PACE 2012

Systems Engineering

14-18 May, 2012

Systems Outline

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PACE Mission Overview

- **Mission Science Objective:**
  - Observation of open ocean (color), atmosphere cloud and aerosol observations, and coastal estuaries.
- **Payload:**
  - OCE (1 assembly) and Polarimeter (2 assemblies) instruments
- **Launch Readiness Date: October 2019**
- **Mission lifetime:**
  - **Design:** 3 years
  - **Mission Goal:** 5 years (used to size consumables)
- **Design Reliability:**
  - **Class C Mission:** Single string with selective redundancy

PACE Mission Requirements

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Parameter	Requirement
Lifetime	3 yr Design, 5 yr mission goal for consumables (prop. SA sizing, battery cycles)
Payload Accommodation	**Mass: 361 kg** (301kg OCE + 60kg Polarimeter) **Power Consumption: Science Mode**: **588 W OAP** (OCE 515W+Pol 73W), **Peak: 748W** (648W during OCE spin-up+100W), **Safehold**/Survival Heater Power: **274W** (244W+30W). **OCE: 515 W** Operating, 244 W Safehold/Survival heaters, **Polarimeter: 85W**(70 W Imaging+15W thermal control), 30W (15W Non-imaging+15W thermal), 100 W pk
Payload Data Rate	**OCE**: **10 Mbps** (after 2:1 compression), 30 Gbit/orbit **Polarimeter: 2.2 Mbps** (after 3:1 compression), 6.6 Gbits/orbit Direct Broadcast Mode(optional): 12.2 Mbps(OCE 10+Pol 2.2)
Observing Angles(FOV)	OCE ±51.0º Xtrack, N/A Polarimeter ±50.7º Xtrack, 42.3º along track
Orbit Parameters	Altitude: 700 km for OCE, 700-800km for Polarimeter, Sun Sync (97-98.6 deg) inclination, Equator crossing: noon +/-10min; 2 day Global Coverage
Timing Accuracy	Absolute 1.0ms and Relative 0.1ms
Launch Vehicle	US Medium Class LVs, e.g. Antares 120, Athena, Minotaur IV, Falcon 9…, etc.
Slew Capability (option)	40 degrees in 15 seconds, if implemented on spacecraft vs. tilt mechanism for OCE

PACE Mission Requirements (cont.)

Parameter	Requirement
ACS Pointing	25 arcsec over 0.1 sec; Control: 0.1 deg, Knowledge: 40 arcsec per axis
Provide data storage and downlink	3 orbits data of storage Svalbard, Fairbanks, etc. used for downlink
Fault Tolerance	Single Point Failure Permitted
Observation Continuity	Continue to observe during downlink
Nominal Launch Date	October 2019
Data Latency	3hrs (180 minutes)
Reliability	S/C component string required for controlled deorbit must have $\geq$ 0.9 reliability

PACE System Design Overview

- **ACS**
  - Primary Sensors: Star Trackers, Gyro
  - Reaction wheels
  - Magnetic torquers for momentum unloading
- **Avionics**
  - Commercially available Integrated Avionics Unit (IAU)
    - Single string spacecraft computer (with a Solid State Recorder), Attitude Control Electronics, and thruster valve drive electronics, a deployment drive electronics
  - Solid State Recorder(SSR)
  - Timing tagged to GPS
- **Communications**
  - X-Band for Science and ancillary data via Svalbard, Fairbanks, etc.
  - S-Band for commanding, health and safety telemetry
  - GPS for positional data, orbit determination and timing
  - X-Band broadcast mode option
  - Design includes 30% data rate margin
- **Electrical Power**
  - 9.14 m^2 Solar Array (active, articulated); increase to 9.67 m^2 to accommodate Direct Broadcast option
  - 145 AH Li-Ion battery
  - Power System Electronics (PSE)
  - Design includes 30% power margin
- **Flight Dynamics**
  - 700 km, 98.2 deg inclination, Noon ± 10 min Descending Node Crossing, Sun Sync orbit; 223 m/s ΔV for Dispersion correction and EOM controlled reentry to 50x700 km
- **Thermal**
  - Passive radiator design with standard coatings, blankets and heaters

