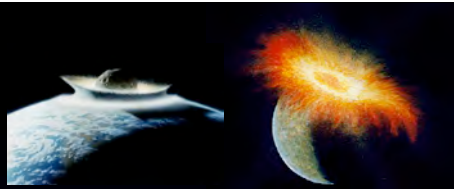


Impact!



*Assessing the Cosmic Threat
from Asteroids & Comets*



Prof. Jim Bell
Cornell University

Impact!

Outline

- Asteroids and Comets
 - What are they?
 - How many are out there?
- Have they / will they hit the Earth?
- How serious is the risk?
- What might be the consequences?
- Is there anything we could do about it?

The Main Points

- Earth has been hit by large asteroids and comets in the past, with devastating consequences.
- Earth will get hit again in the future.
- But now there is a species living on this planet that has the potential to do something about it...

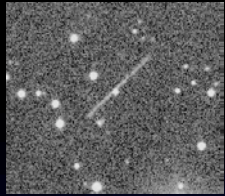


Asteroids

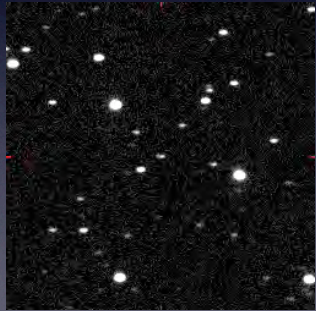
Asteroids are small, rocky and metallic "minor planets". There are many distinct populations of asteroids in our solar system: **Near-Earth Asteroids**, the **Main Belt** between Mars and Jupiter, **Trojans** near Jupiter and other planets, **Centaurs** between Jupiter and Neptune, the **Kuiper Belt** beyond Neptune, ...

Comets

Comets are small, irregular, mostly **icy** bodies that were formed in the **outer solar system** and that evaporate spectacularly if their orbits carry them closer to the Sun



"Vermin of the skies" (!)

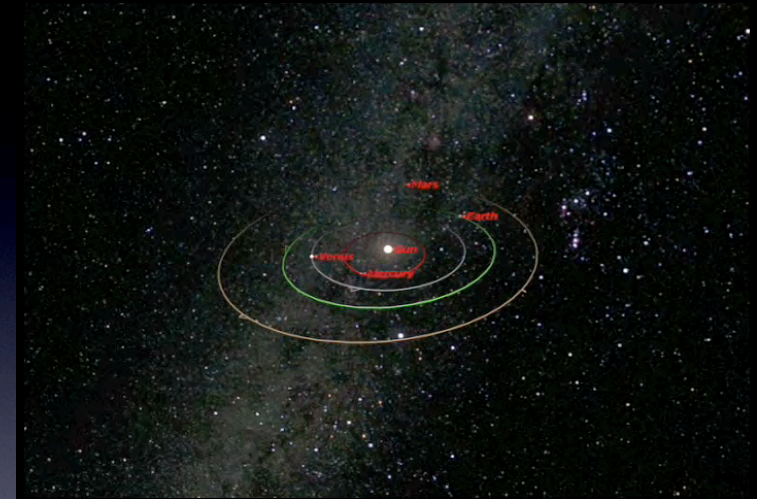
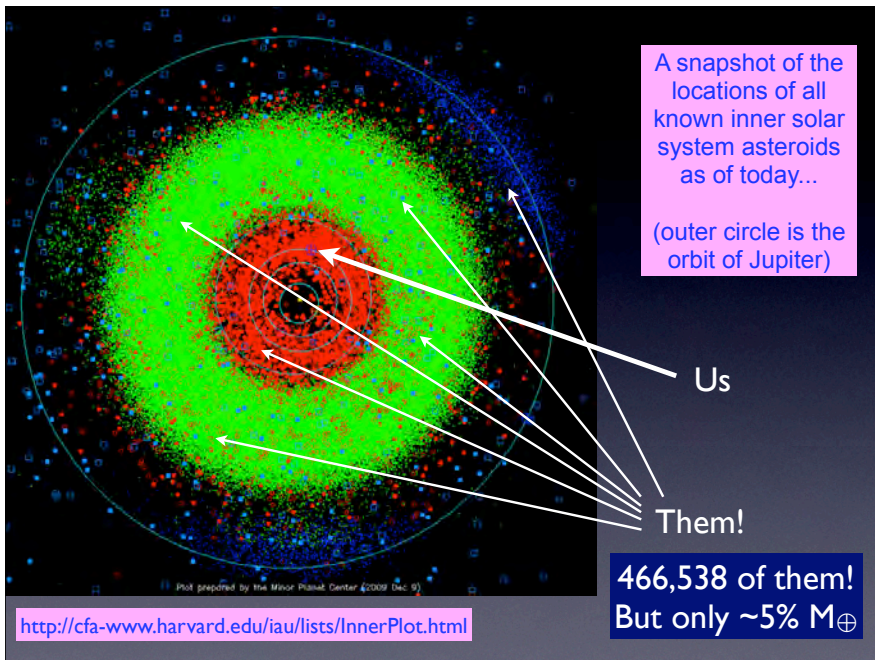


