Gravity assist maneuvers as a tool for asteroid resources use

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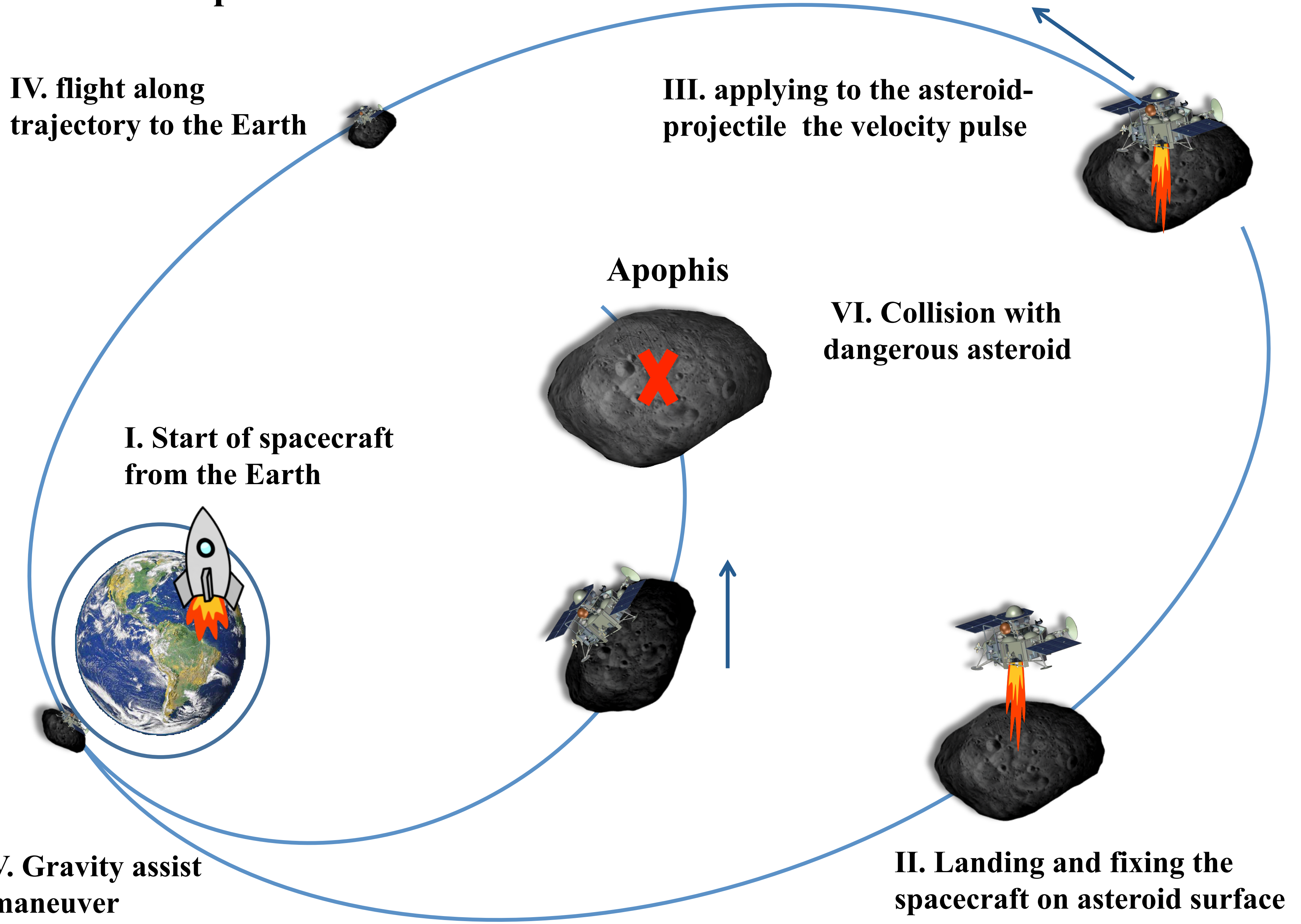
The main ideas

The first idea consists of targeting a very small asteroid to impact a larger dangerous one. The minimum size of this small asteroid is determined by the ability to detect it and to determine its orbit. The small object may have a diameter of about 10 -15 meters. Asteroids are selected from the near-Earth class that have a fly-by distance from Earth of the order of hundreds of thousands of kilometers. According to current estimates, the number of near Earth asteroids with such sizes is high enough. So there is a possibility to find the required small asteroid. Further, the possibility is evaluated of changing the small asteroid’s orbit so that by application of a very limited delta-V impulse to the asteroid, the latter is transferred to a gravity assist maneuver (Earth swingby) that puts it on a collision course with a dangerous asteroid. It is obvious that in order to apply the required ΔV pulse it is necessary to install on the small asteroid an appropriate propulsion system with required propellant mass.

