THOMAS DIGGES, THE DEVELOPMENT OF THE RELATIVITY OF MOTION, AND ITS RELATION TO THE NATURAL PHILOSOPHY OF GIORDANO BRUNO

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Abstract: Since the time of ancient Greek scientists, the appearance of similar physical phenomena for two observers in relative motion has been generally exemplified by means of a moving ship. This proved useful in discussions of the rotation of Earth. We briefly track the evolution of this ideal experiment from the time of the exposition in Euclids' *Optics* up to Middle and Early Modern Ages, with emphasis on the contribution of Oresme and its use in Copernicus' *De Revolutionibus*. Giordano Bruno discussed the motion of a ship in *The Ash Wednesday Supper*, published in 1584, reporting the free fall of a plummet from the mast as a test of the dynamical equivalence of the two reference systems. We show that this phenomenon was already considered and published by Thomas Digges, the leading Copernican scientist in England, in 1576. We argue that during his long visit in London from 1583 to 1585, Bruno adopted this example from this source and therefore he cannot be considered an original contributor to the classic relativity principle, which was clearly established by Galilei in 1632.

Keywords: relative motion, galilean relativity, Thomas Digges, Giordano Bruno

1 INTRODUCTION

The explanation of the diurnal motion of the celestial vault as an apparent effect due to the rotation of the Earth has always clashed with the relativity of movement. In fact, natural philosophers have always wondered why an observer on the Earth's surface saw only the diurnal motion of stars as the unique effect of this rotation and did not perceive other phenomena, such as deflections of objects thrown vertically, like stones or arrows. It is clear that without the knowledge of kinematics, dynamics, and the existence of the gravitational force, a realistic evaluation of these effects was not possible and observers relied on direct experience and simple intuition.

An experience that spanned from the Hellenistic times through the entire Middle Ages up to the seventeenth century and that was capable of representing reference systems in relative motion, was that of a moving ship. The most frequently reported quotation in the modern literature and practically in all textbooks is that from Galileo Galilei's *Dialogue Concerning the Two Chief World Systems* (Galilei, 1632; 1967), from which the generally adopted expression of 'Galilean relativity' derives.

De Angelis and Espirito Santo (2015) questioned Galileo's originality and highlighted how in 1584 Giordano Bruno treated the topic of a ship's motion in the third dialogue of *The Ash Wednesday Supper* (*La Cena de le Ceneri*). This dialogue was written in Italian and printed in London during Bruno's stay in England from April 1583 to November 1585 (Aquilecchia, 1995; Ventura, 2006). Consequently, authors assigned to Bruno the credit of the first clear physical definition of the principle of relative motion and suggested that Galileo may have met Bruno in Venice just before Bruno was imprisoned by the Inquisition. Several texts mention the priority of Bruno, such as Koyré in *Galileo Studies* (Koyré, 1939; 1978: 139), which was based substantially on the same texts. However, we noticed that these authors, and in particular De Angelis and Espirito Santo (2015), did not consider how English Copernicans may have influenced Bruno and that Bruno may have been affected by theories developed by Thomas Digges and published a few years before Bruno arrived in London.

The hypothesis that Bruno was the first person to give a complete physical formulation of the relativity principle appears somewhat doubtful owing to his attitude toward science. Philosophical criticism generally agrees that Bruno was not a scientist and did not accept the use of mathematics, of which he probably had little knowledge, and that Bruno does not appear ever to have performed an experiment or made an astronomical observation. In the defense during his trial by the Inquisition, Bruno always defined himself as a philosopher (Gatti,1989:

18). In Bruno's thinking, various essentially anti-Aristotelian natural philosophical approaches coexisted (Geymonat, 1970: 190), undoubtedly influenced by the Hermetic and Kabbalistic traditions (Yates, 1964), and moreover his writings before his arrival to France and prior to coming to England essentially concerned mnemonic techniques.

In this paper we touch briefly on the topic of the relative motion of moving ships from Hellenistic times to the Renaissance and show how explanations of this phenomenon evolved from a simple geometrical tool to a more physical interpretation that is completely clarified in the Galilean Dialogues. The contribution of Bruno, therefore, appears not as original as was previously thought.

2 THE PHYSICAL BASIS OF THE GALILEAN RELATIVITY

It is useful to recall briefly the physical basis of the 'Galilean relativity principle', whose basic concepts are:

(1) Time is independent of the state of motion of the reference system and, after the choice of the initial instant in which the measurement begins, it flows equally for all bodies in the universe: $Dt = Dt'$.

(2) Speed follows an additive law of composition. The speed of a body measured in a reference system moving with respect to another reference system with a constant velocity V is: $v = v' + V$.

From these two assumptions it follows that the variations in velocity of a body are equal in the two reference systems ($DV = 0$) and, consequently, the accelerations are also invariant: $a = a'$.

