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Paolo Sarpi and the first Copernican tidal theory

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Abstract. Despite his demanding religious responsibilities, Paolo Sarpi maintained an active involvement in science between 1578 and 1598 – as his *Pensieri* reveal. They show that from 1585 onwards he studied the Copernican theory and recorded arguments in its favour. The fact that for 1595 they include an outline of a Copernican tidal theory resembling Galileo's *Dialogue* theory is well known. But examined closely, Sarpi's theory is found to be different from that of the *Dialogue* in several important respects. That Sarpi was a Copernican by 1592 is revealed by other of his *pensieri*, whereas at that time we know that Galileo was not. The examination of Sarpi's tidal theory and of the work of Galileo in this period indicates that the theory Sarpi recorded in 1595 was of his own creation. The appreciation that the theory was Sarpi's and that Galileo subsequently came to change his views on the Copernican theory and adopted the tidal theory has major implications for our understanding of the significance of Sarpi's contribution to the Scientific Revolution. Moreover, it appears that several of the most significant theoretical features of the tidal theory published by Galileo in the *Dialogue* – and which proved of lasting value – were in reality Sarpi's.

That Paolo Sarpi for much of his early life succeeded in combining his duties as a Servite with a scientific programme of experimental and theoretical enquiry is revealed by his carefully kept scientific and philosophical notebooks, his *Pensieri*. Sarpi's outstanding abilities were recognized early by his order and led to him becoming procurator general and in 1585 its representative at the discussions in Rome aimed at the reform of the order. It is known that while there he spent time studying the Copernican theory, and his *pensieri* reveal that thereafter he became a convinced Copernican.[1]

Certain *pensieri* recorded by Sarpi reveal two novel arguments in defence of the Copernican theory which at first sight bear a superficial resemblance to arguments which were later advanced by Galileo in the *Dialogue*, a feature that has led a considerable number of historians to conclude that the original ideas must have been Galileo's. One instance, dating from 1592, concerns the possibility of the extrusion of objects from a rotating Earth. This argument is, however, quite different from one later advanced by Galileo in the *Dialogue*. Another is his tidal theory, and though Galileo later published a similar theory to that found in the *pensieri* it is significantly different from Sarpi's and not actually as directly based on the Copernican theory as Sarpi's original. That theory, recorded in *pensieri* 568–571, is based on the Copernican description of the Earth's orbit as being an eccentric circle where the Sun is not at its centre, whereas in the *Dialogue* the

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1 Libero Socio, 'I *Pensieri* di Paolo Sarpi sul moto', *Studi veneziani* (1971) 13, pp. 328–329, 349–352. That Sarpi studied Copernicus at this time is also the conclusion of John L. Heilbron in *Galileo*, Oxford: Oxford University Press, 2010, p. 81; and that he became a convinced Copernican is the view of David Wootton, *Paolo Sarpi, between Renaissance and Enlightenment*, Cambridge: Cambridge University Press, 1983, p. 18.

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Earth's orbit is said to be a circle with the Sun at its centre.[2] It has been widely recognized that the theory found in Sarpi's notes is highly original in both form and content, being based on a radically new approach involving an unprecedented combination of terrestrial physics and astronomical theory, and as such was a complete break with previous attempts to account for the tides. It was, moreover, an inertial theory and in that respect quite distinct from all earlier theories that regarded attraction or influence as the cause of tidal movement.

Though throughout the sixteenth century there had existed a wide range of theories, this new theory was a striking break with previous explanations in that it accounted for the origin of the tides using an explanation founded on experience with an argument directly based on the Copernican theory. For in these *pensieri* the explanation of the tides is provided solely in terms of the double motion of the Earth – its daily rotation and its annual orbital motion. It is bold yet very straightforward and an entirely two-dimensional explanation. The idea that movements of the Earth were related to the tides had already been suggested by others and there are two notes in the *Pensieri* that reveal that Sarpi had adopted this idea in 1591 – four years before recording the tidal theory and the year before Galileo's arrival in Venice.[3] In the last decade of the century more than one person advanced the view that there could be a link between the motion of the Earth and the tides. Andreas Cesalpino, a physician, had maintained that the movement of the Earth produced the tides.[4] Cesalpino had taught at Pisa in Galileo's time – and Galileo refers to Cesalpino's ideas in the *Dialogue*. But Sarpi's *pensieri* theory is the earliest-known attempt to provide a physical demonstration of the motion of the Earth and had been seen by Drake and many others to be directly related to Galileo's acceptance of Copernicanism.

However, the earliest indication of Galileo's Copernican sympathies is found in the letter he wrote to Kepler in August 1597 thanking him for the copy of the *Cosmic Mystery* he had sent. In doing so he remarked that he had adopted the teaching of Copernicus many years before as it was capable of explaining many physical phenomena.[5] He did not indicate what those phenomena were, however.

Sarpi's *pensieri* outlining the tidal theory, though they are extremely abbreviated, provide a basic explanation of a daily and an annual tidal cycle based on the Copernican theory. My translation of those notes is provided below.

> Note 568: The diameter of the Earth in the orbit of the annual motion subtends just less than 6 minutes [at the Sun] so that the [Earth's] centre moving less than 60 [minutes per day] in its upper part of the daily motion in 30 minutes advances 1/5, and in the other 30 of the lower is as much retarded. The upper is the night, the lower the day, so that every point of the surface is now fast, now middling, now slow, as with the Moon.[6]

2 Paulo Sarpi, *Pensieri Naturali, Metafisici e Matematici* (ed. Luisa Cozzi and Libero Sosio), Milan: Riccardi, 1996, *pensieri* 568–571, pp. 423–426.

