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First draft for SBAG community comment

Goal II: Planetary Defense

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Small Bodies Assessment Group (SBAG) Goals Document – Planetary Defense

Draft version 0.5

Introduction

The objectives of the Small Bodies Assessment Group (SBAG) with regards to planetary defense can be divided into four main categories: 1) finding the potential hazardous asteroids and comets; 2) characterizing them; 3) mitigation through deflection and/or disruption; and 4) civil defense and emergency response. Note that there are significant overlap with the objectives identified in the Science and Human Exploration sections of this document, but that the priority of these overlap varies.

Establishment of Planetary Defense Coordination Office

The 2010 NASA Advisory Council Planetary Defense Task Force, following the NASA Authorization Acts of 2005 and 2008, recommended the establishment of a Planetary Defense Coordination Office. This office would work on policy and responsibilities with respect to a response for threats posed by near-Earth objects. The NASA NEO Observations program is currently being examined with the goal of developing both a complete program plan and an adequately resourced program office by the end of fiscal year 2015. A study of the needs for interface across both US Government agencies and departments and internationally is part of this effort.

Objective: The planetary defense community supports the establishment of a Planetary Defense Coordination Office that will work on policy and responsibilities with respect to a response for threats posed by NEOs.

Survey and Tracking

The discovery and tracking of the NEO population is the first step in a viable planetary defense strategy. An objects orbit defines if, when and how an impact will occur, and is key in defining warning times and deflection requirements. Accurate orbital information is an essential element of this process.

Space-based Survey

NASA has been given by Congress two mandates addressing near-Earth object (NEO) detection. The first, known as the Spaceguard Survey, was to detect 90% of NEOs larger than 1km in diameter before 2008. Data from the NEOWISE space-based survey showed that this goal was reached in 2011 (Mainzer et al. 2011). The second, known as the George E. Brown goal, directed that NASA detect and track 90% of all NEOs larger than 140m in diameter by 2020. In 2013 NASA launched its

Grand Challenge, focused on finding all asteroid threats to human populations and knowing what to do about them. However, the fact remains that the current surveys are not capable of reaching this goal in our lifetime. Several study reports (Stokes et al. 2003; Shapiro et al. 2010) have found that a space mission conducted in concert with observations from a suitable ground-based telescope and selected by a peer-reviewed competition to be the best approach. This combination could complete the survey of objects larger than 140 meter well before 2030 and provide a legacy dataset for both science and planetary defense. The planetary science and planetary defense community has endorsed this approach and the SBAG has through several findings iterated its support for such a fundamental asset.

Objective: Development of a space-based Near-Earth object survey telescope should be undertaken. This is a fundamental asset that would most efficiently achieve the goals of NASA's Asteroid Initiative in the shortest amount of time. Construction and implementation of such an asset should be supported by all three of NASA's major space exploration directorates and not just by the limited resources of the Near-Earth Object Observations (NEOO) program within the Science Mission Directorate (SMD).

Enhanced Monitoring of the Asteroid Detection Pipeline for Imminent Impactors

There have so far been two Earth impacts from asteroids discovered prior to atmospheric entry, and more are likely to follow in the coming decades (Jenniskens et al., 2009; Farnocchia et al. 2015). In both cases to date the objects were discovered only ~20 hours prior to impact. In one case the early recognition and announcement enabled a wide-ranging characterization of the body, both as an asteroid in space and as meteorites in the laboratory. Such events thus provide an opportunity for bonanza of scientific information, with characterization while the object is still in space, during atmospheric passage and finally in the laboratory with recovered meteorite samples. However, early and timely notification of these events is imperative to fully leverage the opportunity that they pose.

Objective: Active monitoring of the MPC's NEO Confirmation Page data stream in an effort to identify potential near-term impactors early enough to gather additional tracking information to refine the orbital predictions and thereby maximize pre- and post-impact characterization.

Characterization

While an object's orbit determines if, when and how an impact will occur, its physical characteristics play a central role in how the object would react to a mitigation mission and the potential damage it could do.

