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"A TRUE AND EXACT DESCRIPTION OF THE SUN'S PALACE": CONSTRUCTING THE IMAGE OF THE SOLAR SYSTEM IN THE SEVENTEENTH AND EIGHTEENTH CENTURIES

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Abstract: The concept of a Solar System, a fundamental Copernican construct, started to gain a footing in the seventeenth century. Although the cosmological debates around the Copernican system are the subject of a vast literature, the role of images in firming the concept of the Copernican Solar System has received scant attention. This paper addresses the emergence and early development of Solar System maps and diagrams, focusing on images produced by Andreas Cellarius, Christiaan Huygens (especially), William Whiston, and James Ferguson between the mid-seventeenth century and the mid-eighteenth century that ultimately turned the Solar System into a cartographic object depicted to scale, in a manner akin to that of terrestrial maps. This paper also shows that while these images were originally produced with the aim of sustaining particular claims and arguments about Copernicanism, the plurality of inhabited worlds, and Newtonianism, they gained a life of their own, codifying a set of visual conventions that have been used to this day to represent the Solar System and its scale.

Keywords: Solar System; Cellarius; Huygens; Whiston; Ferguson; Copernicus; Newton; Plurality of Worlds; maps.

1 INTRODUCTION

"Our most fundamental relation to the gigantic is articulated in our relation to landscape, our immediate and lived relation to nature as it 'surrounds' us ... the gigantic becomes an explanation for the environment, a figure on the interface between the natural and the human." So writes Susan Stewart (1993: 71) in *On Longing …*, analyzing the interplay between the miniature and the gigantic and their broader cultural implications. But notions of 'gigantic' falter when we seek to apprehend the vastest landscape of all—that of the Universe. Today, large-scale models of portions of the Universe (usually the Solar System, but in some cases, beyond) have become popular extravaganzas, abiding at the intersection of science, education, public art, and tourism. The visual strategies these models use to show the landscape of the Universe involve scale and proportionality, and they have a long history. In this paper we argue that the development of such strategies can be seen in a variety of efforts to represent the landscape of the Universe, from the mid-seventeenth to the mid-eighteenth centuries, among which the pivotal example is found in the 1698 *Kosmotheoros …* of Christiaan Huygens. In these efforts various authors sought to convey through scale diagrams their specific ideas about the Universe, as well as data about the vast sizes and distances found within it.

Cosmological diagrams based on concentric circles representing the nested celestial spheres had a steady footing in an astronomical and cosmographical tradition that developed through the Middle Ages and the Renaissance (Crowther and Barker, 2013; Heninger, 1977; Jardine and Jardine, 2011; Mosley, 2011). Pictorial representations of the relative sizes of celestial bodies can be traced back at least to the fifteenth century; for example, the manuscript Christianus Prolianus' 'Astronomia'—Figure 1 (Prolianus, 1478). Albert Van Helden (1985) has noted that the dimensions of the cosmos, and of the bodies contained in it, were routinely learned in medieval universities as a part of the quadrivium; thus they were "… an integral part of the mental picture of the cosmos shared by educated men and women." They were also, as Van Helden further remarks, a

> … mélange of philosophical notions [such as the Aristotelian *horror vacui*] … unverifiable naked eye estimates [of the sizes of the celestial bodies] … such as Ptolemy's statement that Mercury's apparent diameter is one-fifteenth of the sun's diameter … geometrical methods that produced spuriously precise results

Figure 1: Prolianus's representation of the relative sizes of celestial bodies (courtesy: The University of Manchester Library).

that altogether persisted as a set of preconceived notions about the apparent sizes of the planets and fixed stars, because it could not be falsified (Van Helden, 1985: 2).

Though not entirely correct, as we shall discuss shortly, this characterization provides a good summary of the kind of notions that would be significantly challenged throughout the seventeenth century. Optical instruments played a central role here, transforming ideas about scale for both the gigantic and the very small. Alan Chapman (2015: 23) points this out with regard to Robert Hooke's *Micrographia* …, noting that this book evinces

> … the transformative power of precision instruments, meticulously conducted experiments and, most of all, lenses, to transform our knowledge of all natural phenomena: from the anatomy of the common flea to the formation of lunar craters, and on to the seeming infinity of the stellar universe.[1]

The telescope in particular, especially when outfitted with a micrometer[2] for measuring the apparent sizes or separations of astronomical objects, "… made it possible to submit this traditional scheme of sizes and distances to scientific scrutiny." (Van Helden, 1985: 3). As we shall see, however, scientific scrutiny did not always equate to accurate scrutiny. Telescopic observations of the Moon and of the planets might yield results of one kind; telescopic observations of the stars, another.

The impact of the telescope, especially when coupled with the micrometer, was such that, by the end of the seventeenth century, the dimensions of the Solar System and the sizes of the bodies in it were understood roughly as we understand them today (Van Helden, 1985: 3). The telescope also fostered new forms of using and presenting visual evidence in astronomical inquiry and debate, which have been referred to as 'visual astronomy' (Winker and van Helden, 1992). These developments took place alongside other conceptual shifts and technical developments. In the 1600s, space ceased to be conceived in terms of the scholastic debates about substance and accident and became the necessary substratum of all physical processes

(Jammer, 1993: 90). The rise of print culture and the development of copper engraving opened up new possibilities in the creation and diffusion of images (Peters et al., 2009; Stijnman, 2021). The European maritime expansion and the growing importance of maps as tools of power and domain promoted important advances in cartography—even if old cartographic conventions were not immediately abandoned, but simply reworked and re-contextualized to accommodate new geographical information (Woodward, 2007).

All of the above contributed to form a context in which the Solar System map based on scale and proportionality, and its usual companion, the diagram of relative planetary sizes, could emerge and give substance to a new cartographic entity that conferred a degree of realism on the idea of the Solar System itself—a Copernican entity that could be portrayed as measurable, and at least to some extent, mappable. Scale has long been regarded as a defining feature of terrestrial maps, particularly scale as expressed through a numerical ratio. Matthew Edney has revisited the history of scale in maps, arguing that there has been an enduring idealization of proportionality as a necessary and universal attribution of maps. However, proportionality *per se* cannot provide for a supposed direct correspondence between the map and the reality it represents, since any cartographic representation on a flat surface entails some degree of distortion (Edney, 2019: 171). Edney's critique of the idealization of scale and proportionality are of particular interest here, since, as we shall see, they were essential for the construction of Solar System maps and diagrams, which also entailed their own distortions and limitations.

The emergence, development, and consolidation of Solar System maps and diagrams between the mid-seventeenth century and the mid-eighteenth century can be seen in examples from four different authors. The first is an illustration from Andreas Cellarius' (1708) *Harmonia Macrocosmica* titled 'Corporum Coelestium Magnitudines.' This is not a map of the Solar System proper, but rather a diagram showing the relative and absolute sizes of the Earth, the Moon, the planets, and the stars, using various strategies that would become crucial in later efforts. Cellarius, perhaps seeking to promote Copernicanism, bases this diagram on celestial sizes and distances grounded on Ptolemaic astronomy.

Next are the diagrams included in Christiaan Huygens' *Kosmotheoros …* (1698), in which the author presents his arguments for the existence of extraterrestrial life. These diagrams were pivotal in establishing strategies to show scale and relative size in the Solar System—those aforementioned modern large-scale Solar System models echo *Kosmotheoros* ... A closer analysis of the role and function of the *Kosmotheoros* … images leads to a more nuanced appreciation of the role of astronomical measurement in a work that has traditionally been regarded as fundamentally speculative and divorced from Huygens's quantitative empiricism.

Finally, two works are key examples of how the visual techniques of scale and proportion were assimilated into Newtonianism, effectively gaining a solid footing in the visual culture of astronomy. Both were by authors who urged that the Newtonian Universe revealed the character of God: William Whiston's pair of Solar System broadsides (published in 1712 and 1720), and James Ferguson's *Astronomy Explained Upon Sir Isaac Newton's Principles …* (first published in 1756).

These materials show that Huygens established the basic visual strategies to represent scale in the Solar System that are used to this day. They also explain why the stars, which played a fundamental role in the cosmological debates of the seventeenth century, were at one point included but soon withdrawn from these attempts at visualizing astronomical scale. These diagrams and illustrations were not solely intended to represent the landscape of the Universe; they were crafted and presented in order to also reinforce broader claims relating to observational accuracy, the Copernican system, the question of the plurality of inhabited worlds, the strength of the Newtonian system, and the magnificence and benevolence of God.

2 THE SCALE OF THE STARS: CELLARIUS'S 'CORPORUM COELESTIUM MAGNITUDINES' FROM *HARMONIA MACROCOSMICA* (1660)

'Corporum Coelestium Magnitudines' (Figure 2), that is, "Sizes of Celestial Bodies", is a plate within Cellarius' *Harmonia Macrocosmica*, first published in 1660. *Harmonia Macrocosmica* was intended to be the first part of a two-volume atlas, with the second volume covering terrestrial cartography, but only the first came into existence.[3] Daniel Stolzenberg has recently written on *Harmonia Macrocosmica*. He describes it as being among the most recognizable works in the history of science. He ranks its "… spectacular star maps and cosmological diagrams … among the most successful scientific images ever printed." (Stolzenberg, 2019: 1). Those images have seen wide use, as Cellarius' work was re-issued numerous times in

