Astro 210
Lecture 6
Jan 31, 2011

Announcements

- HW2 due Friday
  HW1 Q8 bonus still available
- **register** your iClicker; link on course webpage
- Planetarium shows begin tonight *weather permitting*
  check status at `www.parkland.edu`
- if this is your first class: see me afterward!

Last time: a tale of two cosmologies

- Geocentric
  Q what's that? how does it explain sunrise? retrograde?
- Heliocentric
  Q what's that? how does it explain sunrise? retrograde?

Today: geocentric vs heliocentric cagematch!

Tycho Brahe 1546-1601: Danish Astronomy Extraordinaire

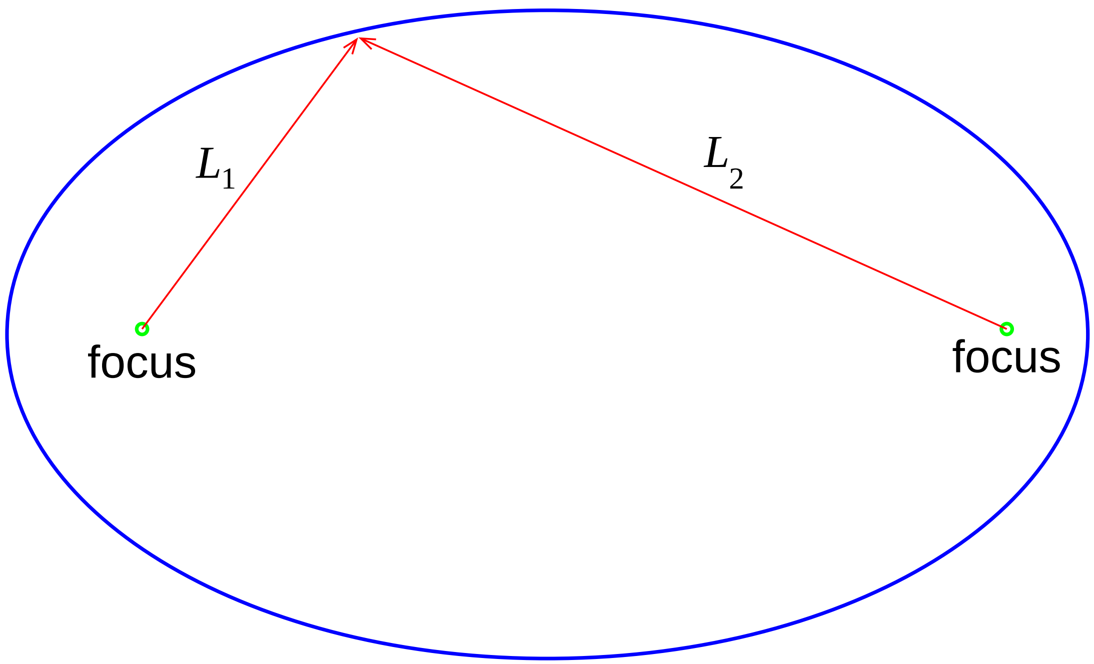
in youth: observed "nova stella" (supernova) `www: Tycho sketch`
  → heavens corruptible!
observed Sun, Moon, planets for 20 years: careful, accurate data
but not a good number cruncher
→ like any good professor: made grad student do the work!

