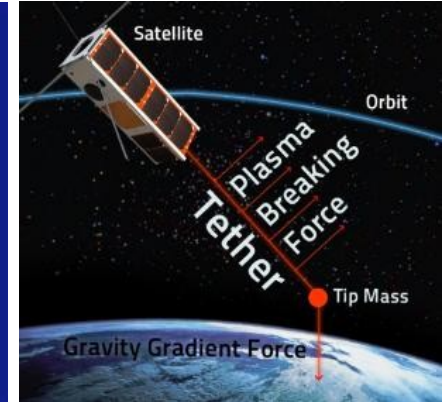
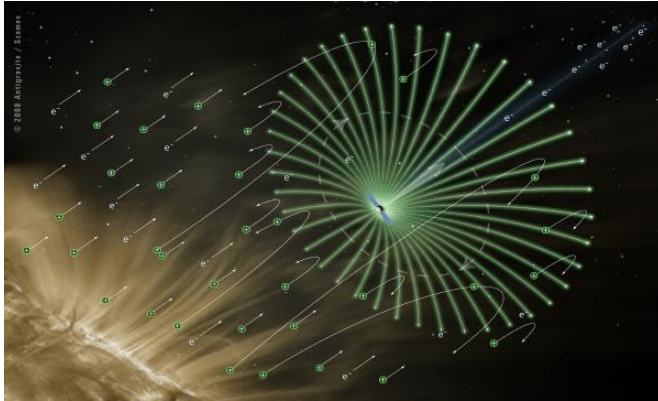




ILMATIETEEN LAITOS  
METEOROLOGISKA INSTITUTET  
FINNISH METEOROLOGICAL INSTITUTE



# ESAIL: Electric SAIL propulsion technology

**“Let's embrace Space”, Rome, Sept 16, 2014**

Pekka Janhunen

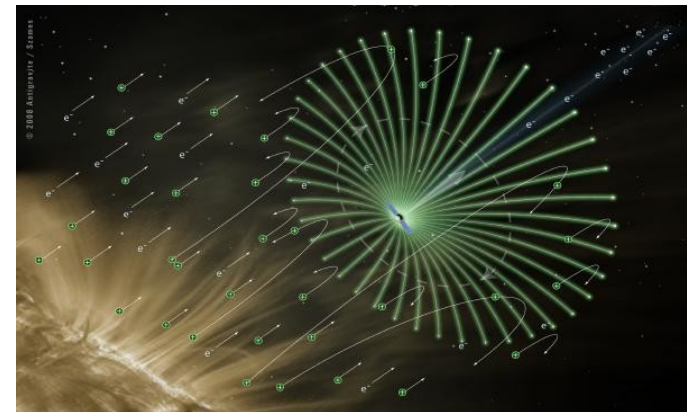
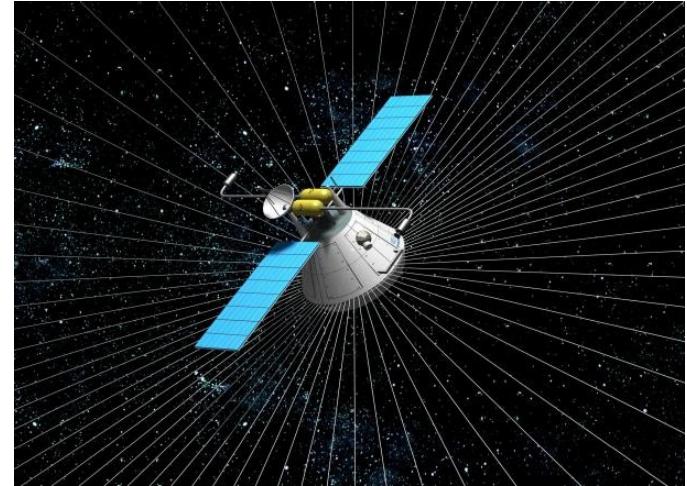
*Finnish Meteorological Institute, Helsinki*

(ESAIL Coordinator)



# Contents

- ESAIL FP7 Partners
- The E-sail effect
- E-sail construction
- ESAIL project results
- ESTCube-1 and Aalto-1 CubeSats
- Planned CubeSat missions
- Conclusions