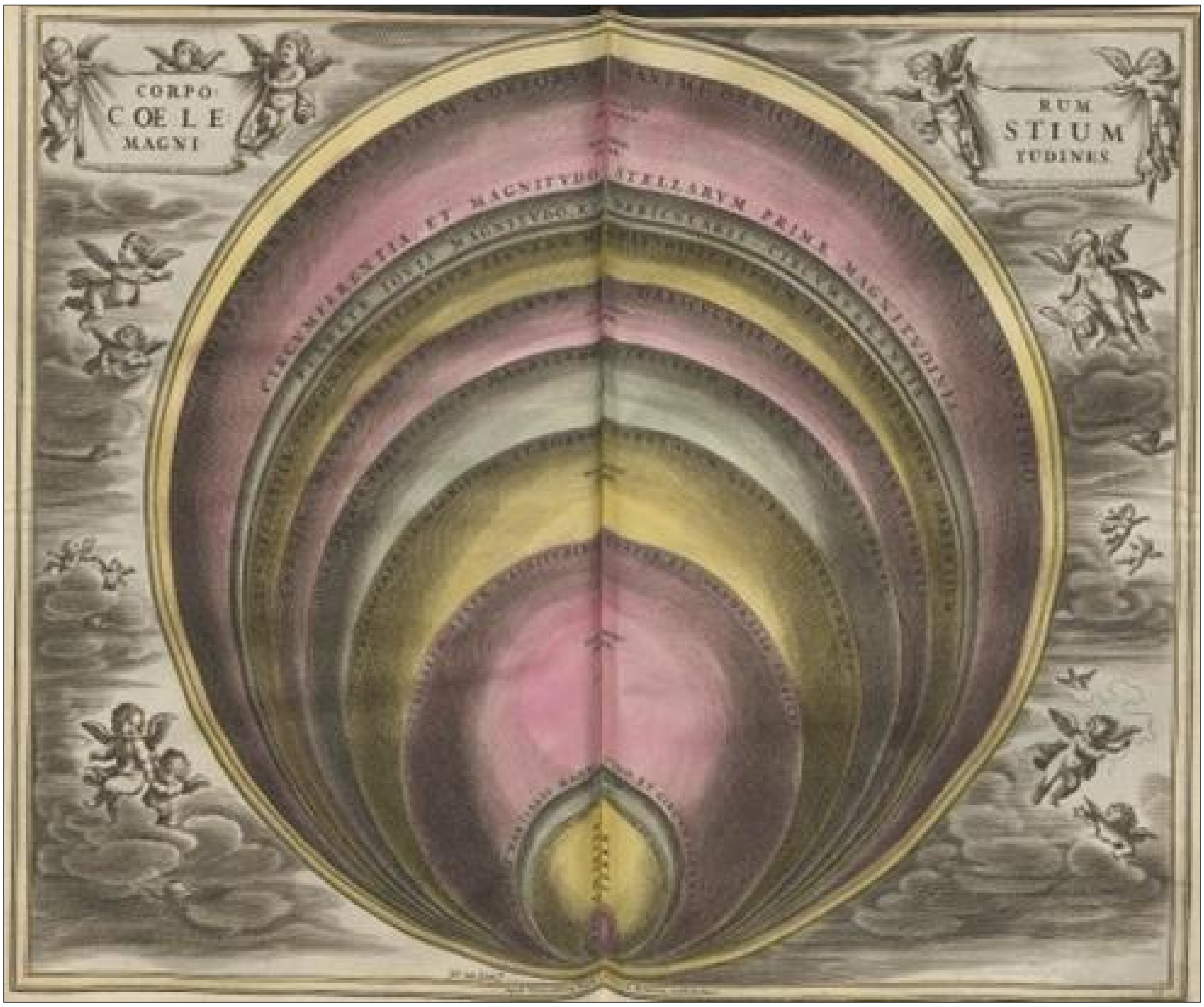

Figure 2: Cellarius' 'Sizes of Celestial Bodies' (courtesy: ETH-Bibliothek Zürich).

the sixteenth and seventeenth centuries, and the images continue to be used today. Stolzenberg characterizes the book as being "… blatantly pro-Copernican … [and indeed] a partisan defense of Copernicanism …", something he says is reflected in its frontispiece (Stolzenberg, 2019: 8–10).

Yet this pro-Copernican work—produced half a century after the advent of the telescope, and containing illustrations of the telescope in action (within the 'Haemisphaerum Scenographicum Australe' plate), and of Jupiter being surrounded by four moons visible only via the telescope (within 'Planisphaerum Copernicum')—includes no images that show the appearance of any celestial body as seen through a telescope. Moreover, 'Corporum' provides a comparison of the sizes of celestial bodies, to each other and to a scale of German miles and Earth diameters, not based on telescopic measurements. Rather, Cellarius cites a pre-telescopic, non-Copernican source—Christopher Clavius' commentary on Sacrobosco's standard text, *The Sphere*—for the numbers used to produce the 'Corporum' diagram. There were many editions of this work (Lattis, 1994). The numbers match those found in a 1601 edition of Clavius (Clavius, 1601: 186; cf. Cellarius, 1708: pars prior 69).

The relative sizes of stars, planets, and the sun based on pre-telescopic numbers are different from those based on telescopic measurements. Nevertheless, as mentioned earlier, it is not entirely correct to say that pre-telescopic conceptions of the dimensions of the cosmos and the bodies contained in it were not verifiable, not scientific, or not falsifiable. Consider Ptolemy's statement, mentioned earlier, that Mercury's apparent (or angular) diameter is one fifteenth of that of the Sun. This naked-eye estimate is indeed 'unverifiable' as a precision measurement. However, keen-eyed observers who observe the Moon and Mercury together in the sky will verify that Mercury is a dot whose angular diameter is much less than that of the Moon, and thus of the Sun (as the Moon and Sun have about the same apparent diameter). Moreover, the question will not be whether

Mercury appears to be one half the Sun's diameter, vs. two thirds or three eighths; the question will be whether Mercury is one fifteenth the Sun's diameter, vs. one twentieth or one tenth. Ptolemy's precise value may not be verifiable, but his general observation is. Likewise, naked-eye estimates will consistently yield Saturn as having a smaller angular or apparent diameter than Jupiter, and Jupiter as having a much smaller such diameter than the Sun or Moon.

Such measurements, combined with estimates of the distances to celestial bodies based on the sorts of factors mentioned by Van Helden, yield relative physical sizes of stars, planets, and the Sun—relative sizes that are part of the preconceived notions associated with a pre-telescopic mental picture of the cosmos that he discusses. The diagram in Prolianus' *Astronomia* from two centuries before Cellarius (Figure 1) illustrates these relative sizes. In it, Jupiter and Saturn both compare to the Sun in physical size.

The telescope yielded different sizes. The explanation for this was that the telescope stripped away the glare or "… spurious rays …" or "… adventitious irradiation …" from the stars and the planets. It revealed their bare bodies[4] and showed their angular sizes to be smaller than previously estimated.

But Cellarius' diagram shows the sizes of planets compared to the Sun based on the larger, pre-telescopic estimates. Whereas, as we shall see, measurements with the telescope reveal Jupiter to be but a fraction of the Sun's size, in Cellarius' diagram it nearly equals the Sun. So does Saturn. In this regard, Cellarius' diagram is much like Prolianus'. However, unlike in the Prolianus diagram, the bodies are shaded somewhat to give some impression of spheroidal bulk.

And unlike the Prolianus diagram, the Cellarius diagram includes fixed stars. To the unaided eye, a modestly bright star compares to Saturn in angular diameter. In a geocentric Universe, the stars can lie just beyond Saturn (van Helden, 1985: 27, 50). And so, being of similar angular size and similar distance, the modestly bright star and Saturn must be similar in physical size as well. And in Cellarius' diagram, based on geocentric numbers from Clavius, they are similar: first magnitude stars, Jupiter, Saturn, and second and third magnitude stars all have diameters between five and four times that of Earth. The Sun, labelled in the diagram as the largest of all the bodies, measures five-and-one-half times Earth's diameter.[5] The celestial object with the smallest physical size is Mercury, which is also smallest in the Prolianus diagram.

Why would a pro-Copernican book of 1660 contain a relative size diagram based on numbers from a pre-telescopic, geocentric work of 1601? Perhaps because no such size diagram was possible using numbers for a Copernican Universe. For the latter, the interplay between the miniature and the gigantic was just too great to be represented, at least when the bodies that were to be represented were the fixed stars.

As stated above, in a geocentric Universe Saturn and the more prominent fixed stars shared similar physical sizes, as represented in the Prolianus and Cellarius diagrams. However, in a Copernican Universe the fixed stars had to be located much farther away than Saturn—sufficiently far that Earth's orbit was as nothing in comparison to their distance, meaning Earth's annual motion about the Sun would not be observably reflected in the fixed stars; i.e., there would be no 'annual parallax'. But if a star of angular size comparable to that of Saturn is located many times farther away than Saturn, it necessarily follows that the star's physical size must be many times greater than Saturn's.

The telescope caused a re-assessment of the angular sizes of the fixed stars. The alleged telescopic stripping away of "… spurious rays …" or "… adventitious irradiation…", revealing the bare body of a celestial object and thus its correct angular size, was thought to work with fixed stars just as it did with wandering stars (planets).[6] The angular sizes of the fixed stars were reduced by the telescope, as they were with the planets, but not enough to compensate for the increase in physical size necessitated by the Copernican system's vast stellar distances. Christopher Scheiner pointed out that so long as the orbit of Earth was nothing in comparison to stellar distances, while stellar bodies were merely small in comparison to such distances, then the stars must be giant—as large as the orbit of the Earth or larger (Scheiner and Locher, 2017: 30). Kepler determined Sirius to be larger than Saturn's orbit (Graney, 2019; 2021a). A variety of other writers, including Tycho Brahe, Giovanni Battista Riccioli, and Andreas Tacquet also pointed out that in a Copernican Universe stars must be bodies whose physical sizes were comparable, not to the Sun as in the Cellarius diagram, but to Earth's orbit (Graney, 2021b, especially regarding Tacquet).

Tacquet, whose relatively obscure writings are remembered primarily because Robert Hooke cited him as a vehement anti-Copernican, demonstrated that the Earth's orbit in a Copernican Universe was equivalent to the Earth's globe in a geocentric Universe: the lack of any observable annual parallax caused by Earth moving about the Sun in the Copernican Universe corresponded to the lack of any observable parallax caused by moving from one observing location to another on Earth's surface in a geocentric Universe. Therefore, said Tacquet, whatever proportion existed in a geocentric Universe between the size of the globe and the sizes of the fixed stars, that same proportion existed in a Copernican Universe between the size of Earth's orbit and the sizes of the fixed stars (Graney, 2021b).

Thus, to create a version of Cellarius' diagram for a Copernican Universe, the scale of 'terrestrial diameters' would become a scale of 'orbital diameters', and the scale of miles would be altered likewise. First, second, and third magnitude stars would all have diameters between five and four times that of Earth's orbit, rather than five and four times that of Earth itself. The Sun and planets in the diagram would be reduced to dots that would be tiny, if visible at all. Therefore, no representation of the relative sizes of the Sun, stars, and planets in a Copernican Universe would be possible.

