Constructing the Solar System: A Smashing Success

Impact Earth:
Chicxulub and other terrestrial impacts

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Compton Lecture Series
Autumn 2012
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Part 1:
Lecture series summary ...

... A Smashing Success!

Image courtesy of NASA/JPL-Caltech
Cloud collapse

- Started from a nebula
- Small overdensity started contraction
- Cloud collapsed to form Sun

Carina Nebula

Image courtesy of NASA, ESA, N. Smith (University of California, Berkeley), and The Hubble Heritage Team (STScI/AURA)
Cloud collapse

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Image courtesy of Don Dixon/NASA
Planetesimals formed in the disk surrounding the Sun

- Disk of gas and dust around the young Sun
- Low velocity collisions between dust particles
  - Growth of meter-sized objects
- Collisions and/or gravitational instability
  - Growth of planetesimals (km-scale)
Building the planets

- Further collisions between planetesimals
  - Growth of terrestrial planets

- Extra mass and condensed ices at greater orbital distances
  - Rapid growth of gas giants

Images courtesy of NASA
Moon formation

- Most likely scenario:
  - Moon formed during collision between **Theia** and **Earth**
Collisions were a vital process

- Collisions were vital for the growth of the planets and the formation of the Moon
- But, how else did collisions affect the Earth?

Image courtesy of Don Dixon/NASA
Part 2: Paucity of Impacts Craters on Earth

Image courtesy of Shane Torgerson/Wikimedia Commons
Known impact craters on Earth
Why are there so few?

183 confirmed impact structures on Earth
Less craters on Earth than on other Solar System bodies

- Geologic processes remove craters over time
  - Weathering/erosion (wind/water)
  - Volcanism
  - Tectonics
- Atmosphere stops smaller projectiles from reaching surface
- Oceans prevent some craters from forming
- Selective searches — economic reasons

- The Moon? No!
Erosion

- Earth’s atmosphere and water cycle unique among the planets
- Over time can remove surface evidence of craters
- Probably not a major effect
Volcanism

- Lava erupted from volcanoes can hide evidence of craters
- We can see this effect directly on Mars and the Moon
  - Younger volcanic surfaces (e.g. Tharsis) exhibit fewer craters
Tectonic plates move around on the Earth’s surface

- Older surfaces are recycled
- Only young craters are still visible
- Oldest sea floor is only ~200 million years old
The atmosphere protects us from many smaller impacts

- Meteoroids are heated as they travel through the atmosphere.
- But, what process causes this heating?

- Common misconception:
  - Friction with the air
- Actually:
  - High speed of meteoroid
  - Compresses air in front of it → Ram pressure
  - Air is heated by pressure
  - This heats the meteoroid

Geminids meteor shower, two nights ago

Image courtesy of John Chumack

Image courtesy of Colin Legg
Tunguska event
Siberia, Russia: 7.14 am June 30, 1908

- Powerful explosion
- Believed to be an airburst from a meteoroid or comet
- 3 – 6 miles above the Earth’s surface
- Flattened 80 million trees
- 830 square miles
- Largest impact event on Earth in recorded history
  → 1000 times more powerful than Hiroshima

Image courtesy of Wikimedia Commons/Vokrug Sveta (1931)
70% surface covered by the oceans

Only around 10% of craters thought to have formed in the oceans

- 15–20 out of 183 known craters
- Most have since moved onshore
- Only 1 deep sea crater known

What happens during an impact into the ocean?

Image courtesy of Don Davis
Impact on land
No water

This movie can be viewed online here:
http://geosci.uchicago.edu/~tdavison/comptonlectures/Lecture8_r0.mov
Impact in shallow sea
100 m water depth

This movie can be viewed online here:
http://geosci.uchicago.edu/~tdavison/comptonlectures/Lecture8_r1.mov
Impact into ocean
400 m water depth

This movie can be viewed online here:
http://geosci.uchicago.edu/~tdavison/comptonlectures/Lecture8_r4.mov
Impact into deep ocean
600 m water depth

This movie can be viewed online here:
http://geosci.uchicago.edu/~tdavison/comptonlectures/Lecture8_r6.mov
Filtering effect of oceans

