Near Earth Asteroids

Prospection, Orbit Modification and Mining

by

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Asteroid Mining : challenge of the future

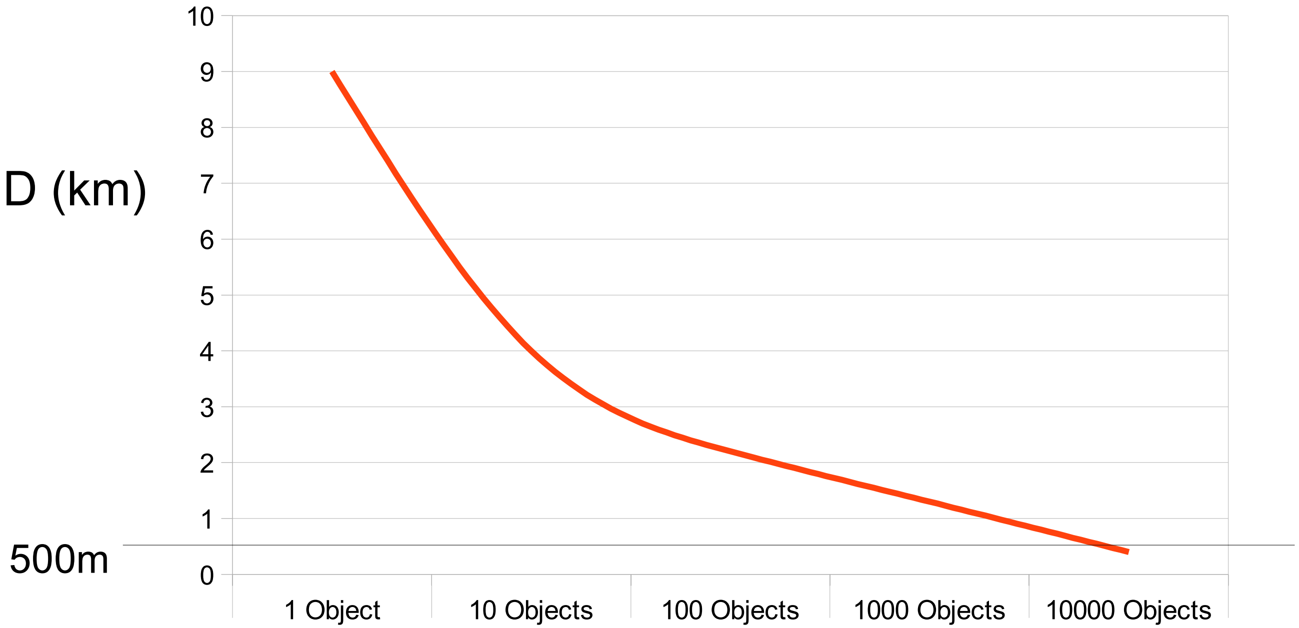
- Geochemical Groups for meteorites and asteroids with typical elements occuring in mineral associations:

Group	Elements (selection)
Siderophile	Fe, Ni, Co, Cu, Au, Pd, Pt, Os, Ir
Chalcophile	Fe, Ag, Cd, In, Th, Pb, Bi, S, Se, Te
Lithophile	Rb, Cs, Be, Al, Sc, Th, U, Ti, Nb, Ta, Cr, Mn, rare -Earth elements

- How to use these resources for the benefit of mankind ?
- First step: sending robotic probes to Near Earth Asteroids, preferably Potentially Hazardous Asteroids

Potentially Hazardous Asteroids (PHAs)

- Minimum intersection distance less than 0.05 AU (approx. 7 500 000 km)
- Velocity change (Δ V) for a spaceship is below 12 km/s to reach the PHA
- Size distribution of PHAs depending on their diameter D (rough estimation) :



Approx. 10000 PHAs between 100 and 500 m diameter are expected

What to do with really Hazardous Asteroids ?

