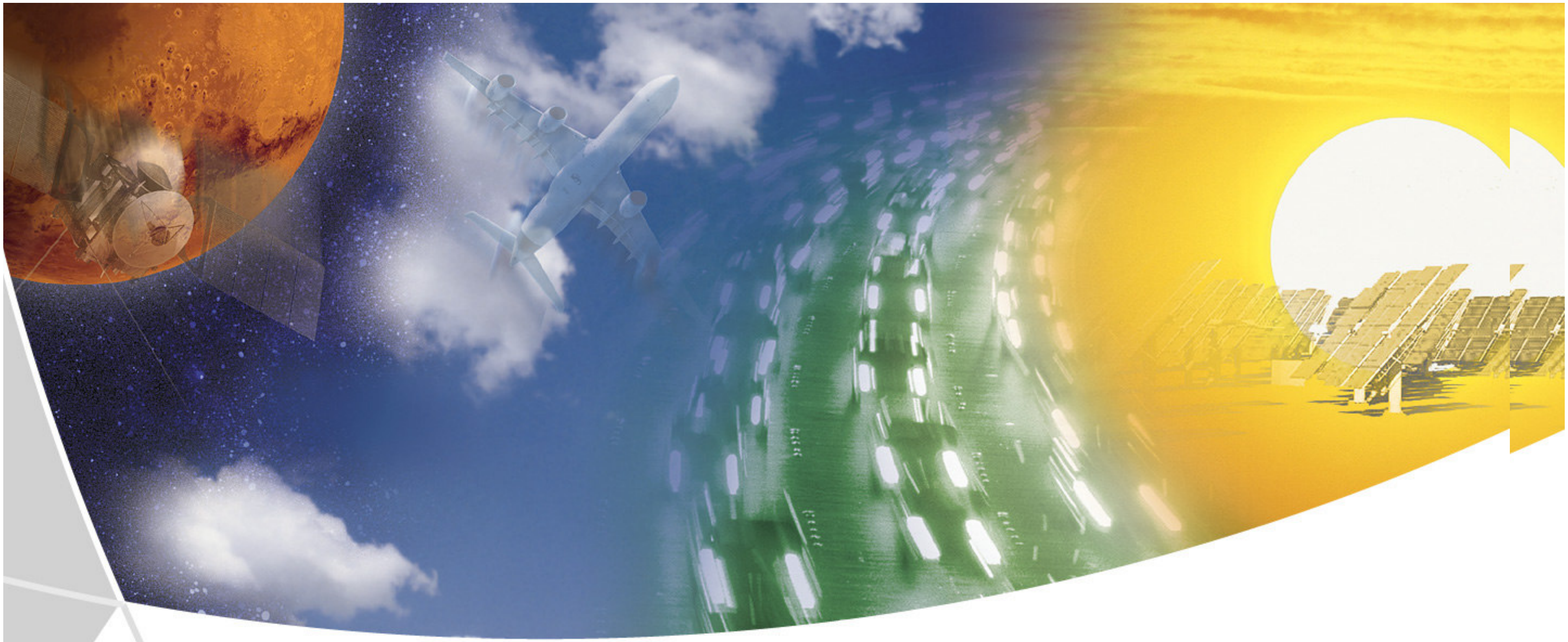

NEO Research Activities in Germany

A Report to the Scientific & Technical Subcommittee of the Committee on Peaceful Uses of Outer Space of the United Nations

44. Session, Vienna 12. – 23. 2. 2007

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Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

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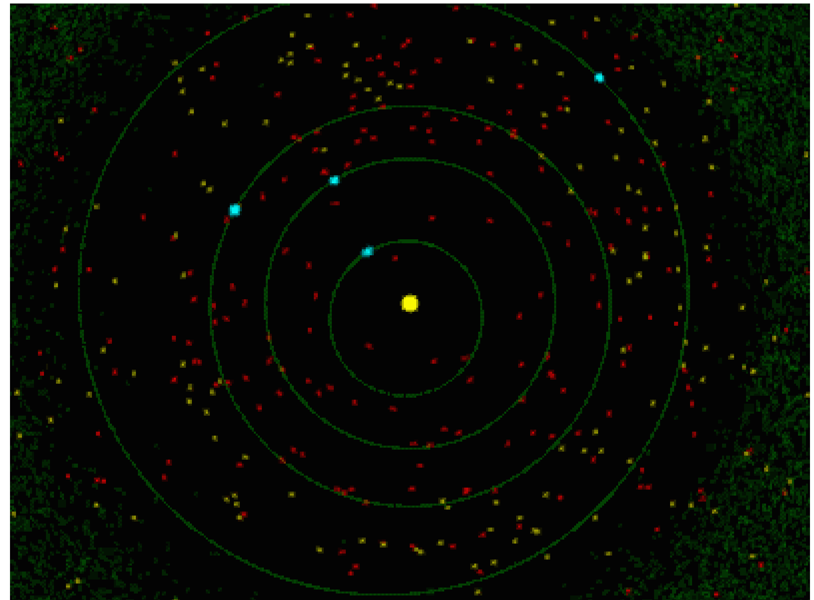


1. Introduction

German Aerospace Center

5.100 employees working in 27 research institutes and facilities

- at 9 sites
- in 7 field offices.

Program Directorates

- Aeronautics
- Space
- Transport
- Energy

NEO activities at DLR are concentrated in the Institute of Planetary Research in Berlin.

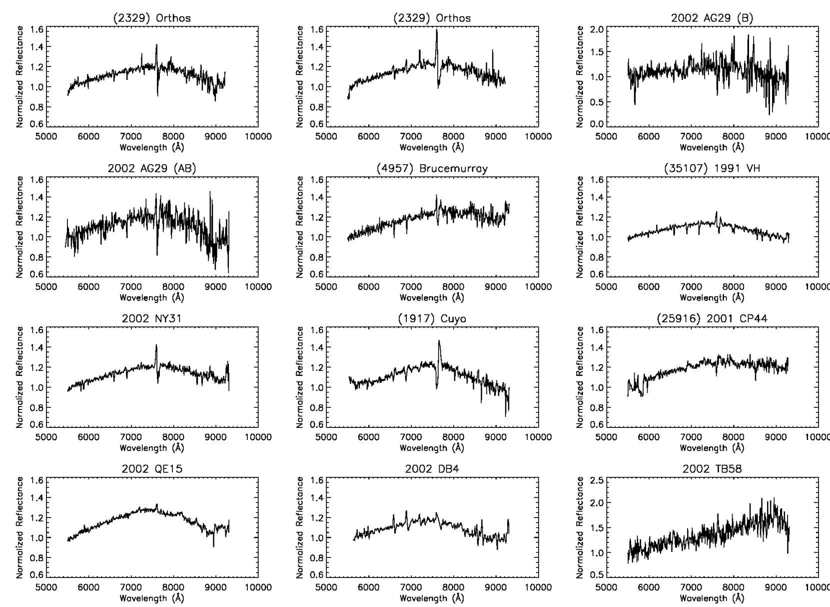
Max-Planck-Institute for Solar System Research

- Spectroscopic survey of NEAs in progress since 2003.

