Science and Mathematics Group of the Anthroposophical Society in Great Britain Newsletter –Autumn/Winter 2019

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Articles

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 fabrications. These fabrications must be replaced by actual facts*." [1]

Introduction

Nicolaus Copernicus (1473-15) was the first astronomer to present a coherent astronomical theory suggesting that Earth and the other planets revolve around the Sun. He moved the centre of the universe from Earth to the Sun. This, the Copernican revolution, marked the beginning of a major stride in the evolution of human consciousness, leading directly to the scientific revolution of the 17th and 18th centuries, and still ongoing today.

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. Aged thirty, he returned to Poland, where he 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 his new theory, to which he didn't put his name, and 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.

By 1530 Copernicus had completed his major work, *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Heavenly Spheres), but again resisted publication. As to whether he was fearful of the reactions it might provoke, 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. Andreas Osiander, who prepared the book for publication, added a cautionary preface which states that the theory is no more than a mathematical hypothesis, and that the book contains no claim about the real structure of the world. Copernicus was unable to change the preface. Internal evidence indicates that he himself believed his theory to describe the (physical) solar system as it is.

Copernicus' basic propositions are:

1. There is no one centre of the celestial spheres along which the planets move.

2. The centre of Earth is not the centre of the universe, but only the centre towards which heavy objects move, and the centre of the lunar sphere.

3. The spheres surround the Sun as if it were in the middle of them all; therefore the centre of the universe is near the Sun.

4. The distance from Earth to the Sun is insignificant in comparison with the distance from the Sun to the height of the firmament (the outermost celestial sphere containing the stars).

5. The apparent motion of the firmament arises from Earth's complete rotation on her fixed axis in a daily motion, while the firmament and highest heaven abide unchanged.

6. The apparent motions of the Sun arise not from its motion but from the motions of Earth, which orbits the sun like the other planets. Therefore, Earth has more than one motion.

7. The apparent retrograde and direct motions of the planets arise not from their motion but from that of Earth. The motion of Earth alone, therefore, suffices to explain many apparent inconsistencies in the heavens.

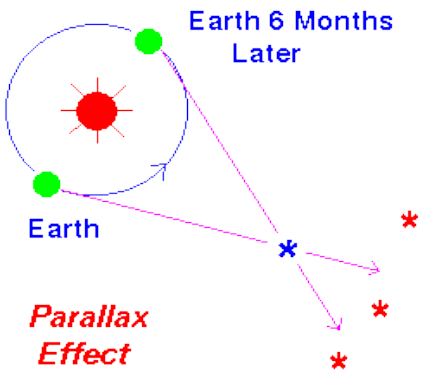
Copernicus's propositions were all the more astonishing in that there was absolutely no physical evidence at the time for any of them! In fact, the first direct evidence that Earth revolves around the Sun was not confirmed until 1838, and the first direct evidence of Earth's rotation on her axis in 1851,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

But Copernicus's 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 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 the Aristotelian cosmology.

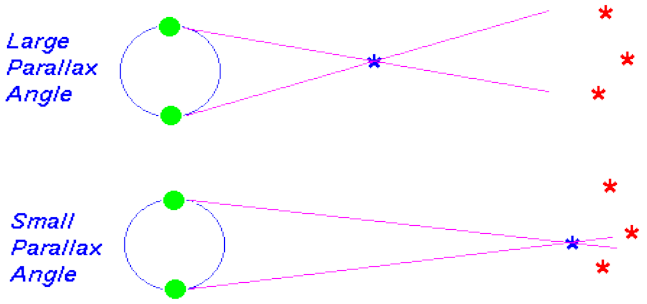
Copernicus gave credit to Aristarchus in *De Revolutionibus Orbium Coelestium*, where he wrote: '*Philolaus believed in the mobility of Earth, and some even say that Aristarchus of Samos was of that opinion.*' [2] This sentence was deleted in the printed version. Whether this was done by Osiander, the 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 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 [3]. If Earth does indeed revolve around the Sun, a star should appear to change its position relative to the background stars as Earth moves along its annual orbit, because it is viewed from a different position in space. See diagram.



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



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.