PACE System Design Overview (cont)

- **Flight Software**
  - Payload Support
  - S/C mechanism control
  - Recorder Memory Management
  - S/C Power System Electronic Support
  - Health and Safety Management
- **Mechanical**
  - Composite skin aluminum honeycomb core structure
- **Mission Ops**
  - Typical Multi Mission MOC
  - Prime Shift 8x5 Operations
- **Propulsion**
  - Propulsion system needed for launch dispersion correction and Controlled deorbit
  - Hydrazine monopropellant blowdown system
  - 4 (four) 22 N thrusters
- **Launch Vehicle: Compatible with Atares 120 and Falcon 9 (Block I / II)**
- **Radiation**
  - 3 year dose is 12 krads (23 krads with margin) for 2.5mm aluminum shielding
  - 5 year dose is 21 krads (41 krads with margin) for 2.5mm aluminum shielding
- **Reliability**
  - Calculated Deorbit reliability: 0.94 after 3 years, 0.90 after 5 years.

PACE System Design Overview (cont)

- **Orbital Debris**
  - Spacecraft is noncompliant for uncontrolled reentry.
  - Baseline for this study: Controlled reentry for EOM disposal that lowers orbit to 50x700 km
  - Alternative EOM disposal strategy: Lower orbit to 510x700 km and have uncontrolled reentry within 25 years. This would require a demisable propellant tank to lower probability of human injury to less than 1 in 10,000. The significantly lower requirement for deorbit propellant may allow a smaller tank that could be demisable at a reasonable cost.

