

# “Cosmic Collisions”

## Planetarium Show

*Theme: A Tour of the Universe within the context of “Things Colliding with Other Things”*

The educational value of NASM Theater programming is that the stunning visual images displayed **engage** the interest and desire to learn in students of all ages. The programs do not substitute for an in-depth learning experience, but they do facilitate learning and provide a framework for additional study elaborations, both as part of the Museum visit and afterward. See the “Alignment with Standards” table for details regarding how *Cosmic Collisions* and its associated classroom extensions meet specific national standards of learning (SoL’s).

*Cosmic Collisions* takes its audience on a tour of the Universe, from the very small (nuclear fusion processes powering our Sun) to the very large (galaxies), all in the context of the role “collisions” have in the overall scheme of things. Since the concept of large-scale collisions engages the attention of most learners of any age, *Cosmic Collisions* can be the starting point of a broader learning experience.

What you will see in the *Cosmic Collisions* program:

- Meteors (“shooting stars”) – fragments of a comet colliding with Earth’s atmosphere
- The Impact Theory of the formation of the Moon
- Collisions between hydrogen atoms in solar interior, resulting in nuclear fusion
- Charged particles in the Solar Wind creating an aurora display when they hit Earth’s atmosphere
- The very large impact that “killed the dinosaurs”
- Future impact risk!?!? – Perhaps flying a spaceship alongside would deflect enough...
- Stellar collisions within a globular cluster
- The Milky Way and Andromeda galaxies collide

## Learning Elaboration While Visiting the National Air and Space Museum

Thousands of books and articles have been written about astronomy, but a good starting point is the many books and related materials available at the **Museum Store** in each NASM building. While at NASM, also check out the following:

### Solar System

The Exploring the Planets Gallery is devoted to all aspects of the Solar System.

The “Voyage” Solar System Scale Model, located outside the NASM building on the Mall side, gives the visitor an appreciation of the scale of the Solar System.

### Meteors and Meteorites

A Mars meteorite is on display in the Exploring the Planets Gallery (and there is one you can touch at SI’s National Museum of Natural History).

The “Touch a Falling Star” Discovery Station, if available, showcases a variety of touchable meteorites, including the “guts of an asteroid,” “the oldest rock you will ever touch,” and “Nature’s version of stained glass.”

### Astronomy

The Explore the Universe Gallery is devoted to Astronomy, including distances, collisions, and dark matter.

The Einstein Planetarium at NASM shows two other programs on astronomical topics:

- *Infinity Express*
- *The Stars Tonight* is NASM’s thrice-weekly “live” star show.

## Post-Visit Discussion Points to Align Program Material with National SoLs

## High School

see High School Alignment Table

“Strong alignment” is shown in red on the Table and in bold-faced text below

### **S A2: Understanding Scientific Inquiry**

*Cosmic Collisions* offers several entry points for discussion of scientific inquiry, including:

- How the various theories of the origin of the Moon came to be proposed, and the observations made recently that favor the Impact Theory.
- The story of Walter and Luis Alvarez, their identification of the impact nature of the K/T boundary, and the (relatively) acceptance of their ideas due to the extraordinary nature of their evidence make for a good case study under the “Understanding Scientific Inquiry,” “Science as a Human Endeavor,” and “Nature of Scientific Knowledge” standards.

### **S B2: Structure / Properties of Matter**

The description in *Cosmic Collisions* of nuclear fusion, the process involving the collision of hydrogen atoms to fuse and form helium to provide the Sun’s power, is an explicit subset of this particular standard.

### **S B4: Motions and Forces**

Several examples of motion and forces were shown in *Cosmic Collisions*, including:

- Friction force between fast-moving meteor and atmosphere create a “shooting star.”
- Impact forces can be sufficient to disrupt an Earth-sized object.
- The motion of Solar Wind charged particles in Earth’s magnetic field and their impact with atmosphere molecules produces aurora displays.
- The K/T impact force was sufficient to damage terrestrial global ecosystems.
- Small forces exerted over long periods of time could deflect a potential impactor enough so that it misses Earth.

