SUMMARY REPORT

2023 IAA PLANETARY DEFENSE CONFERENCE

The 2023 International Academy of Astronautics (IAA) Planetary Defense Conference (PDC2023) was held in Vienna, Austria on April 3-7, 2023. The meetings on April 3-6 were hosted by the United Nations Office of Outer Space Affairs at the United Nations Vienna International Center (VIC); the Austrian Academy of Sciences hosted the April 7 meeting. In addition to the IAA, the conference had twelve sponsors and three supporting organizations. Sponsors provided funds that helped cover major conference expenses. Names of sponsoring and supporting organizations are given in APPENDIX A.

This hybrid conference was the 10th in the series of conferences focused on the threat posed by asteroids and comets and the 8th held under the auspices of the International Academy of Astronautics. There were over 275 in-person attendees, 200 remote participants, and nearly 1000 remote viewers who heard the latest information on our planet's understanding of the threat posed by these natural objects and humanity's ability to mitigate a threat should one be detected.

Figure 1 shows on-site participants surrounding a large meteorite loaned by the Austrian Museum of Natural History for the PDC2023 event. The photo was taken in the Rotunda of the UN facility. In the background are boards with poster papers attached. Nearly 1000 individual observers representing over 60 nations viewed the conference remotely on Day 1. Figure 2 shows locations where remote viewers were located. A list of registered participants is given in APPENDIX B.

Figure 1. Conference attendees in VIC Rotunda (Credit: Max Alexander).

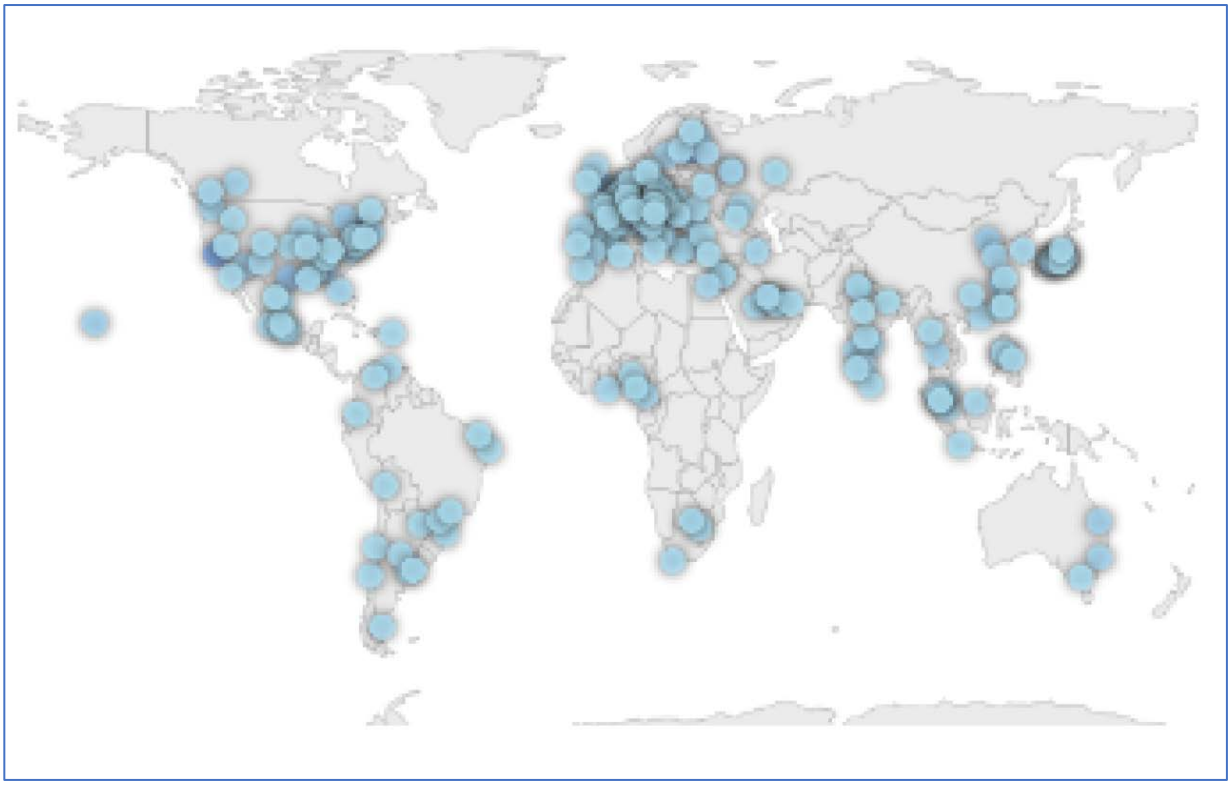

Figure 2. Locations of remote viewers.

Over 100 experts gave oral presentations of their work and results, and authors submitted over 150 poster papers. A highlight of the conference was the asteroid impact threat exercise, which for the first time examined the possibility of a large asteroid on a collision course with Earth. Deflection of the hypothetical threat assumed an asteroid estimated to be from 220 to 660 meters in size at discovery, with a potential impact in several African countries. This scenario was chosen to take advantage of the United Nations location to raise and discuss significant technical, legal and policy issues that would confront world leaders if such a threat was discovered.

The names of the conference chairs and members of the Organizing Committee are given in APPENDIX C. The conference chairs held monthly telecons with the Organizing Committee to organize the conference and develop the program given in APPENDIX D and summarized in Section 3. Several presentations on the Double Asteroid Redirection Test (DART) and its results were presented on April 2, the Sunday afternoon preceding the conference, at the Austrian Academy of Sciences.

This report provides a summary of activities at the conference, feedback and recommendations, and highlights of the fictitious asteroid impact threat exercise that was held on Day 1 of the conference. Videos of conference sessions and activities are available at the UN website[1].

[1] https://www.unoosa.org/oosa/en/ourwork/topics/neos/2023/IAAPDC/index.html.

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CONFERENCE OVERVIEW

As in prior conferences, PDC2023 was a single-track conference—sessions were sequential, and participants were able to attend all sessions offered. This format gave each participant the opportunity to become familiar with virtually all aspects of planetary defense, including what we know about asteroids, how we find and characterize these objects, how we might deflect a threatening object, the effects of an asteroid impact, and response to an asteroid impact disaster.

The conference included a total of over 100 oral presentations. A total of approximately 150 poster papers were accepted and posted at the conference, and posters were highlighted at an end-of- the-day reception on Tuesday. Each session was organized by the chairs of that session. Chairs were free to set time limits for presentations. Presentations were generally limited to 8 to 10 minutes. Questions from the audience were accepted at the end of each session. A meeting timer was used to assure that speakers stayed within allocated time limits.

Each presenter provided briefing charts and either a full-length paper or an extended abstract. Papers, presentation charts, and videos of presentations are available at the conference website.[2]

DAY 1

Session 1: Space Mission Highlights

After welcoming remarks from Mr. Mairus-Ioan Piso, representing the International Academy of Astronautics (IAA), and Mr. Niklas Hedman, Acting Director of the conference's host, the United Nations Office of Outer Space Affairs (UNOOSA), speakers in Session 1 provided highlights from the Double Asteroid Redirection Test (DART) mission and its effects on Didymos and its moon Dimorphos. Included were images captured by LICIACube during and after the DART spacecraft's impact. The session included overviews of ESA's Hera Mission, Japan's Huyabusa2 mission, and requirements for a pre-encounter mission to complement post-encounter studies of the OSIRIS-APEX mission to asteroid Apophis.

Hypothetical Asteroid Impact Hazard Exercise

A highlight of the conference was the tabletop exercise on Day 1 that considered a threat posed by a HYPOTHETICAL asteroid.

First Notification of Possible Impact Threat

The exercise began with a presentation that a 220-to-660-meter asteroid had been discovered that had a 1% probability of impacting Earth on 22 October 2036, ~13 years after discovery.

A panel of decisionmakers was convened to consider details of the threat and discuss options for a fly-by or orbiting mission to enhance knowledge of the object and its orbit. The panel was moderated by Romana Kofler of UNOOSA, and panel members were:

- Matthew Daniels, Assistant Director of White House Office of Science and Technology Policy for Space Security & Special Projects, US
- Halilu Ahmad Shaba; Director-General of the Nigerian Space Agency (NASRDA)
- Rolf Densing, Director of Operations, European Space Agency (ESA)

[2] https://iaaspace.org/event/8th-iaa-planetary-defense-conference-2023/

- Bulbul Mukherjee, Deputy General Manager, Safe and Sustainable Operations Management, Indian Space Research Organization (ISRO) (virtual)
- Erik Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Meshack Kinyua Ndiritu, African Union Commission (virtual)
- Lorant Czaran, Senior Programme Officer, UNOOSA/UN-SPIDER

And two attorneys provided their insights on legal issues that should be considered:

- Prof. David Koplow, Georgetown University
- Prof. Jack Beard, University of Nebraska

In the lead-up to the conference, panel members had been offered a read-ahead package that included the following:

- An interactive "Planetary Defense Decision Tree" presentation[3]
- A draft "Planetary Defense Decisionmaker Guide"[4]
- A two-page "Planetary Defense Pocket Reference"[5]

This afforded those participants who were not Planetary Defense experts with an overview of relevant concepts, capabilities, and challenges. Details on the exercise are provided in APPENDIX F. A summary follows.

As a starting point for the exercise, IAWN provided the panel descriptions of the threatening object based on early observations, current uncertainties of impact (1%), and an overview of possible consequences should impact occur (see APPENDIX F).

Michael Byers of the Outer Space Institute provided a decision tree for planetary defense that included pre-discovery decisions and actions, such as building capabilities, building international cooperation, building consensus on available techniques, and what happens if there is a partial deflection. He suggests the ideal response is to have pre-discovery agreements, early detection, international cooperation, a rapid reconnaissance mission, and a rapid, non-nuclear deflection. He also discusses issues associated with the decision to use a nuclear device (see APPENDIX F).

Alissa Haddaji and David Koplow of the Space Mission Planning Advisory Group (SMPAG's) Ad-Hoc Legal Working Group on Planetary Defense discussed the main legal and policy questions associated with the conference's threat scenario (also in APPENDIX F). They discussed the legality of sending a "nuclear bomb" to the upcoming asteroid and noted that approval of the UN Security Council would be required for that action.

Based on that information, it was recommended that a spacecraft be sent to either fly by, or preferably, orbit the approaching object to provide more precise information on the object's orbit, impact probability and physical properties.

Update on Threat

Based on new observations, IAWN refined the object to be in the size range of 300 to 880 meters, and the refined orbit of the object shows that, without mitigation, there was a 100% likelihood of Earth impact in West Africa, somewhere along a narrow corridor extending from south of the Canary Islands southeast to the southern Congo River region. Information was provided on the possible consequences of impact in the impact corridor, and the IAWN notice stated that based on the latest predicted impact

[3] https://prezi.com/view/1Ts9wLHCOwIfngjeo1em
[4] https://tinyurl.com/Draft-PDDG-2023
[5] https://tinyurl.com/Draft-PDPR-2023

corridor and results of risk modeling: “There is a high probability that hundreds of thousands to millions of people on the African continent could be affected by the potential damage of the impact.”

The Space Mission Planning Advisory Group (SMPAG) provided detailed information on possible space missions to learn more about the asteroid and to deflect the threatening object away from Earth. Given that information plus details on impact consequences, the decisionmaker panel considered issues associated with possible responses to the threat, including use of kinetic impactors and nuclear explosive devices (NEDs) to deflect the object.

The IAWN alerts, details on impact consequences and possible reconnaissance and deflection missions developed by SMPAG, and legal and policy considerations associated with responses to the threat are in APPENDIX F.

DAY 2

Session 2: Key International and Policy Developments

Presentations in Session 2 summarized new and progress on past activities related to planetary defense. These included updates on planetary defense programs in the United States, New Zealand, Brazil, ESA, European Union, Japan, China, and Austria.

Proposal for International Year of Planetary Defense

At the conclusion of Session 2, a special presentation provided information and status of planning of efforts to make the year 2029 (the year asteroid Apophis will make a very close pass to our planet) an international year of planetary defense.

Panels 2/1: National Security Preparedness Roles in Planetary Defense

Panel members were:

- Matthew Daniels, Assistant Director of White House Office of Science and Technology, Policy for Space Security & Special Projects
- Halilu Ahmad Shaba; Director-General of the Nigerian Space Agency and former Director of National Disaster Preparedness Agency
- Andreas M. Herndler, Head of Crisis Management Unit of the Austrian Federal Ministry for Climate Action
- Eric Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Joel Mozer; Chief Scientist, United States Space Force Director of Science, Technology and Research

Moderators: Lindley Johnson, Planetary Defense Officer, NASA PDCO, Juan Carlos Villagran, Senior Programme Officer, UNOOSA/UN-SPIDER

Panel 2/2: UN & International Disaster Management for Planetary Defense

Panel members were:

- Juan Carlos Villagran, Senior Programme Officer, UNOOSA/UN-SPIDER (Multi-hazards and international cooperation).
- Eric Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Muzna Assi, Emergency Preparedness Officer, Incident and Emergency Centre IAEA (Joint Radiation Emergency Management Plan)
- Pierrick Mialle, International Data Centre Division, Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO)

- Denis Chang Seng, Global Ocean Observing System GOOS and Tsunami Resilience Section, Technical Secretary, UNESCO-International Oceanographic Commission (UNESCO-IOC)
- Lara Mani, representative from University of Cambridge Centre for the Study of Existential Risk

Moderators: Juan Carlos Villagran, Senior Programme Officer, UNOOSA/UN-SPIDER,
Leviticus "LA" Lewis, FEMA/Liasson with NASA PDCO.

Session 3: NEO Discovery

Presentations in this session highlighted new developments related to the search, discovery and characterization of asteroids. Included were results of an analysis of the plume of ejecta after the DART impact, assessment of capabilities and limitations of flyby missions, lessons learned from IAWN global planetary defense campaigns, an improved method for estimating asteroid impact probability, and an assessment of using planetary radar to characterize NEOs.

