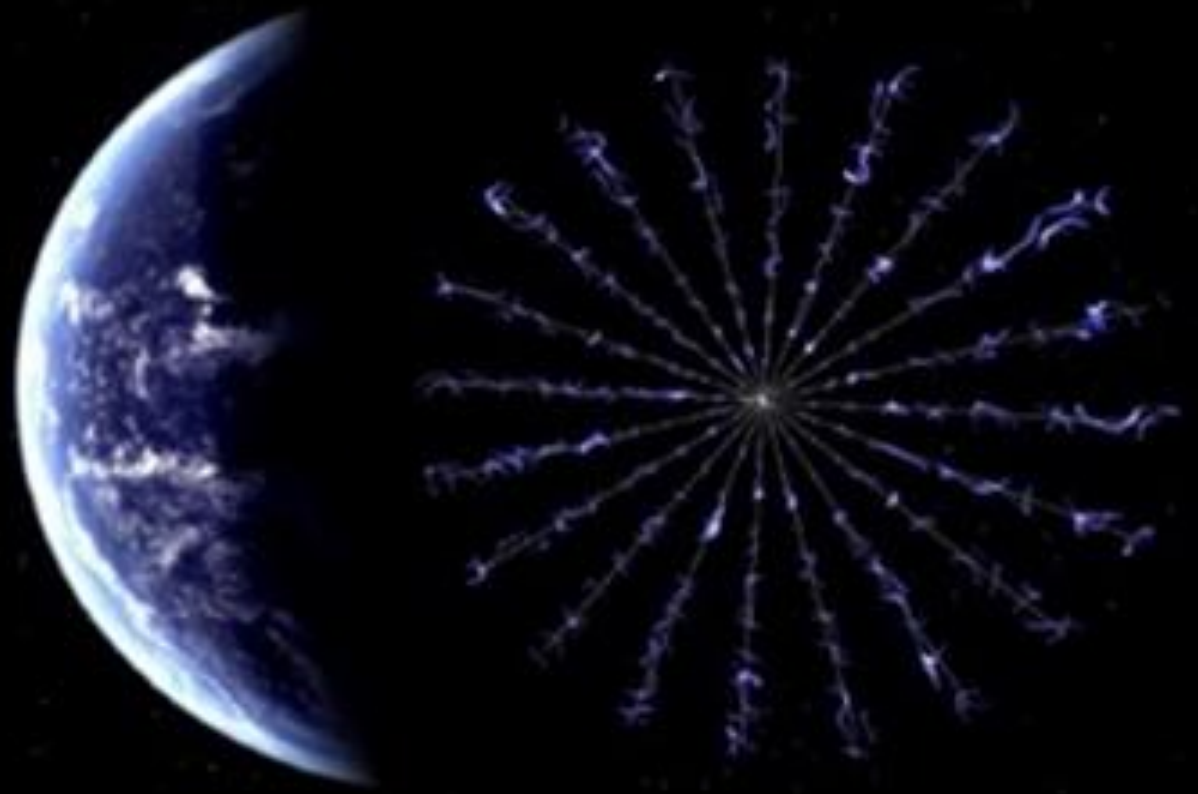
Electric Sail Propulsion for Deep Space Missions



