Astronomy 150:
Killer Skies

<u>This Class (Lecture 10):</u>
Impact Mitigation

<u>Next Class:</u>
The Aging Sun

HW4 due on Tonight.
HW5 due next Monday
EC due Wednesday

Music: *Another One Bites the Dust*– Queen

Question

Friday Oct 1st is Exam 1. How many questions should be on the exam?

a) 25
b) 30
c) 35
d) 40
e) 45

Exam 1

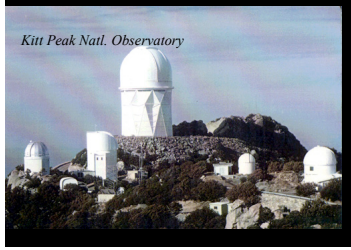
- Exam 1 in this classroom on Oct 1st
- 40 Multiple choice questions
- Will cover material up to and including next Friday.
- May bring 1 sheet of paper with notes
  - Both sides
  - Printed/handwritten/whatever.. I don't really care
- Major resources are lecture notes and homeworks
- Try to understand major points more than anything.
- Have created and posted a study guide

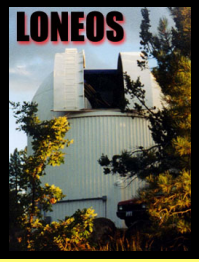
Outline

- What are the odds?
- Mitigation techniques

Near Earth Object Program

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





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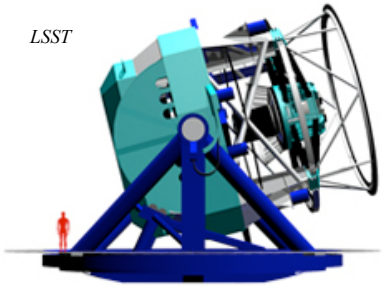
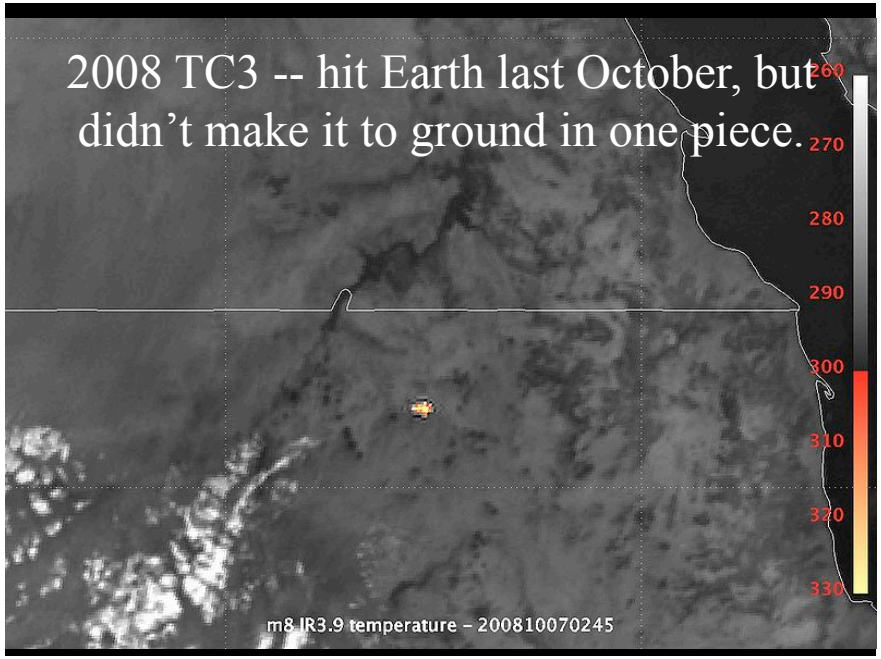
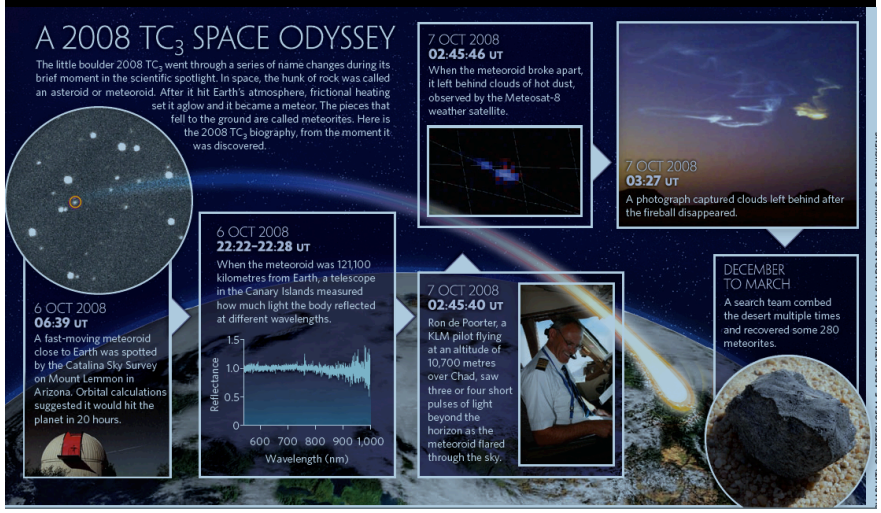


