



PHY1033C/HIS3931/IDH 3931 : Discovering Physics:  
The Universe and Humanity's Place in It  
Fall 2016

Prof. Peter Hirschfeld, Physics




# Announcements

- Reading this week: Gregory, Chapter 8.

[The moon as a falling body](#)

[See for yourself](#)

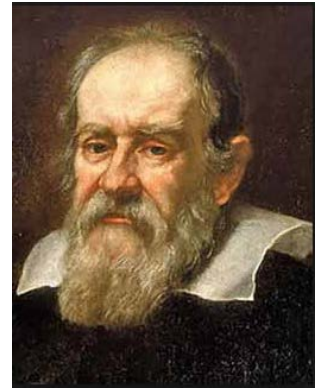
[Newton and the apple](#)

- Apologies for Prob. 2 on HW4 – a & b repeated
- HW3 grades lost  Please bring graded HW3 to class, thanks.
- Test announcements

# Midterm exam

- In class Thursday, Oct. 20
- Covers all material up through end of today (10/11)
- Bring: ID, scratch paper, calculator
- Format: 30% mult. choice 40% short answer 30% essay (choice of 2)
- Review 1: NPB 2205 5pm Monday 10/17 (Ariel)
- Review 2: NPB 2205 5:30pm Wednesday 10/19
- 1 side paper “cheat sheet” (handwritten) allowed

# Last time

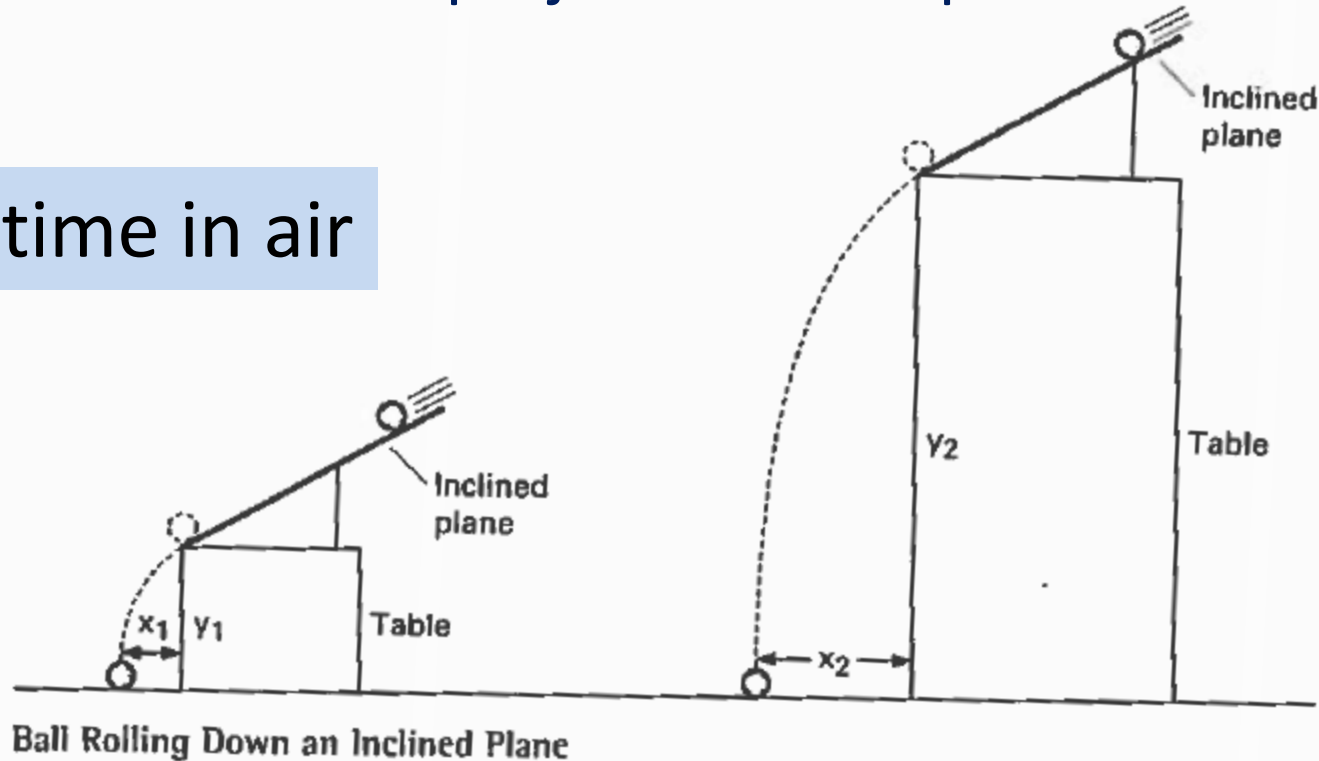


Galileo's ideas about earthly motion:

- Falling bodies: no leaning tower, didn't really believe all bodies fall at same rate (initially)  
Didn't believe Aristotle either: "thought expt."
- Real expts:
  - pendulum: period  $T$  independent of amplitude  
length  $l \propto T^2$
  - using inclined planes showed  $y \propto t^2$
  - results gave him confidence to apply math to earthly realm

