

# Galileo & Scientific Revolution

# Kepler's Third Law: Relating Orbits

The square of a planet's orbital period is proportional to the cube of its orbital semi-major axis:

$$P^2 \propto a^3$$

$$\text{Jupiter: } 5^3 / 12^2 = 125/144 \sim 1$$

Planet	$a$ <u>Semi-Major Axis</u>	$P$ <u>Orbital Period</u>	Eccentricity	$P^2/a^3$
Mercury	0.387	0.241	0.206	1.002
Venus	0.723	0.615	0.007	1.001
Earth	1.000	1.000	0.017	1.000
Mars	1.524	1.881	0.093	1.000
Jupiter	5.203	11.86	0.048	0.999
Saturn	9.539	29.46	0.056	1.000
Uranus	19.19	84.01	0.046	0.999
Neptune	30.06	164.8	0.010	1.000
Pluto	39.53	248.6	0.248	1.001
	(A.U.)	(Earth years)		

# The Baroque Setting

- In the 1600s church through counter-reformation (Council of Trent 1545-1563) much stricter
- G. BRUNO (Italian; 1548) proposes that the Sun is just one star out of an infinite number  
→ burned at the stake for heresy 1600
- 30 Years War (1618-1648) between religions
- New inventions: telescope, air pump, etc.

# Galileo Galilei – The Experimentalist

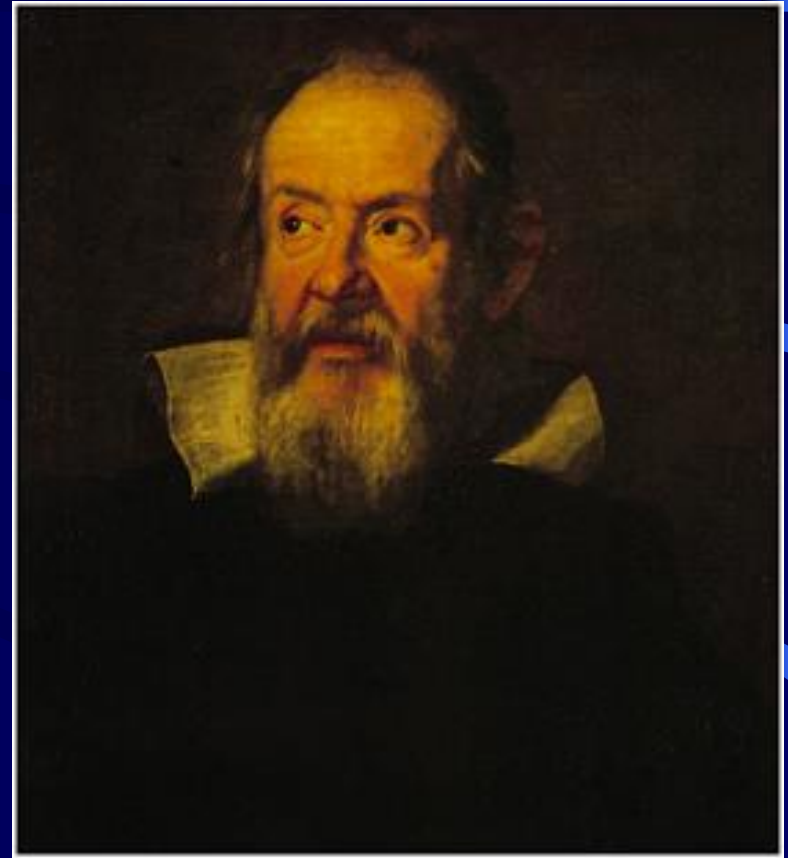
Did experiments (falling bodies) rather than studying Aristotle

## Major Works

- Siderius Nuntius (1610)
- Dialogue concerning the Two Chief World Systems (1632)

The latter discusses Copernicus vs Ptolemy → ban by Church (1633)

