Galileo – Dialogue on Two World Systems

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Biography

Born in Pisa in 1564

Studied to be a priest, then a doctor, then studied math the University of Pisa. Never graduated.

Galileo learned about the invention of the telescope (in Holland 1599) in 1609, built one for himself.

Was the first to systematically study the stars and planets with a telescope and publish his findings: *The Starry Messenger* (1610), *Letters on the Sunspots* (1613)

1613-14 he begins to advocate Copernican astronomy in print

1616 Catholic Church adds the works of Copernicus to it's list of banned books; Galileo is advised by Cardinal Bellarmine not to advocate or teach Copernicanism. Galileo complies for a while.

In *The Assayer* (1623) he advocates a quantitative approach to studying natural phenomena, in contrast to the Aristotelian qualitative approach:

> Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth.

In 1632, Galileo's friend becomes Pope Urban VIII. Galileo feels emboldened, publishes his *Dialogue on Two World Systems*, which advocates Copernicanism[1]. Although the local Florentine Church authorities granted permission to publish, the Roman church authorities did not.

[1] Technically the work is a dialogue in which Copernicanism is merely discussed and compared with Aristotle and Ptolemy's astronomy, so it explicitly advocate anything. But the Aristotelian character Simplicio (translation: Simpleton) loses all the arguments and looks foolish, while the Copernicans appear obviously correct.

1632-3, Galileo was called before the Roman Inquisition and convicted of 'vehement suspicion of heresy' and received a prison sentence, which was commuted to house arrest.

1638 publishes *Discourses and Mathematical Demonstrations concerning Two New Sciences* (in Holland)

1642 Dies

Now to Galileo's 'Dialogue on Two World Systems'

Appeals to (Aristotle's) authority

Aristotelian philosopher Simplicio has a strange methodology: believe whatever Aristotle says:

> I confess to you that I thought about yesterday?s discussions the whole night, and I really find many beautiful, new, and forceful considerations. Nevertheless, I feel drawn much more by the authority of so many great writers, and in particular [Aristotle]. (194)[2]

[2] All page numbers from *The Essential Galileo*.

This style of argument was common at the time, but it's fallacious:

1. Aristotle said that *p*
2. So, *p*

NB: Aristotle himself did not rely on the authority of anyone else, he relied on his own observation and reason.

Salviati (i.e. Galileo) thinks we should do the same.

NB: it's not *always* fallacious to believe authoritative sources

- you should (mostly) trust your professors![3]
- you should (mostly) trust people's reports about their own mental states
- you should (often) treat witnesses

[3] But only when they're speaking to their area of expertise. There's an unfortunate tendency of experts in one field to speak confidently about other fields. Don't be that person!

Salviati's claim is not that we should ignore authoritative testimony; it's that you shouldn't ignore your own reason and experience and blindly follow authority figures.[4]

[4] Notice how impolitic Galileo is being here: he's not just saying that his Aristotelian contemporaries are wrong – including the Pope! – he's calling them irrational and making fun of them! It's not terribly surprising that this got him into trouble with the inquisition. Is this the only way to spark a Kuhnian scientific revolution?

Diurnal Rotation, Simplicity, and Probability

NB: 'diurnal rotation' is the daily change in the position of the Earth relative to the stars and planets. This contrasts with 'annual motion', the change in position of individual stars and planets from night to night.

The topic of *Day II* of our dialogue is whether diurnal rotation is due to the Earth rotating on its axis (Copernicus/ Galileo/ Salviati/ your position), or on the stars and planets spinning around an immobile Earth (Aristotle/ Ptolemy/ Simplicio's position).

Our observations are consistent with both stories[5], so how to choose?

[5] It's a bit more complicated than that: a spinning Earth is only consistent with available observations if that Earth is also in motion around the sun. Together with the then-common assumption that the universe is fairly small (by our standards) implies observable 'stellar parallax', which was then not observable. So, arguably, Aristotle and Ptolemy have the advantage here. See Day III of the Dialogue, and below.

In Day II of the *Dialogue*, Galileo gives seven arguments favoring a spinning earth over a stationary one.

