Magnifying Light by a 100 Billion Times with the Solar Gravity Lens to Image an Exoplanet

Slava Turyshev, Louis Friedman 16 May 2018
KECK INSTITUTE FOR SPACE STUDIES WORKSHOP ON THE TECHNOLOGY REQUIREMENTS TO OPERATE AT AND UTILE THE SOLAR GRAVITY LENS FOR EXOPLANET IMAGING - 15-18 MAY 2018
Motivation

- Space is big
- The Stars are Far
- The Planets are Small

The Interstellar Medium
The Solar Gravity Lens

Image formed in Einstein Ring

---Star Sun

------547 AU------

------547 AU------
550-1000 AU: How to get there?

- Chemical propulsion fly very close to the Sun
- Solar Sail with large Area to Mass Ratio
- Solar Thermal
- Nuclear Electric

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- Electric Sail
- Beamed Laser Electric Drive
## SGLF Mission Architecture - Options

<table>
<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Tradeoffs</th>
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<tbody>
<tr>
<td>Propulsion</td>
<td>Chemical</td>
<td>Big solid rocket motor burn very close to the Sun. Velocity limit ~18 AU/year</td>
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<tr>
<td>Solar Sail</td>
<td>Lightest weight option; 200x200 m sail with 40 kg sc can achieve velocity ~25 AU/year</td>
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<tr>
<td>Solar Thermal</td>
<td>Larger sc, new technology; cost? Also requires operation very close to Sun</td>
<td></td>
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<tr>
<td>SC Mass</td>
<td>&lt;100 kg</td>
<td>Requires new technology, but smallsats are progressing fast</td>
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<tr>
<td></td>
<td>&lt;500 kg</td>
<td>Conventional, capability more certain; likely higher cost and longer trip times</td>
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<tr>
<td>Con Ops</td>
<td>Individual SC</td>
<td>Minimizes complexity; suitable for multiple targeting</td>
</tr>
<tr>
<td></td>
<td>String of Pearls</td>
<td>Robust design, flexible operations</td>
</tr>
<tr>
<td>Comm</td>
<td>Radio</td>
<td>Probably only if sail can be antenna</td>
</tr>
<tr>
<td></td>
<td>Optical</td>
<td>Lower power consumption and mass likely</td>
</tr>
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</table>
Getting the $\Delta v$

Exit Velocity (AU/y) vs. Sail area/SC mass (m²/kg) with perihelion = 0.1 AU

N. Arora, JPL

D. Garber, NXTRAC

P. Lubin, UCSB
Sail area 200x200 meters; less than 2 kg
- Density 0.04 g/cm² e.g. 0.25 micron polyimide or with carbon nanotubes.

30 kg spacecraft bus

15 kg for REP with 100 watts electric power

Perihelion = 0.1 AU

A/m = 400000/50 = 800 m²/kg \Rightarrow velocity = 23 AU/year
Solar Sail Trajectory to the SGLF

- Mars orbit
- Vel ~18 AU/year
- Trajectory out to 125 AU
- $A/m = 500 \text{ m}^2/\text{kg}$; $r_p = 0.1 \text{ AU}$

D. Garber, NXTRAC
Other Mission Examples

- **Chemical mission with Oberth Maneuver**
  - Perihelion = 3 solar radii; velocity = 20AU/year
  - Solid Rocket Motor for large $\Delta v = 12.5$ km/s
  - Large heat shield

- **Solar Thermal Propulsion**
  - JPL/MSFC study, sc mass=560kg $\Rightarrow$ 20 AU/year
  - Perihelion = 3 solar radii, large heat shield

- **Nuclear electric** (ref. J. Brophy)
  - 2-stage 30kW SEP/20 kW NEP reaches 20 AU/year but with 40 year trip time

- **E-sail** (Ref. P. Januhen),
  - 20 tethers, each 10 km length $\Rightarrow$ 23 AU/year

- **Laser** (ref. P. Lubin)
  - 100 GW laser, 1 Km telescope, 10 kg sc $\Rightarrow$ 20 AU/year

- **Laser electric** (Ref. J. Brophy)
  - 100 MW space-laser, $\Rightarrow$ 40 AU/year
The Spacecraft Challenge – Getting and Operating There
2 Examples: Solar Sail, Solar Thermal

Launch Vehicle Adapter
Jettisoned before perihelion maneuver

ISM Probe (single SMRTG, ~560 kg wet)

Extra SMRTGs (providing >1.2 kW for cryocooler)
Jettisoned before perihelion maneuver

Liquid Hydrogen (LH₂) tank (cryocooled)
carrying ~15.7 tons of propellant

Bipropellant System (for TCMs before perihelion)

Solar Thermal Propulsion (STP) Rockets (12x, to limit burn time to <1.5 hrs.)

Sun Shield (double-folded for launch, middle panel is heat exchanger for STP, heating H₂ to 3400K)

Launch Vehicle Fairing (SLS Block 2 - 8.5m)

Launch Vehicle Adapter
Jettisoned before perihelion maneuver

Extra SMRTGs (providing > 1.2 kW for cryocooler)
Jettisoned before perihelion maneuver

ISM Probe (single SMRTG, ~560 kg wet)
Challenge: To Capture the Image in the Einstein Ring
Which propulsion will get us there first?

Time Scale for Propulsion Options

- Laser Electric
- Fusion
- NEP
- Solar Thermal
- Solar Sail
- Chemical

Years to SGLF

Years to Readiness