- Spectral observations in visible and near-infrared wavelengths are carried out at Calar Alto Observatory (Spain) and La Silla Observatory (ESO, Chile).

- Spectra are used for taxonomic classification of NEAs and statistical analysis.

- Participation in the planning of space missions to NEAs.



Spectra of NEAs

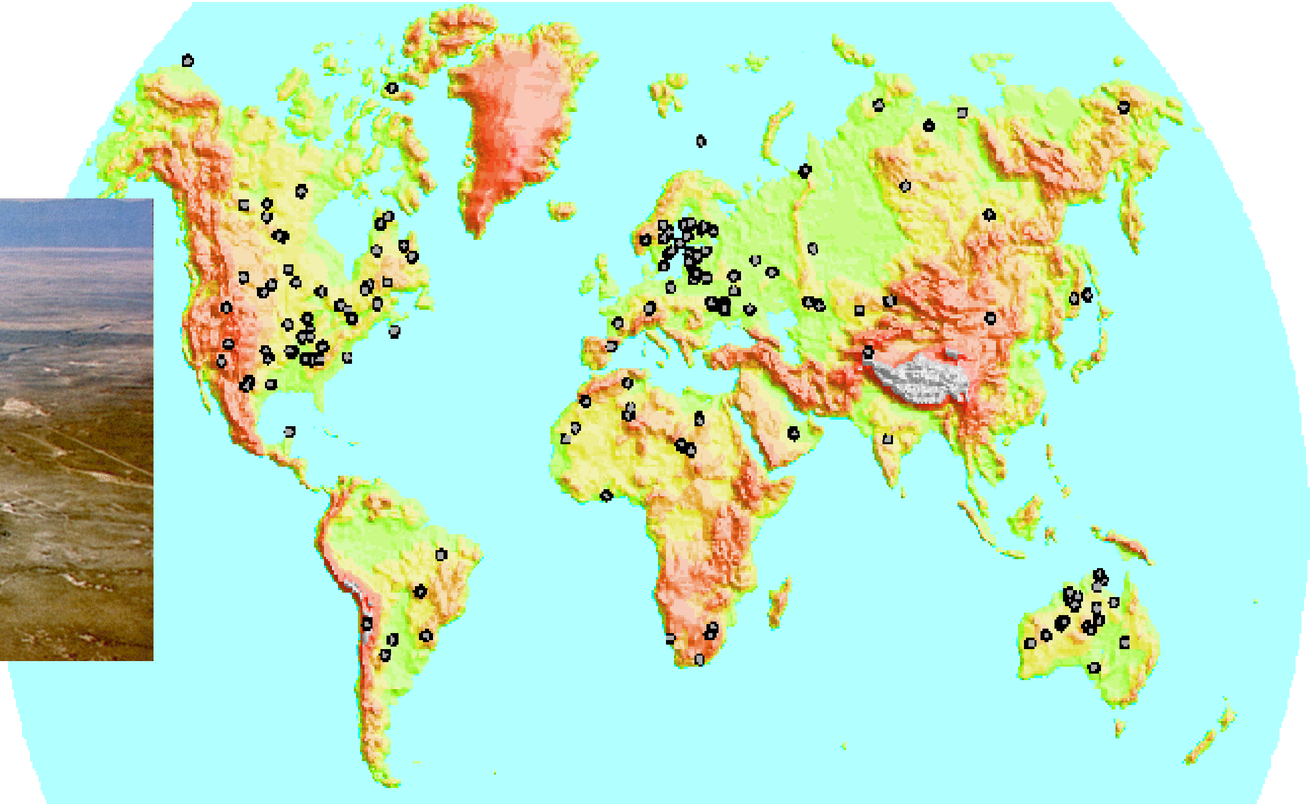
2. Motivation for NEO-Research

- Asteroids and comets (including NEOs) are related to the building blocks of planets and contain information about conditions during planet formation.
- NEOs probably delivered water and organics to Earth, which were essential for the development of life.
- But NEOs are also potential impactors on Earth and could destroy life.
- NEOs are well accessible targets for space missions.

