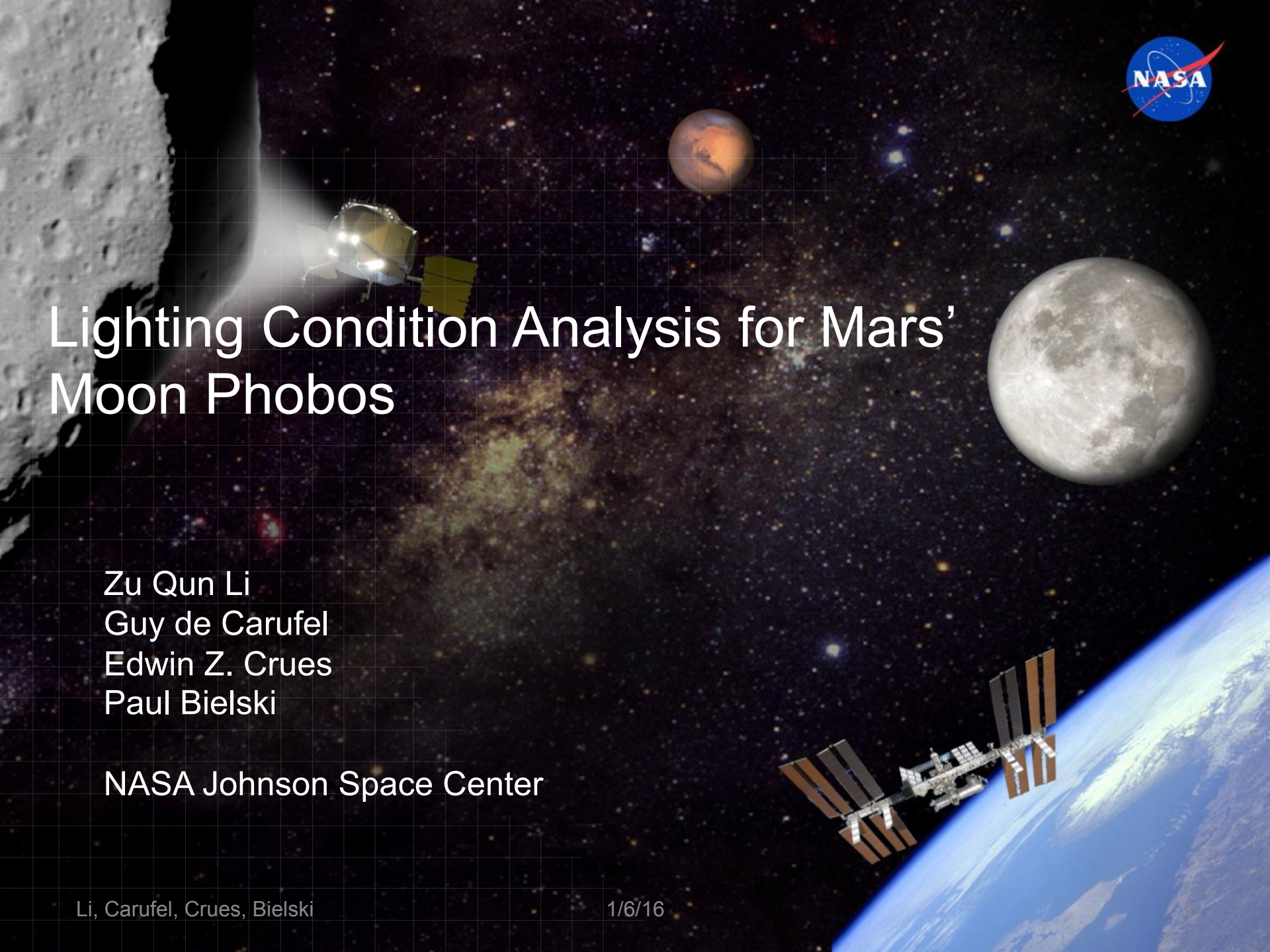

Lighting Condition Analysis for Mars' Moon Phobos

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Edwin Z. Crues
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Overview

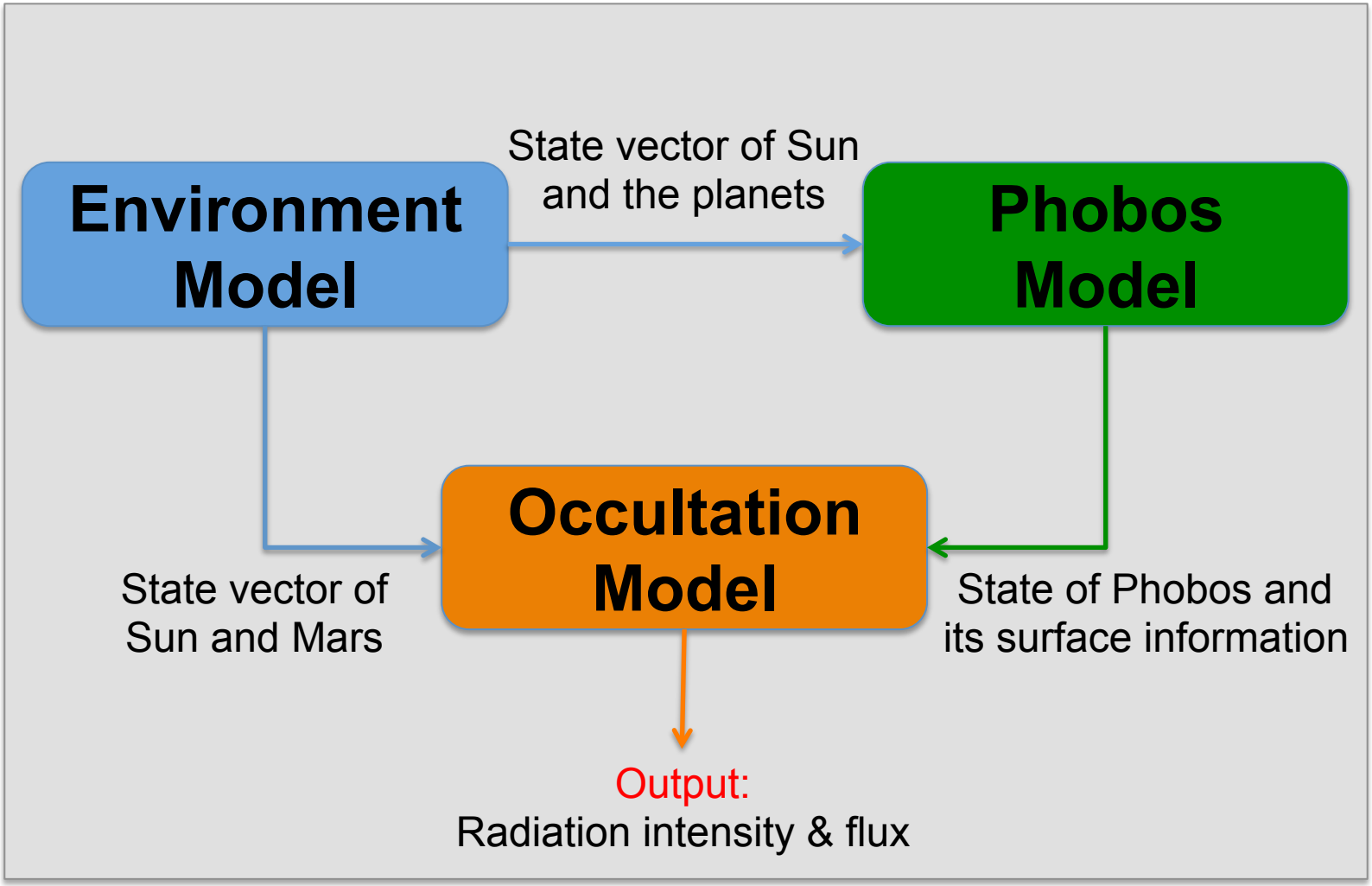
- **Motivation**
- **Phobos Overview**
- **Simulation Development**
- **Phobos Lighting Conditions**
- **Usage Example:**
  - Robotic Lander Preliminary Power Subsystem Analysis
- **Conclusion**

Motivation

- **Need a comprehensive understanding of Phobos' environment**
- **Solar radiation plays crucial role in power and thermal subsystems**
- **Developed a simulation to investigate lighting conditions on Phobos over one Martian year (July 05 2030 to May 22 2032)**

