National Aeronautics and Space Administration

RADIOISOTOPE POWER SYSTEMS

Power System Overview for the Small RPS Centaur Flyby and the Mars Polar Hard Lander NASA COMPASS Studies

Presented by:

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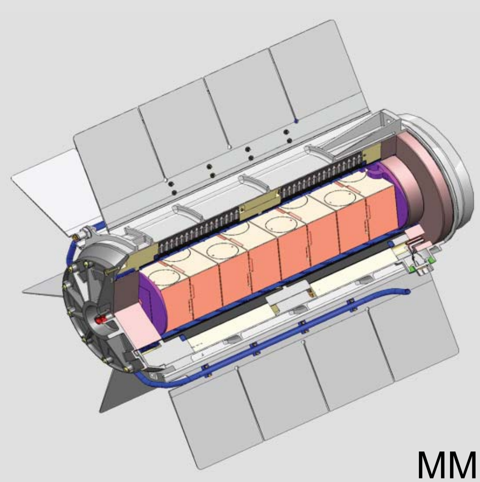
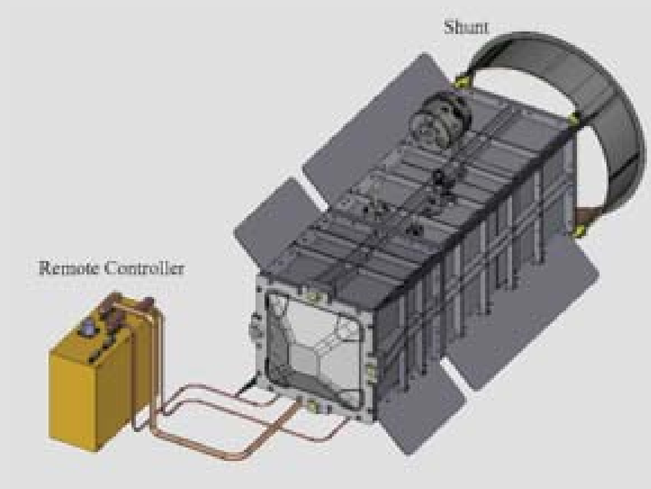
POWER TO EXPLORE

Motivation for the Studies

- Current RPS Program Product Line: 100 We class power with ~ 30 kg
- What other size power systems should be considered for future development?
- Can smaller scale S/C and science utilize a small RPS
- Perform two mission studies with low-cost, low-mass for evaluating small GPHS RPS and RHU milliwatt RPS:
  - Low cost mission goal: equal to or less then Discovery class
  - Stricter mass and volume constraints
  - Lower power requirements



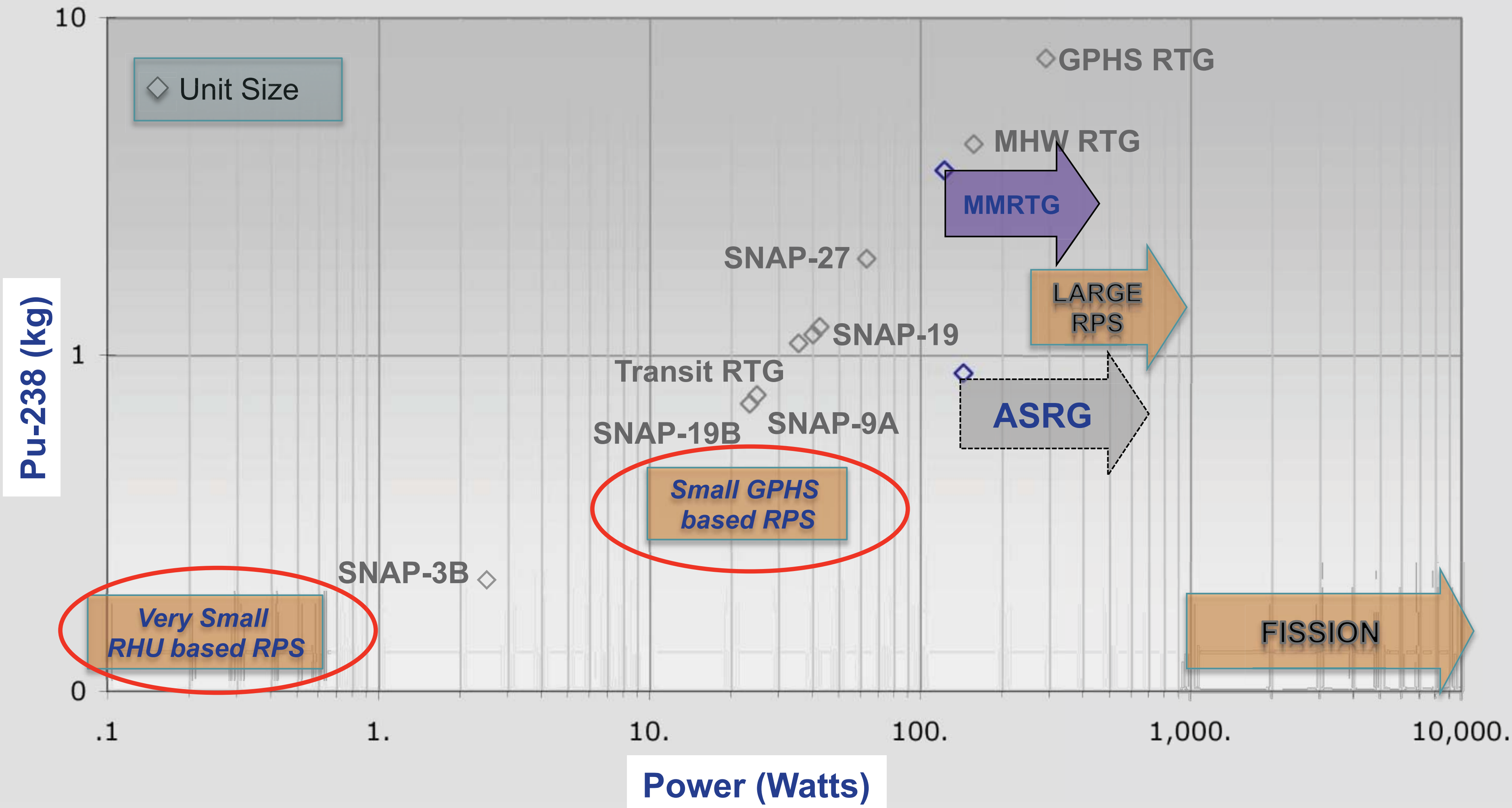
MMRTG



ASRG

RPS Product Line

Power levels supplied: Historical, Current, and Potential RPS

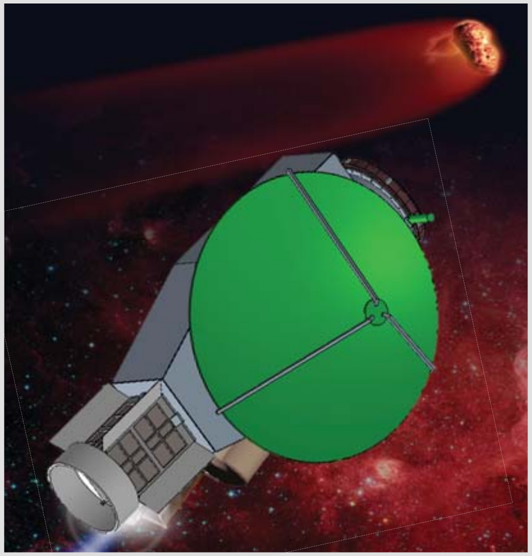


Microsat Study Assumptions

- Low cost spacecraft and mission
  - Discovery “class” cost profile
  - Multiple identical Microsats
  - Multiple targets ?
- Lowest mass/size possible while maintaining high valued science
- Use of small (~60 We or less) radioisotope power to far reaches of solar system
  - Single GPHS module if possible
  - Power for science encounter
  - Reasonable power level available for timely data return
  - Battery supplies additional power during encounter and data return communication periods

RPS Powered Microsat

- Sample Mission
  - Centaur Scout -~4 microsats, launched together and then disperse to flyby different Centaurs (option to flyby in pairs)
- General Purpose Heat Source
  - Designed for launch
  - Provides 250W thermal
  - ~1.5 kg per module
- Power Options
  - Single GPHS Stirling Radioisotope Generator ~60W
  - 3 - GPHS RTG @ ~ 60W
- Microsat
  - Goal ~150 kg each microsat
  - 1-2 instruments



Specific Chiron Mission Goal

A specific, well-defined science mission is detailed here to demonstrate that there is interesting science and determine the power levels and operations concept, which are key drivers for Small RPS missions.

Characterize Chiron: structure, composition, and surface morphology.

Structure will be determined via Doppler radio science for Gravity Science (GRAV).

Composition will be determined by a hyperspectral IR spectrometer (SPEC).

Surface morphology will be determined by camera (CAM).

