Michel Serres and the *Rhuthmoi* of the Flow – Part 1

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Michel Serres (1930-2019), who had made, in the 1960s, the acquaintance of Foucault at the Blaise-Pascal University in Clermont-Ferrand, briefly joined with him the post-1968 experimental Vincennes University, and was eventually appointed to a chair in the history of science at the Sorbonne. In 1977, he published *La Naissance de la physique dans le texte de Lucrèce : fleuves et turbulences – The Birth of Physics* (2000, trans. Jack Hawkes) in which he argued that the Ancients had all necessary mathematical resources to formulate an adequate picture of a flowing Nature; that their model of atomic matter was essentially a fluid one; that their most important concept was therefore that of *dînos* or *dínê* – whirl or turbulence; and, last but not least, that these concepts were direct sequels of that of *rhuthmos*. The recognition of these facts shed light on the subterranean relationship between the newest disciplines of chaos and complexity, and the ancient physics initiated by the first Atomists Leucippus (early 5th century BC) and Democritus (c. 460-c. 370 BC), elaborated further by Archimedes (c. 287-c. 212 BC) and beautifully summarized in Lucretius' *De rerum natura* (c. 99-c. 55 BC).

Rhuthmós as Whirl?

Like Barthes, Serres cited Benveniste's study on "The concept of "rhythm" in its linguistic expression" (1951/1966) but, surprisingly, he first strongly opposed his interpretation. "The linguist," he argued with a bit of philosophical haughtiness, had not recognized the true nature of the pre-Platonic *rhuthmos*, which was, according to him, a "vortex in the flow," a form "adopted by atoms in conjunction in the first *dinos*."

> The linguist, like Heraclitus, Montaigne and the rest, had never sailed in fresh water. Nothing flows as they thought. Direct physical experience, simple practice, reveal the *rhuthmos* in the *rhein*, or the vortex in the flow, or the reversible in the irreversible. Rhythm is a form, yes, it is the form adopted by atoms in conjunction in the first *dinos*. In the beginning is the cataract, the waterfall: here is the reversibility to this irreversibility: thus *rhuthmos*. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 154)

This harsh and surprising critique of Benveniste's contribution was actually supported by very little evidence, if any (I will here limit myself to a rapid philological survey, for a more detailed analysis see Michon, 2018a). Michel Serres was obviously projecting posterior concepts on Democritus' atomism. "The cataract," "the waterfall," the "*clinamen*," and the "vortex" were borrowed from Lucretius (c. 99 BC-c. 55 BC) and applied to older atomist doctrine. Theoretically speaking, this was naturally not a problem and Serres was legitimate in elaborating these concepts as he wished. But philologically, he was clearly mistaken and this came at a certain theoretical cost. All those terms were posterior even to Epicurus

(341-270 BC) and probably dated back to the end of the 3rd century BC.

> The declination or *clinamen* is a term not found in any of Epicurus' texts that have been preserved to us. Everything leads us to believe that this term was forged and introduced by the successors of Epicurus in their polemics against the Stoic Chrysippus (ca. 280-ca. 206 BC) on destiny and liberty. (Dumont, 1991, p. 887, my trans.)

Moreover, in all the texts presenting the atomist *dînos* or *dínê*, the term *rhuthmós* was utterly absent. Diogenes Laërtius (3rd cent. AD), for instance, recalled the role played by the cosmic whirl in Leucippus' and Democritus' physics, but he never used the term *rhuthmós* to name it.

> The worlds are formed when atoms fall into the void and are entangled with one another *[καὶ ἀλλήλοις περιπλεκομένων – kaì allêlois periplekoménôn]*; and from their motion as they increase in bulk arises the substance of the stars. […] In a given section many atoms of all manner of shapes are carried from the unlimited into the vast empty space. These collect together and form a single vortex *[δίνην ἀπεργάζεσθαι μίαν – dínên apergázesthai mían]*, in which they jostle against each other and, circling round in every possible way, separate off, by like atoms joining like. And, the atoms being so numerous that they can no longer revolve in equilibrium, the light ones pass into the empty space outside, as if they were being winnowed; the remainder keep together and, becoming entangled, go on their circuit together, and form a primary spherical system. (*Lives of Eminent Philosophers. Leucippus*, 9.6-31, trans. R.D. Hicks)