Preliminary: relativity of motion

Observations of motion are always relative: one object moving *relative to* another object

General principle: If A and B are both moving together, from A's point of view B doesn't seem to be moving at all.[6]

Example: Two people are in a moving elevator. From their perspective neither is in motion, but from the perspective of a third person outside the elevator[7] both are in motion.

What we seek to explain are the motions of the planets relative to the earth

Since there's apparent motion relative to Earth, clearly something is moving

But, objects on the Earth don't move relative to one another (mostly), and the

In general, apparent motion of objects around a sphere (as observed from the surface of that sphere) can be explained either by moving objects, or by a spinning sphere

Specifically:

If Earth (and everything on it) are still and the stars and planets rotate around it, that would explain our observations

If Earth (and everything on it) are spinning and the stars and planets are stationary (bracketing orbits, etc), that would explain our observations

G's goal is to find further reasons to distinguish between Copernicus and Ptolemy, given that they're on part w/ predications and both are quite complicated

(For now he's bracketing the question of earth's motion around the sun, focusing solely on earth spinning on its axis)

Salviati (i.e. Galileo) offers seven arguments to believe that apparent diurnal rotation is best explained by Earth's rotation

Starting supposition:

> Let us assume that all phenomena which may be naturally dependent on these motions are such that the same consequences follow, without a difference, from one supposition as well as the other one

[6] Aristotle would agree. Galileo's claim is that that he and his followers fail to appreciate the consequences of relative motion for the observations we should expect to make.

[7] Picture an observer on the lawn watching one of those fancy glass elevators moving down the outside of a building.

Below Simplicio disputes whether this is actually true

But suppose it is true: if two theories are both consistent with the observable phenomena, how to decide which is true, or at least more probable?

Galileo's methodological assumption: all else equal, the *simpler* theory is more probable[8]

[8] We'll revisit that assumption below.

The arguments below are meant to show that a rotating Earth is more probable than a spinning sphere of stars and planets

First argument

> let us assume that, in order to bring about the same effect in the finest detail, one can either have the earth alone moving with the whole rest of the universe stopped or have the earth alone still with the whole universe moving by the same motion; if this assumption holds, who will believe that nature has chosen to let an immense number of very large bodies move at immeasurable speed to bring about what could be accomplished with the moderate motion of a single body around its own center? Indeed, who will believe this, given that by common consent, nature does not do by means of many things what can be done by means of a few? (204-5)

Reconstruction: it's simpler to spin one object (the Earth) than to move lots of objects at 'immeasurable speed'

Second argument

> ...if this great motion is attributed to the heavens, it is necessary to make it contrary to the particular motion of all the planetary orbs; each of these unquestionably has its own characteristic motion from west to east, at a very leisurely and moderate speed; but then one has to let this very rapid diurnal motion carry them off violently in the contrary direction, namely, from east to west. On the other hand, by making the earth turn on itself, the contrariety of motions is removed, and motions from west to east alone accommodate all appearances and satisfy them all completely.

Reconstruction:

All heavenly bodies appear to move from east to west across our sky each night[9]

[9] Due to *diurnal* motion.

But, planets also appear to move from west to east little by little[10]

[10] Due to *annual* motion.

For the Aristotelian, this requires attribution of two motions to each planet: westward and eastward.

On Aristotle's/ Ptolemy's model, space isn't a vacuum, it's a crystal or a fluid (there's disagreement). Eastward motion of stars and planets is explained by their participation in the motion of that crystal/ fluid, by being dragged along by the rotation of that crystal/ fluid. Each planet's westward motion is explained by its *characteristic motion*.

Analogy from later in the dialogue: the motion of a sailor walking across a ship's deck is explained by two motions: the motion of the ship sailing toward port, and the motion of the sailor walking. The sailor participates in the motion of the ship/ is dragged along with it, but also has her own characteristic motion due to her walking.

