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ROBERVAL'S SCEPTICISM IN THE *ARISTARCHI SAMII DE MUNDI SYSTEMATE*

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ABSTRACT. This paper argues for a different interpretation of Roberval's scepticism in his *Aristarchi Samii de mundi systemate*. Roberval's mild sceptical attitude, along with his fake attribution of hiscosmological treatise to the ancient Aristarchus of Samos, are explained by prudential reasons related to censure. I will instead provide a more internalist reading. There are deeper metaphysical and epistemological reasons for Roberval's pessimism about the prospect of a perfect science of celestial motions, as well as for his (non-realistic) acceptance of heliocentrism as just a more plausible system than Ptolemy's or Tycho's. I start by spelling out two distinct sceptical worries conflated in the *Aristarchi*. The first is a general agnosticism regarding certainty about the causes of the motions of the heavens—it is more of a worry that the true system of the world can never be known. The second is a particular pessimism regarding the prospects of improving astronomy. The same effect (the apparent motions of the heavenly bodies) can be produced by diverse causes. Judging by what seemed to be the most probable physical causes of the heavenly motions, Roberval saw no reason for the existence of a precisely predictable regularity in heavenly motions. Both sceptical attitudes have to do, aside from the cosmology of the *Aristarchi*, with the theory of science he expounds in his private *Principes du debvoir et des cognoissances humaine*, and in a fragment he wrote for Mersenne's *Curiouse perspective de Niceron*.

Keywords: *Roberval, Aristarchus, Early Modern Scepticism, Early Modern Cosmology.*

Introduction. The context of the *Aristarchi Samii de Mundi Systemate*

In 1644, Gilles Personne de Roberval published a small cosmological treatise entitled *Aristarchi Samii de Mundi Systemate, partibus, & motibus eiusdem, libellus*. The book is attributed to the ancient Aristarchus of Samos, and Roberval claims it

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to be an annotated translation of a recently recovered Arabic manuscript. In the dedicatory epistle addressed to Pierre Brûlart de Saint Martin, Roberval writes:

> Behold, sir, the little book of Aristarchus of Samos on the System of the World revealed to you, which, if I am not mistaken, you and R. P. Mersenne expected from us. It was recovered from an Arab manuscript by a certain stranger proficient in the Arab language, and written in Latin on your expense […] and given to us in order to read and amend.[1]

Roberval tells the reader that the Arabic manuscript was translated under his and Mersenne's supervision, on the expense of the royal counsellor. He does not explicitly defend the authenticity of the manuscript, or even its origin as a true ancient source.[2] Roberval does, however, imply the manuscript's authenticity, at least by the style and disposition of the treatise. The epistle informs us that, in addition to the translated text, Roberval will also help the reader by inserting certain notes. These are given within the text; are labelled as 'NOTA' and end with the abbreviation 'P.N.E.M.'.[3] Usually, the notes present new discoveries which were unknown by the author; with the aim to corroborate or refute Aristarchus's opinions. Roberval does, therefore, refer to Aristarchus at least as the alleged author of the treatise.

Not many took the book to be an authentic ancient treatise.[4] Most philosophers, mathematicians or scientists realized that the book is not authentic, and that the name of Aristarchus was used just as a cover for a seventeenth century author. They were, of course, right. However, as Heath observed more than a hundred years ago, "there was every excuse for Roberval. The times were dangerous."[5] Only ten years before he wrote the *Aristarchi*, Galileo's *Dialogue on the Two Chief Systems*

[1] G. P. de Roberval, *Aristarchi Samii de Mundi Systemate, enpartibus, & motibuseiusdem, libellus*, Paris, Antonium Bertier, 1644, Dedicatory Epistle [1643]. The treatise was republished in M. Mersenne, *Novarum observationum physico-mathematicarum*, Paris, Antonium Bertier, 1647. The only modern translation is in French, G. P. de Roberval, *Aristarque de Samos. Projet de Balance*, ed. tr. Jean Peyroux, Paris, Libraire de A. Blanchard, 2002.

[2] On this point see C. de Waard's note about the *Aristarchi Samii de Mundi Systemate*, in M. Mersenne, *Correspondance du P. Mersenne, Religieux Minime*, eds. Paul Tannery, Cornelis de Waard and Armand Beaulieu, Vol. 14, Paris, Centre National de la Recherche Scientifique, 1980, p. 59.

[3] These letters stand for 'pondere, numero et mensura' and were the motto of the mathematicians of the *Collège royal*. On this issue see A. Gabbey, "«Pondere, Numero et Mensura» Roberval et la Geométrie Divine", *Revue de Synthèse* 122(2), pp. 521-522.

[4] For an overview of the reception of the *Aristarchi* see *Correspondance du P. Mersenne, Religieux Minime*, Vol. 14, Paris, Centre National de la Recherche Scientifique, 1980, pp. 56-64.

