Dr. Eur Ing Malcolm Macdonald
22 April 2009
at the European Week of Astronomy and Space Science

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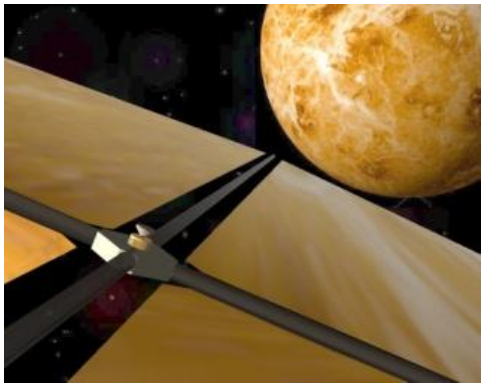
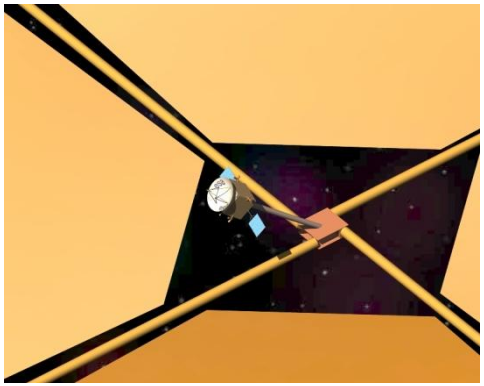
Advanced Space Concepts Laboratory

Solar Sailing as an Enabling Technology



frontier research on visionary space systems



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Overview

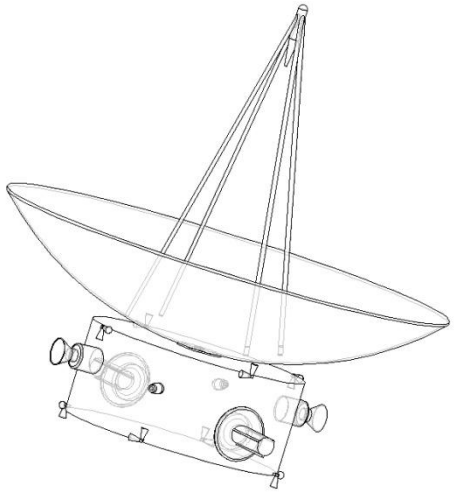
Solar Sailing

- Introduction to concept
- Current technology status & development

Mission Scenarios

- Technology Reference Studies mission catalogue
- Key Technology Reference Study mission concepts
- Technology Requirements

Solar Sailing Development Roadmap



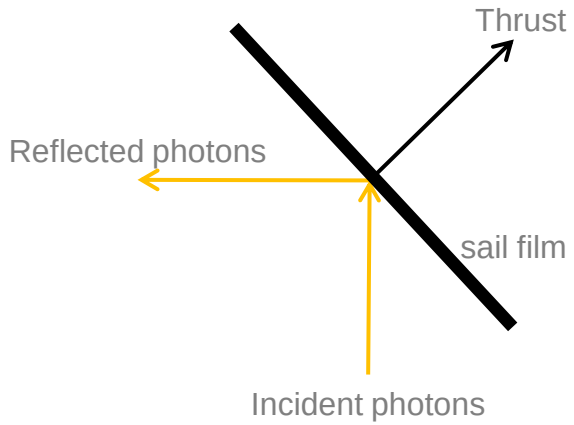
Solar Sail Propulsion

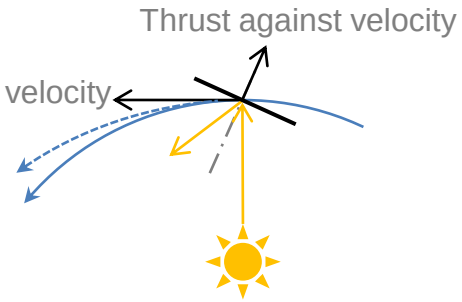
Light pressure for propulsion

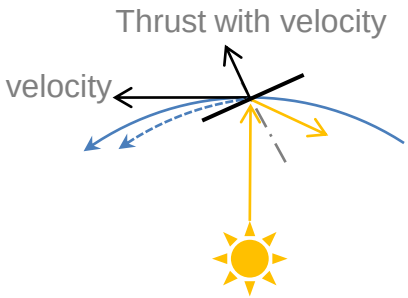
- Small but continuous force
- Large light weight structure

No propellant

- Enables new high-energy/long duration mission concepts
- Enhance existing mission concepts







