The Asteroid-Comet Hazard Problem and the Tunguska Phenomenon

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INASAN
Institute of Astronomy RAS

The Asteroid-Comet Hazard Problem

two decades ago and earlier

was considered mostly as a matter of fundamental science and theme for Hollywood movies

at present days

is recognized as one of the global problems!

Driving factors of new insight and new policy

- New observational techniques → new discoveries
- New theoretical approaches → new estimates of risks
- Growing “popularity” of the topic

United Nations A/AC.105/911

General Assembly

Distr.: General
11 March 2008

Original: English

Committee on the Peaceful Uses of Outer Space
Fifty-first session
Vienna, 11-20 June 2008

Report of the Scientific and Technical Subcommittee on its forty-fifth session, held in Vienna from 11 to 22 February 2008

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12. Near Earth Objects – 4 days

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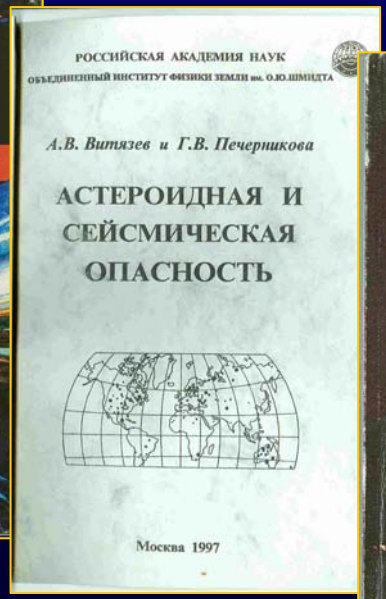
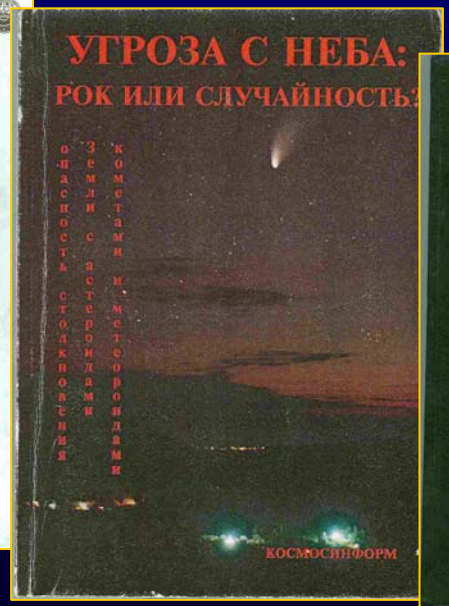
http://www.unoosa.org/oosa/en/COPUOS/stsc/2008/presentations.html

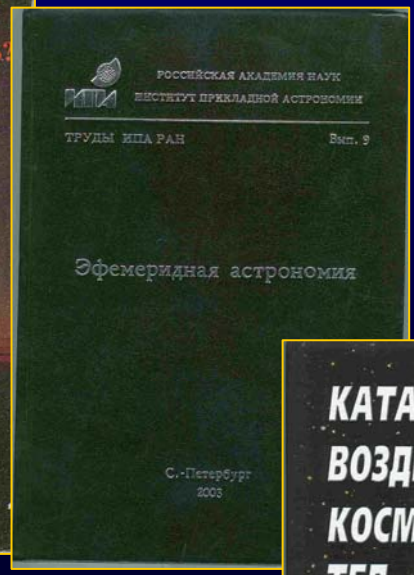
1996



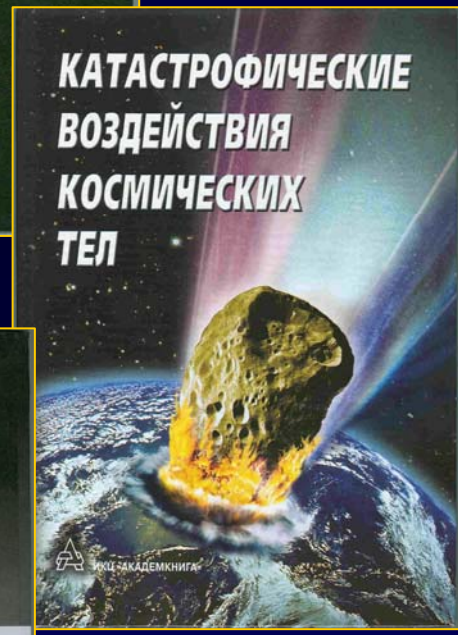
1997



1999



2003



2005

2007

2006 Near-Earth Object Survey and Deflection Study

December 28, 2006
NASA HQ, PA&E

For additional information, please contact the Office of Program Analysis and Evaluation (PA&E) at NASA Headquarters in Washington, D.C.

What I will talk about

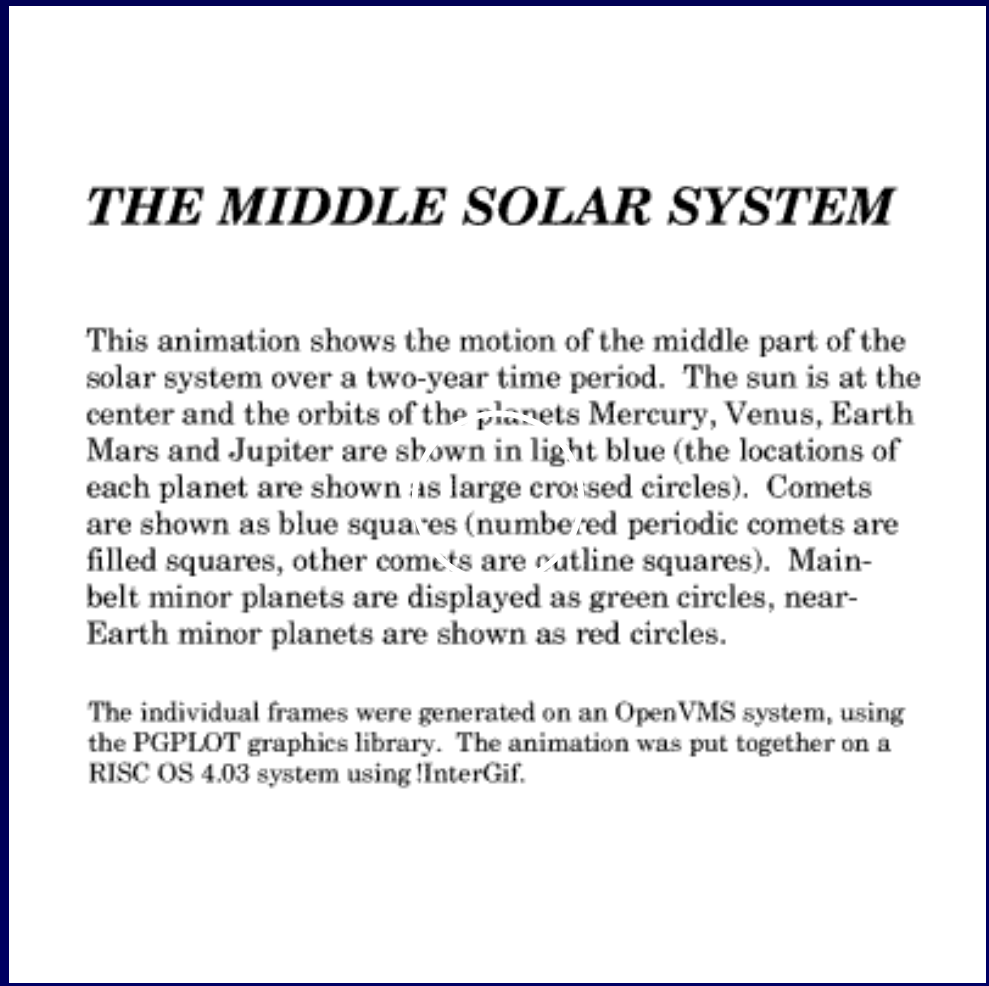
- What is the Asteroid-Comet Hazard (ACH) problem?
- Historical records and how dangerous are Tunguska-like events?
- State of art of the problem
- Directions of future work
- Organizational activities in Russia
- On the prospects of international cooperation

❖ **What is the ACH problem?**

Small bodies in the Solar System

- Dust grains < ~ 1 мм
- Meteoroids < ~ 10 ÷ 100 м
- Asteroids > ~ 10 ÷ 100 м
- Comets > few km (icy bodies!)

