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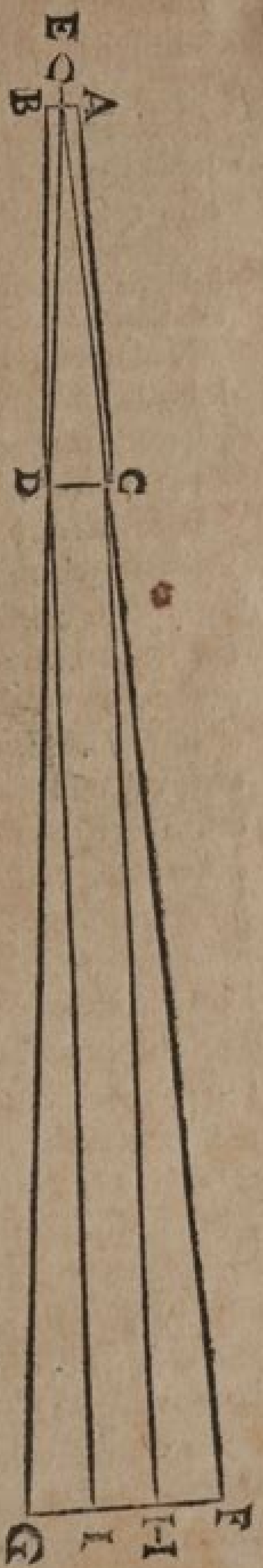

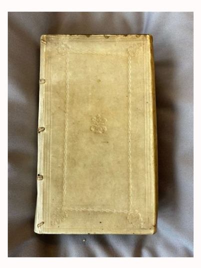

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I wish to express my gratitude to Paolo Bussotti for a great deal of precious advice. 1 Introduction Che fai, tu, Luna, in ciel? dimmi, che fai, sileziosa luna? [What do you do Moon in the sky? Tell me, what do you do, silent Moon?]; [Giacomo Leopardi, Canto di un pastore errante dell'Asia, 1830]. 1Searching for new and original interpretations of Galileo Galilei's statements, ideas and proposals is an enterprise which is surely more doomed to failure than others. This is because of the quantity and especially the quality of the work developed by many historians of science in an attempt to profoundly grasp Galileo's thought. New light has been thrown on the interpretation of Galileo's writings only after many decades of seemingly consolidated positions on Galileo's contribution to the development of science and the basic work of Stillman Drake in the second half of the twentieth century. According to some well-known historiographic interpretations such as the one offered by Alexandre Koyré, Galileo was not a completely experimental scientist.1 Since there have been new interpretations of Galileo's work, it makes sense to look for new nuances within the scientific contribution. A significant part of Galileo's interpreters are not experimental physicists. It is thus reasonable to think that the perspective of an experimental physicist could, to an extent, shed new light on Galileo's research. 2I have spent decades of my working life constructing and using measuring instruments to determine operating characteristics, collect large amounts of data, measure physical quantities and finally to confirm or disprove the laws of physics. Because of this, I might perhaps be able to provide a new standpoint from which to interpret aspects of Galileo's work. 3I shall focus on the Sidereus Nuncius [Starry Messenger], published in Venice on March 12th 1610. Although this work does not present a philosophical elaboration of the expounded observations, it offers a rich series of discoveries and insights for astronomy and science. My general idea is that Galileo is basically an experimental scientist. This idea is connected with the question of whether Galileo was the inventor of his telescope.2 I believe that he was and this position will be clarified in my paper. In fact, the few traces of information that can be found about the "toy" which was patented in September 1608 by three lenses manufacturers in the town of Middelburg in Zeeland would not suggest that it could have been transformed into a powerful instrument to investigate the skies. Indeed, the rudimentary tools found in European fairs for almost a year had aroused no curiosity or interest in many European scientists with the exception of Thomas Harriot. However, even though Harriot could claim the primacy of having first pointed a telescope at the Moon, he only managed to produce and publish a very rough and elementary picture from which no new and useful information can be drawn. Galileo's intuition in constructing and using (August 1609) the telescope cannot be a pure coincidence. 4Galileo's well-known experience in designing technical instruments is a necessary element to understand his success with the telescope. His great technical experience alone enabled him to connect the construction and functioning of a machine with the theoretical principles underpinning that very functioning. 5Therefore, Galileo was able to link the experimental dimension with the theoretical—logical and mathematical—aspects. On the other hand, Galileo himself stated in the initial pages that he was not the original inventor of the telescope, referring instead to a "Flemish".3 However, soon after, he indicates a specific way to calibrate the instrument he built and invites the reader to try this. However he also suggests they take care and use great skill otherwise failure is assured as he was to repeat later before the description of the discovery of the Medicean Planets:4 Figure 1: The cover of the Sidereus Nuncius (1610) 2 The aim of this work 6This paper's aim is to find a few sentences and hints in this work which was written almost spontaneously by Galileo and thus make a different interpretation to the widely shared and consolidated analyses. I will quote and describe statements on several issues and I take a free approach to the text without following the order emerging from the pages of the Sidereus Nuncius. In this manner, it will introduce some interpretative hypotheses to fully grasp the meaning of some of Galileo's statements which, at first glance, might appear rather odd. I am aware what I am claiming verges on the provocative but I will provide evidence to back up my view. 3 A methodological question 7A first, purely methodological question, emerges through analysis of Galileo's progress, starting with the first observations of "the body of the Moon", where he identifies bright spots in the dark and dark shadows on the sunlit parts. He carried out nightly observations