Near-Earth Asteroid Defense

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November 23, 2022

Background

Near-Earth asteroids (NEAs) are asteroids that are close to Earth within a distance of less than 45 million kilometers and may encounter with the Earth orbit, posing a risk of impact on the Earth.

- In 2013, a NEA impacted on Chelyabinsk, Russia, damaged over 3,000 buildings, injured over 1,500 people , and caused over 1 billion RUB economic loss .

- In 2021, about 1500 NEAs approached to Earth and caused over 32 times of bolide event.

Contents

I. Developments and Enlightenments

Developments

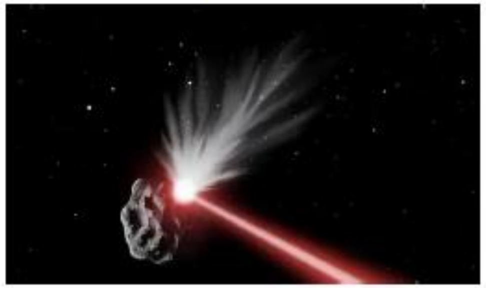
Short-term effects: In-orbit demonstration on kinetic impact, and nuclear explosion, in which kinetic impact has been carried out.

Long-term effects: Technologies on gravitational traction, laser ablation drive, attachment push-off, solar radiation pressure, mass drive, ion beam push-off, etc. are still under conceptual research.

Kinetic Impact

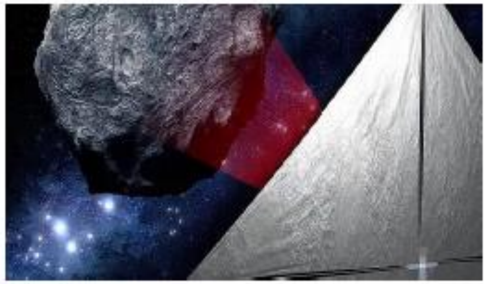
Nuclear Explosion

Gravitational Traction



Laser Ablation

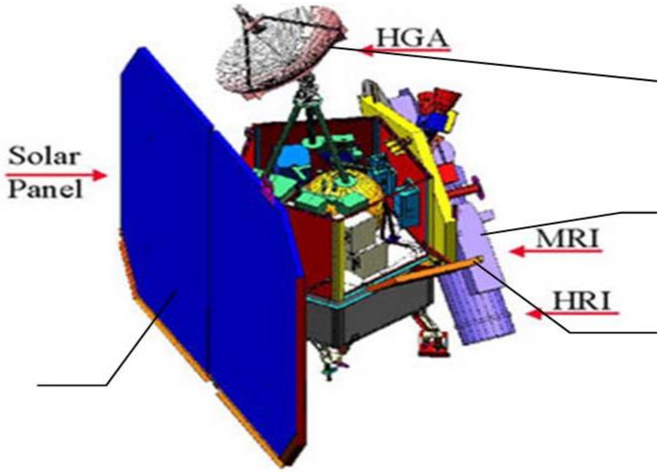
Attached Push-off

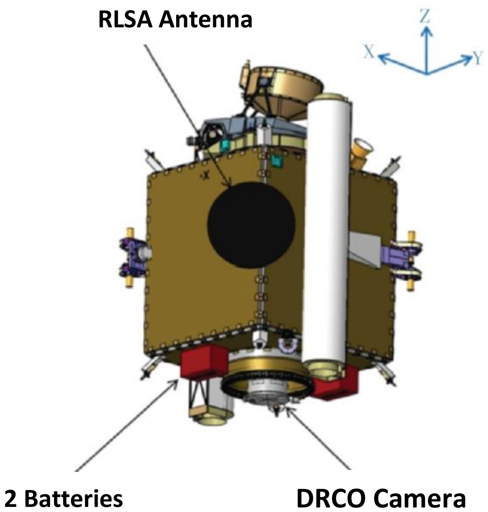


Solar Radiation Pressure

I. Developments and Enlightenments

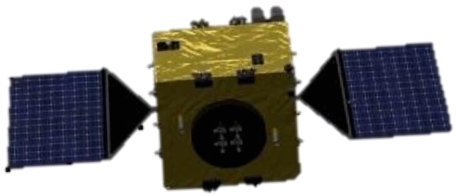
Developments





Mission "Hera" (Europe)

Expected to be launched in 2024 and arrived in 2026



"Double Asteroid Redirect Test" (DART) Mission (USA)

Date: Launched in November 2021 and impacted in September 2022

Object: "Dimorphos" daughter star (160m diameter)

Impact Speed: 6.3km/s

Accuracy: 15m (1σ)

Result: Reduce the orbiting orbital period of the sub star around the main star within 32 minutes

“Deep Impact Mission ” (USA)

Date: Launched in January 2005 and impacted in July 2005

Object: Comet Tempel 1 (6km diameter)

Impact Speed: 10.2km/s

Accuracy: 100m (1σ)

I. Developments and Enlightenments

Current Situation

- In 2018, CNSA represented Chinese government joined in the International Asteroid Warning Network and the Space Mission Advisory Group.
- In 2021, the construction of a near-earth small body defense system was proposed in the white paper "China's Space Program: A 2021 Perspective ". CNSA has organized and carried out the first domestic asteroid impact risk response exercise and participated in the first international planetary defense maneuver activities.
- Breakthroughs on multiple key technologies has been made, such as high-speed impact deflection modeling simulation for typical in-orbit disposal scenarios, and high-speed kinetic impact in-orbit disposal verification system.