Science Interest

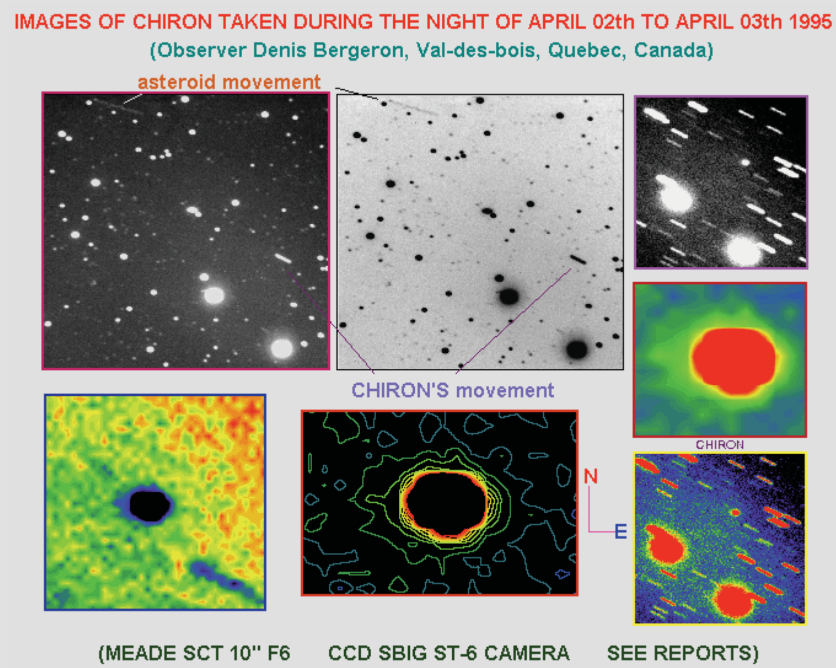
2060 Chiron is a minor planet in the outer Solar System. Discovered in 1977 by Charles T. Kowal (precovery images have been found as far back as 1895), it was the first-known member of a new class of objects now known as centaurs, with an orbit between Saturn and Uranus.

Although it was initially called an asteroid and classified as a minor planet, it was later found to exhibit behavior typical of a comet. Today it is classified as both, and accordingly it is also known by the cometary designation **95P/Chiron**. Its rotational period is 5.917813 hours, a value determined by observing its distinct light curve.

Since the discovery of Chiron, other centaurs have been discovered, and nearly all are currently classified as minor planets but are being observed for possible cometary behavior. 60558 Echeclus has displayed a cometary coma and now also has the cometary designation 174P/Echeclus. After passing perihelion in early 2008, centaur 52872 Okyrhoe significantly brightened.

Size estimates for Chiron:[4]

Year	Radius (km)	Notes
1984	90	Lebofsky
1991	<186	IRAS
1994	74	Campins
1996	90	occultation
2007	117[3]	Spitzer Space Telescope
2013	109[13]	Herschel Space Observatory

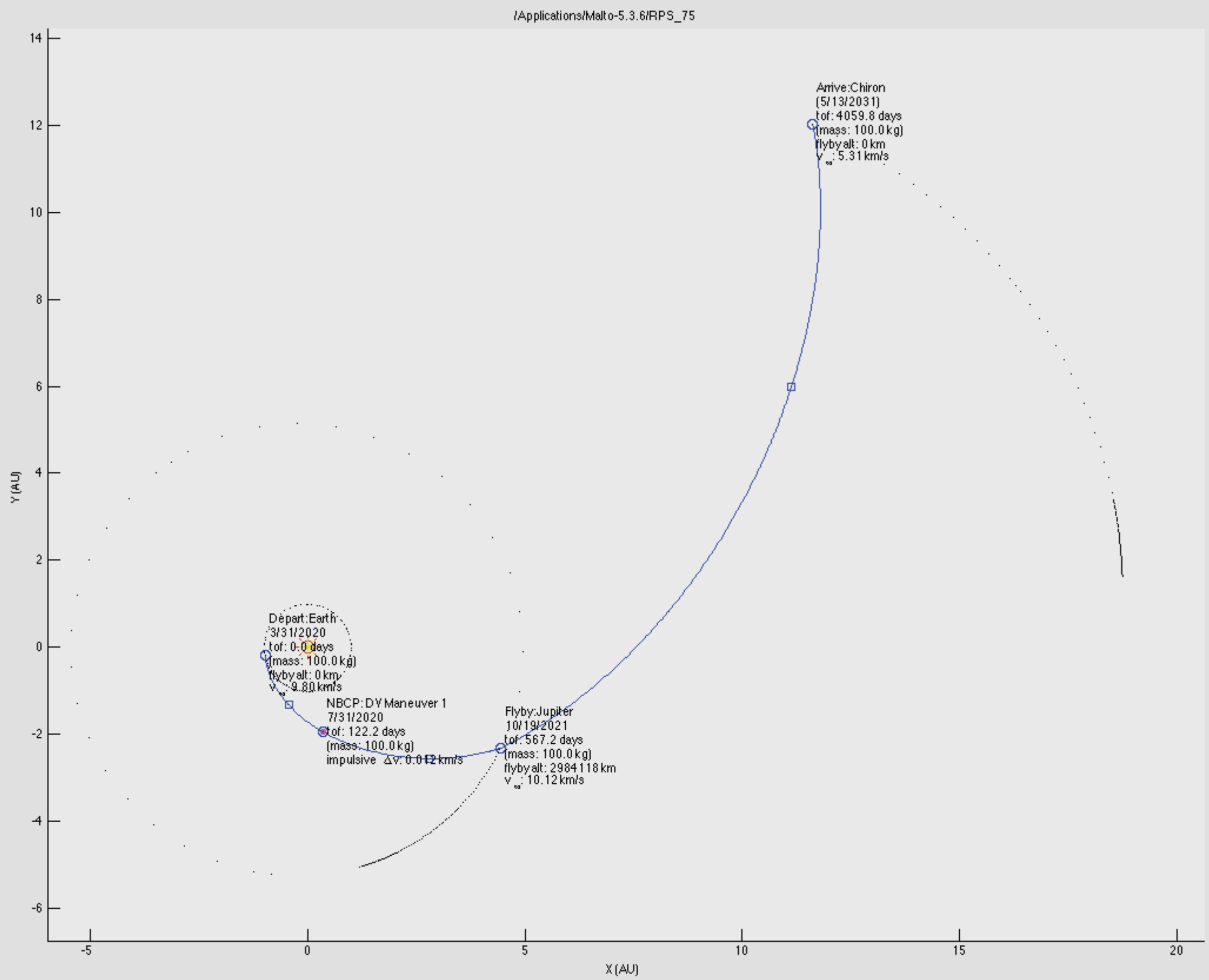


Mission ConOps

The microsats execute a Jupiter gravity assist, and then after separation they can alter their trajectories to fly by different targets depending on various factors.

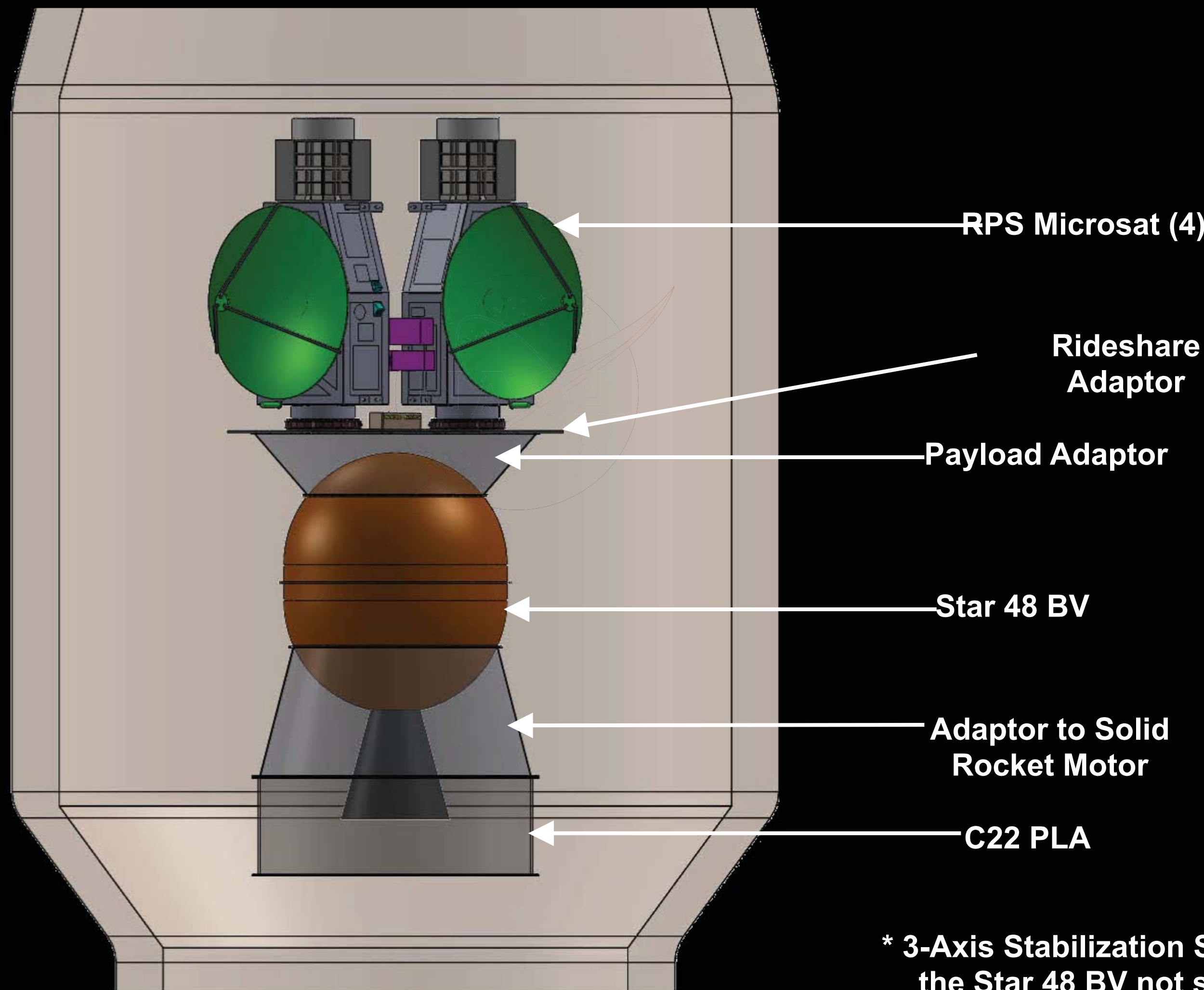
Atlas V 431 + STAR48B	
C3 km2/sec2	Payload (kg)
15	3990
20	3670
25	3370
30	3095
35	2840
40	2605
45	2390
50	2195
60	1850
70	1560
80	1315
90	1115
100	940
110	800
120	675
130	570
140	475
150	395
160	320
170	260
180	205