and obtained both still images and something which could be interpreted almost as a living picture that he seeks to analyze.5 This is a crucial first step: Galileo builds up a three-dimensional representation in movement of what he can see and observe, each time more carefully. He builds a model that he refines night by night as a consequence of his new observations. These models are confirmed by a long series of observations and also by the logic with which Galileo strongly connects those observations. He is aware that his description of the Moon is completely different from that accepted by the astronomers and supported by the Church. In spite of this, he remains firm in his opinion that the Moon is similar to the Earth in all respects and is not a body made out of ethereal matter—the first of the sovralunare world where perfection reigns. And this is in fact a truly great revolution in thought. However Galileo does not just end with a description, albeit far more refined than previous efforts. He goes beyond this and determines the height of the Moon's mountains which was a mere hypothesis at the time. 8Measuring gives a sense of reality which is different from that obtained by descriptions. Measuring involves transforming an "object's" characteristic into numbers. Initially an object may only exist in thought and with measurement it acquires a connotation of reality. This is the essence of any physical quantity, where the term "physical" expresses the link between our mental model and a series of facts related to external reality. Galileo performed the measurement of the height of a mountain on the Moon and found it was 4 Italian miles in height which was a very surprising finding. Figure 2: Procedure followed by Galileo to measure the height of the mountains on the Moon 9However Galileo needed to go further because although he was proposing a simple but effective three-dimensional, geometric model, this was not easy to accept. In fact, the result of his calculation is a value that surprises and maybe even disconcerts because, as he explicitly points out, it goes far beyond the value estimated at that time for the height of the highest European mountains. However, we must remember that the height of a mountain was measured from the valley bottom and this means the otherwise inexplicable discrepancy with the actually measured value is not actually surprising. These surprisingly high mountains could tarnish the validity of Galileo's hypothesis which had upset popular opinion. After centuries of stable belief, it was well established that the lunar surface was smooth, although the question of the nature of the Moon's many, vast and irregular spots remained to be solved and were indeed the subject of many inferences. Nonetheless, the clarity and the simplicity of Galileo's reasoning supported a measurement which made the most amazing hypothesis reality. Figure 3: The Moon in a schematic drawing by Galileo 5 The lunar atmosphere 10Galileo wrote many pages on the description of the Moon. Indeed, he was aware that he needed to provide a series of evidence to support his hypothesis. However there is one aspect which should perhaps be more thoroughly investigated and may hide a more subtle interpretation. Galileo gives one more recommendation on the quality of the instrument to anyone who wanted to confirm his observations. Immediately afterwards, he deals with a question which could also affect his explanation of the nature of the Moon namely why do the edges of the Moon circle appear so perfectly smooth and not rough "like a gear"?6 This objection most certainly was aimed at preventing any critical remarks about his work in the future. However, such an objection has also the aim of reinforcing his own work by showing the reader that he is ready to take possible criticism of his statements into account. Nevertheless there is something more. In fact, Galileo gives two explanations why it is not possible to distinguish the sawtooth mountains' profile on the Moon's edge. 11The first example consists in the vision of several ridges of mountains following each other at increasing distances. This view is also typical on the Earth, which is a confirmation that the nature of the Moon is the same as Earth's. This similarity is now taken for granted. The yokes appear almost continuous because the alternation of peaks and valleys of a chain are positioned at random with respect to the subsequent chain. The mountains on the Earth thus explain mountains on the Moon. 12The second explanation is more picturesque but perhaps less conclusive because the scale factor is completely different and because Galileo now compares the mountains' dimensions with those of sea waves. Galileo uses a beautiful image of a stormy sea with rows of waves advancing parallel to each other but which cannot be perceived individually. Therefore, we see a substantially continuous horizon. These explanations appear logical and strengthen the interpretation of the lunar world as a double of the terrestrial world. Also, they are widely sufficient to justify the observational data, or rather in this case the lack thereof. However, Galileo is not satisfied with this explanation and looks for another. This requires a further hypothesis—the presence on the Moon of a shell-type "atmosphere" similar to the Earth's and thus once again providing a strong analogy between the Moon and the Earth.7 The lunar atmosphere allows Galileo to justify the lack of definition observed on the edge of the Moon which prevents us from perceiving and distinguishing the individual peaks. 