All the planets are related to the Sun. Riccioli and his “spiralized” skies

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Abstract: Planets describe orbits in the fluid heavens in Giovanni Battista Riccioli’s masterpiece. Many astronomers had explained the motion of planets by composing the motions of the First Motor and the skies below. However, a separate First Motor is a pointless hypothesis: even if it had different material nature, its motion would share the same celestial rules with planets. What astronomers needed was a conventional geometrical explanation for heavenly bodies. Riccioli searches for a celestial geometry that is able to describe the complexity of the planetary orbits. For this purpose, his three assumptions are: 1) all the planets are in strong relation with the Sun, thus this relation has to be quantified; 2) the determination of the solar parallax, that is the most important element in understanding celestial orbits (*inuictissimum argumētum à parallaxibus*), would be fundamental in describing the geometrical law of planets, albeit extremely difficult to obtain; 3) the quantification of the apparent planetary magnitude and its real variation cannot be explained through the topic of nature and substance of the skies. Based on these assumptions, Riccioli searches for the geometry of planetary motion, that he does not find directly in the eccentrics-epicycles doctrine. He uses a variable oscillation of the eccentric center and of the diameter of the epicycle, called epicepicycle model (*epicepicyclos*), that allows for planets to move on spiral orbits.

Keywords: Riccioli, planetary orbits, epicycle model.

1. Introduction

Giovanni Battista Riccioli (1598-1671) is known as the astronomer who invented a semitychonian system, a milestone in the transition age between Galileo and Newton. Riccioli’s “semi-geocentric” system, as he himself describes it in *Almagestum Novum* (1651), features an unmovable Earth at the center of the world; Mercury, Venus, and Mars swivel around the Sun, which in turn revolves around the Earth. Jupiter and Saturn, in turn, are in orbit around the Earth. Mars has similar motion both in comparison with Venus and Mercury, and with Saturn and Jupiter (though its motion is slightly similar to that of Venus and Mercury).

Riccioli does not hide the many philosophical issues that such system implies: the nature of celestial bodies, the nature of skies and the trajectories that cross them, the physical cause of the revolutions and the theological dimension of these same problems are some of the themes addressed in book nine of *Almagestum novum* (especially *sectio* II, cap. II) (Marcacci 2018b). In *sectio* I of book IX, Riccioli investigates the nature of the visible sky and wonders whether the sky is pure body, an entity made of matter-form, or both at the same time. His aim is that of investigating the visible sky, not the unobservable Empyrean. The planetary skies are fluid, while the Eighth Sphere's sky is made of frozen water. *Stellis comatis* are particularly essential in indicating the corruptibility of the skies. However, in its entirety, the sky is incorruptible. Therefore, what is its nature? Riccioli solves the issue in an original manner: the visible skies are "*ab intrinseco corruptibiles, extrinseco incorruptibiles*". In *sectio II* of book IX, he wonders what is it that gives skies their movement. Of course, the complex geometry of celestial motions makes believing in Angels as the cause and regulators of said motions quite implausible; the real reasons, he implies, will probably never be completely understood.

2. Only one law for the heavens

If that was the question from a philosophical point of view, Riccioli also insists on explaining celestial mechanisms from a geometrical point of view. He is aware of the fact that many astronomers explained the sky's motions by adding the movement of the *Primum Mobile* to the skies below. However, a separate *Primum Mobile* would be a pointless hypothesis: even if it had different material nature, its motion would share the same celestial rules as planets:

> It is more likely that there is no body similar to what we conceive as the *Primum Mobile* and that there are not two simultaneous movements of the stars towards opposite regions of the world, but – instead – only one movement West-wards through helicoidal spirals.[1]

The same rules and one law alone, that of the helicoidal spirals, are the general rules underlying all celestial motions. Thus, what astronomers need is a conventional geometrical explanation for heavenly bodies (*Almagestum Novum* VII, *sectio* I, cap. VIII). What instruments (*instrumenta*) can astronomers use to devise a single law for the skies? Some astronomers use concentric circles; others use eccentrics, other epicycles. All hypotheses consider observational data: undoubtedly, however, concentric orbits as described by homocentrists do not offer a definite explanation regarding what actually happens in the heavens. Riccioli is very critical of and radically rejects homocentrism. For his geometry of planetary motion, his reference points are Kepler and Bullialdus. Elliptical orbits are a novelty that Riccioli studies and understands very well. He analyses Keplerian data in painstaking detail. However, the Jesuit prefers to apply other types of geometry to the skies: neither made of perfect circles, nor ellipses. Neither

[1] "TERTIA CONCLUSIO. Probabilius est non dari corpus ullum, quod sit Primum Mobile, nec duos motus in stellis simul factos ad oppositas Mundi plagas, sed unicum versùs Occidentem per spiras helicoides, Fixarum quidem in caelo solido, Planetarum autem in fluido. Primi autem Mobilis vicem praestare tempus intelligibile, seu ideam diurni motûs menti cuiusuis Intelligentiae motricis infusam" (Riccioli 1651, p. 260).

