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According to current notions, the method of science follows a specific pattern which distinguishes it from the presumably loose, emotional, superstitious and fallacious thinking of the naturalists of the middle ages, prior to the era of Copernicus, Galileo and Newton. Ancient and medieval scientists, according to this view, were theorizers who never put their speculations to the test of hard facts but honored their theories above evidence and forced the latter into cherished preconceptions. Hence they were uncritical and unexperimental. Such criticism of the past is usually followed in modern textbooks by a detailed list of the steps taken by modern scientists, hence the rules constituting the true method of science. These range from the gathering of facts to the postulation of theories, to testing, to the finding of exceptions, to modification of the theory, or if necessary, its overthrow and replacement, etc.

It is further claimed that a new theory is advanced by a bold genius and opposed by selfish, narrowminded, or bigoted individuals who lack vision and true loyalty to science. The case of Galileo usually serves as the model of this concept of the conflict between the light-bringing new and darkness-defending old.

Needless to say that this simplified picture of man's unique and complex activity, the process of scientific thinking, is far from accurate. Few scholars familiar with the data of the history of science can take seriously any of its stereotyped statements on the method of science or its mode of progress. The day lies far in the future when we shall possess sufficient familiarity with man's mode of creative and productive thinking about nature to express its essence in a pithy scheme. Before that is achieved we shall have to examine many relevant data in the history of science, the kind of men that shaped it, their creative and psychological characteristics, their conformity or uniqueness, their logic, insights, techniques, goals, courage, fears, and hopes. Out of it all might emerge some generalized conception of the creative process in interaction with critical evaluation through the mediation of reason and tests. It is difficult to think of any other approach short of unbridled speculation that could be regarded as reliable and scientific.

Let us consider the genesis and demise of the Ptolemaic theory of celestial phenomena. Because the theory is no longer functional, it is often dismissed too lightly and its inadequacies are exaggerated to boot.

By the second century B.C., the era of Hipparchus, considerable knowledge had accumulated concerning the movements of the heavenly bodies. Ancient man was concerned with these matters because celestial events exerted a stirring impact on his spirit. Says Seneca: (Translation this writer's)

> "No man is so indolent, so obtuse, with head so bent to the ground but will bestir and raise his eyes heavenward with all his thoughtful might when some new phenomenon has lighted its way across the sky. When celestial events follow their usual course, habit robs them of their grandeur. We are so constituted that daily spectacles, no matter how worthy of our admiration pass us by unnoticed; yet we take pleasure in things of no significance as long as they are new to us. For this reason the host of stars which fills the firmament with such beauty elicits no response from the common herd; but let there appear some change in the order of the universe, all eyes turn skyward. The sun goes unnoticed except for an eclipse. The same holds for the moon. Cities then tremble in terror in their childish superstition and people vie with one another in making loud noises. How really glorious are the daily doings of the sun . . ."
>
> (Seneca, *Quaestiones Naturales,*
> Liber Quartus, De Cometes.)

Similarly Pliny:

> "But the wonder of everyone is vanquished by the last star, the one most familiar to the earth and devised by nature to serve as a remedy for the shadows of darkness—the moon. By the riddle of her transformation she has racked the wits of observers, who are ashamed that the star which is nearest should be the one about which we know least—always waxing or waning, and now curved into the horns of a sickle, now just halved in size, now rounded into a circle; spotted and then suddenly shining clear; vast and full-orbed, and then all of a sudden not there

at all; at one time shining all night and at another rising late and for a part of the day augmenting the light of the sun . . . at one time low down and at another up aloft, and not even this in a uniform way . . . We forsooth feel no gratitude towards those whose assiduous toil has given us illumination on the subject of this luminary, while owing to a curious disease of the human mind we are pleased to enshrine in history records of bloodshed and slaughter so that persons ignorant of the facts of the world may be acquainted with the crimes of mankind."

(Book II, pp. 193-5, Vol. 1.
Natural History, Loeb Classical Library)

It is difficult for modern man to grasp the sense of awe, worship and wonder which the sky held at all times for the men of antiquity. They loved to observe the sky in all its moods, and the sun, moon and the wandering planets were as close to them as rivers, pastureland, winds, floods or clouds. They watched the heavenly bodies, sang their praises, worshipped them and composed innumerable fables about them in symbolic abstractions, and made them part and parcel of their folklore and faith.

