Science Definition Team
Solar Study Status Report

Ray Crum

Jet Propulsion Laboratory,
California Institute of Technology

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Pre-Decisional — For Planning and Discussion Purposes Only

Background of Solar Study

- Comprehensive study conducted
  - Year long study involving all relevant disciplines
  - Incorporated Juno lessons learned
  - Multiple trade studies to settle on configuration
  - Detail power sizing model grounded to solar cell & battery test data
  - Comprehensive set of threats/ risks developed
  - Risk reduction activities funded to address top risks
  - Independent review of study
  - Tracking configuration changes since study close out in Oct 2013, but not updating concept design
- This presentation will summarize
  - Concept drivers
  - Spacecraft concepts
  - Power sizing
  - Risk & mitigation
  - Independent review summary

Independent Review Board Confirmed Feasibility of Solar Power for this Mission

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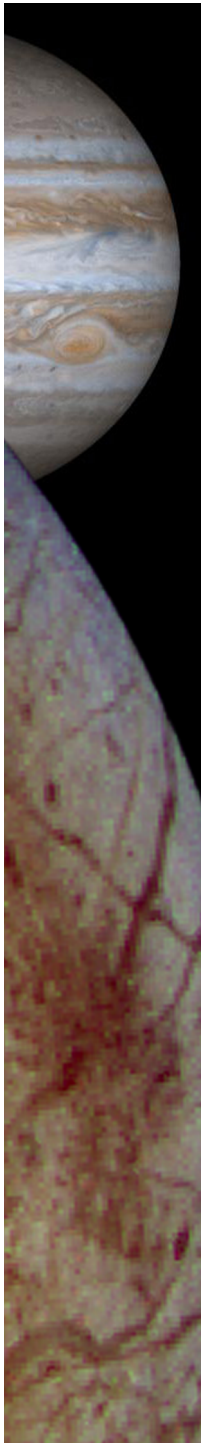
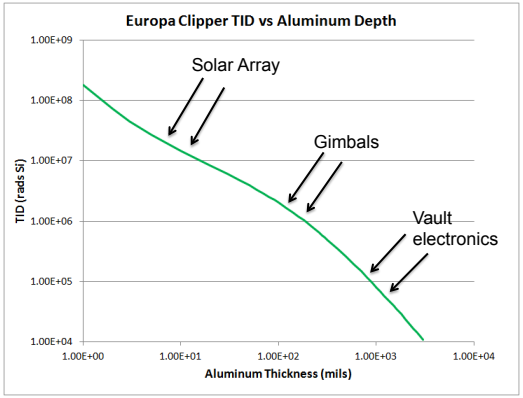


Concept Drivers on using Solar Power 1 of 2

Radiation: Total Dose



Radiation: Cell Displacement Damage

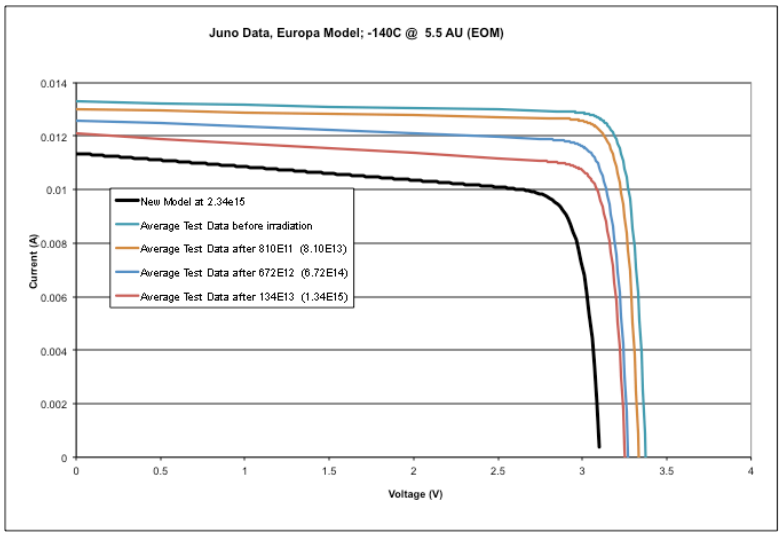
- Testing in 2012 confirmed UTJ degradation at Clipper levels

Summary of 1 MeV equivalent electron fluences in Spectrolab 3J (cm^{-2}) 34 flyby mission (RDF=2)

SiO2 Coverglass thickness			Trapped Protons			Trapped electrons	Total EQ 1 MeV Electron Fluence		
g cm^{-2}	mils	micron	P_{max}	V_{oc}	I_{sc}	P_{max}, V_{oc}, I_{sc}	P_{max}	V_{oc}	I_{sc}
0	0	0	2.65E+18	3.11E+18	3.00E+18	4.92E+14	2.65E+18	3.11E+18	3.00E+18
0.0056	1	25.4	1.77E+17	2.07E+17	1.98E+17	4.67E+14	1.77E+17	2.08E+17	1.99E+17
0.0168	3	76.2	2.15E+16	2.52E+16	2.08E+16	4.38E+14	2.19E+16	2.56E+16	2.12E+16
0.0335	6	152.4	5.80E+15	6.80E+15	5.22E+15	4.06E+14	6.21E+15	7.21E+15	5.63E+15
0.0671	12	304.8	1.58E+15	1.85E+15	1.32E+15	3.60E+14	1.94E+15	2.21E+15	1.68E+15
0.1118	20	508	5.93E+14	6.95E+14	4.79E+14	3.16E+14	9.09E+14	1.01E+15	7.95E+14
0.1676	30	762	2.59E+14	3.04E+14	1.80E+14	2.77E+14	5.36E+14	5.80E+14	4.57E+14
0.3353	60	1524	8.70E+13	1.02E+14	5.80E+13	2.02E+14	2.89E+14	3.04E+14	2.60E+14

