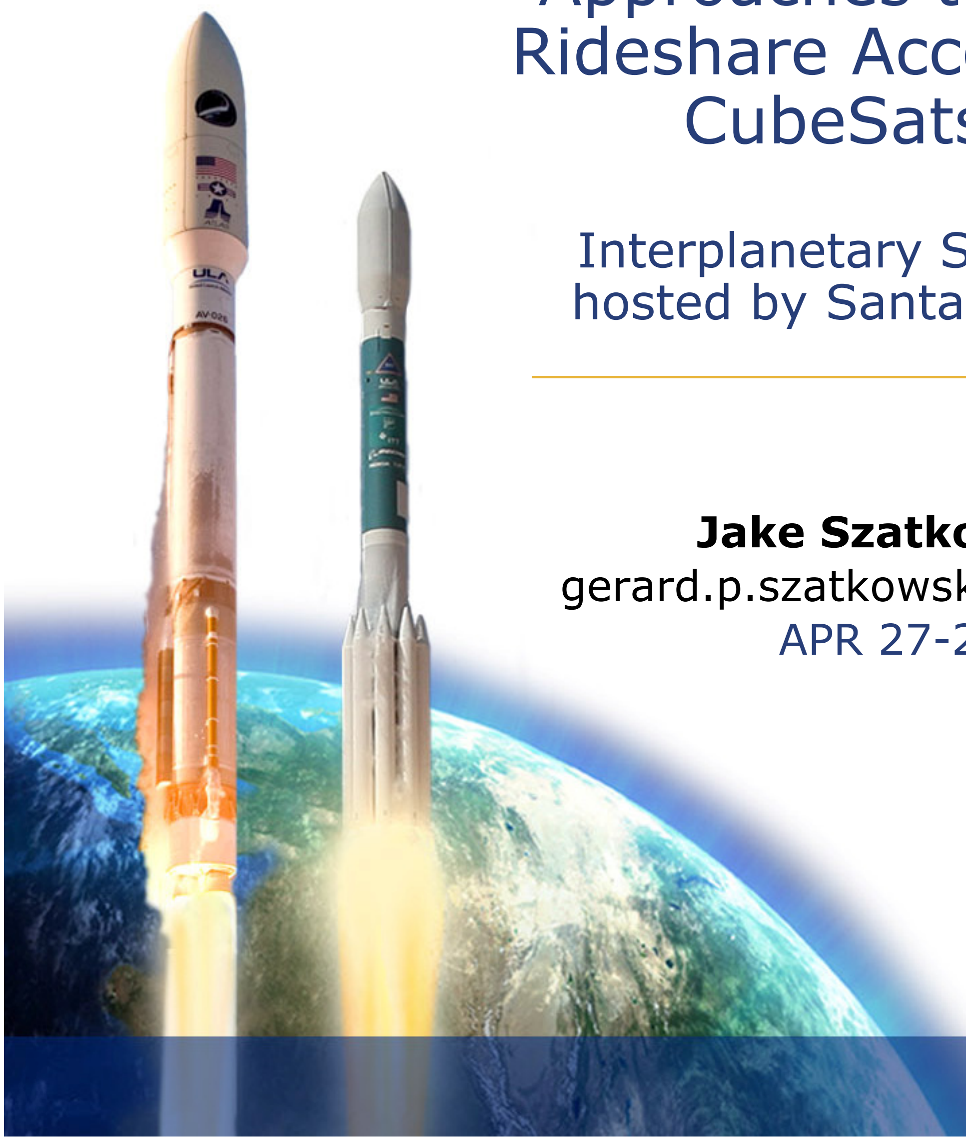
Approaches to Interplanetary Rideshare Accommodations for CubeSats/SmallSats



Interplanetary SmallSat Conference
hosted by Santa Clara University, CA

Jake Szatkowski, phd.
gerard.p.szatkowski@ULAlaunch.com

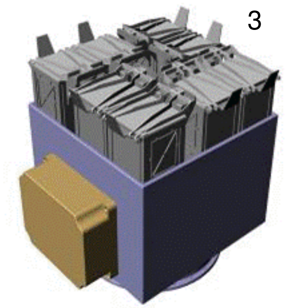
APR 27-28, 2015

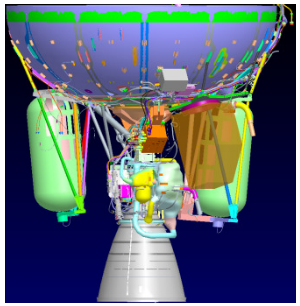
United Launch Alliance

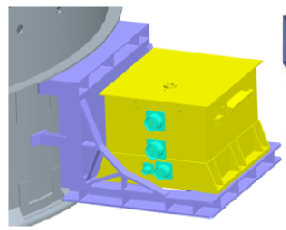
Rideshare Spectrum of Capabilities

A range of capabilities address differing size, mass, and other Requirements, while providing individual operational advantages

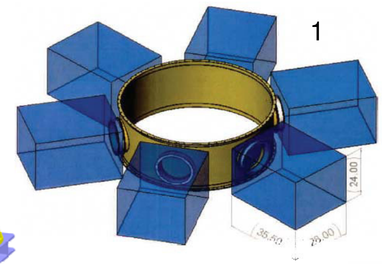
3





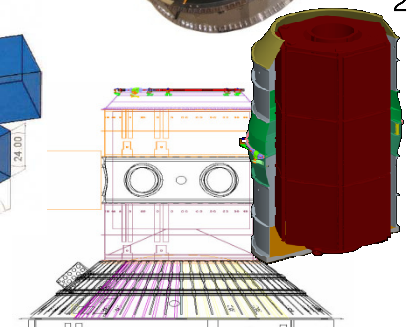


1



4

2

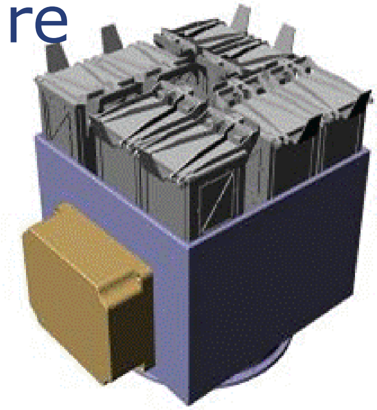


P-Pod°	**ABC**	**CAP**	**ESPA***	**IPC / A-Deck**	**DSS**
Poly PicoSat Orbital Deployer	Aft Bulkhead Carrier	C-Adapter Platform	EELV Secondary P/L Adapter	Integrated Payload Carrier	Dual Satellite System
10 kg	**80 kg**	**100 kg**	**200 kg/ea.**	**500+kg**	**5000 kg**
R&D Development	Releasable in LEO	2-4 Slots per Launch	ESPA Way Fwd Progress	Mix and Match H/W Internal and External P/L	All Flight Proven H/W
Dynamically Insignificant	Isolated from Primary S/C	Less obtrusive than ESPA	STP-1 Flew 2007	SP to 60 in. diameter	Sp to 100 in diam.
First flight ILC 2011	First flight ILC 2010	First flight Fist Flight 2010	SERB List from the DoD Space Test Program	Last Flight LRO/LCROSS	CDR 4Q 2009 ILC 2011

