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# HIERARCHICAL STRUCTURE OF THE UNIVERSE

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**ABSTRACT.** The modern understanding of the structure of the Universe is discussed. The Solar System is viewed as an ordinary planetary system. The neighbourhood of the Sun is specified starting with the nearest stars and nearby clusters and working outward through the Local system of stars, in particular, Gould's belt. The subgroups of the Milky Way, our stellar system, and Andromeda are examined as components of the Local Group of galaxies. Special attention is paid to their astrophysical, kinematic and dynamic properties. A larger agglomeration of galaxies, called the Local Supercluster, which contains the Local Group and its immediate neighbourhood is analysed. And finally, the Laniakea hypercluster to which the Local Supercluster and its environment belong is described along with its neighbours, namely the Perseus-Pisces hypercluster and the Local Void.

**Keywords:** Universe structure; hierarchy; star clusters; galaxy clusters; hyperclusters

**АБСТРАКТ.** Аналізуються сучасні уявлення про устрій Всесвіту по мірі віддалення від Сонця. Сонячна система представлена як рядова планетна система. Далі характеризуються околиці Сонця: від найближчих зір і їх скупчень до устрою Місцевої зоряної системи (МЗС – поясу Гулда). Аналізується гіпотеза щодо припущення, що за структурою і астрофізичними показниками МЗС схожа на маленьку галактику, яка нагадує об'єкт Ходжа в спіральній галактиці NGC 6946.

Будова Галактики, Нашої зоряної системи, підгрупи Андромеди аналізуються з точки зору складових частин Місцевої групи галактик (МГГ). Приділяється увага їх астрофізичним і кінематичним властивостям. За межами МГГ аналізується їх безпосереднє оточення та більш крупна структура – Місцеве Надскупчення (МН), до якої вона належить. Далі розглядається гіперскупчення Ланіакея, в якому містяться МН і його околиці. Характеризуються сусіди гіперскупчення Ланіакея: гіперскупчення Персея-Риб і Місцевий вояд.

Аналізуються прояви просторово-часового устрою Всесвіту та його коміркова структура. Обмірковується область Всесвіту, обмежена хабблівським радіусом і її властивості. Робиться висновок, що основними складовими серед об'єднань зоряних систем різної ієрархії слід вважати групи, надскупчення та гіперскупчення, оскільки проглядається закономірність, за якою, як правило, більш вищий рівень об'єднання галактик включає на два порядки більше об'єктів

нижчої ланки. За такої класифікації, підгрупи та скупчення галактик є проміжними елементами крупномасштабної ієрархії об'єднань галактик.

Остаточний висновок: на теперішній час встановлено повну «адресу», де знаходиться землянин у Всесвіті. Наступною незвіданою структурою світу може бути лише місце нашого Всесвіту серед інших всесвітів, якщо вони існують.

## 1. Hypotheses and evidence of a hierarchical structure of the Universe

The picture of the universe formed in the early days of telescopic astronomy was restricted to the structure of the Solar System. At that time, there was just conjecture about the stellar origin of the Milky Way and philosophic speculations about the presence of planets orbiting stars like those orbiting the Sun [3]. The discovery of the laws of motion and gravity by Isaac Newton definitely established the validity of heliocentric model of the Universe [31]. Systematic telescopic observations initiated accumulation of data on the universe beyond the Solar System and scientific substantiation of the suggested hypotheses about its structure.

### 1.1. First scientific hypotheses

The analysis of the accumulated telescopic astronomical observations allowed making first hypotheses about hierarchical structure of the Universe in the middle of the eighteenth century. In 1750, Thomas Wright proposed a new concept of the Universe consisting of hierarchically arranged systems with one of the components being the disc-shaped Milky Way [44]. In 1755, Immanuel Kant also came to the conclusion that the Solar System formed from gaseous cosmic matter was a constituent part of the Milky Way [21]. In 1771, Johann Lambert hypothesised that our Solar System was a member of one of those larger intermediate stellar systems which constitute the Milky Way [24].

