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Galileo Galilei, Holland and the Pendulum Clock

Galileo Galilei, Holanda e o relógio de pêndulo

Abstract

The pendulum clock was one of the most important metaphors for early modern philosophers. Christiaan Huygens (1629-1695) discovered his pendulum clock in 1656 based on the principle of isochronism discovered by Galileo (1564-1642). This paper aims at exploring the broad historical context of this invention, showing the role of some key figures such as Andreas Colvius (1594-1671), Elia Diodati (1576-1661), Hugo Grotius (1583-1645) and Constantijn Huygens, the father of Christiaan Huygens. Secondly, it suggests - based on this context - that it is hard to believe that Huygens did not know about Galileo's idea to construct a pendulum regulated clock. Finally, this article illustrates how the Dutch philosopher Spinoza (1632-1677) might have been inspired by Huygens' discovery of the synchronization of the pendulum clocks in his views on the agreement between bodies in the universe.

Keywords: Galileo; Pendulum Clock; Huygens; Dutch Republic; Spinoza.

Resumo

O relógio de pêndulo foi uma das metáforas mais importantes para os filósofos modernos. Christiaan Huygens (1629-1695) inventou o relógio de pêndulo em 1656 baseado no princípio do isocronismo descoberto por Galileo (1564-1642). Este artigo busca explorar o amplo contexto histórico dessa invenção, demonstrando o papel de algumas figuras-chave como Andreas Colvius (1594-1671), Elia Diodati (1576-1661), Hugo Grotius (1583-1645) e Constantijn Huygens, o pai de Christiaan Huygens. Em segundo lugar, sugere-se - baseado nesse contexto - que é difícil acreditar que Huygens não sabia da ideia de Galileo de construir um relógio regulado por um pêndulo. Por fim, este artigo ilustra como o filósofo holandês Espinosa (1632-1677) pode ter se inspirado nessa invenção de Huygens da sincronização do relógio de pêndulo em suas visões sobre o acordo entre os corpos no universo.

Palavras-chave: Galileo; Relógio de pêndulo; Huygens; República holandesa; Espinosa.

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1. Introduction[1]

In Holland and abroad, philosophers such as Comenius, Arnold Geulincx, Leibniz, Spinoza, … applied the analogy of the pendulum clock in their philosophies. The Dutch astronomer and physicist, Christiaan Huygens, designed in 1656 his pendulum clock which inspired numerous early philosophers. Moreover, the pendulum clock became one of the leading metaphors of the 17th century. Consequently, it is relevant for the study of early modern philosophy to have a more in depth understanding of the pendulum clock, its history and its context.

After an introductory paragraph (Section 2) wherein the difference between a mechanical clock and a pendulum is explained, this essay focusses in the second part (Section 3) on the relation between Holland and Italy, in the period between 1623 and 1638. In this section, there is particular attention paid to a few people who played a key role in this relation. Furthermore, this essay argues - in a narrative style - that the invention of the pendulum clock by Huygens should be understood in the context of Galileo's proposal for a method for the determination of the longitude at sea (Section 4). Hence, Galileo's correspondence with the representatives of the States General of the Netherlands will be examined more in depth than in the existing historical literature. Furthermore, the paper shows that it is likely that Christiaan Huygens knew about Galileo's design of a pendulum regulated clock which the author of *Dialogo* (1623) describes in his first letter to States General.

In the last section (Section 5), this essay gives an example of an application of the pendulum clock by the Dutch philosopher Spinoza. Martial Gueroult, argued already in his well-known volume entitled *Spinoza – L'âme* (1974) that Spinoza applied the physics of pendulum clock in his conception of a complex and a simple body. However, this section argues that Spinoza applied the phenomenon of synchronization (that Huygens had just discovered) to explain his views on the agreement between bodies in the universe in his *Letter 32* to Henry Oldenburg.

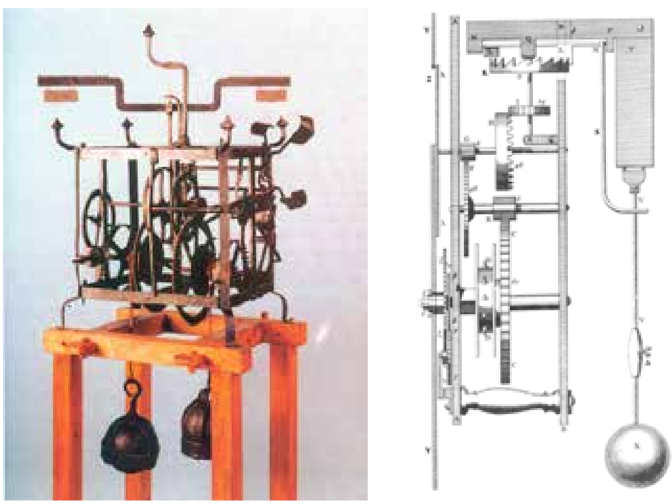
1 In this paper, I use the following abbreviations: GG = Galilei Galileo (Ed. par Favaro, A. et Del Lungo, I.), *Le Opere di Galileo Galilei* (Edizione Nazionale). 20 vols, Florence, Barbera, 1890-1909, OCH = Christiaan Huygens. Œuvres Complètes de Christiaan Huygens (Publ. par la Société hollandaise des sciences). La Haye: M. Nijhoff, 1888-1950 and G = C.I. Gerhardt, *Die Philosophischen Schriften von G.W. Leibniz*. 7 vol., Berlin: Weidmann, 1875-90.

2. The mechanical clock and the pendulum clock: Huygens' invention and Galileo's teaching

The pendulum clock is an example of a mechanical clock but what is a mechanical clock, how does it work and what is the difference between a pendulum-regulated clock and other mechanical clocks?

The essence of a mechanical clock is not to find in the material of which it is composed. The same type of clock can be composed of several materials. The essence of the clock, by contrast, is rather to find in the characteristic relation between its composing parts.

A typical mechanical clock is basically composed of five different elements and each has its own specific function: the energy source that every clock needs to make it work (e.g. the potential energy of a mass hanging at a certain height or the elastic energy of a spring), wheels for the transfer of the energy through the clock, an escapement to stop the potential energy from escaping all at once, the controller which controls the speed of the escapement and the time indicator which is the part of the clock that indicates the time to the viewer.



Left: a traditional mechanical clock; Right: Huygens's pendulum clock[2]

2 Drawing from Christiaan Huygens's treatise *Horologium Oscillatorium*, published in 1673 in Paris. It records improvements to the mechanism that Huygens had illustrated in the 1658 publication of his invention, titled *Horologium*.

However, the difference between the pendulum clock and other mechanical clocks is that a pendulum clock has a pendulum as a regulator. There is no doubt that the Dutch physicist Christiaan Huygens of Zulichem designed his pendulum clock, which he patented in 1657, based on the principle of isochronism invented by Galileo. However, nowhere does the Dutch physicist explicitly reveals how he actually came to the idea to design a mechanical clock based on Galileo's principle, although he wrote two books on his invention: *Horologium*[3] (1658) and *Horologium oscillatorium sive de motu pendularium*[4] (1673). In the first work, written directly after his invention, Huygens obviously does not hide the link between his new design and Galileo's work. On the contrary, in his introduction he writes:

> *Anyone might easily conjecture that the pendulums of astronomers had provided the opportunity to him to him who had known that these were used for some years previously by them. Without doubt, accustomed to the faults in water-clocks and automata of various kinds used for observations, at last, from the original teaching of that most wise man, Galileo Galilei [docente primum Viro sagacissimo Galileo Galilei], the astronomers initiated this method: that they should impel manually a weight suspended by a light chain, by counting the individual vibrations of which just as many should be included as would correspond to an equal number of time-units. By this method they effected observations of the eclipses more accurately than before; in like manner they measured – not unsuccessfully – the sun's diameter and the distances of the stars. But besides the necessary motion of the pendulum [pendulorum motus] failing unless repeatedly assisted by the attendant, a further tedious task was the counting of every oscillation; to this end, indeed, some kept vigil for whole nights with the most wonderful patience, as they themselves testify in their publications*[5].

3 There is an English translation with the original Latin Text in facsimile of this work by Huygens included in Edwardes, Ernest, L., *The Story of the Pendulum Clock*. Altrincham: John Sherratt and son LTD, 1977, 60-95.

4 For an English translation of this work (originally published in Latin) by H.J.M. Bos, see: Blackwell, Richard, J., *Christiaan Huygens' The Pendulum Clock or Geometrical Demonstrations Concerning the Motion of Pendula as Applied to Clocks*. Ames: The Iowa State University Press, 1986.

5 Edwardess, E., op. cit., p.75.

As this passage makes clear, Huygens had been challenged to design a new type of clock by the fact that existing mechanical clocks did not work accurately. Obviously, as he indicates, his source of inspiration was "the original teaching" of Galileo Galilei, "that most wise man" as he calls him. Amazingly, Huygens does not initially refer to Galileo's physics of the pendulum as such but rather to its astronomical applications. In this passage from his *Horologium* (1658), Huygens argues that astronomers had already initiated Galileo's "teaching" successfully so that they affected observations of eclipses much more successfully than before by means of a time-measurer based on counting the vibrations of a pendulum. Interestingly, Huygens here makes a link between Galileo's teachings, the application of the pendulum and astronomical observations; an important relation that will be discussed further in this text. Furthermore, the Dutch astronomer explains that the vibration-counting was done manually which was an immense work that had to be done much more automatically and in a less time-consuming way. This was, according to Huygens, the big challenge that had been at the origin of his design of his new pendulum clock.

