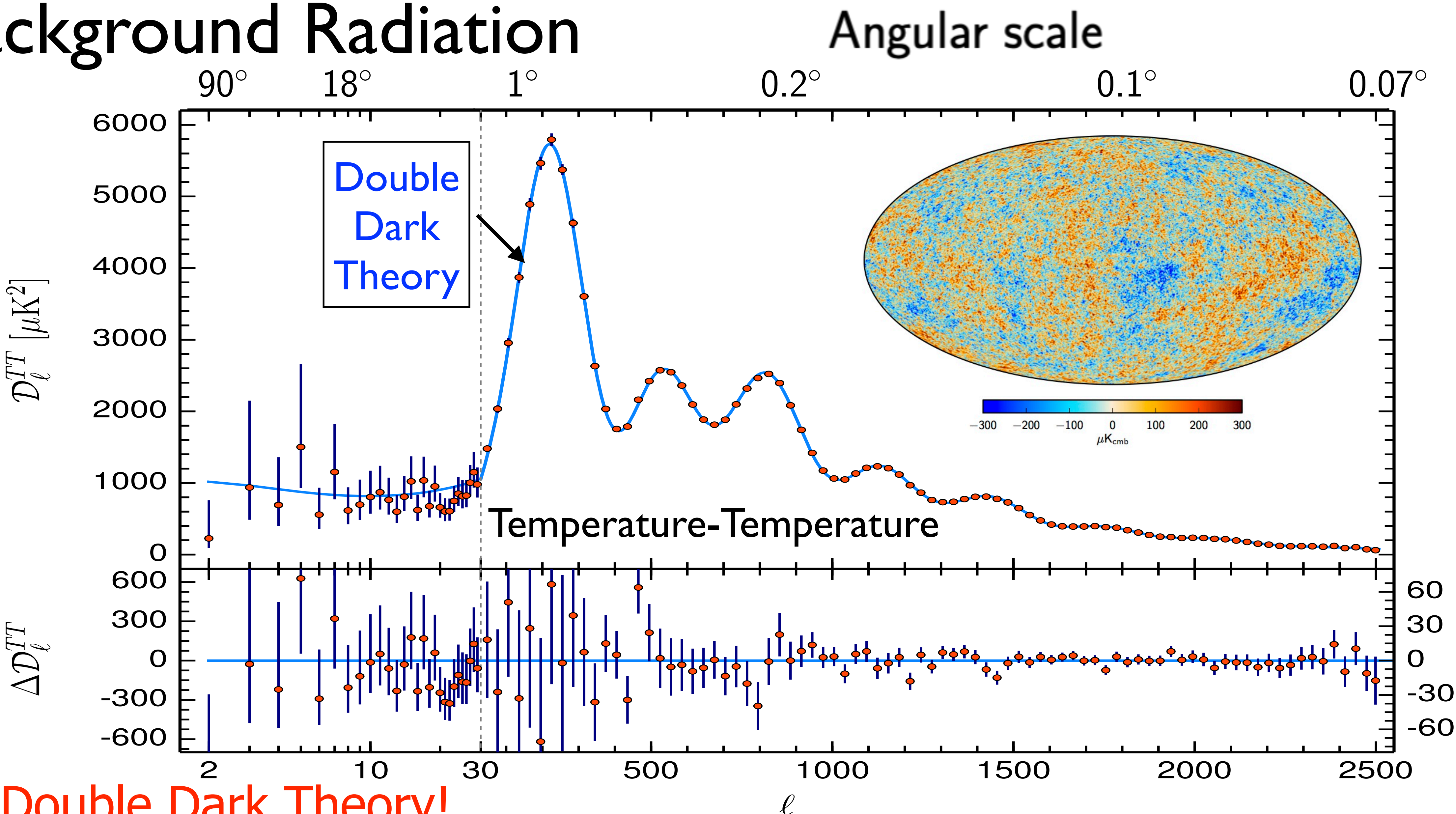


Hlozek et al. 2012

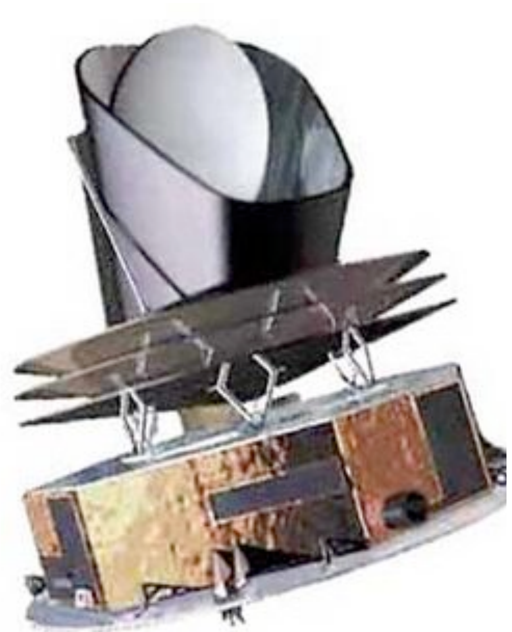
Cosmic Background Radiation

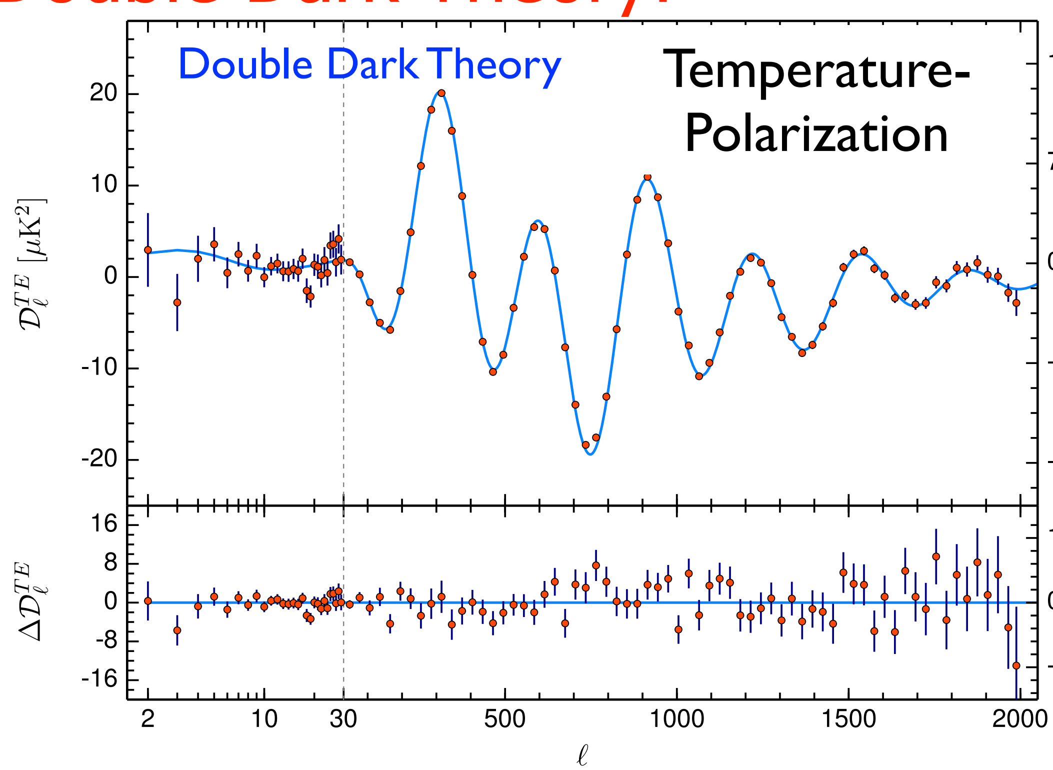
European Space Agency PLANCK Satellite Data

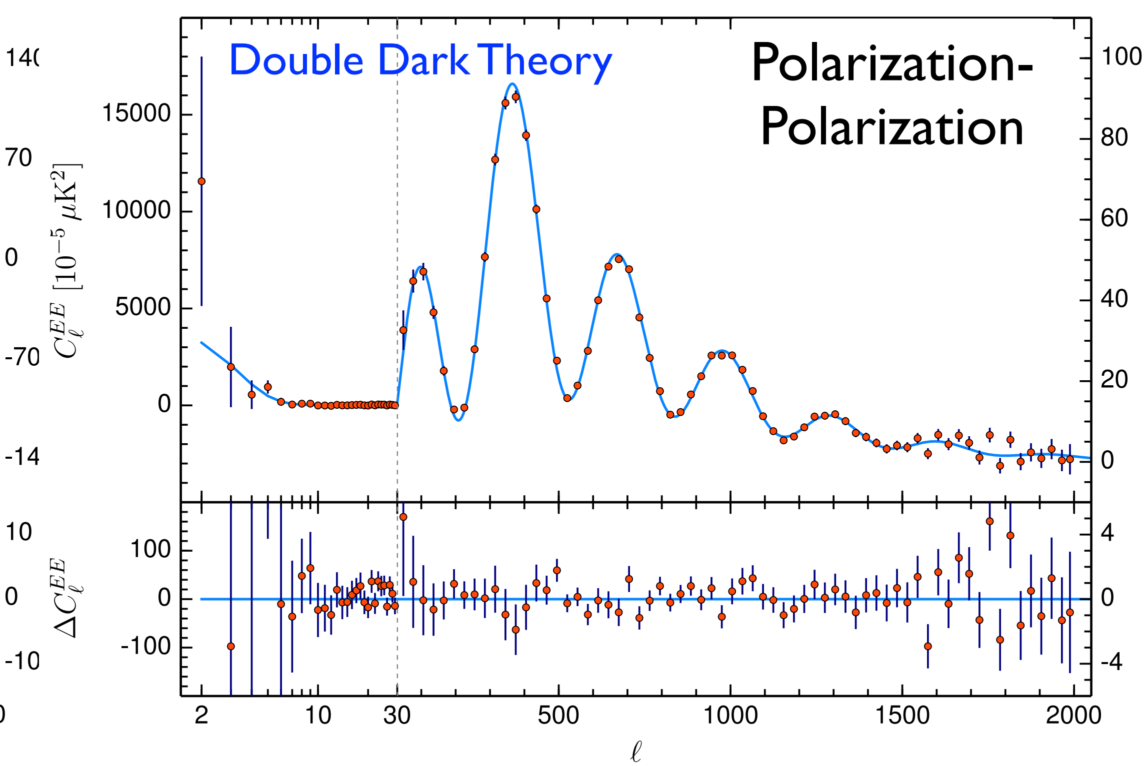
Released September 24, 2019



Agrees with Double Dark Theory!



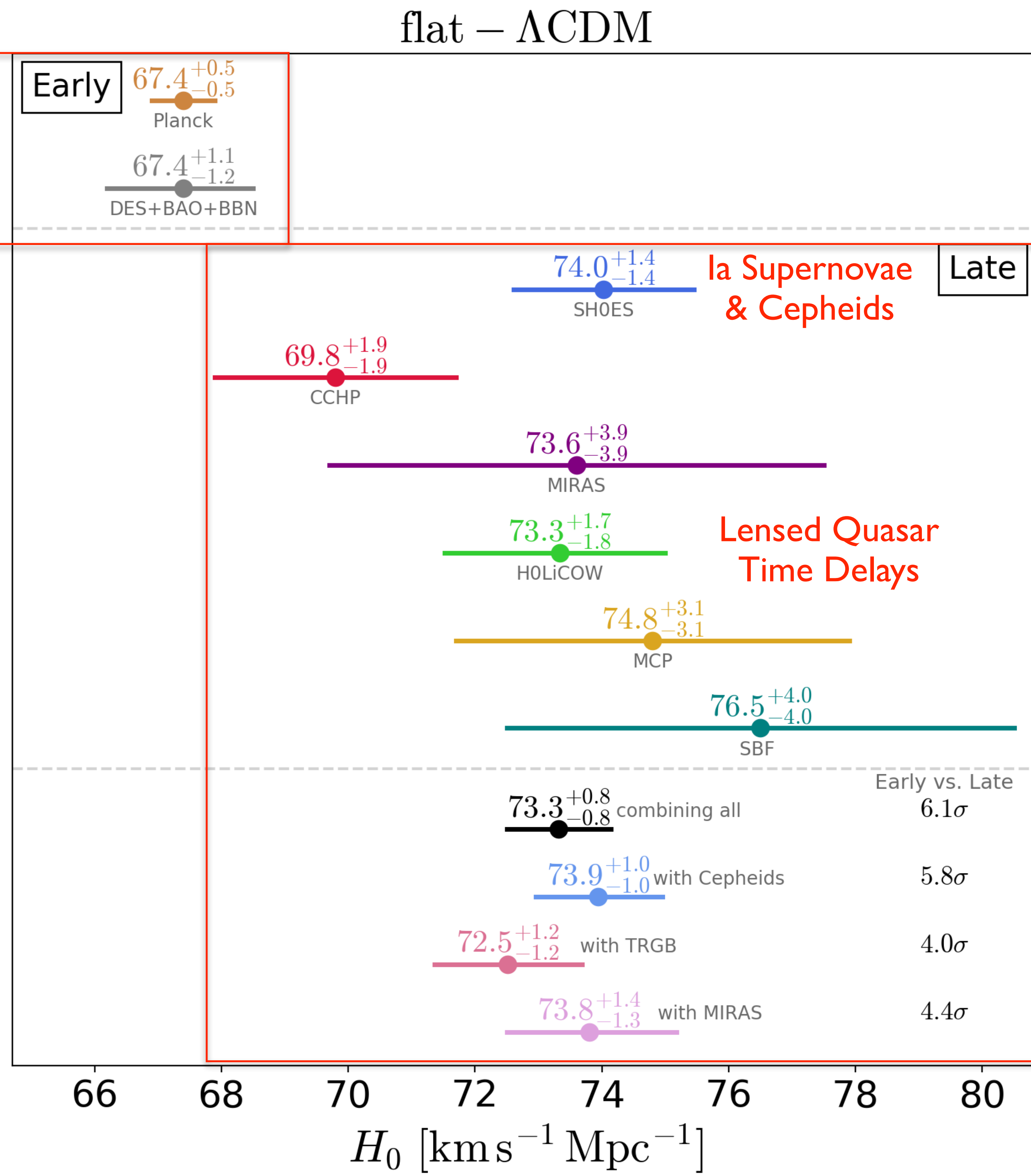




The Hubble parameter H_0 is the expansion rate of the universe today.

A possibly serious difficulty for ΛCDM is the **Hubble parameter tension:**

Cosmic Background Radiation plus ΛCDM gives H_0 = 67.4±0.5



Latest SH0ES paper Riess et al. 2022 gives 73.04±1.04

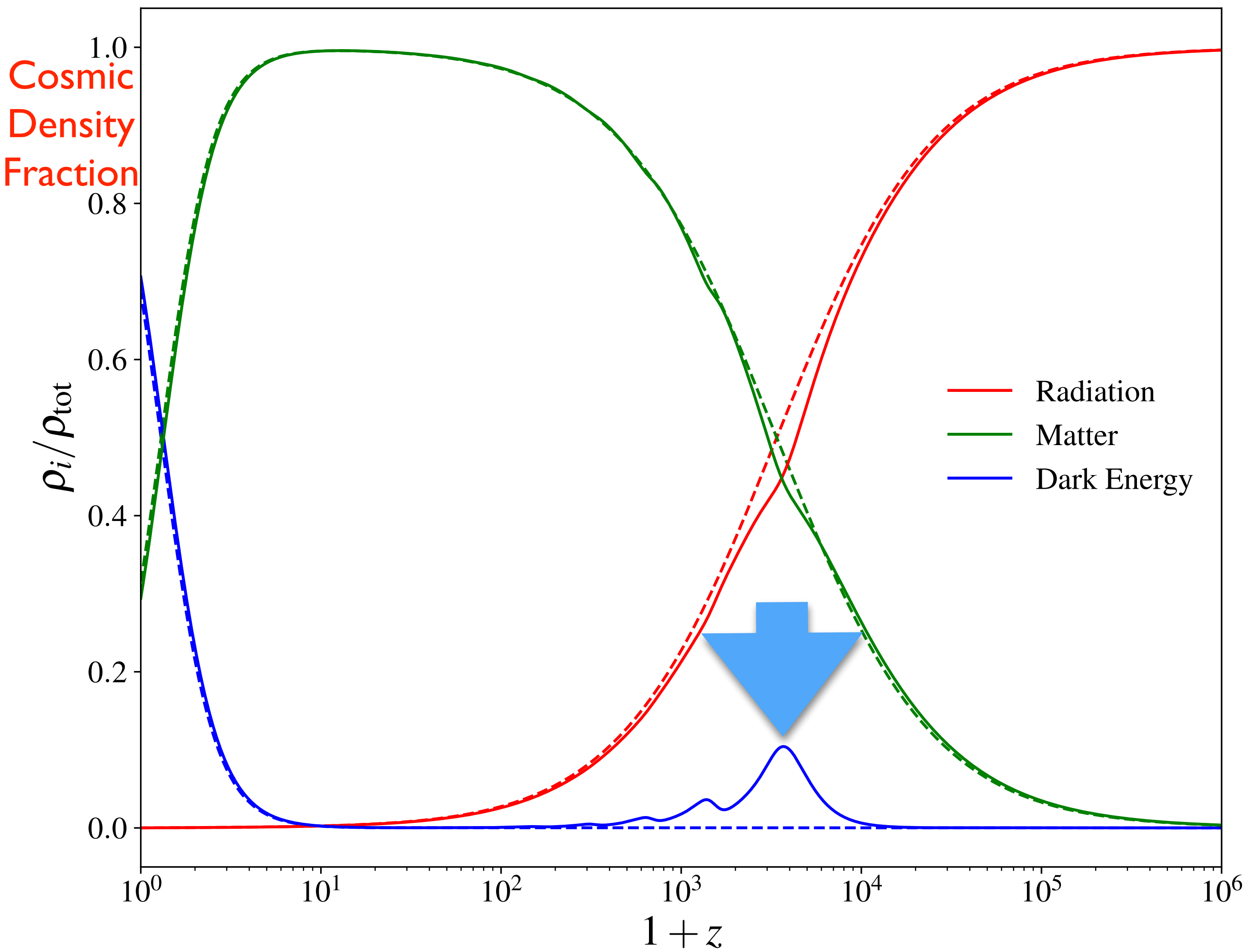
Final Pantheon+ paper Brout et al. 20 Oct 22: 73.5±1.1

Several kinds of nearby observations give H_0 = 73.3±0.8

Verde Treu Riess 2019

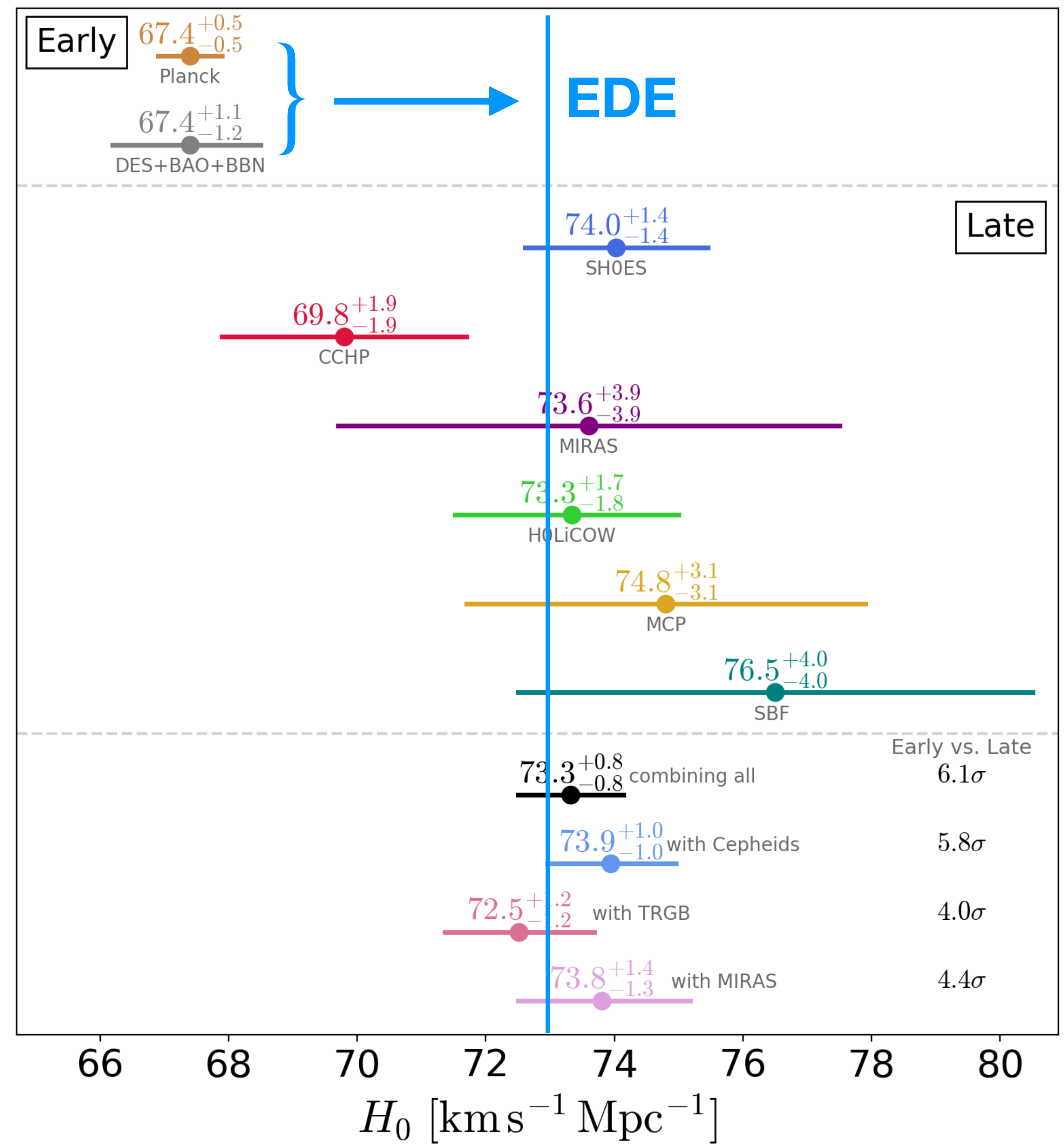
"Early Dark Energy," a brief period of ≲10% extra dark energy at z ~ 3500, could resolve this

A brief episode of Early Dark Energy about 50,000 years after the Big Bang modifies the ΛCDM extrapolation of H_0 and resolves the Hubble tension.



Solid curves represent the ΛCDM+EDE model, and dashed curves are standard ΛCDM with the Planck parameters. Our N-body simulations show that structure forms earlier than in standard ΛCDM, but the present-day universe is very similar.

Klypin, Poulin, Prada, Primack, et al. MNRAS 2021

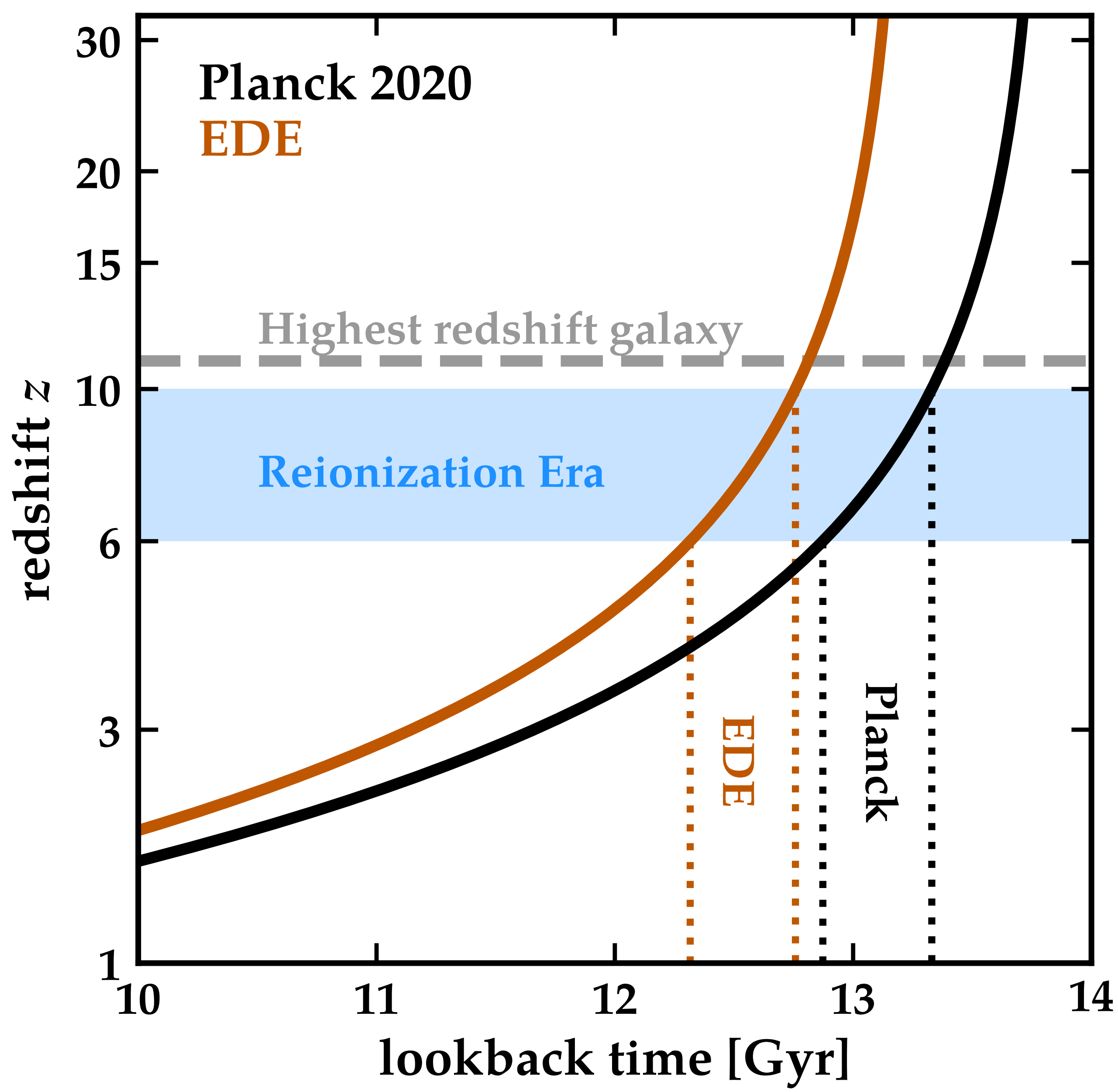


Early Dark Energy ==> age of the Universe is 13.2 Gyr rather than Planck ΛCDM's 13.8 Gyr.

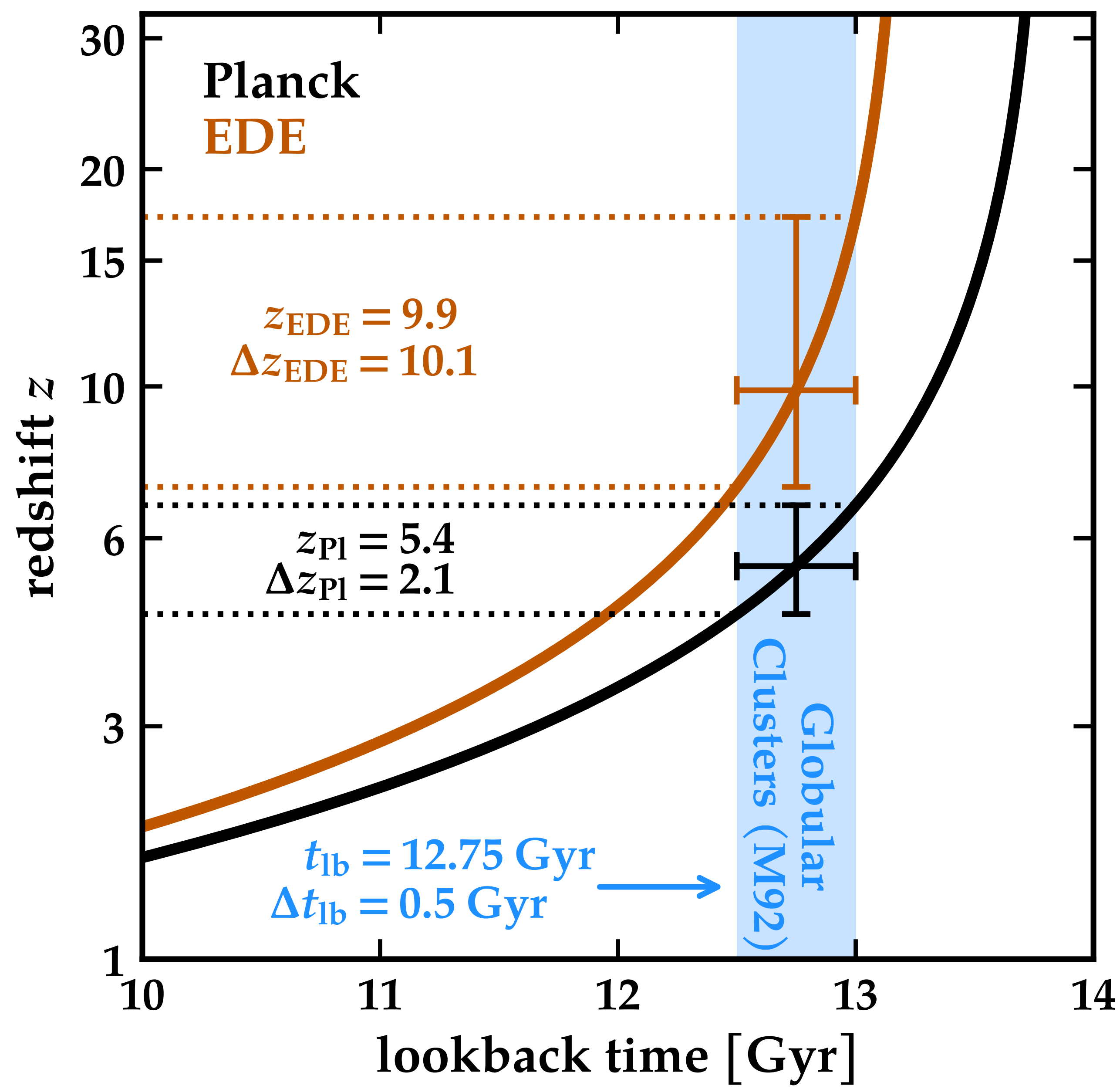
Early Dark Energy ==> age of the Universe t_0 ≈13.2 Gyr rather than Planck ΛCDM's 13.8 Gyr.

