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Solar Electric Propulsion Mission Architectures

Thomas W. Kerslake
Glenn Research Center, Cleveland, Ohio

June 2003

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Abstract

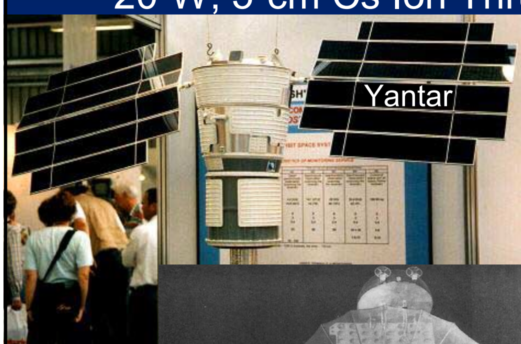
This presentation reviews Solar Electric Propulsion (SEP) Mission Architectures with a slant towards power system technologies and challenges. The low-mass, high-performance attributes of SEP systems have attracted spacecraft designers and mission planners alike and have led to a myriad of proposed Earth orbiting and planetary exploration missions. These SEP missions are discussed—from the earliest missions in the 1960's, to first demonstrate electric thrusters, to the multi-megawatt missions envisioned many decades hence. The technical challenges and benefits of applying high-voltage arrays, thin film and low-intensity, low-temperature (LILT) photovoltaics, gossamer structure solar arrays, thruster articulating systems and microsat systems to SEP spacecraft power system designs are addressed. The overarching conclusion from this review is that SEP systems enhance, and many times enable, a wide class of space missions.

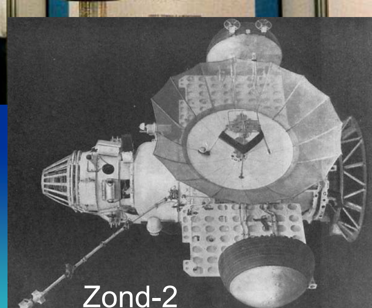
Introduction

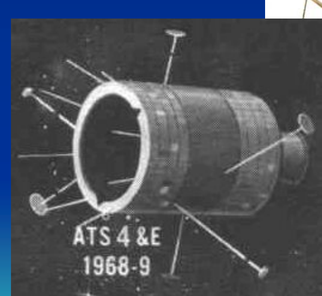
- SEP attractive for missions
  - High Isp, mass savings
- SEP Mission Review
  - Past- Present – Future
    - Robotic
    - Human
  - Technologies, Challenges & Benefits
    - Power Systems
    - Structures

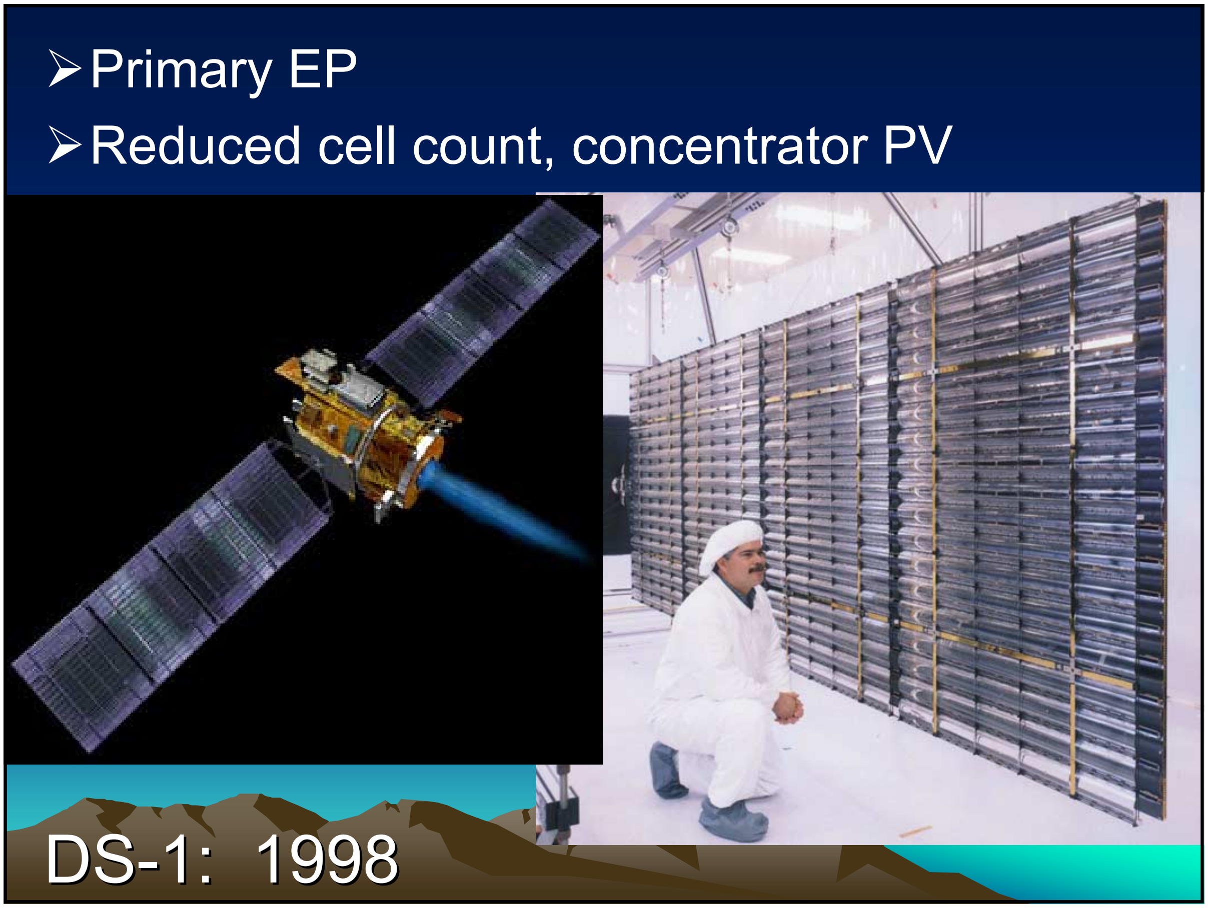
In The Beginning…

- First Russian SEP Missions in 1964
  - Yantar-1 / Ion thruster, Zond-2 / 6 PPTs (Mars Flyby)
- First US SEP Mission 1968: ATS-4
  - 20-W, 5-cm Cs Ion Thrusters, 300-W PVA

