Galileo's Medicean Moons: their impact on 400 years of discovery
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Other Worlds, Other Civilizations?

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Abstract. Galileo's work had a profound influence on our understanding of the question of "other worlds" and the possibility of other intelligent life in the universe. When he saw the Moon with its mountains, and Jupiter with its moons, he implicitly recognized that these were physical places and thus could themselves be possible abodes for life. But some ancient and medieval scholars had already suggested as much, though without the empirical backing that Galileo's observations provided. Thus perhaps an even more important influence on the development of these ideas is that Galileo made them popular with the educated public, rather than merely the speculations of specialists. By inciting the popular imagination to take seriously the possibility of other worlds, he engaged subsequent generations of philosophers and storytellers to explore the possibilities and implications of life on those worlds.

Keywords. History of science, extraterrestrial life.

1. The Discarded Image

As so many of the presentations at this conference have confirmed, Galileo's discoveries with the telescope, epitomized by his discovery of satellites orbiting Jupiter, revolutionized astronomy. They also revolutionized our view of the universe, what has been come to be called our scientific "cosmology." And in the process, they gave a new emphasis to the whole question of other worlds and other civilizations.

To appreciate the impact that Galileo's observations had on our cosmic sense of ourselves and our place in the universe, it is important to begin with an accurate understanding of the old version that his observations overthrew. It is wrong to think that humanity's understanding of the universe was a simple Earth-centered view, that there were no other competing models in the ancient world, or that there was no speculation about other worlds and other civilizations before Galileo. And, indeed, as we know, Galileo did not propose a new model of the universe; that honor, of course, goes to Copernicus. Nor did he improve it, as Kepler did. Nor did he put it on a deeper physical basis, the way Newton did. Nor did his observations even demonstrate that it was true, in a mathematical sense, since certainly the Tycho Brahe model fit Galileo's data as well as the Copernican model did. Nonetheless, Galileo's observations and publications were crucial, indeed a pivotal event, in all of these developments. To see why, it is necessary to see the nature and the role of cosmologies in human culture.

C. S. Lewis (Lewis, 1964) has described the medieval view of the universe as "The Discarded Image". It was an image that underpinned all of art and literature, as the physical universe was thought to mirror the metaphysical. In that context, therefore, it is important to recognize that in the ancient world there were many different models for the universe, reflecting many different systems of metaphysics. While Eudoxus most famously proposed the concept that the planets were carried about the Earth in a series of concentric crystalline spheres, there were other rival ideas as well. Among them, the Atomists proposed that space was infinite, containing an infinite number of atoms, and thus there should be an infinite number of worlds. Aristotle obviously went with Eudoxus' vision and fashioned it into his understanding of the physics of motion. One obvious result of the Aristotelean system is that if the Earth is in a unique location as the natural resting point of the earthly elements, then almost by definition one would not expect there to be other Earths; the idea of other civilizations is ruled out.

Still, other thinkers even after Aristotle had other ideas. Thus, the Roman poet Lucretius, who was admired by Cicero and referenced by Virgil, could continue the ideas of the atomists and the multitude of other worlds. This quotation is from his one surviving poem, *De Rerum Natura*:

"Moreover, when there is an abundance of matter available, when there is space vacant, and no object or reason delays the process, then certainly shapes of reality must be combined and created. For there is such a huge supply of atoms that all eternity would not be enough time to count them; there is the force which drives the atoms into various places just as they have been driven together in this world. So we must realize that there are other worlds in other parts of the universe, with races of different men and different animals."

2. The Birth of Science Fiction

Stories of fantasy, including what we would now call science fiction, closely mirror the scientific advances and popular culture of the times when it is written. Among the few ancient stories of space travel, Cicero wrote a short piece called *The Dream of Scipio.* In it, he imagines Scipio actually physically traveling through the celestial spheres envisioned by Eudoxus. The purpose of this story was to reflect back on the nature of Earth from this celestial vantage point. Several hundred years later, around AD 165, Lucian of Samosata wrote a more adventurous story, *True History*, where he imagined Greek warriors traveling to the Moon where they do battle the King of the Moon and the King of the Sun, and go on to colonize Jupiter. This book was published only about ten years after Ptolemy's *Almagest* and it is reasonable to suggest that perhaps Ptolemy inspired this early bit of science fiction. What is fascinating to us, however, is that Jupiter, the Moon, and the Sun are all thought of not as mere dots of light demarking the location of crystalline spheres, but actual places that are big enough to visit and fight over. (For a further discussion of ancient science fiction, see Gunn, 1975).