Medium Risk for Solar Array

Low Illumination & Low Temperature at Jupiter



The Solar Cell I-V curve validated by JUNO radiation testing and LILT screening of UTJ cells with 12 mil cover glass, RDF 2

Must Quantify for Newer Cell Types

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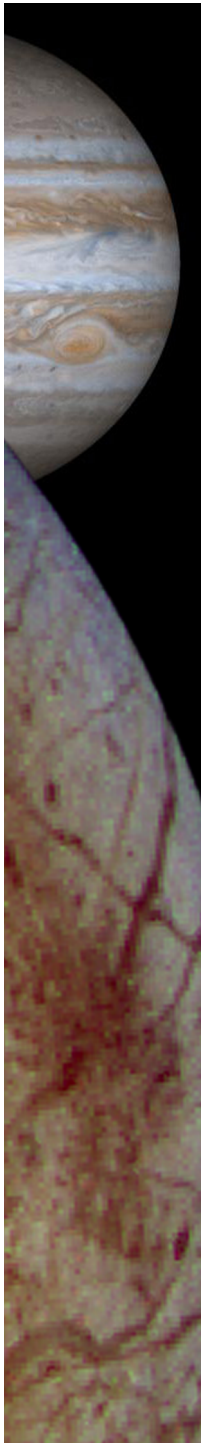
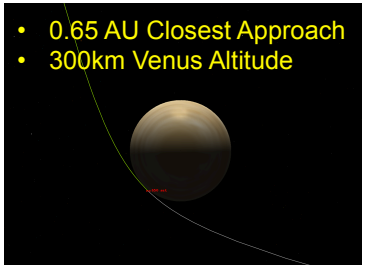
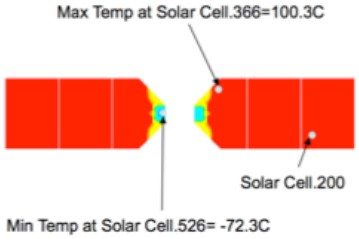
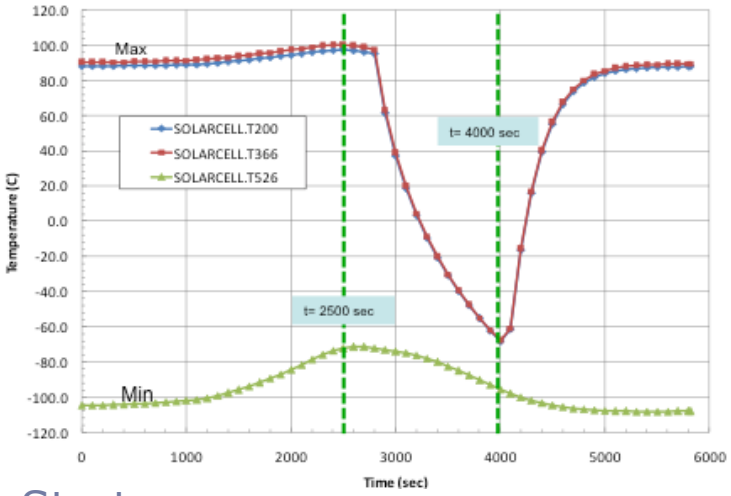


Concept Drivers on using Solar Power 2 of 2

Hot Case: Venus Flyby





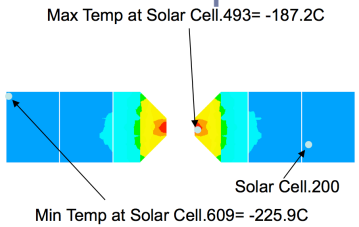


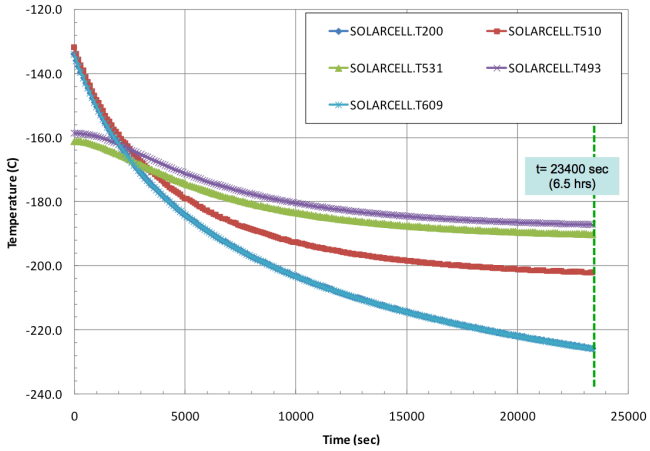
Strategy

- Point vehicle with HGA facing the sun
- Off point (55°) solar panels to manage temperature

Very Low Risk to Solar Array

Cold Case: Jupiter Eclipse





- 13-F7 trajectory has 33 eclipses; 1 at 4.5 hours; 32 at 2-3 hours (average 2.43 hours)
- Juno qualified to -180°C; Clipper expects to see -226°C
- This combined with radiation exposure has never been tested

