FINNISH METEOROLOGICAL INSTITUTE

# Electric Solar Wind Sail tether payloads onboard CubeSats

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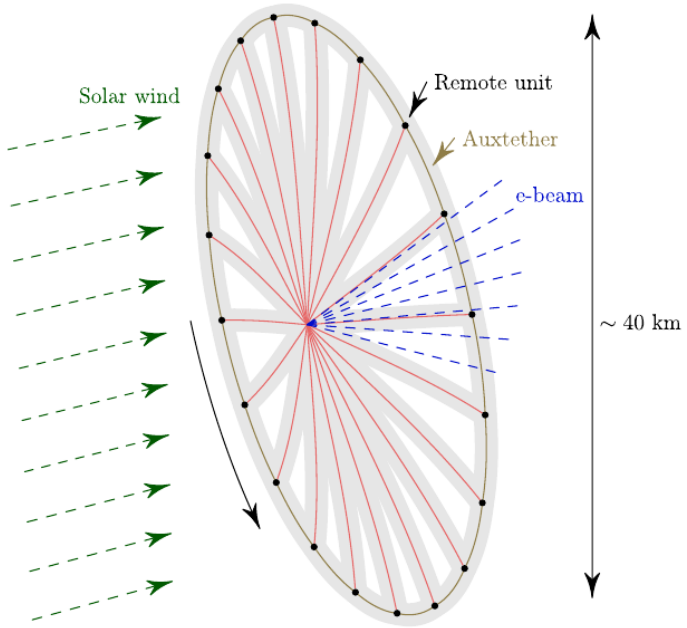
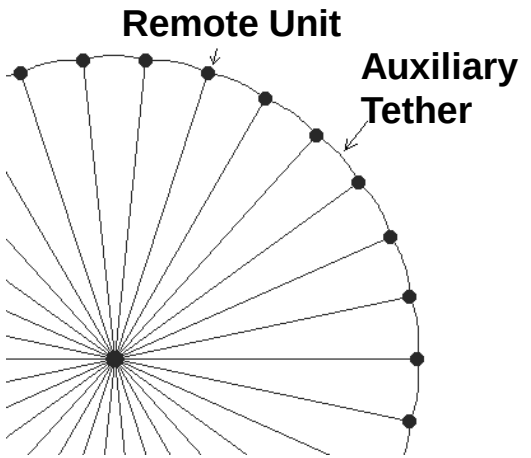
# Outline

- E-sail & Coulomb drag propulsion.
- Missions enabled by E-sail.
- E-sail tether payloads in CubeSats, general.
- Flight history: ESTCube-1 and Aalto-1.
- Tether production.
- ESTCube-2/3.
- Conclusions.

# E-sail

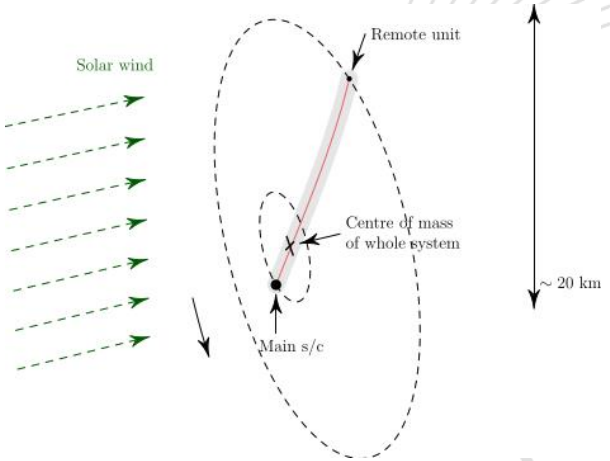
- Charged tether taps momentum by deflecting ion flow of solar wind → “Coulomb drag”.
- One or more tethers.
- Centrifugal force to stretch tethers.
- Auxiliary tethers to stabilize dynamics.
- For 20 kV voltage, F/l = 0,5 mN/km.
- Positive or negative voltage. With positive V, electron gun(s) used to oust excess electrons.
- For 100×20 km tethers, F = 1 N @1 au.
- Thrust scales as $1/r$.
- For 1000 kg spacecraft (propulsion system mass <200kg), $\Delta v$ = 30 km/s/year.
- Power consumption 700 W @1 au.
- Power consumption scales as $1/r^2$.

