

Reading: Chapter 13, Sect. 13.1-13.4, Chapter 14, Sect. 14.1-14.2

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Homework 9 - See course webpage later this week ...

Exam 2 - Tuesday November 12- Physics 5

Practice exam, review sheets posted on WWW

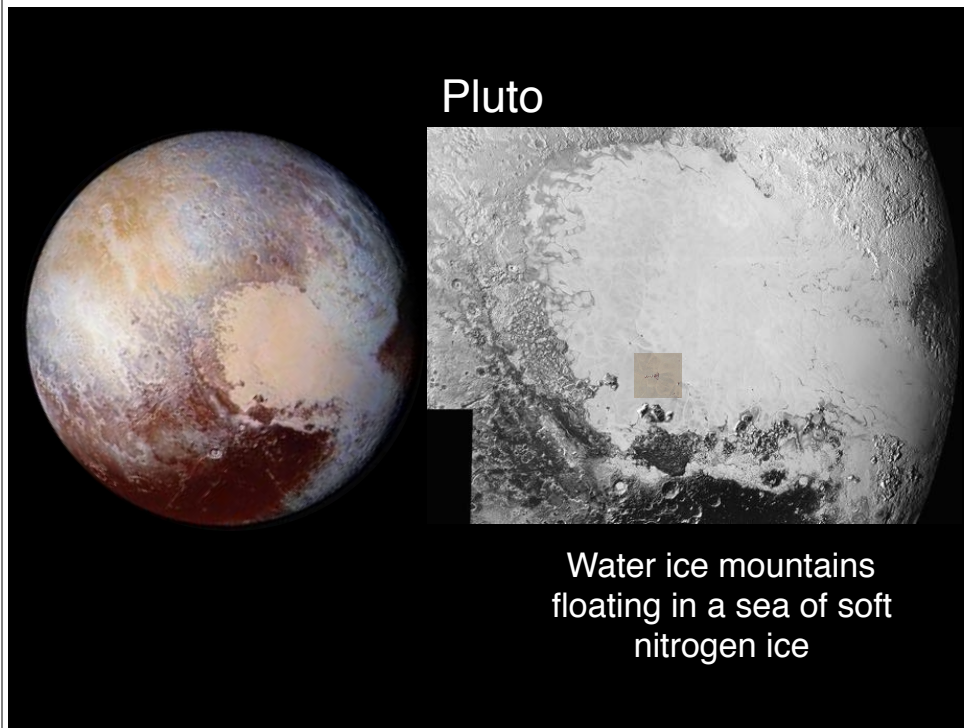
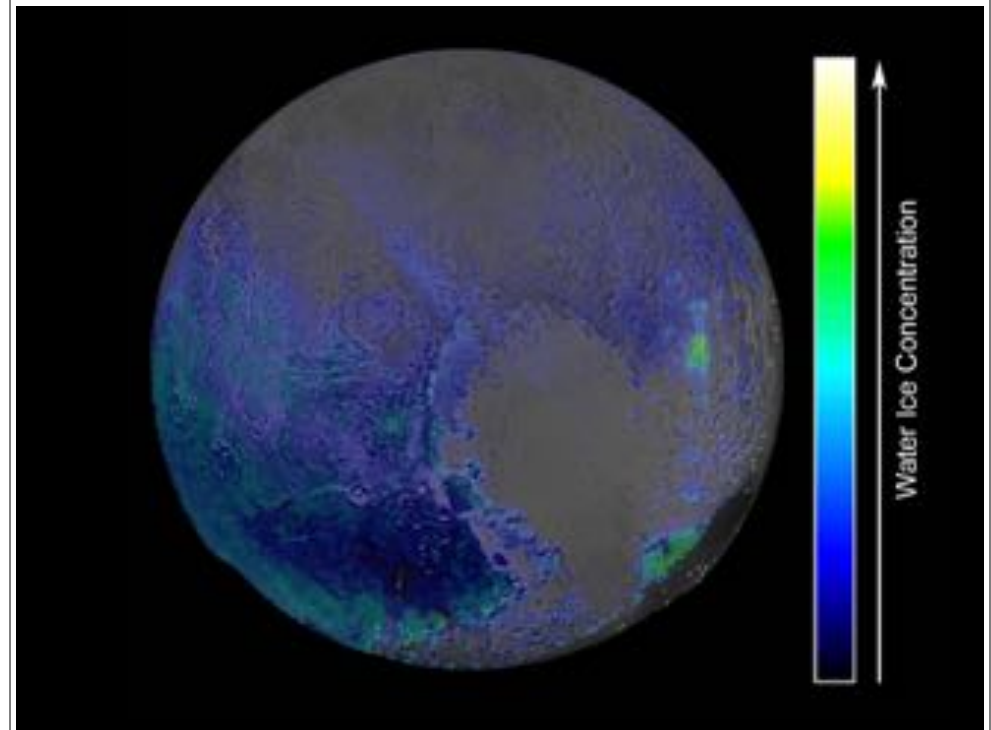
Essay provided in advance on website this Thursday

