Summary

In the third scientific course given to the teachers of the first Waldorf School in January 1921, Rudolf Steiner describes the effects of the Copernican revolution on human consciousness during the sixteenth century, the dawning of our present materialistic age. Copernicus proposed three movements for the Earth; her daily rotation about her axis, her annual orbit around the Sun, and a *complete annual* cycle of precession. Steiner contends that modern astronomers only take the first two movements into account, and that the third is ignored.

A detailed non-mathematical description of the third movement is followed by an explanation of why Copernicus introduced it into his model of the solar system.

Steiner had spoken about the neglect of Copernicus' third movement on several previous occasions; in 1906, 1908, and several times in September 1919. He explained how this neglect led to errors in our understanding of the solar system.

In order to explore Steiner's claim that Bessel's reductions need to be applied to correct the errors caused by neglecting the third movement, the difference between Bessel's reductions, Bessel's equation and Bessel's error calculations is explained. Bessel's discovery of stellar parallax, as well as the discovery by James Bradley of stellar aberration comes naturally into this discussion, as does the gradually shifting celestial co-ordinate system.

In conclusion a suggestion is made that Steiner might have used the third movement of Copernicus as an astronomical concept to emphasize the necessity for a raising of human consciousness, which would enable a (re)enlivening of astronomy with real spiritual experiences.

Earth's Third Movement, a Copernican Enigma

"Just like for the Greeks that which lay beyond the Pillars of Hercules was indefinite and unknown, so today that which lies beyond Earthly consciousness is indefinite and unknown; mere mathematical fancies, Galilean and Newtonian fantasies. These fantasies must be replaced with actual facts." (GA 191, 29)[1]

Introduction

As a teacher of spiritual science, Rudolf Steiner had the supremely difficult task of translating spiritual, super-sensible experiences into a language capable of being understood by ordinary people who did not have such experiences.

Not only did he have to find suitable words to convey his meaning, but the concepts and descriptions he used to describe his spiritual research needed to be presented in such a way that his listeners could grasp them. Building a conceptual bridge between the physical three-dimensional space in which we experience our daily lives, and a dimensionless spiritual cosmic space, presented an enormous challenge.

In the past, spiritual concepts and realities had been made accessible by means of images and myths. Steiner felt that in the present time, which he called the age of the Consciousness Soul, the picture language of ancient mythologies was no

[1] Rudolf Steiner, from a lecture held on 3 October 1919. My translation

longer appropriate. He saw it as his task to reveal spiritual realities not in the form of myths and legends, but in the form of scientific concepts and ideas, which could be grasped by the everyday consciousness of modern humanity.

This approach has been remarkably successful in many areas of human endeavour, particularly in those dealing with life and its rhythms and cycles, such as medicine, education, and agriculture. Here can be found an abundance of evidence for the accuracy and genuineness of his spiritual vision. But Steiner's spiritual science has made little headway in purely physical sciences such as geology and astronomy. By focussing on several enigmatic statements Steiner made about the so-called third movement of Copernicus, this essay discusses a possible reason for this.

Steiner's puzzling statements about the "neglect" of the third Earth movement Copernicus proposed to make his model of a heliocentric solar system agree with physical reality, are examined in detail. Separated from the context of his overall intentions, these statements appear to contradict the very science on which Steiner sought to establish Anthroposophy. They are a clear example of the difficulties faced when explaining super-sensible experiences to an audience who might know a great deal about the super-sensible world, but who have no direct experience of it.

Included in Steiner's task as he saw it, was to point out the profound and accelerating changes in consciousness which began in the sixteenth century, referring to individuals such as Jakob Boehme (1575 – 1624), Giordano Bruno (1548 – 1600), and Nicolaus Copernicus (1473-1543), who lived on the threshold of a new age, a new way of understanding the world.

Copernicus in particular was presented in many lectures as a pioneer, as the first astronomer to experience the dawning of the new age. By moving the centre of the universe from the Earth to the Sun, Copernicus took a major stride in the evolution of human consciousness, leading directly to the scientific revolution of the 17th and 18th centuries.

Again and again Rudolf Steiner pointed out the dramatic change in human thinking brought about by Copernicus, when he imagined the Sun at the centre of the solar system, thereby relegating Earth to the position of an orbiting planet. The "Copernican revolution" changed forever humanity's relation to the super-sensible world.

Nicolaus Copernicus

Nicolaus Copernicus was a Renaissance polymath with interests in several disciplines. He held doctorates in medicine and law, and had studied Plato and the Greek philosophers, as well as the Greek astronomers.

Born in Poland, he studied at the famous university in Kraków (Cracow); later at several universities in Italy where he received a double doctorate. His interest in astronomy, already kindled by the influential Kraków School of Mathematics and Astrology, was further developed by meeting with, and studying the works of Italian astronomers. He returned to Poland at the age of thirty, and took on the clerical duties of canon of the cathedral of Frauenberg, while at the same time continuing his astronomical research and medical practice.

Some years after returning to Poland he wrote a manuscript explaining an astronomical theory he had developed, to which he didn't put his name, and which was never published, but circulated amongst his friends and colleagues. Known as the 'Commentariolus' (the little Commentary), its existence was unknown until a copy was discovered in 1880 in Stockholm, and a second some years later in Vienna.

He developed his ideas further, and by 1530 the 'Commentariolus' had evolved into his major work, 'De Revolutionibus Orbium Coelestium' (On the Revolutions of the Heavenly Spheres). Copernicus again resisted publication. Whether he was fearful of the reactions he might provoke, or for other reasons, remains an unanswered question.

However, his impending death and the encouragement of his friends motivated him to publish the work in 1543, just weeks before his death. As a precaution Andreas Osiander, who prepared the work for publication, added a preface explaining that the theory is no more than a mathematical hypothesis, and that the book contains no claim about the real structure of the universe. Copernicus was unable to change the preface, but it is generally accepted that he himself believed his theory to describe the (physical) solar system as it actually exists.

Copernicus' basic propositions are:

1. The centre of the universe is near the Sun. The centre of the Earth is not the centre of the universe, but only the centre towards which heavy objects move, and the centre of the lunar sphere.
2. The movements of the planets are uniform and circular, or made up of several circles (epicycles).
3. The distance from the Earth to the Sun is insignificant in comparison with the distance from the Sun to the outermost fixed and unchanging celestial sphere containing the stars.
4. The apparent daily movement of the Sun and the stars arises from a complete rotation of the Earth on her fixed axis in the course of a day.
5. The apparent annual movement of the Sun through the Zodiac arises from the movement of the Earth, which orbits the Sun in the course of a year.
6. The apparent retrograde and direct movements of the planets arise not from their movements alone, but from that of the Earth relative to that of the planets.
7. The Earth has a third movement, an annual precession of her axis.

Copernicus' propositions were all the more astonishing in that there was absolutely no physical evidence at the time for any of them! In fact, the first direct evidence that the Earth revolves around the Sun was not confirmed until 1838, and the first direct evidence of Earth 's rotation on her axis in 1851, when Foucault set up his pendulum experiment.