[5] Thomas Heath, *Aristarchus of Samos, the Ancient Copernicus*, Oxford, Clarendon Press, 1913, p. 8.

of the World was condemned. The French context was uncertain, as geocentric systems were actively defended in the 1630s. In 1632, Libert Froidmond, arguing against Philip and Jacob Lansbergen's heliocentric system, published the *Anti-Aristarchus, sive Orbis-terrae immobilis*. Two years later, Froidmond followed up with another treatise, the *Vesta, sive Ant-Aristarchi Vindex*. Furthermore, Roberval's Parisian colleague Jean Baptiste Morin had published the *Famosi et antique problematis de telluris motu*, strongly arguing against Galileo and Copernicanism.[6]

Prudence, it seems, is enough to explain why Roberval chose to cover his identity in publishing his cosmology. After all, his purpose was at least partly that of popularizing some variant of heliocentric cosmology.[7] Roberval's defence of Copernicanism is not, however, neither definitive nor too strong. Both in the dedicatory epistle and in the epilogue, he manifests a very precautious attitude toward the certainty of the heliocentric system and a deep pessimism about the prospect of a science capable of resolving the astronomical issue once and for all. Roberval claims that heliocentrism is just the most plausible explanation, but the true system might be well beyond our knowledge. In the dedicatory epistle, Roberval writes:

> Finally, you will ask what is my own opinion. Am I committed entirely to the prescriptions of Aristarchus against Ptolemy and Tycho? Certainly not! And it is indeed not appropriate to directly follow the opinions of the mathematicians who either adhere or reject them, until a demonstration or a refutation of them appears. One should not assert that any of these three famous systems is the true and natural one. It may be that all of them are false and the true one is not yet known. However, of these three systems, it is that of Aristarchus which seems to us to be the simplest and the one which fits best with the laws of nature so that, even though we do not claim that itis certainly true, we prefer it to the other two.[8]

There are, thus, two virtues which, at least declaratively, Roberval finds in Aristarchus's system: simplicity and a higher degree of concordance with natural laws. However, these virtues are only sufficient for Aristarchus's system to be preferable relative to Tycho's or Ptolemy's. Only a 'mathematical demonstration' could suffice for proving one system as the true and natural one. Why is it that Roberval did not

[6] See a brief survey of the anti-Copernican books and Galileo's condemnation in A. Martinez*, Burned Alive: Giordano Bruno, Galileo and the Inquisition*, London, Reaktion Books, 2018, esp. ch. 3.

[7] De Waard claims that the lack of popularity of the *Aristarchus* eventually led Roberval to abandon cosmology altogether, see *Correspondance du P. Mersenne, Religieux Minime*, Vol. 14, Paris, Centre National de la Recherche Scientifique, 1980, p. 63.

[8] Roberval, *Aristarchi*, dedicatory epistle.

endorse heliocentrism more strongly? What would a 'mathematical argument' be, and how should his general pessimism be interpreted? Roberval elaborates on his sceptical attitude in the epilogue of the *Aristarchi,* this time by using the voice of Aristarchus. He also claims that the prospects of a certain physical science capable of resolving the cosmological and astronomical issues are almost null. He writes:

> It is not yet established if the system of the Earth is simple or composed, animated or unanimated. But if you want to extract an opinion out of this, we estimate that the Earth is composed, and animated by a sensible soul. […] And this soul might be the same in all systems, or there might be different souls in each system.[9]

Roberval is as precautious in physical matters as he is in endorsing a general astronomical system. The causes of planetary movements are, according to Aristarchus, a certain soul inherent in every part of matter, which makes the parts unite into a larger whole. However, immediately after this hypothesis, Roberval (by his Aristarchus avatar) adds that even if this this soul would be absent, the movements of the heavenly bodies could be explained by positing certain qualities. In the last clarificatory note to the purported ancient text, Roberval shows a similar sceptical attitude towards the prospects of a more correct and precise astronomy:

> Therefore, no one in the future could boast about discovering a certain perpetual theory of the planets, or about a perfect science of astronomical movements; most probably, they are exposed to many frequent irregularities, and their causes being so hidden and abstruse, it greatly exceeds the capacity of humans to discover them or to understand them.[10]

Here, in the explanatory note to Aristarchus's alleged epilogue, Roberval elaborates his sceptical and pessimistic attitude about the certainty of the Copernican hypothesis and the prospects of a physical science capable of explaining it. His conclusions are very pessimistic. Not only do we have no satisfactory account about the heavenly motions—but there is no way in which we could ever attain a precise and certain explanation, as the irregularities in the movements of the planets are not periodical, and their causes are obscure and hidden from human knowledge.

[9] Roberval, *Aristarchi*, pp. 139-140.
[10] Roberval, *Aristarchi*, p. 147.

Roberval's scepticism about the true astronomical system and its physical properties is, same as his attribution of the treatise to Aristarchus, usually explained by prudence. Leon Auger argues that, as the Copernican hypothesis was still not too popular in France, Roberval was prudent in his endorsement: without mentioning Copernicus's name, he presented heliocentrism just as one (albeit more plausible) hypothesis among others.[11] De Waard also claims that prudence was responsible for the general tone of Roberval's treatise, and that his scepticism just amounts to a very precautious attitude.[12] Roberval was, however, not alone in endorsing a heliocentric cosmology in the 1640s. Descartes published, in 1644, his *Principia Philosophiae*, and other heliocentric treatises were written. It seems that the general attitude was more nuanced, and Copernican and mixed systems had their own place at that time. Overall, it is arguable whether censure did affect theoretical cosmology and astronomy that much in Catholic France.[13] If this is the case, there actually existed more freedom of opinion regarding the features and plausibility of the true system of the world. Prudence, then, would be enough to explain Roberval's choice of concealing his identity, but would not be a sufficient explanation of his sceptical attitude towards the endorsement of heliocentrism. We can, however, account for Roberval's scepticism in a more 'internalist' fashion, if we examine his other texts about the epistemological status of science(s). In the following sections, I will argue that Roberval is much more internally consistent than hitherto acknowledged. He wrote the *Aristarchi* in accordance with his general ideas about the status of physical and mixed-mathematical disciplines, and was closely following his methodological precepts. Upon closer examination, I will show that Roberval's 'scepticism' actually conflates two distinct sceptical worries. The first is akin to a general agnosticism regarding the certainty about the causes of the motions of the heavens—it is a worry that certainty about the true system of the world can never be attained. The second is a particular pessimism regarding the prospects of improving astronomy. The same effect (the apparent motions of the heavenly bodies) can be produced by diverse causes. Judging by what seemed to be the most probable physical causes of the heavenly motions, Roberval had no hope for a precisely predictable regularity in heavenly motions. I will elaborate on these in the next section.

