

Earth Threatening Asteroids: Issues and Future Actions

William Ailor, Ph.D.

The Aerospace Corporation

Background

- Considerable work over the last several years on understanding the threat, proposing actions
- 2004 & 2007 Planetary Defense Conferences discussed
 - What we know about the threat to Earth from asteroids and comets
 - Consequences of impact
 - Techniques for deflection
 - Deflection mission design
 - Disaster mitigation
 - Political, policy legal issues associated with mounting a deflection mission
 - Details and videos at www.planetarydefense.info

The Threat

March 27, 2003: Chicago



- 27 March 2003, 05:50 UT (12:50 AM local time)
- Southern suburbs of Chicago
- Camera in stationary squad car parked about 150 km away
- Five structures damaged
- Object estimated to be ~2 m in diameter, weigh ~7 tons

*Credit: Sgt. Kile - South Haven Indiana Police Department
Prof. Peter Brown - University of Western Ontario
Dr. Dee Pack - The Aerospace Corporation
Video courtesy of University of Western Ontario, South Haven Indiana
Police Department, and The Aerospace Corporation*

Not Long Ago

- **30,000 to 34,000 years ago: Object exploded over Alaska?**¹
 - Small metallic particles embedded in mammoth tusks, bison skull
 - Zones of shattered material around each particle
 - All particles from same direction
 - Event could have rendered much of northern Alaska inhospitable for decades
- **12,900 years ago: Object exploded over Canada?**²
 - Evidence of NEO impact (characteristic particles; large-scale fires)
 - Massive extinction of the North American fauna
 - Major population declines among PaleoAmericans
 - 10 deg C drop in temperatures in the Northern Hemisphere in the first decades after the event
- **1908: Object exploded over Tunguska, Siberia**
 - Airburst of ~30 m diameter object at ~6 km altitude
 - 2-5 MT explosion
 - Two fatalities
 - Leveled and ignited 2000 km² of forest

¹ R.B. Firestone, "Micrometeorite Impacts in Beringian Mammoth Tusks and a Bison Skull," AGU Fall Meeting, 10-14 December 2007, San Francisco, CA Paper U23A-0865.

² R. B. Firestone, et al, "Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling," PNAS, vol. 104, no. 41, pp 16016–16021, October 9, 2007.

