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Ruggiero Boscovich's Theory of Natural Philosophy

Points, Distances, Determinations

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To my father
and to the memory of my mother

. . . We could not see without inventing what we saw, so at least we could try to do it properly. And then, because she shrugged dismissively and said: Why? Why should we try, why not just take the world as it is? I told her . . . that we had to try because the alternative wasn't blankness—it only meant that if we didn't try ourselves, we would never be free of other people's inventions—Amitav Ghosh, The Shadow Lines

Acknowledgments

This book is the result of 10 years of research, during which I was generously supported by several institutions. I wish to thank the Astronomical Observatory of Brera in Milan, where I started working in 2005 as an editor and collaborator at the Commission for the National Edition of Ruggiero Boscovich's Works and Correspondence. The former directors of the Observatory, Tommaso Maccacaro and Giovanni Pareschi, together with Elio Antonello, the president of the Italian Society of Archeoastronomy, provided optimal conditions for me to work and strongly endorsed the project of the Boscovich Edition. Edoardo Proverbio, without whose efforts such a project could never have been initiated, was, for me, a mentor in the Boscovich studies and a guide in organizing the editorial work. I am in debt to the Department of Physics of the University of Pavia, which funded the study of Boscovich's early works in natural philosophy in 2012–2014 and made possible their publication as vol. 6 of the Boscovich Edition, as well as to the Department of Philosophy of the University of Milan, which, since 2015, has supported my intensive exchange activity and my frequent stays at other research institutions. The Berlin-Brandenburg Academy of Sciences and Humanities hosted me in the fall of 2018 for a research project on Leibniz and Boscovich, funded by the Deutscher Akademischer Austauschdienst (DAAD): I owe a debt of gratitude to both for having made a significant portion of this book possible. Incidentally, the DAAD also granted me a fellowship in the spring of 2008 at the Research Institute of the Deutsches Museum in Munich to investigate Boscovich's sources and his place in early-modern European science. In both places, I met invaluable researchers to whom I address my sincere thanks, in particular, to Ivo Schneider in Munich, a mentor in the history of science who taught me how much the development of mathematics has shaped and still shapes our culture and why it is worthwhile to be aware of this fact—and to Eberhard Knobloch and Harald Siebert in Berlin, who carefully read and commented upon chapters of this book; their generous advice on the history of astronomy, as well as on the Leibnizian science, rescued me from numerous blunders.

Over the years, I discussed many parts of this work—mostly when I did not know that I was, in fact, writing a book—with colleagues and friends. Their contributions in shaping my own views through suggestions and criticisms are so profound and deep-wired in these pages that it is difficult for me to single them out. I only hope that I have not forgetten anybody: Ugo Baldini, Claudio Bartocci, Fabio Bevilacqua, Fabrizio Bonoli, Andrea Del Centina, Paolo Casini, Vincenzo de Risi, Stefano Di Bella, Steffen Ducheyne, Vincenzo Fano, Rivka Feldhay, Alessandra Fiocca, Antonella Foligno, Lucio Fregonese, Giulio Giorello, Pietro Gori, Pierluigi Graziani, Niccolò Guicciardini, Roberto Lalli, Henrique Leitão, Ivan Malara, Alessandro Manara, Ivica Martinović, Gianfranco Mormino, Elio Nenci, Matthias Schemmel, Corrado Sinigaglia, Josip Talanga, Tzu Chien Tho, Hans Ullmaier, Matteo Valleriani, and Ido Yavetz. I am indebted to all of them, in different manners and for different reasons. I am also grateful to two anonymous reviewers for their suggestions and feedback. And many thanks to Amitav Ghosh for allowing me to use a sentence from his inspiring novel *The Shadow Lines* in the epigraph.

* * *

From Boscovich's correspondence, it emerges that he had a difficult, fiery temper—unfortunately, this is the only aspect of his personality that I share. So, the greatest "thank you" is for my beloved Anna, who has not only been my first and most important aid in this peregrination, but also tolerates my worst Boscovichean intemperance.

* * *

I was in the midst of finishing this book when my mother got sick and died. Up to that moment, I never realized the extent to which and at what cost she and my father had influenced my own work—not in regard to having taught me what I should know, but by leaving me free to gain any knowledge I wished. This book is dedicated to them, as a sign of gratitude for having fostered my will to knowledge through their respect for liberty.

