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Galileo's eye: A new vision of the senses in the work of Galileo Galilei

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Abstract. Reflections on the senses, and particularly on vision, permeate the writings of Galileo Galilei, one of the main protagonists of the scientific revolution. This aspect of his work has received scant attention by historians, in spite of its importance for his achievements in astronomy, and also for the significance in the innovative scientific methodology he fostered. Galileo's vision pursued a different path from the main stream of the then contemporary studies in the field; these were concerned with the dioptrics and anatomy of the eye, as elaborated mainly by Johannes Kepler and Christoph Scheiner. Galileo was more concerned with the phenomenology rather than with the mechanisms of the visual process. His general interest in the senses was psychological and philosophical; it reflected the fallacies and limits of the senses and the ways in which scientific knowledge of the world could be gathered from potentially deceptive appearances. Galileo's innovative conception of the relation between the senses and external reality contrasted with the classical tradition dominated by Aristotle; it paved the way for the modern understanding of sensory processing, culminating two centuries later in Johannes Müller's elaboration of the doctrine of specific nerve energies and in Helmholtz's general theory of perception.

1 Introduction

The study of vision was transformed in the early seventeenth century: the passage of light through the eye to focus an image on the retina was described by Johannes Kepler (1604, 1611, 2000; figure 1) and the gross anatomy of the eye was illustrated correctly for the first time by Christoph Scheiner (1619; figure 1). Kepler's dioptrics removed the confusions about light and sight and separated physical from physiological optics; the retina rather than the lens was taken as the receptive structure and extramission theories of light were rejected (Lindberg 1976; Jaeger 1990; Wade 1998). Scheiner related physiological optics to ocular anatomy and addressed issues of image formation and accommodation (Daxecker 2004). Kepler and Scheiner set in train the analysis of vision in terms of optics and anatomy, but they were not the only astronomers who fashioned a new view of vision. Galileo Galilei (figure 2) adopted an alternative approach and one that has received scant attention from historians (see, however, Shea 1970a, Crombie 1972; F Camerota 2004): he refined the observational basis upon which theories should be founded, and linked the lability of the senses with his wider world view.

Kepler and Galileo played critical roles in the scientific revolution as it applied to cosmology. Less attention has been directed to the ramifications of this shift on an analysis of the senses and their relation to the external world. Reflections on the senses, and particularly on vision, played a prominent role in Galileo's scientific and philosophical writings. His conception of sensory function contrasted with the considerations of his contemporaries. Paradoxically, despite his development of the telescope, Galileo did not contribute to the progress of optical science in his day, like that expounded by Kepler and Scheiner (Wade 2007a). Galileo's contribution to sensory science was of a different nature. It played more on the psychological and functional dimensions, and Galileo was more concerned with a general theory of knowledge than with the detailed mechanisms of the senses. Accordingly, his most immediate and direct influence was exerted on philosophy rather than on physiology. It took about two centuries before

Galileo's general conception of the senses would resurface to provide the foundations for modern sensory physiology. In this article we will survey and discuss some of Galileo's overlooked reflections on perception in the context of his general approach to deriving knowledge of the world; we will also try to underline the cultural backgrounds from which his new conception emerged. The relevance of Galileo's elaborations in this field for contemporary sensory physiology will also be discussed.

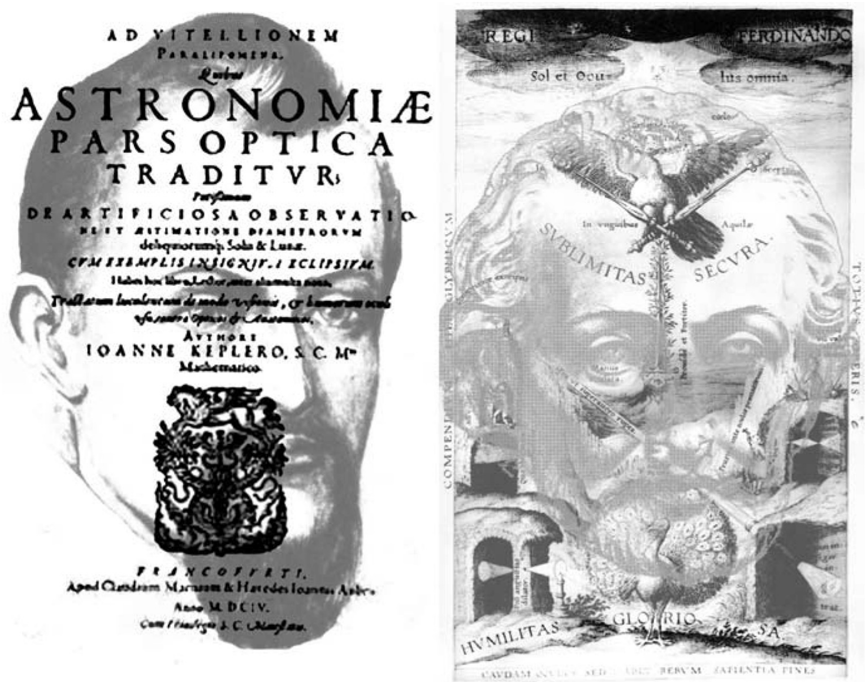

Figure 1. *Visual Revolutionaries* by Nicholas Wade. Left, Johannes Kepler is shown with the title page of his book (Kepler 1604). Right, a portrait of Christoph Scheiner with the frontispiece of his *Oculus* (Scheiner 1619).

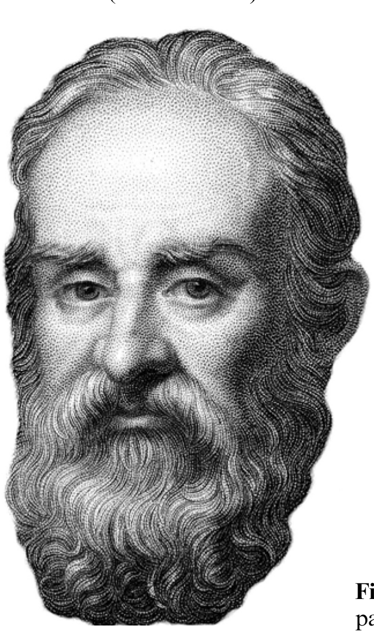

Figure 2. Detail of an engraving of Galileo Galilei based on a painting by Alan Ramsay (from Knight 1834).

2 Galileo, common sense, motion, and frames of reference

Galileo (figure 3) was clearly aware that sensory data do not provide an immediate and unambiguous pathway for disentangling the complexity of reality and for deriving knowledge of the world. For him, there was no doubt that we can acquire knowledge of physical reality through observations and experiments based on the senses ('sensate esperienze', ie 'sensible experiences', but see section 7). In his metaphorical language this can be achieved by directly reading the 'book of the world' (or 'of nature' or 'of the universe'), which is contrasted with the 'world of paper', of books that provide an indirect knowledge of nature based on the authority of ancient authors. However, at the same time as advocating direct observation of nature, Galileo cautioned against the immediate data provided by the senses: he argued that the true knowledge of reality was often contrary to the simple expectations of the senses ('the common sentiment' or 'the manifest senses').

Figure 3. *Galileo's Dialogue with Aristotle* by Nicholas Wade. The embedded face of Galileo is derived from the earliest known portrait of him, painted by Santo di Tito in 1601 (see Fahie 1929), together with the frontispiece of the first edition of the *Dialogo* (Galileo 1632). Galileo's right eye rests on Aristotle's head, who is in earnest metaphorical dialogue with Ptolemy and Copernicus.

Galileo frequently noted how surprising scientific truth might be, leading to unexpected conclusions which contrast with appearances (see Piccolino 2005, 2007). This is evidently the case with the sun that is seen rotating around the earth, but which is (according to the Copernican system) immobile at the centre of the solar system. It is also the case with bodies of different weight like a feather or a lead ball which, in the absence of external factors, would descend with identical motion and reach the ground at the same instant. This applied to all those paradoxes of motion that the ancients could not recognise because of their uncritical confidence in the senses. Experience suggests to us that an object moves only if an external force impinges on it, and that if the force is removed all motion ceases. Galileo wrote about these paradoxes in the *Dialogo sopra i due massimi sistemi del mondo* producing some of his more beautiful passages. For example, that of "the main cabin below deck on some large ship" (Galileo 1632, page 180; ET page 186)[(1)] with "a large bowl of water with some

[(1)] When quoting from Galileo's *Dialogo* we indicate the page numbers of the original Italian edition (Galileo 1632) followed by the notation ET with the page numbers of the English translation by Drake. The same applies to other translations by Drake. Elsewhere, the original Italian text has been translated by the authors.

small fish in it" which, thanks to the inertial principle formulated by Galileo, do not require great effort to keep the same speed as the ship in order to avoid damage against the bowl. The same would also hold for the butterflies and flies which, in spite of the ship's movement, "will continue their flights indifferently toward every side, nor will it ever happen that they are concentrated toward the stern, as if tired out from keeping up the course of the ship, from which they have been separated during long intervals by keeping themselves in the air" (Galileo 1632, page 180; ET page 187). And again, the water droplets that "will fall as before into the vessel beneath without dropping toward the stern, although while the drops are in the air the ship runs many spans". Or the page with "the point of a writing pen that had been on a ship during the whole voyage from Venice to Alexandretta". With his pen, a painter on the ship:

> "would have been able to derive from the pen's motion an entire narrative of many figures completely traced and sketched in thousands of directions, with landscape, buildings, animal and other things. Yet the actual, real, essential movement marked by the pen point [with reference to the earth surface] would have been only a line; long indeed but very simple." (Galileo 1632, page 166; ET page 172)

Galileo devoted many pages to confute some new and old objections against the motion of the earth. For example, in keeping with the common-sense expectation "shooting a cannon ball to the east and another one with equal charge to the west" (Galileo 1632, page 119; ET page 126) the latter should travel "a great deal farther than the other one toward the east" if, as Copernicus assumes, the earth moves at a fast rate in the eastward direction. The naive expectation, based on the immediate sensory experience, would suggest, in the case of the earth's motion, that "the easterly shots would carry high and the westerly low" because of the expected movement of the horizon which is "always falling away to the east and rising in the west" (Galileo 1632, page 120; ET page 127). In a similar vein, a stone dropped from the top of a tower would not fall straight down, along a perpendicular line parallel to the tower wall, because of the movement of the tower associated to the putative rotation of the earth.