Last time: Icy Moons of the Outer Solar System

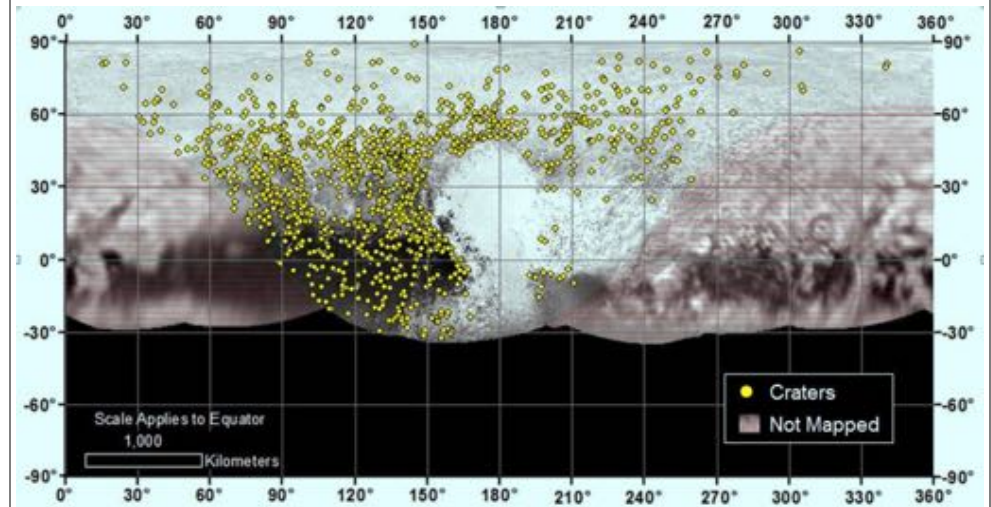
- Captured moons vs. primordial moons: orbits and sizes
- Surface modification processes
- Jupiter's moons - systematics (volcanic/rocky - cold and icy)
- Saturn's Large Satellites, and Titan
- Moons of Uranus and Neptune

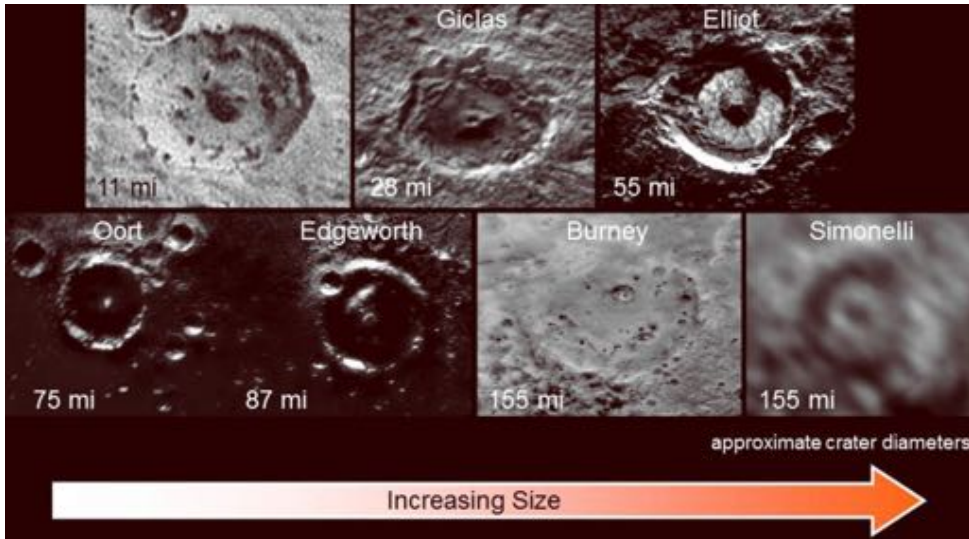
Today: Kuiper Belt objects, asteroids, and meteorites

- Pluto and Kuiper Belt objects
- Asteroids: location, sizes, and compositional families
- Meteorites: irons, stones, stony irons
 - correlation between meteorites and asteroid families
 - some show **no** evidence of heat processing



