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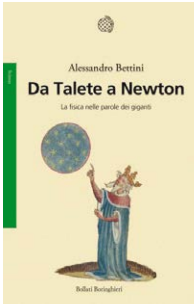

Alessandro Bettini

Da Talete a Newton
La fisica nelle parole dei giganti

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Sometimes, when browsing the new books on "popular science" popping out of Amazon furnaces each month, a famous line attributed to Cicero comes to mind: *These are bad times. Sons no longer obey their parents and everybody is writing books*.

Good books, too. Today, anyone interested in science can get a self-education just browsing wisely the Internet. Books are cheaper than ever, often free. Many good scientists publish outreach accounts on everything ranging from molecular chemistry to genetics, from planetary science to quantum mechanics, from group theory to applied statistics, from neural networks to robotics, from the origin of life to the roots of conscience. Everybody is writing books, indeed, and most of these books are entertaining and educative, yes, but not *illuminating*.

A book is illuminating when it challengers the reader, takes her out of her comfort zone, questions what she thinks she knows and reveals how much she does not know. The work of Alessandro Bettini, *From Tales to Newton, physics in the words of giants*, will do all that.

Science (and technology) is everywhere today. Even the most scientifically illiterate have heard of genes and atoms, of Supernovas and evolution. We carry super computers in our pockets and navigate effortlessly in an Ocean of information incomprehensible just a few decades ago. New planets are discovered every week, super massive black holes are announced in the news. And yet, hundred years ago, most of the planet was still struggling to get out of the middle ages. Health care, public education, access to news, iPhones and the Internet are not granted commodities. They are miracles.

Where do these miracles come from? How did Science came to be? Where, when, and how? These are the questions that Bettini will address.

The very fact that Nature has laws that can be discovered was not obvious at all for the ancients. Realizing this fact was the starting point [of philosophy and science] and we owe it to Tales. Even less obvious was that the laws governing movement on Earth and on the Cosmos were the same, so much so that the second got a different name. Astronomy. The great unification will occur only with the Galilean revolution which introduces the experimental method and accelerates scientific progress together with mechanics whose foundations were laid by Galilei himself and by Newton.

The narrative encompasses, indeed, the twenty centuries that span between these three giants. Tales the Ionian, attempting for the first time to explain the World in terms of logos on the one side, Galilei and Newton, who invented modern science, on the other. Between them, twenty names or so. Just twenty names in twenty centuries, most of them clustering in old Greece. Science and technology, the engines that move our modern World, were almost inexistent during the ten centuries of desert starting hundred years before Christ was born and extending until Copernicus.

The organisation of the book is loosely chronological, but the narrative revolves around the cognitive models. Thus, the first chapter, *mythos*, draws a vivid representation of the World as perceived by the ancient Greeks.

The representation of the physical World, sees still Earth as a flat disk. […] Earth is covered by Sky, which is a half-dome, solid and shiny, like a metal. In the middle, in the lower part is ***aer****, which is not necessarily air, and sometimes is more like a fog; in the upper part, the ether which is like splendorous air. Underground, the Tartarus, less defined and dark. Interestingly, a feature appears little by little: that of symmetry.*

After mythos, *logos* (chapter 2). The miracle of Ionia, this narrow region of seaside *polis*, rich enough and peaceful enough, for a while, to foster the flowering of art, poetry and philosophy. In Ionia, city of Miletus, six centuries before Christ, our first character, Tales, takes the first step towards understanding the World. And this step is at the same time simple and colossal:

Starting from the idea that the world can be <u>understood</u>, that the observed events had a <u>logic</u>, rather than being consequences, out of human control, of the game of Spirits.

Three words define the birth of philosophy and thus science: *Curiosity* to understand Nature. *Stupor*, beholding the wonder of natural phenomena. And the *joy* of comprehension. These three words define the Greek way of thinking and are as valid, among modern scientists now, as were two and a half millennia ago.

But could it have happened without mathematics? The early thinkers, Tales and Anaximander, were already trying to describe the World. Anaximander not only started observational astronomy –using the first scientific instrument –a simple stick to measure the length of the shadow cast by the Sun, and thus its azimuth– he also proposed the first cosmological model, a remarkable one, given the experimental data available at the time, in which Earth was a flat disk surrounded by celestial rings[1]. But Anaximander's language was limited. He had only words. A hundred years later, in Magna Greece, another language, essential for the development of science appears. This language is mathematics and was invented (chapter 3, *Mathematics and harmony*), by a sect, led by a certain Pythagoras.

