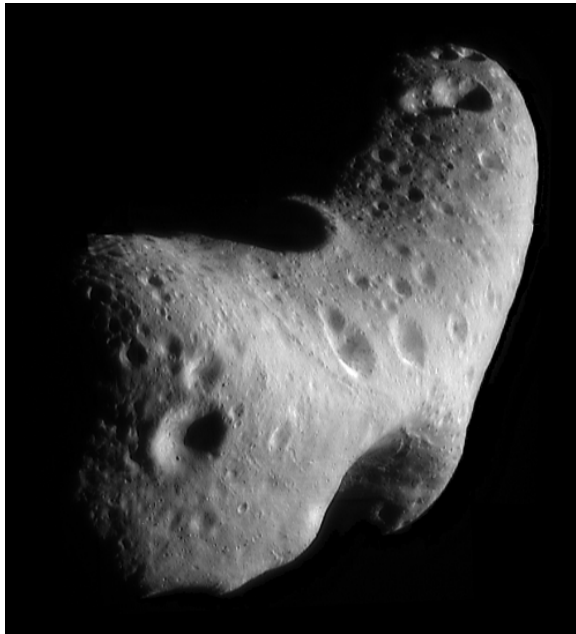


The Asteroid Impact Hazard: Historical Perspective

David Morrison

NASA SSERVI (NASA Ames Research Center)



***Asteroid Grand Challenge
Virtual Seminar***

NASA GRAND CHALLENGE:

***Find all objects capable of
threatening human
populations and determine
how to deal with them.***

Historical Quotes

- **Should a comet in its course strike the Earth, it might instantly beat it to pieces. But our comfort is, the same great Power that made the Universe, governs it by his providence. And such terrible catastrophes will not happen till 'tis best they should ...**
Benjamin Franklin (1757)
- **Men should be free from this fear ... for the probability of [a comet] striking the Earth within the span of a human lifetime is slim, even though the probability of such an impact occurring in the course of centuries is very great ...**
Laplace (c. 1790)
- **Who knows whether, when a comet shall approach this globe to destroy it, as it often has been and will be destroyed, men will not tear rocks from their foundations by means of steam, and hurl mountains, as the giants are said to have done, against the flaming mass? - and then we shall have traditions of Titans again, and of wars with Heaven...**
Lord Byron (1822)
- **Civilization could be entirely destroyed by the unexpected impact of an asteroid or comet. Thousands of years of history could be erased in a single day, and with it the hopes for future generations ...**
Clark Chapman & David Morrison (1989)
- **If some day in the future we discover well in advance that an asteroid that is big enough to cause a mass extinction is going to hit the Earth, and then we alter the course of that asteroid so that it does not hit us, it will be one of the most important accomplishments in all of history...**
U.S. Congressman George Brown (1993)

Chelyabinsk, Ural Mountains, Russia

February 15, 2013









Tunguska Impact

**Impact in Russian Siberia
June 1908.**

**Destroyed more than
1000 square kilometers
of forest**

**Airburst with estimated
energy 3-6 megatons**

**Collision with small
stony asteroid (40 m)**

**Predicted frequency:
several centuries for
entire Earth**



Why Care About NEAs?

- ***Science: Unexplored component of our solar system***
- ***Exploration: Stepping stones to Mars***
- ***Defense: Objects most likely to collide with Earth***
- ***Resources: Most accessible objects in translunar space***
- ***Politics: Of interest to President, Congress, and public***

Prelude

Tunguska impact in Siberia (1908)

***Project Icarus* study of asteroid deflection (MIT 1967)**

KT Mass Extinction due to impact (Alvarez et al. 1980)

Tom Gehrels Spacewatch: First CCD discovery of a NEO (1989)

U.S. Congress asks NASA for Impact Threat Workshops (1990)

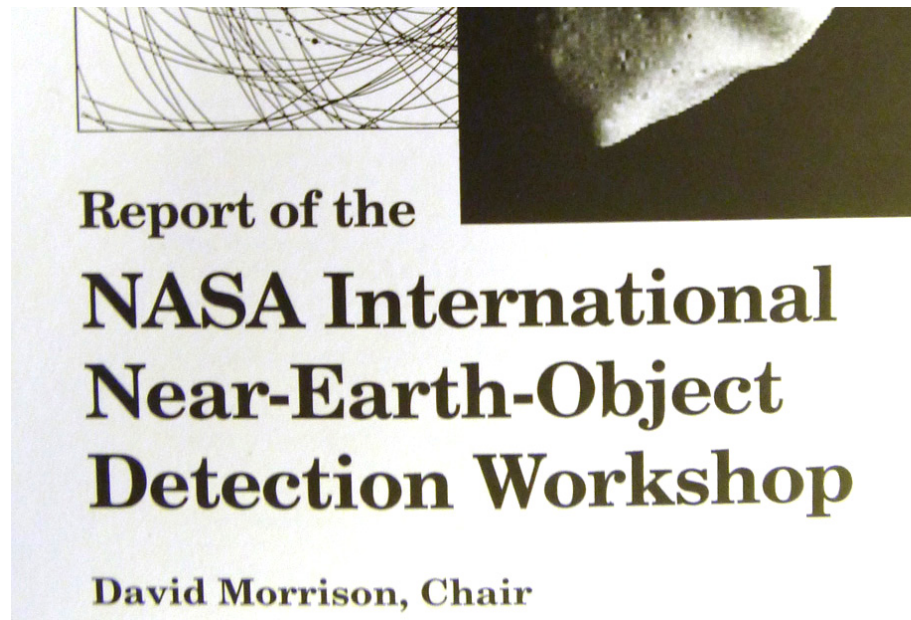
***Newsweek* Cover Story: *Doomsday Science: Comets & Asteroids and How the World Might End* (1992)**

***Economist* Cover Story: *The Threat from Space* (1993)**

NASA Workshops/Studies 1992

SPACEGUARD SURVEY WORKING GROUP (Morrison et al.)