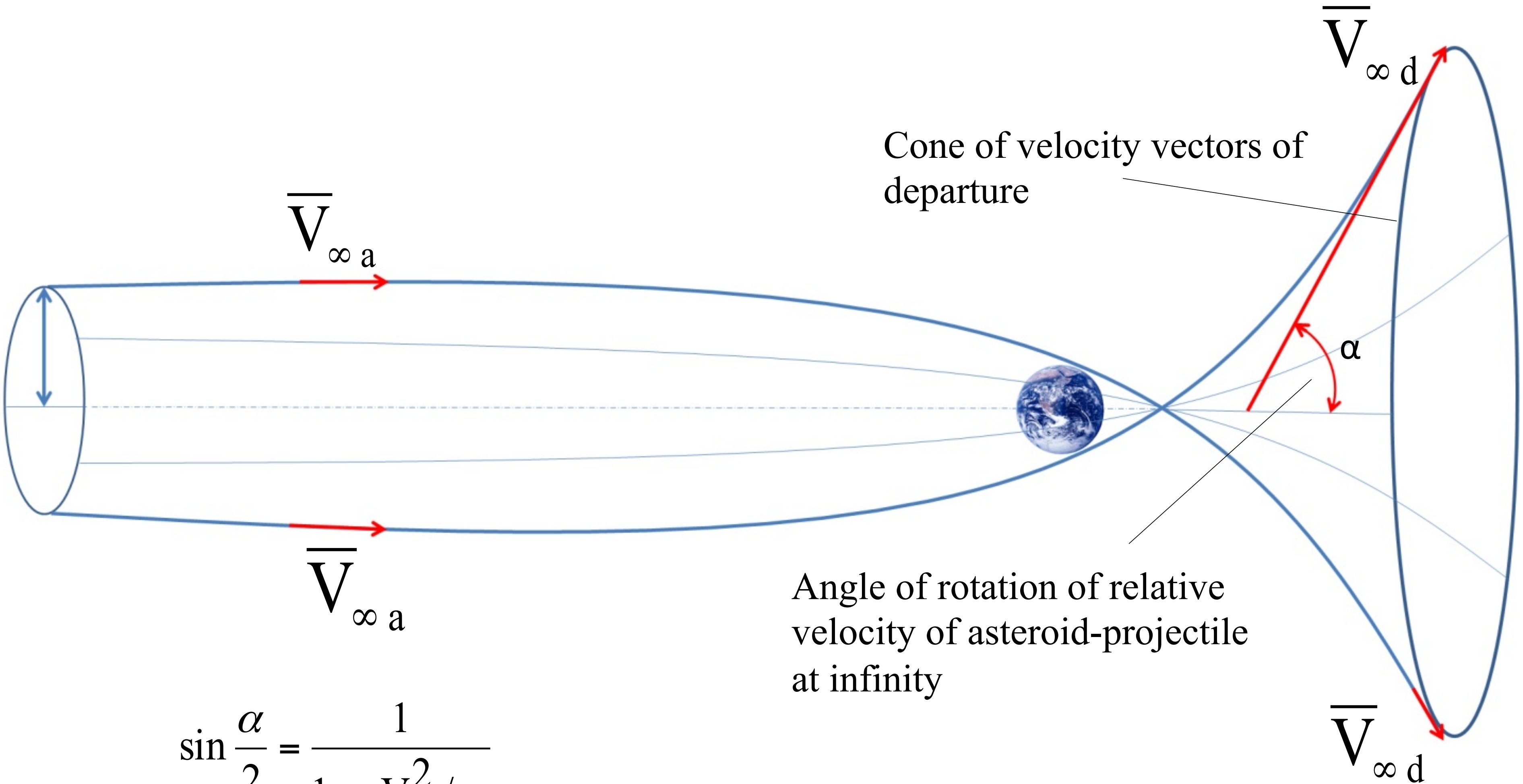
The second idea is to transfer the asteroid onto orbit which is synchronous with Earth orbit using described gravity assist maneuver. In this case it is possible to receive close approach of the asteroid to the Earth each year or even each half of a year. It gives unique possibilities for exploration of the asteroid including manned missions.

Also it allows to keep the possibility to use this asteroid for interception of dangerous near Earth sky object