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

Kepler I: Law of Ellipses

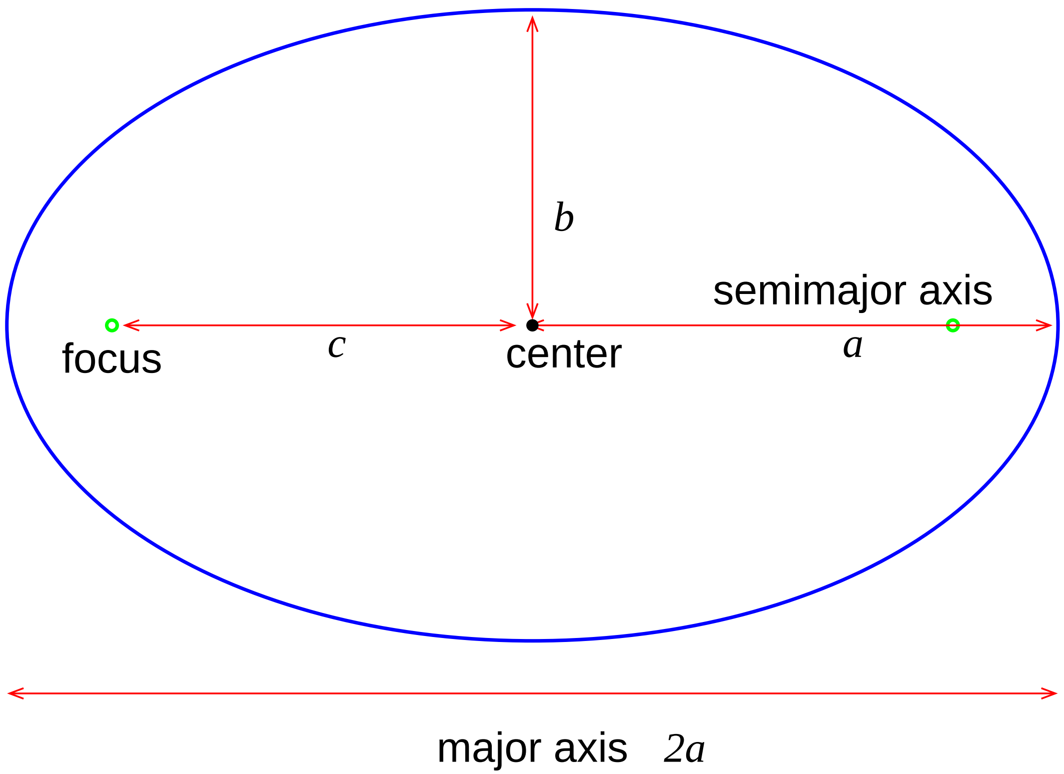
each planet's orbit is an **ellipse**
with the **sun at one focus**



$L_1 + L_2 = constant$

in a plane:
choose two points (foci)
ellipse: set of all points
for which *sum* $L_1 + L_2$
of distances to foci
is *constant*

Ellipse Anatomy



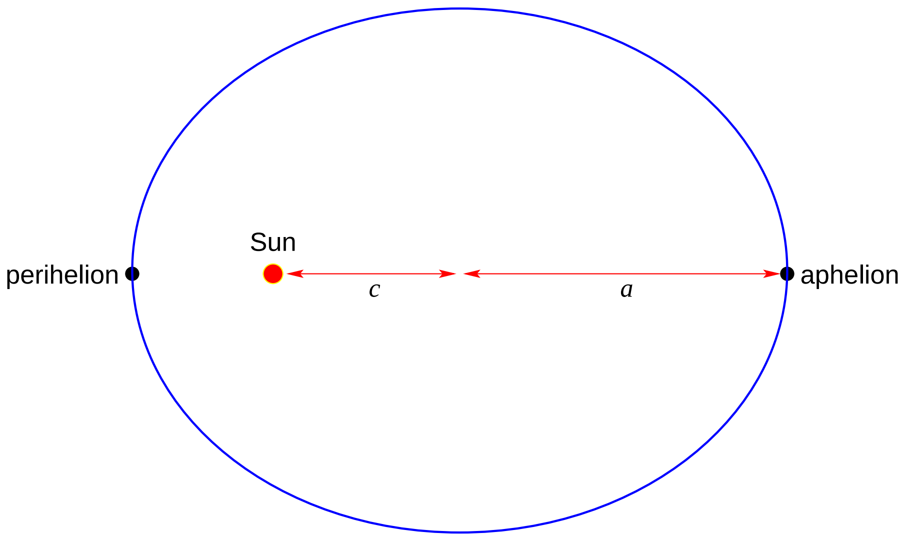
- two foci
- semi-major axis $\boxed{a}$
- focal length c
- semi-minor axis $b = \sqrt{a^2 - c^2}$

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?

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

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

iClicker Poll: Kepler II and Planet Speed

When does a planet move the *fastest*?

