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THINKING DARK ANEW

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Dark(ness) is
Our blindness
To other lights

ABSTRACT: Light by its gradations always speaks of its other, the dark. But as opposed to light which we assume we know the nature of, the nature of dark remains elusive. A key reason for this is that dark is often defined in terms of (absence of) light, and light in turn in relation to the sensibilities of our vision, which makes the demarcation line between light and dark rather arbitrary and difficult to define.

I explore the nature of dark by considering a set of thresholds of dark and ask what the limit of such thresholds may be. Starting with the limitations of the human vision, and those of other species – as well as the physical properties of the electromagnetic waves of which the visible part, *light,* constitutes a very small part - I define the notion of *relative darkness*, in relation to any limited vision. The observer-dependence of this definition raises the interesting question of possibility of *absolute darkness* - i.e., dark(ness) for all possible visions, whether biological or artificial, terrestrial, or extra-terrestrial - defined as the absence of electromagnetic waves across their entire range of wavelengths.

I argue that as opposed to relative darkness that does exist in the natural world, at least within the limits of the sensitivity of our (or any other limited) vision, absolute darkness does not naturally occur in the Universe at present. Furthermore, strictly speaking, it cannot be constructed artificially through any physical process which involves a finite number of steps. I explore the possibility of absolute darkness occurring in the very far future of the Universe and argue that only asymptotically in time (assuming the Universe is future eternal), can the Universe possibly tend towards such a state. But long before such epochs the Universe is likely to be devoid of any observers, with its physics becoming more and more uncertain given our present knowledge.

I also briefly discuss the colour *black* and ask whether *absolute black* can exist in the Universe. I argue that this is similarly unlikely.

Despite the observer-independent nature of the discussion here, dark (and black) carry deep psychological and metaphoric meanings for us. The conceptual realisation of the impossibility of absolute dark in our Universe, where all possible visions would fail, can have great symbolic significance, as well as reminding us of the vast vistas open to other possible visions, that forever remain closed to our eyes.

KEYWORDS: Darkness; Cosmos

PREAMBLE

Light has played a fundamental role in the evolution of life on earth, as one of the main sources of energy for its development and maintenance. This is manifested by the presence of light sensitivity, in the forms of photosensitive cells, in the earliest forms of life (see Williams, D.L. 2016; Schwab, I.R. 2018). Similarly, light remains important for more complex biological species, including ourselves, in variety of essential ways. It is thus no surprise that light, and in turn dark, defined as its absence, have occupied the minds of our ancestors since the dawn of history, and continue to do so today on many levels - including material, psychological and symbolic.

The roots of our association of dark and light may be traced to the nature of vision itself - which at its most basic level is the ability to detect the presence of light - and in turn its absence, the dark. Thus, from the very inception of vision, light and dark must have played key roles in defining one another.

Given the central role that vision has played in our evolution as a species, and still plays in our everyday lives, it is difficult to imagine how a life form totally devoid of light perception could have perceived the larger world[1], given that our other senses despite their central importance, operate on more local (terrestrial) domains. Thus dark, where vision with its ability to inform us of our larger surroundings fails, has come to be associated with the unknown, often invoking a sense of unease, fear, and angst. And given that nights are unavoidable counterparts to our days, constituting a significant part of our lives, dark must have had an impact on the survival strategies of our ancestors, specially before the harnessing of fire, with potential material and psychological consequences during the course of our evolution as a species. It is therefore not surprising to see

[1] This is not to belittle our other senses. To contextualise the importance of vision, imagine the role of hearing in connection with the development of language and hence culture (see Cronin, et al., 2014). Vision, however, does play a unique role in our awareness of the extraterrestrial world.

the deep symbolic and metaphoric meanings that dark (and light) have carried for our ancestors as they still do today for us, and the key roles they have played in our ancestors' myths and religions.

These issues, despite their great interest, will not be the main subject of the discussion in this article. The aim here is rather to look at dark(ness) as a purely physical phenomenon and study its thresholds and possible limit in our Universe.

Interestingly, defining dark in terms of absence of light leads to other interesting questions. To begin with it is necessary to precisely define the nature of light. Furthermore, since light is an observer dependent concept, this points to a possible observer independent concept of dark. So, a key question which follows from these considerations is whether the limit of dark, valid for all possible *visions* whether natural or artificial, which I refer to as *absolute darkness,* is in principle possible in our Universe? I shall discuss these questions in turn.

WHAT IS LIGHT?

Given the ubiquitousness of light in our terrestrial environment, the essential role it plays in our lives, and its unique ability as the carrier of extra-terrestrial information, its nature has been the object of fascination since the dawn of human history (see e.g., Zubairy, M.S. 2016).