With regard to this last experiment, Galileo made (through the words of Salviati, his main alter ego in the *Dialogo*) an important remark signifying his conception of the senses. An expert observer placed on earth would never happen to see, nor even expect to see "the rock to fall any way but perpendicularly", even if his scientific knowledge would indicate that the stone actually moved along a complex path (resulting from the combination of its proper downward movement with that resulting from the earth's motion). Galileo wrote "It is therefore better to put aside the appearance, on which we all agree, and to use the power of the reason either to confirm its reality or to reveal its fallacy" (Galileo 1632, page 250; ET page 256). Moreover, on the third day of the *Dialogo*, Salviati expressed his admiration for those scholars who had kept their faith in the earth's movement in spite of contrary sensory evidence, as was the case for Aristarchus and Copernicus, who "were able in making reason so conquer sense, that, in defiance of the latter, the former became mistress of their credulity" (Galileo 1632, page 235; ET page 328).

3 Galileo's sensory philosophy

Galileo's considerations of visual appearances informed many other aspects of his conceptual analysis of the senses. These he published in *Il Saggiatore*, one of his most important texts, where he dealt explicitly with the senses from a philosophical viewpoint (figure 4). In replying to an objection concerning the origin of heat and of thermal sensations, Galileo developed an important distinction between two different attributes of objects (that would later be referred to as 'primary' and 'secondary' qualities):

Figure 4. *Galileo's Saggiatore* by Nicholas Wade. Galileo's portrait is derived from the painting by Francesco Villamena and is framed by the frontispiece of *Il Saggiatore* (Galileo 1623).

> "I say that, as soon as I conceive a piece of matter, or a corporeal substance, I feel myself necessarily compelled to conceive along with it, that it is bounded, and has this or that shape, that in relation to some other body it is either small or large; that it is in this or that place, and in this or that time; that it is in motion or at rest; that it either touches or does not touch some other body; and that it is one, few, or many; nor can I separate it from these states by any act of the imagination. But I do not feel my mind forced to conceive it as necessarily accompanied by such states as being white or red, bitter or sweet, noisy or quiet, or having a nice or nasty smell. On the contrary, if we were not guided by our senses, thinking or imagining would probably never arrive at them by themselves. This is why I think that, as far as concerns the object in which these tastes, smells, colours, etc appear to reside, they are nothing other than mere names, and they have their location only in the sentient body. Consequently, if the living being were removed, all these qualities would disappear and be annihilated." (Galileo 1623, pages 196 – 197)

To clarify the second type of attribute, Galileo referred to the sensation of tickling:

> "I move one of my hands, first over a marble statue, and then over a living man. As far as concerns the action which comes from the hand, it is one and the same for each subject, and it consists of those primary accidents, namely motion and touch; and these are the only names we have given them. But the animate body which receives these actions feels different affections depending on which parts are touched. For example, when touched under the soles of the feet, on the knees, or under the armpits, in addition to the ordinary sensation of touch, there is another sensation to which we have given a special name, by calling it 'tickling'. This affection belongs wholly to us, and not a whit of it belongs to the hand. And it seems to me that it would be a serious error if one wanted to say that, in addition to the motion and the touching, the hand had in itself this distinct capacity of tickling, as if tickling were an accident which inhered in it. A little piece of paper or a feather drawn lightly over any part of our body performs intrinsically the same action throughout, namely moving and touching us; but on touching us around the eyes, the nose, or under the nostrils, it gives rise to an almost intolerable itching, whereas in other parts we scarcely feel it. This itching belongs entirely to us, and not to the feather. Remove the animate and sentient body, and it is nothing other than a mere name. I believe that many other qualities which have been attributed to natural bodies (such as tastes, smells, colours, and others) have no greater an existence." (Galileo 1623, pages 197 – 198).

Galileo considered the senses of hearing, smelling, tasting, and touching and hypothesised a mechanism whereby each one could be stimulated by the agency of the objective qualities present in external bodies. Moreover, he also tried to establish a relation between each sense and the four classical elements of the universe (earth, water, air, and fire), according to a view that was then common in the framework of the correspondence between microcosm and macrocosm (Doni 1567; see Shea 1970a). Galileo explained most of the tactile and acoustic sensations on the basis of a rather direct and simple mechanical action. However, in order to account for other sensations (thermal, gustatory, and olfactory) he invoked the intervention of minute bodies emanating from external objects and capable of stimulating the specific senses. These bodies are indicated by a variety of expressions ("tiny particles", "minimal corpuscles", "minimal fire corpuscles"—*minimi ignei*—"minimal quanta" or simply "minima"—*minimi*). In elaborating his conception, Galileo was clearly inspired by the atomistic theories of Leucippus, Democritus, and Epicurus which were having a great revival in Renaissance culture, particularly after the circulation of Lucretius's *De rerum natura*. Reference to atomistic theories had already appeared in Galileo's polemical response to a group of Aristotelian philosophers, published in Florence in 1612, and concerning bodies floating in water (see Shea 1970a; Redondi 1983, 1985; M Camerota 2008).

In the case of the discussion on senses, the idea of matter that emanates extremely minute particles in rapid motion (a basic tenet of classical atomism) allowed Galileo to provide a link between external objects and sensory organs or terminations, within the framework of his mechanistic theory. With his minima he was no longer in need of qualities different from the form, shape, and movement that seemed to account for the tactile and acoustic sensations but appeared unsuited to other sensations. The minute corpuscles coming from external objects would stimulate sense organs and produced different sensations, pleasant or unpleasant, mainly "according to the multitude and speed of those minima".

Even though Galileo's conception might now appear as rather naive, it is of great historical importance. It represents a breakthrough in the philosophical and scientific tradition of the study of the cognitive relation between sentient individuals and the universe. Moreover, as we will show, it contains some fundamental principles of the current understanding of sensory neuroscience. Within the framework of the atomistic doctrine, Galileo was actually rebutting a long-established doctrine which had been developed in classical science, particularly by Aristotle. For the Greek scholar (and for most of the scientists and philosophers up to Galileo's time) there were specific qualities indicated as 'sensibles' in the external world, which were selectively aimed at interacting with the senses of animals (and particularly the five senses of humans) to produce sensations. Aristotle's discussion on sensibility is spread throughout his writing but is particularly elaborated in his *De anima* and *De sensu et sensibilibus* (Ross 1931). Two main types were distinguished: the 'proper' (or special) 'sensibles' and the 'common sensibles'. Proper sensibles were those connected uniquely with a specific sense, such as colours for vision, odours for olfaction, flavours for taste. On the other hand, common sensibles were those that could be detected by the interplay of various senses (generally touch and vision) like shape, size, number, position, and movement. In addition to what we now call quality of tactile sensations, the sense of touch (which for Aristotle was of primordial importance and present in all animals) did include the sensations of cold and warm, and of wet and dry. These corresponded to the four qualities—a fundamental aspect of the classical physiological theory—and were connected with the four elements of the universe. Touch sensitivity was particularly developed on the palm and surface of fingertips (as Aristotle clearly pointed out and Galileo recognised), and especially in human fingers, because of their constitution resulting from the perfect mixing (*temperamentum*) of the four elements. By their tactile sensibility, human fingers became as a kind of standard reference to ascertain the elemental composition of objects, both inanimate and animate (see Manzoni 2007).

Another important sensory distinction of Aristotle concerned the so-called 'sensibles by accidents', those forms of sensibles, commonly—but not necessarily and essentially—associated with the perception of proper sensibles. Of fundamental importance in Aristotle's conception of the senses was the relation of different sensibles to the possible occurrence of perceptual errors. Errors can occur only in the case of common sensibles and sensibles by accident, but never in the case of proper sensibles. For these latter ones, the impossibility of sensory errors is part of their definition, as Aristotle put it clearly in his *De anima*:

> "In dealing with each of the senses we shall have first to speak of the objects which are perceptible by each.... I call by the name of object of this or that sense that which cannot be perceived by any other sense than that one and in respect of which no error is possible; in this sense colour is the special object of sight, sound of hearing, flavour of taste. Touch, indeed, discriminates more than one set of different qualities. Each sense has one kind of object which it discerns, and never errs in reporting that what is before it is colour or sound (though it may err as to what it is that is coloured or where that is, or what is sounding or where that is). Such objects are what we propose to call special objects of this or that sense. 'Common sensibles' are movement, rest, number, figure, magnitude; these are not peculiar to any one sense, but are common to all." (Ross 1931, page 418b).

For Aristotle errors always tend to be the consequence of judgments and not of the primitive act of sensation itself which is always veridical. In the case of sensibles by accident errors can arise because—as he put it—in the case of a person who normally wears white clothes, one tends to say, on seeing from a distance a man dressed in white, that he is that particular person. There cannot be errors in the perception of white but in its association with a particular person or object. In the case of common sensibles errors might arise because of possible conflicts of the data from two different senses concerning the same object; however, in general, each sense is truthful with regard to its own sensibles. In the texts of Galileo there is frequent reference to the almost absolute confidence in the senses by Aristotelians. For instance Simplicius (who takes the side of the Greek philosopher in the *Dialogo*) remarks repeatedly that the evidence of the senses is veridical and, in the case of conflicts, they must be trusted more than the conclusions of reasoning. A particularly detailed example of Galileo's criticism of Aristotle's doctrine of the various types of common sensibles can be found in a series of manuscript annotations elaborated in his private copy of *De Phenomenis in Orbe Lunae*, a text by Giulio Cesare Langalla (1612), one of the Aristotelian philosophers who contested Galileo's interpretation of the telescopic observations of the Moon (OG III, pages 309 – 399)[(2)].