Cellarius' choice to represent relative sizes from Clavius reinforces the argument that *Harmonia Macrocosmica* is a pro-Copernican work. Some Copernicans did embrace the giant stars that their system required.[7] Anti-Copernicans, however, viewed the giant stars as an absurdity. As Hooke put it, the giant stars were

> … a grand objection alledged by divers of the great *Anti-copernicans* with great vehemency and insulting; amonst which we may reckon *Ricciolus* and *Tacquet* … hoping to make it [the Copernican Universe] seem so improbable, as to be rejected by all parties. (Hooke, 1674: 26).

Cellarius, in opting to represent the relative sizes of celestial bodies using numbers from Clavius for a geocentric Universe, rather than numbers from Kepler or Riccioli for a Copernican Universe, employed a visual strategy that obscured what many viewed as the Copernican theory's greatest weakness. The question of giant stars in the Copernican theory would eventually be resolved by advances in the understanding of optics (optical systems, be they eyes or telescopes, turn out to produce spuriously large images of brilliant objects of small angular size, owing to the wave nature of light), but that question would endure well into the eighteenth century, through the time of all the works discussed here. The works that follow Cellarius limit themselves to the relative sizes of Solar System bodies.

It is worth noting the resonance between Cellarius' use of a scale of miles in 'Corporum' and the use of similar devices in the terrestrial maps of *Atlas Maior* … by Joan Blaeu (1596–1673; see Blaeu, 1662), of whom the publisher of *Harmonia Macrocosmica*, Johannes Janssonius (1588–1664), was a fierce rival (van Ghent, 2012: 247). Cellarius was not the first to apply strategies of terrestrial cartography to representations of celestial objects. In *Selenographia* …, Johannes Hevelius (1647) presents three *plena facies* maps of the Moon adorned with cherubs holding scales of German miles and other units.[8] Hevelius' maps were widely reproduced and even plagiarized following the publication of *Selenographia* …, but since, contrary to later authors of similar atlases such as Johann Gabriel Doppelmayr (1677–1750; see Doppelmayr, 1742), Cellarius does not include any telescopic map of the Moon in *Harmonia Macrocosmica*, it does not seem that Hevelius' work had a direct influence on Cellarius.

Cellarius combined a visual comparison of relative size with a miles scale, reinforcing the notion that terrestrial mapping conventions could be applied to the celestial bodies. He seems to have done so as a subtle way of safeguarding the Copernican theory. Another Copernican, armed with telescopic measurements, and straightforward in his allegiance to Copernicanism, would also create a visual representation of the relative sizes of the Sun and the planets, and introduce a visual depiction of the relative sizes of planetary orbits according to the heliocentric system. This Copernican was Christiaan Huygens.

3 ASTRONOMICAL SCALE AND THE PLURALITY OF INHABITED WORLDS: THE DIAGRAMS OF CHRISTIAAN HUYGENS' *KOSMOTHEOROS*

Kosmotheoros (Κοσμοθεωροσ) … was published posthumously in Latin in 1698. An English translation titled *The Celestial Worlds Discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets* appeared in the same year (Huygens, 1698). Translations in several other languages ensued throughout the eighteenth century (Dick, 1982: 135).

Kosmotheoros … has been approached mainly in terms of its cosmological and philosophical implications, particularly with regard to its significance to the history of the extraterrestrial life debate. Here Huygens makes his case for the plurality of inhabited worlds (Crowe, 1986: 20–22; Dick, 1982: 127–135; 2013: 52–53; Radelet-de Grave, 2003; van der Schoot, 2014), an idea that he had started to explore in *Systema Saturnium …,* first published in 1659 (Huygens, 1659). Huygens' arguments are similar to those presented eleven years earlier by Bernard Le Bovier de Fontenelle (1657–1757) in *Entretiens sur la Pluralité des Mondes* (Fontenelle, 1686; cf. Crowe, 1986: 18–20). Grounded on an overarching presumption of similarity between the Earth and the other planets, these arguments refer mainly to the impossibility of imagining any use for the planets other than harboring life; the fecundity and magnificence of nature; and the presence of moons around the outermost planets, with Jupiter having four, and Saturn five to reflect light from the Sun for the benefit of their putative inhabitants; and how so much can be said in favor of the existence of life on the other planets, but nothing against. Both Fontenelle and Huygens posited an infinite Universe where the fixed stars are suns, each bearing its own planetary system (Dick, 1982: 128).[9]

Yet, there is another aspect of *Kosmotheoros* … that is worthy of attention: its interplay between textual and visual devices to convey notions of scale grounded on astronomical measurement. *Kosmotheoros* … has traditionally been regarded as a work devoid of significant empirical content, and therefore an oddity in a body of work otherwise marked by a strong commitment to measurement and quantification in the study of natural phenomena (Dick, 1982; Yoder, 1998). There is no doubt as to the speculative character of *Kosmotheoros* …. However, Huygens' speculations and *Kosmotheoros'* … illustrations are informed by some simple experiments to estimate the distances to the stars; by knowledge of telescopic features of the planets such as the ring of Saturn; and by micrometrical measurements of the angular sizes of the planets that, combined with estimates of their distances, gave their physical sizes.

Kosmotheoros … is divided into two parts. The first part addresses the hypothetical inhabitants of other planets; the second describes each planet and how astronomical phenomena would be seen from each, and discusses the existence of planetary systems around other stars. The two best known diagrams from *Kosmotheoros* … are presented in the first part.

The first diagram, Figure 3a here (Huygens, 1698: Figure 1, opposite page 11), shows the orbits of the planets around the Sun, as well as the orbit of the Moon and those of the moons of Jupiter and Saturn. Huygens includes no explicit scale on the diagram, but says the Copernican orbits are "… drawn as near as can be in their true Proportions …" (Huygens, 1698: 11), as in his 'astronomical clock'.[10] Huygens (1698: 12) does state an implicit scale: "You may easily apprehend the Vastness of these Orbits by this, that the distance of the Earth from the Sun is ten or twelve thousand of the Earth's Diameters." The reader can therefore determine distances on the orbit diagram in terms of the Earth-Sun distance.

Huygens' proportional presentation of the planetary orbits, while not wholly original, was unusual. Cellarius, for example, presented a sort of nested spheres diagram of the Copernican system with no concern for proportion. Copernicus himself did the same, as did Brahe, Scheiner, Galileo, Riccioli, and others; Philip van Lansberge (1630), however, had a diagram with proportionally sized orbits in his *Commentationes in Motum Terrae Durnum, & Annuum* … of 1630 (Figure 4).

Huygens' second diagram, Figure 3b here (Huygens, 1698: Figure 2, opposite page 15), shows the relative sizes of the planets to that of the Sun (which is pictured standing against a dark background, as if to give an impression of it in space), by superimposing their depictions to the solar disc, close to its edge. This is very much akin to the way Cellarius represents the relative sizes of celestial bodies, with the Sun being the largest body against which all the others are compared. As with Figure 3a, no scale is explicitly provided, but the Sun's diameter is the implicit scale; Huygens (1698: 16) states all the planetary diameters in terms of the Sun's diameter. And as in the Cellarius diagram, shading, at least on Jupiter and Saturn, indicates that these bodies are spheroids in space. The ring around Saturn, a feature visible only through a telescope, indicates that the diagram is showing the planets as revealed by the telescope.

Huygens notes the diversity in sizes of the planetary bodies—the "… four inmost … [being] far less than *Jupiter* and *Saturn*." He notes further that it is remarkable "… that the Bodies of the Planets do not increase together with their Distances from the Sun, but that *Venus* is much bigger than *Mars*." (Huygens, 1698: 17). This stood contrary to a belief that planetary size increased with distance from the Sun. This idea had appeared in 1662 in the work of Jeremiah Horrocks; it had been illustrated in a Solar System diagram by Otto von Guericke (Figure 4d), published in 1672, that paid no attention to proportion except for showing the planets steadily increasing in size with distance from the Sun.[11]

A first version of Huygens' planetary orbits diagram (that is, of Figure 3a) appeared in an appendix to the 1662 edition of *Systema Saturnium* … shortly after *Harmonia Macrocosmica* was published, and after a letter from Cellarius to Huygens about *Harmonia Macrocos-*

