Hubble Tension from Bubble Tension
Cosmic Voids, Local and Global Scales

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Although the size of the cosmic void is much larger than the size of local scales and much smaller than the size of cosmic scale, it will be shown that they can be considered a very good representative for studying both local and global scales. For this goal, we will first consider the cosmic voids in the cosmic web as interconnected spherical bubbles. We will then show by heuristic calculations that for each cosmic void we obtain different mass densities and cosmological constants that are the same order of magnitude as the entire universe. It will also be shown that the slight difference between the surface tension of the bubbles may be the source of the $H_0$ tension between local and global measurements. As a necessary consequence of this study is that by examining a single cosmic void more seriously, both theoretically and observationally, interesting possible propositions can be made to solve important challenges in physical cosmology at local and global scales.

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I. INTRODUCTION AND MOTIVATION

Some of major problems in modern cosmology are dark matter, dark energy, cosmological constant, and Hubble tension [1, 2]. These serious physical challenges show that the standard model of cosmology, with all its advantages, is not able to solve many of these problems accurately [3]. Dark energy is an energy that the cause of the accelerating expansion of the present universe at large scales. Also, dark matter as the invisible and ghost-like matter is the cause of the, interconnection and balance of the galaxies, clusters and superclusters. Both of dark matter and dark energy has been completely confirmed by various direct and indirect observational methods. But for decades no plausible physical source has been found for this major contribution to the universe’s matter and energy [4, 5].

When the Hubble parameter is measured in local scales by cosmic ladders scaling methods, the values measured for $H_0$ are different from the value reported by Planck, which depends standard ΛCDM model and uses CMB photons. This difference is called the Hubble tension. On the one hand, scientists are looking for more accurate scaling methods, and on the other hand, they are looking for an alternative to the standard model for solving Hubble tension [6-11].

Recently, we have been able to show that a possible source of dark matter and energy could be due to the surface tension on the shell of supervoids [12, 13]. We have assumed that the supervoids dominate in the in the large-scale overview. Cosmic (Vast/Super) voids have been ideally considered to be spherical bubbles. The gravitational integration of galaxies over time, on the one hand, leads to the formation of over-dense regions such as clusters, superclusters, walls, strings, and filaments. On the other hand, as superclusters merge, almost empty spaces are created between them, and we call these under-dense regions among galactic strings and walls as cosmic voids [13].

Hydrodynamic models and simulations of the formation of the cosmic web structure show that these bubbles are also merging [14, 15]. The standard cosmological model ignores the statics, dynamics and evolution of supervoids that make up the main part of the late universe. While the supervoids are not only not completely empty, but also have a density of energy and evolution, and also because they are bulky, they are more likely to merge with each other and are much more suitable candidates for influence on the cosmic scales [13, 14, 16]. Therefore, the possibility of the role of these large inhomogeneities in the dynamics of the universe and the effects of their evolution in determining the value of cosmic parameters seems possible [17-20].

In the proposed hypothesis in [13], cosmic voids are assumed to be spherical bubbles. The walls of these bubbles are surrounded by galactic superclusters. By considering the walls as the ideal separating surface between the low-density bubble-like areas and the high-density droplet-like areas, we have obtained the resulting surface tension by dimensional and heuristic calculation (see TABLE I) [13]. Then, by equating the energy density of cosmic voids with the vacuum energy density, we show that the value estimated for the cosmological constant is very close to that predicted by Planck’s observations and has the same order of magnitude [13].

In this paper, in Sec. II, we discuss the simultaneous coexistence of super-voids and super-clusters as two evolving part in the Cosmic Web. Then in the main Sec. III, we first calculate the mass density of a cosmic void and compare its magnitude with the density of the whole universe. We will then try to answer two important following questions:

i. Given that the average diameter of cosmic voids is usually 100Mpc, might a single cosmic void be a good representation for smaller local scales and larger global scale?

ii. Do the slightly differences between of cosmological constants obtained from our hypothesis can represent the acceptable values of the Hubble constant and could the differences in their values be a possible solution for $H_0$ tension?