- Survey: 1998 to 2009, find >90% of NEOs >1 km diameter (Near Earth Objects)
- Congress ordered NASA to find 90% of NEOs >140 m by 2020
- http://www.youtube.com/watch?v=9_EZfxvTmNA



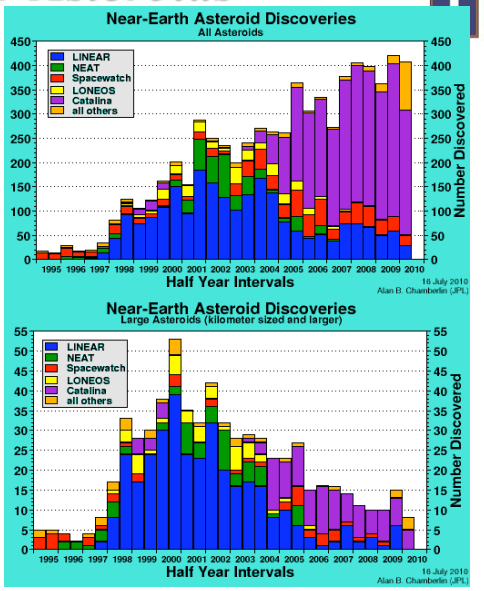
Significance: First asteroid detected before it was going to hit Earth. First meteorite recovered from such an asteroid.



Killer Asteroids

- As of Sept 2010, 7,279 NEAs (>50 meters, so asteroids) are known.
- 818 of these are > 1km
- 1138 of these are classified as Potentially Hazardous Asteroids (PHAs)

http://neo.jpl.nasa.gov/faq/
http://neo.jpl.nasa.gov/stats/



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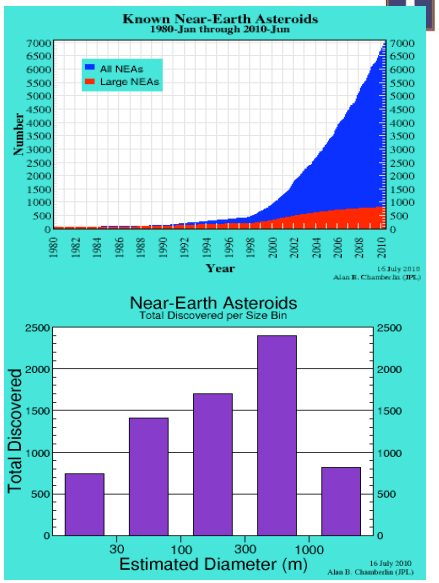
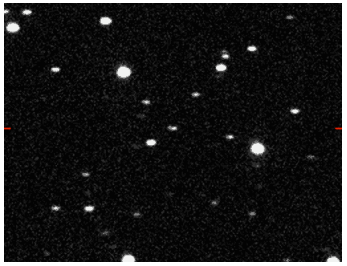


The Asteroid with Our Name on It: The Deadly Impactor

- We haven't seen it yet.
- But we want to find all the "potentially hazardous" asteroids, to be sure nothing's coming soon…. (Though statistics are on our side.)

