

Estudio de la Época de Reionización con simulaciones numéricas de alta resolución

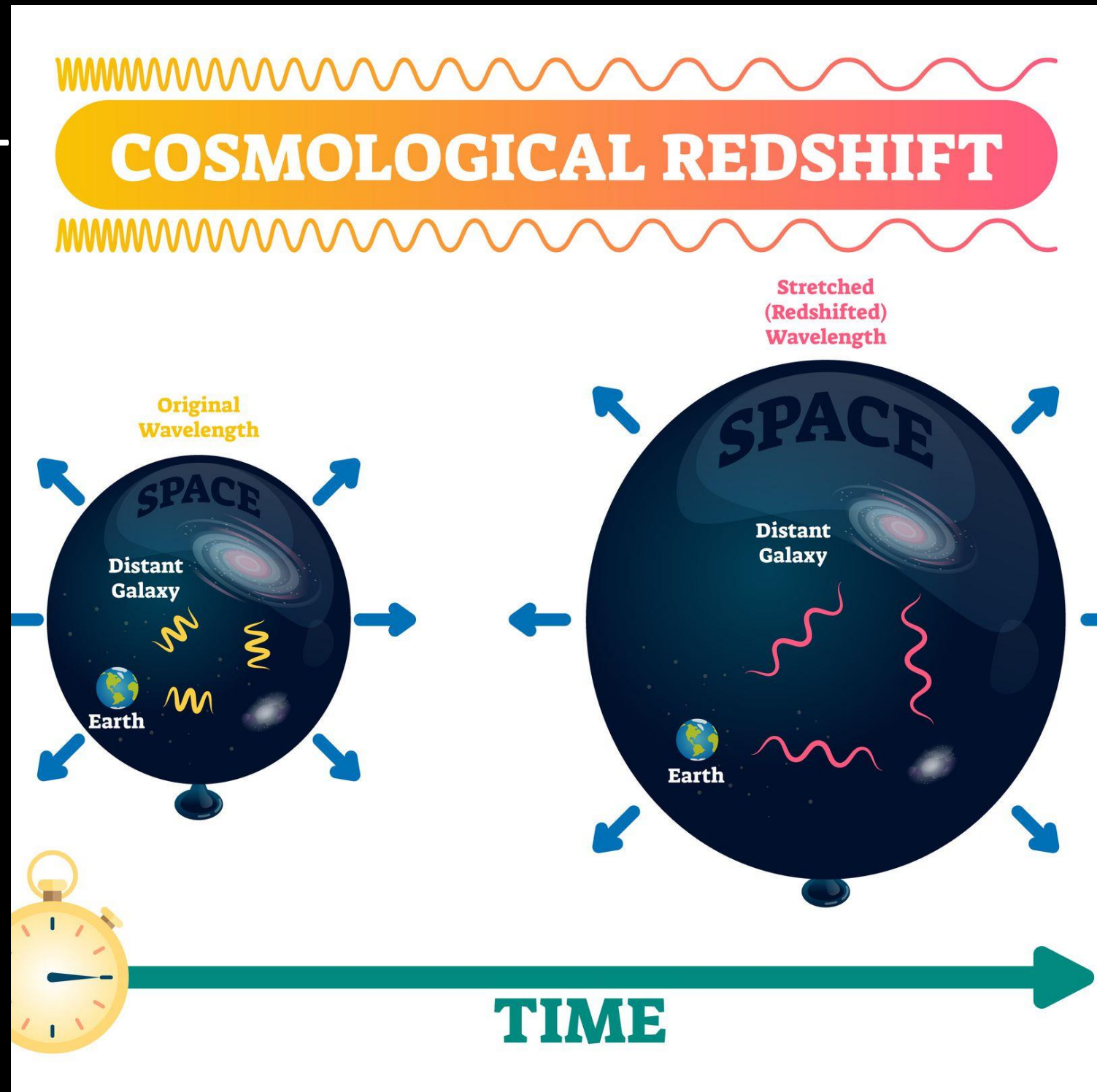
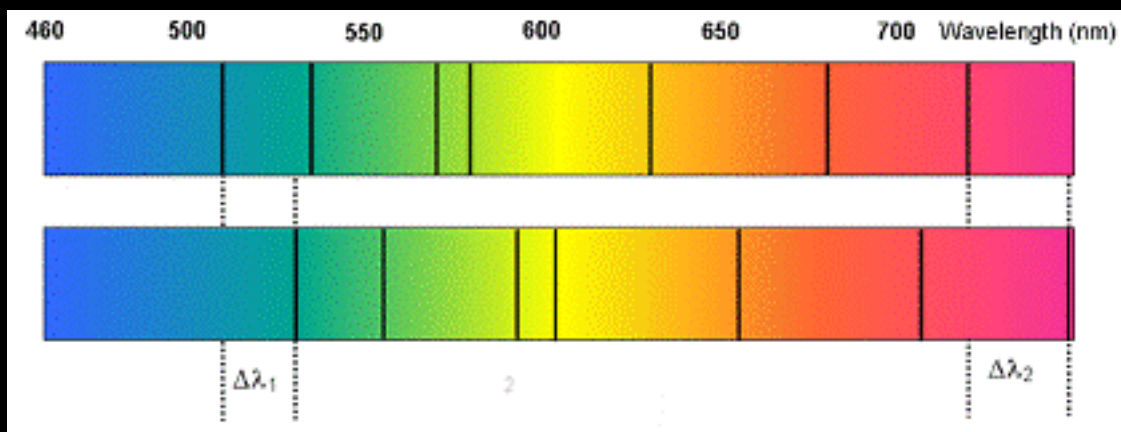
luz ángela garcía peñaloza

Universidad ECCI

Second EPIC School

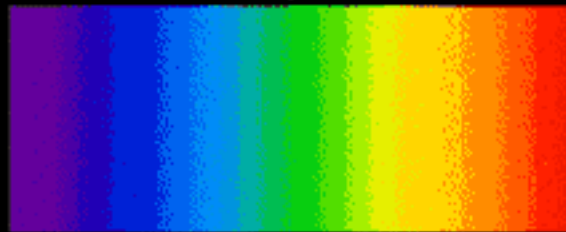
Octubre 13, 2022

ESPECTROS Y REDSHIFT





Stella Spectrum



Wavelength

Shorter = **Blue** = Object towards
Longer = **Red** = Objects away from

DOPPLER PRINCIPLE



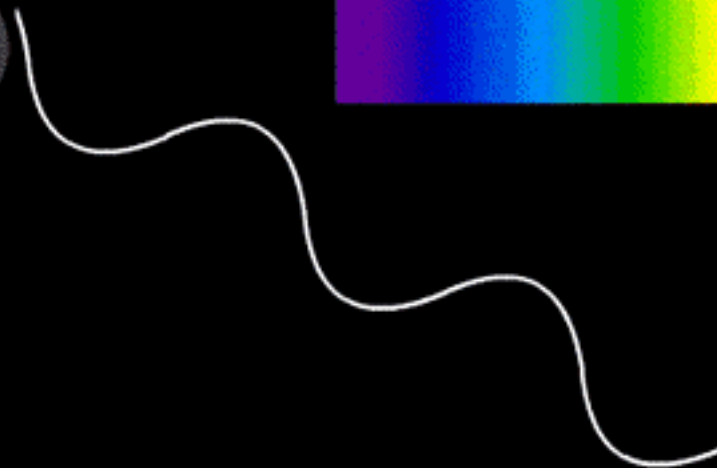
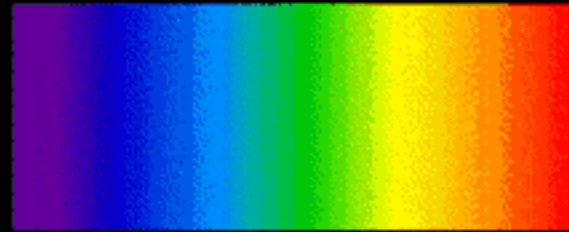
Wavelength