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[11] L. Auger, *Un savant méconnu: Giles Personne de Roberval*, Paris, 1962, pp. 104-116. and L. Auger, "Les idées de Roberval sur le système du monde" in *Revue d'histoire des sciences et de leurs applications*, tome 10, 3, 1957. pp. 226-234;

[12] M. Mersenne, *Correspondance du P. Mersenne, Religieux Minime*, Vol. 14, Paris, Centre National de la Recherche Scientifique, 1980, p. 63.

[13] See J. L. Russell, "Catholic astronomers and the Copernican system after the condemnation of Galileo" *Annals of Science*, 46:4, 365-386, 1989.

The scope and certainty of science. Roberval's scepticism

The dedicatory epistle of the *Aristarchi*, signed by Roberval, is dated July 1643. By this time, Roberval had been occupying the Ramus chair for mathematics at the Collège Royal for ten years. He was a central figure of the Parisian circle of savants and philosophers, and one of Mersenne's closest collaborators. In the early 1640s, Roberval was in very good terms with Pierre Gassendi, often meeting and discussing issues not limited to mathematics.[14] He was also in a very close collaboration with Thomas Hobbes, at a time when the latter was very interested in geometry and the properties of some special types of curves.[15] 'Nostre geometre', as Mersenne used to call Roberval, always benefited from his friendship with the Minim. For instance, Mersenne included Roberval's *Mechanics* in his 1636 *Harmonie universelle*, and he once more published some parts of it in his 1644 *Cogitata physico-mathematica*. The *Aristarchi* was reprinted, with some modifications, in Mersenne's 1647 *Novarum observationum physico-mathematicarum*. However, in cca. 1650, Roberval was to return the favour. Roberval was entrusted by Mersenne to edit and complete the *Perspective curieuse du R. P. Niceron, divisée en quatre livres, avec l'Optique et la Catoptrique du R. P. Mersenne.*[16] In this volume, Roberval wrote a short text expounding his epistemology. The text reveals a sceptical attitude towards the physical explanations of the reflection of light, which is remarkably similar with the one in the *Aristarchi*:

> So it is that, in the matter we are discussing, concerning the equality of the angle of incidence and the angle of reflection, some would have us believe that light is reflected by rebound; others, that it is reflected by a continuation of the actual motion of the corpuscles which are the cause of light; others, by the continuation of that same motion of those alleged corpuscles, not actually but only potentially (like the action of several balls, arranged in a straight line, touching one another, with the first of them touching a wall, and the last pushed by some force designed to make them all move simultaneously along that straight line, towards that wall). Others again make a comparison with a stick thrown forcibly downwards, or obliquely, against a

[14] See a summary of the interactions between Gassendi and Roberval in V. Jullien, "Gassendi, Roberval à l'académie Mersenne. Lieux et occasions de contact entre ces deux auteurs", in *Dix-septième siècle,*2006/4, 233, pp. 601-613.

[15] A substantial account of the interactions between Roberval and Hobbes is provided by Noel Malcolm in N. Malcolm, *Aspects of Hobbes*, Oxford, Oxford University Press, 2002, esp. pp. 156-200.

[16] The 2nd edition of the *Perspective curieuse du R. P. Niceron* was designed to be published independently of Mersenne's own Optics and Catoptrics, but, after Mersenne's death in 1648, the 2 volumes were published together.

> surface; others have other even more implausible visions. But all explain this notable action of nature by some resemblance they think it has with something else, which they believe they know well.[17]

This fragment is in Roberval's handwriting, even if the authenticity of the rest of the text can be doubted.[18] The style of the text deserves some attention. Interestingly, Roberval appeals, in this fragment, to the authority of another author, "equally skilled in philosophy and mathematics"[19]. It is this philosopher who claims that only vanity and arrogance makes people believe they can know the nature of physical phenomena with certainty. Nevertheless, Roberval is in full agreement. After listing the most popular physical explanations of the phenomenon of reflection of light, Roberval presents them as having no other virtue than being familiar comparisons with already known causal relations. He does not bother to compare the plausibility of the hypotheses. The purpose is rather to argue for a general agnosticism regarding physical explanations. This agnosticism is, claims Roberval, justified, as humans simply cannot have sensory access to the nature of the physical world. Roberval goes on to compare the general search for true natural causes with that of a blind man, searching in vain for the nature of the Sun's light. Hypotheses about light are just as imperfect as the ideas which a blind man might have of the Sun. The agnosticism set forth in this fragment is further used to ground a very strong distinction between science and mere opinion. Certainty belongs to science, while probability belongs to opinion. Roberval writes:

> [W]here the human sciences are concerned, we should use pure reasoning as far as possible, so long as it is founded on principles that are clearly and distinctly true, and draw from those principles conclusions that cannot be doubted. That is what we do in geometry and arithmetic […]. In the absence of such principles, we must make use of regular experience, made under the requisite conditions, and draw plausible conclusions from it. And he called the knowledge which comes from the first type of conclusions, 'science'; as for the conclusions drawn from experience, he called the knowledge derived from them 'opinion'.[20]

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[17] *Perspective curieuse du R. P. Niceron, divisée en quatre livres, avec l'Optique et la Catoptrique du R. P. Mersenne*, pp. 88-89. An English translation of the fragment is available in N. Malcolm, *Aspects of Hobbes*, pp. 168-172.