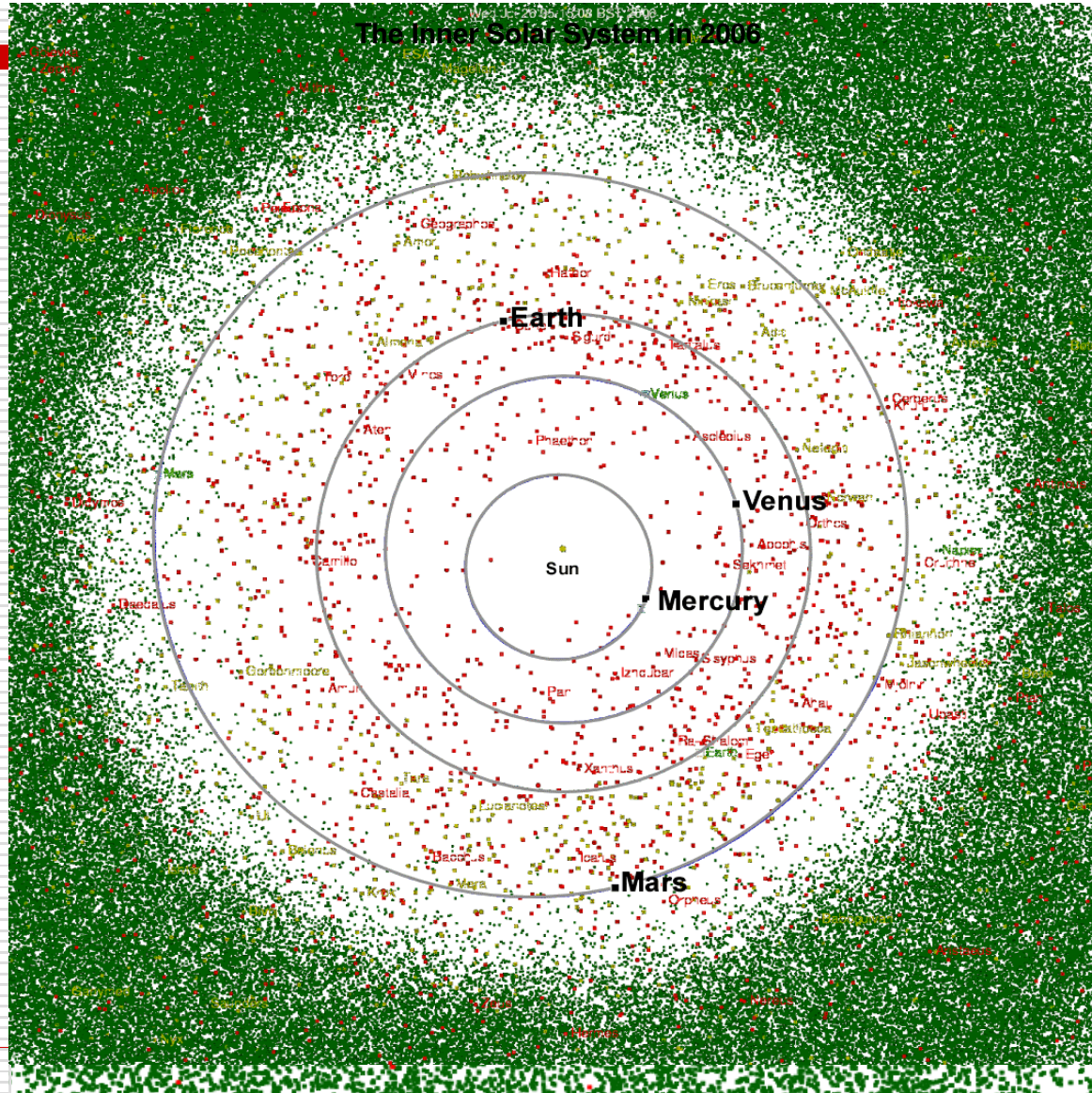
History of Known NEO Population

2006

Earth Crossing ●

Outside Earth's Orbit ●

NEO: Perihelia <1.3 AU
PHO: pass within 0.05 AU of Earth's orbit



Known

- 350,000 minor planets
- 4500 NEOs
- ~830 PHOs

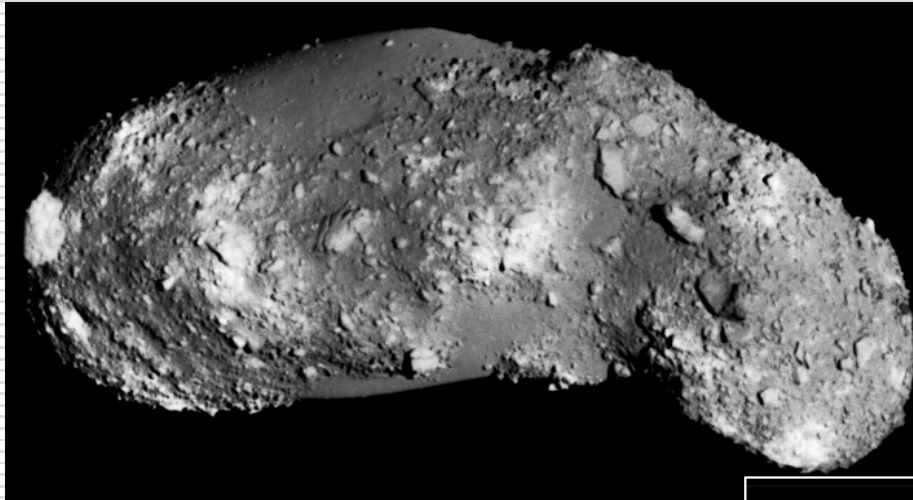
New Survey Will Likely Find

- 100,000+ NEOs (> 140m)
- 20,000+ PHOs

Scott Manley

Armagh Observatory

What do they look like?