Simulation Development

- Simulation Overview



Phobos Overview

- **Martian Season**

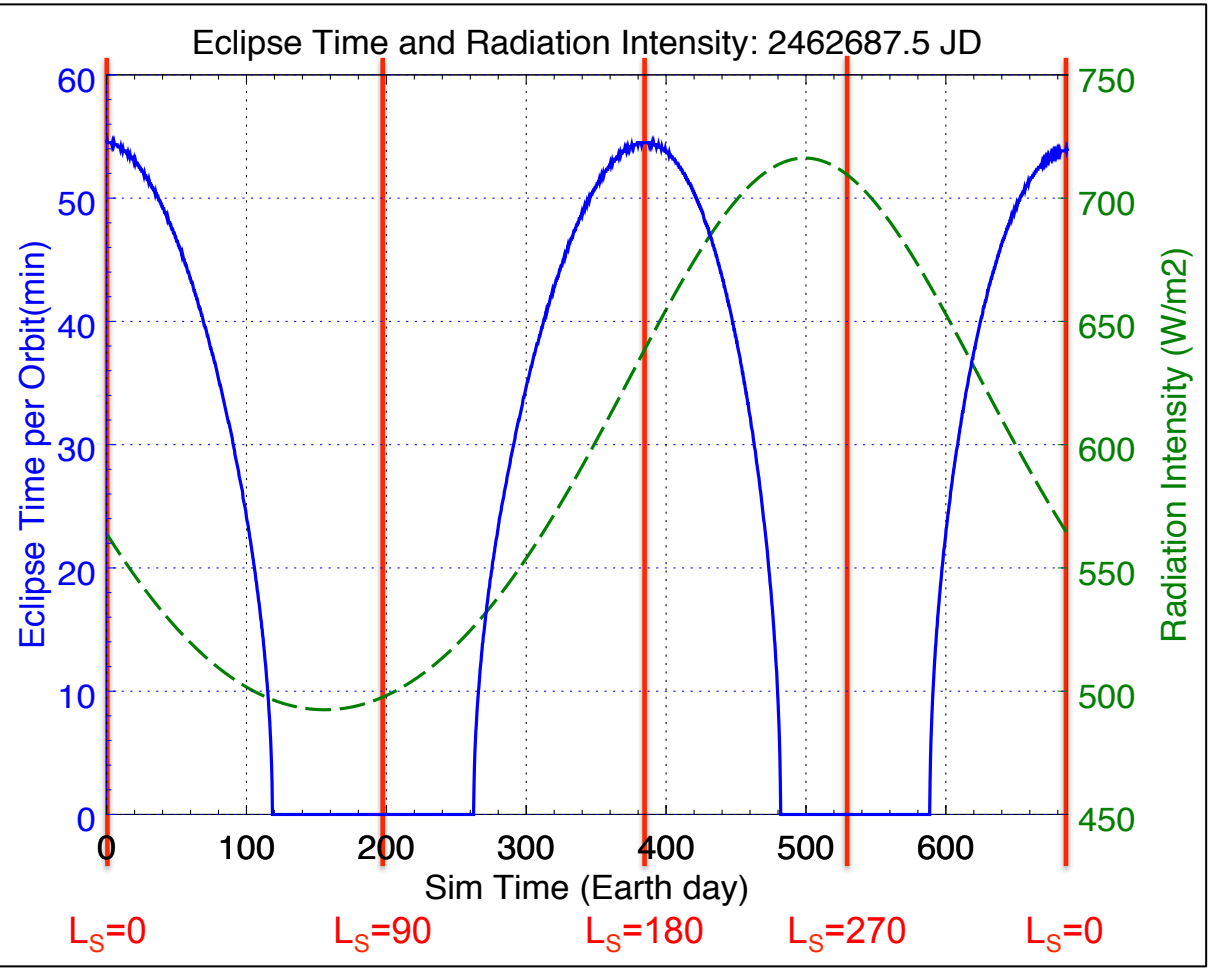
Year	Spring Equinox $L_s = 0°$	Summer Solstice $L_s = 90°$	Fall Equinox $L_s = 180°$	Winter Solstice $L_s = 270°$
1	Apr 11, 1955	Oct 27, 1955	Apr 27, 1956	Sep 21, 1956
⋮	⋮	⋮	⋮	⋮
39	Sep 30, 2026	Apr 16, 2027	Oct 17, 2027	Mar 12, 2028
40	Aug 17, 2028	Mar 03, 2029	Sep 03, 2029	Jan 28, 2030
41*	Jul 05, 2030	Jan 19, 2031	Jul 22, 2031	Dec 16, 2031
42*	May 22, 2032	dec 06, 2032	Jun 08, 2033	Nov 02, 2033
*	estimates based on the orbital period of Mars			

- **Phobos Characteristics**

Semi-major axis	9376 km	Eccentricity	0.0151
Orbital period	7 h 39.2 min	Avg orbital speed	2.138 km/s
Inclination	1.093° wrt Mars' equator		
	26.04° wrt ecliptic		
Rotation period	Synchronous		

Phobos Lighting Conditions

- **Radiation Intensity and Solar Eclipse Time**

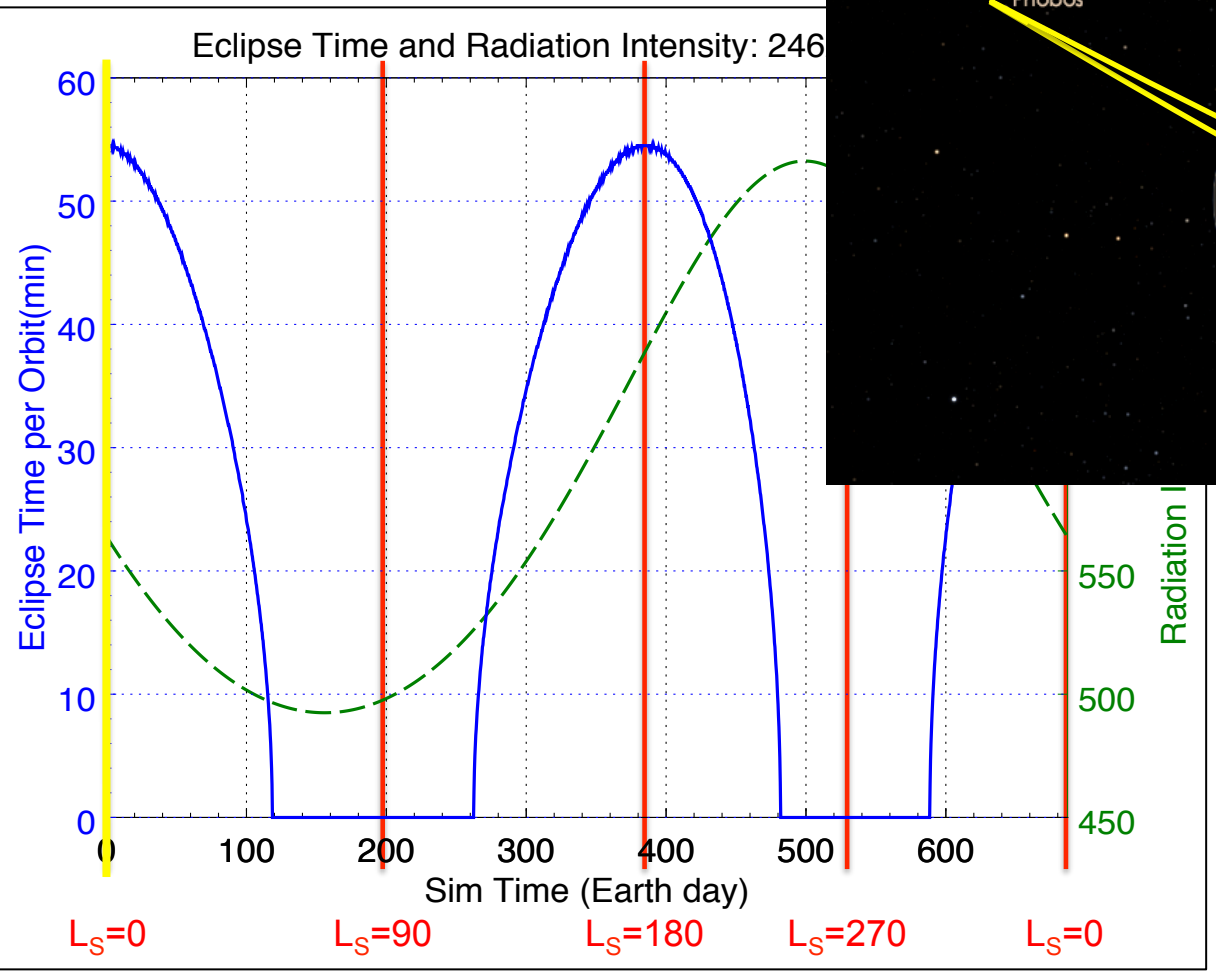


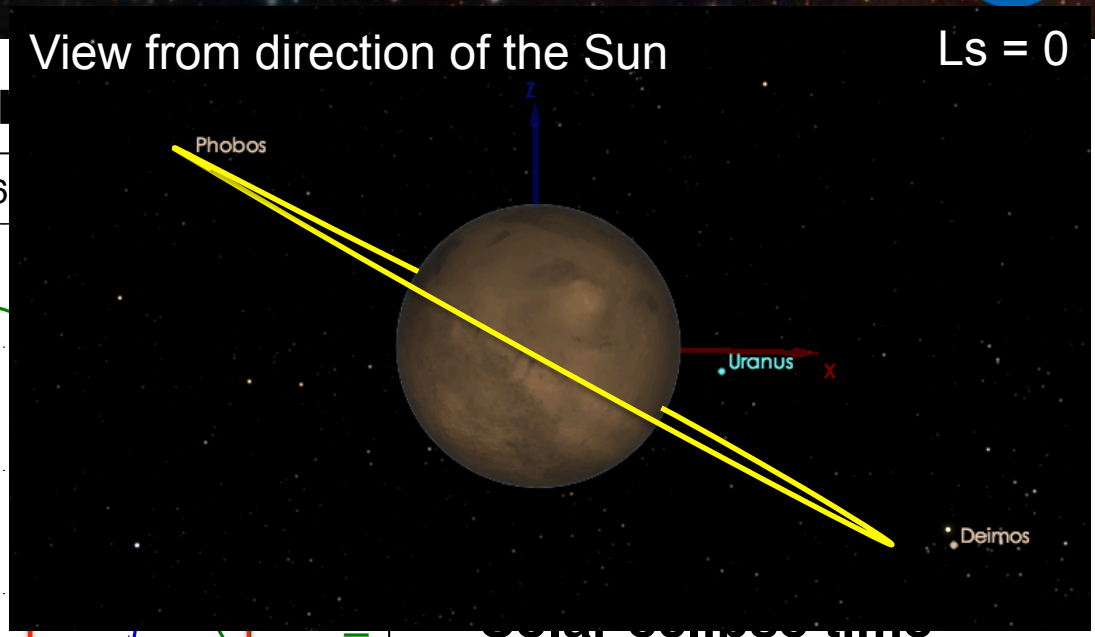
- **Radiation intensity**
  - Smaller during northern hemisphere summer
  - Higher during winter
- **Solar eclipse time**
  - Longer eclipse time during spring and fall
  - NO eclipse during summer and winter