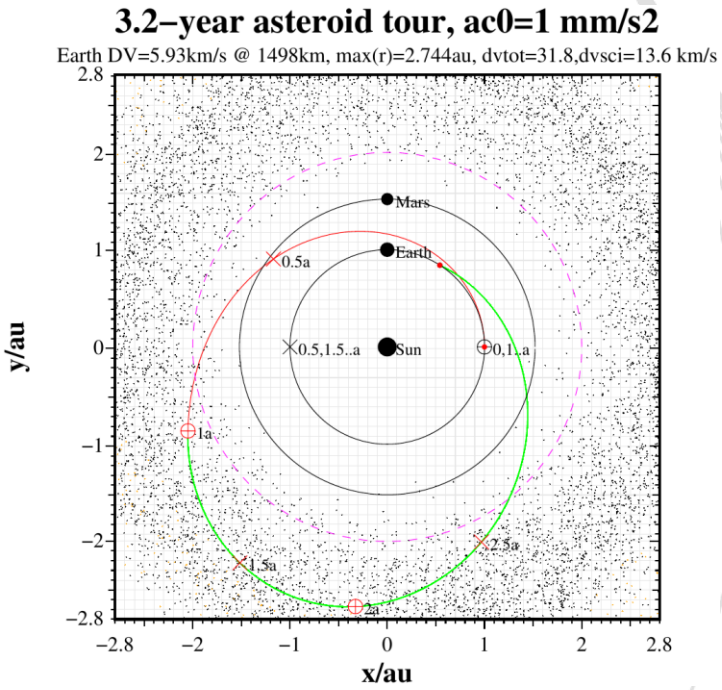


# E-sail mission examples

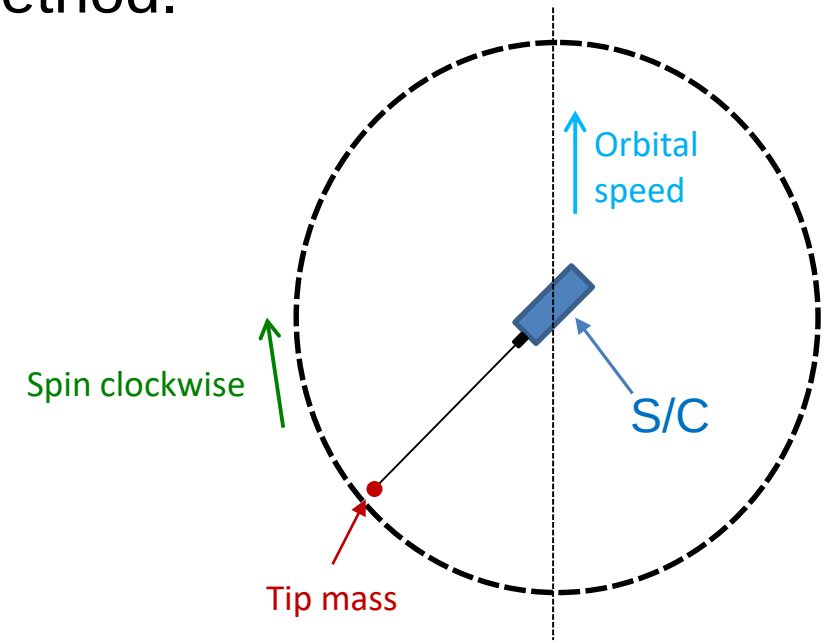
- Science missions to the outskirts of the Solar System (or beyond).
- Spiraling inwards to the inner parts of the Solar System.
- Asteroid tours with scientific or commercial outcome.
- Plan: multi-asteroid touring mission by a fleet of (up to 50) CubeSats. *(Next presentation by Iaroslav Iakubivskyi)*