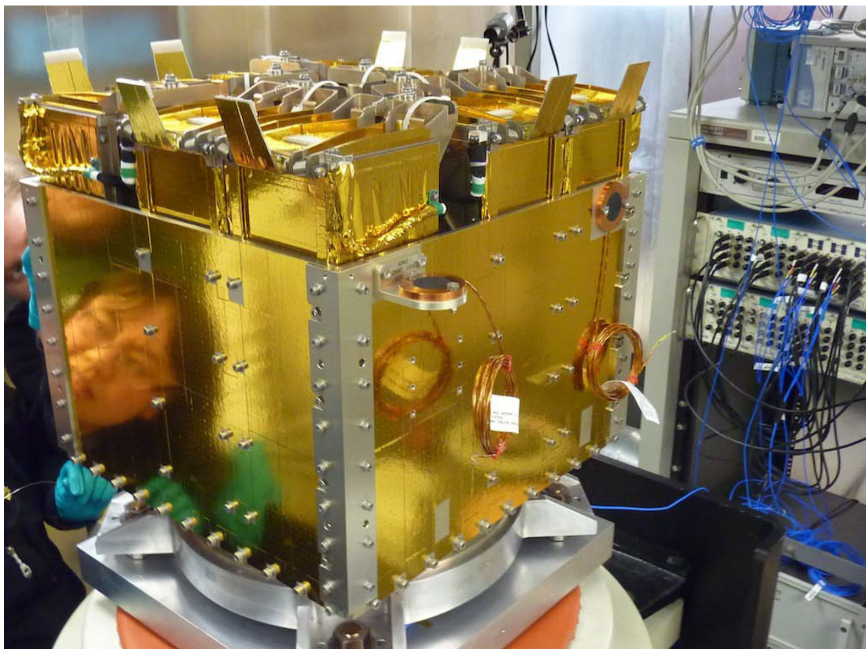
Delivering a Wide Range of Small Spacecraft with the Appropriate Conops and Technical Accommodations

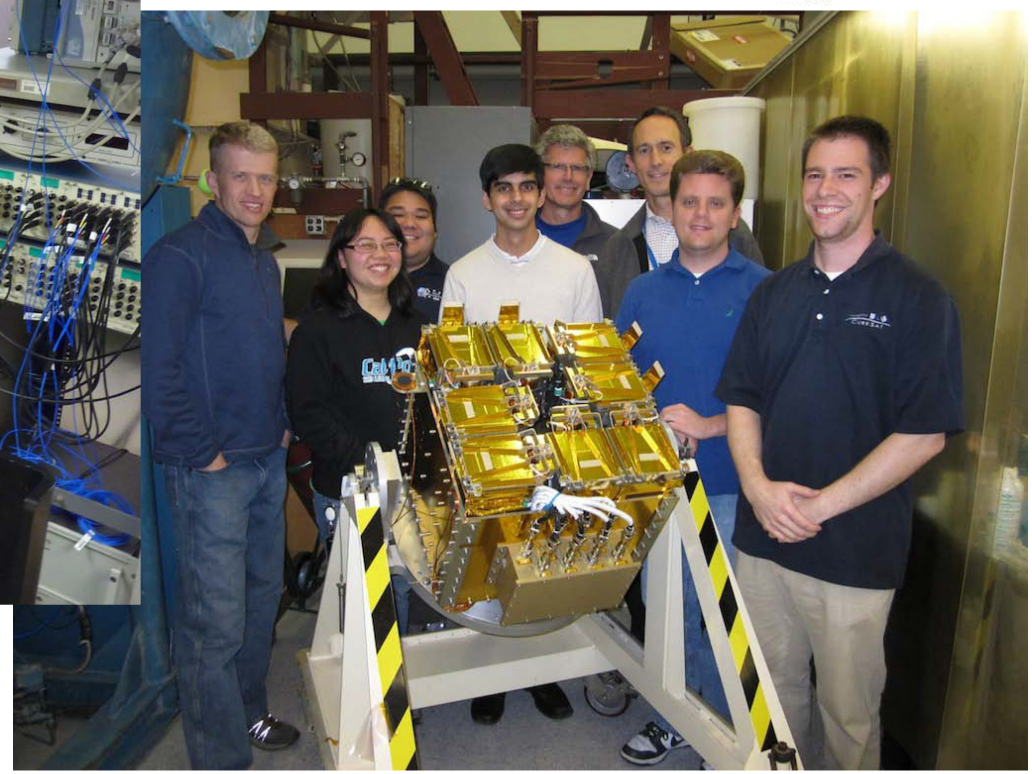
1 ESPA Graphic courtesy of CSA Engineering, Inc
2 COTSAT courtesy of NASA/AMES
3 NPSCuL courtesy of NPS
4 A-Deck courtesy of Adaptive Launch Solutions

NPSCuL Missions
picking up the pace for Rideshare



- L-36/OUTSat Launched SEP 2012 (first-flight)
- L-39/GEMSat Launched DEC 2013
- Next: L-55/GRACE, AFSPC-5/ULTRASat in CY15