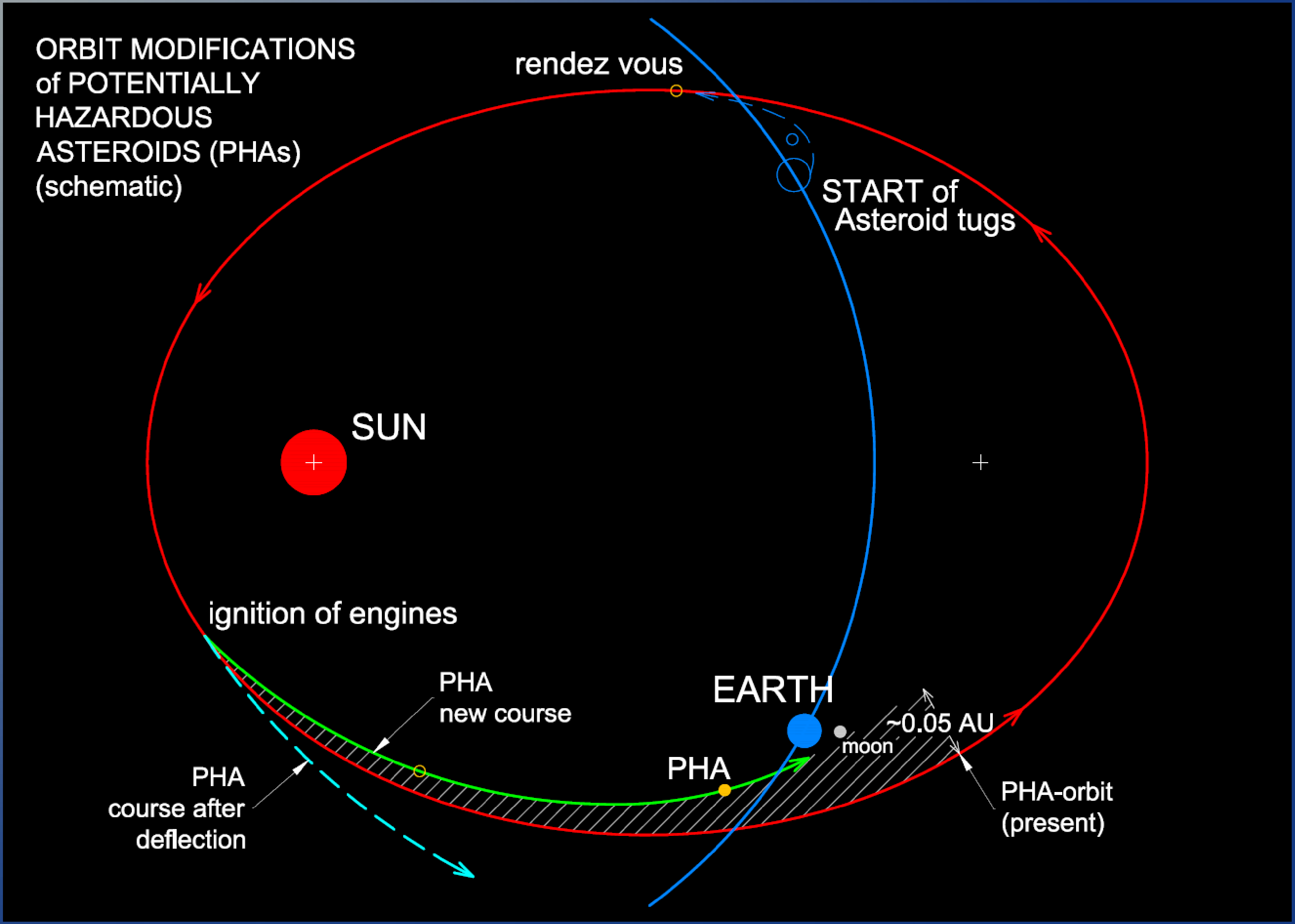
Deflect the asteroid by various techniques:

- kinetic impact
- lateral (nuclear) detonation
- connecting rocket engines (a Space Tug) to the Asteroid

Modify the orbit of the asteroid:

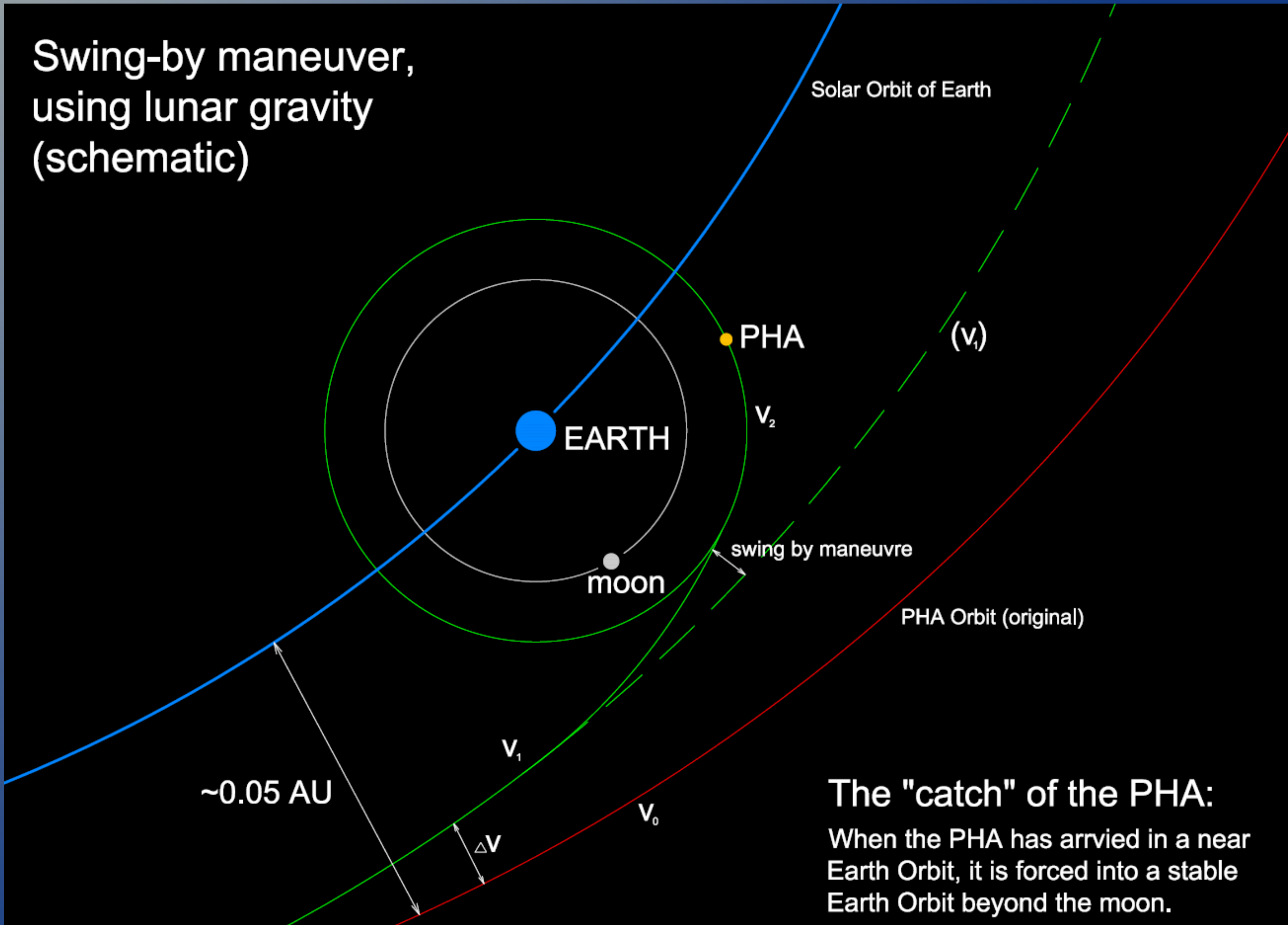
-from current Solar orbit to a stable Earth orbit beyond the Moon

- connecting a Space Tug with advanced propulsion systems to „catch and „ guide“ the asteroid


ORBIT MODIFICATIONS of POTENTIALLY HAZARDOUS ASTEROIDS (PHAs) (schematic)
rendez vous
START of Asteroid tugs
SUN
ignition of engines
PHA new course
EARTH
~0.05 AU
moon
PHA
PHA-orbit (present)
PHA course after deflection

The Arrival of the Asteroid

Swing-by maneuver,
using lunar gravity
(schematic)



The "catch" of the PHA:

When the PHA has arrvied in a near Earth Orbit, it is forced into a stable Earth Orbit beyond the moon.

Potential Candidates of PHAs for Orbit Modification and Mining

List of PHAs with their physical and orbital parameters.
For the calculated mass value a spherical shape with homogeneous bulk density of 3 g/cm^3 has been assumed.

Asteroid	Diameter (m)	Mass (kg)	Semi-major axis (AU)	Eccentricity	Spectral Type
2004 MN4	270	3.092×10^{10}	0.922	0.191	Sq
1982 DB	330	5.645×10^{10}	1.489	0.360	Xe
1998SF36	330	5.645×10^{10}	1.324	0.280	S
2005YU55	400	1.005×10^{11}	1.157	0.430	C
2008 EV5	450	1.431×10^{11}	0.958	0.084	S
1982 XB	500	1.963×10^{11}	1.835	0.446	S
1999RQ36	493	1.882×10^{11}	1.126	0.204	C

← We take 2008EV5 as an example

What is the estimated Transfer Energy (TE) to change the current Solar orbit of the asteroid 2008 EV5 into an Earth orbit ?

