Do the early galaxies observed by JWST disagree with Planck's CMB polarization measurements?

Matteo Forconi at al

A journal club presentation by
Pablo Motta, USP

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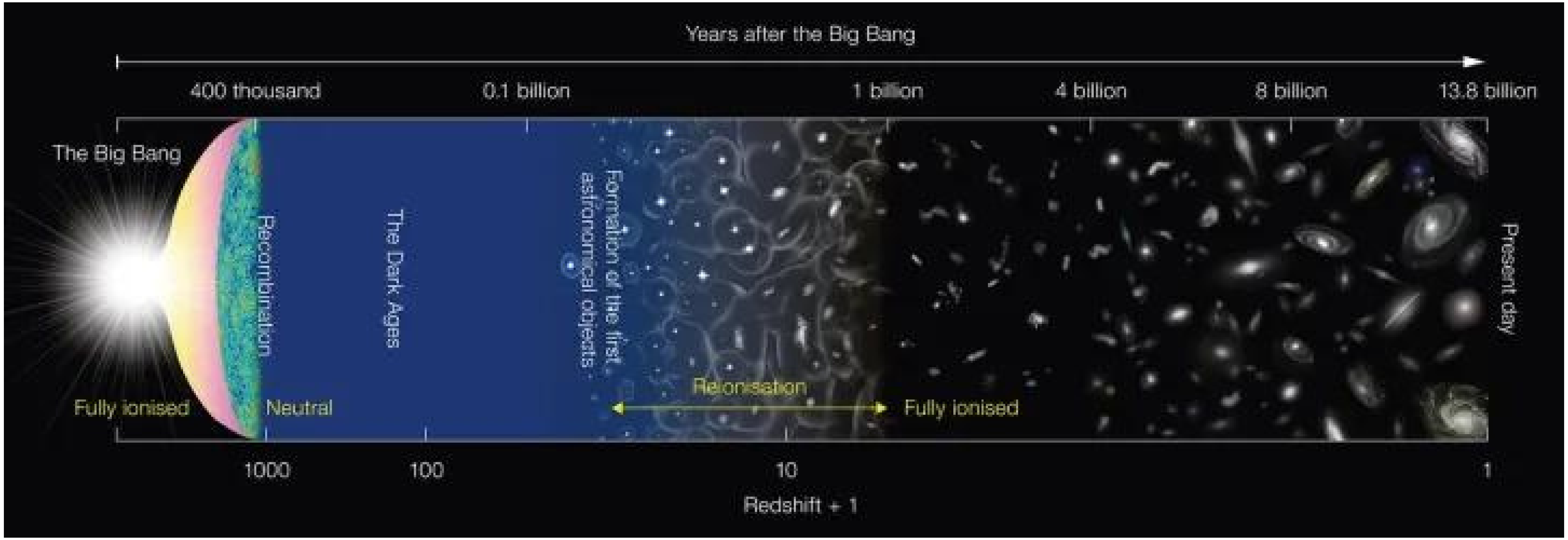
Context