2021MNRAS.505.2764B by Michael Boylan-Kolchin and Dan Weisz shows that

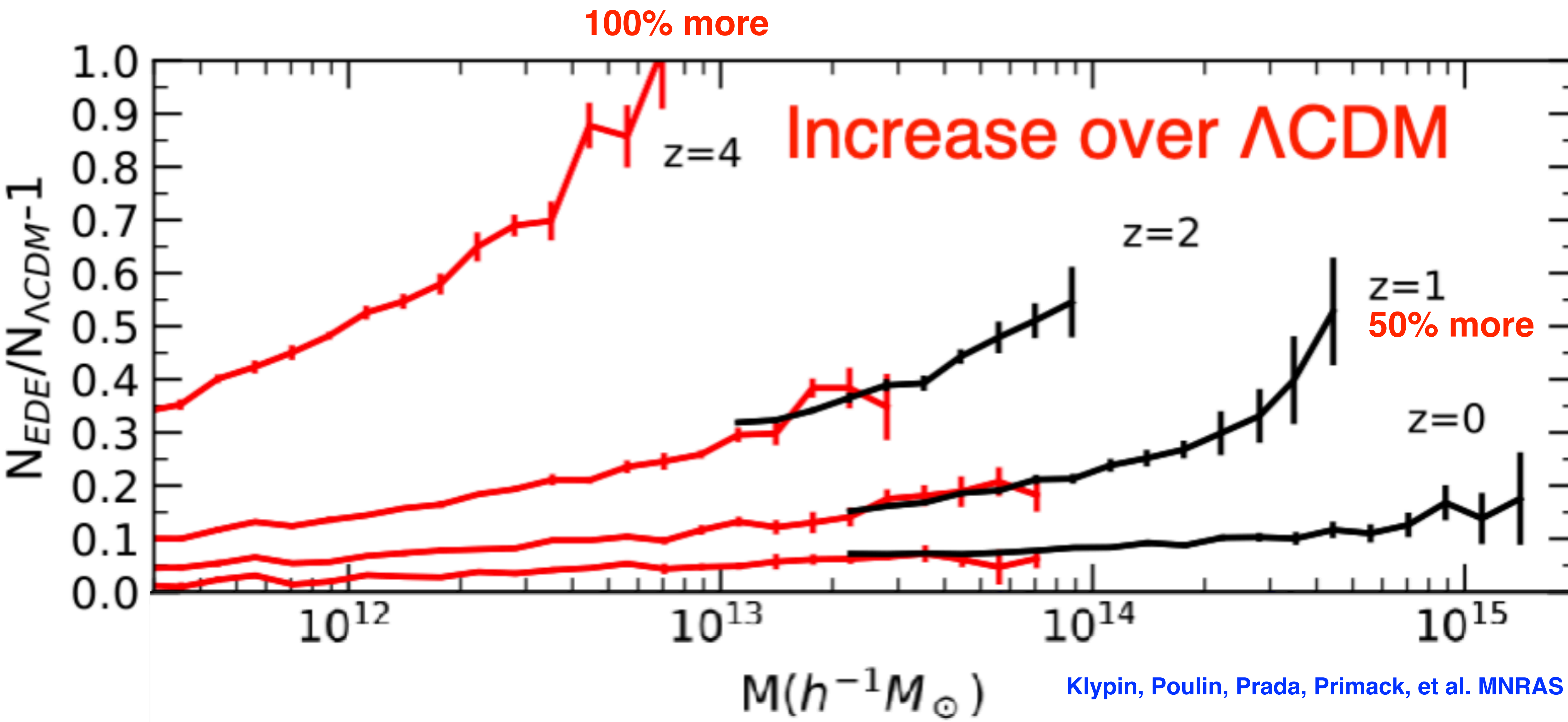
The Reionization Era at z ≈ 6 - 10 corresponds to different cosmic ages for Planck ΛCDM and EDE:



Formation of >12.5 Gyr old Globular Cluster M92 corresponds to different redshifts z_{EDE} ≈ 10 vs. z_{Planck} ≈ 5.4:



The **Early Dark Energy** cosmology results in significantly earlier structure formation than standard ΛCDM, for example increasing the abundance of cluster-mass halos at redshift z ~ 1 (7 Gyr ago) by ~ 50% and massive galaxies at z ~ 4 (1.5 Gyr after the Big Bang) by ~ 2x. EDE also changes galaxy clustering, including increasing the baryon acoustic oscillation length scale but decreasing the correlations of nearby galaxies.



Klypin, Poulin, Prada, Primack, et al. MNRAS 2021

The predicted increase in the number of galaxy clusters will be tested by eROSITA's all sky census of 100,000 galaxy clusters

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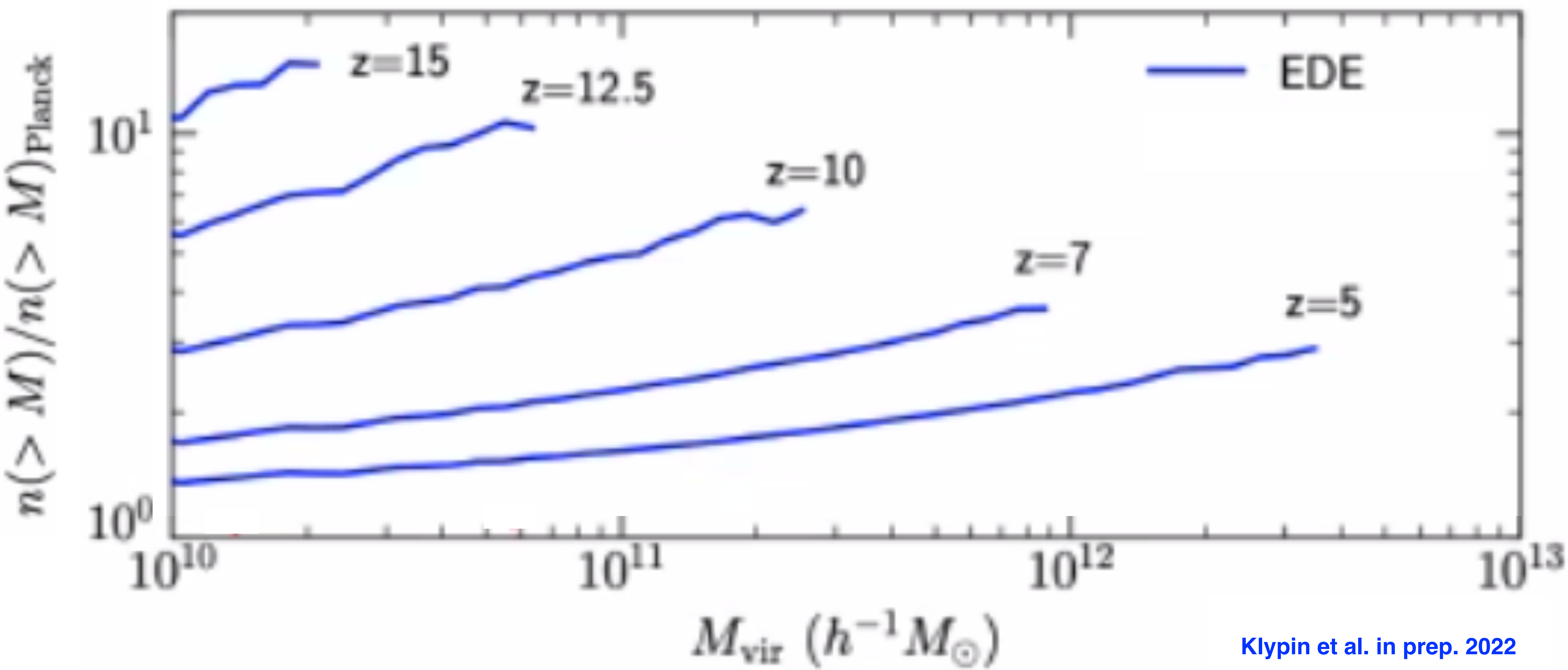
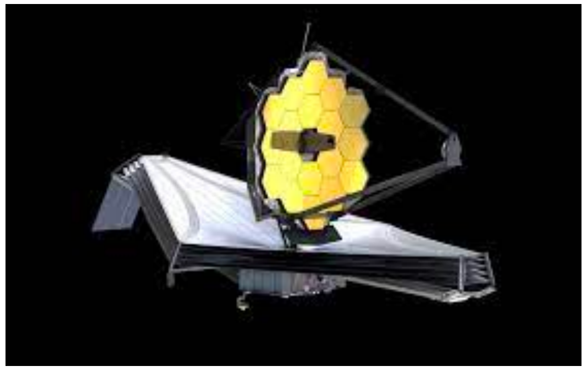


Klypin et al. in prep. 2022

The predicted increase in the number of galaxy clusters will be tested by eROSITA's all sky census of 100,000 galaxy clusters

The predicted increase in the number of massive galaxies in the early universe will be tested by James Webb Space Telescope



EDE is preferred by ACT and SPT ground-based CMB observations.

The Atacama Cosmology Telescope: Constraints on Pre-Recombination Early Dark Energy

J. Colin Hill et al. Phys Rev D 105.123536 (2022)

The early dark energy (EDE) scenario aims to increase the value of the Hubble constant (H0) inferred from cosmic microwave background (CMB) data over that found in the standard cosmological model (Λ CDM), via the introduction of a new form of energy density in the early Universe. … In this paper, we fit the EDE model to CMB data from the Atacama Cosmology Telescope (ACT) data release 4. We find that a combination of ACT, large-scale Planck TT (similar to WMAP), Planck CMB lensing , and BAO data prefers the existence of EDE at >99.7 % C .L …. From a model-selection standpoint, we find that **EDE is favored over ΛCDM by these data at roughly 3σ significance**. …

Hints of Early Dark Energy in Planck, SPT, and ACT data: New Physics or Systematics?

Tristan Smith et al. Phys Rev D 106.042536 (2022)

We investigate constraints on early dark energy (EDE) using ACT DR4, SPT-3G 2018, Planck polarization, and restricted Planck temperature data (at ℓ<650), **finding a 3.3σ preference for EDE over ΛCDM.** … More work will be necessary to establish whether these hints for EDE within CMB data alone are the sole results of systematic errors or an opening to new physics.

A Grounded Perspective on New Early Dark Energy using ACT, SPT, and BICEP/Keck

Juan S. Cruz, Florian Niedermann, & Martin S. Sloth arXiv:2209.02708

NEDE with a SH0ES prior is favored over ΛCDM by 4.7σ

Early versus Phantom Dark Energy, Self-Interacting, Extra, or Massive Neutrinos, Primordial Magnetic Fields, or a Curved Universe: An Exploration of Possible Solutions to the H_0 and σ_8 Problems

Helena García Escudero,[1,*] Jui-Lin Kuo,[1,†] Ryan E. Keeley,[2,‡] and Kevork N. Abazajian[1,§]

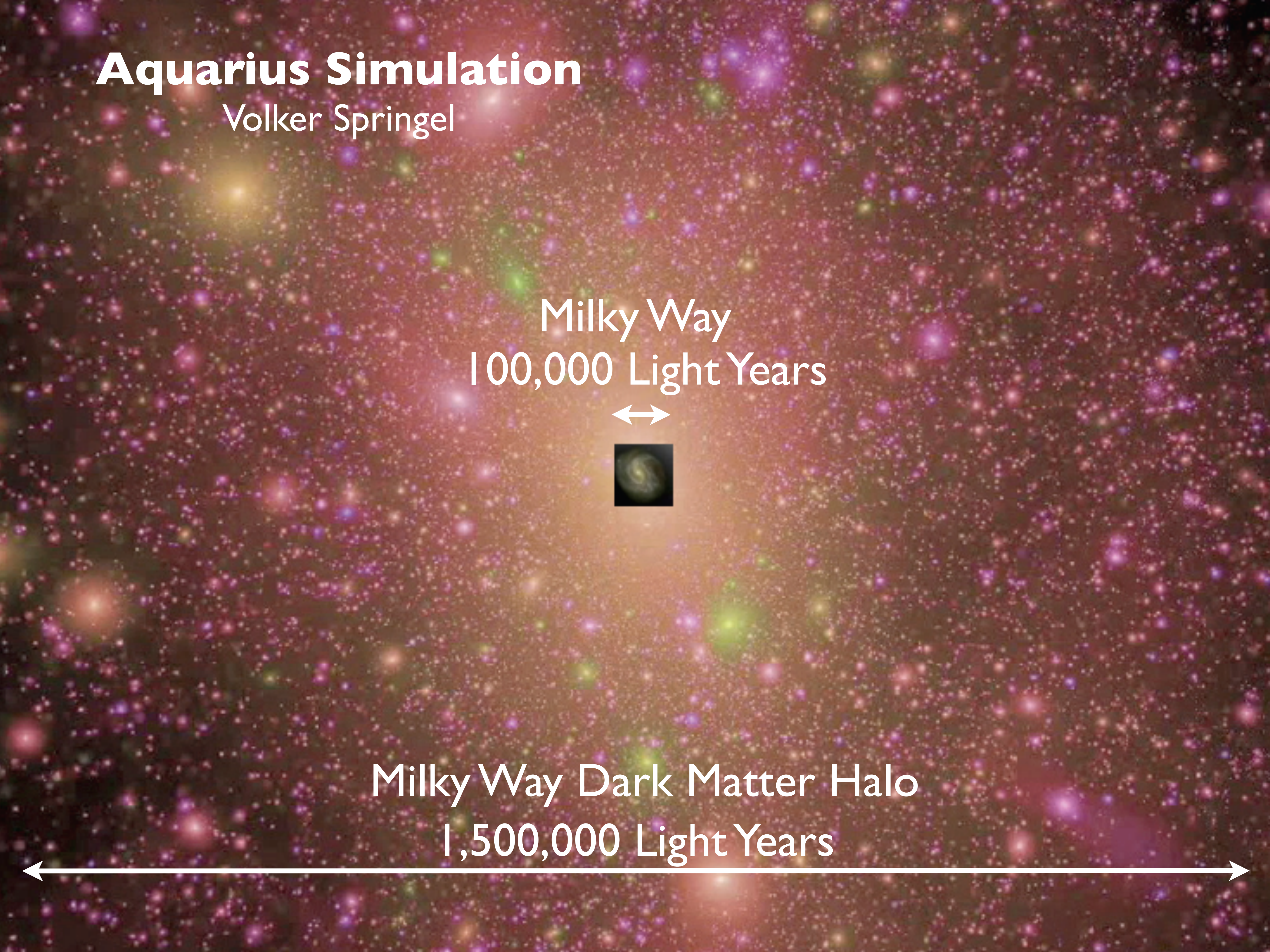
[1] *Department of Physics and Astronomy, University of California, Irvine, CA 92697-4575, USA*
[2] *Department of Physics, University of California, Merced, CA 95343, USA*

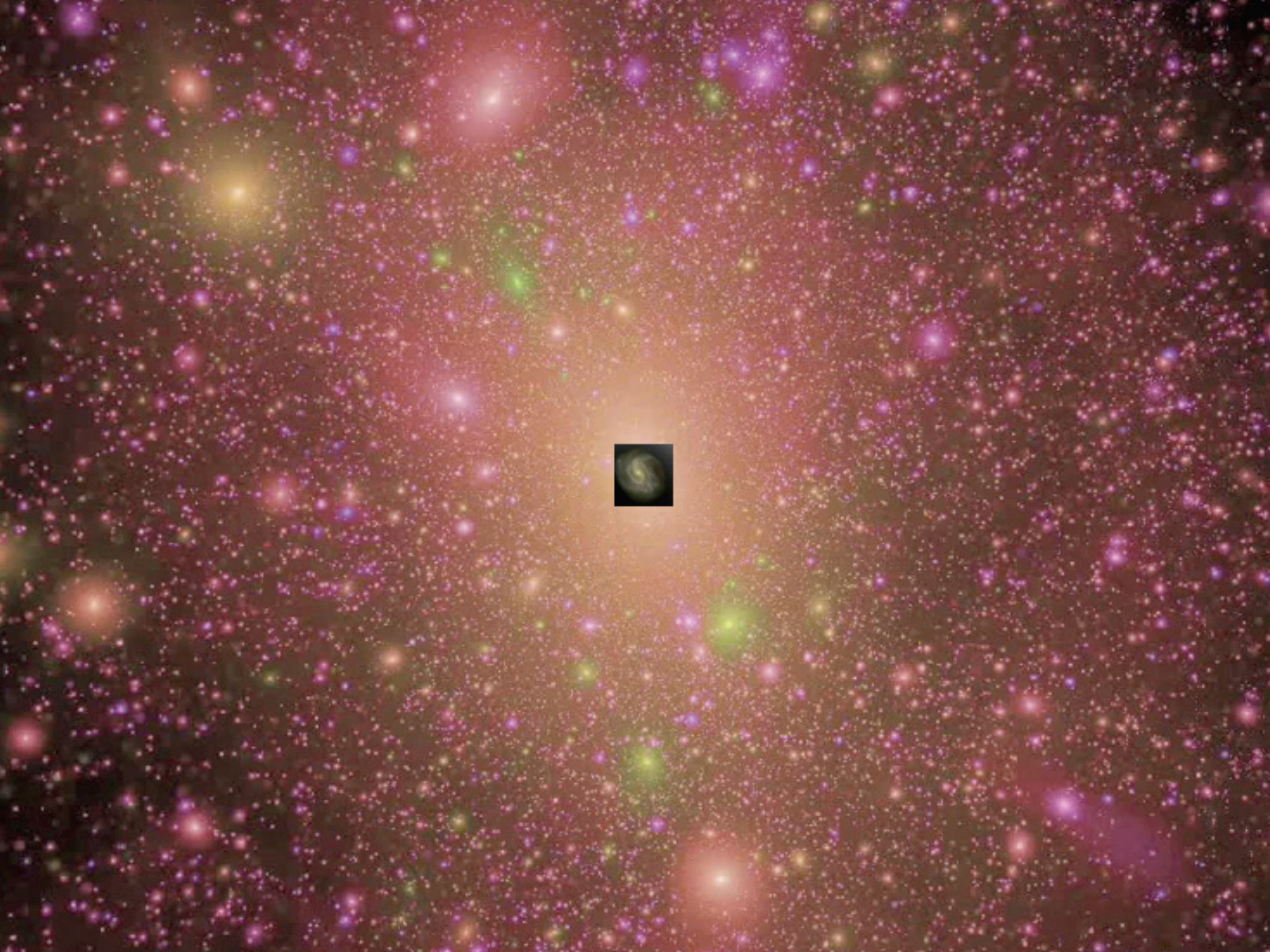
In this paper we explore the existing tensions in the local cosmological expansion rate, H_0, and amplitude of the clustering of large-scale structure at $8\,h^{-1}$Mpc, σ_8, as well as models that claim to alleviate these tensions. We consider seven models: evolving dark energy (wCDM), extra radiation ($N_{\rm eff}$), massive neutrinos, curvature, primordial magnetic fields (PMF), self-interacting neutrino models, and early dark energy (EDE). We test these models against three data sets that span the full range of measurable cosmological epochs, have significant precision, and are well-tested against systematic effects: the Planck 2018 cosmic microwave background data, the Sloan Digital Sky Survey baryon acoustic oscillation scale measurements, and the Pantheon catalog of Type Ia supernovae. We use the recent SH0ES H_0 measurement and several measures of σ_8 (and its related parameter $S_8 = \sigma_8\sqrt{\Omega_{\rm m}/0.3}$). We find that four models are above the "strong" threshold in Bayesian model selection, wCDM, $N_{\rm eff}$, PMF, and EDE. However, only EDE also relieves the H_0 tension in the full data sets to below 2σ. Contrarily, no model alleviates the S_8/σ_8 tension in the full data set, nor does better than ΛCDM in the combined case of both H_0 and S_8/σ_8 tensions.

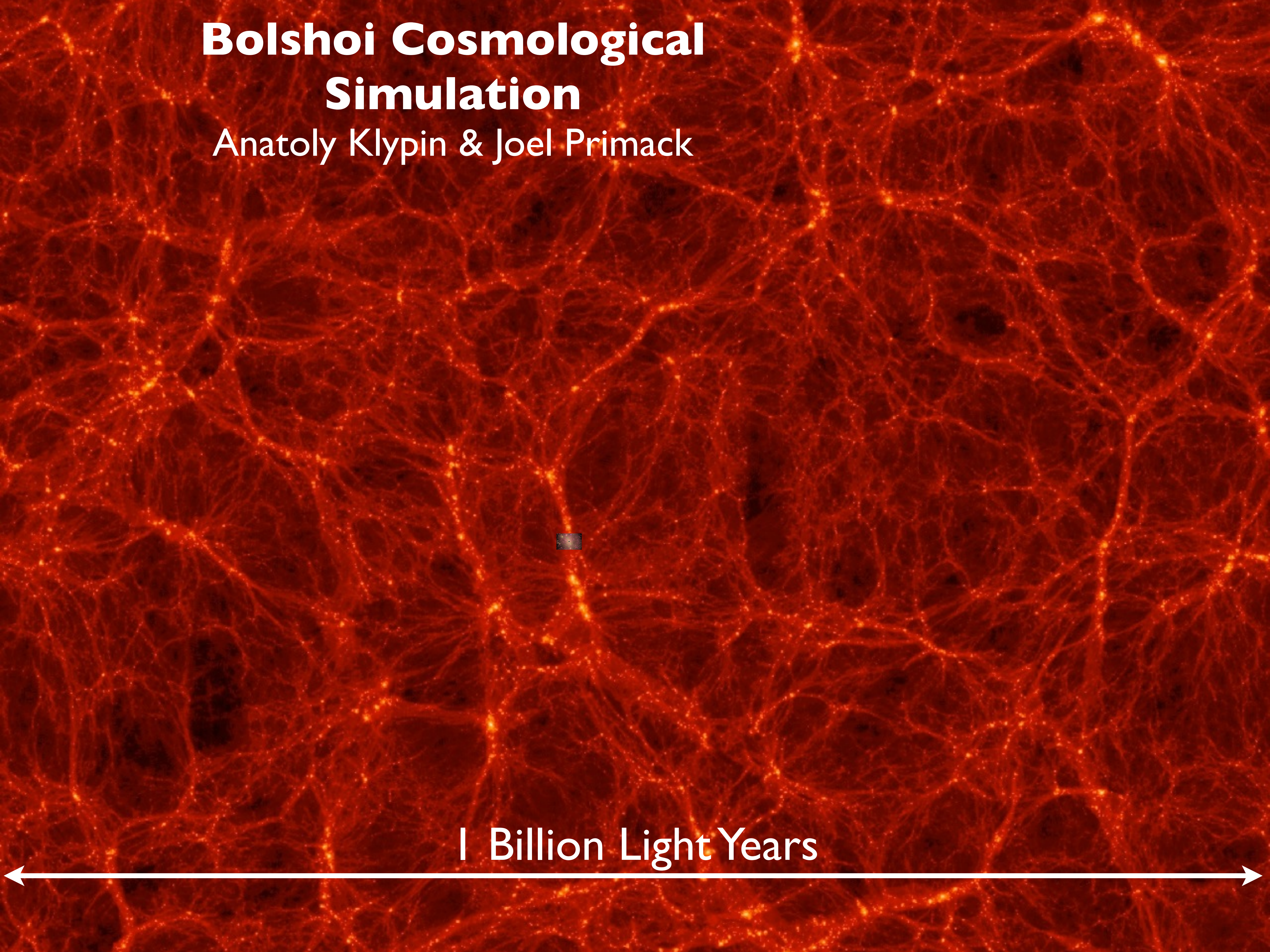
Helena García Escudero will give the UCSC CGI (Cosmology/Galaxies/IGM) Zoom seminar on this next Monday October 24 at 1-2 pm

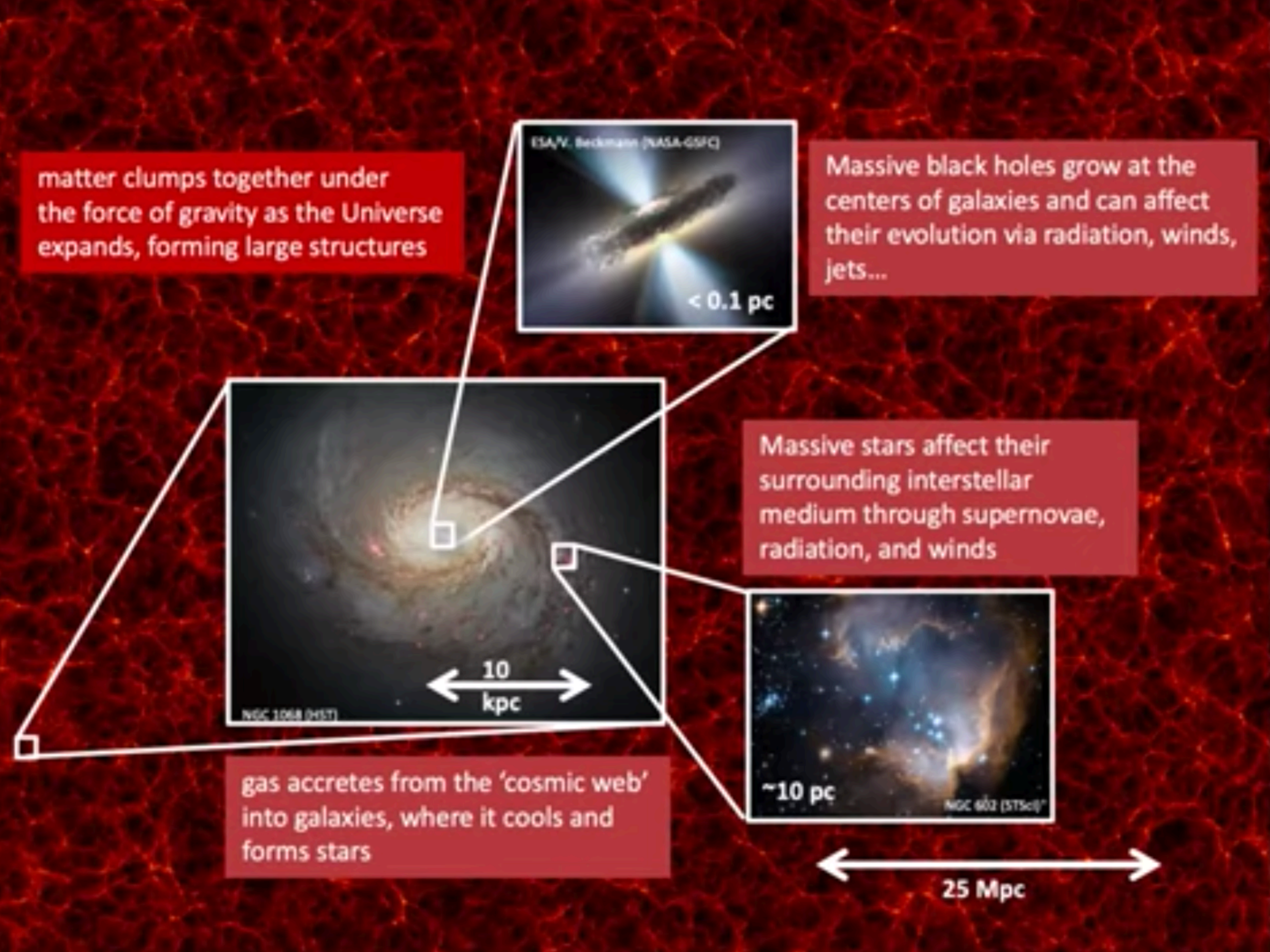
CGI Seminar Zoom invitation:
https://ucsc.zoom.us/j/92764426385?pwd=c1lVVmVCYmlUdHRMTXlMMXV6Q2NyQT09