Validation of the suggested hypotheses required further telescopic observations of celestial bodies. Such surveys of the structure of the Universe were pioneered by William Herschel. He found clumping of nebulae and resolved the richest of them in the constellation Coma Berenices [11] incorporated into a rather narrow region extending through the constellations Virgo, Ursa Major and Andromeda. Since the middle of the twentieth century this region has been identified as a part of the Local Supercluster. In 1785, based on the results of careful

observations and calculations of stellar parameters, Herschel presented the first model of the Galaxy shaped as a flattened disc in the first-order approximation [12]. Herschel's Catalogue of One Thousand New Nebulae and Clusters of Stars [13] published in 1786 gave an impetus to systematic survey of star clusters.

### *1.2. First findings of surveys of the arrangement of stellar systems*

Increasing diameters of telescope mirrors, usage of clock drives to compensate for the celestial sphere rotation, introduction of spectral analysis and its implementation into observational astronomy in the nineteenth hundreds enabled to initiate systematic studies of the stellar systems, such as multiple star systems and star clusters, discovered by that time. Determination of the orbital period of the double star Castor by Herschel in 1803 resulted in the establishment of its physical duplicity and allowed application of Kepler's third law to its investigation [14]. The discovery of the Doppler effect in 1842 marked the start of its implementation in astronomical observations. In particular, it enabled the detection of spectroscopic binaries (Edward Pickering, 1890; [33]). There were a total of about 10 thousand of double and multiple stars comprised of three to sixteen components found at that time. The compiled catalogues of double and multiple stars laid the foundation of their systematic investigation.

The discovery of the first spiral structure in the stellar system Messier 51 (M51) made by William Parsons in 1845 with a six-foot (72 inch) reflecting telescope, which was the largest in the world back then, marked the beginning of surveys of the structure of such stellar systems. By the late nineteenth century, spirality was detected in at least 10 "stellar nebulae"; the existence of elliptical, lenticular and annular structures was also reported [29]. In 1847, John Herschel found out that the brightest stars were concentrated in a narrow region on the celestial sphere; later on, in 1879, having studied that pattern Benjamin Gould established that the ring was inclined to the plane of the Milky Way at an angle of  $18^\circ$ . That finding refuted the arrangement of the Milky Way systematised by the Herschels in the early nineteenth century. Estimates of distances of the investigated stars were needed to evaluate the significance of that discovery. The studies aimed at the stellar parallax determination initiated by Friedrich Struve in 1835 and Friedrich Bessel in 1840 were confined to the immediate solar vicinity. Innovative approach which could allow the estimation of distances of open star clusters and nebulae, as well as determination of the dimensions of the Galaxy, were required.

### *1.3. Investigation and systematisation of data in the 20<sup>th</sup>-21<sup>st</sup> centuries*

The accumulation of data on the stellar distances, as well as the demand for introduction of the concept of luminosity as a measure of intrinsic brightness of stars irrelevant to their distances, actuated Einar Hertzsprung to introduce the concept of absolute magnitude in 1905 and enabled him to establish its dependence on the star's colour [15, 16]. Later on, in 1910-1913, Henry Russel

independently elaborated that idea and inferred a relationship between the stars' spectra and absolute magnitudes [34-36]. The plotted relationship was called the Hertzsprung-Russel diagram, and since then it is of great importance for studying stellar systems.

The detection of the correlation between the luminosity and period of Cepheids in the Small Magellanic Cloud by Henrietta Leavitt in 1908-1912 [26, 27] contributed to the determination of distances to the remotest stellar systems. It enabled Harlow Shapley to deduce the dimensions of the Galaxy from the distribution of globular clusters on the celestial sphere relative to the Milky Way and from the presence of RR Lyrae variable stars in the relevant clusters [38]. It turned out that all discovered star clusters and nebulae could be split into two groups, namely those within and those beyond the Galaxy. Further analysis of extragalactic nebulae revealed that they consisted of stars, and that there was a correlation between their redshifts and distances (Edwin Hubble, 1929; [18-20]). Thus, a real reference framework needed for the determination of the scales of the Universe and its three-dimensional structure became available.