- **Define threshold for globally catastrophic impact**
- **Optimize survey for greatest hazard: NEAs > 1 km**
- **Provide maximum warning lead time (several decades)**
- **Use existing CCD technology to be cost-effective**
- **Optimum survey covers 6000 sq deg per month to $V=22$**
- **Program should be international, since entire planet is at risk**



The Impact Hazard: Context

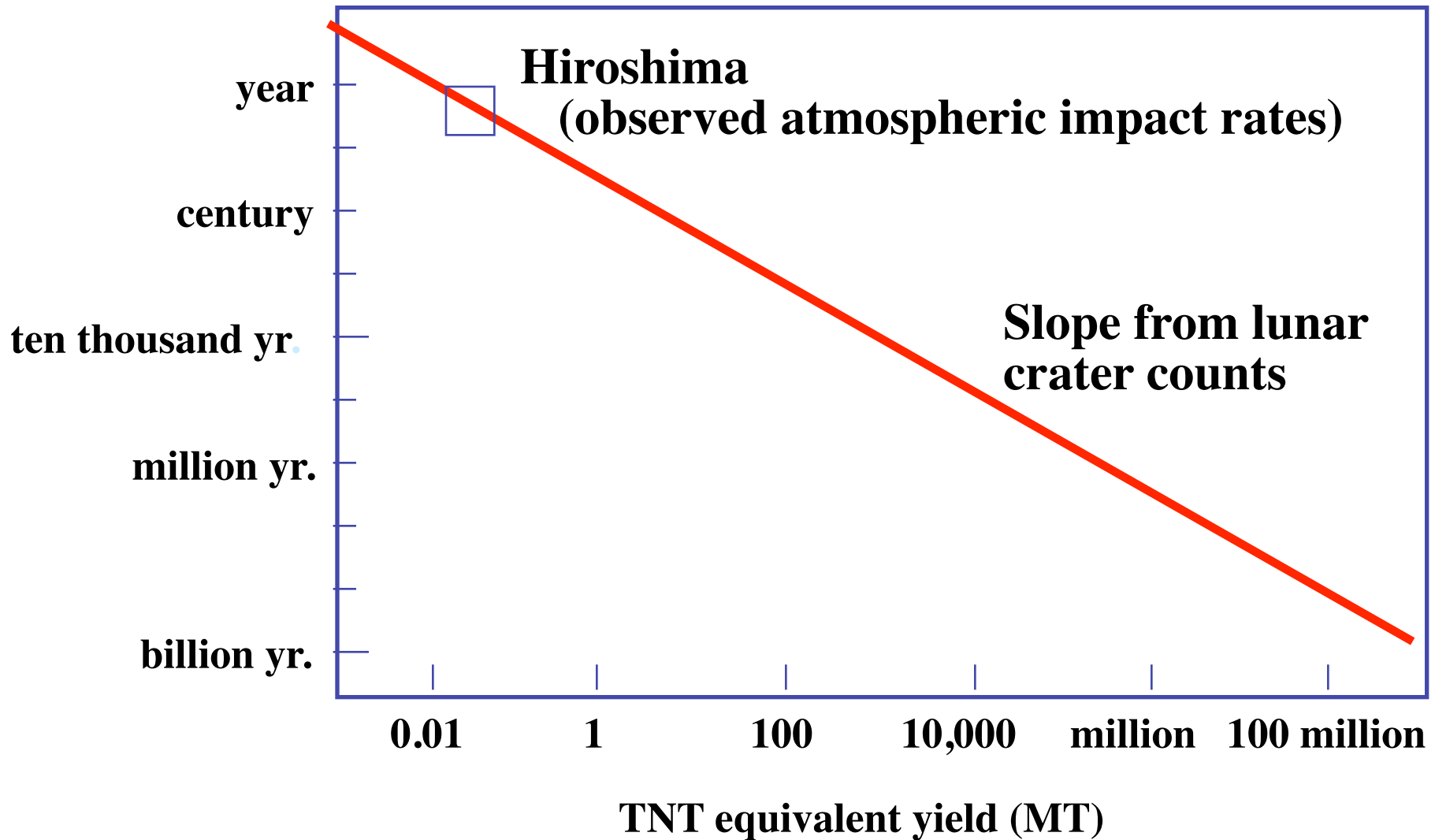
Large cosmic impacts (by comets or asteroids) are the most catastrophic natural events we know (e.g., mass extinction of 65 million years ago at the end of the Cretaceous). These are the most extreme examples of a hazard with very low frequency but extremely high consequences.

The contemporary risk (chances that you will die from an impact) is dominated by moderate size asteroids (1-2 km diameter). These risks are comparable to those of a supervolcano eruption.