Target C_3 102 km^2/s^2 → (pointing to the row C3 = 100)



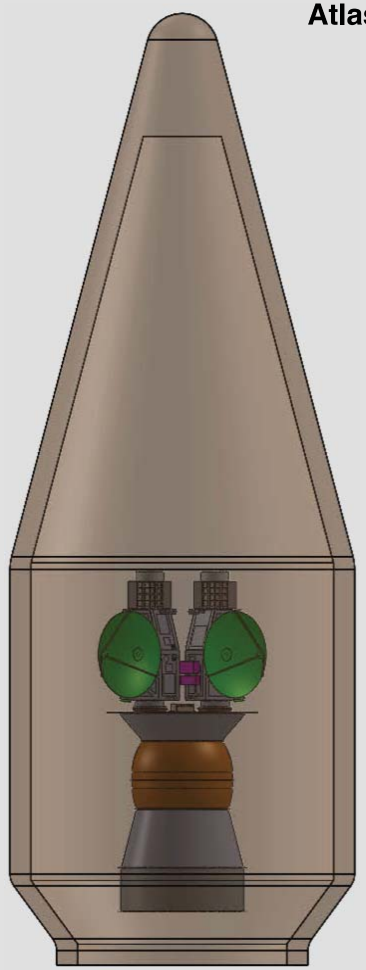
Microsat and Launch Stack Configuration

Atlas 431 w/ STAR 48B kick stage
Four identical microsats each with radioisotope power system

