GALILEAN DEFENSE OF THE HELIOCENTRIC MODEL

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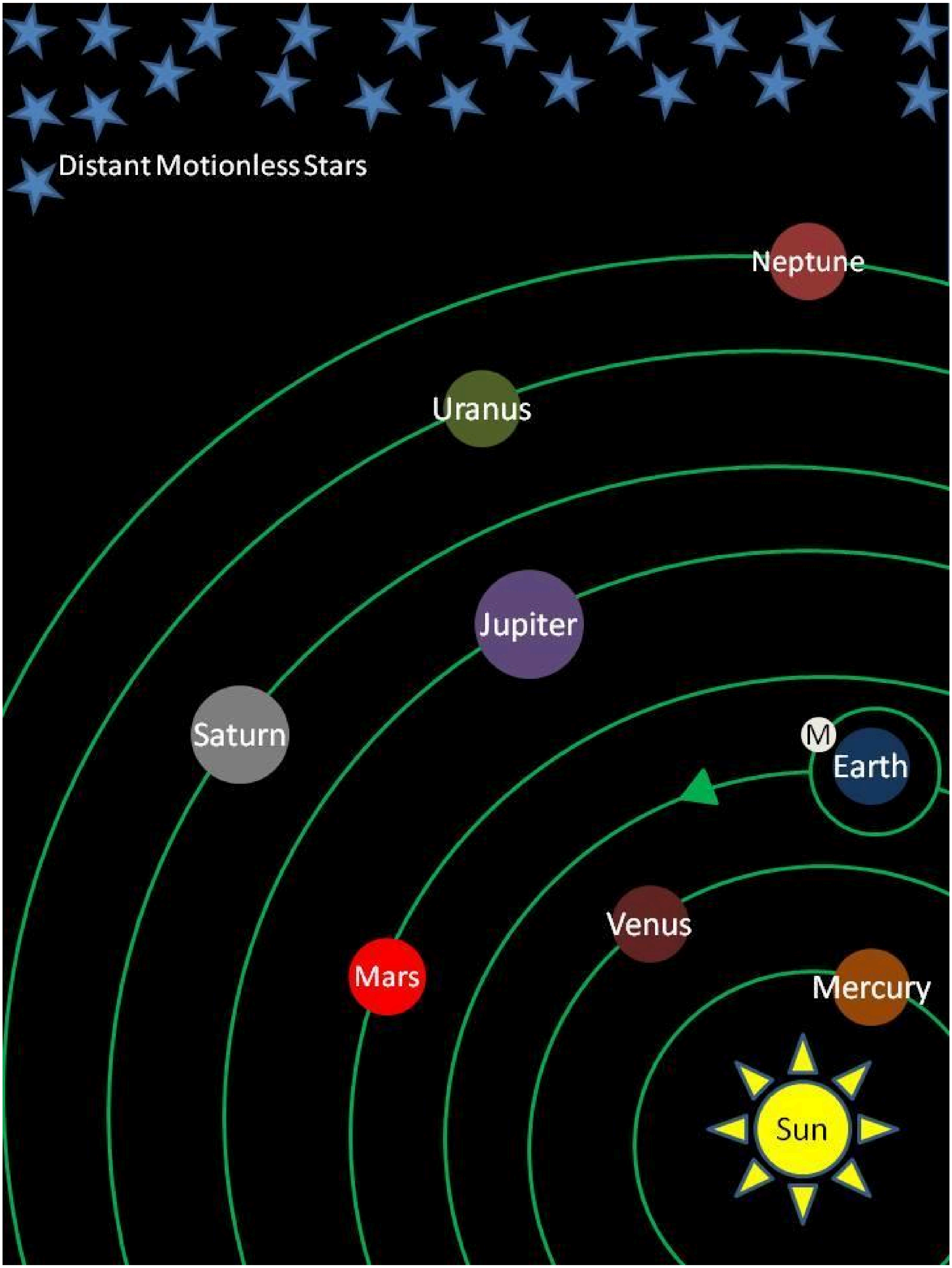
Distant Motionless Stars
Neptune
Uranus
Jupiter
Saturn
M
Earth
Venus
Mars
Mercury
Sun

The diagram depicted on the previous page is our solar system as we currently understand it. The sun is the center of the system, while the planets revolve around the sun on their orbital paths, and also rotate on their own axis. As common as this knowledge may seem, it comes to us from the intellectual labors and personal sacrifices of the 15^{th} century scientist, Galileo Galilei. In Galileo's day, it was heretical to question the geocentric geostatic Ptolemaic model of the solar system. Galileo, for scientific reasons, firmly believed in the Copernican heliocentric model, and adequately, though not always accurately, defended his beliefs. Here we will discuss five arguments comprising the Galilean defense of the heliocentric model: the inertial frame of reference, the phases of Venus, retrograde, the moons of Jupiter, and an explanation of ocean tides.

In order for Galileo to defend the heliocentric model of the universe, he first had to refute the reasonable arguments put for by the geocentric geostatic Ptolemaic system. If the heliocentric model was true, the earth would have to be rotating on its axis, and revolving around the sun. It is important to note that in Galileo's time, there had not been a defined Newtonian law of inertia: "Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it." (Finocchiaro, 1997, p. 50) To the scientists of Galileo's day, if the earth was both rotating and revolving, there were several reasonable questions that could be asked. One frequently asked question was: "why do flying birds not fall behind the earth as it revolved around the sun?" Galileo successfully answered this question by demonstrating that on a moving ship, a rock released from the top of the mast will fall at the foot of the mast, the same as on a motionless ship. (Finocchiaro, 1997, p. 52) Another legitimate question was: "why don't objects fly off the spinning earth?" Galileo answered this question by referencing that when a body subject to circular motion is released, it has the tendency to move along the straight line tangent to the point of release. (Finocchiaro, 1997, p. 52) Though he did not have the law of inertia, Galileo was able to use common knowledge of the day to eloquently argue his position.