### **S B5: Conservation of Energy**

One discussion gambit would be to ask students to describe the energy budget of the Earth-impactor system before and after the impact that created the Moon under the Impact Theory. Another might be to point out that a meteoroid has a lot of gravitational potential energy prior to impacting Earth, then ask, “What happens to that energy during the impact process?”

### **S B6: Interactions of Matter and Energy**

The wave nature of electromagnetic radiation, the different types of radiation as a function of wavelength, the relationship between the moving charges and radiation, and the discrete wavelengths associated with specific atoms are all depicted in *Cosmic Collisions* to some degree; all are subsets of this particular standard.

### **S D3: Origin/Evolution of the Earth System**

Discussion topics pertaining to this standard were raised in *Cosmic Collisions*, including:

- Meteors might be cometary debris, but they can also be asteroid debris, or material left over from the formation of the Solar System. The latter is particularly important, as the chemistry of “left-over” meteorites, such as the famous Allende meteorite, establish the chemical makeup of the proto-Solar nebula.
- The formation of the Moon is an important part of the origin of the Earth System.
- The K/T and other large impacts have had a profound effect on the Earth System.

#### **S D4: Origin/Evolution of the Universe**

*Cosmic Collisions* presents information germane to at least two items under this standard:

- The aforementioned stellar fusion processes are an important part of stellar evolution.
- Stellar and galactic collisions are also an important part of the evolution of the Universe.

#### **S E2: Understanding Science & Technology: Technology changes allow new observations:**

Two outstanding examples of how technology development has allowed new observations to be made for the revision of theories include:

- The observations that led to the Impact Theory for the origin of the Moon were made from samples collected by Apollo astronauts. Without the technology to return lunar materials, those observations could not/would not have been made, and we would have lacked the information necessary to conceive of the origin of the Moon via giant impact.
- The Alvarez's needed sophisticated laboratory technology in order to make the observations that led to their understanding that the K/T changes were due to impact.

#### **S F5: Natural/Human-induced Hazards**

The threat of damaging impact is a classic case study of risk calculation and management!

#### **S G1: Science as a Human Endeavor**

The investigation that first suggested that an impact might be responsible for “killing the dinosaurs” provides two good examples for understanding the human side of science:

- The story of Walter and Luis Alvarez, their identification of the impact nature of the K/T boundary, and the (relatively) rapid acceptance of their ideas due to the extraordinary nature of their evidence apply under the “Understanding Scientific Inquiry,” “Science as a Human Endeavor,” and “Nature of Scientific Knowledge” standards.
- A *Houston Chronicle* reporter played an important role in the identification of the site at which the K/T impact took place (would make a good project topic!).

#### **S G2: Nature of Scientific Knowledge**

The story of Walter and Luis Alvarez, their identification of the impact nature of the K/T boundary, and the (relatively) rapid acceptance of their ideas due to the extraordinary nature of their evidence make for a good case study under the “Understanding Scientific Inquiry,” “Science as a Human Endeavor,” and “Nature of Scientific Knowledge” standards.

#### **S G3: Historical Perspectives**

Many advances in science and technology are gradual, representing improvements and/or refinements of earlier ideas. Occasionally, however, observations/evidence of such an extraordinary nature is uncovered that an equally-extraordinary “paradigm shift” is called for. Examples cited in the SoL's include: the Copernican Revolution (supported primarily by Galileo's observations of Jupiter's moons and the phases of Venus), the rise of the Plate Tectonic model (based on maps of the sea floor showing mid-ocean ridges, and the details of earthquake movements and sea floor ages nearby), and, as specifically covered in *Cosmic Collisions*, the “galactic Universe.”