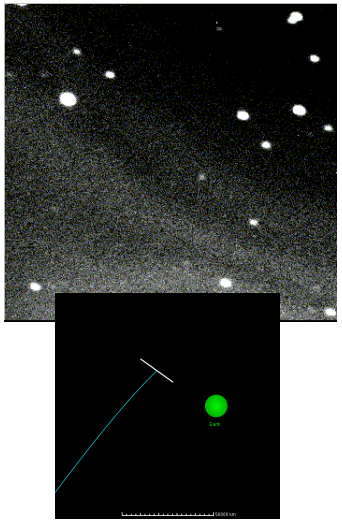


Asteroid 2004 FH. 30 meters in diameter. About 1 Megaton of TNT energy in an Earth impact! Passed within 7 Earth radii of Earth. Hiroshima was 15 kilotons.

http://antwrp.gsfc.nasa.gov/apod/ap040322.html

The Asteroid with Our Name on It: The Deadly Impactor

- The most famous "close call" is asteroid Apophis (which might hit us in 2029 & 2036).
  - 450 meters in diameter, approx.
  - There was a scare for a while because the chance of a hit was 1 in 300 for 2029, now zero.
  - Currently the chance is only 1 in 250,000 for 2036.
  - Highest Ever Ranked NEA on the Torino Scale for a short time.



Scale It! Torino Scale

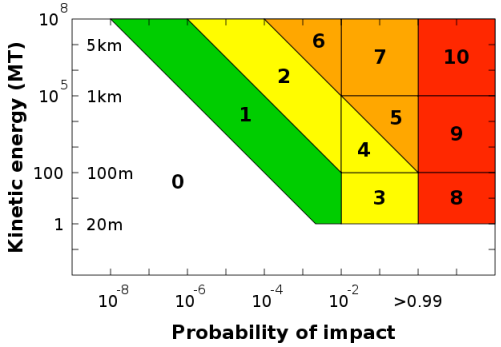
Apophis was ranked a 4!

As a better description of its orbit was found, it dropped to a 1.

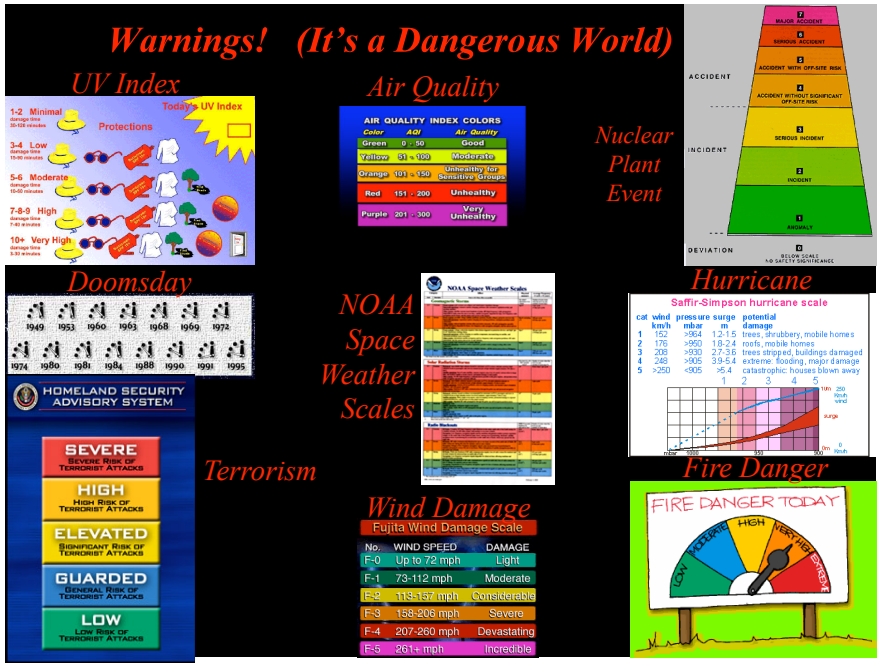
0	The likelihood of a collision is zero, or well below the chance that a random object of the same size will strike the earth within the next few decades. This designation also applies to any small object that, in the event of a collision, is unlikely to reach the Earth's surface intact.
1	The chance of collision is extremely unlikely, about the same as a random object of the same size striking the earth within the next few decades.
2	A somewhat close, but not unusual encounter. Collision is very unlikely.
3	A close encounter, with 1% or greater chance of a collision capable of causing localized destruction.
4	A close encounter, with 1% or greater chance of a collision capable of causing regional devastation.
5	A close encounter, with a significant threat of a collision capable of causing regional devastation.
6	A close encounter, with a significant threat of a collision capable of causing a global catastrophe.
7	A close encounter, with an extremely significant threat of a collision capable of causing a global catastrophe.
8	A collision capable of causing localized destruction. Such events occur somewhere on Earth between once per 50 years and once per 1000 years.
9	A collision capable of causing regional devastation. Such events occur between once per 1000 years and once per 100,000 years.
10	A collision capable of causing global climatic catastrophe. Such events occur once per 100,000 years, or less often.