Factoids

- "Asteroid": Greek for "star-like"
- Asteroids are faint, small objects that look star-like in telescopes, except they move across the sky like the planets
- The first asteroid, 1 Ceres (940 km diameter) was discovered in 1801; 400,000+ now known...
- There could be 1,000,000+ greater than 1 km diameter

Asteroid Populations

- Asteroids can be found throughout the solar system, and there are several main populations:
 - the **Main Belt** between Mars and Jupiter
 - outer solar system **Trojan** and **Centaur** asteroids
 - **Kuiper Belt Objects** beyond Neptune's orbit
 - the **Near Earth Asteroids**—nearby in space



A Cosmic Dance...

"Starry Night" Planetarium Software

What Are Asteroids Really Like?

- Many asteroids visited up close by spacecraft!
 - 951 Gaspra: Galileo flyby in 1991
 - 243 Ida: Galileo flyby in 1993
 - 253 Mathilde: NEAR flyby in 1997
 - 433 Eros: NEAR orbital mission in 2000-2001
 - 25143 Itokawa: Hayabusa mission in 2005
 - 2867 Steins: Rosetta mission in 2008
- The Hubble Space Telescope has taken images and other data of several large asteroids
- Radar images of closest Near-Earth Asteroids
- Also: Spacecraft images of Martian moons Phobos and Deimos: captured asteroids?



"Never tell me the odds!"

A Hollywood View...

From "Star Wars, Episode V: The Empire Strikes Back" (1980)

First Close-up Pictures of Asteroids!

Galileo mission, 1991 & 1993

951 Gaspra
16 x 11 x 10 km

Both have "rocky"
density

243 Ida
60 x 25 x 19 km

Ida's moon,
Dactyl
1.5 km

More Close-up Pictures of Asteroids

NEAR mission, 1997-2001

253 Mathilde
66 x 48 x 46 km
very low density
(porous?)



433 Eros
31 x 13 x 13 km
rocky density
lots of craters

And more Close-up Pictures of Asteroids!

25143 Itokawa
0.5 x 0.3 x 0.2 km: very tiny!

Rosetta Steins flyby, 05 Sep 2008
2867 Steins
~ 5 km across
ESA Rosetta mission

Japan's "Hayabusa" mission...
First attempted asteroid sample return (find out in June 2010!)

Radar Imaging of Asteroids (321 to date) Highlights at <http://echo.jpl.nasa.gov>

4769 Castalia

4179 Toutatis

1999 JM8

from Arecibo Observatory!

The Hubble Space Telescope has also taken high-res photos of some of the largest asteroids

The Moon

1,000 km

4 Vesta: 578 x 560 x 458 km

Targets of the Dawn Mission in 2011-2015

1 Ceres: the largest asteroid!
About 950 km diameter

Phobos and Deimos, the small, rocky moons of Mars, may also be captured Asteroids from the Main Belt...

