The Deep Impact Discovery Mission

M. F. A'Hearn , L.A. McFadden, C.M. Lisse, D.D. Wellnitz (U.Md), M.J.S. Belton, (Belton Space Initiatives), A. Delamere (Ball Aerospace and Technologies Corp), K.P. Klaasen (JPL), J.Kissel (MPI), K.J. Meech (U.Hawaii), H.J. Melosh (U. Arizona), P.H. Schultz (Brown U.), J.M. Sunshine (SAIC), J. Veverka (Cornell U.), and D.K. Yeomans (JPL)

The Deep Impact mission, two spacecraft, a flyby and an impactor, will explore beneath the surface of comet 9P/Tempel 1. The impactor will excavate a crater. Imagers and a spectrometer observe the collision, ejecta curtain and the crater, making a direct comparison of the newly excavated interior to that previously emitted into the comet's coma. Launching together in January, 2004, for a 1.5 year cruise, encounter and impact will be July, 2005. Twenty-four hours before, the two spacecraft will separate. The flyby spacecraft will be slowed and diverted to miss the comet by 500 km. Closest approach occurs ~14 minutes post impact. The impactor, a mostly copper mass of 370 kg, continues under autonomous guidance to hit the comet in a sunlit area. Telescopic observations complement the spacecraft data. The flyby includes a medium resolution imager with narrow-band and medium-band filters and 10 mrad fov monitoring the comet nucleus at high time resolution during and following impact determining fundamental nucleus properties. The high resolution imager with medium -band filters, follows crater formation (spatial resolution 17 m/pixel at impact and 1.4 m/pixel final image). The infrared spectral imaging module will collect spectra between 1-4.8 microns continuously before, during and after impact comparing compositions and looking for spatial variations. The impactor targeting sensor, a white light imager collects high speed images until just before impact. Highest resolution will be 20-30 cm/pixel. An S-band transmitter sends the images to the flyby, then relays them back to Deep Space Network receivers on Earth. We will determine the comet's shape, morphology, albedo and crater density. We will time and map the crater ejecta curtain and debris to determine surface properties (porosity and compressibility) and gravitational force at the comet. We will analyze spectral maps for photometric and compositional variations both before and after impact. With laboratory simulations of the impact we have explored the range of possible crater sizes (diameter and depth) and ejecta evolution. If gravity controls crater growth (strengthless particulate surface), the crater may be as large as 120m and 25m deep. Smaller diameters will occur if the surface is highly compressible or exhibits strength. Ball Aerospace designed and is building the spacecraft and instruments. Mission design and operations is carried out at JPL under its project management.

IMPACT : A Space Contribution to Monitoring the Threat of Potentially Hazardous Celestial Bodies

L. Bussolino and R. Somma
Alenia Spazio, Strada Antica di Collegno 253
Torino, Italy

IMPACT is the acronym for "International Monitoring Program for Asteroids and Comets Threats" coming out as proposal to the Agencies and Government institutions from a series of studies funded by the italian region PIEMONTE throughout the Civil Protection Bureau, the Italian Space Agency and the European Space Agency in different period of time and performed by the Planetology Group of the Astronomical Observatory of Torino in Italy and the Alenia Spazio, the major Italian aerospace company, for the engineering design part. The key point of the study is concerning the best continuation till the completion of the activities of discovery as well as the physical and mineralogical characterization of the potentially hazardous celestial bodies, including a certain families not easy to be seen by the ground telescopes: the new outcome is the utilization of satellites in orbit around the Earth or in other position, in any case suitable for discovering objects type Inner Earth Orbit. The present paper will ponder a synthesis of the activities performed during these series of studies where the space technology, if conveniently integrated with the Earth networks, appears to offer a valuable contribution to the PHA detection and characterization, fundamental activities basic for the risks mitigation. An international approach is then proposed for monitoring this threat.

The Impact Imperative

Jonathan W. Campbell
NASA/MSFC

The Asteroid and Comet impact problem has been with us for millions of years. Only recently however has our awareness expanded to realize that there may be a problem. Our collective awareness as a civilization is now expanding as we learn more. The critical question that remains to be answered is whether our awareness will expand to point that we will take action in time.

Given sufficient priority, we now have the technological capability to begin building a means for deflecting asteroids and comets. These include Earth, LEO, and/or Lunar based laser facilities; transporting the laser to the object; and transporting nuclear devices to the object.

All approaches depend on ablative processes to accomplish deflection. The laser uses slow ablation to minimize fragmentation and gradually shape the orbit. A laser facility has the advantage of being able to respond quickly to a sighting. A nuclear approach requires time of transport and if the explosion is external to the object use rapid, massive ablation to change the orbit. For an explosion inside, the ablation creates gas pressures that may fragment the object and if vented properly could create a jet effect for orbit shaping.

An equally challenging part of this problem is early warning, early detection, and continuous tracking. Again, given sufficient priority, we have the technological means (radar and ladar) in the near term to address this part of the overall problem.

It is imperative that the space priorities in our National and World community's be realigned to place impact mitigation first. Technological roadmaps must be redrawn orienting us towards solving this problem first.

Physical characterization of NEOs by means of remote observations from space

A. Cellino (Torino Astronomical Obs.), K. Muinonen (Helsinki Obs.), E.F. Tedesco (TerraSystems, Inc.), M. Delbo` (Torino Astronomical Obs.), S. Price, M. Egan (Air Force research Lab.), L. Bussolino (Alenia Aerospazio)

Physical characterization of NEOs is essential for a better understanding of the properties and histories of these objects, and to develop credible techniques for hazard mitigation. Many of the relevant physical parameters describing the internal structures of NEOs can only be accurately derived from local "in situ" investigations by space probes. However, remote sensing is still very useful to provide valuable information on the distributions of important physical parameters such as size, geometric albedo and spectral reflectance. Moreover, space-based observations can more readily detect objects having orbits that are mostly or totally interior to the Earth's orbit.

We are currently conducting a study funded by the European Space Agency to assess the options and do preliminary design and performance trade-off analyses for a dedicated space-based NEO observatory. Initial results indicate that observations spanning a wavelength interval including the peak thermal emission between 5 and 12 microns, are needed and suitable to attain the scientific goals of the mission. Different orbital options for the satellite are also being investigated with the leading candidates being orbits around the L2 Lagrangian points of either the Earth or Venus. Both options present advantages and drawbacks that must be carefully assessed. This presentation provides the initial results of the study and a more detailed rationale for the options considered.

Implications of the NEAR mission for Internal Structure

Andrew F. Cheng
The Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723

On 14 February 2000, the Near Earth Asteroid Rendezvous spacecraft (NEAR Shoemaker) began the first orbital study of an asteroid, the near-Earth object 433 Eros. Almost a year later, on 12 February 2001, NEAR Shoemaker completed its mission by landing on the asteroid and acquiring data from its surface. Previously, on June 27 1997, NEAR performed the first flyby of a C-type asteroid, 253 Mathilde. These two asteroid databases provide a basis for inferences to be made regarding physical properties and internal structure relevant to mitigation.

