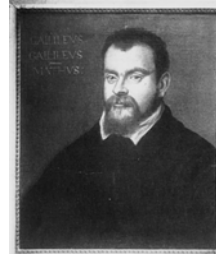


## Copernican Revolution—15 Jan

- Final exam is Wed, May 6<sup>th</sup>, not 5<sup>th</sup>.
- Questions on reading
- Motion of the sun & planets
  - Ptolemy's *Almagest*
  - Copernicus' *de Revolutionibus Orbium Caelestium, (Concerning Revolutions of the Heavenly Spheres)*, 1543
  - Galileo refutes Ptolemy with his observations of the phases of Venus
- Syllabus & homework
  - [angel.msu.edu](http://angel.msu.edu)
- Register your clicker



Nicolai Copernicus  
(1473-1543)



Galileo Galilei  
(1564-1642)



©IMSS- Firenze

Wood, paper; length: 1360mm, lens diameter 26mm  
<http://galileo.imss.firenze.it>

## Copernican Revolution: questions on reading assignment

1. Retrograde or normal motion of a planet concerns
  - a. whether it rises in the east or west
  - b. its motion with respect to the stars behind it.
2. Ptolemy (200AD) believed
  - a. The earth moved around the sun once a year
  - b. The sun moved around the earth once a year
  - c. The earth moved around the sun once a day
  - d. The sun moved around the earth once a day
3. We now know... (Use same answers as in #2.)

## Motions of the sky

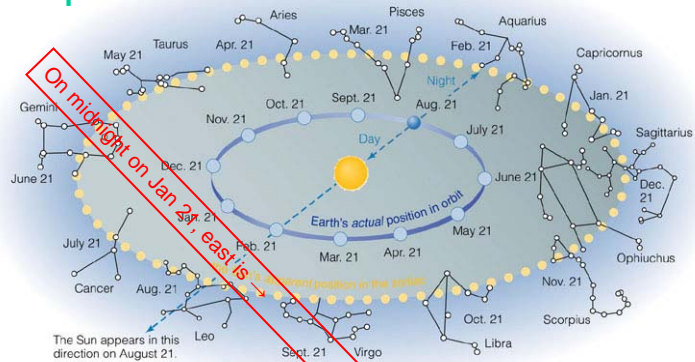
- To make his model, Ptolemy (about 100-170 AD) used observations that you can make without a telescope.
- What motions have you observed?

## Motions of the sky

What motions have you observed?

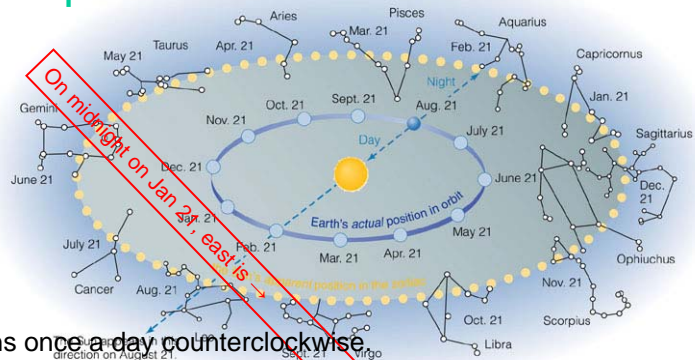
- A. Night & day. Sun rises & sets.
  - B. Stars rise & set.
  - C. Different stars are seen at different times of the year. Eg., Orion is seen in early evening in March. The “Summer Triangle” is seen in early evening in the summer.
  - D. Venus is seen just before sunrise or just after sunset; it is never seen at midnight.
- 1. What model explains observation A?
    - a) The sun moves around the earth.
    - b) The earth moves around the sun.
    - c) The earth turns.
  - 2. What model explains observation B? Use same foils.
  - 3. What model explains observation C? Use same foils.