http://solarsystem.dlr.de/KK

- Summary of our activities
- List of publications

Impact risk and damage

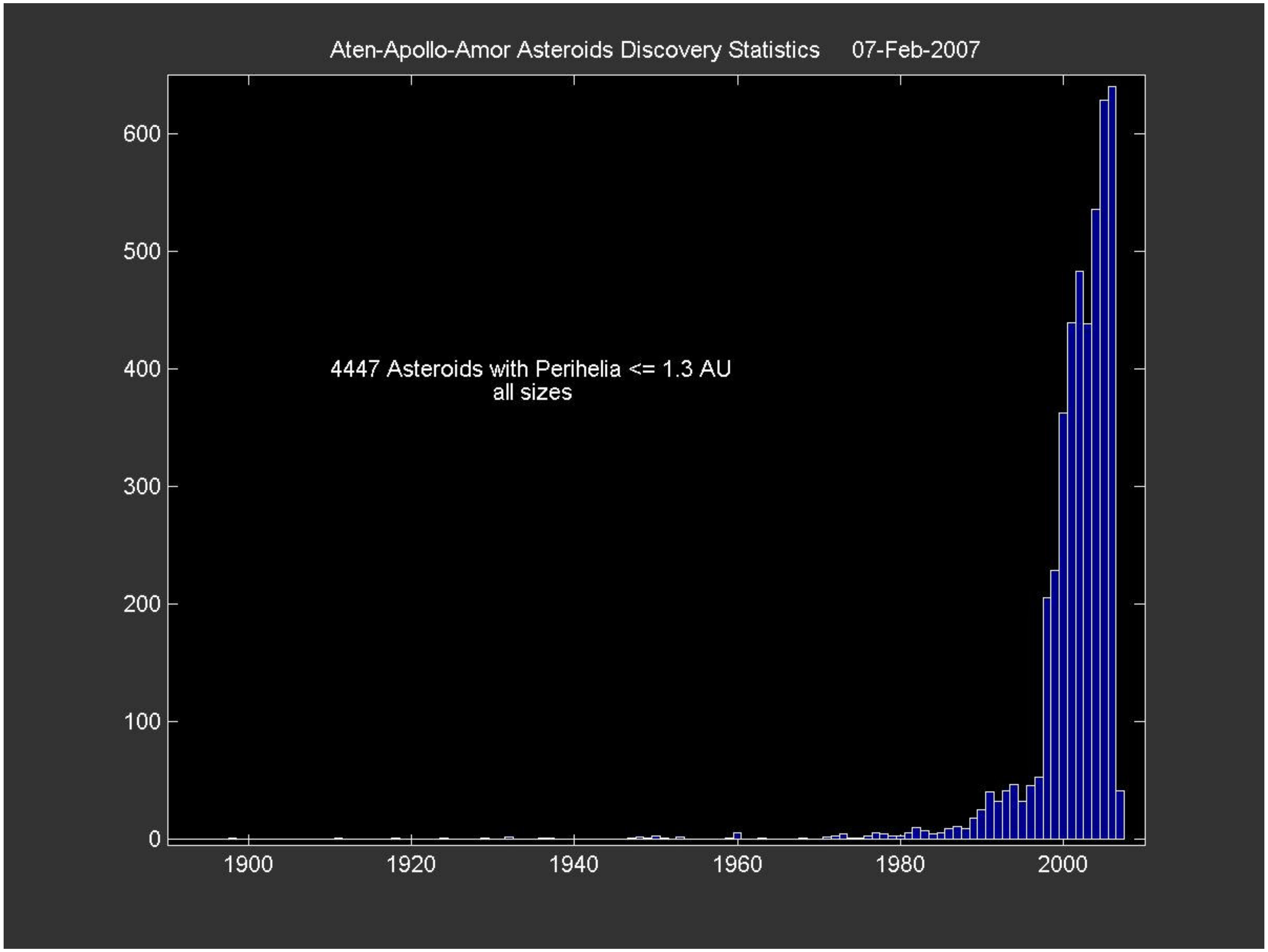


Impact craters on Earth (135)

Impactor Size (m)	Impact energy[1)]	Mean interval between impacts (years)	Crater size (km)	Damage
10000	> 10^{14} t TNT	100.000.000	200	Mass extinction, end of civilization
> 1000	> $8x10^{10}$ t TNT	600.000	> 20	Global catastrophe, tsunamis, earthquakes, climate changes
> 100	> $8x10^{7}$ t TNT	5.000	> 2	Regional damages stronger than by H-bombs
> 30	> $2x10^{6}$ t TNT	250	No crater	Explosion in atmosphere, strong blast wave, big fires (like Tunguska 1908)

[1)] Hiroshima bomb: $1.5x10^{4}$ t TNT

Discovery of NEAs (perihelia < 1.3 AU, all sizes)

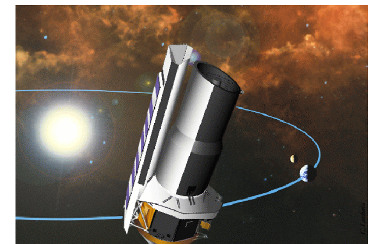


3. Observational Activities

Observation programs

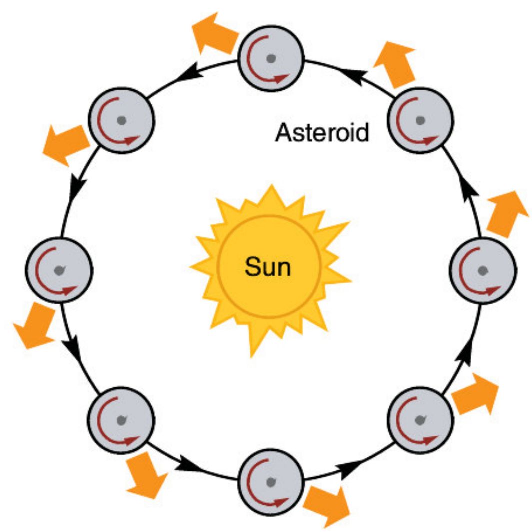
No own search programs but follow-up observations in the infrared and visible wavelength ranges with:

- Spitzer, IRTF and Keck Telescopes in the Thermal Infrared (but no guaranteed access but apply for time in competition with others).
- Nordic Optical Telescope La Palma (in cooperation with the Nordic Group for Small Planetary Bodies).
- Calar Alto 1.2 m telescope (remotely controlled).
- European Fireball Network together with amateurs and Czech colleagues from Astronomical Institute.



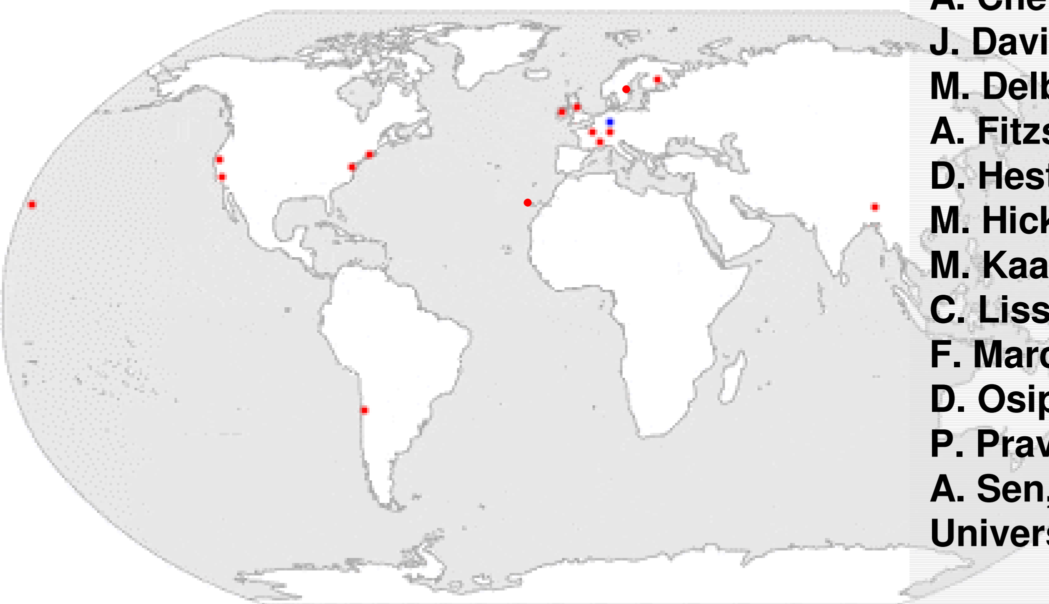

To:

- Determine sizes and albedos of NEOs (risk assessment, statistics, classification).
- Measure light curves (for rotation periods and global shapes).
- Refine orbit parameters by astrometric measurements.
- Determine strength and orbits of fireballs.
- Determine thermal inertia - important for the derivation of the Yarkovsky force which causes orbital drift of NEOs.



Yarkovsky force

Cooperation



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J. Davies, Astron. Techn. Centre, Edinburgh, UK
M. Delbo*, Obs. de la Côte d'Azur, Nice, France
A. Fitzsimmons, Queens Univ., Belfast, UK
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M. Hicks, JPL, Pasadena, USA
M. Kaasalainen, Univ. Helsinki, Finland
C. Lisse, Johns Hopkins Univ., Baltimore, USA
F. Marchis, UC Berkeley, USA
D. Osip, Las Campanas Observatory, Chile
P. Pravec, Ondrejov Observatory, Czech Rep.
A. Sen, Univ. Assam, India
University Uppsala

*M. Delbo was a PhD student in our institute his doctorate was awarded in 2004.