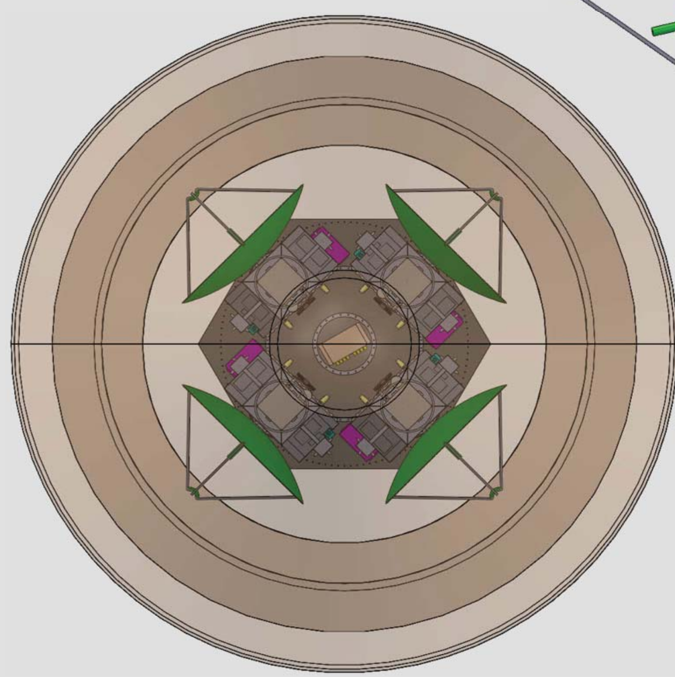


* 3-Axis Stabilization Stage for the Star 48 BV not shown

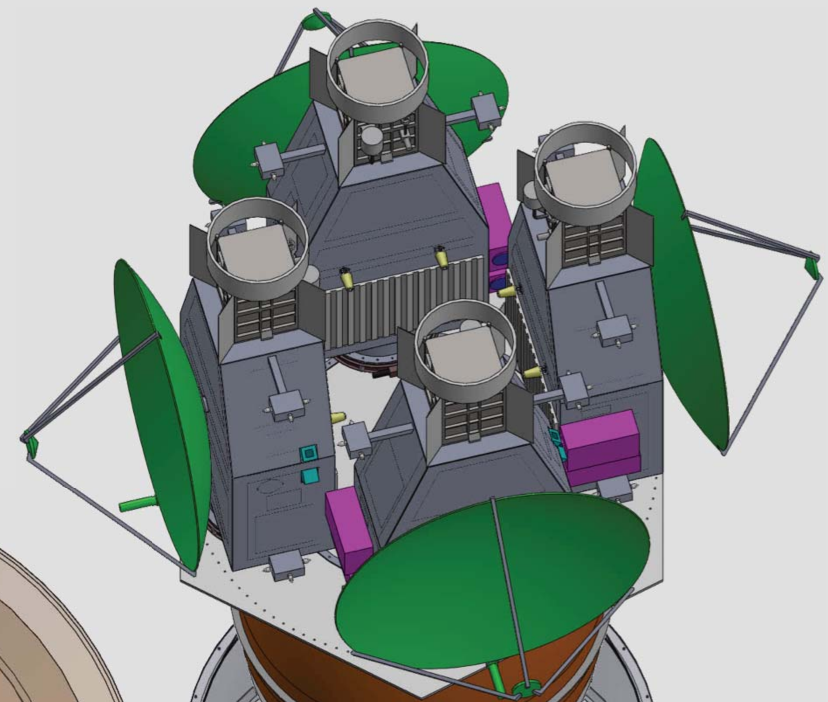
Microsat LV Configuration



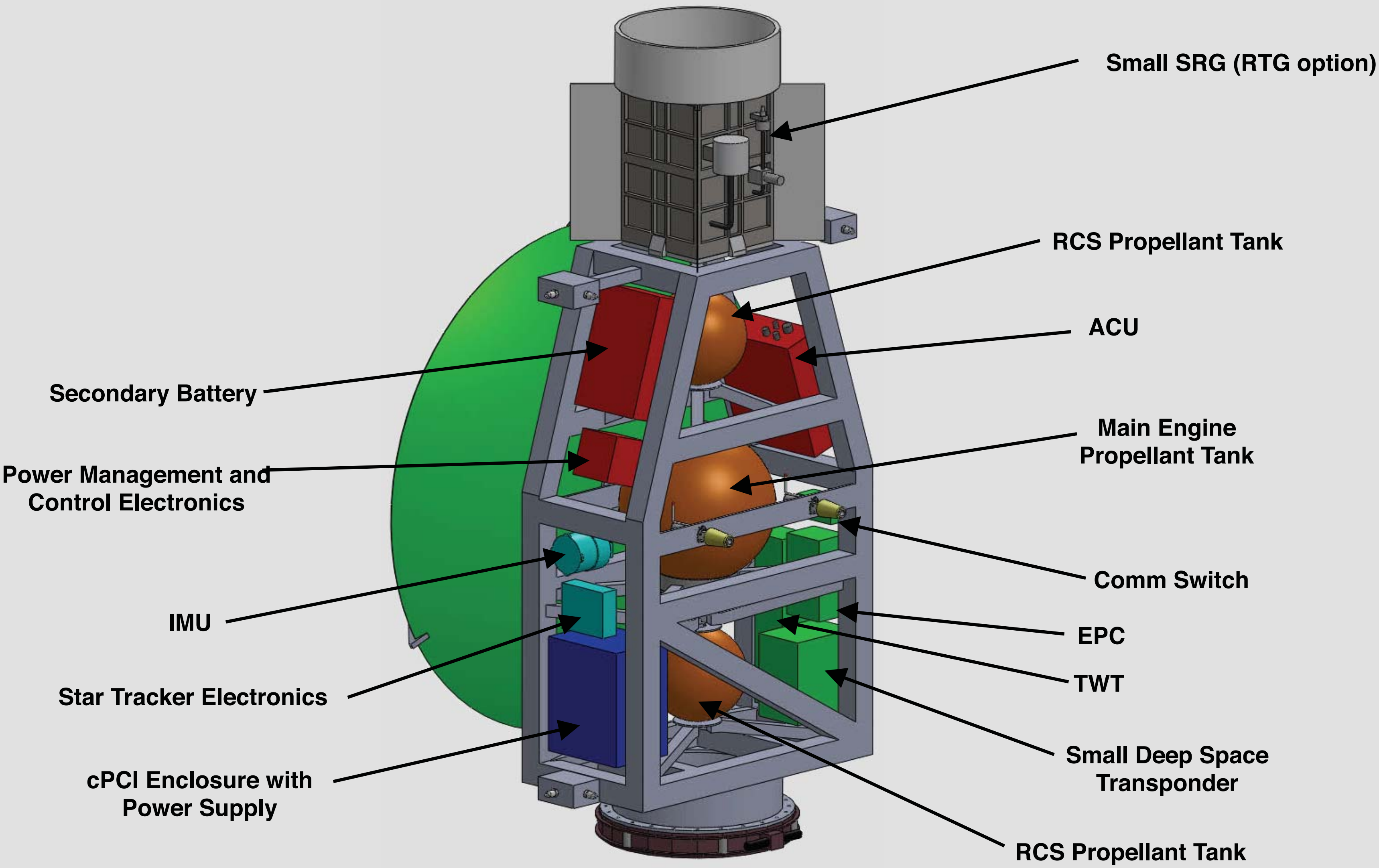
Atlas V 4-meter
LPF



3.75-m Diameter
Payload Envelope

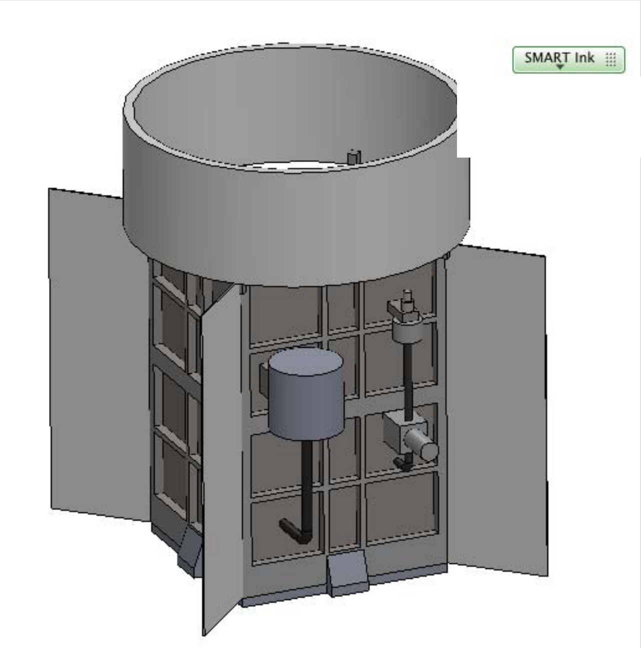


Microsat Components



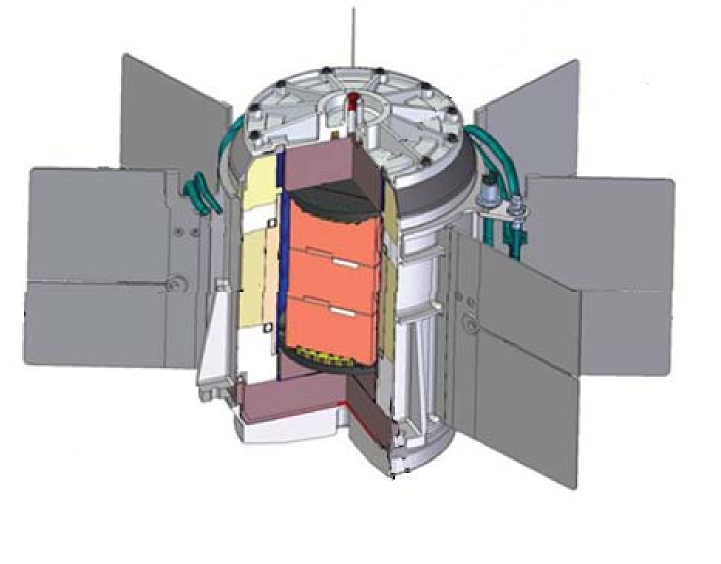
Small Stirling Radioisotope Generator

- sSRG based on ½ ASRG with Dynamic Balancer
- 65 watts BOM (3 watts for balancer-68 watts total)
- 760 C Acceptor Temperature (BOM)
- 38 C Rejector Temperature (BOM)
- 4 K Sink
- Solid Insulation
- Dynamic Balancer sized to reduce vibration below dual opposed ASRG configuration
- 28 +/- 6 volt output
- Includes out of voltage range shunt
- Mass estimate from current ASRG



Small Radioisotope Thermoelectric Generator

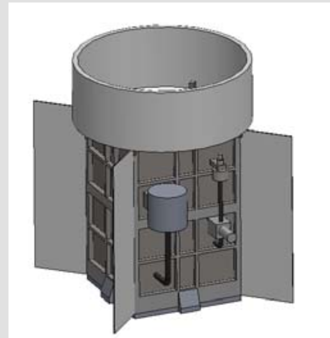
- Study began with a single GPHS RTG
  - Small RTG Assumptions
    - BOL Power: 21.25 We
    - Mass: 10.32 kg
    - Dimensions: 0.64m diameter (including fins), 0.17m height
    - Efficiency: 8.5%
    - Specific Power: 2.06 W/kg
    - Hot Junction: 538 C
    - Cold Junction: 50 C
    - Thermoelectric materials: PbTe/TAGS/BiTe couples with 5V output
    - 1 GPHS Module
    - Output Degrades 2.5% per year (same as advanced eMMRTG)
    - 5 Volt output

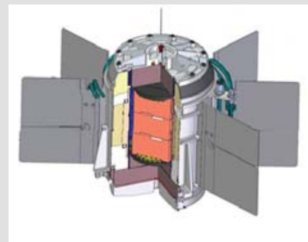


- Final Configuration is a 3 GPHS RTG
  - BOL Power: 63.75 We
  - Mass: 20 kg
  - Dimensions: 0.64m diameter (including fins), 0.31m height
  - Output Degrades 2.5% per year (same as advanced eMMRTG
  - Reconfigured to produce 28 volt output (same as MMRTG)
  - First estimate of 6 parallel strings (16 for MMRTG)

Small RPS Attributes

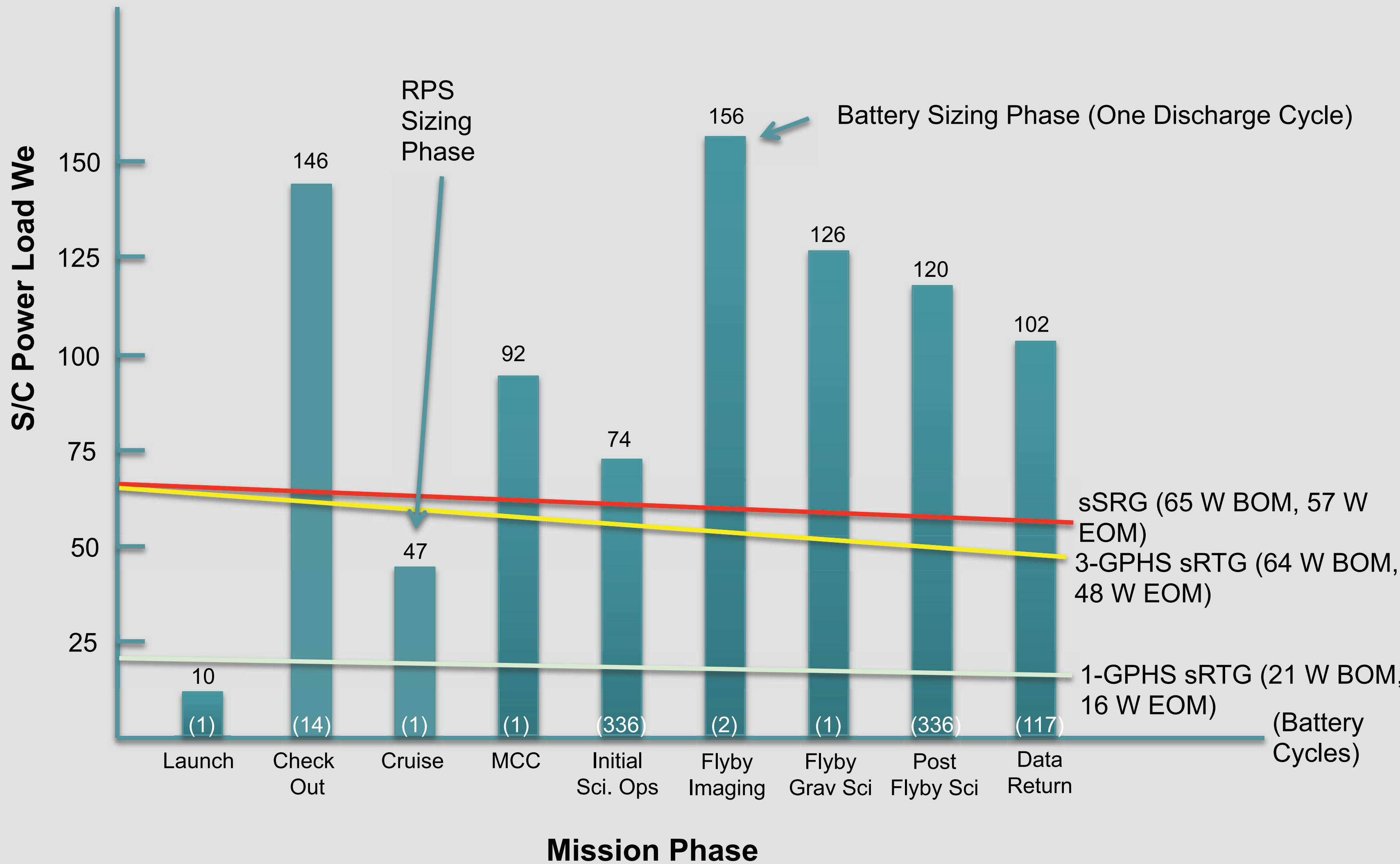
Parameter	Small SRG	Small RTG
BOM Power	65 W	64 W
EOM Power (12 year mission)	57 W	48 W
Mass	18 kg	20 kg
Dimensions	49 cm high 39 cm dia	17 cm high 64 cm dia
Cold-side Temp (BOM, 4K sink)	38 C	50 C
Voltage	28 +/- 6 V	28 +/- 8 V
Degradation	1.16 %/year	2.5 %/year
Efficiency (BOM)	26%	8.5%
# GPHS Modules	1	3