# Galileo showed that projectiles have parabolic motion

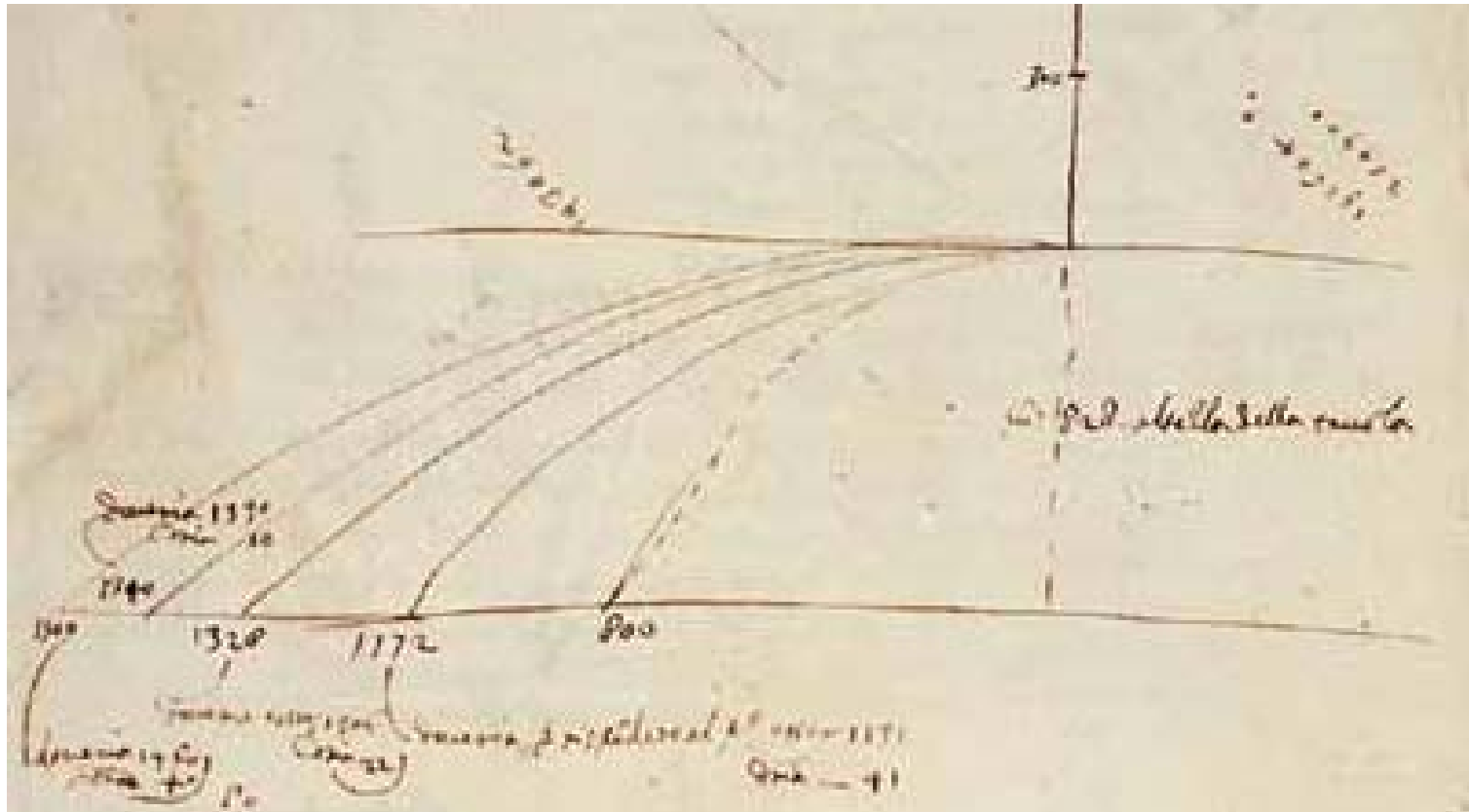
t=time in air



G's measurements showed that  
heights  $y \propto x^2$  (parabola)  
ranges  $x \propto t$   
consistent with  $y \propto t^2$

G analyzed motion in terms of composite ("double") motion in both  $x$  and  $y$  simultaneously. Taken together, two observations imply  $y \propto t^2$  as before

# The actual logbook!



Importance of Galileo's approach to understanding motion: 1<sup>st</sup> combined use of empirical measurements and mathematical analysis to study earthly motions (motion of objects on the Earth)!

# By timing a swinging chandelier in the Pisa cathedral with his pulse, Galileo noticed

1. The period of the chandelier was independent of the length of the cord it hung from
2. The chandelier never stopped swinging
3. The amplitude of the chandelier's oscillation (size of the oscillation back & forth) was proportional to its mass
4. The amplitude was inversely proportional to its period
5. The period of the chandelier was independent of the amplitude

# Galileo deduced laws about falling bodies from inclined plane experiments

1. using a coating of ice to minimize friction
2. because he could slow down the motion and get better accuracy
3. because he was forbidden to use the leaning tower of Pisa due to his Copernican views
4. because he wanted to prove Aristotle's predictions right
5. because Giovanni de Medici had asked him to build a roller coaster in Florence