The analysis of spatial arrangement of galaxies made it possible to establish their inhomogeneous distribution in the universe over a given range of scales. They combine into certain structures which tend to have a common feature – namely, that larger structures consist of those which are smaller and contain fewer galaxies. As a result, galaxy groupings were classified based on different levels of hierarchy from groups and clusters of galaxies to galaxy superclusters. In the second half of the twentieth century, it became clear that such hierarchical structures are confined to hyperclusters which along with galaxy superclusters constitute the cellular space-time structure of the Universe. As regards the distribution of galaxies and different levels of their arrangement, the concept of homogeneous spatial distribution of galaxies can only be employed for cosmological distances.

## **2. Distinctive features of the Solar System and its immediate neighbourhood**

There is no clear definition of the immediate solar neighbourhood to date. A sphere centred on the Sun thus ruling out the existence of any star clusters within itself may be chosen as such a region. In this case, such a region should be limited to the radius of about 20 pc.

### *2.1. Solar System*

Our planetary system is one of the lowest ranked in the hierarchy of multiple systems with only single stars and substars ranked lower. It contains a central main-sequence star, eight planets, two asteroid belts and possibly a cloud of comets. Planets in the Solar System reflect the existing planet classification [47] – namely, that inner planets are referred to as silicate and metal planets while giants are equally split into hydrogen-helium and ice planets. Dwarf planets are more similar to silicate ones; they are present in the main asteroid belt and seen among moons of giant planets. Among moons of giants and Kuiper belt components there are icy and silicate-ice dwarfs. The total number of dwarf planets known so far is 92 [48]. It is supposed that our Solar System is surrounded by a cloud

of comets whose outer edge is likely to be at one quarter of the distance of the nearest triple-star system Alpha Centauri.

### 2.2. Multiple stars and planetary systems nearest to the Sun

As far as within the boundaries of the nearest five stellar systems their significant diversity manifests itself. The triple-star system Alpha Centauri, which is at the distance  $d = 1.30\text{--}1.34$  pc from the Sun, includes two solar-like G and K components and a red dwarf ( $d = 1.30$  pc) with a silicate planet slightly larger than Earth ( $\approx 1.3 M_{\odot}$ ) that lies in the habitable zone of Proxima Centauri. Barnard's Star ( $d = 1.83$  pc) is an individual red dwarf for which the presence of planetary system was claimed earlier [40–42]. However, this claim has never been lent credence with up-to-date exoplanet search methods [7]. Both components of the binary system Luhman 16 ( $d = 2.02$  pc) are L-type dwarfs, i.e. substars. Wolf 359 ( $d = 2.39$  pc) is a single M-type dwarf. It should be noted that there is one more object in the investigated region, namely WISE 0855–0714 ( $d = 2.20$  pc), which is formally not reckoned as a stellar system as its mass is below the brown-dwarf limit [47]. This is grounds for classifying this Y-dwarf as a rogue planet, i.e. single planet with no central star. All the above listed dwarfs are main-sequence stars. Sirius B ( $d = 2.20$  pc) is the closest white dwarf to the Sun while Arcturus ( $d = 11.24$  pc) is the nearest red giant. Epsilon Eridani is the closest planetary system to the Sun ( $d = 3.32$  pc) with two belts of asteroids (debris discs); its structure is similar to that of the Solar System, though  $\epsilon$  Eridani is 10 times younger.

Meanwhile, planetary systems formed longer ago also resemble the Solar System. For instance, within 10 pc there are about 70 planets found around 23 stars, including the Solar System. Among those planetary systems, there are planets of different types, in particular, Jupiter-like planets account for 20 per cent, ice giants – 20 per cent, and Earth-sized planets, including super-Earths, comprise 60 per cent. Such distribution is the same as that in the Solar System.

