The Johns Hopkins University
Applied Physics Laboratory
Laurel, Maryland 20723

Power Subsystem Early Mission Definition Conceptual Design

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Solar STEREO Power Subsystem Requirements (1/4)

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- **Overall**
  - **Power system designs shall be identical between both spacecraft**
    - **Baseline design complies.**
  - **Power system design shall be a minimal departure from existing APL designs**
    - **Baselined as TIMED-type peak power tracking (PPT) system.**
      - **Reduce number of PPT modules**
      - **Eliminate majority voting**
      - **Eliminate pressure controllers and pressure limit sense**
      - **Reduce number of switching functions**
      - **Custom but typical solar array configuration**
      - **NEAR or TIMED type solar cells**
      - **NEAR or TOMS-EP battery (same cells - different packaging)**
      - **Replace battery relay with flight plug**
      - **Change PPT algorithm**
      - **Minor repackaging of PPT modules**
      - **Repackaging of PSE and switching**

Solar STEREO Power Subsystem Requirements (2/4)

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- **Power System Electronics & PPT modules**
  - **Shall not require ground intervention for normal operation**
    - **Battery VT level may require periodic (~months) ground update during mission**
    - **TIMED architecture currently requires IEM to process peak power tracking algorithm (no ground intervention)**
      - **True peak power tracking is not required for the Solar STEREO mission.**
      - **PPT algorithm could be removed from IEM and updated ~weekly by ground command, if this would facilitate IEM and software development.**
  - **Fuses for instruments only**
    - **PPT & LVS modules are currently designed to be fused**
    - **Recommend fusing loads**
      - **Lack of fuses could result in damage to PSE and S/C harness in I&T**
  - **Allow for solar-only operation with all instruments and subsystems simultaneously powered**
    - **Array is sized to maximum allowable package. "Normal" peak loads are supported. Attitude maneuvers require minor battery discharge.**

Solar STEREO Power Subsystem Requirements (3/4)

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- **Solar Array**
  - **Shall support 2 year operation with all systems powered with maximum off-sun pointing of 5°**
    - **Array is sized to maximum allowable package. "Normal" peak loads are supported. Attitude maneuvers require minor battery discharge.**
  - **Shall be shadow tolerant**
    - **Design shall reflect this requirement by TBD method**
      - **Diodes, integral diodes, or 100% screening**
  - **Shall have no gimbals and no intra-panel hinge.**
    - **Current design complies**

Solar STEREO Power Subsystem Requirements (4/4)

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- **Battery**
  - **Shall not restrict launch window**
    - **Desired time from final reconditioning to launch <14 days**
    - **Required time from final reconditioning to launch <28 days**
    - **Desired T-1d top-off on pad (same as NEAR)**
  - **Shall provide power through T-3min to Acquisition+10min**
    - **Preliminary parametric analysis table follows**
  - **Shall provide power through LVS to LVS+12min**
    - **Preliminary analysis follows**

Solar STEREO
Load Power Budget

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Solar Stereo Power Budget	Revision 7	11-Nov-98		
			Solar Only	Battery Required
Subsystem / Component	Average Power	Aggregate Power	Peak Normal Ops	Propulsion Events
Instruments	**52**	**70**	**70**	**70**
EPD	2	2	x	x
HI	15	20	x	x
Mag	2	2	x	x
RBT	4	12	x	x
SCIP	15	20	x	x
SWPA	2	2	x	x
SWPA Electronics	2	2	x	x
DPU	10	10	x	x
IEM	**57**	**61.6**	**57.0**	**57.0**
C&DH Processor		10.4	x	x
C&T Subsystem		2.7	x	x
SSR (3of3)		16.5	x	x
Downlink Subsystem		5	x	x
Uplink Subsystem		7	x	x
RIU (5of5)		1.5	x	x
DC/DC Conv. (70%eff)		18.5	18.5	18.5
RF	**80.8**	**80.8**	**80.8**	**80.8**
SSPA	80	80	x	x
USO	0.8	0.8	x	x
G&C	**74.5**	**125.5**	**74.5**	**125.5**
AIE	7	7	x	x
G&CC	20	20	x	x
RWA	9	60	9	60
ST	12.5	12.5	x	x
Gyro	25	25	x	x
Sun Sensor	1	1	x	x
Propulsion	**3.5**	**56**	**6.0**	**51.0**
Pressure sensor (2of2)	1	1	x	x
HPLV	0	25		non-simultaneous
Thrusters (1 of 4)	0	25		2
Tank Heater	2.5	5	x	
Thermal	**5**	**20**	**20**	**0**
Heaters	5	20	x	
Power	**13.1**	**19.3**	**19.3**	**19.3**
PSE	13.1	19.3	x	x
Average subtotal for thermal:	278.4	System total:	328	404
(S/C and Propulsion heat not included)	20.0%	Allocated Margin:	20.0%	20.0%
	334	Req'd Total:	393	484

