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Modelling the Mass to Light Ratios of High Red-Shift Galaxies

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Abstract- ***The field of astrophysics is a dynamic and rapidly evolving area of research that seeks to understand the universe's structure, evolution, and fundamental laws governing celestial objects. One of the key areas of interest within astrophysics is the study of galaxy formation and evolution. Galaxies are vast collections of stars, gas, dust, and dark matter held together by gravity, and their formation and evolution processes are crucial for understanding the universe's large-scale structure.***

Keywords: *SPHINX, JWST, Mass, Light, Red-Shift*

I– INTRODUCTION

Delving into the profound implications of galaxies with extremely high redshifts highlights the challenges in accurately determining redshifts at such high values, citing limitations in photometric confirmations, potential effects of dust and stochastic star formation, and the reliance on low-redshift templates for redshift calculation [1]. These challenges lead to the possibility that the observed galaxies may not be as bright as initially estimated. Furthermore, the need to consider differences in mass distributions of stellar populations in the early Universe due to higher temperatures is complicating. Accounting for these differences may result in galaxies with significantly smaller calculated masses than previously thought, as detailed in the paper "Galaxy formation from a timescale perspective" by Peter Laursen. These findings underscore the importance of further research and caution in interpreting observations of high-redshift galaxies. The unresolved older stellar population in galaxies may be underestimated due to the dominance of young stars. Additionally, they highlight the potential influence of active galactic nuclei in high-redshift galaxies, which can overshadow starlight and affect the estimation of stellar masses. Observations from the James Webb Space Telescope (JWST) challenge the current paradigm of galaxy formation, particularly in terms of the timescales of structure formation. While the ΛCDM model has been successful in explaining existing observations, recent reports of early and massive galaxies at high redshifts pose challenges to this model [2, 3, 4, 5]. The paper emphasizes the importance of considering various pitfalls before dismissing the ΛCDM model, including the need to reassess its pillars: general relativity, dark matter, and dark energy, in light of recent observations.

II – RELATED WORKS

Focus has been put on modelling high-redshift galaxies using cosmological radiation hydrodynamics simulations to understand the physical properties of these galaxies [6] . The paper by Katz H et al., [6] presents Version 1 of the Sphinx20 public data release, a comprehensive dataset that includes mock images and spectra of high-redshift galaxies, aiming to facilitate comparisons with future observations by the James Webb Space Telescope (JWST). The data set contains intrinsic galaxy properties, photometric properties, and spectroscopic properties, providing a wealth of information on the galaxies' characteristics. One of the key findings in the paper is the demonstration of a diversity of high-redshift galaxy morphologies, exemplifying how galaxies leaking Lyman continuum radiation can look very different. The data set also provides insights into the star formation rates and star formation histories of high-redshift galaxies, showcasing bursty star formation patterns and the diversity of star formation behaviours within this population. Additionally, the data set allows for comparisons between the modelled intrinsic spectra and the observed spectra, shedding light on the challenges associated with interpreting high-redshift observational data. Furthermore, the research emphasizes the importance of understanding the intrinsic properties of high-redshift galaxies through cosmological simulations, providing a valuable laboratory for exploring the accuracy and underlying systematic biases of spectral energy distribution (SED) codes and photoionization model grids. It also highlights the need for more sophisticated models that capture the complex interplay between gas accretion, star formation, and feedback in 3D, as well as the importance of simulations in testing and refining underlying theories of galaxy formation.

The paper presents stellar mass-halo mass relations, star formation histories, and stellar age distributions, providing a comprehensive overview of the physical properties and behaviours of high-redshift galaxies. Additionally, the data release enables comparisons with observational constraints, illustrating the potential for refining theoretical models and enhancing our understanding of high-redshift galaxy formation.

Exploring the mass-to-light ratios and star formation histories of disk galaxies by combining new data from the main sequence of star-forming galaxies and galaxy colors with a flexible stellar population scheme, finds that the main sequence for galaxies, particularly at the low-mass end, combined with the locus of galaxy colors, constrains the possible star formation histories of disk and dwarf galaxies to a similar shape found by previous research. The paper by James Schombert "The Mass-to-light Ratios and the Star Formation Histories of Disk Galaxies" [7] provides prescriptions to deduce Y∗ for optical and near-IR bandpasses, indicating that near-IR bandpasses have the least uncertainty in Y∗ values (from 0.40 to 0.55). Additionally, it discusses the radial acceleration relation and its implications for the role of baryons in the formation and evolution of galaxies. The paper also aims to provide the community with a web tool for generating their own Y∗ values over a broad range of colors and stellar masses. The paper offers a comprehensive analysis of the various factors influencing the mass-to-light ratios and star formation histories of disk galaxies at z = 0, aiming to provide a more robust understanding of the properties and evolution of galaxies. It is an example of how the mass-to-light ratios of galaxies can be calculated.