### 3. Local system of stars

The immediate solar neighbourhood is a part of the Local system of stars, the central region of which is called Gould's belt. Today, the Local system is associated with a region twice (or even four times) as large as the Gould belt distinguished earlier.

#### 3.1. Star clusters and associations nearest to the Sun

Five of seven bright stars in the constellation Ursa Major, namely Alioth, Mizar, Merak, Megrez and Phecda, are associated with the closest stellar moving group (also known as Collinder 285) which is at  $d \approx 25$  pc from the Sun. The total number of stars in the Ursa Major association is about 100; its diameter is 7 pc. The estimated age of this stellar association is 400 Myr.

The Pleiades are the second nearest star cluster ( $d = 135$  pc). It includes about a thousand stars and substars (which account for 25 per cent of the total population) within  $110'$  (4 pc). Its age is estimated to be 100 Myr. This

star cluster is close to the centre of Gould's belt whose distinctive spatial feature is the presence of the so-called doughnut-shaped ring with stellar associations along its outline. These stellar associations contain main-sequence stars, giants, bright giants and supergiants. There is extensive ongoing star formation in these regions.

The Scorpius–Centaurus association is the nearest OB association to the Sun. It consists of three subgroups, namely Upper Scorpius, Upper Centaurus-Lupus and Lower Centaurus-Crux. The mean distances to these subgroups range from 380 pc to 470 pc. Each subgroup has a diameter of about 90 pc; the total number of components in this stellar association is  $\sim 5,000$ ; its estimated age is 11–15 Myr. It is this stellar association to which Antares, the most massive red supergiant, belongs.

The nearest active star-forming region is associated with the Orion Nebula ( $d \approx 410$  pc) which is 10 pc in diameter. Apart from young stars, a protoplanetary disc and several substars have been found there.

#### 3.2. General description of the Local system of stars

The Local system of stars is 8 pc away from the galactic centre. Its inner region is associated with the Gould belt whose radius is  $\approx 500$  pc. There are about 15 nebulae, more than 20 stellar associations and a few tens of star clusters in that region.

The astrometrically determined radius of the Local system can be traced out to 1 kpc [1]. The mass of this region is 20 million solar masses [32]; it includes several hundred of star clusters and a few tens of stellar associations comprised of more than 500 OBA type stars and T Tauri stars [2]. The Local system disc of a thickness less than 380 pc is inclined to the galactic plane at an angle of  $18^\circ$  towards the centre of the Galaxy and North Galactic Pole. There are two stellar populations detected in the Local system – namely, the old population with age of about 600 Myr and the second population which is of an order of magnitude younger. A spike-like formation consisting of  $\approx 4,500$  young stars has been found in the outskirts; it can be traced out to 2 kpc [30]. The Local system rotates differentially at the velocity of  $3 \pm 1$  km s<sup>-1</sup> (maximum 6 km s<sup>-1</sup>). The Sun was also gravitationally bound to the Local system 100 Myr ago when moving at a distance of about 100 pc from its centre at an orbital velocity of 4 km s<sup>-1</sup> [32].

How should we classify the Local system? As is seen from its afore-mentioned features, the Local system has got all the properties of a small galaxy such as, for instance, the Hodge complex in the spiral galaxy NGC 6946 [9, 17, 25].

### 4. The Milky Way subgroup

The galactic disc immersed in the spherical component wherein satellite galaxies are clustered is called our stellar system [45] or the Milky Way subgroup (sometimes family).

#### 4.1. Our Galaxy

The Milky Way consists of a flattened structure and constituents of the spherical and intermediate components

[45]. The flattened structural component of the Galaxy includes the thick and thin discs within the galactocentric radius  $R_{GC} = 15$  kpc. The visible ring (with the radius  $R_{GC} = 8$  kpc) is embedded into the inner (old) halo ( $R_{GC} = 9$  kpc), which is one of the constituents of the spherical component. The bulge ( $R_{GC} = 3$  kpc), 2 pc thick, is considered as an intermediate structural component with a bar-shaped structure while its very centre contains a black hole with a mass equivalent to 4 million Suns. Two major stellar arms, each with one loose spiral spur, extend from the central bulge outwards. The next constituent of the spherical component is the young halo ( $R_{GC} = 9-20$  kpc); moving outwards it is followed by the outer halo ( $R_{GC} = 20-120$  kpc) and the outskirts ( $R_{GC} = 120-254$  kpc) confined to the orbit of the remotest satellite galaxy Leo I [45, 47]. The Local system, which contains the Solar System, resides between the Carina-Sagittarius and Perseus Arms. Sometimes this location is related to the Orion spur.