Earliest systematic studies of light, and vision, go back to at least the atomists in Greek and Hellenistic traditions, for whom vision was caused by the impact of atoms from the observed objects on the eyes. Similar ideas arose later in India. An alternative view, the so called extramission theory (Gross, C. 1999), said to be initiated by the pre-Socratic Alcmaeon and later elaborated by Plato and his followers, assumed that light consists of rays emitted by the eyes.

A fundamental break occurred with the ideas of the Arab scholar Alhazan around 1000 CE, according to whom light is made of particles from the Sun or fire, which bounce off objects and enter the eye, in contrast to the extramission theory and closer to modern ideas.

According to our modern scientific understanding, dating from the end of 19th century, light is nothing but propagating electromagnetic (EM) waves, which do not require a material medium to propagate in, thus being able to propagate in near vacua of the interstellar spaces. Subsequent discoveries showed that EM waves can possess an enormous range of wavelengths, ranging from subatomic scales of less than 10^{-12} meters (gamma rays) to very large macroscopic scales (radio waves). This discovery dramatically highlighted the limitations of our vision by showing that our eyes can only detect an extremely narrow band of wavelengths of EM waves, the so called human visible range (lying in the interval 380-760 billionth of a meter), we call *light* (see Figure 1 below). I shall not discuss colour here. For a further discussion of colour in the cosmological settings see (Tavakol, R., 2020).

Interestingly, photons (the quanta of electromagnetic waves) did not get born immediately after the big bang but appeared as the Universe cooled down enough some seconds later. And then, it took almost 370000 years before the Universe was cool enough for the appearance of the first freely propagating EM waves, the so called *first light,* that first filled the Universe after the big bang, before galaxies and stars that we see at present were born. This *first light* is still permeating the Universe today and is known as the Cosmic Microwave Background (CMB) radiation.

WHAT IS DARK?

Dark is usually defined as the absence of light. What this definition does not make clear, however, is the absence of light for which observer? For an observer with a restricted vision (i.e. sensitive to a restricted range of wavelengths of EM waves), like a member of our species true darkness would imply the absence of electromagnetic waves in the observer's visible range of wavelengths. Thus, for members of our species *total darkness* can exist in practice in settings where EM waves with wavelengths in our visible range are absent or blocked.

Different species, however, have visions that are sensitive to different ranges of wavelengths of EM waves, some outside the human visible range (see e.g., Baden & Osorio 2019; Jacobs 2009; Marshall, Carleton & Cronin, 2015; Osorio & Vorobyev 2008). There is also a range of mechanical optical detectors which have sensitivities over different parts of the spectrum of the EM waves. What all such visions, whether biological or mechanical, share is that they all have sensitivities over a limited range of wavelengths.

The notion of darkness defined relative to a particular set of observers is clearly observer dependent. I shall therefore refer to such a darkness as *relative darkness*.

It is interesting to recall how vast the extent of such a darkness is for our human vision, for example, by comparing the minuscule extent of our visible range (or in fact that of any other species), relative to the vast span of wavelengths that lie outside such a range.

A graphic representation of the relative extent of this darkness is given in Figure 1 below, which shows (not to scale) the tiny visible range of wavelengths, surrounded by an enormous band of dark, representing the wavelengths that lie outside the visible range, to which our eyes remain blind.

Figure 1. Light and dark bands representing the relative size of the visible range compared to the vast spectrum of wavelengths that the EM waves can possess.

The crucial point to note about this Figure is that it is unbounded on the right-hand side. This is because to be able to see the very narrow visible band (shown not to scale here), the scales in this figure have had to be greatly stretched. As a result, to represent the enormous range of wavelengths outside the visible range that the EM can possess, the black band in this figure needs to be continued on the right-hand side far beyond the page, and in fact beyond the planet Earth.

Viewed as graphic art, this figure constitutes an interesting example of an image which extends not only beyond the frames of its canvas (the page here), but far beyond even of the boundaries of the planet Earth.

An important example of this relative darkness is provided by the Universe itself, in the form of darkness of interstellar/galactic spaces (by ignoring the bright stars and galaxies). This darkness is due to the fact that as the Universe has expanded and cooled down during its evolution, the wavelengths of the first light (the CMB radiation) which still fills the Universe at present) have been stretched out to the so-called microwave region, which are no longer visible to our eyes. Clearly, if our eyes could detect EM waves in the microwave range of wavelengths, such spaces would not appear to us as dark.

The above example highlights the observer (vision) dependence of the concept of relative darkness. Clearly the visible range would be wider for beings with a more extensive vision and smaller for those with less. This then raises the important question of whether *absolute darkness*, defined as absence of electromagnetic waves across their entire range of wavelengths, can exist in our Universe? Before discussing this question, it is instructive to first discuss another limitation of vision.