High Risk to Solar Array

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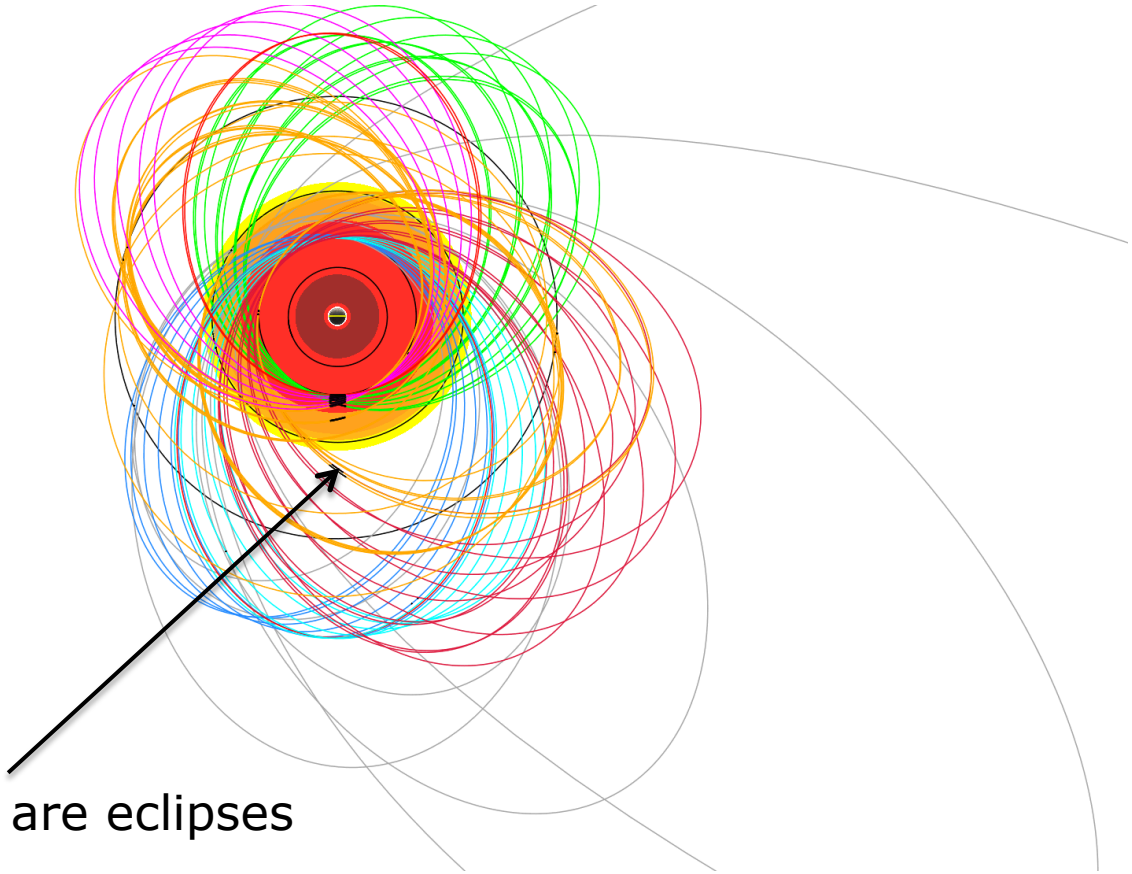
Eclipses at Jupiter



Black strips are eclipses

Mission Concept to Meet Science Requirements Always Results in Eclipses

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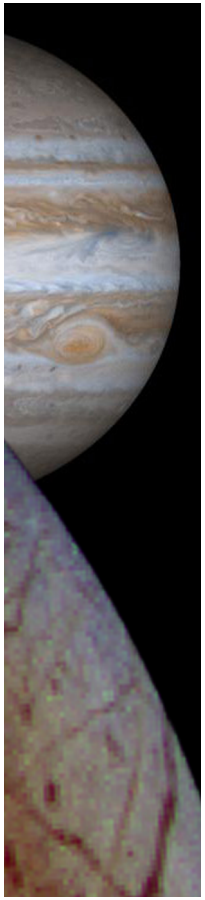
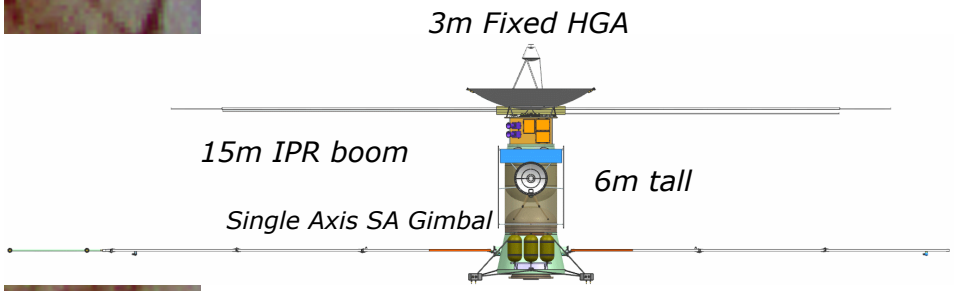
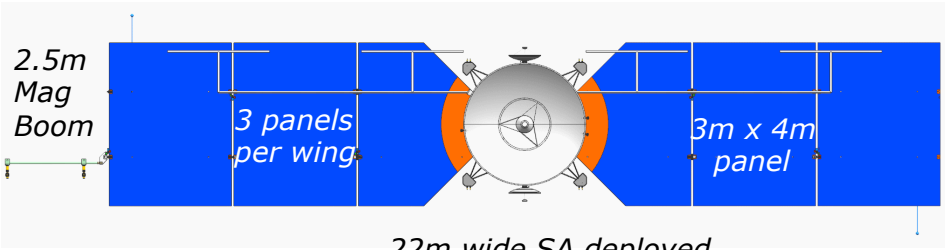


