Astro 210

Lecture 15

Feb 21, 2018

Announcements

- **HW4 due online in PDF, Friday 5:00 pm**
- Hour Exam grading underway
- **Night Observing begins this week**...weather permitting
  Campus Observatory. Wed, Thur. 7–9pm
  bring **report form** available on Moodle
  take and submit **selfie** while there
- extra **extra Planetarium show tomorrow** Thursday Feb 22

Last time: telescopes (optical)
continued a major theme of this course...

> Nature uses only the longest threads to weave her patterns, so each small piece of her fabric reveals the organization of the entire tapestry.
> –Richard Feynman, 1965, *The Character of Physical Law*

example: tight interconnections among
  astronomy, astrophysics, and cosmology
  fundamental physics
  engineering & technology

advances in each area make possible advances on the others

Invisible Astronomy

before 20th century: astronomy = optical astronomy
visible waveband only known form of light

Now: view the cosmos across the full electromagnetic spectrum
$\rightarrow$ radio, IR, UV, X-ray, γ-ray
Q: why? what new information do these bring?

key issue: atmosphere is *not* transparent
to all wavelengths
`www: atmospheric transmittance`
Q: patterns?
Q: implications?

Astronomy Beyond the Visible

the cosmos shines across the entire EM spectrum

- different wavebands $\leftrightarrow$ different emission processes, e.g.,:
  $\lambda = 21$ cm: radio waves from cold, diffuse H atoms
  $E \approx 1$ MeV $\approx m_e c^2$: γ-rays from colliding neutron stars
- our Galaxy is opaque at some λ, transparent at others
  $\Rightarrow$ can't see Galactic center with visible light!

radio, microwave/mm: large antennas
since λ very large
$\rightarrow$ need huge collecting area for angular res.
$\rightarrow$ arrays of antennae
`www: VLA, Arecibo, SPT, ALMA`

infrared: mostly requires space, and cooling *Q: why?*
shortest λ visible from ground
at airline altitudes can see mid-IR `www: Sofia`
for far-IR must go to space `www: Spitzer, JWST`

X-ray: don't penetrate atmosphere
$\longrightarrow$ must go to space
to focus: scatter at glancing angle
detectors: measure energy deposited
`www: Chandra, XMM`

Gamma-ray: stopped by atmosphere

- from ~ 1 to 300 GeV $\approx m_e c^2$ to $m_p c^2$: space-based detectors similar to high-energy physics `www: Fermi`
- $\gtrsim 300$ GeV: each photon creates particle shower that travels through atmosphere, excites molecules detect resulting emission/particles from ground!

`www: HESS, Veritas, HAWC`

Multimessenger Astronomy

20th Century Physics:

- the cosmos contains more particles than photons!
- there are more forces/interactions than electromagnetism

21th Century Astronomy: observe other messengers from afar
$\longrightarrow$ non-electromagnetic radiation!

⋆ **neutrinos**
arise and interact via *weak nuclear interaction*

⋆ **cosmic rays** (relativistic nuclei and electrons)
interact via *strong nuclear interaction* (and also EM)

⋆ **gravitational radiation** ("gravity waves")
arise via strong *gravitational interactions*

Much more about these soon!

The Solar System

The Solar System

`www: Place in the Big Picture`

Why study the Solar System?

▷ it's home!

▷ use present to learn about past

$\rightarrow$ clues for origins of Earth & Sun

▷ help understand origin of exoplanets: compare/contrast

Sociology: traditionally, astronomy divided into study of solar system vs extrasolar objects

boundary is artificial, and somewhat loosening now...

∞

Basic Organization `www: SS lineup`

Terrestrial planets (Earth-like): smaller, rocky, warmer
Mercury, Venus, Earth/Moon, Mars

Asteroid Belt: rocky bodies (Ceres) and debris

Jovian planets (Jupiter-like): large, gaseous, colder
Jupiter, Saturn, Uranus, Neptune

Kuiper Belt: Icy bodies (Pluto, Eris, ...) and debris

Oort Cloud: Very distant icy debris

Pluto: in summer 2006, demoted to “dwarf planet”
$\longrightarrow$ will discuss what’s behind this

Patterns in Planetary Orbital Dynamics

all planets & asteroids:

- **orbit Sun in same direction**
- **orbit planes close to ecliptic** (small inclination)
  ...except Pluto
- **orbits almost circular** (small eccentricity)
  ...except Pluto

But could it have been otherwise?

Q: What rules does Newton impose on bound orbits?