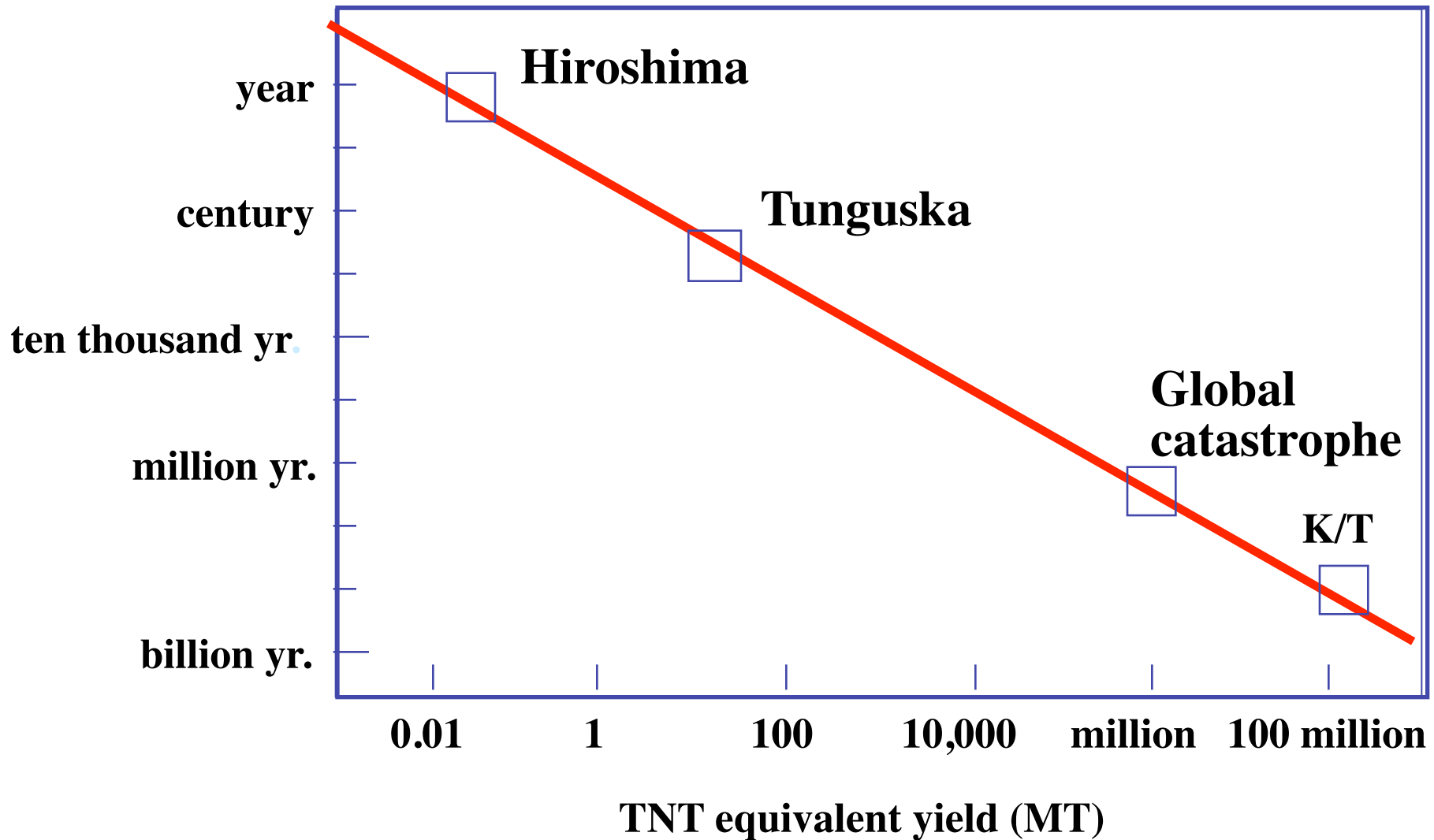
The impact risk can be minimized by a program to find threatening asteroids decades before they hit and develop technology to deflect them (change their orbits so they miss Earth). The Spaceguard Survey begun in 1998 has found 95% of NEAs >1 km.

The basic motivation for detection and deflection is public safety. This is a societal issue as well as a scientific one.

