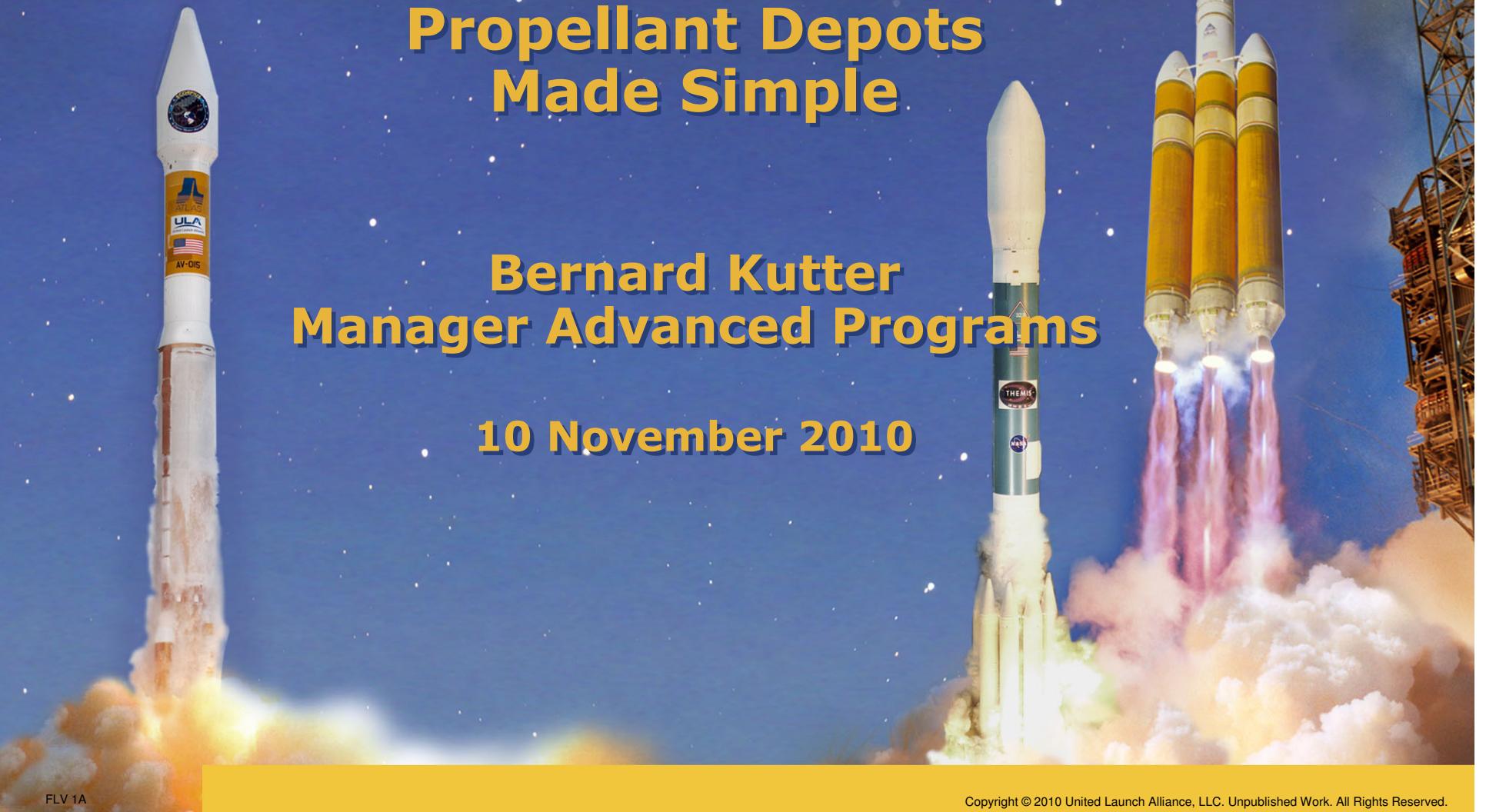




# Propellant Depots Made Simple

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Manager Advanced Programs

10 November 2010





# Discussion Overview

- Brief ULA Background
- “Simple Depot” Concept
- Depot Operations
- Brief Mission Use Examples



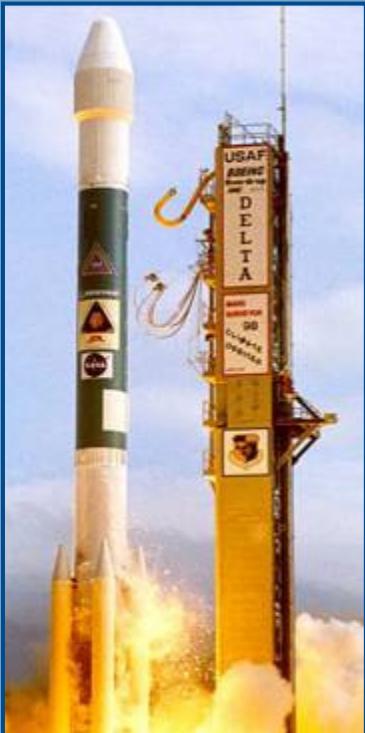
# United Launch Alliance (ULA)

- Two world-class launch systems
  - Lockheed Martin's Atlas program (Atlas V)
  - The Boeing Company's Delta program (Delta II, Delta IV)
  - 50/50 joint Boeing/Lockheed Martin ownership
- Strengthened mission success
- ULA's charter
  - Provide launch services on an equal access to all
    - No discrimination
  - Support commercial launch services through Lockheed Martin and Boeing Commercial launch services

***ULA Can Not Develop/Operate Satellites  
Including Propellant Depots***

# Launch Vehicle Products

## Medium Class



**Delta II**

## Intermediate Class



**Delta IV**



**Atlas V**

## Heavy Class



**Delta IV Heavy**

*A Full Range of Capabilities to All Orbits*

# ULA Cryogenic Upper Stages

- ULA has 3 operational LO<sub>2</sub>/LH<sub>2</sub> upper stages
  - Represents most of America's orbital cryogenic experience



	Centaur	Delta IV stage 2	Delta IV stage 2
Diameter	3m	4m	5m
Propellant	21 mT	21 mT	27 mT
Mass Fraction	0.90	0.87	0.87
# Flights	194	12	4



# 100% Mission Success

## ULA Launch History

NROL-21 - 12/14/06 - Delta II  
THEMIS - 2/17/07 - Delta II  
STP-1 - 3/8/07 - Atlas V  
COSMO-1 - 6/7/07 - Delta II  
NROL-30 - 6/15/07 - Atlas V  
Phoenix - 8/4/07 - Delta II  
Worldview-1 - 9/18/07 - Delta II  
Dawn - 9/27/07 - Delta II  
WGS-1 - 10/10/07 - Atlas V  
GPS IIR-17 - 10/17/07 - Delta II  
DSP-23 - 11/10/07 - Delta IV  
COSMO-2 - 12/8/07 - Delta II  
NROL-24 - 12/10/07 - Atlas V  
GPS IIR-18 - 12/20/07 - Delta II  
NROL-28 - 3/13/08 - Atlas V  
GPS IIR-19 - 3/15/08 - Delta II  
ICO G1 - 4/14/08 - Atlas V  
GLAST - 6/11/08 - Delta II  
OSTM - 6/20/08 - Delta II  
GeoEye - 9/6/08 - Delta II  
COSMO-3 - 10/24/08 - Delta II  
NROL-26 - 1/17/09 - Delta IV