Although based on classical atomism, Galileo's general conception of sensory processes is deeply innovative, relative to the theories of other exponents of Greek and Roman atomists, and it paves the way for the development of modern sensory neuroscience. By saying that tastes, smells, colours, etc would have no existence in the absence of the individuals endowed with sensory capabilities, Galileo is not simply asserting the intrinsic subjectivity of sensations nor is he putting sensation outside the realm of scientific investigation. He is saying, in marked contrast to the dominant Aristotelian tradition, that nature does not contain specific signals for the purpose of sensory communication with living beings. Put in other terms, there is no specific language through which nature talks to living beings (and especially to humans) by signs especially adapted to their sensory processes. For Galileo, sensations are the results of actions exerted on the sentient individual (*corpo sensitivo*) by purely objective elements,

[(2)] OG refers to Opere di Galileo Galilei; it is followed by the volume number in Roman numerals.

lacking any definite sensory attribute. These elements (or agencies) are identified with matter in movement of diverse rarefaction or subtlety: on the one hand the dense and tough matter involved in tactile sensation; and, on the other, the extremely rare "ultimate and deepest level of resolution" of the matter which might possibly account for the light which stimulates vision.

If we take aside the more mechanistic aspects, this is the epistemological conception which underlies modern sensory neuroscience. In the external world there are no flavours, no odours, no colours, no sounds, but only molecules, mechanical or electromagnetic waves (or other types of matter or energies) which are a constitutive part of the universe. All this exists independently and has no definite and constitutive relation with sentient individuals. Throughout evolution, sensory systems have arisen and become accommodated to exploit these moving molecules or energies in order to gather the information about the external (or internal) world with greater adaptive value. By themselves, however, molecules have no taste nor smelling quality, mechanical vibrations are not intrinsically sonorous, and electromagnetic waves are not coloured. Sensory qualifications arise from the interaction of the objective environmental elements with specific biological systems of varying complexity, but all evolved in such a way as to interact effectively with them. Not only the characteristics but also the very existence of these qualifications depend on the characteristics and existence of those biological systems. If they were removed, sensory qualities would lack any definite reality.

This could be stated in a more expressive (and philosophical) way by using Galileo's own words:

> "This is why I think that, as far as concerns the object in which these tastes, smells, colours, etc appear to reside, they are nothing other than mere names, and they have their location only in the sentient body. Consequently, if the living being were removed, all these qualities would disappear and be annihilated. This I say, if we ourselves having imposed on such things individual names which are different from those of the other primary and real accidents, we want to believe that they also truly exist, and are really distinct from the latter." (Galileo 1623, page 197).

To evaluate the modernity of Galileo's conception we could compare his words with a short passage from a contemporary book in which Richard Gregory has pointed out some of the basic principles of visual perception in contemporary science. In considering the relation between the intensity and wavelength of electromagnetic radiations and visual sensation he wrote: "we should realize quite clearly that without life there would be no brightness and no colour. Before life came, especially higher forms of life, all was invisible and silent though the sun shone and the mountains toppled" (Gregory 2005, page 85).

In his criticism of the old scientific and philosophical tradition, Galileo was aware that a conception like that of the proper sensibles of Aristotle would have implied an unjustified multiplication of 'entia' or attributes of the external world (in the form of 'qualities' or 'affections' or 'virtues'). This would have occurred as a consequence of the variety of external things with which they would have interacted (a man or a statue in the case of the tickling sensation in his expressive example). According to an Aristotelian view, any new dimension of sensitivity would require a new proper sensible. The number and characteristics of these proper sensibles thus would depend on the number and characteristics of the sentient individuals—a position that Galileo considered to be unjustified. This difficulty was one of the reasons why the Aristotelian tradition tended to keep a fixed number of senses (five) and refuted, by ad hoc hypotheses, the possibility of new sensations. A particularly serious consequence of this has been the obstacle to accept the existence of other senses like vestibular sense in humans (Wade 2003) and the electroreception typical of fish (Moller 1995).

The idea of a world characterised by definite sensory qualities specifically adapted to senses (particularly to human senses) was diametrically opposed to Galileo's basic principles regarding the nature of the universe. Although the universe can be known to humans according to Galileo's famous aphorism of the "book of universe", it was not specifically constructed to be comprehensible for them. Nature is regulated by well-defined laws, but these laws are difficult to investigate and require considerable effort. For Galileo, nature is 'inexorable', independent of human understanding, and without any specific language for communicating its laws and operations to humans.

This is an important aspect of the general absence of a finalistic view in Galileo's scientific and philosophical conception of the universe, and particularly of an anthropocentric finalism. Nature does not communicate with mankind through specific signals because it is not oriented and centred on humanity. The displacement of humans from a central place in the universe had intellectual implications for Galileo. On the one hand, nature does not communicate with mankind through definite and conventional signals; on the other, it does not receive any ontological or cognitive justification from humans. Objects exist independently of mankind and before they had any knowledge of them, as Galileo explicitly recognised in relation to the many new species of animals and plants that came to the attention of Western scholars following geographical explorations in his day. These new species caused problems for the adherents of Aristotelian philosophy because it was difficult to accept that some things, possibly useful to humans, might have existed for a long time without (Western) philosophers having any knowledge of them. In published texts, manuscripts, and letters Galileo insisted on the unjustified presumption of those who would endeavour to "circumscribe with the narrow limits of his understanding the understanding and operation of Nature" (OG V, page 329). For example, when Sagredo, an alter ego of Galileo, said in the *Dialogo*, that Aristotelian philosophers imagined that:

> "Nature would almost create first the brain of humans, and afterwards would dispose things according to the capability of their understanding. But I would better conceive that nature has first made things in her own way, and after fabricated human discourses capable of understanding (although with labour) something of her secrets." (Galileo 1632, page 258; ET pages 264–265)

For Aristotle things existed only in the function of mankind for whom their existence is justified. The geocentric conception in cosmology was just an aspect of this fundamental anthropocentric view based on the idea that the sun, planets, and stars were there just to make life on earth possible and to exert a variety of influences on mankind. Genuinely new discoveries posed problems because it was difficult to conceive that something, created or existing specifically for man, might have existed for millennia without man having knowledge of it. Besides being centred on mankind the old universe was thus closed not only physically but also because all was created for ever and nothing really new could arise and develop in it. In the cognitive sphere, an earth at the centre of the universe (and a human microcosm at the centre of the macrocosm) corresponded with mankind capable of knowledge because they could interpret the signals that nature was continuously sending to our senses.

The removal of man from this privileged, central situation had far-reaching implications for Galileo's conception of the senses. If there is nothing essentially sensorial in the external world nor specifically accommodated to interact with the senses, then they could accommodate themselves to objects so that information about it could be gathered. Sensory qualities are the consequence of such interactions which are oriented to objects rather than to mankind; objects but not sensory qualities could exist without human knowledge of them. Since this interaction is not inscribed within a providential organisation of the world, it does guard against the possibility of errors which can arise in various ways and are expressions of the limitation of sensory enquiry. However, in spite of these limits, and notwithstanding the complexity of 'nature's way of operating', humans derive knowledge of reality if they are aware of the limits of their senses and submit the sensory appearances to the scrutiny of reason ('the eyes of mind').

The Copernican heliocentric conception removed man from his privileged position in the universe and the new science prompted by Galileo deprived humans of their privileged access to the special language of nature. As would later happen for other revolutionary phases of human scientific progress, this was a price that human arrogance had to pay in order to extend man's inquisitive power on the world and on its laws. It also provided the conditions for novel avenues for investigating sensory physiology. So new that only after about four centuries are we starting to appreciate the importance and novelty of the reflection on the theme of senses in the work of Galileo.

4 Sunspots and moon spots

In addition to a general concern for the validity of human expectations of external reality, there is in Galileo a more direct and specific interest in the senses, and especially in vision, which permeated his work. A particularly expressive example was offered by the three letters that he published in 1613 refuting Scheiner's interpretation of sunspots. Galileo's letters were dedicated to Mark Welser, a banker and statesman from Augsburg, to whom the Jesuit Scheiner (writing under the pseudonym Appeles) had addressed his *Tres Epistolae de Maculis solaribus*; he later wrote a revised and 'more accurate disquisition' on the same theme (Scheiner 1612a, 1612b; see Shea 1970b). Both Galileo and Welser had been recently associated with the *Accademia dei Lincei* in Rome, and Galileo's three letters represented his first text sponsored by *Accademia* in that period.

Besides questions of priority over the discovery of sunspots, the arguments revolved mainly around the physical interpretation of the phenomenon, particularly the location of the spots in relation to the surface of the sun. On the basis of his observations, Scheiner (figure 5) eventually came to the conclusion that the spots had no direct contact with the surface of the sun and their appearance was due to the existence of collections of minute satellites or stars revolving around it, which became visible when they occluded the sun's rays. With this assumption, Scheiner was able to reconcile the apparent variability of the sun's image (due to the presence of spots varying in shape and size) with the principle of the immutability of celestial bodies (a fundamental tenet of the classical cosmological tradition). Galileo (figure 5) adopted a contrary interpretation: the spots were located on or very near to the sun's surface and their presence and variable appearance suggested mutability of this celestial body. He had reached these conclusions following a careful study of the shape and position of the sunspots based on mathematical calculations; he also had a clear awareness of the principles of perspective and of the effects of foreshortening. A particular emphasis was given to the change of the aspect and speed of the spots when they were either close to the centre of the sun or near to the border. From these observations Galileo also reached the conclusion that the sun rotates around its axis with a period of about one month.