#### 4.2. The Milky Way's satellite galaxies

There are 15 known smaller companion galaxies of the Milky Way concentrated in three belts. In the inner belt, there are three satellite galaxies which are highly susceptible to the gravitational tidal interaction with the Milky Way. All these companions lie within the young halo [45, 47]. The second belt with satellites is associated with the Magellanic Stream. It contains seven satellite galaxies, including the Large and Small Magellanic Clouds, within 90 pc from the centre of the Galaxy. These companions are projected as an elongated ellipse outline on the celestial sphere. They are clustered mainly towards the plane inclined to the galactic equator at an angle of  $70^\circ$  [28, 43]. Five satellite galaxies are found in the third belt beyond the central 90 kpc; they are also concentrated towards the plane inclined to the galactic equator at an angle of  $50^\circ$  [46]. There is also an object with no detected emission having a mass equivalent to that of the Large and Small Magellanic Clouds found in the galactic equator plane 90 pc away from the galactic centre [4, 5]. The origin of this object has not been clarified so far.

### 5. Local Group of galaxies

Our stellar system is a member of the Local Group of galaxies which is also home to the Andromeda subgroup. Galaxies which do not belong to any of these subgroups are reckoned as those in the outskirts of the Local Group. There are 50 galaxies in the Local Group known so far.

#### 5.1. The Andromeda subgroup

The internal structure of the Andromeda Galaxy (also known as Messier 31) resembles that of the Milky Way. However, since its luminous mass is half as much again as that of the Milky Way, the estimated number of its constituents (i.e. stars, star clusters, stellar associations and smaller companion galaxies) is greater. The mass of its central black hole is 15 times that of the Milky Way. The Andromeda nebula is an unbarred spiral galaxy. It has less dark matter than the Galaxy, though considering its presence these two subgroups are of the same mass which is corroborated by similar plateaux in their rotation curves [10].

As of today, there are 18 satellite galaxies known in the Messier 31 subgroup, the most distant of which (LGC III and And VI) are 280 kpc away from its centre thus constraining the scale of this subgroup.

Satellite galaxies are concentrated towards two planes inclined to the equator of M31. Most of them are inclined to the galactic plane at an angle of  $30^\circ$  while spheroidal dwarf satellites are inclined at an angle of  $80^\circ$  [47]. Unlike our stellar system, wherein the largest satellite galaxies, namely the Large and Small Magellanic Clouds, are located relatively close to the Milky Way, in the Andromeda subgroup the most massive satellites (M33 and IC 10) reside in the outer reaches (225 kpc and 250 kpc away from the centre of M31, respectively).

#### 5.2. Galaxies in the Local Group outskirts

Fourteen galaxies do not belong to any of the subgroups of the Local Group, and 17 more galaxies are potentially to be classified likewise [47]. Their distances from the Sun range from 400 kpc to 1,360 kpc. Most galaxies in the outskirts of the Local Group are irregular with seven of ten irregulars being barred ones (IB type). Two galaxies in the constellations Cetus and Tucana are classified as elliptical; another two galaxies (in Hydra and Antlia) are contiguous and interact with each other. The Sagittarius Dwarf Irregular Galaxy (SagDIG) is the most distant from the Sun.