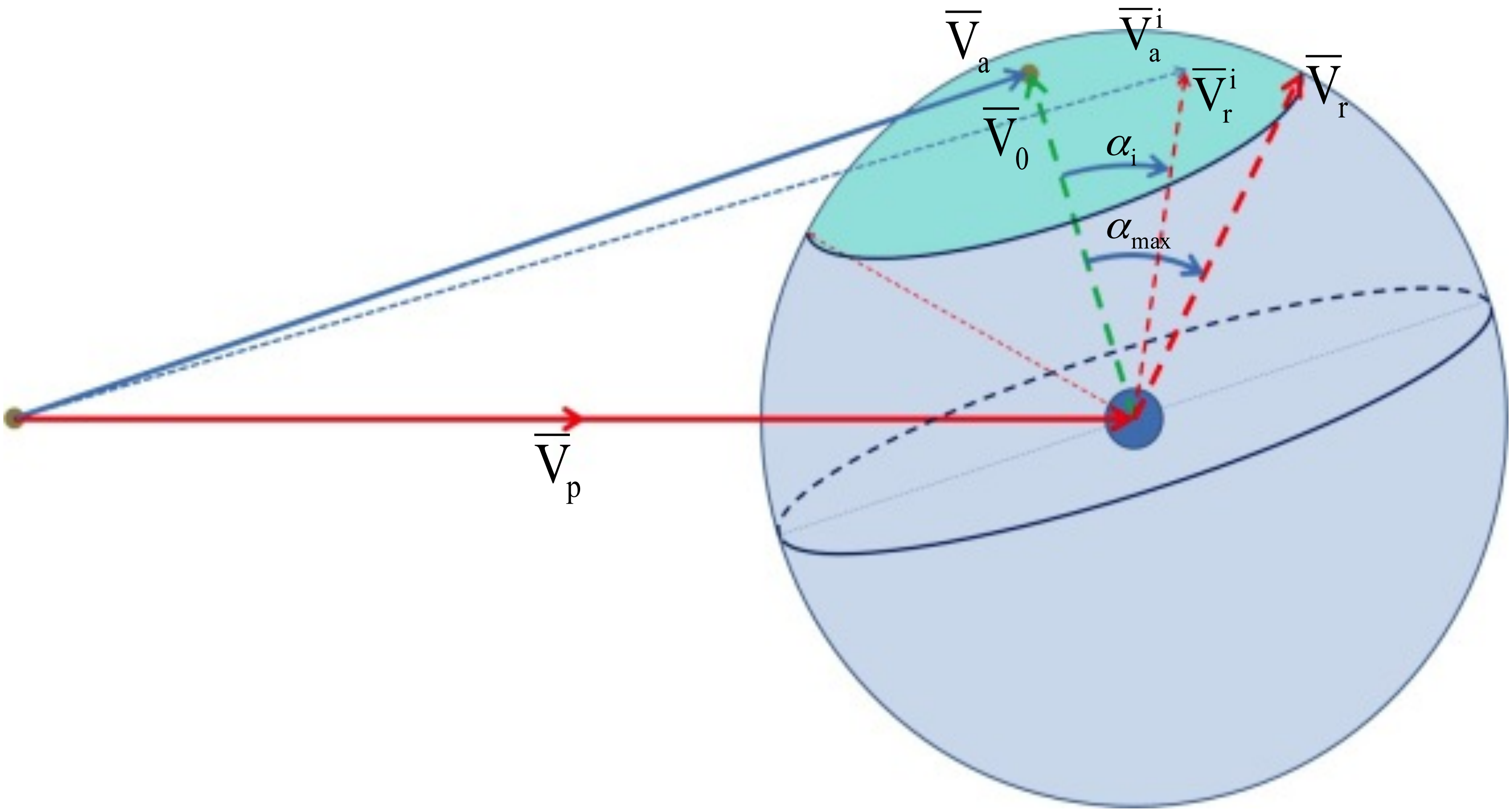
The basic concept



Cylinder of possible vectors of relative velocities at arrival and resulted after fly-by cone of velocity vectors of departure



$$\sin\frac{\alpha}{2} = \frac{1}{1 + rV^2 / \mu}$$



$\overline{V}_a$
$\overline{V}_a^i$
$\overline{V}_r^i$
$\overline{V}_r$
$\overline{V}_0$
α_i
α_{max}
$\overline{V}_p$