Mass of the object is maybe the most important of these physical characteristics, but also one of the most difficult to determine as it is dependent on other physical properties like the size, composition, bulk density and porosity. The objects mass combined with warning times sets deflection difficulty and is also a key parameter in determining the damage the object would inflict. Currently several

methods are used to estimate mass, but the uncertainty can be as large as an order of magnitude. The composition of the object is another physical parameter that plays a central role in how an asteroid reacts to a mitigation attempt using a kinetic impactor or nuclear deflection. In particular recent results show that the presence of high-Z (metals) or low-Z (volatiles) elements plays a big role. Understanding the porosity of the object is key to understand the effectiveness of kinetic impactors, as well as determining the possibility for disruption/fracture of the object. For example, porosity at some distance inside the object can dampen the shock produced by the kinetic impactor and thus limit damage to the object. The shape of the object is also an important factor that influences the effectiveness of a kinetic or nuclear deflection attempt. The slope of the surface at the impact point affects the direction and magnitude of the delta-V imparted to the object from the kinetic impactor. The shape can also diminish or enhance, by more than a factor of two, the effect of a nuclear deflection attempt when compared to a sphere. These objects may also spin, some rather rapidly, which further complicates matters by introducing timing concerns when desiring impact at specific locations on the objects non-spherical surface.

Ground-Based Characterization

A fundamental characteristic of a given asteroid is its color. How incident sunlight is scattered or absorbed by the minerals on the surface varies as a function of wavelength and these data are used to characterize and classify asteroid types. Composition and particle size are the dominant factors that contribute to the optical and color properties of an asteroid, both of which can affect the mechanical properties of the asteroid itself. These are important parameters that need to be characterized to develop rigorous damage and mitigation models; some effort may be necessary to provide an organized data base and understanding of how the variables in these properties are manifested.

Thermal infrared spectroscopy of asteroids provides information about the visual albedo and size of a given body. This knowledge is important for understanding the mineralogy and taxonomy of asteroids, the size-frequency distribution of families, and populations of asteroids. Unfortunately, observations from the ground are limited by atmospheric absorption to wavelength windows between 5-20 microns making it difficult to measure the continuum spectrum around the emission peak for objects out to the main belt, motivating the need for an space-based infrared capability. Composition and size are both important characteristics for understanding the possible outcomes of an impact.

Objective: A concerted effort should be undertaken by the community to use optical, NIR, and infrared facilities and data to characterize potential impactors in an expedient and organized manner.

Planetary Radar

Radar is a powerful technique for constraining asteroid orbits, shapes, sizes and spin states, as well as the potential presence of orbiting companions and surface structures such as boulders. These are all critical properties in predicting the

possibility of impact and any damage that an impact may have. The continually improving capability of radar to reveal the character of small NEOs is exemplified by the recent bi-static observations of 2014 HQ124, where a chirped X-band transmission from Goldstone was received by Arecibo using its new digital receiver.

Objective: enable the ability to characterize potentially hazardous objects to evaluate their risk the planetary radar continues to be a key component of the suite of characterization facilities and should thus continue to be supported by NASA and the NSF.

In Situ

In situ measurements provide one of the best means to understand surface properties, mineralogy, size (including mass and density), shape, porosity, and internal structure of a given asteroid. Currently, a mission to rendezvous with an asteroid takes many years to plan and execute successfully. Thus it is not currently feasible to send missions to many potentially hazardous bodies in order to determine likely asteroid physical properties and structures that might impact the Earth.

Objective: NASA should develop ways to reduce response times when it is necessary to visit or deflect potentially hazardous objects. This may include having small scout-class missions ready to go in order to rapidly characterize objects of interest. Studies by the community may also be used to reduce response time in mission (reconnaissance or mitigation) development and launch.

Mitigation, Risk and Damage Assessment

Early Mitigation Planning for Potential Earth Impactors

Current impact monitoring systems at JPL and University of Pisa continuously scan the NEA orbit catalog for potential impacts within the next 100 years, posting lists of potential impactors publicly online. This is a necessary step in responding to potential impact threats; however, there is so far no systematic examination of the risk lists with a view to identifying cases that need extra attention early for a successful deflection campaign, should one become necessary. This raises the possibility that an object already on the risk list could rise to an intractable deflection problem due to a failure to recognize the appropriate timeline of a potential mitigation mission.