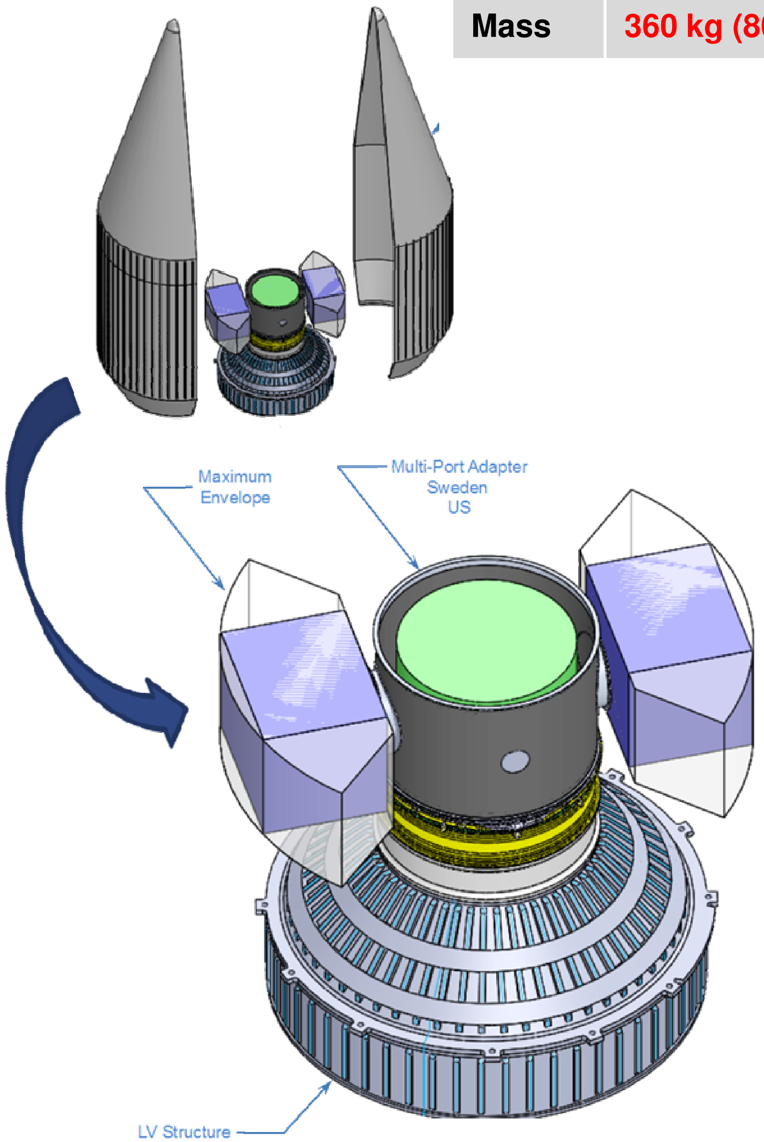


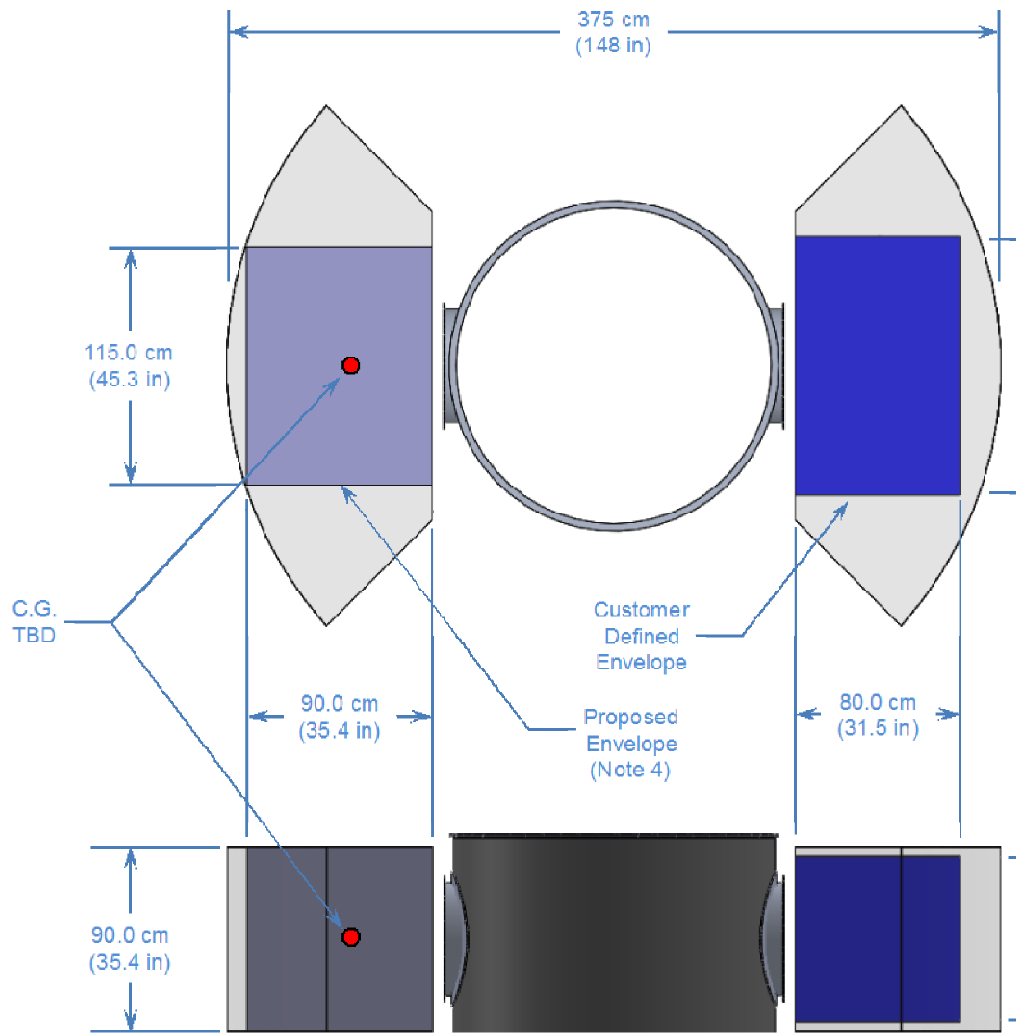


Photos courtesy Maj. Wilcox NRO/OSL

ESPA Grande Class

Mass	360 kg (800 lb)