Galileo had discovered that the time of one oscillation of a pendulum (T) is not dependent on the mass but only on the length (l) of the pendulum. There is historical evidence[6] that the author of the *Dialogo* (1632) had been examining this property since around 1602 and that it would be part of his research activities for the rest of his life. According to this idea of isochronism[7], the oscillation time of a pendulum is constant in time, even when there is friction. Moreover, the oscillating time could be determined by choosing the adequate, corresponding length of the pendulum. For example, a pendulum of ¼ meter in length has an oscillating time of 1 second.

Huygens knew Galileo's works very well and much of his physical as well as his astronomical work can be conceived as a prolongation of that of his Italian master[8]. For instance, he completed Galileo's ideas on isochronism

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6 Cf. Letter of Galileo to Guido Ubaldo dal Monte, from Padua, dated 29 November 1602, in GG X 97-100. For an English translation of the letter see: P. Palmieri, *Reenacting Galileo's Experiments: Rediscovering the Techniques of Seventeenth-Century Science*. Lewiston, NY, 2008, 257–60

7 The term "Isochronism" is derived from the Greek roots "iso" and "chronos" and means, literally, "in the same time." As Palmieri has remarked, this term is not a Galilean word. The author of the *Dialogo* uses other terms to refer what is known today as the property "isochronism". Palmieri, P., *A phenomenology of Galileo's experiments with pendulums*, BJHS, 2009, 1.

8 Cf. Chareix, F., *Le mythe Galilée*. Paris: puf, 2002.

and expressed them in the form of a physical law in the form of a modern mathematical formula. Currently, we know the pendulum law written as (with g = gravitational acceleration):

$$T = \frac{1}{2p}\sqrt{\frac{l}{g}}$$

3. The historical context before 1635: the relation between Galileo and Holland

Huygens designed his clock based on Galileo's physics of the motion of a pendulum. However, there are many other links between Huygens and Galileo which might be relevant and important for a better understanding of the context of the invention of the pendulum clock. Interestingly, these links are situated on different levels: on the level of the broad political context level of Holland and Northern Italy; on the level of the circle around Huygens and the one around Galileo, and on the more personal level between Christiaan Huygens (and his family) and Galileo Galilei's work.

Galileo had at the end of life - for several reasons - a very particular relation with several leading people of Holland which unfortunately had – as I will show - a very tragic end. However, his successes also had obvious link with the Dutch Republic and its citizens. Moreover, Galileo only became very successful and well-known in large parts of Europe after he had improved in 1609 the Dutch telescope [*Hollandsche Kijker*] which had been invented in Middelburg (Holland) one year earlier[9]. With his new telescope, he made the astronomical observations of the craters of the moon and the satellites of Jupiter - that he commented in his bestseller the *Sidereus nuncius* (1610) - which made him not only directly famous in Western Europe, but also led to his appointment as the 'Chief Academician and Mathematician to the Most Serene Grand Duke of Tuscany'. This changed his professional and personal life completely. Interestingly, the works of Galileo which documented his telescopic observations returned as a boomerang back to Holland long before

9 The discussion who the inventor of the telescope was, is an ongoing debate. Traditionally, Lipperhey and Zacharias (or Sacharias) Jansen (or Janssen) are presented as the most probable candidates. However, both candidates are problematic. For a recent discussion of this question, see: Zuidervaart, Huib, J., The 'true inventor' of the telescope. A survey of 400 years of debate. In: van Helden, Albert, et. al., *The origins of the telescope*. Amsterdam: KNAW Press, 2010, 9-44.

his last important work, the *Discorsi* (1638) would be published in Leyden. The earliest mention of Galileo's ideas is already in the works of Gorlaeus[10] (1591-1612) written around 1610, just after the publication of his bestseller, the *Sidereal Messenger* [*Sidereus nuncius*].

Amazingly, Galileo did not become not well-known in Holland because of the rise of copernicanism. On the contrary, several Dutch historians such as Reyer Hooykaas[11] and more recentely Rienk Vermij[12] , Eric Jorink[13] and Djoeke van Netten[14] argue that copernicanism only became more influential because of the works of Galileo and his condemnation by the Roman Church, after the publication of the *Dialogo* in 1632. Indeed, Copernicius was not popular in Holland before 1630 although the heliocentric/geocentric debate was in other European countries already held in the first decades of the 17th century. Even the Dutch editor[15] of a new edition of Copernicus's main work, Nicolaus Mulerius (1564-1630), was not a real Copernican but rather an Aristotelian[16]. Moreover, around 1625 there were only a handful Copernicans[17] in the Dutch Republic, who were all Galileo sympathizers.

A few people played a major role in making Galileo well-known in the Republic. Indeed, in the period before Christiaan Huygens, there were four people who played a key role in the relation and communication between the

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10 Cf. Lüthy Christoph: *David Gorlaeus (1591-1612). An enigmatic figure in the history of philosophy and science*. Amsterdam, Amsterdam University Press, 2012, 27.

11 Cf. Hooykaas, R., The reception of copernicanism in England and the Netherlands. In: Wilson, C., e.a. ed., *The Anglo-Dutch contribution to the civilization od early modern society*. Oxford: OUP, 1976, 33-44.

12 Cf. Vermij, Rienk, *The Calvinistic Copernicans. The Reception of the New Astronomy in the Dutch Republic, 1575-1750*. Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen, 2002, 106-107 and Vermij, R., Het copernicanisme in de republiek, Tijdschrift voor geschiedenis, 16, 1993, 349-367.

13 Cf. Jorink, Erik, Tussen Aristoteles en Copernicus. De Natuurfilosofische opvattingen van Nicolaus Mulerius (1564-1630). In: H. Krop, J. van Ruler en A. Vanderjagt eds, *Zeer geleerde professoren. De beoefening van de filosofie in Groningen, 1614-1996* (Hilversum 1997), 79. .

14 Cf. van Netten Djoeke, Van Netten, Djoeke, Koopman in kennis – De uitgever Willem Jansz Blaeu (1571-1638) in de geleerde wereld van zijn tijd. Proefschrift, Rijkuniversiteit Groningen, Maart 2012,106.

15 Mulerus's edition of Copernicus's *De revolutionibus* was published in 1617, the original work in 1543.

16 Cf. Jorink, E., op. cit., 83.

17 Cf. van Netten, D., op. cit., p. 106.

Dutch Republic and Galileo's Italy: Andreas Colvius, Elia Diodati, Hugo Grotius and Elsevier. As Klaas van Berkel[18] puts it: Isaac Beeckman was most congenial to Galileo in Holland in the period before Huygens. However, it was the Dutch protestant minister and former diplomat Andreas Colvius (1594-1671)[19], who introduced the mechanical philosopher to the works of Galileo and to members of circle around Galileo. From 1620 until 1627, Colvius accompanied the diplomat Johannes Berck as a pastor to the Dutch Embassy to Venice[20]. Interestingly, around 1620, towards the end of the Twelve Years' Truce, Constantijn Huygens (the father of the Christiaan Huygens) also travelled as a secretary of ambassador François van Aerssen to Venice, to gain support against the threat of renewed war.

Colvius was an important intellectual who was interested in natural science. During his lifetime, he was in contact with numerous important natural scientists such as René Descartes, Jacob Golius, Alexander de Bie, Micanzio and many other. In his correspondence with them, he discussed mainly scientific topics. Importantly, while in Italy, he made others copies of Galileo's work which he brought to Holland when he returned. Importantly, he even brought a copy of the unpublished *Discorso sopra Del flusso e reflusso del mare*. Back in Breda, he lent books from his library to natural philosophers such as Christiaan Huygens and Isaac Beeckman (1588-1637). Interestingly, in March 1655 (only one year before he designed his pendulum clock), Christiaan Huygens sent a letter to Colvius, asking him to send him Galileo's manuscripts. Importantly, this source makes clear that the Dutch physicist was at that time especially interested in Galileo's writings concerning the problem of the determination of the longitude: "*Expectabo invicem quae ad longitudinum scientiam pertinent manuscripta, et si quae alia Galilaei posthuma possides; restituturus cum tibi visum fuerit*." Moreover, he was so eager to have these copies of Galileo's work that he tried very tactfully to give Colvius a new microscope that he had just designed as a present in the hope of receiving Galileo's works

18 Cf. Van Berkel, Galileo in Holland before the *Discorsi*: Isaac Beeckman's reaction to Galileo's work. In: Maffioli, C.S. and L.C. Palm (Editors), Italian Scientists in the Low Countries in the XVIIth and XVIIIth Centuries. Atlanta / Amsterdam: Rodopi, 1989, 101.