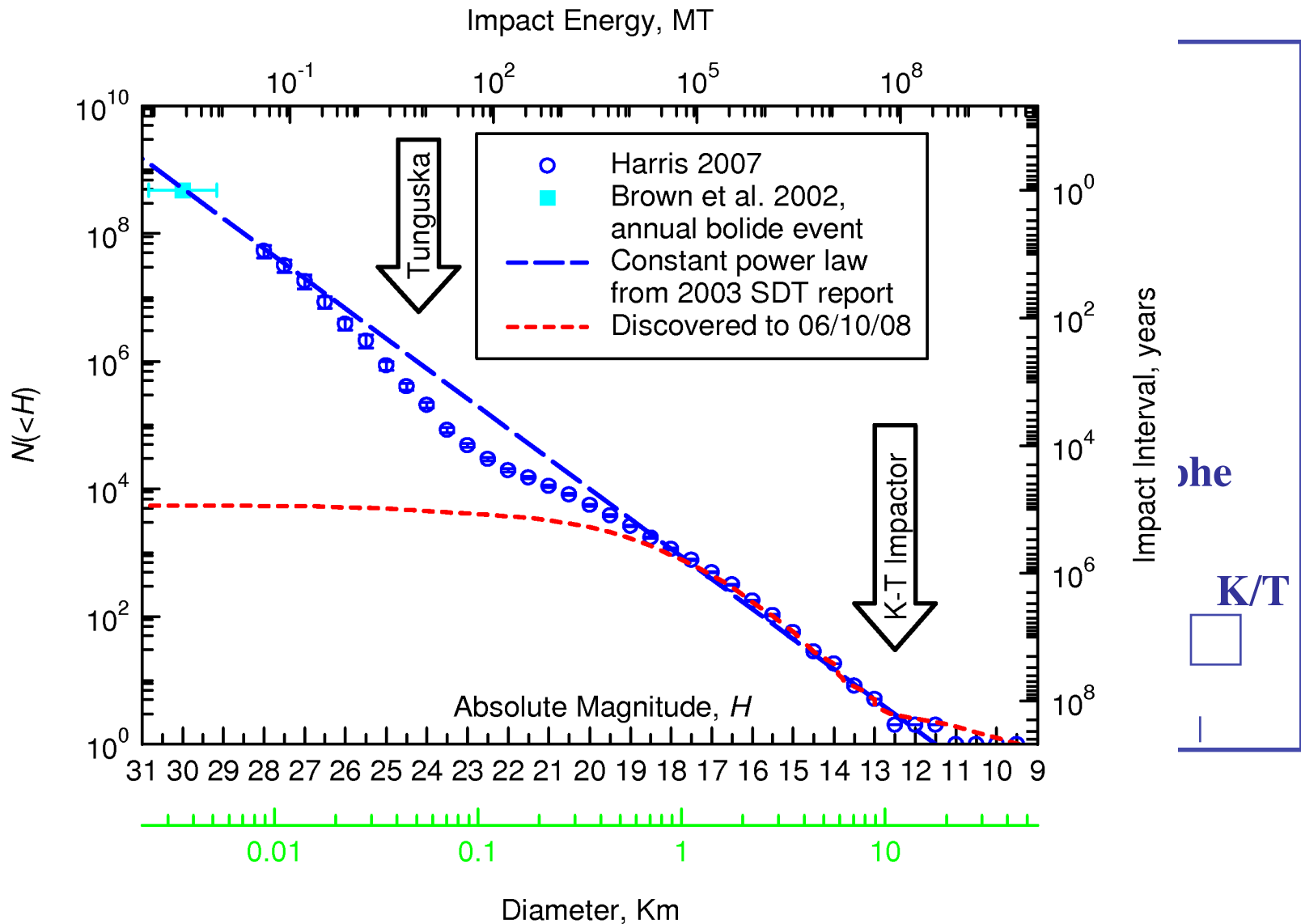
Terrestrial Impact Frequency



Terrestrial Impact Frequency



Terrestrial Impact Frequency (Harris, 2008)



Overall Hazard (from 2003 STD Report)

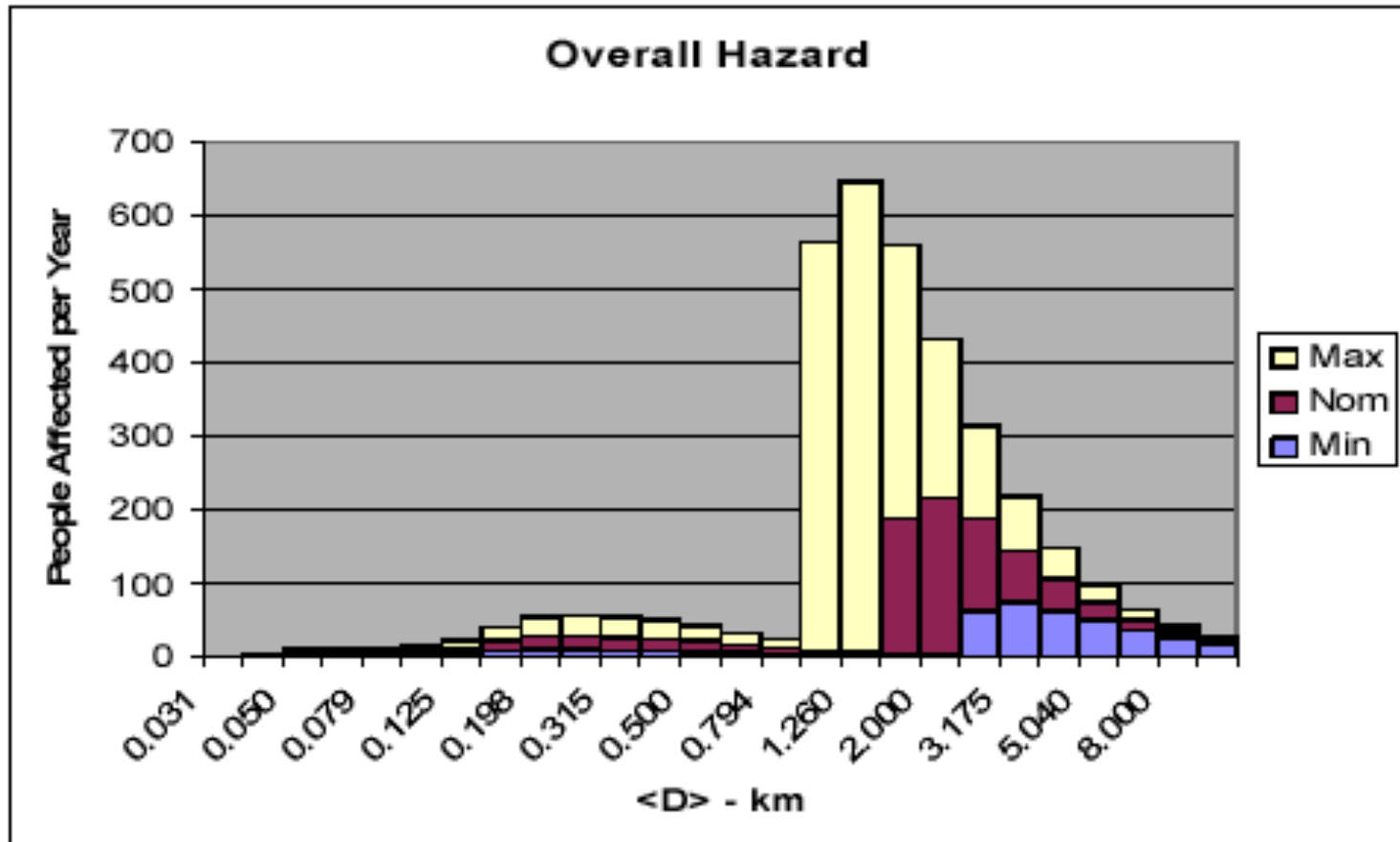
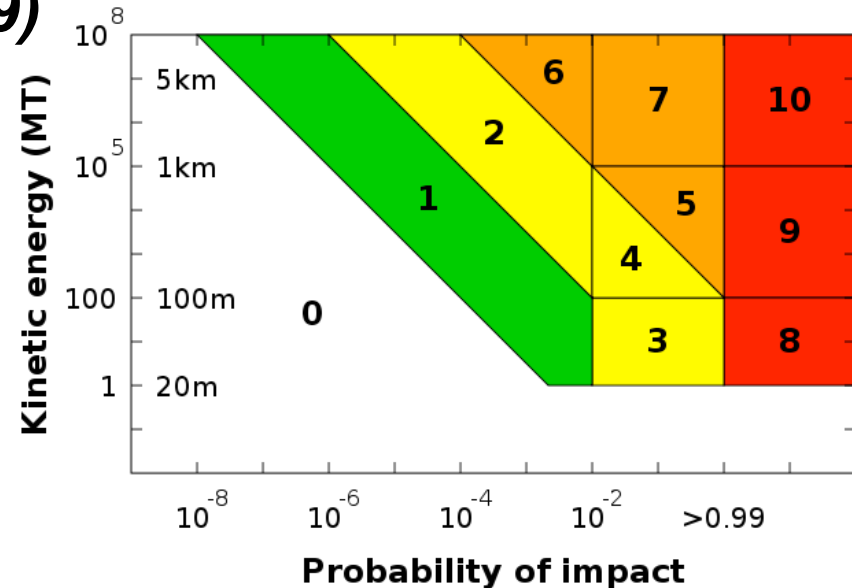