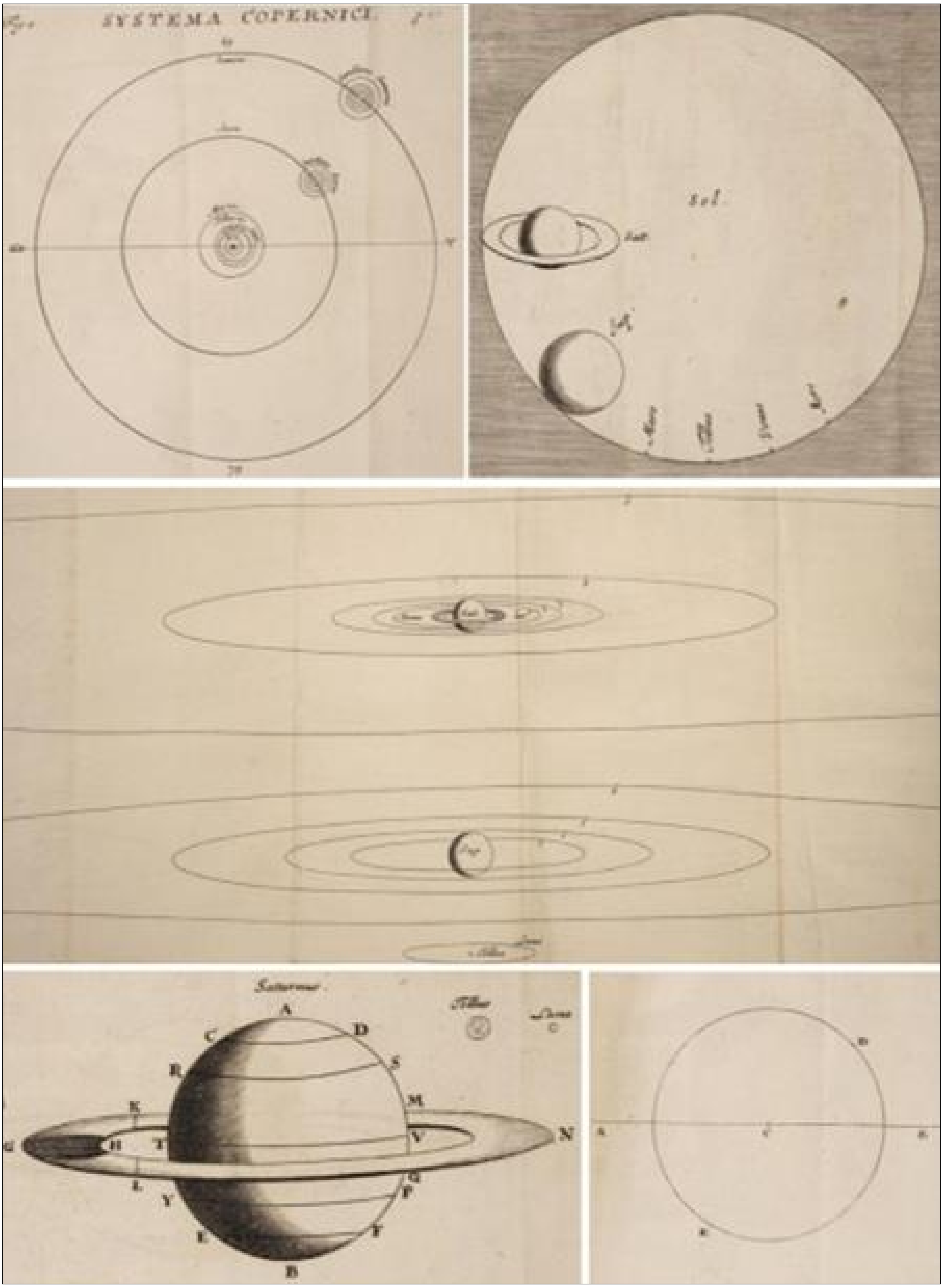

Figure 3: Diagrams from the *Kosmotheoros* of Huygens (courtesy: Archive.org) showing (left to right, top to bottom): (a) the orbits of all the planets and their moons (b) the relative sizes of the Sun and planets (c) Saturn, Jupiter, and Earth, and their systems of moons (d) Saturn, the Earth, and the Moon (e) the Earth on its orbit, circled by the Moon (the circle being the Moon's orbit, the line being the Earth's).

mica (Cellarius, 1661: 446–447). Another version of the diagram, including all known 'secondary planets' or moons, was included in the 1667 edition (Huygens, 1925: 374–375). *Systema Saturnium* … is better known as the book where Huygens presents his ring explanation for the varying appearance of Saturn when seen through a telescope, but it is also where he starts to explore the idea of extraterrestrial life, and importantly, where he elaborates on his ideas and observations on the sizes and distances of the planets.

Systema includes a description of the micrometer that Huygens used to measure angular diameters of planetary discs, and he directs *Kosmotheoros* … readers to it for discussion of those measurements (Huygens, 1698: 16–17). His measurement method consisted in introducing tapered strips of copper into the focal plane of his telescope and determining at what point a strip covered the disk of the observed planet. He also coated the eye lens with a thin layer of soot from a candle in order to reduce the effect of the glare surrounding planetary disks; the glare introduced significant errors, particularly for smaller and brighter disks. Huygens was thus able to obtain results that were more consistent than those of other observers (for a detailed discussion see Van Helden, 1985: 120–123).

Those results, and the results of other telescopic observers, differed considerably from those obtained by Ptolemy and other pre-telescopic observers. Ptolemy had determined planets to have angular diameters roughly one fifteenth that of the Moon. Huygens' values were much smaller. As mentioned, the telescope was thought to strip away the glare or 'spurious rays', revealing the bare body of the planet, and thus its true form and its correct angular size. But, in order to obtain the physical sizes of the planets from measurements of angular diameters, the distances between the planets and the Sun were needed. Huygens, recognizing the limitations of the available methods to obtain those distances, nevertheless was able to calculate the planetary sizes compared to the Sun. He determined Earth's diameter to be 1/111 that of the Sun; the modern figure is 1/109. His other planetary sizes are in general agreement with modern figures as well (Huygens, 1698: 16; Van Helden, 1985: 66–68).

These measurements inform the diagrams included in *Kosmotheoros …,* where they are condensed into pictures that convey a much more direct and persuasive notion of their meaning in terms of the size of our planetary system and the objects that form it. In order to create these visual devices, Huygens just had to revamp the old diagram of nested spheres of the astronomical and cosmographical traditions, and the techniques of proportionality and superimposition employed by Cellarius, combining them with the available figures for sizes and distances. Huygens was aware of the limitations imposed to these illustrations, noting the impossibility of showing the sizes of orbits and the sizes of celestial bodies at the same scale factor, and remarking that the orbits of moons in the first diagram (Figure 3a) were exaggerated, for "… otherwise they could not have been seen." (Huygens 1698: 12).

Nevertheless, the first two diagrams play an essential role in *Kosmotheoros …*, giving substance to an idea central to its arguments: there is nothing particularly remarkable about the Earth. It belongs to a cohort of differing size planets that orbit within a vastness of space around the Sun. If the Earth and the planets all orbit the Sun and belong to the same system, they must be similar in nature; therefore, since the Earth is inhabited, the other planets might be as well (Huygens, 1698: 19–39). And since planets such as Jupiter and Saturn are much larger than the Earth, it would be difficult to conceive of them as lifeless—for Huygens, that would be an inconceivable waste (Huygens, 1698: 117).

The fact that Jupiter and Saturn are surrounded by their own systems of moons is of great relevance in Huygens' conjectures. In the second part of *Kosmotheoros …*, he presents a third diagram, Figure 3c here (Huygens, 1698: Figure 3, opposite page 113) showing Saturn, Jupiter, and the Earth as well as the orbits of their respective satellites, all drawn "… as near the true Proportion as possible." (Huygens, 1698: 113). The orbits are not seen from a bird's-eye view as in the case of the first diagram, but as if the observer were standing above the plane of the orbits looking from an oblique angle. This strategy shows the orbits of all the satellites of Jupiter and Saturn, including the outermost ones, while still having the orbit of Earth's Moon, which Huygens uses for scale (Huygens, 1698: 115), appear fairly large on the page. Again, Huygens seeks to persuade the reader of the seemingly modest position of the Earth:

> Can anyone look upon, and compare these Systems together, without being amazed at the vast magnificence and noble Attendance of these two planets, in respect to this little pitiful Earth of ours? (Huygens, 1698: 117).

To further reinforce this point, Huygens presents a fourth figure (Figure 3d, here), showing

Saturn with its ring, and with the shadow of the planet projected onto the ring (after Huygens, 1698: Figure 4, opposite page 124). The planet, the ring, and the space between the two are shown in proportion. The Earth and its Moon are included for scale. Lines corresponding to different latitudes on Saturn are marked on the planet. Huygens goes on to describe how the putative inhabitants of Saturn would see its ring from each of those latitudes.

This use of images to help readers shift their perspectives is another distinctive feature of *Kosmotheoros ...*. Much of its second part addresses how astronomical phenomena would be seen by observers located on the other bodies of the Solar System. One particular example is the apparent size of the Sun as seen from the other planets, and its implications in terms of the amount of light and heat that they receive; Huygens even suggests a simple experiment with a tube to show the illumination of the Sun as it would be seen by the inhabitants of Jupiter and Saturn (Huygens, 1698: 119–120).

Huygens thus takes the reader on a sort of voyage through the Solar System in the manner of Athanasius Kircher's (1656) *The Ecstatick Journey …*, and Kepler's (1634) *Somnium …*, though he considers both to be fanciful literary exercises. It is instead on the grounds of scale and measurement that Huygens stresses that those other worlds are places like the Earth, and that any preconceptions about the exceptional nature of the latter are a result of our biased perspective as Earthlings. The illustrations in *Kosmotheoros* … are thus meant not only to emphasize the seemingly modest place of the Earth in the Solar System, but also to help readers decenter themselves and assume the vantage point of hypothetical observers situated on other orbs. Perspective played a fundamental role in Huygens' explanation for the appearances of Saturn as seen from Earth, on the assumption that the planet is surrounded by a ring (van Helden, 2004; 2006). He resorts to perspective once again in *Kosmotheoros …*, to address how astronomical objects and phenomena are seen from other worlds than Earth.

To summarize the picture of the Solar System conveyed in *Kosmotheoros …*, Huygens includes a fifth and final diagram depicting a segment of the Earth's orbit with the orbit of the Moon superimposed to it, Figure 3e here (Huygens, 1698: Figure 5, opposite page 139). This diagram seeks to provide the possible depiction of how the latter would look if the first two diagrams (Figures 3a and 3b in this paper) were combined into a single one, using the (implicit) scale factor of the second diagram. The orbit of the Earth would thus have a semi-diameter of 36 feet, and the Earth itself would not be bigger than "… a grain of Millet …" (Huygens, 1698: 139), with the Moon being almost imperceptible. Here the reader must imagine the diagram extending far beyond the confines of the printed sheet of paper.

Huygens notes that thus we have

> … a true and exact Description of the sun's Palace, where the Earth will be twelve thousand of its Semidiameters distant from him, which in German Miles makes above seventeen Millions. (Huygens, 1698: 140).

He further adds an analogy based on a passage in Hesiod's *The Theogony* poem, according to which an anvil dropped from the top of heaven would reach the Earth on the tenth day of its journey. Huygens puts forward a Copernican reworking of this analogy, in which the moving object is no longer a falling anvil, but rather "… a Bullet shot out of a great Gun, which may travel perhaps in a Moment, or Pulse of an Artery, about a hundred Fathom." (Huygens, 1698: 141; note that a modern fathom is six feet). The fact that Huygens employs not only the German miles of the terrestrial cartography of the time but also the fathom, a unit associated with measurements of the depth of water, is also revealing of a form of thinking about space that not only presumes its measurability, but also considers its tri-dimensionality.

The bullet, Huygens adds, would take 25 years to move from the Earth to the Sun, 125 to cover the distance between the Sun and Jupiter, and 250 to travel from Saturn to the Sun. The analogy is further extended to the realm of the fixed stars (the distance to which Huygens estimates by comparing Sirius with the Sun seen through a small hole). The same bullet would "… spend almost seven hundred thousand years in its Journey between us and the nearest of the fix'd Stars." (Huygens, 1698: 154–155).