3 Sarpi, op. cit. (2), *pensieri* 499 and 505, pp. 366–367, 370.

4 Andrea Cesalpino, *Quaestionum peripateticarum libri V*, Venice: Iuntas, 1571, 70r–71v.

5 Galileo Galilei, *Le Opere de Galileo Galilei* (ed. A. Favaro), 20 vols., Florence: Barbera 1890–1909, vol. 10, p. 68.

6 Sarpi, op. cit. (2), *pensiero* 568, p. 423.

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The compounding of the two motions attributed to the Earth by the Copernican theory, its orbital motion and its rotational motion, though not stated, is unambiguously implied. This new form of argument in which the result of compounding the physical effects of two independent velocities is treated in this way was a significant innovation. Sarpi's concluding remark identifies the similarity between the cyclic change in the speed of the Moon's motion relative to the Sun and that of the Earth's surface. The Moon's motion is at a maximum when its orbital motion about the Earth is in the same direction as the Earth's orbital motion and a minimum when a fortnight later it is moving in the opposite direction. The similarity of the two sets of combinations in the motions of the Earth and Moon is stated in so cryptic a fashion that its significance has been overlooked:[7]

> Note 569: Any water carried in a basin, at the commencement of its movement remains behind and rises at the rear, as it has not yet fully received the motion, and when stopped it continues to be moved by the received motion and rises at the front. The seas are waters in basins, so that the annual motion of the Earth has the effect that it is now swift, now slow and then average by the diurnal motion, which is seen in the diverse movement of the basin. And if the seas are so large that they have a quarter [sphere] so that part is in the swift, part in the average, there will be a greater difference, and yet more if they have a half-sphere, so that part is in the swift and part in the slow.
>
> Note 570: Therefore it is manifest that lakes and small seas do not produce this effect being insensible basins. It is also manifest that the variation of the eccentricity, varying the ratio of the diurnal to the annual motion, equalizes the augmentations and the decrements. Also it is manifest, how the different positions of the shores may cause variation, if their length is along or across the motion. Finally it is manifest how the motion of the seasons, carrying the shores now to one site and now to another, makes an annual variation of the augmentations and decrements.

Note 570, though very compressed, does succeed in distinguishing between and distinctly identifying three ways in which the magnitude of the action of the primary cause is altered and how those alterations effect the tide. Two are quite obvious and concern the way in which the effect of the Earth's rotation can be directly reduced. The first is where the total effect of the Earth's rotary action is reduced by the size of the sea or lake. The second, indicated in the third sentence, maintains that the orientation of the sea will determine the effect of rotation – that is to say, the greatest tides are expected in seas that run east–west while the least should occur in those that run north–south.

The third way in which the tide is thought to change is less obvious as the sentence is very compressed and the reasoning supporting Sarpi's conclusion is unstated. That is, he omitted to indicate the crucial assumption that provides the foundation of this argument. It is that the relative magnitude of the tide is always proportional to the ratio of the speed of the Earth's surface produced by the diurnal rotation to the orbital speed of the Earth at that point in its orbit. Thus the third cause of the change in the tides is the change in the ratio of the diurnal rotation to the Earth's orbital speed as it moves along its orbit. It is the change in that ratio produced by the Earth's motion in its eccentric orbit which alters the Earth's speed and accordingly produces a change in the tides. That follows as there is a decrease in the ratio of the Earth's rotary motion compared to its orbital motion over one

7 Here Sarpi identified a symmetry but his cryptic style has led to it being overlooked; Drake misunderstood Sarpi's reference to the Moon. See Stillman Drake, *Galileo Studies*, Michigan: University of Michigan Press, 1970, p. 201.

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half of its orbit and an equivalent increase over the other half. The relative magnitude of the tide is at all times proportional to that ratio. The fourth sentence notes that it follows as a consequence that the magnitude of the tides is related to the seasons – as the magnitude of the tide will depend on where the Earth is in its eccentric orbit about the Sun. Thus each of the four sentences refers to a different consequence of the theory.

The first and third sentences are unproblematic. The second sentence states, 'It is also manifest how the variation of the eccentricity varying the ratios of the annual and diurnal motion equalizes the augmentations and decrements'. The claim that the conclusion is 'manifest' indicates that it follows directly from the preceding assumption, i.e. that the variation in the Earth's orbital speed produced by the eccentricity of its orbit continuously alters the ratio of the speed of rotation to the orbital speed. As the theory assumes that the tide depends inversely on the orbital speed of the Earth it can only be the changes in the Earth's speed which result from the eccentricity of the orbit that could cause the cyclic variation of the tides. That is why the final sentence of the note states that this 'manifestly' produces an annual cycle of variation. The cyclic increase and decrease in the speed of the Earth will mean that over one half of the year as the Earth's orbital speed decreases there is a period in which the daily tide increases to a maximum, followed by a period in which as the orbital speed increases the magnitude of the tides reduces – returning at the end of one year to their initial value. Thus the increase in tides over one half of the year is balanced out by the decrease over the other. Sarpi, in recording his ideas, needs no more than an aide-memoire and simply provides the main outline and the conclusions of his theory, which indicates that, as the theory predicts an annual cycle of change in the ratios between the magnitude of the diurnal and orbital motion of the Earth, then it follows that there will be an annual cycle in the tides – in which the increase in the tides during one half of the cycle is balanced out by the decrease of equal magnitude in the other. The cryptic statement summarizing his conclusion is: 'It is also manifest how the variation of the eccentricity varying the ratios of the annual and diurnal motion equalizes the augmentations and decrements' – a statement so compressed that its meaning is far from obvious.

Thus this tidal theory is founded on the basic assumption of the Copernican theory that the Earth moves in an eccentric orbit about the Sun and that its orbital speed changes cyclically over the year. In that respect it is utterly different from Galileo's later theory. Indeed the unique and fundamental cause of tidal variation in Sarpi's view is the continuous change in the Earth's orbital speed postulated by Copernicus. This follows as we have said because the total mechanical effect is believed to be proportional to the ratio of the speed of the Earth's diurnal motion to its orbital motion. However, this crucial assumption is implicit and, though not stated, it is the foundation of Sarpi's theory. This concept is an idea entirely absent from Galileo's first account of his own tidal theory which appeared in his *Discourse on the Tides* in 1616.