NEAR Shoemaker's study of Eros found an average density of 2.67 +/- 0.03, almost uniform within the asteroid. No evidence was found for compositional heterogeneity or an intrinsic magnetic field. The surface is covered by a regolith estimated at tens of meters thick. A small center of mass offset from the center of figure suggests regionally nonuniform regolith thickness or internal density variation. Blocks have a non-uniform distribution consistent with emplacement of ejecta from the youngest large crater. Some topographic features indicate tectonic deformations. Several regional scale linear features have related orientations, suggesting a globally consolidated internal structure. Structural control of crater shapes hints that such internal structure is pervasive. Eros is interpreted to be extensively fractured but without gross dislocations and/or rotations - it was not disrupted and reaccumulated gravitationally. Some constraints can be placed on its strength. The consolidated interior must support a shear stress at least on the order of a few bars. Crater morphologies can be interpreted as suggesting a "strength" near the surface of a few tens of kPa.

The Eros flyby of Mathilde revealed a heavily cratered surface with at least 5 giant craters (close to geometric saturation). Mathilde's density was unexpectedly low at 1.3 +/- 0.3, indicating a high porosity. Such a high porosity may be consistent with a rubble pile structure. This high porosity is key to understanding Mathilde's collisional history, but there are structural features, such as a 20-km long scarp, and polygonal craters indicating that Mathilde is not completely strengthless. At least one of its structural components appears coherent over a few tens of km.

Impacts Into Porous Foam Targets: Possible Implications For The Disruption of Comet Nuclei and Low-Density Asteroids

Daniel D. Durda (Southwest Research Institute, 1050 Walnut Street Suite 426, Boulder CO 80302), George J. Flynn and Tobyn W. VanVeghten (Department of Physics, State University of New York Plattsburgh, Plattsburgh, NY 12901)

Recent observations by the NEAR spacecraft of asteroid 253 Mathilde [1], determinations of the densities of other C-type main-belt asteroids accompanied by bound natural satellites [2], laboratory measurements of the porosities of meteorites [3,4], and the bulk densities of interplanetary dust particles [5], indicate that many impact targets in the solar system are quite porous, having bulk densities significantly lower than the density of their constituent minerals. Love et al. [6] have shown that it requires significantly more energy to produce craters of the same size in porous targets than in non-porous targets. Chapman et al. [7] have suggested that the four largest craters on the asteroid Mathilde, which exceed the conventionally accepted size limit for crater production without catastrophic disruption or "surface resetting", may be explained by shock dissipation in a porous target.

We performed a series of impact experiments at the NASA Ames Vertical Gun Range (AVGR) in October 2001 and May 2002 to examine the response of very porous foam targets to various impacts. We conducted a total of four shots into two ~10-cm diameter closed-pore polystyrene (Styrofoam) spheres and two 22.9x10.5x7.8 cm blocks of finely-textured, open-pore foam that is usually used as a rigid mounting base for floral arrangements. All impacts were performed with the AVGR impact chamber evacuated to a pressure of about 0.5 Torr.

For shot 011010, we suspended an 11.4-cm diameter (30.5 g) Styrofoam sphere, having a bulk density of ~0.6 gm/cm^3, from the ceiling of the AVGR chamber, and impacted it with a 1/8-inch aluminum sphere having a speed of 1.92 km/s (powder gun mode). Such an impact could simulate the impact of a strong, nickel-iron projectile into a very low-density/high-porosity comet or weak, porous asteroid. We expected beforehand that the impactor might perhaps simply burrow its way through the Styrofoam sphere and emerge out the other side, leaving the sphere more or less intact. Instead, the result was a catastrophic disruption, leaving only cm-scale shards of debris throughout the impact chamber.

For shot 011011, we cut a 1/4-inch (11.4 mg) spherical projectile from the same Styrofoam material as the 8.9-cm diameter (15.5 g) target sphere. The Styrofoam projectile was carefully loaded into a plastic sabot and fired in powder gun mode at a speed of 1.68 km/s. Somewhat unexpectedly, the projectile survived the launching process intact, although it did "pancake" into a somewhat lenticular disk during flight. Once again, the resulting impact was much more catastrophic than we anticipated, yielding the same, almost explosive disruption of the target sphere.

The mass distributions of fragments resulting from the disruption of the two polystyrene spheres from shots 011010 and 011011 resemble the power law-like fragment distributions commonly observed for disruptive impacts into more conventional rock or ice targets.

In contrast to the closed-pore foam spheres for shots 011010 and 011011, the targets for shots 020501 and 020502 were open-pore foam blocks with dimensions of 22.9x10.5x7.8 cm, having a bulk density of ~0.2 gm/cm^3. Projectiles were fired at an angle of 45 deg to the normal of the largest face. For shot 020501, we impacted the block with a 1/8-inch aluminum sphere at a speed of 1.12 km/s (powder gun mode). The projectile tunneled essentially unimpeded through the body of the block, leaving no crater in the surface and carving a cylindrical path completely through the block somewhat larger in diameter than the projectile itself. The entry hole was elliptical, measuring ~4x6 mm, and the exit hole was elliptical, measuring ~7x11 mm.

For shot 020502, we cut a 1/4-inch spherical projectile from the same foam material as the target block. The foam projectile was loaded into a plastic sabot and fired in powder gun mode. Unfortunately, but not unexpectedly, the projectile essentially disintegrated during the firing process, resulting in a shower of foam "dust" being launched toward the target. The surface of the foam block target displayed minor scattered traces of the penetration of the projectile debris, but otherwise yielded no useful cratering or disruption data.

Levison et al. [8] compared orbital distribution and survey discovery models of Oort cloud comets to observations of populations of dormant comets and concluded that 99% of new comets evolving inward from the Oort cloud must physically disrupt (as did comet C/1999 S4 LINEAR; [9]), citing buildup of internal volatile pressure as a possible mechanism. We surmise that the closed-pore Styrofoam that we chose as a target material for the first two shots prevented the interior of the target spheres from being fully evacuated during the pump down of the impact chamber. Thus, an internal pressure probably built up, leading to increased surface and internal stresses in the target spheres that were released when their surfaces were penetrated by the impactors. Although not the simple burrowing or compression cratering outcomes we were anticipating (as we indeed observed in the case of the open-pore floral foam blocks), these results may nonetheless bear some relevance to impacts (either rare natural ones, or artificial ones arranged by curious humans) onto comet nuclei. The Giotto images of Comet Halley and the Deep Space 1 images of Comet Borrelly both showed localized jets of gas and dust emission, suggesting that most of the surface of each of these comets was protected from sublimation by a surface crust impervious to gasses. The relatively collisionally pristine surfaces of volatile rich, dynamically young Oort cloud comets, or surface crusts built up on collisionally and dynamically evolved Kuiper belt comets through the sublimation and loss of ices with retention of rocky/dusty debris, might allow internal volatile pressure to build up within a comet nucleus. Such internal pressures might be released in a violent manner during even small impacts, contributing to the complete disruption of a comet nucleus.

