Selected papers - astrophysics, cosmology, general physics

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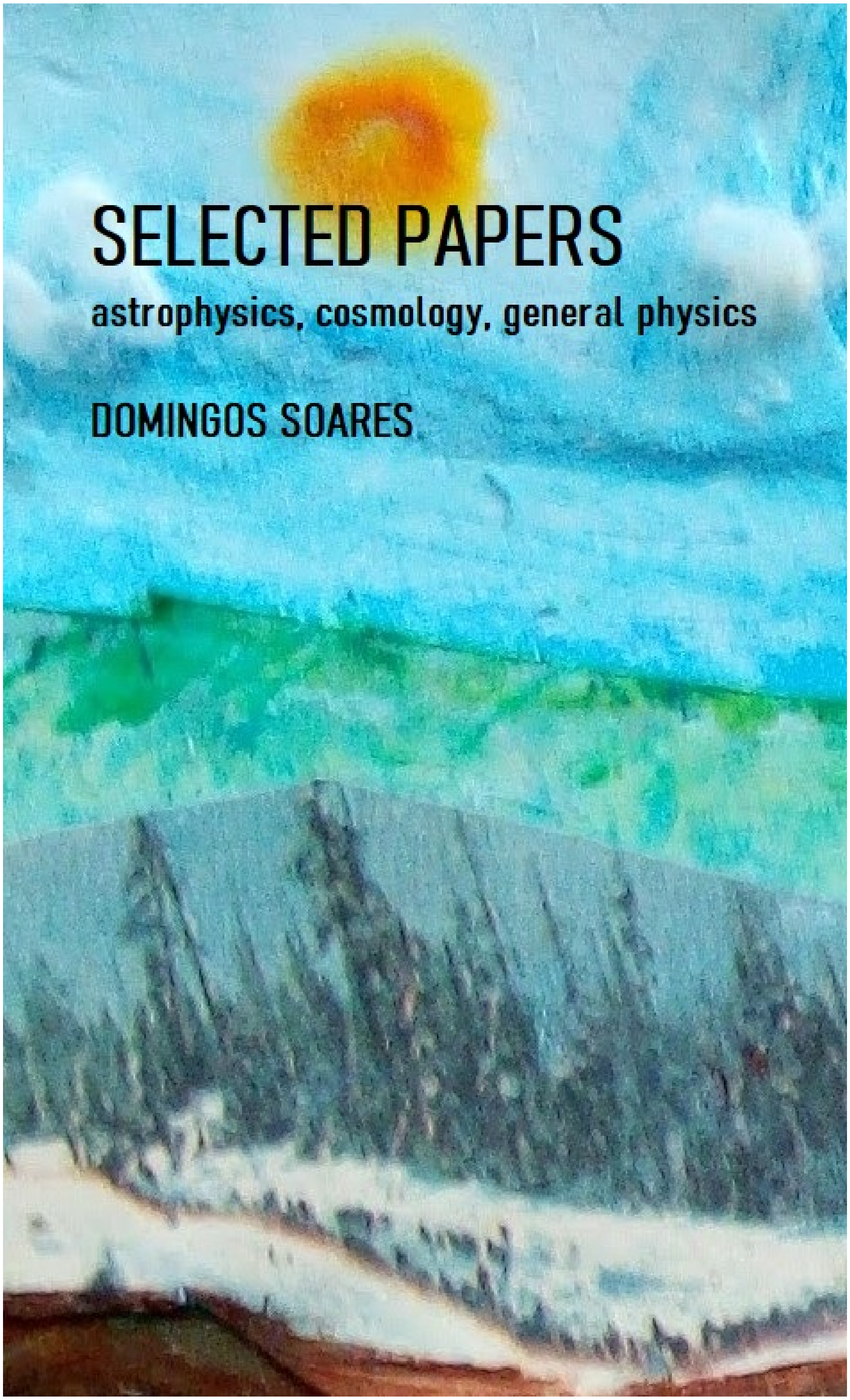
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Contents

Preface

This selection contains articles that I wrote during the first two decades of the 21st century. Its subjects are astrophysics, cosmology and general physics, distributed in four parts. Part I is my Eddington trilogy on astrophysics and cosmology. Part II discusses the inconsistencies I see in Einstein's realm of relativity and physics. The third part is about the general issue of life in the universe. I conclude, in part IV, with three articles on various subjects, namely, general physics, speculative cosmology and the still very current question about the reality of the expanding universe.

There are materials for all tastes and levels of education, but they are intended primarily for readers in the physical sciences.

Most of the articles were written when I lectured relativistic cosmology at the undergraduate physics course of the Physics Department at the Federal University of Minas Gerais, Belo Horizonte, MG, Brazil, during the period of 2001 to 2010. I would like to thank my students of all semesters, during the 10 years I dedicated to the course, for their enthusiastic participation in every activities and for the encouragement they gave me, which led to the compilation of this selecttion of papers.

I am also grateful to Prof. Reynier Peletier of the Kapteyn Astronomical Institute, University of Groningen, The Netherlands, for allowing me to use the Kapteyn Institute computer, which was very helpful, especially in the preparation of several figures and diagrams that appear in some of the articles.

The cover is a painting by my wife Lu Soares entitled *"Pôr-do-sol acima do mar"* ("Sunset over the sea"), for which I am very grateful. This and her other paintings can be seen at `https://www.youtube.com/watch?v=6l9TBeEzIKY`.

All chapters of this selection appear on my personal electronic page at the Physics Department (`http://www.fisica.ufmg.br/dsoares/index-e.html`) in the sections ***"Topics in relativistic cosmology"*** and ***"Texts & News"***. Versions in Portuguese of some of the papers are available at `http://lilith.fisica.ufmg.br/~dsoares/cosmos/21/cosmos16.htm`.

Domingos Soares

Belo Horizonte, MG, December 2021

Part I

Arthur Eddington

Chapter 1

Eddington versus Chandrasekhar on the stellar fate[1]

1.1 Introduction

The facts that motivated the story that I am about to tell occurred in 1935, in the United Kingdom, more specifically in England. The protagonist is the English astrophysicist Arthur Eddington (1882-1944) and the "victim" of his protagonism is the, then young, Indian astrophysicist Subrahmanyan Chandrasekhar (1910-1995). Eddington at that point was the most prestigious astrophysicist of the time, having been one of the greatest responsible for the creation of a new science, namely, the application of physical laws to the study of the structure and evolution of stars.

Chandrasekhar, a 25 years old young man, is initiating himself in the unknown meanders of stellar evolution. His discoveries of that year are in the core of the Nobel Prize in physics that he would earn in 1983, together with the American nuclear physicist William Fowler (1911-1995). But Chandrasekhar's path was not easy, because he, already in the beginning, stumbled upon Eddington's scientific prejudices, who was the herald of what could or could not be true in scientific developments in his field of research. Some authors even state that his castrating actions with respect to Chandrasekhar and the applications that he undertook of the new scientific ideas of the period — Quantum Mechanics (QM) and the Special Relativity Theory (SRT) — may have delayed the development of the studies in stellar evolution for more than 20 years.

Let us know then some details of this interesting and exciting story. In section 1.2, I present the object responsible for Eddington's almost personal reaction, that is, the white dwarf star. I discuss also in this section the cu-

[1] https://www.researchgate.net/publication/334973879

rious concept of "degenerate matter". Section 1.3 is dedicated to the famous "Chandrasekhar limit", that so much repulsiveness caused to the Englishman. The scene is ready for the presentation of yet another manifestation of scientific autocracy by Arthur Eddington, which is done in section 1.4. I show some additional comments in section 1.5.

1.2 White dwarfs

The evolution of a star is marked by the counterpoint between two enormous forces. One, gravitational, resulting from the star own weigh, that impels it to collapse. Another, caused by the pressure existing in the stellar interior, that opposes itself to the gravitational collapse. The star is stable when there is equilibrium between these two forces. When it is broken, the star fate may be characterized by a violent implosion or by a gradual and non violent change in the stellar structure.

According to the Chinese American educator and astrophysicist Frank Shu, the possible final stages of the evolution (of the "life") of a star are [1, p. 125]:

1. Nothing. The star explodes — implodes — and, if the final explosion is energetic enough, nothing is left from the original object. The stellar material spreads to the interstellar medium enriching it with new chemical elements synthesized during the final explosion.

2. A dwarf star of *degenerate matter*, which is the central core of a very old star, whose initial mass is less than $\approx 10\ M_\odot$ (solar mass). Most of the stellar mass is expelled during the pre-dwarf stages. The dwarf star is very bright and because of that is called a **white dwarf**. As time passes by, and the consequent loss of energy, the white dwarf eventually cools and becomes dark. The stability of the white dwarf comes from the quantum behavior of the electrons that exist in its interior. A typical white dwarf **has mass slightly less than the mass of the Sun** and diameter comparable to Earth's diameter ($\approx$ **10,000 km**). That is, extremely dense material.

3. A neutron star, also of degenerate matter, that is left from the implosion of a star of very large mass, between 10 and 30 $M_\odot$. The stability of the neutron star comes in part from the quantum behavior of the neutrons that exist in its interior. A typical neutron star **has mass slightly greater than the mass of the Sun** and diameter of the order of **10 km**, that is, a size comparable to the distance of a 2-hour brisk walk. The neutron star material is about 1 billion times denser than the dwarf star material.

4. A black hole. In fact, if the stellar mass is greater than $\approx 30\ M_\odot$, the fate of the star is not yet fully understood, because for that one needs a **quantum gravity theory**, which does not exist. The **unknown object** is called "black hole", in the orthodox scientific literature, as Shu does, and much *educated* speculation is done around it. General Relativity Theory is

able to describe such an object to a well-defined limit diameter, which is 3 km for a final object of 1 $M_\odot$. The mean density inside a sphere with that diameter and with that mass is about 50 times greater than the density of neutron star with the same mass (further details in [2, 3]).

1.2.1 Degenerate matter

A WD star is extremely compact because the compression due to its auto-gravitation is enormous. Since the beginning it was realized that the pressure of a normal gas is completely inadequate to support the pressure exerted by the WD gravity. Even adding the electromagnetic radiation pressure of the stellar interior, it is impossible to get a star in equilibrium. Quantitatively, this is very easy to show (see [4, p. 583]) and, consequently, the very existence of the WDs constituted a real mystery.

The answer to this problem would be in the then recent theory of quantum mechanics and was discovered in 1926 by the British physicist R. H. Fowler (1889-1944). He applied the new idea of the Pauli exclusion principle to the electrons in the interior of a WD, which form a gas soaked in a sea of heavy ions. He discovered the new quantum phenomenon of the **"degenerate electron pressure"** [4, p. 584] [5, p. 141]. Fowler discovered, in reality, a new inhabitant of the material world, the **"degenerate matter"**.

In the advanced stages of its evolution, the star runs out of its nuclear fuel and starts to lose mass from its external part and collapses until reaching very high densities, when then the matter that is important for the star equilibrium is now degenerate. To understand what degenerate matter is, we need to talk a bit about the fundamental particles in nature. They can be separated in two classes, **bosons** and **fermions**, according to their *spins*, which are quantum properties related to the intrinsic rotations of the particles.

Boson spins are given by whole numbers — the photon is a boson — and fermion spins by semi-integers, 1/2, 3/2, etc. Quarks, electrons, protons, neutrons are examples of fermions. We ourselves and almost everything around us are made of fermions. Bosons and fermions have very distinct quantum behaviors, especially in their mutual interactions. The roots of this difference are in **quantum statistics**, a new form of statistics that describes the behavior of particles at the microscopic level (see [1, p. 50]). For example, the great difference between bosons and fermions that concern us appears in the application of the *Pauli exclusion principle*, that states: **"Two identical fermions cannot occupy the same quantum state"**.

Degenerate matter is formed by a very high-density fermion gas, in which the interaction between its constituent particles is predominantly the quantum repulsion originated in the impossibility of the particles to occupy the same quantum state. The fermions — electrons in WDs and neutrons in neutron stars — are so compressed that they exert a very high pressure, opposed to the gravitational collapse. The interaction between the degenerate electrons is totally due to the Pauli exclusion principle whilst the interaction between the neutrons is partially due to the exclusion principle and partially due to repulsion of the nuclear force that exists between them (the nuclear force becomes repulsive at the distances that occur in the core of neutron stars).

Electrons are the fermions of interest here. They are mixed with positive ions and form a very dense fluid in WD stars, i.e., a degenerate "gas". Such a gas does not obey the classical laws according to which its pressure is proportional to the temperature and density. The equation of state of a normal gas, non-degenerate, is given by pV = nRT or $\mathbf{p} = \boldsymbol{\rho}(\mathbf{R}/\mathbf{M})\mathbf{T}$, where $\mathbf{p}$ is the gas pressure, $\mathbf{V}$ its volume, $\mathbf{M}$ its molecular mass and $\boldsymbol{\rho}$ its density. Now, the equation of state of a degenerate gas is given by $\mathbf{p} \propto \boldsymbol{\rho}^{\gamma}$, where $\boldsymbol{\gamma} = \mathbf{5/3}$ for a non-relativistic gas and $\boldsymbol{\gamma} = \mathbf{4/3}$ for a relativistic gas. The degenerate electronic gas is relativistic when the gravitational compression is very high (much greater than the non-relativistic case), causing the electrons to have relativistic speeds, i.e., near the speed of light. As we shall see, this will occur for WDs with extreme masses.

One consequence of the equation of state of degenerate matter is a peculiar behavior, namely, the **gas volume is inversely proportional to the mass**, that is, $\mathbf{M_{AB} \times V_{AB} = constant}$ [4, p. 589] [1, p. 127]. This is illustrated in figure 1.1.

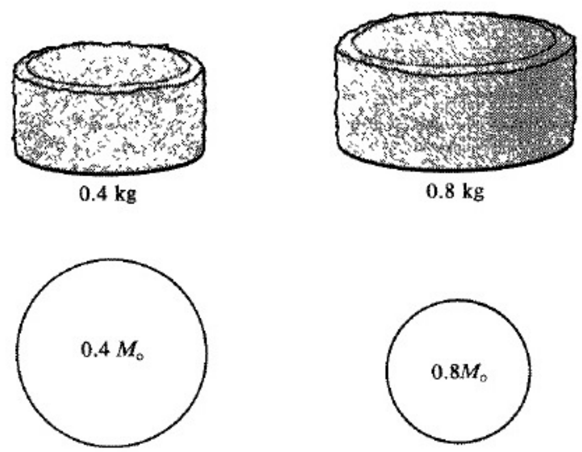


Figure 1.1: Astrophysicist Frank Shu's chocolate cake has a volume twice as large when its mass is doubled. Whereas the WD behaves itself in a totally different manner, because its volume is reduced to half when its mass is doubled. This is so because the degenerate gas repulsion must increase in order to support the larger mass, which only occurs if the degenerate electrons get closer (figure from [1, p. 127]).

To understand this we have to remember that the outward pressure, by the degenerate electrons, is described by two quantum principles. First, the **Pauli exclusion principle**, that guarantees the individuality of the electrons during the compression of the WD. Secondly, the **Heisenberg uncertainty principle**, which states that **it is impossible to know simultaneously the position and the linear momentum of any particle with infinity precision**. Quantitatively, it is expressed as $\mathbf{\Delta p_x \times \Delta\ x > h}$, where $\mathbf{\Delta p_x}$ is the uncertainty in the knowledge of the linear momentum of the particle — ultimately of its velocity —, $\mathbf{\Delta x}$ is the uncertainty in its position and $\mathbf{h}$ is the Planck constant. The WD with the larger mass collapses and makes $\mathbf{\Delta x}$ to decrease tremendously, because the electrons are forced to very small regions and then $\mathbf{\Delta p_x}$ increases enormously — consequently, the electron speeds —, giving rise to the enormous pressures that oppose the gravitational compression of the WD (cf. [1, p. 126]). Therefore, the star with the larger mass, shown in figure 1.1, has to have a smaller volume to support the larger compression of gravitational origin. A final note: the relation $\mathbf{M_{AB} \times V_{AB} = constant}$ is valid for a **non-relativistic** degenerate gas; for the relativistic gas, the volume decreases more than the predicted by this relation [4, p. 589].

We shall see now how the above considerations led Chandrasekhar to discover that the WDs could only exist if their masses were lower than a given maximum value.

1.3 Chandrasekhar limit

Fowler's article treating the subject of degenerate matter, entitled ***On Dense Matter***, was published on the December 10, 1926 edition of the British scientific journal *Monthly Notices of the Royal Astronomical Society.* It was in this article that Chandrasekhar became aware of Eddington's book *The Internal Constitution of the Stars*, where there was a detailed description of the above-mentioned **WD mystery** (cf. [5, p. 141]).

Chandrasekhar understood that the solution of the mystery was in Fowler's new ideas. The stellar internal pressures could not, in these extreme cases, be described by the pressure originated from the gas thermal energy, but by the new quantum phenomenon of the **degenerate electron motions** [5, p. 145]. But he went beyond and here Chandrasekhar's fundamental contribution appears. He realized that the electrons could reach speeds larger than the speed of light for a sufficiently massive WD. What would be impossible, as prescribed by SRT. Then, by including this relativistic effect in the description of the degenerate electrons, he concluded that there ought to exist a mass limit for a WD, in such a way as to avoid the speeds larger than the speed of light. Therefore, for masses larger than this limit, the relativistic degenerate electron gas could not support the gravitational collapse of the star. Figure 1.2 illustrates Chandrasekhar's discovery. As seen above, the equations of state of degenerate electrons are:

- **non-relativistic electrons**: $\mathbf{p \propto \rho^{5/3}}$
- **relativistic electrons**: $\mathbf{p \propto \rho^{4/3}}$

These equations can be expressed in another form, namely, **the pressure versus the external circumference** of the star, being the latter related to its density. This is the way the equations of state of the degenerate electrons appear in figure 1.2.

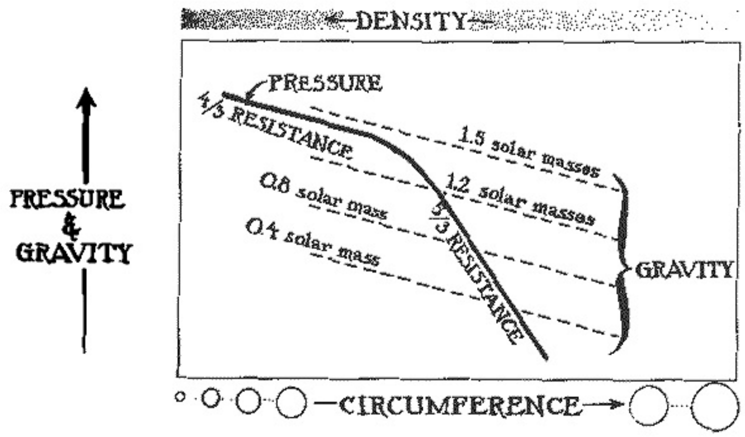


Figure 1.2: Figure presented by Kip Thorne ([5, p. 156]) to explain the origin of the **Chandrasekhar limit**. The intersections of the dashed lines with the solid curves of the equations of state show the WDs equilibrium points. For masses above approximately 1.4 $M_\odot$ there is no point of intersection and gravity will always win the degenerate electron pressure, leading to the final collapse of the star. Notice that the rate of increase of gravity (dashed lines) is analogous to the rate of increase of resistance to compression with exponent 4/3.

Chandrasekhar limit is 1.43 $M_\odot$. The white dwarfs and the degenerate and non-degenerate gases are presented in detail in chapter 15 of ref. [4], entitled *The Degenerate Remnants of Stars.*

1.4 Eddington and the horror to the collapse

As soon as he became aware of the ideas of the young Chandrasekhar, Eddington expressed horror to what could happen to a star whose mass exceeded the limit found by the Indian astrophysicist. From the beginning he denied the existence of a limit, because he believed that nature would find its way to avoid the final collapse.

Indeed, for stars with mass larger than 1.43 $M_\odot$, but smaller than about 30 $M_\odot$, nature solved the problem. The collapse is avoided by the forces of the Pauli exclusion principle of the neutron degenerate gas and by the nuclear force between neutrons. And for stars with initial mass larger than 30 $M_\odot$? Here it seems that Eddington was right, nature must find a way. **but we certainly still don't know what it is**. Unless we wish to follow Professor Frank Shu

— beginning of section 1.2 — and adopt the *science digression* object that goes by the name of *black hole* (cf. [6]).