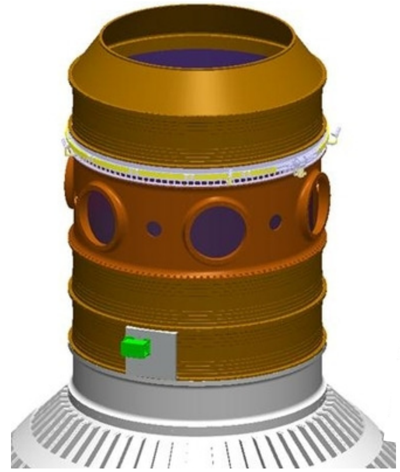


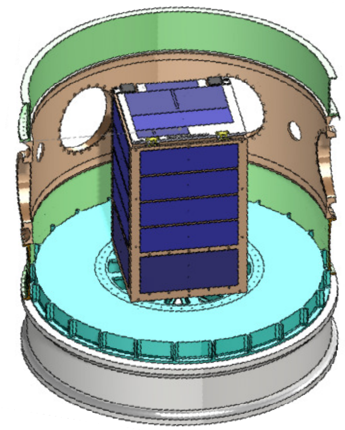
AQUILA

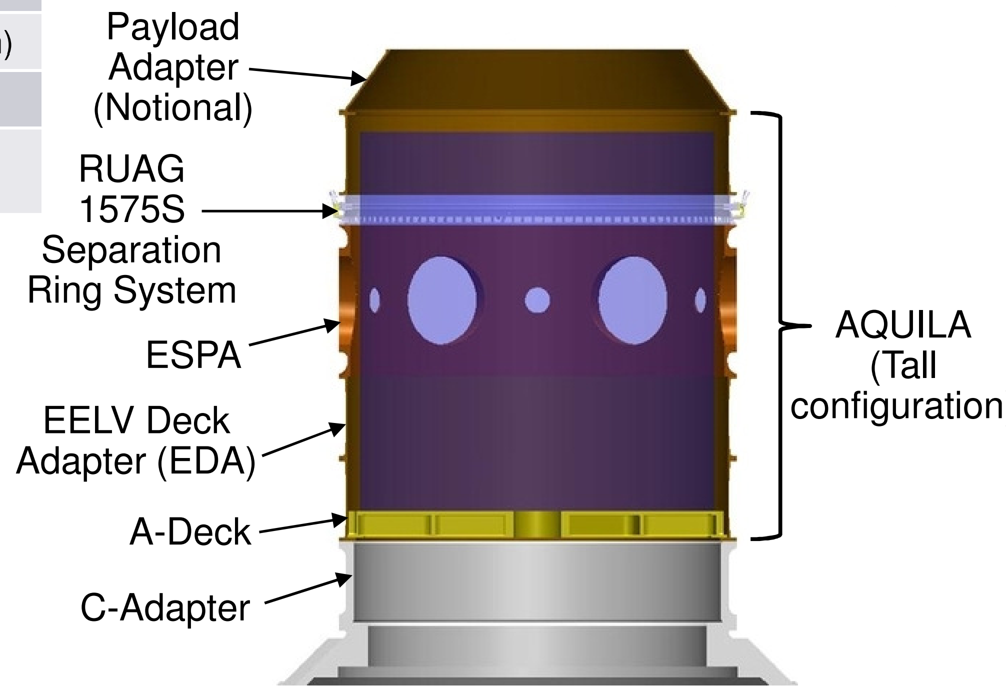
AQUILA	
Description	A flat deck and cylindrical spacers, located between the forward-end of the second stage and the primary payload
Vehicle	Atlas V, Delta IV
Capacity	Multiple payloads per AQUILA
Interface	Variable
Mass	**1,000 kg (2,200 lb)**
Volume	142-cm dia. (56-in dia.) x 152 cm (60 in)
Status	In development; CDR 04-2012
Developer	Adaptive Launch Solutions (ALS) *(Jack Rubidoux, jrubidoux@adaptivelaunch.com)*

Graphics courtesy of ALS

AQUILA modular adapters are rated to support a primary payload mass up to 6,350 kg (14,000 lb)





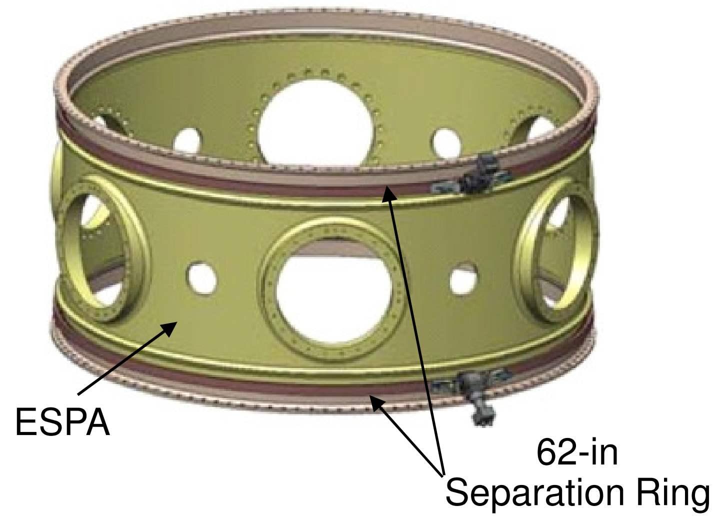


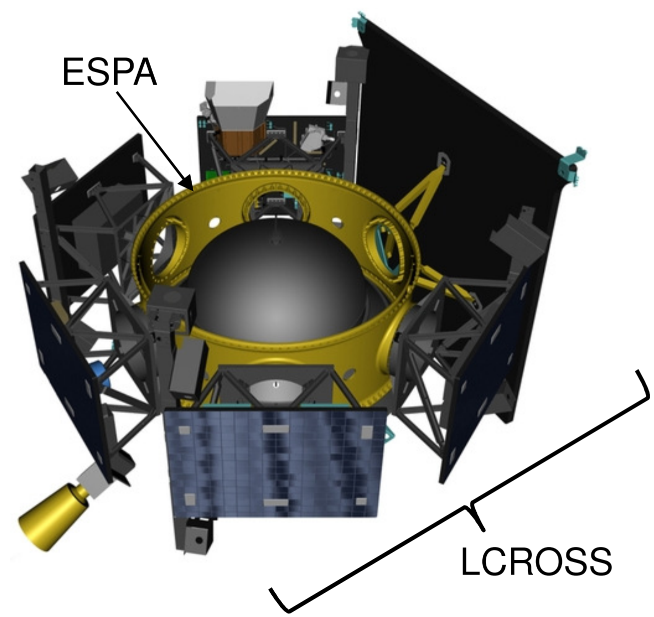
Separating ESPA

Lunar CRater Observation and Sensing Satellite LCROSS

Separating ESPA	
Description	A separating rideshare payload that uses the ESPA ring as the structural bus of the satellite
Vehicle	Atlas V, Delta IV
Capacity	Variable
Interface	62-in Bolted Interface
Mass	**1,360 kg (3,000 lb)**
Volume	350-cm dia. x 61 cm (138-in dia. x 24 in)
Status	Operational; first launch 06-2009 on LRO/LCROSS
Developer	Moog CSA Engineering *(Joe Maly, jmaly@csaengineering.com)*

