The origin of modern astronomical theories of tides: Chrisogono, de Dominis and their Sources

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From the Renaissance to the seventeenth century the phenomenon of tidal motion constituted one of the principal arguments of scientific debate. Understanding the times for high and low water was of course often essential for navigation[1], but local variations (which nowdays are attributed to currents, coastal configurations, prevailing winds, sea-bed shaping and other geographic characteristics) made an inductive approach impractical and precluded the possibility of constructing a universally valid model for predicting these times. Notwithstanding the complexity of the phenomenon and its practical import, however, the early-modern theory of tidal ebb and flow, as clearly emerges from Duhem's analysis,[2], appears to be neither the result of the interpretation of empirical data, nor aimed to their prediction. Rather the interest in tides was of a theoretical nature and was aroused particularly by their double nature, their being at the same time variable and regular, terrestrial and astronomical.

This is particularly shown in the way tidal motion was connected to both diurnal rotation and the phases of the moon (although the monthly cycle of the tides was not evident in all seas). The tides therefore seemed to be proof of a fundamental unity of celestial and terrestrial phenomena; astrologers had traditionally voiced this as evidence of celestial influence on the earth; in any case tides were a decisive bank of proof for any theory aimed at extending to our variable sublunar world the quantitive study traditionally reserved for astronomical phenomena.

In this paper we suggest that a close examination of certain sixteenth- and seventeenth-century works on the nature of tides (particularly the works of Federico Chrisogono, Marco Antonio de Dominis and John Wallis) leads to two conclusions. First, the widespread opinion that holds the theory of gravitation developed by Newton as the sole source of scientific basis for the study of tides must be abandoned; on the contrary, the astronomical theories on tides established in the sixteenth and seventeenth centuries comprised just one of the elements which allowed Newton to achieve his synthesis. Second, these theories were not based on new observations but were themselves attempts to recover knowledge from Hellenistic science.

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We wish to thank those whose

[1] This is not, however, the case for the Mediterranean (where the effect of the tide is negligible practically everywhere) , which may account for the little interest shown in this phenomenon by the Romans.

[2] P. Duhem, *La théorie physique* (Paris, 1914; repr. Paris 1993), chap. VII.

THE STUDY OF TIDES BETWEEN THE MIDDLE AGES AND THE RENAISSANCE

In the Middle Ages many presumed "explanations" for tidal motions were put forward,[3] which may be divided into three groups:

(1) Mythical or vitalistic; amongst explanations of this kind we find those based on the existence of underwater chasms, which periodically draw in and force out the water, and those which tied the movement of the tide to a natural life function of the earth, analogous to breathing in an animal. This second idea, particularly suitable to illustrating the correspondence of the macrocosm with the microcosm, was taken up again and again by Renaissance thinkers.

(2) Naturalistic, non-astronomical; these attributed tides to, among other things, the action of rivers and winds, coast and sea-bed particularities, the salinity of the sea water or to the natural heat of deep water. Apart from the presumption of a role for salt (suggested by the absence of independent tides in rivers), we often encounter factors which do in fact have an influence on tidal phenomena.

(3) Astronomical; principally based on a recognition of the correlation between tides, diurnal rotation and the lunar cycle. Such explanations might also assign roles to the sun and, possibly, to other heavenly bodies.

In order to assess the progress made in the 16th and 17th centuries it is essential to clarify certain aspects of the medieval astronomical explanations.

First of all we notice that such explanations coexisted with arguments from other groups. For example Albumasar (who is the principal Arabian source on the subject, and who, directly and through Robert Greathead, influenced most of the successive literature[4]), after a long exposition on the astronomical origin of tides, adds, as an eighth cause of the phenomenon, the action of the winds.

Secondly, the recognition of a correlation between the movement of the tides and the phases of the moon[5] does not imply, as today seems obvious, the attribution of a role to the position of the sun, evidently due to the fact that the various phases of the moon do not seem to be

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[3] Still very useful on the medieval concepts of tides is R. Almagià, *La dottrina della marea nell'Antichità classica e nel Medio Evo*, 'Memorie della R. Accademia dei Lincei' (Roma, 1905).

[4] The work *Questio de fluxu et refluxu maris*, attributed to Robert Greathead, relies heavily on the theory of tides put forward by Albumasar in his *Introductorium maius*, as demonstrated in E. S. Laird, *Robert Grosseteste, Albumasar, and Medieval Tidal Theory*, 'ISIS', 1990, 81, pp. 684-694.

[5] It should be noted that this recognition, although fairly widespread, was not general. In 1666 Wallis still found it necessary to refute the opinion of Isaac Vossius, who in his work *De Motu Marium et Ventorum* (1663) had considered purely by chance the syncronization of the lunar cycle and the tides. Cf. *An Essay of Dr. John Wallis, exhibiting his Hypothesis about the Flux and Reflux of the Sea*, 'Philosophical Transactions', N.16, August 1666, pp. 263-289 (hereafter Wallis), pp. 286-287.

direct manifestations of the relative positions of the sun and moon but are conceived as different states of the moon itself[6].

Thirdly (an essential point and one which may seem surprising), even the writers who explicity acknowledge a role for the sun in determining tidal characteristics do not offer an explanation for the lunar cycle. In other words the various sources who, starting with Albumasar, affirm that the sun is contributary to the tidal phenomena bring this affirmation to no conclusion, simply letting the matter drop[7].

This attitude needs little explanation. In all probability the medieval scholars who mention the sun's role do not understand it, in that they do not deduce it from a correlation between tide and lunar cycle, but are merely repeating, directly or indirectly, an affirmation of the Elder Pliny[8]. Some authors (for example Duns Scotus[9]) add that besides the sun also the planets influence the tides (their action upon the sea probably not being worse understood than that of the sun).

We should notice, finally, that the recognition of the influence of certain heavenly bodies on the sea leaves ample space for debate on the nature of such influence. A prevalent idea among authors who recognized the influence of the moon was that of the moon's particular affinity to the moistness[10]. This is often reported, in spite of the apparent contradiction, even by those who extend a part in influencing the water to the sun.

On the other hand the acknowledgement of solar influence is often expressed in terms of the dilation of the water caused by heat. Other authors attribute the influence on the water to moonlight[11] (and, occasionaly sunlight). In the 13th century we find an analogy between tidal action and magnetic attraction seen in loadstone; the oldest known work that reports this is *De Universo* by Guillelme d'Auvergne

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[6] Even Descartes, among others, while recognizing the relationship between the tides and the phases of the Moon attributes the tidal action to the Moon alone (see R. Descartes, *Le Monde ... ou le Traité de la Lumière*, chap. XII).