Solar STEREO Power Architecture Trade-Off

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- **Peak Power Tracker - PPT (TIMED Heritage)**
  - **<u>BASELINED</u>**
  - **~$150k less expensive than NEAR + booster.**
  - **Array design more tolerant of orbit eccentricity**
  - **Unregulated bus**
  - **Implementation**
    - **Same Shunt/Fuse box with fewer components**
    - **Reduce size of PPT box for fewer modules.**
      - **Minor mechanical change**
    - **Reduce size of PSE box for fewer relays, non-redundancy, battery relay removal.**
      - **Electrical, mechanical, and thermal design effort.**
- **Direct Energy Transfer - DET (NEAR Heritage)**
  - **Array utilization slightly better with current mission trajectory**
  - **De-couples battery from bus**
  - **1 to 2 kg lighter**
  - **Regulated bus**
  - **Requires addition of booster to handle load excursions**
  - **Implementation**
    - **Redesign NEAR box to remove redundancy and add boost regulator**
      - **Electrical, mechanical, and thermal design effort.**
    - **New box to accommodate power switching functions out of TIMED PSE box.**
      - **Electrical, mechanical, and thermal design effort.**

Solar STEREO Power Subsystem Block Diagram

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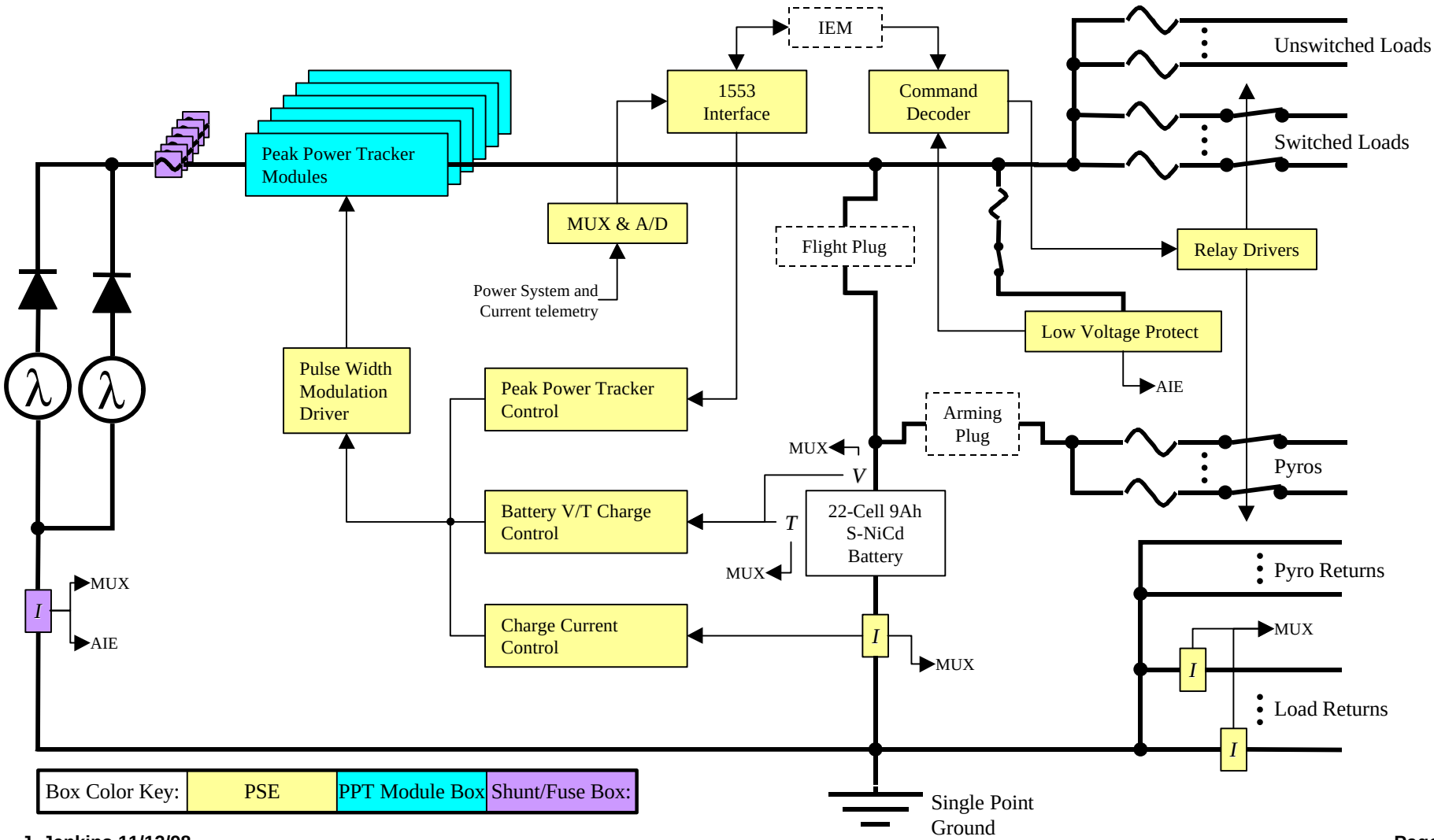