Towards the end of *Kosmotheoros …,* Huygens addresses the problem of star sizes and the effect of the telescope in eliminating the spurious rays. He posits that the stars are not necessarily as large as some critics of the Copernican system insist,[12] and are distributed through the depths of space, with even the nearest ones lying at vast distances from us. He further argues that they must be suns emitting their own light, as it would be impossible for them to reflect so much light from our Sun at such distances. Since stars are similar to our Sun, they must harbor their own planetary systems. If we cannot see those systems, that is because of their great distances. Huygens reinforces this point using the same strategy of change of perspective that pervades the second part of *Kosmotheoros* …, stating that observers in another planetary system staring back at us with their instruments would be equally unable to see the planets that orbit the Sun (Huygens, 1698: 144–150).

In Huygens' Copernican cosmos, not only does the Earth hold no special place among the planets, but the Sun also occupies no special place among the stars. Thus the Solar System can be treated as an example of a planetary system, instead of as the planetary system. Therefore, the inclusion of the fixed stars in maps and scale diagrams addressing the Solar System and its bodies is not only prevented by their great distances and the uncertainty regarding their actual sizes, but is in fact rendered irrelevant by this conceptual shift. A verbal expression of the vast fixed star distances in the guise of the bullet analogy suffices to give the readers of *Kosmotheoros* … an idea of the vastness of space that separates us from them, at a scale even larger than that of the distances between the Sun, our Earth, and the other planets. Huygens has no need, and does not try, to include a diagram showing the

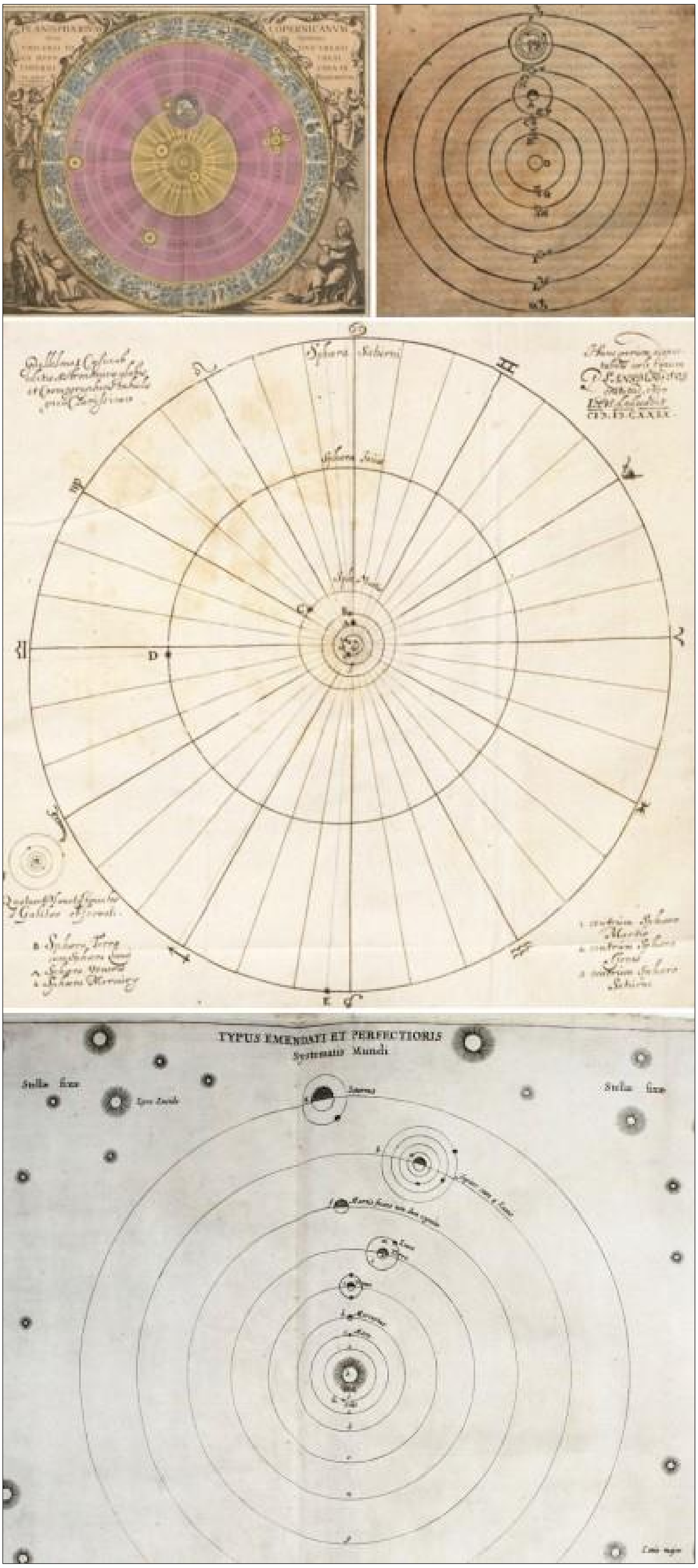

Figure 4 (right): Four diagrams of the Copernican system: Cellarius' (a, top left, courtesy ETH-Bibliothek Zürich), Galileo's from the *Dialogo* (b, top right, courtesy: Google Books), Philip van Lansberge's (c, middle, courtesy: Google Books – National Central Library of Florence), and Otto von Guericke's (d, bottom, courtesy: Smithsonian Libraries). All show the Jovian moons. Philip van Lansberge's represents planetary orbits in proper proportion—note the big gaps between outer planet orbits. Von Guericke's shows fixed stars, and planets whose sizes increase with distance from the Sun.

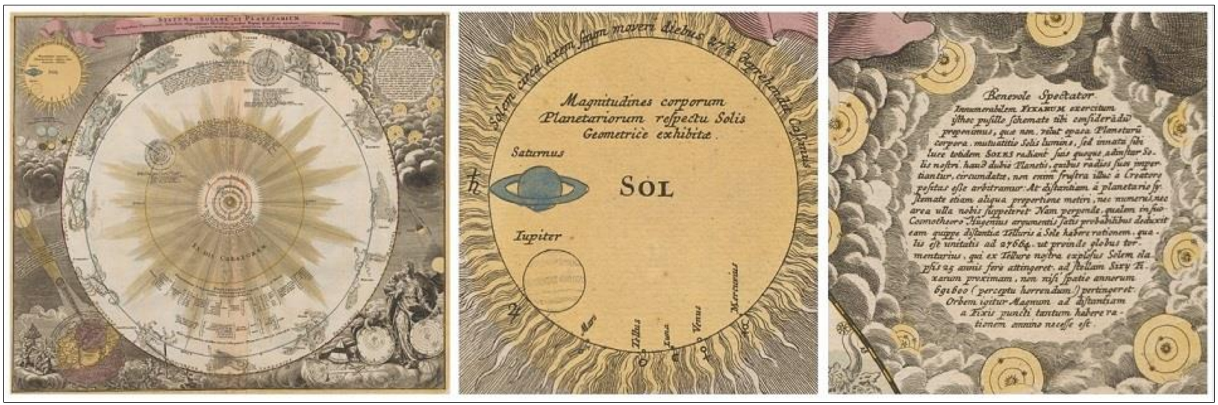

Figure 5: Illustration from Johann Gabriel Doppelmayr's 1742 *Atlas Coelestis* (courtesy: ETH-Bibliothek Zürich) showing to-scale diagrams of the sizes of orbits and the sizes of planets, as well as a discussion of the plurality of worlds. Following Huygens, the orbits diagram shows exaggerated sizes of the orbits of moons. Except for the addition of a fiery edge to the sun and telescopically observable cloud belts on Jupiter, the planet sizes diagram (center) copies Huygens. The illustration of a plurality of worlds (right) reads in part (our English translation): "Kind viewer, for your consideration we display to you in this little sketch the immense swarm of FIXED STARS, which shine not with reflected light of the sun, in the manner of the dark bodies of the Planets, but all shine as SUNS, with light innate to them. And without doubt all are surrounded by their own Planets, in the fashion of our sun, to which they impart their radiance. We suppose these have not been placed there in vain by the Creator …"

stars and planets together.

This stands in contrast to other authors that include the stars within diagrams of the Copernican planetary system. An example of these is the aforementioned diagram by von Guericke (Figure 4d). It features, along with its improperly proportioned orbits and planets increasing in size with distance from the Sun, a scattering of stars, shown just beyond the orbit of Saturn. Thus, von Guericke's diagram, and others like it, conveys no information (or incorrect information) about the true scale of the Copernican starry Universe.[13]

The stars of Cellarius in 'Corporum' are remnants of an old cosmology that, at first sight, does not look totally out of place in an atlas addressing competing cosmological systems. Besides, as shown in the previous Section, they carry the advantage of diverting the viewers' attention from a major objection to the Copernican theory embraced by Cellarius. The militant Copernicanism of *Kosmotheoros* … dispenses with such subtleties. Here the reader is presented with an image of the Solar System and starry Universe grounded on astronomical measurement and carefully presented through a combination of visualization, analogy, and the displacement of the readers, who are invited to abandon their Earthbound perspective and assume the point of view of extraterrestrials inhabiting other orbs, in the Solar System and beyond.

The impact of the visual strategies used in *Kosmotheoros* … can be seen very directly by their near duplication in Doppelmayr's (1742) *Atlas Coelestis* … (Figure 5). But they gained a life of their own even before Doppelmayr, by being not just duplicated but expanded upon. They gained a solid footing in the visual culture of astronomy through their expansion and assimilation into Newtonianism.

4 COMETS, EXTRATERRESTRIALS, AND NEWTONIANISM: THE SOLAR SYSTEM ACCORDING TO WILLIAM WHISTON AND JAMES FERGUSON

In 1712, William Whiston (1667–1752) published a broadside titled 'Mr. Whiston's Solar System *Epitomis'd*' (Whiston, 1712; see Figure 6a). As the title indicates, the broadside was meant to condense the essential knowledge of the Solar System into one single diagram. Huygens is not cited directly, but the resemblance with Huygens' diagrams is clear, growing more so with closer inspection, with two distinctive features equally noticeable.

The first is that Whiston's 'Solar System' shows both the relative sizes of the planets to that of the Sun and the proportional sizes of the planetary orbits in a single diagram. This is accomplished by adding an outer circle beyond the orbit of Saturn, which cuts off the rest of the Solar System that is occupied only by comets. It functions both as a zodiac circle and as a representation of the size of the Sun to which the relative sizes of the planets can be compared (as in Figure 3b).