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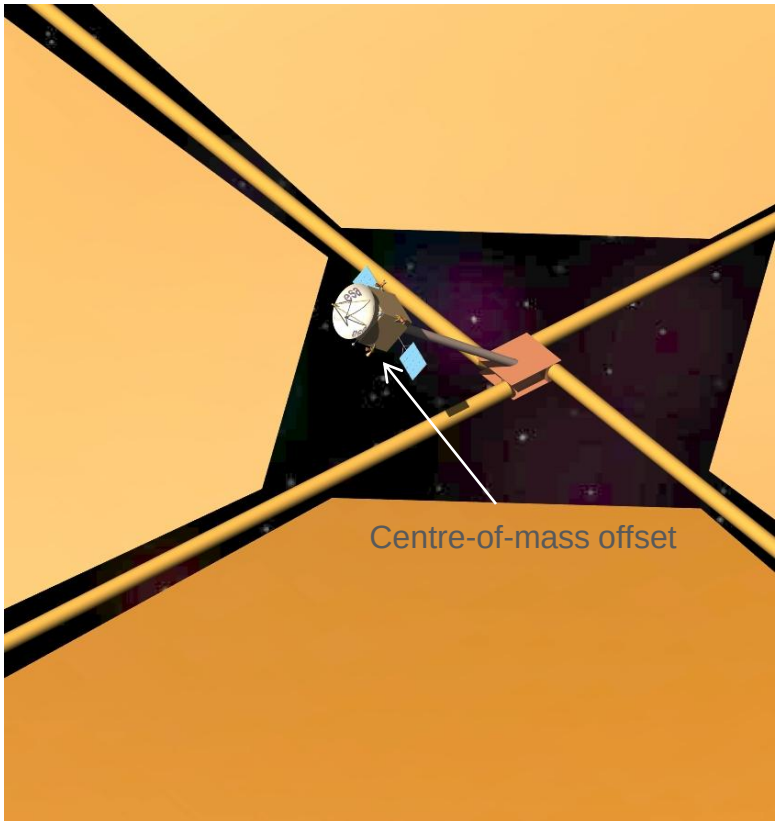
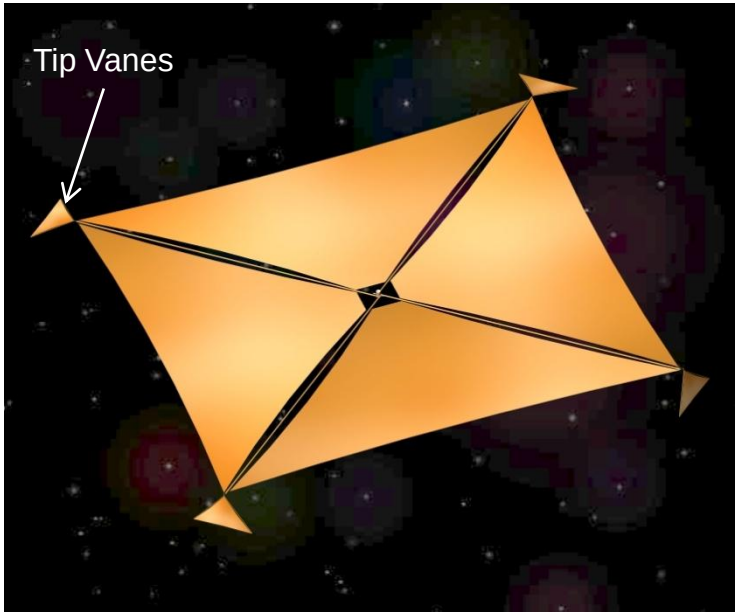
Attitude Control

Two main concepts considered



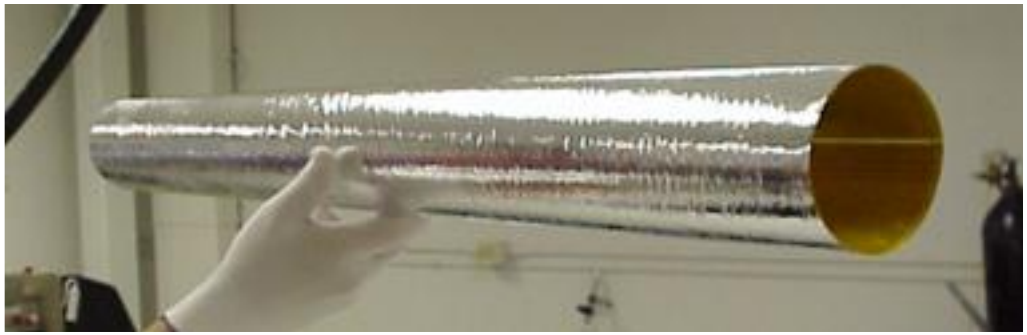


Can also consider μPPT at boom tips

- Introduces reaction mass

Sail Booms

Coilable (ATK Inc)



Inflatable - space rigidised (L'Garde)

Composite (DLR)

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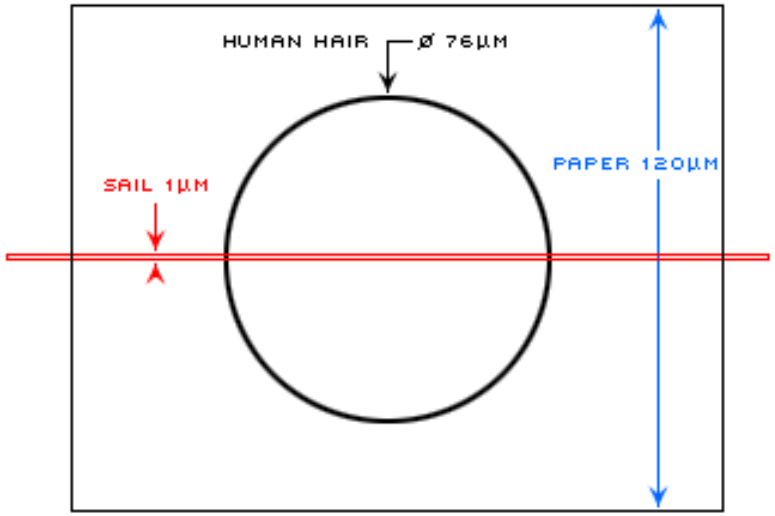
Sail Film



0.9 µm Mylar (L'Garde)

CP-1 film

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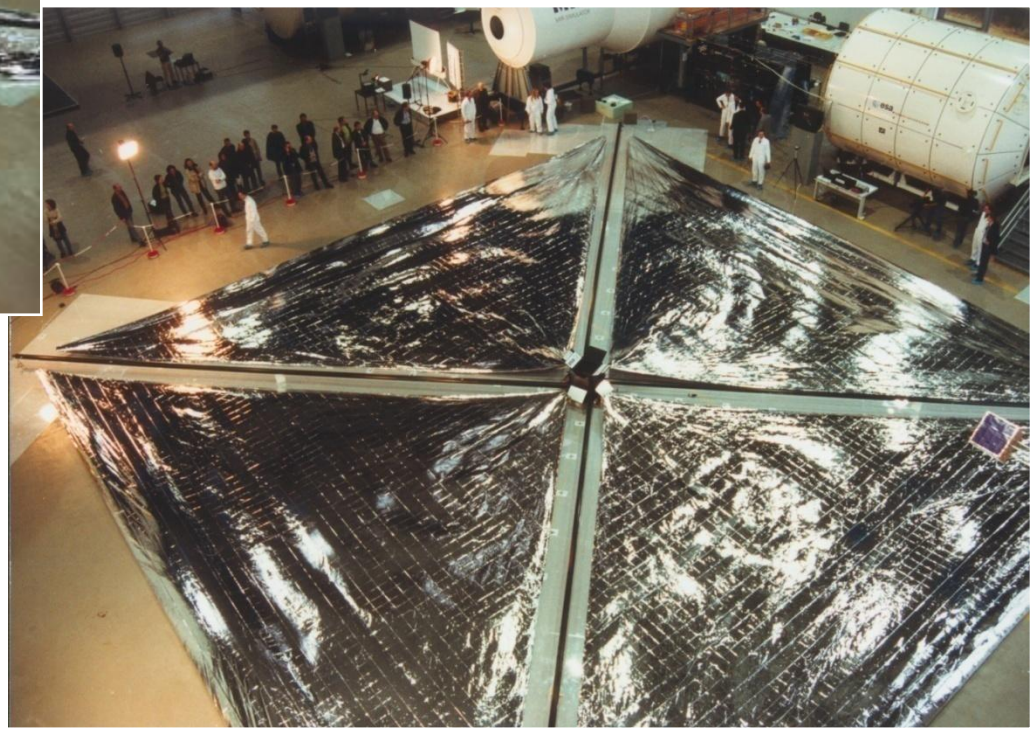
ESA Ground Test (1999)