Solar STEREO
GaAs/Ge Array Analysis

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			PPT System							
			Perihelion				Aphelion			
Solar Stereo		Derating factor	Voc	Jsc	Vmpp	Jmp	Voc	Jsc	Vmpp	Jmp
Select Cell Type from list at bottom:	1		V	mA/cm^2	V	mA/cm^2	V	mA/cm^2	V	mA/cm^2
Spectrolab GaAs	BareCell @28deg		1.020	30.00	0.905	28.40	1.020	30.00	0.905	28.40
Interconnect Drop		0.005	1.015		0.900		1.015		0.900	
Assy loss		0.99		29.70		28.12		29.70		28.12
CMX (6 mil)		0.99		29.40		27.83		29.40		27.83
UV		0.98		28.81		27.28		28.81		27.28
Reverse Bias		0.98		28.24		26.73		28.24		26.73
Measurement Uncertainties		0.98		27.67		26.20		27.67		26.20
Micrometeors		1		27.67		26.20		27.67		26.20
Thermal Cycling		1	1.015		0.900	0.00	1.015		0.900	0.00
Temperature (Deg C)			Temperature =		82.86		Temperature =		12.93	
Voc Temp. Coeff. (mV/C)	-1.8		0.916				1.042			
Isc Temp. Coeff. (uA/cm2/C)	20			28.77				27.37		
Vmpp Temp. Coeff. (mV/C)	-1.9				0.796				0.929	
Impp Temp. Coeff. (uA/cm2/C)	20					27.30				25.90
Radiation Losses										
Voc	V 1-MeV equiv.	0.934	0.856				0.973			
Vmpp	1.67E+14	0.931			0.741				0.864	
Isc	I 1-MeV equiv.	0.908		26.12				24.85		
Impp	1.67E+14	0.903				24.65				23.38
Perihelion Solar Distance - AU	0.86	1.352		35.31		33.32				
Min Perihelion Sun Angle - degrees	0	1.000		35.31		33.32				
Aphelion Solar Distance - AU	1.16	0.743						18.47		17.38
Max Aphelion Sun Angle - degrees	6	0.995						18.36		17.28
Loads (Input)	328									
Margin	65.60	20%	**Cell Summary**				**Cell Summary**			
Trickle Charge	4.31	9 Ah	Voc (V)	Jsc (mA)	Vmp (V)	Jmp (mA)	Voc (V)	Jsc (mA)	Vmp (V)	Jmp (mA)
Harness	5.97	1.5%	0.856	35.31	0.741	33.32	0.973	18.36	0.864	17.28
PPT Inefficiency	21	95%				Pmp (mW)				Pmp (mW)
S/A diode &line losses (DET)	12.06					24.68				14.93
Total Array Power Req. (DET)	**416**		**Panel Summary**				**Panel Summary**			
S/A diode &line losses (PPT)	12.82		Voc (V)	Isc (A)	Vmp (V)	Imp (A)	Voc (V)	Isc (A)	Vmp (V)	Imp (A)
Total Array Power Req. (PPT)	**438**		41.07	21.69	35.55	20.47	46.71	11.28	41.48	10.61
						Pmp (W)				Pmp (W)
Packing Factor (input)	0.88					727.47				440.28
Panel Size (Input)	3.35									
Req'd DET size:	**3.31**				Power Density	217.16			Power Density	131.43
Req'd PPT size:	**3.33**				Active Panel Efficiency	13.5%			Active Panel Efficiency	14.9%
					Total Power Req.	438			Total Power Req.	438
Panel Temperature Calculations (Doug's Method)					Array Size Required	**2.02**			Array Size Required	**3.33**
Stephan-Boltzman (W/(m^2*K^4)	5.67E-08				Array Output at Selected Size	727			Array Output at Selected Size	440
Solar Flux @1AU (W/m^2)	1353.00				Allowed Load at Selected Size	**657**			Allowed Load at Selected Size	**396**
Front Alpha	0.89				Margin at Selected Array Size	**100.4%**			Margin at Selected Array Size	**20.8%**
Front Epsilon	0.85									
Back Epsilon	0.85				Max Bus Voltage	33.5				
					Min PPT Voltage Drop	0.5				
Cell Selection Chart					Diode Voltage Drop	1.0				
Spectrolab GaAs	1				Min Vmp allowed	35.0				
Spectrolab GaAs (old)	2				# of cells for min Vmp	47.3				
Spectrolab K6700B	3				Number of cells (Input)	48				
Sharp 10 Ohm-cm Si	4									
Sharp 2 Ohm-cm Si	5		TRW I-V CURVE MODEL							
TECSTAR GaAs	6				C2	0.04677856			C2	0.03957435
TECSTAR Dual Junction	7				C1	5.1994E-10			C1	1.0614E-11
			Current density at string voltage			29.407158	Current density at string voltage			18.2291347