Scale It!
Torino Scale

Four other objects have been rated a 1, three are still listed as 1's.



http://neo.jpl.nasa.gov/images/torino_scale.jpg



"Apophis" Story

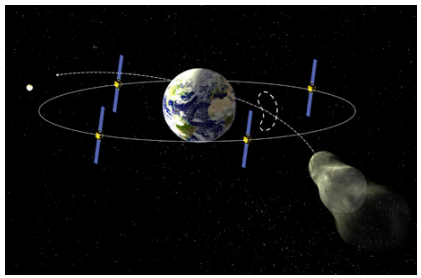
- On Dec. 23rd, JPL and Univ. of Pisa announce that this NEA has 1-in-200 chance of hitting Earth on 13 April 2029 with force of thousands of megatons: first ever TS = 2!
- As of 27 Dec., new observations over holidays *raise* impact chances to 1-in-37: TS = 4!!!
- Uncertainty in object's size could mean TS = 5, or 7.
- Earlier images found (unlikely!) and analyzed on 28 Dec.: it will miss by 5 Earth <u>diameters</u>.

"Apophis" Story

- Month later, Arecibo radar shows that positions are wrong: Apophis will miss by just 5 Earth <u>radii</u>, *under* geosynch. communications satellites.
- If Apophis passes through a small "keyhole" (1-in-several-thousand chance), it would return to impact 13 April 2036. (This chance now reduced to 1-in-250,000.)
- Media frenzy averted by holidays, Indian Ocean tsunami. But many "what if's" and other issues…

"Keyholes"

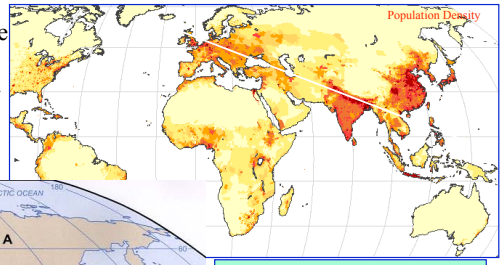
- Calculation of orbits for the future is difficult, small variations or interactions can change future wildly.
- A "keyhole" is an orbit interaction region such that the asteroid will collide with Earth on its next orbital pass.
- For Apophis the keyhole on the next pass is only 600 meters in diameter.



- Error bars on orbit right now are around 3000 km, so we have to wait and see.

To Tell or Not to Tell…

- In the 1-chance-in-37 (wrong) for 2029 impact, extreme destruction would have occured within the zone between the dashed lines, somewhere along the solid red line.
- You can hardly imagine a line crossing more densely populated areas.



There was hot debate about whether to release the possible impact points after they were calculated on Dec. 24th. NASA officials, scientists argued we should wait for perhaps a year. ***But withholding information from the public violates risk-communication principles!***

Interesting Questions

Should possible impacts like Apophis be announced as soon as they are found, or should we wait until it is confirmed?

a) Wait until better than 90% sure.
b) Give us info immediately, then update.