Figure 3-10. Summary of Overall Impact Hazard

Torino & Palermo Hazard Scales

Torino Scale (Rick Binzel, 1999)

**Color-coded 10-level scale
(analogous to earthquake scale)
for communicating impact risk to
a wide audience, based on
impact probability and energy.**



Palermo Scale (Steve Chesley, 2001)

**Technical Impact Hazard represented by a 1-dimensional logarithmic
scale combining impact probability and energy into a single value,
measured with respect to the background impact rate.**

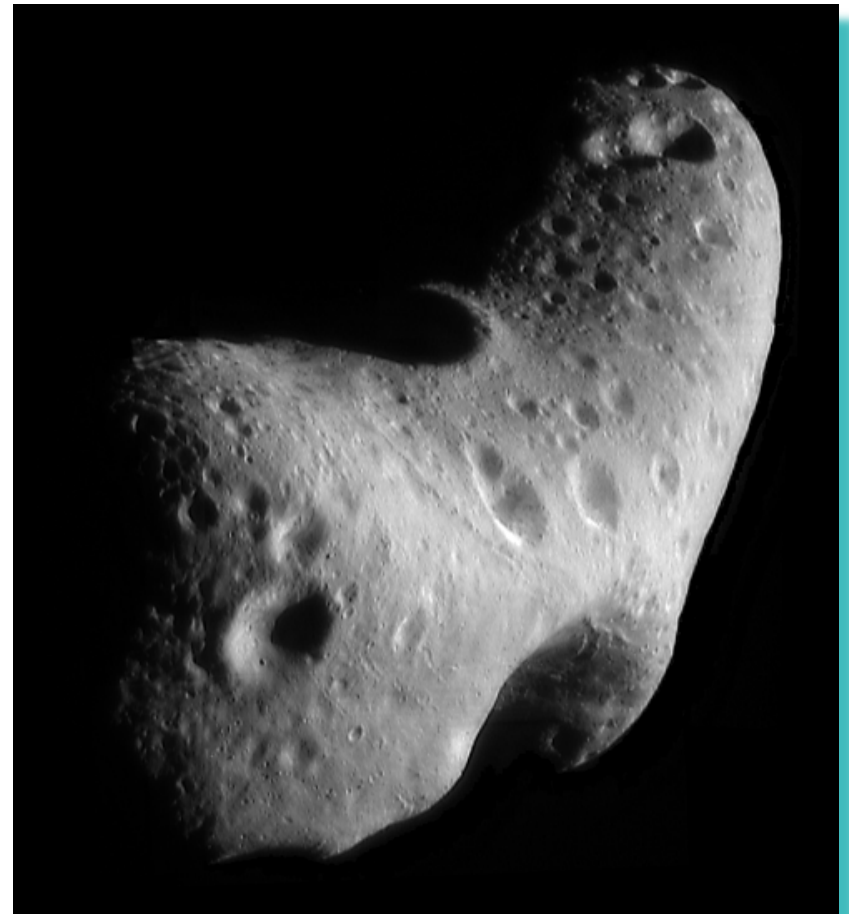
NEAR-Shoemaker Mission to Eros

- **First Mission to an NEA, first orbit, and first landing**
- **NEAR = Near Earth Asteroid Rendezvous**
- **NASA Discovery Mission**

Launch 1996

Land 2001

- **Provided first *in situ* data**
- **Measured bulk properties, composition, mineralogy, morphology, internal mass distribution, magnetic fields, and regolith properties**
- **Discovered unexpected geology (boulders, ponds)**
- **Supported link between S-type NEAs and ordinary chondrites**



Hayabusa Mission to Itokawa



Launch May 2003, rendezvous and station-keeping September 2005, extensive remote-sensing during approach

Brief autonomous landings to collect samples, November 2005

First close-up study of sub-km NEA, revealing Itokawa as a boulder-strewn rubble pile quite different from larger NEAs such as Eros

Earth return 13 June 2010. More than 1000 asteroid particles recovered.

Deep Impact Hits Comet Tempel-1



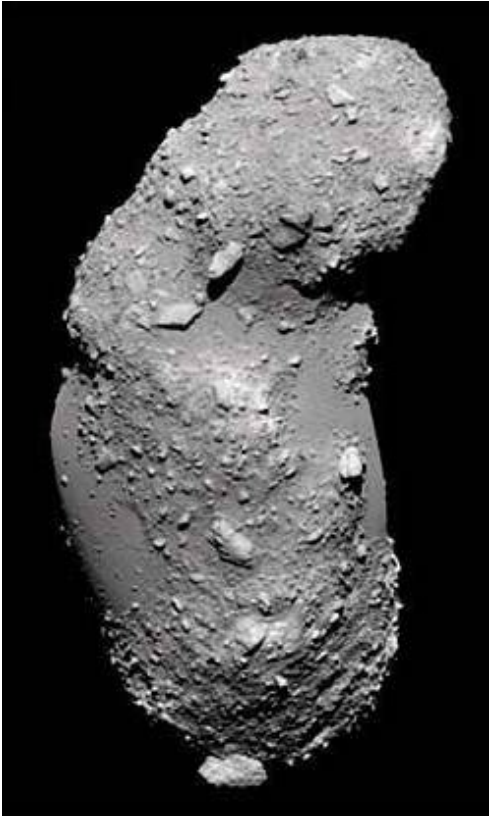
Congressional Statement 1991

The House Committee on Science and Technology believes that it is imperative that the detection rate of Earth-orbit-crossing asteroids must be increased substantially, and that the means to destroy or alter the orbits of asteroids when they do threaten collisions should be defined and agreed upon internationally. The chances of the Earth being struck by a large asteroid are extremely small, but because the consequences of such a collision are extremely large, the Committee believes it is only prudent to assess the nature of the threat and prepare to deal with it.

