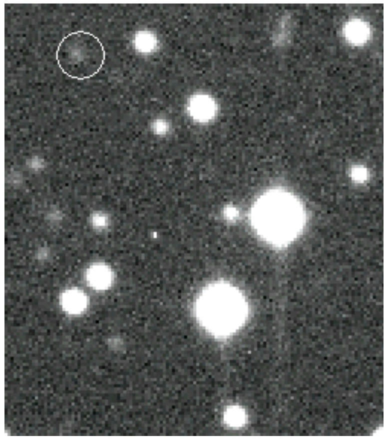
# A Global Approach to Near-Earth Object Impact Threat Mitigation




Alan Fitzsimmons
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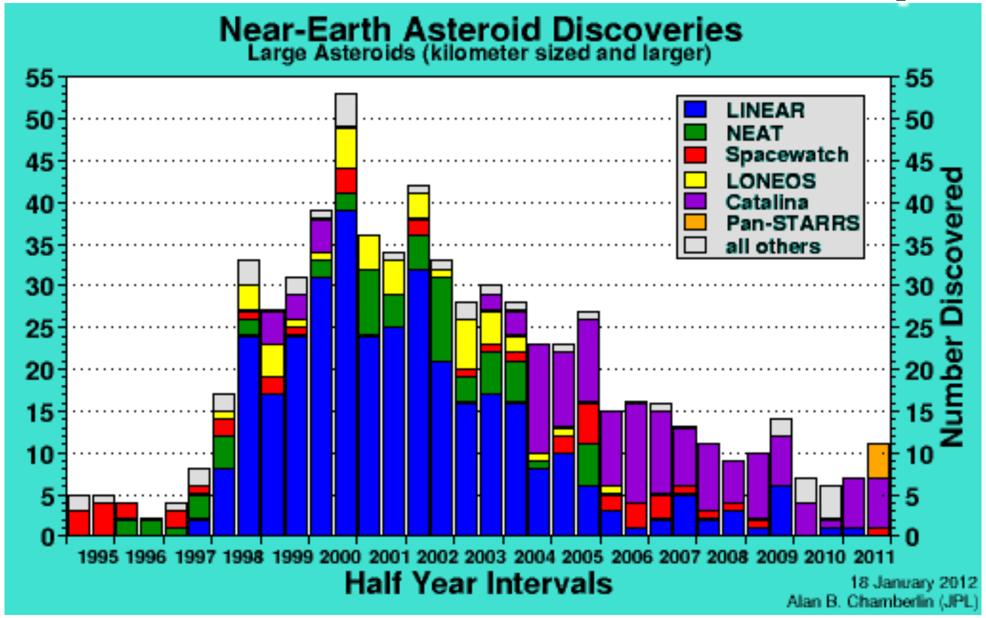
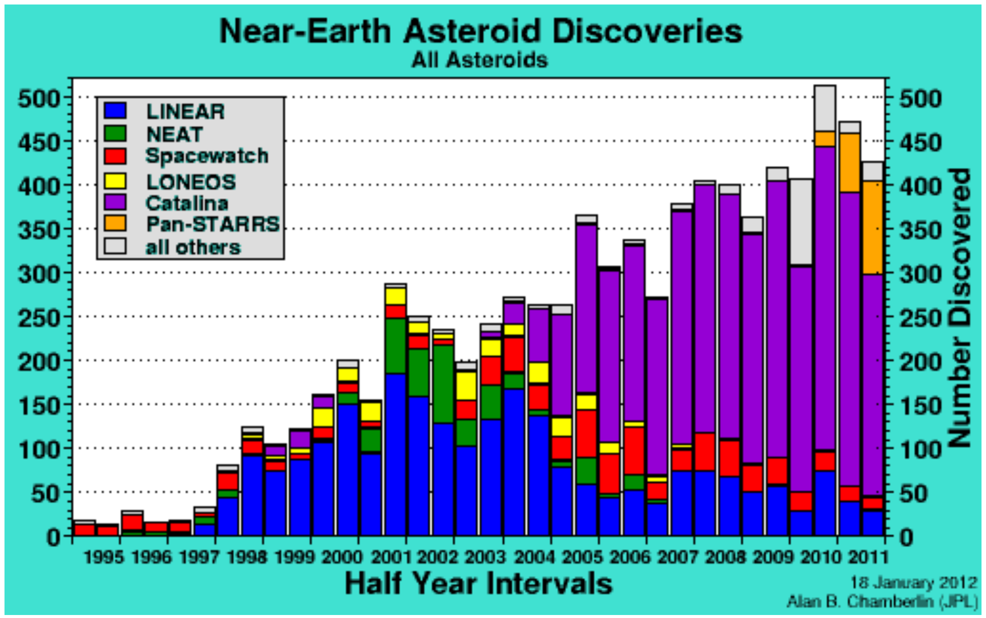
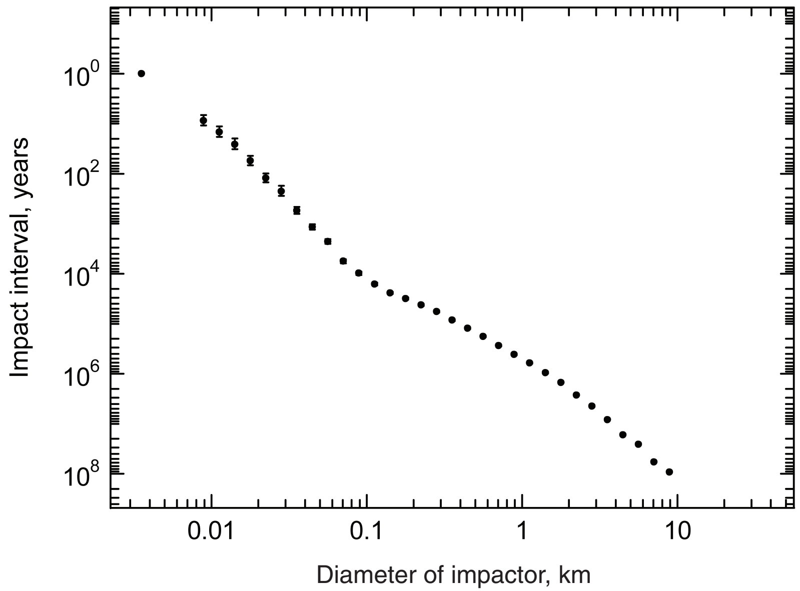
on behalf of
The NEOShield Consortium