Eddington had his own digression ant presented it not only to Chandrasekhar but publicly in a meeting of the *Royal Astronomical Society* on January 11, 1935. In this meeting, first Chandrasekhar talked about his derivation of the mass limit and thereafter Eddington presented a talk under the title *"Relativistic Degeneracy"* [5, p. 156], in which he stated that the union between QM and SRT made by Chandrasekhar was not licit, in his own words, ***"I do not regard the offspring of such a union as born in lawful wedlock"***. And more, ***"I feel satisfied myself that if the meshing is made correctly, the relativity corrections are compensated, so that we come back to the 'ordinary' formula"***, that is, the formula of the equation of state with the exponent 5/3 for all densities, thereby avoiding the establishment of a mass limit. And consequently avoiding the unknown physical problem for masses larger than the limit [5, p. 160]. The situation corresponds, in figure 1.2, to eliminating the curve with exponent 4/3 and considering the curve with 5/3 extrapolated to the region of high density (correspondent to small circumference).

The pressure against Chandrasekhar's ideas was tangible, because Eddington was, at the time, the greatest British astronomical personality. Then, if Eddington thought that the Chandrasekhar ideas were wrong, the widespread thinking was that clearly they *should* be wrong.

Chandrasekhar, in his despair, tried to get the opinion of the Danish physicist Niels Bohr (1885-1962), one of the fathers of QM. Through an intermediary, he got to hear what he wished: Bohr believed that Eddington was wrong and that he should go on with his work (cf. [5, p. 162]). And by the end of the 1930s, even with Eddington's persistence, the majority of the astronomers were convinced of the correctness of Chandrasekhar's analysis in the problem of the WDs, in spite of not speaking out publicly their believes.

1.5 Final comments

In order to appreciate the importance of the theoretical discoveries of Chandrasekhar, in the mid-1930s, it is necessary to reaffirm the extraordinary scientific influence of the other character in this story. Arthur Eddington was the most important astrophysicist in the beginning of the 20th century. His influence was felt in several aspects of theoretical physics, especially in the recent General Relativity Theory of Albert Einstein (1879-1955) and in the, also young, science of cosmology (see [7] for a discussion of his influence in the first case and [8] for the latter).

In stellar astrophysics, Eddington was the first astronomer to put forward detailed theoretical models to study the internal structure of stars, which were able to reproduce their observed properties, such as temperature and physical dimensions (mass, radius, etc.). In 1926, he published one of his most famous books, *The Internal Constitution of the Stars*, that would become the most important reference source for the researchers of stellar structure. And that was what attracted the young Indian astrophysicist Subrahmanyan Chandrasekhar. Of such a magnitude was the influence of Eddington in the astronomical community of the time, that in 1939 Chandrasekhar gave up working with the WDs and turned his attention to other subjects. He would return to the WDs only 25 years later.

The American physicist Kip Thorne is a passionate champion and active theorist of the concept of black hole. In his book, mentioned previously [5], he tells the Eddington-Chandrasekhar *tragedy* in a very vivid and informative manner. His aim is to suggest that Eddington abhorred the possibility of the ultimate gravitational collapse and the consequent formation of an extreme object like the one represented by the black hole. One problem with such an interpretation is that, in the mid-1930s, the concept of black hole was not solid yet. Another contribution of the same suit: in 2005, a competent British scholar in history and philosophy of science treated at great length the dispute between the two astronomers [9]. The title of his book could not be more revealing, namely, *"Empire of the Stars: Obsession, Friendship, and Betrayal in the Quest for Black Holes"*. The correct view, however, seems to be the one totally opposite to that of both scholars, that is, that the question of the black hole had not any role in the scientific dispute between Eddington and Chandrasekhar. The real dispute was between the *novel* scientific thinking, that tried to impose itself, and the retrograde scientific approach, that struggled to preserve itself, even at the cost of using authority, which is unacceptable in the context of the truthful science.

The end of the story is known: Chandrasekhar was right and the Nobel prize in physics that he would earn in 1983 was justified precisely by his original work about the fate of the WDs. The citation for his prize was **"for his theoretical studies of the physical processes of importance to the structure and evolution of the stars"**.

Chapter 2

The 1919 Eddington eclipse[1]

2.1 Introduction

Since ancient times authority has been a leading driving force in the predominance of scientific ideas. Aristotelian thinking dominated western science for centuries, most of the period based solely on the authority of the master, a behavior summarized in the dictum *"Magister dixit"* or *"The master has said it"*, neglecting further discussion on the matter. Things haven't changed, but now with additional flavors.

Modern science is both authority-driven and — a novelty — money-driving. The prototype of the authority-driven type is the 1919 astronomical missions to observe a solar eclipse and designed to "prove" that General Relativity Theory (GRT) was right in a particular prediction, namely, the amount of light deflection by a massive body. The final aim was to prove the supremacy of Einstein's over Newton's theory of gravity. Its main character is the Englishman Arthur Stanley Eddington (1882-1944), who is presented in more detail in section 2.2. Eddington's behavior resonates in a variety of ways over time and still in modern days.

Although not costly as modern science experimental projects, the 1919 solar eclipse — the *Eddington eclipse* — mission could also be considered extremely heavy in financial expenditure, in view of the state of the world in the late 1910s, just freed from a bloody worldwide war. It is presented in section 2.3. Unquestionable money-driven projects are described in section 2.4. Final remarks appear in section 2.5.

[1] `https://www.researchgate.net/publication/332849428`

2.2 Arthur Eddington

The astronomer, physicist, and mathematician Arthur Eddington was a "rising star" in the academic world of Cambridge already at the age of 25: he developed a new statistical astronomical method and for that he won, in 1907, a prestigious prize awarded annually at the University of Cambridge, the Smith's Prize. Shortly after, in 1914, Eddington was named the director of the Cambridge Observatory and elected a Fellow of the Royal Society at that same year.

Soon he became an expert in GRT, published in its final form in 1916. In 1918 he wrote and published the *"Report on the relativity theory of gravitation"* [10], the first account of GRT to the English speaking world. The authority of Eddington regarding GRT was publicly acknowledged. The following anecdote is frequently told when exhalting Eddington's expertise in the matter. I quote Wikipedia [11] (see also [12, p. 353]):

> *(...) He was an early advocate of Einstein's General Relativity, and an interesting anecdote well illustrates his humor and personal intellectual investment: Ludwik Silberstein, a physicist who thought of himself as an expert on relativity, approached Eddington at the Royal Society's (6 November) 1919 meeting where he had defended Einstein's Relativity with his Brazil-Principe Solar Eclipse calculations with some degree of skepticism, and ruefully charged Arthur as one who claimed to be one of three men who actually understood the theory (Silberstein, of course, was including himself and Einstein as the other). When Eddington refrained from replying, he insisted Arthur not be "so shy", whereupon Eddington replied, "Oh, no! I was wondering who the third one might be!".*

The solar eclipse of 1919 would offer an excellent opportunity for an observational test of one of the predictions derived from GRT, namely, the bending of stellar light at grazing incidence on the sun [13]. It can be genuinely called the *Eddington eclipse*, mostly because it was the driving force of reassuring Eddington's preconceptions relative to GRT. Irrespective of the outcome of the observations, Eddington was sure that the eclipse would prove GRT prediction right and it really did it, not without his and collaborators biased analysis of the data. According to [12, p. 353]:

> *Eddington was enthralled by general relativity as soon as he was exposed to it by de Sitter, and he rapidly became Einstein's self-appointed evangelist in Britain. He once admitted that if it had been up to him, he wouldn't have bothered making an eclipse expedition because he was already certain that the theory had to be right.*

Eddington repeat here a well-known behavior of Einstein himself, which is summarized in [14].

2.3 The Eddington eclipse

One of the most famous predictions of GRT was the gravitational deflection of light. The proof of this effect could, in principle, be done during a solar eclipse. Background stars around the solar disc could be used as light sources for an observational experiment. GRT predicts that, at grazing incidence on the solar limb, there is a deflection of 1.75 arc second in the trajectory of a light ray. In other words, the position of a star observed close to the solar disc, during the eclipse, should be displaced of this angle, when observed without the gravitational influence of the Sun on the light, i.e., when observed a few months later. There is also a purely Newtonian prediction for the effect, which is precisely *one half* of the relativistic prediction (more details in [15, p. 188] and a summary in [13]).

There are two pertinent questions, namely:

1. Is there a gravitational deflection of light?

2. If so, what is the better theoretical description of the phenomenon, the Einsteinian, the Newtonian or a third alternative?

In 1919, Frank Dyson (1868-1939), then director of the Cambridge Observatory and Astronomer Royal, with the aid and counseling of Arthur Eddington, organized two scientific expeditions for the observation of the solar eclipse that occurred 100 years ago on May 29th. Astronomers Andrew Crommelin (1865-1939) and Charles R. Davidson (1875-1970) head one of the expeditions, to the city of Sobral, in Northeast Brazil, and Eddington and Edwin T. Cottingham (1869-1940) head the other one, to Principe island, located on the western coast of Africa.

A typical *non critical* account of both expeditions is given in chapter 16 of the most renowned biography of Einstein, that of Abraham Pais [16]; ref. [17] is a recent one, with the same bias. References [12, chs. 14 and 25] and [18] present critical historical accounts of the expeditions, from which I extracted and enumerated below the main technical issues that precluded a definite answer, at the occasion, to question 2 above.

1. A major problem — immediately noticed — for the comparison between the observations during the eclipse, at daytime, and out, at nighttime, was variations in room temperature. These alter the structure of the instruments and, therefore, alter the focuses of the telescopes. The temperature has also influence in the conditions of the atmospheric turbulence. In total, there were twelve different kinds of factors that should be accounted for, which implied in the need of observations of a minimum of six pairs of stars, in and out of the eclipse ([12, p. 356]).

2. There were two instruments in Sobral, an astrographic camera, from Greenwich, and an Irish telescope, with a 10-cm lens. In the Principe island, there was another astrograph. Bad weather predominated at Principe, but Eddington insisted in taking photographs and obtained two plates in which there were only five stars, albeit with blurred images. Even so, Eddington, using additional assumptions and approximations, was able to obtain a result for the deflection of light, namely, 1.61 arc second. In Sobral, the meteorological conditions were better. The Irish telescope gave

the best results: seven plates with seven stars. Eddington's analysis resulted in 1.98 ± 0.12 arc second. The astrograph recorded more stars, but the temperature effect on the instrument was drastic. The result was 0.86 arc second — the Newtonian prediction —, nonetheless, with a large uncertainty. Which would be the correct answer? Eddington decided to neglect the Sobral astrograph result and simply took the mean of the other results. Precisely 1.75 arc second, the relativistic prediction ([12, p. 359]).

3. The local *seeing*, i.e., the blurring of a stellar image due to atmospheric turbulence, in both sites, would avoid measuring details smaller than 2–3 arc seconds. At that time it was already clear that only in exceptional atmospheric conditions a resolution of the order of 1 arcsec could be obtained. Nowadays it is recognized that by means of active and adaptive optics techniques, it is possible to reduce seeing to less than 0.5 arcsec, but still needing exceptional conditions of observation. Such a problem increases during afternoons, due to the heat accumulated in the ground. The observations in Sobral were realized close to noon, and in the Principe island around 2 pm. The seeing for the Irish telescope could never be less than 1.25 arcsec, which would invalidate the quoted accuracy of 0.01 arcsec for some of the results ([18, app. II]).

4. During the stay in Sobral, the temperature varied from 24 °C, at night, to 36 °C, in the afternoon. Effects on the Sobral astrograph were especially disastrous. Its focus seemed to have changed, from the night of May 27th until the beginning of the eclipse, in the early 29th afternoon. When the team returned to Sobral, in July, to record the comparison plates, it was realized that the instrument was back to the previous focus ([18, app. II]).

5. Marmet and Couture [18] also pointed out that the small number of observed stars was an impediment for the correct interpretation of the data.

6. From the theoretical standpoint, it is reported that the Polish-American physicist Ludwik Silberstein (1872-1948) indicated, in a meeting of the Royal Astronomical Society, that the displacements of the stars were not radial, with respect to the Sun center, as predicted by GRT, but sometimes deviated from that direction by up to 35°.

It is worthwhile mentioning at this point that none of later solar eclipse missions in 1922, 1929, 1936, 1947 and 1952 yielded conclusive results about the amount of light deflection (Newtonian or Einsteinian, cf. [19, p. 68]). The GRT result has been indeed confirmed later by observations in the radio wavelength range. Only recently, from observations of the total solar eclipse on August 21st, 2017, it was claimed that the 1.75 arc second bending was observed in visible light, with an accuracy of 3% (cf. [20]). It is an instructive exercise to compare the extreme rigor, the modern techniques and instrumentations used in ref. [20] with the rough experiment undertaken in the Dyson-Eddington missions. The impossibility of a conclusive result therein will clearly emerge.

Nobody really knew, then, the specifics of the data reduction process realized by Dyson in conjunction with Eddington. Marmet and Couture, Appendix C [18] describes the praise of authority in a section of the Royal Astronomical Society:

> *The results from the 1919 expedition were quickly accepted by the scientific community. When preliminary results were announced, Joseph Thomson (from the Chair) said: "It is difficult for the audience to weigh fully the meaning of the figures that have been put before us, but the Astronomer Royal [Dyson] and Prof. Eddington have studied the material carefully, and they regard the evidence as decisively in favor of the larger value for the displacement."*

2.4 Similar cases in modern science

In modern science the "authority" of a person is substituted by the "authority" of, first, a group of scientists that lend their joint support to a particular scientific view, and, second, the enormous financial resources applied to an — often unique in many aspects — experiment. In the latter case, preliminary results are heralded as great discoveries in order to justify the huge investments made (such as LHC, LIGO-Virgo, EHT, etc.).

The prevalence of the Standard Model of Cosmology — with the ad hoc components of dark matter and dark energy — is an example of the first case. The "detection" of the Higgs boson (2013), the "discovery" of gravitational waves (2016) and the putative observed "image" of a black hole (2019) are examples of the second case. All of these are contaminated by the "Eddington effect", that is, by the acceptance through "authority".

Note that the imposition by authority works particularly well for the experiment-authority case because the experiment can only be replicated by the very ones that claim the discovery in the first place. No checks and balances are available whatsoever if there are not independent confirmation of the claimed event.

2.5 Final remarks

It is interesting to see than even now, a hundred years after the Eddington eclipse, learned scholars are eager to prove that Eddington was right, the last example being ref. [17], where one learns that both Sobral and Principe Island photographic plates are nowhere to find, that is to say, there is no way of reanalyzing them with modern and finer techniques. Anyhow, it the plates were still here, an enhanced analysis would not improve the outcome, since the main issue with the observations is the accuracy of the data acquisition procedure.

Frank Dyson, responsible for the expeditions, coordinated the analysis of Sobral's data; he had not been there, though, as seen in section 2.3. It has been said (cf. [17]) that the analysis of Sobral's data, in charge of Dyson, and of Principe's data, in charge of Eddington, was completely independent of each other. That is not true, to say the least. Dyson and Eddington were closely related in their scientific competences and preferences. Eddington was earlier under Dyson orders and was then raising himself to high altitudes in the British scientific community. There is a similar fallacy in modern times in cosmology where the two groups that claim to have discovered the accelerated expansion of the universe are said to have gotten their conclusion in a completely independent way. That cannot be true since the expert in supernovae, crucial in both experiments, was the same, i.e., A.V. Filippenko (cf. [21]). Hence, to make things worse, there was, of course, detailed coordination in the data reduction procedures of both groups, under Eddington's guidance. The independence card is always played when a strong point is intended in a scientific dispute, especially those plagued by the Eddington effect.

It is worthwhile recalling that although the 1919 eclipse be always called upon whenever Einstein's gravity is remembered in a historical context, there are other gravity theories that predicted the same result (cf. [15]).

Sobral and Principe were the scene of a scientific farce, directed by Eddington, that perpetuated and replicated itself in other forms until today.

One can trace some of the roots of modern distrust in science in Eddington's fake result of the 1919 observations. Because of the many examples of Eddington's effect in early and modern science, the lay public often feels justified in its questioning of scientists' assertions that deal with important issues of public life. The most clear cut example is regarding climate change; scientists are not trustworthily considered in the issue.

Chapter 3

Father Lemaître and the expanding universe[1]

3.1 Introduction

The Belgian cosmologist Father Georges Lemaître (1894-1966) is widely considered as one of the "founding fathers" of the expanding-universe paradigm.

In 1922, the Russian cosmologist Alexander Friedmann (1888-1925) put forward a relativistic cosmological model that implied in the concept of an evolving universe departing from an initial state of extremely, if not infinitely, high density — a *singularity*. The idea had little impact until, some years later, when Georges Lemaître came with his investigation, independent of Friedmann, of a relativistic universe also dynamic and that evolved from a high-density initial state, which he called *Primeval Atom*. The English cosmologist Edward Harrison (1919-2007), in his *Cosmology* [22], on page 413, states that, because Lemaître was a priest, some contemporary cosmologists looked at the Primeval Atom with reservations and considered Lemaître's theory as an amalgam of science and religion. Such a reputation also fell over the theory that succeeded the Primeval Atom, namely, the *Hot Big-Bang* theory, being one of its main detractors the English astrophysicist and cosmologist Fred Hoyle (1915-2001).

I return now to the controversial issue of the alleged "expansion of the universe", motivated by the reading of a fairly interesting article, by the Irishman, from Dublin, solid-state physicist Cormac ORaifeartaigh. The article is entitled **The contribution of VM Slipher to the discovery of the expanding universe** [23], in which, on the pretext of claiming a nobler position for the American spectroscopist Vesto Slipher (1875-1969) in the worldwide pantheon of cosmology, ORaifeartaigh makes a general account of modern relativistic cosmology. And, as I said, it is fairly interesting: it presents misplaced generalizations and, to some degree, acceptable overviews.

[1] `http://lilith.fisica.ufmg.br/~dsoares/lemaitre/lemaitre-e.htm`

On page 8, in the second before last paragraph, there is a discussion about Hubble's law, in which ORaifeartaigh writes about the suggestions to change the law's name to "Hubble-Lemaître's law" or even "Lemaître' law". The tale is not new. Amongst others, the French cosmologist Jean-Pierre Luminet praised the Belgian cosmologist in an article entitled **Editorial note to "The beginning of the world from the point of view of quantum theory"** [24], in which the author claims in the first line that *"The year 1931 can undoubtedly be called Georges Lemaître's annus mirabilis"*, and advocates in the following pages the idea that Hubble's law should be called "Lemaître's law".

Let's recall: Lemaître published in 1927, in a Belgian scientific journal (*Annales de la Société Scientifique de Bruxelles*), an article, written in French, in which he puts forward a relativist model of an expanding universe. Lemaître makes a preliminary derivation of the constant of expansion (the future *Hubble constant*), using observational data of velocity and distance available at the time. Hubble would published his analysis of velocities and distances in 1929 — therefore, two years later —, where he presents his famous v×d diagram and the derivation of the constant of expansion. In 1931, Father Lemaître's article is translated to English and appears in the prestigious English scientific periodical *Monthly Notices of the Royal Astronomical Society* (MNRAS). In the translation, the derivation of the rate of expansion does not appear. Much speculation was done about this — *who would have censored the text with the aim of excluding the calculation?* —, until it was discovered by the astronomer Mario Livio (cf. **Mystery of the missing text solved** [25]) that it was Lemaître himself that had translated his paper to English, and that himself had omitted the passage in question.

Now, the Irishman mentions a statement of Lemaître's, in a letter, that accompanies the 1931 article, in which he writes that *"I do not think it is advisable to reprint the provisional discussion of radial velocities which is clearly of no actual interest"*. And many years later, in 1952, Lemaître remembers the case, with the following assertion, that I show in French and in English:

> *"Naturellement, avant la découverte et l'étude des amas des nebuleuses, il ne pouvait être question d'établir la loi de Hubble."*
>
> *"Naturally, before the discovery and study of the clusters of nebulae, it was not possible to establish Hubble's law."*

Why was not of *"actual interest"* the publication of the discussion of the expansion rate in MNRAS? Lemaître's later allegation, in 1952, points to his answer: *since the existence of galaxies was not yet a fully established fact, it was not appropriate, or relevant, the discussion of their expansion rate.*

I see two problems in this answer. First, why was the discussion relevant to the Belgian *Annales* but not for MNRAS? Second, the issue of the existence of galaxies was already being discussed, in objective and scientific manners, since, at least, 1920, when in April of that year, there occurred in the United States the famous *Great Debate*. Also called "Shapley-Curtis debate", the Great Debate was a public discussion, very important and widely spread at the time, between the renowned astronomers Harlow Shapley (1885-1972) and Heber Curtis (1872-1942), about the nature of the spiral nebulae, ultimately, about the size of the universe. Curtis championed that the *spiral nebulae* were independent galaxies of enormous sizes, and Shapley defended the opposing view. This debate did not solve the question, which would only be solved by Edwin Hubble (1889-1953), whose research about the topic was published in a sequence of three articles about galaxies of the Local Group: NGC 6822 (Barnard's galaxy, in 1925), M33 (Triangulum galaxy, in 1926) and M31 (Andromeda galaxy, in 1929). Such a research is masterfully and clearly documented in Hubble's book *The Realm of the Nebulae* [26], in the chapters IV (*Distances of Nebulae*) and VI (*The Local Group*). In other words, already in 1925, galaxies were a scientifically proved reality (see, for example, the article about NGC 6822 in [27]).