References

[1] Yeomans, D. K., J.-P. Barriot, D. W. Dunham, R. W. Farquhar, J. D. Giorgini, C. E. Helfrich, A. S. Konopliv, J. V. McAdams, J. K. Miller, W. M. Owen Jr., D. J. Scheeres, S. P. Synnott, and B. G. Williams 1997. Science 278, 2106 2109.
[2] Merline, W. J., L. M. Close, C. Dumas, C. R. Chapman, F. Roddier, F. Menard, D. C. Slater, G. Duvert, C. Shelton, and T. Morgan 1999. Nature 401, 565 568.
[3] Consolmagno, G. J., and D. T. Britt 1998. Meteoritics Planet. Sci. 33, 1231 1240.
[4] Flynn, G. J., L. B. Moore, and W. Klock 1999. Icarus 142, 97 105.
[5] Flynn, G. J. and S. R. Sutton 1993. Lunar Planet. Sci., 21, 541-547.
[6] Love, S. G., F. Horz, and D. E. Brownlee 1993. Icarus 105, 216-224.
[7] Chapman, C., W. Merline, P. Thomas, and the NEAR MSI-NIS Team 1998. Meteoritics & Planetary Science, 33, A30.
[8] Levison, H. F., A. Morbidelli, L. Dones, R. Jedicke, P. A. Wiegert, and W. F. Bottke, Jr. 2002. Science 296, 2212 2215.
[9] Boehnhardt, H. 2001. Science 292, 1307 1309.

A Space-Based Visible/Infrared System for the Characterization and Detection of Near Earth Objects (NEOs)

M.P. Egan (AFRL/XP), Y.J. King, P.D. LeVan, B.J. Tomlinson, & B. Flake (AFRL/VSSS), & S.D. Price (AFRL/VSB, VSS)

We present the technical capability for a modest sized (third to half meter) space-based visible/infrared instrument to accurately determine the diameters of NEOs and to augment their discovery by extending the survey beyond the limitations of ground-based instruments. Previous analysis demonstrated the measurement capabilities for accurate size determinations (Price and Egan, 2001) and the detection/discovery efficiencies of such a system for objects 200 meter in diameter and larger (Tedesco et al., 2000). The Air Force Research Laboratory's research program in developing spacecraft/sensor technology in the critical areas of focal plane arrays, cryocoolers, on-board signal processing and integrated spacecraft structures is key to being able to field a light-weight, cost effective satellite. Mid-Infrared focal plane arrays are being developed for space observation applications. The mature Si:As FPA technology will be described, as will be other innovative technologies for both the infrared and visible wavelength regions. Current candidates for low background, Mid-Infrared applications require cooling to almost 10 Kelvin. Active low temperature cryogenic cooling for Mid-Infrared sensing applications is being addressed within the Space Vehicles Directorate of the Air Force Research Laboratory (Davis et al. 2001, Tomlinson et al. 2001) to address mid to long term DoD mission requirements. Ten Kelvin cooling technology will soon reach protoflight capability, provides tremendous savings in payload mass versus stored cryogen systems, and greatly increases the payload performance (with increased cooling load capability) and lifetime (10 years and longer). Trade studies will be shown that evaluate the performance versus maturity levels of the subsystem technologies.

S.D. Price and M.P. Egan, Infrared Characterization of Near Earth Objects, Adv. Space Sci., 28 1117 - 1127, 2001.

E.F. Tedesco, K. Muinonen and S.D. Price, Space-Based Infrared Near-Earth Asteroid Survey Simulation, Planetary and Space Science, 48, 801-816, 2000.

T. Davis, B. J. Tomlinson, and J. Ledbetter, Military Space Cryogenic Cooling Requirements for the 21st Century, International Cryocooler Conference 11, 1-9, 2001.

B. J. Tomlinson, T. Davis, and J. Ledbetter, Advanced Cryogenic Integration and-Cooling Technology for Space-Based Long Term Cryogen Storage, International Cryocooler Conference 11, 749-758, 2001

Asteroid 1950 DA's Encounter with Earth in A.D.2880

J.D.Giorgini[1] ,S.J.Ostro[1], L.A.M.Benner[1], P.W.Chodas[1], S.R.Chesley [1], R.S.Hudson[2], M.C.Nolan[3], A.R.Klemola[4], E.M.Standish[1], R.F.Jurgens[1], R.Rose[1], D.K.Yeomans[1] and J.-L.Margot[5]
[1] Jet Propulsion Laboratory, [2] Washington State University, [3] Arecibo Observatory, [4] UCO/Lick Observatory, [5] California Institute of Technology

Initial analysis of the numerically integrated, radar- based orbit of asteroid (29075)1950 DA indicated a 20- minute interval in March 2880 during which the 1.1-km object might have an Earth impact probability of 0.33%. This preliminary value was supported by both linearized covariance mapping and Monte Carlo methods. The dynamical models, however, were limited to gravitational and relativistic point-mass effects on the asteroid by the Sun, planets, Moon, Ceres, Pallas, and Vesta. Subsequent extended modeling that included perturbations likely to affect the trajectory over several centuries generally implies a lower impact probability, but does not exclude the encounter.

Covariance based uncertainties remain small until 2880 because of extensive astrometric data (optical measurements spanning 51 years and radar measurements in 2001), an inclined orbit geometry that reduces in-plane perturbations, and an orbit uncertainty space modulated by gravitational resonance. This resonance causes the orbit uncertainty region to expand and contract along the direction of motion several times over the next six centuries rather than increasing secularly on average, as is normally the case. As a result, the 1950 DA uncertainty region remains less than 20,000 km in total extent until an Earth close-approach in 2641 disrupts the resonance. Thereafter, the same uncertainty region extends to 18 million km along the direction of motion at the Earth encounter of 2880.

We examined 11 factors normally neglected in asteroid trajectory prediction to more accurately characterize trajectory knowledge. These factors include computational noise, Galilean satellite gravity, galactic tides, Poynting-Robertson drag, major perturbations due to the gravitational encounters of the asteroid with thousands of other asteroids, an oblate Sun whose mass is decreasing, planetary mass uncertainties, acceleration due to solar wind, radiation pressure and the acceleration due to thermal emission of absorbed solar energy.

Each perturbation principally alters the along-track position of 1950 DA, either advancing or delaying arrival of the object at the intersection with the orbit of the Earth in 2880. Thermal radiation (the Yarkovsky effect) and solar pressure were found to be the largest accelerations (and potentially canceling in their effects, depending on which of two possible radar-based pole solutions is true), followed by planetary mass uncertainty and perturbations from the 64 principle perturbing asteroids identified from an analysis of several thousand. The Earth approach distance uncertainty in 2880 is determined primarily by accelerations dependent on currently unknown physical factors such as the spin axis, composition, and surface properties of the asteroid, not astrometric measurements. This is the first case where risk assessment is dependent on the determination of an object's global physical properties. As a result of this dependency, no specific impact probability is quoted here since the results would vary with our assumptions of the numerous uncertainties and dynamic models. Within decades, thousands of asteroids will have astrometric datasets of quality comparable to 1950 DA's and similarly have their long-term collision assessments limited by physical knowledge.

