THE NOTION OF PHYSICAL LAW OF NATURE: ASPECTS OF ITS GENESIS AND EVOLUTION IN THE GALILEAN PERSPECTIVE

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Abstract. Some aspects of the genesis and evolution of the notion of physical law of nature are examined from the perspective of Galileo's contribution in establishing this notion in its modern sense. The discovery of first physical laws of nature is briefly presented and the conceptions of Galileo, Kepler and Descartes are compared and analyzed; some new conclusions are formulated, which challenge specific statements of previous historians of science. The contemporary aspect of this problem is discussed as an attempt to emphasize Galileo's importance in this respect, contested in some cultural approaches of History of Science.

Keywords: physical laws of nature, Galileo, Kepler, Descartes, the role of Mathematics, physical experiment.

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Introduction. The present paper considers selected aspects of the genesis and evolution of notion of physical law of nature, necessary here not only because (at least) a part of earlier established statements from the literature has to be periodically reconsidered, but also because relatively recent publications reopened the discussion on Galileo's role and place in the developments of Scientific Revolution.

As it is known, the first physical laws of nature were formulated already in the first decades of the 17th century, this new quantitative approach of science being consolidated in its last decades by Isaac Newton. The discovery and use of laws of nature for its knowledge and the benefit of human society became the declared aim of science, and the scientific discourse gravitated around this new notion.

It must be remarked that, at the beginning of the new science, the scientific research was guided not only by pure logical (professional) considerations but also by the belief that, studying the nature and discovering how it works, the intentions of God with the world could be inferred. The existence of a unique God ensures the unity, rationality and cognoscibility of nature. These religious ideas inspired and favored until certain point the scientific research, even if they were not "clearly and distinctly", or equally, present in the mind of all scholars, some of them rebelling against the established dogma. On the other hand, some non-religious (mythical, archetypal, grammatical or mathematical) influences in conceiving the notion of scientific law cannot be a priori rejected. These inspiration sources could concomitantly be present in different degrees at different persons and act, coherently or not, together or separately with the religious conceptions, on their "hosts".

A "natural" distinction between science and religion appeared then, which can be formulated as follows: while the final aim – the search for God – remains common for both domains, the places to find God are different, respectively, the Book of nature and the Scripture, written in different languages and requiring different methods of study. For the study of nature, the language of Mathematics is needed; its development allowed an astonishing success of scientific research, feeding nowadays hopes to obtain a final scientific theory allowing to foresee the destiny of the universe.

Later on, the absolutization of the idea of classical (Newtonian) deterministic law of nature, extended, *mutatis mutandis*, to the behavior of organisms, individuals and society, raised the problem of divine omnipotence and of human free will. Very naturally, a long debated subject was – and remains – the relation between miracles, present in many religions, and the laws of nature. The actual aspect of this question can be found in the attempt of some authors (see Russell, 2005) to propose concrete modalities by which God is active in the world without perturbing concomitantly the natural order studied by science, a fact that raises serious problems for the relations between Science and Religion. Another challenge for the historians of Physics is the attempt of some historians of religions and culture to relativize not only one or another aspect of Scientific Revolution, but to put on doubt entire categories of achievements of 17^{th} century scientists, insisting on the continuity with Renaissance, and diminishing the elements of novelty.

In European thought and languages, the word *law* is used in three different fields, Religion (for divine or moral law), Justice (for human laws), and Science (for laws of nature) and this fact indicates a common root of all three meanings, besides their linguistic identity[1]. In historical perspective, the notion of scientific law is clearly the newest one, the divine and juridical laws being quite old. Could we retrace their past, so to establish when these three meanings separated themselves from the (supposed) common trunk? Fortunately, the answer is positive. We have a material remaining of the separation of juridical law from the divine one and, to reach it, we have to make a leap back in time, until the times of king Hammurabi of Babylon (~1750 BC) and in space, until the Louvre Museum. There, in the rooms consecrated to the Mesopotamian art and history, the object of our interest is exposed, the stela with the Hammurabi's Code of Laws[2]. It is the oldest code of laws entirely conserved until our days. Written in cuneiform on the polished hard black rock, it contains the complete civil and penal laws to be obeyed not only by Babylonian subjects, but by all people of city-states conquered by Hammurabi. This code is a pure juridical one, as being made by a human for men; the references to Gods are limited to the preamble and end of the writing, being not present in the corpus of laws. God Shamash (of Sun and Justice) is represented in the image on

[1] This statement is true also for all East-Romanic, Slavonic, and Ugro-Finic European languages, and not only for the Western ones, as Needham seems to indicate (Needham 1956, 518). For details, see Annex 1.

[2] See the images at the Internet address: http://cartelfr.louvre.fr/cartelfr/visite?srv=crt_frm_rs&langue=fr&initCritere=true (enter Hammurabi).

the top of the stela, where Hammurabi himself is carved in a respectful attitude towards the God of Justice, who urges the king to establish the law. The only role reserved there to the Divinity is to enforce the king's authority as lawgiver[3]. This beautiful exhibit marks the birth of Human Justice and Law as autonomous from the Divine Justice and Law. To see the analogue process of separation happening for the notion of law of nature, we have to move in time until the 17th century, and in space until Western Europe. We will search for it not in museums, but in libraries.

The relations between these three (nowadays separated and independent) notions were studied, among others, by Joseph Needham in a section of his monumental book (Needham 1956, 518-583) with the aim to know who was the first (Western) author using the word law in its modern scientific sense. Following Needham, the absence of a similar notion from the Chinese science is due to the difference between religion and worldview of Europeans and Chinese: no divine and omnipotent legislator, and consequently, no divine or scientific law in Orient.

The problem why Science was born in the West was considered, among others, by Owen Gingerich in a short remark, where the author hints to its more complex origin:

> "It has been a challenging puzzle to understand why modern science arose in the Latin West in the sixteenth and seventeenth centuries and not in China or the Islamic world. It is unlikely that only one concept can explain the tangled

[3] In spite of the evident influence of Hammurabi Code, later in time, in the Bible, the Divine (moral) law and the juridical law are not separated. This fact will play a role in the elaboration of the scientific law (see below).