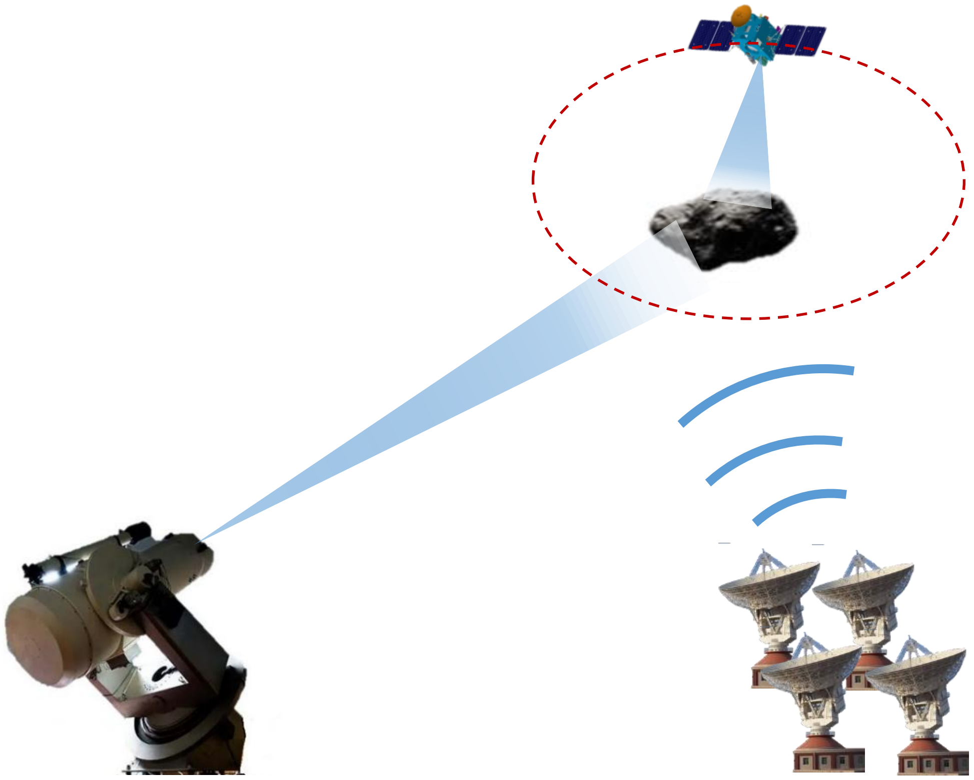
Enlightenments

Kinetic impact is the preferred option

Compared with other methods, kinetic impact has a better preliminary research foundation and technical reserve.

According to the analysis results of the International Space Mission Planning Advisory Organization, kinetic impact is one of preferred means for asteroids defense with its diameter range from 50 to 300m.

II. General Design Concept



Setup: verification target of in-orbit disposal of asteroid kinetic impact and evaluation technology

Select: exploration objective from non-controversial asteroids

Format:

- Mission System: domestic and foreign collaborative observation system
- Impact Mode: **accompanying flight+ impact + accompanying flight**

Objective:

accurate impact	**efficient push**	**available measurement**	**clear statement**

Verify: accurate guidance and control technology

Implement and complete: mission support and decision mechanism of NEA defense

III. Scientific Objectives

Conduct comprehensive research on the orbital characteristics, intrinsic properties and impact effects of target asteroids to provide theoretical support for asteroid defense.

1) To explore the orbital characteristics of target asteroids and reveal the dynamical evolution laws.

2) To explore and study the shape, scale, composition and structure of the target asteroid and reveal its intrinsic properties.

3) To carry out research on impact effects, such as terrain changes and spatter distribution to reveal the impact momentum transfer law.

IV. Mission Objective Selection

1. Selection Principles

Security

Non-threat to Earth after impact, to avoid impact risk items on the list of NASA/ CNEOS/ Sentry.

Accessibility

Diameter within 20m~ 90m, accessible distance to the earth, orbit inclinat ion less than 5°, eccentricity less than 0.3, available of implementation.

Detectability

Brightness magnitude exceeds 26 star magnitude , over one chance of observation available; after kinetic impact, over one chance in 3 years.

Efficiency

The selected targets are available to be launched within 2025-2027.

Scientific

The selected targets should be of scientific research value and can satisfy the impact evaluation target.

2. Selection Results

No.	Target number	Absolute StarMagnitude	Diameter (m)	Semi-major Axis (AU)	Inclination (degrees)	Eccentricity	Orbital Precision Degree	First Observation Time	Number of Orbital Period	Average observation time per Period (min)	Select priority
1	2019 VL5	25.8	24.0	1.0	1.6	0.28	0	2022-11-04	3	Brightest visual star magnitude >20mag	1
2	2020 PN1	25.4	28.5	1.0	4.9	0.12	0	2022-08-01	2	14.8	1
3	2015 MB54	24	54.4	1.3	2.7	0.24	0	2024-02-20	2	41	2
4	2022 DC5	22.9	90.3	1.0	3.9	0.21	3	2023-02-24	2	10.7	2
5	2021 TL	23.3	75.1	0.9	3.2	0.27	3	2022-12-21	3	17.1	3
6	2002 XY38	22.9	90.3	0.9	2.1	0.22	1	2022-12-10	2	32.1	3
7	2017 BM123	23.8	60.5	1.3	7.9	0.30	1	2023-02-08	2	20.9	4
8	2020FN3	24.3	35.3~79.07	1.013	0.9	0.21	1	2025-10-31	1	19.02	5
9	2021UH2	25.1	25.2~56.4	0.982	0.28	0.17	3	2025-01-16	1	21.6	5
10	2020CX1	24.08	54	1.001	12.741	0.163	0	2023-02-06	1	19.95	6
11	2018RY1	24.44	46	0.822	1.168	0.339	0	2024-09-21	1	18.98	6

V. Impact Mission Analysis

1. Impact Target Analysis ---- Launch Window
2. Impact Mode Analysis ---- Observer and Impactor
3. Impact Velocity Analysis ---- Impactor Flight Path
4. Impact Shape Analysis ---- Impactor Shape
5. Impact Influence Analysis ---- Payload Configuration