# E-sail & CubeSats

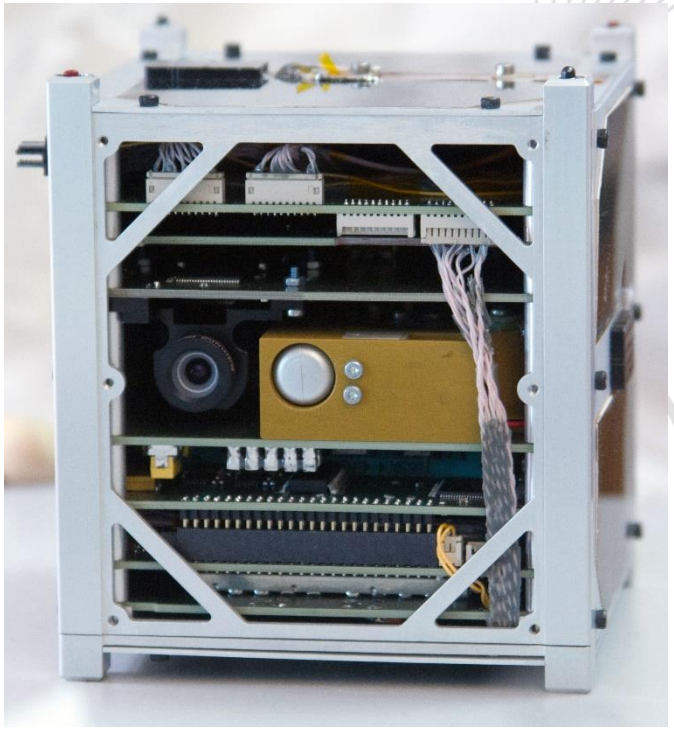
- Typical E-sail mission with CubeSat: 1-3U satellite, single tether (length tens to hundreds of meters; voltage ~1 kV).
- Orbit: so far LEO (ionospheric plasma instead of solar wind).
- Mission objectives: tether deployment by spinning the satellite; observing the Coulomb drag force with a suitable method.

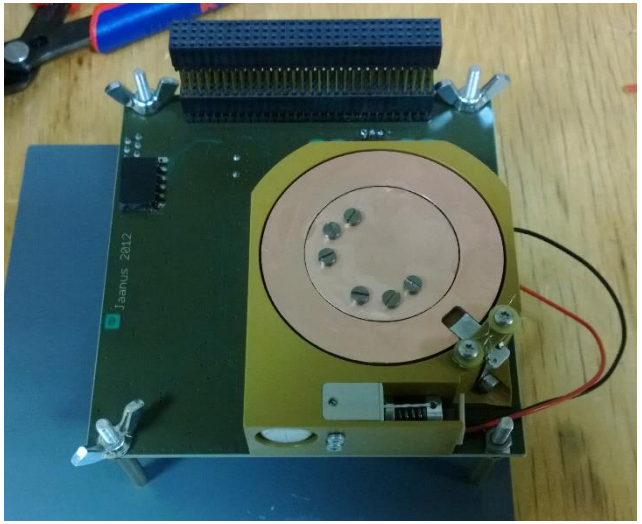



| Left Cycle | Right Cycle | Spin Rate |
|---|---|---|
| V ON | V OFF | Down |
| V OFF | V ON | Up |

# Previous launches, ESTCube-1

- Launched in 2013.
- 1U CubeSat.
- Two filament tether, 16 m.
- Tether voltage ±500 V.
- Two cold cathode e-guns.
- Result of tether mission: failed due to jammed tether deployment system.