20 x 20 m ESA ground test



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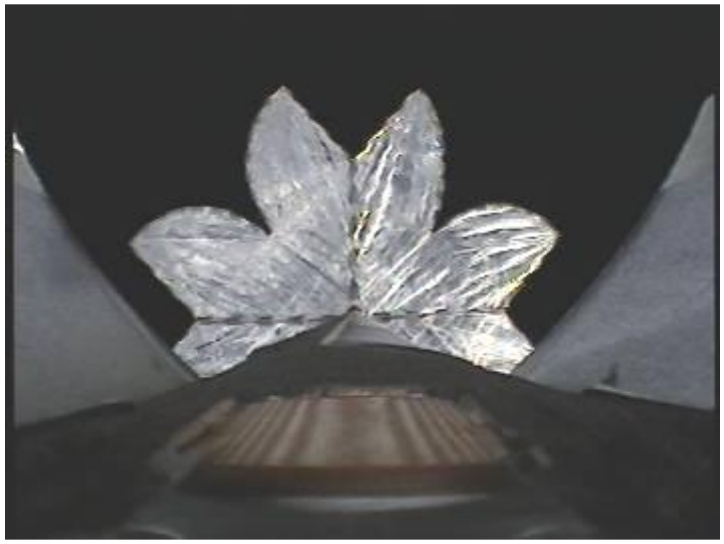
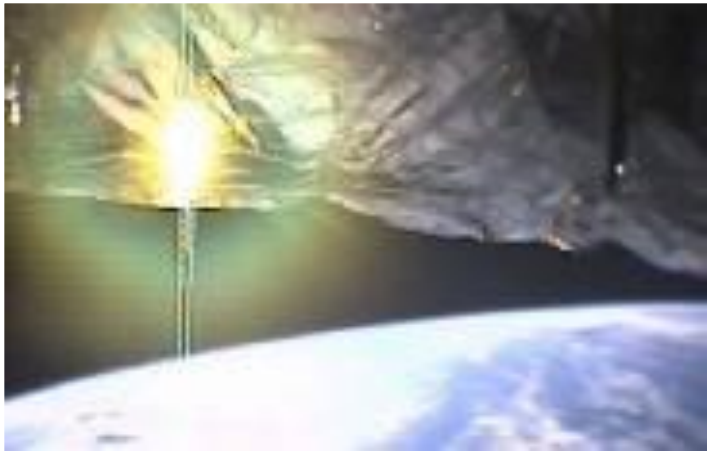
JAXA Test (2004)



JAXA 10 m sail test on suborbital arc



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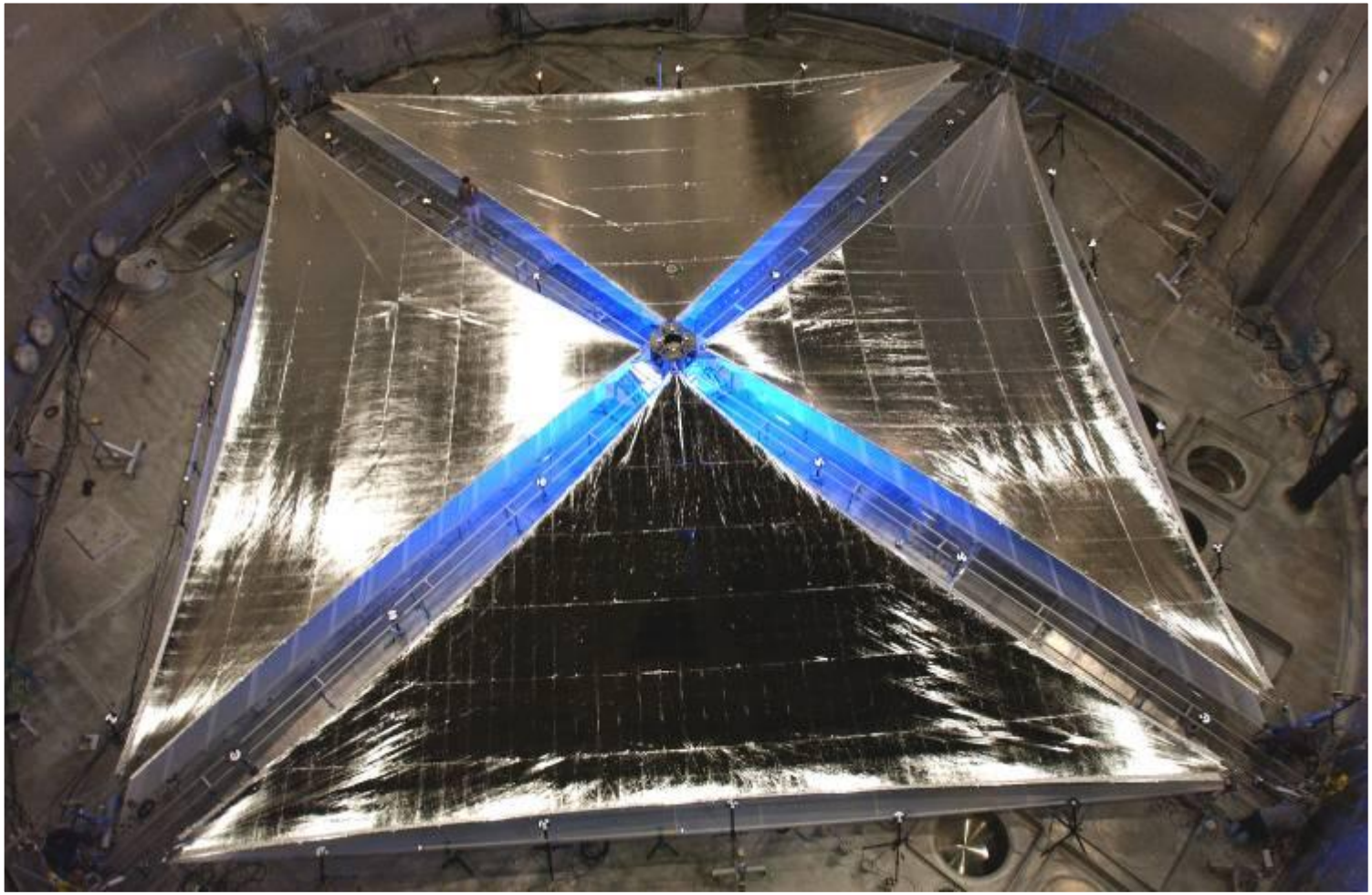
NASA Ground Tests (2005)



