

The Fabric of the Heavens

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There is a marked distinction between the solid earth on which we walk and the celestial vault above our heads. The first is open to all of our senses. We cannot only see it, we can touch and smell it, as well as perceive its sounds. The second though is only perceivable through sight. The Ancient Greeks devised two distinct geometries. One, the flat Euclidean, pertaining to the Earth; the second the spherical, describing the sky. The latter is in fact the most immediate to us, at least optically, as the sphere provides the field of vision. The first is not only explored by vision, but perhaps even more by movement and touch. It is not by sight alone that we get a feel for space, on the contrary without our freedom of movement we would not really acquire the deeper sense of space. There is no reason to assume that those two worlds should be in anyway related, in particular the objects on the sky may very well be infinitely far away, That idea seems not really to have been entertained by the Greeks (in more primitive societies the distinction would not have been possible to formulate as distinctively as to furnish any purchase for further inquiry) at least there is no documentation of such thought. Thus men seem to have implicitly assumed that the earth and the sky are both part of a common 3-dimensional world. Whether this assumption is the consequence of a dearth of imagination, or indeed is the fruit of a bold generalization is hard to definitely settle, but I am inclined to lean against the former view. In the present book, the authors do not touch upon the distinction but seem to assume that there is none, that indeed that the ontology of the universe encompasses a unique space, although practically (and, if you want, from an epistemological view) there are two.

The observation of the sky reveals two features. One a fixed set of configuration of stars, the so called fixed stars. Second one of a set of more or less irregularly moving bodies, out of which two stand out, namely the Sun and the Moon. The Sun in particular proceeds in a fairly regular way in a straight path (meaning along a great circle) along the sphere of fixed stars, while the movement of the Moon is only slightly more complicated. By hindsight of course, this is due to the fact that the Earth moves around the Sun (or conversely if you insist) as well as the Moon rotates around the Earth. While the first orbit is almost circular, the second has a more marked eccentricity. Needless to point out those two objects have a very marked visual distinction from the other celestial objects. In particular the Moon which appears like a stone suspended in the sky, and due to its phases, it is hard not to conceive it as a sphere. While the Sun does not have a spherical aspect but always¹ appears as a disc. Then there are the seven wandering stars - the planets. Any child immediately picks out the Sun and the Moon, but to pick out the planets, require a systematic observation. An individual might easily spend his life unaware of the existence of the planets. Thus the awareness of their existence is a sign of civilization².

¹ Except for the occasional and striking but very rare exceptions

² As the authors point out: It is noteworthy that the big supernova in 1054 which gave rise to the

The planets exhibit highly irregular movements, including those of retrograde ones. We now know that this is due to the composition of two more or less circular movements. And the sustained recording over generations of those can only be done in a stable and fairly sophisticated culture. The observation of the sky serves two important purposes. One real, and one fictional. Without those it is doubtful that such recordings would prevail. The purpose that was real, namely that of time-keeping, has of course tangible practical use, but that which is based on fiction, namely astrology, has had a much firmer hold on the imagination. Astrology, based on the conviction of a fundamental parity between the terrestrial world and the celestial, has been firmly tied to astronomy since time immemorial, parting company only in the 17th century, and without it, astronomy may never have evolved. Astronomy is very much a social enterprise which required in the past not so much horizontal collaboration as vertical, meaning along time. Here the Babylonians stand out. Their recorded observation, as testified by cuneiform tablets³ seems to have spanned thousands of years, at least according to Greek sources, cited by the authors. Those are impressive time series indeed (for obvious reasons unequalled in modern times). As a consequence they were able to predict the movements of the celestial objects (including lunar eclipses, solar ones are of course far more delicate, at least when it comes to total eclipses, due to the projected cone of shadow having its apex almost touching the Earth) with great accuracy. The method employed was to discern the patterns, which were in the form of a sequence of superimposed more or less periodical movements. As always, until the very end, astronomical observations were ocular, but the crudeness of the observations were compensated by their extension in time, and as to prediction, no more precision than could be appreciated by the naked eye was required. But the Babylonians were content with mere predictions, seemingly unaware of any interest in disclosing underlying mechanisms. Different it was with the Greek.