Galileo heard about a new invention



Built one and turned it on the heavens

Publishes *The Starry Message* (in Latin) March 1610

Observed three things

- Moon had rough surface

- Many more stars than thought

- Jupiter had moons

Was a sensation

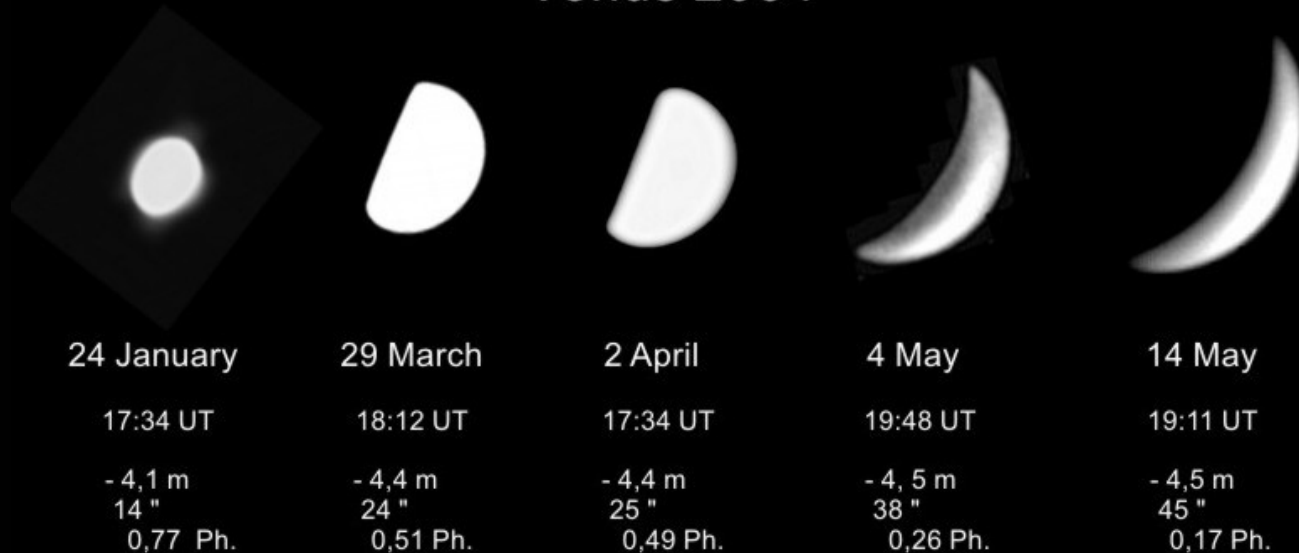
To Florence, 1610, as court philosopher to Cosimo II



