Astro 210

Lecture 21

March 7, 2018

Announcements

- **HW6 due online in PDF, Friday 5:00 pm**
- Office hours: instructor 2:00-3:00 pm today
- **Night Observing this week** – weather permitting
  Campus Observatory. Thursday 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*, **Tonight**, *Lincoln Hall Theater*
  Selfie+online report = *bonus points* ("extra credit")

# Solar System: Themes

clear patterns

- similarities among inner/terrestrial planets
- similarities among out/Jovian planets

but also diversity emerges as we learn more

each planet is unique in important ways
dot on sky $\rightarrow$ new worlds to explore

...and the major planets are not the whole story!

# Solar System Debris

in addition to planets
Solar system contains large amount of smaller junk

- **rocky debris: asteroids**
  concentrated between Mars and Jupiter
  i.e., separates terrestrial & Jovian planets

- **icy debris: comets**
  concentrated outside of Neptune's orbit
  i.e., beyond Jovian planets

# Debris I: Asteroids

**Properties**

"minor planets" number $\sim 10^5 - 10^6$

masses: total $\sim 10^{-5} M_{\text{Earth}}$

sizes: poorly known, but go up to $\sim 300$ km

composition: solid (no gasses, ices)

- 5/6 are "C-type" carbon rich
- 1/6 are "S-type" iron rich

*Q: how do we know this?*

## Asteroid Orbits

asteroids orbit Sun $\rightarrow$ must follow Kepler's laws (of course!)
wide variation in $a$, $e$
but average $a \simeq 2.8$ AU
$\rightarrow$ between Mars & Jupiter
average eccentricity $e < 0.1$: nearly circular
most orbit planes close to ecliptic
`www: Inner Solar System in real time`
`www: Near-Earth objects`

if cross Earth's orbit, enter atmosphere:
friction $\rightarrow$ heat & light $\rightarrow$ **meteor**! `www: Leonids`
`www: fireball`

if survive the fall: land a meteorite
Note: meteorites on display in Natural History Bldg
extraterrestrial matter! go look!



LSST: will identify $> 90\%$ of near-Earth asteroids $> 140$ m

# Chelyabinsk Impactor

Feb 15, 2013: **meteor fall & impact over Chelyabinsk, Siberia**

- impactor $\sim$ 50 m diameter!
- energy release $\sim$ 500 kTon TNT

Yikes.

Debris recovered over fall area and impact on frozen lake

`www: videos of fall`

`www: videos of sonic boom shockwave`

- shock: broken glass – 1,700 injuries

what do asteroids look like? From ground, see only largest
but now have visited some (on the way to outer SS)

`www: Gaspara`

`www: Ida & Dactl`

Near Earth Asteroid Rendezvous
intercept near-earth asteroid 433 Eros
S-type: stony-iron
large: 35 km long, 14 km wide–Chicago
"potato shaped"

`www: NEAR image of 433 Eros`

`www: NEAR movie`

hints of stratification–broken from (much) larger object?

`www: Ceres` – largest, round!

# Debris II: Comets

`www: Hale-Bopp, Hyakutake, Ikea-Seki`
last year: brightest comet in decades! `www: McNaught`

**Comet Structure**: "**dirty snowball**" nucleus: $\sim 10$ km
solid: ices ($H_2O$, $CO_2$, $CH_4$), embedded dust grains

very elliptical orbits: changing $r \rightarrow$ changing $T$
far from Sun: completely frozen
as approach: ice $\rightarrow$ vapor (sublimation)
dust, gas released $\rightarrow 10^6$ km **coma**
`www: HST Hale-Bopp: coma & jets, nucleus unresolved`
pressure from sunlight & solar "wind" of particles
$\rightarrow$ **tails**: Ion, dust

# iClicker Poll: Comet Tails

Cometary dust and ions (=ionized atoms)
feel pressure from sunlight, solar wind of particles
$\Rightarrow$ result in comet tail

Where do comet tails point?

A away from the Sun

B behind the comet (i.e., opposite comet's velocity vector)

C tail direction is random

# Comet Tails and Structure

**ion tail:** small, low-momentum particles

$\longrightarrow$ carried by solar wind

$\longrightarrow$ points *away from Sun*

**dust tail:** larger, higher-momentum particles

$\longrightarrow$ retain $\vec{v}$ component in comet direction

$\longrightarrow$ non-radial *arc tracing comet path*

ESA (Euro-NASA) Mission: *Rosetta*

rendezvous with comet 67P/ Churyumov-Gerasimenko

- orbiter takes images
- lander *Philae* to take surface data (crashed)

density: 470 kg/m$^3$ $\ll \rho_{\text{ice}} \longrightarrow$ *porous*

$70 - 80\%$ of volume is empty

surface dusty but irregular in shape and composition

when heated: dust storms

# Comet Orbits and Populations

**"Long Period"**: $P > 10^5$ yr

$\rightarrow$ $a > 2000$ AU!

all orientations $\rightarrow$ not just ecliptic

originate in **Oort Cloud**

spherical comet "reservoir" at 3000–100,000 AU

not observed directly!

probably did not form there....

ejected by Jovian planets in early SS?

**"Short Period"**: $P < 200$ yr

lie in ecliptic

$\rightarrow$ not from Oort cloud $\rightarrow$ **Kuiper Belt**

semimajor axes $a = 30 - 100$ AU

`www: Outer solar system sketch`

# Trans-Neptunian Objects

first Kuiper belt object (KBO) detected in 1992
also known as *Trans-Neptunian* objects; today, tally is hundreds

typically $\sim$ few% $-$ 10% size of Pluto
probably formed where they are now
estimates: 70,000 KBO's
total mass $\sim 0.1 M_{\rm Earth}$

also: some comets strongly deflected,
have orbits with very small perihelion
(i.e., very close to Sun).
`www: sun-grazing comets`

# A Strange Visitor

Discovered Oct. 19, 2017 by Pan-STARRS1 telescope in Hawai'i

- huge angular speed on sky: 6 deg/day
- orbit tracked, found speed $v > v_{\rm esc}$
  above Solar System escape speed!
- came close to the Sun, but no dust or gas found
- brightness changes by factor 10 every 7.3 hours
- red coloring, similar to outer solar system objects

*Q: what does all of this mean?*

# Oumuamua

Reading the clues:

- $v > v_{\rm esc}$: orbit is *hyperbolic* – unbound!
  one-time visit: *origin outside of Solar System*
- no gas or dust when near Sun → not cometary → *rocky/metallic*
- brightness changes periodically by factor 10: *spinning*
  cross section changes by factor 10: must be *very elongated*
  most extreme elongation of any known asteroid
- red color → "*space weathering*" likely over Myr

name: **Oumuamua** `www: artist's conception`
Hawaiian for "a messenger from afar arriving first"

**first known interstellar/extrasolar asteroid**

LSST likely to find more!

# 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