
# KEY POINTS AND RECOMMENDATIONS

FROM THE

# 2011 IAA PLANETARY DEFENSE CONFERENCE

## Introduction

The 2011 IAA (International Academy of Astronautics) Planetary Defense Conference was held on May 9-12, 2011 in Bucharest, Romania. The 2011 meeting, hosted by the Romanian Space Agency, was the fourth in a series beginning with the 2004 and 2007 Planetary Defense Conferences sponsored by The Aerospace Corporation and the American Institute of Aeronautics and Astronautics (AIAA) and followed by the 2009 and now the 2011 IAA Planetary Defense Conferences. An Organizing Committee, whose members are listed in Attachment 1, planned the conference. The 2011 meeting was supported by the 19 sponsoring organizations listed in Attachment 2 and was attended by over 160 individuals listed in Attachment 3. A final Program is given in Attachment 4.

The Organizing Committee solicited papers and presentations in seven primary topic areas:

- Current state of knowledge on Near Earth Objects (NEOs)[1] (how many, physical characteristics, orbits, current limitations on furthering that knowledge, current risk, etc.)
- Consequences of an impact (tsunami, cratering and blast area, NEO size vs. consequence, economic impact, past events)
- Techniques for deflecting or mitigating a threatening NEO (kinetic impact, gravity tractor, explosive devices, others)
- NEO deflection mission and campaign design (launch requirements, cost, timelines, new tools)
- Political, policy, legal framework for planetary defense
- Increasing public awareness
- Current national and international activities supporting planetary defense

Sessions focused on each topic area, and a special session enabled students to present the results of their research to the full attendance. A panel session was held at the end of the meeting where session chairs discussed key information from their sessions and audience members participated in a discussion of recommendations from the meeting. This White Paper summarizes those key points and recommendations.

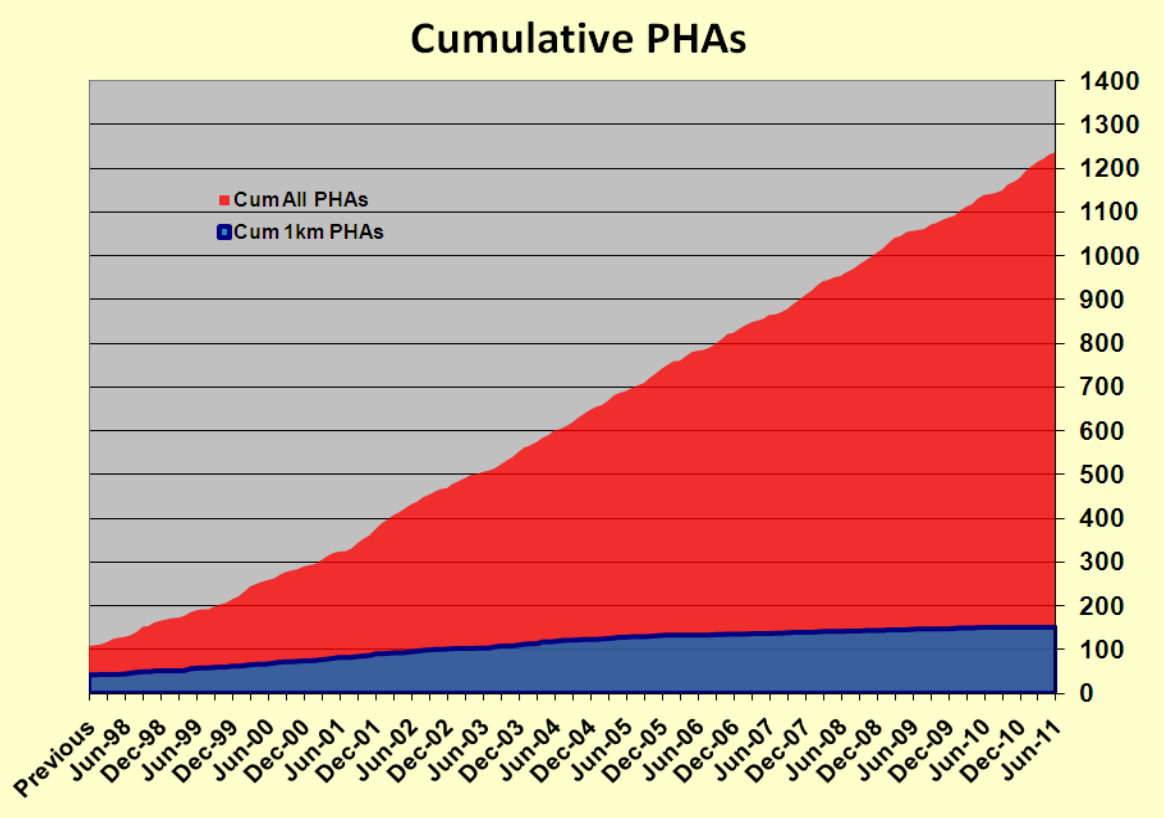
[1] Near Earth Objects (NEOs) are asteroids and comets with perihelion distance less than 1.3 AU.