13Galileo supports this third explanation with one of the few drawings in Sidereus Nuncius. This is not an accurate representation of what he sees but a model. In this picture, a circular ring around the rim of the Moon appears clearly. In other words, Galileo aims to provide an unambiguous description to avoid any misunderstanding. At this point in his work, Galileo is in a hurry to describe his most revolutionary discovery—the Medicean Planets, the last and most important subject of the whole book. Therefore, while this additional explanation may seem superfluous and redundant based on the introduction of a new idea, it could be interpreted as a further similarity between the Moon and the Earth. Perhaps another reason led Galileo to go much further than a mere description of what he saw and also beyond the reference that the reader can share. This is the subject of a hypothesis that I shall propose but first it is necessary to point out another important step in advance. 6 The atmosphere on Jupiter 14The last part of Sidereus Nuncius is dedicated to the discovery of the four Medicean Planets. The description is enriched by dozens of observations collected night after night with meticulous precision and reported in the text with exact drawings, one for each day. Much earlier in the book when Galileo reaches the end of his observations, he introduces the hypothesis that an atmosphere surrounds another celestial body—Jupiter in this case (see above note 6). 15Galileo carefully observes the relative positions of the four satellites whose motion is easily perceivable from one night to the next and measures this with accuracy. At the same time, Galileo also tries to measure the intensity of the satellites' light and notes this with care. However, it must be said that the relative position and the angular distance of a star or planet is an easily measurable quantity and therefore not ambiguous. Instead, it is difficult to measure the light intensity of an object in the black night sky, particularly if this object is observed very close to another brighter body. This is exactly the case when the satellites of Jupiter are observed by Galileo shortly before or after their occultation by the far larger body of the planet. 16Galileo has already encountered a similar problem, i.e., the problem of evaluating the magnitudes of a celestial object through his telescope. He deals with it some pages earlier when describing the difficulty of measuring the apparent magnitude of the stars he had just discovered. Indeed, he describes how the instrument behaves very strangely and shows different magnifications depending on whether the observed object is a planet or a star. In fact, Galileo could not know the physical explanation of the optical aberration phenomenon which is usually associated with the use of an optical instrument. Therefore, he is hesitant to give the description of a mechanism according to which the instrument is apparently able to enlarge the observed objects in different ways, i.e., with different magnifications. For the same reason, he could not give any justification for the apparent malfunctions found in the instrument itself, like, for example, the "brightening rays" he observes in the stars. 17In addition, Galileo misses another crucial issue in the understanding of what "you really see" in the ocular lens which is related to a complex mechanism that would be called "physiology of vision" in the future. At this point, Galileo did not have the time to pursue this matter because he urgently needed to make public his numerous observations of all visible objects in the sky of Padua as soon as possible. In the winter of 1610, despite not being an astronomer he was about to totally and definitively revolutionize the image of the sky and also suggest the need to overhaul the model of the Cosmos through his rich innovations. Indeed, the Aristotelian-Ptolemaic model endorsed by the Church encountered a great deal of difficulty in facing up to the whole complex set of new ideas discovered by Galileo. This depended on the geometric complexity required to take the new, observational data into account and also on the weakness of some of the principles on which the Aristotelian-Ptolemaic system was based. These principles were now being demolished. First of all, the skies' immutability (a secular assumption) was a condition which appeared a necessity because the sky was considered a divine work. The Copernican model was published almost 70 years earlier and was still seen only as an original, mathematical exercise to provide new ephemerides. Nevertheless, from a physical and mathematical point of view the discoveries of Jupiter's satellites was problematic for both the Ptolemaic and