How the Heavens Go

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Heavens unit

Overarching questions:
Are representations of astronomical phenomena true or merely useful?
How does scientific knowledge travel?

I. Galileo and the Inquisition

II. Newton and the Designer

III. Laplace and the Philosophes

Readings: Newton, Letters to Richard Bentley, 330 - 339;
Kragh, Conceptions of Cosmos, 67 - 89.
Galileo’s Path

*Galileo Galilei* (1564 – 1642) was born into court culture: his father was a court musician at the Tuscan court in Florence. Galileo wanted to be a monk; his father wanted him to be a physician.

They reached a compromise: Galileo studied mathematics at the University of Pisa.
Galileo taught mathematics at the University of Pisa and the University of Padua during the 1580s and 1590s. He also served as a consultant to the Venetian Senate.

In 1609 he saw a spyglass, which had just been invented in the Netherlands. He made a few minor improvements and presented it to the Venetian Senate, as if it were entirely his own design.

They rewarded him with an improved salary in exchange for “his” invention.
Turning Skyward

Soon after impressing the Venetian Senate with the new telescope, Galileo turned it skyward. He quickly made three major discoveries:

- craters on the moon;
- resolved the Milky Way into individual stars;
- four moons circling Jupiter.

He quickly wrote up his findings in a tiny book, *Sidereus Nuncius*, or *Starry Messenger* (1610).
Moon’s Surface

Galileo had studied technical drawing, or disegno, as a student. He was adept at using shadowing and perspective to represent 3D structures. He thus painted the moon’s surface to accentuate its Earth-like features: mountains and valleys.

If the moon had craggy features like the Earth, perhaps it was not made of Aristotelian quintessence after all.
Galileo was also the first to resolve the Milky Way into discrete stars, instead of an indiscriminate band of light.

Galileo thus first suggested that the Milky Way was just like other known celestial objects, like the constellations.
Biggest Find of All

Most important – at least for Galileo’s subsequent career – was his discovery of 4 moons orbiting Jupiter.

Galileo saw in the moons an important Copernican message: if both the Earth and Jupiter could have their own moons, maybe the Earth was also “just” a planet – not the special center of the universe.
"Medicean Stars"

Jupiter’s moons became Galileo’s ticket. These were among the first new objects in the sky for millennia – so he had “naming rights.” He chose to call them the “Medicean Stars,” in honor of Cosimo II de Medici, Grand Duke of Tuscany.

Cosimo’s symbol (in family iconography, coat of arms, etc.) was Jupiter; and “Cosimo” was already close to “cosmos.” Now Galileo could show that Cosimo/Jupiter had his own band of loyal followers who never strayed far from their leader.
Court Philosopher

In the *Sidereus Nuncius*, Galileo made passing remarks about Copernicanism. Once he got to Florence, however, he became Cosimo’s *Court Philosopher*, rather than a university mathematician. Now it was his *job* to talk about causes – not just useful calculations but physical truths of astronomy.

His position at court also likely shaped his choice of literary conventions. His later books were published as *dialogues*: part of his job was to entertain the Grand Duke with after-dinner repartee.
Galileo’s Copernicanism

“Horns” [Phases] of Venus:
Galileo reasoned that Venus should exhibit the full range of phases - just like the moon - if it truly orbited the sun and not the earth. He observed the waxing and waning through his telescope.

Galileo failed to mention that the same effect would occur in the Tychonic system.
Letter to Christina

Emboldened by his new position, Galileo wrote an “open letter” to Cosimo’s mother, the Grand Duchess Christina, in 1615. She had asked Galileo how one might reconcile Copernicanism with Scripture.

He used the “open letter” format to avoid having to go through the official Church censors.

Galileo cautioned against literal interpretations of the Bible. The Bible teaches us “how to go to Heaven, not how the heavens go.”
Reaction in Rome

Galileo’s rivals sent copies to the Vatican. Cardinal Roberto Bellarmine responded by placing Copernicus’s *De Revolutionibus* on the Index in 1616: the book could not be re-published until the nature of heliocentrism was made more clearly *hypothetical*.

Bellarmine delivered the verdict to Galileo in person: he was to stop defending Copernicanism.
New Pope, New Hope

Bellarmine died in 1624, and Cardinal Barberini became Pope Urban soon after that. Barberini had a more liberal reputation; he allowed Galileo to discuss Copernicanism, so long as it was properly hypothetical.

Galileo took this as license to publish his *Dialogues on the Two Chief World Systems* (1632).
Trial!