The reason for our lack of sympathy toward this attitude is not hard to find. We live in comfortable homes with firm ceilings and roofs overhead, spend our nights in pleasant homes enlivened by warmth, television, books, music and entertainment. We seldom see the sky for our homes and the dust and smogs of our cities. The only stars we know are the stars of Hollywood, and since man must have love and romance, we read the gossip of Confidential Magazine while reaching for a cigarette or tranquilizer.

Progress, or evolution, is not forged, fought for or made; it just happens. Man's interest in the heavens was deepseated and innate, and his responses to celestial phenomena, whether real or fanciful, quite naturally found their way into his religion because religion is the sum total of the responses, emotions, aspirations, values, poetry, science and ethics of a culture. In the religion of Babylon the reaction to celestial events came to assume a central position so that in time the entire faith devolved about astronomical events. The Hebrew opposition to paganism became almost exclusively an opposition to Babylonian sky-worship. "And if there be found among you . . . man or woman . . . and hath gone and served other gods, and worshipped them, either the sun or the moon or any of the host of heaven . . .

then shalt the throng bring forth that man or woman . . . and shalt stone them with stones until they die" (Deut. 17:5).

With worship came priests who specialized in catering to and expressing these religious needs of the community. In time the priests began observing the planet-gods in earnest. Much knowledge thus accumulated on the motions of the planets which, unlike the fixed stars, shifted their positions in the course of time against the background of the stars. The priests recorded these shifts and thus amassed data on the daily movements of the stars and the orbits of the planets. The fixed stars got to be well known and in time were catalogued and ordered into constellations. These inspired the song-writers and story-tellers of the time to represent them symbolically as animals or heroes and weave alluring tales about them.

The observational data, combined with the prevailing emotional attitude, led to a generalization we know today as astrology and which appealed to the people of the time as a truly up-to-date, courageous and scientifically established cause and effect relationship. It correlated the position of the sun causally with the seasons, fog and clouds with the rain, the moon with the tides, Mars with war, Venus with passion, Saturn with cold and gloom, and the like. It spread rapidly to Greece and enjoyed amazing success in Rome in spite of legislation against it by the state and bitter antagonism toward it by all religions. The state prohibited the consulting of astrologers in private, emphasizing as an exceptional crime any mention of the fate of the emperor, which was a frequent object of such consultations. As in the assassination of Caesar, no such act was ever plotted without an astrologer's advice. On the other hand, all religions proscribed astrology because rule of man and nature by the stars clearly excluded the need for prayer and the sacred tenet of divine intervention in earthly events.

Greece of the second century B.C. had accepted whatever reached it of Babylonian astronomy with its sophisticated child, astrology, and in the spirit of its culture proceeded to enrich and expand both phases of the star-lore. Aided by its elaborate heritage of geometry masterfully gathered by Euclid about 300 B.C., the star-lovers of Greece were ready for a broad and complex mathematical theory that would account for all the data, tie them together with the simple and concise language of mathematics and thereby be able to predict future positions and the spacial relationships of all celestial entities. Many partial or total attempts were made in that direction, all of which culminated in the brilliant and profound work of Ptolemy which for fifteen centuries admirably satisfied the need for a theory desired not by the common man, but by the outstanding mathematicians of the times. And since mathematicians are a questioning, quibbling, exacting, and proof-demanding lot, this is saying a great deal for the theory.

In addition to the vast store of direct data of observation, there accumulated as well many concepts derived both theoretically and mathematically. For example, the sphericity of the earth was established and its diameter measured with the use of geometry. The habit of continuous and unbroken observations, even though carried out casually, led to knowledge of the orbits and periods of revolution of all the planets. Solar and lunar eclipses were studied and recorded, particularly the former, and the periodicity of the recurrence of lunar eclipses was observed so that predictions were quite feasible. The signs of the zodiac were established, as were also the path of the sun within the zodiac and the obliquity of the ecliptic. The measurement of the absolute distance from the earth to the moon was easily achieved and so was an approximation, not too good but cleverly devised, of the relative distance from the earth to the sun. With a stroke of clever wit Aristarchus employed some simple geometry to measure the relative dimensions of sun and moon as compared to the earth. A unique accomplishment was the discernment by Hipparchus of the shift in the relation of the stars to the sun's path from which he deduced the precession of the equinox, or the regular shift in the point of intersection of the ecliptic with the equator, hence in the relative position of the celestial pole.