Results of candidate asteroids choose and orbits design

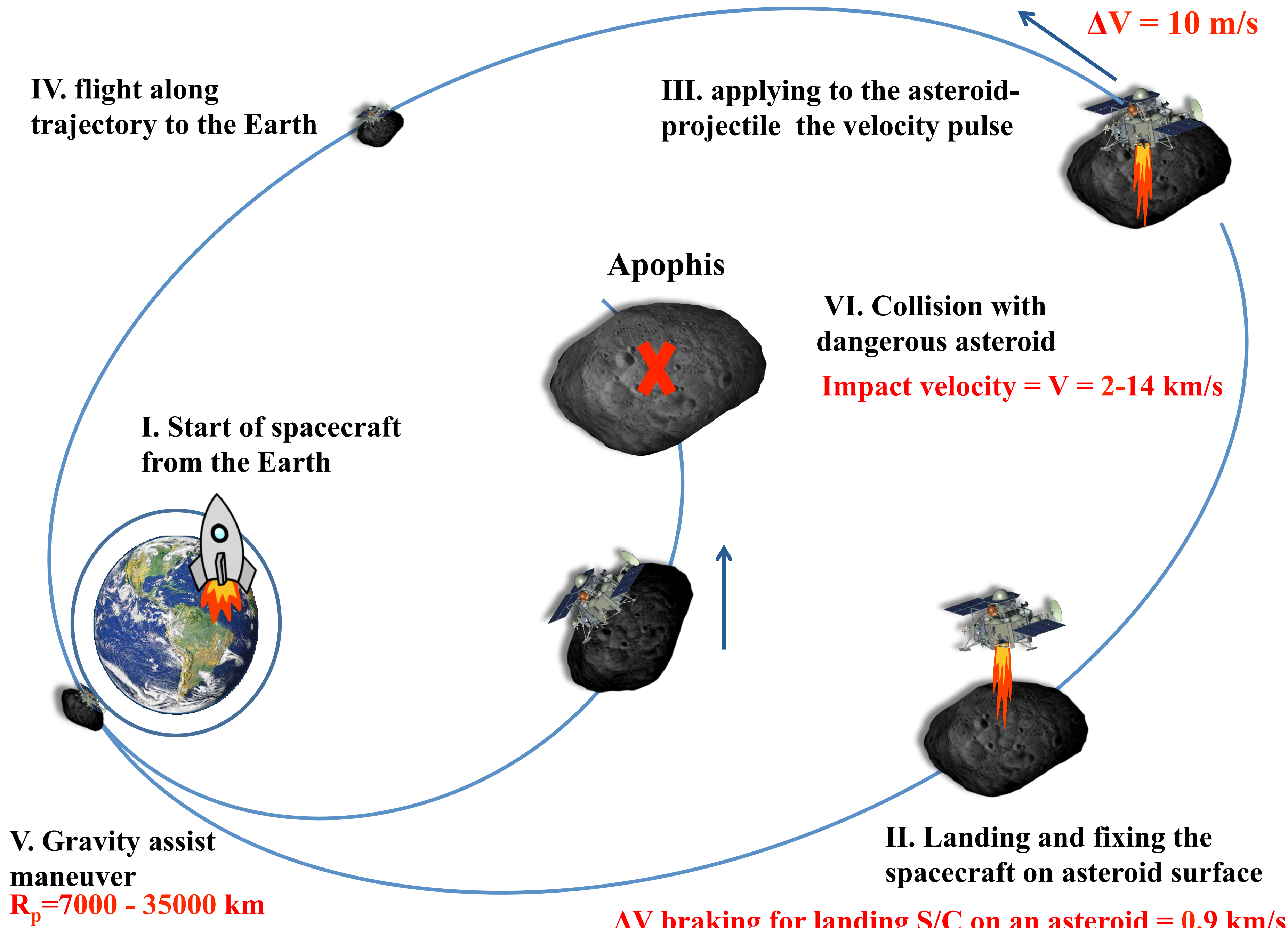
Asteroid	**2006 XV4**	**2006 SU49**	**1997 XF11**	**2011UK10**	**1994 GV**
Delta-V value, m/s	2.38	7.89	10.05	15.94	17.72
Perigee radius, km	16473.19	15873.40	42851.84	31912.94	7427.54
Velocity in perigee with respect to Earth, km/s	9.61	5.03	14.08	8.98	13.37
Angle of the relative to the Earth velocity turn, deg.	23.98	59.78	5.14	21.14	50.85
Date of maneuver execution	2029/03/17	2027/06/11	2027/04/27	2025/09/13	2028/09/12
Date of perigee reaching	2031/12/11	2029/01/23	2028/10/26	2026/10/10	2031/04/13
Date of collision of asteroid-projectile with Apophis	2034/04/08	2029/10/06	2030/08/06	2027/08/06	2031/12/24
Impact velocity with Apophis, km/s	15.3	4.9	11.0	2.3	14.1
Magnitude	24.87	19.54	16.9	24.91	27.46
Size of asteroid-projectile	25 ≈ 60 m	330 ≈ 750 m	1 ≈ 2 km	25 ≈ 60 m	8 ≈ 19 m
V^2 at infinity after s/c launch from near Earth orbit, km^2/s^2	63.1283 (3.7*)	(0.36*)	(6.447*)	47.182 (1.488*)	50.6314 (2.427*)
Delta-V of braking for landing S/C on an asteroid, km/s	0.89 (9.7*)	(4.67*)	(7.89*)	0.543 (5.571*)	0.591 (7.328*)

*for departure delta-V optimization, Red corresponds total Delta-V optimization

Key orbital parameters for transfer mission of the spacecraft to asteroid-projectile

