A new answer to the Needham Question,

or Why Galileo didn't discover universal gravitation

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Abstract —The cultural infrastructure that made possible Galileo's invention of modern physics is discussed. The brand new element of modern physics is claimed to be firm belief in fundamental structure of the Universe, which could be expressed in the following epistemological double postulate: 1) There are fundamental axioms that all the physical laws governing the Universe could be deduced from; those axioms are not evident, as invisible as the underground cornerstones, or, in Latin, FUNDAMENTUM; 2) The human mind is able to probe into this fundamental level of the Universe to understand its working, and any human being is free to contribute in the process of this probing and understanding. Galileo demonstrated that experimentalism and mathematization were just the tools to realize this belief. The modern science was invented in the time when the Bible played the most prominent social role in its history - due to Gutenberg and Reformation. And for all founding inventors who were profound biblical believers their epistemological double postulate was supported by the basic postulates of Biblical worldview.

Keywords — the Needham Question; the Scientific Revolution; modern physics; cultural infrastructure; Biblical civilization; theory of gravity

I. INTRODUCTION

Science, as the process of gaining knowledge about natural world, has no certain date and place of birth. However as far as physics is concerned there is consensus among physicists that something very important happened in the 17th century that deserves to be called the birth of

modern physics. Every modern physicist would agree that Archimedes (III BC) was a physicist and an excellent one. Galileo was greatly influenced by him very much and referred to him as "*the most divine Archimedes*". But it was Galileo who invented something profoundly new to make Einstein to title him "*the father of modern physics"*. [1]

A simple way to see the turning point in the evolution of physics is to compare the pace of its development. The most important predecessors to Galileo – Aristotle and Archimedes – lived two thousand years earlier, while Galileo was the most important predecessor to his students and to Newton who was born in the year of Galileo's death. Very important for Galileo was also an astronomical challenge from Copernicus. So there are good reasons to use the term "the Scientific Revolution" as initiated by Copernicus, and to consider Galileo as the first modern physicist and the very first astrophysicist (after quite a few great astro-mathematicians).

But, again, what did Galileo invent which is so entirely new? It was hardly his insight into a specific phenomenon like inertia. Geniuses are born rarely but uniformly all over the globe. An Islamic scientist Alhazen (965-1040, aka Ibn al-Haytham) had an insight into inertia six centuries before Galileo, and a Chinese philosopher Mozi (470- 391 BC, aka Mo Tzu) - twenty centuries before. But those insights were not developed and laid hidden in old manuscripts until historians discovered them.

Joseph Needham (1900-95, aka Li Yuese) a British biochemist, historian and sinologist, contributed more than anybody in the West to the research on the history of science in China. The question he sought to answer, the so called Needham Question, was: "*Why did modern science, the mathematization of hypotheses about Nature, with all its implications for advanced technology, take its meteoric rise only in the West at the time of Galileo? … why modern science had not developed in Chinese civilization (or Indian* [or Islamic – G.G.]*) but only in Europe?*" For Needham this question was coupled with the question "*why, between the first century B.C. and the fifteenth century A.D., Chinese civilization was much more efficient than occidental in applying human natural knowledge to practical human needs*." [2] No less important is the question, why after modern physics had been born was it not transferred beyond the realm of European culture for centuries? It is well known that European culture borrowed important innovations from Chinese, Indian, and Islamic civilizations, like paper and printing, Hindu-Arabic numerals, algebra, and so on.

This question is more than an exercise in counterfactual history, it is about cultural infrastructure that is most beneficial for progress in science and technology.

The phenomenon of the Scientific Revolution became a hot topic for historians since 1930s, with various factors and facets emphasized, but up to now there is no convincing explanation. The quest was started by Marxist scholars in the wake of the quantum-relativistic revolution in physics and the socialist revolution in Russia. This is no wonder, since Marxists searched for laws of history and laws of revolution, in particular, those similar to laws of physics. Boris Hessen's paper "The Social and Economic Roots of Newton's Principia" (1931) initiated externalist approach to science by promoting the idea that the early modern physics arose from a social context to meet practical demands of capitalist economy. [3] In the line of externalism, Robert Merton adopted Max Weber's explanation of the flourishing capitalism by the Protestant ideology and argued that the latter was especially beneficial to modern physics with its experimentalism as the key feature. Alexandre Koyre, who coined the very term "the Scientific Revolution", claimed that it was brought about by "mathematization of nature" rather than by the experimental method. Edgar Zilsel suggested that the modern physics emerged due to early capitalism which was connected with strengthening individual freedom, quantitative thinking and contacts between the academically trained scholars and superior craftsmen.