NOAA-N' - 2/6/09 - Delta II  
Kepler - 3/6/09 - Delta II  
GPS IIR-20 - 3/24/09 - Delta II  
WGS-2 - 4/3/09 - Atlas V  
STSS ATRR - 5/5/09 - Delta II  
LRO/LCROSS - 6/18/09 - Atlas V  
GOES-O - 6/27/09 - Delta IV  
GPS IIR-21 - 8/17/09 - Delta II  
PAN - 9/8/09 - Atlas V  
STSS Demo - 9/25/09 - Delta II  
WorldView-2 - 10/8/09 - Delta II  
DMSP F18 - 10/18/09 - Atlas V  
Intelsat-14 - 11/23/09 - Atlas V  
WGS-3 - 12/5/09 - Delta IV  
WISE - 12/14/09 - Delta II  
SDO - 2/11/10 - Atlas V  
GOES-P - 3/4/10 - Delta IV  
OTV-1 - 4/22/10 - Atlas V  
GPS IIF SV-1 - 5/27/10 - Delta IV  
AEHF-1 - 8/14/10 - Atlas V  
NROL-41 - 9/20/10 - Atlas V  
COSMO-4 - 11/5/10 - Delta II

National Security

NASA/Civil

Commercial

## Most Recent Launches



**Atlas V**  
**NROL-41**  
**9/20/10**



**Delta II**  
**COSMO-4**  
**11/5/10**

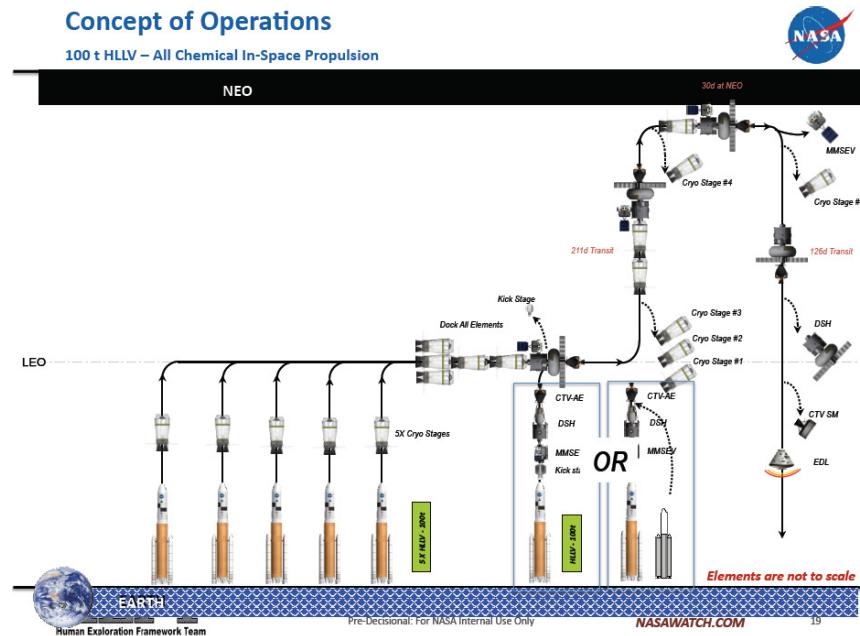


**Delta IV**  
**GPS IIF SV-1**  
**5/27/10**

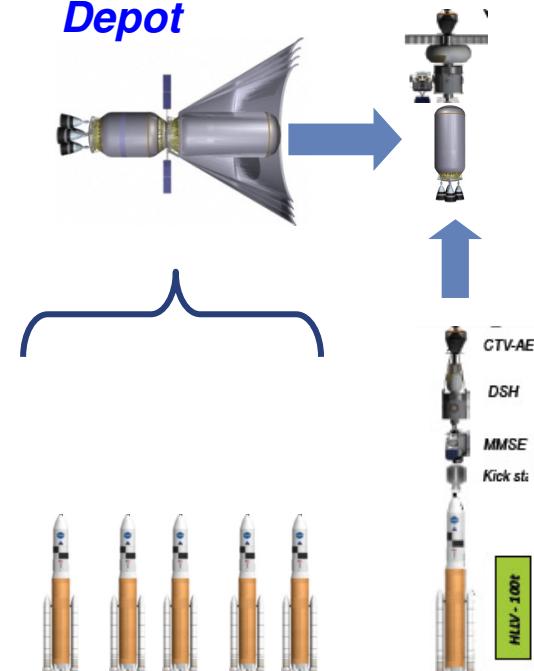
# Why Propellant Depots

- Propellant depots ease aggregation of elements
  - Beneficial with all launch vehicle performance levels

*Cryo Prop Stage Launch  
HEFT 1 DRM 4 all cryo option*



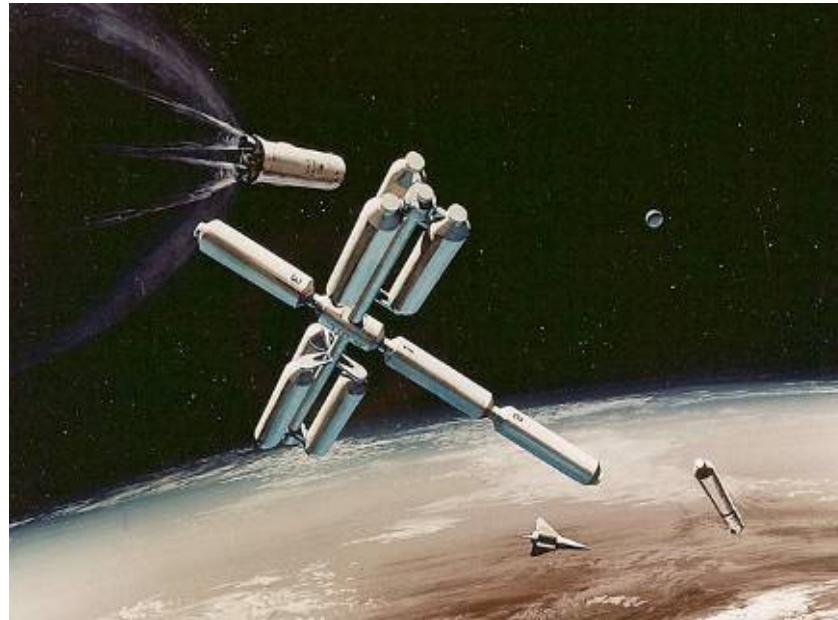
*Propellant  
Depot*



***Propellant Depots Simplify Beyond LEO Exploration***

# Historic Depot Paradigm

- Propellant Depot as a Space Station
  - Numerous launches
  - On orbital assembly
  - Zero-boil-off
  - Zero-G cryogenic fluid management (CFM)



