Astro 210
Lecture 15
Sept 29, 2010

Announcements

- HW4 due next time
  instructor office hours after class today, or by appt
  TA office hours 10:30-11:30 am tomorrow, or by appt
- HW2 Q4 (10 bonus points) available till Friday
- **required** Night Observing begins next week
  check online for schedule and weather info
  download & bring question sheet
- last optional Planetarium shows tonight & tomorrow
  download & bring question sheet; due Friday

Last time: began Solar System

Q: basic patterns: objects? orbits?

Patterns in Planetary Orbital Dynamics

all planets & asteroids:

- move in same direction
- close to ecliptic plane
  ...except Pluto
- note also that *most orbits almost* **circular**
  biggest exception is Pluto

But could it have been otherwise?
Q: What rules does Newton impose on bound orbits?

And note the near-circularity of orbits:
consider a planet at initial distance $\vec{r}_{\text{init}}$
and release it with velocity $\vec{v}_{\text{init}}$
Q: how does orbit depend on $\vec{v}_{\text{init}}$ *magnitude, direction?*
Q: how to adjust $\vec{v}$ *to get a circular orbit?*

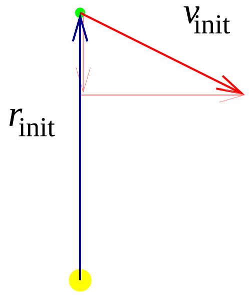
Newton/Kepler Motion and Initial Conditions

Given initial position $\vec{r}_{\text{init}}$ and velocity $\vec{v}_{\text{init}}$
trajectory (orbit) completely determined by Newton's laws

- if $v_{\text{init}} \geq v_{\text{esc}}$, orbit is *unbound*
  $\rightarrow$ leaves solar system on parabolic or hyperbolic orbit
- for $v_{\text{init}} < v_{\text{esc}}$, a *bound* orbit: ellipse or circle...but which one?

What if bound orbit where
$\vec{v}_{\text{init}}$ has *nonzero* component along $\vec{r}_{\text{init}}$?

Q: what kind of orbit will this be?



A ellipse ($e > 0$)
B circle ($e = 0$)
C either ellipse or circle, depending on size of v_{init} at r_{init}

The Miracle of Circular Orbits

- for $v_{\text{init}} < v_{\text{esc}}$, a *bound* orbit

if $\vec{v}_{\text{init}}$ has *any* component along $\vec{r}_{\text{init}}$
velocity is *not purely tangential*
i.e., failure to meet circular requirement $\vec{v}_{\text{circ}} \perp \vec{r}$
$\Rightarrow$ orbit *must* be an **ellipse**

but even if $\vec{v}_{\text{init}} \perp \vec{r}_{\text{init}}$, circle not guaranteed
if $v_{\text{init}} \neq v_{\text{circ}} = \sqrt{GM/r_{\text{init}}}$, orbit *must* be an **ellipse**

circular orbits result *only if* $\vec{v}_{\text{init}} \perp \vec{r}_{\text{init}}$ *and* $v_{\text{init}} = v_{\text{circ}}$ *exactly*!

Lesson: ellipse is "generic" bound orbit
circular orbits are "fine tuned" and special
$\Rightarrow$ the near-circularity of planet orbits cries out for explanation!

Planet Properties

Collected here for reference; discussion follows

Note trends, distinctions between terrestrial/Jovian

Property	Terrestrial	Jovian	Pluto
Members	Merc, Ven, Earth/Moon, Mars	Jup, Sat, Urn, Nep	PL
avg dist. from Sun (a)	0.4 – 1.5 AU	5.2 – 30 AU	39 AU
size R	$\sim$ earth	4–11 earth	$\sim$ 0.2 earth
mass	$\lesssim$ earth	15–300 earth	$\sim$ 0.002 earth
density	3000–5000 kg/m^3	$\sim$ 1000 kg/m^3	$\sim$ 2000kg/m^3
interior	rocks, metals	gas, ice, metal core	?
spin period	$\gtrsim$ 1 day	$\lesssim$ 1 day	6 days
atmosphere	none, CO_2, O_2, N_2	H_2, He, H-compounds	methane CH_4