ESTCUBE
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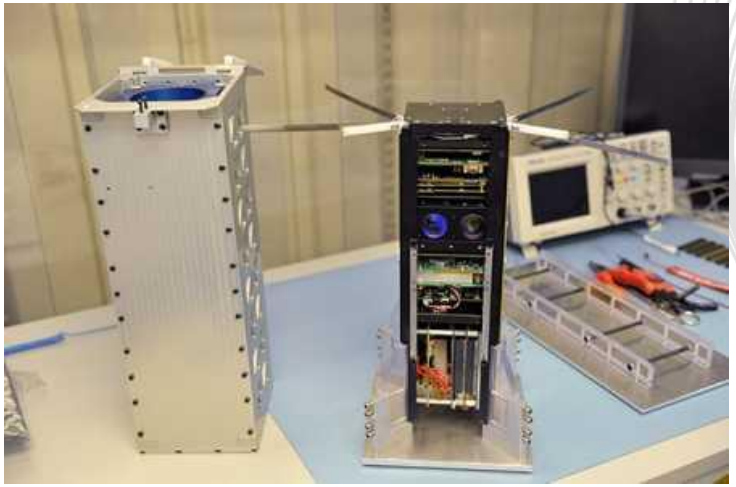
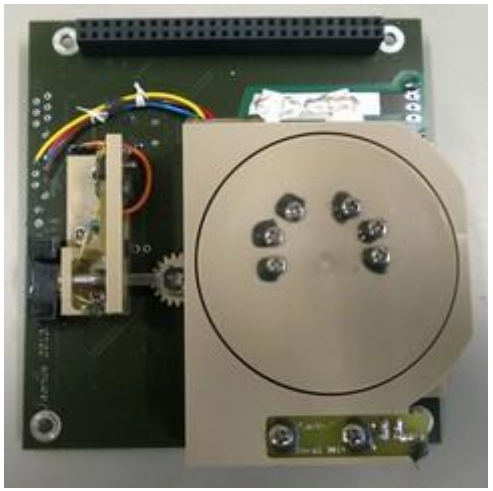
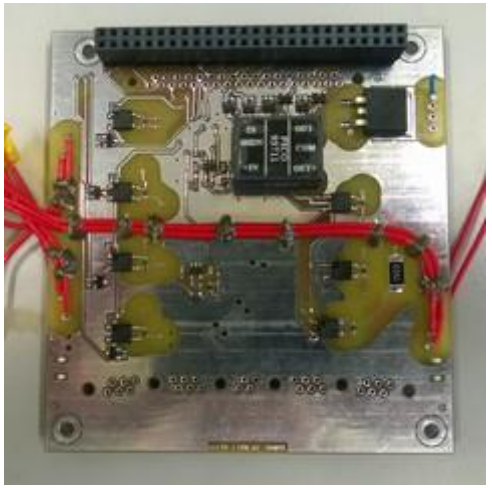
# Previous launches, Aalto-1

- Launched in 2017.
- 3U CubeSat.
- Four filament tether, 100 m.
- Tether voltage ±1000 V.
- Four cold cathode e-guns.
- Result of tether mission: Pending.