Motions of minor bodies in the middle Solar System



THE MIDDLE SOLAR SYSTEM

This animation shows the motion of the middle part of the solar system over a two-year time period. The sun is at the center and the orbits of the planets Mercury, Venus, Earth Mars and Jupiter are shown in light blue (the locations of each planet are shown as large crossed circles). Comets are shown as blue squares (numbered periodic comets are filled squares, other comets are outline squares). Main-belt minor planets are displayed as green circles, near-Earth minor planets are shown as red circles.

The individual frames were generated on an OpenVMS system, using the PGPLOT graphics library. The animation was put together on a RISC OS 4.03 system using !InterGif.

http://www.cfa.harvard.edu/iau/Animations/Animations.html

Terminology: NEO, PHO,…

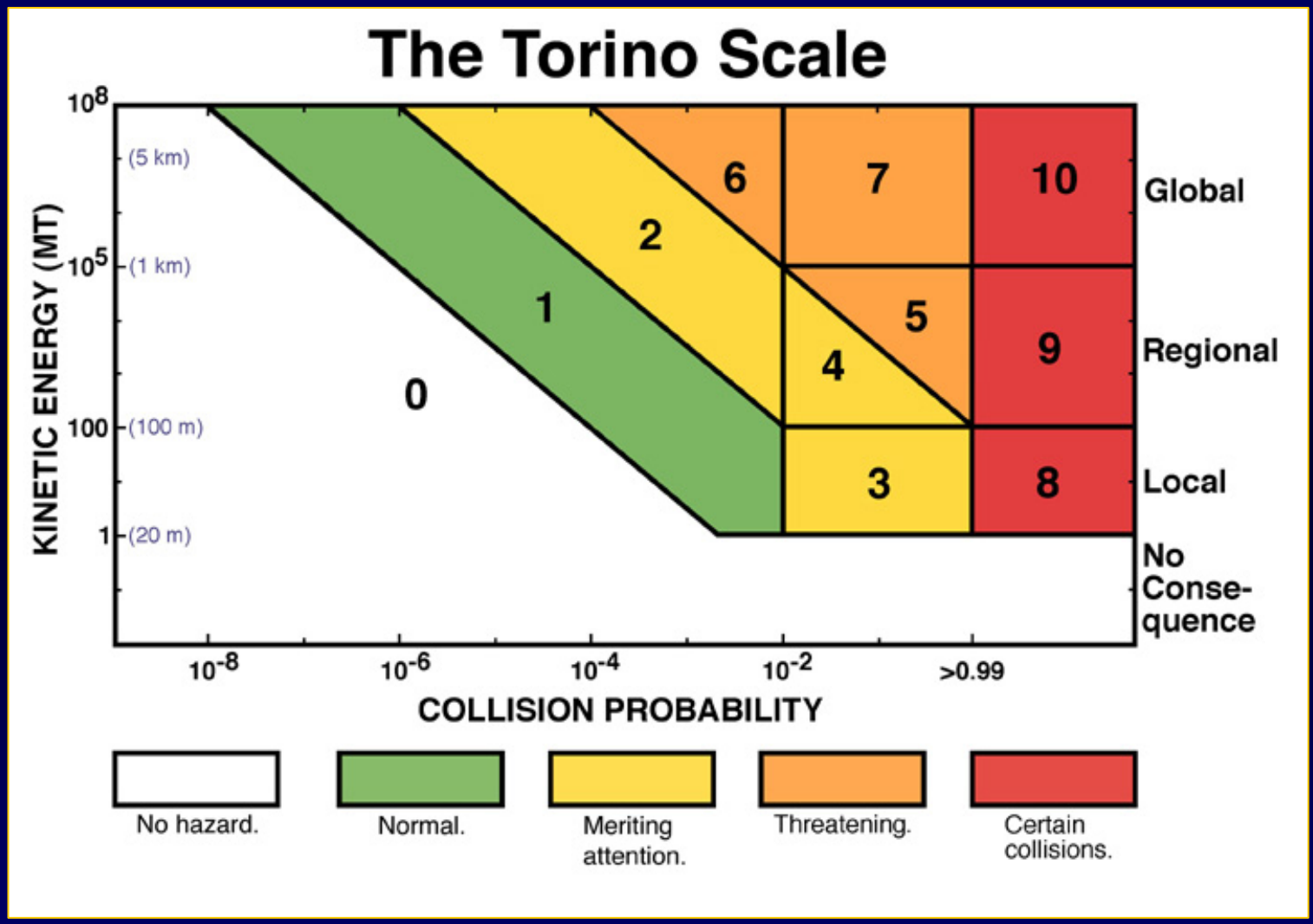
Near Earth Objects (NEO)* – asteroids and comets with orbits having q < 1.3 a.e.

Potentially Hazardous Objects (PHO)* – NEOs passing within less than 0.05 a.u. of Earth's orbit (7.5 million km, ~ 20 times the distance to the Moon). For PHO accept absolut asteroid magnitude $H \leq 22$.
$H = 22$ implies diameter ~140 m (albedo 0.14)

Threatening Objects – PHO of class 4 and higher according to Torino scale .

* *NEA, PHA* – for asteroids, *NEC, EAC – for comets*

Asteroid-Comet Hazard – impact hazard by NEO.


The Torino Scale
KINETIC ENERGY (MT)
10^8
(5 km)
10^5
(1 km)
100
(100 m)
1
(20 m)
0
1
2
6
7
10
4
5
9
3
8
Global
Regional
Local
No Conse-quence
10^{-8}
10^{-6}
10^{-4}
10^{-2}
>0.99
COLLISION PROBABILITY
No hazard.
Normal.
Meriting attention.
Threatening.
Certain collisions.

The Palermo Technical Impact Hazard Scale

Actual scale values less than -2 reflect events for which there are no likely consequences, while Palermo Scale values between -2 and 0 indicate situations that merit careful monitoring. Potential impacts with positive Palermo Scale values will generally indicate situations that merit some level of concern.

$$PS = \log_{10} R.$$

The relative risk R is given by $R = P_I / (f_B \times DT)$, where PI is the impact probability of the event in question and DT is the time until the potential event, measured in years. The annual background impact frequency, $f_B = 0.03 \times E^{-4/5}$ is the annual probability of an impact event with energy (E, in megatons of TNT) at least as large as the event in question.