Solar Vehicle Concept Features & Attributes (v6.5)

Feature	Benefit
MON3/MMH Bi-Propellant	Lower freezing point reduces heating load
Pumped Thermal Loop	Recover waste heat to reduce heating load
No RHU	Reduces NEPA & Launch Approval work
Single Axis Articulation	-Maximize power generation at Jupiter -Reduces SA heating at Venus -Control angles for IPR and gravity science

Attribute	Value
Dry Mass (CBE)	1646 kg (Atlas)
Payload Mass (CBE)	70 kg
Delta V	1675 m/s (Atlas)
Power at EOM	460 W
Array Size	46 m2 cell area
Battery	155 A-h
Pointing	1 mrad RWA
Downlink Max Range	85 kbps
Gravity Science	2 hours per flyby
Design Life	11 years
Reliability	1 fault tolerant





Mass Margin	Energy Balance State of Charge	Power Margin
40%	>30%	40%

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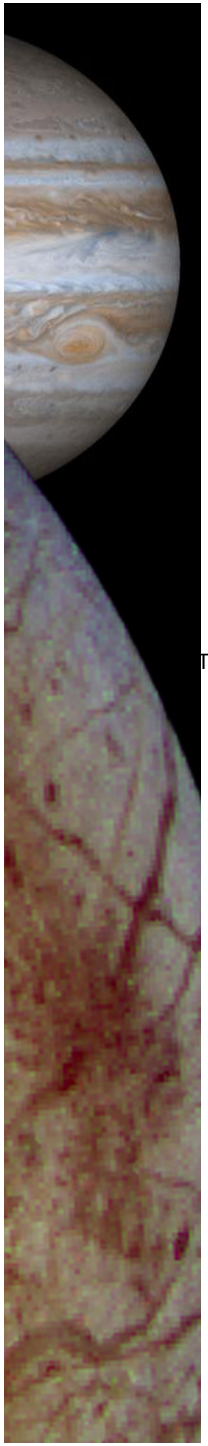
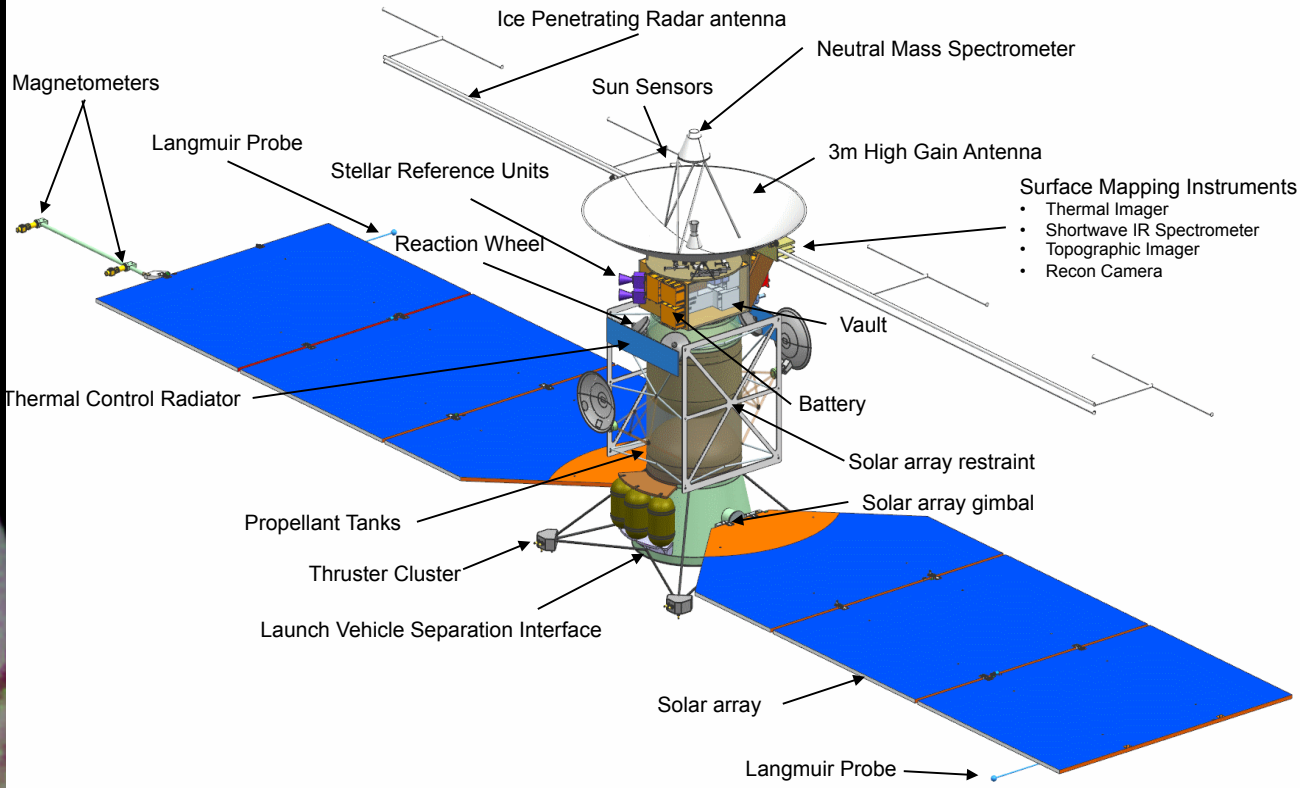
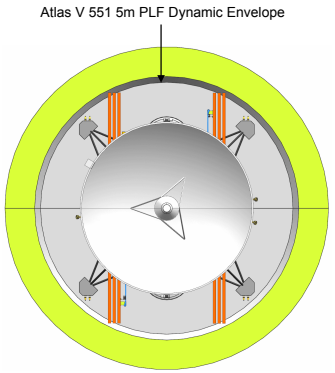
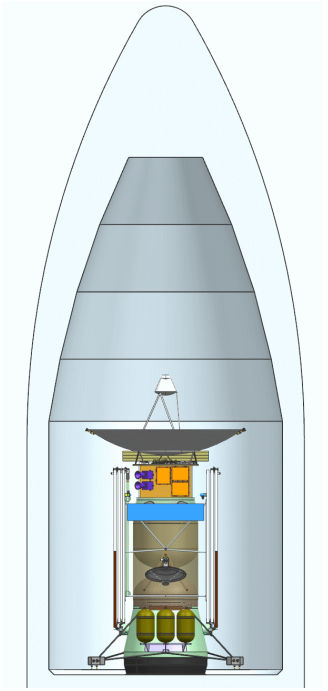