Criterion of optimization $Crio = W_1 C_3 + W_2 \Delta V_a$

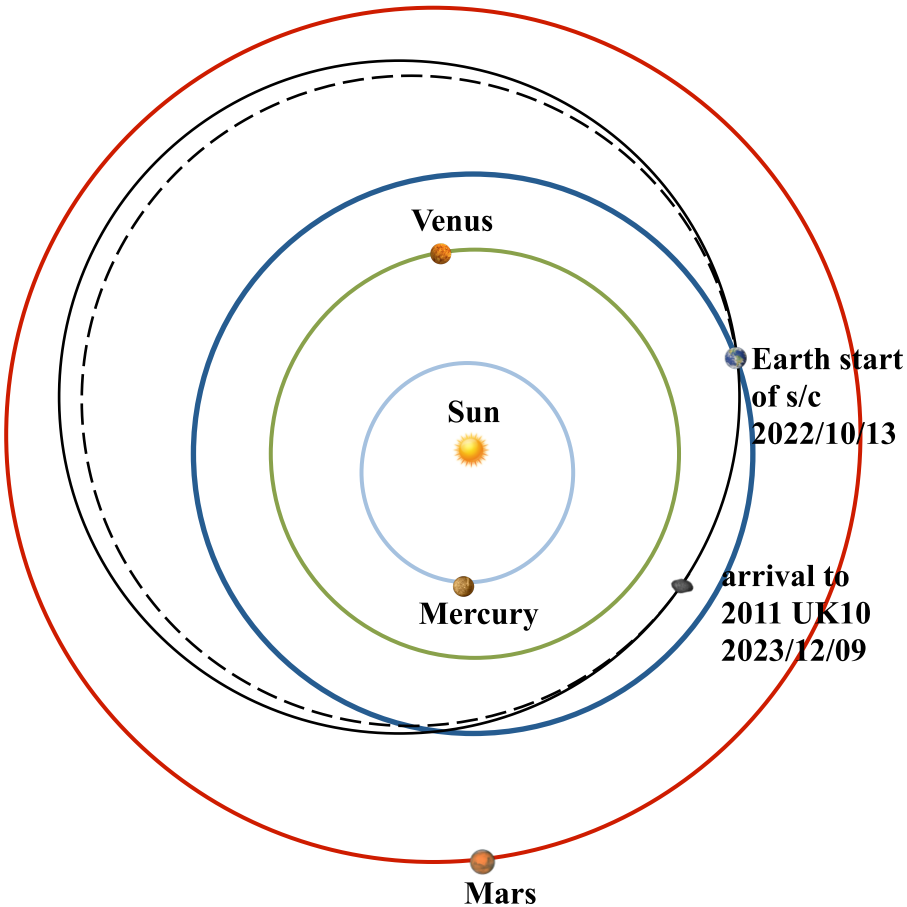
W_2	Optimal time of departure from Earth	Optimal time of arrival to 2011 UK10	C_3, km^2/s^2	ΔV_a, km/s	Duration of transfer days	ΔV_s, km/s	ΔV_t, km/s
1	2021/12/10	2022/08/25	1.4879	5.5709	257.9243	3.302	8.873
2	2021/12/08	2022/08/21	2.023	5.2113	255.1062	3.326	8.537
6	2022/08/20	2023/08/02	6.99	3.4856	346.7858	3.537	7.033
12	2022/08/28	2023/08/08	8.1783	3.3644	345.7742	3.599	6.963
14	2022/09/21	2023/08/18	18.5637	2.5698	330.8983	4.047	6.617
14	2022/10/13	2023/12/10	46.9763	0.55489	422.8127	5.193	5.747
20	2022/10/13	2023/12/09	47.1824	0.54275	422.5234	5.201	5.744
W_2	**Optimal time of departure from Earth**	**Optimal time of arrival to 1994 GV**	**C_3, km^2/s^2**	**ΔV_a, km/s**	**Duration of transfer days**	**ΔV_s, km/s**	**ΔV_t, km/s**
1	2027/04/17	2028/06/07	1.9758	7.3286	416.8176	3.324	10.653
2	2027/03/17	2028/04/22	2.4656	6.86	401.9748	3.346	10.206
6	2027/05/04	2028/05/17	8.3888	5.2059	378.4848	3.609	8.815
7.8	2027/05/04	2028/05/16	8.3904	5.2057	378.4952	3.609	8.815
10	2026/03/17	2028/03/21	30.1283	2.4271	734.6328	4.526	6.954
20	2025/12/03	2028/01/02	50.6314	0.5913	1056.6681	5.333	5.924
W_2	**Optimal time of departure from Earth**	**Optimal time of arrival to 2006 XV4**	**C_3, km^2/s^2**	**ΔV_a, km/s**	**Duration of transfer days**	**ΔV_s, km/s**	**ΔV_t, km/s**
1	01/02/2027	10/03/2027	3.7398	9.7307	273.6634	3.40	13.13
10	12/14/2025	10/03/2027	34.5596	3.5816	658.0781	4.705	8.286
20	11/21/2023	03/28/2027	63.1283	0.89119	1222.5468	5.8	6.69