In the final section of this article, we will briefly discuss the possibility of resolving $H_0$ tension and other possible outcomes.
TABLE I. The surface tension of $\gamma_i$, on the shell of cosmic voids containing disk-shaped superclusters $i = 1, 2, 3, 4$ [13].

| i. Supercluster | $M_i$ $(10^{17}$kg) | $R_i$ $(10^{24}$m) | $\gamma_i$ $(10^{15}$J.m$^{-2}$) |
|-----------------|---------------------|------------------|-----------------------------|
| 1. Corona       | 0.20                | 1.50             | 0.25                        |
| 2. Virgo        | 0.03                | 0.50             | 0.34                        |
| 3. Laniakea     | 1.00                | 2.40             | 0.50                        |
| 4. Caelum       | 4.00                | 4.30             | 0.62                        |

II. COEXISTENCE OF SUPERVOIDS WITH SUPERCLUSTERS IN COSMIC WEB

If we consider part of the present universe, it contains a network of cosmic voids in which several superclusters and small and large galactic objects are merging with each other. It is certain that in the general view, the large scale of the universe is in the void-dominant state, and in the small but dense local scales, it includes super-clusters in the matter-dominant state. The coexistence and continuous integration of superclusters at small scales and supervoids at large scales increase the contribution of each of them to the structure of the universe, and the increase in the size of the cosmic void after merging them leads to an effective repulsive force on the galaxies situated on their shell[13, 14]. Under such conditions, it can be assumed that the cosmic fluid at the large scale overview consists of merging and expanding large bubbles, and the universe is dominated over time by larger bubbles in the accelerating expansion phase.

In the proposed model, dense objects, including galaxies and their clusters and superclusters, are thought of as "drops" and the voids, and supervoids between them as "bubbles"[21]. In a two-phase inhomogeneous mixture of drops and bubbles, the bubbles also absorb other bubbles and disperse the droplets from the center to the periphery, while their own size becomes larger and less dense than before. Physical simulations of redshifts in terms of different displacements show that local scales become denser over time but the density of large scales decreases[14].

III. GLOBAL AND LOCAL BEHAVIOR OF COSMIC VOIDS

In this main part of the paper, we want to show whether a single supervoid can be a good representation of local and global scales or not? For this purpose, we first calculate the mass density of a supervoid and show that its magnitude is about one-tenth of the average density of the universe. Then, by the surface tension of a supervoid, we show that the cosmological constant obtained from it is very close to the cosmological constant measured by Planck 2018[[]. Finally, we will answer the important question that is it possible that the Hubble tension is due to slight differences in the surface tension of the bubbles?

A. Mass Density for a Cosmic Void

For a perfectly empty spherical bubble with a total mass accumulated on the shell, the mass density can be calculated from the simple relation below,

$$\rho_i = \frac{3M_i}{4\pi R_i^3}.$$ (1)
Here $M_i$ is the mass of the supercluster and $\bar{r}_v$ is the average radius of a cosmic void. Taking into account the values of Table 1. for the mass and radius of the Laniakia supercluster, we obtain

$$\rho_3 = 1.70 \times 10^{-27}\text{kg.m}^{-3}. \quad (2)$$

is very close to the universe’s average mass density of the universe [22] i.e.

$$\rho_{0,c} = 1.88 \times 10^{-26}\text{kg.m}^{-3}. \quad (3)$$

and is about one order smaller than that. It seems that this density deficiency is due to the assumption of a completely empty bubble. The densities of the other cosmic voids are listed in TABLE II respectively.