DAY 3

Session 4: NEO Characterization

There were 17 presentations in the session. Two presentations discussed the surface and ejecta reflectance properties of Didymos and Dimorphos derived from DART and LICIACube imagers and a color analysis of the plume of ejecta from Dimorphos after DART impact. Other briefers discussed:

- Didymos energy dissipation prior to the arrival of the Hera spacecraft,
- Limitation of flyby missions to characterize asteroids and using Doppler gravimetry to estimate mass during flyby,
- Current and prospects for using ground-based radars to support planetary defense,
- Long-term impact hazard of kilometer sized NEOs,
- An improved method for estimating asteroid impact probability via swarm intelligence algorithms,
- Size and albedo distributions of NEOs observed by NEOWISE,
- The NEOROCKS project,
- NEO orbits and sizes based on IOTA occultation observations,
- Determination that Asteroid 1998 OR2 has a heterogeneous surface,
- Reconstruction of the shape and spin state of Asteroid (99942) Apophis from its photometric light, and
- Detecting internal shifts within Apophis as it flies by Earth in 2029

Panel 3: Providing Clear, Concise, Correct Information to the Public

Panel members were:

- Peter Kaiser, Crisis Communications Adviser at the International Atomic Energy Agency
- Sonja Wintersberger, Deputy to the Director of the United Nations Information Service
- Mat Kaplan, Senior Communications Adviser and former host of Planetary Radio, The Planetary Society
- Anastasia Medvedeva, International journalist and co-founder of the aerospace marketing and communications agency re.Gravity (virtual)

Moderator: Alex Karl, PDC Chair

Session 5: Deflection / Disruption Testing & Modeling

Presentations in this session discussed:

- 3-D Characterization of the Ejecta Produced by the DART Impact
- Modeling the DART Impact: Effects of Surface Morphology and Rubble Pile Structure on Deflection Observables
- Deflecting rubble-pile asteroids: Lessons learned from the DART impact on Dimorphos
- Simulating the DART impact: Effects of spacecraft and boulder geometry on ejecta
- Spacecraft Geometry Effects for the DART Mission
- Designing the Next Generation of Kinetic Impactors
- Momentum Enhancement of Rubble Pile Simulants At 5 km/s
- Extending NEO Deflection Formulae to High Fluences
- Initiating Nuclear Mitigation Mission Simulations with a Simplified X-Ray Energy Deposition Model

Session 6: Space Mission & Campaign Design

Presenters discussed:

- Rapid-response Flyby Exploration using a Deep Space Constellation deployed on Asteroid Flyby Cyclers
- Planetary Defense Mission Campaign Design for the 2023 PDC Hypothetical Asteroid Impact Scenario
- Defending Earth Against the 2023 PDC Hypothetical Asteroid Impact
- A CubeSat to detect meteoroid impacts on the lunar farside
- Creating a Contact Binary via Spacecraft Impact to Near-Earth Binary Asteroid
- A mission concept to flyby Apophis before its Earth encounter to demonstrate flyby reconnaissance for planetary defense
- Optimal Impulsive/Low-Thrust Trajectories for Asteroid Deflection via Kinetic Impact
- Low-Cost Mission Architectures to Small Bodies
- Prospects for Future Human Space Flight Missions to Near-Earth Asteroids
- Possibilities of Using a Spacecraft Located in the Vicinity of the Libration Point for Near-Earth Objects Exploration
- Apophis Pathfinder: A MILO Space Science Institute Smallsat Mission in Support of Science and Planetary Defense
- Development and Prospects of Chinese Near-Earth Asteroids Monitoring and Early Warning Capability System and International Cooperation

DAY 4

Session 7: Earth Impact Effects & Consequences

Presenters discussed:

- Predicting the Consequences of NEO Impacts on Earth
- Asteroid Impact Risk Across Transitional Hazard Regimes
- Asteroid Impacts and Cascading Hazards
- Machine learning for the prediction of local asteroid damages
- Consequences of Asteroid Characterization on the State of Knowledge about Inferred Physical Properties and Impact Risk

- Numerical Modeling of Asteroid Ocean Impact: Preparing a Pipeline for Future Scenario Modeling
- 2023 PDC Exercise: Global Tsunami from Land or Ocean Impact
- Sensitivity Study of Impact Risk Model Results to Thermal Radiation Damage Model for Large Objects
- Entry Angle Effects on the Ground Signature of the Chelyabinsk superbolide
- Advances in Entry Modeling for Impact Risk Assessment
- Accurate Characterization of Meter-sized Impactors Through Casual Bolide Observations – Novo Mesto Superbolide as Evidence for a New Class of High-Risk Objects
- High-Fidelity Blast Propagation Modeling for Hypothetical Asteroid 2023 PDC
- Tonga Tsunami Provides Data, Verification for Blast-generated Global Tsunami Modeling
- Atmospheric Breakup Behavior Of 2022 WJ1
- Computational Analysis of Ground Effects from Bolide Disruption via the PI Method
- Terminal Planetary Defense

Session 8: Disaster Management & Earth Impact Response

Presenters discussed:

- Results from the EU-ESA Workshop on NEO Imminent Impactors Warning Coordination
- Evacuation and shelter plans for asteroid impacts

Session 9: The Decision to Act: Political, Legal, Social, and Economic Aspects

Presenters discussed:

- To aid or not to aid, should it be a question: the geopolitical ethical concerns in planetary defense missions
- Collective action problems in Planetary Defense
- Legal Framework of the UN Security Council's role in decision and implementation of Planetary Defense action
- Legal considerations on a regional security organization for Planetary Defense
- Diplomatic, Geopolitical and Economic Consequences of an impending asteroid impact threat
- Stressors on international cooperation and coordination in NEO threat mitigation and response
- Planetary defense governance: from ad-hoc decision making to multilateral security regime
- Legal complications of private planetary defense missions
- Proposing a holistic approach to an appropriate legal framework for planetary defense
- Popular Impact: Public Opinion and Planetary Defense Planning

Panel 4: Legal and Policy Issues for Planetary Defense

Panel members were:

- Irmgard Marboe, Professor, University of Vienna
- Kelly E. Fast, IAWN Coordinator
- Detlef Koschny, SMPAG Chair
- Christopher Johnson, Secure World Foundation
- Michael Byers, Professor, University of British Columbia

Moderator: Alissa J. Haddaji, SMPAG Legal WG Coordinator

DAY 5

Session 10: Public Education & Communication

Presenters provided information on:

- A Unique Communication Experience in Planetary Defense as a Possible Starting Point for the Italian Involvement in the International Year of Planetary Defense
- Public Education Activities for Planetary Defense in Japan
- Humans And Hazardous Asteroids - 30 Years of Experience In Education And Communication
- Debunking The Panic Myth and What It Means For NEO Communication Strategies
- Apophis as the Demon Serpent of Darkness: Designing Communication Protocols for Misinformation and Conspiracy Theories in Planetary Defense
- Towards a Robust and Resilient Mechanism for the Distribution of Information During an Asteroid Mitigation Event

In the post-conference wrap-up on Day 5, attendees noted the single-track feature as a very positive aspect of the meeting. During and at the end of the conference, attendees were asked for their input for findings and recommendations that should be carried forward in this summary report. This material is included in APPENDIX G.

APPENDIX A: SPONSORS & SUPPORTERS

The conference was sponsored by:

European Space Agency
National Aeronautics and Space Administration's Planetary Defense Coordination Office
The Aerospace Corporation
The Planetary Society
International Academy of Astronautics (IAA)
B612 Foundation
International Astronomical Union (IAU)
Johns Hopkins Applied Physics Laboratory
Secure World Foundation
GMV Aerospace and Defense
Association of Space Explorers
Austrian Academy of Sciences
FFG (Austrian Research Promotion Agency)

PDC2023 supporters were:

United Nations Office of Outer Space Affairs
Space Generation Advisory Council
Asteroid Day

APPENDIX B: CONFERENCE CHAIRS & ORGANIZING COMMITTEE

CONFERENCE CHAIRS

Bill Ailor	The Aerospace Corporation
Brent Barbee	NASA/Goddard Space Flight Center / University of Maryland
Gerhard Drolshagen	University of Oldenburg
Alex Karl	IAF TC on PD and NEOs
Nahum Melamed	The Aerospace Corporation

ORGANIZING COMMITTEE MEMBERS

Rudolf Albrecht	
James (Gerbs) Bauer	University of Maryland
Randy Belll	The Aerospace Corporation
Bruce Betts	The Planetary Society
Linda Billings	Consultant to NASA's Planetary Defense Coordination Office
Mark Boslough	Los Alamos National Laboratory / University of New Mexico
Marina Brozovic	Jet Propulsion Laboratory
Juan Cano	ESA/ESRIN NEO Coordination Centre (NEOCC)
Ian Carnelli	ESA
Clark Chapman	Southwest Research Intitute
Andrew Cheng	The Johns Hopkins University Applied Physics Laboratory
Paul Chodas	Jet Propulsion Laboratory
Jean-Michel Contant	International Academy of Astronautics
R. Daly	The Johns Hopkins University Applied Physics Laboratory
Doris Daou	NASA/Planetary Defense Coordination Office
Fabrice Dennemont	International Academy of Astronautics
Jessie Dotson	NASA/Ames Research Center
Michael Egan	NASA/HQ
Kelly Fast	NASA/Planetary Defense Coordination Office
Dawn Graninger	The Johns Hopkins University Applied Physics Laboratory
Mariella Graziano	GMV Aerospace and Defence
Phil Groves	
Alissa Haddaji	Harvard Law School
Joshua Handal	NASA/HQ
Alan Harris	Jet Propulsion Laboratory (retired)
Thomas Hollensteiner	Permanent Mission of Austria to the United Nations in Vienna
Curtis Iwata	The Aerospace Corporation
Lindley Johnson	NASA/Planetary Defense Coordination Office
Thomas Jones	Association of Space Explorers
Andrea Kleinsasser	Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, Austria
Christian Koeberl	University of Vienna
Romana Kofler	United Nations Office for Outer Space Affairs (UNOOSA)

Detlef Koschny	ESA and Chair of Astronautics, TU Munich/Germany
Peter Kraan	ESA Conference Bureau Service Provider
Rob Landis	NASA/Johnson Space Center
Leviticus (L.A.) Lewis	DHS/FEMA
Ed Lu	B612 Asteroid Institute / LEOLabs
Joshua Lyzhoft	NASA/Goddard Space Flight Center
Amy Mainzer	University of Arizona
Irmgard Marboe	University of Vienna
Stephan Mayer	Austrian Research Promotion Agency
Patrick Michel	Univ. Côte d'Azur; Observatory, Cote d'Azur, CNRS
Richard Moissl	ESTEC - European Space Research and Technology Centre
David Morrison	SETI Institute
Connor Mulrenin	NASA/Goddard Space Flight Center
Lea Nagel	University of Vienna
Jan Osburg	RAND
Cordula Panosch	University of Vienna
Ryan Park	Jet Propulsion Laboratory
Gisela Poesges	Geopark Ries e. V., Nördlingen, Germany
Andy Rivkin	The Johns Hopkins University Applied Physics Laboratory
Bruno Sarlli	NASA/Goddard Space Flight Center
Liu Sen	China Aerodynamics Research and Development Center
Angela Stickle	The Johns Hopkins University Applied Physics Laboratory
Megan Syal	Lawrence Livermore National Laboratory
Marco Tantardini	Consultant, former Space Policy Officer in the Office of the Italian Prime Minister
Karel van der Hucht	SRON Netherlands Institute for Space Research
George Vardaxis	The Aerospace Corporation
Lorien Wheeler	NASA/Ames Research Center
Kai Wünnemann	Museum für Naturkunde Berlin / Leibniz-Institute for Evolution and Biodiversity Science
Makoto Yoshikawa	Japan Aerospace Exploration Agency (JAXA)

APPENDIX C: IN-PERSON ATTENDEES

Wadud Abdul
Paul Abell
Lauren Abrahams
Elena Adams
Harrison Agrusa
William Ailor
Miguel R. Alarcon
Rudolf Albrecht
Max Alexander
Theodora Andreescu
Simon Anghel
Steven Arnold
Jacques Arnould
Adfa Asd
Justin Atchison
Ronald Ballouz
Nishchal Baniya
Michele Bannister
Brent Barbee
Mfon Bassey
James M Bauer
Jack Beard
Randy Bell
Jim Bell
Jodi Berdis
Patrick Besha
Mirel Birlan
Caterina Boccato
Melanie Bochmann
Mark Boslough
Pierre Bousquet
Marina Brozovic
Megan Bruck Syal
Viktor Bruckman
Ry Bull
Mary Burkey
Melissa Buys
Michael Byers
Wendy Caldwell
Adriano Campo Bagatin
Juan L. Cano
Margherita Cardi
Ian Carnelli
Nancy Chabot
Yu Wei Chen
Andy Cheng
Steven Chesley
Paul Chodas
Gregoire Chomette
Eric Christensen
Richard Cloete
Ashley Coates
Luca Conversi
Bruce Conway
Terik Daly
Simona-Nicoleta Danescu
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Simone Dell'Agnello
J D P Deshapriya
Maxime Devogele
Sanchi Dhamija
Gianpiero Di Girolamo
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Elisabetta Dotto
Casey Dreier
Daniela Drobna
Gerhard Drolshagen
Josef Durech
Karolina Dziadura
Siegfried Eggl
Anietie Ekanem
Charles Emmerson
Raymond Espiritu
Zhengqing Fang
Tony Farnham
Davide Farnocchia
Kelly Fast
Petr Fatka
Marco Fenucci
Marin Ferrais
Fabio Ferrari
Ludovic Ferrière
Lorraine Fesq
Colleen Fiaschetti
Zachary Fletcher
Iosto Fodde
Dora Föhring
Michael Frühauf
Irmgard Fuchs
Oscar Fuentes-Muñoz
Francesco Gianotto
Brett Gladman
Nathan Golovich
Werner Grandl
Dawn Graninger
Hannes Groeller
Phil Groves
Ryan Guglietta
Daria Guidetti
Yingran Guo
Alissa J. Haddaji
Pedro Henrique Hasselmann
Sebastian Henderson
Alain Herique
Daniel Hestroffer
Masatoshi Hirabayashi
Thomas Hollensteiner
Simone Ieva
Dan Ifrim
Anatoliy Ivantsov
Jonathan Iwry
Koji Izumi
Judith Jahnke
Laura Jamschon Mac Garry
Etienne Jeandaux
Youngmin JeongAhn
Peter Jevčák
Jeremy John
Christopher Johnson
Lindley Johnson
Mario Juric
Martin Jutzi
Jason Kalirai
Aurelio Kaluthantrige
Alex Karl
Michael Kelley
Amanda Kerrigan
Kathleen Kiker
Myungjin Kim
Patrick King
Andrea Kleinsasser
Christian Koeberl
Andrew Koehler
Romana Kofler
Tomas Kohout
David Koplow
Detlef Koschny
Peter Kraan
Michael Kueppers
Kathryn Kumamoto
Gaurav Kumar
Jutta Kunz-Drolshagen
Georgios (George) Kyriakopoulos
Rob Landis
Joseph Lazio

Anna Maria R Leenders
Cassandra Lejoly
Leviticus Lewis
Jian-Yang Li
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Javier Licandro
Tim Lister
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Amy Mainzer
Rahil Makadia
Ludovica Malagni
Robert Managan
Lara Mani
Sean Marshall
Joseph Masiero
Donovan Mathias
Hannes Mayer
Monica Maynard
Nahum Melamed
Avishai Melamed
Qingliang Meng
Colby Merrill
Alex Meyer
Patrick Michel
Marco Micheli
Joachim Moeyens
Richard Moissl
Fernando Moreno
Nicholas Moskovitz
Naomi Murdoch
Shantanu Naidu
Ryota Nakano
Arushi Nath
Vikas Nath
Spencer Nelson
Krzysztof Niewęgłowski
Guillaume Noiset
Francisco Ocaña
Dario Oliviero
Roberto Orosei
Jan Osburg
Mike Owen
Naoya Ozaki
Gerhard Paar
Maurizio Pajola
Erika Palmer
Ryan Park
Jason Pearl
Andrea Pellacani
Davide Perna
Marius-ioan Piso
Marcel Popescu
Tony Prater
Petr Pravec
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Sabina Raducan
Emma Rainey
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Edward Reynolds
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Darrel Robertson
Colas Robin
Nathan Roth
Regina Rudawska
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Hannany Salehuddin
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Milos Tichy
Timothy Titus
Christoph Traxler
Stephan Ulamec
Helen Usher
Tom Vanderbilt
George Vardaxis
Dmitrii Vavilov
Matthew Vavrina
Flaviane Venditti
Peter Veres
Bruno Victorino Sarli
Denis Vida
Anne Virkki
Daria Wagner
Richard Wainscoat
James Walker
Dany Waller
Kaiduo Wang
Zhaokui Wang
Dietmar Weinzinger
Robert Weryk
Lorien Wheeler
Connor Wilson
John Wimarsson
Matthias Winter
Nancy C. Wolfson
Kai Wünnemann
Zhen Xiang
Makoto Yoshikawa
Luisa Fernanda Zambrano-Marin
Grace Zimmerman
Hossain Zobayer
Michal Zolnowski