Having outlined the core of his theory, Sarpi records in note 571 the similarity between the motion of the sea and that of the water in the bowl described in note 569:

> The motion of the sea will be a motion composed of two things: first the remaining behind and rising of the water when the motion passes from slow to fast, and from its natural [propensity]

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> to return to equilibrium; the second, of following the motion when it passes from slow to swift [*sic*], and therefore to rise with its natural [propensity] to return to equilibrium.[8]

Note 571 points out that there are two distinct kinds of motion seen in the sea. First is the motion produced by the change in the absolute motion of the Earth in space: when the Earth speeds up, the water is at first left behind – that is the resting and rising of the water when the motion of the Earth passes from slow to swift: the second is when the motion of the Earth slows down and the water surges forward, rising as it does so. The meaning of this passage is unmistakeable and the physical argument perfectly simple in each case. It is, as can be seen, no more than a description of the motion to be expected in the sea that is the equivalent of the account of the motion of the water in a bowl provided in note 569. The notes indicate that Sarpi regarded this parallel as a fundamental basis for the theory and saw the significance of the analogy and the physical process precisely.

The premise that the Earth moves in an eccentric orbit about the Sun is taken directly from the Copernican theory. However, its use as a means of accounting for an annual tidal cycle is unique as there is no known record of anyone else suggesting or using it. When in 1616 Galileo produced his tidal theory in the *Discourse on the Tides* as part of his attempt to prevent a ban on Copernican astronomy, he treated the Earth's orbit as circular, with the Sun at the centre of its orbit, as his words reveal: 'let us briefly explain these motions attributed to the terrestrial globe. The first and largest one is the annual motion under the ecliptic, from west to east, in an orbit or circle whose radius is the distance of the Sun to the Earth'.[9] But this is not the view of the Earth's motion presented by Copernicus, nor that found in Sarpi's outline of the theory, so it does as a consequence provide an account of the tides that is different from that found in Sarpi's *Pensieri*. However, Drake was convinced that the theory in the *Pensieri* was in reality Galileo's and moreover that it revealed his conversion to Copernicanism.[10] Drake's view has come to be widely accepted.[11] Drake argued,

> The absence of previous or subsequent notes relating to the tides or to arguments for or against Copernicus suggests that the above paragraphs [568–571] merely record an interesting theory

8 Sarpi, op. cit. (2), *pensiero* 571, p. 426.

9 Galileo, op. cit. (5), vol. 5, p. 381; Maurice A. Finocchiaro, *The Galileo Affair: A Documentary History*, Berkeley: University of California Press, 1989, p. 122. Drake, op. cit. (7), p. 254.

10 Drake, op. cit. (7), pp. 201–204. Drake, *Galileo: Pioneer Scientist*, Toronto: University of Toronto Press, 1990, p. 72.

11 Sarpi, op. cit. (2), CLVI–CLVII. Albrecht Folsing followed Drake in *Galileo Galilei, Prozess ohne Ende*, Munich: Piper Verlag, 1983, pp. 160–161. Others following Drake's view include Michael Sharratt, *Galileo: Decisive Innovator*, Cambridge: Cambridge University Press, 1996, p. 71; Annibal Fantoli, *Galileo for Copernicanism and for the Church*, Rome: Vatican Observatory Publications, 1996, p. 68; Jurgen Renn, Peter Damerow and Simone Reiger, 'Hunting the white elephant: when and how did Galileo discover the law of fall?', *Science in Context* (2000) 13, pp. 299–423, 350; Wootton, op. cit. (1), pp. 62–63. However, Heilbron, op. cit. (1), pp. 115 and 217, takes the view that Socio and Drake's arguments appear to be equally plausible; Paulo Palmieri, 'Re-examining Galileo's theory of tides', *Archive for the History of the Exact Sciences* (1998) 53, pp. 229–230, regards the issue as open. Socio's strong reasons for rejecting Drake's interpretation are at CLCI–CLIX. Federico Bonelli and Lucio Russo, 'The origin of modern astronomical theories of tides: Chrisogono, de Dominis and their sources', *BJHS* (1996) 29, pp. 385–401, 398, regard Sarpi as the creator of the theory.

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heard from Galileo, with whom Sarpi often talked at Venice or at Padua in these years, rather than one which Sarpi himself had thought out.

But in the *Pensieri* there are earlier notes relating to the tides and there are other arguments in favour of Copernicus that Drake either overlooked or misunderstood. There are no grounds to doubt that these notes were recorded by Sarpi in 1595, however. As Socio has discovered, Sarpi's earlier interest in the tides can be seen in *pensieri* 499 and 505 which date from 1591 – before Galileo's arrival in Padua. There is also one of the *pensieri*, 202, which does refer to Copernicus, written in 1585, in which Sarpi defends the claim that as the Earth's annual orbit is so small in comparison with the distance of the celestial sphere, the effects of its motion might not be detectable. This argument appears in *De Revolutionibus* but Drake maintained that the view defended was Cusanian rather than Copernican, though he failed to explain why.[12]

In another *pensiero*, 540, written in 1592, Sarpi defends the Copernican belief in the Earth's axial rotation. There is also a direct reference to Copernicus in *pensiero* 384 dating from 1588, which, taken in conjunction with the four other direct references to Copernicus – in *pensieri* 639, 640, 643 and 655 – reveals his strong interest in the theory.[13]

