Journal of Modern Physics, 2026, 17(4), 476-482
https://www.scirp.org/journal/jmp
ISSN Online: 2153-120X
ISSN Print: 2153-1196

Holographic Analysis Explains Unexpected High Redshift JWST Data

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How to cite this paper: Mongan, T. R. (2026) Holographic Analysis Explains Unexpected High Redshift JWST Data. *Journal of Modern Physics*, **17**, 476-482.
https://doi.org/10.4236/jmp.2026.174021

Received: February 18, 2026
Accepted: April 10, 2026
Published: April 13, 2026

Abstract

Unexpected JWST observations of large-scale structure in the very early universe are explained by holographic analysis. Traditional galaxy formation models involving mass increase by clustering and merging cannot account for those observations. At a fundamental level, information specifies distribution of matter within the universe. Holographic analysis (based on quantum mechanics, general relativity, black hole thermodynamics, and Shannon information theory) finds only about 10^{122} bits of information on the event horizon will ever be available to describe distribution of matter in the universe. Visible large-scale structures (LSS), comprised of individual stars within isothermal spheres of cold dark matter, can be categorized as galaxy clusters, galaxies, or star clusters. Probability $\frac{K}{m}$ of total LSS mass m in a given LSS category, with constant K, results in greater numbers of small structures than large structures in each LSS category, and uniform distribution of information and matter across the mass range in each LSS category. Holographic analysis provides estimates, consistent with observations, of LSS and central black hole mass range in each LSS category, and stellar mass range as a function of redshift.

Keywords

Unexpected Early Galaxies, JWST, Holographic Analysis

1. Introduction

JWST found large galaxies in the early universe, inconsistent with traditional galaxy formation models involving mass increase by clustering and merging [1]. Consistent with JWST observations and using PDG 2025 [2] data, this holographic analysis accounts for total mass of galaxy clusters, galaxies and star clusters with central black holes, constituting visible large-scale structures (LSS) in our closed, homogeneous, isotropic and vacuum-dominated Friedmann universe.

Probability $\frac{K}{m}$ of LSS mass *m*, with constant *K*, in a given LSS category results in greater numbers of small structures than large structures in each LSS category, and uniform distribution of information and matter across the mass range in each LSS category.

2. Holographic Analysis

At a fundamental level, information specifies distribution of matter within the universe.

Holographic analysis (based on quantum mechanics, general relativity, black hole thermodynamics, and Shannon information theory) finds only the finite number of bits of information on the event horizon will ever be available to describe distribution of matter in the universe [3]. That implies the universe is a closed system described by discrete mathematics.

The event horizon at distance $R_H = \sqrt{\frac{3}{\Lambda}} = 1.661 \times 10^{28}$ cm from any observer's location is the farthest distance observers can ever see out into our vacuum dominated universe, with cosmological constant $\Lambda = 1.088 \times 10^{-56}\ \text{cm}^{-2}$ and vacuum energy density accelerating increase in radius of the closed universe.

This holographic analysis identifies the bits of information available to describe matter distribution within the universe as encoded on areas of l_P^2 on the event horizon, where the Planck length $l_P = \sqrt{\frac{\hbar G}{c^3}} = 1.61625 \times 10^{-33}$,

$\hbar = 1.05457 \times 10^{-27}\ \text{g} \cdot \text{cm}^2/\text{sec}$, $G = 6.67430 \times 10^{-8}\ \text{cm}^3 \cdot \text{g}^{-1} \cdot \text{sec}^{-2}$, and

$c = 2.99792 \times 10^{10}\ \text{cm/sec}$. The maximum number of bits of information that will ever be available to describe the distribution of matter within the universe is $N = \left(\frac{\pi}{\ln(2)}\right)\left(\frac{R_H}{l_P}\right)^2 = 4.741 \times 10^{122}$. Mass of the observable universe inside the event horizon $M_H = \frac{4}{3}\pi(1-\Omega_\Lambda)\rho_{crit} R_H^3 = 5.16 \times 10^{55}\ \text{g} = \left(\frac{0.187\ \text{g}}{\text{cm}^2}\right) R_H^2$ with Hubble constant $H_0 = 67.4\ \text{km} \cdot \text{sec}^{-1} \cdot \text{Mpc}^{-1}$, critical energy density

$\rho_{crit} \frac{3H_0^2}{8\pi G}\ \text{g/cm}^3 = 8.533 \times 10^{-30}\ \text{g/cm}^3$, and vacuum energy fraction $\Omega_\Lambda = 0.685$.