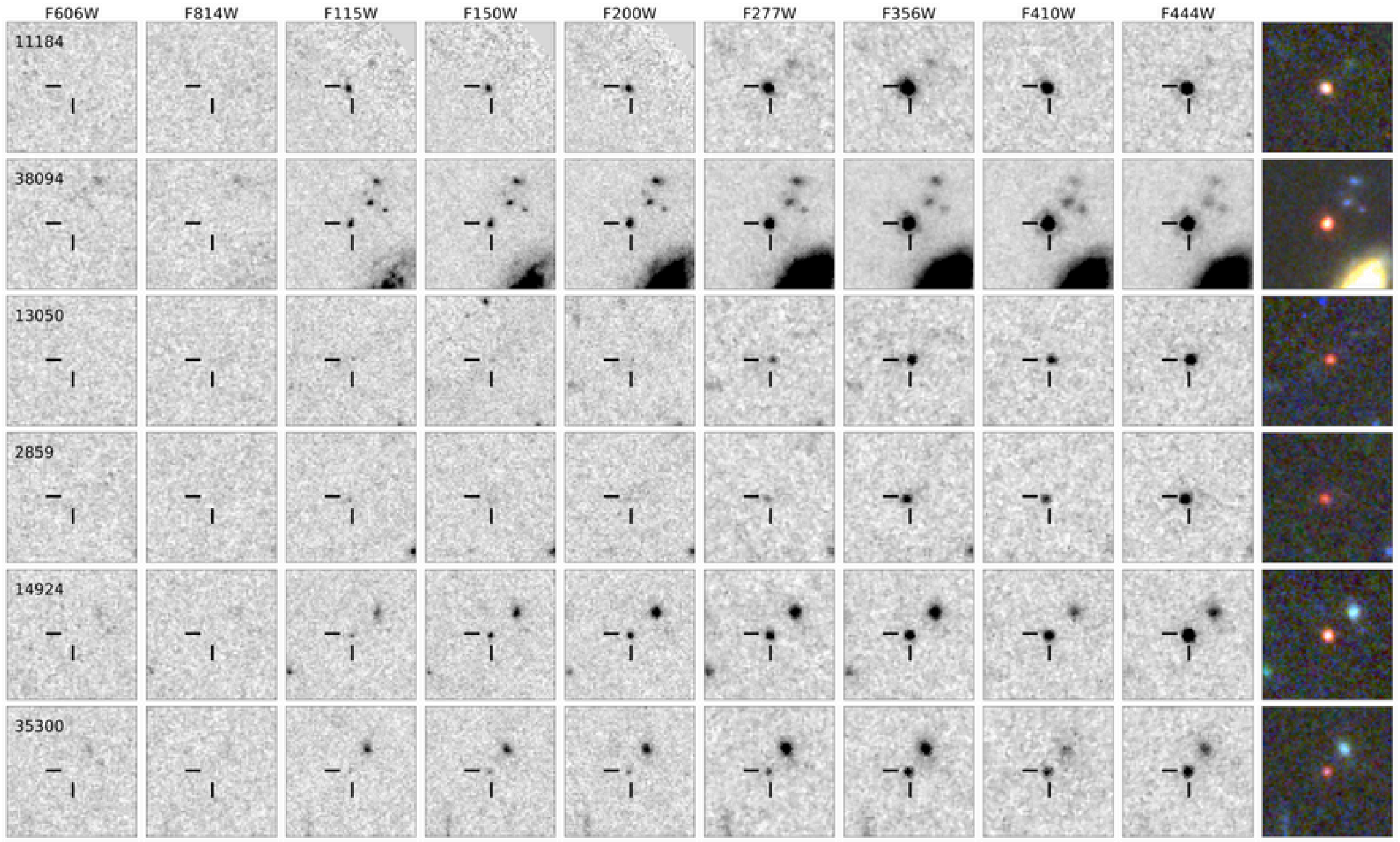
- Recent JWST (James Webb Space Telescope) observations have revealed a population of surprisingly massive galaxy candidates with stellar masses of the order of M ≥ 10^10.5 solar masses.
- JWST data indicates a higher stellar mass density in $7 < z < 11$ than predicted by the ΛCDM model.

We have a discrepancy between JWST observations and what is predicted by ΛCDM model.

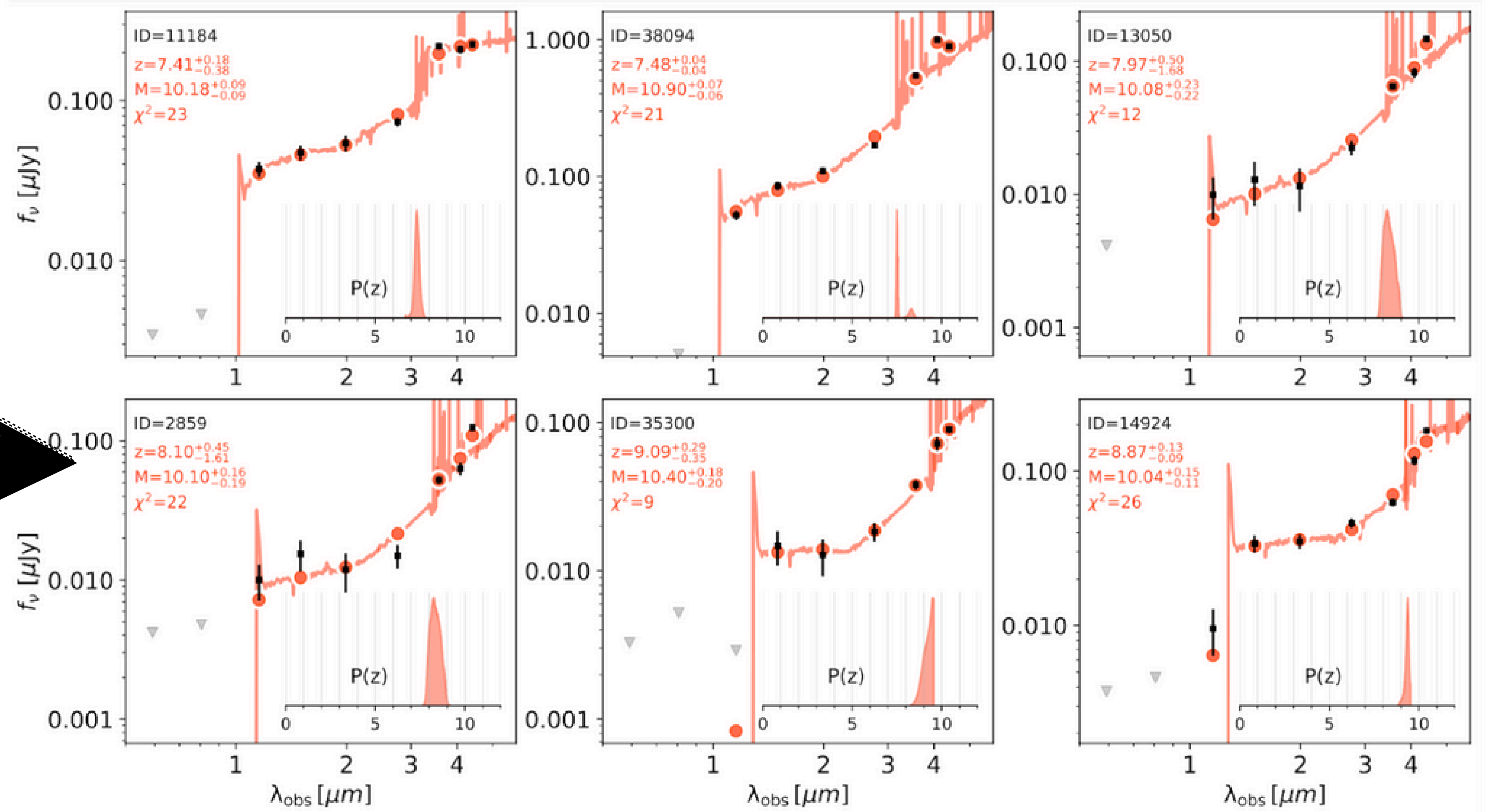
Let's raise some hypothesis that could explain this problem.

