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.

Hazards From Asteroid Impacts

Smallest
Most
Frequent

Huge
Extremely
Rare

Asteroids - fossils of formation of the solar system

~10^6 objects with diameters D > 1 km between Mars and Jupiter

W. Bottke, Arecibo Symposium, Sept 2007
Meteorites are from Asteroids

- Meteorites are hand-samples of asteroids (and possibly comets) that have survived passage through our atmosphere to reach Earth.

NEOs are the “Middlepersons” Between Meteorites and Main Belt Asteroids

Some NEO Science Questions

- NEO orbit and size distributions? Compositions? Internal structures?
- How are NEOs replenished over time? By what populations?
- How do NEOs physically evolve? What does this tell us about planetesimal evolution?
- How are NEOs connected to meteorites? Where did their parent bodies originate?
- Did NEOs deliver water to the Earth?
- How has the NEO impact rate on the terrestrial planets changed with time?

To answer these questions, we need the most accurate model of the NEO population possible.

How Do Near-Earth Asteroids Get Here?

W. Bottke, Arecibo Symposium, Sept 2007
How Do Near-Earth Asteroids Get Here?

![Diagram of the asteroid belt and near Earth objects](image)

**Jupiter Family Comets**

**Asteroid Belt**

**Near Earth Objects**

**Dynamical Escape**

Yarkovsky Effect allows fragments to reach “Escape Hatches” – resonant locations with Jupiter

Sunlight can effectively exert a very tiny force on a small asteroid and very slowly change its orbit – called the Yarkovsky effect

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Mainbelt asteroid Gaspra from the Galileo spacecraft – about 17 km long. Image taken during Galileo spacecraft flyby on Oct 29, 1991 on its way to Jupiter.

Near Earth asteroid 433 Eros – image made from the NEAR-Shoemaker orbiting spacecraft.

Eros is ~33 km long by about 13 km wide – one of the biggest NEAs. It orbits between Earth and Mars so is not a PHA.
Eros from NEAR at 200 km

Eros from 250 m – image 12 m across

Asteroid Itokawa – Image from the Japanese orbiting spacecraft Hayabusa. Itokawa is ~500 m in size. It is a “rubble pile” body and may strike Earth at some distant time (a million years?).

Earth based radar images of NEAs:

Arecibo 1,000ft (300 m) telescope in Puerto Rico

NASA Goldstone 70 m antenna in California

1992 UY4
200 m NEA that came within 1.4 times distance to Moon (334,000 miles).

NEA Golevka - ~0.5 km in size. Angular shape means a solid lump of rock.

Aug 5 Aug 3 Aug 6 Aug 9

NEA 1999 JM8

Time delay

Doppler

Benner et al, 2002

Binary Asteroids

1999 KW4
THE FIRST TRIPLE NEAR EARTH ASTEROID – SN263
Discovered with Arecibo in February, 2008

Image shows a radar “snapshot” of SN263 showing the two smaller bodies orbiting about the main body. The largest body is 2 km in diameter, the next ~1 km and the smallest ~400 meters in size. SN263 was about 7 million miles away when this image was taken. Orbital periods are about 2 days (smaller object) and 4 days. (See Cornell press release of February 13, 2008)

Categorization of NEAs

- Irregular bodies - collisional fragments
- Spheroids – strengthless bodies
- Binaries.
- Bars / Castalias (elongated, “bifurcated”) – stretched strengthless bodies or some tensile strength

Exploring Near Earth Objects

OSIRIS mission to return samples from “1999 RQ36”.

- Another way to determine the context of meteorites is to use spacecraft to return samples from an NEO.
Meteorite Types & Percentage that Falls to the Earth

Stony meteorites (92.8%)
- Chondrites (85.7%): From the planetary nebula. 4.55 billion years old. With spherules in mm size range (chondrules).
- Carbonaceous: Contains carbon compounds.
- Enstatite: Contains MgSiO3
- Achondrites (7.1%): Tectonically processed of varying age. Without spherules.
- HED group: From asteroid Vesta.
- SNC group: From Mars
- Aubrites
- Ureilites

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Stony iron meteorites (1.5%): From mantles and cores of asteroids?
- Pallasites
- Mesosiderites

Iron meteorites (5.7%): From cores of asteroids?