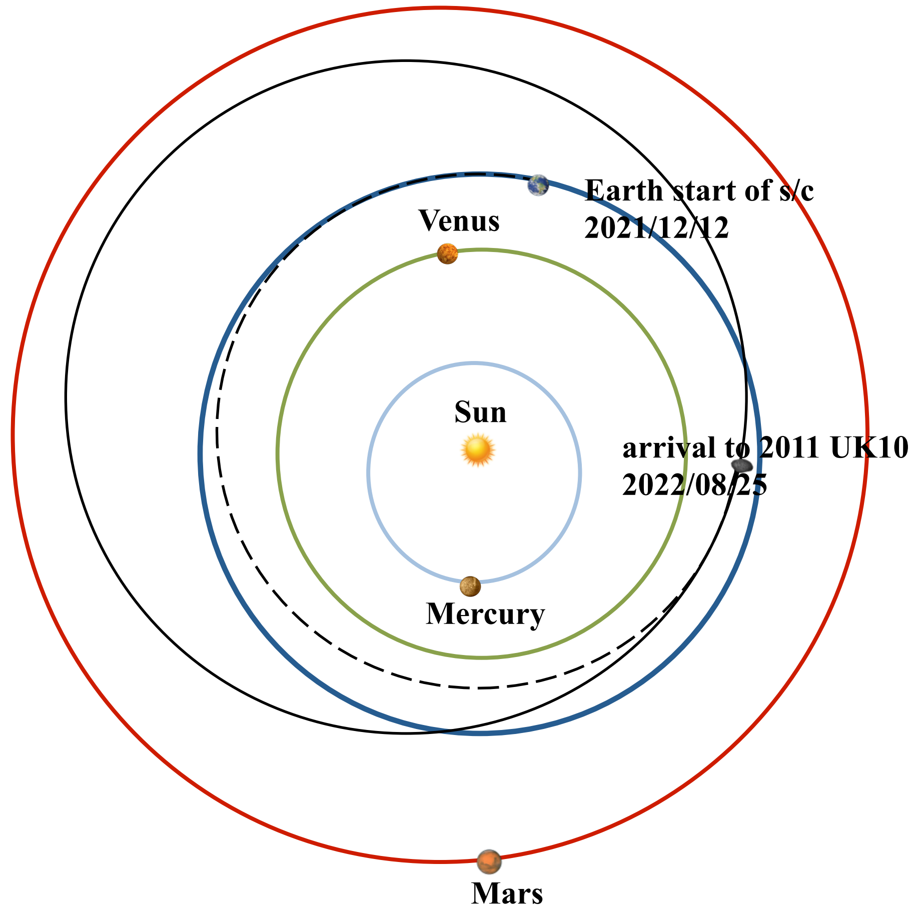
ΔV = 10 m/s
IV. flight along
trajectory to the Earth
III. applying to the asteroid-
projectile the velocity pulse
Apophis
VI. Collision with
dangerous asteroid
Impact velocity = V = 2-14 km/s
I. Start of spacecraft
from the Earth
V. Gravity assist
maneuver
R_p=7000 - 35000 km
II. Landing and fixing the
spacecraft on asteroid surface
ΔV braking for landing S/C on an asteroid = 0.9 km/s

