

Sähköpurjeen sovelluksia osa 2:

Asteroidin siirto sähköpurjetta käyttäen

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Tällä aukeamalla esittelen sähköpurjeen yhden käyttömahdollisuuden, asteroidin hinaamisesta toiselle radalle. Alla oleva posterit esitetään European Geosciences Unionin (EGU) yleiskokouksessa Wienissä 2.- 7. 5.2010.

Julisteen vasemmassa laidassa on yhteenveto asteroideista. Niitä vilisee avaruudessa paljonkin erikokoisia mureikoita ja vaikka joskus tietäisimmekin kaikkien uhkaavan kokoisten asteroidien paikat ja radat, voi niihin tulla keskinäisten törmäysten vuoksi yllättäviäkin muutoksia.

Pienempi kivi saattaa kovalla nopeudella isompaan asteroidiin osuessaan pahimmassa tapauksessa vääntää sen rataa niin, että se yhtäkkiä onkin kurssilla kohti maata.

Asteroidit eivät kuitenkaan ole toivottuja vierailijoita Maassa, joten on ryhdyttävä toimiin asteroidien pitämiseksi pois lähetyviltämme! Jos aikaa ennen törmäystä on tarpeeksi, kymmenisen vuotta, ennätämme kehittää sähköpurjehinaajan ja toimittaa sen perinteisinkin mene-

ON POSSIBILITY OF DIRECT ASTEROID DEFLECTION

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DEFLECTING THE ASTEROID

A rough way to estimate the time required for asteroid deflection is to calculate the time required for an asteroid to travel a distance equal to one Earth radius along a straight line and then to calculate the time required to move it by one Earth radius with the E-Sail:

E-sail thrust	1 N
Asteroid mass	3 million tons
Deflection time	6.2 years

With 2N thrust, the deflection takes 4.4 years. With a 3 N thrust, it takes 3.8 years.



ASTEROID THREAT



Asteroid impact, drawing by NASA

There are an estimated 100 000 Near Earth Objects (NEO) of effective diameter of 140 m or bigger. One fifth are assumed to be potentially dangerous and one will hit us every 5000 years [1]. Asteroid with volume equivalent to 140 m sphere and density of 2.1 g/m³, has a total mass 3 million tons. An asteroid with this mass, hitting Earth 30 km/s, would yield an energy release equivalent of 300 MT of TNT explosive, causing serious regional damage.

Detection and classification of suspect asteroids is an ongoing project. However, even if the orbits of all larger NEOs were known accurately, their collisions with meteoroids and with each other will still occasionally and unpredictably alter the orbits, and potentially render a previously benign object dangerous.

TASK AND FEASIBILITY

If an asteroid is observed on a collision course with the Earth, there are two options. The first is to blow the asteroid apart into smaller pieces, many of which could still cause local damage and problems to near Earth space operations. Thus, time permitting, we should as a first option try to deflect the asteroid gently without breaking it. We propose that this could be done with the Electric Solar Wind Sail (E-Sail). [2]

Our asteroid is 15 million times larger than typical E-Sail payloads. However, its deflection is feasible because the required asteroid Δv is quite small. The continuous propellantless thrust of an E-Sail increases its relative merit over other propulsion systems with increasing deflection mission duration.

ATTACHING THE CORD

Due to its low mass, an E-Sail vessel is easily accelerated. The task is to figure out how to transmit the pull force of the E-Sail to the asteroid. This is a non-trivial task when compared with more violent methods.

1. Harpooning (schematic background picture) Directly attaching a towing cord to the asteroid is needed to fly into the proximity of the asteroid. The cord is attached to the rotational pole of the asteroid. Depending on the asteroid's rotation state. Depending on the rotation state, not, one may attach the cord to both poles.

2. Gravity tractor

By placing a mass close to the surface of an asteroid, the towing force of an E-Sail wirelessly to the asteroid. The tractor mass m and the distance d between the tractor and the asteroid are given by

$$T = \frac{GMm}{d^2}$$

In order to transfer the 1 N force of a baselined E-Sail, the tractor mass m would be 24 500 kg. For a safe operation, the tractor mass should be 98 000 kg. To avoid bringing this mass from Earth, the tractor should be mined from the asteroid itself. For example, the tractor could be then lifted from the surface. The required acceleration is small. The required acceleration may be in controlling the procedure remotely.

telmin tuon Maan rauhaa uhkaavan lohkareen lähettyville. Itse sähköpurje on esitelty posterin oikeassa laidassa.

Keskeisimmän paikan olen antanut yksinkertaiselle laskelmalle yhden Newtonin vetovoimaisen sähköpurjeen hinaustehosta. Kolmen miljardin kilogramman lohkareen siirtämiseksi pois vaaran alueelta tarvitaan reilut kuusi vuotta. Mutta on keinoja rakentaa tehokkaampiakin sähköpurjeita, joko kasvattamalla yhden purjeen kokoa, tai vaikka asettamalla useampia purjeita peräkkäin. Kahden nominaalipurjeen teholla murikkaa tarvitsee vetää enää neljä vuotta ennen kuin päästään turvallisemmille avaruuden alueille.