Small Stirling Radioisotope Generator (sSRG)


Small Radioisotope Thermoelectric Generator (sRTG)

- BOM values are at Beginning of Mission: at launch after 3 years in storage. EOM values are at End of Mission after an additional 12 years of operations.
- SSRG: One ASRG engine with a passive balancer and a two-card controller. The controller is included in the mass above, but not in the volume or diagram. Attributes are based on ASRG current best estimate.
- SRTG: Follows MMRTG design but with 3 GPHS bricks and advanced PbTe/TAGS/BiTe thermocouples. Estimated 6 parallel strings for average 28 V power. Attributes are estimated requirements.
- Systems assumed qualified for 17 year lifetime, including 3 years of storage.
- GPHS stands for General Purpose Heat Source

Mission Phased Power Requirements



Microsat Summary

- Study showed that a small microsat using a compact radioisotope power system for deep space destinations could potentially fit into a Discovery class cost cap and perform meaningful science with a timely return of data.

- Commonality of hardware and science helps reduce costs.

MASER Study

MASER Mission

Technical considerations

Must be enabled by RPS - motivates high latitude target
Preference for low elevation – simplifies EDL
Avoidance of gully/rock hazards – northern plains have low rock density, low slopes, well-characterized following Phoenix mission

Science considerations

Desire to detect many events at multiple stations. Station separation should be small enough to assure intensity fall-off with distance

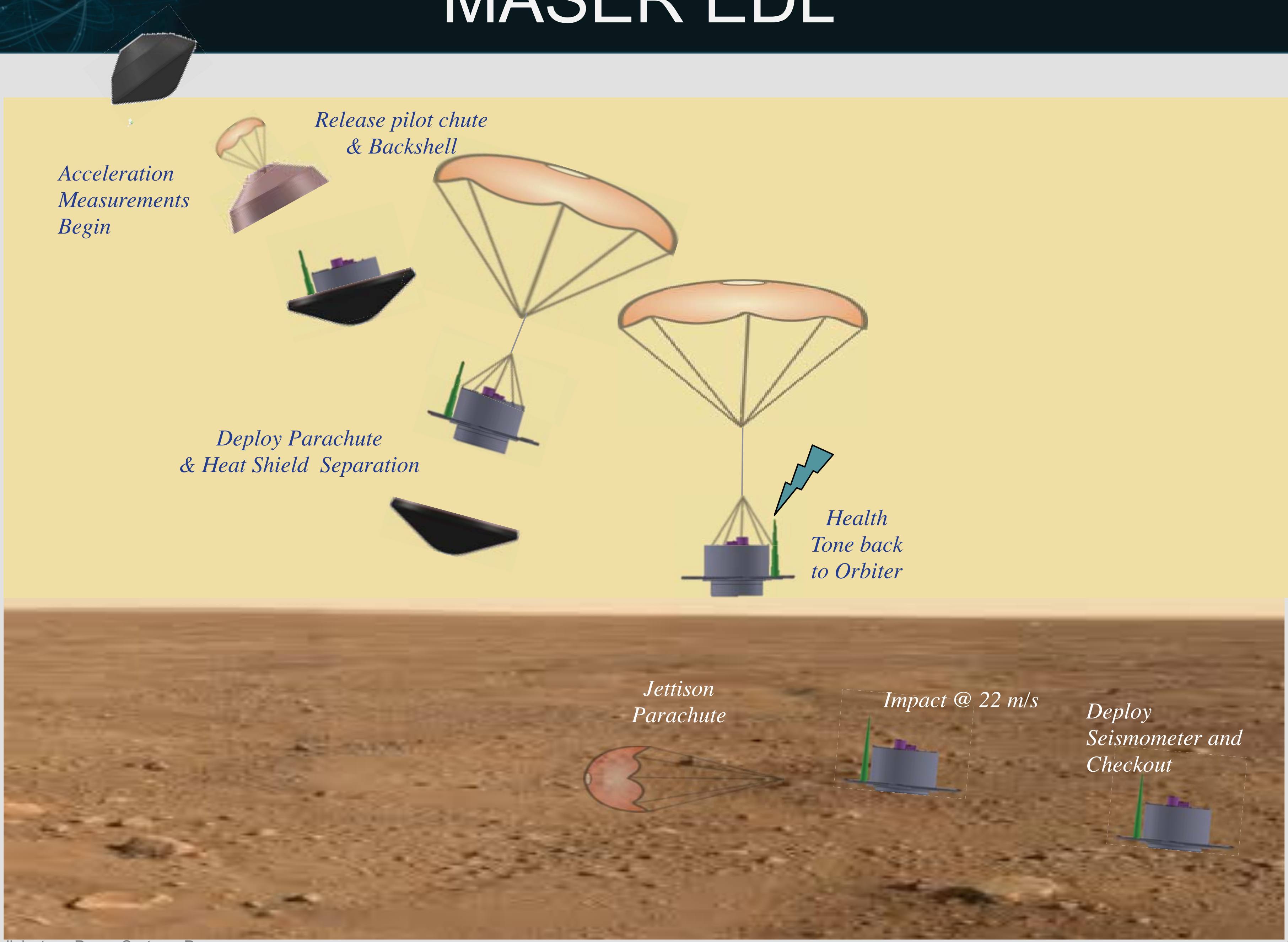
Mesoscale meteorology – waves, cyclonic systems propagation resolved by 50 degree longitude span.

15 deg latitude span will give insight into seasonal change (e.g. H2O release from subliming cap in spring; different crocus dates, thermal cracking of subsurface ice, etc.) 1km elevation span.