## Post-Visit Discussion Points to Align Program Material with National SoLs

### Middle School

see Middle School Alignment Table

“Strong alignment” is shown in red on the Table and in bold-faced text below

#### **S A2: Understanding Scientific Inquiry**

This standard at the MS level focuses in part on the link between technology and the acquisition of data needed to develop and refine theories. Examples of this from *Cosmic Collisions* include:

- The Impact Theory for the formation of the Moon arose from observations made possible by the Apollo program and supporting lunar exploration. We simply did not have the technology prior to 1969 that would allow us to determine the chemical composition of lunar surface materials or date them radiometrically.
- We did not know the true nature of the Solar Wind until we could sample it directly with satellites or on the Moon.
- The mass extinctions that define the K/T boundary in geologic time were well-documented decades ago, but only when geological analysis techniques and instrumentation became sufficiently advanced could the Alvarez demonstrate the extinctions were caused by extraterrestrial impact.
- Recent advances in computing technology now allow astronomers to make detailed computer models of very extreme events, such as galaxies colliding.

#### **S B2: Motions and Forces**

*Cosmic Collisions* provides several discussion topics germane to this particular standard:

- At the MS level, learning about motions and forces is a statement of Newton’s Laws without their mathematical underpinning.
- The depiction of meteors decelerating in Earth’s atmosphere, then colliding to produce craters, aligns well with this standard at the MS level.
- The notion that a potential impactor could be deflected merely by the weak gravitational attraction of a spacecraft traveling nearby also aligns well with this standard.

#### **S B3: Transfer of Energy**

Collisions are intimately involved with “transfer of energy,” so it should not be too surprising that *Cosmic Collisions* provides a number of discussion topics aligned with this standard:

- Collisions are a very good way to transfer energy!
- The kinetic energy of moving planetoids is very large, and can cause extreme damage when collisions take place.
- This standard specifically deals with, among other things, the Sun as a major source of energy, a small percentage of which is received by the Earth. This aligns well with the segment within *Cosmic Collisions* on how the fusion process provides the Sun’s power.

#### **S D1: Structure of the Earth System**

A key part of the Impact Theory of the Moon’s formation are the observations that the Earth and Moon were both made out of the same pool of “stuff” in some ways (oxygen isotope data), yet the Moon is depleted in iron and heavier metals relative to the Earth, suggesting that the Earth has a layered internal structure that had already formed prior to the Moon-

forming impact. The iron, concentrated in Earth's core, was less affected by the impact than was the rocky mantle, much of which was subsequently incorporated into the growing proto-Moon.

### **S D2: Earth's History**

Directly quoting from the MS level of this particular standard, "Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet," illustrates the close fit with *Cosmic Collisions*. The remainder of this standard at the MS level deals with the use of fossils in the determination of geologic time. The boundary between the Cretaceous and Tertiary Periods was established in the first place based on the mass extinctions that occurred abruptly at that particular time.

### **S D3: Earth in the Solar System**

The basic components of the Solar System, their regular movements, and the role of gravity are all specific subsets of this particular standard at the MS level, and all are covered in *Cosmic Collisions*.

### **S E2: Understanding Science and Technology**

*Cosmic Collisions* provides at least two good topics for discussing this particular standing:

- The observations that led to the Impact Theory for the origin of the Moon were made from samples collected by Apollo astronauts. Without the technology to return lunar materials, those observations could not/would not have been made, and we would have lacked the information necessary to conceive of the origin of the Moon via giant impact.
- The Alvarezes would not have been able to make the observations that led to their understanding the impact cause of the changes at the K/T boundary without sophisticated laboratory technology.

### **S F3: Natural Hazards**

This standard at the MS level explicitly includes, "Natural hazards ... even possible impacts of asteroids" and "misidentifying the change or incorrectly estimating the rate and scale of change may result in either too little attention and significant human costs or too much cost for unneeded preventive measures." How society responds to the "very low probability of occurrence but catastrophe if it happens" threat posed by impact, aligns with this standard.