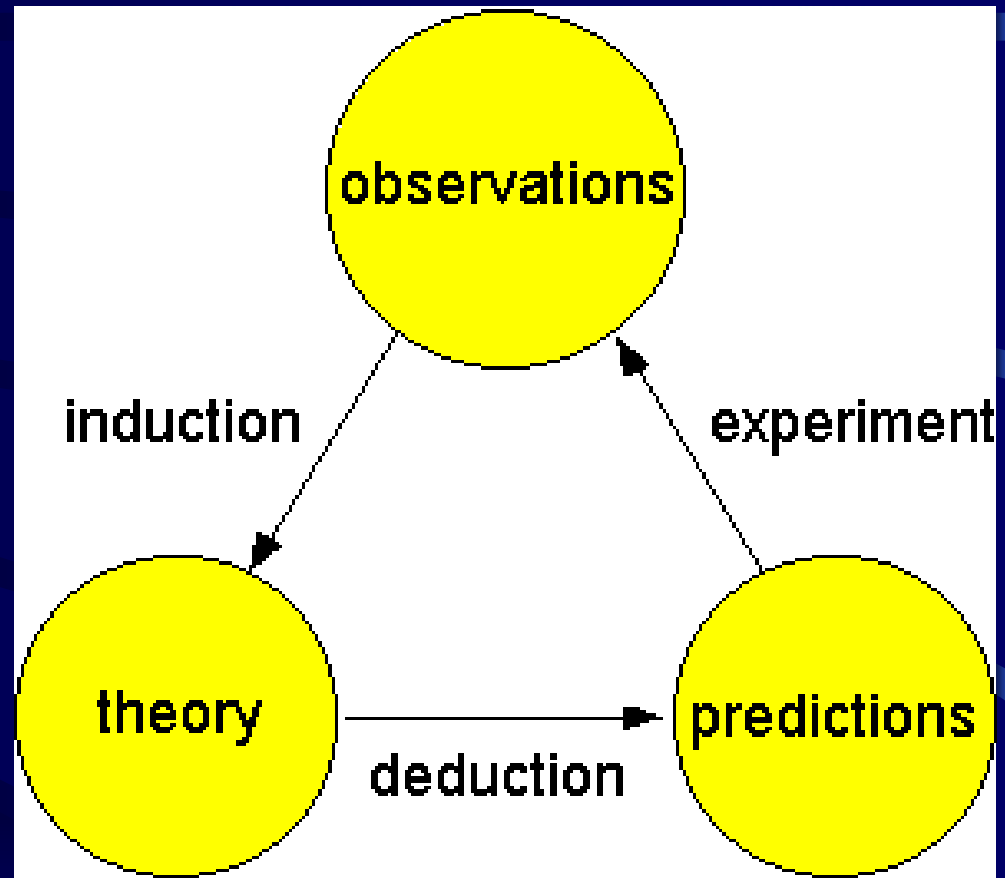
- revoked by pope 1992
- Quotable: “The book of the universe is written in the language of mathematics.”



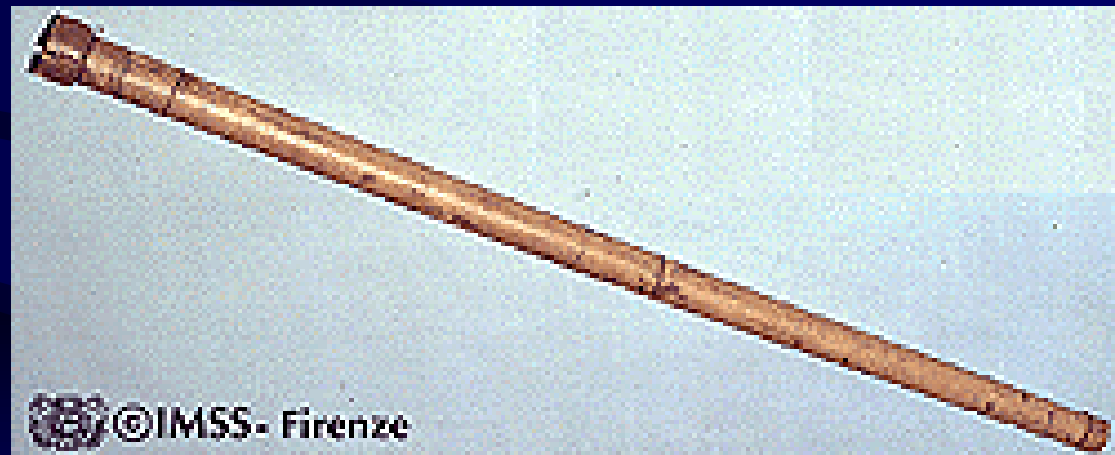
(1564–1642)

# The Scientific Method

- Systematized by Francis Bacon, Descartes and Galileo in the 17<sup>th</sup> century
- Not the only way of knowing, but a very successful one
- A method to yield conclusions that are independent of the individual
- Conclusions are based on **observation**

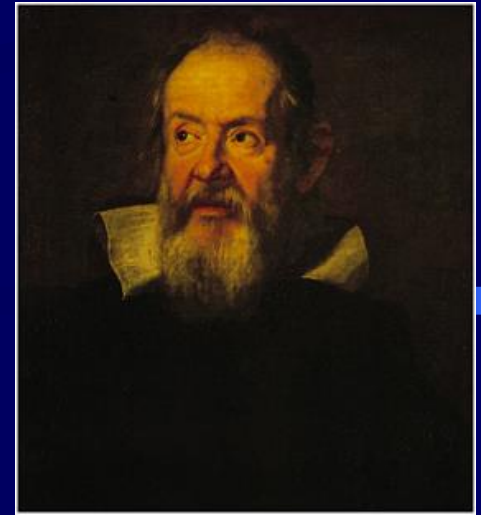


# Galileo's Telescopes



- Galileo's first telescope was 3x magnifying
- his last one 32 x

# Galileo Galilei (1564–1642)



- **Astronomical observations that contradict Aristotle:**
  - Observed mountains on the Moon, suggesting that the Earth is not unique
  - Sunspots; suggests that celestial bodies are not perfect and can change
  - Observed four moons of Jupiter; showed that not all bodies orbit Earth
  - Observed phases of Venus (and correlation of apparent size and phase); evidence that Venus orbits the Sun
- **Also observed**
  - the rings of Saturn
  - that the Milky Way is made of stars