The letters on sunspots represent one of Galileo's first methodological forays into the new science and the ways in which genuine knowledge of the world can be acquired. His reflections on vision reveal his conception of the complex interplay between sensory appearances and physical reality. Two main arguments provide particularly clear examples of Galileo's approach. The first concerned the blackness of the sunspots. In the opening of his *Tres epistolae* Scheiner wrote: "In the sun, a most brilliant body, to put spots, and [make] them much blacker than those which up to now have been seen on the moon (except for a small one), this has always appeared

Figure 5. [In colour online, see http://dx.doi.org/10.1068/p6011] *Sun Spotters* by Nicholas Wade. Christoph Scheiner (left) is shown together with the title page of his *Three Letters* (Scheiner 1612a) written under the pseudonym Apelles—the legendary Greek artist who would listen to comments on his paintings while concealing himself behind them. Galileo (right) was more honest in his defence of the surface properties of the sunspots; he is presented with the title page of his response (Galileo 1613). Both Scheiner and Galileo are surrounded by their own representations of sunspots (from Scheiner 1630 and Galileo 1613). Scheiner's portrait is derived from a painting in the Stadtmuseum Ingolstadt (see Schönewald 2000), that for Galileo is after a painting in the Kunsthistorisches Museum, Vienna (see Tongiorgi Tomasi 2005).

to me inconvenient" (Scheiner 1612a, page 2r). Galileo used Scheiner's term 'blacker' (*nigriores*), attributed to the appearance of the sunspots relative to the dark spots of the moon, in order to give to his adversary a significant lesson on the fallacy of immediate sensory appearances. Galileo argued that the sunspots, far from being blacker than the dark parts of the moon, were even whiter than the bright parts of the moon. He tried to prove his claim through an articulate thought experiment which indicated his awareness of the need of comparing vision under similar viewing conditions; only in this way can accurate information about the physical reality be obtained. To succeed in what seemed impossible (to observe the black spots on the sun and moon against a similar background) Galileo first considered Venus, the brightest planet in the night sky. In twilight Venus starts to be visible only when "it is by many degrees far situated from the sun, particularly when both are high with respect to the orient; this happens because the ethereal parts surrounding the sun are not less brilliant than Venus itself". In a similar way, the shining full moon would become invisible if one could put the moon near the sun, because it "would be positioned in a field not less shining and clear of its own face". Having thus established through Venus a comparison between the moon and the brilliant area around the sun, Galileo tried to compare the brightness of this area with the sunspot appearance. He referred then to telescopic observations of the sun indicating that the black spots were not darker than the area surrounding the sun. He continued by saying: "If therefore the darkness of the sunspots is not more than that of the field that surrounds the sun itself; and if, moreover, the splendour of the moon would remain imperceptible in the brightness of the same ambiance, then, by a necessary consequence, one concludes the sunspots to be not less clear than the most splendid parts of the moon" (Galileo 1613, page 14). Galileo's conclusion was that sunspots are physically more luminous than the bright moon but they appear dark because they are inevitably seen against the bright surface of the sun.

In the same discussion on sunspots, Galileo elaborated on another important argument with relation to the nature of the moon's surface. Scheiner assumed that the surface of the moon was perfectly smooth and the appearance of non-homogeneities was due to the penetration of sunlight to different depths due to the partially translucent nature of the moon's body. This hypothesis would resurface in the *Dialogo* through the words of Sagredo who, in order to illustrate it, would refer to "the mother of pearl which is worked into various shapes; even when brought to an extreme polish, it appears to the eye so pitted and raised in various places that even touching it can hardly make us to believe in its smoothness" (Galileo 1632, page 79; ET page 86). Together with immutability, the essential attribute of celestial bodies was the perfection of their shape based on a perfect sphere and a perfect diamond-like polish of their surface.

Galileo refuted any essential difference between the moon and the earth and, having attributed the brightness of the moon to reflection of sunlight, he also assumed that the earth could reflect sunlight like the moon. For Galileo the classical conception, which considered the earth uniquely as an obscure body, was a perceptual error due to the impossibility for humans to see the earth illuminated by the sun against the dark nocturnal sky. In the third letter on sunspots he tried to determine the reasons for this error:

> "I would not abstain myself from saying that I strongly believe that this common view that the earth could not reflect the light of the sun, because it is extremely opaque, obscure and rough (while on the contrary the moon and other plants strongly reflects sunrays), is common among people because we never happen to see the earth illuminated by the sun while we are on some dark and distant viewpoint. This contrasts with the common occurrence of our observation of the moon when she is in the dark field of the sky while we are encumbered by the nocturnal darkness. So that, if, after having fixated, surely with some wonder, our eyes into the splendour of the moon of stars, we happen, afterwards, to lower the eyes toward the earth, we will remain somewhat saddened by her obscurity. We would come then to the apprehension of the earth as of a body by its nature repugnant to any shining." (Galileo 1613, page 134)

To support his argument, Galileo developed another thought experiment aimed at creating conditions whereby the moon and the earth could be compared under similar viewing conditions. Initially he declared that we could not have developed the idea of the moon as a brilliant body if we had only been able to see it only during the day because:

> "if we would take care of the moon during the day, when—being a little more than a quarter illuminated—she happens to be seen through the breaks of some white clouds or the top of some tower or wall of mid-white colour, when these are rightly illuminated by the sun, such as from their clearness one could establish a parallel with the luminosity of the moon, certainly, in these conditions, it will be found that the brilliance [of these terrestrial objects] is not less than that of the moon. As a consequence, if they might continue to be so illuminated up to the tenebrous moments of the night, they will show themselves not less brilliant than the moon; and, moreover, they will illuminate the surrounding places up to such a distance that their size would appear not less than the moon face; however, those same clouds and walls, being denuded of the sunrays, remain afterwards, during the night, tenebrous and dark, not less than the earth." (Galileo 1613, pages 134–135)

5 Lunar candour

Having, by this first comparison, established that the terrestrial objects do not reflect less sunlight than the moon, Galileo (figure 6) proceeded to compare the illuminating power of the moon with that of a wall which reflects sunlight, taking care to create similar conditions for the comparison:

> "Furthermore, we should be strongly convinced of the effectual terrestrial reflection when we see how much light is reflected into a completely dark room from a wall opposite it that is struck by the rays of the sun. Even if the reflected light enters by an opening so small that from the place where it falls its visual diameter is not greater than that of

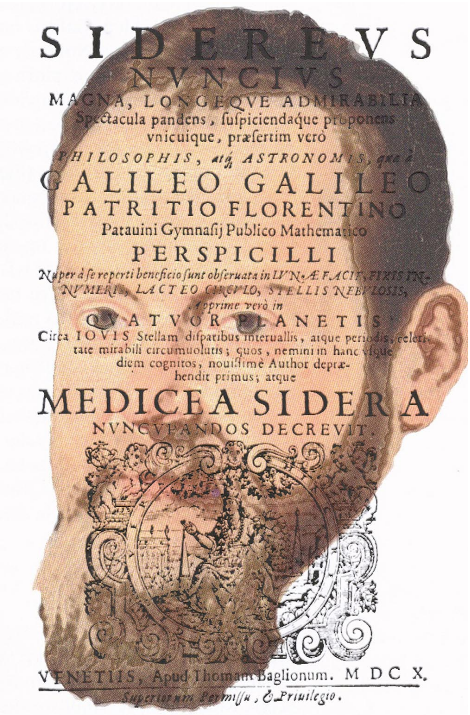

Figure 6. [In colour online.] *Sidereus Nuncius* by Nicholas Wade. The title page of Galileo's (1610) book describing his first telescopic observations carries with it a portrait of him after a painting by an unknown artist, possibly Filippo Furini also known as Pippo Sciamerone (see Tongiorgi Tomasi 2005).

> the moon, nonetheless this secondary light is so powerful that when it is reflected from the first room into a second one, it will still be stronger than the light from the moon. Of this we have a clear and easy experiment since it is easier to read a book by the second reflection coming from the wall than by the direct reflection coming from the moon." (Galileo 1613, page 135)

This comparison is clearly inspired by discussions on the 'secondary lumen' developed in the writings of Italian Renaissance painters (see Reeves 1997). It makes recourse to the expedient of the hole in a wall shining light into a dark room, which was recurrent in the optical treatises of the Middle Ages, both in the Christian and Islamic tradition (Lindberg 1976). It is important to remark that here Galileo tended to use criteria (such as that of the readability of a book) which were a more objective index of the physical level of luminosity than subjective estimation. In the further development of his thought experiment, Galileo made recourse to a series of intermediate elements of comparison between the earth and the moon. At night it might be difficult to decide if a light appearing near the edge of a distant mountain is a (terrestrial) flame or a star low on the horizon. Accordingly, if the earth was on fire and full of flames it could be confused with a star by an observer situated in a remote part of the universe, such as on the surface of the moon. However, a flame may not be more brilliant than a terrestrial object illuminated by the sun as can be shown by noting that a candle flame is almost invisible when viewed against stone or wood directly illuminated by the sun. From these considerations Galileo concluded that the earth illuminated by the sun, seen from a distant and dark site (like the dark part of the moon), would appear as bright as any other planet or star. Moreover, it would reflect more light on the moon than the moon shines on earth, particularly because of the comparatively larger surface area of the earth than that of the moon.

The conclusion that the earth, when illuminated by sunlight, can shine in a way similar to the moon is of great importance for Galileo. It is one of the main elements he uses to undermine the classical separation between the sky (and its globes) and the sublunary world including the earth. In Galileo's opinion, the earth and the moon are able to reflect the light of the sun because both have rough and uneven surfaces, the reflection being in both cases of the diffuse type like that of a wall or any other object with an irregular surface. In other words it was not necessary for him to invoke a perfectly smooth and polished surface in order to account for the shining splendour of the moon.

Because of its importance in the cosmological revolution promoted by Galileo, the theme of the nature of the moon's reflection is present in many of his texts and has a particular relevance in the *Dialogo*. Many of the arguments developed in the letters on the sunspots resurface in the dialogues between Salviati, Sagredo, and Simplicius. By articulate reasoning, Salviati shows that the reflection of the sunlight from the moon corresponds closely to that of a wall whereas it is quite different from that of a mirror. In order to support his argument he performed an experiment based on the comparison between the luminosity of a mirror hanging on a wall and that of the surface of the wall, both illuminated by sunlight. The uncritical apprehension of common sense was that the surface of a mirror is more brilliant than that of a wall. The experiment proved the contrary, leading eventually to the somewhat paradoxical conclusion that if the moon's surface was perfectly polished and mirror-like it would not reflect the sunlight in any sensible way for an earthbound observer.

The discussion on this theme is full of references to visual appearances which indicated Galileo's awareness of the difficulty of their interpretation. In addition to the possible deception in judgments of brightness if the visual background is not taken into consideration, there is a particular concern with the local effects of visual contrast. This is evident from a discussion of the faint luminosity visible in particular circumstances in the part of moon not directly struck by sunlight. Scheiner accounted for this by assuming that the moon was partially translucent. Simplicius, the player of the *Dialogo* who represented the views of Aristotle and his followers, alluded to the argument developed by Scheiner, where the author refuted the hypothesis, maintained by Galileo, that the luminosity of the dark part of the moon could be due to the sunlight reflected by the earth. In the words of Simplicius the phenomenon would occur because the sunlight "more vividly illuminates the surface of the [moon] hemisphere which is exposed to the sun's rays, and the interior, drinking in and soaking up this light so to speak, like a cloud of crystal, transmits it and makes the moon visibly lighted" (Galileo 1632, page 85; ET page 91). To support his contention, Simplicius alluded to a remark made in 1614 by Scheiner in his *Disquisitiones mathematicae de controversiis et novitatibus astronomicis* which was intended to undermine Galileo's views on the phenomenon: the dark light of the moon is more evident on the borders of the moon than at the centre.

