Research on Space-based Kinetic Impactor Destroying Small-sized Asteroids under Short Warning Time Conditions

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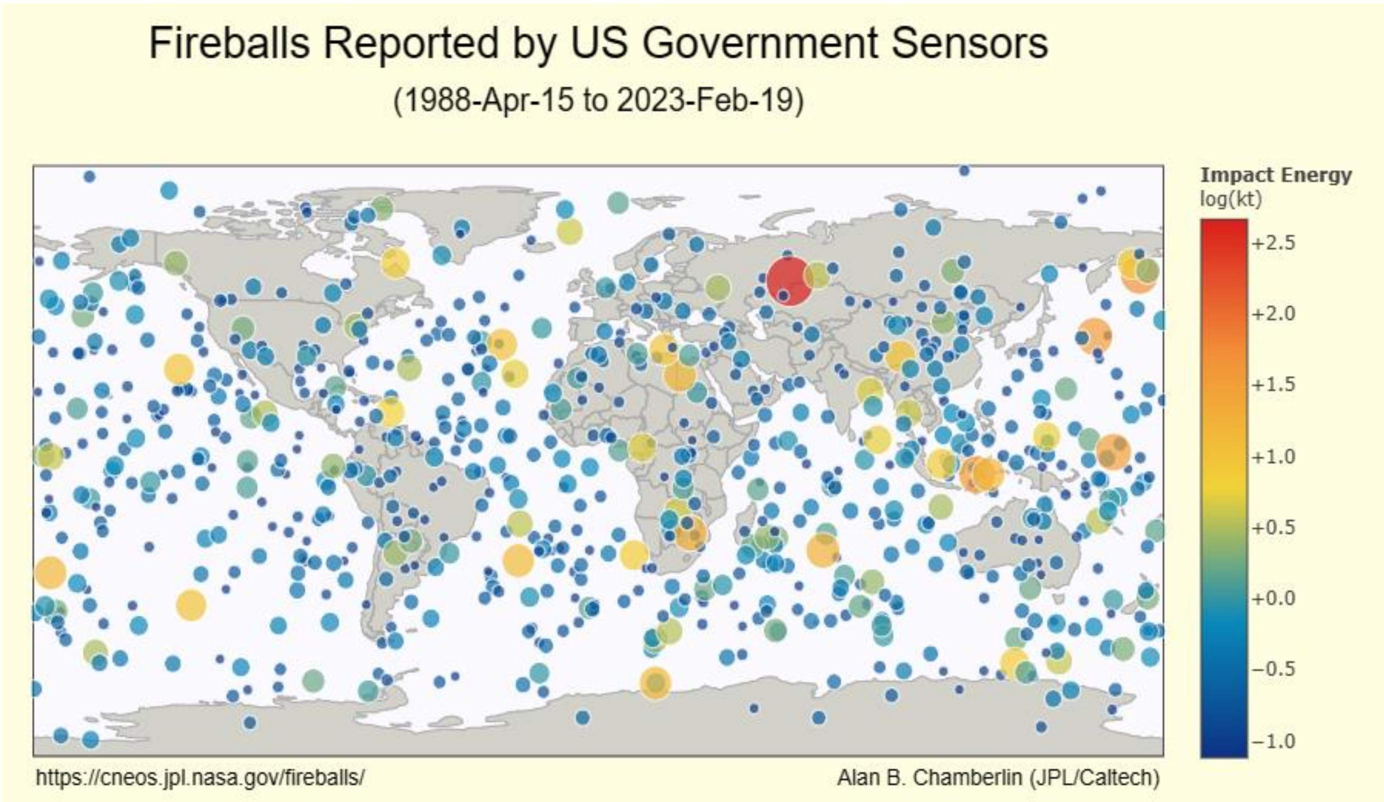
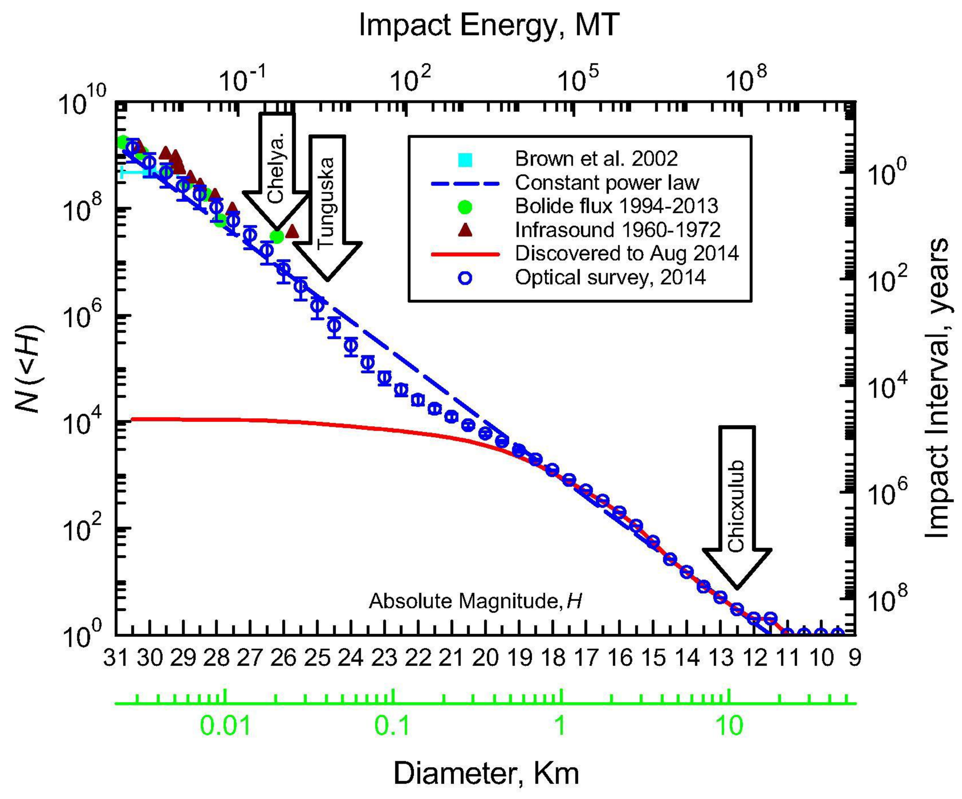
Characteristics of small-sized asteroid impacts on Earth