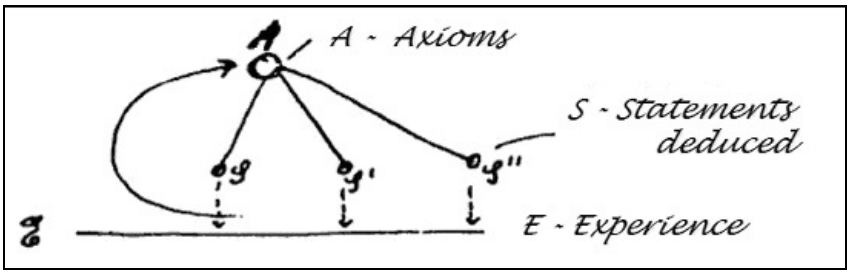
The very diversity of these explanations means the absence of a proper one. Needham in his posthumous publication confirmed that his question still was unanswered.[4] Indeed, the greatest achievement of the Scientific Revolution - celestial mechanics - had no pragmatic value; for all its founding fathers - Copernicus, Galilei, Kepler, and Newton - both the empirical and mathematical tools were indispensable; two of the four were Protestants, and two were Catholics.

To look for a new answer to the Needham question we should start by defining the notion of modern physics invented by Galileo. What distinguishes Galileo's physics from Archimedes' one? And what in Galileo's physics was as modern as in Einstein's?

II. MODERN PHYSICS AND FUNDAMENTAL PHYSICS

To define Einstein's "modern physics", experimentalism and mathematization are not enough since both of these tools were used by Archimedes, who was both a mathematician and an

engineer. Let's rely on Einstein himself who described *his* understanding of *his* science (in a letter to M. Solovine, 1952, May 7):



Here fundamental elements of theory (Axioms A) are free intellectual inventions arising from empiric Experience E by long ascending arrow of intuition. Specific exact statements S are deduced from A to land to the E by short arrows of verification.

This description is actually based on the two most general - epistemological - postulates:

1) There are fundamental Axioms that all the physical laws governing the Universe could be deduced from; those Axioms are not evident, as invisible as the underground cornerstones, or, in Latin, *fundamentum*;

2) The human mind is able to probe into this fundamental level of the Universe to understand its working, and any human being is free to contribute in the process of this probing and understanding.

This double postulate could be a definition of fundamental science. It was such a fundamental worldview that was the real novelty of the Scientific Revolution starting with Copernicus. As to Galileo he invented a specific way to probe into the invisible fundamental level of the Universe's working - by joint use of experimentation and mathematization. He demonstrated his way of making fundamental science in the notion "movement in vacuum" that resulted in the law of inertia, the principle of relativity, and the law of free fall. Galileo never experienced through his senses the vacuum, but by employing experiments, mathematization and the freedom to invent axioms he came to a fundamental notion of an "invisible" vacuum that happened to be so fruitful.

Fundamental physics is only a small part of the modern physics, the larger part is the old good "Archimedean" physics. But in the historical development the small fundamental part

played the role of engine – a jet engine – that propelled the rest of physics by providing it with new basic languages to describe physical reality.

Of course a prerequisite for doing good science is a personal curiosity. Fundamental science requires an extraordinary curiosity, because it is most profitless, with as its only gain some knowledge about the inner workings of the Universe. Thus Galileo was the first fundamental physicist.