> complex of ideas and forces that shaped European scientific renaissance." (Gingerich 2005, 61).

Our research will try to look for such a complex genesis of the notion of law of nature.

So, after Needham, the scientific law of nature, as a basic ingredient of modern science, was generated in West (at the beginning, in metaphoric sense), by analogy with the God's laws. Needham took in consideration, among others, Galileo, Kepler and Descartes. Continuing a previous research (Stratan 2003, 33-60), we will analyze their contribution in establishing the meaning of (physical) law of nature, and discuss specific statements of Needham. Our restricted choice is justified by the argument that the more appropriate authors to be considered are those who were actively implied in finding the laws of nature, in comparison with those who only philosophized about them[4]. We consider Needham's approach to this problem useful and important but somehow restricted to the search in the literary and philosophical area.

René Descartes is clearly the theoretician and philosopher of notion of law of nature, the one who best illustrates Needham's thesis on the divine origin of it. In his *Discourse on Method*, Descartes introduces the notion of law of Nature:

> "I have observed certain laws which God has so established in nature and of which he has impressed such notions in our souls, that having reflected on them sufficiently, we cannot be in any doubt that they are strictly observed in everything which exists or which happens in the world. Then, by considering the series of these laws, it appears to me that I have discovered many truths more

[4] To better situate the three thinkers in time, see the Chronology of Annex 2.

useful and more important than anything I had learned before or hoped to learn." (Descartes [1637] 1968, 610).

In Descartes' opinion, God not only "established laws" to the Nature, but also "impressed such notions" in human intellect. This *build in* human characteristic encourages the endeavor of discovering the laws of Nature by "methodic reflection". If God gave to the humankind this cognitive matrix, the *Method* of finding the laws is offered by Descartes in his *Discourse*. But, in spite of being the creator of Analytical Geometry, and a good connoisseur of Optics, then, so near to Geometry, Descartes had serious doubts on the possibility to use Mathematics for the (physical) description of nature. Almost in the same time with the apparition of the *Discourse***,** its author wrote a letter to Marin Mersenne dated May 17, 1638:

> "Pretending from me Geometrical demonstrations in matters pertaining to Physics is to want from me to do impossible things".[5] (Galilei [1638] 1973, 12).

This last point of view of Descartes is difficult to reconcile with the more optimistic one expressed in his *Discourse*, and sharply contradicts Galileo's strong attachment to Mathematics as the language of Physics (see bellow)**.**

Also, is not so clear where looked Descartes more to observe the laws, in nature or in his soul. The action of laws is described by Descartes as being (from a certain moment) somehow independent from the starting point of creation and (to a certain extension) even from the Creator. Once imposed to the material world, the laws will perform alone their task, putting an end to chaos and transforming it to cosmos. Nevertheless,

[5] Our translation.

Descartes' universe needed a kind of supervision of God, a "preserving action" which, together with the free action of laws, monitors the process of Nature. In comparison with other notions proposed by the French philosopher, the preserving action is quite abstract, and will evolve in a conservation principle.

Descartes performs even a thought experiment on the full scale of Nature, to demonstrate how the laws act:

> "…if God were now to create, somewhere in imaginary space, enough matter to compose [a new world] and if he were to agitate diversely and confusedly the different parts of this matter, so that he created a chaos as disordered as poets could ever imagine, and afterwards did nothing than to lend his usual preserving actions to nature, and let her act according to his established laws. [...] After this, I showed how most of the matter of this chaos must, in accordance with these laws, dispose and arrange itself in a certain way which would make it similar to our skies…" (Descartes [1637] 1968, 62-63).

More than mechanics, this picture suggests the thermodynamics of reversible processes, and even an alternative cosmology, or, with a little effort, the parallel universes. Even if the actual structure of the world is to be destroyed (by agitating "diversely and confusedly the different parts of this matter") the actual world would be recreated. The optimistic idea about the rebirth of the universe is associated with an equally optimistic idea of deciphering the action of the laws on material things "when one sees them being fully made from the start". Descartes seems to recognize in this way the necessity of knowing the initial conditions for a fully deterministic description of the processes in the nature.

Accordingly to the program exposed in his *Discourse,* Descartes tried himself to discover some of laws of nature, starting with the study of light, but, in his *Dioptrics* (published together with his *Discourse* and *Meteors*), Descartes didn't mention the word "law". Even in the *Discourse* this term was not completely adopted by the author, who oscillated between "law" and "rule": "…according to the rules of mechanics which are the same as rules of nature". (Descartes [1637] 1968, 72) Previously, in the same context, he used the term "law". This alternative use of "law" and "rule" indicates an interference between the descriptive character of the former when applied to nature, and the (yet) prescriptive character of the last one. This oscillation between two terms is a typical manifestation of the first period of the development of notion of law: in the triad God, Nature and man, the law is prescriptive in the relation between God (as the Lawgiver) and Nature (which obeys God), and descriptive in the relation between man and Nature. It is interesting to remark here that Descartes' assumed position of intermediary between God and man: God created Nature and gave it laws and the French philosopher invented the method to be followed by man to discover them …

The idea about God as a creator of matter and as a final cause of motion leads Descartes to a kind of conservation laws of matter and motion. If God, sustains Descartes, started *ab initio* with to move the created matter, then God conserves its motion, as well as the matter itself, so that one finds always the same amount of both of them as they were at the beginning.

These statements are called by Descartes principles, as having a primordial importance in his hierarchy of laws of nature. Indeed, from the principles, Descartes deduces his three laws of mechanics, called by him also laws of nature. They are, in fact, two statements of the principle of inertia enounced in a different manner than the modern synthetic formulation, plus one law about the transmission of motion.

