FINNISH METEOROLOGICAL INSTITUTE

Flyby of 300 main belt asteroids by nanosat fleet using single-tether electric sails

***Pekka Janhunen*, Petri Toivanen, Jouni Envall,**
Finnish Meteorological Institute, Helsinki, Finland;
Karri Muinonen, *Univ. Helsinki, Finland;*
Andris Slavinskis, *Univ. Tartu & Tartu Observatory, Estonia*

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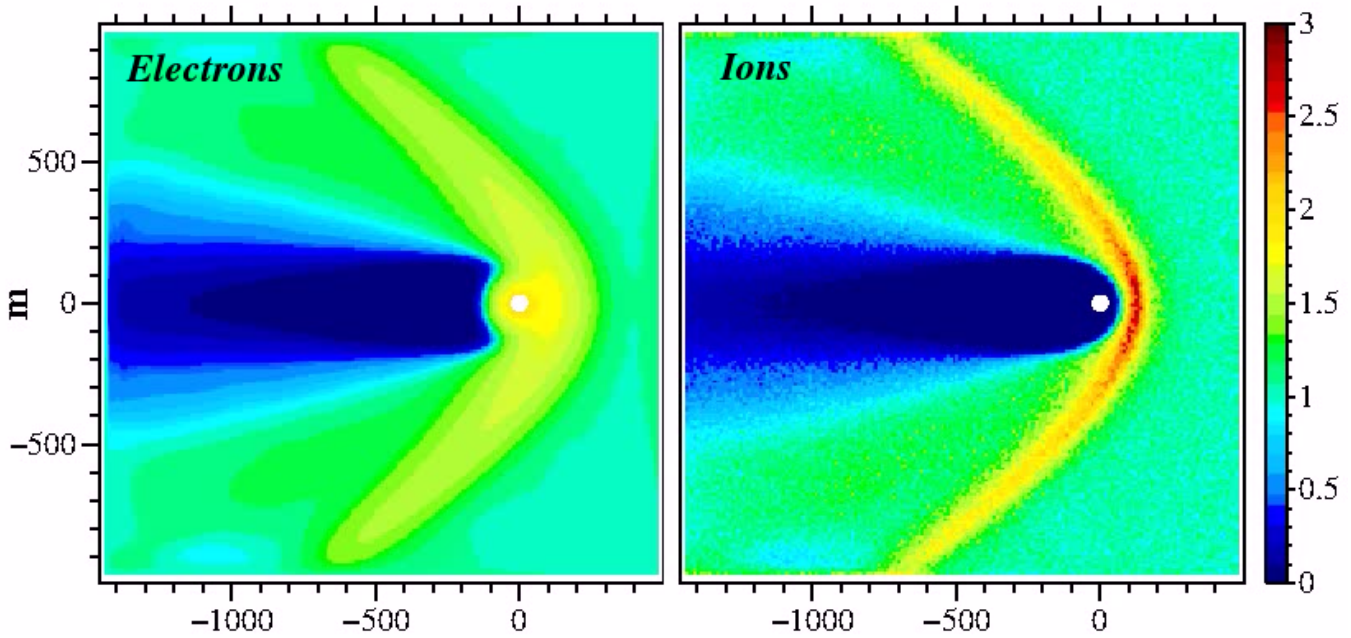
Coulomb drag propulsion

- Way to harness natural space plasma flow for propulsion
  - Charged thin tether taps momentum by deflecting ion flow.
  - One or more tethers: for cubesat, one suffices.
- Two application domains:
  - Solar wind → ***E-sail, interplanetary propulsion***
  - LEO → plasma brake, satellite deorbiting
- At least order of magnitude more efficient than existing methods (efficiency = impulse per propulsion system mass)