### **S F4: Risks and Benefits**

The collision of meteoritic material with the Earth provides a classic case study of risk assessment and management! Some observations that may be useful in a class discussion include, but are not limited to:

- The Earth gets hit more often than we originally thought, with many more small impacts occurring than larger ones. Small impactors (up to a few meters across) either burn up in the atmosphere or have their speeds reduced from miles per second to a few hundred miles per hour. Bigger bodies have so much momentum that atmospheric friction has little effect on their speed.
- The Earth suffers an impact with energy equivalent to 10 kilotons of TNT (the size of a small atom bomb) about once a year on average.
- The Earth has suffered a larger hit in recorded history, the 1908 Tunguska (Siberia) impact.

### **S G1: Science as a Human Endeavor**

## **S G2: Nature of Science**

### S G3: History of Science

As at the HS level for this particular standard, *Cosmic Collisions* can stimulate discussion of all three of these standards at the middle school level for both the Alvarez K/T story and the role of the reporter in facilitating discovery.

### **Life Skills: Thinking and Reasoning 4: Level III: 2. Experimental Verification**

The story of the Alvarez father-and-son team that determined the impact cause of the fossil changes that define the boundary between Mesozoic and Cenozoic Eras of Geologic Time, cited in several places above, makes a very good case study in experimental verification and the nature of science.

- Abrupt change in fossil record had long been noted and used to define major division of geological time units.
- Alvarez team discovers an excess of iridium in clays at the K/T boundary, along with an abundance of free carbon. The iridium matches that found in meteorites.
- The Alverezes conclude that a giant impact event brought in the iridium, burned much of the existing biomass to produce carbon ash, and killed off many species.
- “Experimental verification” in this case includes refining observations, namely the discovery of the impact site, buried by sediments on the continental shelf of the Yucatan Peninsula, and the discovery of special mineral types that can only form under impact conditions.

### Technology: Science, Technology & Society, III, Benchmark 3: Technology influences History

Understanding the process of nuclear fusion was a necessary prerequisite for the creation of the hydrogen bomb. The process of fusion was under investigation prior to World War 2 to understand how stars produce energy. After the war the theory and lab work was used to build the H-bomb. Perhaps someday we will learn how to harness the process to produce electricity or other useful form of energy.

## Post-Visit Discussion Points to Align Program Material with National SoLs

### Elementary School

see Elementary School Alignment Table

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#### **S A2: Understanding Scientific Inquiry**

The points raised under this standard for Middle School students are valid for younger students, too, provided the approach is tailored to the appropriate learning level.

- Learning by asking/answering questions as the process of science
- Using instruments improves powers of observation that lead to questions

#### **S B2: Position and Motion of Objects**

The movement of atoms, planets, stars, and galaxies depicted in *Cosmic Collisions* illustrate motion on a variety of scales, in alignment with the requirements of this standard.

#### **S B3: Light, Heat, electricity, and magnetism**

*Cosmic Collisions* provides several visualizations that teachers can use to prompt discussions on the nature of electromagnetic radiation, electricity, and magnetism:

- The production of heat by nuclear fusion in the Sun, and during the impact process, are both explicitly shown in the film.
- The interaction of charged particles in the Solar Wind with the Earth’s magnetic field as the cause of auroral displays is also shown in *Cosmic Collisions*.

#### **S D2: Objects in the Sky**

The depiction in *Cosmic Collisions* of the Sun and fusion, planets and their movement (and collisions), stars, and galaxies provide K-4 students an engaging introduction to the topics covered in this Standard.

#### **S D3: Changes in Earth and Sky**

The impact process is one way the surface of the Earth changes (not explicitly mentioned in SoL’s, but still important!). Supporting learning about changes to the Earth during its history are the images in *Cosmic Collisions* of the formation of the Moon by collision.

#### **S E2: Understanding about Science and Technology**

*Cosmic Collisions* can foster discussion on two topics which explicitly meet subsets of this particular standard:

- “Science is one way of answering questions and explaining the natural world,” and
- “(Tools) help scientists see, measure, and do things that they could not otherwise see, measure, and do.” The telescope as a “tool” that allowed Galileo to make diagnostic observations is an outstanding example of the material covered under this standard.