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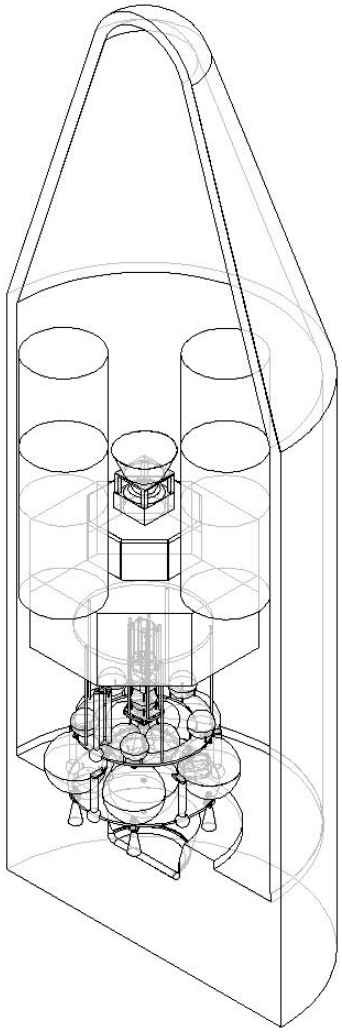
ESA Technology Reference Studies

Solar sailing proponents have historically been engineers

ASCL developed a solar sail science mission catalogue and a technology roadmap

Mission concepts were challenged and compared against other forms of propulsion



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Missions concepts considered

Various Earth missions

Mercury Sun-Synchronous Orbiter

Sample return to the terrestrial planets and a NEA

Solar Polar Orbiter

Various Jupiter missions, including the Galilean moons

Pluto / Kuiper Belt mission

Interstellar Heliopause Probe

Oort Cloud mission

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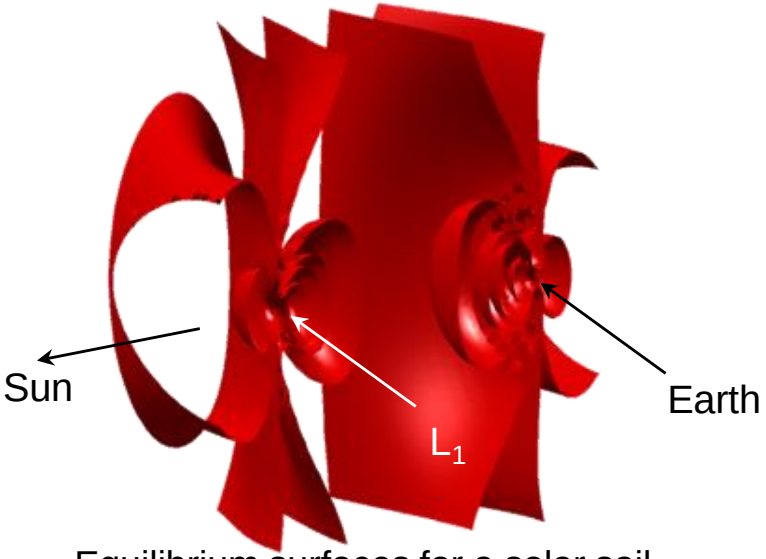
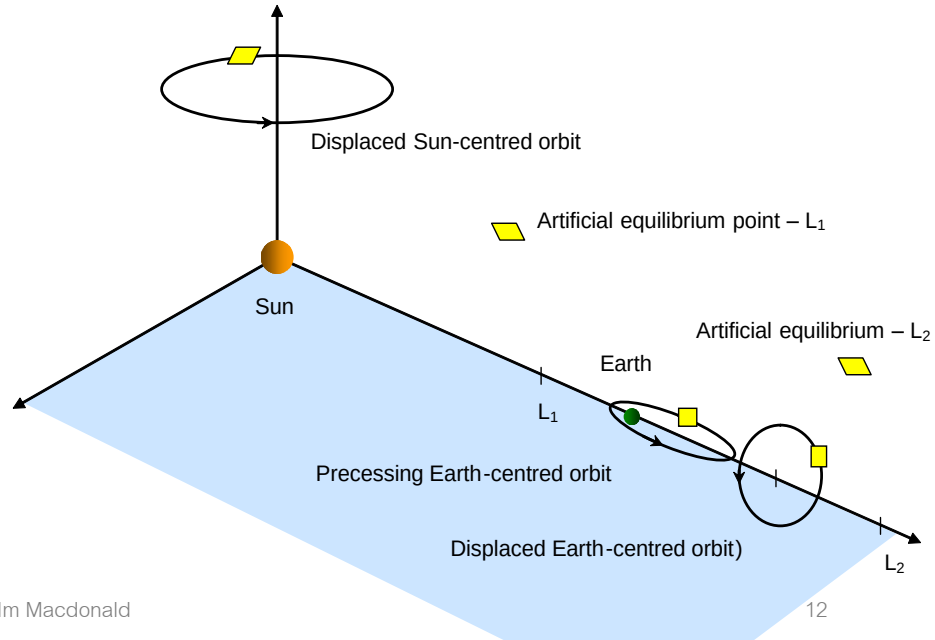
Novel Orbits in Earth Proximity

Any propulsion system can be used to counteract gravity

- Producing non-keplerian orbit
- Such an orbit requires significant fuel mass fraction
- Solar sail has near-zero fuel mass – hence enables non-keplerian orbits!