19 For more information about Colvius, see: Molhuysen, P.C. and Blok, P.J. (Editors), *Nieuw Nederlandsch Biografisch Woordenboek (NNBW)*. Leiden: A.W. Sijthoff's Uitgevers-maatschappij, Deel 1, 1911, 627-629 and Nauta, D. et al (Editors), *Biografisch lexicon voor de geschiedenis van het Nederlands protestantisme*. Kampen: Uitgeversmaatschappij J.H. Kok, Deel 2, 1978, 134-135.

20 Thijssen-Schoutte, C.L., Andreas Colvius, een Correspondent van Descartes. In: Thijssen--Schoutte, C.L., *Uit de Republiek der Letteren.* 's Gravenhage: Martinus Nijhoff, 1967, 67- 89.

from him in return. During the same month, Colvius had already sent his "*Galilaei tractatus*" and his "*aliud manuscriptum ejusdem Galilaei*" to Huygens. The former treats the '*longitudinum scientiam*', the latter was a copy of Galileo's "*del flusso e riflusso del mare*".

Another person who played a major role in the process that made Galileo more well-known and even popular in Holland was Elia Diodati (1576-1661). He was a French jurist and lawyer of Swiss/Italian origin, working as an appointed 'avocat du Parlement' in Paris where he resided until his death in 1661. Importantly, he was a correspondent and good friend of Galileo. He met him for the first time around 1620 during a visit in Italy. Diodati was a member of the noble Diodati/Calandrini/ Burlamacchi family. This influential family had branches in several countries of western Europe: not only in Italy (Lucca), France (Paris, Lyon, Genève), and Germany (Nuremberg) but also in Holland (Amsterdam) where the family was close to the Huygens family[21]. Constantijn Huygens had a correspondence with several members of the Calandrini/Diodati family and - as I will show in the next section - he mediated in the negotiations between Galileo and the States General of Holland. It is important to notice that Elia Diodati met Christiaan Huygens I (1551-1624) - the father of Constantijn Huygens I and the grandfather of the Mathematician (Christiaan Huygens II) - in Paris which was the start of a long-life friendship. This friendship was the reason why Diodati would later contact his son, the Diplomat and poet, Constantijn Huygens I – who had a correspondence with several members of the Diodati/Calandrini Family - in order to ask for mediation in the tough negations between Galileo and the States General; a mediation which might be very important as background information for our discussion of the question who the inventor was of the first pendulum clock.

Elia Diodati was extremely skillful in creating relations with other people. Furthermore, he had a very particular relation with most of this other family members. However, there is no doubt that he was in contact with other family members in Europe, e.g. in Holland. For instance, during his entire life, he was in close relation with his nephew, the leading Calvinist theologian and bible translator Giovanni (Jean) Diodati (1576-1649) who attended the

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21 For a detailed analyzes of Elia Diodati's life, his activities and the relation between Elia Diodati and the other members of his noble family, see: Garcia's doctoral thesis entitled *Elie Diodati (1576-1661): un homme de réseau au service de la cause galiléenne*. Meanwhile this thesis has been published in the form of a book. The references of this work are : Garcia, S., *Elie Diodati et Galilée : Naissance d'un réseau scientifique dans l'Europe du XVIIe siècle*. Bibliothèque d'Histoire des Sciences, Leo Olschki Editions (1 janvier 2004).

synod of Dort (Holland) for reformed churches in 1618-1619 and played a prominent role in it. On this occasion, the theologian did a trip through Holland, met several leading people and was invited by Mauritius to become professor at the University of Leiden; an invitation he declined, although later three of his sons (Philippe, Samuel and Marc) settled in Holland.

Hugo de Groot - who is better known under his Latinized name Hugo Grotius (1583-1645) - was in close contact with Elia Diodati when he lived in exile in Paris. Understandably, the law scholar had a lot of sympathy for Galileo (who had been condemned by the Roman Church in 1633) because he had also been condemned to a life sentence. However, on 22 March 1621, the author *of Mare Liberum* (1604) could - with the help of his wife Maria van Reigersberch - escape in a spetacular way, in a chest of books, from Loevestein. While living in exile in Paris, Grotius organized the plan to smuggle Galileo outside Italy and bring him to Amsterdam where he would be able to live peacefully and focus on his promising work. On 17th of May 1635 these plans were made concrete. Grotius wrote a letter to his friend Gerardus Vossius (1577-1649) asking him if he could find a residence for Galileo in Amsterdam[22]. Grotius suggested that he could become professor at the *Athenaeum illustre* in Amsterdam. Vossius - the first professor of the newly founded school - admired Galileo and was moved about what happened with the Florentine who was convinced that the earth was rotating around the sun. Also, the Amsterdam regents rather welcomed Grotius' proposal.

Already, on May 28 1634, Vossius had expressed his opinion on Galileo's condemnation to Hugo Grotius "… imo Galileus Galilaei Florentinus, quia hanc sententiam et viva voce et scribendo defenderet, in carcerem sit conjectus nec inde emittendus, priusquam poenitentiae satis egerit". However not all people in power were interested and Vossius complained in his letter to Grotius of the 1st of July that: "it would be easier if not so many of these who are in charge were more concerned with money than with the truth and the glory of the city." Unfortunately, within a month already Galileo informed Grotius that he was too old, and his health was too poor to move to Holland.

It is not a coincidence that the few Dutch heliocentrists all had something to do with the *Athenaeum illustre* that had been founded in the year that Galileo had been condemned. This newly founded school situated in Amsterdam had to prepare students for their education at the universities. The pre-university academic school became a real center for Copernicans and Galileo

22 Van Miert, 2009, 56.

sympathizers. Practically, all the few Dutch Copernicans of that time were linked in one or another way to this school. The first professor who taught publicly heliocentristic ideas in Holland, Martinus Hortensius, was appointed in 1634 as mathematics professor at the *Athenaeum*. According to a letter[23] he wrote on the second July 634 to Grotius, his lectures on the elements of astronomy which included a discussion of Galileo's views were initially very successful. According to this source, they attracted a wide audience, not solely intellectuals and clergyman but also seafarers and trade people. Hortensius had been introduced to heliocentristic astronomy by his teacher Isaac Beeckman (1588-1637) who introduced him to the radical Copernican Philip Lansbergen (1561-1632). Interestingly, Galileo had books of Lansbergen in his personal library[24] and Hortensius would later have a correspondence with Galileo. Another Copernican, the cartographer and instrument maker, Willem Jansz Blaeu (1571-1638), was the publisher of the *Athenaeum Illustre*[25]. Hugo Grotius would, after his second condemnation in 1632 (after his return to Holland in 1631), never return to Holland. However, he stayed in close contact with his Dutch publishers, his friends from the *Athenaeum illustre* (such as Vossius), his and his son and several other family members who were students at the newly founded school.

It is well-known that the Elseviers published Galileo's *Discorsi* (1638) but Elsevier (or rather the Elsevier family) did not play only a role in the printing and publication; they were also important for the diffusion of Galileo's ideas in both protestant but also in Catholic countries. Needless to say, these publications and their selling in Elsevier's bookshop in Amsterdam contributed to discussions of Galileo's works among intellectuals in Amsterdam and other Dutch places.

In May 1636, Louis Elsevier visited Galileo in his house in Arcetri and agreed to publish the *Discorsi* in Leyden. The Elseviers did not only play an important role in the publication of Galileo's last important dialogue but also in the publication and diffusion of other works, such as the Latin translation

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23 Cf. Letter of Hortensius to Grotius, 02/06/1634, Gassendi, *Epistolae*, 422.

24 Cf. A. Favaro, La libreria di Galileo Galilei, in « Bullettino di bibliografia e di storia delle scienze matematiche e fisiche», XIX, 1886, p. 219-293 and subsequent appendices of 1887 and 1896; Michele Camerota, La biblioteca di Galileo: alcune integrazioni e aggiunte desunte dal carteggio. In: *Biblioteche filosofiche private in età moderna e contemporanea*. Firenze: Le Lettere, 2010, p. 81-95 and Crystal Hall, *Galileo's library reconsidered*. Galilaeana, a. 12 (2015), p. 29-82).

25 Cf. Van Netten, Djoeke, op. cit., p.159.

of the *Dialogo* which appeared in 1635 under the title *Systema cosmicum*. Moreover, Galileo was at the end of his life negotiating with the Dutch Publishing house concerning the publication of his complete works in one volume in Latin[26]. It is not so well known that Galileo really insisted on this Latin publication. Rather, several scholars - such as Mark Davie[27] - argue that Galileo, in contrast to many of his contemporarie, abandoned Latin in favor of the Italian vernacular.

In sum, different elements resulted in Galileo becoming well-known in Holland in General and to the astronomer Christiaan Huygens in particular. Besides the contacts on the political level between Venice and Holland, the relation between Galileo's circle and the people of Holland via several figures, there was also Huygens's personal affinity with Galileo's work. Indeed, much of Huygens's work can been regarded as a prolongation of that Galileo's. For instance: his discovery of rings of Saturn which he documented in *De Saturni Luna observatio nova* (1656).