3.2 Father Lemaître and the Royal Society

Hence, why did Lemaître avoid the controversial issue in the 1931 English version? The answer is simple: Lemaître, so to speak, *sold his soul!* — which, we should agree, does not bode well, not even for a common citizen, let alone for a member of a religious institution.

Let us now address the nature of the sale.

The main character is the English astrophysicist Arthur Eddington (1882-1944), whom is one of the most influential — if not the most influential — scientific personalities of the time. Eddington was Hubble's friend and admirer and had been Lemaître's advisor, in his initial studies of astronomy in Cambridge during 1923 and 1924. (Then he would depart to the United States, where he would undertake his doctorate under the orientation of Harlow Shapley at the Massachusetts Institute of Technology.) Lemaître in his secular eagerness to become a member of the *Royal Astronomical Society*, and knowing about the influence that Eddington would have in this quest, avoided the conflict with Hubble about the priority in the calculation of the "expansion rate". Hubble had already expressed his will to Eddington that the questions relative to the "velocity" – distance diagram should be considered an undertaking of Mount Wilson Observatory — in other words, of himself and of his immediate collaborators. (And, conceptually, indeed and in practice it was, as all historical records show, if objectively analyzed.)

This is, therefore, the nature of the sale. Some corroborating details of such a hypothesis are in Mario Livio's article mentioned above. There, he states that on May 12, 1939, Father Georges Lemaître was elected member of the *Royal Astronomical Society*. And more, in 1953, he was the first to be awarded with the *Eddington Medal*, of this institution, for his important scientific contributions (*"for investigations of outstanding merit in theoretical astrophysics"*, cf. *Awards, Medals and Prizes of the Royal Astronomical Society* at `http://www.ras.org.uk/awards-and-grants/awards`).

3.3 Charles Darwin and Hubble's law

Let us now examine one more argument against the use of the name Lemaître in the identification of the famous cosmology law. Father Lemaître, in a sense, neglected the importance of the phenomenology expressed in the law and, therefore, must not have any credit whatsoever in its naming. Surprisingly, we can find support for this view in a source that is distant from cosmology, namely, in the thoughts of the great naturalist Charles Darwin (1809-1882), who, as we shall see, would agree with me on this issue.

In an excerpt from the most important edition of his autobiography — that annotated by his granddaughter Nora Barlow [28] —, I found a comment by Darwin in which he discards his primacy in certain discovery in favour of those that best expressed it. In the following text, the reference to his major work *"The Origin of Species"* is made by mentioning the *"Origin"*. Page 102:

> *"Hardly any point gave me so much satisfaction when I was at work on the Origin, as the explanation of the wide difference in many classes between the embryo and the adult animal, and of the close resemblance of embryos within the same class. No notice of this point was taken, as far as I remember, in the early reviews of the Origin, and I recollect expressing my surprise on this head in a letter to Asa Gray. Within late years several reviewers have given the whole credit of the idea to Fritz Müller and Häckel, who undoubtedly have worked it out much more fully and in some respects more correctly than I did. I had materials for a whole chapter on the subject, and I ought to have made my discussion longer;* ***for it is clear that I failed to impress my readers; and he who succeeds in doing so deserves, in my opinion, all the credit."***
>
> (Boldfaces are mine.)

Hubble indeed impressed his readers. Father Lemaître not.

3.4 The role of al-Khwarizmi

It has already appeared another person suggesting that the law should be called "Hubble-Lemaitre-Slipher's law"! Look at **Reasons in favor of a Hubble-Lemaitre-Slipher's (HLS) law** in [29].

Now, if it is to put in the name of the law everybody that collaborated for its formulation, I suggest one more, namely, "Hubble-Lemaître-Slipher-al-Khwarizmi's law", because it would not be possible the formulation of the law without the extraordinary contribution of Muhammad ibn Musa al-Khwarizmi to the fundamentals of algebra and the concept of numbers (see, for example, `https://www.famousscientists.org/muhammad-ibn-musa-al-khwarizmi`).

Epilogue

The renaming of Hubble's law can still be seen from another point of view. The empirical relationship between redshift and apparent magnitude is an observational fact. This is what concerns Hubble's work. Lemaître's work is related to the theoretical relationship between recessional velocity and distance (cf. [30]). The empirical relationship is firmly established, whereas the theoretical relationship is still a hypothetical statement. The IAU motion has the inconvenient and misleading result of equating a truly indisputable relation (Hubble's law) with a clearly disputable theoretical relation, since modern relativistic cosmology strives with multiple unknowns (dark energy, dark nonbaryonic matter, dark baryonic matter, etc.).

Acknowledgment – The epilogue resulted from message exchanges in a discussion group of *A Cosmology Group*, a site maintained by Louis Marmet at the address `http://cosmology.info/`. I acknowledge the contributions of Eric Lerner and Louis Marmet who have drawn my attention to the above argument.

Part II

Relativistic blunders

Chapter 4

Are black holes real?[1]

4.1 Introduction

In 1916, soon after the publication of the articles on General Relativity Theory (GRT) by Albert Einstein (1879-1955), the German astronomer Karl Schwarzschild (1873-1916) solved Einstein's field equations for a very special case, at the same time simple and of great experimental and observational applicabilities. It refers to the determination of the space-time metric in the exterior of a static and spherically symmetric mass distribution M. The Schwarzschild's solution is a vacuum solution, outside the object with mass M, and valid only in this region of space-time.

The metric is very successful in its applications. It is verified in the planetary motion, in the deflection of light due to presence of a mass concentration, in the correct prediction of the advance of Mercury's perihelion — where Newtonian gravity breaks down — and in modern applications of global positioning systems.

Schwarzschild's metric has a caveat that turned out to be very fruitful in its features, namely the existence of two singularities in its mathematical expression. One of the singularities, at the so-called "Schwarzschild radius", raised theoretical discussions on a plausible inhabitant of the natural world, that is, the well-known "black hole" (BH). The existence of the black hole in the physical world is accepted by many but is questioned by others. My main goal here is to answer the question posed in the article's title. I do this both by examining details of the Schwarzschild metric and by comparing it with the gravitational field of a classical Newtonian object, that is, a homogeneous material sphere.

Schwarzschild's metric is discussed in section 4.2 as well as the definition of the black hole as presented by Capelo [31]. In section 4.3, I discuss the Newtonian equivalent to the relativistic Schwarzschild metric field, i.e., the gravitational field of a homogeneous sphere. The proposed question is answered in section 4.4 and additional remarks are presented in section 4.5.

[1] `http://lilith.fisica.ufmg.br/~dsoares/extn/brcs/bhno.pdf`

4.2 Schwarzschild's metric and the definition of a black hole

The definition of the BH used in the present discussion is that by Capelo [31]. He begins with the Schwarzschild metric that is described by the expression of the space-time interval ds:

$$(ds)^2 = -(1-2GM/rc^2)(cdt)^2 + \left(\frac{1}{1-2GM/rc^2}\right)(dr)^2 + (rd\theta)^2 + (r\sin\theta\, d\phi)^2, \tag{4.1}$$

where r, θ and ϕ are the usual spherical coordinates, c is the speed of light in vacuum and M is the source mass. The "Schwarzschild radius" is defined as

$$r_S = \frac{2GM}{c^2}. \tag{4.2}$$

This radius defines the so-called "Schwarzschild sphere". In the language of GRT the metric field is the physical equivalent to the Newtonian gravitational field (cf. [32, sec. 1.1]). Its two-dimensional representation is shown in figure 4.1. It is worthwhile mentioning that such a representation breaks down for $r < r_S$, because in that region there is no known theoretical physical description — eq. 4.1 is not defined there — and hence figure 4.1 shows just a possible, but most certainly unphysical, extrapolation inside Schwarzschild's sphere (more on this in [6]).

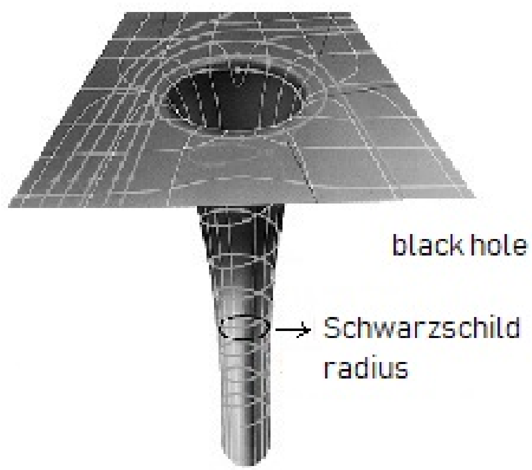


Figure 4.1: The metric field — i.e., the gravity — of a black hole shown as a two-dimensional warped surface. The black hole hosts a physical singularity inside the Schwarzschild sphere. The representation for $r < r_S$ is most certainly invalid because the metric is not defined there.

In his article, Capelo defines the BH and review the main features of various types of BHs. An excerpt of the abstract of Capelo's article reads:

> *"... we introduce the concept of a black hole (BH) and recount the initial theoretical predictions. We then review the possible types of BHs in nature, from primordial, to stellar-mass, to supermassive BHs."*

I treat here only of the definition of a BH; the reader is referred to Capelo's article for the other considerations.

There are two singularities in eq. 4.1. The equation diverges at both $r = 0$ and $r = r_S$. From Capelo's words, *only the former is a true physical singularity (i.e. the Riemann curvature tensor is infinite only at $r = 0$), with the space-time being nonsingular at the so-called Schwarzschild radius.* This fact can be easily seen, according to Capelo, by transforming the system of coordinates in which eq. 4.1 is presented (e.g., [33]).

However, the vicinity of Schwarzschild's radius is a quite peculiar region, because the future of a particle traveling towards the centre is inevitable, that is, when it crosses $r = r_S$ *the only possible future of that particle is the singularity.* The BH is then *unstable* at its conception or, more precisely, it sets off instabilities wherever it is formed (see also [33, fig. 2]).

The external surface of Schwarzschild's sphere is called "event horizon" of the BH. Capelo then describes a very drastic property of the BH with respect to a particle moving near the boundary represented by the event horizon, namely that *a static observer at infinity will never observe such a boundary (or event horizon) crossing, as the observed time will reach infinity (even though the proper time of the particle is finite) and any radiation sent from the particle and reaching the observer will be infinitely redshifted. In other words, a photon sent from r_S would need infinite energy to reach the observer, effectively making the space-time region within the event horizon causally disconnected from the rest of the Universe.* This is the rigorous technical reason for why a mass M confined to r_S is called a "black hole" and represents, therefore, its definition.

Since the mass is confined to the Schwarzschild sphere, it prompts for a parallel with a mass M confined to a given radius R, i.e., a classical Newtonian homogeneous sphere. The great difference between the two is that the gravitational field of the homogeneous sphere is well defined inside the confinement radius ($r < R$) and the great similarity is, obviously, that in both the total mass sits inside a sphere of known radius.

4.3 Gravity of a homogeneous sphere

I consider now a Newtonian classical object, that is, the above-mentioned homogeneous sphere (HS) of mass M and radius R. (Notice that the black hole is, strictly speaking, a classical object as well, since it does not require any quantum mechanical fundamentals in its prescription.) The gravitational field of the sphere is described by:

$$\vec{g}(r) = -\mathrm{Gm(r)}\frac{\vec{r}}{\mathrm{r}^3} \tag{4.3}$$

with

$$m(r) = \frac{M}{R^3}r^3 \qquad (0 \leq r < R),$$
$$m(r) = M \qquad (r \geq R).$$

The magnitude of $\vec{g}$(r) is plotted in figure 4.2.

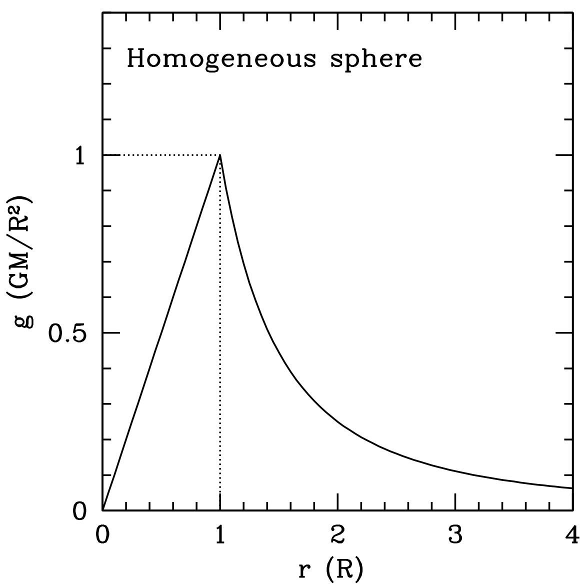


Figure 4.2: The magnitude of the gravitational field inside (r < R) and outside (r $\geq$ R) a homogeneous sphere of mass M and radius R (eq. 4.3). Notice the absence of singularities.

Gravitational fields of the BH and the HS have different descriptions, but it can be shown that in the limit of weak field, i.e., for $r \gg r_S$, the metric field given by eq. 4.1 reduces to Newton's gravitational law (e.g., [34]). Gravity fields of the BH and of the HS show a perfect symmetry for large r. That is not the case for small r, $r < r_S$ (BH) and $r < R$ (HS). The gravitational field is perfectly well defined for the former and diverges for the latter, that is, they show here a perfect asymmetry.

The gravitational field inside the HS is well defined including at $r = 0$. In contrast, the BH has a physical singularity at the very center of the Schwarzschild sphere. Such an asymmetry is striking and indicates that something very crucial is missing in the theoretical description of the Schwarzschild metric, which is, of course, a quantum gravity theory.

4.4 The answer

A tentative answer to the question posed in the title might be framed within three remarkable features of the BH presented in sections 4.2 and 4.3. They are:

1. The BH sets off instabilities wherever it is formed (section 4.2).
2. The space-time region within r_S (the radius of the event horizon) is causally disconnected from the rest of the Universe (section 4.2).
3. Gravity fields of the BH and of the HS show a perfect symmetry for large r, but a perfect asymmetry for small r (section 4.3).

Although points 1 and 2 above are by themselves sufficient to a "no" answer, the most remarkable argument for the answer resides in item 3. The asymmetry observed at small r in the description of these two classical objects is fundamentally an asymmetry between physical and unphysical realms. That is to say, it is not necessarily required that the gravitational fields be the same at small radii as they are for large ones. The crucial requirement is that both fields be physical. Since they are not, the only possible answer is "no".

A well-defined and physical object is suggested by Soares [2] as an alternative to the BH.

4.5 Additional remarks

Although a change of coordinates is able to transform the character of a singularity from physical to non physical (section 4.2), the singularities at $r = 0$ and $r = r_S$ are still uncomfortably concrete in the coordinates of eq. 4.1. Furthermore, it is conceivable that there might exist a system of coordinates in which the singularity at $r = 0$ is removed whilst the singularity at $r = r_S$ is kept and, if that is realized, one would be led to the conclusion that changing coordinates are mere mathematical artifacts that in the end are not really able to remove non physical descriptions.

Assuming that indeed the singularity at the Schwarzschild radius is not physical, it did not exclude the fact that the Schwarzschild sphere harbors a very real physical singularity. Would not that suffice to declare a BH as a non physical object and inexistent in nature? Is not the so-called "Object of Gravitational Extreme" (OGE), put forward by Soares [2], a much more palatable concept than the BH? The OGE has all the physical features of a BH except the singularities at $r = 0$ and at $r = r_S$.

Mathematical maneuvers, such as changing coordinate systems, are incapable of removing non physical characteristics of a BH, because the main issue in all of this is that GRT is an incomplete gravity theory, i.e., still there does not exist a quantum gravity theory that certainly would remove in a natural way both singularities present in the Schwarzschild metric.

The brilliant and clear exposition by Capelo [31] is very useful for those interested in the wonders of the intriguing concept of a black hole. The article almost shook my conviction that BHs are the most subtle expression of a very refined "scientific digression" (cf. [6]).

Additionally, one might want to read the article written by Bernstein [45], which presents a very interesting historical perspective on black holes, by featuring Einstein's denial of their existence in 1939 and the first scientific proposition of the black-hole concept by J.R. Oppenheimer (1904-1967) and H.S. Snyder (1913-1962), in that same year.

Chapter 5

Object of Gravitational Extreme[1]

5.1 Introduction

Immediately after the conclusion of the General Relativity Theory (GRT) by Albert Einstein (1879-1955) in 1915, the German astronomer and physicist Karl Schwarzschild (1873-1916) derived a particular solution of GRT's field equations that revealed itself to be extremely important. He had the intention to apply it to stars without rotation (or with negligible rotation) and perfectly spherical. His solution exhibits a *singularity* in the metric equation, i.e., an infinite result for a given value of the spatial coordinates. Generally speaking, the *metric* represents the space-time geometry of any space-time and gives the way of calculating the distance between any two events, which are characterized by three spatial coordinates and one temporal. Schwarzschild's metric is given by (equation 6 of [34]):

$$(ds)^2 = -(1 - 2GM/rc^2)(cdt)^2 + \left(\frac{1}{1 - 2GM/rc^2}\right)(dr)^2 +$$

$$+(rd\theta)^2 + (r \sin\theta \; d\phi)^2, \tag{5.1}$$

$\boldsymbol{M}$ is the body mass, $\boldsymbol{G}$ is the universal gravitational constant and **c** is the speed of light in vacuum. One sees immediately that Schwarzschild's metric **ds** diverges to infinity at $r = R_S = 2GM/c^2$, where R_S is called ***Schwarzschild radius*** ([36, sec. 2]).

Einstein and the English astrophysicist Arthur Eddington (1882-1944), the greatest authorities in GRT in the early decades after its formulation, rejected any physical meaning associated to the singularity for obvious reasons (see more details in [37]). Researches related to the "Schwarzschild singularity" only began

[1] `http://lilith.fisica.ufmg.br/~dsoares/extn/brcs/grvx.htm`

in the decade of 1960, especially from 1967 onwards, when John Archibald Wheeler (1911-2008) coined the term "black hole" (BH) to identify them.

The BH soon started to have status of "real object" and several physical, astronomical and cosmological consequences were deduced from it. But the BH is fundamentally, and will always be, the name of the "unknown", since it is associated to a mathematical singularity. Such an object, therefore and indeed, does not exist. If BHs do not exist, so what? What astronomical object might be associated to the Schwarzschild singularity? That is what I intend to answer.

In the next section I present some features of the SS that are usually assigned to BHs. Section 5.3 is dedicated to the answer of the question put forward here. I finish with some additional remarks.

5.2 Schwarzschild's singularity

The SS is currently identified with the BH. Normally one says that a BH is an object of extremely high density. It is important to clarify such an idea before we find a better physical conception for the SS, as proposed in the previous section. We shall see that an SS — the BH — can have extremely low density.

Let ρ_S be the mean density inside a sphere of radius equal to the Schwarzschild radius, that is, $\rho_S = M/[(4/3)\pi R_S^3]$. Consider now BHs that are often discussed in modern scientific literature:

1) BH of stellar mass $\mathrm{M}_S = 1\ \mathrm{M}_{Sun}$ and $R_S = 3$ km,

2) BH of mass equal to the BH believed to exist in the center of the Milky Way with $\mathrm{M}_{MW} = 4 \times 10^6\ \mathrm{M}_{Sun}$ (4 million solar masses) and $R_S = 1 \times 10^7$ (10 million) km and

3) BH of mass equal to the BH believed to exist in the center of the giant elliptical galaxy M87 with $\mathrm{M}_{M87} = 6 \times 10^9\ \mathrm{M}_{Sun}$ (6 billion solar masses) and $R_S = 2 \times 10^{10}$ (20 billion) km.