Note: 1 Phobos' Orbital Period = 7hr 39 mins

Phobos Lighting Conditions

- **Radiation Intensity a**



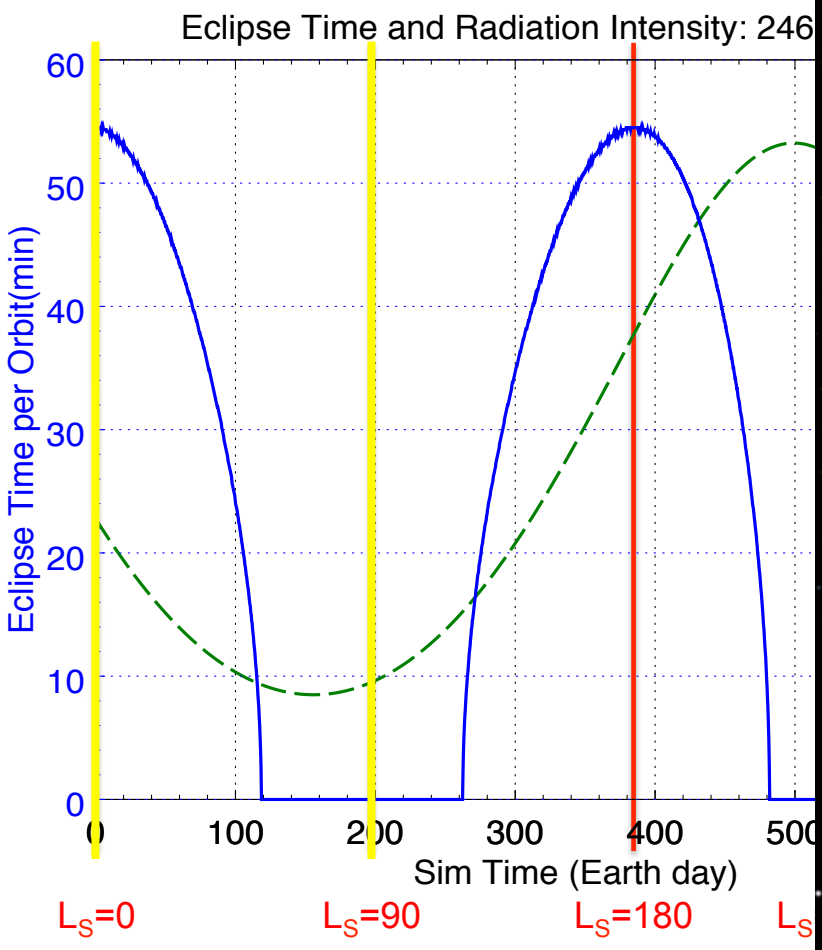


- **Solar eclipse time**
  - Longer eclipse time during spring and fall
  - NO eclipse during summer and winter

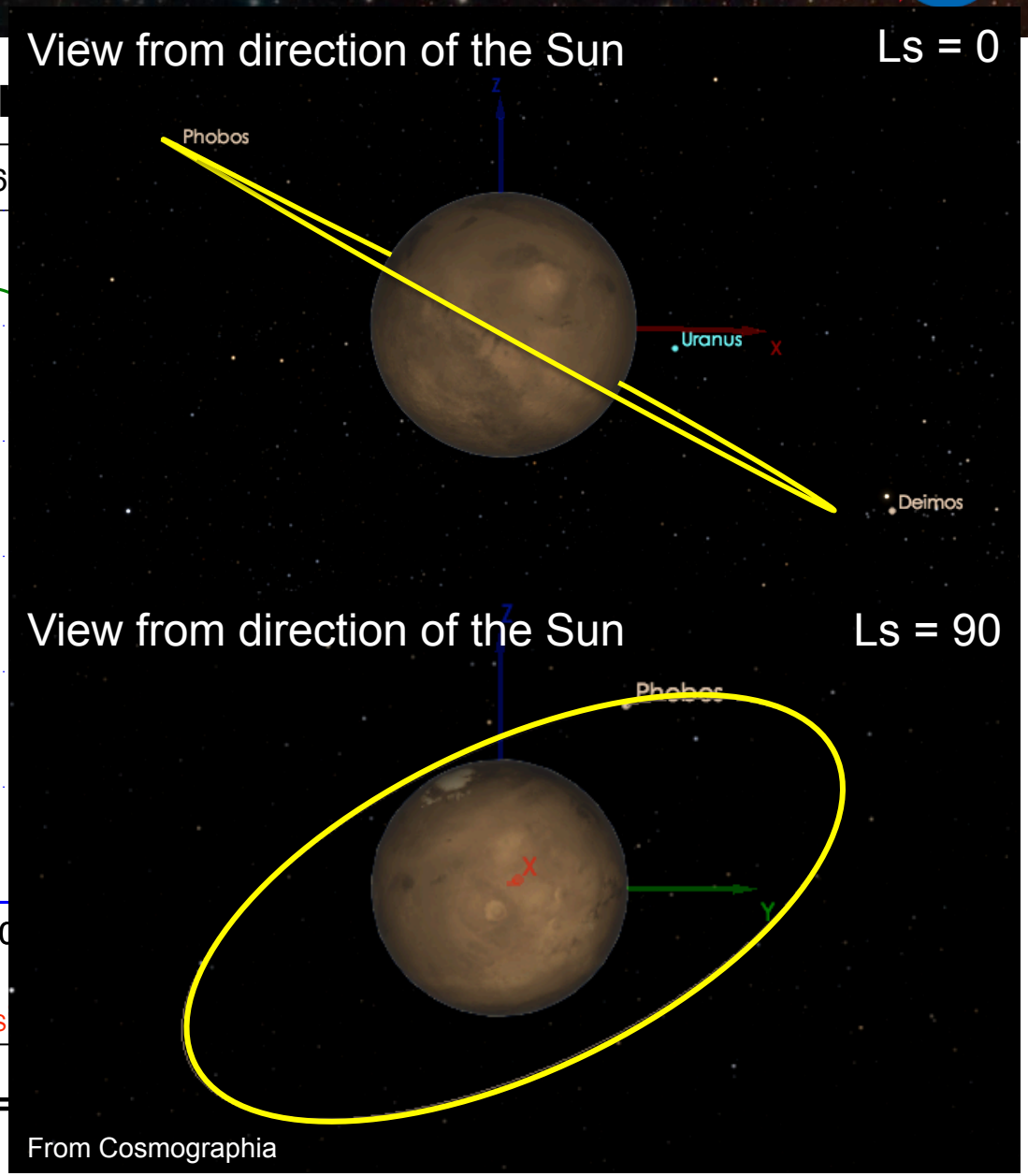
Note: 1 Phobos' Orbital Period = 7hr 39 mins

Phobos Lighting Conditions

- **Radiation Intensity ar**



Note: 1 Phobos' Orbital Period =



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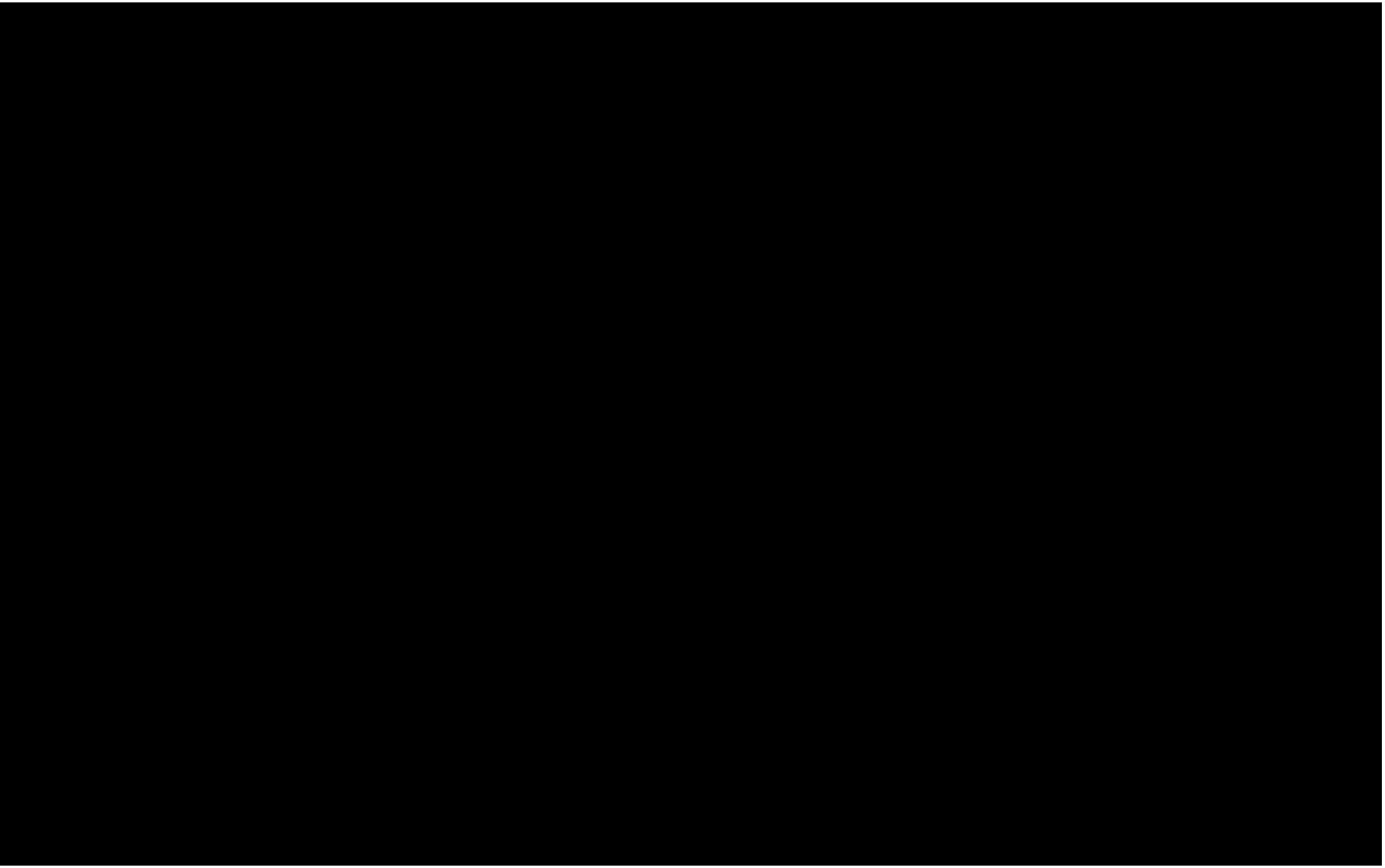
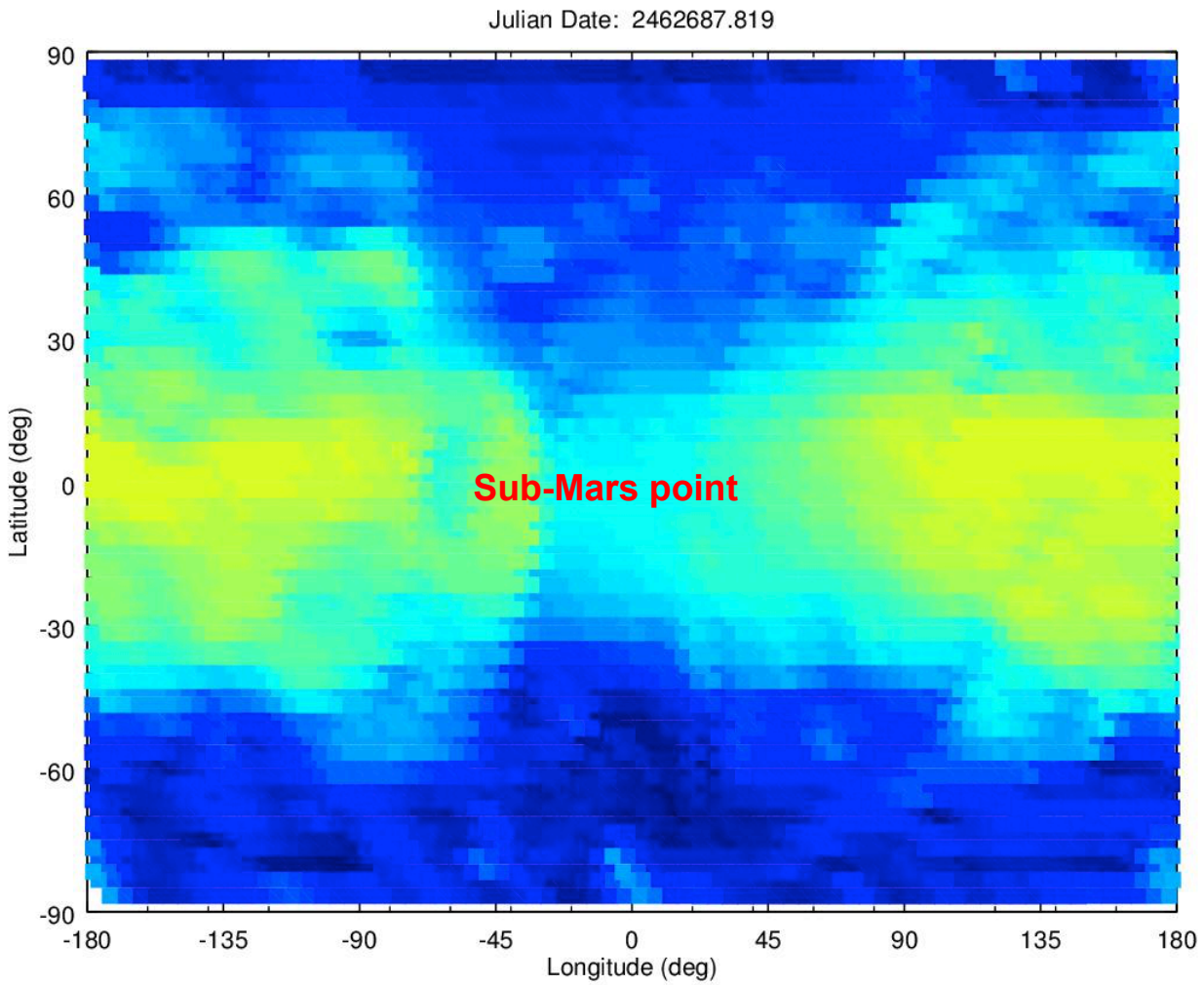
Phobos Lighting Conditions