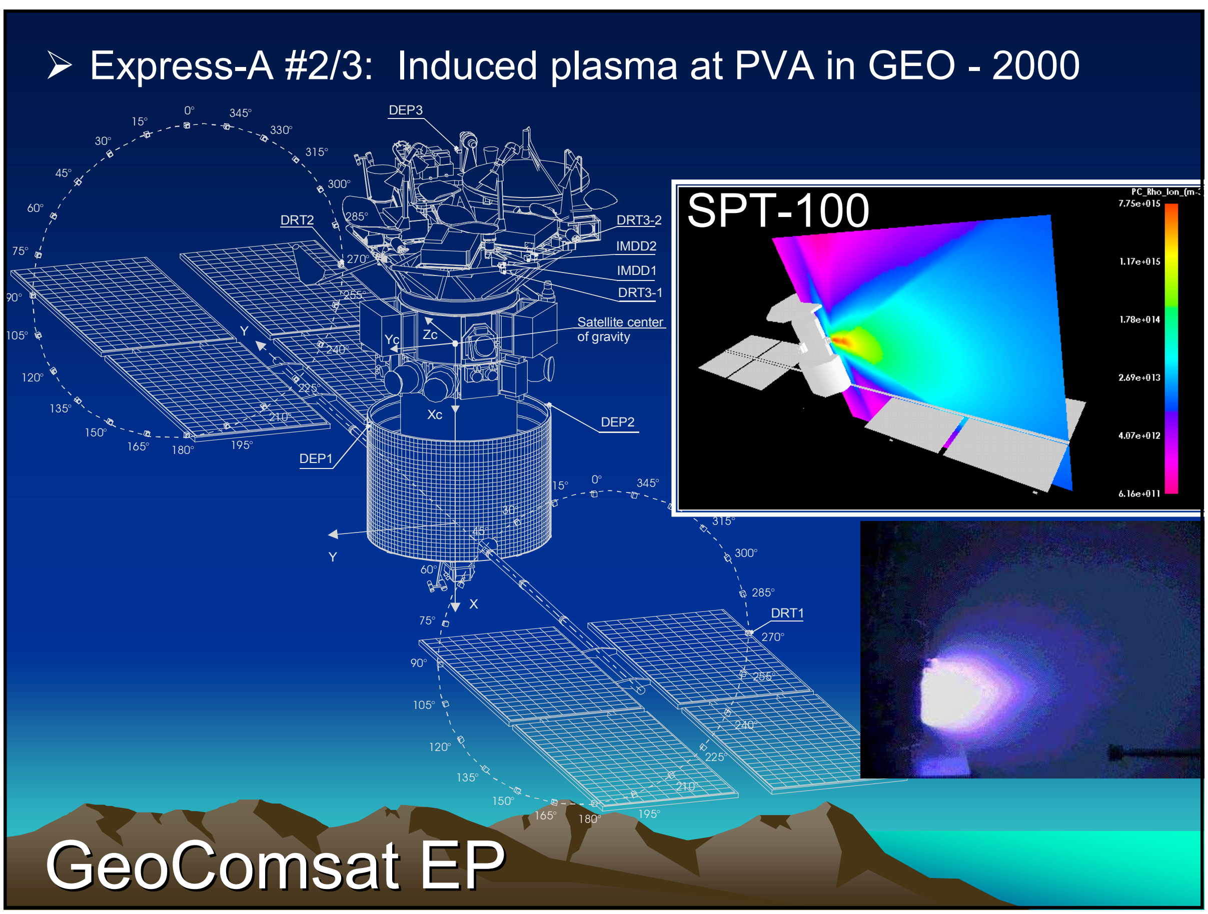






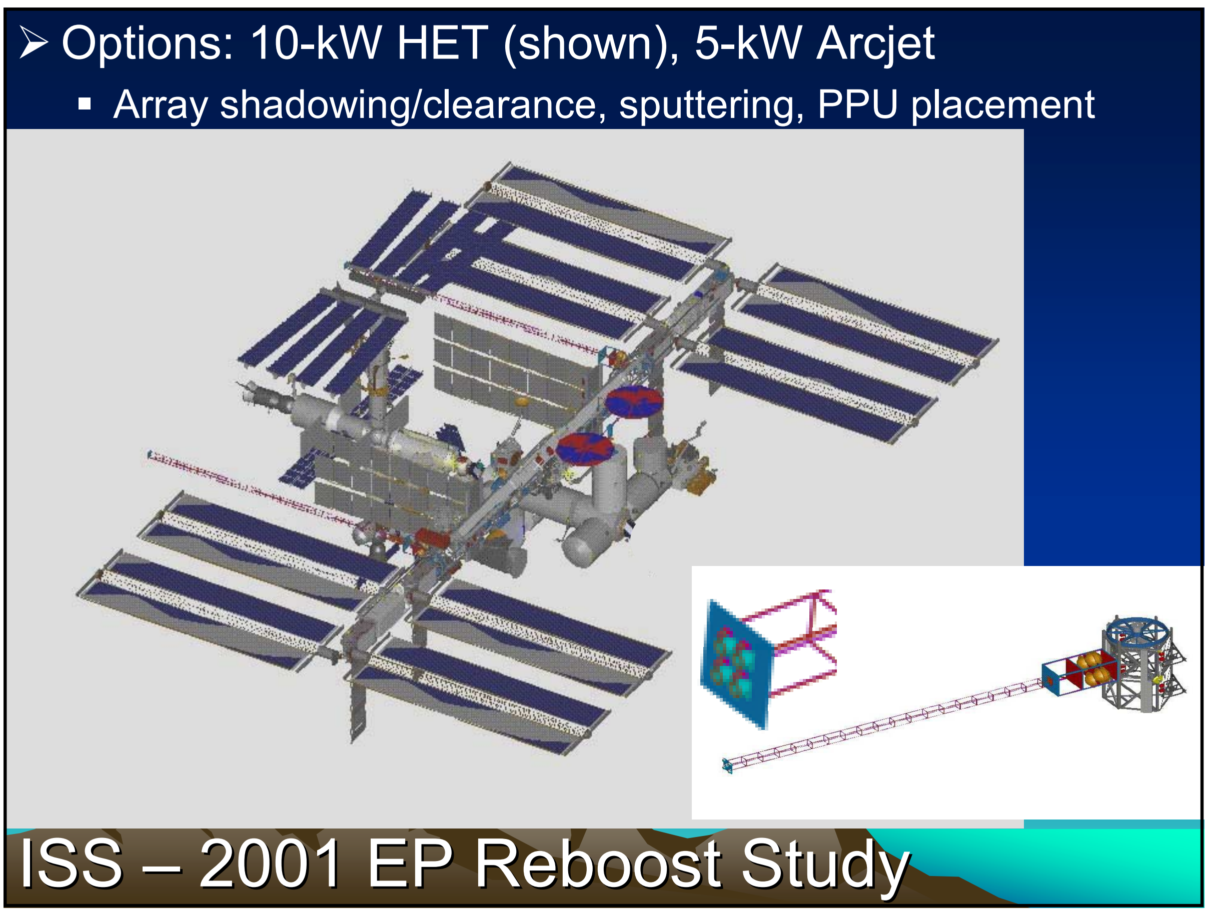


Primary EP
Reduced cell count, concentrator PV
DS-1: 1998

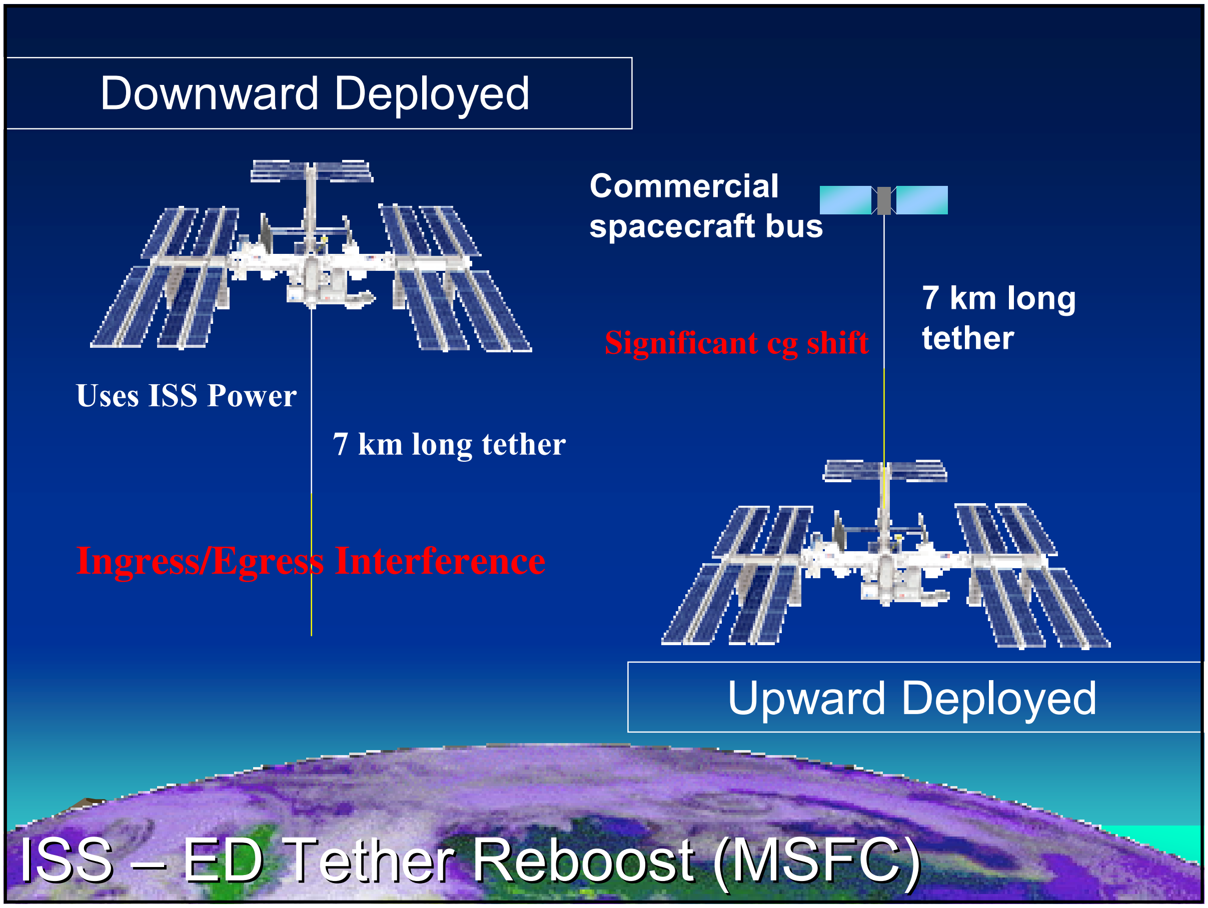


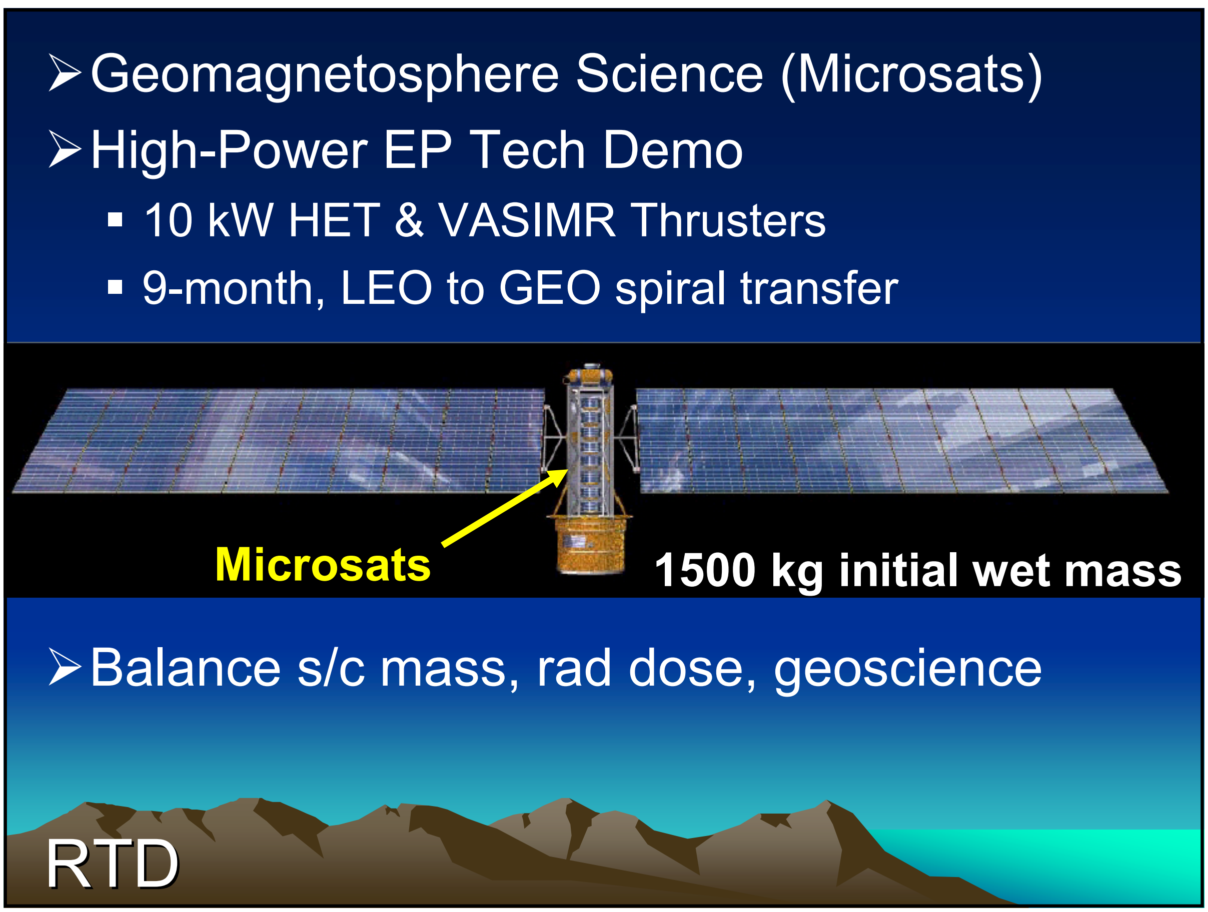