III. WHAT WAS THE SOURCE OF THEIR FAITH IN UNIVERSAL LAWS?

What, besides great talents, helped Galileo as well as Copernicus, Kepler and Newton to become founding fathers of the Scientific Revolution? As Einstein wrote:

«Kepler lived in an age in which the reign of law in nature was by no means an accepted certainty. How great must his faith in a uniform law have been, to have given him the strength to devote ten years of hard and patient work to the empirical investigation of the movement of the planets and the mathematical laws of that movement, entirely on his own, supported by no one and understood by very few!» [5]

All the founding fathers shared such a faith in universal laws, but what was the source of this faith? Wasn't it the genuine religious faith which all our four great did have as well? Connection between these two kinds of faith was established by an atheist and Marxist historian of science Edgar Zilsel in his seminal research "The Genesis of the Concept of Physical Law" (1942), where he showed that the terms "Law of Nature", "Physical Law" were born in 17th century in the midst of religious worldview by transforming a legal metaphor - that the Universe is governed by laws decreed by God - into a basic notion of scientific discourse. [6]

There is not much sense to discuss specific denominations of the four founding fathers. While being genuinely religious they were no less genuinely freethinking and independent in their personal theologies, which resulted in their being at odds with theological officialdoms. The only source of religious authority they did not question was the Bible although they felt free to doubt in its interpretations including translations from the original. It is well known how far they strayed away from official churches.

The connection of their two faiths - in universal laws and in God – and their two forms of freethinking – in science and in theology - seems to be more substantial than just etymology of the terms such as "Law of Nature". Looking at the double postulate of the fundamental science one can recognize the combination of the two most general postulates the Bible teaches – acknowledgement of the supreme Creator-Lawgiver and the human personal freedom endowed by Himself. Regardless of religious diversity in the European civilization this double postulate had been instilled and dissolved in European culture, which more properly could be named the Biblical culture, since the Bible is the most common element of European sub-cultures, as different as Finnish and Italian, Russian and British. Legitimate offspring of the Biblical culture includes also unaffiliated believers as well as atheists, since the freedom of conscience, or separation of state and church were introduced into European cultural agenda by profoundly biblical people like the Puritans.

One should not think that in that old time there was no atheists at all. Atheism was well established back in the time of Archimedes. An overt atheist was a colleague and friend of Newton – Edmond Halley. Of course, there were many more covert atheists. But there was no atheists among the founding fathers of modern physics. It is a fact also that in the next generations of physicists those who were responsible for new fundamental concepts – Maxwell, Planck, Einstein, Bohr were not atheists. In essence the same double postulate was formulated by Einstein: *"Subtle is the Lord, but malicious He is not"*.

While in Einstein time it was easy to have a faith in universal physical laws just because quite a few laws had been discovered, it was not so in the 16th century when there was none. Hence more understandable is the fact that all the founding fathers of the modern physics were Biblical theists. And so were their views, in Galileo's words, on the two Great Books by the same Author –Scripture and Nature.

Thus Galileo's fundamental worldview was supported by his Biblical pre-physics (to avoid words "prejudgment" and "metaphysics").

The hypothesis that the Bible was a main source of the Scientific Revolution is a simple and clear answer to the Needham question since the Bible did distinguish European culture from all the others. To show that this answer is not too simple, let's deal with most evident doubts.

By the time of the Scientific Revolution the Bible was around for many centuries. What had it been waiting for? It waited for the time when the Book took the most prominent social role in its history due to Gutenberg and Reformation. The Scientific Revolution overlapped with a few other major European phenomena: Renaissance, Reformation, Capitalism, and political inhomogeneity, or impossibility to create All-European Empire. All these phenomena mattered for the Scientific Revolution, and all of them required sufficient individual freedom together with respect to the rule of the supreme law - intelligible, rational, even if super-rational, but not irrational law. The most fundamental and all-European base for such a cultural infrastructure was the Bible whose role started to strengthen since 12th century with the principle "Sola Scripture" (by scripture alone).

IV. A PHYSICIST BY THE TREE OF KNOWLEDGE AND BY THE FORBIDDEN TREE

In comparing cultural infrastructures of the four major civilizations it is quite clear that Chinese and Indian cultures had nothing like the Bible as far as its singular social role is concerned. But Islamic culture did have equally singular Sacred Scripture – the Koran containing many stories and characters from the Bible. Let's look at the difference through the eyes not a theologian but an adolescent monotheist endowed with extraordinary curiosity and independent thinking, that is a potential scientist the researcher.