# The Starry Messenger

- Revealing great, unusual, and remarkable spectacles, opening these to the consideration of every man, and especially of philosophers and astronomers;

As observed by Galileo Galilei, gentleman of Florence, Professor of Mathematics in the University of Padua

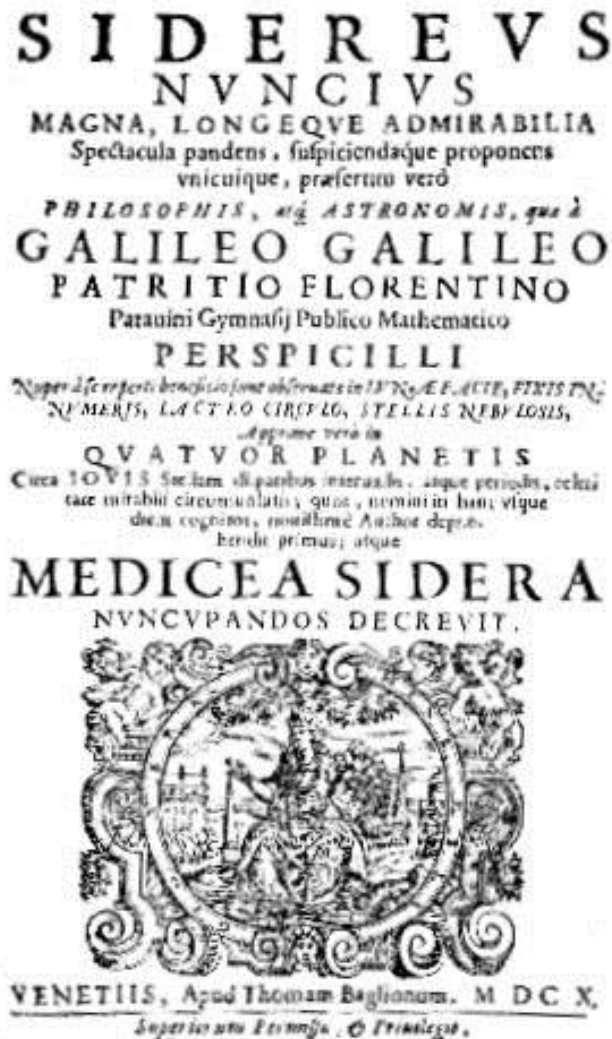
With the aid of a Spyglass recently invented by him

In the surface of the moon, in innumerable fixed stars, in nebulae, and above all:

In four planets, swiftly revolving about Jupiter at differing distances and periods, and known to no one before the Author recently perceived them and decided that they should be named

THE MEDICEAN STARS

Venice, 1610





# Sc<sup>mo</sup> Principe.

Galileo Galilei Humilis<sup>s</sup> Servo della Ser.<sup>a</sup> V.<sup>a</sup> inuigila.  
do assiduamente et di ogni spirito p<sup>o</sup> potere ho solam<sup>e</sup> satisfare  
alvario che viene della Altura di Mathematici<sup>o</sup> nello stu-  
dio di Padova,

Inuere diuere determinate di presentare al Sc<sup>mo</sup> Principe  
l'Orchiale et a p<sup>o</sup> essere di giuamenti inestimabile p<sup>o</sup> ogni  
regio et in ogni marittima o terrestre stia di tenere p<sup>o</sup>  
sto nuovo artificio nel maggior segreto et usque a disposizione  
di v.<sup>a</sup> Ser.<sup>a</sup> L'Orchiale auuto dalle piu<sup>e</sup> di d<sup>e</sup>te speculazioni di  
prospettua ha l'vantaggio di scoprire Legni et Vele dell' inimico  
p<sup>o</sup> h<sup>o</sup>re et p<sup>o</sup> di tempo prima di esse sopra noi et distinguendo  
il numero et la qualita<sup>e</sup> de i Vasselli giudicare la sua forte  
pallottarsi alla caccia al combattimento o alla fuga, o pure esser  
nella battaglia aperta uedere et particolarmente distinguere ogni suo  
moto et propriamente.

Adi 7. di Gennaio  
Gioue si uede con

Adi 8. con

Adi 12. si uede in tale costituzione

Adi 13. si uedono manifesti in Gioue 4 stelle

Adi 14. è angelo

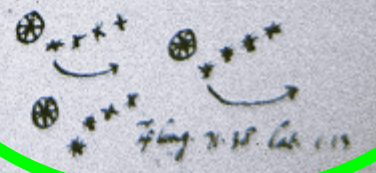
Adi 15. si uede la prima

stante dalla 3<sup>a</sup> l'Orchiale

Lo spazio delle 3. stelle

maggiore del diametro di 7<sup>a</sup>

sono in linea retta.



Adi 7. di Gennaio 1610 Gioue si uede con la lampone  
3. stelle p<sup>o</sup>ffe. con \* \* \* della quali se il uenire  
minore si uede con \* \* \* a di 8. appariva con \* \* \* era dug  
diretto et no retrogrado come sogliono i calcolatori.

