The Balloon Universe

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Abstract: *Space is a highly relevant research topic in contemporary physics, as it tackles the unification of general relativity and quantum theory. In physics, space is a very special research topic: the traditional method to isolate the studied object is not possible. Thus, physical investigations into space need to be accompanied by philosophical considerations. In this paper, conceptions of space will be addressed from a multidisciplinary perspective ranging from physics and philosophy to arts-based research. In particular, the geometry of the universe, especially the Balloon model, will be examined in accordance to recent experimental findings.*

Prologue

On September 14th, 2015, only a few scientists noticed that this was the start of a new era in astronomy. Months later, after rigorous testing, it was published in February 2016 that the first direct observation of gravitational waves had been achieved by the Laser Interferometer Gravitational-Wave Observatory (LIGO) (Abbott et al. 2016). The finding is significant due to multiple reasons: at last, a century old prediction derived from Albert Einstein's theory of general relativity could be proven experimentally. Even more so, gravitational waves open a new window into the cosmos and offer an unprecedented opportunity for sensing and making sense of the universe.

Ever since humans started to observe the sky, the only resource of data was electromagnetic waves, mostly in the visible spectrum. In the course of the 20th century the frequency spectrum of cosmic inquiries broadened, e. g. when taking radio waves into account.

Eventually, a second resource of cosmic information was established but remained much less important than electromagnetic waves: cosmic particles. The dawn of gravitational wave astronomy allows for studying astronomical objects that remain largely obscure to electromagnetic waves and particles, such as black holes. As gravitational waves encode gravity-based information about the universe, their detection raises physical as well as epistemological issues (cf. e. g. Bunge 2018).

When the concepts of spacetime are at stake, the traditional method of the physical sciences to isolate the studied object fails. Thus, Einstein himself championed interdisciplinary scholarship such as the history of science when inquiring the very concept of space:

> In the attempt to achieve a conceptual formulation of the confusingly immense body of observational data, the scientist makes use of a whole arsenal of concepts which he imbibed practically with his mother's milk; and seldom if ever is he aware of the eternally problematic character of his concepts. […] He [the scientist] will however, be grateful to the historian if the latter can convincingly correct such views of purely intuitive origin. (Jammer 1993, xiii–xiv)

While since Kant's *Critique of Pure Reason* the concept of intuition is most relevant for the philosophical discourse when addressing space, when Einstein refers to "views of purely intuitive origin", he appears to not use "intuition" as a technical philosophical term but rather as a synonym for instinct.

It is our hypothesis that cross-disciplinary explorations such as philosophical inquiry, historical analysis, and arts-based research are most valuable contributions to the physical investigation into concepts of space and time and vice versa.[1] The following analysis of conceptions of space and time, the origin and genesis of the universe, and the nature of reality will be accompanied by dialogues in the tra-

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1 See performance by Jyoti Dogra, *Black Hole* (2018). Available at: https://www.youtube.com/watch?v=DQP1Gg89TWU (Accessed: July 23rd, 2024).

dition of a Platonic symposium from a three-act play as presented in a lecture performance by the authors in October 2019.[2]

The Beginning of All Beginnings

Is space a substance that acts as an absolute container within which material objects are placed? Or is space a relative quality which refers to the relational status of objects and does not possess any independent physical reality? Questions like these, spanning between Isaac Newton's absolute and Gottfried Wilhelm Leibniz's relative conception of space, set the intellectual stage for Immanuel Kant's investigations of space. In his *Kritik der reinen Vernunft* (*Critique of Pure Reason*) of 1781, Kant contrived to develop a theory of space that would consider elements of both the absolute and the relative conception (Kant 2009 [1781, 1787]). This unification came at a price: no longer is space conceived as a phenomenon that is accessible by observation, but according to Kant's critical philosophy the structure of space itself is inscribed into the human subject as an a priori intuition. Thus, scholarly knowledge of space is inseparable from the means of representing space to ourselves by experience (DiSalle 2006, 56). This means that space is a problem of both, of consciousness and of our bodily embeddedness in space: one needs to be in space to be able to imagine empty space (Böhler 2024).

