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THE ACHIEVEMENTS OF THE NEOShield PROJECT AND THE PROMISE OF NEOShield-2

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Introduction

In 2011 the European Commission issued a call for proposals, as part of its seventh research Framework Program (FP7), for projects to address the near-Earth object (NEO) impact hazard and feasible mitigation measures. The NEOShield project, proposed by a consortium of 13 partner organizations from academia and industry, received funding for 3.5 years from January 2012 (Harris et al., 2013). A similar call for proposals was issued by the European Commission in the framework of its Horizon 2020 program in December 2013, resulting in the granting of funding for the 11-partner NEOShield-2 project for 2.5 years from March 2015. The organizations involved in both projects are listed in Table 1. We report on the significant results and experience of NEOShield, drawing to an end at the time of this conference, and the plans and expectations for NEOShield-2.

The main areas addressed by NEOShield include NEO physical characterization, laboratory experiments to investigate the material properties of asteroid analog materials, NEO modeling and computer simulations, a trade-off study of different deflection techniques, and detailed designs of deflection test missions. Following on from this work, NEOShield-2 will investigate in more detail key technologies crucial to space missions to deflect NEOs, including autonomous guidance, navigation, and control systems, and carry out observations of selected NEOs for the purposes of broadening our knowledge of their mitigation-relevant physical properties, and increasing the list of suitable candidate targets for deflection test missions. Other themes, common to both NEOShield projects, are the design of an international strategy or “roadmap” for responding to the discovery of a significant impact threat, and the role of the NEOShield projects in relation to current impact-hazard response activities on the international stage.

NEOShield

While the NEOShield project is Europe-based, the European Union’s research funding program allows non-European partners to receive funding from the EU, which has enabled partners from Russia and the USA to participate in the project. The FP7 program has therefore provided a unique opportunity for a large international group of scientists and space engineers to pool their expertise and work together on a closely coordinated program of research and technical development, covering diverse aspects of NEO impact hazard mitigation. For the design of any mission to deflect a NEO, an important prerequisite is relevant knowledge of the nature of the target so that the outcome of the deflection attempt can be predicted. The knowledge required depends on the deflection technique in question, but would include such parameters as mass, shape, spin vector, albedo, and in some cases surface porosity, regolith structure, and mineralogy. The NEOShield project has benefitted from the close contact between scientists investigating, for example, the physical and dynamical properties of NEOs, target selection for deflection test missions, and post-deflection orbit evolution, and engineers developing spacecraft systems for different deflection techniques and designing realistic missions to test currently feasible techniques.

Scientific results from NEOShield include those obtained with hypervelocity gas guns and associated modelling and computer simulations, and the analysis of observational data from infrared telescopes, such as NASA’s Wide-Field Infrared Survey Explorer (WISE).

Table 1. NEOShield and NEOShield-2 partner organizations (partners contribute to both projects unless otherwise indicated).

Partner name	Country	Role/main contributions
German Aerospace Center (DLR) Institute of Planetary Research, Berlin	Germany	NEOShield project coordinator; supervision of scientific work for NEOShield-2; NEO science: data analysis, modeling; global mitigation strategy; public outreach.
Airbus Defence & Space	Germany	Supervision of technical work for NEOShield; NEOShield-2 project coordinator; detailed designs and technology development for the kinetic impactor; public outreach.
Paris Observatory	France	NEO science: observations, data analysis, orbital dynamics, space-mission instrumentation; global mitigation strategy.
Centre National de la Recherche Scientifique (CNRS), Côte d'Azur Observatory	France	NEO science: computer modeling of NEO material and structural properties.
The Open University	UK	NEO science: gas-gun experiments. (NEOShield)
Fraunhofer Ernst Mach Institute, Freiburg	Germany	NEO science: gas-gun experiments, computer modeling of NEO material properties; in-situ sampling.
Queen's University Belfast	UK	NEO science: observations, data analysis, deflection test-mission target selection.
Airbus Defence & Space	UK	NEO deflection techniques trade-off study; global mitigation strategy; NEO material sampling concepts.
Airbus Defence & Space	France	Kinetic-impactor guidance concept: GNC subsystem design and technology development.
Elecnor Deimos	Spain	NEO reconnaissance spacecraft guidance concept: GNC sub-system design and technology development; global mitigation strategy; NEO physical properties database and support tools.
Carl Sagan Center, SETI Institute, Mountain View, California	USA	Gravity tractor concept; space mission design. (NEOShield)
TsNIIMash, Russian Federal Space Agency	Russia	Blast deflection concept; space mission design; global mitigation strategy. (NEOShield)
University of Surrey	UK	Gravity tractor concept. (NEOShield)
GMV Aerospace and Defence S.A.U.	Spain	GNC subsystem design for material sampling, and associated technology development and testing. (NEOShield-2)
National Institute for Astrophysics	Italy	NEO science: observations, data analysis. (NEOShield-2)