Express-A #2/3: Induced plasma at PVA in GEO - 2000
DEP3
DRT2
DRT3-2
IMDD2
IMDD1
DRT3-1
Satellite center of gravity
DEP2
DEP1
DRT1
SPT-100
GeoComsat EP

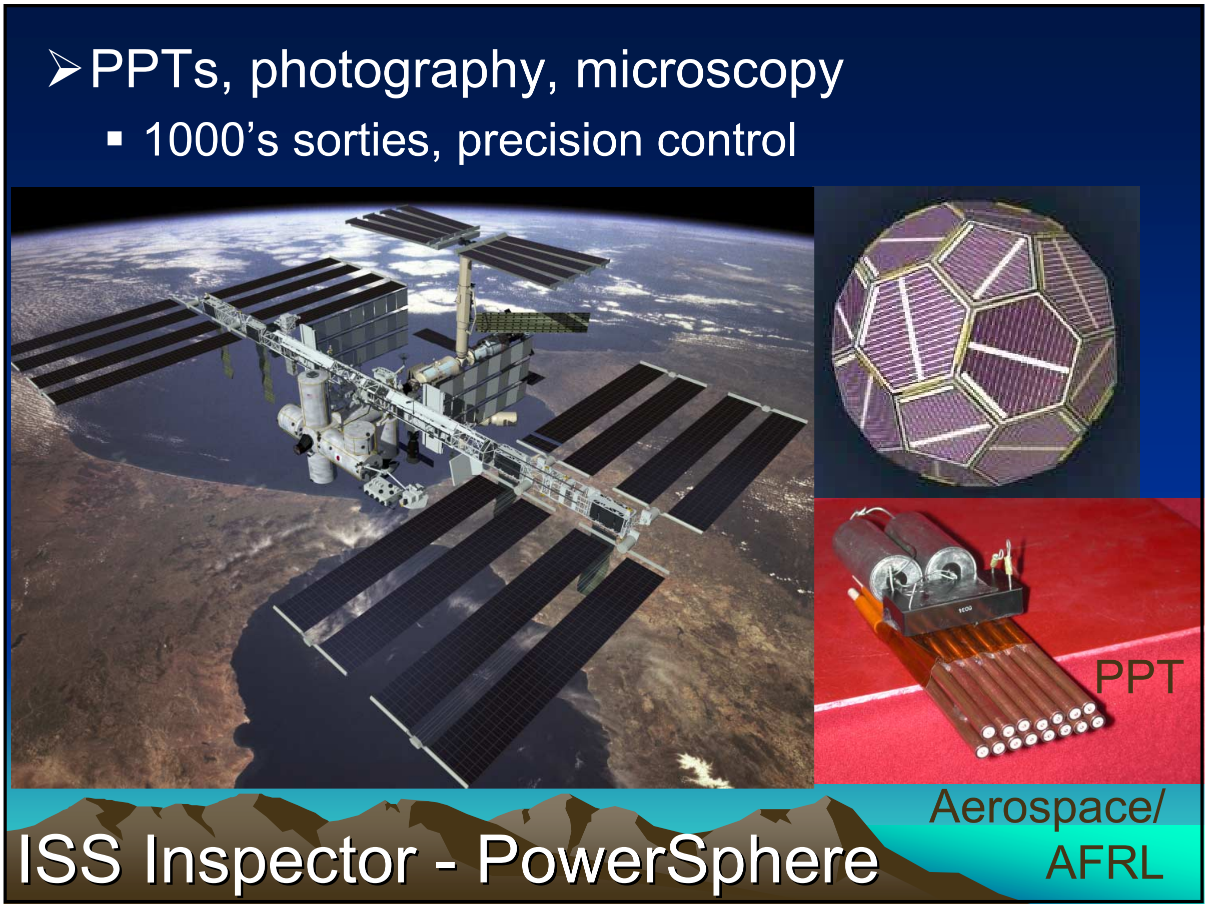
➢ Waste Gas Management, Reboost
4x500-W, 0.33 N,
100-500 sec Isp
SSF Resistojet