APPENDIX D: PROGRAM

2 April 2023: DART Mission Overview

Program:

Christian Köberl	Chair, Commission for Geosciences and Deputy Chair, Commission for Astronomy, OeAW & University of Vienna *Impacts on Earth and in the Solar System*
Lindley Johnson	National Aeronautics and Space Administration (NASA), USA *Planetary Defense at NASA: Defending planet Earth one rock at a time*
Elena Adams	Johns Hopkins Applied Physics Lab, USA *Double Asteroid Redirection Test (DART): What does it take to impact an asteroid?*
Nancy Chabot	Johns Hopkins Applied Physics Lab, USA *DART Post-Impact: What have we learned about deflecting asteroids?*
Michael Kueppers	European Space Agency (ESA), Germany *Die ESA Mission Hera: Wie sehen Didymos und Dimorphos nach dem Einschlag von DART aus?*

DAY 1

Day 1	Monday	3 April, 2023, Board-room D, Vienna International Centre (VIC)	
Start	**Duration**		**Speaker / Presenter**
9:50	0:10	Opening of the Conference	Conference Chairs
10:00	0:10	Welcoming Remarks: **Mr Marius Ioan Piso, IAA Vice-President for Scientific Activities**	IAA
10:10	0:10	Keynote Address**: Mr Niklas Hedman,UNOOSA Acting Director**	UNOOSA
CHAIRS: Ryan Park Ian Carnelli Richard Moissl		**Session 1a: Space Mission Highlights - DART, LICIACube**	**Speaker / Presenter**
10:20	0:10	DART Mission - Getting to Dimorphos impact and lessons learned	Elena Adams
10:30	0:10	Didymos and Dimorphos before, during, and after the DART impact	Andy Rivkin
10:40	0:10	Change in the mutual orbit of Dimorphos due to the DART impact	Shantanu Naidu
10:50	0:10	Determination of Dimorphos's Change in Velocity Resulting from the DART Kinetic Impact	Harrison Agrusa
11:00	0:10	Determination of Momentum Transfer to Dimorphos from the DART Kinetic Impact	Andrew Cheng
11:10	0:10	LICIACube: the witness of the DART impact	Elisabetta Dotto

11:20	0:15	Q&A / Discussion	
11:35	0:30	**COFFEE BREAK**	
CHAIRS: Ryan Park Ian Carnelli Richard Moissl		**Session 1b: Space Mission Highlights (continued) - Hera, Hayabusa2, OSIRIS-REx/APEx**	**Speaker / Presenter**
12:05	0:10	The ESA Hera Mission: Detailed Investigation of the NASA DART Impact Outcome and Characterization of the Binary Asteroid Didymos	Patrick Michel
12:15	0:10	The Hera mission	Ian Carnelli
12:25	0:10	What if Ryugu hits on Earth?	Satoshi Tanaka
12:35	0:10	Hayabusa2 Extended Mission: Hayabusa2#	Makoto Yoshikawa
12:45	0:10	Pre-encounter mission requirements to complement OSIRIS-APEX post-encounter-studies of the asteroid Apophis	Thomas Kohout
12:55	0:10	Q&A / Discussion	
13:05	1:25	**LUNCH**	
CHAIRS: Romana Kofler William H. Ailor		Afternoon programme: **Hypothetical Asteroid Impact Hazard Exercise: Decision-Making, Legal, Policy and Disaster Preparedness Implications**	**Speaker / Presenter**
14:30	0:10	Introduction to IAWN, SMPAG, and The Hypothetical Impact Exercise	Kelly Fast
14:40	0:15	Decision Tree Presentation	Michael Byers
14:55	0:15	Legal and Policy Issues	Alissa Haddaji, David Koplow
15:10	0:25	IAWN: Presentation of hypothetical asteroid impact hazard scenario & potential impact consequences for Epoch 1	Paul Chodas, Lorien Wheeler, Kelly Fast
15:35	0:45	**PANEL 1 for Decision-Makers (1.part)**	
16:20	0:20	**COFFEE BREAK**	
16:40	0:05	SMPAG Epoch 2 Update Summary	Detlef Koschny
16:45	0:15	SMPAG: Presentation of space mission options analysis	Brent Barbee, Detlef Koschny
17:00	0:60	**PANEL 1 for Decision-Makers (2.part), to include audience/media discussion/ Q&A**	
18:00		**END OF DAY 1**	
18:00		Welcome reception and exhibition in the Rotunda, VIC	
20:00		**END OF RECEPTION / EXHIBITION**	

Day 1 Panels 1 and 2:

- Matthew Daniels, Assistant Director of White House Office of Science and Technology, Policy for Space Security & Special Projects, US
- Halilu Ahmad Shaba; Director-General of the Nigerian Space Agency (NASRDA)

- Rolf Densing, Director of Operations, European Space Agency (ESA)
- Bulbul Mukherjee, Deputy General Manager, Safe and Sustainable Operations Management, Indian Space Research Organization (ISRO) (virtual)
- Erik Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Meshack Kinyua Ndiritu, African Union Commission (virtual)
- Lorant Czaran, Senior Programme Officer, UNOOSA/UN-SPIDER
- Legal experts:
  Prof. David Koplow, Georgetown University
  Prof. Jack Beard, University of Nebraska
  Moderator: Romana Kofler, Programme Management Officer, Committee, Policy and Legal Affairs Section, UNOOSA

DAY 2

Day 2	Tuesday	4 April, 2023, Board-room D, Vienna International Centre (VIC)	
Start	**Duration**		**Speaker / Presenter**
9:00	0:05	Welcoming Remarks	Conference Chairs
CHAIRS: Lindley Johnson Detlef Koschny		**Session 2: Key International and Policy Developments**	**Speaker / Presenter**
9:05	0:08	Update on NASA's Planetary Defense Program	Lindley Johnson
9:13	0:08	Planetary Defense: Findings and Recommendations from the National Academies Planetary Science and Astrobiology Decadal Survey 2023 - 2032	Paul Abell
9:21	0:08	New Zealand's contribution to planetary defence	Michele Bannister
9:29	0:08	Proposal of Creation of a Planetary Defense Office in Brazil Based in Existing Capabilities	Ana Lucia Pegetti
9:37	0:08	ESA's activities in Planetary Defence	Richard Moissl
9:45	0:08	JAXA activities in NEOs and planetary defence	Makoto Yoshikawa
9:53	0:08	Near-Earth Asteroid Defence (Lunar Exploration and Space Programe Centre, CNSA)	Qi Chen (virtual)
10:01	0:08	NEOROCKS: The 2020-2023 EU Programme for Planetary Defence	Elisabetta Dotto
10:09	0:08	How NASA's Planetary Defense Budget Grew by More Than 4000% in 15 Years: Lessons in Strategic Alignment	Casey Dreier
10:17	0:08	Current Activities in the Field of SSA: Contributions by the MOD Austria to the Ongoing Discussion	Norbert Frischauf
10:25	0:20	Q&A / Discussion	
10:45	0:25	Topic: Updated U.S. National Strategy for Planetary Defense	Matt Daniels
11:10	0:30	**COFFEE BREAK**	

11:40	1:00	**PANEL 2/1 : National Security Preparedness Roles in Planetary Defence**	
12:40	1:00	**LUNCH**	
13:40	0:20	**Keynote** Bhavya Lal, NASA Associate Administrator	NASA (virtual)
14:00	1:00	**PANEL 2/2: UN & International Disaster Management**	
15:00	0:15	Plans for the International Year of Planetary Defense	Doris Daou
CHAIRS: James M Bauer Kelly E. Fast		**Session 3: NEO Discovery (16 talks plus 12 posters)**	**Speaker / Presenter**
15:15	0:30	Observational Activities and Key Results from ESA's Planetary Defence Office	Marco Micheli
15:23	0:08	The Pan-STARRS Search for Near-Earth Objects	Richard Wainscoat
15:31	0:08	Catalina Sky Survey: NEO Discovery, Follow-Up and Beyond	Eric Christensen
15:39	0:08	Detection of small, hazardous asteroids by ATLAS and contemporaneous NEO surveys in the era of LSST	Larry Denneau
15:47	0:08	Surveying the interior secrets of the Solar System	T. Santana-Ros
15:55	0:08	Updated Digest2 – the NEO classification code	Peter Veres
16:03	0:08	JPL Scout's Imminent Impactor Warning Performance: 2022 EB5 and 2022 WJ1	Stephen Chesley
16:11	0:08	The two timing campaigns of the International Asteroid Warning Network	Davide Farnocchia
16:19	0:13	Q&A / Discussion	
16:32	0:10	**BREAK**	
16:42	0:08	First Results of a Fireball Flux Measurement with the AllSky7 Fireball Network	Michael Fruhauf
16:50	0:08	Real-time synthetic tracking for near-Earth asteroids detection	Malin Stanescu
16:58	0:08	Near Earth Objects in the recent Isolated Tracklet File	Robert Weryk
17:06	0:08	Rubin Observatory LSST: Status, NEO Expectations, and Community Readiness	Mario Juric
17:14	0:08	ATLAS-Teide: the next generation of ATLAS units at Teide Observatory	Javier Licandro
17:22	0:08	ESA's Flyeye Telescope Network	Dora Fohring
17:30	0:08	The Near-Earth Object Surveyor Mission	Amy Mainzer
17:38	0:08	NEOMIR: A Space-Based Infrared Mission for NEO Detection, Characterisation, and Early Warning	Luca Conversi
17:46	0:14	Q&A / Discussion	
18:00		**END OF DAY 2**	
18:00		**POSTER VIEWING*, Rotunda/PHOTO taking**	
20:00		**END OF POSTER VIEWING IN THE ROTUNDA**	

*** See APPENDIX E for a listing of Poster Papers.**

Day 2 Panel 1: National Agency Preparedness Roles for Planetary Defense, 11.40-12.40 CEST:

- Matthew Daniels, Assistant Director of White House Office of Science and Technology, Policy for Space Security & Special Projects
- Halilu Ahmad Shaba; Director-General of the Nigerian Space Agency and former Director of National Disaster Preparedness Agency
- Andreas M. Herndler, Head of Crisis Management Unit of the Austrian Federal Ministry for Climate Action
- Eric Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Joel Mozer Chief Scientist, United States Space Force Director of Science, Technology and Research

  Moderators: Lindley Johnson, Planetary Defense Officer, NASA PDCO, Juan Carlos Villagran, Senior Programme Officer, UNOOSA/UN-SPIDER

Day 2 Panel 2: UN & International Disaster Management for PD, 14.00-15.00 CEST

- Juan Carlos Villagran, Senior Programme Officer, UNOOSA/UN-SPIDER (Multi-hazards and international cooperation).
- Eric Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Muzna Assi, Emergency Preparedness Officer, Incident and Emergency Centre IAEA (Joint Radiation Emergency Management Plan)
- Pierrick Mialle, International Data Centre Division, Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO)
- Denis Chang Seng, Global Ocean Observing System GOOS and Tsunami Resilience Section, Technical Secretary, UNESCO-International Oceanographic Commission (UNESCO-IOC)
- Lara Mani, representative from University of Cambridge Centre for the Study of Existential Risk

  Moderators: Juan Carlos Villagran, Senior Programme Officer, UNOOSA/UN-SPIDER, Leviticus "LA" Lewis, FEMA/Liasson with NASA PDCO.

DAY 3

Day 3	Wednesday	5 April, 2023, Board-room D, Vienna International Centre (VIC)	
Start	**Duration**		**Speaker / Presenter**
9:00	0:05	Welcoming Remarks	Conference Chairs
9:05	0:20	**Keynote Address: Rolf Densing, ESA Director of Operations**	ESA
CHAIRS: James M Bauer Marina Brozović Andy Cheng		**Technical Session 4a: NEO Characterization**	**Speaker / Presenter**
9:25	0:08	Dydimos and Dimorphos surface and ejecta reflectance properties through DART and LICIACube imaging	Pedro Henrique Hasselmann
9:33	0:08	The Color Analysis Of Dimorphos Plume Produced By Dart Impact Using Liciacube-luke Data: Results On Physical Properties And Composition To Better Constrain Planetary Defence Efficency	Giovanni Poggiali
9:41	0:08	Energy Dissipation in Didymos Prior to Hera's Arrival	Alex Meyer

9:49	0:08	Assessing The Capabilities And Limitations Of Flyby Missions For Planetary Defense Characterization	Jodi Berdis
9:57	0:08	Hypothetical Asteroid 2023 PDC Mass Measurement Via Doppler Gravimetry In A Reconaissance Flyby	Ry Bull
10:05	0:08	IAWN Global Planetary Defense Campaigns: Lessons Learned	Michael Kelly
10:13	0:08	Ground-based Planetary Radars: Current And Future Prospects	Joseph Lazio
10:21	0:08	The Long-term Impact Hazard Of km-sized Near-Earth Objects	Oscar Fuentes-Muñoz
10:29	0:08	An improved method for asteroid impact probability due to swarm intelligence algorithms	Andrew Koehler
10:37	0:13	Q&A / Discussion	
10:50	0:20	**BREAK**	
CHAIRS: James M Bauer Marina Brozović Andy Cheng		**Technical Session 4b: NEO Characterization (continued)**	**Speaker / Presenter**
11:10	0:08	Size And Albedo Distributions Of Near-earth Asteroids Observed By Neowise	Akash Satpathy
11:18	0:08	NEOROCKS Project: Spectrophotometry Of Small Near-Earth Asteroids	Maria Antonietta Barucci
11:26	0:08	Binary Systems Among Near-Earth Asteroids Observed Within the NEOROCKS project	Petr Pravec
11:34	0:08	NEO Orbits and Sizes From IOTA Occultation Observations	David Dunham
11:42	0:08	Characterization Of Near-Earth Objects Using Planetary Radar Observations And Numerical Modeling	Anne Virkki
11:50	0:08	Physical Characterization and Shape Model of 1998 OR2 Shows Its Surface is Heterogeneous	Maxime Devogèle
11:58	0:08	Reconstruction Of The Shape And Spin State Of Asteroid (99942) Apophis From Its Photometric Light	Josef Durech
12:06	0:08	Detecting Internal Shifts Within Apophis Across its Earth Flyby	Daniel Scheeres
12:14	0:16	Q&A / Discussion	
12:30	1:00	**LUNCH**	
13:30	1:00	**Panel 3: Providing clear, concise, correct information to the public**	
CHAIRS: Megan Bruck Syal Dawn Graninger Patrick Michel		**Session 5: Deflection / Disruption Testing & Modeling**	**Speaker / Presenter**
14:30	0:08	3D Characterization of the Ejecta Produced by the DART Impact	Tony Farnham
14:38	0:08	Modeling the DART Impact: Effects of Surface Morphology and Rubble Pile Structure on Deflection Observables	Emma Rainey
14:46	0:08	Deflecting rubble-pile asteroids: Lessons learned from the DART impact on Dimorphos	Sabina Raducan
14:54	0:08	Momentum Enhancement of Rubble Pile Simulants At 5 km/s	James Walker
15:02	0:08	Simulating the DART impact: Effects of spacecraft and boulder geometry on ejecta	Kathryn Kumamoto
15:10	0:08	Spacecraft Geometry Effects for the DART Mission	Dawn Graninger

