Astro 350

Lecture 3

Aug 31, 2011

Announcements:

- Homework 1 available, due at start of class next Friday
  turn in paper copy, but can Compass
  online submission gives record if question of HW loss
- Discussion 1 on Compass, due by start of class next Wednesday
- **register** your iClicker; link on course webpage

Last time: naked-eye cosmology

Q: How are the Sun, Planets, Stars arranged in the sky? in 3-D?

Q: How do they move in the sky each day?

relative to one another?

Q: what is a geocentric cosmology? how does it explain these?

Geocentric framework not a crazy idea!
explained data available at the time
and gave strong evidence **against** Sun-centered picture!

also note–*based on everyday experience*:

- not obvious that any objects in sky are larger than Earth!
  lunar eclipses show Moon smaller than Earth!
  need accurate distances to know Sun is larger
- not obvious that planets and stars have any size at all!

so perhaps Earth is the largest object in the Universe!?!?
  and thus, of course it should be at the center!

but one element of naked-eye motion not yet explained
Q: what are we missing so far? 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

Science

science is a human activity → actual real-life practice
very interesting and very complicated
will see complexity through examples, but for starters:

science is a systematic, logical set of ideas about Nature
and the test of all scientific knowledge is **observation**.
→ **Experiment** is the final judge of scientific truth.

If experiment is the Judge, then the Court is the
Scientific Method:

observation & experiment → tentative model → predictions
→ further experiment → refined model → repeat ↑
end product: **theory**

Scientific Models must:

- explain *all* existing observations
- predict future observations
- *change* or even be *abandoned*
  if in conflict with *any* observations

sounds simple–but surprisingly complex in practice

this process has forced us, kicking and screaming,
to take seriously ideas like dark matter, dark energy

Cosmologist Richard Feynman

> The scientific method is a way of *finding what works*
>
> The first principle is that you must not fool yourself
> –and you are the easiest person to fool.

Cosmologist Henri Poincaré:

> Science is built up with facts, as a house is with stones.
> But a collection of facts is no more a science
> than a heap of stones is a house.

Also note: scientific theory $\neq$ offhand idea or wacky notion!
despite common usage...

from *Webster's Collegiate Dictionary*

theory

1 : the analysis of a set of facts in their relation to one another

2 : abstract thought : SPECULATION

6 (a) : a hypothesis assumed for the sake of
argument or investigation
(b) : an unproved assumption : CONJECTURE

Not how we will use the term!

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`

- Mercury & 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`

But: have to explain *all* data

Q: how would Nick account for non-observation of star parallax?

Copernicus 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

Copernicus: What's New and What's Not

- planets still on spheres
- Copernicus still used epicycles!
- predictions *not* better than in Ptolemy's model
  $\rightarrow$ geometrically equivalent *Q: meaning?*
- 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 Extraordinare

in youth: observed "nova stella" (supernova) `www: Tycho sketch`
→ change observed in 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!

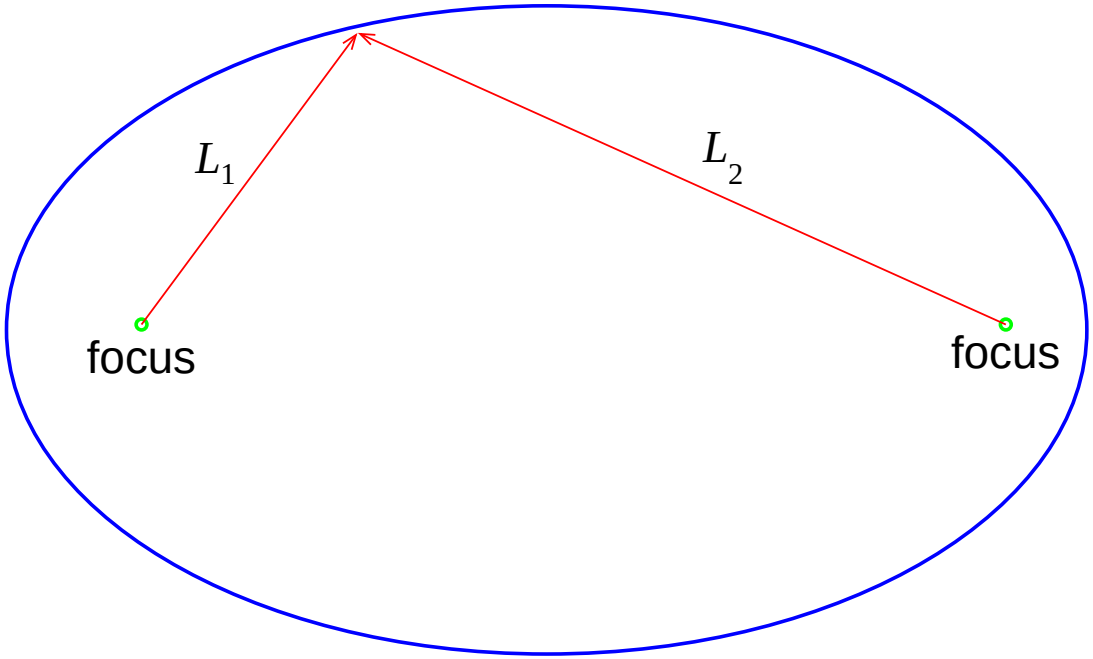
Johannes Kepler 1571–1630: Harmony of the Worlds

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 trial & error:
completely & accurately described planet orbits

Q: Kepler's Laws?