There are more small-sized asteroids;
a larger proportion of them are uncatalogued;
small-sized asteroid impacts may be more frequent;
currently, most asteroid defense research focuses on celestial bodies of 140 meters in size, with little research on the defense of asteroids below 50 meters in size.

The warning time is less than 2 years
Impacting the Earth can cause a Chelyabinsk-level disaster
Nuclear explosion: prone to security issues
Kinetic Impact: can effectively defend, but it takes a long time
Kinetic destruction - effectively addressing the problem of short warning time for small-sized asteroids.

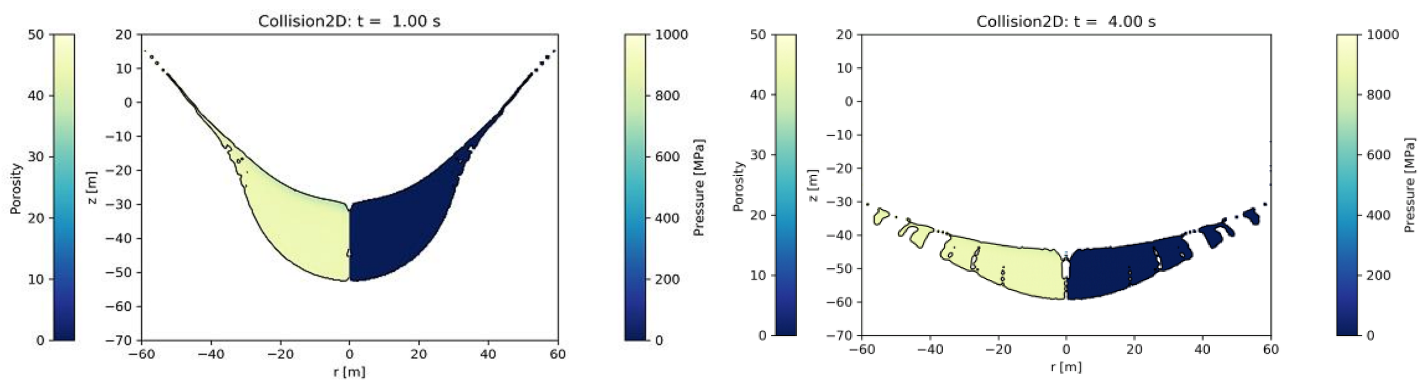
Only seven asteroid impact events (fire meteor events) have been successfully warned before they impact the Earth
The most recent impact warning: 13 February 2023, an asteroid was discovered only a few hours before impact

Conditions of destruction

iSALE is an impact dynamics code jointly developed by Imperial College London and the Berlin Leibniz Institute based on the SALE.

