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THE NEVER–ENDING STORY OF THE INFINITE COSMOS

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ABSTRACT

When philosophers, poets or astronomers have tried to comprehend the vastness of the universe, from early times to the present days, the possibility of an infinite universe has appeared as an appealing speculation. Although, we do not yet have a compelling answer to the question: "is the universe infinite?" our present cosmological knowledge provides us with some clues to delineate which is the most likely answer. This contribution aims to address this question from the point of view of the history of thought, from the ancient philosophers to the present astronomers, taking into account the interweaving relationship between scientific knowledge and culture. Its connection with the solutions to the so–called Olbers' paradox will be analysed in detail, including those appearing in literary works, like the prose poem *Eureka* (1848) by Edgar Alan Poe.

KEYWORDS: Infinite universe, cosmology, myths, philosophy, fractal universe, Olbers' paradox, galaxies, background microwave radiation

1. INTRODUCTION

The idea of an infinite universe has been present since the time where the first cosmological mythologies appeared, thousands of years ago, until nowadays, when modern cosmological theories rely on Physics. Is therefore the universe infinite? The question is not simple. We still cannot provide an accurate response based on our present knowledge of the origin and evolution of the universe. All we can say is that the universe as a whole is far larger than the observable universe, i.e., the region of the universe that can be observed from the Earth at the present time. But do we live in an extremely large but finite universe, or is it indeed infinite? Modern Cosmology provides some clues to test the first possibility, but even if the test failed (as it has happened up to now), we cannot conclude that the universe is infinite. Moreover, present Cosmological Physics could be more confortable with the idea of an infinite universe, although this hypothesis cannot be proved. A Bayesian model comparison approach which can applied to reject the hypothesis of a finite closed universe (being unable to measure a positive curvature) has been presented by Vardanyan, Trotta and Silk (2009). The goal of this contribution is to provide an historical and cultural account of how philosophers in the past and scientists in modern times have tried to understand the possible infiniteness of the universe, summarizing the story of the different conceptions that have shaped the idea of the cosmos in each period.

2. ANCIENT MYTHS: THE EGYPTIAN COSMOGONY

For the Egyptians, Shu (air) kept Nut (the sky) above Geb (Earth). Nut and Geb were siblings and lovers. Ra separated them to rise above the earth and over humanity, so that Shu, Nut's father, was entrusted to hold Nut, because with the height she began to wobble. Similar versions of this account exist in Chinese and Babylonian mythologies. For the Babylonians, Enlil separated Anu (Earth) from Ea (the waters of the heavens and the oceans). But for the Egyptians, the underworld, called Duat also existed. It was the dark region of their celestial world where the Sun and its retinue travelled during the night. The Duat is known by the gods and dead, and only partially by the living people. Is anything else in the Egyptian universe? Yes, as Lull (2004) and Kragh (2007) pointed out, above the sky and below the Earth, there is the Nun, the primeval waters: a boundless, dark, unknown and inert ocean (Figure 1). This infinite mass of water enveloping the world could be one of the first infinite containers appearing in an ancient cosmogony. It has always existed, it is silent, not even known by the gods and darker than the Duat.

