

Commercial applications of electric sailing

*Pekka Janhunen
Finnish Meteorological Institute,
(Kumpula Space Centre)*

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Outline

- General about E-sail applicability
- Asteroid Resource Utilisation schemes
 - why electric sail is good here
 - water; electrolysis rocket OTV
 - platinum group metals
- Benefits of E-sail in asteroid resource utilisation

General

- Electric Sail is a propellantless non-impulsive propulsion method, suitable for small and medium payloads
- Electric Sail does not produce much thrust inside the magnetosphere, i.e. at Earth orbit
- Water mining and transporting from asteroids, for producing chemical propellant, is a way to use the E-sail to the utility of *any* space activity

Asteroid Resource Utilisation

- Chemical rocket
 - Can be used, if propellant can be mined for return trip
- Electric propulsion
 - Problem: Good ion engine propellants are volatile (so that they don't clog engine and s/c). But volatiles are non-existent on atmosphereless bodies.
 - H_2O and O_2 are nasty propellants for ion engine
- Solar sail
 - Should be “parked” at asteroid by inclining at 90 deg. Thermally cumbersome!
- Electric sail

Asteroid mining schemes

- Water
 - Mine water at ice-containing asteroid (KY-26 ?)
 - Transfer to Earth orbit by E-sailer
 - Water customers at LEO, GTO or MEO:
 - ISS
 - Electrolysis spacecraft (Orbital Transfer Service for satellites)
- Platinum group metals:
 - Challenge: mining
 - Transfer by E-sailer to Earth reentry
 - PGMs are rare on Earth (differentiated planet), needed as catalysts (fuel cells + other “green” tech's)
- Structural materials (bricks, stones, basic trusses)

Icy asteroids

- Carbonaceous chondrites (they are probably old cometary nuclei) are believed to have water (~10%), at least if they are not too close to Sun
 - How close is too close, is not known
 - With E-sail (no rocket equation), the delta-v distance matters less, however, than with chemical propulsion.
 - One should first *find* icy asteroids. E-sail mission could flyby multiple asteroids
 - Known case: KY-26, 30-metre c.c. asteroid
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How to mine water

- Straightforward way: Dig out material one piece at a time. Put piece into container, close the lid and heat. Container fills with vapour. Open pipe into cold trap where let H_2O condense.
- Another way: Enclose whole asteroid in gold-covered bag so that it gets heated. Install pipe to a cold (white) bag where ice condenses. Might be feasible for small asteroid such as KY-26. Benefit: insensitive to type of asteroid material.

How to transport water

- Many ways:
- E-sailer can have integrated tank, or it can tug a payload with a tether
- Tank could also be flexible (non-stiff)
- Can use storage as ice or as liquid