- We take the difference in Kepler Energy (ΔK) between the asteroid´s current Solar orbit (K_1, a_1) and Earth´s orbit (K_2, a_2) :

$$\Delta K = K_2 - K_1 = GM/2 \cdot (1/a_1 - 1/a_2) \qquad \text{(Roy 1988)}$$

G Gravitation constant M Mass of the Sun a semi-axis

$$\Delta K = (6.67\times10^{-11} \cdot 1.99\times10^{30})/2 \cdot (1/1.433\times10^{11} - 1/1.496\times10^{11}) = \underline{1.941\times10^{7}} \text{ J/kg}$$

- We multiply it with the mass (m) of 2008 EV5 : 1.431×10^{11} kg

$$\Delta K \cdot m = TE \text{ (Joule)}$$

$$1.941\times10^{7} \cdot 1.431\times10^{11} = 2.778\times10^{18} \text{ J}$$

The required Transfer Energy is approx. 2.778 Exajoule

(2.778 million Terajoule)

We need an advanced propulsion system :

e.g. the BUSSARD FUSION ENGINE , also called the „quiet-electric- discharge (QED) engine“ (Robert W. Bussard, 1997, 2002)

- Deuterium and Helium-3 are fusing to Helium-4 plus *protons*

$$_2H + _3He = _4He + p$$

- Each reaction releases an energy of approx. 18.3 MeV

- For the Deuterium-Helium-3 fuel R. Bussard gives a specific energy of 3.5×10^{14} J/kg

-For the 2008 EV5 maneuver we can compute the required fuel mass:

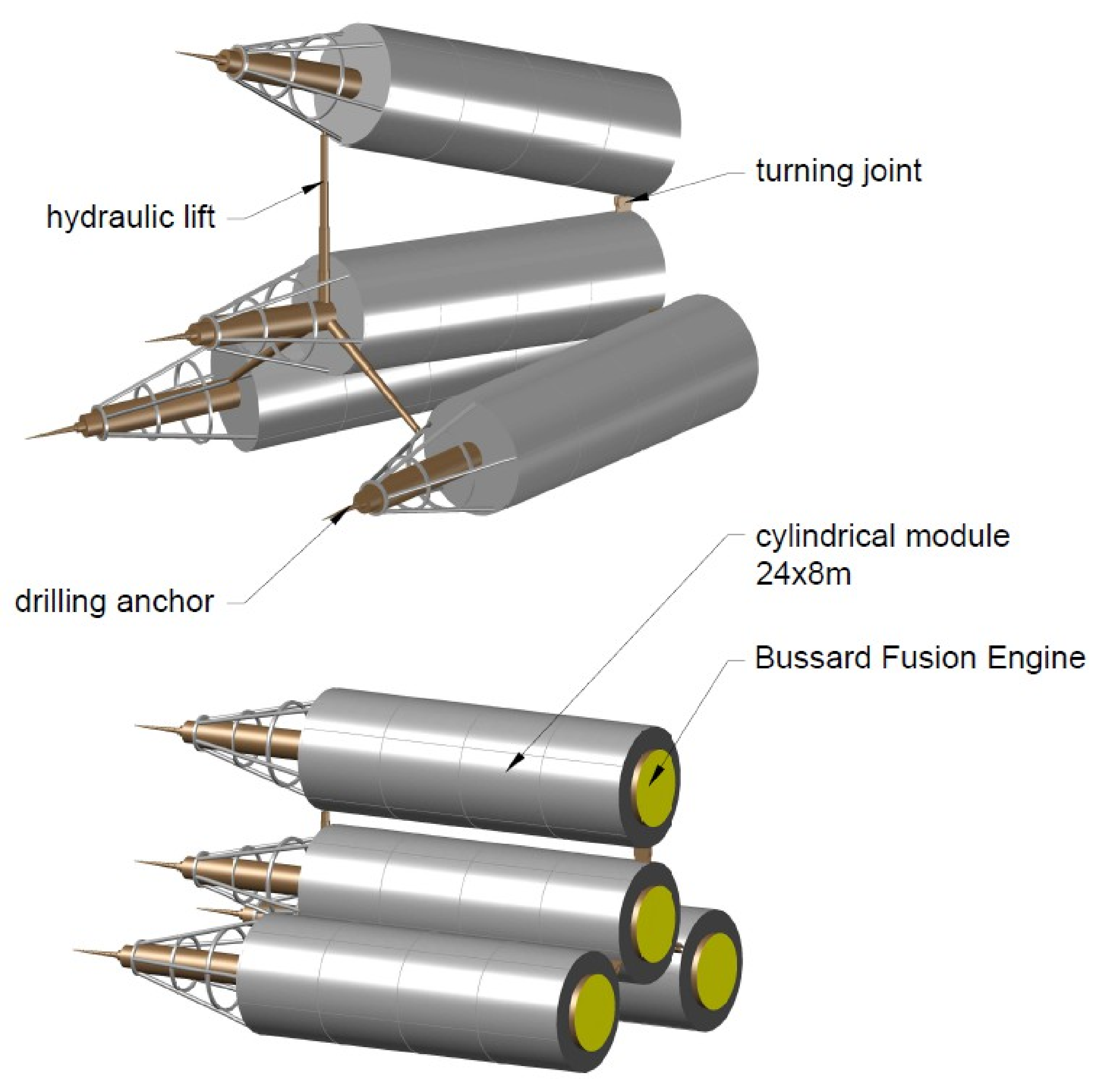
2.778×10^{18} (J) / 3.5×10^{14} (J/kg) = 7937 kg (8 tons of fuel)
(Transfer Energy)

