THE CONTRIBUTION OF GIORDANO BRUNO TO THE PRINCIPLE OF RELATIVITY

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Abstract: The trial and condemnation of Giordano Bruno was mainly based on arguments of a philosophical and theological nature, and therefore different from Galileo Galilei's trial. Such elements contribute to unfairly devalue the scientific contribution of Bruno and do not properly account for his contribution to physics. This paper discusses the contribution that Bruno made to the principle of relativity. This was first discussed by Galilei in 1632 using the metaphor known today as 'Galileo's ship', but we shall show that this same metaphor and some of the examples in Galilei's book were already contained in a dialogue published by Bruno in 1584. In fact, Bruno largely anticipated the arguments of Galilei on the relativity principle, in particular to support the Copernican view. It is likely that Galilei was aware of Bruno's work, and it is possible that the young Galilei discussed it with Bruno, since they both stayed in Venice for long periods in 1592.

Keywords: Galileo Galilei, Giordano Bruno, principle of relativity, heliocentric system, Nicolaus Copernicus, Doctores Parisienses, Jean Buridan, Nicole Oresme.

1 INTRODUCTION

The principle of relativity states that it is impossible to determine whether a system is at rest or moving at constant speed with respect to an inertial system by experiments internal to the system, i.e., there is no internal observation by which one can distinguish a system moving uniformly from one at rest. This principle played a key role in the defence of the heliocentric system, as it made the movement of the Earth compatible with everyday experience.

According to common knowledge, the principle of relativity was first enunciated by Galileo Galilei (1564–1642; Figure 1) in 1632 in his *Dialogo Sopra i Due Massimi Sistemi del Mondo* (*Dialogue Concerning the Two Chief World Systems*) (Galilei, 1953), using the metaphor known as 'Galileo's ship': in a boat moving at constant speed, the mechanical phenomena can be described by the same laws holding on Earth.

Many historical aspects of the birth of the relativity principle have received little or scattered attention. In this short paper we put together some evidence showing that Giordano Bruno (1548–1600; Figure 2) largely anticipated Galilei's arguments on the relativity principle (Bruno, 1975). In addition, we briefly discuss Galilei's silence about Bruno, and the connection between the lives and careers of the two scientists.

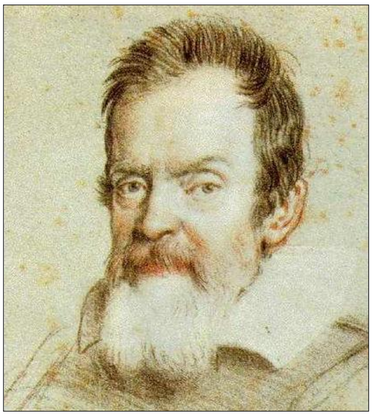

Figure 1: A portrait of Galileo Galilei by Ottavio Leoni (en.wikipedia.org).

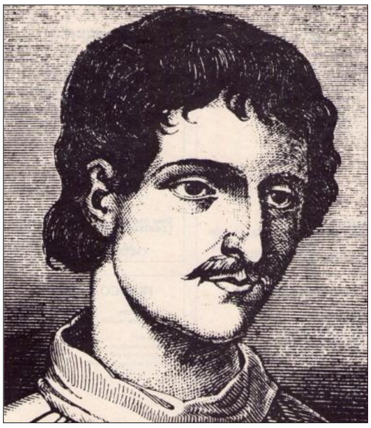

Figure 2: An eighteenth century egraving of Giordano Bruno (http://www.thehistoryblog.com/wp-content/uploads/2012/02/bruno-giordano.jpg).