In particular, examples of this invariance are considered crucial for a complete definition of the relativity principle as we will discuss in this paper. The underlying assumption is the existence of an absolute time and space to which all motions can be referred, as Newton stated toward the end of the seventeenth century.

3 THE RELATIVITY OF MOTION IN ANCIENT EPOCH: FROM EUCLID TO PTOLEMY

3.1 Euclid

In the fourth to third centuries BCE, Euclid (1945) did not mention explicitly the motion of a ship, although in Οπτικά (*Optics*) at Proposition 51 he considered visual observation of objects moving with different velocities. Euclid thus introduced the 'relativity of vision', or 'optical relativity' as it was once called (Koyré, 1939; 1978: 163).

3.2 Lucretius, Virgil and Seneca

In the Book IV of the philosophical poem *De Rerum Natura* written in the 1st century BC, Titus Lucretius Carus (ca. 94–50 BC) describes for the first time the relative motions as observed from a moving ship. In the following verses, he relates the appearance of motions to the rotation of stars, the Moon and the Sun (Lucretius, 1921: 149):

> When we travel aboard ship,
> it is carried forward, although it seems
> to be standing still, while another boat
> which remains tied up is, so we believe,
> moving past us. When we drive our ship on
> and fly under full sail, then hills and fields
> appear to run off to the stern. All stars
> in the celestial vault seem fixed in place,
> quite motionless, yet every one of them
> is always moving, since they rise, and then,
> when their bright bodies have crossed the heavens,
> they return back to their distant settings.
> So, too, the sun and moon in the same way
> seem to remain in place, but facts themselves
> indicate that they are carried forward.

The source of inspiration for this description is unknown. It might be derived either from some Pythagoric or Epicurean tradition or from an unknown lost book. Another poetic mention of relative motion seen from a floating ship can be found in the *Aeneid* (III, 72) by Virgil (70 BC–15 BE):

> Provehimur portu, terraeque urbesque recedunt
> (Forth from the harbor we sail, and the land and the cities slip backward)

This gives no information on the physics, but it is quoted by Copernicus (*De Revolutionibus*, Book I, Chapter VIII) and by Thomas Digges.

A third Latin author who considered effects seen from a moving ship was Lucius Anneus Seneca (4 BC–65 CE) in the IV Book of *Naturales Questiones*, written a few years be-fore his death. In this case, the context of the work is not poetic but scientific: he compared the apparent rest of planets with the stillness of a ship despite its sails being full (Seneca, 1971).

3.3 Ptolemy

In his major astronomical treatise Μαθηματικὴ σύνταξις (*Mathēmatikḕ Sýntaxis*) also known as *Almagest*, Ptolemy (ca 100–168 CE) did not consider the example of the moving ship. But following Euclid, in Book II of the *Optics*, there is a discussion of the “relativity of the vision” (Smith, 1996: 124):

> Likewise, if we sail in a boat along the shore during the twilight, or if we move in something other than a boat, and if we do not sense the motion and thing carrying us, then we judge the trees and topographical features of the shoreline to be moving. This illusion stems from the fact that, when the visual rays are displaced (laterally), we infer that the visible objects are moving because of the displacement of the visual rays. Although the visible objects are stationary, then it is assumed that the apparent motion belong to them.

4 REVISION IN THE MIDDLE AGES: BURIDAN AND ORESME

Scholars at Merton College in Oxford and Jean Buridan (c. 1300–1361) in Paris criticized Aristotelian mechanics and Buridan introduced the theory of impetus. Buridan’s analysis is presented in his *Expositio et Quaestiones in Aristotelis De Caelo* (*Questions on Aristotle’s On the Heavens*) and is clearly translated in the paper by De Angelis and Esprito Santo (2015) together with some interesting quotations. In Question 22 of the Book II, Buridan gave the usual example of a moving ship. More important were the contributions of Nicola Oresme (or d’Oresme) (1321–1361), a student of Buridan, who in his *Le Livre du Ciel et du Monde* (Figure 1, the manuscript dates back to 1377) developed the kinematics of relative motion. Oresme’s text is extensively reported in detail by Clagett (1961: 601), who in presenting it refers to Ptolemy’s *Optics*. Also, De Angelis and Espirito Santo (2015) discussed some topics of Oresme’s text which, however, deserves a more extended analysis. Here we report only some particularly relevant passages from the Book I (Chapter 25, particularly Sections 3, 4 and 5). Oresme writes:

> The third experience is the one adduced by Ptolemy: whoever was on a ship moving rapidly towards the east and shot an arrow vertically upwards would not see it fall back on the ship but far away towards the west. And similarly, if the Earth moved so quickly, rotating from west to east, whoever threw a stone vertically upwards would not see it fall back to the starting point but far away towards the west; while in fact the opposite appears. It seems to me that the same response given to these experiences could be extended to all the others that were adduced in this regard ...
>
> [Sect.] 3. I suppose that local motion cannot be perceived by senses except in the same way as a different arrangement of one body with respect to another body is perceived. For example, if a man finds himself on a ship called *A*, which is moving with a regular motion, quickly or slowly, and if this man sees nothing other than a ship called *B*, which is moving with a motion exactly equal to that of *A*, in which he is found, I say that it will appear to this man that neither of the two ships is moving. And if *A* is immobile and *B* moves, it will seem to him that *B* is moving; and if *A* moves if *B* is immobile, it will still seem to him that *A* is immobile and *B* is moving. And so, if for one hour *A* remained still and *B* moved, and in the following hour and conversely *A* moved and *B* remained still, this man would not be able to perceive this change or variation, but he would continually have the impression that it was moving *B*, and this results from experience. And the reason is that these two bodies *A* and *B* are always in the same reciprocal disposition, whether *A* is moving and *B* is at rest or, and conversely, whether *C* is moving and *A* is at rest ...
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> [Sect.] 4. The answer to the second (experiment) is clear because, according to this opinion, not only the earth moves in this way, but also water and air with it, as has been said, although the “water and air here below” are moved and moved differently by winds and other causes. And similarly, if the air were closed in a ship, whoever was in that air would feel it to be immobile.
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> [Sect.] 5. To the third experience, which seems stronger, of the arrow or the stone thrown upwards, etc., one could reply that the arrow thrown upwards is moved quickly towards the east together with the air through which it passes and together with all the matter of the aforementioned lower part of the world, which moves by diurnal motion; for this reason the arrow falls back to the place on the earth from where it was shot. This appears possible by analogy, since if a man were on a ship moving very quickly towards the east and he did not perceive such movement, and he lowered his hand in a straight line along the mast of the ship, he would have the

Figure 1: The first page of the *Le Livre du Ciel et du Monde* by Nicole Oresme, with a miniature of the author (from the manuscript of 1377 in the Bibliotheque National de France, in Paris).

impression that his hand had no other movement than the straight line ... If now a man were to walk on that ship towards the west with a speed lower than that with which the ship goes towards the east, he would appear to him to be going towards the west when in reality he would be going towards the east; similarly, in the case now described, all the motions that occur in this lower world would be as if the ship were at rest.

The text written by Oresme is very clear and well organized. His first point concerns the relativity of motion perceived by two observers and the impossibility of establishing which of them is really at rest or in motion. Then Oresme discusses the old topic of an arrow shot vertically and this leads him to analyze the composition of motions. Oresme, following the classic Aristotelian treatment, assumed that basic motions are circular or straight but the resulting trajectory of their combination is a different curve. It is interesting that Oresme introduces also the concept of a motion relative to the mast of the ship using an example of a man moving a hand along the mast and not observing any other motion except the displacement made by himself.

5 RELATIVITY IN THE NEW ASTRONOMY: COPERNICUS AND DIGGES

The example of the motion of the ship is found less extensively but is substantially similar in Copernicus' Book I of *De Revolutionibus* where he still uses it to explain the possibility of the Earth's rotation. From Rosen's translation of chapter VIII of Copernicus (1543; 1978: 25), we read:

> Why then do we still hesitate to grant it the motion appropriate by nature to its form rather than attribute a movement to the entire universe, whose limit is unknown and unknowable? Why should we not admit, with regard to the daily rotation, that the appearance is in the heavens and the reality in the earth? This situation closely resembles what Vergil's Aeneas says: "Forth from the harbor we sail, and the land and the cities slip backward" [Aeneid, III, 72]. For when a ship is floating calmly along, the sailors see its motion mirrored in everything outside, while on the other hand they suppose that they are stationary, together with everything on board. In the same way, the motion of the earth can unquestionably produce the impression that the entire universe is rotating.
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> Then what about the clouds and the other things that hang in the air in any manner whatsoever, or the bodies that fall down, and conversely those that rise aloft? We would only say that not merely the earth and the watery element joined with it have this motion, but also no small part of the air and whatever is linked in the same way to the earth. The reason may be either that the nearby air, mingling with earthy or watery matter, conforms to the same nature as the earth, or that the air's motion, acquired from the earth by proximity, shares without resistance in its unceasing rotation. No less astonishingly, on the other hand, is the celestial movement declared to be accompanied by the uppermost belt of air.

In the first part of this quotation Copernicus presents essentially the classic 'relativity of vision', but in the second part he introduces a physical connection between the air and the Earth so that the former governs the motion of the latter and thus the rotation of our planet does not produce any effect on things in the air.