PACE Mission Level Schedule

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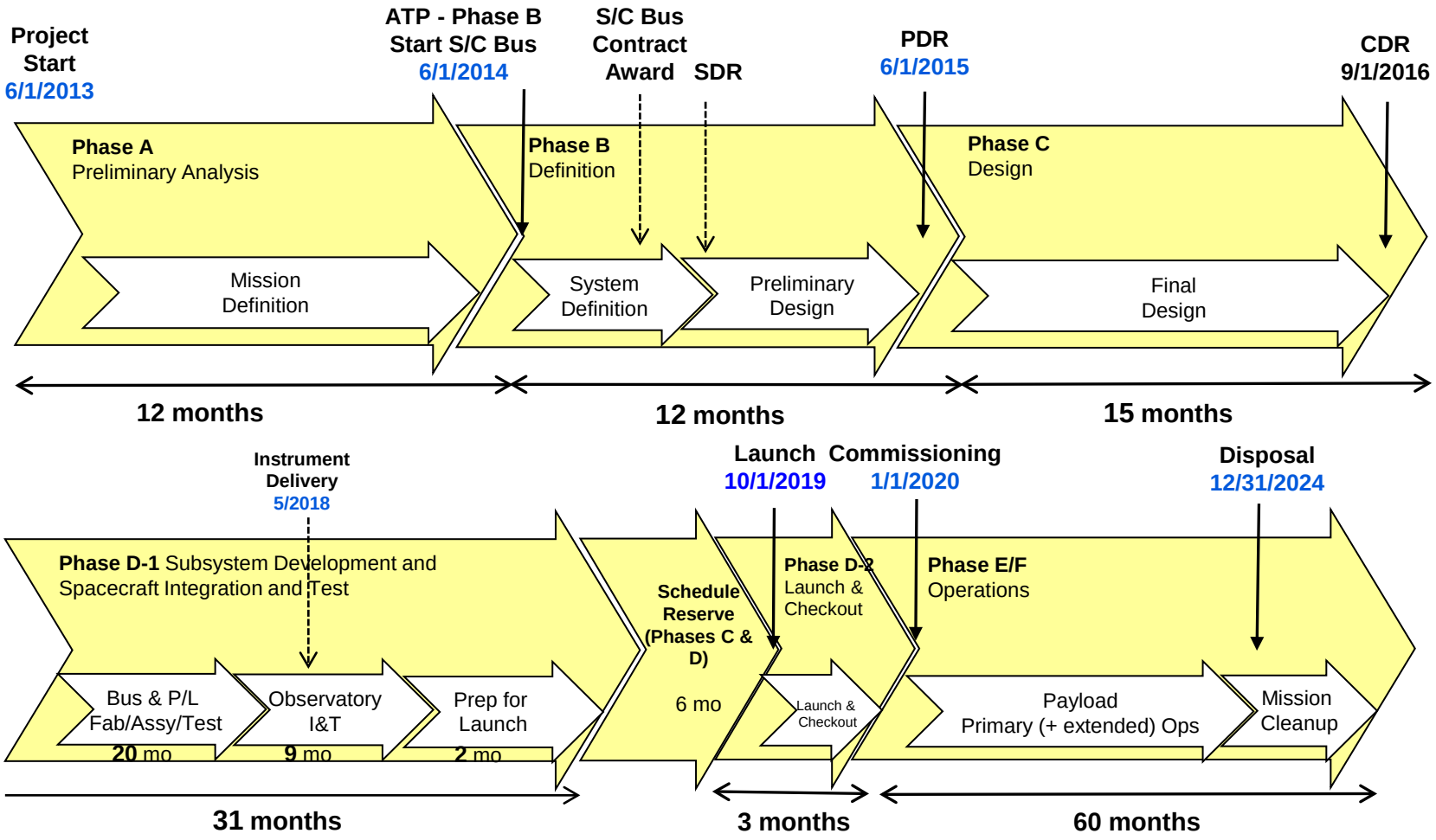
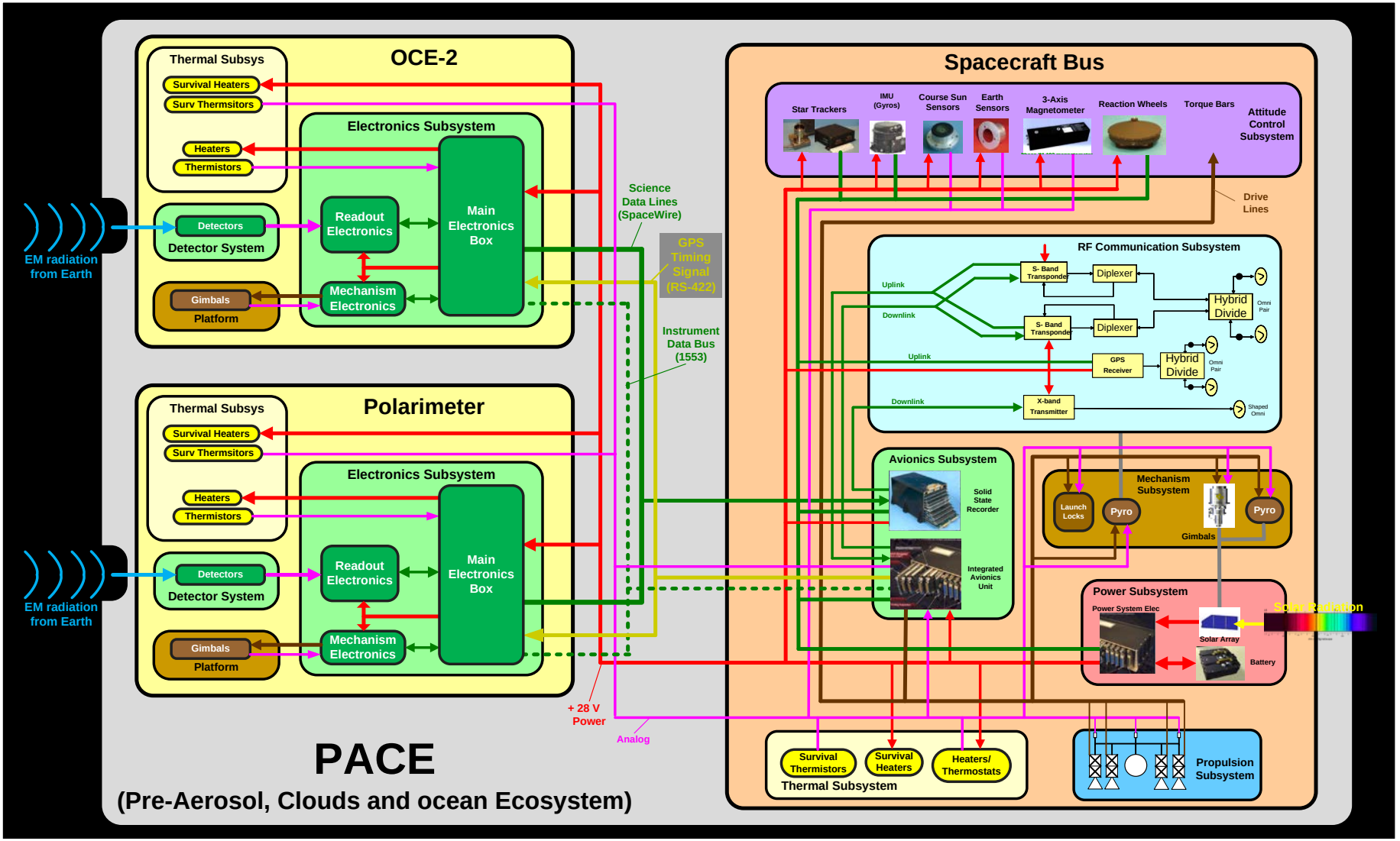