Pythagoras was certainly a special character, a genius and a charlatan. He was a philosopher, a mathematician and a politician. He believed in the immortality of the soul and in metempsychosis (transmigration of the souls)… [His] school had all the features of a religious sect.

Paradoxically, the Pythagorean were at the same time the first serious mathematical Academia, and a bunch of *illuminati*, whose

[1] Thus, Anaximander predates the modern proponents of Flat Earth by twenty five centuries. One wonders if Flat Earth societies (`https://en.wikipedia.org/wiki/Modern_flat_Earth_societies`) are nothing but a cover-up for smug philosophers trying to convince us that we should read the Greeks.

methods were as distant as those of scientists as it gets.

The Pythagorean school was based on principles distant from a scientific Academia. Obedience, secretiveness and the authority principle as a means of establishing the truth.

And yet, that very same school not only revolutionize mathematics. They also paved the road to modern physics, by using the mathematical language to describe physical phenomena. By 490 BC, Filolao of Crotone, a late Pythagorean had developed an astonishing model of the Cosmos, in which the Earth and the other known celestial objects (the five planets, the Sun and the Moon), together with a mysterious "Anti-Earth" (whose purpose was to explain the Moon eclipses) all circled … a central fire, which provided heat and light. Sun and Moon are the objects closer to Earth (after all, they look pretty similar to the naked eye) and the fixed stars the external vault.

So, chapter 4 is devoted to the (absolutely not obvious) notion that the Earth is a planet. One is amazed by the ingenuity of Filolao's Anti-Earth, that mysterious planet which humans could never see directly, but whose evidence would appear in Eclipses. At the same time, the reading takes us out of our comfort zone (as advertised), and we wonder about recent inventions such as Dark Matter, also impossible to observe, so far, and also needed to explain phenomena that we could not account for otherwise. Is there a simpler, deeper alternative to Dark Matter? Will the physicists of the distant future smile at our feeble attempts to account for a Cosmos in which gravitational attraction between galaxies is much stronger that what one would expect adding up the luminous mass? A Universe which appears to be accelerating faster and faster, as if inflated by this strange substance that we call Dark Energy? Will those physicist admire our ingenuity, given the lack of data and deeper insight (that they will have and we have not), as we admire Filolao? Bringing back to life the pristine thinking of those geniuses is like showing us a trail of footsteps that lead no other place than home.

And the path that those footsteps follows is all but straight. A century after Filolao, the great Aristotle decided that Earth must be at rest in the center of the Universe. He did not sustain his belief in observations but in a sort of abstract aesthetics. He came up with what appeared to him as the most beautiful model. A model which also explained physical phenomena, such as why a stone falls to the ground (the stone is made of a "heavy" element, earth) and fire burns out to Heaven (fire is a light element, whose natural place is the Moon). Thus, according to Aristotle, movement depends on the substance of elements are made of. We know that this is not the case, but Aristotle didn't and didn't bother to check. This will need to wait almost a thousand years, until Galilei.

A fixed, immobile Earth on the center of the Cosmos fitted well with the Christian view of the Cosmos that run all through the middle ages, and thus, in one unexpected detour, logos was defeated –for a long time– by mythos.

But if Aristotle was king during the Middle Ages, the Greek thought didn't take long in returning to the path of science. Aristarco of Samos invents a way to measure the size of the Moon and the Sun, relative to Earth, using eclipse observation. He finds that the Sun is much larger than the Earth, and concludes (correctly) that the Sun should be the center of the Universe. Not only that, his model implies that the Universe is much larger than what was previously thought. All of that happens 300 BC, and will be lost before long.

A second dimension of Greek thought is presented in chapter 5 (*Geometrical point and physical point*). We have seen that they wondered about the composition of the Cosmos. They also wanted to know what were the elementary constituents of matter. Everyone of the philosophers we have just introduced had something to say about it. Tales imagines the ***idor***, Anaximander the ***ether***, Aristotle the four elements, water, earth, air and fire. All of them were wrong. Worse, none of their hypotheses was experimentally verifiable. That particular fact, which defines Science as we understand it, was largely absent in the Greeks. Instead, they passed us the astonishing hypothesis of reductionism, the idea that everything can be reduced to a small set of elementary constituents.