Introduction

The Man for Wisdom's Various Arts Renown'd

The intellectual portraits of Ruggiero Giuseppe Boscovich are at least as numerous as the media that portrays his features. Among the latter, the most famous is perhaps the painting by Robert E. Pine, which traces back to Boscovich's 1760 trip in England. However, if one types "Boscovich" into the search box of an Internet browser and selects "images," numerous pictures of him in many different poses and situations will surface. His sometimes round, at other times thin face is directed toward the viewer or appears in profile on modern stamps, banknotes, medals, and publications, as well as on bags and t-shirts.[1] In addition, many different spellings of Boscovich's name have been employed thus far. The most usual form in the English-speaking world (as well as in French) is Roger Joseph Boscovich, whereas in Croatia and the other Slavonic territories, his name is frequently written as Ruđer Josip Bošković, according to orthographic standards that trace back to the first half of the nineteenth century. Moreover, he was christened with the Latin version of his name, Rogerius Iosephus, and nicknamed Ruge within his family, as his sister Anica's letters confirm (for more details, see Boscovich 2012c, 1–2). I adopt here the spelling Ruggiero Giuseppe Boscovich, which reflects how he signed his own letters beyond the familiar circle.

This abundance of representations and identifications vividly epitomizes Boscovich's polytrophic personality. Born in 1711 in the independent Republic of

[1]In 2011, on two different occasions during the celebrations of Boscovich's tercentenary in Italy and Croatia, I was presented with bags—one from the University of Pavia and the other from the city of Dubrovnik—bearing Boscovich's portrait. Sometime later, during a conference, I saw a colleague wearing a t-shirt with Boscovich's face. I envied him a lot, but I must admit that I have a weakness for the mug that features a drawing of Boscovich's curve, which I received as one of the participants in the Boscovich Conference held at Pavia in September 2011. To the interested reader, another exemplar of a Boscovich mug can be seen (and used) at the Max Planck Institute for the History of Science in Berlin.

Ragusa on the Dalmatian coast (now Dubrovnik, Croatia), he began attending the Ragusinum, the Jesuit college in his city, during childhood. As one of its most talented pupils, at the age of 14, he was encouraged to go to Rome and pursue a career there as a Jesuit of the Roman College. In the citadel of Catholic orthodoxy, he received the typical training of the Society of Jesus, accomplishing each stage of the *Ratio Studiorum*. As a gifted young mathematician, he was appointed the chair of mathematics of the college in 1740–1741—thus becoming a successor of such regarded scholars as Clavius, Grienberger, Maelcote, and Gottignies. Contemporaries highly regarded and welcomed his mathematical and astronomical works, but his publication record extends well beyond mathematics, astronomy, and natural philosophy. It encompasses fields as diverse as geodesy, both practical and theoretical optics, meteorology, hydraulics, building engineering, gnomonics, and even the science of antiquity and poetry (most of all, didactic or occasional). In addition, he is also the author of an interesting travel journal that recounts his return trip from Constantinople to Rome through Eastern Europe.

His scientific vocation and the turbulent events of the mid-1700s factored into his frequent journeys throughout Europe. He routinely accepted—willingly and gratefully at certain times, out of necessity and due to force majeure at others—a variety of positions in different countries for limited periods. He preserved his post as the *professor matheseos* of the Roman College until 1763–1764, but during his 30 years of activity in Rome, he often traveled throughout Italy or abroad. In the early 1750s, he wandered throughout the Papal State, along with his confrere Christopher Maire, as a means to prepare for a new detailed geographical map commissioned by Pope Benedict XIV. Other travels, associated with various scientific interests or diplomatic tasks, included destinations such as Vienna (1757–1758), England and continental Europe (1760–1761), and Constantinople (1761–1762). The courts he visited in those circumstances often requested his expertise and advice on technical matters. Upon his return to Rome, the Senate of the Habsburg Milan appointed him professor of mathematics at the University of Pavia; he welcomed the new position and began his course of lecture in 1764, subsequently contributing, in the early 1770s, to the foundation of the Astronomical Observatory of Milan in Palazzo Brera, the seat of the Jesuits in the city.