[7] Others apart from Albumasar and Robert Greathead behave in this way, for example Albertus Magnus (1193-1280) in his treatise *De proprietatibus elementorum.*

[8] The main extant sources on the Hellenistic theories of tides are the *Naturalis Historia* by Pliny and *Geography* by Strabo. Such testimonies strongly suggest that in the Hellenistic period an explanation, based on an interaction with the Sun and the Moon, of the forthnightly cycle of the tides had been obtained. In particular Pliny (who is the preferred source of all medieval authors who are concerned with natural history) states that the Sun and the Moon cause the tides (*Naturalis Historia*, II, 212), although he does not give an explicit explanation for the forthnightly cycle, which in all probability he was unable to report. The role of the Sun in the phenomenon was presumably clear to Seleucus (who, as we shall see, had studied the annual cycle of the tides). For a reconstruction of Hellenistic knowledge on the subject and especially the contribution of Seleucus, see L. Russo, *L'astronomo Seleuco, Galileo e la teoria della gravitazione*, Quad. Urb., 1995 (hereafter Russo^1).

[9] *Meteorologicorum,* II, *Quaest. 2.* Cf. Almagià, pp. 468-470.

[10] In fact this idea, like many of those quoted above, was preserved long after the end of the Middle Ages. Even Kepler asserts that as the Moon grows fuller all things containing moistness grow larger. Cf. J. Kepler, *De fundamentis astrologiae,* (Pragae, 1602), thesis xv.

[11] Obviously this explanation is difficult to reconcile with the observation that the tide is the same at the full and new moons; to resolve this blatant contradiction several elaborate explanations were put forward; it is not worth the trouble referring to them in full here.

(died in 1245)[12]; the analogy is taken up by Pietro d'Abano (1250-1310) and from then on with greater frequency.

In the Reinassance, in the realm of astronomical explanations, there arise two apparently new lines of thought: one, which we will be discussing in the following three sections, tries to deduce the level of the sea from the positions of the sun and moon; the other, which we shall return to in section 5, has its origin in the Copernican revolution and attributes tidal motion to movements of the earth. Galileo is the most famous exponent of the second line of thought, but in fact it neither originated with him nor concluded with him.

FEDERICO CHRISOGONO AND HIS BOOKLET

Federico Chrisogono, member of the nobility of Zara, was concerned mainly with medicine and astrology, teaching these in Padua from 1495 to 1498[13]. His booklet on the tides, *Tractatus de occulta causa fluxus et refluxus maris*, was printed, with other of his works, in Venice in 1528[14].

The booklet is very short, only eight pages in length (sheets from 23v to 27r in the edition quoted). The work, although verbose and repetitive (in spite of its brevity), is none the less of great interest in that it contains (for the first time to our knowledge) an effective explanation of the principal cycles of the tides based exclusively on the positions of the moon and the sun[15].

In what we may refer to as the introduction to this work the Paduan physician explains, amongst other things, his interest in the influence of the tides on the outcome, happy or otherwise, of attacks of serious illness[16]. The main body is divided into 15 "conclusiones"[17].

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[12] Cf. Almagià, p. 454.

[13] The period of teaching in Padua is reported by Almagià (p. 500) who takes it from Facciolati, *Fasti Gymnasii Patavini* (Padova, 1757), pp. 117-118. Beyond this, we may gleam a little on Chrisogono from the edition of his works.

[14] *Federici Chrisogoni nobilis Jadertini Artium et Medicine doctoris Subtilissimi et Astrologi excellentissimi de modo Collegiandi Prognosticandi et curandi Febris Necnon de humana Felicitate ac denique de Fluxu et Refluxu Maris Lucubrationes nuperrime in Lucem edite MDXXVIII. ... Editum ab eximio Doctore Federico Chrysogono nobile Jadertino. Et Venetiis impressum a Joan. Anto. de Sabbio et fratribus. Anno a partu Virgineo MDXXVIII. Kal. Aprilis* (hereafter Chrisogono). We have used the copy of this rare work preserved in the Biblioteca Angelica in Rome.

[15] Almagià (ibid.) declines to describe the booklet on the tides in detail for the reason that the particular caracteristics of the work would regain a place for Chrisogono among modern scholars. Duhem (p. 368) emphasizes the importance of Chrisogono's writing, but refers very briefly (and not at all accurately) to their content. Other authors seem to hear of Chrisogono through Duhem.

[16] This premise finds a place for Chrisogono's work in a very old medico-astrological tradition, going back to Galen at the very least (Galen having associated the critical period of the nasal mucous membrane diseases with the phases of the Moon).

[17] Chrisogono calls all the affirmations in his work "conclusiones" without discrimination between initial assumptions and their logical consequences. Another particular demonstrates the lack of familiarity with the methodology of exact science: he asserts that he is following the habit of mathematicians in using letters to indicate, for maximum clarity, the *parts* of a figure (...*Quas equidem partes totius figure signabimus cum literis more mathematico: ut facilius demonstrare valeamus ea que intendimus docere*; *tertia conclusio*, f. 24v). He fails to realize that mathematicians had

Chrisogono begins by acknowledging that the sun and moon cause the sea to rise to its highest level where they are at the zenith or nadir[18] and it to sink to its lowest level where they are at the horizon[19]. As a consequence the sea produces four pointed protuberances, the peaks directed at each of the two luminaries and away from them[20] (further on, however, he attributes a smoother form to the water[21]).

From these assumptions Chrisogono deduces both the twice-daily[22] and the forthnightly[23] cycles; this second being explained by combining the effects of the two astral bodies, the effectings being summed during the full moon and the new moon and being subtracted from each other during the quadrature. This explanation is similar to modern static theory of the tides, but is notably different in one particular: since the effects of the sun and moon are considered to be equal, during the quadrature the tidal influence is cancelled out[24]. This is revealing in that it goes against observable facts (such as the existence of tides during the quadrature in many seas) while at the same time abandoning the traditional belief in the predominant action of the moon. This can only be explained, we feel, as the effect of the simplification of an already existing theory[25].

The annual cycle of the tides was also deduced from the same premises, related to the consideration of the annual movement of the sun[26]. It should be noted however that he considered only the annual

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denoted the points of a figure with letters and not generally the zones. Since the time of Vitruvius the concept of geometrical point had presented great difficulties in the attempts to render the Greek scientific works into Latin. See L. Russo, *The astronomy of Hipparchus and his time: a study based on pre-Ptolemaic sources*, 'Vistas in Astronomy', 1994, 207-248 (hereafter Russo^2), pp. 227-228.

[18] The 'Prima conclusio' of the work runs «*Sol et Luna sic maris tumorem ad se contrahunt: quod sub ipsis perpendiculariter est maximus tumor maris: qui quidem tumor fluxus maris dicitur et aquarum crementum et similiter diametraliter in parte opposita (que nadir dicitur) est eadem vel consimilis eleuatio vel tumor maris maximus; ergo duo maximi tumores maris sunt semper et uniformiter: alter scilicet sub luminaribus et alter in parte opposita: que nadir luminarium est vocata que oppositionem significat secundum astronomos.*» (Chrisogono, f. 24v).