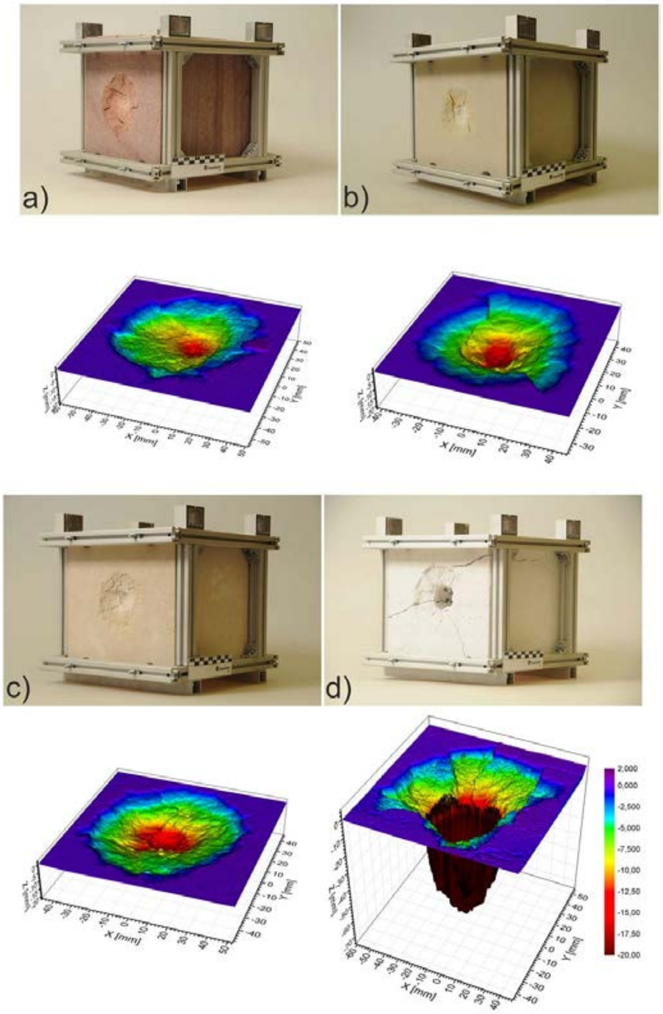

Figure 1. Examples of the results of gas-gun experiments on asteroid surface analog materials carried out by NEOShield partner Fraunhofer Ernst Mach Institute, Freiburg, Germany. The impact craters in different target materials with porosities, φ, were formed by projectiles with approximately the same impact velocity: a. Quartzite (φ ~ 3 %); b. sandstone (φ ~ 25 %); c. limestone (φ ~ 31 %); d. aerated concrete (φ ~ 87 %). In each case a photograph of the target after the impact is shown above a three-dimensional model of the crater morphology. The colour code shown adjacent to the bottom right crater model applies to all four models. The experiments demonstrate that large craters are formed in highly porous material but in contrast, the ejected mass is small. © Fraunhofer EMI.

The gas-gun experiments (Fig. 1) have produced data on the behavior of asteroid surface analogue materials when impacted by a projectile at high velocity. The results of the NEOShield experiments have provided a vivid demonstration of the dependence of the momentum multiplication factor β (the ratio between the target momentum change as a result of the impact and the momentum of the projectile) on the porosity and other properties of the target material. Furthermore, computer modelling of the effects of various material properties on the β factor have shown that using a higher tensile strength leads to less ejecta and therefore a smaller β value. Using a target with a strength corresponding to laboratory scales (cm-sized bodies) leads to a significantly smaller β value than that found for a target with a strength corresponding to a 300-m diameter object, which is about 20 times smaller (for details see Jutzi and Michel, 2014). These results have demonstrated that understanding the relevant physical properties of a potentially hazardous NEO is of fundamental importance for the prediction of its response to a kinetic impactor.