Some of his deductions (laws and rules) are erroneous and the vulnerability of his system is due mainly to Descartes' conception about the relation between the logical deduction and experiment. Without rejecting it, Descartes doesn't give to the experiment the decisive role of ruling out the theoretical statements. He reduced the experiments to a formal inquiry, having a minor status in comparison with his aprioristic considerations. Practically, with a few exceptions, Descartes reduced Physics to mathematical principles. This fact had as a consequence the impoverishment of his notion of law of nature and the loss of the possibility of experimental verification. The errors from Descartes "rules" of collisions between bodies were evident even in his time and easy to discover through simple experiments, never done by him. (Scott 1976, 163)

From principles to laws and from laws to rules, there is a hierarchy of statements, which begins with God, to descend to bodies. Descartes' laws of nature are deterministic, causal and repetitive. They were considered by him keys to understand nature.

The mathematization of notion of law of Nature performed by Descartes has nevertheless one negative feature: as a mathematical relation, the physical law must involve exact values of variables, which is not the case in the physical world, where the measured values can be only approximate. This problem was correctly understood and solved by Galileo, who was a complementary thinker in respect to Descartes and Kepler.

Johannes Kepler, the discoverer of laws of planetary motions, hold a firm, enthusiastic adherence to Copernicanism, dated from his years at the Tuebingen University, and nourished the conviction that mathematics can reveal the secrets and the beauty of nature. Many of his ideas were aprioristic and had a clear metaphysical and archetypal origin. Kepler's concept of mathematical beauty of Nature (the harmony and the music of spheres) was even older than Platonism. His conception was mainly a revival of Pythagorean mystic of numbers and forms, less evident at his inspirer, Copernicus, and absent at his contemporary, Galilei.

Kepler's first book, *Mysterium Cosmographicum***, (**Kepler [1596] 1937-1963, vol. 1) contains his first idea about how the solar system is organized. He wanted to obtain a rule for the intervals between the planetary trajectories and believed that it must be found somehow from geometrical considerations. Kepler wished also to have an explanation why the planets are "exactly" six (Mercury, Venus, Earth, Mars, Jupiter, Saturn). After trying some combinations with regular polygons, Kepler went to the regular solids, known from Euclid as being only five. This number attracted him also because the six planets have five intervals between them. He inscribed each orbit in a sphere and inserted between these spheres the five regular solids, so that each solid was circumscribed to the smaller sphere and inscribed in a greater one. (See Annex 3). Even with the arbitrary chosen order of the five regular solids, it was impossible to obtain the correct sequence of the intervals between planets. Even if Kepler finally renounced at this geometrical model, the idea of planetary intervals will germinate until guiding him to his third “law”, which connects the distances of planets to their period of revolution around the Sun.

The detailed story of the discovery of what is called now the first Kepler’s law (about the form of planetary orbits) can be found in *Astronomia Nova*. Kepler found once the ellipse, but dismissed this result on pure esthetical criteria. Previously, he disliked other closed curves. When Kepler realized which was the right trajectory, he wrote:

> “With reasoning derived from physical principles aging with experience, there is no figure left for the orbit of the planet except a perfect ellipse.” (Kepler [1609] 1937-1963, 3:336)[6].

It is evident that Kepler didn’t stress the importance of his “laws”, nor called them by this word. The reader of *Astronomia Nova* can much easier find “the first Kepler’s law” from the summary of chapter LIX, (*Argumenta capitum, caput LIX*): “… orbitam … Planetae esse Ellipticam”, (no translation necessary) than from the text itself. The same chapter contains “the second Kepler’s law”, (equal areas are swept by the planet in equal intervals of time) hidden between the geometrical properties of ellipse, and demonstrated following the methods of Apollonius and Archimedes.

The third law is presented also in *Epitome***,** under the title *On the causes of the proportions of periodical times* (Kepler [1618-1621] 1937-1963, 7:307) as a proportion

[6] Quoted by Owen Gingerich (Gingerich 1975, 277)

of segments[7]. Later on, Kepler considers the rotation of Sun (proved by the motion of sunspots) as the true cause of motion of planets.

It is interesting that both findings from *Astronomia Nova* are only byproducts of his activity devoted to put into evidence the cosmic harmony. For Kepler, the notion of harmony of spheres was not only a metaphor, but a real working hypothesis, which took mathematical form and exhibited esthetical features. If previously he connected the intervals between planetary spheres with the regular polyhedrons, in his *Harmonice Mundi*, the planets are supposed to emit sounds. Kepler connected the velocity of planets with the pitch of the sound and obtained a kind of melody for each of them. (See Annex 4.) In the Book III, in the part called *Digressio Politica*, Kepler tried a parallel between Geometry and Justice. Here, the word law (*lex*) can be found in a juridical context. Was Kepler aware also of the existence of physical laws? Following Needham's reasoning, merely based on linguistic arguments, the fact that Kepler didn't call his laws by this word pleads for a negative answer to that question. Nevertheless, in *Epitome* Kepler uses the word law in a clear physical sense: "Which are its laws of celerity and retardation and examples?" (Kepler [1619] 1937-1963, 7:332). It isn't an isolated reference; in the same context of planetary motion, and in the same *Epitome*, (Kepler [1619] 1937-1963, 7:338), Kepler uses again (two times) the word law with the meaning of physical law. The first mention refers to the laws of (planetary) motion, "leges motuum", imposed by (or to) the nature. The planets, writes Kepler, move on their precise orbits in free ether under the

[7] The interpretation of this proportion is not easy and the editor, Max Caspar, made a comment to show its meaning.

influence of two laws, one of attraction, other of repulsion, comparable between themselves, “comparatae leges”; the orbit is the result of their permanent equality.

These examples contradict Needham’s affirmation about Kepler:

> “By a remarkable paradox, Kepler, who discovered the three empirical laws of the planetary orbits, one of the first occasions on which the laws of Nature were expressed in mathematical terms, never himself spoke of them as laws, though he used the phrase in other connections. Kepler’s first and second “laws” given in Astronomia Nova of 1609, are paraphrased in long expositions, the third, published in Harmonices Mundi (1619), is called a “theorem”. Yet he speaks of “law” in connection with the principles of the lever, and in general uses the words as if it were synonymous with measure or proportion.” (Needham 1956, 541).