Main results of observations I

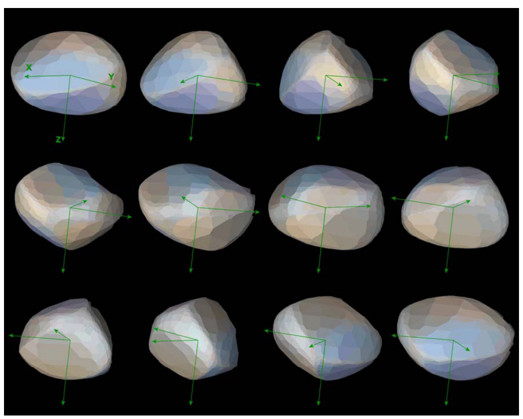
- By our observations together with sophisticated model we have multiplied the number (from about 20 to about 60) of NEOs having well determined sizes and albedos.
- Our results have facilitated the most reliable quantitative assessment to date of the risk of NEO impacts on the Earth.
- First study of the mean thermal inertia of km-sized NEOs (4 times more than lunar regolith but much less than bare rock).
- Determination of diameter, albedo, and taxonomic type of the potential target asteroid (10302) 1989 ML of the Don Quijote mission.

Some results in detail

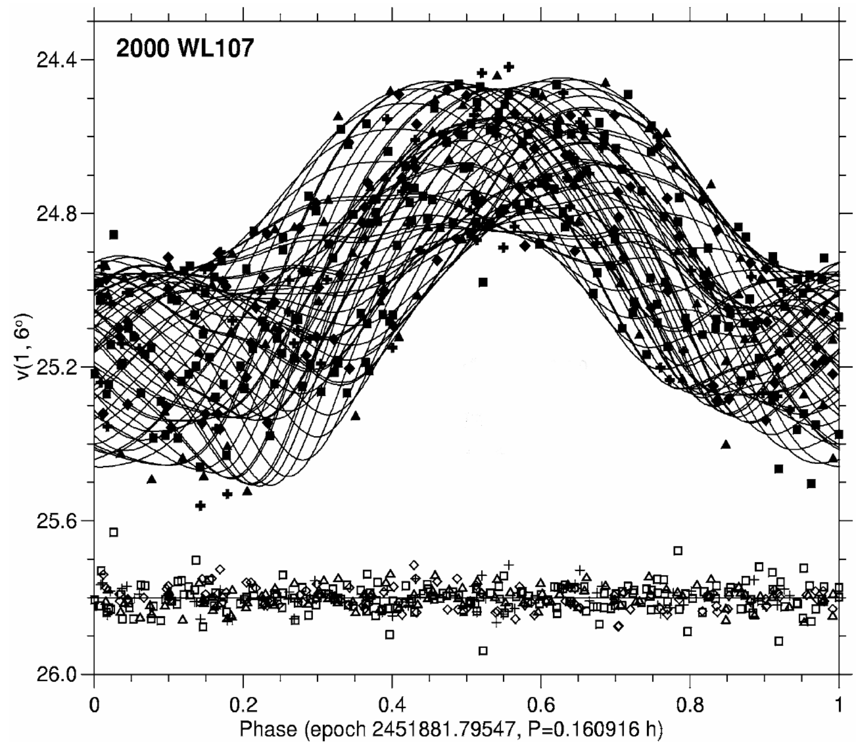
Near Earth Asteroid	Diameter (km)	Albedo	Taxonomic Class
1627 Ivar	9.12	0.15	S
1866 Sisyphus	8.48	0.15	S
2100 Ra-Shalom	2.78	0.082	Xc
4034 1986 PA	0.42	0.52	O
4055 Magellan	2.49	0.31	V
4660 Nereus	0.33	0.55	E
5587 1990 SB	3.57	0.32	Sq
5604 1992 FE	0.55	0.48	V
14402 1991 DB	2.30	0.36	E
5751 Zao	0.60	0.14	C
16834 1997 WU_{22}	1.87	0.22	S
19356 1997 GH_3	0.91	0.34	S
25330 1999 KV_4	3.21	0.052	B
1999 FK_{21}	0.59	0.32	S
1999 NC_{43}	2.22	0.14	Q
2000 BG_{19}	1.77	0.043	P
2000 PG_3	4.60	0.042	D
2001 FY	0.32	0.52	S
2002 BM_{26}	0.84	0.023	P
2002 CT_{46}	0.16	0.32	Sr

Main results of observations II

- Discovery of the chaotic rotation state of 2000 WL107 - a NEA with a principal rotation period just under 10 min.
- Global shapes from only long-term photometric observations.



Global shape from photometry

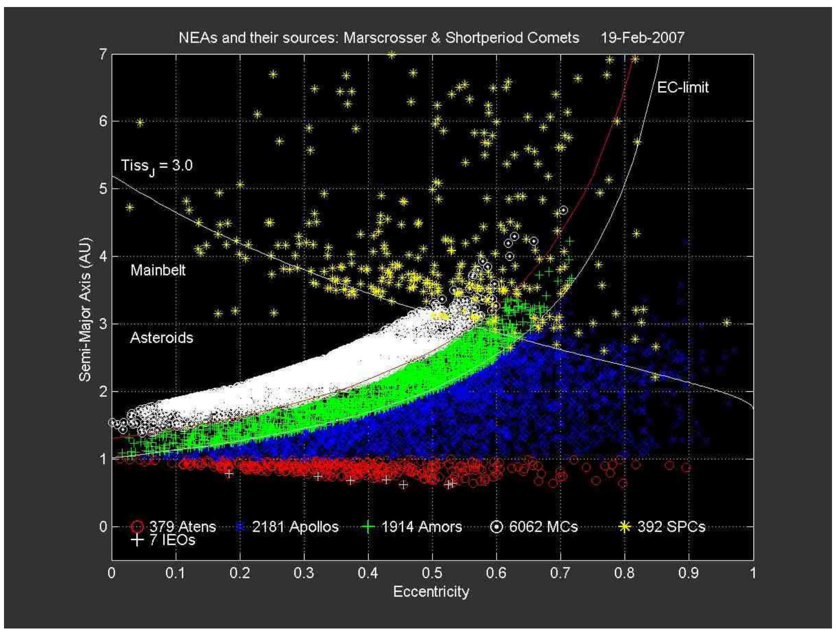


The chaotic rotation of asteroid 2000 WL107

4. Data base of physical properties of NEAs

We maintain and update a database of physical physical properties of all known NEAs that is widely used:

http://earn.dlr.de/nea



1862 Apollo

Discovery Circumstances:	K. Reinmuth - Heidelberg-Konigstuhl 24 Apr 1932	(1)
Orbital Type:	AP	(*)(2)
Taxonomic Type:	Q	(3)(4)(5)
Albedo:	0.26	(6)(7)(8)
Diameter:	1.4 km	(9)(10)(11)
H:	16.23	(12)
G:	0.23	(13)
U-B:	0.43	(14)
B-V:	0.79	(14)
Rotation Period:	3.065 hr	(15)(16)(17)(18)(19)
Quality:	4BR !	(15)(16)(17)(18)(19)
Lightcurve Amplitude:	0.15-0.60 mag	(15)(16)(17)(18)(19)
Spin Vector:	l=56,b=-26	(20)
Radar Observations:	Y	(21)(22)(23)(24)
Spectral Observations:	Y	(25)(26)
IR Observations:	-	-