V. Impact Mission Analysis

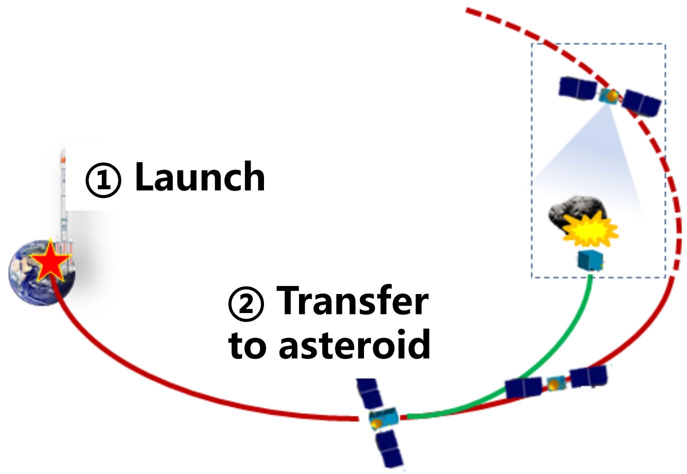
1. Impact Target Analysis

Launch year	2025		2026		2027
Target asteroids	2019 VL5	2020 PN1	2020 FN3	2019 VL5	2022 DC5
Nominal size	24	28	50	24	90
Deflection distance (km)	2071	249	308	3967	46.9
Distance at impact (km)	10.52 million	61.6 million	150 million	160 million	140 million
Star magnitude at impact	22.7	25.9	26.6	27.95	25.1
Star magnitude after impact	23.6	24.7	23.6	24.3	21.9
Efficient push	★★★★★	★★★★★	★★★★	★★★★★	★
Available measure	★★★★★	★★★★★★	★★★★	★	★

Considering the principle—" accurate impact, efficient push, available measurement, clear statement" , we set **2019 VL5** as target and determine to launch it **in 2025**.

2. Impact Mode Analysis

"Impact + Flyby"



Advantages: 1) simple mission process , and 2) short mission period.

Features: 1) Similar mission profile with the “Deep Impact” of NASA.

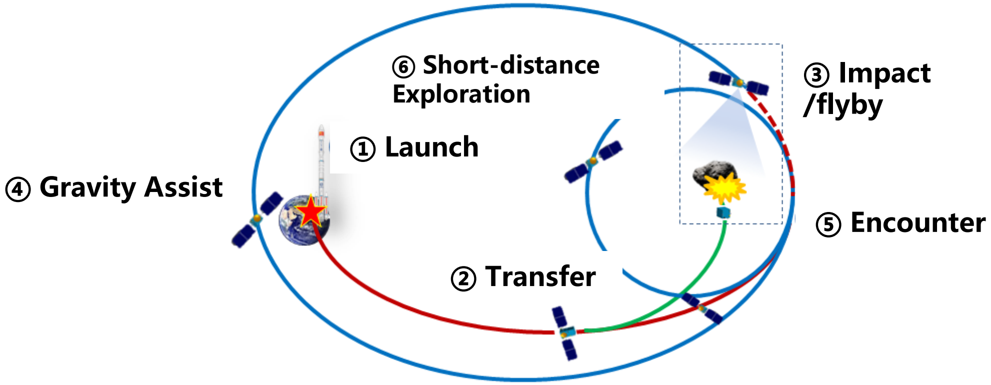
2) To evaluate orbit completely based on ground-based telescopes before and after impact, which requires high observation capability of ground-based telescopes, while space-based assessment capability is not required.

3) To flyby the asteroid at long distance with low imaging resolution and short observation period. The imaging results are uncertain.

V. Impact Mission Analysis

2. Impact Mode Analysis

"Impact + flyby+ Accompanying Flight"



Advantages: 1) Asteroid exploration has better effect than impact +flyby.

Features: 1) Similar to the "DART+HERA" mission profile by NASA and ESA.

2) Completely rely on ground-based telescopes to determine the asteroid orbit before impact and is of high requirement on ground-based telescopes.

3) The observation result of flyby is limited.

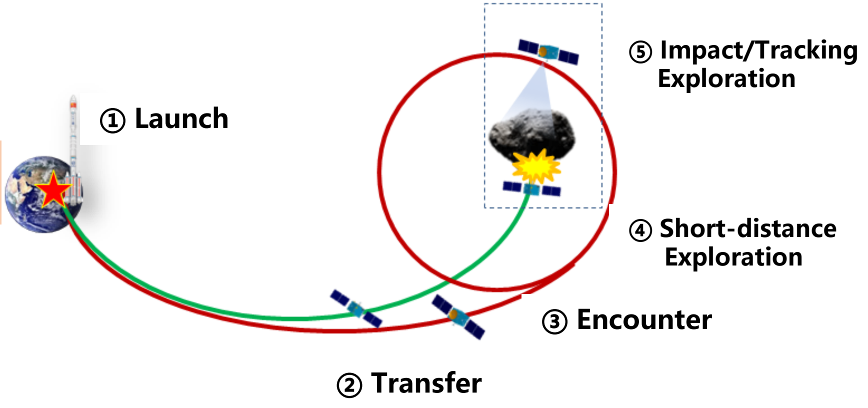
4) Due to the requirement on Earth gravity assist to return to asteroid, the accompanying flight will be 2.5 years after the impact causing long mission period .

5) Observation on crater is uncertain with deficiency on data before impact and low precision.

V. Impact Mission Analysis

2. Impact Mode Analysis

“Accompanying Flight + Impact + Accompanying Flight"



Advantages: 1) To achieve kinetic impact and in-orbit effect evaluation in one mission, highly innovative.

2) To precisely determine and to compare and analyze the asteroid orbit and topography via accompanying flight before and after impact with high precision and less reliability on ground-based telescopes.

3) The mission period is acceptable.

Characteristics: 1) The flight path needs to take into account both the impactor and the observer with high difficulty design.

2) Higher velocity increment demand and slightly lower impact velocity.

V. Impact Mission Analysis

2. Impact Mode Analysis

No.	Mission	Speed Increment	Impact speed	Mission Period	Evaluation	Precision	Implementation	Innovativeness
1	Impact+Flyby	0.96km/s	8km/s	12 Months	Ground	Low	Good	Weak Same as Deep Impact mission
2	Impact + Flyby + Accompanying	2.67km/s	8km/s	51 months	Ground	Low	Worse	Weak Same as "DART+HERA" mission
3	Accompanying+ Impact +Accompanying	4.1km/s	6km/s	22 months	Sky + Ground	High	Good	Strong First International evaluation with Chinese characteristics

After comparation, the mission form of **"Accompanying flight + Impact + Accompanying flight"** can realize "kinetic impact + space-based assessment" at one time**,** with proper mission period, rich assessment means and high assessment precision.

