

GALILEO AND KEPLER ON THE SUN AS PLANETARY MOVER

Wilbur Applebaum and Renzo Baldasso

Copernicus's leading champions in the early seventeenth century were concerned not only to establish the centrality of the Sun, but also to give it a role in the movements of the planets. Johannes Kepler's ideas on a rotating Sun as planetary mover and his insistence on the creation of a physical astronomy are well known. Less well understood, and commonly misunderstood, is the development of Galileo's ideas on the causes of the celestial motions, in which the rotating Sun also played a significant part. One assumption has been that, having abandoned impetus and the search for causes in his creation of a fruitful kinematics for terrestrial bodies, Galileo likewise abandoned the search for causes in the heavens. Noel Swerdlow in a recent work, for example, holds that Galileo did not "search for the physical principles governing the motions of the heavens as Kepler and later Newton did".¹ If what is meant by "physical principles" is what we now think of as forces or mathematical "laws", this is certainly true. Stillman Drake contended that "Galileo did not speculate about celestial physics as did Kepler".² If what is meant by "celestial physics" is the absence in Galileo's writings of speculation concerning a *means* by which the Sun moves the planets, this too is true.

It has been held by some, however, that Galileo's concept of "circular inertia", in the absence of resistance on the surface of the earth, was carried

¹ Swerdlow, N. M., "Galileo's discoveries with the telescope and their evidence for the Copernican theory", in Machamer, P. (ed.), *The Cambridge companion to Galileo*, University of Cambridge Press, Cambridge, 1998), 244-270, p. 244.

² Drake, S., *Galileo* (Past Masters Series) Hill and Wang, New York, 1980, 42.

over to the heavens, so that no mover was required to move the planets.³ Evidence for this position may also be thought to have been found in Galileo's discussion of a Platonic cosmogony in the early part of the First Day of his *Dialogue concerning the two chief world systems—Ptolemaic and Copernican* and in his *Two new sciences* of 1638, where no mover of the planets in their orbits seems to have been required.⁴ It is the thesis of this paper that in his search for proof of the heliocentric system Galileo did indeed speculate about a cause for motions of the planets. Fully aware of a long-standing tradition concerning the Sun's power to confer motion, Galileo's telescopic investigations of the Sun and the discovery and systematic observations of sunspots and their movements led him to conclude that the Sun rotates and thereby moves the planets.

The concept of the Sun as a source of motion in a general sense originated in Antiquity. Plato's *Timaeus* developed the pre-Socratic idea of a natural tendency of spheres, including the stars and "planets", including the Sun, to rotate.⁵ Subsequent Neoplatonic literature divinized the Sun, frequently cited it, although itself unmoved, as governor and regulator of the cosmos, and a source of light, heat, nourishment, and motion.⁶ Copernicus wrote that "the Sun as if seated on a royal throne governs his household of Stars as they circle around him".⁷ The Sun as a source of motion is found in pseudo-Dionysius the Areopagite, as well as in Marsilio Ficino, Patrizi, Telesio, Rheticus, Bruno, Gilbert, and Campanella, among others.⁸ Early in his career as a Copernican, Kepler held the Sun to be immobile, yet a source of motion.

³ Shea, W. R., *Galileo's intellectual revolution*, Macmillan, London, 1972), 139; Koyré, A., *La révolution astronomique*, Hermann, Paris, 1961, 468; Hall, A. R., *The revolution in science 1500-1750*, Longman, London and New York, 1983, 109; Cohen, I. B. *The birth of a new physics*, Doubleday, New York, 1985, 142; Aiton, E. J., *The vortex theory of planetary motions*, Science History Publications, New York, 1972, 20; Stillman Drake, however, did not share their opinion. See Drake, S., *Discoveries and opinions of Galileo*, Doubleday: Garden City, NY, 113-114 n. 8. The indexes to *Le opere di Galileo Galilei*, (ed.) Favaro, A., 20 vols., Barbèra, Florence, 1890-1909, hereafter cited as Galileo, *Opere*, only mention solar rotation in the entry for "Sunspots", but not in connection with planetary motion.