The development of these ideas over the next thousand years is beyond the scope of this paper (see Hannam, 2009); it is sufficient here to note that even in the difficult times after the fall of Rome and the temporary loss of much of Greek science to the West (though it survived in the Byzantine and Arabic worlds) there were thinkers, like John Scotus Eriugena, who continued to ponder what we would call cosmology. Eriugena even considered a system of planets orbiting the Sun, which then orbited the Earth, similar to that proposed seven hundred years later by Tycho Brahe.

It is certainly true that by the medieval period the cosmology of Aristotle and Ptolemy was the common assumption in both philosophy and literature. Dante's *Inferno* is only the most famous of a large body of literature that assumed a single "world" made up of concentric spheres. Note, however, that in the medieval vision, the result of the marriage of Greek science with Christian sensibilities, the Earth is not at the center of this universe, as you might imagine from an image like this. Rather, it is at the bottom of the universe, only one step above the Damned and the Inferno. The eternal motions of the planets are occasioned by their proximity to the Prime Mover in the Firmament; Earth is so humble that it doesn't even get to move. Indeed, Lewis (1964) cites medieval thinkers who argue that the physical cosmology is in fact an exact *inverse* of the metaphysical reality...where God in the Firmament is the true center, and Earth is relegated to the furthest reaches.

But even with this cosmology predominating in medieval times, there were other ideas argued as well in the medieval university.

When 13^{th} century philosophers at the University of Paris rediscovered Aristotle's ideas, like a universe without beginning or end, they came in conflict with the Christian teaching of an omnipotent creator God. In 1277 the Bishop of Paris, Stephen Tempier, responded by listing 219 philosophical propositions that he banned from his diocese. Among them was the assertion that "God could not have made other worlds." The Bishop reasoned that God is omnipotent, and so he must have the power to make other worlds. Given their vision of the universe, "other worlds" in this sense is more closely associated with what we would call "alternate universes."

The historian David Lindberg (1992) has noted: "...the articles that stressed God's unlimited creative power gave license to all manner of speculations about possible worlds and imaginary states of affairs that it was evidently within God's power to create. This led to an avalanche of speculative or hypothetical natural philosophy in the fourteenth century, in the course of which various principles of Aristotelian natural philosophy were clarified, criticized, or rejected."

Just as one example of this "avalanche", consider this passage from Bishop Nicholas of Cusa's *De Docta Ignorantia* of 1440 (Book II, Chapter 11):

Therefore, the earth, which cannot be the center, cannot be devoid of all motion...just as the earth is not the center of the world, so the sphere of fixed stars is not its circumference...Therefore, the earth is not the center either of the eighth sphere or of any other sphere... ... In like manner, we surmise that none of the other regions of the stars are empty of inhabitants...the one universal world is... in so many particular [parts] that they are without number except to Him who created all things...

John Buriden and Nicholas Oresme had written on the possibility that the Earth could be moving and spinning nearly 300 years before Galileo, and Cusa's work predated Galileo (and Giodarno Bruno, who is often credited with these ideas) by some 200 years. Even Copernicus's work was nearly 100 years old by the time of Galileo.

Ten years before Galileo got started, William Gilbert actively pushed Copernicanism in his book on the Earth's magnetic field, *De Magnete*. However, in his introduction, he specifically criticized those who would think to pander to the public by popularizing science, and so even in the religious turbulence of Elizabethan England, this barely caused a stir. By contrast, when Galileo dusted off these ideas, he wrote about them in Italian, and campaigned them like a 17^{th} century Carl Sagan in the fashionable salons of Italy.

The result? Unlike the reaction to any of these other thinkers, people were shocked by Galileo's concepts. This reaction has fed the Renaissance (and modern) prejudice that the medieval times were a period of religious fundamentalism, some sort of dark age. In fact, it was a combination of Renaissance politics, bad theology, and bad Renaissance science that ganged up on Galileo. But, more crucially, it happened to Galileo and not any of his predecessors because he was the first to push these ideas into the popular culture.