Plasma simulation of E-sail

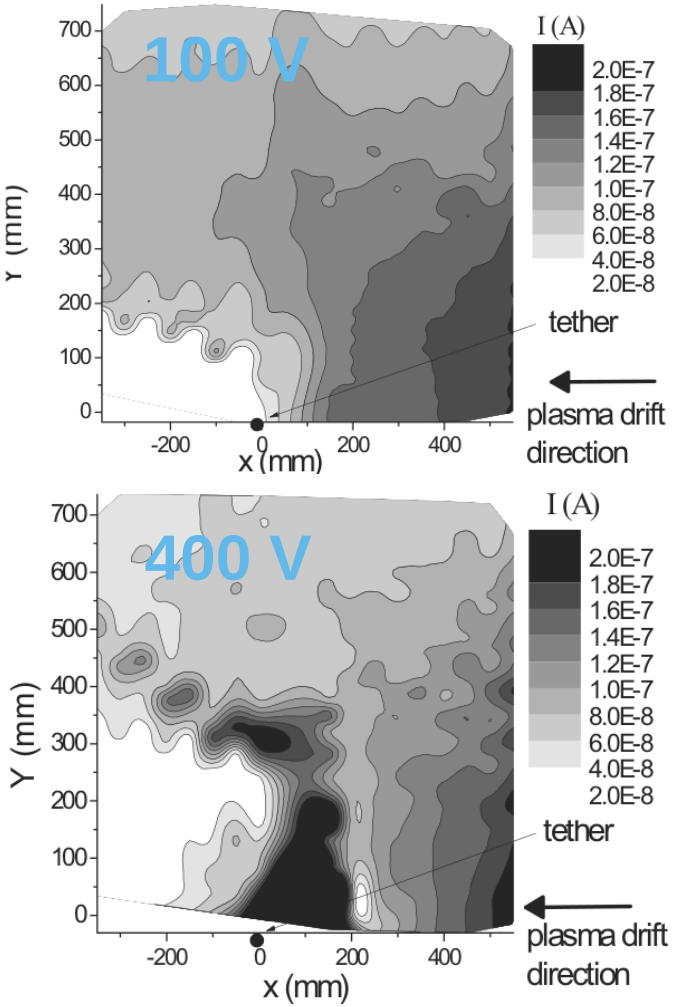


- Nominal solar wind parameters at 1 au

- Typical thrust per length 0.5 mN/km at 20 kV tether voltage
- Typical tether mass per length 10 grams/km
- Tether only: $a=F/m$ = 50 mm/s² = 130 km/s/month
- E-sail system: $a=F/m$ ~ 5 mm/s² = 13 km/s/month

Laboratory experiment

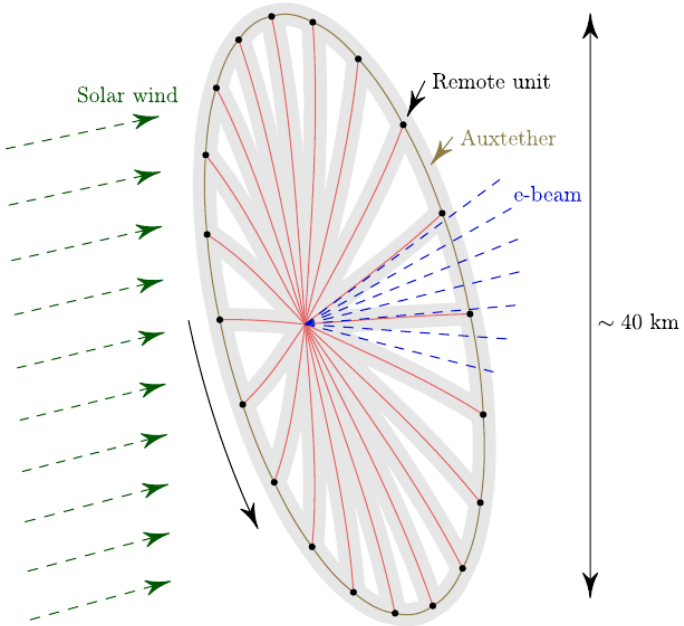
- Sheath width as function of tether voltage (Siguier et al., 2013*)
- LEO-like plasma, tether voltage 100 V and 400 V
- Good agreement with plasma simulation
- Sheath width is a proxy for thrust