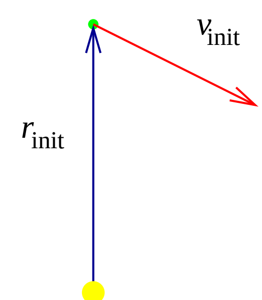
And note the near-circularity of orbits:

consider a planet at *initial distance* $\vec{r}_{\rm init}$

and release with *initial velocity* $\vec{v}_{\rm init}$

Q: how does orbit depend on $\vec{v}_{\rm init}$ *magnitude, direction?*

Q: how to adjust $\vec{v}$ *to get a circular orbit?*



Newton/Kepler Motion and Initial Conditions

Given:

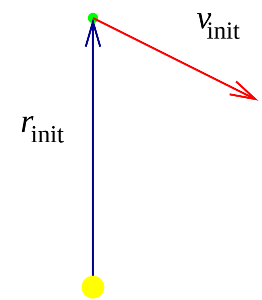
- initial position $\vec{r}_{\rm init}$, and
- velocity $\vec{v}_{\rm init}$

trajectory (orbit) completely determined by Newton's laws

- if $v_{\rm init} \geq v_{\rm esc}$, orbit is *unbound*
  $\rightarrow$ leaves solar system on parabolic or hyperbolic orbit

- for $v_{\rm init} < v_{\rm esc}$, a *bound* orbit: ellipse or circle...but which one?

iClicker Poll: Orbits and Initial Conditions



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 $v_{\rm init} < v_{\rm esc}$, a *bound* orbit

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

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

circular orbits result *only if* $\vec{v}_{\rm init} \perp \vec{r}_{\rm init}$ *and* $v_{\rm init} = v_{\rm circ}$ *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	**Mercury, Venus** **Earth+Moon, Mars**	**Jupiter, Saturn** **Uranus, Neptune**	**Pluto** similar for KBOs=Eris+...?
semimajor axis 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	rocky core + ice mantle?
spin period	$\gtrsim$ 1 day	$\lesssim$ 1 day	6 days
atmosphere	none, CO_2, O_2, N_2	H_2, He, H-compounds	N_2, methane CH_4, CO

Composition

composition = what mix of elements

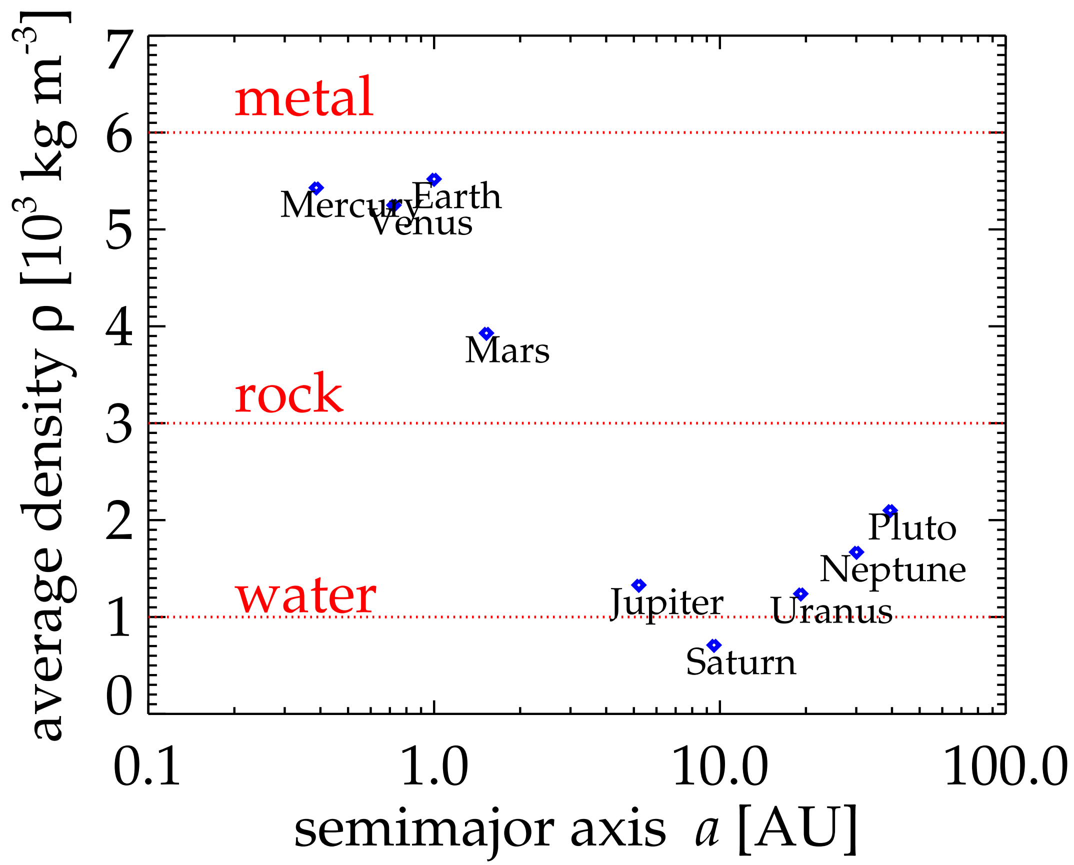
note: density $\leftrightarrow$ composition connection

density: mass/volume M/V
for solids & liquids: denser $\rightarrow$ 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?

Planet Spins

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.: $\uparrow_{\text{orbit}}\uparrow_{\text{spin}}$
$\rightarrow$ another highly organized pattern demanding explanation

note: important exceptions do exist

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

`www: planetary obliquities`

$\rightarrow$ 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: $R_{\text{Huge}} > R_{\text{Tiny}}$

Vote your conscience:
Which planet is hotter?

A planet Huge

B planet Tiny

C they have the same temperature