Meteors, Asteroids and Comets

Shrapnel from the heavens

Alexei Gilchrist
Historical context

• Heavens seen as fixed with precise motion as a clockwork
  e.g. Aristotle (4th century BC) - heavens pure and harmonious (comets not part of that therefore atmospheric)

"Gentlemen, I would rather believe that two Yankee professors would lie than believe that stones fall from heaven." -- Thomas Jefferson, 1809

• Comets seen as omen or curse
  The sky would fall, great dragons, gigantic snakes, heavenly brooms sweeping the sky of evil...

Comets blamed for Black Plague in London (1665); eruption of Vesuvius and destruction of Pompeii (79); Invasion of Normans (1066); ...

Halley’s comet in 1910 (Earth would pass through tail) - people panicked, shut themselves in to avoid gas, suicides, special comet-protecting umbrellas and anti comet pills sold ...

http://cometography.com/hysteria.html
http://cseligman.com/text/meteors/meteorites.htm
Meteors, meteoroids, meteorites and all that

[Voyages, 13.1-13.2]
Stony-iron Meteorite

Iron Meteorite (Sikhote 3)

Willamette Meteorite

Carbonaceous Chondrite

Some Terms

**Meteoroids** - lumps of rock in space

**Meteors** - glowing lumps of rock in atmosphere

**Meteorites** - lumps of rock that hit the ground

**Bolides** - large lumps of rock that hit the ground

**Tektites** - Molten splashes from a crater
Are meteorites hot or cold?
Meteor Showers and Storms

**Meteor shower** - earth passes through a band of meteoroid particles

- best known annual meteor showers are
  - the Perseids (in August),
  - the Geminids (in December),
  - and the Leonids (in November)

**Meteor outburst** - occasionally earth passes through a particularly dense band

**Meteor storm** - If it’s very heavy it’s called a storm as many as 10 or more meteors every second (rare ~ once in decades)

http://science.nasa.gov/headlines/y2001/ast08nov_1.htm
http://www.meteorobs.org/storms.html#storms

Leonids, Nov 2001
Some History

• 1766 Johann Titus some numerology...
• 1772, Johann Bode republished missing planet?
• 1800 ‘Celestial Police’ – look for missing planet (Schroeter, Xaver von Zach, Harding, Olbers…)
• 1801, Giuseppi Piazzi discovered Ceres (just before being asked by ‘police’)
• 1802 Pallas (Olbers)
• 1804 Juno (Harding)
• 1807 Vesta (Olbers)
• 1815 Celestial Police ended work
• Estimated to be ~ million asteroids with diameter > 1km ...
Biggest 4

• 1 Ceres 940km
  (goddess of harvest and grain)

• 2 Pallas 540km
  (equivalent of Greek goddess Athena)

• 4 Vesta 510km
  (Roman goddess of hearth, home and family)

• 10 Hygeia 410km
  (goddess of good health)

c.f. Moon's diameter 3,500 km

Symbols from http://en.wikipedia.org/wiki/Asteroid
Composition

- **C** extremely dark, *primitive*, silicates with carbon compounds
- **S** relatively bright, sillicate plus metals
- **M** bright, pure nickel-iron (fragments from a core?)
- ~ dozen other categories
Determining Mass

If it has a moon – can determine the mass

\[ D^3 = P^2 \cdot M_1 \]

\[ M_1 \propto \frac{D^3}{P^2} \]

\[ \approx 6 \times 10^{16} \text{ kg} \]

Kepler's 3rd Law (via Newton)

\[ D^3 = P^2 \left( M_1 + M_2 \right) \]

Period \( \sim 24 \text{ hrs} = 1/365 \text{ years} \)

http://www2.jpl.nasa.gov/galileo/mess35/DACTYL.html

243 Ida and Dactyl

Normal value \( 4.2 \times 10^{16} \text{ kg} \)

Calculation more complex
Where are they?

- Main belt (between Mars and Jupiter)
- Near Earth Asteroids (NEAs)
- Trojans – at Jupiter’s L4 & L5 Lagrange points ~ 1000

Some nice animations here:
http://www.cfa.harvard.edu/iau/Animations/Animations.html
http://en.wikipedia.org/wiki/Trojan_asteroid
Lagrange Points

5 equilibrium points in rotating 3-body system
- non-inertial frame! Ficticious forces - centrifugal and Coriolis.
- L1, L2 & L3 are saddle points
- L4 & L5 are actually stable (due to Coriolis force)

http://map.gsfc.nasa.gov/mission/observatory_l2.html

http://cseligman.com/text/asteroids/trojan.htm
Hildas

Three points - opposite Jupiter and L4 & L5
In three orbits each Hilda asteroid passes through all three points

http://en.wikipedia.org/wiki/Hilda_family
Comets

Comet 1993a Mueller

Comet Ikeya-Seki

Comet Hale-Bopp

Comet West (1975)

Comet Neat

http://www.solarviews.com/eng/comet.htm
Some more examples

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

Comet Hale-Bopp, Joshua Tree National Park, 1997

Comet Hyakutake, March 1996

Giotto probe image during the Comet Halley encounter of March 1986.