As Drake was convinced that Galileo was the first to devise a tidal theory based on the Copernican theory, he would not accept that Sarpi's notes might represent his own ideas. Drake appreciated that Fulgenzio Micanzio knew that Sarpi had a particular interest in the tides and that he at one time contemplated writing a treatise on the subject, so there exists no prima facie reason to suppose that the ideas in the notes could not have been his own.[14] Drake also recognized there was nothing to indicate that these notes were a record of Galileo's ideas, but felt that this could be explained by the fact Sarpi did not indicate his use of the ideas of others in his *pensieri*. But this is not so. Sarpi cites seven of his contemporaries in the *pensieri* – including Galileo in one case, as Socio has pointed out.[15]

Though Drake looked for textual evidence to support his claim he could find nothing in the way the notes were presented to suggest that Sarpi was simply recording views heard in conversation. For he admitted that 'if Sarpi made these entries to record a theory heard in conversation, it is undeniably odd that four separate paragraphs rather than a single one should be devoted to it'.[16] Nor is there any evidence to support the claim that Sarpi may have recorded the ideas of others *without citing them*. And as it is known that there are indeed cases in the *pensieri* when a clear reference to the author of the views considered is made, that obviously weakens Drake's claim for there is no reference to Galileo in the *pensieri* recording the tidal theory. Nor is there any reference

12 Drake, op. cit. (7), p. 202; Sarpi, op. cit. (2), p. 182.

13 Sarpi, op. cit. (2), pp. 290, 477–483, 496. For Socio's discussion of *pensiero* 401 see CXLVIII–CXLIX.

14 Stillman Drake, *Galileo at Work*, London: The University of Chicago Press, 1978, p. 37; Drake, op. cit. (7), p. 204.

15 Drake, op. cit. (7), p. 203; Cozzi, in Sarpi, op. cit. (2), CLVII, who identifies references to Benedetti (twice), Vesalius, Bartoleme de Medina and Agostino da Mula, as well as Galileo and a number of lesser figures like il Panizza and il Valier.

16 Drake, op. cit. (7), p. 203.

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to Galileo in relation to any of the Copernican *pensieri*. There is therefore no evidence at all that Sarpi recorded Galileo's rather than his own views at any time.

In order to judge the merits of Drake's widely accepted interpretation of the notes, it is necessary to examine in detail his translation with his editorial additions, which is therefore provided:

> Note 568: The diameter of the Earth subtends six minutes and a bit less, in the orbit of annual motion; so that, the centre [of the Earth] moving less than 60 [minutes, or one degree, per day], in the upper part of the daily motion advances one-fifth in thirty minutes, [of arc; that is, in half a day], and in the other thirty [minutes, or half-day] it is retarded by that amount. The upper [part] is the night, and the lower the day. Whence every point on the surface is now fast, now average, and now slow, as in [i.e. with respect to] the [stellar] sphere.
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> Note 569: Any water carried in a basin, at the beginning of its transport, remains behind and rises at the rear, because the motion has not been thoroughly received; and when stopped, the water continues to be moved by the received motion and rises at the front. The seas are waters in basins and by the annual motion of the Earth make that effect, being now swift, now slow, and again average through the diurnal [motion], which is seen in moving the basin diversely. And if the seas are so large that they have a [quarter-sphere (?)] so that part is in the swift and part in the average [motion] there will be greater diversity, and still greater if they have a half-sphere, so that part is in the swift and part in the slow [motion].
>
> Note 570: Hence it is manifest that lakes and small seas do not produce this effect, being insensible basins. It is also manifest how the variation of the eccentricity varying the ratios of the annual and diurnal motion equalizes [*sic*] the augmentations and decrements. Also it is manifest how the motion of the seasons, carrying the shores now to one site and now to another, makes an annual variation of the augmentations and decrements.
>
> Note 571: The motion of the sea will therefore be a motion composed of two things: first, of the resting behind and rising of the water when the motion passes from slow to swift; and, from its natural [tendency] to return to equilibrium, the second, of following the motion when it passes from slow to swift [*sic*] and therefore to rise with its natural [tendency] to return to equilibrium.[17]

However, because Galileo rejected the idea that the Earth moved in an eccentric circular orbit, it is not possible to reconcile the reference to the eccentricity of the Earth's orbit in note 570 with Galileo's explanation of the tides found in the *Dialogue*. In attempting to explain this Drake felt compelled to argue that note 570 should not be read literally. That nevertheless appears to be the only justifiable procedure and evidently the most promising means of arriving at Sarpi's intended meaning. For that reason the most credible reading of the note is naturally one in which the word 'eccentricity' had its known and accepted meaning. But for reasons he did not make clear, Drake maintained that Sarpi actually intended to record something quite different, claiming that he actually meant to refer to 'differences in latitude' – and not 'eccentricity' at all. Thus in Drake's view the passage should read,

> Hence it is manifest that lakes and small seas do not produce this effect, being insensible basins. It is also manifest how the variation of the differences in latitude varying the ratios of the annual and diurnal motion equalizes the augmentations and the decrements.[18]

17 Drake, op. cit. (7), pp. 201–202.
18 Drake, op. cit. (7), pp. 201–202.

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But the obvious puzzle this presents is that if Galileo had said that then why would Sarpi not have written it down?

Moreover there appears to be no evidence to support the view that Sarpi, or Galileo, when dealing with an issue where a particular concept would directly express their intended meaning, would not use it. It also implies that either Sarpi or Galileo was unfamiliar with or did not understand the meaning of the term 'eccentricity' (*eccentricita*). For that reason alone the claim that Sarpi, when he wrote 'eccentricity', had meant 'differences in latitude' is implausible. It would be particularly misleading to write 'eccentricity' here if it was not meant as it had an obviously relevant meaning within the context. Eccentricity is, in any case, quite unrelated to difference in latitude. It is hard to see what grounds there might be for anyone with a knowledge of astronomy to use one as a synonym for the other. Therefore to claim that someone of Sarpi's or Galileo's knowledge might do so is not credible. The argument advanced by Drake would not therefore seem to justify setting aside the obvious meaning of Sarpi's note 570 and substituting another for which no evidence of any kind has been produced. On the contrary, there is no reason to suppose that the term 'eccentricity' in note 570 does not have its accepted meaning and applies to a motion referred to in the same sentence – the Earth's annual motion.