The research paper "A population of red candidate massive galaxies ~600 Myr after the Big Bang" by Ivo Labbé et al. focuses on identifying a population of red candidate massive galaxies approximately 600 million years after the Big Bang using early release observations from the James Webb Space Telescope (JWST). The study leverages the 1-5 µm coverage of the JWST to search for intrinsically red galaxies in the first ≈ 750 million years of cosmic history. The survey area resulted in the identification of six candidate massive galaxies at redshifts $7.4 \leq z \leq 9.1$, 500–700 million years after the Big Bang, including one galaxy with a possible stellar mass of ~10^11 solar masses. The paper examines the spectral energy distributions, photometric redshifts, and stellar masses of these galaxies, while also discussing the potential impact of exotic effects, AGN, and uncertainties in photometric redshifts on the interpretation of the results. Acknowledging the need for future spectroscopy to confirm the findings, the study provides insights into systematic offsets in photometry as a function of wavelength to inform data analysis and interpretation. The data and analysis methodologies used in this study are publicly available for further research and validation. The paper also presents a study of high redshift galaxies' stellar populations, focusing on their images and spectral energy distributions. It identifies seven galaxies with low apparent mass ($\log(M_*/M_\odot) < 10$) that satisfy color-color selection criteria. The spectral energy distributions of these galaxies suggest extremely young ages at specific narrow redshift intervals. Results from stellar population fitting reveal masses, redshifts, and fit quality for the selected galaxies. Additionally, the study investigates the color difference between emission line and continuum-dominated models and includes a stacked redshift probability distribution of the galaxies, revealing high and low mass solutions concentrated at narrow redshifts.

The findings suggest challenges in distinguishing between continuum and strong emission lines at certain redshifts, impacting the identification and characterization of high redshift galaxies.

The study by Prada et al. provides a critical analysis of the findings by Labbé et al. regarding a population of red massive galaxies formed approximately 600 million years after the Big Bang. While Labbé et al. reported an unusually high density of these galaxies, which could challenge the standard cosmological model, Prada et al. argue that the stellar mass-to-light ratio at such early epochs could not have reached the values reported. They base this argument on a galaxy formation model that suggests the formation of massive galaxies with higher ultraviolet (UV) luminosity and significant dust, predicting several hundred solar masses of stars formed per year. Prada et al. suggest that discrepancies with Labbé et al. may stem from overestimation of stellar masses, systematic uncertainties, lack of JWST/MIRI data, heavy dust extinction affecting UV luminosities, or misidentification of faint red active galactic nucleus (AGN) galaxies at closer redshifts. They propose that the current JWST/HST results, when combined with a realistic galaxy formation model, strongly confirm the standard cosmology. Furthermore, Prada et al. present the rest-frame UV luminosity function at high redshifts derived from galaxy samples selected photometrically in the rest-frame UV, and validate predictions by comparing them with galaxies detected with JWST and HST. They suggest that the discrepancies with Labbé et al. could potentially challenge the standard cosmology, indicating the presence of potential systematic errors in their findings.

Similarly, the article by Michael Boylan-Kolchin examines high-redshift galaxy candidates and their unexpectedly high stellar masses, probing the consistency of these candidates with the standard cosmological model Lambda Cold Dark Matter (ΛCDM) paradigm. It emphasizes that the ΛCDM model imposes an upper limit on the stellar mass of galaxies based on the available baryonic reservoir of their host halos. Using observations from the James Webb Space Telescope (JWST), the author demonstrates that the most massive galaxy candidates at redshifts ∼7−10 are at the edge of these limits, indicating potential unresolved issues with galaxy properties derived from observations or with the standard cosmology itself. The research employs the Sheth & Tormen dark matter halo mass function to compute the comoving number density and mass density of galaxies more massive than a certain threshold. It shows that the observed high-redshift galaxy candidates lie at or beyond the stellar mass density constraint in the ΛCDM model. The discrepancy between the observed high-redshift galaxy candidates and ΛCDM expectations is robust, even considering uncertainties in the cosmological parameters. The paper dedicates attention to the implications and potential challenges these observations pose for the ΛCDM model, highlighting the need for further research and forthcoming JWST surveys to confirm or refute the tension.

The findings have significant implications for our understanding of galaxy formation and cosmology at high redshifts, with more exciting surprises expected with continued JWST observations.

The data used in this research are made publicly available, contributing to ongoing investigations in this field. Overall, the paper provides a comprehensive analysis and critical evaluation of high-redshift galaxy candidates, emphasizing their potential to test and potentially challenge the ΛCDM model in the context of galaxy formation and cosmology.

III - METHODOLOGY

The mass-to-light (M/L) ratio is a crucial parameter in understanding the properties and evolution of galaxies. In this study, we investigate the M/L ratio of galaxies using data from the James Webb Space Telescope (JWST) and the Sphinx simulation [6]. We review the literature on M/L ratios, discuss the significance of JWST data, and analyze articles claiming the existence of high-redshift (HzRG) galaxies. Our analysis of Sphinx simulation data includes fitting the M/L ratio function and examining how it depends on redshift.

The mass-to-light ratio (M/L) of galaxies is a parameter that provides insights into their formation and evolution. Recent advancements in observational capabilities, such as the JWST, have opened up new possibilities for studying the M/L ratio and its implications for galaxy evolution. Previous studies have shown that the M/L ratio varies across different types of galaxies and can be used to infer the presence of dark matter. Various methods, including gravitational lensing and dynamical modeling, have been used to estimate the M/L ratio. The JWST is expected to provide high-quality data on galaxy properties, including stellar masses and luminosities, which are essential for calculating the M/L ratio. Its ability to observe in the infrared will enable more accurate measurements of stellar populations and dust content. We utilize data from the Sphinx simulation [6], which provides simulated galaxy populations with known properties. This allows us to study the M/L ratio as a function of redshift and compare our results with observational data. Using the data from the Sphinx simulation, we fit the M/L ratio function to understand how it varies with redshift. We also discuss the relationship between magnitude and luminosity, which is essential for calculating the M/L ratio.