# The Impact Hazard




- **>8740 NEOs now catalogued.**

  **(~6230 recoverable)**

- **Majority of bright D>=1km NEOs now discovered.**

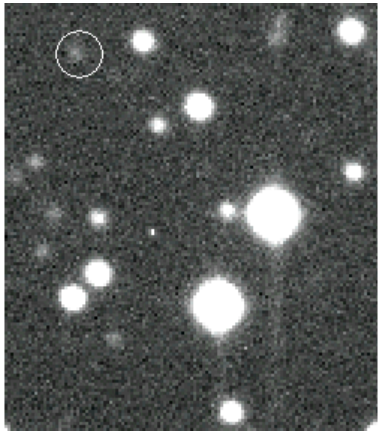
  **(840 out of ~1100)**

- **Number of small NEOs (<1km) still increasing, ~900 discoveries per annum.**

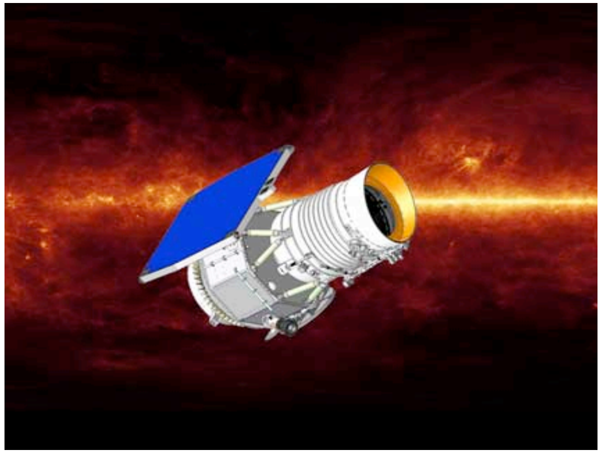
# The Impact Hazard
# What Should We Do?