15:18	0:08	The Evolution of Shape: Designing the Next Generation of Kinetic Impactors	Patrick King
15:26	0:08	Extending NEO Deflection Formulae To High Fluences	Robert Managan
15:34	0:08	Initiating Nuclear Mitigation Mission Simulations with a Simplified X-Ray Energy Deposition Model	Mary Burkey
15:42	0:10	Q&A / Discussion	
15:52	0:20	**BREAK**	
CHAIRS: Marco Tantardini George Vardaxis (virtual) Bruno Victorino Sarli		**Session 6: Space Mission & Campaign Design**	**Speaker / Presenter**
17:12	0:08	Rapid-response Flyby Exploration using Deep Space Constellation deployed on Asteroid Flyby Cyclers	Naoya Ozaki
16:20	0:08	Planetary Defense Mission Campaign Design for the 2023 PDC Hypothetical Asteroid Impact Scenario	Brent Barbee
16:28	0:08	THEO & MUFN: Defending Earth Against the 2023 PDC Hypothetical Asteroid Impact	Melissa Buys
16:36	0:08	LUMIO: a CubeSat to detect meteoroid impacts on the lunar farside	Fabio Ferrari
16:44	0:08	Creating a Contact Binary via Spacecraft Impact to Near-Earth Binary Asteroid (350751) 2002 AW	Colby Merrill
16:52	0:08	Flyby Asteroid Reconnaissance (FLARE) mission to Apophis: A mission concept to Apophis before its Earth encounter to demonstrate flyby reconnaissance for planetary defense	Ronald Ballouz
17:00	0:08	Optimal Impulsive/Low-Thrust Trajectories for Asteroid Deflection via Kinetic Impact	Alessia Speziale
17:08	0:08	Low-Cost Mission Architectures To Small Bodies	Lorraine Fesq
17:16	0:08	Possibilities of Using a Spacecraft Located in the Vicinity of the Libration Point for Near-Earth Objects Exploration	Maxim Pupkov (virtual)
17:24	0:08	Prospects for Future Human Space Flight Missions to Near-Earth Asteroids	Brent Barbee
17:32	0:08	Apophis Pathfinder: A MILO Space Science Institute Smallsat Mission in Support of Science and Planetary Defense	Jim Bell
17:40	0:08	Development and Prospects of Chinese Near-Earth Asteroids Monitoring and Early Warning Capability System and International Cooperation (National Asteroid Monitoring and Early Warning Research Center, CNSA)	Fengyu Wang (virtual)
17:48	0:12	Q&A / Discussion	
18:00		**END OF DAY 3**	
20:15-22.30		IMAX Movie: Asteroid Hunters & The Planetary Society Public Event at the Cineplexx Donau Zentrum	

Day 3 Panel: Providing clear, concise, correct information to the public

- Peter Kaiser, Crisis Communications Adviser at the International Atomic Energy Agency
- Sonja Wintersberger, Deputy to the Director of the United Nations Information Service
- Mat Kaplan, Senior Communications Adviser and former host of Planetary Radio, The Planetary Society
- Anastasia Medvedeva, International journalist and co-founder of the aerospace marketing and communications agency Re. Gravity (Virtual)

Moderator: Alex Karl, PDC Chair

DAY 4

Day 4	Thursday	6 April, 2023, Board-room D, Vienna International Centre (VIC)	
Start	**Duration**		**Speaker / Presenter**
9:00		Welcoming Remarks and Information about Conference Poll results	Conference Chairs
CHAIRS: Mark Boslough Jessie Dotson Christian Koeberl		**Session 7A: Earth Impact Effects & Consequences (part A)**	**Speaker / Presenter**
9:25	0:10	Predicting the Consequences of NEO Impacts on Earth	Robert Luther
9:35	0:10	Asteroid Impact Risk Across Transitional Hazard Regimes	Lorien Wheeler
9:45	0:10	Asteroid Impacts and Cascading Hazards	Timothy Titus
9:55	0:10	Machine learning for the prediction of local asteroid damages	Gregoire Chomette
10:05	0:10	Consequences of Asteroid Characterization on the State of Knowledge about Inferred Physical Properties and Impact Risk	Jessie Dotson
10:15	0:10	Numerical Modeling of Asteroid Ocean Impact: Preparing Pipeline for Future Scenario Modeling	Lauren Abrahams
10:25	0:10	2023 PDC Exercise: Global Tsunami From Land or Ocean Impact	Mark Boslough
10:35	0:10	Sensitivity Study of Impact Risk Model Results to Thermal Radiation Damage Model for Large Objects	Ashley Coates
10:45	0:10	Entry Angle Effects on the Ground Signature of the Chelyabinsk Superbolide	Jason Pearl
10:55	0:10	Advances in Entry Modeling for Impact Risk Assessment	Eric Stern
11:05	0:10	Accurate Characterization of Metre-sized Impactors Through Casual Bolide Observations – Novo Mesto Superbolide As Evidence for a New Class of High-Risk Objects	Denis Vida
11:15	0:10	Q&A	
11:25	0:20	**BREAK**	
CHAIRS: Rudolf Albrecht Leviticus L.A. Lewis Jan Osburg		**Session 8: Disaster Management & Earth Impact Response**	**Speaker / Presenter**
11:45	0:12	Results from the EU-ESA Workshop on NEO Imminent Impactors Warning Coordination	Juan L. Cano
11:57	0:12	Evacuation and shelter plans for asteroid impacts	Darrel Robertson
12:09	0:41	Q&A / Discussion	
13:00	1:00	**LUNCH**	
CHAIRS: Doris Daou Alissa J. Haddaji		**Session 9: The Decision to Act: Political, Legal, Social, and Economic Aspects**	**Speaker / Presenter**

Irmgard Marboe			
14:00	0:08	To aid or not to aid, should it be a question: the geopolitical ethical concerns in PD missions	Sanchi Dhamija
14:08	0:08	Collective action problems in Planetary Defense	Jonathan Iwry
14:16	0:08	Legal Framework of the UNSC's role in decision and implementation of PD action	Krzysztof Nieweglowski
14:24	0:08	Legal Considerations on a regional security organisation for PD	Mag. Stephanie Stipsits
14:32	0:08	Diplomatic, Geopolitical and Economic Consequences of an impending asteroid threat	Laura Jamschon Mac Garry
14:40	0:08	Stressors on international cooperation and coordination in NEO threat mitigation and response	Chris Johnson
14:48	0:08	Planetary defense governance: from ad-hoc decision making to multilateral security regime	Nikola Schmidt
14:56	0:08	Legal complications of private planetary defense missions	Judith Jahnke
15:04	0:08	Proposing a holistic approach to an appropiate legal framework for planetary defence	George Kyriakopoulos
15:12	0:08	Popular Impact: Public Opinion and Planetary Defense Planning	Avishai Melamed
15:20	0:15	Q&A / Discussion	
15:35	0:20	**BREAK**	
15:55	1:00	**Panel 4: Legal and Policy Issues for Planetary Defense**	
CHAIRS: Mark Boslough Jessie Dotson Christian Koeberl		**Session 7B: Earth Impact Effects & Consequences (part B)**	**Speaker / Presenter**
16:55	0:10	High-Fidelity Blast Propagation Modeling For Hypothetical Asteroid 2023 PDC	Michael Aftosmis (virtual)
17:05	0:10	Tonga Tsunami Provides Data, Verification For Blast-generated Global Tsunami Modeling	Vasily Titov (virtual)
17:15	0:10	Atmospheric Breakup Behaviour Of 2022 WJ1	Peter Brown (virtual)
17:25	0:10	Computational Analysis Of Ground Effects From Bolide Disruption via the PI Method	Dharv Patel (virtual)
17:35	0:15	PI - Terminal Planetary Defense	Philip Lubin (virtual)
17:50		**END OF DAY 4**	
19:00		Conference Dinner at the Rathauskeller	
15:00		Museum Tour	

Day 4 Panel: Legal and Policy Issues for Planetary Defense

- Irmgard Marboe, Professor, University of Vienna
- Kelly E. Fast, IAWN Coordinator
- Detlef Koschny, SMPAG Chair
- Christopher Johnson, Secure World Foundation
- Michael Byers, Professor, University of British Columbia

Moderator: Alissa J. Haddaji, SMPAG Legal WG Coordinator

DAY 5

Day 5	Friday	7 April, 2023, VENUE - Festsaal, Austrian Academy of Sciences	
Start	Duration		Speaker / Presenter
9:20		Welcoming remarks for Day 5	Conference Chairs
CHAIRS: Linda Billings (virtual) Doris Daou Alex Karl		**Session 10: Public Education & Communication**	**Speaker / Presenter**
9:25	0:08	Sorvegliati Spaziali – A Unique Communication Experience in Planetary Defense as a Possible Starting Point for the Italian Involvement in the International Year of Planetary Defense	Daria Guidetti, Caterina Boccato
9:33	0:08	Public Education Activities For Planetary Defense In Japan	Seitaro Urakawa (virtual)
9:41	0:08	Humans And Hazardous Asteroids - 30 Years Of Experience In Education And Communication	Milos Tichy
9:49	0:08	Debunking The Panic Myth And What It Means For NEO Communication Strategies	Alex Karl
9:57	0:08	Apophis As The Demon Serpent Of Darkness: Designing Communication Protocols For Misinformation And Conspiracy Theories In Planetary Defense	Robert Atchison
10:05	0:08	Towards a Robust and Resilient Mechanism for the Distribution of Information During an Asteroid Mitigation Event	Rudolf Albrecht
10:30	0:17	Q&A / Discussion	
12:00		Reception	
13:00		**END OF CONFERENCE**	

APPENDIX E: POSTER PAPERS

Highlights Posters

Title	POC Author Name
After DART: Spectroscopic characterization of the Didymos system	Simone Ieva
The effect of Didymos internal structure on the dynamics	Stefania Soldini
The Dimorphos boulder size-frequency distribution derived from DART/DRACO images: Preliminary results	Maurizio Pajola
The character of the DART impact site and shape of Dimorphos	Terik Daly
DART guidance, navigation and control: System performance and challenges	Daniel O'Shaughnessy
Didymos in a context of the population of binary asteroids	Petr Pravec
LICIACube ground segment activities at SSDC: Image processing, calibration and archiving following PDS4 standards	Angelo Zinzi
Post-impact mutual orbit of the Didymos binary system derived from photometry	Peter Scheirich
Automated data processing and image quality analysis pipelines for the DART DRACO instrument	Dany Waller
DRACO – Testing and preparation for impact	Zachary Fletcher
DART mission space and ground based archived data products	Raymond Espiritu
Lightcurve photometry of Didymos in support of NASA's DART mission	Nicholas Moskovitz
Solar electric propulsion options for future planetary defense missions based on DART flight experience	Jeremy John
Orbital evolution of levitated regolith particles in the 65803 Didymos binary system	Aleksander Fiuk
The Double Asteroid Redirection Test (DART): Navigating to obliteration	Julie Bellerose
JWST observations of the Didymos-Dimorphos System	Cristina Thomas
DART mission design and navigation lessons learned for future planetary defense missions	Justin Atchison
Impact simulations provide critical information to constrain Dimorphos' material properties and better understand the DART impact	Angela Stickle
Boulder morphology at the DART impact site	Colas Robin
Ejecta plume reconstruction following the DART impact	Alessandro Rossi
A first assessment on the origin of Didymos and Dimorphos, NASA's DART mission targets	Fabio Ferrari
Dynamical interpretation of observed ejecta features following NASA's DART impact on Dimorphos	Fabio Ferrari

Preliminary results from modeling the kinetic impact of the DART spacecraft into Dimorphos	Wendy Caldwell
Low-speed ejection mechanisms in the DART experiment	Gonzalo Tancredi
Monte Carlo modeling of the dust ejecta generated by the DART impact on Dimorphos surface	Fernando Moreno
DART-driven ejecta cone geometry measurement from Hubble Space Telescope and LICIACube	Masatoshi Hirabayashi
ALMA observations of the DART mission: Characterizing the impact ejecta at sub-millimeter wavelengths with ALMA	Nathan Roth
Rotationally-resolved characterization of the near-Earth DIDYMOS-DIMORPHOS binary system after the NASA/DART impact	Monica Lazzarin
DART'S planetary defense investigation and achieving the mission's Level 1 requirements: Current status and ongoing activities	Nancy Chabot
Observations of the DART impact from Kenya and Chile	Colin Snodgrass
Milani Laser Retroreflectors for Hera, ESA's mission to a double asteroid	Simone Dell'Agnello
Juventas/HERA CubeSat landing and surface operations on asteroid Dimorphos	Özgür Karatekin
Hayabusa2#'s exploration to asteroids 2001 CC21 and 1998 KY26 provides key insights into planetary defense	Masatoshi Hirabayashi
OSIRIS-APEX: implications of mission objectives for planetary defense	Edgard Rivera-Valentín
SMART NAV - performance in flight	Justin Atchison

International Policy Posters

Title	POC Author Name
An (historical) overview of planetary defence initiatives	Mayer, Mr Hannes
PLANETARY DEFENSE AS PEACE IN SPACE	Leenders, Ms. Anna Maria R

Discovery Posters

Title	POC Author Name
Future Planetary Defense from the Moon, both Nearside and Farside	Antonietti, Nicolò
NSOS-ALPHA: the first Korean asteroid survey telescope	Kim, Myung-Jin
The Impact of Satellite Constellations on Solar System Science with LSST	Srivastava, Sanjana
Fast identification of streak-shaped NEOs in astronomical images through heterogeneous computing	Polo, Manuel C.
Astrometric and photometric observations of PHAs with 70 cm telescope	Silha, Jiri

FITS image archive at ESA'S NEO Coordination Centre	Rudawska, Regina
Scientific CMOS sensors in Astronomy: QHY600 and QHY411	Alarcon, Miguel
High cadence all-sky survey for the detection of Earth-threatening bolides	Webb, Jasper
The Discovery and Observation of Comets by NEO Surveys	Bauer, J.
Validation Of The Survey Simulator Tool For The Neo Surveyor Mission Using NEOWISE Data	Masiero, Joe
Studying impactors with the NEO SURVEYOR mission	Dahlen, Dar