Hipothesis 01: inaccuracies in measuring the properties of galaxies (mass and redshift)

- Properties of the galaxies are derived from fitting a template of spectral energy distributions (SEDs) to the emissions in different photometric bands.
- It is possible that techniques that have been calibrated with lower redshift objects are not applicable.



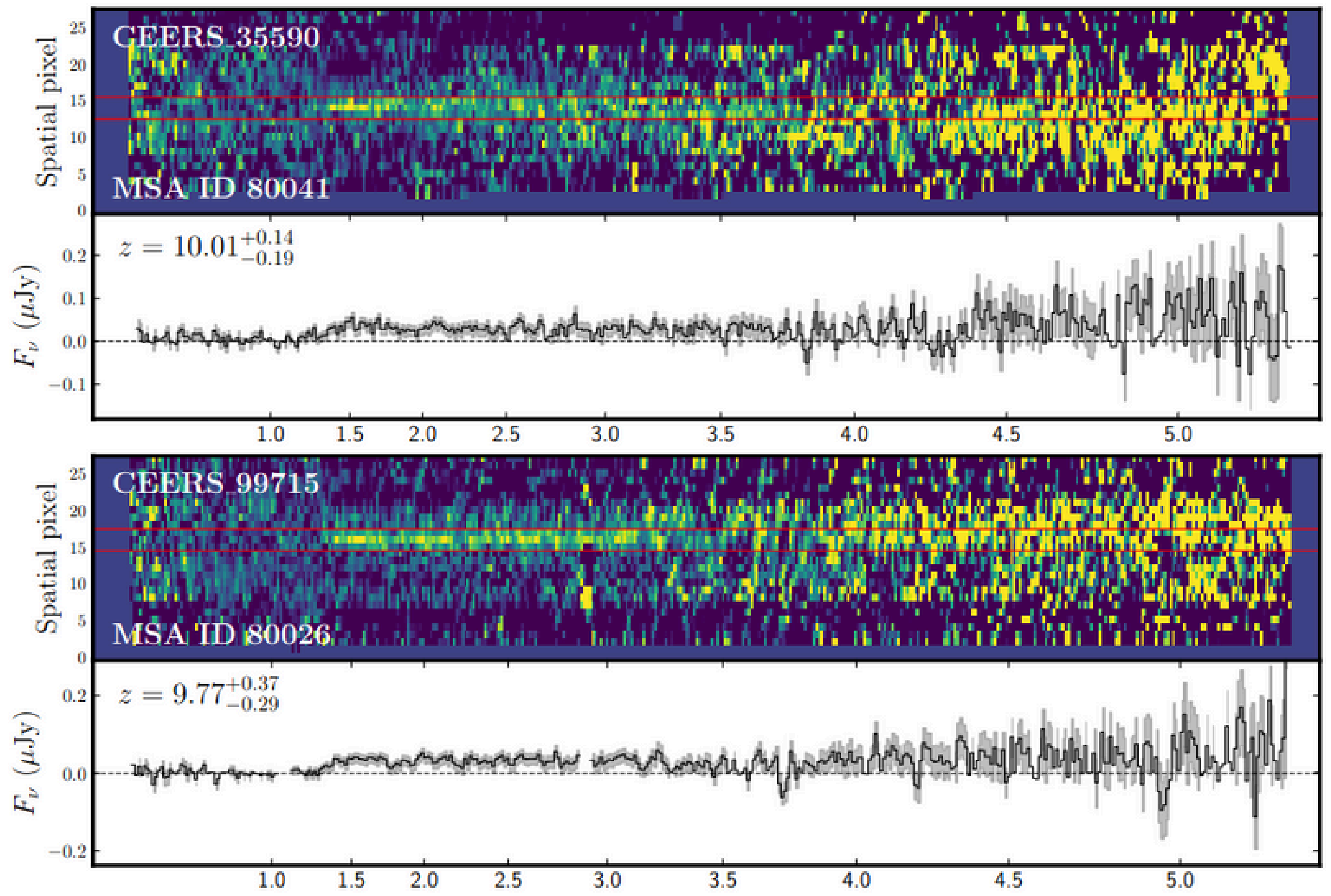
Photometric bands.