***Assumed Depot Complexity has Effectively Prevented Depot Deployment for 5 Decades***

# Simple Depot Concept

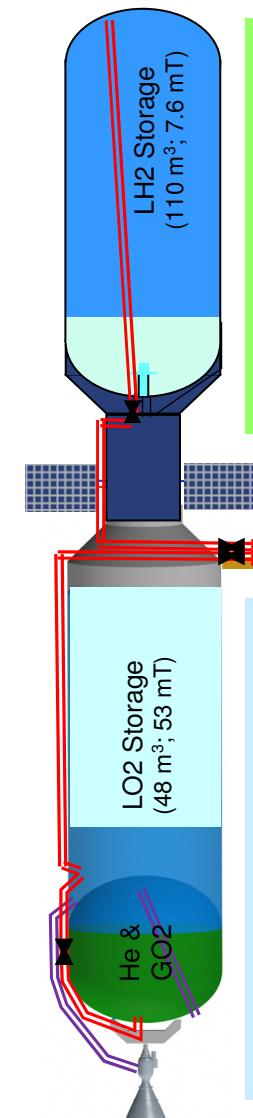
- Simple depot side steps historic barriers
  - Single unit, single launch, no orbital assembly
  - Settled CFM (Transverse spin)
  - Simplified thermal management
  - H<sub>2</sub> boil-off for station keeping
- Key cryo storage principles
  - Minimize penetrations
  - Minimize surface area
  - Segregate cold-hot elements



Atlas 551 Launch



↑ Mission Module  
↓



↑  
**LH<sub>2</sub> Module**  
**L=16.3m**  
↓

↑  
**Centaur**  
**LO<sub>2</sub> Module**  
**L= 9.6m**  
↓

***NASA Should Lead Propellant Depot Development***

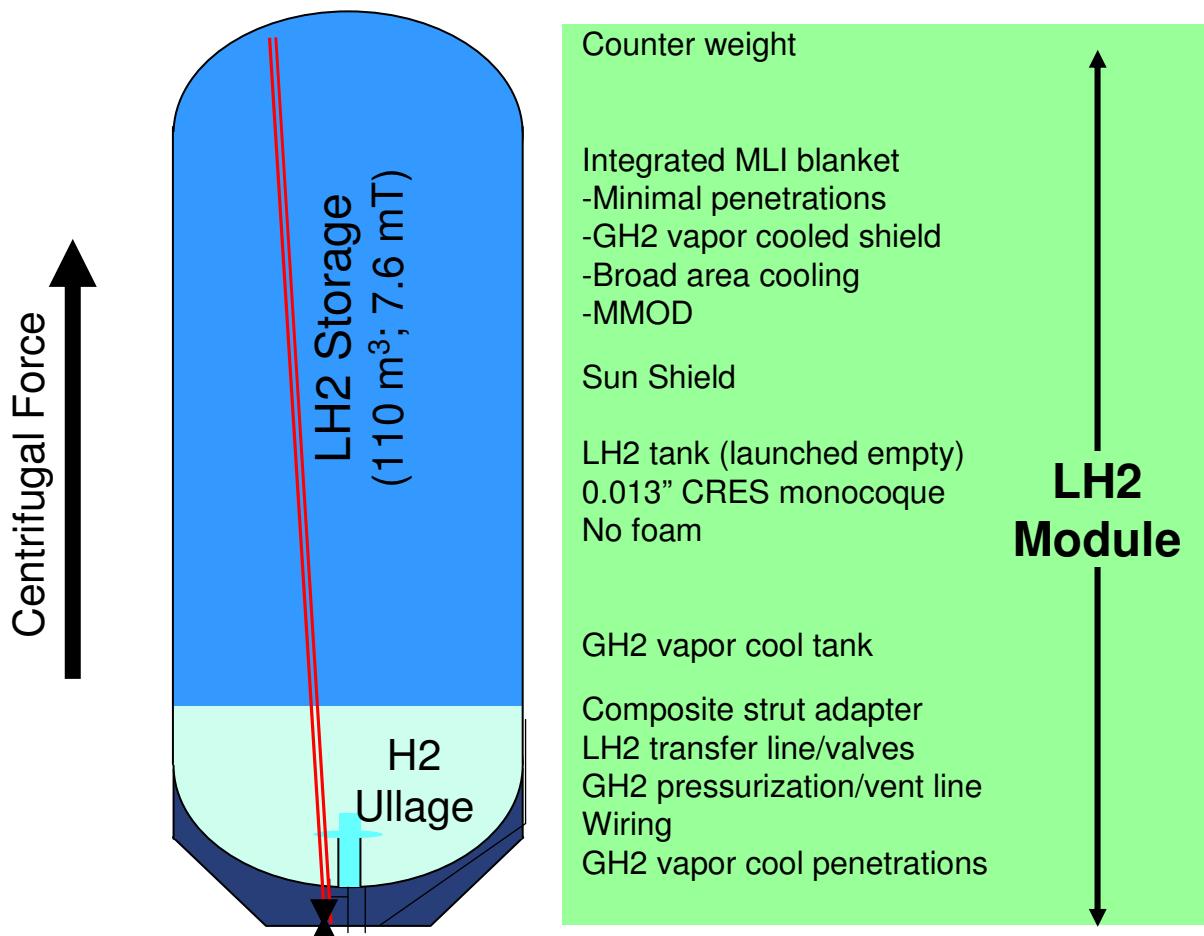


# Historic Cryogenic Storage

Program	Cryogen	Company	Tank capacity (kg)	Operating temp (K)	Life-time (mo)	Flow-rates per day (%)
Gravity probe-B • SMD/EDD	Superfluid helium (SFHe)	LMC	334	1.8	16	0.17%
	SFHe		29	1.8	2	1.34%
SHED	SFHe	LMC	29	1.8	30	0.09%
WIRE	Solid hydrogen	LMC	4	12	5.4	0.49%
SPIRIT III	Solid hydrogen	LMC	85	9.5	10	0.264%
CLAES	Solid hydrogen	LMC	85	10.4	21.4	0.15%
CLAES (2-stage) (Post Challenger)	Solid Neon	LMC	449	14	19.8	0.16%
	Solid CO2		340	125	25	0.13%
Extended life cooler (ELC)	Solid methane	LMC	150	65	66	0.04%
	Solid ammonia		73	145	64.9	0.07%
Long-life cooler (LLC) (2-stage)	Solid methane	LMC	91	65	44.9	0.07%
	Solid ammonia		42	145	40.4	0.08%
IRAS	SfHe	BATC	70	1.7	10	0.32%
COBE	SfHe	BATC	83	1.5	49	0.07%
Spitzer	SfHe	BATC	45	1.3	66	0.05%
HTTA	Liquid hydrogen	Beech	446	20	150	0.022%
OTTA	Liquid Oxygen	Beech	7186	90	150	0.022%
		BATC				
Power Reactant Storage Assy (PRSA)1	ScH2	BATC	42	20-83	0.5	~7%
	ScO2		354	90-211	0.5	w/ heaters
PRSA2	ScO2	BATC	354	90-211	14.8	0.22 % s
PRSA Enhanced	ScO2	BATC	354	90-211	38.4	0.0085 %
HALE	Liquid hydrogen	BATC	426	20	5.1	19.6% SOFI
Centaur	Liquid hydrogen & oxygen	ULA	20,900	20 & 100	Hours	2.0%