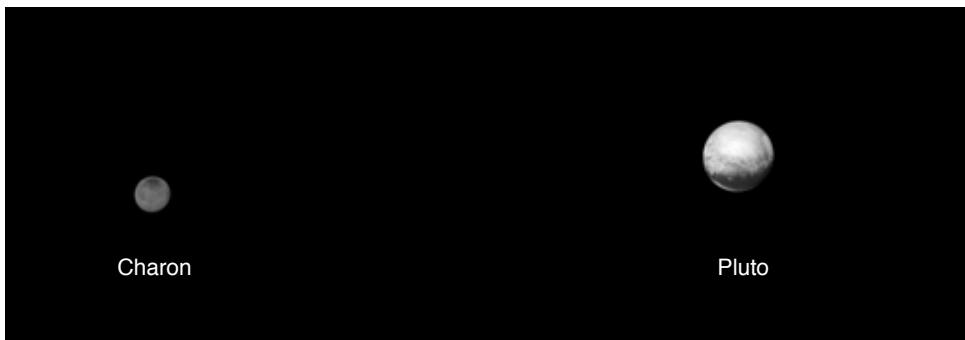
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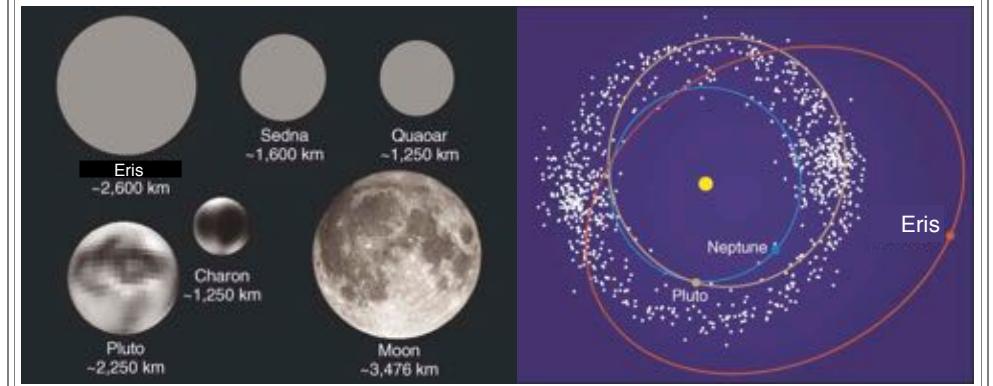


Pluto is not alone out there

- Pluto is one of many “trans-neptunian objects” (TNOs)
- a.k.a. **Kuiper Belt objects (KBOs)**
- 1st KBO found in 1992, Quaoar found in 2002
- ERIS - found in 2005 is 25% bigger than Pluto



Charon and the Small Moons of Pluto



Ultima Thule - flyby: January 1, 2019

35 km long; 6.5 billion km from Earth



Color

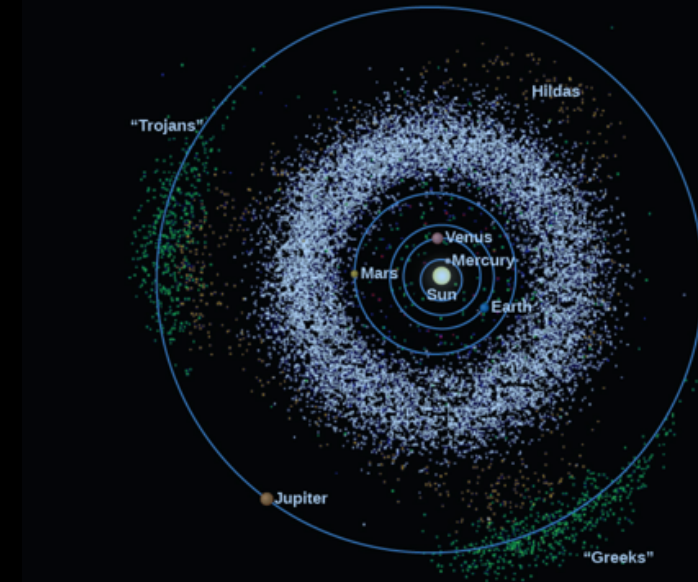


Stereo (cross-eyed) view



Crescent

Asteroids



The Case of the missing planet

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Bode's law (1772) "predicts" semi-major axes

#	x 0.3	+	0.4	=	Pred	Planet	actual
0	x 0.3	+	0.4	=	0.4	Mercury	0.39
1	x 0.3	+	0.4	=	0.7	Venus	0.72
2	x 0.3	+	0.4	=	1	Earth	1
4	x 0.3	+	0.4	=	1.6	Mars	1.5
8	x 0.3	+	0.4	=	2.8	????	? 1801
16	x 0.3	+	0.4	=	5.2	Jupiter	5.2
32	x 0.3	+	0.4	=	10	Saturn	9.5
64	x 0.3	+	0.4	=	19.6	Uranus	19.2 1781

Asteroids

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swarm of small bodies orbiting (mostly) between Mars & Jupiter

Numbers

- over 8,000 orbits known
- brightest still invisible to unaided eye
- largest = Ceres: 1000km diameter
- a few dozen bigger than 100 km
- common size: 10-20 km
- countless more of smaller size