1950 DA's trajectory dependence on physical properties also illustrates the potential for hazard mitigation through alteration of asteroid surface properties in cases where an impact risk is identified centuries in advance. Trajectory modification could be performed by collapsing a solar sail spacecraft around the target body, or otherwise altering the way the asteroid reflects light and radiates heat, thereby allowing sunlight to redirect it over hundreds of years.

The next radar opportunity for 1950 DA will be in 2032. The cumulative effect of any actual Yarkovsky acceleration since 2001 might be detected with radar measure ments obtained then, but this would be more likely during radar opportunities in 2074 or 2105. Ground-based photometric observations might better determine the pole direction of 1950 DA much sooner.

Reference :
Giorgini,J., et al, Science 296, 132-136 (2002).
http://neo.jpl.nasa.gov/1950da

E-Mail:Jon.Giorgini@jpl.nasa.gov

How well do we understand the cometary hazard?

Matthew Knight and Michael A'Hearn
University of Maryland

A preliminary study of comets discovered by amateur astronomers finds that a significant fraction should have been found by surveys prior to their discovery by amateurs. A sample of 34 comets discovered by amateurs between 1990 and 1999 contained at least 7 comets which should have been in the field of view of at least one of the following surveys prior to discovery: the Palomar Digital Sky Survey (DPOSS), the Second Palomar Observatory Sky Survey(POSS ii), or the Second Epoch Southern Red Survey (AAOR). Extension of this analysis to other available catalogs is expected to increase the number of pre-discovery observations. While the preliminary sample displays no apparent trends in orbital elements or ecliptic latitude-longitude, it is hoped that a larger sample will reveal trends in the distributions of the amateur-discovered comets. A better understanding of the selection effects which allow amateurs to detect these comets and/or prevent surveys from detecting them is critical for the success of future surveys as well as the search for potentially hazardous comets and asteroids.

Deflecting Impactors at 90°

Claudio Maccone
Member of the International Academy of Astronautics
Via Martorelli, 43 - 10155 Torino (TO) - Italy
E-mail: clmaccon@libero.it

In a recent paper (Acta Astronautica, Vol. 50, No. 3, pp. 185-199, 2002) this author gave a mathematical proof that any impactor could be hit at an angle of 90° if hit by a missile shooted not from the Earth, but rather from Lagrangian Points L3 or L1 of the Earth-Moon system. Based on that mathematical theorem, in this paper the author shows that:

1) This defense system would be ideal to deflect small impactors, less than one kilometer in diameter. And small impactors are just the most difficult ones to be detected enough in advance and to a sufficient orbital accuracy to prove that they are impactors indeed.
2) The deflection is achieved by pure momentum transfer. No nuclear weapons in space would be needed. This is because the missiles are hitting the impactor at the optimum angle of 90°. A big steel-basket on the missile head would help.
3) In case one missile was not enough to deflect the impactor off its Earth-collision hyperbolic trajectory, it is a wonderful mathematical property of confocal conics that the new slightly-deflected impactors hyperbola can certainly be hit at 90° by another and slightly more eccentric ellipse! So, a sufficient number of missiles could be launched in a sequence from the Earth-Moon Lagrangian points L3 and L1 with the absolute certainty that the SUM of all these small and repeated deflections will finally throw the impactor off its collision hyperbola with the Earth.

Comet/Asteroid Protection System (CAPS): A Space-Based System Concept for Revolutionizing Earth Protection and Utilization of Near-Earth Objects

Daniel D. Mazanek
NASA Langley Research Center, Hampton, Virginia USA

There exists an infrequent, but significant hazard to life and property due to impacting asteroids and comets. Earth approaching asteroids and comets are collectively termed NEOs (near-Earth objects). These planetary bodies also represent a significant resource for commercial exploitation, long-term sustained space exploration, and scientific research. The goal of current search efforts is to catalog and characterize by 2008 the orbits of 90% of the estimated 1200 near-Earth asteroids larger than 1 km in diameter. Impacts can also occur from short-period comets in asteroid-like orbits, and long-period comets which do not regularly enter near-Earth space since their orbital periods range from 200-14 million years. There is currently no specific search for long-period comets, smaller near-Earth asteroids, or smaller short-period comets. These objects represent a threat with potentially little or no warning time using conventional terrestrial-based telescopes. It is recognized, and appreciated, that the currently funded terrestrial-based detection efforts are a vital and logical first step, and that focusing on the detection of large asteroids capable of global destruction is the best expenditure of limited resources. While many aspects of the impact hazard can be addressed using terrestrial-based telescopes, the ability to discover and provide coordinated follow-up observations of faint and/or small comets and asteroids is tremendously enhanced, if not enabled, from space. It is also critical to ascertain, to the greatest extent possible, the composition and physical characteristics of these objects. A space-based approach can also solve this aspect of the problem, both through remote observations and rendezvous missions with the NEO. A space-based detection system, despite being more costly and complex than Earth-based initiatives, is the most promising way of expanding the range of objects that could be detected, and surveying the entire celestial sky on a regular basis. Finally, any attempt to deflect an impacting NEO with any reasonable lead-time is only likely to be accomplished using a space-based system.

This poster presentation provides an overview of the Comet/Asteroid Protection System (CAPS), and discusses its primary goal of identifying a future space-based system concept that provides integrated detection and protection through permanent, continuous NEO monitoring, and rapid, controlled modification of the orbital trajectories of selected comets and asteroids. The goal of CAPS is to determine whether it is possible to identify a "single" lunar based or orbiting system concept to defend against the entire range of threatening objects, with the ability to protect against 1 km class long-period comets as the initial focus. CAPS would provide a high probability that these objects are detected and their orbits accurately characterized with significant warning time, even upon their first observed near-Earth approach. The approach being explored for CAPS is to determine if a system capable of protecting against long-period comets, placed properly in heliocentric space, would also be capable of protecting against smaller asteroids and comets capable of regional destruction. The baseline detection concept advocates the use of advanced, high-resolution optical/infrared telescopes with large, mosaic image plane arrays, coordinated telescope control for NEO surveying and tracking, and interferometric techniques to obtain precision orbit determination when required. The primary orbit modification approach uses a spacecraft that combines a high energy power system, high thrust and specific impulse propulsion system for rapid rendezvous, and a pulsed laser ablation payload for changing the target's orbit. This combination of technologies may offer a future orbit modification system that could deflect impactors of various compositions without landing on the object. The system could also provide an effective method for altering the orbits of NEOs for resource utilization, as well as the possibility of modifying the orbits of smaller asteroids for impact defense. It is likely that any NEO defense system would allow for multiple deflection methods.

Although laser ablation is proposed as the primary orbit modification technique, alternate methods, such as stand-off nuclear detonation, could also be part of the same defensive scenario. Advanced technologies and innovation in many are as critical in adequately addressing the entire impact threat. Highly advanced detectors that have the ability to provide the energy and time of arrival of each photon could replace current semi-conductor detectors in much the same way as they replaced photographic plates. It is also important to identify synergistic technologies that can be applied across a wide range of future space missions. For example, technologies permitting humans to traverse the solar system rapidly could be highly compatible with the rapid rendezvous or interception of an impactor. Likewise, laser power beaming (visible, microwave, etc.) may be applicable for space-based energy transfer for remote power applications, as well as NEO orbit modification.