[19] ... *in orizonte autem medio istorum duorum centrorum oppositorum est semper maxima depressio et decrementum aquarum vel refluxus maris.* (Chrisogono, *secunda conclusio*, f. 24v).

[20] ... *ideo erunt etiam quattuor profunditates maris semper uniformes: quarum due erunt a luna causate et eius nadir: alie vero due a sole scilicet et eius nadir: et omnes predicte figure a dictis centris sunt equaliter terminantes in cuspidem vel quandam piramidem* (Chrisogono, *tertia conclusio*, f. 24v).

[21] Chrisogono, *septima conclusio*, ff. 25r-25v. Duhem (ibid.) interprets the form here described as an ellipsoid and ignores the previously described peaks.

[22] Chrisogono, *sexta conclusio*, f. 25r.

[23] Chrisogono, *decima conclusio*, f. 26r.

[24] *Sed causis efficientibus motum equalibus existentibus in posse et oppositum motum intendentibus: mobile non mouebitur: motus enim prouenit a victoria maioris inequalitatis motoris: ergo mare in illa hora non mouebitur ... quod bis accidit in singulo mense in prima quadratura scilicet septima die: et in secunda scilicet vigesimaprima die. ...* (Chrisogono, *undecima conclusio*, f. 26v).

[25] It should be noted that Chrisogono's theory, taken literally, can explain the real motion of the tides with much the same approximation as a theory based on the action of the Moon alone. The original introduction of a role for the Sun in the theory of the tides presumably produced better results.

[26] Chrisogono, *decimaquarta conclusio*, f. 27r.

cycle of the highest points of the tide, leaving aside consideration of the yearly cycle of the difference between the two daily tides.

The booklet was accompanied by a set of concentric card disks, one fixed and two free to rotate about the centre, which allowed the calculation of the relative positions of the earth, moon and sun.

The ideas on the tides expounded by Chrisogono were taken up by many authors, mainly (but not exclusively) Venetians. The booklet is explicitly drawn from by Federico Delfino in his work on tides published in Venice in 1559[27], by Ludovico Boccaferri in 1570[28], and by Girolamo Cardano in a work in 1587[29]. Chrisogono's work is reproduced in its entirety by Paolo Galluccio in 1588[30], and his theory was taken up in Venice by Raimondo in 1589[31] and in France by Duré in 1600[32]. Among works explaining tidal phenomena on the ground of sun's and moon's positions, we finally mention Ambrosio's work[33].

All these works notwithstanding, the ideas set out by Chrisogono were not easily accepted. An especially significant example of this is given by Stevin, one of the greatest scientists of his time, 80 years after Chrisogono's booklet was published. In the work *Van de Spiegheling der Ebbenvloet,* published in Leiden in 1608 as part of his *Wisconstighe Ghedachtenissen*[34], Stevin aims at the same objective as Chrisogono: an explanation of the principal characteristics of the tides based on simple assumptions about the relation of tide to astral body position.

The two authors differ greatly in method; while Chrisogono lists his "conclusiones" without concern for their logical order (sometimes deducing logical consequences from preceding "conclusiones", in some instances contradicting them, often repeating them), Stevin follows classical Greek method arranging his arguments in postulates, clearly demonstrated propositions and explanatory notes. Stevin however makes no mention of any role of the sun in affecting tides, nor, as a consequence, can he offer any explanation for the observable monthly cycle, although he acknowledges it.

Evidently the knowledge possessed by Chrisogono was very difficult to get at: not only did Galileo, interested as he was in an explanation based on completely different principles, fail in this, but so also did Stevin, who had even intended to establish an astronomical

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[27] F. Delfino, *De fluxu et refluxu aquae maris* (Venetiis, 1559). A second edition of this work was printed in Basel in 1577.

[28] Ludovico Boccaferri, *Lectiones ... in secundum ac tertium meteorum Aristotelis* (Venetiis, apud Hieronim. Scotum, 1570). Chrisogono's theory is given in ff. 14 v. ff.

[29] G. Cardano, *De rerum varietate* (Basel, 1587).

[30] Giovanni Paolo Galluccio, *Theatrum Mundi et Temporis* (Venetiis, apud Jo. Bapt. Somascum, 1588), chap. XII, pp. 70-82.

[31] Annibale Raimondo, *Trattato utilissimo e particolarissimo del flusso e del riflusso del mare* (Venetiis, apud Domenico Nicolini, 1589), ff. 3r-7v.

[32] Claude Duré, *Discours de la vérité des causes et effects des divers cours, mouvements, flux, reflux et saleure de la mer Océane, mer Méditerrannée et autres mers de la Terre* (Paris, 1600). Duré simply plagiarizes the work by Delfino cited above; cf. Duhem, ibid.

[33] Florido Ambrosio, *Dialogismus de natura universa maris ac eius genesi et de causa fluxus et refluxus eiusdem ...,* (Padova, 1613).

[34] The work, with an English translation, is to be found in *The Principal Works of S. Stevin* (Amsterdam, 1961), vol. III, pp. 323-357.

static theory of tides, that is a theory based on the same premises as those of Chrisogono.

ARCHBISHOP MARCO ANTONIO DE DOMINIS

Marco Antonio de Dominis (1560-1624) had to play an important part in the religious and political debate of his time. Born into a Dalmatian family of ancient lineage, and who, in particular, had produced three bishops to the diocese of Segna (Senj) in the preceding centuries, he was himself first Bishop of Segna, playing a part in a delicate political problem involving the Uskok pirates, Venice and the Empire, going on to become Archbishop of Spalato (Split). He later converted to Anglican Church and emigrated to England, only to reconvert to Catholicism on the succession of his friend Cinzio Aldobrandini (as Gregory XV) to the papacy, who received him with great honour in Rome. Gregory was however rapidly succeeded by Urban VIII who dispatched the Archbishop to Castel S. Angelo prison, where he died a few months later[35].

Taking a position close to that of Paolo Sarpi (for whom he edited the *Historia del Concilio Tridentino*), de Dominis long held on to his dream of a reconciliation of Catholics and Anglicans. However his two conversions, first from Catholicism to the Anglican Church and then vice-versa, had the unfortunate effect of him being considered apostate by both, so much so that in the trial in 1624, concluded in Rome after his death, he was sentenced to be burned at the stake (post-mortem)[36] and to "damnatio memoriae".

De Dominis, although involved above all in theologico-legal works, which were to become an important source of jurisdictionalism[37], also published two scientific works: one on optics[38] (which contained an explanation for rainbow phenomena and a theory concerning telescopes) and the other on the tides, that is the short treatise *Euripus seu de fluxu et refluxu maris sententia,* published in Rome in 1624[39].