***Efficient Cryogenic Storage Already Demonstrated  
Need to Develop Large Scale, Mass Efficient Storage***

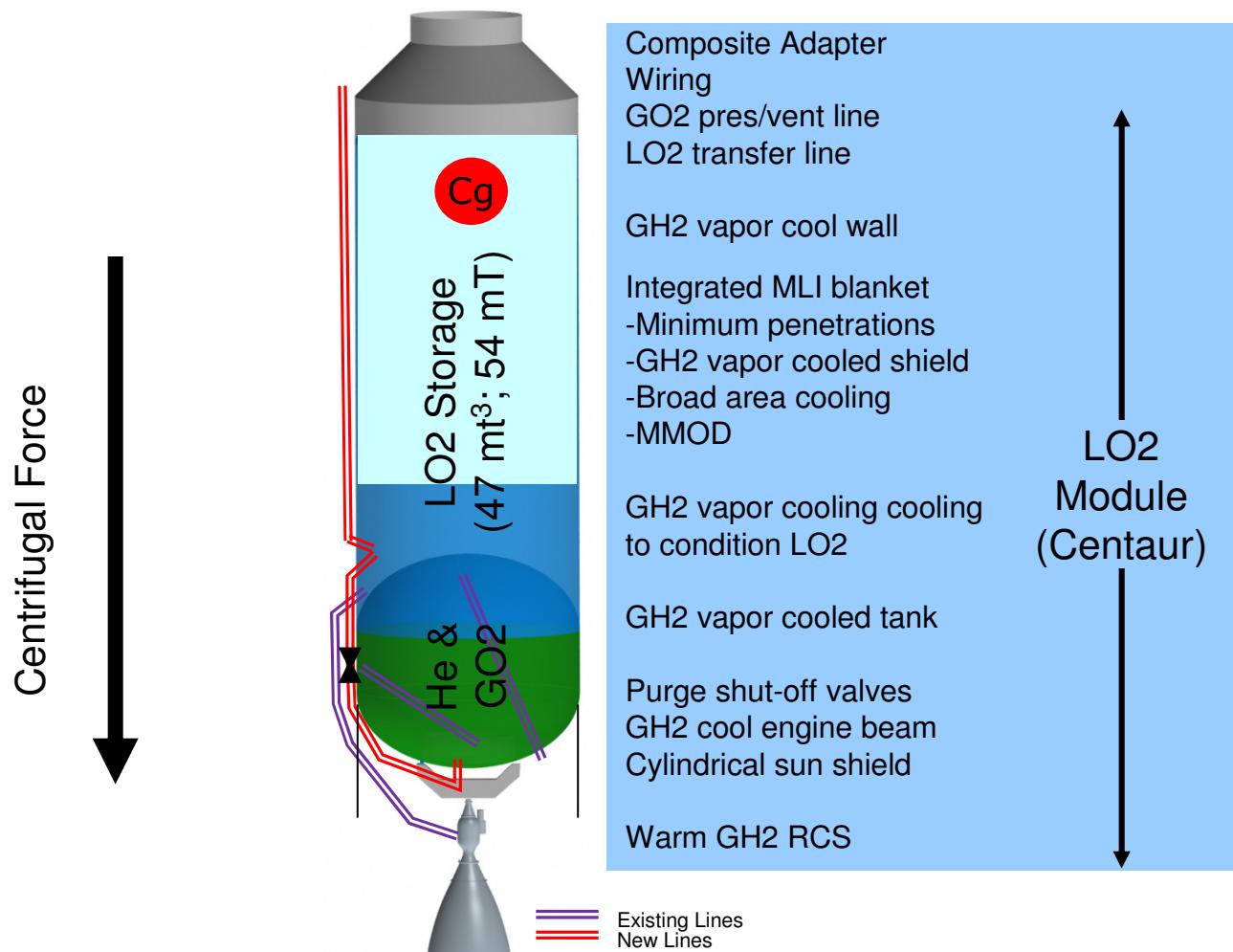
# LH<sub>2</sub> Module



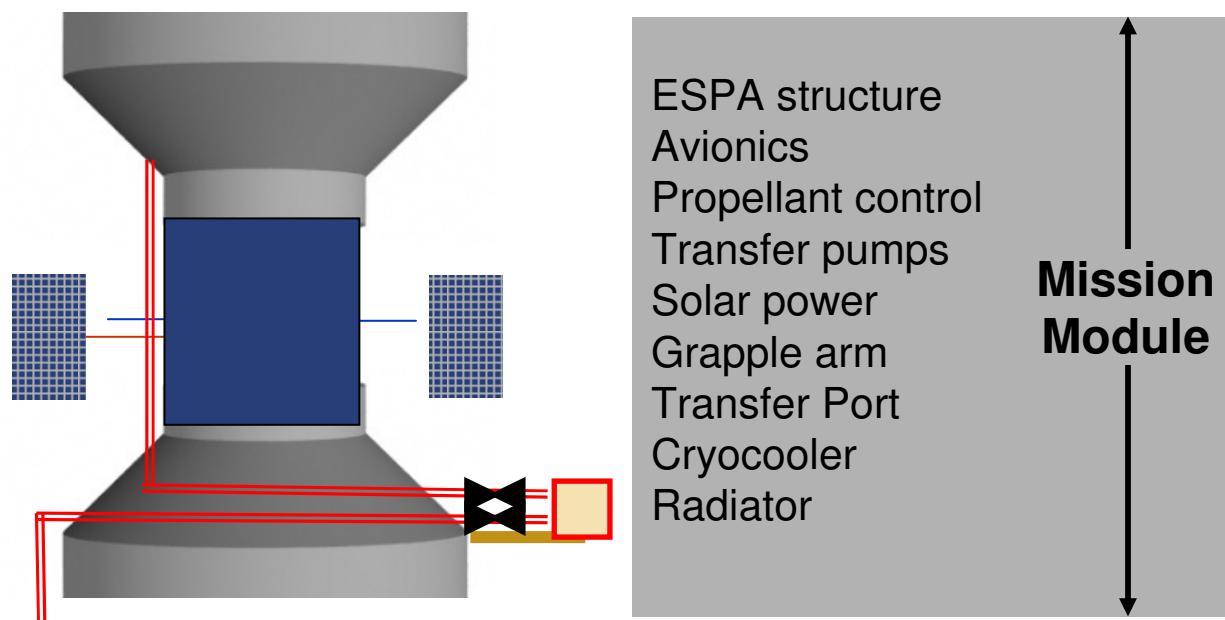
Built using existing  
Centaur tooling



# LO2 Module



# Depot Demonstration



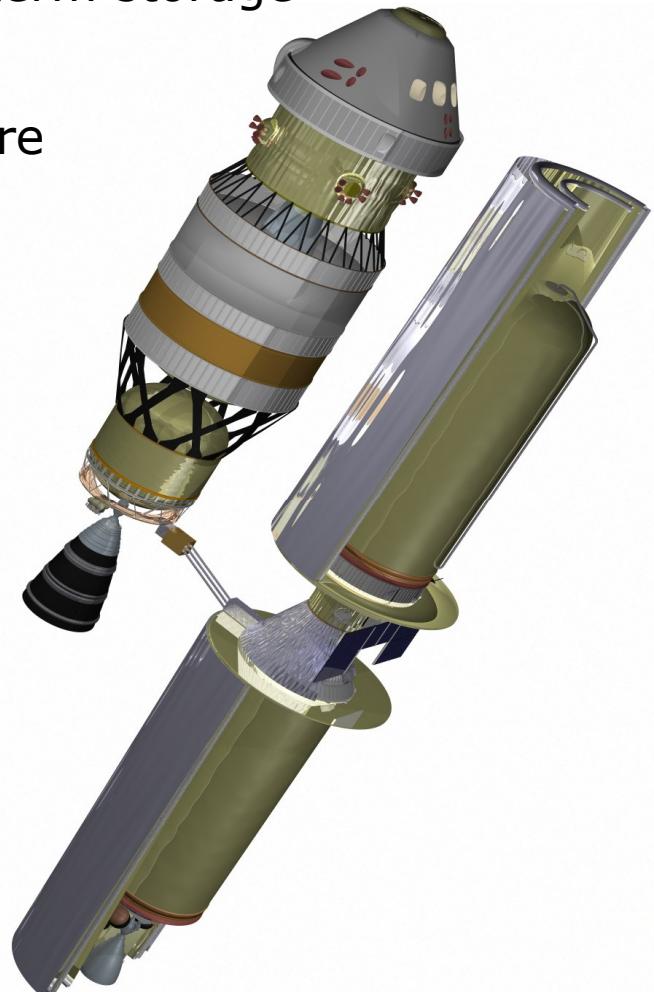
# Technology Readiness

Cryo Transfer Technology	Current TRL	
	0-G	Settled
Transfer System Operation	4	5
Pressure Control	4	9
Low Acceleration Settling	Na	9
Tank fill operation	4	5
Thermodynamic Vent System	5	5
Multi-layer insulation (MLI)	9	9
MLI Integrated Micro Meteorite Protection	3	3
Vapor Cooling (para ortho conversion)	9 (4)	9 (4)
Broad Area Cooling	4	4
<i>Active cooling (LH2)*</i>	3	3
Ullage & Liquid Stratification	3	9
Propellant acquisition	4	9
Mass Gauging	4	9
Propellant Expulsion Efficiency	3	9
System Childdown	4	5
Propellant Subcooling P>1atm (P<1atm*)	9 (5*)	9 (5*)
Fluid Coupling	3	3
AR&D	7	7