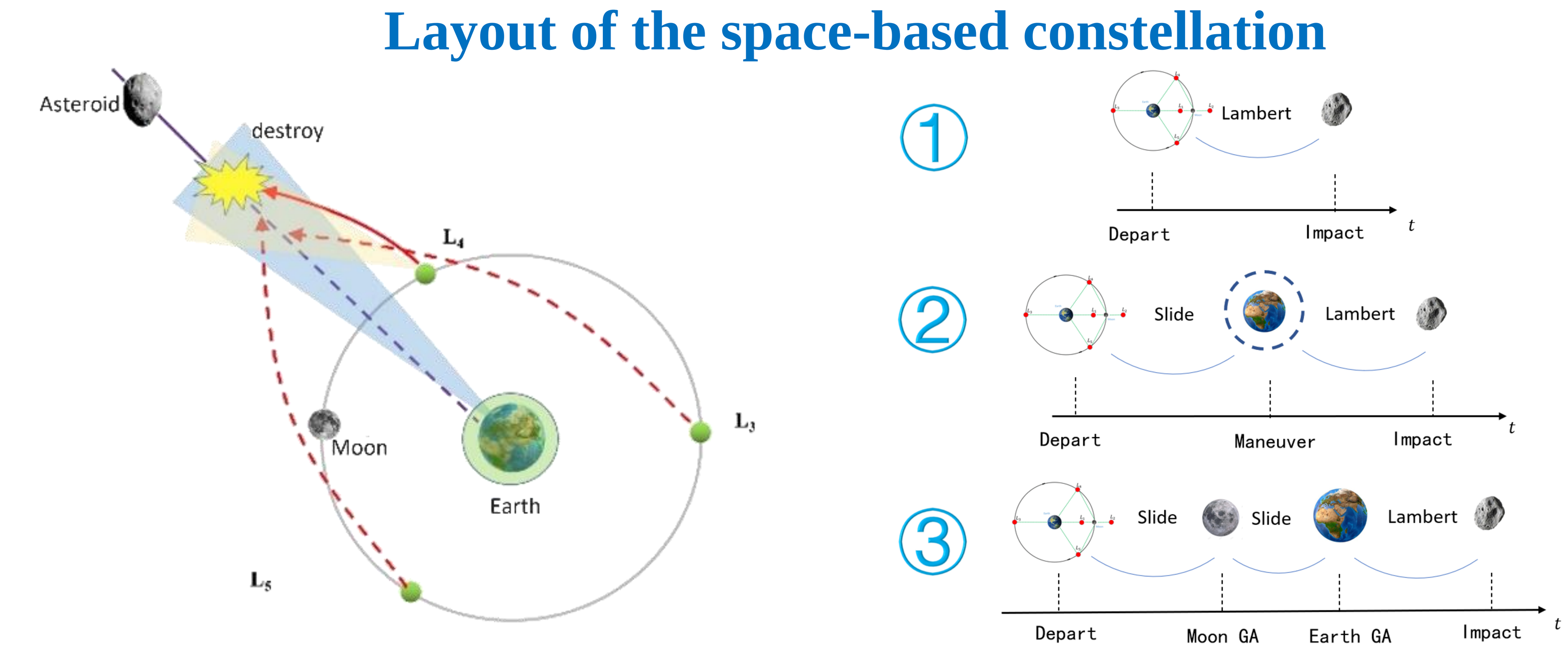
Grid type: ALE

Features : 2D+3D, Finite Difference Method, Allowing material rheology, The strength/damage model usually used is the yield stress-deviatoric strain damage model based on Collins et al. (2004), Porosity: ε-α porosity model.



A 2t impactor, impacting an S-type asteroid with a diameter of about 50 meters and a porosity of 45% at a speed of 7km/s, can destroy it.