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[35] The biography of de Dominis, giving attention to his juridico-religious rather then his scientific work, has been the object of various monographs: H. Newland, *The Life and Contemporaneous Church History of Antonio de Dominis, Archbishop of Spalato* (Oxford/London, 1859); S. Ljubic, *Prilozi za z;ˇ ivotopis Markantuna de Dominisa Rabljanina, spljetskoga nadbiskupa*, ‘Starine na sviet izdaje Jugoslavenska Akademij Znanosti I Umjetnosti’, 2 (1870), pp. 1-270; S. Ljubic, *O Markantunu Dominisu Rabljaninu, historic;ˇ ko kritic;ˇ ko iztraz;ˇ ivanje*, ‘Rad Jugoslavenska Akademija Znanosti i Umjetnosti’, 10 (1870), pp. 1-159; A. Russo, *Marc'Antonio de Dominis Arcivescovo di Spalato e Apostata* (Napoli, 1964). N. Malcom, *de Dominis (1560 - 1624): Venetian, Anglican, Ecumenist and Relapsed Heretic* (London, 1984). The works of Ljubic contain richly detailed biographical documentation.

[36] The body of the Archbishop was taken from the crypt of S. Maria della Minerva, where it was laid waiting for the end of the trial, for public burning, along with his works, in the Campo de' Fiori, Rome.

[37] Especially his *De Republica Ecclesiastica.* Cf., for ex., A.C. Jemolo, *Stato e Chiesa negli scrittori politici del Seicento e del Settecento* (Napoli, 1972), p. 70; Malcom, pp. 81 ff.

[38] M. A. de Dominis, *De radiis visus et lucis in vitris perspectivis et iride tractatus* (Venetiis, 1611).

[39] Hereafter *Euripus*. We refer to copies of this extremely rare work preserved in the Vatican and Marcian Libraries.

The work on optics was published in 1611, but in the preface the editor Bartolo states that it was composed in de Domini's youth in the years 1588-1592 while teaching mathematics and natural science at the Jesuit College in Padua. The above-mentioned theory concerning telescopes was to become of great interest due to the publication, the year before, of *Sidereus Nuncius* by Galileo. Bartolo's dating, which implies a priority to de Domini's work, has a distinct anti-Galilean flavour[40]. The claims for the date are not however to be totally discounted, as the theories put forward do not seem the fruit of a few years of labour[41].

Since in the last years of his life de Dominis was apparently too preoccupied with the legal-religious problems which were to ruin him to give his undivided attention to the tides, it may be conjectured that also the work on tides was based on material put together during his years in Padua[42]. It is probable that *Euripus* is another example of work inspired by a desire to attack Galileo's position. De Dominis, his position in Rome made precarious by the death of his protector Gregory XV, probably sought merit in the eyes of Pope Urban VIII by offering arguments against the Copernican explanation of tides sustained in Galileo's *Dialogo del flusso e del riflusso del mare*, censored by the Church in 1616. If this was his aim, he was not to succeed, since the work, dedicated as it was to the nephew of the Pope Francesco Barberini, did nothing to prevent his arrest which followed soon after its publication.

DE DOMINIS' TREATISE ON THE TIDES

Euripus is a brief work consisting of 72 pages divided into 43 sections, the first 25 of which contain the author's explanation of his theory, this being followed by the successive sections in the form of six questions and their answers. In fact a good sixteen of the first 25 sections (the 10th to 25th) are not concerned in themselfs with the tides but with the spherical nature of the earth. We begin with this part of the work as it precedes the rest logically.

A series of arguments in favour of the earth being spherical are not interesting in themselves: it is a classical topic, having its principal natural sources in Aristotle's 2nd book of *De Caelo* and the 1st book of *Almagest* by Ptolemy (who himself uses Aristotle as a source). It is not

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[40] Tommaso Baglioni, who printed de Dominis' work, was also the publisher of *Sidereus Nuncius* but had argued with Galileo over, amongst other things, the quality of the print of his work. He subsequently printed a series of scientific works characterized by their distinct anti-Galilean flavour(**).

[41] The explanation of the phenomenon of the rainbow is based on experiments with spherical bowls filled with water, which de Dominis claims personally to have conducted. It is probable, however, the experiments were carried out much earlier, since the same experiments were described both by Theodoric from Vriberg, around the year 1300, and previously by Arabian writers. Cp., for example, A. C. Crombie, *Augustine to Galileo* (London, 1957), chap. 3.

[42] This is also the opinion of A. Ziggelaar (*Die Erklärung des Regenbogens durch Marcantonio de Dominis, 1611. Zum Optikunterricht am Ende des 16. Jahrhunderts*, ‘Centaurus’, 23, 1979, 21-50).

by chance that de Dominis, in order to make his argument of more contemporary interest, uses the device of a dialogue with an opponent to his theory of his time, Otho Casmannus, who had taken up the arguments of the humanist Patrizi (de Petris) in negating the spherical nature of the earth[43].

It must however be emphasized that de Dominis differs from Ptolemy in that he does not restrict himself to providing empirical proofs for the earth's sphericity[44] but goes on to deduce from his arguments, which are effectively a vulgarization of Archimedean hydrostatics, both the necessity of a spherical form for the earth and the interesting consequence that the density of the earth should increase proceeding from the surface to the centre[45]. The contradictory existence of land above the water is justified as divine intervention: God, in order to make the earth inhabitable, allowed a small suspension of the laws of physics[46].

On the main argument of the treatise, the tides, we can isolate two essential affirmations:

The tides are due to the interaction of sun and moon which exert an effect on the water similar to magnetism[47].

The action of the two luminaries is at its maximum not only where they are at the zenith but also at the antipodal point[48].

The second affirmation was to be modified, as we shall see. From this two points he deduces both the twice-daily and fortnightly cycles. In particular he demonstrates that the tides are highest in the syzygy and lowest in the quadrature[49].

He also highlights other characteristics of tides, such as the geographical variation in height and the possibility of horizontal "tidal

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[43] The german theologian Otho Casmannus had published the *Marinarum quaestionum tractatio philosophica bipartita ...* (Francofurti, 1598).

[44] De Dominis reproposes, for example, the classical arguments of the boats of which the hulls disappear before the sails, as they move away; and of the circular form of the Earth's shadow during lunar eclipses.

[45] *Euripus*, §22, pp. 37-38.

[46] *Euripus*, §22, pp. 38-40.