Statistics of NEO and PHA

State of art at the date June 25, 2008

NEO - 5515

NEA - 5450

Comets - 65

PHA - 959

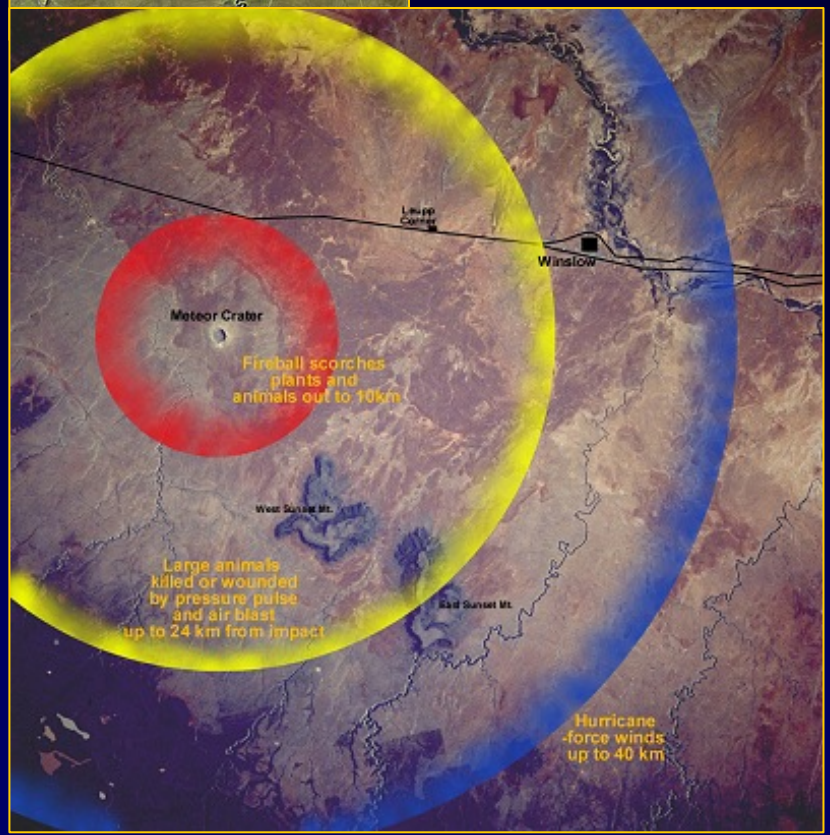
Appears to be almost 20% of all NEOs discovered.

http://neo.jpl.nasa.gov/stats/

❖ **Historical records and how dangerous are Tunguska-like events?**

Barringer Crater

Winslow, Arizona

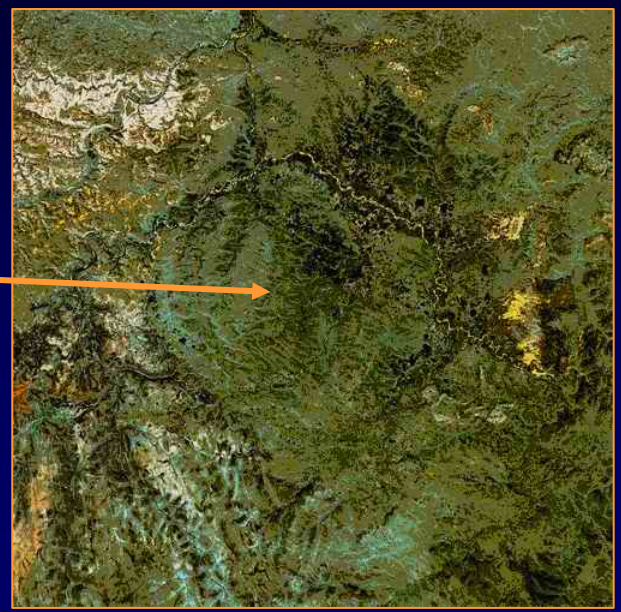


Diameter – 1240 m
Depth – 170 m
Age ~ 50,000 yrs

Impactor size - ~ 50 – 60 m
Energy released - ~ 5 -20 Mt
fragments of Ni, Fe body found

Large meteorite craters in Russia

Crater name	Coordinates		Diameter km	Age mln. years
	latitude	longitude		
Popigay (Попигай)	71°38'	111°11'	100	35.7 ± 0.2
Kara (Кара)	69°06'	64°09'	65 ?	70.3 ± 2.2
Puchezh-Katun (Пучеж- Катун)	56°58'	43°43'	80	167 ± 3
Kamensky (Каменский)	48°21'	40°30'	25	49.15 ±0.18
Logancha (Логанча)	65°31'	95°56'	20	40 ±20
Elgygytgyn (Эльгыгытгын)	67°30'	172°05'	18	3.5 ± 0.5
Kaluzhsky (Калужский)	54°30'	36°12'	15	380
Yanisyarvi (Янисъярви)	61°58'	30°55'	14	700 ± 5
Karlinsky (Карлинский)	54°55'	48°02'	10	5 ± 1

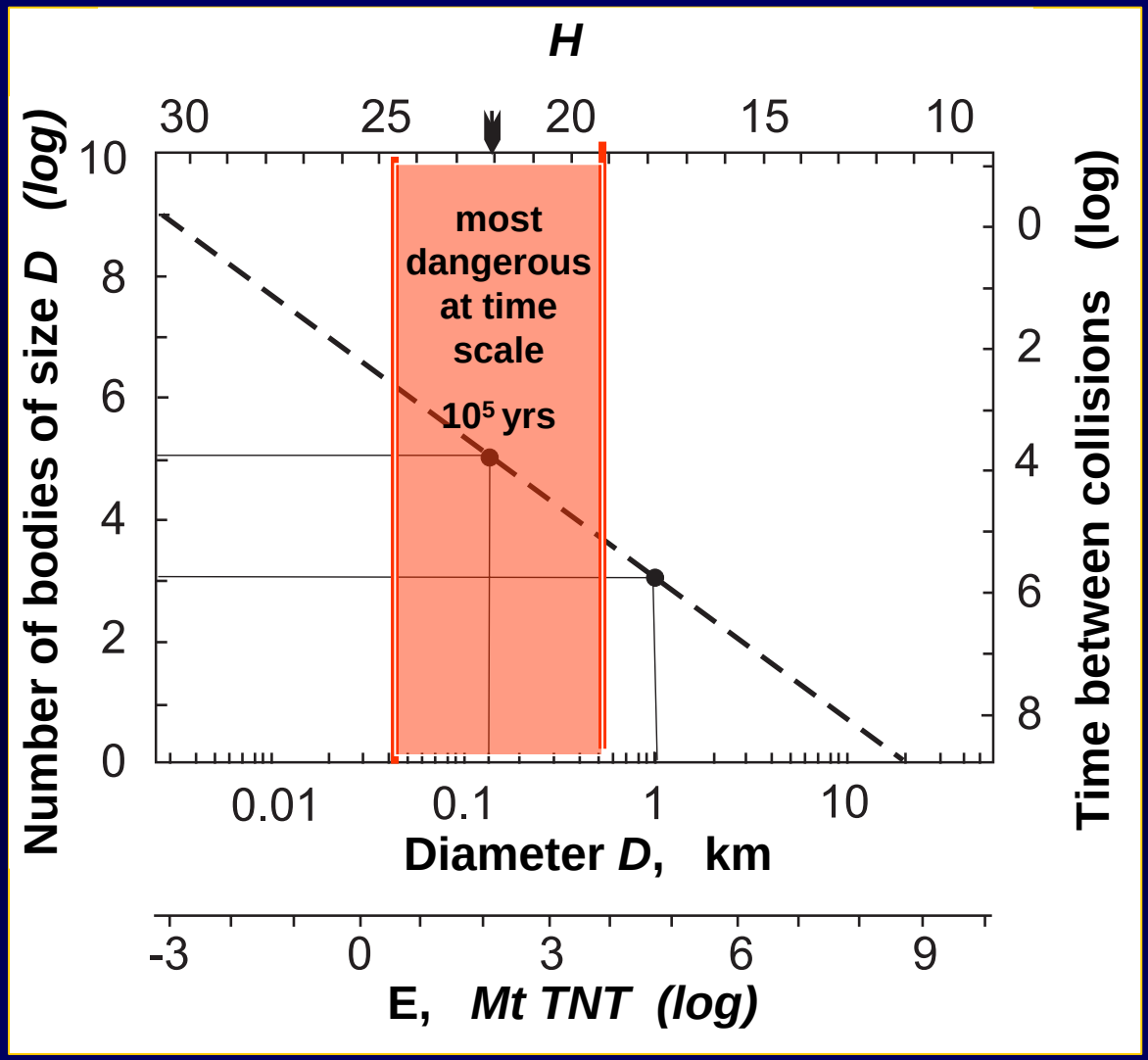


Object	Size of impactor	Freq. (once per .. yrs)	Crater size (km)	Consequence of collision
Dust grain	D < 0.1cm			-
Meteoroid	0.1 см < D < 0.5 m			-
	0.5 m < D < 20-30 m			Could reach the Earth surface
	> 30 m	250	no > 0.5	Tunguska -like Barringer crater
Asteroid	> 100 m	5 000	> 2	Regional catastrophe
	> 1 km	600 000	> 20	Global catastrophe
	10 km	100 million	200	End of civilization

DOCTOR FUN

11 April 96

"Today's asteroid encounter was a near miss, but some scientists warn that an actual impact could have serious long-term effects on life on Earth as we now know it."