⁴ *Dialogue concerning the two chief world systems—Ptolemaic and Copernican*, trans. Stillman Drake, University of California Press, Berkeley and Los Angeles, 1953, hereafter cited as *Dialogue*, 21-22, 29 and *Two new sciences: Including centers of gravity and force of percussion*, trans. with introduction and notes by Stillman Drake, University of Wisconsin Press, Madison, 1974, hereafter cited as *Two new sciences*, 233.

⁵ Plato, *Timaeus*, 33B-34A, 40A,B.

⁶ Macrobius, in his *Commentary on the Dream of Scipio* referred to the Sun as the "regulator" of the other planets. Grant, E., *Planets, stars and orbs*, Cambridge University Press, Cambridge, 1994, 453. Similar ideas may be found in Pliny, Cleomedes, and Theon of Smyrna. See also Koyré, *op. cit.* [Note 3], 63 ff.

⁷ Copernicus, N., *On the revolutions of the heavenly spheres*, trans. A. M. Duncan, David & Charles, Newton Abbott, 1976, 50.

⁸ Galileo quoted from pseudo-Dionysius's *Of divine names* on the Sun's powers in a letter to Piero Dini in the spring of 1615 and in his letter to the Grand Duchess. Drake, S. *Galileo at work: His scientific biography*, University of Chicago Press, Chicago, 1978, 247 and

With the failure to observe parallaxes for the nova of 1572, the comet of 1577, and subsequent novae, the existence of celestial spheres was called into question. Since they naturally rotated and carried the planets, the dissolution of the celestial spheres required that other means be sought to account for the motions of the planets.⁹ Some, including Giordano Bruno, and Kepler initially, drew on ancient traditions of internal movers of the celestial bodies. Noting that, in the absence of celestial spheres, Copernicus's third motion of the Earth was unnecessary, Bruno began to speculate on alternative causes of the Earth's rotation.¹⁰ In his *La cena de le ceneri* of 1584 he put forward the concept of the Sun's rotation and the rotations of the planets as caused by internal movers.¹¹ After studying cosmological theories in Germany, he proposed in his *De immenso* of 1591 that the twinkling of the stars was the result of their rotation and, since our Sun is a star, it too rotates, its light moving the planets and causing the rotation of the Earth.¹² He further explained that the light of the Sun is emitted by periodic solar contractions, like those of the heart, a conception likewise with Platonic roots.¹³ Although the impact of his cosmological treatises on the astronomical community remains to be determined, it is certain not only that Bruno's novel and anti-Aristotelian views were widely known, but also that his statements on solar rotation found echoes in Kepler and Galileo.

Edmund Bruce, a Scot travelling in Italy, in a letter to Kepler on 5 November 1603, put forward some ideas based on Bruno's cosmology. He

Drake, S., *Discoveries and opinions of Galileo* [Note 3], 213; Ficino wrote in his *Liber de sole* that the Sun "nourishes all things and is the universal generator and mover." *Marsilii Ficini Florentini... Opera*, Petrina, Basel, [1576], I, 966. Reticus held that the Sun "may be said to be the source of motion and light." *Narratio prima*, in *Three Copernican treatises*, trans. with introduction and notes by Edward Rosen, Dover, New York, 1959, 107-196, p. 146. For Telesio, see Ingegno, A., "The New Philosophy of Nature", in Schmitt, C. B. *et al* (ed.), *Cambridge history of Renaissance philosophy*, Cambridge University Press, Cambridge, 1988, 236-263, p. 251. For Campanella as a Copernican, see Lerner, M-P., "Campanella et Copernic", in Delorme, S. *et al.* (ed.) *Avant, avec, après Copernic: La représentation de universe et ses conséquences épistémologiques*, Blanchard: Paris, 1975, 221, 223, 225. For Gilbert, see his *De magnete*, trans. P. Fleury Mottelay, Dover, New York, 1958, 345. For Kepler, see Kepler to Maestlin 3 October 1595, in Kepler, J. *Gesammelte Werke*, (ed.) Max Caspar *et al.*, 20 vols. in 22, Beck, Munich, 1937 - , XIII, 35, hereafter cited as Kepler, GW.

