Reading: Chap. 8, Sec. 8.5, Ch. 13, Sec 13.2; Sect. 13.3 –13.4
Homework 9 - See course webpage soon …
Exam 2 - Tuesday evening, Nov. 12, 6:45-8:00PM
Practice exam, review sheets posted on WWW
Essay! on website today

Brief review of last time: **KBOs, Asteroids and Meteorites**

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

Today: **Collisions: Past, Present and Future**

- Collisions in the past
  - Cratering rates then and "now"
- Impact Energetics & Frequencies
- Recent Examples
- The K-T Impact –> Death to all Dinosaurs?
  - evidence and consequences
- The Threat Today

The 1992 Peekskill Fireball / Meteorite Fall
October 1992 - 0.1 kTon TNT equivalent

The 2013 Chelyabinsk Meteorite Impact
February 15, 2013 - 500 kTon TNT equivalent (25x Hiroshima)

The 2013 Chelyabinsk Meteorite Impact
February 15, 2013 - 500 kTon TNT equivalent (25x Hiroshima)

Impacts in the Inner Solar System

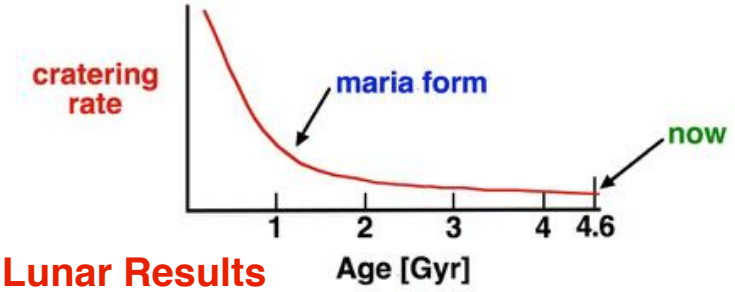
- **Collisions have played a key role in the past**
  - formation of planets by accretion
  - fragmentation (formation of the Moon)
  - sustained planetary melting
  - global surface structures
  - atmospheric composition (?)
- **Collisions play a key role in the present**
  - continued modification of planetary surfaces
  - meteor storms
  - large and small extinction events
- **Collisions will play a key role in the future**
  - the threat of future mass extinctions on Earth

Catastrophic impacts in past:

- formation of planets by accretion of smaller bodies
  (more later)
- High density of Mercury– too-large an iron core:

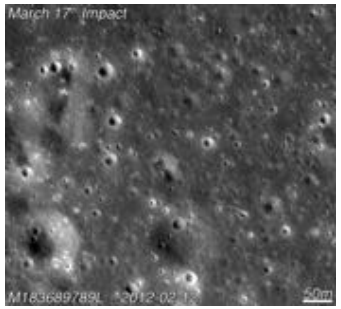
- Formation of the Moon – the Giant Impact theory
- Huge impacts basins on Moon, Mercury
- Anomalous rotation of Venus, Uranus
- Bizarre Moons: Phobos, Miranda, Triton

Cratering rates then and "now"

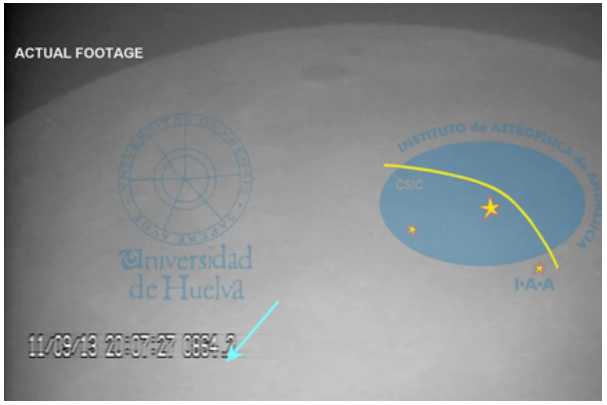


- **Lunar Results**
  - high rate in past (4 Gy ago)
  - now nearly steady
- **"recent" impacts**
  - Tycho: 100 My ago
  - Copernicus: 600 My ago