\* Upgrade option for enhanced long duration operation

# Demonstration to Orion Mission

- Atlas 551 launch of depot
  - Transfer 12 mT Centaur residuals for long term storage
- Demonstrate DCSS operations
  - Docking, propellant transfer, Earth departure
- Refuel depot
- Orion Lagrange/Lunar fly by mission

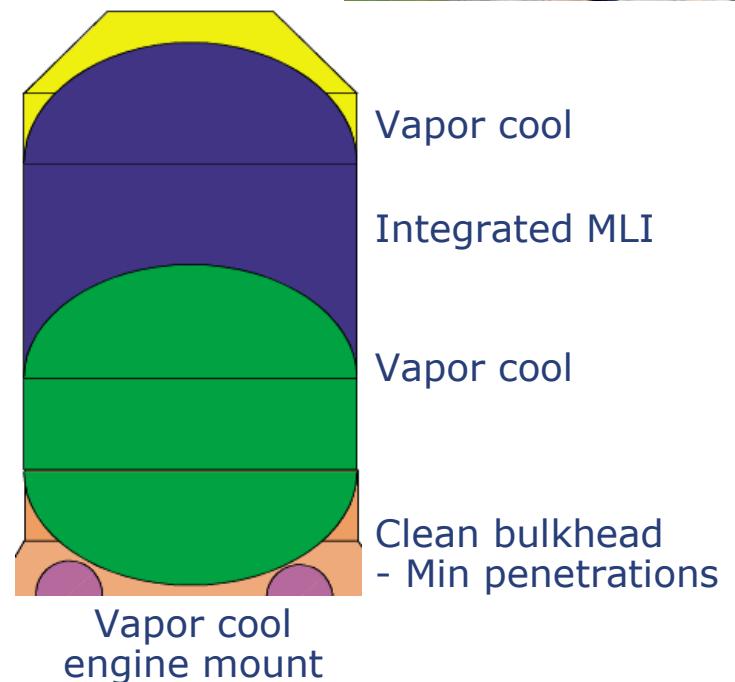


# Large Scale Plum Brook Cryo Test

- ❑ Allows near term full scale technology demonstration
- ❑ Thermal vacuum test of flight cryo tank (Centaur) at Plum Brook
  - ULA loans Centaur tank (2011)
  - NASA outfits tank to NASA requirements
  - NASA performs testing (2012)
- ❑ Test Objectives
  - Enhance CFM confidence enabling use for exploration missions
  - Demonstrate low boil-off storage
    - ~2%/day current flight demonstrated
    - ~0.25%/day with existing Centaur
    - Guide future vehicle design to support <0.1%/day boil-off



**Enhanced Thermal Protection**

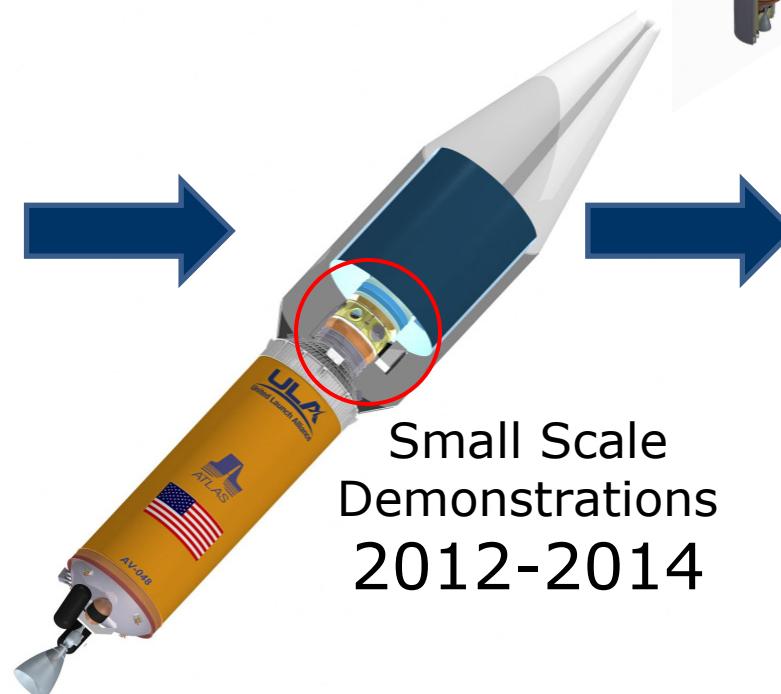
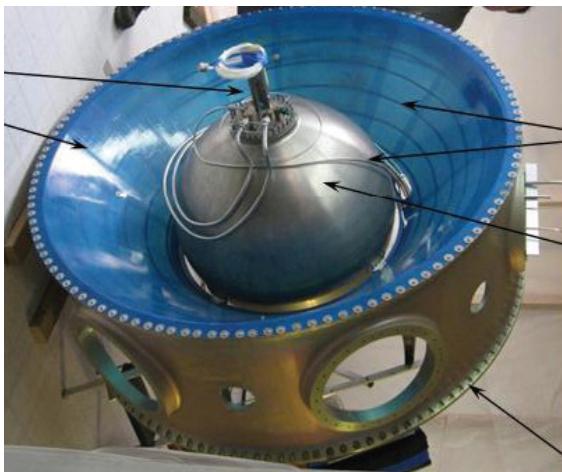