Cooperation

Armagh Observatory
Astronomical Observatory in Belgrade
Astronomical Observatory of the Kharkiv State University
DLR - Asteroid Research Team
CNR - Institute for Space Astrophysics - Planetology Group
Klet Observatory
DESPA - Departement de Recherche Spatiale - Small Bodies Group
OCA - Observatoire de la Côte d'Azur
Ondrejov Observatory
Osservatorio Astronomico di Torino
Osservatorio Astrofisico di Catania
Poznan Observatory
Queen Mary and Westfield College - Solar System Dynamics Group
Queen's University of Belfast - Astrophysics and Planetary Science Division
University of Pisa - Space Mechanics Group
Uppsala Astronomical Observatory - The Planetary System Group
Observatory - University of Helsinki

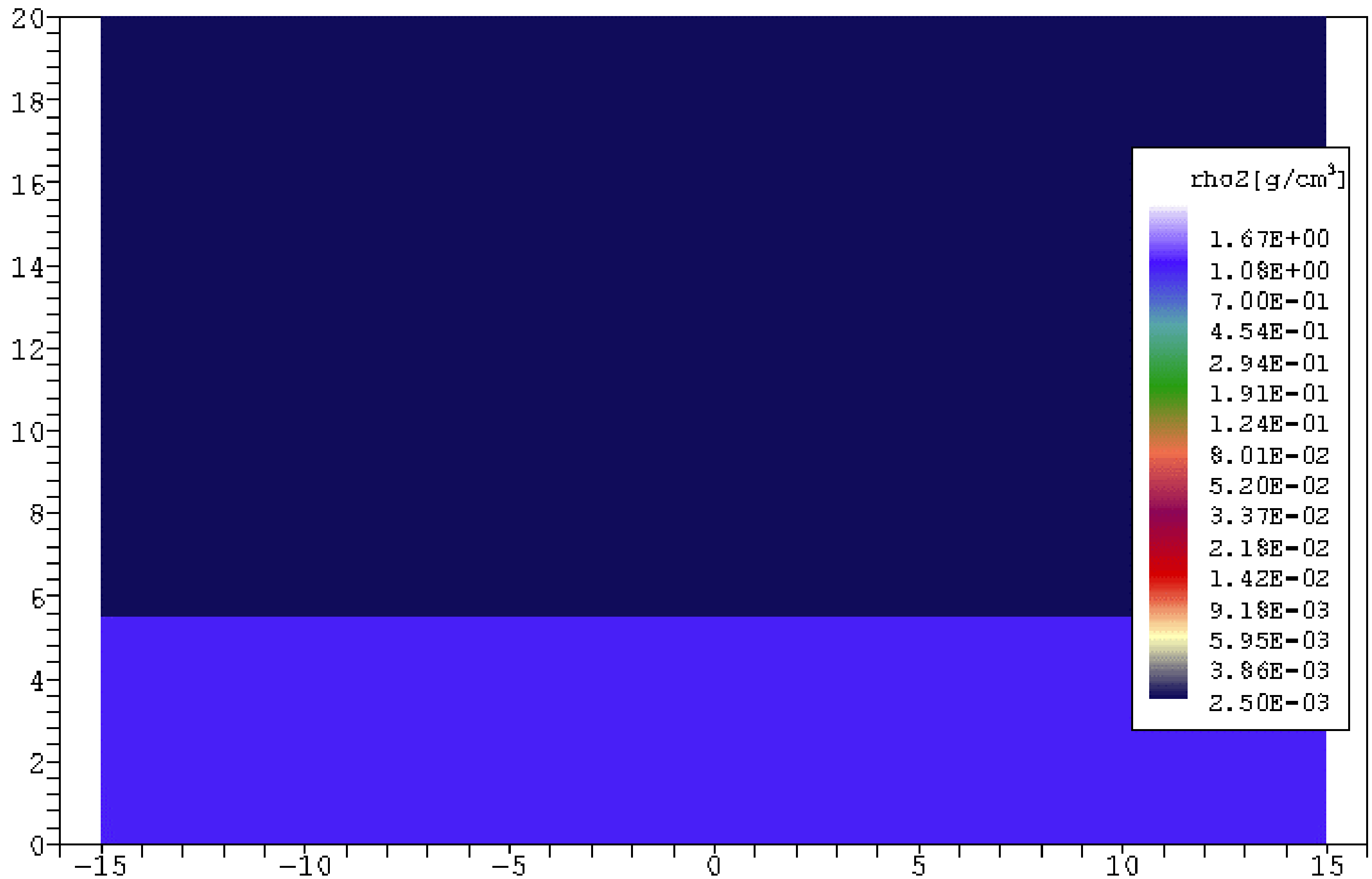
5. Impact Simulation Tools

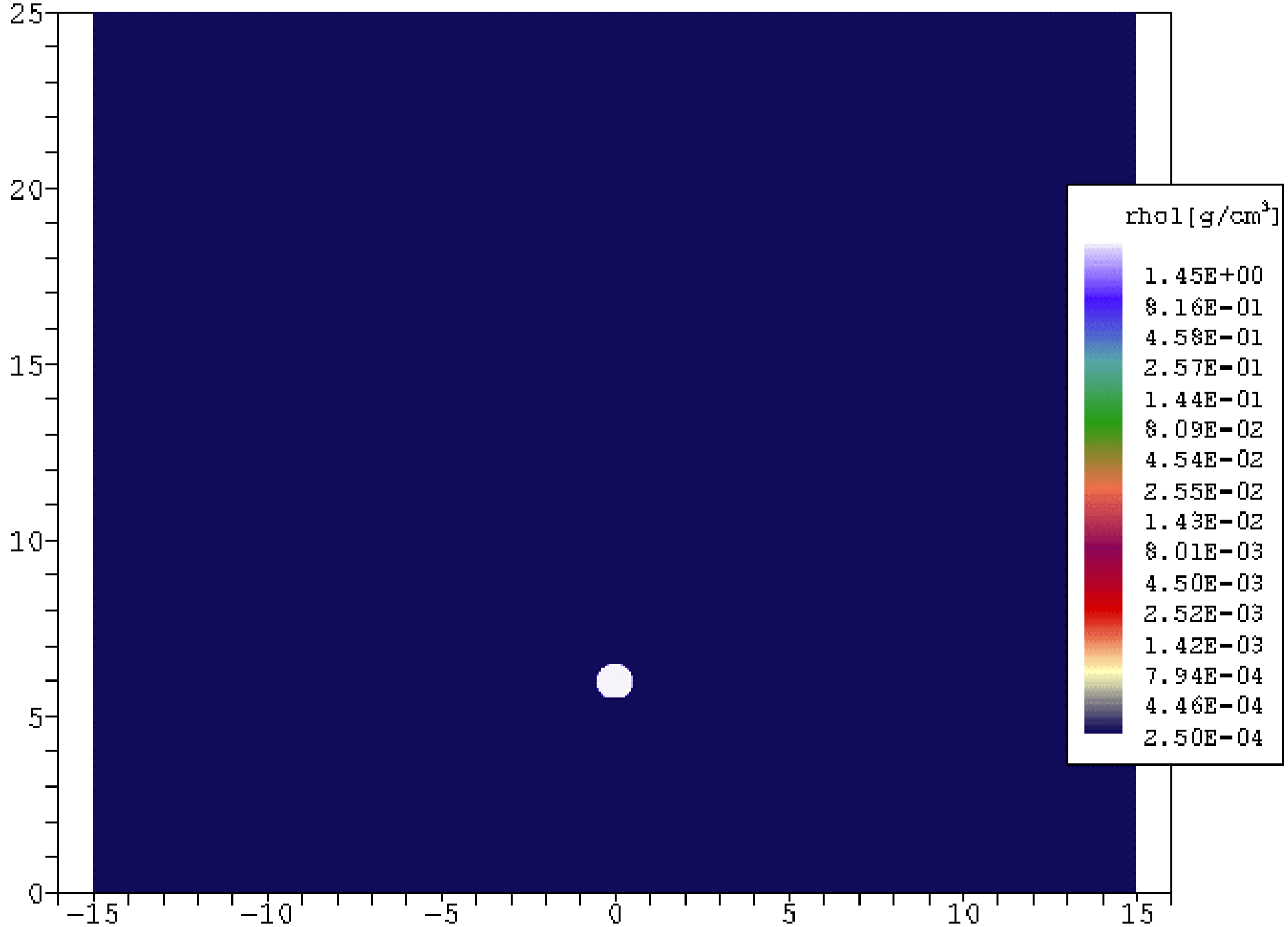
Tool description

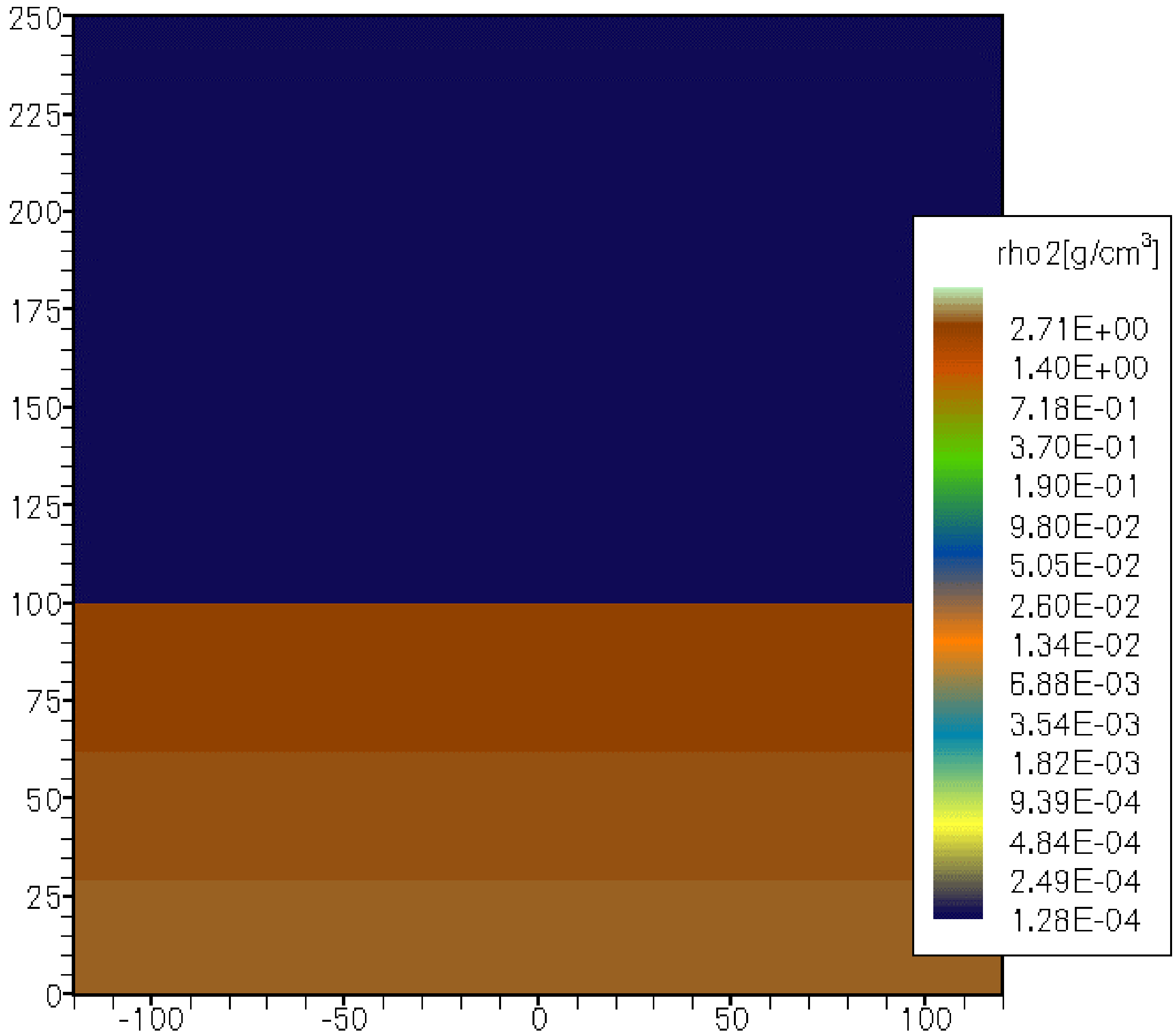
A sophisticated and robust new 2D multi-material hydrocode has been developed and applied to analyze high-energy impacts onto a continent and impacts into the ocean.