In 1755, decades before the publication of *Critique of Pure Reason*, Kant anonymously published a thin monograph which went almost unnoticed: *Allgemeine Naturgeschichte und Theorie des Himmels* (*Universal Natural History and Theory of the Heavens*). During the printing of the book its publisher went bankrupt, therefore no more than just a few copies were circulated (Kant 1955, 10). The book re-

2 A video of the lecture performance "Das Universum ist ein Luftballon!" (German) by Tanja Traxler & Reinhold A. Bertlmann in the course of the Globart Academy 2019, on October 4th, at Essl Museum in Klosterneuburg, is available at: https://www.youtube.com/watch?v=joliWeOzynk (Accessed: June 29th, 2021).

ceived hardly any attention despite its monumental contribution – to cosmology and far beyond.

In *Universal Natural History and Theory of the Heavens* Kant presented an original theory of the genesis of the cosmos, in which the formation and evolution of stars, planets, and among them, Earth, were not guided by a supernatural power but solely by the physical behavior of matter. Evidently, mathematical techniques and empirical findings have evolved dramatically since Kant, but nevertheless his proposed nebular hypothesis comes in large parts close to modern explanations of the formation of celestial objects as outlined by the so-called solar nebular disk model.

Intriguingly, before Kant, inquiries in natural history were mainly concerned with evolution in space, while human history dealt with changes over time. Kant's *Universal Natural History and Theory of the Heavens* brought the scope of the latter into the scholarship of the former and thus paved the way to framing natural history as an evolution in time. This fundamental shift was hardly noticed, even less cherished by his contemporaries and successors. Early credit came from dialectical materialism: in *Dialektik der Natur* (*Dialectics of Nature*) Friedrich Engels referred to Kant's *Universal Natural History and Theory of the Heavens* as the "point of departure for all further progress" (Marx and Engels 1987, 324).

Fueled by advances in astronomical measurement techniques, plenty of empirical evidence could be contrived which set the foundation for Kant's philosophical analysis: by and large it had become clear that the surface of the moon is much bumpier than previously believed. Even more so, with his changing appearance through the seasons, Mars seemed to be a world like earth. Through the comparison of old and more recent star charts in the beginning of the 18th century it was revealed that presumably fixed stars had changed their positions. Also, the discovery of supernovae called into question the unchangeable and unmovable character of stars. However, most relevant for Kant's reasoning was the observation of blurred astronomical objects which Thomas Wright believed to be huge assemblages of distant stars (Kant 1955, 9). At that time, the term "nebulae" referred to diffused astronomical objects of any kind. Only later the notion was exclusively reserved for interstellar clouds of dust, hydrogen, helium, and other ionized gases, but not for distant galaxies.

Based on these observations, Kant proposed the idea that Earth, the solar system, and even the fixed stars were created by natural processes from primitive matter such as nebulae. Within the framework of this nebular hypothesis, the planetary system did not require a creator, as it did according to Newton's understanding. The only action that Kant left to a supernatural being was the creation of some initial matter in the distant past, from which everything else has developed through natural processes alone.

Thus remained the question how and why the beginning of the universe took place – unless the universe has been there forever. While Kant favored the idea that initial, unstructured matter took over from pure nothingness, later scholars retrieved Aristotle's eternity of the cosmos. The 20th century brought a major shock to the believers in an eternal universe: by help of yet even more powerful astronomical observation technologies, Edwin Hubble proved that many astronomical objects classified as nebulae were not clouds of cosmic dust but galaxies beyond the Milky Way. On top of that, Hubble provided evidence that all these nebulae appeared to recede from Earth. To account for this fact, it was useful to assume that the universe was expanding, alas distant galaxies do not actually travel away from Earth, but through the expansion of the universe space itself is swelling and the distance between remote galaxies increases with by the overall flow.

How could believers in the eternal cosmos save their cosmogony in the face of these findings? Steady-state model was the name of their last resort, which was proposed by Fred Hoyle, Thomas Gold, and Hermann Bondi. Inspiration came from the movie *Dead of Night* of 1945, which was a favorite of these three scientists. *Dead of Night* served as a metaphor that something can be dynamic by being unchangeable, like an evenly flowing river (Clegg 2012, 188ff.). Analogously, the steady-state model suggested that even an expanding universe could be eternal, assuming that its density remained unchanged due to a continuous creation of matter. It was thus a physical theory to account for eternity – yet the final nail in its coffin was already waiting around the corner, within our own galaxy.