Asteroid Itokawa

500 x 300 x 200 meters

Photo courtesy JAXA

Photo courtesy NASA

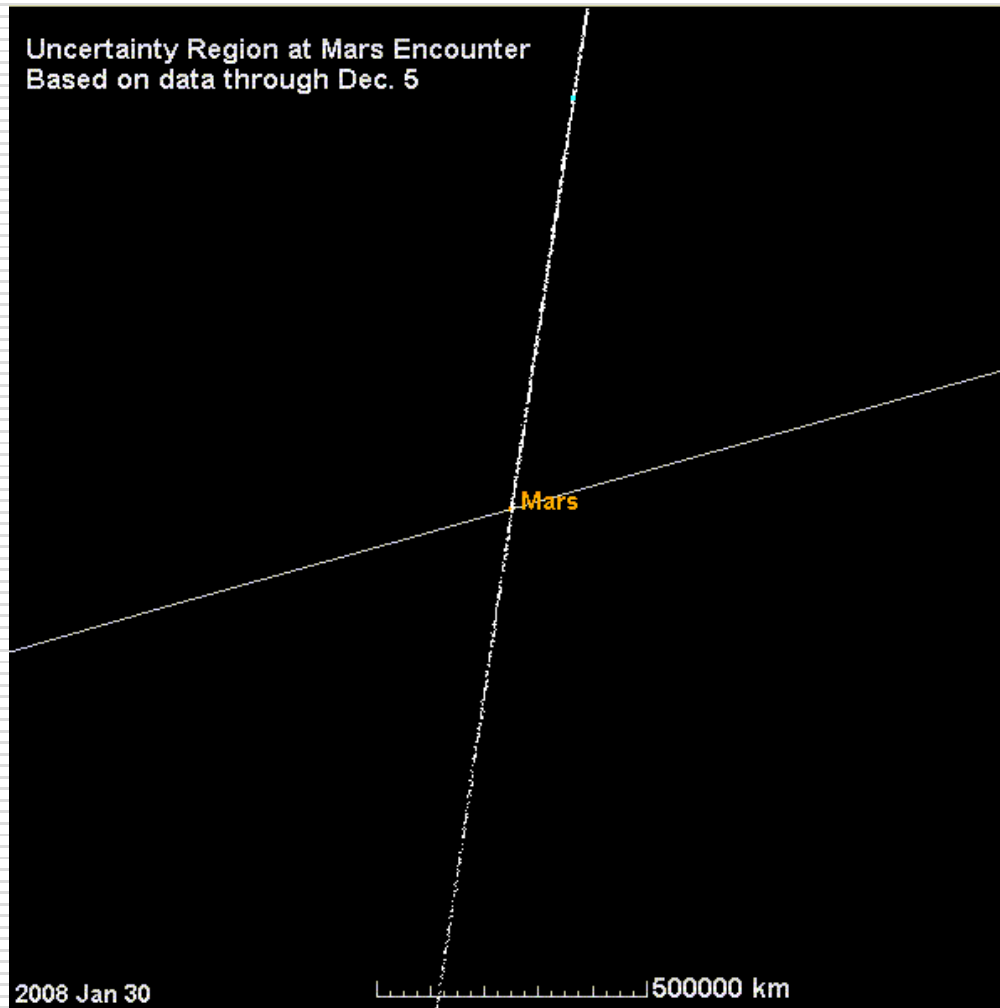
**Asteroid Ida and its moon
Dactyl**

Ida: 54 x 24 x 15 km

Dactyl: 1.4 km diameter



Mars Encounter, January 30, 2008



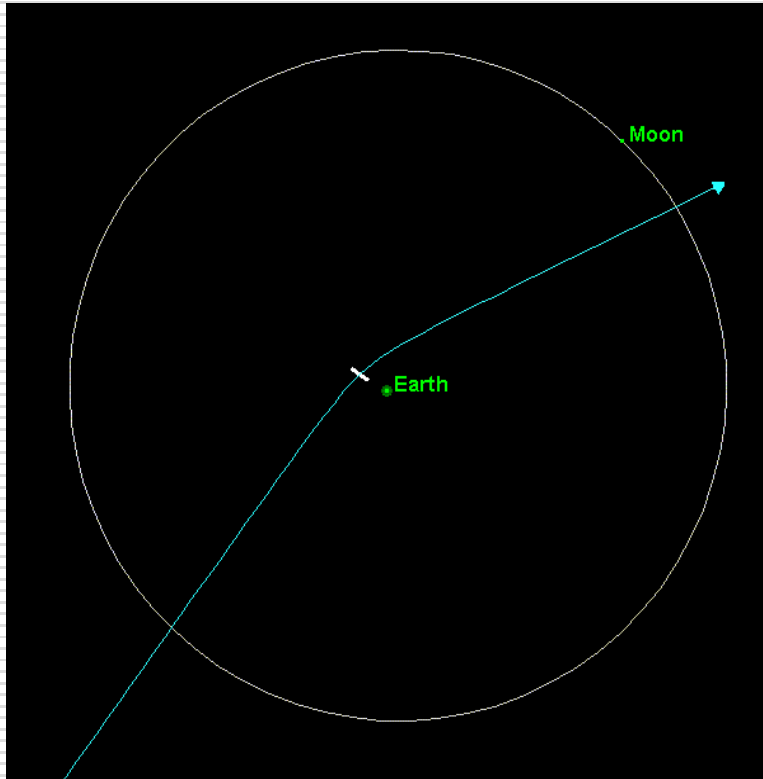
- ❑ Asteroid 2007 WD5 discovered late November 2007 (**2 months** before possible Mars impact)
- ❑ ~50 meters in diameter
- ❑ Initial probability of Mars impact ~1 in 350
- ❑ Increased to 1 in 75
- ❑ Increased to 1 in 25
- ❑ Late January: 1 in 10,000
- ❑ Could be similar for Earth encounter

Image reprinted courtesy of NASA/JPL

How likely is an impact?