NASA Authorization Bill, 1991



Congressional Mandate 2008



The NASA Administrator shall plan, develop, and implement a Near-Earth Object Survey program to ***detect, track, catalogue, and characterize the physical characteristics*** of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth.

Assignment of Responsibility

From John Holdren (White House) to Congress (11/15/10)

- ***Any strategy for addressing the potential hazard of a NEA impact depends in the first instance on detection, precision tracking, and characterization.***
- ***NASA retains primary responsibility for discovery, tracking, and characterization, including threat identification and notification.***
- ***For mitigation of short-term threats, NASA works with Homeland Security, Department of State, and FEMA.***
- ***For assessment of potential technologies for mitigation/deflection, NASA takes lead working with DoD and DHS. Recommends senior-level interagency simulation exercises, and outreach to private-sector stakeholders.***
- ***Plans should involve cooperation with UN/COPUOS, EU, and ISECG.***
- ***This approach is subject to further review as more information becomes available.***



How can we protect our planet and ourselves?

- **The first task is to find potentially hazardous asteroids**
- **The second task is to find hazardous asteroids and calculate their orbits**
- **The third task is to find hazardous asteroids and calculate their orbits long before they hit.**

Perspective #1: Assessing the Hazard

- During the 1990s, the standard scientific tools of sampling and statistical analysis were essential to understand the impact hazard and communicate the risk to decision makers. Chapman & Morrison and others compared the impact risk to other natural hazards, estimated the risk as a function of NEO size, and laid the foundation for establishing the Spaceguard Survey.
- Congressional language (in 1991) reflected this perspective: *The Committee believes it is only prudent to assess the nature of the threat...*
- More sophisticated studies of NEA populations and impact consequences by Harris, Chesley and others were used in the 2003 NASA SDT Report.
- Note that while these statistical studies provide a tool to analyze various mitigation schemes, *they do not in themselves reduce the hazard.*

Perspective #2: Mitigating the Hazard

- The public and decision-makers are interested in warning and protection. *The public-policy goal is not to refine the estimate of the risk but to identify the next impactor and do something about it.*
- Changed perspective is reflected by Congress (2005): *The objectives of the NEO survey program are to detect, track, catalogue, and characterize the physical characteristics of NEOs ... (not assess risk).*
- NEA surveys are designed to provide decades of warning.
- The objective is increased public safety, not to improve scientific understanding of either NEOs or the impact risk, although these are worthy byproducts.

Perspective #3: Responding to Public Concerns

- **Issues that worry the public (and most decision makers) are not necessarily the greatest threats. The very rare large impacts pose the greatest hazards, but most people are more concerned about the next impact.**
- **From this perspective, it is the frequency of threat warnings that matters, not the size of the threat.**
- **What is minimum size impactor that is a threat? Chelyabinsk was 20m, Tunguska 40m.**
- **Ideally we should design a system that detects both distant large NEAs and close small ones, but this does not seem possible, so choices must be made.**

Spaceguard Survey (1998-present)

NASA-funded Survey to find asteroids potentially capable of causing a global catastrophe, officially begun in 1998

Most asteroids have been discovered by just 4 small (1-m) telescopes with NASA and USAF support

Spaceguard Goal: find 90% of NEAs > 1 km (but note majority of discoveries are smaller than this 1-km metric)