The very first chapters of the Bible contain the story most related to the situation of fundamental scientific inquiry – the story around the Tree of Knowledge of Good and Evil. First, our independent smart reader would grasp that this story is about scientific knowledge in general, for to do good in a specific situation one have to know the working of this situation, for example, to know what would heal the specific sickness of a suffering person. Second, our reader would grasp that God's words not to eat the fruit from the Tree of Knowledge lest to become mortal, was not an outright prohibition but a kind of forewarning, for God's prohibiting commandment ("Thou shalt not …") didn't include consequences of its violation. And finally a potential scientist could easily comprehend the main motivation of Eve to eat the fruit from the Tree of Knowledge because of longing for knowledge. Since it was the very first action of Eva, apparently both her freedom of choice and her longing for knowledge had been provided to her by her Creator. Hence

a potential fundamental scientist would feel free to be dying for a new piece of knowledge about the Universe.

The Koran's version of this story is quite different. The tree has no name, it is just a forbidden tree. There is nothing about opportunity to gain knowledge. The status of man is quite different as well, he is farther from the God, the Koran doesn't state that man was created in the image and likeness of God. The first man is vicegerent (khalif) rather than the crown of creation. So much more questionable is the human ability to probe into and to understand God's laws of the Universe. Hence the difference in spiritual supports of a religious scientist in the Bible and the Koran.

Even within Biblical cultural domain there is evidence of such a support from the Bible. The idea that Protestant ideology was a boon to the science was based on the statistical fact of the disproportionately high contribution of Protestants to science since 17th century. [7] This fact is supported by statistics of religious background of Nobel laureates (1901-2002): those with Catholic background are 9% of Nobel laureates and 17% of the world population, while those with Protestant background are 30% of Nobel laureates and 7% of the world population.[8] Such a difference is a result of a few centuries of stronger development of science in the Protestant world, while in the early 17th century science in the Catholic world was no weaker than in the Protestant one. Such a developing disparity is to be explained.

Despite all the differences within Biblical civilization, the difference between it and other civilizations in ability to adopt modern science was much greater. Instructive is comparison between Russian and Chinese Empires.

China was much more advanced with her "Four great inventions" in technology, traditions in philosophy and astronomical observations. The modern science was brought to China by Jesuit missionaries back in 17th century and was welcomed by Chinese emperor, who appointed a missionary his main scientific adviser.

More than a century later, the modern science was brought to Russia thanks to Peter the Great. It started with bringing outstanding scientists from Europe, including Euler and Bernoulli. However very soon a powerful indigenous figure of Lomonosov appeared, and the first world-class results in exact sciences - Lobachevski's geometry, 1826, and Mendeleev's periodic table of elements – emerged more than a century before Chinese. So strong disparity could be explained

by the fact that Russia belonged to Biblical civilization despite all the socio-economical differences. As far as tiny minority of potential scientists in Russia is concerned, they relied on the same biblical cultural infrastructure as the same minority in the Western Europe.

In China the main hindrance was apparently the lack of a concept of "law of nature". When in 18th century a missionary tried to explain to Chinese *"that God, who created the universe out of nothing, governs it by general Laws, worthy of his infinite Wisdom, and to which all creatures conform with a wonderful regularity, they say, that these are high-sounding words to which they can affix no idea, and which do not at all enlighten their understanding. As for what we call laws, answer they, we comprehend an Order established by a Legislator, who has the power to enjoin them to creatures capable of executing these laws, and consequently capable of knowing and understanding them. If you say that God has established Laws, to be executed by Beings capable of knowing them, it follows that animals, plants, and in general all bodies which act conformable to these Universal Laws, have a knowledge of them, and consequently that they are endowed with understanding, which is absurd."*[9]

Some Merton's followers pointed out the role of "biblical worldview" in the rise of modern science by focusing on active, optimistic "Christian empiricism" as new respect to the facts of nature rather than to old-fashioned intellectual speculations. [10] However such empiricism was characteristic only for Protestant ideology and insufficient for the first major triumphs in astronomy and physics authored both by Catholics and Protestants. And this approach had nothing to explain specific intellectual contribution into the new – modern – science.