By end of the year he'd discovered a new phenomenon

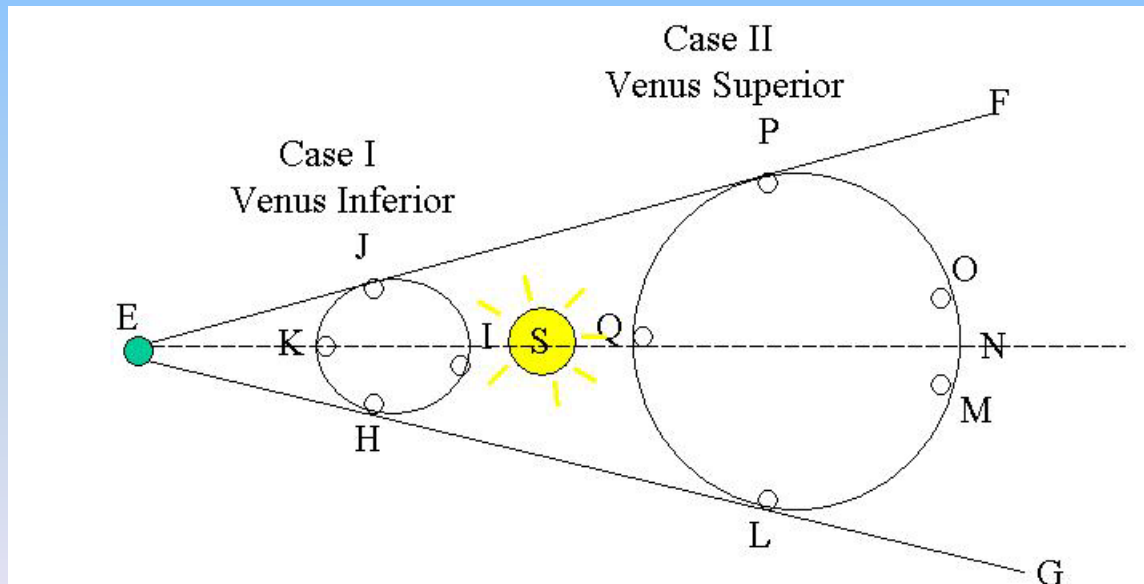
## The phases of Venus

### Venus 2004

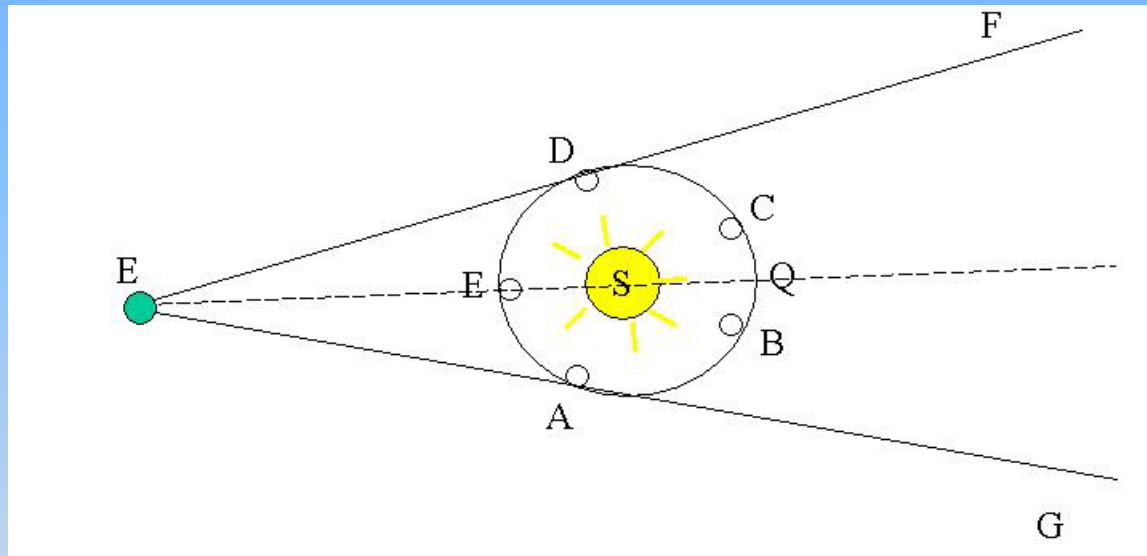


Telescope: Celestron SC G-8 (D=203mm, F=2032mm), Philips ToUcam, K3CCD Tools  
Author: Zlatko F. Kovacevic, Virovitica, Croatia

But... according to Ptolemy Venus can't have phases



Venus *would* show phases in a Copernican system



But so would it in a Tychonic system

So, while Venus's phases *do* disprove Ptolemy, they *don't* prove Copernicus



Galileo is invited to Rome where he is celebrated for his achievement

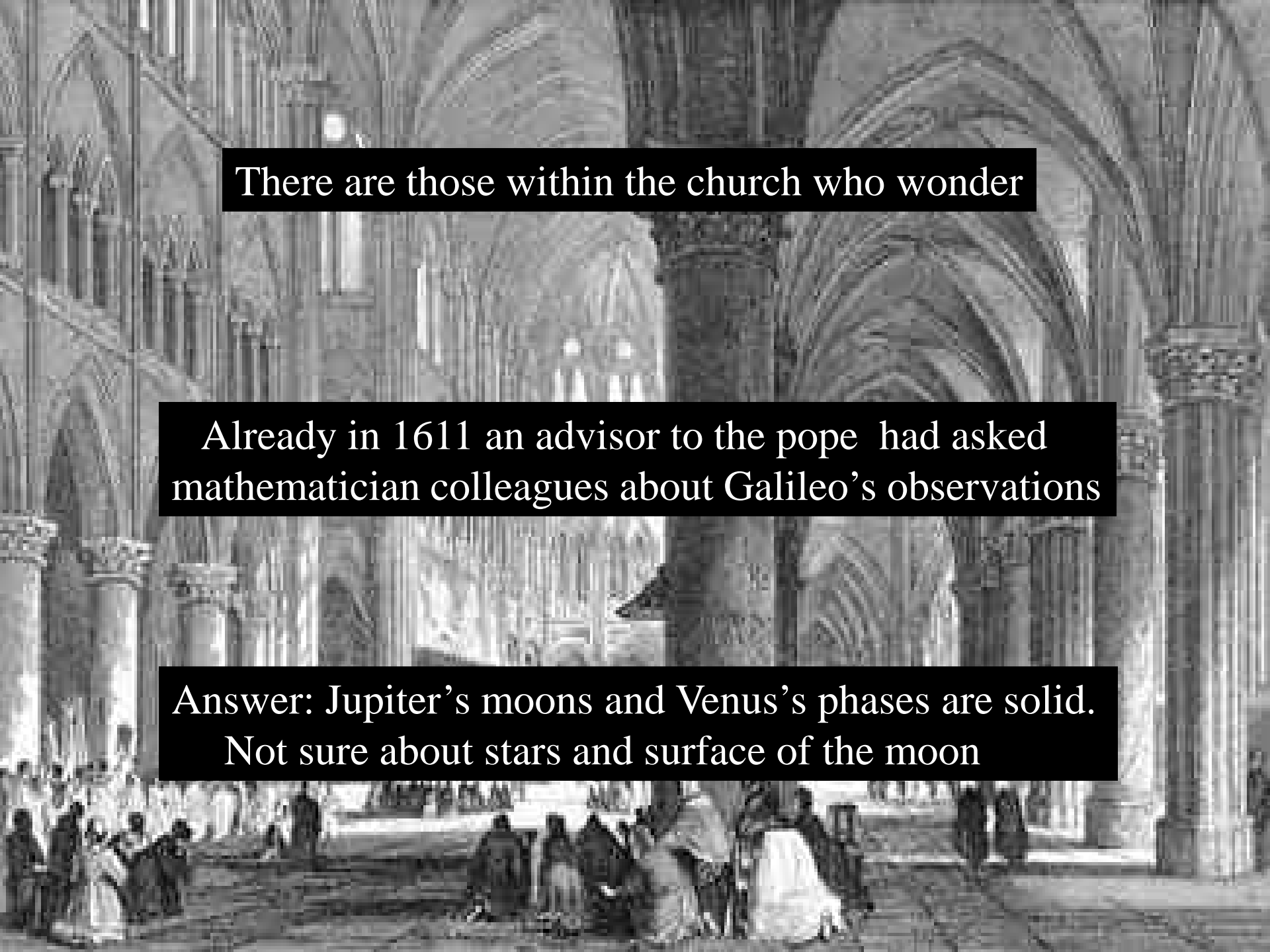


**Between 1610 and 1616 Galileo chooses to ignore Tycho's system**

**Even though he cannot prove the earth's motion,  
he begins more and more to tout the truth of Copernicus**

**It's not long before people begin to assume that  
Galileo backs Copernicus**





There are those within the church who wonder

Already in 1611 an advisor to the pope had asked mathematician colleagues about Galileo's observations

Answer: Jupiter's moons and Venus's phases are solid.  
Not sure about stars and surface of the moon

The image shows the front facade of the Basilica of Santa Maria Novella in Florence, Italy. The facade is a masterpiece of Renaissance architecture, featuring a large central rose window, a triangular pediment with a blue and gold star, and a series of arched doorways. Scaffolding is visible on the right side of the building, indicating restoration work. A street lamp is on the left, and a statue on a pedestal is in the foreground. The sky is blue with scattered white clouds.