Layout of the space-based constellation

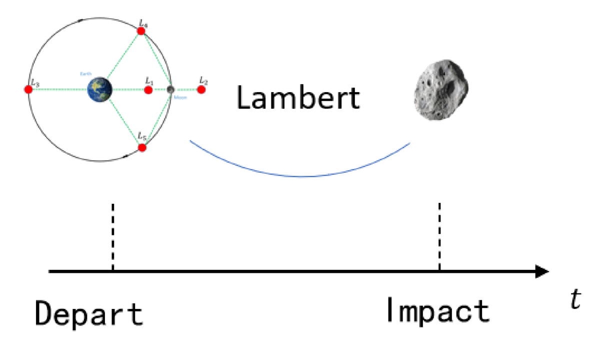


Advantages: Quickly intercept asteroids from all directions and can take into account monitoring and early warning.

$$\frac{d^2\boldsymbol{r}}{dt^2} = -\frac{\mu_s}{|\boldsymbol{r}|^3}\boldsymbol{r} - \sum_{i=1}^{8}\mu_{pi}\left(\frac{1}{|\boldsymbol{r}_{pi}|^3}\boldsymbol{r}_{pi} + \frac{1}{|\boldsymbol{\rho}_{pi}|^3}\boldsymbol{\rho}_{pi}\right) + \boldsymbol{a}_{moon} + \boldsymbol{a}_{GR}$$

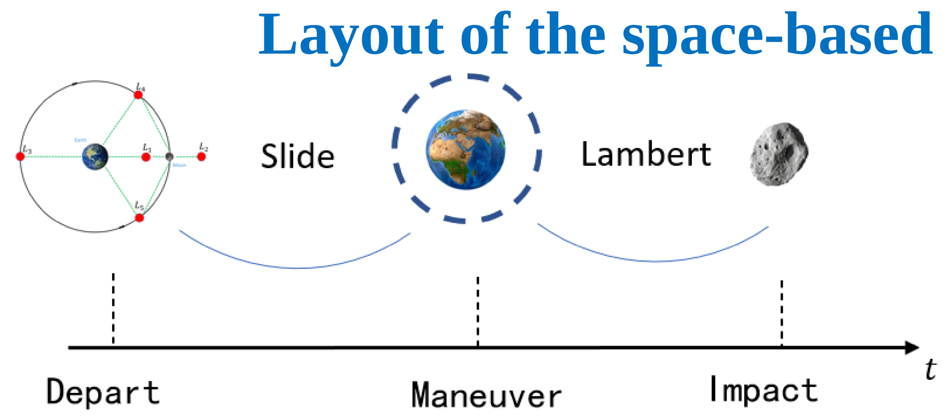
Dynamic Model: Central body, Third body, Relativistic effects

Layout of the space-based constellation——Trajectory design



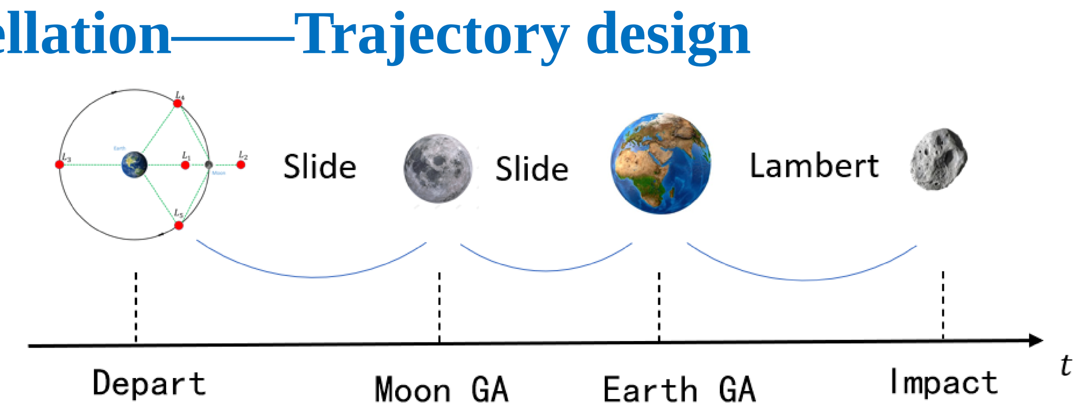
$$\vec{X} = [jd_{depart}, jd_{impact}]$$
$$maxmize\ J(\vec{X}) = r_{Crater}$$
$$subject\ to\ dv < 1.2km/s,\ dis_{impact} > 1.5e6km$$