It would also appear that Drake either overlooked or failed to recognize the significance of Sarpi's astronomical *pensieri*. For they reveal very directly that the idea that Sarpi may have misused or mistaken the meaning of the term *eccentricita* is unrealistic. In *pensiero* 638 Sarpi demonstrates his familiarity with the concept 'eccentricity' beyond any shadow of a doubt. In it Sarpi writes,

> There is no difference between an eccentric circle and an epicycle, provided the eccentricity [*eccentricita*] is equal to the semi-diameter of the epicycle. If the epicycle moves equally [at the same rate] as the homocentric [deferent], that makes the eccentric circle stable, if more slowly it lags in consequence, if more swiftly it moves ahead.

From which we see that Sarpi was conversant with the mathematical technicalities of Copernican astronomy – a fact also revealed by several other of his *pensieri* concerned with astronomical problems of a mathematical nature. In view of this there is hardly room for doubt that when in *pensiero* 570 Sarpi referred to *eccentricita* he knew precisely what he meant. It is also the case that study of the notes relating to Copernican astronomy cited above reveals quite unmistakably that Sarpi examined the eccentricity of several planetary orbits and had much more than a passing knowledge of mathematical astronomy.

There are further serious difficulties with Drake's interpretation. The theory outlined in Sarpi's *pensieri* refers to two basic and well-known tidal phenomena – the daily tide and the annual tidal cycle. The first is explained in *pensieri* 568 and 569, the second in 570. Drake's proposed reading of the text suggested that the theory indicated that the tides vary with latitude and that Sarpi had recorded that idea by writing 'the variation of eccentricity'. But Drake did not intend to suggest that any part of the theory outlined was of Sarpi's own creation. So he was not advancing the opinion that the idea of relating tide to latitude was Sarpi's. But if it had been Galileo's belief then that would mean that

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he had discovered a significant consequence of the theory. But unlike the case of the daily tide and the annual tidal cycle this would have had the consequence of introducing a novel and quite unsuspected feature of the tides – for this was definitely not a known feature of the tides. It does therefore appear somewhat incongruous in a basic outline of the theory.

The aim of the notes was to briefly outline how the theory could account for the annual and daily tidal phenomena. But on Drake's interpretation there is no explanation of the annual tidal cycle. Moreover, neither Galileo nor Sarpi could have had any grounds for believing in a variation of tidal flow with latitude. If eccentricity was taken to mean 'differences in latitude' that would explain (or rather predict) a variation in the diurnal tide with latitude, from a maximum at the equator to zero at the poles. That is Drake's proposed interpretation of the text. Nevertheless, and as Drake appreciated, it is quite unmistakable that Sarpi believed that the explanation provided an account of the cause of the annual tidal cycle. Drake's response to this was to suggest that the *pensieri* imply an understanding of Galileo's quite different explanation, which appeared thirty-seven years later in the *Dialogue*, whereby the annual tidal cycle is said to be a consequence of the inclination of the Earth's axis. But Drake did not identify the sentence concerned, or what he regarded as a sign of the presence of this explanation. Study of the notes reveals that there is no reference to the Earth's axis – nor to its inclination. Sarpi's explanation is entirely two-dimensional. So there is no evidence to support Drake's explanation.

There is, in any case, nothing to suggest that Galileo arrived at the view that the inclination of the Earth's axis influenced the tides until sometime after 1616. For even in his *Discourse on the Tides*, which he completed in that year, and where he explains the tidal phenomena in far greater detail than anything in Sarpi's notes, we find that there is no mention of an annual tidal cycle. He does, however, refer to the inclination of the Earth's axis in the *Discourse* so that an indication that this gave rise to an annual tidal variation could have considerably strengthened his argument. That was certainly his view in the *Dialogue* and it is a view that has been accepted since by many historians. But he made no mention of it.[19] The obvious explanation for his failure to use that argument is that it had not at that point occurred to him. The puzzle that is presented by Drake's claim that Galileo believed that the tidal theory predicted a change of tide with latitude does not end with the Sarpi notes. If it was true, and if, according to Drake's interpretation, Galileo regarded it as significant in 1595, why is there no mention of it in the *Discourse on the Tides* or in the *Dialogue*? A crucial element in Drake's interpretation is that when Galileo informed Sarpi of his new theory Sarpi then decided to record it, but Sarpi had not at that point fully grasped the nature of Galileo's explanation. This, Drake claimed, was revealed by certain slips Sarpi made in recording it. However, only one is identified in the text – which is the simple reversal of the word order of 'slow' and 'swift' in line 5 of *pensiero* 571 – which in reality is hardly a convincing argument – and insufficient to support Drake's claim. Such a trivial slip on its own could hardly justify the claim that Sarpi did not understand the argument.

19 Galileo, op. cit. (5), vol. 5, p. 381; Finocchiaro, op. cit. (9), p. 122.

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(The only other instance cited by Drake is the claim that 'renders equal' should have been written rather than 'equalizes' – but that does not affect the meaning and is certainly not an obvious slip).[20]

Drake's pivotal argument in effect amounted to the claim that the reversal of two words in line 5 of note 571 indicated that Sarpi was uncertain of the whole explanation. But the argument involved is so simple that it is hard to see how a misunderstanding could arise. There seems no room to doubt that Sarpi understood the effects of the moving basin referred to in note 569. But as 571 is in reality no more than a reformulation of the first part of 569 and the argument in both cases is straightforward, there really do not appear to be any grounds for supposing Sarpi did not understand it. There is in any case a further severe difficulty with Drake's argument, as Cozzi and Sosio pointed out. As Drake recognized, the *Pensieri* text we now have is a copy of the original made in the eighteenth century.[21] The original notes perished in a fire. It is therefore impossible to know whether any slips of this kind were in the original or made during transcription. It is, moreover, part of Drake's interpretation that someone to whom the explanation was unfamiliar would be more likely to make a slip than someone who understood it – that would point to the time when the copy was being made as the most likely occasion for such a slip to occur. Thus Drake's own explanation evidently rules out any reliance on such a detail.