(Schwarzschild radii R_S were calculated with the expression $R_S = 3\ (\mathrm{M}/\mathrm{M}_{Sun})$ km, cf. [6, sec. 2.2].)

Figure 5.1 shows the location of these BHs on the diagram $\rho_S \times R_S (\rho_S \propto 1/R_S^2$; the scales of the axes are expressed as logarithms of the coordinates). The density of water (H_2O) is marked and one can see that we can have BHs with any mean densities, much larger and much smaller than the density of water. In particular the putative BH of stellar mass has $\rho = 2 \times 10^{16}$ (20 thousand trillion) g/cm^3, the BH at the center of the Milky Way has $\rho = 10,000$ g/cm^3 and the BH at the center of M87 has density equal to 0.0004 g/cm^3.

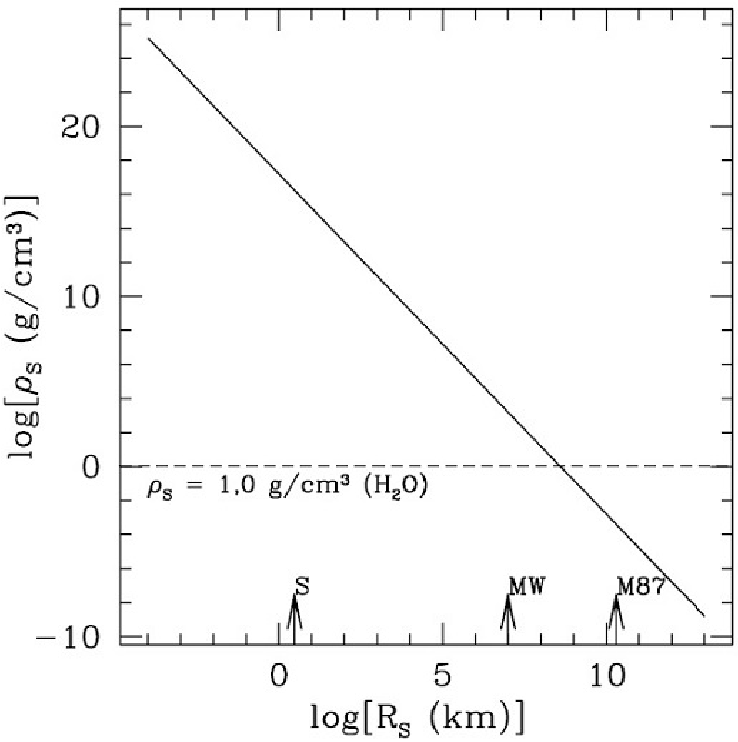


Figure 5.1: Schwarzschild's singularities in the diagram $\rho_S \times R_S$: S, mass equal to 1 $M_{Sun}, R_S = 3$ km, MW, mass equal to $4 \times 10^6 M_{Sun}, R_S = 1 \times 10^7$ km $\approx 15 \times R_{Sun}$ and M87, mass equal to $6 \times 10^9 M_{Sun}, R_S = 2 \times 10^{10}$ km $\approx 130 \times d_{Sun-Earth}$.

This analysis shows that the object associated to the SS does not necessarily have extremely high density. The object cannot be also associated to $r = R_S$ because we have there an infinite value for the metric. Hence the object must be defined for $r > R_S$, but as close as to R_S as one wishes, i.e., the object is to be defined for $r \to R_S$. Let us go now to its definition.

5.3 Object of Gravitational Extreme

In the neighborhood of $r = R_S$ the space-time curvature is very large. The space-time curvature is GRT's representation of the Newtonian gravitational potential. In fact, one has for $r \to R_S$ an extreme space-time curvature and, therefore, a *gravitational extreme*. Or else, let us see.

If we are so close to the SS as we wish we have, thus, $r \to 2GM/c^2$, whose terms may be rearranged in the form $GM/r \to (1/2)c^2$. We see then that $\mathbf{M/r}$

($\propto$ gravitational potential) tends towards an **extreme** ($c^2/2G$). Whereas M/r^3 ($\propto$ density inside the sphere of radius r) may be, as we saw, **large or small**. In other words, the packing of matter-energy is an extreme, but that does not necessarily mean that the density is an extreme inside $r = R_S$ as well. What is an extreme is the packing and consequently the gravitation in the neighborhood of $r = R_S$.

From what has been said above the new object, that exists immediately before Schwarzschild's radius, may be appropriately called "object of gravitational extreme" (hereafter *"gravex"*). Before achieving the stage of a gravex we can have objects with large gravitation like white-dwarf stars and neutron stars, if we consider only objects of stellar masses. These stars are compact ones but have radii that are larger than the Schwarzschild radii corresponding to their masses.

Figure 5.2 illustrates the space-time configuration of the gravex next to white dwarfs and neutron stars. The Schwarzschild radius defines, in this new context, a spherical surface called "horizon of gravitational extreme"; a gravex, of any mass, by definition, never reaches such horizon. Gravex, like BHs, may have stellar masses, be microscopic or supermassive.

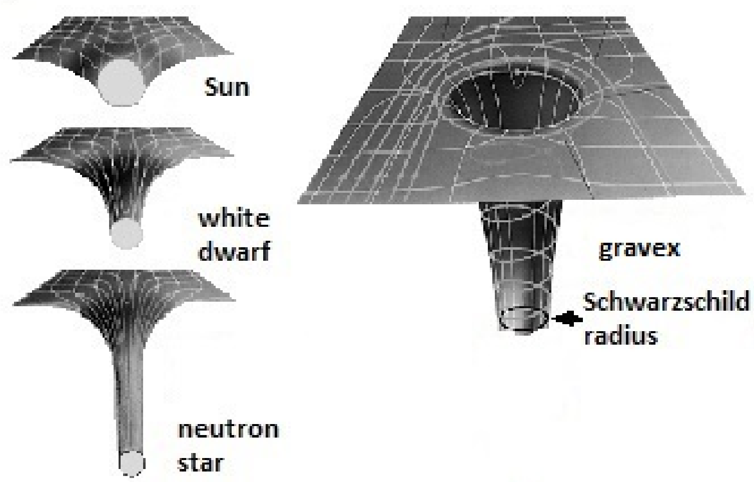


Figure 5.2: GRT shows us that space — more precisely, space-time — curves itself near any body. It is as space were a rubber sheet and the bodies "sank" on it. Above we see space curvature around the Sun, a white-dwarf star, a neutron star and a gravex. Notice that the gravex is formed before the "horizon of gravitational extreme", defined by the sphere whose radius is "Schwarzschild radius" shown in the figure (adapted from figure 3 of [6]).

As we see in figure 5.2, the gravex have conventional space-time structures similar to those of white dwarfs and neutron stars. The stellar-mass gravex may be called *stellar extremes*, or simply *extremes*, and represent the next objects in the sequence of stellar objects of large gravitation already known. The BHs are the ones that occupy this place in the vision of orthodox modern science. As mentioned above, one can talk also of microgravex and supermassive gravex.

There are two important questions to be addressed with respect to the gravex.

1) What is the physical mechanism (the force field) that support the structure of a gravex? We know the mechanisms for white dwarfs (degenerate electron repulsion) and for neutron stars (degenerate neutron repulsion and repulsion due to the strong interaction, the same that exists in the atomic nucleus).

The answer to the first question pave the way for the formulation of the second.

2) Will be a gravex stable or will not be the case that, from a given limit mass, a gravex breaks itself in stable gravex of smaller masses?

These questions are intellectually more satisfactory than living with the unknown scenario in which the BH inhabits, always waiting for the advent of a redeeming new theory of gravitation that solves the problem of the singularity. The gravex avoids the singularity and may — or not — be the definitive answer to the question of objects with large gravitation.

5.4 Final remarks

The existence of the SS denounces in a clear way the necessity of a quantum gravity theory (QGT) and emphasizes the precariousness of the classical theories of gravity such as GRT and Newtonian gravity (see an ampler discussion about this aspect in [6]). A QGT would expand the scope of the Schwarzschild solution in the domains constrained by the existence of the singularity.

The mean densities of the SSs illustrated in figure 5.1 cover an enormous range, from 10^{-4} g/cm^3 (supermassive SS) to 10^{16} g/cm^3 (stellar SS). In this range we have, in absolute terms, very small values and very large values. Nevertheless, it is worthwhile pointing out that such values are extraordinarily large when compared to the mean densities of the sites where it is assumed that the SSs are found. For example, the mean densities in galaxies range from $\sim 10^{-24}$ g/cm^3 in the outer regions to $\sim 10^{-21}$ g/cm^3 in the nuclear regions. A stellar SS located in the external regions has a mean density of about 10^{40} times as large as the mean density of its neighborhood, whereas a supermassive SS located in the center of a galaxy has density about 10^{17} times as large as the galactic nuclear density. This is the reason why SSs are usually associated to objects of enormous densities, that is, extremely compacts, instead of to objects of gravitational extremes, as it is conceptually more appropriate.

Supermassive gravex resemble the “superstars” discussed by the American physicist Richard Feynman (1918-1988) in his book ***Lectures on Gravitation*** [38], especially in Lecture 14. Feynman’s Lectures were given in the beginning of the decade of 1960, well before the BH "fever" being installed. Feynman has verified that the superstars are unstable relativistic objects. Incidentally, it is worthwhile reading the comments by physicists John Preskill and Kip Thorne presented in the ***Lectures*** preface. This preface is by its own an interesting lecture on gravitation and is available in [39].

As Einstein in 1939, Feynman was concerned about the SS issue. On p. 156, section 11.4, he states the problem: "*The metric eq. (11.3.6)* [eq. 5.1 here] *has a singularity at r=2m* [$r = 2Gm/c^2$ in my system of unities]. *To find out whether this is a physically troublesome or meaningful singularity, we must see whether this corresponds to a physical value of the measured radius from the origin of the coordinates (which is not the same as our coordinate r!) (...)*" The result of his analysis is the permanence of the singularity, now in another system of coordinates. What is impressive to me in Feynman words above are the expression "*physically troublesome or meaningful singularity*". A "*physically troublesome*" singularity must be discarded, this is easy to understand. But what is a "*physically meaningful singularity*"? Can, to begin with, a singularity be "*physically meaningful*"? Feynman's calculations — and common sense— seem to show it cannot. Again, one sees here the need of a QGT to solve the problem and eliminate the singularity.

In section 11.5 of Feynman's Lectures we have a curiosity in the realm of "science digression" (cf. [6]). Feynman presents an initial discussion about the possible extrapolations around SSs, which at that time were, according to him, "*called 'wormholes' by J.A. Wheeler*". J.A. Wheeler is the already-cited John Archibald Wheeler, whom some years later would christen such "possible extrapolation" as "black hole", giving up the initial denomination of wormhole. This, afterwards, would be applied to another extremely aberrant object (see [6, sec. 2.1]). It is worthwhile remembering that the Lectures were given in the years 1962 and 1963 and that Wheeler invented the black hole in 1967, as history records.

Acknowledgment – Jos Victor Neto, subscriber and frequent commentator of my cosmology list **COSMOS** (`http://www.fisica.ufmg.br/dsoares/cosmos/cosmos.htm`, in Portuguese), brought to my knowledge a most interesting book by Feynman ***Lectures on Gravitation***, which I mention in this article; I certainly share his enthusiasm for this remarkable work.

Chapter 6

Science digression: relativistic holes[1]

6.1 Introduction

Science fiction (ScF): the Merriam-Webster dictionary [40] quotes the following. *"Stories about how people and societies are affected by imaginary scientific developments in the future."* As a general rule then when one speaks of "science fiction" one thinks of a "story", an artistic and literary creation. But there is another kind of scientific discourse that I shall call **"science digression"** (ScD). (Warning, not to be confused with "science dissemination", which is a different story.) ScD is the extrapolation of established scientific knowledge by means of the consideration of future possibilities of theoretical, experimental and observational scientific advancements.

ScF is completely free — the artistic activity is free by definition; ScD has limited freedom, because it has one foot on the known laws of natural sciences and other in the "well-educated speculation".

One of the greatest exponents of ScD is the American physicist **Kip Thorne**. He was a student of the great John Archibald Wheeler (1911-2008), who was his mentor both in theoretical physics and in ScD — which, by the way, is a branch of theoretical physics. ScF drinks from the wellhead of ScD and ScD drinks from the wellhead of ScF.

Kip Thorne was the protagonist of a recent episode of ScF and ScD: the movie **Interstellar**. I shall not comment on the movie, but on some ScD aspects present therein. Those interested on the movie might watch Kip Thorne himself talking about it in a curious one-hour presentation in *The Science of Interstellar* [41].

Kip Thorne is also the author of a scientific dissemination book entitled *Black Holes & Time Warps* [5], where one can find the most precious pearls of his crop of ScD, many of them present in Interstellar. My purpose is to comment

[1] `http://lilith.fisica.ufmg.br/~dsoares/extn/brcs/holes.htm`

on some of those pearls, especially **wormholes** (WHs), **time machines** (TMs) and **black holes** (BHs).

In the examples discussed below, namely, WHs, TMs and BHs, the plausibility of the specific ScDs of each case are frequently supported by the belief that we shall achieve in the future a theory of **Quantum Gravity** (QG), that would vindicate and justify the speculations done. This sort of belief — that of the emergence of a more complete theory in the future — is a distinct feature of ScDs in general.

6.2 Pearls of Science Digression

According to [5, p. 485], WHs were mathematically discovered in 1916 by the Austrian physicist Ludwig Flamm (1885-1964) as a solution of the field equation of Albert Einstein (1879-1955), a few months after Einstein formulated his equation of the General Relativity Theory (GRT). Einstein and the American physicist Nathan Rosen (1909-1995) explored them in the decade of 1930 and Wheeler and his group (which has Kip Thorne as a member) in the 1950s. WHs are the most popular candidates for being TMs in all modern ScDs.

The modern conceptual possibility of the existence of BHs arose also in 1916, as a direct consequence of the work of the German astronomer and physicist Karl Schwarzschild (1873-1916). His solution of GRT's field equation showed a *singularity*, i.e., an infinity result for a given value of the spatial coordinates. Any physical meaning associated to this singularity was rejected by Einstein and by the English astrophysicist Arthur Eddington (1882-1944), the greatest authorities in GRT during the first decades after the formulation of the theory ([5, p. 134]). Only in the 1960s the researches with BHs, as we know them today, began to be done, especially after 1967, when Wheeler coined the term "black hole" ([5, p. 256]).

Next, I shall briefly talk about each of these ScDs.

6.2.1 Wormholes and time machines

WHs are tunnels through hyperspace (hypothetical space where real space-time is embedded), which connect a space-time region of the universe to another. They are like space-time shortcuts. Its name come from the analogy with the hole that a guava's worm does when it traverses it through its interior. Its path from one point on the guava peel to another point on the peel can in this way be smaller than the path made over the guava peel. Figure 6.1 shows examples of these two paths.

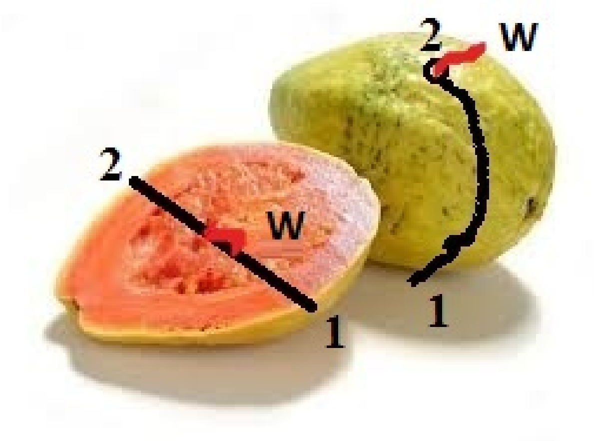


Figure 6.1: The guava worm W can go from point 1 to point 2 by the two paths shown in the figure. The "wormhole" inside the guava represents the shortest.

Interstellar travels would then be possible, in spite of the enormous distances to the nearest stars. The travel could be done more quickly by a shortcut through the hyperspace with the aid of a WH. Kip Thorne uses another nomenclature in his talk mentioned above: he calls **Brane**, short for "Membrane", the four-dimensional (3 spatial coordinates + 1 temporal) universe where we live. Hence, the Brane contains the 4 dimensions of our universe. Outside the Brane is the hyperspace, that he calls the **Volume**, which is space of more dimensions where the Brane is embedded. It is worthwhile to point out that hyperspace (the Volume) is a hypothetical space, it does not exist, but is useful for the understanding of the phenomena that occur in the Brane.

Figure 6.2 illustrates the case described above. The four-dimensional Brane is represented by a surface. The WH connects two points of the Brane by a shortcut through the Volume. In the guava example of figure 6.1, the guava peel is the Brane and its pulp is the inside Volume and the region exterior to the guava is the outside Volume. The hole of the worm may be considered as an alteration of the topology — i.e., of the shape — of the peel, being, therefore, an extension of the Brane that traverse the inside Volume.

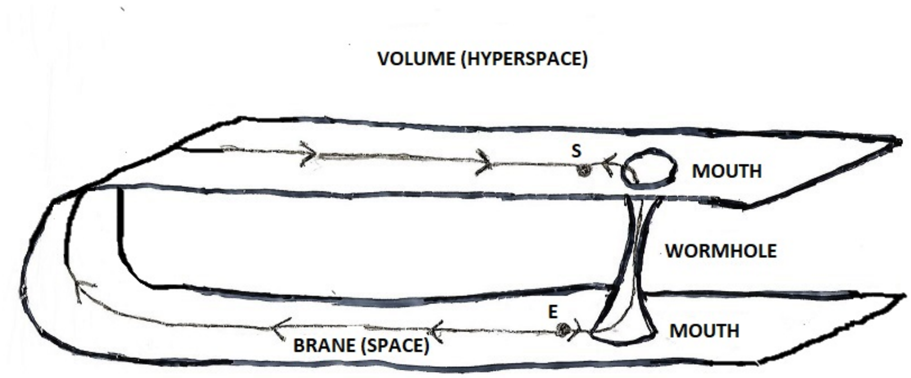


Figure 6.2: The interstellar voyager can go from Earth (E) to the star S by the two ways shown in the figure. The "wormhole" through the Volume (hyperspace) represents the shortest. The Brane entry and exit regions are called "mouths" of the WH.

The important issue is that since the discovery of the WHs it was verified that they are unstable. After being created they are quickly destroyed by the shrinking of their walls. And the contraction of the walls is so rapid that not even a light ray is able to travel the path from mouth to mouth. Here comes then the ScD. The shrinking of the WH can be avoided if there exists in its interior a reservoir of "negative energy" which would exert pression against the gravitational contraction. Is that possible? Yes, but the substance that has such a negative energy is yet to be found. It might be similar to the dark energy of the Standard Model of Cosmology (the Hot Big Bang model, cf. [42]), which exerts the cosmic pression that resists the decelerating gravitational pression and makes the expansion of the universe accelerated from recent epochs onwards. Everything is possible, but it requires an high dose of ScD, with frequent references to the putative theory of QG.

What about TMs? The TMs can be WHs (amongst other curious ScDs, which I shall not treat here). Now, due to the fact that WHs connect two spacetime events of the universe, they can very well connect two points of space, one of them being in the present and the other in the past. That is, one may go into a WM mouth in the present and come out the other one in the past. Of course, if one could avoid the contraction of the WH, which a highly advanced civilization would be able to do. The problem is that in addition to the technological limitations *there may be* a natural limitation, which I shall refer to below, through Kip Thorne's words.

6.2.2 Black holes

The black hole is a singular theoretical object that appears in one of the solutions of the GRT field equation, namely, the Schwarzschild solution (cf. section 15.2

of [36]). The Schwarzschild solution gives the spacetime structure in the exterior of a spherical body that does not rotate. The BH is a *singularity* of this solution. In theoretical physics, a singularity is something that does not exist, neither in nature nor in the formal conception of the theory, ultimately, is the collapse of a theory. In physics jargon, one says that that the solution "explodes" when it encounters a singularity. In general, in a singularity the solution tends to an infinite value. That is what happens with Schwarzschild solution. It explodes in the so-called *Schwarzschild radius*, which is given by:

$$R_S = \frac{2GM}{c^2},$$

where M is the body mass, G is the universal gravitation constant and c is the speed of light in vacuum. A BH is characterized by the so-called *event horizon* — or simply *horizon* — which is a spherical surface of radius R_S. Classically, i.e., outside the QG domain, the BH is a body of mass M that occupies a spherical region of radius R_S, in spite of the fact that the solution is not defined at $R = R_S$.