[47] *Itaque dicimus luminaria illa duo Solem & Lunam habere vim magnam, quasi magneticam erga aquas huius mundi inferioris, ...* (*Euripus*, §5, p. 5). We have already seen that the comparison of the magnetic attraction to the action of the Sun and the Moon on the tides goes back to the 13th century and had come into common use. De Dominis however, introducing the analogy, describes the effect of loadstone on iron not only in terms of attraction but of attraction towards one part and repulsion from the other. (*Si enim Magnes, ..., trahit ad se ferrum ex una parte, ex alia vero opposita id a se propellit, & amouet, cur aliquid simile esse in caelestibus illis corporibus multo nobilioribus & efficacioribus negabimus? Euripus*, §4, p.4). This is exactly what the Moon and the Sun seem to do, attracting the water in some points and repulsing it at their antipodes. The idea is dropped in the following section, where the high tide in the point opposite to the luminary, instead of being attributed to the repulsion of the Sun and Moon, is attributed rather to the attraction of the point in the heavens opposite the luminary concerned. It may be asked if the idea had been developed more consistently by other authors.

[48] *Euripus*, §5, p. 5.

[49] This point is developed in particular in his answer to the fifth query (*Euripus*, pp. 59-64). De Dominis actually uses here the modified hypothesis (which we shall meet below), which does not substantially alter the deduction of the fortnightly cycle.

currents", which are not explicable on astronomical data alone but which depend on the size and depth of the seas concerned[50].

The major interest, however, does not lie in these affirmations, which are in substance simply re-proposing Chrisogono's theory, but in de Dominis' elaborate attempt to reconcile theory and observation in his 5th section, in which he hints at two different tidal theories. The first is based on the points above, in particular on the hypothesis that the action of the sun and moon is at the maximum where they are at the zenith and nadir[51]. The second, which the author asserts he had put together in answer to the objections advanced by certain scholars to the first, is based instead on the hypothesis that the action of the moon (like that of the sun) exerts its maximum influence not only where it is at the zenith and nadir but also along the whole meridian to which these two points belong. This second theory, which seems to be de Dominis' personal contribution to the argument, is however less interesting than the objection which caused him to abandon the first theory.

This objection takes the following form: if the actions of the sun and moon are at the maximum where they appear to be at the zenith and at the nadir, the two points at which the tide is highest run, in the course of one day, two different parallels, symmetrical with respect to the equator. Therefore, of the two daily tides we find at each parallel, only one can reach maximum height. Suppose for simplicity the sun and moon are in the same direction (as during the new moon); then at one latitude there would be a maximum high tide when both bodies were at the zenith, and at the other there would be a maximum when they were at the nadir: except of course when the two parallels coincide with each other and the equator, that is during the equinox. In more general terms, it may be deduced the difference in height between the two daily high tides should be at a maximum during the solstice and at a minimum during the equinox[52]. De Dominis explains that since, on the contrary, the two daily tides are always equal to each other he had to abandon the theory. In fact in various seas (for example the Arabian Sea) the tides follow the pattern that he had correctly deduced from the discarded theory.

THE SOURCES OF CHRISOGONO AND DE DOMINIS AND HELLENISTIC STUDIES OF THE TIDES

Euripus shares important characteristics with Chrisogono's work on tides. Both works deduce the daily and monthly cycles of the tides

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[50] Cf. especially *Euripus*, §3.

[51] *Putavi ego aliquandiu vim hanc maris tractiuam, & eleuatiuam esse aeque in ipsis Solis, & Lunae corporibus, atque in punctis eis diametraliter oppositis ...* (*Euripus*, p. 5).

[52] *Altera difficultas est, quod Nadir Solis, & Lunae, cum ipsi Soli & Lunae diametraliter opponantur, necessario semper motu diurno diuersum & oppositum percurrunt & discribunt parallelum, exceptis solis aequinoctiorum diebus. Si igitur Corpus luminaris sit in tropico Cancri, ipsius Nadir erit in tropico Capricorni: & ita vertex alterius coni describet parallelum extremum borealem, alter vero oppositi coni vertex describet eodem die alterum extremum parallelum australem, cum differentia notabili graduum 47, quae differentia in cono facit notabile discrimen ipsius crassitici* (*Euripus*, pp. 6-7).

from the assumption that both the sun and the moon provoke a maximum raising of the sea-level at two antipodal points. More significantly de Dominis, like Chrisogono, attributes to this attraction the effect on the water of producing four pointed cusps, two pointing towards the luminaries and two diametrically opposite. Since these affirmations run counter to experience and intuition, it seems unlikely that the concordance of the works on this is casual. Both authors were of Dalmatian origin and had taugth mathematics and astronomy in Padua; Chrisogono's work, we have seen, was taken up by several (mainly Venetian) scholars and was, in particular, the object of Federico Delfino's teaching at Padua. It is therefore very unlikely that de Dominis ignored his predecessor's work when he wrote his own.

Although we may therefore consider Chrisogono a natural source for de Dominis, *Euripus* differs from other works quoted in that it is far from being a simple reworking of Chrisogono's material. Firstly *Euripus* deals with two important arguments which are totally missing in the 16th century booklet: the cause of the earth's sphericity and the yearly cycle for the inequalities between the two daily tides. Secondly, even when the arguments are similar important differences emerge: not only does de Dominis, unlike Chrisogono, recognize that the moon has a greater effect on the water than the sun[53], but he also offers a different interpretation of the marine cusps[54]. That these novelties were de Dominis' own contribution seems implausible when we consider the scant scientific coherence of his work: for example, he appears to be totally unaware that the theory on tides he elaborates in the first 9 sections (and in particular the existence of aquatic cusps) is incompatible with the perfect sphericity of the earth sustained in the following 16 sections[55]. We should also note that the most interesting ideas are among those mentioned by the author but then discarded, including not only the correct explanation for the daily inequalities but also the idea that the tides cause the oceans to assume an *oval* form[56].

That de Dominis' scientific knowledge is of classical origin is at all obvious; we may also observe that he had translated into Italian Francis Bacon's *De Sapientia Veterum* and that his treatise alludes to Greek antiquity from the title onwards[57]. Unfortunately he follows ancient tradition in preferring to quote his rivals Casmannus and De Petris and leaving his sources largely unmentioned. Of the classical authors he

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[53] *Euripus*, §6, p. 10.

[54] While Chrisogono speaks of *pyramids*, de Dominis affirms that the oceans form *cones*; this difference disappears when we consider the figures they both refer to, in which the form of the water is represented by triangles whose vertices are directed both towards the luminaries and away from them. The two authors could therefore have been giving different interpretations to the same figure.

[55] Eratosthenes had noted that the phenomenon of tide calls for a modification of the Archimedean theory of the sphericity of the oceans, but Strabo (*Geography,* I, iii, 17) considered such criticism of Archimedes inconceivable. De Dominis took up both Strabo's position against Eratosthenes (in §10-25) and, conversely, Eratosthenes's ideas on the tides against which Strabo had argued (in §1-9).

[56] *Euripus*, §5, p. 7.