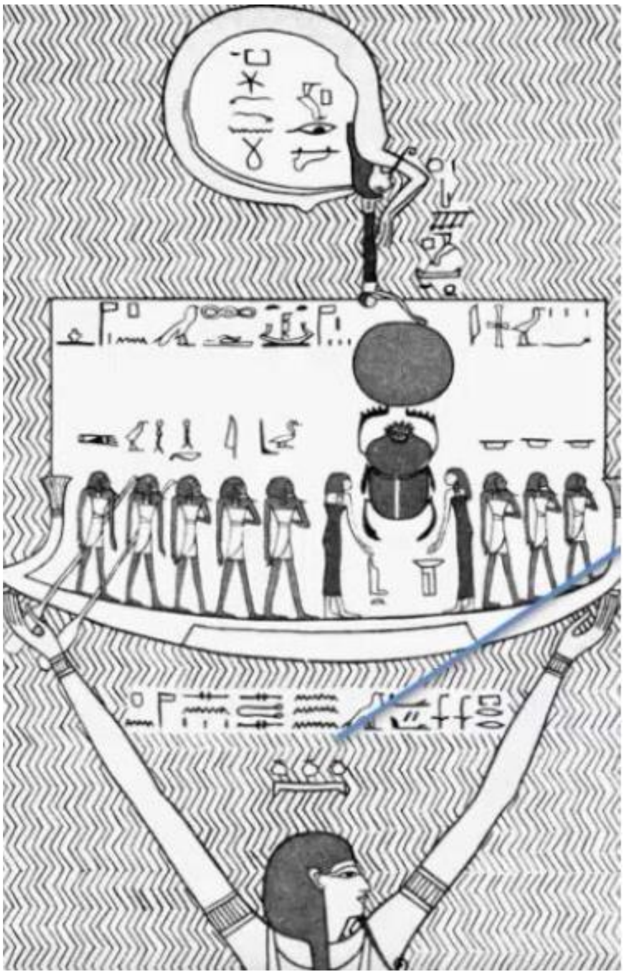

Figure 1. The Nun (which is personified by the figure of raised arms) holds the solar boat (therefore it is beyond the Duat, since the boat sails along the Duat during the night). The Nun, the primordial ocean, surrounds the Duat. 12 hour of the Book of Gates. The Sarcophagus of Seti. Sir John Soane's Museum. Image from E.A.W. Budge, The Gods of the Egyptians. Studies in Ancient Egyptian Mythology, vol. I (New York: Dover Publications, 1969, republication of original 1904), between pp. 298–299.

3. THE GREEKS

3.1. The Atomistic Philosophy

Democritus of Abdera (c. 460–370 BC), disciple of Leucippus and nicknamed during the Renaissance "the laughing philosopher," has been considered the main philosopher of atomism and father of one of the most interesting cosmological theories of antiquity. Formed by Chaldean scholars during the Persian wars, he demonstrated a profound predisposition to philosophy and astronomy. Democritus developed the so–called "atomistic theory of the universe," already initiated by the founder of the atomistic school, Leucippus, and clearly influenced by the philosophy of Anaxagoras. In the light of this theory, everything that exists is made up of atoms, particles that are infinitely small and imperceptible to the senses, homogenous and eternal, that move incessantly in a void. Atoms were similar except by their shape and size. In the atomist view, the different quality of matter that conforms the reality was determined by the different groupings of atoms. The atomistic theory was also followed by Epicurus (341–270 BC).

Atomistic cosmology discarded divine directives in natural processes, not guided by any guiding principles or dependent on any design. The celestial disposition of Democritus placed the Earth (considered oval) in the centre, followed by the Moon, the Sun, and the planets, surrounded by a thick stellar sphere of fixed stars. Outside this physical cosmos there exists an infinite region of chaotically moving atoms. Our known cosmos, and this should be seen as Democritus' main contribution, should be only one out of an infinite number of similar systems (Kragh, 2007).

The Roman poet and philosopher Titus Lucretius Caro (99–55 BC) was nourished by the philosophy of Leucippus, Democritus and Epicurus at the time of writing his only known and recovered work: *De rerum natura*. This didactic poem, divided into 6 books, was considered lost during the Middle Age until its reappearance in a German monastery in 1417. Being a follower of the preceding atomists, Lucretius argued for an infinite universe (Kragh, 2007): "All that exists, therefore, I affirm is bounded in no direction; for if it were bounded, it must have some extremity of anything, unless there be something beyond, which may limit it...Now, since it must be confessed that there is nothing beyond the whole, the whole has no extremity."

The immense quantity of atoms that make up all there is invited the Roman poet to argue for the existence of other universes that, like ours, could well be inhabited by humans and different animal species: "If there is such a vast multitude of seminal atoms as the whole age of all living creatures would not suffice to enumerate, and if there remains the same force and nature...one must necessarily assume that there are other orbs of earth in other regions of space, and several races of men and generations of beasts."

While the Lucretian universe was presented as infinite in space, it was not in time. Lucretius claimed that the history of mankind was brief. The small number of writings from older generations was the proof that the universe had a beginning, and this happened a short time ago. Also, he asserts that the universe should have an end: the cosmos should be irremediably subject to a future deterioration.