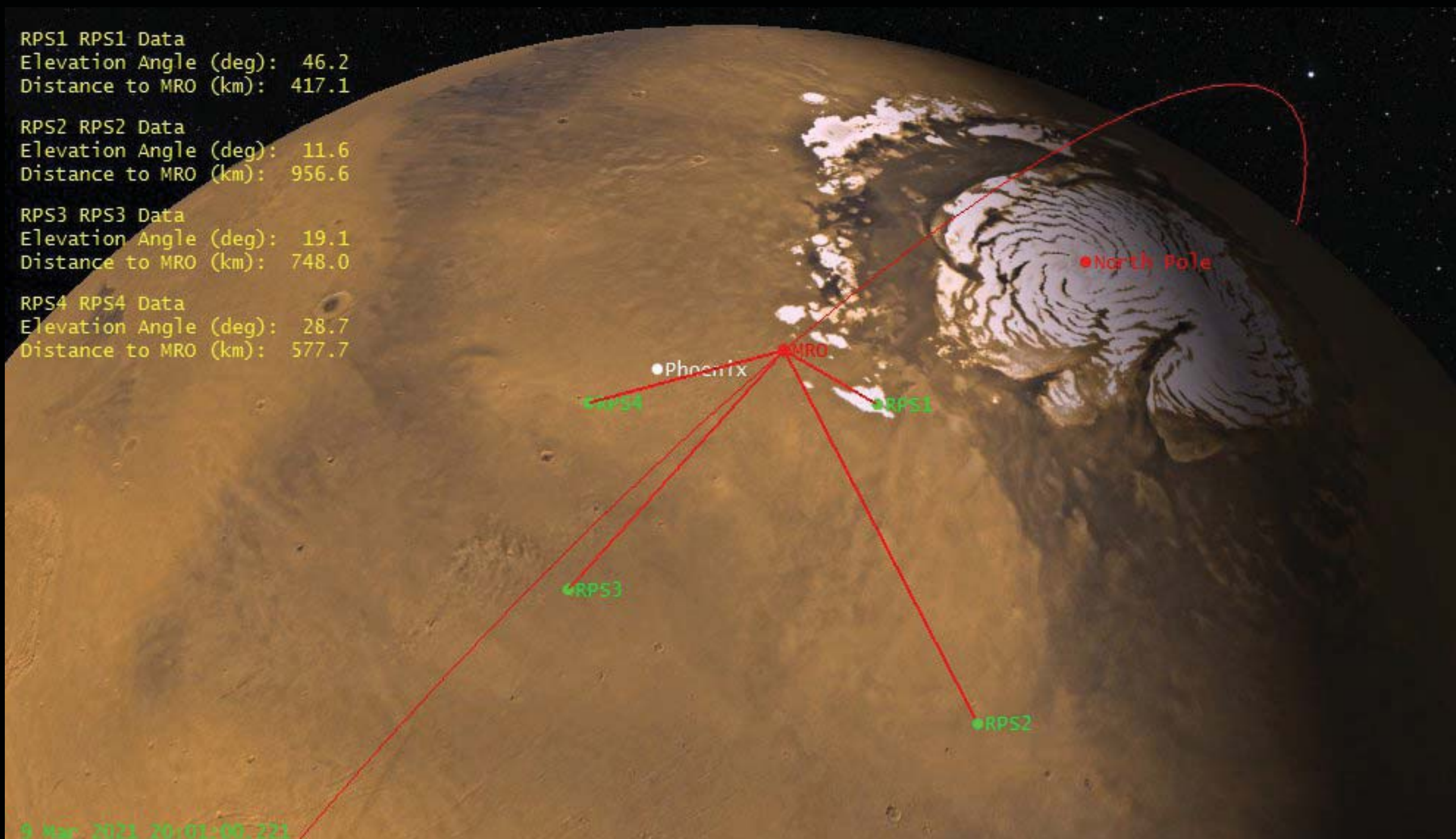
MASER Science Payload

Instrument	Measurement/Rationale	Basis	Mass (kg)	Dimensions/ Configuration/Mounting
Pressure / Temperature	Seasonal pressure cycle, atmospheric tides, cyclonic systems, dust devils. MEMS diaphragm pressure sensor or ion current gauge	Phoenix, Mars-96	0.07	Internal sensor, enclosure must be vented. Stable temperature essential. 1.5x2x2cm / 1x1x1cm
Seismometer	Seismic monitoring (short period seismic signals only). MEMS micro-seismometer or Ranger/Lunar-A geophone type.	Lunar-A, Ranger, Insight	0.5	Forebody (for minimal wind effects and maximum seismic coupling). 10cm x 10cm diameter
Optical Monitor	Set of windowed up-looking photodiodes/ filters to measure UV/near-IR light levels for water vapor, cloud, dust loading	Beagle / Mars-96 / MSL	0.1	Top side, sky view 2x6x5cm
Accelerometer Package	MEMS. Atmosphere profile during entry/ descent. Surface mechanical properties; post-impact tilt	DS-2	0.05	Entry/Tilt accel near c.g. Impact accel in forebody $1cm^3$ each.
Wind	Hot film anemometer. Seasonal, synoptic and diurnal weather systems, dust devils and gusts.	Beagle/ MSL	0.15	Top side, minimal azimuthal obstruction 4cm x 6cm diameter