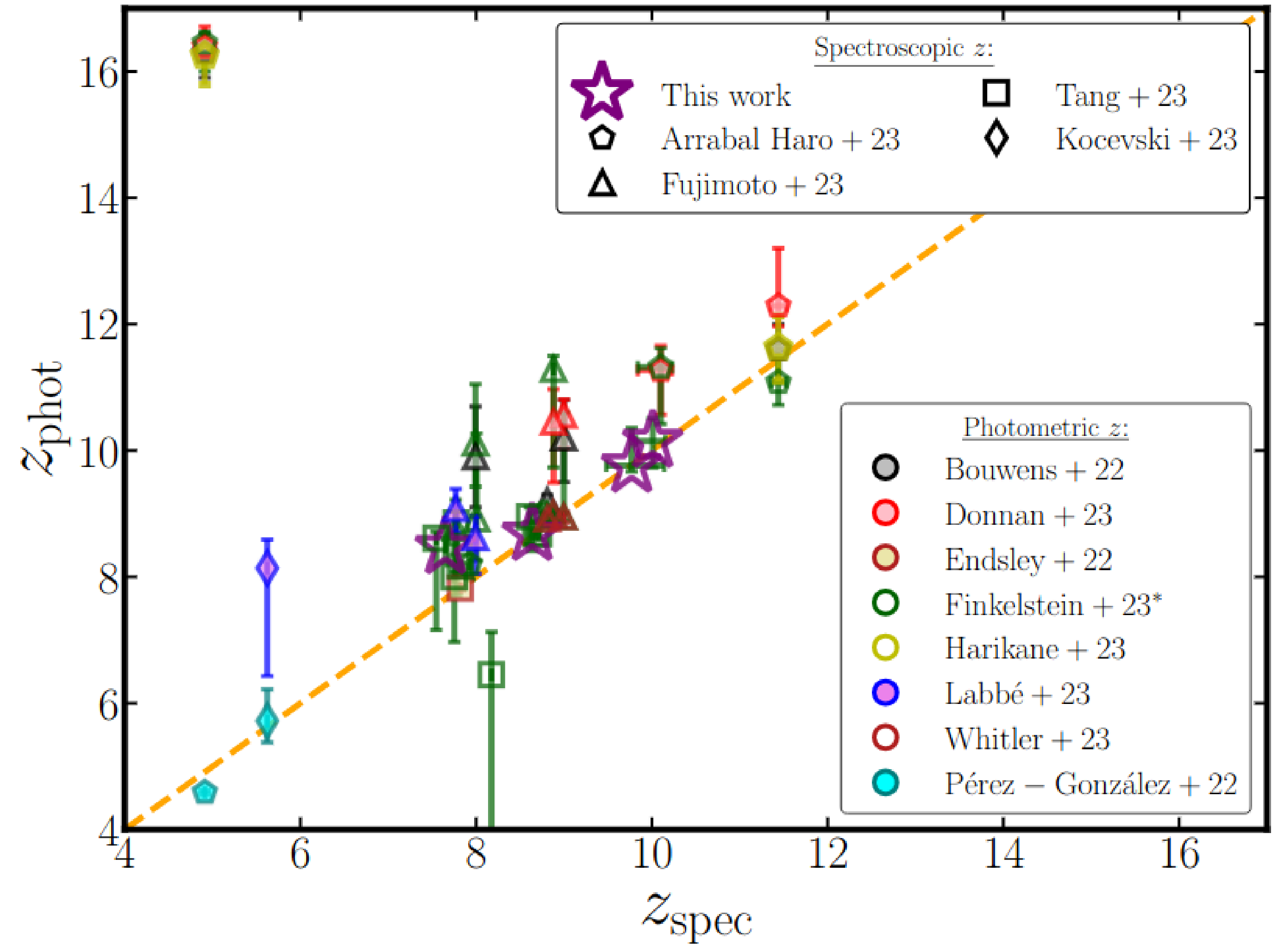
SED, mass and redshift of galaxies

Images: "A population of red candidate massive galaxies ~600 Myr after the Big Bang", Ivo Labbé at al, Arxiv:2207.12446