Spacecraft Electrical System Schematic Diagram



Launch Configuration (Antares)

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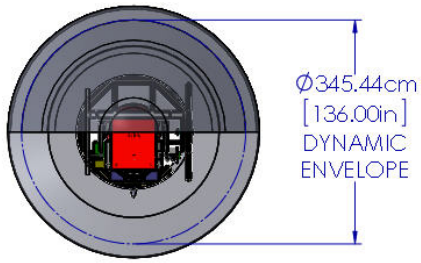
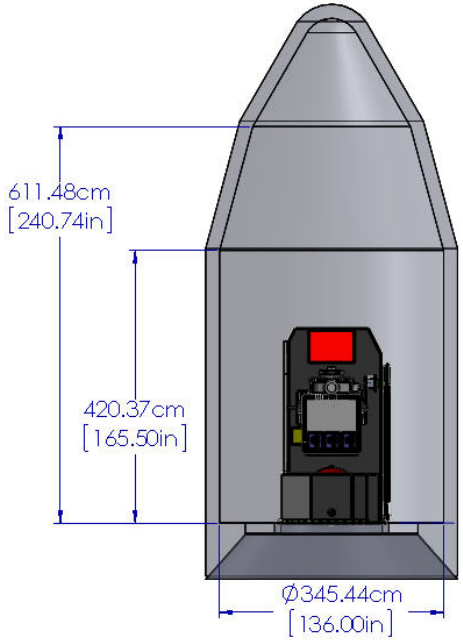
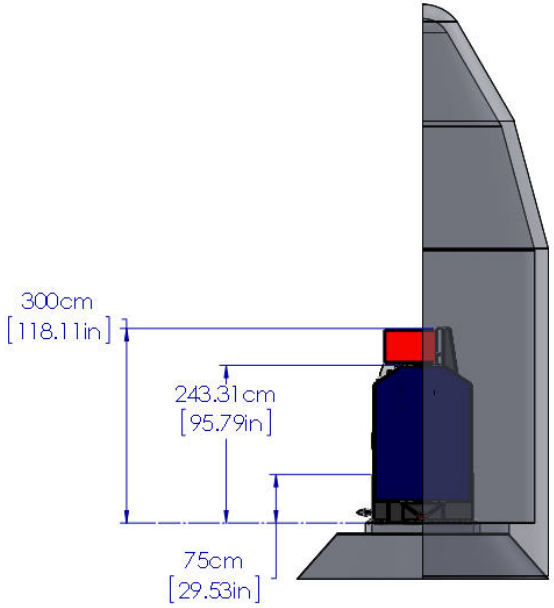
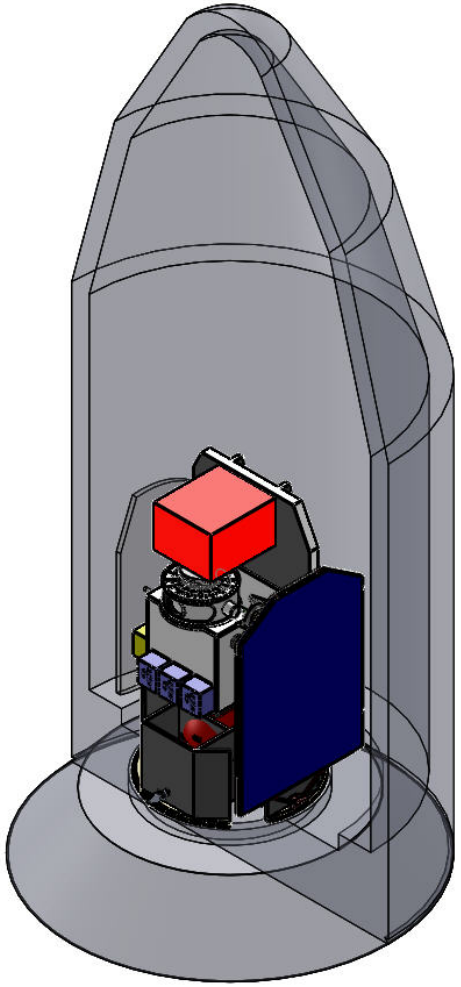
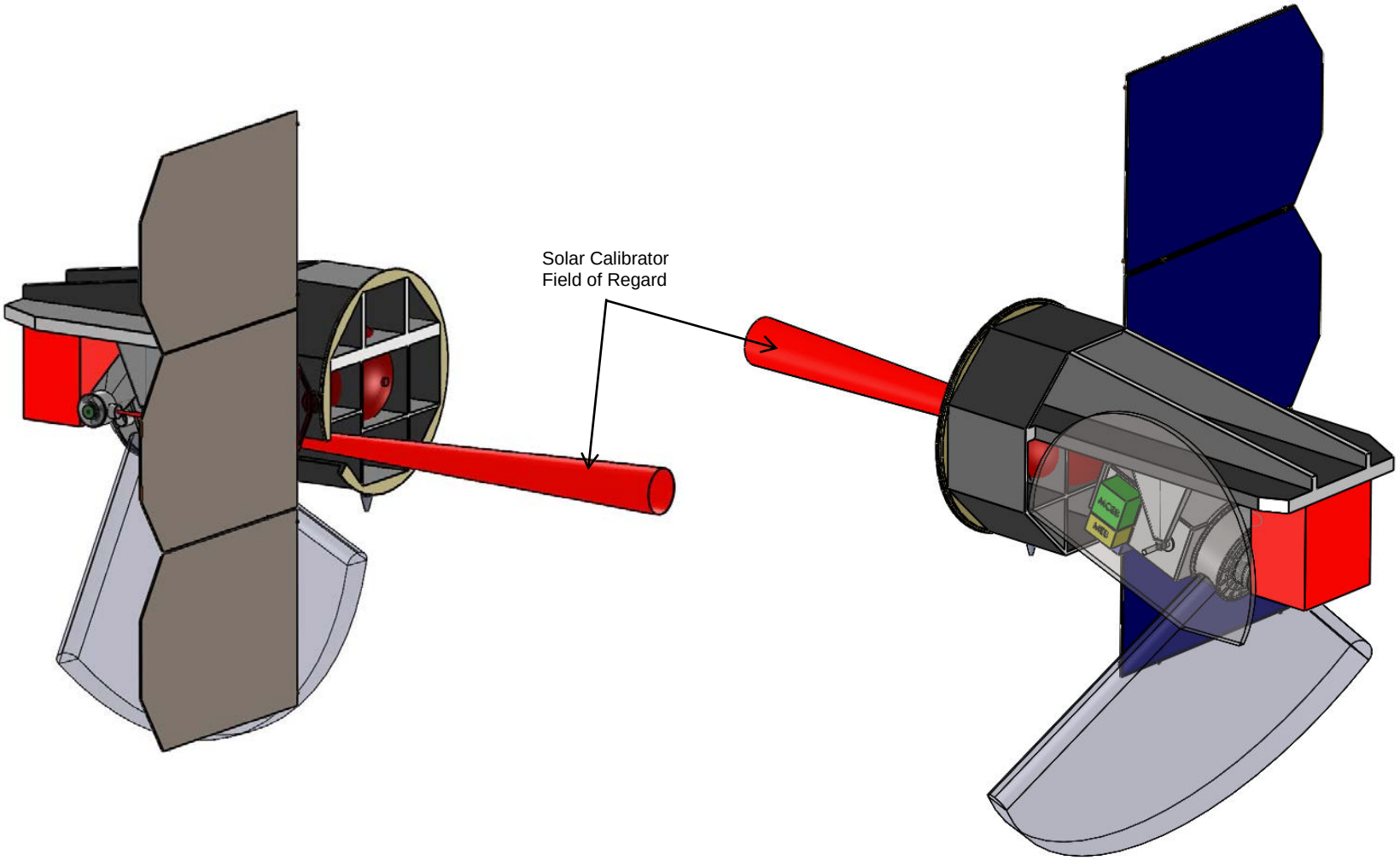