Mala tempora currunt, however. In August–September 1772, as a consequence of the continuous fight between Boscovich and his confreres at the Brera Observatory, he was removed from his responsibilities as an astronomer, and resigned from the Pavia professorship some months later. He initially thought of going to Poland and visiting his native Ragusa. But ultimately—mostly due to the suppression of the Jesuit Order (1773), which rapidly extended from the European countries to the Papal State—some of his friends convinced him to go to France, where a post as the Director of Naval Optics of the French Navy was created for him. He returned to Italy in the mid-1780s to oversee the publication of his *Opera pertinentia ad opticam et astronomiam* (Bassano del Grappa: Remondini 1785); by this time, an agreement with the Habsburg administration, one that included bringing him back to Milan, seemed possible. His tasks might possibly have included cooperation with the astronomers of the now well-established observatory of Brera, who were charged with drawing a new map of Lombardy. However, his delicate health worsened soon after arriving there. He died on February 13, 1787, and was buried at the Church of Santa Maria Podone in Milan.[2]

* * *

My effort in this book is not for the purpose of bringing unity back to a wandering existence, nor making the intellectual life of its subject, which cut across a number of interests and disciplines, seem less nomadic. On the contrary, I believe that multiple, differing images of Boscovich are possible and that they are equally legitimate. The portrait I want to draw is that of "Boscovich the natural philosopher." Of course, this can be superimposed (and, in this study, *will* be superimposed) over other images of his activities, but it is also endowed with peculiarities that I hope will emerge on their own throughout the book.

The attempted portrayal, however, is only seemingly unambiguous. In fact, it requires that one at least approximately know what "natural philosophy" is. As remarked by Blair (2006, 365), in order to avoid appearing anachronistic, historians of science often use this phrase "as an umbrella term to designate the study of nature before it could easily be identified with what we call 'science' today." But this exact use involves some elusive degree of anachronism. As Blair continues, "'natural philosophy' (and its equivalents in different languages) was also an actor's category, a term commonly used throughout the early modern period and typically defined quite broadly as the study of natural bodies." It cannot simply be employed as an intemporal historical category, because it *was* a category on its own. It is, therefore, highly context dependent. Reacting against a possible unhistorical (as well as unphilosophical) adoption of this label, I agree with Schaffer (1980, 72) that "natural philosophy" cannot be taken as "a system of connected concepts and axioms with no definite associated form of practice," but should become a historical object itself and be understood as a form of (scientific) practice.

Of course, there is a simple and straightforward answer to the question "what is Boscovich's natural philosophy?" It is plainly all that which is contained in his fundamental book (1758, 1763) in this field, *Theoria philosophiae naturalis redacta ad unicam legem virium in natura existentium* (*A Theory of Natural Philosophy Reduced to a Single Law of the Forces Existing in Nature*). As a first approximation, this is almost tautologically true. We only have to single out its core and show its derivative concepts.

In a nutshell, the theory prescribes that every process in the world, beginning with those regarding the farthest stars down to those of the smallest particles, is an effect of a unique force that is repulsive at minute distances, attractive at large distances, and alternatively attractive and repulsive at intermediate scales. More exactly, bodies tend to move away from one another (repulsion) at very short distances, with a

[2]Two biographies of Boscovich are available to the English reader: Hill (1961) and Marković (1973, as part of the *Dictionary of Scientific Biography*). The comprehensive study by Marković (1968), in two volumes, is unfortunately only available in Croatian. Other two valuable biographical studies have appeared in Italian: Casini (1971) and Paoli (1988).

repulsive force that grows to infinity when the gap dividing them is infinitely small. However, they tend to move toward one another (attraction) when the interval involved is large enough (e.g., at planetary distances), so that it approximates Newton's gravitational law. Between these two extremes (infinitesimal distances—planetary distances), bodies alternatively approach and move away from one another depending only on the distances at which they are posed. Boscovich argued that, at distances greater than those characterizing the solar system, the force could become repulsive again, so that the stability of the system is ensured.

The idea of the curve was first introduced in a 1745 dissertation, *De viribus vivis* (*On the living forces*), in order to avoid the abrupt changes of velocity that were prompted, according to Boscovich, by the Cartesian treatment of collision. For Descartes and his devotees, Boscovich contends, velocity changes—hence motions—are generated through collisions. However, he observed that the Cartesian rules of impact allow for an immediate inversion of velocity in the instant of collision:

> Let us assume—as in (Fig. 1)—that two identical elastic spheres *AB*, *CD*, moving with equal velocities (which are expressed by the lines *AF*, *DO*, perpendicular to *AD*) collide in *E*. In the same instant of time when the points *C*, *B* of the diameters touch one another, they necessarily arrest their motion, while the diameters *BA*, *CD* end up in *Ea*, *Ed*, equal to one another. However, all the remaining particles except of the first ones, but including the last ones (*a* and *d*), keep on moving with always reducing speeds, until their velocity are entirely extinguished in *M* and *N*, now with changed form and shortened diameters. If the spheres would be soft, they will preserve this state; if they would be elastic, the individual particles will bump back with the same degree of velocity. Let us keep on drawing the perpendiculars *BG*, *aH*, *EI*, *dK*, *CL* up to the line *FO*, then the velocities of the points *A* and *D* will obviously be expressed through ordinates to *FO*, which ordinates will be equal to one another until *H* and *K*; then through ordinates to the endlessly decreasing lines *HM*, *KN*. But the velocities of the particles *B* and *C* . . . would totally be extinguished in an instant of time and [. . . they] would be at rest for all the continuous time *a* and *d* would take to reach *M* and *N*. So, those velocities are given through ordinates referred to the line *FO* until *I*; then in *I* every