THE LIMITS OF VISION: BIOLOGICAL AND MECHANICAL

In addition to restrictions of the human vision due to the narrowness of the visible range of wavelengths, there is another possible limitation that could result in darkness, even within our visible range. This would occur if there existed a limit to the light intensity below which our eyes could not register light, i.e., if there existed a minimum number of photons in order for our eyes to register light.

This question has been studied since the1940's, when it was originally shown that a light signal with as few as 5 to 7 photons could be detected by the human eyes (Hecht, S., Schlaer, S. & Pirenne, M. H., 1942). Modern technology has allowed this limit to be further refined, reducing this limit first to three photons (Holmes, R. 2014) and then with the latest results indicating that a single photon could in fact be sufficient for the detection (of light) by the human eyes (for details see Tinsley, J. et al., 2016). If substantiated, this is an astonishing fact showing that human vision has evolved to such a level of sensitivity that even the minimum possible number of photons can in principle be detected.

To contextualise this incredible ability of human vision, it is interesting to note that the quantum mechanical devices capable of producing single photons and similarly the mechanical detectors with such accuracy are extremely sophisticated and are often required to operate at very low temperatures of few degrees above the absolute zero of temperature (defined as -273.15 degree centigrade), which is of course difficult and costly to maintain.

To summarise, interestingly both human vision and mechanical detectors seem capable of detecting light at the lowest level of intensity of one photon. Despite this, it is very important to note that all such detections are confined to restricted ranges of wavelengths: the visible range in the case of the human eyes, and rather more extended but still a limited range in the case of mechanical detectors.

DARK VERSUS BLACK

Before exploring the theoretical possibility of the absolute darkness in the Universe, it is useful to briefly discuss the difference between dark and black, since they are sometimes used interchangeably. Whereas (relative) dark is defined as total absence of visible light, black is a *colour* which results from the total absorption of visible light (or its total absence). In analogy with dark, it will prove useful to define *relative* and *absolute black,* as total absorption of visible light and the total absorption of EM waves over their entire range, respectively.

Interestingly, there are naturally occurring, as well as artificially constructed, examples of black and dark in the Universe which may in the first instance appear as potential candidates for absolutely dark/black. As naturally occurring examples I shall consider Black Holes, Dark Matter and Dark Energy. There are also attempts at artificially producing the blackest possible material, the so called blackest black. I shall briefly discuss each of these in turn.

BLACK BODY

Before proceeding to consider these examples, it is useful to introduce the concept of *black body* which is a very important conceptual tool in physics, and also proves very useful in our discussions of dark and black below. Black bodies are defined as idealised physical bodies that absorb all EM radiation incident upon them, irrespective of their wavelengths. When in thermal equilibrium, such black bodies emit thermal radiation, the so-called *black body radiation*, which has a well-defined spectrum determined solely by the black body's temperature. The importance of these idealised bodies for our discussion below are twofold.

First, the emitted radiation from many real objects of interest, such as stars as well as the Universe itself (i.e., the CMB radiation), can be well approximated as black body radiation. Secondly, and importantly, **a**ny black body with a temperature above absolute zero would emit electromagnetic radiation.

BLACK HOLES

According to their initial classical definition, black holes (BHs) are astronomical objects that absorb all radiation falling upon them while allowing no light/radiation to escape. Were this definition to hold strictly, BHs would be expected to appear as absolutely black. There are, however, two important facts that change this outcome, one theoretical, the other practical.

First, in a seminal work Hawking (Hawking, 1974) showed that all black holes have an associated temperature which is non-zero, and that they radiate with a nearly perfect black body radiation. These facts have the consequence that in reality black holes are not be totally black. Furthermore, by radiating black holes would lose energy (and equivalently mass) and as a result eventually evaporate. It was further shown by Hawking that the temperature of a black hole, and hence the rate of its evaporation, is inversely proportional to its mass. For example, for a black hole with the mass of the Sun the associated temperature would be extremely small, amounting to only a few millionth of a degree above absolute zero. For much larger black holes, for example the so called supermassive black holes with masses of tens or hundreds of millions of times bigger than that of the Sun, the associated temperatures would be correspondingly, tens or hundreds of millions of times lower still, which would make them extremely close to the absolute zero of temperature. This implies that for the temperature of the black hole to be appreciably above the absolute zero of temperature, its mass needs to be very small.

Even though the temperatures associated with such macroscopic black holes are far smaller than the temperature of the CMB radiation filling the Universe today, nevertheless, all black holes have nonzero temperatures, however small, and hence radiate, however faintly and slowly, and thus strictly speaking are not black.