## Celestial sphere



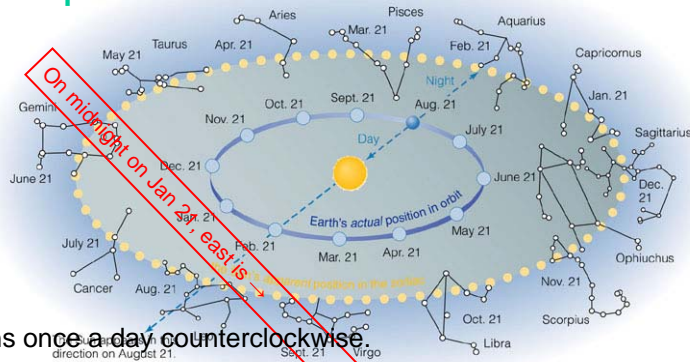
- The stars are so far away that they appear to be on a distant sphere.
- Earth turns once a day counterclockwise.
- Earth moves around the sun.

## Celestial sphere



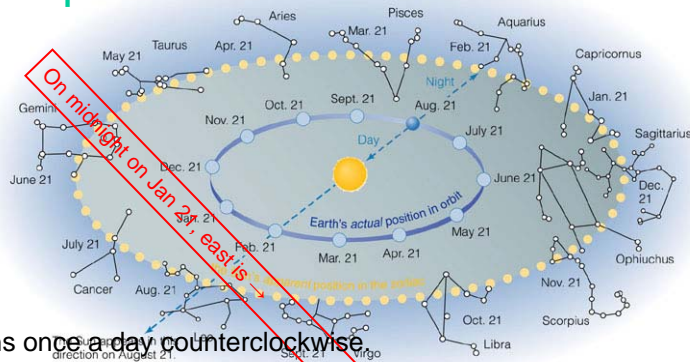
- Earth turns once a day counterclockwise.
  - Earth moves around the sun.
1. Which constellation(s) are high in the sky at midnight on 1/21?
    - a. Cancer
    - b. Sagittarius
    - c. Aquarius
    - d. Taurus

## Celestial sphere



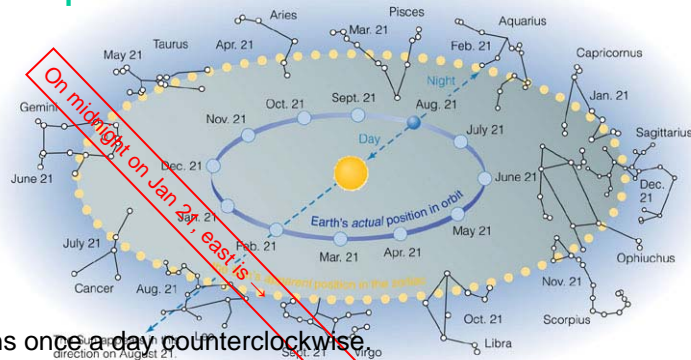
- Earth turns once a day counterclockwise.
  - Earth moves around the sun.
1. Which constellation(s) are high in the sky at noon on 1/21?  
Imagine you could turn off the sun.
    - a. Cancer
    - b. Sagittarius
    - c. Aquarius
    - d. Taurus

## Celestial sphere



- Earth turns once a day counterclockwise.
  - Earth moves around the sun.
1. Which constellation(s) are high in the sky at 6am on 1/21?
    - a. Cancer
    - b. Sagittarius
    - c. Aquarius
    - d. Taurus

## Celestial sphere



- Earth turns once a day counterclockwise.
  - Earth moves around the sun.
1. Which constellation(s) are high in the sky at midnight on 6/21?
    - a. Cancer
    - b. Sagittarius
    - c. Aquarius
    - d. Taurus

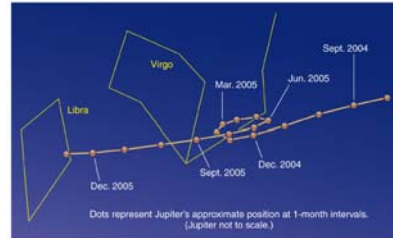
Copyright © 2004 Pearson Education, publishing as Addison Wesley.