SHORTER WAVELENGTH
Objects towards us

LONGER WAVELENGTH
Objects away from us



Stella Spectrum



Wavelength

Shorter = **Blue** = Object towards
Longer = **Red** = Objects away from

DOPPLER PRINCIPLE



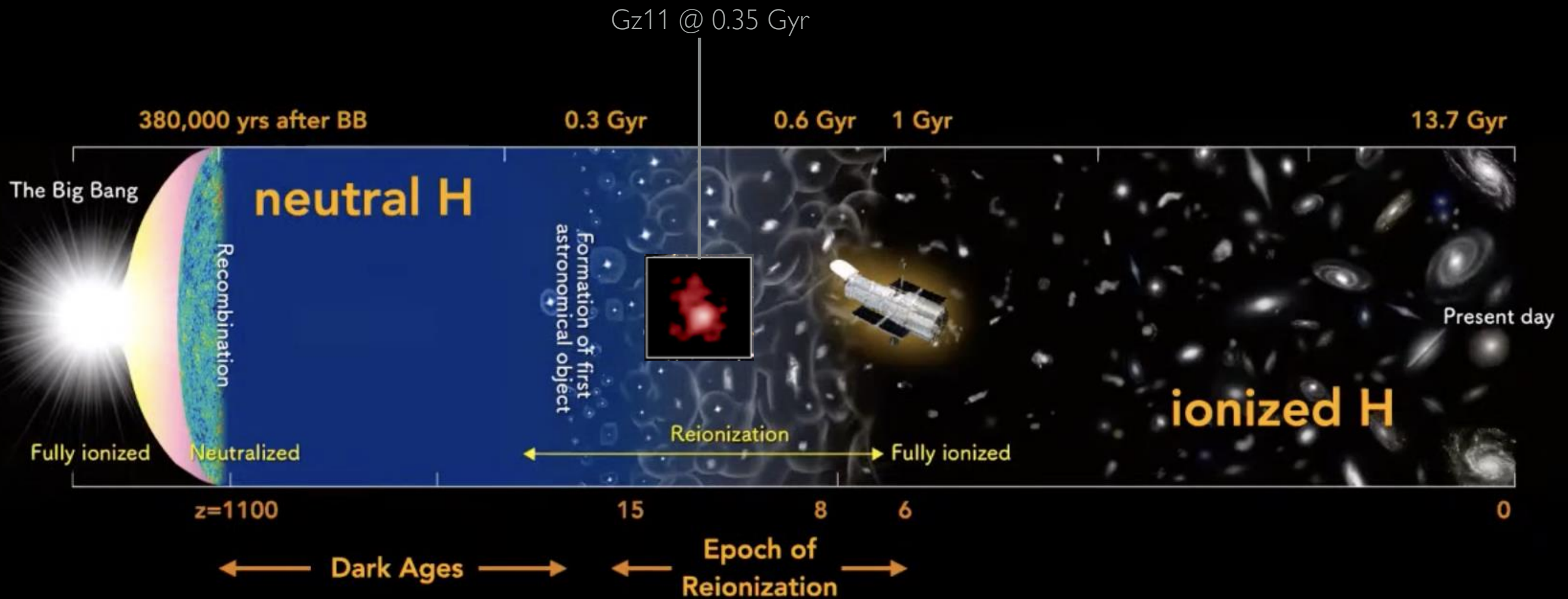
Wavelength

SHORTER WAVELENGTH
Objects towards us

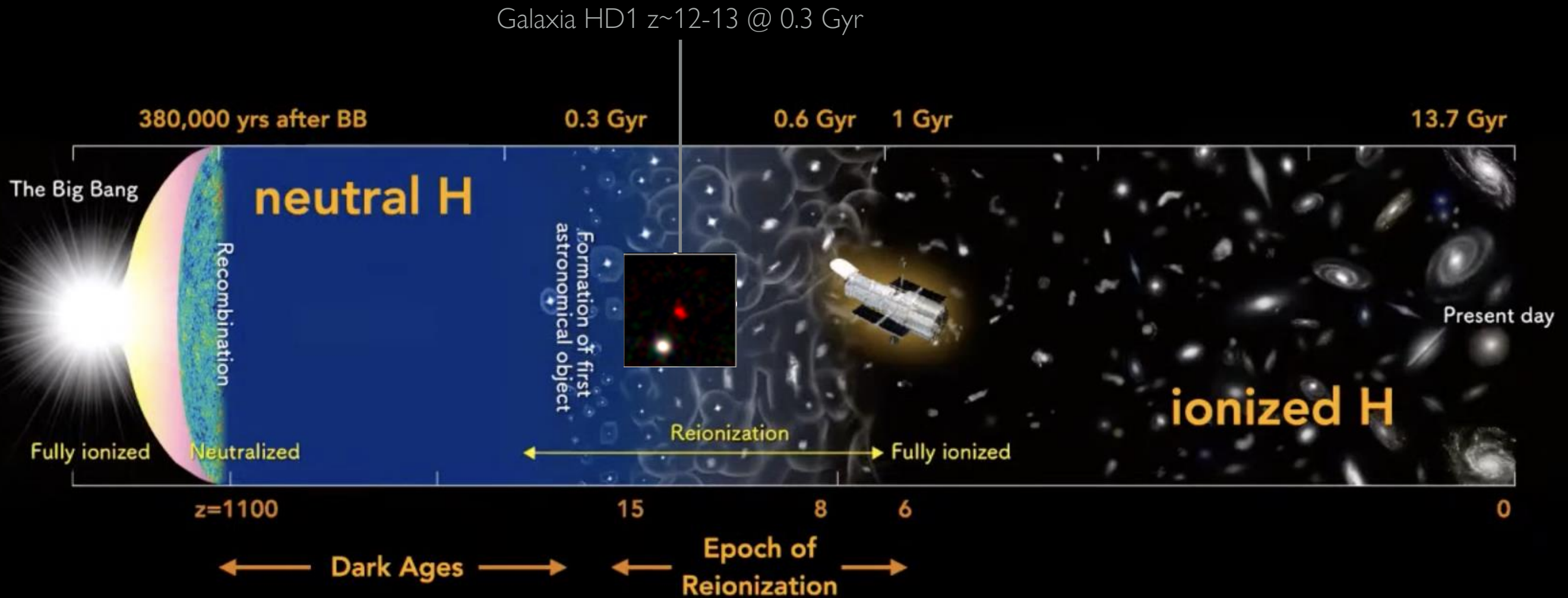
LONGER WAVELENGTH
Objects away from us



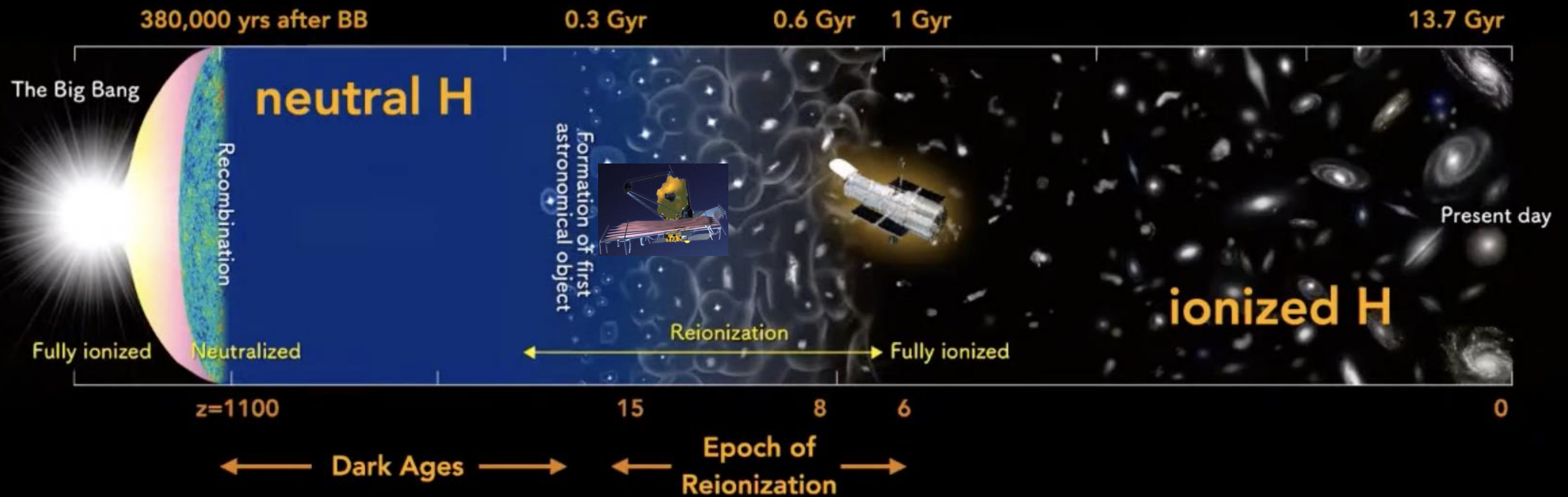
Breve historia del universo

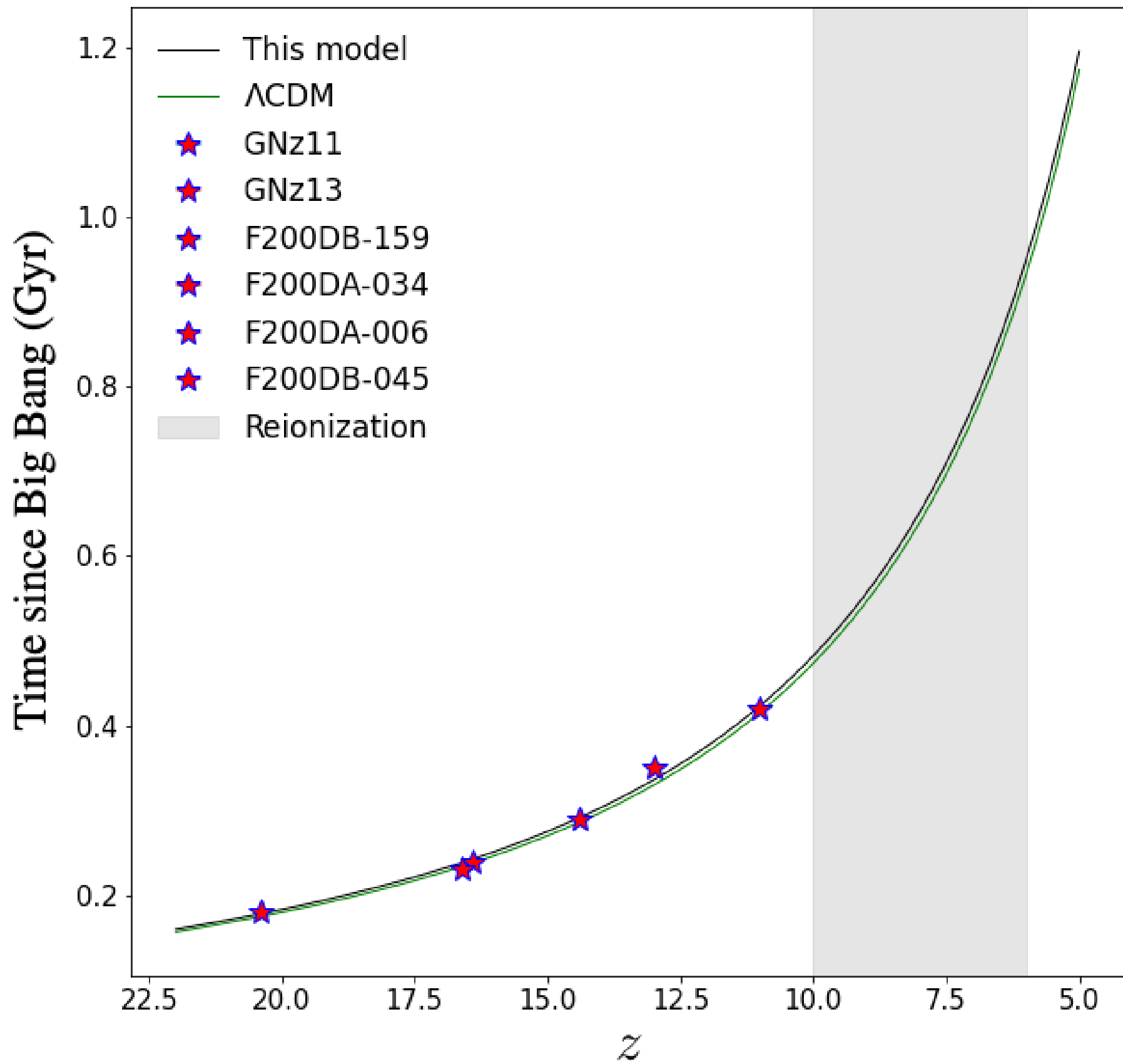


Breve historia del universo

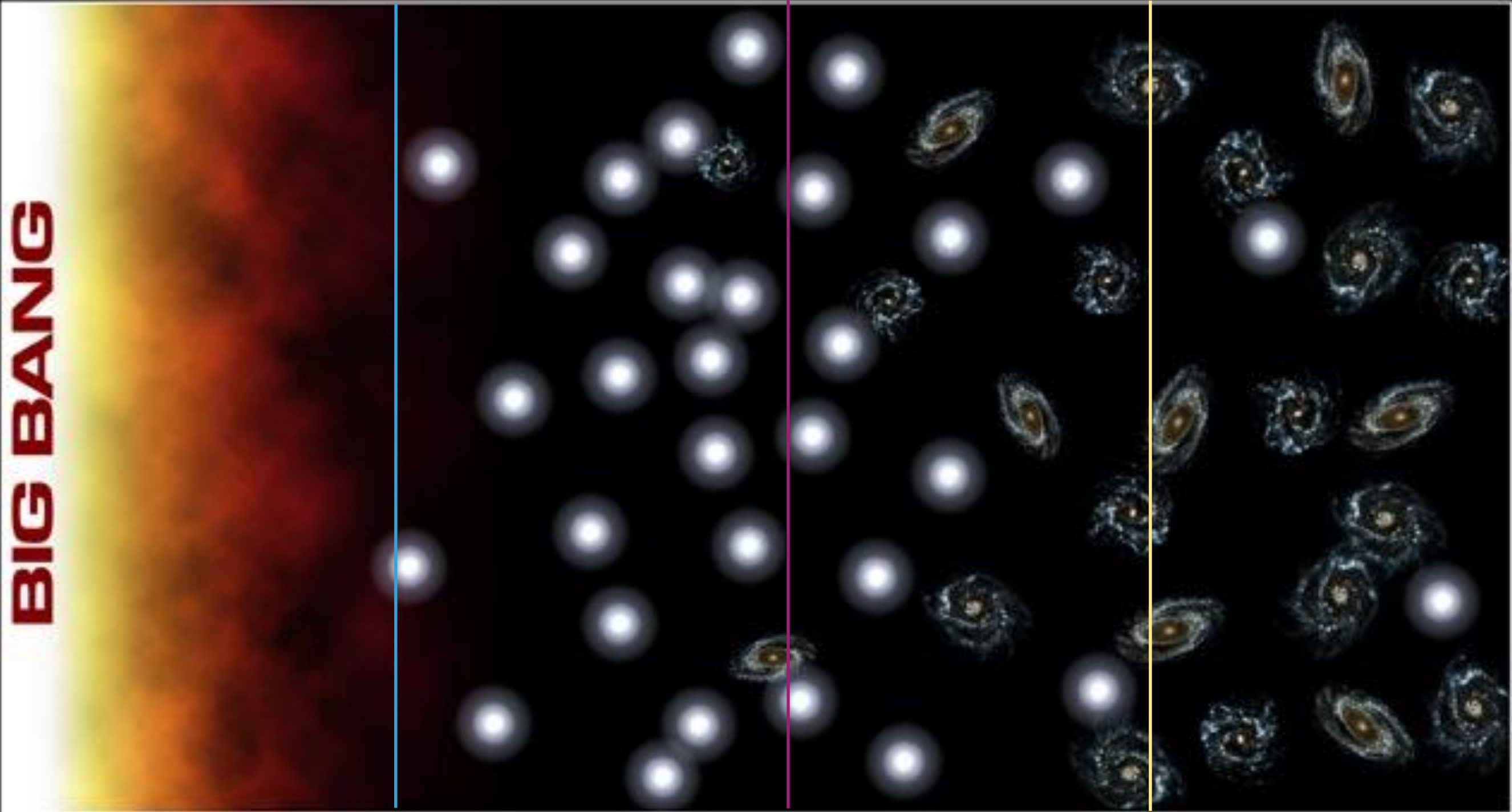


Breve historia del universo





Timeline of the Universe



BIG BANG

POPIII

POPII

POPI

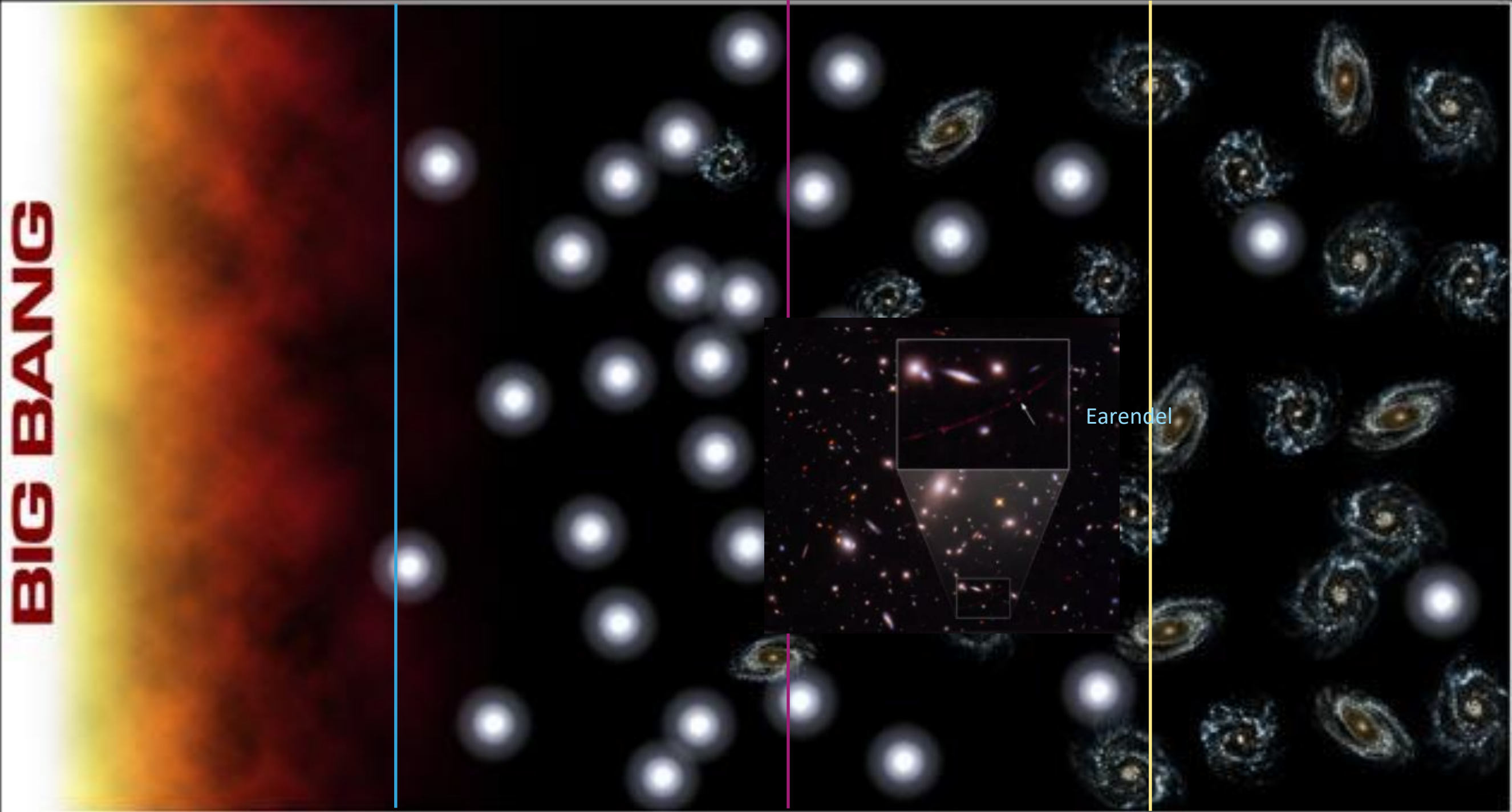
Early Universe

Galaxy Formation

Today

Timeline of the Universe

BIG BANG



POPIII

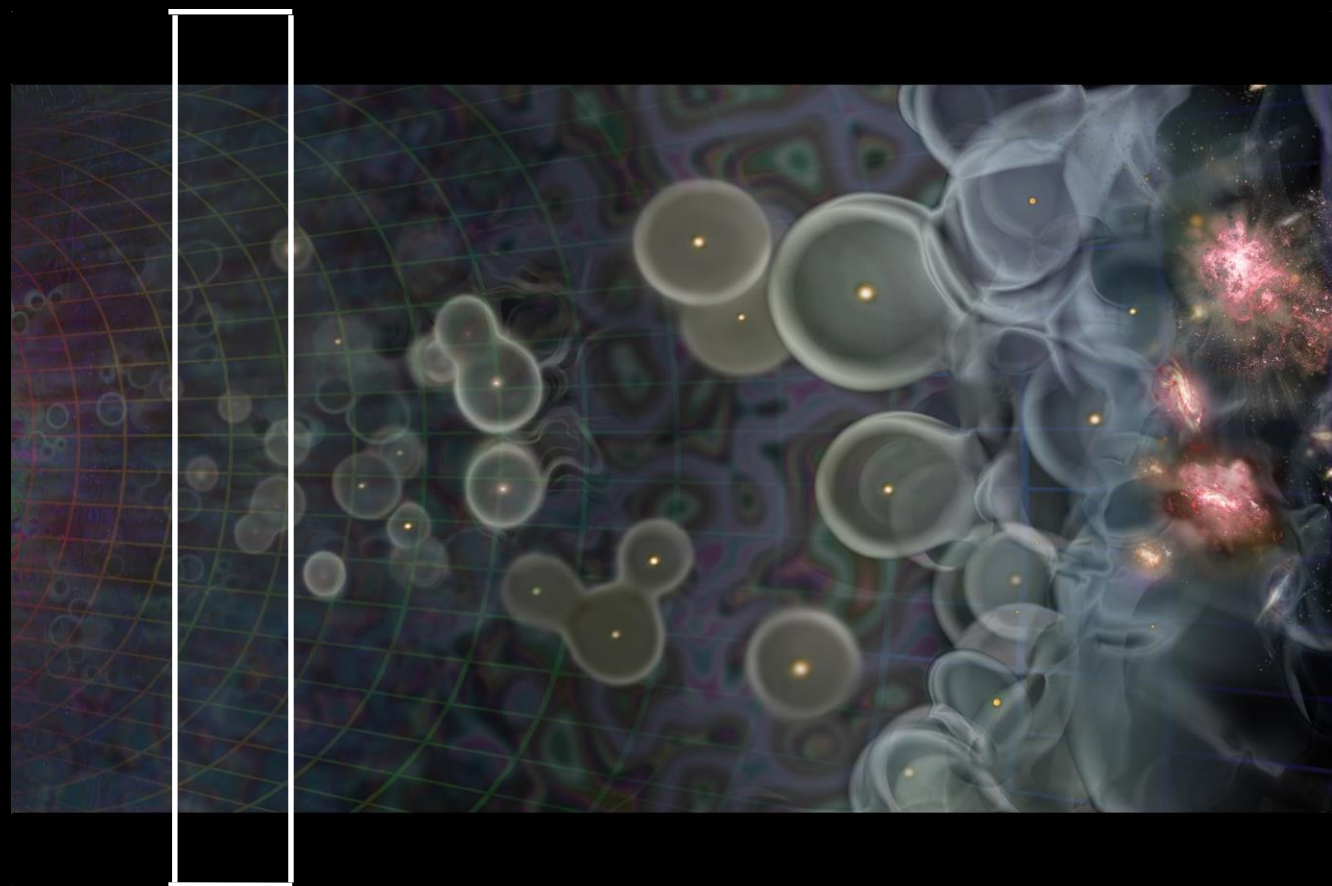
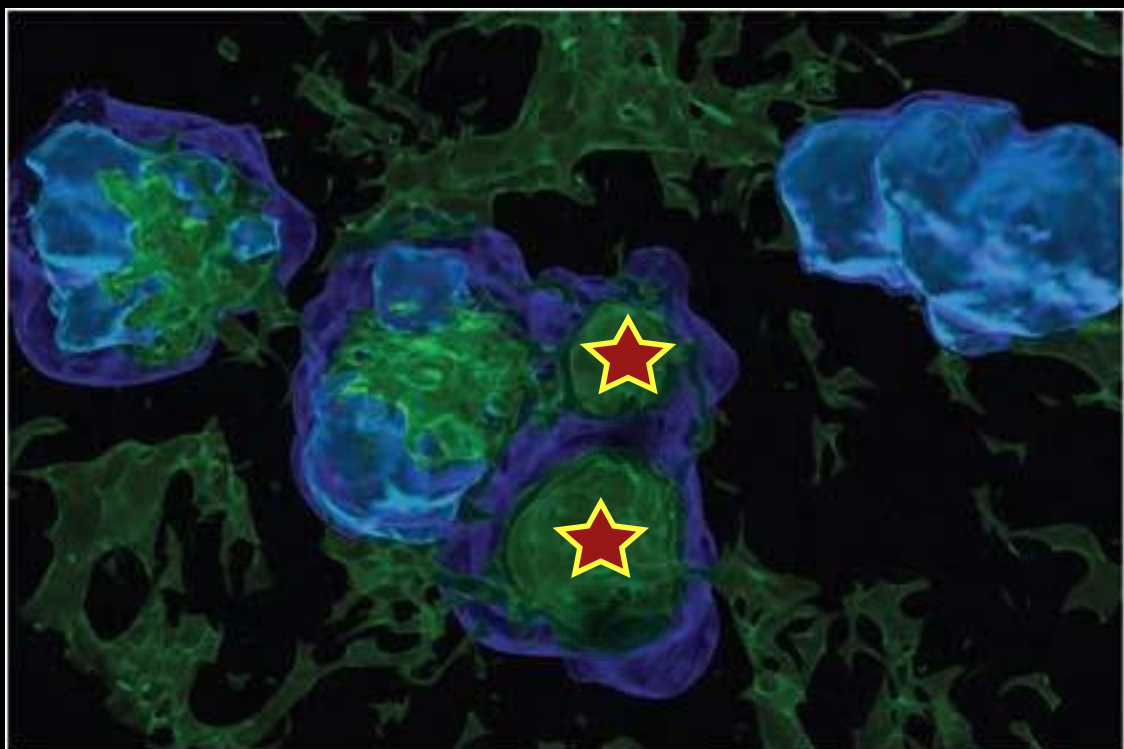
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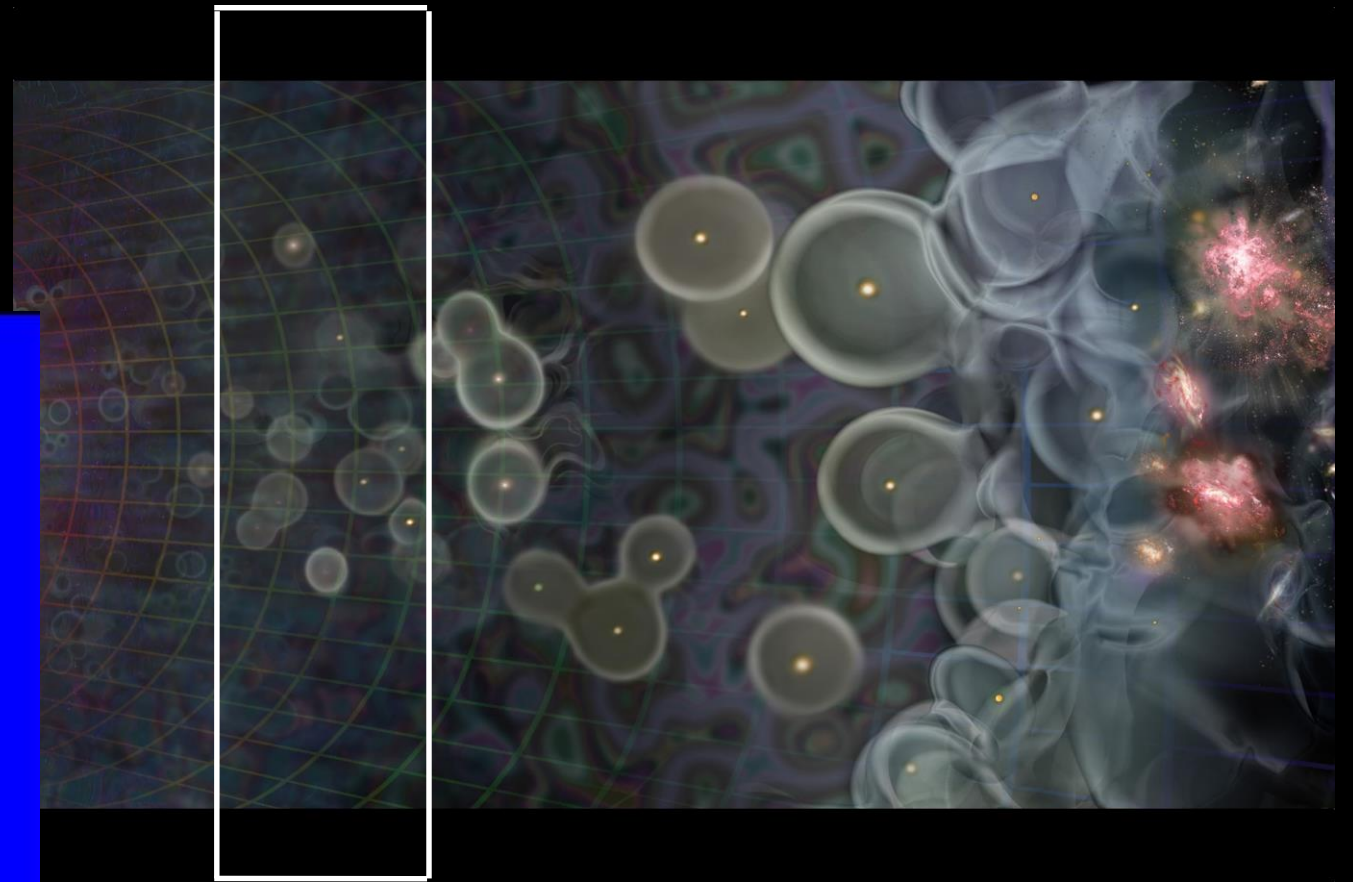
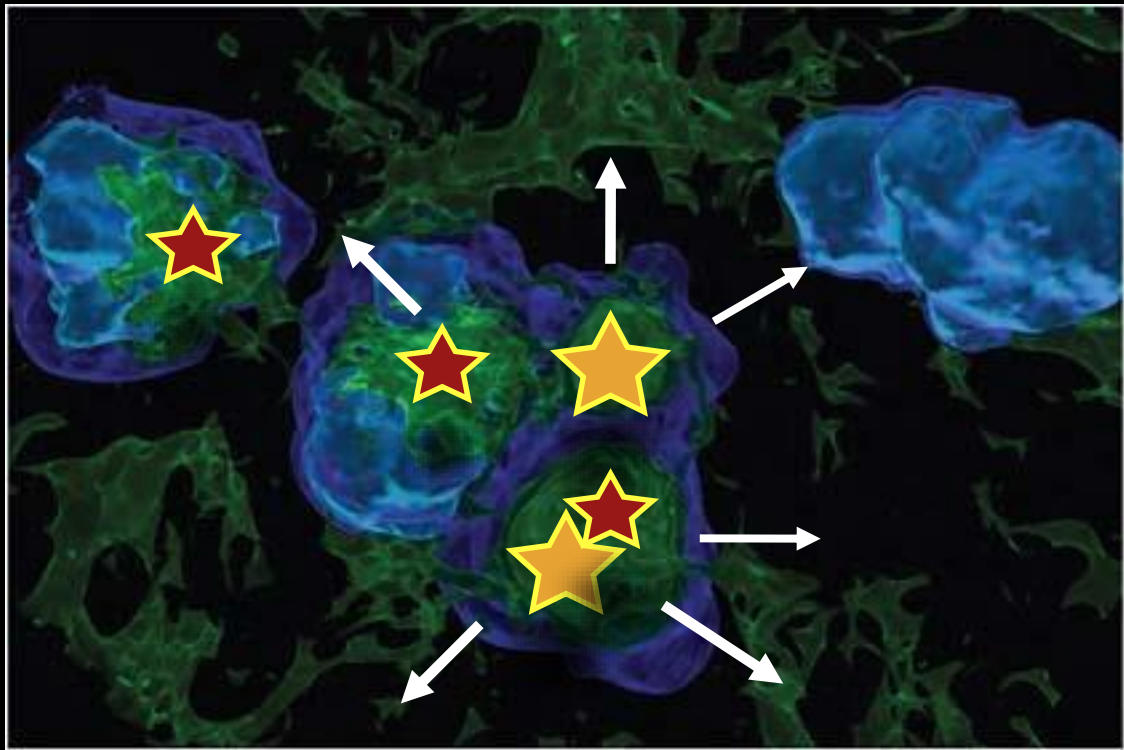
POPI

Early Universe

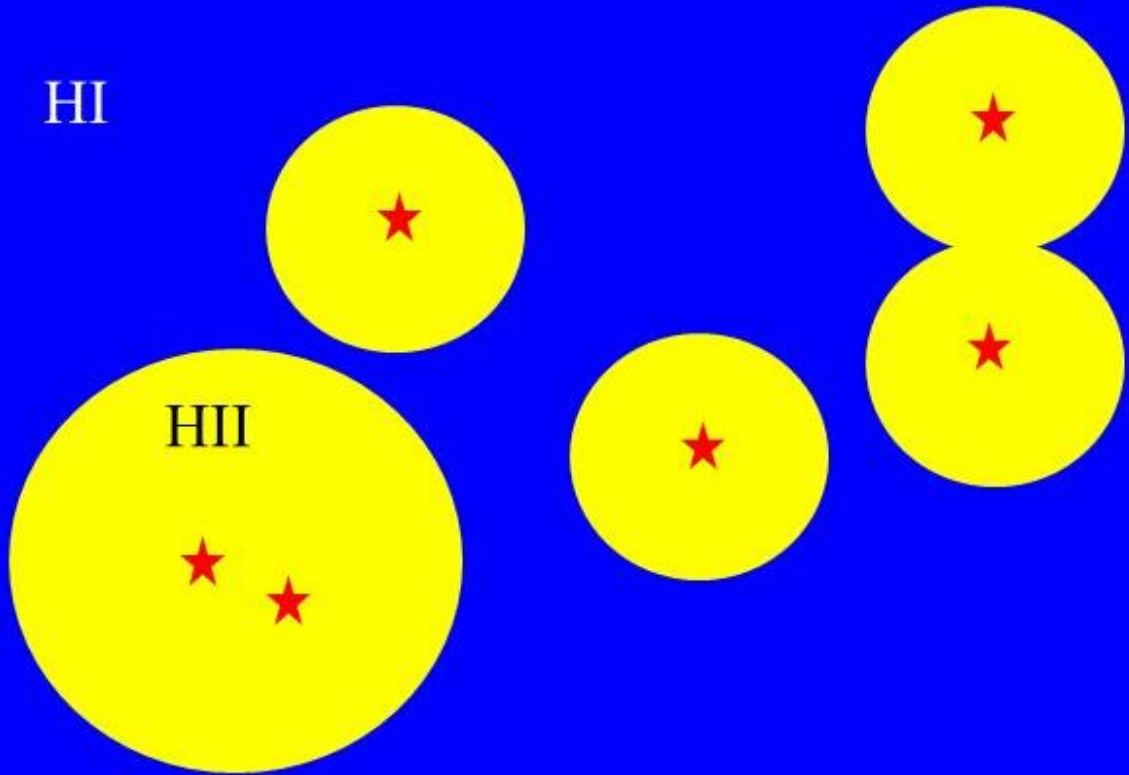
Galaxy Formation

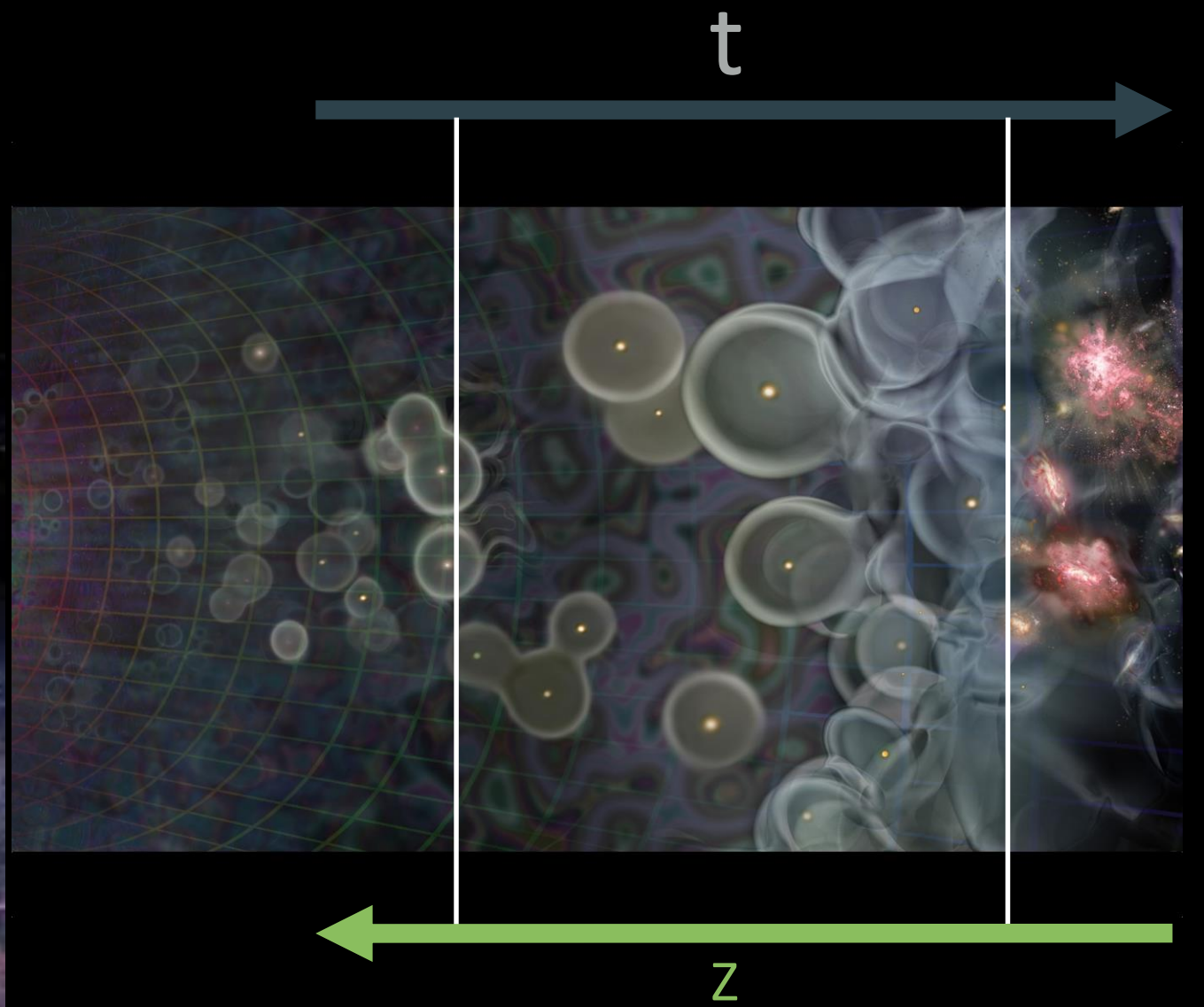
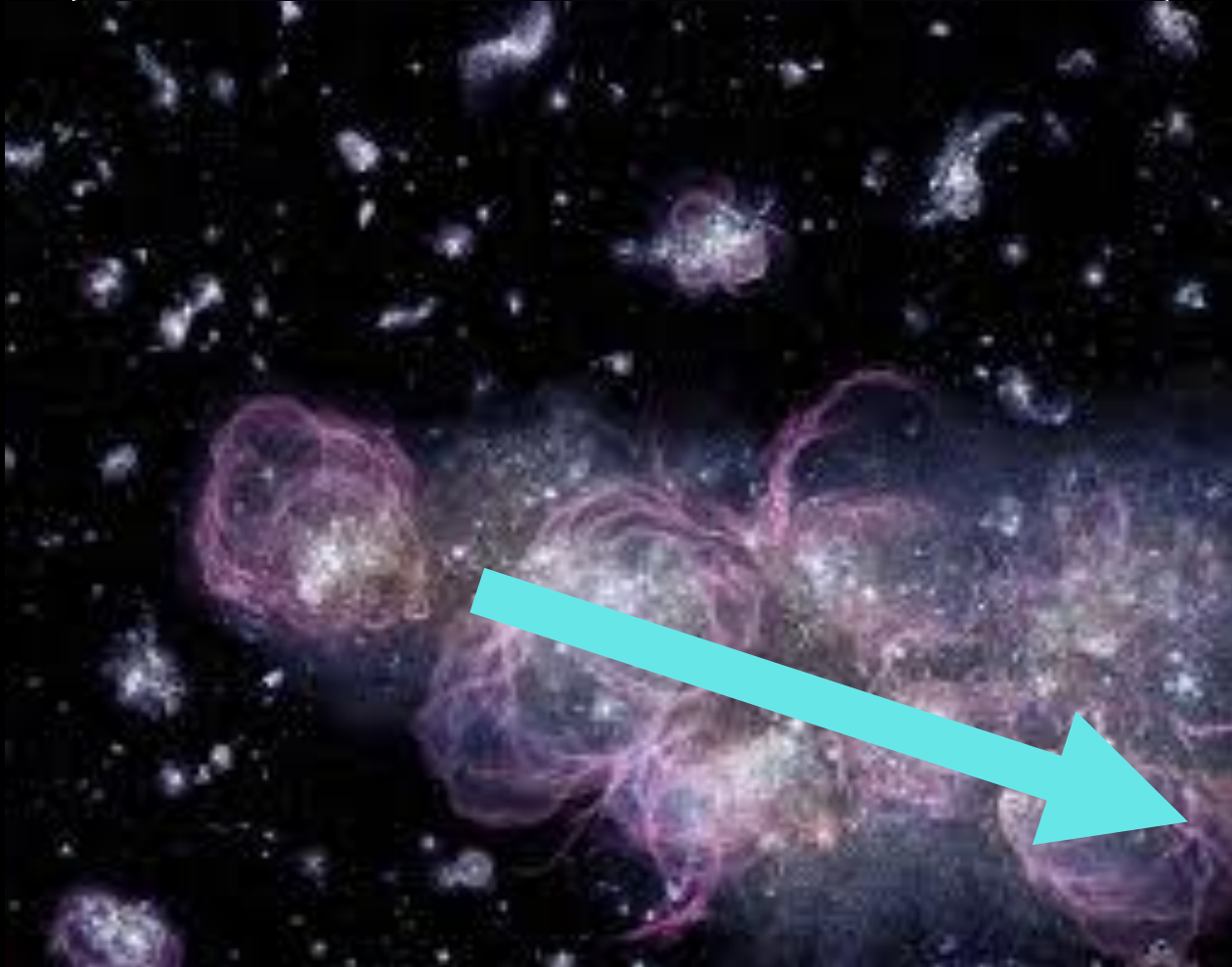
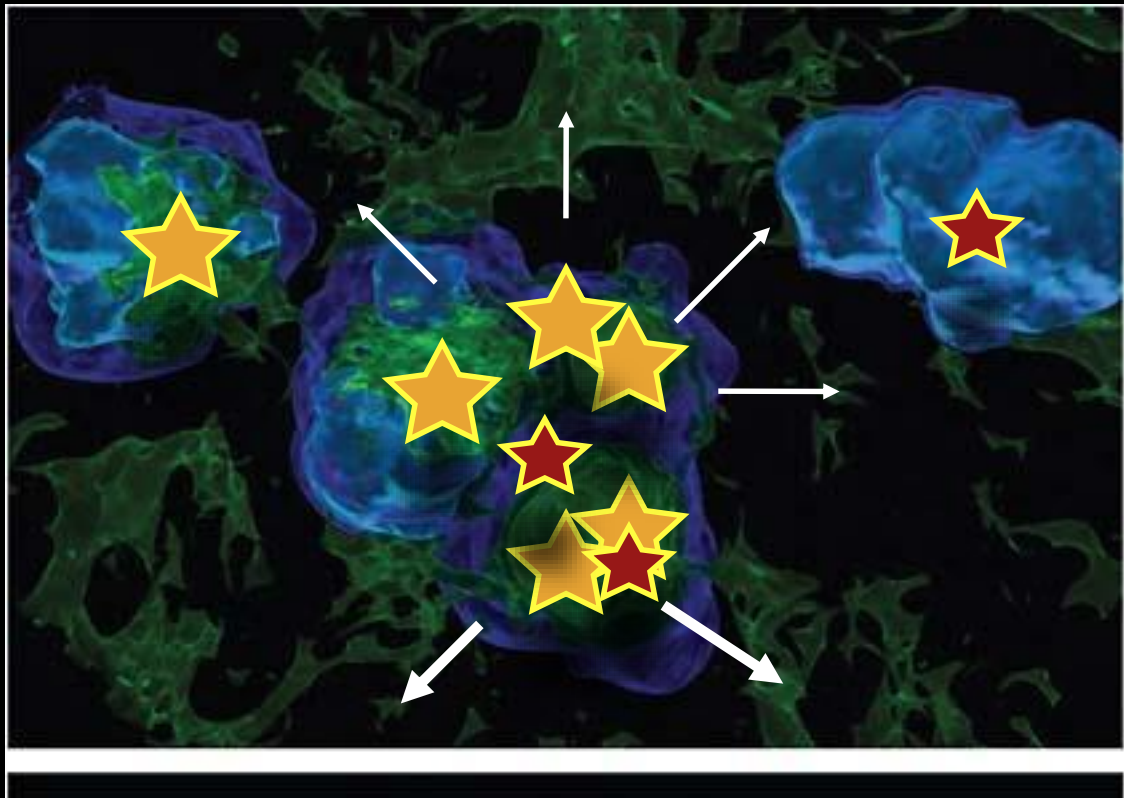
Today





HI

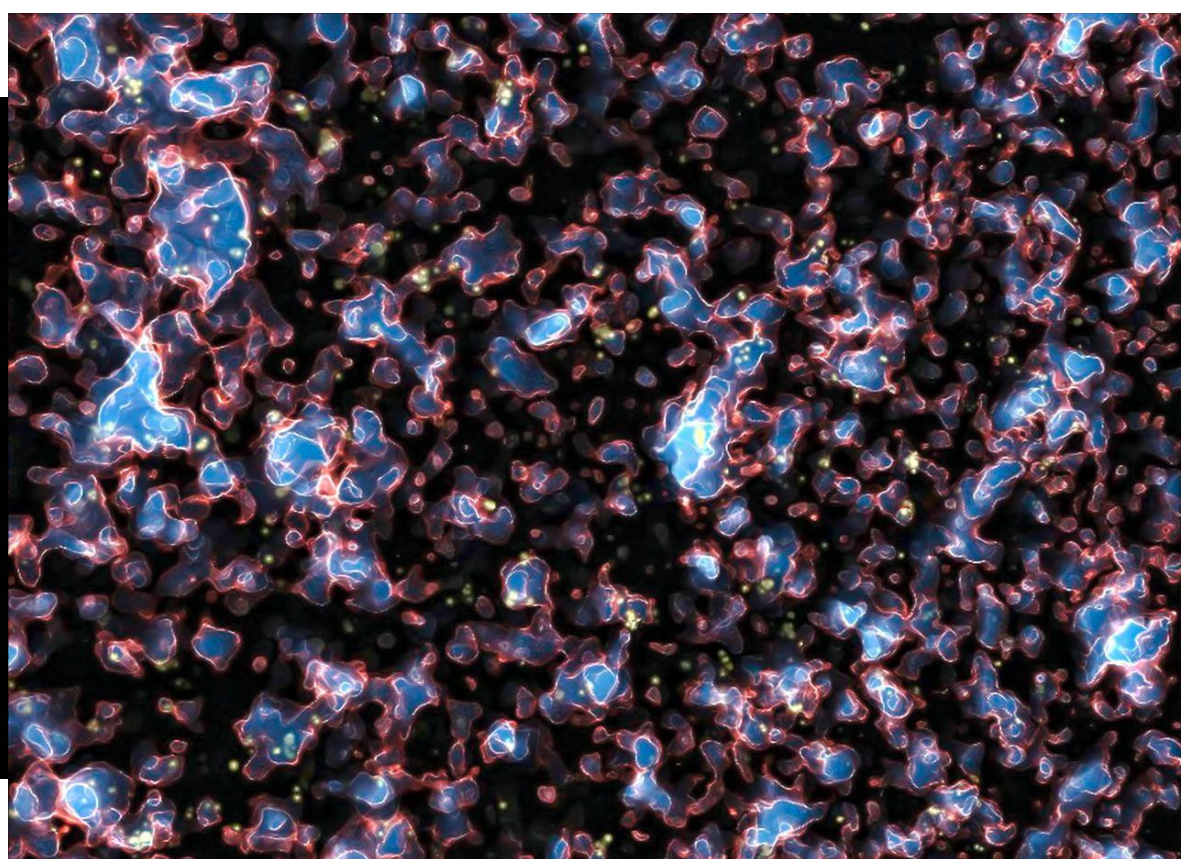
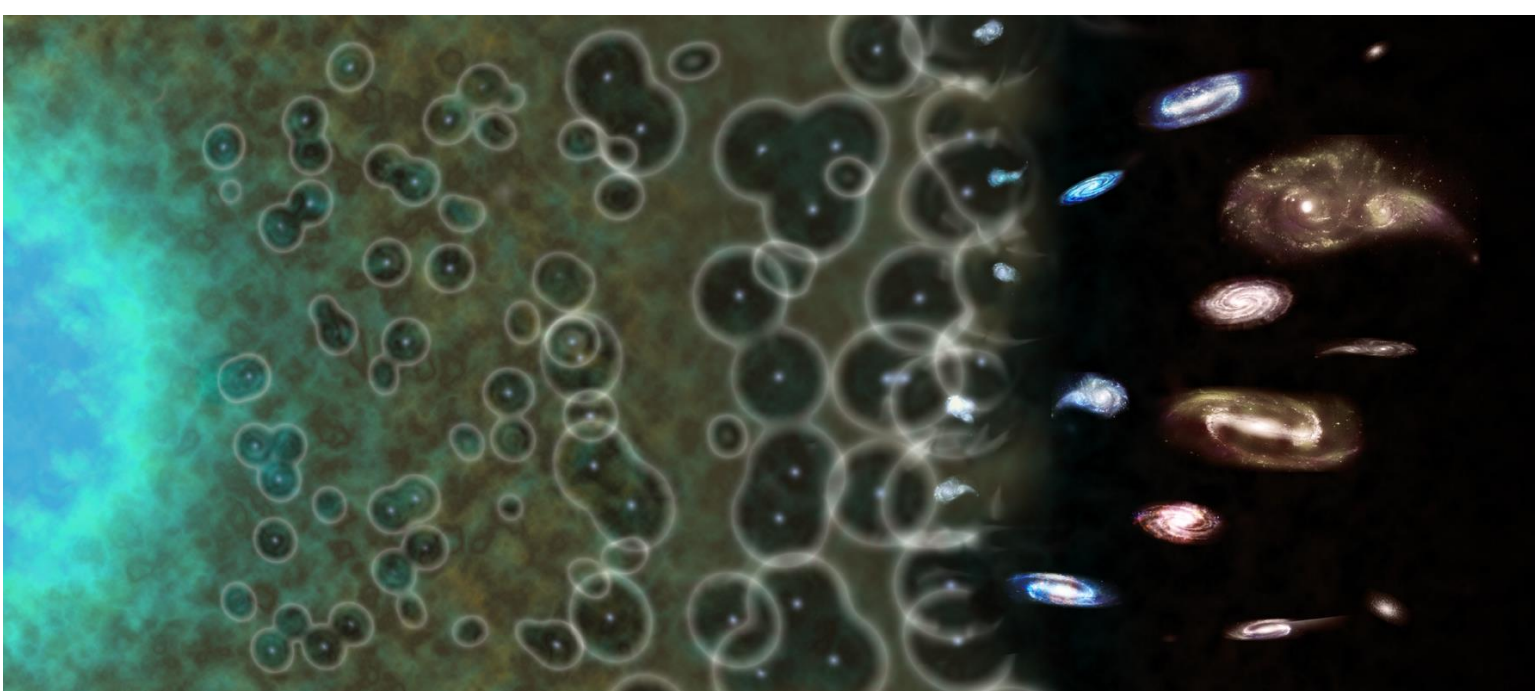