Equilibrium surfaces for a solar sail about the Earth – Sun L_1



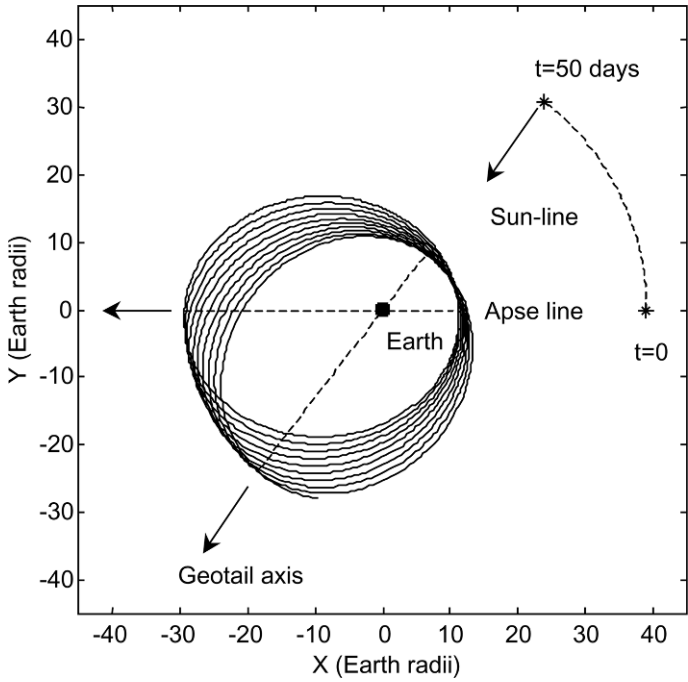
GeoSail

Engineering demonstration mission

- Validate ground tests/models of deployment and operation, *id est*, Attitude control, optical surface degradation, et cetera

Modest acceleration continuously rotates orbit apse-line at ~1 deg/day

- Maintain space physics payload within the magnetotail throughout the year



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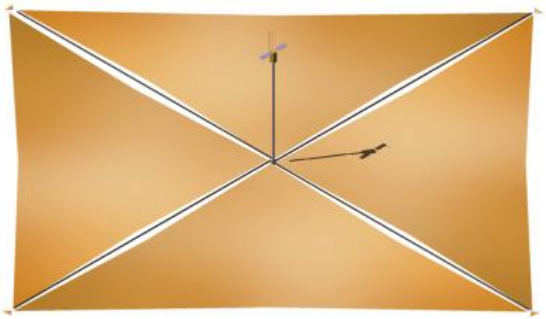
GeoSail

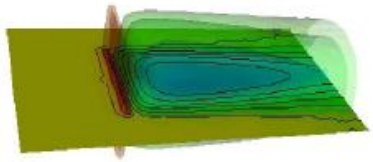
Attractions of mission

- 43 m square sail, delivering < 0.1 mm s^{-2}
  - Require booms smaller than the space station
- Perform novel science within SMART-like mission
  - Can still do science if sail fails!
- Proximity to Earth aids observation
- 30 % cost reduction over equivalent SEP or chemical



Key Issues

- Sail interference with space physics payload unknown



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Geostorm

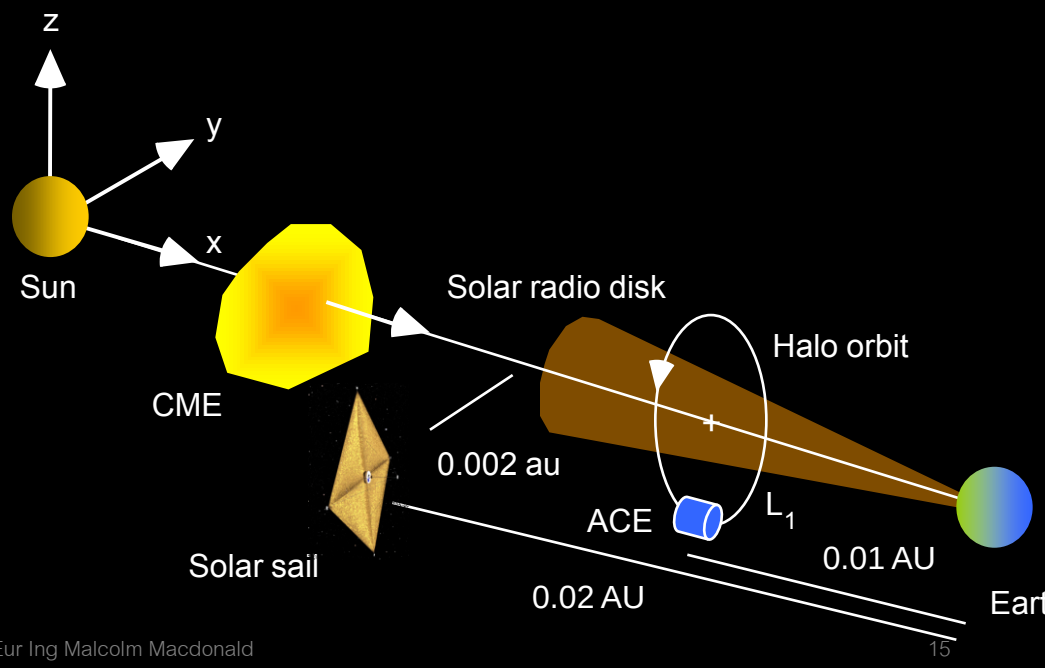
Displace L_1 point sunwards with 80 m square sail, delivering 0.3 mm s^{-2}

Magnetometer detects polarity of solar wind field

- Hence can detect solar storms

Provide early warning (x 2) relative to spacecraft at L_1 point

Sail interaction with space physics payload is unknown..!