But Copernicus' central idea was not completely new. As early as 200 BCE, Aristarchus of Samos (an island off the coast of Turkey) had already proposed that the Earth rotated on her own axis, and that she orbited around the Sun, an idea that at the time made no headway against the compelling authority of Aristotelian cosmology.

Copernicus gave credit to Aristarchus in 'De Revolutionibus Orbium Coelestium', where he wrote: "Philolaus believed in the mobility of the Earth, and some even

say that Aristarchus of Samos was of that opinion." [2] This sentence was deleted in the printed version. Whether this was done by Osiander, the book's publisher Johannes Petreius, or Copernicus himself, is another question which remains unanswered.

Stellar Parallax

One of the main objections to a heliocentric universe was that no stellar parallax could be observed. Parallax is the apparent shift in position caused by viewing an object from two different vantage points. The phenomenon of parallax was known to the ancients. The Greek astronomer and mathematician Hipparchus had already calculated a good estimate of the distance to the Moon by using lunar parallax in about 120 BCE. He was able to do so by two observers simultaneously observing a solar eclipse in Hellespont (where the eclipse was total), and in Alexandria (where it was partial). He knew the latitude of both places, so he was able to estimate the distance between them. By assuming that the angular sizes of the Sun and the Moon are the same (a good approximation), a simple geometric calculation enabled him to estimate the distance to the Moon.[3]

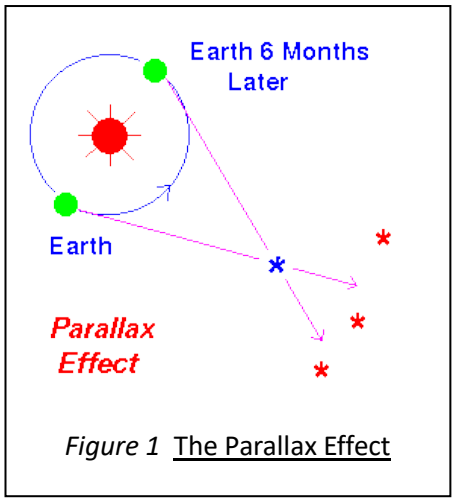

Figure 1 The Parallax Effect

If the Earth does indeed revolve around the Sun, a star should appear to change its position relative to the background stars as the Earth moves along her annual orbit, because it is viewed from a different position in space. See Figure 1.

The failure to observe stellar parallax was a consequence of what we now know to be the vast distance to the stars. The amount of parallax (the angle subtended at the star by the lines of vision) decreases with increasing distance. See Figure 2.

The stars are so far away that their parallax can only be observed with very precise instruments. Indeed, stellar parallax was not measured conclusively until 1838.

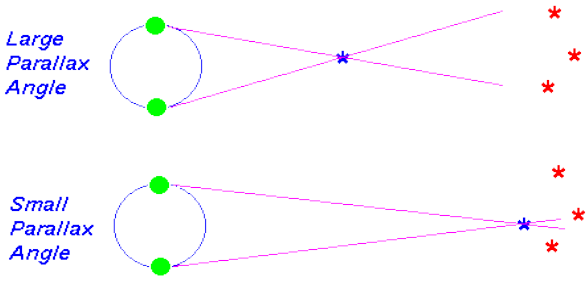

Figure 2 The Effect of Distance on Parallax

Rudolf Steiner's Astronomy Course

Rudolf Steiner's third natural scientific course (the Astronomy course, in 1921) was presented, as the previous two, mainly to the teachers of the Stuttgart Waldorf School founded in 1919. In lecture two he discussed the importance of Copernicus in the evolution of Western thought. The Earth, and by implication humankind, was no longer experienced as at the centre of the universe. The importance of Copernicus' astonishing idea lay in the dramatic change from a

[2] Quoted in https://www.thoughtco.com/aristarchus-of-samos-3072223

[3] https://pwg.gsfc.nasa.gov/stargaze/Shipparc.htm

geocentric to a heliocentric universe. By placing the Sun in the centre of the universe, Copernicus brought about a revolution in human consciousness

After introducing Copernicus' first movement, the daily rotation of Earth about her North-South axis, Steiner describes the second movement as follows (GA 323, 40):

> The second principle on which Copernicus bases his picture of the Heavens is that Earth moves round the Sun. In its revolution round the Sun the [axis of the] Earth itself, of course, also revolves in a certain way. This rotation, however, does not occur round the North-South axis of Earth, which always points to the North Pole, [Polaris, the Pole Star] but round the axis of the Ecliptic, which, as we know, is at an angle with Earth 's own axis. Therefore, Earth goes through a rotation during a 24-hour day round its own N. S. Axis [the first movement], and then, inasmuch as it performs approximately 365 such rotations in the year, there is added another rotation, an annual rotation, if we disregard the revolution round the Sun. Earth, then, if it always rotates thus, and then again revolves round the Sun, behaves like the Moon as it rotates round Earth, always turning the same side towards us. Earth does this too, inasmuch as it revolves round the Sun, but not on the same axis as the one on which it rotates for the daily revolution. It revolves through this 'annual day' on another axis; this is an added movement, besides the one taking place in the 24-hour day.[4]

Copernicus imagined that during the course of a year, the axis of the Earth must always be inclined towards the Sun, in his words, that "it would follow the movement of the centre."[5] The best way to visualize the movement described here, is to push a toothpick through a ping-pong ball to represent Earth's axis of rotation, and place it firmly on a turntable (on a piece of blue-tack) with the 'North Pole' facing the spindle representing the Sun. As the turntable rotates, the 'North Pole' always faces the Sun, and during one revolution the toothpick (Earth's axis) describes the surface of a cone.

Copernicus realized that this was wrong because in this configuration it would always be summer in the Northern hemisphere. There would be no seasons,

> because, if they [Earth's axis and equator] persisted in an invariable direction and simply followed the movement of the centre, no dissimilarity of day and night would arise, but it would always either be solstice, or the shortest day, or equinox, either summer of winter, or any other season that would always remain the same.[6]

He therefore introduced a third movement to bring about the seasons, which he called the "movement in declination".

Steiner continues, and describes the third movement as follows:

> Copernicus' third principle is that not only does such a revolution of the Earth take place round the North-South axis, but that there is yet a third revolution which appears as a retrograde movement of the North-South axis round the axis of the Ecliptic. Thereby, in a certain sense, the revolution round the axis of the Ecliptic is cancelled out. By reason of this third revolution Earth's axis continuously points to the North celestial pole (the Pole-Star). Whereas, by virtue of revolving round the Sun, Earth's axis would have to describe a circle, or an ellipse, [actually a cone] round the pole of the Ecliptic, its own revolution, which takes the opposite direction (every time Earth proceeds a little further its axis rotates backwards), causes it to point continually to the North Pole. Copernicus adopted this third principle, namely: The continued pointing of Earth 's axis to the Pole comes about because, by a rotation of its own — a kind of 'inclination' (?) — it cancels out the other revolution.

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[4] Lecture on 2 January 1921. Translation from https://wn.rsarchive.org/GA/GA0323/19210102p01.html

[5] Vreede (2001), 376.

[6] Vreede, op. cit., 377.