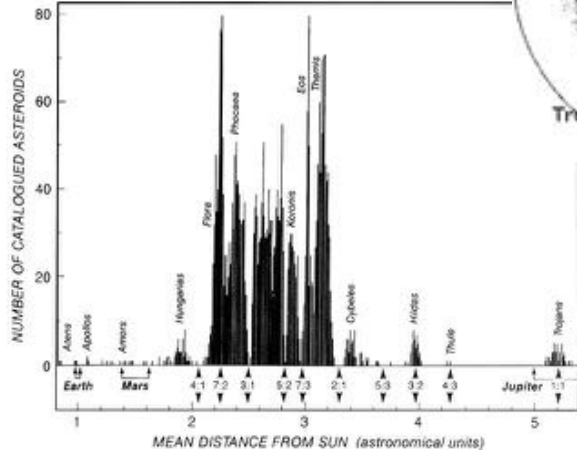
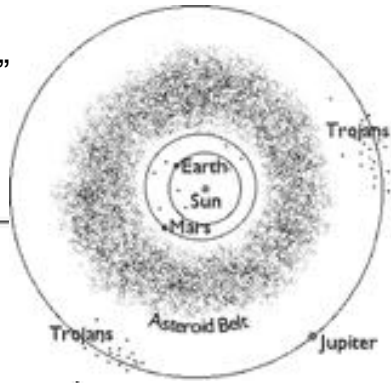


The Main "Asteroid Belt"

- semi-major axes between 2.1 and 3.3 a.u.
- average = 2.81 - very close to Bode prediction!
- total mass << Mass of our Moon

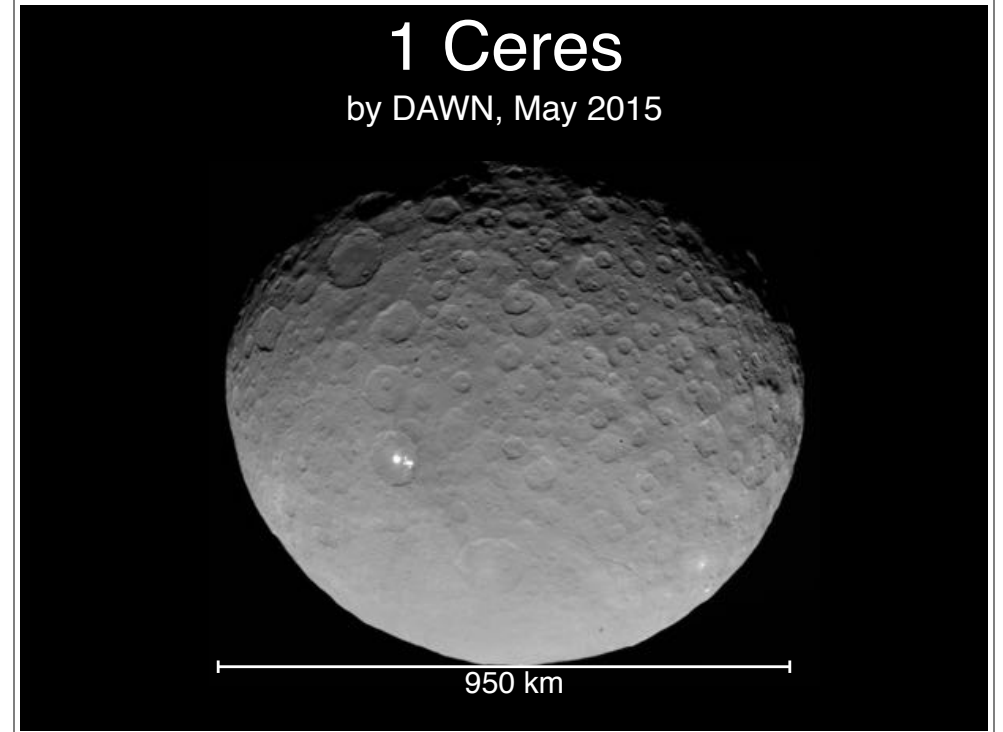
Asteroid Groups:

- main belt
- Trojans @ “Lagrangian Points”
- Earth-crossers
- Hidalgo - beyond Jupiter
- Chiron - beyond Saturn