At time scale of existence of *homo sapiens* (few 10^5 yrs)

most dangerous are bodies of size:

50-100 m air, ground

100-200 m water

Adapted from NASA's 2006 NEO Survey and Deflection Study

What is the total number of PHO ?

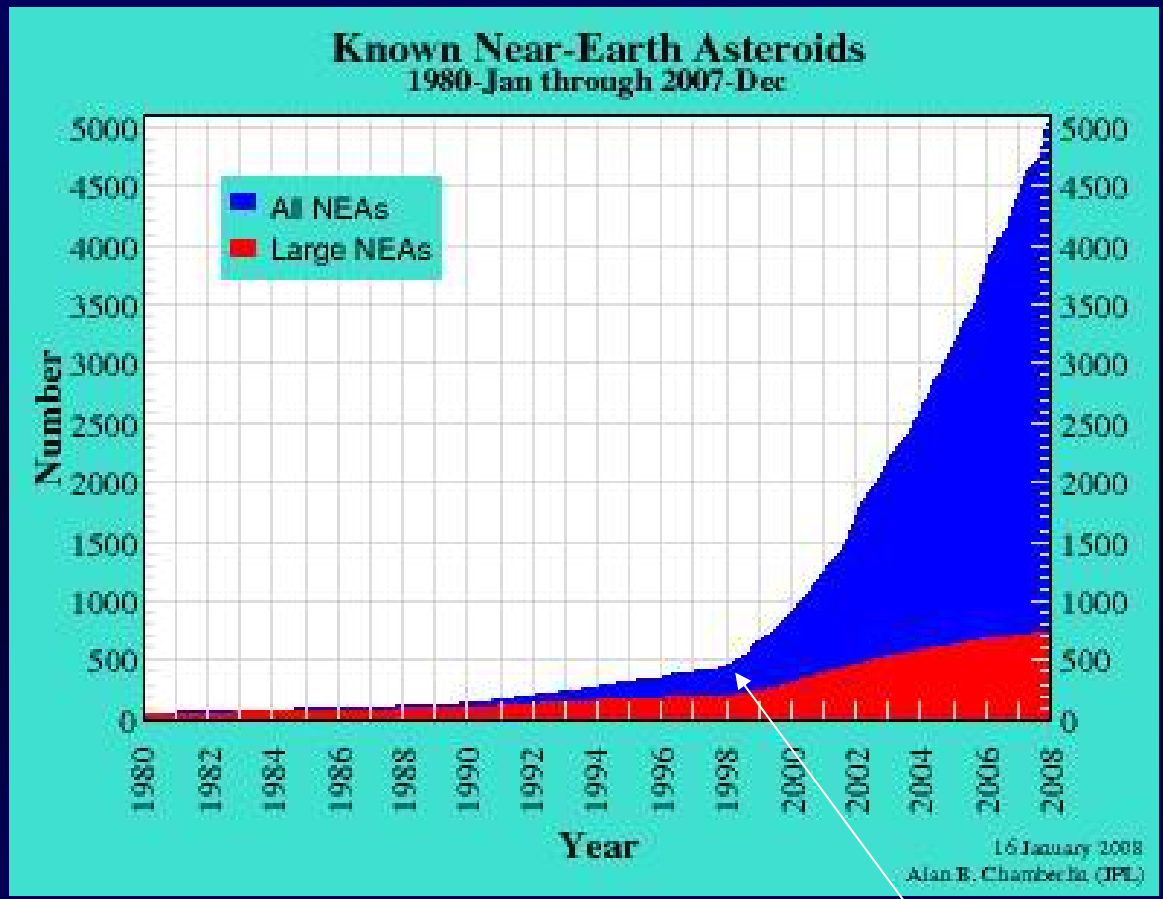
My estimates

$> 2 \times 10^4$ (D > 140 m)

$> 2 \times 10^5$ (D > 50 m)

State of art of the ACH problem

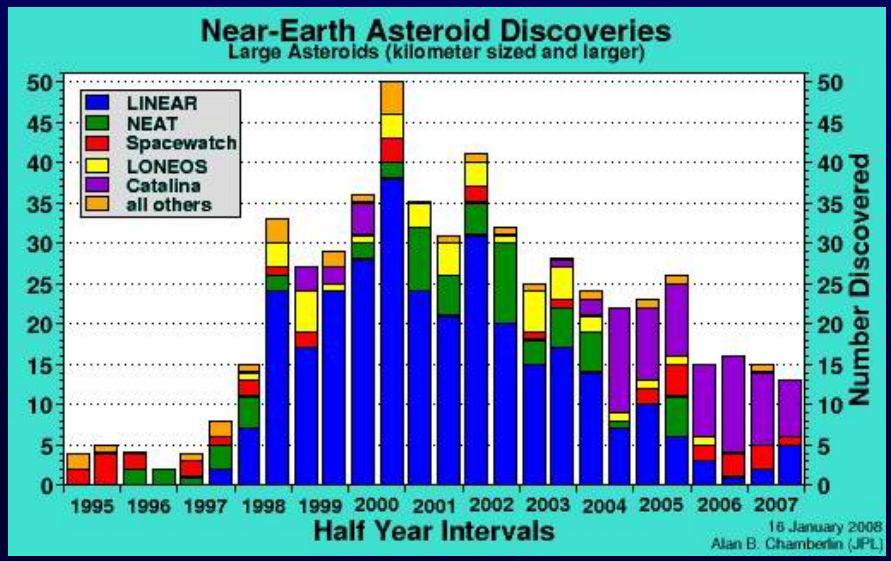
Dynamics of NEA discovery

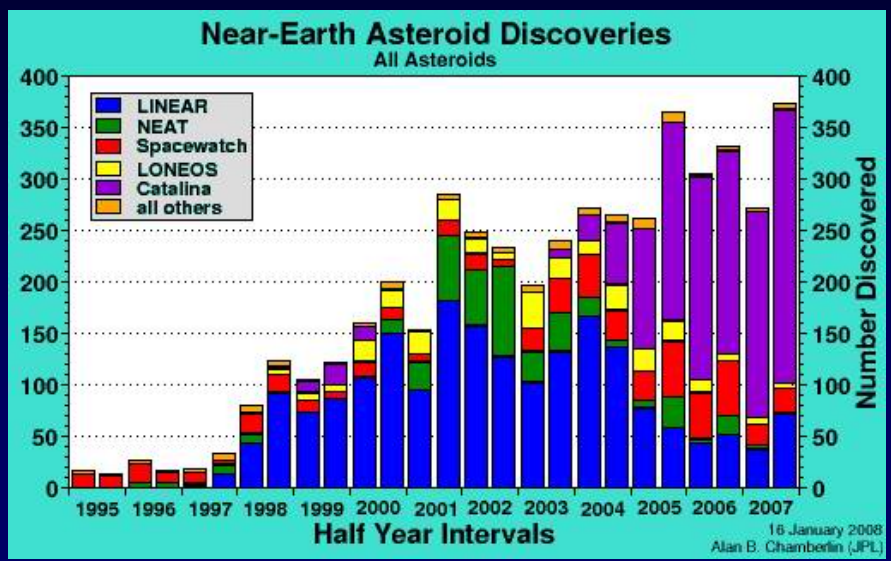


Spaceguard Program started!