> This latter therefore has no effect in the course of the year, for it is constantly being annulled.[7]

In terms of our turntable model, instead of fixing the ping-pong ball onto the turntable, we have to imagine that as it revolves around the spindle (the Sun) in the course of a 'year', it precesses once in the opposite direction about a distant point on the ceiling (the Pole star), not about the spindle.

A better way to get a feel for the third movement is to go to the local playground and step onto a merry-go-round (Earth's orbital plane). Face the axis of the merry-go-round (the Sun), and point your arm (Earth's axis) towards the top of a nearby tree (Polaris). Ask a nearby child to give the merry-go-round a gentle push (Copernicus' second movement). You will face the 'Sun' throughout the 'year', and your arm will trace out the surface of a cone relative to the playground (the fixed stars).

Now, to bring about the seasons, you yourself are going to execute Copernicus' third movement. As you rotate around the axis of the merry-go-round, turn your whole body so as to keep pointing towards the top of the nearby tree. You'll find yourself turning in retrograde motion, and your arm will trace out the surface of a cone *relative to the merry-go-round* (the revolving plane of Earth 's orbit).[8]

Ptolemy (approx.100CE - approx.170CE) had imagined the planetary orbits as made up of more than one movement; planets moving on epicycles which in turn moved on deferents.[9] He considered these to be descriptions, not explanations, of the planetary movements.

In the same way, Copernicus imagined Earth's orbit as being made up of more than one movement, namely his second and third movements as described above. He too considered these to be a description, not an explanation, of Earth's movement around the Sun. He imagined quite reasonably that on her orbit around the Sun, the Earth behaved like the Moon on his orbit around the Earth, always keeping the same side facing the centre of rotation. Because this natural motion wasn't what was observed, Earth's axis must itself be rotating (precessing) to keep it pointing in the same direction. To align his model with reality, Copernicus introduced his third movement, thereby bringing back the seasons. But by introducing it, Copernicus brings about more than just the seasons.

Copernicus made the third movement slightly shorter than the second, so that they do not overlap exactly. The duration of the third movement, the tropical year (the time from one summer solstice to the next), is about 20 minutes shorter than the duration of the second movement, the sidereal year (the time it takes the Sun to return to the same position relative to the fixed stars). Copernicus incorporated into his third movement the precession of the equinoxes.

Copernicus knew from historic observations dating back to the Greek astronomer Timocharis (320 BCE – 260 BCE) that the rate of precession varied. In his

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[7] The question mark does not appear in the German original. It simply says "*eine Art Inklination*", paraphrasing Copernicus' "movement in declination".

[8] This is probably what is meant by the "kind of 'inclination' (?)" in Steiner's lecture. Your arm (Earth's axis) is *inclined* at 23.5° towards the axis of rotation of the merry-go-round (the axis of Earth 's orbital plane, i.e. the ecliptic). But it's also possible that Steiner had in mind Copernicus' words 'movement in *declination*'.

[9] Further complicated by his use of equants and eccentrics, which Copernicus did away with.

geocentric model Copernicus assumed a uniform precession and superimposed on this an irregular variation.[10]

By explaining precession as a very slight difference in time between the second and third movements, Copernicus had greatly simplified its calculation, and this was one of the advantages of his system over the older geocentric calculations.

The third movement has been a hotly debated topic ever since Isaac Newton introduced new concepts such as mass and gravity into astronomical calculations. The American astronomer Will Rufus (1876-1946) summed up the debate as follows:

> For this third assumption he [Copernicus] has been harshly criticised by his opponents, and partially pardoned by his followers. [Some of these] have been reconciled to the needless third motion of the Earth, because in its consideration Copernicus contributes the correct explanation of the [precession of the] equinoxes. We are not entirely reconciled; but we believe that this third assumption was a master stroke of genius. . .
>
> His keen analysis detected the difference between the annual component due to the moving radius vector and the small component due to precession, which is correctly explained by the third movement of the Earth. This is a real motion, and is so accepted by astronomers today.[11]

Still in the same lecture, Steiner continues:

> In modern Astronomy, founded as it is on the Copernican system, it has come about that the first two axioms are accepted and the third is ignored. This third axiom is lightly brushed aside by saying that the stars are so far away that the Earth-axis, remaining parallel to itself, always points practically to the same spot. Thus it is assumed that the North-South axis of the Earth, in its revolution, remains always parallel to itself. This was not assumed by Copernicus; on the contrary, he assumed a perpetually revolving [precessing] of Earth 's axis [the third movement].

Copernicus introduced his third movement, which considered by itself is just short of a full cycle of precession within the space of a year, in order to accommodate the fact that Earth's axis remains (almost) parallel to itself, because he knew that that was the case. He was well aware that his third movement cancels the false assumption inherent in his second. For he wrote:

> It is thus clear how the two contrary movements, namely that of the centre [of the Earth], and that in declination [of her axis] oblige the axis of the Earth to remain in the same inclination, and in an exactly similar position, that is, remain parallel.[12]

Copernicus constructed his model so that the twenty-minute difference between the second and third movements accounts for the fact that Earth's axis doesn't remain exactly parallel to itself during the course of a year. This was known to the Greeks, and was the phenomenon which enabled Hipparchus to discover precession.

Copernicus was even able to take into account the slow observed variation in obliquity (axial tilt) in his calculations. The Greek astronomers (and their predecessors) knew that the tilt of Earth's axis remains (almost) constant, and were even able to measure it. They noticed that a rod placed vertically into the ground casts a midday shadow, whose length varies throughout the year; in particular that a rod placed on the Tropic of Cancer does not cast a shadow at

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[10] 'On the Copernican Theory of Precession' by Noel Swerdlow follows the mathematics step by step. p. 49 ff.

[11] W. Carl Rufus, 'The Astronomical System of Copernicus', 518,519

[12] Vreede, op. cit., 378.

midday on the day of the Summer Solstice. The latitude of the Tropic of Cancer is Earth's angle of tilt.

Notwithstanding the accuracy of his calculations, they did not provide an explanation. There was no physical explanation for precession until Isaac Newton introduced the concept of angular momentum into astronomical calculations.

Newton pointed out that the axis of rotation of a spinning object remains parallel to itself unless an external torque is applied (the gyroscope effect). The combined second and third movements (i.e. with the axis of rotation pointing towards the Pole Star throughout the year) comes about because the Earth has mass, and the rotating Earth has angular momentum (rotational inertia).[13] Earth's daily rotation is fast enough to give her the angular momentum necessary to keep her axis pointing towards the Pole Star. Precession brings about the small annual deviation, and is caused by the small external torque brought about by gravitational forces acting on Earth's equatorial bulge. It is for this reason that astronomers have no use for Copernicus' third imagined movement. It is an integral part of the second which, if separated from it, would do away with the seasons.

Earth follows her pre-ordained orbit round the Sun regardless of the model used to describe it. We might say that all the details had been taken care of when the physical solar system was created. Why then did Steiner draw the attention of his listeners to the third movement of Copernicus, knowing that what he said contradicted the discoveries of modern astronomers? Were there perhaps consequences, spiritual or otherwise, of the 'neglect' of Copernicus' third movement?