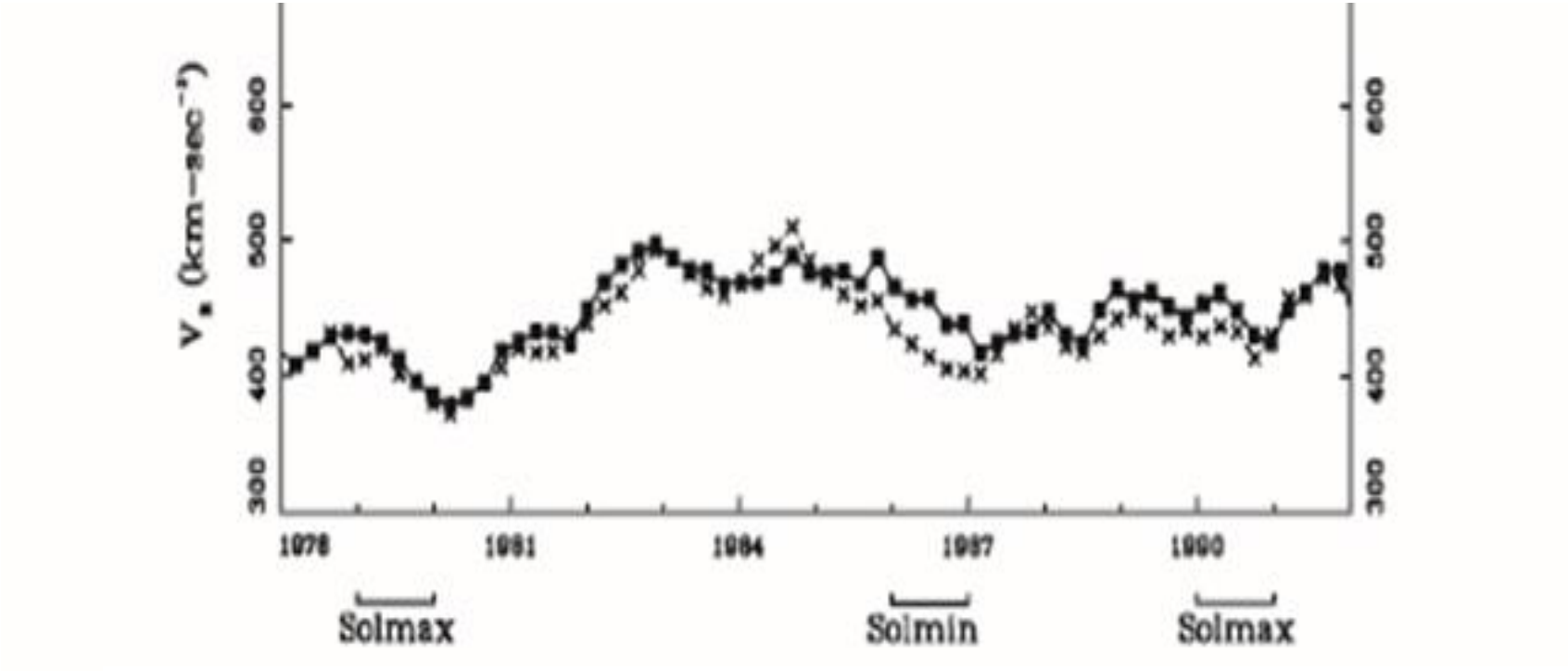
NASA Image

Les Johnson

Kurt Polzin

NASA
Marshall Space Flight Center

Solar Wind --> Electric Sail

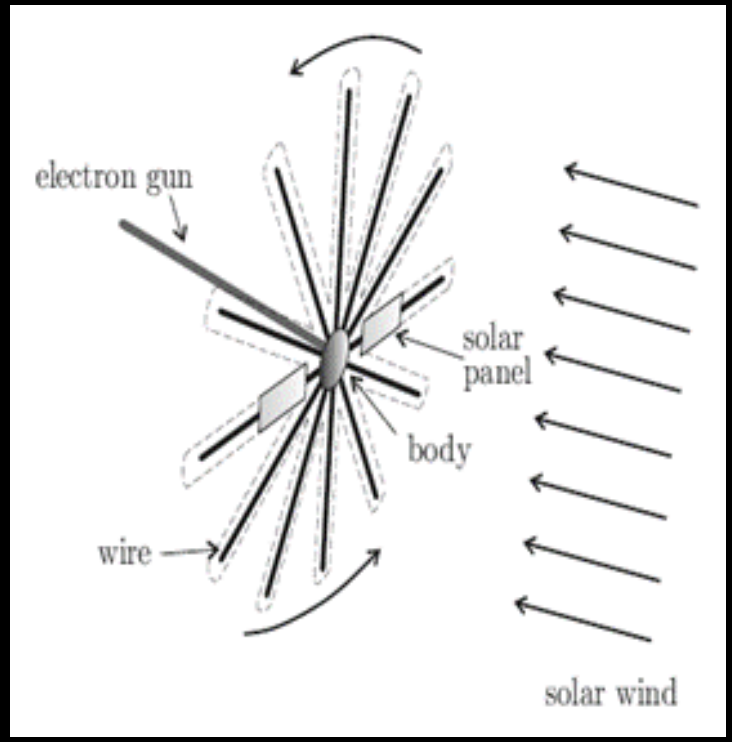


- **The relative velocity of the Solar Wind through the decades**

The solar wind ions traveling at 400-500 km/sec are the naturally occurring (free) energy source that propels an E-Sail