- **Each frame represents instantaneous surface radiation flux**



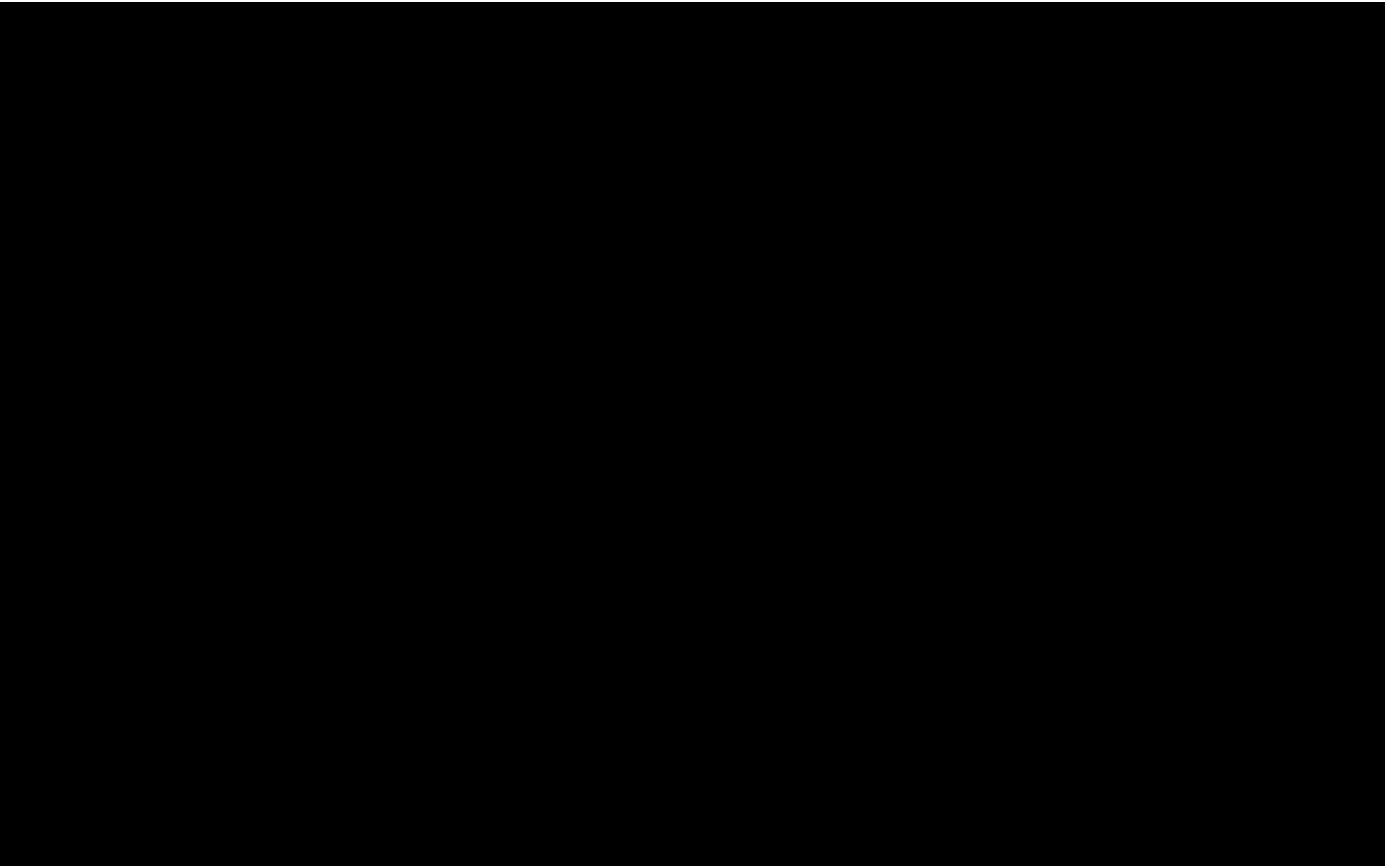
Phobos Lighting Conditions

- **Each frame represents radiant exposure (kJ/m^2) for one Phobos orbit (7hr 39min)**