Composition

composition = what mix of elements

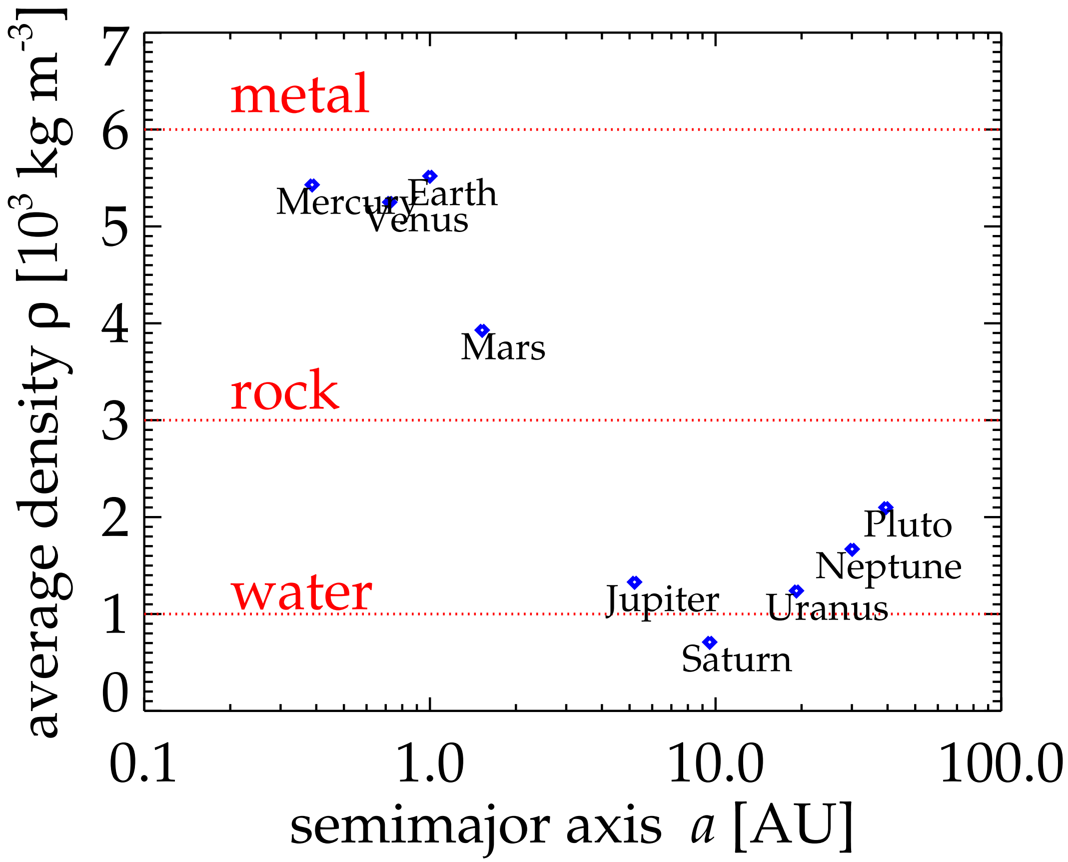
note: density ↔ composition connection

denser → richer in heavy elements
e.g., water (H_2O): $\rho = 1000\,\mathrm{kg/m^3}$
rocks (O,Si): $\rho \sim 3000\,\mathrm{kg/m^3}$
metals (Ni,Fe): $\rho \sim 6000\,\mathrm{kg/m^3}$

for planets, once mass M and radius R are known *Q: how?*
can compute *average* density

$$\langle\rho\rangle = \frac{M}{V} = \frac{3M}{4\pi R^3} \tag{1}$$

Average Planetary Density



Q: what trends do you notice?
Q: what does this teach us?
Q: what are limitations of this comparison?

Spin Rate

Use Doppler effect!

spinning planet: $v = 2\pi R/P$ at equator
v_r w.r.t. observer:
- on edge receding: $v = -2\pi R/P$ → redshift
- on edge approaching $v = +2\pi R/P$ → blueshift

diagram: top view

total Doppler “width” of a line: $\delta\lambda/\lambda = 4\pi R/cP$
observe $\delta\lambda$, infer width

$$P = \frac{4\pi R}{c}\frac{\lambda_{\mathrm{em}}}{\delta\lambda} = 243 \text{ days (Venus)} \tag{2}$$