Clipper Solar Power Spacecraft Concept







Concept Accommodates All Instruments & Fits on Atlas V 551 Launch Vehicle

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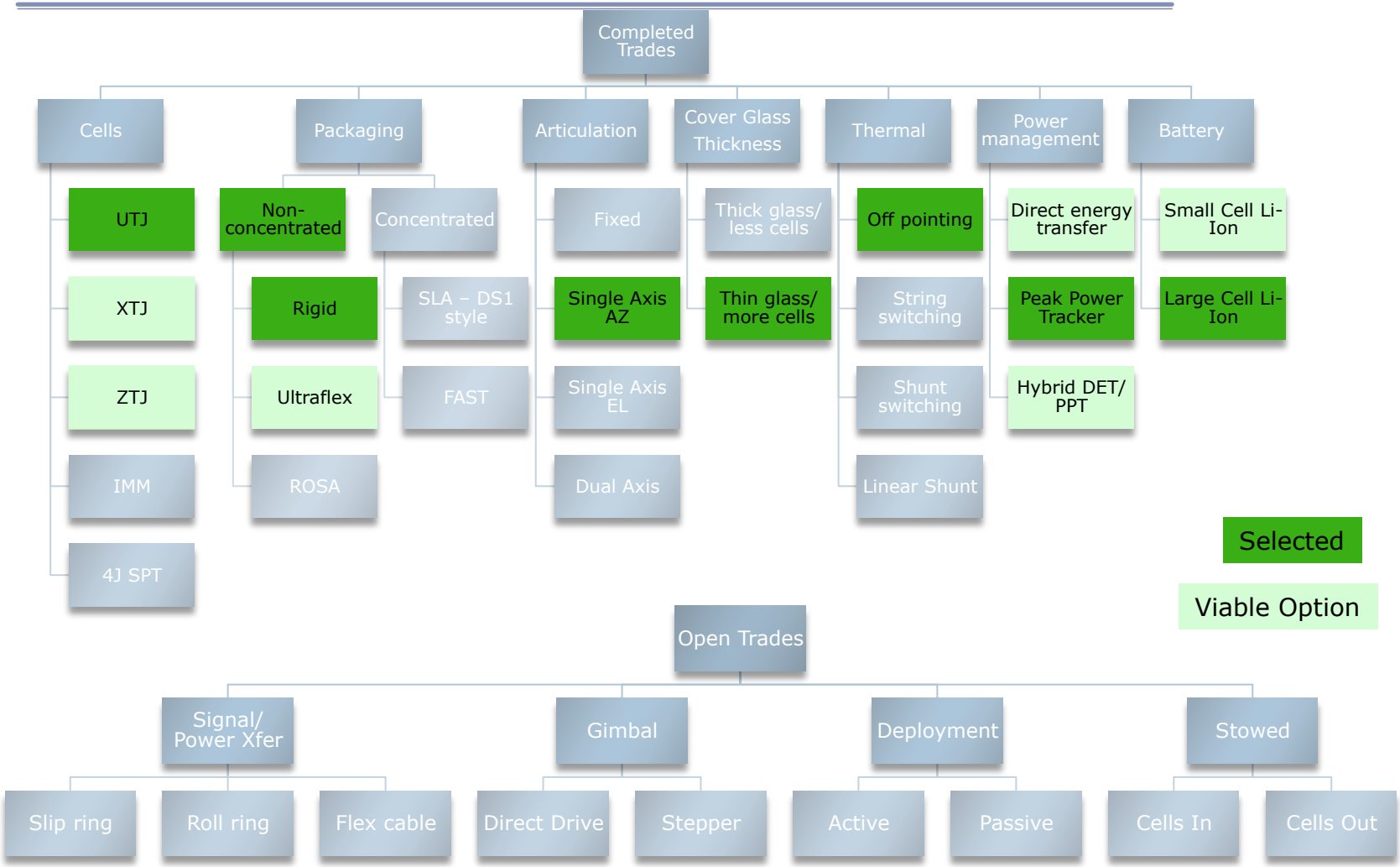
Major Solar Concept Trades