Characterization Posters

Title	POC Author Name
An improved method for asteroid impact probability due to swarm intelligence algorithms	Koehler, Andrew
Risk assessment pillar at ESA's Planetary Defence Office	Faggioli, Laura
Near-Earth Objects' Forecast of Collisional Events (NEOFORCE)	Vavilov, Dimitrii
An improved method for asteroid impact probability due to swarm intelligence algorithms	Ivantsov, Anatoliy
Impact probability estimation with Partial Banana Mapping: search for virtual impactors	Vavilov, Dimitrii
DART time of impact observations and long-term photometry of Didymos from the LCOGT Network	Lister, Tim
Constraining the ejecta cone geometry following the DART impact on Dimorphos using LICIACube data	Deshapriya J.D.P.
Jura: The JUVENTAS radar on Hera to fathom Didymoon	Herique, Alain
The NEO-MAPP project, funded by the European Commission in support of the ESA Hera mission	Ulamec, Stephen
Pose estimation of Hera spacecraft around Didymos' moon using CNN-based image processing algorithm	Kaluthantrige, Aurelio
Post-impact polarimetry and photometry of Didymos	Krugly, Yu
Methods for studying the Didymos - Dimorphos system using the observations from HyperScout-H instrument onboard of Hera mission	Popescu, Marcel
Towards a 3D-GIS for Hera	Paar, Gerhard
The ACROSS network: coordinating observation campaigns for occultations by Dydimos	Tanga, Paolo
The Didymos system characterization campaign in support of the Double Asteroid Redirection Test	Rivkin, Andy
DROID: a mission concept to accompany and characterize Apophis through its 2029 Earth closest approach	Raymond, Carol
DROID: Bistatic Low-Frequency Radar Sounding of 99942 Apophis in 2029	Henrique, Alain

Enabling rapid response missions to near-Earth objects, long period comets, and interstellar objects: results of a Keck Institute for Space Studies workshop	Raymond, Carol
On-board limb-based shape modeling for small body navigation	Lyzhoft, Joshua
NEOCC analysis of 2023 PDC asteroid impact exercise	Moissl, Richard
Enabling Small Body Precovery Searches in Any Astronomical Dataset	Moeyens, Joachim
The Southern Hemisphere Asteroid Radar and Optical Program	Kruzins, Ed
NEOROCKS: Investigating the physical nature of the small asteroid population	Petropoulou, Vasiliki
NEOROCKS: Compositional properties of near-Earth objects from sky surveys	Sergeyev, Alexey
The NEO physical properties database: future perspectives of the NEOROCKS EU project	Di Pietro, Ilaria
The NEOROCKS “rapid-response experiment”	Perna, Davide
Spin and shape models of 16 near-Earth asteroids observed within the NEOROCKS project	Fatka, Petr
Calibrate the polarization-albedo relationship for NEOs by combining radar, polarimetric and optical lightcurves data	Oliviero, Dario
Calibrate the polarization-albedo relationship for NEOs by combining radar, polarimetric and optical lightcurves data	Ferrais, Marin
NEO radar observations in Europe	Orosei, Roberto
Visible spectroscopic survey of potentially hazardous asteroids from the Asiago observatory in the Framew	Lazzarin, Monica
The Potentially Hazardous Binary and Triple Near-Earth Asteroids Observed with the Arecibo Planetary Radar System	Venditti, Flaviane
Mineralogical analysis of 14 PHAs from VINOS data	Morate, David
Automatic Yarkovsky effect detection procedure at the ESA NEO Coordination Centre	Fenucci, Marco
Changes in Apophis rotation and surface gravity during its 2029 Earth flyby	Noiset, Guillaume
2020 BX12: The last binary asteroid discovered by Arecibo observatory	Zambrano-Marin, Luisa Fernanda
Characterization of near-earth object 2020 PN1: proposed target of Chinese planetary defense test	Reddy, Vishnu
Spectroscopic and photometric properties of (98943) 2001 CC21, the target of Hayabusa2# space mission	Popescu, Marcel
Physical characterization of 99942 Apophis from ground-based radar assets in 2029	Brozović, Marina
Capabilities of past, present, and future radar systems for observations of near-Earth objects	Marshall, Sean
Artificial Lunar Flashes as a useful tool in benchmarking small optical telescopes	Żołnowski, Michael
Photocenter offset: Case study of two NEAs	Dziadura, Karolina

Planetary defense grant opportunities: 25 years of Shoemaker NEO GRANTS and the NEW STEP GRANTS	Betts, Bruce
Tidal effects on the shape and structure of Apophis during the Earth flyby in 2029	Liu, Po-Yen
Thermal Infrared Multiband Imager TIRI onboard Hera to Investigate S-type Binary Asteroid Didymos and Dimorphos	Okada, Tatsuaki
Hubble space telescope observations of the evolution of Dimorphos's ejecta created by the DART impact	Li, Jian-Yang
Origin of the Didymos binary system: Insights from SPH simulations	Xiang, Zhen
Hypervelocity Bolide Disruption Simulations for Planetary Defense	Cohen, Alexander
Monte Carlo modeling of the dust ejecta generated by the DART impact on Dimorphos surface	Moreno, Fernando
DART-driven ejecta cone geometry measurement from Hubble Space Telescope and LICIACube	Hirabayashi, Masatoshi

Testing and Modeling Posters

Title	**POC Author Name**
Applying Centrifugal Propulsion to Enable Asteroid Deflection	Dr. Nahum Melamed
Thermal Infrared Multiband Imager TIRI Onboard Hera to Investigate S-Type Binary Asteroid Didymos and Dimorphos	Dr. Tatsuaki Okada
X-Ray Ionization and Electrostatic Induction in Space Debris	Mr. Sirapat Lookrak
The Effect of Surface Ejecta due to Ion Beam Impingement for An Asteroid Redirection Mission	Dr. Alexander Vazsonyi
Transfer Trajectory Optimization of Kinetic Impactor Technology Based on Multiple Spacecraft	Mr. Wenbao Fan
A Virtual Cocoon of Possible Trajectories Of A Projectile Asteroid As A Tool For Planetary Defence	Mr.Vladislav Zubko
Deep-Learning Optimization of A Time-Critical Multispacecraft Swarm NEO Deflection Approach	Dr. Antoni Perez-Poch
Application of IoT in Planetary Defense	Mr Ádám Attila Hepp
Measurability Of the Heliocentric Momentum Enhancement of the Didymos System from the DART Impact	Mr Rahil Makadia
Hubble Space Telescope Observations of The Evolution Of Dimorphos's Ejecta Created By The Dart Impact	Dr. Jian-Yang Li
Origin of the Didymos Binary System: Insights from SPH Simulations	Ms. Zhen Xiang
Using Geometrical Algorithms to Facilitate Hand-Off Between SPH And N-Body Modelling Of Ejecta Evolution	Mr John Wimarsson
Numerical Models of Mitigation Options For Hypothetical Threat Object 2023 PDC	Dr. Catherine Plesko

NASA's Double Asteroid Redirection Test (DART): Orbit Perturbations Due to Dimorphos's Reshaping And Mass Loss After The DART Impact	Mr Ryota Nakano
Reconstructing The Dimorphos Ejecta Plume By Means Of Non-Spherical Dust Simulations, DART And LICIACube Data, And Laboratory Experiments	Dr. Stavro Ivanovski
Hypervelocity Bolide Disruption Simulations for Planetary Defense	Mr Alexander Cohen
Experimental Study on The Interaction Of Pulsed Laser Ablation Of Asteroids For Planetary Defense	Dr. Guangming Song
Calculation And Experimental Verification of Driving Force For Ablation of Irregular Asteroid By Pulsed Laser	Dr. Guangming Song

Mission Design Posters

Title	POC Author Name
Research on Defense of Small Size Asteroids with Both Monitoring Warning and In-Orbit Disposal of Kinetic Impact	Mr Kaiduo Wang
The HERA GNC subsystem, the State-of-the-Art Autonomy for Planetary Exploration	Andrea Pellacani
An Alternative Ptolemaic Approach For Conjunction Analysis In LEO	Mr. Pietro De Marchi
Planetary Defense in the Age of Space Industrialization	Mr. Mark Sonter
Spherical Mobile Robot for Asteroid Exploration and Defense	Dr. Boxin Li
Out of the Shades – Analysis of NEO Deflection using Planetary Sunshade Sailcraft for Planetary Defence	Ms. Fabienne Seibert
Exploring space mission design	M.r Myles Harris
Airborne, multiwavelength astronomical instruments for planetary defense.	Mr. Alexander Michael Schuster
OPERA: Novel Opportunistic Missions for NEO Exploration	Mr. Madhu Thangavelu
JEDI – Joint Earth-Moon Extraterrestrial Threats Defense Architecture	Mr. Madhu Thangavelu
Compact Geophysical Instrumentation For Asteroid Exploration	Dr. Naomi Murdoch
Trajectory and GNC Strategy Design for a Fast Development Mission to Apophis	Mr Francisco Cabral
The Potential Benefits of An Ion Beam Deflection (IBD) Demonstration Mission	Dr. John Brophy
Rapid reconnaissance missions based on ESA's Comet Interceptor	Dr. Colin Snodgrass
Deflection And Disintegration of Asteroid by Kinetic Penetration	Prof. Yonghe Zhang
Hayabusa2#'s exploration to Asteroids 2001 CC21 and 1998 KY26 provides key insights into planetary defense	Dr. Masatoshi Hirabayashi
A Network of Imminent Impactor Sentinels	Dr. Marta Ceccaroni
System of Observation of Daytime Asteroids (SODA)	Mr Andrey Shugarov
Robust Trajectory Design for the Hera Experimental Phase Using Intrusive Polynomial Algebra	Mr Iosto Fodde

Co-Orbital Convergence – Rallying Solar Sails, Small Solar-Electric Spacecraft and Nanolanders to Help Save Us from a Nasty Neighbour Soon	Mr. Jan Thimo Grundmann
Rendezvous Mission Design and Deflection of Asteroid 2023 PDC	Ms. Dhanisha Sateesh
Comprehensive Mission Design Architecture Trade Study for Planetary Defense Missions	Mr. Matthew A. Vavrina
Applying Centrifugal Propulsion To Enable Asteroid Deflection	Dr. Nahum Melamed
Mechanical Analysis and Testing of the ASPECT Payload for Milani CubeSat	Swati Thirumangalath

APPENDIX F: DETAILS OF ASTEROID IMPACT THREAT EXERCISE

As with past conferences, PDC2023 included a hypothetical asteroid impact threat exercise. Given the location of the conference at the UN's Vienna International Center, the threat exercise was held on the first day of the conference, and UN individuals were invited to participate in a "decisionmakers" panel that would consider response options for the hypothetical threat. Panel members were:

- Matthew Daniels, Assistant Director of White House Office of Science and Technology Policy for Space Security & Special Projects, US
- Halilu Ahmad Shaba; Director-General of the Nigerian Space Agency (NASRDA)
- Rolf Densing, Director of Operations, European Space Agency (ESA)
- Bulbul Mukherjee, Deputy General Manager, Safe and Sustainable Operations Management, Indian Space Research Organization (ISRO) (virtual)
- Erik Hooks, Deputy Administrator of Federal Emergency Management Agency (FEMA)
- Meshack Kinyua Ndiritu, African Union Commission (virtual)
- Lorant Czaran, Senior Programme Officer, UNOOSA/UN-SPIDER

And two attorneys provided their insights on legal issues that should be considered:

- Prof. David Koplow, Georgetown University
- Prof. Jack Beard, University of Nebraska

Threat Exercise: Epoch 1--Discovery

Discussion of the impact threat began with presentations by two originations that were established following a 2013 UN resolution[6]. The first, the International Asteroid Warning Network (IAWN), coordinates observations from observatories worldwide and brings an asteroid impact threat to the UN when an object is discovered that has a probability of impacting Earth that is 1% or higher and the object size is estimated to be 10 meters or larger.

The first observations[7] of asteroid 2023 PDC indicated that the object might be much larger than the 10-meter threshold and that the object had a 1% chance of Earth impact. Given that, IAWN sent the threat notice given below, and Dr. Paul Chodas (representing IAWN) provided Decisionmakers an overview of the threat and noted that should additional observations show impact is likely, the object could impact anywhere in the region defined by the red dots shown on page 2 of the notification.

[6] "Recommendations of the Action Team on Near-Earth Objects for an international response to the near-Earth object impact threat," AC.105/C.1/L.329, Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee Fiftieth session Vienna, 11-22 February 2013, United Nations, 21 December 2012 (https://www.unoosa.org/pdf/limited/c1/AC105_C1_L329E.pdf).

[7] See https://cneos.jpl.nasa.gov/pd/cs/pdc23/PDC23-ImpactRisk-Epoch1.pdf

EXERCISE EXERCISE EXERCISE

INTERNATIONAL ASTEROID WARNING NETWORK (IAWN)

POTENTIAL ASTEROID IMPACT NOTIFICATION – HYPOTHETICAL SIMULATION

Date: April 3, 2023

From: International Asteroid Warning Network

To: Chair, Space Mission Planning Advisory Group (SMPAG);
United Nations Office of Outer Space Affairs

Title: Potential for Impact of Near-Earth Asteroid 2023 PDC

Impact Probability:	1% as calculated by NASA JPL CNEOS and ESA NEOCC
Impact Date:	22 OCTOBER 2036
Impact Risk Corridor:	From the South Pacific to the southern Indian Ocean, crossing North America, the Atlantic Ocean, and Africa
Approximate Size:	220 - 660 meters (720 - 2160 feet) determined from its observed brightness and an assumed range of most likely surface reflectivities
Expected Damage Level if Impact Occurs:	Uncertain – Regional to Continental. Energy released most likely to be in the range 54 Mt to 5.5 Gt

ADDITIONAL DETAILS:

- There is a 1% probability that asteroid 2023 PDC will impact Earth on 22 October 2036 as calculated by the NASA JPL Center for Near-Earth Object Studies and the ESA Near-Earth Objects Coordination Centre. While there is uncertainty in whether the asteroid will impact Earth, if an impact occurs it will be on this date.
- The impact risk corridor, which is the region of Earth where it is possible that 2023 PDC could impact, extends from the South Pacific to the southern Indian Ocean, crossing North America, the Atlantic Ocean, and Africa.
- The asteroid 2023 PDC has been tracked since it was first observed on 10 January 2023 by an international team using the Dark Energy Camera (DECam) at the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile and searching in the twilight region of the sky looking for asteroids in the inner Solar System.
- Further observations will reduce the uncertainty in the asteroid's trajectory and impact probability. The asteroid will be almost continuously observable after late 2023, although it will be distant and quite faint and will likely require large (2-meter) telescopes.
- The asteroid size of 220 - 660 meters (720 - 2160 feet) is determined from its observed brightness (absolute magnitude H is determined to be 19.4) and an assumed range of most likely surface reflectivities.
- The size cannot be estimated with further precision without radar observations or imagery from a spacecraft that can closely approach the asteroid. The asteroid is too distant for radar observations and will not come within range until 2036.