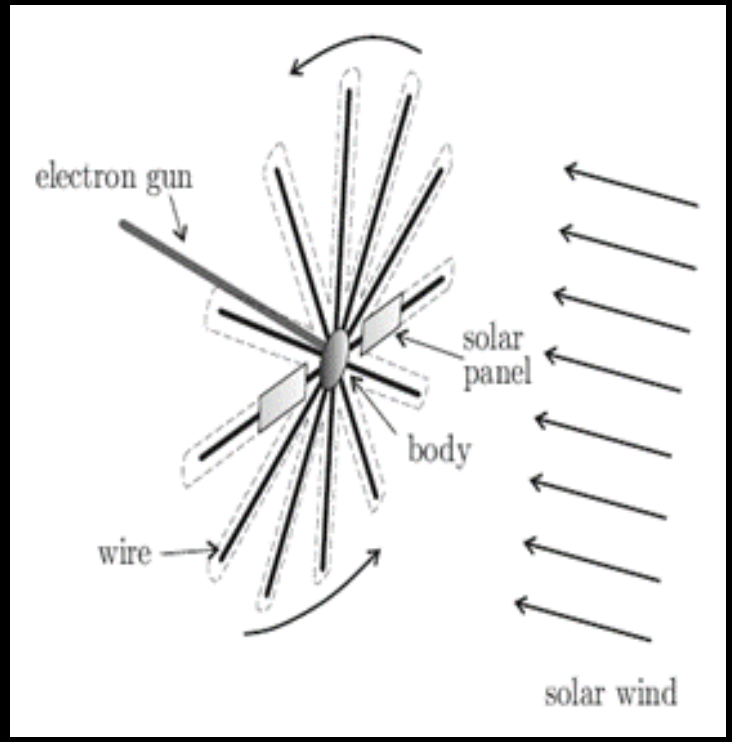
Electrostatic Sail (E-Sail): Operational Principles

- The E-sail consists of 1 to 20 conducting, positively charged, bare wires, each 1–20 km in length.
- Wires are deployed from the main spacecraft bus and the spacecraft rotates to keep wires taut.
- The wires are positively biased to a 6 kV-20 kV potential
- The electric field surrounding each wire extends ~ 66 m into the surrounding plasma at 1 AU
- Positive ions in the solar wind are repulsed by the field created surrounding each wire and thrust is generated.