## Key Points

Key points from the meeting were accumulated in the following areas:

### Discovery and Characterization

The figure below shows one reason for the increased interest in planetary defense. As shown, our knowledge of Potentially Hazardous Asteroids (PHAs)[2] is increasing sharply as our efforts to discover such objects improve, and that the most frequent risk is from objects smaller than 1km in diameter. The fact that the number "All PHAs" is growing rapidly while the number of PHAs larger than 1km in size is leveling off indicates that there are many potentially hazardous objects in the smaller size range yet to be discovered.




Number of known potentially hazardous objects over time.

Papers were presented that relate to the discovery and characterization of asteroids and comets. The current estimate is that there are 990±35 NEOs greater than 1km in diameter, objects whose impacts could produce disasters on a planetary scale. We have discovered over 90% of these objects. Within this

[2] Potentially Hazardous Asteroids (PHAs) are currently defined based on parameters that measure the asteroid's potential to make threatening close approaches to the Earth. Specifically, all asteroids with an Earth Minimum Orbit Intersection Distance (MOID) of 0.05 AU or less and an absolute magnitude (H) of 22.0 or less are considered PHAs. In other words, asteroids that *can't* get any closer to the Earth (*i.e.* MOID) than 0.05 AU (roughly 7,480,000 km or 4,650,000 mi) or are smaller than about 50 m (1500 ft) in diameter (*i.e.* H = 22.0 with assumed albedo of 13%) are *not* considered PHAs.

group are 150 known Potentially Hazardous Asteroids (PHAs) greater than 1 km in diameter. These objects have orbits which have a high likelihood of intersecting that of the Earth at some point in the future. Fortunately, no asteroids in this size range pose a significant threat over the next 100 years. However, an estimated 80% of objects with diameters between 150 meters to 1 km, and an even greater percentage of the smaller objects remain undiscovered at present. Funding for discovery efforts is proposed to increase (e.g., funding provided by the European Commission for space situational awareness, NASA budget for the Near Earth Object Observations Program), and significant progress is being made in the discovery of objects larger than 300m, where it is estimated that as many as 45% of the total number have been discovered.

## Threats

Approximately 350 NEOs have been discovered with non-zero probability of impact this century, but for most of them, the estimated probabilities of impact are much less than 1 in a million. Two known objects with diameters of approximately 140m have current assessed impact probabilities of approximately 1/4000 in the next 40 years. The kinetic yield, a measure of energy released at impact, would exceed 100 megatons of TNT for either of these objects. To provide a scale for this type of event, in 1908 an object estimated to be between 30 and 50-meters in diameter entered the atmosphere and exploded over a remote area of Siberia. Known as the Tunguska event, this explosion was equivalent to 3 to 5 megatons of TNT and leveled trees over an area of more than 2000 $km^2$, an area larger than that of most any western city. If one of the aforementioned objects were to strike the Earth, the explosion would be 20 to 30 times larger than the Tunguska event.

New search systems described at the conference could provide a short period of warning for impacts of objects in the 30 to 50 m diameter range and larger, providing potentially enough time to evacuate the predicted impact area. Currently it is probable that a Tunguska-class disaster could occur with little or no warning.

If an asteroid passes through a small region of space known as a “keyhole” during a close approach of Earth, it will return to strike Earth at some time in the future on a resonant return. Any attempt to deflect an object away from an Earth impact should avoid moving it to a new orbit that passes through one of these keyholes. Analyses show that deflecting an object before a keyhole passage will generally require less energy than after such a passage.

## Deflection and Disruption

If a threatening object is discovered, options to either deflect or disrupt the object will be a critical part of the decision process. Presentations at the conference highlighted developments in a number of proposed deflection techniques. Characterization of deflection and disruption techniques is advancing, with a general recognition that nuclear explosives provide the only possible means to deflect or disrupt large objects and objects with a short warning time.