Galileo's objection:

> ...it is much simpler and more natural to explain everything by means of a single motion rather than by introducing two of them... I am not saying that this introduction of opposite motions is impossible; nor am I claiming to be giving a necessary demonstration, but only inferring a greater probability. (206)

I.e. it's simpler to explain westward motion to Earth's rotation and eastward motion to the annual motion of the planets.

Third argument

[too long to quote]

Observed pattern:

- larger orbits take longer to complete than shorter ones.
- inner moons of Jupiter orbit faster than outer ones
- inner planets orbit faster than more distant: Mars (2 years), Jupiter (12 years), Saturn (30 years)

NOTE: there's something deceptive about the video of Ptolemy's model that I showed (see video):

- This visualization of the model is designed to show orbital motions of planets
- Showing apparent diurnal motion requires whole thing to spin around the earth once a day
- Moon orbits once every second
- So, everything has to rotate around the earth every .03 seconds for the model to capture diurnal motion

Consequence:

on the Ptolemaic model, the fixed stars are MUCH further from Earth than Saturn

So, diurnal motion of stars must be MUCH, MUCH faster

Question: what exactly is the alleged problem Galileo identifies?

first possibility: it's implausible that things could be moving that fast

At the time no reason to imagine a universal speed limit

Second possibility: it's the lack of uniformity that's bothering Galileo
- why the massive disparity in speed?

I'm guessing it's the second possibility

- all of his objections in this section focused on simplicity/ uniformity

Fourth argument

> The difficulty is the immense disparity among the motions of the stars: some would move at very great speed in very large circles, while others would move very slowly in very small circles, depending on whether they are respectively further away from or closer to the poles. This is problematic because we see those heavenly bodies whose motion is not in doubt all moving in great circles, as well as because it does not seem to be good planning that bodies which are supposed to move in circles be placed at immense distances from the center and then be made to move in very small circles.

If the stars are set in a sphere around the earth which is spinning once a day, then:

- stars near the equator travel in very large orbits, very fast
- stars near the poles travel in much smaller orbits, much more slowly

Why that's problematic:

- lack of uniformity of stellar velocity
- poor planning (?)

Fifth argument

Observation: some stars have been observed to have 'moved' from the celestial equator to 'many degrees' towards the poles over previous 2000 years. Other stars don't appear to change location relative to the equator in this way.

Suppose sphere of fixed stars is spinning, not the earth:

Then the orbital circumferences of these moving stars have shortened, so their distance traveled in 24 hours has decreased, so their speed has decreased, even while other fixed stars show no such change.

Comment: not clear why this is problematic. Lack of simplicity?

Sixth Argument

Claim: Either the sphere of the fixed stars (the sphere itself) is solid, or it's fluid

If you're Ptolemy this is problematic either way

if it's solid, then you can't explain changes in position of the stars relative to one another (see fifth argument)

If it's fluid – if each star's orbit is explained independent of every other star's orbit – then there's no systematic explanation for why the stars all orbit the earth every day

But if you're Copernicus it's not problematic:

the stars don't move at all, the earth moves. No explanation for their motion necessary, since there's no motion.

Problem: what about the motion of stars relative to one another? (see fifth argument)

Seventh argument

Everyone agrees: the earth is tiny relative to the vastness of the sphere of fixed stars

> ...if we attribute the diurnal turning to the highest heaven, it must have so much force and power as to carry with it innumerably many fixed stars (all very huge bodies and much larger than the earth) and also all the planetary orbs, even though both the latter and the former by nature move in the contrary direction; moreover, it is necessary to admit that even the element fire and most of the air would be carried along as well, and that only the tiny terrestrial globe would be stubborn and recalcitrant vis-à-vis so much power; this seems to me to be a very problematic thing, and I would be unable to explain how the earth (as a body suspended and balanced on its center, indifferent to motion and to rest, and placed in and surrounded by a fluid environment) would not yield and be carried along the rotation. However, we do not find such obstacles in giving motion to the earth; it is an insignificant and very small body compared to the universe, and thus unable to do any violence to it. (209)

Simplicio's methodological objection:

> It seems to me that in general you base yourself on the greater simplicity and facility of producing the same effects; you do this when you

> judge that, in regard to the fact of causing them, it is the same to move the earth alone as to move the rest of the universe without the earth, but in regard to the manner of operation, the former is much easier than the latter. To this I answer that it seems the same to me too as long as I consider my own strength, which is not only finite but very puny; but from the standpoint of the power of the Mover[11], which is infinite, it is no harder to move the universe than the earth or a straw. Now, if the power is infinite, why should He not exercise a greater rather than a smaller part of it? Thus it seems to me that your account in general is not cogent.