Figure 1: This composite image of the Orion Nebula, retrieved by the Hubble Space Telescope and the Spitzer Space Telescope, shows gaseous swirls of hydrogen, sulfur, and hydrocarbons that hold a collection of infant stars. (Credit: NASA/JPL-Caltech STScI)

Figure 2: Tanja Traxler & Reinhold A. Bertlmann during the lecture performance “Das Universum ist ein Luftballon!” at Globart Academy, October 4th, 2019.
(Credit: Zentralbibliothek für Physik der Universität Wien)

The Curvature of Space and Time

Jamming signals or pigeons' shit? Those were the options that Arno Penzias and Robert Wilson faced in 1965 when their high precision measurements by help of a radio telescope showed a faint background noise which they were unable to get rid of. After rigorous testing, both interference signals and feces could be ruled out, and fortunately colleagues of Penzias and Wilson offered another explanation – of extraterrestrial origin. As it was established by Hubble's measurements that the universe expands, two rival theories were left to provide a proper description of cosmogony: the steady-state model and the Big Bang theory.

As George Gamov had first realized, if the Big Bang theory was correct, then space across the universe should be filled with remnant photons from this creation event. The calculations placed the frequencies of these photons in the microwave spectrum. Eventually it turned out that it was exactly this cosmic microwave background that Penzias and Wilson had accidentally detected (Penzias and Wilson 1965, 419). According to Stephen Hawking, the discovery of the cosmic microwave background served as the "final nail in the coffin of the steady-state theory" (Hawking 2002).

By addressing most remote astronomical phenomena that are entirely alien to everyday physics, both Hawking and his colleague Roger Penrose made major contributions to our understanding of how the universe has evolved ever since its fulminant beginning. Among their favored objects of inquiry were black holes. So, what is a black hole?

A region respectively an object[3] in spacetime is called a black hole if the gravity there is so strong that nothing – no matter, no light – can escape. According to Einstein's Theory of General Relativity which predicts that a sufficiently large mass can curve spacetime so much as to form a black hole, such regions do exist. A black hole can be the final stage of a star when it is massive enough. The star after

3 Depending on perspective, a black hole can either be conceived of as a region in spacetime which is extremely curved through gravity, or as an object with sufficiently large mass to curve spacetime.

its explosion to a supernova collapses under its own gravitation and forms a black hole. The boundary of the region from which escape is impossible is called the *event horizon*. In the center there is a *singularity*, a point with infinite density, see Fig. 3.

However, a black hole is not entirely black, the quantum field fluctuations allow the black hole to emit radiation – the so-called *Hawking radiation*. Thus, a black hole evaporates. While the *Hawking radiation* still needs to be experimentally verified, there is broad agreement that it exists, and there are several attempts to detect it by help of laboratory systems (Robertson 2012).

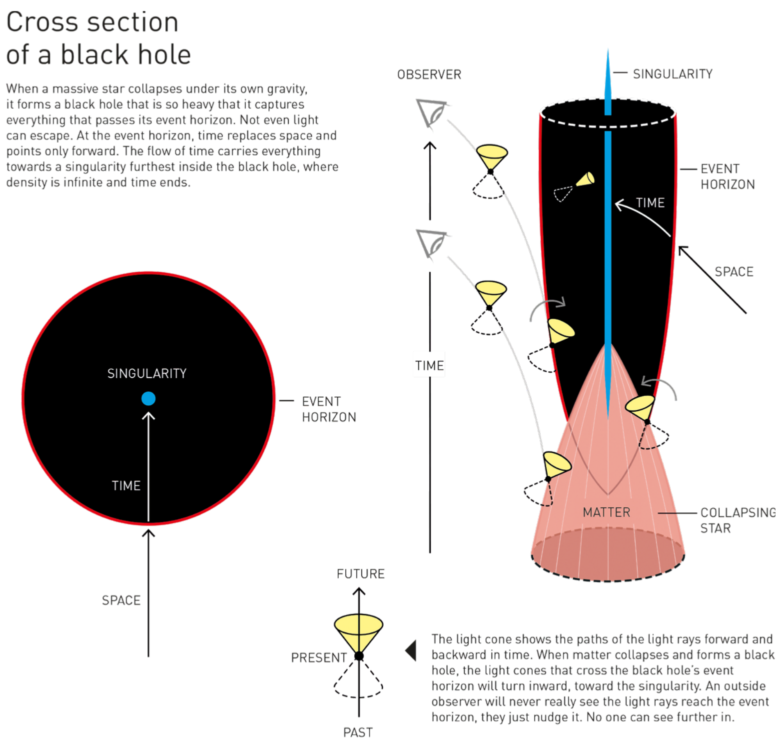

Figure 3: The graphics to the left display a black hole with the singularity in the center and the event horizon. To the right, the evolution of a collapsing star is presented, time is in the vertical, space in the horizontal. (Credit: Nobelprize.org)