As noted, the greatest probability of impact may be from smaller objects where the warning time could be short. Recognizing that the time to mount a mitigation campaign might be short, one presenter suggested that a catalog of components available and critical for such missions be developed, maintained, and updated. Components would be selected from the catalog and used to fabricate a mitigation payload.

Proposed human missions to asteroids were described, and presentations discussed how these could provide information that would help reduce uncertainties for planetary defense efforts.

### Educating the Public

Presentations described new internet-based tools that are coming on-line that will enable development of preliminary mission and campaign designs. A major feature of the tools is to help inform the public about the nature of planetary defense and the challenges of designing effective campaigns to deflect an oncoming object. These will join currently available interactive tools for assessing impact consequences.

A survey of students was presented that indicated an interest in past impacts and their consequences, leading to suggestions for increasing discussions about these topics and about planetary defense in schools and planetariums to help educate the public on the nature of the threat and how responses might evolve. The implications of a future impact on human society might also be included.

### Civil Defense

Notification of the public, evacuation of areas that might be affected by an impact, and other civil defense activities should be essential components of a threat response. Future conferences will increase focus on these areas. Relating the NEO threat to other natural hazards that are treated in a similar manner by existing agencies is a good first step.

### Legal & Policy

UN COPUOS Action Team 14 is developing recommendations for a processes to coordinate information on NEO discoveries and tracking from international sources, bring together spacefaring nations to design mitigation missions and campaigns, involve the civil defense and disaster response agencies in campaign planning, and make decisions associated with mitigation efforts. The work is based on inputs received from Action Team members and in particular the report of the Association of Space Explorers and its Panel on Asteroid Threat Mitigation entitled “Asteroid Threats – A Call for Global Response.”

## Recommendations

There were a number of recommendations from the conference that should be considered by major space agencies. These include the following:

- Plans should be developed describing what would be done in the event an object with a short warning time is discovered. These would include both civil defense and possible deflection or disruption options.
- Recognizing that there may be long time periods between threats that require action, studies should be conducted to determine what resources should be maintained over the long term to assure adequate planetary defense and civil defense actions when they are required. Such studies should consider launch and payload availability for short warning events.
- Missions should be planned to demonstrate and validate the most promising deflection or disruption options.
- A space telescope should be placed interior to Earth’s orbit to help us discover objects whose orbits keep them mostly to the sunward side of Earth, making them extremely difficult to detect with Earth-based telescopes.

- Polls should be conducted to assess public understanding of the threat and of planetary defense-related activities. Results of these surveys should be used to guide public education efforts.
- In addition to immediate blast and impact effects, studies should examine the short and long-term consequences of energy transported into the atmosphere by such an event.
- We should use "teachable moments" such as this November's close approach of asteroid 2005 YU55 to help the public understand asteroid risk and mitigation. YU55 is a 400-meter diameter asteroid that will pass within the orbit of the moon on November 8, 2011.
- Establishing a network of university and amateur telescopes should be considered as a cost-effective way to increase warning time for short-warning threats and help refine orbits of newly discovered objects.
- Current UN COPUOS efforts to evolve a framework for international decisions and coordinated actions are essential. Other legal and policy issues that might affect decisions relating to planetary defense should be examined and resolved.
- Recognizing that resources are limited, we should look for ways to leverage funding to space-related programs to increase progress on planetary defense-related activities and programs.

## Next Meeting

The 2013 IAA Planetary Defense Conference will be hosted by NASA's Planetary Science Division and will be held in Flagstaff, Arizona in April 2013. A feature of the conference will be a tour of Meteor Crater.

# 2011 IAA Planetary Defense Conference

## Organizing Committee

| | |
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| William Ailor* | The Aerospace Corporation |
| Ivan Bekey | |
| Bruce Betts | The Planetary Society |
| Mark Boslough | Sandia National Laboratory |
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http://www.esa.int/


http://www.rosa.ro/


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http://www.telespazio.it/ http://www.ballaerospace.com


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ATTACHMENT 3

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**Monday, 9 May 2011**

08:00 Registration

09:00 Welcoming remarks

09:30 Keynote: Dr. Anders Sandberg

***10:00 Coffee break***

**Session 1 History & Current Status**
*Chairs: Ray Williamson, Detlef Koschny*

10:30 Historical Overview of the Cosmic Impact Hazard
*David Morrison* (*UNITED STATES*)

11:00 US/NASA NEO Program Status and Plans
*Lindley Johnson* (*UNITED STATES*)