To Simplicius, Salviati replied with words which highlighted the subtlety of Galileo's reflections on visual appearances:

> "First it is false that this secondary light is brighter around the extreme margin than in the central parts, so that a sort of ring or circle is formed that is more brilliant than the rest of the field. It is true that the moon shows such a circle when observed in twilight after its first appearance after new moon, but that originates deceptively in differences between the boundaries which terminate the lunar disc over which this secondary light is spread. For on one side toward the sun, the light is bounded by the bright horn of the moon; on the other side, it has for boundary the dark field of the twilight, in relation to which it appears lighter than the whiteness of the lunar disk—which on the other side is obscured by the greater brilliance of the horns." (Galileo 1632, pages 86–87; ET page 93)

To prove that the difference in luminosity was indeed due to effects of visual contrast Salviati proposed a simple experiment based on the occlusion of the bright horn of the moon by "some screen as the roof of a house, or some other partition".

In this condition the observer would see the zone of the moon not directly struck by sun rays as equally bright. The visual trick invoked by Salviati in order to counteract the effects of the luminous contrast is present in other writings of Galileo, and particularly in the *Sidereus nuncius*, the first announcement of his telescopic observations, which is also full of reflections on visual appearances. In this text, with reference to the phenomenon of the dark light, and particularly to the brighter appearance of the boundary separating the obscure zone of the moon from the sky, Galileo wrote:

> "If with a more exact observation we consider the phenomenon, we will see not only the extreme border of the tenebrous part to shine such uncertain glare, but we would also see the entire moon face, which does not yet receive the sun rays, whitening by a not so scant lumen. Nevertheless, only a thin luminous circle appears at first sight because of the dark parts of the sky surrounding it; the other surface appears instead darker due to the vicinity of the bright horns that dazzle our sight. If, however, we choose a suitable place where only the bright horns would be screened from our sight, by a roof or a chimney (yet far from the eye), the other part of the lunar body remaining visible, we would see a not small candour also in this other region of the moon, in spite of the absence of sunlight; this would occur particularly if the obscurity of the night is already deep because of the absence of the sun; since, in a darker background the same light appears more bright." (Galileo 1610, pages 14 – 15)

Discussions about the dark light of the moon (referred to variously as 'ash light', 'secondary lumen', 'lunar candour') are present in many of Galileo's texts and they are particularly important in a long letter addressed to Prince Leopold of Tuscany; this was Galileo's last published work which appeared in 1642, the year of his death. It was written in 1640 and circulated widely in the manuscript form before being included in a work *De lunae suboscura luce prope conjunctiones et in eclipsibus observata* written by the Aristotelian philosopher, Fortunio Liceti. The reason for Galileo's letter was the publication by Liceti (1640) entitled *Litheosporus, sive De lapide Bononiensi* a lengthy treaty about the causes of luminosity of the so called 'Bologna stone'. This was a phosphorescent mineral discovered at the beginning of the seventeenth century by an alchemist from Bologna. It is now known to consist of barium sulphate and it has been called 'Luciferine stone', 'Moon stone', *spongia lucis*, *lapis illuminabilis*, and also *litheosphorus*. These names alluded to its property of becoming luminous after a short exposure to light and keeping its luminosity for a while in the dark. Galileo adhered to an atomistic conception of matter and accounted for the properties of the stone by assuming that the light was a corpuscular emanation: in the presence of a source of light the stone would absorb the corpuscles and would afterwards release them, thus producing its faint luminosity (contrasting starkly with the Aristotelian physics of light).

In the *Litheosporus*, Liceti made reference to the properties of the singular stone in order to account for the faint luminosity of the dark part of the moon: "the moon could keep for a certain period, in the part not struck by solar rays, the light she had absorbed from the sun, in the absence of the sun, and in the shadow both of the earth, when she sets, both of her own, ie in the conjunctions with the sun" (Liceti 1640, pages 247 – 248).

The letter to Leopold of Tuscany (also referred to as the letter on the 'lunar candour' because this expression was normally used to indicate the dark light of the moon) is Galileo's response to Liceti's *Litheosphorus*. His discussion on visual appearances is one of the central themes of the letter, written in a period in which Galileo had become almost completely blind (having lost his sight in 1639). Some of his arguments are similar to those presented in the 1613 discussion on sunspots with Scheiner. For instance, Galileo was concerned why humans had failed for millennia to recognise the cause of phenomena that were within their intellectual grasp, by attributing an unjustified faith in the immediate sensory appearances. In the specific case of the discussion with Liceti he suggested that the difficulty in identifying the real cause of the phenomenon (ie the reflection of sunlight from the earth) was due to invisibility of the lunar candour for a human observer when the earth is illuminated by the sun, and to its appearance after the sunset: "This is why once that the sun has set and the earth has browned, at the moment that one sees the lunar candour unveiling itself, the popular judgment could refer its cause to all but to the earth" (OG VIII, page 505).

We will limit ourselves to the way by which Galileo succeeded in realising a comparison between the luminosity of the dark part of the moon illuminated by the reflection from the earth with that of the dark part of the earth illuminated by the moon, under similar viewing conditions. This comparison is needed because Liceti remarks that the lunar candour is hardly visible to us, while the light that the earth receives from the moon is strong and clearly visible. For Galileo, Liceti's argument was flawed, because of the different distances by which we observe the two phenomena: "the earth illuminated by the sun is from our eye not farther than three or four ells, a length comparably smaller than that of the moon" (OG VIII, page 512).

Physically the comparison sought for by Galileo was in his day an impossibility because it would have required a journey to the moon. As a matter of fact, since we can observe the lunar candour only from the earth, a correct comparison would have required that the observer could transport himself to the moon in order to view the earth from an equivalent distance. Galileo brought about the impossible comparison by means of a thought experiment. As in the case previously considered, he made recourse to an intermediate element in order to achieve a correct assessment of what he called, respectively, 'candour of the moon' and 'lumen of moon on earth'. In this case, the intermediate element is twilight at sunset—the moment when the lunar candour is particularly visible. The reasoning developed by Galileo is of particular interest for the theme of senses and warrants quoting at length:

> "Since we cannot put one against the other, the candour of the moon and the lumen of the moon on the earth, it seems to me that we could judge between them with enough assurance if we make comparison of both of them with a third illuminated body; since, if it were that the splendour of this third body would exceed the lumen of the moon, but would in turn be won by the candour of the moon, we could then assert without doubt that the candour of the moon exceeds the lumen of the moon on the earth. An appropriate middle term for this comparison appears to me to be the splendour of the sunset, if we establish a comparison between it and the other two. Once the sun has set, one would see for a good space of time the earth surface to be more clear because of the twilight than when it is illuminated by the full moon. We can be ascertained of that from seeing any minuteness whatsoever on the earth in a much more distinct way in the sunset light than what we can see, after the twilight has passed over, in the presence of moon light. This effect can be, moreover, confirmed in a manifest way: if indeed we would have on the earth some obscure body, as for instance a column, or even our own body, the light of the full moon would not produce a shadow of the tenebrous body until the twilight has so decreased that the lumen of the moon might prevail on it. This is a clear indication that the lumen of the moon is for a long time, after the beginning of the sunset, much less than the twilight. Let us then add another experience, also useful to confirm that the illumination of the twilight is much stronger than that of the full moon. Let us look from far to some large building situated on some eminent place, distant from us, say, three or four miles. Certainly, we could keep seeing it well for a long time at the sunset, and we would lose its view only after a notable diminution of the twilight. However, after twilight when the illumination of the full moon would appear, it could easily happen that we could no longer see that same building. Less is therefore the lumen of the moon on the earth compared to the lumen of twilight; on the other hand, we need not wait until the twilight has greatly weakened in order to see the candour of the moon, since we could see it whitening in the same lumen of the twilight; but, on the contrary, a rather long time is required before the moon would be able to produce shadows. Less is therefore the lumen of the moon on the earth compared to the candour of the moon surface." (OG VIII, pages 513–514)

Let us summarise Galileo's reasons for concluding that the earth illuminates the dark part of the moon more than the moon illuminates the earth: (1) For some time after sunset, the twilight is more intense than the light the earth receives from the full moon. To ascertain this important point he went beyond the immediate appearances, and made recourse to three more reliable criteria, namely (a) in twilight we could see more minute details than those visible in full moonlight, (b) it requires a long time after the sunset for the moonlight to produce an evident shadow, and (c) if we keep sight of a distant building in twilight it remains visible for a long time after the sunset, whereas it would hardly be visible by moonlight. (2) The light on the dark part of the moon is faintly visible soon after sunset, which means that it is comparable to the twilight in the first period after the setting of the sun. (3) It is thus logical to conclude that the light reflected from the earth onto the moon's surface is more intense than the light of the sun reflected from the moon onto the earth.

By examining the ways in which Galileo dealt with visual appearances, one gets the impression that he became particularly able to deconstruct the phases of the visual process. In this way, he was able to derive from his visual investigations a large amount of information that remained hidden from the eyes of an uneducated observer. The senses are potentially deceptive for Galileo, but, in spite of their limits, they are nonetheless a fundamental path for acquiring knowledge of the world. To see something was for Galileo not simply to look at it and to register its instant impression. On the contrary, it was a complex operation in which the immediate appearance had to be interpreted in a conscious (and, to some extent, also unconscious) way with reference to our previous sensory experience. Galileo's recurring expression signifying the importance of such critical reflection for extracting useful information from potentially deceptive sensory appearances is 'eyes of mind'.