## Ptolemy's model of the universe

- Ptolemy lived around 100AD in Alexandria (now Egypt)
- Ptolemy followed Aristotle's ideas
  - The earth is at the center. The earth does not move.
  - Heavenly objects move in the most perfect way. Circle is most perfect shape. Heavenly objects move in perfect circles.
- Ptolemy's model
  - Stars are on the celestial sphere. The sphere turns around the earth once a day.
  - The sun's path is a circle. The sun orbits the earth once a day.
  - The sun's orbit moves a little each day with respect to the celestial sphere of the stars.

## Motion of planets: Ptolemy's *Syntaxis* (*Almagest*), 140AD

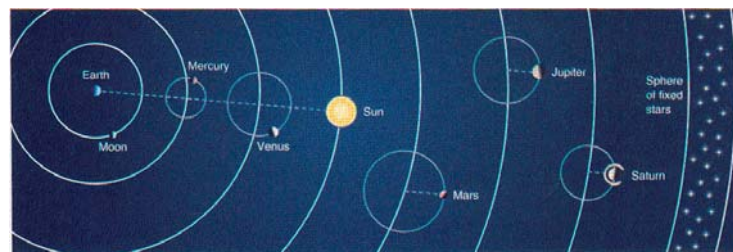
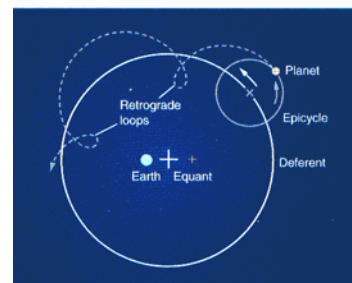
- Motion of the planets was the big unsolved problem for astronomy for over 1400 years until 1630
- With respect to the stars, planets usually move eastwardly from night to night.
  - Easy to explain for Ptolemy: Just as sun is on a separate sphere and its path is a circle, each planet has its own circular path.
- Sometimes they move westwardly with respect to the stars. (Called retrograde motion.)
  - Tough to explain.



Copyright © 2005 Pearson Education, publishing as Addison-Wesley

## Motion of planets: Ptolemy's *Syntaxis* (*Almagest*), 140AD

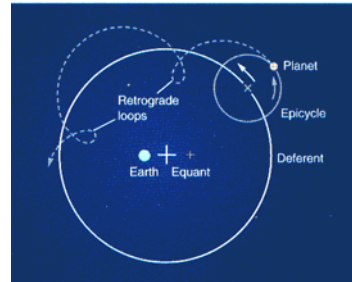
- With respect to the stars, planets usually move eastwardly from night to night. Sometimes they move with retrograde motion.
- Aristotle: Heavenly objects move in a circle centered on Earth.
- Ptolemy's model
  - Circular, Earth-centered motion
  - Planets are on a deferent & epicycle.



Blue figures are from  
Seeds, *Horizons:*  
*Exploring the*  
*Universe.*

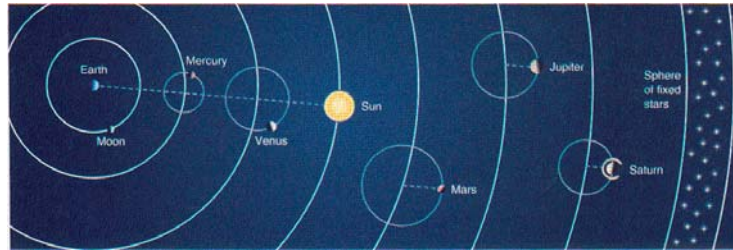
## Motion of planets: Ptolemy's *Syntaxis* (*Almagest*), 140AD

- Added feature to explain why Venus & Mercury are always seen near sunset or sunrise.
- Ptolemy's model
  - Circular, Earth-centered motion
  - Planets are on a deferent & epicycle.
  - Deferent for Mercury & Venus is stuck on a line between Earth & sun.



epicycle

Blue figures are from  
Seeds, *Horizons:*  
Exploring the  
Universe.