![Graph showing the number of craters formed in the last 100 Ma based on final crater diameter. The graph compares Dry Earth, Earth, and Terrestrial craters, past 100 Ma.]
Economic selectivity

- Most craters found in areas of intense geologic study
  - i.e. where the money is!
  - N. America, Europe and Australia
  - Many craters probably still to be found

Image courtesy of Planetary and Space Science Centre, University of New Brunswick/NASA/Google
Part 3:
Impacts on Earth

Image courtesy of Don Dixon/NASA
Barringer Crater, Arizona (Meteor Crater)
1.2 km diameter; 50,000 years old

Image courtesy of Shane Torgerson/Wikimedia Commons
Carancas Crater, Peru
15 m diameter; Oct 15 2007

Image courtesy of P. Schultz, Brown University
Chesapeake Bay
85 km diameter; 35.5 million years old

Image courtesy of Powers and Bruce (1999)/USGS
Manicouagan Crater, Canada
100 km diameter; 215 million years old

Part of a crater chain with Rochechouart and St. Martin craters

Image courtesy of Image Science & Analysis Laboratory, NASA Johnson Space Center
Vredefort Dome
250 – 300 km diameter; 2023 million years old

Image courtesy of NASA/Wikimedia Commons
Chicxulub
180 km diameter; 65.5 million years old

- Bouguer gravity anomaly map
- Crater not exposed at surface
- Seismic surveys show it is buried 100’s to 1000’s meters deep
- Sits astride the Mexican coastline in the Yucatán Peninsula

Image courtesy of the Geological Survey of Canada
K-Pg Extinction Event

75% of all species became extinct
All Non-avian dinosaurs included

Image adapted from Wikimedia Commons
How do we know the Chicxulub Crater caused the mass extinction?

- Evidence around the globe of the impact event
- High-energy deposits found around the world
- Global layer rich in Iridium
  → High concentrations in meteorites, low concentration in the Earth’s crust

Image courtesy of Schulz et al (2010), *Science*
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- Effects of impact felt around the world

Image courtesy of P.E. Olsen / Alvarez et al. (1980), Science
Impactor estimated to have been 10 km in diameter
What are the effects of an impact like this?

- Magnitude > 11 earthquakes
- Tsunamis
- Ejected material distributed globally
  - i.e. iridium rich, high-energy layer
  - Dust cloud — blocked out sunlight for < 1 year
  - Sulfuric acid aerosols < 10 years — reduced sunlight by 10 – 20 %
  - Infrared radiation on re-entry to atmosphere
    → Kill exposed creatures and start global wildfires

→ Extinctions!

Images courtesy of Don Davis
Part 4:
Collateral effects of impacts on Earth

Image courtesy of Don Dixon/NASA
Impact Earth! web calculator

http://www.purdue.edu/impactearth

Go and try it out yourselves!
Also, Google maps version

http://impact.ese.ic.ac.uk/ImpactEffectsMap
How frequent are big impacts

Currently know of 1360 potentially hazardous objects

- Annual event, ∼ 20 kilotons
- Tunguska, ∼ 20 kilotons
- Meteor Crater
- Global Catastrophe

Researchers

- Image courtesy of Paul Chodas/NASA/JPL
- Image courtesy of David A.Hardy/Photo Researchers
What can we do if there is a serious threat?

- Several possible asteroid deflection strategies
- Best strategy depends on how long we have
- If long enough, only need to change the orbital speed by a few cm/year
  1. Nuclear Bomb
  2. Kinetic Impact
  3. Gravity Tractor (0.22 μm/s/day)
  4. Focussed Solar Energy
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Image courtesy of ESA
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Image courtesy of Dan Durda/FIAAA/B612 Foundation
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Image courtesy of NASA
Image courtesy of JAXA
Political implications!

Map courtesy of the CIA World Factbook
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Impacts have played a key role in the history of the Earth, and the Solar System as a whole.

Key events such as the extinction of the dinosaurs and the formation of the Moon can be attributed to impacts.

Several strategies have been devised in the event we discover an NEO on a collision course with Earth.
Thank you

Questions?