[18] See the discussion in N. Malcolm, *Aspects of Hobbes*, p. 172 and notes.

[19] Noel Malcolm argues that this philosopher is, most likely, Thomas Hobbes.

[20] *Perspective curieuse du R. P. Niceron, divisée en quatre livres, avec l'Optique et la Catoptrique du R. P. Mersenne*, p. 91.

Is it the case that in optics and astronomy we can have plausible conclusions at best? Indeed, the nature of the propagation of light and the true motions of the astronomical system of the world, along with their cosmological explanation, remain uncertain, and can gain plausibility just if the system provides enough "regular experience made under the requisite conditions". However, Roberval nuances this agnosticism. There are, of course, disciplines such as mechanics, astronomy and optics, which borrow both from mathematics and from sensible experience. It is, claims Roberval, just a matter of names if we chose to call these 'sciences', be they mixed, or 'very certain opinions'. Anyway, these mixed sciences inherit their fallibility from experience—for Roberval, the cleavage between science and opinions is very strong.

If the fragment from Mersenne's *Catoptrique* appeals to the testimony of some other philosopher, Roberval himself shows the same agnosticism in a fragment from a conference against Cartesian theories written in 1647. Here he repeats the same agnosticism:

> Regarding the parts of philosophy, metaphysics is very chimerical, physics is very true, but it is very hidden: it only reveals itself through its effects. It does not flatter and it cannot be flattered: all chimeras are destroyed with the same ease with which light removes darkness at night time. [Physics] is never contrary to itself, even if it produces contrary effects, or which merely seem this way to us.[21]

We can see, once again, Roberval's general attitude about the scope of physical theorizing and its certainty. Metaphysics, which includes, for instance, speculations about the nature of light in the phenomenon of reflection, is just a chimera. It is no more than a vain fiction—for we, same as the blind man who lacks the appropriate sense to perceive light, are missing the appropriate sense to access he nature of physical phenomena. This sensory lack is the reason why physics is concealed, and can only be known via its effects. Notice that Roberval is not a complete sceptic here: even if we do not have sensory access to its nature, physics is nevertheless true, and it is never contrary to itself. The only way to arrive at an adequate knowledge of physical effects is to establish a mathematics of constant experience. Roberval continues:

[21] G. P. de Roberval, *L'Évidence, — le fait avéré — la chymere*, my translation. The Lecture is reproduced in B. Pascal, *Oeuvres de Blaise Pascal*, eds. L. Bruncschvicg, P. Boutroux, vol. 2, Paris, Hachette, 1908, pp. 49-51; and in L. Auger, *Un savant méconnu*, *Giles Personne de Roberval*, pp. 136-137.

> Mathematics […] is true immutable and invincible, while not hidden: it is clear and evident in its proper object [grandeur or number, provided that this object is considered geometrically and arithmetically, and *not in the composition of material things*. In this composition, mathematics, *being founded on the same principles as physics*, takes as its foundations facts which are certified by a constant experience, and on these bases it establishes mechanics, optics, astronomy and music, and other particular sciences.[22]

Roberval uses a common-place distinction between pure and mixed mathematics. Pure mathematics considers discrete and continuous quantity in themselves: these are arithmetic and geometry. The particular, mixed sciences of mechanics, optics, astronomy and so on are established as soon as mathematics is considered "in the composition of material things", via the warrant of a constant experience. Whatever this vague latter statement is intended to mean, one thing is clear from this philosophical text: Roberval reiterates the cleavage between mathematical and physical knowledge. The former is evident and certain, while the latter is concealed, and can only be attained by a systematic inquiry into the constant effects of nature.

The most illuminating account of Roberval's scientific methodology and epistemology comes, however, from another source. In 1845, Victor Cousin published his *Fragments de Philosophie Cartésienne*. In it, he publishes and attributes, for the first time, one of Roberval's more private writings on the theory of science. The dating is imprecise, but the fragment is considered authentic.[23] In Cousin, the title appears as *Principes du debvoir et des connoissances humaines*.[24] The text begins by drawing a distinction between propositions so evident that they cannot be doubted just by understanding the meaning of the words (like "the whole is greater than the part"), and those which are plainly false (like "the part is greater than the whole"). The former are first truths and the latter first falsities. Any other proposition can be doubted:

> There are some propositions that do seem at first either false nor true, as there are four elements, a triangle has its three angles equal to two right angles rights; but, if we show that they are based on first truths, they are held to be true. If we show

[22] G. P. de Roberval, *L'Évidence, — le fait avéré — la chymere*, my translation and emphasis.