Lunar impacts Now

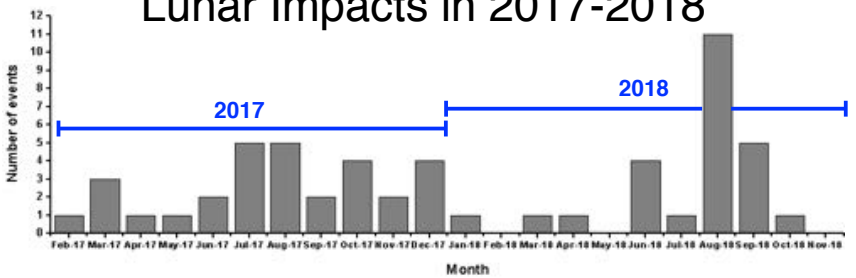


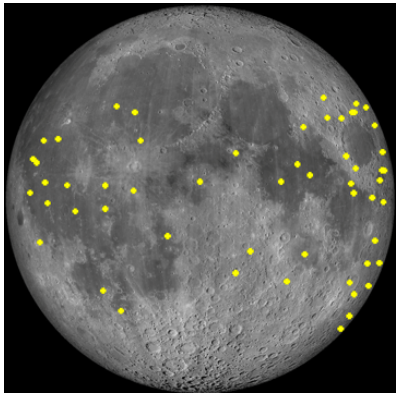
5 tons TNT
60 foot crater
March 17, 2013