The Third Movement and the Spiralling Solar System

For Rudolf Steiner the rejection of Copernicus' third movement was an important topic which he felt his listeners, particularly the teachers at the Waldorf school in Stuttgart, should be made aware of. He graphically describes several different consequences of this rejection, which we shall consider next.

On the first two occasions he linked Copernicus' third movement to a spiralling of the Earth/solar system through cosmic space. This was during the time he was conducting his research for his major book 'Occult Science – an Outline', in which he gives a detailed description of Earth's spiritual cosmology. In a September 1906 lecture (GA 95, 108) he said:

> Generally, we hear that Copernicus taught only two movements: that the Earth revolves on her own axis and that Earth moves round the Sun. It is seldom noticed that he taught also a third form of movement — that the whole solar system moves onward in a spiral. For the present this fact will be left aside, but in the future humanity will return to it. Copernicus stood on a frontier, and the old outlook was strongly present in him. [14]

Copernicus's third movement is not a spiralling solar system, but in April 1908 (GA 98, 230) Steiner made his meaning clear:

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[13] The angular momentum of a rotating body depends on its mass and its speed of rotation, as well as on the distribution of the mass.

[14] Lecture 11 in *At the Gates of Spiritual Science*, 1 September 1906. Translation from https://wn.rsarchive.org/Lectures/GA/GA0095/19060901p01.html

> Copernicus based his conception on three principles, of which present day science has only accepted two, the third was swept under the carpet. In reality the Sun races through space at great speed in the direction of the constellation of Hercules.[15] Such a movement, as it's normally presented, is only apparent, because the planets move with the Sun. Earth's true orbit is a helix. What is called the inclination of the ecliptic is the gravitational field [*Schwerkraftlinie*] between Sun and Earth. It has been forgotten that during the course of a year Earth rotates once about the axis of the ecliptic, and this rotation combines with the helical movement. Copernicus still kept these two things apart, today it's not done anymore. The movement with the ecliptic has been dropped. [16]

With the Sun "racing through space at great speed", it is not difficult to imagine that Earth's orbital path around the Sun traces a spiral or helix around the trajectory of the Sun (as do the orbits of the other planets). Early in the twentieth century astronomers had become aware that our solar system is not at the centre of the Milky Way galaxy, and had used Kepler's laws to estimate its orbital period and speed about the Milky Way centre. However, Copernicus introduced the third movement into his model so that it would represent the known phenomena (an almost parallel axis, the seasons, and precession), and he was unlikely to have been aware of the Sun's movement towards Hercules. Note that in this excerpt Steiner also mentions gravity, which he rarely does, and then usually to relate gravity to specifically human experiences. I am not aware of any other occasion where Steiner specifically describes gravity as a force between the Earth and the Sun.

More than ten years later, during September and early October 1919 Steiner related the elimination of Copernicus' third movement to the need to apply Bessel's reductions, which he also referred to as Bessel's equations (although these are quite different aspects of Bessel's achievements). He spoke about Bessel's work to the teachers of the newly founded Waldorf School [17] on at least three occasions. On 4 September, during a teacher discussion about the type of maths problems suitable for older pupils, and in response to a question about calculation (or computational) errors ('*Fehlerrechnungen*'), Steiner quite unexpectedly brought Copernicus' third movement and Bessel's equation, (which is (there is only one) decidedly not for upper school pupils!) into the conversation. Whether the question was about calculation errors typically made by students, or were errors of a more complex nature, is not known, but Steiner appears to have chosen the second option, so at this point we need to turn to the work of Friedrich Bessel.

Friedrich Bessel

Friedrich Wilhelm Bessel (1784-1846) was a German astronomer whose rigorous observation methods and accurate measurements of star positions took astronomy to a new level of precision. He was the first to measure the parallax of a star other than the Sun, thereby providing the first physical proof that the Earth revolved around the Sun.

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[15] The solar apex, i.e., the point in the sky which marks the direction in which the Sun is moving in its orbit around the centre of the Milky Way galaxy, is located within Hercules, close to Vega in the Lyra constellation. https://en.wikipedia.org/wiki/Hercules_(constellation)

[16] Lecture given on 29 April 1908, my translation.

[17] The school opened on 7 September 1919.

He was apprenticed at an early age to a shipping company in Bremen. In this way he became interested in navigation and astronomy. Although he had no formal higher education, at the age of just 20 he calculated the orbit of Halley's comet, based on observations made 200 years earlier. He sent his calculations to Wilhelm Olbers, at the time a leading German astronomer, who was sufficiently impressed to arrange for his work to be published. Olbers then secured him a position as an assistant at the Lilienthal observatory near Bremen.

Four years later he was commissioned by the Prussian government to construct the first major German observatory in Königsberg, where he was director from its completion in 1813 until the end of his life. (Although he often complained about the poor weather on the Baltic coast!) He made a systematic study of instrumental, atmospheric, and even human errors, in the determination of a star's position, and used his results to standardize the observations of other astronomers by correcting their observations for these errors. He reduced the positions observed by other astronomers, in particular those of James Bradley (see below), to one fixed date, and eliminated the effects of Earth's movements, i.e. of precession, nutation, and aberration. He thereby established the exact positions of well over 3000 stars. These standardized observations are known as 'Bessel's reductions'.

In his quest to minimize all possible errors in the observation and recording of star positions, Bessel contributed original ideas to the theory of errors. He introduced the concept of a 'probable error' ('*wahrscheinliche Fehler*') of an observation, and derived a 'precision formula' to obtain an estimate of the mean of a number of observations, and its probable error. 'Bessel's correction' is the use of n-1 instead of n in the formula for calculating the variation (the standard deviation) in a small number of observations (n). This corrects the bias inherent in all small sets of observations; a correction still used in even the most basic statistical analyses to this day.

It was while investigating the mathematics of Kepler's second law (Earth's radius vector sweeps equal areas in equal times) that he introduced what are today known as the 'Bessel functions', which are the solutions of a particularly difficult differential equation known as 'Bessel's equation'. He developed these further in his later investigation of planetary perturbations brought about by gravity.

He was now ready for what was possibly his greatest achievement; providing the first ever physical evidence for stellar parallax. He chose the star 61Cygni (a barely visible star in the constellation of the Swan), and showed, after correcting for all possible sources of error, that it appeared to move in an almost imperceptible ellipse every year. As hoped for, this apparent movement mirrored that of the Earth on her annual journey around the Sun. This major achievement proved the reality of stellar parallax, thereby providing the first direct evidence for a heliocentric solar system. Bessel's calculated parallax of one third of an arcsecond[18] corresponds to a distance to 61 Cygni of 10.3 light years.[19] Bessel presented his conclusions to his erstwhile mentor Olbers on the latter's eightieth birthday. Olbers responded by saying that the gift "put our ideas about the universe for the first time on a sound basis".

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[18] An arcsecond, or a second of arc, is one sixtieth of one sixtieth of a degree of arc. One third of an arcsecond is very small angle indeed!

[19] Alpha Centauri, Earth 's nearest star is 4.3 light years away.