To sustain his statement, Needham quotes Edgar Zilsel, (Zilsel. 1942, 245-279) but in the Zilsel’s article no reference is made to the Kepler’s *leges motuum,* nor to the last two places in *Epitome* were Kepler used the notion of law, quoted above. Kepler doesn’t use the word “law” in direct “connection with the principles of lever”, as affirms Needham, but in connection with the motion of extremities of it, given as example for the non-uniform motion of planets.

Following Needham,

> “… Kepler, like Bruno, conceived of planets as partly animated, and raised the question of ‘whether the laws are such, that they can probably be known to the planet’”. (Needham 1956, 541).

Here, Needham and Zilsel, whom Needham cites intensively, seem to not be aware of Kepler's evolution which started, indeed, with the phase of "partly animated" planets from *Mysterium Cosmographicum***.** Nevertheless, in *Astronomia Nova***,** (Kepler [1609] 1937-1963, 3: sec. III. 39), Kepler decides to renounce at the soul of planet. The reason for this decision is the difficulty with which the soul will be confronted when it will have to calculate the orbit followed by the planet. Later, in *Epitome***,** (Kepler [1618-1621] 1937-1963, 7:229), Kepler went to a deterministic and objective conception about the motion of planets, rejecting the intervention of planetary intellect and rejecting his previous position of nested spheres from Mysterium**.** This new Kepler's position, exposed in different contexts in *De motu latitudinis* from *Epitome* is clearly sustained:

> "Nor the Sun is the cause [of motion in latitude], … nor the Mind of planet stands for this effect, nor the already refuted superposition of solid orbs ... but a certain composition of planetary bodies themselves alone suffices …" (Kepler [1618-1621] 1937-1963, 7:343).

Similar statements, this time about the corporeal nature of action of Sun can be found in Epitome, (no translation necessary): "…corporalis est virtus, non animalis, non mentalis." (Kepler [1618-1621] 1937-1963, 7:299).

The problem why Kepler didn't use the word law for his laws remains one of the most discussed ones. It may be, as many authors suggested, the secondary interest given by Kepler to his laws, in comparison with his assumed task, to demonstrate his aprioristic ideas.

Kepler's elaboration of laws shows a gradual gain of independence from his archetypal ideas which were the point of their departure. His own way to scientific truth represents a difficult, but successful transition from the old science to the new one. Often, it is difficult to understand on which way went Kepler to his discoveries: by induction, by (aprioristic) hypothesis, by pure empiric or intuitionist means, etc. Most probably, he used all these methods. Useful details on this last item can be obtained from Robert S. Westman (Westman 1975, 713-720) and Owen Gingerich (Gingerich 1975, 261-278).

In contrast with Descartes, Kepler cannot be invoked for proving the pure religious derivation of notion of law of nature. Like all the scientists of that period, he has been influenced by the Christian thinking, but his image of the world was based on different starting point and many of the intermediate phases of his discourse were connected with other considerations and sources of inspiration.

Galileo occupies a special place in History of Science, as the founder of experimental method, which leaded him to the discovery of the first empirical laws of nature. Without contesting totally Galileo's experiments, J. D. Bernal considers that the Florentine scientist performed at least a part of them not to convince himself, but merely other people (Bernal 1957, sec. 7.5). Bernal diminishes so the heuristic value of Galileo's such experiments, lowering their rank to a kind of show. Of course, taking into account the historical conditions, we cannot exclude the demonstrative character of some experiments shown for the Grand Duke and his court. But Galileo's relations between the period and length of pendulum, or his remarks about the motion of bodies in resistant media, and many other statements, were the results of his keen observations and straightforward and ingenious experiments organized to obtain an answer to these problems. A few years after the apparition of Bernal's book, Thomas B. Settle repeated Galileo's experiments with the accelerated motion, showing that they were possible with the devices and instruments described by the Florentine (Settle 1960, 23). Bernal's doubts could have been inspired by a fact that happened in Galileo's time: the French mathematician Marin Mersenne, the translator of the Florentine in French[8], tried without success to repeat some of Galileo's experiments. Due to Settle's work, at least a part of reasons of Mersenne's failure become clear. The main one is, probably, the difference between the approaches to the experiment itself: Galileo was an inspired and active inventor and innovator, while Mersenne remained a passive observer. Another explanation is the absence of a real detailed protocol of the performed experiment, so to allow its repeating by others. The fundamental concepts of newborn science of Physics were not uniformly defined, nor completely elaborated, making the task of reproducing the experiments more difficult.

Galileo's clear experimental approach to the natural philosophy has, besides other possible explanations, the fact that in his childhood, he assisted, presumably, to the musical experiments made by his father, a distinguished musician and author in this field. His contacts with the Murano glass masters and Venetian Arsenal skilled workers played also a role, as well as his involvement in Architecture, military teaching, engineering works, etc.

The experimental arsenal developed by Galileo counts at least nine instruments (Leschiutta 2000, 65-80) and many new procedures, like the repetition of measurements

[8] See (Galilei [1638] 1973).

and proofs ("provando e riprovando") to obtain a good statistics (Settle 1961, 20). Galileo's attachment to the experimental method and his experimental deduction of physical laws mark a very important difference between himself and Descartes.

Their different approaches to the notion of law of nature come also from a different role attributed by the two scientists to Mathematics. Descartes' statement from his letter to Mersenne (see above) must be compared with the well-known conception of Galileo, about the Book of nature, which

> "is written in the language of mathematics, and its characters are triangles, circles and other geometric figures without which is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth." (Galilei, [1623] 1957, 237-238).

In contrast with Descartes, that shows the importance given by Galilei to the role of Mathematics in the physical discourse. Galileo's declared aim is to "demonstrate everything by geometrical methods ... starting from established principles" (Galilei [1638] 1916, 6). Even the original title of the *Dialogues* contains this program: *Dialogues and Mathematical Demonstrations Concerning Two New Sciences* ...