### B. Cosmological constant from Surface Tension of Comic Void

The internal pressure of a single bubble (drop) is usually greater than its external pressure, and the pressure difference with the outside comes from the Young-Laplace formula [23, 24]

$$\Delta P = \frac{2\gamma_i}{\bar{r}_v}. \quad (4)$$

Here, $\gamma$ represents the surface tension for bubble (drop). To calculate the surface tension of a single bubble, we use the following heuristic method [12, 13],

$$\gamma_i \equiv \frac{\text{Energy}}{\text{Area}} = \frac{M_i c^2}{\pi R_i^2}. \quad (5)$$

Taking account of the calculations in the previous section, the average density of a cosmic fluid is very close to the density of a single bubble. In the present void-dominant cosmic fluid we can assume that ($\rho_\Lambda \equiv \rho_v$) and ($\Delta P \simeq P_v$), by considering (4) we obtain

$$P_v = wc^2\rho_v. \quad (6)$$

Therefore, to have a cosmological constant caused by bubbles, we will reach the following relation [13],

$$\Lambda_i = \frac{8\pi G 2\gamma_i}{wc^4/\bar{r}_v}. \quad (7)$$

By placing the necessary values [13], we reach the results in TABLE II. The cosmological constant in the latest Planck data is reported as below [25],

$$\Lambda_{\text{obs}} = 1.1056 \times 10^{-52}\text{m}^{-2}. \quad (8)$$

In our model, for the Laniakia supercluster in which the Milky Way galaxy is located, the cosmological constant of the model is obtained as follows[13],

$$\Lambda_3 = 1.2979 \times 10^{-52}\text{m}^{-2}. \quad (9)$$

As we can see in TABLE II, the cosmological constant and the mass density for each of the supervoids are the same as values for the entire universe (8) and(3) and are very close to them. Thus, given the values obtained for the $\rho_i$ and $\Lambda_i$, it seems that a cosmic void can be a good indicator of the global behavior of the universe.
C. Is Hubble Tension from Bubble Tension?

For the slight differences between the values of the cosmological constant for the different supervoids listed to TABLE II, we will calculate the corresponding Hubble constant. We will show that our void-based model confirms $H_0$ values that reported locally measured \cite{6-8} and the value inferred from the cosmic microwave background (CMB) \cite{26}. Assuming the ΛCDM-based cosmology, the Hubble constant of the late universe (model dependent) is inferred as \cite{25},

$$H_{0,\text{global}} = 67.66 \pm 0.42 \text{ km.s}^{-1}.\text{Mpc}^{-1}$$ (10)

But from Hubble Space Telescope (HST) observations of 70 long-period Cepheids in the Large Magellanic Cloud, the best measurement of the cosmological constant has been estimated as \cite{27},

$$H_{0,\text{local}} = 74.03 \pm 1.42 \text{ km.s}^{-1}.\text{Mpc}^{-1}$$ (11)

Now, we will continue to calculate the cosmological constant in our void-dominant model. The Hubble constant is related to the cosmological constant according to the following relation

$$H_i^2 = \frac{\Lambda_i}{3}\Omega_i^{-2}$$ (12)

So $H_i \propto \Omega_i^{\frac{1}{2}}$ and we will have

$$H_i = H_{0,\text{obs}} \left( \frac{\Lambda_i}{\Lambda_{\text{obs}}} \right)^{\frac{1}{2}}$$ (13)

For observational Hubble constant $H_{0,\text{obs}}$, we have two selections (10) and (11). If we consider $H_{0,\text{obs}} = 67.66$ \text{ km.s}^{-1}.\text{Mpc}^{-1} from Planck 2018 data \cite{25} and considering (8), the equation (13) gives the following value for the cosmic void that surrounded by Laniakea supercluster

$$H_{3G} = 73.31 \text{ km.s}^{-1}.\text{Mpc}^{-1}$$ (14)

On the other hand if we consider $H_{0,\text{obs}} = 74.03$ \text{ km.s}^{-1}.\text{Mpc}^{-1}, for the cosmic void that surrounded by Virgo supercluster we obtain

$$H_{2L} = 66.68 \text{ km.s}^{-1}.\text{Mpc}^{-1}$$ (15)