Spectroscopy with NIRSpec confirm photometric results



Spectral line measurement

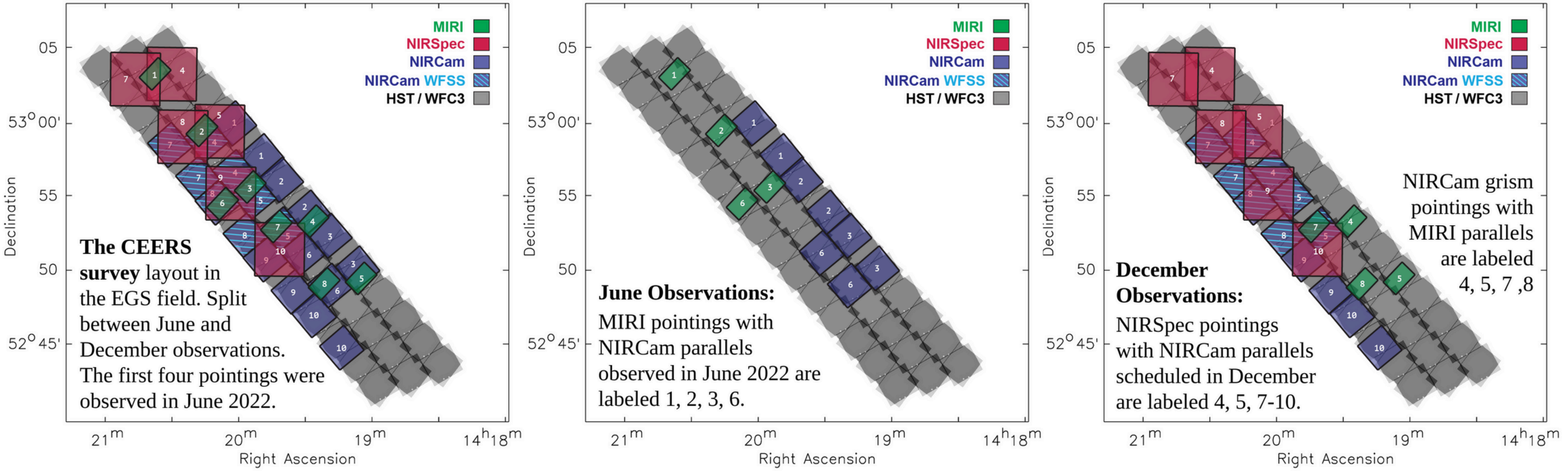


Spec−z in agreement with photo−z

See: "Spectroscopic confirmation of CEERS NIRCam−selected galaxies at $z \simeq 8$–10", AriXiv: 2304.05378.

Hipothesis 02: the obervation may be a highly atypical and unusually dense region of the Universe.

- JWST observations thus far covers an area of approximately 38 square arcminutes
- This hypothesis can be tested through upcoming JWST surveys like COSMOS–Web.



Hipothesis 03: The cosmological model should be modified

Some possible theoretical alternatives:

- Alternatives models within the dark matter and dark energy sector
- Primordial Black Holes solutions
- Cosmic strings
- Large scale–dependence Non–Gaussianity

Hipothesis 04: the presence of possible, unknown, systematics in the Planck polarization data.

- The CMB photons are scattered off by the free electrons generated by the reionization which affected the polarization patterns.
- Reionization occurring earlier would result in a larger polarization signal, which contrasts with Planck's observations.