These data were gathered with many simple instruments, such as Ptolemy's quadrant and the instrument for measuring azimuth and altitude. Many tools were available for measuring solar elevation throughout the year at any particular horizon. But there were in addition such ingenious instruments as the armillary and planimetric astrolabes which could perform many functions at one time. There was also the intricate and no doubt accurate planetarium of Archimedes which is referred to by Cicero and hence ascribed in the first century B.C. Mention should be made of the various calendars, lunar, lunar-solar and solar, all of which had to their credit long years of empirical service and as high a degree of refinement as could be wished for.

The field was clearly ripe for a theory and many attempts had been made at it by quite a few brilliant practitioners. Ptolemy's theory was an eclectic compilation of all the suggestions offered before and during his lifetime which he utilized wherever possible.

If it were not for the peculiar motions of the planets, the forging of a theory to unite all the celestial phenomena into one integrated formulation capable of making verifiable predictions, would have been a relatively simple matter. To the calibre of philosophers and mathematicians of the time, the task would have been childishly simple. The stars move at the same angular velocity around the earth hence are probably in the same sphere. Spheres, or orbs, as carriers of bodies were invariably postulated because motion, like force, was conceived in mechanical terms and not as the self-contained abstractions in which we conceive them today. Motion implied being moved by something and force meant an action resulting from some mechanical mover. Hence all the stars were attached to one sphere, though they varied in magnitude. This was the outer sphere which revolved around the earth once in 24 hours. That the stars moved in circular orbits around the earth was established beyond a shadow of doubt by observation. All one had to do is look at the circumpolar stars even as one records their circular path today with a camera.

There were in addition seven planets that could be observed by the senses. If there were individuals who postulated more than seven, such men were poets or dreamers who heard the music of the spheres or saw angels in the sky. Those planets which completed their circuit in shorter periods were nearer the earth, the point of observation, than the planets which took longer in running their orbits. Hence the sequence from the earth outward was the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, as was incontrovertibly indicated by the data. They were imbedded on separate orbs, concentrically placed, one within the other.

The spheres carrying the planets did not revolve around the earth at the same rate as did the stellar sphere surrounding them, as was plainly indicated by the evidence. From day to day the planets showed a lag behind the stars. In fact it was this phenomenon that enabled the observers of the time to determine the period of a planet's orbit, the time it took a planet to return to any initially chosen position from which it began its leftward (eastward) displacement.

These data did not present any obstacles to a theory, but unfortunately the movement of the planets showed a peculiarity which proved most difficult to harmonize with the rest of the evidence. Instead of shifting daily at a constant pace to the left against the background of stars, indicating thereby that the planetary sphere revolved more slowly than the stellar one, the planets did that well enough for a stretch of sky, but then they would stand still, next move in the opposite (clockwise) direction, hence from east to west, as if they now revolved faster than the stars, and finally resumed their original leftward or eastward shift as viewed against the stars. This meant that their motion in this situation described a loop which the Greek scholars regarded as most unseemly and ill-becoming a celestial body. Since it had been established that celestial bodies moved in circles, philosophers speculated that the circle was the divine, noble, self-contained and eternal figure just as the sphere had similar virtues as a solid body.

With suggestions from mathematicians who preceded him, Ptolemy then developed the concept of the epicycle and the deferent, thus succeeding in accounting for the looped orbits by postulating motion of the planet in a small circle about a center which in turn moved along a central orbit. Draw a circle around the earth and this circle would then be the path of a center around which a little circle would be revolving. This little circle is the epicycle carrying the planet.

Ptolemy's objective in devising a theory was "to save the phenomena", meaning to account for, hence explain, the data. To this day this is still the best definition of a theory, and on that point he showed more insight than Kepler and some modern historians who are annoyed with Bishop Osiander for the statement he made in his introduction to the *De Revolutionibus Orbium Coelestium* by Copernicus, and which is regarded as shameful appeasement or cowardice. Says Osiander: "For these hypotheses (of Copernicus) need not be true nor even probable; if they provide a calculus consistent with the observations, that alone is sufficient . . . In this study there are other no less important absurdities . . . For it is quite clear that the causes of the apparent unequal motions are completely and simply unknown to this act. And if any causes are devised by the imagination, as indeed very many are, they are not put forward to convince anyone that they are true, but merely to provide a correct basis for calculation."