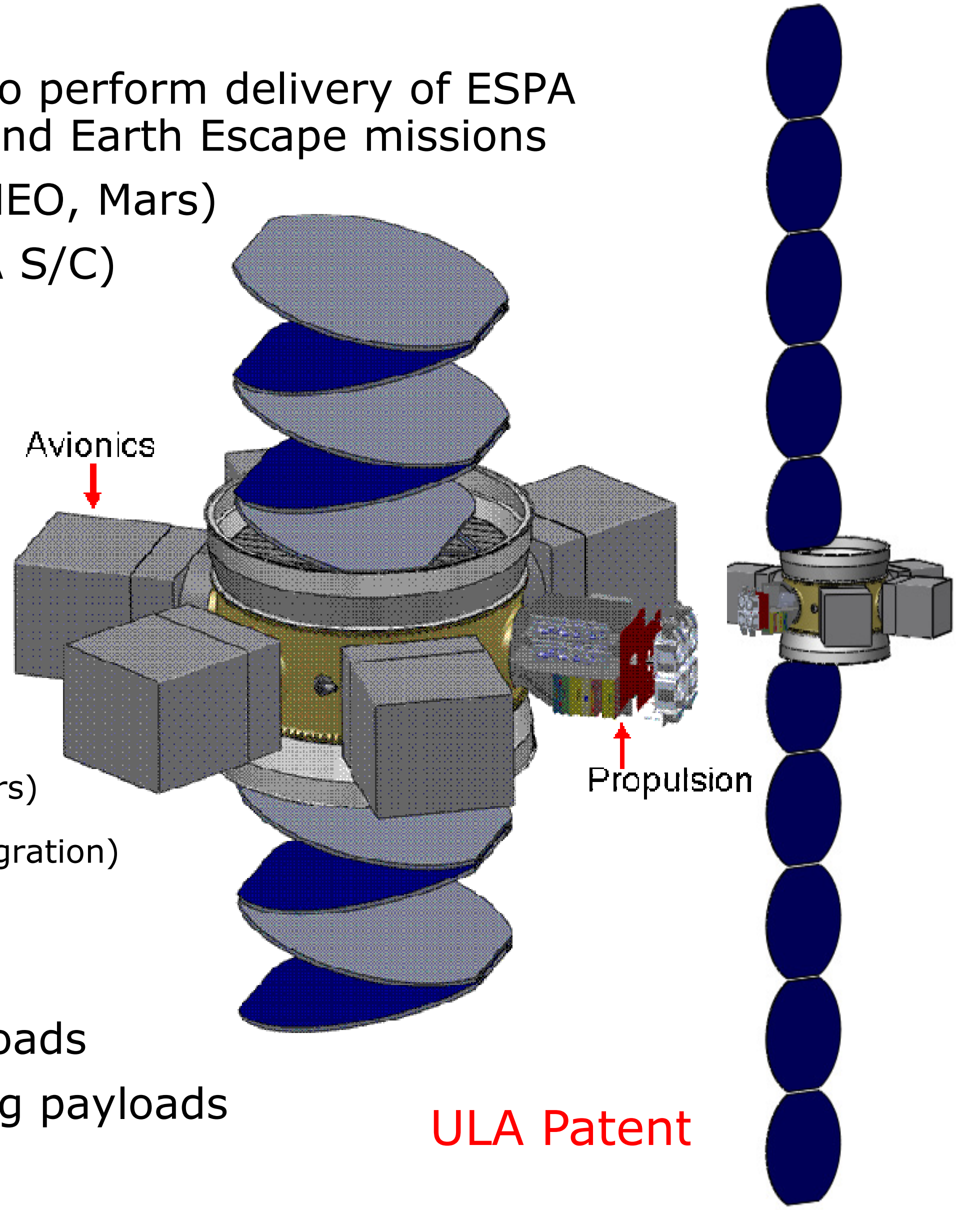
A separating ESPA can use various separation ring hardware solutions from a number of vendors to separate from the ULA launch vehicle





MULE Third Stage
(Multi-payload Utility Lite Electric)

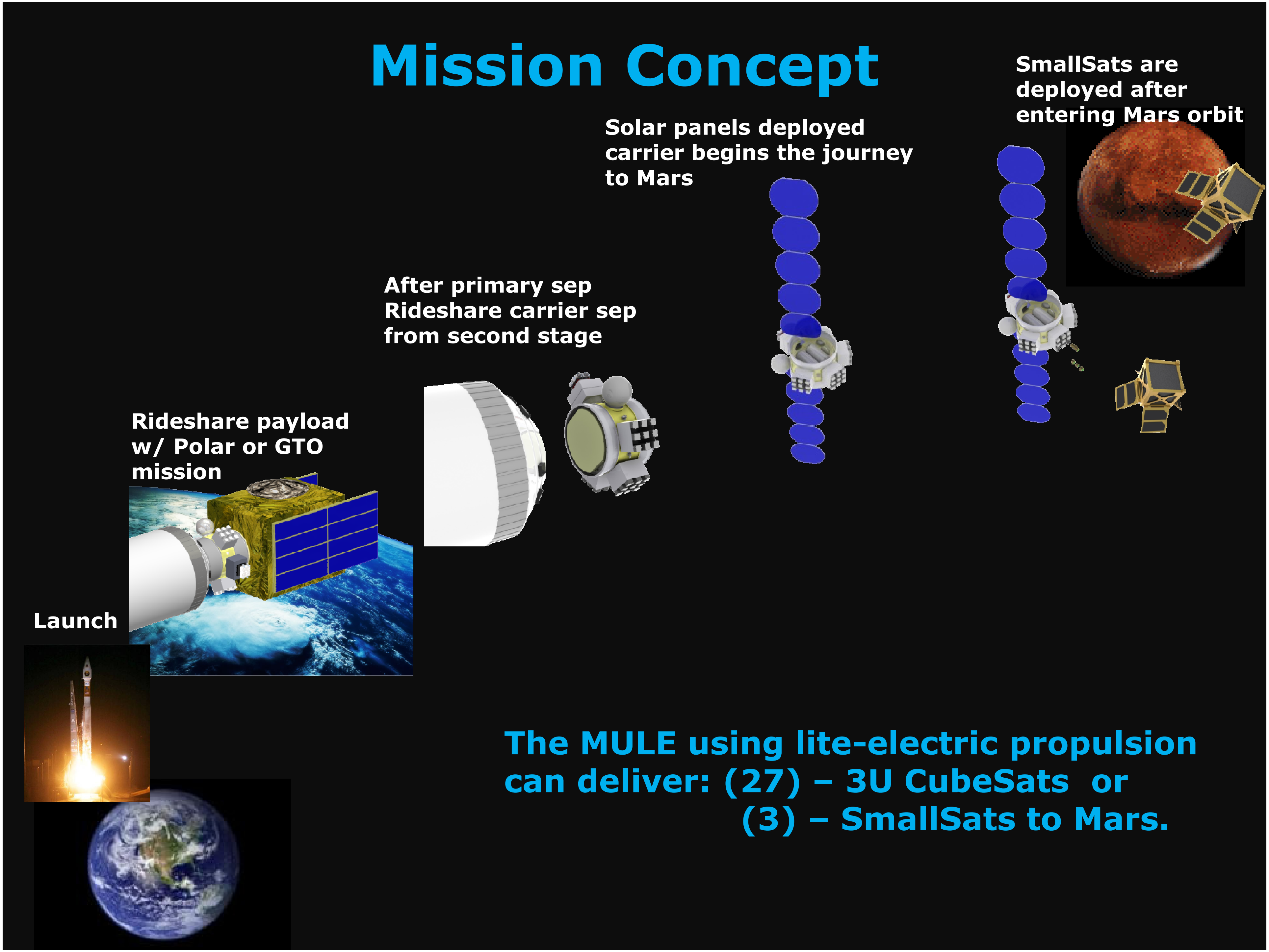
- **MULE stage** provides high deltaV to perform delivery of ESPA class payloads to a variety of orbits and Earth Escape missions
  - Delivery to Earth Escape (Lunar, NEO, Mars)
  - Delivery of a constellation (3 ESPA S/C)
  - Solar Electric propulsion
  - >10 m/s delta-V
  - Laser comm or high-gain antenna
  - On-orbit operations multi-yr
  - Potential to add another ESPA



- Co-sponsors:
  - Busek Space Propulsion (Hall Thrusters)
  - Adaptive Launch Solutions (S/C Integration)
  - Oakman Aerospace (Avionics)