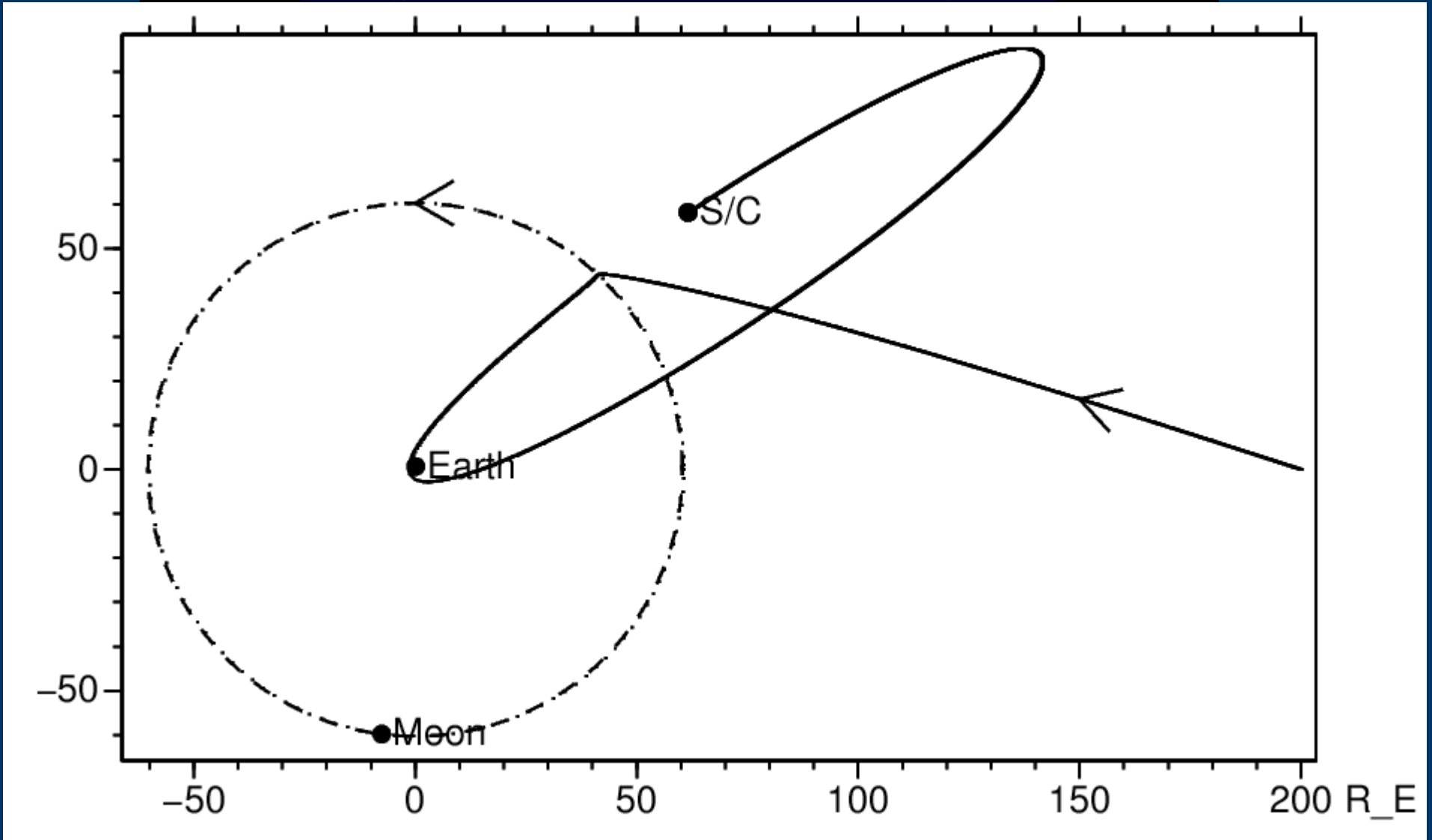
How to use water at Earth orbit

- Electrolysis Orbital Transfer Vehicle:
 - Store propellant as water
 - Electrolyse into GH_2 , GO_2 continuously
 - Store GH_2, GO_2 in moderate-sized tanks
 - Make impulsive burns with small GH_2/GO_2 rocket engine at optimal place in trajectory (apogee/perigee)
 - Best Isp of any chemical rocket
 - No cryogenics
 - Simple and robust hardware
 - No ion engine Isp overhead since burns are impulsive
- ISS (?): water or O_2 for human consumption

Getting to Earth orbit from asteroid

- E-sailer used to get payload to Earth-Moon system rendezvous
 - Lunar capture used to kill incoming delta-v (up to 1.5 km/s) ==> get into high elliptic orbit (stable for ~1 year)
 - Use aerobrakings to lower apogee (using solar panels, like Mars missions do) until at GTO or LEO
 - E-sailer can detach before Moon ==> no need to fly with E-sail through near-Earth region ==> no risk of tether breakage by space debris
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Lunar capture manoeuvre



Mining platinum group metals

- Many benefits and one big challenge
- Benefits:
 - Easy to store in space during E-sail transportation
 - Easy to sell once dropped to Earth
 - Precious enough ($> 10,000$ eur/kg)
 - Guaranteed, growing market (automotive industry)
- Challenge:
 - Mining (enrichment) at asteroid is probably not simple
 - Can be done, since can be done at Earth; but at what initial cost?

What to do with OTVs

- Assume we have asteroid water using electrolysis
Orbital Transfer Vehicles available, fed by E-sail
logistics chain. How to use that capability?
- Cheaper launch to GEO, MEO:
 - Commsats
 - Active space debris removal
 - Solar power satellites
 - Manned Mars (req. LH2/LOX factory)
 - LEO launch still needs to be done in conventional way.
Could use suborbital RLV and “grab” to orbit, however.
(req. LH2/LOX factory as well)

Is E-sail required in all this ?

- If icy asteroids exist nearby, water can be fetched by electrolysis rockets without losing too much on the way. But E-sail is more lightweight than any electrolysis rocket.
 - “Dry” ores reasonable to fetch by electrolysis rocket only if water is also mined nearby. E-sail is not dependent on any fuel supply.
 - E-sail has better thrust/power ratio than ion engines, plus needs no propellant
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Summary

- E-sail well suited for asteroid transfer service
 - Electrolysis rockets are an alternative, but feasible only for rather nearby asteroids (rocket equation!)
 - Ion engines not so good because no easy propellant supply
 - Solar sails? How to make them? How to park?
- Water-fuelled electrolysis rocket OTVs
- “Roadmap” of applications, small and large