[11] I.e. God.

Galileo has argued that the rotating Earth hypothesis is simpler than Ptolemy's hypothesis, i.e. it offers a simpler explanation of the observable phenomena, and for that reason it's more likely to be true. To give that thesis a label,

Principle of Simplicity When all else is equal, the simpler theory is more likely to be true[12]

[12] Versions of this principle go by other names: Ockham's Razor, the Principle of Parsimony, etc.

But why think that increased simplicity is correlated with higher probability of truth?

Before looking at Galileo's response, consider the question on it's own.

Two notions of theoretic simplicity:

Elegance simplicity as fewer and less complex hypotheses[13]

Parsimony simplicity as fewer posited entities[14]

[13] What's the criteria for hypothetical simplicity? Good question! We can point to paradigmatic examples (see the case of Neptune and Newton's gravitational laws below), but it's difficult to spell out an actual criteria.

[14] Is parsimony simply a matter of how many objects are posited to exist, or the number of *types* of objects? Is it more parsimonious to posit the existence of 100 otters and one unicorn, or to posit 102 otters?

Example:

The orbit of each planet is (mostly) explained by its gravitational interactions with the Sun and with other planets, as described by Newton's gravitational law. In 1781, observations of the orbit of Uranus fail to comport with Newton's law: $F = G\frac{m_1 m_2}{r^2}$

First possible response: complicate the gravitational law[15]

Second possible response: introduce a new, heretofore unknown object that's interacting with Uranus according to the unrevised version of Newton's law[16]

Which approach is simpler?

The first approach is more *parsimonious* but less *elegant*

The second approach is less *parsimonious* but more *elegant*

NB this is a common tradeoff: elegance for parsimony

[15] Example: gravitational attraction is *usually* the inverse square of the masses of the two bodies, but in the case of the orbit of Uranus things get sort of weird and do x, y, and z.

[16] As it happens, the surprising facts about Uranus's orbit were caused by its gravitational interaction with Neptune, which at this point had not been observed to exist. On that basis some astronomers predicted Neptune's existence, which was observationally confirmed in 1846.

The big question: why think that simpler theories are more likely to be true?

Clarification: it's easy to see *pragmatic* benefits of simpler theories: they're easier to work with, require less computing power, etc.

But that's not the question. Why think that they're more likely to be true?

One possible answer: like the Principle of Non-contradiction[17], this is a basic principle of reason, and so there is no *further* reason to believe it

[17] PNC says that all contradictions are false

However, PNC is a *logical* principle, while the Principle of Simplicity is not

But suppose you're unsatisfied with that answer:

Justifications for the Principle of Simplicity

Theological Justification: god(s) exists, and the properties of god suggest that the world is simple

Example: God is perfect, and God created the world. A perfect being would create a perfect world, and perfection is simple. So, the world is simple.

Problems:

1. Why think there's a god with the relevant properties?[18]
2. Why think perfection is simple? A blank canvas is simpler than the painting, but the painting is often more beautiful and hence more perfect. Why think the universe isn't like that?

[18] NB: even those who think there *is* such a god might hesitate to base scientific theories on their theological convictions.

Rationality-based Justification: principles of rational inquiry suggest that simpler theories are more likely to be true

Example: thesis of *Epistemic Conservatism* says that there's a (defeasible) rational bias towards the beliefs that you currently hold, whatever those might be. So, there's a rational bias *against* believing in new things. So, there's a rational bias towards parsimony. Rationality is indicative of truth, so parsimonious beliefs are more likely to be true.

