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Anaxagoras and his contributions to astronomy

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The contribution to the development of astronomy and astrophysics by one of the most important philosophers of Ionia, Anaxagoras from Klazomenes of Asia Minor, is discussed. In particular, his explanation of the creation of the Universe considering the existence of fundamental components of matter (homeomerias) and mind, his views on the fiery nature of stars, and attempts to describe their nature without mythology and deities; as well as a fragment of his theory, which maybe indicates the belief in the existence of other worlds like ours.

Keywords: History of astronomy, Anaxagoras, philosophy of sciences, Presocratics

1 Introduction

The philosopher Anaxagoras was one of the most significant and influential scholars of the Presocratic period of ancient Greek philosophy. Scholars most commonly accept that he was born c. 500 B.C. in Klazomenes of Minor Asia and died c. 428 in Lampsacus. He spent a large part of his life, around 30 years, in Athens at the time of Pericles, coming into contact with great personalities of the time in spite of the fact that his teaching about the nature of the Sun caused severe reactions in the Athenian society of his time. He was accused of impiety due to his teaching proposing that the Sun is a fiery rock greater in size than the Peloponnese; he left Athens and spent the rest of his life in Lampsacus.

Diogenes Laërtius states in *Vitae Philosophorum* that Anaxagoras wrote only one book, a treatise on natural philosophy, probably not a very long work, since Plato in *Apology* (26d; West, 1979) tells us that the price of it is "a drachma, at most". Only fragments of this work exist in ancient sources. Particularly significant continuous pieces, presenting the philosophy of Anaxagoras, are in the work of Simplicius (sixth century when Anaxagoras' writings still existed). It should be noted that various

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interpretations of these fragments exist and that there are disagreements about the explanation of some of the basic principles of his philosophy.

This paper presents his contribution to the evolution of astronomy and astrophysics. Initially we present his theory about the fundamental elements of nature, the *homeomerias* and the *mind* that sets these elements into rotating motion, thus creating the Universe. Also we will examine his views about the nature of celestial bodies and his contributions to the development of science.

2 Homeomerias, mind and the creation of the Universe

Anaxagoras' view was that instead of the existence of one or more initial elements there are an infinite number of fundamental components of matter (Simplicius, *In Physicorum*, 155, 24–26 (B1)) from which the Universe has been created. For the consideration of his views on the structure of matter the following fragment is essential:

And since the portions of both the large and the small are equal in amount, in this way too all things would be in everything; nor can they be separate, but all things have a portion of everything. Since there cannot be a smallest, nothing can be separated or come to be by itself, but as in the beginning now too all things are together. But in all things there are many things, equal in amount, both in the larger and the smaller of the things being separated off. (Anaxagoras, frag. 6 in Patzia, 2017.)

There are different opinions about Anaxagoras' definition of "things". Various authors use also the term "seeds" (e.g. Warren, 2007) or "stuffs" to depict this notion (e.g. Patzia, 2017). Aristotle, considering them as parts that are similar to the whole, first used the term "homeomerias" (Warren, 2007), which is now also used by different authors (see e.g. Mann, 1980; Graham, 1994; Furley 1989). For example pieces of iron or silver are homeomerias since their parts are also iron or silver. Some commentators think that Anaxagoras' "things" are not iron or flesh or hair, but homeomeric seeds of gold, flesh and so on. "Things" of Anaxagoras are homeomerias, since they contain a portion of everything. Also, they are infinitely divisible into smaller and smaller parts, and each smaller part also contains "seeds" of everything.

In the initial mixture which consisted of these homeomerias, qualities or individual substances could not be discerned, a view leading to the conclusion that Anaxagoras described a chaotic state of the prime matter of the Universe ($\pi\acute{\alpha}\nu\tau\alpha\ \chi\rho\acute{\eta}\mu\alpha\tau\alpha\ \tilde{\eta}\nu\ \grave{o}\mu o\tilde{\upsilon}$) (Diogenes Laërtius, *Vitae*, II, 6-15 (B1)). His key statement is that a quantity of everything is in everything which is obvious in food where all the components from which flesh, bones and nerves are created can be found (Aetius, *De Plac*, I, 3, 5 (A 46); see also Kalachanis, 2014). From Anaxagoras' conclusion that everything exists in everything it clearly follows that all beings as well as objects are formed essentially from the same material, and they are different because the proportions of various homeomerias are not the same. The idea that all beings are formed from the same basic material, developed by Anaxagoras and other Greek natural philosophers, is analogous to the findings of modern science that beings are formed from chemical elements dissipated by cataclysmic supernova explosions and created in thermonuclear reactions in stellar interiors, especially in the interiors of massive stars (see e.g. Field and Chaisson, 1999) (Fig. 1).



Figure 1 Veil Nebula Supernova Remnant consists of the expanding remains of a 20 times more massive star than our Sun that exploded about 8,000 years ago. Source: Hubblesite.org.