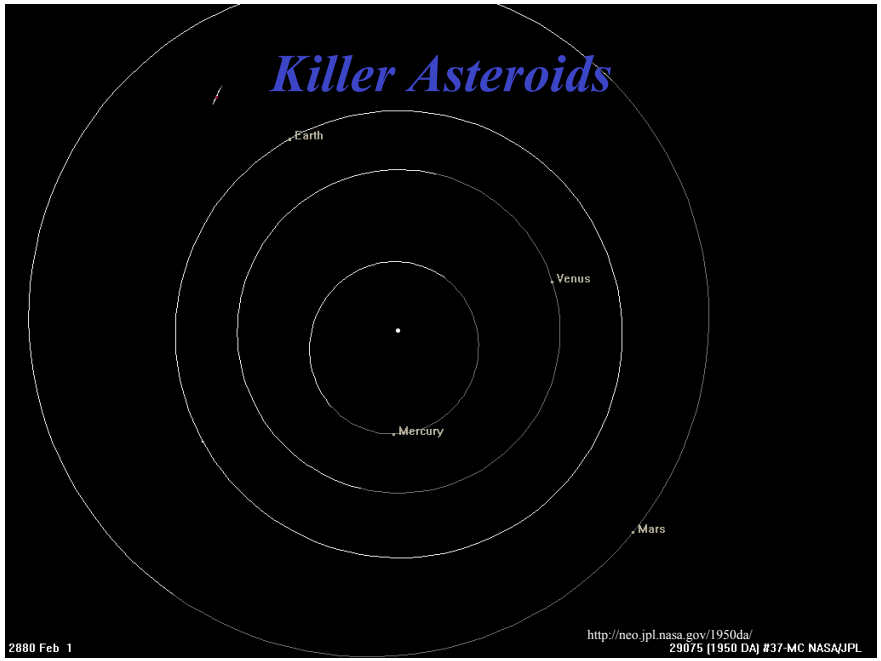
What Today's Dangerous Rock?

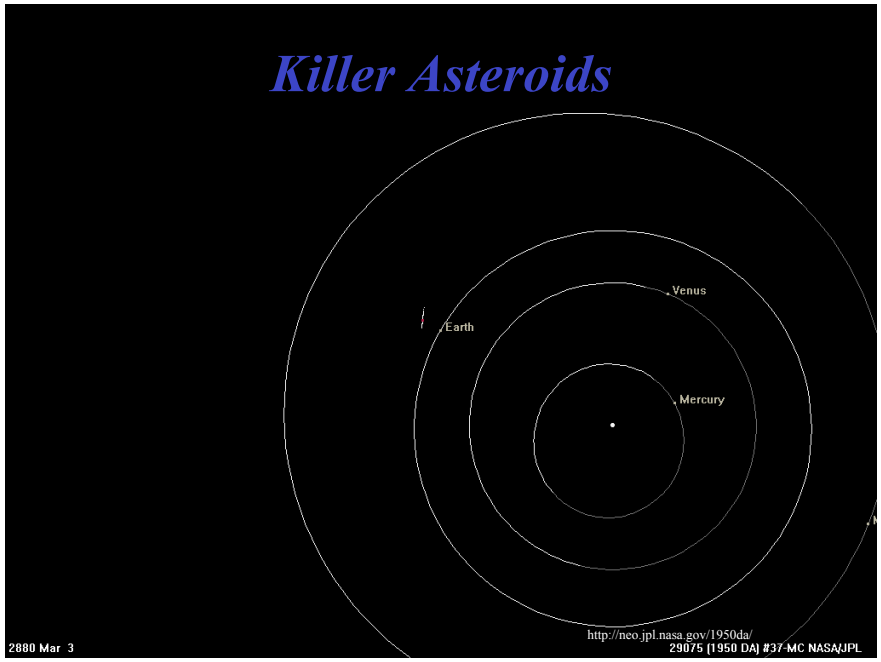
- http://neo.jpl.nasa.gov/risk/index.html

Killer Asteroids

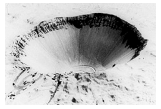
- The most dangerous known is 1950 DA (~1km), will get close in March 2880 (0.33% chance of collision).
- We can not accurately predict orbits more than 20 years in advance, but 1950 DA would have 100,000 Megatons of energy.