# CRYOTE

## □ CRYOTE (CRYogenic Orbital TEstbed)

- In-space laboratory for cryo fluid management (CFM) technologies
- Uses residual Centaur LH2 after primary payload separation

2010 Ground test  
2012 Orbital flight  
(Geoeye) in work



Leading to Large Scale Cryo-Sat Flagship Tech Demo  
2015



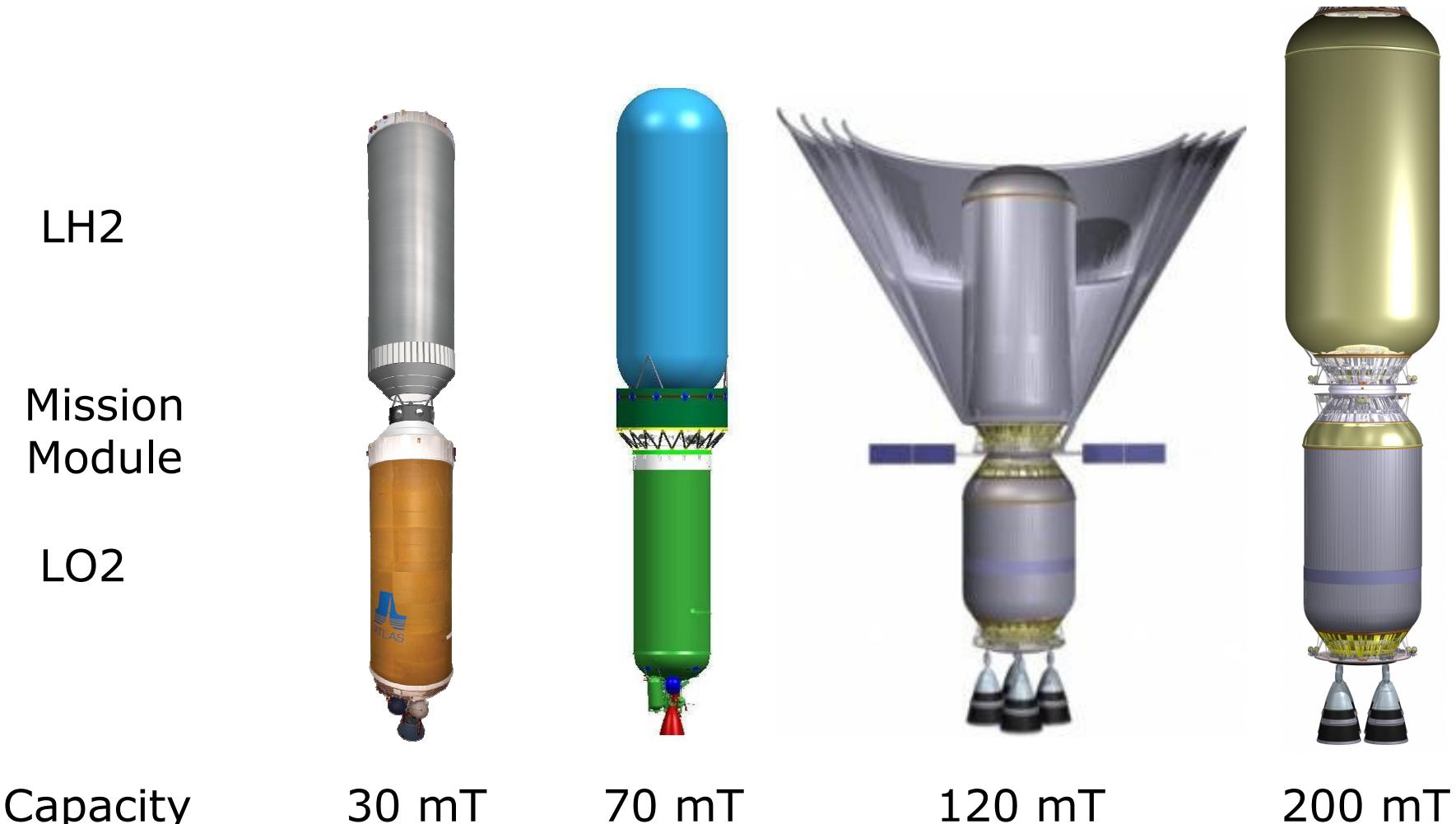
***Quickly Demonstrates Critical CFM Capabilities***

# Technology Readiness

Cryo Transfer Technology	Current TRL		Post-CRYOTE Lite TRL	
	0-G	Settled	0-G	Settled
Transfer System Operation	4	5	4	6
Pressure Control	4	9	6	9
Low Acceleration Settling	Na	9	na	9
Tank fill operation	4	5	4	6
Thermodynamic Vent System	5	5	6	6
Multi-layer insulation (MLI)	9	9	9	9
MLI Integrated Micro Meteorite Protection	3	3	5	5
Vapor Cooling (para ortho conversion)	9 (4)	9 (4)	9 (6)	9 (6)
Broad Area Cooling	4	4	4	4
<i>Active cooling (LH<sub>2</sub>)*</i>	3	3	3	3
Ullage & Liquid Stratification	3	9	6	9
Propellant acquisition	4	9	6	9
Mass Gauging	4	9	4	9
Propellant Expulsion Efficiency	3	9	6	9
System Chilldown	4	5	4	6
Propellant Subcooling P>1atm (P<1atm*)	9 (5*)	9 (5*)	9 (5*)	9 (5*)
Fluid Coupling	3	3	3	3
AR&D	7	7	7	7