The vision for CAPS is primarily to provide planetary defense, but also provide productive science, resource utilization and technology development when the system is not needed for diverting threatening comets and asteroids. The vision is for a future where asteroids and cometary bodies are routinely moved to processing facilities, with a permanent infrastructure that is capable and prepared to divert those objects that are a hazard. There is tremendous benefit in "practicing" how to move these objects from a threat mitigation standpoint. Developing the capability to alter the orbits of comets and asteroids routinely for non-defensive purposes could greatly increase the probability that we can successfully divert a future impactor, and make the system economically viable. It is likely that the next object to impact the Earth will be a small near-Earth asteroid or comet. Additionally, a globally devastating impact with a 1 km class long-period comet will not be known decades, or even years, in advance with our current detection efforts. Searching for, and protecting ourselves against these types of impactors is a worthwhile endeavor. Current terrestrial-based efforts should be expanded and a coordinated space-based system should be defined and implemented. CAPS is an attempt to begin the definition of that future space-based system, and identify the technology development areas that are needed to enable its implementation.

A Requirements and Missions Roadmap for Non-Terrestrial Empirical Verification of NEO Effects Thresholds: Objectives for the Determination of True Lower Limits on Atmospheric Penetrations and Global Effects

Drake A. Mitchell, MIT '87, Planetary Defense

Recent computer-based simulations have investigated the atmospheric penetrations of Near-Earth Objects (Hills and Goda, 2001[1]), their sub-global effects (Lewis, 2000 [2]), and the extended cratering process (Kring and Durda, 2001 [3]). Simulations of global-effects thresholds are expected (Holsapple, 1981 [4], 1993 [5]; Holsapple and Housen, 2002 [6]; Mitchell, 2002 [7]).

In a responsible, robust, and cost-justified campaign to attack the NEO problem, such simulations would be verified, e.g. calibrated, by space-based empirical investigations in non-terrestrial planetary environments. Simulation verification objectives and requirements are proposed that would also synergistically verify both the true annualized economic exposure to the hazard, and the viability of the many technologies and methodologies that have been proposed for NEO hazard mitigation missions but that have never been realistically tested or even adequately simulated.

Several classes of space-based platforms are reviewed for NEO surveillance, reconnaissance, modification, resource utilization, and deflection objectives. Mission optimizations and synergies are identified. It is shown that the proposed investigations can be achieved within existing or modified international conventions for the peaceful uses of outer space, and within the economic parameters justified by a program that would finally pass legal tests of negligence, i.e. specific programmatic and budgetary standards, e.g. $75 billion expended by 2010. Guidelines for such a program are derived from analyses of the Manhattan Project under the leadership of Lt. General L. R. Groves, and the subsequent development of the United States Nuclear Navy under the leadership of Admiral H. G. Rickover.

[1] http://abob.libs.uga.edu/bobk/ccc/cc071702.html See #7, "[5]"
[2] http://abob.libs.uga.edu/bobk/ccc/cc012602.html See #4, "[3]"
[3] http://www.lpi.usra.edu/meetings/lpsc2001/pdf/1447.pdf
[4] http://adsbit.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1981LPICo.449...21H
[5] http://adsbit.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1993AREPS..21..333H
[6] http://www.lpi.usra.edu/meetings/lpsc2002/pdf/1857.pdf
[7] http://abob.libs.uga.edu/bobk/ccc/cc062502.html See #6, "[17]"

Determining High-Accuracy Positions of Comets and Asteroids

Alice K B Monet
US Naval Observatory Flagstaff Station

Beginning in 1991 with the Galileo spacecraft encounter with Gaspra, the USNO Flagstaff Station has been providing highly-accurate astrometry of comets and asteroids to NASA/JPL in support of a variety of missions and observing programs. Over the years, no effort has been spared to attain the greatest possible accuracy. This has led to improvements in hardware, detectors, supporting electronics, observing strategies, astrometric analysis, and - perhaps most significantly - in astrometric reference catalogues. USNO is proud to have contributed to the many successful encounters, flybys, radar ranging experiments, and improved orbits for targets of particular interest. While each solar system body seems to present its own peculiar observing challenges, we have developed a certain level of confidence in our astrometric methods. If an object is detectable with our instrumentation, we can accurately determine its position.

In this report, I will discuss what we have come to regard as the key elements in a successful astrometric campaign. These include a wide-field of view and target-appropriate centroiding algorithms. Perhaps the most important is an accurate, dense, reference catalogue of faint objects. In recent years, the Naval Observatory has produced a number of such catalogues - most notably the USNO-A2.0 catalogue and the UCAC. The 8-inch FASTT telescope has also been used to densify regions of the TYCHO catalogue, for particular applications. At the time of this Workshop, new versions or expansions to these existing catalogues are under development, and new survey programs are being planned which will yield yet-more accurate and dense reference grids. All of these factors contribute to improved accuracy for asteroid and comet positions. Certainly, the accuracy of the astrometric positions is one of the essential ingredients in the effort to identify those comets and asteroids which pose a potential threat to our planet.

Warning the Public about Asteroid Impacts

David Morrison
NASA Astrobiology Institute

Unlike other natural hazards, the impact of an asteroid can (in principle) be avoided entirely by deflecting the object while it is still several years (and hundreds of millions of kilometers along its orbit) from the Earth. The requirement is to predict the potential impact sufficiently far in advance. The NASA Spaceguard Report of 1992 articulated the strategy of carrying out a comprehensive survey of NEAs, taking advantage of the fact that impacts are very rare and that NEAs will typically pass close by Earth thousands of times before they hit. Under these circumstances, it is extremely likely that any impact will be predicted decades or centuries in advance (if at all). The chances of finding a NEA on its final plunge to Earth are negligible. This is true whatever the magnitude (size) limit of the search. The lead-time for a Tunguska-class impactor (60 m diameter) is no different from that of a civilization-threatening impactor (2 km diameter), once we have invested in the larger telescopes that are needed to reach such small NEAs.

The purpose of the Spaceguard Survey is to provide long-lead warning of possible impacts. To date, there have been no such confirmed warnings, nor was any expected. However, during the past 5 years there has been approximately one warning issued in the press per year (e.g., 1997 XF11, 1999 AN10, 1950 DA, 2002 MN, and 2002 NT7). Of these, only 1950 DA was legitimate, and the low-probability chance of a collision with this asteroid does not materialize for nearly a millennium. The others were all cases where a rather poorly defined orbit indicated a possible (but very improbable) impact. Additional observations and orbital calculations eliminated this low-probability threat within a few days. While such media scares may have helped sensitize the public to the impact hazard, they have also demeaned the credibility of astronomers in the public eye. There is the potential for disutility in such warnings, which undermine confidence in the asteroid surveys and distract the public from more important issues. Astronomers are learning to play down such false alarms, but most of us have concluded that it is undesirable to suppress information and impossible to control the media. As survey capabilities improve and we discover more and more of the NEA population, we can expect more such media flaps, unfortunately.