Rudolf Steiner's Astronomy Course

Rudolf Steiner's third natural scientific course was presented, as the previous two, mainly to the teachers of the Stuttgart Waldorf School founded in 1919. In lecture two he discusses the importance of Copernicus in the evolution of Western thought; Earth, and by implication humankind, was no longer the centre of the Universe. In this lecture cycle Steiner refers to the Copernican system as if it could still be used by astronomers today. He was of course well aware of Kepler's second law, i.e. that the planetary orbits are ellipses, and discusses all three in the next lecture. The importance of Copernicus' astonishing idea lay in the dramatic change from a geocentric to a heliocentric universe. By referring to the work of Copernicus Steiner emphasized that it was him, rather than Kepler, who brought about the first 'giant leap for mankind'. After introducing Copernicus' first movement, the daily rotation of Earth about her North-South axis, Steiner describes the second movement as follows [4]:

"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 oc-

cur 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."

Copernicus imagined that during the course of a year, the axis of 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 (the axis) describes the surface of a cone.

Copernicus realized that this was wrong because with this set up 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 describes the third movement as follows:

"*Copernicus' third principle is that not only does such a revolution of 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. 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 rotates once in the opposite direction about the spindle, not about its own axis.

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 also 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 de-

scription, not an explanation, of Earth's movement around the Sun. He imagined quite reasonably that on her orbit around the Sun, Earth behaved like the moon on his orbit around Earth, always keeping the same side facing the centre of rotation. Because this natural motion wasn't what was observed, Earth's axis itself must itself be rotating to keep it pointing in the same correction. To align his model with reality, he introduced his third movement, which also brought back the seasons. But by introducing it, Copernicus brings about more than just the seasons.

Copernicus knew from historic observations dating back to the Greek astronomer Timocharis (320 BCE – 260 BCE) that the rate of precession varied. In his geocentric model he assumed a uniform precession and superimposed on this an irregular variation. In his calculations Copernicus also took into account the slow observed variation in obliquity. [10]

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 'built into' his third movement the precession of the equinoxes. [11]

By explaining precession as a very slight difference 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) sums 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 equinoxes.'

'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. A complicated fourth motion due to nutation has also been added.' [12]

In the 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 Earth, in its revolution, remains always parallel to itself. This was not assumed by Copernicus; on the contrary, he assumed a perpetually revolving 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 does remain (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 Earth), and that in declination (of her axis) oblige the axis of Earth to remain in the same inclination, and in an exactly similar position, that is, remain parallel.*' [13] 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.

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

But descriptions are not explanations, and there was no physical explanation for this phenomenon 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 ef-

fect). The combined second and third movements (i.e. with the axis of rotation pointing towards the Pole Star throughout the year) comes about because Earth has mass, and a rotating Earth has angular momentum (rotational inertia). [14] 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 gravitational forces acting on Earth's equatorial bulge. Therefore astronomers had 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. All the details had been taken care of when the physical solar system was created. So what was the point Steiner was seeking to draw the attention of his listeners to with his enigmatic statement? Were there any underlying 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 the 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', which gives a detailed description of Earth's spiritual cosmology. In a September 1906 lecture he said:

"*Generally, we hear that Copernicus taught only two movements: that 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."* [15]
Copernicus's third movement is not a spiralling solar system, but in April 1908 Steiner's meaning becomes clear:

"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. [16] *Such a movement, as its 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 its not done anymore. The movement with the ecliptic has been dropped.*" [17]

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 his third movement into his model so that it would represent the observed 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 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 work). He spoke about this to the teachers of the newly founded Waldorf School [18] 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 equations, (which are 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 parallax to a star other than the Sun, at the same time providing the first physical proof that Earth revolved around the Sun.

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 the at the time leading German astronomer Wilhelm Olbers, 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 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 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'.

The Third Movement, Stellar Aberration, and Bessel's Equations

In his 4 September response to the question about calculation errors Steiner is recorded as saying:

"*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's third movement. Kepler did indeed ignore Copernicus' third movement, as well as the second, because he based his law on years of painstaking work trying to keep the orbit of Mars circular. He could not get a circular orbit to fit Tycho Brahe's data, and so he was forced to consider an elliptical orbit. There appears to be no reasonable explanation as to 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 as it carried by 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.

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 its position but in an unexpected manner. The changes were three months out of phase, and different stars gave different results. The slight changes they observed in the apparent position of a star could not be due to parallax, but to what then? After many more observation, 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 boat relative to the wind which changed every time they put about.

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 sketch at end of article). 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.

A good 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.