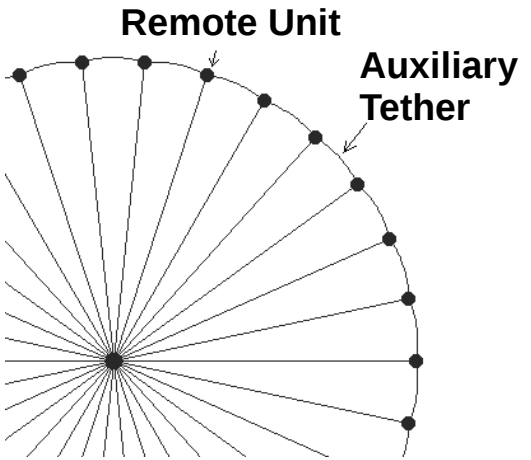


(*)Siguier, J.-M., P. Sarrailh, J.-F. Roussel, V. Inguimbert, G. Murat and J. SanMartin, Drifting plasma collection by a positive biased tether wire in LEO-like plasma conditions: current measurement and plasma diagnostics, IEEE Trans. Plasma Sci., 41, 3380-3386, 2013

Multi-tether E-sail

- Centrifugal force to stretch tethers
- Auxiliary tethers to stabilise dynamics
- 20 kV voltage, 0.5 mN/km thrust
- If 100x20 km tethers →1 N thrust at 1 au
- Thrust scales as $1/r$
- 30 km/s delta-v per year if 1000-kg s/c, propulsion system mass <200kg
- Power consumption 700 W at 1 au
- Power consumption scales as $1/r^2$





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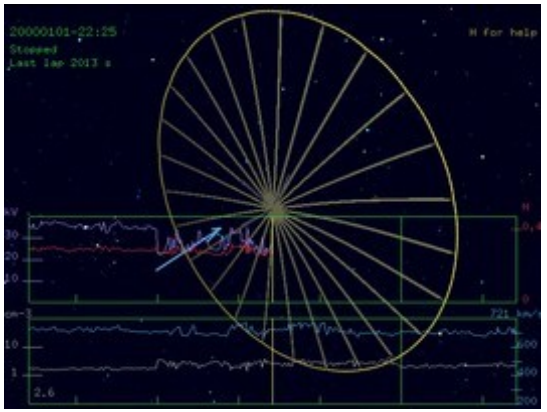
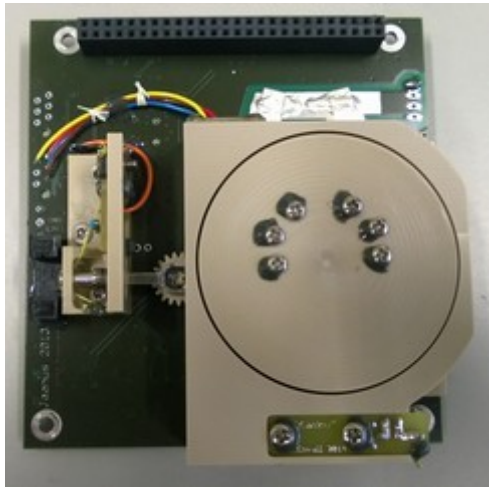
FP7 “ESAIL” project outcomes (2013)