The same observation could be made concerning most of the texts presenting or alluding to the atomistic primordial *dînos*: Aristotle (384-322 BC), *Physics*, 2, 4, 196a; Epicurus, (341-270 BC), *Letter to Pythocles*, quoted by Diogenes Laërtius, *Lives*, 10, 88-90 ; Diodorus Siculus (1st cent. BC), *Bibliotheca historica*, I, 7 ; Aetius of Antioch (1st or 2nd cent. AD), *Opinions of the Philosophers*, 1, 4, 1-4; Sextus Empiricus (ca. 160-ca. 210 AD), *Against the Mathematicians*, 9, 113; Hippolytus of Rome (170-235 AD), *Refutation of All Heresies*, 1, 12; Simplicius (ca. 490-ca. 560). Among Latin writers, in his *De rerum natura*, 5, 621 *sq.*, Lucretius (99 BC-ca. 55 BC) naturally referred many times to *turbinatio* but never linked it with rhythm or *numerus* either.

A fundamental reason why Serres was here misled is that the coming-to-be of the atomic clusters that constituted the existing cosmic bodies as the earth, the moon or the sun, were said, both by Leucippus and Democritus, to be resulting indeed of enormous rotating movements, whirls or vortices. But most of the smaller bodies were just clumping of atoms occurring by chance after shocks, disorderly bouncing and movements spreading in all directions.

This was quite clear in Aristotle's accounts of Democritus' physics. The atoms "act and suffer action wherever they chance to be in contact." Consequently, all things "are generated by their interlocking and bouncing in all directions."

> The "many" move in the void (for there is a void): and by coming together they produce "coming-to-be," while by separating they produce "passing-away." Moreover, they act and suffer action wherever they chance to be in contact (for there they are not "one"), and they generate by being put together and becoming intertwined. (*On Generation and Corruption*, I, 8, 325a, trans. H. H. Joachim)

> The primary masses, according to them [Leucippus and Democritus], are infinite in number and indivisible in mass: one cannot turn into many nor many into one; and all things are generated by [their interlocking and bouncing in all directions] *[συμπλοκῇ καὶ περιπλέξει – sumplokêi kaì peripléxei]*. (*On the Heavens*, 3.4, 303a, trans. J.L. Stocks, my mod.)

Dionysius of Alexandria (190-265 AD), who as a committed Christian criticized the Atomists but did not lack accuracy, reported their belief that

> these atoms, as they are borne along casually in the void, and clash all fortuitously against each other in an unregulated whirl, and become commingled one with another in a multitude of forms, enter into combination with each other, and thus gradually form this world and all objects in it. (Dionysius of Alexandria, *On Nature*, in Eusebius, *Praepar. Evangel*. 14, 23-27, trans. S.D.F. Salmond)

The stochastic nature of the atomic movements was also suggested by Simplicius' *Commentary on Aristotle's On the Heavens* (c. 490-c. 560 AD) which explained that

> in the unlimited void the atoms, separated from each other and differing in size, position, and order, move in a vacuum and, after meeting each other, collide with one another, bounce in the direction in which chance launches them, while the others agglutinate according to the congruence of figures, magnitudes, positions and orders, and remain together to complete in this way the generation of compounds. (Simplicius, *Commentary on Aristotle's On the Heavens* 242.15, my trans.)

As far as the Atomists' *dînos* was concerned, all available evidence thus supported Benveniste's view and not Serres'. But this was the same with the texts referring to the notion of *rhuthmós* in which that of *dînos* never appeared.

In *Metaphysics*, Aristotle made it clear that *rhuthmós* meant shape in Leucippus as well as in Democritus. He even criticized the atomists for not paying enough attention to motion. This was evidently untrue and related with his polemic against their conception of motion devoid both of prime mover and final cause. In any event, the Democritean *rhuthmós* did not appear as a vortex. Aristotle explicitly equated it with *skhêmá*, as that of a letter: "Rhythm *[ῥυσμὸς – rhuthmós]* means shape *[σχῆμά – skhêmá] […]* e.g. A differs from N in shape *[σχήματι – skhêmati]*." (*Metaphysics*, 1.4, 985b, trans. Hugh Tredennick, my mod.)

In *On Generation and Corruption*, Aristotle repeated the same idea. For Leucippus and Democritus, the atoms

> differ from another according to their "shapes" *[μορφάς – morphás]* and the compounds they form to "the elements which constitute them"—hence to their variable shapes—their "positions" and "groupings." (*On Generation and Corruption*, I, 1, 314a, trans. H. H. Joachim, my mod.)