The planets are depicted in proportion in the upper part of the diagram, between the orbits of Jupiter and Saturn, against the face of the Sun, as Huygens did. As in the Huygens diagram, shading indicates that the planets are spheroids, and the telescopically visible ring around Saturn is also shown. Additional telescopic details include the Cassini Division (the major gap in Saturn's ring system, first observed by Giovanni Domenico Cassini in 1675), as well as the belts of clouds and a spot on Jupiter.[14]

The planetary orbits are displayed on the face of the Sun, within the zodiac circle. Like Huygens, Whiston exaggerates the sizes of the orbits of moons. For example, on the broadside he states that the radius of Saturn's orbit is 777 million miles, implying one scale, while the radii of the orbits of the outer moons of Jupiter and Saturn are 1 and 1.8 million, respectively, implying another scale.[15] These latter are scant thousandths of the radius of Saturn's orbit, and thus should be invisible on the diagram. But the moon orbits are visible, much as in Huygens's and in contrast to van Lansberge's (which does not show the orbits of Jupiter's moons within the diagram proper, but shows them separately outside the planetary orbits (Figure 4c). Whiston thus combines Huygens' pair of diagrams into a single map of the Solar System with multiple scales in play (the planetary sizes implying a third scale).

A second distinctive aspect of Whiston's diagram is the inclusion of twenty-one cometary orbits, not present in Huygens' diagram (and not present in the later diagram by Doppelmayr (see Figure 5).

These make the diagram

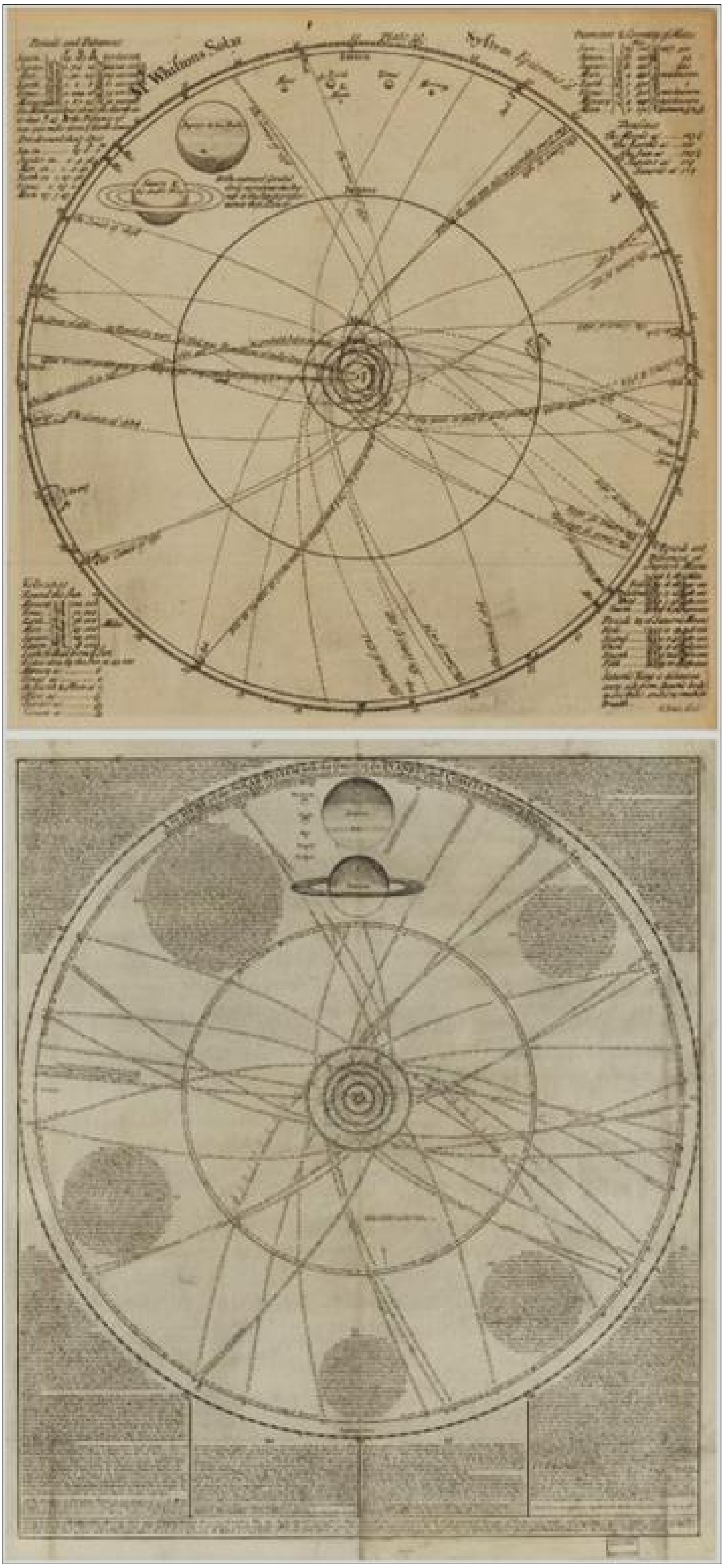

Figure 6: William Whiston's 'Solar System *Epitomis'd*' (a, top, courtesy: Barry Lawrence Ruderman Antique Maps, Inc.) and 'A SCHEME of the SOLAR SYSTEM' (b, courtesy: Library of Congress).

look busier while also conveying a more dynamical view of our planetary system. Each cometary orbit is labelled with the latest known appearance of the respective comet and, where known, its orbital period and expected return date. The outer parts of the cometary orbits are cut off, much as Newton cut off the outer portion of the cometary orbit illustrated in later editions of his *Principia.*

Comets occupied a central role in Whiston's Newtonian view of the Universe. He had embraced Newtonianism while still a student in Cambridge, becoming one of its most ardent advocates. Newton himself secured Whiston's nomination to succeed him in the Lucasian Chair of Mathematics at Cambridge in 1701. Whiston's espousal of Newton's ideas and beliefs went beyond the concept of an orderly Universe governed by the principles of gravitation and inertia. Like Newton, Whiston favored biblical literalism, a return to primitive Christianity, and non-Trinitarian views that were considered heretical, and which eventually led him to be ousted from the University of Cambridge in 1710 (Westfall, 2006: 501, 594).

In Whiston's worldview, comets reconciled the Newtonian Universe with the Holy Scriptures. Their orbits as calculated by Edmond Halley evinced the order of nature as established by God, while indicating the strength of Newton's ideas to apprehend it. Importantly, Whiston also adopted Newton's and Halley's conception of comets as agents that God used at will to disrupt the established order. Whiston believed that comets had played a central role in the origins of the Earth and in the Deluge, and that their enduring effects had since continued to manifest in calamities such as volcanic eruptions, earthquakes, stormy rains, and outbreaks of disease. He equally believed that the final conflagration would be ignited by the return of a comet (Schechner, 1999: 102, 188–193).

Whiston's broadside must be understood against this background. The diagram illustrates how God wisely arranged the system of the world so that comets would not collide with Earth or each other (Schechner, 1999: 197). And while evincing this fine-tuning of celestial mechanics, the diagram also suggests how this benevolent order could easily give way to catastrophe if God wished so; the central area of the diagram is quite compelling, with the apparent swarm of cometary orbits crossing the environs of the Earth's orbit, all portrayed with proportional precision. Following its regular path around the Sun, our cosmic abode was protected by the reliability of celestial mechanics and the vast distances between celestial bodies and their orbits, although still remaining at the mercy of God.

Whiston's message is further reinforced by the large size of the broadside in which the diagram is presented (approximately 10 by 10 inches; 25 by 25 cm). In the seventeenth century broadsides were used to present a mixture of news, science, and astrological speculation regarding celestial phenomena, particularly comets. This kind of publication, which typically combined text and illustrations on a large, single-sided printed sheet, was particularly suited to circulate such content among a wider audience, as broadsides were more affordable than books and could be displayed in spaces of socialization for collective reading and discussion.

In the first decades of the eighteenth century, Halley and Whiston, working with the cartographer and publisher John Senex, repurposed the broadside into an additional vehicle for promoting Newtonian science (Walters, 1999). Particularly significant in this regard are the eclipse maps that they produced during the first decades of the eighteenth century for eclipses with totality paths predicted to cross England and continental Europe (Pasachoff, 1999a; 1999b; Walters, 1999). Halley's maps for the solar eclipses of 1715 and 1724 (Halley, 1715a; 1715b; 1715c; 1724a; 1724b) showed their predicted shadow paths superimposed on maps of England and continental Europe, in some cases combining the predicted and observed shadow path. Whiston's maps for the eclipse of 1715 were more schematic, particularly the one titled *A Calculation of the Great Eclipse of the Sun, April 22.d 1715 in y.e Morning* (Whiston, 1715a; cf. Whiston, 1715b). It presents the shadow path of the eclipse projected on a terrestrial sphere with a grid of latitude and longitude, where parallels for selected cities are highlighted so that users could calculate the beginning and the end of the eclipse for those places. Halley's maps were, unsurprisingly, more successful than Whiston's, as they required less effort from the reader and showed the shadow of the Moon in a bird's-eye view extending over British territory, represented in the more familiar style of a chorographic map. These eclipse maps brought terrestrial and celestial elements together in a striking visual display of precise Newtonian science, with the maps' scale bars serving to emphasize the accuracy of predictions and observations of the path and width of the Moon's shadow, which could be checked on the maps to a few miles.

Whiston certainly recognized the strength of Halley's maps over his, as he went on to produce a map for the solar eclipse of 1724 ("The

Transit of the Total Shadow of the moon over Europe in the Eclipse of the Sun May 11th, 1724", etc.) depicting the predicted shadow path of the Moon across Great Britain and part of continental Europe in a style similar to Halley's. Whiston's engagement with the production of eclipse maps might also have influenced the production of a second Solar System broadside, which was published in 1720 under the title "A SCHEME of the SOLAR SYSTEM with the *ORBITS* of the PLANETS and COMETS belonging thereto" (Figure 6b).

This second version is similar to the first. It depicts the orbits of twenty-one comets as calculated by Halley and shows the relative sizes of the planets to that of the Sun, together with the proportional sizes of their orbits. It includes shading to emphasize the shapes of the planets, and telescopic detail on Jupiter and Saturn (although less than the 1712 diagram). A noticeable difference is the greater amount of text, making the whole composition look more saturated than the first version. Here Whiston goes further in his celebration of Newtonianism by inserting passages from Newton's *Opticks* in the blank areas of the diagram. These are arranged so as to form circles, probably to make use of the available space while keeping the harmony with the prevailing form in the composition, that of the circle, while also alluding to the circular shape of telescope lenses.