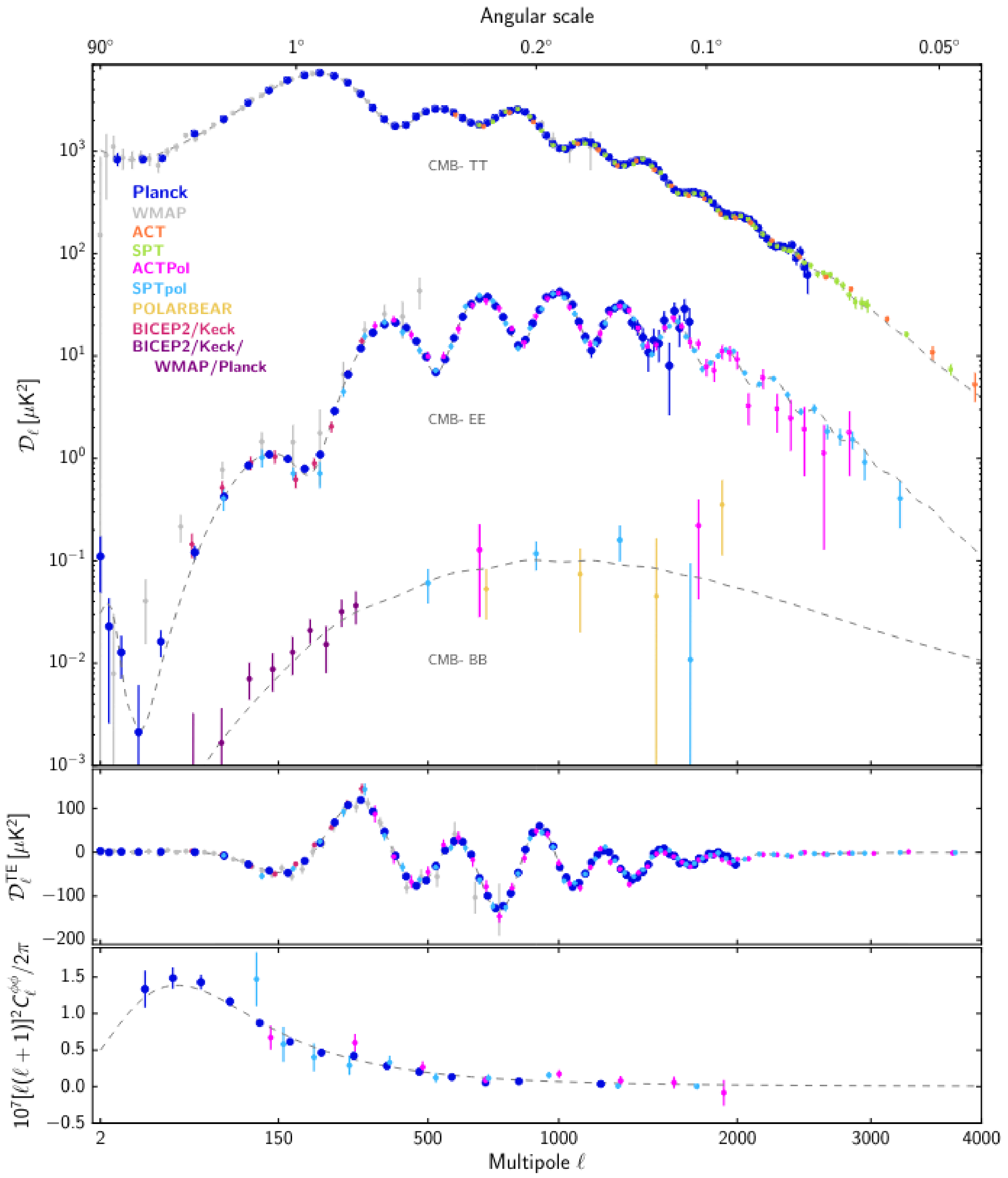


Image: Planck 2018 results 1. https://doi.org/10.1051/0004-6361/201833880

The last hypothesis is the one Forconi at al aim to investigate.

They propose to asses in a quantitative way the level of compatibility of the measurements from JWST and the Planck measurements under the assumption of the ΛCDM model.

Methods

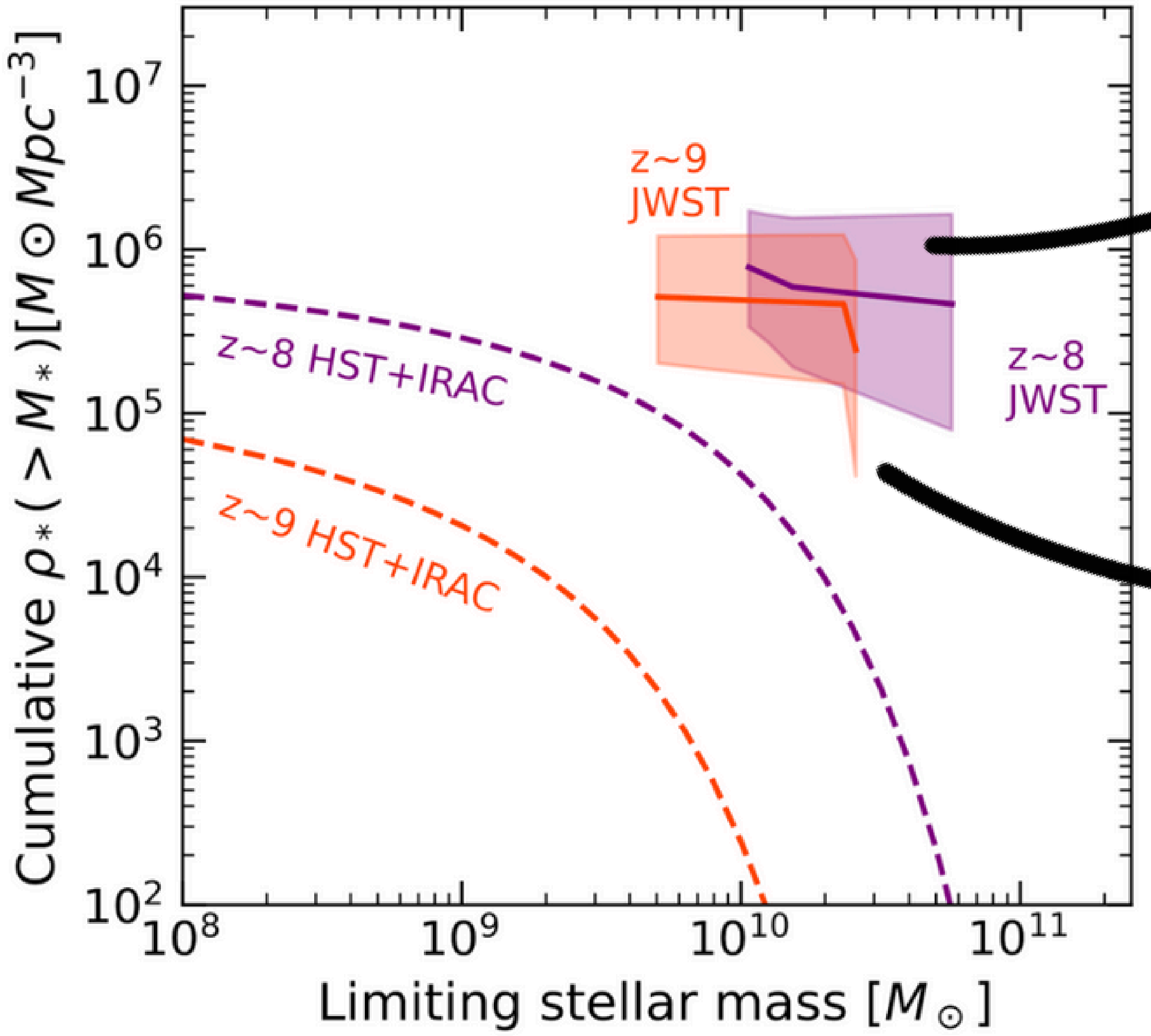
- They perform MCMC analysis with *CosmoMC* and *CAMB* using Planck and JWST data.
- They sample the 06 cosmological parameters: $\{\Omega_b, \Omega_c, \theta_s, \tau, n_s, A_s\}$.
- For the Planck data, they consider the following CMB temperature and polarization power spectra from the final Planck release:

1. The full Planck Temperature and Polarization anisotropies power spectra Planck TTTEEE+lowℓ+lowE.
2. As above but excluding the large angular scale polarization (Planck TTTEEE+lowℓ).
3. The full Temperature anisotropies spectra (Planck TT+lowℓ).
4. As above but considering only the small scale anisotropy (Planck TT).

- For the JWST they consider measurements of the Cumulative Star Mass Density (CSMD) for two redshifit bins: $7<z<8.5$ and $8.5<z<10$.

Datasets

- *Forconi at* at use the data of JWST's Cumulative Star Mass Density (CSMD) from *Labbé at al* for performing MCMC with Planck CMB. The CSMD values assume that the estimated masses are correct.



Ivo Labbé at al, Arxiv:2207.12446

7.0 < z < 8.5

- $\log_{10} \rho_*^{obs}(M_1) = 5.90 \pm 0.35$ at $log_{10}(M_1) = 10.1$
- $\log_{10} \rho_\star^{obs}(M_2) = 5.70 \pm 0.65$ at $log_{10}(M_2) = 10.8$

8.5 < z < 10

- $\log_{10} \rho_\star^{obs}(M_1) = 5.7 \pm 0.40$ at $log_{10}(M_1) = 9.7$
- $\log_{10} \rho_\star^{obs}(M_2) = 5.40 \pm 0.65$ at $log_{10}(M_2) = 10.4$

Modeling of the CSMD

Our main observable is the Cumulative Stellar Mass Density (CSMD) given by

$$\rho_\star(\bar{M}) = \epsilon f_b \int_{z_1}^{z_2} \int_{\bar{M}}^{\infty} \frac{dn}{dM} M\,dM \frac{dV}{V(z_1, z_2)}$$

Eficiency of converting baryons into stars

$f_b = \Omega_b/\Omega_m$

Number density of collapsed objects (ellipsoidal collapse)

Coming volume = $4/3\pi[R_2^3 - R_1^3]$

$$\frac{dn(M,z)}{dM} = F(\nu)\frac{\rho_m}{M^2}\left|\frac{d\ln\sigma(M,z)}{d\ln M}\right|$$ where $\nu = \frac{\delta_c}{\sigma(R)}$

Sheth–Tormen Halo mass function (observational fitting)

Rescaling data

$$\rho^{obs}(M_i, \bar{p}) = \frac{V_C^{Planck}}{V_C(\bar{p})} \rho_*^{obs}(M_i)$$

χ ² function

$$\chi^2_{\rm JWST}(\bar{p}) = \sum_{i=1}^{2} \left[\frac{\log_{10} \rho^{\rm th}(M_i, \bar{p}) - \log_{10} \rho^{\rm obs}(M_i, \bar{p})}{\sigma_i} \right]^2$$

Results

Dataset	$\Delta\chi^2$ $7 \leq z \leq 8.5$	$\Delta\chi^2$ $8.5 \leq z \leq 10$
$\epsilon = 0.1$		
Planck TT +JWST	20.14	25.71
Planck TT+Lowℓ+JWST	21.61	28.11
Planck TTTEEE+Lowℓ+JWST	26.30	33.03
Planck TTTEEE+Lowℓ+LowE+JWST	42.20	52.71
$\epsilon = 0.2$		
Planck TT +JWST	5.69	7.49
Planck TT+Lowℓ+JWST	5.49	7.65
Planck TTTEEE+Lowℓ+JWST	6.42	10.30
Planck TTTEEE+Lowℓ+LowE+JWST	11.87	17.76
$\epsilon = 0.32$		
Planck TT +JWST	2.11	2.53
Planck TT+Lowℓ+JWST	2.34	3.06
Planck TTTEEE+Lowℓ+JWST	2.17	2.88
Planck TTTEEE+Lowℓ+LowE+JWST	3.68	6.19

Table I. $\Delta\chi^2$ between the best fit model in the corresponding Planck and Planck+JWST chains.