The Third Movement and Bessel's Reductions

In his 4 September response to the question about calculation errors Steiner is recorded as saying (GA 295, 141):

> Error calculations [*Fehlerrechnungen*] of this kind are generally very common. It is quite usual to reckon the errors in with the whole. There is one error calculation made now-a-days, which sometime or other will have to be corrected. When Copernicus formulated his Copernican System, he set forth three laws. If all three were to be used to sketch the path of Earth through space, one would get quite a different movement from that now accepted by our astronomers, and taught in our schools. This elliptical movement is only possible if the third law is disregarded. When the astronomer aligns his telescope, things do not tally. On this account errors [*Fehler*] are inserted into the calculations; through Bessel's equations [*Besselschen Gleichungen]* errors [*Fehler*] are introduced every year to account for what does not tally with reality. In Bessel's error equations [*Fehlergleichungen*] there is to be found the third law of Copernicus. [20]

Here Steiner appears to be saying that Kepler was only able to work out his first law (the elliptical orbit of Mars, and hence of all the planets, including Earth) because he ignored Copernicus' third movement. Kepler was of course well aware of the calculations of Copernicus, including his third law. Kepler's calculations however, were empirical. He based his derivation of elliptical orbits on the observations of Tycho Brahe, and was forced to abandon Copernicus' circular orbits, because he could not get a circular orbit to fit Tycho Brahe's data. He spent years of painstaking calculations trying to keep the orbit of Mars circular, but was eventually led to consider an elliptical orbit. In the end he took into account neither Copernicus' third movement, nor the second. It is not immediately obvious why Steiner might have said this.

But the second point Steiner makes is easier to understand; namely that whenever astronomers align their telescopes, they need to take into account what he called 'Bessel's equations' to get the alignment correct. A telescope cannot be aimed directly at the known position of a star. It must be ever so slightly tilted in the direction of the telescope's motion, relative to the star, as it carried by the Earth around the Sun. Starlight arrives at a telescope which is itself in motion, and the velocity of light relative to the velocity of the telescope must be taken into account when aligning it. This phenomenon is known as stellar aberration, and makes it necessary for a telescope to be tilted ever so slightly in the direction of the forward motion of Earth.

James Bradley and Stellar Aberration

Stellar aberration was first noticed by the English astronomer James Bradley (1693-1762) in 1727, while working together with his friend Samuel Molyneux, who had set up a telescope in his mansion in Kew gardens. They were attempting to prove the existence of parallax, using the star γ Draconis. They found that γ Draconis did indeed vary in its apparent position, but in an unexpected manner. The variations were three months out of phase with what was expected, and the

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[20] There is some confusion in the penultimate sentence of the German text, in that it says 'errors' where one might expect 'corrections'. This translation is of Steiner's actual words as published in GA 295. English translations of the discussion have corrected the apparent error (no pun intended). See 'Discussions with Teachers', 13th Discussion on 4 September 1919, 143.

results varied according to whether the observed star was at its zenith or closer to the horizon. This proved that the slight changes they observed in the apparent position of γ Draconis could not be due to parallax. But to what then?

After many more observations, the most accurate ever made at the time, considerable thought, and a flash of inspiration, Bradley (Molyneux had died just six months earlier) realized that the phenomenon they had observed was caused by the movement of Earth relative to γ Draconis.

As is often the case when important scientific discoveries are made, the answer occurred to Bradley when least expected. He was on a sailing party on the river Thames. There was a moderate wind, and the vane on top of the mast indicated its direction. The party sailed up and down river several times, and Bradley noticed that every time they put about the wind (as indicated by the vane) seemed to change direction. He mentioned this to one of the crew, expressing his surprise that every time the boat turned, the wind shifted as well. The crewman explained that it was not the wind that shifted, but the direction of the wind relative to the boat which changed every time they put about.[21]

Bradley realized that the apparent changes in the position of γ Draconis through the year were due to the speed and direction of the orbiting Earth, relative to the speed of light from γ Draconis (See Figure 3). He returned to his data (the same data that Bessel later 'reduced'), and showed that stellar aberration varies during the year between –20.43 and +20.43 arcseconds, depending on the time year and on the time of day of the observation.

V_S = velocity of starlight towards Earth

V_E = velocity of Earth

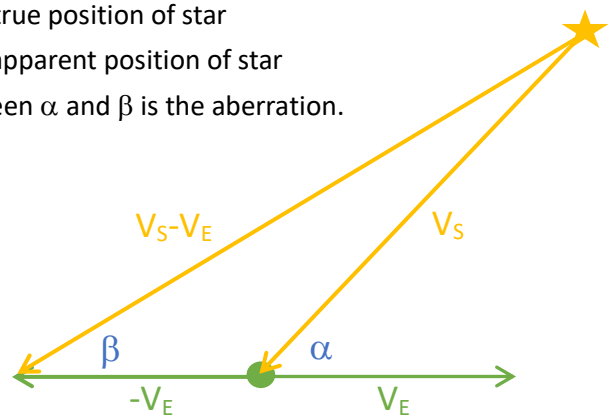
V_{-E} = negative velocity of Earth

V_S-V_E = velocity of starlight relative to Earth

α = angle indicating true position of star

β = angle indicating apparent position of star

The difference between α and β is the aberration.



Maximum aberration occurs when α = 90°. Using 2.998×10^8 m/sec for the velocity of light, and 30,000 m/sec for the velocity of the Earth around the Sun. a rough calculation for maximum aberration would be

$$Invtan\left(\frac{30{,}000}{2.998 \times 10^8}\right) \times 60 \times 60 = 20.6 \text{ arcseconds.}$$

Figure 3 Vector diagram to illustrate how the velocity of starlight relative to the velocity of Earth gives rise to stellar aberration

[21] There is no mention of this story in Bradley's written work, and it may therefore be apocryphal.

A simple down to Earth example of aberration is when you see someone running through a downpour with their umbrella tilted in the direction in which they're running, even though the rain is falling vertically.

The Third Movement and Stellar Aberration

Three weeks later, in response to a question whether it might be possible to derive the spiral movement of the Earth from facts known to astronomy, Steiner told the same group of teachers (GA 300a, 94):

> "Why not? Just as you teach the theory of Copernicus today. The whole thing is based on the ridiculous fact that of the three laws of Copernicus only the first two are taught and the last is omitted. If you put in the third you will find that you have a simple spiral round the Sun. This is what Copernicus did. You merely have to take his third law. You merely have to take the book 'De revolutionibus corporum coelestium' [sic] seriously, and take all three laws instead of just the two. Only two have been taken, but that doesn't tally with the movements we see. That's why the so-called Bessel's corrective equations ['*Besselschen Korrekturgleichungen*'] are inserted. One doesn't see the stars as Copernicus described them. One has to rotate the telescope, and that is done according to the Bessel equations. You only have to eliminate this to arrive at what is correct.[22]

Earth's spiralling movement is mentioned again, but with no further explanation as to how this relates to the third movement of Copernicus. From the context (rotating the telescope) of the second point, it is clear that Steiner is referring to stellar aberration, which is one of the sources of error eliminated by Bessel in his 'reductions'. As described earlier, to correct for aberration a telescope needs to be rotated by a very small angle in the direction of Earth's movement relative to the observed star. Again, it is not at all obvious why Steiner linked stellar aberration to Copernicus' third movement.