6 Mountains on the moon

In September 1611 Galileo (figure 7) put forward his general conception of the visual process in a long letter to Cristoph Grienberger, a Jesuit who was professor of mathematics at the Collegium Romanum (the University of the Order). This was during the bitter debates arising from Galileo's (1610) first telescopic observations published in *Sidereus nuncius*. The letter was occasioned by a critical remark by one of the Jesuits of the College of Parma, at a series of conferences held at Mantua. The text of these conferences had afterwards circulated in the form of a manuscript entitled *De lunarium motium altitudine problema mathematicum* which was drawn to Galileo's attention (printed in OG III, pages 298 – 307). The criticism concerned an apparently minor point of Galileo's discovery—the contention that mountains and irregularities on the moon were present not only on the main body of its surface but also at its visible border. This view was stated in *Sidereus nuncius* in spite of the fact that no mountains could be seen at the border; the peripheral rim was clear-cut under telescopic observation. Noting this apparent inconsistency in Galileo's account, the Jesuit used it as a criticism of the way Galileo arrived at his conclusions on the basis of the telescopic observations. Galileo was seen as committing one of the most serious errors of philosophy, that of "multiplying without necessity the entities [*entia*], giving them as certain". The essential point of the criticism was contained in a passage which divulged a reliance on sensory appearances: "Do protuberances [*tumores*] appear on the face of the moon directed to earth, as we have observed? There is thus reason to affirm that they are there. Do they then appear in the extreme periphery? There is therefore no reason to affirm that they are there, because, if they really were, no valid reason would prevent them from appearing" (OG III, page 304).

In his response to this criticism Galileo put forward the reasons why, even in the absence of clearly evident irregularities in the extreme rim of the moon, one can nonetheless

Figure 7. *Galileo's Moon* by Nicholas Wade. Galileo's portrait, derived from the engraving by Ottavio Leoni in 1624, is enclosed within an illustration of the moon from *Sidereus Nuncius* (Galileo 1610).

positively assert that mountains are present not only in the centre of moon surface but also at the periphery of the visible part. Galileo's assertion was the final conclusion in a series of elaborations on the appearance of telescopic images of the moon, interpreted with relation to the mathematical laws of perspective and optics (particularly of foreshortening). Galileo pointed to the difference between lines of sight and the direction of the sun's rays illuminating the central surface and the edge of the moon. It is due to this difference that the shadows of mountains present in the main part of the moon are visible.

Having counteracted the negative part of the Jesuit's criticism, Galileo attacked the affirmative part of his argument—that there are mountains where they are seen. He started quoting the Latin form of the question raised by the Jesuit father:

> "The Father writes: *Apparent in Lunae facie, quae terras aspicit, tumores?* I answer not [ie they do not appear], and I say that protuberances and eminences of the moon (as eminences) not only cannot be seen from such a long distance, but that they could not even be seen from as close as 100 miles; similarly to our hills and to the major mountains which by no means would be discerned to arise from the flat regions from an altitude and distance of 50 miles, and even less. How then could we say that the moon is mountainous? We do not know it simply with the sense, but by coupling and joining the [logical] discourse with the observation and the sensible appearances, by arguing in such way." (OG XI, page 183)

For Galileo the existence of mountains and craters on the moon was not simply the outcome of the simple act of vision. It was, instead, the result of a complex visual experiment, based on the accurate comparisons derived from a series of observations. This comparison took into account the change of the relative position of the sun and moon in order to account for the variable aspect of the moon spots as due to shadowed and bright parts which vary in their appearance because of their position relative to the direction of sun rays. The interpretation was based on previous visual experience and depended on knowledge of the mathematical laws of perspective and optics. It also made recourse to the knowledge concerning the importance of shadows and chiaroscuro in suggesting the three-dimensionality elaborated by the painters of the Renaissance in their attempt to conjure up the impression of relief in two-dimensional paintings.

First, Galileo remarks, the boundary between the illuminated part and the dark surface of the moon (the terminator) is irregular. Moreover, on either side of this border can be seen more or less minute spots, light ones on the dark side, and dark ones on the light side. The positions and characteristics of these spots relative to the light – dark border change gradually with the change of the position of the moon with respect to the sun. The change is such that it can be argued that the light spots in the dark part are the peaks of high mountains which receive the light of the sun when this is low at the horizon and thus unable to illuminate the surrounding flat regions. On the other hand, the dark spots on the illuminated part of the moon correspond to depressions of the lunar surface which are not illuminated when the sun is low on the horizon. For Galileo all this was in agreement with the variable light and shadow features produced on bodies with irregular surfaces illuminated by a light source that changes position over time. It thus supported his conclusion about the presence of mountains on the moon's surface. However, nobody could say that mountains are on the moon simply because they saw them. The moon seen through the telescope is too ambiguous to provide definite evidence of mountains, so it was necessary to submit them to complex analytical interpretation.

It seems somewhat paradoxical that Galileo asserted that the mountains on the moon would not be seen even from a relatively short distance "similarly to our hills and to the major mountains which by no means would be discerned to arise above the flat regions from an altitude and distance of 50 miles, and even less" (OG XI, page 183). This was so only for those who believe uncritically that 'things are exactly as we see them', and do not consider that what we see results from a complex series of unconscious and conscious judgments which allow us to decipher which aspects of visual appearances are ambiguous and potentially deceiving.

The potential ambiguity connected to three-dimensionality is significant for distant objects of unknown shape like the mountains and craters of the moon. It is only the variable play of light and shadow, the variation of luminosity (and sometimes also of colour) that makes possible the apprehension of the three-dimensionality of distant objects. This was well known to painters who, in addition to perspective, used chiaroscuro, light and shade, and particular colour effects in order to simulate relief on a two-dimensional surface.

For a distant object like the moon, the effects of light and shadow are particularly useful as visual indicators of depths that are situated near the border between the illuminated and dark parts and when the direction of the light rays is very oblique in relation to eminences or depths. This is now well known to astronomers who take pictures of specific craters or mountains on the moon when these are near the light–dark boundary. In other conditions, the irregularity of the moon's surface is more difficult to detect. This is particularly so with the full moon, also because of the fact that there is then an almost perfect coincidence between the sightline and the direction of the sun's rays, which means that shadows could not be detected even if they were present.

The attention to the light – shadow effects were particularly intense among Italian painters in the Renaissance and during Galileo's life. Ludovico Cardi (Cigoli), a Tuscan painter and a great friend of Galileo, wrote in his *Prospettiva pratica* (most probably known to Galileo): "Objects seen on the illuminated part of the scene, are without relief for want of shadows, and when seen on the strongly-shaded side appear unpleasant; on the other hand, if the view is placed mid-way between light and shadow they show their colour and their relief in a better way" (Cardi 1610, page 82r).

Galileo had a thorough understanding of the art of his day. In addition to his friendship with painters, he was an art expert and a painter himself: his watercolour images of the moon seen through the telescope served as a reference for the illustrations in *Sidereus nuncius* (Bredekamp 2007). The use of shade and chiaroscuro as means of producing the impression of the solidity of objects was central to a famous letter he wrote to Cigoli in which he established a comparison (*paragone*) between sculpture and painting: "A statue does have relief not because it is wide, long and deep, but because it is light in some parts and dark in others... of the things that appear and are seen we see but the surface.... We know therefore the depth, not as an object of vision by itself and absolutely, but by accident and with relation to the clean and obscure" (OG XI, page 341). It is possible, as suggested by the art historian Erwin Panofsky (1954), that artistic education and art connoisseurship, together with other aspect of humanistic education, contributed to Galileo's science. They are likely to have had an important impact on his capability of interpreting visual appearances and on his attention to the phenomena of vision.

7 Cosmology

Galileo's discovery of the irregularities on the moon's surface and the demonstration that the moon reflected light from the sun because of these irregularities, together with the understanding that the earth reflected sunlight in a similar way, were of great importance in undermining some of the basic tenets of classical cosmology. In the cosmos of Aristotle and Ptolemy there was a fundamental separation between the sublunary world with the earth on one side and the sky with planets and stars on the other. The two worlds differed essentially in terms of their form and their laws. The earth was considered to be irregular unlike the perfectly spherical heavenly bodies, and different physical laws were thought to govern the two regions. The similarity of the reflection of sunlight between the moon and the earth also concurred to disprove the difference between the earth and the sky. In classical cosmology there was another essential difference between the earth and the sky, connected to the difference in their elemental composition: the sublunary world, being made of four elements in continuous dynamic interplay, was the site of mutations, of changes, of life and death, of corruption; whereas the sky, being made up of an ethereal fifth element, the 'quintessence', was immutable and incorruptible. The problem of the immutability and incorruptibility of the sky was one of the other aspects of the separation between the earth and the heavens addressed by Galileo (figure 8). Galileo pointed out clearly that these distinctions derived mainly from an uncritical faith in the immediate visual appearances. In the *Dialogo* the immutability of the heavens is at the centre of a discussion between Salviati and Simplicius where the latter expressed the traditional doctrine in these words: "Sensible experience shows that on earth there are continual generations, corruptions, alterations, etc, the like of which neither our senses nor the traditions of memories of our ancestors have ever detected in heaven; hence heaven is inalterable, etc, and the earth alterable, etc, and therefore different from the heavens". Upon Salviati's request he described the mutations that can be seen on the earth: "On earth I continually see herbs, plants, animals generating and decaying; winds, rains, tempests, storms arising; in a word, the appearance of the earth undergoing perpetual change. None of these changes are to be discerned in celestial bodies, whose positions and configurations correspond exactly with everything men remember, without the generation of anything new there or the corruption of anything old". Salviati replied humorously by saying: "But if you have to content yourself with these visible, or rather these seen experiences, you must consider China and America celestial bodies, since you surely have never seen in them these alterations which you see in Italy" (Galileo 1632, pages 39–40; ET pages 47–48).

The *Dialogo* was published in 1632, more than twenty years after Galileo's first telescopic observations. However, Galileo abandoned the classical cosmology of Aristotle and Ptolemy and adhered to the theory of Copernicus well before he could see, with the help of his powerful instrument, mountains and craters on the moon. Galileo himself acknowledged his Copernican faith in a letter addressed to Kepler in 1597 (OG X, page 57).

Figure 8. Solidity and chiaroscuro in Galileo: a photograph of Galileo's statue by Emilio Demi which stands at the rear of the Aula Magna Storica, University of Pisa. Galileo is holding a globe in his left hand with a scroll of astronomical designs on his lap.