Comment: this justification seems much better suited to a parsimony-based understanding of simplicity, rather than an elegance-based understanding.

Problems:

1. It's truth that coming to believe in new things is less parsimonious than not changing beliefs at all, and in that case Epistemic Con-

servatism and the Principle of Simplicity advise against belief revision. But coming to believe in *fewer* things is *more* parsimonious than not changing beliefs at all, and in that case Epistemic Conservatism and the Principle of Simplicity offer conflicting advice. So how can the latter be rooted in the former?

2. Epistemic Conservatism tells you to preference your current beliefs, whatever those happen to be. But different people have different beliefs. Suppose person A believes that p and person B doesn't: then Epistemic Conservatism offers A and B different advice about what to believe. But presumably there's no difference in what it's *parsimonious* to believe. So again, there's something of a conflict between Epistemic Conservatism and the Principle of Simplicity.

Naturalistic Justification: Consider appeal to the Principle of Simplicity as an important part of a broad scientific methodology.

- The above justifications seem to presuppose that philosophical speculation about methods have authority over the methods of science: before we employ the principle in science we must justify it in philosophy.
- Alternative picture: philosophical speculation about methodology is not prior to, and has no authority over, the practice of science.
- Alternative method for justifying appeals to Principle of Simplicity: look to the actual, existing practice of science, and if you find appeals to the Principle of Simplicity, take that as good evidence that the principle is true

Problems:

1. actual scientific practice underdetermines which principles are being employed. Qualitative parsimony? Quantitative parsimony? Parsimony about causal mechanisms? Something more bespoke?
2. Is/ ought confusion?[19]

[19] The mere fact that a scientist appeals to a principle doesn't imply that they *should* appeal to that principle. Compare: the mere fact that Anne stole the car doesn't imply that she should have done-so.

Now back to Simplicio, who rightly points out that Salviati's argument appeals to some version of the Principle of Simplicity. Which one?

Again:

> ...you base yourself on the greater simplicity and facility of producing the same effects; you do this when you judge that, in regard to the fact

> of causing them, it is the same to move the earth alone as to move the rest of the universe without the earth, but in regard to the manner of operation, the former is much easier than the latter. (211)

Background assumption: motions of stars and planets are due to facts about God's creation and/ or God's intervention, and God is all powerful, all knowing, and perfectly good[20]

[20] What we'll later call an 'O3' God: omnipotent, omniscient, and omnibenevolent.

Notion of simplicity at question: the most plausible cause is the one that expends the least effort necessary to achieve the relevant goal

So Simplicio thinks that Salviati's argument is essentially that God could expend less effort by spinning Earth than by rotating the entire rest of the universe, so (probably) God spins the earth.

Simplicio's objection: certainly it would take *you or I* more effort to rotate the entire universe than to spin the Earth, but the comparison makes no sense when you're talking about a being with infinite powers: x/ infinity = 2x/ infinity = 0. So this appeal to simplicity makes no sense.

Galileo's response:

> What I said does not regard the Mover but only the bodies moved; that is, not only their resistance, which is undoubtedly less for the earth than for the universe, but also the other particulars mentioned above... from the standpoint of the things moved, there is no doubt that the shorter and quicker mode of operation is to move the earth rather than the universe; let us also keep in mind the many other conveniences and benefits it brings about; and let us remember the very true Aristotelian principle saying that it is useless to do with more means what can be done with fewer (211-2)

It's not entirely clear what standard of simplicity Galileo is appealing to. Ideas?

One possible reconstruction:

- The standard of simplicity Simplicio describes makes no sense, so if the relevant principle instructs to maximize simplicity *of that sort* then the principle should be rejected
- Nonetheless, *some* principle of simplicity must be accepted: even Aristotle accepts that![21]
- Possible alternative: accounts positing less force are simpler

[21] Note the appeal to authority! Or is this an ad hominem? Some questionable rhetoric here....

Arguments against terrestrial motion

Thing to take away from this section: Aristotelians were wrong, but they weren't crazy; they had sophisticated arguments backing up their theories. Some observations (seemed to) support their position better than the Copernican rival.

