

The End of the World...

as we know it.

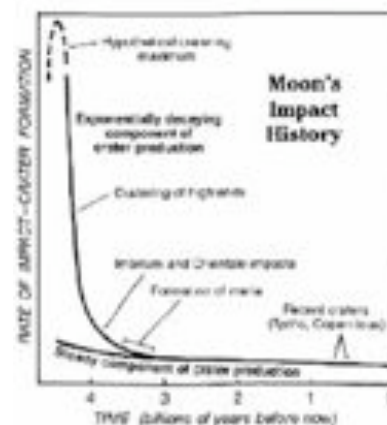
Impacts in the Inner Solar System

- **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 have 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

The 1992 Peekskill Fireball / Meteorite Fall
October 1992



Cratering rates then and “now”

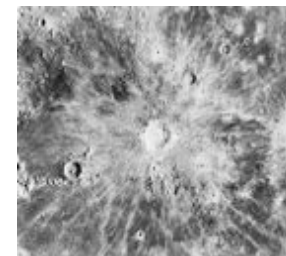


● Lunar Results

- high rate in past (4 Gy ago)
- now nearly steady

● “recent” impacts

- **Tycho**: 100 My ago
- **Copernicus**: 600 My ago



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

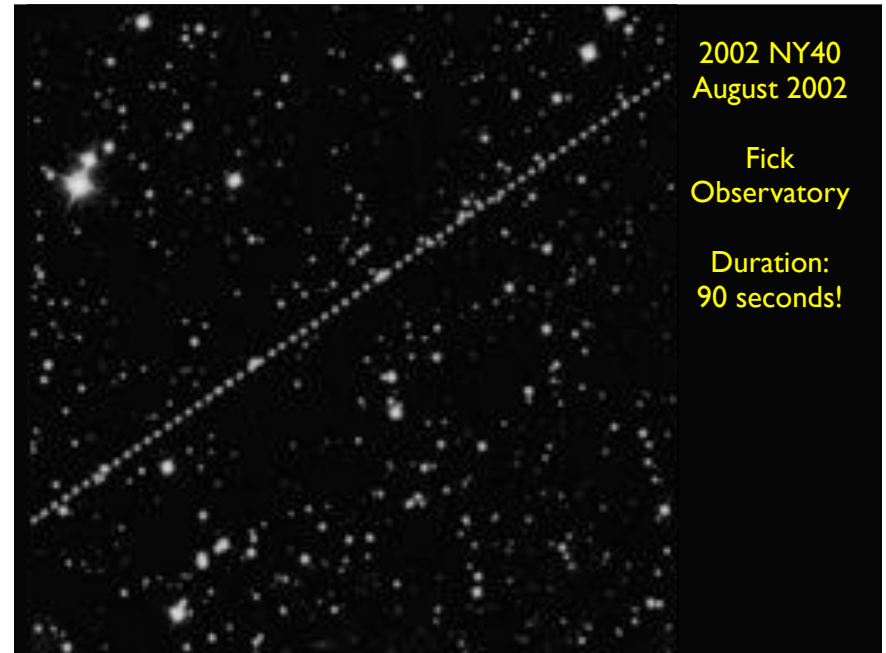


- **Apollo asteroids**

- very elliptical orbits
- perihelion well inside 1 a.u.
- aphelion well beyond 1 a.u.
- all < 8km across



3753 Cruithne



2002 NY40
August 2002

Fick
Observatory

Duration:
90 seconds!

A Ride With the Earth

An animation centered on Earth showing the known objects that have approached to within 20 million km during 2002.

See the Animations Page on the MPC website for a description of the symbols used in this animation.