In the heliocentric universe of Copernicus, it was implausible to conceive of an essential separation between the sky and the earth. Moreover, no justification could exist for the idea that, in contrast to earth, the moon and the other heavenly bodies would be perfect spheres. When he aimed his telescope at the moon, Galileo was not influenced by theories which precluded him from interpreting correctly what he saw. Nor did he have similar constraints when other observations suggested irregularities and mutations in the sky. Galileo, in contrast to other astronomers and philosophers of his era, displayed the capability of critically analysing what he saw with the new instrument.

It is indeed highly probable that, even before aiming his '*perspicillum*' (the first term he used for the telescope) at the sky, Galileo already knew that there were irregularities on the moon's surface. We have an indication of that from a booklet published in 1606 in Florence and dealing with the apparition of the new star of 1604, *Considerazioni d'Alimberto Mauri sopra alcuni luoghi del discorso di Ludovico delle Colombe intorno alla stella apparita nel 1604*. In the *Considerazione XXVIII* the author held the view that the moon is similar to the earth, or, as he said, that:

> "it is likewise not entirely even, but there are also in the moon mountains of gigantic size, just as on earth; or rather so much greater, as they are sensible to us. For from these, and from nothing else, there are in the moon scabby little darknesses, because greatly curved mountains (as Perspectivists teach) cannot receive and reflect the light of the sun as the rest of the moon, flat and smooth. And for proof of that I shall adduce an easy and pretty observation that can be made continually when she is in quadrature with respect to the sun; for then the half circle is not smooth and clean, but always has a certain boss in the middle. For this what more plausible cause can be adduced than the curvature of those mountains? By those, and particularly in that place, she comes to lose her perfect rotundity." (Galileo 1606, page 15r; ET pages 104 – 105)

The author of the *Considerazioni d'Alimberto Mauri* was Galileo himself, who at that time, preferred to publish his works in a pseudonymous form, as had been the case for another booklet written in the Paduan dialect and published in 1605. Also this booklet, entitled *Dialogo de Cecco di Ronchitti da Bruzene in perpuosito de la stella nuova*, dealt with the new star of 1604. By concealing his name, Galileo could more easily express his opinions in a free and mocking style in order to ridicule the opinions of his adversaries (peripatetic philosophers) convinced of the immutability of the sky even in the face of the apparition of a new star. There is little doubt that Galileo is the author of the *Dialogo de Cecco di Ronchitti*, even though in this case he probably collaborated with a Benedictine monk, father Girolamo Spinelli, an expert of the idiom of Padua. That Galileo is also the author of the *Considerazioni d'Alimberto Mauri* is supported by an important Galilean scholar, Stillman Drake. There are other indications to support Galileo's authorship of this book, which have to do with the interest evident in the theme of the senses in relation to the astronomical observations. In this respect, a particularly interesting passage is in *Considerazione VI* where Galileo contests the idea of the immutability of the sky advocated by his adversary, the Florentine philosopher Ludovico Delle Colombe:

> "Here is an argument for the incorruptibility of the sky drawn from the difference of elemental and celestial matter; behold: On the earth beans are seen to dry, cucumbers to appear, and at the same time many animals decay. None of these effects is seen in the sky. Therefore the matter of the sky is different from that of this inferior world. Therefore if the latter is corruptible and changeable it follows that the celestial [matter] is completely alien to such properties. But I hear someone whispering to my ear: "Oh, but if the Author will have that stars of the first magnitude, which are more than 107 times as large as the earth, cannot be seen without spectacles, how will he ever know whether up above, even 100 miles away from us, things that small are created or destroyed? For even a distance of twenty miles loses mountains from our view, to say nothing of oaks and beeches."—An objection that indeed will lose the Author some little reputation among the learned, unless I remind them that he is a supernatural Astrologer, and hence able quite well to divine whether or not those bagatelles exist up there." (Galileo 1606, page 4r; ET page 83)

These words appear to anticipate those pronounced in the *Dialogo* by Simplicius regarding the similar discussion on the theme of the immutability of the sky. Other passages of the *Considerazioni* would resurface again in the main works of Galileo, as for instance, the interpretation of the illusion of the sun (and of the moon) discussed in the *Considerazione XLIII* (figure 9). He returned to considerations of celestial illusions of size in *Il Saggiatore* but the phenomenon was treated in more detail by his pupil,

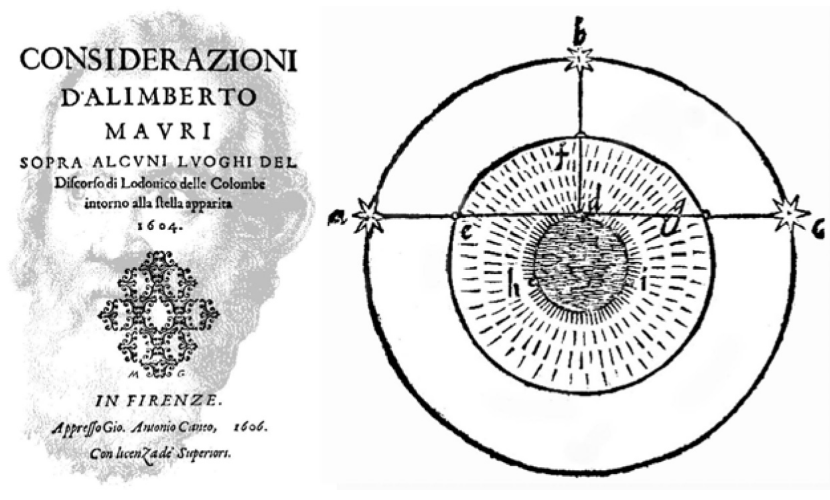

Figure 9. Left, *Galileo-Mauri* by Nicholas Wade. Galileo's portrait is derived from an engraving in Bethune (1829) and is shown hiding behind the title page of Galileo (1606). Right, an illustration of the sun illusion from Galileo (1606): a, b, and c are the positions of the sun at sunrise, noon, and sunset, respectively; the observer is at d, on the surface of the earth h, d, i; the vaporous zone surrounding the earth is represented by e, f, g. Galileo suggested that the difference in apparent size was due to an optical effect depending on the difference between distance d – f and d – e (or d – g).

friend, and supporter, Benedetto Castelli (1639/1669; see Ariotti 1973; Wade 2007b). If Galileo was indeed the author of the *Considerazioni d'Alimberto Mauri*, as is highly probable, we are obliged to admit that when he first aimed his *perspicillum* toward the sky, in 1609, he already entertained the notion of irregularities on the moon. This raises the question whether Galileo arrived at his revolutionary achievements in many fields of science because he was driven by a superior theoretical framework, or if he was led to his discoveries by an extraordinary capability of experimentation and observation (which would be consistent with his great concern with appearances).

In this regard we could refer to Galileo himself, by quoting a passage from one of his main works, the *Discorsi su due nuove scienze*. Here Simplicius wondered if the time-squared law of the motion of falling bodies (which had just been demonstrated by mathematical deduction) could apply to real falling bodies. The response given by Salviati conveys Galileo's view of the relation between mathematical theories and experimental observations:

> "Like a true scientist you make a very reasonable demand, for this is usual and necessary in those sciences which apply mathematical demonstrations to physical conclusions, as may be seen among writers on optics, astronomers, mechanics, musicians, and others who confirm their principles with sensory experiences, those being foundations of all the resulting structure." (Galileo 1638, page 175; English translation in Drake 1977, page 108)

In spite of the fallacies to which they are prone, the information provided by the senses is necessary for confirming the conclusions of mathematical reasoning and thus stands as the basis for any knowledge of the physical world science may reach. As underlined by Drake, whose translation of the quotation above we are using, the original Italian text is potentially ambiguous and difficult to render into English. Galileo paid careful attention to the language in which his ideas were expressed. Ambiguity, far from being a drawback, was often used to convey the richness and complexity of concepts (see Piccolino and Wade 2007, pages 49 – 119). In the passage quoted, the English 'sensory experience' does not fully convey the significance of the original phrase 'sensate esperienze', where 'sensate' means, at the same time, 'based on senses' (and thus 'sensory'), but also 'meaningful', 'well done', 'substantial', 'making sense', 'appropriate', a meaning which is partially preserved by the English 'sensible'. In Galileo's writings this secondary meaning is attested by expressions like 'ragioni sensate', 'argomento sensato', and by the very frequent use of the antonym 'insensato', to mean 'senseless', 'foolish', or 'of no value'.(3)

There has been much debate about whether Galileo did really perform many of the experiments described in his writings; this applies particularly to the opinions expounded by Alexandre Koyré (1953a, 1953b) who considered Galileo mainly as a mathematician and a theorist who paid little heed to his experiments. Modern historiography (reviewed in M Camerota 2004) tends to see Galileo more as an experimentalist than Koyré assumed (see particularly Settle 1961, 1983; MacLachlan 1973). Perhaps we could say that the potential ambiguity intrinsic in the expression 'sensate esperienze' somewhat encapsulates Galileo's complex relation with senses and the importance he placed on them. Experiments are important and they must be based on senses, but, in this context, 'senses' must be intended as an educated capacity of seeing and critically interpreting the nature of phenomena, based on a strong interplay between reasoning ('*discorso*') and observation.

(3) The meaning of 'sensate esperienze' in Galileo has been the subject of a considerable debate among historians. A particularly careful study of the matter, illustrating the historical complexity and richness of the expression, and also the various meanings it may assume in Galileo's writings, is found in Baroncini (1992).

