

# Average Luminous Mass of Early Galaxies at $z = 10 - 20$ Predicted as $\sim 10^9$ Solar Masses

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## Abstract

This paper predicts the average luminous mass of galaxies that will be detected by JWST space telescope at redshift  $z \approx 10 - 20$ . The prediction, derived in the paper, is based on holographic analysis, developed from quantum mechanics, general relativity, thermodynamics, and Shannon information theory. Consistent with early JWST data,  $\sim 10^9$  solar masses is the predicted average luminous mass of early galaxies at  $z \approx 10 - 20$  that will be detected by JWST.

## Keywords

Galaxies: High-Redshift

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## 1. Introduction

Luminous galaxy candidates at  $z > 10$  revealed by JWST indicate “future deep JWST observations may identify relatively bright galaxies to much earlier epochs than might have been expected” [1]. As explained below, holographic analysis based on quantum mechanics, general relativity, thermodynamics, and Shannon information theory indicates galaxies with mass  $\sim 10^9$  solar masses should be expected at  $z = 10 - 20$ . The analysis does not assume or require a theory specifically relating arrangements of bits of information on holographic screens to distribution (as opposed to amount) of mass within such screens.

Behroozi *et al.* [2] listed some early predictions for what JWST will see, and then used a supercomputer simulation to predict JWST will find galaxies  $z > 10$  with masses considerably below those revealed by early JWST data. In contrast, the prediction from holographic analysis below,  $\sim 10^9$  solar masses for average luminous mass of galaxies at  $z \approx 10 - 20$ , is consistent with early JWST results.

## 2. Holographic Analysis

Our post-inflationary universe, dominated by vacuum energy, has cosmological constant  $\Lambda = 1.088 \times 10^{-56} \text{ cm}^{-2}$  [3] and event horizon radius

$$R_H = \sqrt{\frac{3}{\Lambda}} = 1.661 \times 10^{28} \text{ cm} .$$

Holographic analysis [4] finds only a finite number

$$N = \frac{\pi}{\ln(2)} \left( \frac{R_H}{l_p} \right)^2 = 4.741 \times 10^{122}$$

of bits of information on the event horizon are available to describe our universe, where Planck length

$$l_p = \sqrt{\frac{\hbar G}{c^3}} = 1.616 \times 10^{-33} \text{ cm} .$$

Friedmann's general relativistic equation  $H_0^2 = \frac{8\pi G}{3} \rho_{crit} + \frac{\Lambda c^2}{3}$  for a flat Euclidean universe with critical density and cosmological constant requires

$$\Omega_\Lambda \equiv \frac{\Lambda c^2}{3H_0^2} .$$

PDG 2022 [3] lists present day Hubble expansion rate

$$H_0 = 67.4 \text{ km}/(\text{sec} \cdot \text{Mpc}) ,$$

critical density  $\rho_{crit} = \frac{3H_0^2}{8\pi G} = 8.53 \times 10^{-30} \text{ g}/\text{cm}^3$  , dark energy density parameter  $\Omega_\Lambda = 0.685$  , Hubble length  $c/H_0 = 1.37 \times 10^{28} \text{ cm}$  , and

$$\text{matter density } \rho_m = (1 - \Omega_\Lambda) \rho_{crit} .$$

PDG parameters result in  $\frac{\Lambda c^2}{3\Omega_\Lambda H_0^2} = 0.997$  ,

so our universe is indistinguishable from flat Euclidean space to three significant figures. Mass within the event horizon

$$M_H = \frac{4}{3} \pi (1 - \Omega_\Lambda) \rho_{crit} R_H^3 = \frac{(1 - \Omega_\Lambda) c^2}{2G} \sqrt{\frac{3}{\Lambda}} = 5.14 \times 10^{55} \text{ g}$$

is constant in time,

$$\text{and } M_H = \left[ \frac{(1 - \Omega_\Lambda) c^2}{2G} \left( \frac{H_0}{c} \right)^2 \sqrt{\frac{3}{\Lambda}} \right] R_H^2 = (0.187 \text{ g}/\text{cm}^2) R_H^2 .$$

The constant mass

$$\text{per bit of information } m_{bit} = M_H / N = 1.08 \times 10^{-67} \text{ g} .$$

In a fundamental sense, information specifies location of matter in space, and holographic analysis indicates  $4.741 \times 10^{122}$  bits of information on the spherical holographic screen (SHS) of the event horizon are associated with matter within our observable universe. Holographic analysis then indicates information and associated mass  $M$  within isolated gravitationally bound systems relates to radii  $R$  of spherical holographic screens around system centers of mass by

$$M = (0.187 \text{ g}/\text{cm}^2) R^2 .$$

Cosmic microwave background (CMB) radiation density at redshift  $z$  is  $\rho_r(z) = (1+z)^4 \rho_r(0)$  , where mass equivalent of today's radiation energy density  $\rho_r(0) = 4.59 \times 10^{-34} \text{ g}/\text{cm}^3$  . Matter density  $\rho(z)$  is much greater than radiation density and Jeans mass [5]

$$M_J = \frac{\pi}{48\rho_m^2} \left[ \frac{2c}{3} \sqrt{\frac{\pi\rho_r(0)}{G}} \right]^3 = 2.30 \times 10^{50} \text{ g} ,$$

the upper

limit on mass of gravitationally bound systems stable against gravitational collapse, is independent of  $z$  . Large scale structures at  $z > 10$  are gravitationally bound systems of individual stars with masses between Jeans mass  $M_J$  and

minimum stellar mass  $m_{*min}(z)$  at redshift  $z$ .