Others worried if Galileo's claims square with Scripture?

In this church in (Santa Maria Novella) in 1613 Thomasso Caccini denounced Galileo's view as incompatible with Scripture and later forces the issue with the church hierarchy

A wide-angle photograph of St. Peter's Basilica and its square in Rome. The large dome of the basilica is prominent on the left, and the colonnade of the square extends towards the right. The sky is clear and blue. The image serves as a background for the text overlays.

In 1616 Galileo decided to go to Rome to clear things up

Things do not go as anticipated

The pope appointed a commission to advise him, which resulted in a general prohibition for everyone against holding a Copernican view



Cardinal Robert Bellarmine

In a famous meeting with Bellarmine Galileo was told he could not hold or defend the Copernican view

Others were present, but it's not clear what if anything they said to Galileo

To quell rumors, Galileo obtained an affidavit from Bellarmine confirming that he had not been condemned

In 1620 Galileo's protector,  
Grand Duke Cosimo II, died  
at the age of 30



Cosimo II

Ferdinando II



The new grand duke was only an adolescent,  
so Tuscany was ruled by his mother and  
grandmother until he came of age in 1628

Galileo now comes up with an answer to a major objection to Copernicus

Why don't we sense the motion of the earth?

Develops a **new physics of motion**

Aristotle was wrong – not all motion requires a mover

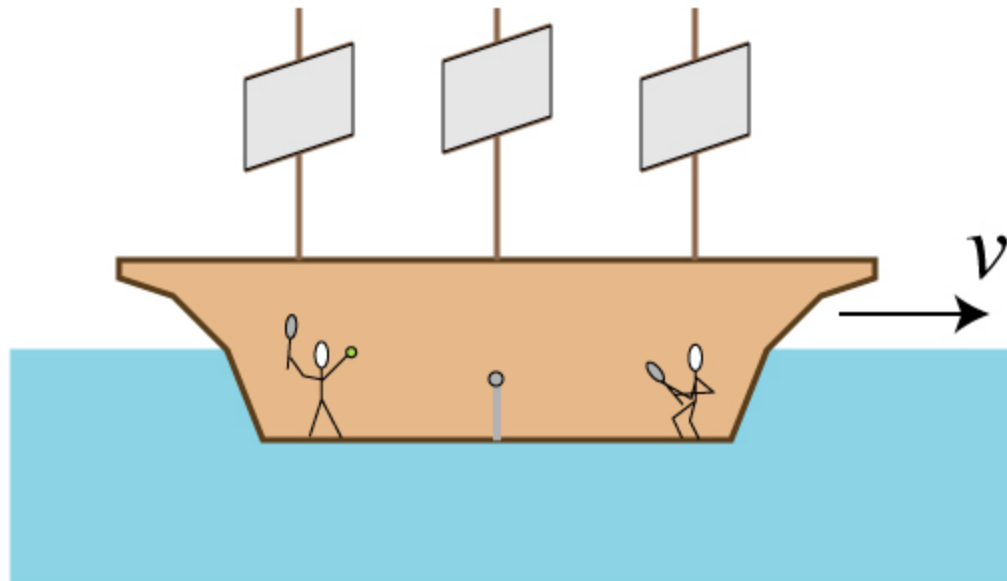
Uniform motion in a perfect circle is a natural state