The Dutch physicist and astronomer had almost all of Galileo's works in his personal library: the *Opere di Galileo Galilei* (Bologna, 1656), The *Discorsi e demonstrazioni Mathematiche e I movimenti locali* (Leyda, 1639), *Les Nouvelles pensées de Galilée* (translated by Mersenne, 1639), the *Dialogo di Galil. Galilei sopra i sistemi del Mondo* (1632), the *Trattato della Sfera di Gal. Galilei* (1656), the *Discorso intorno alle cose che stanno in su l'acqua*, the *Historia e Demostrationi intorno alle macchie Solari in 3. Lettere al Sign. Mr. Velseri*, (Firenze 1612) and L'usage du quadrant ou de l'horologe [Galilei, 1639]. Furthermore, there were not only books of Galileo in his personal library but also books about Galileo's work such as: *Jo. Kepleri Dissertatio a Galilaeo* (Pragae 1610) and *Galilei scienza universale delle Proportioni, & alia posthuma*, Fiorenza, 1674. en veau [Viviani; BZ: 670], illustrating his enormous interest in Galileo's work and their interpretations.

However, besides his publications and his condemnation there was another main reason why Galileo became well-known to intellectuals as well as to ordinary people in Holland. This brings us to the next section on his proposal to States General of the Netherlands for the determination of the longitude at sea.

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26 Cf. OG XVI 510-511, OG XVII 94-96, OG XVII 173, OG XVII 247-248, OG XVII 281, OG XVII 308, OG XVII 347, OG XVII 369-372, OG XVIII 203-204 and OG II 398-399 and Favaro, A., Adversaria galileiana: serie I-VII, Trieste, Lint, 1992, 177.

27 Prof. em Mark Davie is the co-editor and co-translator of *Galileo, Selected Writings*, Oxford: OUP, 2012.

4. Galileo's proposal to the States General

4.1 The Dutch States General offers a prize of 30 000 scudi

Obviously, as Christiaan Huygens indicates in his *The Timepiece* [*Horologium*] (1658) the invention of the pendulum clock is inevitably closely linked to the problem of the determination of the longitude at sea, although at this stage of his publications he omits its discussion from his explanation. The perfection of the clock is the only way to get a really useful tool for navigation, he argues:

> *I omit to speak of the so-called science of longitude, which, if ever it existed, and so had provided the greatly desired help to navigation, could have been obtained in no other way, as many agree with me, than by taking to sea the most exquisitely constructed timepieces free from all error. But this matter will occupy me or others later; now I will submit the diagram of my invention for inspection, and explain the figure as clearly as possible*[28].

The problem of the determination of the longitude at sea was for a very long time a real problem for countries of seafarers such as Spain, Portugal, England, not to mention Holland, which by the 17th century had developed trade with different parts of the world. Hence, the Dutch States General decided to offer a prize to anyone who could invent a method for the determination of the longitude at sea. The prize was 30 000 *scudi*. This was a very important sum given the fact that Galileo, for instance, earned a salary of only 60 *scudi* per year when he was a professor in Pisa.

On 25 October 1627[29], Galileo received a letter from Alfonso Antonini (1584-1657) in The Hague informing him about the prize:

> *.... Qui io sperava di trovar ocasione di scriverle nella curiosita delle osservationi che costoro fanno nelle loro nuove et ardite navigationi, e l'ho trovata, ma in soggetto molto diverso da quelle che io cercava.*
> *Trovo che le Compagnie de' Mercanti 6) e gli Stati hanno messo insieme una grossa somma di oro e depositata (dicono che sia intorno a m/30 scudi*

28 English translation by Ernest L. Edwardes in Antiquarian Horology Volume 7, No. 1, December 1970.

29 S.A. Bedini mentions incorrectly that the letter was dated October 22 which should be October 25. Cf. Bedini, Silvio A., *The Pulse of Time*. Florence: Leo S. Olschki, 1991, 1991, 18.

> *7)), per darli a chi potra insegnare il modo di trovare la longitudine per uso della navigatione ....Ramentandomi questi particolari, ho risoluto di scrivergliene et avisarla. Ella potra prender sopra l'afare quella resolutione che le parera: se vora abbracciar la ocasione, che a me pare bella e grande, io godero non solo di haverle fatto la propositione, ma d'impiegarmi per far riuscire il negotio con tutta la prontezza maggiore. Et se desiderara per aventura ch'esso negotio passi con secretezza, si asicuri della mia fede, che non ha mai mancato a persona del mondo e non mancara mai ....*[30]
>
> *Only eight years later, Galileo let the States General know that he had found a method which he wanted to present for examination. More precisely, on 15 August 1636, Galileo sent his letter (written in Italian) with his proposal to the States General together with three letters: one addressed to Grotius, one addressed to Hortensius and one addressed to Laurens Reael (1583-1637). Reael, who could read Italian, copied and translated the letter into Dutch and presented it to the Dutch States General (hereunder you can see the first page of that letter) on 11 November 1636.*

In their report of 5 December 1635 the States General announced that: "through his zealous research Galileo believes to have found a certain method to determine at every moment and in every place of the world, at sea as on land, the true longitude of the location, and how much more to the east or to the west this location is situated from the Meridian of any city or port, that may be chosen freely; presenting this invention with regard to the laudable reputation [to be gained for himself] and the government in this country, and also [with regard to] the premium offered to the first author who would show and dedicate [his invention] to Her Great Power."[31]

Why did Galileo reply only after 8 years to Antonini's invitation? There were at least two main reasons. First, because Galileo was still busy negotiating with Spain concerning the introduction of his method for the determination of the longitude at sea based on the satellites of Jupiter. In 1610, he had discovered the "Medicean planets". Subsequently, shortly after his appointment by the Grand Duke Cosimo II de Medici, he sent his proposal for the determination to the king of Spain as part of trade negotiation between Spain

30 C. de Waard, Journal tenu par Isaac Beeckman de 1604 à 1634, IV (Supplément).

31 For the integral, original text of this report with an English translation see Vanpaemel, G., 1989. In: Maffioli, C.S. and L.C. Palm (Editors), op. cit., p.129.

Fig. 1: This is the first page of Galileo's first letter to the States General of the Netherlands with his proposal for the determination of the longitude at sea. This document is currently stored in the Dutch National Archives in The Hague (Holland). As you can see the document is in a terrible state.

and the Grand Duke. However, his method was not accepted officially because a similar method by a Spanish mathematician was being investigated. After his first condemnation by the Roman Chrurch in 1616, however, he did in June put a second proposal to the king of Spain, this time on his own behalf with the support of the Tuscan ambassador in Spain. Galileo even proposed to come to Spain to demonstrate his method. Despite Galileo efforts further negotiations did not lead to a successful decision by the Spanish State Council. Around 1618, it became obvious that Galileo's method was not accepted. The application of a high-performance telescope at sea in moving water was regarded as far too problematic despite Galileo's efforts to overcome these problems by means of a special device, a headgear fitted with one or two telescopes, which he named the *celatone*. Galileo's proposal was renewed in 1620, 1629 and 1631 but each time with a negative result[32]. A second reason why Galileo do not answer more directly to Antonini's invitation was that he was very busy finishing his last chapters of his last big publication, the *Discorsi,* during that period.

Diodati hat sent on 20 September 1636[33] Galileo's letters to Laurent Reael and Martin Hortensius and informed Reael that Grotius and himself would mediate the negotiations between Holland and Galileo. Three days later, more precisely on 23 September 1636[34], Diodati informed Galileo that he had delivered the letter to Grotius and the people in Holland and that Grotius and himself would do everything within their possibilities to promote his method in Holland.

Reael submitted Galileo's first letter with the proposal to the States General which on 11 November 1636 composed directly a committee that had to evaluate Galileo's proposal. The members of that committee were initially Laurens Reael, Martinus Hortensius, the carthographer Blaeu and Jacobus Golius. Initially, as mentioned in the report of 5 December 1635[35], it was decided by the States General that not Golius but Isaac Beeckman would