With the Greek came the real revolution in mans intellectual development. They brought about the true scientific attitude, where it was not enough to observe but one should above all require an understanding of the phenomena. This fostered a speculative approach, constrained of course by observation, but as I never tire of repeating, there is nothing like constraint that stimulates the imagination. And speculation is a matter of imagination, and science is above all an imaginative enterprise, well on par with the artistic. This Modern Greek attitude is well represented by Platonism, meaning to disclose the simple principles which underly the confusing and bewildering appearance of the sensual world. In fact Plato suggested as a research project to delineate the underlying structure of planetary movements, and for that reasons emphasizing solid geometry, only the plane one having been studied systematically. Once again a realization that celestial space was an integral part of Euclidean geometry.

Eudoxus of Knidos heeded the call and came up with a very ingenious system involving

Crab nebula, went unrecorded by the Europeans, although documented by the Chinese

³ This must count among one of the greater ironies of human technology. As means of writing they certainly tended to be a bit cumbersome, but while an ordinary library of paper burns, everything goes up in smoke, but one of clay tables becomes eternal, as the soft clay hardens into brick. Thus they were never meant to be permanent, but their very permanency has proved to be their greatest asset, providing us with a window of the past

twenty-seven spheres with different axes of rotations all rotating with uniform speed. It would be pointless to discuss his model in detail, it is enough to marvel at its intricacy and elegance, and to appreciate the amount of dogged work and pure cleverness and inspiration that went into it. An individual feat more or less from scratch few modern mathematicians may have been equal to. People in the past were not stupid. One should also pause and consider the exquisite Platonic nature of the model, if model is the right word, giving in 3-dimensional geometric terms and explanation of a confused 2-dimensional projection. Eudoxus' construction was taken up by Aristotle, and later on developed further by Ptolemy a few centuries later. But while Eudoxus and Ptolemy were content with giving geometrical constructions, mere mathematics, as the authors somewhat disparagingly put it, Aristotle was more interested in the ontological aspect. Did those spheres really exist physically, and if so why did they move. Eudoxus and Ptolemy were concerned with mere kinematics, in the words of the authors, while Aristotle was actually interested in the physics, transforming kinematics (a subdivision of mathematics) into true dynamics (involving physics). As to the kinematic explanations they could be seen as mere models, not too to be taken too literally, and as we would see, subjected as models are, to incessant tinkering.

The model of Ptolemy is often ridiculed by hindsight, but it provided predictions of high accuracies with the potential for indefinite improvements, by adding more and more epicycles on an ad hoc basis, as well as other ingenious, if contrived tricks. But in fact the notion of successive improvements is a key one in modern science and computation, and above all the process of endless tinkering is something that plays an important part in modern science, most of whose branches have in no way reached the level of Ptolemaean accuracy.

Classical Greek culture morphed into Hellenistic, its center of gravity shifted from Athens to Alexandria. This was due mainly to external political reasons, namely the subjugation of the Greek City states by Alexander and the emergence of the Greek empire. This change had many beneficial aspects. Apart from preserving and developing the classical tradition, one thinks about Euclid, Greek science became more applied, in particular in mathematics, something which enriched the later, and eventually produced the most distinguished mathematician of ancient times ever. Yet the speculative side that initially had sparked it subsided, and with that, the authors seem to hold, the Greek scientific tradition eventually petered out, although one should not discount the additional negative effect of the growing political power of the Church starting with Constantine, and the subsequent decline of the Roman Empire and Barbarian invasions ushering Europe into the Dark Ages. The Eastern Greek dominated Empire held out, but dogmatic Christianity was not compatible with the freethinking spirit, and e.g. the Academy of Plato was closed down. The light brought by the Greek was in dire threat of being extinguished, and just as the evolution of intelligent life is in no way inevitable, pace the opinions of science fiction fans, neither is the birth of science. What kept the light from being totally extinguished was that the Greek tradition was left smoldering on one hand through the preservation of Greek treatises by translations into Arabic, on the other hand through their passive survival in the Byzantine. The Arabic did not really improve on the Greeks in the sense of reviving the tradition, but they kept it from obliteration and subsequent oblivion. Much of the Greek heritage was lost, but it is remarkable nevertheless how much was actually