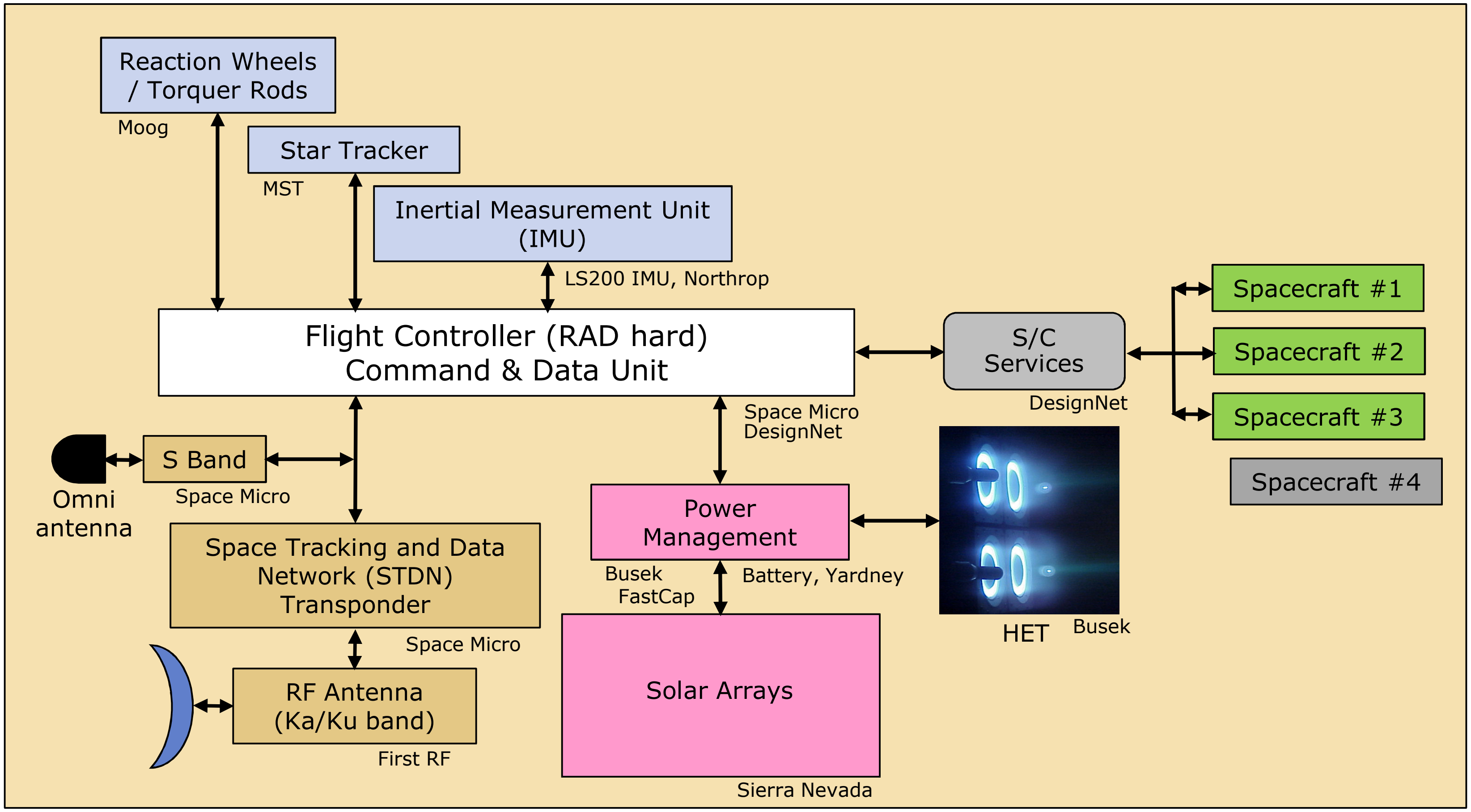
- Specs: 1400 kg wet mass w/o payloads
  2400 kg wet w/ (4) 180 kg payloads

ULA Patent

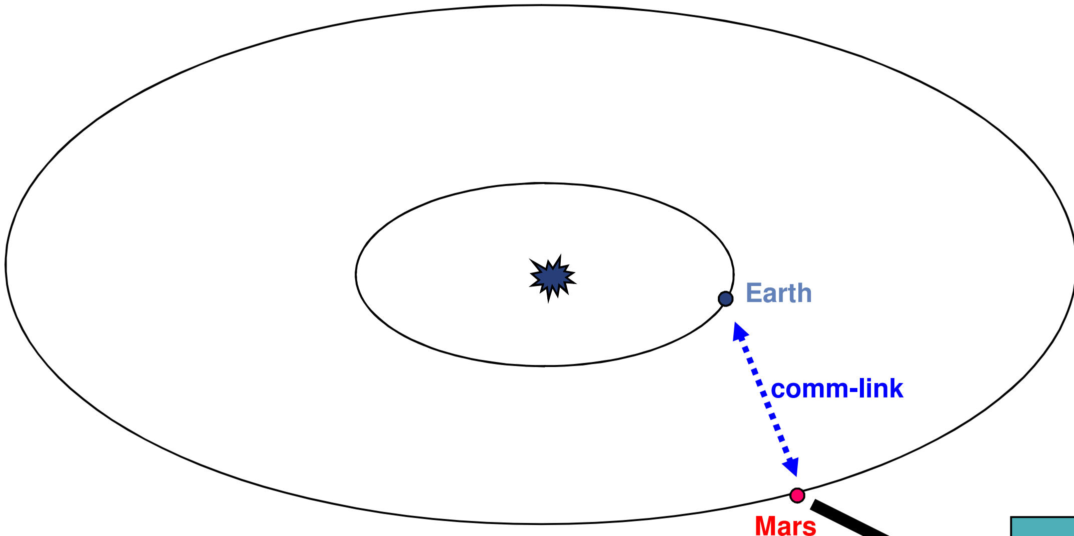

Mission Concept
SmallSats are deployed after entering Mars orbit
Solar panels deployed carrier begins the journey to Mars
After primary sep Rideshare carrier sep from second stage
Rideshare payload w/ Polar or GTO mission
Launch
The MULE using lite-electric propulsion can deliver: (27) – 3U CubeSats or (3) – SmallSats to Mars.