#### **S F4: Changes in Environments**

The potentially-huge change in surface environment and its effect on the global ecosystem caused by large-scale impact is not listed as an explicit example of a drastic change in environment, but it could have been! Widespread mass extinctions have been the consequence of several large impact events over the course of Earth history.

## S G1: Science as a Human Endeavor

*Cosmic Collisions* can be used as the basis of a discussion of this standard, particularly “men and women using scientific inquiry have learned much about the objects, events, and phenomena in nature, (but) much more remains to be understood.”

### Life Skills: Thinking and Reasoning 4.II.3: Distinguishes between observations / inferences

The observations that led to the Impact Theory for the origin of the Moon can make a case study of the process of inferring causes from observations.

- Observation: The oxygen in the Earth is the same as the oxygen in the Moon.
- Observation: The Moon is less dense than the Earth.
- Observation: Lunar samples indicate the crust of the Moon was once liquid.
- Inference: If the Earth and Moon have the same oxygen details, then they both formed from the same material. However, if the Earth is denser, then the proto-Earth must have formed an iron core (iron sinks to middle, lighter stuff like rocks floats above it) before the Moon-forming impact. The core material was protected by the overlying mantle from being blasted into Space, and remained behind to form the core of the present Earth.

Similarly, the story of the discovery by the Alverezes of the evidence (observations) that led to the notion that a large impact “killed the dinosaurs” also could be used to showcase how observations led to new explanations.

- Observation: A large number of species went extinct ~65 million years ago. The abruptness of the change in biota caused geologists to use the extinctions to define the boundary between the Cenozoic and Mesozoic Eras of Geologic Time (“K/T Boundary”).
- Observation: Clay deposited at the K/T boundary contains iridium matching that in meteorites.
- Observation: Those same deposits contain an abundance of free carbon.
- Inference: The iridium comes from a giant asteroid/comet that impacted Earth, causing global environmental damage severe enough to render many species extinct.
- Inference: The carbon is ash from the burning of much of Earth’s biomass as a consequence of the impact.

Other potential elaboration activities when using *Cosmic Collisions* to supplement learning:

- Small objects in space are called “meteoroids.” If they survive passage through the atmosphere to hit the ground, they are termed “meteorites.” Only during the brief moments when they are actually being heated to incandescence during their atmospheric transit are they appropriately termed “meteors.” The Ancient Greeks thought meteors were an atmospheric, not celestial, phenomenon, and hence gave them a Greek root name that we use today for weather and weather forecasters: *meteorology* and *meteorologists*!
- Most meteor “showers” can be correlated with a specific comet, and are probably the best opportunity for students who have not seen meteors before to actually see one fall. In general, the best time to see meteors is during the Perseid meteor shower in mid-August. Alas, the best time to see meteors is after midnight (explaining why would make a good science project, too!).

## Resources for Learning Elaboration after the Visit to NASM

Thousands of books and articles have been written about astronomy, but two good starting points are the many books and related materials available at the **Museum Store** in each NASM building, and the list of research and publications of NASM's expert curators:

- Aeronautics: <http://www.nasm.si.edu/research/aero/research.cfm>
- **Center for Earth and Planetary Studies**: <http://www.nasm.si.edu/research/ceps/research/research.cfm>
- **Space History**: <http://www.nasm.si.edu/research/dsh/research.cfm>

### Meteors and Meteorites

NASA webpage on comets and meteors: <http://www.nasm.si.edu/research/ceps/etp/comets>

NASA asteroid, comet, and meteor links: <http://www.nasm.si.edu/research/ceps/etp/links/ACMLinks.html>

NASA webpage on impact cratering: <http://www.nasm.si.edu/research/ceps/etp/compare/craters/craters.html>

SI National Museum of Natural History meteorite info and photo gallery: <http://www.minerals.si.edu/meteor.htm> and <http://www.minerals.si.edu/images/gallery/meteorite.htm>

NASA's StarChild website: <http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question12.html>