Derivation of Equations:

The M/L ratio is defined as the ratio of the total mass of a galaxy to its total luminosity. We derive the equations used to calculate the M/L ratio and explain their significance for galaxy studies.

IV – DATA

To derive the mass-to-light ratio (M/L) using stellar mass and stellar light, we start with the basic definition of the M/L ratio, which is the ratio of the total mass of the galaxy to its total luminosity. We can express this as:

$$M/L = M_{\{stars\}} + M_{\{gas\}} + M_{\{dark\ matter\}} / L_{\{stars\}} + L_{\{gas\}} + L_{\{other\}}$$

Where:
- ($M_{\{stars\}}$) is the total mass of stars in the galaxy,
- ($M_{\{gas\}}$) is the total mass of gas in the galaxy,
- ($M_{\{dark\ matter\}}$) is the total mass of dark matter in the galaxy,
- ($L_{\{stars\}}$) is the total luminosity emitted by stars in the galaxy,
- ($L_{\{gas\}}$) is the total luminosity emitted by gas in the galaxy, and
- ($L_{\{UV\}}$) is the luminosity emitted by stars in the UV region of the electromagnetic spectrum

However, since we are concerned with the ratio of baryonic mass to luminosity, or more specifically the ratio between stellar mass and luminosity, we can simplify the equation to

$$\frac{M}{L} \approx \frac{M_{stars}}{L_{UV}}$$

This equation relates the mass-to-light ratio of a galaxy to the ratio of its stellar mass to its stellar light. Due to this paper analysis the mass-to-light ratios of high red-shift galaxies in particular, regions on the electromagnetic spectrum other than the ultraviolet region can be left unconsidered.

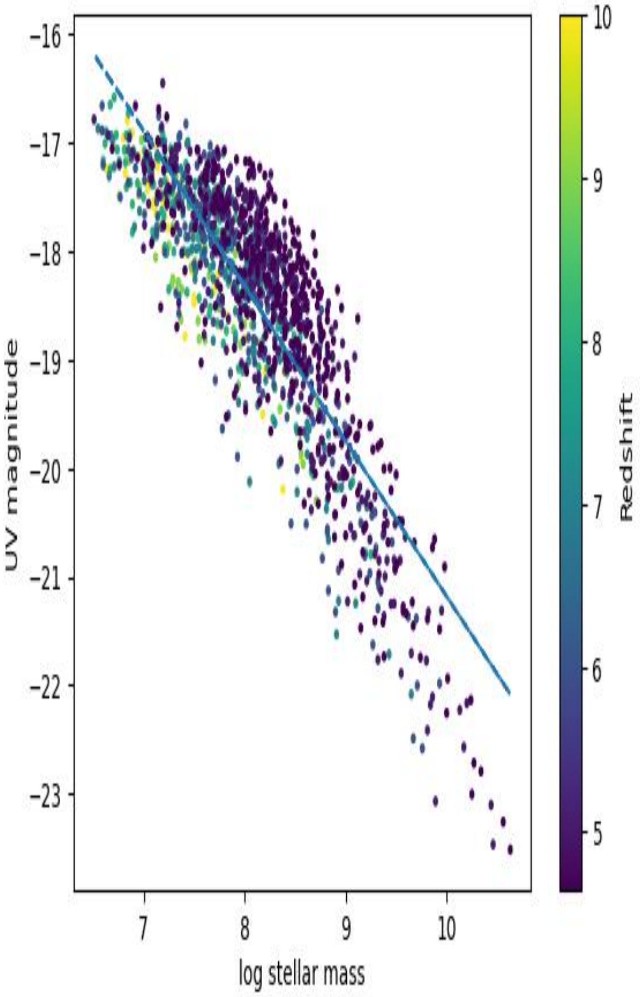
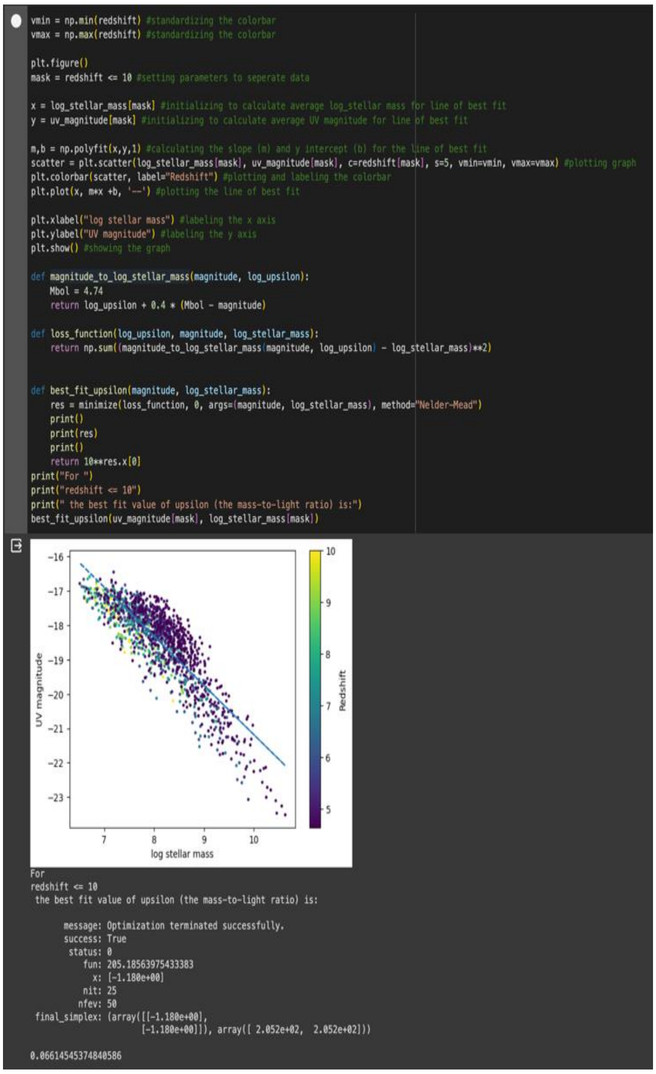