Figure 6.3 shows the singularity called BH. The question mark indicates that for $R \leq R_S$ the Schwarzschild solution is unknown, or more precisely, does not exist.

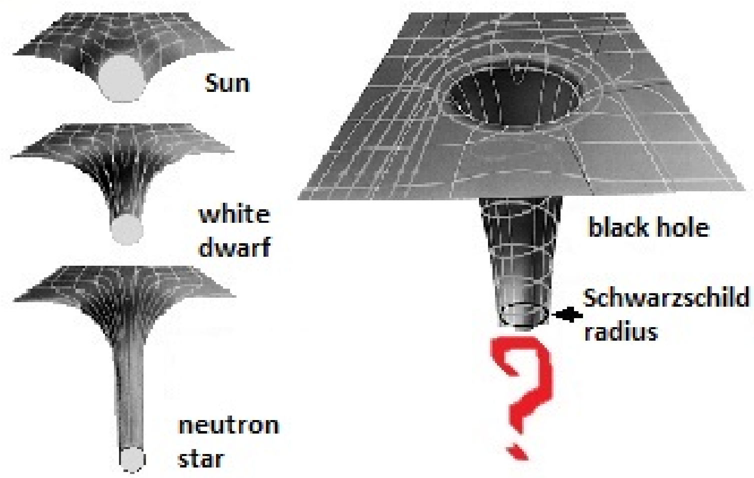


Figure 6.3: GRT shows that space — more precisely, space-time — curves near any body. It is as space behaves like a rubber sheet that is warped by the bodies sitting on it. Above one sees the warping of space around the Sun, a white-dwarf star, a neutron star and a black hole. The black hole makes a "bottomless pit" in space, or in other words, a hole whose bottom is completely unknown.

Space around the black hole is well-defined only for $R > R_S$, where R_S, the *Schwarzschild radius*, is shown in the figure. The question mark draws attention to this fact. The representations shown above are two-dimensional analogies of three-dimensional space realities. Try to imagine the latter.

The Schwarzschild radius can be written in terms of the Sun mass as $R_S = 3(M/M_{Sun})$ km. That is, a BH with the mass M equal to the Sun mass will have $R_S = 3$ km and its event horizon will be the spherical surface of 3 km of radius.

Strictly speaking, all scientific research about BHs belongs to the realm of the purest ScD. Incidentally, contrary to what is frequently stated, the singularity is not inside the event horizon; *the singularity is the event horizon*, located at $R = R_S$. For those interested in the subject, [5, chap. 3] is the finest piece of black-hole ScD.

6.3 Kip Thorne speaks up

Let's move now to Kip Thorne's labor with respect to the ScDs presented in section 2. First, I show excerpts about WHs and TMs and next those related to BHs.

> We can imagine two strategies for constructing a wormhole where before there was none: a *quantum strategy*, and a *classical strategy*. The quantum strategy relies on *gravitational vacuum fluctuations*, the gravitational analogue of the electromagnetic vacuum fluctuations...
>
> In 1955, John Wheeler, by combining the laws of quantum mechanics and the laws of general relativity in a tentative and crude way, deduced that in a region the size of the *Planck-Wheeler length*, 1.62×10^{-33} centimeter or smaller, the vacuum fluctuations are so huge that space as we know it "boils" and becomes a froth of quantum foam — the same sort of quantum foam as makes up the core of a spacetime singularity [5, p. 494].

Notice that this is the same quantum foam that is believed to reside inside of a black-hole singularity (cf. [5, p. 478]).

> We do *not* understand the laws of quantum gravity well enough to deduce, in 1993, whether the quantum construction of wormholes is possible. We *do* understand the laws of classical gravity (general relativity) well enough to know that the classical construction of wormholes is permitted only if the construction machinery, whatever it might be, twists time up so strongly, as seen in all reference frames, that it produces, at least briefly, a time machine [5, p. 498].

Kip Thorne's book [5] was written in 1993, which explains mentioning the year; the issue related to QG remains the same nowadays. "Twisting time" seems something weird, but it is worthwhile recalling that in GRT "twisted time" is one of the names of "gravitation". The matter-energy content of the universe and their pressure twist time and space, being this the way GRT describes gravitational effects, which are described in another way by Newtonian theory.

> The laws of general relativity predict, unequivocally, the flow of time at the two mouths [of the WH], and they predict, unequivocally, that the two time flows will be *the same* when compared through the wormhole, but will be *different* when compared outside the wormhole. Time, in this sense, hooks up to itself differently through the wormhole than through the external Universe, when the two mouths are moving relative to each other.
>
> And this difference of hookup, I then realized, implies that *from a single wormhole, an infinitely advanced civilization can make a time machine* [5, p. 502].

The TM requires, therefore, an *infinitely advanced civilization.* The TM is also closely related to a *Time Warp* (the *Time Warp* of [5]), i.e., to a different perception of the flow of time from different frames of reference.

The English theoretical physicist Stephen Hawking believes that TMs are impossible to exist in nature. In the absence of a QG theory he cannot proof his belief — his ScD —, then he put forward a conjecture about the issue. The following are Kip Thorne's words about it.

> Hawking has a firm opinion on time machines. He thinks that nature abhors them, and he has embodied that abhorrence in a conjecture, the *chronology protection* conjecture, which says that *the laws of physics do not allow time machines* [5, p. 521].

If some day, the conjecture can be proved, even an infinitely advanced civilization will not be able to build a time machine. Perhaps Hawking is right and for this reason until now, as it seems, we did not receive the visit of a inhabitant of the future.

Kip Thorne is so convinced of the urgent need of a QG theory that he makes mistakes when writes about Einstein's aspirations for an unified physical theory. Let us read:

> Albert Einstein spent most of his last twenty-five years in a fruitless quest to unify his general relativistic laws of physics with Maxwell's laws of electromagnetism; he did not know that the most important unification is with quantum mechanics. He died in Princeton, New Jersey, in 1955 at the age of seventy-six [5, p. 525].

Kip Thorne errs here. The desired unification is much ampler and Einstein certainly knew that. Long before 1955 there were already works on the unification of electromagnetism and quantum mechanics, which would result in quantum electrodynamics. The unification of quantum electrodynamics with the weak nuclear interaction was underway and would be crowned with the 1979 Nobel prize to its developers, whom have created the "theory of the electroweak interaction". There was in addition the strong nuclear interaction, that was not unknown to Einstein. In other words, the unification project is much more than the one depicted by Thorne and attributed to Einstein.

About Karl Schwarzschild, whose particular solution of Einstein's field equation led to the idea of BH, Kip Thorne states:

> The first step (after the inaugural presentation of GRT in 1915 [34]) was made by Karl Schwarzschild, one of the most distinguished astrophysicists of the early twentieth century.
> (. . .)
> Almost immediately he set out to discover what predictions Einstein's new gravitation laws might make about stars. Since it would be very complicated, mathematically, to analyze a star that spins or is nonspherical, Schwarzschild confined himself to stars that do not spin tat all and that are precisely spherical, and to ease his calculations, he sought first a mathematical description of the star's exterior and delayed its interior until later.
> (. . .)
> His calculation was elegant and beautiful, and the curved spacetime geometry that it predicted, the *Schwarzschild geometry* as it soon came to be known, was destined to have enormous impact on our understanding of gravity and the Universe [5, p. 124].

The BH is, as mentioned above, a singularity of Schwarzschild's geometry, and was known as "Schwarzschild's singularity" during a long time. The singularity has had other names, until the name coined by John Wheeler ended up prevailing. Schwarzschild's solution represents the greater — if not, so far, the only — contribution of GRT to gravitation. It possesses several applications of real success like, for example, in the calculation of the dynamics of planetary systems (amongst these, the solar system), in the calculation of the deflection of light by a given body and in the development of technologies of localization by satellites like GPS (*Global Positioning System*). The BH is a ScD of the Schwarzschild solution. Gravitational waves and other extreme gravitational phenomena are out of the scope of Schwarzschild's solution, but belong to the most genuine ScDs, some of them for requiring extremely sensitive and special detectors being, therefore, not observed, and others for waiting "a complete theory of QG". Schwarzschild's solution does not wait for anything and has practical applications of high experimental accuracy. The enormous scientific consideration enjoyed by GRT comes precisely from the solution found by Karl Schwarzschild in 1916 (cf. stressed in [34]).

Einstein himself did not like Schwarzschild's singularity:

> "The essential result of this investigation," Albert Einstein wrote in a technical paper in 1939 [37], "is a clear understanding as to why the 'Schwarzschild singularities' do not exist in physical reality." With these words, Einstein made clear and unequivocal his rejection of his own intellectual legacy: the black holes that his general relativistic laws of gravity seemed to be predicting [5, p. 121].

The above-mentioned Einstein's quotation is in the penultimate paragraph of the 15 pages of the 1939 article and the last one has the following words (boldface added): *"This investigation arose out of discussions the author conducted* *with Professor H. P. Robertson and with Drs. V. Bargmann and P. Bergmann* ***on the mathematical and physical significance of the Schwarzschild singularity****. The problem quite naturally leads to the question,* ***answered by this paper in the negative****, as to whether physical models are capable of exhibiting such a singularity."*

Contrary to what is often stated, BHs are still pieces of ScD. Rigorously, they do not exist, but represent unknown limits of known physics. Kip Thorne validates this judgement in many places of his book [5].

6.4 Final remarks

The recurring mention of the need of a theory of **Quantum Gravity** highlights the factual precarity of the ScDs mentioned here. They are clear examples of the concept of ScD, i.e., fiction coupled to educated speculation, the latter frequently anchored in the possibility of a QG in the future.

In this short inventory of relativistic holes certainly someone might have missed **white holes**. These may be thought as "time-reversed" black holes, that is, their physical processes occur in a way that is reversed to the way they occur in BHs. For example, matter and radiation emerge from a white hole with high energy. This ScD was popular in the decade of 1970, according to the English cosmologist Edward Harrison (1919-2007), and the idea seems not sustainable any more, as he mentions in passing in the chapter about BHs of his *Cosmology, The Science of the Universe* (2000). The white hole was a ScD that did not hold water. Incidentally, there is no mention whatsoever about white holes in [5].

Metaphorically, relativistic holes constitute true "holes" in the formal structure of GRT. According to many, Kip Thorne amongst them, such holes only will be plugged when we have a repairing theory of QG.

Kip Thorne, with his book [5], was our main reference in the discussion of relativistic holes. The quality of [5] as work of scientific **dissemination** may be questioned, but certainly one has there one of best compendiums of science **digression**.

Chapter 7

Einsteinian blunders[1]

We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising.

Mathematical Principles of Natural Philosophy, Book III
– I. Newton, 1687

7.1 Introduction

"The World Year of Physics 2005 is an United Nations endorsed international celebration of physics. Events throughout the year will highlight the vitality of physics and its importance in the coming millennium, and will commemorate the pioneering contribution of Albert Einstein in 1905."

This is the opening statement that appears in the electronic page `http://www.physics2005.org`, which is dedicated to the World Year of Physics. The idea seems to be, first, to celebrate physics, and, second, to commemorate Einstein. However, one sees without much effort that already, in the beginning of the year, there has been too much talking and writing on Einstein, with a noticeable bias to scientific *idolatry*, an unimaginable feature in science. We, scientists, are supposed to respect Nature as the sole source of inspiration for our activities both in the experimental and theoretical realms.

It is beyond of doubt that 1905 was Einstein's *annus mirabilis*. In that year the world witnessed the publication of three masterpieces in the literature of contemporary physics.They were the work on Brownian motion, establishing the reality of atoms, the work on the photoelectric effect establishing the quanta of radiation, and the special theory of relativity. There was though an antecedent

[1] `https://arxiv.org/abs/physics/0502142`

of such a high moment in science: the year 1666 is often remembered as Isaac Newton's *annus mirabilis*. From 1665 to 1667 he also opened the doors to three new areas of scientific research, namely, he laid down the foundation of differential and integral calculus, he developed the theory of colors, and put forward his theory of gravitation. The publication in 1687 of his *Mathematical Principles of Natural Philosophy* marked the beginning of a new era in the scientific endeavor. There is a clear parallel with Einstein's contribution to modern science.

In the following three sections I comment on aspects of Einstein's scientific life that are often seen with *respectful acceptance*, in spite of being bad examples of scientific manners.

7.2 The cosmological constant

In an important paper published in the Annals of the Royal Prussian Academy of Sciences in 1917 entitled *"Kosmologische Betrachtungen zur Allgemeinen Relativitätstheorie"*, i.e., *"Cosmological Considerations on the General Theory of Relativity"*, Einstein inaugurated the era of modern cosmology applying his ideas from General Relativity to the universe as a whole. Towards that aim, he abandoned his original field equations in favor of a new law in which there was an additional constant term that represented a constant repulsive gravitational potential. The term gives a small repulsion near the origin but increased directly proportional to the distance until counterbalance the gravitational attraction between masses. His intention was obviously obtain a *static* model. Remember that at that time even galaxies were not known as independent cosmological entities. Only in the late 1920s, with the work of the astronomer Edwin P. Hubble the existence of galaxies came to be definitely proved. The solutions he had initially obtained with the application of the original field equations were unstable for gravitational collapse. The modification preserved the general covariance of the theory and solved the instability problem [19, chap. 5]. The constant became known as the *cosmological constant*, and is until today the matter of much debate.

I describe now some facts that led to the first *Einsteinian blunder*. It turns out to be a *double-blunder*, as I suggest below.

The introduction of the cosmological constant led to a great debate on many aspects of the new horizons opened up by General Relativity concerning the universe. A infinite model has obvious boundary condition problems, something that was recognized even in the context of a Newtonian cosmology (see [22], chapter 16). With the cosmological constant, Einstein solved all problems by introducing a *finite, spatially closed* and *static* model, the latter feature being a result of Einstein's — and of most scientists at the time — belief concerning the physical world.

Nevertheless, Einstein came later to reject his own modification of the field equations. North ([19, p. 86]) quotes that already by 1919 Einstein considered that the introduction of the constant was *"gravely detrimental to the formal* *beauty of the theory"*; he considered it as an *ad hoc* addition to the field equations. Later on, he was further led to such a rejection by two new developments: on the observational side, Hubble's work on the redshift-distance relation for galaxies was being interpreted as an indication of an expanding universe[2] — no need of static solutions —, and on the theoretical side, the 1922 solution of the field equations by the Russian Aleksandr Friedmann and the 1927 solution by the Belgian Georges Lemaître which allowed for expanding models.

George Gamov [43] tells the now legendary story that Einstein once has said to him that the cosmological constant was *"my biggest blunder"* [3].

But why a double-blunder? Einstein rejected the cosmological constant based on what he found to be physical and aesthetic inconsistencies that resulted from its adoption. Here he saw a blunder, his biggest one. On the other hand, from the strict theoretical and formal point of views, General Relativity is in fact *enriched* by the addition of the new term, while still keeping its features as a viable general covariant theory of gravitation. And that is where the *double* character comes from. The simple fact of abandoning it constitutes a blunder after a blunder. This is also suggested by Norh's arguments [19, p. 86], who writes that *"he finally discarded the term in 1931, and in doing so deliberately restricted the generality of his theory."*

Recent claims, from the late 1990s and on, of a *accelerating* expanding universe have led to the resurrection of the cosmological constant, which would give the *cosmic repulsion* responsible for the acceleration. This idea and other variants became a strong feature of modern cosmology. The present *status quo* of modern cosmology is not though free of opposition. An example of that has recently materialized in *An Open Letter to the Scientific Community* [44].

7.3 The 1919 solar eclipse

In a short biography [45], Einstein's reactions to the scientific results obtained from the solar eclipse of 1919 are described. The main issue was light bending by a gravitational source, and the occasion was most appropriate for the observational tests.

Two astronomical expeditions, one in Brazil and another in the African coast, were organized by Sir Arthur Eddington, a renowned scientist at the time, in order to measure the stellar positions around the solar disk during the total eclipse of May 29, 1919. Ilse Rosenthal-Schneider, Einstein's student, tells

[2]It is worthwhile to note at this point that the interpretation of Hubble's redshift-distance relation as indicative of an expanding universe is only true when one takes for granted that the underlying theory under consideration, i.e., General Relativity in modern cosmology, is true. This is still a matter of debate since present cosmological models have led to a variety of hypotheses concerning the matter-energy content of the universe, such as *baryonic dark matter, non-baryonic dark matter* and the yet more mysterious *dark energy.* None of these have been so far proved to exist by any experimental or observational means.

[3]This of course entirely justifies the title of the present article: if Einstein admits his "biggest" *blunder*, that implies the existence of the "smallest", and a whole gradation of *blunders* in between.

that Einstein's first reaction to the news that the measurements pointed to an agreement with General Relativity predictions for the light bending was: *"— I knew it was correct"*.

She asked him: *"— What would it be if your prediction was not confirmed?"*. He replied: *"— Da könnt' mir halt der liebe Gott leid tun, die Theorie stimmt doch."* Or, *"— Then I would be sorry for the good Lord, but the Theory is correct."*

Is this an acceptable reaction of a theorist when confronted with experiments or observations that are relevant to his theory? Certainly not.

7.4 Einstein meets Hubble

The protagonist here is another Einstein — Elsa — Einstein's second wife. She is sometimes featured as a woman of somewhat *faint* character (see [46]). The story appears in many sources. The one I quote here is from the probably best biography of the great extragalactic astronomer Edwin Powell Hubble [47], the man that successfully proved the existence of external galaxies and would be awarded the Nobel prize in Physics in the early 1950s. It did not happen due to his premature death in 1953 (for a short account, see [48]).

Einstein's visit to the institutes of Caltech, in early 1931, was motivated by his curiosity on the work in mathematical physics done by Richard Tolman, who was working on relativity, and on the observational work by Hubble at the Mount Wilson Observatory.

He and wife made their first trip to the mountain, where the Observatory was located, in mid-February. They were accompanied by Hubble and others.

They visit all the installations in the Observatory, including the 100-inch dome, which houses the Hooker telescope — then the largest telescope of the world —, where most of Hubble's work on extragalactic astronomy was being conducted.

Hubble's biographer writes (p. 206): *"When Elsa Einstein, who seemed always to be in the defensive, was told that the giant Hooker telescope was essential for determining the universe's structure, she is said to have replied, 'Well, well, my husband does that on the back of an old envelope.' "* As in the previous section, one sees here the diminution of the relevance of experimental (strictly speaking, observational) science.

One could argue that this is not a legitimate Einsteinian blunder because it was Mrs. Elsa's mouth that has spoken out the words. There are two counter-arguments against such a claim. The *weak* and the *strong* arguments. The weak one is just a play on words and goes like this: "Elsa is Einstein therefore it is an Einsteinian blunder". The strong argument is that the episode appears very frequently in Einstein's biographies and in writings of various nature about both Einstein and Hubble. It is an Einsteinian feature. As such, it might with justice be included in the gallery of authentic Einsteinian blunders.

7.5 Concluding remarks

It is understandable that amongst us, physicists and astronomers, there is frequently almost an adoration of Albert Einstein. He is without doubt the greatest scientist of the Twentieth century. Such an involuntary worship is everywhere: the most celebrated Einstein's biography, namely, that by Abraham Pais [46] is also contaminated. He adopts the usual trend of skipping uncomfortable details of Einstein's personal and scientific life [49].

The reader certainly noticed that none of the above-mentioned stories refers to Einstein's *annus mirabilis* works but are at some extent related to General Theory of Relativity, which was developed ten years later. The explanation is simple. It is the result of a *selection effect*, given that the author of the present article is an extragalactic astronomer. That is to say, it does not means that there are not Einsteinian blunders related to that period. They can be mined, for example, in Abraham Pais' book. Not without some effort, it should be added, as implied by the first paragraph,

And what about the atomic bomb? Certainly it cannot be classified as an Einsteinian blunder, in spite of Einstein's deep involvement with the issue (especially on the political side, see [46] for details). The atomic bomb is rather the *world biggest blunder.*

Scientific impartiality excludes, by definition, worshiping and the cult of personality. To err is *human* and so has Einstein erred in many occasions. This is the plain message to the younger generation of students and scientists.

Finally, young and old, let us all remember the famous Brazilian playwright Nelson Rodrigues that always used to say that *"any unanimity is stupid."* Definitely right.

Part III

Life in the universe

Chapter 8

Search for Extraterrestrial Intelligence[1]

Are we alone in the cosmos?