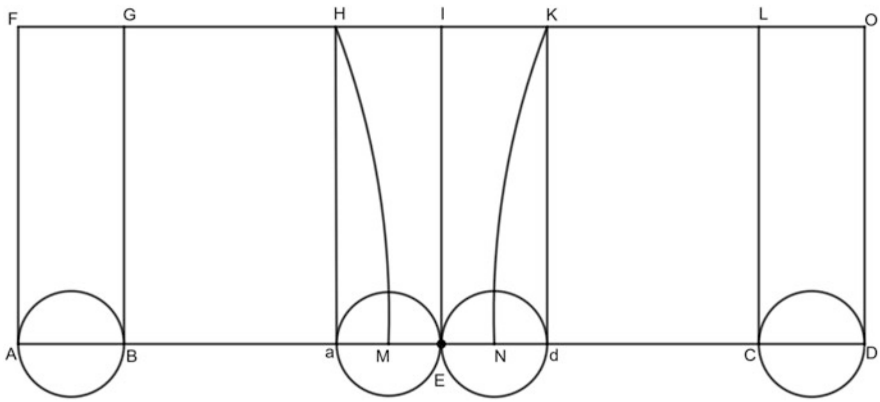

Fig. 1 Diagrammatical representation of the supposedly instantaneous annihilation of velocity according to Boscovich (Modern adaptation from Table I, Fig. 9, of Boscovich 1745)

expression by means of the ordinates breaks down, and the ordinate *EI* will be followed by a point. (Boscovich 1745, § 46)

In brief, if Descartes was right, then the velocities would abruptly be destroyed and immediately re-created at the instant of contact. But this was something that Boscovich was not willing to accept. On the contrary, he proclaimed that instantaneous changes in the state of motion of bodies should be avoided as contrary to nature, for "it is already widespread the judgement of many people, that in nature nothing happens by jump" [*Communis iam est multorum sententia, nihil in natura per saltum fieri*] (Boscovich 1745, § 45). Continuity of natural processes, Boscovich insinuates, must simply be assumed as real (as I shall remark in Chap. 5, this continuist position was a result of his strong commitment to the Aristotelian doctrine of continuity.) Conversely, there is a version of the Newtonian theory of distant forces that is able to preserve the continuity of processes: there should be a certain mechanism according to which bodies slow down when approaching one another and pass through all velocity degrees before stopping, changing, or inverting their directions. Such a mechanism was explained in terms of a repulsive force (determination) acting at a short distance and growing when the distance lessens:

Let us assume that no velocities can be extinguished in an instant of time. [In this case] the spheres do not keep on moving with uniform velocity until contact, but whenever particles *B* and *C* would arrive at a very little distance, some repulsive force will push them back endlessly, so that their velocities will gradually be extinguished before contact. By replacing rigid bodies with soft or elastic bodies, there will be no jumps in the velocities of particles *A* and *D*. But the jump in the velocities of particles *B* and *C* cannot be avoided, unless such repulsive force will be assumed at the smallest distances. (Boscovich 1745, § 47)

In the following 10 years or so, Boscovich would develop this early concept of a force law and enhance it with other elements, such as the investigation of matter composition, the law of continuity that he had used since 1745 as a heuristic principle, and the development of adequate mathematical tools. The final formulation of the law of forces would appear, in the abovementioned book of 1758/1763, in the form of an elegant diagram that vividly represents the most important features of the theory. These can be described in qualitative terms as follows: The curve expresses a force acting between two points, one at the origins of the axes in A and the other moving along the *x*-axis. With the distances plotted on the *x*-axis, the force intensity is represented on the *y*-axis. It is a continuous quantity that varies with distances: at each distance, there is only one possible force value (or magnitude or degree); if distance is only slightly varied, then force is also varied. In this sense, the force is a continuous function of the distance. Repulsion and attraction are not different forces, but rather different phenomenal manifestations of the same force. Looking at the graph (Fig. 2), force is repulsive when the curve is above the *x*-axis and attractive when it is under it. Moreover, it is infinitely repulsive when the distance is infinitely small (ED grows asymptotically), and infinitely small when the distance grows infinitely (more precisely, as explained in § 405 of *Theoria*, it is very small at planetary distances). In between, the force is alternatively repulsive and attractive, depending on distances, and, because force is conceived as a continuous