does he find the solution in the classic eccentrics-epicycles doctrine. He uses a variable oscillation of the eccentric center and the diameter of the epicycle, and consequently deduces that planets move in spiral orbits. The astronomer writes:

> Planets' motions are not made for concentric circles in the center of the world but for eccentric or circular circles, or equivalent to eccentric.[2]

Riccioli uses something similar to the epicycle doctrine, but the focal point is that his circles are just instruments aimed at obtaining spirals, and his "rings" are not perfect circles revolving around a central point, but rather eccentric loops oscillating along a line. An explanation of this will be given below. But first, let us illustrate the assumptions that act as basis of the geometrical reasoning:

1. All the planets are in substantial relation to the Sun, and this relation has to be quantified. Riccioli is well aware this is not a novelty. The connection with the Sun had always been studied and quantified in the past as the "second inequality", precisely the appearance according to which planets seem to have a retrograde motion and go backwards (Evans 1998, p. 337). Both the Earth-to-planet and Sun-to-planet distance is necessary to determine the real place of the Planet:

> Once the distance of the Sun from the Earth has been acquired, the distances of the other planets become known, since they have no minor connection with the sun, but their motion with the motion of the Sun. In fact, the true equations of the movements and the positions of the planets cannot be deduced except assuming a different distance of those from the Sun and the Earth.[3]

The point of reference equals 7327 terrestrial semi-diameters, a figure obtained by combining the diurnal parallax, calculating distances during the eclipses and considering the lunar parallax. In Riccioli's world-system, 7327 terrestrial semi-diameters is the exact median distance between Mercury and Venus, since this is the sum of the eccentric circle's radius and the distance from the center of the eccentric circle to the Earth, the center of the world.

The distance is also useful in determining the proportions between planetary distances. Riccioli recognizes the third keplerian law (the proportion between the square of the orbital period and the cube of the semi-major axis of its orbit). Even though he criticizes Kepler's *Mysterion*, he still accepts its proportions and harmonies.

[2] "Planetarum motus non fiunt per circulos concentricos mundi centro, sed per Excentricos circulos aut quasi circulos, aut per Excentricis aequivalentes" (Riccioli 1651, p. 253).

[3] "Acquisitâ autem variâ Solis distantiâ à Terra, notae fiunt distantiae reliquorum Planetarum, quia non minorem habent connexionem cum Solis distantia, quàm motus eorum cum motu Solis […] non possunt enim æquationes congruae motibus veris ac locis Planetarum obseruatis deduci, nisi supponendo in illorum hypothesi diversam distantiam à Sole & a Terra" (Riccioli 1651, p. 252).

2. The determination of the solar parallax, which is the most important asset in understanding celestial orbits (*inuictissimum argumētum à parallaxibus*), would be fundamental for describing the geometrical law of the planets, although this is very difficult to obtain. For this reason, we often have to use substitutive proof: for example, the lunar parallax.
3. The quantification of the apparent planetary magnitude and its real variation cannot be explained by analyzing the nature and substance of skies (for example, the fact that they are filled with substances such as vapors, or that their density differs in the various regions of the sky). This argument is inconsistent, since the variation of the planets' apparent magnitude depends on their different distances from Earth.

3. The Epicepicyclos method

Riccioli considers his method an extension of the ancient hypotheses. He names it "*per circulos Eccentricos, aut etiam Eccētrepicyclos, vel Epicepicyclos*" (Riccioli 1651, p. 681). In a word, *epicepicyclos* (Marcacci 2018a). Some important remarks:

1. The best figure one can use in the analyses of the planetary motion is not a straight line, circle, pentagon, hexagon or ellipse. The ellipse, as in Kepler's and Bullialdus' systems, does have some advantages, but also some useless complications. Kepler and Bullialdus decide to resort to the ellipse after splitting eccentricity in half, but with great effort and without achieving excellent results.
2. It is humanly preferable to reduce irregular motions to regular ones, and preferably around a center.
3. The apse line is conducted through the center of the Earth in the geocentric hypothesis.
4. The second inequality must be measured taking into account the real motion of the Sun rather than its average motion.
5. Eccentricity has to be varied. This method, in a way, is similar to the Keplerian approach, but according to Riccioli it is more exact and practical, it being identical to the classical approach astronomers were accustomed to.
6. If one prefers not to change eccentricity, then the semi-diameter of the epicycle must vary.