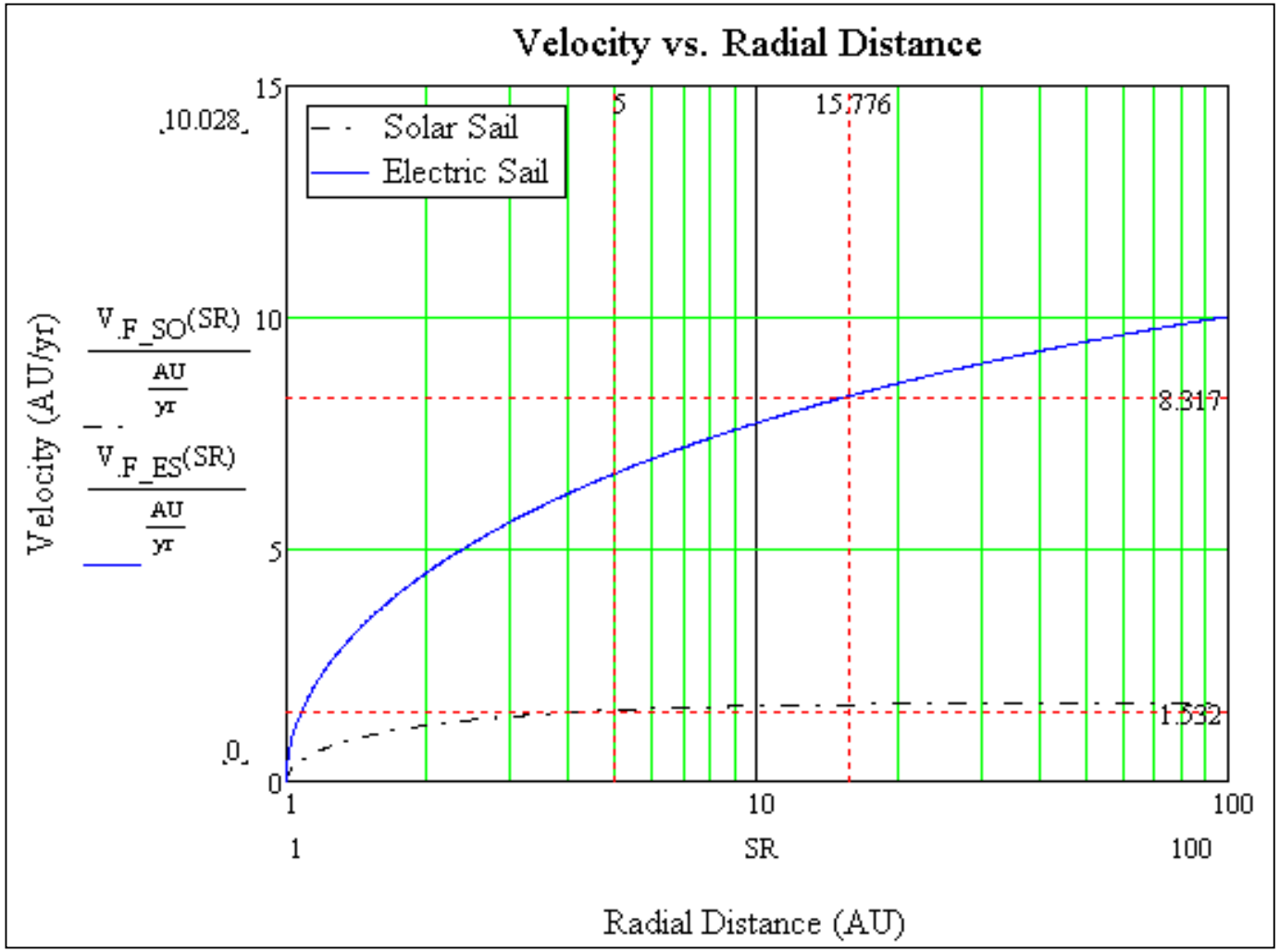


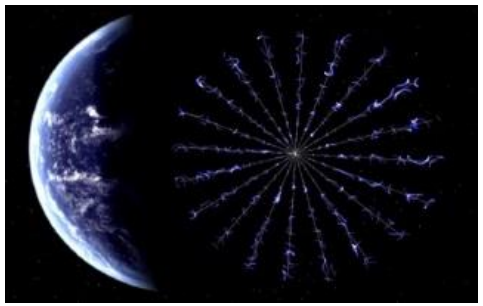
Electrostatic Sail (E-Sail): Operational Principles

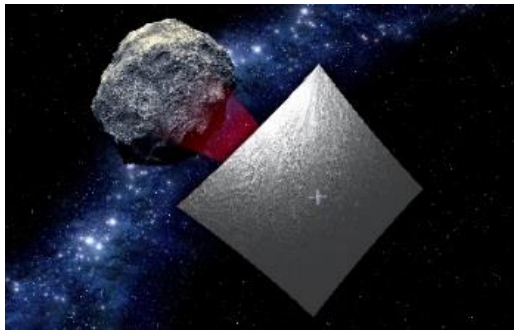
- As the E-sail moves away from the sun and the plasma density decreases (as $1/r^2$), the electric field around the wires gradually expands (to 180 m at 5 AU), partially compensating for the lower plasma density by increasing the relative size of the 'virtual' sail.
  - The thrust therefore drops only as ~ $1/r$, instead of $1/r^2$
- An electron gun is used to keep the spacecraft and wires in a high positive potential (~kV).
- Wire length and voltages are mission specific and determine the total ΔV available