Optimized Configuration for Mass, Risk, and Environments

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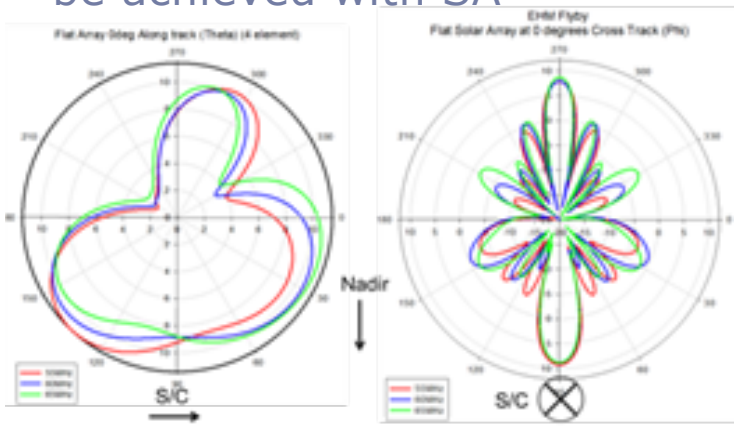
Key Analysis for Solar Powered Concept

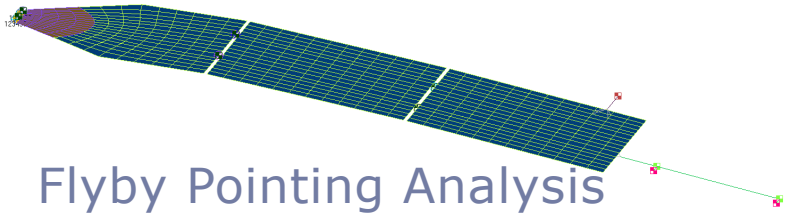
IPR Beam Pattern Distorted by Solar Arrays

- Analysis by D. Kirchner, University of Iowa
- 60 MHz some perturbations; SA angles of 0-45° are best
- 9 MHz not sensitive to SA angle
- Fix SA during IPR operation
- Successful IPR operation can be achieved with SA

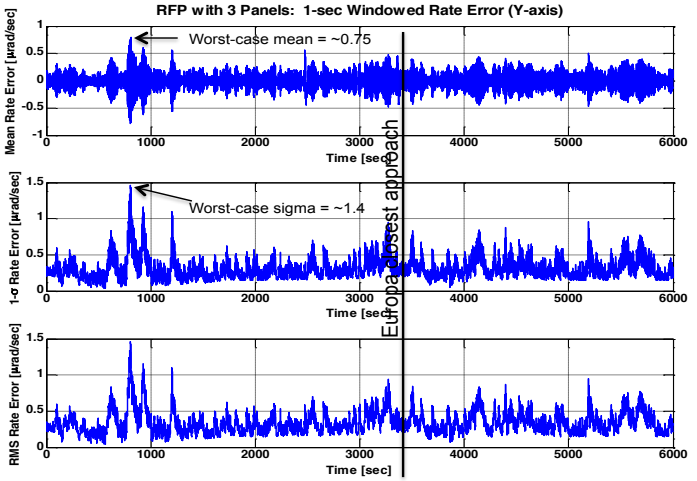


Stability Analyses

- FEM of SA; 1st Mode 0.18 Hz



- Flyby Pointing Analysis
  - Recon < 50 urad/sec
  - SWIRS < 25 urad/sec



"3-sigma" rate error = ~0.75 + (3 x 1.4) = ~ 5 urad/s

Low Risk Continue Analyses and Model Validation via Test

Low Risk But Must Be Managed Throughout Development

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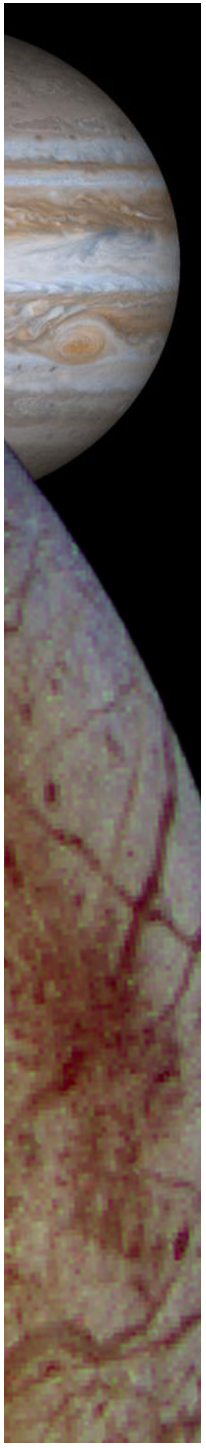