“Inertial motion” is a state of being equal to rest

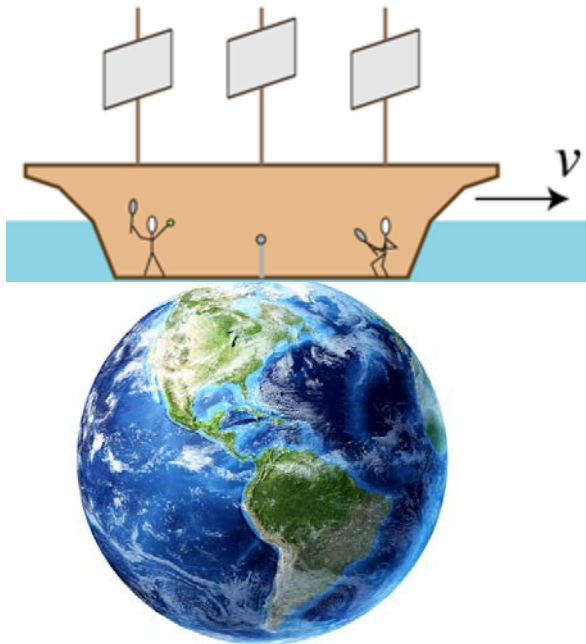


**Galileo:** Uniform circular motion will, like rest, continue forever  
unless interrupted

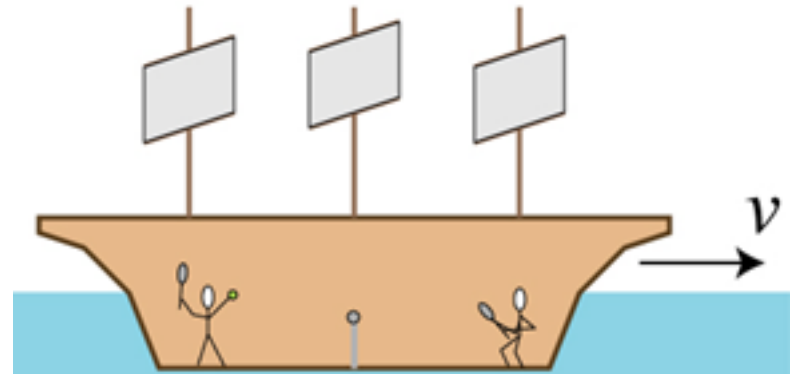
If rest and (uniform circular) motion are equivalent states of being, then our experience will be the same at rest as in uniform motion – I can't be sure if I'm at rest or in motion unless I can detect another frame of reference – **motion is relative**



Galileo's own notion that motion could be uniform and unending applied really only to circular motion **at the Earth's surface!** He didn't quite get to idea that motion would continue in straight line unless something changed it (Newton)



Galileo: you can't tell you're moving in a ship because it is going around the Earth in uniform circular motion

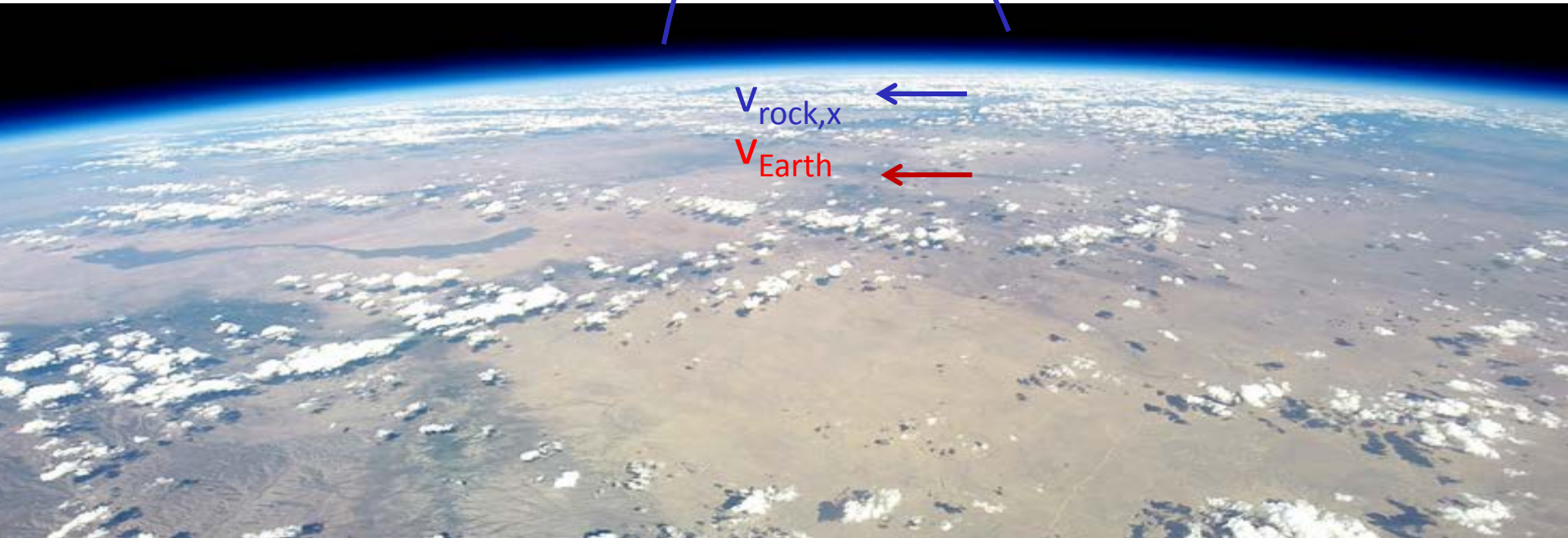
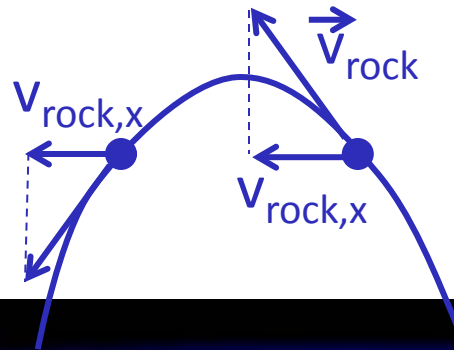


Modern view: a "reference frame" moving at constant velocity can't be distinguished from any other reference frame, incl. one at rest!