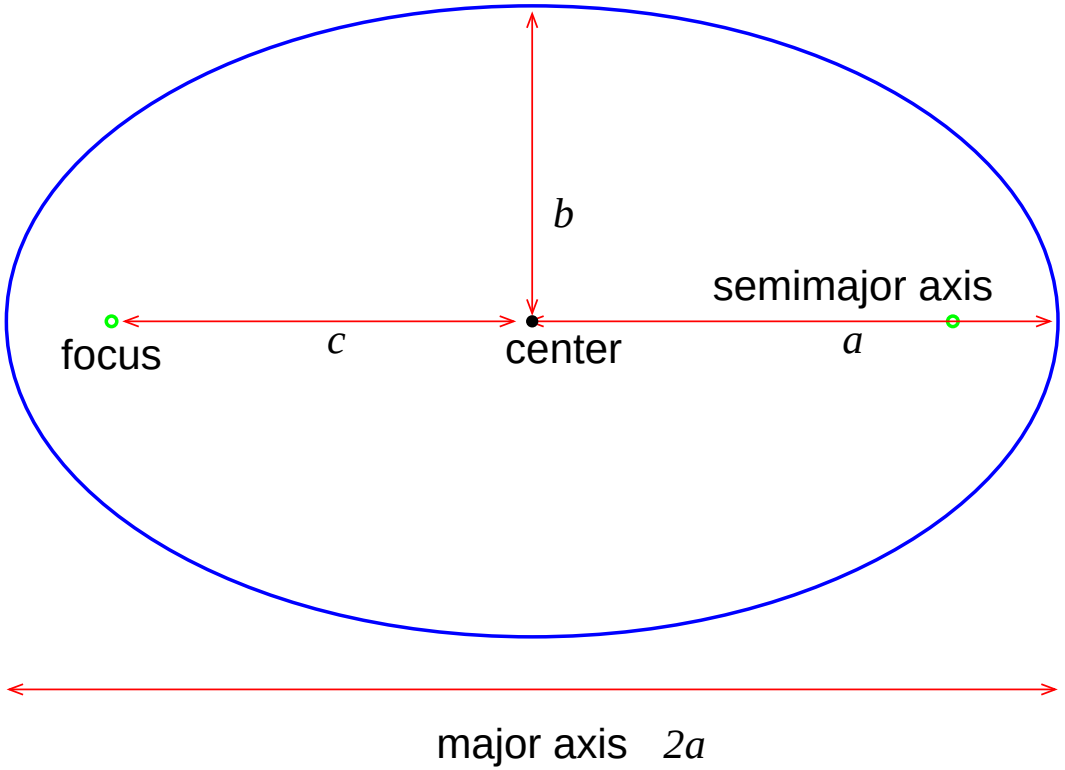
Kepler I: Law of Ellipses

each planet's orbit is an **ellipse**
with the **sun at one focus**



$$L_1 + L_2 = constant$$

Ellipse Anatomy



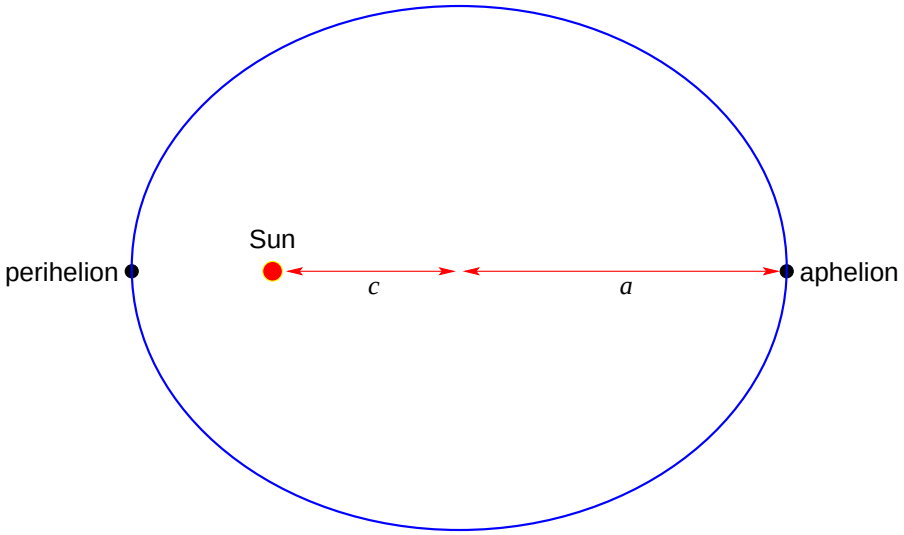
- two foci
- semi-major axis $\boxed{a}$
- focal length c
- semi-minor axis $b = \sqrt{a^2 - c^2}$

any ellipse fully characterized by:

a and eccentricity $\boxed{e = c/a}$

Q: what do we get for $e = 0$*?* $e = 1$*?*

Kepler I: orbit is **ellipse** with **sun at one focus**



Orbit anatomy

aphelion: *farthest* point from Sun

perihelion: *closest* point to Sun

Q: what is aphelion distance in terms of a *and* e*?*

$$r_{\text{ap}} = a + c = a + a\frac{c}{a} = (1 + e)a \qquad (1)$$

Q: If the Sun's at one focus, what's in the other focus?

Q: What does Kepler I not *say about orbits?*

At the other focus: nothing! (sorry!)

Note: Kepler I only gives orbit *shape*
but says *nothing* about how orbit evolves in time
$\rightarrow$ need more info to fully describe orbit, hence...

Kepler II: Law of Equal Areas

a straight line from the planet to the sun
sweeps out equal areas in equal times

diagram: sketch areas

note that this amounts to telling about speed of planet
Q: where fastest? slowest?
`www: area animation`

Q: This still doesn't fully characterize an orbits–why not?