<http://antwarp.gsfc.nasa.gov/apod/ap060328.html>

Current Impacts: Energetics

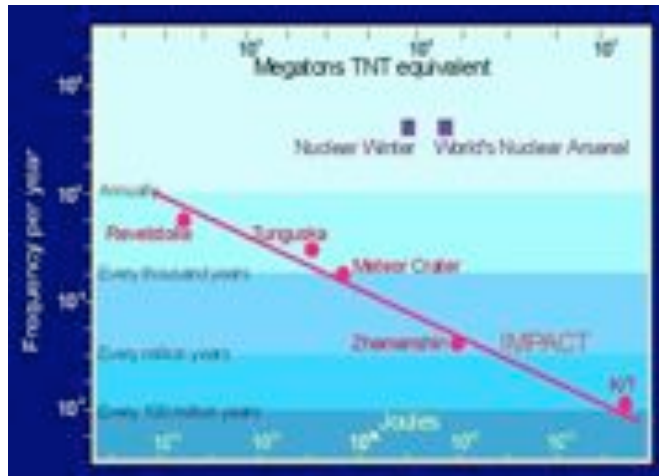
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- unit we'll use = 1 **Megaton (Mton)**
= 1,000,000 tons of TNT
= 54 x Hiroshima A-bomb

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



Okay, but how often on Earth?



Recent Examples:

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



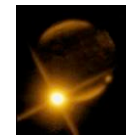
- impact energy = **200 Mton**
- 1.3 km diameter impact crater
- environmental impact uncertain

- **Tunguska (Siberia) – 1908**

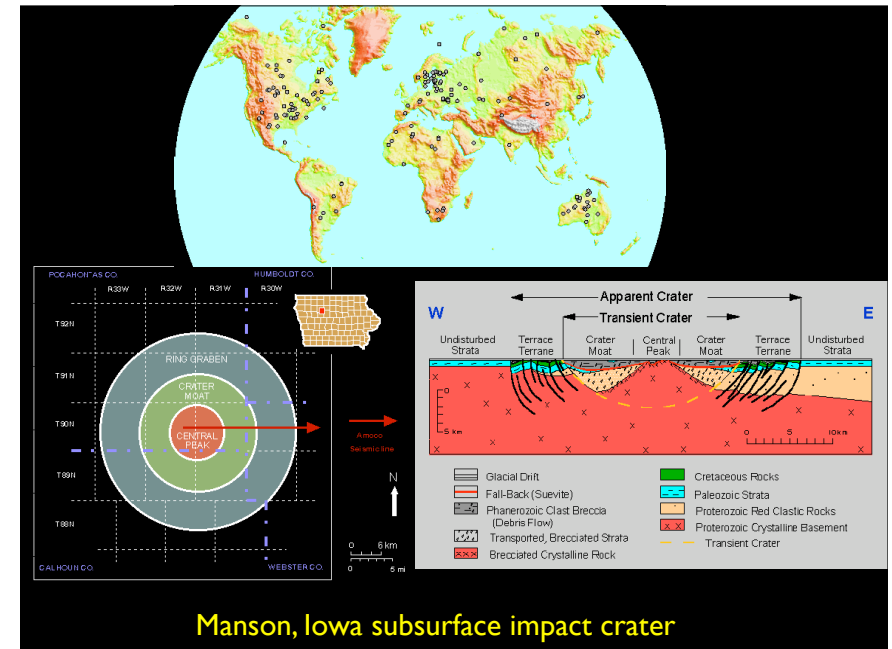
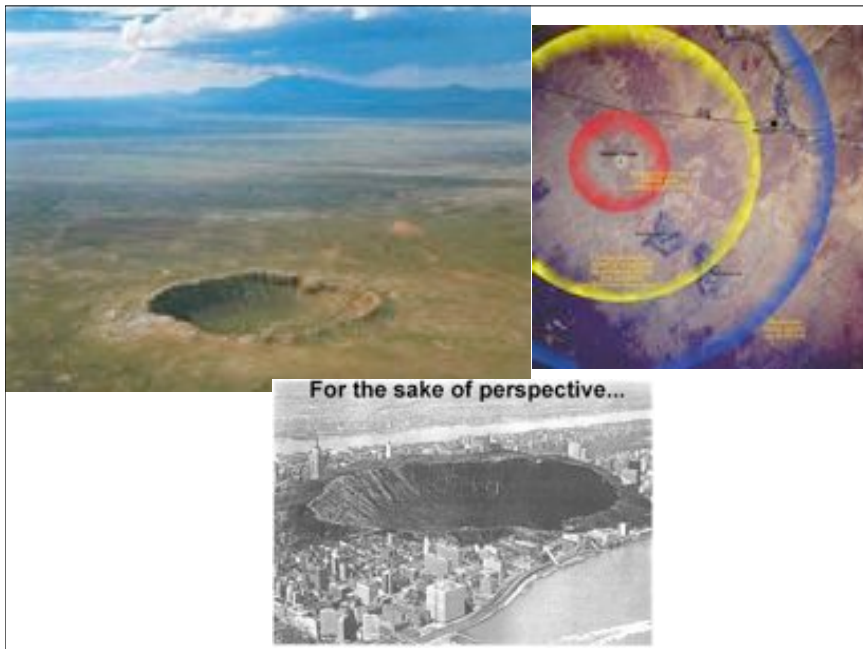