Solar STEREO Solar Array I-V Characteristics

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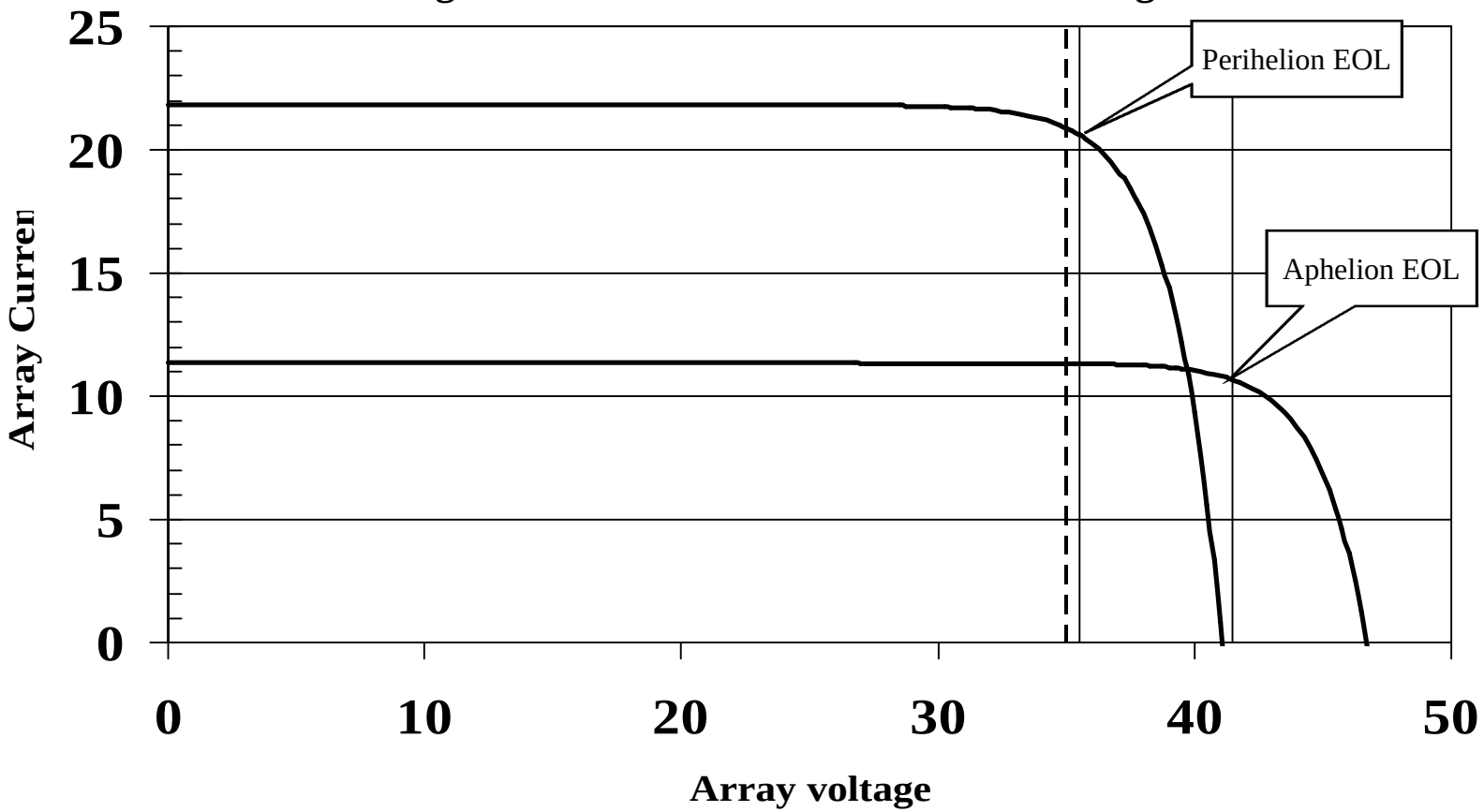
- **Perihelion Performance**
  - **657W Available to Loads**
  - **100.4% Margin**
- **Aphelion Performance**
  - **396W Available to Loads**
  - **20.8% Margin**