Adi 9. fu rugolo. a di 10. si uede con \* \* \* di è di  
gioue si uede con \* \* \* che la uenire si uede con \* \* \* si uede con \* \* \*

Adi 11. era in questa guida \* \* \* et la stella più vicina  
a Gioue era la metà minore dell'altra, et uicinissima all'altra  
come che le altre pare erano le dette stelle apparite tutte tre  
di equal grandezza et tra di loro equali. Dal che  
appare intorno a Gioue esser 3. altre stelle erranti uicinissime ad  
ogniuno sino a questo tifo.

Adi 12. si uede in tale costituzione \* \* \* era la stella  
occidentale poco minor dello orientale, et gioue era in mezzo tra  
da l'una et dall'altra quoto il suo diametro e uenire: o forse era  
una terza mediana et uicinissima a 7<sup>a</sup> verso oriente; anzi pur in era  
venisse h<sup>o</sup>re in di più diligente osservato, et uede più imminente  
notte.

Adi 13. hauendo benis<sup>o</sup> formato lo scrupolo si uedono uicinissimi a Gioue  
4. stelle in questa costituzione \* \* \* o meglio con \* \* \*  
e tutte apparivano della med<sup>a</sup> grandezza, lo spazio delle 3. occidentali  
ad era maggiore del diametro di 7<sup>a</sup>. et erano fra di loro notabil-  
mente uicinissime che le altre pare; ne erano in linea retta equidistanti come  
p<sup>o</sup> auuto ma la media delle 3. occidentali era a poco eleuata, l'altro la  
più occidentale alquanto depressa; sono queste stelle tutte molto lucide bene  
fississime et altre due et appariscono della med<sup>a</sup> grandezza ad essere  
con splendore.

Adi 14. fu rugolo. Adi 15. era con \* \* \* in pross<sup>a</sup> a  
7<sup>a</sup>. era la minore et le altre dimano erano maggiori: gli inter-  
tra 7<sup>a</sup> et la 3. seguiva erano, quoto il diametro di 7<sup>a</sup>. ma la 4<sup>a</sup> era di-  
stante dalla 3<sup>a</sup> il doppio di circa; ad fice

4. lung. 71. 38. lat. 1. 13. n. 34 uano iterare linea retta, ma uenire mossa  
l'esempio, erano al solito lucide. Se le più  
6. et niente uicinissime come auuto.

Galileo's Journal on the Discovery of Jupiter's Moons



buoto et propriamente.