COSMOLOGY
GALAXIES

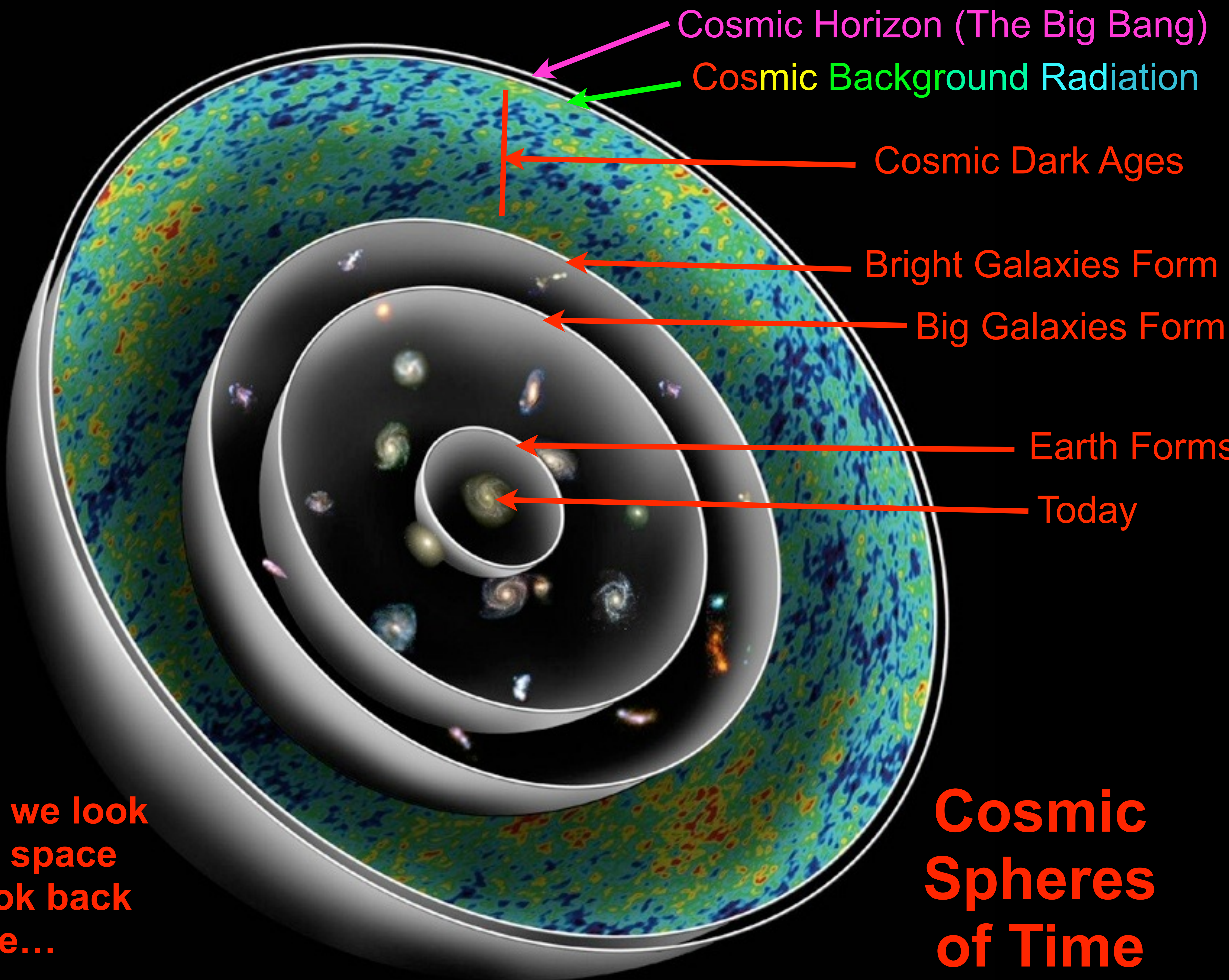

Aquarius Simulation
Volker Springel
Milky Way
100,000 Light Years
Milky Way Dark Matter Halo
1,500,000 Light Years




Bolshoi Cosmological Simulation
Anatoly Klypin & Joel Primack
1 Billion Light Years



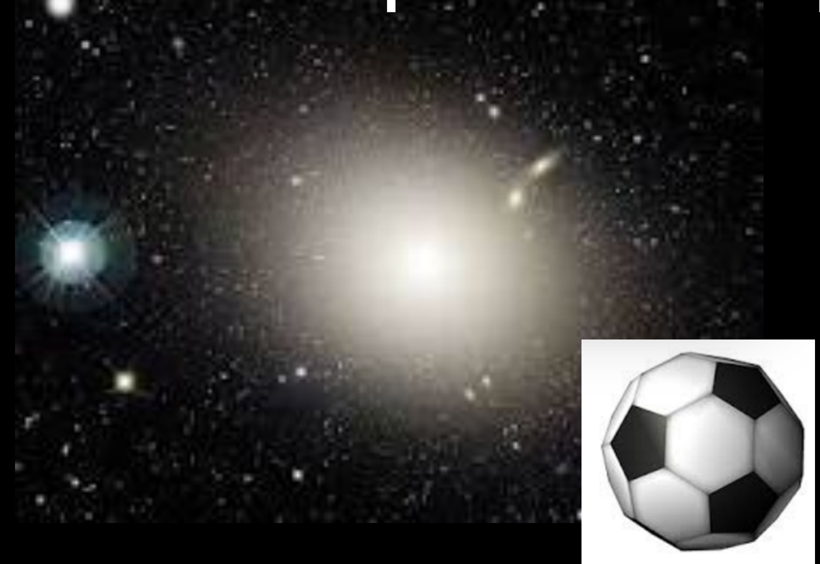
matter clumps together under the force of gravity as the Universe expands, forming large structures
ESA/V. Beckmann (NASA-GSFC)
< 0.1 pc
Massive black holes grow at the centers of galaxies and can affect their evolution via radiation, winds, jets...
Massive stars affect their surrounding interstellar medium through supernovae, radiation, and winds
10 kpc
NGC 1068 (HST)
~10 pc
NGC 602 (STScI)
gas accretes from the 'cosmic web' into galaxies, where it cools and forms stars
25 Mpc



When we look out in space we look back in time…

Cosmic Spheres of Time

Almost all the stars today are in large galaxies like our Milky Way. Nearby large galaxies are disk galaxies like our galaxy or big balls of stars called elliptical galaxies. But most galaxies in the early universe didn't look anything like our Milky Way. Many of them are pickle-shaped and clumpy.



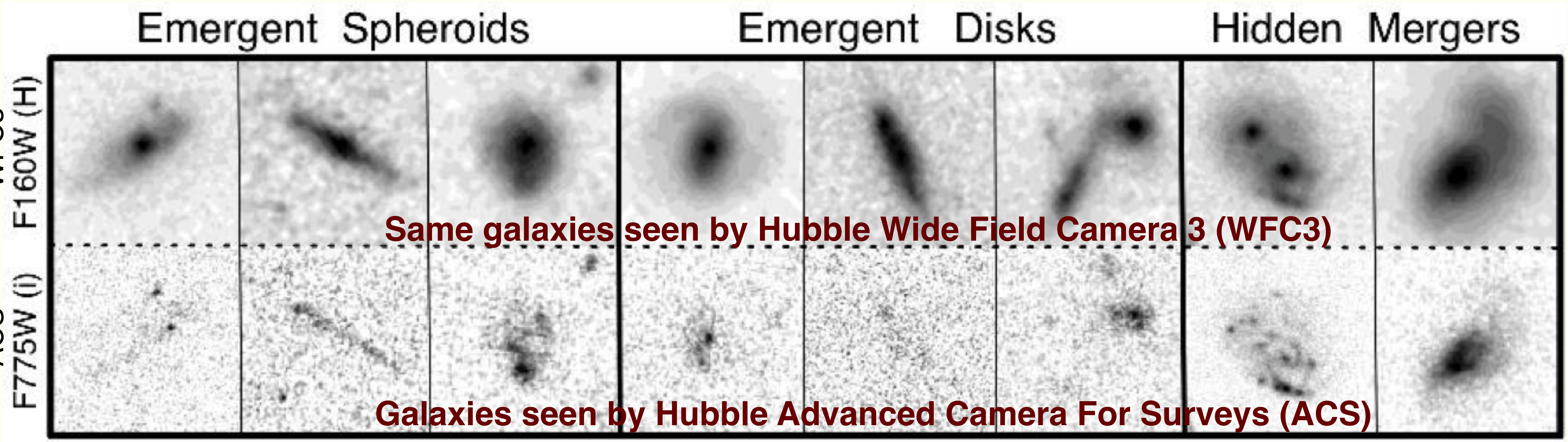
We are just now figuring out how galaxies form and evolve with the help of big ground-based telescopes, and Hubble, Webb, and other space telescopes that let us see radiation clearly without interference from earth’s atmosphere.

Astronaut Andrew Feustel installing WFC3 on the last visit to HST in 2009

The infrared capabilities of HST Wide Field Camera 3 allow us to see the full stellar populations of forming galaxies out to redshift $z \sim 2$ (~10 billion years ago)

The CANDELS Survey shows shapes of $z \lesssim 2.5$ galaxies

candels.ucolick.org



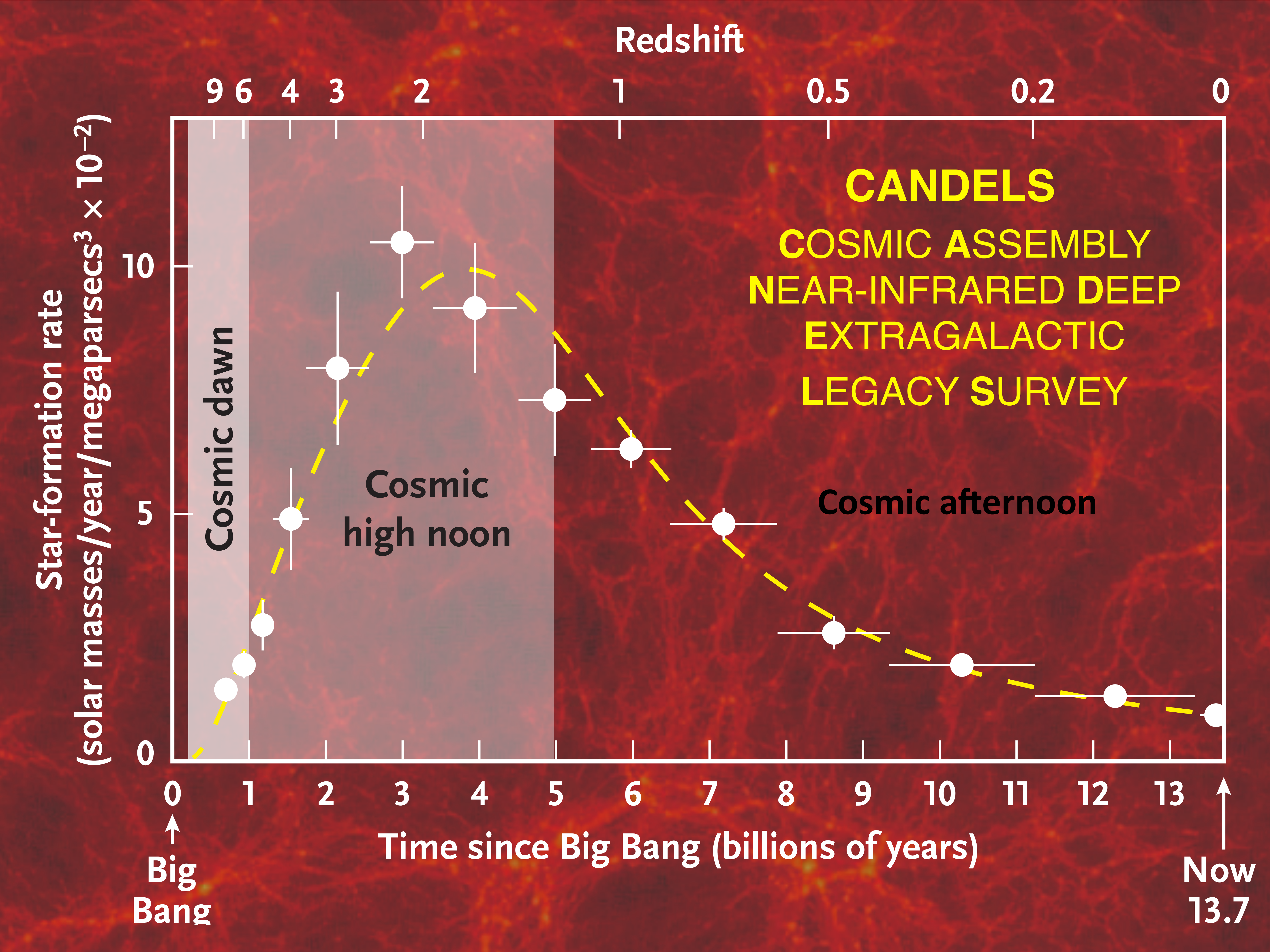
CANDELS: A Cosmic Odyssey

(blue 0.4 μm)(1+z) = 1.6 μm @ z = 3

(orange 0.6 μm)(1+z) = 1.6 μm @ z = 1.7

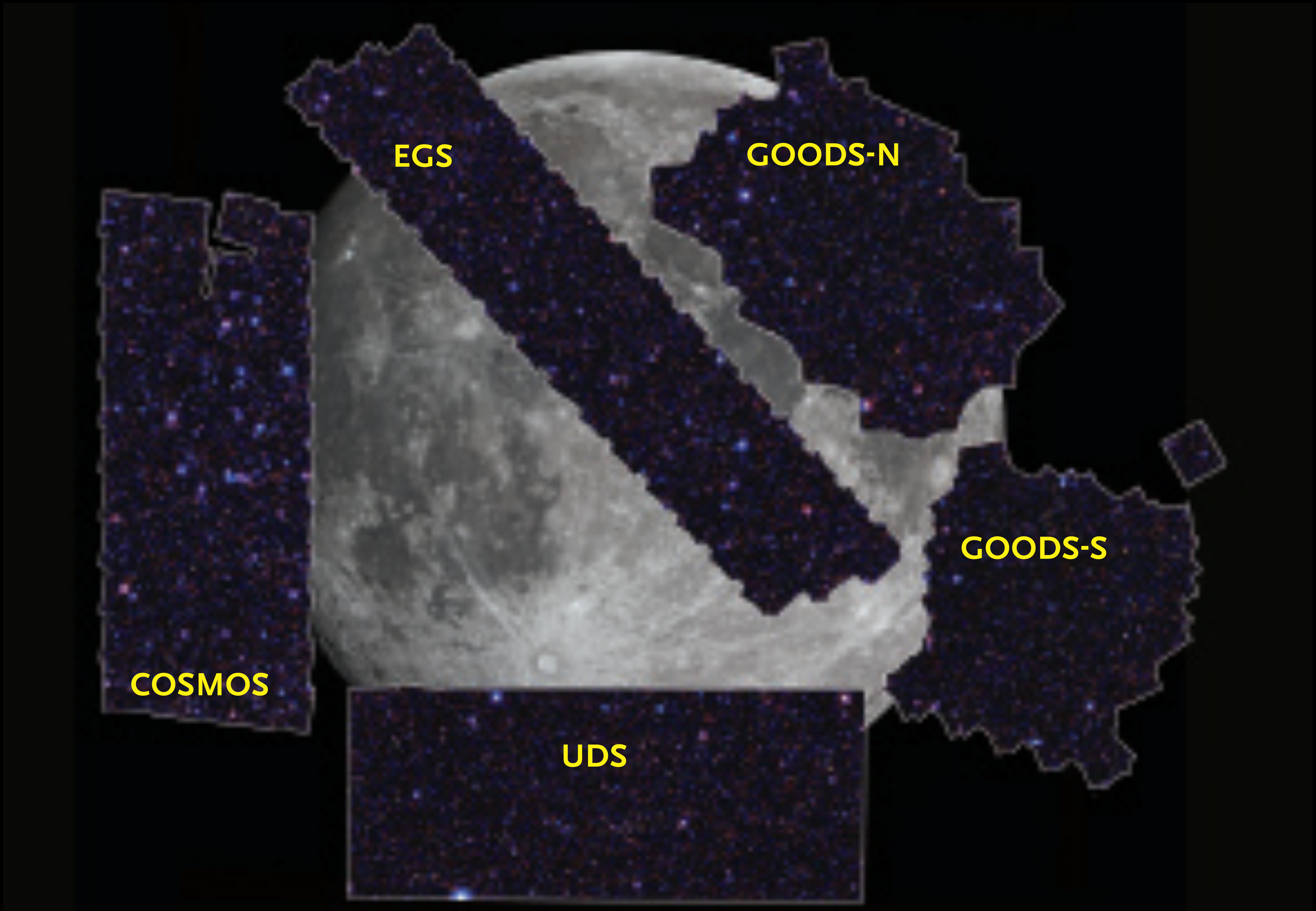
CANDELS is a powerful imaging survey of the distant Universe being carried out with two cameras on board the Hubble Space Telescope.

- CANDELS is the largest project in the history of Hubble, with 902 assigned orbits of observing time. This is the equivalent of four months of Hubble time if executed consecutively, but in practice CANDELS will take three years to complete (2010-2013).
- The core of CANDELS is the revolutionary near-infrared WFC3 camera, installed on Hubble in May 2009. WFC3 is sensitive to longer, redder wavelengths, which permits it to follow the stretching of lightwaves caused by the expanding Universe. This enables CANDELS to detect and measure objects much farther out in space and nearer to the Big Bang than before. CANDELS also uses the visible-light ACS camera, and together the two cameras give unprecedented panchromatic coverage of galaxies from optical wavelengths to the near-IR.
- CANDELS will exploit this new lookback power to construct a "cosmic movie" of galaxy evolution that follows the life histories of galaxies from infancy to the present time. This work will cap Hubble's revolutionary series of discoveries on cosmic evolution and bequeath a legacy of precious data to future generations of astronomers.

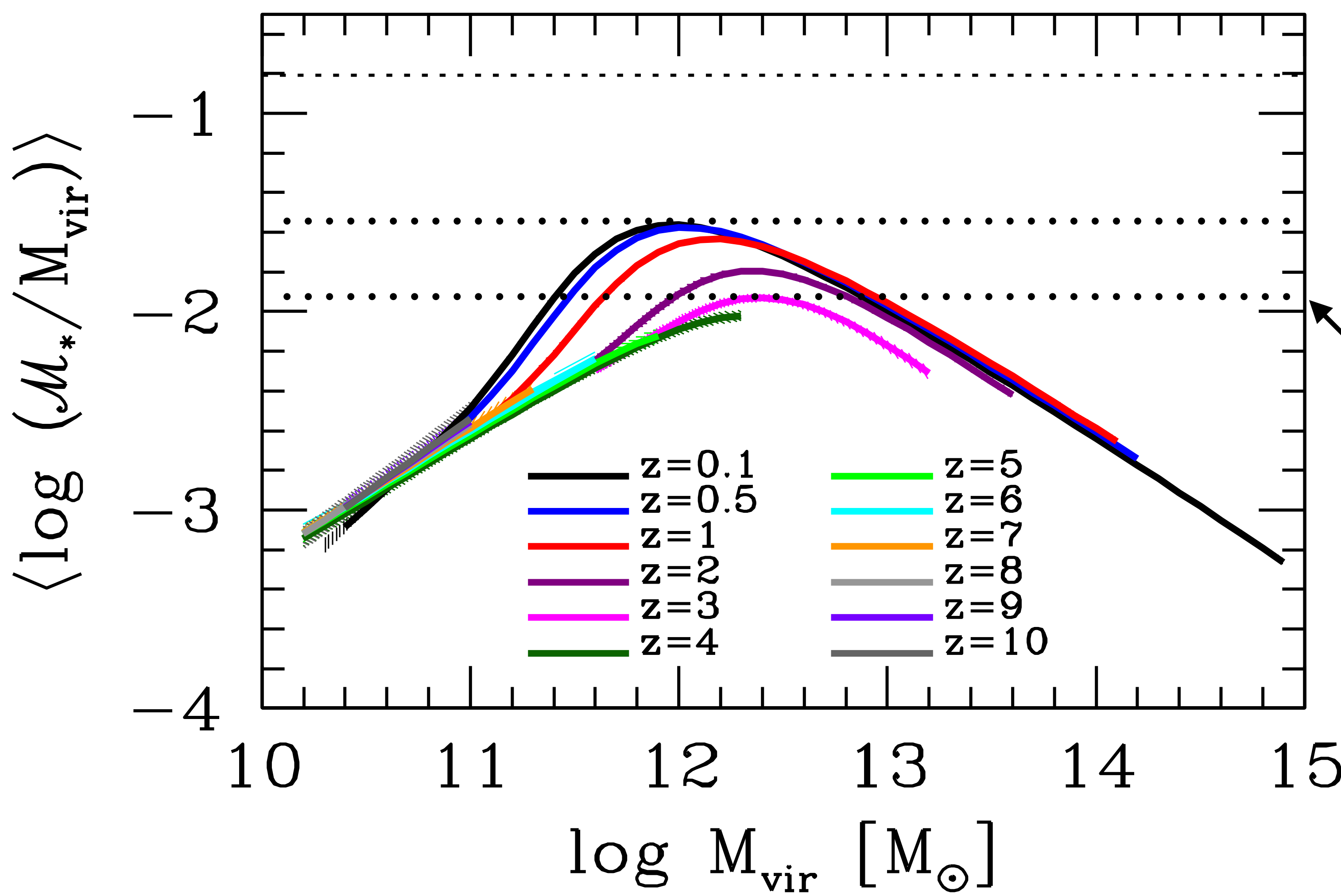


Redshift
9
6
4
3
2
1
0.5
0.2
0
Star-formation rate (solar masses/year/megaparsecs³ × 10⁻²)
10
5
0
Cosmic dawn
Cosmic high noon
Cosmic afternoon
CANDELS
COSMIC ASSEMBLY NEAR-INFRARED DEEP EXTRAGALACTIC LEGACY SURVEY
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Time since Big Bang (billions of years)
Big Bang
Now 13.7

ALL 5 CANDELS FIELDS COVERED ABOUT THE AREA OF THE FULL MOON



Galaxy Stellar Mass, Baryon Mass, and Halo Mass



$$\frac{\rho_{baryon}}{\rho_{total}} = \frac{5\%}{30\%} = 0.17$$

$$\frac{\text{Stellar Mass}}{\text{Halo Mass}} \lesssim 0.04$$

at high redshifts $\varepsilon \lesssim 0.1$

Rodriguez-Puebla, Primack, Avila-Rees, Faber 2017

$$\frac{\rho_{baryon}}{\rho_{total}} = \frac{5\%}{30\%} = 0.17 \quad \text{but} \quad \frac{\text{Stellar Mass}}{\text{Halo Mass}} \lesssim 0.04 \quad \text{and} \quad \varepsilon \equiv \frac{\text{Stellar Mass}}{\text{Baryon Mass}} \lesssim 0.25$$

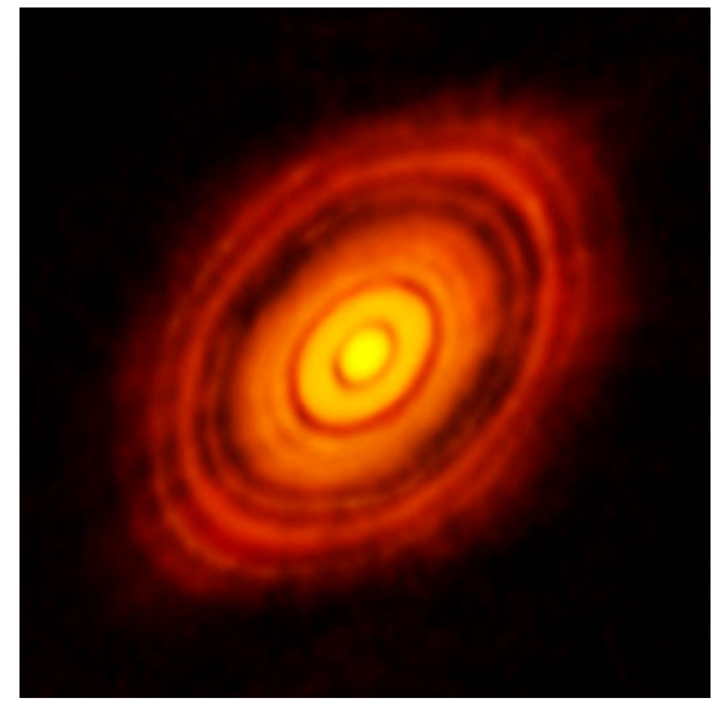
at high redshifts $\varepsilon \lesssim 0.1$

Galaxies turn at most about 25% of their gas into stars, less than that for high or low mass galaxies or at high redshifts. That's why stars are only about 0.5% of cosmic density, while ordinary matter is 5% of cosmic density.

Do Galaxies Start as Disks?

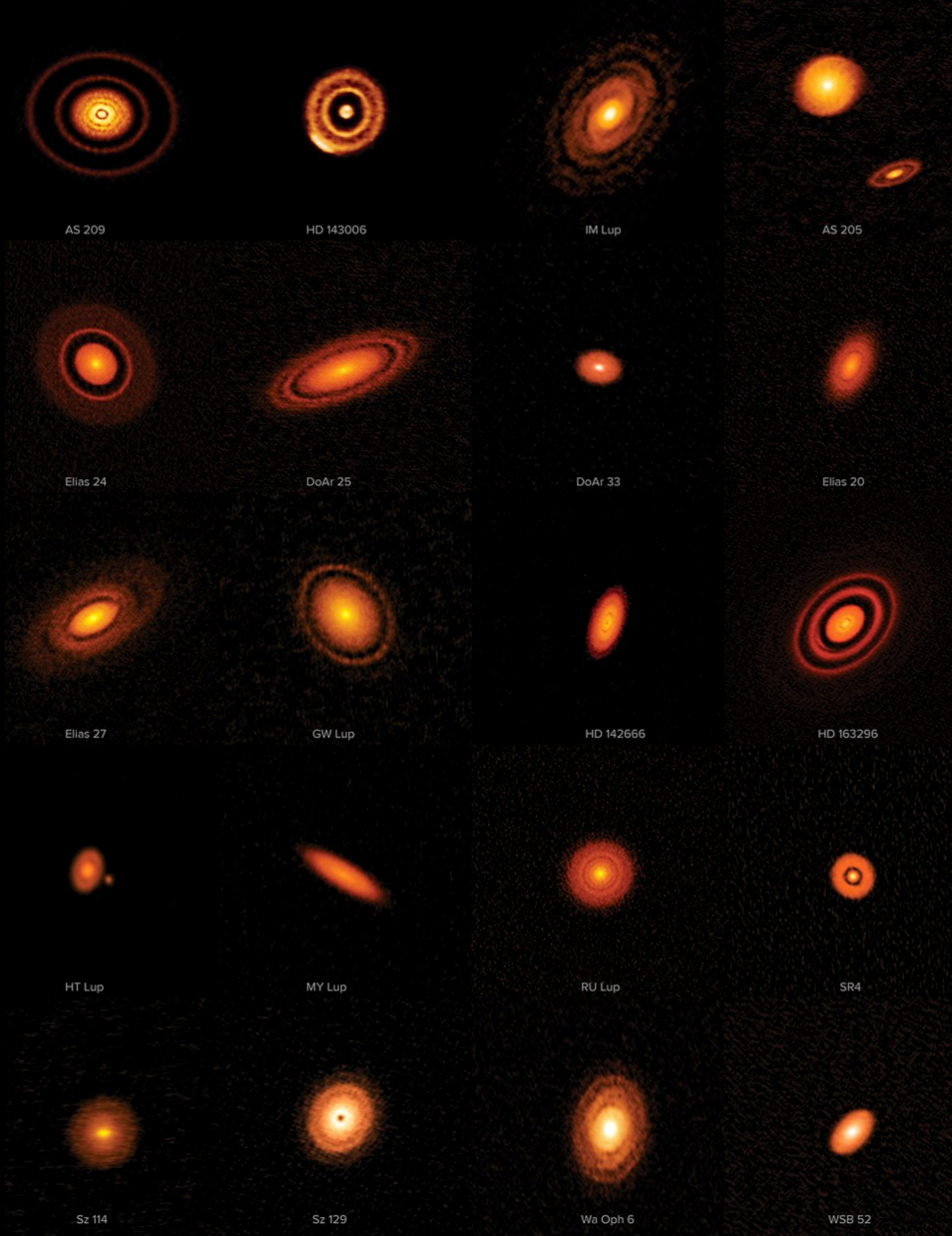
Newton's laws explained why planetary orbits are elliptical, but not why the planetary orbits in the solar system are nearly circular, in the same plane, and in the same direction as the sun rotates.