MULE System Architecture

- Flt-proven, Fault tolerant, RAD hard avionics suite
- ESPA-Class Spacecraft accommodations

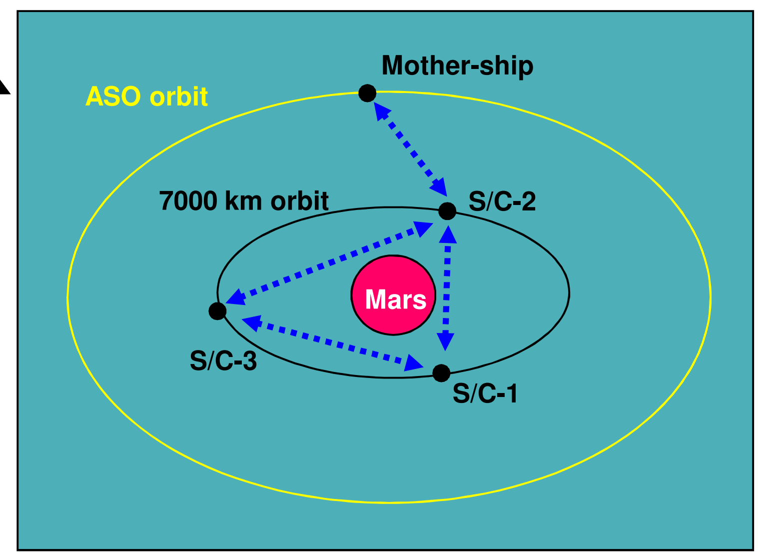


Mars “TDRSS-lite” Delivery



Con-Ops

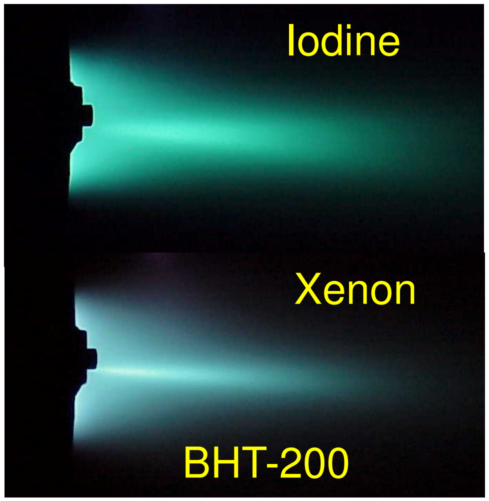
- Rideshare Earth escape
- MULE Mars Rendezvous
- Deploy ea free-flyer s/c
- Move MULE to high orbit
- Deploy High-gain antenna



Operations

- Mother-ship moves to L1 position
- MULE Stage switches power to high-gain
- Permits comm links:
  - Surface to Surface
  - Surface to Earth
  - Continuous surface observation
  - Internet-like service

Thruster Performance and Delta-V Comparison



Gas	Power (W)	Thrust (mN)	T/P (mN/kW)	Anode Isp (s)	Anode Eff (-)
I2	155	11.1	71	1110	0.39
Xe	156	11.2	72	1151	0.41
I2	211	14.3	68	1436	0.48
Xe	203	13.5	67	1394	0.46
I2	133	8.3	62	1350	0.41
Xe	134	8.0	60	1409	0.41
I2	187	12.1	65	1506	0.48
Xe	193	11.9	62	1544	0.47

Table indicate that iodine is a drop-in replacement for xenon.

It's high storage density has the potential to yield a significant increase in spacecraft delta-V, when propellant volume is restricted. This is illustrated by using the rocket equation and assuming a fixed propellant volume and dry mass. With iodine (Table 1) the delta-V increases by a factor of 2.4 with respect to Xe allowing the iodine fueled MULE to take payloads from GTO/Polar to Mars, Venus, or an Asteroid, using low-pressure, conformal, composite fuel tanks.

Gas	Units	Iodine	Xenon
Storage Density	g/cc	4.9	1.6
Specific Impulse	S	1909	1882
Propellant Mass	Kg	1225	400
Dry Mass of a typical S/C for 1500 W HET	Kg	1300	1300
Final Mass / Initial Mass	-	0.51	0.76
Delta-V	Km/s	**12.4**	5.0

Future Interplanetary Missions

- Example mission: DMSP-19 (flew APR 2014)
  - S/C wt 2559 lbs
  - Atlas 401 (4m fairing, no solids)
  - Single injection burn 460 NM circular polar
  - Disposal burn to Earth Escape
  - Un-used performance to a C3 of 0 > ~3000 lb (**1360 kg**)
  - Addition of 1 solid (+1900 kg performance)
  - Would have enable Mars MULE mission w/ 3 ESPA payloads (need **2400** kg for the MULE system wet & loaded
- Potential missions for Rideshare? (protected dates)

WR	WV	(CY16)
	DMSP	(ILC CY17-18)
	LDCM	(CY19)
	Weather FO	(CY21)
ER	GPS IIF	(CY16)
	GEO	(CY17)
	TDRS	(CY18)
	GEO	(CY20)

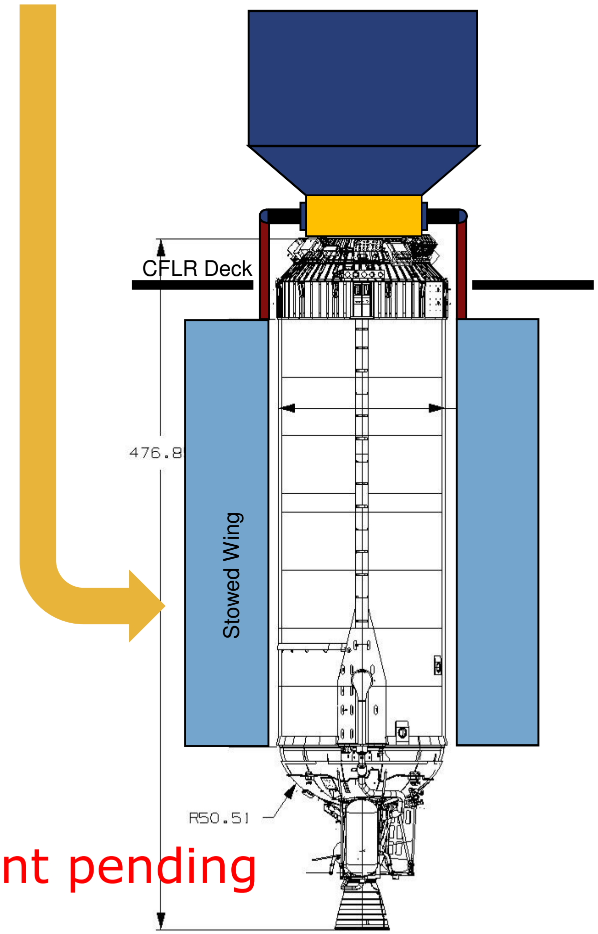
Adding Performance via SRM's

- ULA's Atlas V and Delta IV launch vehicles have multiple configurations based on the number of solid rocket motors (SRMs) flown
- For both current missions, or when designing a new rideshare mission, the addition of an SRM can provide an appreciable amount of mass capability to orbit, as shown below

