Astro 210
Lecture 5
Jan 26, 2018

Announcements
- HW1 due today at 5pm
- HW2 available; due in 1 week
- **register** your iClicker; link on course webpage
- first Planetarium shows Mon Feb 5 and Wed Feb 7
  info online: **reservations**, schedules, directions, report form
- if this is your first class: see me afterward!

Last time: planets
- paths on celestial sphere are (nearly) great circles
  stay near ecliptic, in zodiac *Q: and so?*
- motion: mostly eastward w.r.t. celestial sphere, like Sun, Moon
- but sometimes *retrograde Q: what's that?*
- retrograde occurance related to planet angle from Sun *Q: how?*

Today: building scientific models to explain naked-eye sky

Cosmological Models: Naked-Eye Sky

any viable model must *explain all observations*
including retrograde motion of planets

models change:
- when predictions fail
- when new observations require new explanations

model refined → **theory**
theory is *end product* of model ↔ data
  not mere speculation or offhand/wacky idea

Greek Cosmology

Pythagoreans
outlook: geometry is everything, perfected in spheres

- earth: spherical shape

observations of Eratosthenes (276-195 BC)
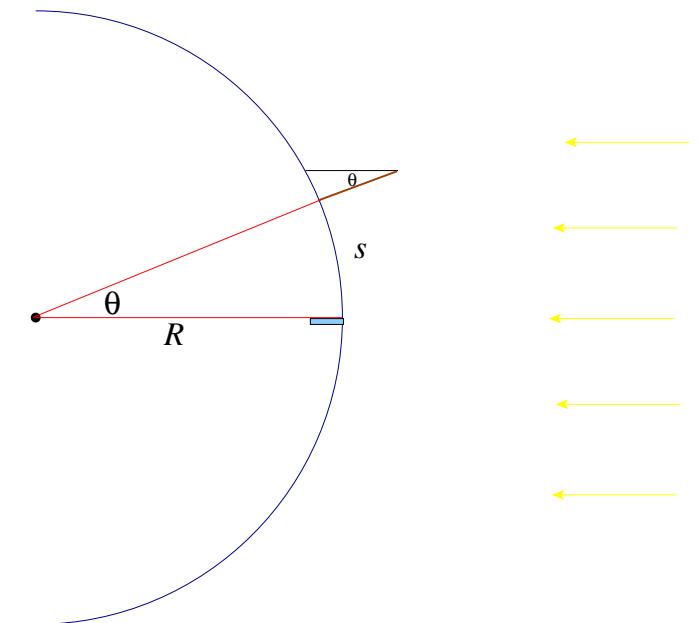
altitude of noonday Sun at solstice:

- directly overhead at Syene, Egypt

  $\theta = 7°$ 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: $s/R = \theta_{\text{radians}} = 2\pi(7°/360°)$

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

- 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
   $\rightarrow$ why aren't we flung off?
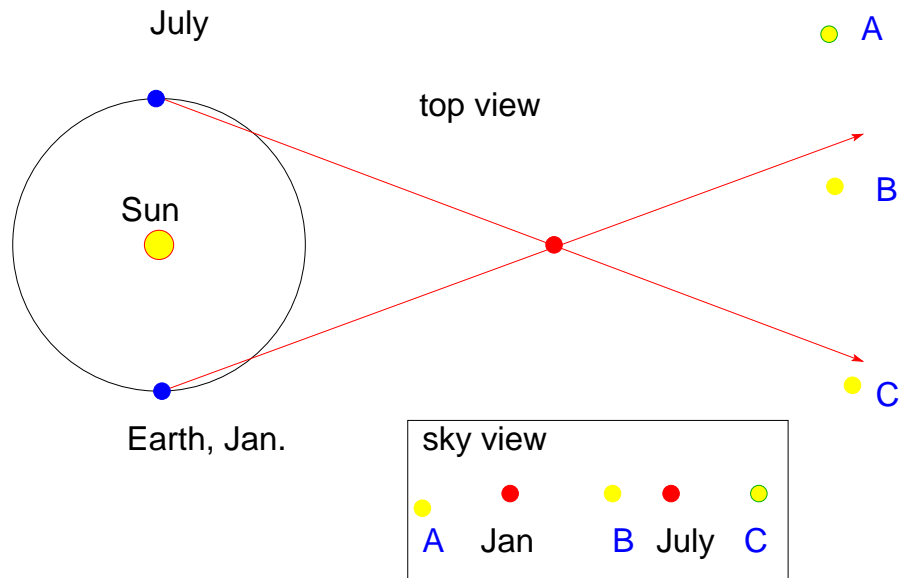★ apparent lack of **stellar parallax**