In Galileo's time the role of Mathematics in Natural Philosophy was not yet acknowledged, nor well understood. The arguments against the use of Mathematics in Physics are synthesized by Galileo Galilei through a phrase of Simplicio in the *Dialogue*:

> "The arguments and demonstrations which you [Salviati, i. e. Galileo himself] have advanced are mathematical abstract, and far removed from concrete matter;

> and I do not believe that when applied to the physical and natural world these laws will hold." (Galilei [1638] 1916, 52).

On the other hand, even when Mathematics was accepted, its use, reserved "only for mathematicians", was regarded merely as an instrument to "save the phenomena", without a correspondence into the real world. Pleading for the unity of Science, and so, for the liberty to transfer the methods between different fields, Galileo knew that his opinion will be rejected by many:

> "Here I expect a terrible burst from someone of my adversaries; and I already feel in my ears the intonation that is one thing to treat the things physically, and another mathematically, and that the geometers must remain between their circles and not to make brotherhood with the philosophical matters, the truth of which being different from the mathematical truth; as the truth could be more than only one, as that it were impossible to be geometer and philosopher, and, by a necessary consequence, someone who knows geometry, couldn't know physics and so, couldn't discuss and treat physically physical matters. This consequence is not less stupid than that one of a physical doctor who, pushed by some envy, said that the physician Aqquapendente, being a great anatomist and surgeon, had to content himself remaining between his instruments and ointments, without wanting to interfere in physical cures, as the knowledge of surgery could destroy -- and were against -- physics. (Galilei 1890-1908 , IV:49).

He was aware of the real difficulty of passing from one science to another; as early as in 1602, in a letter to his friend and protector, Guidobaldo del Monte, Galilei makes the distinction between pure Mathematics and its application to Physics:

> "When we begin to refer to the matter, because of its contingency, the alteration of the abstract propositions considered by the geometer begins also." (Galilei 1890-1908 vol. X:100).

In this way, Galilei makes an attempt to deal with the apparent contradiction between the exact character of Mathematics and the necessary approximate character of Physics, which determined Descartes to object against the possible link between the two fields, rejecting the use of Mathematics for proving matters "pertaining to Physics".

Galileo's research doesn't show any predilection for archetypal ideas, like the five regular solids or the music of spheres, which played a so important role in the building of Kepler's planetary model; even if the sphere and circle were considered perfect by Galileo, their perfection was seen as being purely geometric, without bearing any heuristic or mythical value in themselves. Galileo was more lucid and less disposed to metaphysical speculations than Kepler. In his Copernican writings, the Sun doesn't play the same role in moving the planets; quite contrary to Kepler, Galileo considers the influence of earth on the motion of sunspots. (See the discussion in William R. Shea and Mariano Artigas' book (Shea 2003, 127)).

So we have three distinct relations to the problem of how to find the laws of nature: Descartes looked for them in the human intellect having God's laws as guide, Kepler in the harmony of heavens, using archetypal patterns, and Galileo in the nature itself, using

Mathematics and experiment. In modern terms, Descartes is the theoretician of the notion of physical law of nature, Kepler the phenomenologist (as trying to fit his models with the astronomical data) and Galileo the experimentalist.

All of them were embedded in Christian culture and, from this point of view, we have no reasons to doubt that they looked at nature as at God's creation, on which God has jurisdiction and imposed the laws. The marked distinctions between their approaches to the concrete problem of finding the physical laws of nature (in the skies or on the earth) and so, to the notion of law itself, must come then from different sources: their psychology, their lectures, their general background. These sources contributed also to the emergence of the new notion and cannot be ignored.

Needham's considerations about the religious filiation of notion of law of nature were challenged by Jane E. Ruby, who considered that "the explanation of scientific law as arising from the idea of divine legislation is highly possible, [but] it is for the most part mistaken" (Ruby 1986, 342). Ruby's arguments are based on extensive study of a series of sources from the Latin (ancient and medieval) literature, including some authors absent from Needham's work[9]. Ruby proposed the rules of Grammar, or equivalent statements of Mathematics, as more plausible genealogical sources of the notion of law of nature. (Ruby's suggestion about the Optics as a potential field of emergency of notion of law of nature is to be considered mainly because Optics was studied intensively from Antiquity with geometrical models and, most probably, the literature in that field was

[9] The voice Lex appeared in the series of *Thesaurus Linguae Latinae* after Needham's book was first published.

known al least by Kepler[10].). The main problem which appears is if, from the multitude of authors quoted by Ruby, some of them really influenced the three above mentioned scientists, and in what extent. Copernicus' and Brahe's authorities were incontestable in the field of Astronomy, and they were studied carefully at least by Kepler and Galileo. Both the elder ones are credited by Ruby with a religious approach to the notion of astronomical (albeit yet prescriptive) law which was imposed by God. (Ruby 1986, 356). On the other hand, we have to be careful in accepting without analysis of each concrete case the thesis of an exclusive religious derivation of notion of law of nature. Kepler and Galileo were both believers, but they confronted courageously the dogmatic interpretations of their contemporary theologians, when the last ones interfered with science. Galileo wrote:

> "Let us grant then that theology is conversant with the loftiest divine contemplation, and occupies the regal throne among sciences by dignity. But acquiring the highest authority in this way, if she does not descend to the lower and humbler speculations of the subordinate sciences and has no regard for them because they are not concerned with blessedness, then her professors should not arrogate to themselves the authority to decide on controversies in professions which they have neither studied nor practiced." (Galilei [1615] 1957, 193).

Galileo is known for his rejection of mythical and mystical ideas, so dear to Kepler. (This is, presumably, also the reason of his reserved attitude towards the German astronomer.)

[10] Galileo knew Kepler's work in Optics, but probably didn't completely understand it, writing ironically about its author.

In the introductory part of *Astronomia Nova*, Kepler sustained even more radical opinions, contesting openly the right of Holly Office to use its authority and that of the Fathers of the Church against the scientific truth. (Kepler [1609] 1937-1963, vol. 3). Nevertheless, both of them, and especially Galileo, took from certain moment precautions in their relations with the authorities of Church. Some of apologies, not necessarily requested by the context, and, nevertheless, present in Galileo's late works, could be explained also by a such a conjecture. The same kind of considerations could explain why Galileo didn't use the word *law* for his findings: after his 1633 trial, he presumably wanted to avoid a term which had religious implications[11].