http://neo.jpl.nasa.gov/stats/

Major NEA search programs

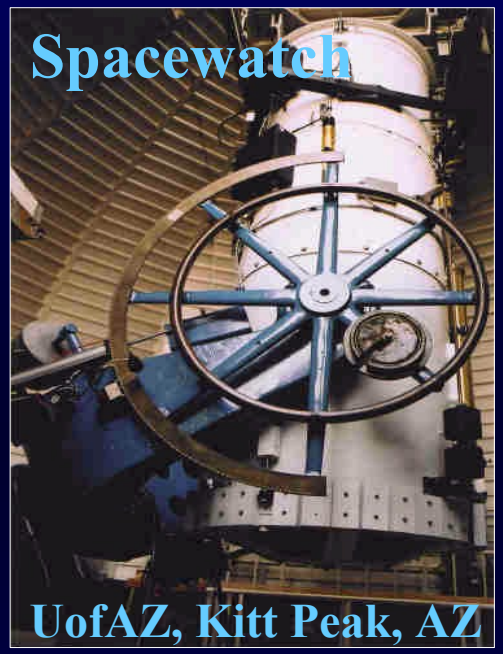




- Lincoln Near-Earth Asteroid Research (LINEAR)
- Near-Earth Asteroid Tracking (NEAT)
- Spacewatch
- Lowell Observatory Near-Earth Object Search (LONEOS)
- Catalina Sky Survey
- Japanese Spaceguard Association (JSGA)
- Asiago DLR Asteroid Survey (ADAS)

+ some instruments in China, Germany, Korea, Russia etc.

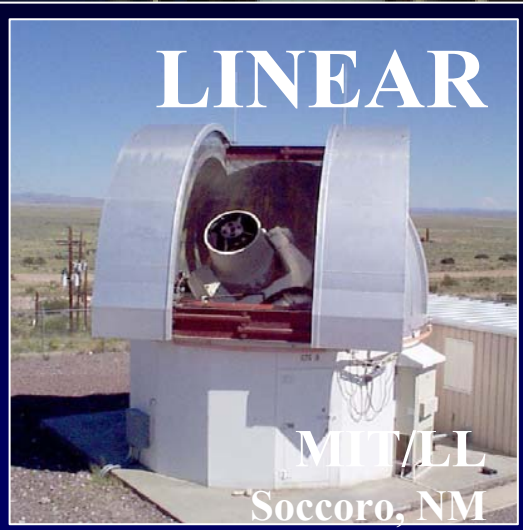
NASA's NEO Search Projects (at peak – 2005)



NEO Program Office @ JPL
- Program coordination
- Automated SENTRY

http://neo.jpl.nasa.gov/

Minor Planet Center (MPC)
- IAU sanctioned
- Discovery Clearinghouse
- Initial Orbit Determination



Spaceguard Survey

US component to international Spaceguard Survey has provided 98% of new detections of NEOs. Began with NASA commitment to House Committee on Science in May, 1998
Scientific Objective: Discover 90% of NEOs larger than 1 kilometer in size within 10 years (1998 – 2008)

Spaceguard-2 Survey ???

NASA Authorization Act of 2005 provided additional direction (but no additional funding)

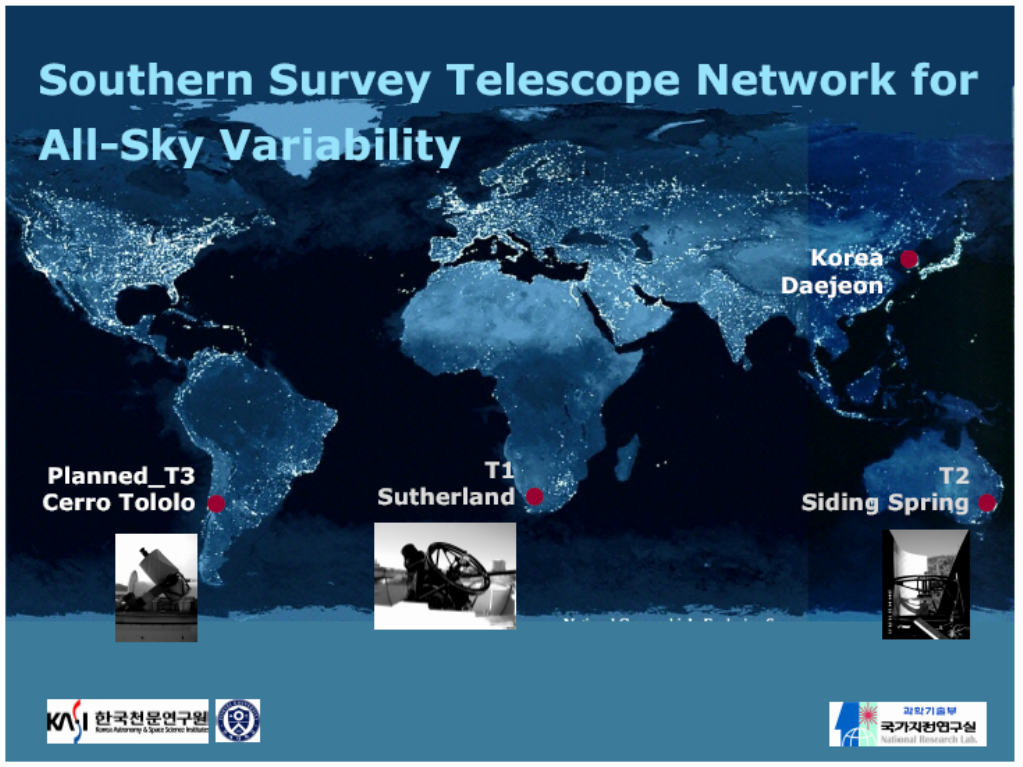
"…plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue (based on statistically predicted populations of near-Earth objects) within 15 years after the date of enactment of this Act."

ROBOTIC TELESCOPE SYSTEM

- 0.5 meter aperture, very fast optics
- FOV 1.73 × 1.73 deg with 2k CCD
- Reaches ~ 17th mag with 60 sec expos
- High speed mount, 10 deg/sec