Adi 7. di Gennaio

Gione si vede a N

Adi 8. a N

era d'uy diretto et no retrogrado

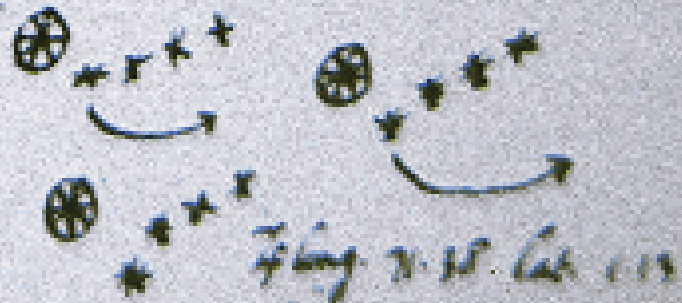
Adi 12. si vede in tale costellazione

Il 13. si vedono minime a Gione 4 stelle

Adi 14. è angelo

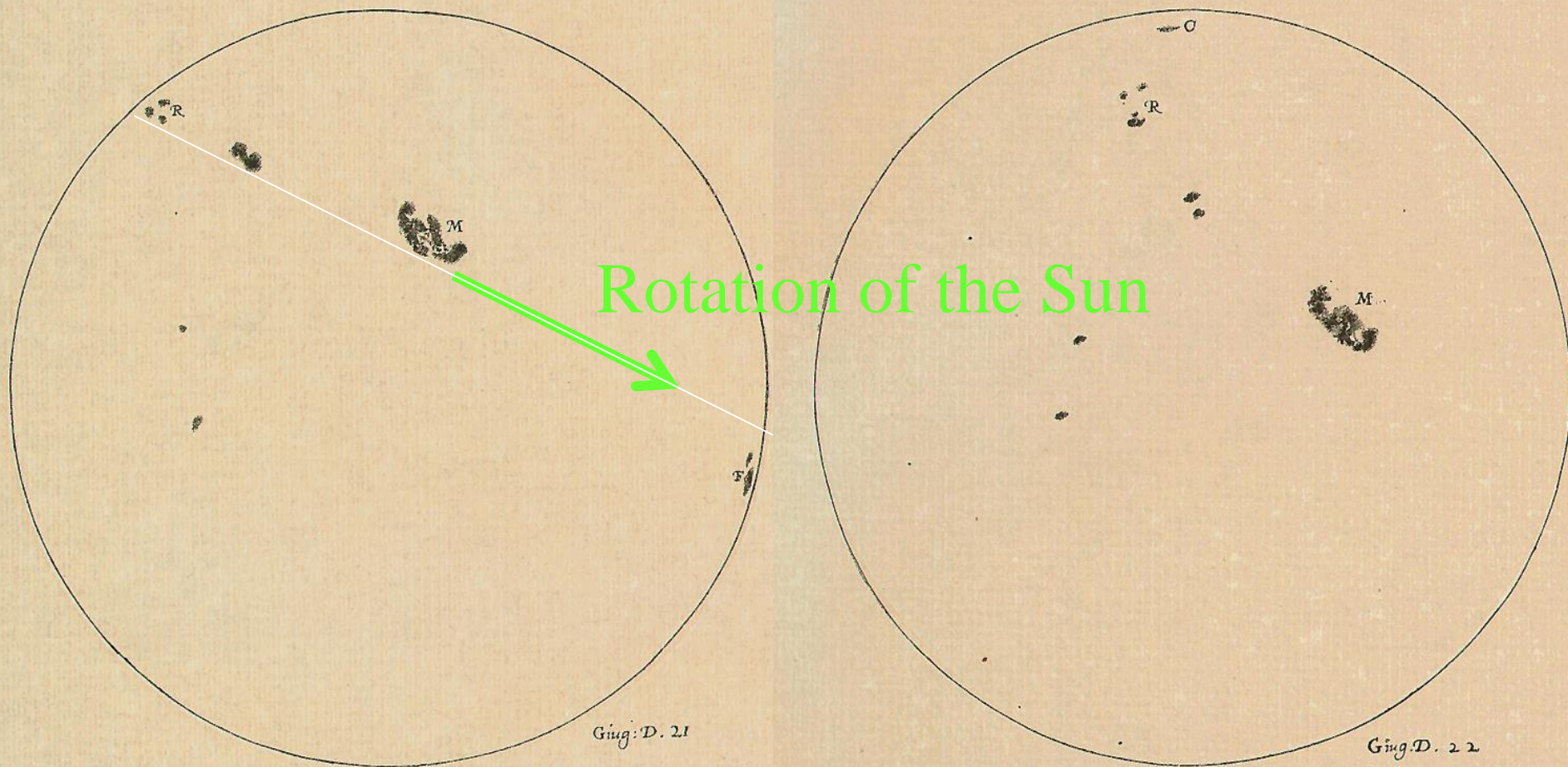
Il 15. la pross<sup>a</sup> a 4 era in min<sup>a</sup> la 4<sup>a</sup> era di-  
stante dalla 3<sup>a</sup> il doppio l'altra

Lo spazio delle 3. antiche ad ora  
maggiore del diametro di 7. et c.  
sono in linea retta.



