

Astro 210  
Lecture 5  
Sept 1, 2010

## Announcements

- HW1 available; due in class next time  
most problems geometrical → suggestion: **draw diagrams**
- Instructor office hours **changed!**  
11am-noon Wed, or by appointment  
TA office hours 10:30-11:30am tomorrow, or by appointment
- **register** your iClicker; link on course webpage  
to be sure, redo even if did registered in past semesters

Last time:

lunar eclipses: occur twice a year (“eclipse season”)

note: lunar orbit plane inclined  $5^\circ$  to ecliptic

nearly coplanar  $\rightarrow$  *always* eclipses when orbit planes intersect

in fact: sometimes *multiple* eclipse events per season

over  $\sim 1$  month timespan

www: 2011 eclipse schedule

planet motions: paths are great circles on celestial sphere

motion: mostly eastward w.r.t. celestial sphere, like Sun, Moon

but sometimes *retrograde* Q: *what's that?*

Today: building scientific models to explain naked-eye sky

# Greek Cosmology

Pythagoreans

outlook: geometry is everything, perfected in spheres

- earth: spherical shape

observations of Eratosthenes (276-195 BC)

altitude of noonday Sun at solstice:

- directly overhead at Syene, Egypt

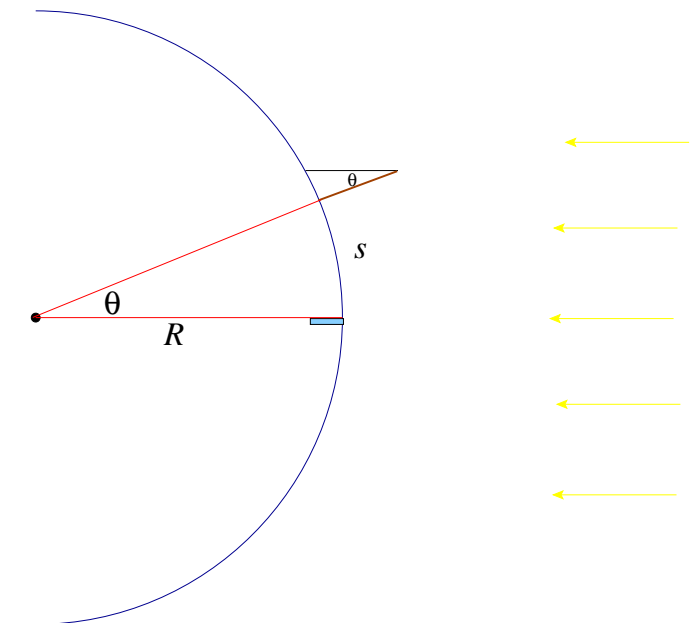
$\theta = 7^\circ$  from vertical at Alexandria

*Q: what do we learn from the simple fact that the angles differ?*

- pace off distance  $s \sim 800$  km

geometry:  $s/R = \theta_{\text{radians}} = 2\pi(7^\circ/360^\circ)$

$\Rightarrow R \sim 6700$  km: close!



$\omega$

- Moon, Sun, planets, stars fixed on spheres which move in uniform circular motion

# Geocentrism

Ancient Greeks: **Earth is center of universe** (“geocentric”)

★ rise & set of sun/moon/planets can be explained Q: *how?*

★ we don't *feel* Earth is spinning

would mean we move at 900 mph w.r.t. Earth center

→ why aren't we flung off?

★ apparent lack of **stellar parallax**

Proof by contradiction: *what if* earth orbits sun?

*diagram: Sun, Jan, July, star, lines of sight*

foreground star should appear to *shift* w.r.t. background stars

⇒ but parallax effect *not* observed!

Why? eye cannot resolve angles  $\lesssim 1' = 1 \text{ arc min} = 60 \text{ arc sec}$

but typical shift on sky:  $\sim 1'' = 1 \text{ arc sec}$  – very small effect!

parallax not detected until  $\sim 1830(!)$

⊢

Aristotle explained data available at the time

and gave strong evidence **against** Sun-centered picture!

## iClicker Poll: The Geocentric Celestial Sphere

Consider the geocentric picture of Aristotle and Ptolemy, in which the celestial sphere is literally a sphere.

What is the motion of this sphere?

- A no motion; at rest
  - B uniform rotation with period = 1 year
  - C uniform rotation with period = 1 day
  - D nonuniform rotation, period = 1 year, precession by  $\pm 23.5^\circ$
- 

5 Q: What does the geocentric model (described thus far) explain?  
what not?

## Geocentric Grunge

must explain **Retrograde motion**  
cannot do this with circular orbits  
(having constant angular velocity)

solution must complicate the orbit:

add deferent and **epicycle**

*diagram: Earth, deferent path, epicycle, motion arrows*

www: epicycle animation

## Claudius Ptolemy ~ 125 AD

Constructed complete geocentric model  
every planet had epicycles—in fact, epicycles on top of epicycles  
complicated/elaborate model, but also sophisticated

Ptolemy accounted for

- non-uniform angular speed
- retrograde motion
- Mercury and Venus *never* in opposition  
center of epicycles always on line  
connecting earth and sun

how good: observations decide!

- ∩ Errors generally  $< 5$  deg: not bad but observable!  
remained in use for ~1400 years!!

## iClicker Poll: Ptolemy & Science

Vote your conscience!

Is Ptolemy's system a scientific model for the naked-eye sky?

A yes

B no



# A Cosmological Revolution

we fast forward 1.5 millenia → Renaissance Europe  
the age of da Vinci, Michelangelo, Elisabeth I, Shakespeare  
...and:

## Nicolaus Copernicus 1473–1543 Polish

offended by Ptolemy's equants (on esthetic grounds: "ugly")  
adopted *heliocentric* cosmological model

## Copernican Model

- *Earth spins* ⇒ daily motion of celestial objects
- *Earth orbits Sun* ⇒ apparent Sun motion in zodiac
- Mercury & Venus orbits inside Earth's ⇒ always seen near Sun
- retrograde motion: naturally caused by Earth–planet passing

www: animation

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simply explains retrograde correlations w/ planet location

- lack of stellar parallax ⇒ must assume large distance to stars

Copernicus also calculated relative distances of planets  
e.g.: Venus as max angle (max “elongation”) from sun  
*diagram: max elongation geometry*

$$\sin \alpha_{\max} = \sin 46^\circ = R_V / R_E$$
$$\Rightarrow R_V = 0.72 R_E$$

New unit: **“astronomical unit”** = average Earth-Sun distance  
 $1 \text{ AU} \equiv R_E = 1.50 \times 10^8 \text{ km}$

**Note:**

- planets still on spheres
- Copernicus still used epicycles!
- predictions not better than in Ptolemy’s model
- → geometrically equivalent
- Copernicus’ model not generally accepted  
and Ptolemaic–Copernican disagreement though to be  
metaphysical, *unanswerable* question

## Tycho Brahe 1546-1601: Danish Astronomy Extraordinaire

in youth: observed “nova stella” (supernova) [www: Tycho sketch](#)

→ heavens corruptible!

observed Sun, Moon, planets for 20 years: careful, accurate data  
but not a good number cruncher

→ like any good professor: made grad student do the work!

## Johannes Kepler 1571–1630: Harmony of the Worlds

Analyzed Tycho’s data for **20 years**(!), especially Mars motions

used heliocentric model with circles

but observations didn’t quite agree

a small error (few arc min!) remained...took seriously

⇨ → after years of trial & error:

completely & accurately described planet orbits