3.2. *Aristotle*

Atomistic cosmology, like so many others, was eclipsed by the Aristotelian cosmological conception, whose postulates were valid for many centuries, practically until the appearance of *De revolutionibus orbium coelestium* by Nicolaus Copernicus (1473–1543). The astronomical ideas of the philosopher of Estagira were expressed in his works *On the Heavens*, *On Generation and Corruption* and in some fragments of *Physics*.

Aristotle (384–322 BC) proposed a geocentric cosmological model in which the universe, finite and eternal, was constituted by two realms: the sublunar and the supralunar (this model expresses the dualistic influence of his teacher Plato). The sublunar world would be made up of the four Empedoclean elements (water, earth, fire and air) and would be subject to continuous change and movement, generation and corruption. The existence of a vacuum was not accepted: the space is a volume filled with matter. The supralunar world, on the contrary, was made up of a single material: the quintessence. This substance was eternal and incorruptible and was linked to the uniform circular revolutions (considered the perfect movement in Aristotelian and Platonic philosophy). The supralunar sphere was constituted by a set of six "planets" (Mercury, Venus, the Sun, Mars, Jupiter and Saturn) located in transparent, concentric (homocentric), corporeal spheres whose movement would be transmitted by the movement of the last of the spheres: the sphere of the fixed stars (Figure 2). There was nothing after this last sphere. Aristotle's universe was therefore spatially finite, but eternal.

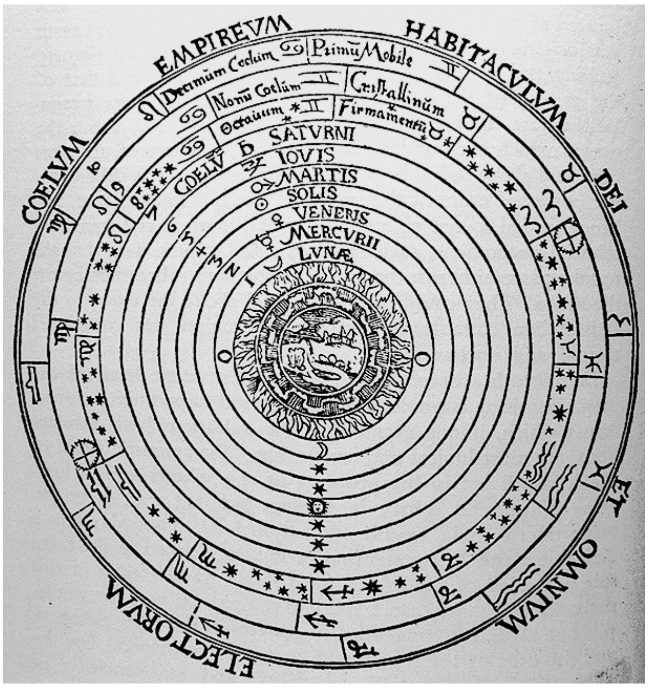

Figure 2. The Aristotelian cosmos, in an engraving from Peter Apian's Cosmographia, 1524.

Aristotelian astronomy was influenced by the contributions of Eudoxus of Cnidus (390–337 BC) and his disciple Callipus of Cyzicus (370–300 BC), who assumed the existence of 33 concentric spheres that accounted for the movement of the planets. Aristotle, however, increased the number of spheres to 55, adding 22 spheres that turned in the opposite direction to explain the retrograde movement of the planets, erratic and apparently far from circular perfection.

3.3. *The Stoics*

The Aristotelian cosmology, despite its absolute later preponderance, had serious opponents in classical antiquity. Among them we should highlight the role of the Stoics. Although Stoic astronomy affirmed, together with Aristotle, the absence of emptiness in the material world, for the Stoics this rule was not followed outside the physical cosmos. In fact, they affirmed the existence of a non–physical infinite void surrounding the physical finite cosmos (Figure 3).