The predicted value (15) is very close to the value obtained in \cite{9}. For other cosmic voids, the values of the Hubble constant are also listed in TABLE II. Given the value obtained (14) and (15) in the proposed bubble model, it can be concluded that the Hubble constant values in it are close to the values (11) and (10), in which measured by both of the local and global groups, respectively. As one can see in TABLE II, the values obtained for the Hubble constant in our model include the values reported by both local and global measurements. However, given the value obtained for the Laniakea supercluster (14), the model results are closer to local measurement (11). Given the high accuracy of measurements that reported by local groups on the one hand and the independence of these data from the model on the other, it seems that the main reason for $H_0$ tension is related to $\Lambda$ in the standard ΛCDM model that assumed completely constant. Since, according to our hypothesis, the surface tension values of the supervoids are slightly different, as a consequent of it we can have different $H_0$. Thus, given the values obtained for the Hubble constant $H_i$ in TABLE II, it seems that cosmic voids can be a good indicator to study on both the global and local scales.

Also, the $H(z)$ values listed in Table 1. on page 5 of \cite{28}, which have been published in various journals, show that the Hubble parameter decreases as the redshift $z$ decreases. This is a confirmation of our model that over time the amount of surface tension of the cosmic voids becomes smaller. Therefore we now have the smallest possible value for the Hubble parameter as $H(0)$. 

\[ H(0) \]
TABLE II. Cosmological constant $\Lambda_i$, mass density $\rho_i$, and global and local Hubble constant $H_{iG}$ and $H_{iL}$ for different cosmic voids surrounded with superclusters $i = 1, 2, 3, 4$.

| Cosmic Parameter | $\rho_i$ $\times 10^{-26}$kg.m$^{-3}$ | $\Lambda_i$ $\times 10^{-52}$m$^{-2}$ | $H_{iG}$ km.s$^{-1}$.Mpc$^{-1}$ | $H_{iL}$ km.s$^{-1}$.Mpc$^{-1}$ |
|------------------|---------------------------------|------------------|-----------------|-----------------|
| 1. Corona Sc     | 0.14                            | 0.6645           | 52.45           | 57.39           |
| 2. Virgo Sc      | 0.60                            | 0.8970           | 60.94           | **66.68**       |
| 3. Laniakea Sc   | 0.17                            | 1.2979           | **73.31**       | 80.21           |
| 4. Caelum Sc     | 0.12                            | 1.6172           | 81.83           | 89.53           |

IV. CONCLUSIONS

We have considered supervoids as expanding spherical bubbles in a void-based cosmic fluid. The total supervoid mass is situated on the shell and the shell is formed by the disk-shaped superclusters. Then, by heuristic calculating the mass density and cosmological constant of a single supervoid, we have been shown that the value obtained is very interestingly the same as their corresponding values for the entire universe.

On the other hand, for the Hubble tension, we have been shown that the value obtained from the void-dominant universe hypothesis can represent the values obtained from local and global data, but is more consistent with local measurements. As we know, the data reported from global groups such as Planck depends on the $\Lambda$CDM model. Therefore, small changes in $\Lambda$’s value can greatly affect the results of measurements. But on the other hand, the data reported from local groups are independent of each model and have a very high measurement accuracy. Therefore, from our point of view, the main problem in Hubble tension originated from the slight changes in $\Lambda$’s value, which also depends on changes in surface tension and the size of super voids.

So the interesting result of this study is that a cosmic void can be a good candidate to describe the behavior of the universe both on a large and local scale. As an important consequence of this research, by examining static and dynamic behavior of cosmic voids more seriously, both theoretically and observationally, possible plausible solutions to the important challenges of physical cosmology on a local and global scale can be offered. In future work, we will address important issues such as dark matter and the problem of vacuum energy within the framework of this hypothesis.

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