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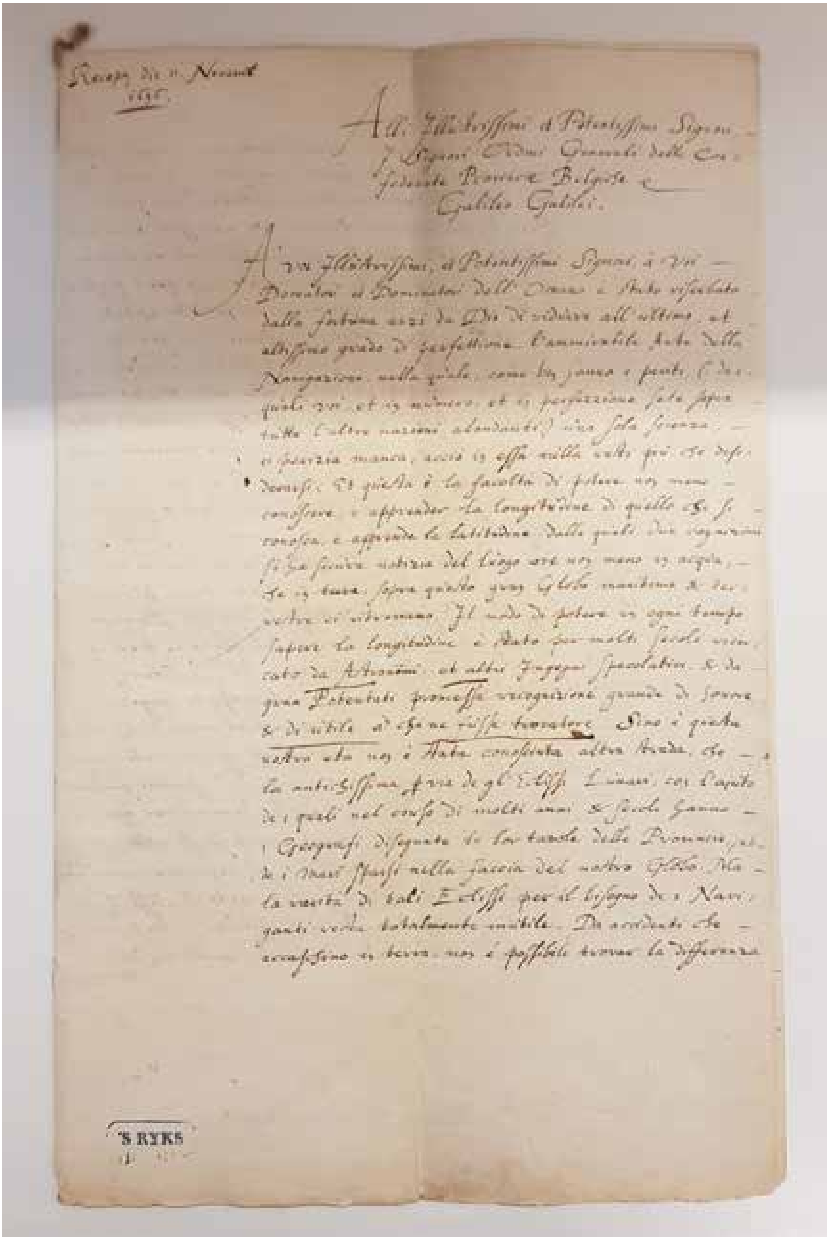
32 Cf. Van Berkel, K., 1989. In: Maffioli, C.S. and L.C. Palm (Editors), op. cit., 113-17.

33 Cf. OG XVI 491-492.

34 Cf. OG XVI 489-491.

35 Obviously, in this report, it is mentioned that: " … it was deliberated: agreed and accepted that would be invited and authorized doctor Hortensius as president, mathematician of Amsterdam, Willem Jansz Blaeu, also [living] in Amsterdam, Willem Jansz Blaeu, also [living] in Amsterdam, Isaac Beeckman rector at Dordrecht to open [the negotiations on] the Suppliant's invention by letter and to examine it, and to report to Her Great Power."



All'Illustrissimi et Potentissimi Signori

li Signori Ordini Generali delle Con-

federate Provincie Belgiche

Galileo Galilei.

Fig. 2: This is the first page of a copy of Galileo's letter with his proposal. This document is also stored in the Dutch National Archives in The Hague (Holland).

examine Galileo's proposal. Beeckman was not a later member, as mentioned by Van Berkel, on the contrary, he was one of the first members of the committee. However, Beeckman died on 19 May 1637.

On 7 april 1637, the report of the committee was presented to the States General which decided that a second committee composed of Rantwijck, Weede and Schoneburch had to decide subsequently (in collaboration with Reael) what steps had to be taken. Two weeks later, it was decided that Galileo would get a golden chain, worth 500 florins[36] and that Reael would get 1 000 florins for the funding of instruments that he needed for further research of Galileo's method. However, Galileo did not receive the 30 000 scudi that had been promised by the States General. And, as we will see in the next section, this gift was certainly not the end of the communication concerning the proposal between Galileo and the States General. On the contrary!

How did Galileo's method work? His method was based on the position of the four[37] satellites of Jupiter, that he had discovered with his improved Dutch telescope. Tactfully, he had called these satellites - which he had discovered in January 1610 - the "Medicean Stars" referring to the Medici family. His method[38] was as fellows. At each moment of the day, the four moving planets had a characteristic position and were eclipsed in a specific way. This time-dependent picture of the satellites Jupiter, however, was place-independent. So, if the picture was known at a certain position A, you could know also the time at this place. And if you know, additionally, at the same moment the arrangement of the satellites at another position B on earth you could in principle calculate the difference in longitude. Based on the difference in time, it was possible to calculate the difference in place or more precisely the longitude between A and B given the fact that the earth makes one turn (360°) around its axe in 24 hours. Therefore, a difference in 4 hours for instance corresponds with a difference in longitude of 60° (= 4/24 multiplied by 36 °).

However, Galileo's method could only work if two conditions were realized. First of all, there was a need for a very good telescope in order to observe the satellites of Jupiter at a given moment in time. Secondly, the

36 500 florins were approximately equivalent with 1000 scudi.

37 Today, we know that there are not less than 69 objects turning around Jupiter and 18 of them are considered to be moons.

38 Cf. Matthews, Michael R., *Time for Science Education. How Teaching the History and Philosophy of Pendulum Motion Can contribute to Science Literacy*. NY: Kluwer Academics/Plenum Publishers, 2000, 90-91.

observer needed a time measurement in order to know the time at place A after some days of travel. Besides these two elements, there was another major problem to overcome: the telescope and the time measurer had to work perfectly well at sea in moving water. That this was a big challenge.

4.2 The idea of the pendulum clock

Already, in Galileo's first letter (1635) of the correspondence between Galileo and the Dutch States General concerning the method for the determination of the longitude at sea, the idea of timekeeper based on a pendulum seems to occur:

> *I have such a time -measurer that if 4 or 6 examples of this instrument were constructed, and if they were allowed to operate at the same time, we would find that in confirmation of their accuracy, the times measured and indicated by these time-measurers would show differences of only one second, not only from hour to hour, but from day to day and from month to month, so uniform would be their operation; these clocks are really admirable for the observers of motion and celestial phenomenon, and in addition, their construction is very simple and far less subject to outside influences than are other instruments which have been invented for a similar purpose*[39].

Obviously, the time-measurer [*numeratore del tempo*] that Galileo describes in the passage above is not a traditional mechanical clock. Galileo describes his "*orologii veramente pur troppo ammirabili*" as something revolutionary and new, very different and much more accurate than the clocks which had been used up until then. Several interpreters argue that Galileo must have a form of vibration counters (or forerunners of the pendulum-regulated clock) here

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39 From Galileo's letter (dated August 15, 1636) to the States General of the Netherlands. *Opere*, XVI, 463-469. The English translation is by Silvio A. Bedini. In the original text, Galileo writes: " […] Finalemente, circa il 4° requisito, io ho tal misurator del tempo, che se si fabbricassero 4 o 6 di tali strumenti et si lasciassero scorrere, troveremmo (in confermazione della lor giustezza) che i tempi da quelli misurati et mostrati, non solamente d'hora in hora, ma di giorno in giorno et di mese in mese non differirebbero tra di loro nè anco d'un minuto secondo d'hora, tanto uniformemente caminano : orologii veramente pur troppo ammirabili per gl'osservatori de i moti e fenomeni celesti ; et è di più la fabrica di tali strumenti schiettissima e semplicissima, et assai meno sottoposta all'alterazioni esterne di qual si voglia altro strumento per simile uso ritrovato."

in mind. As Silvio A. Bedini puts it: "More likely they were a form of vibrations counter, consisting of a pendulum bob suspended on a string which was given impulse manually or by clockwork."[40] This seems to be confirmed by the fact that around the same period Galileo wrote his "*L'usage du cadran ou de l'horloge physique universel*" which was published in 1639 in Paris[41]. In this work, the Tuscan physicist explained his views on the the motion of the pendulum and its application for the determination of the longitude and observing eclipses. Galileo argued that for this application it is necessary to have a pendulum that is "used for regulating the movement of the clock"[42]. Hence, the clock in Galileo's letter to the States General of the Netherlands must be a kind of first version of a pendulum regulated clock.

According to a letter of Galileo's last student and first biographer, Galileo conceived of his pendulum regulated clock a few years later, more precisely in 1641. This is 25 years before Christiaan Huygens would conceive of his pendulum clock. However, it is important to notice that Viviani (1622-1703) wrote this letter to Prince Leopold in 1659, after having heard about Huygens' invention:

> *One day in the year 1641, whilst I was living with him in his country house in Arcetri, I recollect that it came into his mind that the pendulum could be adapted to clocks driven by weight or spring, in the hope that the perfect natural equality of its motion would correct the imperfections of mechanical construction. But, being deprived of sight and unable himself to execute the plans and models which would be required to ascertain which would be best adapted for carrying out this project, he communicated his idea to his son Vicenzio, who had come out one day from Florence to Arcetri. They had several discussions on the subject, with the result that they fixed upon the method, of which the accompanying drawing is a copy; and they decided to proceed at once with its execution, in order to determine what were the difficulties, which, as a rule, in the construction of machines, a theoretical design does not reveal. But Vicenzio, being desirous to construct the instrument with his own hands, for fear the artificers who might be employed*

40 Cf. Bedini, S., op.cit., 20.

41 Galileo, Galilei, L'usage du quadran ou De l'horloge physique universel sans l'ayde du soleil ny d'autre lumière. Paris : Hachette Livre BNF, 2016.