The question is the research subject of the American astrophysicist Frank Drake for over 50 years. On October 19, 2017, I attended to a lecture given by him, promoted by the Department of Astronomy of Cornell University, in Ithaca, NY. This lecture was part of the cellebration of the 40 years of the Voyager 1 and 2 missions for the exploration of Jupiter and Saturn (see `https://www.nasa.gov/centers/jpl/missions/voyager.html`).

Frank Drake, 87 at the time, is a researcher at the SETI (*Search for Extraterrestrial Intelligence*) Institute and is known, amongst other things, by the **"Drake equation"**, which is a probabilistic formulation for the estimation of the number of intelligent and technological civilizations in the Milky Way galaxy, our galaxy, also called the Galaxy. Frank Drake considers an advanced civilization as one capable of having radio astronomy. It is a limited definition, but it makes it possible to estimate its number $\mathbf{N}$, which will be the result of the product of the factors of the equation:

$$\mathbf{N} = \mathbf{N}_* \times \mathbf{f_p} \times \mathbf{n_e} \times \mathbf{f_l} \times \mathbf{f_i} \times \mathbf{f_c} \times \mathbf{f_L}.$$

The estimations of the factors on the right-hand side of the Drake equation are shown below and were put forward by Carl Sagan (1934-1996) in chapter XII of his book **COSMOS**, where a more thorough discussion of the equation and of the reasons for the choice of each factor can be seen. The factors are then:

$\boldsymbol{N}_* =$ number of stars in the Galaxy ($4 \times 10^{11} \equiv 400$ billion)

$\boldsymbol{n}_p =$ fraction of stars with planetary system (1/3; 100% is the modern value, see below)

[1] `http://lilith.fisica.ufmg.br/dsoares/extn/adou/18/adou3-e.htm`

$\boldsymbol{n}_e =$ number of planets, in a given system, ecologically suitable for life (2; in the solar system, for example, one has Earth, possibly Mars, Jupiter and Titan, a satellite of Saturn, being, therefore, 2 a prudent number)

$\boldsymbol{f}_l =$ fraction of suitable planets in which life really blossomed (1/3)

$\boldsymbol{f}_i =$ fraction of inhabited planets in which intelligent life evolved

$\boldsymbol{f}_c =$ fraction of planets inhabited by intelligent beings in which a communicative technological civilization developed ($\boldsymbol{f}_i \times \boldsymbol{f}_c = 1/100 \equiv$ one percent)

$\boldsymbol{f}_L =$ fraction of the duration of planetary life favored by a technological civilization ($1/10^8 \equiv$ one per 100 million; fraction characteristic of Earth, that has life with some billion years and a technological civilization characterized by radio astronomy of only some decades)

With the relatively arbitrary factors adopted above (with the exception of $\boldsymbol{N}_*$), we obtain $\boldsymbol{N} = 10$ planets with advanced intelligence in the Galaxy. We are sure that $\boldsymbol{N}$ must be at least equal to 1 (the Earth!) but, if we have erred in some of the factors above, $\boldsymbol{N}$ could be much larger than 10. Only the technological development will enable us to a more precise estimation of the factors of Drake's equation and consequently of $\boldsymbol{N}$.

Let's go back now to Frank Drake's lecture. Next, I enumerate some points I found interesting, not exactly in the order they were presented but according to my recollections.

1) The scientific interest for the search of extraterrestrial intelligence dates back to XIX century with the German physicist, mathematician and astronomer Carl Gauss (1777-1855) and the Italian physicist and inventor Guglielmo Marconi (1874-1937). Marconi tried to send radio signals to space, but he would not succeed due to the fact that the frequency he used does not go out (nor comes in) the Earth, because it is blocked by the atmosphere.

2) Nowadays, the SETI research uses radio telescopes all over the world, such as, Parkes, 65-m aperture, in Australia, Green Bank, 100 m, United States, Arecibo, 305 m, Puerto Rico (United States; it was damaged by the 2017 Hurricane Maria, but it will soon return to full operation), FAST (*Five-hundred-metre Aperture Spherical Radio Telescope*), 500 m (400-m effective), China, the largest radio telescope in the world.

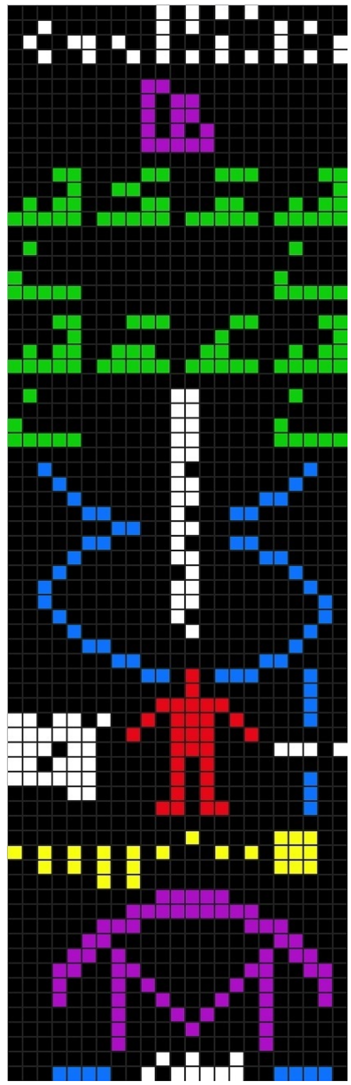
3) SETI is beginning to adopt visible light in its searches, an old idea, but only now starts to be used. Laser beams are directed to all regions of our galaxy and detectors try to observe pulsating lasers eventually transmitted by extraterrestrial civilizations.

4) Pano-SETI or *Panoramic SETI* is a new SETI project that aims at observing all the sky continuously. There exists on average 1 star per 24 cubic light-years in the Milky Way and according to the results of the

Kepler probe all stars have planetary systems and 1 in 5 stars has planets in the so-called "habitable zone" (region around a star that offer similar conditions to those prevailing on Earth to the development of life).

5) In 1974 there was a great investment for the reform of the Arecibo radio telescope that had been inaugurated in 1963. It is located on the island of Puerto Rico, an United States territory in the Caribbean sea. To commemorate the reinauguration of the telescope, Drake and colleagues had the idea of using the telescope to send a message to our likely neighbors of the Milky Way. The message could not be long in order not to bother the authorities — it was a monotonous radio signal coded in such a way to correspond to an audible sound signal. The radiofrequency used was 2380 MHz, which corresponds to the wavelength of 12.6 cm. The message should contain images and information in the form of a sequence of binary numbers (0 and 1), so as to be understood by a civilization that has the logical characteristics of a intelligent mind — that was the idea of Drake and colleagues. And so, they did. With the technology of the time, the message was sent at a rate of 10 bit/s for 3 minutes, that is, $10 \times 3 \times 60 = 1800$ bits $= 1800/8 =$ simple 225 bytes (1 byte = 8 bits).

Exercise: look at the image of the Arecibo message below and count the approximately 1800 little squares, 1 bit for each one; anyone wanting to check his counting with the exact number of bits in the image may email me (dsoares@fisica.ufmg.br).



The **Arecibo message** was sent on November 16, 1974 by the Arecibo radio telescope. The colors are just for illustration.

6) The great difficulty of SETI is the profusion of spurious local radio signals and especially signals from artificial terrestrial satellites. There are about 200 satellites in Earth orbit emitting signals (communication, meteorological, military, etc.). All those signals must be identified and excluded from the data base.

7) SETI counts primordially with private funding for its researches, because

> governmental agencies have difficulties in accepting research projects that have no perspective of an ending. The success, or failure, of the search for extraterrestrial intelligence cannot be predicted. Drake cited the example of a Russian immigrant and investor that has made a commitment to ensure to the SETI Institute a non-repayable grant of 100 million dollars in 10 years. His name is Yuri Milner.

As we see, the Search goes on and with the trends of increasing sophistication, keeping up with the scientific and technological development of humanity.

Chapter 9

Death and life in the Moon: exploring the limits of exobiology and exoecology[1]

On 20 July 2009 we celebrated 40 years of the descent of man on the Moon. The extraordinary enterprise was realized by the Americans with the Apollo 11 mission. They repeated it five times more, up to number 17. The exception in the row is Apollo 13. That mission did not succeed but was a great success of human persistence and creativity, to save the lives of its three astronauts, in risk after the explosion of an oxygen tank in the service module.

The Saturn rocket, used to propel the command, service and lunar modules, was gigantic. Its 120 m of height can be grossly compared to that of a 40 store building.

Fortunately, nobody died on the Moon soil. We might well ask ourselves: *what if that happened?*

The Moon is a tremendously inhospitable environment for humans. No sign of atmosphere, let alone oxygen. Regarding room temperatures, NASA's probe Lunar Reconnaissance Orbiter has recently informed us again: from +100 degrees centigrades in daytime to -180 degrees at night.

Incidentally, on Earth, there exist certain organisms — generally called "extremophiles" — that live under extreme environmental conditions, such as those prevailing on the depths of the oceans, in hot springs and ice caps.

Let us now imagine an astronaut that for some reason dies on the Moon surface. The astronaut is an organism consisting of about 10 trillion cells — much more than the number of stars in the Milky Way, around 100 billion. He is not alone, though. It is estimated that the average human body has about ten times as much as that number of microorganisms, sitting mainly in the gut, but also in the skin, in the mouth, and in almost every human organ. They live

[1] http://lilith.fisica.ufmg.br/dsoares/UAI/moon.pdf

in our body in a symbiotic relationship, performing a number of useful functions for our health.

In other words, the astronaut dies but this may not immediately be true for his trillions of space-journey companions. We are faced, therefore, with a potentially extraordinary experience of exobiology — biology outside Earth — and of *exoecology.* Figures are astonishing: trillions and trillions of microorganisms — bacteria, fungi, etc — fighting for survival. The theory of evolution by natural selection of Charles Robert Darwin (1809-1882) rests especially on these two ingredients: the fight for survival and a large number of "fighters". Would there be a winner? Would there be then "life after death" in the Moon? Or, would there be an effective and full "pasteurization"?

Anyhow, it is comforting to know that no astronaut died in the Moon, and that the experience in exobiology put forth above happens only in our imagination.

I thank my wife Lu for helpful discussions.

Chapter 10

On the Rare Earth Hypothesis[1]

Peter D. Ward and Donald Brownlee wrote an intriguing book, published in 2000, whose title is "Rare Earth" and subtitle "Why Complex Life Is Uncommon in the Universe" [50]. In what follows I suggest that while they are convincing in the title, they have most likely failed in the subtitle.

The Rare Earth Hypothesis states that microbial life is common in the universe but advanced forms, from simple multicellular organisms to large animals, are uncommon and may even not exist outside Earth.

Throughout the book the authors elaborate on the several factors that make Earth unique as a habitat for the evolution of advanced life forms. Earth has the right mass, sits at the right distance from its star, which in turn has also the right mass. Earth follows a stable orbit, has a large Moon that stabilizes its rotation axis tilt, which has the right value for avoiding severe seasons. More, Earth has a giant neighbor – Jupiter – that prevents impacts from comets and asteroids, and it has plate tectonics that ultimately provides a global thermostat mechanism by means of recycling greenhouse gas, especially carbon dioxide. Earth has a magnetic field of the right magnitude so as to shield the surface from energetic cosmic particles. Earth sits in the right galaxy, at the right location, in a galaxy that has the right heavy element abundances. Furthermore, a dozen or so *mass extinction events* had driven biological evolution towards the highly developed mammals present on Earth today.

The combination of such specific conditions has led in the course of time to the development of specific life forms, all DNA-based organisms. Life on Earth is intrinsically a rare chemical phenomenon. Here the authors are probably right: Earth as a laboratory is rare, the possible chemistry is rare, the resulting life forms are rare.

There are two problems though in extrapolating the "rare" reasoning above to complex life in the whole universe. First of all, life is not a chemical phe-

[1] `http://lilith.fisica.ufmg.br/~dsoares/rare/rare.htm`

nomenon, rather, it is a *physical* phenomenon. A living organism is a system that by energetically interacting with its neighborhood has its entropy decreased. In other words, it maintains itself in a *state of order* compared to the *disordered* neighborhood [51]. Secondly, being a physical phenomenon, life may manifest itself in unconceivable different chemical and non chemical processes. They are in principle as innumerable as the different environments that exists in the universe, and may be even spread *"serene in the space between the worlds"* like the structured minds envisaged by science-fiction author Ken MacLeod [52], or like Fred Hoyle's living interstellar cloud [53].

Ward and Brownlee's book is in the order of the day for two seemingly different reasons: the Rare Earth hypothesis will soon be tested because the search of extrasolar planets is almost reaching the earth-like domain, with many planned space missions worldwide, and, their somber suggestion that *"the rise of an intelligent species on any planet might be a common source of mass extinction"* due to their profligate use of planetary resources. Present global warming warnings show that they might not have erred in the latter.

Chapter 11

The Aleph Cosmological Principle[1]

I saw the Aleph from every point and angle, and in the Aleph I saw the earth and in the earth the Aleph...

The Aleph
– Jorge Luis Borges, 1945

11.1 Introduction

The Anthropic cosmological principle [54, 55] has been criticized, and eventually rejected as inadequate by some authors, for being heavily *inspired* on unproved cosmological models, namely, those known as Hot Big Bang models [56].

Carter [54] presented his Anthropic principle in two versions, weak and strong, whilst Barrow & Tipler [55] described other versions. The great novelty lies in the weak version. The discussion that is done here focuses, therefore, upon the weak version of the principle.

In fact — and it is worth-stressing —, the different versions of the Anthropic Principle are not different versions of the same principle but rather are *independent principles by themselves,* which is totally opposed to the view expressed mainly by Barrow & Tipler. Such a thesis is further elaborated elsewhere [57].

Towards a broader and unprejudiced view, one can depart from the idea of a universe as a *world ensemble* (e.g., [54]), except that in a different perspective from what is usually found in the literature, namely, that of a *multiverse* (see details in [58] and references therein). Let each world vector — i.e., each element

[1] `https://arxiv.org/abs/physics/0409003`

in the ensemble —, in fact, belong to the *same* universe, not being a *universe* by itself, with its own cosmology, as assumed in the usual world-ensemble approach. That is to say, the total mass-energy content of the universe is given by adding up the mass-energy content of each world vector. Furthermore, each world vector is assumed as potentially suitable for the existence — or development — of life. In other words, the overall conditions in that — and all — world element are such that live organisms are bound to emerge. It is thus characterized by a *X-Life world principle*, which simply states that world is as it is because of restrictions imposed by X-Life being the way it is. These are essentially the same words in Carter's formulation of his Anthropic principle. Here they are used in the context of a much broader cosmological view as it will be apparent below.

The Anthropic principle has been used in many ways since its proposition. A sort of strange *devotion* sometimes characterizes those dealing with the principle. This resulted into an exaggerated *bending of the bow* towards one direction. The situation, comprehensibly, led Soares [56] to use irony on the whole issue, in an attempt to bend the bow to the opposite direction, eventually reaching a state of reasonable equilibrium. That is also the spirit pervading the present essay, except that now with a grave approach.

11.2 The E-Life world principle

Ours — the only presently *applicable* X-Life world principle —, conveniently, could be termed *E-Life world principle*, where "E" stands obviously for "Earth". Since the DNA-molecule is the unifying feature of terrestrial life, the principle is thus stated as constraints derived from DNA-based life upon the world vector properties. Very much so, it is the present general idea pervading the Anthropic principle.

Except for the cosmological implications, much of the conclusions derived from the Anthropic principle [55] surely still holds. For example, the prediction by Fred Hoyle concerning the 7.7 MeV excited state of ^{12}C, which was necessary in order to increase the probability of the reaction between helium and beryllium to produce carbon, might be considered as a genuine E-Life world principle prediction. In 1952, from the evident abundance of carbon — namely, E-Life —, Hoyle predicted the existence of a resonance of ^{12}C, in nuclear reactions, at around 7.7 MeV, and almost immediately, in 1953, D.N.F. Dunbar, R.F. Pixley, W.A. Wenzel & W. Whaling [59], at Kellogg Radiation Laboratory, Caltech, discovered a state with the correct properties, at 7.68$\pm$0.03 MeV excitation energy. E-Life would not exist without the 7.7-MeV excited state of ^{12}C. Such a prediction is, of course, often mentioned in classic Anthropic discussions (see [55, p. 252]).

The reason why general cosmological implications are not valid is that a given cosmology must be applied to the whole world ensemble and not to a sole element of it. *Aleph* is the applicable principle here (see below). *Cosmological predictions are always biased when based in a X-Life world principle.*

Intelligent life is always an issue whenever one speaks of *life*. Intelligence, another variable in the general cosmological equation, is not considered in the present discussion. Irrespective of its prevalence, communications between world-ensemble elements, e.g., between a particular X-based organism and a DNA-based one, may or may not be possible. In any case, whether or not two elements of the world ensemble are or may be connected in one or other way — communication being one of them — is entirely irrelevant here.

11.3 A hypothetical X-Life world principle

Sagan & Salpeter [60] discuss many aspects of a possible Jovian biology, an investigation motivated mainly by the fact that contemporary Jovian atmosphere has many similarities to the primitive terrestrial atmosphere. They hypothesized the characteristics of Jovian live organisms — in the form of sinkers and floaters, understandable in a gaseous environment — departing from chemical composition, temperature, density, pressure and other known features of the planet atmosphere. Fundamental for the origin of life in Jupiter is the time-scale taken by synthesized complex molecules to move towards large depths, as a result of convective streaming. The time-scale should be short enough to avoid reaching pyrolytic depths, which would severe restrict the possibility of biological evolution.

Now, take the Sagan-Salpeter problem in the reverse order. Assume sinkers and floaters *are* abundant in the Jovian atmosphere. One may then formulate the *J-Life* world principle — "J" for "Jupiter". With such a life principle, properties of the Jovian atmosphere might be obtained in the same way E-Life — Anthropic — predictions are made.

Incidentally, Jovian live balloons would be, in principle, totally disconnected from DNA-based terrestrial life. In other words, J-Life world and E-Life world would be disconnected from each other.

I am assuming here that Jovian organisms are not DNA-based, which may not be true. But that does not invalidate the example.

11.4 Aleph and Copernicus principles

The Aleph Cosmological Principle is the underlying principle to the world ensemble, i.e., to the universe. Predictions about the formation, evolution and structure of the universe — cosmology — are related to the Aleph principle. It is much more general in scope than each X-Life world principle.

Strictly speaking, X-Life world principles do not need *intelligent* life to hold. In particular, E-Life world principle would still hold even *in the absence of mankind*, of human beings. This is the essence of what could be termed *the Strong Copernicus principle*. As long as any sort of DNA-based life do exist, the E-Life principle would still be there. Useless, due to the absence of intelligent life. But still there. The Strong Copernicus principle does not require the existence of human beings. Man is not central in the universe, it may even not exist. Putting it in another form, amongst all DNA-based forms of life, man is not special. Consciousness makes mankind *different* — not special — from other E-life organisms, in the sense that mankind is dotted with moral and ethical values. These are fundamental aspects of human life but do not change the biological status of human life. In conclusion, the Strong Copernicus principle is an imperative *scientific* principle.

The philosophical implications herein are innumerable and will not be treated here.

11.5 Conclusion

At this point in time there is only one X-Life principle known. Conceivably, the Aleph cosmological principle is a matter of speculation. Conceptually, however, it leads to a broader scenario for the knowledge of the universe we live.

Soares [61] suggests that the arrow of time is given by the prominence of life, that is, the universe evolves towards life. In an eternal universe, that would lead to the startling conclusion that the *universe itself is alive!* The Aleph principle is, then, at a certain point, vindicated.

The Aleph cosmological principle is the Aleph-Life principle. It is of course prompted to speculation what is the nature of Aleph-Life, in a way or other, the live universe. Highly speculative matter, on the other hand, scientifically unavoidable.

Chapter 12

Do we live in an anthropic universe?[1]

Amongst all possible universes we live in one that *deserves* us. This is what could be called the *naive version* of the anthropic principle. At what extent this view is consistent with modern scientific results obtained from theoretical and observational work in cosmology?

The anthropic principle was originally put forward by the cosmologist Brandon Carter [54] with the statement that 'our location in the universe is necessarily privileged to the extent of being compatible with our existence as *observers*'. (The italic is mine). The definite status as a consensual principle of nature has been crowned with the thorough account of its implications in seemingly unpaired areas of human knowledge such as philosophy, quantum mechanics, cosmology, biochemistry, the search for extraterrestrial life and ultimately the future of the universe, by John D. Barrow and Frank J. Tipler, in the now classical book entitled *The Anthropic Cosmological Principle* ([55]but see Soares [61]).

