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Historical Perspectives on Planetary Defense

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Abstract: The recent history of the recognition of an impact hazard and of approaches to planetary defense is summarized.

Interest in the asteroid impact hazard was born out of public fascination with the Alvarez discovery that the dinosaurs died as a consequence of a cosmic impact. At a July 1981 NASA Workshop, Gene Shoemaker made the first modern quantitative estimate of the impact hazard. Further progress depended on new technology that was first demonstrated by Tom Gehrels, who used CCD cameras and more powerful desktop computers to automate the discovery of Near Earth Asteroids (NEAs). The early observations, as well as the emerging ideas about planetary defense, were summarized in a thousand-page multi-author volume *Hazards Due to Comets and Asteroids*, edited by Tom Gehrels and published by the University of Arizona in 1994.

In the early 1990s the U.S. House of Representatives called upon NASA to evaluate the impact hazard and assess the costs of carrying out a comprehensive NEA search (subsequently called the Spaceguard Survey), as well as to consider (in consultation with U.S. Department of Defense) future technology for defense. In 1988, after a series of technical meetings and workshops, the NASA Planetary Science Division formally began the Spaceguard Survey, supporting several ground-based telescopes and a new NEO Program Office. At the same time, scientists at JPL and in Pisa Italy developed the software for accurate forward computation of NEA orbits and impact risks.

Astronomers led in establishing the Spaceguard Survey and initiating physical studies of NEAs and comets. They took advantage of new telescopes and rapid increase in the capability of astronomical instrumentation. Especially fruitful were studies with the powerful planetary radar systems at Arecibo in Puerto Rico and

at Goldstone in California, both supported by NASA. Radar provided the first images of NEAs and discovered the unexpected prevalence of NEA binary and satellite systems, as well as the data to compute extremely accurate orbits. These ground-based data were greatly augmented by the first spacecraft visits to NEAs and comets. NASA's NEAR-Shoemaker mission, launched in 1996, orbited the large NEA Eros for a year before landing on the surface in 2001. The JAXA mission Hayabusa, launched 2003, achieved a rendezvous with the small NEA Itokawa, touched down to collect samples, and returned these samples to Earth 2010. Comet missions from ESA and the USSR made close flybys of the nucleus of Comet Halley in 1986, and subsequently several missions have achieved flybys of smaller comets. NASA's Deep Impact mission deployed an impactor that hit the nucleus of Comet 9P/Tempel in 2005.

Planetary Defense (or Mitigation) Workshops were held in Los Alamos, New Mexico, in 1993, at the Russian Federal Nuclear Center in Snezhinsk in 1994, at the DOE Livermore National Lab in California in 1995, and in Arlington Virginia in 2002. In the same time-frame there were also a number of workshops focused on NEO detection and dynamics, including San Juan Capistrano CA (1991), Vulcano Italy (1995), Torino Italy (1999), and Palermo Italy (2001). A NASA Science Definition Team analyzed advanced NEA surveys in 2003.

The first Planetary Defense Conference (PDC), combining surveys, NEA science, mitigation, and public communications, was held in February 2004 in Garden Grove, California, under the sponsorship of the AIAA and the Aerospace Corporation. The conference chair was William Ailor, who has organized all subsequent PDCs. The second PDC was held March 2007 in Washington DC, and the third in Granada Spain in April 2009. Reflecting increased international interest in this topic, primary sponsorship was assumed in 2009 by the International Academy of Astronautics, who also sponsored the 2011 PDC in Bucharest, Romania, and the 2013 PDC in Flagstaff, Arizona.

Public communication has always been an important goal of the impact hazard and planetary defense community. For much of the 1990s, we were concerned about a "giggle factor", with most people unwilling to take seriously a threat from space that had never happened in recorded history. The 1994 impact on Jupiter of Comet Shoemaker-Levy 9 did much to legitimize the impact hazard in the eyes of the public, generating front-page newspaper articles and cover stories in popular magazines such as *Time* and *Newsweek*. Subsequently there were many documentaries made for television as well as two popular Hollywood films, *Deep Impact* and *Armageddon*. Both scientists and journalists also wrote trade books in the 1990s, two of the most technically accurate being *Rogue Asteroids and Doomsday Comets* by Duncan Steel (1995) and *Rain of Fire and Ice* by John S. Lewis (1996).