Objective: Active monitoring of the Potential Impactor Risk List and development of quick assessments of mitigation timelines to ensure that potential threats are addressed with appropriate resources and in a timely manner.

Simulation of Atmospheric Airburst and Surface Damage

Reliable prediction of the level of direct or indirect damage caused by the airburst or surface impact on either land or water based is currently unavailable. This knowledge is an important consideration in formulating a proper response to possible impact threats. The foundation for our current knowledge can be found in Hills & Goda (1993), Stokes et al. (2003) and Boslough & Crawford (1997,2008). While foundational, the first two are primarily empirical, and the latter two are of reconstructive nature (i.e. damage is predicted based on an assumed near field energy deposition). Thus, true first principle predictive capability is lacking.

In order to improve the reliability and bound the expected damage based on the uncertainty of the properties of the NEO, there is a need to develop physics-based tools that can reliably predict the energy deposition of the break up or airburst of NEOs during atmospheric entry, as well as surface impact damage (including cratering) that the objects may inflict. Development of these tools should be led by NASA, leveraging the agency's expertise in NEO dynamical and physical properties as well as its expertise in the design of re-entry vehicles. This effort should also leverage the considerable simulation capabilities existing in other government labs, especially those supported by the DoE (blast damage) and NOAA (tsunami prediction and effects). In addition to extending existing flow solvers to entry speeds applicable for NEOs (12 to 30 km/s), upgrades to tools used to propagate near-field disturbances to the surface, research on modeling of fracture/fragmentation, and multi-body and multi-phase flow is needed.

Objective: NASA should lead the development of a multi-agency capability to reliably predict the damage for an airburst or surface impact (both land and water based) caused by a NEO. The agency should encourage development of a similar capability by the international community with the objective of evaluating the reliability of the tools.

Planetary Defense Flight Validation Mission

At present there have been no flight mission to validate planetary defense techniques or technologies. While numerous spacecrafts have performed flybys or rendezvous with asteroids, only the Deep Impact mission has successfully deployed an impactor. However, these science missions require at least several years, usually five or six, from mission concept development to launch. From a planetary-defense stand point it should be noted that several of these science missions were sent to back-up targets due to schedule slips and missed launch windows. Additionally, several missions have experienced hardware and software problems that have compromised the completion of mission objectives. A planetary-defense mission aimed at deflecting or disrupting an incoming NEO, possibly with relative little warning, would not be able to tolerate similar issues. Thus, while the impressive scientific missions that have been sent to asteroids and comets thus far have certainly provided future planetary-defense missions with good heritage on which to build, we are clearly not ready to respond rapidly and reliably to a threatening NEO scenario.

A number of studies conducted over the past decade have found the following three proposed PD systems to be the top candidates for missions: Nuclear Explosive Device, Kinetic Impactor, and Gravity Tractor. None of these potential planetary-defense mission payloads to deflect or disrupt an NEO have ever been tested on NEOs in the space environment. Significant work is, therefore, required to appropriately characterize the capabilities of those systems, particularly the ways in which they physically couple with an NEO to transfer energy or alter momentum and ensure robust operations during an actual emergency scenario.

Objective: A planetary defense flight validation mission should be conducted so that we may become operationally ready for the preparation and execution of future planetary defense missions to deflect or disrupt an NEO on relative short notice with high reliability.

A further complication is that our science missions have in general visited asteroids and comets that range in size from a few hundred meters to tens of kilometer in size. For Planetary Defense Missions requiring NEO intercept, the requirements on spacecraft guidance and control will likely be far more stringent, since smaller NEOs are far more numerous than large ones. NEO targets with diameters as small as several tens of meters may have to be reliably be tracked and intercepted at hypervelocity, with impact occurring within meters of the targeted point on the NEO's surface. This will require significant evolution of the autonomous Guidance, Navigation and Control (GNC) technology currently available for spacecraft missions to NEOs.