In practice, however, all black holes in the Universe are expected to be surrounded by gases which are continuously pulled into them. As they fall towards the black holes, these gasses are accelerated under the gravitational pull of the black holes to speeds close to the speed of light, and in the process heat up to enormous temperatures. Thus, in the real Universe, rather than the radiation from the black holes, it is the radiation from these hot in-falling materials shielding the black holes that are observed by outside observers. In this sense even though very massive black holes would be expected to constitute the coldest and hence blackest objects practically possible in the Universe, they are bound to be shielded by the much hotter radiation due to the inflating materials, unless of course they are truly isolated which is very unlikely.

BLACKEST BLACK

Given that black holes are not absolutely black in practice, the question arises as to whether a totally black object can be constructed artificially?

The blackest material that has so far been produced artificially is made of vertically aligned carbon nanotubes (Cui, K. and Wardle B. L., 2019), which allow very high absorption of EM waves. This material is reported to be able to absorb about 99.995 percent of the incoming light, which makes it about 10 times more black than the previously reported blackest material (the so called Vantablack[2]).

Despite their enormous absorptivity, such materials do not absorb the incoming light fully, since they still reflect a small amount of light that can in principle be measured. Importantly also, this enhanced absorptivity holds over a restricted range of wavelengths only, spanning from the ultraviolet to the microwave range, rather than the entire range of wavelengths of EM radiation. Of course, this range of wavelengths does cover the visible range and is therefore important as far as its visibility to human eyes is concerned. However, from the point of view of our discussion here such materials would still remain non-black to instruments or visions that are sensitive to ranges of wavelengths outside these ranges.

Thus the blackest black materials so far constructed are not even true examples of relative black, since they do not absorb all the inflating EM radiation over the visible range, let alone being examples of absolute black, given their absorptivity over a limited range of wavelengths.

2 Curiously the use of this material in art has been monopolized. See https://news.artnet.com/art-world/anish-kapoor-first-vantablack-sculptures-venice-biennale-1801614

DARK MATTER, DARK ENERGY

Perhaps the most puzzling feature of our modern picture of the Universe is that about 95 percent of its content appears to be `dark', consisting of about 27% of so called dark matter and about 68% dark energy, respectively (Aghanim, N. et al, 2020).

As the major components of the Universe, Dark matter acts gravitationally on large scale structures in the Universe, such as galaxies and galaxy clusters, affecting their structures and dynamics. Dark energy, on the other hand, acts as a repulsive force on cosmological scales, significantly affecting the overall dynamics of the Universe by accelerating its expansion, over its relatively recent history.

It is important to recall the fundamental difference between the term *dark* used in relation to the invisible parts of the EM spectrum, and that appearing in the expressions of dark matter and dark energy. The former, though invisible to our eyes, consists of radiation whose nature is known and is detectable through its interaction with mechanical detectors. The latter, on the other hand, are referred to as dark because their natures are unknown, and furthermore because they do not interact with EM forces and hence are not visible - and even more importantly because they are not currently detectable by any mechanical instruments. At present they are thought to exist purely based on their gravitational effects.

Thus dark matter and dark energy can be said to provide cosmologically important examples of very dominant `presences' (albeit not clearly understood) in the Universe that cannot be `seen' or detected by any current instruments.

A possible way of graphically representing this disparity between the light and dark components in the Universe is given in Figure 2 below, where the bright rectangle represents the ordinary matter (which includes the luminous starts, galaxies etc.), with an area equal to five percent of the total area of the black canvas (the fading is meant to figuratively represent the depth of the distribution of matter). The remaining 95 percent black areas represent the combined proportion of dark matter and dark energy.