## Copernicus proposed the idea that sun is at center



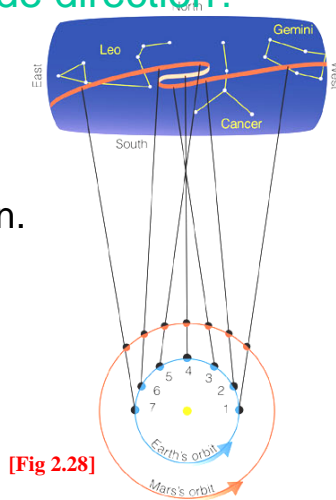
WE ARE HERE!

- Copernicus proposed that each planet is on circular orbit about sun.
  - Simpler than Ptolemy's model
  - Accuracy is worse than Ptolemy's model
  - Model violates Aristotle's "truths"
    - Heavenly objects, being perfect, move in a circle, which is the perfect shape.
    - The earth is stationary at the center.
    - Heavenly objects move at constant speed.
- Copernicus wrote *de Revolutionibus Orbium Caelestium*, (*Concerning Revolutions of the Heavenly Spheres*), 1543, published after his death.



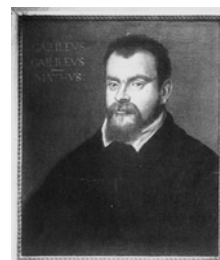
## Why do planets sometimes move in retrograde direction?

- Earth moves in orbit around sun.
- The other planets move on their own orbits around the sun.



## Galileo (1610) invents telescope

- Discoveries
  - Milky Way is made of myriads of stars.
  - Phases of Venus, disprove Ptolemy's geocentric model.
  - Craters, maria on Moon.
  - Rings of Saturn
  - 4 Moons orbiting Jupiter



Galileo Galilei  
(1564-1542)

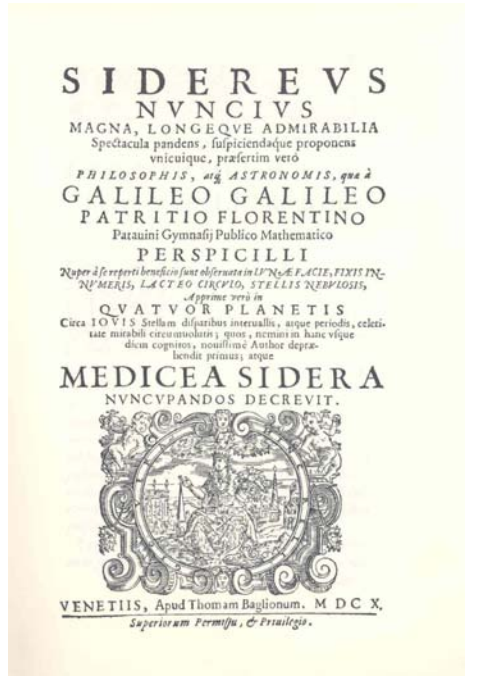


Galileo's telescopes: ~1" in diameter x 24-30" long



# Starry Messenger

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  
SEXYGLASS  
lately 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



# Galileo saw 4 moons orbiting Jupiter

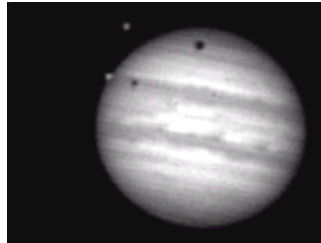
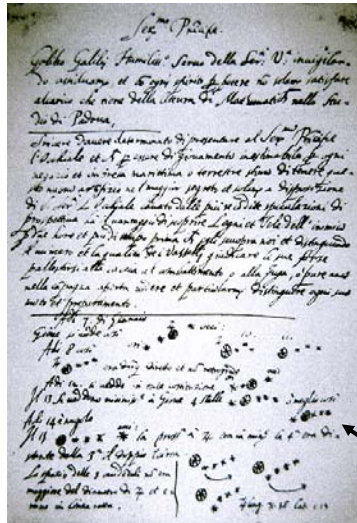