- ❑ The probability of a “dinosaur-killer” impact ~ **1 in one million** this century
- ❑ The probability of a civilization-ending impact is ~ **1 in 1000** this century
- ❑ The probability of a small or Tunguska-class impact (near the lower size for penetration of the atmosphere, but still large enough to destroy a city) is ~ **1 in 10** this century.

Coming Event: Apophis



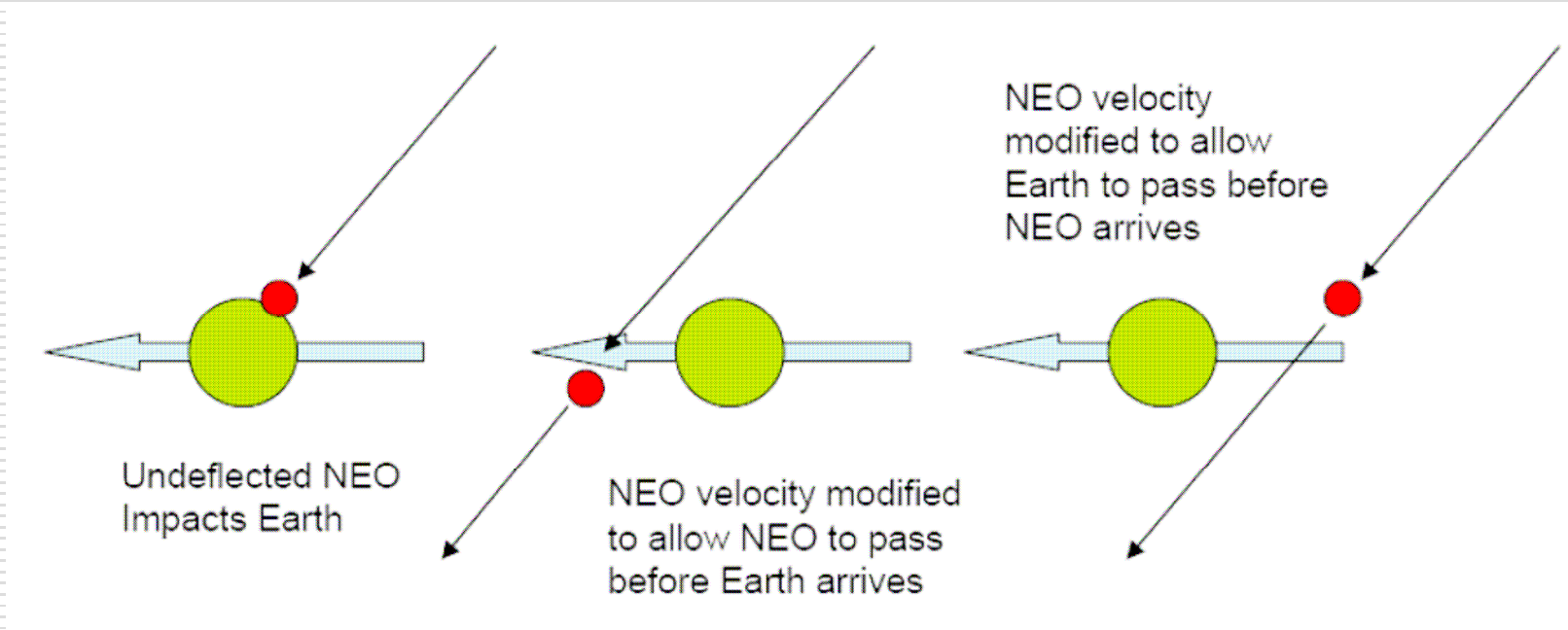
*Paul Chodas,
NASA/JPL*

Asteroid 2004 NM4 (Apophis) will pass 4.7 Earth radii (30,000 kilometers, or 18,600 miles) from Earth's surface on **April 13, 2029**

- ~300 meters in diameter
- Impact energy ~ 850 megatons (15 times more powerful than the largest hydrogen bomb ever tested; ~150 times more powerful than the 1908 Tunguska explosion over Siberia)
- 1 in 45,000 chance of impacting Earth in 2036