Observatory Concept (Deployed Configuration)



PACE System Design Overview

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NOTE:

1. No contingency in this Mass Rackup per customer direction
2. If alternative EOM disposal strategy is used (see P13 - 15 of "Propulsion"), assuming 1100 kg S/C dry mass, ***S/C Propellant*** will be reduced from 165 kg to 55 kg, ***Propulsion*** mass reduced to 18 kg, ***Bus Total*** reduced to 451 kg, ***S/C Dry Mass*** (CBE) reduced to 812 kg, and ***Launch Mass*** (CBE) reduced to 867 kg;

PACE Mass Rackup			
Module			
	CBE	**Cont.**	**Allocation**
OCE and Polarimeter Total	**361.00 kg**	**0%**	**361.0 kg**

S/C Bus			
Attitude Control	74 kg	0%	74 kg
Mechanical	104 kg	0%	104 kg
Thermal	19 kg	0%	19 kg
Propulsion	29 kg	0%	29 kg
Power (SA Active Area, Battery, Harness)	190 kg	0%	190 kg
Avionics	24 kg	0%	24 kg
Communications	22 kg	0%	22 kg
Bus Total	**462 kg**		**462 kg**

S/C Dry Mass			
	CBE	**Cont.**	**Allocation**
OCE and Polarimeter Total	361 kg	0%	361 kg
S/C Bus Total	462 kg	0%	462 kg
S/C Dry Mass	**823 kg**	**0%**	**823 kg**
Payload Propellant	**0 kg**	0%	0 kg
S/C Propellant	**169 kg**	0%	169 kg
Launch Mass			**992 kg**

LAUNCH VEHICLE EVALUATION	
Antares to LEO	2000 kg
Throw Mass Margin	1008 kg
Throw Mass Margin %	102%

PACE Data Volume 2 Orbits

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Data Acquisition - Broadcast Option			Data Storage - Baseline				Data Downlink - Baseline	
Data Source or type	Average Raw Data (compressed) Rate (kbps)	Average Raw Data Acquisition Period (minutes)	Total Data Volume Per Orbit Before Margin (Gbits)	Data Rate Margin or Contin - gency (%)	Data Volume Per Orbit with Data Rate Margin & CCSDS (Gbits)	Data Volume Two Orbits with Data Rate Margin (Gbits)	Downlink Data Rate (Mbps)	Trans— mission Time for Two Orbit Data (minutes)
OCE-2 Science + H/K	10,000	47	28.2	30%	37.43	74.9	105	14.5
Polarimeter Science + H/K	2,200	47	6.2	30%	8.23	16.5		
Spacecraft H/K Data	4	99	0.024	30%	0.03	0.1		
Total	**12,204**		**34.5**		**45.70**	**91.4**		

PACE Power Requirements (load Analysis)