42 Cf. Robertson, J. Drummond, *The Evolution of Clockwork*. Wakefield: S.R. Publishers Ltd., 1931, 93.

> *should divulge it before it had been presented to the Grand Duke and to the States-General of Holland for the measurement of longitudes, kept putting off its execution, and a few months later Galileo, the author of this admirable invention, fell ill, and died on January 8, 1642. As a consequence, Vicenzio's enthusiasm cooled, so that it was not until the month of April 1649, that he took in hand the manufacture of the present clock made in accordance with the conception which his father had already imparted to him in my presence.*
>
> *Vicenzio Galilei engaged a young locksmith, who had some experience in construction of large wall clocks. He caused him to make the iron framework, the wheels, and their arbors and pinions, but without cutting them, and the executed the rest of the work with his own hands. (Letter of Viviani of August 20, 1659 to Prince Leopold)*

In the passage above, the author of '*Racconto istorico della vita del Sig.*[r] *Galileo Galilei'* (1654), writes that Galileo even wanted to construct his pendulum regulated clock that he had in mind. However, at this moment he was already blind so he asked his son to construct his clock. Vincenzio started with this work. However, his father died on January 8, 1642. Subsequently, his son finished – according to Viviani – the construction with the help of a young locksmith. It is important to notice that Viviani mentions that Galileo wanted to present his clock not only to the Grand Duke but also to the States-General of Holland. This confirms once again how the design of the pendulum clock was linked to Galileo's method for the measurement of longitudes and should be understood in this context.

4.3 The role of Christiaan Huygens's father in Galileo's correspondence

Christiaan Huygens explains in two books his design of his new pendulum clock, its physics and its functioning. However, nowhere does he clarify how he came to the idea of conceiving a clock based on a pendulum as a regulator. Moreover, he seems to exclude quite explicitly this question from his writings. In his *Horologium* (1658) he writes about this question: "But this matter will occupy me or others later". Did he want to hide something? Did he really design his pendulum regulated clock completely independently as he always argued?

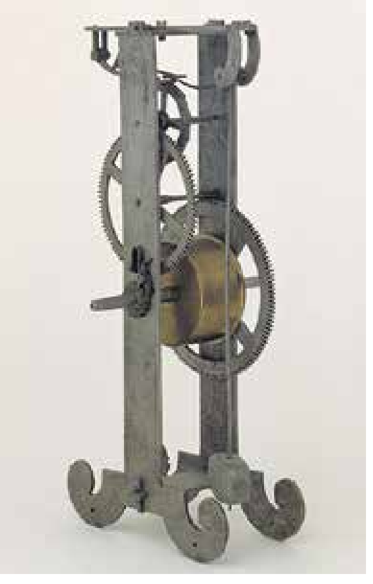

Fig. 3 (Right): Drawing made in 1659 by Vincenzo Viviani of the Galilean clockmodel in its unfinished state of 1649.

Fig. 4 (Left): reconstruction of this clock by Eustachio Porcellotti (1879) based on Vincenzo's Galilei's model.

Is there somebody who knew the content of Galileo's secret correspondence with the States General who might have given the Dutch physicist and astronomer this idea? Theoretically there is always the possibility that one of the members of the committee that examined Galileo's proposal could have informed somebody else so that Christiaan Huygens got informed about Galileo's "*orologii veramente pur troppo ammirabili*". And there is evidence that there were leaks so that this possibility cannot be excluded. For instance, in his letter of 16 Mars 1637 to Hortensius, Diodati accuses the Dutch professor of mathematics of violating the secrecy of the correspondence concerning Galileo's method. However, Hortesensius had already explained in his former letter to Galileo's correspondent that he thought he was allowed to do this because another committee member, Isaac Beeckman, had already informed Mersenne. Moreover, Hortensius replied that Galileo nor Diodati had never asked for secerecy of the correspondence.

However, it is much more likeley that Christiaan Huygens' father – Constantijn Huygens – has informed his "petit Archimède" about Galileo's idea. The role of Constantijn Huygens might have been very important here and might explain how his son came to the idea of designing a clock based on isochronism. Initially, it took some time until Galileo had received an official answer from the States General, although Hortensius had sent Diodati on 24 November 1636 a personal letter confirming that Galileo's proposal had been very well accepted by the States General and that a commission had been installed which would examine his proposal. However, after a year, he lost his patience and Diodati started to take steps.

But, let's give an overview of the history of the correspondence in order to have a more detailed and better picture of Constantijn's role. In his letter[43] of 16 mars 1637 to Hortensius, Diodati complains that Galileo had still not received any official word nor sign of gratitude from the States General. Four days later, he writes very tactfully a letter to the diplomat Constantijn Huygens explaining the promising future of Galileo's method for Holland and asking him to intervene in this question. The father of Christiaan Huygens replies in his letter[44] of 13/23 Avril written in French.

Cristiaan Huygens's father accepts Diodati's invitation, but he underlines very clearly that there are two major problems which are essential for the success of Galileo's method. First of all, Huygens asks for a performant telescope so that he can test Galileo's method and actually see the satellites of Jupiter which was impossible to see with the telescopes that were at that moment available in Holland. Secondly, Huygens stresses that Galileo's method should work on boats at sea. It is important to notice that Huygens shows here that he was very well informed of Galileo's method and that he knew extremely well the problems of Galileo's method.

In his letter[45] of 8 May 1637 to Constantijn Huygens, Galileo's correspondence thanks the diplomat for his mediation but repeats that he expects soon an official answer from the States General of the Netherlands. Only after a word of gratitude, he clarifies, Galileo will reveal some unknown, promising aspects of his method. A week later, more precisely on 15 Mai 1637, Galileo's correspondent writes once more a letter[46] to the States General (and another letter to Constantijn Huygens), repeating that Galileo expects an official letter from the States General and that Galileo will only reveal other aspects of his method after having received that letter.

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43 Cf. OG XVII 43.

44 Cf. OG XVII 59-60.

45 Cf. OG XVII, 73-74.

46 Cf. OG XVII 79.

Interestingly, during the period of his correspondence with the States General, Galileo had a personal correspondence with the president of the committee that had to examine Galileo's proposal. As I have mentioned already, Hortensius, had written[47] him already on the 24th November 1636 congratulating him with his proposal and telling him that he would soon receive an official letter from the States General. In his letter of 1 February 1637, Hortensius explains that the evaluation by the committee took more time because the Reael could not work permanently on it. In the same letter, he also reveals that he had informed Jean-Baptist Morin about the importance of Galileo's new method. In his letter of 16 Mars to Hortensius, Diodati accuses the Duch professor of mathematics of violating the secrecy of the correspondence concerning Galileo's methods and he repeats once more that is scandalous that Galileo has still not received any official reply from the States General. However, Hortesensius had already explained in his former letter that he thought he was allowed to do this because another committee member, Isaac Beeckman, had already informed Mersenne. And in his letter of 27 Avril, Hortensius defends himself against Diodati's allegations and argues that Diodati nor Galileo had never asked for secrecy. Moreover, he could not have revealed all the secrets of the method yet because Galileo had not yet delivered a solid proof of the usefulness of the method at sea and not yet given all the details.

In the same letter, Hortensius assures Galileo's correspondent that he is convinced that Galileo's method is applicable. He informs Diadati also that Galileo will soon receive his award. A month later, more precisely, in his letter[48] of 22 Mai 1637, Diodati accepts Hortensius's explanation but complains once again about the fact that Galileo has still not received any official reply from the States General. Subsequently, he invites Hortensius to meet Galileo in the Embassy of Venice where Galileo would reveal all the details of the method.

4.4 The tragic end

What had announced itself for Galileo as something really promising: the proposal of his method for the determination of the longitude to the States General and the publication of his complete works in Latin in one volume by Elsevier, finished as a tragedy.

47 Cf. OG XVII 521.

48 Cf. OG XVII 84-85.

Galileo never received the 30 000 scudi which would have awarded to somebody who solved the problem of the determination of the longitude at sea. He only received a collar worth 500 florins which he refused to accept[49]. Unfortunately, he could never deliver the instruments that the committee had asked for to test his method, because meanwhile, he was becoming blind. Furthermore, there was no meeting between Galileo and Hortensius or any other member of the committee because they all died in a short period of time: the president of the committee that had to examine his proposal died on the 17th of August 1639 and before, other members had died: Beeckman on the 19th May 1637 and Reael on the 10th October 1637. Blaeu would die a year later, on the 26th of October 1638. Meanwhile, Galileo had become completely blind and he died a few years later, on January 8 in 1642 in Artcetri.