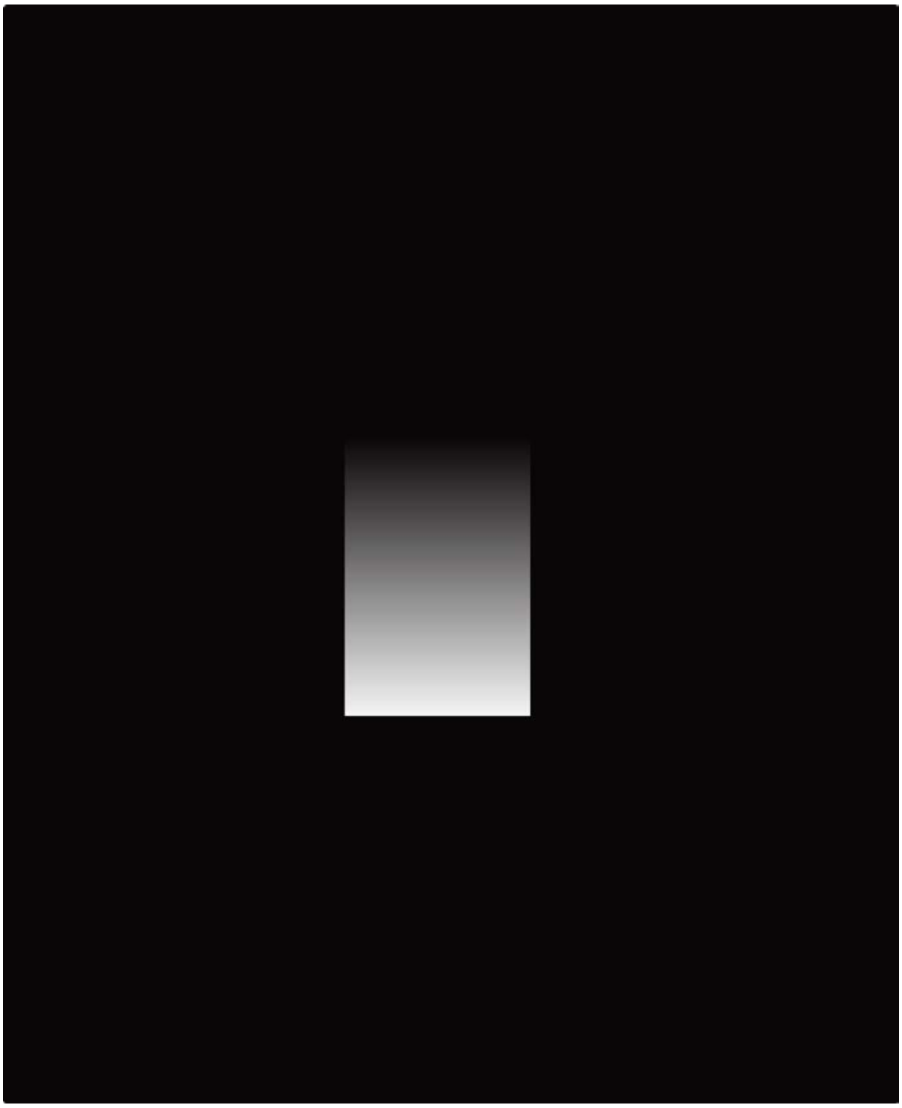

Figure 2. Depiction of *light* and *dark* components of the Universe, with the bright rectangle representing the ordinary matter, constituting five percent of the total area of the black canvas.

ABSOLUTE DARKNESS?

As was defined above absolute darkness, defined as total absence of EM waves over their entire range of wavelengths, is darkness for all possible visions, whatever their nature. An interesting question is whether such darkness can possibly exist in our Universe, either naturally or through artificial construction?

As was mentioned above, the darkness of intergalactic spaces is relative, since the Universe is still permeated with CMB radiation which at present has a temperature of about 2.7 degrees above absolute zero and would therefore be visible to visions (natural or artificial) sensitive to microwave region of the EM wavelengths.

A necessary requirement[3] for the existence of absolute darkness in the Universe is for its temperature, including that of CMB radiation, to reduce to absolute zero. This follows from the fact that any black body with a non-zero temperature would emit electromagnetic radiation. The present non-zero temperature of the CMB radiation, as well as those of luminous and non-luminous bodies in the Universe, including black holes, suggest that absolute darkness does not naturally occur in the Universe at present.

To achieve temperatures below the current temperature of CMB, there are at least three possibilities: (i) occurrence of natural transient phenomena in the Universe that can temporally produce temperatures below that of CMB; (ii) artificial production of such temperatures in the laboratory; (iii) cooling down of the Universe due to its expansion in the very far future.

The coldest example of a naturally occurring place so far observed in the Universe is within the so-called Boomerang Nebula, with the temperature of 1 degree above absolute zero (Sahai, R. and Nyman, L.Å., 1997). Such planetary nebulae are formed around central stars, when they expel gasses towards the end of their lives, which results in their cooling.

The lowest temperature achieved artificially in the laboratory so far is about 450 pico Kelvin (i.e., 4.5×10^{-10} above absolute zero) (Leanhardt, A.E. et al, 2003). This is far colder than the temperature of the CMB, or that of the coldest location found so far in the Universe.

3 Though necessary, this may not be a sufficient condition due to quantum mechanical considerations at absolute zero of temperature.

Despite the closeness of such temperatures to absolute zero, to reach absolute zero, however, is totally another matter. In fact, according to the third law of thermodynamics, absolute zero of temperature cannot be achieved in practice in a finite number of steps (Masanes, L., Oppenheim, J. A., 2017). Thus, even though we could get extremely close to the absolute zero of temperature, we could never truly get there in finite time. This in turn would imply that absolute darkness is impossible to achieve in a finite number of steps, and hence in practice.

This leaves the future cooling of the Universe due to its evolution, and whether EM waves (including light) will ever completely die in very far, but finite future.