The approach suggested here starts with selecting astronomy and physics as the core of the Scientific Revolution. The "Biblical worldview" is reduced to two very basic postulates on an invisible, fundamental and super-intelligent Creator-Lawgiver who endowed human being with the free intelligent ability to understand His will and deeds. Those postulates were intellectual and inspirational support for a religious scientist to make fundamental science. The source of those postulates was the Bible itself whose role climaxed in the era of Reformation in both Catholic and Protestant parts of Europe. It did climax regardless of the difference in dogmatic roles of the Bible in the Catholic tradition and the Protestant innovation, and due to the very fact of debates around the role of the Bible together with its mass printing and translations into vernaculars. As far as

science is concerned, the basic theological counterpart of the double postulate seems to be much more important than theological subtleties which are too far from scientific problems.

After the debates of Reformation had been over, Protestant innovation became a new tradition, and different roles of the Bible started to work differently in Catholic and Protestant parts of Europe. The Protestant tradition promotes a much more active role of the Bible in daily life that could explain more active development of science than in Catholic and Orthodox traditions.

As to the science beyond physics, it was the very striking success of fundamental physics in demonstrating the ability of the human mind to probe and understand Nature that became a great inspiration and encouragement for scientists the non-physicists.

Since the modern physics was invented in the time when the Bible's social role was the greatest in the European history, no wonder if contribution of the Bible into the genesis of the modern science was no less than the Bible's contributions into European languages and literatures. In Europe even hard-core atheists have to use biblical phrasing. And those Westerners who are open to Eastern wisdoms of Zen, Yoga and so on, implicitly follow the cultural genome of Biblical- European civilization, with its powerful genes of openness, activity, high freedom and responsibility per capita.

V. WHY GALILEO DIDN'T DISCOVER UNIVERSAL GRAVITATION?

Yet the biblical predisposition was not absolutely beneficial. According to a Russian proverb and unregistered law of dialectics there is no bad without some good and no good without some bad.

The very first discovery in fundamental physics, made by Galileo, - the law of free fall - was also the first discovery in physics of gravity. It was the starting point for Newton's law of universal gravitation a few decades later. Was it possible for Galileo himself to discover the law of universal gravitation at his level of mathematization and by his style of doing science?

Yes it was, although Galileo's predisposition was very unfavorable, since he rejected statements on attraction as an explanation of the Solar system. But nevertheless Galileo could

come to the law of universal attraction by a way starting with his discovery that free falling object is moving on parabolic trajectory. He understood that parabolic trajectory was but an approximate result for "flat Earth", or for small initial velocity. He didn't know the form of trajectory in general case but he would grasp that very high initial horizontal velocity would make the object to go far away from the Earth.

Galileo is often reproached for his keeping to "backward" ideally circular planetary orbit despite the observational reality summarized in Kepler's law of elliptical orbits. Galileo ignored rather than reject Kepler's laws of planetary motion. Circular planetary orbit was the simplest model to probe into physics of planetary motion, and Galileo could do this. Even without knowing the general form of trajectory of free falling object, he could ask what initial horizontal velocity $\boldsymbol{V}$ would make the object to move at the same distance from the surface of the Earth. And he could answer this question by means of math no more sophisticated than the theorem of Pythagoras: $\boldsymbol{V} = (\boldsymbol{gR})^{½}$, where $\boldsymbol{g}$ is the acceleration of free fall and $\boldsymbol{R}$ is the radius of the Earth.

The motion at a constant distance from of the Earth resembles the Moon's motion too much for Galileo to miss this resemblance. But Galileo would find that the relation $\boldsymbol{V} = (\boldsymbol{gR})^{½}$ holds for the Moon only if acceleration of free fall on the Moon's distance from the Earth $\boldsymbol{g}_{\mathrm{M}}$ is about 400 times less than $\boldsymbol{g}_{\mathrm{E}}$ he had measured on the Earth, while the distance to Moon $\boldsymbol{R}_{\mathrm{M}}$ is about 60 times more than $\boldsymbol{R}_{\mathrm{E}}$. It would hint at relation $\boldsymbol{g}(\boldsymbol{R}) \sim \boldsymbol{R}^{-2}$.

Combining it with the previous, he would get a relation for the astronomically observable parameters $\boldsymbol{V} \sim \boldsymbol{R}^{-½}$.

Having verified this relation for the planets in the Solar system and for the satellites of Jupiter, Galileo would realize that he got the 3rd Kepler's law of planetary motion ***as a result of universal attraction that he had studied in the phenomenon of free fall***.

Thus Galileo would come to the law of universal gravitation. Why didn't he do it ?