[57] The title refers to one of antiquity most famous tidal phenomena, that of the Strait of Euripus (between the Isle of Euboea and Boeotia) where the current reverses itself several times a day due to the tides.

cites Aristotle twice only and Euclid and Strabo once each, and these two second-hand through Casmannus and De Petris.

Even when not mentioned explicitly we can sometimes individuate the origin of some passages. We can recognize Strabo, for example, as the source of arguments against people who refuses to have an isthmus removed for fear of disastrous flooding caused by the difference in the sea-levels on either sides, which de Dominis believes to be absurd in the light of the earth's perfectly spherical nature [58]. As noted before, Aristotle and Ptolemy were the sources of empirical arguments for this spherical form.

Looking closely at de Dominis' affirmations on the sphericity of the earth and the increase in density with depth, we note that we are dealing with arguments outlined by Aristotle[59] and which can be partly deduced from Archimedes' treatise *On Floating Bodies*[60] but not expounded explicitly by either, nor mentioned at all by Ptolemy in his proofs of the earth's sphericity. These arguments were certainly known in the Hellenistic Age (hinted at by Diodorus Siculus[61] and the Elder Pliny[62], amongst others) and had been subject to a growing interest in the Renaissance[63].

The transmission of this knowledge from antiquity to the Renaissance was assured not only by way of Archimedes and the others mentioned above, but more by way of a series of works from Late Antiquity, such as those of Theon of Smyrna and of Simplicius, and through medieval intermediaries[64]. Although it is difficult to make out

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[58] *Euripus*, §10, p.14. Strabo (*Geography*, I, iii, 11), taking Archimedes as his authority, criticizes Eratosthenes, who had believed in the difference in level which had been measured on both sides of the Isthmus of Corinth. De Dominis brought Strabo's argument up to the moment by substituting what is now known as the Isthmus of Panama for that of Corinth.

[59] Aristotle, *De Caelo*, II, 287a, 30-287b, 14; attributing spherical form only to the water however. Since the deductions are based on the special property of the water to find its lowest level, the presence of land above it raises no difficulties for those merely taking the opinions put forward in *De Caelo*.

[60] The first book of the treatise is in fact dedicated by Archimedes to the demonstration of the spherical nature of the surface of the oceans, based on his hydrostatic postulate. Of course the proof can be interpreted as referring to the entire Earth, but in order to do this it is necessary to add to the Archimedean presuppositions the hypothesis that the Earth was originally fluid: hypothesis quoted in various classical sources but not in Archimedes' treatise.

[61] Diodorus Siculus states that Earth, while it was still fluid, assumed its form being compressed by the force of gravity (*Biblioteca historica*, I, vii, 1-2); see also Russo[2], §11.

[62] *Naturalis Historia*, II,2.

[63] Cf., for example, N. Copernicus, *De Revolutionibus*..., I, 9, where the hydrostatic argument is also used to justify the spherical form of the Sun, Moon and other heavenly bodies.

[64] Many sources for the ancient hydrostatic proof of the sphericity of the Earth are collected in Duhem, *Les origines de la statique* (Paris, Hermann, 1906); see also Duhem, *La théorie physique* , op. cit., pp. 345 ff. It is interesting however to compare this with what Whewell writes in 1837: *Newton's attempt to solve the problem of the figure of the earth, supposing it fluid, is the first example of such an investigation, and this rested upon principles which we have already explained, applied with the skill and sagacity which distinguished all that Newton did.* (W. Whewell, *History of inductive Sciences*, London, 1837, vol. II, p. 111).

the direct sources used for the arguments in *Euripus*[65], we can be sure that they were of classical origin, that de Dominis was well aware of this and that he had preferred not to make them explicit.

Turning to the origin of the most interesting ideas put forward by de Dominis, those on the cause of the annual cycle of the daily inequalities of the tides, we know from Strabo that Seleucus of Babylon had studied and described this cycle, basing his work, probably, on the study of the Arabian Sea [66]. On the other hand de Dominis gives a theoretical explanation, not mentioned by Strabo, going on to deny the existence of the cycle it explains[67]. It seems Strabo cannot therefore be his sole source since it is highly unlikely that a busy legal and religious reformer could first have worked out the correct mathematical theory of the annual cycle of the daily inequalities of the tides and to have done this demonstrably in ignorance of the existence of such inequalities. We are in fact dealing with a phenomenon observable in seas such as the Arabian Sea, which were studied in the Hellenistic period but of which nothing was heard in the 17th century[68].

It can thus be seen that de Dominis' work provides support for the conjecture, expounded elsewhere[69], that Seleucus discovered the theoretical grounds for the difference in daily tides in the Arabian Sea, which suggests that there was other information on the Hellenistic studies of tides still available in the 16-th century, apart from that imparted by Strabo and Pliny.

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[65] Due to the fact that these notions were reasonably widespread at the time. The law of increase in density with depth had been discussed by, for example, Patrizi and by Casmannus, who, not believing in the Earth's sphericity, had not accepted it; cf. *Euripus*, §22, p. 40.

[66] Strabo, *Geography*, III, v, 9. Strabo refers to the *Erythrean Sea*, which in antiquity comprised both the present Red Sea and Arabian Sea. However, since Strabo reports Seleucus in one place coming from the region of the *Erythrean Sea* (*Geography*, III, v, 9) and in another as coming from Babylon (*Geography*, I, i, 8-9) (apparently considering them the same place), it appears that in the case of Seleucus Strabo probably means the Arabian Sea when he states *Erythrean Sea*.

[67] It might seem strange that de Dominis (who quotes passages by Strabo on the tides sometimes explicitly and at other times implicitly) denies the existence of a phenomenon referred to by Strabo. Strabo however, immediately after mentioning the studies of the tides by Seleucus, relates that Posidonius had tried without success to discover in the Atlantic Ocean the yearly cycle of the daily inequalities that Seleucus had described in the Erythrean Sea (*Geography*, ibid.). De Dominis had probably deduced from this not that the tides in the two seas had different qualitative characteristics but that Seleucus had been mistaken in his affirmations.

[68] Important testimony on this point is furnished by one of the greatest experts on the subject. George Darwin (who had read the passage by Strabo on Seleucus' studies of the tides in a collection of fragments edited by the Dutchman Bake in 1810) noted the correspondence between the description given by Strabo (which he first interpreted correctly) and the actual process of the tides in the Arabian Sea. He observed that the passage by Strabo could not have been understood by Bake by reason of the near ignorance of the tides in such distant regions they had at the time (that is in 1810!). Cf. G. Darwin, *The Tides and kindred phenomena in the solar system*, London, 1898, p. 76.

[69] Cf. Russo[1] and Russo[2], §11.

The originality of de Dominis' work on optics has been also doubted with good reasons [70] but it has been impossible to identify its sources [71].