Velocity vs. Radial Distance Comparison for Equal Mass Spacecraft



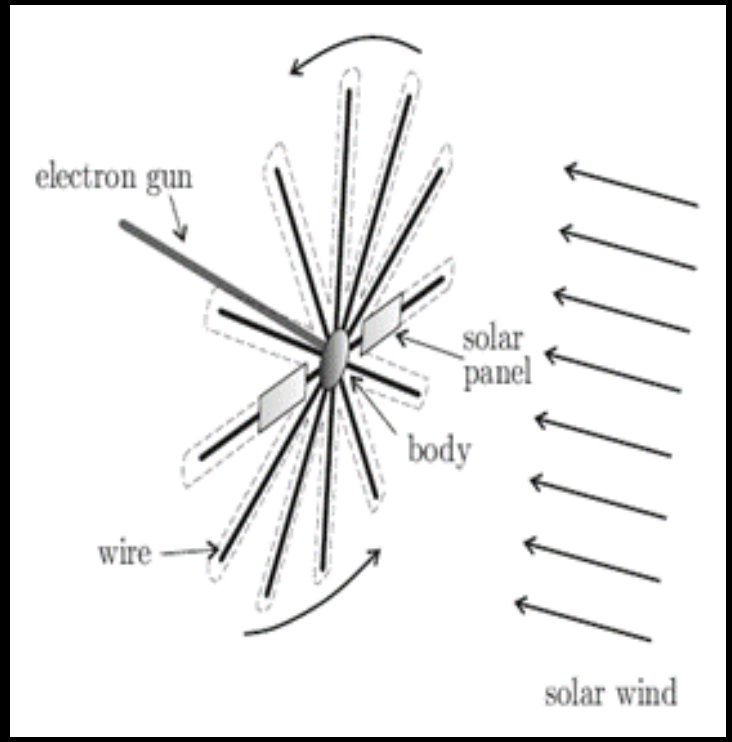




Electrostatic Sail (E-Sail): Operational Principles

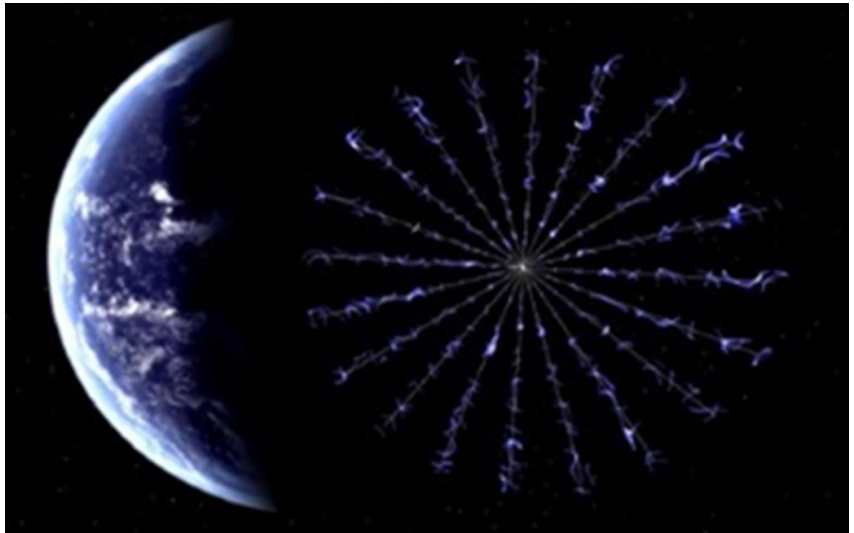
Characteristic accelerations of 1 – 2 mm/sec^2