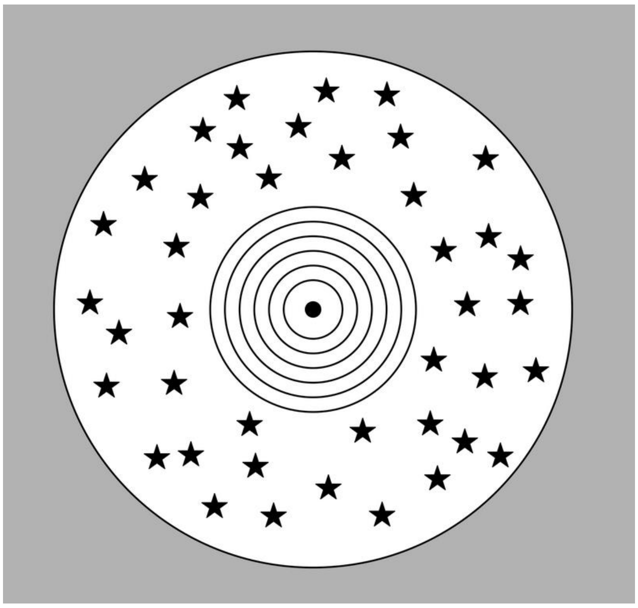

Figure 3. The Stoic's world model. Beyond the finite physical cosmos there exits a non–physical infinite void.

The eternity of the cosmos of the Aristotelian model would be a subject debated by the Stoic sages. If Aristotle had an aprioristic astronomical conception (the obligation of the stars to follow the perfect circular movement was just one example), the Stoics did not hesitate to resort to the observed phenomena to refute, among other things, the eternity of the universe.

Zeno de Citium (336–264 BC), founder of the Stoic philosophical school, eloquently affirmed that certain unidirectional processes of nature served as proof to conclude that the world could not have always existed. The erosion of mountains would have flattened the world if its action had been developed for an unlimited time. However, the observable world contains simultaneously high and low peaks, plains and elevated mountains. The lack of uniformity in the Earth was enough for the Stoic to argue against the eternity of this world.

4. THE EARLY MODERN PERIOD

4.1. *Thomas Digges*

Thomas Digges (1546–1595) published in 1576 *A Perfit Description of the Caelestiall Orbs* as an appendix in the reissued version of a perpetual almanac that his father, Leonard Digges, had written years before (Figure 4). This work features a diagram of the heliocentric Copernican system with the sphere of the fixed stars "extending infinitely in altitude." According to Edward Harrison (1987), with this diagram, Digges pioneered the idea of a spatially infinite universe. The sentence written in the star orb of his diagram reads: "This orb of stars fixed infinitely up extends itself in altitude spherically, and therefore immovable the palace of felicity garnished with perpetual shining glorious lights innumerable, far excelling over [the] sun both in quantity and quality the very court of celestial angels, devoid of grief and replenished with perfect endless joy, the habitacle for the elect." It is unclear however whether this theological infinite universe should be also infinite for Digges in a physical or astronomical sense (Kragh, 2007; Koyré, 1968). Digges exerted a notable influence on the cosmology of Giordano Bruno and William Gilbert, and he was probably the first scientist who considered the so–called Olbers' paradox (see Section 5).

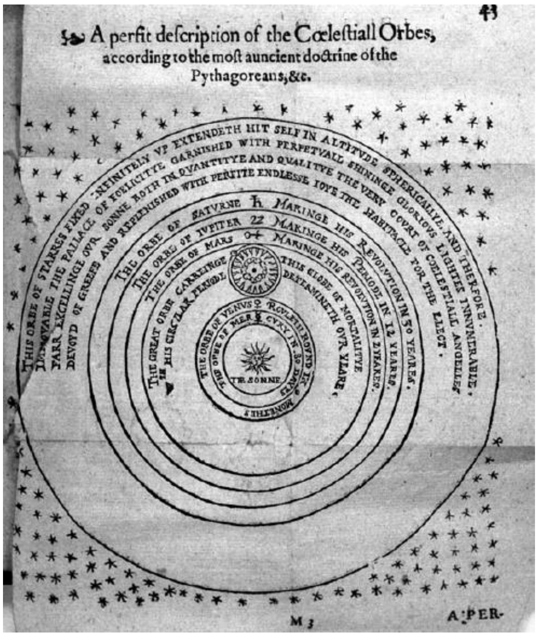

Figure 4 The heliocentric diagram depicted in A Perfit Description of the Caelestiall Orbs (AD 1576) by Thomas Digges, with the star orb extended infinitely in altitude. Courtesy of the History of Science Collections, University of Oklahoma Libraries.