Weighing Needham and Ruby's statements, Mario Dorato writes: "In spite of the fact that the theological origin of the concept of law of nature sustained with vigorously by Edgar Zilsel, [and] Joseph Needham […..] was recently put in discussion by Jane Ruby, no historian of science doubts the fact that, in the antique thinking and religions, the concept of law of nature, in the pure descriptive sense familiar today, is totally absent." (Dorato 2000, 25). In comparison with Dorato's considerations, which, together with Needham's ones, pleaded for the (exclusive) religious origin, we tried here to argue in the favor of a multiple origin of the notion of law of nature, as imposed by the thinking of the first discoverers of physical laws.

At this point, some questions remain to be considered. Why the first laws of nature were discovered only in the 17th century, in spite of the fact that some conditions were already ripe for that before? Was that connected with the religious evolution in Europe, like some

[11] The author of this paper has in preparation a work on this subject.

cultural approaches to the History of Science hinted? In what extent the dominant culture, in the broadest sense of this notion, including religion, philosophy, education, etc., which, of course, drives intellectually the members of society, can influence also – and in the same measure – the great (in our case, scientific) personalities, who are merely exceptional, and "out of range" people? Here, returning to the quotation from Gingerich[12], we will mention the fact that the discovery of the first laws of nature became possible also by a progress accomplished in many fields of European society and learning. The scientific research (especially the experimental one) needed financial and logistic support and a certain intellectual liberty offered through the protection of emperor, prince, doge, duke, etc. From the religious point of view, a more liberal atmosphere favored science, like in Venetian Republic, or, in certain limits, the Duchy of Tuscany. The division of Europe, which took place following the Reform, in spite of troubles, war and social unrest, created a new situation, which was cleverly used by the "dissidents". (Galileo published his *Two New Sciences* in Protestant area). Some achievements were also the result of chance, like the meeting in 1600 of Tycho, the author of the best observational data and Kepler, the most fertile theoretical mind of the period …

The notion of law of nature had a glorious career. After being coined by Newton in *Philosophiae Naturalis Principia Mathematica*, this new notion decisively influenced the evolution of European science, the aim of it becoming the discovery of laws of nature and

[12] (Gingerich 2005, 61).

their use for the benefit of human society[13]. The main difference between Galileo's (and Kepler's) laws and Newton's ones is the pure geometrical character of the first two ones. The first physical laws were expressed in form of proportions and didn't need constants, nor an universal system of physical units.

The appearance of the first deterministic laws and, consequently, of the mechanistic worldview induced a tension between science and the idea of miracles, which are an important component of the religious worldview. The miracles received at the beginning a relative definition, connected mainly with the human ignorance, which will be removed by the progress of science; for Galileo, the knowledge of causes of a phenomenon dissipates the aura of miracle. So, following Galileo's line of thinking, along the development of Science, the number of phenomena considered miracles must decrease, as it happened in reality.

Turning now to the actual cultural perception of Galileo and of his time, even a quick survey of the literature in the field can put in evidence a tendency to underestimate his personal contribution to the new science and the new science in general. It is quite normal to find different opinions on one aspect or other of the Scientific Revolution of the 17th century (and even if it was a revolution in the proper sense of the term!), but the case proposed here for discussion is something else; it characterizes a series of theories of the

[13] In spite of the importance of approaching nature through the search for its laws, some philosophers absolutized their approximate character until considering the laws erroneous. So, Nancy Cartwright wrote about "How the laws of Physics lie" (Cartwright 1983).

post-modernist current in the history of culture and religions. Usually, the scheme is to absolutize the continuity between Renaissance and the 17th century, underestimating, or even neglecting the elements of novelty brought by Galileo and his contemporaries and followers. To illustrate this approach we give here an excerpt from Ioan P. Culianu[14], as being typical (Culiano 1987, Introduction):

> "There is a persistent habit of thinking that our contemporaries' view of the world and our own are abysses away from that of the Renaissance man. Current technology, the product of the 'quantitative science' that began to develop in the 17th century has been cited as the visible mark of this fracture. So, even though the greatest authorities in the history of science have clearly informed us that the ideas of Newton, Kepler, Descartes, Galileo, and Bacon had absolutely nothing to do with the so-called 'quantitative science', these mistaken opinions of our forefathers, the 19th century rationalists, are still very much alive."

Culiano did not care to identify those "greatest authorities in the history of science" that are supposed to have told us the ideas of the said scholars "had absolutely nothing to do with the so-called 'quantitative science.'" In the circumstances, we have no way to check if their original statements were as clear-cut as he depicted them. Anyway, he apparently took them for granted. While Culiano did not make any objection, we will make one and say that the five scientists in question spanned a combined lifetime of nearly 17 decades,[15] while their scientific activity extended over more than 140 years, from the 16th

[14] Ioan Petru Culianu followed Mircea Eliade as professor of history of religions of University of Chicago. Born in Romania, Culianu studied in Bucharest, Perugia, Milan, Paris and Chicago.
[15] Bacon was born in 1561, and Newton died in 1727, and the three others lived in between.

century to the 18th. Despite some similarities among their works, the five can hardly be lumped together, given their vast range of concerns, their diverse intellectual backgrounds, the variety of their environments, their different approaches to research, etc. What Newton, Kepler, Descartes, Galileo, and Bacon do have in common and the very reason that made them go down in the history of science is their being the founding fathers of modern quantitative science (without quotation marks!). No one could play down their personal contributions to, say, the development and broad acknowledgment of the concept of natural (physical) law, based on mathematics, which is a cornerstone of quantitative science. And this is but one aspect of the enormous progress they made in building up the structure of modern science, as has been recognized by different schools of science historians from Koyré to Kuhn and from Needham to Bernal, to cite only a few[16]. But the arguments of science historians may not look very convincing, particularly in a debate of ideas, in which they represent a secondary source that only provides guidance in an extremely vast domain. We will therefore confine ourselves to Galileo's work, the only one that can speak for its author. As we will see, it will provide us evidence that falls far short of verifying Culiano's peremptory statement.