Copernican systems (at least in the version expounded by Copernicus where the system was based on circular motion). Though the Astronomia Nova were published in 1609, when Galileo published the Sidereus, Kepler's work had little influence on astronomers. However, while there were several difficulties with the Copernican system, the situation for its Ptolemaic counterpart was undoubtedly even worse. Thus Copernicus's theory represented a very new horizon for knowledge of the sky. 18A further remarkable element is explained in the last pages of the Sidereus Nuncius where Galileo writes about the variable intensity of the light of Jupiter's satellites when they are close to the planet. This observation may indeed appear superfluous when compared with the astonishing announcement of the existence of four new planets. Moreover, Galileo does not provide many details regarding this problem although he was precise and meticulous in describing these observations. Notwithstanding, these references appear significant. Galileo advances a hypothesis that can explain this apparent variability of the light reflected by satellites after a very long thought process. Initially, he provides the hypothesis that their orbits can be highly elliptical, being the major axis along the line of sight of the observer. This meant he could explain the weakening of the light by the increased distance of the satellite. Galileo certainly knew from his previous experience that light intensity decreases with increasing distance from the source. 19Whatever the function which connects light intensity and the distance of the light source, it seemed implausible that the decrease in light intensity was as strong as Galileo's observation suggested. Galileo saw that the brightness of the satellites was at its minimum when they came close to the planet. The only theoretical possibility is thus that the satellite moves away far from Jupiter, its center of motion and therefore that the orbit must be greatly elliptical in relation to the weakening of the light output observed and recorded by Galileo. The logic that supports this argument may seem compelling. However, Galileo does not bother to justify the images described although the satellite's brightness does not change when they depart even slightly from Jupiter. Anyway, this behaviour of the phenomenon is not compatible with the previous hypothesis which seems artificial. However, this hypothesis is a scientific-literal artifice used by Galileo to lead up to a second explanation. In this explanation, he returns strongly to the hypothesis that an atmosphere could surround a celestial body—Jupiter in this case. The presence of a dense shell would weaken the light absorbing a large proportion of the emission from satellites.8 With this explanation, Galileo seeks to make the results of his observations compatible with a model—some demonstrations, which he uses to validate the sensitive experience. 7 A hypothesis 20Given the deep differences between the Moon and Jupiter as observed by Galileo, the existence of an atmosphere on both could appear a strange coincidence. This incited me to search for a different, more general motivation underlying Galileo's words. It is fascinating to imagine that Galileo had a common purpose for giving an account of two different events which acquires the value of a universal statement—planets have a shell of air around themselves. Nevertheless, this statement is not particularly significant if it is limited to an explanation of observational data but if used as a starting hypothesis which is well supported by observations, it could have deep, cosmological implications. It would indeed be linked to the disputes concerning the De revolutionibus orbium coelestium of Nicolaus Copernicus. In fact, if the Moon and the planets have an atmosphere in their circular movement around their center-of-motion, then the motion itself is not incompatible with the existence of an atmosphere. Also, if this logical consequence is valid for the Moon and planets as shown by Galileo and if they are similar to the Earth, this obstacle is overcome by imagining an Earth moving around the Sun. Therefore, the movement of the Earth around its axis and around the Sun does not imply the atmosphere is stripped away. Of course, such a deduction is not evident or explicit in Galileo's words. Therefore any such proposal should be maintained in the field of the inferences which can be made by speculating on Galileo's words to reconstruct his possible thought. However, if this hypothesis is correct, why was Galileo not more explicit? This is impossible to answer. Again, it should be recalled that the heliocentric system was not accepted by most theologians, astrologers, astronomers and scholars, even if De revolutionibus had not yet been rejected. As is well known, Copernicus's theory was condemned in 1616 while Galileo was to add many other discoveries to those announced in the Sidereus Nuncius in the 1610-1616 period. All these observations were to be as fundamental as the previous ones. Galileo discovers Saturn to have a strange shape like a small olive. He first recognizes the sunspots to be on the Sun's surface and not far from the Sun. 21Finally he made his most important observation. Venus was watched nightly and every week which showed phases similar to those of the Moon. It therefore became geometrically evident that the Mother of Loves was moving around the Sun as Copernicus had suggested, unheeded, for decades. 