An additional element, not immediately noticeable amidst the abundance of visual and textual information but highly relevant, is a scale of statutory English miles placed between the lower arcs of the orbits of Mars and Jupiter, slightly off-centered to the right. It helped viewers apprehend the vastness of the Solar System in the same kind of units that were then used in terrestrial maps, like what is found in Cellarius' 'Corporum' diagram, and before that, in the *plena facies* maps of the Moon in Hevelius' *Selenographia ...* This scale of miles is needed because, unlike the 'Solar System' broadside or the text of *Kosmotheoros …*, 'Scheme' contains no prominent listing of distances to serve as an implicit scale.

All this information, combined with the dual depiction of planetary and orbital sizes on a large, stand-alone broadside, effectively transforms the Solar System map into an entity of its own—a stand-alone reference work. Nevertheless, like Huygens, Whiston was aware of the limitations of his diagram. These he makes explicit to the reader. Echoing Huygens' explanation of the *Kosmotheoros …* diagrams, Whiston remarks in the extensive caption of 'Scheme' that showing the relative scale of both orbital and planetary sizes using the same proportion factor would be impossible in practice, thus the need to include two complementary but distinct arrangements for orbital and planetary sizes. Whiston duly remarks that both were carefully calculated, with the relative orbital sizes being based on a solar parallax of 10″ (Whiston followed Newton's assumption of 10″, taking it as an upper limit; the currently adopted value is just under 9″), and the solar and planetary diameters represented "… all according to the exact Observations of Mr. Flamsteed with the Micrometer." And in order to confer an additional degree of astronomical realism, "… the planets are placed as they will stand at Noon the last day of December A.D. 1720."

Despite the somewhat distracting effect of its abundant text, Whiston's 1720 broadside overall conveys the same idea of a benevolently ordered Solar System where the Earth's vicinity is prone to cometary visits, but in which, unless God wishes otherwise, our planet and its counterparts safely proceed in their orbits around the Sun by the combined effect of gravity and inertia. Thus, it constitutes an additional seal of Whiston's commitment to promoting Newtonianism in tandem with the religious beliefs that he shared with Newton.

Referring to the publication of the 1712 version, Whiston noted in his recollections that the "*Scheme* has been of great reputation and advantage among the curious ever since." (Whiston, 1753: 191). The fact that Whiston's broadside went through at least two editions does suggest that there was demand for his Solar System diagrams. While Huygens' diagrams were conceived as book illustrations carefully intertwined with textual devices, Whiston's broadsides synthesized the knowledge of the Solar System on a single large sheet. Nevertheless, Huygens' visualization techniques were again to be adopted in a book: *Astronomy Explain Upon Sir Isaac Newton's Principles, and Made Easy to Those Who Have Not Studied Mathematics* by James Ferguson (1710–1776), a similarly keen Newtonian of a later generation.

Ferguson pursued a successful career as an author of popular books, instrument-maker, and lecturer, which garnered him a Royal stipend and admission as a Fellow of the Royal Society. *Astronomy Explained …* was his most successful publication. Originally published in 1756, it celebrates astronomy as, in Ferguson's own words, "… the most sublime, the most interesting, and the most useful …" of the sciences, through which the intellect is led to embrace the existence, magnificence, and benevolence of the Supreme Being (Crowe, 1986: 59–60). *Astronomy Explained …* offers an elementary

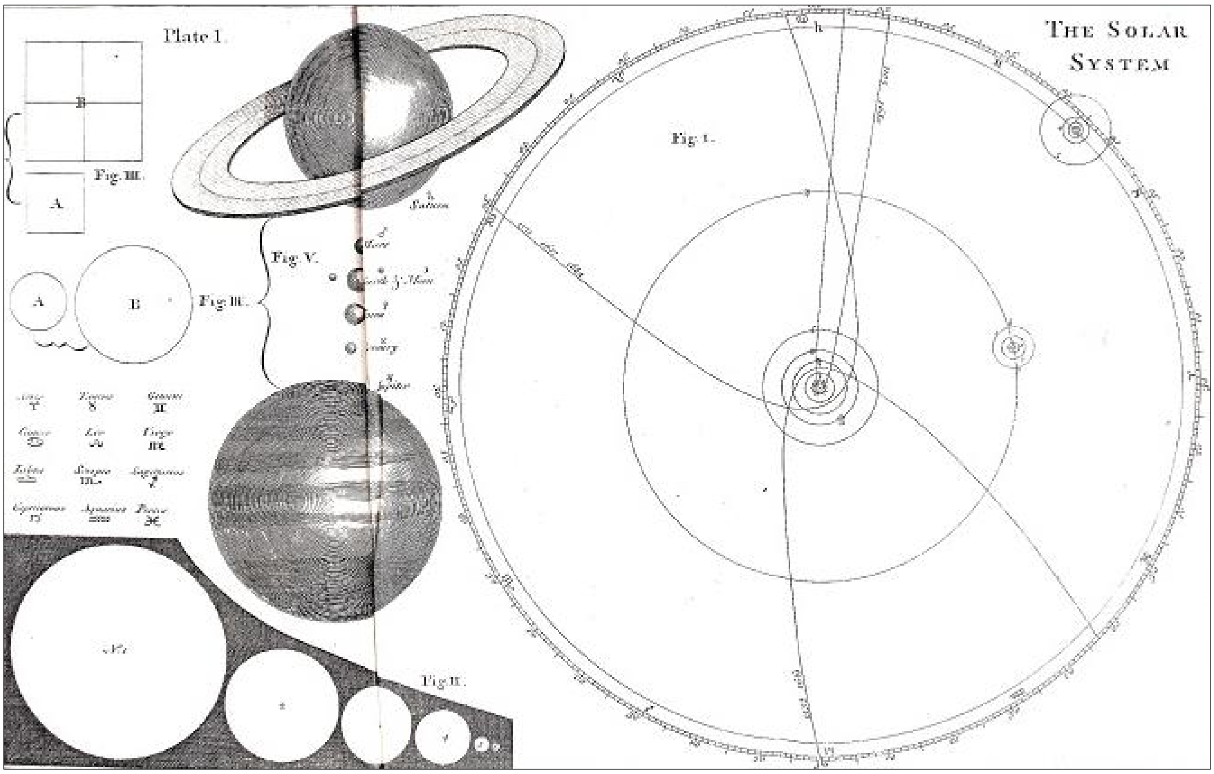

Figure 7: Ferguson's 'The Solar System' (courtesy: Wikimedia Commons).

exposition of the main concepts of astronomy and related sciences. It is divided into chapters, which are complemented by a number of fold-out plates with various diagrams. Of particular interest here is Plate I, 'The Solar System' (Figure 7). It comprises a total of five illustrations plus a list of the zodiac symbols. As in *Kosmotheoros …*, the illustrations are directly connected with the text. This plate serves to complement the content of the chapter on the Solar System.

Ferguson was aware of both Huygens' and Whiston's maps and diagrams; he cites both authors, and the similarities with their Solar System and planetary size diagrams are evident. The first figure in the order of illustrations is a diagram of the orbits of the Solar System akin to those of Whiston and Huygens. The moon orbit sizes are exaggerated. The outer ecliptic circle is used to represent the size of the Sun, but in this case the planets are shown outside of it, although close enough for a quick comparison. The planets are depicted with light and shadow effects that strongly communicate their nature as real spheroids in space. Jupiter and Saturn are presented with telescopically visible features including the cloud belts of Jupiter (but not spots), Saturn's ring (with the Cassini division), and the shadow of Saturn's globe falling across the ring.

As in *Kosmotheoros …*, these visual strategies of telescopic realism stressed the nature of the planets as worlds of their own, and thus more likely to host their own inhabitants. Ferguson was a keen advocate of the plurality of inhabited worlds, which he also regarded as an expression of God's magnificence. This idea permeates *Astronomy Explained …*, where Ferguson, similarly to Huygens decades before, leads the reader into picturing how certain celestial objects and phenomena would be seen by the putative inhabitants of the Moon and the other planets. One of the illustrations in Figure 7 (bottom left corner) combines this sense of displacement and relocation with an indirect indication of relative distance, by comparing the relative apparent size of the Sun as seen from Earth and the other planets, with the Sun appearing increasingly smaller in the sky as we move from Mercury to Saturn (left to right on the figure). But as Ferguson explains in the text, the inhabitants of Jupiter and Saturn counted on their respective satellites and, in the case of Saturn, on a ring, to reflect additional sunlight towards their planetary abodes, thus compensating for the greater distances to the Sun (Ferguson, 1756: 23–25). This is not substantially different from what we find in *Kosmotheoros …*, the distinctive element being the inclusion of a diagram that provides a direct visualization of what Huygens asks the reader to imagine and to visualize empirically with the tube experiment.

Ferguson's *Astronomy Explained* … went through at least seventeen editions, becoming one of the most influential works of popular science in the eighteenth century and a major steppingstone in the dissemination of Newtonianism. It also likely served as a vehicle for the circulation of the visual strategies to represent scale codified by Huygens and then Whiston among a wide readership, influencing authors of subsequent generations. Identical Solar System maps as well as diagrams representing the apparent size of the Sun as seen from the various planets became a staple in textbooks, popular works, and didactic materials relating to astronomy.[16] They retained an enduring presence that lasts to this day—to the point of even being taken out of the printed sheet of paper and superimposed to actual landscapes.

5 BEYOND THE PRINTED PAGE: MODERN SCALE REPRESENTATIONS OF THE SOLAR SYSTEM

Science museums, universities, science centers, and planetaria commonly use the visual strategies of Huygens and others in large displays showing sizes of the planets of the Solar System relative to the Sun and each other. One of the better-known examples is that at the Rose Center for Earth and Space of the American Museum of Natural History in New York City. Some undertakings of this nature have gone to extremes in order to show both relative sizes and distances on the same scale factor, contrary to the examples discussed in this paper. This implies going beyond the confines of a building and its immediate surroundings, such is the vastness of space and the gigantism of the bodies that sparsely populate it.