Two main interpretations of Galileo’s trial by the Inquisition of 1632:

1. Galileo was rational; the Church was backward or stubborn.

2. The Church was reasonable; Galileo was stubborn. He repeatedly overstepped his bounds (lecturing Cardinals how to interpret the Bible; placing the Pope’s positions in mouth of Simplicius); he overclaimed what he could prove; he left out the Church’s preferred system (Tychonic) altogether; and he misunderstood the nature of scientific theories, which are always subject to revision.
House Arrest

Galileo was forced to recant (“Eppur si muove”) and sentenced to house arrest. His daughter — a nun — said all of his penitence prayers on his behalf.

While under house arrest, he wrote his *Discourses on Two New Sciences*, and had it smuggled out for publication in the Netherlands.
“Let Newton Be...”

Isaac Newton (1642 – 1727) introduced universal gravitation in his Principia (1687), alongside his three laws of motion.

“Nature and nature’s laws lay hid in night. God said, ‘Let Newton be!,’ and all was light.”

Alexander Pope (1688 – 1744)
Inverse-Square Law

Newton began with Kepler’s third law \( \frac{R^3}{T^2} = \text{constant} \), assuming *circular* orbits. The latest data from the Astronomer Royal, John Flamsteed, showed that most planetary orbits were indistinguishable from circles.

Newton had already derived \( a = \frac{v^2}{r} \) for circular motion. To obey Kepler’s law, the force of gravity between the sun and planet must then vary as \( \frac{1}{r^2} \).

From his own third law of motion, Newton then deduced that \( F = \frac{G m_1 m_2}{r^2} \).
Where’s That Data?

Flamsteed on Halley, ca. 1686: his most remarkable quality was “his art of filching from other people, and making their works is own.”

Flamsteed showed Newton much of his data on the Moon, subject to Newton’s promise not to share them...

Flamsteed: “I complained then of my Catalogue being printed without my knowledge, & that I was Robd of the fruits of my Labours.”
Newton demonstrated that universal gravitation could account for both objects’ motion.
Things Fall Down

\[ m_a a_{\text{apple}} = \frac{G m_a M_E}{R_E^2} \]
\[ m_M a_{\text{moon}} = \frac{G m_M M_E}{R_M^2} \]

\( a_{\text{apple}} = 32 \text{ ft/sec}^2 \), and
\( d = \frac{1}{2} a t^2 \). In one second, the apple will fall 16 feet.

\( R_M = 60 \ R_E \), so \( a_{\text{moon}} = a_{\text{apple}}/3600 \).
In one second, the Moon should fall \( 16 \text{ ft}/3600 = 0.053 \text{ inches} \).

The motion caused by gravitation exactly matched the amount by which the moon must fall each second in order to remain on its orbital path.
Biblical Preoccupations

Newton spent even more time scrutinizing Biblical passages than he spent on natural philosophy. Like a true Renaissance Humanist, Newton was convinced that the true meaning of the Scriptures had been obscured by centuries of shoddy translations.

Based on his intensive study, Newton secretly broke from Anglicanism. He was devout but anti-Trinitarian.
Wisdom of Design

Newton believed the cosmos displayed clear evidence of a “Master Architect,” or of intelligent design. If the Earth’s distance from the sun had been slightly different, the planet would not be habitable by life as we know it.

Newton’s position, as articulated in letters to the theologian Richard Bentley, 1690s, helped launch “natural theology.”
Beyond a Watchmaker

Newton saw evidence of God’s hand in more than just setting up the universe. Newton studied *perturbations* to the planets’ orbits, and became convinced that instabilities would *accumulate* over time.

Jupiter and Saturn perturb each other’s orbits; Newton feared that these perturbations would grow without bound.

So Newton concluded that God must *constantly intervene* in the universe, to keep the whole system stable.
Age of Enlightenment

Inspired by natural philosophy

Faith in reason and principles

Suspicion of authority or tradition
Enter Laplace

Pierre Simon de Laplace (1749 – 1827) grew up studying “natural theology” arguments inspired by Newton. But by the time of his childhood — even before the French Revolution — such arguments held much less sway, even among theology students like the young Laplace.

After studying theology, Laplace moved to Paris and studied under Jean d’Alembert, famous philosophe and co-editor of the Encyclopédie. D’Alembert recommended Laplace for a mathematics professorship.
Jupiter and Saturn Again

The latest observational data indicated that Jupiter was *accelerating* in its motion, while Saturn was *decelerating*.

In 1786, Laplace demonstrated in a calculational *tour de force* that the two effects balanced each other, and in fact they should reverse in roughly 900 years.
Beyond the case of Jupiter and Saturn, Laplace demonstrated that such perturbations do not grow without bound; the solar system is stable. Newton’s laws alone — with no divine intervention — could account for all observations.
Any Place for God?

In 1802, Laplace reported to Emperor Napoleon Bonaparte, “a chain of natural causes would account for the construction and preservation of the wonderful system of the world.”

Napoleon inquired: “Where is the place for God in your system?”

Laplace: “I have no need for that hypothesis.”
Reading Meaning in the Heavens