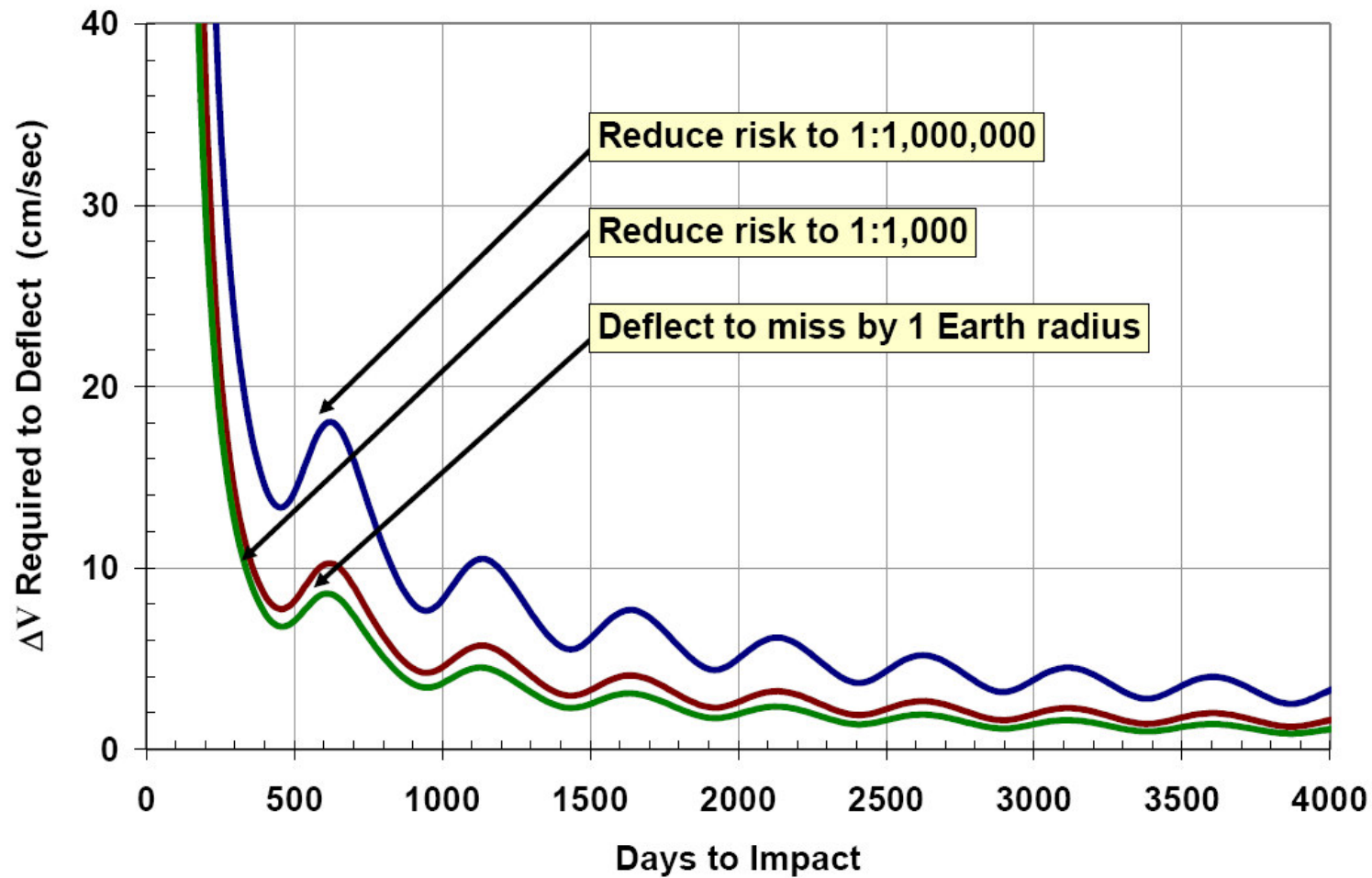
Deflection

Deflection Basics



Objective: Apply velocity change so that NEO arrives when Earth is not there

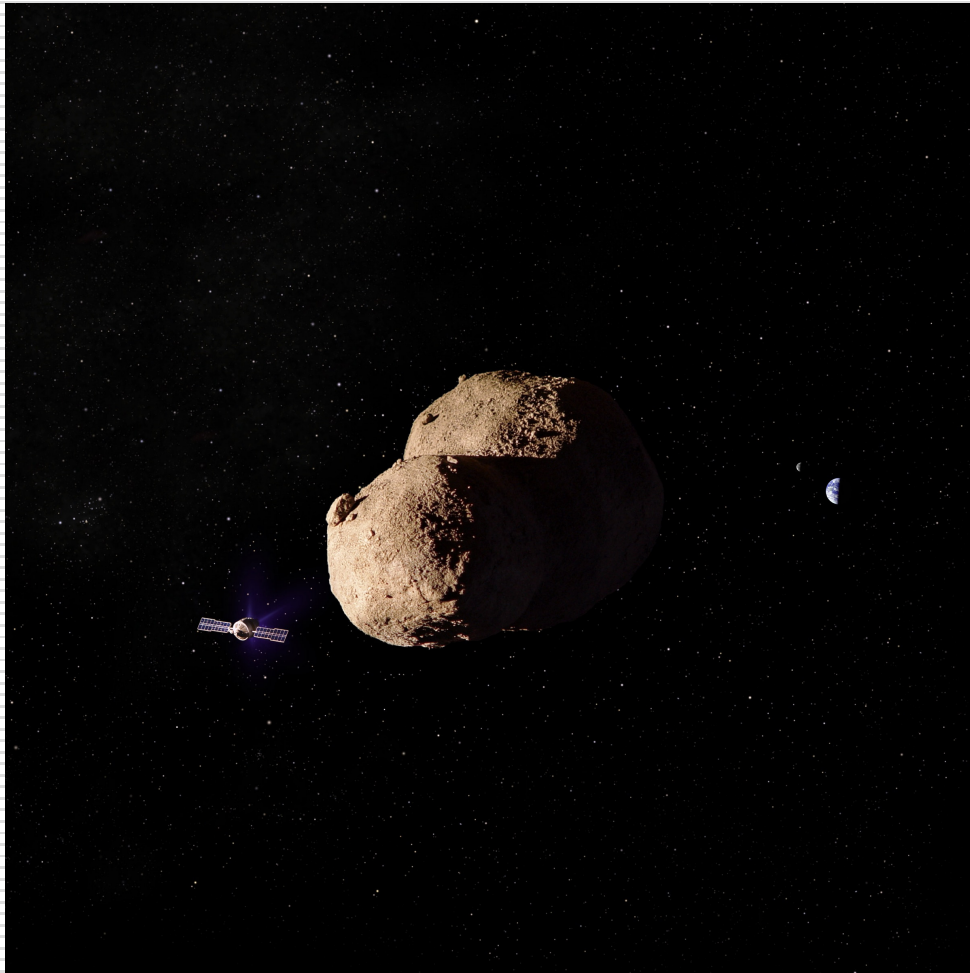
Impulse Required vs. Time



Deflection Options

- Slow-push techniques
 - Provide velocity increment over extended period
- Impulsive
 - Instantaneous velocity increment

Slow Push: Gravity Tractor



- Station-keep very close to NEO
- Gravitational attraction slowly pulls NEO

Image courtesy Dan Durda, FIAAA