KASI 한국천문연구원

Southern Survey Telescope Network for All-Sky Variability

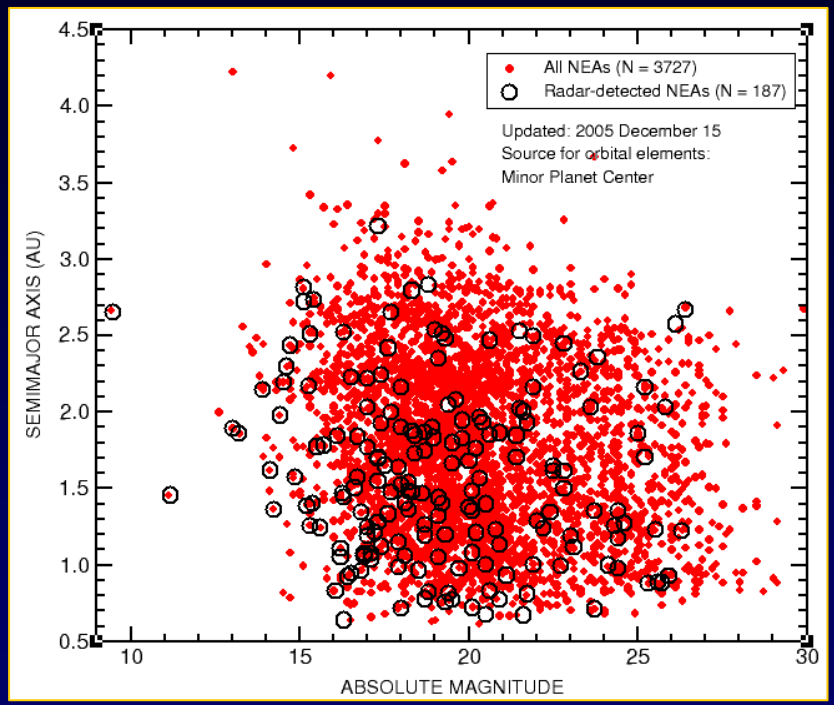


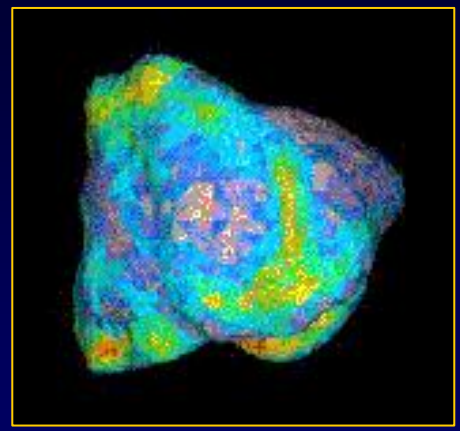
KASI 한국천문연구원

과학기술부 국가지원연구실 National Research Lab.

Radar Studies

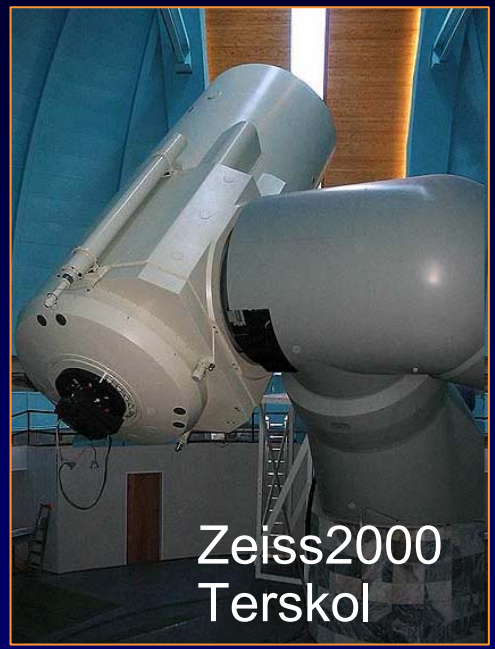
- Observations on the limited accessible objects
  - 10 to 15 NEOs/year from Goldstone and Arecibo
  - Required for timely precision orbit determination
  - Shape modeling with sufficient signal strength





L.Johnson

Some observational facilities in Russia



NIIPP, GAISH

D=350 mm

FOV = 5°

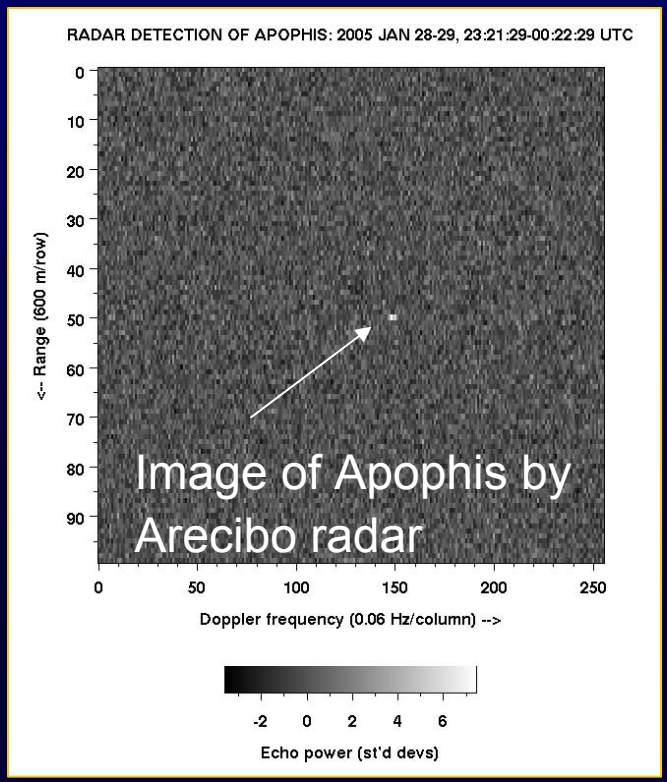
4K*4K KODAK

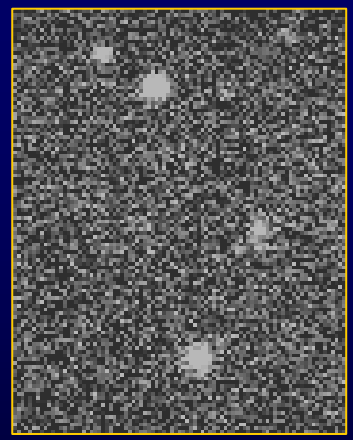
DYNACON II

Near Earth transitions of asteroids

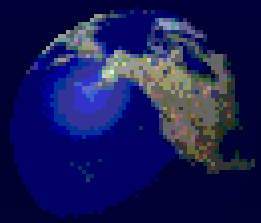
Number	*Name*	*Date of closest passage*	*Distance, a.u.*
(99942)	Apophis	2029 Apr. 13.91	0.0002318
	2005 YU55	2011 Nov. 8.98	0.001065
	2000 WO107	2140 Dec. 1.82	0.001623
	2001 WN5	2028 June 26.23	0.001670
(85640)	1998 OX4	2148 Jan. 22.14	0.002004
	1999 AN10	2027 Aug. 7.29	0.002654
	1998 MZ	2116 Nov. 26.98	0.002750
(35396)	1997 XF11	2136 Oct. 28.49	0.002762
	2004 XP14	2006 July 3.18	0.002891
	2003 QC10	2066 Sept.24.86	0.003396

