Positions of all known asteroids projected onto the plane of the Earth’s orbit on Jan 20, 2008

Red ones (Apollo and Aten) cross the orbit of Earth so are potentially hazardous. Yellow ones (Amors) don’t cross Earth’s orbit now but could in the future if their orbits are disturbed.

NEAR-EARTH ASTEROIDS

Comet/Asteroid Impact Hazard in Perspective
- To “scientists” the fact that asteroids and comets strike the Earth is obvious
- Greatest natural disasters on Earth are caused by the impacts of large asteroids and comets
- They are so infrequent that they are normally disregarded
- At present, only one known object has even a small likelihood of impacting Earth soon (Apophis).
- So what is the urgency?
- We now have the technical capability to find and, possibly, divert/destroy any small asteroid that threatens Earth
- Should we use resources for this purpose?

How Well Do we Know?
- Level of the hazard: Well
- Energy released in a collision: Very well
- Physical and chemical side effects: Some
- Biological and social side effects: Not much
Some useful NEO/Impact Hazard Websites:

NASA Near Earth Object web site at JPL:
http://neo.jpl.nasa.gov

NASA/Ames NEO Impact Hazard page:
http://impact.arc.nasa.gov

Spacewatch Project:
http://www.lpl.arizona.edu/spacewatch/

Torino Scale:
http://impact.arc.nasa.gov/torino/index.html

- Smallest asteroid known: 1993KA2  4-9 meters
- Closest approach by an asteroid: Apophis on April 13, 2029
- 250 m sized object, will pass inside orbits of geosynchronous sats.

The B612 Foundation

“Our goal is to significantly alter the orbit of an asteroid in a controlled manner by 2015”

Asteroid and comet impacts have both destroyed and shaped life on Earth since it formed.

The Earth orbits the Sun in a vast swarm of near Earth asteroids (NEAs).

The probability of an unacceptable collision in this century is ~2%. We now have the capability to anticipate an impact and to prevent it.

* B612 is the asteroid home of the Little Prince in Antoine de Saint-Exupery’s child’s story The Little Prince.

http://www.b612foundation.org

Article Posted: October 31, 2005
By: David Morrison

During its close passage by the Earth on April 13 2029, it is possible (but improbable) that asteroid Apophis will pass through a keyhole leading to a collision in 2036. Recent concern has centered on how to evaluate the possibility of a collision in 2036 and take action, if necessary, to deflect the asteroid.

The Torino Scale

Figure 2. Frequency of NEOs by Size, Impact Energy, and Magnitude

HAZARDS
DUE TO COMETS & ASTEROIDS
T. GERBELS, EDITOR
TABLE II
Summary of Impact Effects as a Function of Energy

<table>
<thead>
<tr>
<th>Yield T/MO</th>
<th>log y</th>
<th>RNO</th>
<th>Distance</th>
<th>F Init</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10^-10</td>
<td>3.0</td>
<td>75 m</td>
<td>1.5</td>
<td>1</td>
<td>Upright strewn features of stone and concrete. Only air shock wave penetrates to surface.</td>
</tr>
<tr>
<td>10^-10</td>
<td>3.6</td>
<td>160 m</td>
<td>3</td>
<td>1</td>
<td>Iron and stone produce gas proglacial, concrete produces fallout. Land impacts destory area of large捎通(dillas, New York, Tokyo).</td>
</tr>
<tr>
<td>10^-7</td>
<td>4.2</td>
<td>150 m</td>
<td>6</td>
<td>1</td>
<td>Iron impacts destroy area of large craters (Washington, Paris, Munich).</td>
</tr>
<tr>
<td>10^-5</td>
<td>4.8</td>
<td>65 km</td>
<td>12</td>
<td>1</td>
<td>Tectonic release of seismic energy, second damage from land impacts. Land impacts destroy area of large craters (Washington, Tokyo).</td>
</tr>
<tr>
<td>10^-3</td>
<td>5.4</td>
<td>1.7 km</td>
<td>30</td>
<td>1</td>
<td>Large wave produces large shock wave and air blast. Large impacts destroy area of large craters (Washington, Paris, Munich).</td>
</tr>
<tr>
<td>10^-1</td>
<td>6.9</td>
<td>1 km</td>
<td>60</td>
<td>1</td>
<td>Both land and ocean impacts cause major change climate. Large impacts destroy area of large craters (Washington, Tokyo).</td>
</tr>
<tr>
<td>10^-2</td>
<td>7.6</td>
<td>7 km</td>
<td>125</td>
<td>1</td>
<td>Protracted climate effects, global contamination, possible mass extinction. Large impacts destroy area of large craters (Washington, Tokyo).</td>
</tr>
<tr>
<td>10^-1</td>
<td>7.2</td>
<td>10 km</td>
<td>250</td>
<td>1</td>
<td>Large mass extinctions (D/T).</td>
</tr>
</tbody>
</table>

Reference: Hazards Due to Comets and Asteroids,*

Morrison et al. "Hazards" p. 59 (1994)

**Blast Wave:**
- Shock wave expands through atmosphere from impact site at hypersonic speed
- About 1/2 of energy goes into shock waves
- Destruction depends on energy released, altitude of explosion
- Atmo can "Stop" objects ranging from 40 m (iron) to 400 m (comet stuff)
- For such objects "Airburst" can cause more damage than equivalent surface explosion

What are the effects that cause the most widespread "destruction"?