- **Continue surveys for Near-Earth Objects.**
- **Understand their physical properties**

**Telescopes on Earth.** E.g. Pan-STARRS: Panoramic Survey Telescope & Rapid Response System




**Visiting asteroids and comets.**
E.g. Hayabusa 1+2, OSIRIS-REx, MarcoPolo-R



**Space Observatories.** E.g. WISE: Wide-field Infrared Survey Explorer

# The NEOShield Project

*"The dinosaurs became extinct because they didn't have a space program"*
*- Larry Niven.*

**Jan 2012 for 3.5 yrs, Funded at €4M**

| Participant organisation | Leading personnel | Country |
|---|---|---|
| German Aerospace Center (DLR), Berlin | A. W. Harris | Germany |
| Observatoire de Paris (LESIA and IMCCE) | LESIA: M. A. Barucci, M. Fulchignoni<br>IMCCE: D. Hestroffer, W. Thuillot | France |
| Centre National de la Recherche Scientifique | P. Michel | France |
| Open University | S. F. Green | UK |
| Fraunhofer – Ernst-Mach-Institut | F. Schäfer | Germany |
| Queen's University Belfast | A. Fitzsimmons | UK |
| Astrium (*supervisory interface for technical work packages*) | W. Lork, A. Rathke, P. Blanc-Paques<br>P. D'arrigo, C. Brown | Germany<br>France, UK |
| Deimos Space | J. L. Cano, L. F. Peñín | Spain |
| Carl Sagan Center, SETI Institute | D. Morrison | USA |
| TsNIIMash (Roscosmos) | S.A. Meshcheryakov, Y.M. Lipnitsky | Russia |
| University of Surrey | V. Lappas | UK |

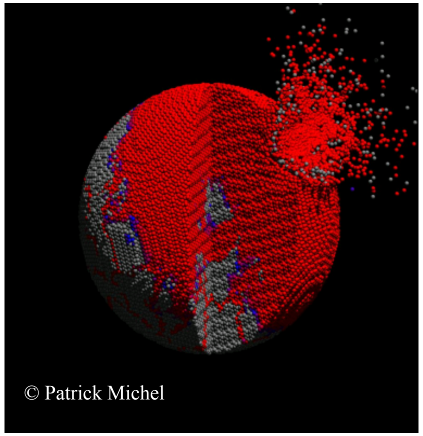
# The NEOShield Project
## Brief description (1/3)

**PRIMARY AIM:** investigate in detail the most promising mitigation techniques, promote a mitigation test mission, create a roadmap of response options.

**Main themes/tasks of the project:**

**1. Science**

- **Physical properties of NEOs:** Analyze properties from the point of view of mitigation requirements; estimate most likely properties of the next mitigation candidate; provide requirements for lab. impact experiments and modelling.




- **Mitigation precursor reconnaissance:** Determine requirements, strategy, instrumentation, for ground-based facilities and space missions.

- **Lab. experiments on impacts** - into asteroid surface analogue materials; validation of impact modelling at small scales.

- **Numerical simulations:** Impact and momentum transfer modelling scaled to realistic NEO sizes.

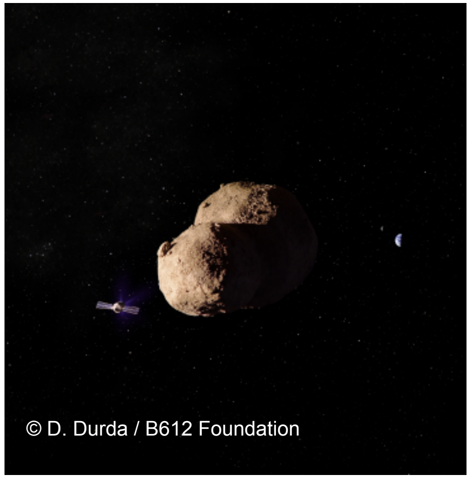
# The NEOShield Project
## Brief description (2/3)


**Main themes/tasks of the project (continued):**

**2. Mitigation demonstration missions**

- **Suitable mission targets:** Identify suitable target NEOs for mitigation demo missions.

- **Space mission design:** Provide detailed designs of technically and financially realistic missions to demonstrate the effectiveness of mitigation techniques. Investigate mission funding and implementation options.



