Astro 210

Lecture 18

February 28, 2018

Announcements

- **HW5 due online in PDF, Today 5:00 pm**
- **HW6 posted, due online next Friday March 9**
- **Night Observing next week**
  Campus Observatory. Mon, Tue, Thur 7–9pm
  bring **report form** available on Moodle
  take and submit **selfie** while there
- **Distinguished Lecture & Extra Credit Opportunity**
  Prof. Sara Seager, MIT,
  "Exoplanets and the Search for Habitable Worlds"
  7-8 pm, Wed March 7, Lincoln Hall Theater
  Selfie+online report = *bonus points* ("extra credit")

Right After the One Small Step

(Garbled) the surface is fine and powdery. I can kick it up loosely with my toe. It does adhere in fine layers, like powdered charcoal, to the sole and sides of my boots. I only go in a small fraction of an inch, maybe an eighth of an inch, but I can see the footprints of my boots and the treads in the fine, sandy particles. [...] It [the landscape] has a stark beauty all its own. It's like much of the high desert of the United States. It's different, but it's very pretty out here. – Niel A. Armstrong

Magnificent desolation.
– Buzz Aldrin

July 21 1969
Mare Tranquillitatis–Sea of Tranquility

★ "soil" **regolith** = "rock blanket"

`www: footprint`

`www: moonwalk video`

dust, rock fragments: mostly pulverized Moonrock

a few% accumulated debris from many impacts

★ tips for lunar tourists/settlers:

- no significant atmosphere → no UV, X-ray protection
  but can do high-energy astronomy from the ground!
- slow rotation → long "days"
  huge day/night temp diff: 370K vs 125 K
  Q: why?

Lunar Cratering and Solar System Impact History

highlands: lighter in color, heavily cratered
maria smooth: fewer craters

Why the difference?
⋆ impactor bombardment random but same over all Moon
large regions cannot "hide"
⋆ cratering differences immediately show maria younger!
⋆ combine with lunar rock composition (maria basaltic)
→ maria formed by lava flows due to large impacts
→ younger surface → fewer craters

Implications

- violent impacts common in the past
- fewer impacts after maria formed → bombardment has slowed
- can use cratering counts to deduce impact history
⇒ huge bombardment rate initially

The Moon: Origin

Earth & Moon similar in composition of crust, different in core

- Fission model ("separated at birth") :

moon spun out from rapidly rotating earth

- Binary ("Sister") model

earth and moon formed together as binary system

- Capture model

"vagabond" moon gravitationally captured by earth

- giant impact model

Moon created in collision of Mars-sized object with early Earth

Q: pros, cons of each?

• Fission model ("separated at birth") :
unlikely: ang mom problem–Earth wouldn't rotate fast enough

• Binary ("Sister") model
unlikely: where do differences come from?

• Capture model
unlikely: where do similarities come from?

• giant impact model
"least unlikely"–accounts for both differences and similarities
$\rightarrow$ early solar system a violent place!

`www: impact movie`

Moon Wrapup

`www:  image comparison`

Q: compare/contrast?

Mercury

short year, but long days: $P_{\text{spin}} = 59$ Earth days

huge temperature swings:
$T_{\text{day}} = 700$ K, $T_{\text{night}} = 80$ K

Moonlike in many ways
- only slightly larger than the Moon
- cratered surface, muted colors
- no permanent atmosphere, but escaping O_2, Na, H_2, He, K

Venus

Properties

M, R, ρ_{avg} almost identical to Earth's: "sister planet"

$\rightarrow$ probably very Earth-like initially

now: hellish!

atmosphere: thick

mostly CO_2; clouds of concentrated sulfuric acid

surface pressure $P_0 = 90\text{atm} = 90\times$ Earth

surface $T = 750\text{K} = 380$ C $= 800$ F; melts lead!

`www: Venera 9 & 10 comparison`

`www: Venera 13 image`

landers lasted for $\sim 1 - 2$ hr, then got cooked

found: flat rocks, basaltic soil $\rightarrow$ volcanic activity

other evidence for "geo"logical activity on Venus:

`www: Guinevere plains---stretching forces from mantle`

`www: Venus craters`

crater counts similar to Earth–a few 100 Myr old

but no plates! Has to be resurfaced some other way, perhaps active volcanism?

`www: radar map: volcano lava flows?`

Note: $T_{\text{surface}} \gg T_{\text{eq}}(a_{\text{Venus}}) \approx 230$ K from our master equation

$\rightarrow$ i.e., much *hotter* than expected *equilibrium temperature*

Q: Why so hot?

Greenhouse Effect

basic idea: atmosphere traps thermal energy
surface region at different T than top of atmosphere
in HW6 you work this out in detail
note: important for Earth and Mars too

Consider radiative energy flows
incoming: sunlight–visible wavelengths, atm transparent
  Venus surface not dark!
outgoing: surface thermal (BB) emission: IR
  but CO_2 in atm blocks IR, absorbs energy
$\Rightarrow$ atmosphere acts like blanket

iClicker Poll: CO_2 and Surface Temperature

Imagine Sun's radiation and Venus orbit fixed
but more CO_2 added to Venus' atmosphere

What would be the effect on Venus' surface temperature T_s?

A T_s stays the same

B T_s increases

C T_s decreases

Venus: probably initially cooler, had liquid water(?)
  note–early Sun was 30% dimmer!

if so, CO_2 dissolved in oceans, rocks
  note: CO_2 in Earth rocks, oceans is enough
  for 70 atm! ...just like Venus!

Now imagine: watery Venus heated a bit
Q: What is effect of heating on atmosphere? on temperature?

if early water-bearing Venus heated, positive feedback loop:
Heat $\rightarrow$ surface $T \uparrow$
$\rightarrow$ H_20 evap, atm $\rightarrow$ CO_2 released as well
$\rightarrow$ repeat until all H_2O evaporated!

also: H_2O molecules lighter than CO_2
$\rightarrow$ all H_2O evaporated
$\rightarrow$ go to upper atm
$\gamma + H_2O \rightarrow H + OH$, H escapes
$\Rightarrow$ water lost! $-$ warming irreversible
$\rightarrow$ **runaway greenhouse effect**

Mars

Vital Statistics:
$R \simeq 1/2\ R_{\text{Earth}}$
$M \simeq 10\%\ M_{\text{Earth}}$
$\rho_{\text{avg}} = 3900\ \text{kg/m}^3\ <$ Earth $\rightarrow$ smaller core

atmosphere thin: $P_0 \sim 1/200$ Earth atm
$\rightarrow$ liquid water cannot exist! sublimates, freezes
composition: heavy species–95% CO_2, $\sim 2\%$ N_2, Ar
- smaller mass $\rightarrow$ more escape
- no ocean to absorb CO_2

surface temperature: $T \sim$ 190–240 K
polar caps: frozen water, CO_2; cap sizes vary: seasons!

soil – iron rich (red color $\rightarrow$ iron oxide=rust)