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PACE-2012										
5.0	Mission Life in Years									
EPS Load Item Description				Launch Power	Sun Avg. Power Watts	Eclipse Avg. Power Watts	Safehold Power in Watts	Peak Power	Comm Downlink	Slew Maneuver
Total Power				**66.9**	**1,231.8**	**1,148.2**	**977.5**	**2,851.8**	**1,289.8**	**1,260.84**
Time Period Over Which Averaging Is Done For Each Mode (min.)		Contingency								
	Inst Global Contingency	30								
Instruments with Contingency				**0.0**	**764.1**	**708.5**	**591.2**	**1426.1**	**708.5**	**764.1**
Ocean Color Experiment 2 (OCE)				0.0	515.0	515.0	214.0	648.0	515.0	515.0
	Contingency	30		0.0	154.5	154.5	64.2	194.4	154.5	154.5
Polarimeter				0.0	72.8	30.0	30.0	100.0	30.0	72.8
	Contingency	30		0.0	21.8	9.0	9.0	30.0	9.0	21.8
OCE Survival Heater				0.0	0.0	0.0	244.0	349.0	0.0	0.0
	Contingency	30		0.0	0.0	0.0	30.0	104.7	0.0	0.0
Spacecraft Loads with Contingency				**66.9**	**467.7**	**439.7**	**386.3**	**1425.7**	**581.3**	**496.7**
	Spcft Global Contingency	30								
PSE	MAP like (95.4% eff)	56.66		3.1	56.7	50.4	41.7	121.2	55.6	55.4
	Contingency	30		0.9	17.0	15.1	12.5	36.4	16.7	16.6
Electrical - Harness Losses	BGB			0.2	4.2	3.9	3.3	9.7	4.4	4.3
	Contingency	30		0.1	1.3	1.2	1.0	2.9	1.3	1.3
Command & Data Handling	Porfi B.			0.0	83.0	38.0	46.0	92.0	83.0	54.0
	Contingency	30		0.0	24.9	11.4	13.8	27.6	24.9	16.2
Solar Array Drive Motor	BGB			1.1	5.7	5.7	1.1	17.2	8.5	5.7
	Contingency	30		0.3	1.7	1.7	0.3	5.1	2.5	1.7
Solar Array Drive Electronics	BGB			2.2	10.9	10.9	2.2	13.8	10.9	10.9
	Contingency	30		0.7	3.3	3.3	0.7	4.2	3.3	3.3
Attitude Control	Eric S.			22.8	140.2	140.2	123.2	653.2	140.2	202.2
	Contingency	30		6.8	42.1	42.1	37.0	196.0	42.1	60.7
Thermal	Kim B.			20.0	30.0	60.0	60.0	75.0	30.0	30.0
	Contingency	30		6.0	9.0	18.0	18.0	22.5	9.0	9.0
Propulsion	Bob E.			2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Contingency	30		0.6	0.6	0.6	0.6	0.6	0.6	0.6
Data Systems	Blake L.			0.0	27.1	27.1	17.6	112.6	112.6	17.6
	Contingency	30		0.0	8.1	8.1	5.3	33.8	33.8	5.3

Impacts of Direct Broadcast Option

- **Limited Impacts on Communication, Power, Avionics & FSW**
  - **Use same X-band RF equipment**
  - **Solar Array size increases from 9.14 m^2 to 9.67 m^2 (6.36 kg extra mass)**
  - **Avionics & FSW need to provide Real time data in CCSDS format to X-band**

MDL Design vs. RSDO RAPID III Catalog S/C

- **The Table on the page following the next lists MDL design against the capabilities of 9 out of 11 RSDO RAPID III catalog spacecraft**
  - RAPID III data taken from Data Summary Spread Sheet
  - Orbital 300S and SSTL-150 are not
  - Not all parameters are listed
  - Science Data Downlink unit changed from kbps to Mbps
  - Data Storage unit changed from Mbit to Gbit
  - This Table merely summarizes the characteristics of the Contract S/C Baseline Configuration, for additional S/C capabilities, options, and past mission accommodations, please select “Catalog” at the RSDO web site RSDO.GSFC.NASA.GOV
- **Make sure to read the RSDO CATALOG ADVISORY NOTICE on the following page before proceeding to read the Table**
  - Note especially that “EACH SPACECRAFT IS CAPABLE OF BEING MODIFIED TO MEET OTHER MISSION SPECIFIC CAPABILITIES“
- **It appears the MDL design can be met by some RAPID III catalog S/C with changes in certain areas**

RSDO Catalog Advisory Notice

NOTE THE FOLLOWING:

THE SET OF RAPID III CATALOG SPACECRAFT SERVE AS A STARTING POINTS FOR MEETING YOUR MISSION SPACECRAFT REQUIREMENTS.