Sometimes sees 2,3,4 objects, sometimes left,  
sometimes right of Jupiter

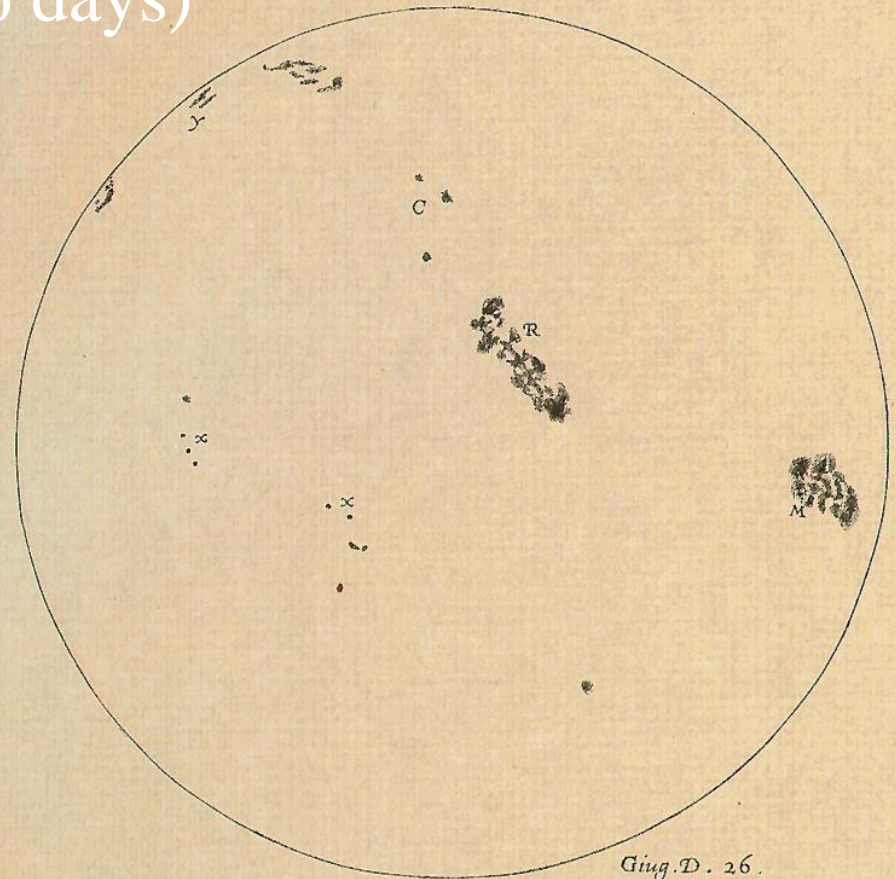
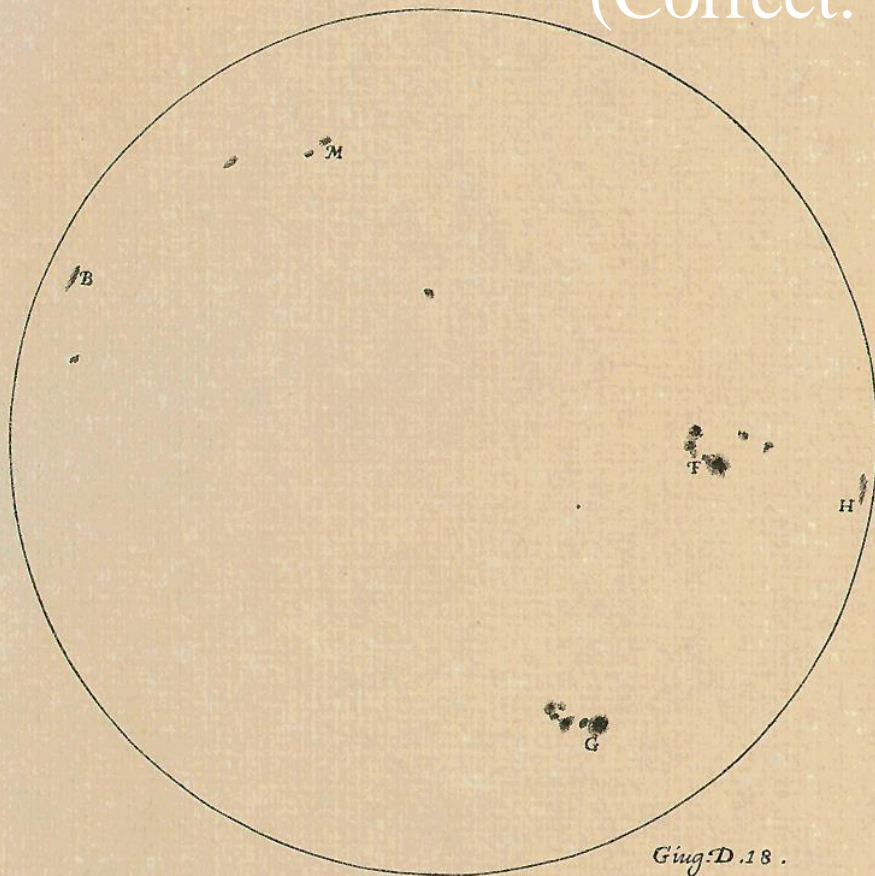
# Sunspots (Video)



# Rotation Period of the Sun

Sunspot moves about  $\frac{3}{4}=75\%$  of diameter in 8 days  $\rightarrow$  rotation period roughly  $8 \times \frac{2}{3} = 21$  days

(Correct: 26 days)





# Debate over Sunspots

- Who saw them first? Scheiner vs Galileo
  - Neither!
- What are the sunspots?
  - Could they be clouds across the sun or inner planets transiting the Sun to save Aristotle?
  - No! Appear to move with the sun, no parallax, show appearance like dots painted on a rotating ball