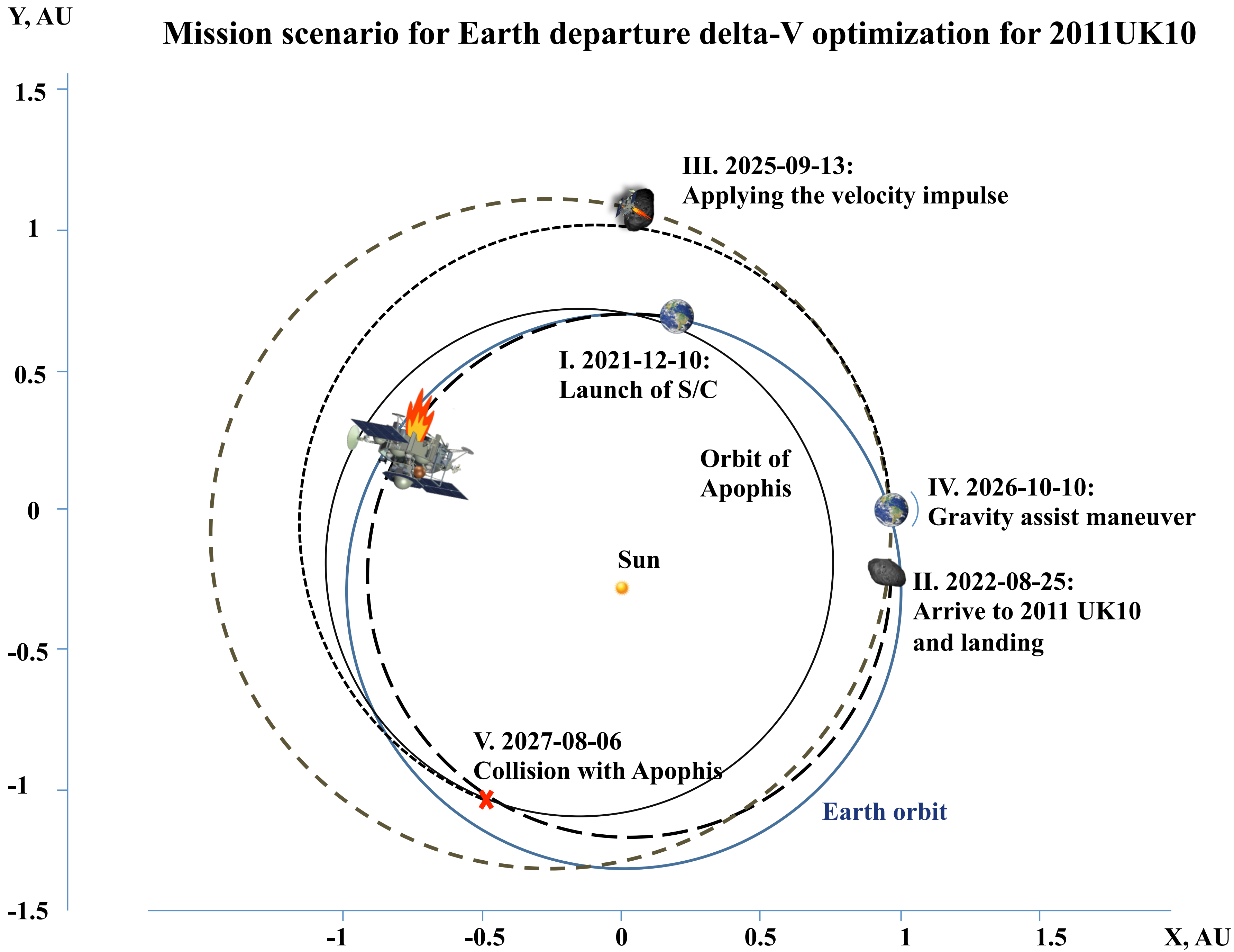
Asteroid 2011 UK 10

a) Optimal transfer trajectory to 2011UK10 asteroid with minimum total delta-V=5.744 km/s, departure delta-V=5.201 km/s

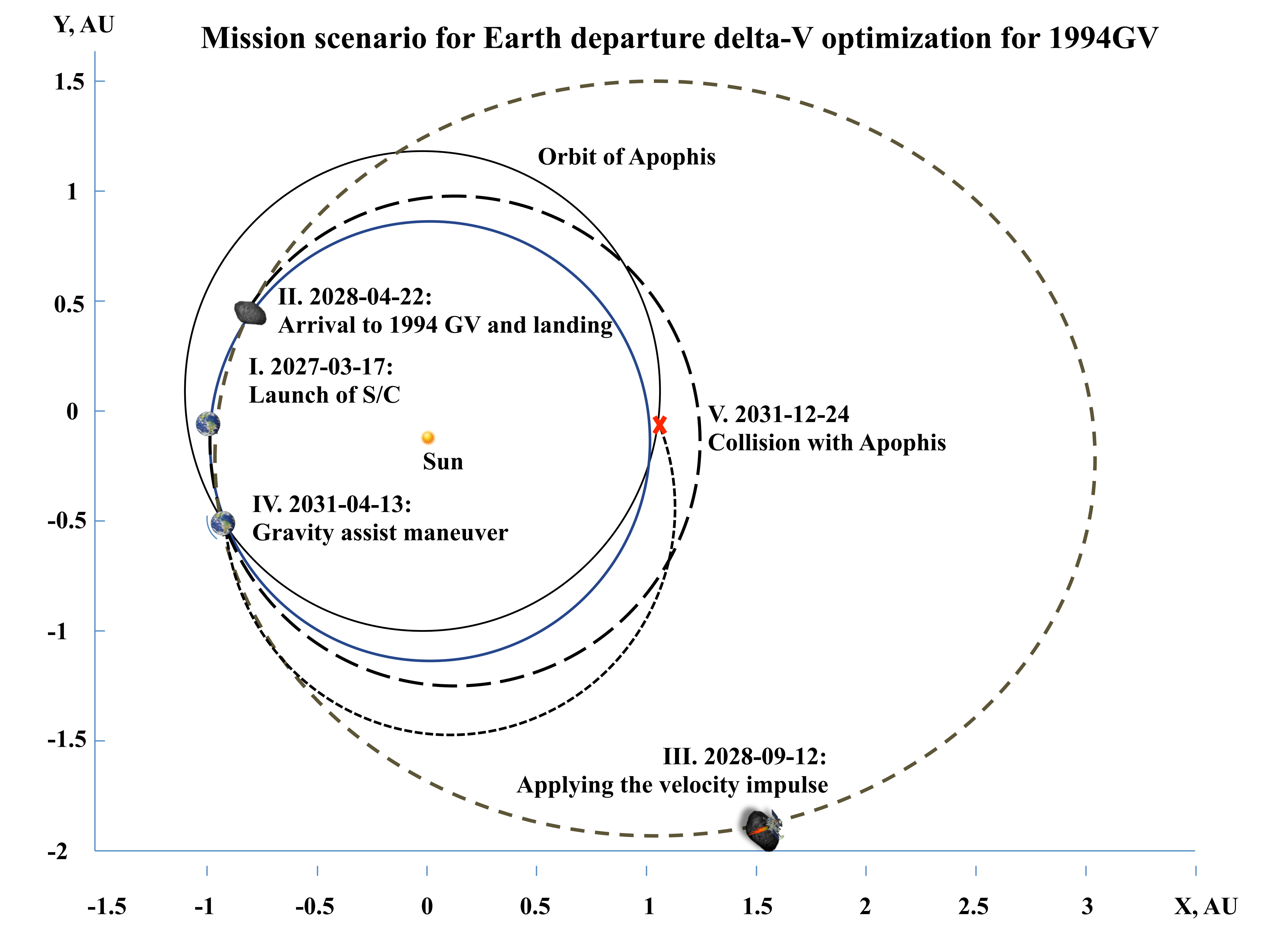


b) Transfer trajectory to 2011 UK10 asteroid with minimum departure delta-V=3.302 km/s, total delta-V=8.872 km/s