A When it is closest to the Sun

B When it is farthest from the Sun

C Trick question! In vacuum of space, planet speeds must be constant

`www: area animation`

∞

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

Kepler I gives orbit shape in space
Kepler II gives orbit evolution over time

but haven't yet connected the two:
how does spatial character (e.g., semimajor axis a)
relate to time character (e.g., period P)?

Need one last law...

Kepler III: The Mighty Equation

period P and a are related:

$$P^2 \propto a^3$$

$\Rightarrow P^2/a^3 = const$, and since must hold for Earth:

$$\boxed{P_{\text{yrs}}^2 = a_{\text{AU}}^3} \tag{2}$$

Q: ok for earth?

where P written in years, a in AU

Fine print: eq. (2) valid *only* for these units, and for orbits around Sun

Very powerful! e.g.:

Asteroids exist with orbits inside 1 AU (and some cross 1 AU!!)

`www: inner solar system objects--in real time!`

iClicker Poll: Kepler III

Kepler III: $P_{\text{yrs}}^2 = a_{\text{AU}}^3$

Consider an asteroid with an orbit entirely inside 1 AU

Is its period longer or shorter than a year?

A $P > 1$ yr, no matter eccentricity e

B $P < 1$ yr, no matter what e

C can't answer without knowing e

Kudos to Kepler

Several points worth noting...

★ An amazing discovery–mathematics underlies the workings of the cosmos!

★ Keplers laws remain accurate to this day–indeed, in slightly generalized form will show up in many (most!) situations where motions are controlled by gravity

★ Yet note what we still don't have:
an understanding of *why* Kepler's laws hold
→ that is, what is the *mechanism* that makes
planets move this way
...for that, need to wait for Kepler's successors...

Galileo Galilei

First to use telescope in Astronomy

`www: Galileo shows scope to Duke`

contributions:

- mountains on the moon
- moons of Jupiter
- sunspots
- phases of Venus

`www: Venus phase animation`

observations contradicted Aristotle

supported Copernicus

"paradigm shift" (Kuhn)

radical change in outlook/conceptual framework

Galileo brilliant but also arrogant and politically naive
$\rightarrow$ offended powerful people, including the Pope, a former ally
tried in Inquisition and forced to recant geocentric view

- his work, Copernicus, Kepler banned until 1832
- official semi-apology ("mistakes were made") 1992(!)

complex situation: crackdown as much political as theological

Note:

1. really not at all obvious to people that Earth orbits Sun
2. the paradigm shift was difficult and threatening

With earth removed from center of universe,
Aristotle's division of terrestrial and heavenly
no longer made sense as physics

$\Rightarrow$ need to re-examine "natural motion"
$\Rightarrow$ search for force that keeps planets in place
$\Rightarrow$ Galileo's **experiments**

Dynamics & Gravity

Galileo not only great astronomer
but also a great physicist
paved way for Newton's dynamics by study of
two special cases of motion

1. **"free body"** – *no* external influences
natural motion: coast in *straight line* with *const speed*
$\rightarrow$ retain current state of motion
$\rightarrow$ bodies have **inertia**

2. **"free fall"** – when only influence is *gravity*
Galileo recognized another key motion
Demo: Tower of Pisa expt
$\rightarrow$ *constant acceleration* **indep of mass**!
$a = g$, $g = 9.8\,\mathrm{m/s^2}$

Galilean free fall: constant acceleration $a = g$
So speeds change, linear with time

$$v = v_0 + gt \tag{3}$$

if start from rest, $v_0 = 0$, and then we have $v = gt$

Distance traveled is quadratic in time (starting from rest):

$$d = \int_0^{t_f} dt\, v(t) = \int_0^{t_f} dt\, gt = \frac{1}{2} g t_f^2 \tag{4}$$

Example: how long does it take to drop from table to floor?
$d \sim 1\text{m} \Rightarrow t^2 = 2d/g = 2 \times 1\text{m}/9.8\,\text{m/s}^2 \sim 0.2s^2 \Rightarrow \boxed{t \sim 0.45 \text{ s}}$

motion near Earth's surface well-described this way
(for speeds at which air resistance negligible)