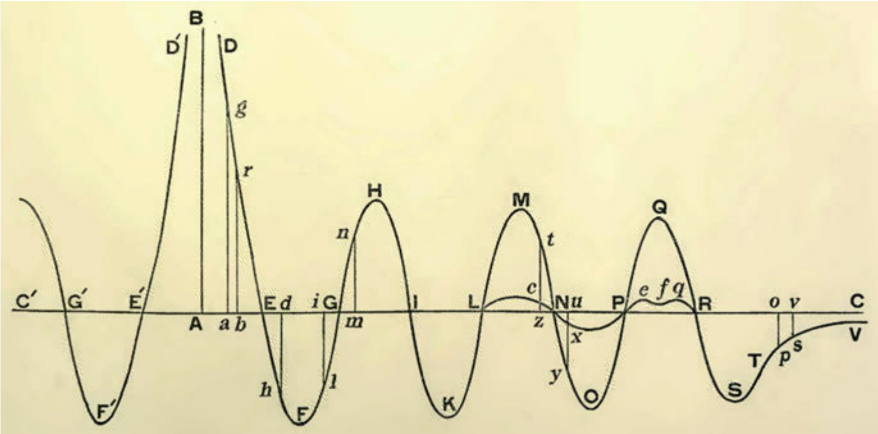

Fig. 2 Boscovich's curve. (From Ruggiero Giuseppe Boscovich, *A Theory of Natural Philosophy*, ed. by J.M. Child, New York: The Open Court, 1922). In truth, this is just a basic instantiation out of many possible shapes, as can easily be seen from the analytical expression of the force function that Boscovich published in one of the "Supplements" to the treatise (see *this book*, Sects. 4.3, 6.4, and 6.5)

function of x, there must be distances at which attraction turns into repulsion, and *vice versa*.

Determining the distances at which force inverts its "sign" or "direction" is a matter of experimental physics: as Boscovich already emphasized in one of his early works, finding the points at which inversions occur (i.e., the points at which the curve cuts the axis) is an empirical problem "to be investigated from the phenomena" (Boscovich 1745, § 56). Yet, he never proposed or performed any experiments, nor did he develop quantitative methods to prove his theory. Ultimately, an analytic solution complemented the graph of the curve: as we shall see in Chap. 6, this was a convoluted ratio between two polynomials, with an undetermined number of parameters.

By these means, Boscovich maintained, all natural phenomena are described: gravitation on the largest scale; the impenetrability of matter at infinitesimal distances (so that no actual contact takes place); cohesion as a balance between attraction and repulsion in the shortest range; "fermentation" (i.e., broadly speaking, chemical processes involving a transformation of one substance into another through the release of air from solids or liquids), and electricity and magnetism in the intermediate range, where both repulsive and attractive behaviors manifest themselves.

* * *

This is, roughly speaking, the kernel of Boscovich's book *Theoria philosophiae naturalis*. But, of course, his natural philosophy as a whole cannot be reduced to this—in the same sense that, for example, Newton's natural philosophy cannot be reduced to the Law of Universal Gravitation. In fact, most reconstructions of

Boscovich's natural philosophy so far have insisted that its main feature was a certain tendency toward unification. After all, the second part of the title of Boscovich's book on natural philosophy, with its emphasis on a "single law of forces," seems to announce that the author's intention was to provide a *unified* theory of forces. Accordingly, many discussions of Boscovich's theory have emphasized that, at the midpoint of the eighteenth century, researchers had available a crowd of forces associated with their carriers. Boscovich explicitly intended to unify that variety of interactions by gathering them into a single law that, in the end, associated every force with a definite interval between point-like particles. A plurality of forces; a unified framework.

Indeed, this image of Boscovich's natural philosophy was codified in the late nineteenth century as an effect of achievements made in physics. It was the theory of field developed by Faraday and Maxwell that unified diverse phenomena, which had up to then been viewed as distinct effects of different forces, into a single framework. The theoretical field conception, sanctified by Heinrich Hertz's 1888 experiments, primarily applied to electricity, magnetism, and optics—but their champions allowed for speculation that further extensions were possible. In light of this, they took Boscovich as their precursor toward unification. They interpreted his "points of matter" as point atoms or, more radically, as force centers; finally, Boscovich's force—like "an atmosphere ... grouped around" a mere mathematical point, as Faraday (1844, 290) put it—would be the ultimate reality, and no less than the ancestor of the almighty, all-embracing field. From this point on, Boscovich's natural philosophy has been interpreted, virtually with no exceptions, as a forerunner of the theory of field, force as a physical entity unto itself, and his points of matter as point atoms or force centers.

