# The Electric Solar Wind Sail
# - New Propulsion Innovation for Solar System Travels

Sini Merikallio
Finnish Meteorological Institute, Helsinki, Finland (Sini.Merikallio@fmi.fi / GSM: +358-50 409 7566)

## Abstract
The Electric Solar Wind Sail (aka. E-sail) is a novel propulsion concept that enables fast and economic space travel within the solar system. As the source of its propulsion the E-sail utilizes charged solar wind particles. This is achieved by deploying long, conducting and charged tethers, which through electric force interaction get pushed by the solar wind particles, mainly protons. [1]

E-sail was invented in 2006 by Pekka Janhunen [2,3] and is currently under development by Finnish Meteorological Institute https://www.electricsailing.fi/), NASA (project is named HERTS; Heliopause Electrostatic Rapid Transit System), and ESA (as of yet unpublished information).

Among others E-sail could be used in supporting manned Mars flight [4], towing an Earth threatening asteroid to a more benign track [5], and investigating the asteroids [6, 7]. Moreover, a spin-off from the E-sail technology, a so-called plasma brake, could be used to bring small satellites down from their orbits in the end of their lifetimes [8].

## Electric Solar Wind Sail
The produced thrust of an E-sail is inversely proportional to the distance from the Sun as $F \alpha (1/r)$ [1]. The E-sail requires no propellant and discharging of the wires by solar wind thermal electrons can be counteracted by an electron gun powered by solar panels of a modest size. To enable maneuvering and trajectory control, the E-sail thrust can be steered in a cone of about 30° around the solar wind velocity vector. At 1 au distance from the Sun, approximately 2000 km of E-sail tether is required to produce 1 N of thrust. This could be achieved for example by having hundred 20 km long tethers spun out centrifugally from the spacecraft in the center. This kind of propulsion system would weigh roughly 200 kg and be able to transport 400 kg vessel into the Jovian system in a mere year. It could also accelerate a smaller 200 kg payload at over 50 km/s out of the solar system or deflect a threatening three million ton asteroid in ten years [5].

## Structure
An E-sail spacecraft consists of a central unit out of which one or more highly charged tethers are centrifugally deployed. Baseline length of a tether is 20 km, but with current technology and materials (aluminium alloys) lengths of up to 100 km could be achieved.

At the end of each tether is a Remote Unit (RU). These Remote Units weigh a few hundred grams and are connected with each other by flexible auxiliary tethers. Auxiliary tethers only insure mechanical stability and can thus be made out of non-conductive and durable materials such as polyimide (Kapton). A schematic sketch of an E-sail is shown in Figure 1.

The E-sail thrust is produced by charged tethers interacting with the solar wind particles. E-sail tethers need to be lightweight, conducting, micro-meteoroid impact resistant and be able to withstand the pull created by the centrifugal acceleration keeping them outstretched. Yet they must not have too high a surface area so as not to collect extensive thermal electron current, which would be driven by the electron gun and the power system.

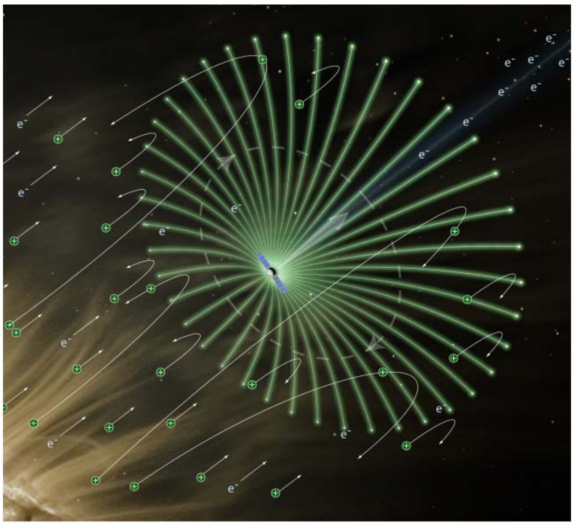

Figure 1. An artist's impression of an Electric Solar Wind Sail showing the central spacecraft out of which several main tethers are deployed. The whole structure rotates in a cartwheel fashion around the center spacecraft in order to keep the tethers centrifugally stretched. Shown are also the solar wind particles, and their tracks that are affected by the electric charge of the tethers. Auxiliary tethers are not visualized and widths of the main tethers, as well as the size of the central space craft are highly exaggerated. Graphics by Szames /Antigravite.

The design requirements of the tethers can be met by knitting four 25-50 µm thin aluminum wires into a 2-3 cm wide mesh-like tether. Initially, the auxiliary tethers are on reels in RUs while the main tether is reeled to the central craft. Whilst deploying, the rotation of the whole system is kept up by small thrusters at RUs. Deployment of both the main and auxiliary tethers are timed and controlled.

## Test missions

An E-sail payload is currently flying on a low Earth orbit (LEO) CubeSat test mission, Aalto-1 (Finland) and waiting to be tested. Aalto-1 will deploy short E-sail tether (100 m). The relative speed of the spacecraft and ionosphere (~7 km/s) is not comparable with the real solar wind speed (~400 km/s). However, as the tether voltage is varied in sync with the rotation of the satellite, the E-sail effect can be observed in changing of the cubesats rotational speed.

## Summary and discussions

The design and production of Electric Solar Wind Sail prototypes is in good progress. E-sail technology could be available for solar system research within ten years and if successful, might revolutionize the way we think and do space travel, and plan our future exploration missions. Electric solar wind sail enables affordable continuous manned Mars presence, considerably decreases travel times within the solar system and also could be a key technology in facilitating asteroid mining operations. The E-sail thus holds great promises for accessing both scientific and economical treasures of our solar system.

## References


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