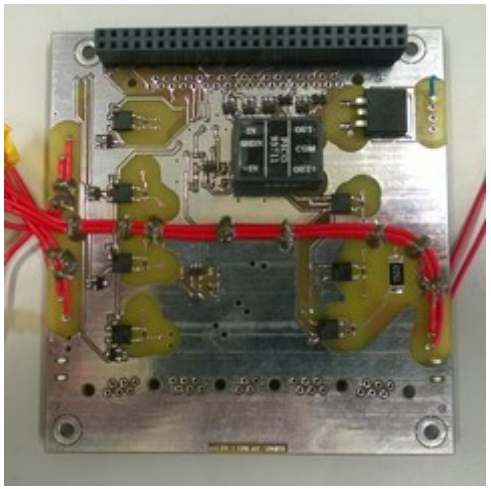
- 1 km tether
- Remote unit for 0.9-4 au
  - TRL 5 environmentally tested
  - Mass 0.56 kg

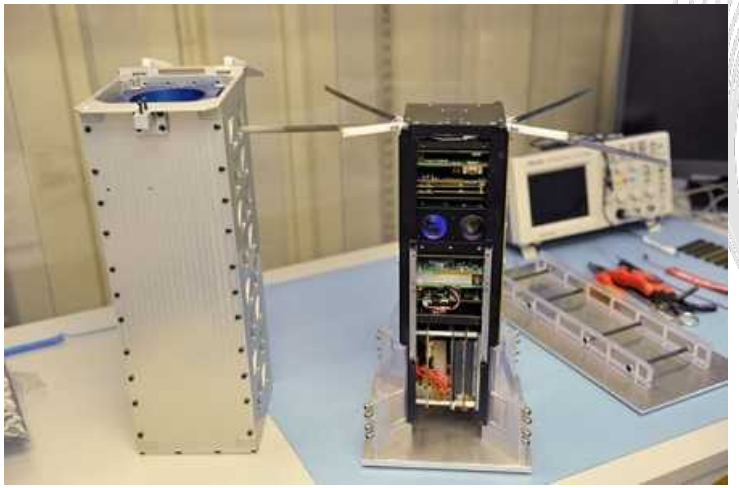
- “Flight simulator”