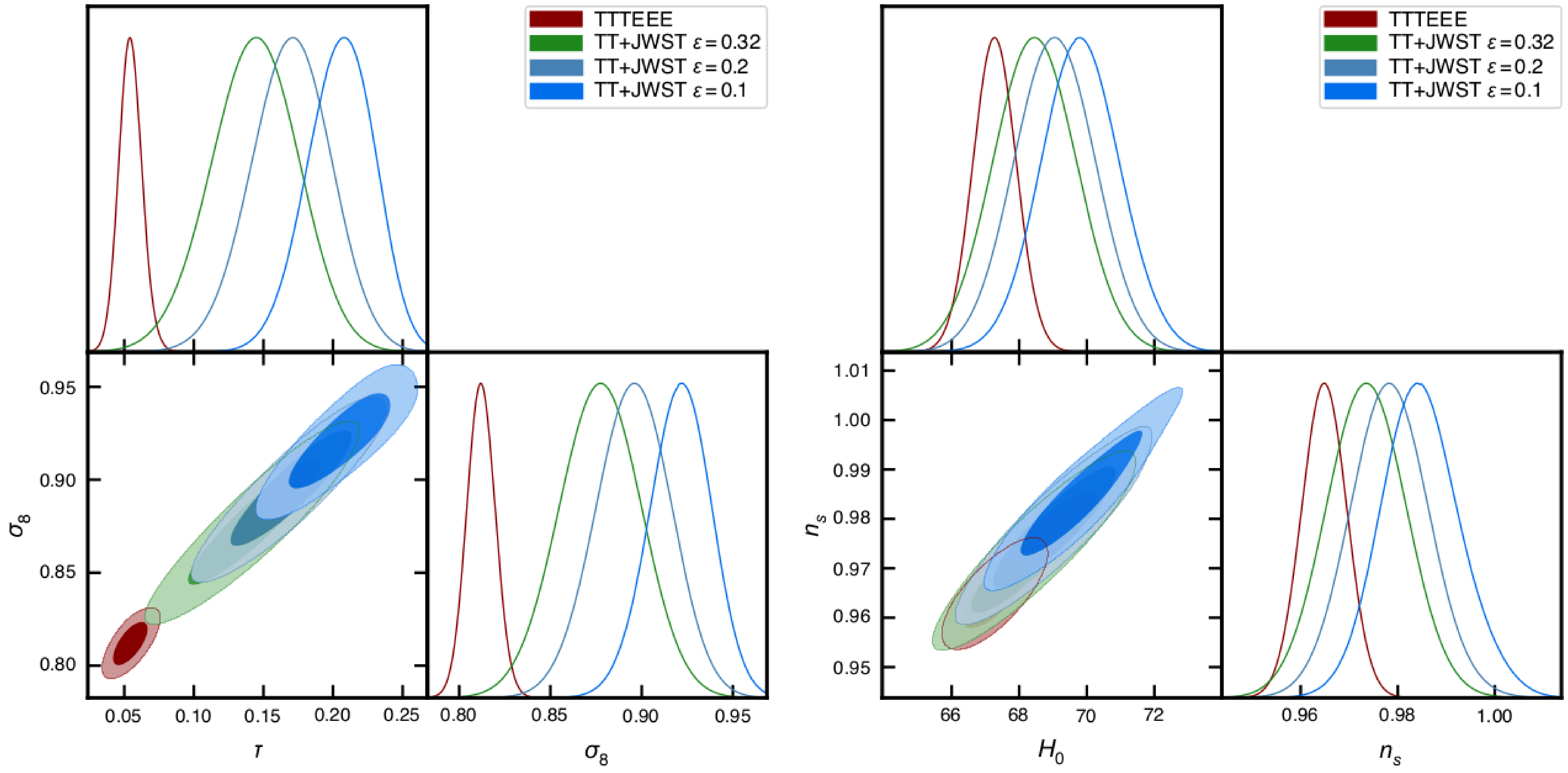
For 02 degree of freedom:

95% C.L.: $\Delta\chi^2 < 5.991$

99% C.L.: $\Delta\chi^2 < 9.210$

99.9% C.L.: $\Delta\chi^2 < 13.816$

Marginalized posterior distribution



$$8.5 \leq z \leq 10$$

Conclusions

- Due to the numerous assumptions involved and the potential for systematic uncertainties in the data, we cannot draw definitive conclusions at this stage.
- Up to ϵ 0.3, there is a strong disagreement between the full Planck CMB angular spectra measurements and the CSMD derived from JWST observations.
- This suggests that a value of $\epsilon > 0.3$ is necessary for compatibility, assuming the validity of the ΛCDM model and the absence of systematics in both datasets.
- If the Planck large angular scale EE data is omitted, there is a much better agreement between the Planck temperature data alone and the CSMD from JWST even for a lower efficiency of $\epsilon = 0.2$.