Thus, Bettini will introduce Leucippus and Democritus. Their atomic theory is shockingly close to the current notion of atom (actually, their atoms would resemble more our elementary particles). But, the notion that matters can be divided into smaller and smaller parts until one reaches the indivisible will have to wait centuries until getting its first experimental confirmation (with Dalton and Avogadro), and a few centuries more before becoming the big business of modern Particle Physics.

Change the scenario to Alexandria, the city of the fabled library, which, according to tradition, "contained all the books in the World". The metropolis will foster enormous progress in medicine (Eorfilo of Calcedony studies human anatomy dissecting corpses), civil engineering develops powerfully, geometry reaches classic perfection with the *Elements* of Euclid, the great Aristarchus and Hipparchus of Nicaea advance astronomy and Eratosthenes of Cyrene, third director of the Library, measures, with great precision, the size of Earth, a marvellous feat that lends its title (*Measuring Earth*) to chapter 6. One wonders what the World could have been if the path of progress of the third century before Christ in Alexandria had not been sustained.

But it was not. Scientific and technological progress is not granted (the reader will be reminded of this simple fact more than once). After the second century BC science declines more and more. Eventually the pogroms against the Greeks start and in 146 BC scientists and intellectuals are spelled out from the city.

Chapter 7 feeds forward 300 years. We are still in Alexandria, but this is now a Roman city. Once again, a period of relative calm, where Science has another chance to develop. A period which produces nothing other than Claudius Ptolemy.

… We know almost nothing of his life. He left an enormous scientific opus. In mathematics, he developed trigonometry […] In geography produced a chart of the World […] in physics gave great contributions to music theory and to optics […] In astronomy, Ptolemy invents the epicycles.

Ptolemy model is often referred to as Aristoteles-Ptolemy, a wrong and unfair term […] Ultimately, and this is perhaps the most important aspect, Ptolemy model is exquisitely scientific, while that of Aristoteles is abstract and unscientific. Ptolemy works imagining a model that provides a mathematical description of the observed phenomena which is at the same time precise and as simple as possible, without divagating about first principles. He also computes the predictions, confronting them with experimental data and adding to the model the needed corrections to obtain good agreement.

Not in vain, chapter 7, devoted to the genius of Ptolemy and his great woks is called *The great model*. With him, science reaches a true pinnacle, that won't be equalled until Copernicus. Between the death of the former and the birth of the second, 1305 years pass by. Many things did happen in thirteen centuries, including the rise and fall of empires, the diffusion of the two great monotheist religions, Christianism and Islam, and the great plagues. Great works of art were carried out, cathedrals were built, innumerable wars were fought. Science, meanwhile, was Sleeping Beauty, waiting for the kiss of the Prince Charming. Or perhaps not quite sleepy, at least for a few more centuries, where she dwelled in Bagdad. Chapter 8 (*A renaissance*) offers the reader the works of the greatest of the scientists of the Arab World, Ibn al-Haytham, also known as Alhazen. Bettini proposes that the two fundamental contributions of Alhazen were, first, the rational doubt (or scepticism), needed since "truth is always immersed in uncertainties". Second, the need to add experimental data, that is, what we learn from experimentation, to what we learn by induction. By formulating these two principles he aligns himself with Galiei, and departs from the Greeks for whom experiments were secondary to inductive truth. Alhazen, whose exploits are the core of the chapter becomes thus, the first true experimental physicist.

The second part of Bettini's book starts in chapter 9, *Earth is not the centre of the Universe.* We start in the tenth-century Spain where king Alphonse X, called "the wise", recruits a bunch of Hebrew, Arab and Christian scientists in Toledo –perhaps the first big shot in history to realise and support the international and multicultural character of science–. The main task of this group is to translate from Arab the works of Aristoteles, Euclid, Apollonius and Ptolemy. Two astronomers of the group, Jehuda ben Moses and Isaac ben Sidi, also elaborate new astronomical charts, which are completed in 1252 and known as the *Tavole Alfonsine*. They are an update of the works of Ptolemy, which add eleven centuries of data collected by the Arabs, Persians and Byzantines (while, presumably, the Europeans were busy with other more mundane chores, such us fighting among themselves). The tables went to press for the first time in Venice, in 1483 (publishing took longer then than now), and became available to the scientists of the time, among them, a youngster called Copernicus.