Consider next Thomas Digges (1546–1595) who is considered the leading Copernican personality of the English Renaissance. Digges wrote several books but his contribution to astronomy consists in two rather short texts: *Alae seu Scalae Mathematicae* … (Digges, 1573) in Latin, and *A Perfit Description of the Caelestiall Orbes* … (Digges, 1576) written in English as a sort of appendix to the 1576 edition of an almanac written and produced through the years by his father Leonard. The former booklet was published a few months after the appearance of the bright supernova in November 1572 (generally known as Tycho Supernova, or SN 1572) and deals with new mathematical methods for measuring parallaxes of planets and of this New Star. These are alternatives to the method proposed for comets by Regiomontanus (1436–1476) and published for the first time in 1531. Digges' second contribution is an essay mainly devoted to the popular diffusion of the Copernican planetary system, and is a rather simple text without detailed mathematical demonstrations. However, it contains some interesting innovations, the most known, shown in the frontispiece, is the elimination of the sphere of fixed stars with the assumption of an endless space containing an infinite number of stars. The text contains translations of several passages of the Book I of *De Revolutionibus* (Chapters 10, 7, and 8) and the discussion on the relativity of motion starts with the same Virgilian passage quoted by Copernicus. Afterward he writes:

> For a ship carried in a smooth Sea with such tranquility doth pass away, that all things on the shores and the Seas to the sailors seem to move, and themselves only quietly to rest with all such things as are aboard with them, so surely may it be in the Earth, whose Motion being natural and not forcible, of all other is most uniform and unperceivable, whereby to us that sail therein, the whole world may seem to roll about .... And of things ascending and descending in respect of the world, we must confess them to have a mixed motion of right and circular, albeit it seem to us right and straight, not other-

> wise than if in a ship under sail a man should softly let a plummet down from the top along by the mast even to the deck. This plummet, passing always by the straight mast, seemeth also to fall in a right line, but being by discourse of reason weighed, his motion is sound mixed of right and circular. For such things as naturally fall downward being of earthly nature there is no doubt, but as parts they retain the nature of the whole. No otherwise is it to these things that by fiery force are carried upward.

From the point of view of dynamics, Digges is more complete and precise than Copernicus, because he adds the behavior of a plummet dropped near the mast which, for an observer on board the ship, does not deviate from its straight downward trajectory, while for an observer in the terrestrial reference the motion is combined with the translational one and develops along a curved trajectory in accordance with what Oresme had already shown. It is a matter of fact that the two references are equivalent as concerns accelerations. Digges did not write explicitly that trajectories of falling bodies depend on the motion of the observer. A possible inspiration of this passage could be the experiment of the hand in the Oresme's treatise, but here Digges implicitly reports that the free fall of body does not depend upon the velocity of the uniform motion of the ship and cannot be noticed by any observer on board. It is interesting that Galileo in the second day of *Dialogue of Maximum Systems* (Galilei, 1632; 1967) mentioned exactly this experiment as a basic proof that the motion of a ship does not produce differences in the fall of a body.

One has to consider that the art of navigation and cartography were particularly relevant in Elizabethan England, as also illustrated in the frontispiece of the 1571 edition of *Pantometria* (Figure 2). The book was written by his father Leonard and edited by Thomas, and therefore one cannot exclude that Digges had the inspiration to perform an experiment while testing distance estimate techniques. In the first printed edition of *Stratoiticos,* Digges (1579) wrote a list of six titles of book that he began to write and two of them deal with the art of navigation and Naval architecture, confirming that in the 1570s he was interested in these topics. In the Preface of the last edition of *Stratioticos* Digges (1590: Bijv) wrote "… I spent fiteene weekes in continuall Sea services upon the Ocean ...", during which he could investigate several problems concerning navigation and particularly the correct use of the magnetic compass.

6 THE VERSION OF BRUNO

The topic of the ship's motion was taken up again by Bruno in the third dialogue between Smitho and Teofilo (Theophilus) in *The Supper of the Ashes*, where the latter supports the Copernican system and represents Bruno himself. We recall that he used to write his complete name as Philotheus Iordanus Brunus Nolanus (see for instance Rowland, 2015: 105; note also that the first name is the anagram of Theophilus). Again, this text is reported by De Angelis and Espirito Santo (2015: 245) and therefore we consider here only some relevant passages:

> Smitho – You have satisfied me most sufficiently, and you have excellently opened many secrets of nature which lay hidden under that key. Thus, you have replied to the argument taken from winds and clouds; there remains yet the reply to the other argument which Aristotle submitted in the second book of On the Heavens [De Caelo] where he states that it would be impossible that a stone thrown high up could come down along the same perpendicular straight line, but that it would be necessary that the exceedingly fast motion of the Earth should leave it far behind toward the West. Therefore, given this projection back onto the Earth, it is necessary that with its motion there should come a change in all relations of straightness and obliquity; just as there is a difference between the motion of the ship and the motion of those things that are on the ship which if not true it would follow that when the ship moves across the sea one could never draw something along a straight line from one of its corners to the other, and that it would not be possible for one to make a jump and return with his feet to the point from where he took off. (Bruno, 1975: 121).
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> Theophilus – With the Earth move .... all things that are on the Earth. If, therefore, from a point outside the Earth something were thrown upon the Earth, it would lose, because of the latter's motion, its straightness as would be seen on the ship *AB* moving along a river, if someone on point *C* of the riverbank were to throw a stone along a straight line, and would see the stone miss its target by the amount of the velocity of the ship's motion. But if someone were placed high on the mast of that ship, move as it may however fast, he would not miss his target at all, so that the stone or some other heavy thing

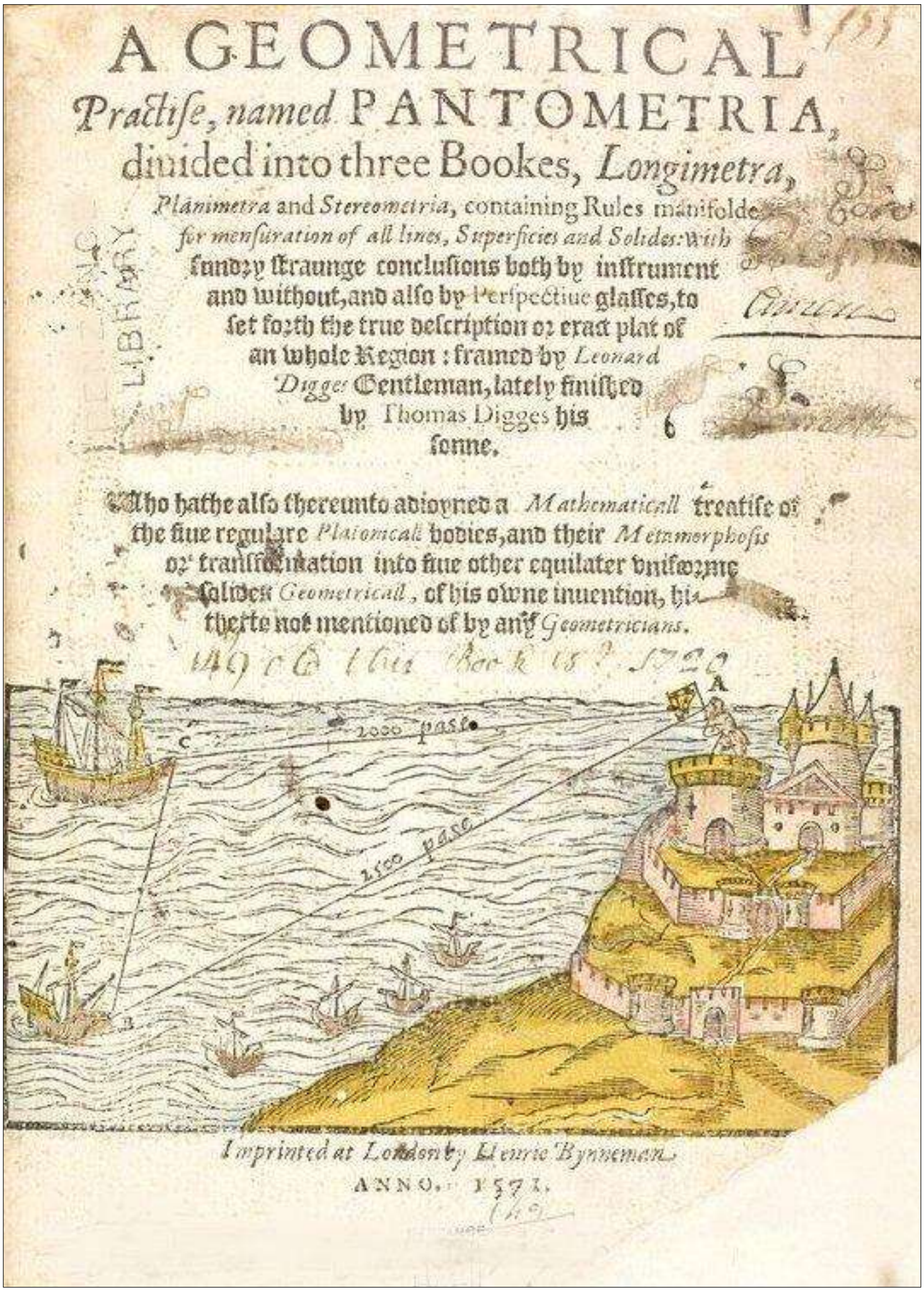

Figure 2: The frontispiece of the edition of 1571 of *Pantometria* written by Leonard and Thomas Digges, showing some floating ships and an observer on a tower measuring their distances.