15 tons TNT
September 11, 2013

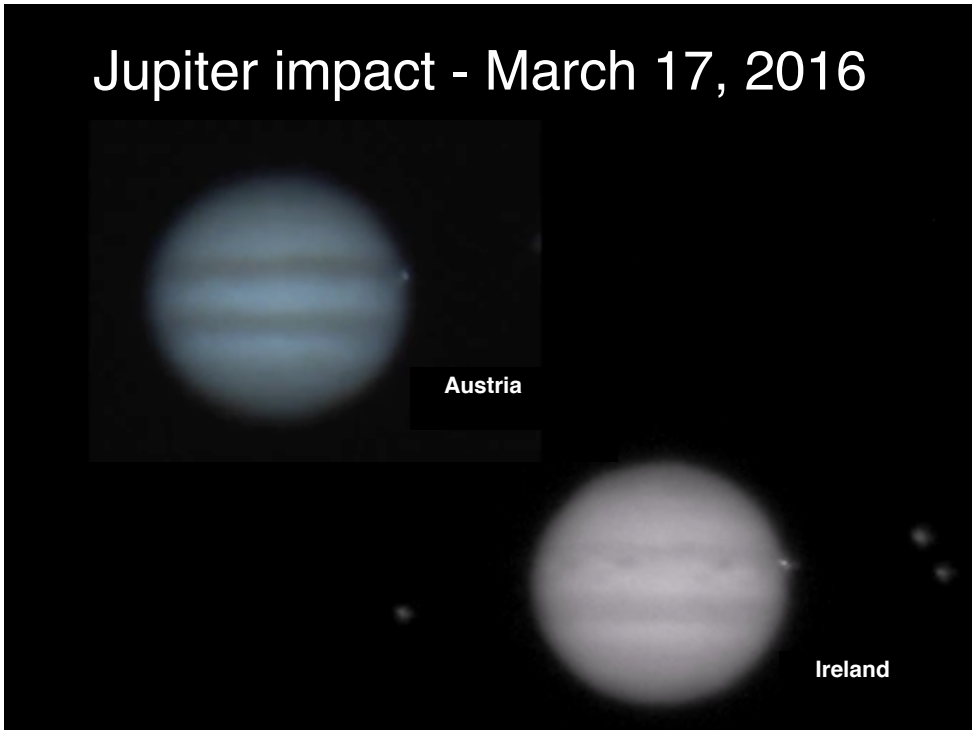
Lunar Impacts in 2017-2018





https://neliota.astro.noa.gr/Statistics

Jupiter impact - March 17, 2016

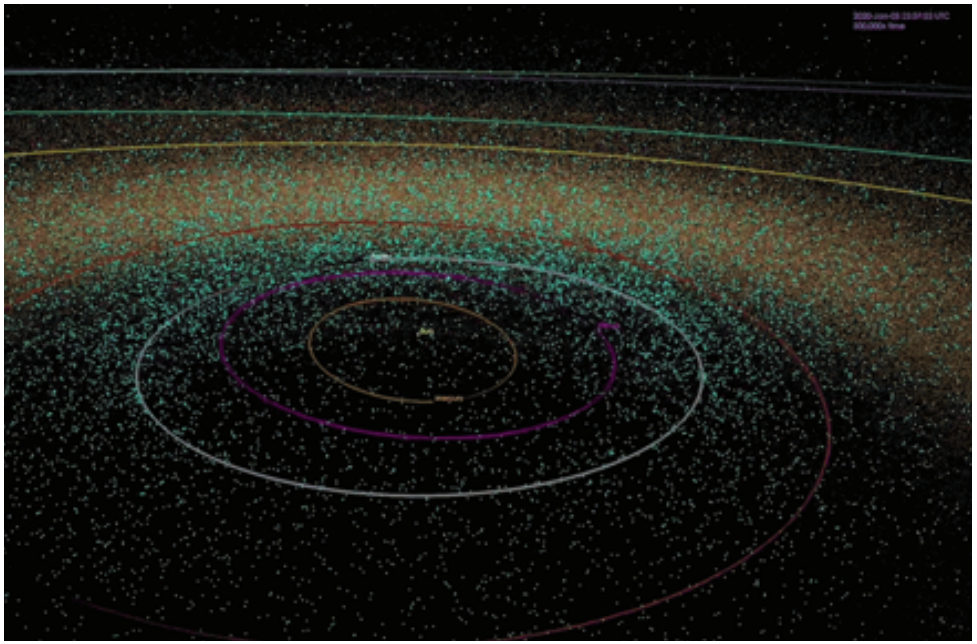


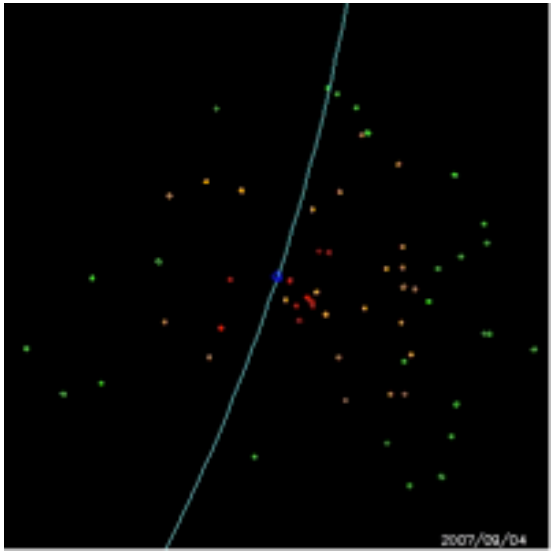
Current Impacts: Energetics

- unit we'll use = 1 Megaton (Mton)
  = 1,000,000 tons of TNT
  = 54 x Hiroshima A-bomb

impactor size	Energy (Mton)	Crater size
20 m	5	0.2 km
100 m	100	1.0 km
1 km	10,000	10 km
10km	10,000,000	100 km