The "Accompanying Flight + Impact + Accompanying Flight" scenario could be available for first asteroid defense mission.

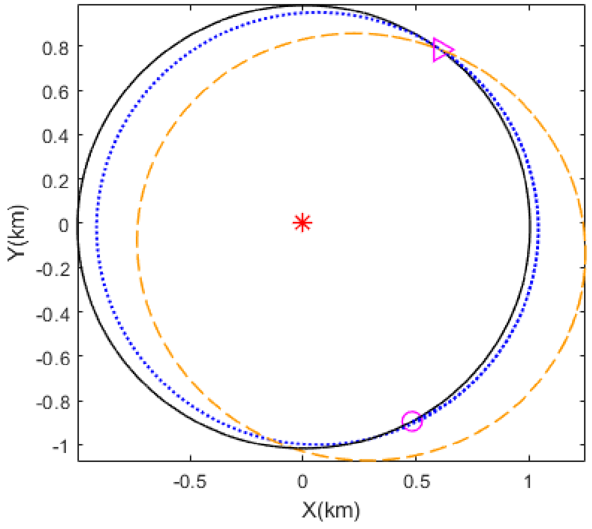
3. Impact Velocity Analysis

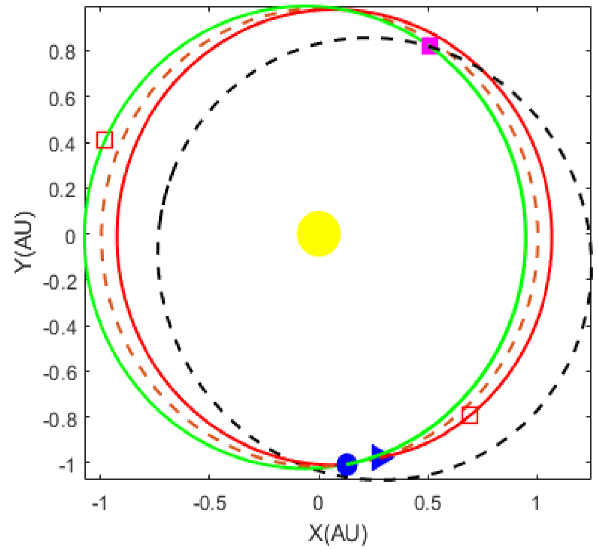
Compared to **"direct transfer"** , the **"gravity assist"** approach allows for **higher impact velocities**, **slightly higher velocity increment requirements**, and over **12-month** impact time, resulting in a 12-month longer task period.

No.	Flight mode	Speed Incremental	Impact speed	Moment of Impact	Task Period
1	Direct Transfer	4.1km/s	6.4km/s	2026-11-11	22 months
2	Gravity Assist	4.3km/s	10km/s	2027-11-15	34 months

According to the analysis, impact velocity of 6.4 km/s can cause an orbital deflection of about 2000km in 6 months for asteroid, which is sufficient for effective evaluation; impact velocity up to 10 km/s will not benefit the enhancement to the mission implementation while increases the uncertainty.

"Direct Transfer" **could be the flight mode for the first Near-Earth Asteroid Defense Demonstration (NEADD) mission.**





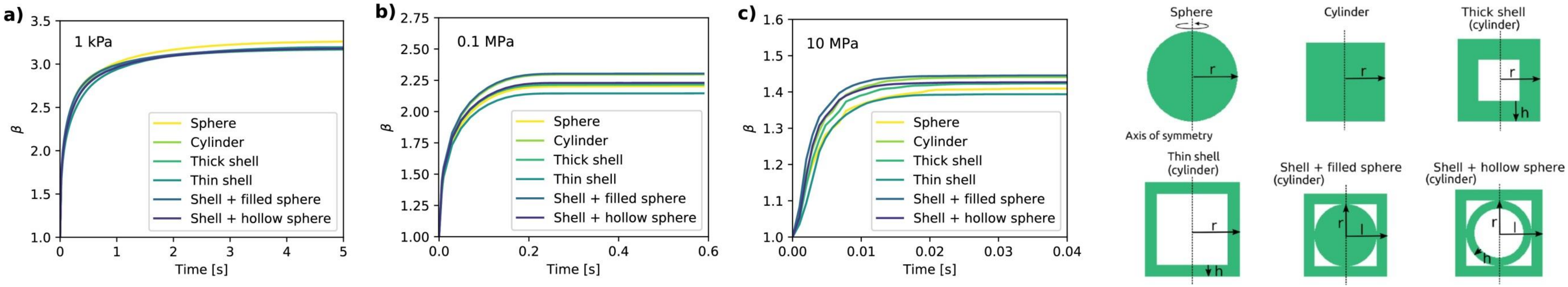
4. Impact Shape Analysis

The impact of momentum gain factor β

For target asteroids with **weak cohesive strength** (＜1kPa), momentum enhancement factor of the sphere impactor is **2%** ＞ other shapes.

For target asteroids with **large cohesive strength** (≥0.1 MPa, the larger the cohesive strength the closer to the monolith), the cylinder impactor is one of the shapes with the optimal momentum gain factor, outperforming other shapes such as spherical by about **3% to 6%**.