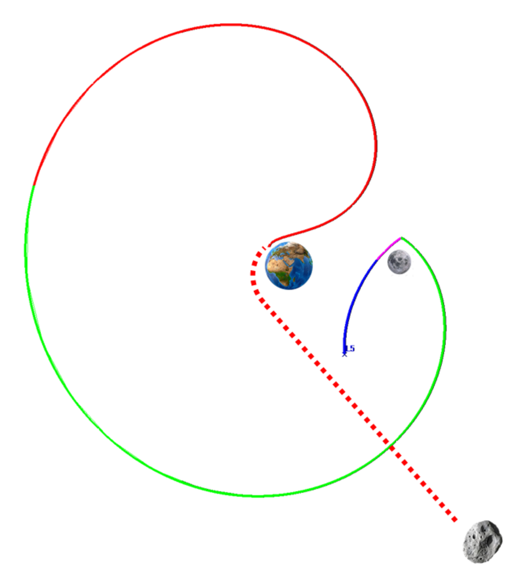
Asteroid	2003 RU11
Diameter	27.26m
Date CA	2034 9 17
Distance CA	3.8 E_M distance
Depart Date	2034 7 27
Impact Date	2034 9 5
Trans Days	40 days
dv	1.04 km/s
Impact v	5.80 km/s
Impact mass	714 kg



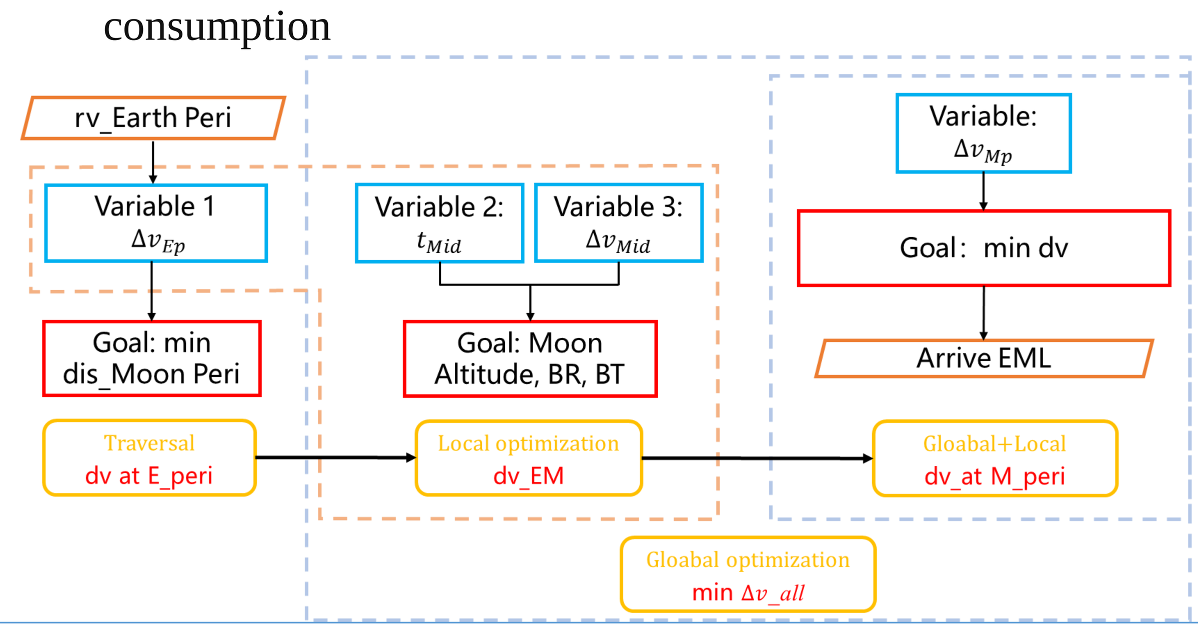
$$\vec{X} = [jd_{depart}, trans_{2ESOI}, RA_{ESOI}, DE_{ESOI}, jd_{impact}]$$
$$maxmize\ J(\vec{X}) = r_{Crater}$$
$$subject\ to\ dv < 1.2km/s,\ dis_{impact} > 1.5e6km$$

Asteroid	2020 UC4
Diameter	20.78m
Date CA	2033 6 17
Distance CA	2.36 E_M distance
Depart Date	2031 10 27
Impact Date	2032 7 20
Trans Days	268 days
dv	0.52 km/s
Impact v	9.04 km/s
Impact mass	846 kg





Advantages: By using the gravity assist of the Earth and Moon to change the orbital energy, the defense range can be expanded
The combination of Earth gravity assist + Moon gravity assist + long-distance transfer mode can effectively reduce fuel consumption