Many of the considerations applied to de Dominis are equally applicable to Chrisogono, both being eclectic in approach, both reporting contradictory considerations, and both having their main interests a long way outside the subject of tides. It is conceivable that the affinity between their works is explicable in that the sources used (directly or indirectly) by de Dominis were also known to Chrisogono. It is interesting to note that Chrisogono criticizes the Elder Pliny for not having noted for posterity the causes of the cycles of the tide in book II of the *Naturalis Historia*[72], never doubting that these were made clear in Pliny's sources.

We find a possible precedent to the works we have been referring to so far in a 13th century work by Jacopo Dondi on the subject of the tides in which he also tried to explain them in terms of the position of the sun and moon[73]. This work is specially interesting for two particulars. The first is a gross error; the changeover of two orthogonal directions leads to the confusion of the tides in the syzygy with those in the quadrature, thus exchanging the timings for maximum and minimum tides. The astronomical explanation, potentially correct, becomes clearly contrary to the evidence[74]; impossible for a scholar working from observations but easily explicable as an error in the interpretation of a source. The second particular is geographical: Jacopo Dondi was another Paduan scholar.

The problem of individuating the sources of the authors we have considered must be left open. It may however be no accident that the main astronomical ideas concerning tides first appear in authors who all show little familiarity with astronomy and who have geographical origin in common: the territories of Venice. It is possible that there had been information available, perhaps since 13th century, and probably not completely understood, on a static astronomical theory of tides.

TIDES AND MOVEMENT OF THE EARTH: GALILEO, BALIANI AND WALLIS

According to modern classical mechanics tides are due to the contemporary action of two kinds of force: gravitational forces from the sun and the moon, and inertial forces caused by the acceleration of the

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[70] Cf. A. Ziggelaar, *op. cit.*

[71] Malcom (p.9) writes "no direct source has ever been found for his account", and records that de Dominis claims to have personally carried out the experiments with the water-filled spheres. However cf. note 41 above.

[72] Cf. *Chrisogono*, f. 24r.

[73] Dondi's theory is referred to by Boccaferri (op. cit.). According to L. Thorndike the original work is to be found in a manuscript, dated to the XVI century, preserved in the Ambrosian Library (n. 334 sup.); cf. L. Thorndike, 'Archeion', XVIII (1936), 308-317. The contents of the manuscript referred to by Thorndike seem to be however less interesting than the theory referred to by Boccaferri.

[74] It is on the basis of this error that we had affirmed that the first astronomical explanation of the principal cycles of the tides is that of Chrisogono.

earth. While the interactions conjectured by Chrisogono and de Dominis anticipate the forces of the first type their explanations contain nothing analogous with the second; this is the reason for which they were obliged to postulate that the action of the sun and the moon extends from the region in which they appear to be at the zenith to the corresponding antipodal region, without offering any explanation for so a strange characteristics of this action.

A second line of thought, of which Galileo is the most illustrious representative, prepares the ground for the consideration of inertial forces.

On the fourth (and final) day of the *Dialogo sopra i due massimi sistemi del mondo* Galileo believes that he demonstrates that the tides are an effect of the movements of the earth[75]. His main idea is that the rotational movement of the earth with that of its revolution (around the sun) combine to give rise to a non-uniform motion of the sea-bed which is translated to the water much in the way energy is transferred from an oscillating basin to the water in it. Galileo's reasoning (in which he treats as "childish" the idea that there could be a role for the moon in creating tides) is plagued with inconsistency, in particular his attempts to account for the well-known monthly cycle seem forced and necessarily doomed to failure, depending as they do upon combinations of daily and annual movements.

The concept of the motion of the earth as an explanation for tides was not original, Galileo being preceded in the 16th century by at least Calcagnini, Cesalpino and Sarpi. In fact the idea was of much earlier origin. Neugebauer writes:

> In modern times Seleucus has become famous as supporting Aristarchus in the assumption of an axial rotation of the earth, relating it to his theory of the tides...[76]

Neugebauer's statement is based on three testimonies: Plutarch's famous passage in which he affirms that Seleucus had demonstrated the movements of the earth[77]; Strabo's witness that Seleucus had obtained important results concerning tides[78]; a relatively obscure passage by Aëtius in which, referring to Seleucus, he makes affirmations concerning the tides and terrestrial rotation[79].

The sources do not necessarily lead to Neugebauer's conclusion; we may sustain that Seleucus' demonstration was based on the phenomenon of tides but concerned not the rotation but the revolution of the earth[80]. Plutarch's testimony, however, leaves no doubt as to the fact that Seleucus was a forerunner of Galileo in attempting to demonstrate in some way the existence of motions of the earth. And the

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[75] It is well-known that for Galileo the explanation of the tides constitutes the essential matter of the treatise, to which he had originally given the title *Dialogo del flusso e riflusso del mare*. The title whas changed following the above mentioned papal censure.

[76] O. Neugebauer, *A History of Ancient Mathematical Astronomy* (Berlin/ Heidelberg/ New York, 1975), p. 611.

[77] Plutarch, *Platonicae Quaestiones*, VIII, i (= *Moralia*, 1006C).

[78] Cf. especially the passage by Strabo already cited (*Geography*, III, v, 9).

[79] Cf. H. Diels, *Doxographi Graeci*, (Berlin, 1879), 383a, 17-25 and 383b, 26-34.

[80] This thesis is sustained in Russo[1], where the extant testimonies on Seleucus are examined.

passage by Aëtius actually suggests a role for the rotation of the earth, along with tides, in Seleucus' argument.

In the 16th century a knowledge of passages of Plutarch and Aëtius (whose work was mistakenly included in Plutarch's *Moralia*) was essential for anyone interested in the movements of the earth. It is therefore very probable that not only Neugebauer, but also many scholars of the 16th century were convinced that Seleucus had deduced the tidal phenomenon from terrestrial movements. It should not seem strange then that some of them, including Calcagnini [81], Sarpi [82], Cesalpino [83] and Galileo, would attempt to reconstruct the proof.

Galileo's explanation, although internally weak and despite the fact that it was probably influenced by a philological error, by way of developments by later authors, eventually resulted in an important contribution to modern theory of tides and in more general terms to modern mechanics.

Galileo's idea was accepted by Gassendi[84], amongst others, and was subsequently developed, in a way that at first sight seems quite bizarre, by Giambattista Baliani. We have already seen that the most obvious limit of the explanation in *Dialogo dei Massimi Sistemi* is its incapacity to account for the monthly cycle of tides. Baliani thought he could overcome this difficulty while saving the substance of Galileo's theory by introducing a third movement of the earth alongside its rotation and revolution: one of monthly period, around the moon. In other words Baliani thought he should complete the Copernican revolution by explaining the apparent motion of the moon around the earth with a motion of the earth, just as Copernicus had done in the case of the sun.