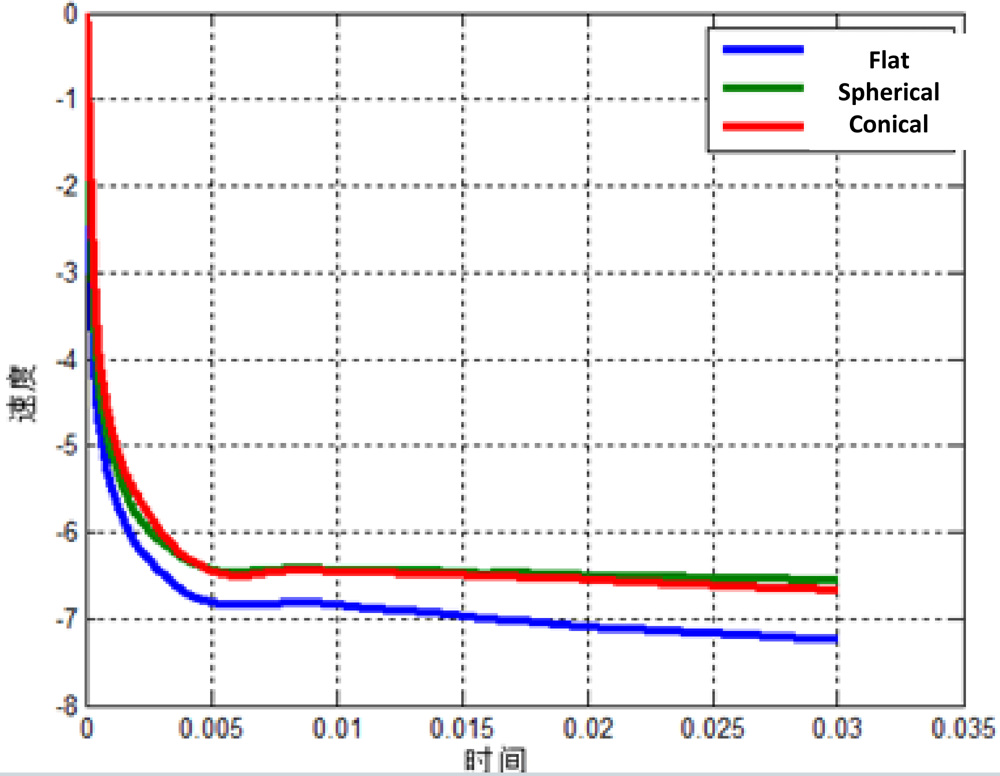
Due to simulation uncertainty, **the impactor shape has little effect on the momentum gain factor .**

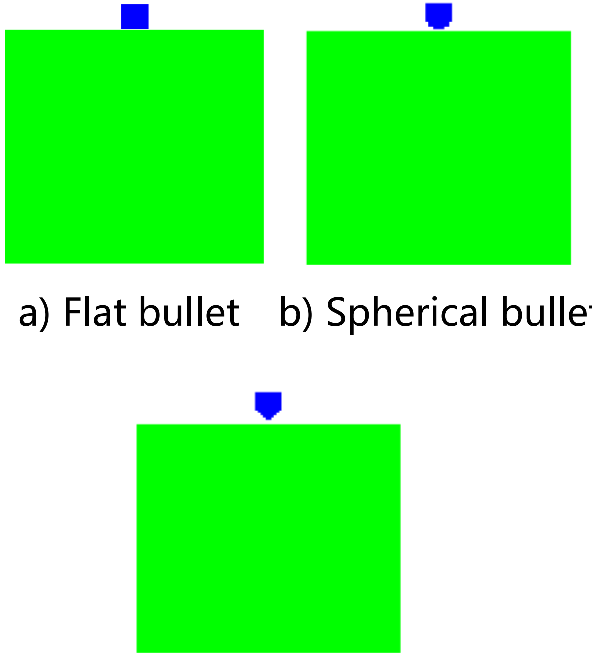


4. Impact Shape Analysis

Effect on asteroid velocity variation

The flat, spherical, and conical bullets are close to the velocity change in the impact direction with **deviations within 10%,** and slightly higher for the **flat bullet**. Considering the simulation uncertainty, **the impactor shape has little effect on the asteroid velocity change.**