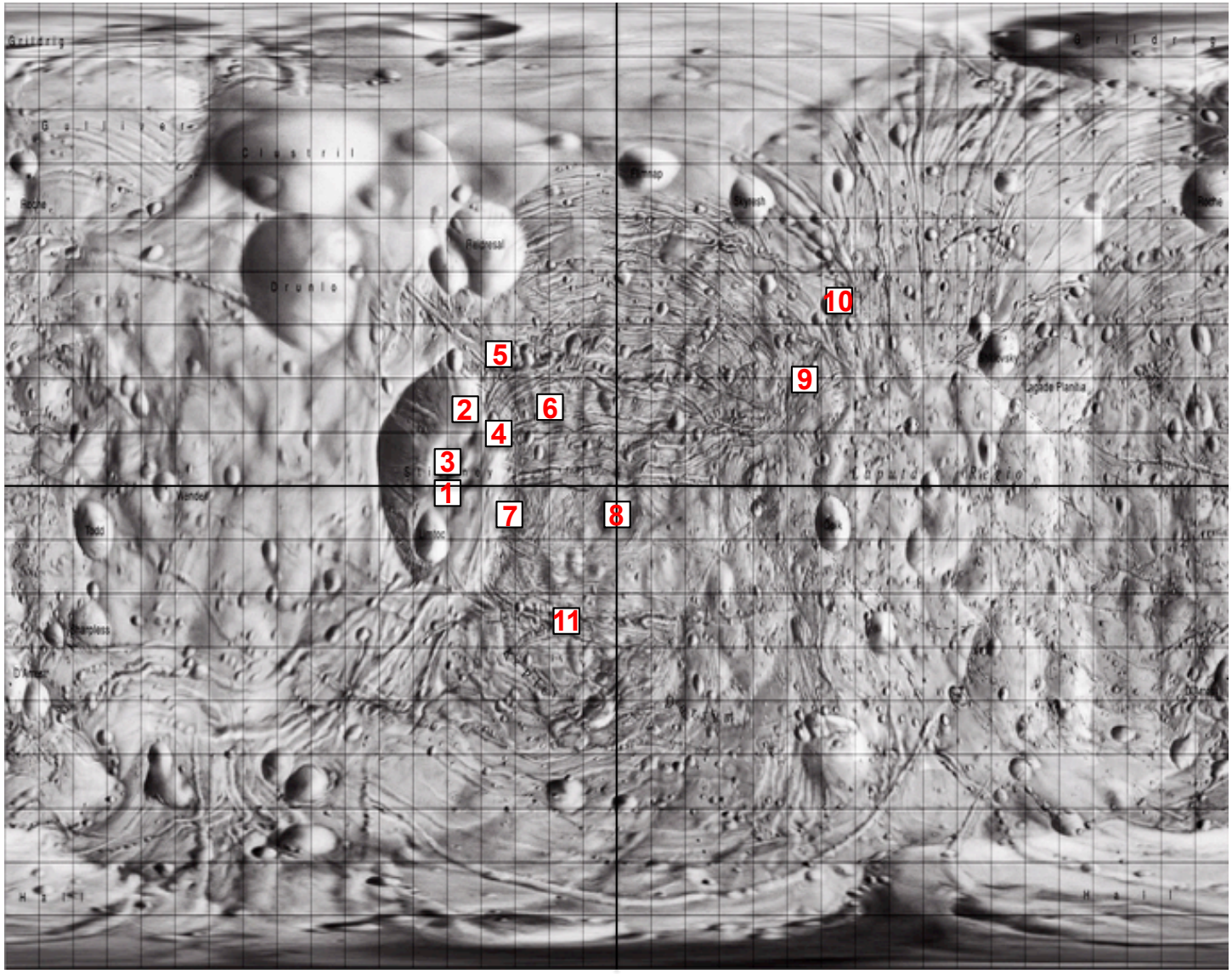


Phobos Lighting Conditions

- **Each frame represents exposure time (min) for one Phobos orbit (7hr 39min)**



Usage Example



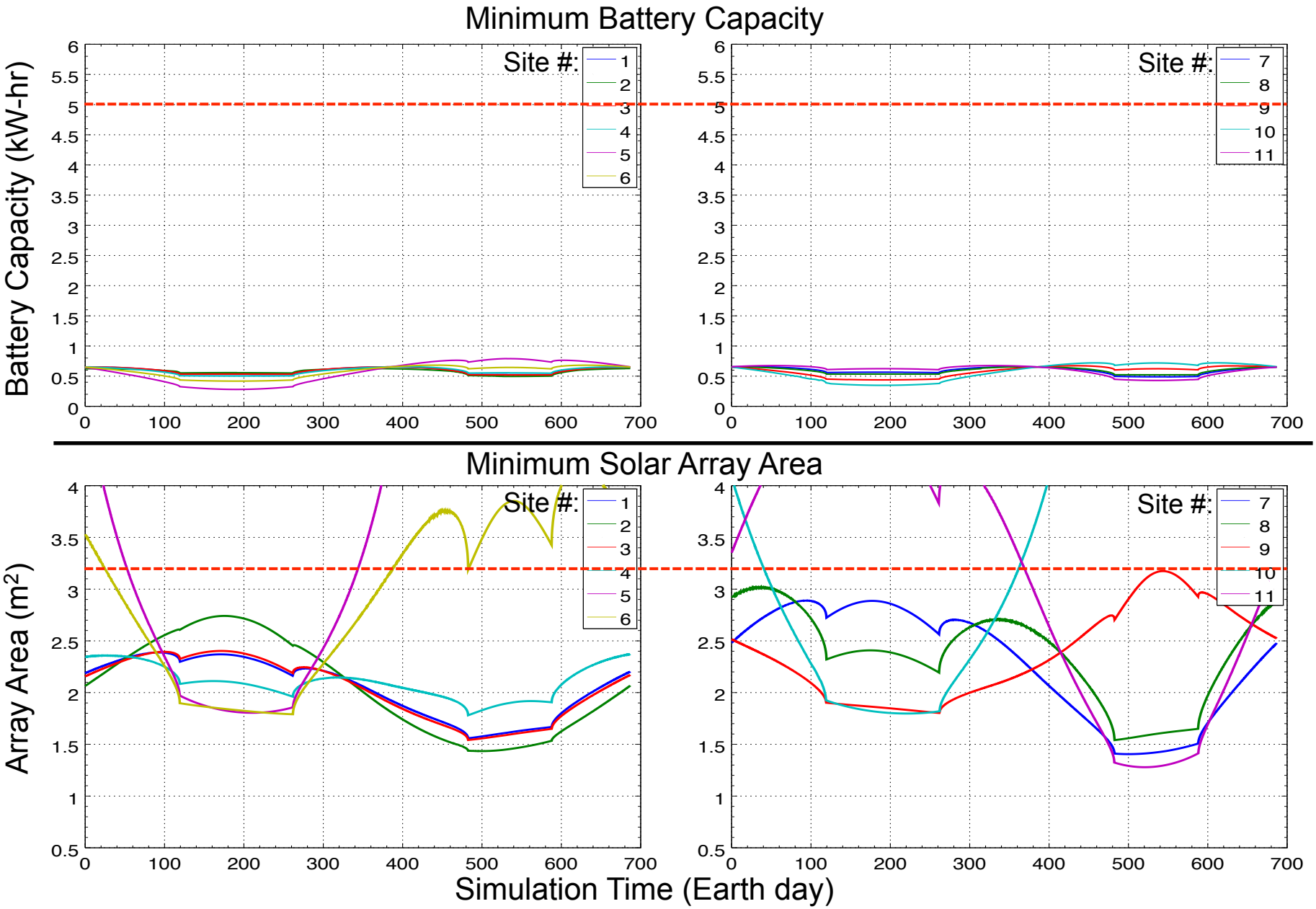
#	Lat	Lon
1	-2	-50
2	15	-45
3	5	-50
4	10	-35
5	25	-35
6	15	-20
7	-5	-32
8	-5	0
9	20	55
10	35	65
11	-25	-15

Robotic Lander Preliminary Power Analysis

- **Power subsystem requirements**

Attribute	Value	Unit
Mass	270	kg
Average power load	350	W
Hotel power load	100	W
Solar array efficiency	30	%
Solar array type	Fixed	--
Solar array area	?	m^2
Battery capacity	?	kW-hr
Battery maximum discharge percentage	80	%

Robotic Lander Preliminary Power Analysis

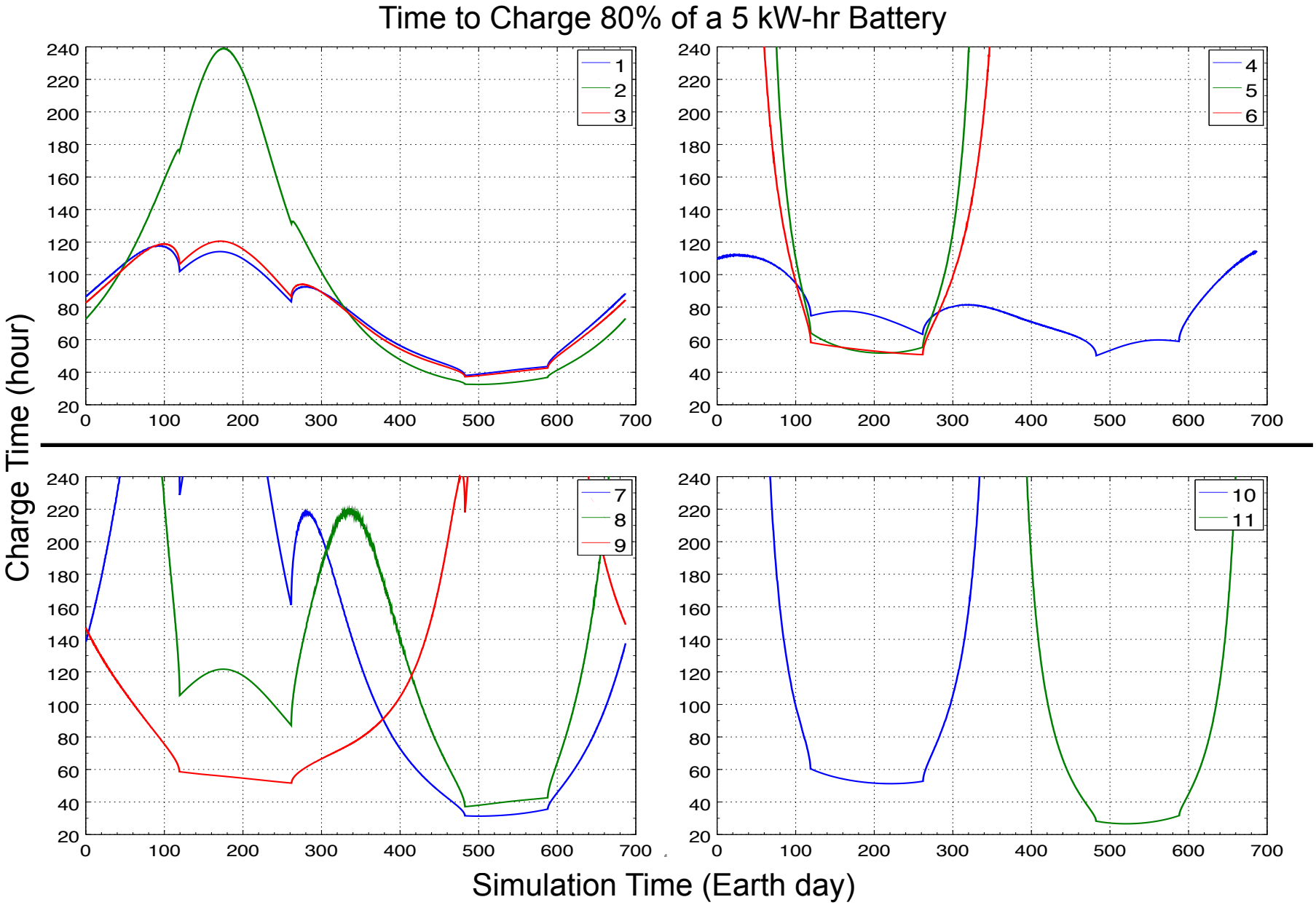


Robotic Lander Preliminary Power Analysis

- **Design Parameters**

Attribute	Value	Unit
Mass	270	kg
Average power load	350	W
Hotel power load	100	W
Solar array efficiency	30	%
Solar array type	Fixed	--
Solar array area	3.2	m^2
Battery capacity	5	kW-hr
Operation time	~11.4	hr
Battery maximum discharge percentage	80	%