Observed spins: general trends

almost all planet spin in roughly same direction as orbit
i.e., angle (“obliquity”) between spin and orbit axes is *small*
and so spin angular momentum vectors $\vec{J}$
typically roughly aligned with orbit angular momentum $\vec{L}$
i.e.: $\uparrow_{\rm orbit}\uparrow_{\rm spin}$
→ another highly organized pattern demanding explanation

note: important exceptions do exist

- Venus: spin is retrograde (“upside-down”) $\uparrow_{\rm orbit}\downarrow_{\rm spin}$
- Uranus: sideways $\uparrow_{\rm orbit}\rightarrow_{\rm spin}$

`www: planetary obliquities`

→ these too needs to be understood

Surface Temperature

Measuring Temperatures

Q: How to measure planet surface temperatures?

...before visiting! have plan ahead to decide on wardrobe!

hint–*not* Wien's law in simpleminded way! (consider blue Earth!)

Q: expectations from trends of T *vs distance* d *from Sun?*

iClicker Poll: Temperature and Planet Size

Consider two planets both at same distance d from Sun
and identical (same composition, etc), *except*
planet Huge is larger than planet Tiny: $R_{\mathrm{Huge}} > R_{\mathrm{Tiny}}$

Vote your conscience:

Which planet is hotter?

A planet Huge

B planet Tiny

C they have the same temperature

Measuring Temperatures

key point: the visible light that lets you see the planet
is not blackbody emission → reflected sunlight
but: there *is* black body emission at longer λ: infrared
`www: IR Moon, Mars`

General trends:
indeed, T drops with distance d
but less strongly than $1/d$ (*not* an inverse square law for T!)
we would like to (and can!) understand in detail

Understanding Temperatures

Q: what are sources of heating? of cooling?
Q: what physical laws/conservation principles are important?
Q: what sets planetary surface temperatures?

The Astrophysics of Planetary Temperatures

- ▷ surface heating dominated by radiation ‘
  (i.e., energy flow) from the Sun’s emission, peaked at optical λ
  “geo” thermal (usually) small contribution (but large for Jupiter)
- ▷ cooling also due radiation (blackbody emission, peaked at IR)

Note: Sun is steady source of light
i.e., constant luminosity = power = Wattage = $L_{\odot}$
each planet constantly receives this radiation
and also emits its own, according to its T
★ planet $T \rightarrow$ constant value (in time),
★ set by an **equilibrium**:
incoming/outgoing energy flows exactly balance!

Q: Why? What would happen if inflow $>$ outflow? vice versa?

planetary energy flows (i.e., power or wattage W):

- W_{in} = absorbed sunlight energy: constant power flow in
- W_{out} = blackbody emission:
  strong increasing function of T

What if $W_{\text{out}} > W_{\text{in}}$*?*
energy conservation → planet has net energy loss
→ suffers cooling → reduces W_{out}
if new $W_{\text{out}} > W_{\text{in}}$? still, then lather, rinse, repeat
until $W_{\text{out}} = W_{\text{in}}$! equilibrium achieved!

What if $W_{\text{out}} < W_{\text{in}}$*?*
can convince yourself: planet warms until $W_{\text{out}} = W_{\text{in}}$!
equilibrium achieved in this case too!

lesson: all roads lead to equilibrium!
If Sun's emission steady, then planet T must go to
steady value, set by energy-conserving balance: $\boxed{W_{\text{out}} = W_{\text{in}}}$

Plantary Temperatures Calculated

Can get excellent estimate of planetary T from
(fairly) simple first-principles calculation!

key is energy (power) balance: $\boxed{\text{absorption} = \text{emission}}$
diagram: sun, planet. label $R_\odot$, d, R

$\boxed{\text{Absorption}}$
recall: if surface of area S_{surf} emit flux F_{surf}
then radiated power = luminosity [energy/sec] is $L = F_{\text{surf}} S_{\text{surf}}$
Sun: $L_\odot = F_\odot S_\odot = 4\pi R_\odot \sigma T_\odot^2$
at planet, flux is $F = L/4\pi d^2 = \sigma T_\odot^4 (R_\odot/d)^2$ [energy/area/sec]

....but we know not all incoming sunlight is absorbed!
Q: Why not?
Q: What substance would *absorb all incident sunlight?*
Q: What substance would absorb no *incident sunlight?*
Q how could we simply quantify all of this?