⁹ On the dissolution of the spheres, see Donahue, W., *The dissolution of the celestial spheres, 1595-1650*, Arno, New York, 1981. On the concept of a rotating Sun, see Lerner, M-P., "Sicut nodus in tabula": De la rotation propre du soleil au seizième siècle", *Journal for the history of astronomy* 11 (1980), Cambridge, 114-129.

¹⁰ There are several references in Bruno to the nova of 1572 and the comet of 1577. Ingegno, A., *op. cit.* [Note 8] 257.

¹¹ Bruno, G., *Opere Latina conscripta* (ed.) Fiorentino Tocco, 3 vols. in 8, Morano, Naples, 1884, vol. I, ii, pp. 2, 42, 44.

¹² *Ibid.*, I, pp. 191-398; ii, p. 45. Bruno was influenced by Ficino according to Ingegno, *op. cit.* [Note 8], p. 246.

¹³ Garin, E., *Astrology in the Renaissance: The Zodiac of life*, trans. Carolyn Jackson *et al.* Routledge, London, 1983 (1976), 12.

maintained that the Sun, at the center of the planetary orbits, turns on its axis and thereby drives the planets around in their orbits, the more distant more slowly than those closer to the Sun. The light of the stars, he went on, is due to their motion, not their matter. Several years later, on 5 April 1610, Kepler commented that he had forgotten this letter, but marveled that it truly summarizes his celestial physics as found in his *Astronomia nova*.¹⁴ Neither Kepler nor Galileo accepted Bruno's ideas on the infinity of the universe. While no works by Bruno were to be found in Galileo's library, when Galileo arrived in Padua, he frequently used the library of Cosimo Pinelli, who was very much interested in Bruno's philosophy.¹⁵ Kepler, unlike Galileo, referred to Bruno in his work and correspondence and chided Galileo for failing to mention Bruno in his work.¹⁶

Kepler and Galileo had first become aware of each other, and began a correspondence after Galileo received two copies of Kepler's *Mysterium cosmographicum* in 1597. Galileo's response on 4 August of that year indicated his interest in the work and expressed his own Copernican sentiments.¹⁷ Before the development of his more mature celestial mechanics, Kepler's *Mysterium* included a possible role for the Sun in moving the planets.¹⁸ Galileo's interest in Kepler's first book, beyond its preface, which is all he had read before he quickly wrote a letter of thanks to Kepler, is reflected in the "Platonic" cosmogonies proposed in his *Dialogue* and the *Two new sciences*. Galileo does not refer to Kepler in these passages, but his debt to Kepler is seen in a manuscript in which he used data on planetary distances and speeds provided in chapter 21 of Kepler's book. Galileo refers to his cosmogonical passages as based on Plato, but nowhere in the *Timaeus* is a description like Galileo's or Kepler's to be found.¹⁹ That may also have been behind the ambiguous reference by Edmund Bruce, then in

¹⁴ Kepler, GW, XIV, 450-51.

¹⁵ Yates, F. A., *Giordano Bruno and the Hermetic tradition*, University of Chicago Press, Chicago, 1964, 358-59, citing Antonio Favaro, *Galileo Galilei e lo studio di Padova*, Florence, 1883, 226.

¹⁶ Martin Hasdale to Galileo 15 April 1619. Galileo, *Opere*, X, 315; Kepler, GW, VI, 300-301. See also Kepler, J., *Dissertatio cum Nuncio Sidereo nuper ad mortales misso a Galileo Galilae*, Sedesanus, Prague, 1610, in Kepler, GW, IV, 308; also Kepler, J., *Kepler's conversation with Galileo's Sidereal Messenger*, trans. with introduction and notes by Edward Rosen, New York, Johnson Reprint, 1965, 22. For Kepler's knowledge of Bruno's ideas, see also Kepler, GW, IV, 289, 302, 304-305, 308-309, 317; VII, 43; XVI, 142.

¹⁷ Kepler, GW, XIII, 130-131.

¹⁸ Kepler, J., *Mysterium cosmographicum: The secret of the universe*, trans. A. M. Duncan, introduction and commentary by E. J. Aiton, preface by I. B. Cohen, Abaris, New York, 1981, 199, chs. 20-21.