ESA's Kids Page on Meteorites: [http://www.esa.int/esaKIDSen/SEM99WJD1E\\_OurUniverse\\_0.html](http://www.esa.int/esaKIDSen/SEM99WJD1E_OurUniverse_0.html)

NASA's "Imagine the Universe" website: Basics: <http://imagine.gsfc.nasa.gov/docs/science/science.html>

Advanced: [http://imagine.gsfc.nasa.gov/docs/science/advanced\\_science.html](http://imagine.gsfc.nasa.gov/docs/science/advanced_science.html)

NASA Space Academy: <http://liftoff.msfc.nasa.gov/academy/space/solarsystem/meteors/Meteors.html>

SEDS' "Nine Planets" website on meteors: <http://seds.lpl.arizona.edu/nineplanets/nineplanets/meteorites.html>

David Kring's on-line *Meteoritics* text (University of Arizona): <http://meteorites.lpl.arizona.edu>

NASA's Solar System Exploration webpage on Meteoroids:

<http://solarsystem.nasa.gov/planets/profile.cfm?Object=Meteors&Display=Overview>

NASA JSC "Meteorites from Antarctica" website: <http://www-curator.jsc.nasa.gov/antmet/index.cfm>

Lunar and Planetary Institute's meteor webpage: <http://www.lpi.usra.edu/education/resources/system/acm.shtml>

Arizona State University Center for Meteorite Studies: <http://meteorites.asu.edu>

American Meteor Society: <http://www.amsmeteors.org>

The Meteoritical Society: <http://www.meteoriticalsociety.org>

Lawrence Grossman paper on the Allende meteorite: <http://geosci.uchicago.edu/~grossman/G80AR.pdf>

Smithsonian paper on the Allende meteorite: [http://www.sil.si.edu/smithsoniancontributions/EarthSciences/pdf\\_hi/sces-0025.pdf](http://www.sil.si.edu/smithsoniancontributions/EarthSciences/pdf_hi/sces-0025.pdf)

Tunguska Impact: <http://www.psi.edu/projects/siberia/siberia.html>

### Selected Books and Articles:

Gehrels, T., *et al.* (eds.), 1994, *Hazards Due to Comets and Asteroids*, University of Arizona Press, ISBN 0-816-515-050

Kerridge, J.F and M.S. Matthews (eds.), 1988, *Meteorites and the Earth Solar System*, Univ. of AZ Press, ISBN 0-816-510-636

McSween, H.Y., 1993, *Stardust to Planets*, St. Martin Press, 241 pp., ISBN 0-312-093-942

McSween, H.Y., 1999, *Meteorites and Their Parent Planets*, Cambridge University Press, ISBN 0-521-587514

Norton, O.R., 1994, *Rocks from Space*, Missoula: Mountain Press, ISBN 0-87842-302-8

Norton, O.R., 2002, *Cambridge Encyclopedia of Meteorites*, Cambridge University Press, ISBN 0-52162-143-7

Gehrels, T., 1996, Collisions with comets and asteroids, *Scientific American*, v. 274, p. 54-59.

### Origin of the Moon

NOTE: The Impact Theory presented in *Cosmic Collisions* is the favored, but not the only, model of the formation of the Moon!

NASA's StarChild webpage: <http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question38.html>

SEDS "Nine Planets" website Moon page: <http://seds.lpl.arizona.edu/nineplanets/nineplanets/luna.html>

The Planetary Science Institute "origin of the Moon" webpage: <http://www.psi.edu/projects/moon/moon.html>

Same idea, different "originator": <http://www.xtec.es/recursos/astromoon/cameroone.htm>

A conference on the "Origin of the Moon" was held at the Lunar and Planetary Institute in 1998: Conference:

<http://www.lpi.usra.edu/meetings/origin98>; One paper: <http://www.lpi.usra.edu/meetings/origin98/pdf/4045.pdf>

LPI Education page about the Moon: <http://www.lpi.usra.edu/education/resources/system/moon.shtml>