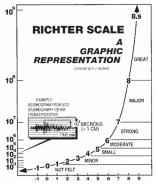
http://neo.jpl.nasa.gov/1950da/



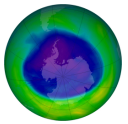


Environmental Consequences of Civilization-Threatening Impact

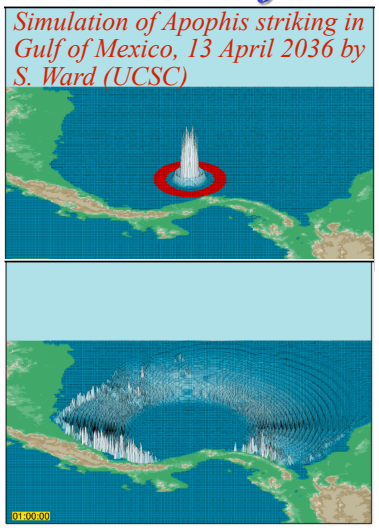




- Total destruction in near-crater zone
  - Destruction zone 30 times the size of the asteroid
- Tsunami ("tidal waves")
  - Inundation of shores of impacted ocean
- Stratospheric dust obscures sun
  - Sudden global climate change threatens agriculture
- Widespread fires
  - Re-entering ejected material broils Earth's surface
- Poisoning of the biosphere
  - Sulfates, nitric acid, ozone layer destroyed
- Earthquakes
  - Modest effects compared with everything else



Consequences of Ocean Impact of 300-meter NEA



- Crater (and central "peak") in water collapses, generating a high but short-wavelength tsunami
- Run-up on proximal coasts depends on dissipation, off-shore topography, etc.
- Within minutes to hours, major destruction is possible within kilometers of coastline
- Consequences approximately like those of Dec. 2004 Indian Ocean tsunami

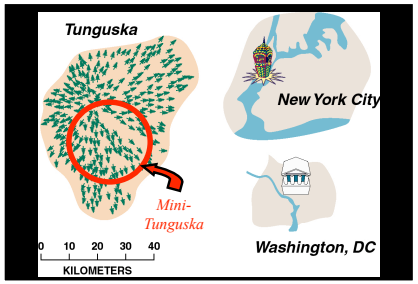
Consequences of Land Impact by 200 meter to 2 km NEA

- ***Consequences are well understood from nuclear bomb tests and studies of terrestrial and lunar impact craters.***
- Crater rim ~15 times diameter of NEA; total destruction zone twice as big (4 – 40 km from ground-zero)
- Explosion fireball: 3rd deg. burns 10 – 100 km from ground-zero; firestorm 30 – 300 km from ground-zero
- Air-blast, overpressure destroys all structures 10 – 100 km away; poorly-built structures destroyed (within minutes) by winds, earthquake, falling debris up to 70 – 700 km from ground-zero
- Ozone layer destroyed globally by NEAs >500 m diameter
- Atmospheric pollution (sulfate aerosols, nitric acid rains, injection of dust and water into atmosphere); "year without summer" for NEAs ~1 km diameter, global agricultural disaster ("impact winter") possible for NEAs >2 km diameter (land or ocean impact).
- Electromagnetic Pulse? Could bring down power-grid and communications just when they are most desperately needed.

Help!

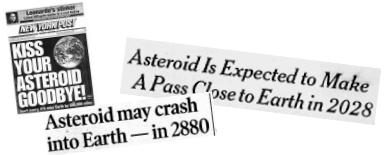
"Mini-Tunguska": Once-in-a-Century Atmospheric Explosion

- Nature of Devastation. *30-40 m "office building" rock hits at 100 times speed of jetliner, explodes ~15 km up with energy of 100 Hiroshima A-bombs. Weak structures damaged/destroyed by hurricane-force winds out to 15 km. If over land, dozens or hundreds may die, especially in poor, densely populated areas (minimal damage in desolate places).*
- Probability of Happening. *but most likely over an ocean or sparsely-populated area.*
- Warning Time. *Very unlikely to beforehand; no warning at all.*
- Mitigation Issues. *Little can be done in advance (an adequate search system would be very costly). Rescue and recovery would resemble responses to a "normal" civil disaster. No on-the-ground advance preparation makes sense, except public education about this possibility.*



Secondary Consequences from Small, Likely Events

OVER KASHMIR? OVER ISRAEL? HOW WOULD THE GENERALS RESPOND?