Cubesat testing



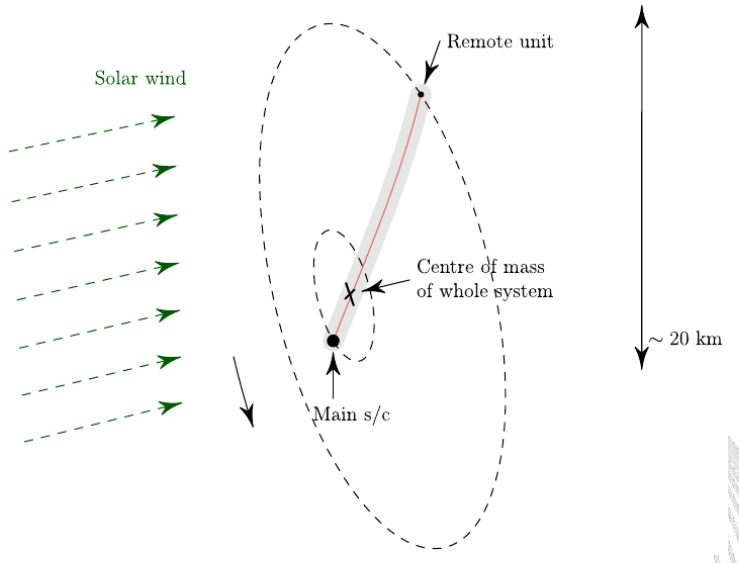


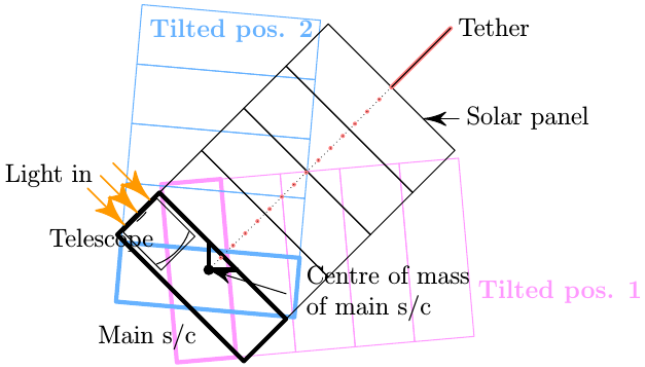


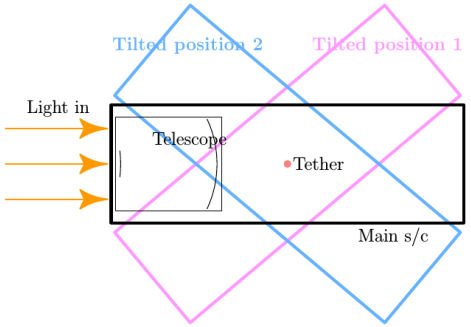
- Aalto-1 (3-U LEO cubesat):
  - 100 m tether
  - 2 PCBs: HV card and motor card, ~300 gram total mass
  - Launch June 2017 (?) by PSLV
- Forthcoming: ESTCube-2, 300 m tether

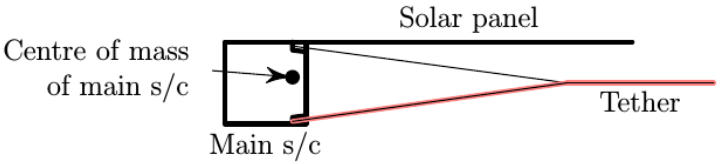
Single-tether E-sail for nanosats

- 10-20 km tether
- 10-20 kV voltage
- 2.5-10 mN thrust at 1 au
- Spacecraft pointing possible









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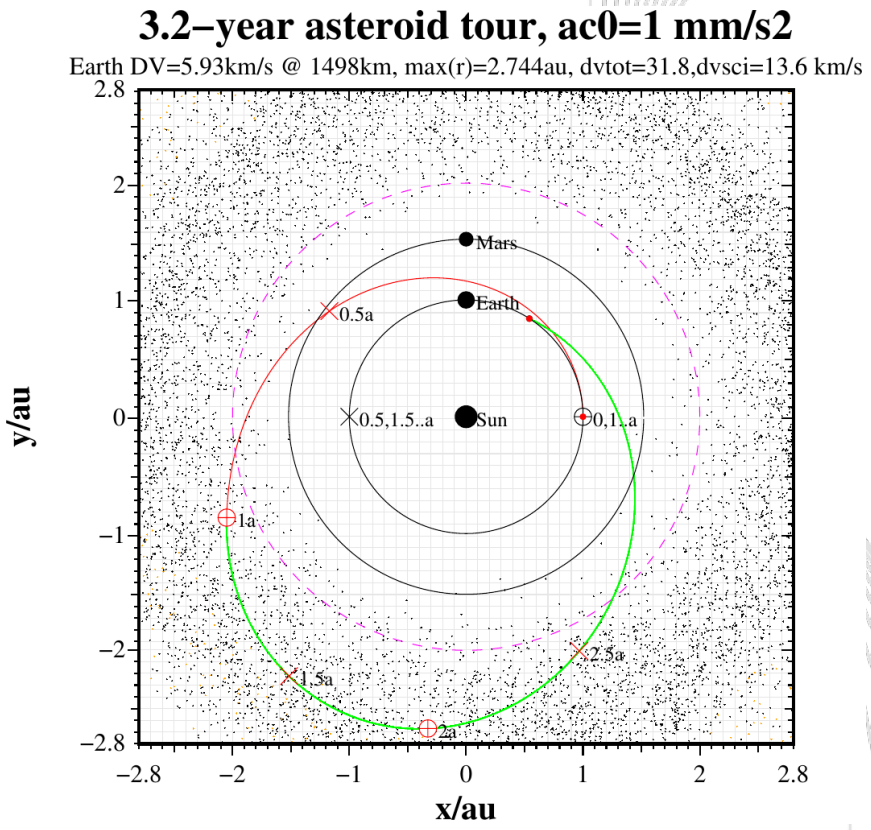
Flyby of 300+ asteroids