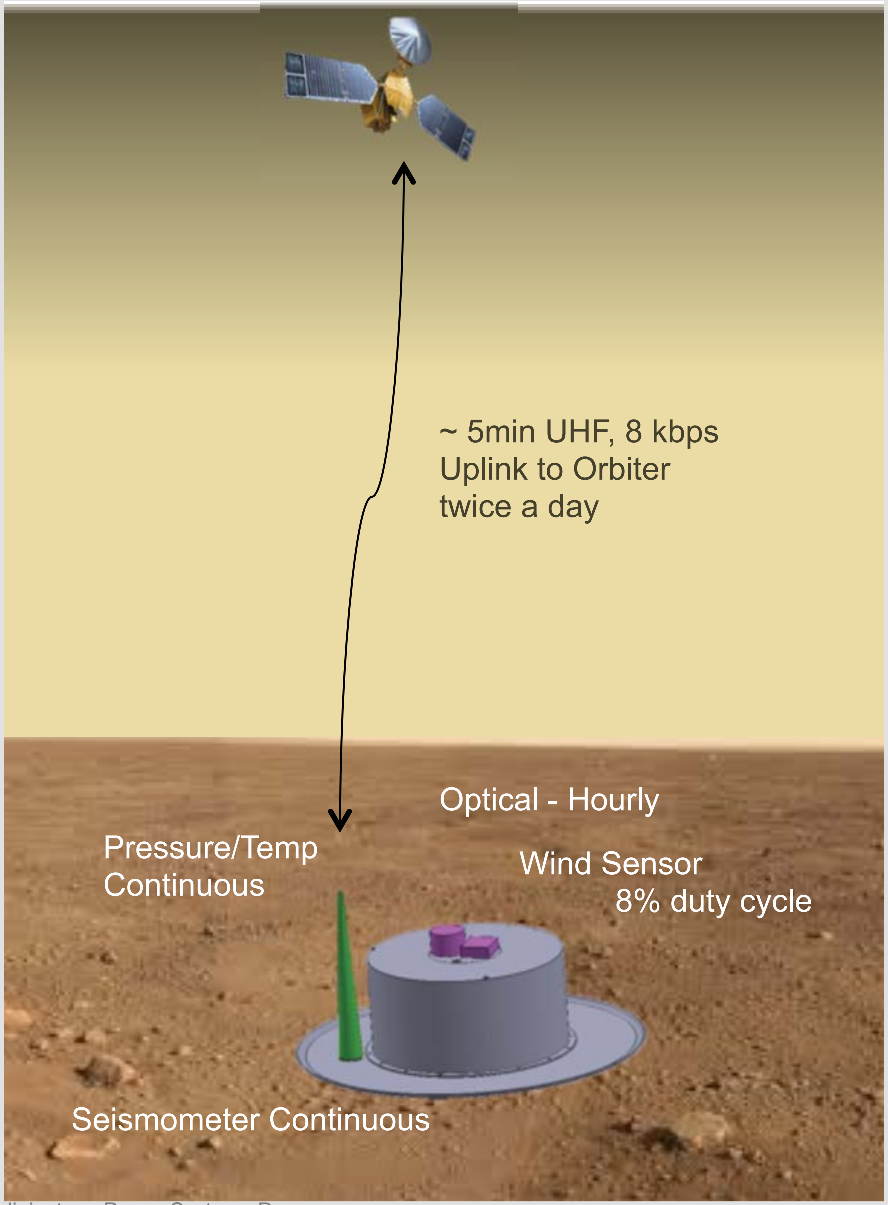
MASER EDL

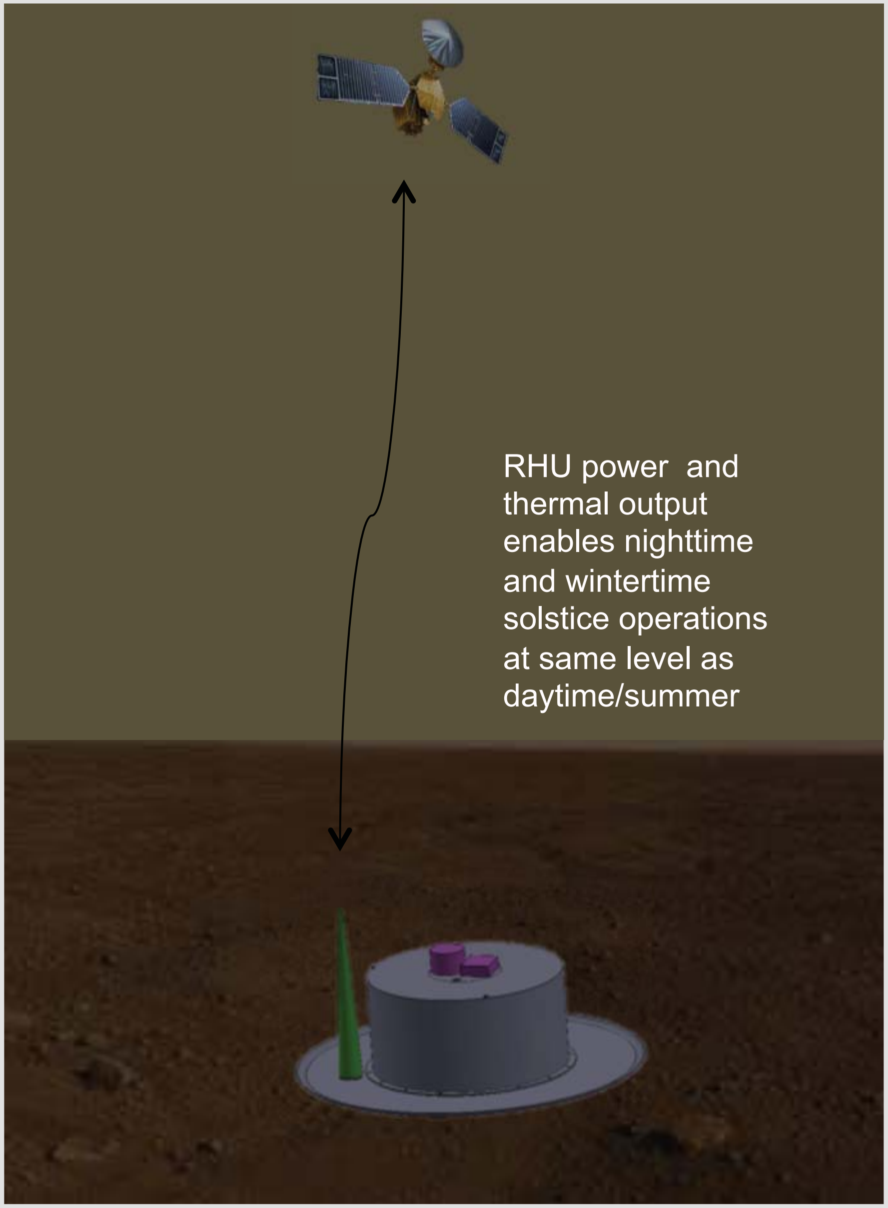

Release pilot chute
& Backshell
Acceleration
Measurements
Begin
Deploy Parachute
& Heat Shield Separation
Health
Tone back
to Orbiter
Jettison
Parachute
Impact @ 22 m/s
Deploy
Seismometer and
Checkout