Robotic Lander Preliminary Power Analysis



Robotic Lander Preliminary Power Analysis

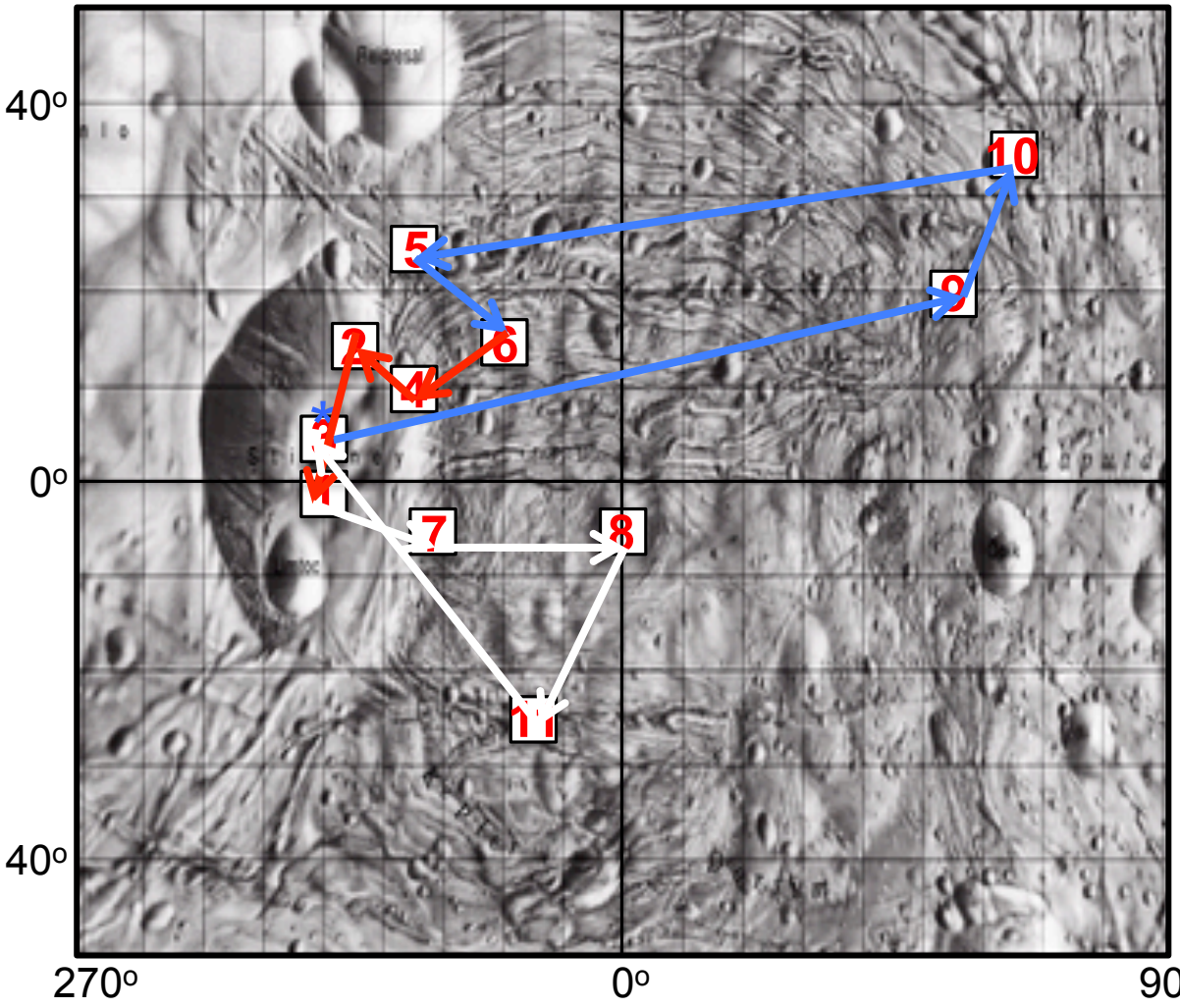
- **Duty Cycle = 100% * Ops time / (Ops time + Charge time)**

Site	Ls=0 Day=0	Ls=45 Day=99	Ls=90 Day=198	Ls=135 Day=290	Ls=180 Day=382	Ls=225 Day=455	Ls=270 Day=529	Ls=315 Day=608
3	12.16	8.77	8.94	11.05	16.19	20.68	22.49	17.83
9	7.21	13.02	17.27	15.14	10.95	5.76		2.68
10		10.14	18.11	11.29				
5		9.16	18.03	10.11				
6		10.49	17.71	11.71				
4	9.41	10.70	13.19	12.65	13.37	15.51	16.50	12.59
2	13.59	6.77	4.80	9.39	17.61	23.73	25.68	20.85
1	11.69	8.88	9.39	11.10	15.72	20.11	22.02	17.28
7	7.61	3.02	3.25	5.07	11.53	20.49	26.45	18.42
8	2.66	4.70	8.81	6.41	6.33	14.54	22.35	13.11
11					2.19	18.68	29.97	17.77

> 20%	> 15%	> 10%	> 5%	> 2%	< 2%

Robotic Lander Preliminary Power Analysis

- **Site exploration order with lighting constraints**



Site	Duty Cycle	Estimated distance (m)	Ls
3	12.16	--	0
9	13.02	20110.37	45
10	18.11	3323.46	90
5	18.03	16577.63	90
6	17.71	3716.08	90
4	12.65	3501.60	135
2	17.61	2438.84	180
1	20.11	3581.98	225
7	26.45	3902.73	270
8	22.35	7156.60	270
11	29.97	5359.72	270
3	17.83	9469.80	315

Conclusions

- **Lighting condition changes significantly throughout Martian seasons**
- **Solar radiation intensity is close to minimum during the northern hemisphere summer and close to maximum during the winter.**
- **Solar eclipse time is longer during spring and fall, and no eclipse during summer and winter**
- **Lighting data is extremely useful in high fidelity vehicle simulation and exploration path planning.**

Questions

Zu Qun Li

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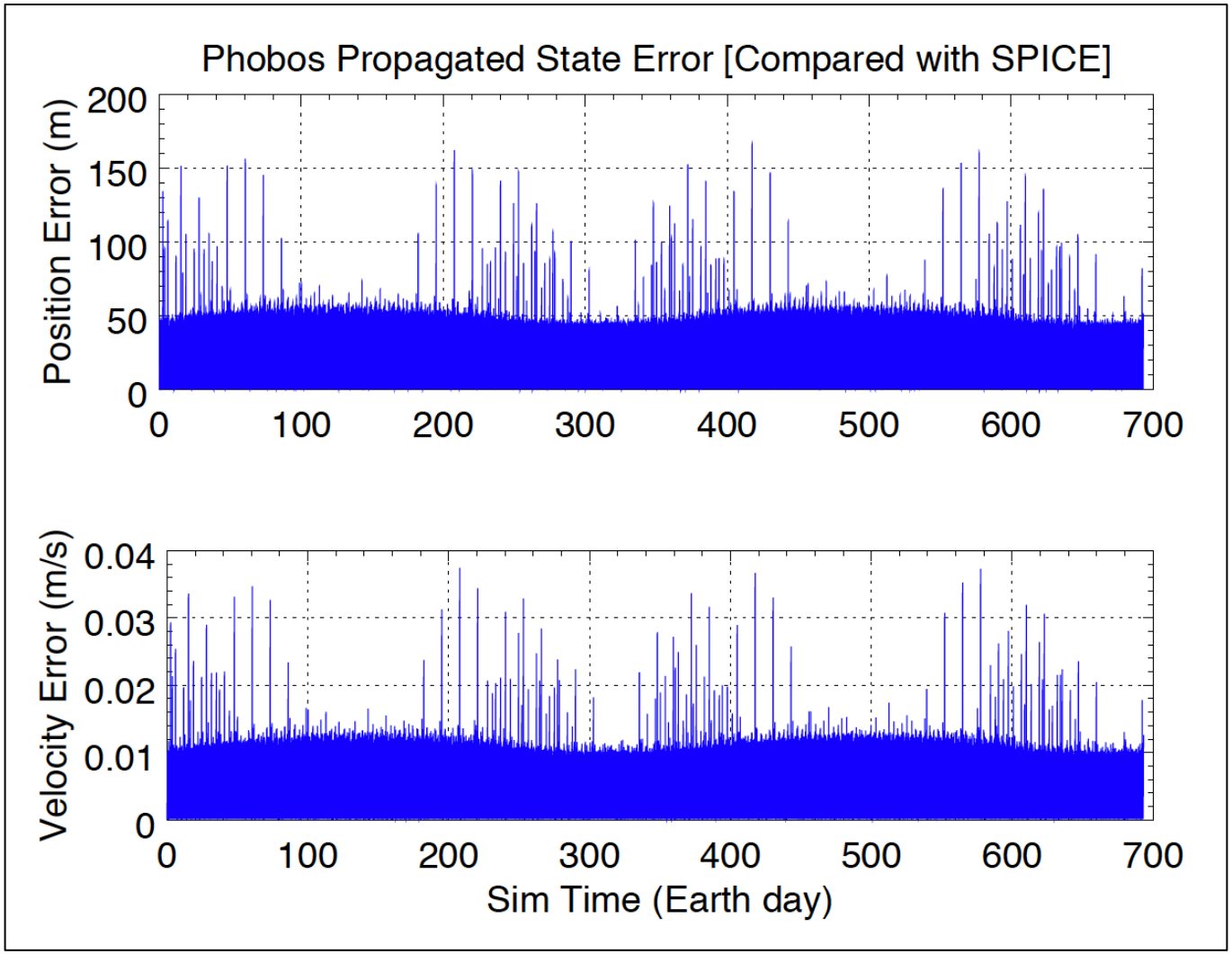
Back-up