THE RSDO CATALOG SPREADSHEET IDENTIFIES THE CHARACTERISTICS OF EACH CATALOG SPACECRAFT IN THE CONTRACT BASELINE CONFIGURATION.

EACH SPACECRAFT IS CAPABLE OF BEING MODIFIED TO MEET OTHER MISSION SPECIFIC CAPABILITIES.

THE CONTRACT CONFIGURATION IS ONLY ONE OF MANY POSSIBLE MISSION CONFIGURATIONS.

TO LEARN MORE ABOUT THE FULL CAPABILITY OF EACH RSDO SPACECRAFT, PLEASE CONTACT THE RSDO AT RSDO@GSFC.NASA.GOV OR PHONE: 301-286-1289

MDL Design vs. RSDO RAPID III S/C

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Contractor Spacecraft Name	Units	MDL Design	Ball Aerospace BCP2000	Lockheed Martin LMX	Northrop Grumman Eagle 0	Orbital 300HP	Orbital LEOStar 2	SST-US LLC SSTL-300	SST-US LLC SSTL-600	Thales Alenia France PROTEUS	Thales Alenia Italy PRIMA
Orbit Average Payload Power	W (EOL)	588	400	427	100	775	850	140	386	300	1,100
Maximum Payload Mass	kg	361	500	460	Panel: 86 Axially: 3000	3,000	500	150	200	300	1,138
Science Data Downlink	Mbps	105	80	mission-specific	1	40	300	105 Mbps (X-Band)	105 Mbps (X-Band)	1	up to 0.31
Science Data Storage	Gbit	100	56	mission-specific	0 (up to 384 Gbits can be added)	160	500	16	0.128	2	up to 1.2 (EOL)
Pointing Knowledge	arcsec	40	10.5	60 (3s)	1,550 (3s)	6 radial (1s)	42	72	360	20	< 18
Pointing Control	arcsec	360	10.5	130 (3s)	1,550 (3s)	120 (1s)	48	360	605	72	< 36
Pointing Stability (Jitter)	arcsec/sec	25 over 0.14 sec	0.5	20 (3s)	12	1	1	2	mission-specific	3	< 1
Slew rate	deg / min	4	18	23	90	0.125 deg/sec	60	0.75 deg/sec	1 deg/sec	n/a	up to 1°/sec
Mission Design Life	years	3 with consumble for 5	5	3	1	5	5 with expendables for 7	7	4	5	7
Compatible LVs	(names)	Antares 120 (OSC), Falcon 9	Delta II, EELV, Taurus XL, Taurus 2, Falcon 9, Minotaur IV	Taurus 2, Delta II, Falcon 9, Minotaur IV, EELV	EELV, Falcon 9, Taurus II	EELV, Delta, Taurus II	Delta II	Falcon 1e, Atlas, Delta, Athena and other launchers	Falcon 1e, Atlas, Delta, Athena and other launchers	Ariane 5, Athena 2, Cosmos, LM-2D, PSLV, Rockot, Spoyuz, Taurus	Soyuz, Delta II,Zenit, Ariane 5, EuRockot, Dnepr, PSLV, Cosmos, Taurus, Falcon 9
Nominal Orbit	Altitude, Inclination, Type, Other	700 km, 98.2 deg Sun Sync	600 km, 94 deg all-Beta	681 km, 98 deg, Sun Synch	Lunar Impactor	565, 25.6, all	600 km 97.8 deg Sun Synch	700km, 98.7 deg	23,590km, 56 deg	1,396 km, 66 deg	620 km, 98°, Sun Synch
Types of Orbits Available	as needed	LEO Sun Sync polar	LEO 400 - 900 km 0 to 108 deg	LEO 400-1,000 km 0° to Sun Synch	LEO (28 - 90° incl & altitudes from 425 km to 1,000 km), GEO, and interplanetary	As needed with impacts to other parameters.	400 km to 1,000 km at any inclination	LEO from 400km to 2,000km, any inclination	LEO, MEO, GEO	Inclination from 20° to 140°, altitude from 600km to 1,500km	LEO from 0 deg to SSO inclination, up to 1,500 km