Comet Schwassmann-Wachmann 3, 1995
Recent history

- comet – from Greek “kometes”, for “hairy one”
- 1700s Isaac Newton – suggested they had elliptical orbits (and members of solar system)
- 1705 Halley – book with orbits of 24 comets, noticed orbits comets in 1531, 1607 and 1682 too similar – suggested they were one and the same
- Halley’s comet appears every 76 years or so – all it’s passes have been observed and recorded since 239BC (e.g. taken as warning of fall of Jerusalem (66), heavenly approval for invasion of Constantinople by the Turks (1456) ...)
- observational record for 1,000s of comets
- Rosetta orbiter (http://rosetta.esa.int) rendezvous with Comet 67 P/Churyumov- Gerasimenko

Anatomy of a comet

V. light - points away from sun (solar wind)

Not visible from earth (atmosphere absorbs)

Heavier dust curved away from sun

http://www.solarviews.com/eng/comet.htm

Comet Hale-Bopp, March 1997
http://cseligman.com/text/comets/pix.htm
Flybys

Comet Halley from Giotto spacecraft 1000 km

Comet Wild-2 from 400km
Deep Impact

July 4th 2005

view from Deep Impact’s flyby showing the impactor colliding with comet Tempel 1

six minutes before it hit NASA’s Deep Impact probe. The picture was taken by the probe’s impactor targeting sensor.

taken from the side of the comet opposite the impact, by the high-resolution camera on the flyby spacecraft after the collision.

One of the last images of Comet Tempel 1 sent back by the flyby spacecraft before the collision

http://www.world-science.net/othernews/othernews-nfrm/050704_comet.htm
Orbits of comets

See http://cfa-www.harvard.edu/iau/lists/OrbitDiagrams.html
Where do comets come from?

- Short period small orbit (orbits of 10s AU and 100s years)
  - made up mostly of icy material -> originated in outer solar system
  - can go around the sun 10s-100s of times only
  - lifetime will be of the order of \(200 \times 200 = 40,000\) years or less

Solar system 4.5 billion years old -> short period comets created since

- Interaction with planets
  - speed up comet (and potentially lose it)
  - slow it down and trap it in short period orbit

http://cseligman.com/text/ssevolve/cometorigin.htm
Where do comets come from?

Long period large orbit
(orbits of ~10000 AU and a million years)

Again 100 orbits takes 100 million years << age of solar system (4.5 billion years)

Must be being created since

Also the larger the orbit the more there seems to be and they come from all directions

Assumed to be a large reservoir of icy material from which the comets originate - Oort cloud

Revisit this and Kuiper belt in 10th week when we look at the formation of solar system
Oort cloud

http://en.wikipedia.org/wiki/90377_Sedna
Comets and life

- Life requires carbon-based molecules, water and energy ... process not understood
- First billion years - “late heavy bombardment” period - earth heavily bombarded by asteroids and comets and life not possible (ended 3.8 billion years ago)
- Life began immediately after this period (earliest fossils 3.5 billion years ago) and took off
- Essential materials provided by comets?
Impacts
Movie Impacts

http://www.badastronomy.com/bad/movies/di2.html

Synopsis – science not too shabby

“Armageddon got some astronomy right. For example, there is an asteroid in the movie, and asteroids do indeed exist”

http://www.badastronomy.com/bad/movies/armpitageddon.html

Also: http://www.jupiterscientific.org/sciinfo/armageddon.html
Earth under fire

Vredefort, South Africa, 300km diameter, 2023 Ma

http://www.unb.ca/passc/ImpactDatabase/images/vredefort.htm
Earth under fire

Sudbury, Ontario Canada, 250km diameter, 1850 Ma

http://www.unb.ca/passc/ImpactDatabase/images/sudbury.htm
Earth under fire

Chicxulub, Yucatan Mexico, 170km diameter, 65 Ma

http://www.unb.ca/passc/ImpactDatabase/images/chicxulub.htm
Earth under fire

Popigai, Russia, 100km diameter, 36 Ma

http://www.unb.ca/passc/ImpactDatabase/images/popigai.html
Earth under fire

Manicouagan, Quebec Canada, 100km diameter, 214 Ma

http://www.unb.ca/passc/ImpactDatabase/images/manicouagan.htm
Earth under fire

Acraman, South Australia, 90km diameter, 590 Ma

http://www.unb.ca/passc/ImpactDatabase/images/acraman.htm
Earth under fire

Chesapeake Bay, Virginia, U.S.A, 90km diameter, 36 Ma

http://www.unb.ca/passc/ImpactDatabase/images/chesapeake.htm
Earth under fire

and many others...