However, further down, while discussing Democritus' conception of "coming-to-be," "alteration," and "passing-away," Aristotle referred to the atoms by using directly the term "figures" *(skhêmata)*, as if their figure or shape was one of their most essential features. (I, 1, 315b) Whence a very simple fact: in *On*

Generation and Corruption, the terms *morphê* or *skhêmá* were clearly used instead of what was called *rhuthmós* in *Metaphysics*. Since the atoms were hard and unbreakable entities, their shape could not change. Therefore *rhuthmós* meant here, without a shadow of a doubt, *fixed form*, *shape* or *figure*. Besides, the same kind of use equating *rhuthmós* with *skhêmá* was found in his famous psychological essay *On the Soul*.

> The spherical atoms are identified with soul because atoms of that [rhythm – shape] *[τοὺς τοιούτους ῥυσμοὺς – tous toioútous rhusmoùs]* are most adapted to permeate everywhere, and to set all the others moving by being themselves in movement. (*On the Soul*, 1, 2, 404a 1, trans. J.A. Smith, my mod.)

Thus, this second series of evidence confirmed once again Benveniste's interpretation and contradicted Serres'. In the Atomists, just as the *dînos* was not called a *rhuthmós,* the *rhuthmós* was never termed a *dînos*, a whirl, but a shape.

There was however something in Serres' misplaced critique that remained enlightening because it hinted at an important point in the older Atomist doctrine—precisely that one which Benveniste had been the first to reveal.

There were indeed a few good reasons to believe that *rhuthmós* was also used to denote the *changing forms*, *shapes or figures* of the *atomic compounds* themselves. In these cases, the term was probably employed according to the common pre-Platonic meaning of "impermanent form" and—but this is only a guess—maybe sometimes philosophically "remotivated"—as Saussurean linguists would say—according to the etymological structure of the word as "way of flowing," if we retain Benveniste's suggestion concerning the morphology of the word as composed of *rhein* (flow) + *–thmos* (manner or way of).

As a matter of fact, a list of Democritus' works preserved by Diogenes Laërtius (3rd cent. AD) showed that Democritus wrote a book entitled *Περὶ τῶν διαφερόντων ῥυσμῶν – Perì tôn diapheróntôn rhusmôn – Of the Different Rhythms (of Atoms)*, which was consistent with the use of *rhuthmós* as shape, but that he also wrote another book entitled *Περὶ ἀμειψιρυσμιῶν – Perì ameipsirusmiôn – Of Changes of (Atomic) Rhythms*, which implied, since the atoms could not change shape, that *rhuthmós* was used as changing form of the compounds they constituted. Hence the Greek grammarian Hesychius of Alexandria (5th or 6th cent. AD) noted in his *Lexicon*: "*Ameipsirusmeîn* (Democritus) : [concerning] the compound, to change [rhythm] or form." (p. 110, my trans.) In this particular case, Jean-Paul Dumont noticed,

> the term *ῥυθμός [rhuthmós]* can hardly designate, as Diels and Liddell and Scott claim, the *form* or *figure (σχῆμά [skhêmá])*, notably because the atoms cannot change form, as it was supposed by the following title. In this last text, the figure is not that of the atoms, but that of the compound. (Dumont, 1991, p. 885, my trans.)

To tell the truth, there are few philological evidence that *rhuthmós* was used to designate the changing shapes of the atomic compounds—another one was yet given by Theophrastus (ca. 371-ca. 287 BC), the successor of Aristotle as head master of the Peripatetic School (see Michon, 2018b)—but such kind of use was quite likely for theoretical reasons too. Since all atomistic doctrines considered that the countless bodies populating the universe were undergoing constant changes concerning their matter as well as their form, the essentially changeable nature of their atomistic compounds must have triggered the elaboration of a new concept of form.

According to Simplicius of Cilicia (ca. 490-ca. 560 AD), who probably quoted directly from Aristotle's lost monograph *On Democritus*, in Democritus' physics the atomic compounds took shape by the gathering of clusters of "resembling" atoms, "for by nature like is moved by like, and things of the same kind move toward one another, and each of the shapes produces a different condition when arranged in a different combination." (Simplicius, *Commentary on Aristotle's Physics*, 28.4-26) As already mentioned above, in another treaty, he also explained that

> in the unlimited void the atoms, separated from each other and differing in size, position, and order, move in a vacuum and, after meeting each other, collide with one another, bounce in the direction in which chance launches them, while the others agglutinate according to the congruence of figures, magnitudes, positions and orders, and remain together to complete in this way the generation of compounds. (Simplicius, *Commentary on Aristotle's On the Heavens* 242.15, my trans.)