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

Consider view of stars from moving Earth
Q: diagram?

Stellar Parallax: Take One

if earth moves → star positions change on celestial sphere

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

but parallax effect *not* observed!

Q: why?

Q: if you are Aristotle, what do you conclude?

Why no parallax?

eye cannot resolve angles $\lesssim 1' = 1$ arc min $= 60$ arc sec
turns out−typical shift on sky: $\sim 1'' = 1$ 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 $\pm 23.5°$

∞

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

`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
- because Mercury and Venus *never* seen in opposition
  center of their epicycles placed 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 system (on esthetic grounds: "ugly")
adopted **heliocentric** (Sun-centered) 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
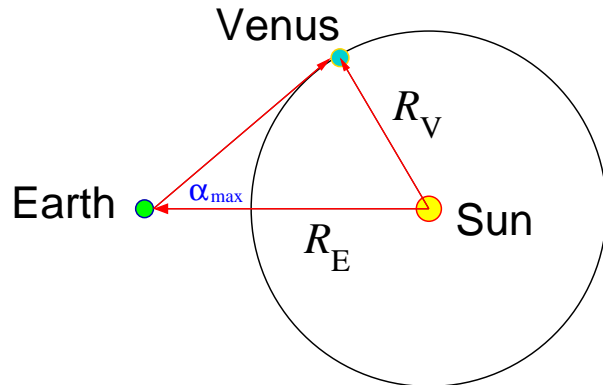 `www:   animation`
  simply explains retrograde correlations w/ planet location
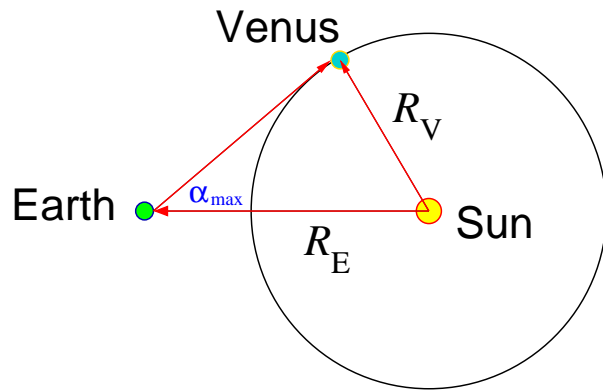- lack of stellar parallax ⇒ must assume large distance to stars

Copernicus and Distances

Copernicus model also allowed him to calculate
relative distances of planets

Venus: maxium angle (max "elongation") from Sun
  observed as $\alpha_{\mathsf{max}} = 46°$

Q: max elongation geometry in heliocentric model?
Q: that is, what's special about this triangle?

from diagram: right triangle, Earth–Sun distance is hypotenuse

$\Rightarrow \sin \alpha_{max} = R_V/R_E$

$\Rightarrow R_V = R_E/\sin \alpha_{max} = 0.72\, R_E$

New unit: "astronomical unit" = average Earth-Sun distance

$$1\ \text{AU} \equiv R_E = 1.50 \times 10^8\ \text{km}$$

- Earth (average) orbit radius: 1 AU
- Venus orbit: 0.72 AU