Galileo's pursuit of quantitative relations in physical phenomena and in the world at large recurred as a leitmotiv throughout his intellectual evolution. An early literary-scientific piece he wrote under scholastic influence dealt with *The Location, Shape, and Dimensions of Dante's Inferno* (see Galilei 1890-1908, IX)—an opportunity for Euclidian speculations, admittedly naïve and soon to be outdistanced in others of his

[16] We will examine some of their shortcomings concerning the appreciation of Galileo in another work. See also (Maccarrone, 1997).

early writings. Depending on the subject of his studies, he would always select an adequate mathematical instrument, whether Euclid's geometry, or Archimedes' works, or the graphic (imagistic) methods which are still in use in today's astronomy. He made, for example, a remarkably realistic description of the sunspots in his *Delle macchie solari*, (On Sunspots, see Galilei 1890-1908, IV); the paper is accompanied by beautiful drawings *manu propria* that were cited as experimental evidence, which he rendered graphically in terms of time and which allowed his discovery of solar rotation. His scientific methods culminated with the geometrical descriptions of physical phenomena from *Two New Sciences*. These facts do not sustain another cultural thesis, about the genesis of new science by the "censorship of the collective imaginary", presented by many literati, including Culianu. This approach considers the Counter-Reform, which censored the imagistic richness of the Renaissance, the cause of passing to a more abstract representation of the physical world, but this theory is not supported by the chronology of History of Science and by the sheer examination of facts, including the ones presented here[17].

A correct understanding of Galileo from both scientific and cultural point of view supposes a dialogue between scientists and humanists, and the present paper intended to make only a step forward to accomplish such a long term task.

Acknowledgements. Parts of the present work were communicated in conferences and seminars delivered in several Italian universities and institutes during the last decade. It is a pleasant duty to express once again my profound gratitude for this warm hospitality.

[17] A more complete treatment of this subject can be found in (Stratan, 1997), a book consecrated to the cultural reception of Galileo in Romania (and not only).

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Annex 1.

The three meanings of the notion of law and the word law in ancient and modern European languages.