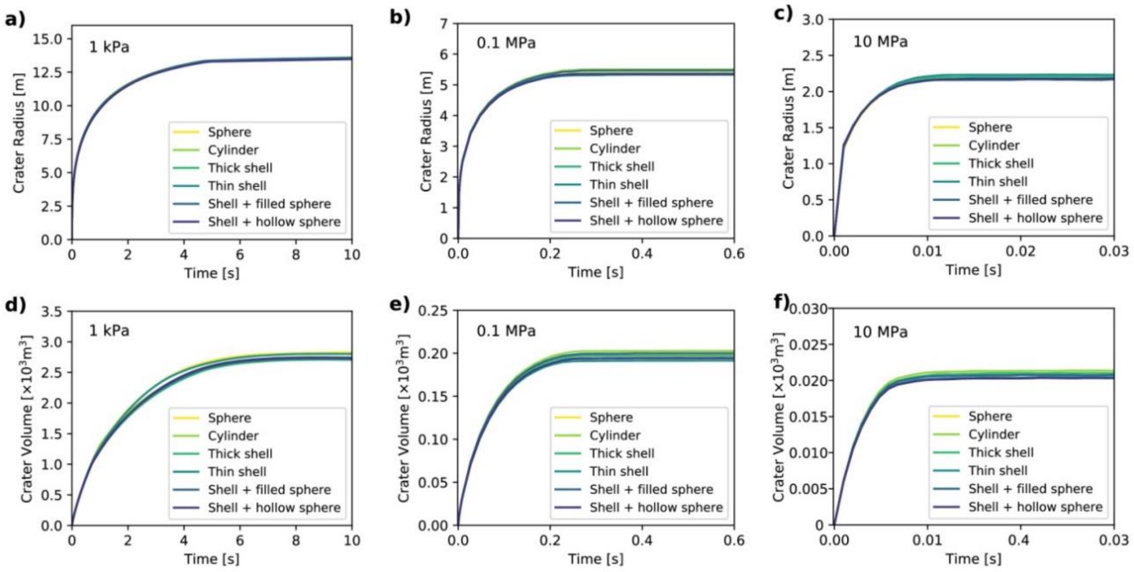
a) Flat bullet b) Spherical bullet

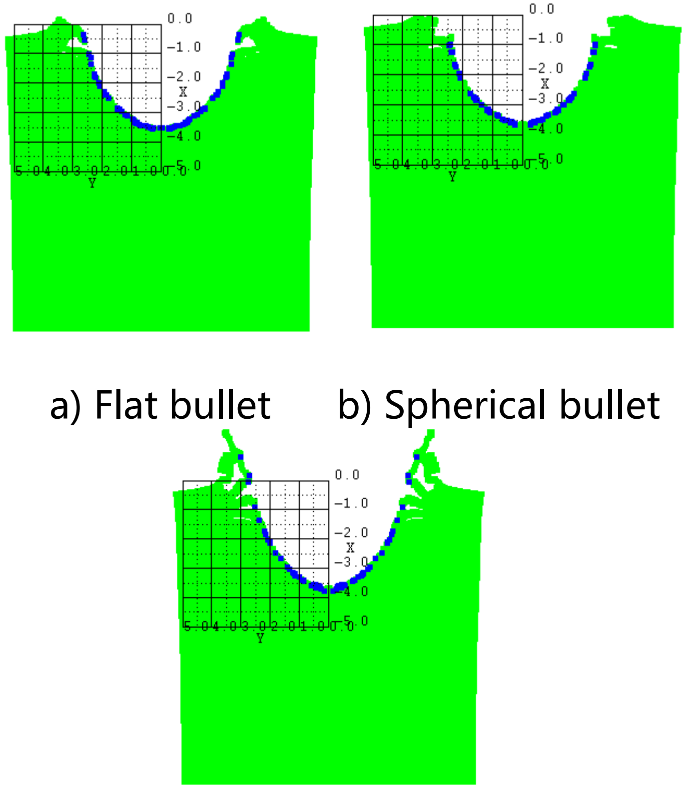
c) Conical bullet

4. Impact Shape Analysis

Effect on impact crater formation

Impact craters are all typical impact craters with a near bowl shape. Its radius and volume are slightly affected by impactor shape. The impact crater by flat bullet is shallowest, followed by the **spherical type,** and **conical type is deepest**, with **deviations less than 5%.**





a) Flat bullet b) Spherical bullet

c) Conical bullet

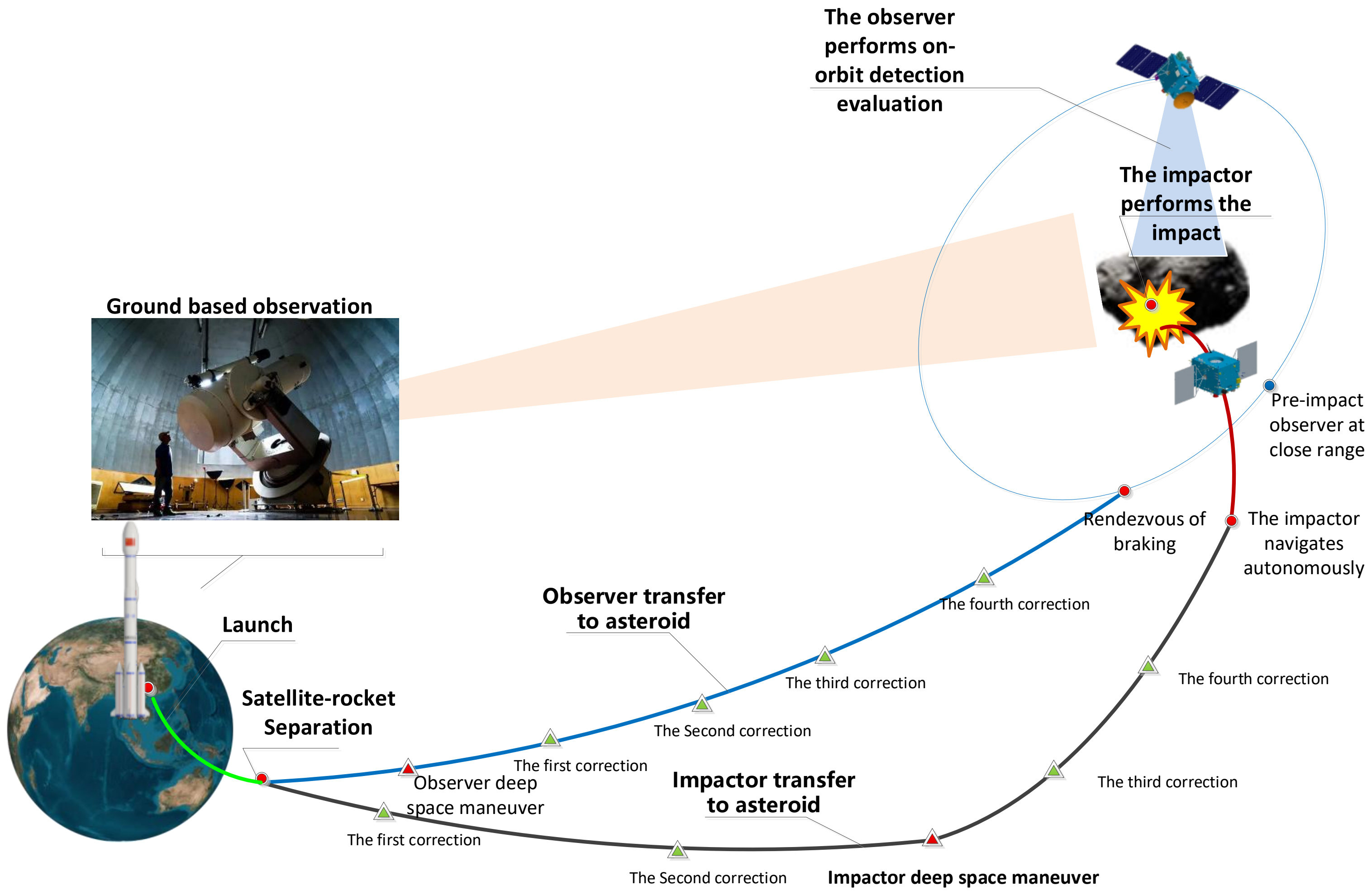
Due to simulation uncertainty, shape is not the main factor on evaluating impact effectiveness.

5. Impact Influence Analysis

Influence factors on impact efficiency mainly includes basic parameters of the asteroid, material parameters, structure and topography.