época de reionización



www.eso.org





Credits: NASA Goddard



Telescopio

o

Instrumento

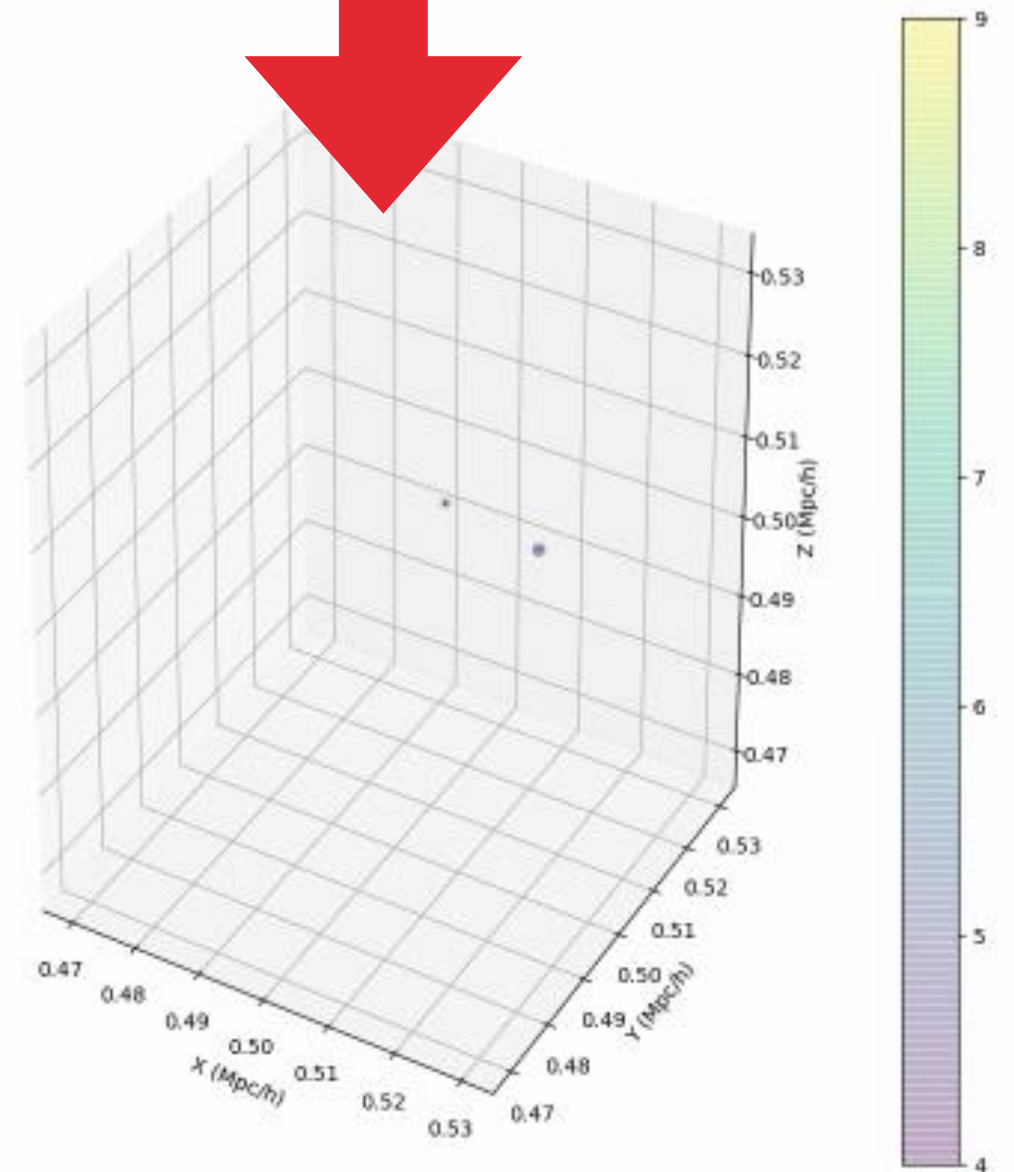
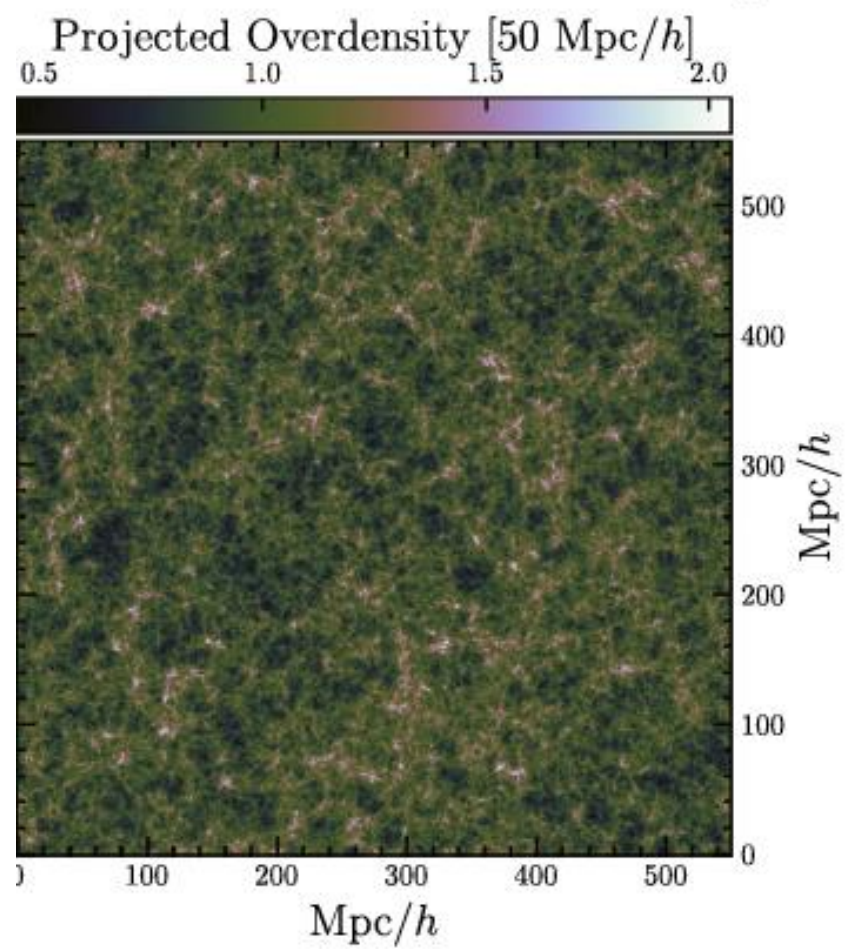
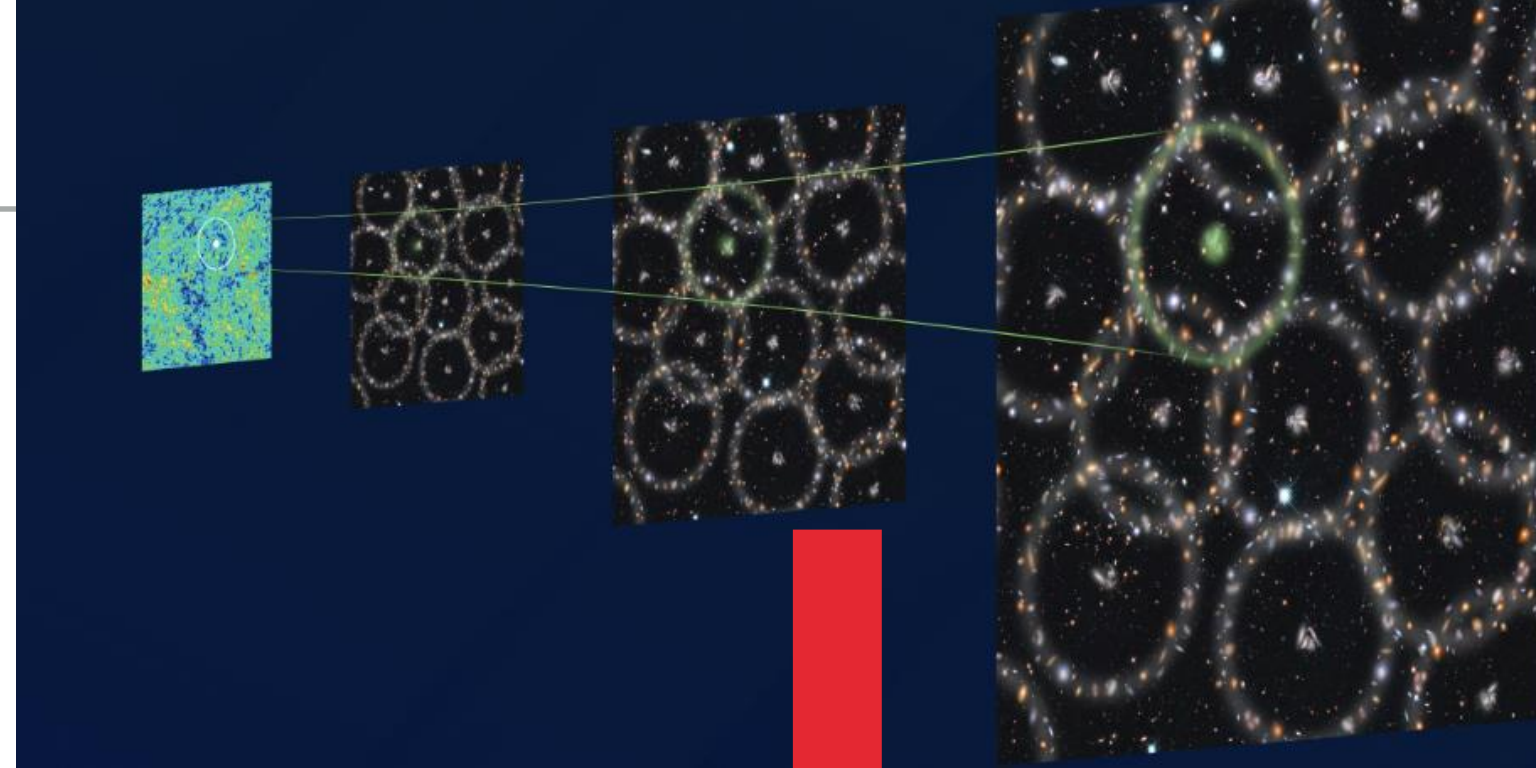
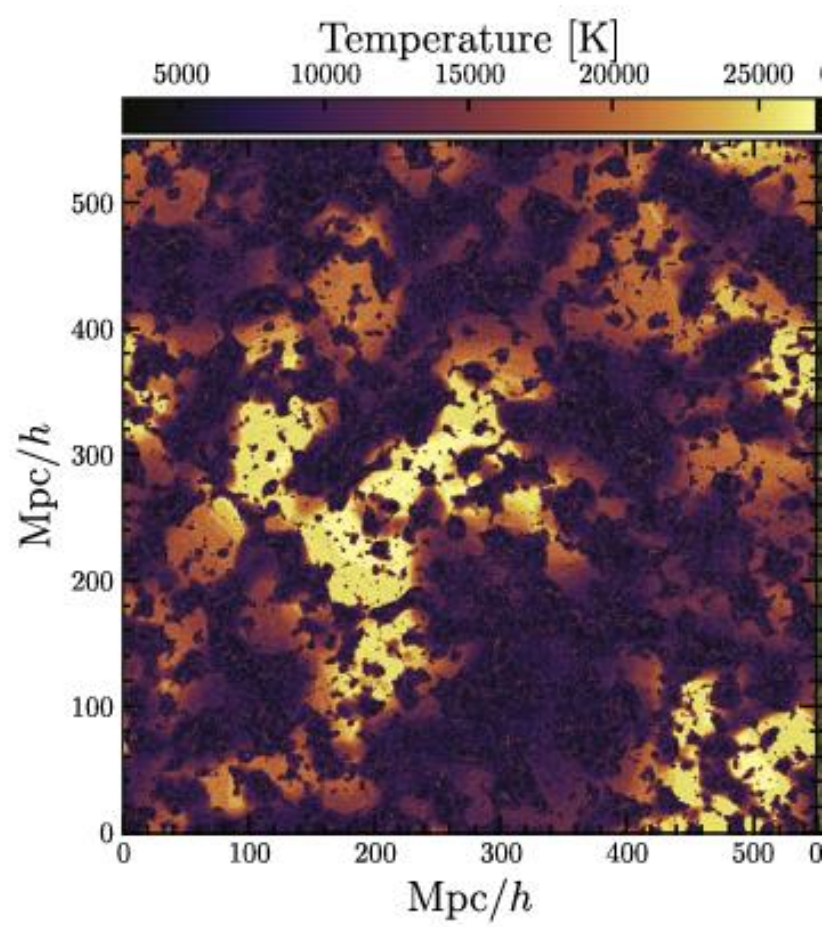
Supercomputador

Código

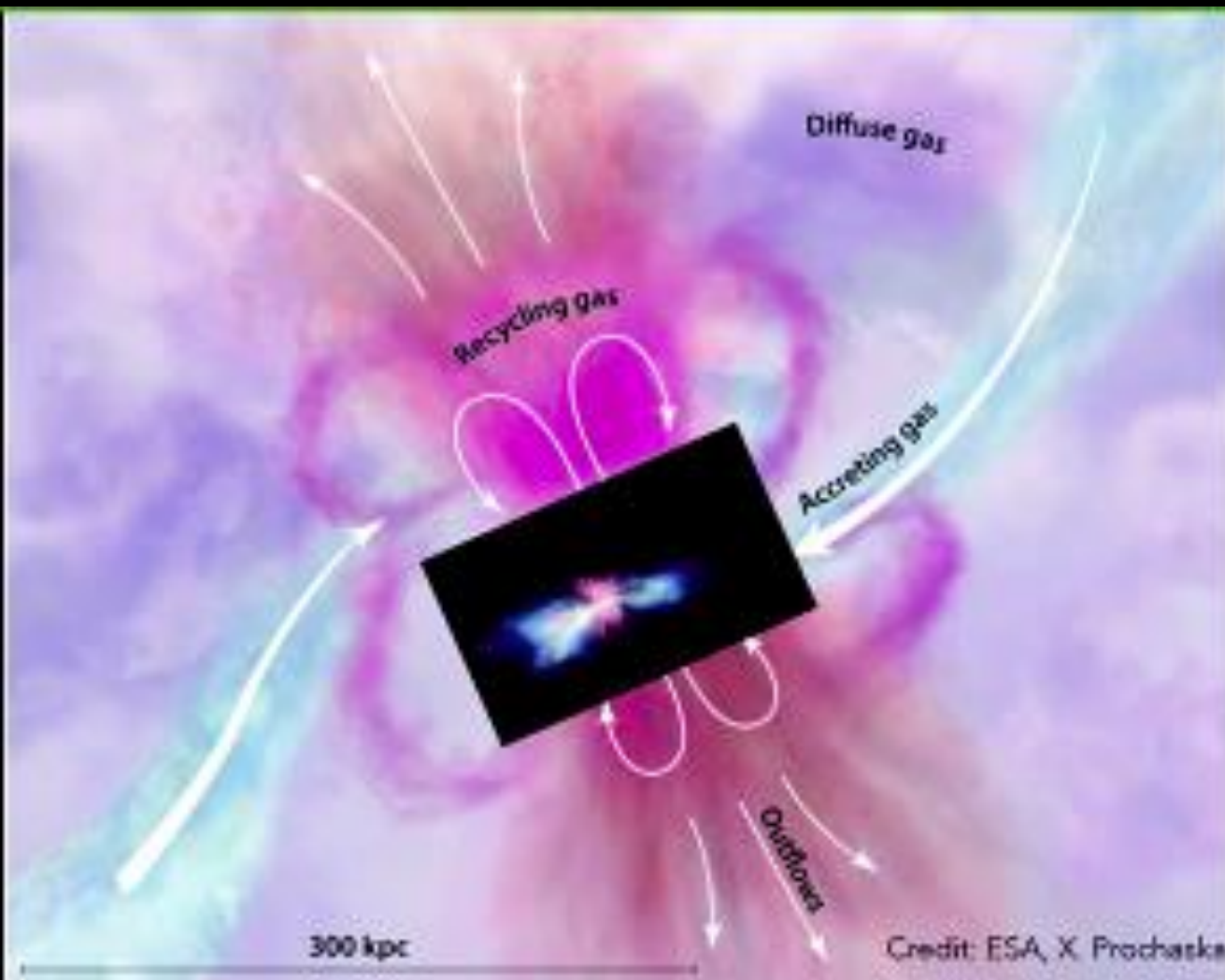


Analogía





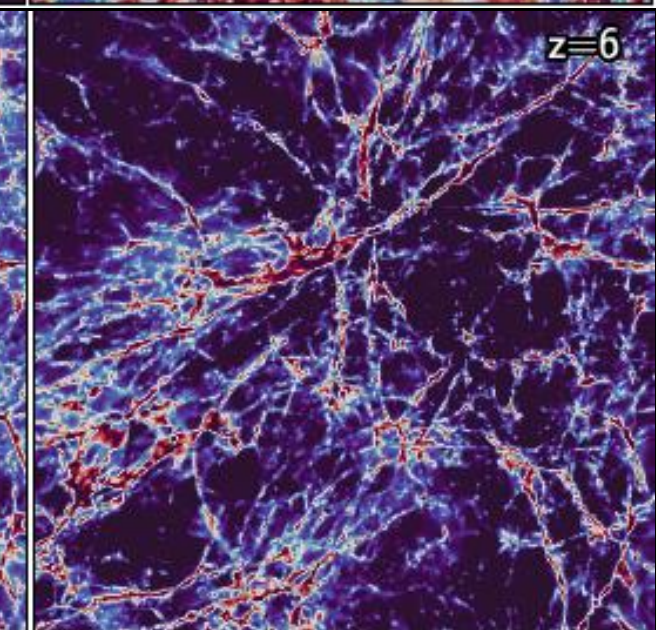
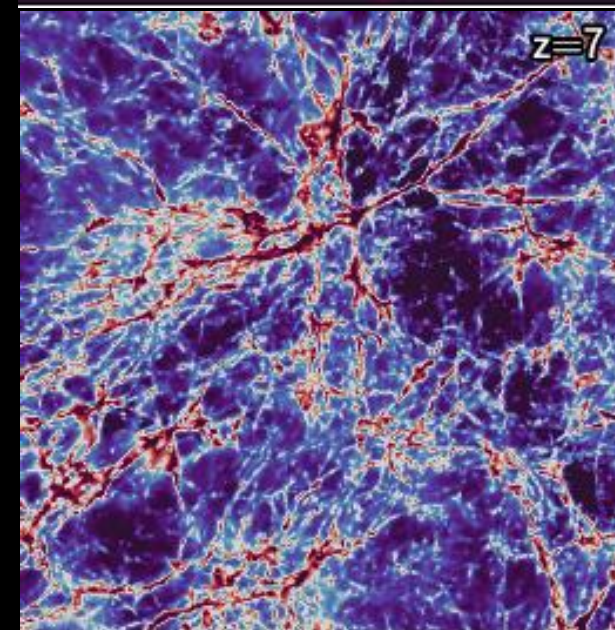
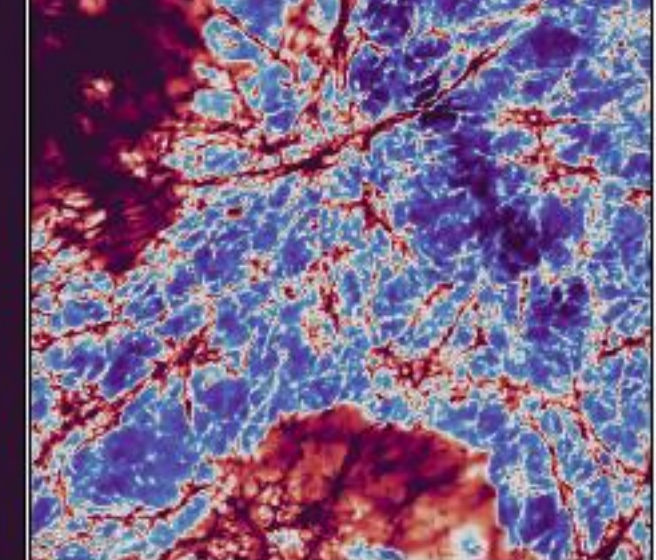
Becker et al 2018



$M_h = 3 \times 10^{12} M_\odot$ $z=9$



$z=8$



gas cooling	inter-stellar medium	star formation	stellar feedback	super-massive black holes	active galactic nuclei	magnetic fields	radiation fields	dust
atomic/ molecular/ metals/ tabulated/ network	effective equation of state/ multi- phase	initial stellar mass function/ probabilistic sampling/ enrichment	kinetic/ thermal/ variety of sources from stars, supernovae	numerical seeding/ growth by accretion prescription/ merging	kinetic/ thermal/ radiative/ quasar model/ radio mode	ideal MHD/ cleaning schemes/ constrained transport	ray tracing/ Monte Carlo/ moment- based	Production/ grain size distribution/ attenuation

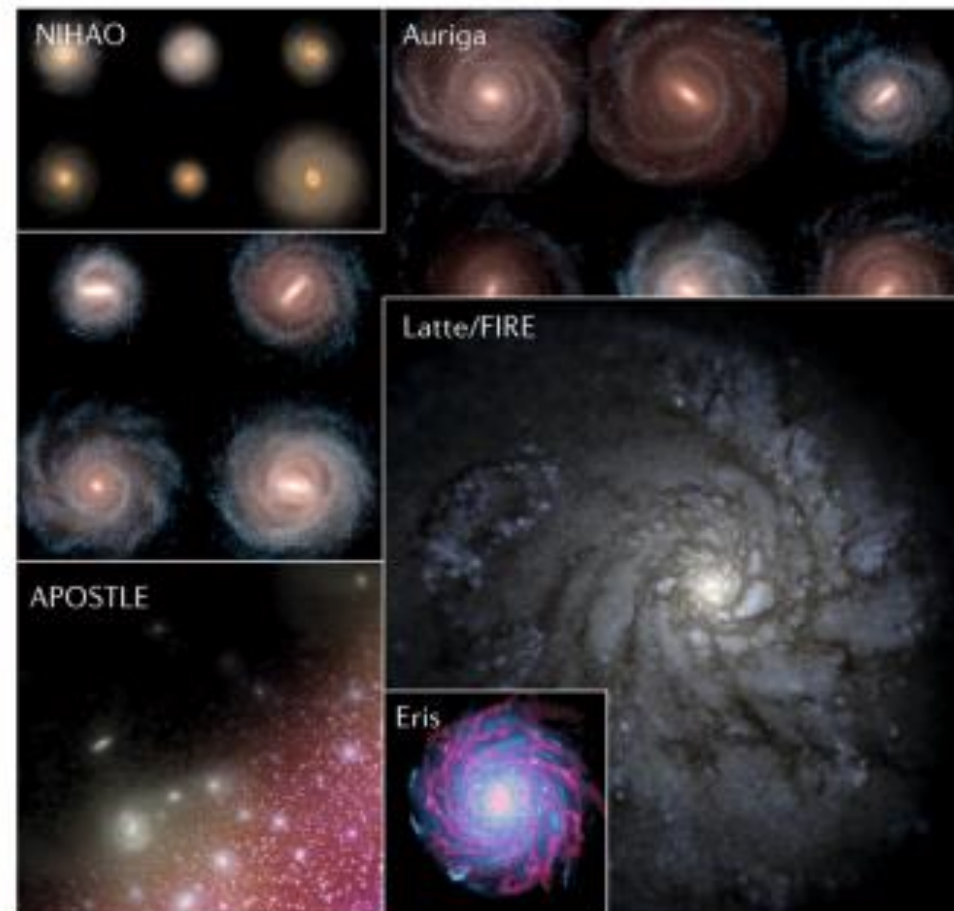
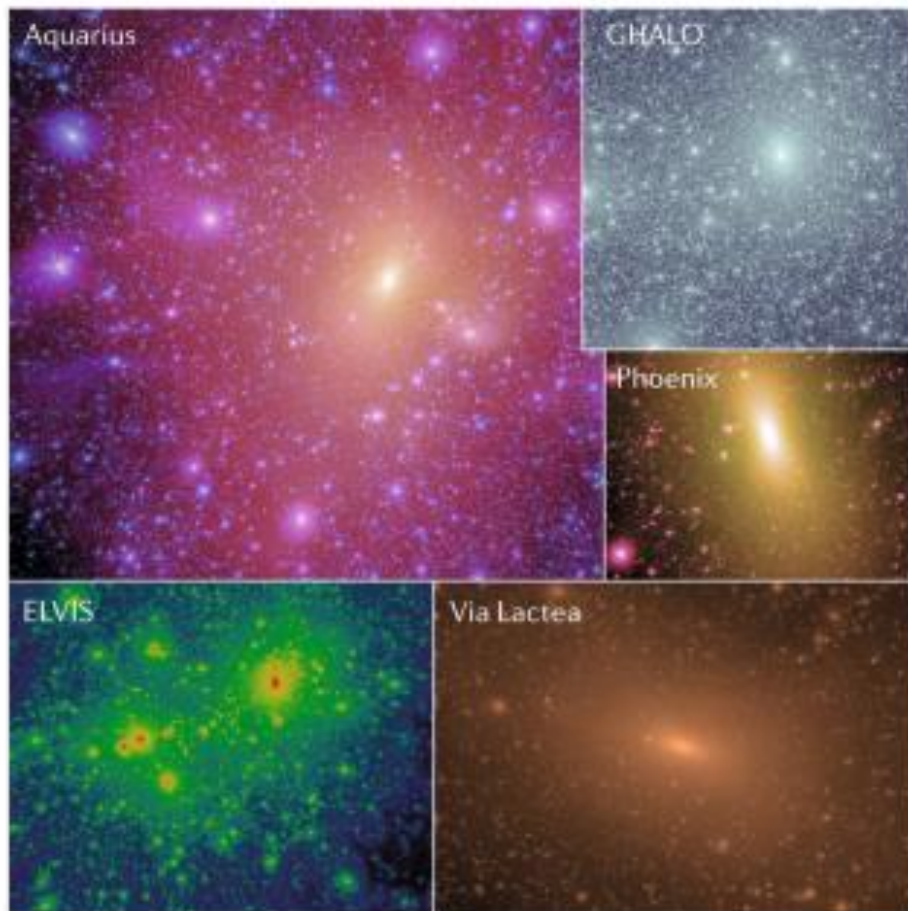
most important astrophysical processes