There is, however, the legitimate question of a real confirmed warning, which could be issued when sufficient data are accumulated to provide a secure orbit. The most likely such case will indicate a significant probability (above 10%) of impact several decades in the future, by an object near the lower size limit of the surveys that are current at that time. If the object is smaller than 50 m diameter, there will be no danger of penetration to the surface or troposphere. If it is between 50 and 100 m diameter and is not targeted toward a densely populated region, it may be best to begin planning for possible evacuations. If it is larger than 100 m, undoubtedly proposals will be made to intercept and deflect it.

The issue arises of what organization, national or international, should issue such a confirmed warning. One proposal is to assign this responsibility to the U.S. Air Force Space Command, where a permanent NEA warning center might be established. The primary purpose of this paper is to examine the possible role of such a warning center. How often will it be activated? The Earth can expect an impact from a Tunguska-size asteroid (60 m) about once per millennium. With present survey telescopes the chances of predicting such an impact are very small, but a survey could be constructed that would operate even down to such sizes. Meanwhile, the frequency of impact of the 1-km NEAs that are the focus of the current Spaceguard Survey is about once per million years. Thus today we would anticipate that the warning center might issue a confirmed warning of an impact at the 10% probability level about once every 100,000 years. If we had a survey that targeted completion at the 50-m level, such a warning might be issued about once every 50-100 years. This is the maximum frequency, since impactors smaller than 50 m dissipate their energy in the upper atmosphere. This is not very much work to keep a permanent center staffed and operational. On the other hand, if the proposed center anticipates issuing warnings much more frequently (say every year, for example), then it will quickly lose its credibility, since the vast majority of such warnings will be false alarms. It is difficult to envision how a warning center devoted to the NEA impact hazard can be justified given the infrequency of expected impacts or even of credible possibilities of impacts. Warning centers make sense for severe storms today, and they would also make sense for earthquakes if we knew how to predict them. But for events as infrequent as asteroid impacts, this is not a credible option.

Impact of GAIA on Near-Earth-Object Collision Probability Computation

K. Muinonen (Univ. Helsinki Observatory, Finland),
J. Virtanen (Univ. Helsinki Observatory, Finland), and
F. Mignard (Observatoire de la Cote d'Azur, France)

We are studying the effects of high-precision astrometric observations on the computation of near-Earth object (NEO) orbits and collision probabilities. In addition to standard astrometry, we are examining differential astrometry, that is, either differences of two positions from standard astrometry or the actual sky-plane motion. GAIA, the next astrometric cornerstone mission of ESA, is due for launch no later than 2011. The duration of the GAIA survey will be 5 years, the limiting magnitude equals V = 20 mag, and full sky will be covered some dozen times a year. In particular, GAIA promises to provide an unprecedented NEO search across the Milky Way area typically avoided by groundbased searches. The extraordinary precision of the astrometry, varying from 10 micro-arcseconds at V = 15 mag to a few milliarcseconds at V = 20 mag, will have a major impact on NEO orbit computation, in particular, on the derivation of NEO collision probabilities and the assessment of the collision hazard. In addition to standard positional astrometry, GAIA will obtain differential astrometric observations: it promises to detect an object's motion across the field of view. The accuracy of the GAIA astrometry imposes a challenge for orbit computers, as an NEO's size, shape, and surface properties will have an effect on the astrometry. This effect will depend on the NEO orientation with respect to the Sun-NEO-GAIA plane and, in particular, on the solar phase angle (the angle between GAIA and the Sun as seen from the NEO). We show tentative simulations about the improvement of NEO orbits by the GAIA data. Finally, we show predicted NEO detection statistics for the GAIA mission.

Communicating about Cosmic Catastrophes

Brendan M. Mulligan, CIRES, Univ. Colorado (Boulder) and Clark R. Chapman, Southwest Research Inst. (Boulder)

The history of the Earth, and all the bodies in the solar system, has been marked by cosmic catastrophes of epic proportions: impacts due to asteroids and comets. Large-scale impacts have occurred in the past and, despite a decline in impact flux, the potential for future impacts constitutes a legitimate threat to human civilization. Communicating about the risk that near-Earth objects (NEOs) pose to the general public presents a serious challenge to the astronomical community. Although the NEO hazard has a unique character, comparisons with other natural hazards can readily be drawn and lessons can certainly be learned from years of experience that other researchers have in risk communication.

Just as specialists dealing with other hazards have done, the NEO community has addressed the challenge of risk communication by developing tools, most notably the Torino Impact Hazard Scale, capable of conveying useful information to a diverse audience. Numerous researchers and commentators have critiqued the scale, some suggesting modifications or proposing particular significant revisions. These critiques have dominantly focused on the Scale's perceived technical weaknesses, neglecting the central issues concerning its ability to inform the public in a satisfactory way. For instance, an issue that has already been dealt with in other cases (e.g. the "terrorism scale" of the U.S. Dept. of Homeland Security) concerns the degree to which the wording in the public scale tells people what they should specifically do in response to a particular warning level. The American Red Cross, for example, tabulated different responses that might be appropriate for different groups (individuals, families, neighborhoods, schools, and businesses) as to how they should respond to a particular level of security threat. Similar clarification of the Torino Scale might be in order. We hardly expect the public to "carefully monitor" an NEO predicted as having a Torino Scale "1" close encounter; those words were intended for astronomers. But given recent hype in popular media concerning 2002 NT7, further clarification for science journalists about appropriate levels of response for different interest groups (astronomers, space agency or emergency management officials, ordinary citizens) might be appropriate.

The NT7 hype was further confused by media reference to the event's numerical value on another scale (PTS) that is only a year old and is intended for technical purposes only. Again, the existence of multiple scales occurs for other natural hazards. But, despite internal debates about how to announce an earthquake Magnitude and the existence of multiple seismic scales, the public has been shielded from such internal, technical dissension and has become quite comfortable with Magnitudes, even though the appellation "Richter" has officially disappeared. Clearly, the NEO community's efforts to help the public place in context any news about possible future impacts remain only partially effective; NEO impact predictions continue to be met with confusion, misunderstanding, and sensationalism. The Torino Scale value is not the only information about impacts available to the public and, indeed, scales of any sort are not the only way to bring some convergence into public discussion of particular predictions. Astronomers have a public responsibility to develop simple protocols for honestly but understandably communicating about the inherently tiny chances of potentially huge disasters that characterize the impact hazard. Drawing from experience with other scales, we advocate that the IAU and other players and entities develop policies grounded in previous experience that can ensure accuracy, consistency, and clarity in reports of impact predictions. Only if we get our scientific house in order can we demand responsibility on the part of the science communicators and journalists who constitute the next link in the chain of communication.

Using a Solar Collector to Deflect a Near Earth Object

James F. Pawlowski
Human Exploration Science Office, Johnson Space Center, Houston, TX.