In an effort to improve communication about risks that are very rare but potentially catastrophic, astronomers defined two risk scales that incorporated

the magnitude of a predicted Earth impact, the uncertainty (often large) in the prediction, and the time until the predicted hit. The Torino Scale (Rick Binzel and colleagues, 1999) was adopted by the International Astronomical Union (IAU) and has been widely used. The Palermo Scale (Steve Chesley, 2001) is more generally used by scientists. Increasingly, the Internet is the primary organ for public communications about impact risks. The NASA NEO Program Office at JPL has the most comprehensive coverage, with NEA tables that are updated daily to provide predictions of future close approaches to Earth, web tools to calculate orbits and encounters, and extensive background material. The IAU Minor Planet Center in Cambridge, MA, is the clearinghouse for all discoveries and orbital data, serving both the professional and amateur NEA observers. Other popular information resources include the IAU, Spaceguard UK, and NASA Ames Research Center.

Natural events as well as technological advances have played important roles in the history of planetary defense. Following is a chronology of major events (through 2000) that have influenced our field, selected from a much longer list posted on the Internet from the IAU.

- 1893: G.K. Gilbert suggests that lunar craters are the result of impacts
- 1898: Discovery of Eros, first NEA
- 1908: Tunguska impact (5-10 Mt) in Russian Siberia
- 1932: Discovery of Apollo, first Earth-crossing NEA
- 1947: IAU Minor Planet Center established
- 1947: Sikhote-Alin iron meteorite strike in western Russia
- 1949: Ralph Baldwin's *The Face of the Moon* discusses Earth impacts
- 1952: E.J. Opik "Collisions with heavenly bodies" estimates impact risk
- 1959: Pribram meteorite fall traced to asteroid belt
- 1961: E.M. Shoemaker impact origin of both Meteor Crater and Ries Crater
- 1969: Close encounter with Icarus; first radar detection
- 1969: Allende and Murchison carbonaceous meteorite falls
- 1971: First IAU Colloquium on Physical Studies of Minor Planets
- 1972: Daylight Fireball over western U.S. and Canada: Earth-grazing asteroid
- 1980: Identification of KT mass extinction with cosmic impact (L. Alvarez et al.)
- 1981: NASA workshop on "Collision of Asteroids and Comets with the Earth"
- 1981: E. Shoemaker makes first modern estimate of impact hazard
- 1981: First Snowbird conference on Geology of Large Body Impacts
- 1983: First international ACM conference on "Asteroids, Comets, Meteors"
- 1984: Spacewatch (Gehrels & McMillan) first CCD discovery of NEAs
- 1989: Discovery of Toutatis, largest known hazardous asteroid (PHA)
- 1989: First radar image of NEA (Castalia), Ostro & Hudson, using Arecibo
- 1990: AIAA recommends impact study to U.S. Congress
- 1991: House authorization bill directs NASA to study impact risk and defense
- 1991: NASA International NEO Detection workshops (D. Morrison chair)
- 1991: IAU establishes Working Group on NEAs
- 1992: NEO Interception Workshop, Los Alamos NM

1992: Peekskill fireball, good orbit, meteorite struck car
1993: N.L. Johnson coins term "planetary defense"
1993: Major workshop on Hazards Due to Comets & Asteroids (Tucson)
1993: First U.S. Congress hearing on "The Threat of Large NEAs"
1993: Workshop on Hazards Due to Comets & Asteroids (Erice Italy)
1994: Marshall Islands fireball & airburst, estimated at 100 kT
1994: Collision of Comet S-L 9 with Jupiter
1994: IAU establishes Working Group on NEOs (A. Carusi, Chair)
1994: First International Conference "Space Protection of Earth", Russia
1995: Report of NASA NEO Survey Working Group (E. Shoemaker, chair)
1995: U.N. conference on NEOs, New York
1995: Start of NASA/JPL Near Earth Asteroid Tracking (NEAT)
1996: Council of Europe resolution on detection of asteroids and comets
1995: Foundation of Spaceguard Foundation in Italy
1996: Foundation of Japanese Spaceguard Association
1996: Foundation of Space Shield Foundation in Russia
1996: Foundation of Spaceguard UK
1997: Start Lincoln NEA Research (LINEAR) using U.S. Air Force telescopes
1998: Start of Lowell Observatory NEO Search (LONEOS)
1998: B.G. Marsden announces possible impact by NEA 1997XF11
1998: Start of Catalina Sky Survey
1998: NASA announces start of Spaceguard Survey in Congress Hearing
1998: IAU announces that detection of NEOs is an "international responsibility"
1998: Spectacular Leonid meteor shower
1999: NASA NEO Program Office established at JPL
1999: Threat from NEOs is debated in UK Parliament
1999: NEO Dynamics (NEODyS) website established in Pisa, Italy
1999: Torino Impact Hazard scale adopted by IAU & NASA
2000: Tagish Lake (Canada) meteorite, exceptionally primitive object
2000 NASA/APL NEAR-Shoemaker spacecraft orbits NEA Eros
2000: Report of UK Task Group on Potentially Hazardous NEOs
2000: Approximately 900 NEAs known

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