11:30 The Near-Earth Objects Segment of the European Space Situational Awareness Prog
*Gerhard Drolshagen*[1]; *D. Koschny*[1]; *N. Bobrinsky*[2]
[1](*NETHERLANDS*); [2](*SPAIN*)

12:00 Introduction to UN COPUOS and NEOs
*Richard Crowther* (*UNITED KINGDOM*)

12:20 A global Approach to Near-Earth Object Impact Threat Mitigation
*Harris, A.*
*DLR (GERMANY)*

***12:30 Lunch***

**Session 2 Discovery & Tracking Resources and Plans**
*Chairs: Alan Fitzsimmons, Lindley Johnson*

14:00 Update of Estimated NEO Population and Current Survey Completion
*Alan Harris* (*UNITED STATES*)

14:25 Comparing the Earth Impact Flux from Comets and Near-Earth Asteroids *Donald Yeomans*; *D.K. Yeomans*; *A.B. Chamberlin* (*UNITED STATES*)

14:50 The Catalina Sky Survey, Past, Present, and Future
*Edward Beshore*; *S. M. Larson* (*UNITED STATES*)

15:15 The Pan-STARRS search for Near Earth Asteroids - present status and future plans
*Richard Wainscoat* (*UNITED STATES*)

***15:40 Coffee break***

16:10 Near Earth Object Detection with LSST
*R. L. Jones* (*UNITED STATES*)

16:35 Gaia Astrometry of Near-Earth Objects
*Daniel Hestroffer*; *D. Bancelin*; *W. Thuillot*; *P. Tanga* (*FRANCE*)

17:00 The Near Earth Object Surveillance Satellite (NEOSSat) Will Search near-Sun along the Ecliptic Plane to Efficiently Discover Objects of the Aten and Atira Orbital Classes
*Alan Hildebrand*[1]; *B. Gladman*[1]; *E.F. Tedesco*[2]; *R.D. Cardinal*[1]; *P. Gural*[2]; *M. Granvik*[2]; *S.M. Larson*[2]; *K.A. Carroll*[1]; *P.G. Brown*[1]; *P. Wiegert*[1]; *P. Chodas*[2]; *B.J. Wallace*[1]; *S.P. Worden*[2]; *J.M. Matthews*[1] [1](*CANADA*); [2](*UNITED STATES*)

17:25 A Space-Based Near-Earth Object Survey Telescope in Support of Human Exploration, Solar System Science, and Planetary Defense
*P. A. Abell*; *R. G. Mink*; *J. B. Garvin*; *B. W. Barbee*; *D. Mazanek*; *D. R. Komar*; *D. Adamo*; *A. Cheng*; *A. S. Rivkin*; *K. Hibbard*; *K. L. Miller*; *R. Dissly*; *A. Mainzer*; *D. K. Yeomans*; *L. N. Johnson* (*UNITED STATES*)

***Evening:*** ***Welcome reception at The Scientists Club***
***(bus transfer from the Conference centre at 19:00hrs)***

**Tuesday, 10 May 2011**

09:00 Intro & Welcome

**Session 3 Potentially Hazardous Objects - Recent Progress**
*Chairs: Don Yeomans, Giovanni Valsecchi, Pedro Gutierrez*

09:10 Physical Properties of NEOs that Inform Mitigation
*Patrick Michel*[1];
[1](*FRANCE*)

09:35 NEOWISE – An Infrared View of NEOs and the Solar System
*Amy Mainzer*; *J. Bauer*; *T. Grav*; *R. M. Cutri*; *J. Dailey*; *J. Masiero*; *R. S. McMillan*; *R. Walker*; *E. Wright*; *D. Tholen* (*UNITED STATES*)

10:00 Radar Tracking and Near-Earth Object Characteristics
*Lance Benner*; *L. A. M. Benner* (*UNITED STATES*)

10:25 Orbital Distribution of Near-Earth Objects
*Vacheslav Emel'yanenko*; *Sergey Naroenkov*; *Boris Shustov* (*RUSSIAN FEDERATION*)

***10:50*** ***Coffee break***

11:20 1999 RQ36 Impact Risk and Modeling the Long-Term Yarkovsky Effect
*Andrea Milani*; *F. Bernardi*; *D. Farnocchia*; *G.B. Valsecchi* (*ITALY*)

11:45 Asteroid Impact Hazard Assessment Over Long Time Intervals
*Steve Chesley* (*UNITED STATES*)