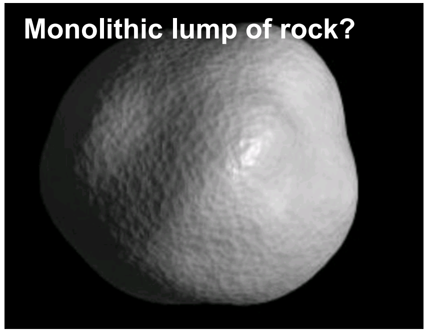
# Mitigation Techniques and NEO Physical Properties

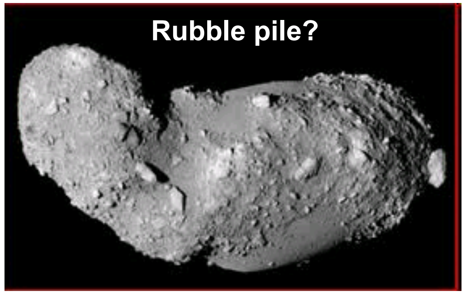
## Kinetic Impactor:

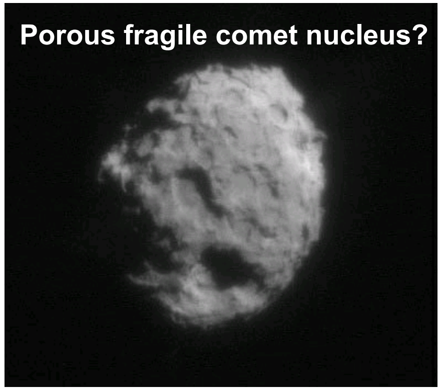
- How does impactor momentum transfer depend on the bulk density, porosity, mineralogy, internal structure, etc. of the target NEO?

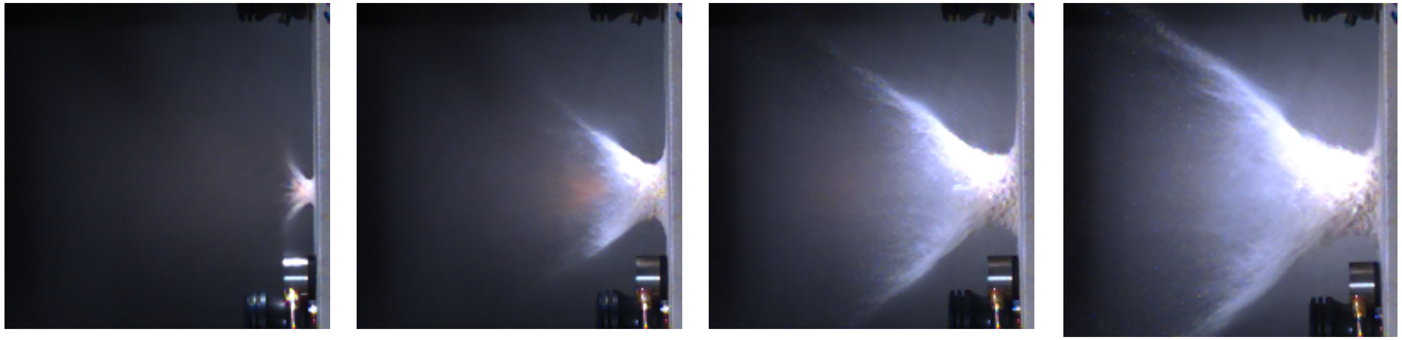
$$M_{NEO}\,\delta V_{NEO} = m_{impact}\,v_{impact}\ \ \beta$$

- How much impactor kinetic energy may be wasted in fragmentation and restructuring?
- The NEOShield project includes laboratory work with gas guns on high velocity impacts to provide data for numerical simulations. Various “asteroid regolith analogue” target types will be investigated, with different block sizes and void fractions to represent a range of realistic cases.