### 3. Minimum Stellar Mass at Redshift $z$

Minimum stellar mass  $m_{*min}(z)$  is estimated by setting escape velocity of protons at SHS radius  $R_{*min}$  for minimum stellar mass equal average velocity of protons in equilibrium with CMB radiation outside the SHS for  $m_{*min}(z)$ . Protons in equilibrium with CMB outside the SHS for stellar systems with mass  $< m_{*min}(z)$  can transfer energy to those systems until they reach  $m_{*min}(z)$ . Escape velocity  $v$  for protons of mass  $m_p$  gravitationally bound at radius  $R$  from system center of mass  $M$  is calculated from  $\frac{1}{2}m_p v^2 = \frac{GMm_p}{R}$ . Escape velocity of protons on the SHS for minimum mass stars with mass  $M$  at redshift  $z$  is velocity of protons in thermal equilibrium with CMB, so  $\frac{3}{2}kT(z) = \frac{GMm_p}{R}$ ,

where CMB temperature  $T(z) = (1+z)2.725$  K and Boltzmann constant  $k = 1.38 \times 10^{-16} (\text{g} \cdot \text{cm}^2 / \text{sec}^2) / \text{K}$ . With radius  $R = \sqrt{M / (0.187 \text{ g/cm}^2)}$  for structures of mass  $M$ ,  $m_{*min}(z) = \frac{1}{0.187} \left( \frac{1.5k(1+z)2.725}{Gm_p} \right)^2 \text{ g}$ , so

$m_{*min}(10) = 8.26M_\odot$ ,  $m_{*min}(12) = 11.5M_\odot$ , and  $m_{*min}(20) = 30.1M_\odot$ , with solar mass  $M_\odot = 2 \times 10^{33} \text{ g}$ . If outgoing protons at the SHS are in thermal equilibrium with outgoing photon flow from minimum mass stars, stars must have mass  $> m_{*min}(z)$  to appear against the CMB background. Maximum star mass  $6 \times 10^{35} \text{ g} \approx 300M_\odot$  [6] coincided with minimum star mass at  $z \approx 65$ , consistent with indications stars first formed at  $z \approx 65$  [7]. At  $z = 0$ , minimum star mass  $\approx 1.4 \times 10^{32} \text{ g} = 0.07M_\odot$ , consistent with hydrogen burning mass threshold separating brown dwarfs from lowest mass stars [8].

### 4. Average Galactic Mass at Redshift $z$

With no good reason to suspect information describing gravitationally bound systems is not uniformly distributed between mass bins, the number of gravitationally bound systems of mass  $m$  at redshift  $z$  can be taken as  $n(m) = K/m$  with constant  $K$ . Then total mass of observable gravitationally bound systems at redshift  $z$  is  $M_H \approx \int_{m_{*min}(z)}^{M_J} m \left( \frac{K}{m} \right) dm = K(M_J - m_{*min}(z))$  and

$K \approx M_H / M_J = 2.24 \times 10^5$ . The number of observable gravitationally bound structures in Jeans mass  $M_J$  at redshift  $z$  is

$N(z) = \int_{m_{*min}(z)}^{M_J} \frac{K}{m} dm = K \ln(2.30 \times 10^{50} \text{ g} / m_{*min}(z))$ . Estimated average total mass

of observable gravitationally bound structures at redshift  $z$ ,

$M_{avg}(z) = M_J / N(z)$ , at  $z = 10 - 20$  is  $\sim 1.4 \times 10^{10} M_\odot$ , between estimated Milky Way mass  $\sim 10^{45} \text{ g} \sim 10^{12} M_\odot$  and dwarf galaxy masses  $\sim 10^{40} \text{ g} \sim 10^7 M_\odot$ .

PDG 2022 [3] lists baryon density fraction of the universe  $\Omega_b = 0.0493$ , so stellar mass is  $\Omega_b / (1 - \Omega_\Lambda) = 0.0720$  times total galactic mass. Then stellar mass

$\sim 10^9 M_{\odot}$  of galaxy candidates at redshift  $z \approx 10 - 12$  identified by Naidu *et al.* in JWST data is consistent with “early appearance of UV-luminous galaxies with stellar masses as high as  $\approx 10^9 M_{\odot}$  already at few 100 Myr after the Big Bang” [1].

## 5. Conclusion

Holographic analysis predicts the average galaxy detected by JWST space telescope at redshift  $z \approx 10 - 12$  will have luminous mass of about  $10^9$  solar masses, consistent with early JWST data.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

## References

- [1] Naidu, R., Oesch, P., van Dokkum, P., *et al.* (2022) *The Astrophysical Journal Letters*, **940**, L14. <https://doi.org/10.3847/2041-8213/ac9b22>
- [2] Behroozi, P., Conroy, C., Wechsler, R., *et al.* (2020) *Monthly Notices of the Royal Astronomical Society*, **499**, 5702-5718. <https://doi.org/10.1093/mnras/staa3164>
- [3] Workman, R., Burkert, V., Crede, V., *et al.* (2022) *Progress of Theoretical and Experimental Physics*, **2022**, 083C01.
- [4] Bousso, R. (2002) *Reviews of Modern Physics*, **74**, 825-874. <https://doi.org/10.1103/RevModPhys.74.825>
- [5] Mongan, T. (2013) *Journal of Modern Physics*, **4**, 50-54. <https://doi.org/10.4236/jmp.2013.47A1006>
- [6] Crowther, P., Schnuur, O., Hirschi, R., *et al.* (2010) *Monthly Notices of the Royal Astronomical Society*, **408**, 731-751.
- [7] Naoz, S., Noter, S. and Barkana, R. (2006) *Monthly Notices of the Royal Astronomical Society: Letters*, **373**, L98-L102. <https://doi.org/10.1111/j.1745-3933.2006.00251.x>
- [8] Mireles, I., Shporer, A., Grievess, N., *et al.* (2020) *AJ*, **160**, 133.