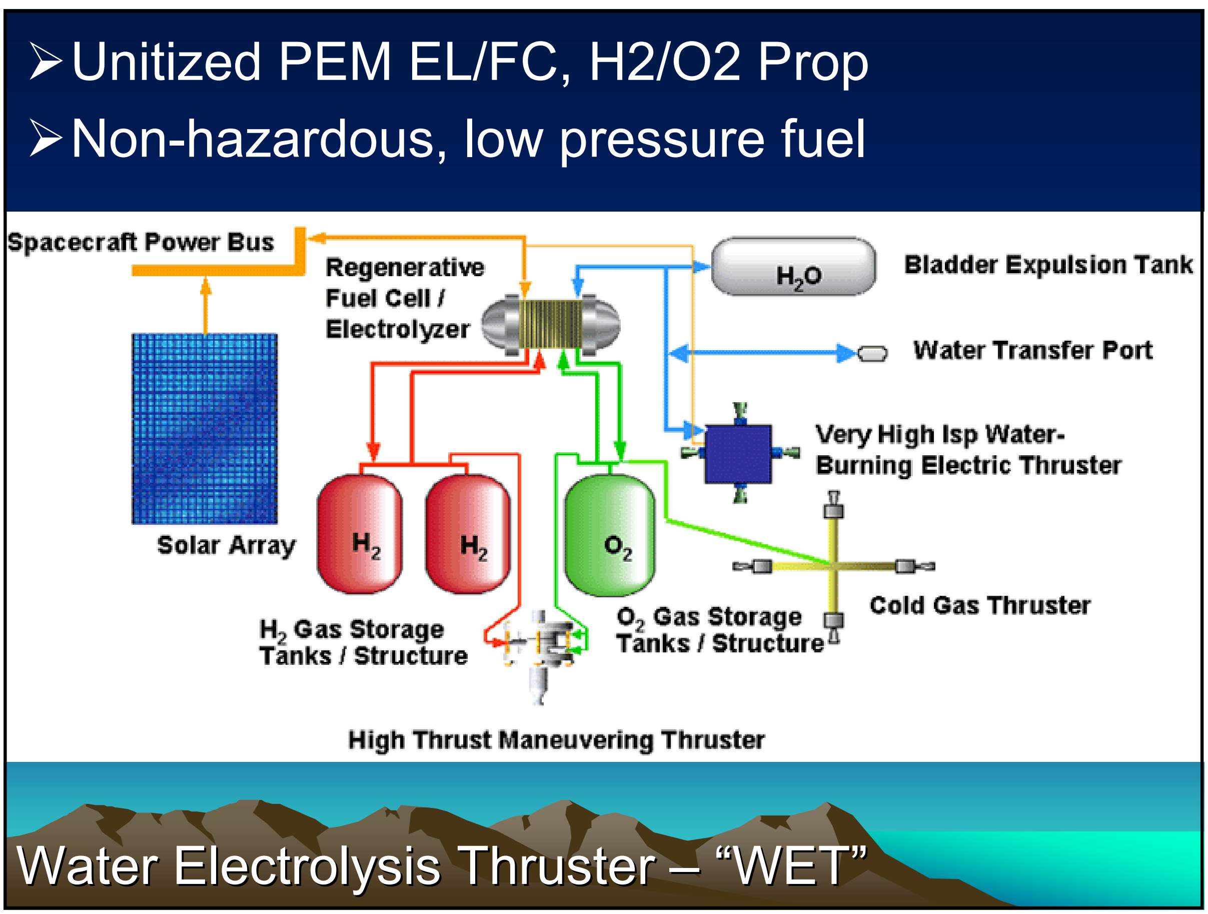


➢ Options: 10-kW HET (shown), 5-kW Arcjet
▪ Array shadowing/clearance, sputtering, PPU placement
ISS – 2001 EP Reboost Study

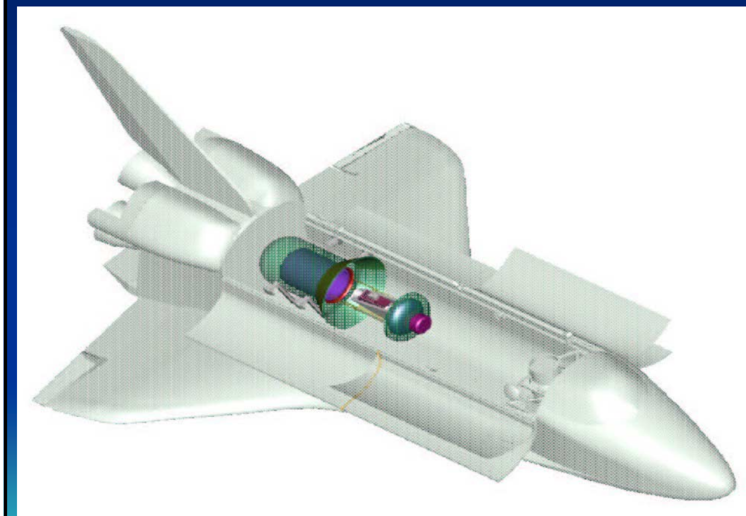

Downward Deployed
Commercial spacecraft bus
7 km long tether
Significant cg shift
Uses ISS Power
7 km long tether
Ingress/Egress Interference
Upward Deployed
ISS – ED Tether Reboost (MSFC)

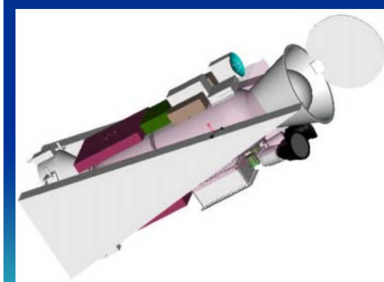

➢Geomagnetosphere Science (Microsats)
➢High-Power EP Tech Demo
▪ 10 kW HET & VASIMR Thrusters
▪ 9-month, LEO to GEO spiral transfer
Microsats
1500 kg initial wet mass
➢Balance s/c mass, rad dose, geoscience
RTD


➢PPTs, photography, microscopy
▪ 1000's sorties, precision control
PPT
Aerospace/
AFRL
ISS Inspector - PowerSphere


➢Unitized PEM EL/FC, H2/O2 Prop
➢Non-hazardous, low pressure fuel
Spacecraft Power Bus
Regenerative
Fuel Cell /
Electrolyzer
H_2O
Bladder Expulsion Tank
Water Transfer Port
Solar Array
Very High Isp Water-
Burning Electric Thruster
H_2
H_2
O_2
Cold Gas Thruster
H_2 Gas Storage
Tanks / Structure
O_2 Gas Storage
Tanks / Structure
High Thrust Maneuvering Thruster
Water Electrolysis Thruster – "WET"

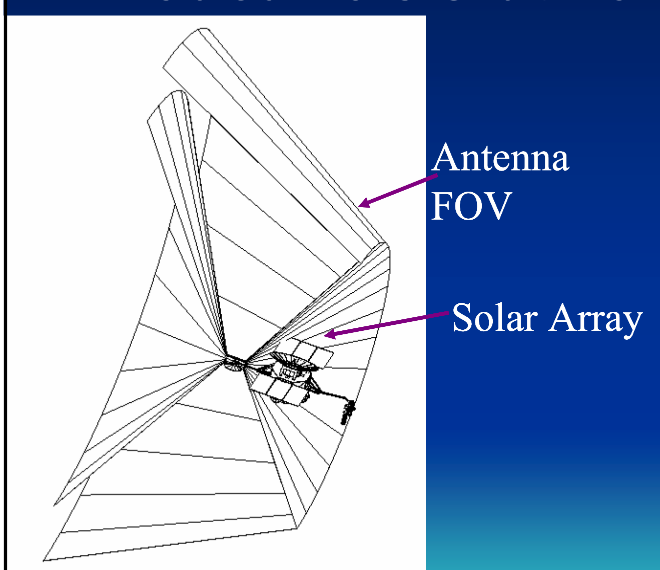
- Shuttle launched/retrieved
- 10 kW Xe Ion Thrusters, Xe resistojet ACS
- 20 kg canister returned LMO->LEO