However, if one reads Boscovich's own presentation of his theory carefully, such an interpretation does not seem very accurate, to say the least. Let us examine an example of such a presentation:

> I ... admit that any two points of matter are subject to a determination to approach one another at some distances, and in an equal degree recede from one another at other distances. This determination I call force; in the first case attractive, in the second case repulsive; this term does not denote the mode of action, but the determination itself, whatever it comes from, of which the magnitude changes as the distances are changed. This determination follows a certain law, which can be exposed through a geometrical curve or an algebraic formula, and represented to the eyes, as it is usual to the scholars of Mechanics. (Boscovich 1763, § 9)[3]

[3]"*Censeo ... bina quaecunque materiae puncta determinari asque in aliis distantiis ad mutuum accessum, in aliis ad recessum mutuum, quam ipsam determinationem appello vim, in priore casu attractivam, in posteriore repulsivam, eo nomine non agendi modum, sed ipsam determinationem exprimens, undecunque proveniat, cujus vero magnitude mutatis distantiis mutetur et ipsa secundum certam legem quandam, quae per geometricam lineam curvam, vel algebraicam formulam exponi possit, et oculis ipsis, uti moris est apud Mechanicos repraesentari.*" Quotations from Boscovich's *Theoria* are mainly taken from J.M. Child's Latin-English edition (and are referred to as Boscovich 1763); some changes might have been introduced in the translations. In all other cases, translations are my own, unless they are otherwise noted. Quotations from

I will postpone a more detailed commentary of this and other passages, as well as a discussion of Faraday's contention about Boscovich and his theory, until subsequent chapters (see, in particular, Sect. 3.4.2). Here, I only want to remark that Boscovich is not saying that, in nature, there are many qualitatively different forces that are going to be unified by means of his single law or curve. If we take his statement at face value, as historians (and also philosophers, hopefully) are supposed to do, he is, rather, stating that every *couple* of *points* (and not every *individual* point, as Faraday's image of an atmosphere surrounding each point suggests) is subject to *one* mutual force—and always the same force—which would be better called a *determination*, that is, a measure of the propensity to perform a certain motion, irrespective of its cause (I will explain this notion in Chap. 2). This determination has two opposite expressions: two points can mutually be determined to approach one another (in which case, as Boscovich claimed, we call it a force of attraction) or they can mutually be determined to separate (in which case we call it a force of repulsion). The quality of the forces involved—chemical, magnetic, electric, gravitational, etc.—does not play any role, to the extent that it is not even mentioned, and to the extent that Boscovich added that the term force "does not denote the mode of action." Indeed, we are told that the only thing that matters is the *distance* between points: the determination of approaching or separating not only generically depends on distances; it is a function of the distance; its "magnitude changes as the distances change," according to a certain law that can be visualized by means of a curve, whose graph represents how force intensity varies over distances.

In view of this, it seems to me that a discussion of Boscovich's conception should not start with presupposing force unification as a reaction to a previous force proliferation, and should also avoid starting with the presumption that such a conception is a forerunner of whatever theory has later appeared (which does not mean, of course, that it had no effect on later developments in physics or other fields).[4] On the contrary, I think that a more adequate image of Boscovich's natural

Boscovich's works refer to the relevant paragraphs, introduced by the sign §. Where this sign is not present, the numbers are meant to refer to the relevant pages.

[4]So, the view expressed in this book is at odds with the now widespread tendency to read the *Theoria philosophiae naturalis* while taking on the background modern conceptions of matter constitution. This kind of modernizing reading is instantiated in the entry "Ruđer Bošković" of the *Hrvatska enciklopedija* ("Croatian Encyclopedia," vol. II, Zagreb: Leksikografski zavod Miroslav Krleža, 2000, 270–272), which has made available in English on the occasion of the Croatian celebrations for the 300th anniversary of Boscovich's birth. One of the most interesting (and, to me, astonishing) passages reads as follows: "A single law of forces existing in nature (lat. *lex unica virium in natura existentium*), i.e. the idea that one law can explain all of reality, constitutes Bošković's main contribution to science. The same idea has been entertained by A. Einstein, W. Heisenberg and more contemporary scientists, but the four forces in nature (gravitational, electromagnetic, weak and strong nuclear energy forces) have yet to be described by a unified theory. Bošković's single law is a framework for a unified theory of fields or, even more so, for a Theory of Everything." Other attempts within this approach have been more cautious. For example, cosmologist John Barrow (2007, first published in 1991) has presented Boscovich's theory as the first serious effort to attain unification of the fundamental forces governing nature, but not necessarily in the sense of a TOE. In addition, Ullmaier (2005) has offered a comprehensive and