Laplace explained this as a consequence of angular momentum conservation as the sun and planets formed in a cooling and contracting protoplanetary gas cloud that formed a disk— like this one:



ALMA image of HL Tauri

20 Protoplanetary Disks from ALMA's High Angular Resolution Project DSHARP (2019)



Do Galaxies Start as Disks?

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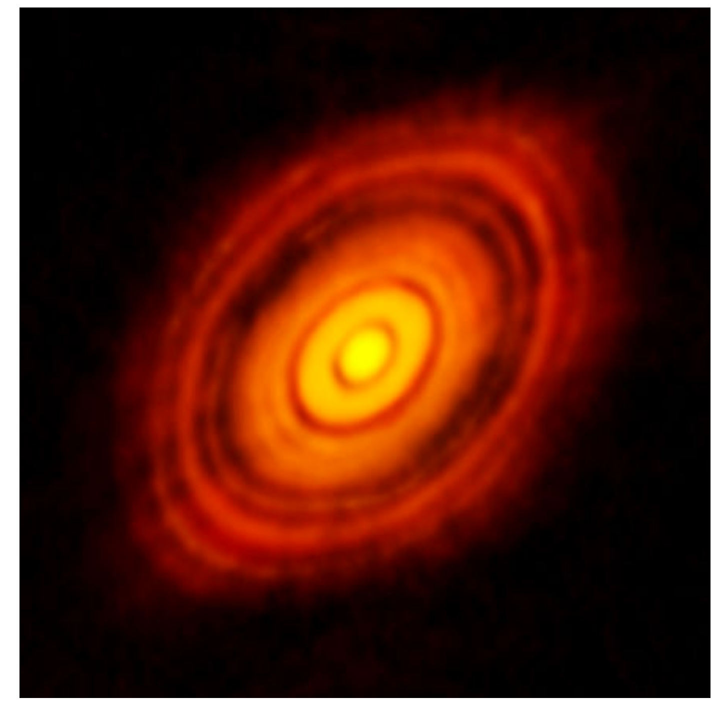


ALMA image of HL Tauri

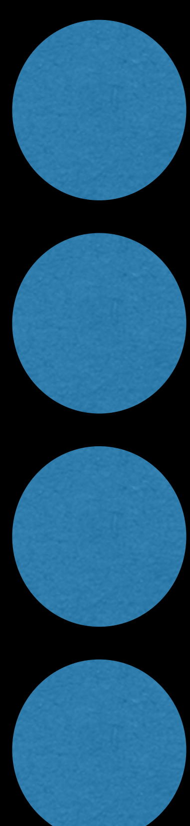
For similar reasons, many astronomers once thought that galaxies would start as disks. But Hubble Space Telescope images of forming galaxies instead show that most forming galaxies are prolate – that is, pickle-shaped. As we will see, this is a consequence of most galaxies forming in prolate dark matter halos oriented along massive dark matter filaments.

Nearby large galaxies are mostly spheroids and disks — but they start out looking more like pickles.

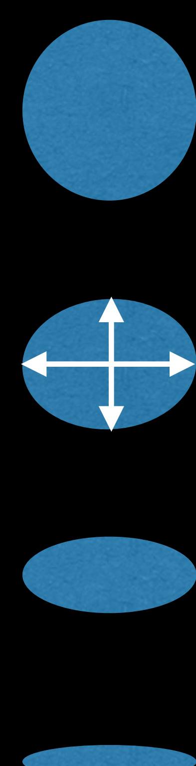
How Can We Determine 3D Galaxy Shapes from 2D Telescope Images? Statistics!

We see galaxies in all possible orientations

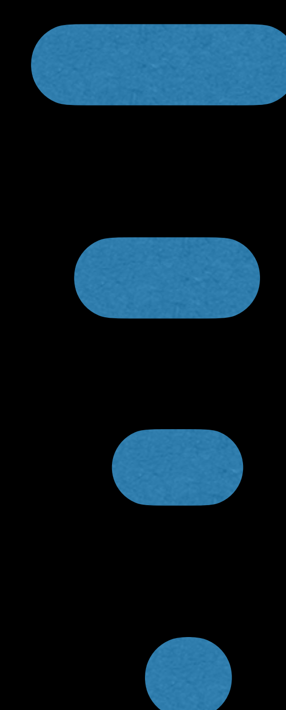
Let's orient them with their long axes horizontal and see the short/long axis ratio distribution



Spheroidal galaxies always have large axis ratio



Disk galaxies have even distribution of axis ratios



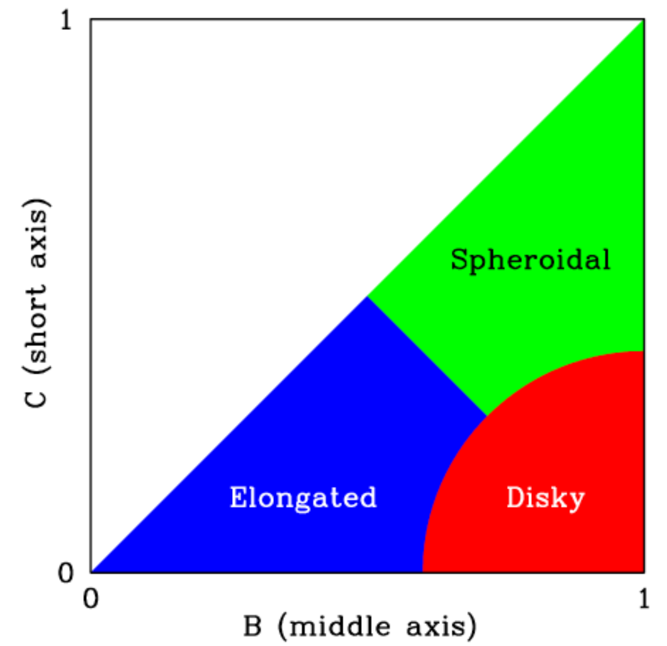
Prolate galaxies have small axis ratios except end-on

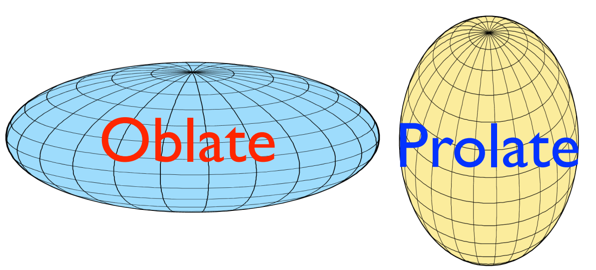
The Evolution of Galaxy Shapes in CANDELS: from Prolate to Oblate

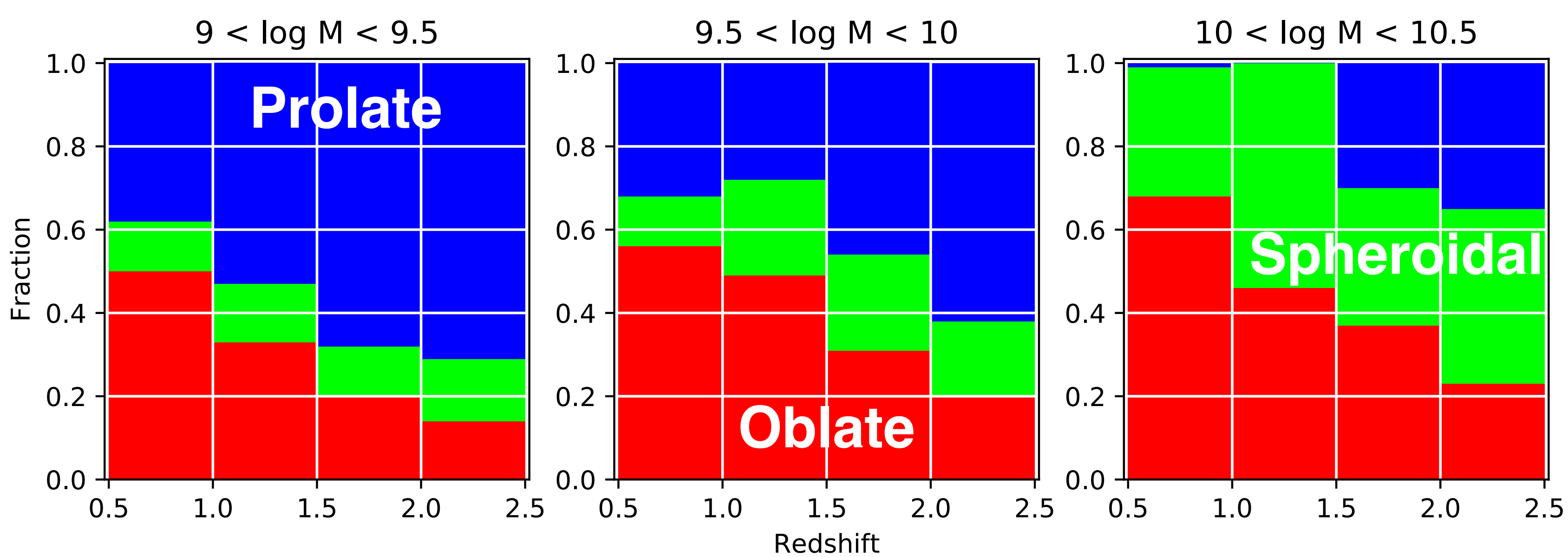
Haowen Zhang, Joel R. Primack, S. M. Faber, David C. Koo, Avishai Dekel, Zhu Chen, Daniel Ceverino, Yu-Yen Chang, Jerome J. Fang, Yicheng Guo, Lin Lin, and Arjen van der Wel MNRAS 484, 5170 (2019)

ABSTRACT

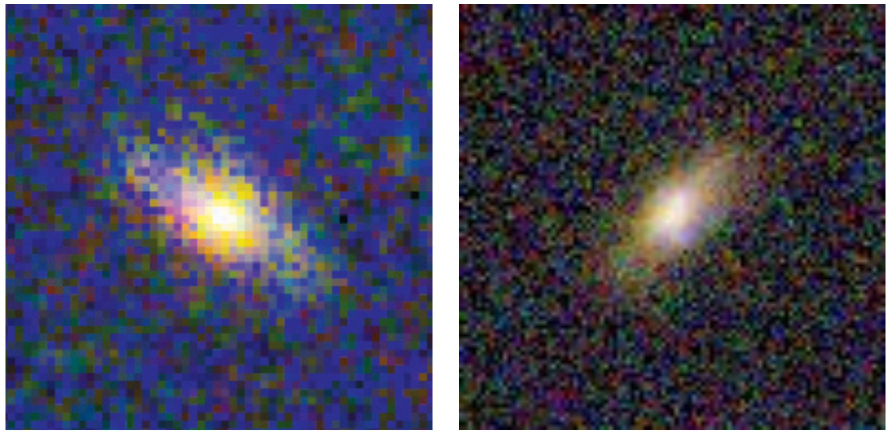
We model the projected $b/a - \log a$ distributions of CANDELS main sequence star-forming galaxies, where a (b) is the semi-major (semi-minor) axis of the galaxy images. We find that smaller-a galaxies are rounder at all stellar masses M_* and redshifts, so we include a when analyzing b/a distributions. Approximating intrinsic shapes of the galaxies as triaxial ellipsoids and assuming a multivariate normal distribution of galaxy size and two shape parameters, we construct their intrinsic shape and size distributions to obtain the fractions of prolate, oblate, and spheroidal galaxies in each redshift and mass bin. We find that galaxies tend to be prolate at low M_* and high redshifts, and oblate at high M_* and low redshifts, qualitatively consistent with van der Wel et al. (2014), implying that galaxies tend to evolve from prolate to oblate. These results are consistent with the predictions from simulations (Ceverino et al. 2015, Tomassetti et al. 2016) that the transition from prolate to oblate is caused by a compaction event at a characteristic mass range, making the galaxy center baryon dominated. We give probabilities of a galaxy's being prolate, oblate, or spheroidal as a function of its M_*, redshift, and projected b/a and a, which can facilitate target selections of galaxies with specific shapes at high redshifts. We also give predicted optical depths of galaxies, which are qualitatively consistent with the expected correlation that A_V should be higher for edge-on disk galaxies in each $\log a$ slice at low redshift and high mass bins.







Observed **Simulated**



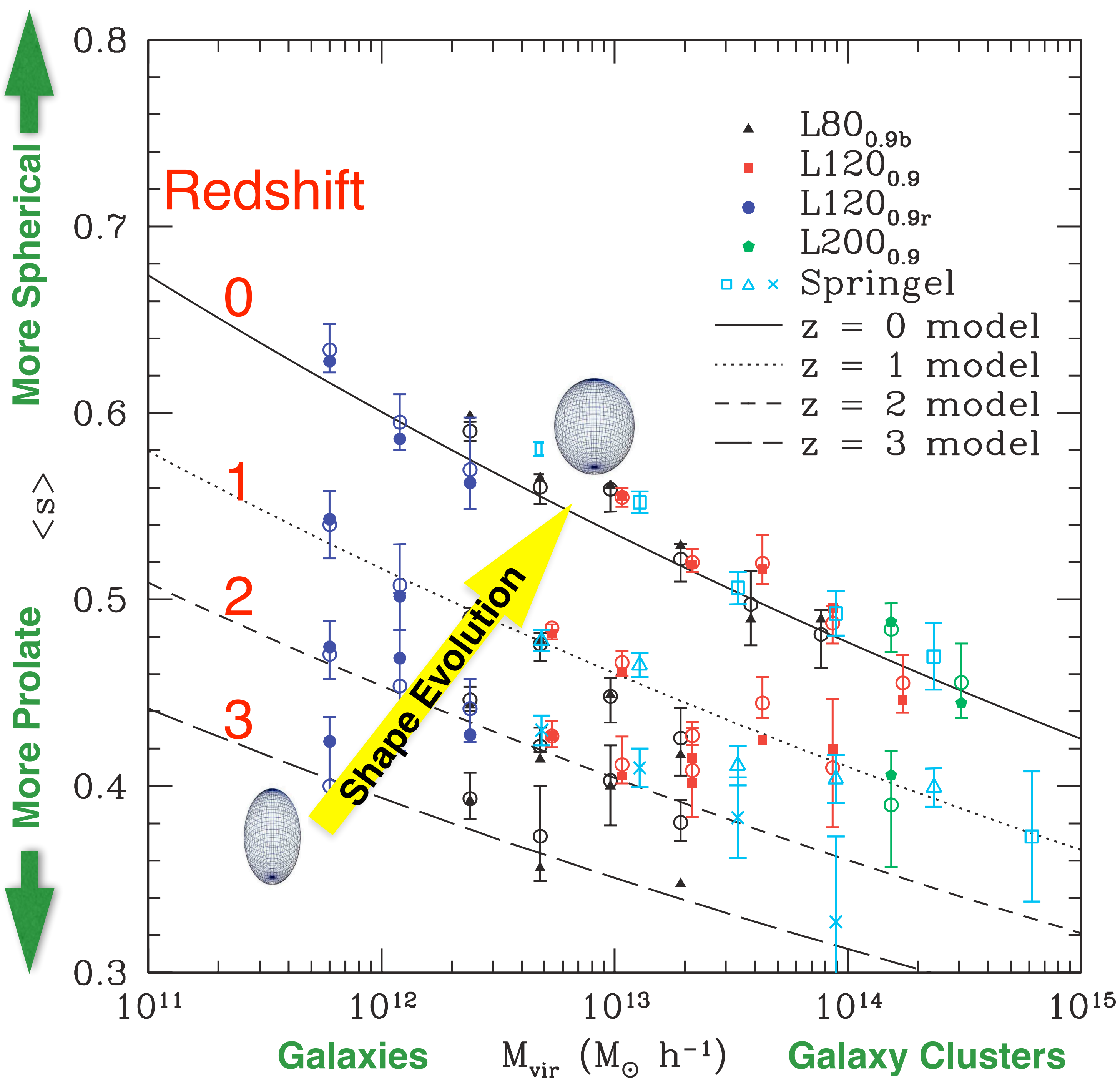
(a) CANDELS galaxy (b) VELA galaxy

MNRAS 367, 1781–1796 (2006)

The shape of dark matter haloes: dependence on mass, redshift, radius and formation

Brandon Allgood, Ricardo Flores, Joel R. Primack, Andrey V. Kravtsov, Risa Wechsler, Andreas Faltenbacher and James S. Bullock

$s = c/a$ = short axis / long axis



Halos are approximately triaxial ellipsoids

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \qquad a \geq b \geq c$$

Halos start prolate, especially at low radius, and later become more spherical.

Low-redshift halo, accreting more spherically

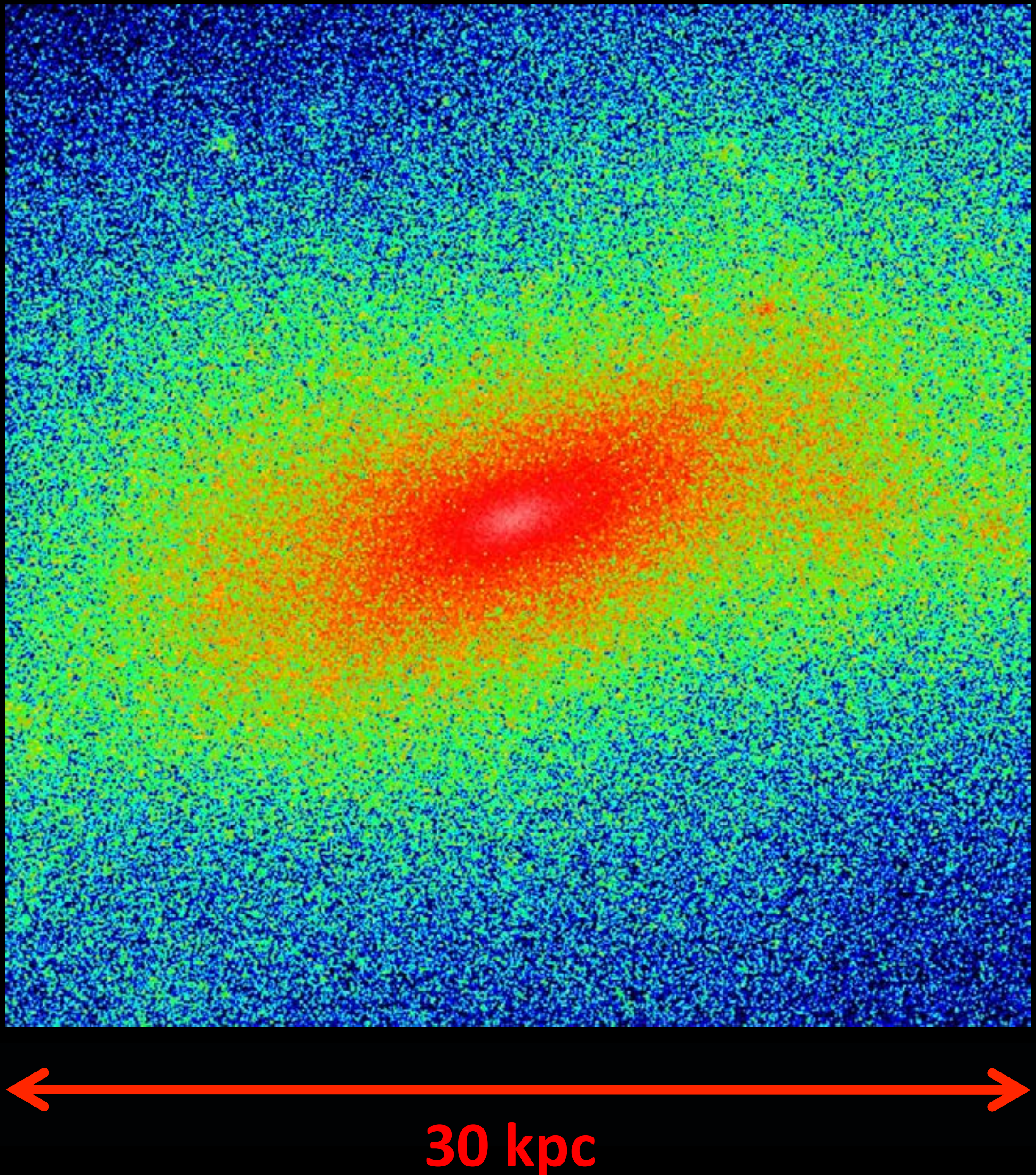
High-redshift halo, accreting mainly along filament

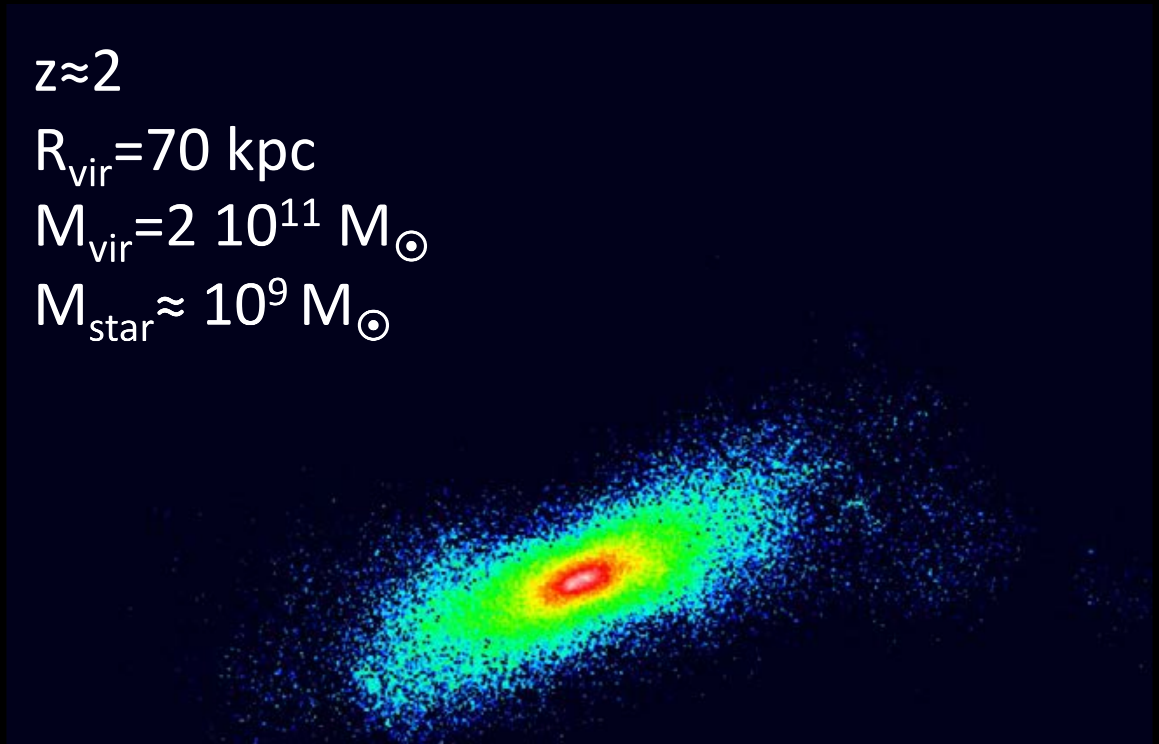
supported by anisotropic velocity dispersion, larger along principal axis

Our cosmological zoom-in simulations often produce elongated galaxies like the observed ones. The elongated distribution of stars follows the elongated inner dark matter halo.

Prolate DM halo → elongated galaxy

DM **VELA28RP** **stars**



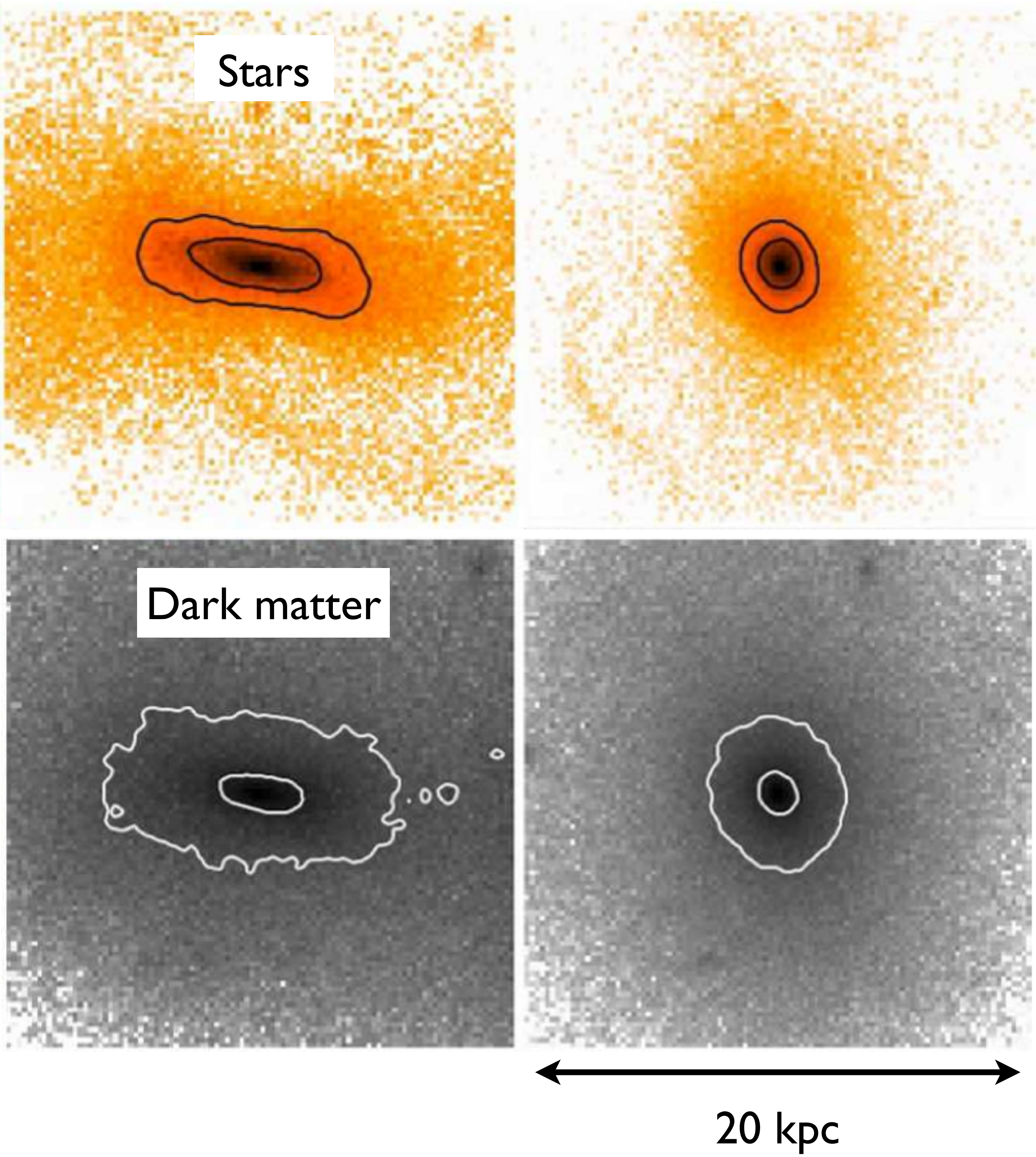


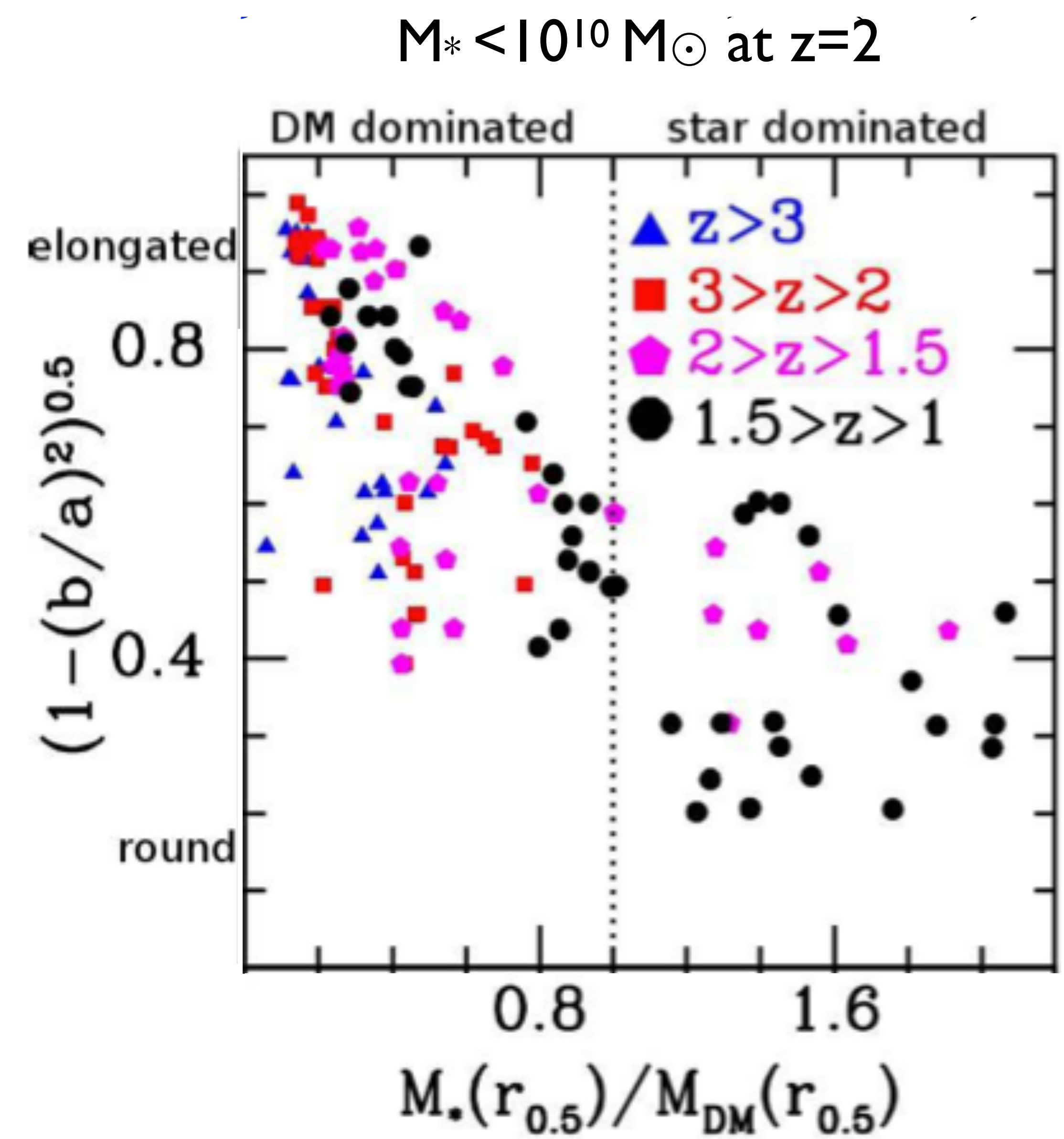
Dark matter halos are elongated, especially near their centers. Initially stars follow the gravitationally dominant dark matter, as shown. But later as the ordinary matter central density grows and it becomes gravitationally dominant, the star and dark matter distributions both become disky — as observed by Hubble Space Telescope (van der Wel+ ApJL Sept 2014).