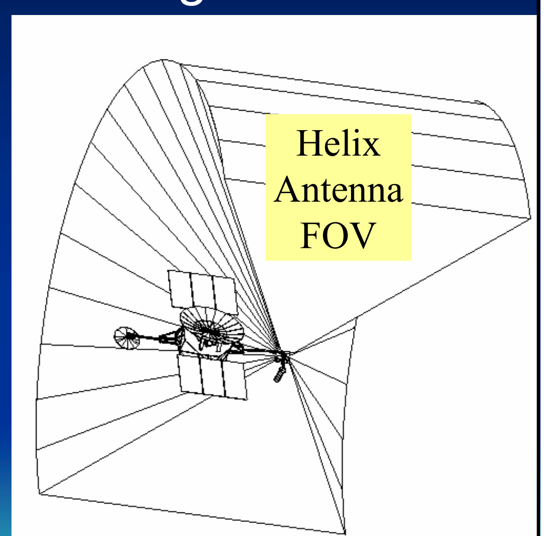




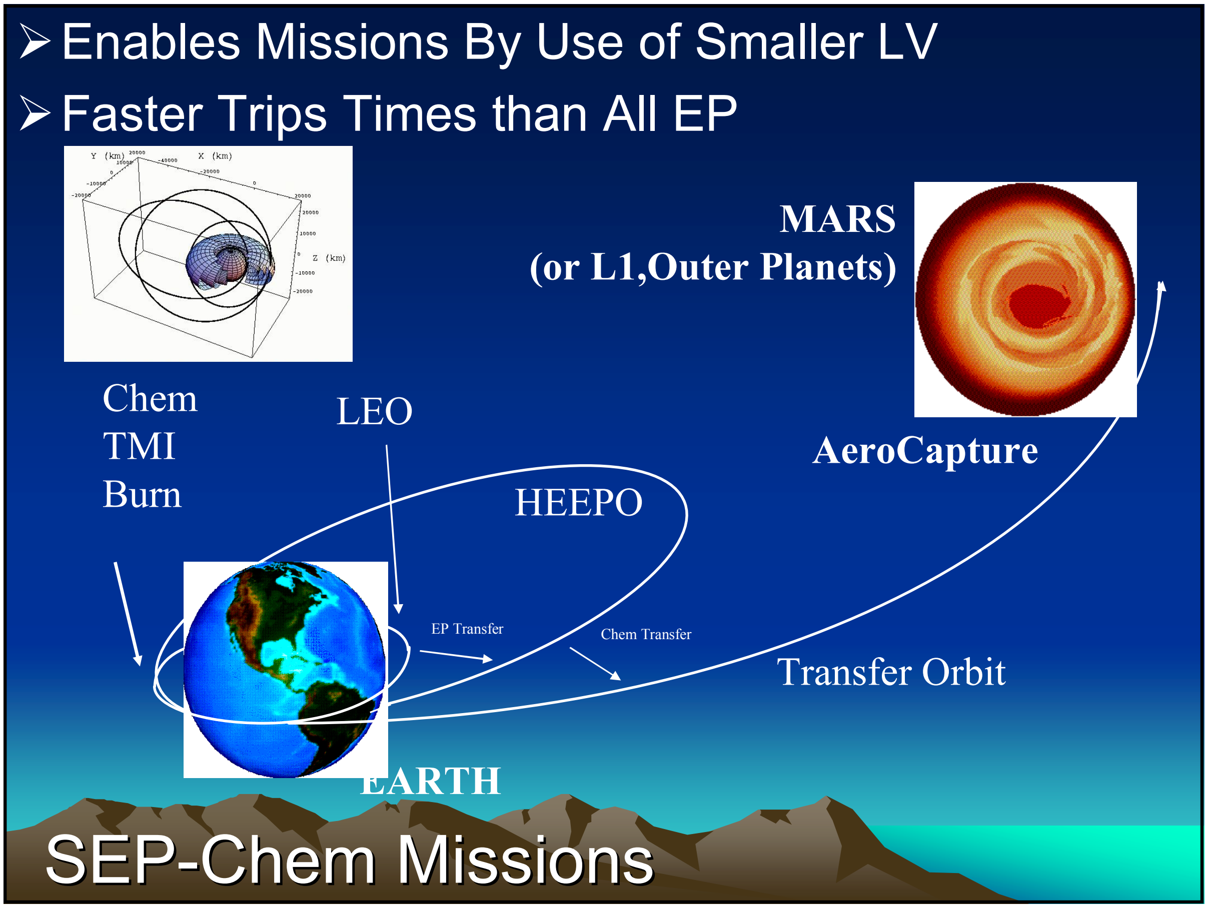
Mars Sample Return (JSC)

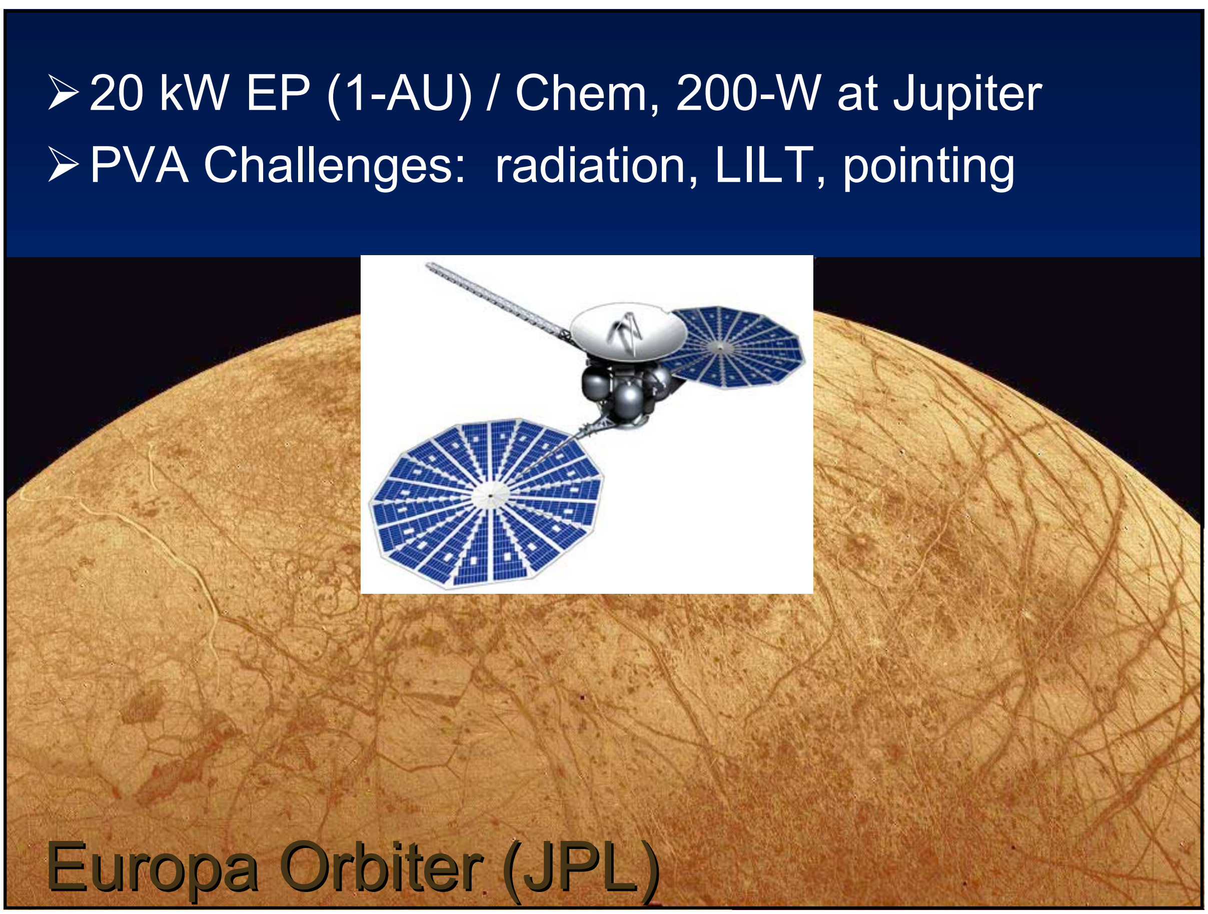
- 6-12 kW Ion/Hall EP plus Chem Prop.
- Enabled launch on Delta 7925
- Enabled Mars Orbit Maneuvering – KOZ Issue