[23] There are, however, some clues that the fragment was written before 1647. In the 24th principle, Roberval talks about nature's horror of the void—and in 1647, Roberval learned about Pascal's experiments affirming the existence of void in nature. See also G. P. Roberval, *Eléments de géométrie*, ed. tr. Vincent Jullien, Paris, Vrin, 1996, p. 23.

[24] The text is available in V. Cousin, *Fragments de Philosophie Cartésienne*, Paris: Charpentier, 1845, pp. 242-261. All hence forth translations are mine.

> them to be based on first falsities, they will be considered false. If there is no such connection available, they must remain doubtful. […] there is difference between being true or false and being known to be true or for false.[25]

Even geometrical theorems, by this account, are bound to remain doubtful until a demonstration is provided. Geometrical theorems, nonetheless, do not *become* true once they are proven. They have always been true, and our demonstrations bring them from the realm of unknown truths to that of known truths. Furthermore, this distinction grounds Roberval's definition of science. The seventh principle begins: "I call *belief* a proposition that can be true or not. I call *science* the belief which is grounded in first truths and which is proved by them. But when a belief is a proposition which is not a first truth nor proven by one, I call this belief *opinion*".[26] As was the case with the fragment from Mersenne's *Catoptrique* and with *L'Évidence, — le fait avéré — la chymere*, Roberval follows a very strong definition of science. Again, we see an account in which mixed mathematics do not count as real sciences, as they are not (or cannot be) deduced from first truths. Only logic and—maybe—pure mathematics satisfy these demands.

If we take this definition to be Roberval's definitive view on the nature of scientific knowledge, then the scepticism about heliocentrism in the preface of *Aristarchi* becomes trivial. "One should not assert that any of these three famous systems is the true and natural one. [without a mathematical demonstration]"[27] simply means that there is no science available in astronomical claims, and, indeed there cannot be any certainty in these claims. But there is more. As we have seen, Roberval acknowledges that mathematics can be considered "in the composition of material things" and this type of knowledge has the warrant of constant experience available. Only certainty is at issue here: generally, any explanation of a natural phenomenon is bound to remain uncertain, and this is what Roberval's general agnosticism amounts to. In choosing from alternative and incompatible explanations of natural effects, one must always keep in mind that alternatives, which are equally intelligible propositions, may be impossible in nature. In Roberval's words, "Everything which is intelligibly possible is not possible in nature; but everything which is possible in nature is intelligibly possible".[28] On these terms, one cannot help but remain agnostic about the general

[25] *Principes du debvoir et des cognoissances humaine*, principe 3. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 244

[26] *Principes du debvoir et des cognoissances humaine*, principe 7, my emphasis. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 245

[27] G. P. de Roberval, *Aristarchi*, dedicatory epistle.

[28] *Principes du debvoir et des cognoissances humaine*, principe 16. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 248.

truths of physics. Recall that, in Roberval's view, physics is very hidden; Nature only reveals itself through its effects, and any effect can have a multitude of possible causes. The only ground of our physical knowledge is that "nature is not contrary to itself".[29] Roberval repeats this axiom here, but he does not elaborate on its justification. Instead, he builds on it. He assumes that "the same, a similar, or a similarly disposed cause produces, in the same, a similar, or a similarly disposed subject a similar effect."[30] There is, therefore, the epistemological possibility of anticipating a cause by knowing if the subject (a substance) is similar or similarly disposed. We do not need to enter into Roberval's scholastic terminology here; suffice it to say that he accepts substantial forms, material substrata, and the Aristotelian causes. The Aristotelian terminology is described as follows:

> There are certain things I call substances, like an apple, a tree, a mountain, the sea, the water, the earth, the sky […] I call qualities of the substances, the colour, gravity, beauty, heat […], which cannot survive naturally without some substance. […] There is something in natural substances which is like the foundation of their qualities and which is not lost, even though the qualities are lost […] I call it the matter of substances.[31]

The interesting element in his Aristotelian vocabulary is the relation between qualities and matter. Roberval claims that the natural qualities are nothing other than the disposition of matter to produce or receive certain effects. Therefore, there is no quality which is immaterial, and no natural effect which lies outside the material world. An investigation of nature is, thus, an investigation of the actual material effects within nature. Given that similar causes should produce, in a subject, similar effects, one can progress by comparing the possible causes by which a natural effect might be produced. This can be done by arriving at a consistent conventional classification of qualities, which can afterwards be evaluated. If qualities are nothing other than material dispositions towards causes and effects, the scientist can learn, in a piecemeal fashion, the probable causes in nature, by inquiring into the *signs* of the object in question. Both the causes and the effects of something are signs of that thing. For instance, rain is a sign for the presence of clouds, in the same way as heat is a sign for the expansion of air. In principle 35, Roberval claims that the signs of a

[29] *Principes du debvoir et des cognoissances humaine*, principe 15. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 247.

[30] *Principes du debvoir et des cognoissances humaine*, principe 15. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 247.