Formation of elongated galaxies with low masses at high redshift

Daniel Ceverino, Joel Primack and Avishai Dekel

MNRAS 2015





Tomassetti et al. 2016 MNRAS

Simulated elongated galaxies are aligned with cosmic web filaments, become round after compaction (gas inflow fueling central starburst)

Pandya, Primack, et al. 2019 Alignments of prolate galaxies trace cosmic web?

“Face Recognition for Galaxies”

Deep Learning Identifies High-z Galaxies in a Central Blue Nugget Phase in a Characteristic Mass Range

Marc Huertas-Company, Joel Primack, Avishai Dekel, David Koo, Sharon Lapiner, Daniel Ceverino, Raymond Simons, Greg Snyder, et al. ApJ 2018

Cosmological zoom-in simulations model how individual galaxies evolve through the interaction of atomic matter, dark matter, and dark energy

Our VELA galaxy simulations agree with HST CANDELS observations that most galaxies start prolate, becoming spheroids or disks after compaction events

A deep learning code was trained with VELA galaxy images plus metadata describing whether they are pre-BlueNugget, BlueNugget, or post-BlueNugget

The trained deep learning code was able to identify the BlueNugget and post-BlueNugget phases in CANDELized images

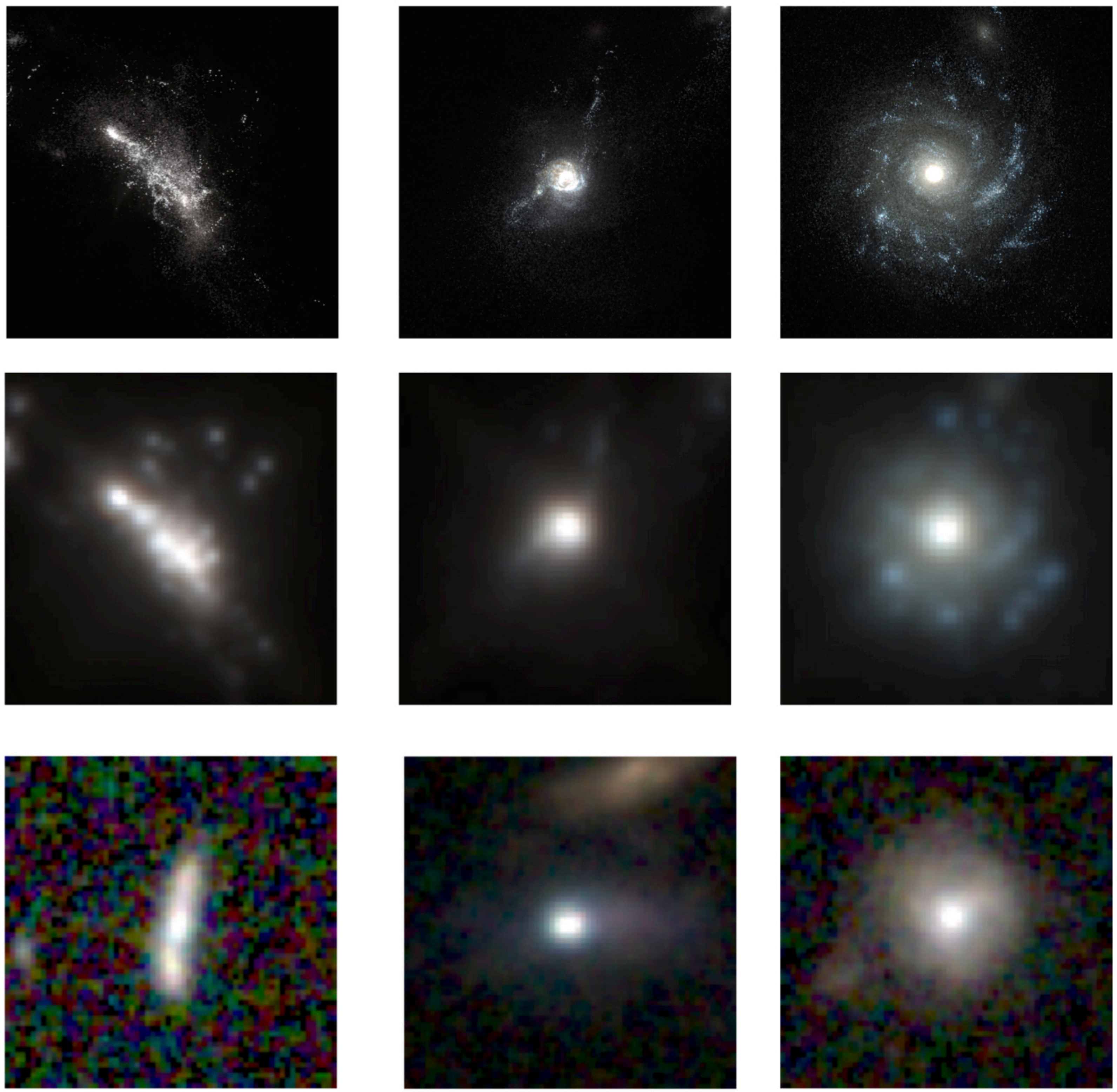
The trained deep learning code was also able to identify these phases in real HST CANDELS observations, finding that compaction occurred for stellar mass $10^{9.5\text{ -}10.3}$ M_{sun}, as in the simulations

James Webb Space Telescope will allow us to do even better

“Face Recognition for Galaxies”

Huertas-Company, Primack, et al. ApJ 2018

Pre-BN	BN	Post-BN
Pre-Blue-Nugget-Stage	Blue-Nugget-Stage	Post-Blue-Nugget-Stage

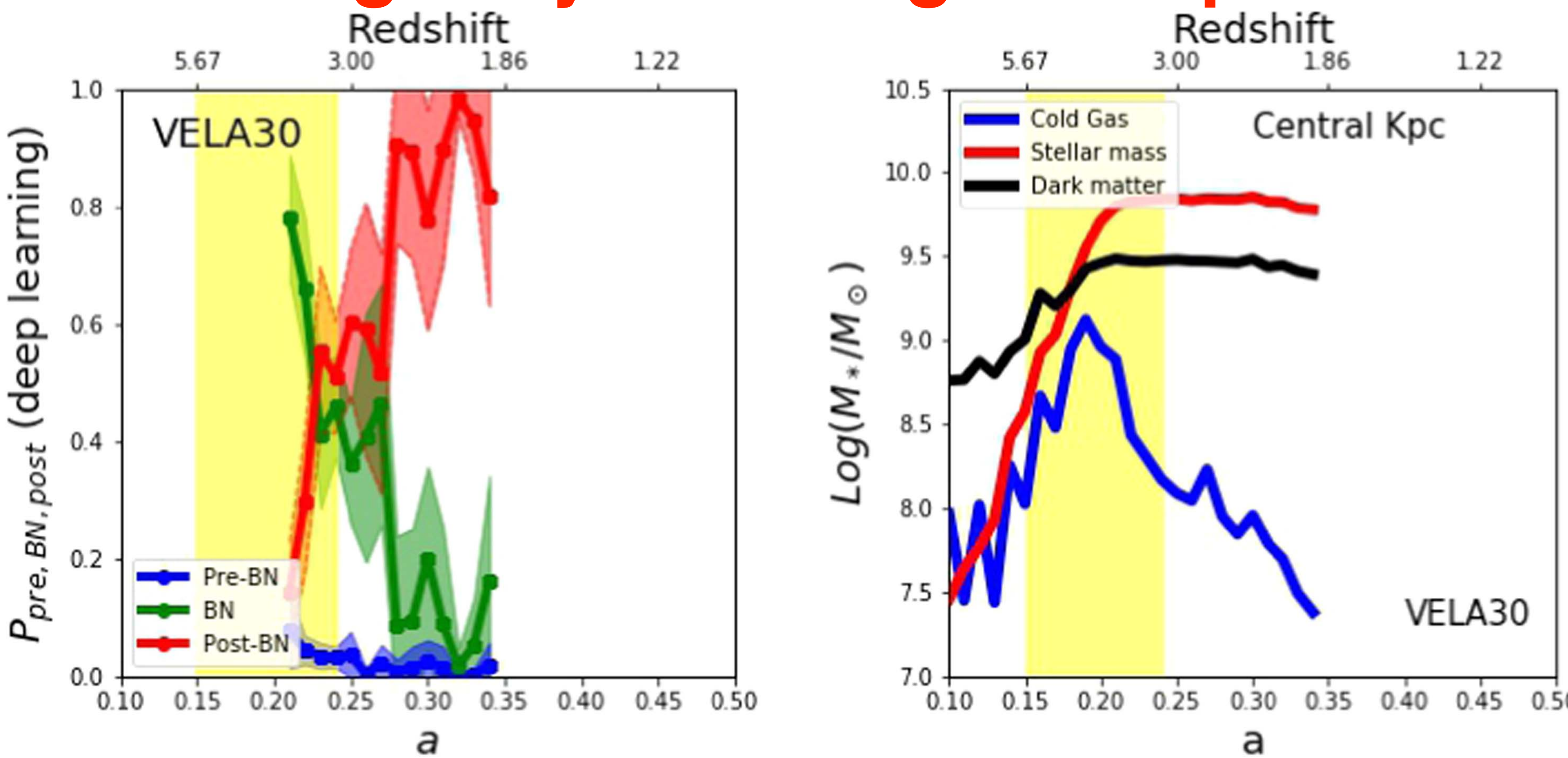


VELA High-Res Sunrise Images

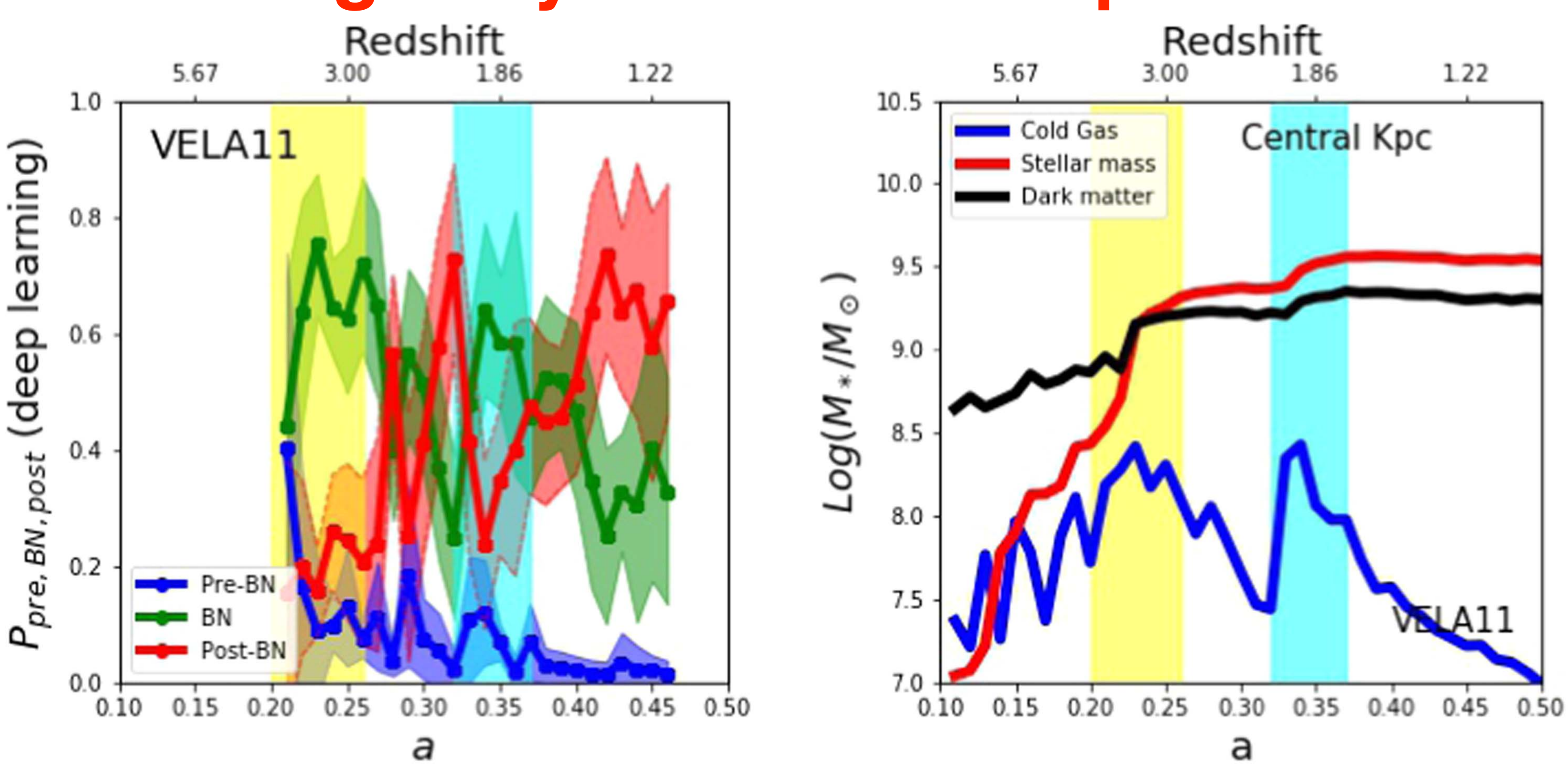
VELA HST-Res Sunrise Images (CANDELized)

CANDELS HST Images

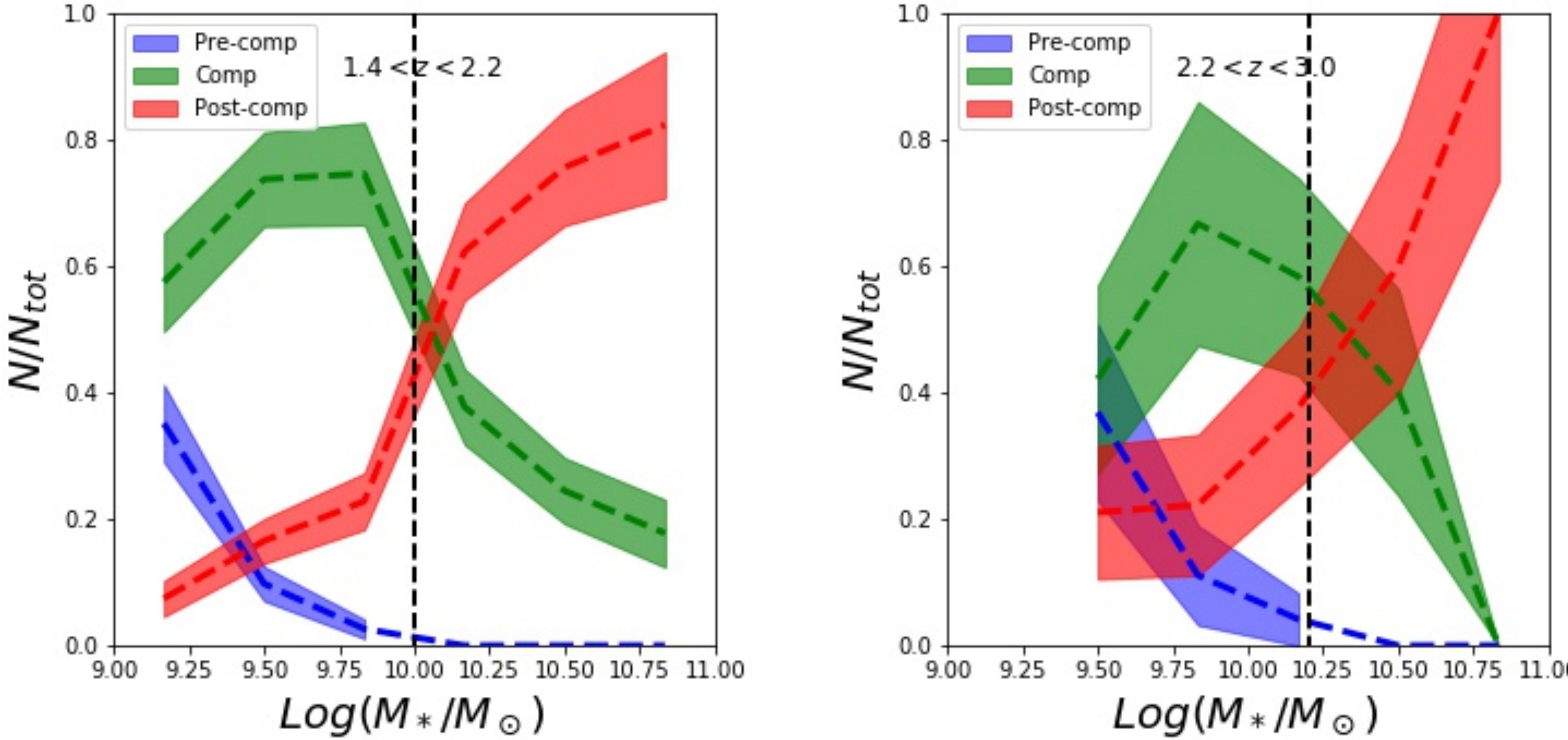
Simulated galaxy with single compaction event



Simulated galaxy with two compaction events



Applying the Trained Deep Learning Code to CANDELS Galaxies

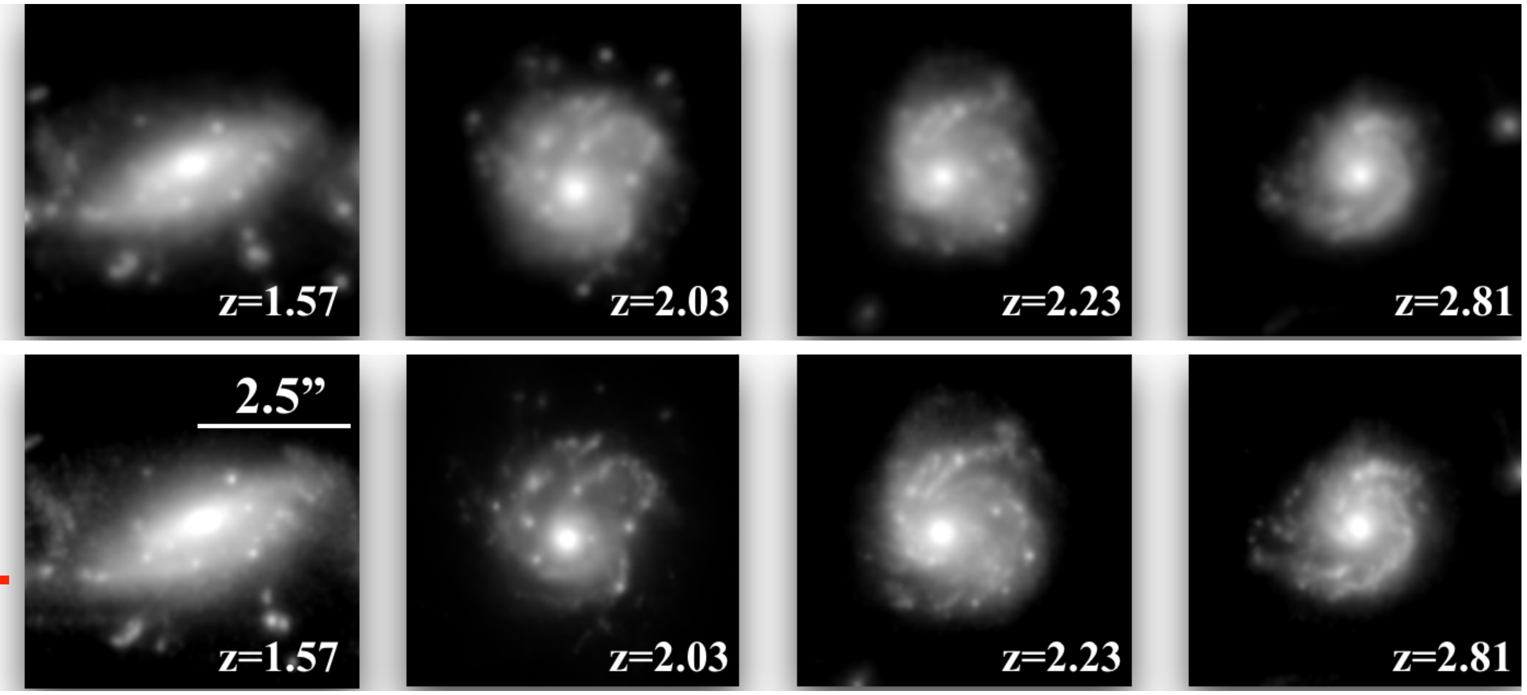


Stellar mass distributions of HST CANDELS galaxies in pre-compaction, compaction, and post-compaction phases in different redshift bins. The DL code correctly shows the temporal evolution. Galaxies in the compaction phase typically peak at stellar masses $10^{9.5–10}$ M_{sun} at all redshifts, as in the VELA simulations.

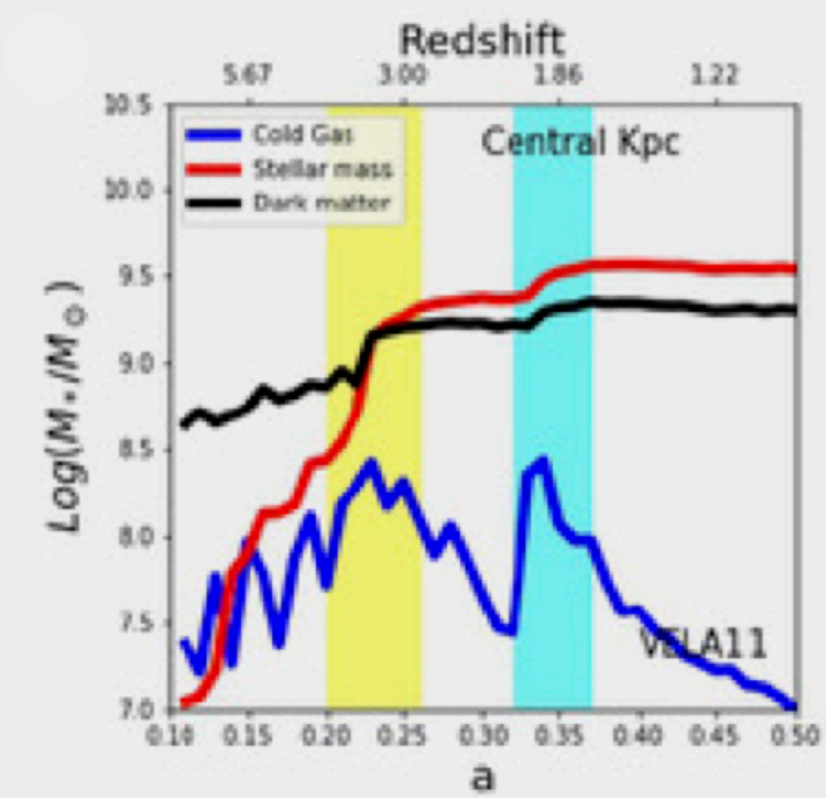
Convolutional Neural Net (Deep Learning) Galaxy Evolution Phase Determination: HST vs. JWST

WFC3 F160W **HST**

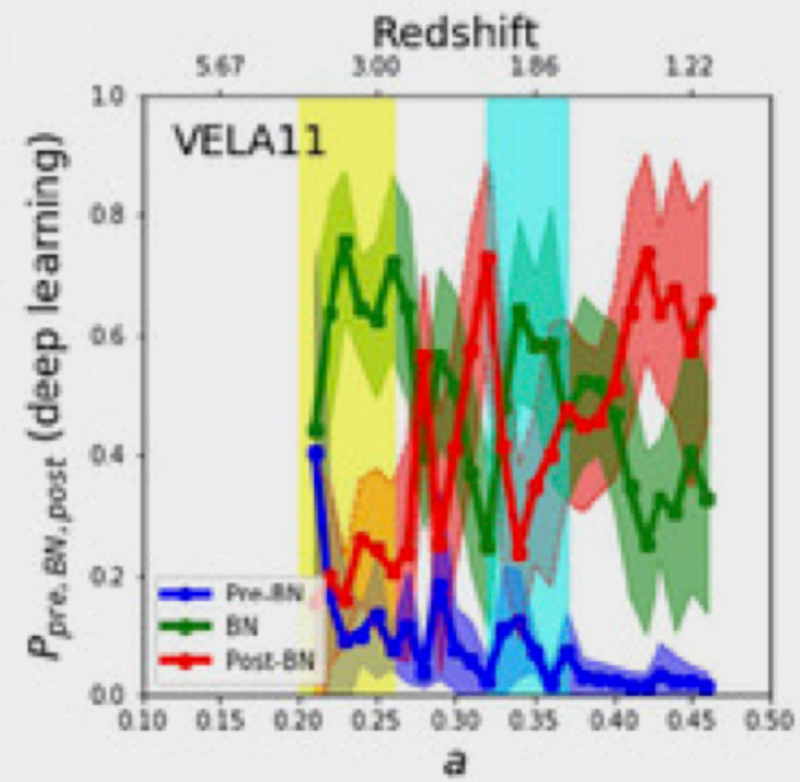
NIRCam F200W **JWST**



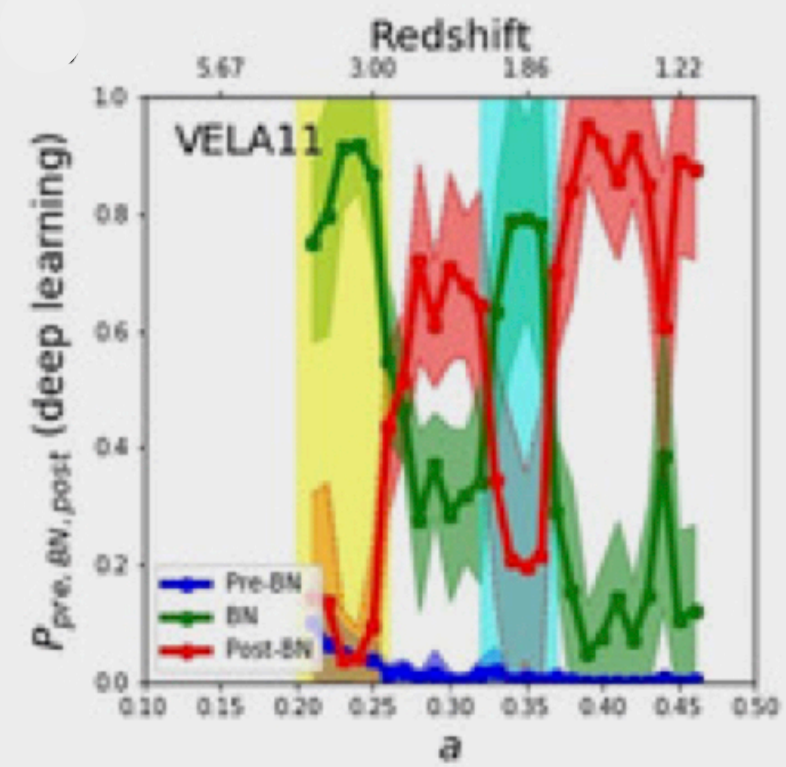
Simulation Metadata



CNN Trained with HST-like Images (3 NIR filters)