Half of the bits of information on the horizon provide information on distribution of *matter* within the horizon and the other half of the bits of information on the horizon provide information on distribution of *anti-matter* within the horizon. So the mass of matter associated with one bit of information is

$$m_{bit} = \frac{M_H}{2.371 \times 10^{122}} = 2.17 \times 10^{-67}\ \text{g}.$$

This holographic analysis then finds the bits of information describing an isolated system with definite mass m within the universe are available on a spherical surface surrounding the system with radius $r = \sqrt{\frac{m}{M_H}} R_H$ and holographic radii of isolated systems with definite mass m are $r = \sqrt{\frac{m}{0.187\ \text{g/cm}^2}}$.

3. Large-Scale Structures and Redshift

Visible large-scale structures (LSS) in our expanding universe, comprised of individual stars, exist within isothermal spheres of cold dark matter. Three levels of LSS, respectively categorized as galaxy clusters, galaxies, or star clusters, consist of widely separated sub-elements in a sea of cosmic microwave background radiation.

Looking out in the universe at distant luminous objects, light traveling at constant speed c shows those objects at the time in the past when the light was emitted. Wavelength of light emitted by sources moving away from us is increased (redshifted), and redshift z relates wavelength observed $\lambda_{observed}$ to wavelength emitted $\lambda_{emitted}$ by $\lambda_{observed} = \lambda_{emitted}(1+z)$.

Radius $R(t)$ of our observable closed, homogeneous, isotropic, and expanding Friedmann universe at time t years ago was $R(t) = R_H/(1+z)$, with radius R_H today at $z = 0$. In our expanding universe, all LSS move away from us and redshifted light from those distant structures reveals conditions in the smaller universe in the past. Total matter density in the universe today is $\rho_m(0) = 2.304\times10^{-30}\ \text{g/cm}^3$ and radiation density is $\rho_r(0) = 4.519\times10^{-34}\ \text{g/cm}^3$. Total matter density in the universe at redshift z was $\rho_m(z) = \rho_m(0)(1+z)^3$ and radiation density was $\rho_r(z) = \rho_r(0)(1+z)^4$.

Jeans length $L_{J1}(z) = c_{s1}(z)\sqrt{\frac{\pi}{G\rho_{m1}(z)}}$ is the scale of the largest structures of matter (galaxy clusters) stable against gravitational collapse at redshift z, where speed of pressure waves in matter in the universe is

$c_{s1}(z) = c\sqrt{\frac{4(1+z)^4\rho_r(0)}{12(1+z)^4\rho_r(0)+9(1+z)^3\rho_{m1}(0)}}$ and $\rho_{m1}(z) = \rho_m(0)(1+z)^3$. So,

Jeans mass $M_{J1}(z) = \frac{4}{3}\pi\left(\frac{L_{J1}(z)}{2}\right)^3\rho_{m1}(z) = \frac{\pi^{5/2}}{6}c_{s1}^3(z)\frac{1}{G^{3/2}\sqrt{\rho_{m1}(z)}}$, is maximum galaxy cluster mass at redshift z. $M_{J1}(0) = 1.26\times10^{18} M_\odot$, with solar mass $M_\odot = 1.99\times10^{33}\ \text{g}$, is consistent with the $2.1\times10^{17} M_\odot$ mass of Quipu, the largest cosmic structure found to date [4].

Average density within Jeans mass holographic radius is

$\rho_{m2}(z) = M_{J1}(z)\bigg/\frac{4}{3}\pi\left(\frac{M_{J1}(z)}{0.187}\right)^{3/2} = \frac{3}{4\pi}\frac{0.187^{3/2}}{\sqrt{M_{J1}(z)}}$ and second level Jeans mass, the maximum mass of galaxies within galaxy clusters at redshift z, is

$M_{J2}(z) = \frac{\pi^{5/2}}{6}c_{s2}^3(z)\frac{1}{G^{3/2}\sqrt{\rho_{m2}(z)}}$ with

$c_{s2}(z) = c\sqrt{\dfrac{4(1+z)^4 \rho_r(0)}{12(1+z)^4 \rho_r(0) + 9\rho_{m2}(z)}}$. $M_{J2}(0) = 4.48 \times 10^{13} M_\odot$ is consistent with estimated mass about $10^{13} M_\odot$ for IC 1101, one of the most massive galaxies found to date.