#### 5.3. Kinematics of the Local Group galaxies

Hubble's law does not hold within the Local Group. The Milky Way and M31 subgroups are approaching each other at a radial speed of about  $120 \text{ km s}^{-1}$ . However, as far as beyond the Local Group Hubble's law starts being applicable. A rather plausible explanation of such behaviour of the law is that the subgroup dimensions are governed by the balance between the forces of attractive and repulsion (dark energy) [6]. It means that attraction dominates within subgroups while repulsion prevails beyond their boundaries. Therefore, it would be more reasonable to interpret Hubble's law with respect to the recession of galaxy subgroups rather than that of galaxies.

### 6. Local Supercluster

Based on the analysis of 1,250 galaxies from the Harvard Survey of Galaxies Brighter than the Thirteenth Magnitude (Shapley & Ames, 1932; [37]), Gerard de Vaucouleurs [8] deduced the existence of the next level of the hierarchical structure, namely the Local Supercluster, comprising the Local Group. In fact, it was a re-discovery of what William Herschel had noticed more than 150 years earlier [11] since the richest portion of clumping which he had detected (with no photo available!) in Coma Berenices turned out to be a constituent part of the supercluster discovered later by de Vaucouleurs.

#### 6.1. The Local Group surroundings

There are five groups of galaxies in the immediate surroundings of the Local Group ( $< 5$  Mpc), namely the Sculptor group (at a distance  $d = 2.8$  Mpc), IC 342/Maffei ( $d = 3.1$  Mpc), M81 ( $d = 3.7$  Mpc), M94/Canes Venatici I

( $d = 4.0$  Mpc) and Centaurus A/NGC 5128 ( $d = 4.3$  Mpc) groups [47]. Thus, the Sculptore group of galaxies is the closest to the Local Group. Five of these six groups of galaxies (along with the Local Group) have two subgroups each [47]; these subgroups are well-defined with pronounced dominant galaxies, and at least one dominant galaxy in each pair of subgroups is spiral. In general, the largest of these dominant galaxies are smaller than the Milky Way. The Andromeda galaxy is the largest in this region while the Milky Way is the fourth in size. The discussed region comprises about 200 galaxies (a quarter of which belong to the Local Group); it is a component of the Local volume which contains more than 630 galaxies detected within 10 Mpc from the Local Group [22, 23].

### 6.2. Structure and kinematics of the Local Supercluster

The Local Supercluster encompasses more than 30 thousand galaxies, classified into about 100 groups and clusters of galaxies [47]. About 60 per cent of galaxies belonging to the Local supercluster are concentrated in a narrow disc of 50 Mpc in diameter and 3 Mpc thick (which is twice the diameter of the Local Group). Almost 98 per cent of all the galaxies are members of 11 galactic clouds; they are well-separated and constitute 5 per cent of the Virgo supercluster volume.

The central region of the Local Supercluster comprises three galaxy clusters, the closest of which ( $d = 16$  Mpc) is found in the constellation Virgo. Virgo A (M87) galaxy is an cD galaxy dominant in this region. The diameter of the Virgo cluster is 5 Mpc; its spatial number density is an order of magnitude higher than that observed in the groups of galaxies ( $500 \text{ galaxies Mpc}^{-3}$ ). There are about 200 galaxies with high and moderate luminosities observed in this cluster, and two thirds of them are spiral galaxies. A total of  $\approx 2000$  galaxies are expected to be detected in this region.

The Local Group moves at a speed of  $300 \text{ km s}^{-1}$  relative to the Local Supercluster and at a velocity of  $620 \text{ km s}^{-1}$  with respect to the cosmic microwave background [47]. Employing the composite velocity vector allowed the detection of the so-called ‘‘Great Attractor’’ [39] estimated to be a much more massive structure as compared to the Local Supercluster. It has emerged that in the Local Universe such massive agglomerations have an impact on the local value of the Hubble parameter; hence, the local velocity field is characterised by the following values of the Hubble tensor depending on the directions towards the Local Supercluster:  $81 \text{ km s}^{-1} \text{ Mpc}^{-1}$  towards its nucleus;  $48 \text{ km s}^{-1} \text{ Mpc}^{-1}$  towards its polar axis and  $62 \text{ km s}^{-1} \text{ Mpc}^{-1}$  towards the plane perpendicular to the direction towards the Local Supercluster [22, 23].