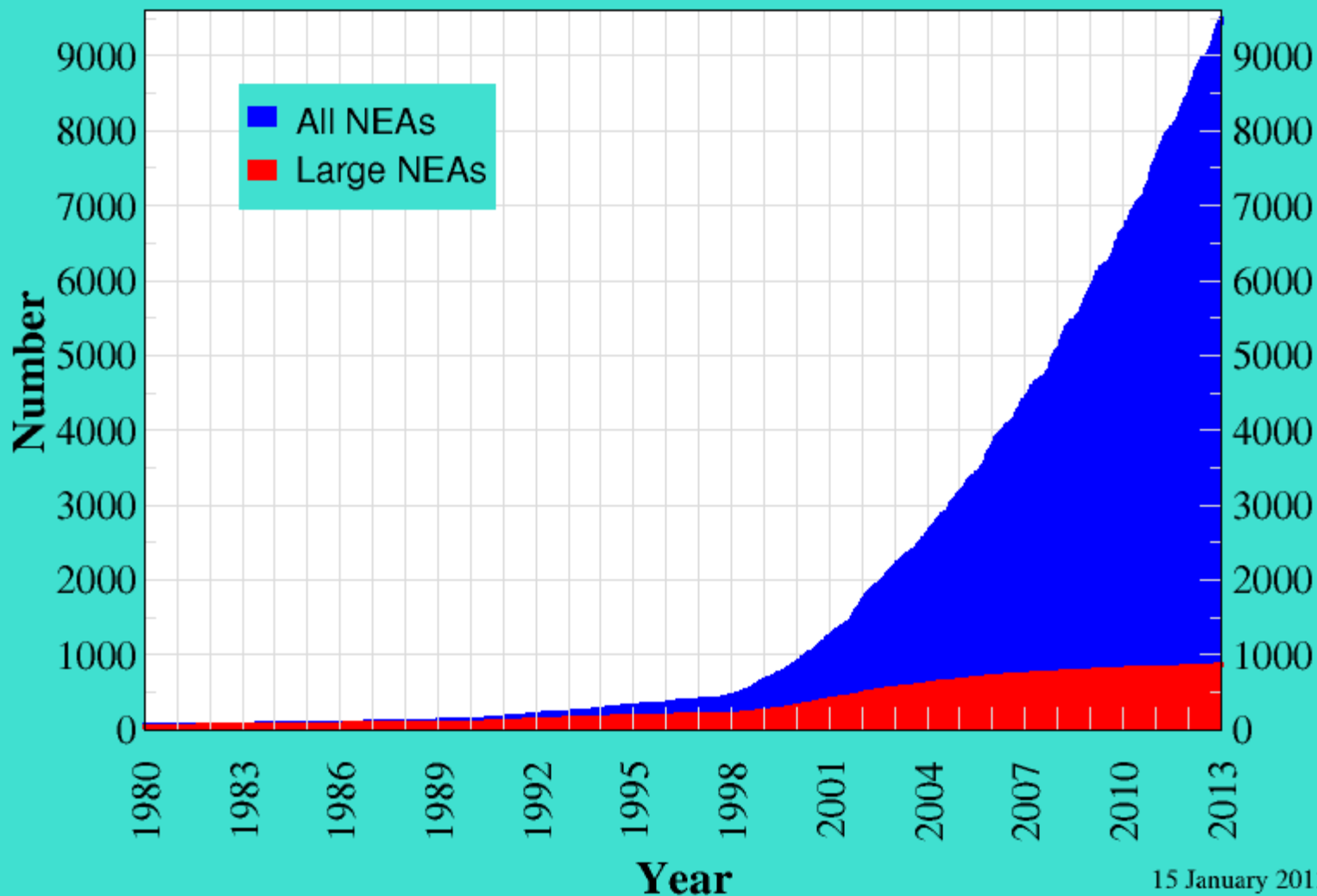
Astrometric follow-up mostly by amateurs (international)

Supporting orbital analysis from MPC, JPL NEO Program Office, U. Pisa



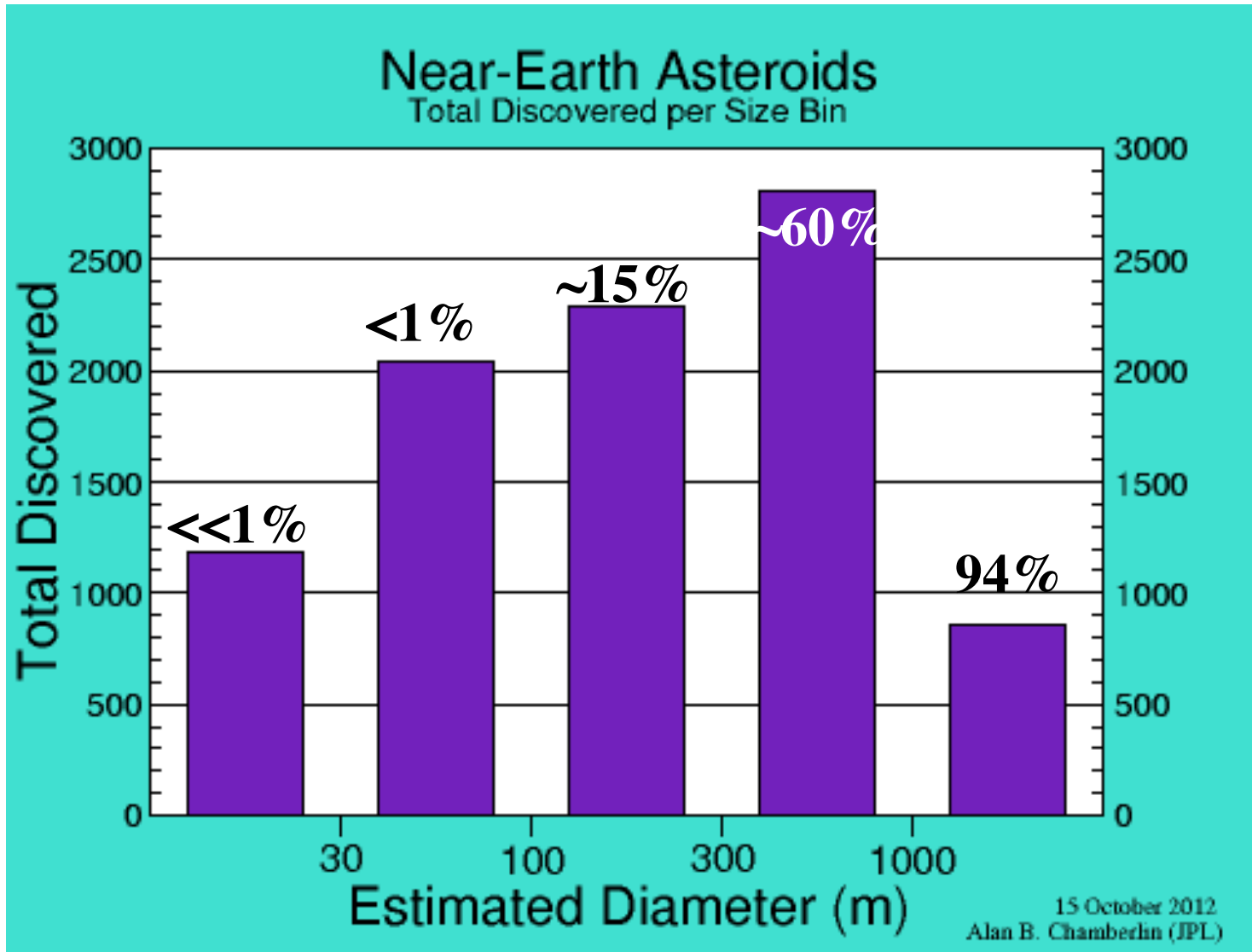
Spaceguard Discovery Progress (1)

Known Near-Earth Asteroids 1980-Jan through 2012-Dec



15 January 2013
Alan B. Chamberlin (JPL)

Spaceguard Discovery Progress (2)



Next-Generation NEA Surveys

Surveys can be done from the ground, from Earth orbit, or from deep space.