Still we call this principle "Galilean relativity"



Revisit old problem posed by Ptolemy and others:  
throwing a rock up when Earth is spinning

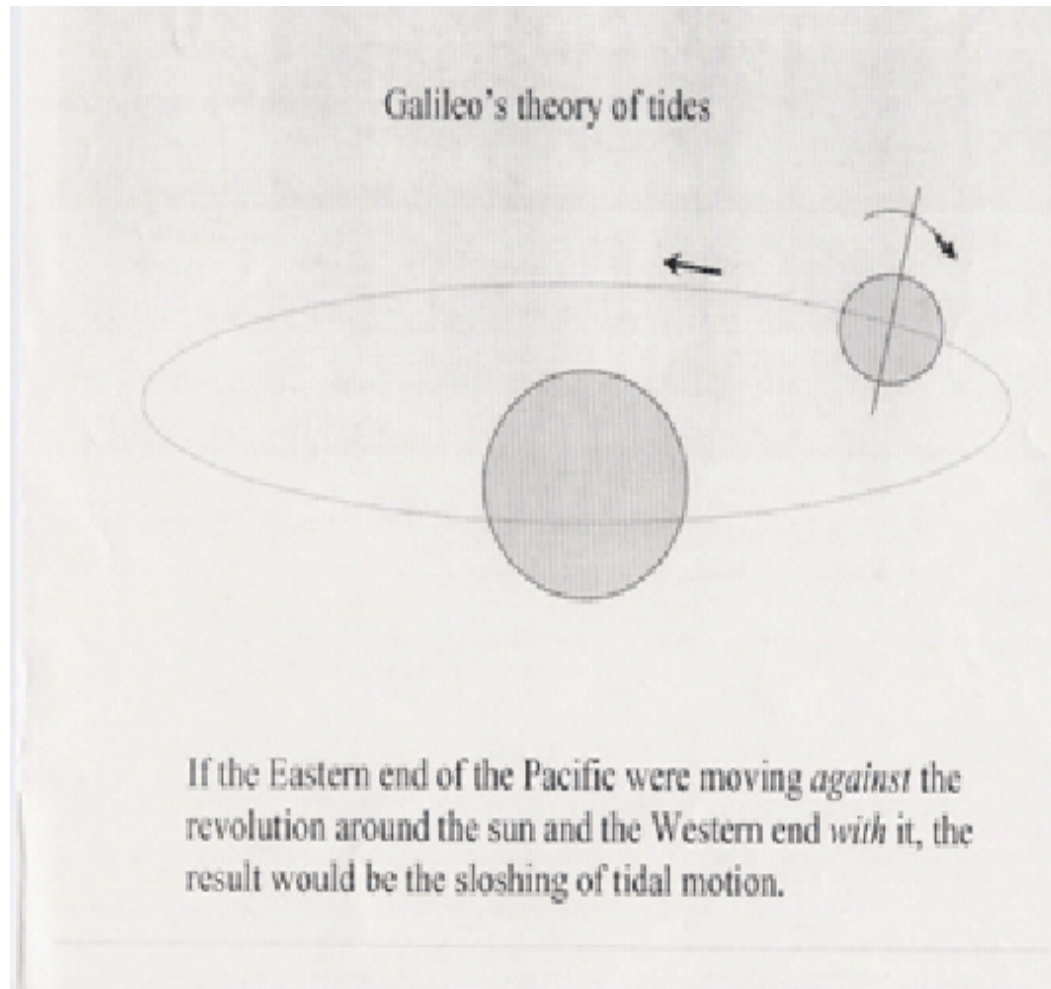


Q: what property of an object makes it stay going in straight line, resist friction, air resistance, etc.?

Inertia: the tendency of an object to resist changes to its state of motion (including rest!)

Equivalent to *mass*!

Galileo also tried to develop a proof that the earth moved –  
his theory of tides



N.B. Kepler had already pointed to Moon as causing tides via something akin to gravitation!