thrown downward would not come along a straight line from the point *E* which is at the top of the mast, or cage, to the point *D* which is at the bottom of the mast, or at some point in the bowels and body of the ship. Thus, if from the point *D* to the point *E* someone who is inside the ship would throw a stone straight up, it would return to the bottom along the same line however far the ship moved, provided it was not subject to any pitch and roll. If there are two, of which one is inside the ship that moves and the other out-side it, of which both one and the other have their hands at the same point of the air, and if at the same place and time one and the other let a stone fall without giving it any push, the stone of the former would, without a moment's loss and without deviating from its path, go to the pre-fixed place, and that of the second

> would find itself carried backward. This is due to nothing else except to the fact that the stone which leaves the hand of the one supported by the ship, and consequently moves with its motion, has such an impressed virtue, which is not had by the other who is outside the ship.
>
> Smitho – ....
> Theophilus – If there are two, of which one is inside the ship that moves and the other outside it, of which both one and the other have their hands at the same point of the air, and if at the same place and time one and the other let a stone fall without giving it any push, the stone of the former would, without a moment's loss and without deviating from its path, go to the prefixed place, and that of the second would find itself carried backward. This is due to nothing else except to the fact that the stone which leaves the hand of the one supported by the ship, and consequently moves with its motion, has such an impressed virtue, which is not had by the other who is outside the ship, because the stones have the same gravity, the same intervening air, if they depart (if this is possible) from the same point, and arc given the same thrust. From that difference we cannot draw any other explanation except that the things which are affixed to the ship, and belong to it in some such way, move with it: and the stone carries with itself the virtue of the mover which moves with the ship. The other does not have the said participation. From this it can evidently be seen that the ability to go straight comes not from the point of motion where one starts, nor from the point where one ends, nor from the medium through which one moves, but from the efficiency of the originally impressed virtue, on which depends the whole difference.

The description of the motion of the ship in Bruno's words is somewhat unclear and the use of some letters is confusing. In the original printed edition, there is a picture of a ship, but it is seen on the stern side without any letter identification, there is no observer on the coast, and there are high waves on the sea. Thus, it is purely pictorial and not explicative. In the text, the letters A and B are used as an indication of the ship but it is not explained to which points they correspond, for instance whether the bow and the stern, or two different positions of the ship. The point C is referred to the position of an observer on the bank who throws a stone along a straight line, but the direction is not specified if toward the instantaneous place of the floating ship or somewhere different. Thus, this kinematical description is much less precise than that of Oresme; it appears like an approximate report of an explanation heard or read by Bruno rather than a description of dynamical processes intended for uncultured readers.

An important topic is that of the motion of a body falling along the mast while maintaining a rectilinear trajectory in the ship's reference system. This is precisely what De Angelis and Espirito Santo attribute to having been originally proposed by Bruno, who therefore would be considered by them a precursor of Galileo. As we have seen in the previous section it had already been described in a similar form by Digges in *A Perfit Description*, and therefore again this is not a new physical insight.

In the last part of this dialogue Bruno tries to clarify how the free fall of a body appears in two reference systems in relative uniform motion. Theophilus considers a couple of observers: one inside the ship (observer 1) and the other outside (observer 2) and at the same time and from the same point each drops a stone. The stone of observer 1 will reach the 'prefixed place' (likely it will fall vertically towards the feet of this observer), while the one of observer 2 will move backward. This is considered by Theophilus as evidence that the stone maintains the translation motion of the ship. To complete the description of relative motion Theophilus should make explicit that these displacements are seen by observer 1, but not by observer 2 who sees his stone moving downward and the other stone moving forward with the ship. One can conclude that Bruno was not interested in investigating the problem of relative motions but only the inertial properties of the stone in the ship.

7 THE DIGGES–BRUNO CONNECTION

In the previous sections we have summarized the main steps of the development of relative motion along a *fil rouge* starting from the Hellenistic period to the Renaissance. The same steps are generally found in the literature from the first analyses of Koyré (1939; 1978) in *Galileo Studies* to some recent ones, but with the relevant exception of Thomas Digges. This is ignored by the large majority of scholars, despite some important works written by Francis

R. Johnson in the 1930s. Johnson and Larkey (1934) reprinted the astronomical sections of *A Perfit Description* … and studied the debate on the infinity of the Universe, and in a subsequent paper Johnson (1936) proposed the likely connection between Digges and Bruno. Koyré (1957: 38) mentioned Digges in the subsequent book *From the Closed World to the Infinite Universe* and, quoting Johnson and Larkey (1934), agrees that Digges has the priority of the idea of an infinite Universe, but writes that Digges "… placed stars in a theological sky, not in an astronomical one." This last statement cannot be accepted. In fact, Koyré does not consider the previous Digges' scientific work in *Alae seu Scalae*. He takes the references to God as a fundamental assumption, while it could reasonably be only the simplest way to avoid a charge for blasphemy in a popular book necessary for his public role.