2 GALILEI AND THE PRINCIPLE OF RELATIVITY

The *Dialogo Sopra i Due Massimi Sistemi del Mondo* is the source usually quoted for the enunciation of the principle of relativity by Galileo Galilei. However, its publication in 1632 was certainly not a surprise, as Galilei had expressed his views much earlier, in particular when lecturing at the University of Padova from 1592 to 1610. Some aspects of the evolution of Galilei's ideas, from the *Trattato della Sfera …* (D'Aviso, 1656) in which the Earth is still placed at the centre of the Universe, towards the *Dialogo*, and passing through his heliocentric correspondence with Kepler from 1597 onwards (Galilei, 1890–1907), are examined, for example, by Barbour (2001), Crombie (1996), Clavelin (1968), Giannetto (2006), Martins (1986) and Wallace (1981; 1984).

In February 1616, the Roman Inquisition condemned the theory by Nicolaus Copernicus (1473–1543) as being foolish and absurd in philosophy. One month before, the inquisitor Monsignor Francesco Ingoli (1578–1649) addressed Galilei in the essay *Disputation Concerning the Location and Rest of Earth Against the* System of Copernicus (Ingoli, 1616). This letter listed both scientific and theological arguments against Copernicanism. Galilei only responded in 1624, and in his lengthy reply he introduced an early version of the 'Galileo's ship' metaphor, and discussed the experiment of dropping a stone from the top of the mast. Both arguments, as we shall see, had previously been raised by Bruno, and later were used again by Galilei, although with small differences, in the *Dialogo*.

In the *Dialogo Sopra i Due Massimi Sistemi del Mondo*, Galilei discusses the arguments then current against the idea that the Earth moves. The book is a fictional dialogue between three characters. Two of these, Salviati and Sagredo, refer to figures in the book that disappeared a few years after the publication of the book. Salviati plays the role of the defender of the Copernican theory, putting forward Galilei's point of view. The second character, Sagredo, is a Venetian aristocrat who is educated and liberal, and he is willing to accept new ideas. Thus, he acts as a moderator between Salviati and the third character, Simplicio, who fiercely supports Aristotle. The name of this last character (reminiscent of 'simple-minded' in Italian) is in itself a clear indication of Galilean dialectics, which are designed to destroy opponents. Despite being a famous commentator of Aristotle, Simplicio manifests himself with an embarrassing simplicity of spirit. Galilei uses Salviati and Simplicio as spokespersons for the two clashing world views; Sagredo represents the discreet reader, the steward of science, the one to whom the book is addressed, and he intervenes during the discussions, asking for clarification, contributing conversational topics and acting like a science enthusiast.

On the second day, Galilei's dialogue considers Ingoli's arguments against the idea that the Earth moves. One of these is that if the Earth is spinning on its axis, then we would all be moving eastward at hundreds of miles per hour, so a ball dropped from a tower would land west of the tower that in the meantime would have moved a certain distance to the eastwards. Similarly, the argument goes that a cannonball shot eastwards would fall closer to the cannon compared to a ball shot to the west since the cannon moving east would partly catch up with the ball.

To counter such arguments Galilei proposes through the words of Salviati a *gedanken-experiment*: to examine the laws of mechanics in a ship moving at a constant speed. Salviati claims that there is no internal observation which allows them to distinguish between a smoothly-moving system and one at rest. So two systems moving without acceleration are equivalent, and non-accelerated motion is relative:

> Salviati – Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though doubtless when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still. In jumping, you will pass on the floor the same spaces as before, nor will you make larger jumps toward the stern than toward the prow even though the ship is moving quite rapidly, despite the fact that during the time that you are in the air the floor under you will be going in a direction opposite to your jump. In throwing something to your companion, you will need no more force to get it to him whether he is in the direction of the bow or the stern, with yourself situated opposite. The droplets will fall as before into the

vessel beneath without dropping toward the stern, although while the drops are in the air the ship runs many spans. The fish in their water will swim toward the front of their bowl with no more effort than toward the back, and will go with equal ease to bait placed anywhere around the edges of the bowl. Finally the butterflies and flies will continue their flights indifferently toward every side, nor will it ever happen that they are concentrated toward the stern, as if tired out from keeping up with the course of the ship, from which they will have been separated during long intervals by keeping themselves in the air. And if smoke is made by burning some incense, it will be seen going up in the form of a little cloud, remaining still and moving no more toward one side than the other. The cause of all these correspondences of effects is the fact that the ship's motion is common to all the things contained in it, and to the air also. That is why I said you should be below decks; for if this took place above in the open air, which would not follow the course of the ship, more or less noticeable differences would be seen in some of the effects noted. (Galilei, 1953: 217).