No.	Parameter	Specific parameters	Payload Configuration
1	Basic parameters of asteroids	scale, shape, density, mass, surface gravitational acceleration	Mid-field color camera Spectral and Laser 3D Probe
2	Asteroid material parameters	porosity, cohesive strength, internal friction coefficient	Dust and particle analyzer Spectral and Laser 3D Probe Detection Radar
3	Asteroid structure	monolithic / rubble mound structure / layered structure	Mid-field color camera Detection Radar
4	Asteroid topography	impact area topography, rock abundance, surface slope	Mid-field color camera Spectral and Laser 3D Probe

VI. Mission Profile



Flight Phase

① Launch

② Observer transfer to asteroid

③ Impactor transfer to asteroid

④ Observer approach to asteroid

⑤ Observer-asteroid rendezvous

⑥ Observer proximity exploration asteroid

⑦ Impactor approach to asteroid

⑧ Impactor approximate to asteroid

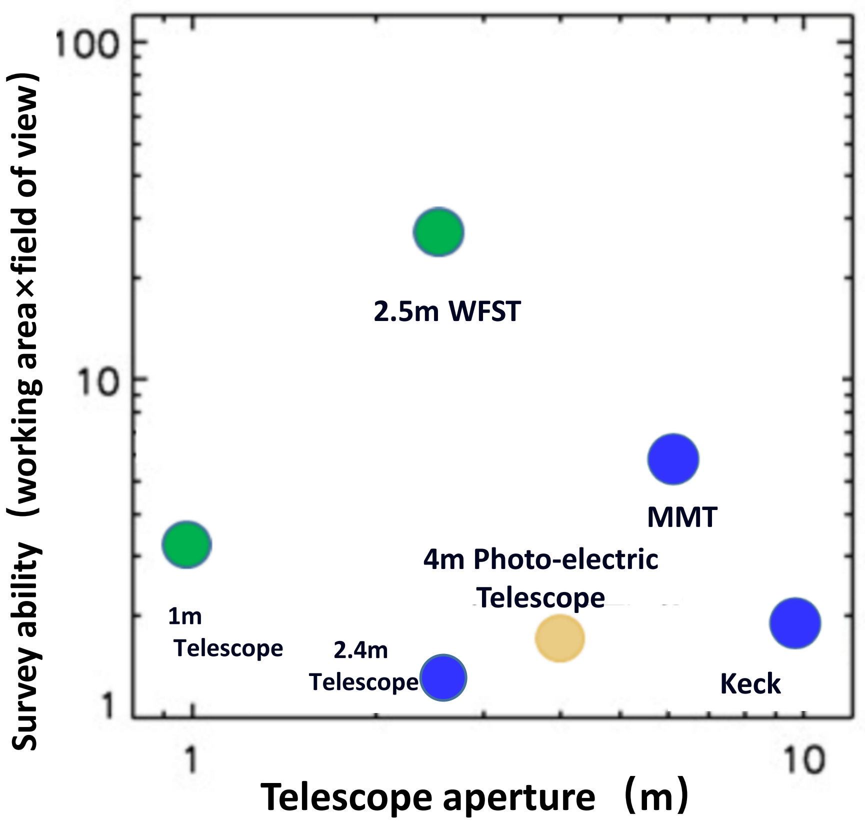
⑨ Impactor impact on asteroid

⑩ Evaluation after impact

VI. Mission Profile

Target asteroid 2019VL5, an annual observation window within in October-November

- In October-November 2022, observation via telescope is better than 1-meter class.
- In October-November 2023 and 2024, observations via 1-meter and 2-meter class telescopes, respectively.
- In October-November 2025, 2026, and 2027, observations via Cold Lake 2.5-meter Large Field Survey Telescope WFST (Deep Space Exploration Laboratory), the Moustakas 4-meter Photo-electric Telescope, and the CSST space telescope.
- October-November 2028, observations with foreign telescopes.