Then three weeks later, in response to a question whether it might be possible to derive the spiral movement of the Sun and Earth from facts known to astronomy, Steiner told the same group of teachers:

"*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 his 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.*" [21]

The spiral crops up again, but no further explanation as to how this relates to the third movement of Copernicus is given. From the context (rotating the telescope) of the second point, it is clear that by Bessel's corrective equations (*Besselschen*

Korrekturgleichungen) Steiner is referring to stellar aberration. 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, there appears to be no rational explanation linking stellar aberration to Copernicus' third movement.

And just a week later in a lecture to members of the Anthroposophical Society, where most if not all of the teachers would have been present:

"*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' are applied. These 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 the whole business of the planetary orbits around the Sun. Then one has to think of a different world system.*" [22]

Steiner is here again describing the need to correct for stellar aberration, which are 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 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 appears to touch 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 coordinate 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 Earth like a great dome. In order to specify a point on the 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 out from 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°.

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. [23] 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.'

For nearby objects such as the Sun, Moon, and planets, right ascension and declination are often given for the 'equinox of date': the right ascension and declination values that are correct for the actual date listed.

The Larger Picture

In the Astronomy course, 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 build the bridge between the spiritual world and ours. That this wasn't always successful merely underlines the radical difference, the *totaliter aliter*, 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 begins the very first lecture [24] 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 (or weight) of the 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 begin to include mass into their theories.

Unlike pure movement, mass is something we cannot penetrate with our consciousness, [25] even though 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. Somehow, according to Steiner, by taking into account mass and its physical manifestations, gravity and inertia, the pursuit of natural science has led human souls away from an awareness of the spiritual world.

Steiner would have preferred it if teachers "*could manage to get out of the habit altogether of speaking about gravity*" as a metaphysical concept. [26] 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 is empirical, but still a kinematic one. His model was based on actual observations, observations which were so accurate that they forced Kepler to abandon the Aristotelean perfection of circular for the more dynamic imperfections of elliptical orbits. He was unable to explain their elliptical shape except as by the will of God, because he discovered that it is the elliptical orbits which generate the harmony of the universe, the music of the spheres. [27]

Newton's model is a dynamic one. 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. Like his predecessors, Newton did not enquire after the origins of gravity. He did not 'feign hypotheses'. [28] Working through the calculus he had developed, he proved mathematically that the planetary orbits were elliptical. Although Steiner had studied calculus while a student, he apparently did not hold it in high esteem [29]. He considered Newton's method contrived, and therefore incapable of presenting an accurate (spiritual) representation of the solar system.

A further clue about the importance of the third movement is given by Steiner in his lecture cycle

'*The Origins of Natural Science'*. [30] Here he explains how the abstractions of mathematics and geometry have arisen from the sense of movement now residing unconsciously in our limbs, and in our will.

In earlier times, when mathematics was still mysticism, human souls measured the cosmos with their own movements. They lived as it were 'inside' astronomy. Geometry and mathematics too were inner experiences. Copernican astronomy and abstract mathematics only became possible with a fundamental change in the constitution of human soul. Mass, gravity, and inertia began to be experienced in a different, more down to Earth way.
Is it possible that Copernicus experienced Earth's three movements 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*." [15] Was Steiner drawing his listeners' attention to what is really missing from modern cosmology: an inner experience of the soul?

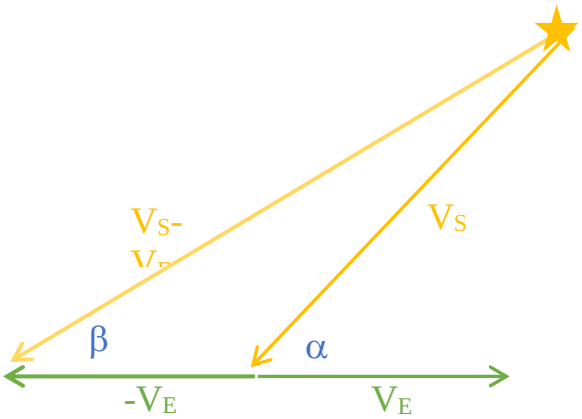
A clear description of movement as an inner experience was given by Steiner in another lecture held in September 1919. He does not elaborate further on the importance of Copernicus' third movement, and the enigma remains unsolved. But he does reveal the spiritual heights from which he was able to speak:

