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A Dark Energy Hypothesis V

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Abstract

The subject is the mass of the three dominant, equilibrium cosmological objects: the irregular galaxy (dwarf), the regular galaxy (Hubble's "tuning fork"), and the galactic cluster. The standard ΛCDM theory and a DEH offer contrasting views on the origin of these masses. The latter suggests that they are relics of the early universe.

Keywords

Cosmic Structure, Irregular, Regular Galaxies, Galactic Clusters

1. Introduction

Structure means galaxies and galactic clusters. Their origin means their appearance in time out of a matrix of dark matter and baryonic matter. The time period is the early universe, defined here as $\eta < 1$, when the conformal time is less than unity, which in the DEH formalism means $t < 19.5$ Myr. The earliest time of interest is $t = 3$ minutes, $\eta = 6.76 \times 10^{-5}$, when baryonic matter has completely precipitated from cooling thermal radiation. Dark matter has by then appeared at $\eta = 0$ as described in DEH I and II.

For those interested in following the argument closely, the thoughts and equations below taken from DEH II should suffice [1]. The sum of dark energy and dark matter is conserved, with dark energy continuously increasing at the expense of dark matter. However, in the early universe, the quantity of dark matter is roughly constant. In the DEH formalism, the dimensionless parameters λ and $\chi(m)$ represent dark energy and matter, resp., so the conservation law is

$$\lambda + \chi(m) = \lambda + \chi(dm) + \chi(b) = 1$$

where $\chi(b) = 0.05$ = constant for baryonic matter. The flow of dark matter into dark energy is $d\lambda = -d\chi(dm) > 0$.

The dark energy parameter is

$$\lambda = \frac{\cosh(\eta) - 1}{6\eta^2}$$

where η and the scale factor "a" are given by $ad\eta = cdt$. The scale factor and cosmic time are

$$a = \frac{\Gamma}{6}\left(\cosh(\eta) - 1\right) \quad \& \quad ct = \frac{\Gamma}{6}\left(\sinh(\eta) - \eta\right)$$

Given the energy inventory for the current epoch, that λ:$\chi(dm)$:$\chi(b)$:7/10:1/4:1/20, then Γ is the total energy of the universe expressed as a length: $\Gamma = 6.306 \times 10^{24}$ m, which is conserved and hence valid for all epochs. To express it as an energy, divide by the Einstein gravitational constant, $\kappa = 2.076 \times 10^{-43}$ m J^{-1}. The total mass M and dark energy U_λ for any epoch are

$$Mc^2 = \frac{\Gamma\chi(m)}{\kappa} \quad \& \quad U_\lambda = \frac{\Gamma\lambda}{\kappa}$$

Finally, for $\eta \le 10^{-2}$, to a high degree of accuracy

$$a = \frac{\Gamma\eta^2}{12} \quad \& \quad ct = \frac{\Gamma\eta^3}{36}$$

2. The Argument

Three equilibrium masses. The regular galaxy (Hubble's "turning fork") is the principal structure in cosmology, ranging from 10^9 to 10^{12} solar masses, although the brightest cluster galaxy, a giant elliptical, may contain 10^{13}, but that's probably due to growth by "cannibalizing" other galaxies in the cluster. Two other structures bracket the regular galactic mass. The irregular or dwarf galaxy on the low end has masses up to about 10^8 solar masses; these are typically satellites of the regular. The galactic cluster is on the high end, consisting of 50 to a few thousand regulars. These three consist of structural units in the sense that they are gravitationally relaxed [2]. The supercluster is often cited as a fourth structure, but it is more of an incipient structure since it is not gravitationally relaxed and hence not a sharply observationally defined unit in and of itself.

Radiation and matter. Their relationship differs between the standard ΛCDM theory and a DEH. In the former, radiation density is greater than the density of baryonic matter in the early universe, whereas in the present epoch radiation density is unimportant. Hence, there is a time of radiation/matter equality at $t = 0.050$ Myr and $z = 3440$ [3].

In a DEH, the early universe is massive: neglecting radiation momentarily, of the remaining energy, 1/12-th is dark energy and 11/12-th matter, both dark and baryonic. Radiation/matter equality never occurs, matter dominating at all epochs. In the early universe, the densities are

$$\varepsilon(m) = \frac{Mc^2}{a^3} = \frac{C_m}{\eta^6}$$

$$\varepsilon(r) = \frac{3c^2}{32\pi Gt^2} = \frac{C_r}{\eta^6}$$

where $C_m = 1.92 \times 10^{-4}$ Pa and $C_r = 1.18 \times 10^{-4}$ Pa. Hence, matter/radiation = 1.63 for sufficiently small times. The ratio falls to 1.40 at $\eta = 1$, but then grows because of the difference in scaling, that $\varepsilon(r) \sim a^{-4}$, but $\varepsilon(m) \sim a^{-3}$.

Jeans mass. Given a sphere of radius R and uniformly distributed mass M, will it be gravitationally stable or unstable? According to the Jeans theory, if $M < M_J$, the mass density will oscillate but not collapse; if $M > M_J$, it will be gravitationally unstable. Jeans developed the theory for a Newtonian distribution of "fixed stars", but Narlikar [4] shows how to adapt it to an expanding universe.

The Jeans mass is

$$M_J = \frac{4\pi\rho}{3}\left(\frac{2\pi}{K_J}\right)^3$$

where K_J is the Jeans wavenumber:

$$K_J = \left(\frac{4\pi G\rho}{c_s^2}\right)^{1/2}$$

In the latter equation, the denominator is the speed of sound in the medium,

$$c_s^2 = \frac{\partial p}{\partial \rho}$$

which in this case consists of a solution of matter and thermal radiation; p, of course, is the pressure.