Vogelsberger+20

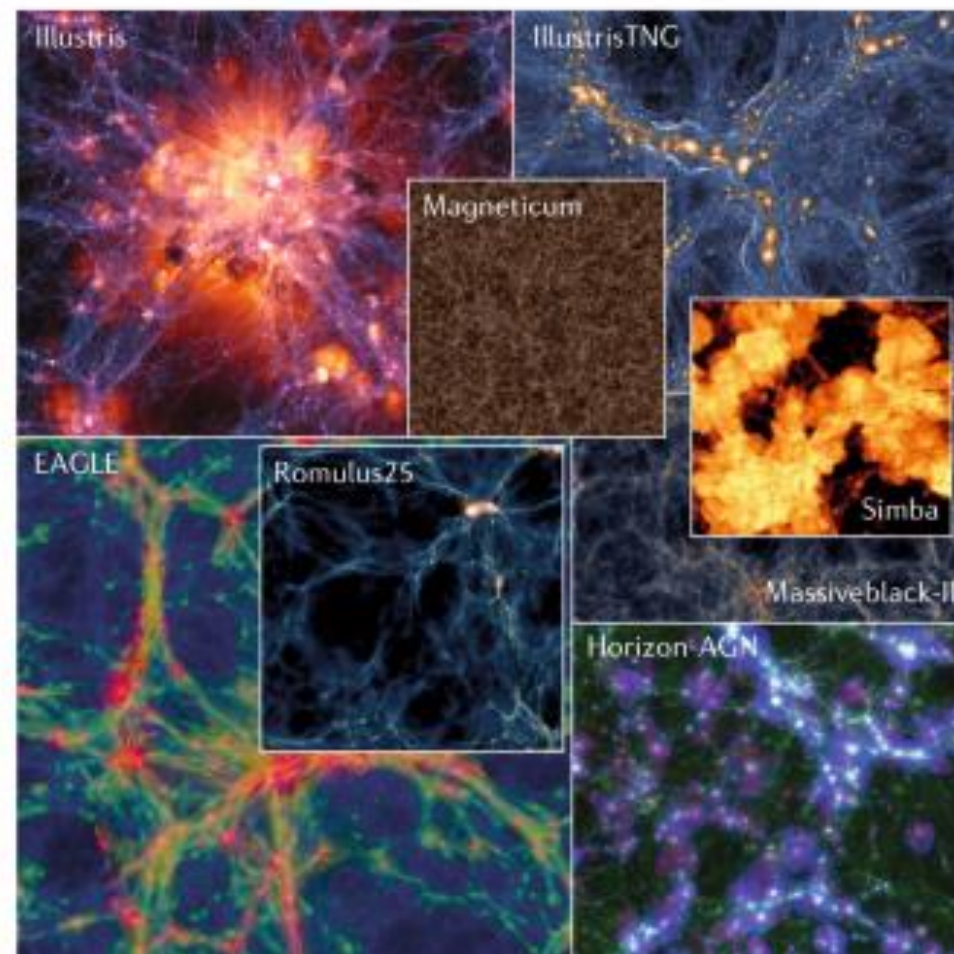
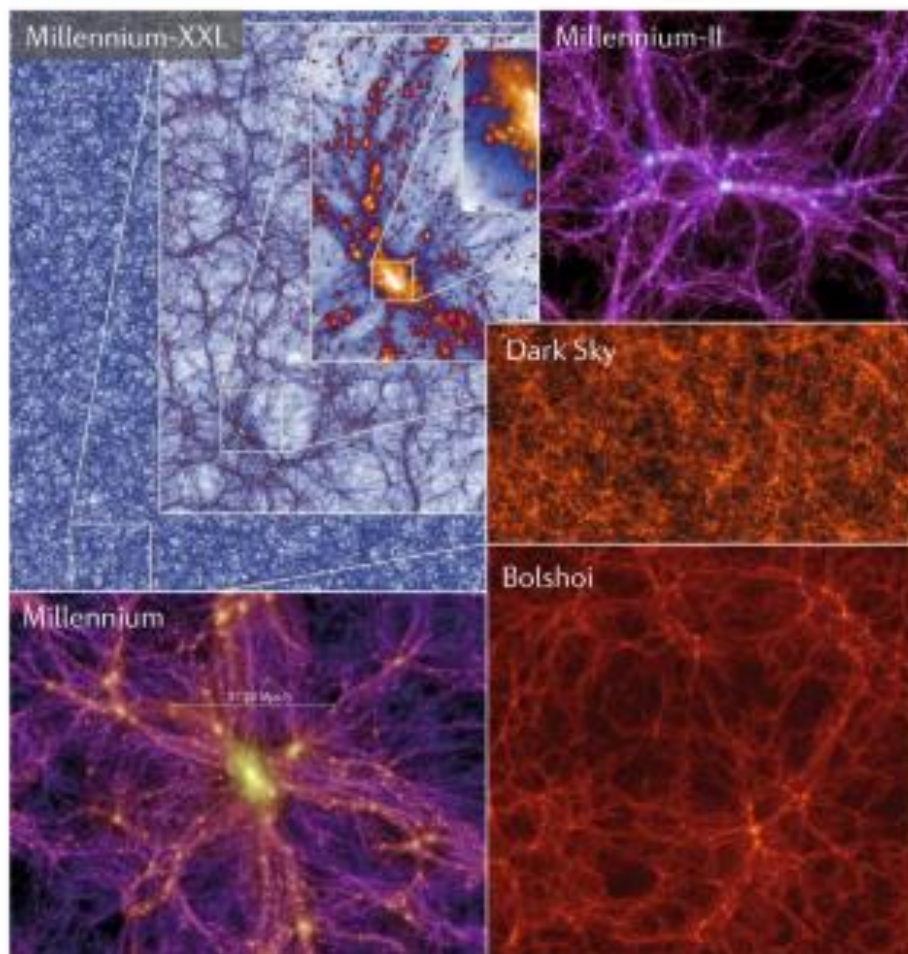
Dark matter only (N-body)

Dark matter + baryons (hydrodynamical)

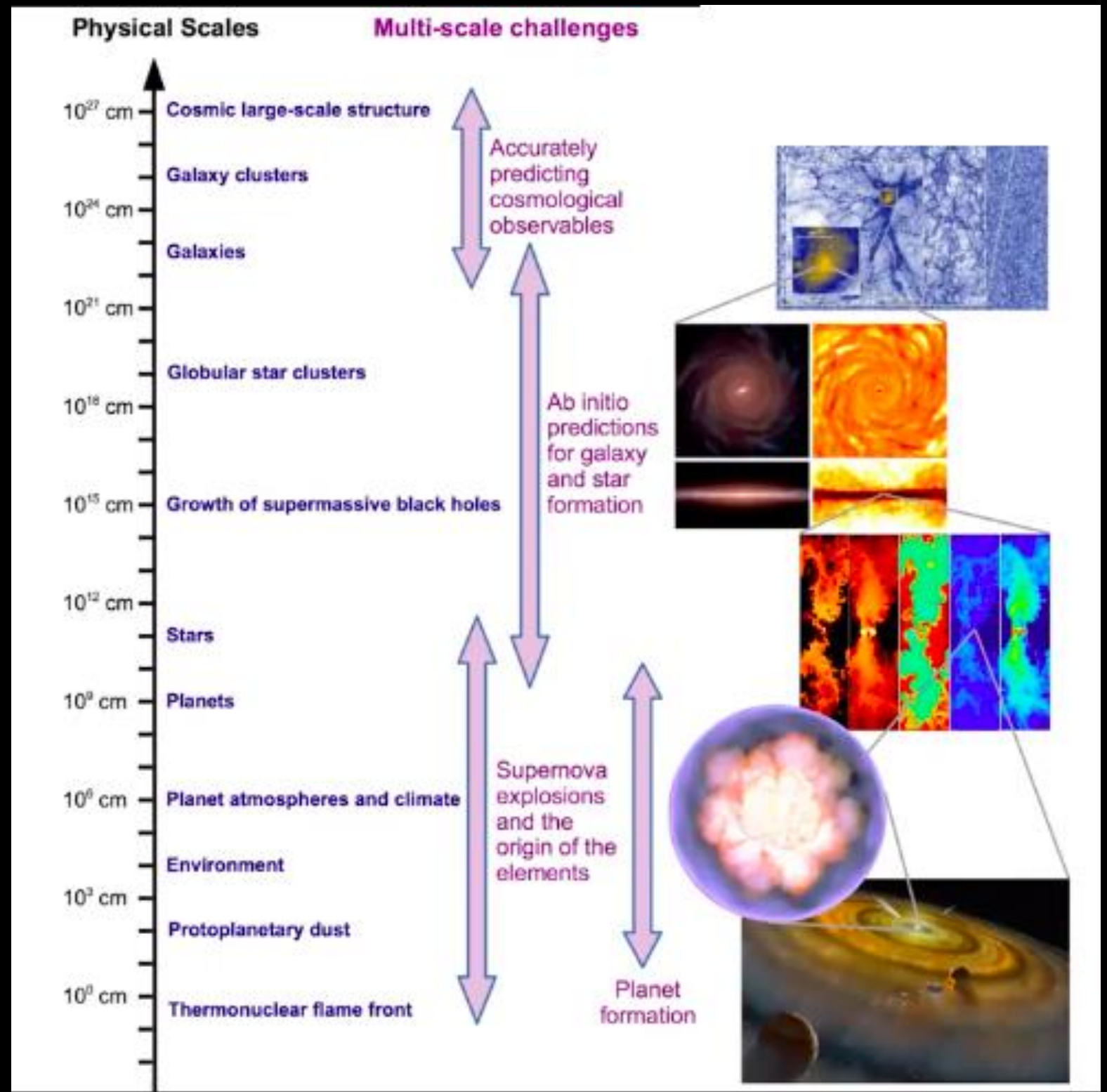
Zoom (details)



Large volume (statistics)

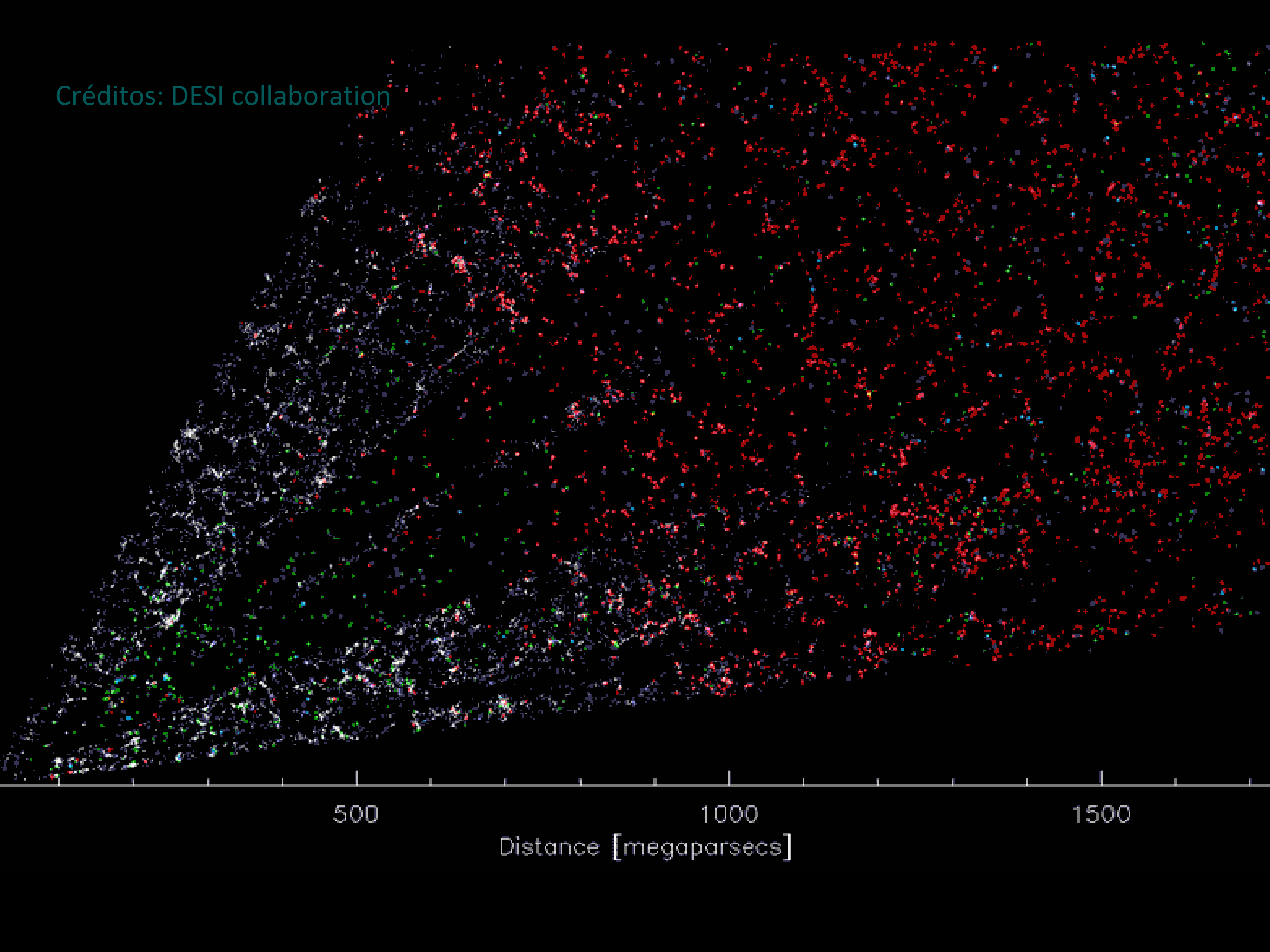


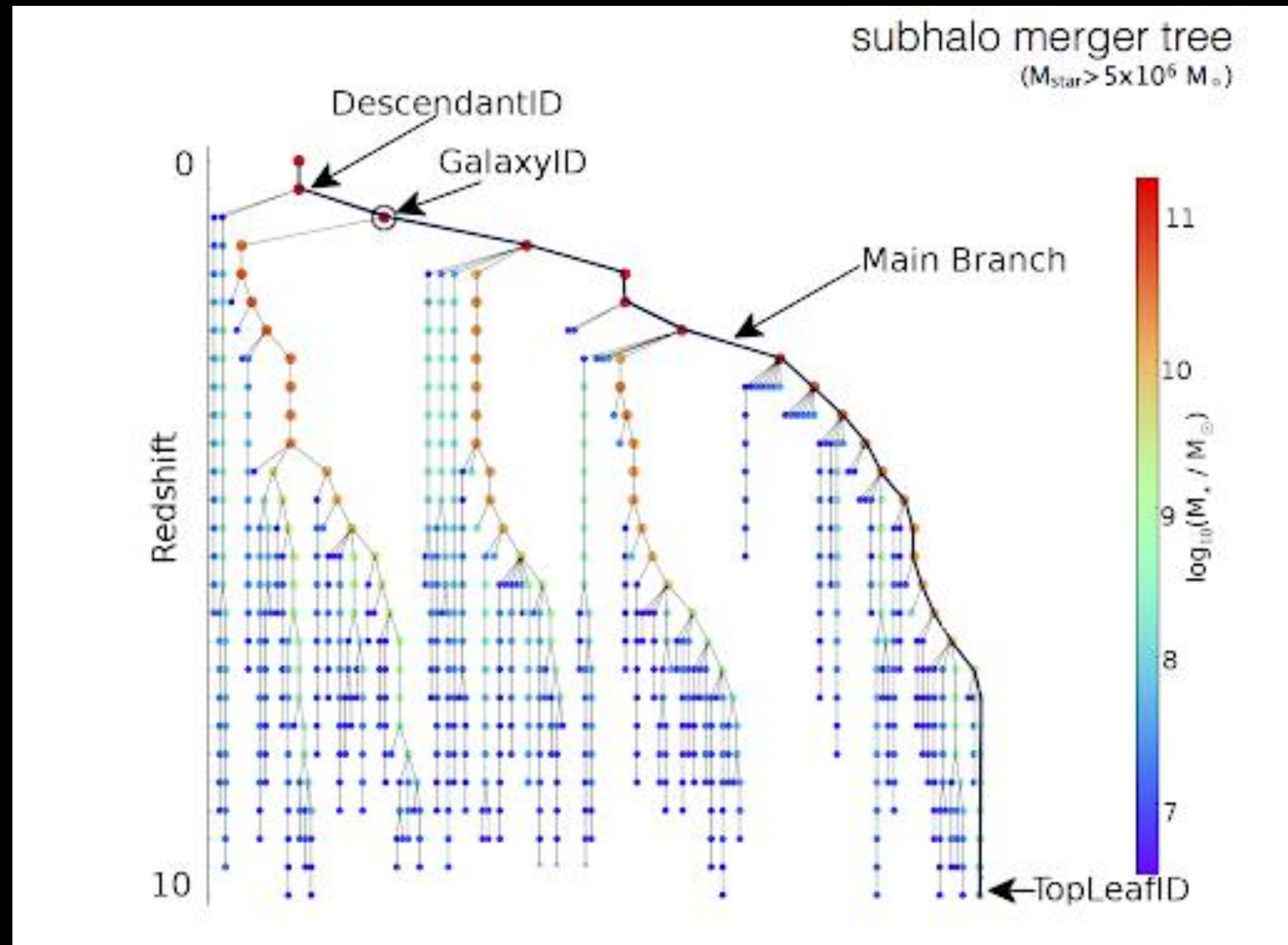
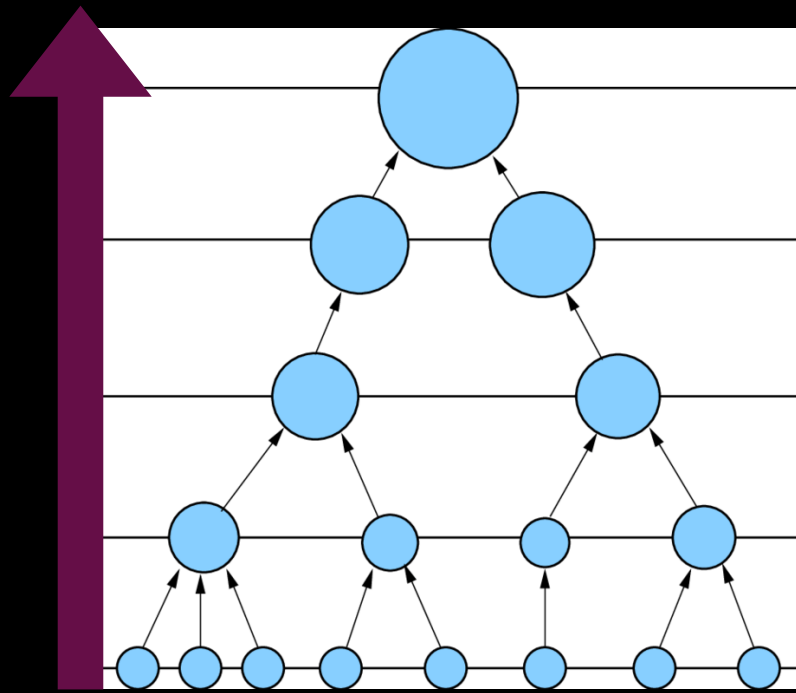
Rango dinámico

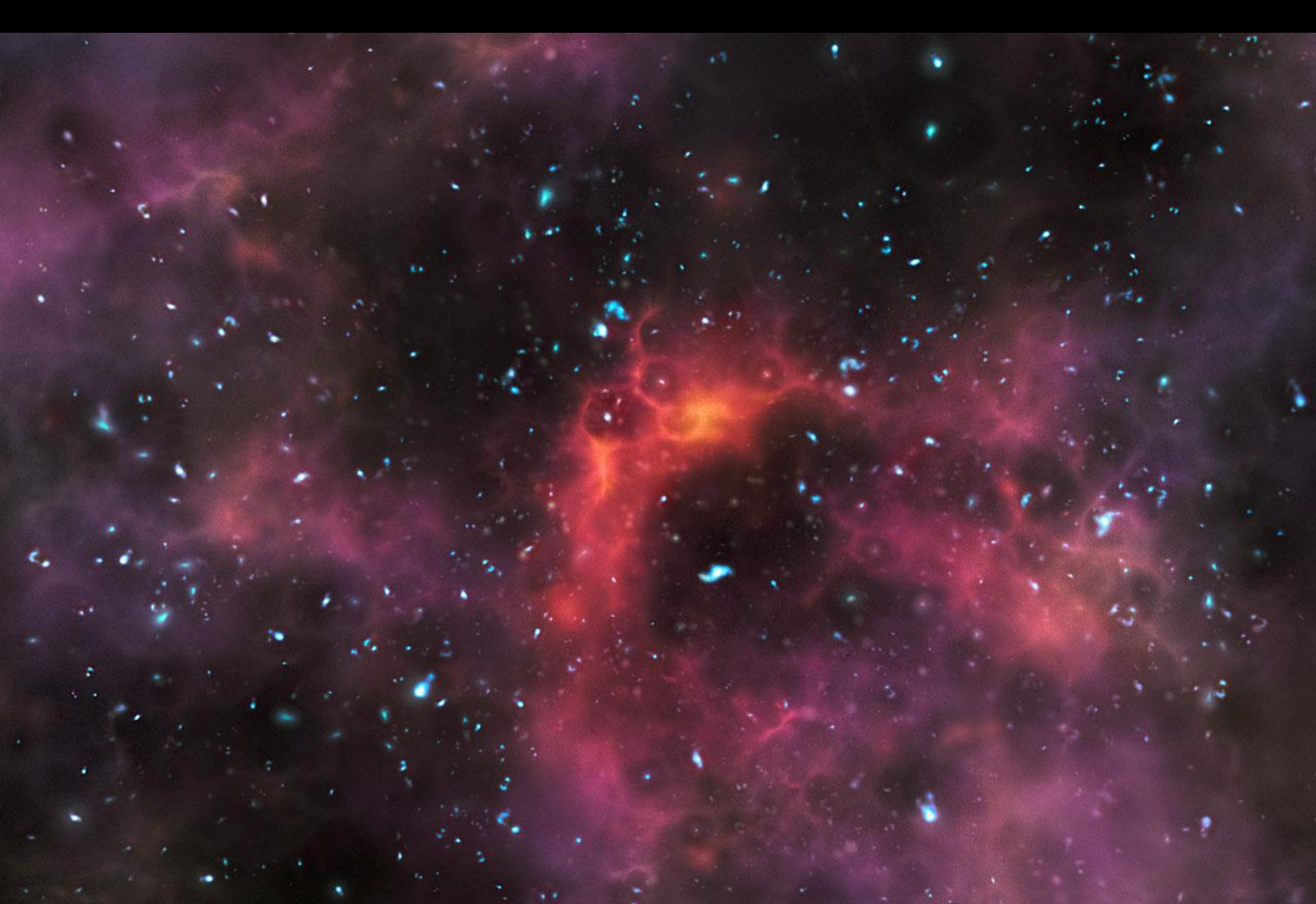


Tomado de Volker Springel

Créditos: DESI collaboration







Propiedades de galaxias a alto redshift

parte I

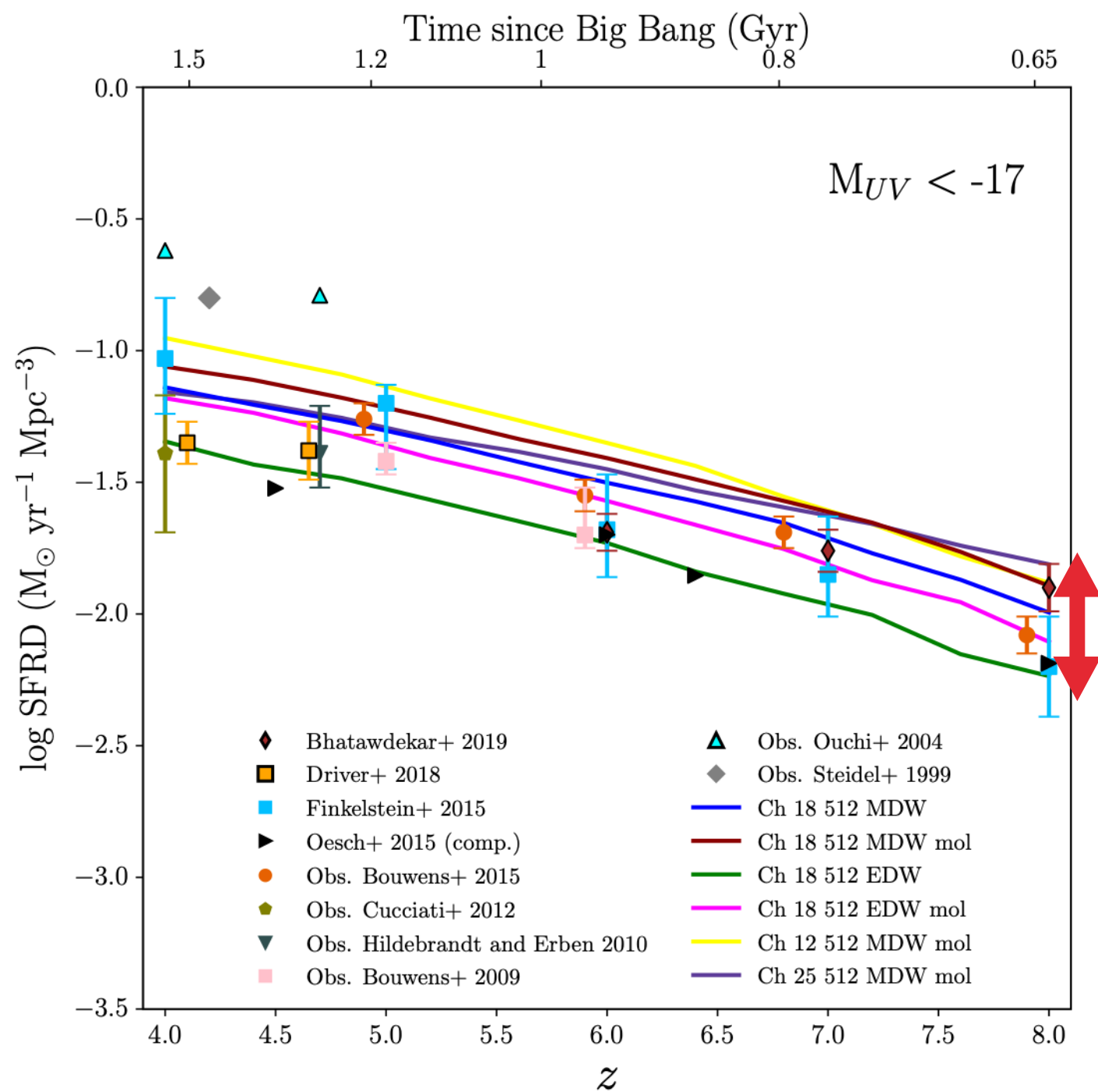
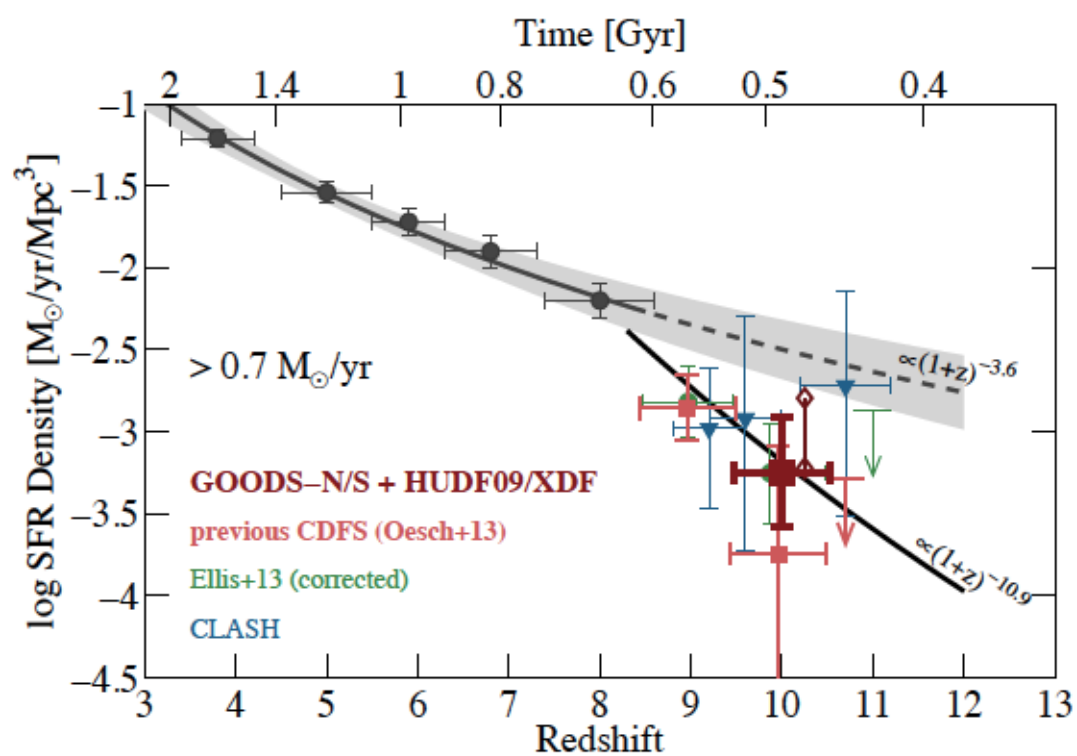
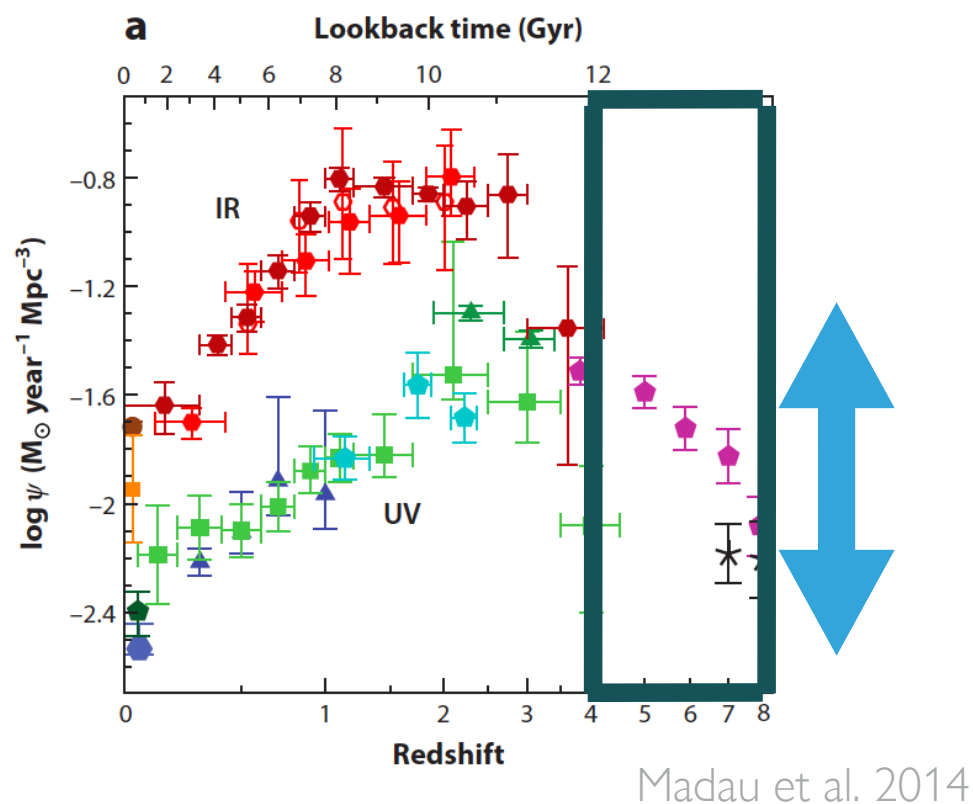
Simulation	Box size (cMpc/ h)	Comoving softening (ckpc/ h)	M_{gas} ($\times 10^5 M_{\odot}/h$)	M_{DM} ($\times 10^6 M_{\odot}/h$)
Ch 18 512 MDW	18	1.5	5.86	3.12
Ch 18 512 MDW mol	18	1.5	5.86	3.12
Ch 18 512 EDW	18	1.5	5.86	3.12
Ch 18 512 EDW mol	18	1.5	5.86	3.12
Ch 12 512 MDW mol	12	1.0	1.74	0.925
Ch 25 512 MDW mol	25	2.0	15.73	8.48

Modelo P-GADGET3 (XXL) que incluye de forma autoconsistente **la formación estelar** y **enriquecimiento químico**.