4.2. *Giordano Bruno – the modern atomist*

Giordano Bruno (1548–1600) was certainly not a scientist and his views of the universe were mainly poetic and speculative. He defended many unorthodox religious ideas considered heretical. For this reason he was burned at the stake in Rome's Campo de' Fiori in AD 1600. On his book *De l'infinito universo et mondi* (AD 1548) Bruno states that the real universe is infinite in extension, contains innumerable suns and an infinite number of earths revolve around those suns. Moreover, he affirms that those earths are inhabited planets like ours.

Bruno recovered and popularized the atomist Epicurean view, defended by the roman poet Lucretius, of an infinite space and the idea of the plurality of worlds. Although the infinite universe was also defended by Nicolas of Cusa a century earlier and by Thomas Digges 28 years after the publication of Bruno's book, in both cases the infinite extent of the universe has a much more theological sense, related with the infiniteness of God, than in Bruno's statements. Moreover, as Steven Soter [1] points out, Bruno's intuition was remarkable when he affirmed that "the composition of our own star and world is the same as that of as many other stars and worlds as we can see."

4.3. *Johannes Kepler – the modern Stoic*

Johannes Kepler (1572–1630) was horrified by Bruno's view of the infinite universe. He enclosed his singular and finite, sun–centred cosmos with an impenetrable shield, filling up the empty bits with ether (as well as nested Platonic solids). In 1610, he obtained a copy of Galileo's *Siderius Nuncius,* and after a month he published a comment on it, *Dissertio cum Nuncio Sidereo,* where we can read, "You do not hesitate to declare that there are over 10,000 stars. The more there are and the more crowded they are, the stronger becomes my argument against the infinity of the universe. This world of ours does not belong to an undifferentiated swarm of countless others." In a sense, we could say that Kepler aligned himself with the Stoics, postulating a single finite world (he also rejected the idea of this finite cosmos being contained within an infinite void). It was possible to find stars only up to the edge of this finite universe. For Kepler, stars were very small bodies in comparison to the Sun, and they occupied a very thin shell having a radius of about four million solar radii (Van Helden, 1985), and that was the edge of the universe.

4.4. *Isaac Newton*

Isaac Newton (1643–1727) assumed that the universe was spatially and temporally infinite and on a large scale evenly populated by stars. His infinitely sidereal system is mainly explained in his correspondence with Richard Bentley and is based, as Silk (2007) and Kragh (2007) pointed out, in the Gravitation paradox, in which stars were "so accurately poised one among another, as to stand still in a perfect Equilibrium." In a finite world of stars, all matter will eventually collapse into a big mass. Moreover, if the stars were not disposed in the right way in an infinite universe governed by gravitational forces, the universe will become gradually unstable. For this reason, Newton needs the initial action divine cause,

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1 http://blogs.discovermagazine.com/outthere/2014/03/13/cosmos-giordano-bruno-response-steven-soter/

and writes in the first letter to Bentley[2] "...and to compare and adjust all these things together in so great a variety of bodies argues that Cause to be not blind and fortuitous, but very well skilled in Mechanicks and Geometry."

5. OLBERS' PARADOX

Why is the sky dark at night? This simple question was brought to public attention by the German astronomer Heinrich Olbers (1758–1840), though to trace the whole story requires an entire book (Harrison 1987). A beautiful account of the riddle appears in *Eureka* (1848), a non–fiction work written by the American author Edgar Allan Poe[3] (Figure 5): "Were the succession of stars endless, then the background of the sky would present us an uniform luminosity, like that displayed by the Galaxy – *since there could be absolutely no point, in all that background, at which would not exist a star.*" The paradox arises (in a Newtonian universe) because the inverse–square law dilution of the flux is compensated by the growth of the volume of the sphere by the second power of its radius.