In a nutshell, the physics of black holes implies that spacetime is curved substantially in the presence of massive astronomical objects. However, there remains the question of the overall curvature of three-dimensional space across the universe.

Until the 1800s it went without saying that it is possible to mathematically describe physical space by means of Euclidean geometry. This assumption was called into question by a mathematical discovery by Carl Friedrich Gauss, János Bolyai, and Nikolai Lobachevsky: these three mathematicians discovered independently that there were other logical possibilities for a uniform three-dimensional space. Unlike Euclidean space, the geometries presented by Gauss, Bolyai, and Lobachevsky lead to spaces that are not flat but curved.

To make sense of curved spaces it is useful to image two-dimensional surfaces within three-dimensional space and draw a triangle on these surfaces. For a positively curved space, which can be imagined e.g. as the surface of a sphere, the angles of the triangle will add up to more than 180 degrees. For a negatively curved space, which may look like the surface of a saddle, the sum of the angles will be less than 180 degrees, while for a flat space the sum will be exactly 180 degrees.

The radical insight by Gauss and others was that space can be curved all by itself, even if it is not the surface of an object. This proposition remained purely obscure until Einstein proposed his General Theory of Relativity which allows physical space to be curved in the presence of massive objects. However, General Relativity does not give an answer to the question whether the universe as a whole is curved positively, negatively, or flat – so how to resolve this cosmic puzzle?

ACT TWO: The main characters encounter an obstacle.

Physicist: As density increases and space shrinks when approaching the Big Bang, the laws of classical physics are no longer valid, but those of quantum physics apply. In quantum theory, the uncertainty relations play a major role: the deviation of energy multiplied by the deviation of time equals approximately the

Planck constant. For extremely short durations, the energy can grow almost infinitely. Thus, the Big Bang may have evolved from quantum fluctuations.

Philosopher: But what preceded the Big Bang? How can there be a deviation of time if there was no time at all? In Plato's Symposium, Socrates makes a surprising conviction: he states that the only subject he can claim to know about is love (Plato 2008b, 8). This is what the Symposium, the universe and everything, is all about: a kind of love which perceives the intellectual by the sensual and which respects the sensual without getting lost in it. This kind of love is philo-sophia, the love of wisdom. And there is no one who could tell us more about it than Socrates.

Physicist: What preceded the Big Bang? For the universe to come into existence, two ingredients are necessary: space and energy. Space and energy have both evolved during the Big Bang and space has expanded ever since. At least three dimensions are needed that living beings can evolve. With only two dimensions it is not possible to obtain a digestive system and all those things. From energy, matter was derived and from matter galaxies evolved. Within those there are stars and planets, but also extremely massive objects, such as black holes. It happens time and again that two black holes orbit one another, they become closer and closer and eventually merge abruptly. This process results in a strong shaking of the fabric of space and time. Such gravitational waves can be measured here on the earth.

Philosopher: Aristophanes reminds us that love is the power that brings the greatest happiness to the humans (Plato 2008b, 22). Initially, humans had a completely round form, with four arms, four legs, two faces exactly alike set on a round neck, and there were three sexes: male, female and a combination of the two (cf. ibid., 22–23). Because of their attempt to attack the gods, Zeus split all humans into two. Since this time, everyone is longing for his or her lost half. "After the original nature of every human had been severed in this way, the two parts longed for each other and tried to come together again. […] We are all continually searching for our other half." (ibid., 23) Thus, love is always the love for something, so it needs what it longs for. But what is love when its essence is desire?

Physicist: When approaching the Big Bang, gravity increases. As we know from Einstein, time is not a constant, but it slows down with increasing gravity. This means that when approaching the Big Bang time slows down and down and down until it stops. Before the Big Bang there was nothing, not even time, not even space. When there is no time, there can be no cause and no effect. Thus, there is no cause for the Big Bang.