12:10 The search for Earth impacting asteroids by the Pan-STARRS
*Veres Peter*[1]; *Robert Jedicke*[2]; *Mikael Granvik*[2]; *Steve Chesley*[2]; *Richard Wainscoat*[2]; *Shinsuke Abe*[3]; *Larry Denneau*[2]; *Tommy Grav*[2]
[1](*SLOVAKIA*); [2](*UNITED STATES*); [3](*TAIWAN*)

12:35 Keyholes as Providers of Deflection Leverage
*P.W. Chodas* (*UNITED STATES*)

***13:00*** ***Lunch***

**Session 4 Impact Consequences & Education**
*Chairs: Mark Boslough, Alan Harris*

14:30 Consequences of the Tunguska Impact and their Interpretation
*Giuseppe Longo; L Gasperini; E Bonatti; C Stanghellini; R Serra (ITALY)*

15:00 Creating Awareness - The Impact Hazard in Public Education Curricula Content, Students'Interests and Concepts and Educational Implementation
*M. Mueller* (*GERMANY*)

15:30 New Classification Scale for Impact Consequences
*Maria Gritsevich*; *V. P. Stulov* (*RUSSIAN FEDERATION*)

***15:50*** ***Coffee break***

16:10 Airburst Warning and Response
*Mark Boslough* (*UNITED STATES*)

16:40 Calculation of the Impact of a Small Asteroid on a Continental Shelf
*Galen Gisler* (*NORWAY*)

17:10 Dynamics of Tsunamis Generated by Asteroid Impact in the Black Sea
*Dragos Isvoranu*; *S Danaila*; *V Badescu* (*ROMANIA*)

17:40 The Protective Role of the Earth's Atmosphere against the Threat of Asteroids
*Jean-Luc VERANT*; *J.-M. MOSCHETTA*; *L. FERRIER* (*FRANCE*)

**Wednesday, 11 May 2011**

09:00 Intro & Welcome

**Session 5 Campaign Planning**
*Chairs: Nahum Melamed, A.C. Charania*

09:10 AsteroidSQUADS/iSSB - a Synergetic NEO Deflection Campaign and Mitigation Effects Test Mission Scenario
*Jan Thimo Grundmann*; *S. Mottola*; *M. Drobczyk*; *R. Findlay*; *M. Hallmann*; *A. Heidecker*; *R. Kahle*; *E. Kheiri*; *A. Koch*; *O. Mierheim*; *F. Nohka*; *D. Quantius*; *M. van Zoest* (*GERMANY*)

09:30 Target Selection and Mission Analysis of Human Exploration Missions to Near-Earth Asteroids
*Aline Zimmer*; *E. Messerschmid* (*GERMANY*)

09:50 Effects of NEO Composition on Deflection Methodologies
*Yohei Sugimoto*; *G. Radice*; *J. P. Sanchez* (*UNITED KINGDOM*)

10:10 Mission Concepts and Operations for Asteroid Mitigation Involving Multiple Gravity Tractors
*Cyrus Foster*; *J Bellerose*; *D Mauro*; *B Jaroux* (*UNITED STATES*)

***10:30 Coffee break***

11:00 Development of a Handbook and an On-Line Tool on Defending Earth against Potentially Hazardous Objects
*Nahum Melamed* (*UNITED STATES*)

11:20 ESA NEO missions studies: what have we learned?
*Andres Galvez, Ian Carnelli (SPAIN)*

11:40 Robotic and Human Exploration/Deflection Mission Design for Asteroid 99942 Apophis
*Sam Wagner*; *B. Wie* (*UNITED STATES*)

12:00 Near Earth Object Interception Using Nuclear Thermal Rocket Propulsion
*Steven Howe*; *X. Zhang*; *C. Granier*; *E. Ball*; *L. Kochmanski* (*UNITED STATES*)

***12:20 Lunch***

**Session 6 Mission Planning & Technologies**
*Chairs: Mariella Graziano, Ian Carnelli, Bong Wie*

14:00 Measuring the Momentum Transfer for Asteroid Deflections
*Kevin Housen*; *K.A. Holsapple* (*UNITED STATES*)

14:20 Influence of intermediate-scale structures on Yarkovsky and YORP effects
*Oleksiy Golubov*[1]; *Yurij N. Krugly*[2]
[1](*GERMANY*); [2](*UKRAINE*)

14:40 Improved Navigation Techniques for Asteroid Landers and Impactors
*Andrew Klesh*; *T. Kubota*; *T. Yoshimitsu* (*JAPAN*)