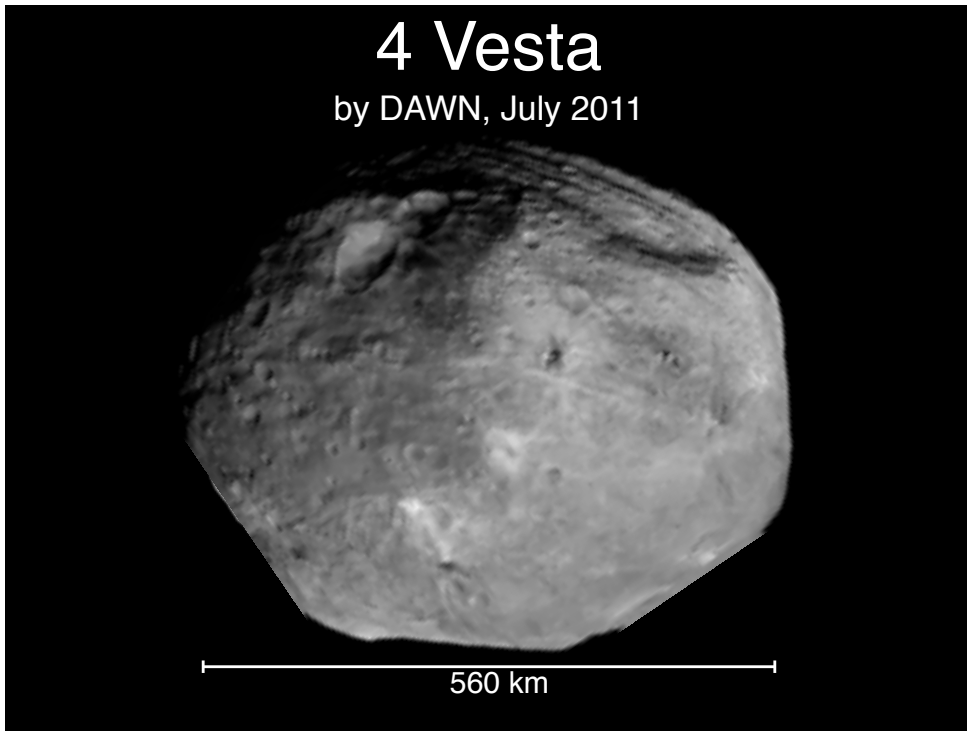
1 Ceres

by DAWN, May 2015



4 Vesta

by DAWN, July 2011



Mathilde

Gaspara

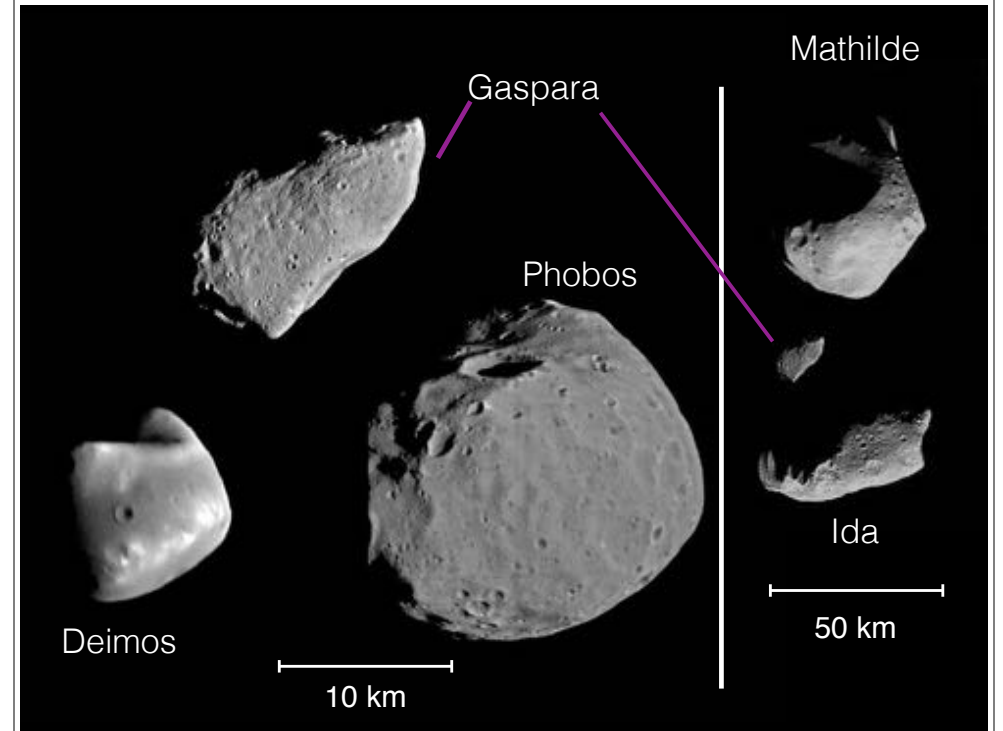
Phobos

Ida

Deimos

10 km

50 km



Types of Asteroids

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composition from reflectance and spectra

- **C-type (common in outer asteroid belt)**
 - extremely dark - low reflectivity
 - 75 % of all asteroids
 - no evidence of high mineral content
 - carbon rich
- **S-type (silicates - inner belt)**
 - spectral evidence for olivine - a silicate mineral
- **M-type (rare)**
 - metallic iron/nickel

Asteroid origins:

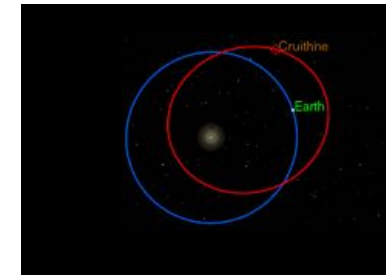
- total mass much less than a small planet
- some evidence of differentiation
- ???