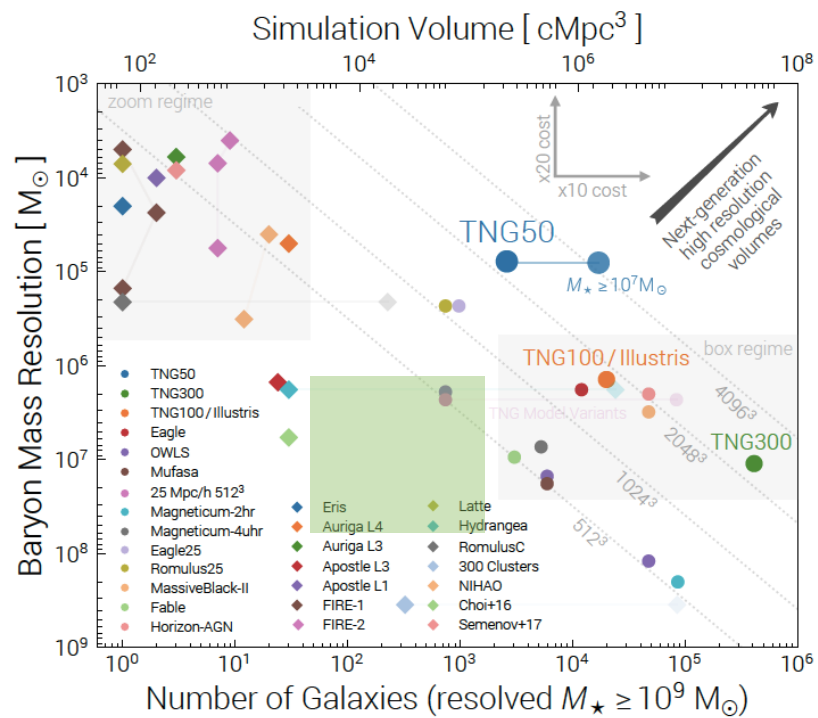
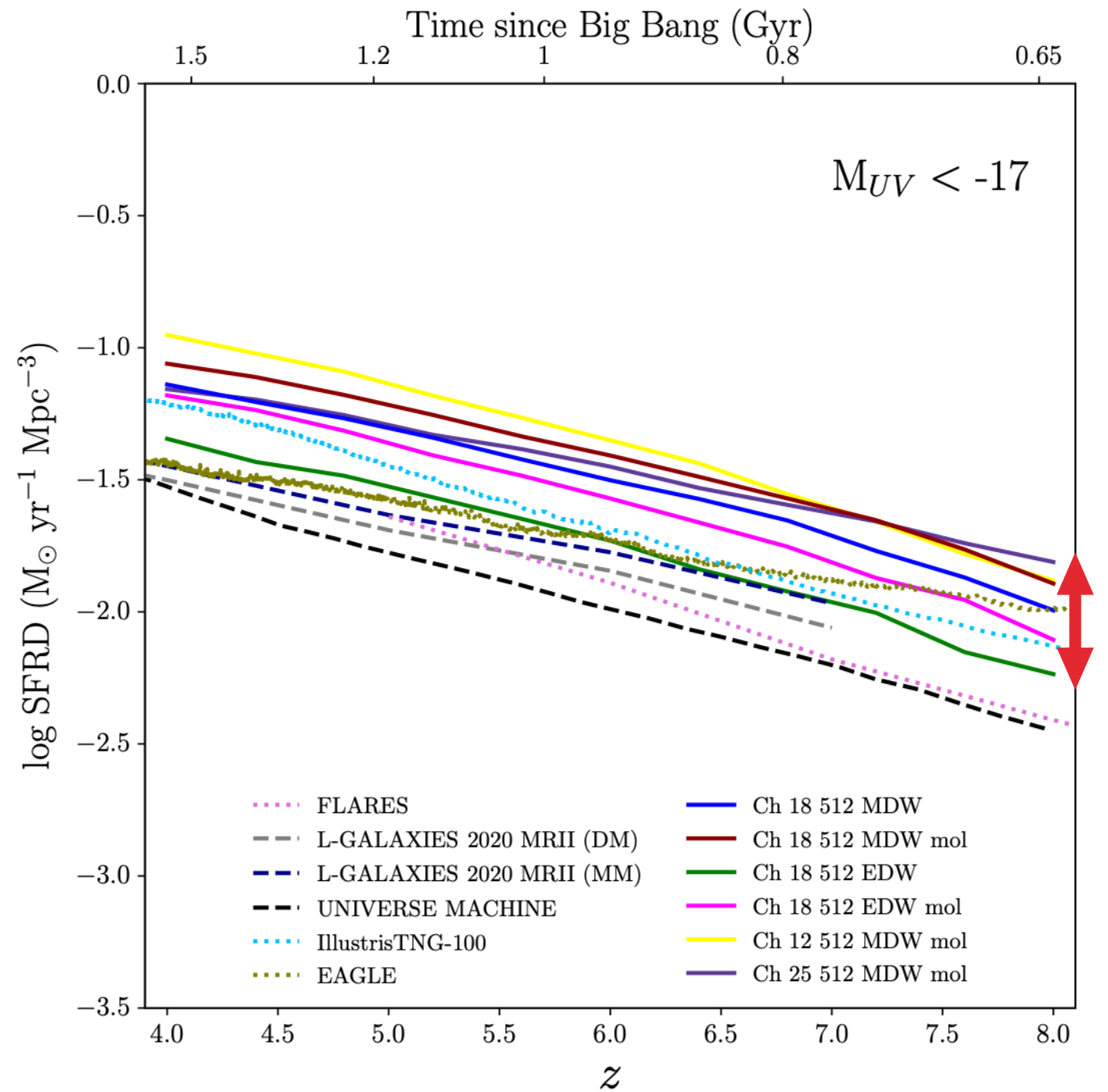
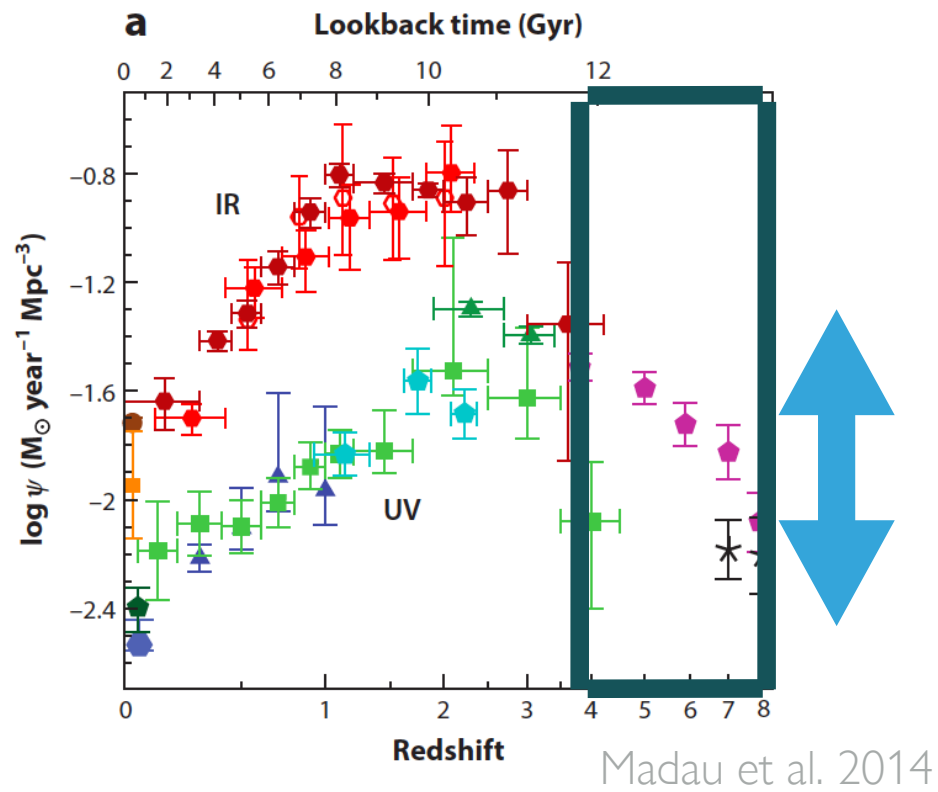
Modelo Λ CDM espacialmente plano + parámetros cosmológicos de **Planck 2015**.

MDW / EDW: vientos impulsados por momentum / energía.

-
- ✳️ **UniverseMachine**: basado en la simulación Very Small MultiDark-Planck (VSMDPL). Behroozi et al. 2021.
 - ✳️ **L-Galaxies 2020**: basado en la simulación Millennium-II. Henriques et al. 2020, Yates et al. 2021a.
 - ✳️ **Eagle**: Evolution and Assembly of GaLaxies and their Environments, una versión modificada de Gadget-3. Crain et al. 2015, Schaye et al. 2015.
 - ✳️ **IllustrisTNG**: Simulaciones gravo-magnetohidrodinámicas basadas en el proyecto Illustris. Nelson et al. 2018, Pillepich et al. 2018, Naiman et al. 2018, Marinacci et al. 2018, Springel et al. 2018.
 - ✳️ **Flares**: First Light and Reionisation Epoch Simulations, una re-simulación de **Eagle** de 3.2 cGpc/h (DM only). Lovell et al. 2021, Vijayan et al. 2021.

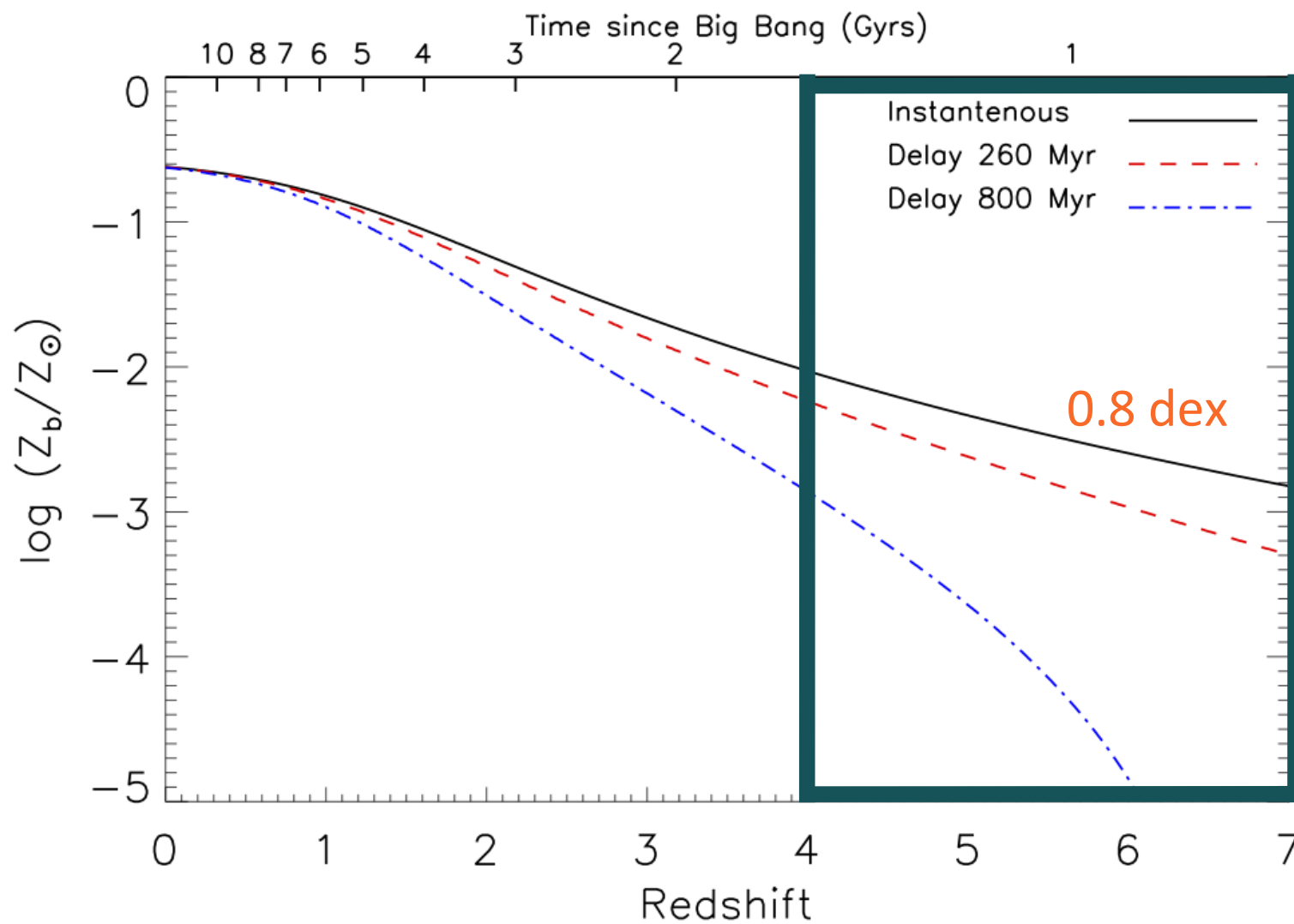


García 2022



Nelson et al. 2019

García 2022



$$Z_b(z) \equiv \frac{y \rho_*(z)}{\rho_b}$$

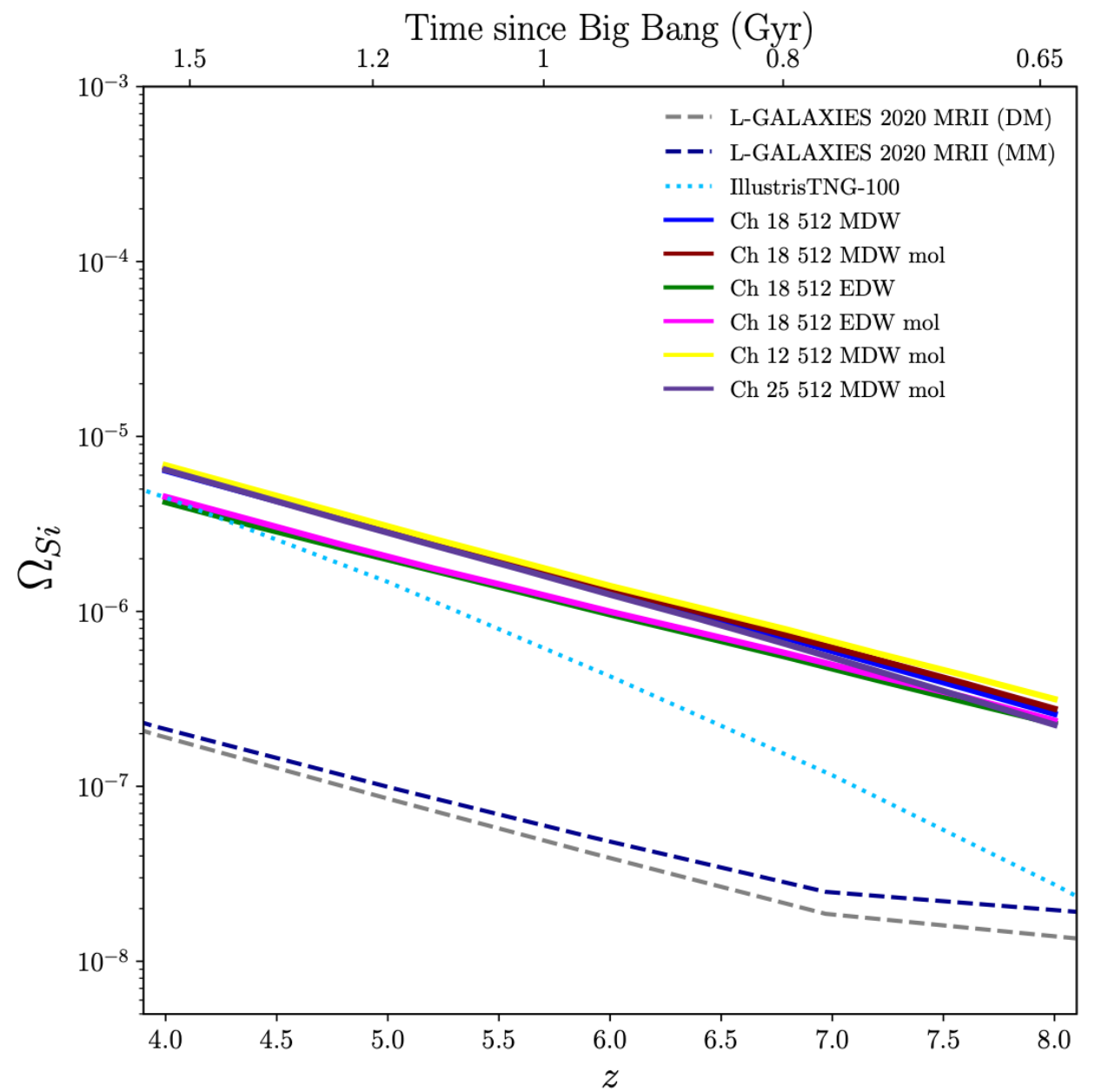
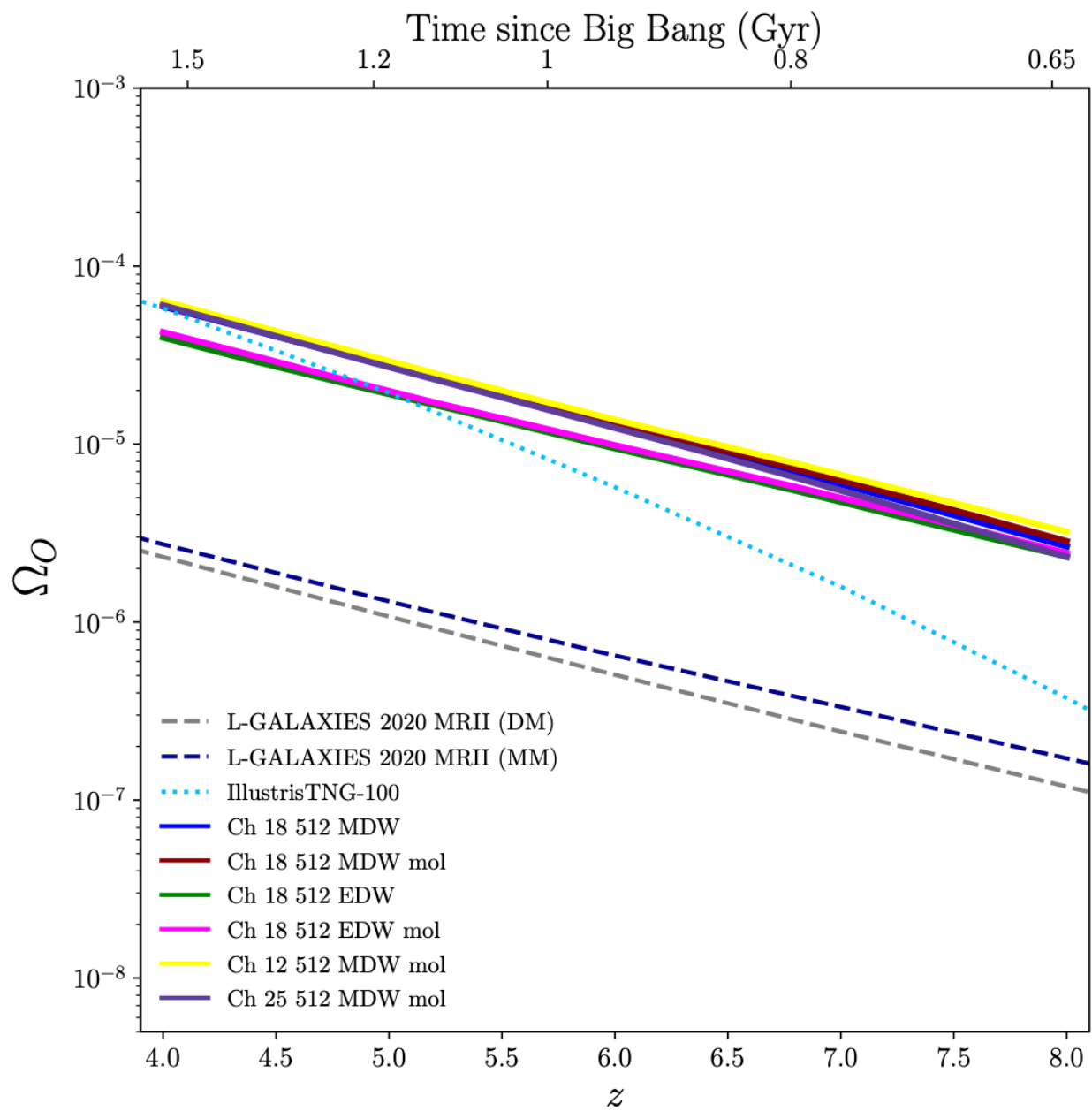
Metalicidad media del Universo:

y: cantidad de metales pesados

Modelo SFR

$\rho_*(z)$ IMF

Eficiencia estelar



Fondo ionizante de UV

parte II

Evolución del campo de fotones

$$\dot{n}_{\text{ion}} = N_{\text{gal}} \times n_{\text{ion}} (\text{per gal}) \times f_{\text{esc}}$$

Densidad número de fotones ionizantes.

$$\frac{df_{\text{HII}}}{dt} = \frac{\dot{n}_{\text{ion}}}{\langle n_{\text{H}} \rangle} - \frac{f_{\text{HII}}}{t_{\text{rec}}}$$

IGM

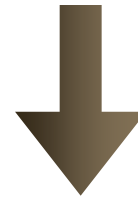
Balance entre ionizaciones y recombinaciones.



Public Data Access Overview

All the results and data from the three IllustrisTNG simulation volumes – TNG50, TNG100 and TNG300 – are publicly available here, as described in [Nelson+ \(2019a\)](#). Getting started tutorials, complete reference documentation, and a number of online tools for exploration and analysis are available.

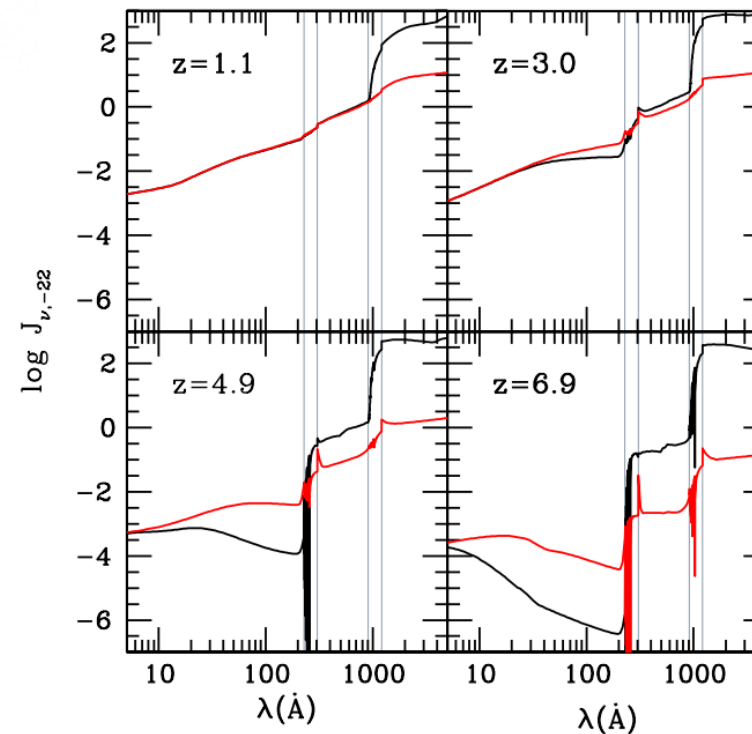
The underlying data formats (and helper scripts) for TNG data are essentially identical to those we have developed for the original Illustris simulation. All TNG data can be accessed with the same methods (i.e. direct-download and/or web-based API). Your existing user account gives access to both Illustris and TNG.



$$\left(\frac{\partial}{\partial t} - vH \frac{\partial}{\partial v} \right) J_\nu + 3HJ_\nu = -c\kappa_\nu J_\nu + \frac{c}{4\pi} \epsilon_\nu$$



Haardt & Madau 2012

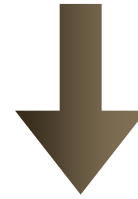


$$Y_{\text{HI}} = (1 + R_{\text{HI}})^{-1}$$

$$R_i \equiv \frac{\Gamma_i}{n_e \alpha_i}$$

CAMPO UV IONIZANTE UNIFORME: FONDO DE RADIACIÓN DEBIDO A FOTONES DE CMB + ULTRAVIOLETA /RAYOS X DE CUÁSARES Y GALAXIAS CON ATENUACIÓN TIPO SERRUCHO.