Recent observations suggest that the Universe is flat (more precisely the 3-dimensional space section of the spacetime is very nearly flat). Furthermore, due to the dominant presence of the dark energy, the Universe is accelerating at present.

Assuming the Universe to be flat, and depending on the nature of the dark energy, it could keep on expanding forever. With these assumptions, the question is what would be the asymptotic fate of the Universe - and whether it could approach absolute darkness?

The possible fate of the Universe has been the subject of a great deal of study and speculation. Interestingly, despite the vast progress made in cosmology over the recent decades, the very far asymptotic future of the Universe remains uncertain due to a number of major unknowns. Important among these are: whether the laws of physics as we understand them today remain unchanged indefinitely; and whether our current picture of cosmology will continue to hold for all future times?

Assuming affirmative answers to these questions, studies have been made of the fate of the vast spectrum of structures that are known to populate the Universe, ranging from subatomic particles to stars, black holes, and clusters of galaxies; as well as the CMB radiation permeating the Universe. For a detailed summary of these results see for example (Adams, F.C. and Laughlin, G., 1997).

It is, for example, known that stars have finite lifetimes which rapidly increase with the decrease in their masses. Thus, stars can have vast ranges of lifetimes ranging from millions of years for very massive stars, to about 100 trillion years for the lowest mass stars. Interestingly, the latter is enormously long even compared to the present age of the Universe, which is estimated to be about 13.8 billion years.

Clearly stars will keep on forming in the Universe as long as there are gasses to collapse to form them. It is estimated that it takes between about a trillion to about 100 trillion years for the star formation process to end (Adams, F.C. and Laughlin, G., 1997). Thus, there will be stars flickering in the Universe for enormously long times into future, however faintly.

As the Universe continues to expand, the distance between its constituent parts will grow, making it more and more sparse. Eventually, there will come an epoch when even the galaxies closest to us will be outside our horizon and hence unobservable - and the CMB radiation will get redshifted into relative insignificance. At such epochs the dominant radiation permeating the Universe will no longer come from the CMB, but instead from the contributions of long living stars and evaporating black holes.

Moving further into the distant future, the underlying physics becomes more uncertain. This is mainly due to the uncertainty about the nature of the dark energy that is dominating the overall dynamics of the Universe at present and the details of particle physics. For example, if protons turn out to be unstable, with a finite lifetime, there would be contributions from their decay into photons (EM radiation). Under this assumption, it has been estimated that all atomic nuclei in the observable Universe would eventually decay over the very long-time scales of the order of 3×10^{43} years (de Grasse et al, 2000). Similarly, if dark matter was to decay, it could make a contribution to the background radiation. If these rather speculative predictions turn out to be true, then black holes would be the only objects left and the Universe would enter the Black hole era (Adams, F.C. and Laughlin, G., 1997). As time advances ever further, the picture will become even more uncertain.

The crucial point as far as our discussion here is concerned is that for extremely long times into the future, that is times vastly longer the present age of the Universe, there will still be EM radiation in the Universe, however faint, and in that sense the Universe will not be absolutely dark.

A key question regarding the possibility of absolute darkness is whether photons (and hence EM radiation) themselves remain stable on extremely long-time scales? This will in turn depend on whether photons have a non-zero mass, contrary to what is widely believed at present. See (Heeck, J., 2013) for a discussion of possible consequence of photons possessing a non-zero mass.

So unless photons, i.e. EM waves (including light), decay, there will still be EM radiation - getting fainter and fainter - for stupendously long times into the future, even as the Universe becomes colder and darker. It is difficult to talk with certainty about the state of the Universe in infinite future, as a great deal remains unknown regarding future of cosmology, particle and quantum physics.

A final interesting question is how long into the future can such an expanding Universe support observer? There are widely different answers to this question. For example, Dyson argues that life and communication can continue forever (Dyson, 1979; see also Hooper, D., 2018), whereas others take the opposite view (see e.g., Krauss, L.M. and Starkman, G. D., 1999).

DARKNESS FOR US

The above discussion has concentrated on the physical nature of light and dark, mainly independently of observers. Given their significance in our material lives, light and dark have also carried a great deal of symbolic and metaphoric significance throughout the history of our ancestors, as they continue to do for us today. For example, over time light has often been associated with the good, the positive and the perfect - while dark has been associated with fear, the unknown and evil.

Such associations of light and dark have played important roles in forming our ancestors' myths and religions. For example, light has been associated with gods, as for example with the open eyes of the god Ra by ancient Egyptians, or with Ahura Mazda, as the god of light and fire, by Zoroastrians. Light and darkness also appear as motifs in biblical narratives (see Lemmelijn, B., 2012). Similarly, light has been associated with the idea of salvation in Greek myths; and dark with the underworld in the Dionysiac cult and the Orphic movements (Christopoulos, M. et al. 2010).