Copernicus was born in 1473. About forty years later he conceived his revolutionary heliocentric model. He worked on it for the rest of his life. His opera magna, *De revolutionibus orbium celestium* was published only few days before his death, in 1543.

Today, kids learn in primary school that the Earth and the rest of the planets rotate around the Sun. In the sixteen century the notion was not only weird. It was heretic. Bettini reminds us of the opinion of no other than Luther:

This is the way of things now. Whoever wants to show off as intelligent must disagree with everything that the rest of us hold as true. He must do something personal, like those that intend to set Astronomy upside down. But even with all this disorder I still believe in the Sacred Scripts, because Joseph commanded the Sun to stop, not the Earth.

Luther attacks the central element of scientific progress, that is, *independent thinking*. He is not the first to do so and won't be the last. If the hostility of Luther delays the publication of Copernicus work, Calvin will attack *De revolutionibus* with all his might.

We see that some […] will say that the Sun does not move and is Earth which travels and spins. When we see such spirits we must say they are possessed by the Devil.

Possessed by the Devil. At least Calvin was straightforward in his assessments. For him, the only agent behind Nature was God, and Copernicus model was a major threat to that belief. Mythos against logos again, a battle that will carry on with Galilei and beyond.

The chapter reads as a detective story. The reader is presented with a beautiful description of the theory, its predictive power, and its revolutionary assumptions. At the same time, the connections with Aristoteles and Ptolemy are drawn artfully. Copernicus didn't destroy everything that came before him, as the priests would have it. He simply improved the model.

But that improvement was not obvious, even for the astronomers of his own time, since, although conceptually simpler, it was as complex, in practice, as Ptolemy's epicycles, and rigged with imprecise data to boot. And this is the title of chapter 10, *Precision*. Precise data was desperately needed to support the theory. This data was collected by Tycho Brahe.

Brahe invents what Bettini calls "The art of experiment". This includes not only technical inventions and new methods, but also a scrupulous methodology to analyse the data, that he was collecting still with the naked eye ("the devil is in the details"). Brahe will do all that, and more. He will be able to carefully plan his scientific program over a long period, probably the first scientist in history who can afford that luxury. The outcome of that scientific program is mind blowing. He invents or perfects astronomic instruments, and collects and organises an ocean of data that will be essential for the incoming revolution of Kepler. And yet, it is said that his last words were: "Seems that I have lived in vain". He died at 54, fearing that all his life work would be wasted. It would be not. Shortly before his death he had hired a new assistant called Johannes Kepler, who would solve, once and for all, the mystery of the Solar System.

The title of chapter 11 is precisely this, *The solution of the Solar System*. The main character is the very same Kepler that we just met in the previous chapter. Another genius, and very precocious at that. Like Copernicus, Brahe, and later Galilei, he will also pay a heavy toll for being a scientist. He is expelled of the Lutheran faith after his refusal of accepting their dogma, but he refuses to convert to Catholicism and ends up rejected by both. In the words of Bettini:

Bickering about everything, at war to grab power, the two confessions agreed about one point. The prohibition of free thinking, and even more, the prohibition of its teaching.

At the same time, a strike of luck. Kepler meets Brahe and starts to work in the "theory of Mars", trying to understand the details of the orbit of the planet. Actually Kepler's luck is not only to meet Brahe and gain access to the wealth of data that the former has collected, but also to get involved with the problem of the only planet in the Solar System whose elliptical orbit could be demonstrated to be different from an eccentric circular orbit within the precision of the data accumulated by Brahe. So, serendipity. The battle against Mars (as Bettini puts it), leads Kepler to the new astronomy. A battle that was not easily won, but without which the subsequent discoveries could have been long delayed.

In 1609, Kepler publishes *Astronomia Nova*, one of the master works of scientific literature. Technically complex, full of sophisticated calculations, its message, however, can be summarised in two lines:

The orbit of planets are ellipses, of which the Sun occupies one of the foci.

The area covered by the ray vector that joins the Sun and the planet, is proportional to the time involved (in completing a rotation).