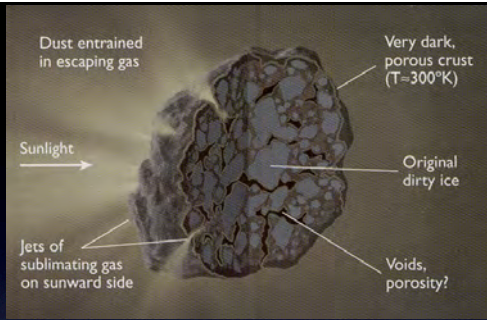
Phobos

Deimos

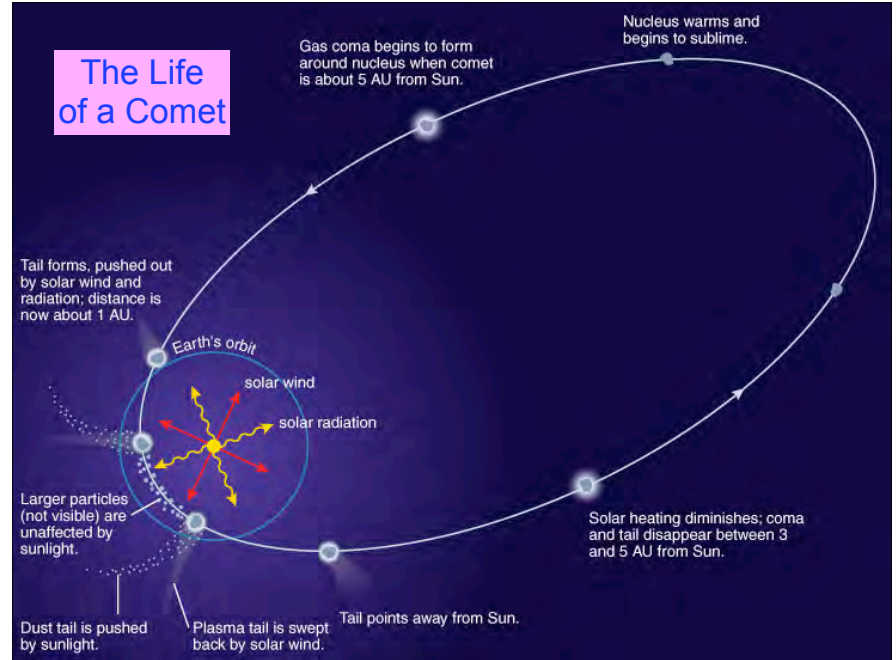
Comets

- Comets are essentially "dirty snowballs" that evaporate (spectacularly!) as they get closer to the Sun
- The solid part of a comet (the nucleus) is very small – only a few km across – and has a low density because it is mostly ice, not rock
- However, many comets travel at extremely high velocities (many tens of km/sec), meaning they can have the same impact *energy* as slower-moving, rocky asteroids

$$E = \frac{1}{2} mv^2$$

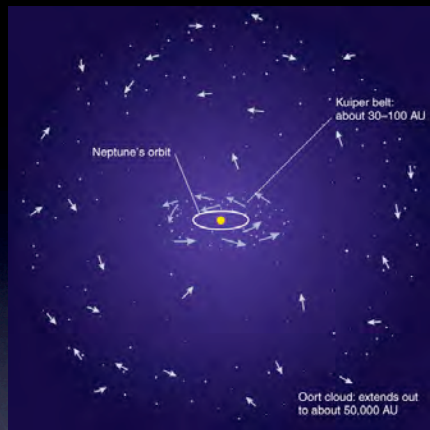


The Life of a Comet



- Comet orbits show that they come from two distinct sources:

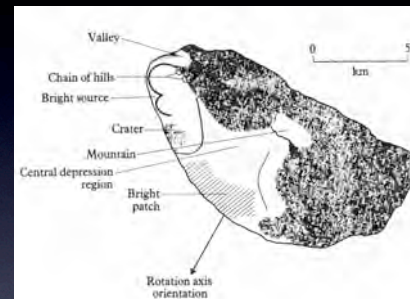
- The Kuiper Belt, a large population of icy bodies beyond the orbit of Neptune
- The Oort Cloud, a vast spherical cloud of small icy bodies that extends out to perhaps a third of the way to the nearest star!



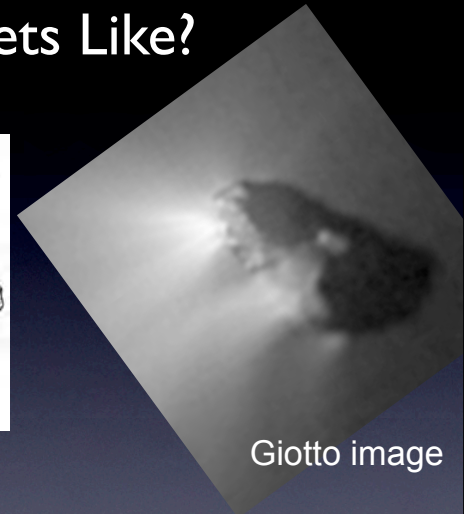
- There may be *100 billion* to *1 trillion* comets (or more) in the Oort cloud, with a total comet mass > 1000 M_⊕

✓ Stars passing "close" to the Sun can jostle Oort cloud objects and cause them to fall inwards

What Are Comets Like?