## 7. Large-scale structure of the Universe

Superclusters of galaxies assemble into larger structures which are referred to as hyperclusters. These enormous hyperclusters, in their turn, aggregate into the large-scale three-dimensional cosmic web of thickness reckoned by its constituent superclusters of galaxies. Such a complex arrangement is referred to as the cellular

structure of the Universe while the formed vast spaces are called the voids.

### 7.1. The Laniakea hypercluster and Local Void

As it has turned out, both the Local Supercluster and the Great Attractor are members of the Laniakea hypercluster (the name ‘‘Laniakea’’ means ‘‘immense heaven’’ in Hawaiian). This aggregation stretches out over 160 Mpc, encompasses  $\sim 100$  thousand galaxies and consists of about 100 superclusters of galaxies (including the Local Supercluster). Laniakea neighbours another huge grouping, namely the Perseus-Pisces hypercluster; they are separated from each other by the Local Void, which is the nearest vast empty region of space with the cross-section extent of more than 45 Mpc. This void comprises three separate sectors separated by ‘‘filament bridges’’ and lies adjacent to the Local Group (at  $d = 23$  Mpc from Earth); one of its boundaries is delineated by the Local Sheet which is a galaxy filament containing the Local Group.

### 7.2. Cellular structure of the Universe within the Hubble length

The cellular structure of the Universe becomes apparent on the scales of an order of billions of light-years. It is possible to distinguish large-scale filaments comprised of super- and hyperclusters of galaxies spaced by voids. Such an arrangement is also typical for larger scales, for which another specific rule holds: the more distant an object is, the earlier in its evolution the object can be surveyed. The most distant structures tend to show main features of the early Universe. Features of galaxies and large-scale structures into which they combine differ from those observed at noticeably shorter distances. This is the manifestation of the space-time structure of the Universe.

In compliance with Hubble’s law, the increase in the velocity of the observed objects is limited by relativity to the speed of light. Substituting the speed of light for the recessional velocity in the equation for Hubble’s law yields the Hubble distance to the objects currently receding at the speed of light. This distance is referred to as the radius of the Hubble sphere (or the Hubble length). Any objects beyond the Hubble length cannot be seen by observed from Earth. On the other hand, any quant of light of our universe cannot get outside the Hubble sphere. It means that for an external observer our universe appears to be as a black hole. Is there such an external observer? Nobody knows. Certain cosmologists allow for the existence of wormholes where the mouth of each is a black hole; if this were true, it would be a chance to survey other universes since theoretically a photon could traverse from one universe to other ones through such wormholes. And perhaps, if a spatial resolution of an interferometer with an extremely large database sufficient to clearly resolve the Schwarzschild radius of supermassive black holes (for which such radius should be immense) is reached one day, these black holes will serve as peculiar windows through which we will be able to take a look at other universes.

## 8. Conclusions

As can be seen from the brief analysis of the observed stellar systems and their groupings of different levels of complexity, their general hierarchy is quite evident with simple systems being included into larger structures.

There are three levels of the stellar system hierarchy:

- 1) multiple stars and planetary systems;
- 2) star clusters and associations;
- 3) galaxies.

On a larger scale, galaxies combine into

- 1) groups;
- 2) clusters;
- 3) superclusters;
- 4) hyperclusters.

For the latter, the following pattern of arrangement is assumed:

- a) ~ 100 groups form a supercluster;
- b) ~ 100 superclusters form a hypercluster.

Therefore, subgroups and clusters of galaxies are intermediate structural components of a large-scale hierarchy of the assembly of galaxies.

So far, for us, Earth's inhabitants, the full address has been established according to our location in the Universe – namely, that from the residence in the Solar System in our Galaxy to the Laniakea hypercluster beyond which the large-scale space-time cosmic web only exists. The next aspect of the universe structure to be explored is the position of our Universe among other universes if they exist...

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