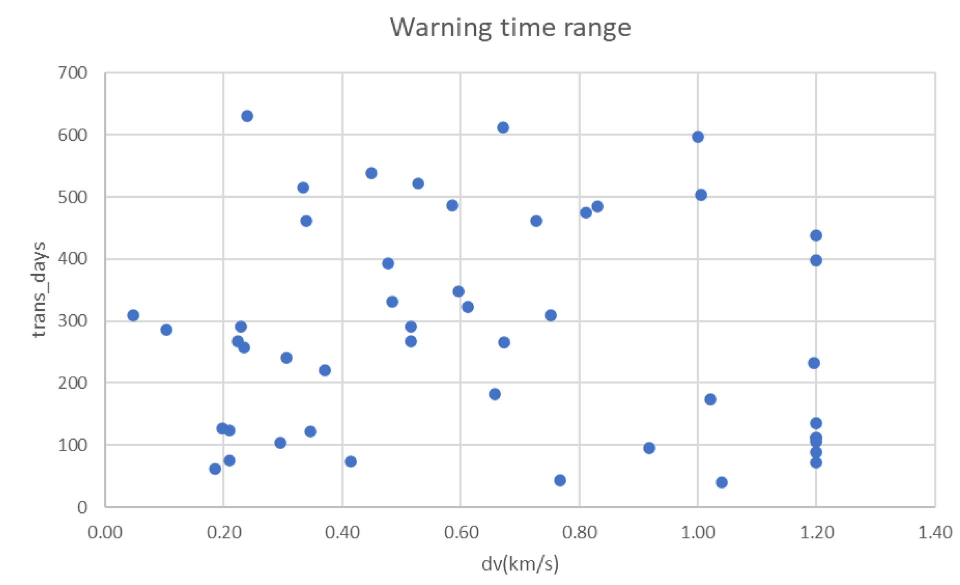
小行星	2021 RO16
直径	16.88m
近地日期	2034 4 22
近地距离	1.94 E_M distance
Depart Date	2031 12 12
Moon Ga Date	2031 12 28
Earth Ga Date	2032 1 9
Impact Date	2034 4 15
dv	1.03 km/s
Impact v	7.09 km/s
Impact mass	710 kg

Analysis of defensive effects

Asteroid	Diameter	cal_CA	distance
2020 GB1	14.30	2035 4 7 16	1.35
2020 GY1	16.42	2033 4 5 5	2.45
2021 RO16	16.88	2034 4 22 4	1.94
2020 KQ4	17.20	2031 5 24 7	3.77
2016 JA6	18.86	2031 11 6 3	2.84
2014 XC8	18.86	2034 5 24 15	3.55
2004 DF2	20.68	2032 4 22 21	3.25
2020 DK	21.06	2032 2 9 14	3.74
2020 UC4	20.77	2033 6 17 20	2.36
2022 CO6	21.16	2033 2 15 12	3.22
2011 AH5	21.65	2031 7 20 19	3.90
2008 DB	23.74	2032 8 14 14	0.33
2016 DY21	23.74	2035 2 17 20	4.19
2014 YN	24.86	2030 11 11 6	3.38
2020 UE	26.76	2034 10 15 14	2.95
2003 RU11	27.26	2034 9 17 14	3.80
2022 SW	32.17	2035 9 16 2	4.25
2018 VB7	32.77	2032 10 31 20	3.40
2019 WG2	37.63	2032 11 22 6	2.75
2022 QX4	39.58	2031 9 7 5	3.67
2020 TJ3	41.26	2035 5 3 12	3.88

Select 21 asteroids as simulation targets based on the following criteria:

· real asteroids
· with a diameter of 15-50m
· Flyby Earth between 2031 and 2035
· flyby at a distance less than 5 times the Earth-Moon distance.



The impact can be completed within two years, with a minimum transfer time of 40 days and a maximum of no more than 630 days. The impact locations are all outside the Earth's Sphere of Influence. The average velocity increment is 0.6km/s. The maximum velocity increment does not exceed 1.2km/s. All asteroids can be destroyed.

Sequence 1	All
Sequence 2	2020KQ4, 2020DK, 2020UC4, 2014YN, 2022SW, 2022QX4, 2020TJ3 (7 NEOS)

	dv limit	warning time	impactable asteroids	positive deflections	disruption	effective disposal	average dv
21 Asteroids	1.2km/s	2years	21	4	21	21	608.95m/s

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