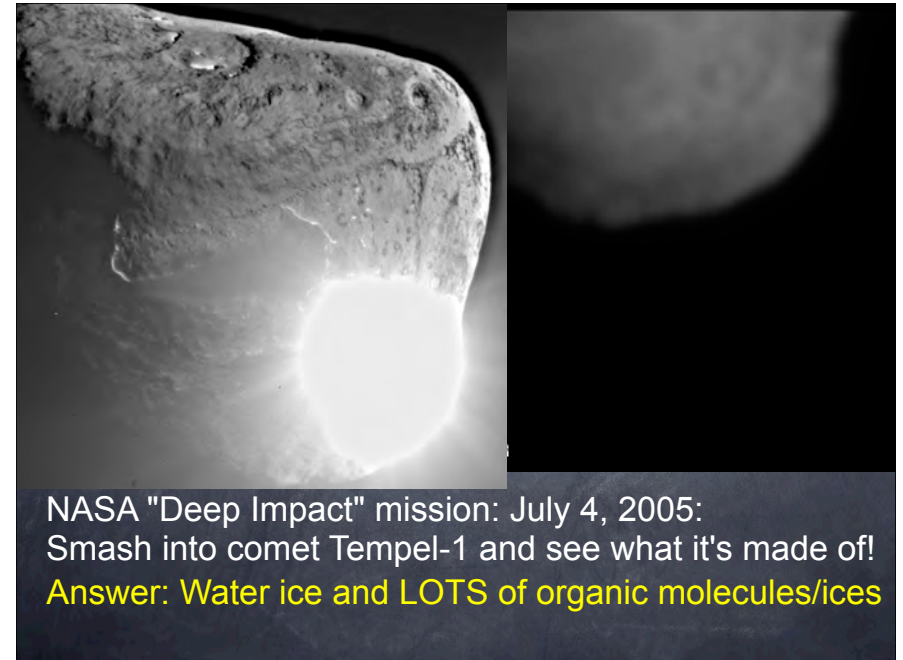
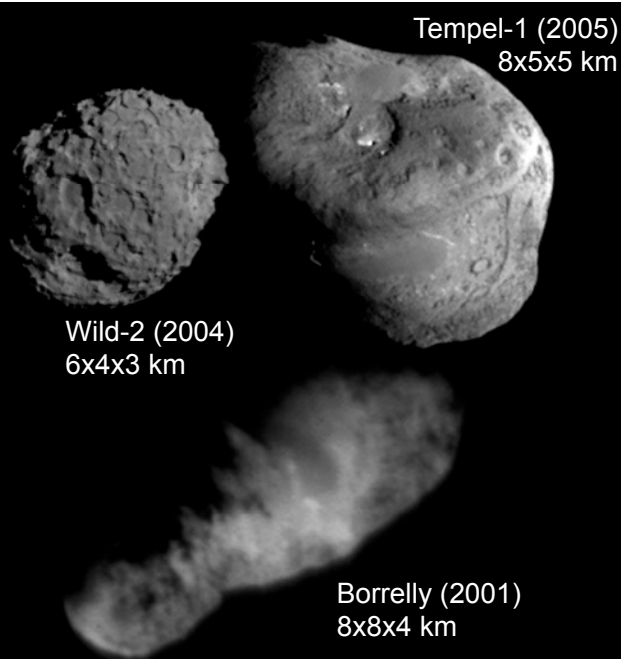
Sketch map



Giotto image

- First images and other data from the VEGA and Giotto spacecraft flybys of Halley's comet in 1986

More recently, we have been getting better spacecraft images of comet nuclei...



- Comets are sort of big celestial chemistry sets!
 - Heat, light, water, organic chemicals...
 - Aren't these the building blocks of life?
- Comets occasionally impact the Sun & planets...
 - They deliver water and organic molecules (**Bringers of Life!**)
 - They can also cause massive ecological disasters (**Bringers of Death!**)



Comet Impacts!