Slow Push: Mass Driver



Image Copyright 2004 by SpaceWorks Engineering, Inc., Artwork by Nathan Phail-Liff. Image reprinted with permission of SpaceWorks Engineering.

- Land on NEO
- Mine NEO material and eject at high speed
- Use multiple devices

Impulsive: Kinetic Impact

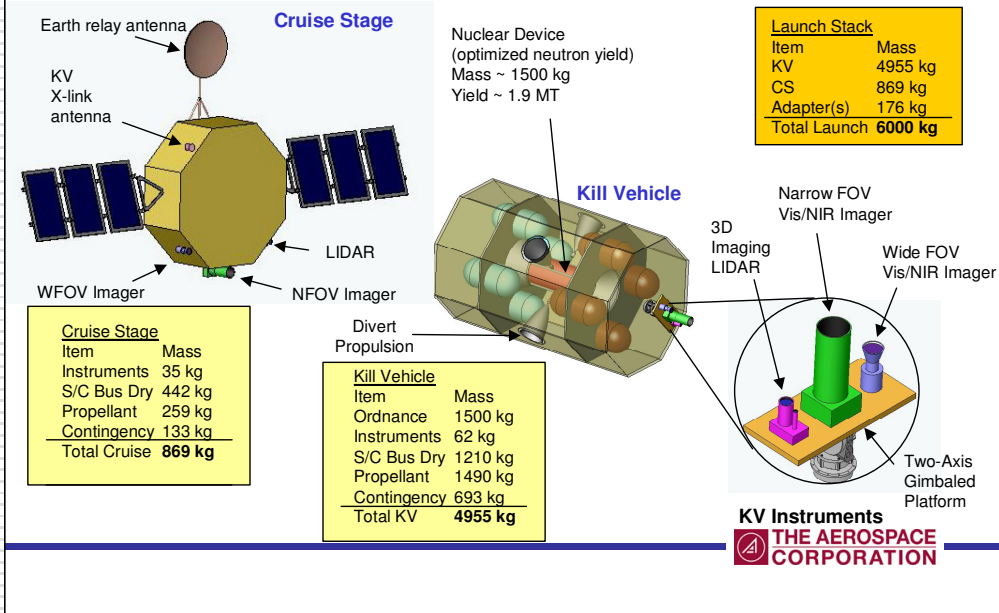


Photograph reprinted courtesy of NASA

- ❑ High-velocity impact
- ❑ Similar to “Deep Impact” mission
- ❑ Instantaneous momentum change
- ❑ Ejecta from impact crater amplifies effectiveness