Average density within second level Jeans mass holographic radius is $\rho_{m3}(z) = M_{J2}(z) \Big/ \dfrac{4}{3}\pi\left(\dfrac{M_{J2}(z)}{0.187}\right)^{3/2} = \dfrac{3}{4\pi}\dfrac{0.187^{3/2}}{\sqrt{M_{J2}(z)}}$ and third level Jeans mass, the maximum mass of star clusters within galaxies at redshift z, is

$M_{J3}(z) = \dfrac{\pi^{5/2}}{6} c_{s3}^3(z) \dfrac{1}{G^{3/2}\sqrt{\rho_{m3}(z)}}$ with

$c_{s3}(z) = c\sqrt{\dfrac{4(1+z)^4 \rho_r(0)}{12(1+z)^4 \rho_r(0) + 9\rho_{m3}(z)}}$. $M_{J3}(0) = 1.60 \times 10^9 M_\odot$ is consistent with an estimated upper limit on total star cluster mass [5].

Average density within third level Jeans mass holographic radius is $\rho_{m4}(z) = M_{J3}(z) \Big/ \dfrac{4}{3}\pi\left(\dfrac{M_{J3}(z)}{0.187}\right)^{3/2} = \dfrac{3}{4\pi}\dfrac{0.187^{3/2}}{\sqrt{M_{J3}(z)}}$ and fourth level Jeans mass, an upper bound on stellar masses within star clusters at redshift z, is

$M_{J4}(z) = \dfrac{\pi^{5/2}}{6} c_{s4}^3(z) \dfrac{1}{G^{3/2}\sqrt{\rho_{m4}(z)}}$ with

$c_{s4}(z) = c\sqrt{\dfrac{4(1+z)^4 \rho_r(0)}{12(1+z)^4 \rho_r(0) + 9\rho_{m4}(z)}}$ and $M_{J4}(0) = 56900 M_\odot$.

In what follows, $M_{\max}(z)$ is maximum mass (Jeans mass) for LSS at a given structural level and $M_{\min}(z)$, minimum mass for LSS at that structural level is Jeans mass for the next lower structural level (or, in the case of star clusters, maximum stellar mass).

4. Minimum Stellar Mass at Redshift *z*

Star formation results from thermonuclear reactions between strongly interacting protons in the baryon fraction of matter density in the universe. Mass of the smallest gravitationally bound systems (stars) at redshift z is estimated by setting escape velocity of protons at holographic radius $R_{\min}^*(z) = \sqrt{\dfrac{M_{\min}^*(z)}{0.187\ \text{g/cm}^2}}$ of stars with minimum mass $M_{\min}^*(z)$ equal to average velocity of protons in thermal equilibrium with CMB radiation at redshift z outside $R_{\min}^*(z)$.

Escape velocity v_{Ep} for protons with mass m_p gravitationally bound at radius R from the centroid of a structure with mass M is determined by $\dfrac{1}{2} m_p v_{Ep}^2 = \dfrac{GMm_p}{R^2}$. If proton escape velocity v_{Ep} at holographic radius $R_{\min}^*(z)$ of minimum mass stars at redshift z is proton velocity in thermal equilibrium with CMB radiation at redshift z, $\frac{3}{2}k(1+z)2.7255\ \mathrm{K} = \frac{GM^*_{\min}(z)m_p}{\left(R^*_{\min}(z)\right)^2}$. With CMB temperature $2.7255°K$ at $z=0$ and Boltzmann constant $k = 1.381\times10^{-16}\left(\mathrm{g}\cdot\mathrm{cm}^2/\mathrm{sec}^2\right)/\mathrm{K}$, $M^*_{\min}(z) = \frac{1}{0.187}\left(\frac{1.5k(1+z)2.7255}{Gm_p}\right)^2\ \mathrm{g}$.