Objective: Support should be given to the development and testing of next generation GNC technology to ensure that adequate systems are available for any future planetary defense missions.

Development of Risk Assessment Tools

The current and improved knowledge about the orbital and physical characteristics of the NEO population and the damage they may cause through airburst or surface impact should be used to provide a set of Risk Assessment Tools to support and advise decision makers in the event of a discovery of an impact threat. These tools should be able to provide near-real time updated information on the risk assessments (impact probability, expected impact corridor, expected range of damage, etc.) as knowledge of the approaching PHA improves.

Objective: Development of Risk Assessment Tools, capable of near-real time risk and damage assessment to support and advise decision makers in the event of an imminent impact threat, should be carried out.

Civil Defense (Emergency Response and Recovery)

US Interagency Cooperation

On February 15, 2013, the city of Chelyabinsk, Russia, experienced the effects of an atmospheric burst of an asteroid estimated at about 20m in diameter, through

a blast wave that collapsed building walls, shattered windows, and reportedly injured over 1000 people. Since that time NASA has provided several NEO briefings to several FEMA and other interagency audiences. FEMA and NASA have also conducted two tabletop exercises, exploring two different scenarios. Both agencies also participated in the tabletop exercises at IAA Planetary Defense Conference in 2013 and 2015.

FEMA and NASA are now in the process of formally chartering the Planetary Impact Emergency Response Working Group (PIERWG). The purpose of this group is to educate the federal agencies and other concerned organizations on the science and possible challenges in responding to impact/airburst events, which have low probabilities of occurring, but have extreme consequences.

Objective: Continue the development of the PIERWG to provide the framework for the establishment and structure of an interagency team to coordinate responsibilities and resolve preparedness and operational issues relating to interagency response and recovery activities on the national level in the event of a predicted or actual impact on an NEO in the US or its territories.

International Cooperation

Recently the UN's Scientific and Technical Subcommittee on the Peaceful Uses of Outer Space put together an action team to develop a plan for coordinating the international mitigation efforts of NEO threats. In March 2015 the action team announced the establishment of the Space Mission Planning Advisory Group (SMPAG) and the International Asteroid Warning Network (IAWN). The primary purpose of the SMPAG is to prepare for an international response to an NEO threat by facilitating exchange of information, encourage collaborative research and mission opportunities, and providing mitigation planning activities. IAWN's purpose is to improve communication between the many actors in the worldwide effort to detect, track and physically characterize the NEOs.

Objective: Continue the work of establishing the SMPAG and IAWN as active, vibrant groups that can properly serve the functions they are intended. There is a need to increase the awareness of these groups and their function among the Planetary Science and Planetary Defense communities.

Impact Disaster Planning

A large impact will be an international event whether it causes local or large scale national level damage. Therefore we support an effort to involve international disaster relief governmental agencies and non-governmental organizations to participate in the planetary-defense dialogue. The UN COPUS should reconsider establishment of the Impact Disaster Planning Advisory Group (IDPAG) along the lines of the SMPAG and IAWN discussed above. The IDPAG should be a venue for discussion of risk assessment, damage assessment and modeling, mitigation possibilities and civil defense.

Objective: The UN COPUS should consider the establishment of an IDPAG to foster discussion of a range of topics on risk assessment, damage assessment and modeling, mitigation strategies and how these issues influence impact disaster planning and civil defense.

Risk-Assessment Map

The location of impact (as well as the impact energy) is key in determining the risk and damage that would occur during an impact event from an NEO. For example, an ocean impact might cause tsunamis which could impact population centers far from the source, while a similar impact into a desert, tundra or arctic area might result in limited damage to population centers. Impacts in urban areas, clustered in small regions of the world, would cause disproportionate consequences, as would impacts in the vicinity of key infrastructure nodes.

Objective: A composite risk assessment map should be developed to fully evaluate how impact location could influence the damage evaluation, thus guiding mitigation strategies. Such a world map would illustrate “composite risk” for a range of scenarios and could be published as GIS Layers. It would be of use in training, planning exercises, and integrated-risk assessments, and (eventually) as an element of decision making in the course of a real event.

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