The possibility that Bruno's ideas were inspired by Digges' scientific achievements was early proposed by Johnson (1936; 1937) and subsequently reconsidered by M.A. Granada (1994). Mori (2014: 519) suggested again that Bruno derived the example of the falling plummet from Digges, but did not develop the point. We do not know if Digges and Bruno together discussed the Copernican system, the structure of the Universe, or the new physical view of relative motion. Also, it is not known when Bruno became aware of the Copernican system, but he must have accepted the new structure of the Universe before his arrival in London during his stay in Paris from 1579 and 1582 (Yates, 1947: 102; Gatti, 1999: 38; Granada, 2010). Likely, he read and understood the fundamental treatise *De Revolutionibus Orbium Coelestium*, but probably, he limited his study to some chapters of Book I and abandoned reading the treatment that used geometric and mathematical methods, which he was unable to understand, so much so that he blamed Copernicus for having used them too much. It is also possible that Bruno read the *Narratio prima* by Rheticus (1514–1574) (Rheticus, 1540; 2017) that in 1540 presented to Europe a first synopsis of the Copernicus' work in less than 70 pages and without the use of mathematics (Granada, 1990). Despite a lack of scientific approach, Bruno became a convinced Copernican perhaps owing to his vision lying between Neo-Platonism (Farinella, 2002; Rowland, 2002; Stamatellos, 2017; Zaffino, 2017) and Neo-Pythagoreanism for which the Earth was no longer the center of the planetary system. He also proposed an infinitely extended space filled with stars with planetary systems possibly hosting living beings and civilizations. It cannot be ignored that Bruno learned about and explored these ideas in France, and during his stay in England, having accepted this innovative philosophy, he decided to write about them in Italian books. In the present paper we focus on the specific item of the understanding of the relative motion to show that it was not an original idea by Bruno, but it was very likely borrowed from contemporary English scientists, and particularly from Thomas Digges if not directly from him.

The citation of the mast experiment, in addition to the idea of an infinite Universe, is another support of the hypothesis that Bruno was acquainted with the *Perfit Description* and accepted the Digges' physical and astronomical views in order to present them to Italian readers. Bruno explained the infinite size of the Universe by means of theological and philosophical reasonings. This is not substantially different from Digges in *The Perfit Description,* which was likely motivated by science. In fact, in *Alae seu Scalae*, Digges wrote that the absence of even a minimum displacement of SN1572 located it in the Orb of fixed stars, but he posited that its change of brightness implies changes of distance that must huge to explain its ultimate disappearance. This implies that a solid sphere cannot exist and that stars must be distributed in space. Another possibility is that Digges used the 'perspective glass', an optical device working as a telescope and designed by his father, to observe the sky and noticed stars which were invisible to unaided eyes (Usher and Massaro, 2024, and references therein).

In June 1583, a few months after his arrival to London, Bruno moved to Oxford where he attended a philosophical debate and delivered lectures at the University, but he soon encountered severe criticisms from some members of the Academy who were close followers of Aristotelian doctrine (Aquilecchia, 1995; Limentani, 1922, Yates, 1939). Bruno visited the University again in the summer of the same year. According to George Abbot, who at that time was at Balliol College and wrote some rather sarcastic notes about these lectures (see Aquilecchia, 1995), Bruno had discussed the Copernican system, mentioning rotations, circumferences, centers, and the immobility of stars, but there is no comment about the infinity of the universe probably because it was such a scandalous topic. It is possible that, after his return to London, Bruno tried to establish relations with cultural circles outside the academic world like those in which English Copernicanism developed and where Digges was one of the leading exponents. Unfortunately, the only available documents about Bruno's English period concern merely his activity in Oxford (Aquilecchia, 1995), but it is difficult to believe that he spent more than one year without contact with some in philosophical circles. Such a possibility could remain secret because of the Pythagorean attitude assumed by Digges after 1576, as he wrote in the Preface of the first edition of 1579 of *Stratioticos* (Digges, 1579: aij):

> … by the example of my father,
> Pithagorically I will contente my selfe
> Per Manus tradere, and to
> communicate … onely with a fewe
> selected friendes.

Johnson (1936) suggested the that a possible contact person between Bruno and Digges was Edward Dyer, friend of John Dee, collaborator of Thomas Digges in the project for the new harbor of Dover, and also fellow of the 'Aeropagus' group of Sidney and Greville, an intellectual circle that knew Bruno. It is interesting that the location of *The Ash Wednesdey Supper* was selected by Bruno as the London royal house used by Fulke Greville (or Folco Grivello as Bruno wrote in the dedication letter of the book), likely on the 15 February 1584, while later in testimony at the Venetian Inquisition, Bruno affirmed that it actually was in the residence of the ambassador of France (Aquilecchia 2002). For this reason, in *The Ash Wednesday Supper,* Bruno cast academicians as two fastidious characters. In any case, as written above, this is conjectural as no documents about such a meeting are known to exist.