Besides homeomerias, Anaxagoras includes the Mind (*Nous*) as the reason for the motion of the initial mixture producing different combinations of the elements. The initial mixture is unlimited, and at some moment it is set into motion by the action of the Mind. The nature of the Mind Anaxagoras considers to be superior to the homeomerias (Simplicius, *In Physicorum* 176, 33–36). In Anaxagoras' cosmology, the Mind not only starts the rotation of the mixture of homeomerias, but also controls this rotation, as well as the other local rotations aside from the large cosmic whirl. According to Curd (2015) the Mind is not only the first cause, but also "the preserver of order in the cosmos, as it maintains the rotations that govern all the natural processes" and control the cosmos as "we control our bodies by our thoughts". It is important to note that in extant Anaxagoras' fragments the Mind is never identified with a divine principle or god (Curd, 2015) but its role is explained as a kind of motor force (Waren, 2007).

According to him, the Mind initiated the rotational motion ($\pi\epsilon\rho\iota\chi\acute{\omega}\rho\eta\sigma\iota\varsigma$) of the homeomerias in the initial mixture, with the movement of the heaviest bodies towards the center and movement of the lighter bodies upwards (Simplicius, *In Physicorum* 300, 27 (B13)). In the beginning the motion was slow and then started to increase, which resulted in the separation of elements of matter and celestial bodies such as the Sun and the Moon.

According to the views of Anaxagoras:

(1) Due to the turbulence the heavier bodies accumulate at the center and the lighter bodies move upward. Moreover, the accumulation of more mass in the center accelerates the turbulent motion.

(2) The Anaxagoras' cosmology refers to the mechanical behavior of matter, contributing to the creation of the world (Kalachanis, 2016).

This intuitive description by Anaxagoras of the creation of the Earth and Sun by rotational motion of the primordial chaotic mixture of homeomerias is in fact similar

to the nebular hypothesis, first proposed (partially) in 1734 by Emanuel Swedenborg and developed by Immanuel Kant in 1755, and later independently by Pierre-Simon Laplace. According to the modern variant, stars form in massive and dense gravitationally unstable clouds of molecular hydrogen. Matter in these clouds coalesces to form smaller rotating clumps, which due to rotation and gravitational force collapse and form stars, as well as our Sun (Fig. 2).

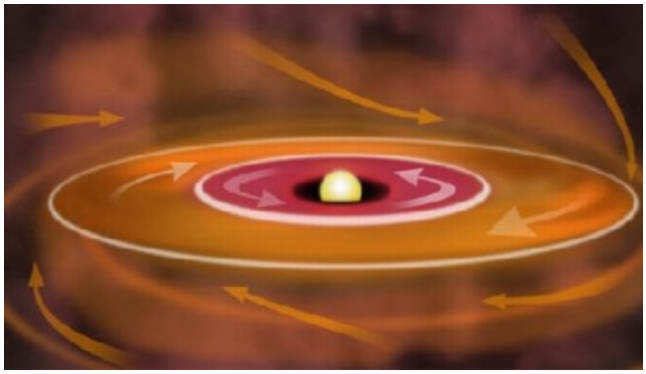


Figure 2 Representation of the motion of the primary nebula that leads to the creation of a protostar (source: centauri-dreams.org).

In our Solar System, the majority of the collapsing mass formed the Sun in the center, while from the rest a flattened protoplanetary disk has been created, where during further evolution due to constant rotation the planets, moons, asteroids, and other small Solar System bodies originated (Bouvier and Wadhwa, 2010).

It is obvious that Anaxagoras' model of the creation of the Universe through rotation of matter in the primordial chaotic mixture could be considered as an early precursor, preparing the way for such a theory.

3 Anaxagoras on celestial bodies

Like all Presocratic philosophers, Anaxagoras tried to explain not only the creation of the Universe but also the nature of celestial objects. The motion of the Sun, stars and the Moon were studied in ancient Greek astronomy (from the words $\acute{\alpha}\sigma\tau\rho o + \nu\acute{o}\mu o\sigma$) for the purposes of organisation of daily activities, agricultural work and navigation, namely astronomy was exercised not only by philosophers who were trying to explain the creation of the Universe, to understand the ordered Universe, its nature and its hidden laws which govern it, but also for practical reasons. *Science and Philosophy emerged as a result of human efforts to live even more successfully within a hostile environment* (Moussas, 2013).

Anaxagoras was not interested to study the motion of celestial bodies as an astronomer but he also tried to understand the nature of celestial bodies, contributing in this way to the evolution of astrophysics, so that, according to Keeler (1897), he uses the principles of physics and chemistry "to ascertain the nature of the heavenly bodies, rather than their positions or motions in space". Anaxagoras scientifically

and accurately concludes from his observations that the Moon does not have its own light, but receives it from the Sun (*τὸ δὲ φῶς τὴν σελήνην μὴ ιδιον εχειν, αλλὰ απὸ τοῦ ηλίου*) (B 42). He also states that the Moon is made of the same material as the Earth with plains and gullies existing on its surface (Hippolytus, *Refutatio*, I, 8) (Fig. 3).