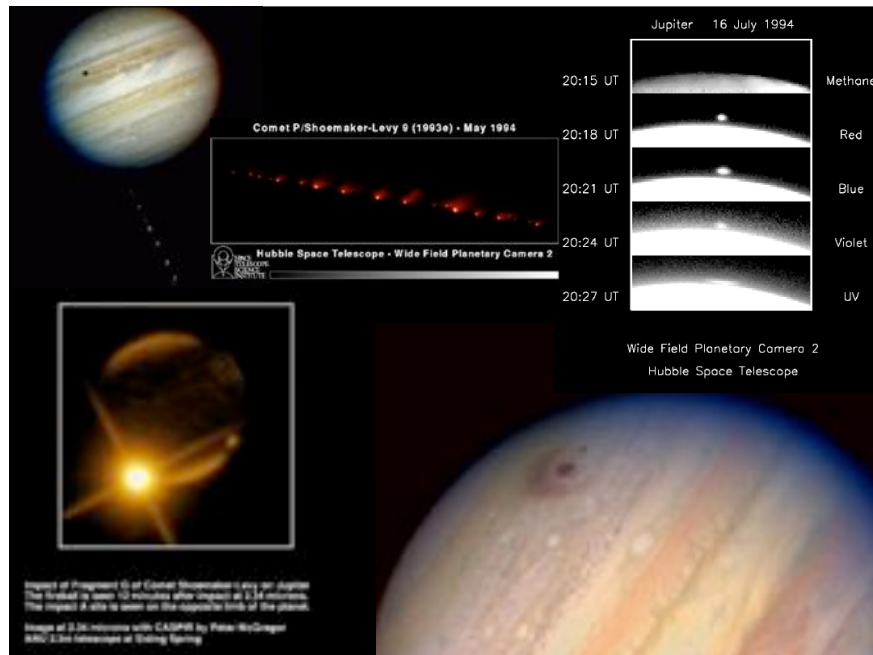
- comet (?) impact energy = **15 Mton**
- **total** devastation over 1000 square km
- would have been mistaken for nuclear blast today