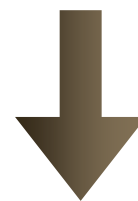
Haardt & Madau 2012



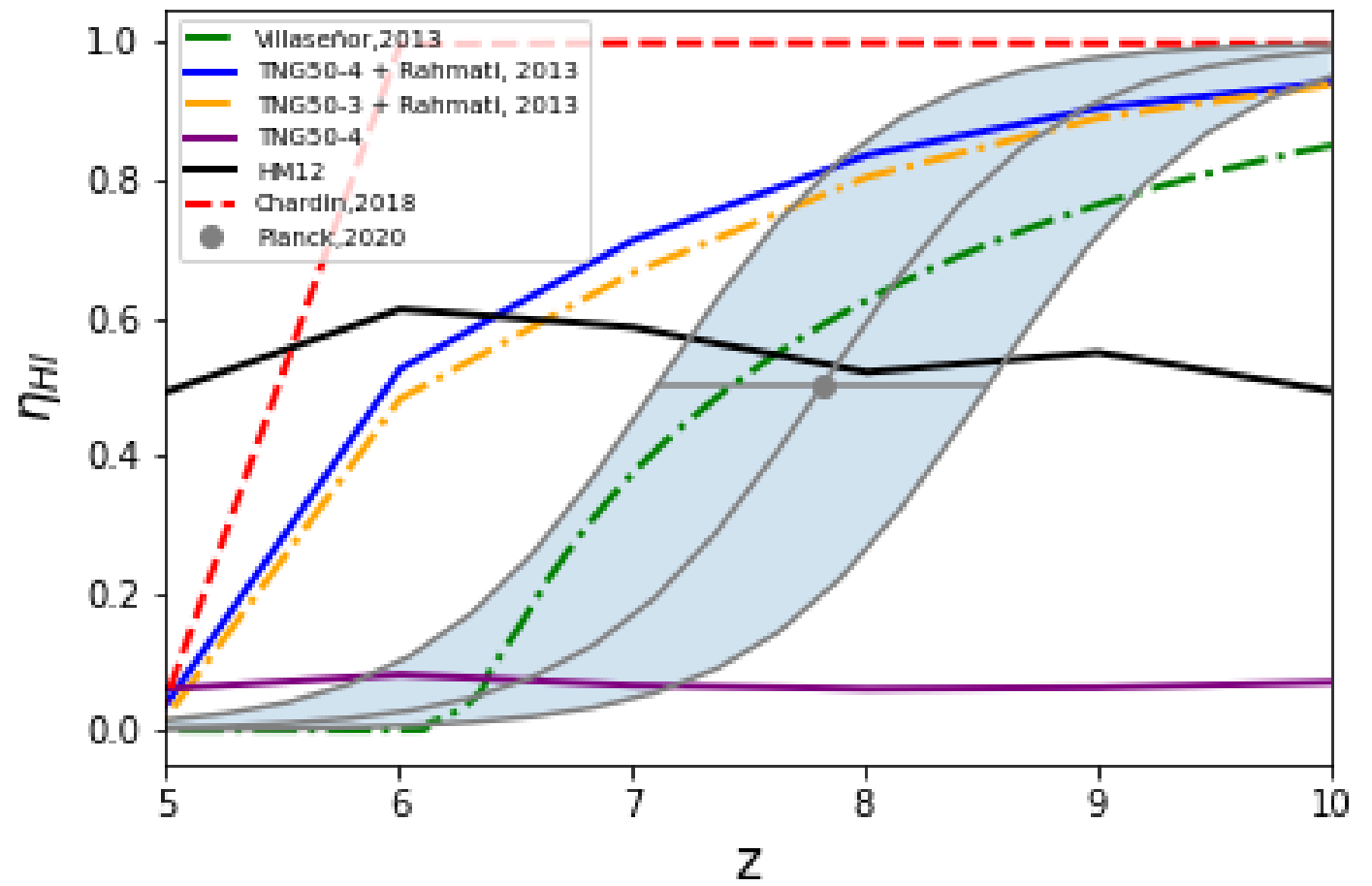
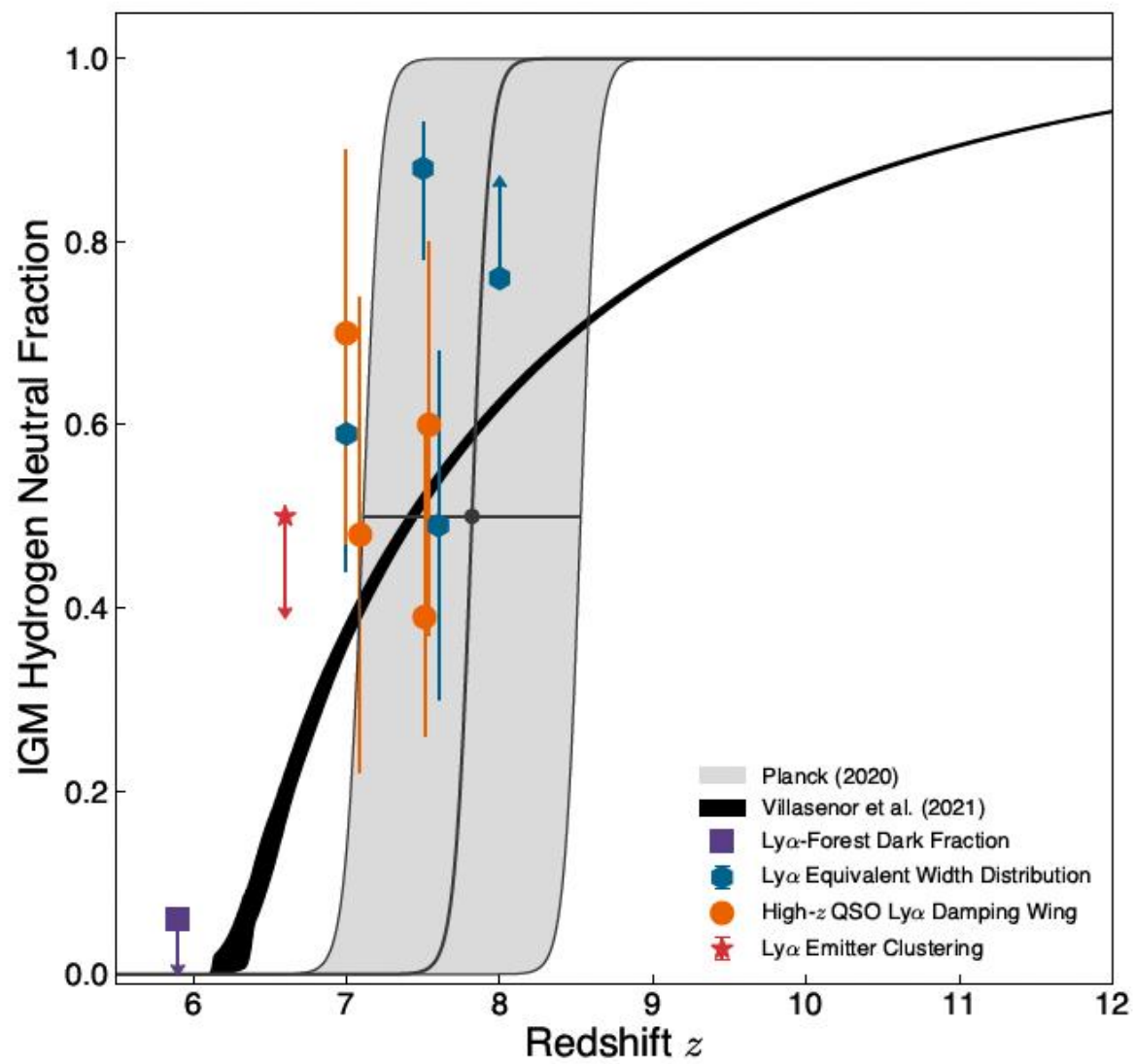
BURBUJAS DE HIDRÓGENO NEUTRO APANTALLADAS POR ALTAS DENSIDADES DEL GAS DEL MEDIO INTERGALÁCTICO.

$$\frac{\Gamma_{\text{phot}}}{\Gamma_{\text{UVB}}} = (1 - f) \left[1 + \left(\frac{n_H}{n_0} \right)^\beta \right]^{\alpha_1} + f \left[1 + \frac{n_H}{n_0} \right]^{\alpha_2}$$

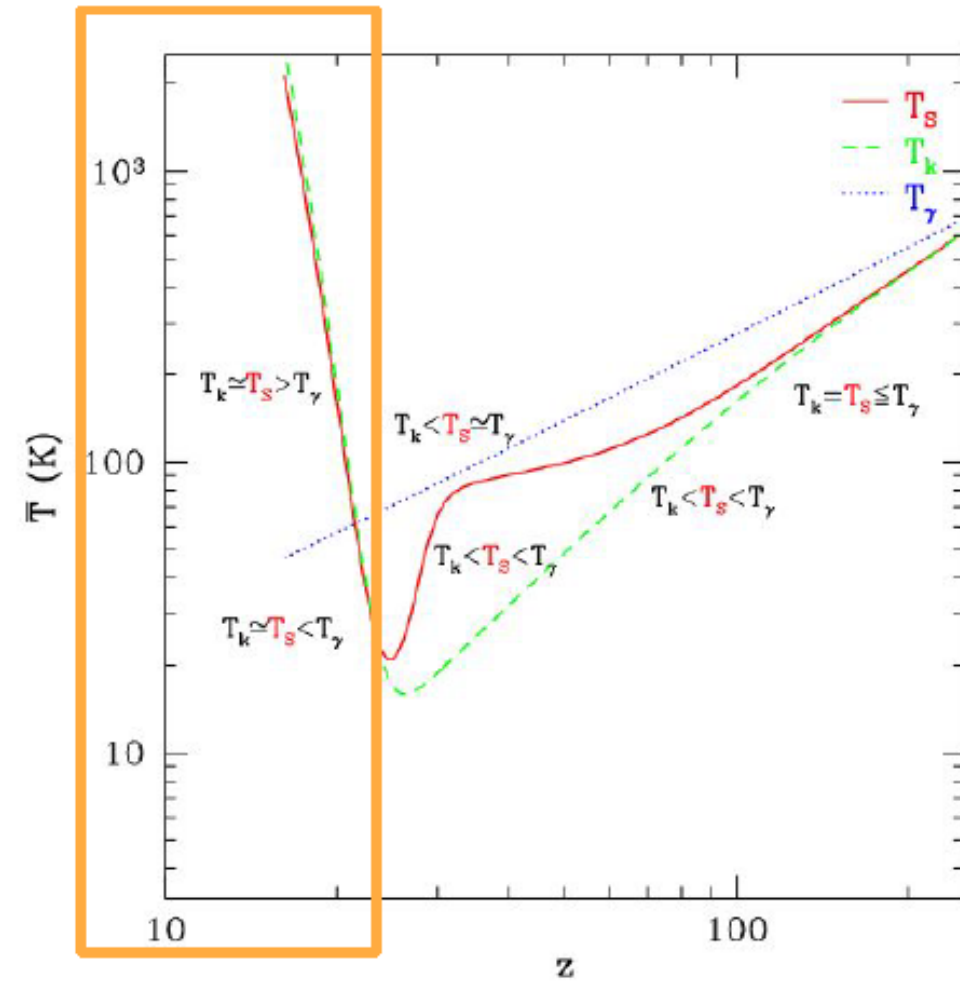
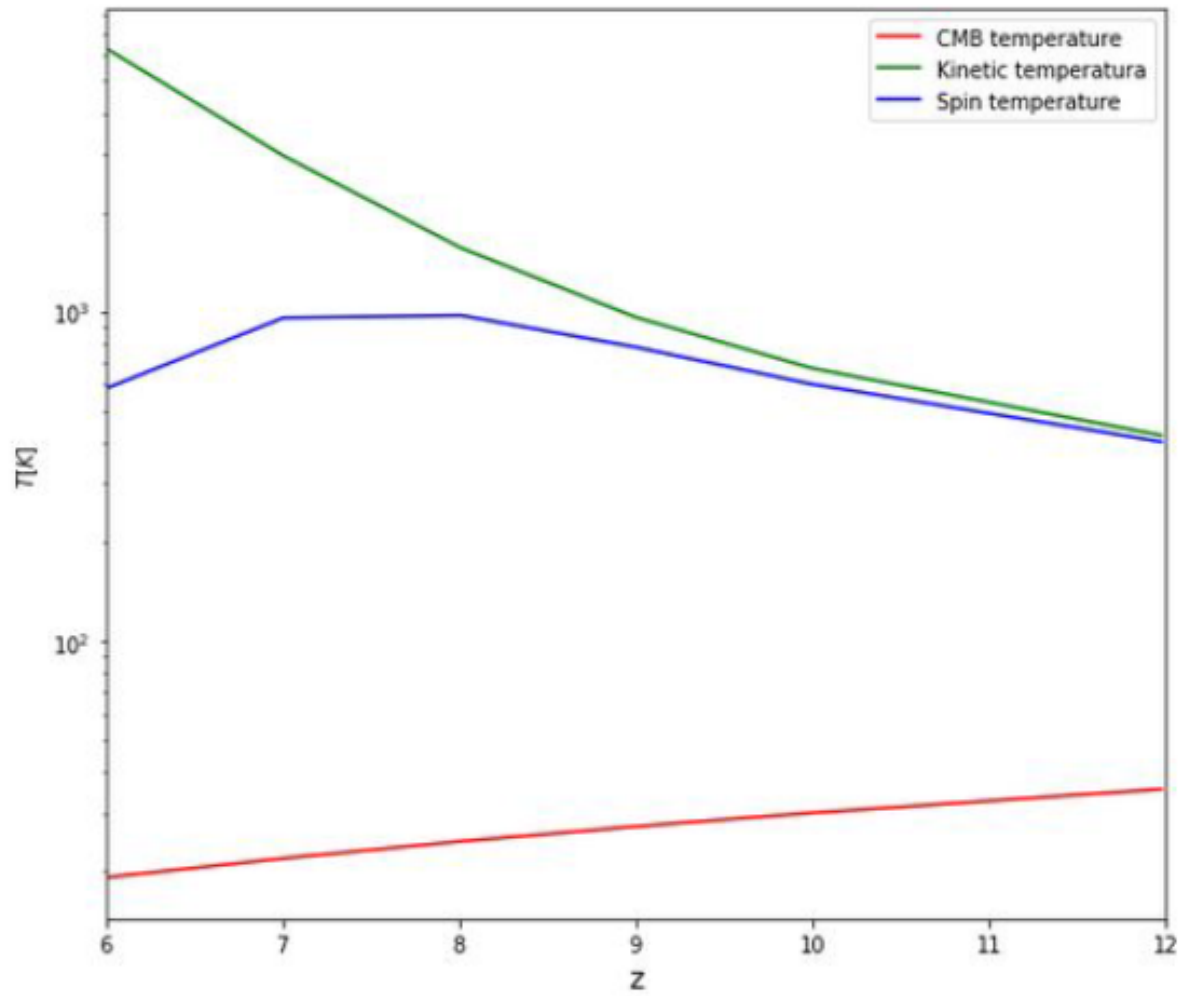
Rahmati et al. 2013
CHARDIN et al. 2018




$$Y_{\text{HI}}$$



RESULTADOS CON TNG50-4 (LOW-RES)



Weltman et al. 2020

$$T_s^{-1} = \frac{T_\gamma^{-1} + x_c T_k^{-1} + x_\alpha T_k^{-1}}{1 + x_c + x_\alpha}$$

T_s Temperatura del spin

T_γ Temperatura del CMB

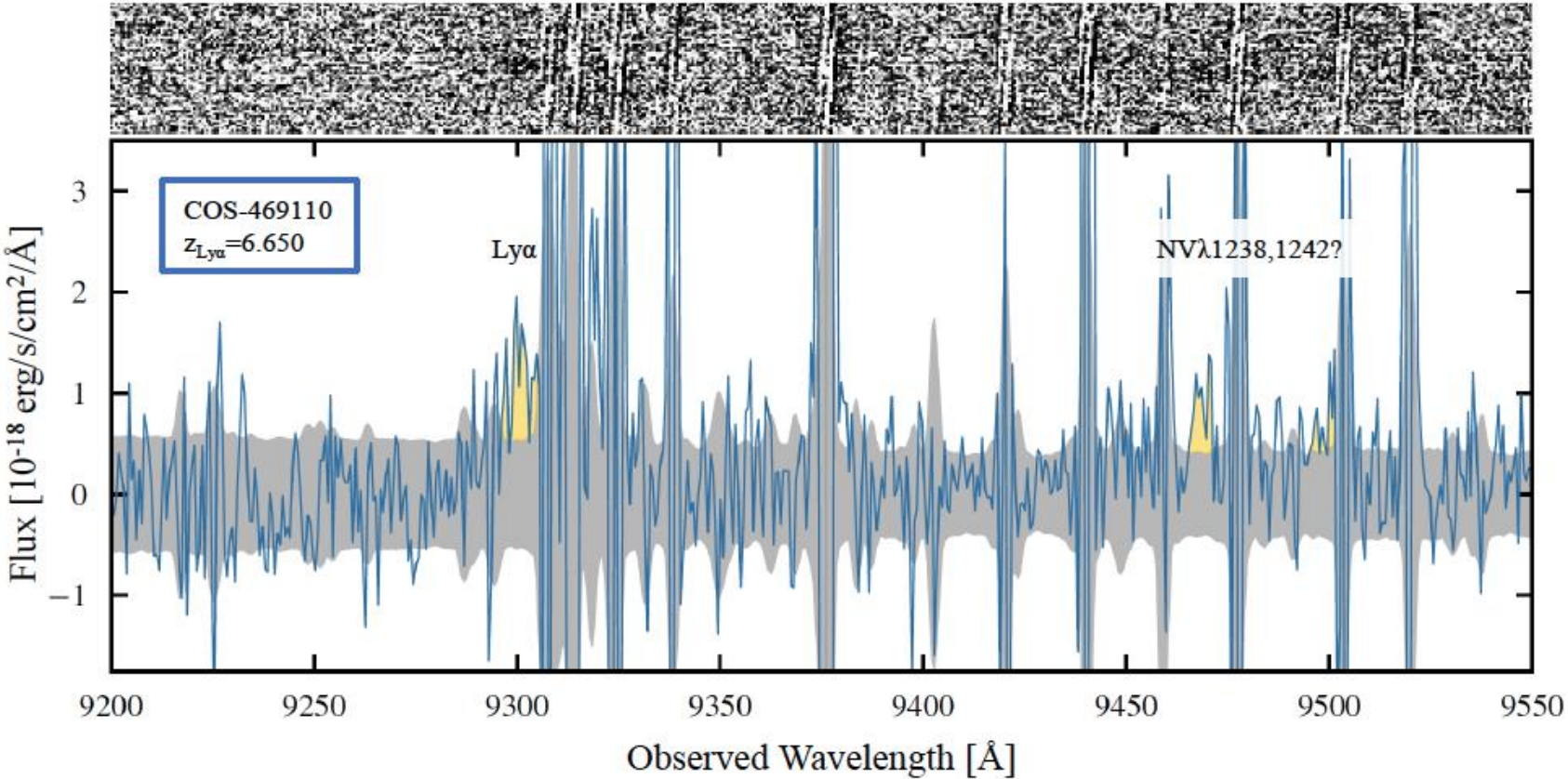
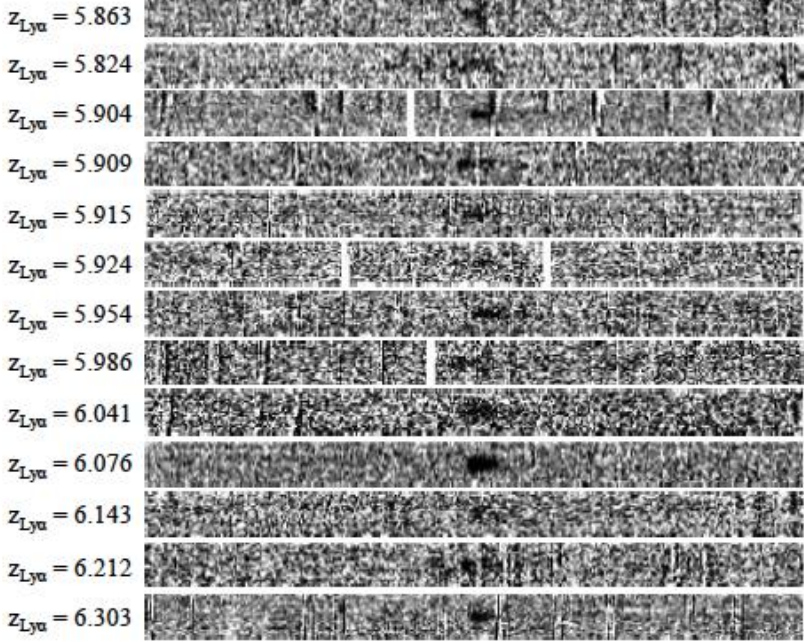
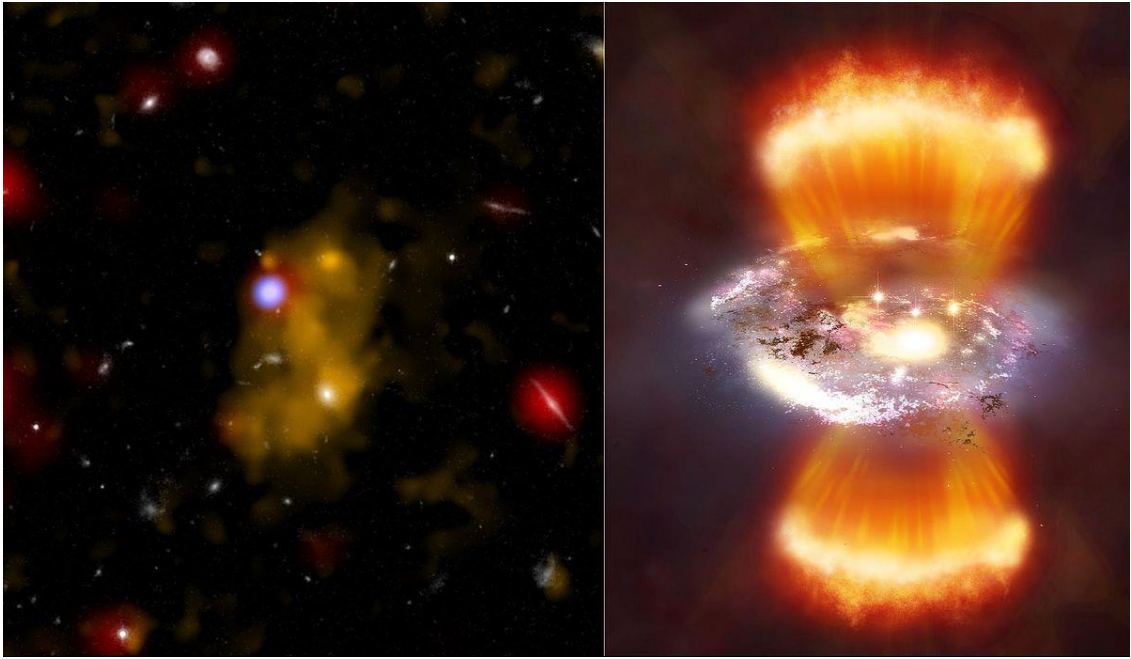
T_k Temperatura cinética

Galaxias LAE a $z=6$

parte III

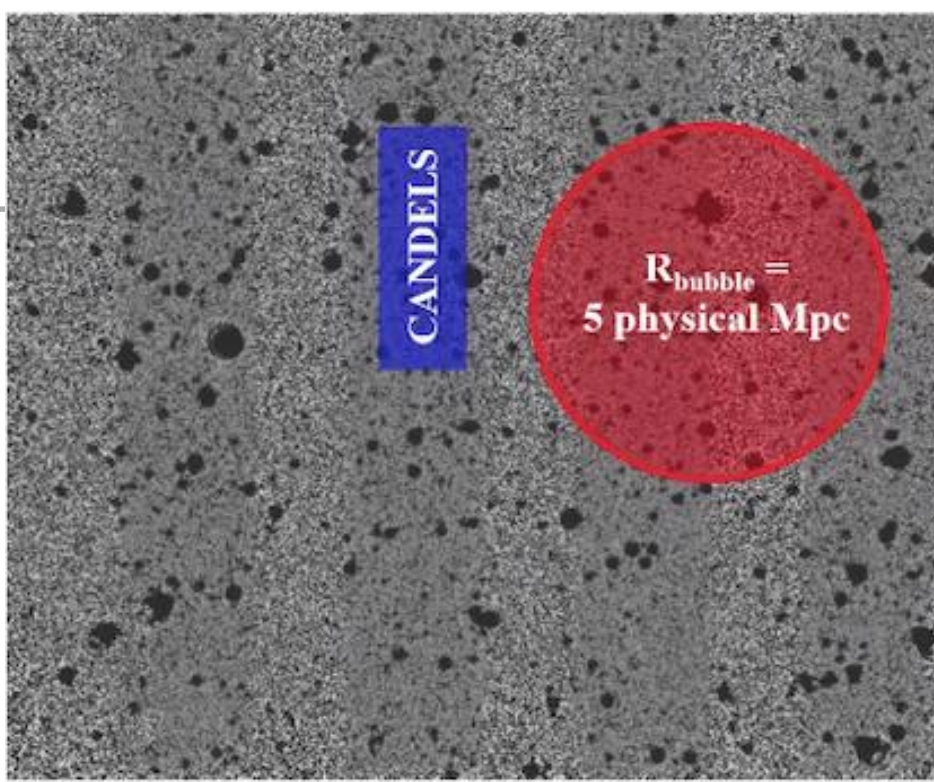
En colaboración con Aaron Smith (Harvard) & Emma Ryan-Weber (Swinburne)

Galaxias LAE (Lyman alpha emitter)



Endsley et al. 2021

Galaxies LAEs



CANDELS

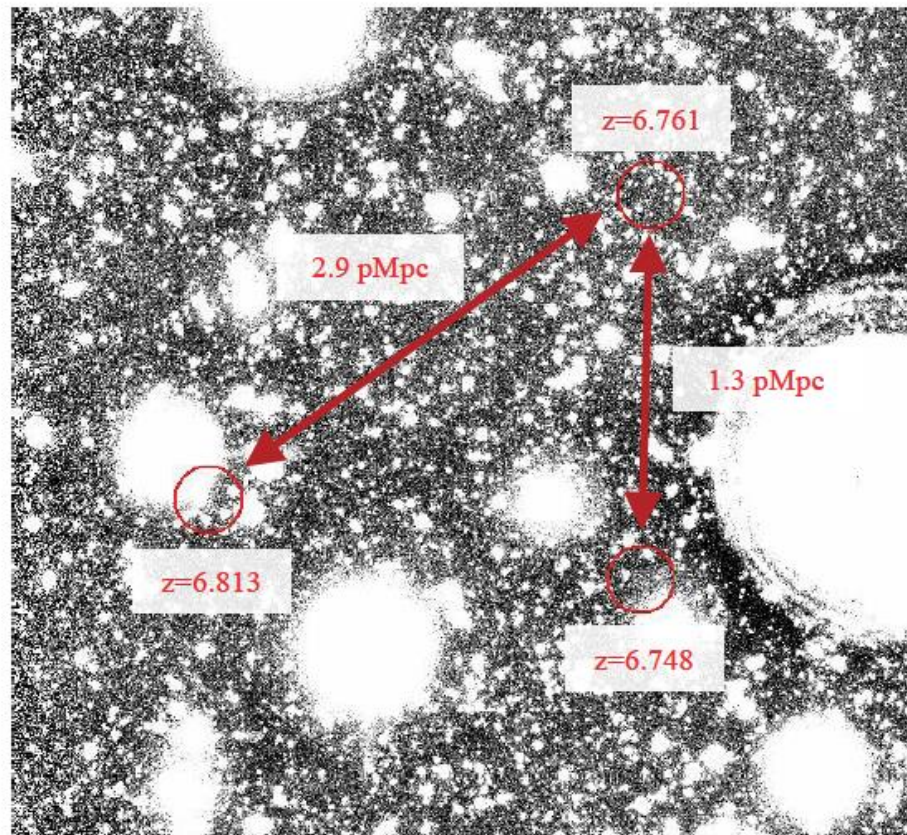
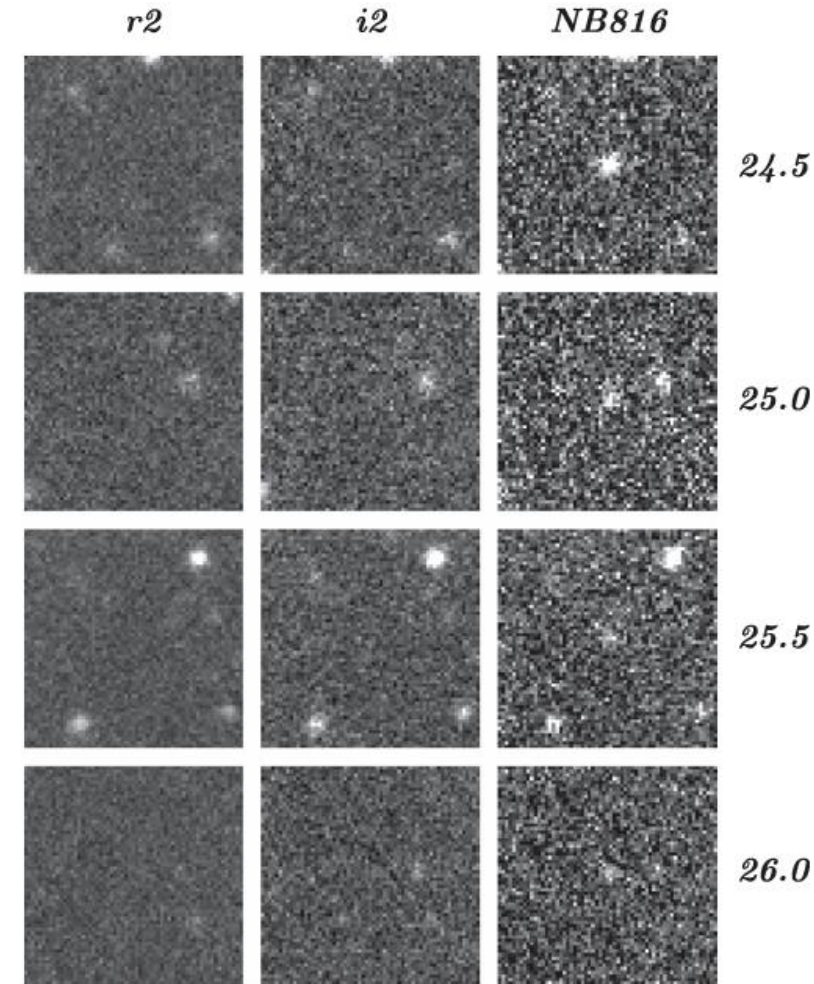


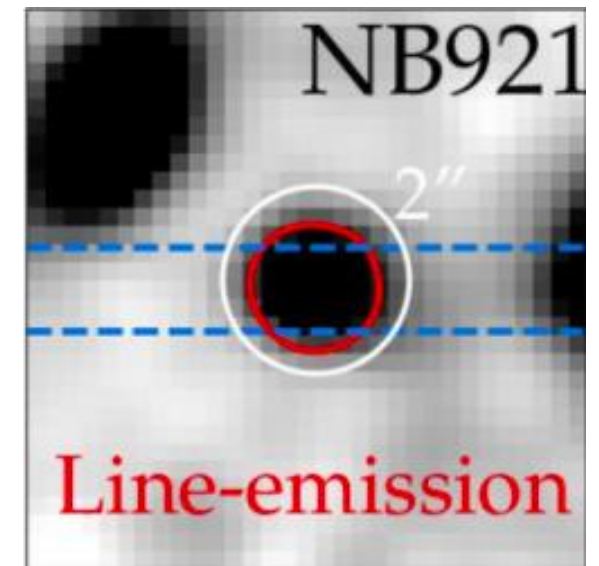
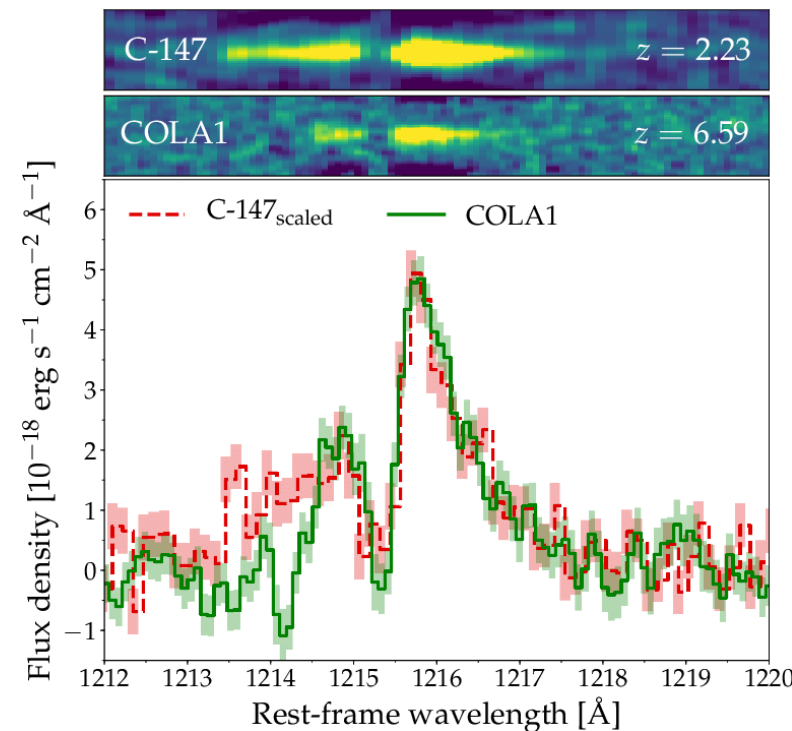
Figure 8. Illustration of three closely separated Ly α emitters in our $z \approx 7$ sample. All three sources fall within a spherical region with radius $R = 1.7$ physical Mpc, consistent with the expected sizes of HII regions at $z \approx 7$ (e.g. Lin et al. 2016). The proximity of these Ly α emitters thus may plausibly reflect the presence of a large ionized bubble.