Tether board



High voltage board

**Aalto-1**

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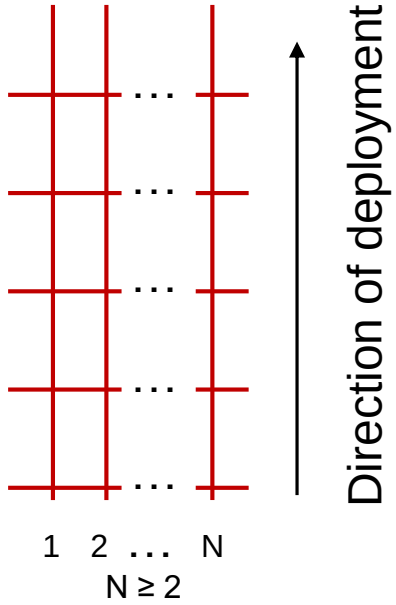
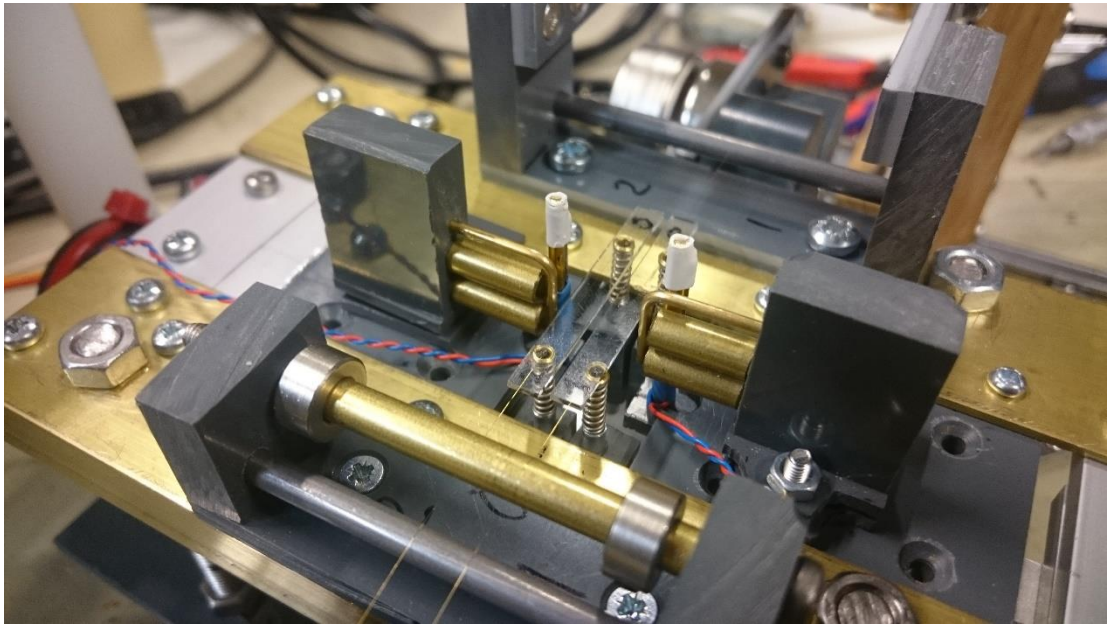
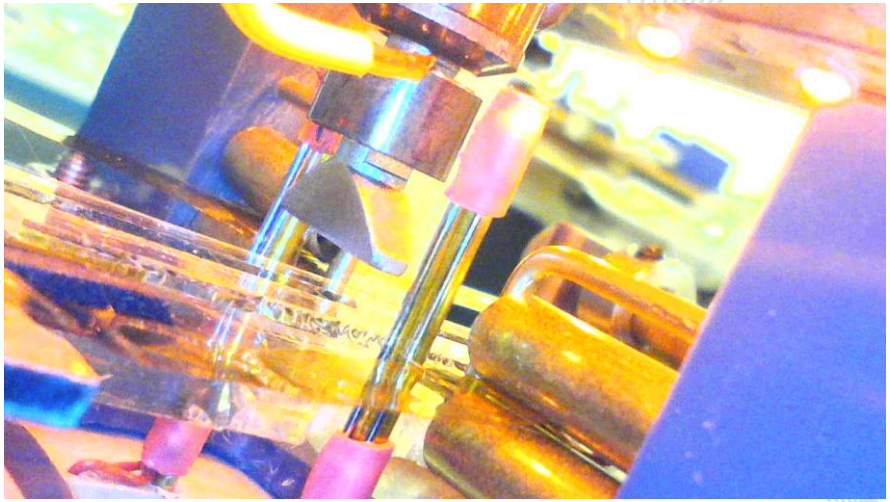
# Tether production

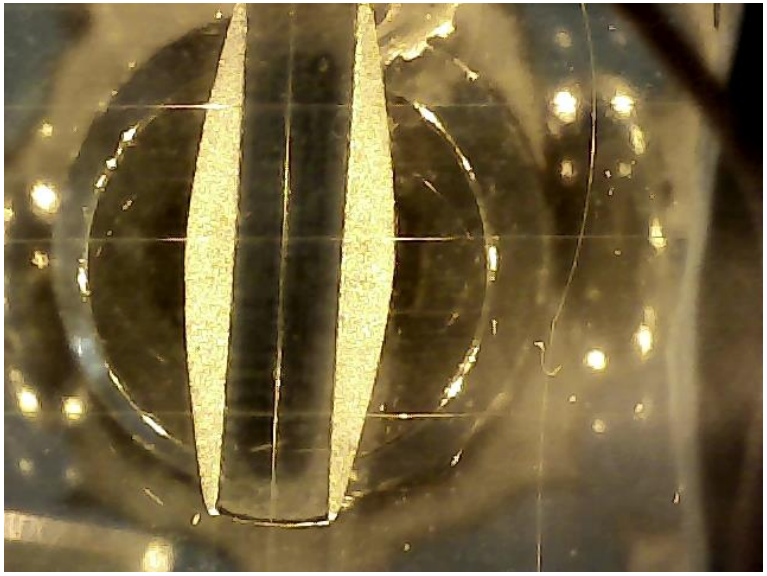
- E-sail tether requirements: high electrical conductivity; sufficient mechanical strength; suitable thermal characteristics; low mass; ***multifilament*** etc.
- Novel tether production facility under development (PI Envall). Ladder shaped tether, metal wires, cold welded bonds. Wire thickness 20 µm to 35 µm.