Note that Galilei does not state that the Earth is moving, but that the motion of the Earth and the motion of the Sun cannot be distinguished (hence the name 'relativity'):

There is one motion which is most general and supreme over all, and it is that by which the Sun, Moon, and all other planets and fixed stars – in a word, the whole universe, the Earth alone excepted – appear to be moved as a unit from East to West in the space of twenty-four hours. This, in so far as first appearances are concerned, may just as logically belong to the Earth alone as to the rest of the Universe, since the same appearances would prevail as much in the one situation as in the other. (Galilei, 1953: 132).

3 RELATIVITY AND CELESTIAL MOTIONS BEFORE COPERNICUS

The possibility that the Earth moves had been discussed several times, in particular by the Greeks, mostly as a hypothesis to be rejected. Also an annual motion of the Earth around the Sun had been considered by Aristarchus of Samos (c. 310–c. 230 BC). Later, some medieval authors discussed the possibility of the Earth's daily rotation. The first was probably Jean Buridan (c. 1300–1361; Figure 3), one of the 'doctores parisienses'—a group of professors at the University of Paris in the fourteenth century, including notably Nicole Oresme.

Buridan's example of the ship, which was later used by Oresme, Bruno and Galilei, is contained in Book 2 of his commentary about Aristotle's *On the Heavens* (1971):

It should be known that many people have held as probable that it is not contradictory to appearances for the Earth to be moved circularly in the aforesaid manner, and that on any given natural day it makes a complete rotation from west to east by returning again to the west – that is, if some part of the Earth were designated [as the part to observe]. Then it is necessary to posit that the stellar sphere would be at rest, and then night and day would result through such a motion of the Earth, so that motion of the Earth would be a diurnal motion. The following is an example of this: if anyone is moved in a ship and imagines that he is at rest, then, should he see another ship which is truly at rest, it will appear to him that the other ship is moved. This is so because his eye would be completely in the same relationship to the other ship regardless of whether his own ship is at rest and the other moved, or the contrary situation prevailed. And so we also posit that the sphere of the Sun is totally at rest and the Earth in carrying us would be rotated. Since, however, we imagine we are at rest, just as the man on the ship

Figure 3: Jean Buridan (www.buscabiografias.com/biografia/verDetalle/576/Jean%Buridan).

moving swiftly does not perceive his own motion nor that of the ship, then it is certain that the Sun would appear to us to rise and set, just as it does when it is moved and we are at rest. (Buridan, 1942: Book 2, Question 22).

Here we agree with Barbour (2001), that what Buridan is referring to is kinematic relativity. To Barbour,

… we have [here] a clear statement of the principle of relativity, certainly not the first in the history of the natural philosophy of motion but perhaps expressed with more cogency than ever before. The problem of motion is beginning to become acute. We must ask ourselves: is the relativity to which Buridan refers kinematic relativity or Galilean relativity? There is no doubt that it is in the first place kinematic; for Buridan is clearly concerned with the conditions under which motion of one particular body can be deduced by observation of other bodies. (Barbour, 2001: 203).

Later, Buridan (1942) writes:

> But the last appearance which Aristotle notes is more demonstrative in the question at hand. This is that an arrow projected from a bow directly upward falls to the same spot on the Earth from which it was projected. This would not be so if the Earth were moved with such velocity. Rather, before the arrow falls, the part of the Earth from which the arrow was projected would be a league's distance away. But still supporters would respond that it happens so because the air that is moved with the Earth carries the arrow, although the arrow appears to us to be moved simply in a straight line motion because it is being carried along with us. Therefore, we do not perceive that motion by which it is carried with the air.