\* Upgrade option for enhanced long duration operation

# Depot Capacity Options

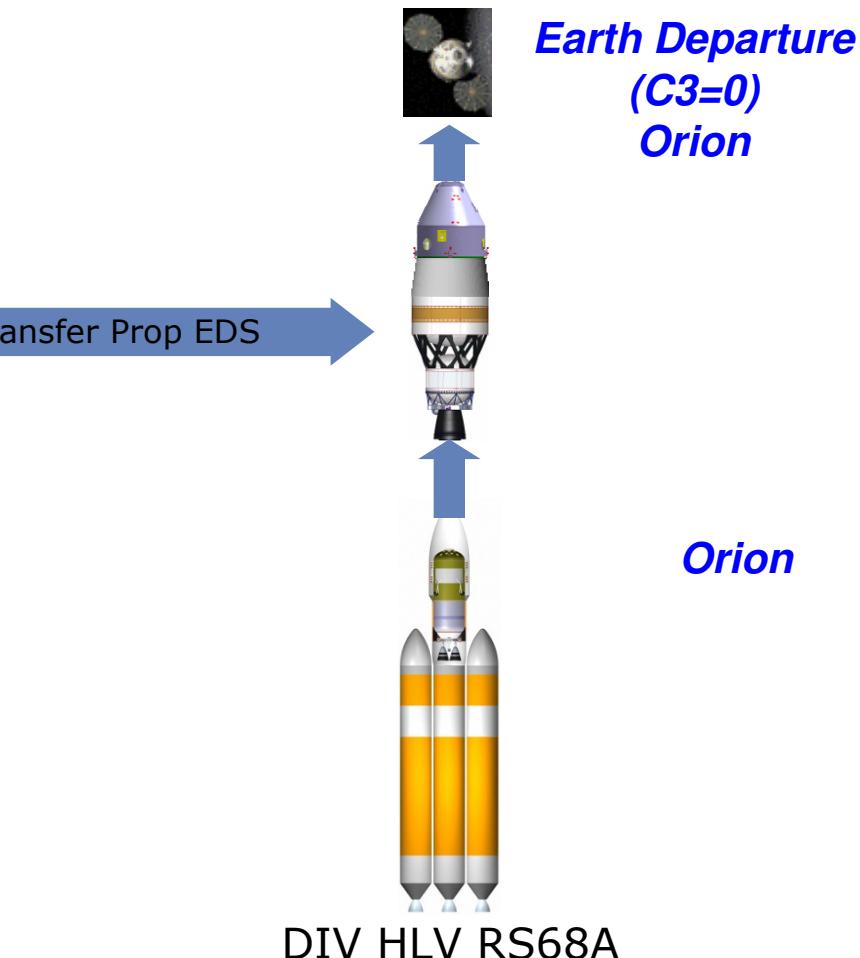
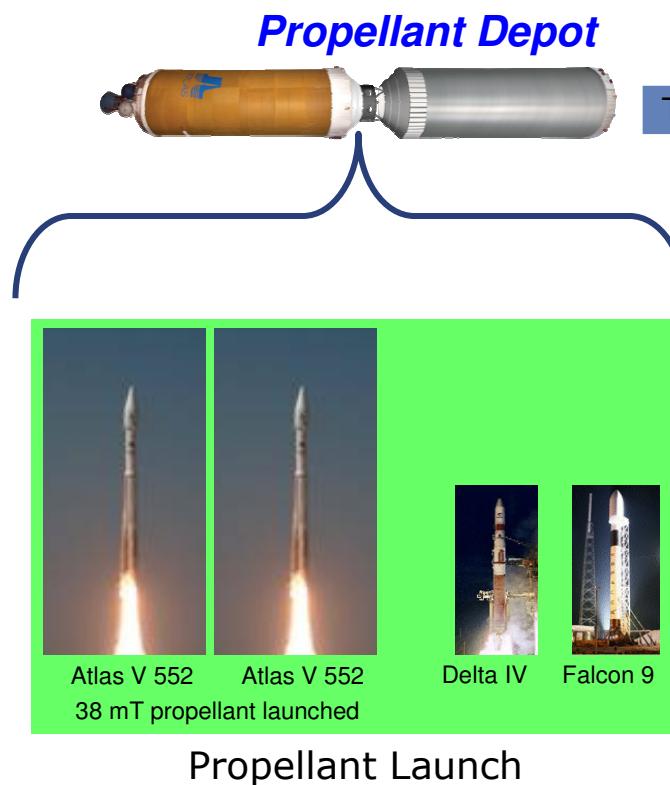


***Launch Using Existing or Future Rockets***

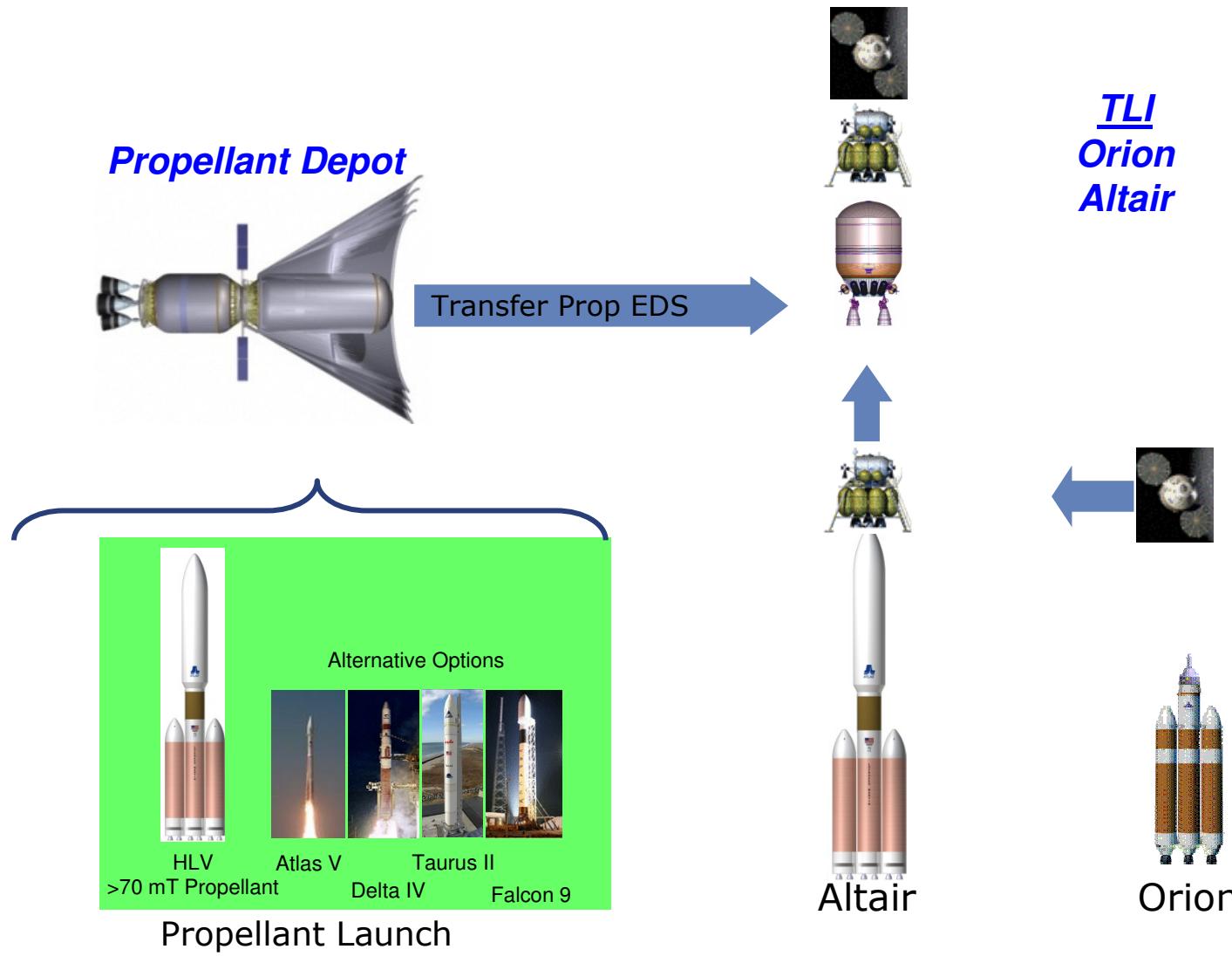
# Lagrange Mission or Lunar Fly By Example

Requires:

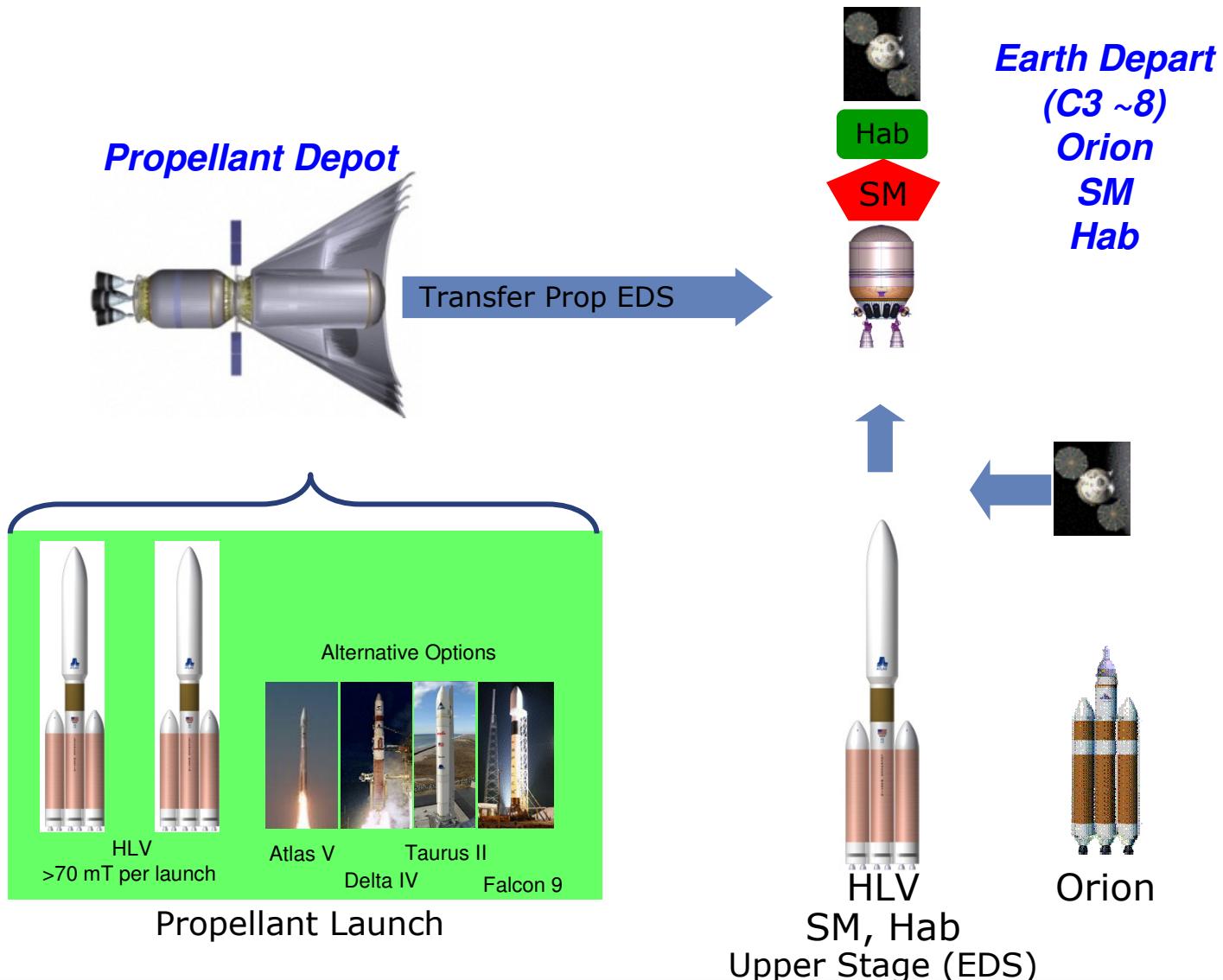
- Propellant depot
- Earth departure stage
- Propellant delivery



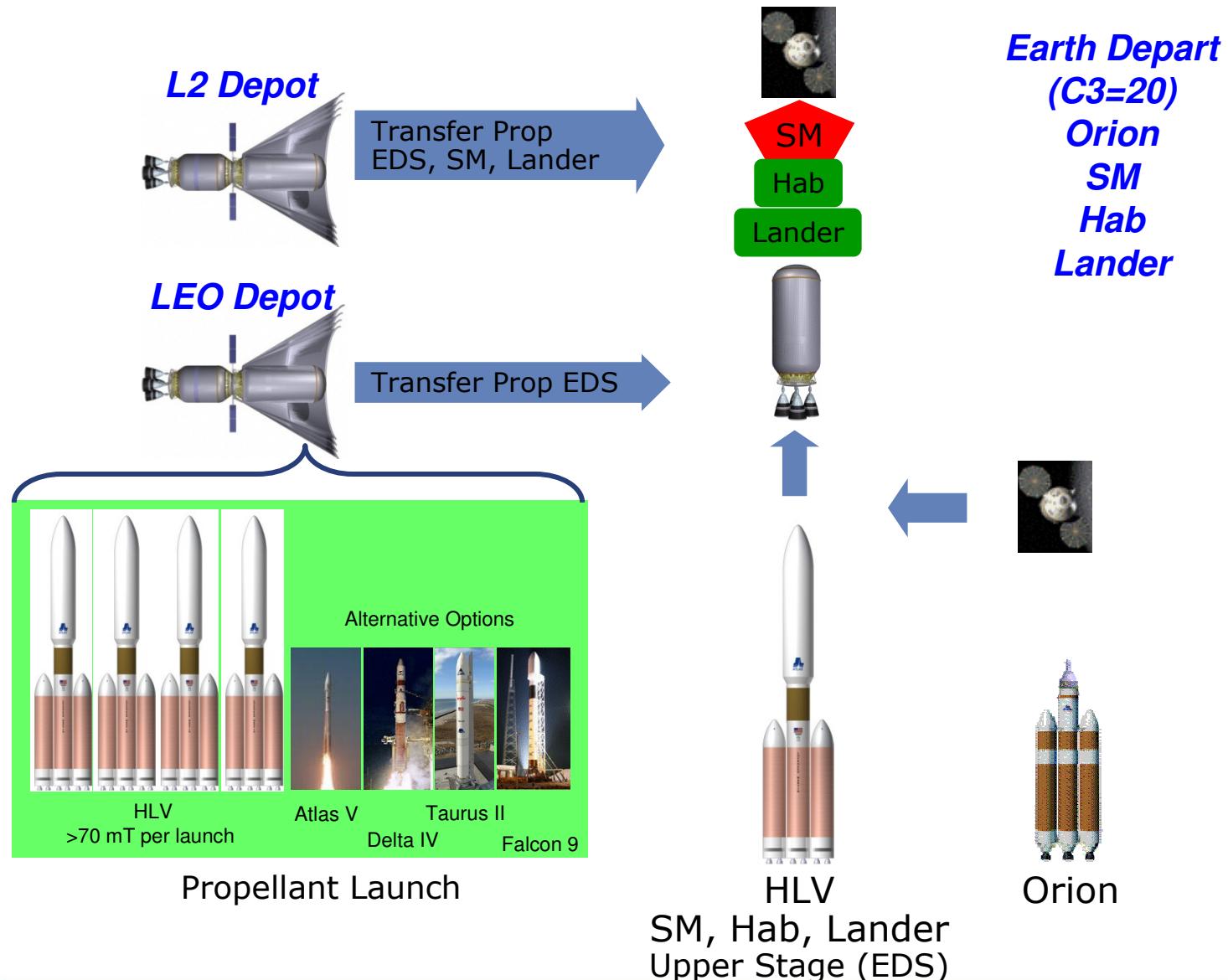
# Lunar Surface Mission Example



# NEO Mission Example



# Mars Mission Example



**Early launch of  
Orion from LC-39  
can enable  
crewed missions  
beyond Earth  
orbit as early as  
2016**