[31] *Principes du debvoir et des cognoissances humaine*, principe 26. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 250.

thing are its causes and effects, its qualities, or what usually precedes or accompanies it. A thing is not absolutely certain and infallible if, differently put, we could have similar signs and appearances of another thing.[32]

By Roberval's account, many things can be signs of a particular object which is inquired: causes, effects, qualities, or just other phenomena which usually correlate with the inquiry. The 'similarity' between causes, effects, and signs plays a big role in Roberval's account. He does not, however, elaborate on what a 'similar cause', 'similar effect' or 'similar appearance' mean. He only illustrates this similarity by some examples:

> It is very likely that correlated causes will produce effects which are or seem to be correlated. […] as, if the Sun's rays bend entering into the water, those of a candle will also very likely bend; and if they bend entering glass, it is very likely that they will bend entering crystal or the like, if experience does not show the contrary.[33]

The decision whether this or that cause and effect are or are not similar need not concern us at this point. It is only relevant that the decision is made by the individual scientist, based on what histories, communities or conventions might indicate. All these decisions are, of course, fallible: the signs of a thing might be misleading in different contexts, so the inquiry into the natural causes of a phenomenon is bound to be a step by step process; It should consider each causal relation at a time, and gradually move up on the chain of causes in the order of nature, until one reaches a tentative first cause. Roberval argues that any natural phenomenon has a multitude of natural causes, although this number must be finite:

> There is one or more first causes for each effect, but, at the same time, there cannot be an infinity of causes of the same effect […] The land dries because the water rises, it rises because it becomes lighter, it becomes lighter because it expands, it expands because it is heated; but it cannot be that there do not exist one or more first causes of all these effects.[34]

This type of causal chain should be investigated by the scientist, step by step, all the way up towards the first principles. There is no guarantee of achieving certain knowledge about the first causes; some degree of arbitrariness in

[32] *Principes du debvoir et des cognoissances humaine*, principe 31. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 252.

[33] *Principes du debvoir et des cognoissances humaine*, principe 35. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 258.

[34] *Principes du debvoir et des cognoissances humaine*, principe 19. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 248.

unavoidable in establishing the first causes of physical effects. However, one must aim for corroborating purported causes of physical phenomena by as many experiences as possible. When there is no available access to the proper cause of a particular phenomenon in a causal chain, the inquirer must tentatively hold an already available cause as the natural cause.

Related to Roberval's earlier example of a natural causal chain, he writes: "When we cannot establish a cause of a natural fact […] we will regard as a first natural cause the one on which this [unknown cause] depends, as, if we cannot establish the cause which makes hot air expand, we will regard as *the first natural cause that air is expanded by hea*t."[35] This example is interesting for more than its illustrative purposes. As we will see, one of the physical principles of heavenly motion set forth by Roberval in his *Aristarchi* is precisely this: The Sun's heat rarefies matter and pushes it towards the extremity of the system of the world.

In the general context here, notice however that there are two reasons why ascribing natural causes to physical phenomena in this way is provisional. The first reason regards the actual mechanism by which the purported cause produces the effect. Heat might be the cause of the expansion of air, but this does not explain *how it is* that heat causes the expansion. The scientist would have to fill this explanatory gap. The second sense of the provisional state of first causes regards the possibility of error. In Roberval's example, heat might not be connected to the expansion of air at all—they could both be the effect of another cause. The scientist must always be prepared for this type of error, and be ready to give up the previously held explanations. In case the alternative conflicting causal explanations of physical phenomena, corroboration with other established causal chains plays a major role for Roberval: "When we have diverse appearances that cannot be together true, we have to believe the stronger and clearer appearances, which are in more conformity between themselves and with the previous ones held for certain."[36] *Fr*. "apparences" does not mean here sensory input—which might be deceitful. It refers to the provisional causal explanations of some physical effect. That is, explanations should be as consistent (within themselves and with each other) and as evident as possible. The same goes for systems of explanations, which are presupposed in accounting for signs and appearances, e.g. the observed celestial motions. When deciding between incompatible systems, such as the Ptolemaic, Tychonic

[35] *Principes du debvoir et des cognoissances humaine*, principe 35, my emphasis. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 257.

[36] *Principes du debvoir et des cognoissances humaine*, principe 35. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 257. my emphasis.

or Copernican systems, the inquirer must evaluate system based on some criteria: "One system is more credible than another when it explains [*fr*. rend raison] all or most appearances more exactly, simpler, more clearly, and more related to other natural things."[37]

The similarity of this passage with the preface of the *Aristarchi* is striking. Recall that in the preface, Roberval claims that "it is [the system of Aristarchus] which seems to us to be the simplest and the one which fits best with the laws of nature so that, even though we do not claim that it is certainly true, we prefer it to the other two."[38] There are, therefore, consistent reasons, on Roberval's part, both for his preference for the Copernican system, and of his (only) moderate acceptance of it just as a more probable explanation than the alternatives. I will elaborate on these particular astronomical and cosmological reasons in the next section. For now, let us recapitulate Roberval's precautious methodological tenets. These constitute the first part of Roberval's fairly sceptical epistemology, what I have called his general agnosticism about the real physical causes of natural phenomena.

In all of Roberval's philosophical writings, there is a fundamental difference between science and opinion. Only the claims of the former can be absolutely certain. The domain of science *per se* is (in a very traditional Aristotelian way) greatly restricted: only logic and pure mathematics may count as sciences. Roberval constantly wavers between describing claims of optics, mechanics, astronomy etc. as highly probable opinions, or sciences founded on the constant experience of physical phenomena whose causes are not directly accessible. Regardless, establishing the natural cause of a physical phenomenon is never certain. The main epistemological reason of this uncertainty is this: there can be multiple possible and incompatible causes of a particular effect. All alternatives may be equally intelligible. However, not all intelligible causes are, in fact, possible in nature. The scientist must establish a hierarchy of possible causal relations, by corroborating as many signs as possible. This hierarchy should build up (probable) causal chains, representing the causal order of nature, all the way up to the first principles. As the chain of causes can only be probable, the established first principles are bound to be provisional and revisable. If two or more of these accounts of causal chains prove to be incompatible, the inquirer has to choose the most probable one by criteria such as precision, consistency, corroboration, simplicity. We are never, however, entitled to believe that the resulting systems or first principles are anything more than probable opinions—opinions which, at some

[37] *Principes du debvoir et des cognoissances humaine*, principe 35. See V. Cousin, *Fragments de Philosophie Cartésienne*, p. 260.