- **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

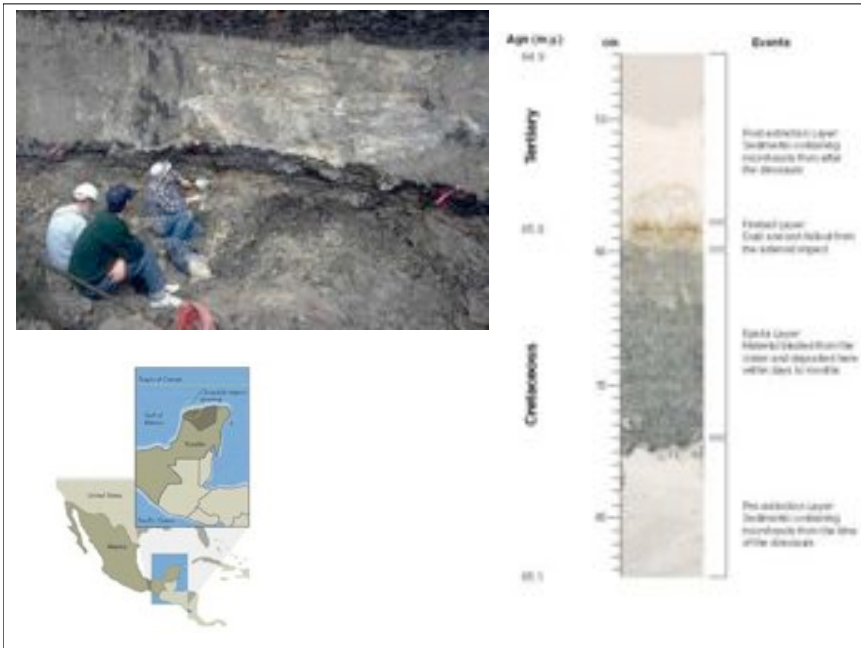




The K-T Impact → Death to all Dinosaurs?

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- **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 → ~ 108 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	<ul style="list-style-type: none"> • local devastation • other severe local effects • similar to Tunguska
100 m	1000 yr	100	1 km	<ul style="list-style-type: none"> • damage to ozone layer • local incineration • local devastation • other severe local effects • societal chaos ...if populated area
1 km	100,000 yr	10,000	10 km	<ul style="list-style-type: none"> • suspended dust for months • lower global temperature • agricultural failure • ocean hit? Tsunami! • mass starvation • comparable to S-L 9 on Jupiter
10 km	10^7 yr	100,000,000	100 km	<ul style="list-style-type: none"> • 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	3×10^8	300 km	<ul style="list-style-type: none"> • geologically significant impact • relax; not likely any more

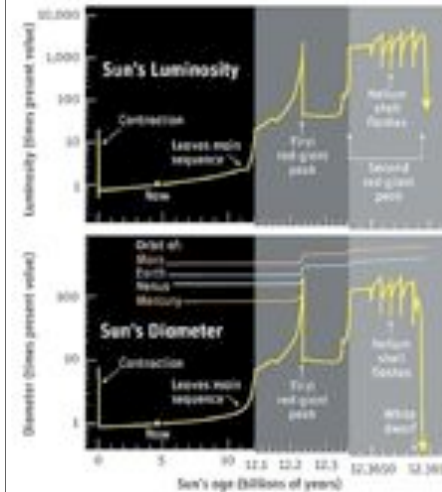
Tidal evolution of the earth-moon system

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- moon slows Earth rotation
 - day is lengthening by 0.09s / century
 - 4 Gyr ago - 1 d = 6 hours
- moon's orbit grows
 - month is lengthening by 0.038 s / century
- Day length = month in 4×10^9 y
 - day, month = 49 (current) days

future solar evolution

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- L increase by factor of 2
- H exhaustion
- Red Giant (R ~ Venus orbit)
- mass loss - planets move away
- He core burning
- AGB -> PN -> WD
- 10^{10} yr - crystalline white dwarf

consequences for the Earth

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- continued solar brightening
- The wet greenhouse -> global warming v. 2.0
 - warm greenhouse (hot-house!)
 - water vapor saturated atmosphere
 - upper atmosphere photolysis
 - $\text{H}_2\text{O} \rightarrow \text{H} + \text{OH} \rightarrow \text{H}$ escapes, O binds with C and others
 - permanent loss of water
- dry greenhouse (approx. 3 billion years from now)
 - CO_2 and other gasses
 - Venus-like climate - surface temperature in excess of 800F
 - did this happen to Venus in the past?
- Red Giant phase
 - continued surface warming - atmosphere loss
 - surface melting...

the rest of the Universe

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- **3 billion years (Gyr) from now:**
 - Andromeda - Milky Way collision
- **175 Gyr**
 - $Z=0.7$ or so (no more free hydrogen for star formation)
- **10,000 Gyr**
 - lowest mass stars (0.1 Mo) become white dwarfs
 - heat death for the Universe
- **10^{57} Gyr:**
 - proton decay - dissolution of stellar remnants
 - evaporation of lowest-mass black holes (1 solar mass)
 - Volume of Universe is $(10^{56})^3$ times bigger (or more with acceleration)
 - single, isolated galaxies with no interactions
 - (any) light from distant galaxies is invisible