preserved. It is doubtful whether a revival of the scientific spirit would have spontaneously been accomplished had the tradition been really cut off. But the glowing embers were ready to fire once enough wind would come their way.

The Dark Ages can conveniently be divided into two. The really dark ones lasting until the first Crusades and the subsequent ones ending in the Renaissance. The first brought about contacts with the Arabs, the second following the fall of Constantinople, contact with original Greek manuscripts. With the first Aristotle was brought into the Catholic intellectual tradition, although as Russell sarcastically remarks, Plato would have been a more congenial philosopher, after all one of the formative sources of Christian religion was neo-platonism. The role of the Church has often been caricatured as an obstruction to progress. The truth is of course more complicated and subtle. The Church in fact provided the only outlet for intellectual activity, be it in ecclesiastic activity or in monastic seclusion. Thus in particular it produced a handful of influential intellectuals such as Thomas of Aquinas and Oresme. And here we come to the central thesis of the book based on current scholarship at the time, that there was no true discontinuous revolution brought about by Galileo as to dynamics, but more of an evolution throughout the latter more enlightened period of medieval times. And more specifically that Galileo surpassed Aristotle not through observation. In fact Aristotle was stymied by too much observation, sticking too close to what he saw and noticed. But one cannot deny that Galileo was a pioneer when it came to systematic quantification in physics. Rightly famous were his repeated experiments showing that a ball rolling along an inclined plane has a constant acceleration, provided we measure change in velocity in time not in distance. As Oresme well understood, a body moving under constant acceleration along a path, does not reach its mean velocity halfway, as many people would thoughtlessly assume.

Now we talk about the Copernican revolution, although Copernicus was anticipated by some of the Greeks. In fact Copernicus did not have better arguments for his heliocentric claim than Aristarchos had had, in fact he was opposed by the same arguments that the Greeks had already formulated, namely the lack of parallax, but they were presented in a more congenial setting. Aristarchos was truly ahead of his time, Copernicus was luckier in this regard. Copernicus was motivated by finding a simpler and more conceptual description of the motions of the planets, and realized that the apparent retrograde movements of the planets could be naturally explained by the heliocentric arrangement (or if you prefer that the planets move around the Sun, which mathematically at least, can be seen as moving around the earth). The issue of whether the Sun moves around the Earth or the other way around is, as the scholastics realized a convention; the real issue was whether there were other bodies than the Earth around which objects revolved. In fact the introduction of formal epi-cycles introduced a lot of centers around which centers and even bodies revolved, but those centers were not really existing objects. Now Copernicus countered the argument of the lack of parallax with the distances to the stars being so far away, just as Aristarchos had done. But the idea of such vast distances seemed to be abhorrent, a fact which in a way is strange, as I have already explicated in the beginning. Why could they not even be infinitely far away? In fact at the time daring speculations about the infinitude of the universe, with its implications of other worlds, were not surprisingly seen as heretical and treated accordingly. Galileo had much cause for caution.