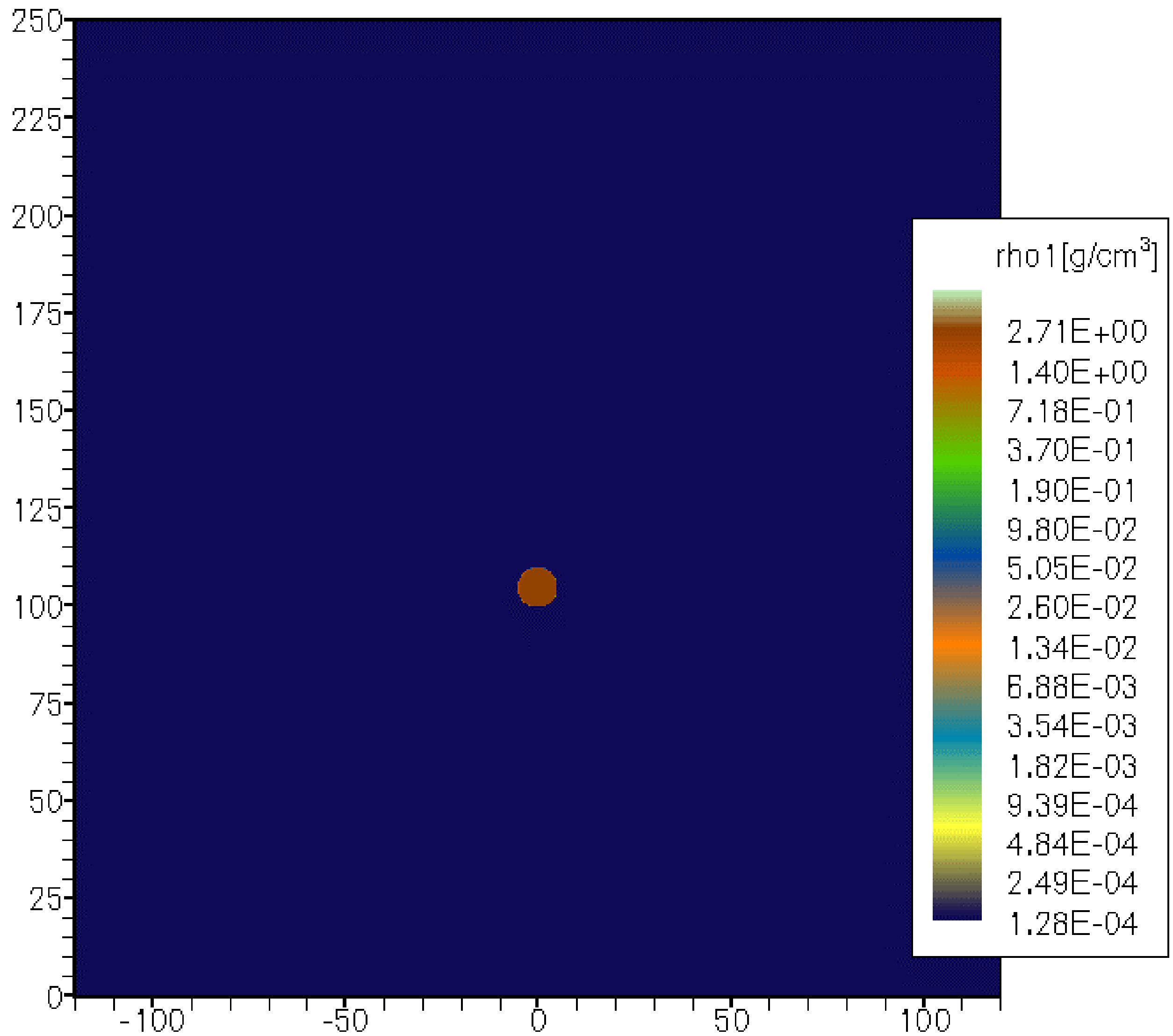
Main results

- Density, pressure, and velocity distributions of the impactor and the ground material up to several hundreds of seconds after the impact.
- Range of ejecta in giant Chicxulub type impact (ejecta are distributed over wide ranges, several 1000 km, by ballistic transport but not around the world).

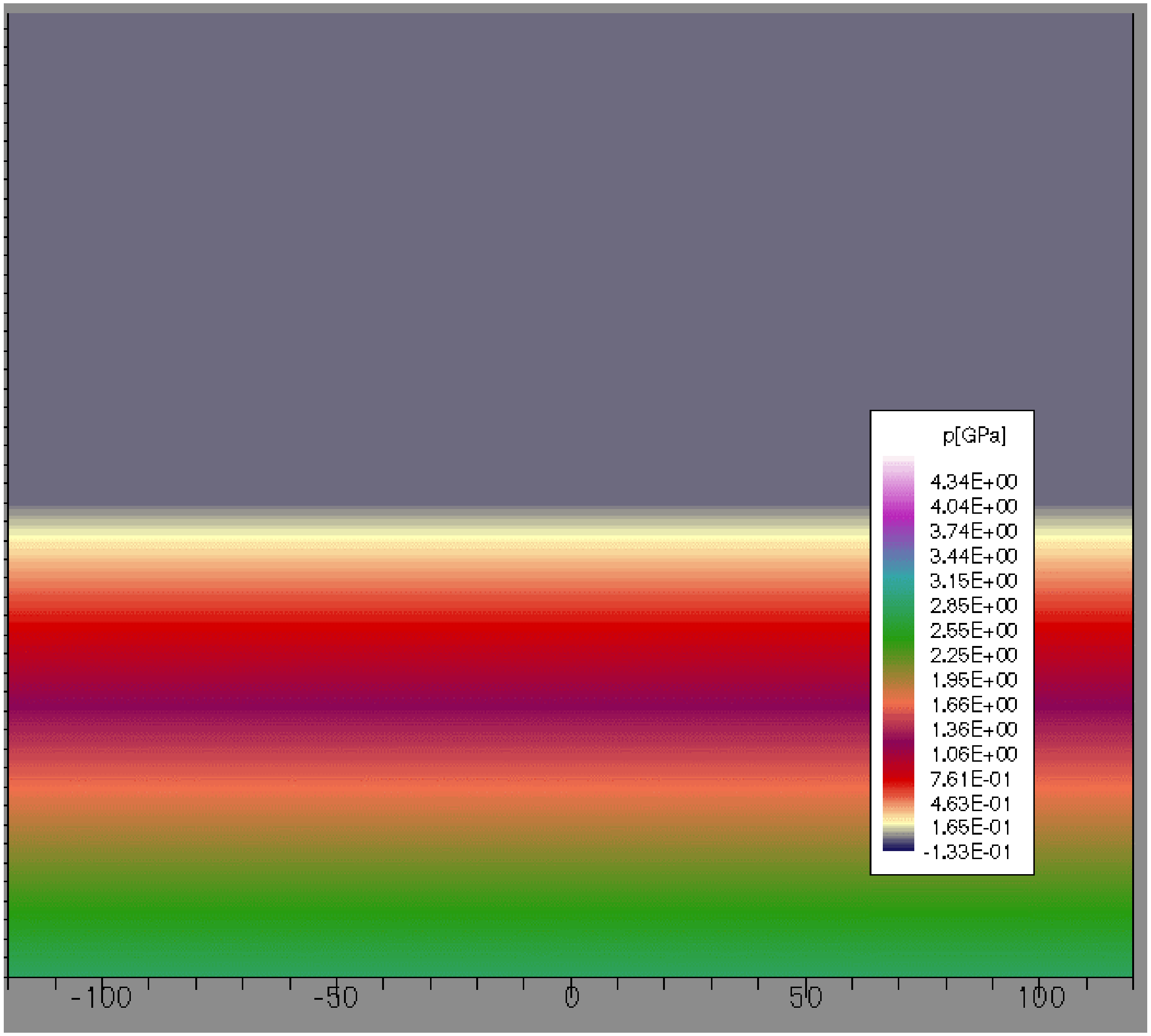

20
18
16
14
12
10
8
6
4
2
0
−15
−10
−5
0
5
10
15
rho2[g/cm³]
1.67E+00
1.08E+00
7.00E−01
4.54E−01
2.94E−01
1.91E−01
1.24E−01
8.01E−02
5.20E−02
3.37E−02
2.18E−02
1.42E−02
9.18E−03
5.95E−03
3.86E−03
2.50E−03