Solar STEREO Hypothetical Case Solar Array Sizing

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- **Current mission, load, array size and power system architecture:**
  - **3.35 m^2 (20.8% load margin)**
- **Limit margin to 20% of present load:**
  - **3.33 m^2 (20.0% load margin)**
- **Reduce lag rate to 15°/yr:**
  - **2.83 m^2 (20.0% load margin, 1.06 AU aphelion assumed)**
- **Replace leading S/C with second lagging:**
  - **No change with PPT**
- **Replace lagging S/C with second leading:**
  - **2.60 m^2 (20.0% load margin, 1.01 AU aphelion assumed)**
- **Use dual junction solar cells:**
  - **2.88 m^2 (20.0% load margin)**

Solar Stereo Eclipse

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- **Assumptions:**
  - **10% occultation conservatively applied at 1.16 AU aphelion.**
- **Result:**
  - **Total load capability decreases from 410W to 360W**
    - **9.6% margin at existing load**
    - **39.8% margin with all instruments off**
  - **Eclipse comfortably survivable without battery with minor load management.**

Solar STEREO Preliminary Launch Load Assumptions

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- **Phase 1 (T-3min to Separation)**
  - **97.1W + 20% + 1.5%= 118W**
    - **IEM = 50W (Adj for BOL, RF update & Downlink Off)**
    - **USO = .8W**
    - **PSE = 19.3W**
    - **AIE = 7W**
    - **FC = 20W**
    - **Instrument heaters 10W (Allocated value)**
- **Phase 2 (Separation to Acquisition-1min)**
  - **118W + (68.5W + 20% + 1.5%) = 201W**
    - **Gyros = 25**
    - **Wheels = 30W (Allocated value)**
    - **Star Tracker = 12.5**
    - **DSADs = 1**
- **Phase 3 (Acquisition-1min to Acquisition+10min)**
  - **201W + (87W + 20% + 1.5%) = 307W**
    - **SSPA=80**
    - **RF Downlink = 7W**