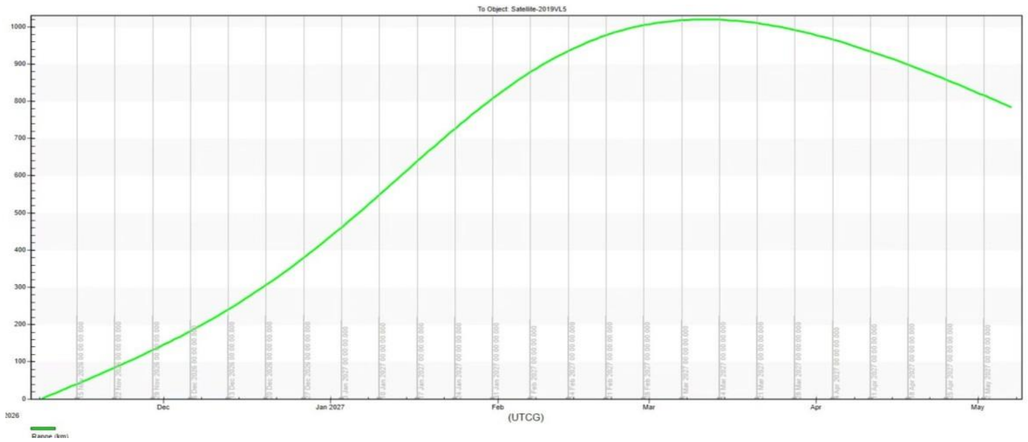


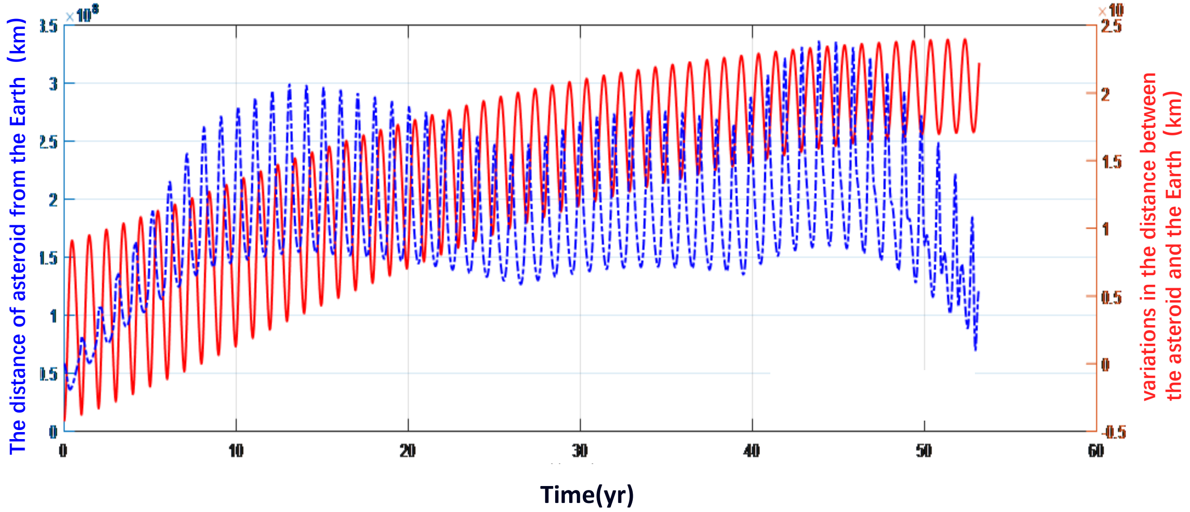
VII. Impact Effect Evaluation

1. Impact Effect Prediction

Evaluation on impact the asteroid 2019VL5 is based on the elastic collision model analysis, with relative impact velocity of 6.4 km/s and velocity increment of the asteroid after impact more than 5 cm/s.

The relative distance between the asteroid and the Earth after the impact will increase gradually. According to calculation, the maximum relative distance is up to 1800 km in 180 days.





VII. Impact Effect Evaluation

2. Evaluation Scheme

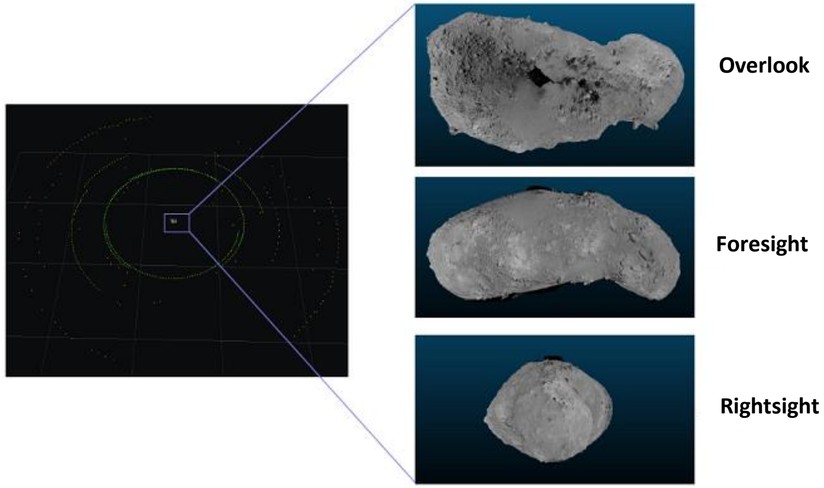
The impact effect evaluation mainly includes orbit evolution evaluation, topography change evaluation, and sputtering observation evaluation.

Orbit evolution evaluation: by applying ground-based and space-based observation facilities to carry out collaborative measurements, fusing measurement and control data as well as observation data of ground-based monitoring facilities both before and after impact， to carry out precise orbit prediction of target asteroid.

2. Evaluation Scheme

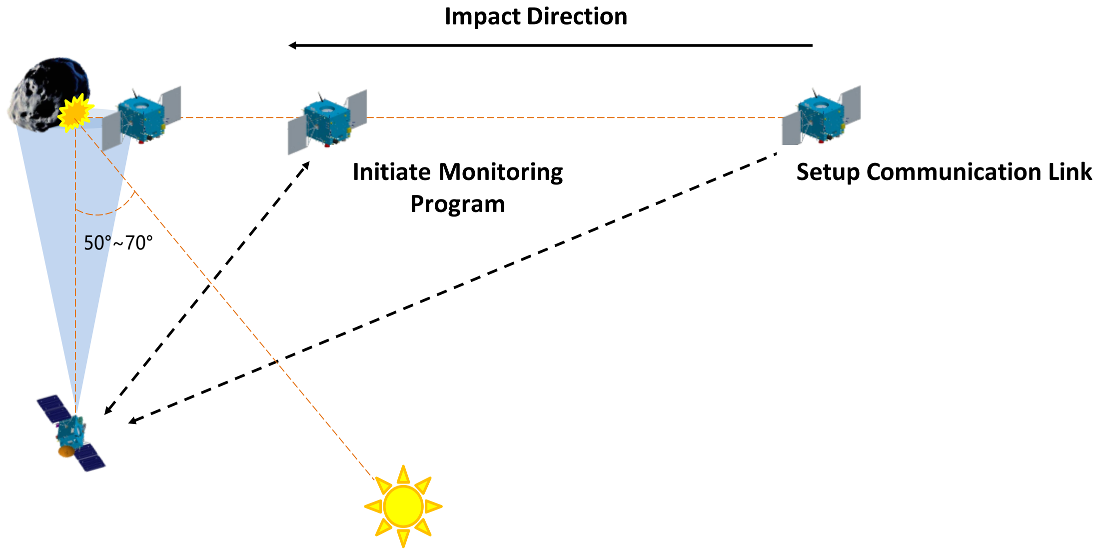
Topography change evaluation:

Hovering detection is applied to obtain a global 3D model with expected resolution and elevation accuracy of cm level.



Sputtering observation evaluation:

taken by high-resolution camera on observer at 30km orbit perpendicular to observe sputtering objective (maximum velocity 50m/s) .



Conclusion

NEA defense concerns the common destiny of all mankind. China is actively taking the first step to setup an asteroid defense system.

It is welcomed of all nations to participate in this program. We are open for opportunities on multifaceted international cooperation.

Thank you!

Deep Space Exploration Laboratory

November 23, 2022