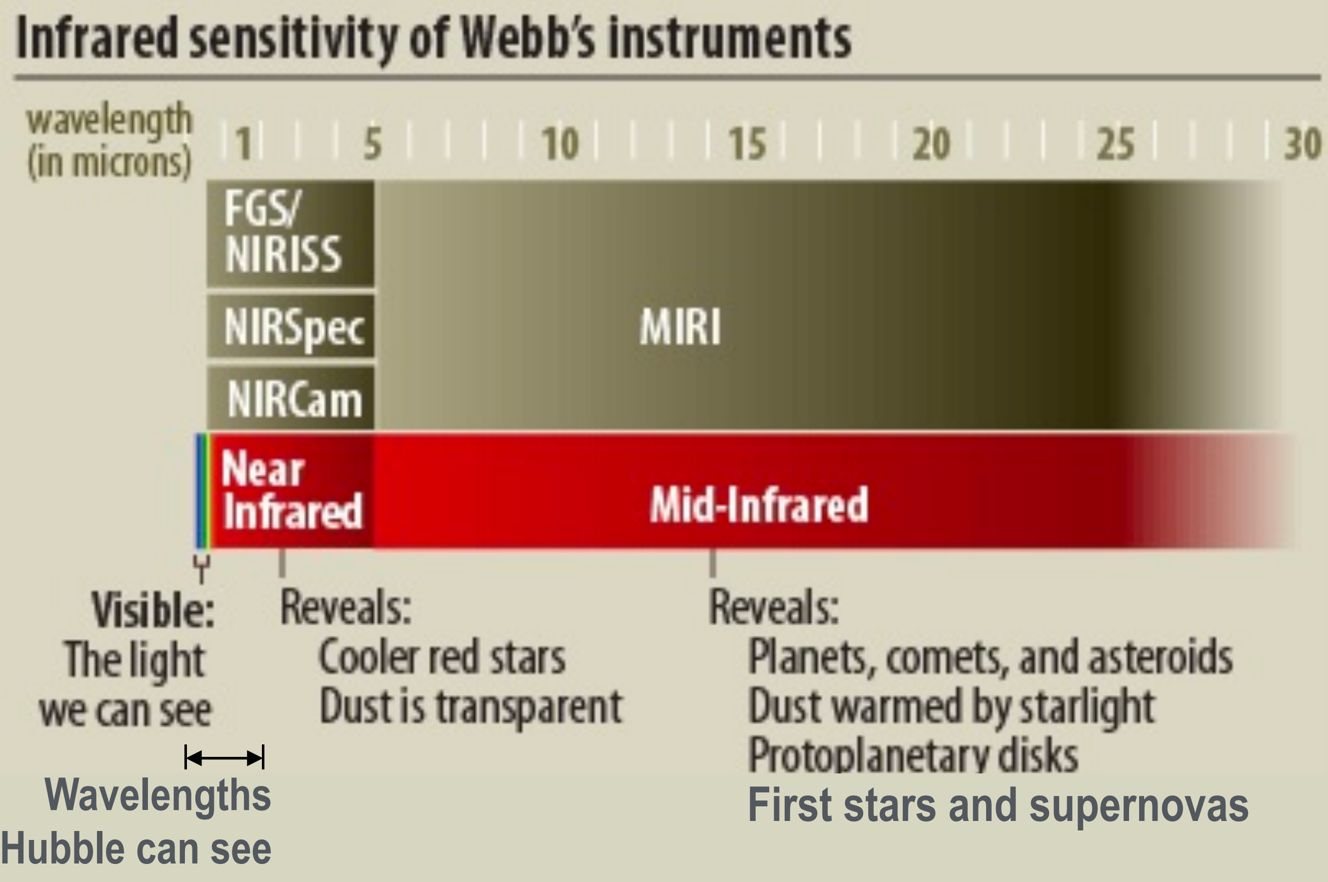
CNN Trained with JWST-like Images (3 NIR filters)

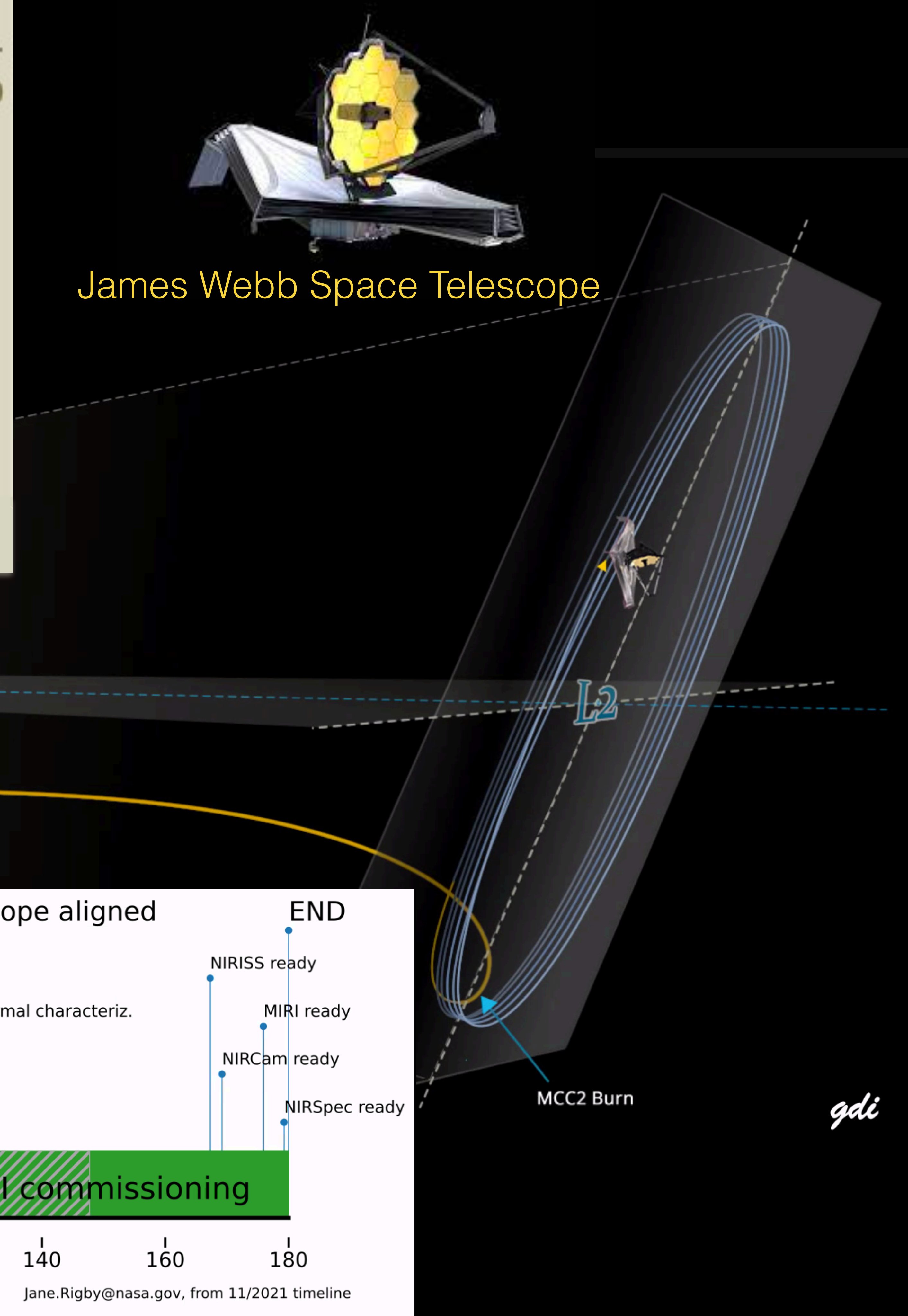


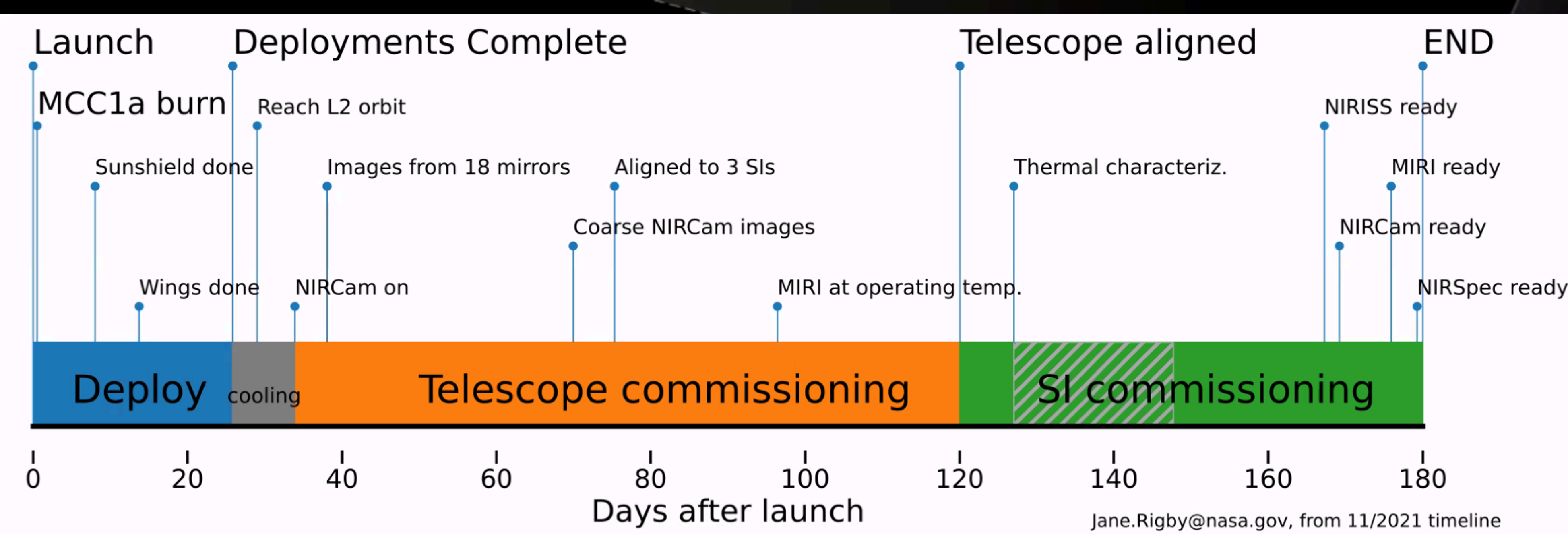
Simulated galaxy with two compaction events

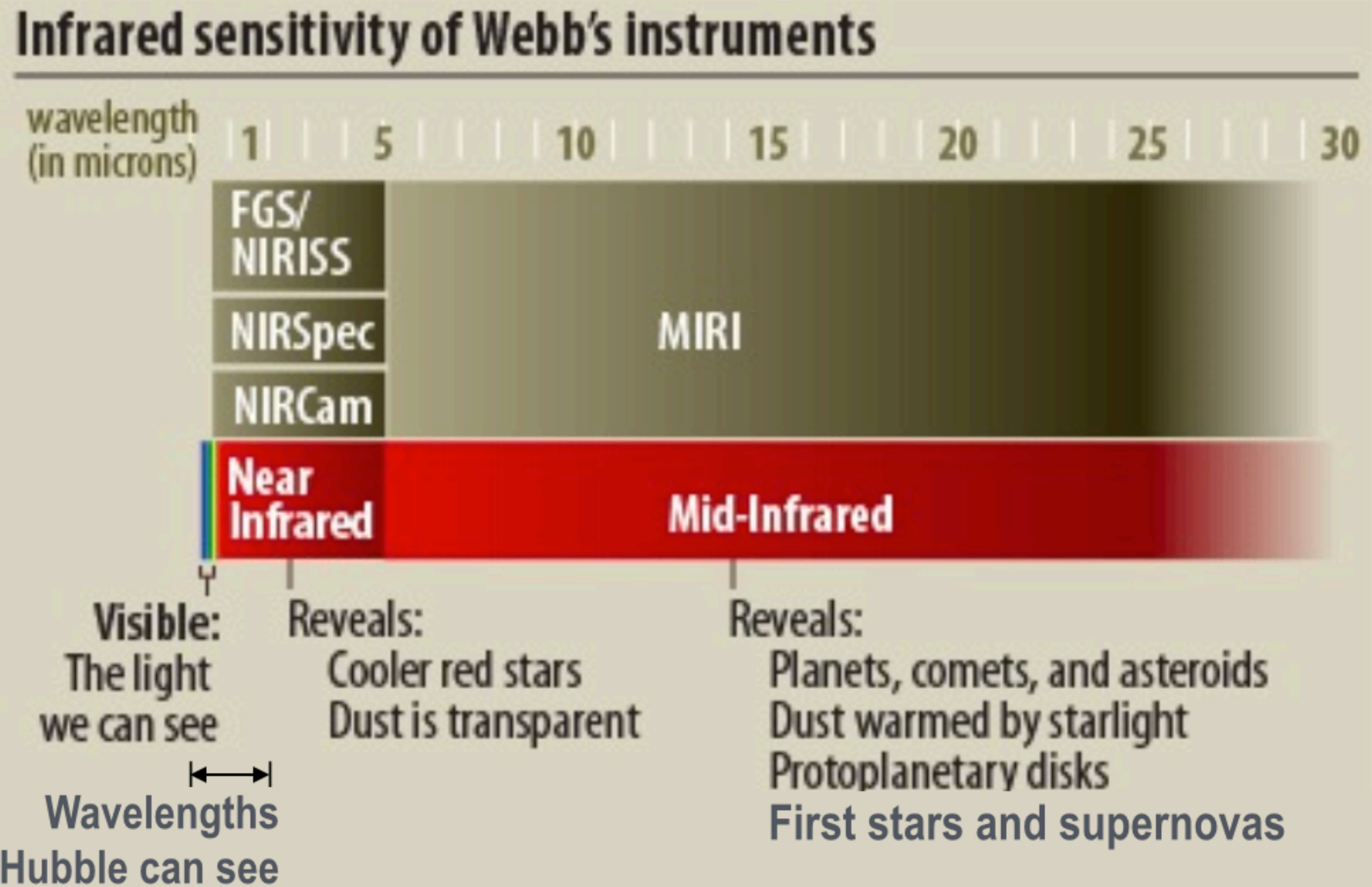
Deep Learning struggles with mock HST images

Deep Learning does much better with JWST images


Infrared sensitivity of Webb's instruments
wavelength (in microns)
1
5
10
15
20
25
30
FGS/ NIRISS
NIRSpec
NIRCam
MIRI
Near Infrared
Mid-Infrared
Visible:
The light we can see
Reveals:
Cooler red stars
Dust is transparent
Reveals:
Planets, comets, and asteroids
Dust warmed by starlight
Protoplanetary disks
First stars and supernovas
Wavelengths Hubble can see


James Webb Space Telescope
Sun
L2
MCC2 Burn
gdi


Launch
Deployments Complete
Telescope aligned
END
MCC1a burn
Reach L2 orbit
NIRISS ready
Sunshield done
Images from 18 mirrors
Aligned to 3 SIs
Thermal characteriz.
MIRI ready
Coarse NIRCam images
NIRCam ready
Wings done
NIRCam on
MIRI at operating temp.
NIRSpec ready
Deploy
cooling
Telescope commissioning
SI commissioning
0
20
40
60
80
100
120
140
160
180
Days after launch
Jane.Rigby@nasa.gov, from 11/2021 timeline



Infrared sensitivity of Webb's instruments
wavelength (in microns)
1
5
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FGS/ NIRISS
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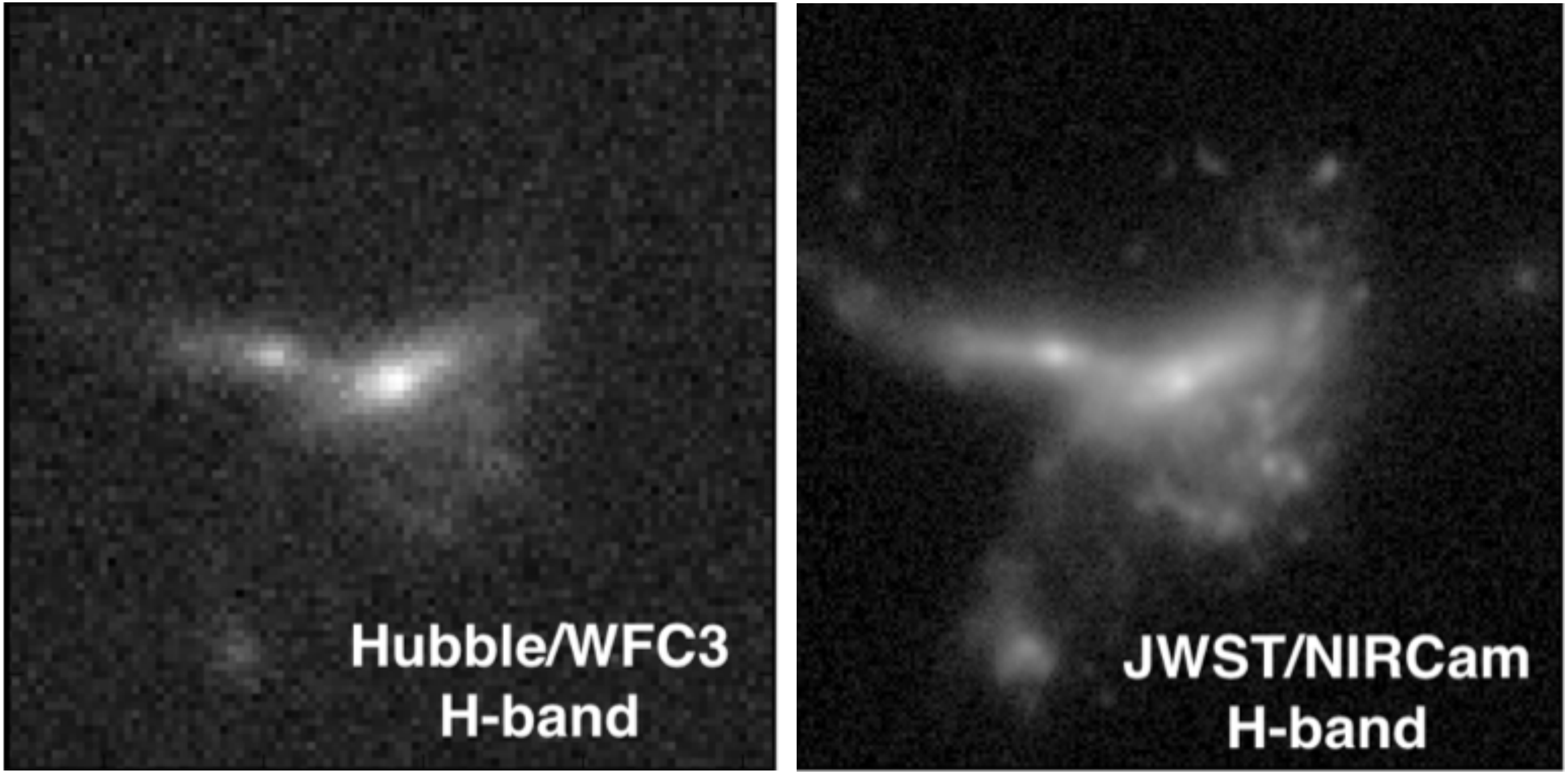
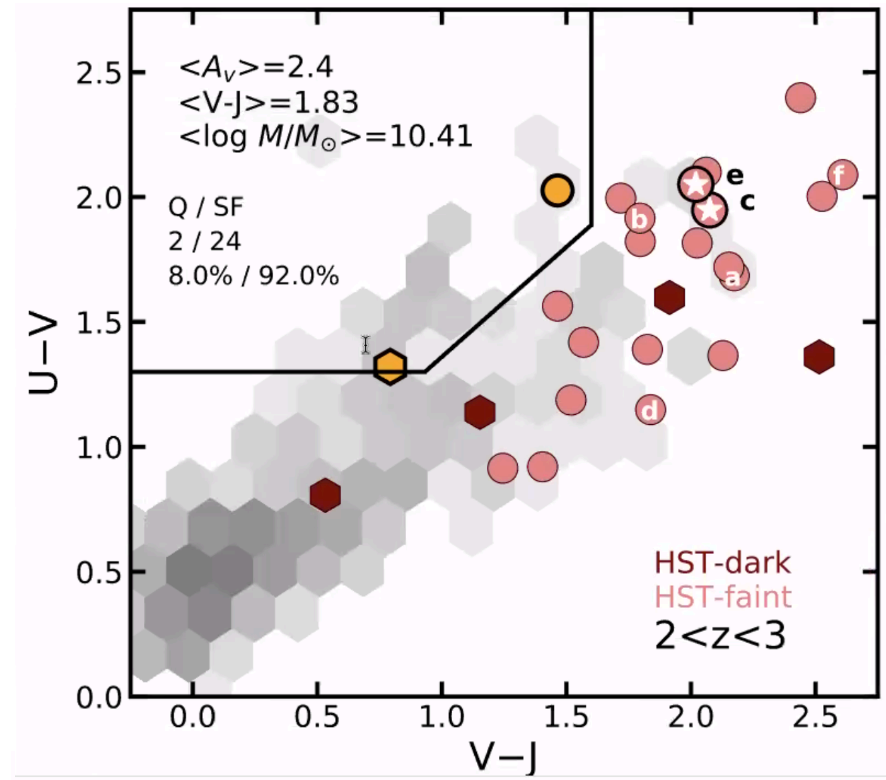
NIRCam
MIRI
Near Infrared
Mid-Infrared
Visible:
The light we can see
Reveals:
Cooler red stars
Dust is transparent
Reveals:
Planets, comets, and asteroids
Dust warmed by starlight
Protoplanetary disks
First stars and supernovas
Wavelengths Hubble can see

Mock Images for HST and JWST of a Simulated Galaxy Merger

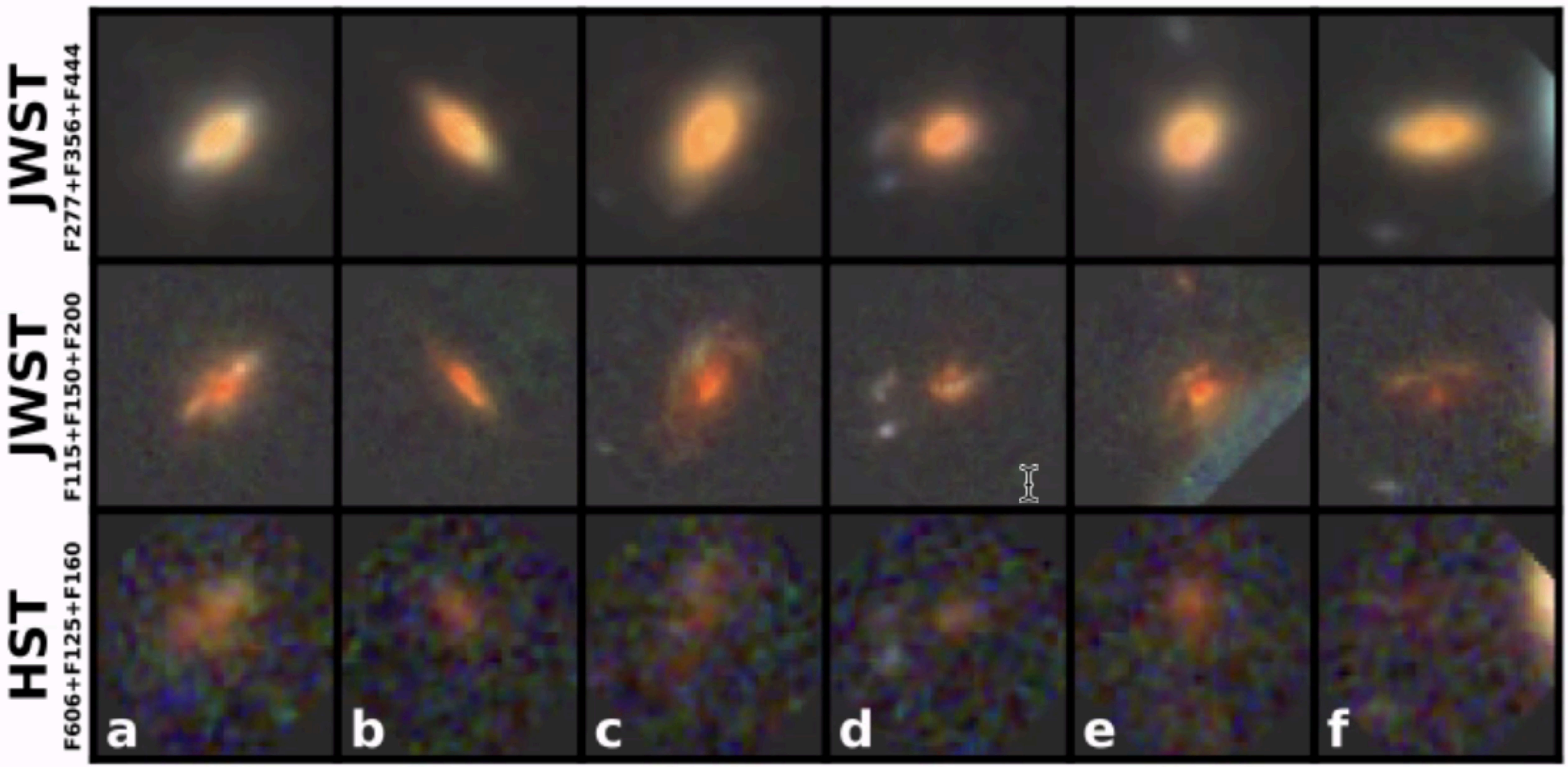


JWST sees the same simulated galaxy much more clearly than HST!

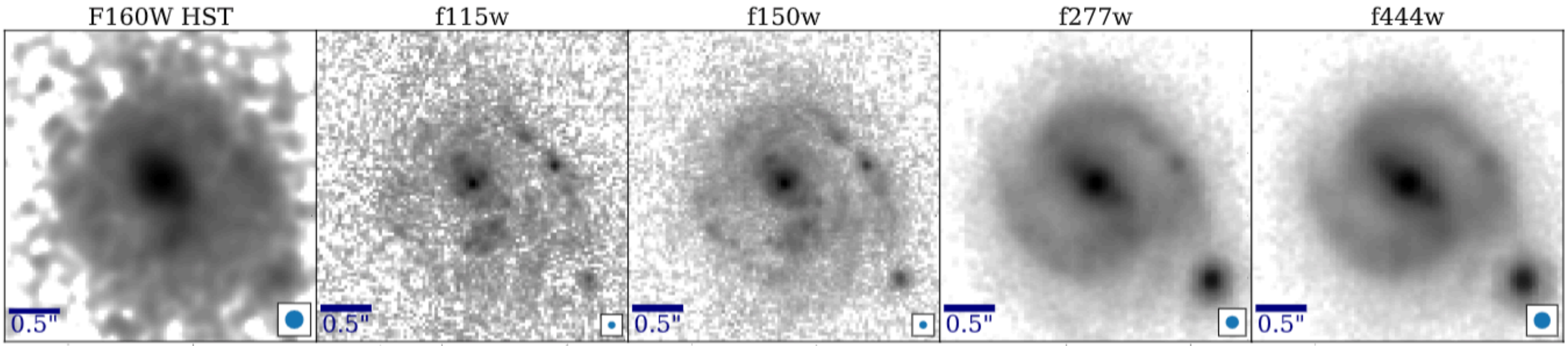
HST vs JWST Images of 2 < z < 3 Galaxies



Source: JWST/CEERS & Guillermo Barro



HST vs JWST Images of a z = 2.136 Galaxy

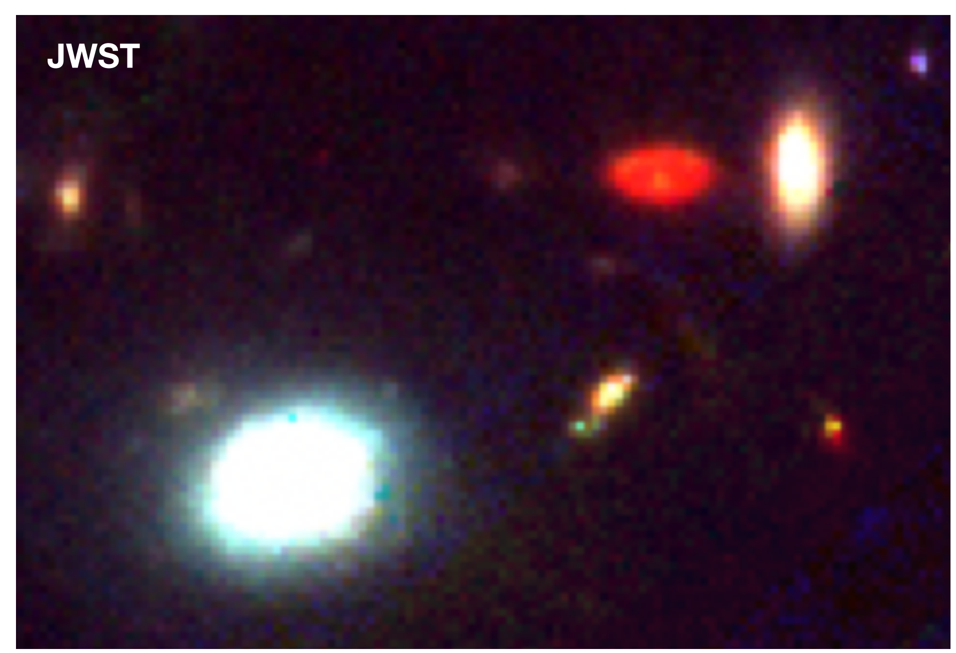


λ_{rest} = 0.5 μm 0.37 μm 0.5 μm 0.9 μm 1.4 μm

Figure 1. The *HST* WFC3 F160W, and *JWST* NIRCam F115W, F150W, F277W, and F444W images for the galaxy EGS-23205 at redshift $z \sim 2.136$. The blue circle at the bottom right of each image represents the point spread function (PSF) FWHM of each band (0.18″, 0.07″, 0.07″, 0.13″, and 0.16″, respectively, and the horizontal bar shows a 0.5″ scale for reference. The underlying stellar mass distribution and galactic components, such as the stellar bar, are better traced by the rest-frame NIR light in the *JWST* F444W image than by the rest-frame blue-optical light in the *HST* F160W or *JWST* F150W images or the rest-frame UV light highlighting regions of recent star formation in the *JWST* F115W image.

