Astro 210

Lecture 22

March 9, 2018

Announcements

- **HW6 due online in PDF, Today 5:00 pm**
- **Night Observing next week** – great weather for sure :¿
  Campus Observatory. Monday through Thursday 7–9pm
  bring **report form** available on Moodle
  take and submit **selfie** while there

Last Time: Solar System Debris = Small Bodies

Unfinished business: `www: Daily Show Chelyabinsk punchline`

Q: patterns?

Q: debris populations/concentrations?

Q: Kuiper Belt vs Oort cloud – similarities? differences?

`www: Kuiper Belt sketch`

`www: Oort Cloud sketch`

Pluto

Orbit

- $a = 39.5$ AU, $P = 285$ yr
  has not made a full orbit since discovery in 1930
- $e = 0.25$ – largest for any planet, crosses Neptune orbit

Properties

spherical shape. $R = 1151$ km $\approx R_{\oplus}/6$
$\rho_{avg} \simeq 2000$ kg/m^3 $\rightarrow$ ice, rock
surface: N_2 and methane ice, coating water ice
atmosphere: very thin, $P = 10^{-5}$ earth
  appears at aphelion, freezes and snows out at perihelion

July 2015: *New Horizons* flyby – first closeup look

- Pluto surface: mountains, valleys, plains
- very few craters! $\rightarrow$ tectonic activity, possibly ice volcanos

`www: New Horizons multimedia`
Jan. 1, 2019 ring in New Year: close flyby of KBO 2014 MU69

Pluto's largest moon: Charon
together a "*double planet*" system

Mass $M_{\mathrm{PL}} + M_{\mathrm{C}} = 0.0024 M_{\mathrm{Earth}}$; $M_{\mathrm{C}} \simeq 0.12 M_{\mathrm{PL}}$
$R_{\mathrm{PL}} = 1151$ km, $R_{\mathrm{C}} = 604$ km $\approx \mathrm{R}_{\mathrm{PL}}/2$

both spins & orbit all have *same period*:

- system *tidally locked* into co-rotation
- each keeps same face to other

similar to comet nucleus, other Kuiper Belt objects
Pluto: smallest planet or largest KBO?

Pluto: History and Status

Clyde Tombaugh (1930): Pluto discovered in sky scan
totally unlike its gas giant and ice giant neighbors

1930's-1950's: Kuiper belt idea proposed
1990's: Kuiper belt objects discovered
2002–present: more large outer solar system objects

- Quaoar ("Kwawar"): $\approx$ 60% Pluto size
- Sedna: $\approx$ 70% Pluto size
- Eris: initial size estimates larger than Pluto!!
  New Horizons data: Pluto slightly larger! but Eris more massive

all these are spherical rocky iceballs: "*plutoids*"
largest of huge population of object beyond Neptune
orbits more elliptical than planets, but still $\approx$ in ecliptic
Trans-Neptunian objects = KBOs, plutoids are largest
smaller Kuiper belt members sometimes scatter $\rightarrow$ comets

To Be Or Not To Be

2006: International Astronomical Union redefines "planet"
Pluto demoted to "dwarf planet"
along with Ceres (asteroid belt), and KBO's Eris + 2 others

Revise you vote–or not: Is Pluto a full-fledged, non-dwarf planet?

A No way! Good riddance!
And I've got my eye on you, Neptune!

B Umm, probably not?

C Umm, probably so?

D Yes way! Pluto was robbed! Long live Pluto!

My Personal Take: We Have Lived Sheltered Lives

it's not nature's job to fit into human-created categories
it's the other way around!

Parable: growing up with cows as the only known animals
then leave town and for the first time see a dog

- can call it a "dwarf cow" – a good start, but too limited
- really: the Universe is more diverse than you realize!

Lesson: *we need to get out more and see the wide world!*
this is a main goal of science and especially astro/cosmo

The Age of the Earth & Solar System

Very useful, important to know
age of Earth, other solar system bodies

"gold standard" method: radioactive dating

Radioactivity

recall: nucleus = collection of protons and neutrons
not all atomic nuclei are stable! some spontaneously decay!

why? rough rule of thumb:
nuclei "prefer" $\#n$ and $\#p$ roughly *equal*
if too many extra n or p $\rightarrow$ change to make more even

example: Carbon-14
$^{14}\mathrm{C} = \boxed{\text{6p} \quad \text{8n}}$: 2 extra n $\rightarrow$ unstable, radioactive
decay to Nitrogen-14: $^{14}\mathrm{N} = \boxed{\text{7p} \quad \text{7n}}$; has equal n and p, stable
how? change one $n \rightarrow p$
Q: why can't this be all that occurs in decay?
Q: how to predict when one ^{14}C nucleus decays?