[38] G. P. de Roberval, *Aristarchi*, dedicatory epistle.

point, might be abandoned. Seen in this light, Roberval's tempered endorsement of the Copernican system is no little thing—it is actually the most we could hope for in astronomy.

But Roberval's pessimistic attitude towards the prospect of a perfect astronomy expounded in the epilogue is of a different nature: it bears on the particular type of available knowledge about heavenly motions and their causes. I will now turn to a contextualisation of Roberval's methodological precepts to his own physical system described in the *Aristarchi*.

The Physical System of the *Aristarchi*

In the *Aristarchi*, Roberval articulates the physical causes of the movements of the heavenly bodies. In this sense, his work is closer to a cosmology than to an astronomy. As we have seen, knowledge about physical causes is bound to be uncertain. Still, the purported physical causes have to be taken as valid until one finds a better, more corroborated replacement.

What are Roberval's reasons for his pessimism about the prospect of astronomy? The first already assumes a heliocentric system of the world: it is the irregularity of the variation of the Earth's diurnal and periodical movement. The most nefarious effect of this irregular variation is the unreliability of observation. Without inaccurate way of establishing sidereal time, no observation about the position of heavenly bodies can be completely reliable:

> Notice that […] both periodical and diurnal movement of the Earth and of the planets, is irregularly irregular in many of its points. From which it follows that the natural or astronomic days are irregularly unequal. And yet we do not have another movement, aside from the diurnal natural motion of the Earth, which is irregular, *from which we can measure and discern time in astronomical observations*. And the method or the ways in which these measurements are done are not enough to correct and equalize time-keeping itself, because of the irregularity of all the movements. Because time is unequal and irregular, astronomical observations are doubtful and uncertain, and insufficient to create perfect we cannot make perfect tables of the celestial movements. Furthermore, the limit from which we can establish the celestial longitude, the vernal equinox, is absolutely uncertain, as it was explained in the chapter on the precession of the equinoxes.[39]

[39] G. P. de Roberval, *Aristarchi*, pp. 146-147.

On the practical side, there is no hope for ever devising a method for determining, *e.g.* celestial longitude if neither the observations nor the astronomical tables are reliable. The same goes for the hope of further developing the science of astronomy itself—if the variations in movement are irregular, there is no hope of discovering any general law of these deviations.

Aside from the fallibility of observation, there is yet another reason which undermines the hope for a better astronomy. This has to do with the purported physical cause of all the movements of celestial bodies, including the system of the Earth. Let us follow Roberval's methodological precept and examine this effect (the appearance of the irregular variation of the motion of the Earth) by the cause which produces it, through the natural causal chain, all the way up to the first cause(s). Roberval claims that the movements vary irregularly (as does the precession of the equinoxes) because the system of the Earth, including here the smaller system of the Moon, possesses an oscillatory motion, a certain irregular trepidation, in its periodical movement around the Sun and in its diurnal motion.

I will trace the source of the irregular periodical and diurnal movement of the Earth, all the way back to the very first cause of the motioning the system of the world. They are as follows, from the most general to the most particular: 1. The heat generated by the Sun expands and rarefies the adjacent matter and pushes all matter towards the outskirts of the system. This determines the outward push by which the Sun acts on all the celestial bodies in the world; 2. The way in which the systems of the Earth and planets, by virtue of their material properties, react to this pushing. This step is twofold: on the one hand, is has to do with the universal property of the fluid, diaphanous matter which fills the heavens. On the other hand, it has to do with the irregular way in which the terrestrial elemental matter is disposed within the system of the Earth. 3. The motion of the Moon, which, by its oval orbit, irregularly influences the ebb of the sea and the diurnal motion of the Earth. I will treat them individually.

1. The Sun as a cause of motion. From the very first chapter of the *Aristarchi*, Roberval explains all motion of the system of the world by two principles. One of them is a principle of attraction, stating that the fluid heavenly matter has, in every one of its parts, a certain property by which it tends to unite with all the other parts of matter.[40] If the Sun would be absent from the world, all heavenly matter would reunite in a perfect sphere. The second principle concerns the action of the Sun. By its heat, the Sun continuously rarefies the surrounding matter. The rarefaction results in the elongation of matter, which is pushed towards the extremity of the

[40] G. P. de Roberval, *Aristarchi*, pp. 2-5.

system. The sun also has an axial motion of its own, by which the eviction of the rarefied matter takes place.[41] This motion impresses upon the celestial bodies their periodical movement around the Sun. However, throughout the Sun's axial rotations, the ejections of rarefied matter do not have a constant flux, and thus the motions of heavenly bodies around the sun are not uniform.