Even before Galileo began, there were logical reasons to believe that at least some of planets revolved around the sun rather than the earth. It was known that the outer planets of Mars, Jupiter, and Saturn went through great variations in distance relative to both the sun and the earth. These variations were so significant that when Mars was closest, it appeared sixty times larger than when it was farthest. In contrast, such extreme variations in distance relative to the sun and the earth were not noticed in the inner planets of Venus and Mercury. It was also known that during their planetary orbits, the outer planets could only be seen beyond the sun, but the inner planets of Venus and Mercury, could sometimes be seen beyond the sun, but sometimes be seen between the sun and earth. From this knowledge, it was logical to deduce that at least Venus and Mercury could revolved around the sun, but if this was true, it was also logical to expect Venus and Mercury to have observable shape changing "phases" as they orbited the sun (similar to the moon), and no such phases of Venus or Mercury had ever been observed. (Finocchiaro, 1997, p. 226) With his invention of the telescope, Galileo discovered the sequential, cyclical, and incremental shape changing phases of Venus, which had not been observed with the naked eye due the extremely long period of Venus' shape changing cycle. Thus, Galileo provided the conclusive empirical evidence that Venus revolves around the sun. (Finocchiaro, 1997, p. 398)

Assuming that natural laws are as simple as possible, Galileo demonstrated that the Copernican geocentric model provided the least complicated explanation for the apparent retrograde motion of the outer planets of Mars and Jupiter. From an earthly perspective, astronomers observed that the outer planets like Mars and Jupiter would often slow down, stop, or even seem to move backward. Ptolemy had created a series of extremely complicated diagrams and equations (which will not be detailed here) in order to try to explain the phenomenon of retrograde. Not only was the Ptolemaic heuristic model cumbersome, it was not very good at making accurate predictions about retrograde motion. Galileo argued that if the heliocentric model was true, the apparent retrograde motion of the other planets was easily explainable as an optical illusion. Since earth was closer to the sun then both Mars and Jupiter, it had a smaller orbit, and so it would have a shorter revolution period. The observation of apparent retrograde was simply earth overtaking the outer planets in their orbital courses around the sun. (Galilei, 1953, pp. 342-344)

Galileo's discovery of Jupiter's moons did not provide direct evidence for the Copernican heliocentric model so much as it displayed the immaturity of Ptolemaic geocentric model's explanation of the universe. It was already known at the time that the periods of the planetary revolutions proportionally increased as their orbits (presumably around the earth) grew larger. However, the idea that revolution period was proportional to orbital size in any instance where several bodies were revolving around a central body was not considered a uniform law of nature, since there was no other know instance of several bodies revolving around a common center. It was assumed by the disciples of Ptolemy that this law of revolution-orbital proportion was unique to the planets revolving around the earth. However, when Galileo discovered four moons orbiting Jupiter in 1610, he also discovered that the revolution periods of the moons also proportionally increased as their orbits grew larger. This discovery dampened the sacredness of the Ptolemic model by showing that *if* the planets revolved around the Earth, the Earth was not the only orbital center in the universe, and that the other orbital systems followed the same laws, making the whole system more natural, and less exultingly unique. (Finocchiaro, 1997, p. 398)

Galileo's assertion of how the ocean's tides prove the earth not only revolves around the sun, but also rotates on its axis, is perhaps his most creative rebuttal to Ptolemy's geostatic model, but is definitely his least accurate. In a letter written to Johannes Kepler (a contemporary astronomer) Galileo describes the many ways water contained in a vase can move. The relevant cause described by Galileo for water moving in a vase is the motion of the vase itself. Galileo compares the moving water in the vase to the ocean tides, and the moving vase to the earth diurnally rotating on its axis while simultaneously revolving around the sun, illustrating that the changes in the motion of the water (ocean tides) can be effected by changes in the direction the vase is being moved (irregularities in the earth's motion). (Gigli, www.galileo.rice.edu)

Galileo explains this phenomenon as such:

> Thus, for 12 hours, a point on the earth's surface will move eastward, in opposition to the global westward movement of the earth, and for 12 hours it will move westward, in the same direction as the annual motion. The composition of these motions causes on one hand a slackening (due to a subtraction of two opposite motions) and on the other hand an acceleration (due to an addition of two motions in the same direction). (Gigli, www.galileo.rice.edu)

Even though this explanation did not withstand the test of Newtonian mechanics, it helped lubricate the minds of scientist, allowing them to question the geostatic theories of Ptolemy.

Given the intellectual restraints of the time, it is amazing that Galileo laid the foundations for our current understanding of the solar system. Without being able to rely on Newton's law of inertia, Galileo used common knowledge to demonstrate how the idea of a rotating revolving earth could be reasonable. With his invention of the telescope and discovery of the phases of Venus, he provided the empirical evidence Copernican's had been looking to prove at least one planet could revolve around the sun. With his simplistic geocentric explanation for apparent retrograde motion, Galileo won support from disenchanted Ptolemy supporters. His discovery of the moons of Jupiter shed doubt on whether the universe was *truly* geocentric. And even his clever yet inaccurate theory of the ocean tides kept scientists thinking about the Copernican model. For all of these things we are indebted to the heretic Galileo Galilei.

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