# Scientific Method – Applied by Galileo to Sunspots

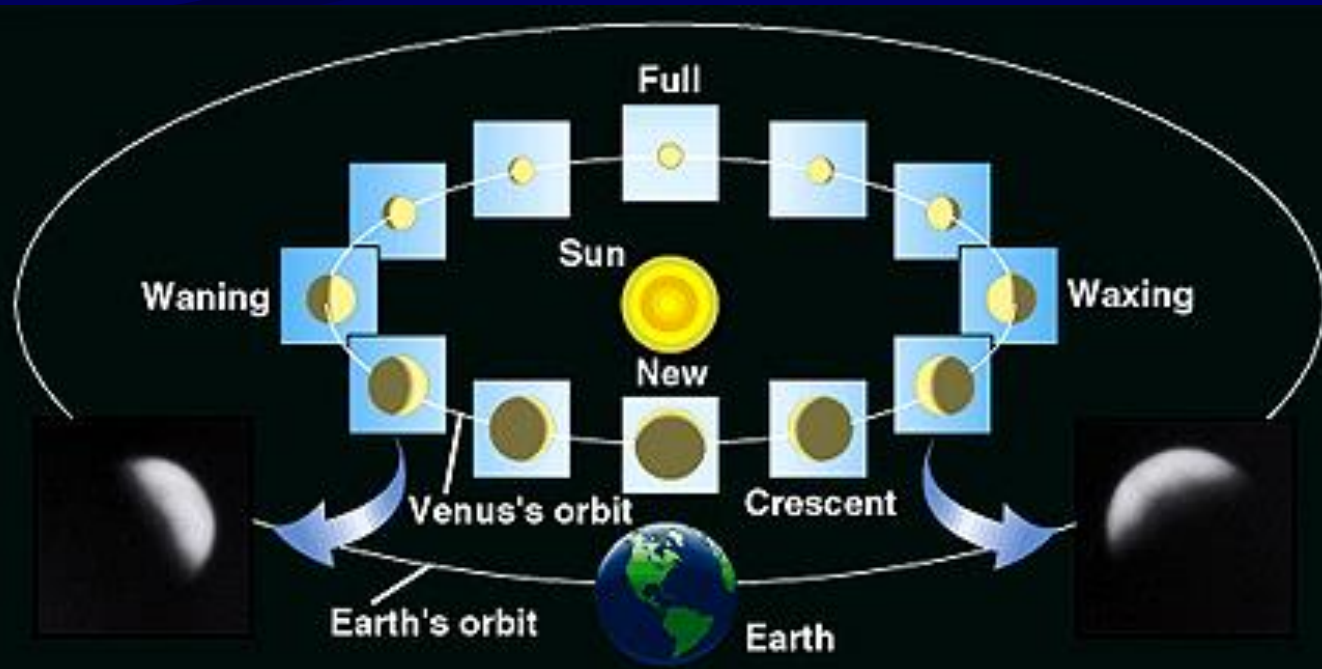
- Careful observation of a phenomenon
  - Observes sunspots (as did others before him)
  - Follows them over several weeks
- Deriving conclusions from “data”
  - Concludes that these are things very close to the Sun’s surface
- Making new predictions
  - Deduces that the sun rotates around itself in 26 days
  - Makes a prediction as to the Sun’s rotational axis
- Publishing results “for everyone” [in Italian]
  - “Letters on Sunspots” (1612)
- Anticipates his opponents arguments, and nullifies them by using stringent logic
  - Shows that sunspots can’t be inner planets

# Geocentric vs Heliocentric: How do we know?

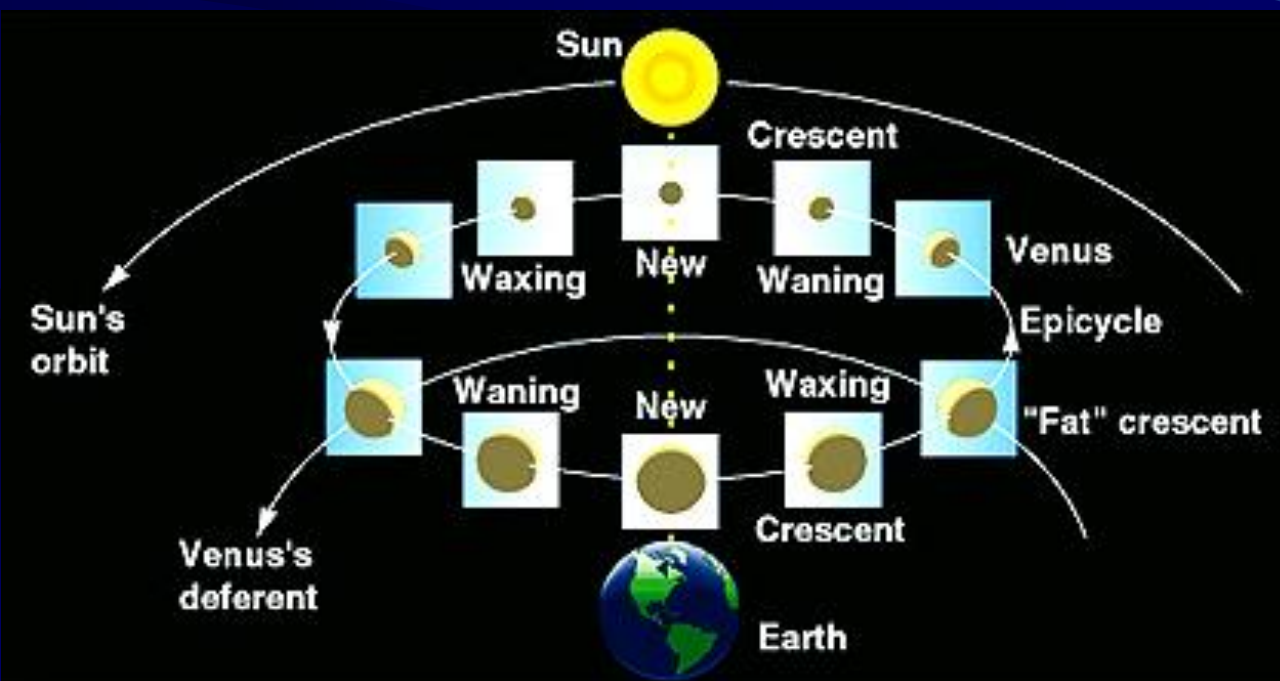
- Is the Earth or the Sun the center of the solar system?
- How do we decide between these two theories?
- Invoke the scientific method:
  - both theories make (different) predictions
    - NOT about planetary motion BUT phases of Venus
  - Compare to observations
  - Decide which theory explains data