Models of the Solar System have been made by placing globes (or graphical depictions or monuments of some kind) representing the Sun and the planets at their relative sizes in selected points across vast areas, so that the distances between those planetary markers correspond to the spacing between their orbits according to the same scale factor. Examples include the 40-mile (64-kilometer) long model from the Sun to Pluto installed in Aroostook County, Northern Maine in 2003; the model that uses the building known as the 'Globen' in Stockholm as the Sun, and which goes as far as 590 miles (950 kilometers) from that origin point to include a marker for the transition between the solar wind and the surrounding galactic gas; and the Peoria Riverfront Museum's Central Illinois Community Solar System, which covers the entire Solar System, includes comet markers, and—going beyond the Solar System to the stars—takes the Alpha Centauri system (the closest star system to the Sun) to be represented by a Moon crater in the Apollo 11 landing site.[17]

These models seem to provide an illustration of Susan Stewart's point (noted at the start of this paper), as they seek to present the gigantic scale of the Solar System by superimposing it to known terrestrial landscapes. They all do what Huygens set out to do—invite us to abandon our Earthbound perspective and go on a sort of voyage through the Solar System. These models can be those extravaganzas abiding at the intersection of science, education, public art, and tourism, drawing in people who would not read a book like *Kosmotheoros* ... They may not seek to persuade their viewers to embrace Copernicanism, or extraterrestrial life, or points of theology, but they may seek to persuade, nevertheless—that science is 'cool', perhaps; or that planets are diverse (especially if the planets are painted to emphasize, for example, Jupiter's colorful clouds); or that space exploration is worthwhile; or that the Hollywood image of the nearest star being just a short 'warp speed' hop away is misleading. The strategies employed by Huygens and others endure.

6 CONCLUDING REMARKS

The strategies employed by Christiaan Huygens in his *Kosmotheoros* … were pivotal in the development of the Solar System map. In the development of terrestrial and maritime cartography in the Renaissance, the content and scope of maps changed substantially, without a sudden break with the past. Similarly, with Solar System maps, visual representations of proportional size were not totally innovative, and diagrams based on arrangements of concentric circles to represent nested spheres were part of an astronomical and cosmographical tradition that had developed from the Middle Ages. Nevertheless, the combination of those visual strategies with telescopic measurements and observation plus elements from terrestrial cartography provided an enduring set of techniques to visualize and represent the size and scale of the Solar System. The diagrams Huygens included in *Kosmotheoros …* established, in a pivotal manner, that essential set of visual techniques, giving the Solar System the status of a cartographic object.

Cellarius helped the Solar System map to emerge by combining proportionality and numerical scales in a diagram showing the relative physical sizes of the Sun, Moon, planets, and fixed stars. Cellarius' use of Ptolemaic and pre-telescopic numbers in the construction of his scale diagram, apparently in order to eschew objections against Copernicanism relating to the sizes of stars, evinces how flexibly such visual techniques, which later proved crucial in the construction of Solar System maps, could be adapted to promoting different views of the Universe. But it also hints at their limitations and at why in ensuing Copernican diagrams the fixed stars would necessarily be left out—their purported sizes and distances were just too large to fit with the Solar System on the same sheet of paper according to a common scale factor.

However, it was not just because of these limitations that stars were left out of the ensuing Copernican representations of our Solar System studied here. By equating the Sun with the fixed stars, Huygens turned our own planetary system into one among many others. Therefore, there was no conceptual reason to include the stars in cartographic representations. Whiston effectively brought the concept of the Solar System map to full effect with his broadsides, while Ferguson helped turned their conventions into staples of the visual culture of astronomy.

Similar to terrestrial maps, both Cellarius' diagram and the Solar System maps analyzed here were not meant to be neutral entities. Their authors resorted to these visual devices in order to illustrate and reinforce broader claims beyond the strict scope of astronomical dimensions and measurement, namely with regard to the plurality of inhabited worlds, certain theological positions, Copernicanism, and Newtonianism. Thus, the Solar System maps discussed here, like the popular modern versions of these maps, are persuasion devices that, like all maps, make it feasible to visualize a gigantic entity. But in this case the real scale of the entity far exceeds the limits and scale of terrestrial experience and maps.

There are constraints to what can be done in this regard. A terrestrial scale map has limitations, and so, for example, in highway maps of states or countries, cities are shown in insets at different scales. Huygens and the other authors discussed in this paper were well aware of these constraints. They were careful to explain the construction and limitations of their Solar System maps to readers, such as the use of multiple scales for planet orbits, moon orbits, and planet sizes. They complemented the maps with textual explanations and analogies, as well as ancillary visual devices that conveyed a sense of realism and displacement, such as Ferguson's illustration of the Sun as successively seen from different planets and representations of the planets that emphasized their nature as spheroidal bodies with surface features like Earth.

Ensuing generations of authors have continued recycling the same visualization strategies, which in that process have been stripped of their historical character and context, but not of their allure. That allure persists, as shown by the contemporary fascination with scale models of the Solar System. Here these strategies are transposed from printed page to actual urban areas and natural landscapes, resulting in large installations that attract, educate, and entertain. These installations superimpose the astronomically gigantic on actual large landscapes whose gigantism is more immediately apprehensible and familiar. They reaffirm that the techniques developed by Huygens and others are still the best means to represent the gigantic scale of the Universe, which might explain why they have endured for so long—even if those who use and enjoy them know little of their history.

7 NOTES

1. See also Bennet (2003: 85–100) and Hunter (2003: 124–145).
2. A 'micrometer' can be any device that allows the telescope user to make measurements of what is seen through the telescope. For example, Galileo developed what is often referred to as a 'micrometer', described by his contemporary Giovanni Alfonsi Borelli as a rule that could slide along the telescope tube, against which whatever was being viewed through the telescope could be compared (see Drake, 1990: 189).
3. For an introduction to this work and a description of each plate, see van Gent (2012), where the plate analyzed in detail in this section is reproduced (from the copy of *Harmonia Macrocosmica* at the Universiteitsbibliotheek Amsterdam) and described on 82–87. See, also, Kanas (2007: 191–194).
4. See Galilei (2001: 418–419) for a discussion. Here Galileo refers to the telescope as "… showing the disc of the star [either wandering, such as Venus, or fixed] bare and very many times enlarged." Galileo uses Venus as a point of illustration in this discussion. See also Graney (2015: 45–61).
5. In the Cellarius diagram: 'Solis, omnium coelestium corporum maximi orbicularis circuitus, et magnitude.' For numbers, see Cellarius (1708: par prior 69).
6. For a full technical discussion of 'adventitious rays' and the sizes of celestial bodies seen through early telescopes, see Grayson and Graney (2011). For a broader, less technical discussion, see Graney (2015: 53–61).
7. Kepler, for example, used the giant stars to oppose Giordano Bruno's ideas regarding a Universe of other suns orbited by other Earths. As every visible star was so giant (and dim, according to Kepler's reckoning,

since stars provided such poor illumination despite their vast sizes), there could be no possible other suns in the visible Universe. The giant, dim stars and the contrastingly tiny, brilliant Sun with its lively retinue of planets revealed different aspects of God's power, Kepler said (Graney, 2019).

8. After Hevelius (1647: Figure P, inserted between pages 222 and 223, Figure Q, inserted between pages 226 and 227, and Figure R, inserted between pages 262 and 263). For a contextualization and analysis of the cartographic and visual content of this work see Vertesi (2007), Müller (2010) and Whitaker (1999: 50–57).
9. This positing of an infinite Universe of other suns, much like the Universe posited by Bruno, was even at the time of the publication of Huygens (1698) *The Celestial Worlds Discover'd …* still subject to arguments such as Kepler had made (see Note 7), thanks to ongoing questions about the apparent diameters of stars as seen through a telescope (see Graney, 2021c; 2023).
10. The 'clock' was actually a mechanical planetarium built in 1682 (Huygens, 1944: 133–163; King and Millburn, 1978: 113–117). This planetarium is now part of the collections of the Rijksmuseum Boerhaave.
11. See Guericke (1672), which includes not only the image seen in Figure 4d but another, on page 9, with the planets all in a line, emphasizing their progressively increasing size. Horrocks (published by Hevelius) promotes the idea in discussing his telescopic observations of Venus transiting the Sun, and notes Kepler's enthusiasm for the idea (see Jeremiah Horrocks, 2012: xiii, 66–71).
12. Huygens was one of several astronomers whose work would contribute to the previously mentioned advances in the understanding that optical systems produce spuriously large images of small angular sized objects (see Graney, 2021b: 220–224).
13. Other examples include Thomas Digges' (1576) 'Perfit Description of the Celestiall Orbs …', which may not intend to convey that its stars "… farr excellinge our sonne …" are suns (see Graney, 2015: 77–80) and the frontispiece in John Wilkins' (1638) *The Discovery of a World in the Moone*. The frontispiece in Fontenelle's (1686) *Entretiens …* does convey that stars are suns, as does de Mornas' (1790) 'Systême de Descartes' in his *Atlas Methodique …*
14. Note that although observations of spots on Jupiter were reported since the seventeenth century, it was only in the 1880s that the existence of the permanent feature known as the Great Red Spot became a matter of consensus (see Hockey, 1999).
15. The diagram is complemented with additional information including the periods and distances of the planets; their diameters, masses (compared to that of the Earth), densities, and orbital velocities; the amount of light and heat received from the Sun (compared to the Earth and the Moon); the periods of the four Galilean moons of Jupiter and their distances to the latter; the period of the five Saturn moons known at the time; the width of Saturn's rings and their distance to the planet.
16. See, for example, the following diagrams: Bryan (1799: opposite page 110); Keil and Le Monnier (1746: opposite page 352); Meijer (1763: 28–29); Möller (1817: Plate B).
17. Maine: "The Main Solar System Model", https://www.mainesolarsystem.com/wp-content/uploads/sites/19/2021/08/maine-solar-system-brochure_web.pdf;
Stockholm: "Experience the World's Biggest Solar System Model",
http://www.swedensolarsystem.se/en/;
Peoria: "Community Solar System",
https://www.peoriariverfrontmuseum.org/dome-planetarium/community-solar-system.
All were last consulted on 7 May 2024.

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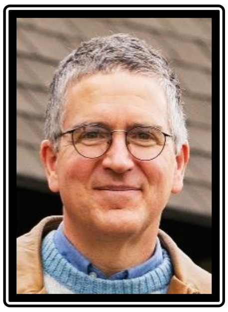
It was in that context that he became interested in Solar System maps and diagrams and joined forces with Christopher M. Graney in the research presented in this paper.



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