"*But by rising to this height of contemplation, our soul life changes considerably. Once we have really got to the point where we see in our surroundings the activities of spiritual beings, then we also get to a point where we are able actually to observe the differences in the soul life of the different epochs of which I have already spoken. And then, when we have learnt (it is difficult to learn, but it can be learned), to take account of these inner changes in concrete inner experiences, then we observe ourselves to be travelling through universal, or cosmic space. And then we know, not by means of external mathematical considerations, nor by means of telescopes or angle considerations, but by a sequence of inner experiences, that we together with Earth have changed our position in cosmic space. And then cosmic space becomes a very different thing to the mathematical-mechanical space conceived of by Copernicus, Kepler, Galileo, and Newton. It becomes something that is inwardly alive. We learn to distinguish movement which we make as human souls in universal space. We learn too, to distinguish movements which we make in an absolute sense in cosmic space. We learn to distinguish a movement we make from left to right — that is an actual movement which we make with the Earth from left to right. We learn about another movement, an ascending one. We make it in such a way that we realise that in turning, we also ascend in space. Yet a third movement — a pacing movement I might call it — we make as a forward movement, but backwards. This is not the same thing as moving on Earth, but is something which is done together with Earth, and which can be verified by inner experience. We can verify for ourselves that when we turn from left to right, that we ascend as we turn, and at the same time step forward. So, as an 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."*

"Now of course you will say that the present consciousness of humanity is a long way away from having even a notion that humans are in this sense cosmic travellers, let alone that they are able to verify the reality of such a cosmic journey. Yet there are means whereby such consciousness can be acquired, however far away from these things human consciousness nowadays may be. What I have described is a reality, even if human souls to-day know nothing about it. Their ignorance can be compared to the belief which may be held by a person in a train who imagines that he is at rest, whereas he is actually moving with the moving train. Now why is this belief general?"

"*In the first place the purely mathematical and mechanical Copernican cosmology has for the last three or four hundred years had more of a lulling to sleep, than an enlightening influence on humanity. I have often said that this purely mathematical-mechanical world conception is really based upon an error which is fairly obvious. It presents a convenient picture of space, but really no more than that. In the well-known work of Copernicus about the revolutions of the heavenly bodies in space, three movements are to be found, but modern science bases itself only an the first two and takes no account of the third. Copernicus knew 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 it. (Astronomical) observations do not agree with the Copernican system, but modern science simply explains this away. Today, when under certain conditions someone investigates empirically where some star or other ought, according to the correct calculations set forth in the Copernican system, to be found at a particular point of time, it is not there. But then*

there is the so-called Bessel correction, and it is applied in order to obtain the right result. The application of this correction is only necessary because the third movement of Copernicus has not been taken into account. Because of this, a convenient, schematic, mathematical-mechanical world conception or cosmology has come into existence during the last three to four hundred years. It is not in accord with many things, but of course today anyone who mentions this fact is put down as a scientific simpleton. It is scientific to believe that the various facts are quite in accord with each other. Humanity has been lulled to sleep by the Copernican conception of the world with reference to certain facts — facts which can nevertheless be substantiated by inner experience. Human consciousness has been dulled, and in the future care will have to be taken that it is dulled no longer." [31]



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

Endnotes and References

1. Rudolf Steiner, from a lecture held on 3 October 1919, in GA 191.
2. Quoted in https://www.thoughtco.com/aristarchus-of-samos-3072223
3. In this case independent of the diameter of Earth's orbit.
4. 2 January 1921, translation taken from https://wn.rsarchive.org/GA/GA0323/19210102p01.html
5. Elizabeth Vreede, Anthroposophy and Astronomy: The Astronomical letters of Elizabeth Vreede (2001) p. 376.
6. Ibid. Vreede, p. 377.
7. The question mark does not appear in the German original - "eine Art Inklination".
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.
10. "On the Copernican Theory of Precession" by Noel Swerdlow follows the mathematics step by step; Chapter III in "The Copernican Achievement" by Robert S Westman (1976).
11. The phenomenon of precession was first noticed by Hipparchus in about 120 BCE. Timocharis had recorded the star Spica to be located 8° West of the autumn equinox. Hipparchus observed that Spica was only 6° West of the autumn equinox. He was able to work out the dates of Timocharis' observations by the records kept of lunar eclipses and established that the longitudes of the stars had changed over time. He calculated that the rate of precession was between 1° and 2° per century. Modern calculations give 1° every 72 years.
12. W. Carl Rufus, The Astronomical System of Copernicus, http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1923PA.....31..510R&defaultprint=YES&filetype=.pdf
13. Vreede, op. cit., p. 378.
14. 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.
15. At the Gates of Spiritual Science, GA 95, lecture 11, 1 September 1906.
16. The solar apex, i.e., the point on 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)
17. Lecture given on 29 April 1908, in GA 98, my translation.
18. The school opened on 7 September 1919.
19. Alpha Centauri, Earth's nearest star is 4.3 light years away.
20. Discussions with Teachers, 13th Discussion on 4 September 1919, in GA 295. There is some confusion in the German text, in that it says 'errors' where one might expect 'corrections'. This transla-