HST Missed a JWST Reddened Edge-on Disk Galaxy

HST F606W F125W F160W color composite

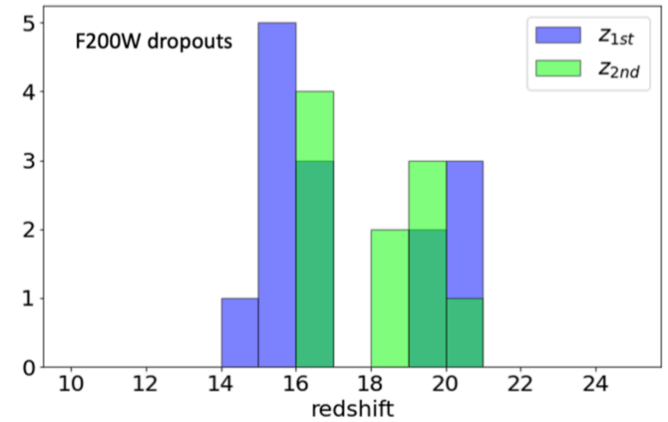


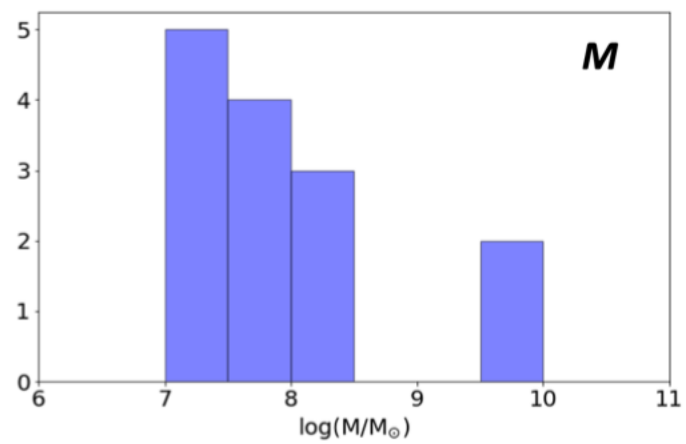
JWST F150W F277W F444W color composite

Nelson+2208.01630

JWST is finding massive galaxies at high redshifts

In the SMACS 0723-73 lensing cluster and a flanking field, Yan et al. arXiv:2207.11558 found 88 candidate galaxies at 11 < z < 20.





Atek+2207.12338 found 2 candidates each at z~16 and 12, and 11 candidates at z~10-11

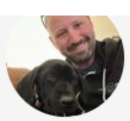
JWST is finding massive galaxies at high redshifts

Adams, Conselice+2207.11217 finds 4 z > 9 galaxies in the lensing cluster SMACS 0723 field, with a z ~ 9.9 galaxy having M* ~ $10^{10.2}$ M_{sun}.

Labbe, van Dokkum+ 2207.12446 find 7 M* > 10^{10} M_{sun} galaxies at z > 7.5 in JWST/CEERS

Finkelstein+2207.12474 finds a M* ~ $10^{8.5}$ M_{sun} galaxy at z ~ 12 in JWST/CEERS

These observations are a challenge for ΛCDM. But at z~14 EDE produces about 10x as many Mvir ≥ 10^{11} M_{sun} halos as ΛCDM.



Steve Finkelstein
@astrosteven · **Follow**

If these galaxy redshifts hold up, the finding of a few z~12 galaxies last week, this z~14 galaxy, and I'm sure others at similar and higher redshifts in the days and weeks to come means that our early universe is more exciting than we could have ever imagined!

5:52 PM · Jul 25, 2022

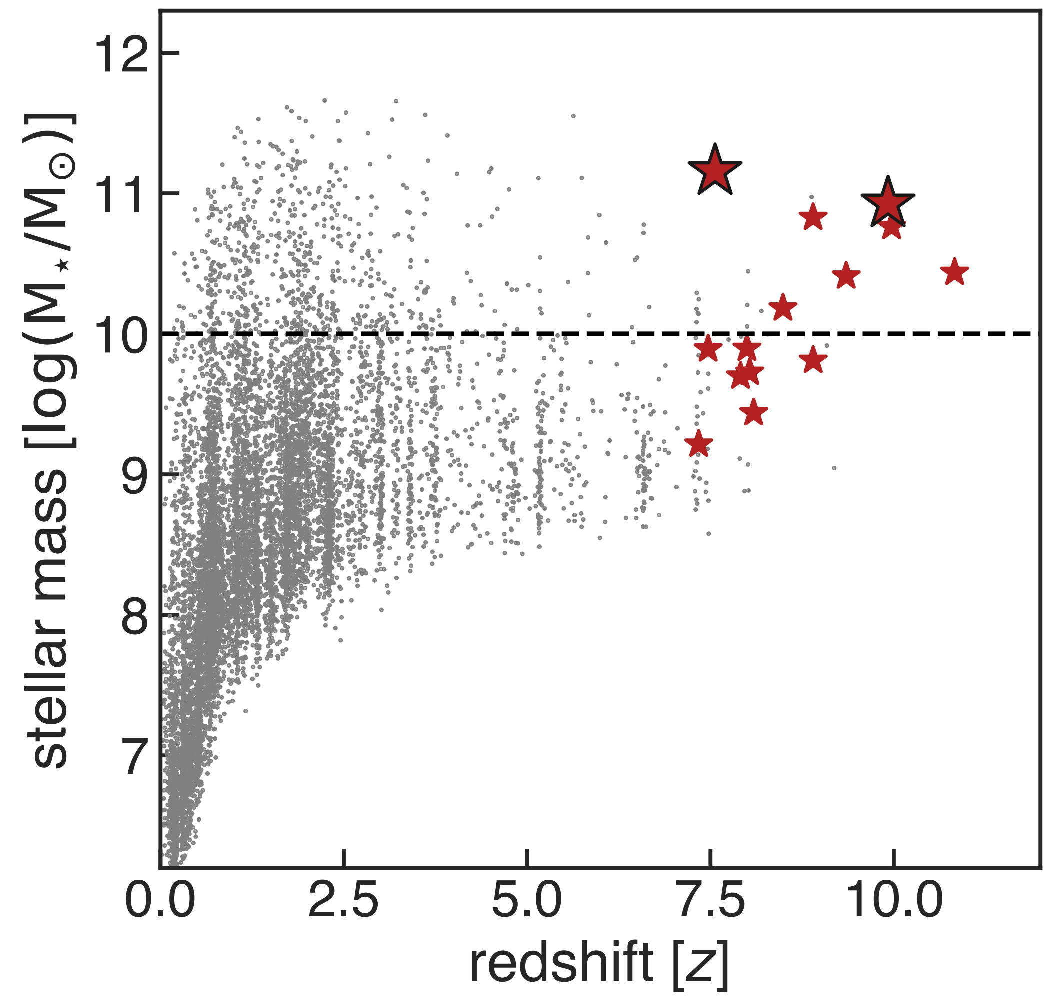


Figure 1: Double-break selected galaxies. EAZY-determined redshifts and stellar masses of all objects with S/N> 8 in the F444W band are shown. Galaxies that satisfy our double-break selection (having no optical flux, a blue color below 2.7 μm, and a red color beyond that) are shown by the large symbols. All these galaxies have photometric redshifts $7 < z < 11$ and high masses. Seven have $M_* > 10^{10}\,M_\odot$.

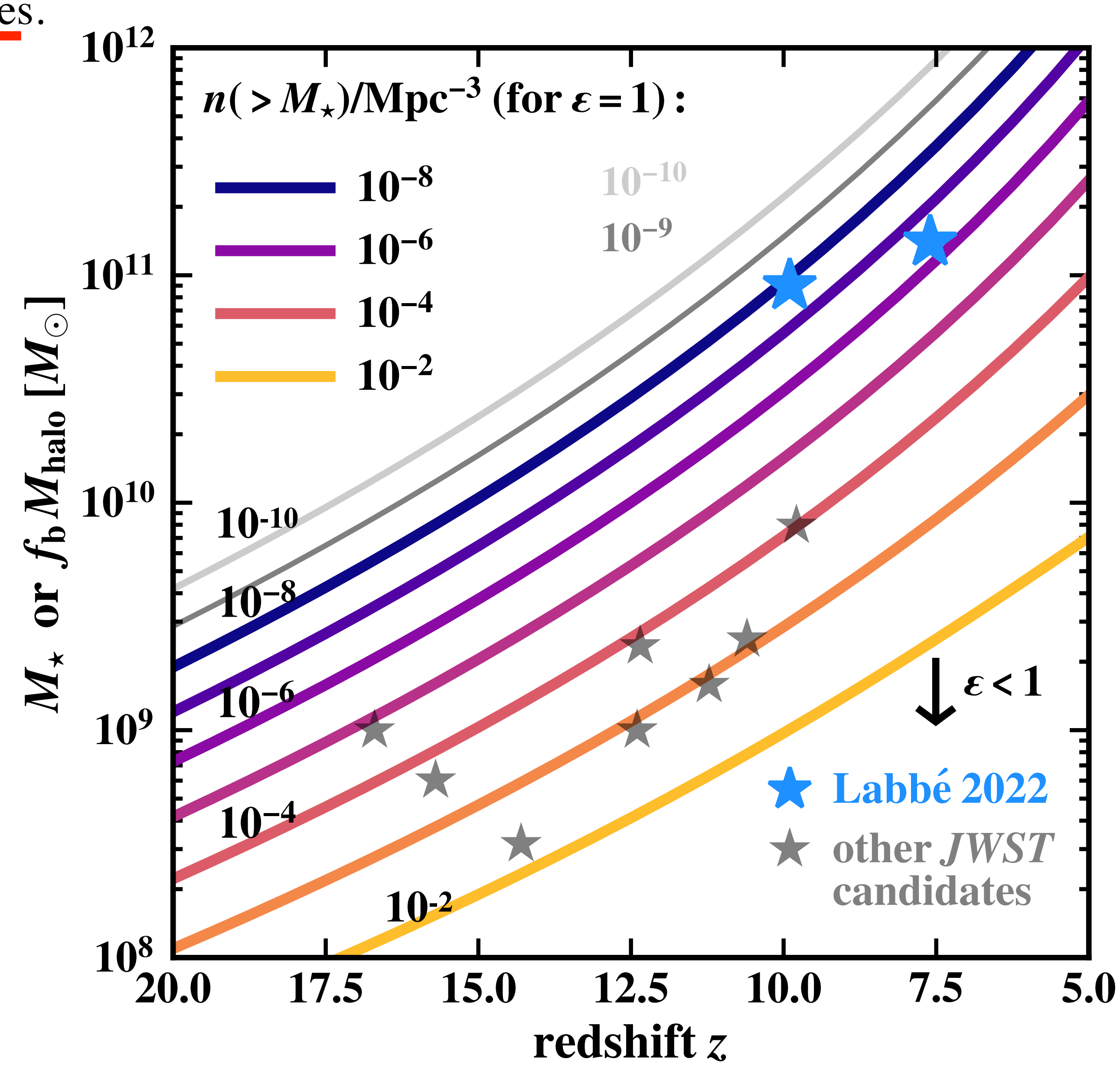
Labbe, van Dokkum+ 2207.12446

See also Boylan-Kolchin 2208.01611

Stress testing ΛCDM with high-redshift galaxy candidates **Michael Boylan-Kolchin 2208.01611**

Early data from *JWST* have revealed a bevy of high-redshift galaxy candidates with unexpectedly high stellar masses. For a given cosmology, the abundance of dark matter halos as function of mass and redshift sets an absolute upper limit on the number density $n(> M_\star, z)$ and stellar mass density $\rho_\star(> M_\star, z)$ of galaxies above a stellar mass limit of $M_\star$ at any epoch z. The reported masses of the most massive galaxy candidates at $z \sim 10$ in *JWST* observations are in tension with these limits, indicating an issue with well-developed techniques for photometric selection of galaxies, galaxy stellar mass or effective survey volume estimates, or the ΛCDM model. That the strongest tension appears at $z \sim 10$ Labbé et al. (2022), and not (yet?) at the highest redshifts probed by *JWST* galaxy candidates ($z \sim 16 - 20$), is promising for tests of the ΛCDM model using forthcoming wider-area *JWST* surveys. Intriguingly, models with enhanced values of σ_8 — such as some Early Dark Energy models whose aim is to resolve the Hubble Tension (e.g., Smith et al. 2022) — come closer to producing the requisite baryonic reservoirs for obtaining the most massive Labbé et al. candidates.

The plot at the right shows the abundance of galaxies as a function of stellar mass $M_\star$ predicted by ΛCDM with the **unrealistic assumption that all the gas turns into stars (ε=1)**. The blue stars represent the Labbé et al. (2022) most massive $z = 7.5$ and 10 galaxies that are the greatest challenge to ΛCDM. The $z = 10$ $M_\star = 10^{11}$ $M_\odot$ galaxy would be expected to have a number density $<10^{-8}$ per Mpc^{-3}, so it should not be seen in the CEERS survey volume $V \approx 10^5$ Mpc^3 at $z = 10\pm1$.



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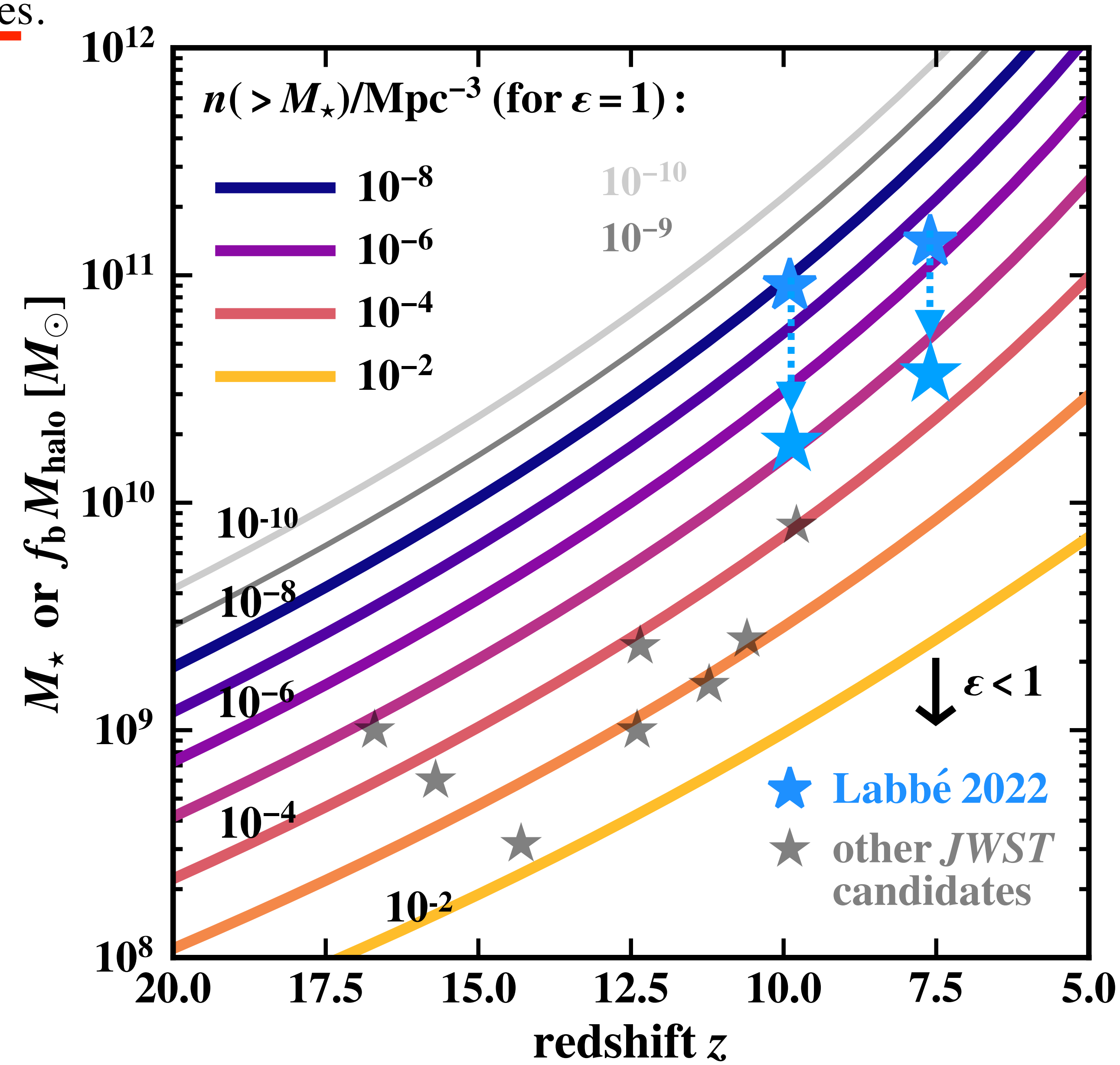
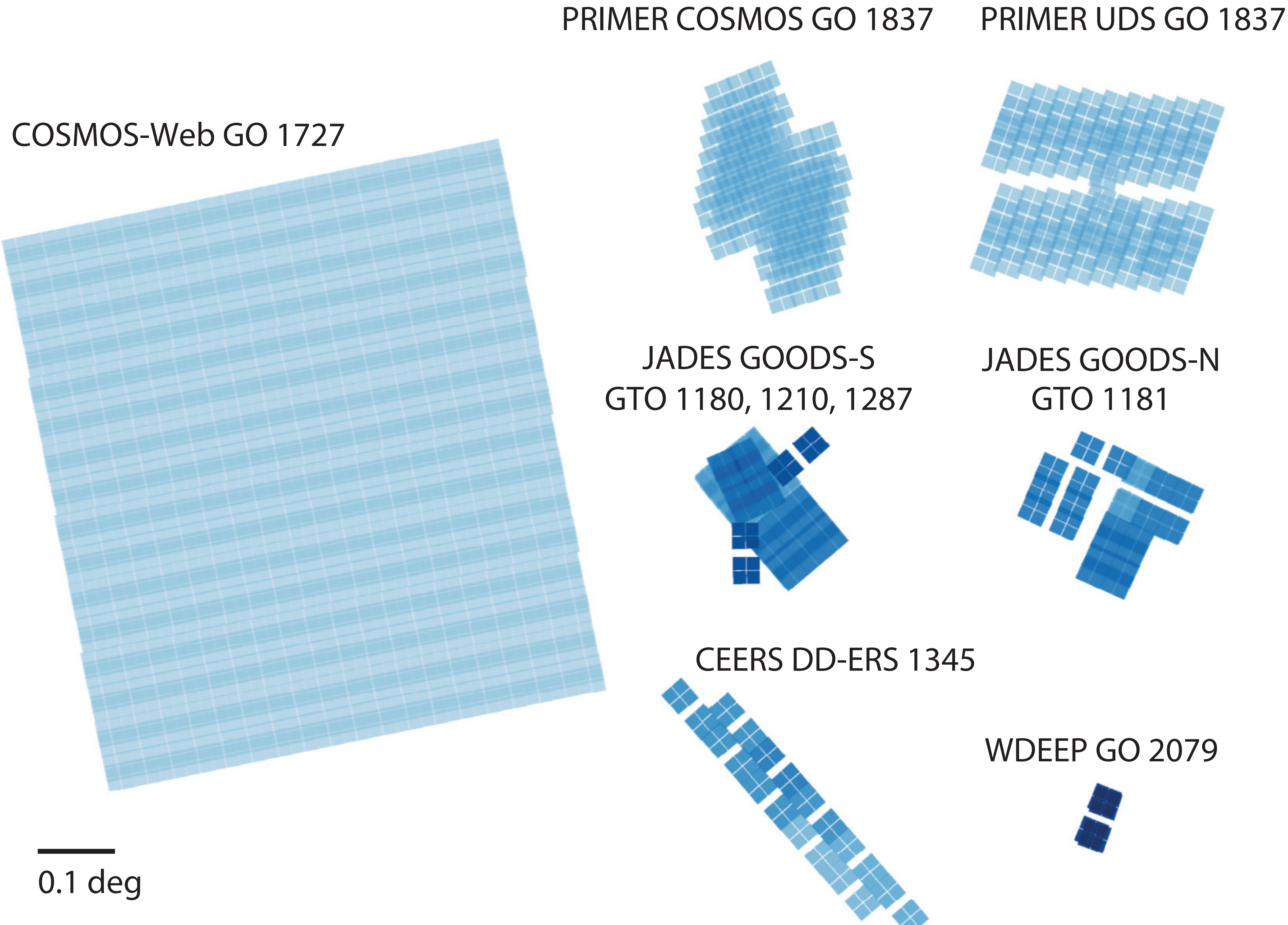
If the stellar masses of these galaxies were overestimated by nearly a factor of 10, which may be plausible, they would still be unexpected in ΛCDM. But Early Dark Energy predicts nearly 10x more such galaxies at $z \sim 10$, so they would be more in line with theoretical expectations. The stellar masses of these high-z galaxies will be better measured by NIRSpec and MIRI observations of these and other fields.

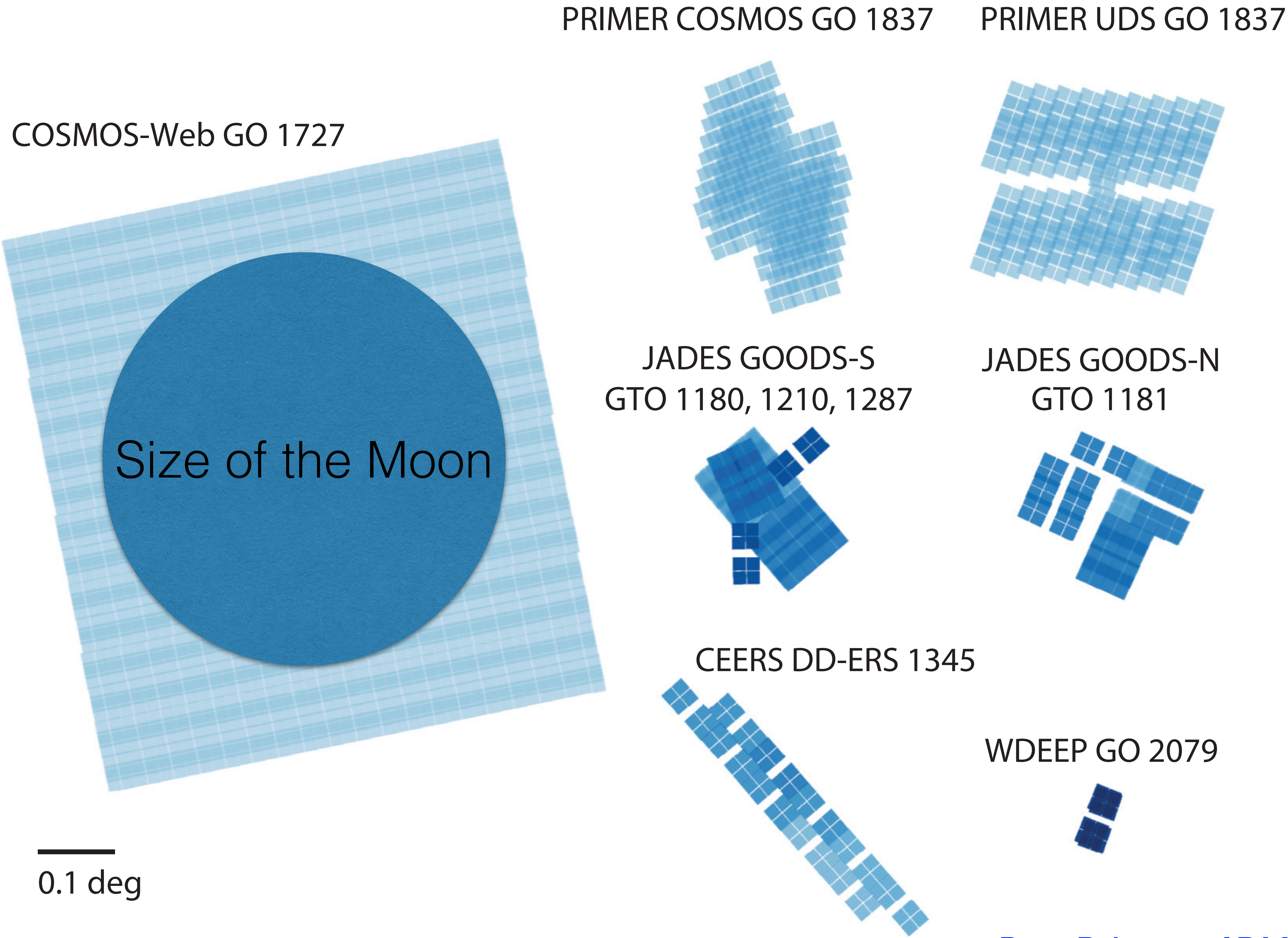


JWST will soon be observing galaxies over large areas



Brant Robertson ARAA 2022

JWST will soon be observing galaxies over large areas



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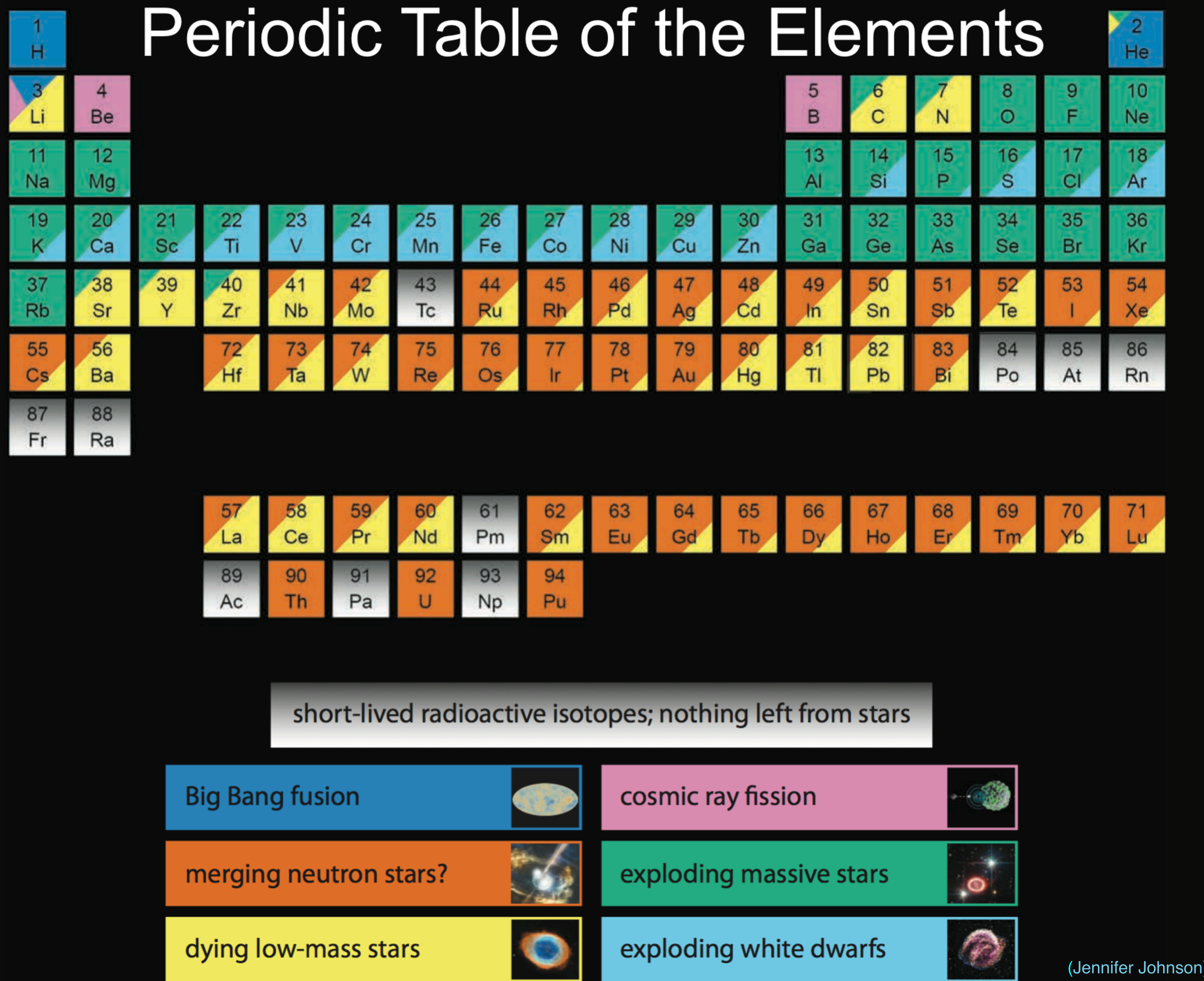
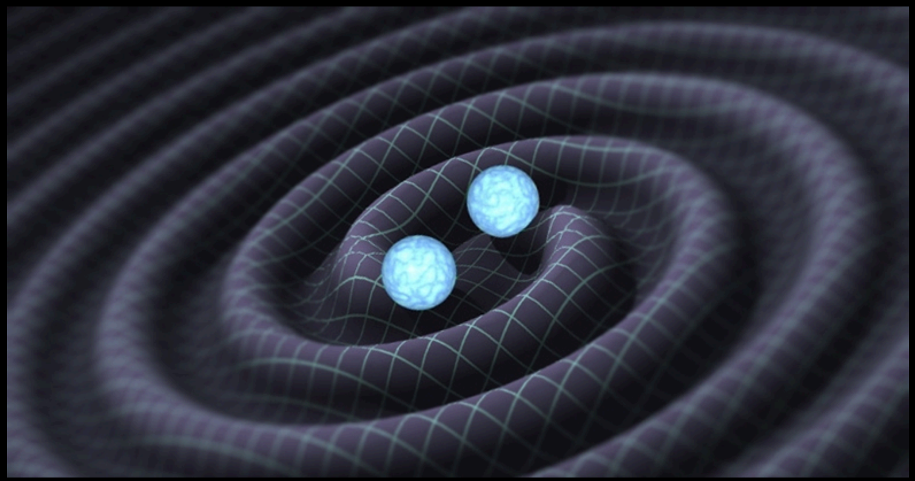
COSMOLOGY