EXERCISE EXERCISE EXERCISE

IAWN Notification (page 1 of 2)

EXERCISE EXERCISE EXERCISE

This notification is issued by the International Asteroid Warning Network (IAWN) in accordance with report SMPAG-RP-003 on Recommended Criteria & Thresholds for Action for Potential NEO Impact Threat that defines the threshold for issuing warnings of possible impact effects, which is a probability of impact is greater than 1% and a rough size estimated to be greater than 10 meters (33 feet).

IAWN is a worldwide collaboration of asteroid observers and modelers that was recommended by the United Nations. https://iawn.net

Point of Contact: IAWN Coordinating Officer for the IAWN Steering Committee [email]

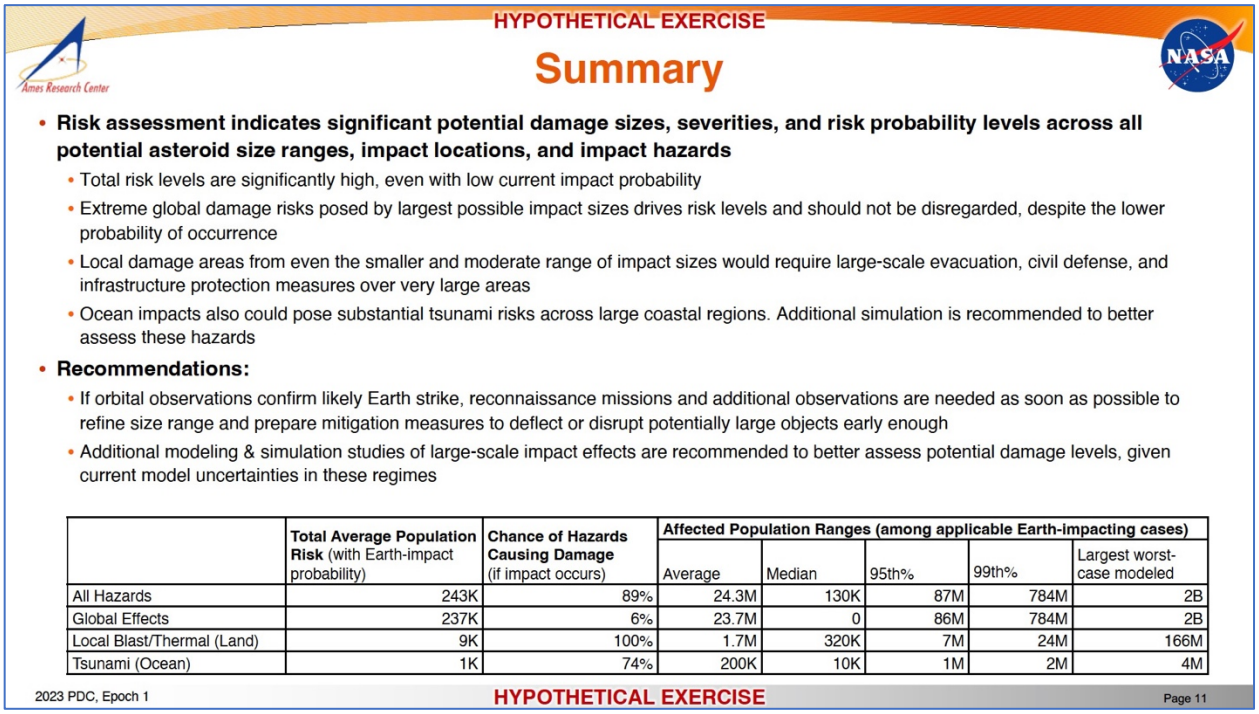
Graphics:

- Helio-centric orbit diagram relative to Earth orbit
- Impact risk corridor maps

EXERCISE EXERCISE EXERCISE

IAWN Notification (page 2 of 2)

Dr. Lorien Wheeler provided a first look at potential consequences[8] should the object impact, and a summary is below. A mission to flyby or orbit the object was recommended to develop a more accurate orbit and improve mass and size estimates of the threatening object.



HYPOTHETICAL EXERCISE

Summary

- **Risk assessment indicates significant potential damage sizes, severities, and risk probability levels across all potential asteroid size ranges, impact locations, and impact hazards**
  - Total risk levels are significantly high, even with low current impact probability
  - Extreme global damage risks posed by largest possible impact sizes drives risk levels and should not be disregarded, despite the lower probability of occurrence
  - Local damage areas from even the smaller and moderate range of impact sizes would require large-scale evacuation, civil defense, and infrastructure protection measures over very large areas
  - Ocean impacts also could pose substantial tsunami risks across large coastal regions. Additional simulation is recommended to better assess these hazards
- **Recommendations:**
  - If orbital observations confirm likely Earth strike, reconnaissance missions and additional observations are needed as soon as possible to refine size range and prepare mitigation measures to deflect or disrupt potentially large objects early enough
  - Additional modeling & simulation studies of large-scale impact effects are recommended to better assess potential damage levels, given current model uncertainties in these regimes

	Total Average Population Risk (with Earth-impact probability)	**Chance of Hazards Causing Damage** (if impact occurs)	**Affected Population Ranges (among applicable Earth-impacting cases)**				
			Average	Median	95th%	99th%	Largest worst-case modeled
All Hazards	243K	89%	24.3M	130K	87M	784M	2B
Global Effects	237K	6%	23.7M	0	86M	784M	2B
Local Blast/Thermal (Land)	9K	100%	1.7M	320K	7M	24M	166M
Tsunami (Ocean)	1K	74%	200K	10K	1M	2M	4M

2023 PDC, Epoch 1 HYPOTHETICAL EXERCISE Page 11

Summary of initial estimate of potential damage should there be an impact.

At this point, decisionmakers heard two presentations related to the decision-making process.

Decision Making for Asteroid Impact Threat

To begin discussions, Michael Byers provided a "decision tree" for planetary defense noting that "failed or accidental partial deflections using a nuclear explosive device (NED) are the most precarious branches of the decision tree" and for that reason, the use of a NED should not be taken lightly. He noted that such use might require authorization by the Security Council and asked if there is not widespread support in General Assembly, were there "circumstances precluding wrongfulness" (such as necessity) that would excuse an action by one state that causes serious harm to other states? He suggested that the "ideal" response would require early pre-discovery agreements, early detection, international cooperation, a rapid reconnaissance mission, a rapid non-NED deflection mission. He suggested that "even if one element is absent, it is important to try to maintain the "other elements" of the ideal response.

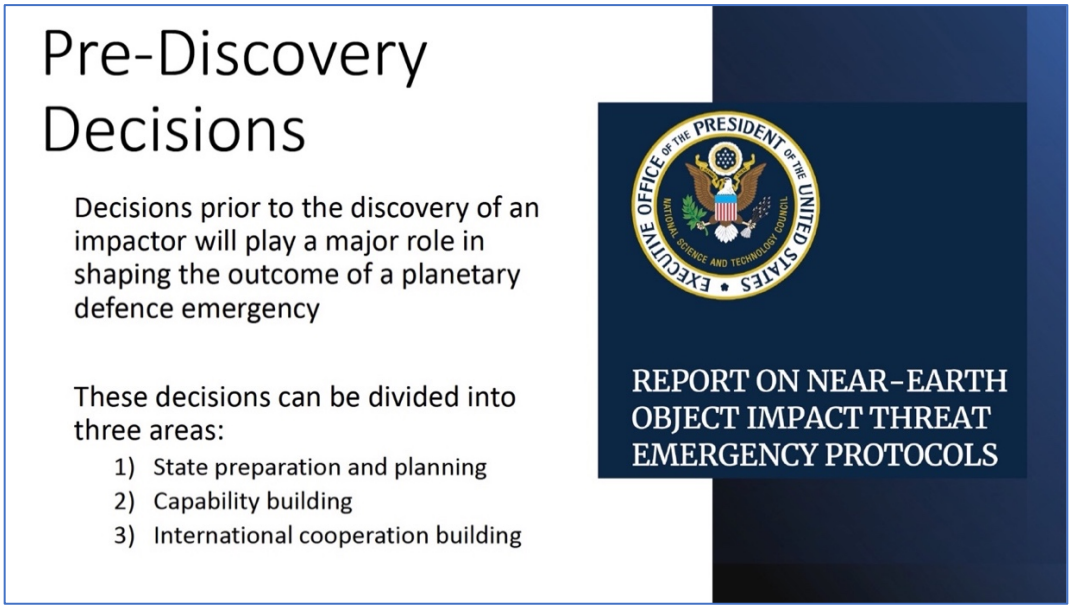
The second presentation was given by Alssa Haddaji and David Koplow, who summarized legal and policy issues developed by the Space Mission Planning Advisory Group's (SMPAG's) Ad-Hoc Legal Working Group on Planetary Defense. discussed the main legal and policy questions associated with the

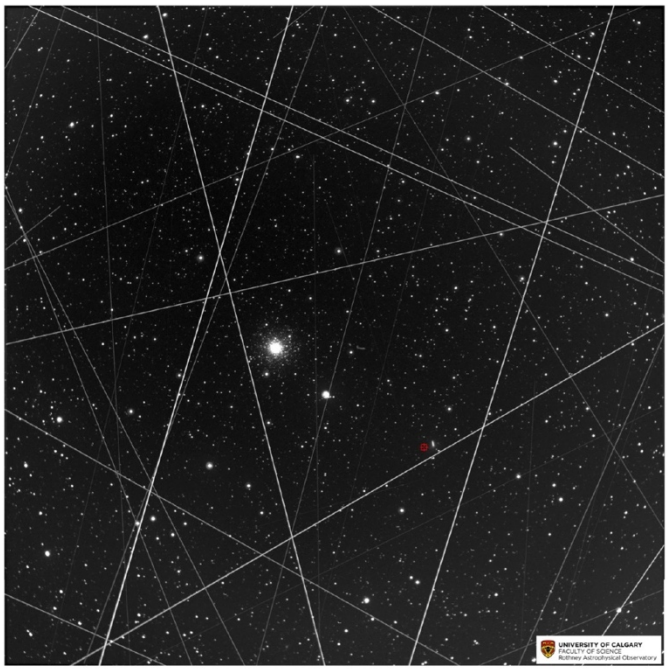
[8] See https://cneos.jpl.nasa.gov/pd/cs/pdc23/PDC23-ImpactRisk-Epoch1.pdf

conference's threat scenario. They discussed the legality of sending a "nuclear bomb" to the upcoming asteroid and noted that the UN Security Panel would be the final decider of that action.

Both presentations are below.

Planetary Defense Decision Tree





State Preparation and Planning

Domestic plan for planetary defence emergencies?

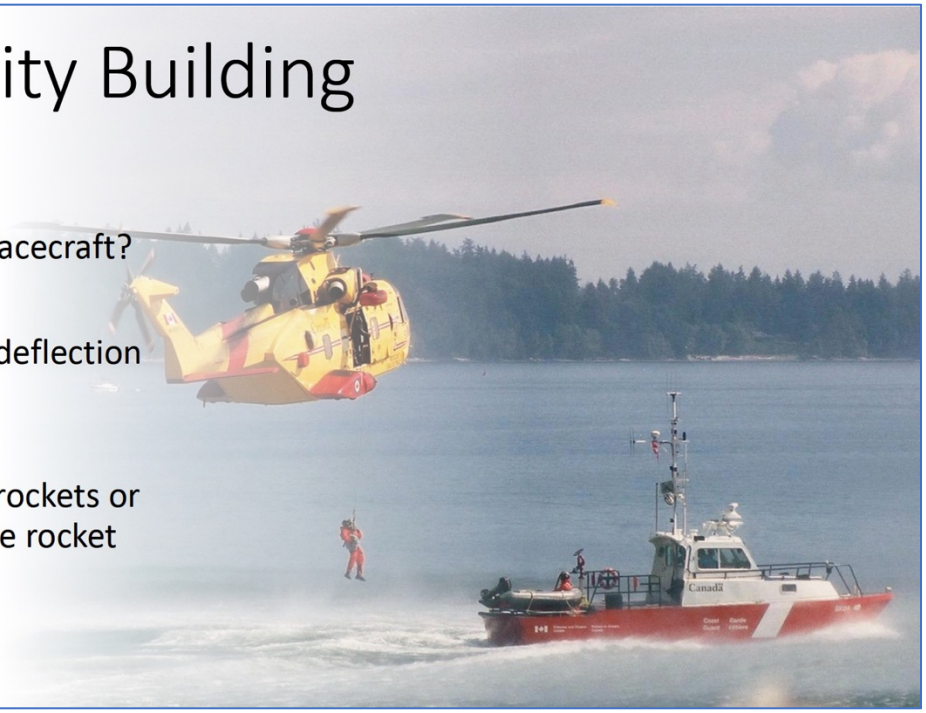
Greater support for NEO detection capabilities?

Protect detection capabilities from light pollution, including from satellite mega-constellations and space debris?

Cooperation is <u>not</u> a given

- Cooperation is an ongoing yet often fluctuating process: it can start, stop, and start again
- Does SMPAG continue operating if one or two space agencies refuse to cooperate?
- Does Security Council exert control?
  - Could require states to act on SMPAG recommendations
  - What happens in the face of a veto? Does the UN General Assembly adopt a resolution?
- At a minimum, cooperation involves sharing information from observations and reconnaissance missions

Capability Building



Maintain standby reconnaissance spacecraft?

Maintain standby deflection spacecraft?

Maintain standby rockets or ensure short-notice rocket availability?

International Cooperation Building

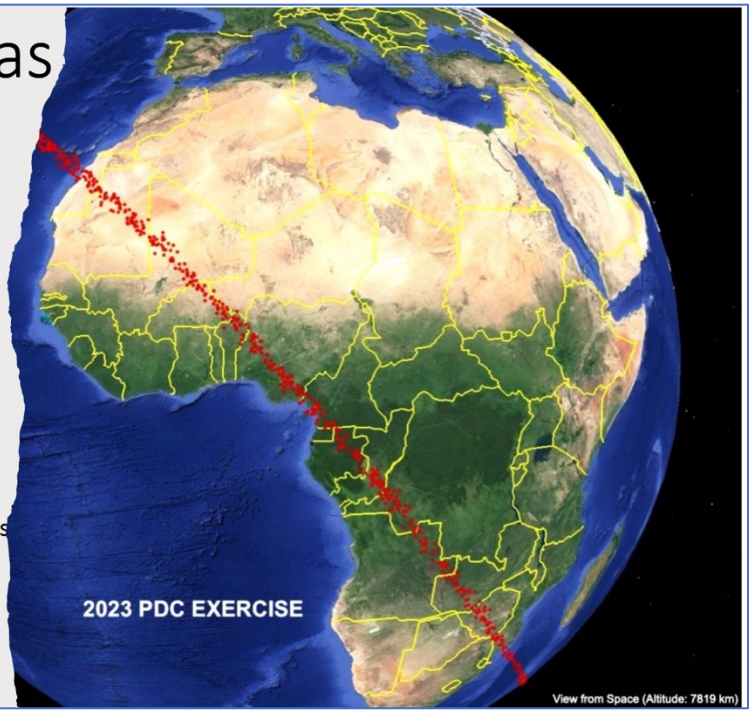
Develop cooperative mechanisms for resolving a future crisis?