- Public and government over-reaction to 9/11 (e.g. stock market volatility, homeland security hysteria) could be replicated by a modest, unexpected impact disaster.
- An otherwise harmless but brilliant bolide (fireball) could be mistaken for an atomic attack, causing a dangerous response.
- Even sensational journalism or a mistaken prediction about a possible future impact could be disruptive.

What Do We Know About the Impact Hazard?

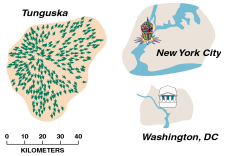
WE KNOW THIS…

- Very Well — How many asteroids and comets there are of various sizes in Earth-approaching orbits (hence, impact frequencies are known).
- Very Well — How much energy is delivered by an impact (e.g. the TNT equivalence, size of resulting crater).
- Somewhat — How much dust is raised into the stratosphere and other environmental consequences.
- Poorly — Biosphere response (agriculture, forests, human beings, ocean life) to environmental shock.
- Very Poorly — Response of human psychology, sociology, political systems, and economies to such a catastrophe.

The Consequences in Perspective…

Meteorite punctured roof in Canon City, CO

- Most effects are individually familiar (fire, wind, falling debris, seismic shaking…)
  - First-responders face nothing truly alien, no radiation
  - Synergy of many different effects in first 10 minutes
- Warning versus no warning (time and location)
  - Deaths and injuries dramatically reduced with warning
  - Property damage can be lessened somewhat
  - Even with no warning, individuals can reduce exposure by taking cover (within seconds to minutes) if they have been educated to recognize what's happening (Indian Ocean tsunami analogy)
- Impact disasters: local/regional versus global
  - Like Katrina, earthquakes, or wars…unaffected cities or nations can provide emergency response and recovery…
  - …Unless the consequences are global



Mitigation by Civil Defense

- If a NEA strikes without warning, or if deflection seems uncertain or fails
- Warn, evacuate, store food supplies, plan for a large medical emergency, response and recovery operations…

Asteroid Histories Sampler

- Billions of yrs ago (Mars-sized): Creation of Moon
- 65 Million yrs ago (~10 km): Dino-killer
- 15 Million yrs ago (~10 km): fragmented before impact, but ~1km objects impacted Bavaria, destroyed much of Europe
- 50,000 yrs ago (~50 m): Arizona meteor crater
- 1908 AD (~50 m): Tunguska

Asteroid Histories Sampler (Recent)

- 1972 (~ 10m): The Great Daylight 1972 Fireball, went through the atmosphere, getting as low as 58 km over Montana
- 1989 (~300 m): missed by 700,000 km (where the Earth had been 6 hours earlier)
- 2002 (~100 m): 1/3 Earth-Moon distance, 120,700 km, only discovered three days after pass!
- 2004 (~500 m): 400,00 km, rediscovered 1 week before.
- 2009 (~30 m): 60,000 km, discovered 1 month before.

Asteroid Histories Sampler (Future)

- 2029 (~ 450 m): Apophis will come within 40,000 km. **In very dark sites, it will be visible with naked eyes** (Europe, Africa, and W Asia).
- 2036 (~450 m): Apophis is back. We don't know how close it will get, possible impact. We'll know better soon.
- 2880 (~1.1 km): 1950 DA, huge miss or impact?

Lifetime Chances?