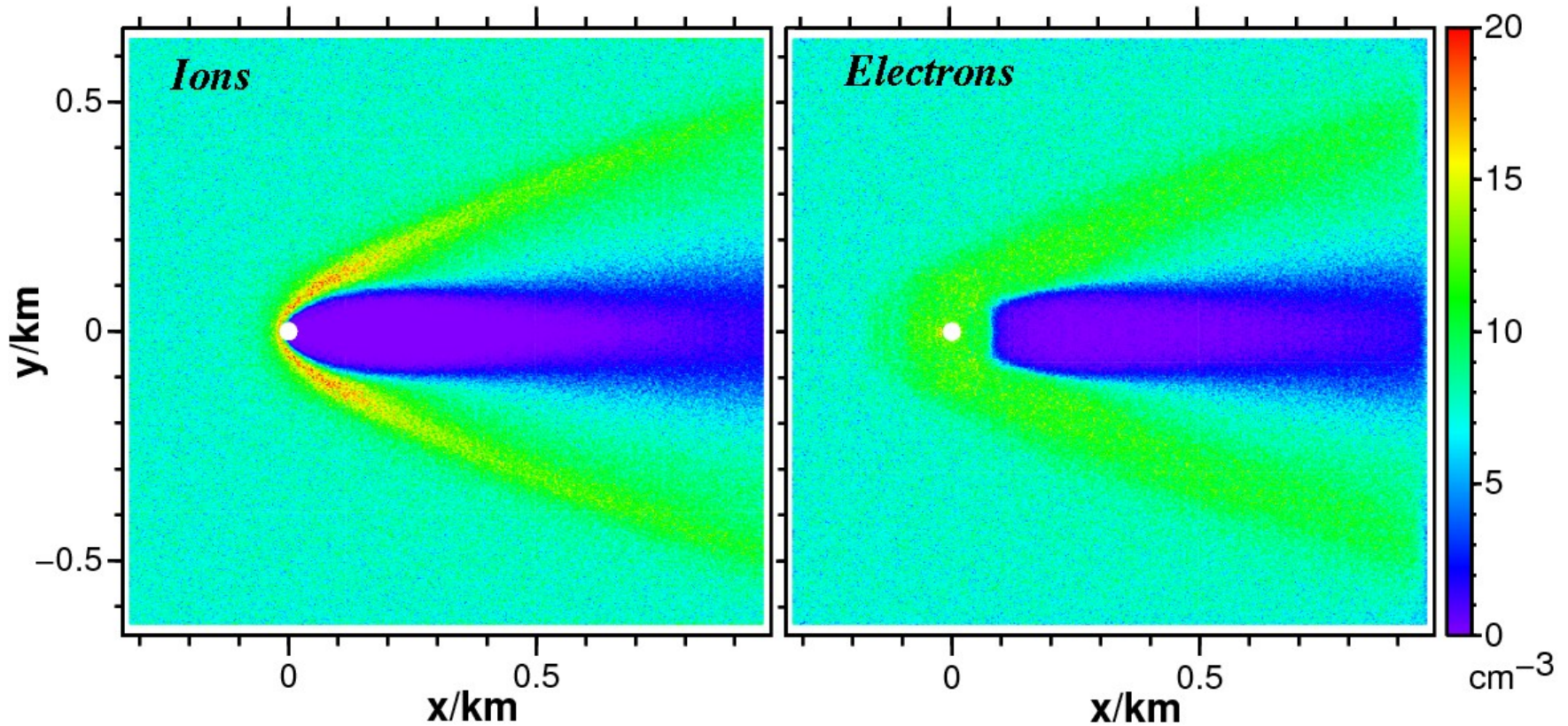
# ESAIL Partners and their roles

- Finnish Meteorological Institute, Finland: **Coordinator & inventor group of E-sail**
- University of Helsinki, Finland: **Ultrasonically bonded E-sail tether**
- University of Jyväskylä Accelerator Lab., Finland: **Various vacuum tests of tether**
- DLR-Bremen, Germany: **Tether reel**
- Ångström Space Technology Centre, Uppsala University, Sweden: **Remote Unit**
- Nanospace AB, Uppsala: **Remote Unit cold gas thruster option**
- Tartu Observatory, Tartu, Estonia: **Some subsystems of Remote Unit**
- University of Pisa, Italy: **E-sail mission orbit calculations**
- Alta S.p.A., Pisa, Italy: **Remote Unit ionic liquid FEEP thruster option**