2. The movements of the Earth's system. As one of the planetary systems, the Earth is moved around the Sun by the continuous pushing of the elongated matter, coupled with the attractive property of the celestial matter. The system of the Earth retains its quasi-spherical shape due to an analogous attractive property of the elemental matter, which accounts for the weight of terrestrial bodies.[42] The terrestrial matter is, however, different from the heavenly matter. It is very mixed, and it is unevenly disposed on the surface of the Earth.[43] Therefore, the Sun unevenly elongates the airy and fiery atmosphere surrounding the Earth and, as a result, the diurnal motion of the Earth is irregular. To this is added a third reason of the irregularity, the influence of the Moon.

3. *The periodical movement of the Moon*. According to Roberval, The Moon is a part of the system of the Earth. Its density is similar to that of the superior atmosphere, such that it revolves, together with the air and fire, around the Earth. Roberval claims that the moon floats in the superior atmosphere in the same way as a submerged piece of wax floats in water.[44] Its orbit, however, in not circular but oval-shaped. This shape is responsible for the ebb of the seas: at its perigee, the Moon it compresses the air below it which, in turn, exerts a pressure on the ocean. Likewise, the Moon disturbs the flow of rarefied matter coming from the Sun, which also affects the diurnal motion of the earth.

All these physical causes render the diurnal and periodical motion of the Earth "irregularly irregular". These causes are more and more particular, starting from the first principle of motion (the Sun's heat) and ending with the interaction between the Moon and the superior atmosphere. Still, all of them are prior to the

[41] This motion is described in G. P. de Roberval, *Aristarchi*, pp. 23-36.

[42] This property of terrestrial matter is, however, different from the attraction inherent in heavenly matter. This point is sometimes neglected. Leon Auger, for instance, in his *Un savant méconnu: Giles Personne de Roberval*, pp. 106-108, claims that Roberval's principle is one of universal attraction. This is not true, as the attractive properties of the small systems are different in nature from the attraction of the celestial matter. See also P. Duhem, *The Aim and Structure of Physical Theory*, Princeton, Princeton University Press, 1954, pp. 243-244; and E. J. Aiton, The Vortex Theory of Planetary Motions, New York, American Elsevier, 1972, pp. 57-58 and notes.

[43] See the description of the movement of the system of the Earth in G. P. de Roberval, *Aristarchi*, pp. 44-59.

[44] See the explanation of the motion of the Moon in *Aristarchi*, pp. 59-67.

earthly effect—the observed irregularity of the Earth's motion. All in all, according to Roberval, the probable evidence, *i.e.* the probable individual causes acting upon the Earth, indicate that the movement of the Earth is irregular without following any general rule. If this is the case, then the expectations of achieving a "perpetual theory of the planets" are indeed totally unwarranted.

Roberval's whole pessimism about the prospects of a better astronomy is not, as his more general agnosticism, epistemological. The latter is a general worry about the impossibility of attaining certainty in physical and (to a lesser degree) mixed-mathematical sciences. The main reason for this is that one can explain the same phenomenon in multiple, equally intelligible ways. The pessimism about astronomy, on the other hand, is not epistemological at all: it does not have to do with the nature or status of astronomical or cosmological knowledge. It only has to do with the particular causes which are envisaged by Roberval to be producing the motions in the heavens. If these causes (heat, attraction of matter, the irregular composition of the Earth and the influence of the Moon) would not have been real, or if later astronomers will discover a more fundamental cause of all these, the prospects of a perfect astronomy would be revived.

Conclusion

As is Roberval's fake attribution of his treatise to Aristarchus of Samos, his attitude towards the certainty of astronomical and cosmological knowledge is usually explained in terms of prudence related to censure. The purpose of this article has been to provide a more internalist reading of Roberval's mildly sceptical view about astronomy and cosmology. I have showed that Roberval's *Aristarchi* is consistent with the epistemological and methodological precepts set forth in his philosophical writings. I have also argued that this attitude conflates two quite different strains of scepticism.

The first, which I have called his general agnosticism about physical causes is essentially an epistemological matter. It concerns the status of physical (and mixed) sciences within Roberval's general theory of science. Physics is bound to be a science in which no absolute certainty can be attained. Humans simply lack the appropriate sense in order to know the true causes in nature. Every natural effect may have a variety of equally intelligible, but not equally possible, natural causes. As a result, inquirers must learn to discern the most probable explanation between incompatible alternatives. All probable explanations are, however, provisional and revisable. This is the case of the Copernican system. By all the amount of available evidence, it is the most plausible planetary system—and this is the most an astronomical system could hope for.

The second, which I have called Roberval's pessimism about the prospects of a perfect astronomy, is not an epistemological worry. It is the consequence of the particular physical cosmology which Roberval proposes. The probable physical causes of motion in the system of the world are such that the precise movement of celestial bodies can never be accurately predicted. The first principle of motion, *i.e.* the heat generated by the Sun, along with the motion of the Moon and the irregular disposition of terrestrial elemental matter affect the diurnal and periodical movement of the Earth. The effect is that the Earth possesses an irregular movement which is not uniform, and does not vary according to any law. Because there is no natural law of these irregularities, astronomers cannot even hope to construct precise astronomical tables based on accurate observations. This conclusion of Roberval is, however, only as sound and probable as his explanations of the physical causes of heavenly motions.

Both of these strains of scepticism shape Roberval's philosophical and physical endeavours. He is, nevertheless, consistent: in the *Aristarchus*, the choice of the astronomical system, as well as all physical explanations, are presented as mere probable, and his methodology leaves open the possibility of improvement. One thing to be further investigated is the philosophical influence which Roberval's closest collaborators, Mersenne, Hobbes and Gassendi, had on his twofold scepticism.

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