Again, in the words of Bettini:

The discovery in itself can be written in two lines. But the physics is much richer than those two lines. Kepler does not simply offer here the result of his research, as Ptolemy did […] but reports the full Odyssey needed to arrive at those results. Like Ulysses he had sailed long without ever reaching Ithaca, in many stages, with victories and defeats. He sailed by provisional hypotheses, calculations comforted with data, the discovery that the hypotheses were wrong followed by the quest for better approximations until his final victory over Mars, the God of war. The errors were not considered failures by Kepler, but steps towards truth. The rules of the game were not fixed a priori, but discovered along the way. The hypotheses that were in the very same foundations of the astronomy of millennia, those of circular and uniform movement were analysed, confronted with data, found false and rejected. And a revolutionary work that marks the birth of modern astronomy occupied their place.

Let's reluctantly leave the genial Kepler to meet another giant. Galileo Galilei, one of the great scientists of all time.

Chapter 12 is called *The experiment*, and the title is well deserved. Let's hear why in the words of Bettini:

We have seen how many elements of the scientific method were introduced starting from the Ionian "Enlightenment", along two millennia. But the true revolution was the works of Galilei and the price he had to pay was very high. The first attacks came from the very same Academia, the scientific establishment itself, the scholars whose dogmas and above all whose methods were questioned. Then the attacks of Luther, Calvino and the Christian church followed. He was ultimately condemned to renegade of his own ideas, prevented from teaching and imprisoned in his home.

To Galilei we own, of course, the telescope, or to be exact, the scientific instrument version of the telescope. Previous incarnations, as Bettini explains, were mere toys, and the description he makes of the design and construction of the scientific instrument is simply marvellous. For an experimental physicist, like this reviewer, the story is simply sublime. Galilei builds his tool and points it to the night sky… how did we feel when the Milky Way resolves in an explosion of stars, when the constellations revealed many more of those stars that anyone could have imagined, when he discovers four moons circling around Jupiter? *Lord, I was blind, I could not see,* he must have intoned, but the miracle who has bestowed him –and all humanity– the grace of sight, is not due to any supernatural being, but to his own genius and work … and that of all those who lived before him.

To Galilei the instrumentalist and Galilei the astronomer, we have to add Galilei the physicist. His experiments with inclined planes established the laws of mechanics. He discovered that the period of a pendulum is independent of its amplitude, and applied that knowledge to build precise clocks. He made three fundamental discoveries: the law of inertia, the law of movement uniformly accelerated, and the equivalence between inertial and gravitational mass. His two first discoveries will become the first and second laws of Newton, the third, will be the starting point of Einstein's general relativity.

After Galilei, Newton. A giant climbs on the shoulders of another giant and completes the great building of theoretical mechanics. If Galilei invented experimental physics, Newton was the first fully accomplished theoretical physicist. Thus, *The great synthesis*, the last chapter (except for the *Epilogue*) of the book.

The first thing Newton does is to develop the infinitesimal calculus he will need for his mechanics. On doing so he creates a full and very rich branch of mathematics. Then, in physics his first field of research is Optics. He studies the refraction and dispersion of light and proposes the hypothesis that light is composed of corpuscles with mass. That hypothesis was not correct and eventually questioned by Robert Hooke, to the chagrin of a still young Isaac.

His main and monumental contribution to science, however, was the theory of mechanics and gravitation that would remain unchallenged until Einstein, his famous *Philosophiae Naturalis Principia Mathematica*, published in three volumes in 1687.

Galilei had tried. He imagined that gravitation was a universal law (far from the Aristotelic notions of *gravitas* and *levitas* which sends "earth" objects down and "moon" objects up) but he didn't know what kind of law. Newton will take that step. A giant's step, yes, that will also make the works of other giants, such as Einstein, possible. But a step that leaned heavily on the work –and perhaps is fit to say also, the suffering, remembering Galilei, among others– of those other giants before him.

We started with the night sky and the stars which shine and move slowly. They fascinate and excite the fantasy of men resulting in poetry and mythos. With the development of logic and its rules, the rational thinking of the Greeks took the first step towards physics, discovering the logic of man and the logic of Nature. The successive steps were the understanding that natural phenomena can be described in terms of laws, that is mathematical relationships between measurable physical quantities. We conclude with the discovery of one of the most important laws of physics, the law of universal gravitation of Newton.

In between, two millennia of going forward and backward, of discoveries and misunderstanding, of support and hostility from the powerful, of attacks from conservatives and reformists alike, always trying to break free from dogma.

Perhaps the most illuminating aspect of this illuminating book is this. It shows us the value, the costs and the ultimate rewards of free thinking, as needed as ever in the Brave New World of the XXI century.

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