Eliminating the Jeans wave-number gives

$$M_J = \frac{9}{2}\frac{1}{\rho^{1/2}}\left(\frac{c^2}{G}\right)^{3/2}$$

$$M_J = \frac{2.226\times 10^{41}\ \text{kg}^{3/2} m^{-3/2}}{\rho^{1/2}}$$

with the speed of sound that in light, $c_s = c/\sqrt{3}$. Given that the early universe is massive and dense, it is not surprising that $M \gg M_J$. The mass density scales as $\rho \sim a^{-3} \sim \eta^{-6} \sim t^{-2}$, so $\rho^{-1/2} \sim t$. At $\eta = 10^{-3}$, $M = 3.098 \times 10^{50}$ kg, $a = 5.255 \times 10^{17}$ m, and $\rho = 2.135 \times 10^{-3}$ kg m^{-3}, giving $M_J = 4.818 \times 10^{41}$ kg. The total mass changes little in the early universe, but the mass density decreases because of expansion, so the Jeans mass grows. When $\eta = 0.4$, $t = 1.19$ Myr, $M_J = 3.1 \times 10^{50}$ kg $\approx M$.

The inference is that structure building occurs in the early universe from the formation of dark matter at $\eta = 0$ to about 1.2 Myr.

A causally disconnected early universe. A galaxy emits a light ray at time η_e from the comoving coordinate χ_e that is received at $\chi = 0$ and time η_r. The distance, d, to the galaxy at the time of light reception is

$$d(\eta_r) = a_r(\eta_r - \eta_e) = a_r \chi_e$$

where a_r is the scale factor at the time of reception. If light emission occurs at the earliest possible time, $\eta_e = 0$, then the distance is to the particle horizon:

$$d_{PH} = a\eta = a\chi_{PH}$$

where it is understood that a and η refer to reception of the light ray. This analysis is the same in the ΛCDM theory and a DEH.

Consider the early universe where $\eta < 1$, which means that the distance to the particle horizon is less than the scale factor. Since the particle horizon distance is the maximum distance that a cause may be connected to an effect, it follows that the early universe is divided into causally disconnected regions or cells. Let the early universe be represented by an array of cubes, each cube having an edge length a_c equal to the particle horizon length. The number, N, of cells within the space given the scale parameter "a" will be

$$N = \left(\frac{a}{a_c}\right)^3 = \frac{1}{\eta^3}$$

As time passes the number of cells decreases, that is, the number of regions not connected by causality decreases, until the cell structure dissolves at $\eta = 1$, and $d_{PH} > a$ for later times. The distance to the particle horizon at the present epoch in a DEH is

$$d_{PH}\left(t_0\right) = a_0\eta_0 = 5.571a_0$$

Structure formation. The formation of structure differs in a DEH from that in the standard ΛCDM cosmology.

In the latter, it begins at the radiation/matter equality [5]. Spontaneous density fluctuations that appear against the smooth density background ρ_m are represented by a dimensionless density contrast parameter, δ:

$$\delta\left(\boldsymbol{x},t\right) = \frac{\rho\left(x,t\right) - \rho_m}{\rho_m}$$

The bold symbol $\boldsymbol{x}$ represents dimensionless comoving coordinates: the Hubble flow for a galaxy corresponds to $\boldsymbol{x}$ = constant (Weyl hypothesis), so $\boldsymbol{x} \neq$ constant in structure formation when matter leaves the Hubble flow. For an overdense fluctuation, $\delta > 0$, the expansion rate is slower than in the smooth background density, ρ_m, so the density contrast grows $\mathrm{d}\delta/\mathrm{d}t > 0$. Hence, structure formation begins because small regions of space expand sluggishly. The growth can be followed analytically in its early stages, which leads in a straight forward, though not trivial, way to the following time-dependence:

$$\delta = At^{2/3} + Bt^{-1}$$

where A and B are functions of the comoving coordinates. Eventually, however, this growth law fails when the growth stops, the density contrast breaks free of the sluggish expansion mode, and begins to collapse. At this point, analytical methods become difficult, and investigators proceed by approximations, numerical integration, and numerical simulations.

A DEH setting for describing the emergence of three dominant sizes has already been given: no matter/radiation equality; a massive early universe of causally disconnected regions or cells; and an era of structure formation $\eta = 10^{-5}$ to 0.40. The total mass M remains constant at 3.1×10^{50} kg during this era to a good approximation. Imagine distributing this mass uniformly across the cells for each time period, the Cosmological Principle requiring a uniform distribution. The following Table 1 provides a sample: N_c is the number of cells, M_c is the mass of a cell in kg in the fourth column and in solar units, $\odot$, in the fifth.

Table 1. Structural masses against time.

η	t	N_c	M_c (kg)	M_c ($\odot$)
10^{-4}	10 min	10^{12}	$\sim 10^{38}$	$\sim 10^{8}$
10^{-3}	7 days	10^{9}	$\sim 10^{41}$	$\sim 10^{11}$
10^{-2}	20 yr	10^{6}	$\sim 10^{44}$	$\sim 10^{14}$
10^{-1}	16 kyr	10^{3}	$\sim 10^{47}$	$\sim 10^{17}$
0.40	20 Myr	Structure formation ends		

3. Conclusion

The masses of the three equilibrium cosmological structures appear on the backward lightcone, most recently, for example, in the Local Group with its three major galaxies, the Milky Way, M31, and M33, its many dwarfs, and the Local Group's association with the Virgo Cluster. In a DEH, these same masses occur in the early universe in causally disconnected cells. A straight forward inference is that what's seen on the backward lightcone is a relic of the early universe.

Conflicts of Interest

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

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