Astro 210

Lecture 5

Jan 28, 2011

Announcements

- HW1 due now
- HW2 available; due in 1 week
  HW1 Q8 bonus still available
- **register** your iClicker; link on course webpage
- first Planetarium shows next Monday, Thursday
  info online: **reservations**, schedules, directions, report form
- if this is your first class: see me afterward!

Last time:

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

Building a Scientific Model

Scientific Models must:

- explain observations
- predict future observations

> The principle of science, the definition, almost, is the following: *The test of all knowledge is observation.* Experiment is the *sole judge* of scientific "truth."
>
> The first principle is that you must not fool yourself–and you are the easiest person to fool.
>
> —Richard Feynman

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 $\rightarrow$ **theory**
theory is *end product*
  not mere speculation or offhand/wacky idea

Greek Cosmology

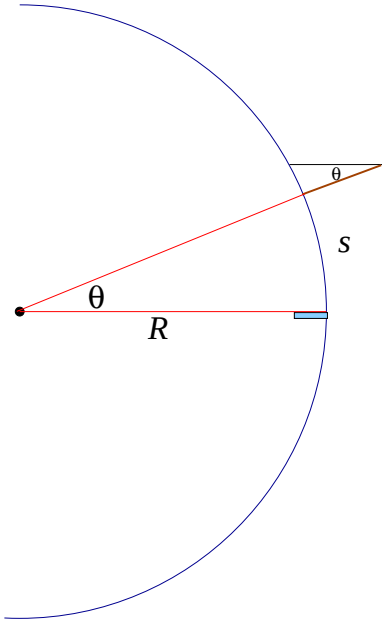
Pythagoreans
outlook: geometry is everything, perfected in spheres

- earth: spherical shape

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

- directly overhead at Syene, Egypt
  $\theta = 7^\circ$ 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!

- 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 appears to *shift* w.r.t. background stars

⇒ but parallax effect *not* observed!

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

but 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 $\pm 23.5^\circ$

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 $\sim$ 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 $\sim$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 $\alpha_{\text{max}} = \sin 46^\circ$

Q: max elongation geometry in heliocentric model?

from diagram: $\sin \alpha_{\text{max}} = \sin 46^\circ = R_{\text{V}}/R_{\text{E}}$
$\Rightarrow R_V = 0.72\ R_{\text{E}}$

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

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

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

Copernicus: What's New and What's Not

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

Q: so how do we decide which is right?

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