¹⁹ Galileo, *Dialogue*, 20-21, 29; Galileo, *Opere*, VII, 44-45, 53ff.; Galileo, *Two new sciences*, 233. See Drake, S., "Galileo's 'Platonic' cosmogony and Kepler's *Prodromus*", *Journal for the history of astronomy* 4 (1973), Cambridge, 174-191. Mersenne and Gassendi also sought them in Plato, but couldn't find anything like Galileo's description. Sambursky, S., "Galileo's attempt at cosmogony", *Isis*, 53 (1962), 460-464, p. 463.

Padua, in a letter to Kepler, dated 21 August 1603, alleging that Galileo was lecturing on Kepler's ideas without acknowledgment.²⁰

According to Bruno, the pulsation of the Sun is analogous to the systole of the heart, which thereby provides vital spirit to the body's organs, and is the means by which the Sun emits light. That concept is also found in Kepler's *De stella nova* of 1606.²¹ Galileo was familiar with that work—he owned a copy—and he used Kepler's argument in it in reply to objections to Copernicus's stretching of the stellar sphere.²² Kepler, however, would substitute means other than Bruno's idea of the Sun's light as the planetary mover. In his *Astronomia nova* of 1609, he also dispensed with his earlier views concerning a solar soul or planetary souls. Still subscribing to the Aristotelian principle that everything that moves must have a mover, Kepler used the term *inertia*, by which he meant a tendency of bodies to remain at rest or come to rest in the absence of a mover or moving force. His celestial dynamics, therefore, proposed his rotating Sun with quasi-magnetic emissions acting like levers to move the planets non-uniformly in elliptical orbits. Galileo may not have read the entire work, although he had a copy, but the front of the book has a summary of each chapter, including chapter 34, where the hypothesis of a rotating Sun is set out.²³

Galileo's publication of his *Sidereus nuncius* in 1610 elicited a prompt response from Kepler in a letter to Galileo, to be published later that year as *Dissertatio cum Nuncio Sidereo*, which we may be sure was carefully perused by Galileo. There it could be read that “in the center of the world is the Sun, heart of the universe, font of light, source of heat, origin of life and cosmic motion.”²⁴ Furthermore, in another part of that work Kepler reminded Galileo that in his *Astronomia nova* he had written that “the font of the motion of the five planets to be in the Sun itself. It is very probable therefore that the font of the earth's motion is the same as the font of the motions of the rest of the five planets; namely, the Sun.”²⁵ In a letter to Galileo in January 1611, Kepler once again called Galileo's attention to his affirmation in the *Astronomia nova* that the Sun's rotation moved the Earth.²⁶

Shortly after the publication of his *Sidereus nuncius*, Galileo turned his telescope to the Sun, possibly in the hope of finding evidence in support of Copernicus and perhaps stimulated by Kepler's and Bruno's speculations

²⁰ Kepler, GW, XIV, 441.

²¹ *Ibid.*, I, 235.

²² Galileo, *Dialogue*, 269; Galileo, *Opere*, [Note 3], II, 280.

²³ Galileo's copy is listed in Favaro, A, “La libreria di Galileo Galilei descritta ed illustrata”, *Bulletino di bibliografia e di storia* 19 (1886), 219-293, p. 250. The likelihood of Galileo's having read at least the front matter of Kepler's book is seen in Galileo's notorious reference to Kepler's puerility in having the Moon as the cause of the tides. *Dialogue*, 462. The reference is to a passage in Kepler's Introduction to his *Astronomia nova*, Kepler, GW, III, 26.

²⁴ Kepler, J., *Kepler's conversation*, [Note 16], 42, 45.

²⁵ *Ibid.*, 42.

²⁶ Kepler, GW, XVI, 357.

and the tradition concerning the Sun's power. Early in April 1612, in the introduction to the first edition of his *Discourse on bodies in water*, after reviewing his telescopic discoveries, he announced his observation of certain dark spots seen on the solar body. By their changing positions on the Sun these spots suggested several options: the Sun may be rotating, or perhaps other celestial bodies like Mercury or Venus are revolving about it, or both alternatives are true. "The truth of these matters cannot be undervalued or dismissed".²⁷

In the second edition of the *Discourse*, published in the autumn of 1612, Galileo states that

at last, my repeated observations have made me certain that those spots are substances contiguous with the surface of the solar body, and that many are produced and then dissolved continuously, some lasting for very brief intervals of time, and others for longer times, and they are carried around by the rotation of the Sun on itself, completing its period in approximately one month, an occurrence in itself most great and important for its consequences.²⁸

Galileo also pointed out that the solar rotation was in the same direction as the revolutions of the planets.