Of all the various non-nuclear techniques for deflecting a Near Earth Object (NEO) on a collision course with Earth, one of the most promising methods uses a solar collector. This method was studied by H.J. Melosh et al* and uses a solar collector to focus the Sun's rays on the NEO's surface. Evaporation by heat creates a thrust which modifies the NEO's trajectory over a period of time.

Such a technique has an advantage because it neither requires stabilizing nor landing on the NEO. As the NEO rotates under the illuminated spot, fresh material is brought into the heated area so evaporation is continuous. Furthermore it does not, for the most part, depend on the composition of the NEO. It can evaporate stony or icy bodies but probably not iron NEOs, but these are rare. The steady push also minimizes the danger of disrupting the NEO in contrast to a severe impulse.

There are a number of technical hurdles to overcome in maturing this technique, but none seem improbable or any more difficult than any other methods.

*Melosh, H. J., Nemchinov, I. V., Zetzer, Y. I. : 1994, Hazards Due to Comets and Asteroids, PP. 1119 - 1127

Near Earth Object Explorer (NEOX): A High Performance and Cost-effective Spacecraft for NEO Exploration

Rich Reinert and Richard Dissly
Ball Aerospace & Technologies Corp.

We present the design and describe the capabilities of a Solar Electric Propelled (SEP) microsatellite appropriate for a cost-effective and comprehensive program of NEO exploration.

Use of the Xenon-ion SEP approach proven on NASAs DS-1 Mission provides the NEOX S/C with 12km/s of Delta-V. Previous mission studies show that this Delta V will allow a single NEOX S/C to rendezvous with one to two NEOs when launched from an Ariane-5 ASAP, and with three to four NEOs when launched by a Delta-II.

A spacecraft mass <200kg provided by advanced technology enables launch as a secondary payload (e.g., Ariane-5 ASAP) or launch of multiple spacecraft from a single dedicated launch vehicle (e.g., 4 from a Delta II 7925). These low-cost launch options can enhance prospects for NEO exploration and characterization, as up to 16 NEOs could potentially be characterized using multiple NEOX spacecraft manifested on a single Delta-II launch vehicle. An interesting alternative would be to launch one to four vehicles annually as secondary payloads on the Ariane-5 LV. Possibly the modest cost of these secondary launches could be provided as a contribution by ESA in return for carriage of ESA payloads.

The NEOX spacecraft is designed to support a 20kg science payload drawing 100W average during SEP cruise, with >1kW available to instruments during a NEO orbital phase when the SEP thrusters are not powered. Rendezvous and NEO orbit will provide determination of the target object mass and density, and will allow for multiple phase angle imaging. The spacecraft is 3-axis stabilized with better-than 1 milliradian pointing accuracy to serve as an excellent imaging platform, and the telecommunications system can support a downlink data rate of 6.4 kbps at 3 AU earth range.

We will present candidate instrument suites and further discuss the advanced but proven technologies that make this spacecraft design possible.

Imaging the Interiors of Near-Earth Objects with Radio Reflection Tomography

Ali Safaeinili and Steven J. Ostro
Jet Propulsion Laboratory

Scenarios for mitigation of asteroid/comet collisions include the use of explosives to deflect or destroy the projectile (Ahrens and Harris 1995). However, as demonstrated by Asphaug et al. (1998), the outcome of explosive energy transfer to an asteroid or comet (via a bomb or a hypervelocity impact) is extremely sensitive to the pre-existing configuration of fractures and voids. A porous asteroid (or one with deep regolith) significantly damps shock wave propagation, sheltering distant regions from impact effects while enhancing energy deposition at the impact point. Parts of multi-component asteroids are similarly preserved, because shock waves cannot bridge inter-lobe discontinuities. Thus our ability to predict the effect of detonating a nuclear device at an asteroid or comet will rest on what we know about the object's interior.

Information about the interiors of near-Earth objects is extremely limited. Results from NEAR-Shoemaker's year-long rendezvous of Eros (Prockter et al. 2002, Veverka et al. 2000) suggest that it is somewhat consolidated, with a pervasive internal fabric that runs nearly its entire length and affects some mechanical responses such as fracture orientation. However, Eros' detailed internal arrangement of solid and porous domains is unknown, and in any case, Eros is not hazardous and is orders of magnitude more massive than any potentially hazardous asteroid. For much smaller asteroids whose shapes have been reconstructed from ground-based radar imaging (e.g., Hudson and Ostro 1995, Hudson et al. 2000) and for radar-detected comet nuclei (Harmon et al. 1999), some interesting but non-unique constraints on density distribution have resulted.

We would like to suggest that Radio Reflection Tomographic Imaging (RRTI) (Safaeinili et al.) is an optimal technique for direct investigation of the interior of a small body by a spacecraft in orbit around it. The RRTI instrument's operating frequency is low enough so that its radio signals are able to probe the target body's interior. The data obtained by RRTI is three-dimensional since it consists of wideband echoes collected on a surface around the object. This three-dimensional data set can be operated on to obtain the three-dimensional spatial spectrum of the object. The inversion of the RRTI data can yield the three-dimensional distribution of complex dielectric constant, which in turn can reveal the presence of void spaces, cracks, and variations in bulk density.

The mathematical basis of the technique is similar to that of ultrasonic reflection tomography (Kak and Slaney 1988) and seismic imaging (Mora 1987). Design of a spaceborn RRTI instrument for a small-body rendezvous can be based on the heritage from other planetary radar sounders like MARSIS (Picardi et al. 2001) and radar sounding experiments used to study glaciers (Gudmandsen, 1971) or contemplated for searching for a Europa ocean (Johnson et al. 2001). However, unlike these planetary radar sounding instruments, RRTI of NEOs would exploit the spacecraft's access to all sides of the body. Global views of the object make it possible to solve for the three-dimensional dielectric constant variations within the object down to the size of the shortest observing wavelength.

RRTI is distinctly different from radio transmission tomography techniques (e.g. the CONSERT experiment on Rosetta; Kofman et al. 1998) whose purpose is not imaging but rather to study material properties of radio-transparent comets. RRTI is an imaging technique that uses a co-located transmitter and receiver, and therefore does not require that the illuminating signal pass entirely through the target. Therefore, an RRTI system can be used to image the interiors of both comets and asteroids throughout the volume penetrated by the radar echoes.

The volumetric dielectric properties of the asteroid or comet can be reconstructed using least-squares inversion (e.g., a conjugate gradient search; Safaeinili and Roberts 1995, Lin and Chew 1996) driven by the observed difference between model-predicted radio echoes and the measured radio signals. A computationally less intensive and reasonably accurate inversion is possible with the Born approximation, which ignores multiple reflection within the target and linearizes the dependence of the scattered field on dielectric variations.

See our poster for examples of simulated RRT images of the interiors of very simple models.