philosophy should include an effort to explain how these three elements—*points* of matter, *distances* between points, and the *determinations* that arise from them—could possibly provide an efficient basis for it, at what cost, and with what consequences. This book, titled according to such a triptych, represents this kind of effort.

* * *

In another respect, this discussion of Boscovich's natural philosophy is different from the presentations made so far. Some of them are invaluable contributions to the history of science, but they offer an example of natural philosophy conceived as a *system of connected concepts and axioms*, to pick up Schaffer's phrase. They tend to consider natural philosophy as a stable form that can be filled in with changeable content: in the end, all of the natural philosophers do the same thing; they only disagree on how to do it. They can have different ideas regarding forces, matter, and their interactions, but the kind of connections among these concepts does not change.

For example, we learn from Mary Hesse's influential book *Forces and Fields* that Boscovich's theory of force as a continuous function of the distance between two points

> may be criticised on grounds of being *ad hoc*, but Boscovich was misled by his data rather than his method. Considering the confused state of the theory of matter and of chemical interaction at the time Boscovich wrote, it was not to be hoped that the details of his theory would survive, but his method was in the tradition of mathematical physics, leading from Newton to the present time, indeed the method of deriving a force-function *ad hoc* from the phenomena is very similar to that used at present in postulating short-range nuclear forces. (Hesse 1961, 165)

One could even imagine that, had he only known all of that which we now know about the structure of matter, he surely could have improved the content of his theory, because the method was sound. Indeed, he actually did what we are currently doing, that is, what we have always done in practicing physics—what else? It is, of course, of minor importance, for example, what Boscovich's institutional role was (if any), in which intellectual and material environment he was educated, with whom he shared ideas (and with whom he did not), or according to which criteria he presented his results, data, or conjectures. After all, theories are impersonal; once they are articulated, they live on as their own, as a crystal-clear texture of logical interrelations.

In this book, I will avoid this kind of Platonism. Beginning with Fleck's pioneering study *Entstehung und Entwicklung einer wissenschaftlichen Tatsache* (1935), it has been abandoned in practically all fields of the integrated history and philosophy of science, not to mention disciplines like social epistemology, the sociology of science, cultural and material studies, etc. So, I do not feel any need

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valuable overview of the analogies and differences between Boscovich's insights and modern theories of matter.

to justify my dismissal, even if there are some pockets of resistance. As regards the Boscovich studies, I simply suggest turning things upside down: not to consider his natural philosophy as a system of *concepts*, but as a scientific *practice*—more precisely, as a result of a web of practices. So, the starting point (and, to some extent, the most important point) of this book will not be concepts, but the practice in which Boscovich was educated and to which he was supposed to contribute as the *professor matheseos* of the Roman College, the citadel of Jesuit orthodoxy: namely, mathematics. I will argue that Boscovich's theory was the outcome of a peculiar epistemic attitude that was deeply rooted in his mathematical education—and I will use the phrase "agnostic neutralism" or similar expressions to label this attitude.

Chapter 1 analyzes the mathematical tradition in which Boscovich grew up—the tradition of Cristophorus Clavius. It discusses the emergence and development, within the Roman College, of the so-called *physico-mathesis*, a noticeable propensity of the seventeenth- and eighteenth-century mathematicians to expand the scope and methods of their discipline and colonize physics. It emphasizes that the peculiarity of the Jesuit *physico-mathesis*, together with the obligation for the Order to defend a geostatic and geocentric cosmology (which remained in effect until 1757), drove the mathematicians of the Roman College to support geostatic-geocentric systems that were mathematically compatible with that of Copernicus. It argues that a persistent trait of Boscovich's epistemology, i.e., a certain *agnosticism* about the true intentions of God as the "Author of Nature" and a corresponding *neutralism* regarding the variety of physical interpretations that we can give to a mathematical law, is essentially based on this kind of compatibilism, to which he contributed in an original manner. (Sometimes, I will refer to Boscovich's approach as a *physico-mathematical style*, hinting at "his" mathematical tradition.)