To what extent was Galileo aware of Bruno's ideas on the rotating Sun? There is no reference to Bruno at all in anything Galileo published or in his manuscripts. Although they shared a belief in the revolution of the planets about the Sun, Bruno's ideas deviated in significant respects from those of Galileo and Copernicus. Bruno sought in Copernicus support for the metaphysical and religious beliefs on which his philosophy was based.²⁹ Although Bruno's condemnation does not seem to have been based on his Copernicanism, his Copernican beliefs were doubtlessly seen as heretical in a "broad sense". He was asked at his trial to abjure his belief in the motion of the Earth.³⁰ Although there can be no doubt that Galileo knew of Bruno's ideas, he must have felt that referring to Bruno in the climate of the day would not have been helpful for the promotion of Copernicanism or for his own safety.³¹

²⁷ Galileo, *Opere*, V, 287-88. Galileo was at the time unaware of the publication of Johann Fabricius's *De maculis in sole observatis et apparente earum cum sole conversione*, Wittenberg, 1611, which held that the spots were on the Sun's surface and that it was likely that the Sun rotated on its axis.

²⁸ Galileo, *Opere*, IV, 64. See also his letter of May 26, 1612 to Prince Cesi along similar lines, *Opere*, XI, 301-302, and to Maffeo Barberini on June 2 of that year, *Opere*, XI, 304-306. Kepler seems to have written to Galileo some time after 1613 on sunspots, but that letter has been lost. *Kepler's Conversation* [Note 16], 98, n. 180.

²⁹ McMullin, E., "Bruno and Copernicus," *Isis* 78 (1987), Washington, D.C., 55-74.

³⁰ Fantoli, A., *Galileo: For Copernicanism and for the Church*, trans. George V. Coyne, Vatican Observatory Publications, Vatican City, 1996 (1994), 45 n. 61, 244.

³¹ *Ibid.*, 35.

What had been speculation on the part of Bruno and Kepler about the role of the Sun in moving the planets, Galileo felt had been established by his discovery of the sunspots as a phenomenon of the solar surface. He wrote Benedetto Castelli in December 1613 that he had “revealed and necessarily demonstrated that the globe of the sun is turned on its [own] axis, making an entire revolution in about one lunar month in the same direction in which all the other celestial rotations take place”.³² He went on to say that if the Sun were halted by Joshua as in the Biblical account, the rotation of the earth would cease. In a subsequent letter to Dini in March 1615, Galileo reiterated these points, and also added answers to objections from Scripture referring to a mobile Sun.³³

In his famous letter to the Grand Duchess Christina, likely written in 1615, Galileo made the same points with some elaborations as he had in his letters to Castelli and Dini.

I think that although the solar body does not move from the same place, it turns on itself, completing an entire rotation in about one month, as I feel I have conclusively demonstrated in my *Sunspot Letters*; this motion is sensibly seen to be inclined southward in the upper part of the globe, and thus to tilt norward in the lower part, precisely in the same manner as the revolutions of all planetary orbs... insofar as it is the greatest minister of nature and, in a way, the heart and soul of the world, it transmits to the surrounding bodies not only light but also (by turning on itself) motion; thus, just as all motion of an animals limbs would cease if the motion of its heart were to cease, in the same way if the sun's rotation stopped then all planetary revolutions would also stop.³⁴

Stillman Drake insists that Galileo's arguments in the letters to Castelli, Dini, and the Grand Duchess, unlike Kepler's, were “purely logical” and “meant to show his adversaries on their own grounds they would be obliged to abandon literal interpretation” of the Bible.³⁵ Perhaps Drake, by

³² Galileo, *Opere*, V, 287-88. Trans. Stillman Drake, *Galileo at Work* [Note 8], 229. The Sun, like the heart in the middle of the body was a common theme in the Middle Ages. Grant, *op. cit.* [Note 6], 227-33; Garin, *Astrology* [Note 13], 11.