- Comets crash into the Sun all the time!
 - SOHO movie of Sun-grazing comets
- Comets have crashed into Jupiter recently!
 - Shoemaker-Levy 9, "string of pearls," July 1994
 - Another un-named comet in July 2009

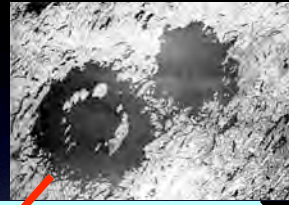
A collage of images related to comet impacts, including a comet near the Sun, a comet impact on Jupiter, and a comet impact on Earth.

Have asteroids and comets hit the Earth?

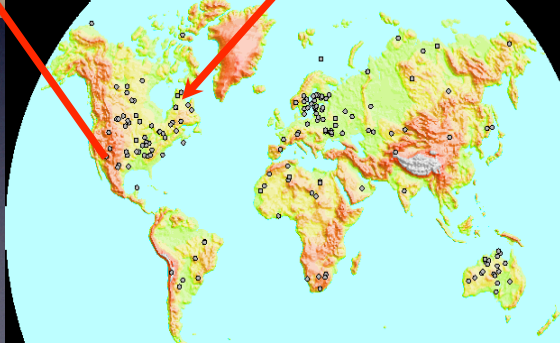


Meteor Crater, Arizona

Yes!



Clearwater Craters, Quebec



- Several hundred impact craters have been found on Earth
- Most are highly eroded by wind, water, ice, tectonics
- Geologically "rare"

The Impact Rate



Fireball over Peekskill, NY
October 9, 1992

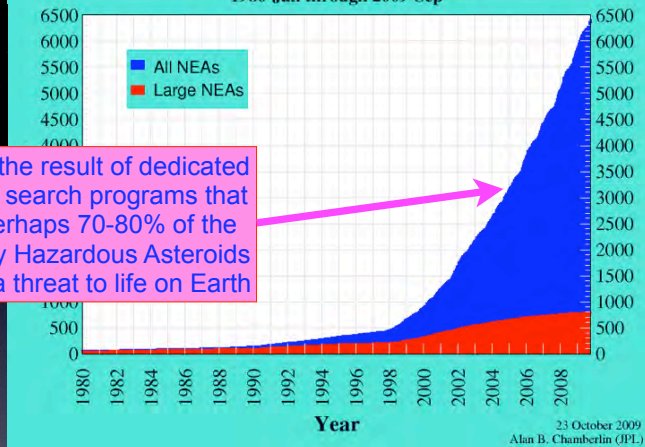
- ✓ How often does Earth get hit?
 - And by what SIZE objects?
 - Both **Mass** and **Velocity** Matter

$$\text{IMPACT ENERGY} = \frac{1}{2} mv^2$$

- ✓ We can address the question by:
 - Studying Earth's craters and cratering record (extinctions?)
 - Counting craters and measuring the impact rates on the surfaces of the Moon and other planets
 - Surveying the population of near-Earth asteroids, comets, and meteors

<http://neo.jpl.nasa.gov/stats>

Known Near-Earth Asteroids 1980-Jan through 2009-Sep



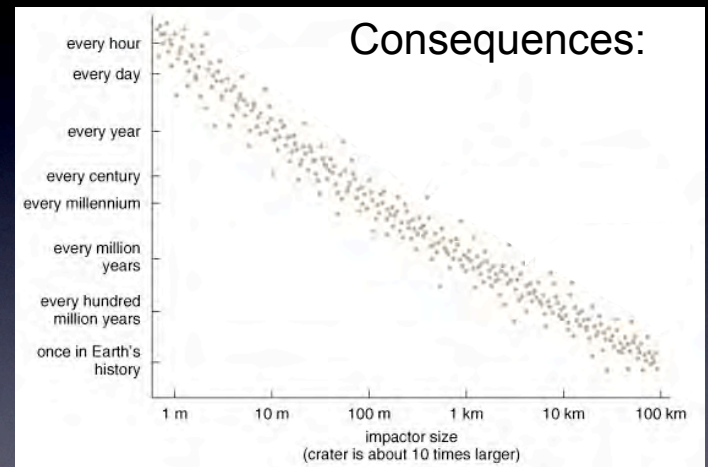
This big jump is the result of dedicated NASA and other search programs that have located perhaps 70-80% of the >1 km Potentially Hazardous Asteroids that could pose a threat to life on Earth

<http://cfa-www.harvard.edu/iau/lists/Unusual.html>

Presently-Known Near-Earth Asteroid Population:

6519 Close Approach Objects & 1072 Potentially Hazardous Asteroids (PHA) [big and approach within 0.05 AU]

The Impact Rate

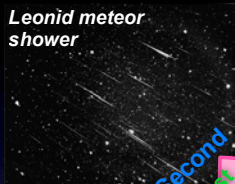


Consequences:

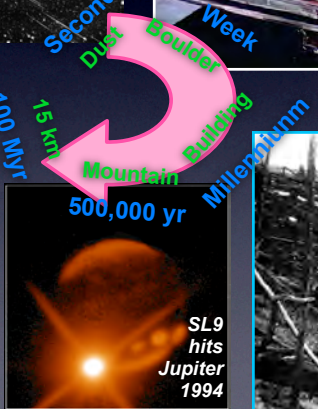
from data and models compiled by Chapman & Morrison (1994)

The Impact Rate

Smallest, most frequent



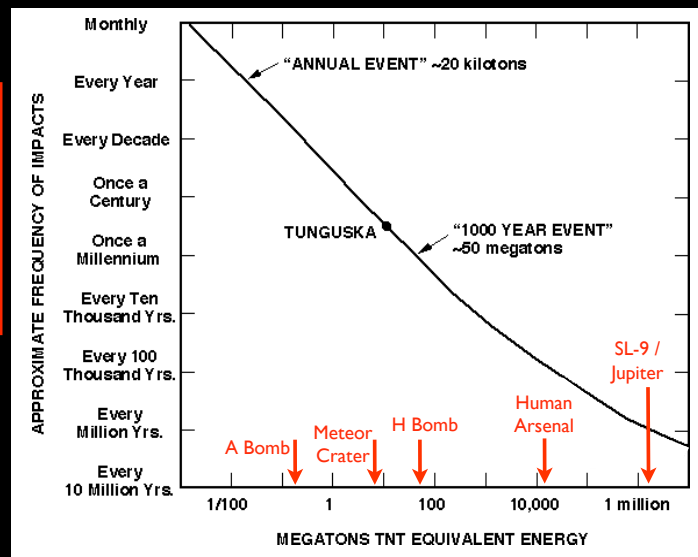
Huge, extremely rare



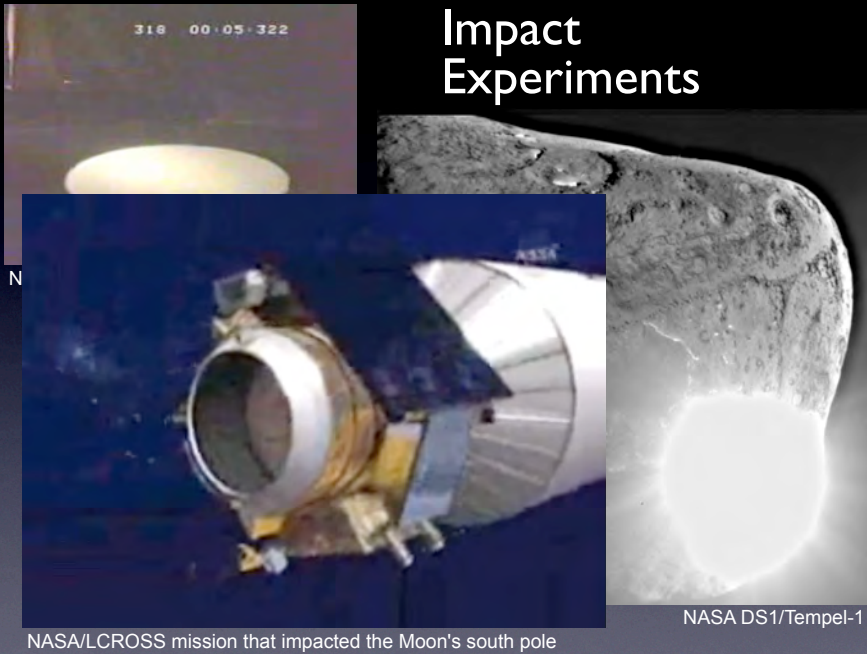
C. Chapman (2003)