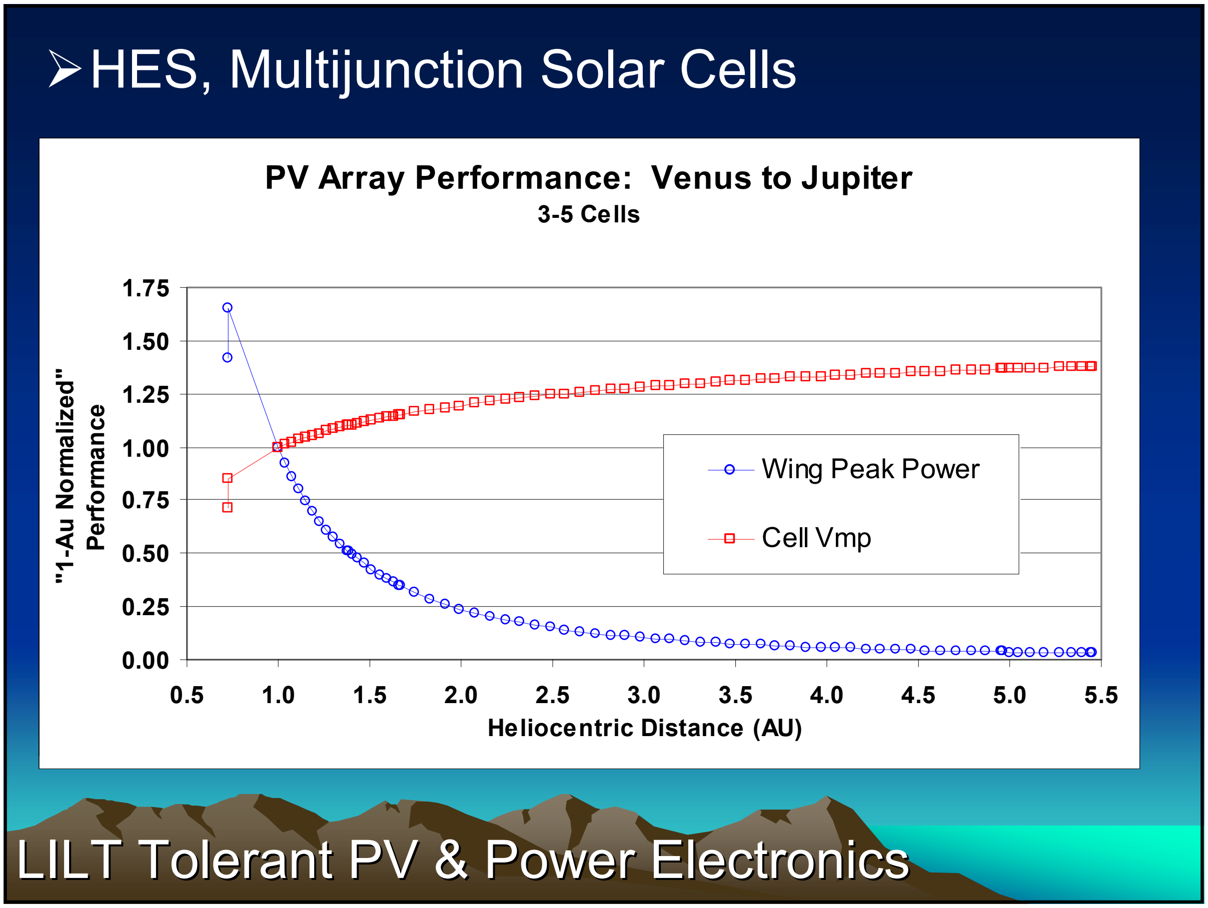




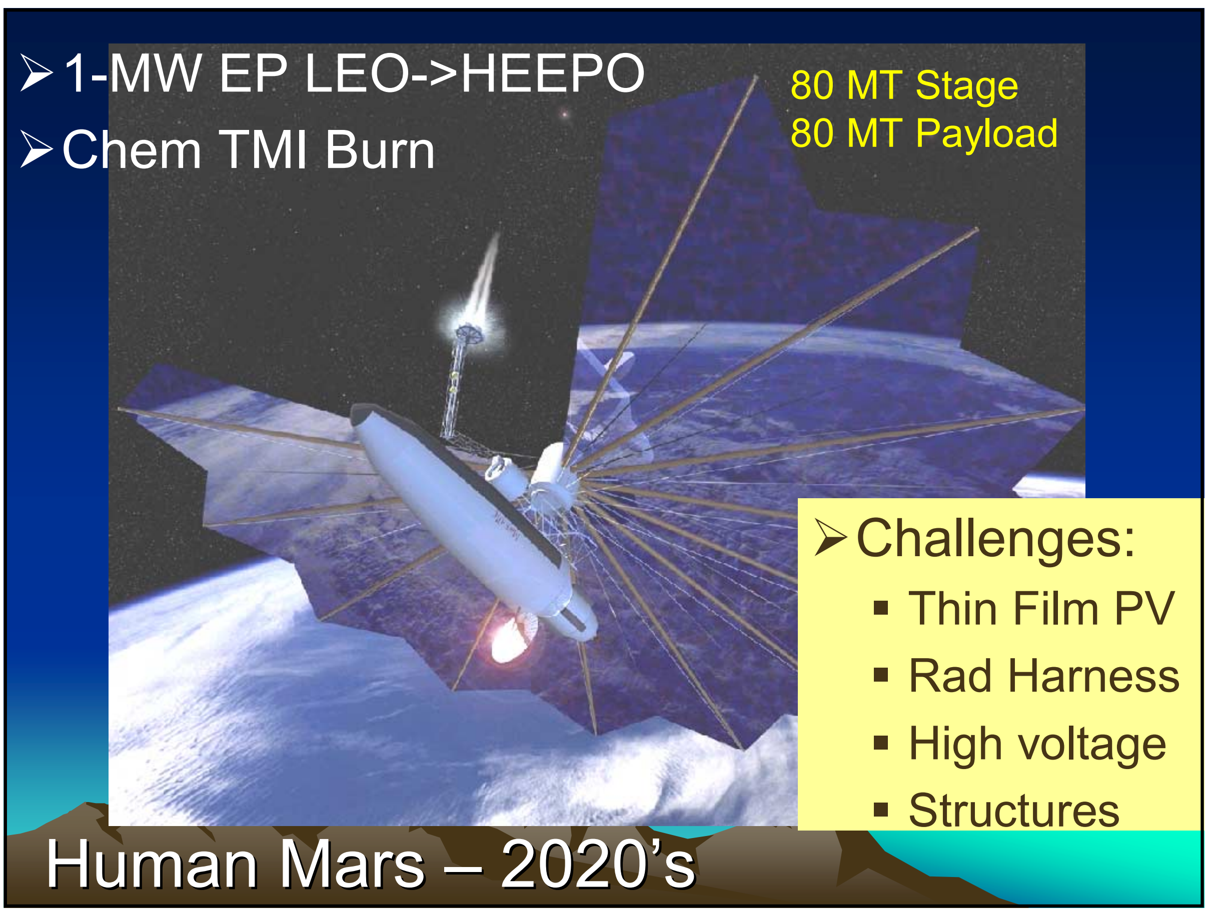
Mars ComSat (GSFC)


➢ Enables Missions By Use of Smaller LV
➢ Faster Trips Times than All EP
MARS
(or L1,Outer Planets)
Chem
TMI
Burn
LEO
HEEPO
AeroCapture
EP Transfer
Chem Transfer
Transfer Orbit
EARTH
SEP-Chem Missions

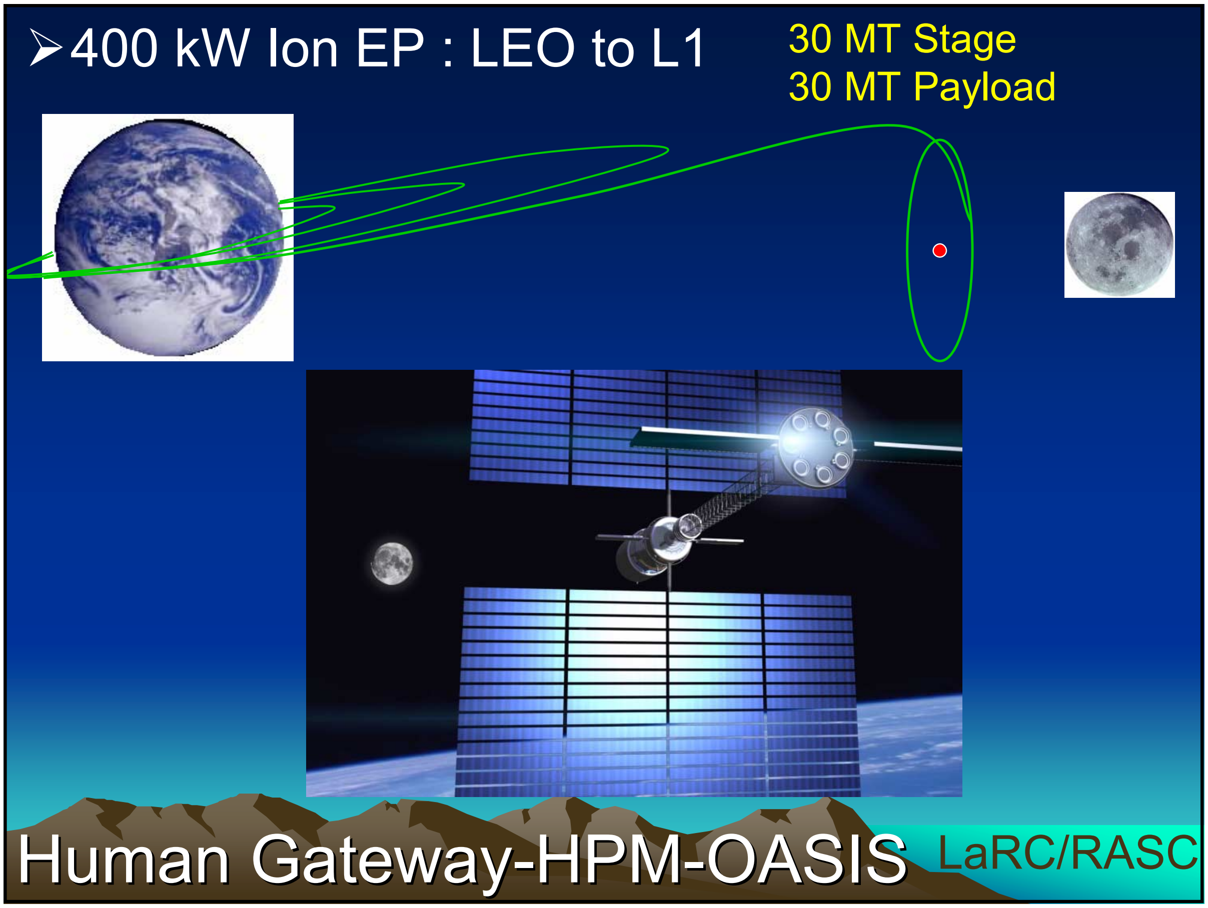

➢ 20 kW EP (1-AU) / Chem, 200-W at Jupiter
➢ PVA Challenges: radiation, LILT, pointing
Europa Orbiter (JPL)