Figure 4: A miniature portrait of Nicole Oresme included in his Traité de la sphère. Aristotle, Du ciel et du monde (n.d.) (en.wikipedia.org).

Buridan already expresses some concerns about the dynamics involved, but his conclusion is that

> … the violent impetus of the arrow in ascending would resist the lateral motion of the air so that it would not be moved as much as the air. This is similar to the occasion when the air is moved by a high wind. For then an arrow projected upward is not moved as much laterally as the wind is moved, although it would be moved somewhat. (ibid.).

Thus, the theory of impetus is not pushed to the limit in which one would identify it with the principle of inertia, nor with a dynamical concept of relativity.

A further step was implicitly taken a few years later by Nicole Oresme (c. 1320–1382; Figure 4). Oresme first states that no observation can disprove that the Earth is moving:

> … one could not demonstrate the contrary by any experience … I assume that local motion can be sensibly perceived only if one body appears to have a different position with respect to another. And thus, if a man is in a ship called *a* which moves very smoothly, irrespective if rapidly or slowly, and this man sees nothing except another ship called *b*, moving exactly in the same way as the boat *a* in which he is, I say that it will seem to this person that neither ship is moving. (Oresme, 1377; our English translation).

Oresme also provides an argument against Buridan's interpretation of the example of the arrow (or stone in the original by Aristotle) thrown upwards, introducing the principle of composition of movements:

> … one might say that the arrow thrown upwards is moved eastward very swiftly with the air through which it passes, with all the mass of the lower part of the world mentioned above, which moves with a diurnal movement; and for this reason the arrow falls back to the place on the Earth from which it left. And this appears possible by analogy, since if a man were on a ship moving eastwards very swiftly without being aware of his movement, and he drew his hand downwards, describing a straight line along the mast of the ship, it would seem to him that his hand was moved straight down. Following this opinion, it seems to us that the same applies to the arrow moving straight down or straight up. Inside the ship moving in this way, one can have horizontal, oblique, straight up, straight down, and any kind of movement, and all look like if the ship were at rest. And if a man walks westwards in the boat slower than the boat is moving eastwards, it will seem to him that he is moving west while he is going east. (ibid.).

Also, Nicolaus Cusanus (1401–1461) stated later, without going into detail, that the motion of a ship could not be distinguished from rest on the basis of experience, but some different arguments need to be invoked—and the same applies to the Earth, the Sun, or another star (Cusanus, 1985).

All this happened before Copernicus: a discussion of how things could be, not so much about how things really are. This viewpoint would change after Copernicus.

4 GIORDANO BRUNO AND THE PRINCIPLE OF RELATIVITY

In April 1583, forty years after the publication of the book by Copernicus and nine years before the 28-year old Galilei was called to the University of Padova, Bruno went to England and lectured in Oxford, unsuccessfully looking for a teaching position there. Still, the English visit was a fruitful one, for during that time Bruno completed and published some of his most important works, the six 'Italian Dialogues', including the cosmological work *La Cena de le Ceneri* (*The Ash Wednesday Supper*, 1584) (see Bruno, 1975).

This latter book consists of five dialogues between Theophilus, a disciple who exposes Bruno's theories; Smitho, a character who was probably real but is difficult to identify, possibly one of Bruno's English friends (perhaps John Smith or the poet William Smith)—the Englishman has simple arguments, but he has good common sense and is free of prejudice; Prudencio, a pedantic character; and Frulla, also a fictional character who, as the name in Italian suggests, embodies a comic figure, provocative and somewhat tedious, with a propensity towards stupid arguments.