Ground-based (telescopic) surveys represent a straightforward extension of current Spaceguard technology. Costs are reduced by combining NEA survey with astrophysics objectives.

For surveys from Earth, the time-scale is defined primarily by the Earth-approach interval for NEAs with long synodic periods -- about a decade from the start of the survey.

Space IR surveys from heliocentric orbit are faster, more complete.

Any deep survey will find many more objects below the nominal target size than above.

NEA Characterization Issues

Characterization is needed for science, defense, resource assessment, and as precursor for human flights.

How much can be done from the ground? Do we need dedicated follow-up observing facilities, such as the Arecibo & Goldstone radars?

Do missions need to land (trade-off with multiple targets)? What level of knowledge of interiors is needed, and are seismic or radar techniques practical? Do we need better understanding of Yarkovsky effect?

Should characterization missions be flown now, or wait for identified threat and/or selection of deflection technology?

Planetary Defense

- **Impacts are the only natural hazard that can, in principle, be eliminated.**
- **We could develop the technology to change asteroid orbits.**
- **Earth moves its own diameter in 6 minutes -- thus to avoid a collision we need only change the arrival time of the asteroid by 6 minutes.**
- **Technologies considered to change orbits include ballistic impact, gravity tractor, and nuclear explosives.**
- **Key to any defense effort is early detection. Surveys are the front line.**



Defense Strategy

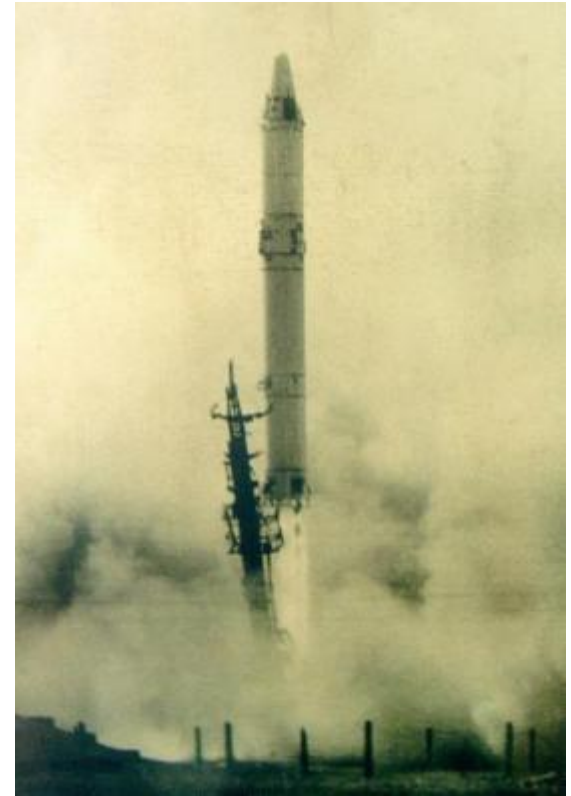
If an object >100 m is heading toward us, we will want to deflect it irrespective of its exact size. More complex questions arise if it is <100 m. If such an object were headed for the ocean, or for an uninhabited region of the Earth, we would probably opt to take the hit.

Given adequate warning, the simplest option both technically and politically is to deflect a threatening NEA by ballistic impact.

The most likely impact event in the next two decades will be a strike without prediction or warning. In this case mitigation falls to disaster-relief teams rather like the response to a large earthquake. International planning and cooperation are required.

Issues in Planetary Defense

- **Should we develop this technology now? Or wait until a specific threat is identified?**
- **Should this be an international effort? If so, how should it be organized?**
- **How much should we spend to protect our planet?**
- **Who can be trusted with this responsibility?**
- **How do we ensure that asteroid defense systems are not misused?**



International Programs

- **For the past decade the UN has been studying planetary defense through their UN Action Team on Near Earth Objects (Action Team 14)**
- **The UN Committee on the Peaceful Uses of Space meeting this month in Vienna approved an international warning network and a planning advisory group. *"It was emphasized by several participants ... that the NEO threat concerns everyone and international coordination and cooperation is essential in this field."***
- **ESA/ESTEC have established a Space Situational Awareness Program to coordinate European responses to the impact hazard.**

Robust Conclusions from the Hazard Analysis

- **Cosmic impacts represent an extreme example of the class of hazards with low probability but high consequences.**
- **Unlike other natural hazards, impacts can kill billions of people and endanger the survival of civilization.**
- **The total risk increases with the size (energy) of the projectile; thus any effort at hazard reduction focuses first on the rare events associated with the larger impacting bodies. There is no consensus as yet on how to deal with smaller more frequent impacts.**
- **Unlike other natural catastrophes, large impacts can, in principle, be avoided by deflection to alter the orbit of the projectile.**
- **The initial step in any mitigation scheme is to survey the near-Earth asteroids and determine their orbits.**

Why did Dinosaurs go Extinct?

- **They were big and strong and beautiful and even pretty intelligent**
- **They occupied environments all over the planet – on land and sea and air**
- **They had ruled the world for more than 100 million years**

Why did Dinosaurs go Extinct?

- They were big and strong and beautiful and even pretty intelligent
- They occupied environments all over the planet – on land and sea and air
- They had ruled the world for more than 100 million years
- BUT:
- THEY DIDN'T HAVE TELESCOPES
- THEY DIDN'T HAVE A SPACE PROGRAM

***Asteroids are nature's
way of checking on
our space program.***