In 1623 Galileo's friend, Mafeo Barberini, was elected pope

Galileo visited him in 1624  
and again in 1630

Urban knew Galileo was  
working on a new book  
dealing with Copernicus

Urban had 2 requirements

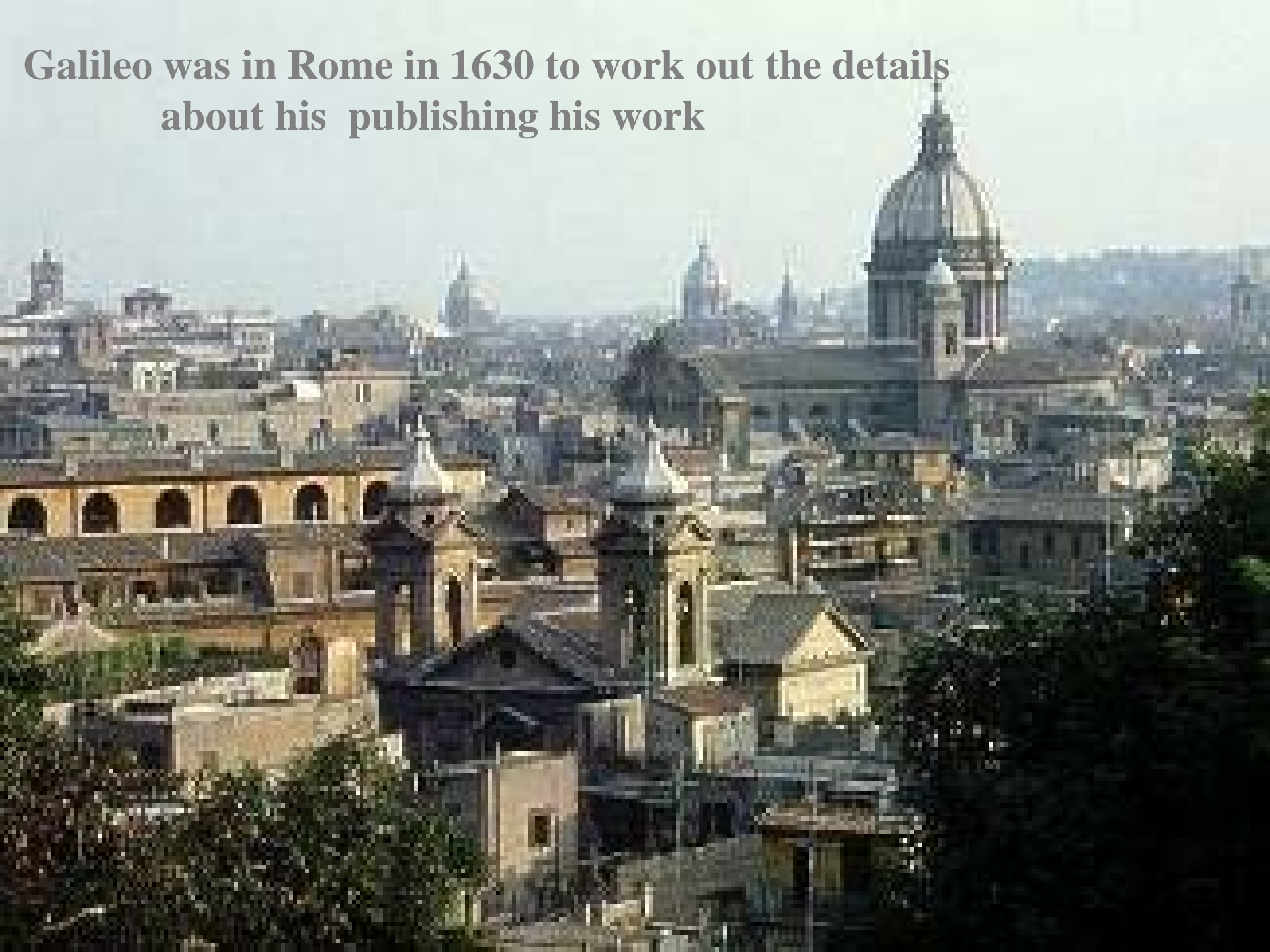
Must treat Copernicus as hypothesis

Must not title the book *On the Ebb and Flow of the Sea*

Pope Urban VIII



**Galileo was in Rome in 1630 to work out the details  
about his publishing his work**







Galileo believed he could meet Urban's first requirement by creating a discussion among three interlocutors

Eventually he was able to get church representatives to sign off on the book

In the course of these negotiations, Galileo did not mention anything about the meeting with Bellarmine in 1616

The book came out in February of 1632 as *Dialogues on the Two Chief Systems Of the World*

Galileo's critics soon persuaded the pope something had to be done

The trial began in April of 1633 and turned on documents from 1616



Galileo was convicted of  
Heresy and recanted his  
Belief in the Copernican  
system

He was not tortured, but  
Placed under house arrest







Galileo's tomb in Sante Croce

## What happened in 1616?

After hearing the commission's report the pope was specific about what was to be done

“Thursday, 25 February 1616. The Lord Cardinal Mellini notified the Reverend Fathers, the Assessor, and the Commissary of the Holy Office that the censure passed by the theologians upon the propositions of Galileo—to the effect that the Sun is the centre of the world and immovable from its place, and that the Earth moves, and also with a diurnal motion—had been reported; and His Holiness has directed Lord Cardinal Bellarmine to summon before him the said Galileo and admonish him to abandon the said opinion; and, *in case of his refusal to obey*, that the Commissary is to enjoin on him, before a notary and witnesses, a command to abstain altogether from teaching or defending this opinion and doctrine and even from discussing it, and, if he does not acquiesce therein, that he is to be imprisoned.”

**In a meeting of the Holy Office of March 3, 1616  
Bellarmine reported on his meeting with Galileo**

**“The most illustrious Lord Cardinal Bellarmine having  
given the report that the mathematician Galileo Galilei  
*had acquiesced* when warned of the order of the Holy  
Congregation to abandon the opinion which he held till  
then, to the effect that the sun stands still at the center of  
the spheres but the Earth is in motion”**

**It would seem that an intervention by the commissary  
was unnecessary**

But, according to disputed document

Friday, the twenty-sixth. At the palace, the usual residence of Lord Cardinal Bellarmine, the said Galileo, having been summoned and being present before the said Lord Cardinal, was, in the presence of the Most Reverend Michelangelo Segizi of Lodi, of the order of Preachers, Commissary-General of the Holy Office, by the said Cardinal, warned of the error of the aforesaid opinion and admonished to abandon it; **and immediately thereafter, before me and before witnesses, the Lord Cardinal being present, the said Galileo was by the said Commissary commanded and enjoined, in the name of His Holiness the Pope and the whole Congregation of the Holy Office, to relinquish altogether the said opinion that the Sun is the center of the world and immovable and that the Earth moves; *nor further to hold, teach, or defend it in any way whatsoever, verbally or in writing; otherwise proceedings would be taken against him by the Holy Office*; which injunction the said Galileo acquiesced in and promised to obey. Done at Rome, in the place aforesaid, in the presence of R. Badino Nores, of Nicosia in the kingdom of Cyprus, and Agostino Mongardo, from a place in the Abbey of Rose in the diocese of Montepulciano, members of the household of said Cardinal, witnesses.**

Did the church forge this document at the time of the trial?

No

All the documents are in the same handwriting

Why would the church create a document that showed the the pope's instructions had not been followed in 1616?

In other words, the church did not agree that the work was hypothetical

Galileo was guilty of holding and defending Copernicus