# The E-sail effect



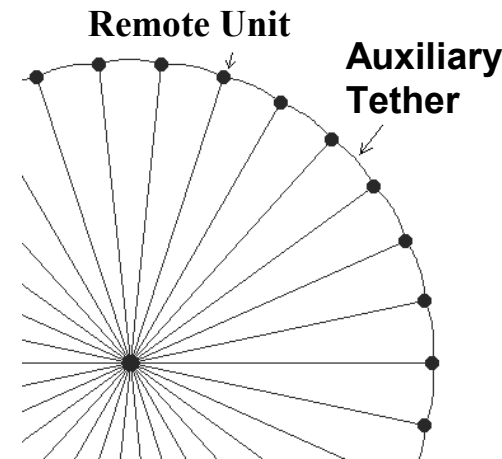
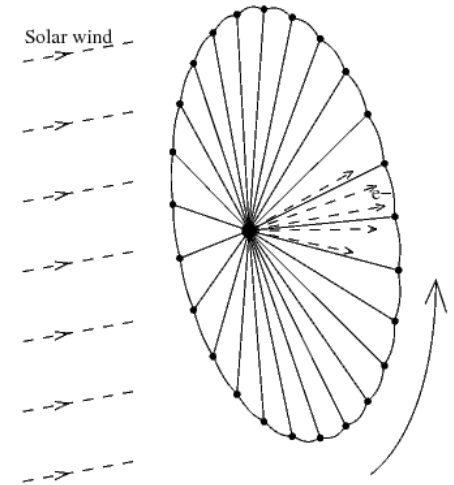
- PIC simulation with solar wind parameters

<http://www.electric-sailing.fi>



# E-sail construction

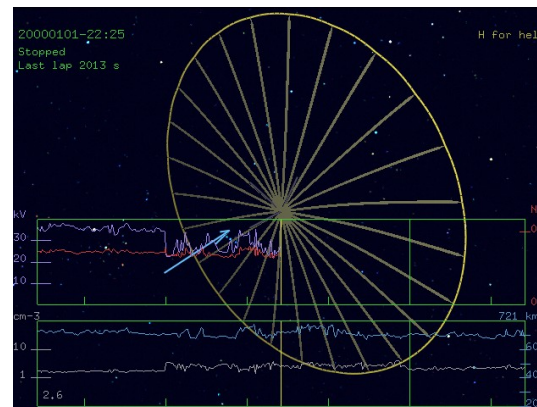
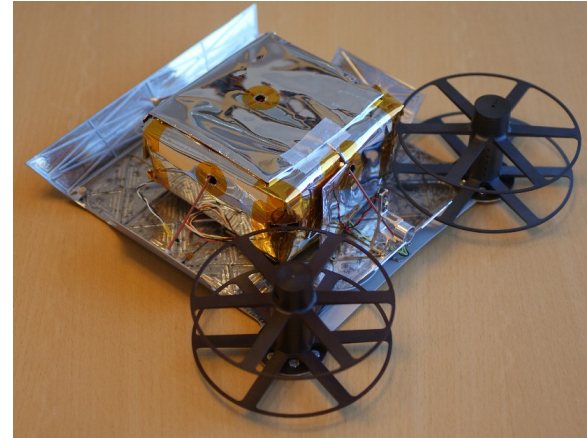
- Positive tethers (10-20 km length made of 25-50  $\mu\text{m}$  wire, +20-40 kV voltage)
- Up to 1 N thrust (scales as  $1/r$ ) from 100-200 kg unit (30 km/s delta-v per year to 1000 kg spacecraft)
- Power consumption modest, scales as  $1/r^2$
- Baseline approach uses non-conducting **Auxiliary Tethers** to stabilise flight without active control
- “**Remote Units**” at tips contain aux tether reels and spinup propulsion/spin control





# ESAIL FP7 project results

- Produced **1 km tether**
- Demonstrated unreeling after vibration test
- Tested in vacuum & under HV
- Prototyped and tested the **Remote Unit**
- E-sail “**flight simulator**”