MASER Network and MRO

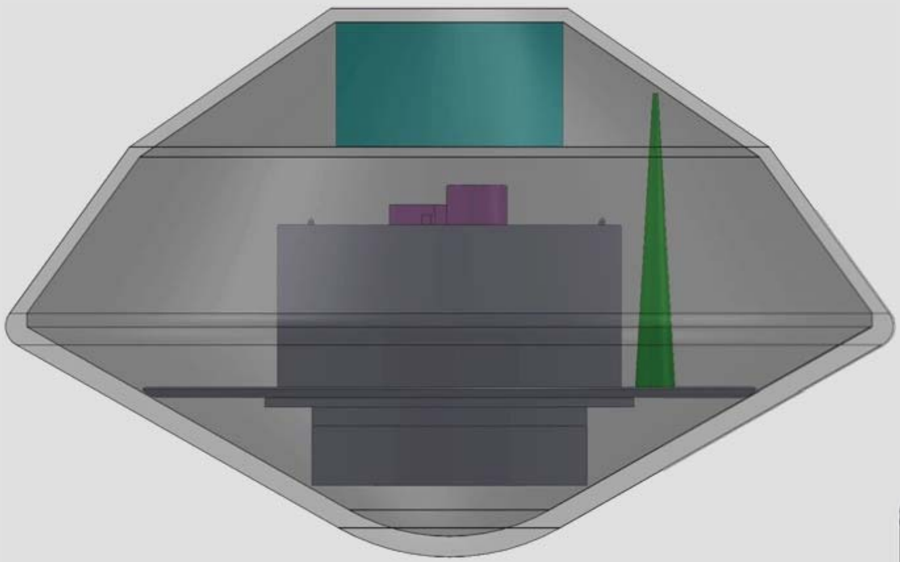


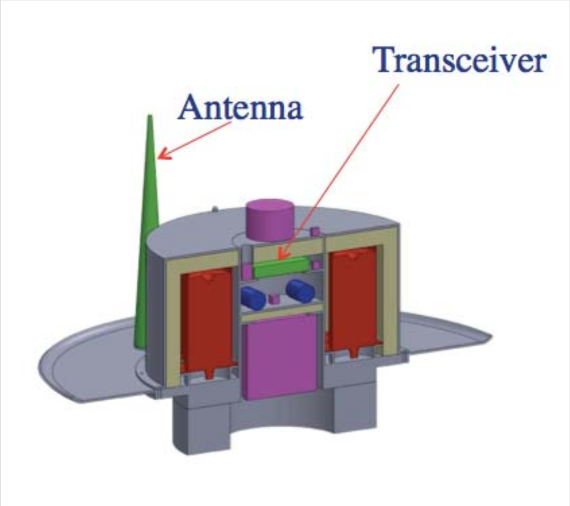
MASER Landed Operations

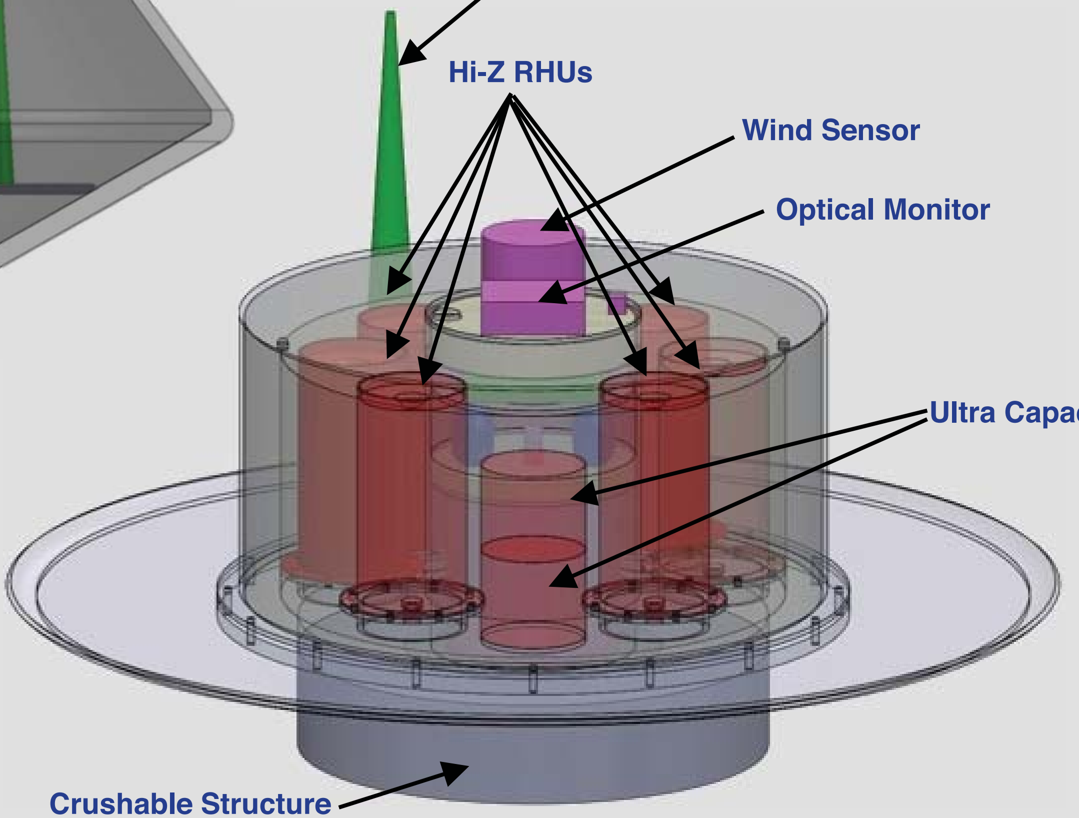




MASER Components



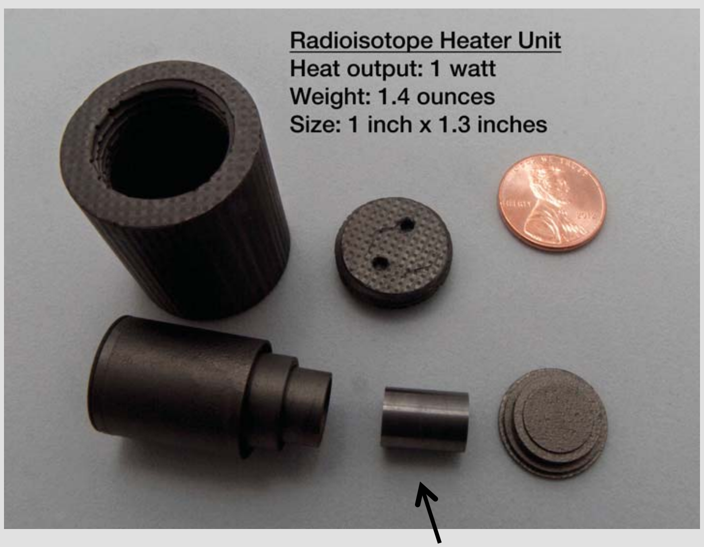




RHU Based RPS

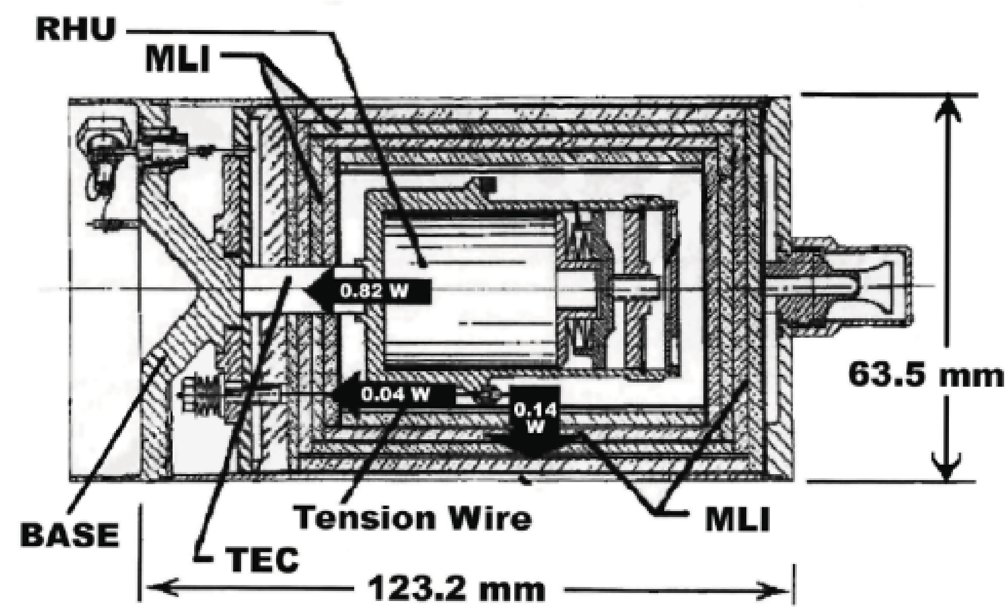
- Current RPS use GPHS modules as a heat source
- Radioisotope Heater Units (RHUs) are an alternative heat source
  - Produce 1 W of heat
  - Flight qualified and extensive heritage
- Radioisotope Heater Unit (RHU) based RPS, producing power in the 40 mW_e range

Radioisotope Heater Unit (RHU) Components



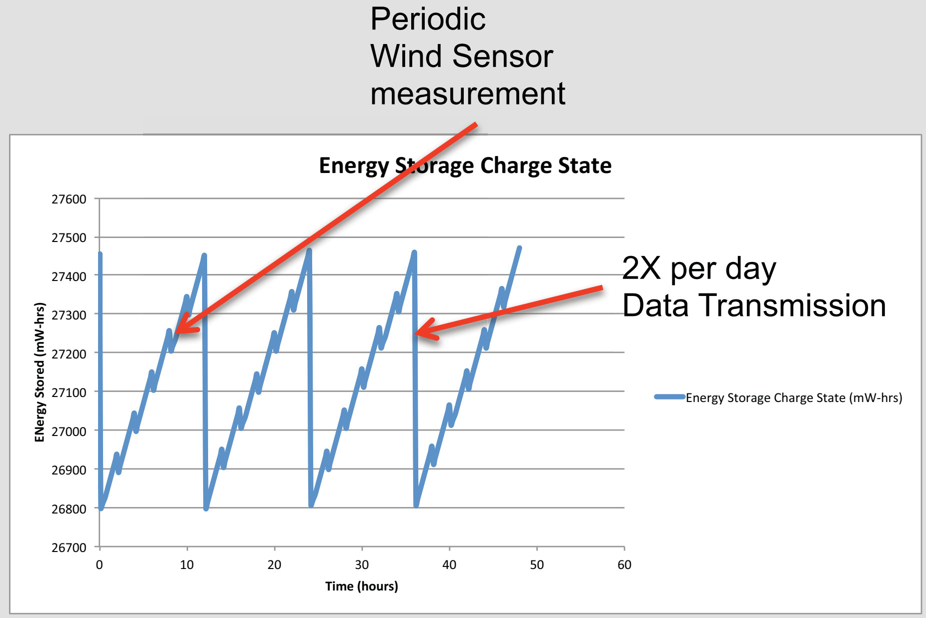
Plutonium Pellet

Hi-Z 1-RHU RHU-RTG



Power System Findings

- Power subsystem architecture:
  - Six RHU-RTGs producing 38 mW each.
  - Four ultra-capacitors (2 in series, with 2 series in parallel), to provide power at 5.4 V. Only 5% depth of discharge; this keeps voltage very steady.
- Operations are essentially steady state on a day-to-day basis
  - Avionics a continuous draw
  - Pressure sensors, temperature sensors, and seismometer operated at 100% duty cycle
  - Charge capacitors for periodic operation of wind sensors, and telecom twice a day

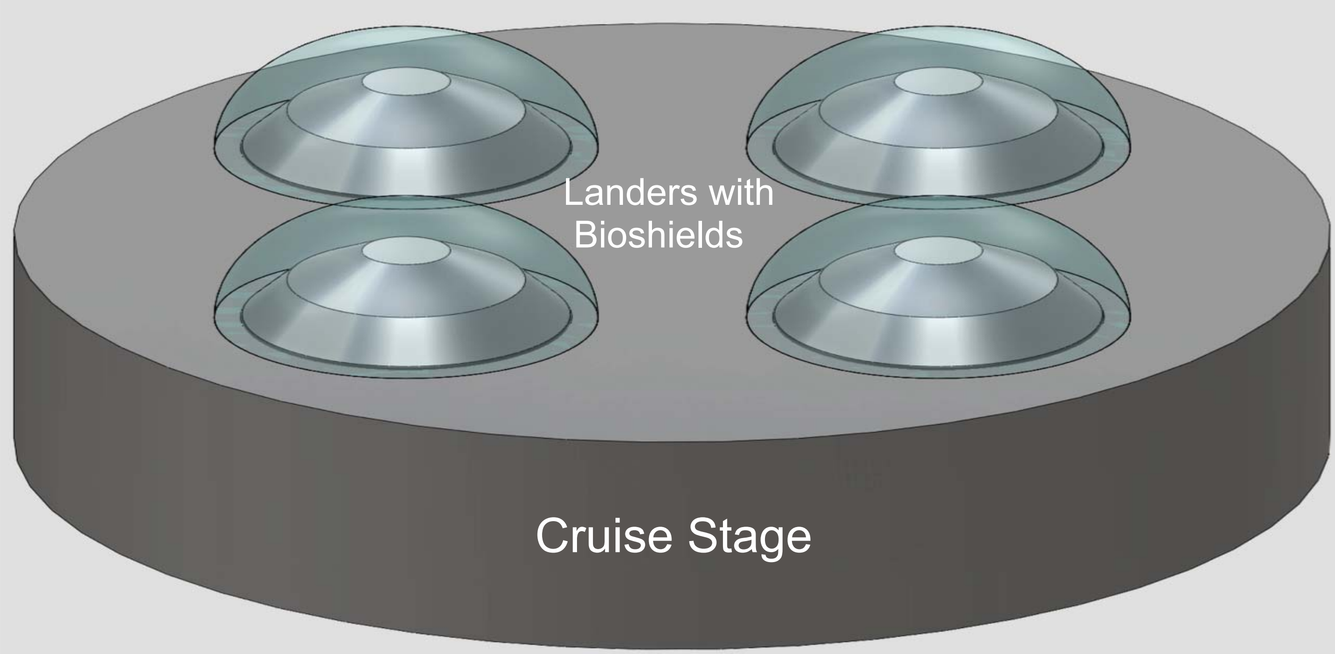


Energy Storage Profile

Energy Budget

Baseline - Six 1-RHU RHU-RPSs	Basic Power (mW)	Power with Margin (mW)	Duty Cycle	Total Energy Spent (mW-hrs)
Continuous Power for Electronics	50	65	100.0%	1560
Pressure + Temperature Sensors	2	2.6	100.0%	62
Seismometer	50	65	100.0%	1560
Wind Sensor	250	325	8.3%	650
Optical Monitor	20	26	8.3%	52
Transmitter	2500	3250	1.4%	1083
Capacitor Charge/Discharge Losses				509
Daily Energy Used				**5477**
	# RHUs	EOM Power per RHU (mW)		
Daily Energy Produced	6	38		**5472**

Final Cruise Stage Upper Deck Configuration



- Four sterilized landers encased in individual bioshield.
- Top portion of bag jettisoned prior to S/C Mars atmosphere trajectory insertion as done with Viking Landers

MASER: Study Conclusions

- Even at ¼ W of power mW RPS systems can enable hard landers that house long duration sensors in challenging environments
  - Power/heat enables night-time and year round operations
  - Power/heat simplifies in-space free flight (no solar arrays/batteries needed after carrier separation 1 Week before entry)
- The heat from the RPS combined with low temperature tolerable capacitor and electronics (-40°C) enable this mission concept
- RHU-RPS installation not typical for RTGs
  - Looked at installing at PHSF as done with RHU (e.g., Cassini, Huygens Probe)
  - Polar landing site might require Cat IVc Planetary Protection DHMR Standard (Viking Landers)
  - Future work would include more detailed ATLO conops and nuclear safety assessment

Acknowledgements

<u>Microsat Study:</u>

Brian Bairstow[1], Rashied Amini[1], Young H. Lee[1], Steven R. Oleson[2], Dr. Andrew Rivkin[3], Dr. Julie Castillo[1], Robert. L Cataldo[2] and COMPASS Team[2]

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Questions?