orbits of potentially hazardous asteroids



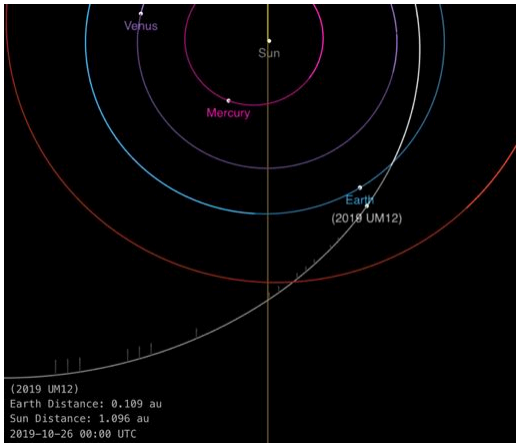


http://www.minorplanetcenter.net/iau/Animations/Animations.html

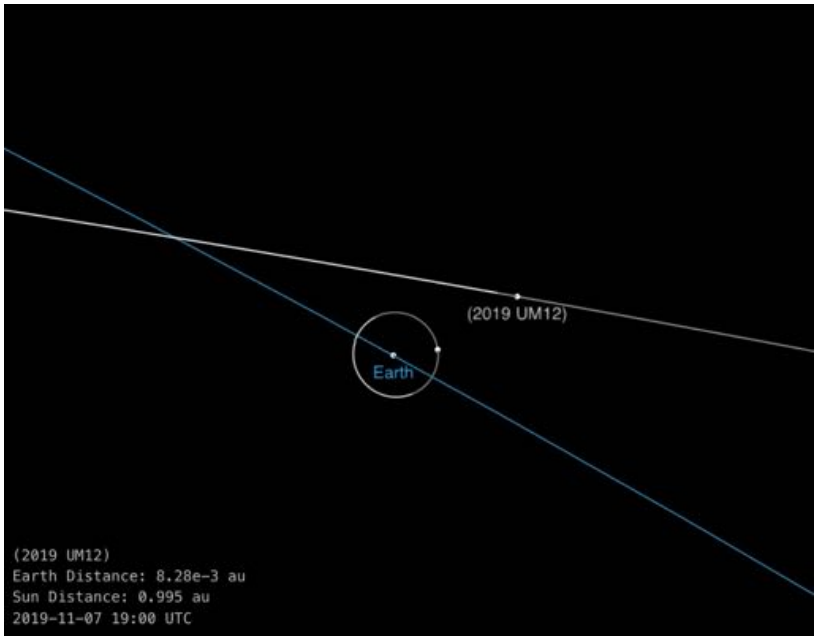
https://www.jpl.nasa.gov/asteroidwatch/widget/

2019 UM12
Apollo-type NEO

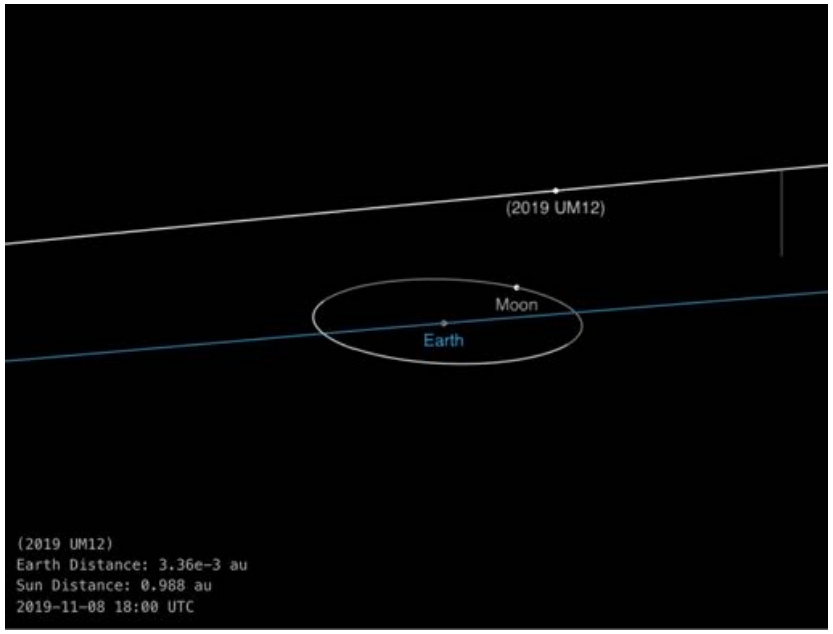
- **closest approach**
  - Friday, November 8, 2019 11:41 AM
  - distance, 1.27 x Earth-Moon
- **discovery**
  - Thurs., Oct. 24, 2019
- **size**
  - **100-300 feet across**