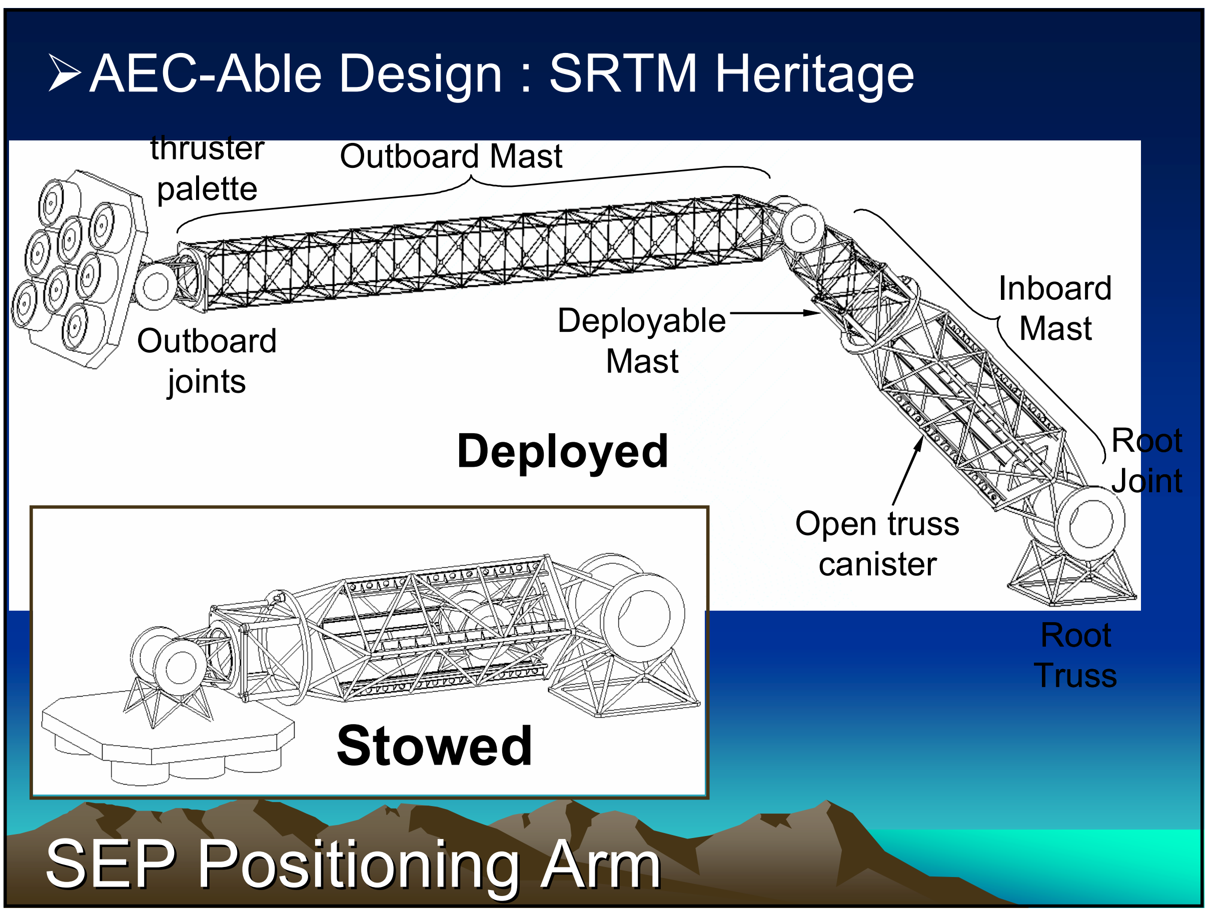


HES, Multijunction Solar Cells
PV Array Performance: Venus to Jupiter
3-5 Cells
"1-Au Normalized" Performance
Heliocentric Distance (AU)
Wing Peak Power
Cell Vmp
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
LILT Tolerant PV & Power Electronics



1-MW EP LEO->HEEPO
Chem TMI Burn
80 MT Stage
80 MT Payload
Challenges:
Thin Film PV
Rad Harness
High voltage
Structures
Human Mars – 2020's


400 kW Ion EP : LEO to L1
30 MT Stage
30 MT Payload
Human Gateway-HPM-OASIS
LaRC/RASC

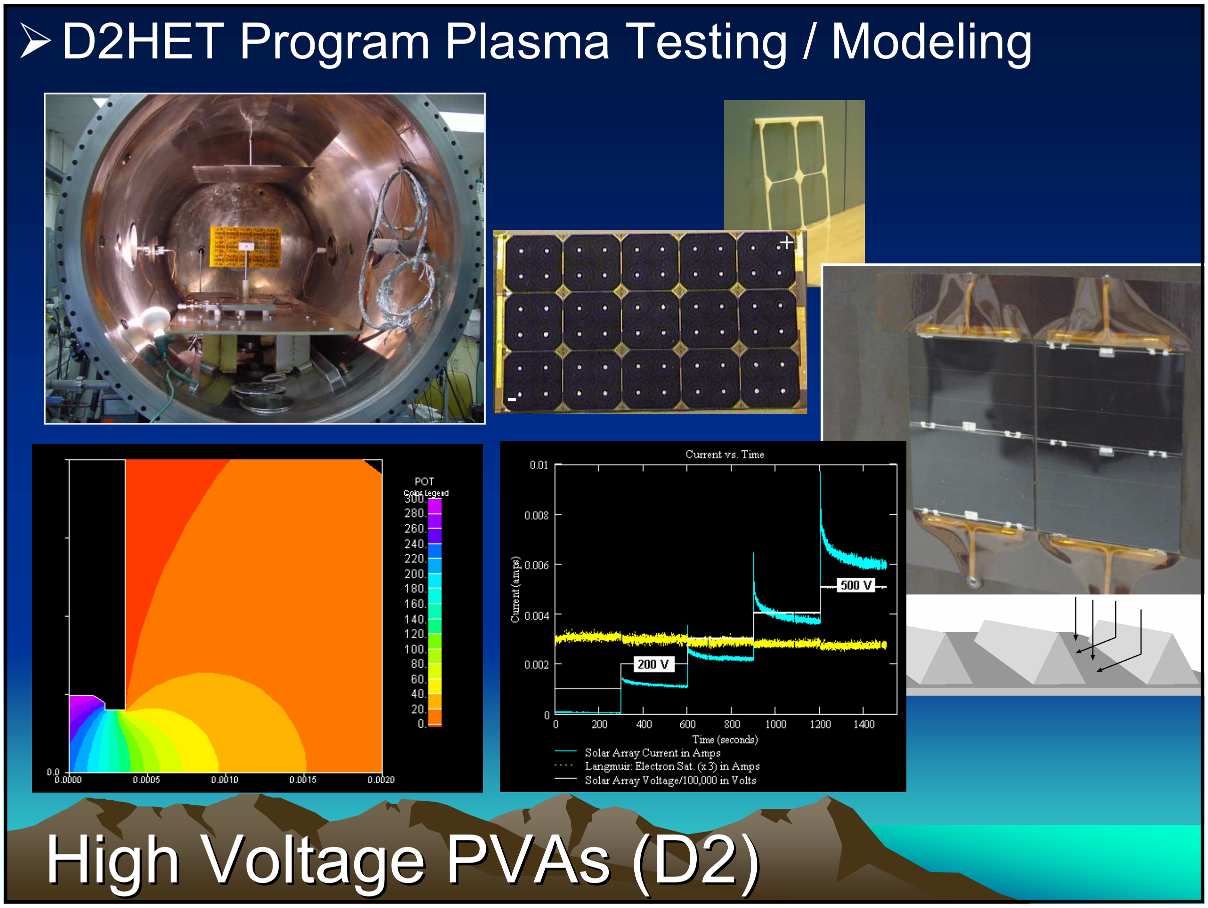

AEC-Able Design : SRTM Heritage
thruster
palette
Outboard Mast
Inboard
Mast
Deployable
Mast
Outboard
joints
Deployed
Root
Joint
Open truss
canister
Root
Truss
Stowed
SEP Positioning Arm

- High efficiency (15-20%)
- Low mass substrates (0.1-0.2 kg/m2)
- Encapsulated for High Voltage Operations
- Low cost