LPI's webpage on activities / information related to the Moon: <http://www.lpi.usra.edu/education/resources/standards>

Southwest Research Institute's Moon formation website: <http://www.swri.edu/3pubs/today/spring99/moon.htm>

National Geographic webpage on Moon's formation: [http://news.nationalgeographic.com/news/2001/08/0820\\_moonimpact.html](http://news.nationalgeographic.com/news/2001/08/0820_moonimpact.html)

### Nuclear Fusion in the Solar Interior

NASA's StarChild webpage: [http://starchild.gsfc.nasa.gov/docs/StarChild/solar\\_system\\_level1/sun.html](http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level1/sun.html)

NASA's "Imagine the Universe" website: [http://imagine.gsfc.nasa.gov/docs/science/known\\_12/sun.html](http://imagine.gsfc.nasa.gov/docs/science/known_12/sun.html)

NASA's Sun-Earth Education Forum website: <http://sunearth.gsfc.nasa.gov>



Sun-Earth Day website: <http://sunearthday.nasa.gov>

NASA's SOHO satellite website: <http://sohowww.nascom.nasa.gov>

Stanford University Solar Center website: <http://solar-center.stanford.edu>

SEDS "Nine Planets" website Sun page: <http://seds.lpl.arizona.edu/nineplanets/nineplanets/sol.html>

LPI resource page on the stars and galaxies: [http://www.lpi.usra.edu/education/resources/stars\\_galaxies](http://www.lpi.usra.edu/education/resources/stars_galaxies)

McMath Solar Telescope at Kitt Peak website: <http://nsokp.nso.edu/mp>

Legend has it that famed scientist Hans Bethe figured out the "Triple Alpha" process, one way in which atomic collisions within a star release energy, on the back of an envelope during a train trip! Maybe, maybe not; but he was awarded the Nobel Prize for Physics for that work in 1967; see also: <http://bethe.cornell.edu>

## Solar Wind and the Aurora

Sun, solar wind, auroras: <http://pwg.gsfc.nasa.gov/istp/outreach/todayingeospace.html>

"Science @ NASA" page: [http://science.nasa.gov/newhome/headlines/ast08dec98\\_1.htm](http://science.nasa.gov/newhome/headlines/ast08dec98_1.htm)

NOAA's "Space Weather Now" page: <http://www.sec.noaa.gov/SWN>

NOAA's "Question of the Month" about auroras: [http://www.noaa.gov/questions/question\\_030502.html](http://www.noaa.gov/questions/question_030502.html)

## Impact and the K/T Boundary

NOTE: "K/T" is shorthand for "Cretaceous – Tertiary," the division in geologic time 65 million years ago between the last period of the Mesozoic Era (Cretaceous Period, symbol "K" since "C" is used for another time period) and the first period of the Cenozoic Era (Tertiary, symbol "T").

The hypothesis that an asteroid impact was responsible for the mass extinctions defining the K/T boundary was published by a father-son team: Alvarez L.W, Alvarez W, Asaro F, Michel H.V, 1980, Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science*. v. 208, p. 1095–1108

NASA Jet Propulsion Lab Feature Story: <http://www.jpl.nasa.gov/news/features.cfm?feature=8>

American Geophysical Union's *Reviews of Geophysics* paper: <http://www.agu.org/revgeophys/claey00/node7.html>

University of Arizona's K/T website: [http://www.lpl.arizona.edu/SIC/impact\\_cratering/Chicxulub/Chicx\\_title.html](http://www.lpl.arizona.edu/SIC/impact_cratering/Chicxulub/Chicx_title.html)

Proceedings National Academies of Science paper: <http://www.pnas.org/cgi/content/full/95/19/11028>

Did the impact actually kill the dinosaurs? <http://www.gsjournals.org/perlserv/?request=get-document&doi=10.1130%2F1052-5173%282005%29015%3C4%3ATEOTDI%3E2.0.CO%3B2#i1052-5173-15-3-4-Alvarez1>