Ongelmallisinta on sähköpurjeen kiinnittäminen hintavaan asteroidiin, joka saattaa pyöriä villisti ja olla muodoltaan hyvinkin epäsäännöllinen. Käyn läpi kaksi eri tapaa, yksinkertaisen harppunoinnin, sekä niisanotun gravitaatiotraktorin. Traktori tarkoittaa isoa, tässä tapauk-

ssa vajaan 30 tonnin massaa, jota roikotetaan hinausköydestä lähellä asteroidin pintaa. Tämän traktorimassan ja asteroidin keskinen painovoima välittää sähköpurjeen aiheuttaman vedon, ja niin isokin asteroidi liikahtaa.

Molemmissa lähestymistavoissa on ongelmansa. Traktoria varten täytyy vaikkapa asteroidin pinnalta kerätä suuri määrä irtomurikoita tarvittavaksi massaksi. Tämän toteuttamiseen tarvitsee kehittää paljon mutkikasta tekniikkaa, jotta työ saadaan toteutettua hyvinkin kaukana Maasta ja jotta traktorin massaa voidaan onnistuneesti tasapainoittaa epästabailissa tilassaan asteroidin ja sähköpurjeen välillä.

Sähköinen aurinkotuulipurje tarjoaa oivan vaihtoehdon asteroidien ratojen muuttamiseen, kunhan aikaa operaation toteuttamiseen on useita vuosia. Kiireellisemmissä tapauksissa joudutaan turvautumaan ydinräjähteisiin tai muihin väkivaltaisempiin tapoihin. □

ASTEROID DEFLECTION BY ELECTRIC SOLAR WIND SAIL

ASTEROID

It is assumed that Earth is heading towards an asteroid. The goal is to pull the asteroid away from Earth's way.

Time t to move the asteroid away from collisional trajectory:

$$t = \sqrt{\frac{2r \cdot m}{F}}$$

r is deflection distance, m is asteroid mass and F denotes the E-Sail force.

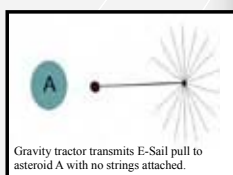
At least it takes 3.6 years.

MOVING THE E-SAIL TO THE ASTEROID

The E-Sail is carried (or carries itself) to the asteroid. This leaves the problem of how to get the E-Sail to the asteroid. The continuous, gentle pull of the E-Sail facilitates the use of methods such as nuclear explosives or ordinary rocketry. One can use either:

1. A harpoon (structure) is attached to the asteroid. The harpoon is the most straight-forward solution. An assisting small spacecraft is used to shoot the harpoon, which carries the towing cord to the asteroid. As the harpoon is pulled along the rotation axis, the process does not much disturb the asteroid's rotation. In some cases this may or may not be close to optimal pulling direction. If it is not, the harpoon can be used to pull sideways or to reattach the cord again when needed.

2. A gravity tractor. If the asteroid is spherical, their mutual gravitational attraction can be used to transfer the E-Sail to the asteroid [7]. The towing force T is dependent on the asteroid mass M and the distance r between the asteroids and the tractors centres of mass:

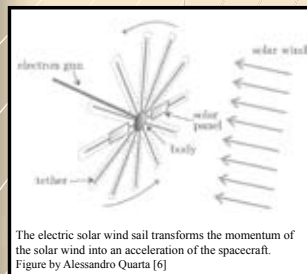


The mass of the E-Sail to a spherical asteroid of radius R is M . At a distance of one asteroid radius away from the asteroid, the needed mass m is $M/8$. The required tractor mass would rise to $M/4$ if the tractor is at the Earth's surface, the mass should be $M/2$.

Small rocks and regolith could be collected by a robot to a bag which is attached to the tractor. If auxiliary chemical propulsive maneuvers are modest; the main challenge is to get the tractor to the asteroid.

NOVEL PROPULSION METHOD

The Electric Solar Wind Sail (E-Sail) uses charged tethers to extract momentum from the solar wind particles to obtain propulsive thrust. It is a new propulsion method for interplanetary travel, which was invented in 2006 and is currently under development [3, 4]. According to current estimates, the E-Sail is 2-3 orders of magnitude more efficient than traditional propulsion methods (chemical rockets and ion engines) in terms of produced lifetime-integrated impulse per propulsion system mass.



The force of an E-Sail is inversely proportional to the distance from the Sun as $F \propto (1/r)$ [5]. In comparison, the force produced by a photonic solar sail is $F \propto (1/r^2)$. The E-Sail has thus particular potential for outer solar system missions, on more eccentric asteroid tracks and on sample return missions.

As the E-Sail requires no fuel (charging of the wires can be accomplished by an electron gun

powered by modest-sized solar panels), it allows quite small total spacecraft mass. The E-Sail thrust can be steered in a cone of 30° around the solar wind velocity vector. By inclining the sail in a braking orientation, E-Sail can also track towards the Sun.

Once developed, the E-Sail would appear to provide a safe and reasonably low-cost way of deflecting dangerous asteroids and other heavenly bodies in cases where the collision threat becomes known several years in advance. The first test mission to measure the E-Sail effect in small scale is ESTCube-1, which is to be launched in 2012 (www.estcube.eu).

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