	1) Divine
LAW	**2) Juridical**
	3) of Nature

NOMOS;	**LEX, LEGIS**
Ancient Greek	**Latin**

LEGE,	**LOI,**	**GESETZ,**	**ЗАКОН,**	**TŐRVENY**
IT. ROM.	**FR.**	**GERMAN**	**RUSSIAN**	**HUNG.**

Annex 2

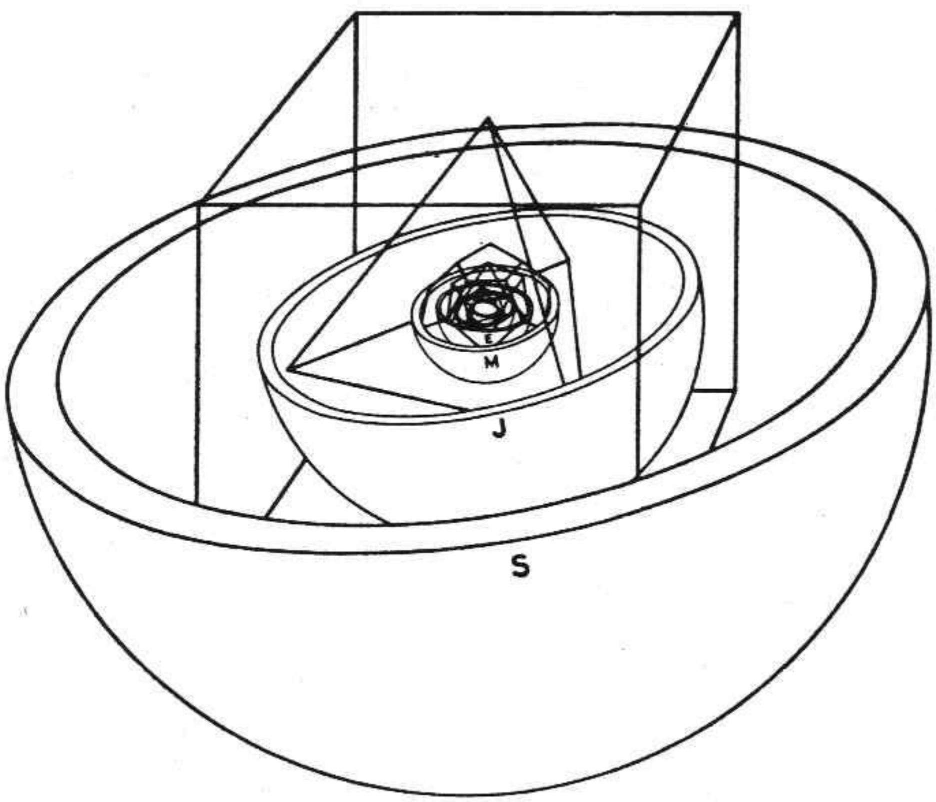
Chronology

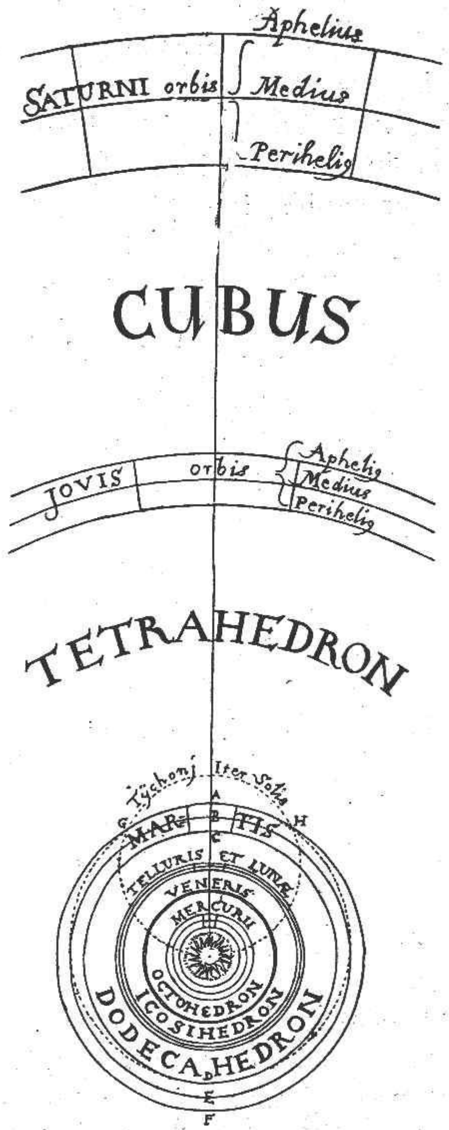
YEAR	DESCARTES	KEPLER	GALILEO
1564			BORN
1571		BORN	
1596	BORN	Mysterium Cosm.	
1600			
1609		Astronomia Nova	
1610			Nuncius
1613			Sunspots
1618 ----WAR			
1619		Harmonice Mundi	
1621		Epitome (1618-1921)	
1623			Saggiatore
1630		DIES	
1632			Dialogue
1633			TRIAL
1637	Method (Diopt., Met., Geom.)		
1638			Two New Sci.
1642			DIES
1648 ----WAR ENDS			
1650	DIES		

Observation: For the complete titles of the books, see the references in the text.

Annex 3

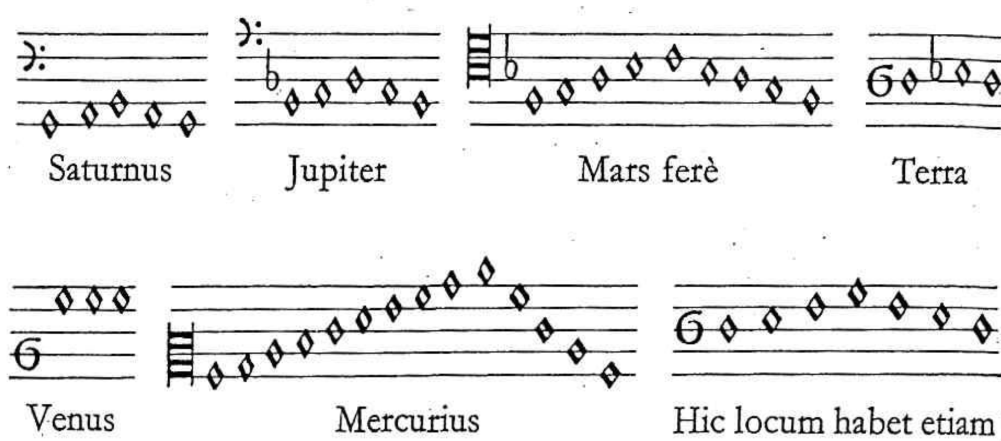
***Mysterium Cosmographicum*, (Kepler [1596]). The model of five regular solids.**




Aphelius
SATURNI orbis
Medius
Perihelis
CUBUS
JOVIS orbis
Aphelis
Medius
Perihelis
TETRAHEDRON
Tychonis Iter Solis
MARTIS
TELLURIS ET LUNÆ
VENERIS
MERCURII
OCTOHEDRON
ICOSIHEDRON
DODECAHEDRON

Annex 4

The music of planets (Kepler, Harmonice Mundi, 1619)



Annex 5

The complete Italian quotation (Il Saggiatore,   Galilei, 1890-1908, vol. VI, 232)

La filosofie e` scritta in questo grandissimo libro che continuamente ci sta aperto innanzi a gli occhi (io dici l'universo), ma non si puo` intendere se prima non s'impara a intender la lingua, e conoscer I caratteri ne'quali e` scritto. Egli e` scritto in lingua matematica, e I caratteri son triangoli, cerchi , ed alter figure geometriche , senza I quail mezi e` impossibile a intenderne umanamente parola; senza questi e` un aggirarsi vanamente per un oscuro laberinto.

Annex 6

Discorsi e dimostrazioni, (1638), Galilei, 1890-1908, vol. VIII, p. 96.

Simplicio. … e le considerazioni e dimostrazioni sin qui fatte da voi, come che sono cose matematiche, astratte e separate dalla material sensibile, credo che applicate alle materie fisiche e naturali non camminerebero secondo coteste regole.

Annex 7

Frammenti attenenti al trattato delle cose che stanno su l'acqua, (1611), Galilei, 1890-1908, vol IV, p. 49.

Qua io m'aspetto un rabuffo terribile da qualcuno de gli avversarii; e gia` parmi di sentire intonar negli orecchi che altro e` trattar le cose fisicamente ed altro matematicamente e che i geometri doveriano restar tra le loro girandole, e non affratellarsi con le materie filosofiche , le cui verita` sono diverse dalle verita` matematiche; quasi che il vero possa esser piu` di uno; quasi che la geometria a i nostril tempi pregiudichi all'acquisto della vera filosofia, quasi che sia impossibile esser geometra e filosofo, si` che per necessaria in consequenza si inferisce che chi sa geometria non possa saper fisica ne` possa discorrere e trattar delle materie fisiche fisicamente. Conseguenze non meno sciocche di quella di un tal medico fisico, che spinto da un poco di livore, deiceva che il medico Aqquapendente, essendo grande anatomista e chirurgo, doveva contentarsi di stare tra i suoi ferri ed unguenti, senza volersi ingerire nelle cure fisiche, come se la cognizione della chirurgia distrugesse e fusse contraria alla fisica.

Annex 8

Considerazioni di Vincenzo di Grazia (1613), Galilei, 1980-1908, vol. IV, p. 385.

"le dimostrazioni del Sig. Galileo ci e` paruto necessario il dimostrare quanto sieno lontani coloro dal vero, che con ragioni matematiche vogliono dimostrare le cose naturali…