Earth-Crossing Asteroids

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~ 1000 objects whose orbits cross 1 a.u.

- **Aten asteroids:**
 - perihelion inside 1 a.u.
 - aphelion beyond 1 a.u.
 - nearly circular orbits
 - about 100 known
- **Apollo asteroids**
 - very elliptical orbits
 - perihelion well inside 1 a.u.
 - aphelion well beyond 1 a.u.
 - all < 8km across



3753 Cruithne

162173 Ryugu

Hyabusa 2 + landers, June -October 2018
sample return in December 2020



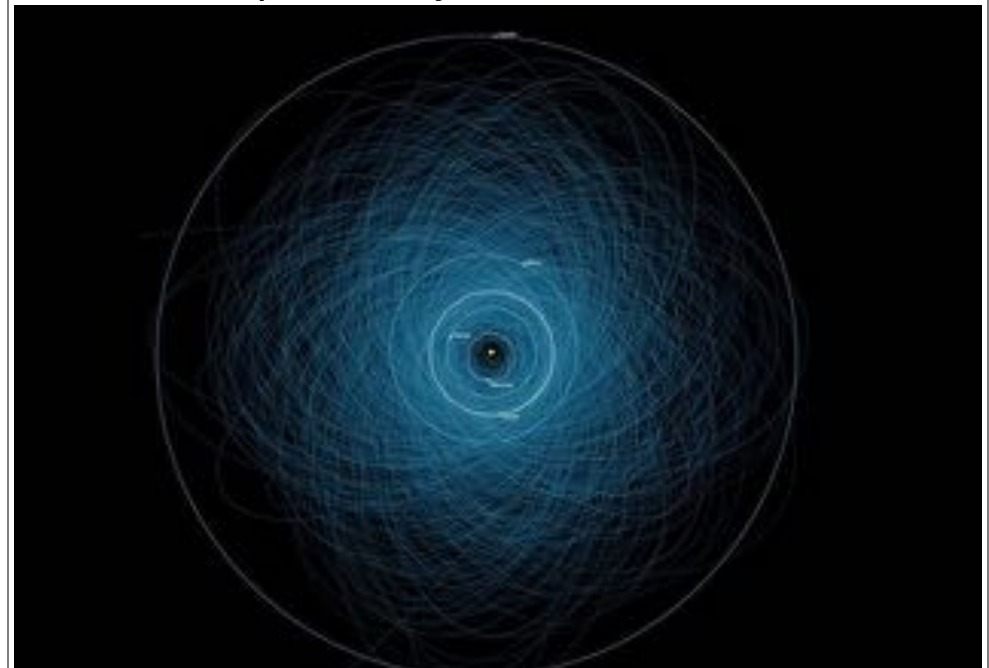
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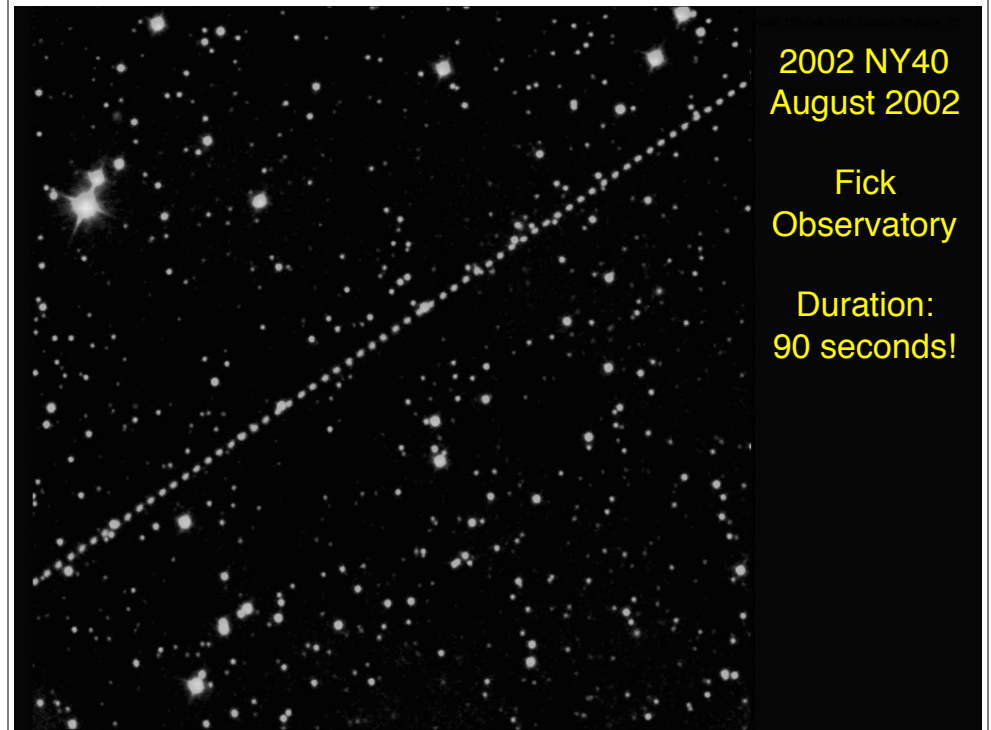
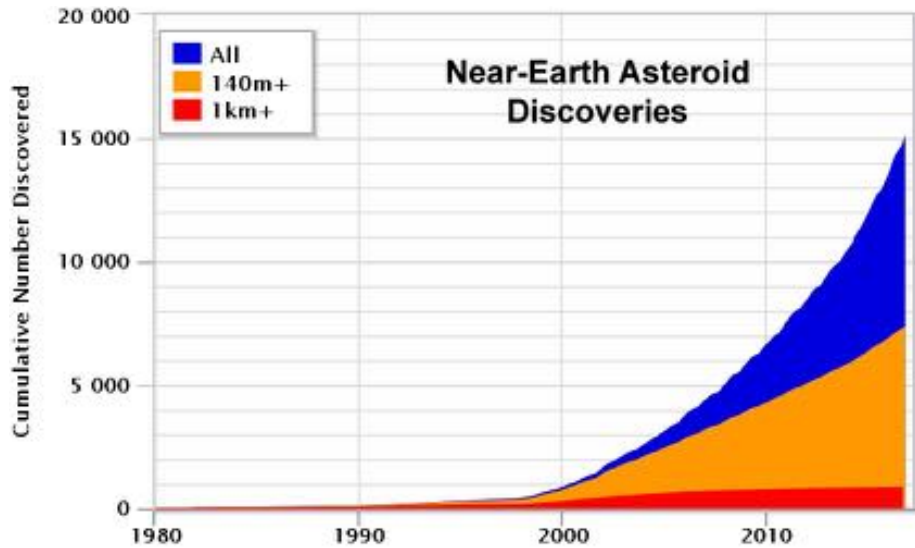
500 m