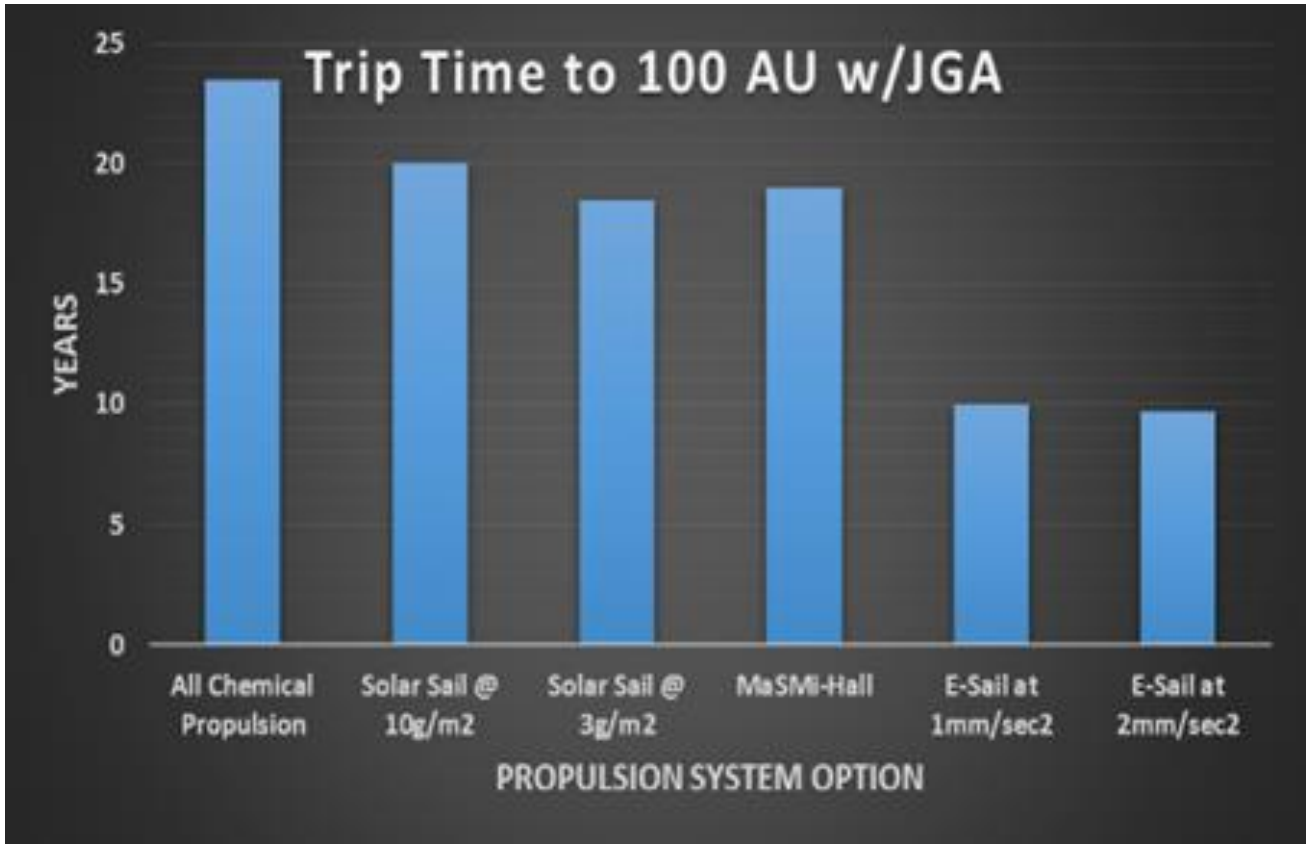
Spacecraft velocities of 10 – 15 AU/year possible (3X -4X faster than Voyager)



Electric Sail Performance

E-Sail propulsion can significantly reduce travel time to 100 AU compared to more conventional propulsion systems

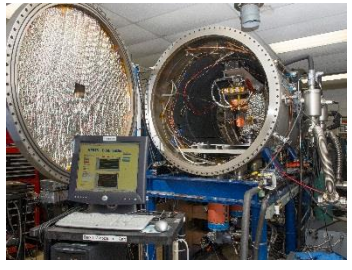


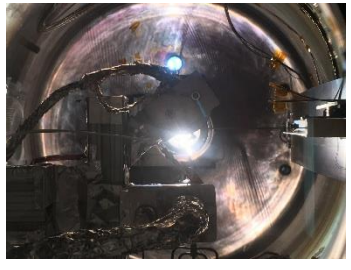


Plasma Testing was Key to Advancing Knowledge of Space Plasma Physics

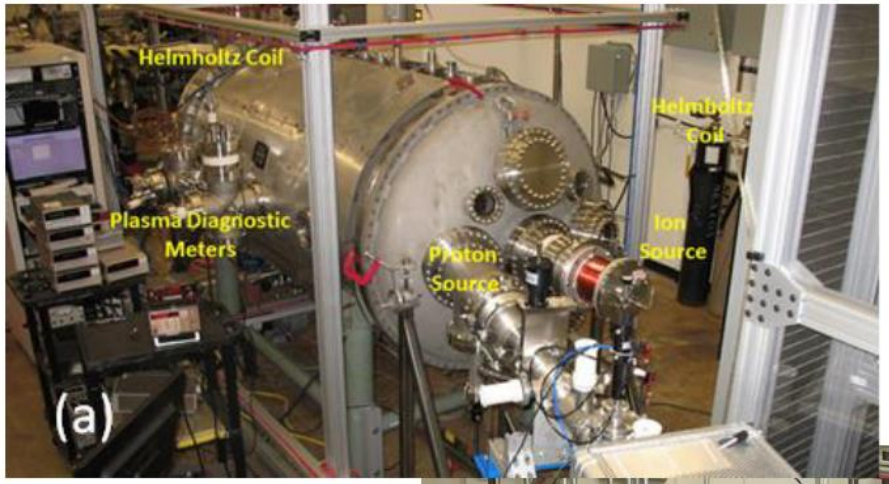
- **The Phase II experimental testing enabled a ‘knowledge bridge’ to be constructed from the testing performed > 30 years ago on negative biased objects operating in a space environment to recent testing on positive biased objects operating in a similar space environment**