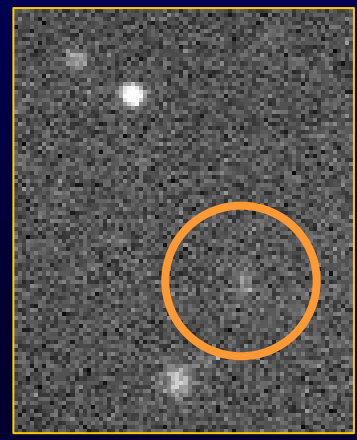
Apophis





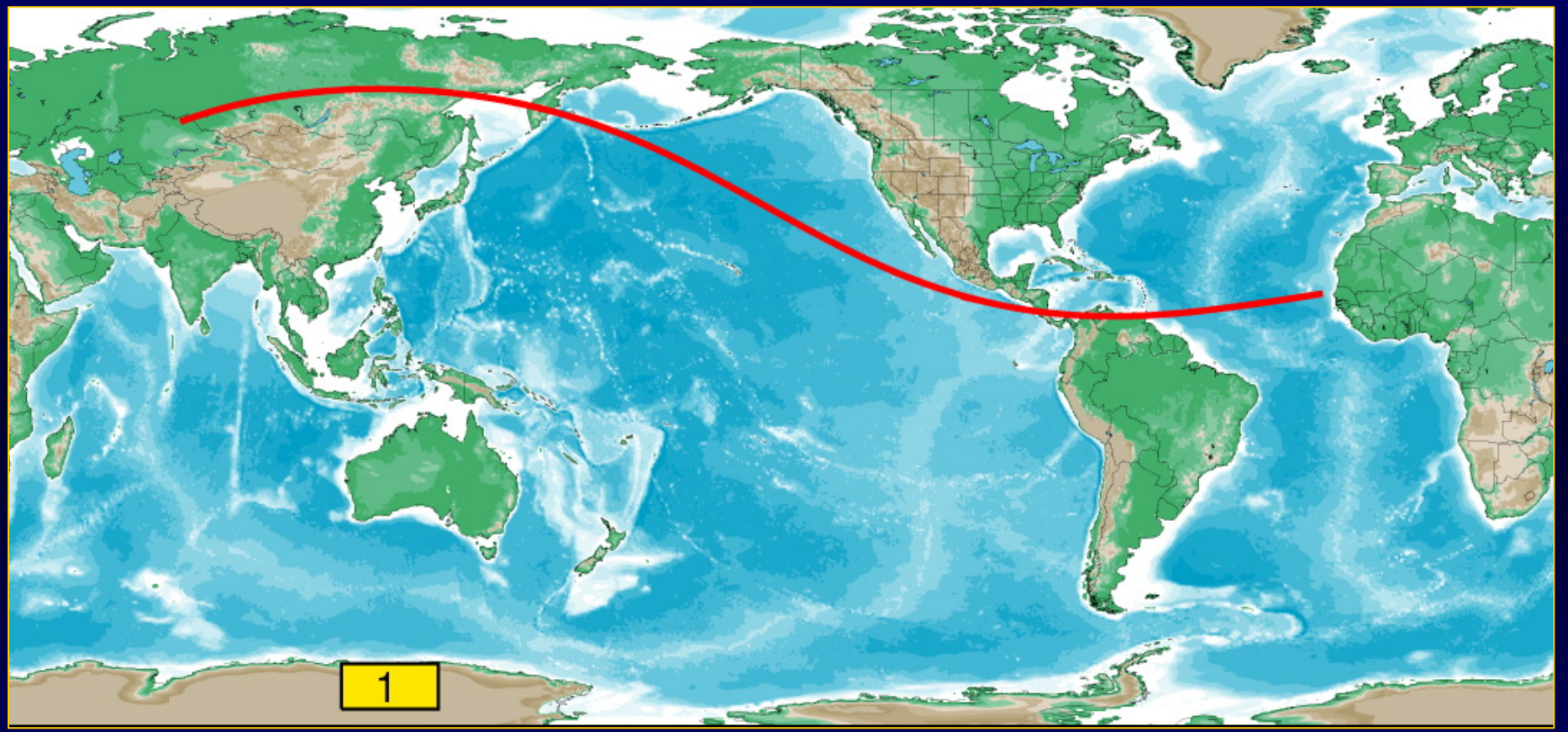
2004mn4
11.05.2005
(Terskol
Observatory)





Discovered in 2004 potentially dangerous 120-350 m size object 2004MN4=(99942) Apophis will pass in the risk proximity to the Earth in 2029. The probability of the collision with the Earth (or falling into the geostationary orbit zone) in 2036 is non-zero ($2x10^{-5}$). At Torino scale 0, at Palermo scale -2.4.

Apophis provides the mankind with the natural opportunity of close multilateral cooperation in space.



Path of risk for Apophis in April 2036.

From report of ASE, R.Schweickart 2007

For asteroid 2004 VD17 probability of collision in May 4, 2102 г was initially estimated as 0,001! 2 at Torino scale.

We understand that unexpected discovery of threatening object is not a fiction. This could happen any moment!

Humankind should be ready to the sudden space menace!

❖ Directions of future work

- Detection, remote characterisation, orbit determination and cataloguing of NEO. This requires development of system (participation in the international system) of NEO detection and monitoring;

- In-situ characterisation (investigation of physical and chemical properties of minor bodies). This requires dedicated space mission(s) ;

- Deflection techniques

- Mitigation

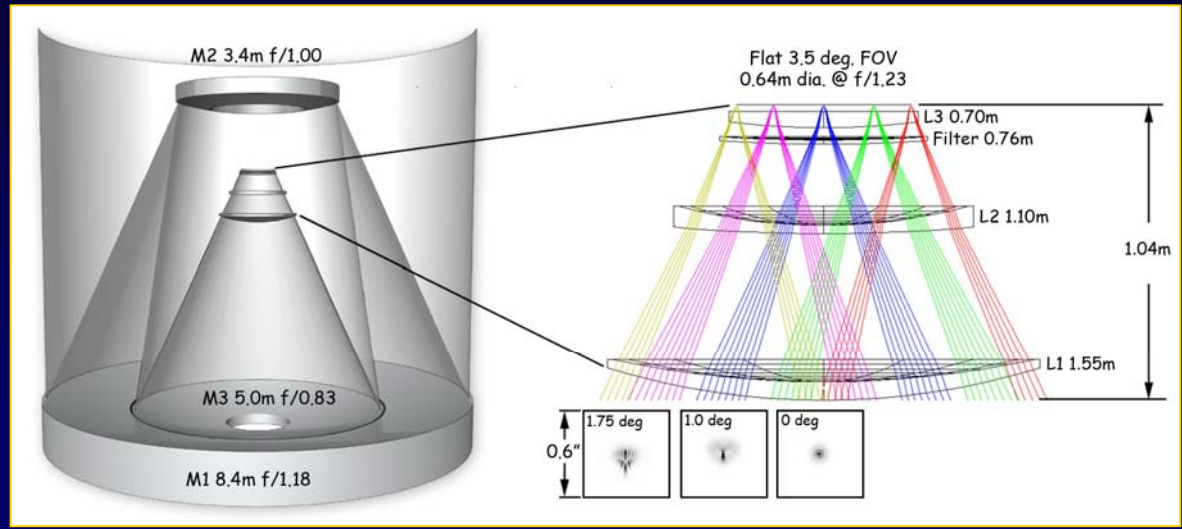
- International coordination

«Pan-STARRS”

- four 1.8 m telescopes
- 3 degree field of view
- camera with 1.4 billion pixels.
- spatial sampling of the sky about 0.3”
- in survey mode will cover 6,000 deg2 per night.
- limiting magnitude of 24 (With exposure times up to 60 seconds)

Large Synoptic Survey Telescope (LSST)

2014



It is desirable to get observational data for all minor bodies larger than 50 - 100 m. This is somewhat unrealistic at the moment. In Russia there exist no dedicated instruments. Special system for monitoring near Earth space (like “Okno”) are not designed for NEOs.

Construction of the telescope of PanSTARRS type is under consideration .

Space missions

- Near-Earth Asteroid Rendezvous (NEAR) 1996 -1998 (Eros)
- Deep Space 1 (DS1) 1998 -1999 (Braille, Borelli)
- Deep Impact 2005 (Tempel 1)
- STARDUST 1999 – 2004 – 2006 (Wild 2)
- Hayabusa (MUSES-C) 2003-200? (Itokava)
- Dawn 2006 – 2010 (Vesta, Ceres)
- Rosetta 2004 -2008 -2010 -2014 (Stein, Lutetsia, Churyumov-Gerasimenko)
- Marco Polo – NEO?
- Don Quichote (Phase A)
- A mission for detection of Inner Earth Objects by means of observations from an orbiting compact satellite (Astreroid Finder)

Mission goals - to deliver soil samples from Phobos to the Earth and to carry out scientific studies of Phobos and Mars.