Fig. 1. Plotted with the help of data from Katz H et al.,

Fig 1. is the combined scatter plot of the log Stellar mass against the UV Magnitude of all available galaxies in the simulation [6]. Isolated, at interval values of redshifts, the slope of the line of best fit of each graph will represent the mass to light ratio of galaxies at that interval of redshift. By plotting each of these values of epsilon on a separate graph, it is possible to extend the Line of Best fit and extrapolate to show what the mass-to-light ratio would be for high red shift galaxies.

The average value for upsilon (mass-to-light ratio) of galaxies from redshifts <5 – 10 can be derived by the following code using the simulation data from the “The Sphinx Public Data Release”.



```
vmin = np.min(redshift) #standardizing the colorbar
vmax = np.max(redshift) #standardizing the colorbar

plt.figure()
mask = redshift <= 10 #setting parameters to seperate data

x = log_stellar_mass[mask] #initializing to calculate average log_stellar mass for line of best fit
y = uv_magnitude[mask] #initializing to calculate average UV magnitude for line of best fit

m,b = np.polyfit(x,y,1) #calculating the slope (m) and y intercept (b) for the line of best fit
scatter = plt.scatter(log_stellar_mass[mask], uv_magnitude[mask], c=redshift[mask], s=5, vmin=vmin, vmax=vmax) #plotting graph
plt.colorbar(scatter, label="Redshift") #plotting and labeling the colorbar
plt.plot(x, m*x +b, '--') #plotting the line of best fit

plt.xlabel("log stellar mass") #labeling the x axis
plt.ylabel("UV magnitude") #labeling the y axis
plt.show() #showing the graph

def magnitude_to_log_stellar_mass(magnitude, log_upsilon):
    Mbol = 4.74
    return log_upsilon + 0.4 * (Mbol - magnitude)

def loss_function(log_upsilon, magnitude, log_stellar_mass):
    return np.sum((magnitude_to_log_stellar_mass(magnitude, log_upsilon) - log_stellar_mass)**2)


def best_fit_upsilon(magnitude, log_stellar_mass):
    res = minimize(loss_function, 0, args=(magnitude, log_stellar_mass), method="Nelder-Mead")
    print()
    print(res)
    print()
    return 10**res.x[0]
print("For ")
print("redshift <= 10")
print(" the best fit value of upsilon (the mass-to-light ratio) is:")
best_fit_upsilon(uv_magnitude[mask], log_stellar_mass[mask])
```

```
For
redshift <= 10
 the best fit value of upsilon (the mass-to-light ratio) is:

       message: Optimization terminated successfully.
       success: True
        status: 0
           fun: 205.18563975433383
             x: [-1.180e+00]
           nit: 25
          nfev: 50
 final_simplex: (array([[-1.180e+00],
                       [-1.180e+00]]), array([ 2.052e+02,  2.052e+02]))

0.06614545374840586
```

Fig 2. Google Colab Interface

The code follows as :

```
mask = redshift <= 10
x = log_stellar_mass[mask]
y = uv_magnitude[mask]
m,b = np.polyfit(x,y,1)
scatter = plt.scatter(log_stellar_mass[mask], uv_magnitude[mask], c=redshift[mask], s=5, vmin=vmin, vmax=vmax)
plt.colorbar(scatter, label="Redshift")
plt.plot(x, m*x +b, '--')
plt.show()
def magnitude_to_log_stellar_mass(magnitude, log_upsilon):
    Mbol = 4.74
    return log_upsilon + 0.4 * (Mbol - magnitude)
def loss_function(log_upsilon, magnitude, log_stellar_mass):
    return np.sum((magnitude_to_log_stellar_mass(magnitude, log_upsilon) - log_stellar_mass)**2)
def best_fit_upsilon(magnitude, log_stellar_mass):
    res = minimize(loss_function, 0, args=(magnitude, log_stellar_mass), method="Nelder-Mead")
    print()
    print(res)
    print()
    return 10**res.x[0]
print("For ")
print("redshift <= 10")
print(" the best fit value of upsilon (the mass-to-light ratio) is:")
best_fit_upsilon(uv_magnitude[mask], log_stellar_mass[mask])
```

Equation:

$$\frac{L_{UV}}{L_{\odot}} = 10^{\,0.4(M_{\odot} - M_{UV})}$$

Where $M_{\odot} = 4.74$

$$\Upsilon = \frac{M_{\star}}{L_{UV}}$$

$$\begin{aligned} \therefore \log\Upsilon &= \log M_{\star} - \log L_{UV} \\ &= \log M_{\star} - 0.4(M_{\odot} - M_{UV}) \\ \therefore \log M_{\star} &= \log\Upsilon + 0.4(M_{\odot} - M_{UV}) \end{aligned}$$