³³ *Opere*, V, 304-305. Nicole Oresme in the 14th century had also pointed out that “when the Sun stopped in Joshua's time, the entire heavens ceased moving.” *Le livre du ciel et du monde*, ed. Albert D. Menut and Alexandre J. Dony, trans. Albert D. Menut, University of Wisconsin Press, Madison, 1968, 375.

³⁴ Galileo, *Opere*, V, 345. Finocchiaro, M. A., *The Galileo affair: A documentary history*, University of California Press, Berkeley and Los Angeles, 1989, 116. John Wilkins, later to become a founding member of the royal Society of London, published a work of popular science, whose frontispiece depicted Copernicus, Galileo and Kepler under a shining Sun, which says “Omnibus Do lucem, calorem, motum”. Wilkins, J. *A discourse concerning a new world & another planet*, Maynard, London, 1640.

³⁵ See, for example, Drake, *Galileo at Work* [Note 8], 492 n. 16. This issue, among others, is addressed by Rossi, P. “Galileo e il libro del Salmi”, in *La scienza e la filosofia dei moderni*,”

stressing Galileo's Biblical hermeneutics, wished to indicate that at this point Galileo was not yet entirely convinced of the Sun as planetary mover, since he would not publish his opinion for many years. Galileo, however, certainly appears to be convinced of a physical relationship between the solar rotation and the revolution of the Earth and the other planets. Galileo also felt it important that observations of the sunspots showed that the Sun rotated uniformly in a lunar month; such a period would make it possible to explain the motion of the Moon around the Earth.³⁶ Moreover, in his letter to the Grand Duchess, Galileo chose not to limit his argument to the point made before his citation of his sunspot "evidence" about the weakness of a literal interpretation of the Bible.

Galileo did not publish on the idea of the Sun as planetary mover until additional evidence for it came to him shortly before the publication of his *Dialogue*. Francesco Sizzi's discovery of the variation in the course of a year in the inclination of the Sun's axis of rotation to the ecliptic came to Galileo's attention. Christopher Scheiner had also written about the phenomenon in his *Rosa Ursina* of 1630.³⁷ In the *Dialogue* Galileo elaborates on the role of the rotating Sun as planetary mover without raising any of the issues in Biblical interpretation in his letters written during the second decade of the century.³⁸

Galileo's supposed lack of interest in celestial dynamics is also contradicted by his discussion in the Fourth Day of his *Dialogue* on the tides as demonstrating the double motion of the Earth. His comments on the role of the Moon in the spring and neap tides, in particular, illustrates his interest in and concern with celestial dynamics. Galileo here speaks of a "force [*virtù*] which moves the earth and moon around the sun".³⁹ He goes on to say that the Earth and the Moon would move more rapidly when closer to the Sun than when farther. "From this it may be clear that the annual movement of the earth along the ecliptic is not uniform, and that its irregularity derives from the Moon and has its periods and restorations monthly".

Galileo's description of the motions of the Earth and Moon is certainly not how Kepler describes the non-uniform terrestrial motion, but what is of interest here is that up to that point only Kepler (and his very few followers) had been thinking of a solar *power* and non-uniform planetary motion. Did Galileo independently conceive of non-uniform motion of the earth in ignorance of Kepler's position or, rejecting Kepler's quasi-magnetic forces, did he see in the pendulum, which he cited by analogy, a mechanical and more rea-

Bollati Boringheri, Torino, 1989, 67-89, and Bucciantini, M., "Dopo il Sidereus Nuncius: Il Copernicanismo in Italia tra Galileo e Kepler", *Nuncius* 9 (1994), 15-35.

³⁶ Galileo, *Dialogue*, 345.

³⁷ Drake, S., "Sunspots, Sizzi, and Scheiner", in Drake, S., *Galileo studies: Personality, tradition and revolution*, University of Michigan Press, Ann Arbor, 1970, 177-199, p. 180.

³⁸ Galileo, *Dialogue*, 345ff., 462; Galileo, *Opere*, VII, 372.