Impact Energy Matters Most

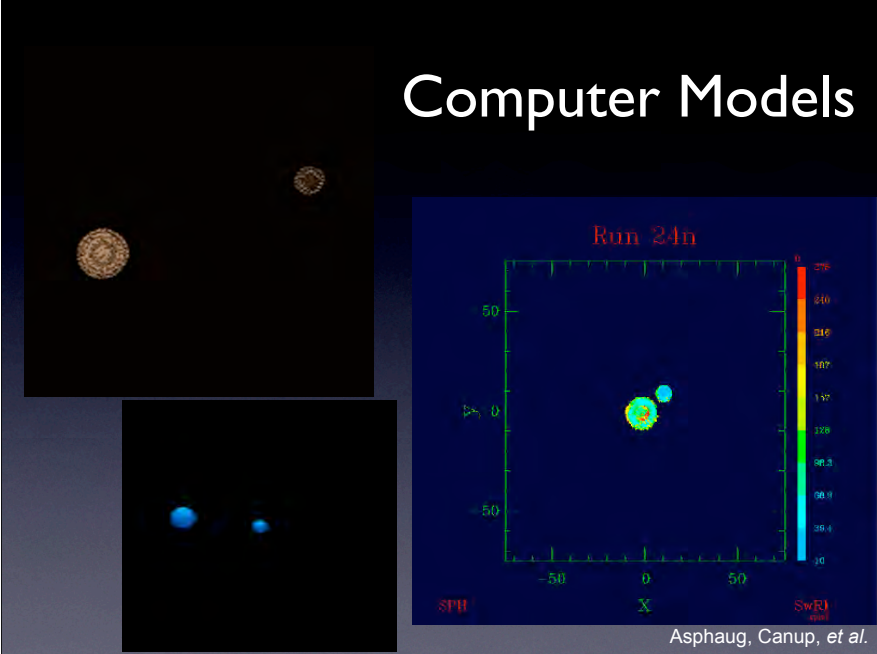
How can we tell how much energy an impact will have?



Impact Experiments



Computer Models



What's Hollywood's View?



Scenes from "Armageddon" (1998) and "Deep Impact" (1998)

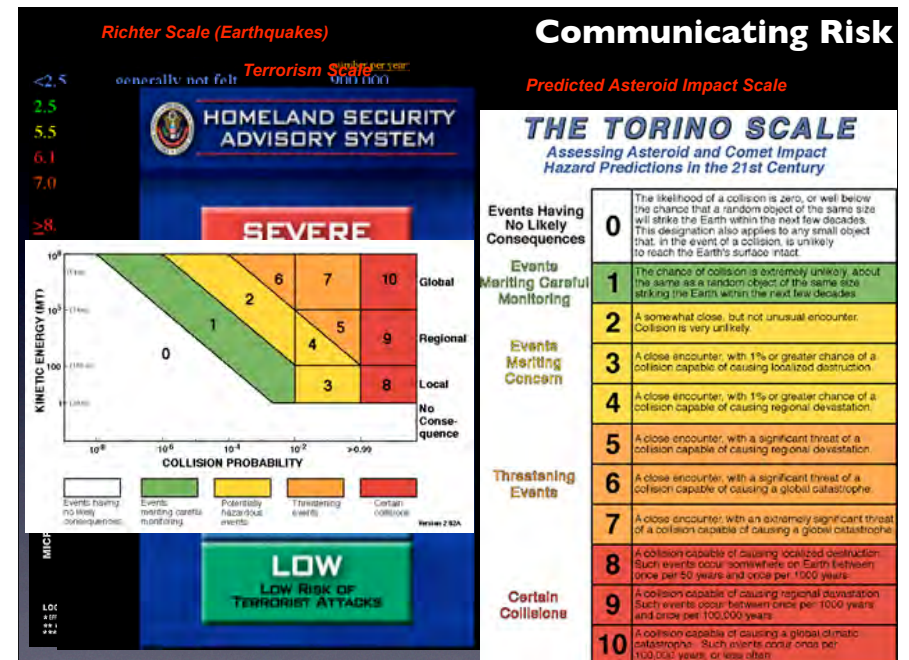
What are the Real Risks?

- An actuarial exercise
- Perhaps morbid, but *essential* to understanding and gauging society's response to the risk
- The result is surprising to many!
- Impacts are *rare* but the consequences are *huge*

Cause of death	Chance of death over course of lifetime
Motor vehicle accident	1 in 100
Murder	1 in 300
Fire	1 in 800
Firearms accident	1 in 2,500
Asteroid/comet impact (lower limit)	1 in 3,000
Electrocution	1 in 5,000
ASTEROID/COMET IMPACT	1 in 20,000
Passenger aircraft crash	1 in 20,000
Flood	1 in 30,000
Tornado	1 in 60,000
Venomous bite or sting	1 in 100,000
ASTEROID/COMET impact (upper limit)	1 in 250,000
Fireworks accident	1 in 1 million
Food poisoning by botulism	1 in 3 million
Drinking water with EPA limit of TCE*	1 in 10 million

* EPA, Environmental Protection Agency; TCE, trichloroethylene.