- Helium-3 can be found on the Lunar surface as a product of the Solar wind.

Asteroid Space Tugs (unmanned)

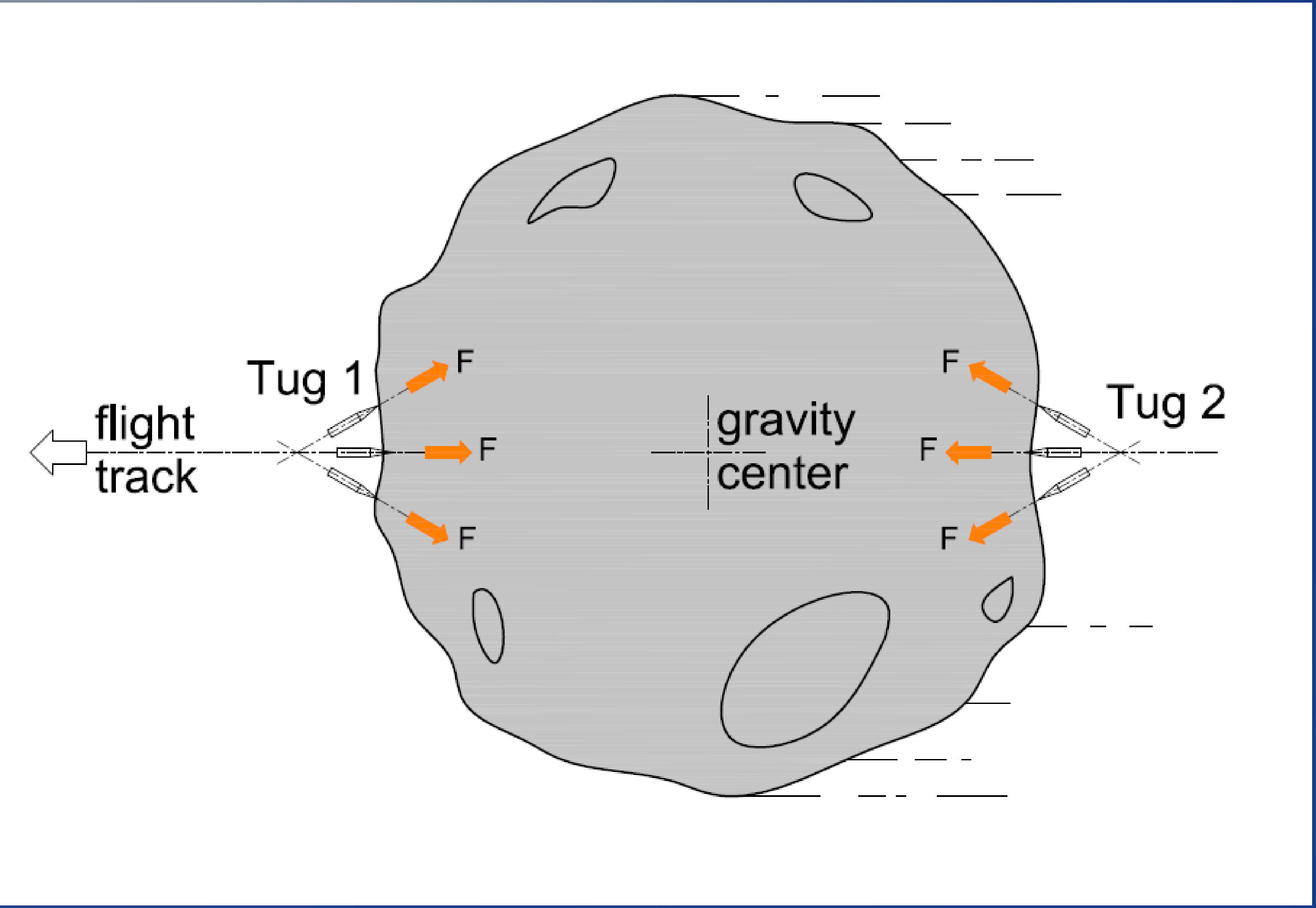
The tugs and the Bussard Fusion Engines have to be produced in series production.