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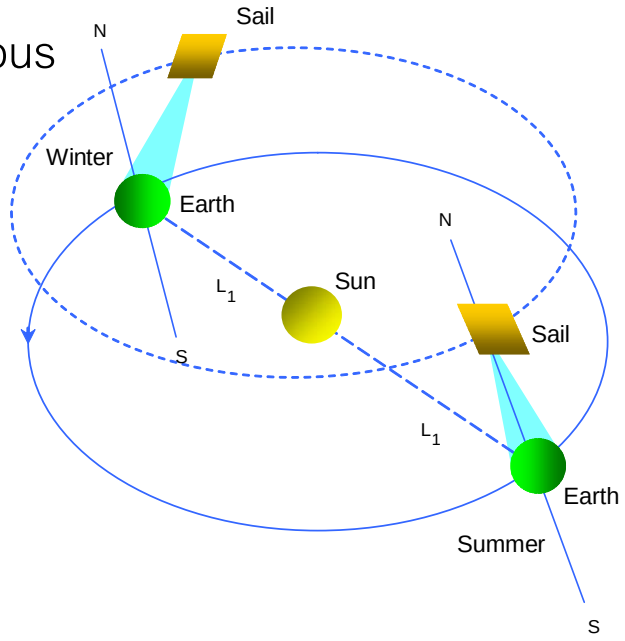
Polar Observer

Displace L_1 point out-of-plane with 120 m square sail, delivering 0.5 mm s^{-2}

- Provide real-time hemispheric view of polar regions
- Applications to climate study and telecommunications
- Can also provide continuous line-of-sight telecomms with Lunar South pole



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Solar Polar Orbiter

Ulysses provided field and particle data at high solar latitudes (80 deg)

- Orbit imposed long re-visit durations (>6 years)

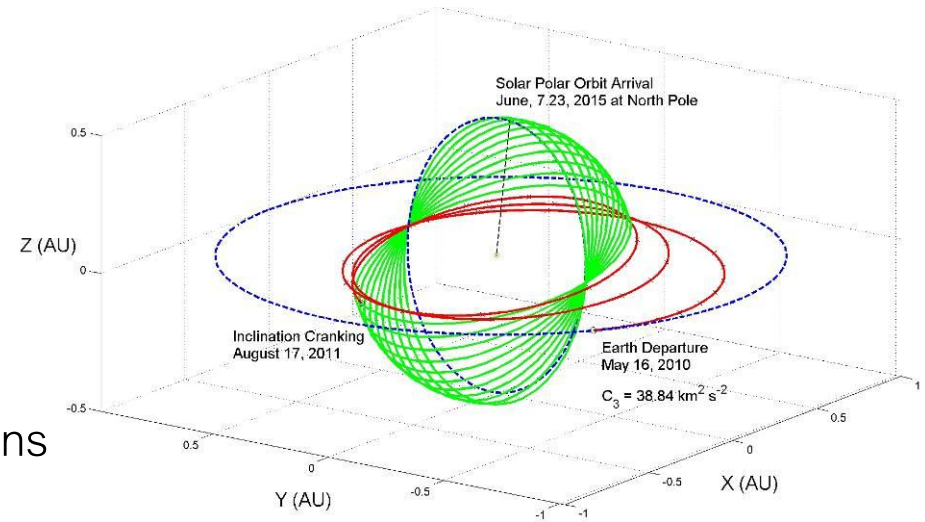
Solar Orbiter, an ESA M-class mission in assessment, aims for >30 deg

Using a solar sail we can enable a true solar polar orbit in < 5 years

- 153 m sail, delivering 0.42 mm s^{-2}

Spacecraft above solar limb as seen from Earth

- Orbit resonant with Earth's orbit, at 0.48 AU, with no solar conjunctions



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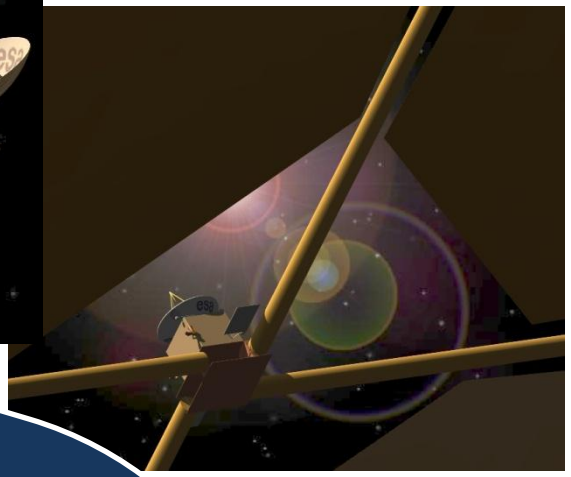
Solar Polar Orbiter