<table>
<thead>
<tr>
<th>Agent</th>
<th>Mechanism</th>
<th>Value</th>
<th>Scale</th>
<th>Geographical Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust leading</td>
<td>Cooling</td>
<td>V</td>
<td>G</td>
<td>R-T</td>
</tr>
<tr>
<td>Fires</td>
<td>Burning</td>
<td>M</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>NO_2</td>
<td>Oxidation</td>
<td>Y</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>So_2</td>
<td>Oxidation</td>
<td>W</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Shock wave</td>
<td>Mechanical pressure</td>
<td>I</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Tectonic wave</td>
<td>Drowning</td>
<td>I</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Heavy metal, etc.</td>
<td>Poisoning</td>
<td>Y</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Water/Oxygen</td>
<td>Poisoning</td>
<td>D</td>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

* I = instantaneous, M = moderate, Y = years, D = decades.
** K = Expanded to (Krater) or (crater)

Toon et al., Hazards" p. 791 (1994)

**Blowwave:**
Severe effects locally
Even K-T event affected only a few % of the Earth's surface

Toon et al., Hazards" p. 791 (1994)
TSUNAMIS – Tidal waves

Oceans cover 70% of Earth
High probability of impact
Wave height depends on impact energy and depth of ocean
1m to 10m waves very destructive

Toon et al., Hazards’ p. 791 (1994)

2004 Sumatran Earthquake and Tsunami – 9.3 on Richter scale – huge!
Energy released was (only!) ~26 MT

Toon et al., Hazards’ p. 791 (1994)

Dust and smoke

Figure 4. The transmission of visible light through a given optical depth of smoke or dust. Smoke is less transmitting than dust because it absorbs much of the light. Also noted in the figure are the light levels which correspond to various natural phenomena.

Toon et al., Hazards’ p. 791 (1994)
Dust loading - K-T event deposited ~1 cm of fine powder over whole Earth

- About ~5x10^6 MT

Expect dust cloud to cover Earth in a few weeks or less
Removed by fallout or by washout by rain within ~6 months
What are the climatic effects?

Ignition Threshold for Impact Generated Fires


**On Earth it takes**
Crater > 85 km for Continental Scale Fires
Crater > 135 km for Global Scale Fires

Chicxulub Crater (K-T event) is 170 km!
Caused by heating of the atmosphere as ejecta from the impact falls back into the atmosphere
**How serious can an asteroid impact be?**

**TABLE 1**

<table>
<thead>
<tr>
<th>Type of Event</th>
<th>Energy (MT)</th>
<th>Diameter</th>
<th>World Deaths / yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>High atmospheric break up</td>
<td>$10^6$</td>
<td>&gt;50 m</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Tunguska-like events</td>
<td>$10^3 - 10^4$</td>
<td>50 m-300 m</td>
<td>55</td>
</tr>
<tr>
<td>Sub-global local impacts</td>
<td>$2 \times 10^5 - 5 \times 10^6$</td>
<td>300 m-2 km</td>
<td>30</td>
</tr>
<tr>
<td>Sub-global ocean impacts</td>
<td>$2 \times 10^7 - 5 \times 10^8$</td>
<td>1 km-2 km</td>
<td>300</td>
</tr>
<tr>
<td>Threshold global catastrophe</td>
<td>$10^9 - 10^{10}$</td>
<td>&gt;4 km</td>
<td>3000</td>
</tr>
<tr>
<td>Mass extinction events</td>
<td>$&gt;10^{10}$</td>
<td>&lt;4 km</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>