Mission scenario for Earth departure delta-V optimization for 2011UK10
Y, AU
1.5
1
0.5
0
-0.5
-1
-1.5
III. 2025-09-13:
Applying the velocity impulse
I. 2021-12-10:
Launch of S/C
Orbit of
Apophis
IV. 2026-10-10:
Gravity assist maneuver
Sun
II. 2022-08-25:
Arrive to 2011 UK10
and landing
V. 2027-08-06
Collision with Apophis
Earth orbit
-1
-0.5
0
0.5
1
1.5
X, AU



Mission scenario for Earth departure delta-V optimization for 1994GV
Y, AU
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
X, AU
Orbit of Apophis
II. 2028-04-22:
Arrival to 1994 GV and landing
I. 2027-03-17:
Launch of S/C
V. 2031-12-24
Collision with Apophis
Sun
IV. 2031-04-13:
Gravity assist maneuver
III. 2028-09-12:
Applying the velocity impulse

Resonance orbits as the basis for construction planetary defense system.

The proposed concept of using small asteroids to deflect the hazardous objects from the trajectory of collision with Earth may be developed further. The idea is to transfer small asteroids onto Earth resonance orbits, for example with period of one year, using described above method of gravity assist maneuver. Our preliminary studies have confirmed that it is possible to find 11 asteroids which are possible to transfer on such orbits by apply the delta-V not exceeding 20 m/s. Thus a system is constructed which allows sending asteroid-projectile to the hazardous object approximately each month during year

Resonance orbits as a room for easy accessible asteroids storage

- After transfer asteroid onto resonance orbit with one year period one receives possibility to continue further gravity assist maneuvers of asteroid. By sequence of such maneuvers the asteroid may be transferred onto orbit similar to the Earth orbit, i.e. it may be considered as Earth orbit rotated by some angle with respect to ecliptic plane. In this case asteroid will approach to Earth close proximity twice a year. It means that missions to the asteroid with return to the Earth in half of an year time with minimum delta-V become possible.

One year period resonance orbits

ID	ΔV_3 m/s	|a| km/sc	|b| km/s	|c| km/s	φ deg	α deg.	V_{smin} km/s	V_{smax} km/s	V_s km/s	T_3	T_4
2004 MN4	2.2	5.8	29.7	28.4	71.6	78.8	23.9	34.9	29.7	2028/11/13	2029/04/13
2012 TC4	5.6	6.6	29.8	33.9	123.0	71.0	26.3	36.2	29.8	2016/12/12	2017/10/12
2006 SU49	7.9	5.0	30.3	34.3	140.0	89.1	27.4	33.8	30.3	2027/06/11	2029/01/23
2011 AG5	9.9	9.5	30.2	34.4	108.0	46.6	27.0	39.0	30.2	2021/08/14	2023/02/04
1997 XF11	10.0	14.1	30.0	34.2	95.1	26.7	28.0	39.2	30.0	2027/04/27	2028/10/26
2011 ES4	11.0	7.7	29.5	30.8	92.0	59.8	23.3	36.5	29.5	2027/10/27	2028/09/01
2012 VE77	12.6	15.4	30.1	35.4	97.0	23.3	29.7	40.1	30.1	2030/01/05	2031/11/18
2010 VQ	14.0	4.6	29.8	27.3	53.4	95.5	26.6	33.8	29.8	2034/03/04	2034/10/08
2012 KP24	14.6	12.7	29.4	34.0	100.2	31.1	27.5	39.0	29.4	2021/08/12	2023/05/29
2011 UK10	15.9	7.5	29.8	32.5	104.3	62.2	24.8	37.1	29.8	2025/09/13	2026/10/10
2006 SR131	16.8	8.4	29.7	33.3	108.5	54.1	25.7	37.8	29.7	2016/08/06	2017/09/23
2012 PB20	18.8	4.0	30.2	30.9	97.4	103.7	26.2	33.9	30.2	2024/06/11	2025/02/11
2010 CA	19.3	14.6	29.4	32.8	90.2	25.2	26.7	38.0	29.4	2027/03/07	2028/08/06

T_3 – date of velocity impulse applying to asteroid
T_4 – date of gravity assist maneuver to transfer asteroid onto Earth resonance orbit
c - asteroid absolute velocity before gravity assist maneuver
b – Earth absolute velocity
a - asteroid velocity with respect to Earth
V_s – asteroid velocity after gravity assist maneuver corresponding 1:1 resonance
V_{smin} – minimum reachable absolute velocity of asteroid
V_{smax} – maximum reachable absolute velocity of asteroid
α – maximum angle of relative asteroid velocity rotation by gravity assist maneuver

Conclusions

The described method of dangerous asteroids deflection from the trajectory of collision with the Earth as it was shown on the example of Apophis may be considered as doable. It was found that very small delta-V (2.38 m/s) may be required to transfer small asteroid to the trajectory, what includes gravity assist maneuver near Earth, followed by collision of this asteroid with the hazardous object like Apophis. Proposed method allows to change velocity of dangerous object by the value unachievable by any other contemporary technologies. For practical implementation of the proposed approach some further progress in broadening the catalogue of candidate asteroid-projectile is needed especially as it is related to small asteroids. Construction the system consisting from resonance asteroids which periodically fly by the Earth to be ready targeted to hazardous sky object is shown to be doable.

References

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