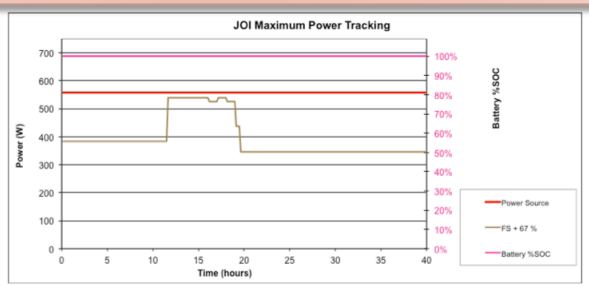
Power System Sizing

Conservative Sizing Approach
- RDF 2 applied degradation SA cell degradation
- EOM degradation for battery and solar cell
- UTJ Cell performance test data (LILT and radiation to Clipper levels)
- >=40% power margin, exceeds JPL DP
- JPL DP for allowable battery state of charge
- Detail array dynamic power modeling: Used trajectory, shadowing, eclipses, pointing, cell degradation
- Detail power modes
- 3% I2R losses
- Maximum Power Tracking architecture, 90% efficiency
- Results in
  - 155 A-hr battery, end of mission
  - 460 W array, end of mission
  - 46 m2 active/55 m2 packaged

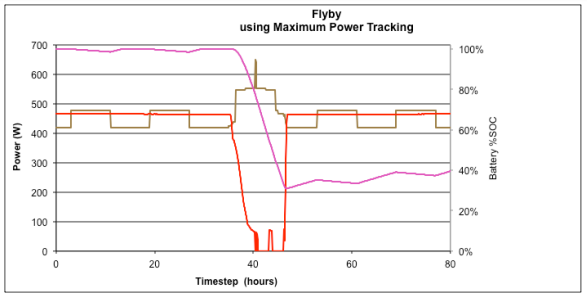
Currently funding technology development for higher energy density battery as opportunity to decrease mass & lower heating demand on battery

Conservative Sizing Performed Lowers Development Risk

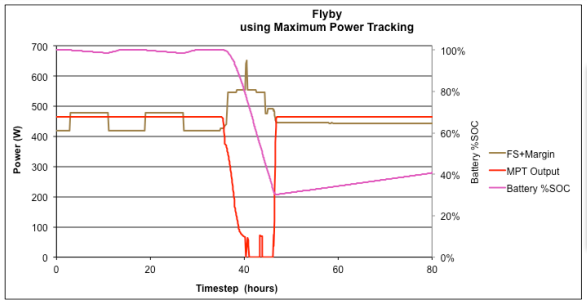
JOI: Power positive through event



Flyby E39: Sizes the battery



Safemode: Power positive at EOM sizes array



Safemode Entry after lowest battery SOC

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Risk Identification for Solar Array Concept

Risk	Impacts	Risk	Study Assessment	Disposition
Eclipse cold survival after radiation exposure	SA	1-High	Test	Mitigate
Unknown SLS launch acoustic environment	SA	2-Medium	None	Mitigate
UTJ Cells become obsolete	SA	2-Medium	Analysis	Mitigate
IPR shadowing	SC	2-Medium	None	Mitigate
ESD for Solar Arrays	SC	2-Medium	Test	Mitigate
ESD impact on plasma instrument	Payload	2-Medium	Test	Mitigate
Array deployment	SC	2-Medium	Similarity	Mitigate
Flexible mode impact	SC	3-Low	Analysis	Mitigate
Contamination from Plumes	SA	3-Low	None	Research
Cover glass cracking	SA	3-Low	Similarity	Mitigate
Wearout of Molybdenum solar cell interconnects	SA	3-Low	None	Research
DHMR on solar arrays	SA	3-Low	Analysis	Watch
SC control system complexity	SC	3-Low	Similarity	Mitigate
Temperature management of large battery	SC	3-Low	None	Mitigate
RCS plume impingement contamination	SC	3-Low	Analysis	Mitigate
Max Power Tracking electronics EMI	SC	3-Low	None	Mitigate
Qual approach for SA at cryogenic temps undefined	SC	3-Low	Analysis	Mitigate
Gimbal life	SC	3-Low	Similarity	Mitigate
FOV/Stray Light Interference	Payload	3-Low	Analysis	Mitigate
Impact on IPR beam pattern	Payload	3-Low	Analysis	Mitigate
Magnetic Cleanliness	Payload	3-Low	Similarity	Mitigate
Contamination from SA outgassing	Payload	3-Low	Similarity	Mitigate
Contamination from Sputtering	Payload	3-Low	Analysis	Accept