8 Stars and comets and the sphere of heaven

Galileo's writings display many instances of his constant and critical analysis of visual appearances. A particularly important one concerned the possible fallacies in estimating the size of stars and planets (and of other distant luminous objects) on the basis of their appearances. As he clearly recognised, the size of distant luminous objects can be grossly overestimated on the basis of observations with the naked eye because of the visibility of large haloes of 'adventitial rays'; these are variously referred to by terms like 'headgear', 'hairs', or 'coiffure' (*capelli, capillizio, capellatura*) and 'irradiation' (see Frankel 1978). The argument was of great astronomical relevance, particularly because it was connected with the problem of the estimation of the physical dimension of the stars. Additionally, it related to the assumption that stars were all situated at the same distance from the earth (and all included in the crystalline 'eighth heaven', which was a fundamental aspect of the classical cosmology). Galileo clearly described the phenomenon and showed that it was mainly produced by mechanisms inherent in our eyes. One of his conclusive arguments was based on a 'real' experiment, involving the visual occlusion of a star by placing a cord between it and the eye. The angular size of the cord at the distance at which occlusion occurred was much smaller than that assumed on the basis of the apparent size of the star. With this experiment, Galileo succeeded in partially unveiling imperfections in the optics of the eye; we now know that this is due to the blurring function of our eye. Galileo disclosed this long before careful optical investigations could be carried out (see Helmholtz 1867; Barlow and Mollon 1982).

Connected to the problem of the apparent size of stars was that of the magnifying power of the telescope. This was central to the bitter debate between Galileo and the Jesuit Orazio Grassi on the nature and trajectory of comets, expounded by Galileo in the *Discorso delle comete* (Guiducci and Galileo 1619) and in *Il Saggiatore*. Galileo succeeded in disproving Grassi's inference that the magnifying power of the instrument decreased with the distance of the observed object. He did so by proposing two (real or thought?) experiments. The first was used to rebuke Grassi's assertion that the telescope does not magnify the stars because they are too distant. Galileo considered aiming a telescope without lenses at "two fixed stars separated one from the other by such distance that they are seen just inside the circular field of the tube pointing at them" (Guiducci and Galileo 1619, page 26). When appropriate lenses are inserted in the tube, the two stars would not appear inside the field of the telescope, but would be seen as very far apart—an indication that the telescope has a strong magnifying power also for very distant objects. In a second experiment Galileo considered two discs of paper placed at different distances and of such size that the nearest one just fails to occlude the sight of the far one when viewed with naked eye. When the discs are observed with a telescope, the nearer one still does not fully occlude the further one, which clearly contradicts the assumption of a greater magnifying power of the telescope for near objects. It is of interest to note that in each case Galileo succeeded in solving optical problems associated with vision without any recourse to optical reasoning. This supports the argument that his interests in vision were more concerned with observation than optics, and more related to a theory of knowledge than to physiological mechanisms.

One of the main aspects of the discussion with Grassi, in the *Discorso della comete* and in *Il Saggiatore*, concerned the path of motion of comets that became visible in 1618. In this case Galileo also shows a clear awareness of the fallacies to which observers are open if visual appearances (like the paths of the distant comets) are interpreted in a simple and direct way. Because of the limits of the perception of distance, celestial objects tend to be located at the same distance—on the apparent surface of the heavenly sphere. However, a given visual path of motion on such a vault of the heavens could be generated by a multitude of different real motions. Failing to appreciate this would lead to both visual and logical fallacies, thus precluding our extension of knowledge of the universe.

9 From Galileo to modern neurosciences through philosophers and physiologists

The particular nature of Galileo's interest in the senses, and especially in vision, may explain why his reflections had initially more impact on philosophical thinking than on the progress of sensory science. His elaboration of the two classes of sensory attributes of objects became the basis of Locke's (1690) distinction between 'primary' and 'secondary' sensory qualities expounded in the *Essay Concerning Human Understanding*. Galileo's general reflections on the senses exerted an important influence on the debate concerning the cognitive relation with reality. It involved various philosophers like Descartes, Gassendi and Malebranche in France; Hobbes, Locke, Berkeley, and Hume in Britain; and Leibnitz in Germany.

It was via a philosophical route that Galileo's sensory science resurfaced in the nineteenth century, to lay the grounds of modern sensory physiology. At the end of section 1 of the first volume of his *Critic of Pure Reason*, Kant (1787), who was familiar with Galileo's work, expressed a conception of colours, tastes, etc, "not as properties of things, but only as changes in the [sentient] subjects, which can be different in different men". This is a clear echo of Galileo's views. Kant influenced Johannes Müller in formulating his doctrine of 'specific nerve energies'. This doctrine states that the modality of the sensations produced by different stimuli on a given nerve was relatively independent of the nature of the stimulus, but was a specific expression of the sensory nerve stimulated. As he put it "the same external cause excites different impressions in different senses, according to the nature of each sense, namely the sensation of the specific nerve" (Müller 1840, page 251). Even if determined normally by external causes, sensations are always expressions of internal 'conditions or qualities' of the nerves. The action of external stimuli is only to excite these internal conditions of the nerves, also referred to as 'energies' from the Greek term *ενεργεια* (action, vigour) used by Aristotle. Müller provided many examples of the subjective and internal nature of sensations, and of its specific dependence on the characteristics of the different sensory apparatus. For instance: "the same number of vibrations in a tuning-fork, which impart its sensations to the auditory nerve, will be perceived as tickle in the nerves of feeling. Something completely different to vibrations must be produced if it should be experienced as sound, and this requirement lies in the auditory nerve" (Müller 1840, page 256). As he warned afterwards, with words which resound with the passage from *Il Saggiatore*, "there is no sound in the world without a living ear, but only vibrations; without a living eye there would be no light, no colour, no darkness in the world, but only the imponderable oscillations that correspond to light and its matter, or their absence" (Müller 1840, page 261).

In elaborating his general views of sensory physiology, Müller was summarising and extending observations and conceptions developed before him by several scientists, but the philosophical grounds of his doctrine were undoubtedly inspired by Kant, as is also clear in the work of his student, Hermann Helmholtz. In his monumental volumes on physiological optics and hearing, and in other texts as well, Helmholtz elaborated Müller's views of senses on both a physiological and a philosophical basis, and thus laid the theoretical framework for the subsequent development of modern sensory neuroscience (see Finger and Wade 2002a, 2002b). As with Müller, Helmholtz rebuked any close correspondence between the sensations on one side and the reality they represent on the other. The process whereby sensations are produced involved both the external objects and the sentient individual: the way they interacted was somewhat similar to a chemical reaction. The outcome depended on the nature of both reacting elements and the laws of the process can only be specified with relation to the properties of the two elements. For Helmholtz, sensations were 'signs', 'tokens', or 'representations', which, in order to provide us with a knowledge of the reality, need to be 'interpreted' or 'deciphered' by our mind; they need not be similar to the external things they represent. In spite of this, and of the consequent impossibility of knowing the ultimate nature of the world [Kant's '*Ding an sich*' ('thing in itself')], the representations derived from senses are of fundamental significance: "It is in this way that the representations of the outer world are images of the regular flow of natural events, and if they are formed correctly following the laws of thought, and if by our actions we can interpret them correctly in reality, then these interpretations are the only true ones; all others are false" (Helmholtz 1867, pages 446 – 447).

To exemplify the errors which might be made by assuming a close correspondence between the external world and sensations, Helmholtz referred to the long-held supposition of the existence, in the rays of the sun, of a heating agent distinct from light, by which the sun might produce a sensation of heat, in addition to that of light: "As long as humans did not reflect on the nature of sensations, they were inclined to report immediately on the quality of sensations of external things, and to assume two agents corresponding to two sensations" (Helmholtz 1867, page 195).

Helmholtz was a contemporary of Charles Darwin. An important aspect of the new conception of the senses that emerged from his own work (and from that of Müller) is that it removed the obstacles that, in the Aristotelian tradition, prevented sensory science from becoming a part of the Darwinian paradigm. In the course of evolution, living organisms could develop new senses, adapted to their evolving life style and to their habitat; in order for this to be possible, the existence in the external world of proper sensibles, specific for any new sense, need not be invoked. In the universe there is nothing specifically 'sensible', but only matter in movement, oscillations and energies as Helmholtz argued in the nineteenth century and Galileo 'prophetically' foresaw more than two centuries earlier, in the pages of *Il Saggiatore*.

10 Conclusions

Galileo's conception of the senses had relatively little influence on the science of his own day. In the context of vision, this was due largely to the success of the advances made by Kepler and Scheiner, which shifted the emphasis from observation to optics. It is a sad irony that Galileo became completely blind in old age; he was in this condition when Sustermans painted what is perhaps the most famous portrait of him in 1640 (figure 10).

Figure 10. [In colour online.] *Galileo's Penetrating Gaze* by Nicholas Wade. The portrait of Galileo is based on the painting by Justus Sustermans in 1640 (when Galileo had become blind), and is combined with the title page of the book (Liceti 1642) in which his "Letter on lunar candour" (also written in 1640) was printed; it contains many of Galileo's reflections on visual appearances and their importance for astronomical investigations.

Galileo's eyes elaborated many novel aspects of visual contrast in the context of astronomical observations. His penetrating gaze was applied to the phenomena of vision but not to the process of vision itself. He also tempered the Aristotelian confidence in the veracity of vision (and of senses in general). Fallacies of the senses occur but they should not cloud the conclusions reached regarding external events. Fahie (1903) summarised this well.: "He [Galileo] was not content, like his precursors, with merely giving an opinion, supported or not by wordy metaphysical arguments, but what he asserted as well as what he denied he *proved* to ocular demonstration" (page 23). The revolution ushered in by Kepler and Scheiner placed the stimulus rather than sensation at the centre stage. Galileo took the contrary approach: in expanding on the relation of stimulus to sensation in *Il Saggiatore*, he devoted more attention to the senses of hearing, taste, smell, and touch than to vision. It was in the context of the mechanical senses that Galileo's putative doctrine of the senses was adumbrated.

Even if Galileo's conception of the senses was not absorbed by his contemporaries, its vitality and importance in the history of science is becoming evident. It might seem surprising that a scientist has influenced the progress of culture mainly through the work of philosophers. There are two main conclusions that we can draw in this regard. One concerns the anachronism of the term scientist when applied to natural philosophers of the past, whose interests and culture were extremely broad. This is particularly the case for Galileo whose elaborations were significant in the field of both science and philosophy. The other conclusion concerns the vitality of scientific ideas across the centuries. As the Italian philosopher of science, Giovanni Vailati (1899), put it, great scientific ideas are like the basins of some rivers which progress along irregular and intricate lines, sometimes growing suddenly because of unexpected influences, and at other times seeming to disappear, as if they had sunk in the depths of the earth, only to reappear and flourish again, potent with unforeseen developments.

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