(c) JAXA, U. of Tokyo, Kochi U., Rikkyo U., Nagoya U., ChibaTech, Meiji U., U. of Aizu, AIST

orbits of potentially hazardous asteroids

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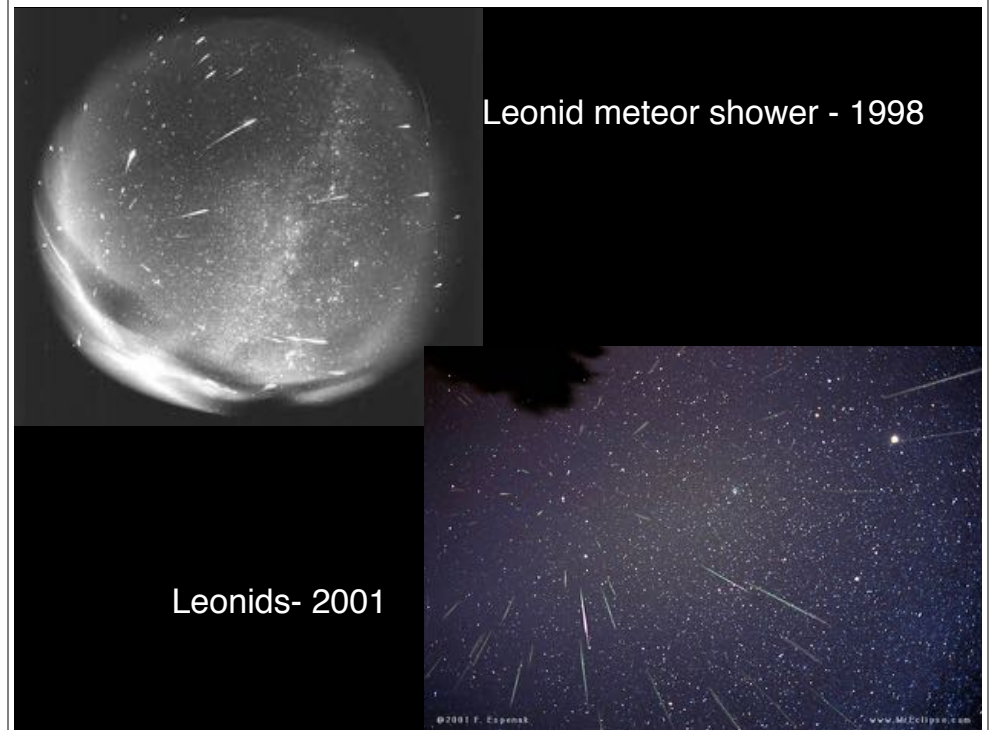