# Phases of Venus

Heliocentric



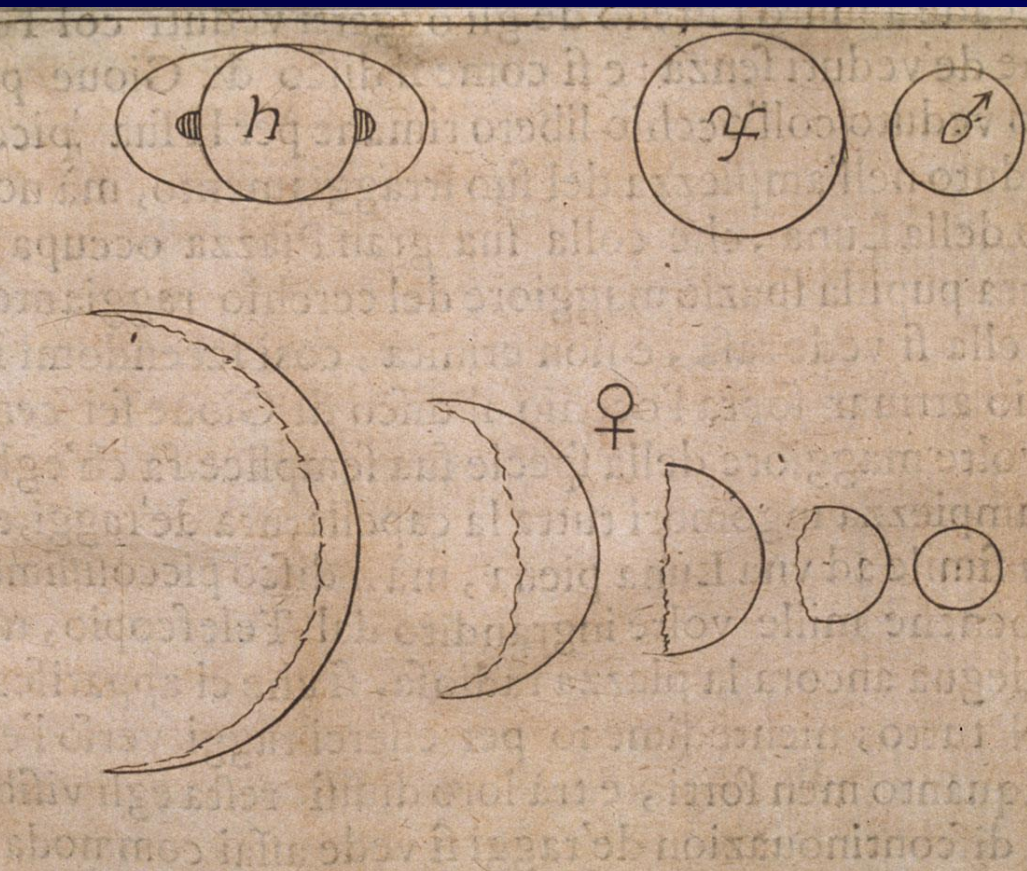
Geocentric

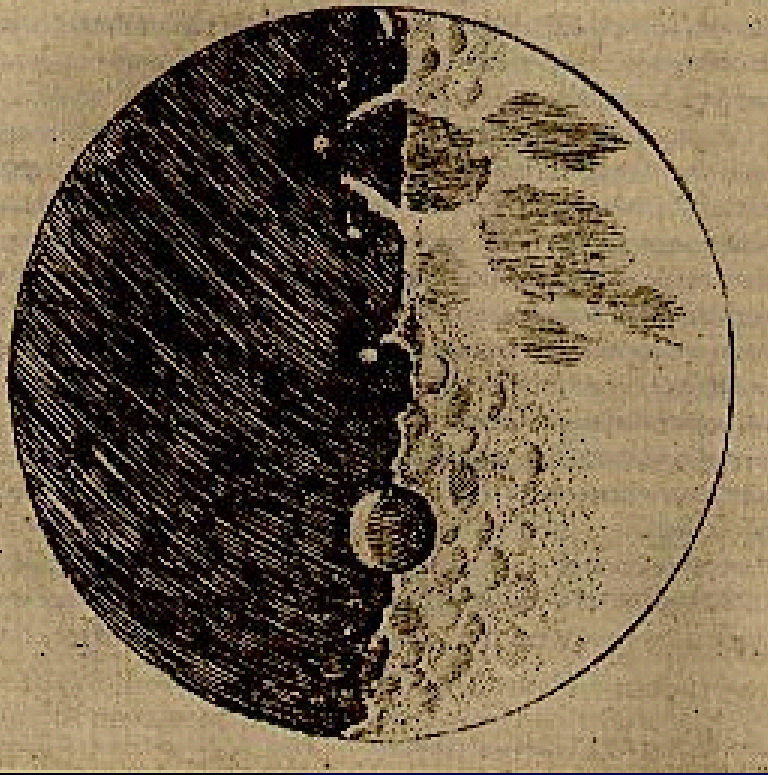




# Venus Phases

- Galileo's eyepiece sketches





# Mountains on the Moon

- Galileo observed the mountains of the Moon with his telescope
- Estimated their elevation correctly