A third point which supports Bruno's pre-knowledge of Digges' works is that he cited the same poetic source that was much admired by Digges, viz., *Zodiacus Vitae* in twelve books one for each sign of the Zodiac, by Marcellus Palingenius Stellatus (1536, 1908). This poem was prohibited by the Catholic church and remained very poorly known in the Italian countries, while it had a large circulation in Europe (Beckwith, 1983; Bacchelli, 1999; de Vivo, 2015) and particularly in England where it was used in grammar schools. Digges mentioned briefly the *Zodiacus Vitae* in *Alae seu Scalae*, and more extensively in *The Perfit Description*, where he reported in the address "To The Reader" several verses from the books named Scorpius (8th) and Aquarius (11th). Bruno mentioned Palingenius' poem later in his Latin work *De Immenso et Innumerabilibus*, written in England but printed in 1591.

8 THE RELATIVITY OF GALILEI AND THE PRINCIPLE OF INERTIA

Relative motion of ships was considered by some scholars, including Kepler, in the years before the publication of Galilei's *Dialogo sopra I Due Massimi Sistemi del Mondo* (*Dialogue Concerning the Two Chief World Systems*) in 1632 (see Fiasconaro, 2010) either supporting or contrasting the rotation of the Earth. Galilei discussed the experiment of the free fall of a body from the top of the mast in a resting and moving ship in the letter to Monsignor Francesco Ingoli, written in 1624 (Galilei, 1896), and later the relativity of motions was again described in the famous passage of the second day conversation of the *Dialogue*, also reported in De Angelis and Espirito Santo (2015). For the first time, Galileo stated the complete equivalence of reference systems in uniform relative motion, that is clearly demonstrated with the example of a ship. In this case Galileo considered an observer closed in a cabin and unable to see if the ship is moving or not. The invariance of accelerations and the consequent impossibility of distinguishing the state of motion of the ship is also illustrated by means of the free fall of water droplets, equivalent to the mast experiment, or the flight of birds and butterflies. This description of relative motion is much more exhaustive that those of previous authors and it is, therefore, fully justified that an elementary relativity principle is usually named for Galilei.

The approach of Galileo is based on his dynamical researches which lead him to apply the first two laws of motion. In the *Discorsi e dimostrazioni matematiche sopra due nuove scienze* (*Discourses and Mathematical Demonstrations Relating to Two New Sciences*), published in Leiden (Galilei, 1638). In the third dialogue Galileo explains the properties of the uniform motion and the uniformly accelerated motion and in the fourth one demonstrates that the velocity of a body can be computed applying the Pythagoric relation to its components, and with the words of Sagredo (Galilei, 1638: Hh2), "… these motions combine together without modifications, perturbations …"

This linear superposition of perpendicular motions is considered an important step for establishing the law of inertia and the equivalence of reference systems in uniform motion.

It is noteworthy that Galileo did not mention Bruno or Copernicus or some other scholar about relative motions, but this was rather common in those times, and in this way he based his physics on observational evidence instead of the authority of someone. Furthermore, naming Bruno in that epoch would be only a severe risk. We do not know which sources were eventually considered by Galileo: surely he knew the Copernicus treatise and it is very likely that he read Bruno's dialogues, but the possibility that he also knew of the Digges' booklet which was written in English albeit not specifically intended for academic circulation, seems unrealistic. The works of Bruno, written in Italian during his English period, appear therefore as a bridge connecting the new Diggesian view of the Copernican Universe with Italian scholars.

9 CONCLUDING REMARKS

The correspondences between the Bruno's Italian dialogues, particularly *The Ash Wednesday Supper*, and Digges' Copernican text *The Perfit Description* strongly supports the possibility that Digges' work was the main scientific source used by the Nolan philosopher. In particular, the common topic of the free fall of a plummet along the mast of a moving ship indicates that the original test of the invariance of the acceleration between two reference frames in uniform relative motion, was fully realized by Digges before 1576. Bruno may have grasped the idea of an infinite Universe on the basis of Niccolo da Cusa's suggestions independently of Digges, but the picture of an unlimited population of stars, of which only a few thousand are visible, follows strictly the figure in the frontispiece of *The Perfit Description.* The fact that Bruno specifies that these stars have planets and can host living people may be a further development of his naturalistic philosophy.

Digges and the English Copernican circles are perhaps the most relevant cultural bridge across which the new conception of the Universe diffused throughout Europe. This diffusion occurred together with the development of new instruments and a new approach to astronomical observations and physical experiments supported by the necessary mathematical demonstrations.

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