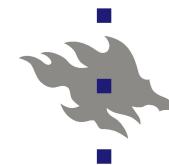




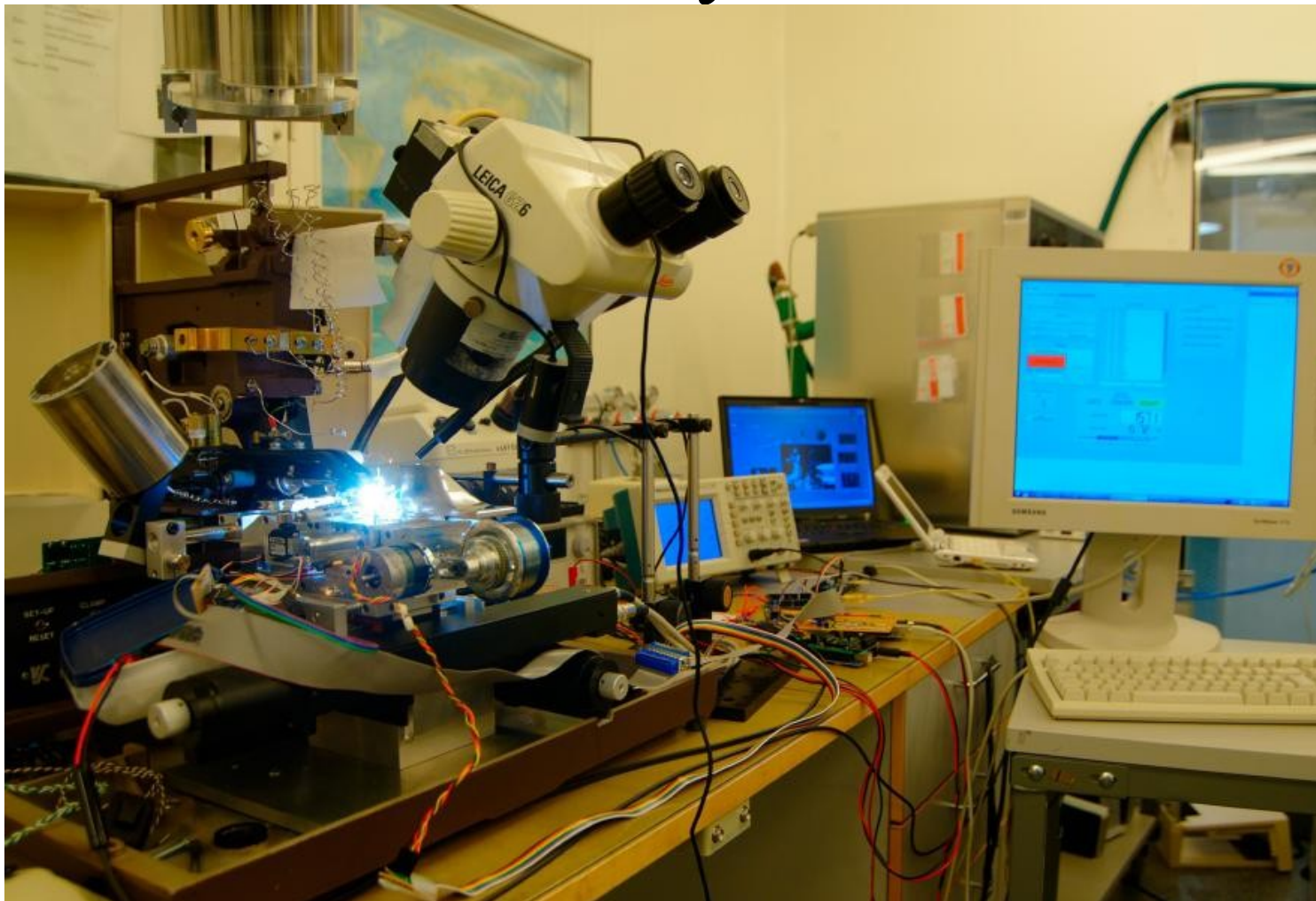
ILMATIETEEN LAITOS  
METEOROLOGISKA INSTITUTET  
FINNISH METEOROLOGICAL INSTITUTE