During the last years before his death, Galileo still did try to restore the negotiations between him and the States General. In his letter[50] of the 30th December 1639 to Diodati, he proposes that if necessary one of his disciples, Vincenzo Renieri, would go to Holland in order to explain his method. On the 28 of February 1640, Diodati again asks Constantijn Huygens for assistance[51]. The father of Constantijn Huygens answers two months later that he wants to help but that given the new circumstances it will be necessary to start from the beginning, and suggests contacting some influential Dutch people such as A. Boreel.

After Galileo's death, more precisely on the 21th February 1657, Louis Elsevier wrote a letter[52] to Diodati saying that he had never had the plan to publish Galileo's complete works in one volume and that - after having heard about the publication of Viviani edition of Galileo's works in Italy - no Dutch publisher would ever publish such a volume.

The end of Galileo's life and that of the committee members, however, was not the end of the relation between Galileo's circle around Viviani and the Dutch Republic. On the contrary, the publication of *Horologium* in 1658 by Christiaan Huygens lead to an enormous dispute about who was the first to have designed and constructed a pendulum clock. A dispute which had an international dimension.

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49 Cf. OG XVII 369-372.

50 Cf. OG XVIII 132-133.

51 Cf. OG XVIII 151-152.

52 Cf. Favaro, A., Documenti inediti per la storia dei manoscritti galileiani nella Bibliotheca Nazionale di Firenze. In: Bollettino di Bibliografia e di Storia delle Scienze matematiche e fisiche, 18 (1885), 113.

5. Was Spinoza inspired by Huygens's invention of the synchronization of pendulum clocks[53]

In Holland, after Huygens's design of the pendulum clock, several early modern philosophers applied this sophisticated device as an analogy in their philosophy. Not only Dutch philosophers but also foreign philosophers who moved to Holland applied the clock analogy. Good examples are the Flemish philosopher Arnold Geulincx (1624-1669) and Comenius [Jan Amos Komenský (1592-1670)][54]. They both used the clock to clarify the harmony between things. Another obvious example is Leibniz who applied in 1696 the clock analogy in his explanation of the relation between the mind and the body in his letter to Basagne[55], referring to Christiaan Huygens: "This is the way with which Mr. Huygens experimented, with results that greatly surprised him."

The French Spinoza scholar, Martial Gueroult[56] has already argued that Spinoza applied the pendulum analogy in his conception of the complex bodies as well as in his conception of the simplest bodies in the *Ethics* (1677). However, the French structuralist did not say a word of Spinoza's possible application of the synchronization which Huygens discovered in his *Letter 32*. Hence, this section will focus on this subject.

Spinoza writes in his *Letter 32* (1665), the following sentences as an answer to a question of Robert Boyle, transmitted by his Boyle's friend Henry Oldenburg:

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53 The abbreviations applied for Spinoza's works: E – *Ethics (Ethica)*. Passages in Spinoza's *Ethics* will be referred to by means of the following abbreviations: a (axiom), ap (appendix), c (corollary), d (demonstration), def (definition), p (proposition), le (lemma) and s (scholium). For instance: E2p16c2 = Part 2 of the *Ethics*, proposition 16, corollary 2.
All citations in English from Spinoza's work are translations by Edwin Curley unless otherwise mentioned. All translations from Christiaan Huygens' correspondence are from Alex Boxel. These translations can be found on the following site: *http://idolsofthecave.com*

54 See *Comenius, Opera didactica omnia* (Oeuvres didactiques complètes) (1657) D 42; Comenius, J.A., *The Great Dictatic* (Translated from the Latin, and edited by, M.W. Keatinge), London: Adam and Charles Black, 1657/1910, 47-48; Comenius, *The Great Didactic*, 47-48; McReynolds, *The Clock Metaphor*, 99 and Matthews, *op. cit.,* p. 217 and Annotata ad Ethicam, Sämtlichen Schriften [10.24], 3:211-12; cf. Annotata ad Metaphysicam, Sältkichen Schriften [10.24], 2: 307.

55 G IV, Leibniz to Basagne (1696) 498-500,

56 Gueroult, M, *Spinoza II: L'âme*. Paris: Aubier, 1974, 159-165.

> *"By coherence of parts I mean simply this, that the laws or nature of one part adapts itself to the laws or nature of another part in such wise that there is the least possible opposition between them. On the question of whole and parts, I consider things as parts of a whole to the extent that their natures adapt themselves to one another so that they are in the closest possible agreement. Insofar as they are different from one another, to that extent each one forms in our mind a separate idea and is therefore considered as a whole, not a part."*[57]

This is for several reasons a very remarkable text. First of all, because Spinoza gives on other occasions very different explanations of similar questions. Secondly, because the Dutch philosopher writes here "odd sentences" which seem to be in clear contradiction with typical elements of his metaphysics. Indeed, what Spinoza writes in the passage above seems to be in contradiction with his radical, metaphysical determinism which is an essential and characteristic part of his philosophy.

According to E1p28, a body which is determinate or finite (according to the first definition[58] of E2) is necessarily determined by another finite thing. Moreover, according to E1p10 and E2p6 this finite[59] thing should be of the same attribution of the unique and eternal substance. Consequently, a body (a mode of the attribute Extension) is always determined by another body to act in a determinate way. Spinoza expressed this idea in Lemma 3 of the *Physical Interlude* and he referred to it several times in the course of his *Ethics*, highlighting the importance of this principle. In his *Letter 58* (1674) to

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57 Spinoza, B. *Complete Works*, Ed. M. L. Morgan and tran. S. Shirley, Indianapolis: Hackett, 2002, 848. In the original version, we read : "Per partium igitur cohaerentiam nihil aliud intelligo, quàm quòd leges, sive natura unius partis ità sese accommodat legibus, sive naturae alterius, ut quàm minimè sibi contrarientur. Circa totum, et partes considero res eatenus, ut partes alicujus totius, quatenus earum natura invicem se accommodat, ut, quoad fieri potest, inter se consentiant, quatenus verò inter se discrepant, eatenus unaquaeque ideam ab aliis distinctam in nostrâ Mente format, ac proinde, ut totum, non ut pars, consideratur. Ex. gr. cum motûs particularum lymphae, chyli, etc. invicem pro ratione magnitudinis, et figurae ità se accommodant, ut planè inter se consentiant, unumque fluidum simul omnes constituant, eatenus tantùm chylus, lympha, etc. ut partes sanguinis considerantur : quatenus verò concipimus particulas lymphaticas ratione figurae, et motûs, à particulis chyli discrepare, eatenus eas, ut totum, non ut partem, consideramus."

58 In the Latin text, the definition of the body is: "*Per corpus intelligo modum, qui Dei essentiam, quatenus, ut re extensa, consideratur, certo, et determinatio modo exprimit; vid. Coroll. Prop. 25.p.1*."

59 Spinoza defines "a finite thing" in E1d2 as: "That thing is said to be finite in its own kind that can be limited by another of the same nature. For example, a body is called finite because we always conceive another that is greater. Thus a thought is limited by another thought. But a body is not limited by a thought nor a thought by a body."

G.H. Schüller, Spinoza explains his metaphysical determinism also, this time through the example of a moving stone, emphasizing that what is true for a stone is true for each individual thing.[60]

By contrast, in the passage quoted above from *Letter 32*, Spinoza does not write that the parts (or natures) of a body are externally caused by other bodies. On the contrary, he writes that they "adapt" themselves: "the laws or nature of one part adapts itself to the laws or nature of another part." Moreover, he does not write this once, as though it were a mere exception, but it appears several times: "their natures adapt themselves to one another," suggesting here a spontaneous, internal cause.

Secondly, as Albert Rivaud[61] already remarked, Spinoza explains in *Letter 32* the coherence between the parts of a body in a very different way than in the *Physical Interlude* and in a letter written in 1661/62. In letters known as the Boyle/Spinoza correspondence,[62] transacted after Oldenburg's visit to Spinoza during the summer of 1661, Spinoza writes in *Letter 6* (December 1661) the following explanation:

> *To understand the first, it must be noted that bodies in motion never meet other bodies with their largest surfaces, whereas bodies at rest lie on others on their largest surfaces.*

And, in Axiom 3 of the *Physical Interlude* of the second part of the *Ethics*, just after his definition of the body, the Dutch philosopher writes:

> *As the parts of an Individual, or composite body, lie upon one another over a larger or smaller surface, so they can be forced to change their position with more or less difficulty; and consequently the more or less will be the difficulty of bringing it about that the Individual changes its shape. And therefore the bodies whose parts lie upon one another over a*

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60 What Spinoza writes here in this letter on freedom and necessity might be inspired by chapter 21 of Hobbes' *Leviathan*, a book translated in 1667 into Dutch by Spinoza's friend Abraham Van Berkel.

61 Cf. Albert Rivaud, La physique de Spinoza. *Chronicon Spinozanum* 4 (1924-1926): 24-57.

62 The correspondence between Baruch Spinoza and Henry Oldenburg is composed of 17 letters from Oldenburg to Spinoza and 10 from Spinoza to Oldenburg. This correspondence was between 1661 and 1676 with hiatuses between 1663 and 1665 and between 1665 and 1675. What is known as the 'Spinoza-Boyle' correspondence forms a part of this larger whole and consists of the letters 6, 11, 13 and 16 written between 1661 and 1663.