Copernicus too was cautious. When his book was published, it came with a preface by a friend, who stressed the formal aspects of his theory, that it was only meant as a convenient stratagem for calculations, and with that the Church had no problem at all. Galileo would become the most vocal proponent of the Copernican view, abetted by his rhetorical proficiency and the fact that by his time the printing of books had become well established so he could reach a large audience. What was new was the telescope that more than anything else have revolutionized astronomy. No science is more closely associated with an instrument than astronomy with the telescope (just as no city is more closely represented by a logo, than Paris by the Eiffel tower). With the telescope unsuspected riches in the sky were revealed to the human observer. It is remarkable that the telescope had not been invented earlier, the technology was available, and maybe even more remarkable that when it was invented that it was not immediately turned to the sky. In fact Galileo was the first to do so after he had heard about the rumor and been informed of the principle soon made his own. Turning the telescope to the Moon he saw a scarred surface, far from the smooth perfection with which celestial objects had been associated, projecting its image he discovered spots even on the Sun, but maybe the most momentous discovery was that of the four moons revolving around Jupiter. Here was an object, different from the Earth, around which objects rotated. So why not around the Sun as well? Galileo's vocal championship of the new world order earned him enemies in the church and proceedings against heresy. He recanted as soon as he saw the instruments of torture, being after all a man of imagination, but under his breath he muttered. 'But still she moves'. The reasons for the actions against Galileo may never be fully disclosed, and the attitude of the ecclesiastical may have been quite complicated. Galileo ended his days in confinement to his home.

Kepler on the other hand had no such troubles with the Church although being a convinced Copernican since early youth⁴ He was the assistant of the Danish Astronomer Tycho Brahe who had in his possession the most systematic and extensive record of planetary movements, all of them obtained by the naked eye. Mars showed a particularly complicated orbit and Kepler was given the assignment of clarifying it. He eventually did, showing that a good fit could be obtained would one assume that it traveled in an elliptical orbit around the Sun in one of its foci, and in such a way that the radius vector swept out equal areas in equal time, something he claimed as natural as circular motion and constant angular speed (of course for circular motion the two notions agree, but diverge for elliptical). He also discovered a simple relationship between mean distance to the sun and the orbital period. Those three Keplerian laws are hidden in his voluminous publication, most of which contains little of interest to the modern reader, although his efforts to explain the distances to the planets by inscribed and circumscribed Platonic solids has a charming quaintness about it. However, what is noteworthy is that he tried to account for some physical mechanism that explained the movements.

Now it all culminated by Newton. As he famously admitted not everything he did was without precedent, referring to his allusions of the shoulders of giants. That the inverse square law of attraction is easily seen to be equivalent to Kepler's third law for circular orbits had been observed by Huygens and possibly also Hooke, and no doubt independently

⁴ He had to deal with the accusations against his mother of being a witch, but that is quite another matter.

by Newton himself before he had learned about it. But Newton synthesized everything into a simple and logical compelling picture which really brought about the greatest scientific revolution ever in my opinion. Newton showed how one could think about physics and the universe by the power of thought along and he instigated research projects and became an exemplar for all scientific endeavor. Newton was apparently so much smarter than anybody else around, and almost everything he touched in physics became a great success earning him a kind of authority that might not have been entirely healthy to his successors. Newton himself, although a hero and an icon of the Enlightenment, was personally not that sympathetic, intensely jealous of his achievements, although closer scrutiny might reveal that he had a point.

Now with Newton in a sense our story has come to an end, the mystery of celestial movements having been dispersed once and for all. The story is, as the authors claim elsewhere, a traditional fairy-tale, with a good and limpid plot, easily to be digested. But the authors do not stop but discuss briefly Einstein, many of whose ideas had been anticipated by Newton (that light bends in a gravitational field can also apparently be deduced from Newtonian mechanics, as mentioned by Eddington, but subtly differing from the predictions by Einstein, just barely confirmed empirically). It was Newton who was the first clearly to form the assumption that a body traveling under the influence of no external forces will go in a straight (infinite) line, while Galileo thought that it might still travel in a circle, as if around the Earth. Finally the book is dated by treating at the final pages the idea of Big Bang as a tenuous speculation treating the alternative of spontaneous creation by matter respectfully.

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