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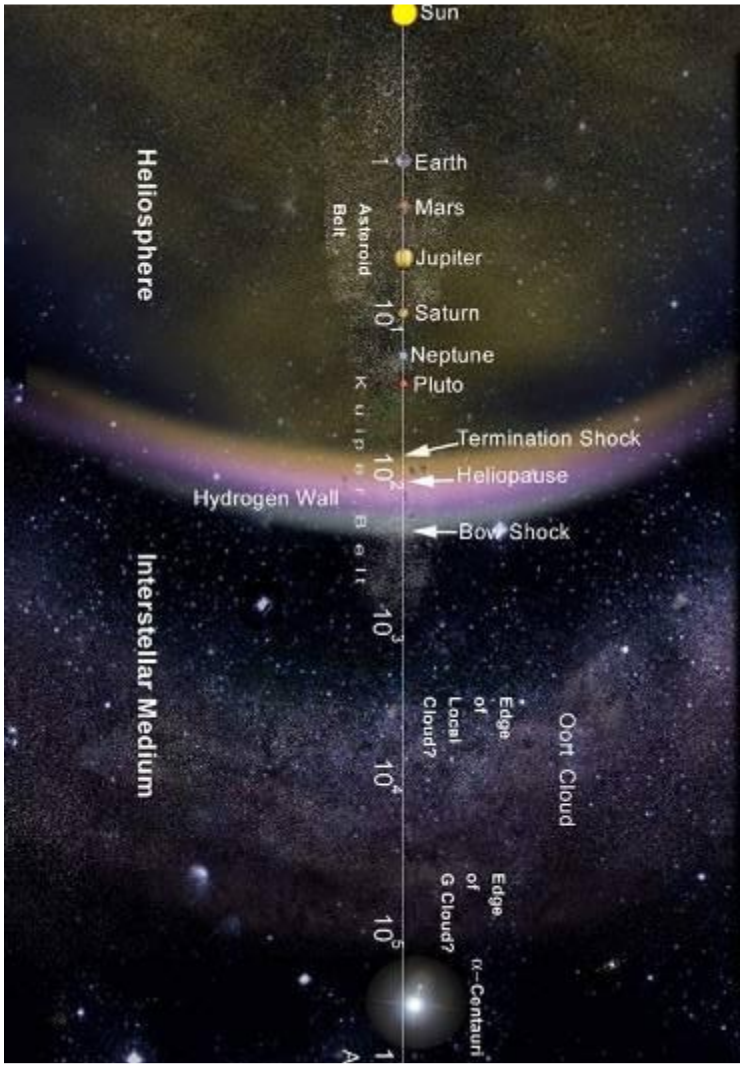
Interstellar Heliopause Probe

Heliopause at 120 – 170 AU due to interaction of solar wind and ISM

Mission requirement is 200 AU in < 25 yrs

- Chemical propulsion requires massive burn at 4 solar radii
  - Requires C-C heat shield
- SEP requires (lengthy) multiple solar loops to avoid gravity losses
- NEP poses problems for science payload



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Interstellar Heliopause Probe

Mission goals achieved by a 137 m disc sail, delivering 1.5 mm s^{-2}

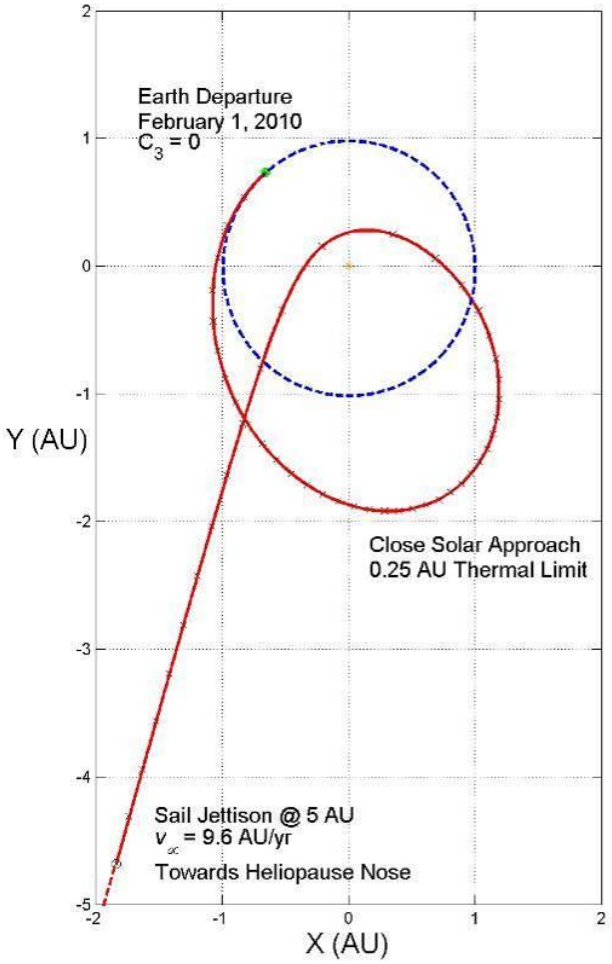
Soyuz Fregat launch

Close solar pass of 0.25 AU

Sail jettison at 5 AU

- No science interference from sail
- Also enable Ka band HGA use

Requires nuclear power source at 12 W / kg



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Technology Roadmap

The first solar sailing mission must provide confidence and heritage to the next mission

- A demonstration mission which does not do this is just a publicity stunt
- Must be instrumented and documented
- Must be a demonstration NOT an experiment