- Fleet of 50 nanosatellites (scalable)
- Launch to marginal escape, e.g. PSLV
- Each s/c makes flyby of 6-7 asteroids
- Ø=4 cm telescope + NIR spectrometer
- Use the telescope also for navigation
- Data (10 GB per s/c) retrieved at final Earth flyby: dipole antenna is enough
- Proposal *"**Multi-asteroid touring**"* to ESA's "Call for new science ideas" (submitted Sept 2016, selected 2017)
- Cost level: ~60 M€ (S or F mission)



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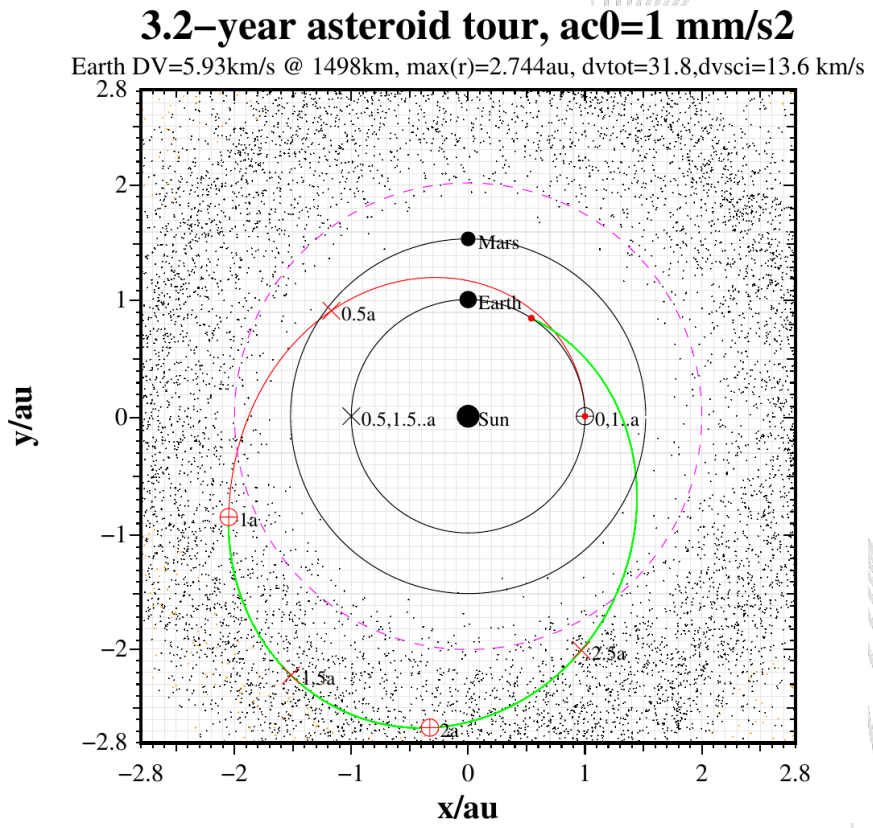
Highlights

- Cheap: 0.2 M€ per imaged asteroid.
- 1000 km nominal flyby distance: diffr. limit surface resolution 17 m.
- PSLV can lift ~50 sats which corresponds to 300+ asteroids.
- Enabling techs: 1) E-sail, 2) flash memory, 3) autonomous optical navigation.
- The fleet can be targeted for science or for asteroid mining.
- Advanced version for Jupiter Trojans might also be feasible (8 year tour).



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Conclusions

- We propose using the single-tether E-sail to tour the asteroid belt using cubesat platforms.
- Low-cost way of getting flyby data of asteroids (0.2 M€ per asteroid).
- The low cost is enabled by low mass of spacecraft and low telemetry costs due to executing an Earth flyby at the end.
- The proposal was selected by ESA for further study in 2017.