Since then, two major achievements in cosmology lie on our pathway, two brilliant milestones. On the theoretical side, Alan Guth invented the inflationary theory [62] in the early 80's, and on the observational side, the first results from the Cosmic Background Explorer satellite were published in the early 90's [2]. The expanding universe paradigm gained strength with renewed blood from these sources. Two recent reviews by Michael S. Turner [42] and Max Tegmark [63] give a clear picture of the present situation. The evidence for a flat global topology comes from both inflation and measurements of the anisotropy of the cosmic microwave background on angular scales of about 1 degree. The measurements were triggered by COBE's spectacular results, from a plethora of satellite and balloon experiments (see [63]).

Current cosmological models should be at least reassuring of an anthropic

[1] `https://arxiv.org/abs/physics/0209094`

[2] See COBE's homepage at `https://lambda.gsfc.nasa.gov/product/cobe/`

universe. But, what does the cosmic budget tell us? Following Turner one has:

- Bright stars: 0.5%
- Baryonic dark matter: 3.5%
- Nonbaryonic dark matter: 30%
- Dark energy: 66%

Flatness requires that everything adds up to 100% of the closure density. Except for a half per cent of visible, ordinary, *observable* matter, we are left with dark, exquisite, *unobservable* stuff.

Now, back right to the beginning: aren't we in the *wrong* universe?

Chapter 13

Time is life[1]

A non-specialist's comment on extraterrestrial life

13.1 Introduction

Life is an event which is intrinsically non-deductible from first principles. This idea, in a different context, has been claimed and argued by the biologist and Nobel laureate Jacques Monod in a book published in 1970 [51, chap. II].

Since locally life can neither be denied nor fully predicted, a further step follows, namely, the declaration of the existence of *extraterrestrial* life as a *principle* of Nature.

The main advantages of a principle for the existence of extraterrestrial life are: (i) the solution of paradox-like statements concerning extraterrestrial life (e.g., Fermi's question), (ii) the suppression of geo- and anthropocentric ideas, and (iii) the creation of a logical basis for future theoretical and experimental investigations. In practice the latter means that one does not need to justify any scientific project on extraterrestrial life searches (for example, [64]) regarding its logical foundations: the principle provides (is) the foundation.

The crucial experiment for the origin of life has not to be done; it was already done on Earth. It seems fair to believe that given a set of yet unknown environmental conditions life is bound to flourish. Examples of such a conception, i.e., that life is not a privilege of our local environment, are multiple in the literature, from the early incursions by Giordano Bruno (e.g., [65]) and Christiaan Huygens [66] through the modern ages with Robert Goddard (see [67, chap. 18]), Sagan and Salpeter [60], and others.

It is worthwhile pointing out that the meaning of life used here is definitely not restricted to carbon-based organisms developed upon watery substrates. A broader concept is envisaged, which is not new and may be found, for example, in the investigations by Sagan and Salpeter [60] of a possible Jovian ecology, or in the literary speculations of a living interstellar cloud, by Hoyle [53], and of

[1] `http://arXiv.org/abs/astro-ph/0108180`

a structured cometary mind, by MacLeod [52] — incidentally, both likely being fed by some sort of ubiquitous cosmic plankton.

Asserting the precise meaning of life is otherwise beyond the scope of the present note; the reader is referred to the above-mentioned book by Monod for a thorough discussion on the definition of a living organism.

13.2 Time is life: a principle

The principle is set up along the following two lines of arguments. (1) The existence of life on Earth affirms the crucial experiment for the existence of life. (2) The universe is empirically found to be at least three times as old as life on Earth. The age of the oldest stars in the Milky Way is taken as a *lower* limit estimate for the age of the universe, and the age of the solar system as an *upper* limit estimate for the age of life on Earth. Both time-scales are observational facts resting on well-established scientific studies. The first one, on the physics of energy production in stars, and the second one, on the laws of radioactive decay applied to meteorites.

The universe is old enough such that life and a local ecology are expected features of any environment.

Time is life, that is to say, give it *time* and *life* is the irremediable end product.

13.3 Discussion

In the light of the principle, a number of other topics deserve renewed attention. Below, four of them are briefly touched: Fermi's question, the anthropic principle, extraterrestrial intelligence and panspermia.

The famous question posed by Enrico Fermi in an informal conversation during a lunch at Los Alamos, in the summer of 1950 (see later account by Eric M. Jones [68]), became central in the discussion of the existence of extraterrestrial civilizations (e.g., [69]). *"— Where is everybody?"*, asked Fermi, talking about extraterrestrial life. The answer to Fermi's question is plain and uninteresting: *"— They are where they belong to"*. Yet they are, states the extraterrestrial life principle.

The anthropic principle (see, for example, [55]), which certainly with justice should be dubbed *the masterpiece of the cosmological arrogance*, is thus irrelevant since the human ecology is but one amongst many.

The search for extraterrestrial intelligence (e.g., the SETI project, see `http://www.seti.org/`) is strengthened by the principle. But an eventual absence of contact with extraterrestrial civilizations should not be confused with their non-existence. Establishing contact with alien populations is not a prerogative of intelligent life but of a given cultural and social characteristic of intelligent life (e.g., mercantilism, in the case of mankind, as a driving force for contact between distinct societies on Earth in the XV and XVI century).

Finally, it is important to remark that the acceptance, or the eventual empirical verification, of the so-called *panspermia paradigm* (see electronic links to this and related issues in `http://www.panspermia.org/`) makes the extraterrestrial life principle obvious.

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Part IV

Various subjects

Chapter 14

Falls on the Moon: *"That's one small fall for a man..."*[1]

I fall, therefore I am.

– Mário Novello, 2012[2]

The Brazilian GloboNews cable TV show *Espaço Aberto – Ciência e Tecnologia* exhibited, on August 08, 2011, an interview with the ex-astronaut Eugene Cernan (1934-2017), whom, amongst other missions, commanded in December 1972, the last manned mission to the Moon, the Apollo 17. He became known as *the last man on the Moon*, because he was the last to enter the lunar module at the end of the mission.

The interviewers were three boys and a girl and the interview lasted a little more than 20 minutes. The Apollo 17 mission was the last to bring astronauts to the surface of the Moon. The mission was 3 days long on the Moon, and occurred in December 1972, more than 40 years ago.

[1] `http://lilith.fisica.ufmg.br/~dsoares/apolo-17/apolo-17-e.htm`
[2] Cosmos e Contexto (`http://www.cosmosecontexto.org.br/?p=885`)

Eugene Andrew Cernan, engineer and astronaut, was born on March 14, 1934 and passed away on January 16, 2017 (aged 82). (Photo: NASA).

One of the interviewers, the boy Daniel Turela Rodrigues (14 years old), asked the following question: "— *How was that moment that you fell on the Moon, took a tumble?*"

Eugene Cernan explained that the weight of anything on the Moon is 1/6 of the weight on Earth, and that makes jumping easy on its surface. Then, the most efficient way of moving there was through little jumps, like rabbits. On the other hand, whenever he had to stop, or make a turn, it was very difficult and many times they took small tumbles.

Tumbles on the Moon highlight three important laws of **Newtonian mechanics**: the law of universal gravitation, the 1st and the 2nd laws of motion. The law of universal gravitation explains why the weight on the surface of the Moon is equal to one sixth of the weight on the surface of Earth. With the help of this law one can mathematically express that statement writing

$$\frac{\mathbf{GM_{Moon}}}{\mathbf{R^2_{Moon}}} = \frac{\mathbf{1}}{\mathbf{6}}\frac{\mathbf{GM_{Earth}}}{\mathbf{R^2_{Earth}}}$$

where G is the universal gravitational constant, the Ms represent the masses

(7.349×10^{22} kg and 5.9736×10^{24} kg) and the Rs represent the radii (1,737.4 km and 6,378.1 km) of the Moon and of the Earth, respectively. $\mathrm{GM_{Moon}/R^2_{Moon}}$ is a constant and is called the *gravitational acceleration on the Moon* (g_{Moon}). Likewise, $\mathrm{GM_{Earth}/R^2_{Earth}}$ is a constant and is called the *gravitational acceleration on Earth* ($g_{\mathrm{Earth}} \approx 9.8$ m/s^2). According to the law of universal gravitation, a body of mass m has the weight $\mathrm{mg_{Moon}}$ on the surface of the Moon and $\mathrm{mg_{Earth}}$ on Earth, therefore, $\mathrm{mg_{Moon}} = 1/6\ \mathrm{mg_{Earth}}$ because $\mathrm{g_{Moon}} = 1/6\ \mathrm{g_{Earth}}$.

The 1st law is the famous *law of inertia*, and it states that every body stays at rest or at uniform rectilinear motion unless there are forces acting upon it. To change its state of motion, the 2nd law states that it is necessary a force *proportional* to the desired change — that is, to the acceleration — multiplied by the *mass* of the body, which is a measure of its inertia. All bodies have inertia, the property to resist any change in their state of rest or motion.

Now, the weight on the Moon is 1/6 of the weight on Earth but the mass does not change! In other words, the inertia of a body does not change. And note that Eugene Cernan used an equipment of almost 100 kg! Summing everything up, he "*carried*" an inertia of almost 180 kg! His own mass — about 80 kg — plus the mass of his vest and equipment that, as mentioned, was of about 100 kg. When he tries to stop or make a lightly curved turn he needed the muscular strength to stop 180 kg, or to have an 180 kg mass making a lightly curved turn! Add the fact that his speed was often large and, therefore, the needed acceleration to make a sudden stop or make a fast turn would be large as well. The required force becomes also large because it is equal to *mass times acceleration*, as we saw.

What is the best strategy for not falling? Mass cannot be changed, therefore one must change the acceleration. Eugene Cernan and his fellow should stop *slowly* and make turns at *low speed* (remember that things get yet more complicated in a curve, because the acceleration is proportional to the *square* of the speed).

The astronaut also drew the attention to the high center of gravity, with respect to the ground, of the combined set of astronaut, vest and equipment. Especially in the curves, that increases considerably the instability leading to falls. And we can add: irregularities on the terrain and the low flexibility of the vest and equipment of the astronaut. All these factors, plus the implacable play between weight and mass (inertia), discussed above, were responsible by the innumerable falls on the Moon.

Let us appreciate now the lunar tumbles of Eugene Cernan and his fellow? Watch here: `https://www.youtube.com/watch?v=ZjOnsbodCus`.

Chapter 15

Observational tests of the microwave background radiation[1]

15.1 Introduction

The concept of a "cosmic" microwave background radiation is introduced in the standard Big-Bang model in a *ad hoc* fashion. In spite of that, it is sometimes taken as a proof of the model. But the MBR may not be cosmic in the first place. Therefore there is a real necessity of investigating other causes or sources for it. The present paper considers a *local* origin for the radiation (see more details in [70]).

Following the discovery of the MBR, Penzias & Wilson published their findings in the 142nd volume of ApJ, in 1965. An accompanying paper, by Dicke et al. claimed the *cosmic* nature of the phenomenon, establishing therefrom the key foundation of the Big Bang cosmological model. They have in fact appropriated themselves of the discovery without leaving any room for other tentative interpretations of the finding.

But why, at that time, *immediately* cosmic?

In principle, there is no reason to believe that the MBR is of cosmological origin, except if one is willing *to accept* a coordinated set of theoretical propositions – with no firm and definitive observational bases – only in order to legitimate a given cosmological model.

The plan of the present paper is as follows. In section 15.2, the magnetic bottle scenario for a local MBR is presented and features of a related physical model are summarized. Section 15.3 discusses observational tests of a local MBR. In section 15.4, final remarks are presented.

[1] `http://lilith.fisica.ufmg.br/~dsoares/mbr/otmbr.pdf`

15.2 The Microwave Background Radiation and the magnetic bottle scenario

Let us then consider a *local* approach to the Microwave Background Radiation (MBR). Earth's magnetosphere is seen as a *magnetic bottle* whose walls are made by solar wind particles trapped along the magnetic lines of the Earth field. A minute fraction of Sun's light reflected by the Earth surface is caught within such a bottle and is thermalized through Thomson scattering on the bottle walls. The first consequence is that one would expect that the thermalized radiation should exhibit a *dipole anisotropy*, given the nature of Earth's magnetic field. And that is precisely what was observed by the COBE satellite from its 900-km altitude orbit.

Although WMAP, the *Wilkinson Microwave Anisotropy Probe*, sits far away from Earth, at the Lagrangean L2 point of the Sun-Earth system (see WMAP electronic page at the URL `http://map.gsfc.nasa.gov/m_mm/ob_techorbit1.html`, which means about 1.5 million km from Earth, that is not enough for it to be released from the magnetic influence from Earth.

It is located precisely and deep inside the bullet-shaped magnetopause, which extends to 1000 times the Earth radius or more – approximately 10 million km (see `http://www-spof.gsfc.nasa.gov/Education/wmpause.html` for details of the magnetopause).

Figures 15.1 and 15.2 display the same geometry, as far as the Sun-Earth system is concerned. It is clear from the figures that as the Earth revolves about the Sun the Lagrangean point L2 – thus WMAP – sits all the time inside Earth's magnetopause.

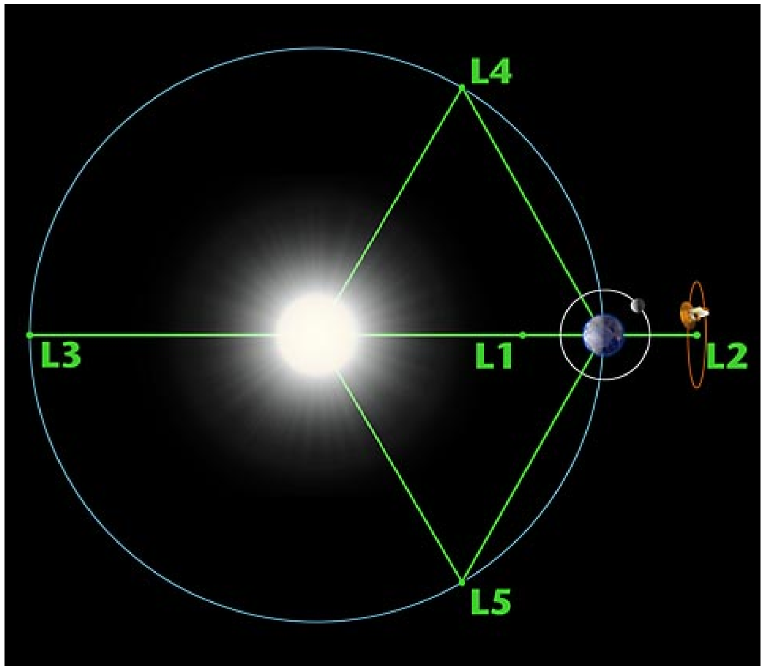

Figure 15.1: Lagrangean points of the Sun-Earth system. WMAP satellite is shown at point L2. (Image credit: Wilkinson Microwave Anisotropy Probe electronic page.)

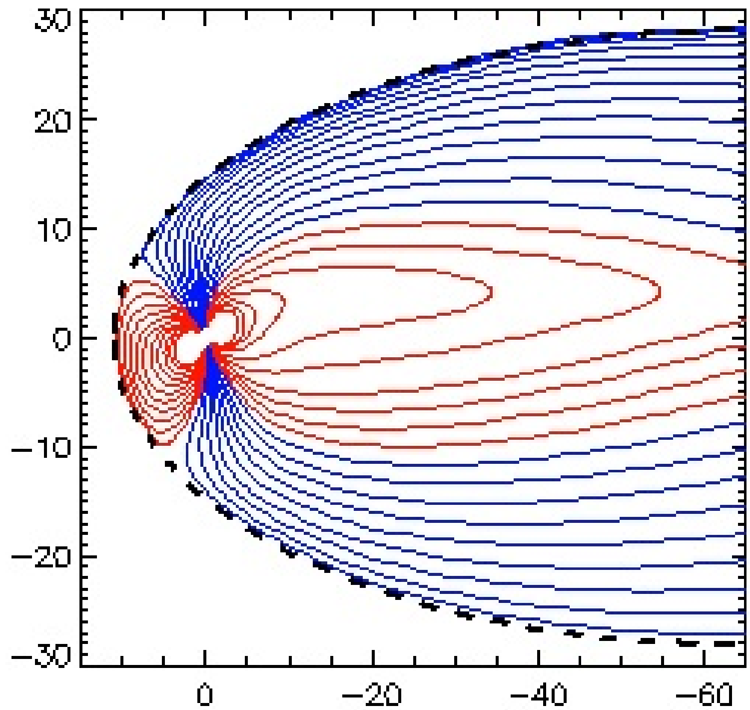

Figure 15.2: A view of Earth's magnetopause. The bullet-shaped magnetopause is always along the Sun-Earth direction (coordinates in Earth radii). The magnetopause extends to up to 1000 Earth radii. L2 is inside the magnetopause at about 230 Earth radii. (Image credit: "The Exploration of the Earth's Magnetosphere", an educational web site by David P. Stern and Mauricio Peredo.)

The Earth magnetosphere has a complex structure with variable electron densities in multiple layers around a neutral sheet at its mid-plane. The tail boundary – the magnetopause – can reach 500-1000 Earth radii (Figure 15.2).

A simple model for the blackbody cavity may, in a first approximation, neglect anisotropies in the thermal spectrum [71]. The magnetopause is modeled as a cylindrical cavity with its axis – the z-direction – running along the Sun-Earth direction. Being R the polar radius, the electron density $n(z, R)$, averaged over the azimuthal angles, is a well-known observed quantity. Microwave photons are Thomson scattered inside the cavity till thermal equilibrium is attained in a time-scale much shorter than Earth's age. The precise source of the microwave photons is not critical since there are many possibilities. The most obvious is the long wavelength tail of the solar spectrum; far infrared photons from Earth itself might be another possibility (see below the discussion of radio thermal emission from solar system planets). Anisotropies are considered with a more realistic electron density distribution [71].

15.3 Observational tests

As long as one considers a local MBR, a plethora of observational tests come to light. Three major tests are discussed here.

15.3.1 Non earthly MBR probe

A straight consequence – easily testable – is that the background radiation from other "magnetic bottles" – other planets – will be different, with a different thermal spectrum, possibly non thermal and even nonexistent. A probe orbiting another solar system planet like Mars, Venus, etc, would verify the hypothesis.

15.3.2 MBR anisotropy time variation

The Earth magnetotail oscillates about its axis during the yearly revolution around the Sun by as much as 5 to 20 degrees [72]. This introduces a measurable time variation on MBR anisotropies. An observational program that measures the MBR at different phases of Earth's orbit would detect such variations.

15.3.3 Planetary thermal glow

The importance of radio thermal emission from planets is twofold. First, thermal emission may be the source of background radiation photons, and, second, the thermal glow may be the exterior manifestation of the background radiation itself. That is, the radiation which is interpreted as a "cosmic" background radiation when measured from within the planetary environment – the magnetic bottle – is observed as a thermal glow from the outside.

There are many antecedents in observing thermal glows from planets in the radio-wave range. Mercury has a thermal 400 K glow and Venus was found to have an approximate 500 K glow by Mayer et al. [73]. Radio emission from Mars and Jupiter at 3.15 cm and 9.4 cm are reported by Mayer et al. [74]. A blackbody temperature of 210 K was found for Mars and 140 K for Jupiter.

A reasonable prediction is that if one looks at the right wavelength range, one should be able to find the magnetic bottle signature of planetary emission. Thus, the detection of Earth's 3 K thermal emission from the *outside* would be a strong indication of a local MBR.

15.4 Concluding remarks

The next MBR anisotropy probe, NASA's Planck satellite, is scheduled for launch in 2007. Again, it is planned to sit at Lagrangean L2 point, just like

WMAP (see briefing of Planck mission at `https://www.esa.int/Enabling_Support/Operations/Planck`).

It would be a great opportunity to test the validity of the magnetic bottle scenario if Planck's observation site is moved to outside the earthly environment. The immediate suggestion is a stationary point on a Mars orbit, with the probe being obscured from solar radiation by the planet, similar to the Sun-Earth-WMAP configuration.

Planck will measure, like WMAP did, background anisotropies. To measure the background radiation spectrum a COBE-like probe should be sent to Mars, with replicas of COBE's three instruments, FIRAS, DMR and DIRBE. The goal is to measure Martian background radiation spectrum and its anisotropies, just like COBE did on Earth.