This entry into the popular culture went beyond merely the discussion of Galileo's works among the educated gentry. It also is reflected, and carried further, by the creation of popular stories that took as their basic premise the new concept of the universe that the culture first learned about from Galileo.

In 1616, Kepler wrote a of a dream voyage to the Moon, which was finally published in 1634 as *Somnium*. It was based on contemporary astronomy, and the Moon depicted in the story was that seen in the telescope: his Moon had mountains, and the day there lasted 14 Earth days. Another pioneer of this sort of space fiction was John Wilkins, an Englishman who was one of the founders of the Royal Society and later became a bishop and noted theologian; his book, *The Discovery of a World in the Moon*, was published in 1638 and it also described traveling to our neighbor satellite. Likewise another bishop, Francis Godwin, the same year wrote about a trip to visit *The Man in the Moon.*

This sort of storytelling continued throughout the 17^{th} century, including the 1657 adventure by Cyrano de Bergerac, *Voyages to the Moon and Sun*, and the 1686 publication by Bernard de Bovier de Fontenelle, *Conversations on the Plurality of Worlds.* The latter book is notable in that he discussed not only the possibility of visiting other planets but in fact the idea that the stars themselves might each have their own collection of planets: *"One vortex may have many planets that turn round its sun, another may have but a few; in one there may be inferior or lesser planets, which turn about those that are greater; in another, perhaps, there may be no inferior planets; here all the planets are got round about their sun, in the form of a little squadron, beyond which may be a large void space, which reaches even to the neighboring vortexes; in others, the planets may make their revolutions towards the extremity of their vortex, and leave the middle void..."*

This concept was illustrated in the 18^{th} century in a marvelous painting on the ceiling of the "New Mathematical Hall" (dating from 1760) of the Jesuit college in Prague, the Klementinum (now part of the National Library of the Czech Republic.) The artist, believed to be Josef Kramolín, depicts a number of cherubs using a variety of astronomical and other scientific instruments to study the universe. One cherub, holding a banner reading "sapientissimi opus" ("the work of the wisest") is flying in a sky filled with stars and each star is surrounded by a series of elliptical planetary orbits, and radiating rays that may represent the tails of comets (Oulíková, 2006).

Not everyone in that era accepted the wisdom of dreaming of such voyages, however. The English poet John Milton, in *Paradise Lost*, has the archangel Raphael say to Adam (in Book 8, lines 172-178):

Heaven is for thee too high
To know what passes there; be lowly wise:
Think only what concerns thee in thy being;
Dream not of other Worlds,
what creatures there Live,
in what state, condition, or degree,
Contented that thus far hath been revealed
Not of earth only but of highest heaven.

It is not clear that Milton himself believes this; he was of course a great admirer of Galileo, citing him (referencing the "optic glass of the Tuscan artist") in this same epic poem. He had traveled to Florence when he was young and met with an aged Galileo after his trial. Maybe Milton is just quoting what he heard his detractors say to him about his love of that "crazy science fiction stuff".

Elsewhere (Consolmagno, 1996) I have discussed the mutual development of astronomy and science fiction. As each new development has occurred in the world of astronomy, an imaginative storyteller has been able to translate that idea into a story and thus bring that development to the attention of the general public. Some more famous examples include Jules Verne adapting the Moon maps of Beer and von Mǻdler into his *De la Terre á la Lune* (*From the Earth to the Moon*) and *Autour de la Lune* (*Around the Moon*);

Percival Lowell's vision of Mars becoming alive in H. G. Wells' *War of the Worlds*; and even the 1920s debates over the nature of our lens-shaped galaxy becoming the basis for E. E. Smith's *"Skylark of Space"* and "Lensman" books, the first classic space operas. And even today, most people probably first heard about black holes from watching *Star Trek*.