The mystery associated with the dark persists today as can, for example, be seen by the deep and diverse set of feelings that the total eclipse of the Sun evokes in so many of us. We can only try to imagine the possible picture that beings with far more extended visions than ours would have of a solar eclipse, and the range of feelings that the possibility of absolute darkness may evoke in any being with a finite vision.

Light and dark can also have important psychological effects on us (see e.g., Tomassoni, R. et al., 2015), and hence the potential of impacting our literature and arts. They have also been the subject of philosophical debates (see e.g., Sorrensen, R. 2008 and Badiou, A. 2019).

It would also be interesting to wonder about the significance of light and dark for other species, especially given the vast variety of visions that have evolved over the course of evolution, ranging from light receptors in single cell organisms, to animals without eyes but with dermal light sense instead, such as freshwater hydra or Kauai cave wolf spider (Desmond Ramirez, M. et al. 2011), all the way to animals with visions more extensive than ours, such as Humming birds (see e.g Stoddard, M.C. et al. 2020).

Importantly also, light (and more generally EM waves) is the key language through which the Universe speaks to us directly through our senses. This is related to the ability of the EM waves to travel through the vacuum of the vast intergalactic spaces. Thus, an epoch of absolute dark, were it to ever exist in the Universe, would amount to a total *blindness* to larger Universe not only of our human vision, but of *all possible visions,* whatever their nature, if any observers were to exit in such an epoch.

Interestingly, the impossibility of absolute darkness reminds us of its opposite: the vast vistas open to other visions.

Given these important symbolic dimensions of light and dark, the impossibility of absolute darkness (or absolute black) in our Universe can potentially carry great significance.

CONCLUSION

By considering different thresholds of dark, I have defined two notions of darkness: relative and absolute. I have argued that as opposed to the former, which is achievable, absolute darkness does not at present exist in the Universe and is not possible to construct artificially in a finite number of steps.

Similarly, by considering the future evolution of the Universe I have argued that up to extremely long times into the future there will still be EM radiation - albeit a fading one. I have argued that it is difficult to talk about the state of the

Universe in infinite future, as great deal of unknowns remain regarding cosmology, particle physics and quantum effects.

In a way we could say it is that very far asymptotic future of the Universe that remains truly dark for us at present! Is this metaphoric darkness necessarily shared by all other possible inhabitants of the Universe, if they exist, and for all times? That is another question the answer to which remains in the dark at present.

I have also discussed the possibility of occurrence of absolute black in the Universe and argued that it is not in practice possible, as its only real candidate the black hole has in fact been shown to radiate. Also, all attempts at artificially constructing the so called *blackest black* have so far only produced a nearly relative black, i.e. nearly black over a restricted range of wavelengths.

Relative darkness by its definition points towards a restricted set of visions (*eyes*), and the closure of their respective visual spaces. Absolute darkness, by contrast, points to darkness shared by *all possible visions*, whether biological, artificial, terrestrial, or extra-terrestrial, and hence the closure of all possible visual spaces imaginable. Even though our eyes are unable to distinguish between relative and absolute dark, the conceptual realisation of the impossibility of absolute darkness in our Universe has symbolic significance on variety of levels that go far beyond human vision, by potentially opening the doors of imagination to other *lights* and the vistas they *illuminate* - that are open to *other visions* - which we shall never see.

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REFERENCES

Adams, F. C.; Laughlin, G., `A dying universe: The long-term fate and evolution of astrophysical objects', *Reviews of Modern Physics*, vol. 69, no. 2, 1997, pp. 337–372.

N. Aghanim, Y. Akrami, M. Ashdown, J. Aumont, C. Baccigalupi, M. Ballardini, A. J. Banday, R. B. Barreiro, N. Bartolo et al. (172 more) `*Planck* 2018 results - VI. Cosmological parameters', *Astronomy & Astrophysics*, vol. 641, 2020, A6.

Baden, T and Osorio, D., `*The retinal basis of vertebrate color vision'*, *Annual Review of Vision Science*, vol. 5, 2019, pp. 177-200.

Badiou, A. (2019) *Black, The brilliance of non-color*. Polity Press.

Christopoulos, M., Karakantza, E.D. and Levaniouk, O. (Eds) (2010), *Light and Darkness in Ancient Greek Myth and Religion*. Lexington Books, Rowman & Littlefield Publishers, Inc.

Cronin, T.W., Douglas, R.H, `Seeing and doing: how vision shapes animal behaviour', *Phil. Trans. R. Soc.* B, vol. 369, 2014, 20130030.