In the third dialogue, the four mostly comment on discussions heard at a supper attended by Theophilus in which Bruno—called in the text 'il Nolano' (the Nolan), because he was born in Nola near Naples—was arguing in particular with Dr Torquato and Dr Nundinio, representing the Oxonian faculty. Bruno starts by discussing the argument relating to the air, winds and the movement of clouds, and he largely uses the fact that the air is dragged by the Earth:

> Theophilus ... If the Earth were carried in the direction called East, it would be necessary that the clouds in the air should always appear moving toward west, because of the extremely rapid and fast motion of that globe, which in the span of twenty-four hours must complete such a great revolution. To that the Nolan replied that this air through which the clouds and winds move are parts of the Earth, because he wants (as the proposition demands) to mean under the name of Earth the whole machinery and the entire animated part, which consists of dissimilar parts; so that the rivers, the rocks, the seas, the whole vaporous and turbulent air, which is enclosed within the highest mountains, should belong to the Earth as its members, just as the air does in the lungs and in other cavities of animals by which they breathe, widen their arteries, and other similar effects necessary for life are performed. The clouds, too, move through happenings in the body of the Earth and are based in its bowels as are the waters ... Perhaps this is what Plato meant when he said that we inhabit the concavities and obscure parts of the Earth, and that we have the same relation with respect to animals that live above the Earth, as do in respect to us the fish that live in thicker humidity. This means that in a way the vaporous air is water, and that the pure air which contains the happier animals is above the Earth, where, just as this Amphitrit [ocean][1] is water for us, this air of ours is water for them. This is how one may respond to the argument referred to by Nundinio; just as the sea is not on the surface, but in the bowels of the Earth, and just as the liver, this source of fluids, is within us, that turbulent air is not outside, but is as if it were in the lungs of animals. (Bruno, 1975: 117).

The Dialogue then moves to discussing the motion of projectiles, and Bruno starts by explaining the Aristotelian objection to the stone thrown upwards:

> 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*[2] 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).

In Theophilus' speech, Bruno then gives the following reply (in reference to the ship shown in Figure 5):

> 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 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 mov-

ed, provided it was not subject to any pitch and roll. (Bruno, 1975: 121).

He then continues with the statement that the movement of the ship is irrelevant for the events occurring within the ship, and he explains the reasons for this:

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.

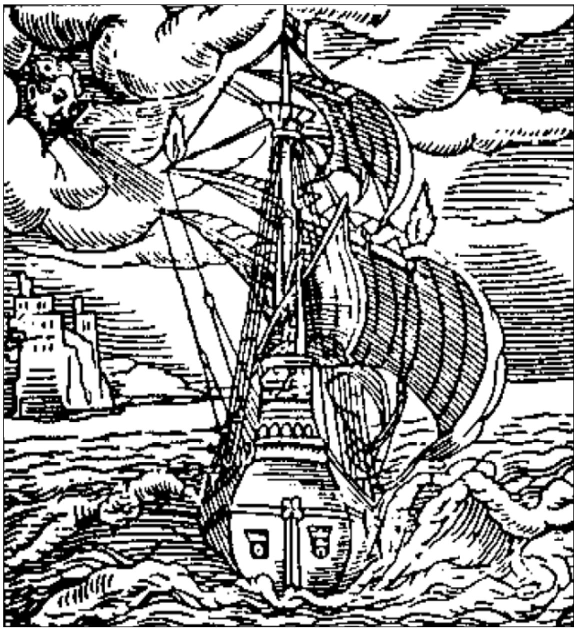

Figure 5: The ship referred to in the dialogue; note that the letters are missing (math.dartmouth.edu).

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. And it seems to me that enough consideration was given to the propositions of Nundinio. (Bruno, 1975: 123).

The experiments carried out in the ship are thus not influenced by its movement because all the bodies in the ship take part in that movement, regardless of whether they are in contact with the ship or not. This is due to the 'virtue' they have, which remains during the motion, after the carrier abandons them. Bruno thus clearly expresses the concept of inertia, using the word 'virtu`', in Italian meaning 'quality', which is carried by the bodies moving with the ship—and with the Earth. Bruno's arguments certainly constitute a step towards the principle of inertia.