2019 UM12 at 1pm today

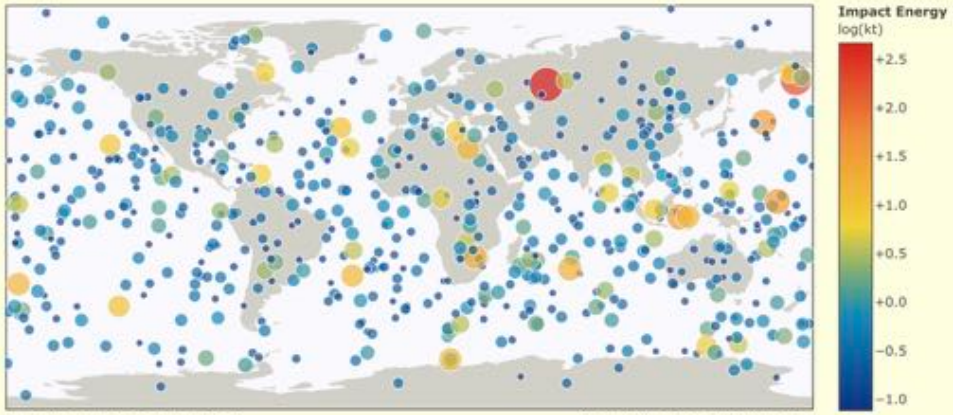


2019 UM12 at 12pm tomorrow



Fireballs Reported by US Government Sensors

(1988-Apr-15 to 2019-Oct-22)



https://cneos.jpl.nasa.gov/fireballs/ Alan B. Chamberlin (JPL/Caltech)

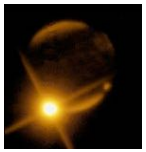
Recent Examples:

- Tunguska (Siberia) – 1908
  - comet (?) impact energy = **15 Mton**
  - total devastation over 1000 square km
  - would have been mistaken for nuclear blast today

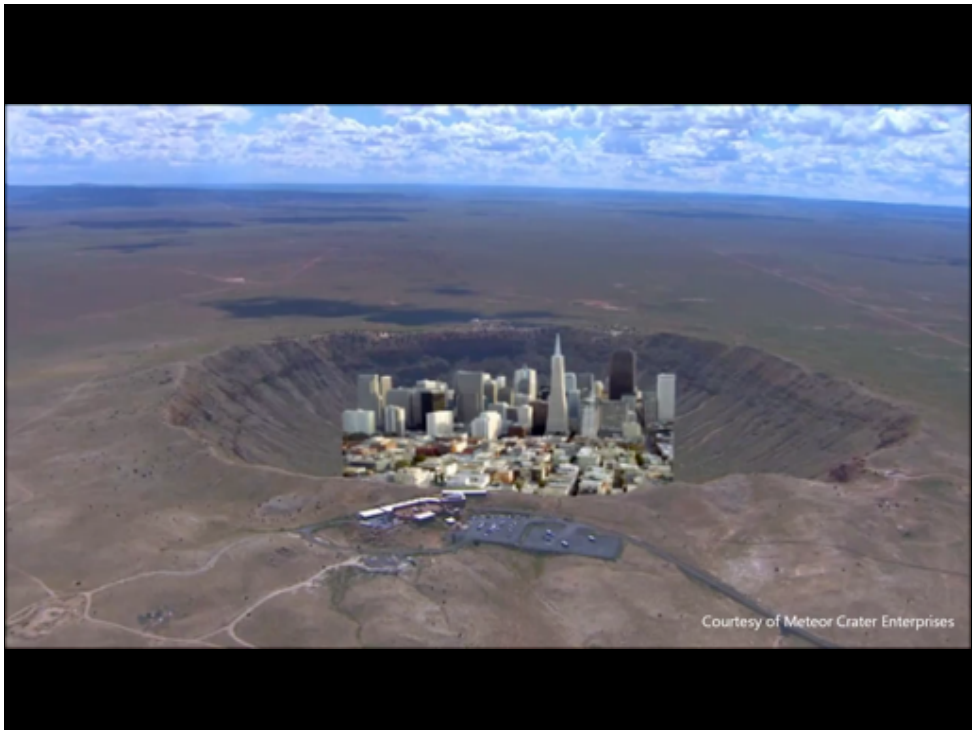
- Meteor Crater (Arizona) – 50,000 yr ago