This idea had already worried Thomas Digges, although he argued that the light from very distant stars was too weak to be seen by the eye (Harrison, 1987). With the rise of the Newtonian infinite world system, the paradox was the focus of the attention of many scientists. Edmund Halley (1656–1742) calculated the total amount of light we should receive adding up the contribution of all stars in an infinite universe. The result implied a bright night sky, but he justified the darkness of the night with a similar argument used by Digges 150 years earlier: the "extreme minuteness" of the distant stars was the reason for them being unable to "move our senses."

Jean–Philip Loys de Cheseaux (1718–1751) wrote about the "propagation of light in the ether" and the interstellar absorption was the reason for the darkness of the night sky. Today we know that this hypothesis is unsustainable for thermodynamic reasons. Absorption cannot in any way hide a whole universe of stars, as the potential absorbent matter would heat up in such a way that it would reradiate the absorbed light.

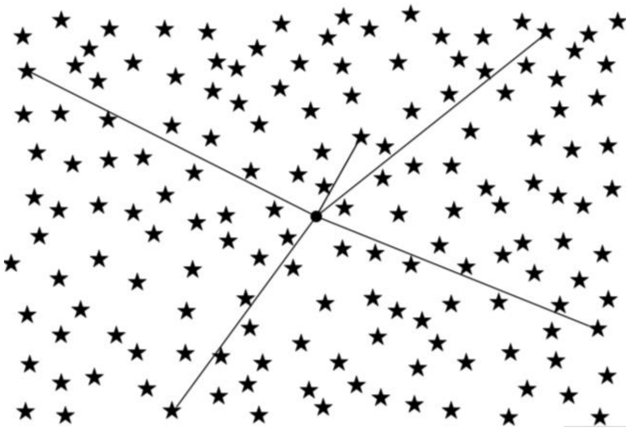

Figure 5. Illustration of Olbers' paradox: in an infinite universe, in all lines of sight an observer sees a star.

A third solution was advocated by John Herschel (1792–1871) and Richard A. Proctor (1837–1888). It was based on abandoning the idea of uniform distribution on a large scale, and it suggested a hierarchy of groupings of cosmic matter (stars come together to form galaxies, these in turn form clusters of galaxies, and so forth). This was an idea that had already been set out by Immanuel Kant (1724–1804) in 1755, and in modern terminology it is known, following Benoît Mandelbrot, as "fractal structure." Lambert, Fournier d'Albe, Charlier advocated for this hierarchical universe (Figure 6). Because in a fractal the density of matter decreases as the scale expands, if there was no end to this hierarchy, there would always be starless gaps in the sky, and the night would continue to be dark. In any case, this solution is not valid either, since from the study of large–scale cosmic structure we have learned that the fractal system is observed in the distribution of galaxies only at particular scales, and it disappears at the largest scales. There is therefore no basis for the fractal universe. Therefore, fractals are no longer needed to keep the sky dark (Trimble et al., 2012).

Olbers' paradox can be resolved simply by taking into account that the stars that populate the expanding universe do not live forever and that their light travels at a finite speed. This means that the sum of their light cannot, in any moment of cosmic history, light up the night sky. The solution was indeed encapsulated also by Edgar Allan Poe in *Eureka* and a more physical explanation appeared in a forgotten paper published by Lord Kelvin in 1901 (Thomson, 1901), as Harrison pointed out in 1987. Poe's words in *Eureka* were: "The only mode, therefore, in which, under such a state of affairs, we could comprehend the *voids* which our telescopes find in innumerable directions, would be by supposing the distance of the invisible background so immense that no ray from it has yet been able to reach us at all."

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[2] http://www.newtonproject.ox.ac.uk/view/texts/normalized/THEM00254