Drake also claimed that had the theory been Sarpi's, Galileo's use of it in the *Dialogue* would have been recognized by Micanzio – and Galileo would have been accused of plagiarism as a consequence. Drake's hypothesis is entirely speculative since there is no evidence of any kind in its favour, whereas there do exist several perfectly good reasons for thinking that Micanzio had no knowledge of the theory and additionally that he would not have understood the *Pensieri* theory.

There is no evidence of any kind that Sarpi went any further with his tidal theory than is seen in the *Pensieri* notes. If he had, one might expect to find some indication of that somewhere. Nor do we have any evidence that Micanzio had any definite knowledge of Sarpi's theory, or that he understood it. Why would he have done? There is certainly no evidence that he had seen Sarpi's *Pensieri* notes or discussed the theory with him. This examination of those notes has revealed that their meaning is far from obvious. There are in fact no grounds for supposing that Micanzio could have understood Sarpi's theory. What is known is that Micanzio refers to Sarpi communicating with Mariote concerning a treatise on the tides – but as Socio has pointed out there are no grounds to suppose that Sarpi did more than provide an exposition of what he had proposed in the *Pensieri*.[22]

This exposition, Socio suggests, was probably an amplification of the ideas in the notes with a fuller explanation. As far as understanding the theory was concerned, Socio is unconvinced either that Micanzio would have fully grasped what the theory was about or that he had ever seen any treatise on the tides. Thus, though Socio believes that Sarpi

20 Drake, op. cit. (7), p. 203.
21 Drake, op. cit. (7), p. 201.
22 Sarpi, op. cit. (2), CLVII–CLVIII.

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may have provided Mariote with an outline explanation of his theory, he is doubtful that a treatise as such had ever existed anyway. Socio's account is a perfectly credible explanation of what is known. So Drake's claim that Galileo would inevitably have been accused of plagiarism by Micanzio on publishing his own theory proves entirely speculative.

Though there is no evidence that Sarpi never managed to complete a treatise on the tides, there is no reason to suppose that he may at one time have intended to write one. Naturally one would expect to find some evidence of his own theory in his working notes. Drake accepted that Sarpi planned to write a treatise and so presumably that Sarpi had some ideas of his own on which to base it. The earliest signs of this interest Socio has found in *pensieri* 499 and 505 written in 1591.[23] There Sarpi raised the idea that movement of the Earth's centre would create motion in the sea. In 1592 we have the earliest signs of Sarpi's belief in the Earth's rotation in *pensiero* 540. But only in 1595 are the tides linked to Copernicanism in *pensieri* 568–571. Thus it is possible to see evidence of the development of Sarpi's attempt to explain the tides over time. But the six *pensieri* cited above represent the only surviving evidence of a completed theory of the tides – which naturally suggests that it was in reality his only theory. Drake, we must assume, never noticed what would appear to be a very unexpected feature of the *Pensieri* according to his interpretation – a complete absence of any of Sarpi's own ideas on the tides. That appears to be a particularly perplexing consequence of his view. As Sarpi was meticulous in keeping a careful record of his most significant ideas, how could there not be some record of the ideas that were to form the basis of his projected treatise?

A claim fundamental to Drake's interpretation of the *Pensieri* is that there is no evidence whatever of Sarpi's Copernican belief anywhere within it. But he evidently overlooked *pensiero* 540 composed in 1592. Drake believed that it was clear from *De Motu* that Galileo was not a Copernican at that time. However, *pensiero* 540 reveals belief in the rotation of the Earth – and provides an entirely original argument to support it. It points out that the Earth's rotation meant that an object on the Earth's equator moves at fifteen miles a minute. It concludes that the force (*la forza*) causing that motion would be less than the force that moved the object towards the Earth's centre – as that would cause it to move more than fifteen miles in a minute.[24]

23 Sarpi, op. cit. (2), pp. 366, 370.

24 Sarpi, op. cit. (2), p. 401, *pensiero* 540. The evidence of *pensiero* 540 reveals that in 1592 Sarpi believed in the Earth's rotation. Galileo did not believe in the Earth's rotation at that time and there is no indication of his influence in any case. Socio and Cozzi maintain that the *Pensieri* indicate that Sarpi influenced and preceeded Galileo at several points. Renn, Damerow and Reiger argued that the claim that Galileo could have taken ideas from Sarpi is unconvincing in view of the shared sources of their ideas. However, Renn, Damerow and Reiger argue that it is possible to reach the opposite conclusion, that Sarpi was influenced by Galileo, but provide no indication of how that could be done. Thus it is argued that the tidal theory was Galileo's. See Renn, Damerow and Reiger, op. cit. (11), p. 350, and that Sarpi's non-extrusion argument is an anticipation of Galileo's later version, at p. 351 n. 54. However, Cozzi and Socio's interpretation appears more convincing. See Sarpi, op. cit. (2), p. 400. In Socio's subsequent article, 'Paolo Sarpi, un frate nella rivoluzione scientifica', *Rispensando Paulo Sarpi. Atti del convegnointernationale di studi nel 450 anniversario della nascita di Paolo Sarpi.* A cura di Corrado Pin. Ateneo Veneto, 2006, the case is again made for the independence of Sarpi's thought from Galileo's influence. It is argued that Sarpi was effectively a mentor for Galileo in a number of respects.