Negotiate an international agreement on decision-making?

- Could be done through SMPAG, UN COPUOS, a UN General Assembly resolution, a UN Security Council resolution, or a multilateral treaty

General dilemmas

- Do space agencies lead?
  - Militaries are better funded, more politically powerful
  - Question is more likely to arise if a NED is involved
- What about partial deflections?
  - Whether deliberate or accidental, could put populations at risk that were not previously threatened
  - The 'Trolley Problem'
  - State consent would be required
  - Human rights issues might arise
- How should states respond if another state is proceeding with a deflection attempt that they consider too risky?
  - Sanctions?
  - Preemptive self-defence?



Previous options may need to be revisited during development, including gathering additional observational information

Which deflection mission?

The selection of deflection mission will be driven by the specific facts, such as lead time, asteroid size and mass (if known), orbital accessibility, and impact location, as well as the social and political context

NED

High Impulse

Low impulse

OSI

Is the low-impulse mission succesful?

This choice of deflection implies that substantial lead time is available

These methods are gentle and avoid risks associated with sudden asteroid manipulation, such as asteroid fragmentation

Progress can be monitored and adjusted

This is one of the most complex general mission types

The long lead times could make the mission more susceptible to changes in the global political context

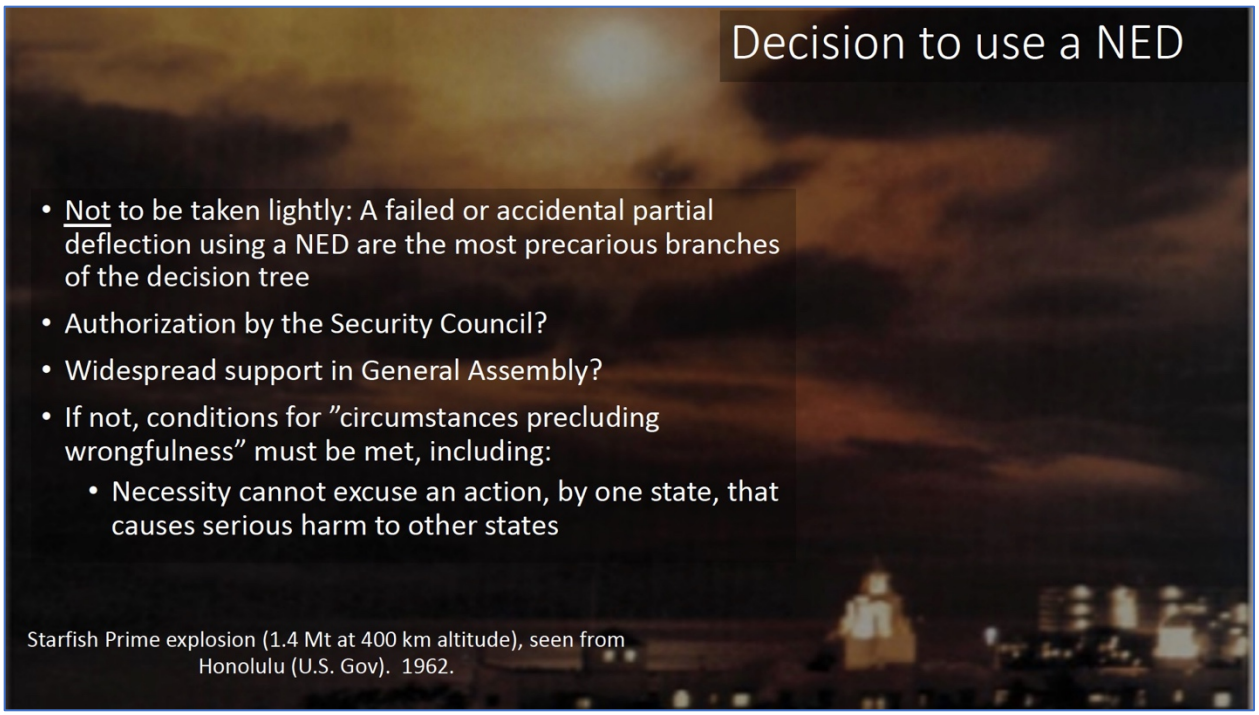
Yes

No

What is the 'ideal' response?

1. Pre-discovery agreements
2. Early detection
3. International cooperation
4. Rapid reconnaissance mission
5. Rapid 'conventional' (i.e. non-NED) deflection mission

Even if one element is absent, it is important to try to maintain the other elements.



Legal & Policy Considerations

The Space Mission Planning Advisory Group's (SMPAG's) Ad-Hoc Legal Working Group on Planetary Defense provided the following input for consideration:

The SMPAG Ad-Hoc Legal Working Group (SMPAG LWG)

HISTORY

- Created in 2016, the SMPAG LWG is currently composed of 15 international space lawyers from NASA, ESA, DLR and the Mexican, Italian, Austrian and UK Space Agencies. The role of the SMPAG LWG is to answer SMPAG's legal questions regarding a Planetary Defense mitigation mission.

PDC 2023 Scenario: Main Legal and Policy Questions

- Obligations to inform and to act
- Liability for damage
- Legality of planetary defense methods (including the question of potential use of a nuclear device in space)
- Considerations for decision bodies

« Would my head of state have to do something? »

- If your country is threatened to be impacted, yes. If there is a NEO threat, each State has the **right and obligation to try to protect its territory and its population**, **but there is no obligation under international law to assist other States** in any particular way or to any particular degree.

« Are private companies allowed to send a mission on their own ?»

- Under the Outer Space Treaty, each party is internationally responsible for the space activities of its **non-governmental entities.**

« Would my country be liable if it tried to help? »

- It could. A State has liability for damage done by any space object for which it is a launching State. For damage inflicted on Earth, the liability is 'absolute' (that is, it applies even without any wrongdoing). **Absolute liability includes cases where an asteroid is insufficiently deflected and impacts at a different location compared to where it would have struck if there had been no intervention.**

« Would it be illegal to send a nuclear bomb to the upcoming asteroid? » (1/2)

- The OST (1967), Article IV :

States Parties to the Treaty undertake not to place in orbit around the earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner.
The moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on celestial bodies shall be forbidden.

- The Limited Test Ban Treaty (1963):

It prohibits nuclear weapons tests "or any other nuclear explosion" in the atmosphere, in outer space, and under water.

« Would it be illegal to send a nuclear bomb to the upcoming asteroid? » (2/2)

- The Outer Space Treaty **prohibits placing a nuclear weapon in orbit, installing it on a celestial body, or stationing it in space in any other manner**.
- The Limited Test Ban Treaty **prohibits any nuclear explosion in outer space, regardless of its intended purpose**.

« Who could authorize the use of a nuclear device?»

- Regarding possible decision-making bodies for planetary defense action planning, **the United Nations Security Council (UNSC) has extraordinary power to supersede rules of international law** through a decision, which requires the votes of **nine out of fifteen Members** and no opposing vote by one of the Permanent Five (P5) Members of the UNSC.

Threat Exercise: Epoch 2--Update

Phase 2 of the exercise began with an IAWN warning that predictions based on new observations show a 100% likelihood that an asteroid of 300 to 880 meters in size would impact on 22 October 2036 with impact occurring in “West Africa, extending from south of the Canary Islands southeast to the southern Congo River region.” Details are summarized in the Potential Asteroid Impact Notification given below. Page 2 of the notification includes the region where impact might occur and gives a summary of potential consequences of impact.

EXERCISE EXERCISE EXERCISE

INTERNATIONAL ASTEROID WARNING NETWORK (IAWN)

POTENTIAL ASTEROID IMPACT NOTIFICATION – HYPOTHETICAL SIMULATION

Date: October 23, 2024

From: International Asteroid Warning Network

To: Chair, Space Mission Planning Advisory Group (SMPAG);
United Nations Office of Outer Space Affairs

Title: Potential for Impact of Near-Earth Asteroid 2023 PDC

Impact Probability:	100% as calculated by NASA JPL CNEOS and ESA NEOCC
Impact Date:	22 OCTOBER 2036
Impact Risk Corridor:	West Africa, extending from south of the Canary Islands southeast to the southern Congo River region
Approximate Size:	300 - 880 meters (970 - 2980 feet) determined from observations of brightness and color, and an assumed range of surface reflectivities
Expected Damage Level if Impact Occurs:	Uncertain – Regional to Continental. Energy release estimated to be 76 MT to 10 Gt.

ADDITIONAL DETAILS:

- There is a 100% probability that asteroid 2023 PDC will impact Earth on 22 October 2036 as calculated by the NASA JPL Center for Near-Earth Object Studies and the ESA Near-Earth Objects Coordination Centre, based on observations from the worldwide network of observatories.
- The impact risk corridor, which is the region of Earth where it is possible that 2023 PDC could impact, extends from south of the Canary Islands southeast across West Africa to the southern Congo River region.
- The asteroid 2023 PDC has been tracked by Earth-based telescopes except for late June – Nov. 2023 when it was too close to the Sun to observe. Since observations resumed in Nov. 2023, the impact probability of asteroid 2023 PDC has risen to 100%.
- The size of 2023 PDC is estimated to be 300 - 880 meters (970 - 2900 feet). This updated size estimate is based on color data from ground-based telescopes, which indicates something about the surface reflectivity and the type of asteroid, along with its observed brightness (absolute magnitude H is determined to be 19.4).
- The asteroid is too distant for radar observations and will not come within range until 2036.
- There is a high probability that hundreds of thousands to millions of people on the African continent could be affected by the potential damage of the impact based on the latest predicted impact corridor and risk modeling. See Impact Risk Summary quad chart below for further details.

EXERCISE EXERCISE EXERCISE

EXERCISE EXERCISE EXERCISE

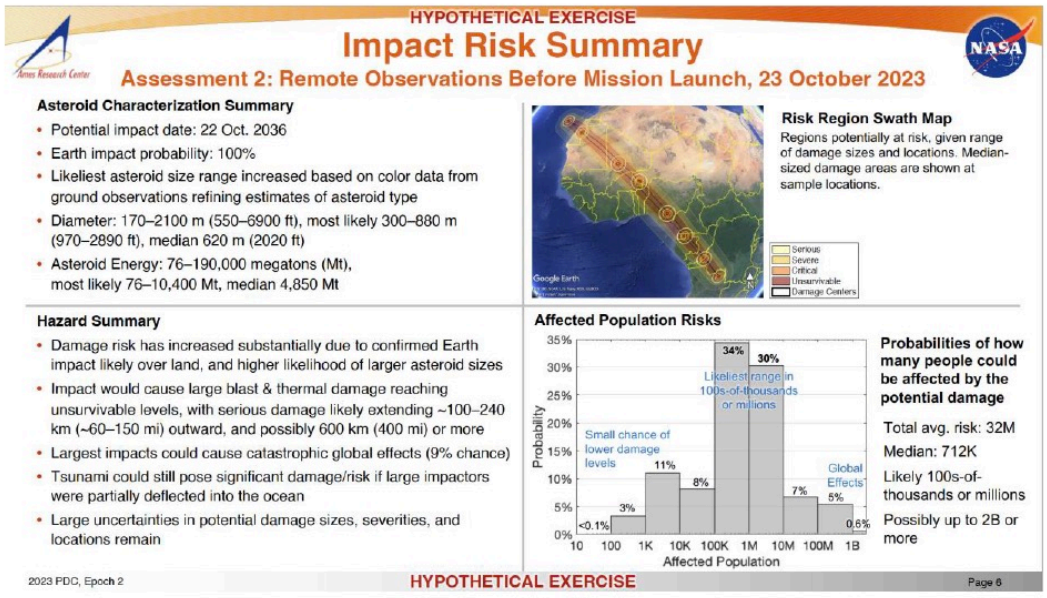
This notification is issued by the International Asteroid Warning Network (IAWN) in accordance with report SMPAG-RP-003 on Recommended Criteria & Thresholds for Action for Potential NEO Impact Threat that defines the threshold for issuing warnings of possible impact effects, which is a probability of impact is greater than 1% and a rough size estimated to be greater than 10 meters (33 feet).

IAWN is a worldwide collaboration of asteroid observers and modelers that was recommended by the United Nations. https://iawn.net

Point of Contact: IAWN Coordinating Officer for the IAWN Steering Committee [email]

Graphics:

- Impact risk corridor map
- Impact Risk Summary quad chart

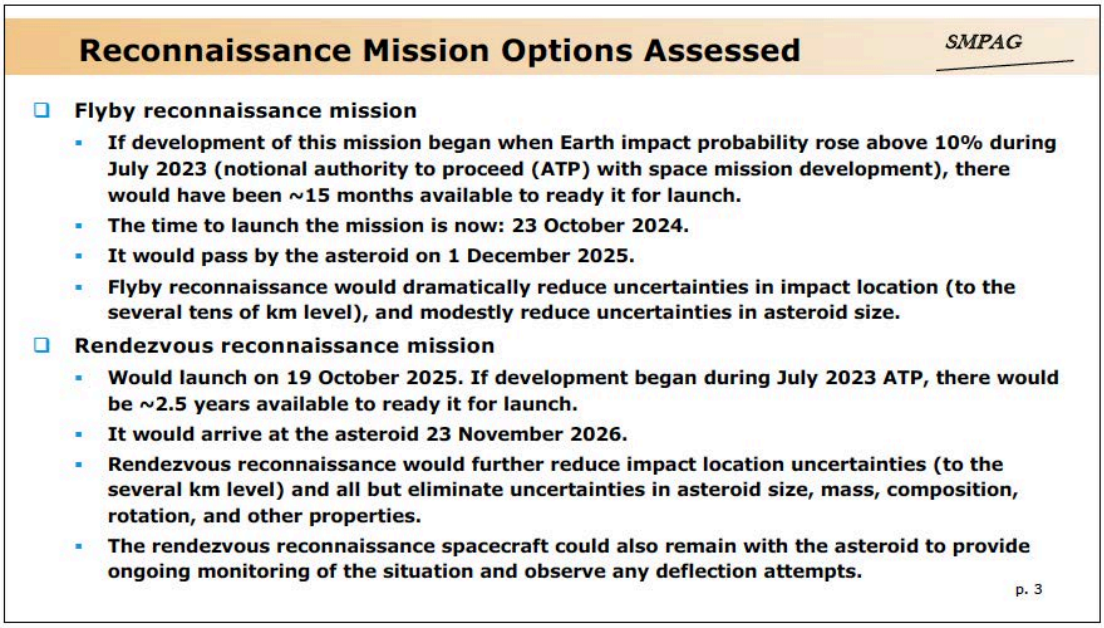


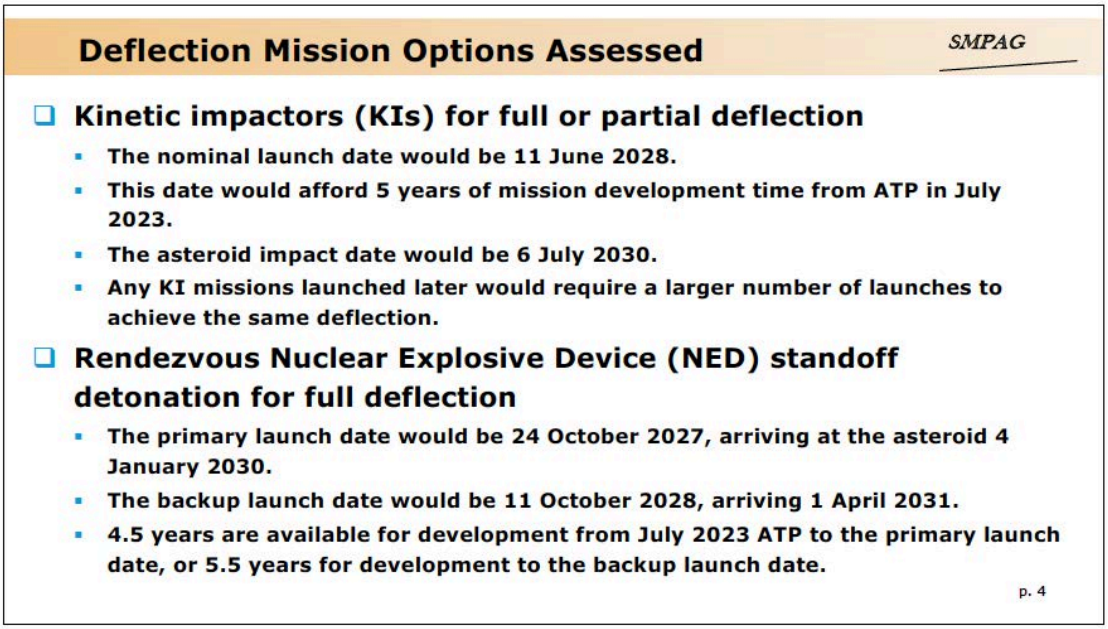
EXERCISE EXERCISE EXERCISE

Reconnaissance and Deflection Options

At this point, SMPAG presented details on options for space missions to fly-by the object, to orbit the object for a more complete survey, and on two options for deflecting the object away from Earth.