Image through modern telescope showing 2 of Galileo's satellites and their shadows

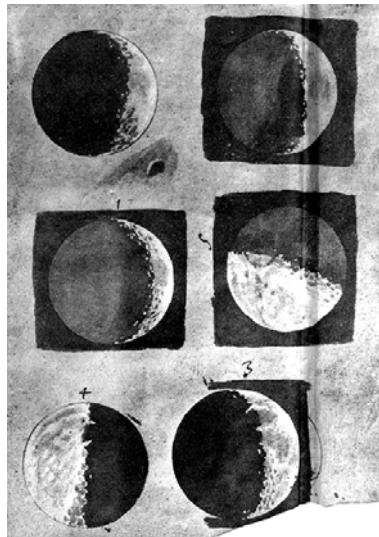
Observing notes

## What Galileo Saw:

The milky way = jillions of stars



## More Galileo discoveries

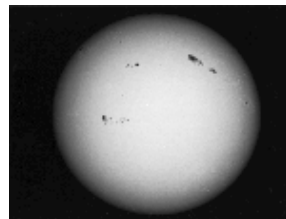


Craters, maria on moon



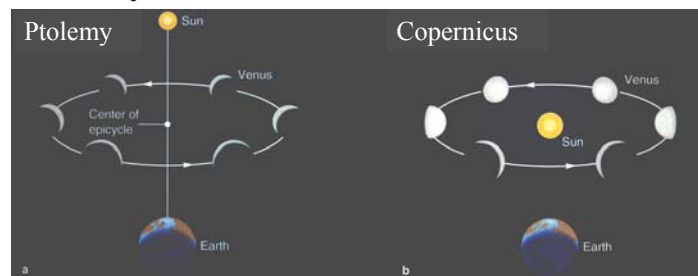
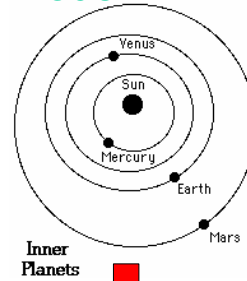
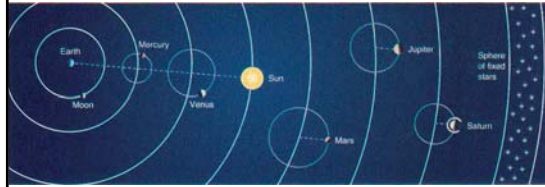
Galileo's sketch.. 1616

Rings of Saturn



Sunspots

## Galileo saw the phases of Venus & disproved Ptolemy's model



## Angel

- Use [angel.msu.edu](http://angel.msu.edu) to access slides from class.
- Use angel for homework.

## Registering your i-clicker



Until you register your i-clicker, your responses are tied to your clicker remote ID (located on the back of your clicker), rather than to you.

If you do not register, your answers are recorded, but you will not get credit.

When you do register, your previously recorded answers will be assigned to you.

## Registering your i-clicker online



**1.** Go to [www.iclicker.com](http://www.iclicker.com).

**2.** Click "REGISTER."

**3.** Enter these 4 details and click "submit."

**IMPORTANT!!**  
You **MUST** enter your **MSU email** in the **STUDENT ID** field to ensure proper crediting.  
My email is [LOH@msu.edu](mailto:LOH@msu.edu)  
My **STUDENT ID** is **LOH**

**REGISTER AT [www.iclicker.com](http://www.iclicker.com)**

## Questions on reading

1. When Kepler was a college student, the most accurate description of the motion of planets uses the terms
  - a. Velocity, position, & acceleration
  - b. Circular orbits
  - c. Elliptical orbits
2. Same question for Newton
3. Today the most accurate description of the motion of planets uses the terms
  - a. Velocity, position, & acceleration
  - b. Circular orbits
  - c. Elliptical orbits