NEOShield studies of data from NASA's infrared space telescope, WISE, have shown that the sunward surfaces of some asteroids appear cooler than others at similar distances from the Sun, a finding that we have modelled on the basis of enhanced surface thermal conductivity. From comparisons of the emitted thermal radiation with radar reflectance measurements, NEOShield research has uncovered a potentially very valuable relationship between a thermal-model fitting parameter, related to the surface temperature distribution, and the metal content of asteroids. On the basis of this relationship 18 NEOs have been identified as metal-rich candidates, 9 of which are classified as potentially hazardous (for details see Harris and Drube, 2014). A threatening NEO containing a large amount of metal would presumably be relatively robust and massive, depending on its internal structure, factors that would require careful consideration by deflection-mission planners and/or those mandated to manage mitigation, e.g. evacuation, activities on the ground in advance of a possible impact.

A review of scientific results from NEOShield is given by Drube et al. (2015).

Further NEOShield results are described in a number of peer-reviewed and conference papers, including solutions to issues concerning the operation of gravity tractor and kinetic impactor NEO deflection missions (Ummen and Lappas, 2014, Chapuy et al., 2014, respectively), an investigation of impulsive deflection methods (Meshcheryakov and Lipnitskii, 2015), a discussion of the importance of high precision astrometry of NEOs for asteroid threat assessment and mitigation (Eggl et al., 2013), and the development of a suite of software tools for performance evaluation of different NEO deflection options in realistic circumstances, including associated orbit and trajectory considerations (Cano et al., 2013). The final tasks of NEOShield, which include the development of systems for, and the detailed design of, space missions to test deflection methods, are still in progress at the time of writing: The results of more recent NEOShield work will be published in due course. Links to NEOShield publications and project documents can be found on the NEOShield public website (www.neoshield.net).

NEOShield-2

Many aspects of the work of NEOShield will be further developed in the course of the NEOShield-2 project. NEOShield-2 will focus on technological development and maturation tasks, which will serve to minimize the necessary preparation time for a NEO deflection mission, and be of benefit to the design of NEO reconnaissance and sample return missions for the purposes of mitigation-relevant physical characterization. Essential techniques and instruments needed for guidance, navigation and control (GNC) in close proximity to NEOs will be developed up to a technology readiness level (TRL) of 5-6, in particular to allow deployment of a high-velocity kinetic-impactor spacecraft and observations of the target before, during and after a deflection attempt. Moreover, detailed concepts and techniques will be addressed and technology developed for fast and precise orbit determination and monitoring of NEOs.

For the GNC development work it is important to understand the relevant size range, shapes, spin rates, albedos, and as far as possible the densities and mass distributions of potential target NEOs. Interaction with the surface for sample collection and in-situ analysis and/or return to Earth requires knowledge of NEO regolith characteristics and surface structure. Results to date obtained in the course of the existing NEOShield project have significantly advanced our understanding of the mitigation-relevant parameter distributions for sub-kilometer NEOs, but much more observational work and research is required to provide the requisite knowledge for the more numerous and frequent impactors at the small end of the size range of interest (diameter < 300 m). The NEOShield-2 work plan, in contrast to that of NEOShield, contains a work package for observational work on mitigation-relevant NEO targets and associated data reduction and analysis. Analyses and modeling will also be carried out of relevant NEO physical properties, including statistical studies, based on a wide range of existing and newly available published data sets.

The NEOShield-2 project includes the provision of a project data repository with an interface to ESA's Space Situational Awareness NEO Coordination Centre, in order to allow optimum access to NEOShield-2 results on the physical characteristics of NEOs most relevant for space mission planning. We aim to ensure complementarity and harmonization of our work with the ESA NEO technical developments and activities.

The membership of NEOShield-2 personnel in the bodies recently established under the auspices of the United Nations, namely the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG), will facilitate synergy between the research and development work of NEOShield-2 and the activities of these groups. The

SMPAG aims to coordinate the relevant work of national space agencies and other competent bodies by recommending space-mission-related actions addressing the impact hazard and mitigation measures. The recommendations of SMPAG concerning future work could form the basis of calls for research proposals by funding agencies.

The interfaces of the NEOShield-2 project with the activities of ESA on the one hand, and the IAWN and SMPAG on the other, represent a unique coordinated strategy for NEO impact mitigation, which could form the basis for a truly global coordinated network of competent partners tackling the challenge presented by the NEO impact hazard.

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