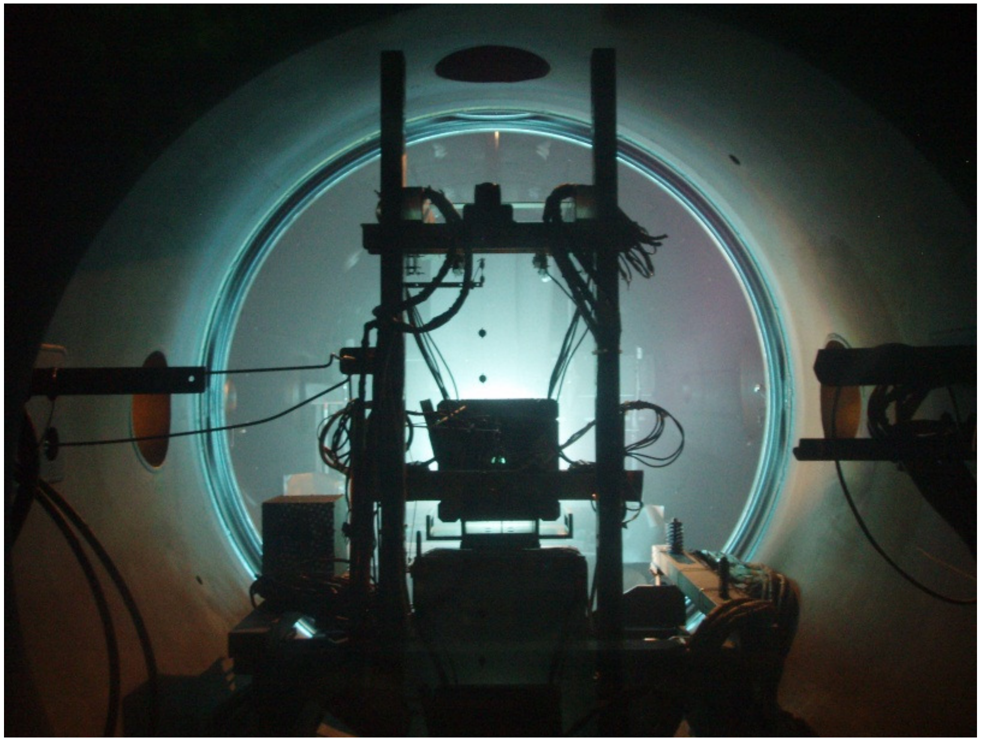
		All values are in kg					
ORBIT	**VEHICLE**	**0 SRMs**	**1 SRM**	**2 SRMs**	**3 SRMs**	**4 SRMs**	**5 SRMs**
GTO (35,786 X 185 km @ 27.0 deg)	Atlas V 4-m	- 4,750	*+ 1,200* 5,950	*+ 940* 6,890	*+ 810* 7,700		
	Atlas V 5-m	- 3,780	*+ 1,470* 5,250	*+ 1,230* 6,480	*+ 970* 7,450	*+ 840* 8,290	*+ 610* 8,900
	Delta IV 4-m	- 4,210		6,160 *+ 1,950*			
	Delta IV 5-m			- 5,080		*+ 1,810* 6,890	
LEO Polar (200 km circular @ 90 deg)	Atlas V 4-m	- 8,080	*+ 1,900* 9,980	*+ 1,160* 11,140	*+ 990* 12,130		
	Atlas V 5-m	- 6,770	*+ 2,200* 9,060	*+ 2,100* 11,160	*+ 1,720* 12,880	*+ 1,600* 14,480	*+ 1,280* 15,760
	Delta IV 4-m	- 7,690		*+ 2,840* 10,530			
	Delta IV 5-m			- 9,610		*+ 1,990* 11,600	

High Power System

- Large KW stowed config.

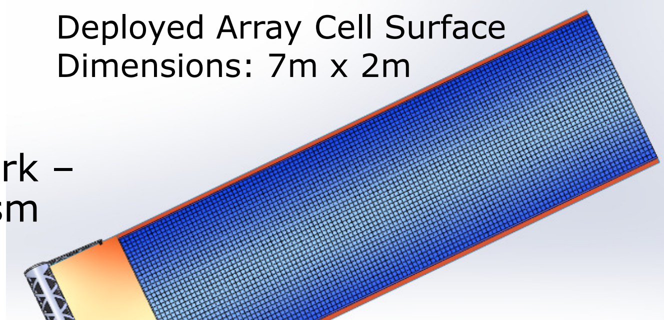


Patent pending



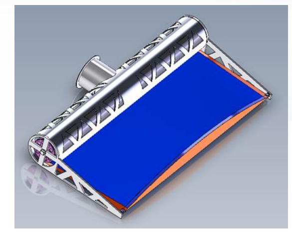
Busek 20-kW Thruster at GRC VF5

Composite Beam Roll-up Array (COBRA)



COBRA Solar Array Design

- Lenticular composite face-sheet with integrated PV network – stows rolled-up & deploys/retracts using simple mechanism
- Integral structural design provides high specific power, efficient stowage, and very low part count / cost
- Provides benefits of Rigid panel Shielding plus Flexibility / High Specific Power of blanket technologies
- Compatible with all Solar Cell technologies and Satellite Power Levels



COBRA Solar Array Performance

Metric	Performance		
PV Technology	ZTJ Luna	IMM4	IMM6
Specific Power	177 W/kg	236 W/kg	302 W/kg
Stowed Specific Volume	36 kW/m^3	38 kW/m^3	43 kW/m^3
Power (two wings)	8.8 kW BOL	9.4 kW BOL	10.5 kW BOL
Voltage	300V	300V	300V
Deployed dimensions	2m x 7m	2m x 7m	2m x 7m
Deployed Frequency	.7 Hz	.8 Hz	.9 Hz

alliance spacesystems

What does it mean for Interplanetary Missions?

- Some of our missions (particularly polar ones) do Earth-escape disposal of the upper stage
- Some of the missions have fairly large margins
- It is possible to add up to 5 solids boosters (1000 lbs margin ea)
- It is possible to raise the apogee to beyond L1 for separation
- The primary will dictate the time of launch.
- However, if a Lunar/Mars exploration s/c could loiter long enough it could sync with orbital maneuvering for insertion.

- ULA can work to help broker rideshares with primary customers
- ULA can assist for specific mission applications
- ULA can assist in schedule/milestone planning
- New R&D developments are in-work
  - New disposal techniques that add margin coming on-line
  - New heavy solar array system available
  - New extended mission systems in development
  - New Vulcan rocket capabilities anticipated
  - New ACES upper stage capabilities anticipated

United Launch Alliance

BUSEK Space Propulsion and Systems

MULE Summary

- MULE stage built on ESPA ring and standard ULA separation system
- Total mass of the MULE stage with Primary (14,055lb SV) is ~19,500lb
- ~5kW solar array
- 4 of Busek 1.5kW thrusters on 2 gimbals
- GTO to Lunar transit time <140 days
- Mars transit <3 years
- ULA has been working w/ Busek Propulsion on the Hall Effect thruster
  - Iodine I_{sp} = 1506 for I_2 at 250 V, 200 W
- Iodine solution launches as a solid in lite-wt composite tank and sublimates with a low power heater, thus eliminating the need for heavy pressurized tanks
- Minimum development/delivery time first flight ~3 years
- EP Upper stage first-flight cost (including NRE) <$50M
- Re-flight unit <$30M
- No significant technical challenge