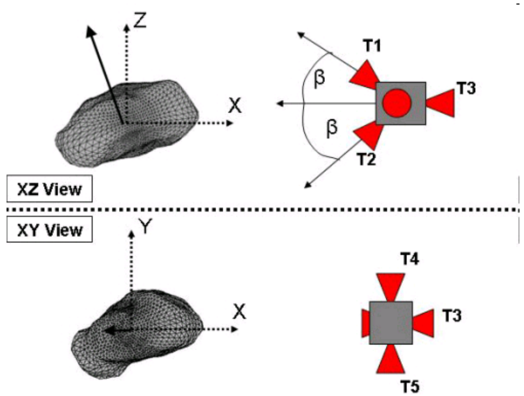
# Mitigation Techniques and NEO Physical Properties

## Gravity tractor:

- A massive spacecraft positions itself close to the NEO and fires its thrusters so as to maintain a constant distance from the target. The weak gravitational force between tractor and NEO acts as a tow-rope.

$$m_{tractor} = r^2\, \delta v_{NEO} / (\delta t\; G)$$

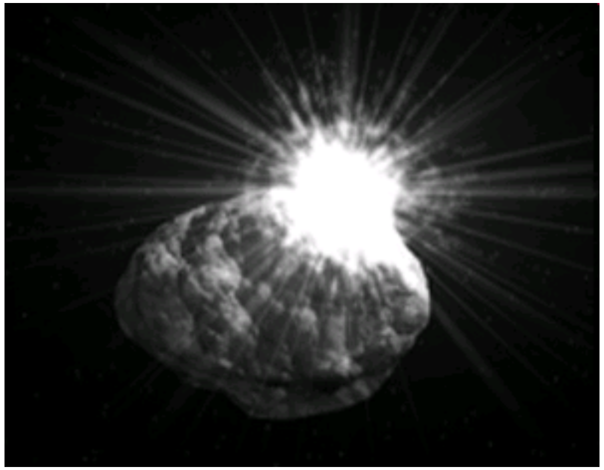

- A gravity tractor, offering a controllable slow-pull approach, could be the ideal mitigation technique in the case of a near-miss fly-by with key holes prior to a predicted impact.
- Big advantage: No contact with the NEO; very little prior knowledge of physical properties required (only mass, shape, rotation vector).
- Big challenge: Requirements for autonomous spacecraft control procedures to manage hovering station keeping and maintain stability of the traction system over a long period of time (decade or more?) in the (very nearby) presence of an irregular rotating mass.



# Mitigation Techniques and NEO Physical Properties

## Blast Deflection:

- **Nuclear explosives** might be considered a last resort in the case of a large NEO or short warning time.
- What is the risk trade-off between construction, preparation and launch of explosive devices and dismissing blast-deflection as a mitigation option?
- **Under what circumstances would stand-off or surface blasts be more effective?** Would surface ejecta significantly enhance the impulse? If so, how can the production of ejecta be maximized?
- How does the danger of complete disruption of the NEO depend on its mass, structure, mineralogy and other physical properties? Under what circumstances might disruption be a desirable option?
- **Big advantage:** Highly efficient impulse/kg.
- **Big challenge:** Security, politics.



# Demonstration Missions

- **Back-of-the-envelope calculations can give us some confidence, but there's no substitute for proving we can move an asteroid by actually doing it.**
- **NEOShield funding does not allow launching a space mission but we aim to provide detailed designs of feasible mitigation demonstration missions, at least of the kinetic impactor and/or gravity tractor methods.**
- **We will talk to colleagues at ESA (SSA programme), the UN (COPUOS, Action Team 14 on NEOs), NASA, the European Commission, etc. to lobby for the funding of a mitigation demonstration mission.**

# Demonstration Missions: Target Selection

- Over 8700 NEOs have now been discovered. Individual targets for space missions include Itokawa (Hayabusa), 1999 RQ36 (OSIRIS-REx), 1996 FG3 (MarcoPolo-R), 2000 SG344 (NHATS).
- The operation of current facilities such as Catalina and Pan-STARRS1 will ensure that over >$10^4$ NEOs will be known by the end of this project.
- **Which of the known NEOs should be used as targets for mitigation demonstration missions?**
- Suitability depends on factors such as accessibility, diameter and shape, mass, Earth MOID, mineralogy, albedo, spin vector, possible binary nature.
- We aim to produce a list of the most important NEO dynamical and physical characteristics required of a demo-mission target and the best potential targets within the known NEO population,