# E-sail tether factory



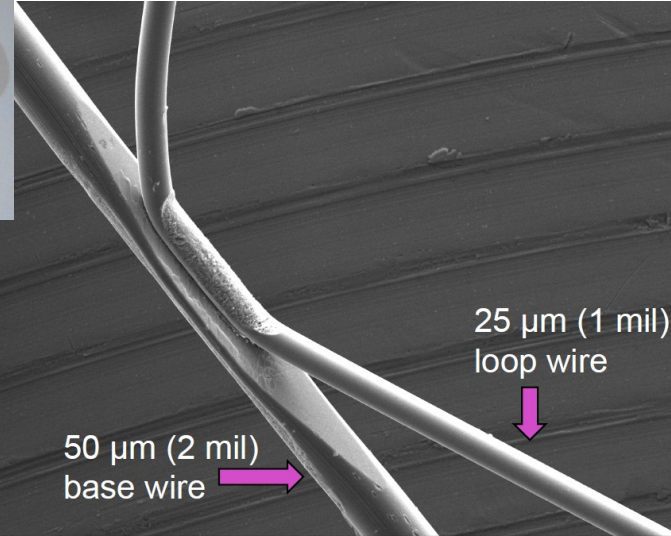
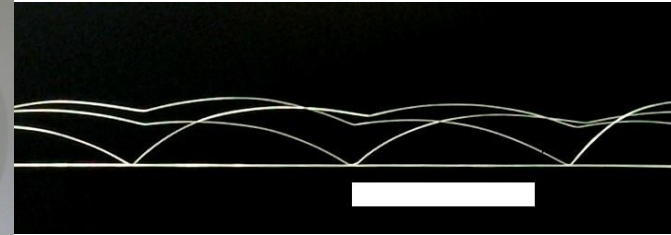
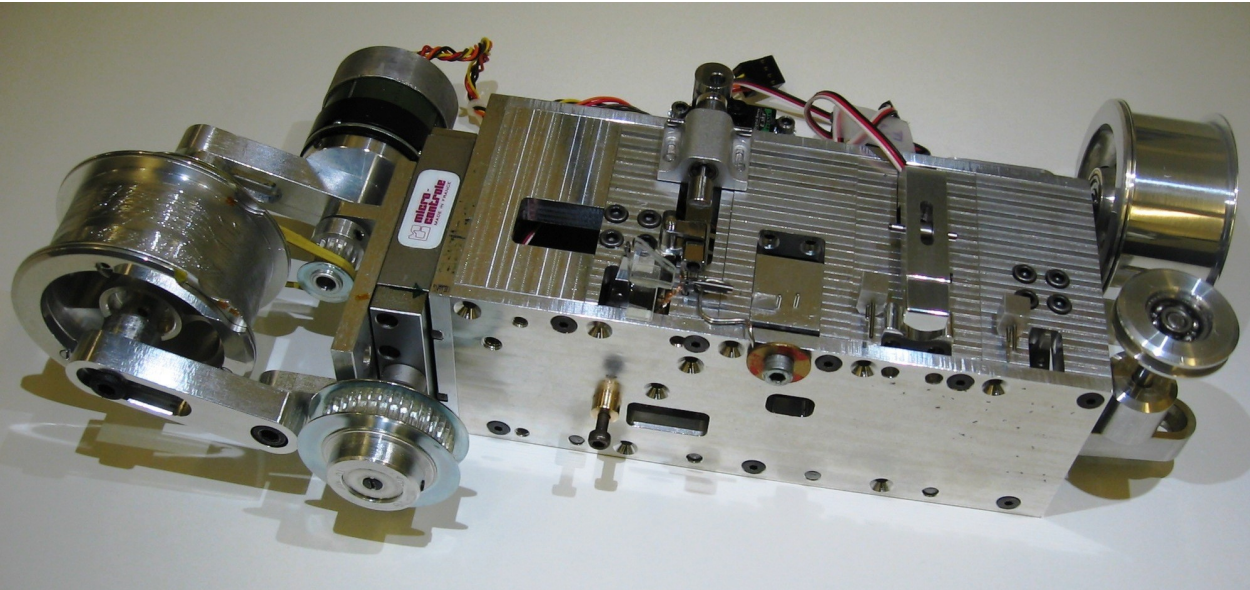
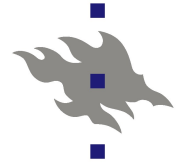
UNIVERSITY OF HELSINKI