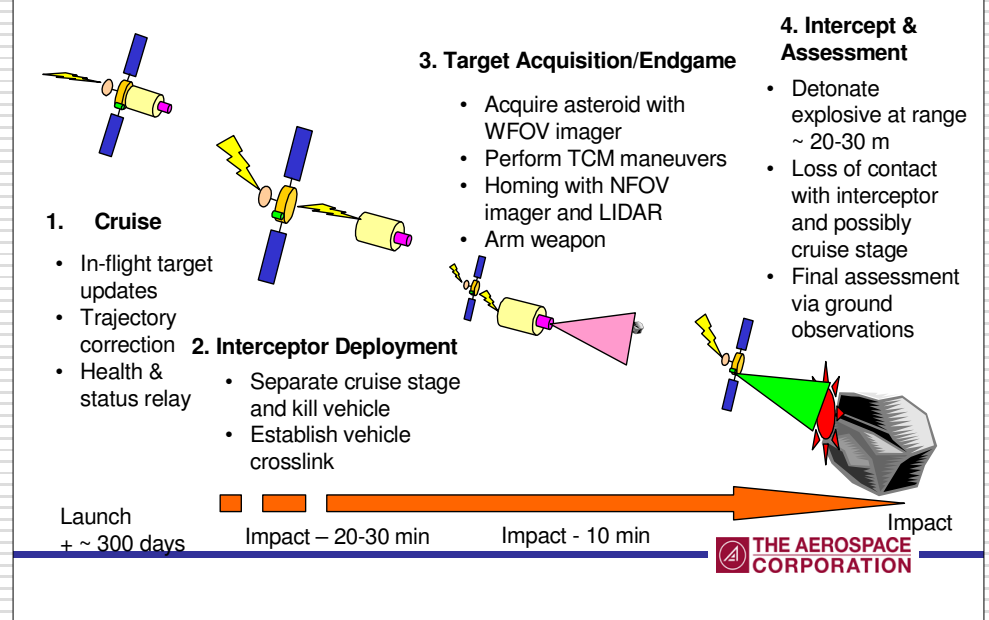
Impulsive: Stand-Off Nuclear Explosive

Interceptor Design



- Detonation above surface
- Less chance of fragmenting NEO
- Use multiple interceptors

Interceptor Concept of Operations



- Political and policy issues

Issues

Possible Scenario

- ❑ **140-m object detected, ~1 in 100 probability of striking Earth in 10 years**
- ❑ **Engineers tell us:**
 - 2 years required to design mission and vehicles and launch first wave (must have highest priority)
 - Transit time to object is 1 year
 - Must launch multiple interceptors from multiple launch sites to assure mission success
 - May require two waves
- ❑ **Estimated cost of campaign is over \$10 Billion**
- ❑ **Must start work now**

Political, Policy, Legal

- Effort must be initiated without certainty of impact
- Decision to proceed and fund effort is a political decision
 - World-wide issue and consequence
 - Decision made by one nation?
 - How is effort funded?
 - Who leads effort?
- Use of nuclear explosives acceptable?
- Activities must be coordinated
- What is reaction
 - If effort fails?
 - If no action taken and object hits?
 - If collision ruled out by additional tracking data (false alarm)?

False Alarms

- Most likely event is that additional tracking will eliminate hazard, but
- Timing may force initiation of deflection campaign
- How do we maximize utility of false alarms?
 - Development of lessons learned during evolution of scenario
 - Develop timeline for critical technologies and decisions
- How do we maintain trust of public and decision makers in predictions and calls for action?

Recommendations: Political, Policy, Legal

- ❑ Develop an international protocol for use in situations when critical decisions relating to threat and disaster mitigation are required
- ❑ Increase international collaboration on efforts aimed at detection and characterization, mission planning, and research related to deflection
- ❑ Maintain funding for critical technologies and efforts over the long term
- ❑ Develop a policy framework for the use of nuclear explosives for NEO deflection before a credible threat is identified
- ❑ Develop international agreements limiting the liability related to making impact predictions, taking or not taking action on a NEO threat
- ❑ Develop protocol for action that includes possibility of false alarm

Public Perception & Trust

Public perception and trust will affect decision to act and response to warning or disaster

- ❑ Involve professionals and practitioners from social and behavioral sciences
- ❑ Educate public and decision makers on the NEO threat (Apophis is good opportunity)
- ❑ Educate public and decision makers on possible evolution of threat for specific cases (e.g., false alarms, critical decision points)
- ❑ Use demonstration missions to increase confidence
- ❑ Conduct periodic survey to help assess public understanding