Kepler said what he did in a moment of heated argument. He insisted that Copernicus did not postulate the earth's motion "to provide a calculus" but as an actuality, hence as a verifiable fact. The modern claimants, who are not motivated by the need for defense of a new and stimulating idea nor irritated by the stubborn resistance to it for the sake of defending a much weaker one, want us to believe that a correct theory postulates a patent truth. The neutrino would then be a reality worth fighting for because if the theory is sound, this fiction must be a fact. It is doubtful that the originator of the neutrino, or theoretical physicists in general, would make such claims. Certain it is that Ptolemy never bothered to claim any more for his theory than that it "saved the phenomena." His proof for the epicycle was: "Consider a circle. Assume the planet to be on the circle and moving in a clockwise or counterclockwise direction", etc. then the following will take place. Employing geometry and making use of generally established data, he then deduced with mathematical strictness the relative radius of the epicycle and of the deferent, and emerged with a scheme which "saved the phenomena" as then known for each planet.

While the solar system does not play the role in modern astronomy which it did in ancient times, its mechanism must still be considered complex by all standards. The epicycle is only part of Ptolemy's intricate scheme, the child of the concept of the sanctity or reality of the circle. But in his theory there was also the equant, a geometrical scheme devised to soothe the mind's preference for uniform angular velocity in accounting for observations which in themselves did not demonstrate it. The postulation of the equant was linked to the fact known to ancient astronomy that the earth was not situated in the center of the universe. If the year was the time-equivalent of the sun's circle around the earth, then the two halves of that circle were not equal. The number of days from the vernal equinox (March 21) to the autumnal equinox (Sept. 22) comprises 186 days while the other half of the circle, Sept. 22 to March 21, has only 179 days. This could only be explained by assuming that the earth was off center. And Appolonius and others did postulate eccentric orbits which, as Ptolemy points out, are as good as epicycles in saving the phenomena. The equant corresponds to equal distances set off from the true center of the planetary orbits, whose magnitudes are the distances of the earth from that center so as to yield uniform angular velocities.

We cannot enter into all the clever and intriguing assumptions which Ptolemy advanced to render his theory intellectually, mathematically and functionally successful. The fact is that it was a good theory because it performed most effectively what a theory should perform. It was brilliant and intellectually gratifying; it organized and coordinated the entire field of astronomy; it utilized all the known geometry and enriched it with novelty here and there; it retained generalizations from observed data which in themselves had strong validity; it was aware of technical and theoretical imperfections here and there and urged their clarification; it could make predictions which were adequate for the needs of the times, and those who mastered it felt justly proud of their educational acquisition and literally worshipped their master, Ptolemy. Few people in fact did gain mastery over the complete Almagest because of its difficulty, witness the fact the medieval universities used almost exclusively superficial condensations of it.

Why did the theory endure unchallenged for fourteen centuries? The only answers one can suggest is that it catered well to the human desire for a theory and that it was not easy to think of a new one equally serviceable and attractive. The human mind had reached its climax in ingenuity and no new data came up to disturb the smooth reign of the Ptolemaic construction.

But then came an ideological disturbance in the form of the *De Revolutionibus.* The salient and central idea which Copernicus put forward was not new, nor was it so regarded by his contemporaries. It had been known all along the fourteen centuries as the Pythagorean scheme and was viewed as ingenious and amusing but left alone at that by the scholars. Apparently the mind lacked the courage to give it even a theoretical chance. Ptolemy himself gives it brief mention and a quick dismissal: "Now some people, although they have nothing to oppose to these arguments, agree on something, as they think, more plausible. And it seems to them there is nothing against their supposing, for instance, the heavens immobile and the earth as turning on the same axis from west to east very nearly one revolution a day . . . But it has escaped their notice that indeed, as far as the appearances of the stars are concerned, nothing would perhaps keep things from being in accordance with the simpler conjecture, but that in the light of what happens around us in the air such a notion would seem altogether absurd" (Almagest, Great Books, vol 16, p 12). Obviously all his successors shared his view and facts in league with common sense prevailed over the imaginative faculty which could ultimately permit the new theory to harmonize with the facts but could not do so at the time.