22This, in fact, was the most conclusive observation in support of the Polish astronomer's revolutionary idea. 23 Figure 4: Saturn and the phases of Venus as represented by Galileo in Il SaggiatoreAgrandir Original (jpeg, 68k)8 On the nature of the nebulous stars 24Let us make one last incursion into the sensitive and dangerous field of "possible interpretations" of what Galileo wrote in the Sidereus Nuncius. 25I attempted to read between the lines of this small book, a true cornerstone of the history of astronomy and also a turning point for the whole of science. The next step examined is that in which Galileo describes what he sees pointing his telescope towards the nebulae, or nebulous stars. Immediately he proposes a new radical change in the interpretation of those indistinct spots that had long been considered one of the most mysterious objects in the sky when viewed with the naked eye. Philosophers, priests, astronomers had provided several proposals to explain their nature which were mostly mythologically based. Also the analogy with the Milky Way had been used to find some explanations but this was done without "sensible experiments and necessary demonstrations".9 26Galileo does not hide his surprise and also his satisfaction in revealing what he sees in the ocular lens of his telescope. This is, once again, a real revolution. In fact, the interpretation of these objects changes dramatically because Galileo reveals that they are composed of myriad stars which are so weak and apparently mutually close that they cannot be distinguished by the human eye. Thus one has the perception that they are made of a continuous material. This was the "essence" of the nebulous stars before Galileo discovered and announced their discrete nature.10 27Certainly, this discovery by Galileo—this invention, because he based this idea on observations—is not among the most remarkable if compared with the others expounded in the Sidereus Nuncius. Figure 5: Nebulous stars in the Galileo's drawings 28In fact, the other discoveries represent the foundations of a completely new scheme in the description of the sky. This scheme supports the heliocentric model. But another revolution which would have to wait several more centuries to be accepted was smouldering under the ashes. It was proposed more than two thousand years ago and it concerns the real composition of nature of matter around us. Does matter have a continuous structure or is it composed by the atoms that Democritus and Leucippus imagined in a remote corner of Greece? In those years the implications of the atomistic hypothesis were rather hazardous. Asking yourself this question at that period had a dangerous implication because the atomic theory was strongly opposed by the Church. Consequently, philosophers who supported it were considered blasphemous and heretical and therefore under the menace of the Inquisition. Why not therefore imagine that Galileo, who was always ready to make daring and surprising logical connections and analogies, had found this idea attractive. After the Milky Way and the nebulous stars, i.e., celestial matter and terrestrial matter, too, could he reveal his true, discrete nature? 9 Conclusions 29My references to Sidereus Nuncius and to the logical deductions developed in this work by Galileo have been based merely on what Galileo himself explicitly wrote. Certainly, they are read today more than 400 years later at the dawn of the twenty-first century. Obviously, the meanings that we now assign to the words of Galileo, have in some cases been completely revolutionized by the historical and scientific background. Profound differences are also evident from an epistemological point of view. 30However, many aspects of Galileo's thought are still alive and his teaching is still of great significance and relevance particularly his reference to sensible experiences and necessary demonstrations. Galileo left his revolutionary message relying upon experiments and observations, rather than upon the theoretical, dialectic sophistry which characterizes the speculation of several other philosophers. As I have tried to show, it is not impossible to search for and maybe even find different interpretations from the classical one which is accepted by history of science. It is very difficult to determine whether they are correct and really match with the thought of Galileo and I think no one can state this with reasonable certainty. However nor perhaps can this be completely denied. È la prima volta che la luna diventa per gli uomini un oggetto reale [...]. [Calvino 1968] Page 2 26-2 | 2022Patrimonialisation des mathématiques (XVIIIe-XXe siècles) Heritage Building in Mathematics (18th-20th Centuries) 26-1 | 2022La désuétude conceptuelle : abandon ou transformation ? 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