COSMOS

Endsley et al. 2021



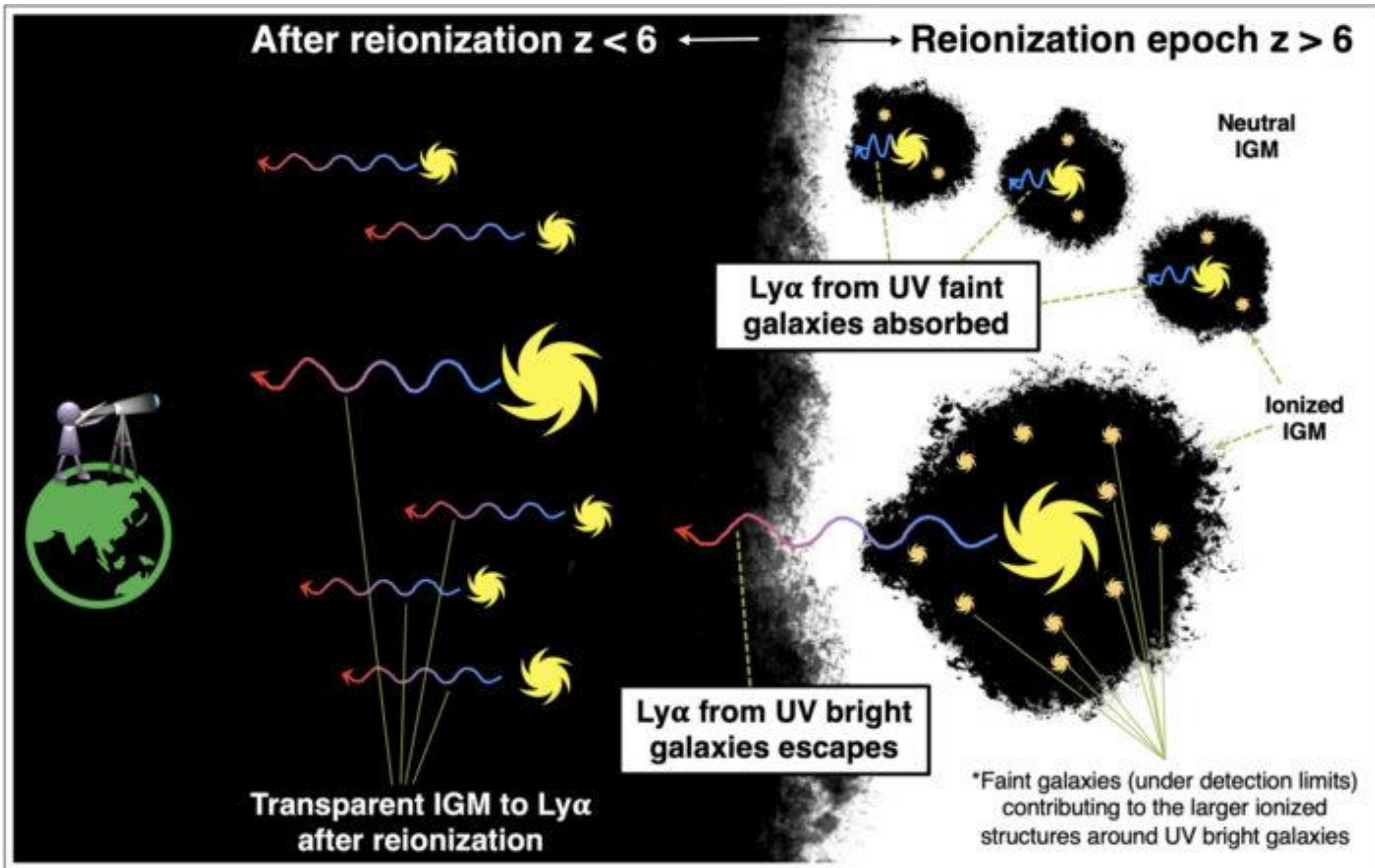
SILVERRUSH /HSC
Becker et al. 2018



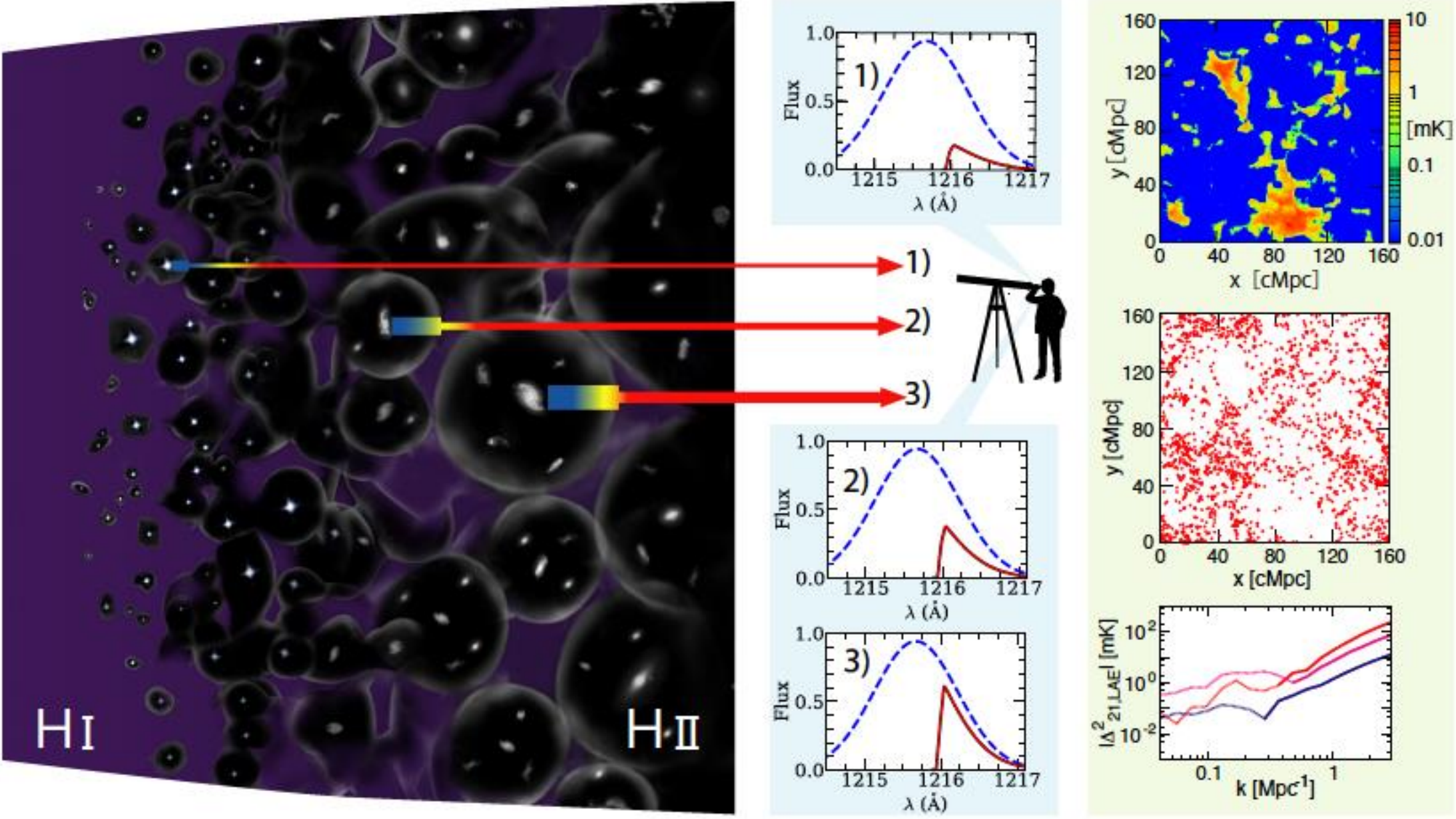
Matthee et al. 2018

X-SHOOTER / VLT

Galaxias LAE (Lyman alpha emitter)



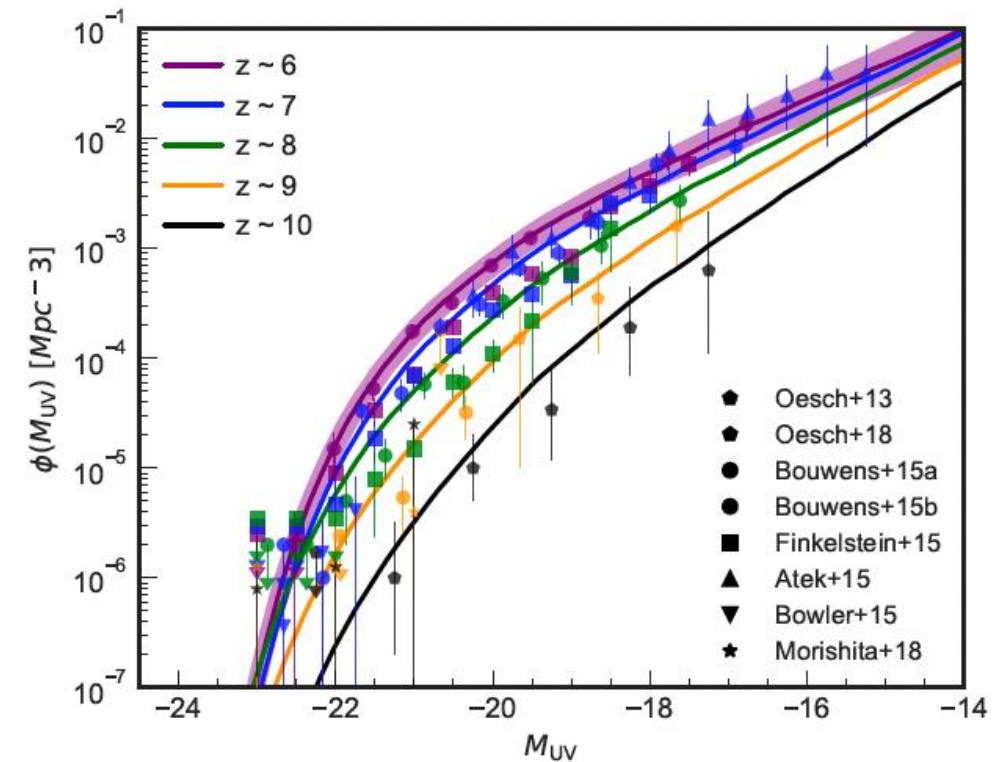
Galaxies LAE (Lyman alpha emitter)



Búsqueda de Galaxias LAE a $z=6$

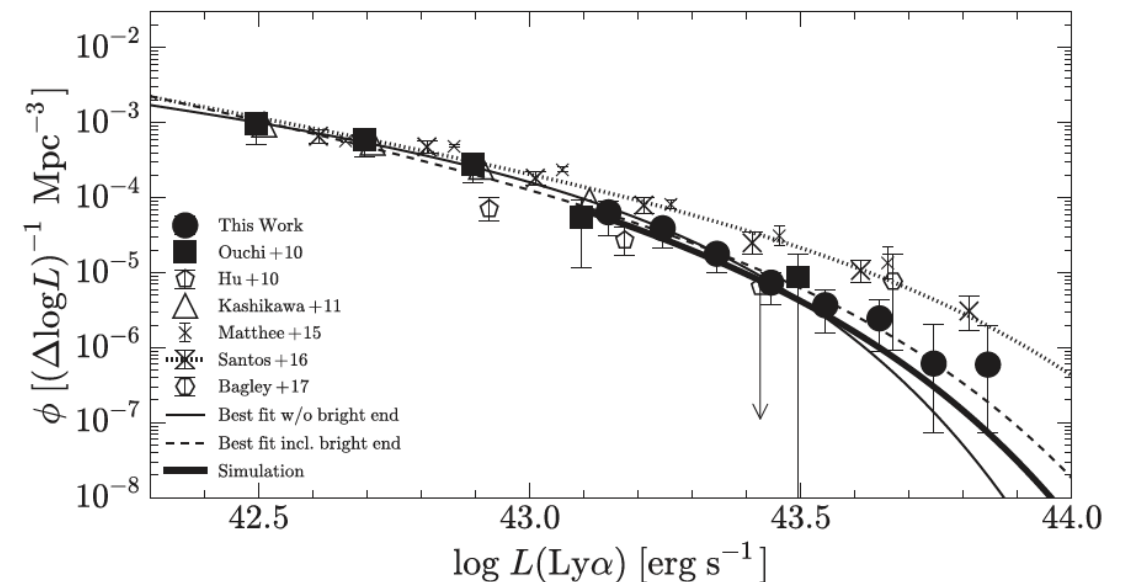
- ★ Incremento del número de galaxias en el tiempo del modelo jerárquico de formación de estructura.
- ★ Expansión del Universo y disminución de la densidad media del gas.
- ★ Evolución del fondo ionizante con el progreso de la época de Reionización.
- ★ Aumento de la transmisión de los fotones Lyman Alfa con la conclusión de la Reionización.
- ★ Absorción de los fotones Lyman Alfa emitidos por las galaxias por el polvo.

Morales et al. 2021

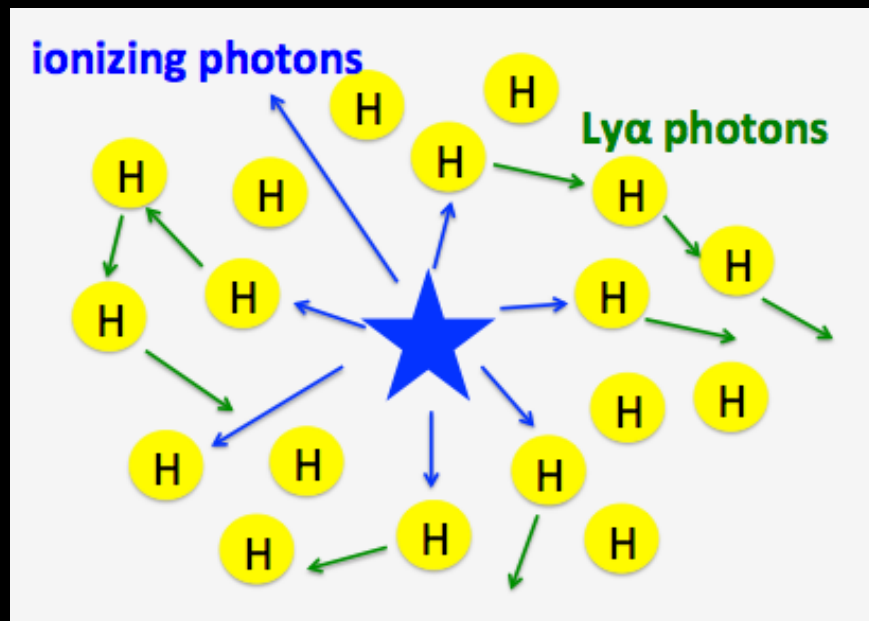
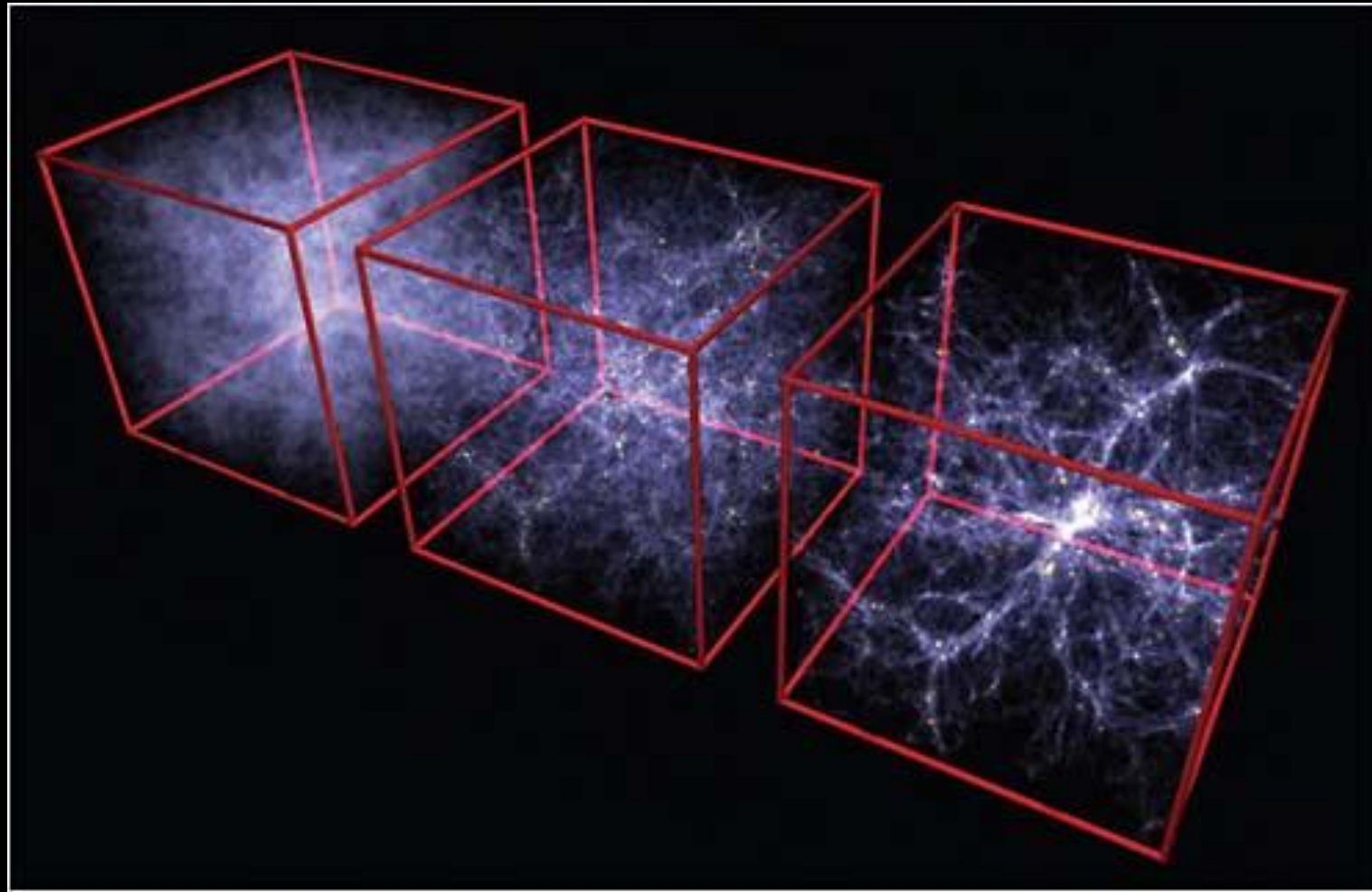


Brillante

Tenue



Konno et al. 2018



+



Simulaciones THESAN (Illustris TNG)

Name	L_{box} [cMpc]	$N_{\text{particles}}$	m_{DM} [M_{\odot}]	m_{gas} [M_{\odot}]	ϵ [ckpc]	$r_{\text{cell}}^{\text{min}}$ [pc]	z_{end}	f_{esc}	Description
THESAN-1	95.5	2×2100^3	3.12×10^6	5.82×10^5	2.2	~ 10	5.5	0.37	fiducial

Field	Units	Description
L_{α}	erg/s	Total Ly α luminosity ($L_{\alpha} = L_{\alpha}^{\text{rec}} + L_{\alpha}^{\text{col}} + L_{\alpha}^{\text{stars}}$)
L_{α}^{rec}	erg/s	Ly α luminosity from resolved recombination
L_{α}^{col}	erg/s	Ly α luminosity from collisional excitation
$L_{\alpha}^{\text{stars}}$	erg/s	Ly α luminosity from unresolved H II regions
$L_{\lambda,1216}$	erg/s/Å	Stellar continuum spectral luminosity at 1216 Å
$L_{\lambda,1500}$	erg/s/Å	Stellar continuum spectral luminosity at 1500 Å
$L_{\lambda,2500}$	erg/s/Å	Stellar continuum spectral luminosity at 2500 Å
$L_{\text{ion}}^{\text{AGN}}$	erg/s	Ionizing luminosity from active galactic nuclei
r_{α}	kpc	Center of Ly α luminosity position in the box
v_{α}	km/s	Center of Ly α luminosity peculiar velocity
σ_{α}	km/s	Center of Ly α luminosity 1D velocity dispersion

Smith et al. submitted

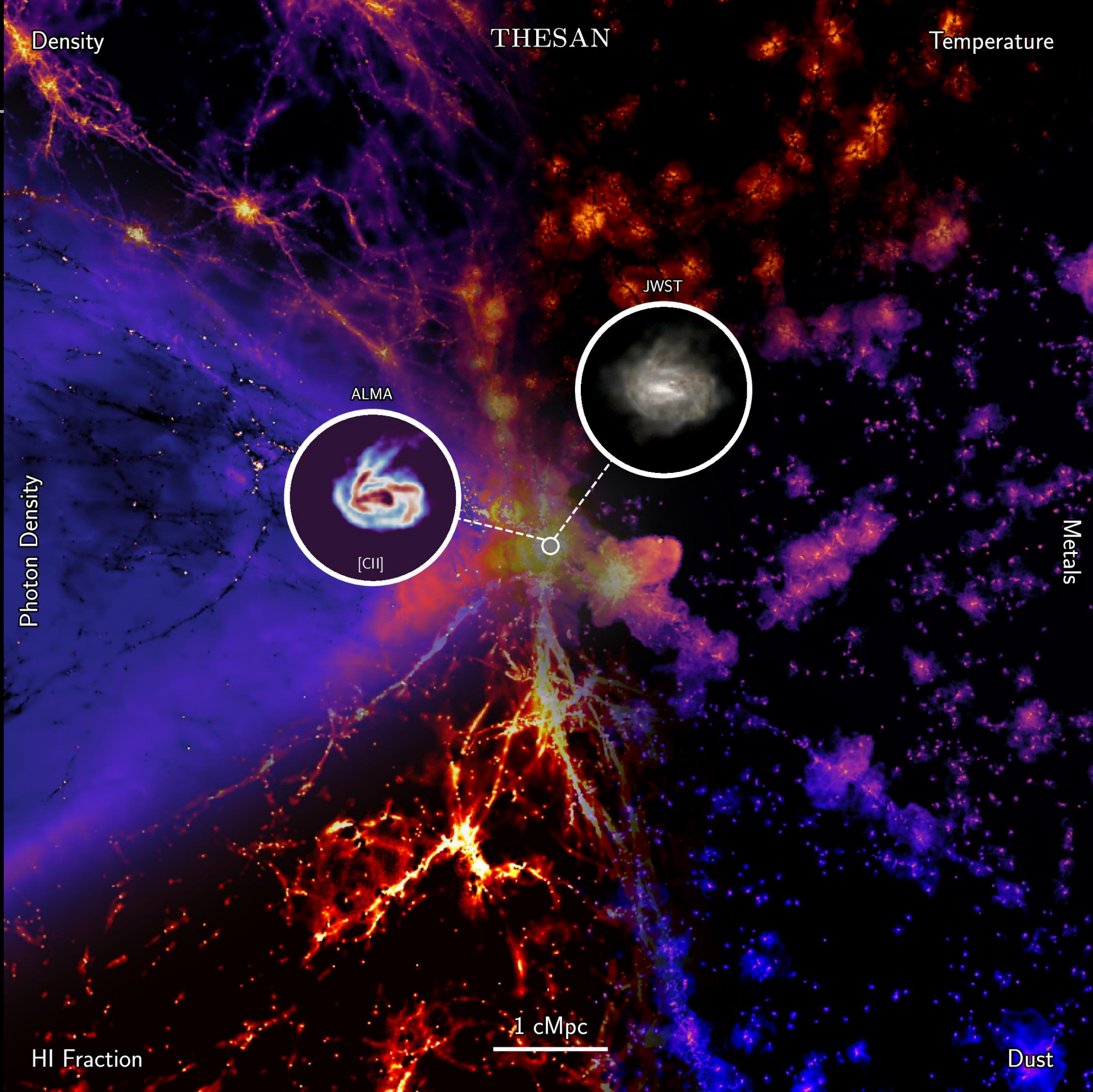


Cosmic Ly α Transfer code

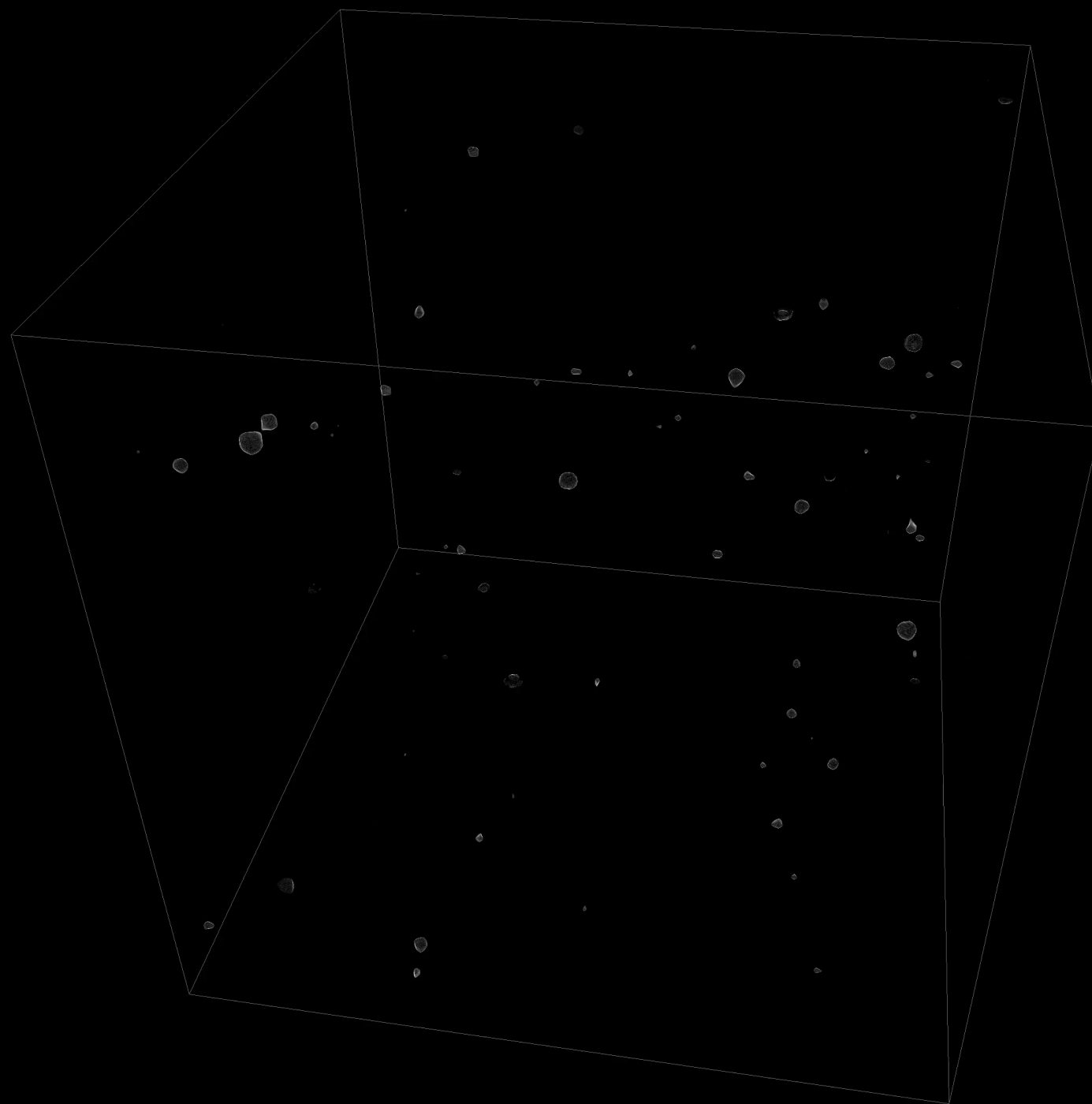
El proyecto THESAN se basa en las simulaciones **Illustris TNG**.