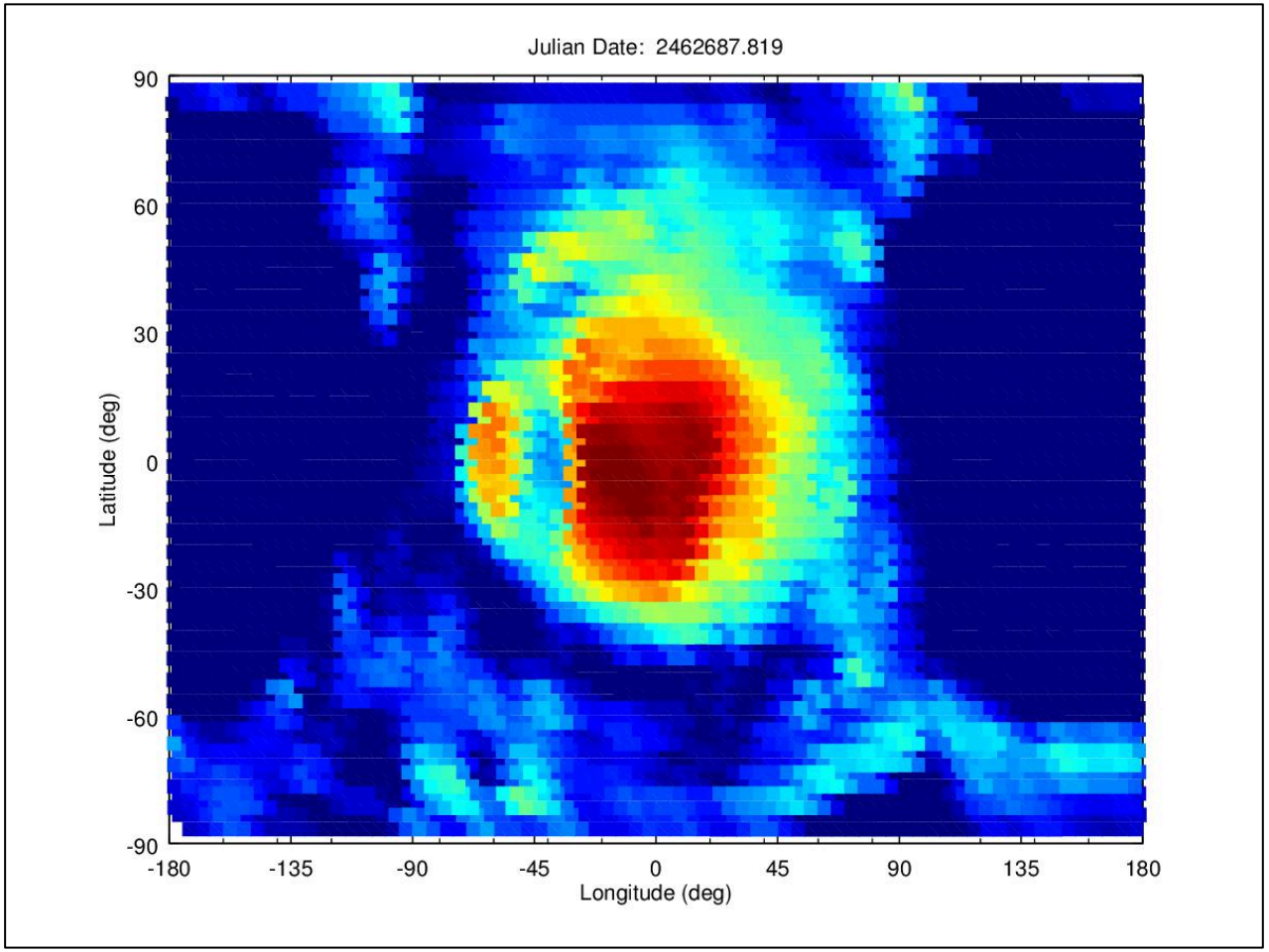
Simulation Development

- Phobos Propagated State Error



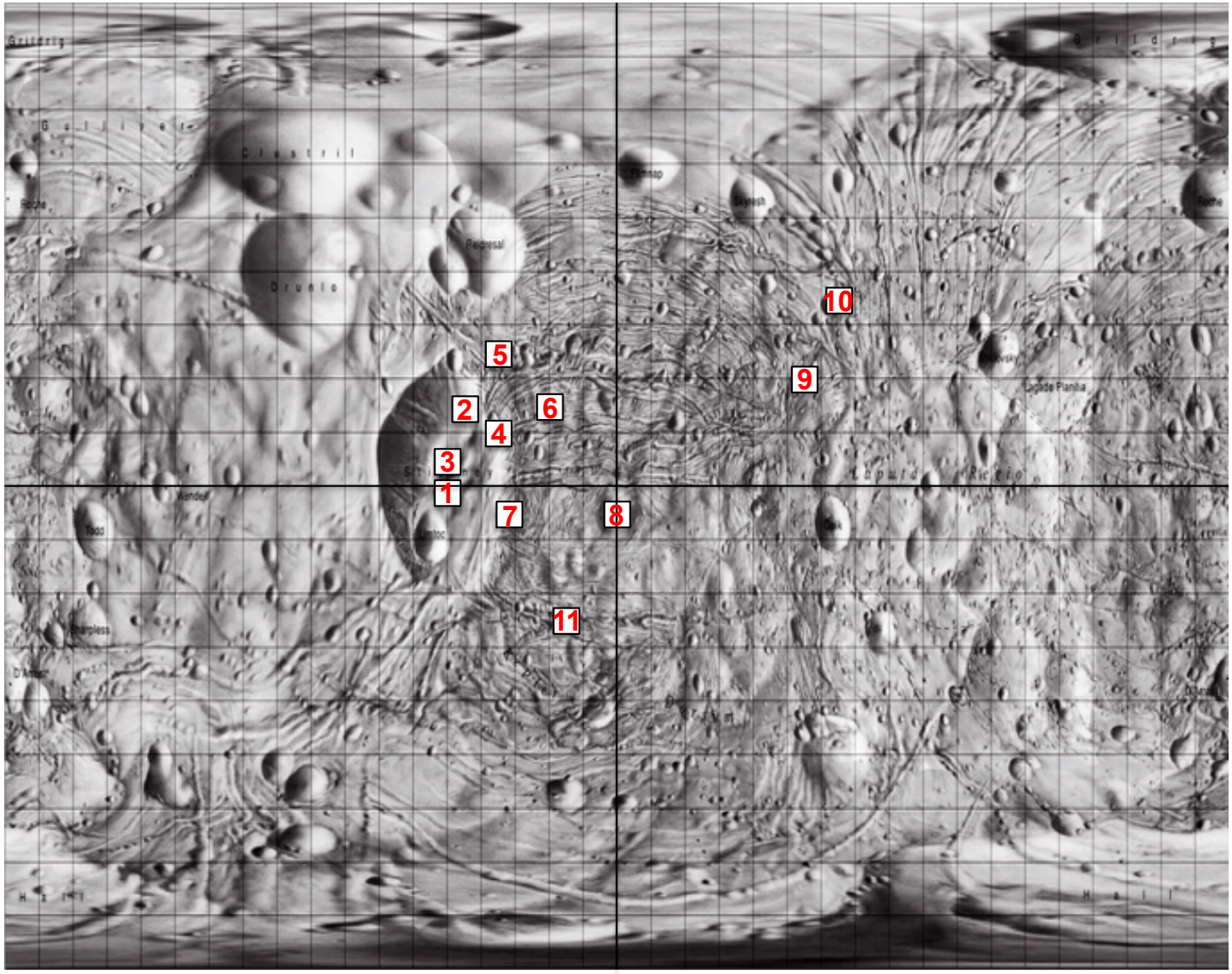
Simulation Development

- Phobos Orientation Validation



Lighting result when Mars is the only light source

Specific Site Lighting



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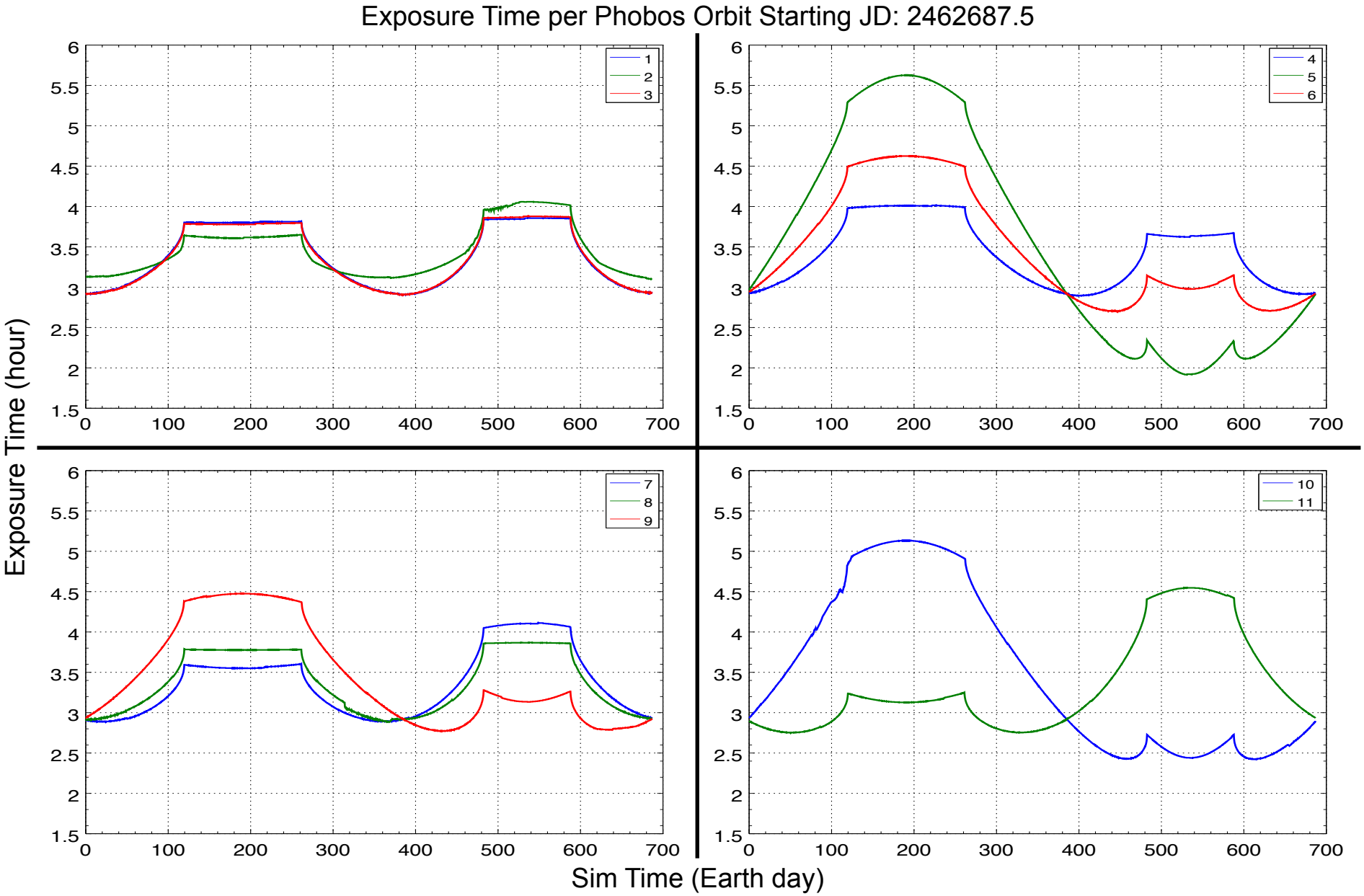
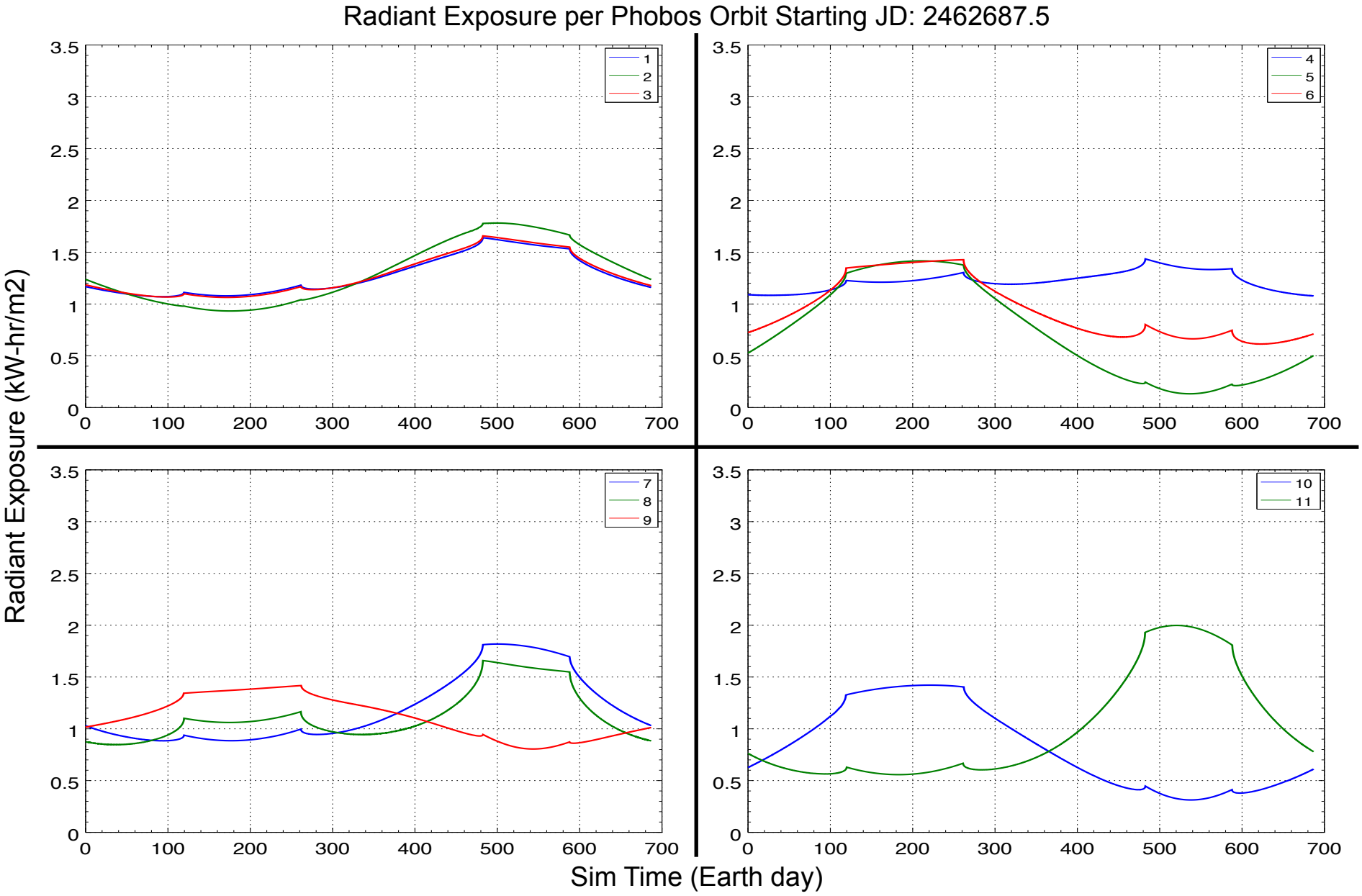