Top Risk Understood > Mitigation Test Underway

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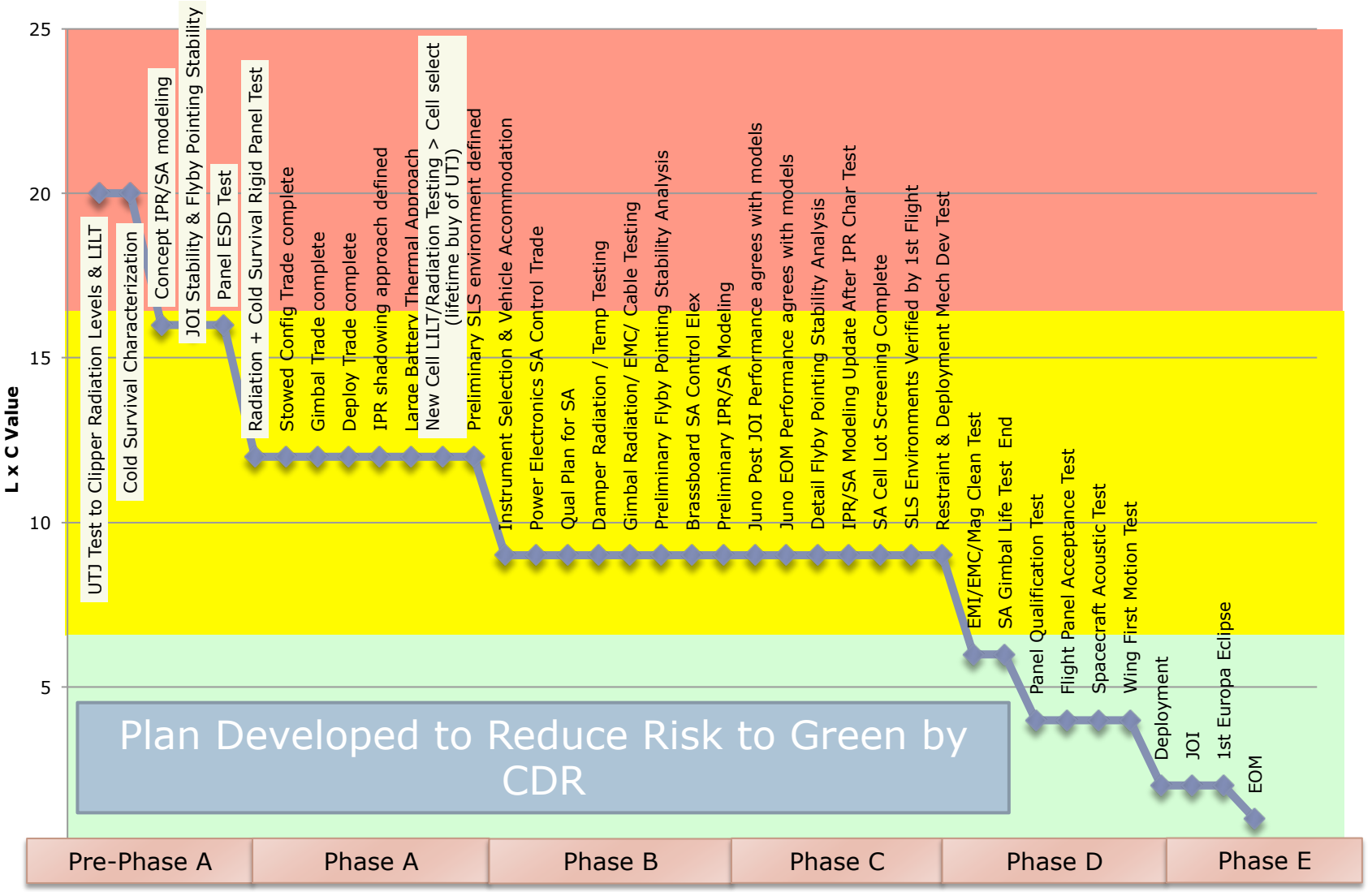
Risk Mitigation Burn Down Plan



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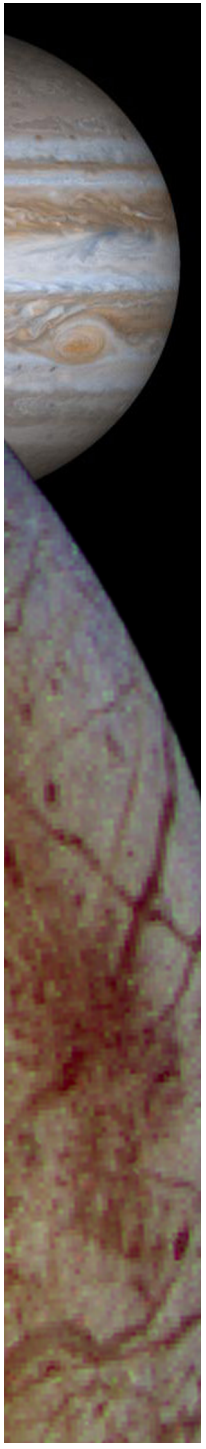

Independent Review Board Assessment

Findings

1) Is solar power feasible for clipper mission?

- Yes
- Manageable engineering challenges
  - No new technology identified
  - Nothing beyond what's normally needed for a project of this scale
- The question of "how reasonable" solar is for Europa Clipper is a harder question
  - There are risks to retire in going solar
  - A function of the option space and budgets
  - Beyond trade space of this team who strictly looked at technical feasibility

2) Have all the critical risks been identified

- No unidentified "critical" risks
  - Numerous risks identified and considered
  - Primary risk: cold temperature combined with radiation

Review Held 8/2/2013

Board

- Chair: Chris Iannello, NASA Technical Fellow for Power
- Doug Bernard, JPL, Project System Engineering
- Rich Ewell, JPL, Power Section, Deputy Manager
- Steve Battel, Consultant
- Mike Piszczor, GRC Solar Array Technology
- Ed Gaddy, APL, Solar Array Implementation
- Ken Hibbard, APL, Project System Engineering
- Gentry Lee, JPL, Office of the Chief Engineer

Independent Review Agreed with Feasibility & Top Risks

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Forward Work

- Resurrect solar vehicle concept and mature to support a trade and selection prior to MCR
- Risk mitigation funded for
  - Cold survival following radiation testing
  - ESD testing
  - XTJ/ZTJ/IMM Radiation & LILT testing

Solar Power is Feasible
Must retire risk with cold survival before solar power is viable

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