tion is of Steiner's actual words as recorded by the stenographer.
21. Conferences with the Teachers of the Waldorf School, Volume One, on 25 September 1919, in GA300a.
22. GA 191, 3 October 1919.
23. 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.
24. On 23 December 1919., GA 320.
25. Even the Large Hadron Collider hasn't provided the final answer on the 'real' nature of mass, supposedly lurking in the elusive Higgs boson.
26. Op. cit., Conferences with the Teachers, on 25 September 1919.
27. 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.
28. When asked about the underlying causes of gravity Newton is said to have replied, 'Hypotheses non fingo', 'I do not feign hypotheses.'
29. See for example, lecture 4 (27 December 1922) in The Origins of Natural Science, GA 326.
30. Ibid, lecture 3, 26 December 1922.
31. The Necessity for Spiritual Knowledge, 28 September 1919, in GA 192, from https://wn.rsarchive.org/GA/GA0192/19190928p01.html with minor corrections.

Maarten Ekama

Reports

Forming and Fluidity
Symposium June 6th–8th at the Field Centre, Gloucestershire

The symposium was subtitled, 'How can flowing water help us discover a more dynamic thinking?' This relates to the words of Theodor Schwenk in his introduction to his book *Sensitive Chaos*: "Through watching water and air with unprejudiced eyes, our way of thinking becomes changed and more suited to the understanding of what is alive." It was his opinion than this transformation of thinking is a decisive step which is urgently needed in our time. Given this was written in 1961, I wonder how would he speak of the urgency now. The other inspiration for this study was a comment by the science philosopher Henri Bortoft who, when asked what benefits could there be if more people take up a participatory holistic science, suggested that life would be a little less depressing! We knew from past experience that the experiments, especially when done collaboratively, could engender feelings of wonder. We also thought there might be potential to work together in the future with more public offerings in the field of Flow science. These were the hopes and intentions behind our exploration.

The programme for the symposium included a range of tabletop experiments and outdoor activities with water flowing over and in clay channels and vessels. These were to reveal different gestures in the flow and had been worked out by the co-ordinating group – Philip Kilner, Nigel Wells, David Auerbach, Eva Wohlleben and myself, all of whom in their own ways are engaging with water phenomenology. Although many of us have various ideas of the character of the archetypal gestures in flow and have formed our own threefold concepts etc, this was not intended to be explicit in the programme. Rather than impart any such understanding we wished the flow phenomena to speak in their own way to each participant. We scheduled reflective periods after every experiment and activity, and there were discussion times to share these soundings. Finally, at the end there was a discussion as to what further activities and events might be done and who might carry them.
Not many who came were normally involved with research and just before the event there was a worry that all the reflection would be a burden for the participants. As it transpired this was an unnecessary worry -all appeared to appreciate the reflection time and it helped establish a good breathing rhythm in the engagement with the flow phenomena.
In the reflection participants were invited to write responses to the following questions: What were the first impressions? What happened? What changed? What stayed the same? What experiences and phenomena might this relate to?
So what? and what further questions are arising?

I will not describe all the experiments with dropping and stirring water in jars, trays and tanks, observing trickles and the inner dynamic responses in the water and ourselves. To even name the phenomena is not always helpful. Many people found the collaborative work with the clay vessels and channels most meaningful, and there many surprising discoveries for all of us .The written reflections from the event have all been worked through and further reflections

in the days afterwards have been collected as well. One or two comments might be worth sharing:
"A meeting of the visible and the invisible"
"Resistance calls forth beauty"
" I now have a better sense of a dynamic wholeness at work"
"The stage and the actor are the same medium yet are also different"
"An epidemic of wonder."
"These events are always different and always the same"

The questions raised may prove the most valuable things in future work:-
"So how does one define a single experiment? "
"Where does the context end?"
"How are the velocities of rotation and translation maintained so well in the movement?"