**TABLE III**

<table>
<thead>
<tr>
<th>Energy Effect</th>
<th>$10^6$ Mt</th>
<th>$10^7$ Mt</th>
<th>$10^8$ Mt</th>
<th>$10^9$ Mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>Nuclear winter cooling</td>
<td>Photo-synthesis cessation</td>
<td>Vision cessation</td>
<td></td>
</tr>
<tr>
<td>Fires</td>
<td>Global ejecta, regional fires</td>
<td>Global</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO &amp; Loss of O$_3$ shield</td>
<td>Local</td>
<td>Regional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast</td>
<td>Regional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal waves</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$O injection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Toon et al., Hazards” p. 791 (1994)
TABLE III  
Ranked Selected Causes of Mortality (World)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Major diseases (e.g., heart disease, cancer)</td>
</tr>
<tr>
<td>2.</td>
<td>War and genocide</td>
</tr>
<tr>
<td>3.</td>
<td>Epidemics</td>
</tr>
<tr>
<td>4.</td>
<td>Pandemic</td>
</tr>
<tr>
<td>5.</td>
<td>Other diseases (pulmonary, pneumonia, influenza)</td>
</tr>
<tr>
<td>6.</td>
<td>Major accidents (motor vehicle, falls)</td>
</tr>
<tr>
<td>7.</td>
<td>Suicide and homicide</td>
</tr>
<tr>
<td>8.</td>
<td>Cyclones and floods</td>
</tr>
<tr>
<td>9.</td>
<td>Lesser accidents (poisoning, fires/burns, suffocation)</td>
</tr>
<tr>
<td>10.</td>
<td>Earthquakes</td>
</tr>
<tr>
<td>11.</td>
<td>Rare accidents (falling object, railway accident, airline crash)</td>
</tr>
<tr>
<td>12.</td>
<td>Globally catastrophic impact</td>
</tr>
<tr>
<td>13.</td>
<td>Rare natural disasters (thunderstorms, volcanoes)</td>
</tr>
<tr>
<td>14.</td>
<td>Venomous bite or sting</td>
</tr>
<tr>
<td>15.</td>
<td>Tunguska-like locally catastrophic impact</td>
</tr>
<tr>
<td>16.</td>
<td>Airline hijacking aftermath</td>
</tr>
<tr>
<td>17.</td>
<td>Drinking water with EPA limit on TCE</td>
</tr>
</tbody>
</table>

**Priority?**

- Government disaster planning is based on events with *timescales < 100 yrs*  
  => Impacts "not important" by this criterion.

- How about on basis of "annual fatalities"?

  Every 10 yrs a major impact kills 3 x 10^6 people  
  => 3,000 per year  

  In USA alone, 46,000 per year are killed in car accidents

  - "Based on normal methods of evaluating risks such as fatality rate or frequency of occurrence, the impact hazard does not appear to have higher priority than many other problems which society deals.

  - "Developing an asteroid and comet defense is neither necessary, nor prudent at this time.

How do you respond to a very low probability event with a very high potential damage level?

---

**Species Extinctions**

![Species Extinctions Graph](image)

---

**Species Extinctions**

![Species Extinctions Graph](image)

Figure 8: Fourier power spectrum for 22 extinction events from Fig. 2 (0-515 Myr), computed as described in Rampino and Caldeira (1993). The highest peak is at 27.3 Myr.
### Topics:
- Finding them – How? How do we tell their size?
- Tracking and predicting orbit
- Characterizing population and specific objects
- Mitigation options
- How is mitigation decision made?

---

**How do we detect NEAs**

Stars are at fixed distances and shine because they are very hot – e.g. our Sun. If we know its surface temperature – can tell from studying the spectrum of the light:

Then:  \[
\text{Apparent brightness of the star } \propto \frac{\text{size}}{\text{distance}^2}
\]

Asteroids shine by reflected sunlight – their surfaces are cold.

**Brightness determined by:**
- How big the are
- How reflective their surfaces are – typically they reflect about 10% of the incident sunlight
- How far they are from the Sun
- How far they are from Earth

\[
\text{Brightness } \propto \frac{\text{size} \times \text{albedo}}{D_{\text{Sun}}^2 \times D_{\text{Earth}}^2}
\]

*Both Ds vary with time as asteroid moves in its orbit*

---

**Not interested in all NEAs, only ones that threaten Earth – PHAs**

i.e. Apollo and Aten NEAs. But have to find all to determine which are PHAs

---

**Spaceguard Survey**

- **Initiated ~ 1992**
- **Aim:** Find 90% of NEA’s bigger than 1 km by 2009
- **How many expected?**
  - Shoemaker et al. ~1000
  - Bottke et al. ~ 900
- **By November 2006 ~ 700 found**
- **Total number (all sizes found) ~ 4400**

In 2005 Congress requested NASA study how to:
- Detect objects \( \geq 140 \text{ meters} \) – regional damage
- Find 90% by 2020, determine which are potentially hazardous
- Investigate ways to mitigate the threat
- Report due in early 2007
The blue area shows all near-Earth asteroids while the red area shows only large near-Earth asteroids.

In this context, "large" is defined as an asteroid having an absolute magnitude (H) of 18.0 or brighter which roughly corresponds to diameters of 1 km or larger.
HOW CAN WE MITIGATE THE THREAT (WITHOUT BRUCE WILLIS)