Philosopher: What concerns the creation of all living beings, Agathon states: "And who will deny that it is by the wisdom of Love that all living things are begotten and born? Do we not know that in the practice of craft any man who has this god for a teacher will turn out to be brilliant and famous, while the man untouched by Love will remain obscure?" (ibid., 31)

Physicist: In quantum field theory, nothing does not exist. All of space is filled with fields. When space evolved during the Big Bang, also fields emerged. The ground state of these fields is called vacuum, but because of the permanently fluctuating fields, quantum vacuum is quite large, practically infinitely large.

Philosopher: Well, what to do about infinity?

Physicist: We need to regularize it! By the means of mathematics, we can extract something finite from these infinities.

Is the Universe an Expanding Balloon?

Imagine you are an ant. Your body is quite flat, and you spend your life on a two-dimensional surface. Eventually, you might wonder what the overall curvature of the space you inhabit is. This is a simplified version of pretty much the situation we humans face when thinking about the geometry of the universe. The task is: draw triangles and determine the sum of the angles. The trouble is: the triangles need to be really, really huge in order to retrieve any meaningful information.

To determine the curvature of the universe, again the cosmic microwave background radiation serves as a crucial tool for investigation. As the universe does not look the same everywhere (there are stars and galaxies here and there, and emptiness in other regions), it was assumed that there are fluctuations in the cosmic microwave background radiation. And indeed, those temperature fluctuations could be detected (Mather et al. 1990; Smoot et al. 1992).

The peaks in the microwave background radiation also allow for retrieving the desired cosmic triangles to determine the curvature of space: if physical space were curved like a spherical surface, the angle covered by each microwave-background peak would be bigger and thus shift the peaks in the power-spectrum curve to the left. On the other hand, if space had a negative curvature, the peaks would look smaller and would be shifted to the right (Tegmark 2014, 78).

By measuring the cosmic microwave background radiation with increasing accuracy, various independent experiments such as WMAP, BOOMERang, and Planck have confirmed that space is flat, the margin of error could be reduced to only 0.4 percent by 2013 (NASA 2014). In the years after, the most precise data has been provided by the Planck ESA-mission and allowed for the conclusion that the universe is flat, with an accuracy of 0.2 percent (Aghanim et al. 2020). However, recent studies (Park and Ratra 2019; Di Valentino et al. 2020; Handley 2021) come to a different interpretation, claiming that the universe is not flat at all but positively curved. While the established view is that the universe is flat, discussions are heating up.

But what does it actually mean to state that the universe is flat respectively curved? The mathematics of General Relativity refer to four-dimensional spacetime, which can be flat or curved, depending on the mass distribution. As discussed above, the more massive an object is, the stronger is the resulting curvature of spacetime. Experimentally, the universe is the observable universe. For a specific instant of time it is possible to obtain a three-dimensional slice in the four-dimensional spacetime. When astronomers conclude that the universe is flat/curved according to their observations, this statement refers to the three-dimensional space of the observable universe.

Obviously, the geometry of four-dimensional spacetime exceeds human intuition. Yet sense-making in scientific terms requires more than 'just' mastering mathematics. As physical theories are grounded in mathematical descriptions, scientists have always thrived to offer intuitive analogies to communicate their findings and push the frontiers of knowledge. Inevitably, such intuitive images can never fully capture the mathematical description of a theory. Still, they may prove valuable for highlighting certain aspects of a physical theory.

In this sense, we consider the balloon analogy of cosmology insightful, as it alludes to two main features of the universe – the curvature of space and the expansion of the universe. More precisely, the analogy refers to the two-dimensional surface of an inflating balloon (not the three-dimensional balloon itself): if an ant is crawling on the surface of a large balloon, the ground would appear flat to the ant. Yet, global geometry is a positively curved space. In addition, if the balloon is being inflated and there are several ants on its surface, the distance between the ants increases; the further the ants are apart, the faster they are moving away from one another. This is essentially what happens to galaxies in our universe.

Besides the debate concerning the Planck data on the curvature of the universe, it needs to be considered that experimental data is only accessible for the observable universe. If the entire universe is sufficiently large, it might well be that despite actually being curved, data from the observable universe suggests that it is (nearly) flat.