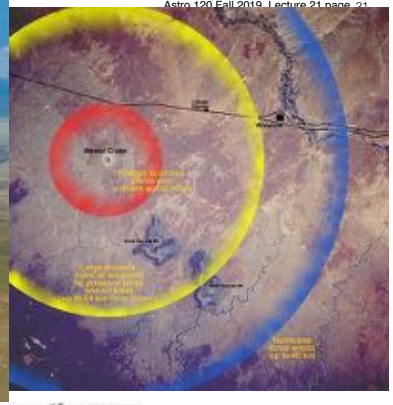
  - impact energy = **200 Mton**
  - 1.3 km diameter impact crater
  - environmental impact uncertain

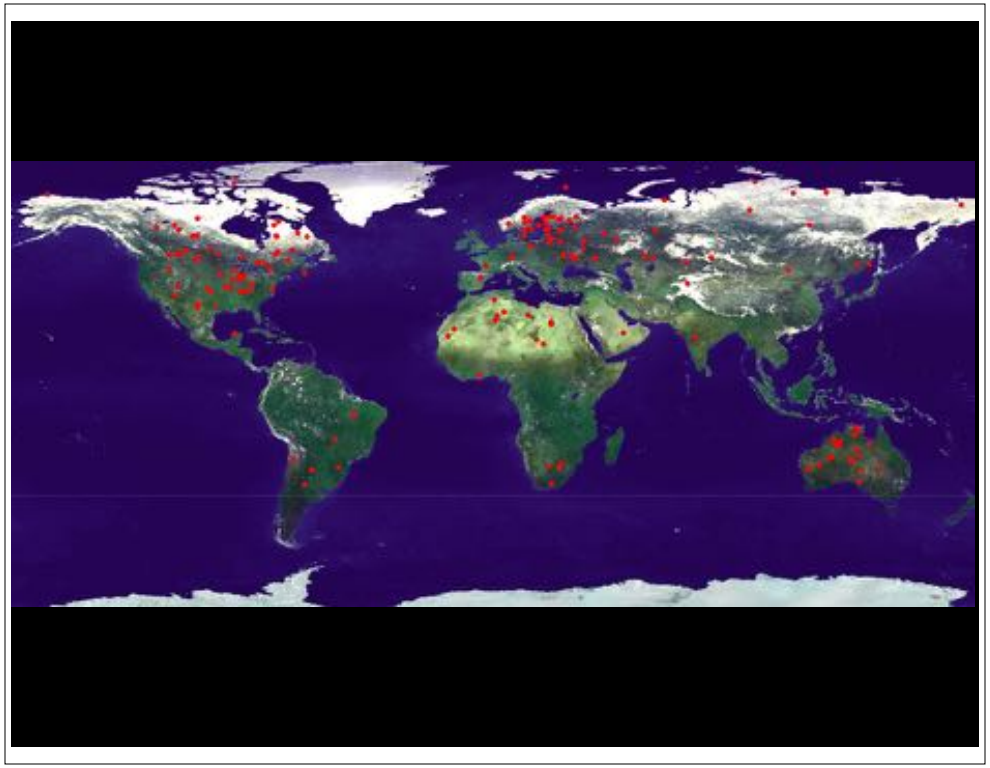
- Comet SL-9 and Jupiter - July 1994

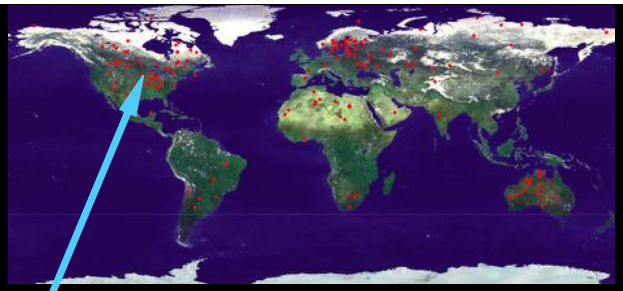


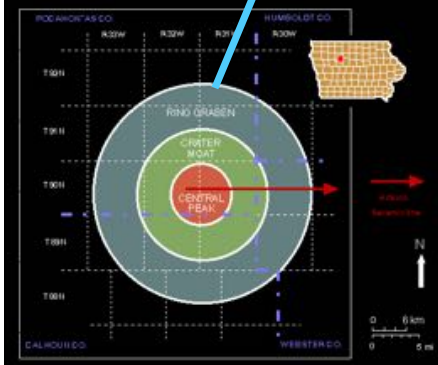
  - comet impact energy = **100,000 Mton**
  - several dark markings lasting many years
  - would form a 7km crater on Earth