Given that impact was certain, the primary discussion topic of the decisionmaker panel was how to deflect the oncoming object of uncertain size away from Earth. Results of analyses show over 1200 successful launches of kinetic impactors would be required to provide high confidence that, given the uncertainties, the oncoming object would not impact Earth. A single successful launch of a nuclear explosive device (NED) would fully deflect the object away from Earth. There was considerable discussion of these alternatives by decisionmakers.





Kinetic Impactor Deflection Performance Summary (2/3)

SMPAG

- **KI launch requirements for full deflection of the asteroid off the Earth, from the worst-case impact location:**
  - **5th percentile asteroid mass: 9 FH launches (~62300 kg total KI spacecraft mass)**
  - **50th percentile asteroid mass: 85 FH launches (~588000 kg total KI spacecraft mass)**
  - **95th percentile asteroid mass: 1256 FH launches (~8.7 million kg total KI spacecraft mass)**
- **The best-case Earth impact location for KI performance is the easternmost edge of the impact footprint, with eastward deflection directions.**
  - **The number of FH launches required for 5th, 50th, and 95th percentile asteroids would be 4, 39, and 565, respectively.**
- **TBD additional launches beyond those listed above would be required for redundancy**

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Kinetic Impactor Deflection Performance Summary (3/3)

SMPAG

- **KI requirements for partial deflection of the asteroid into the Atlantic ocean:**
  - **The example target ocean impact point for partial deflection requirements analysis is at 24 W longitude (1663 km from the coast of Western Sahara)**
  - **The worst-case impact location for partial deflection performance (where deflection is equally difficult in either direction) is at the eastern end of the impact footprint**
  - **The deflection distance from the worst-case impact location to the targeted ocean impact point is ~7500 km**
  - **5th percentile asteroid mass: 4 FH launches (~27672 kg total KI spacecraft mass)**
  - **50th percentile asteroid mass: 33 FH launches (~228290 kg total KI spacecraft mass)**
  - **95th percentile asteroid mass: 487 FH launches (~3.37 million kg total KI spacecraft mass)**
- **TBD additional launches beyond those listed above would be required for redundancy**
- **Even before considering the effects of an ocean impact (e.g., on coastlines, atmospheric effects, etc.), note that the number of required KI launches is of similar magnitude to the required launches for full deflection**

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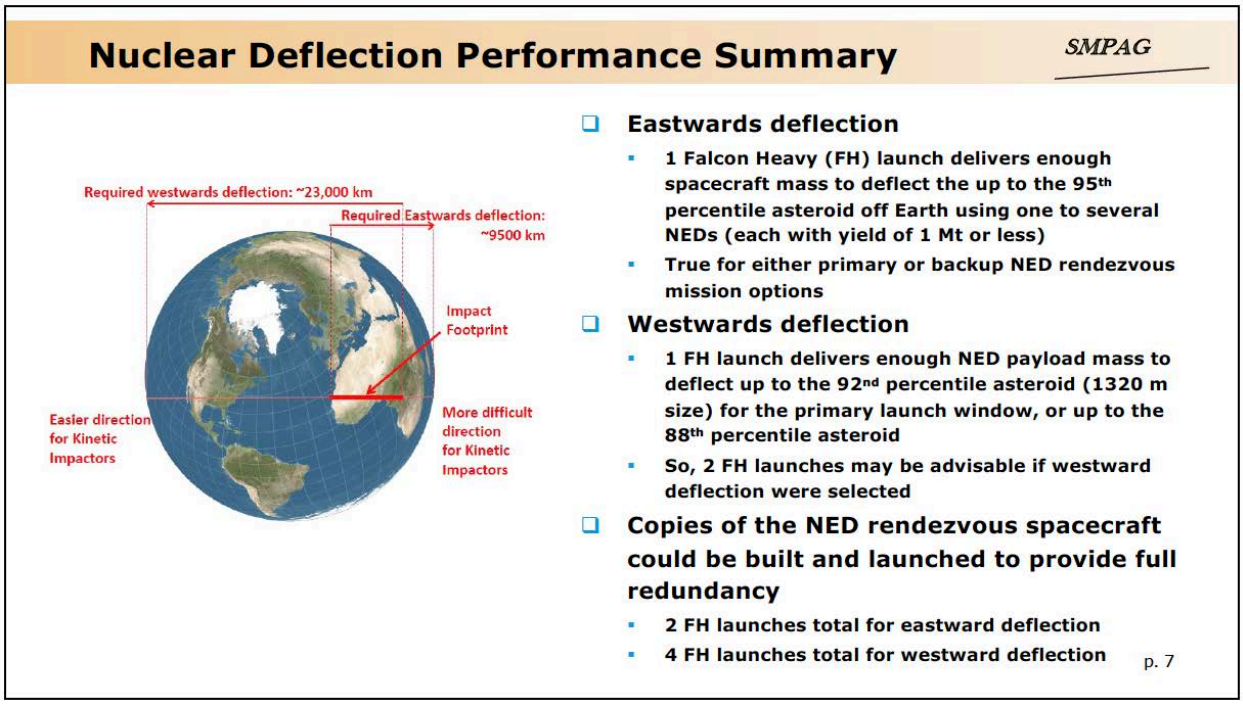

Figure E-5: Concluded.

APPENDIX G: FEEDBACK FROM ATTENDEES

This appendix summarizes and provides specific feedback from individuals attending the conference in person and virtually, and summarizes comments provided verbally during the conference's last session.

Logistics in person: Overall great feedback on venue and organization. Coffee breaks to engage with others have been highly appreciated. Recommendations to be more mindful and inclusive of folks with allergies and mobility issues. Communication of certain aspects could be more streamlined.

Logistics online: Overall, very positive feedback from online participants on use of Teams and Slido to follow and participate. Recommendations to be more involved by having participant chat function to allow discussions, posting of side event pictures.

Content: Overall, content was very well received. Topic variety as well as the quality of presentations and panels was highlighted. Well received were also the diverse groups of participants although it was strongly recommended to further broaden cultural diversity and international representation. Recommendations were made to have more time for discussions and Q&A, longer talks, a more engaging exercise, poster lightning talks, topic summaries before the sessions for non-specialists to be able to better follow and more.

Organization:

- Authors send a one-sentence summary and thumbnail image, and have the session chair give a few minutes intro of the topics there (rather than just saying there is a poster section)
- Have a dedicated poster session
- Open poster section a week before PDC to allow participants to view and post questions that could be answered online or in dedicated session
- Post the full exercise (all days) before the conference so participants can also submit papers about the exercise response, which might also help focus the panel discussions
- Add peripheral workshops; e.g., on outreach
- Have more representation at the decision maker level. Include military and private industry with capabilities in the fields
- Provide better, clearer communication about submission and attendance. There was confusion about e-lightning material and how to attend the conference (it was not clear that daily invitations would be sent out)
- Have an icebreaker type of event for younger participants
- Have special issue of Acta Astronautica
- Concerns that a hybrid meeting will be disadvantageous for US civil servants to get funding for travel when a virtual option is available – in-person attendance preferred statement?
- Have a permanent archive of proceedings
- Upgrade the exercise with social aspects; e.g., invite The Institute for the Future (iftf.org)

Technical:

- Separate Chat and Q&A inputs to better keep track of questions to panelists or have a dedicated person to track the chat for questions so the session chair/moderator doesn't have to.
- Upload recordings quicker and perhaps piecemeal to give folks who missed AM session to catch up by PM
- If possible, make slides and recordings accessible in advance

The tables below provide attendee responses to specific polling questions.

PDC

	What is your reason for attending the PDC?	Results	
A:	I work in the field	83/94	88%
B:	I want to get involved	6/94	6%
C:	I'm just curious	0/94	0%
D:	To see what the risk really is and what we can do	5/94	5%

	Did the PDC 2023 meet your expectations?	Results	
A:	It exceeded my expectations! Well done!	11/59	19%
B:	Yes, fully. I learned a lot.	31/59	53%
C:	Yes, but it could have been better	16/59	27%
D:	No, I'm disappointed.	1/59	2%

	Single vs multi-track	Results	
A:	Keep the single track	44/56	79%
B:	Go multi-track	7/56	13%
C:	Make the conference longer, e.g. 6 days	10/56	18%
D:	Talks should be longer (~15 mins)	20/56	36%
E:	Upload some talks to an online platform 1-2 weeks before PDC	7/56	13%

	What do you think of a virtual PDC lite event in the even years (1-2 days about topics/talks chosen by the community)?	Results	
A:	Great idea!	17/58	29%
B:	No, thank you.	12/58	21%
C:	Maybe, I need more information	29/58	50%

Exercise

	Is the exercise still useful for you?	Results	
A:	Yes, very much	23/59	39%
B:	Yes, somewhat	29/59	49%
C:	Not much added value	7/59	12%
D:	Not at all. Waste of time.	0/59	0%

	Have you heard about IAWN and SMPAG before?	Results	
A:	Yes, and I was aware of their roles and functions.	33/53	62%
B:	I heard about them but was not sure what they do	9/53	17%
C:	No. First time I hear about them.	11/53	21%

	How would you react to the scenario?	Results	
A:	1% chance of hitting us is pretty low. Nothing to worry about.	10/62	16%
B:	Even if it comes our way, it's in 13 years, so we have plenty of time!	9/62	15%
C:	DART just proved we can deflect asteroids, so we're safe, no?	8/62	13%
D:	I'm really worried!	35/62	56%

	Which course of action do you support?	Results	
A:	Full deflection using the nuclear option	48/91	53%
B:	Partial deflection using conventional methods	11/91	12%
C:	Continue to study alternatives	28/91	31%
D:	Do nothing	4/91	4%

IYPD

	How do you see yourself supporting the efforts for an IYPD?	Results	
A:	Contact my nation's UN representative to support the idea	16/84	19%
B:	Get in touch with people in my country who could form a working group to coordinate the national efforts	33/84	39%
C:	Disseminate the idea within my community	57/84	68%
D:	Get resources to learn more	28/84	33%

Multiple answers were possible.

Communications panel

	Who's information do you trust?	Results	
A:	Official sources, such as government, space agency	47/66	71%
B:	Traditional news agencies (newspaper, TV)	30/66	45%
C:	Social media	8/66	12%
D:	I trust no one	11/66	17%
E:	Other	10/66	15%

Multiple answers were possible.

IMAX Public Event

	How did you like the event?	Results	
A:	It was great!	38/52	73%
B:	It was okay.	13/52	25%
C:	I did not enjoy it.	1/52	2%

Session 8 - Disaster Management & Earth Impact Response

	Are general terrestrial emergency response capabilities sufficient to also cover Planetary Defense emergencies, or are there any Planetary Defense-specific ones that are needed?	Results	
A:	Existing capabilities are sufficient.	5/53	9%
B:	PD-specific capabilities are needed for pre-impact preparedness	14/53	26%
C:	PD-specific capabilities are needed for post-impact response	0/53	0%
D:	PD-specific capabilities are needed for both, pre- and post-impact response	34/53	64%

Legal panel

	If other options were available but had a lower rate of success, would you prefer NOT to use a nuclear explosive device to mitigate an impact treat of a large asteroid?	Results	
A:	Yes	12/55	22%
B:	No	32/55	58%
C:	I'm not sure	11/55	20%

	Who do you think will end up making the decision to send a nuclear explosive device to deflect a potentially threatening asteroid?	Results	
A:	The US	11/55	20%
B:	The UN Security Council	31/55	56%
C:	Elon Musk	5/55	9%
D:	SMPAG	2/55	4%
E:	I don't know	6/55	11%

COMMENTS PROVIDED AT DAY 5 WRAPUP SESSION

The last session of the conference provides an opportunity for conference attendees to provide additional comments. A collection of those comments follows:

Exercise:

- Like 1-day exercise, but want more audience feedback and group feedback
- Like opportunity to interact with others
- Too much discussion of Epoch 1
- More discussion of ethics
- Like approach used in Flagstaff, Frascati—Tables with focus groups and feedback
- Want more on aftereffects and how to prepare
- Want media workshop and feedback from media on what to expect
- Need to simplify info that would go to leaders; stick to the facts; should include discussion of international procedures for disasters

Overall Conference:

- Large support for single-track conference
- Extended abstract should be optional; people could record track for papers or posters
- Include affiliations of speakers on program and on conference badges
- Would like more time for Q&A
- Would like a disaster response panel
- Prefer fewer, longer presentations (also had comments that the short presentations and Q&A worked well)
- Keep two-year spacing
- Should have more media and more media presentations
- Provide poster authors 2-minutes to present topic during regular session (e.g., Frascati)
- Include more questions from on-line participants
- Send on-line questions to experts for response post-conference
- Provide seating for handicapped
- Consider discussion of "black-swan" events
- Encourage international participation: Have an official invitation to government entities
- Report on what's new from last meeting
- Consider binary as threat object (we did that for Japan)
- The six panel sessions were a good number
- Should focus on new ways to deflect
- NASA should explain origin of "140-meter" goal (Lindley did that)

International Year of Planetary defense:

- Need to discuss how to involve international leadership
- Goal is to Keep Earth Safe
- Encourage space entrepreneurship and new tech industries
- Should broaden participation on panels
- Should look for ways to get public involved