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There is no reason to suppose that this argument was not Sarpi's. Drake's original claim that the Copernican arguments in the *Pensieri* must be Galileo's as Sarpi had no interest in the Copernican theory and was not ever a Copernican has been disproved. That he had studied Copernicus since 1585 and did become a Copernican is now recognized. Consequently Heilbron, from an extensive study of the evidence, concluded the claims to be evenly balanced as to the authorship of the tidal theory. Others, like Wootton, still follow Drake and regard Galileo as the Copernican innovator and its creator.[25] But the existence of the Copernican argument in *pensiero* 540 does inevitably change the situation. The recognition that Sarpi was a Copernican and did devise pro-Copernican arguments reveals the claim that all Copernican arguments in the *Pensieri* are inevitably Galileo's to be fallacious. Drake's argument that Sarpi's tidal theory was Galileo's was reliant on those claims and on the claim that Sarpi's theory was fundamentally the same as that in the *Dialogue*. But we have seen that the latter assertion is mistaken. On the contrary, Sarpi was obviously a long way ahead of Galileo in 1595 and not surprisingly this was also the case in 1592. As Sarpi devised his tidal theory in 1595, it is clear now that Galileo subsequently adopted it, extended it and changed it in a number of ways. That same process also occurred with Sarpi's argument in *pensiero* 540. For Galileo made fundamental changes to that argument also – his own in the *Dialogue* conflicts with Sarpi's. Moreover, the form of the two arguments is quite different – though they may appear to have a superficial resemblance.

There are in any case serious difficulties for any claim that Galileo was a Copernican in 1592 for the evidence is strongly against it. We know from *De Motu* that in 1592 Galileo was definitely not a Copernican – a point made by Drake, who did not believe that Galileo became a Copernican until 1595. Drake believed, as Wootton and Heilbron do, that Galileo was not a Copernican when he left Pisa in the summer of 1592 and retained his *De Motu* theory through 1592. Wootton also believes that Sarpi, if he was presented with Galileo's *De Motu* theory of motion late in 1592, would not have accepted it.[26] For the study of *De Motu* and the *Dialogue* reveal beyond question that Sarpi's and Galileo's views on motion – including circular motion – were in 1592 utterly different – and that they remained so.

Sarpi's argument in *pensiero* 540 allows that a force tending to cause extrusion from a rotating body does exist and at a given speed of rotation will cause extrusion. But to Galileo in 1592 circular motion was a case of neutral motion, requiring no (or minimal) force for its continuation. So a sphere moving or at rest on a smooth globe continues undisturbed, no matter what its speed. Therefore extrusion would not occur. This belief that there was no possibility of a force of extrusion disrupting the circular motion of a body moving about the Earth's centre was retained by Galileo throughout his life. The claim that extrusion as a consequence of rotation about the Earth's centre was a physical impossibility was strongly argued in the *Dialogue* but an argument that rules such an event out as a physical possibility is of course entirely different from one like Sarpi's which maintains that it is a case decided only by the relative magnitude of the force of

25 Heilbron, op. cit. (1), p. 217; Wootton, op. cit. (1), pp. 62–63, 149–150.
26 Wootton, op. cit. (1), p. 45.

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extrusion and the force of attraction of the Earth on the object concerned. Even when Galileo's argument is examined it is found to be based on a completely different and rather obscure argument which physically is utterly unlike Sarpi's. Galileo's view of the physical situation was evidently always quite different from Sarpi's. It would be quite impossible to arrive at Sarpi's correct conclusion from either of Galileo's false views of the physical situation. Moreover, Sarpi's argument that extrusion was possible and depended on the speed of rotation was correct, whereas Galileo's opposing view that it could never occur was wrong. Sarpi and Galileo prove to be totally opposed to each other here. Thus though both shared the aim of explaining why extrusion of objects from the Earth's surface does not occur, Sarpi's explanation was not in any sense an anticipation of Galileo's.

Though Wootton's views are a development from Drake's position, the task of claiming that Galileo was the conceptual innovator who first believed in the Copernican theory is now considerably more difficult than Drake found it. Since Wootton appreciates that Sarpi studied Copernicus and became a Copernican, that removes any support for Drake's claim that any pro-Copernican argument in the *Pensieri* must be Galileo's. Added to which there seems little prospect of making credible the claim that Galileo might have so suddenly adopted a pro-Copernican view during the dying days of 1592. How or why that could have come about so rapidly does in reality prove inexplicable. Therefore the claim that Galileo might have changed his outlook from being sceptical regarding Copernicanism to accepting it within a month or so of arriving in Venice proves implausible.

Consequently the claim that with *pensieri* 540 Galileo was the Copernican innovator while Sarpi is presumed to have recorded his ideas is not credible. On the contrary, it appears that *pensiero* 540 presents us with a further instance where Sarpi's argument is new and distinctly different from Galileo's later treatment – and provides strong evidence that Sarpi was a Copernican who developed his own ideas independently. For not only is there the evidence of the pro-Copernican argument found in *pensiero* 202 written in 1585, but also we can see that it was Sarpi who was the creator of the relatively complex tidal theory in the period leading up to 1595. All three represent cases of new pro-Copernican arguments. There is no sign of Galileo's creation of any pro-Copernican arguments before 1610, however – even with the support of his remarkable telescopic discoveries he evidently hesitated right up until the last minute before revealing his support for the theory. For his decision to make comments favourable to the Copernican theory in the *Starry Messenger* was made very late in the day and only just before it went to press – which Wootton has rightly identified as significant.[27]

Galileo, we know from *De Motu* and his 1597 letter to Kepler, and from other evidence, was very circumspect and took time to make up his mind on major issues. He was in no rush to make a decision regarding the Copernican theory in 1592, nor in the following years. We know he was cautious at this point and revealed little of his views. That he said to Kepler in 1597 that he had found the Copernican theory capable of explaining many phenomena has often been regarded as an indication that he believed