<http://www.electric-sailing.fi>



# Tether factory and its product



S4800 20.0kV x200 SE(M)

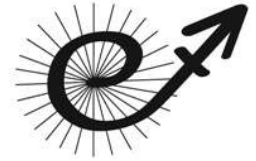
200 $\mu\text{m}$



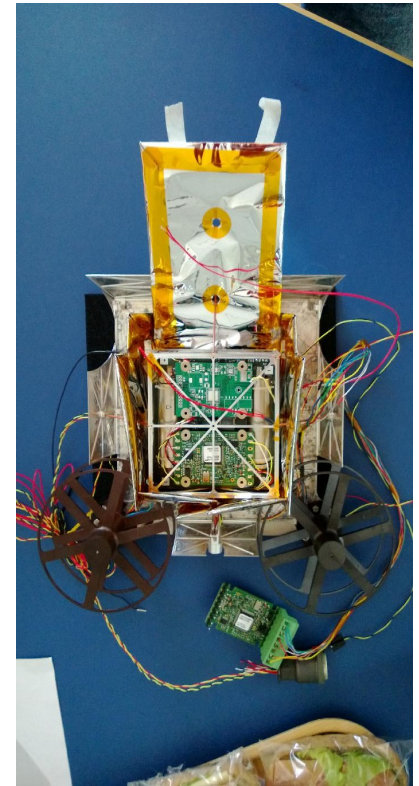
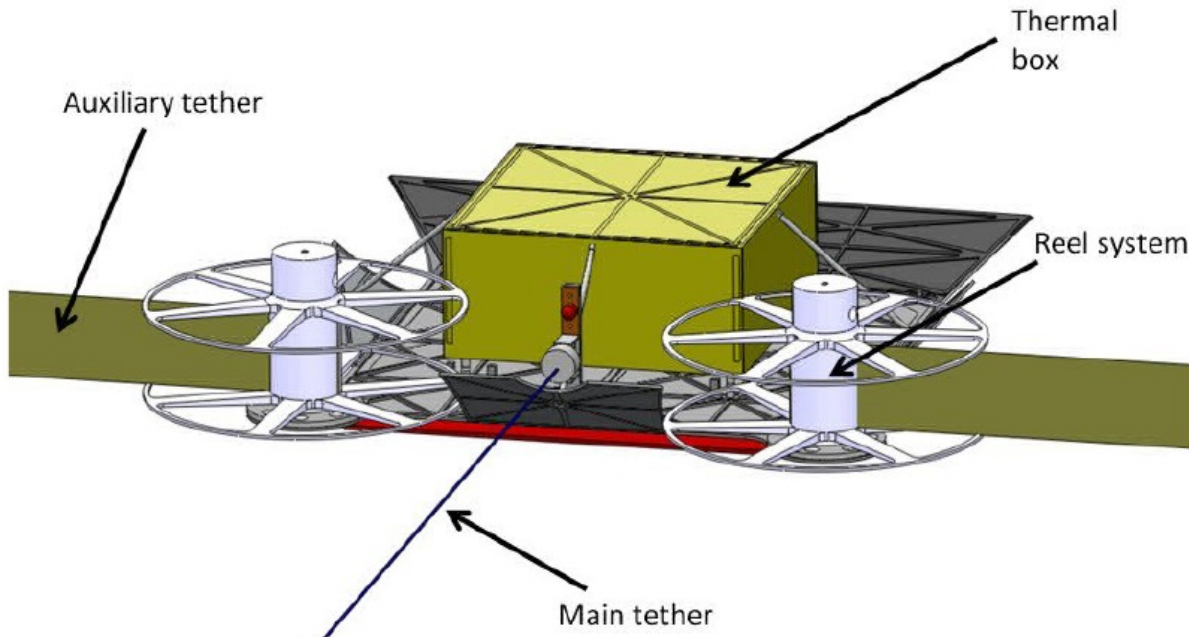