Arguments come in roughly two varieties: arguments from astronomical observation, and arguments from terrestrial motion

Argument from astronomical observation

Argument from Stellar Parallax:

1. Suppose that the Earth orbits around the Sun, and so it it undergoes very large changes in position throughout the year.
2. If object A is closer to your point of observation than object B, and your point of observation changes, then the apparent relative positions of A and B change as well[22]
3. So, as the Earth undergoes annual motion, the apparent relative positions of the stars should change.
4. But the apparent relative positions of the stars don't change
5. So, the Earth does not orbit the Sun

[22] Hold one finger six inches in front of your face, and another finger at arm's length. Close one eye and move your head from side to side while holding your fingers still. The relative positions of the two fingers will appear to change. This is the phenomenon of *parallax*.

Problem with this argument: the farther away the observed objects, the less parallax.

- Gallileo and his contemporaries thought stars were millions of miles away, but they're much, much farther than that
- So the parallax effect is extremely small, so small as to be undetectable with instruments available in the seventeenth century[23]
- So, the intermediate conclusion at line (3) depends on background assumptions about the distance of the stars and the quality of instruments, assumptions that turned out to be false
- Galileo and his contemporaries didn't know any of this, and Galileo himself didn't have a good response to the argument from stellar parallax; it was one of the chief pieces of observational evidence agains the Copernican/ Galilean theory

[23] Instruments capable of detecting stellar parallax was not developed until the nineteenth century.

Arguments from terrestrial motion

These arguments begin with observations of the motions of ordinary physical objects, and extrapolate to predictions of what we would observe *were the Earth in motion*. Since we do not in fact observe those extrapolations, we conclude that the Earth is not in motion.

Salviati (on behalf of Simplicio) describes several observable ‘facts’ about ordinary objects in motion that support a stationary Earth[24]

[24] NB that some of those ‘facts’ are disputed, in particular the claim that a weight dropped from the mast of a ship moving at constant speed will land far away from the base of the mast, against the direction of travel. This is false.

1. Drop a rock from a high tower and it lands at the base of the tower. If the Earth were in motion then it would land far away, as the Earth would have rotated or traveled (via annual motion) a great distance.
2. Shoot a cannonball straight up and it will come straight back down to its point of origin. If the Earth were in motion then it would have moved while the cannonball was in the air, so that cannonball would land far away.
3. Shoot one cannonball to the east and one to west under similar circumstances and they will travel the same distance. But if the Earth were in motion, spinning eastward, then you’d expect the westward shot to travel much farther
4. Fire your cannon directly at a castle to the north and you’ll hit it. But if the were rotating eastward then in the interval between when the shot leaves the cannon and when it hits something the castle will have moved, so you’ll miss it – the ball would land far to the west of the castle.

More carefully:

Aristotle’s Tower argument reconstructed:

1. If you drop a rock from a high tower it lands at the base
2. The rock travels in a straight line toward the center of the earth
3. So, the Earth is not in motion

Is Aristotle begging the question?

But how do we know (2)?

Simplicio claims we know it by observation: the tower wall is straight and perpendicular to the horizon (i.e. if extended downward it would hit the center of the earth), and when the rock is dropped it falls at a uniform distance from that wall, so the rock must be traveling in a straight line towards the center of the earth.

But there's an alternative explanation: the rock has both a vertical (i.e. toward the center of the Earth) and a horizontal motion, and the reason it travels parallel to the tower wall is that the rock and the tower are both traveling horizontally together.

So which is correct?

Roughly, if the Earth is stationary then the rock's motion must be in a straight line toward the center of the earth, but if the Earth rotates on its axis then the rock's motion must be something else.[25]

[25] NB that the rock could still be traveling in a straight line, depending on the speed of rotation and the speed of fall. As a matter of fact, thought, it isn't: the rock's horizontal motion is uniform, but its vertical motion increases as it falls.

So, (2) is not supported by observation, unless we presuppose that the Earth is not in motion.

If we don't make that supposition, then the argument has an unsupported premise, so we have no reason to accept its conclusion.