The obvious prediction is that the thermal background – if it is indeed thermal – will be totally different from the 3 K spectrum observed from Earth's magnetic bottle.

The MBR investigation would be considerably enriched by the following crucial observational tests:

1. time variability of the MBR on the scale of fraction of a solar year, and

2. measurement of the MBR in another planetary environment.

Both tests are unthinkable in the framework of a MBR with a *cosmic* origin but are quite natural experiments from the point of view of a local origin for the MBR.

Chapter 16

Sandage versus Hubble on the reality of the expanding universe[1]

> *We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising.*
>
> Mathematical Principles of Natural Philosophy, Book III
> – I. Newton, 1687

16.1 Introduction

To begin with let us state clearly what are Sandage's and Hubble's opinions on the reality of the expanding universe.

Since his discovery of the redshift-distance linear relation, Hubble did not accept the direct interpretation of a Doppler effect as being responsible for the spectral shifts. He was still reluctant in accepting the reality of the expansion as late as 1953, the year of his death ([75], hereafter LS01).

Sandage, on the contrary, mainly based on his and collaborators' long time work on the Tolman effect (in fact, since 1991, see references in LS01), believes that the expansion of the universe is a reality.

Now, LS01's conclusion is rather *inconclusive*, if one sticks to basic concepts of epistemology. After their analysis of the surface brightness (SB) of 34 early-type galaxies is completed, they state, at the end of §4.2: "Therefore, we assert

[1] `https://arxiv.org/abs/physics/0605098`

that we have either (1) detected the evolutionary brightening directly from the $\langle SB \rangle$ observations *on the assumption that the Tolman effect exists* or (2) confirmed that the Tolman test for the reality of the expansion is positive, *provided that the theoretical luminosity correction for evolution is real* (emphases added)."

What do they assert anyway? We shall keep for the purposes of the present paper what they write in the abstract: "We conclude that the Tolman surface brightness test is consistent with the expansion to within the *combined* errors of the observed $\langle SB \rangle$ depression and the *theoretical* corrections for luminosity evolution (emphases added)." The effect may be consistent but given the conditional statements it may not exist at all.

On the other side, Hubble's position was much more coherent, from the scientific point of view. Although referred to as "a reductionist bench scientist" (LS01, §1.3), Hubble solely relied (mistakenly, according to Sandage) on the interpretation of his observational data and their accuracy. As far as we know, such a procedure — as regular scientific behavior — was inaugurated by the brilliant Danish astronomer Tycho Brahe, in the XVI century, and has proved wise and successful beyond any doubt. But Sandage adds that besides that *mistake*, Hubble used also a *mistaken* theory of how redshifts should vary with distance. Why, one should ask: how could Hubble use the correct theory if he was, to begin with, looking for the correct theory?

The approach adopted by Sandage in his investigation of the Tolman effect is in fact a masterpiece of *tautology and hermeneutical circularity*, in spite of his clear intention of hiding it (some hints in §2).

In the XXI century, Sandage still plays with $q_\circ$, $H_\circ = 50$ and Mattig's equations. When he is warned that his cosmology mates are talking now about a Lambda-dominated universe, he reduces (a reductionist?) all of the entire new-cosmology standard model to a simple and empty $q_\circ = 0$ universe (quoted as *"almost identical"*, see LS01, end of §5).

Cosmology is still a heavy-speculated field in spite of the enormous efforts on presumable cosmology-sensitive observations. In such an environment, scientists are not expected to make incisive statements unless they are supported by definitely secure evidence, both on the theoretical and experimental or observational sides. The paper under criticism is an example of *the uncertain chain that links speculation to speculation in order to confirm speculation.* The scientific procedure is there but the scientific soul is not. In other words, pretty and nice formal science leading to no real scientific conclusion. That is the way LS01 should be read.

16.2 The Tolman effect

The Tolman test [76] for the reality of the expansion, in Friedmann-Robertson-Walker universes, predicts a $(1+z)^4$ dependence of the surface brightness with redshift. It is formulated as follows. Consider a source of luminosity L_e at emission, located at comoving distance D, on the time of reception. An observer receives the luminosity $L_e/(1+z)^2$, dimmed by both the redshifted photons and by time dilation on reception. The flux detected by the observer is then given by $F = L_e/[(1+z)^2 4\pi D^2]$.

The observed angular size of the source, with linear size R_e at emission, is $\theta = R_e(1+z)/D$. The average surface brightness is calculated from $\langle SB \rangle = F/(\pi\theta^2) = L_e/[4\pi^2 R_e^2(1+z)^4] = \langle SB_e \rangle/(1+z)^4$. This can be expressed in magnitudes as $\langle SBM \rangle = \langle SBM_e \rangle + 2.5\log(1+z)^4$, which is the usual presentation of the Tolman surface brightness test for the reality of the expanding universe.

16.3 Sandage and collaborators' inconsistencies

There are a number of inconsistencies in Sandage and co-workers' approach to the Tolman test. Of course, these are often overlooked by a biased Reader. In their last paper, LS01, the following list shows the main drawbacks in their study.

1) The analysis is made upon a toy model of the universe. A Friedmann model characterized by the deceleration parameter $q_\circ$, a Hubble constant of 50, and the classical Mattig's equations for the dependence of the quantities of interest on the redshift z.

2) Three decisive proofs, presented in LS01, that the expansion is real are everything but *decisive* (see §1.4 and references therein). Two of then, the time dilation test in the light curves of supernovae, and the running of the blackbody radiation as a function of redshift are jeopardized by evolutionary effects, still unsolved. To accept these tests as real tests is left to anybody's wish. The third, namely, the so-called "vertical normalization" of the background Planckian curve is justified by a conversation between Sandage and P.J.E. Peebles, as stated in the acknowledgments. Now, science needs more than *authoritative* discussions as scientific demonstrations. Incidentally, the third proof is considered by LS01 (§1.4.3) as the definitive proof of the Tolman effect. One might with reason then ask: why go on further with the investigation?

Speaking of authority, it is worthwhile mentioning two authoritative opinions on the significance of the microwave background radiation in cosmology. Fred Hoyle [77] states that

> *"There is no explanation at all of the microwave background in the Big Bang theory. All you can say for the theory is that it permits you to put it in if you want to put it in. So, you look and it is there, so you put it in directly. It isn't an explanation."*

And Jean-Claude Pecker [78] reaffirms:

> *"Actually, the 3 degree radiation, to me, has not a cosmological value. It is observed in any cosmology: in any cosmology you can predict the 3 degree radiation. So it is a proof of no cosmology at all, if it can be predicted of all cosmology."*

3) Section 5 of LS01 is dedicated to the tired-light *speculation*, as they put it. To be fair, the discussion presented in this section is useless, from the scientific point of view, since it compares a speculation with a toy model (the Friedmann cosmology). Besides that, "tired light" is in fact the name of a general paradigm: it is still *a paradigm in search of a theory* (note that the same epithet has been already addressed to another speculation, namely, Guth's inflation). Being such, there are many possible theories of the tired-light mechanism. It is not clear what theory LS01 considers, which is another weak point of their comparison. By the way, their intention is to compare the tired-light model with *observations*. As shown above, epistemology again teaches us that their approach is not valid.

4) LS01 naturally recognizes that luminosity evolution affects both the observed surface brightness and the absolute magnitude of galaxies. But they make the crucial assumption that it does not affect galaxy radius (§3.1). Now, such an assumption is probably not true since the radius is calculated from the Petrossian metric radius, defined as the difference in magnitude between the mean surface brightness averaged over the area interior to a particular radius and the surface brightness at that radius (see §1.5).

5) The calculation of the theoretical luminosity evolution from stellar population synthesis is also plagued with LS01's naive assumptions. The age as a function of redshift, T(z) (eqs. 8 and 9), is taken from their preferred *toy model*. Of course, Sandage's stickiness to $H_\circ = 50$ is somewhat alleviated here. In his (their) words (§4.1): "For these calculations, we must use the *real* value of $H_\circ$ (emphasis added)." One should not be surprised to know that his real value of $H_\circ$ is 58 km/s Mpc^{-1}.

6) In §4.2, with the evolutionary calculation, they assume overall solar abundances because the metallicities of cluster galaxies are not strongly constrained from the observations. It is well known that different input metallicities onto evolutionary codes lead to substantial different synthesis results.

7) In section 7, they explicitly admit two systematic uncertainties in the study. First, a minor technical problem in the galaxy radius calculation — already contaminated by a major problem, as shown above –, and, second, they acknowledge the selection bias present in the galaxy sample. Anyway, as expected, they assure that "neither of them are severe enough to jeopardize the results." We may otherwise simply disagree with that.

16.4 Concluding remarks

As a matter of science, the Tolman surface brightness test for the reality of the expansion of the universe remains inconclusive.

16.4.1 The contemporaneity of the doubt

Hubble versus Sandage: two antagonized scientific attitudes. Both scientists are confronted with the unknown and their reactions are completely opposite to each other. Why would Sandage's attitude be on the wrong track? Simply because Friedmann models were at Hubble's time as valid as arguing for an still *unknown* behavior of Nature as the cause leading to the redshift-distance relation. As time went by, such an attitude revealed itself to be more and more trustful. Nowadays, one see that modern cosmological models — in fact, modified Friedmann models — are totally unsatisfactory. One of the main desired outcomes of modern cosmology, namely, the matter-energy content of the universe does not conform to the real world: out of the total matter-energy budget only 0.5% is proved to exist from direct observations (see summary in Soares [79]).

One might well ask: how can Sandage and collaborators make so many weak assumptions, in the dangerous terrain of the gravely *unknown*, yet be tolerated by their science mates, and at the end conclude that *something* that is consistent with the expansion model is indeed true, when even the expansion model itself is totally in question because of its definitively wrong matter-energy budget prediction?

Hubble's initial caution would be much more desired, and remains valid today. He had the essential skeptical attitude of a real investigator of Nature.

Today, we must doubt the reality of the expansion because the expansion scenario is part of a cosmological model that has failed in giving a consistent picture of the universe we live.

16.4.2 Sandage's style

The fragility of Sandage's scientific approach is hidden under an extreme pedagogical style of paper writing. His copious use of scientific references and textbook style confuses rather than convinces the critical Reader.

It is curious — and one is referred here to the realm of psychology — that Sandage does not mention the most likely and scientifically palatable reason for Hubble's reluctance in accepting the expanding universe explanation of his redshift-distance law: *the age problem*. With Hubble's constant of the time, the age of the universe turns out to be about half of the geological age of the Earth. Hubble died in 1953, precisely when Walter Baade made the first substantial revision of Hubble's constant. History tells us then that Sandage himself devoted a gigantic effort to put it even down, reaching finally the now famous 50 figure. One might well speculate — in the realm of psychology still — that Sandage does not mention the age problem as the main scientific reason for Hubble's doubt because he would be revealing his *own personal hell*: he fights also with an age problem — remember, he is a celebrated champion of modern cosmology — and that is the reason of his beloved 50 or lower.

16.4.3 Last

The age problem, again and again. Where has it led modern Big Bang cosmology to? To *a completely dark and unknown universe.* But, in principle, that is not a big problem at all, as long as one is satisfied with playing with universe toy-models. Exactly the way we witness Sandage and collaborators doing with their investigation of the Tolman effect.

16.4.4 But not least

A. Brynjolfsson [80] discussed Lubin and Sandage's data in the light of plasma redshift theory. He claims that the Tolman test is consistent with plasma redshift cosmology [81] which predicts that the Tolman factor is close to $(1{+}z)^3$ and not to $(1{+}z)^4$, as required by the Big-Bang cosmology. It is worthwhile to reproduce the abstract of Brynjolfsson's work [80] mentioned above.

> "Surface Brightness Test and Plasma Redshift"
> The plasma redshift of photons in a hot sparse plasma follows from basic axioms of physics. It has no adjustable parameters [81]. Both the distance-redshift relation and the magnitude-redshift relation for supernovae and galaxies are well-defined functions of the average electron densities in intergalactic space. We have previously shown that the predictions of the magnitude-redshift relation in plasma-redshift cosmology match well the observed relations for the type Ia supernovae (SNe). No adjustable parameters such as the time variable "dark energy" and "dark matter" are needed. We have also shown that plasma redshift cosmology predicts well the intensity and black body spectrum of the cosmic microwave background (CMB). Plasma redshift explains also the spectrum below and above the 2.73 K black body CMB, and the X-ray background. In the following, we will show that the good observations and analyses of the relation between surface brightness and redshift for galaxies, as determined by Allan Sandage and Lori M. Lubin in 2001 [75], are well predicted by the plasma redshift. All these relations are inconsistent with cosmic time dilation and the contemporary big-bang cosmology.

C.F. Gallo [82] presented, in the 2006 April meeting of the American Physical Society, work in progress, in which he discusses a general thermodynamic argument that would justify a *"Tired Light Concept"*. In order to duplicate a Doppler Redshift it is required a detailed microscopic treatment of the photon/light interaction with the interacting medium (plasma, atoms, molecules, negative ions, etc), which has not been conclusively demonstrated theoretically or experimentally yet.

Gallo's abstract presented at the APS meeting is reproduced below.

> "Thermalization Tendency of Electromagnetic Radiation in Transit Through Astrophysical Mediums"
> As Electromagnetic Radiation from a hot source transits through a cooler interacting medium, the following are demonstrated from thermodynamic arguments.
> (1) The "hot" radiation always loses some energy to the cooler interacting medium.
> (2) Detailed behavior depends upon the microscopic nature of the

interacting medium.
(3) A Redshift will occur, but not necessarily imitate the wavelength dependence of the Doppler Redshift.
(4) A Doppler-type redshift will occur only under certain conditions.
(5) The loss of radiative energy to the intergalactic medium will contribute to the Cosmic Microwave Background Radiation.
The following characteristics depend upon the detailed nature of the interacting medium.
(1) The photon energy loss per collision.
(2) The magnitude (cross-sections) of the thermalization process.
(3) The energy dependence of the cross- section for various mediums.
(4) Forward propagation characteristics of the Redshifted EM radiation.
Although the effects are small, the cumulative redshift in astrophysical situations can be significant. Earthly experiments are planned.

At this point it is interesting to recall what happened in the past, in a similar situation, when Einstein gave a heuristic interpretation to the *photoelectric effect*. One can make an useful counterpoint to the *redshift effect* observed by Hubble.

Einstein's heuristic model departed from the following experimental evidences (e.g., [83]):

(a) the effect does not depend on the intensity of the radiative source;

(b) short wavelength blackbody radiation is described by the Wien limit;

(c) large wavelength blackbody radiation is described by the Rayleigh-Jeans distribution.

A heuristic program for the redshift effect might likewise consider at least the following observational evidences:

(a) the effect depends on the flux of the source according to Hubble's law;

(b) the effect does not depend on the wavelength of the radiation;

(c) the effect is quantized ([84, 85] and references therein).

Such a program would certainly clear the way for a theory to the tired-light paradigm.

Turning now to the Microwave Background Radiation (MBR), Halton Arp in one of his books [85, p. 237] cites an authentic Fred Hoyle's aphorism:

> *"A man who falls asleep on the top of a mountain and who awakes in a fog does not think he is looking at the origin of the Universe. He thinks he is in a fog."*

Let us then consider a *local* approach to MBR. Being freed from the "prison" of the Hot Big Bang Cosmology one may speculate on an earthly origin for the MBR. Earth's magnetosphere can be seen as a *magnetic bottle* whose walls are made by solar wind particles trapped along the magnetic lines of the Earth field. A minute fraction of Sun's light reflected by the Earth surface is caught within such a bottle and is thermalized through Thomson scattering on the bottle walls. The first consequence is that one would expect that the thermalized radiation should exhibit a *dipole anisotropy*, given the nature of Earth's magnetic field. And that is precisely what was observed by the COBE satellite from its 900-km altitude orbit.

A straight consequence — easily testable — is that the background radiation from other "magnetic bottles" — other planets — will be different, with a different thermal spectrum, possibly non thermal and even nonexistent. A probe orbiting another solar system planet like Mars, Venus, etc, would verify the hypothesis. Although WMAP, the *Wilkinson Microwave Anisotropy Probe*, sits far away from Earth, at the Lagrangean L2 point of the Sun-Earth system (see WMAP electronic page at the URL `http://map.gsfc.nasa.gov/m_mm/ob_techorbit1.html`), which means about 1.5 million km from Earth, that is not enough for it to be released from the magnetic influence from Earth (Figure 16.1).

Although its large altitude, it is located precisely and deep inside the bullet-shaped magnetopause, which extends to 1000 times the Earth radius or more — approximately 10 million km (see Figure 16.2 and `http://www-spof.gsfc.nasa.gov/Education/wmpause.html` for more details about the magnetopause).

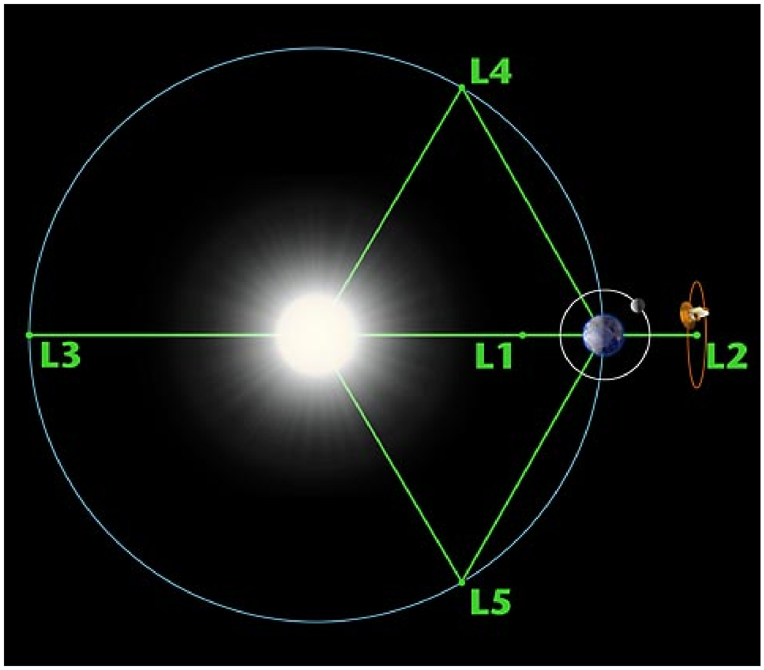

Figure 16.1: Lagrangean points of the Sun-Earth system. WMAP is shown around L2. Image credit: Wilkinson Microwave Anisotropy Probe electronic page.

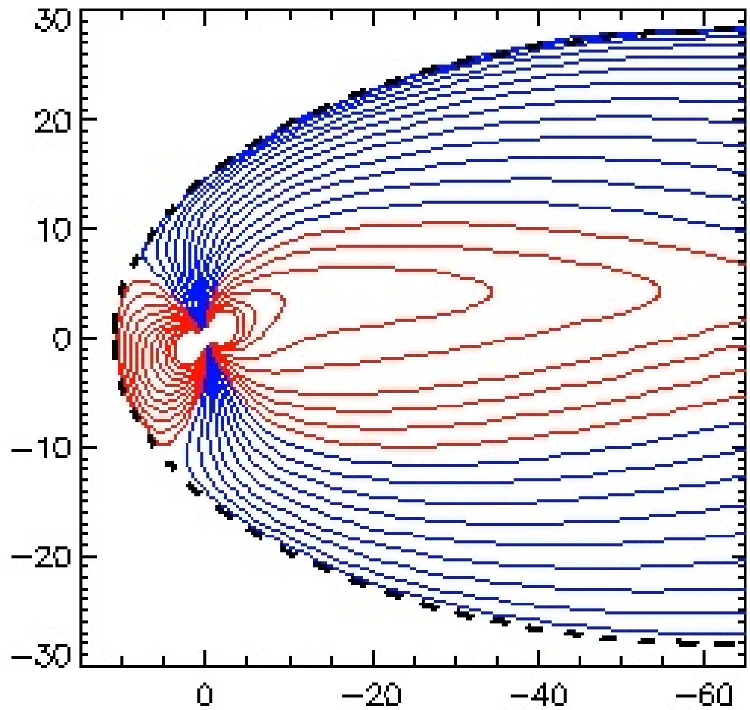

Figure 16.2: A view of Earth's magnetopause. The bullet-shaped magnetopause is always along the Sun-Earth direction. L2 is inside the magnetopause at about 230 Earth radii. Image credit: "The Exploration of the Earth's Magnetosphere", an educational web site by David P. Stern and Mauricio Peredo.

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