References

1. Ahrens, T. J., and A. W. Harris (1995). Deflection and fragmentation of near Earth asteroids. In Hazards Due to Comets and Asteroids (T. Gehrels, ed.), Univ. of Arizona, pp. 897-927.
2. Asphaug, E., S. J. Ostro, R. S. Hudson, D. J. Scheeres, and W. Benz (1998). Disruption of kilometer- sized asteroids by energetic collisions. Nature 393, 437-440.
3. Gudmandsen, P. (1971). Electromagnetic probing of ice. In Electromagnetic Probing in Geophysics, Golem Press, pp. 321-348.
4. Hudson, R. S., and S. J. Ostro (1995). Shape and spin state of asteroid 4179 Toutatis from radar images. Science 270, 84-86.
5. Hudson, R. S., S. J. Ostro et al. (2000). Radar observations and physical modeling of asteroid 6489 Golevka. Icarus 148, 37-51.
6. Harmon, J. K., D. B. Campbell, S. J. Ostro, and M. C. Nolan (1999). Radar observations of comets. Planetary and Space Science 47, 1409-1422.
7. Johnson, W.T.K., R.L. Jordan and A. Safaeinili (2001). Europa Orbiter Radar Sounder. In Proceedings of Remote Sensing by Low Frequency Radars Conference, Naples, Italy.
8. Kak, A.C., and M. Slaney (1988). Principles of Computerized Tomographic Imaging, IEEE Press.
9. Kofman, W. et al., (1998). Comet nucleus sounding experiment by radiowave transmission. Advances in Space Research 21, 1589-1598.
10. Lin, J.H. and W.C. Chew (1996). Three-dimensional electromagnetic inverse scattering by local shape function method with CGFFT. In Proceedings of the 1996 AP-S International Symposium & URSI Radio Science Meeting. Part 3 (of 3), Jul 21-26 1996, Baltimore, MD, pp 2148-2151.
11. Mora, P. (1987). Nonlinear two-dimensional elastic inversion of multi-offset seismic data. Geophysics 52, 1211-28.
12. Picardi, G., et al. (2002). The Mars advanced radar for subsurface and ionosphere sounding (MARSIS) on board the Mars Express Orbiter, to be published in Mars Express Science Summary, ESA.
13. Prockter, L. P. et al. (2002). Surface expressions of structural features on Eros. Icarus 155, 75- 93.
14. Safaeinili, A., and R.A. Roberts (1995). Support minimized inversion of incomplete acoustic scattering data. J. Acoust. Soc. America 97, 414-424.
15. Veverka, J. et al. (2000). NEAR at Eros: Imaging and spectral results. Science 289, 2088-2097.
16. Safaeinili, A., S. Gulkis, M.D. Hofstadter, R.L. Jordan. Probing the interior of asteroids and comets using Radio Reflection Tomography. Submitted for publication.

Inferring Interior Structures of Comets and Asteroids by Remote Observations

Nalin Samarasinha
National Optical Astronomy Observatory

Detailed determinations of the interior structures of comets and asteroids require space missions equipped with suitable instruments. While such missions are essential for the furtherance of our knowledge on the interior structures of comets and asteroids, cost considerations alone may force such studies to be focused on a selected set of targets. Additional useful and complementary information on the interior structures can be derived by studying the spin states of asteroids and spin states and activity of comets, primarily via groundbased studies. Structural information based on rotation depends on (a) fastest spin rates for an ensemble of asteroids (or comets) and (b) the damping time scale for non-principal axis rotators. I will discuss capabilities and limitations of both these procedures for determining structural parameters. In the case of comets, activity and associated effects could provide additional useful information on the interior structure. I will also discuss how activity and splitting events could affect the size distribution of cometary nuclei and by extension a significant fraction of NEOs.

Eddy Current Force on Metallic Asteroids

Duncan Steel
University of Salford, UK

In order to make accurate predictions of the future orbital evolution of Earth-approaching asteroids it is necessary to take into account non-gravitational forces. As Giorgini et al. (Science, 296, 132-136, 2002) have recently shown, radiation forces depending on the surface properties of a specific relatively large asteroid will affect whether it will impact the Earth some centuries hence. Since the surface area varies as r^2 the perturbation varies as 1/r, and so smaller asteroids may be affected on shorter time scales.

Astronomers studying meteoroids and interplanetary dust have studied such radiative perturbations for some decades, and also considered the Lorentz and Faraday forces due to interactions with the interplanetary magnetic field strength. For objects of asteroidal size the perturbations produced are much smaller than the radiation-induced effects.

Another class of force due to the magnetic field is the eddy current force that would act on a metallic asteroid. This depends on the (square of the) gradient of the interplanetary magnetic field, which may be substantial at sector boundaries or in a turbulent magnetic field. It may thus act only episodically. This force is always dissipative, slowing down the object in question.

The important point about the eddy current force is that it varies as r^3 and so the perturbation produced will be size/mass independent. On the other hand, voids within an asteroid will inhibit the eddy currents and so limit the force imposed. Rough calculations of the eddy current force indicate that it is much smaller than the radiative forces, but show that the internal structure of an asteroid may be significant with regard to specifying its dynamical evolution.

NEA deflection: sometimes resonant returns are of not much help

G.B. Valsecchi and A. Carusi
IASF-CNR, via del Fosso del Cavaliere 100, 00133 Roma, Italy

The Delta V needed to deflect a Near-Earth Asteroid (NEA) in order to prevent a collision with the Earth can be significantly lower if the NEA in question has a close encounter with our planet before the one in which the collision is bound to happen.

In fact, Carusi, Valsecchi, D'Abramo and Boattini (2002, Icarus, in press) show that, in the hypothetical case of the 2040 collision of (35396) 1997 XF11, which would be preceded by an Earth encounter in 2028 putting the asteroid in a resonant orbit, if the deflection takes place a short time *before* 2028, then Delta V is about two orders of magnitude smaller than the one needed in case the deflection takes place a short time *after* 2028.

The amount of the Delta V saving is strictly related to the different mean motion perturbations imparted by the 2028 Earth encounter to two fictitious particles on nearby trajectories; the difference in mean motion leads to along-track separation and this, in turn, leads to different b-plane coordinates in 2040. Valsecchi, Milani, Gronchi and Chesley (2001, Astron. Astrophys., submitted) give for these quantities analytic expressions that turn out to be in good agreement with the numerical integrations in the case of (35396) 1997 XF11.

The formulae show that the ratio between the separation of the b-plane coordinates at the *second* encounter and the separation at the *first* encounter increases essentially linearly with time; however, the coefficient of the linear increase varies significantly as a function of some of the orbital parameters of the asteroid, and can become very small in some cases. When this happens, one can *a priori* expect that a significantly reduced Delta V saving would be obtained with a pre-first-encounter deflection of a NEA impacting at a resonant return.

As a practical example, we discuss the case of 1994 GV, a very small (H of approx 27) NEA that has, among others, a Virtual Impactor (VI) that, after an encounter with the Earth in 2031, hits the Earth at a resonant return in 2048.

We present numerical integrations showing that, as expected, the Delta V saving obtained with a pre-2031 deflection of the 2048 VI associated with 1994 GV is more than an order of magnitude smaller than the Delta V saving obtained with a pre-2028 deflection of the 2040 VI associated with (35396) 1997 XF11.