Chapter 2 contends that Boscovich's agnostic-neutral perspective, along with its mathematical background, was instrumental in the development of his concept of force and guided him toward the formulation of the curve of forces. I argue that there is a strong relation between his agnosticism-neutralism and his considering forces as "mathematical determinations," as can be understood from a close examination of the early writings of mechanics, in which both inertia and external forces are defined in those terms. A comparison of the early texts with later works, such as the 1745 dissertation *De viribus vivis* and the 1758/1763 *Theoria*, in which those definitions are repeated, suggests that the notion of determination was the most important element in Boscovich's epistemology of force.

It is a reasonable expectation that different epistemic attitudes, possibly stemming from different practices, may also result in different conceptual constellations—even if superficial analogies can emerge from a sea of diversity and stand out as dominant features. Chapter 3 contrasts Boscovich's conception of force with other coeval and apparently similar approaches. He often emphasized that he was inspired by the originally Newtonian insight that, at certain distances, an inversion in the direction of force takes place, so that attraction turns into repulsion. In fact, this idea can easily be found in the final Query to the *Opticks* and, as often pointed out by historians, it was developed in the first half of the eighteenth century by "Newtonianizing" British physicists like Stephen Hales, John Theophilus Desaguliers, Gowin Knight, and John Michell. They are usually labeled as "dynamical corpuscularists" (e.g., by Schofield 1970), and it has often been claimed that their theories are an anticipation of Boscovich's. More precisely, the latter's natural philosophy would be none other than a variety of a "dynamical theory of matter" based on Newton's notion of active principle. I will discuss this view and argue that, once Boscovich's physico-mathematical style is taken into consideration, things are not as linear as they seem *prima facie* and I will advance a different framework for understanding the relationship between Boscovich and this group of British "Newtonians." This picture might also help reframe a couple of questions about his alleged influences. So, in the final section, I will discuss the two "vexed questions" of how his natural philosophy would be influenced by Leibniz's concept of force and how it might have influenced Faraday's idea of field.

To the present portrait of Boscovich as a natural philosopher, Chap. 4 adds strokes different in kind and coming from a different source. Based on his correspondence, I emphasize, and provide documentary evidence for, the influence of the Aristotelian tradition in the theory of matter involved in his conception of force. Several studies have investigated the role and the many nuances of Aristotelianism within the Society of Jesus (see, e.g., Crombie 1975, Dear 1987, Feldhay 1987, Baldini 1992b and 1998, Simmons 1999, Feingold 2003). To a mathematician trained in the Jesuit tradition, Aristotle surely had something important to offer: the analysis of continuum. I contend that Boscovich's notion of material point (or point of matter) as the elementary constituent of bodies—a typical *non*-Aristotelian doctrine—was the combined effect of his mathematical interests and the *Aristotelian* treatment of potential infinity as the outcome of an iterated operation of dividing a continuous quantity. This also provides the background for Boscovich's concept of mass and his conception of the material world as an aggregate of aggregates of different orders of size.

The problem of continuity in Boscovich's theory is specifically addressed in the subsequent Chap. 5. It has often been emphasized that he explicitly took continuity as a "metaphysical assumption" (see, e.g., Martinović 1987; Čuljak 1998, 2008; Talanga's Introduction to Boscovich 2001; Heilbron 2015)—a principle that he expressed with reference to Leibniz's law of continuity in order to justify the curve of forces. I will discuss how the role of continuity has changed and gradually acquired importance in the development of Boscovich's natural philosophy. In particular, starting with Aristotelian premises, he arrived at formulating a principle of continuity that introduced and reinterpreted elements from Leibniz's doctrines. However, in this process of adoption and adaption, a substantial role was played by a particular aspect of Boscovich's mathematical practice, namely, the use of geometric diagrams. (The title of the chapter takes inspiration from Leibniz's statement in the *Theodicy* about the "two famous labyrinths," the one concerning freedom and necessity and "the other consist[ing] in the discussion of continuity.")

Chapter 6 argues that the explicit articulation of the concept of continuity that found expression in *De continuitatis lege* (1754), together with the exploration of its mathematical underpinnings taking place in coeval works on conic sections, curves, and the philosophy of mathematics, guided Boscovich to the final refinement of the law of forces and to his search for its analytical formula. Here, I will pay particular attention to the mathematical constraints of the curve of forces and comment on the six fundamental conditions that, according to him, the formula is supposed to satisfy. Finally, I will give a global assessment of his natural philosophy in light of such strong mathematical commitment.

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