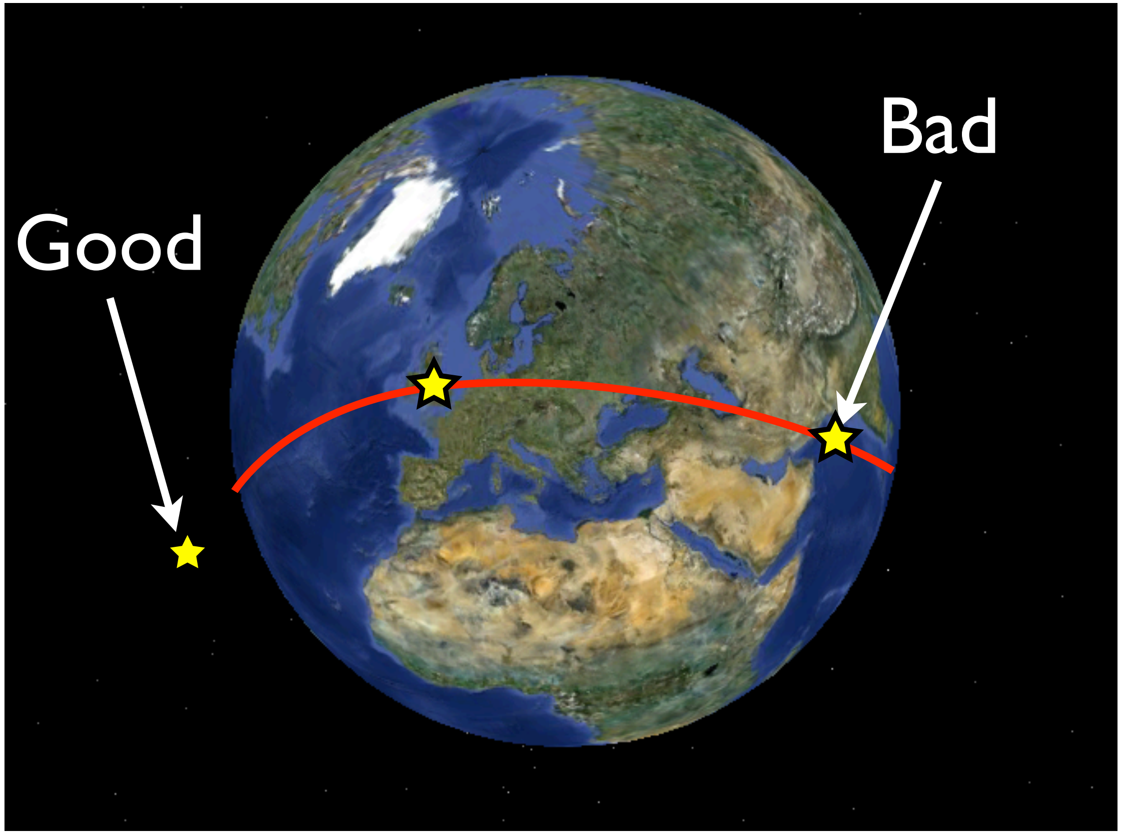
*Note: We will ensure that there is no possibility of a previously benign demo-mission target being deflected into a potentially hazardous orbit.*