Via Simulation :
$\Upsilon = 0.06614545374840586$

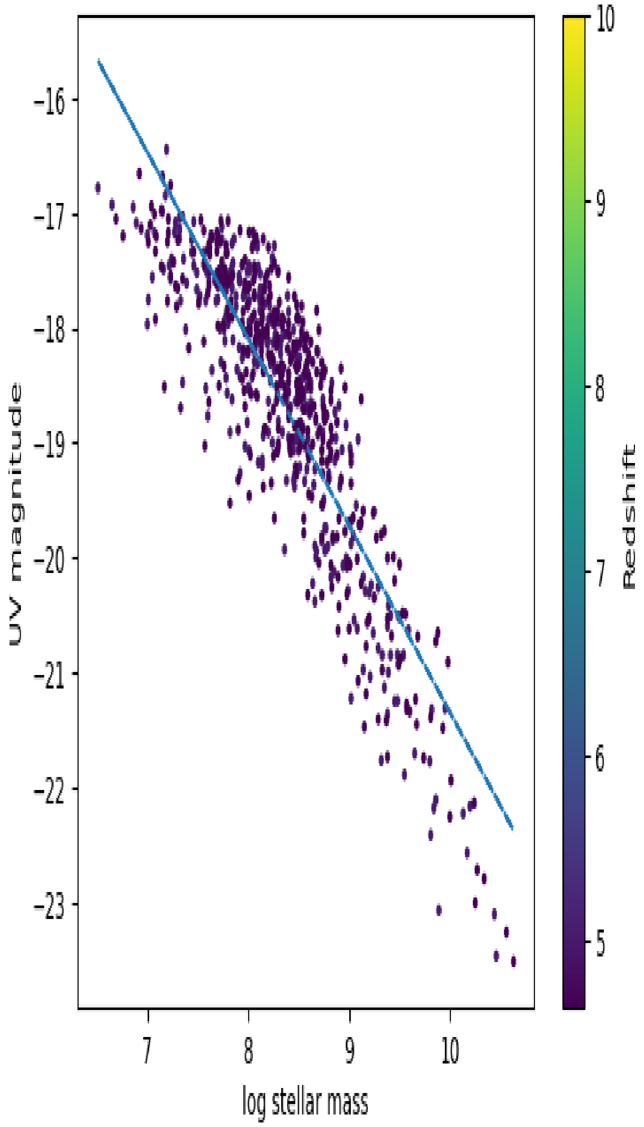


Fig. 3. Galaxies with redshift 5
Υ = 0.09797719458640136

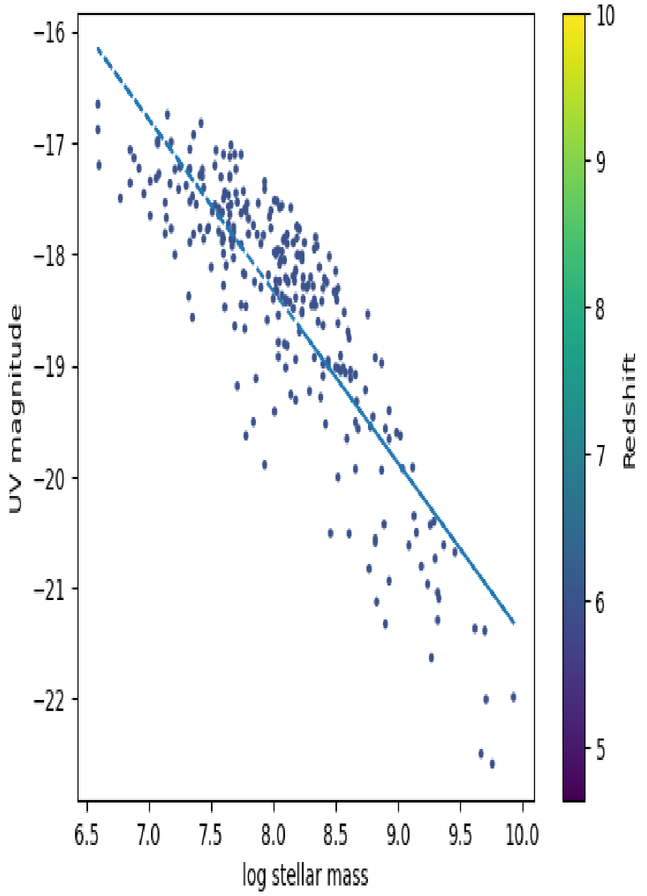


Fig. 4. Galaxies with redshift 6
ϒ = 0.06276065970501264

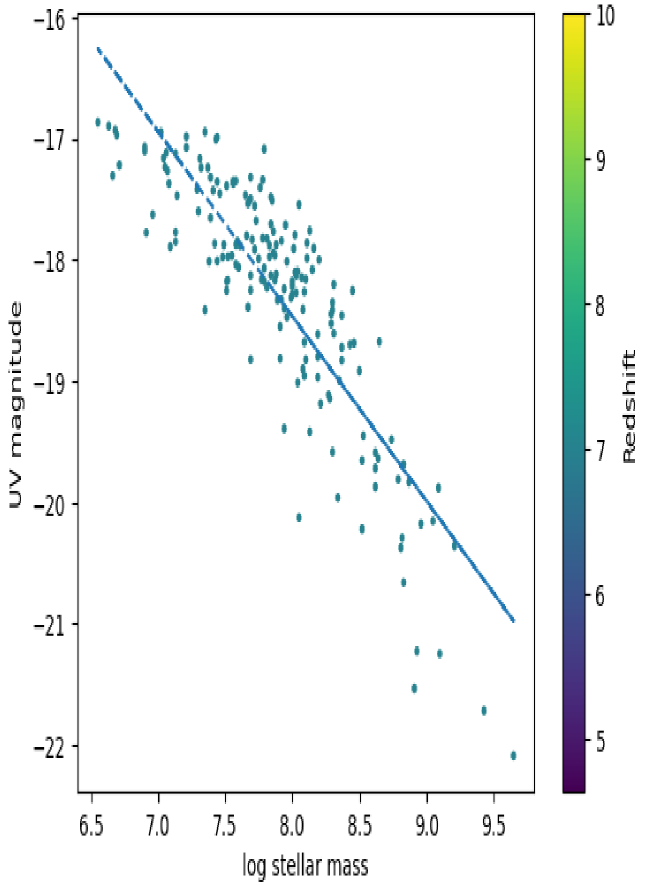