[3] http://www.gutenberg.org/ebooks/32037

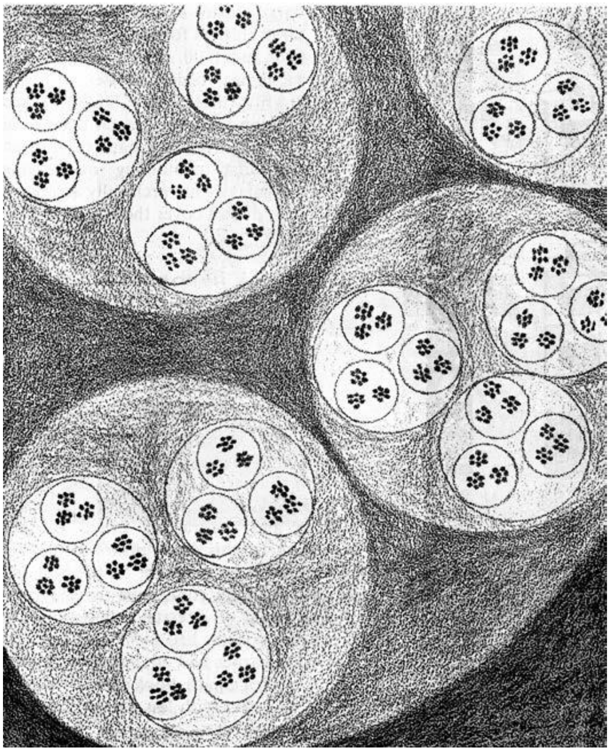

Figure 6. Hierarchical or fractal universe. Courtesy of Edward Harrison, reproduced with permission.

6. THE GREAT DEBATE

The Stoic idea of a finite cosmos of stars (also championed by Kepler) was backed in the twentieth century by astronomers such as Harlow Shapley. In his view, everything that we see in the sky formed part of a large galaxy with a diameter of around 300,000 light years – an immense lone island in an infinitely large, oceanic void. On 26 April 1920, Harlow Shapley debated in Washington D.C. this view of the cosmos against Heber D. Curtis, who considered that the already known spiral nebulae were indeed separate galaxies or "island universes" similar to our Milky Way galaxy.

Shapley's picture of the cosmos was erased when on 1 January 1925 he heard Henry N. Russell read out the communication that Edwin P. Hubble had sent to the joint meeting of the American Astronomical Society and the American Association for the Advancement of Science, in which he clearly demonstrated that Andromeda (M31) was far beyond the limits suggested by Shapley's Great Galaxy (Hubble, 1925). This discovery expanded the universe enormously in the minds of astronomers. Within a few years, hundreds of galaxies in our local environment had become known to us. Successive mapping of the cosmos carried out with increasingly powerful telescopes revealed to us an observable universe whose building bricks are hundreds of billions of galaxies. This represented a huge leap forward in our understanding of the cosmos.

7. CONCLUSION: IS THE UNIVERSE INFINITE?

We do not know if the universe is infinite or not, but it has to be much larger than our visible horizon. The geometry of the universe is characterized by the curvature parameter, which is zero for a flat infinite universe.[4] Current cosmological data suggest that the curvature is very close to flat (this is also a prediction of the inflationary models for the early universe; an exponential expansion occurred in a tiny fraction of time between 10^{-33} and 10^{-32} seconds after the singularity). Within these models, it has been shown that the geometry of the universe cannot be known if the value of the curvature parameter is below 10^{-4} (Vardanyan et al., 2009). The number of observable universe–sized patches can be determined from knowledge of the cosmological parameters. Several authors have shown that a lower limit for this number is 21 (Scott and Zibin, 2006) or 5 (Vardanyan et al., 2009). The Cosmic Microwave Background (CMB) radiation analysed by the WMAP and PLANCK satellites confirms that the geometry of the universe is flat with precision better than 1%. If the universe is flat, it is infinite unless it has a non–trivial compact topology like a torus (Levin et al., 1998). The topology of the universe describes the properties of its overall shape. If the universe were indeed infinite, it would be impossible to design an experiment to test it. It could happen, however, that the expanding universe was in fact finite, although very large. This expanding universe will be infinite only in the infinite future (Silk, 2006), but in that case, we could try to test this hypothesis by analysing the universe topology imprinted in the CMB, looking for particular patterns that could be the fingerprint of the finiteness of the universe. These patterns have not been detected so far (Cornish et al., 2004). It could also happen that these patterns exist, but they were too weak to be detected because the finite universe was too large. If this is the case, with the present technology, a very large and finite universe would be, in principle, indistinguishable from an infinite universe. The never–ending story of the infinite cosmos continues.

[4] Flat here has to be understood as a two-dimensional analogy, in reality we mean Euclidean space.

ACKNOWLEDGEMENTS

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