*GSA Today* paper about dinosaur extinction: <http://www.gsjournals.org/perlserv/?request=get-document&doi=10.1130%2F1052-5173%282005%29015%3C4%3ATEOTDI%3E2.0.CO%3B2>

Planetary Science Institute website on Impact Cratering: <http://www.psi.edu/explorecraters>

## Impact Risk and Risk Assessment

NASA Ames Research Center's Impact Hazard website: <http://impact.arc.nasa.gov> and

AIAA Position Paper on Impact Hazard: [http://impact.arc.nasa.gov/gov\\_aiaa95.cfm](http://impact.arc.nasa.gov/gov_aiaa95.cfm)

NASA's Near-Earth Object Program website: <http://neo.jpl.nasa.gov/risk>

NASA's NEO Sentry System website: <http://neo.jpl.nasa.gov/risk/doc/sentry.html>

RAND Ph.D. Dissertation on Impact Risk: [http://www.rand.org/pubs/rgs\\_dissertations/2005/RAND\\_RGSD184.pdf](http://www.rand.org/pubs/rgs_dissertations/2005/RAND_RGSD184.pdf)

Will Earth get hit in March, 2880?: <http://www.sciencemag.org/cgi/content/abstract/296/5565/132>

*Nature* article on deflection by spacecraft: <http://www.nature.com/nature/journal/v438/n7065/full/438177a.html>

*National Geographic* article: [http://news.nationalgeographic.com/news/2003/06/0619\\_030619\\_killerasteroids\\_2.html](http://news.nationalgeographic.com/news/2003/06/0619_030619_killerasteroids_2.html)

## Stellar collisions (within globular clusters)

NOTE: Stellar collisions can occur anywhere, but since stars are so far apart in most galaxies, stellar collisions are quite rare. A globular cluster is more densely packed with stars (although they are still very far apart!), making stellar collisions more probable from a statistical viewpoint.

Visualizations (Hayden Planetarium): <http://haydenplanetarium.org/resources/ava/category/?category=S>

Hubble Space Telescope images: Globular Cluster M-80: <http://hubblesite.org/newscenter/archive/releases/1999/26>

Core of Globular Cluster Omega Centauri: <http://hubblesite.org/newscenter/archive/releases/2001/33>

"Vampire" Star collisions and mass transfer: <http://www.eso.org/outreach/press-rel/pr-2006/pr-37-06.pdf>

## Galactic collisions

Visualizations (Hayden Planetarium): <http://haydenplanetarium.org/resources/ava/category/?category=G>

NASA's Astronomy Picture of the Day showing collision aftermath: <http://apod.nasa.gov/apod/ap970224.html>

CNN story: <http://www.cnn.com/TECH/space/9911/22/hubble.galaxies>

Kitt Peak images of galactic collisions and more: <http://www.noao.edu/outreach/aop/observers/gcollide.html>

## Other

VOYAGE Solar System Model at NASM: [http://www.voyagesolarsystem.org/downloads/Voyage\\_Exhibition\\_Overview.pdf](http://www.voyagesolarsystem.org/downloads/Voyage_Exhibition_Overview.pdf)

Dark matter from NASA's Imagine the Universe website: [http://imagine.gsfc.nasa.gov/docs/science/known\\_12/dark\\_matter.html](http://imagine.gsfc.nasa.gov/docs/science/known_12/dark_matter.html)  
and [http://imagine.gsfc.nasa.gov/docs/science/mysteries\\_12/dark\\_matter.html](http://imagine.gsfc.nasa.gov/docs/science/mysteries_12/dark_matter.html)  
NASA's "StarChild" website has a very good "Resources" section: [http://imagine.gsfc.nasa.gov/docs/resources/resources\\_a.html](http://imagine.gsfc.nasa.gov/docs/resources/resources_a.html)

*Cosmic Collisions* was produced by the American Museum of Natural History and others. They have produced an on-line Educators' Guide to support *Cosmic Collisions*, see:

<http://www.amnh.org/education/resources/rfl/web/cosmicguide/index.html>