A week later, in a lecture to members of the Anthroposophical Society in Dornach (GA 191, 26) Steiner says:

> Taking into account only the first two propositions, the Copernican system, developed further in the spirit of Kepler and Newton, emerges. But this system doesn't add up. When, according to this system, a planet ought to be in a certain position, and one points the telescope in this direction – it's not there! But it must be there according to this system. That's why for quite a while now the so-called 'Bessel Reductions' [*Besselschen Reduktionen*] are applied. When the telescope is set up, it is pointed not in the direction in which it should be pointed according to this system, but in the direction to which Bessel's Corrections [*Besselschen Korrekturen*] have been applied. These Bessel Corrections, what is their meaning? They mean that one always has to apply anew that which one would apply only once, if all three Copernican laws were taken into account, namely if the third had not been ignored. But when the third Copernican law is taken into account, discrepancies appear in those neat planetary orbits around the Sun. Then one has to think of a different world system. But they will also not think about a different world system before they are thoroughly prepared for such a rethinking by an Anthroposophically aligned spiritual science.[23]

Steiner is again describing the need to correct for stellar aberration, which is indeed an element of Bessel's reductions, as explained earlier.

But here he also gives an additional consequence of neglecting the third movement; the need to apply anew "that which one would apply only once, if all three Copernican laws were taken into account." In 1919 Bessel's reductions had

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[22] *Conferences with the Teachers of the Waldorf School, Volume One*, on 25 September 1919, 53.

[23] Lecture on 3 October 1919, my translation.

been in use for almost a century, so there was really no need to re-apply them every time a telescope was pointed at the sky. Steiner here touches upon a different problem, that of the continuous slippage of the celestial co-ordinate system relative to the stars, a phenomenon brought about by precession, which does have to be regularly corrected for.

Precession and the Celestial Grid

The physical cause of precession is the gravitational force which the Sun and the Moon exert on Earth's equatorial bulge. As noted earlier, Steiner said as much on 29 April 2008. Precession brings about a gradual shift in the orientation of Earth's axis relative to the fixed stars. The North celestial pole, which is currently located close to Polaris, swings in a wide loop around the North pole of the ecliptic roughly every 25,920 years. The South celestial pole makes a similar movement. The moving celestial poles pull the celestial co-ordinate system along with them.

The geometry of the celestial co-ordinate system was first worked out by the Greeks. They believed that Earth was motionless and at the centre of creation. The sky, they thought, was exactly what it looks like: part of a hollow sphere arching over the Earth like a great dome. In order to specify a point on the inner surface of that sphere, they used spherical co-ordinates.

On Earth's surface, the grid lines of spherical co-ordinates are called latitude and longitude. If the lines of latitude and longitude are imagined as expanding outward from Earth's surface and printing themselves on the inside of the celestial sphere, they become declination and right ascension respectively.

Directly above the Earth's equator at 0° latitude, is the celestial equator, 0° declination. The celestial equator passes directly over Earth 's equator. Directly over the North Pole, latitude 90° N, is the North celestial pole, declination +90°; the South celestial pole is declination —90°. Note the +sign for North declination, and the –sign for South declination. A star passing directly overhead in London, latitude 51.5°N, has declination +51.5°. Degrees are further subdivided into minutes (′) and seconds (″).

The 0° line of longitude (the prime meridian) is defined as a line passing through a brass plate set in the floor of the Greenwich observatory in London. The corresponding line on the celestial sphere separating East from West is marked by the position of the Sun on the first day of spring, the vernal equinox, also referred to as the first point of Aries, where the plane of the ecliptic crosses the celestial equator. Right ascension, like time, is measured in hours, minutes and seconds, because time is manifested by Earth's daily rotation, so the zero point of right ascension is called '0^h' for 'zero hours'. Unlike longitude, right ascension is measured in just one direction, East. Because there are 24 hours in a day, each hour of right ascension measured along the equator equals 15° longitude. Hours are subdivided into minutes (m), and seconds (s).

Polaris for example is located at right ascension $2^h\ 41^m\ 39^s$, declination +89° 15′ 51″.

Unlike terrestrial coordinates, celestial coordinates slowly change. Precession brings about a slow change in the orientation of Earth's axis relative to the stars, causing the equinox points to drift Westward at a rate of 50.3 arcseconds

annually.[24] As the equinox shifts, it takes the celestial coordinate grid with it, thereby changing the declination and right ascension of every celestial body.

That's why star catalogues have to be regularly updated. To fix a star's position a date on which right ascension and declination applies needs to be specified. The current standard is 'equinox 2000.0', shorthand for 'right ascension and declination at the moment the year 2000 began.'

The Larger Picture

In the Astronomy course, and indeed on many other occasions, Rudolf Steiner was speaking directly from his experiences in the spiritual world. He used the concepts of physical and mathematical astronomy as illustrations, to encourage his listeners to raise their awareness to a "higher" level, to build a conceptual bridge between the world of the senses and the spiritual world. That this wasn't always successful merely underlines the profound difference between clairvoyant consciousness and ordinary everyday consciousness.

What was it about Copernicus' third movement, the "perpetual revolving of Earth's axis", that Steiner considered so important for a real understanding of our solar system? After all, Copernicus' circular orbits were replaced by Kepler's ellipses, which were later underpinned by the mathematics of Newton.

A possible clue may be found in the first natural science course (the Light Course) Steiner held for the Waldorf teachers at the close of 1919. Steiner began the first lecture[25] by drawing a sharp distinction between kinematics (the study of movement without reference to the forces causing it), and dynamics (the study of movement under the action of forces). For the former there is no need to know anything about the mass of a moving object, for the latter the mass of the object is decisive. A definite boundary exists between kinematics and dynamics, and for Steiner a problem arises when scientists cross that boundary, and begin to include mass into their theories. (GA 320, 32ff.)

Unlike pure movement, mass, and its manifestation as weight, is something we cannot penetrate with our consciousness,[26] even though, according to Steiner, while we live on Earth, we are fully engaged with mass through our will. We learn to live with mass (but not understand it) from the day we're born. Just watch the look of amazement, surprise, joy? on a toddler's face as she lets go of her spoon and watches it drop to the floor for the tenth time from the safety of her high chair. It *always* falls in the same direction. How amazing! This is an experience of gravity which can only be had on Earth, and her amazement is an expression of just how different things were in her pre-Earthly life.

Somehow, according to Steiner, by taking into account mass and its physical manifestations, weight, gravity, and inertia, the pursuit of natural science has led human souls away from an awareness of the spiritual world. He would have preferred it if teachers "could manage to get out of the habit altogether of

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[24] At 50.3 arcseconds per year it takes 360×60×60÷50.3 = 25765 years for a full cycle of precession, almost the 'traditional' Platonic year. No calculation is exact because the rate of precession varies ever so slightly.

[25] On 23 December 1919.