Further investigations will be required to address the question of the flatness respectively curvature of the universe. As the results depend crucially on energy density and the amount of dark energy in the universe (Tegmark 2014, 83), experimental methods sensitive to gravity such as gravitational waves may be valuable resources.

So, what about gravitational waves? As mentioned above, according to Einstein's General Theory of Relativity, gravity arises as a geometric property of spacetime. More precisely, the *curvature of spacetime* is determined by the energy and momentum of matter and radiation (Rogers 2017). When massive objects accelerate, they cause changes in the spacetime curvature which travel outwards at the speed of light in the forms of waves – these are known as *gravitational waves*. In essence, gravitational waves are ripples in spacetime caused by accelerated masses.

When such a gravitational wave passes by, it distorts spacetime, and an observer could – in theory – experience this distortion. This very tiny effect can be observed by help of most sophisticated detectors based on laser interferometry. Even tiniest differences in the path lengths of the interferometer can be retrieved by detecting interference fringes. This effect is used by the Laser Interferometer Gravitational-Wave Observatory, in short LIGO: two interferometers with arm length of about four kilometers are placed in Hanford and Livingston (US), see Fig. 4. The LIGO collaboration was first able to detect gravitational waves in September 2015. The waves were caused by two black holes with 29 and 36 solar masses, which orbited each other and finally merged about 1.3 billion light-years away. The mass of the new, merged black hole was 62 solar masses, thus the energy equivalent to three solar masses was emitted as gravitational waves, see Fig. 4.

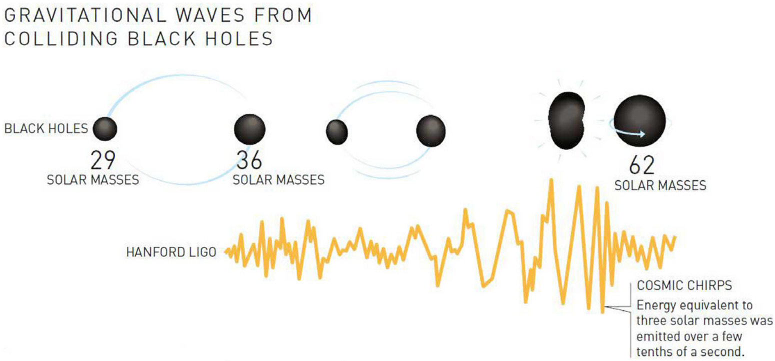

Figure 4: The spiralling and merging of two black holes with masses of 29 and 36 solar masses to a black hole of 62 solar masses is shown together with the corresponding LIGO signal. (Credit: Nobelprize.org)

As Gamov was the first to predict, after the Big Bang the universe was filled with plasma. While cold hydrogen gas is transparent and invisible, hot hydrogen plasma is opaque and glows brightly – just like the surface of our sun. For this reason, it is not possible by help of electromagnetic waves to see further back than about 400,000 years after the Big Bang. However, for gravitational waves the initial state of the universe is not opaque but transparent. Therefore, by way of gravitational waves it might be possible to uncover what precisely happened, and we might be able to gather information about the Big Bang, the most bizarre prediction of Einstein's Theory of General Relativity, where all matter, energy and spacetime originates from.

ACT THREE: The climax occurs as well as the resolution.

> **Philosopher:** If the universe expands and everything recedes from us, will it not be that one day we can see no more stars?
> **Physicist:** Yes, I fear so. I am also not satisfied with this outlook, although this will take place only in billions of years from now. I would love to be still around in 500 years, when humankind will have much more advanced technology and will thus have been able to entirely revolutionize our understanding of the universe. 1000 years ago it was believed that angels move around the stars like little light bulbs. Maybe our contemporary conception is just as naïve compared to what humans will know in 500 or 1000 years from now – assuming that humankind will last until then.
> **Philosopher:** Speaking of this, I am reminded of Chaerephon. Already as a young man he was a friend of Socrates. As the latter reported, Chaerephon was not shy to ask the Oracle of Delphi if there was someone who was wiser than Socrates. The Oracle replied that no one was wiser than Socrates. Based on this information, Socrates concluded: "I am wiser than this man [an unnamed public man of Athens, note by the authors]; for neither of us really knows anything fine and good, but this man thinks he knows something when he does not, whereas I, as I do not know anything, do not think I do either." (Plato 2005, 83)
> **Physicist:** In the beginning, the universe was extremely hot. Only through expansion the universe cooled down, and only then the different interactions appeared, which had before only been some kind of soup. One second after the Big Bang the temperature of the universe was one thousand times higher than the temperature of our sun today. At that time electrons did already exist, as well as neutrinos, photons and the respective anti-particles. But all these particles were free. Only later, when the temperature had decreased again, electrons and positrons met because of the expansion of space – and annihilated one another. The same was true for