The aforementioned method is also similar to what Ptolemy and Regiomontanus implied a system with mobile eccentric. In Riccioli, the eccentric does not only move: it even changes (*Almagestum Novum* VII, section I, cap. V; VII, section II, cap. VI). Kepler is undoubtedly more present in Riccioli's mind than Ptolemy. The Jesuit uses eccentricity and the eccentric point moves along a line that defines the distance between Earth and the Sun. Kepler, too, had reasoned upon orbital eccentricity; however, he employed what Riccioli called "maximum eccentricity", rather than average eccentricity (that would have been more correct). In the following image, the line that includes all possible values of eccentricity is Bz:

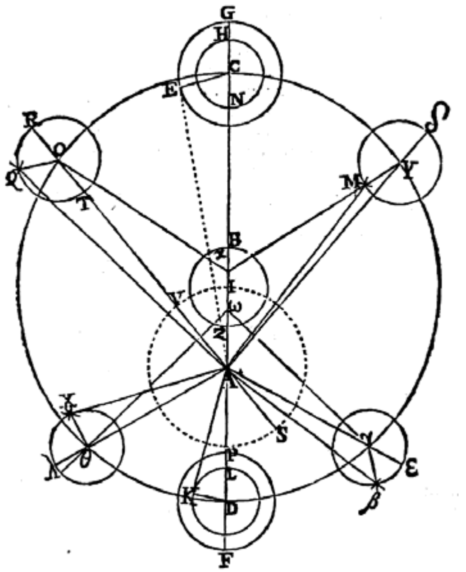

Fig. 1. Maximum eccentricity (Riccioli 1651, p. 538).

Of course, some astronomers, like Copernicus, Amici or Fracastoro, knew how to use two circular motions to obtain a linear one. Riccioli could have been inspired by these techniques. A suggestion could also have come from Peuerbach, who Riccioli read through other commentators.

So, he considers the case where the motion of the epicycle of the planet in H travels on a oval-like (*quasi-ovalem*) trajectory. Riccioli tries to minimize the use of circles to ensure that the spirals are the principal figure in his astronomy. Let's dive deeper into the subject.

Giving a detailed and thorough explanation of each passage in Riccioli's method is beyond the scope of this paper. Rather, we'll focus on a section of the image, with a superior planet in position Q and the center of the epicycle in O. The center of the eccentric is in x. AI is the average eccentricity. CxO is the average anomaly of the eccentric and the OAC angle is the real anomaly of the eccentric (*locum verum*, *anomalia coequata*). The small circle with its center in I (*circellus* – its diameter being Bz), is the line that contains the oscillation of the eccentric.

When the center of the epicycle is in C, the center of the eccentric is the apogee of the *circellus* in B, so we have AB as the maximum eccentricity. When the epicycle goes to point O, then the center of the eccentric is in I, and we thus have average eccentricity (AI). When the epicycle is in D, then the eccentric will be in its perigee (z) and the eccentricity will have the minimum value (AZ).

In this way, Riccioli wants to explain the first inequality, that is the variation of speed along the trajectory (Evans 1998, p. 340). By varying the eccentric, Riccioli is also able to "obtain" the spirals. By changing the epicycles, Riccioli captures the variability of the spirals (*spirae varietatem*) and by employing this variability, he is capable of justifying the second inequality, namely the planets' retrograde motion in the form of a bow. Apogee and perigee of the epicycle have to have a maximum and minimum value, included between CE and DK.

Riccioli describes how to calculate the different values for the eccentricities and then to derive the position of a planet (Riccioli 1651, pp. 537-539).

4. Conclusion

Step by step, the planet describes a portion of a curve that is very likely an ellipse. The final result could of course be a spiral and a variable spiral. Riccioli could have imagined something like curves on an ellipsoid, with the latter formed by the oscillation of the planetary orbit. He was convinced his geometry gave the best results for the description of the real planetary orbits, and did not believe a circle was the best figure for describing planets, but rather just the best instrument with a secondary role: indeed, the geometry of the circle is very well known and easily used, and even if the circles do not exist in heaven they are useful to obtain spirals. There is a single movement, somewhat of a single "law", for all the planets. The center of the eccentric changes for Venus, Mercury, and Mars and for Moon, Jupiter and Saturn, for "likeness" reasons. Lastly, the single movement takes the form of spirals.

Not needing a First Mover, the existence of a single rule to describe all celestial movements and the use of a geometry specifically designed for its system: these are some of the most characteristic features in Riccioli's astronomy, an original theory capable of explaining the data he acquired through the telescope. The Jesuit scientist was a rigorous example of astronomy in the latter's shift between ancient and new traditions, an invaluable resource in understanding how complex the birth of modern science really was.

References

Evans J. (1998). *The History and Practice of Ancient Astronomy*. New York-Oxford: Oxford University Press.

Marcacci F. (2018a). *Cieli in contraddizione. Giovanni Battista Riccioli e il terzo sistema del mondo*. Perugia: Aguaplano.

Marcacci F. (2018b). "Natura e moto dei cieli visibili secondo Giovanni Battista Riccioli. Analisi di *Almagestum Novum*, vol. II, lib. IX, sect. I e II". *Rivista di filosofia neoscolastica*, 110 (1-2), pp. 301-321.

Riccioli G.B. (1651). *Almagestum novum astronomiam veterem novamque complectens*. Bononiæ: ex Typographia hæredis Victorij Benatij.