The agglutination of these resembling atoms was brought about through their "weaving together" that "Abderites, such as Democritus, called 'interlocking.'" Then they hold together "up to the time when some stronger force reaches their environment and shakes them and scatters them apart." (Simplicius, *Commentary on Aristotle's On the Heavens*, 303a7, and 295.1-22, trans. I. Mueller – trans. J. Barnes)

Therefore we can readily agree with Pierre Sauvanet's conclusion.

> Leucippus and Democritus provide to rhythm its very first conceptual meaning as "rhythm" of atoms. But it is clear that we must not mean by this their fall, their deviation, in short, their movement, but their design, their structure, in a word, their *schema*, and even more precisely not the schema of the atoms themselves but that of their compounds. Rhythm is the form taken by atoms in ephemeral conjunction. The rhythm of atomists is the instantaneous schema of the underlying structure of the world, through the incessant combination of atoms of matter. (Sauvanet, 1999, pp. 43-44, my trans.)

In the pre-Platonic atomistic world forms did exist, individualized entities did last for a certain period of time, but they were essentially changeable, transitory, fluent. Accordingly *rhuthmós* was probably a key concept in this worldview. Direct evidence favorable to this hypothesis was scarce but acceptable; but there was plenty of indirect evidence which made it more than plausible. In any case, contrary to Serres' claim, it was not a whirl nor a vortex. Such concepts seemed to be posterior by at least a century.

As far as we know, Leucippus and Democritus did not use the term *rhuthmós* to name the primordial *dînos*, nor the term *dînos* to refer to the generation processes of the bodies populating. Except for the larger cosmic bodies, like the moon, the sun and the earth, those were brought about by stochastic encounters, bouncing and agglutination of atoms. However, there were sufficient evidence to legitimately think that *rhuthmós* was then used to refer to the impermanent yet consistent forms of the atomic compounds that had formed through these processes—an maybe to the specific manner of these very processes.

Rhuthmic Mathematics

This lack of interest and understanding for Benveniste's work was quite unfortunate. It severed Serres from an important resource that could have helped him to address the issues he was otherwise so luminously discussing.

Nevertheless, his reflection remains enlightening, rhythmologically speaking. As a matter of fact, although he could not see clearly the real relationship between the first Atomists and their followers, he uncovered two important aspects of Greek science that before his research were, if not entirely ignored, at least largely underestimated: the genuine power of the ancient mathematics to develop infinitesimal calculus and the central significance of the hydraulic model for physics. Since both innovations allowed to overcome some limitations of former arithmetic and geometry and get beyond those of physics due to the primacy of statics and Pythagorean mathematics, both have produced the conditions for a significant transformation of the notion of *rhuthmos* into that of *dinos*.

According to Serres, the Greeks opened, much before it has been commonly admitted, the path that would lead to the infinitesimal calculus. In the 5th century BC, some thinkers, Democritus (ca. 460-ca. 370 BC) and maybe others, already realized that it was possible "to construct or perceive the first possible angle, or the smallest that may be formed, so that nothing can be inserted between the two lines which open," by considering a curve and its tangent. This subtle idea resulted in a bunch of revolutionary discoveries that fecundated Greek mathematics up to Archimedes (287-212 BC), that were eventually to be lost but that we can reconstruct from some sufficiently convincing pieces of evidence.

> If we are calculating with shapes or rectilinear solids we only need, in general, ordinary mathematics. If, on the contrary, we square or cube curved elements, we must at least switch to a differential proto-calculus. And thus to Democritus. He left two lost books on irrational lines and solids [...] we know, from a reference in Plutarch and by a section of Archimedes' *Method*, that Democritus provided solutions for the volume of a cone or a cylinder, or for that of their sections, and doubtless more generally for that of a solid of revolution. Heiberg and Philippson think, correctly, that he achieved this by integration. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 10, same idea p. 101)

This "integral pre-method," which for the first time "raised the question of the infinitesimal" (p. 101), was called "exhaustion." It was a well-known calculus method that was usually attributed to Archimedes but for which, Serres claimed, we actually should credit Democritus as well. Serres presented its general features for two and three dimensions problems, while emphasizing its dynamic aspect.