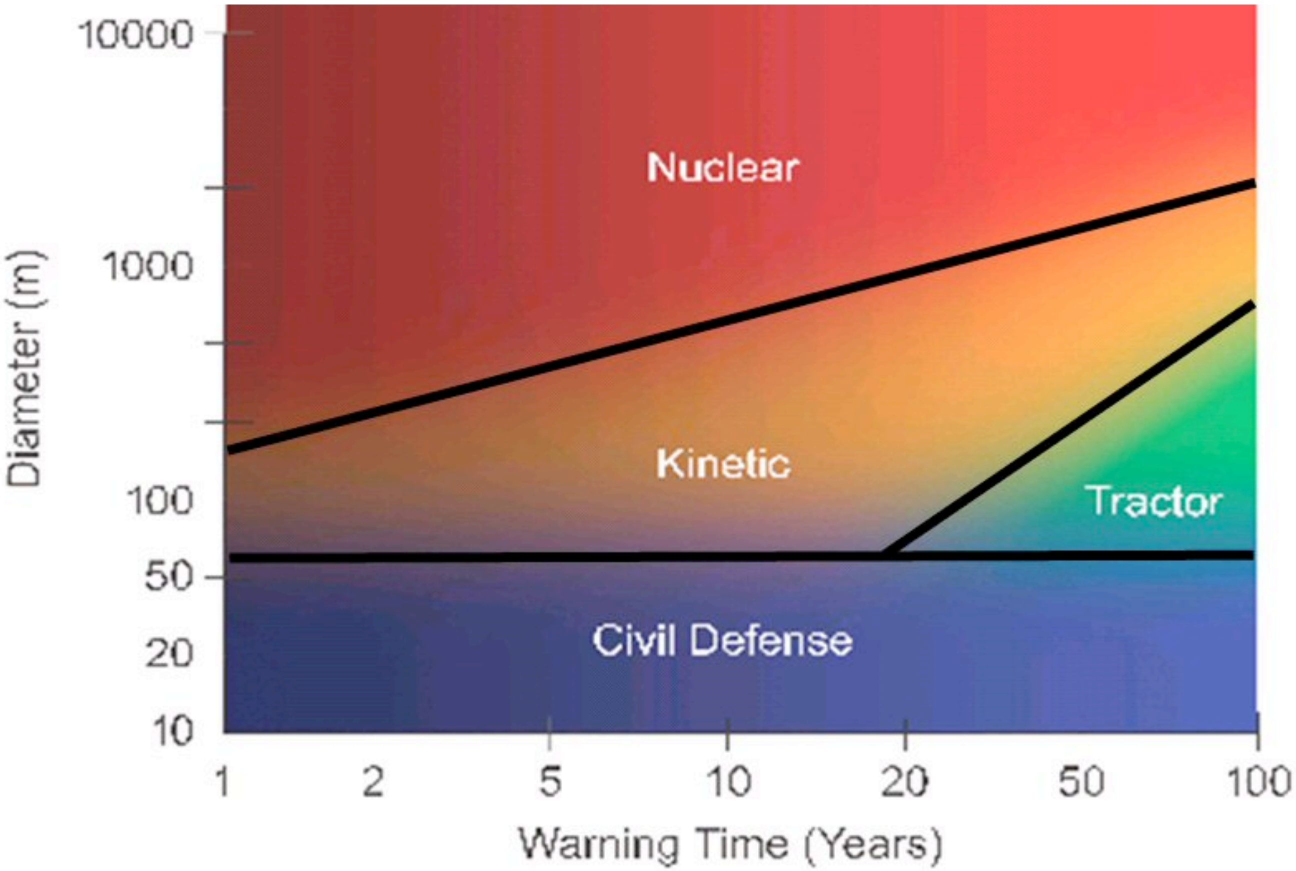

# The NEOShield Project
## Brief description (3/3)

**Main themes/tasks of the project (continued):**

### 3. Global response campaign roadmap

- **Impact threat response strategy:** Develop a decision-making tool to aid in response planning. Develop a global response roadmap in collaboration with partners such as the UN, space agencies, etc. Needs to cover all possible threat responses from evacuation to international mitigation mission.






**Credit: Tim Warchocki (adapted from National Research Council Final Report: “Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies”).**

***It may be that the Last Deflection Date (LDD) to avoid an impact is politically equivalent to the Last Decision Date (Planetary Defence Conference 2011).***

# Summary

***There is no currently concerted international plan on how to deal with the impact threat and how to organize, prepare and implement mitigation measures.***

**The main thrust of the NEOShield project will be in the following areas:**

- **Mitigation methods: The kinetic impactor, blast deflection, and the gravity tractor.**
- **Physical properties of NEOs: Lab experiments on high-speed impacts into asteroid surface analogue materials and data analysis with specially adapted state-of-the-art computer simulation code.**
- **Technology development: Investigation and further development of crucial technologies, such as s/c guidance, navigation and control.**
- **Demonstration missions: The feasibility of appropriate mitigation demonstration missions will be examined and appropriate detailed mission designs provided. Suitable targets for mitigation demonstration missions will be identified.**
- **Global response campaign roadmap: The roles and responsibilities of international organizations such as the UN and the EU, in addition to space agencies and other authorities, will be considered. Account will be taken of complementary efforts currently in progress (e.g. UN Action Team 14 on NEOs, ESA's SSA programme).**