Chapman & Morrison (1994)





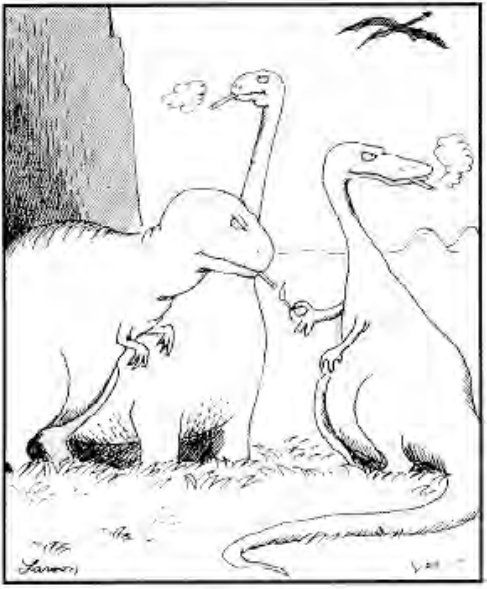
Consequences...



- *Future impacts will* occur, and could have enormous ecological consequences
- It is now fairly well established that *past impacts* have also had an enormous influence on the biosphere of our planet:
 - Geologic devastation...
 - Climate changes...
 - Mass Extinctions...




An alternate hypothesis...



(c) Gary Larson

The real reason dinosaurs became extinct

Mitigation...



- Impacts are potentially preventable natural disasters
 - Modern technology might be able to deflect or disrupt an incoming object
 - But a long lead time is required!
- Deflection (change of orbit) is preferred approach
 - Try to impart a very slight change in velocity (few cm/s) years in advance
 - Requires advanced warning (maybe a decade or more? is that even enough time?)
 - Probably requires some kind of rendezvous spacecraft (like NASA NEAR mission)
 - Some schemes require one or more nuclear explosives (up to MT yield)— controversial! ("space nukes")

Mitigation...



- Disruption of the incoming object might be possible if warning time is less and strength is roughly known
 - Might require greater yield explosives to ensure no large fragments
 - Requires fully-developed defense system (on the pad)
- Subject of studies by US Air Force, US weapons labs (Livermore, Los Alamos), Russian defense industry, United Nations, other countries

Congress is getting the message:

The House Committee on Science and Technology believes that it is imperative that the detection rate of Earth-orbit-crossing asteroids must be increased substantially, and that the means to destroy or alter the orbits of asteroids when they do threaten collisions should be defined and agreed upon internationally. The chances of the Earth being struck by a large asteroid are extremely small, but because the consequences of such a collision are extremely large, the Committee believes it is only prudent to assess the nature of the threat and prepare to deal with it.

- NASA Authorization Bill

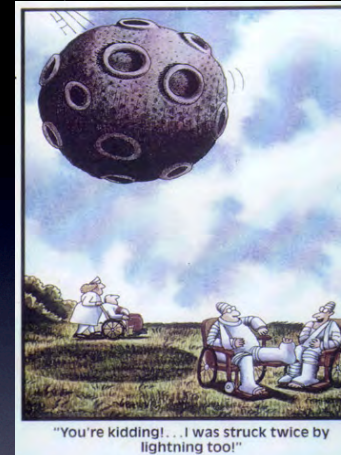
Net result: "Spaceguard" and other potentially hazardous object surveys are now being funded at a few \$M/yr

The Main Points

- Earth has been hit by large asteroids and comets in the past, with devastating consequences.
- Earth will get hit again in the future.
- But now there is a species living on this planet that has the potential to do something about it...



(c) Gary Larson



Will we (can we)?

Some say the world will end in fire,
Some say in ice.

From what I've tasted of desire
I hold with those who favor fire.

But if I had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

- Robert Frost

Check out more online resources:

<http://neo.jpl.nasa.gov>

<http://impact.arc.nasa.gov>

http://en.wikipedia.org/wiki/Near-Earth_object

http://www.planetary.org/programs/list/near_earth_objects