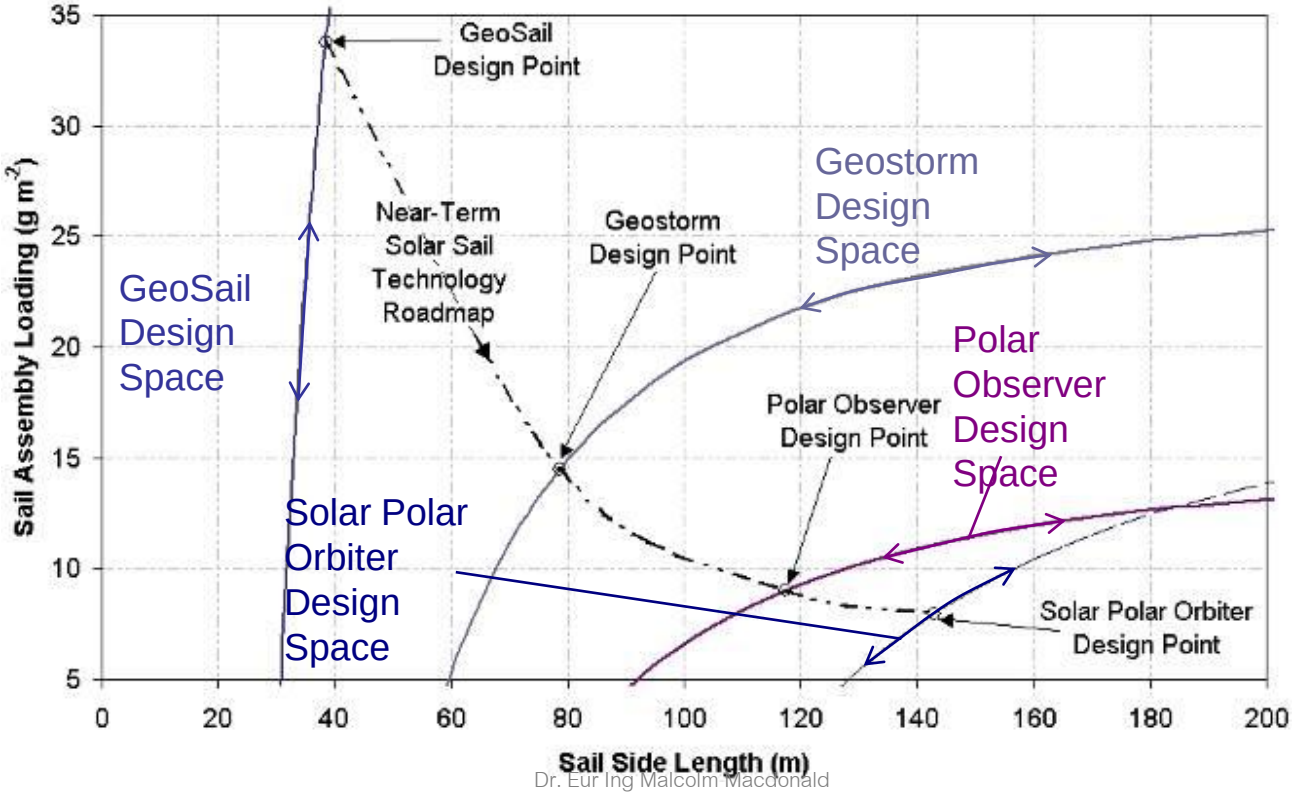
Each subsequent mission must provide confidence and heritage to the next mission

- If IHP is target of roadmap what is the point of flying a square sail for GeoSail or SPO if they can also be achieved by a disc sail?

Near-Term Roadmap

Several compelling missions in the early roadmap

Initial missions need to over-reach requirements to provide heritage to subsequent missions



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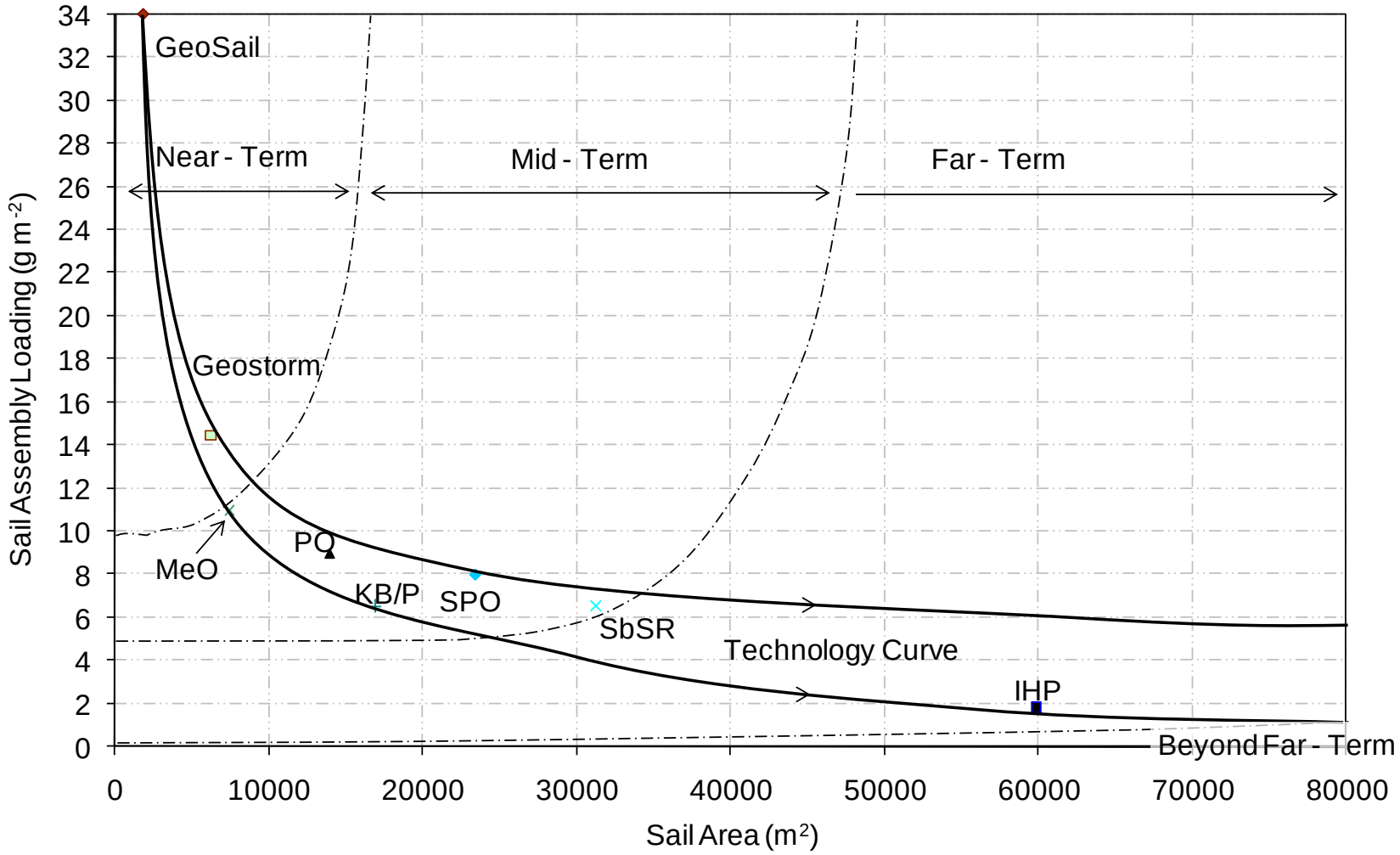
Long-Term Roadmap



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thank you

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