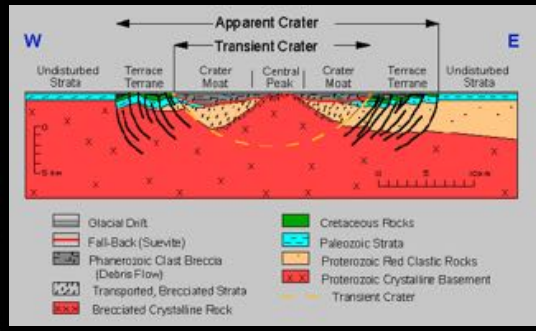




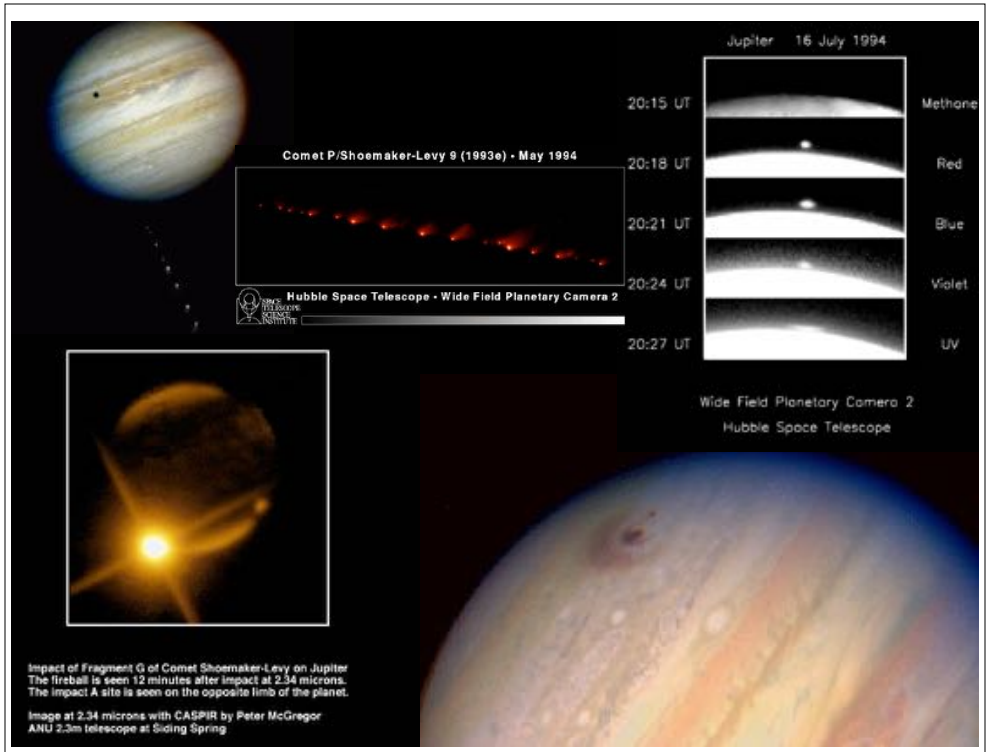




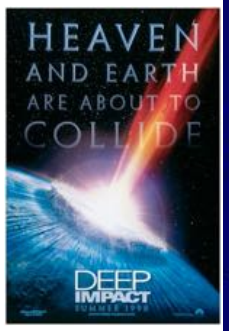


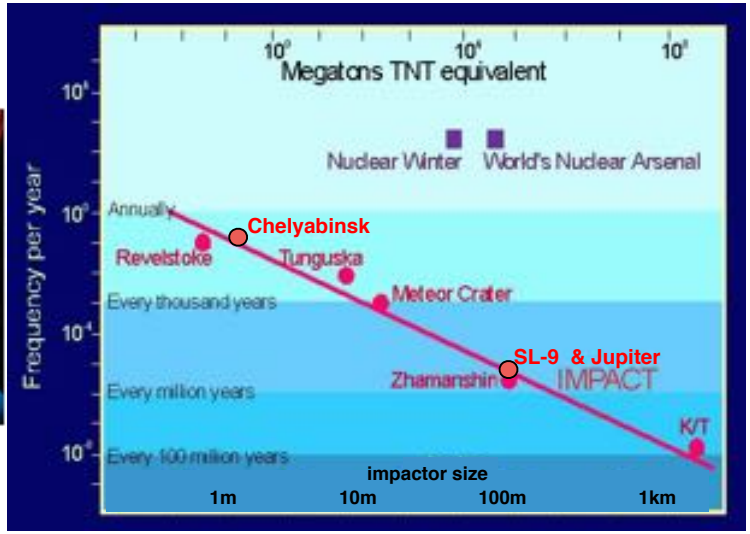


Manson, Iowa subsurface impact crater



Okay, but how often on Earth?

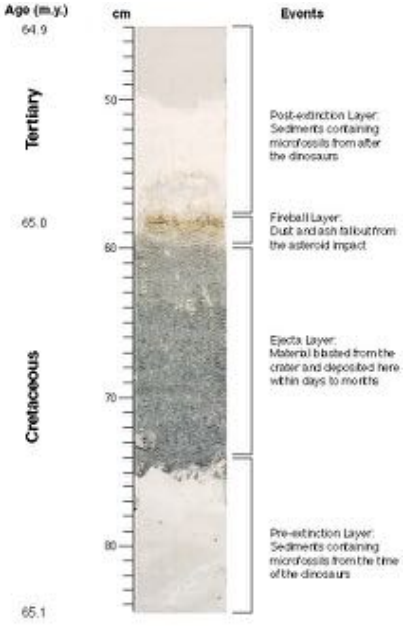




The K-T Impact –> Death to all Dinosaurs?

- Global iridium layer at K-T boundary (65 Myr ago):
  - iridium is extraterrestrial
  - global layer ~ 2 cm thick
  - parent body size –> 13 km (taller than the atmosphere!)
  - crater diameter –> 130 km
  - impact energy –> ~ 10^8 Mton

- Results of this impact:
  - A global "Nuclear Winter" lasting years
  - major disruption of climate
  - major disruption of food chain
  - large–scale extinctions (90% of all species extinct)



The Impact Hazard Scale

Size of body	How often? once every	Energy (Mton)	Crater size	Consequences
20 m	50 yr	5	0.2 km	• local devastation • other severe local effects • similar to Tunguska
100 m	1000 yr	100	1 km	• damage to ozone layer • local incineration • local devastation • other severe local effects • societal chaos ...if populated
1 km	100,000 yr	10,000	10 km	• suspended dust for months • lower global temperature • agricultural failure • ocean hit? Tsunami! • mass starvation • comparable to S-L 9/Jupiter
10 km	10^7 yr	100,000,000	100 km	• suspended dust for years • total darkness for a year • massive die-off of vegetation • mass extinction • i.e. K-T dinosaur extinction
30 km	10^9 yr	$3x10^8$	300 km	• geologically significant • relax; not likely any more