ASTEROID COMPOSITIONS – SIMILAR TO METEORITES

BUT ONLY REMOTE SENSING SO NOT EASY TO DETERMINE

ASTEROID COMPOSITIONS – a resource

<table>
<thead>
<tr>
<th>Meteorite Type</th>
<th>Stony Meteorite</th>
<th>Earth’s Crust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron 91%</td>
<td>Oxygen 36%</td>
<td>Oxygen 49%</td>
</tr>
<tr>
<td>Nickel 8.5%</td>
<td>Iron 26%</td>
<td>Silicon 26%</td>
</tr>
<tr>
<td>Cobalt 0.6%</td>
<td>Silicon 15%</td>
<td>Aluminum 7.5%</td>
</tr>
<tr>
<td></td>
<td>Magnesium 14%</td>
<td>Iron 4.7%</td>
</tr>
<tr>
<td></td>
<td>Aluminum 1.5%</td>
<td>Calcium 3.4%</td>
</tr>
<tr>
<td></td>
<td>Nickel 1.4%</td>
<td>Sodium 2.6%</td>
</tr>
<tr>
<td></td>
<td>Calcium 1.3%</td>
<td>Potassium 2.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnesium 1.9%</td>
</tr>
</tbody>
</table>

Sources: Encyclopaedia Britannica, space.com, and the Space Studies Institute

Asteroids as Resources

Asteroids are rich in the metals and minerals needed for needed for building space facilities, comets are rich sources of the water and carbon-based molecules needed to maintain life.

According to John Lewis (a University of Arizona planetary scientist), for example, the smallest Earth-crossing asteroid 3554 Amun is a 2 km lump of iron, nickel, cobalt, platinum, and other metals; it contains 30 times as much metal as Humans have mined throughout history, although it is only the smallest of dozens of known metallic asteroids and worth perhaps US$ 20 trillion.

Water ice in comets can be converted to liquid hydrogen and oxygen, two of the primary ingredients in rocket fuel today. Thus, some believe that that, as we begin to colonize the inner Solar System in this new millennium, NEAs will become convenient sources of the raw materials needed for building space habitats while NECs will become vital “watering holes” and gas stations for interplanetary spacecraft.

Humans could eventually colonize the Kuiper Belt living on cometary resources and migrating from comet to comet as each is mined out.
Impacts
Evidence for recent impacts on Mars

Viking image 1976   MGS 1999   MGS 2005
Probable impact date in 1980s - crater about 25 m across

Cratered surface of the Moon

Meteor crater, Arizona.
~1 km in diameter
Impact of a ~50m diameter ion asteroid about 50,000 years ago
Long controversy as to volcanic vs impact origin

Manicouagan Crater in northern Canada
70 km in diameter
About 200 million years old – one of oldest known craters on Earth
Photo from Columbia shuttle

Dione - ~1,000 km diameter satellite of Saturn seen from the Cassini orbiter in front of Saturn and its ring plane.
Wolf crater, Australia. 0.9 km diameter, 300,000 years old.

Bosumtwi, Ghana; 10 km in diameter, ~1.3 million years old.

Chicxulub crater, Yucatan Peninsula, 170 km, 64.98 million years

World wide sedimentary layer with a high iridium content. Iridium not found in Earth rocks but is present in asteroidal material.

30 m impact crater in Peru made in September, 2007
A US firm specialising in sending people's cremated ashes into orbit is going to turn the moon into a graveyard for earthlings beginning next year. Instead of caskets or urns, ashes of the dearly departed will be sealed in capsules built into lunar landing modules, which will serve as communal crypts on the moon's surface. Celestis Inc will charge about $US10,000 ($10,910) to send a single gram of human remains to the moon and plans a deal for couples - 14 grams of ashes from two people for approximately $32,700.

Celestis has confirmed that it has deals with private firms Odyssey Moon Limited and Astrobotic Technology Inc to send cremated human remains to the lunar surface via private rocket flights by the end of 2009. Luna Service missions will be a "special honour available to all who share the vision of extending humanity's reach to the stars," the company said in a written release.

Celestis has specialised in "memorial spaceflight" for more than a decade. Celestis provided NASA a capsule in 1998 to send remains of Eugene Shoemaker on a spacecraft that orbited the moon for a year before crashing at its South Pole. Shoemaker became the first person to be laid to rest some place other than Earth. Celestis has sent small portions of people's cremated remains into orbit around the Earth in six memorial spaceflights. Those whose ashes have been carried into space include Gene Roddenberry, who created the successful Star Trek science fiction television series in 1966.

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