Clark R. Chapman
Southwest Research Institute

Cause of Death	Chance: 1 in
Motor vehicle accident	90
Suicide	120
Homicide	185
Falls	250
Terrorism (Middle East)	1,000
Fire or smoke	1,100
Electrocution	5,000
Drowning	9,000
Flood	27,000
Airplane crash	30,000
Lightning strike	43,000
Asteroid impact (global)	**75,000**
Terrorism (non Mid-East)	80,000
Insect bite or sting	100,000
Natural tsunami	100,000
Earthquake	130,000
Asteroid impact (regional)	**1,600,000**
Food poisoning (botulism)	3,000,000
Asteroid impact (local)	**5,700,000**
Shark attack	8,000,000

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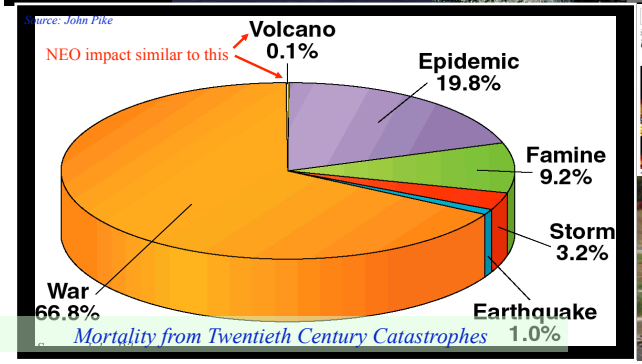
This is hard to understand as there is very little chance that anyone in your lifetime will die from an impact. BUT, if a global impact occurs within the next 100 million years, billions of people will die, so the average per year is still relevant. Low chance, but high risk events!

How Important is NEO Threat? We've Many Other Things to Worry About!



Comparing NEO Impacts and Climate Change

NEO Impact

Similarities…

- They can potentially affect the globe
- Asteroids can be deflected to miss Earth

Dissimilarities…

- Global effects within 2 hours, global climate change within months
- Extremely unlikely to happen this century

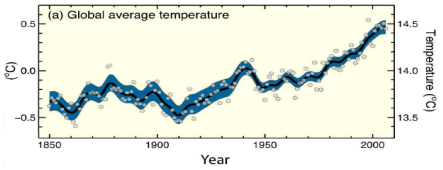
Climate Change

Similarities…

- Global warming is planetary in scale
- Society can reduce greenhouse gases

Dissimilarities…

- Timescale for major changes: about one century
- Actually underway right now



So can we ignore the risks?

- Well, an asteroid impact would be like a plane crash…. It doesn't happen very often at all -- air travel is very safe -- but when it does happen, a bunch of people die at once.

- It all depends on what risks humanity is willing to live with (e.g. cars kill lots more people, but no-one wants to ban them…).

What do you think?

Right now, the US Government is spending money on finding potentially hazardous asteroids -- asteroids that would not necessarily cause a mass-extinction but would probably wipe out millions to billions of people and decimate civilization.

As we saw, the chance of an asteroid doing this in the next few thousand years is remote…. But if it comes, it would be a big problem!

How much money should we be spending on this issue?

A. $0 per year -- we've got bigger problems to worry about.
B. Few million $ per year -- get some people working on it, and this cost is a drop in the bucket compared to e.g. DoD.
C. Few billion $ per year -- given the consequences, this requires lots of resources.
D. Few trillion $ per year -- Holy Crap, this should be our top priority!

What do you think?

A more immediate problem are the small asteroids that cause Tunguska like events. On a city they'd cause thousands to millions of deaths, but civilization would not be destroyed. Something like this could very well happen within the next hundred years…. Or it might not…

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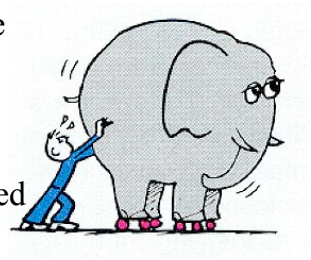
Early Detection is Key

- The earlier we can detect a threat, the easier it is to mitigate the danger. http://www.youtube.com/watch?v=XPS-m_sI7_k
- A very small change in velocity (speed or direction) can make a huge difference in months.
- Remember inertia (the resistance of mass to change motion), and these things are massive.
- And new comets would only have warnings of a few months!



http://sol.sci.uop.edu/~jfalward/physics17/chapter2/chapter2.html

Mitigation

- The problem is the possibility of little or no warning
- There are proposals to use nuclear weapons and satellites to "shoot down" or destroy such killer objects (good idea?)
- For further edification, rent "Armageddon" (1998)
- http://www.youtube.com/watch?v=iq6q2BrTino