Cui, K. and Wardle B. L., `*Breakdown of Native Oxide Enables Multifunctional,* Free-Form Carbon Nanotube–Metal Hierarchical Architectures', *ACS Applied Materials & Interfaces*, vol. 11, no. 38, 2019, pp. 35212-35220.

Desmond Ramirez, M., Speiser, D., Sabrina Pankey, M., & Oakley, T., `*Understanding the dermal light sense in the context of integrative photoreceptor cell biology'*, *Visual Neuroscience*, vol. 28, no. 4, 2011, pp. 265-279.

Dyson, F., `Time without end: Physics and biology in an open universe', *Rev. Mod. Phys.*, vol. 51, 1979, pp. 447-460.

Freese, K., Kinney, W.H., `*The Ultimate Fate of Life in an Accelerating Universe'*, *Physics Letters B*, vol. 558, no. 1-2, 2003, pp. 1-8.

de Grasse Tyson, N.; Tsun-Chu Liu, C.; Irion, R. (2000), *One Universe: At Home in the Cosmos*. Joseph Henry Press. ISBN 978-0309064880.

Gross, C., `The fire that comes from the eye', *The Neuroscientist*, vol. 5, 1999, pp. 58-64.

Hawking, S. W., `Black hole explosions?', *Nature*, vol. 248, no. 5443, 1974, pp. 30–31.

Hecht, S., Schlaer, S. & Pirenne, M. H., '*Energy, quanta and vision*', *J. Opt. Soc. Am.*, vol. 38, 1942, pp.196–208.

Heeck, J., `How Stable is the Photon?', *Phys. Rev. Lett.*, vol. 111, 2013, 021801.

Holmes, R. et al., `Determining the Lower Limit of Human Vision Using a Single-Photon Source', in *Research in Optical Sciences*, OSA Technical Digest (online) (Optical Society of America, 2014), paper QTu2A.2.

Hooper, D., `Life Versus Dark Energy: How An Advanced Civilization Could Resist the

Accelerating Expansion of the Universe', *Phys. Dark Univ.*, 2018, vol. 22, pp. 74-79.

Jacobs, G.H., `*Evolution of colour vision in mammals'*, *Phil. Trans. R. Soc.* B, vol. 364, 2009, pp. 2957–2967.

Krauss, L.M. and Starkman, G. D., `Life, *The Universe, and Nothing: Life and Death in an Ever-Expanding Universe'*, *Scientific American*, vol. 281, no. 5, 1999, pp. 58-65.

Leanhardt, A.E., Pasquini, T.A., Saba, M., Schirotzek, A., Shin, Y., Kielpinski, D., Pritchard, D. E. , Ketterle, W., `*Cooling Bose-Einstein Condensates Below 500 Picokelvin'*, *Science*, vol. 301, Issue 5639, 2003, pp. 1513-1515.

Lemmelijn, B., `Light and darkness: from reality to literature', *Scriptura*, vol. 111, 2012, pp. 555-568.

Masanes, L., Oppenheim, J. A., `General derivation and quantification of the third law of thermodynamics', *Nat Commun*, vol. 8**,** 2017, 14538.

Osorio, D. and Vorobyev, M., A review of the evolution of animal colour vision and visual communication signals, *Vision Research*, vol. 48, 2008, pp. 2042–2051.

Sahai, R. and Nyman, L.Å., `The Boomerang Nebula: The Coldest Region of the Universe?', *The Astrophysical Journal Letters*, vol. 487**,** 1997, pp. 916-920.

Schwab, I.R., `The evolution of eyes: major steps. The Keeler lecture 2017: centenary of Keeler Ltd', *Eye*, vol. 32, 2018, pp. 302–313.

Sorrensen, R. (2008), *Seeing Dark Things*, Oxford University Press.

Stoddard, M.C., Eyster, H. N., Hogan, B.G., Morris, D.H., Soucy, E.R. and Inouye, D.W., `Wild hummingbirds discriminate nonspectral colours', *PNAS*, vol. 117, no. 26, pp.15112-15122.

Tavakol, R., `World without Colour and its Photographs & Optical Images', *Philosophy of Photography*, vol. 11, nos. 1-2, 2020, pp. 79-97.

Tinsley, J., Molodtsov, M., Prevedel, R. et al., `Direct detection of a single photon by humans', *Nat Commun*, vol. 7, 2016, 12172.

Tomassoni, R., Galetta, G., & Treglia, E., `Psychology of Light: How Light Influences the Health and Psyche', *Psychology*, vol. 6, 2015, pp. 1216-1222.

Williams, D.L., `Light and the evolution of vision', *Eye*, vol. 30, 2016, pp. 173–178.

Zubairy M.S. (2016) A *Very* Brief History of Light. In: Al-Amri M., El-Gomati M., Zubairy M. (eds). *Optics in Our Time*. Springer, Cham.