http://www.solarviews.com/eng/tercrate.htm
## Frequency

<table>
<thead>
<tr>
<th>Average Period</th>
<th>Size and Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day</td>
<td>~100 tons of dust and sand-sized particles</td>
</tr>
<tr>
<td>1 year</td>
<td>an automobile-sized asteroid hits Earth’s atmosphere, creates an impressive fireball, and burns up before reaching the surface.</td>
</tr>
<tr>
<td>100 years</td>
<td>a meteoroid the size of a football field hits Earth and causes significant damage to the area / tidal waves</td>
</tr>
<tr>
<td>100,000 years</td>
<td>&gt;1km asteroid - global disasters</td>
</tr>
</tbody>
</table>

[Link](http://neo.jpl.nasa.gov/neo/target.html)
[Link](http://www.jpl.nasa.gov/multimedia/neo/neo_flash2.cfm)
How big a bang?

\[ E_K = \frac{1}{2} m v^2 \]
\[ E_K = \frac{\pi}{12} V^2 (\text{density}) d^3 \]

Volume of sphere
\[ \frac{4}{3} \pi r^3 = \frac{\pi}{6} a^3 \]

Density [kg/m³]
- 1000 ice
- 1500 porous rock
- 3000 dense rock
- 8000 iron

V: 17 Km/s - 51 Km/s

1 Mt TNT ≈ 4.2 \times 10^{15} J
How big is a megaton of TNT anyway?

Little Boy atomic bomb dropped on Hiroshima on August 6, 1945, exploded with an energy of about 15 kilotons of TNT.

The largest nuclear weapon ever detonated was the Tsar Bomb, detonated at 4km off the ground and produced a fireball 8km in diameter - yield of ~ 50Mt (This is equivalent to ten times the amount of all the explosives used in WW2 combined.)
Impacts Effects

have a play with: http://www.lpl.arizona.edu/impacteffects/
Tunguska Event

7:14am June 30 1908

- Air burst from disintegrating meteoroid or comet ~10 km up
- few 10s of meter across
- all the trees were flattened in an area 2000 square kilometers
- The sound of the explosion was heard half-way around the world in London
- Was thought blast was ~ 10-20 Megatons of TNT
- New simulations suggest much smaller (3-5Mt)
Tunguska Event
Tunguska Event


Previous calculations overly simplified - didn’t take into account entry momentum
  e.g. 0km/s & 20km/s (5Mt 5km up)

15Mt & 18km up

5Mt & 18km up

Tunguska more like 3-5 Mt

Much smaller than previously thought ... Event like this is more probable ...
Chicxulub
Mayan name, "the tail of the devil."

~10km diameter asteroid hits earth 65Ma

- Massive fireball
- Megasunamis
- Enourmous shockwaves leading to earthquakes and volcanic eruptions
- Ejected material incandescent on reentry heated atmosphere, created wildfires
- Dust blocks sunlight

K-T boundary - 65 Ma

- 75% of species became extinct
- >90% plankton extinguished
- High iridium concentrations in KT layer (associated with meteorites)

http://www.lpl.arizona.edu/SIC/impact_cratering/Chicxulub/Chicx_title.html
Some recent near misses...

Selected roughly first by proximity then by size
[http://neo.jpl.nasa.gov/cgi-bin/neo_ca]

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>Closest (LD)</th>
<th>Dia.</th>
<th>Discovery lead</th>
<th>V (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 CN26</td>
<td>1985-Sep-02</td>
<td>0.6</td>
<td>200m</td>
<td>-7831 days</td>
<td>8</td>
</tr>
<tr>
<td>2002 MN</td>
<td>2002-Jun-14</td>
<td>0.3</td>
<td>80m</td>
<td>-3 days</td>
<td>11</td>
</tr>
<tr>
<td>2002 XV90</td>
<td>2002-Dec-11</td>
<td>0.3</td>
<td>31m</td>
<td>-2 days</td>
<td>8</td>
</tr>
<tr>
<td>2004 FH</td>
<td>2004-Mar-18</td>
<td>0.1</td>
<td>30m</td>
<td>3 days</td>
<td>8</td>
</tr>
<tr>
<td>2004 YD5</td>
<td>2004-Dec-19</td>
<td>0.09</td>
<td>5m</td>
<td>-2 days</td>
<td>25</td>
</tr>
</tbody>
</table>
How many NEAs?

Known Near-Earth Asteroids
1980-Jan through 2008-Jun

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