> Let us return to exhaustion. Imagine a square inscribed in a circle. It does not fill it, by any means. It leaves empty places, like hollows outside the fullness of its angles. It leaves empty places. An imprint inscribed in the circle, and that does not describe it faithfully. Let us increase the number of sides, this operation absorbs the voids and fills their emptiness. The imprint little by little, begins to take up the outline, by closer and closer approximation. As the number increases, the two schema tend towards the same shape. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 102)
>
> If he [Democritus] knew how to integrate the volume of a conic section, or of a cone from that of a cylinder and in relation to that of the pyramid, it is no doubt because, before the great Syracusean [Archimedes], he had conceived the idea of exhaustion: to fill a curve with a polygonal outline, a circle with a square turned myriagon, a cone with a pyramid that has an increasing number of faces. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 102)

Then Serres convincingly emphasized the philosophical consequences of this new "pre-method." This proto-integral-calculus and the theory of irrational numbers that accompanied it had probably been the mathematical basis for Democritus' atomistic ontology and therefore, I shall add, of his theory of form.

> It is reasonable to suppose, as do Heiberg and Tannéry, that the theory of irrational numbers served him as a springboard to atomic interpretation. In both cases, it is a question of divisibility and indivisibility. In both cases, the last division recedes beyond our reach. [...] This [the volume of a solid of revolution] presupposes a differential division, and so once again an atomist interpretation. [...] It is inevitable that the first integrator should take things to be formed of a crowd of subliminal atoms. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 10)

He even credited Democritus for having anticipated Lucretius' concepts of *clinamen* and *simulacra*.

> Through his approach to irrational numbers and introduction of the infinitesimal, Democritus the mathematician produces the conditions of atomism, its instruments and its objects alike; through the question of the minimum angle in contact with the circle and the sphere, he brings out declination, tangency and contingency; through the volume of solids and the pre-method of integration, he makes the theory of simulacra quantifiable and plausible. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 103)

The second major contribution Serres was referring to is that of Archimedes of Syracuse (287-212 BC). We do not know if Democritus was already capable to address, based on his lost works on differential calculus, the complex mathematical problems raised by fluid mechanics or hydraulics that ensued from his atomic ontology. But, Serres argued, we have strong evidence that Archimedes produced all necessary concepts to that end and therefore was, maybe for the first time, able to fully mathematize the Democritean atomic model (Serres, 2000, p. 11-12).

> To mathematize the model successfully, I therefore need: 1. A mathematical or arithmetic theory of element. 2. A geometrical theory of tangent. 3. A geometry of forms of revolution. 4. A theory of spirals. 5. An infinitesimal calculus. 6. A mechanics of equilibrium. 7. A hydrostatics. Now, as if miraculously, this list of requisites corresponds exactly to a very well-known catalogue of works [those of Archimedes]. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, p. 12)

Archimedes provided during the 3rd century BC a theory of numerical increase with his *Sand-Reckoner*, a theory of spirals already integrating tangents and differential calculus with the book *On Spirals*, a theory of deviation and a theory of equilibrium with *On Plane Equilibriums*, a theory of forms of revolution with the two treatises *On Conoids and Spheroids*, and *On the Sphere and Cylinder*, and a theory of hydrostatics with his essay *On Floating Bodies*.

> Nothing is missing, now, for the mathematization of the model. It is furnished with a geometry, with a theory of numeration and numbers, with an analysis of series and large populations, with an axiom of the infinite, with a metrics and a refined description of the forms of revolution (in general conic), of spirals or vortices, of the agitated profile of the flow, with a statics and a hydrostatics of the declining angle. And its disciplines, taken together, are not disparate: they are focused, like the model itself, on a global theory of deviation. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, pp. 23-24)

To conclude his comments on this matter, Serres underlined both the novelty of Archimedes' thought, compared to the more famous Plato and Euclid, and consequently of his own views concerning the history of the mathematization of physics.

> Archimedes is the Euclid of the Epicurean world. […] Everything is there, nothing is lacking, the inventory is complete. Atom-grains in the infinite void, the minimal of differential angle of the vortex produced, and the deviation from equilibrium in the fluid medium. […] It begins with Democritus, and the edifice is completed, crowned, by Archimedes. A mathematical physics, close to the world and proven, in fact existed among the Greeks, who were not supposed to have one. (*The Birth of Physics*, 1977, trans. Jack Hawkes, 2000, pp. 24-25)

One could add that this mathematization of Democritean physics entailed also, most probably, the mathematization of one of the atomist concepts in which we are most interested: that of *rhuthmós* as an "impermanent form" or possibly a "way of flowing." Let us see how we can, thanks to Serres' contribution, give credit to this conjecture.

Next chapter