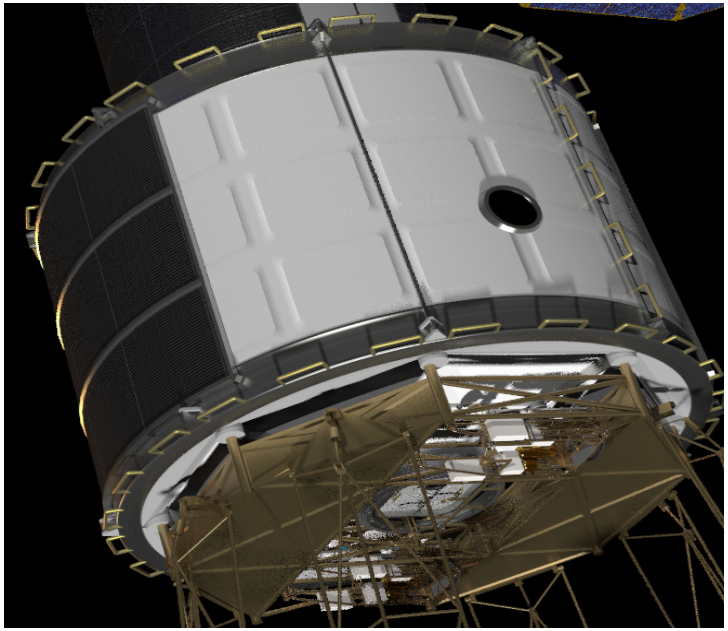
Specific Site Lighting



Specific Site Lighting

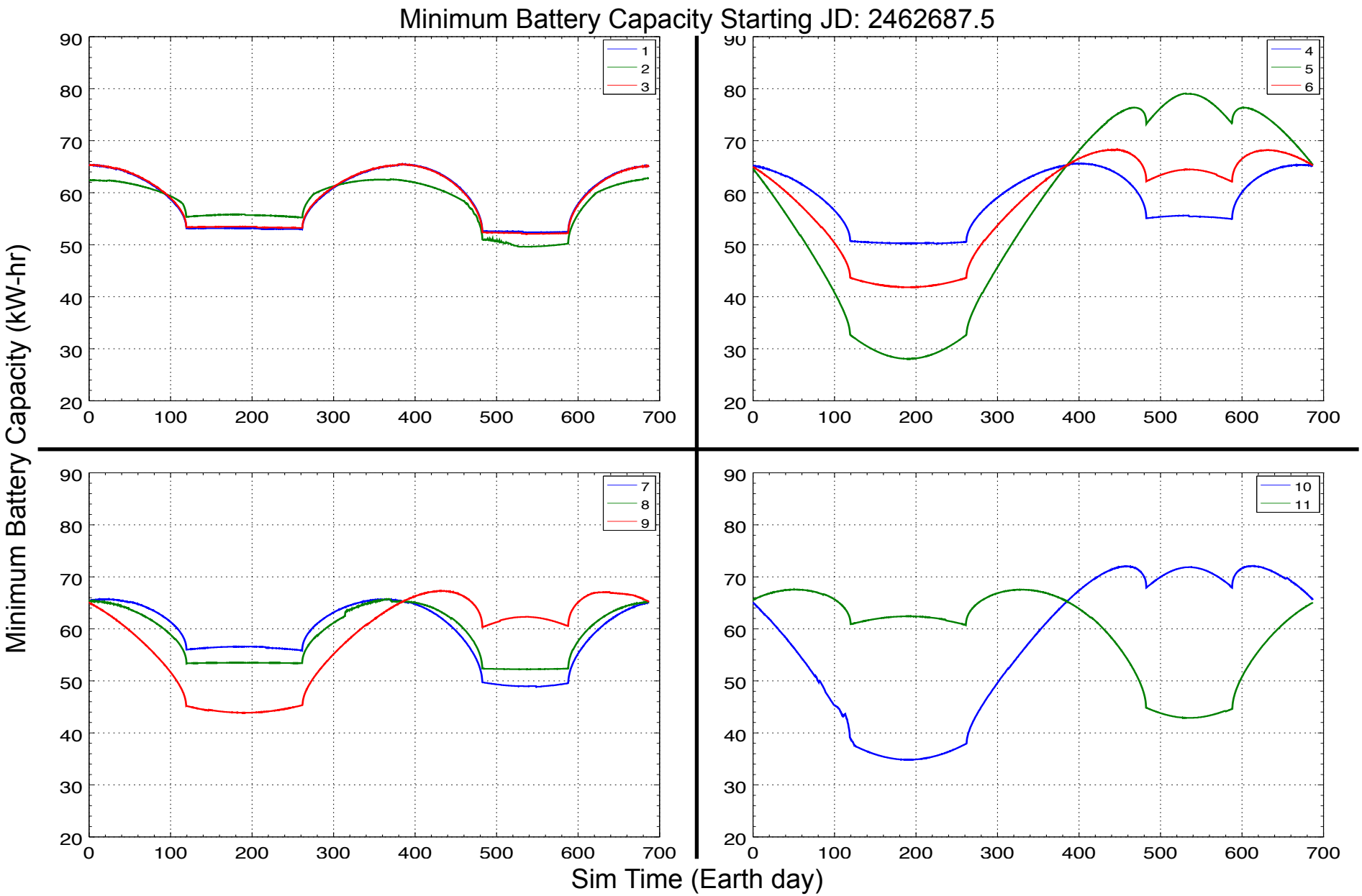


Usage Example: Preliminary Power Subsystem



Attribute	Value	Unit
Power load	10	kW
Solar array efficiency	30	%
Battery maximum discharge percentage	80	%
Solar array type	Sun tracking	--

Usage Example: Preliminary Power Subsystem



Usage Example: Preliminary Power Subsystem