[26] Even the Large Hadron Collider hasn't provided the final answer on the 'real' nature of mass, supposedly concealed within the elusive Higgs boson.

speaking about gravity" (GA 300a, 94)[27]as a metaphysical concept. It should be treated purely as a phenomenon.

The heliocentric model of Copernicus is a kinematic model, but not an empirical one, for there was no direct evidence that the Sun is at the centre of the solar system. Copernicus gave no thought to the causes of his movements. Kepler's elliptic model was also kinematic, but is empirical. His model was based on actual observations, observations which were so accurate that they forced him to abandon the Aristotelean perfection of circular for the much more interesting imperfections of elliptical orbits. He was unable to explain their elliptical shape except as created by the will of God.[28] To his great joy, he later discovered[29] that it is the eccentricity of the elliptical orbits which generates the harmony of the universe, the music of the spheres. Circular orbits are mute.

Newton's model is dynamic. Like that of Copernicus it is not empirical, but derived purely from his universal law of gravitation ($F = (Gm_1m_2)/d^2$, and his second law of motion ($F = ma$), both of which encompass mass. Newton did not enquire after the origins of gravity. He did not 'feign hypotheses'.[30] Working through the calculus he had developed, he proved mathematically that the planetary orbits are elliptical. Although Steiner had studied calculus while a student, he apparently did not hold it in high esteem (GA 326, 66).[31] He considered Newton's method contrived, and therefore incapable of providing an accurate (spiritual) representation of a living solar system.

It therefore seems likely that he preferred Copernicus' kinematic model of the solar system as an aid to understanding its (spiritual) nature.

A further clue about the importance of the third movement was given by Steiner in his lecture cycle '*The Origins of Natural Science'*.[32] Here he explained how the abstractions of mathematics and geometry have arisen from the sense of movement now residing unconsciously in our limbs, and in our will power. (GA 326, 45ff.)

In earlier times, when mathematics was still mysticism, human souls measured the cosmos with their own movements. Astronomy was alive 'inside' their consciousness, as it were. Geometry and mathematics too were inner experiences. Copernican astronomy and abstract mathematics only became possible with a fundamental change in the constitution of the human soul. Weight, gravity, and inertia began to be experienced in a different way, 'outside' their consciousness. The movements of the planets were no longer experienced inwardly, but were explained in a purely mechanical manner, as pure clockwork. For Steiner the loss of our ability to experience planetary movements inwardly, was part of the price to be paid for the further evolution of consciousness, which he hoped would be redeemed in the future.

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[27] Op. cit., *Conferences with the Teachers*, on 25 September 1919.

[28] Kepler was convinced that an unknown force emanated from the Sun, which guided the planets on their elliptical paths; a force which he first thought of as a 'soul', but later compared to the light emanating from the Sun.

[29] In 1619, as he was completing his book 'Harmonices Mundi', 'The Harmony of the World'.

[30] When asked about the underlying causes of gravity Newton is said to have replied, '*Hypotheses non fingo'*, 'I do not feign hypotheses.'

[31] See for example, lecture 4 (27 December 1922) in *Origins of Natural Science*, GA 326.

[32] Ibid, lecture 3, 26 December, 1922.

As there was no external evidence for earth's three movements, is it possible that Copernicus experienced them inwardly, as an experience in his soul? Steiner hints at this in the first lecture cited: "and the old outlook was strongly present in him." (GA 95, 108) Again, it seems plausible that Steiner was drawing his listeners' attention to what is really missing from modern cosmology: a spiritual experience of cosmic movements within the human soul.

A brief diversion is necessary before considering this topic.

Regional and Global Consciousness

The ancient Greeks were not a politically unified nation, nevertheless, they did succeed in spreading and maintaining a common culture all around the Mediterranean Sea. They had a strong awareness of their Greekness, of their country and of the surrounding regions "between the pillars of Hercules and the river Phasis".[33] They were conscious of the fact that they inhabited but a small part of the Earth, living around the Mediterranean Sea, "like frogs around a pond".[34] Their limited geographical knowledge was bounded by the encircling sea god Oceanus.

The geography of what lay beyond these regions was unknown to them, but they described their inhabitants in the imaginative language of myths. Beyond the Pillars of Hercules, lived the Hesperides, the nymphs of the West; beyond the North Wind lived a race of giants, the Hyperboreans; the Pygmies inhabited a country near the source of the Nile on the Southern shores of Oceanus.

Humankind today is aware of the Earth as a whole. We all share in a global consciousness. Steiner pointed out that with the emergence of a global consciousness from the regional consciousness of the ancient Greeks, a mathematical-mechanical imagination of what lies beyond the Earth began to take shape. (GA 192, 369)

The regions beyond the Earth are not described with the same mythic imaginations as was the case with the ancient Greeks when describing what lay beyond Oceanus, but are enclosed in what Steiner called "mathematical imaginations".[35] "The essential feature of the attitude adapted by present day humanity is to conceive of the Earth as a great sphere in universal space, and to embrace what is beyond the Earth by mathematical and mechanical concepts." (GA 192, 370) Awareness of spiritual forces and beings, the 'inhabitants' of the regions beyond the Earth has been gradually lost.

Although mathematical and mechanical concepts have no place in describing the phenomena of a super-sensible world, they do have their rightful place in describing the physical world. Calculations used to describe extra-terrestrial phenomena reach into human history as far back as written records exist. As

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[33] Plato, *Phaedo* 109b. The river Phasis flows between the Caucasus Mountains and the Black Sea.

[34] Ibid.

[35] In this lecture I have chosen to translate Steiner's "*mathematische Phantasie*", as 'mathematical imaginations', as it's clear from the context that Steiner is referring to the same power of soul which the Greeks used to describe their mythological world, a world inhabited by real, not fanciful or fantastic, spiritual beings. On the other hand, in the context of the quotation introducing this essay, the same two words seem to imply a merely fanciful, not a real, mathematics.

mentioned earlier, the phenomenon of precession was first noticed, and calculated, by the Greek astronomer and mathematician Hipparchus about 120 BCE.

Both the myths and the mathematical skills of the Greeks were adventures in consciousness, which enabled them to make sense of what lay beyond their Oceanus. Modern mathematical-mechanical concepts are also adventures in consciousness, but narrowly restricted to physical phenomena. Nevertheless, they enable present-day humanity to make sense of the *physical* aspect of the boundless universe beyond our planet. Steiner foresaw that this one-sidedness would lead to an increasing desolation of human souls.

The problem then, is that in the age of the Consciousness Soul, humanity has established a robust relationship to the physical, material world, but has lost its rapport with the spiritual world. Steiner was acutely aware that the time had come for the mathematical-mechanical concept of space "to be enlivened by something else, by something empirical, something that can be experienced". (GA 192, 370)

Just a few days after his meetings with the teachers, Steiner gave a lecture (on 28 September, 1919) to the Stuttgart members of the Anthroposophical Society, where most of the teachers would have been present as well. He summed up the situation as follows:

> Just as the ancient Greek had a territorial, or regional consciousness, and humanity has, since the beginning of what is called the modern historical epoch [of the Consciousness Soul], developed a global consciousness, so from now onwards, there must be an expansion to a universal or cosmic consciousness.[36] (GA 192, 371)

The Movement of the Soul

In the 28 September lecture, speaking directly from his own personal experience, Steiner described three soul movements in spiritual space. He does not link these movements directly to Copernicus' third movement, which is mentioned only in passing. But in revealing the spiritual heights from which he spoke on this occasion, he pointed his listeners in the direction of a possible solution to the 'Copernican enigma'.