15:00 Design Options for NEO Missions
*Jesus Gil-Fernandez*; *R. Cadenas*; *T. Prieto*; *D. Escorial* (*SPAIN*)

15:20 Numerical Models of Hazard Mitigation by Nuclear Stand-Off Burst
*Catherine Plesko*; *R. P. Weaver*; *W. F. Huebner* (*UNITED STATES*)

15:40 Limits on the Use of Nuclear Explosives for Asteroid Deflection Megan Bruck (Brown University) and David Dearborn (LLNL)
*David Dearborn*; *M Bruck* (*UNITED STATES*)

***16:00 Coffee break***

16:30 Hypervelocity Nuclear Interceptors for Asteroid Deflection and/or Disruption

*Bong Wie* (*UNITED STATES*)

16:50 Gravity Tractor Strategies for Deflecting a Binary Asteroid System
*Julie Bellerose*; *Cyrus Foster*; *David Mauro*; *Belgacem Jaroux* (*UNITED STATES*)

17:10 Meeting Objectives for Human Exploration of Near Earth Objects: First Steps in Understanding How to Explore
*Victoria Friedensen*; *P. Abell*; *B. Drake*; *P. Guirgis*; *K. Larman*; *D. Mazanek*; *D. Reeves* (*UNITED STATES*)

17:30 The Ion Beam Shepherd: A New Concept for Asteroid Deflection.
*Claudio Bombardelli*; *Jesus Pelaez*; *Eduardo Ahedo* (*SPAIN*)

18:10 Outline of Hayabusa-2, next asteroid sample return mission of Japan
*Makoto Yoshikawa*; *H. Minamino*; *S. Nakazawa*; *M. Abe*; *Y. Tsuda*; *J. Kawaguchi* (*JAPAN*)

***Evening: Conference Dinner & Student Award Ceremony at the The Diplomatic Club***

***(bus transfer from the Conference centre at 19:00hrs)***

**Thursday, 12 May 2011**

09:00 Intro & Welcome

**Session 7 Student Session**
*Chairs: Mariella Graziano, Alex Karl, Dario Izzo*

09:00 On Testing Laser Ablation Processes for Asteroid Deflection
*Alison Gibbings*; *M Vasile*; *J-M Hopkins*; *D Burns* (*UNITED KINGDOM*)

09:30 Detecting Radiation Pressure on NEOs: The Case of 2009 BD
*Marco Micheli*; *D. J. Tholen*; *G. T. Elliott* (*UNITED STATES*)

09:50 NEOMiSS: A Near Earth Object decision support tool
*Charlotte Norlund*[1]; *H. G. Lewis*[1]; *P. M. Atkinson*[1]; *J. Y. Guo*[2]
[1](*UNITED KINGDOM*); [2](*UNITED STATES*)

10:10 The Performances of a Wide Survey on a Population of Impactors
*D. Farnocchia*; *F. Bernardi*; *A. Milani* (*ITALY*)

***10:30 Coffee break***

11:00 Near Earth Asteroids Orbits from Gaia and Ground-Based Observations
*D. Bancelin, D. Hestroffer, W. Thuillot*
*IMCCE, Paris Observatory (FRANCE)*

11:20 Nuclear Fragmentation/Dispersion Modeling and Simulation of Hazardous Near-Earth Objects
*Brian Kaplinger*; *B. Wie*; *D. Dearborn* (*UNITED STATES*)

11:40 Development Of Mission Design Process For Collision Avoidance Of Near Earth Objects
*Nitin Kumar Mishra*; *G Patel* (*INDIA*)

**12:00 POSTER SESSION**

***12:25 Lunch***

**Session 8 Legal Policy, Political Framework for Planetary Defense**
*Chairs: Frans von der Dunk, Brian Weeden*

14:00 Recommendations of the U. S. NRC Study on NEOs
*Michael F. A'Hearn* (*UNITED STATES*)

14:25 Progress of NEO Activities Within UN COPUOS
*Sergio Camacho* (*UNITED STATES*)

14:50 Towards National NEO Program
*B. Shustov* (*RUSSIAN FEDERATION*)

15:15 US Government Policy and Approach to Planetary Defense
*Lindley Johnson* (*UNITED STATES*)

***15:40 Coffee break***

**16:05 PANEL SESSION: Discussion & Next Steps**
*> Summary of key points from presentations*
*> Discussion of next steps*