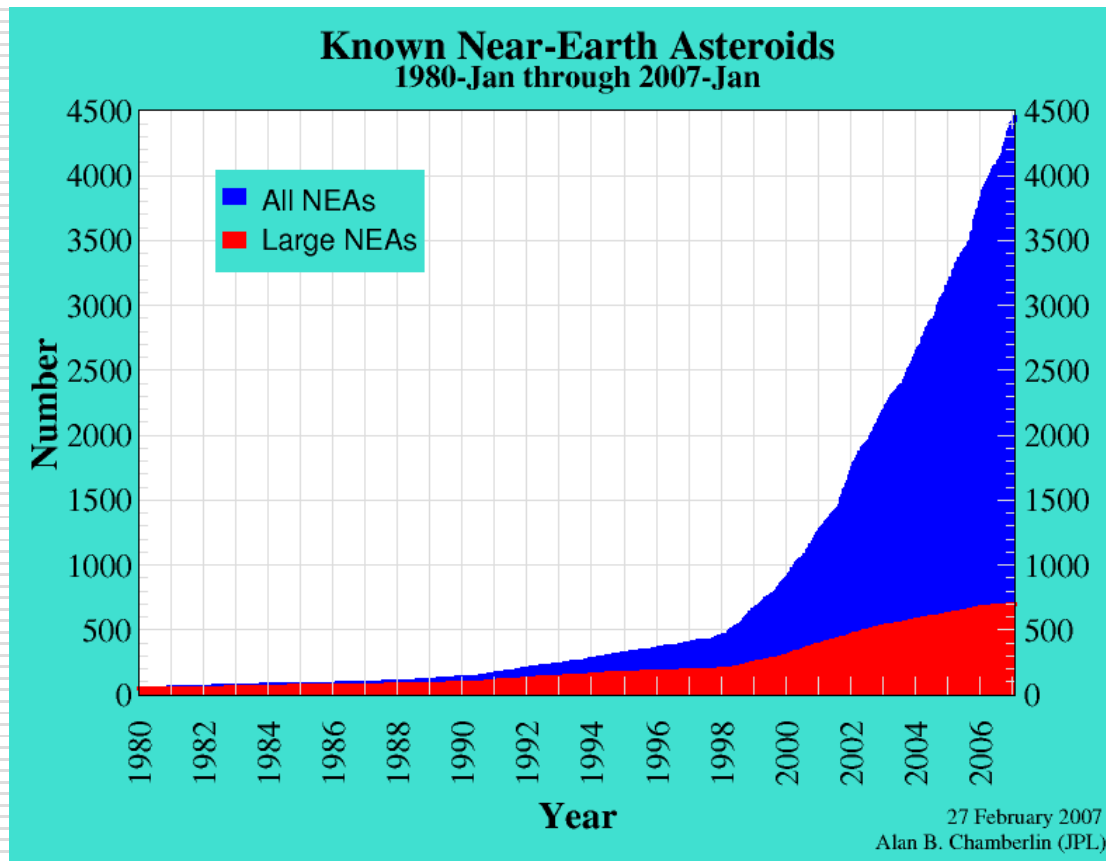
Deflection Option: Do nothing/Take the hit

- Take no action
 - Could be false alarm
 - Less cost if let it hit
- Evacuate affected areas and let NEO impact
 - Should this be an option for objects below some size?
What is the size limit?
 - What are decision criteria (e.g., cost of deflection, remote impact area)?
- Who decides? What are liabilities?

Suppose There's an Impact

- Result of NEO impact would be
 - Confusion at all levels of leadership
 - Delayed initial response
 - Additional loss of life and suffering
- Recommendations
 - Include NEO disaster (50 to 140-meter class) in mandate for disaster response agencies
 - Conduct Impact Response Exercise
 - Involve military, press, local and national governments
 - Similar to exercises for tsunami, earthquake disasters

Current Status



Need to know where they are

- Current goal: find 90% of objects larger than 1 km by 2008
- U.S. Congress requested proposal to detect and track 90% of the potentially hazardous larger than 140m by end of 2020
- Budget not yet allocated

Current Status 2

- No complete campaign/mission designs
- Deflection methodologies and effectiveness untested
- General lack of priority
- Opportunity for research
- “Giggle factor?”—Should we really be concerned?

What's Next?

- ❑ Discover and track objects < 1 km
- ❑ Maintain resources critical for NEO characterization (e.g., Arecibo)
- ❑ Improve and verify deflection-related technologies
- ❑ Develop complete mission and campaign designs
- ❑ Develop protocols and thresholds for action
- ❑ Add NEO impact to suite of possible disasters
- ❑ Watch Apophis
- ❑ Improve public understanding