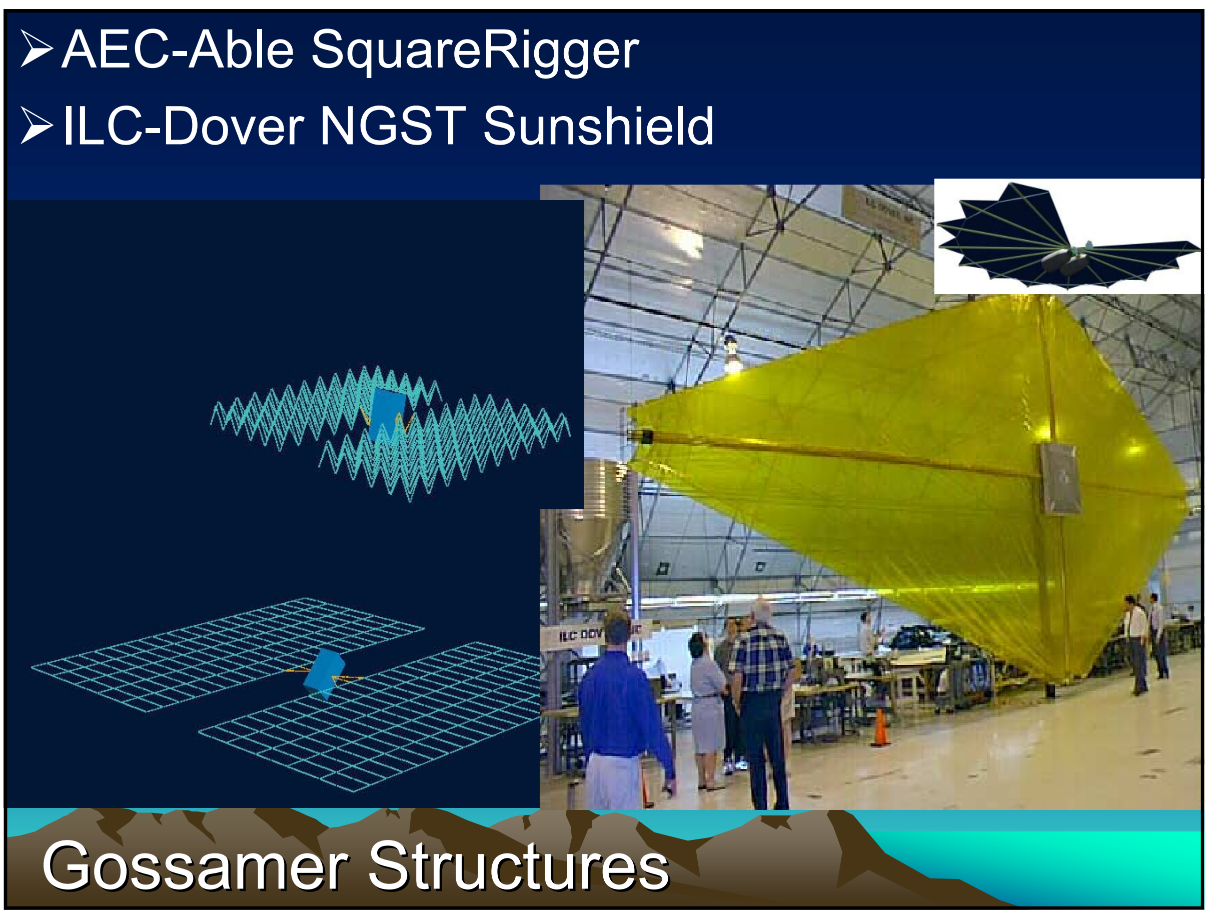
Thin-Film Photovoltaics

- Thin Film PV
- Entech SLA

Radiation Hardness

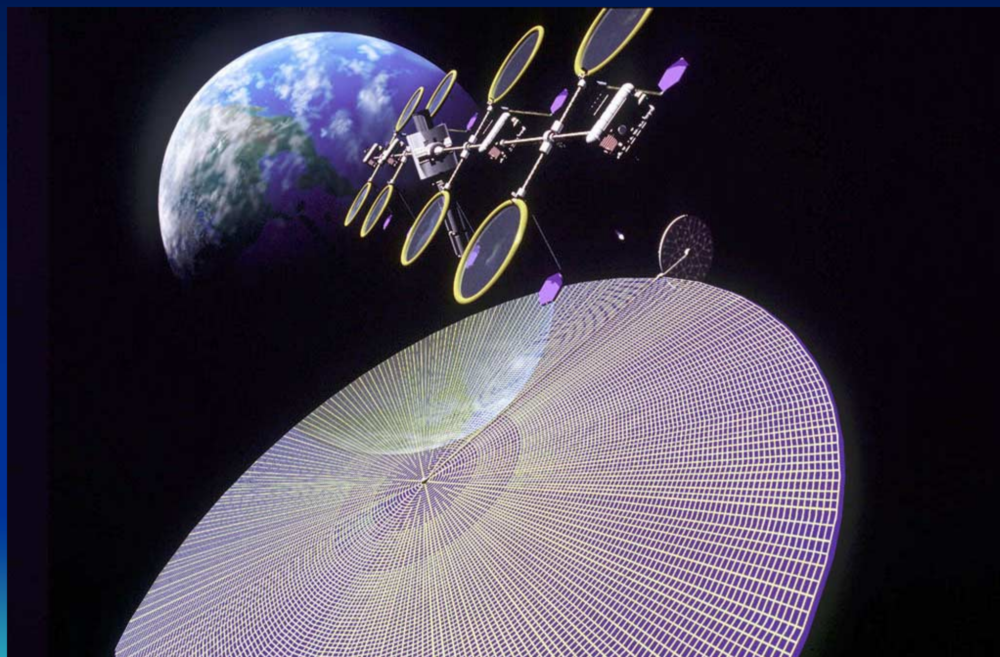


D2HET Program Plasma Testing / Modeling
POT
Current vs. Time
Current (amps)
Time (seconds)
200 V
500 V
Solar Array Current in Amps
Langmuir: Electron Sat. (x 3) in Amps
Solar Array Voltage/100,000 in Volts
High Voltage PVAs (D2)



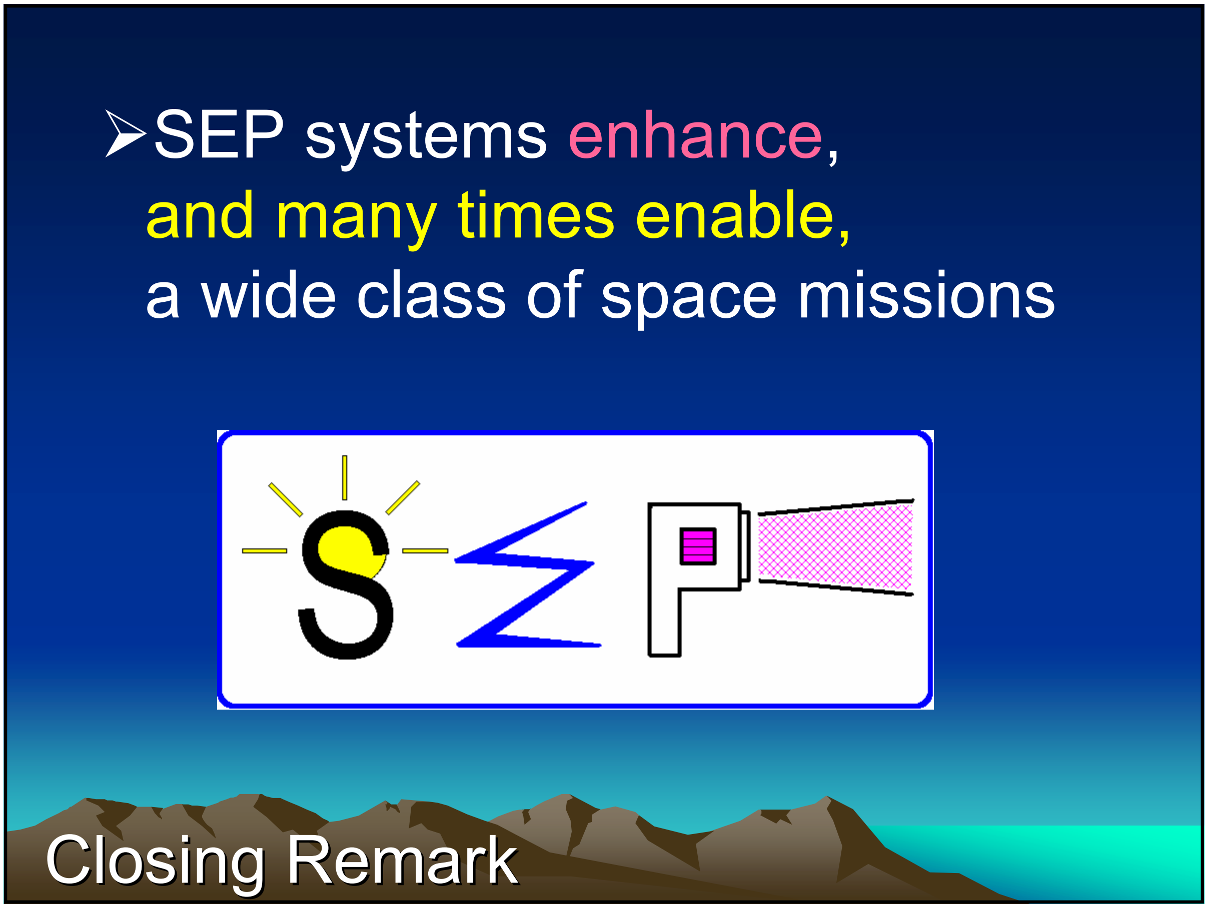
AEC-Able SquareRigger
ILC-Dover NGST Sunshield
Gossamer Structures

➢ 200 kW HET per node; 20 MT LEO->GEO, ACS



The Future? Space Solar Power

Or The Future? “SolarBird”


SEP systems enhance,
and many times enable,
a wide class of space missions
Closing Remark

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13. ABSTRACT ***(Maximum 200 words)***
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