Figure 3 The Moon's surface resembles that of the Earth. Photo taken from mission Apollo 15. Source: nasa.gov.

We note that one of the major theories about the origin of the Moon suggests that a Mars-sized body called Theia collided with the Earth, creating a large ring of debris around it, from which the Moon has been formed by accretion. The consequence of this collision is also the inclination of around 23.5° of the Earth axis, causing the seasons (Canup, 2012).

Anaxagoras is also credited as the first to identify and describe the cause of eclipses writing that lunar eclipses take place when the Earth cuts off the light, and also if the bodies below the Moon cut off the light. Eclipses of the Sun occur at new moon, when the Moon cuts off the light (Hippolytus, *Refutatio*, I, 8). Of course, a solar eclipse occurs when the Moon is between the Earth and the Sun and its shadow crosses the Earth while a lunar eclipse arises during the Moon's motion into the Earth's shadow. The importance of these conclusions of Anaxagoras is in the fact that the celestial phenomena are explained as a mechanical phenomenon, in a scientific way, without involvement of mythology and whims of the gods. Anaxagoras' conclusion that stars are flaming masses of rock and iron enabled him to describe meteorites as bodies that are from time to time ejected from the cosmic vortex and fall to the Earth. Also, Pliny (*Naturalis Historia*, 284) writes that he predicted the fall of a meteorite in Aegos Potamoi in 467/6 B.C. and that the fallen stone existed even in his days.

According to Anaxagoras the Sun is a fiery rock (*μύδρον διάπυρον*) greater than the Peloponnese (Diogene Laërtius, *Vitae* II, 8), but he does not say that the Sun is greater than the Earth. It is Aristotle (*Meteorologica*, 345 b 2-5) who writes that the Sun is greater than our planet. The Sun is not a rock but its nature is indeed "fiery". Our star is a luminous ball of plasma, containing about 90 % hydrogen, 9 % helium, and only 1 % of all the other elements such as carbon, oxygen, silicon, and calcium.

Its diameter is about 1,39 million kilometers (865,000 miles), or 109 times larger than that of the Earth, while its mass is 330,000 times larger than the Earth's mass.

Concerning the nature of our planet, Anaxagoras believed that the Earth is flat, staying up due to its size, since there is no void, and because the Earth rests on the air, supporting it (Hippolytus, *Refutatio*, 1, 3). Anaxagoras also tried to explain the nature of the Milky Way claiming that it is the light of stars which are not lit up by the Sun (Diogenes Laërtius, *Vitae*, II, 8).

4 Plurality of inhabited worlds

Curd (2015) underlines curious aspects hinted at in the fragment B4a of the Anaxagoras' theory:

Since these things are so, it is right to think that there are many different things present in everything that is being combined, and seeds of all things, having all sorts of forms, colors, and flavors, and that humans and also the other animals were compounded, as many as have soul. Also that there are cities that have been constructed by humans and works made, just as with us, and that there are a sun and a moon and other heavenly bodies for them, just as with us, and the earth grows many different things for them, the most valuable of which they gather together into their household and use. I have said this about the separation off, because there would be separation off not only for us but also elsewhere.

The questions where there is the "elsewhere" and where "there would be separation off not only for us but also elsewhere" and where are "a sun and a moon ... for them, just as with us" have not attracted particular attention in ancient sources. However Curd (2015) enumerates a number of different propositions and thoughts of modern commentators. There were suggestions that the place where the other worlds exist is on the moon and/or other planets (Jöhrens, 1939; Zeller, 1923), or elsewhere on our Earth (Cornford, 1934). A proposition is that according to Anaxagoras' statement that "everything is in everything" there are infinite worlds within worlds and that they are even contained within ourselves and within all other things (Mansfeld, 1980; Schofield, 1996; Sisko, 2003). Some authors suppose that Anaxagoras in fact wants to show by a thought experiment how the rotation would work (Fränkel, 1969; Vlastos, 1975; Schofield, 1996). Curd (2007) also suggests that the rotation which begins in a small area of unlimited mixture and expands indefinitely, pulling yet unmixed matter into the whirl, could produce smaller local rotations where separation, mixture, and dissociation would also occur. The result of this would be the formation of systems similar to our world, so that our world system, containing different beings including humans, is not unique in the Universe.

5 Conclusions

One of the most important philosophers of Ionia, Anaxagoras from Klazomenes, presented a different approach from prior cosmogonies and his predecessors and proposed a causal explanation of the origin of the Universe and the initiation of its creation

without mythology and deities. Also, Anaxagoras' conclusion that the nature of stars is fiery belongs in modern science to astrophysics, so that he contributed to the development of science in this direction. His attempts to liberate the philosophy of nature from the intervention and whims of deities and mythology and to give rational explanations are very important because they opened the way to the idea that natural phenomena can be explained by the knowledge of natural laws. His work and considerations occupy a prominent position in the history of sciences and the philosophy of nature and contributed significantly to the development of astronomy and astrophysics.

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