The novelty Copernicus introduced lay in taking the "Pythagorean" scheme seriously and in arranging the available data and some of the accepted conceptions, such as epicycles, upon its foundations. He placed the sun not quite at but near the center of the planetary motions thus rendering equants unnecessary, then took the data of each planet and showed that the new theory could well stand the test of the evidence or at least was not thrown out of court by the observed facts.

What was the reason for the step taken by Copernicus? No new data to speak of had come to the fore within the intervening fourteen centuries and no hopeless contradictions sprang up within the old theory. His own explanation is merely that "my knowledge that mathematicians have not agreed with one another in their researches moved me to think out a different scheme of drawing up the movements of the spheres of the world" (*De Revolutionibus* (Great Books,) Vol. 16, p. 507).

Clearly the idea merely struck him that the Pythagorean theory was not as silly as it seemed. Had he invented it, which was perfectly possible, we would have said the idea came to him and that like God after creation, he saw it was good, proceeded to work it out in detail and either found it superior to the old one, or more attractive, or more promising, or simply preferable. Copernicus obviously thought the new theory well worth his lifetime of effort, though he was never insistent on its "truth" nor was he adamant against its competitors. His followers acted in that manner, not he.

There was opposition to his theory and it came mostly from astronomers. All human beings reject or oppose novelty, some more strongly than others, some for longer periods. It was not the "Church" that opposed the Copernican theory but the people who lived and functioned in the framework of the existing culture with all its practical, scientific and religious values and beliefs. The spokesman and leaders of the contemporary culture-web felt the will to resist most strongly and acted for society as a whole. They became therefore the leaders and spokesmen of the opposition.

With the coming of the new theory, society developed a period of vacillation, of ambivalent or conflicting loyalties, pros and cons, shrewd evaluation, indecision and partisan passion. This is all part of what may be called the "Culture Wobble". It is a phenomenon which has been little studied and in our present state of knowledge is deeply buried in emotion, superficial labels and ignorance. Yet this phase comprises a fascinating process of transition, requiring for its comprehension a tough analytical mind, much psychological insight and freedom from slogans.

The Copernican-Ptolemaic culture wobble is rich in drama, both hidden and overt. Galileo's writings occupy the central spot in the wobble zone. Many high churchmen were for the validity of the new theory and many astronomers and mathematicians against it. All were pious Christians, Catholic or Protestant. Some archbishops and cardinals saw good possibilities for a compromise between the new scheme on the one hand, and the common sense data arranged in a matrix of the biblical heritage, on the other. Some brilliant astronomers, churchmen and mathematicians saw no such prospects and struggled hard and fast against the new theory. All pros and cons were completely personalized. The conflict between the inner loyalties were as bitter in the minds of those sages and scholars as it has been in our own days in the minds of such men as Andre Gide, John Dos Passos, Whittaker Chambers, Langston Hughes, H. J. Muller and others who had to struggle with a loyalty to Leninist Marxism in the light of new events or the basic values of democracy and humanity to which they had always been dedicated.

The period of the culture wobble is further enriched by such phenomena as Tycho Brahe's search for a compromise which, though widely appealing at the time, proved futile. It is also enlivened by Galileo's battle with the Church which, though widely lauded and honored today, has, in my opinion, been thoroughly futile and harmful to science and progress. In the "Dialogues" that sparked his second trial, Galileo did what every Catholic friend of science begged him not to do and thus estranged those who could have done more for the acceptance of the new ideas than a hundred trials. Moreover, his "Dialogues" contained not one valid *proof* of the Copernican theory since his arguments from the tides and winds were false and the phases of Venus which he discovered could well be explained by Tycho's scheme of compromise. Had Galileo dedicated his passion, genius and energy to science instead of to his will to glorify the Church by having it accept Copernicanism, (and true faith is independent of any and all scientific theories) science would have been the richer. Had he as much as read Kepler's works that gathered dust on his desk and learned about the ellipse and the other laws, he would no doubt have greatly increased his already immense contribution to man's knowledge. As it happened, he was condemned by friends, admirers, enemies, scholars and fanatics. As a result, scholarship suffered, confusion raged, personal tragedies beset the helpless victims and only the wobble gloried in its own turbulence.

But such and many more are the vagaries, vicissitudes, and the price we pay for the natural pains of transition. Yet the transitional period offers a wealth of insight into man and science, begging for scholars who can free themselves of slogans and preconceived formulas to study it objectively and enrich mankind with their findings.