neutrinos and anti-neutrinos, and this way radiation was created. We can imagine the universe as a balloon that is being inflated: the galaxies, the stars and we humans are sitting on the surface of this balloon like flattened ants. When calculating the temperature of the universe, the universe is conceived as a global container, and an average is derived. Naturally, there are local fluctuations, and these are very important, as they are responsible for the formation of galaxies. When density increases, this has an immediate effect on geometry, and this way expansion is slowed down and gravity increases.

Philosopher: How can we reach the ideal state, this question was intensively discussed by Timaios. Plato wrote down Timaios' considerations on the subject: "the best kind of movement is one that is generated by oneself within oneself, because there's no movement that has more natural affinity with the movement of the thinking part and of the universe as a whole. Somewhat worse than that is any externally generated movement, but worst of all is the one that affects only parts of a supine, still body, and uses substances that are different from the bodily parts affected." (Plato 2008a, 94)

Physicist: Quantum fluctuations are entirely random – it is not possible to attribute any cause or any effect. This troubled Albert Einstein when he stated: God does not cast dice. But when we look at the evolution of the universe, we have to say: God actually does cast dice! The universe can be compared with a large casino. If the universe is large, this means that the dice fell many times. And whenever I cast dice many times, I will obtain an average – this is classical physics. If the universe is small, much less gambling took place – in this scenario the uncertainty relations play an important role, and quantum fluctuations will be substantially large. As the universe has allowed for our evolution, also we are the product of quantum fluctuations in an early universe.

Philosopher: For Timaios, there are cosmic causes of reason for seeing and hearing. We were supplied with vision "to enable us to observe the rational revolutions of the heavens and to let them affect the revolutions of thought within ourselves," (ibid., 38) he states. "That is, the gods wanted us to make a close study of the circular motions of the heavens, gain the ability to calculate them correctly in accordance with their nature, assimilate ours to the perfect evenness of the god's [sic!], and so stabilize the wandering revolutions within us." (ibid.)

Physicist: I need to say one more thing, and this is my philosophical legacy: the universe possesses a directionality. This has been acknowledged by many, also by theologists. I do not believe that we humans are the last stage, but evolution continues to allow for the existence of further and further developed living beings which have consciousness and which perceive the cosmos within which they live and thus also perceive what is behind everything. By seeing the universe within which we live, the universe intuits its own existence. The universe had to let us evolve in order to perceive itself. This is the only thing that makes sense – not in total but at least approximately. When it comes to the question why we live, we have to acknowledge the fact that we are close to a star from which we receive energy. Everything has evolved in a way that planets could form and that through nuclear synthesis heavy elements like iron were generated. Exactly those heavy elements and the radiation pressure from the sun allowed for life to develop. Life in the sense that molecules reproduce. It requires a lot for this to be possible. The natural constants need to be tuned with one another, there is a kind of cosmic architecture. For me, this is the hint that there is a directionality, a kind of "behind", one could say, a "hidden intelligence". The universe is more than mere random chaos.

Epilogue

Modern physics confirmed that Plato was right, after all: for Max Tegmark, both the physical investigation of the macrocosm and of the microcosm changes some of our most basic ideas about reality (Tegmark 2014, 15). He thus states: "If my life as a physicist has taught me anything at all, it's that Plato was right: modern physics has made abundantly clear that the ultimate nature of reality isn't what it seems." (Ibid., 17)

Reality is not what it seems. One reason for this is our so very limited means to explore the world around us. Throughout the history of science, collecting empirical data about the universe was primarily bound to vision. With the increasingly frequent detection and analysis of gravitational waves, this proposition is changing fundamentally – with unforeseeable consequences for our understanding of reality and the universe we are part of.

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