- **Phase II experimental results were a combination of:**
  - Extensive plasma chamber testing, and
  - Rigorous analysis of data collected on positive biased objects for an appropriate set of dimensionless space plasma parameters under the condition of Debye length (λd) < tether diameter
    - Normalized Potential (Φb)
    - Mach Number (S)

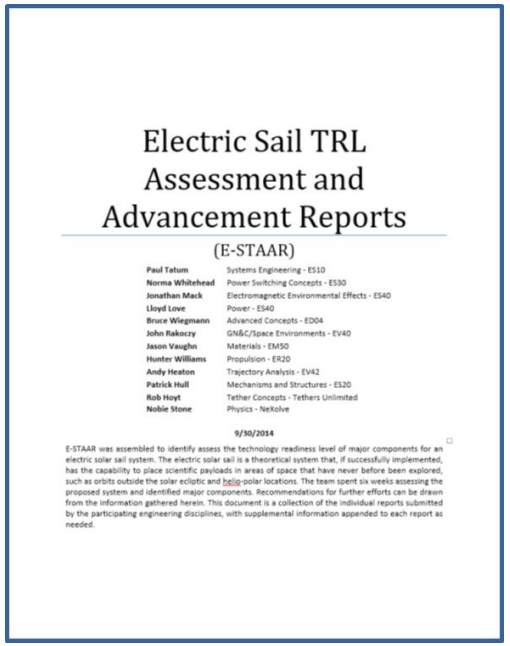




E-Sail Plasma Physics Testing at MSFC



E-Sail Technology Readiness Level (TRL) Assessment and Advancement (E-STAAR)



Electric Sail TRL Assessment and Advancement Reports

(E-STAAR)

Paul Tatum	Systems Engineering - ES10
Norma Whitehead	Power Switching Concepts - ES30
Jonathan Mack	Electromagnetic Environmental Effects - ES40
Lloyd Love	Power - ES40
Bruce Wiegmann	Advanced Concepts - ED04
John Rakoczy	GN&C/Space Environments - EV40
Jason Vaughn	Materials - EM50
Hunter Williams	Propulsion - ER20
Andy Heaton	Trajectory Analysis - EV42
Patrick Hull	Mechanisms and Structures - ES20
Rob Hoyt	Tether Concepts - Tethers Unlimited
Nobie Stone	Physics - NeXolve

9/30/2014

E-STAAR was assembled to identify assess the technology readiness level of major components for an electric solar sail system. The electric solar sail is a theoretical system that, if successfully implemented, has the capability to place scientific payloads in areas of space that have never before been explored, such as orbits outside the solar ecliptic and helio-polar locations. The team spent six weeks assessing the proposed system and identified major components. Recommendations for further efforts can be drawn from the information gathered herein. This document is a collection of the individual reports submitted by the participating engineering disciplines, with supplemental information appended to each report as needed.

- MSFC Engineering Directorate conducted a TRL assessment of E-Sail systems and components
- Most components are at relatively high TRL (with flight heritage for other applications – *hence lower TRL for this application*)

Subsystem	TRL
GN&C / System dynamics	3
Thrust vector control	3
Tether Deployment	3
Plasma Acceleration / Charge Control	3
High Voltage Switching	3/4
Electron Emitter	4
High Voltage Power Supply	4
New Tether Materials State of Art (SOA) Tethers	4/5
Command, Control & Comm. (NEA Scout Heritage)	7+
Power Generation	7

* Updated to reflect advancements made resulting from NIAC and MSFC internal funding

Questions?