Baliani's attempt would remain a simple curiosity were it not for the fact that his ideas were to be taken up and developed in interesting directions by John Wallis[85], who, anticipating a notion which would

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[81] The affirmation that the tides are caused by the variations in the movements of the Earth can be found in the work *Quod caelum stet, terra moveatur, vel de perenni motu Terrae,* published posthumously in *Caelii Calcagnini Ferrarensis opera aliquot* (Basel, 1544).

[82] The ideas of Paolo Sarpi on this subject can be found in handwritten notes. Some passages, in which Sarpi gives the same analogy as Galileo between the tide and the movement of water in an oscillating basin, were published by L. Sosio in the essay *Galileo e la cosmologia*, in his introduction to Galileo Galilei, *Dialogo sopra i due massimi sistemi del mondo, tolemaico e copernicano* (Torino, 1970), p. LXXVIII. The notes go back to 1595 and therefore precede Galileo's treatment of the subject.

[83] *Quaestio V* in the book III of *Quaestiones peripateticae* by Andrea Cesalpino (Venetiis, 1571) is entitled *Maris fluxum, et refluxum ex motu Terrae non Lunae fieri.* Sosio (p. LXXV) observes that the title promises more than it delivers. Cesalpino, who was not of a Copernican turn, does not in fact refer to either the rotation or the revolution of the Earth but to a strange small movement communicated to the Earth by the movement of the heavens. We are dealing therefore with an attempt to explain the tides through movements of the Earth by an author who differs from the others quoted in that he has no reason to believe in the movements of the Earth and must introduce one "ad hoc". What better confirmation that the association between tides and movements of the Earth was suggested to different authors not by having arguments in common, but by having reading resources in common?

[84] P. Gassendi, *De motu impresso a motore traslato* (Paris, 1641).

[85] Baliani's theory, which he did not publish, came to Wallis' notice by means of a report by Riccioli in his *Almagestum Novum* (Bononiae, 1651); cf. Wallis, p. 270.

become part of our "classical mechanics", sustained that the motion of two interacting bodies must be calculated around the centre of mass of the system[86].

According to Wallis the earth is actually given a monthly movement caused by the moon, as asserted by Baliani, but with the earth moving around the barycentre of the earth-moon system (rather than just the moon) thus accounting for the monthly cycle of tides. It is not difficult to see an important antecedent of an essential element of modern tides theory in this idea of Wallis: the existence of what were to come to be called inertial forces relative to earth's acceleration due to the interaction with the moon. In order to arrive at modern theory the next step would be understanding that Wallis' argument should not put in contraposition to the explanations by Chrisogono and de Dominis but would be complementary to them, recognizing that the tides are created from a combination of two kinds of forces: those due to the direct gravitational interaction with the sun and moon, and the inertial forces due to earth's movements.

CONCLUSIONS

In the developments of the study of the tides in the 16th and 17th centuries we have made out two principal lines.

That to which Galileo belongs, based on the motion of the earth, contrary to a popular and widely held opinion, neither begun with him nor was it exhausted in the argumentation of the *Dialogo dei Massimi Sistemi*. This line, probably originating in attempts at interpreting ancient sources, led up, by way of Baliani, to the important developments made by Wallis, who, in his turn, anticipated the understanding of some essential elements in the theory of tides (and of mechanics) which would be formulated by his pupil Newton.

The other line, to which Chrisogono and de Dominis belong, is that based on the attraction of the sun and the moon and provides an equally essential element to what was to become modern theory.

We have tried to trace back both these lines and in both cases we have met with testimonies to the ancient studies of Seleucus.

We have encountered notably little interest in the scholars we have been considering, and in de Dominis' case this lack has been particularly noticeable: none of the monographs on him [87] take into account any contribution to science beyond a mention regarding the theory of rainbows[88] and works in the history of science usually ignore him[89]. One of his scientific works is praised by Newton, who considers it a probable source of Descartes[90]. The other, which dealt with tides,

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[86] This is the main argument in Wallis' paper.

[87] Cf. note 35 above.

[88] The theory of rainbows by de Dominis is recorded in various works on the history of science; for example, it is mentioned by Crombie.

[89] For example the work on tides is neither mentioned by Almagià (who even has a chapter dedicated to modern pre-Newtonian theory of tides) nor by Duhem.

[90] Newton, who refers to de Dominis as *the famous Antonius de Dominis Archbishop of Spalato*, considers his theory of rainbows the first complete explanation of the

was attacked by Galileo in the *Dialogo dei Massimi Sistemi*, de Dominis being vindicated by later scientific developments. This disinterest therefore demands explanation.

One suspects the decree of "damnatio memoriae" by the Holy Office would have had some considerable effect, rendering it more difficult to individuate the archbishop's scientific achievements. His name does not appear on the copy of *Euripus* in the Marcian Library, having been cancelled in obeyance to the decree (although in one case imperfectly erased)[91]. Probably for the same reason Galileo, even when arguing with de Dominis over the tides, avoids mention of his name. For the fact that his name appears with regard to rainbows we have to thank Newton, who, not being bound by papal decree, may quote him explicitly.

There is however another possible explanation. In the works of intellectuals such as Chrisogono and de Dominis modest skilling argumentation, incoherence and inadeguate use of the knowledge in their possession are found side by side with results ahead of their time, only later to be sufficiently argued, exploited and accepted into "official" science. The analysis of such works (with their essential contribution to the birth of modern science) could bring to light embarassing problems, with the risk of seriously upsetting the balance of the accepted relationship between ancient and modern science. In other words, the undervaluation of the debt modern science owes to ancient calls for a loss of memory concerning certain links between them. Perhaps the loss of memory concerning de Dominis is an example of this, and if it is, it is not the sole example; until only a few years ago the works of Newton in which the connection with classical antiquity were more evident were left unpublished in response to the same logic [92].

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phenomenon and suggests that his work was the unacknowledged source of Descartes on the subject. Cf. I. Newton, *Opticks* (New York, 1952), p. 169.

[91] No cancellation is to be found in the copy in the Vatican Library however. Since this volume is part of the library stock donated by the Barberini family, it may be the personal copy of the cardinal Francesco Barberini to whom the author had dedicated the work.

[92] Some of Newton's scholia concerning classical antiquity were published for the firat time in P. Casini, 'Newton, gli Scolii Classici; presentazione, testo inedito e note' 'Giornale critico della filosofia italiana' (1981), **60**, 7-53. They arethe scholia to the propositions iv-ix of book iii of Principia (Royal Society of London, Gregory MSS 247, fols. 6-14). In the introduction to his edition Casini discusses at length the interest of Newton in *sapientia veterum* but without giving consideration to the ancient scientific knowledge in which Newton was interested.