If outgoing protons at $R^*_{\min}(z)$ are in thermal equilibrium with outgoing photon flow from minimum mass stars, stars must have mass > $M^*_{\min}(z)$ to appear against the CMB. If population III stars first appeared [6] when $M^*_{\max}(z) = M^*_{\min}(z)$ at $z = 65$, they may have had mass $M^*_{\min}(65) \approx 300M_\odot$. Minimum star mass today [7] $M^*_{min}(0) \approx 0.07M_\odot$ is consistent with hydrogen burning mass threshold separating brown dwarfs from lowest mass stars.

5. Central Black Holes in Large-Scale Structures at Redshift *z*

In isothermal spheres of cold dark matter inhabited by LSS, core radius $R_c(z)$ of an LSS containing concentrated mass in the central black hole is determined by the holographic radius of sub-elements orbiting the center just outside the core without being disrupted and drawn into the central black hole. Sub-elements of an LSS at a given structural level are LSS in the structural level in the next lower LSS mass range. Central black hole mass is $M_{CBH}(z) = \sqrt{M_{LSS}(z)M_{se}(z)}$, where $M_{LSS}(z)$ is total large-scale structure mass and $M_{se}(z)$ is mass of LSS sub-elements that can occupy a circular orbit just outside the core without being disrupted and drawn into the central black hole.

The most massive black holes allowed by holographic analysis are at the center of the most massive galactic clusters with Jeans mass $M_{J1}(0) = 1.26\times10^{18}M_\odot$ after all but lowest mass galaxies (with mass $M_{J3}(0) = 1.60\times10^{9}M_\odot$) are engulfed in the central black hole. The $4.49\times10^{13}M_\odot$ holographic upper limit on black hole mass is considerably greater than $10^{11}M_\odot$ mass of the most massive black hole found to date.

6. Holographic Analysis Predicts Unexpected JWST Observations

Holographic analysis determines total mass $M_{gtot}(z)$ of galaxies at redshift z as $M_{gtot}(z) = \int_{M_{gmin}(z)}^{M_{gmax}(z)} \frac{K}{m} m\mathrm{d}m = K\left(M_{gmax}(z) - M_{gmin}(z)\right)$ and total number of galaxies at redshift z as $N_{gtot}(z) = \int_{M_{gmin}(z)}^{M_{gmax}(z)} \frac{K}{m}\mathrm{d}m = K\ln\left(\frac{M_{gmax}(z)}{M_{gmin}(z)}\right)$. Average total galaxy mass at redshift z is

$$M_{gavg}(z) = \left(M_{gmax}(z) - M_{gmin}(z)\right) \Big/ \ln\left(\frac{M_{gmax}(z)}{M_{gmin}(z)}\right)$$ and

$M_{gavg}(14.4) = 5.191\times10^{10}M_\odot$. Average visible mass $8.143\times10^{9}M_\odot$ for galaxies at $z = 14.4$ identified by holographic analysis is consistent with JWST data finding early galaxies with stellar masses $\sim 10^9 M_\odot$ when the universe was only a few hundred million years old. Such large galaxies in the early universe were not expected in traditional galaxy formation models involving galaxies increasing in mass by clustering and merging [1].

JWST found abundant compact red sources, called Little Red Dots (LRDs), within large-scale structures. LRDs were largely missed by previous telescopes.

LRDs, with masses ranging from about $10^9 M_\odot$ to $10^{12} M_\odot$, are within the holographic radii of large-scale structures. Possible explanations for LRDs include:

- Primordial galaxies [8]. This holographic analysis finds galaxies with masses ranging from about $10^9 M_\odot$ to $10^{12} M_\odot$ existed in the very early universe at redshift $z = 14.4$.
- Quasi-stars (black hole stars) [9]. This holographic analysis shows central black holes with masses ranging from about $10^9 M_\odot$ to $10^{11} M_\odot$ existed in early galaxies at redshift $z = 14.4$. If some of them were quasi-stars, they could appear as LRDs.
- Star clusters containing supermassive stars [9]. At redshift $z = 14.4$, this holographic analysis shows star clusters with masses ranging from $5.66 \times 10^4 M_\odot$ to $1.59 \times 10^9 M_\odot$ existed in early galaxies at redshift $z = 14.4$, and supermassive stars with masses up to $5.66 \times 10^4 M_\odot$ could be present.

Conflicts of Interest

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

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