radioactive decays: to try to balance n and p
decays can change $n \rightarrow p$, or $p \rightarrow n$
but note: electric charge(p) $\neq$ charge(n)
$\rightarrow$ need another charged particle–electron!
turns out: yet another particle too (neutrino)

for the case $n \rightarrow p$, really have

$$n \rightarrow p + e + \nu_e \tag{1}$$

where ν_e is a (electron-type) neutrino (more on these later)

note:

- at deeper level, decay is quark change $d \rightarrow u + e + \nu_e$
- decay produces have high kinetic energy $\rightarrow$ heat

Radioactive Decay Law

When will a given nucleus decay?
Trick question! In subatomic quantum world, decays are *random*!
cannot predict when individual particle will decay!
But *can* predict very accurately how a large sample will decay
`www: decay simulations`

The rule: starting with n_0 radioactive nuclei at time $t = 0$
decay rate $\propto$ number n of nuclei still alive
$dn/dt = -\lambda n$
w/ "decay constant" λ, depends on isotope

$$\frac{dn}{n} = -\lambda dt \qquad (2)$$

$$\ln\left(\frac{n}{n_0}\right) = -\lambda t \qquad (3)$$

$$n(t) = n_0 \, e^{-\lambda t} \qquad (4)$$

exponential decay law

fixed time for half of present sample to decay: *half-life*

rewrite:

$n = n_0\ 2^{-t/t_{1/2}} = n_0\ (e^{\ln 2})^{-t/t_{1/2}} = n_0 e^{-\lambda t}$

$\rightarrow$ half life and decay rate are inverses: $t_{1/2} = \ln 2/\lambda$

Radioactive Dating

radioactive material can be age-dated:

⋆ decay rate predictable: "clock"

⋆ both undecayed "parents" and decay "daughters" observable
  $\rightarrow$ can infer amount of decay

⋆ some nuclei have very long $t_{1/2}$ $\rightarrow$ can measure very old ages

Example: Potassium–Argon dating *Demo: banana*

^{40}K is rare, unstable potassium isotope

decays to argon $^{40}\text{K} \rightarrow {}^{40}\text{Ar}$ with $t_{1/2} = 1.3 \times 10^9$ yr

Worked Example

Experiment: in rock, measure *ratio* $n(^{40}\mathrm{Ar})/n(^{40}\mathrm{K}) = 10.6$

assume $n(^{40}\mathrm{Ar}) = 0$ at rock formation *Q: why*?
$\longrightarrow$ what is age t of rock?

1. find $n_0(^{40}\mathrm{K})$:

$$\frac{n(^{40}\mathrm{Ar})}{n(^{40}\mathrm{K})} = \frac{n_0(^{40}\mathrm{K}) - n(^{40}\mathrm{K})}{n(^{40}\mathrm{K})} = 10.6 \tag{5}$$

$\longrightarrow n_0(^{40}\mathrm{K})/n(^{40}\mathrm{K}) = 11.6$

2. now get age:
$n_0(^{40}\mathrm{K})/n(^{40}\mathrm{K}) = 2^{t/t_{1/2}}$
$\Rightarrow \log_{10}(n_0/n) = t/t_{1/2} \log_{10} 2$

$$t = \frac{\log_{10}(n_0/n)}{\log_{10} 2}\ t_{1/2} = 4.6 \times 10^9\ \mathrm{yr} \tag{6}$$

Ages of Earth and the Solar System

Earth

^{40}K $-$ ^{40}Ar clock "reset" whenever rocks melted *Q: why?*

- gives a range of dates for earth rocks
  Q: why does this make sense?
- oldest earth rocks give

$$t(\text{oldest rocks}) \approx 4.3 \times 10^9 \text{ yr} \ \leq t_{\text{earth}} \tag{7}$$

Solar System

radioactive dating show: **meteorites** oldest objects
strictly speaking: give *lower bound* to solar system age
practically: likely formed quickly $\rightarrow$ give SS age

$$t_{\text{SS}} = 4.6 \times 10^9 \text{ yr} = 4,600,000,000 \text{ yr} = \boxed{\text{4.6 billion years!}} \tag{8}$$

Origin of the Solar System

theory building!
recall: geocentric/heliocentric theories...

Input SS data, laws of physics

Output: Model
sequence of events, predictions for evolution up to present

patterns in the solar system to be explained by
a theory of solar system origin
Q: solar system patterns?
Q: planet similarities? differences?

Solar System Data to be Explained

dynamics: orbits, spins

- planet orbits in ecliptic plane
- rough spin/orbit alignments
- but some spins misaligned

structure: Terrestrial/Jovian differences:

- composition
- location
- size
- spacing

debris = small bodies:

- rocky asteroids between Terrestrial & Jovian planets
- icy comets/KBOs/Oort cloud beyond Jovian

Hour Exam 1

Scores posted on Moodle
Solutions will be posted online.

Recall:

- this exam worth 100 points = 10% of final grade
- equivalent to 2 HW grades

Many people did well – congratulations if you did!
keep up the good work

regardless of how you did on this exam:
don't lose perspective on the other 90% of the course!