If we do make that supposition, then the argument is question-begging: it presumes the conclusion as one of its premises. Question-begging arguments are fallacious, so they offer no reason to accept their conclusions.

So either way, whether we make the supposition or not, the argument provides no reason to accept the conclusion.

Galileo's refutation of the 'drop a rock from a mast' argument

Recall the argument: if you drop a rock from the mast of a ship, and that ship is in motion, then the rock will not land next to the mast: it will land far away, toward the rear of the ship.

This supports a fundamental tenant of Aristotle's theory of motion: when you stop imposing any outside force on an object, its motions are governed only by its characteristic motion, which in this case is *in a straight line towards the center of the universe.*

Galileo's strategy: refute the tenant by denying the observation, make an argument! Very surprising!

Argument:

- Imagine a perfectly spherical ball on a perfectly smooth plane, all in a vacuum.
- what happens when the plane is inclined?
  - the natural motion of the ball is to roll down the plane, in a continuously accelerated motion, ad infinitum; the only way to stop it and make it stand still is to impose some force upon it
  - it would only roll *up* the plane if some 'force were impressed upon it' – if it were pushed – and after that its speed would gradually decline until it stops and changes direction

But what happens if the plane is perfectly level?

SIMP. Since there is no downward slope, there cannot be a natural tendency to move; since there is no upward slope, there cannot be a resistance to being moved; thus, the body would be indifferent to motion, and have neither a propensity nor a resistance to it; I think, therefore, that it should remain there naturally at rest. Sorry to have forgotten, for I now remember that not long ago Sagredo explained to me that this is what would happen.

SALV. I think so, if one were to place it there motionless; but if it were given an impetus in some direction, what would happen?

SIMP. It would move in that direction.

SALV. But with what sort of motion? A continuously accelerated one, as on a downward slope, or a progressively retarded one, as on an upward slope?

SIMP. I see no cause for acceleration or retardation since there is neither descent nor ascent.

SALV. Yes. But if there is no cause for retardation, still less is there cause for rest. So, how long do you think the moving body would re- main in motion?

SIMP. As long as the extension of that surface which is sloping neither upward nor downward.

SALV. Therefore, if such a surface were endless, the motion on it would likewise be endless, namely, perpetual?

SIMP. I think so... [yes]

Comment so far:

This is all coming in the context of agreement that physical objects have characteristic motions, as Aristotle supposed, and that the characteristic motion of the sphere is towards the center of the Earth. Galileo's point is that, when the sphere is prevented from moving according to that characteristic motion, but no other forces are acting upon it, the result is not immobility, but continuity

Application to the 'drop a rock from the mast' example:

What shape would a surface have to be in order to slope neither up nor down, relative to the center of the Earth?

It would have to be spherical, just like the surface of the Earth (some idealization here)

A ship traveling on the sea is just like the sphere on the horizontal plane: its travel is neither upward nor downward. So, like the sphere, it should move endlessly with uniform motion until some force is imparted upon it[26]

The rock at the top of the mast is also traveling on a horizontal plane, so it too should maintain its uniform speed until acted upon

Dropping the rock does not impart a *horizontal* force upon it, it merely removes the force opposing its downward motion

So, the rock should travel with the ship, and land directly beneath the point from which it was dropped.

Big picture lesson:

Suppose the Earth rotates, the tower rotates with it, and the rock is dropped from the top of the tower. The rock and the tower share the same horizontal motion. Dropping the rock does not impose any new *horizontal* motion on it; rather, it removes the force opposing its downward motion.

Aristotle supposed that, were the Earth in motion, the rock would land far from the base of the tower. That's not what we observe, so the Earth is not in motion.

But we now see that Aristotle is incorrect: whether the Earth is in motion or not, we should expect the rock to land at the base of the tower. So the tower example provides no reason to believe that the Earth is not in motion.

[26] Note the idealization here: of course the ship encounters resistance form the water it passes through, so we never actually observe a ship traveling endlessly at uniform speed in the absence of some force (a sail, a propellor, etc).