Solar STEREO Preliminary Parametric Battery Performance on Launch

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					Battery Sizes (Ah)		
					9	12	21
	Load with 20% Margin (W)				Median DOD's		
	118	201	307		86.9%	65.2%	37.2%
Coast time	**Phase 1**	**Phase 2**	**Phase 3**				
(min)	(min)	(min)	(min)		DOD	DOD	DOD
0	3	8	11		35.3%	26.5%	15.1%
5	8	8	11		39.2%	29.4%	16.8%
10	13	68	11		**122.9%**	**92.2%**	52.7%
15	18	38	11		**86.9%**	65.2%	37.2%
20	23	26	11		**74.8%**	56.1%	32.1%
25	28	20	11		**70.8%**	53.1%	30.3%
30	33	14	11		**66.7%**	50.0%	28.6%
35	38	11	11		**66.6%**	50.0%	28.5%
40	43	8	11		**66.5%**	49.9%	28.5%
45	48	5	11		**66.4%**	49.8%	28.5%
50	53	5	11		**70.3%**	52.8%	30.1%
55	58	17	11		**90.2%**	**67.6%**	38.7%
60	63	14	11		**90.1%**	**67.6%**	38.6%
65	68	8	11		**86.0%**	64.5%	36.9%
70	73	8	11		**89.9%**	**67.5%**	38.5%
75	78	5	11		**89.9%**	**67.4%**	38.5%
80	83	2	11		**89.8%**	**67.3%**	38.5%
85	88	2	11		**93.7%**	**70.3%**	40.1%
90	93	11	11		**109.5%**	**82.2%**	46.9%
95	98	11	11		**113.4%**	**85.1%**	48.6%
100	103	134	11		**280.9%**	**210.6%**	**120.4%**

Solar STEREO Preliminary Post-LVS Life Expectancy

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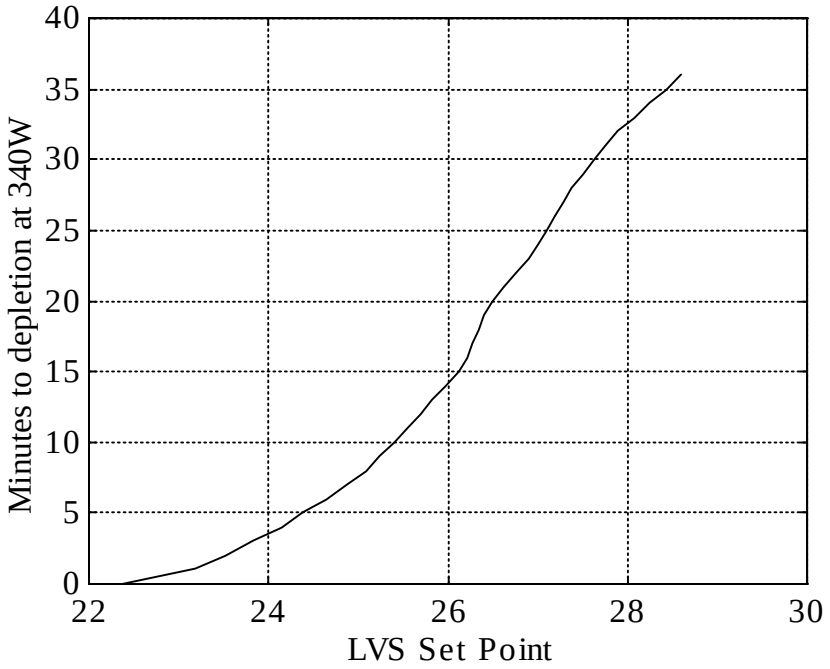
- **LVS Assumptions**
  - **283W + 20%**
    - **IEM, RF, G&C, and PSE are fully on.**
    - **Instruments, thermal, and propulsion are all off.**
  - **9Ah battery model**
- **Resulting Preliminary Performance:**
  - **>12 minute post-LVS life for set-point of 25.7V or greater**
  - **Requirement shown to be attainable - Further optimization required.**



Solar STEREO Power Component Mass / Dimensions

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Item	*Mass*	*Dimensions*	*Assumptions*
Battery	12.3 kg	15”x8.05”x5.65”	NEAR design
Solar Array	17.2 kg	3.35 m^2	NEAR mass scaling of analyses results
PSE	13.5 kg	13”x10”x10.5”h	Scaled from TIMED
PPT	4 kg	7”x6”x5”h	Scaled from TIMED
Shunt/Fuse Box	.5 kg	4.5”x4.5”x2.5”h	TIMED actual