EPSC Abstracts
Vol. 11, EPSC2017-215-1, 2017
European Planetary Science Congress 2017

Asteroid touring nanosat fleet with single-tether E-sails

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Abstract

The electric solar wind sail (E-sail) is a method for generating efficient low-thrust propulsion outside Earth's magnetosphere. In its simplest form the E-sail is a single spinning ~ 20 km long tether biased at ~ 10 kV positive voltage by an onboard electron emitter and high-voltage source. Here we consider a fleet of ~ 5 kg spacecraft, propelled by the E-sail tether and making quasi-elliptic passes through the asteroid main belt. Each spacecraft also uses its tether to make a ~ 1000 km flyby of 6-7 asteroids. Data are stored in memory and downloaded at a final Earth flyby at the end of the mission using conventional non-directional radio subsystem. Using this mission architecture, the cost per imaged asteroid is only ~ 200 k€ which is a reduction by about 3 orders of magnitude with respect to the state of the art.

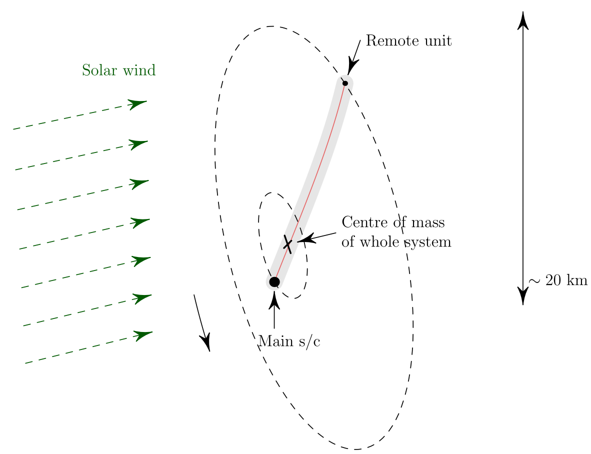

Figure 1: The single-tether E-sail spacecraft.

1. Introduction

The electric solar wind sail (E-sail) uses the natural solar wind for generating efficient propellantless propulsion [1]. The E-sail is very well suited for asteroid missions because they typically have high low-thrust delta-v requirements and many applications have been proposed and analysed [3, 4, 5, 6]. Here we consider a fleet of nanosatellites propelled by a simple single-tether E-sail [2] (Figs. 1, 2). Using only a single tether increases reliability and makes it possible (by attaching the tether at the spacecraft's centre of mass) to point the spacecraft to a target without moving parts other than internal momentum wheels.

2. Single-tether E-sail nanosat

With 10 kV tether voltage, the tether generates 250 nN/m thrust per unit length at 1 au in average solar wind. Hence, if a 5 kg spacecraft has a 20 km tether, characteristic acceleration of 1 mm/s^2 is obtained at 1 au. Orbital calculations show that this level of E-sail acceleration is enough to make the spacecraft fly through the asteroid main belt in a quasi-elliptic orbit taking ~ 3.2 years (Fig. 3). The E-sail uses full thrust after leaving Earth and before entering the main belt, and then enters reduced thrust science mode where the available E-sail propulsion is used for active manoeuvring to maximise the number of asteroids flown by at close range. The number of well-known (numbered) asteroids reached by the spacecraft is then typically 6-7. Data are stored in flash memory chips during the mission and downloaded at a final Earth flyby so that only ~ 3 hours of deep-space network time is required to download the ~ 10 GB of data. The surface resolution of the flyby images is 100 m pixel size or better (with 4 cm telescope at 1000 km distance the diffraction limit would be even ~ 20 m) and a separate NIR spectrometer can be used to identify surface minerals.

The main science instrument is a 4 cm telescope which is used to image the asteroids at ~ 1000 km flyby range. Between the asteroid encounters, the telescope is also used for autonomous optical navigation based on known nearby asteroids. Typically, more than 5 asteroids are observable within 10 million km

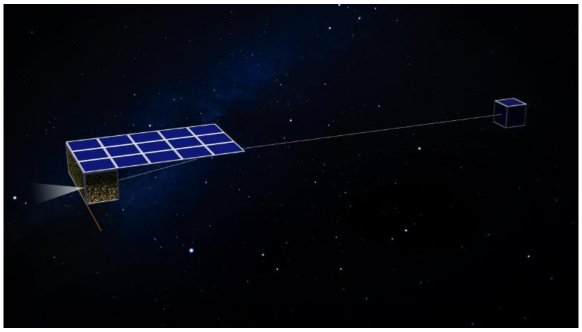

Figure 2: Artist's concept of the spacecraft.

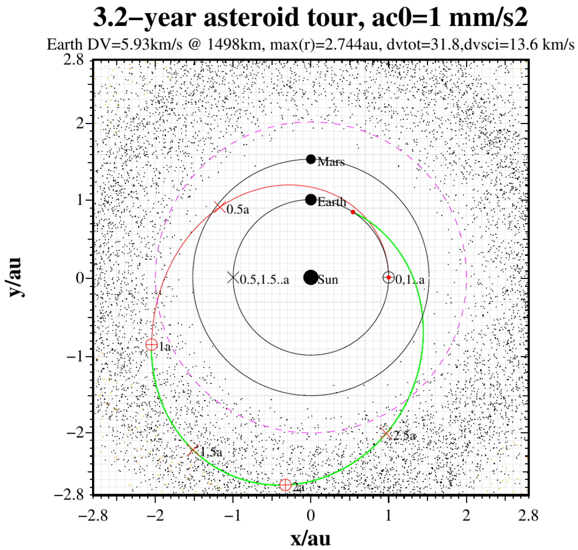

Figure 3: Mission trajectory.

range, and with 10^{-4} angular accuracy (a conservative estimate because 7 times less than diffraction limit for a 4 cm telescope), 1000 km or better orbital accuracy is obtained. Pointing the telescope towards the asteroids is possible because the spinning tether is attached at the centre of mass of the spacecraft: the spacecraft can turn in two axes by using its internal momentum wheels.

3. Fleet mission

Any number of the nanosats can be launched and the escape or high elliptic orbit launch mass is $\sim 10\,\mathrm{kg}$ per spacecraft including the launch pod. For example, the PSLV can lift $\sim 500\,\mathrm{kg}$ to such orbit and thus could launch a cluster of 50 asteroid touring nanosats. Because of satellite makes a flyby of 6-7 asteroids, the total number of asteroids imaged is over 300. The mission total cost is ~ 60 M€ including R&D, launch and operations, so that the cost per asteroid is ~ 0.2M€.

4. Rationale

- Asteroids are very diverse target, hence a large number of them should be studied *in situ*. The only cost-effective way to do it is to use small spacecraft.
- Lightweight optical+NIR instrumentation yields lot of information: size, shape, collision history, presence of moons if any, mineral composition, amount of regolith...
- Low cost: few hundred thousand per asteroid.
- Flexible launch: single or small groups of spacecraft can be piggybacked with any planetary, lunar or Lagrange point missions, or the whole fleet can be launched at once e.g. by PSLV. The requirement is to reach high elliptic or escape orbit, but otherwise the launch orbit's parameters do not matter. The E-sail only needs to get outside Earth's magnetosphere to have access to the solar wind.
- Low telemetry cost since Earth flyby is used to download data. The nanosatellites do not need high-gain antennas.

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