27 Wootton, op. cit. (1), p. 103.

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that it could account for the tides, and Drake, like many others, has taken that to be an indication that he had devised a theory. But that statement could be accounted for in a number of ways, one of course being that he had at that point seen and discussed Sarpi's treatment of extrusion and his tidal theory. It is widely believed that he was familiar with both of these arguments by 1597 in view of the *Pensieri* evidence and of his discussions with Sarpi. Such differences of view that exist concern the question who thought of these arguments first. Galileo only had to have become convinced that each contained the kernel of a valuable argument in favour of Copernicus to make the remark he did to Kepler. That he was quick to see such possibilities we know. That he quickly grasped the potential value of Scheiner's discovery of the sunspot cycle in 1630 to devise a Copernican explanation is unmistakable. That appears to represent a parallel case to the tidal theory. He claimed Scheiner's discovery and advanced it in the *Dialogue* as a demonstration of the truth of the Copernican theory – to the horror of the actual discoverer.[28]

From 1592 on we know that Galileo benefited greatly from his discussions with Sarpi and grew to have a high estimation of his remarkable knowledge and his mathematical ability. They exchanged ideas regularly and worked together on a number of scientific investigations. He was later to observe 'no one comes before him in knowledge of the mathematical sciences'.[29] From the outset, Galileo, like the rest of the circle of intellectuals that met at Pinelli's house in Venice, had found Sarpi to be both stimulating and a source of new ideas. But the extent of his originality and his influence on Galileo has, it appears, been generally underestimated.

Wootton judges that as soon as Galileo arrived in Venice he could have found his views on motion challenged by Sarpi. It is certainly true that for the first time he had met an original thinker with radical ideas who was his intellectual equal. That Galileo repeatedly sought his views we know. Galileo's changing views on Copernicanism and motion would appear to have been stimulated by his exposure to Sarpi and those of his Venetian associates he met while residing at the Pinelli residence. That he did over time become more sympathetic to the Copernican theory was a consequence of this. During that time the most interesting and important ideas found in Sarpi's tidal theory were adopted by Galileo and contributed significantly to his physics and to his astronomy – and subsequently to the scientific revolution. The unavoidable implication of Sarpi's authorship of the first Copernican tidal theory is therefore that Sarpi's role in the scientific revolution, significant though we know it to have been, has so far been underestimated. That he had made important discoveries in other fields, and was

28 Drake, op. cit. (7), pp. 185–186, indicates that the evidence rules out the possibility that Galileo ever observed the sunspot cycle as he claimed; while Heilbron, op. cit. (1), p. 280, observes that Galileo simply stole Scheiner's observations and the solar theory based on them and made both serve his Copernican cosmology.

29 Galileo, op. cit. (5), vol. 2, p. 549. However, the general view of the significance of Sarpi's influence is probably more typically reflected in Sharratt, op. cit. (11), p. 77, who sees Sarpi as no more than a gifted amateur 'who was good enough for Galileo to bounce important ideas off'. Even if this is a widely held view others rate his influence as considerable, not only Cozzi and Socio but Galileo's recent biographer Heilbron, who comments, op. cit. (1), p. 80, 'He was to serve Galileo as a guide post, and a sounding board, and, very probably, as a model.' Somewhat similar estimations of Sarpi's significance may be found in E. Reeves, *Painting the Heavens: Art and Science in the Age of Galileo*, Princeton: Princeton University Press, 1997.

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recognized for it at the time, we know from the testimony of the great Paduan anatomist Fabricius of Acquapendente, who acknowledged that Sarpi had pointed out the mechanism of the accommodation of the eye to him. He was, in his view, 'master of all the mathematical disciplines, especially optics'. Fabricius's discovery of the valves in the veins similarly owed more than a little to Sarpi's acute anatomical investigations. It was recognized that Sarpi had aided these discoveries – indeed freely admitted by Fabricius, as was his mastery of the subject of magnetism by Giambattista della Porta – who like Pinelli appeared to regard him as a master of the age. He freely admitted his own intellectual debt:

> I not only confess that I gained something, but I glory in it, because of all the men I ever saw, I never knew any man more learned, or more ingenious, having obtained the whole body of knowledge; and is not only the Splendour and Ornament of Venice or Italy, but of the whole world.[30]

Sarpi's 1595 tidal theory was a radical development that grew out of his aim of supporting Copernicanism and was unrelated to any preceding tidal theory. In that respect it was unlike any of the theories Galileo had developed up until that time in so far as it was completely original and was not a development of existing ideas. It is because of the originality of the theory that Galileo has so often been singled out for particular praise regarding it. He has been applauded for devising the first mechanical tidal theory – and also for providing the first major theoretical attempt to bridge the traditional divide between the physics of heavens and of the Earth. And as it is the first theory in which the physical effect of compounding two motions was treated, this too is regarded as a very important development. Indeed the theory represents the earliest theoretical attempt to examine the physical effects of motion in absolute space and that too has been judged to be very significant.

These innovations were certainly bold and impressive – and so it is hardly surprising to learn that Galileo is said to have been immensely proud of the theory. But it was only the revised non-Copernican version of the theory that could be said to be his – whereas the original theory, and the one that introduced all these bold and praiseworthy innovations into the mathematical and physical discourse of the scientific revolution, was Sarpi's. On these particular points I believe we should henceforth conclude that it was Sarpi who was the bold innovator – rather than Galileo.

30 Cozzi, in Sarpi, op. cit. (2), p. xix, quote from Fabricius, pp. xx, xlii–xliv; Della Porta, *Natural Magick*, London: Young and Speed (1658), p. 190. The translations of Fabricius from Cozzi are those of Heilbron, op. cit. (1), p. 80.

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