# Tether production (2)



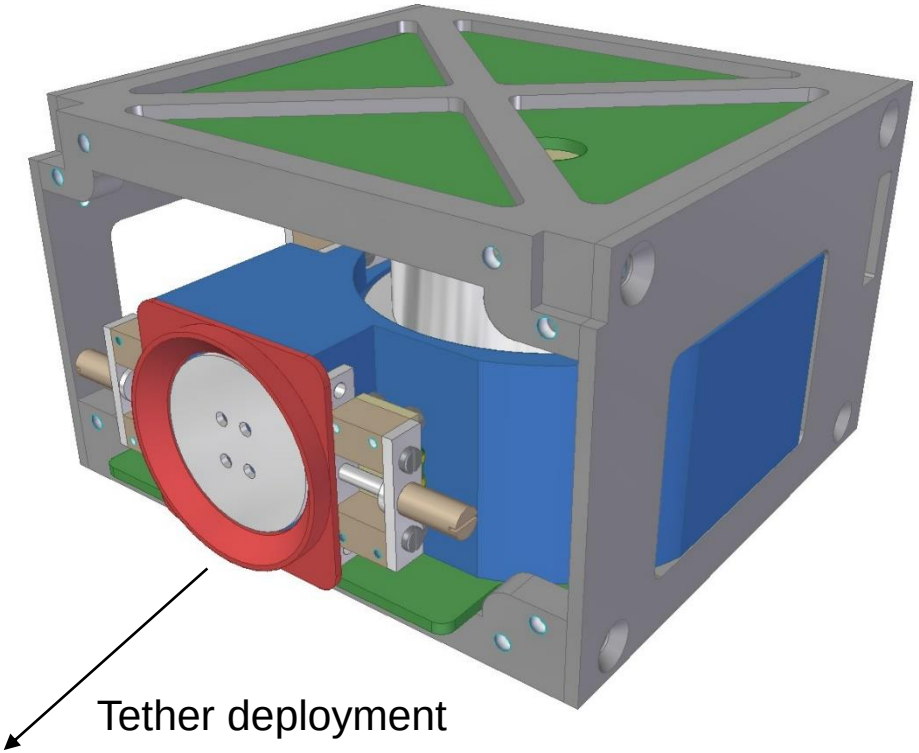


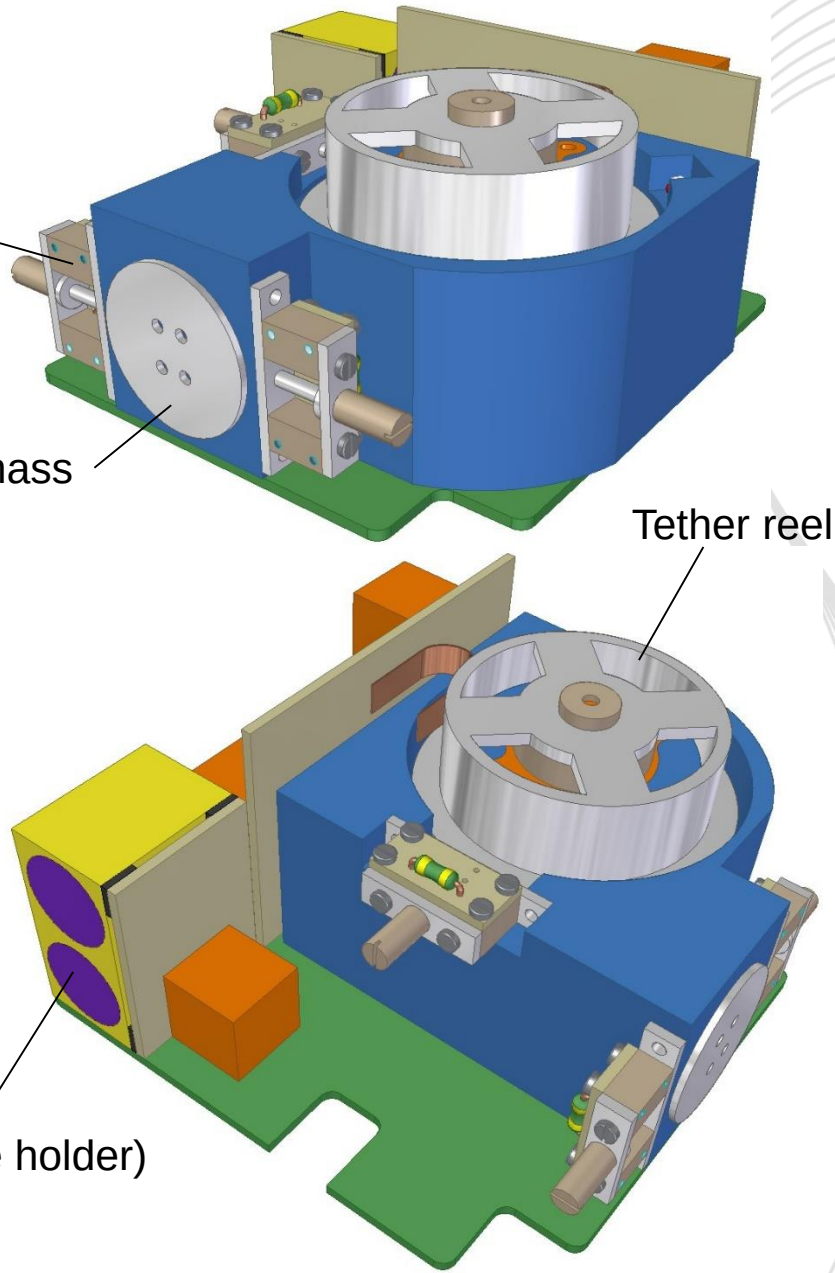


# ESTCube-2/3

- Both Coulomb drag test CubeSats thus far have remained at LEO → no solar wind plasma.
- ESTCube-3 to be the first to reach solar wind, e.g. lunar orbit or Lagrange point (L1, L2).
- ESTCube-2 will test novel key technologies of EC-3 in LEO. These include CubeSat compatible cold gas thrusters, star tracker based attitude determination system and high speed telecommunications system.
- Also additional LEO data received from ESTCube-2 (plasma brake).
- Satellites are close to identical by design.
- Tether length 300 m, voltage −1 kV…+6 kV.
- Expected Coulomb drag force in solar wind: 60 μN.