A probable reason was his religiosity. Being quite serious about his biblical worldview – regardless of how far he was from official theology – Galileo was unable to accept a quite friendly suggestion from the Pope (who was his admirer) to write about his science freely but without claiming that his theory was real truth rather than a hypothesis, even if the best one compare to others. If Galileo had been an atheist he could condescend to scientific backwardness of the

religious authority, and in his writing to address to his colleagues the scientists with obviating repercussions by proper hypothetical wording. But being an honest biblical believer he had to defend his truth-seeking. So he invented a literary form to obviate administrative restrictions in his Dialogues and had to spend too much time and effort for his kind of popular-science writing. Nevertheless he failed to circumvent the scientific ignorance of society and the Church and, as a result of persecution, his intellectual and social freedom was harshly restricted for the rest of his life.

Of course in the history of science Galileo's "unnecessary" popular-science writings played a very important role in propagating the new method of doing science all over Europe. But being too busy for too long with such writings and with opposition to ideological officialdom Galileo left the honor for developing his research on gravity to Newton.

VI. ON SCIENTIFIC PROGRESS, INTELLECTUAL FREEDOM AND SOCIAL RESPONSIBILITY

In thinking about the beneficial cultural infrastructure for scientific progress, comparative history of science might be the main resource. In the 21st century the best way to create such an infrastructure is hardly to promote the Bible. Thanks to the amazing advancement of science, nowadays the double postulate of fundamental science is self-evident without biblical support.

Various social forces are working in a society to find out persons endowed with extraordinary curiosity and independent thinking and to provide them with necessary freedom to develop their gifts into new inventions in science and technology. Here, as the history of science shows, the intellectual freedom, including religion, is the most relevant among all the human rights. Instructive is the comparison of two sciences – biology and physics – against the same totalitarian background of Stalin's Russia.

An agronomist T. Lysenko, enthroned in the Soviet biology directly by Stalin, effectively suppressed intellectual freedom in Soviet biology to result in its major destruction.

On the other hand, Stalin's urgent need for nuclear weapon made Soviet leaders restrain their control over the intellectual freedom of physicists, and the highest level of the freedom was allowed at the closed nuclear center where nuclear weapons were designed.

One of the weapons designers, the theoretical physicist Andrei Sakharov, in 1968, was expelled from this center after he had written an article "Reflections on Progress, Peaceful Coexistence, and Intellectual Freedom". [11] It transformed the secret "father of the Soviet H-bomb" into a public figure. But his way to publicity was unique. Being a top expert in strategic balance and privy to strategic information in full, in 1967, he became gravely concerned with a problem of strategic antiballistic defense. He sent a secret detailed letter to the Politburo explaining the increased threat of nuclear war. Then he considered himself a defender of socialism and a non-dogmatic Marxist. Sakharov saw the fact that the founders of Marxism didn't foreseen: due to advancement in science and technology humanity was facing the threat of total suicide within half an hour, the travel time for a nuclear missile. Sakharov actions were exercises in intellectual freedom coupled with social responsibility. He was well aware that the real intellectual freedom could thrive only on the basis of respect for the rule of law.

However, the Soviet leaders had no respect for both intellectual freedom and social responsibility of citizens, they did not heed the advice of a top non-dogmatic expert and didn't allow Sakharov to publish a non-secret version of his analysis. Sakharov found that his intellectual freedom, so necessary in his profession, was dangerously restricted. Feeling his personal responsibility, he went public to prevent nuclear war. Correcting the old formula, Sakharov wrote that "*evolution, not revolution, is the best locomotive of history*" and confessed himself to be a "*convinced evolutionary, reformer, and principled foe of violent revolutionary changes of the social structure, which have always led to the destruction of the economic and legal system, to mass suffering, lawlessness, and horror*."

Soviet leaders failed to make the necessary reforms, and the regime collapsed.

Chinese economic reforms show that it was not the only possible outcome. And if Chinese reformers could also create a beneficial cultural and social infrastructure for scientific inventiveness it would be the best practical response to the grand question of Needham, who was so very sympathetic to Chinese civilization. History hints that respect for intellectual freedom and for the rule of law is the best secular approximation to the Biblical prerequisites for fundamental physics in the 17th century.

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