> *large surface, I shall call hard; those whose parts lie upon one another over a small surface, I shall call soft; and finally those whose parts are in motion, I shall call fluid.*

Thus, in both the *Physical Interlude* (1677) and *Letter 6* to Boyle (1661), Spinoza conceives of the agreement of coherence between the constituent parts of bodies in a purely mechanistic way, in contrast to the explanation of *Letter 32* to Boyle (1665). In other words: coherence is conceived of in terms of relative position, contact, motion and the rest of the parts that constitute the whole.[63] Nowhere in this context does Spinoza write that the natures of bodies adapt themselves spontaneously to other bodies in order to form a single unity. On the contrary, in the definition of a body that he gives in the *Physical Interlude*, Spinoza states clearly that a new physical individuality is a whole of bodies "constrained by other bodies" [*a reliquis ita coërcentur*]

How can this apparent paradox be resolved? This paper argues that Spinoza applied here a principle that Christiaan Huygens's had just discovered. This hypothesis would explain why the Dutch philosopher could write the odd sentences in his *Letter 32* without violating his mechanistic ideas.

Around the 22 February 1665, while Christiaan Huygens was sick and lying in his bed, he observed that two pendulum clocks, which were hanging in front of him, started to beat in synchronicity. He couldn't believe his eyes. Initially, he was unable to explain this phenomenon and referred to it as "some sort of sympathy" [une *espèce de sympathie*]. He struggled to find a causal explanation for this effect. Why did the clocks mysteriously synchronize with each other? How could mechanical objects transmit an influence when they were not touching? What is the cause of this "odd kind of sympathy?"

Initially, Huygens was convinced that there could not be any other cause of the agreement of the clocks "*than an imperceptible agitation of the air which is produced by the movement of the pendulums.*" However, a few days later he wrote with a pencil in the margin of his notes: *"causam hujus rei postea inveni ex communi fulcro."* More precisely, o*n the first of March,* he conducted some additional experiments and determined that not the air, but rather the mechanical connection between the two clocks was essential for their synchronization.

63 Cf. Rivaud, A., op. cit., 24-57.

Synchronization is not a state. On the contrary, it is a dynamic, equilibrium process.[64] Today we can demonstrate this phenomenon perfectly well by placing metronomes[65] upon a thin board that is isolated from a table using, for example, empty soda cans. The synchronization takes place with two or more metronomes which were initially in motion but which need not be in phase. Additional metronomes can be added which, after a brief time, will also start to synchronize. Even if the synchronized system is disturbed (for example, by touching one of the metronomes to block its motion), the synchronization will spontaneously restore itself after a suitable interval. In sum, the pendulums have the capacity to adapt themselves so that they form a unity. As Kurt Wiesenfeld puts it: "The phenomenon of spontaneous mutual synchronization offers perhaps the most primitive example of emergent behavior."[66] Needless to say, this behavior perfectly suits Spinoza's description of the behavior of parts that adapt themselves in his definition of coherence in *Letter 32*.[67]

For several reasons the hypothesis that Spinoza applied the principle of synchronization seems to be plausible. First of all, there is historical evidence that Spinoza visited Huygens in that period when they both lived in Voorburg. Hence, it is not incorrect to assume that the Dutch philosophers was informed about Huygens' discovery. Of course, there is also the date. Spinoza wrote his *Letter 32* in November 1665, just a few months after his neighbor, Christiaan Huygens, had discovered "the sympathy of the clocks." Moreover, according to his diary,[68] Huygens was still busy doing research on this subject when Spinoza visited him in May of 1665 and wrote his *Letter 32* in November of the same year.

Secondly, there is the fact that "clocks" became a paradigmatic example for understanding the supposed agreement or harmony between bodies in the universe, at least for philosophers in the region where Spinoza lived around 1665.

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64 Bennett, M., M. F. Schatz, H. Rockwood & K. Wiesenfeld. "Huygens's clocks", Proceedings of the Royal Society A458 (2002): 563-579.

65 Pantaleone, J., "Synchronization of Metronomes," American Journal of Physics 10 (2002): 992-1000.
For a simulation of this experiment, please visit the site of the Harvard Natural Sciences Lecture Demonstrations at: https://www.youtube.com/watch?v=Aaxw4zbULMs (accessed on 12/12/0217).

66 Wiesenfeld, K. and D. Borrero-Echeverry, "Huygens (and others) revisited," 047515.1 and Bennett, M., op. cit., 563-579.

67 Cf.: https://www.youtube.com/watch?v=nkXl8JJBH7E or https://www.youtube.com/watch?v=3mclp9QmCGs (Accessed on 12/12/2017).

68 See OCH XVII, 187, note 3.

There was already a longstanding tradition[69] among natural philosophers going back to innovators such as Leonardo da Vinci, Giovanni de' Dondi (c.1330-1388), Richard of Wallingford (1292–1336),[70] and Oresme (c.1323-1382), of using the mechanical clock as a metaphor for understanding the universe and natural phenomena. And, it is well documented that later also Kepler, Descartes, Malebranche and other early modern philosophers applied this metaphor. However, this tradition was completely renewed after 1658 when Christiaan Huygens, with the help of his technician, invented and constructed his pendulum clocks, which were of a much better quality than former versions of the mechanical clock. The clock was in the air so to speak! People were enthusiastic about this discovery and they hoped that this sophisticated thing would solve the long existing problem of determining longitude at sea.

Third, there is the argument that in his definition of *Letter 32* Spinoza refers to laws which he identifies with the nature of parts: "the laws *or* nature of one part adapts itself to the laws or nature of another part." Why does Spinoza mention "law" in this context? And, what is the link with "the nature of a part"? The reason might be that he is referring here to an early version of the pendulum law. This law expresses the relation between the natural frequency of a pendulum and the elements that determine this frequency: the length of the pendulum and the acceleration of gravity. Galileo had formulated in his *Dialogo* (1632)[71] the concept of isochronism, arguing that it is not the mass of the pendulum but the length that is decisive. But, it was Christiaan Huygens who discovered the pendulum law in 1673. This law was - according to Vincent Icke[72] - the first modern physical law expressed in the form of a mathematical formula. It is therefore possible that Spinoza had an anticipation of this physical law in mind when he discussed the agreement between the parts of a whole in his *Letter 32*.

Of course, our hypothesis could be challenged by the fact that Spinoza never mentions the pendulum clock in his *Ethics* (1677). In contrast to several contemporaries whose work he knew such as Robert Boyle he never applied

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69 See Wootton, D., *The invention of Science*. Milton Keynes: Penguin [2015] 2016),437-441, 484-486.

70 See North, J., *God's Clockmaker: Richard of Wallingford and the Invention of Time*. Oxford: Oxbow Books, 2004.

71 Galileo G, *The Dialogue*, New York: The Modern Library, 2001, 267.

72 Cf. Vincent Icke, *Christiaan Huygens in de onvoltooid verleden toekomende tijd*. Groningen : Historische Uitgeverij, 2005.

the analogy of the clock in a very explicit way. What is this so? Probably, the reason is that he avoided using artefacts as models for natural things because this might suggest that things are created by a creator distinct from his creation. In the appendix of *De Deo* in the *Ethics* for instance, Spinoza radically refutes this kind of "divine finalism" and instead argues that the human body should not be conceived as mechanical artefact and is not created but generated.

6. Conclusion

This paper shows that the design of Huygens's pendulum clock must be understood in the context of Galileo's search for a method to determine the longitude at sea, based on the satellites of Jupiter. The big historical question - whether Galileo or Huygens was the first to have invented the pendulum regulated clock - does not have an easy answer. Huygens always maintained that he did not know about Galileo's design of a pendulum regulated clock, but Viviani argued that his master had invented the first pendulum clock a long time before Huygens.

However, this paper shows that it is hard to believe that Christiaan Huygens found his clock completely independently from Galileo given the fact that: he knew Galilean physics extremely well, that he had almost all works of Galileo in his personal library (also: *L'usage du quadran ou De l'horloge physique universel sans l'ayde du soleil ny d'autre lumière*) and that he had asked Colvius for copies of Galileo's writing on the longitude only one year before his invention. Moreover, his father who knew the content of the correspondence - that included Galileo's idea of a pendulum regulated clock - very well so that he could have informed his "Little Archimedes". In sum, it is probably more correct to state that the design of pendulum regulated clock is the result of the work of Galileo and Huygens.

Pendulum clocks were much more accurate than traditional mechanical clocks. Consequently, their application as timekeepers had an enormous impact on the social and professional life of people. However, after Huygens's design in 1656, this device was also applied by philosophers as a mechanical analogy. Moreover, it became a leading metaphor for early modern philosophers in the 17^{th} century.

Around 1665, Spinoza was in contact with Christiaan Huygens. As this this paper argues the Dutch philosopher might have been inspired by Huygens's discovery of the synchronization of pendulum clocks in his views on the agreement between bodies in the universe. This hypothesis resolves the otherwise paradoxical phrases in his *Letter 32* (1665) to the secretary of the Royal Society.

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