Se obtiene de forma autoconsistente la emisión de Ly α de las galaxias a alto z .

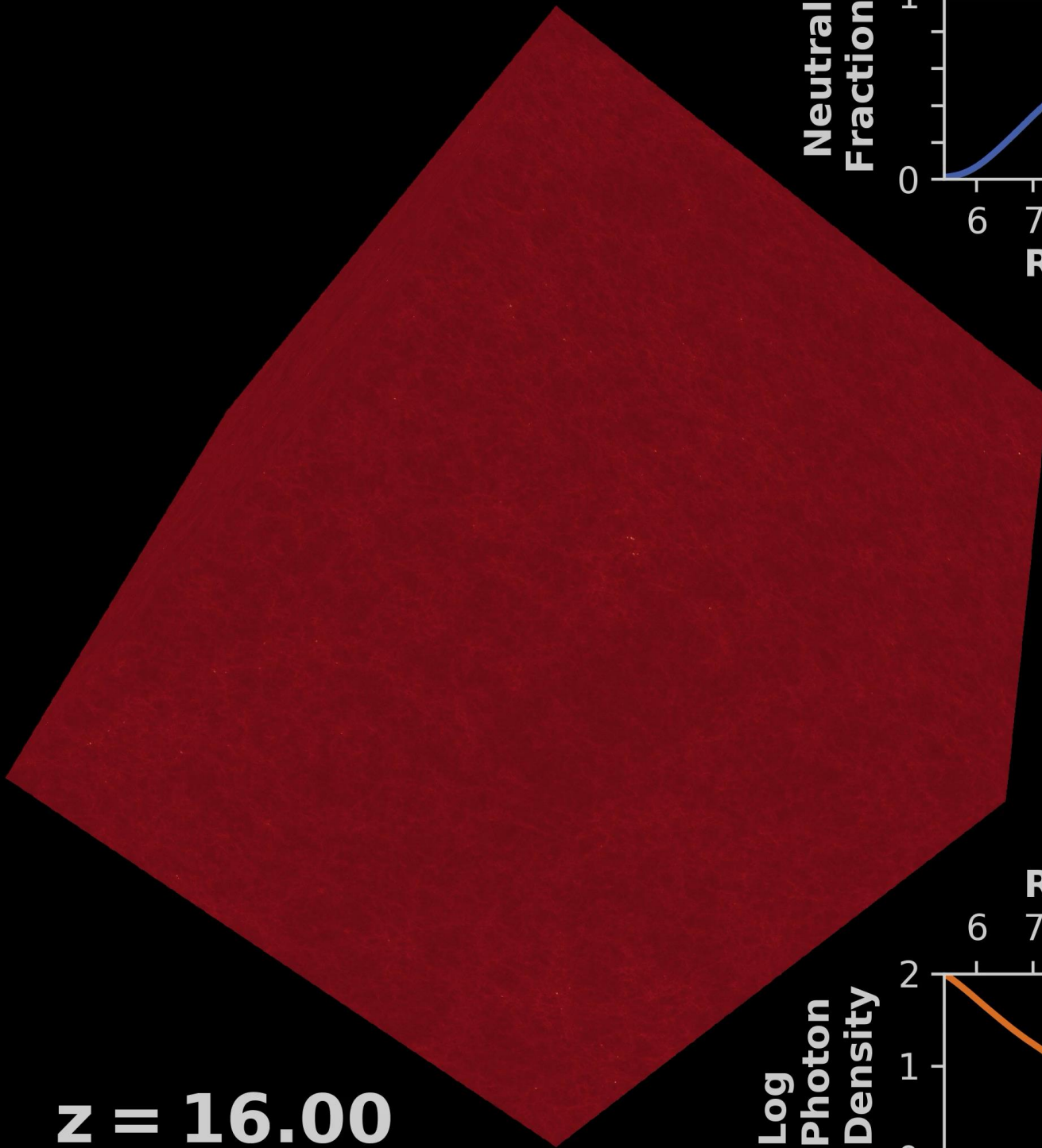
Para más detalles, ver Kannan et al. 2021.



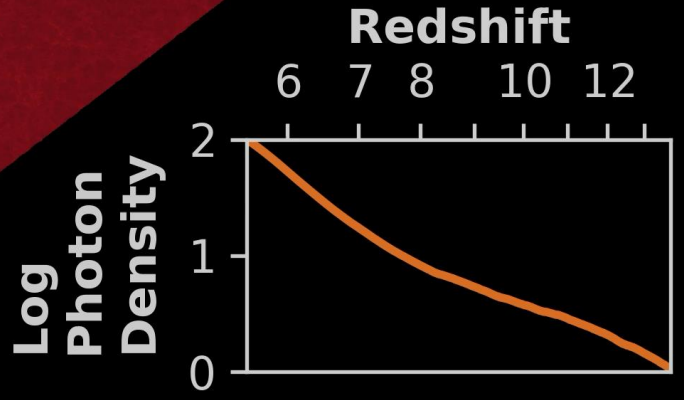
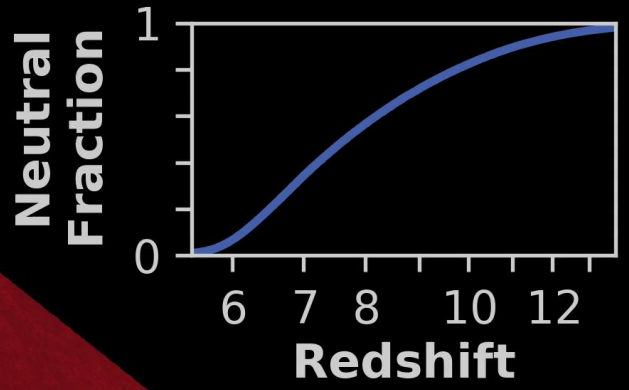
$z = 14.3$
288.1 Myr



Topología de los frentes ionizantes

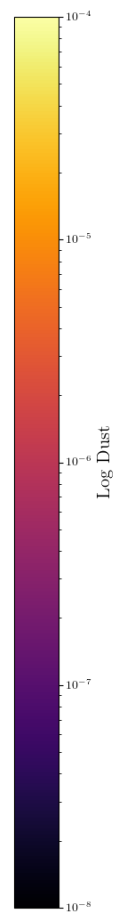
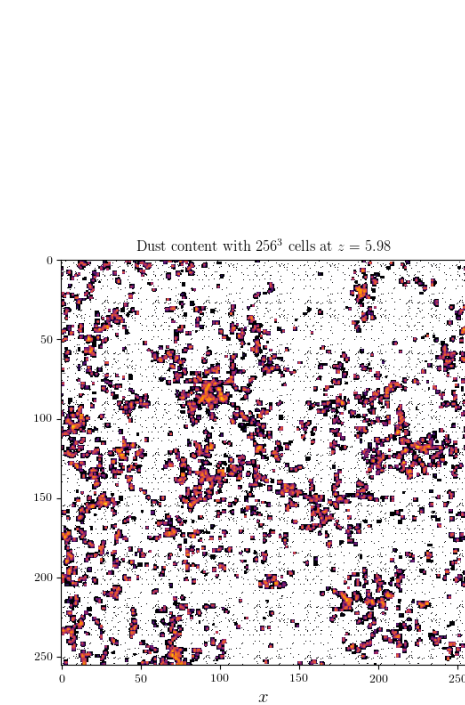
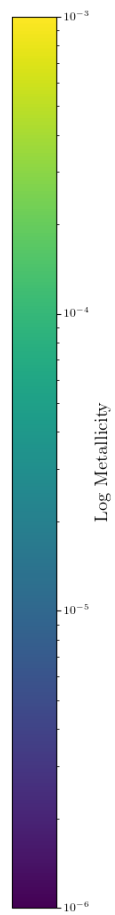
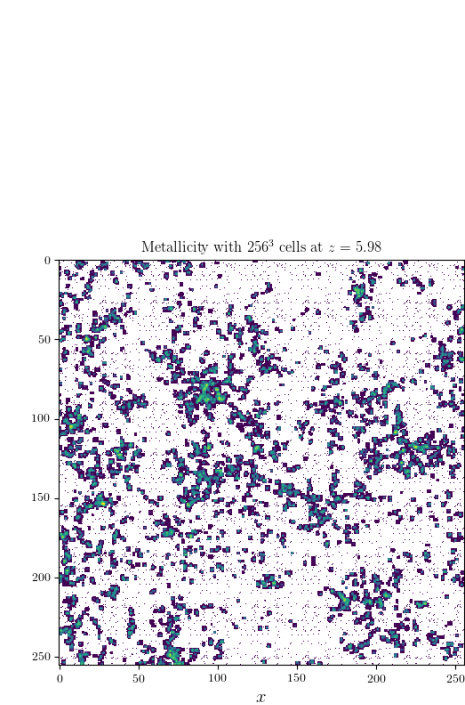
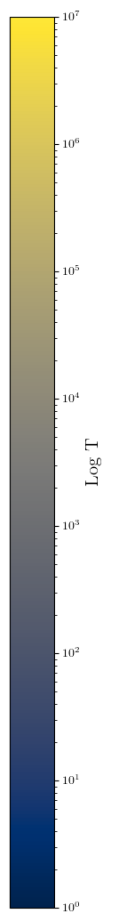
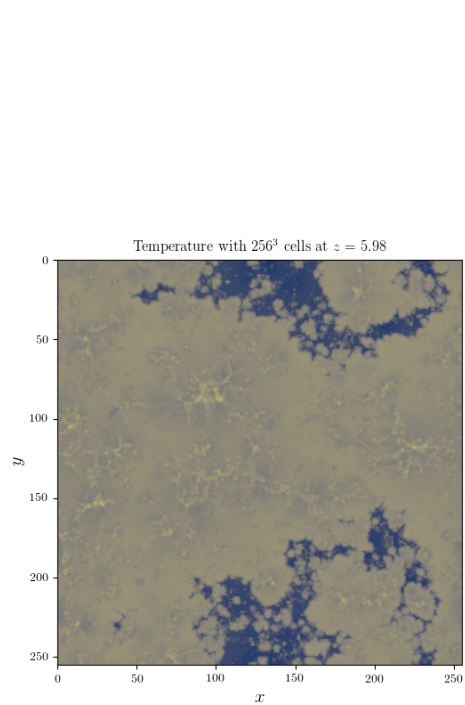
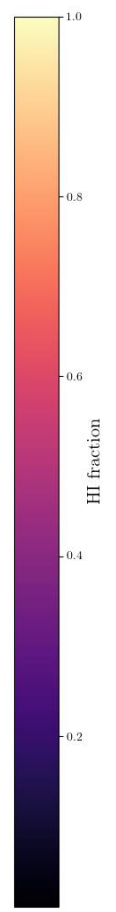
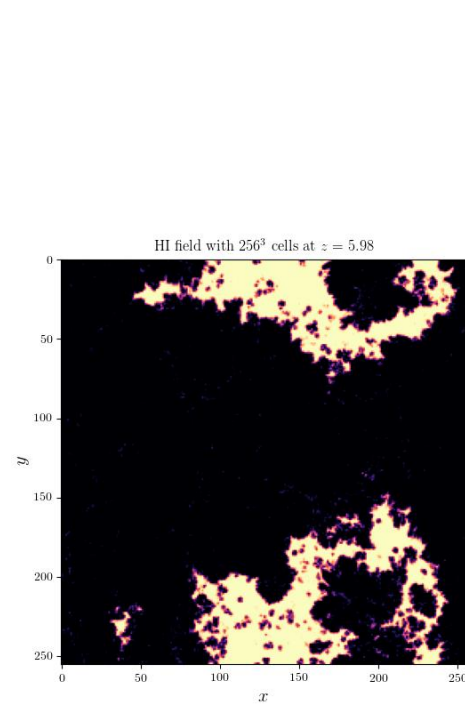
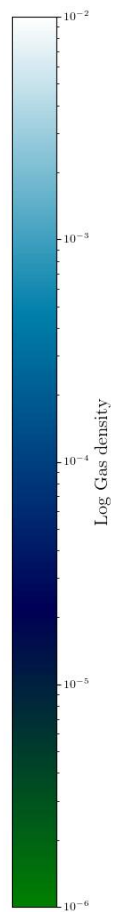
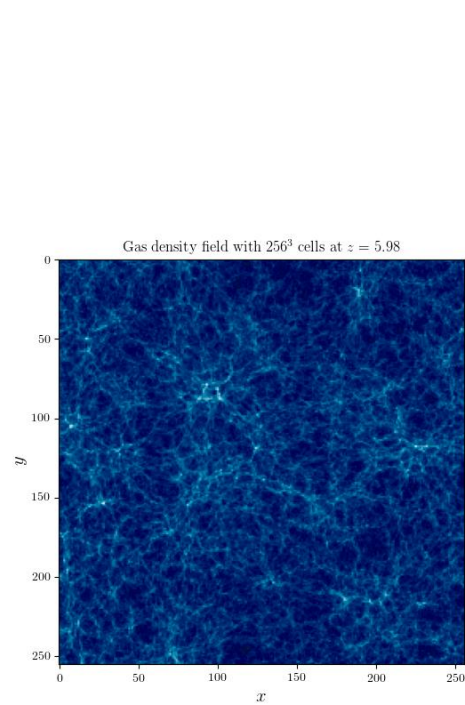
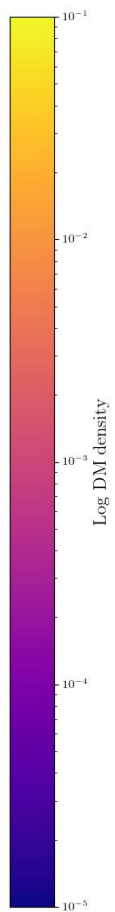
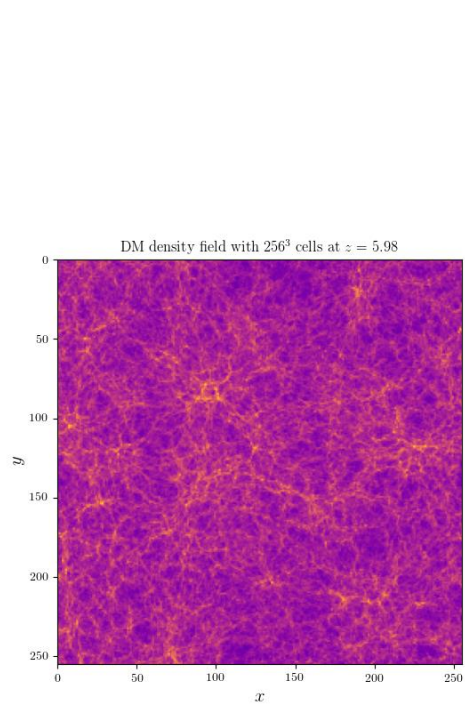


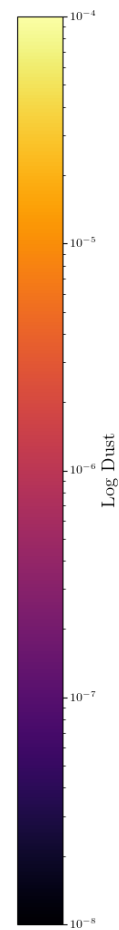
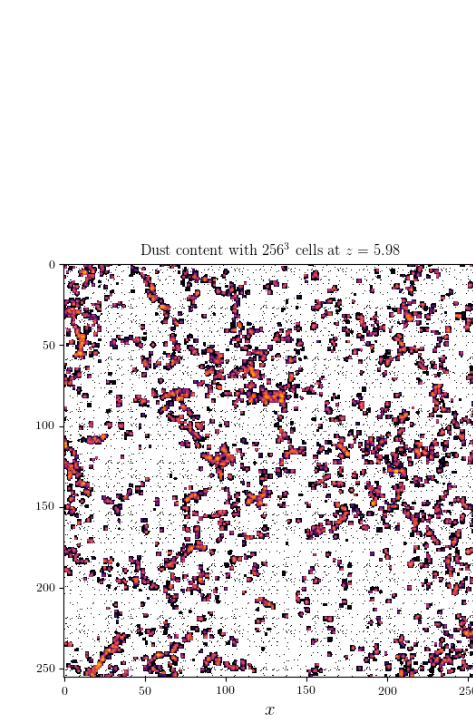
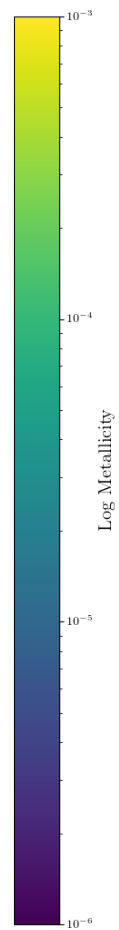
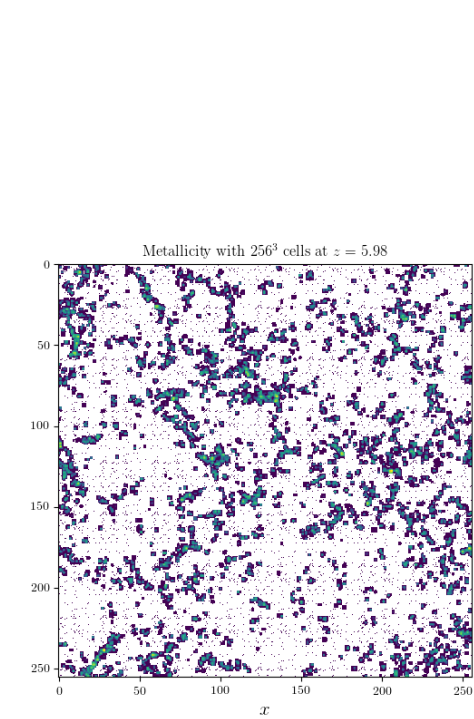
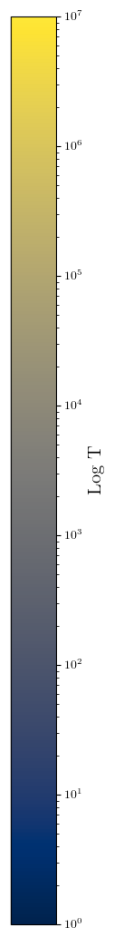
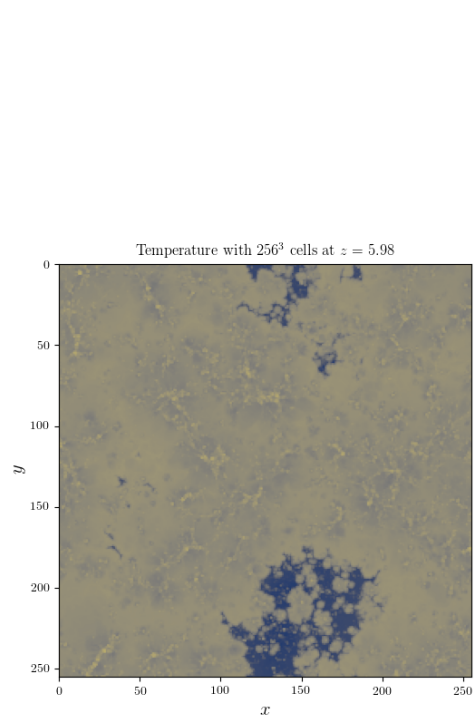
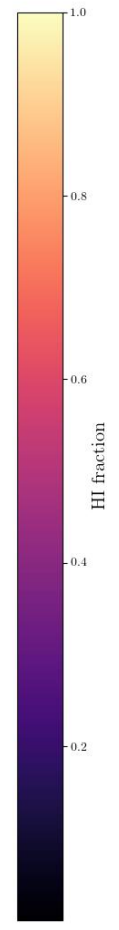
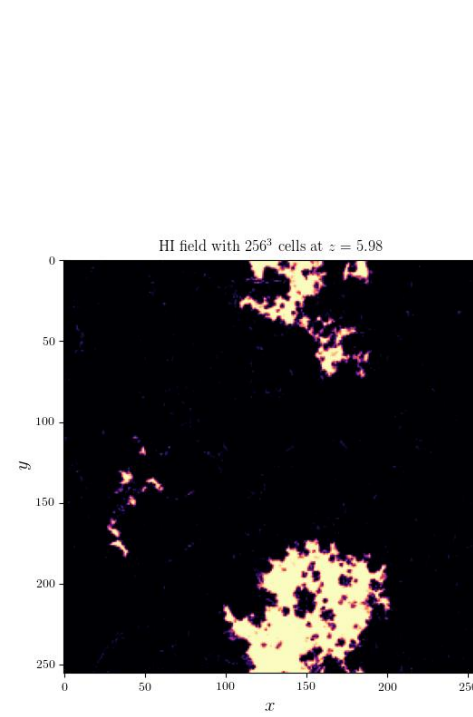
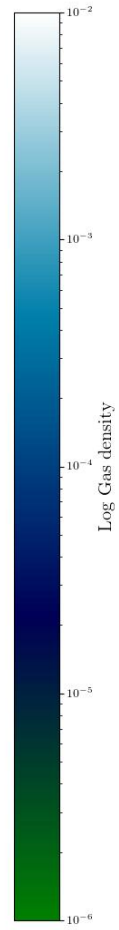
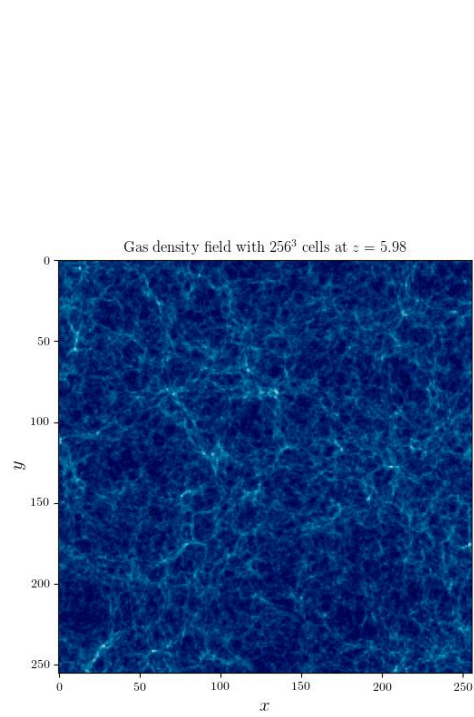
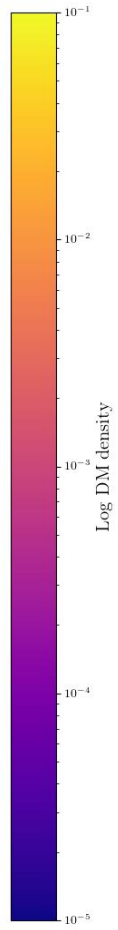
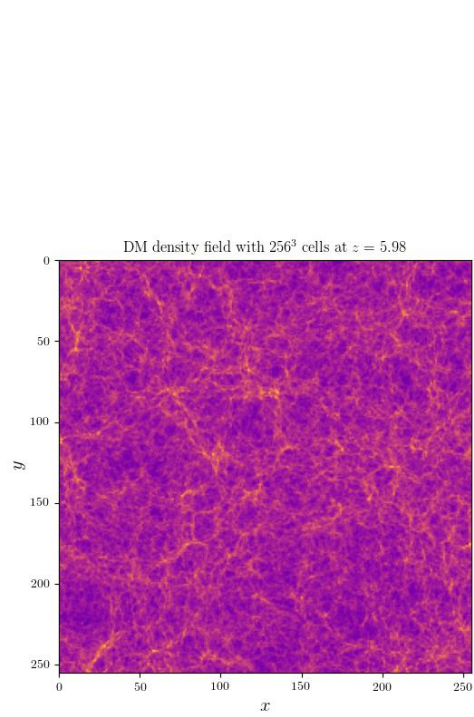
$z = 16.00$



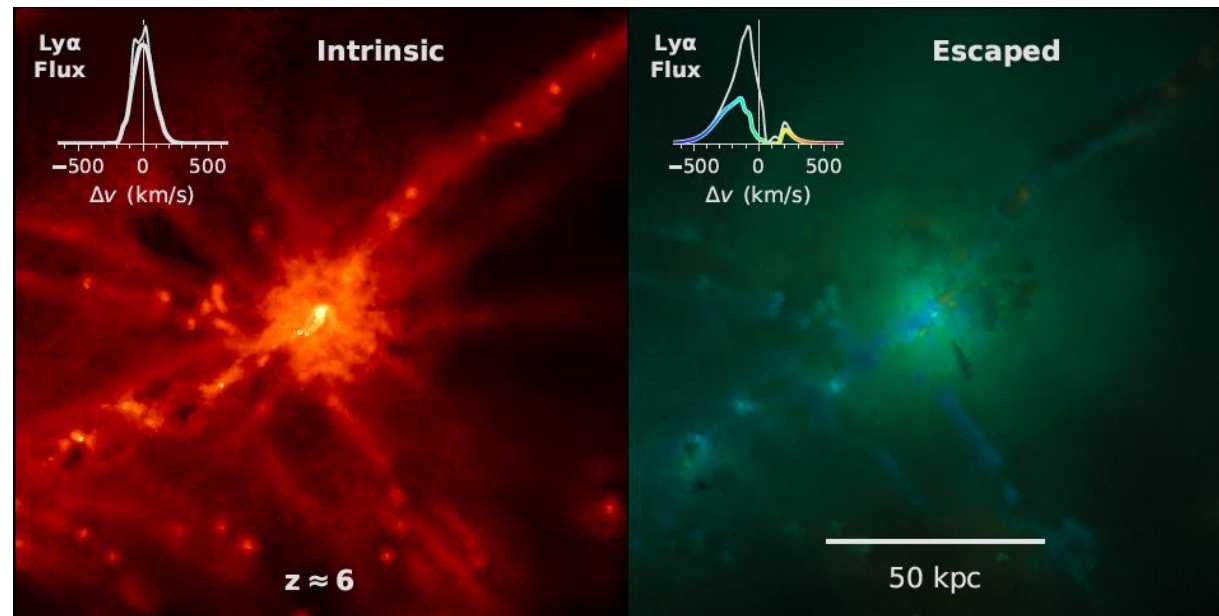
THESAN

Cubo de hidrógeno neutro

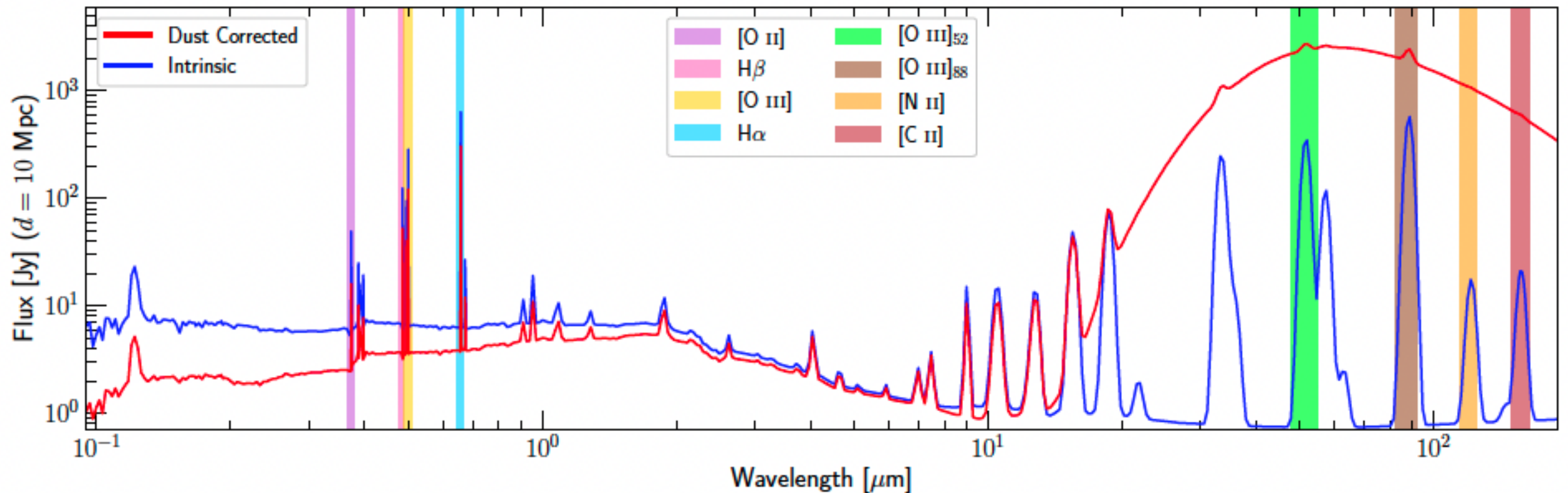




SED simuladas de Galaxias LAEs



Smith et al. submitted



Kannan et al. 2022

Conclusiones

- * Modelos teóricos son compatibles con la mayoría de observaciones con las que contamos hoy en día. Sin embargo, existe una alta diversidad en las predicciones de las simulaciones.
- * Una alternativa al tratamiento integral de transferencia radiativa en las simulaciones cosmológicas es la implementación de un fondo ionizante UV con apantallamiento del hidrógeno neutro en regiones de alta densidad para describir de forma efectiva la progresión de la Reionización.
- * Las predicciones teóricas con respecto a la **Época de Reionización** propuestas por las simulaciones numéricas serán testeadas y revisadas por futuros telescopios como JWST, Euclid, Vera Rubin Observatory (LSST) y el Nancy Roman (WFIRST).