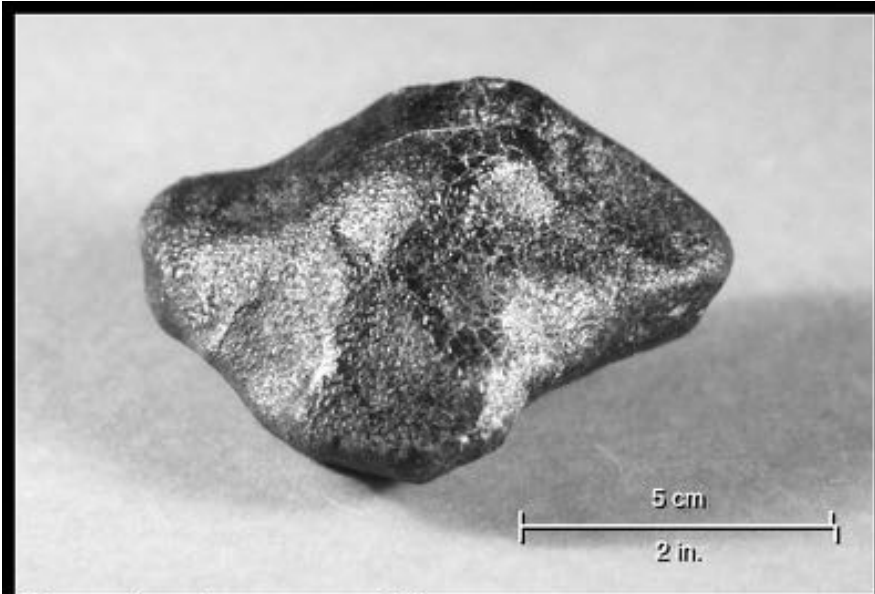


Asteroids on Earth: Meteors and Meteorites

- **Meteorite**
 - tiny body (< 1cm to ~10 m) entering atmosphere
 - nearly all burn up completely - comet dust?
 - fragment(s) that survive to ground
- **Meteor** - a “shooting star”
 - flash of light as meteoroid burns up
 - 80-90 km high at brightest
- **average meteor rate** - about 7/hr (in a dark sky)
- **BUT: METEOR SHOWERS:**
 - occur when Earth passes through orbit of a comet
 - annual events - up to 60 or more per hour
 - mostly small particles, but still bright meteors
 - appear to radiate from a point in sky: “**radiant**”

i.e. Leonids - Nov 17





Meteorite - Fragment of Vesta

Lab Photograph - Russel Kempton, New England Meteoritical Services
PRC95-20B - ST Sci OPO - April 19, 1995 - B. Zellner (GA Southern Univ.), NASA

Types of Meteorites

primitive or processed, they are all older than dirt

- **Stony meteorites** (94% of all falls)
 - ordinary **chondrites** (~80%)
 - chondrules - silicate balls
 - other inclusions - Al, Mg, S
 - **achondrites** (~10%)
 - stones with no inclusions
 - **carbonaceous chondrites** (~4%)
 - carbon-rich inclusions
 - complex organic molecules (amino acids)
 - water-rich chondrules - never melted!
- **Iron meteorites** (5% of all falls)
 - nearly pure iron/nickel alloy
 - large crystals - very slow cooling
- **Stony-Iron meteorites** (1% of all falls)
 - mixture of iron and silicates



Meteorites and Asteroids

- **Irons (M-type asteroids):**
 - ages of 4.6 Gyr - among oldest objects known
 - clear evidence of melting, and **slow cooling**
 - remnant of a **differentiated** protoplanetary core
 - size of body > 100 km
- **Ordinary chondrites: (S-type asteroids)**
 - also 4.6 Gyr old
 - matrix and chondrules - once molten
 - possible crust/mantle of parent body
 - others maybe from never-differentiated bodies
- **Carbonaceous chondrites: (C-type asteroids)**
 - some inclusions possibly older than 4.6 Gyr
 - water-rich minerals, fragile carbon compounds never melted!
 - **pristine material out of which planets formed?**

most are leftovers from formation of the planets

Asteroid & Meteorite Types