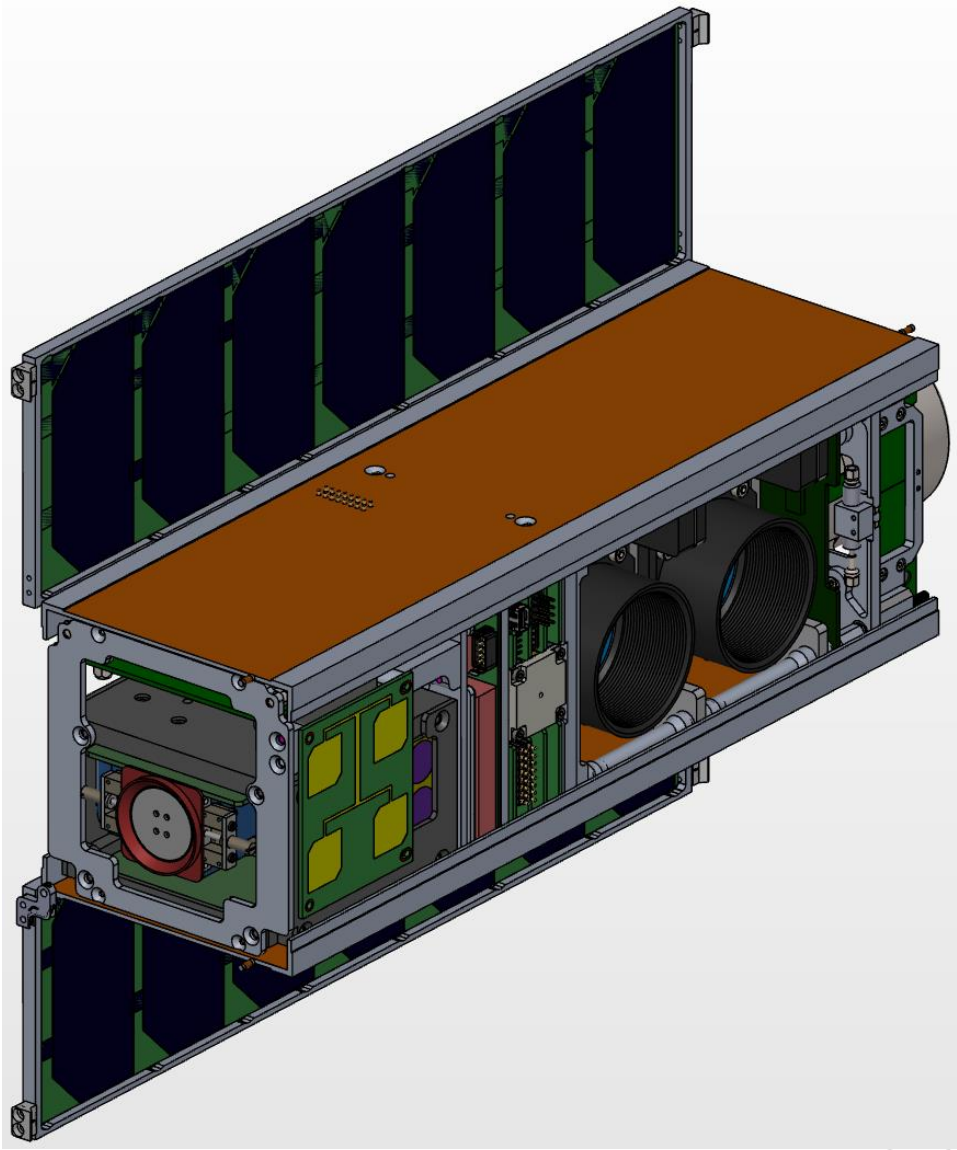
# ESTCube-2/3 (2)


Tether deployment


Launch lock × 3
Tip mass
Tether reel
E-guns (place holder)

# ESTCube-2/3, tether PL mass

| Item | Mass, g |
|---|---|
| Supporting structure | 133 |
| Control board PCB | 29 |
| Control Board Electronics | 20 |
| Launch Locks | 12 |
| Tether Chamber | 68 |
| Diagnostics | 10 |
| Tip mass | 3 |
| Tether Reel, incl. Tether | 34 |
| Reel Adapter | 2 |
| Reel Motor | 48 |
| Bus Connector(s) | 8 |
| HV PCB and electronics | 58 |
| Screws and Fasteners | 25 |
| Misc (cabling, adhesives etc.) | 15 |
| | |
| Sum | 465 |
| Margin, 20% | 93 |
| | |
| Total with margin | 558 |



# Conclusions

- Test missions of E-sail tether hardware have begun in 2013 (launch of ESTCube-1).
- A lot of progress has taken place on ground (novel tether topology, in-house production of tether, improved flight mechanics and diagnostics etc.)
- First proper test results from orbit are still waited for.
- Tether mission of Aalto-1 expected to start during summer.
- Next ESTCube satellites are already in development phase.
- ESTCube-3 is expected to be the first spacecraft to demonstrate the use of solar wind for spacecraft propulsion.