Fig. 5. Galaxies with redshift 7
ϒ = 0.04692183629788036

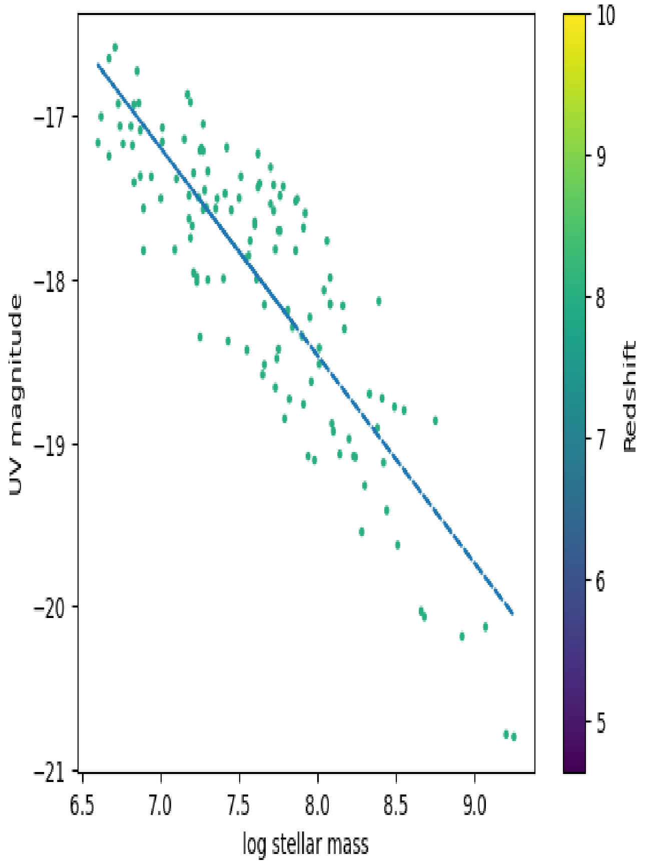


Fig. 6. Galaxies with redshift 8
ϒ = 0.034405272346500246

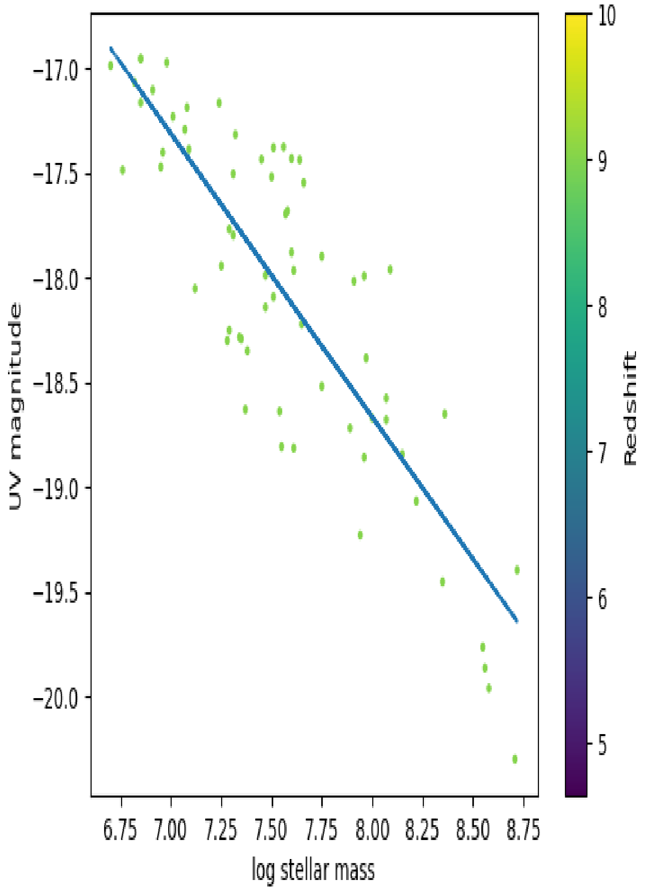


Fig. 7. Galaxies with redshift 9
ϒ = 0.02742758060188486

By plotting these values of Upsilon on a graph:

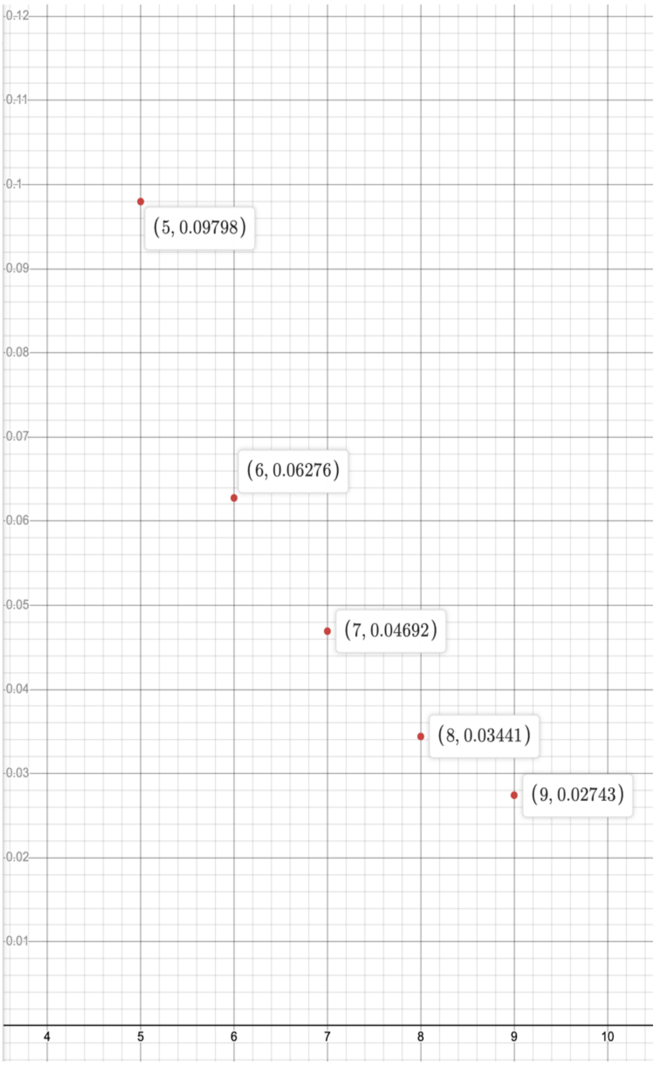


Fig. 8. Desmos Graphing Calculator

We can see a trend form, for which an equation can be derived.

For points:

(5,0.09797719458640136),
(6,0.06276065970501264),
(7,0.04692183629788036),
(8,0.03440527234650024б),
(9,0.02742758060188486)

Potential Lines/Curves that fit are:

$Y = - 0.0169454x + 0.17251673$
$Y = 0.44040906 * e^{-0.3147389x}$
$Y = 0.00076133 x^4 - 0.0224706x^3 + 0.24895042x^2 - 1.2396997x + 2.40570987$
$Y = 0.004.2714x^2 - 0.0767454x + 0.3732737$
$Y = 3.08526281x^{-2.156083}$

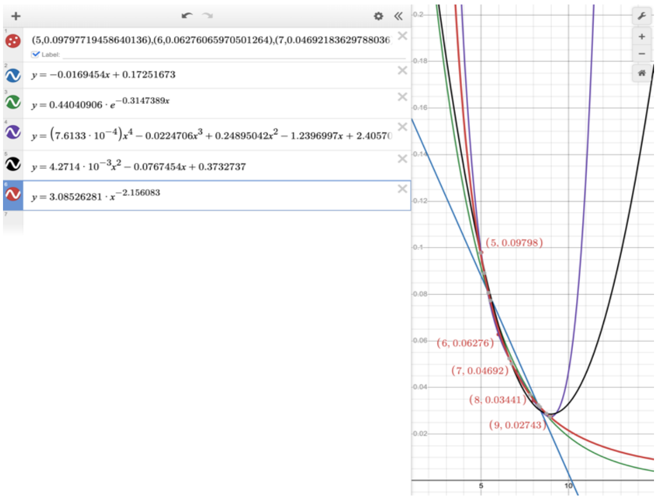

(5,0.09797719458640136),(6,0.06276065970501264),(7,0.04692183629788036
$y = -0.0169454x + 0.17251673$
$y = 0.44040906 \cdot e^{-0.3147389x}$
$y = \left(7.6133 \cdot 10^{-4}\right)x^4 - 0.0224706x^3 + 0.24895042x^2 - 1.2396997x + 2.4057$
$y = 4.2714 \cdot 10^{-3}x^2 - 0.0767454x + 0.3732737$
$y = 3.08526281 \cdot x^{-2.156083}$

Fig. 9. Desmos Graphing Calculator

The seemingly best equation for the value of Upsilon against Redshift is

$Y = 3.08526281x^{-2.156083}$

with an r^2 value of 0.99810856

This graph gives a value for upsilon of 0.02154 for a redshift 10. By comparing to our simulation:

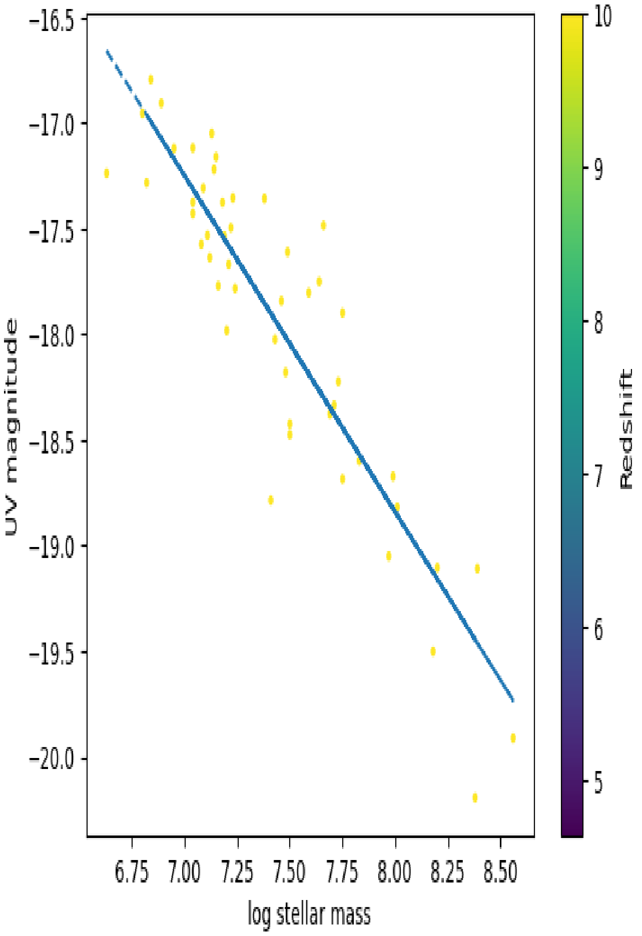


Fig. 7. Galaxies with redshift 10
Y = 0.023011106371380843

Our extrapolated value for upsilon at redshift 10 is not very far off.
Revising our graph using
(10, 0.023011106371380843)
Gives us a graph of

$Y = 2.75651132\ x^{-2.0938532}$
with an r^2 value of 0.99711146

where x is the redshift of the galaxy, and Y is the value for Upsilon.

We can use this equation to assume the values of Upsilon, or the mass-to-light ratios of high red-shift galaxies.

V – Conclusion

In conclusion, the expected mass-to-light ratio for galaxies at redshift 10, following the trend of other values of Y, is 0.02154. However, the measured value from the simulation based on JWST data is 0.023011106371380843. This slight discrepancy suggests that the galaxies appear to be more massive than expected. Nevertheless, this difference can be attributed to errors caused by gravitational lensing and other phenomena that haven't been fully accounted for. These findings highlight the complexities and challenges involved in accurately determining the properties of galaxies in the early universe.
The research underscores the importance of continued advancements in observational techniques and modelling approaches to better understand high-redshift galaxies. Further refinements in models and accounting for uncertainties will be essential for interpreting observational data accurately and advancing our understanding of galaxy formation and evolution in the early universe.

Overall, while the discrepancy between the expected and measured mass-to-light ratios is notable, it does not fundamentally challenge the ΛCDM model. Instead, it underscores the need for a comprehensive and nuanced approach to studying galaxies at high redshifts, considering the complexities of observational data and the uncertainties inherent in early universe studies.

REFERENCES

[1] Laursen, P. (2023). Galaxy Formation from a Timescale Perspective. In Multiplicity of Time Scales in Complex Systems (pp. 105–145). Springer International Publishing. https://doi.org/10.1007/16618_2023_71
[2] Pultarova, T., & SPACE.com. (2023, February 23). JWST Discovers Enormous Distant Galaxies That Should Not Exist. Scientific American. https://www.scientificamerican.com/article/jwst-discovers-enormous-distant-galaxies-that-should-not-exist/
[3] Scientists Keep Discovering ‘impossible Galaxies’. What Does This Mean? (2024, February 16). Cosmos. https://cosmosmagazine.com/space/galaxies-that-shouldnt-exist-keep-being-discovered-by-jwst/
[4] Team of Astronomers Discovers Galaxy That Shouldn't Exist. (2024, February 2). Phys.org - News and Articles on Science and Technology. https://phys.org/news/2024-02-team-astronomers-galaxy-shouldnt.html
[5] The Webb telescope spots six galaxies that shouldn't exist. (2023, February 22). TIME. https://time.com/6257544/webb-telescope-galaxies/
[6] Katz, H., Rosdahl, J., Kimm, T., Blaizot, J., Choustikov, N., Farcy, M., Garel, T., Haehnelt, M. G., Michel-Dansac, L., & Ocvirk, P. (2023). The Sphinx Public Data Release: Forward Modelling High-Redshift JWST Observations with Cosmological Radiation Hydrodynamics Simulations.
[7] Schombert, J., McGaugh, S., & Lelli, F. (2018). The Mass-to-light Ratios and the Star Formation Histories of Disk Galaxies. Monthly Notices of the Royal Astronomical Society. https://doi.org/10.1093/mnras/sty3223
[8] Labbé, I., van Dokkum, P., Nelson, E., Bezanson, R., Suess, K. A., Leja, J., Brammer, G., Whitaker, K., Mathews, E., Stefanon, M., & Wang, B. (2023). A population of red candidate massive galaxies 600 Myr after the Big Bang. Nature, 616(7956), 266–269. https://doi.org/10.1038/s41586-023-05786-2
[9] Prada, F., Behroozi, P., Ishiyama, T., Klypin, A., & Pérez, E. (2023). Confirmation of the standard cosmological model from red massive galaxies \sim600 Myr after the Big Bang.
[10] Boylan-Kolchin, M. (2023). Stress testing ΛCDM with high-redshift galaxy candidates. Nature Astronomy, 7(6), 731–735. https://doi.org/10.1038/s41550-023-01937-7