According to my wife, who, while providing important nutritional input to the event, had a more detached onlooker consciousness, it was rather amusing and a bit baffling to see grown men and women trying to run while carrying a tray of water without spilling too much. This was another attempt to get to know the nature of 'water' and it proved also an excellent way to switch off our overactive intellectual minds for a moment.
Another more playful engagement involved a large rubber drum with water on top. This created a flexible receptacle for the moving water, which is also more appropriate for modelling physical flow of fluid in higher animals. Several people could be positioned around this and through collaborative movement of the rubber membrane, some extraordinarily life-like rhythmically changing forms can arise.
This experiment has emerged for me as an unexpected and very effective method for participatory group research with the forming of flow.

All 14 participants have expressed the wish to support and develop further studies and to make them as widely accessible as we can. 9 of us met subsequently for a telephone conference, and 6 people for 2 days of refining the experiments and planning a future exhibition and workshop (in April 2020).

Seeing and reflecting on the way we all engaged with flow and its lawful inherent forming capacity in these days, I become more convinced of the value of studying this in relation to active thinking, as well as to the understanding of what is alive as suggested by Theodor Schwenk . Especially in flowing water I see so many clear yet flexible ideas which are also at work in living organisms. I realise, however, that everyone may discover these principles in their own way and that this is a realm of work where we may begin to touch into an understanding of life, but there is always further aspects to be revealed . The wonder is what activates the exploring.

Simon Charter

If interested in joining in with this research please get in touch simon.charter@live.co.uk, 01453 882114.

The event was supported by the Field Centre and sponsored by Ruskin Mill Land Trust and the Mathematics and Science Group. The ongoing research and development of this programme has been supported by the Anthroposophical Society in GB. We are very grateful for all this assistance.

Next Forming and Fluidity Meeting
The next Forming and Fluidity event will be April 16th to 18th 2020, with an exhibition running for 3 weeks around it at Ruskin Mill and Horsley Mill, (not the Field Centre as in previous years).

IMPORTANT NOTICE: AGM COMING UP 9th NOVEMBER 2019

AGM

Annual Meeting of the Science Group of the Anthroposophical Society in Great Britain
Saturday November 9th 10:00 AM to 4PM at The Field Centre Nailsworth GL6 0QE

1.An Introduction to a planned phenomenological study of Silica in the mineral, plant, animal and human kingdoms. Contributions in Chemistry and Geology are planned, and other contributions are welcome. This is the first of probably a year-long study.

2. Experimental study, Comparing two ways a fluid surface bears movement: the half-ring vortex and the wave (both can travel with remarkably little energy loss). Can one idea be seen in both of these?

3.A discussion on Ernst Schumacher's concept of *Adequatio* (Schumacher, E. F. (1978). *A guide for the perplexed*. New York: Harper & Row). How must our thinking develop to make it adequate to get to know the different levels in Nature?

4. A review of the year's activities, and a preview of 2020.

Other presentations are warmly invited and this is an open event for everyone interested in open-minded scientific work.
Further details available
from simon.charter@live.co.uk , 01453 882114

Grants

Science and Mathematics Group Funding: Call for Applications

We are pleased to announce that small grants are available to members of the Science and Mathematics Group. We can contribute to projects and travel costs (e.g. to conferences). Please contact the treasurer Simon Charter, with a brief proposal outline and a breakdown of costs.
simon.charter@live.co.uk, 01453 882114.

Membership

Note from the Treasurer and Membership Secretary.

The subscription for membership of the Science Group (including receipt of Newsletter) stands at £10 per year. If you have not already done so, please update your standing orders and let me know when this is done. I can still accept cheques but the local bank has closed so paying cheques in is more difficult. Standing orders or direct payment are preferable.

Our account is "The Science Group"
Sort code: 20-23-97
Account No. 90800007 with Barclays.

Membership subscription is £10 (UK), £12 (Europe) or £14 (elsewhere). For all membership and subscription queries please contact Simon Charter, simon.charter@live.co.uk, 01453 882114.

Next Issue

This newsletter is issued to members twice each year. There is no set date for the next newsletter. Please send copy to Dr. Judyth Sassoon, School of Earth Sciences, University of Bristol, Queen's Road, Bristol, BS8 1RJ. Tel: 00 44 7811 323658
Email: js7892@bristol.ac.uk
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Acknowledgments

We would like to thank the Ruskin Mill Trust for their help in printing the Newsletter.