Astro 350
Lecture 3
Aug 26, 2011

Announcements:

- Discussion Question 1 posted on Compass, due Wed nite
- HW1 posted today, due at start of class Friday
  turn in paper copy, but can & should upload on Compass
  online submission gives record if question of HW loss
  note: wordy questions – don't be intimidated!

Last time: naked-eye cosmology
Today: making sense of it all–theories of the universe

Warmup:
Q: How are the Sun, Planets, Stars arranged in the sky?
Q: What does this mean about their 3-D arrangement?
Q: How do they move in the sky each day?
relative to one another?

Geometry of the Sky: Sun and Planets

Sun

stays on a circle (a great circle!) of cel sphere ("ecliptic")
moves among constellations

Planets

Greek: "wanderers" – move among constellations
on the sky: found on ≈same ecliptic path
(great circle) as Sun

in 3-D:

Sun, Earth, planets, (and Moon) all lie in ≈one single *plane*
...but still need to find shape of orbit in plane

Other patterns found:

- Mercury, Venus always near the Sun, never opposite on sky
- other planets can be near or opposite
- plant motions thru celestial sphere usually same direction
  ...but sometimes brief backwards "zigzag"
  $\rightarrow$ retrograde motion

Clearly: then naked-eye sky is highly organized
motions show clear patterns
these cry out for explanation!

We have collected data: on to theories!

iClicker Poll: Your Background

What Astronomy courses have you taken?

A ASTR 100

B ASTR 121 or 122

C ASTR 210

D none of the above, but I'll keep up

Classical Greek Cosmology: Geocentric

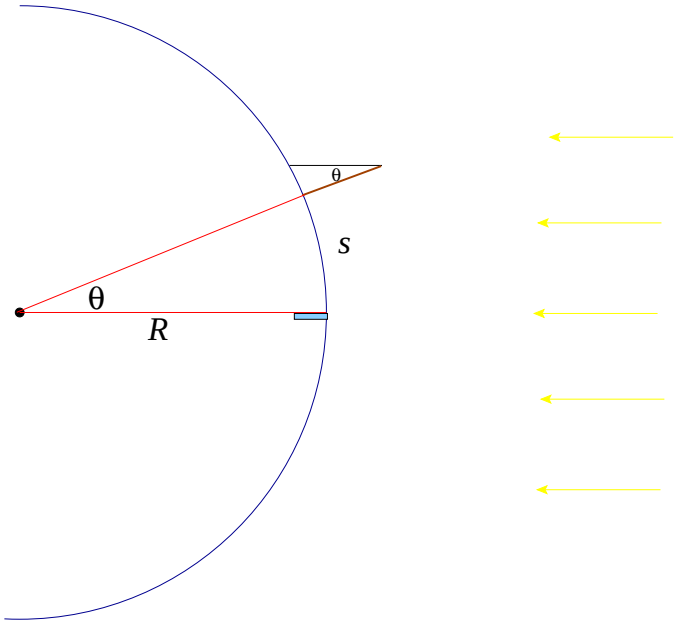
Classical Greek Cosmology

Pythagoras (Mr. Triangle!) and followers:
universe founded on **geometry**, which is 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
spinning around us in uniform circular motion

Aristotle (284-322 BC)

Two realms, where different physical principles apply

	heavenly	**terrestrial**
realm	above moon	below moon
status	"incorruptible" unchanging, perfect	"corruptible" changeable, imperfect
natural motion in realm	uniform circular rotation	earth, air, water, fire: toward natural place in universe earth lowest, then water, air, fire

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(!)

These are not crazy ideas!
Aristotle explained data available at the time
and gave strong evidence **against** Sun-centered picture!

Q: what are we missing? what's the fix?

Retrograde Motion and Epicycles

theory has to explain *all* data
if contradicted by some data, either:
- improve theory
- dump it and get a new one

Tricky balance: don't want to be too hasty
Q: why not immediately abandon theory if new data contradicts?
but also don't want to stubbornly cling to sinking ship

any cosmology must explain **Retrograde motion**
Greeks: deferent and epicycle
diagram: Earth, deferent path, epicycle, motion arrows

`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 motion
- retrograde motion
- Venus and Mercury never in opposition
  center of epicycles always on line
  connecting earth and sun

Errors generally < 5 deg: not bad but observable!
remained in use for $\sim$1400 years!!
Newton has not done as well! ...yet

iClicker Poll: Ptolemy & Science

Vote your conscience!

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

A yes

B no

C maybe

In Praise of Ptolemy

It is science? I'd say: Yes!

⋆ gives a logical way of organizing, picturing, and understanding the world

⋆ explains a large set of data both qualitatively and quantitatively

Q: which is to say?

⋆ based on a set of physical principles

Shortcomings:

- weak on predictions–no idea when/where will need new epicycle
- good but not perfect agreement with observations available at the time

Give Claudius his due:

given the data *available to him*

Ptolemy did a well as, or better than, all contenders

$\Rightarrow$ remained in use for $\sim$1400 years!

(Newton/Einstein can't touch that!)

Indeed, at the time big problems with sun-centered model

(where's the parallax?)

Today, geocentric has numerous problems:

we know more physics, and have better observations

But: if naked eyes are what you have, Ptolemy is legit

Renaissance Cosmology: Revolution!

Nicolaus Copernicus 1473–1543 Polish

adopted *heliocentric* cosmological model:

Note: motivation was *not* Ptolemaic disagreement with data but rather aesthetic – i.e., intuitive sense of beauty

`www: Copernican model`

- Mars & Venus closer to sun ⇒ always seen near sun
- earth spins ⇒ daily motion of celestial objects
- earth orbits sun ⇒ apparent sun motion in ecliptic
- retrograde motion: during earth–planet passing

`www: retro animation`

- lack of stellar parallax ⇒ large distance to stars

Bonus: calculated relative distances of planets!

recall: Venus never seen too far from Sun
largest angle from Sun: maximum "elongation" $\alpha_{\text{Venus}} = 46\,\text{deg}$

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 of distance/length:
"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