The goal is to „catch“ a number of asteroids within some decades.



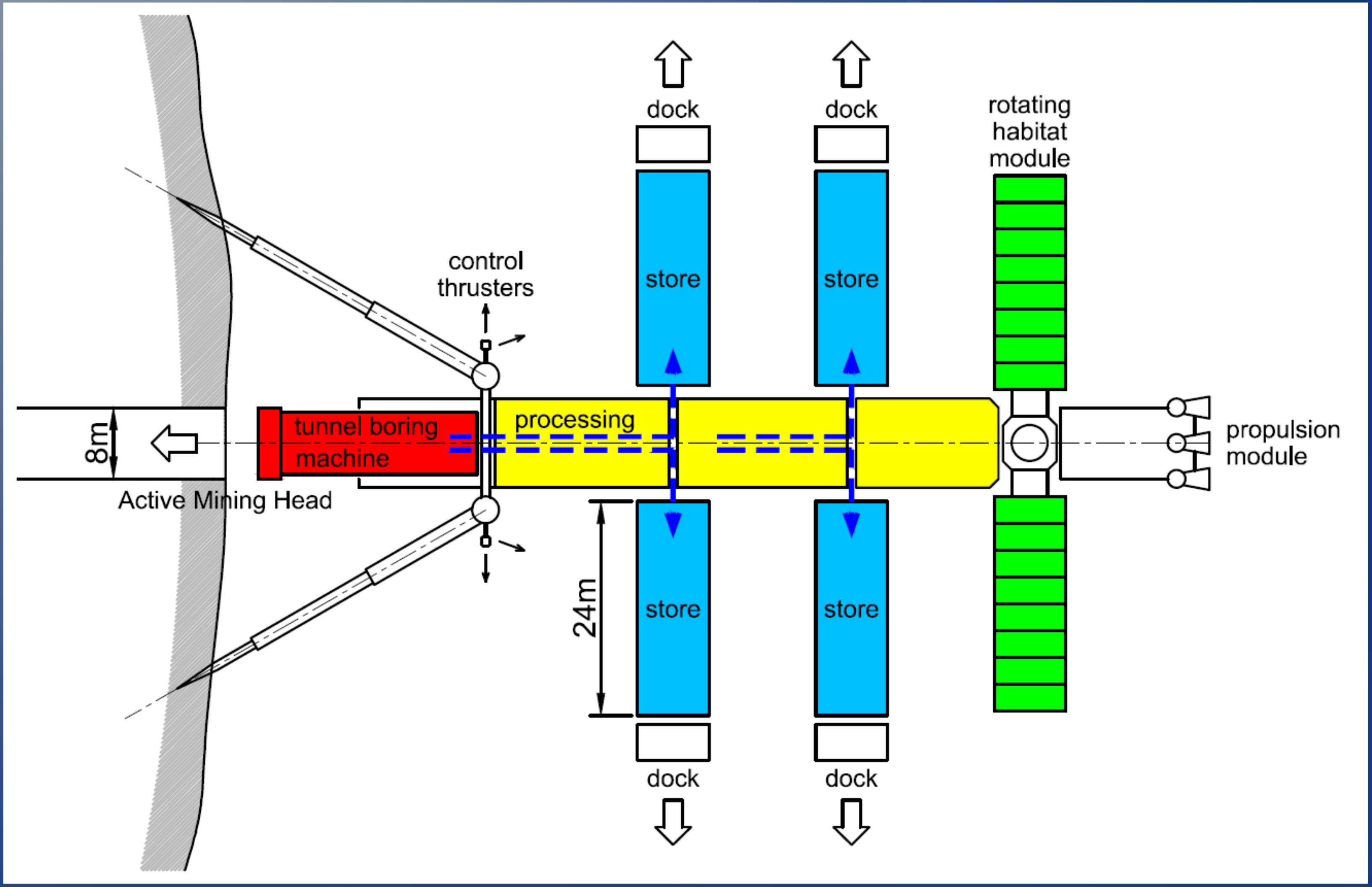
Asteroid 2008 EV5, guided by Space Tugs

-The tugs can apply forces in every direction
-Tug 1 adjusts the fligt track by short engine thrusts
-Tug 2 applies the primary force for the orbital maneuvers



Mining the Asteroid :

Once stabilized in an Earth orbit beyond the Moon, the mining process is started along the major axis of the asteroid.
A Manned Mining Station is docked to the asteroid.