rhol[g/cm³]
1.45E+00
8.16E-01
4.58E-01
2.57E-01
1.44E-01
8.09E-02
4.54E-02
2.55E-02
1.43E-02
8.01E-03
4.50E-03
2.52E-03
1.42E-03
7.94E-04
4.46E-04
2.50E-04
25
20
15
10
5
0
-15
-10
-5
0
5
10
15


250
225
200
175
150
125
100
75
50
25
0
-100
-50
0
50
100
rho2[g/cm^3]
2.71E+00
1.40E+00
7.18E-01
3.70E-01
1.90E-01
9.80E-02
5.05E-02
2.60E-02
1.34E-02
6.88E-03
3.54E-03
1.82E-03
9.39E-04
4.84E-04
2.49E-04
1.28E-04



250
225
200
175
150
125
100
75
50
25
0
-100
-50
0
50
100
rho1[g/cm3]
2.71E+00
1.40E+00
7.18E-01
3.70E-01
1.90E-01
9.80E-02
5.05E-02
2.60E-02
1.34E-02
6.88E-03
3.54E-03
1.82E-03
9.39E-04
4.84E-04
2.49E-04
1.28E-04


p[GPa]
4.34E+00
4.04E+00
3.74E+00
3.44E+00
3.15E+00
2.85E+00
2.55E+00
2.25E+00
1.95E+00
1.66E+00
1.36E+00
1.06E+00
7.61E-01
4.63E-01
1.65E-01
-1.33E-01
-100
-50
0
50
100

6. Risk Assessment and Mitigation

Risk assessment tools

- Highly precise orbit simulation taking into account gravity of all planets and Earth Moon.
- Evaluation of minor disturbances on orbit (Yarkovsky effect, radiation pressure, gravitational influence of large asteroids, nongravitational forces at comets).
- Atmospheric entry simulation (aerobraking, ablation, fragmentation)
- Damage estimation of impacts (earthquakes, tsunamis).

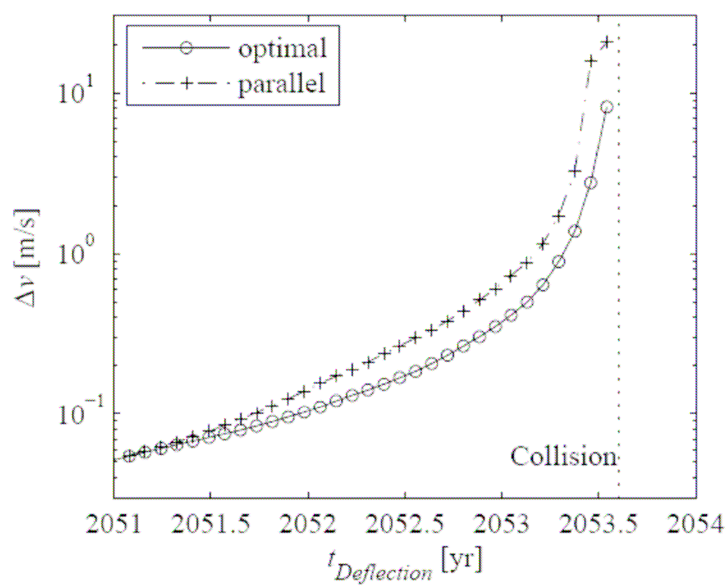
Risk mitigation

- Study of different methods for risk mitigation (orbit change by projectiles, solar collector, or fragmentation of the target by explosions).
- Optimization of mission strategies (transfer orbits, nonparallel attack) for deflection of hazardous targets.
- Calculation of the momentum transfer enhancement by ejecta production after impact (in difference to classical elastic billiard ball problem).

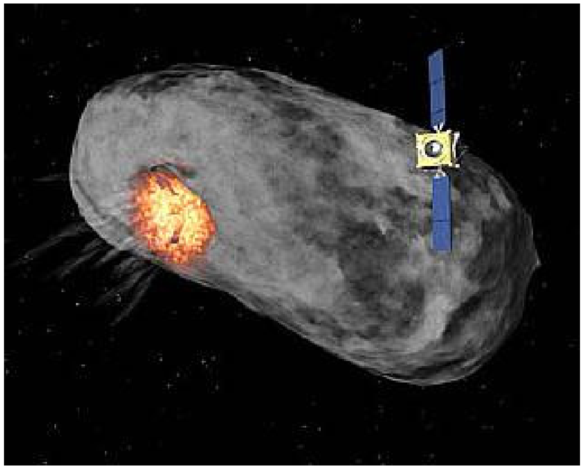
Main results

- 80 % of a representative model population of 100 hazardous NEOs could be safely deflected by one or two impacts of spacecraft if the warning time is large enough (10 to 30 years).
- For short warning times (<< 10 years) an optimized non parallel attack (relative to target orbit) of an impactor is of great advantage but 10 years may be too short for an effective reaction.
- Solar reflectors are problematic for deflecting NEOs due to mirror contamination and focusing difficulties.

Effectivity of an optimal (nonparallel) attack on a fictitious NEO compared to the common approach



7. Contributions to NEO Space Missions



Don Quijote (ESA Phase A)

- Consultant to one of three study teams to define the payload.

Asteroid Finder (DLR study)

- To define a mission for detection of Inner Earth Objects by means of observations from an orbiting compact satellite.

A Cosmic Vision program

- Support of a European proposal for a NEO sample return mission (Leonardo).

8. Conclusions

- To protect our Earth from disastrous NEO impacts international activities are needed for discovering, investigating, and deflecting hazardous objects. This requires good international coordination and informed strategies.
- DLR has strengthened its efforts in NEO research and is prepared to support international NEO activities. We are interested in a cooperation with the United Nations' NEO Action Team.
- Our future activities will include:
  - follow up observations of NEOs to determine their physical and dynamical properties
  - impact simulations
  - hardware development and planning of space missions to NEOs