All of this delightful activity can ultimately be traced directly to Galileo. First, his observations made the Copernican system seem reasonable, if not precisely proven; and the Copernican system, unlike the crystalline spheres of Eudoxus, makes other planets around other worlds possible. Secondly, his popularization of those observations made the Copernican system well known; an idea must be known before it can be the basis of a story. And finally, Galileo's imagination allowed him to see the planets as indeed other worlds, not just in a philosophical sense but also a physical, tangible way: by seeing mountains on the Moon, and seeing moons around other planets, they became places where human beings could, conceivably, have adventures.

3. The Cetaceans of Europa?

After the Second World War, not only did the science fiction of alien civilizations mature into more respectable work; so did the science. Project Ozma, the attempt in 1960 to look for radio signals from other intelligent civilizations, was the beginning of a scientific treatment for the search for extraterrestrial intelligence. Soon thereafter, Frank Drake derived an equation that attempted to calculate the probability of us humans encountering other civilizations around other worlds by multiplying the odds of a favorable outcome to a number of functions necessary for such a detection. Among the key probabilities in this equation are the number of "earthlike" planets per star, and the fraction of those fit for life. The observational evidence to date still indicates that the number of intelligent civilizations in the universe is one, at most. As Enrico Fermi famously asked, if they exist, where are they?

Again, however, I suggest that Galileo's discovery may hold a clue to a new way of thinking about this problem.

In the early 1970s I was a student at MIT under professor John S. Lewis, who had just published (Lewis, 1971) a remarkable paper on the nature of the icy satellites orbiting Jupiter and the other giant planets, moons first discovered by Galileo 400 years ago. Lewis showed, with some simple but profound calculations, that a mixture of rock and ice with the density and size of an icy moon should have enough radioactive elements to cause the ice to melt. The result would be a differentiated moon with a rocky core, icy crust, and the possibility of a liquid water mantle.

His models were simple steady-state calculations; my task, for my master's thesis, was to create models to show how these moons would evolve with time, including such effects as the heat of fusion, convection in the liquid layers, and phase transitions between the different solid phases of water.

I was very young at the time . . . and indeed an avid science fiction fan. That no doubt is what led to this, the final sentence in my thesis: "Given the temperatures of the interiors, and especially of the silicate layers through which liquid will be percolating, the possibility exists of simple organic chemistry taking place, involving either methane from the ice or carbon in the silicate phase. However, we stop short of postulating life forms in these mantles; we leave such to those more experienced than ourselves in such speculations" (Consolmagno, 1975).

The Voyager (and later, Galileo) spacecraft confirmed that this was very likely a reasonable picture for Europa. They also confirmed, of course, that my models were fatally

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flawed. By considering radioactive heating alone, I had underestimated the heat input in Europa due to tidal heating by an order of magnitude; on the other hand, by neglecting solid state convection in the icy crust, I had also underestimated the heat flow out of Europa by an order of magnitude. My models gave the right answers, thanks to two huge but offsetting mistakes.

The "others more experienced" in such speculations were of course, Carl Sagan and his students. When I first mentioned this idea of sub-crustal life inside Europa at the Jupiter meeting in Arizona in 1975, Sagan himself challenged me by pointing out that such oceans would be too removed from sunlight, too dark to have an energy source to support life. But just a few years later, life forms such as tube worms were discovered in deep, dark parts of Earth's ocean which derive much of their energy from hydrothermal vents. Inspired by this discovery, Sagan's student Steve Squyres was among the authors proposing the habitability of Europa (Reynolds *et al.*, 1983).

If you can have life in a moon of a gas giant, then you can have life anywhere gas giants are found. This greatly increases the "number of habitable planets" in the Drake equation. Given the large number of gas giants already discovered around other stars, it seems now that life may be very possible indeed. But consider what sort of life! If you were an intelligent dolphin in Europa (perhaps breathing ammonia instead of oxygen), your universe would have a rocky center and be surrounded by concentric spheres of crystalline ice. Shades of Eudoxus! You would never know that there was a whole universe outside the upper sphere. No wonder you'd never think to communicate, much less travel to other planets around other stars. While the Drake number increases by including such possible habitats, the Fermi paradox is perhaps explained. Unless, of course, in one of those civilizations, an imaginative fantasy storyteller imagines a trip through the upper sphere. Imagine the shock if our dolphins should actually break through the crust to discover a universe above full of stars!

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