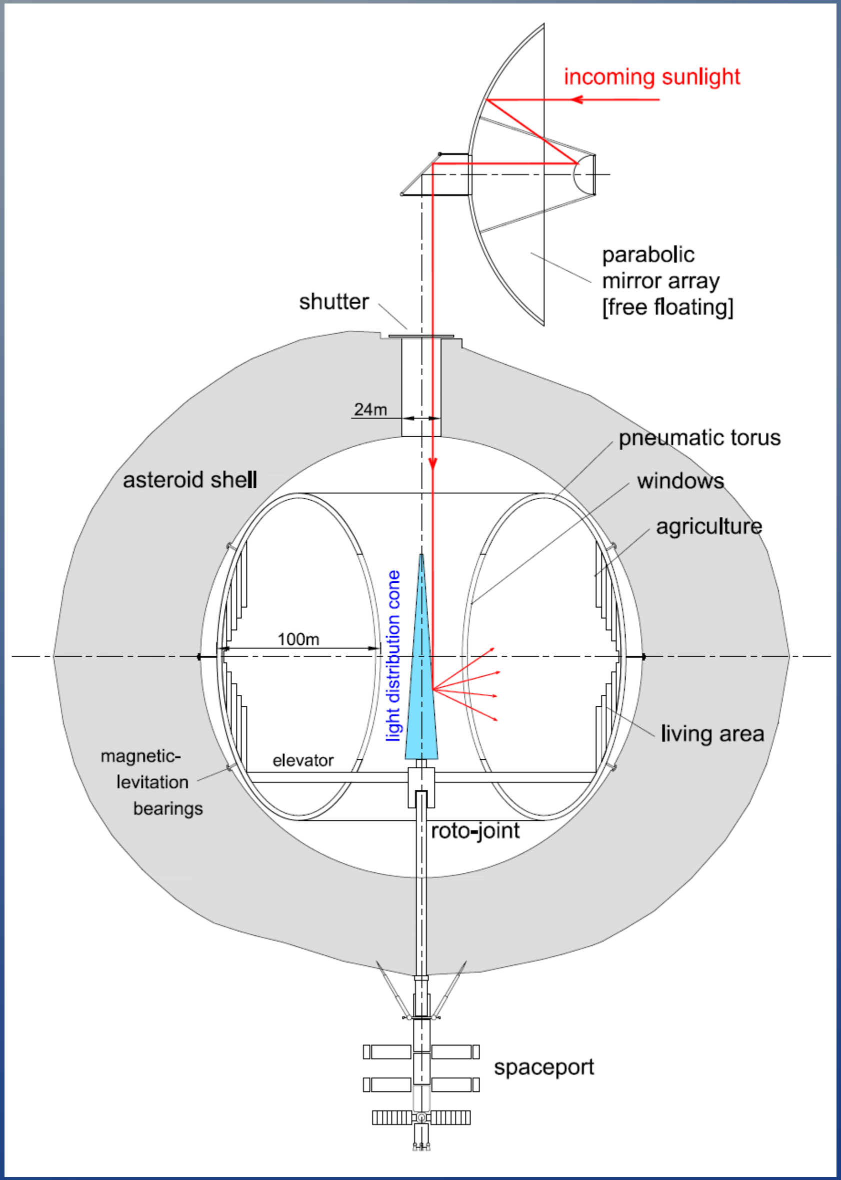


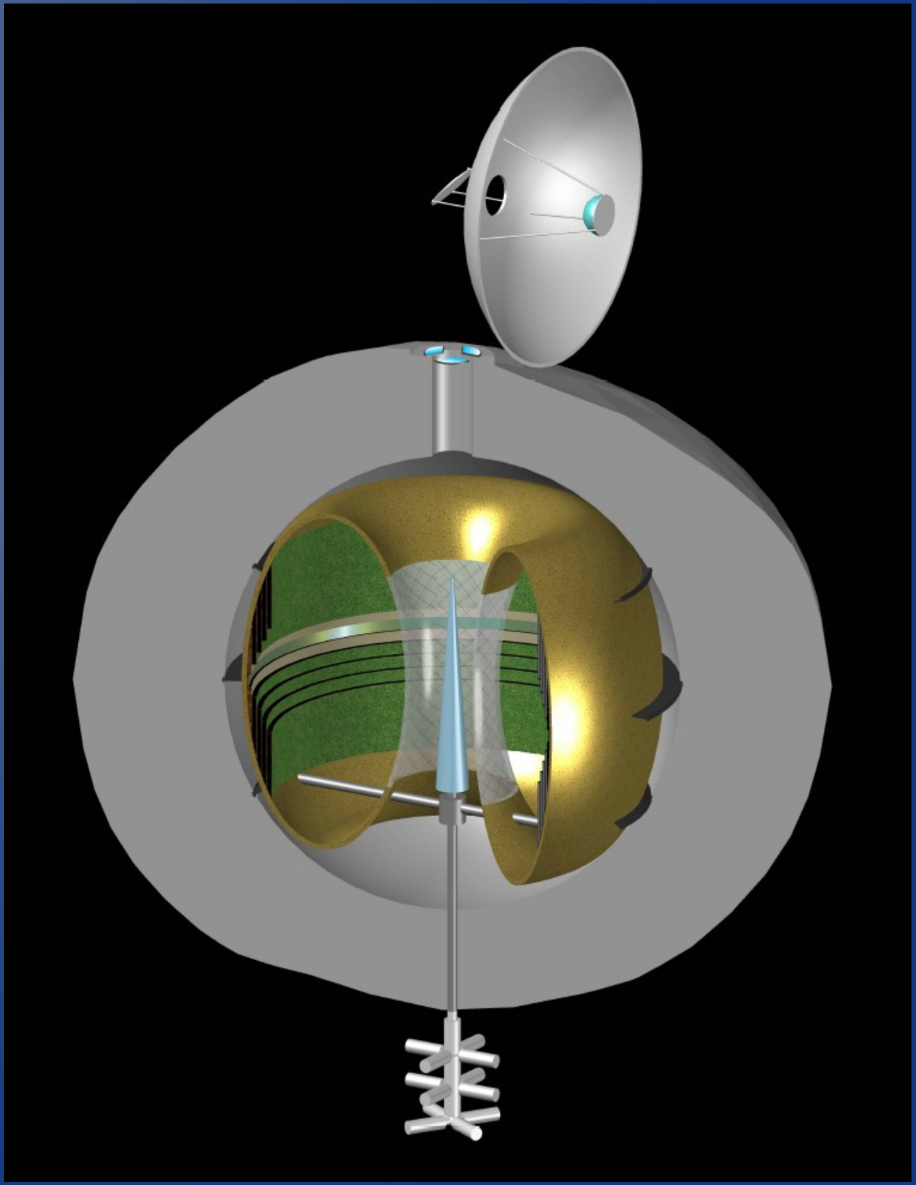
Advantages of an asteroid´s Earth orbit :

- Short flight time from Earth (5 to 7 days)
- Rate of mining advance, removal of ore and storage can be kept equal to the rate of cargo shipping
- After mining : the hollow asteroid can be used as a shelter for industrial facilities or storage (water, oxygen, etc.) for industry in space
- Asteroids with more than 400 m in diameter can be used for Rotating Human Colonies with artificial gravity.
- The remaining stony crust provides shelter against cosmic rays, Solar flares and meteorites

Asteroid Colony (sections)

The rotating torus inside provides artificial gravity.
Natural sunlight is collected by parabolic mirrors and beamed into the cave.





Supplementary sheet 1:

How to apply an energy of 2.778 $x10^{18}$ Joule to an asteroid of 450 m in diameter ?

- connect a spaceship (space tug) with usual LOX/LOH rocket engines?

- Specific Energy (*calorific value*) of Hydrogen : 1.418 $x10^{8}$ J/kg

$$2.778 \times 10^{18}\ (J)\ /\ 1.418 \times 10^{8}\ (J/kg) = 1.96 \times 10^{10}\ kg \text{ of } H_2$$

-We would need a fuel mass of 20 million tons of Hydrogen !

- Is this feasable ??

Supplementary sheet 2 :

The Mining Process :

- The asteroid is excavated up to 50 % of its volume
- Heavy elements are supposed to be in its core
- The excavated cave is filled with a pressurized gas
- The muck (the rock chips) are removed in a vacuum conveyor tube to the Mining Station
- The raw material is processed and stored in the Manned Mining Station
- Cargo ships transport the material to Low Earth Orbit or to the Lagrange Points for further industrial use, e.g. in metallurgical plants

Thank You for Your attention !

Drawings by C. Böck