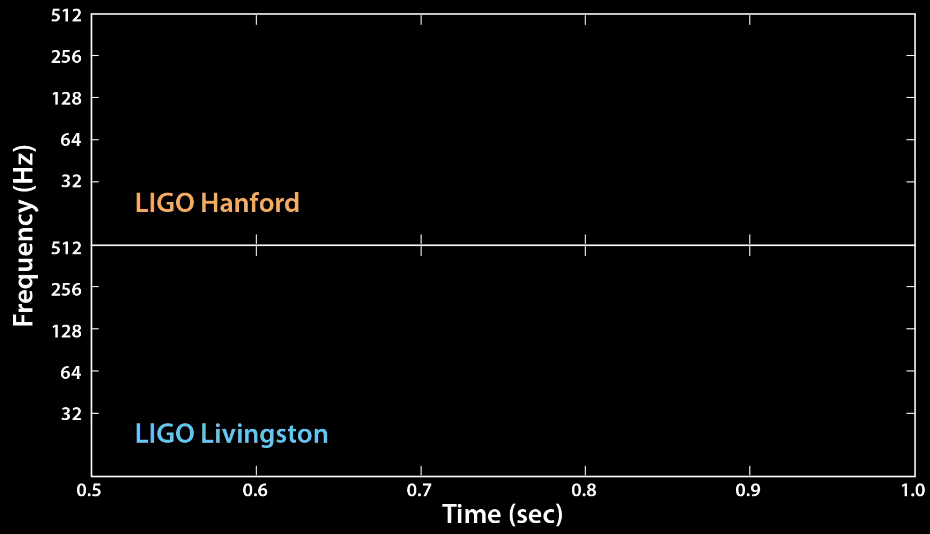
GALAXIES

PLANET HABITABILITY


Periodic Table of the Elements
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pu
short-lived radioactive isotopes; nothing left from stars
Big Bang fusion
cosmic ray fission
merging neutron stars?
exploding massive stars
dying low-mass stars
exploding white dwarfs
(Jennifer Johnson)

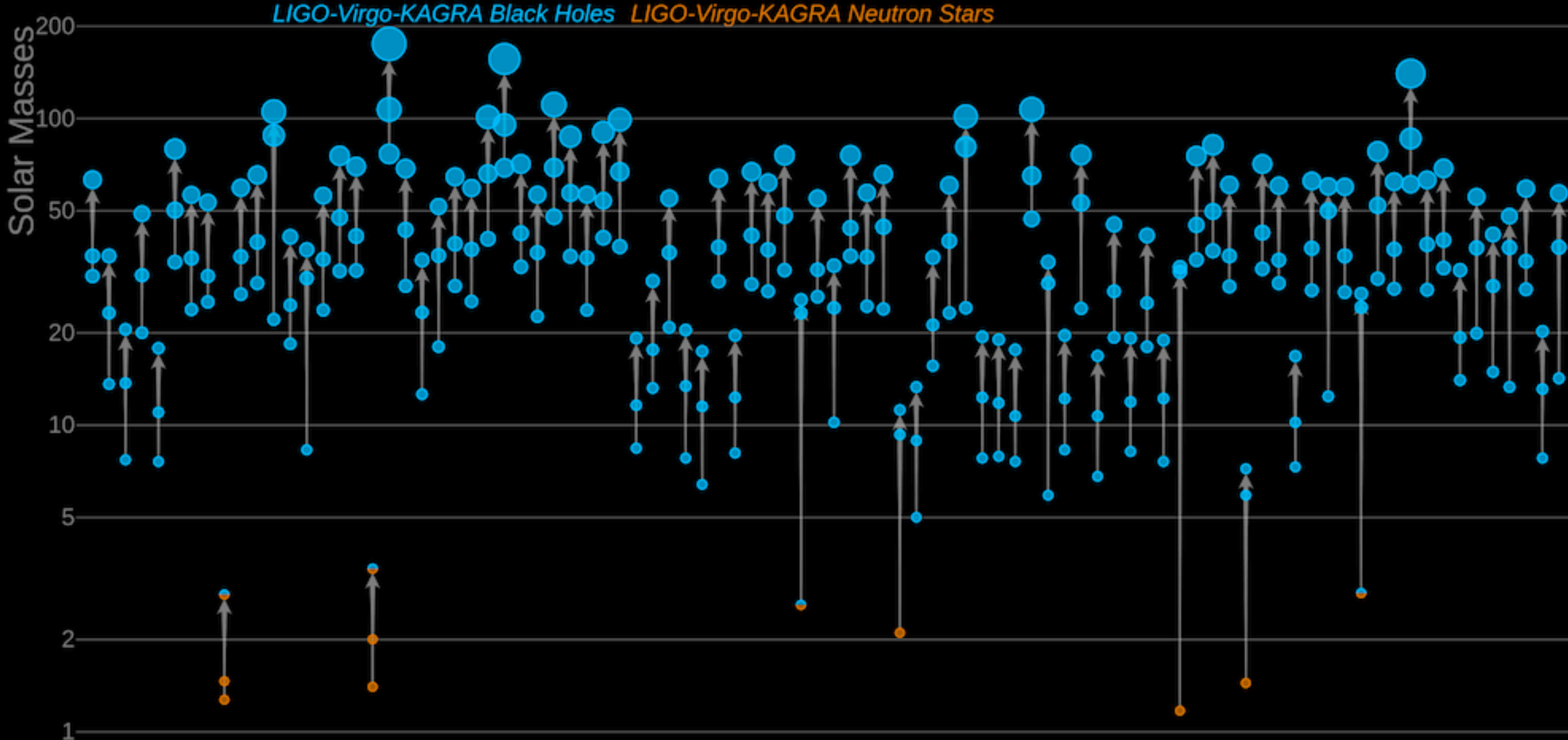
Many stars in the very early universe may have been much more massive than our sun, in binary star systems with other massive stars. When these stars ended their lives as supernovas, they became massive black holes. The Laser Interferometer Gravitational-wave Observatory (LIGO) has now detected > 90 mergers of massive black holes. This confirmed predictions of Einstein's general relativity that had never been tested before.





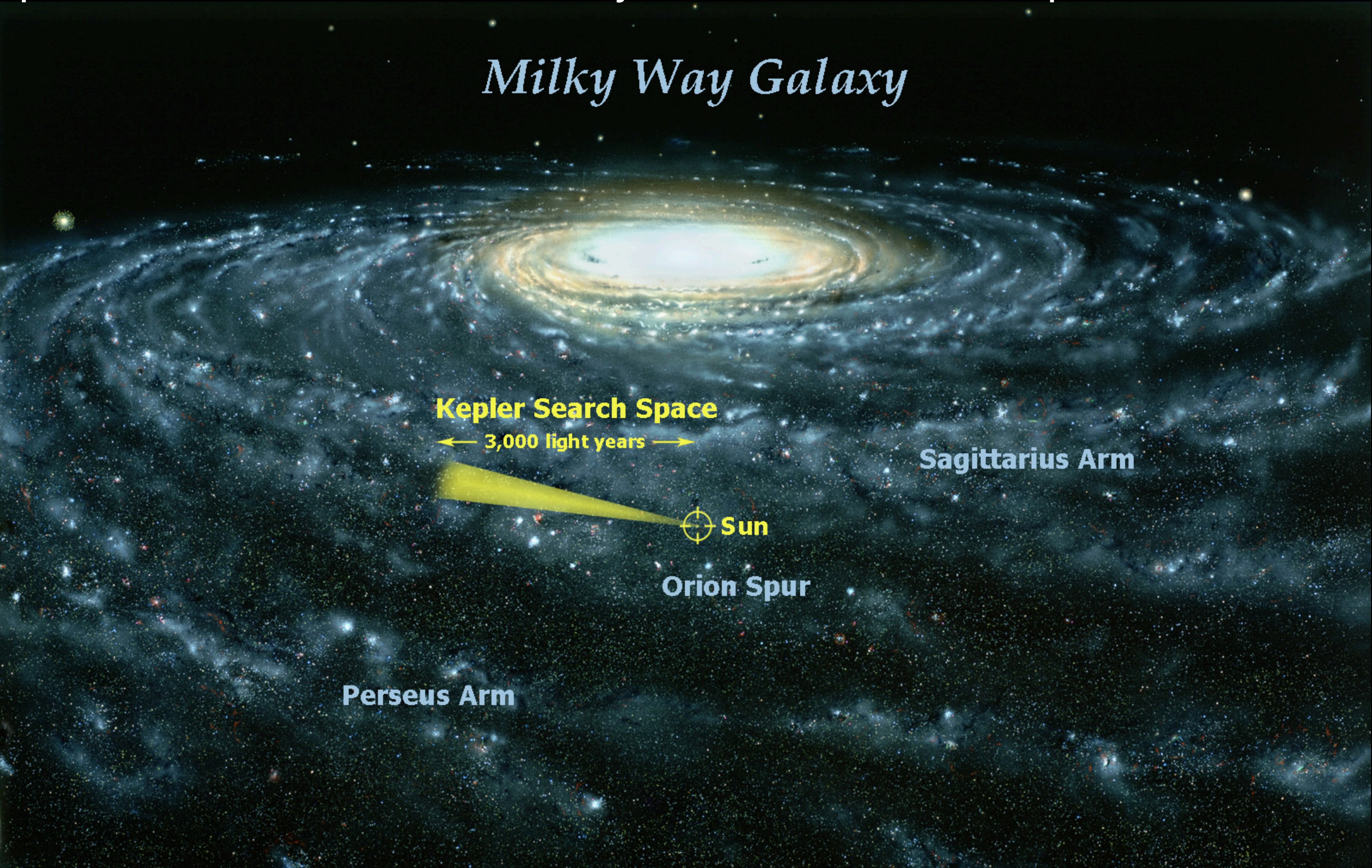
In August 2017 LIGO and Virgo announced the discovery of gravity waves from merging neutron stars. Data from telescopes shows that such rare events probably generate most of the heavy elements like europium, gold, thorium, and uranium.

Masses in the Stellar Graveyard

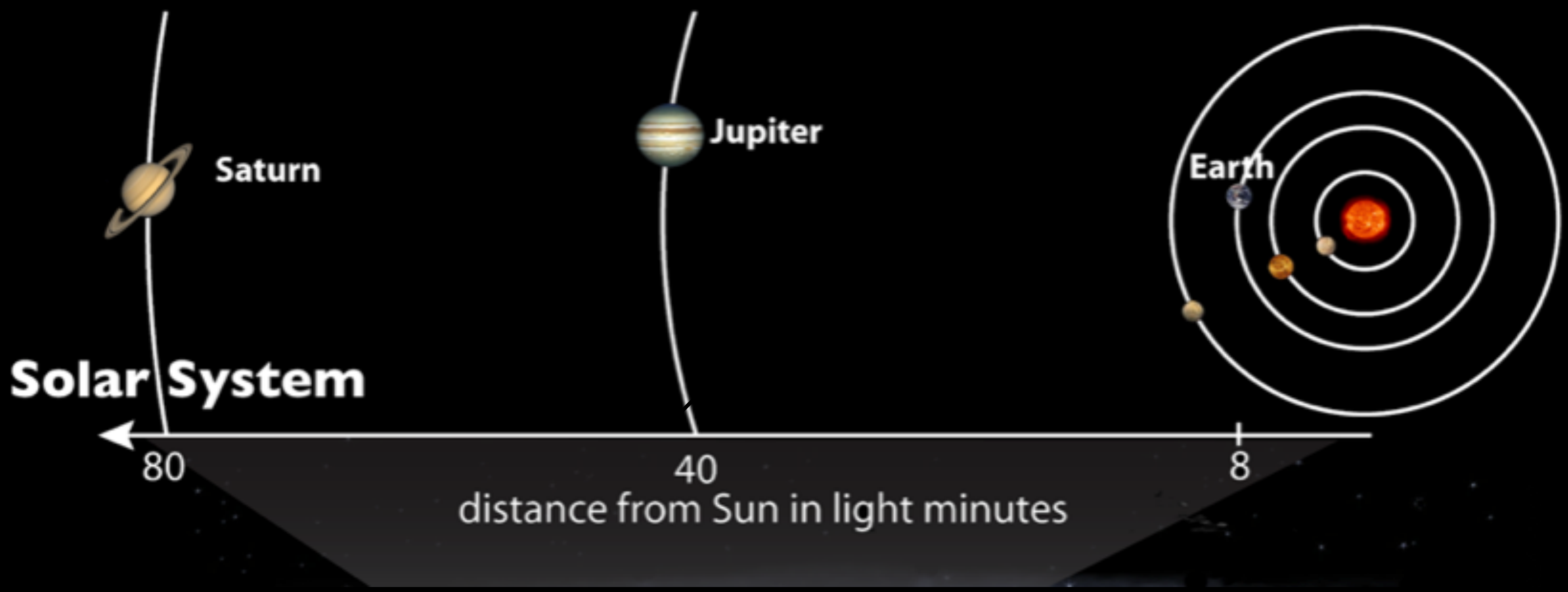


LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

We have now discovered about 5000 planetary systems, mainly using star radial velocities from ground-based telescopes and planet-star transits observed by NASA's satellites Kepler and TESS.



We used to think that our system is typical, with rocky planets near our star and gas giants farther away.



Of the ~ 5000 planetary systems astronomers have discovered, there are very few like ours, with all the planets widely spaced in nearly circular orbits. Most planetary systems are much smaller.

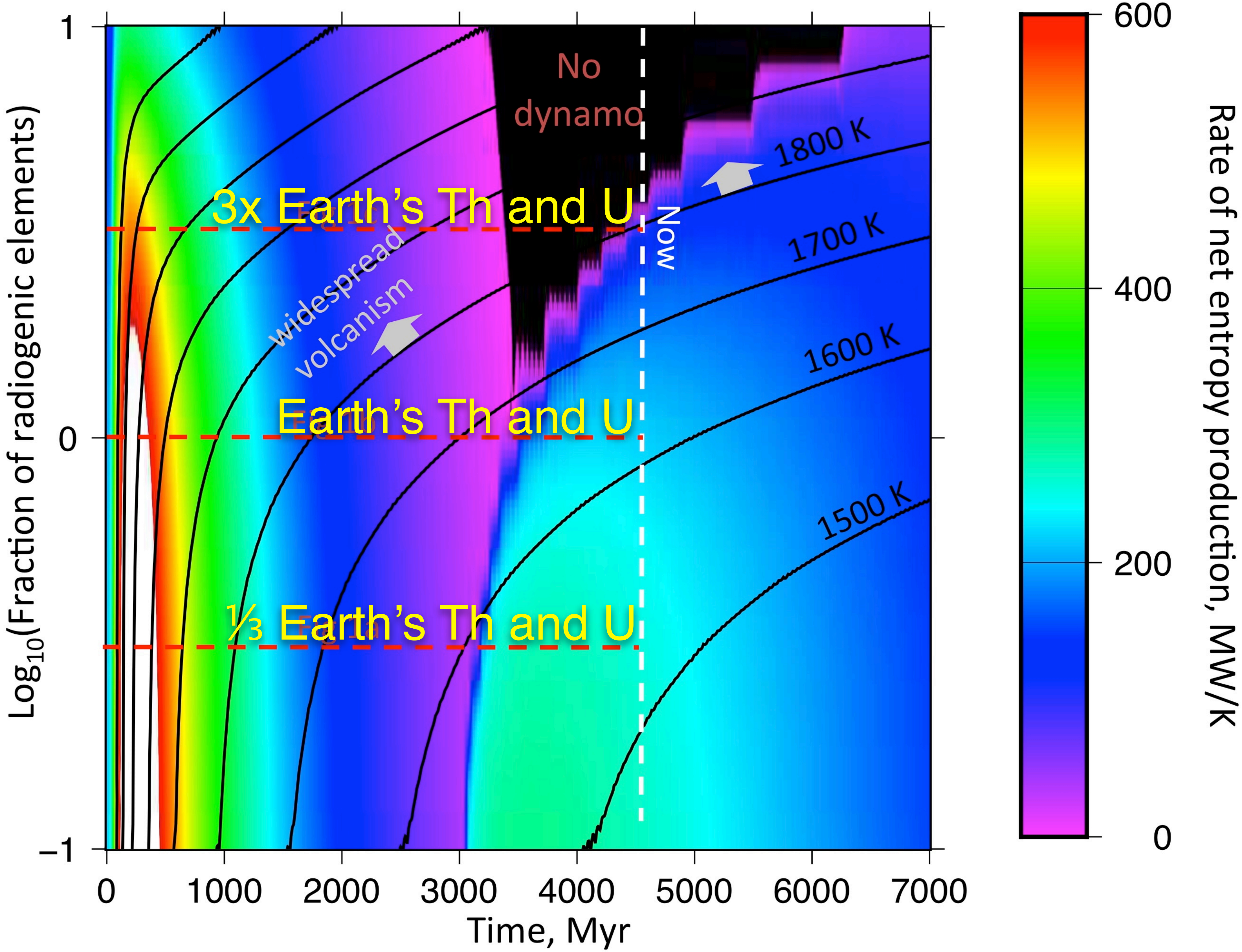
The most common type of planet seems to be 2 to 6 times Earth's mass, a "**super-Earth**". No such planet exists in our Solar System.

Some planets are in the **habitable zone around their stars** in which surface water would be in liquid form, but most of these planets are probably not hospitable to advanced forms of life. For one thing, they might not have an optimal abundance of the long-lived radioactive elements thorium and uranium to power plate tectonics and permit a magnetic dynamo. Such heavy elements are mainly produced by neutron star mergers and other very rare events, so the distribution of such elements is inhomogeneous. Nimmo, Primack et al. 2020 showed that too much Th and U would result in a lava world with frequent flood vulcanism, which caused the greatest mass extinction events on Earth. **Our living Earth may be a rare "Goldilocks" planet** with just the right amount of Th and U.

Radiogenic Heating and its Influence on Rocky Planet Dynamos and Habitability

Francis Nimmo, Joel Primack, S. M. Faber, Enrico Ramirez-Ruiz, and Mohammadtaher Safarzadeh

Astrophysical Journal Letters (November 2020)



3x Earth’s Th and U

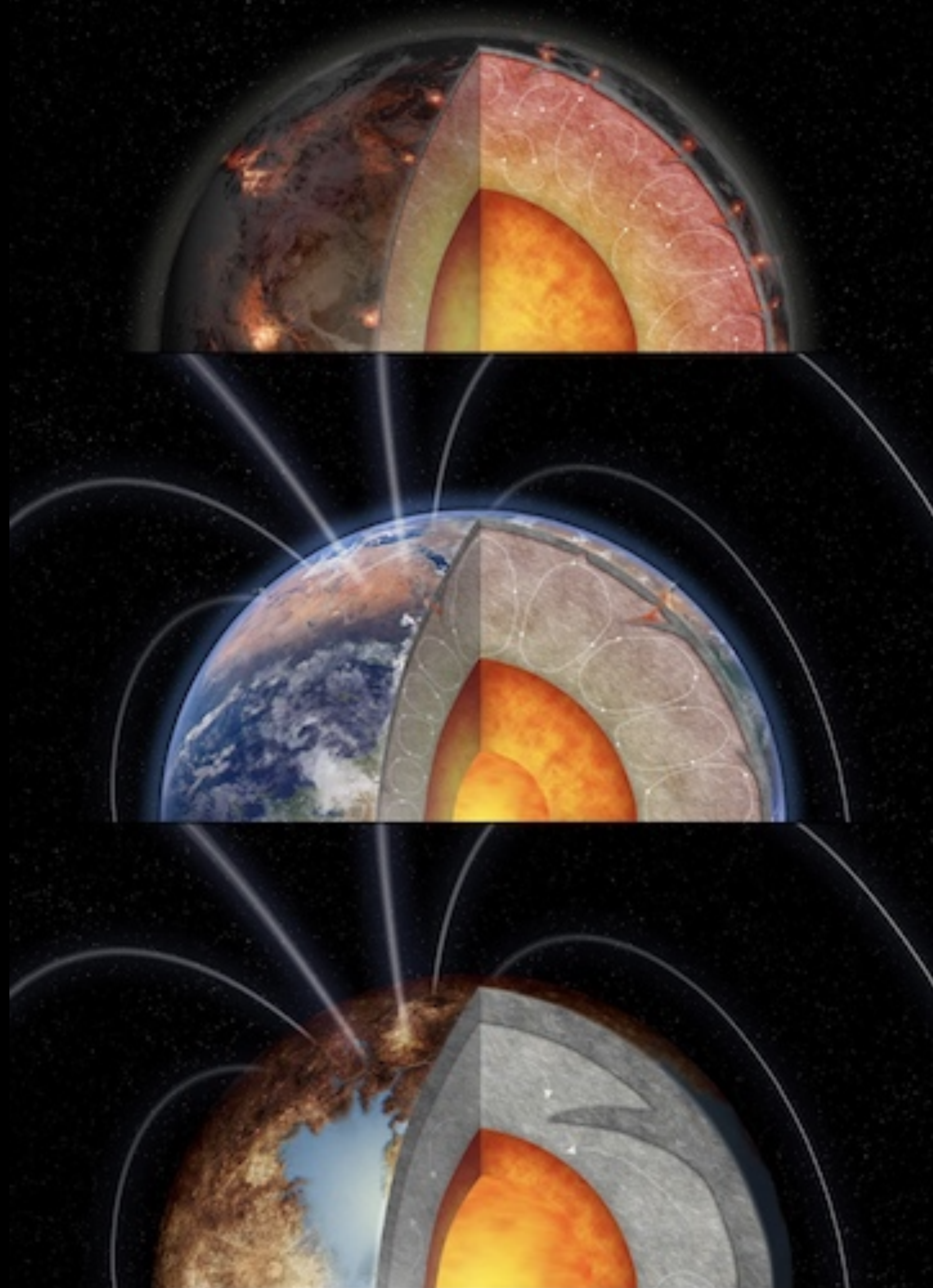
No magnetic dynamo &
frequent flood vulcanism

Earth’s Th and U

Magnetic dynamo &
plate tectonics

⅓ Earth’s Th and U

Magnetic dynamo
but no plate tectonics



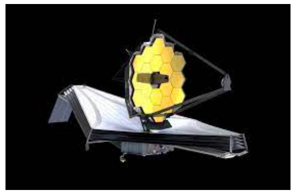
Looking for Biosignatures

To detect life on a distant planet, we study starlight that has interacted with the planets's surface or atmosphere. JWST is the first telescope with the capability to detect characteristic spectra of chemical elements or compounds in the light from planets that could be signatures for life. But JWST can do such searches only for rather nearby planets. Subsequent telescopes will be able to look farther away. But such searches are likely to require a lot of telescope time, so it will be helpful to be able to narrow down the search to planets in which complex life is more likely to have evolved. In addition to being in the "habitable zone" — the distance from its star where water will be liquid — it may also be helpful to determine whether the radioactive heating from the long-lived radioactive elements Thorium and Uranium is compatible with a magnetic field and tectonics.

Periodic Table of the Elements

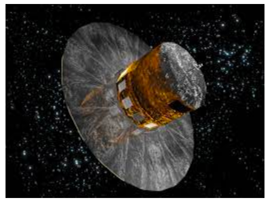
James Webb Space Telescope Joins the League of Super-Telescopes

Like geology and evolutionary biology, astronomy is an historical science. The goal of the historical sciences is to reconstruct the past and thereby understand the present. But astronomy has a great advantage over these other sciences. Landforms on Earth erode and only a tiny fraction of organisms fossilize, but almost all the energy that was ever radiated by galaxies is still streaming through the universe in some form. The trick is to be able to detect all this energy and be clever enough to understand it. Fortunately, new observatories on the ground and in space are making this possible.



Webb's most important superpower is its ability to collect and analyze light of much longer wavelengths than visible light, including heat radiation from planets and the light from very distant galaxies.

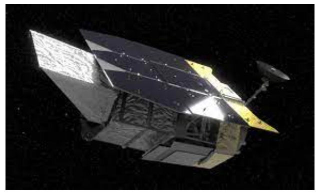
LIGO opened a new window on the universe when it started detecting gravity waves from merging black holes in 2015 and merging neutron stars in 2017. LIGO is now working with the **VIRGO** gravity-wave detector in Italy and **KAGRA** in Japan, and they will be joined by a similar detector in India.



Gaia, launched in 2013, is mapping more than a billion stars in our Milky Way galaxy so precisely that it can measure their velocities across the sky by seeing how their locations change over a few years.

eROSITA, launched in 2019, is an X-ray telescope that for the first time is cataloging the 100,000 brightest clusters of galaxies and the brightest quasars over the entire sky.

Vera Rubin Observatory in northern Chile is the first wide-field giant telescope and its Legacy Survey of Space and Time (**LSST**) will soon begin making a high-resolution movie of the entire southern sky.



Nancy Roman Space Telescope is like Hubble on steroids. Every image of the sky from Roman Space Telescope will cover about 100 times the area of each Hubble image with almost the same resolution.

Square Kilometer Array (SKA) of thousands of radio telescopes, now being built in southern Africa, Australia, and New Zealand, will discover how the universe evolved during the cosmic dark ages, before the first stars formed. SKA will also search for signals from intelligent life in the universe.

Some Concluding Thoughts

Without Dark Matter We Wouldn't Exist

With only the ordinary matter, the universe would be a low-density featureless soup

Dark matter started to form structures very early

Galaxies formed within bound "halos" of dark matter

Stars formed within galaxies, and stars made elements beyond hydrogen and helium: carbon, oxygen, …

Rocky planets formed from these heavier elements

Life began and evolved on one such planet

Dark matter is our ancestor and our friend!

Science Is Much Stranger Than Fiction

Before the discovery that most of the density of the universe is invisible, no one imagined this

What else remains to be discovered?