# E-sail “Remote Unit”



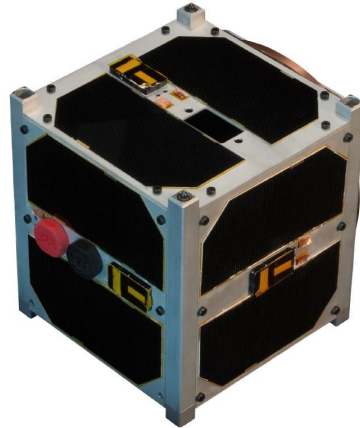
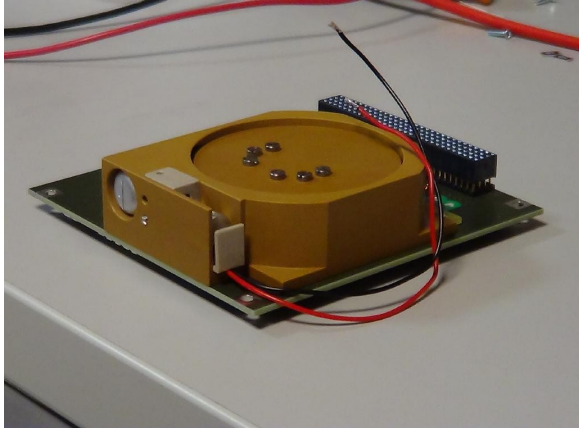
- Reels of auxiliary tethers and cold gas (or FEEP) thrusters to initiate and control spin



- Remote Unit  $m=0.56$  kg (CG version dry), allowed solar distance range 0.9-4 au



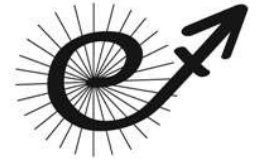
# ESTCube-1 E-sail test mission



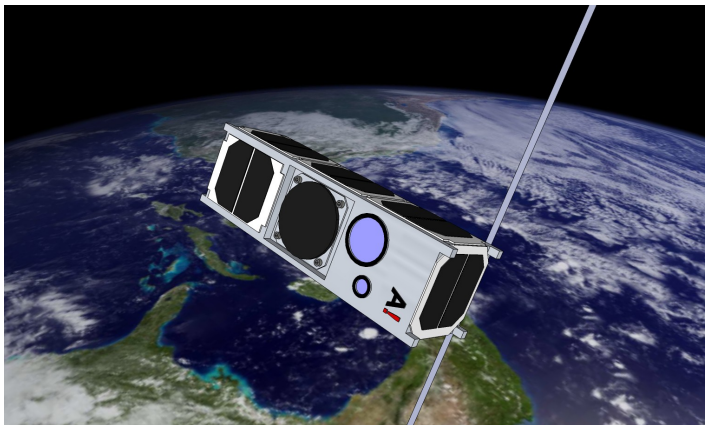
- 1-U CubeSat built by Estonian students, 670 km orbit
- 10 m tether,  $\pm 500$  V
- Launched May 7, 2013 (Vega/Kourou)
- Tether experiment scheduled for September 14, 2014 (!)



# Aalto-1 E-sail test mission



- 3-U CubeSat, work led by Aalto University, Finland
- 100 m tether, similar orbit as ESTCube-1
- Satellite carries also other payloads
- Planned launch 2015





# Planned E-sail missions

- BCUBE: 3-U CubeSat in LEO with 1 km tether
  - Demonstrate Plasma Brake deorbiting of the satellite
  - Flight-validate hardware for ECUBE
- ECUBE: 3-U CubeSat in solar wind with 1 km tether
  - Nearly identical with BCUBE, but different orbit
  - Measure E-sail effect in solar wind (for example, lunar mission piggyback)
  - Demonstrate simple E-sailing in solar wind
- OLCUBE: 3-U CubeSat near Lagrange L1 point for off-Lagrange solar wind monitoring
  - First scientific/commercial application of E-sail: space weather prediction with longer warning time
- “Production-scale” E-sail demonstration mission (NEO?)

*<http://www.electric-sailing.fi>*



# Conclusions

- ESAIL reached its goal: E-sail technology is at TRL 4-5
- 1 km piece of tether was successfully made
- Predicted E-sail performance level is revolutionary
  - Disruptive technology
- Outside ESAIL: ESTCube-1 is in orbit (10 m tether), Aalto-1 launched 2015 (100 m tether)
- Roadmap (still unfunded) of three CubeSat missions
  - The third one is scientific/commercial mission (off-Lagrange point solar wind monitor)

*<http://www.electric-sailing.fi>*