³⁹ *Ibid.*, 453; Galileo, *Opere*, VIII, 477-478. Galileo also uses "magnetic force" as an analogy to explain why the Moon keeps only one face toward the Earth. *Dialogue*, 67.

sonable explanation for an increase in planetary speed with proximity to the sun, an idea which might be of service for his theory of the tides? In any case, Galileo could have read in Kepler's works the astronomer's conjecture about the Sun's power as the cause of each planet's variation in speed as a function of its changing distance from the Sun in the course of its orbit. Kepler had gone beyond the observations of the ancients that each planet's speed in its homocentric orbit is slower the farther it is from the Sun.

Why didn't Galileo address, as Kepler had, in his speculations, the means by which the Sun moves the planets? One may be convinced, as were Kepler and Galileo, that two distinct processes or sets of observations are related in some manner, and yet be unable to demonstrate convincingly that one is a consequence of the other. With regard to the relationship between a rotating Sun and planetary motion, Kepler was willing to speculate, while Galileo was not. The medieval theory of the emission of *species*, whose function was to excite or engender activity across an intervening space in a body with which they come in contact was initially used by Kepler to account for the role of the Sun in planetary motion. Kepler later, in his *Epitome of Copernican astronomy* (1618-1621), abandoned what he had called "immaterial species" for a corporeal force.⁴⁰ Neither concept would have suited Galileo, who did not speculate on the means by which the solar *virtù* accomplished the revolutions of the planets, as did Kepler. Kepler justified his speculations thus:

For since I have mingled celestial physics with astronomy in this work, no one should be surprised at a certain amount of conjecture. This is the nature of physics, of medicine, and of all the sciences which make use of other axioms besides the most certain evidence of the eyes.⁴¹

This was not for Galileo: "I think that in disputes about natural phenomena one must begin... with sensory experience and necessary demonstrations".⁴² He has Salviati expound on this in the *Dialogue*.

I did not say that the earth has neither an external nor an internal principle of moving circularly; I say that I do not know which of the two it has. My not knowing this does not have the power to remove it... that which makes the earth move is a thing similar to whatever moves Mars and Jupiter...

He just does not know the "motive power."⁴³ In the *Two new sciences*, in response to the same problem, Salviati urges his listeners to move away

⁴⁰ Kepler, *GW*, III, 34; VII, 299.

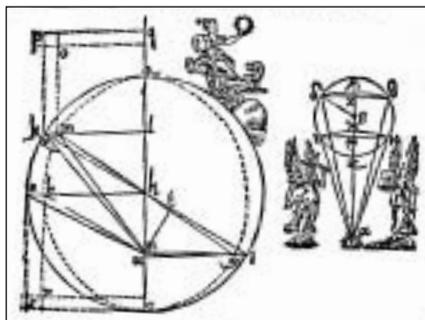
⁴¹ *Ibid.*, III, 19; Kepler, J., *New astronomy*, trans. W. H. Donahue, Cambridge University Press, Cambridge, 1992, 47.

⁴² From the letter to the Grand Duchess. Finocchiaro, M. A. *The Galileo affair* [Note 34], 116.

⁴³ Galileo, *Dialogue*, 234.

from “fantasies” involving causal hypotheses, and just investigate motion, whether in the heavens or on the earth, regardless of cause.⁴⁴

Nevertheless, Galileo, almost echoing Kepler on the proper goals of astronomy, distinguishes between the “mathematical astronomers” who assume “eccentrics, deferents, equants, epicycles and the like... in order to facilitate their calculations” and the “philosophical astronomers who, going beyond the demand that they somehow save the appearances, seek to investigate the true constitution of the universe—the most important and most admirable problem that there is.”⁴⁵ When Galileo wrote this in 1612, it had been Kepler above all who had advocated and practiced this new conception of the dual role of the astronomer. But we do not wish here to imply that it was from Kepler that Galileo took this at the time still novel goal for astronomy. For Galileo, now a committed and out-of-the-closet advocate of the centrality of the Sun, such a conclusion would have been a natural consequence of his Copernicanism.



⁴⁴ Galileo, *Two new sciences*, 159.

⁴⁵ *Letters on sunspots*, in Drake, S., *Discoveries and opinions*, [Note 3], 96-97; Galileo, *Opere* V, 102.