A cosmic consciousness which is aware of the activity of spiritual beings in its surroundings, is also aware of itself as travelling through cosmic space.

> And then cosmic space becomes a very different thing to the mathematical-mechanical space conceived of by Copernicus, Kepler, and Newton. It becomes something that is inwardly alive. We learn to distinguish absolute movement, not relative to anything else, which we make as human beings in cosmic space. We learn too, to distinguish a movement, which is made from left to right, that is an actual movement which we make with the Earth. We learn about another movement, which is an ascending one as it were; we realise that in turning, we also ascend in space. And a third movement - a forward pacing movement I might call it - an onward movement from behind. This is not the same thing as moving on the Earth, but is something that is done together with the Earth, which can be verified by inner experience. We can verify for ourselves that when we turn from left to right, we ascend and at the same time go forward. So, by inner experience, we observe a threefold movement made, not in relation to some other heavenly body but a movement in an absolute sense in space. (GA 192, 377)

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[36] Lecture on 28 September 1919. *The Emergence of Cosmic Consciousness from Earth Consciousness*, Lecture 2. Translation from rsarchive.org/Lectures/GA/GA0192/19190928p01.html , with minor corrections.

The movements described here are soul movements in a difficult to imagine spiritual 'space', having any number of dimensions between zero and four.[37] The Copernican movements take place in physical three-dimensional space, which is considerably easier to visualize. This suggests that Steiner anticipated that his listeners, in forming an understanding of the neglected third movement, would be able to use their understanding as a bridge, or at least as a stepping stone, into that spiritual 'space'. Steiner concluded: "Copernicus knew something more than what is admitted by modern astronomical science. And this 'more' he concealed in his third movement, but no account is ever taken of that third movement." (GA 192, 378)

In the same lecture he again describes the three soul movements in 'cosmic space'.

> To speak in pictures for a moment, but the picture is really a good one - it is as if one learns to feel oneself as a traveller through cosmic space - a traveller whose movement consists of a turning combined with a forward movement, and a movement from below upwards. If we sketch the result of these movements - moving upwards in rotation, moving forward in this upward spiral movement - the curve will represent the path of the Earth through cosmic space, not mathematically and dynamically as it is built up through the Copernican-Newtonian world conception, but as a result of inner observation. This is the way in which it ought to be arrived at, for then we get something that is not abstract like the Copernican-Newtonian world conception, but very concrete. Something that is actually super-sensible is experienced empirically, if one may be allowed to use this tautology. (GA 192, 381)

The implications of the tautology are clear: super-sensible experiences are always *real* experiences, not fantasies in the usual sense of the word, but real Imaginations (with a capital I). Spiritual experiences enliven the mathematical mechanical concepts used to describe the extra-terrestrial regions of space.

The importance of this for Steiner was not that a soul carrying out these three movements has arrived at a spiritual truth. More important was the fact that the soul learns to experience itself not merely as a member of humanity on Earth, but as part of a cosmic community, emerging from a global to a cosmic consciousness.

> [Consciousness of] the world expands, as it were, for anyone who approaches the forces which are actually operative in these movements. In turning from left to right are to be perceived the activities of the Angels; in ascending from below upwards the activities of the Archangels; and by advancing forward in universal space the direction and forces of the Archai, the Time Spirits. By taking into his consciousness this absolute movement through the cosmos man turns his gaze into spiritual space, and becomes aware that physical space is only an abstract image of this concrete spiritual space, in which the activities of the higher Hierarchies are what is real. (GA 192, 381)

An awareness of the real and eternal presence of the spiritual world - a cosmic consciousness - this is what Rudolf Steiner sought to instil in his listeners.

Conclusion

This essay focussed on Steiner's attempt to enliven our understanding of the solar system, and by implication, of the cosmos, by bridging the gap between our everyday awareness of physical three-dimensional space and a consciousness of

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[37] See for example *On the Dimensions of Space*. Lecture given in Dornach 24 June, 1922.

spiritual cosmic space; specifically, by replacing "mathematical fantasies with actual facts". (GA 191, 29)[38] This attempt was unsuccessful for several reasons.

First: the third movement of Copernicus has not been "swept under the carpet". It is an integral part of his second movement, and the two movements together take into account the rotational inertia of the Earth, which is in turn a result of the first movement, her daily axial rotation.

Second: By referring to the concepts and mathematics used to describe the physical solar system as "Galilean and Newtonian fantasies", he considerably weakened his argument for a spiritual interpretation of Earth's movements. From our materialistic point of view, these "fantasies" provide a satisfactory explanation of the mechanics of the solar system, just like the Greek myths provided a satisfactory explanation of their world. Indeed, they are all we have at the present, Consciousness Soul, stage of our evolution. In modern parlance, this is 'where we're at'. Denying their reality in the physical world was unhelpful.

That these mundane concepts have no place in the higher (cosmic) consciousness to which Steiner had access, where the true "facts" underpinning the spiritual dimensions of our solar system are to be found, goes without saying, and should be obvious to anyone who has ever looked up in awe at the brilliance of the Milky Way. Steiner's failure to distinguish between the physical and the spiritual sides of reality in this instance was unfortunate.

Third: His suggestion that Bessel's reductions were needed to correct for the errors introduced into astronomy by the neglect of Copernicus' annual precessional cycle, did not lead to a better understanding of our solar system, as he had intended, but had the opposite effect. Bessel's achievements were a direct continuation of the achievements of Galileo and Newton, which Steiner swept aside as "fantasies". To argue that Bessel's reductions (a continuation of Newton's "fantasies") corrected for the errors contained in these "fantasies" is counter-intuitive.

If modern astronomy is "mere Galilean and Newtonian fantasy", we must ask with Faust: What then is "the inmost tether that binds the world together".[39] What are the "actual facts" which Steiner insisted must replace the "fantasies"? What are the forces, physical and spiritual, that hold the solar system together? Wherein lies their difference? Or are they perhaps the same, just experienced with a different degree of consciousness?

The need for a bridge towards the distant shores of a higher consciousness, accessible to everyone, "swarming with travellers", as Goethe imagined it in his Fairy Tale, is greater than ever. This is what Steiner wanted to convey to the teachers of the first Waldorf School in 1919, and continues to be his message in a world more and more constricted by an increasingly aggressive and virulent materialism.

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[38] See quotation introducing this essay.

[39] Goethe's *Faust*, Part One; Night, Faust's Study.

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List of Illustrations

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Figure 2. The Effect of Distance on Parallax.

Figure 3. Vector Diagram to illustrate how the Velocity of Starlight relative to the Velocity of Earth gives rise to Stellar Aberration.