5 DISCUSSION AND CONCLUDING REMARKS

We have seen that in *La Cena de le Ceneri* Giordano Bruno anticipates to a great extent the arguments of Galileo Galilei on the principle of relativity. In fact, his explanation contains all of the fundamental elements of the principle. The idea that the only movement observable by the subject is the one in which he does not take part, was presented earlier by Jean Buridan and Nicole Oresme, together with the notion of the composition of movements, which was alien to Aristotelian mechanics (see Barbour, 2001). Similar arguments were used by Nicholas Copernicus (1543). The main missing ingredient was the idea of inertia, which explains the fact that projectiles move along with the Earth. In fact, while there is a continuous line between Buridan, Oresme, Copernicus, Bruno and Galilei, the arguments of Bruno on the impossibility of detecting absolute motion by phenomena in a ship constitute a significant step towards the principle of inertia and providing a dynamical context for relativity. What is new in Bruno, and what brings him almost exactly to where Galilei stood, is a clear understanding of the concept on inertia.

The arguments and metaphors used in discussions concerning the world systems were common to different authors, and were largely derived from Aristotle, Ptolemy and their commentators. Often they were used without referencing, and sometimes they were attributed to the wrong source. For example, in his *On the Heavens*, Aristotle uses as experimental argument the one about the stone that is sent upwards. In their comment on this work, Buridan and Oresme used a modified version of this experiment in which an arrow is sent upwards in a ship—although this was possibly introduced by an earlier unidentified commentator/translator. Nevertheless, the description by Galilei of exactly the same ship experiment that Bruno used in the *Cena* makes it very likely that Galilei knew this work. The use of the dialogue form with a similar choice of characters can also be seen as a possible sign that Bruno influenced Galilei.

However, Galilei never mentions Bruno in his works, and in particular there is no reference to him in Galilei's large *corpus* of letters, even though he references the 'doctores parisienses' in his MS 46 (Galilei, c. 1584),[3] a 110-page long manuscript containing physical speculations based upon Aristotle's *On the Heavens*. Some authors (e.g. Clavelin, 1968) have commented on Galilei's silence about Bruno, putting forward reasons of prudence, but as pointed out by Martins (1986) this can hardly explain the absence of any mention also in his personal correspondence. Furthermore, although Galilei himself never mentions Bruno's name in his personal notes and letters, several of his correspondents do mention the Nolan. In a letter to Galilei dating to 1610, Martin Hasdale tells him that Kepler had expressed his admiration for Galilei, although he regretted that in his works the latter failed to mention Copernicus, Giordano Bruno and several Germans who had anticipated such discoveries—including Kepler himself:

> This morning I had the opportunity to make friends with Kepler ... I asked what he likes about that book of yourself and he replied that since many years he exchanges letters with you, and that he is really convinced that he does not know anybody better than you in this profession ... As for this book, he says that you really showed the divinity of your genius; but he was somehow uneasy, not only for the German nation, but also for your own, since you did not mention those authors who introduced the subject and gave you the opportunity to investigate what you found now, naming among these Giordano Bruno among the Italians, and Copernicus, and himself.

Thus, we can say that Galileo Galilei was probably aware of Giordano Bruno's work on the Copernican system. When Galilei arrived in Padova in 1592 it is also possible that the two scientists met, because Bruno was a guest of the nobleman Giovanni Mocenigo in Venice at the time and Galilei shared his time between Padova and Venice. In 1591, Bruno had unsuccessfully applied for the Chair of Mathematics that was assigned to Galilei one year later. Although it might be impossible to prove that the two astronomers met, it is hard to believe, given the motivations and characters of the two men and the circumstances of their lives during those years, as well as the small size of the Italian scientific community in those days, that they failed to discuss their respective arguments concerning the defence of the Copernican system.

6 NOTES

1. Amphitrite was in Greek mythology the wife of Poseidon, and therefore the Goddess of the Sea.
2. See Aristotle (1971: Section 296b).
3. Although Antonio Favaro, the Curator of the National Edition of Galilei's works, dates it to 1584, Crombie (1996) and Wallace (1981; 1984) prefer a date of around 1590.

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