Leading organizations:

Scientific payload

- IKI RAS, GEOKHI

Space mission components

- Lavochkin Association

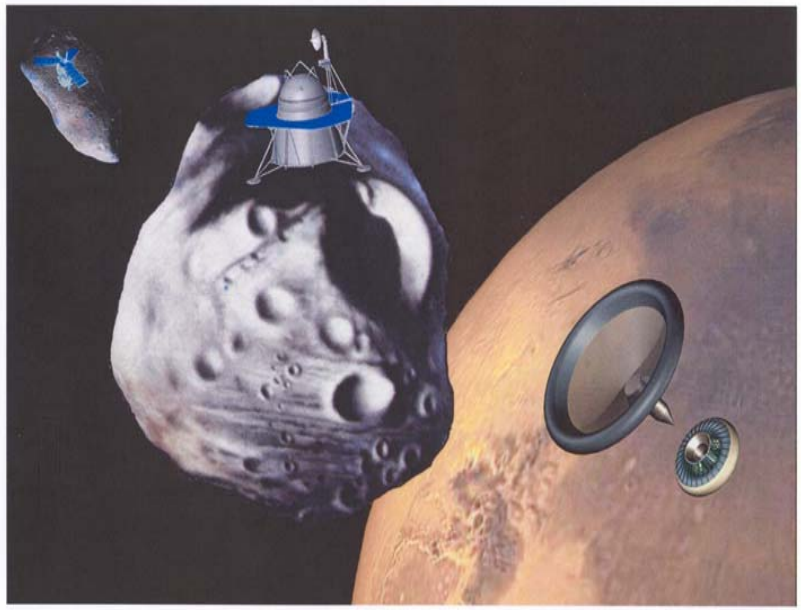
Launch - 2009

Mass of the Phobos soil sample delivered to the Earth – 0,1 kg.

Duration of flight to the Mars activity sphere - 850 days. Duration of flight to the Earth - 285 days.

Study of small bodies of the Solar System in-situ

(Phobos-Grunt Mission)



Thinking on Apophis?

Dispersion or deflection?

Deflection
in principle is preferable but:
- high cost
- low reliability of space missions
- lack of full and exact information 10 -20 years before the possible impact.

Dispersion
at present easier to realize but:
consequences are not completely predictable.

❖ **Organizational activities in Russia**

The Expert Working Group on the Asteroid/Comet Impact Hazard Problem was formed in Feb 2007 at the RAS Space Council. The group includes representatives from RAS, Universities, Roscosmos, EMERCOM, Rosatom as well as from other organizations interested in the problem.

http://www.inasan.ru/eng/asteroid_hazard/

The most ambitious task of the Group is to work out the draft of the Federal Scientific and Technical Program (FSTP) "Asteroid/Comet Impact Safety".

Research centers of the RAS as well as those of universities are doing studies on some aspects of the problem. However they have not enough funds to create an efficient system of detection, monitoring and characterization of NEOs (especially if it requires space born facilities). Moreover the expensive technologies of deviation and destroying of hazardous NEO and/or mitigation are far out of responsibilities of research centers doing fundamental science.

That is why the FSTP could be realized only at the national level!

The are six subprojects proposed for the FSTP:

1. ***Cooperation***
2. ***Monitoring***
3. ***Characterization***
4. ***Space missions***
5. ***Preventing***
6. ***Apophis***

To be considered by Roscosmos in the nearest future!

- On the prospects of international cooperation

Russia as the most geographically extended country (therefore having the highest probability to suffer from asteroid and comet impact) as well as the country that tries to stay at its positions in the world will not remain aloof from international attempts to solve the Asteroid-Comet Impact Hazard Problem.

UN Action Team 14
February 2008

Statement of Russian delegation:

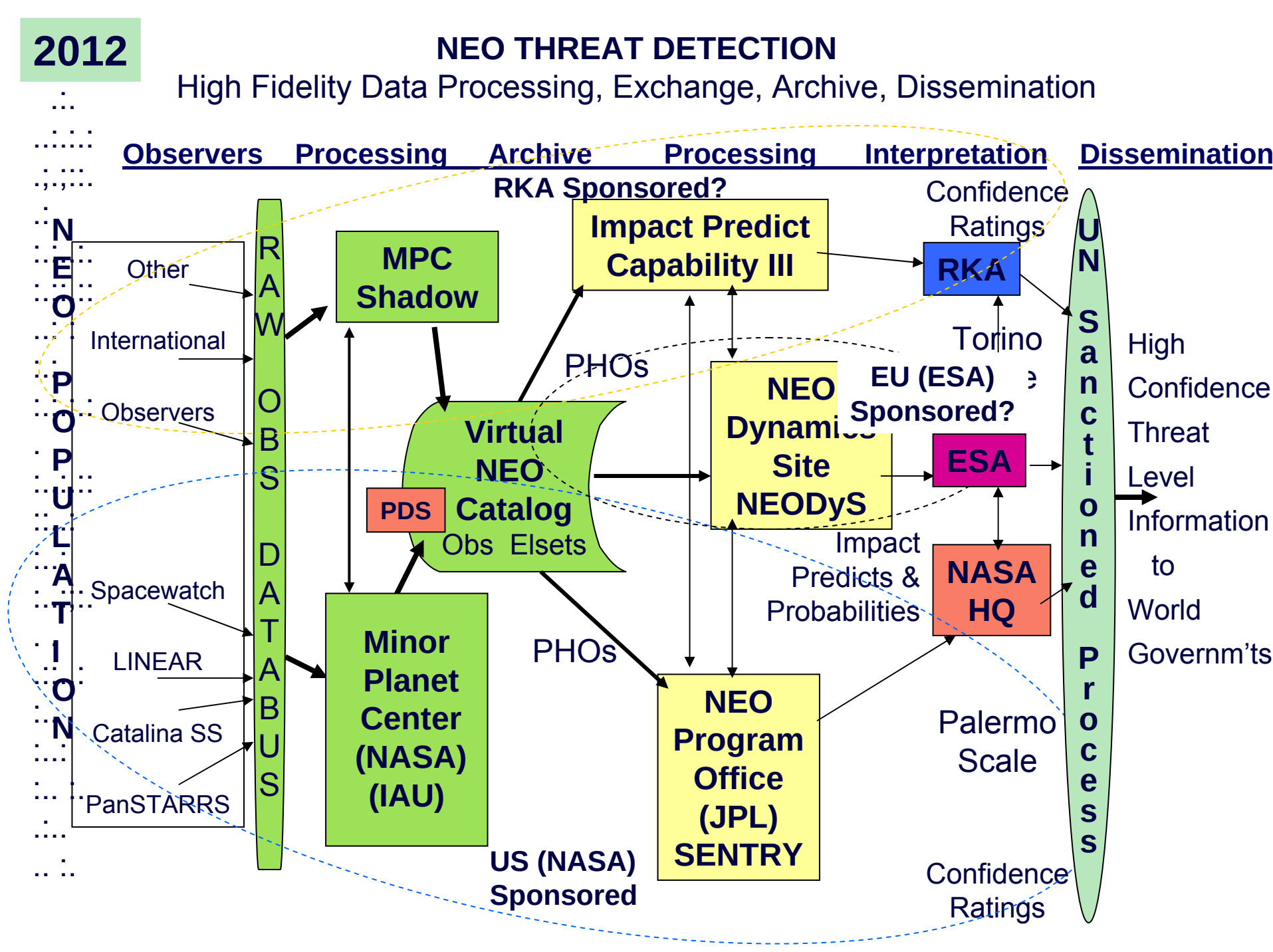
We support colleagues from USA and other countries who emphasize role of UN in elaboration of making decision mechanism accepted by international community.

from

Proposed Evolution of NEO Threat Determination Process

Lindley Johnson

NASA HQ/SMD


2012
NEO THREAT DETECTION
High Fidelity Data Processing, Exchange, Archive, Dissemination
Observers
Processing
Archive
Processing
Interpretation
Dissemination
NEO POPULATION
Other
International
Observers
Spacewatch
LINEAR
Catalina SS
PanSTARRS
RAW OBS DATABUS
MPC Shadow
Minor Planet Center (NASA) (IAU)
US (NASA) Sponsored
RKA Sponsored?
Impact Predict Capability III
PHOs
Virtual NEO Catalog
PDS
Obs Elsets
NEO Dynamics Site NEODyS
EU (ESA) Sponsored?
PHOs
NEO Program Office (JPL) SENTRY
Confidence Ratings
RKA
Torino
ESA
Impact Predicts & Probabilities
NASA HQ
Palermo Scale
Confidence Ratings
UN Sanctioned Process
High Confidence Threat Level Information to World Governm'ts

Thank you for your attention!