DELPHI

Final Presentation – Moon Team 1 Fall 2014

16 December 2014

University of Colorado Boulder

Presented for ASEN 5158

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Mission Statement

Design and validate a mission architecture that supports permanent human habitation, exploration, and research on the lunar surface by 2034.

Ground Rules & Assumptions

	Ground Rules
GR1	There shall be synergistic usage of NASA investments.
GR2	Self-sufficiency shall be established within 20 years.
GR3	Eight people shall be supported at a time.
GR4	There shall be yearly rotation of four crew members.
GR5	A maximum of 10 tons of logistics per year shall be delivered.
GR6	The project will use a gradual build-up of capabilities, infrastructure, and risk reduction.
GR7	All NASA programs will continue with 80% or more of current funding (except ISS and SLS)
GR8	NASA investments shall be augmented by, or used in conjunction with, those from commercial and/or international partners.
GR9	Proposed scenarios should address novel and robust applications.
GR10	The program will have an objective of NASA sustaining a permanent and exciting space exploration program
GR11	Systems will be reusable where practical.

Ground Rules & Assumptions

	Assumptions
A1	Assume the habitat requires no end-of-life analysis (occupied and supported indefinitely) (End of life is outside of project scope)
A2	Assume no political barriers (Partner with whomever and Congress won't cancel the program)
A3	Assume international financial and technical support at ratios equivalent to ISS ratios
A4	Assume SLS is available indefinitely, starting at NASA expected times, and launching at rates consistent with current NASA expectations
A5	Assume private rockets and spacecraft are available at their current stated prices and availability
A6	Assume that the habitat design and operations will focus primarily on self-sufficiency, secondarily on space research and exploration
A7	Assume a focus on being a stepping stone for Mars technology
A8	Assume brief gaps between crew rotations such that only four crew members inhabit Delphi for two weeks

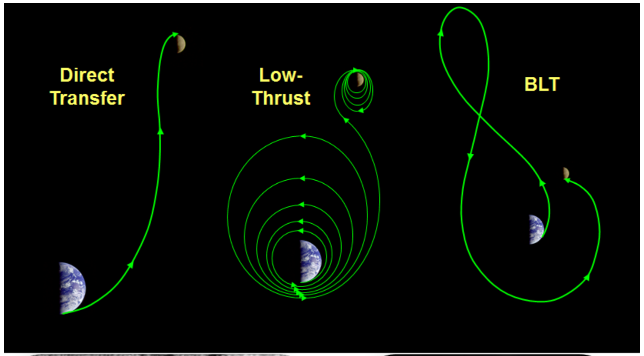
Functional Objectives

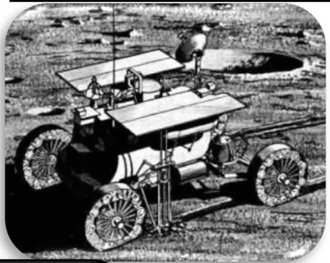
	Functional Objectives
FO1	Safely transport cargo between the Earth surface and the lunar habitat
FO2	Safely transport crew between the Earth surface and the lunar habitat
FO3	Build a lunar habitat with supporting infrastructure
FO4	Live in, maintain, and sustain the habitat
FO5	Conduct research and exploration projects

Candidate Architecture Options

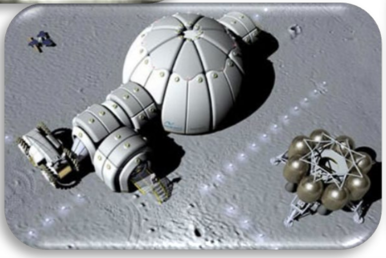
- **Launch and Transfer**
  - Vehicles
    - Space Launch System
    - Falcon Heavy
  - Transfer Methodology
    - Ballistic
    - Low Energy
- **Construction**
  - Robotics
  - Crew
  - Hybrid
- **Surface Transfer**
  - Lunar Buggy
  - Traipsing
- **Habitat**
  - Above Ground
  - Below Ground









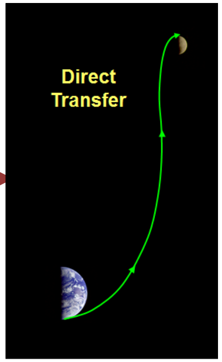


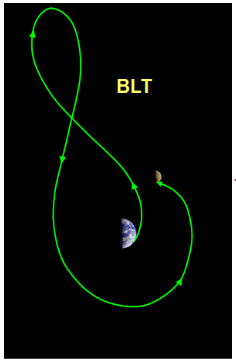

Selected Architecture

LAUNCH

SLS

TRANSFER



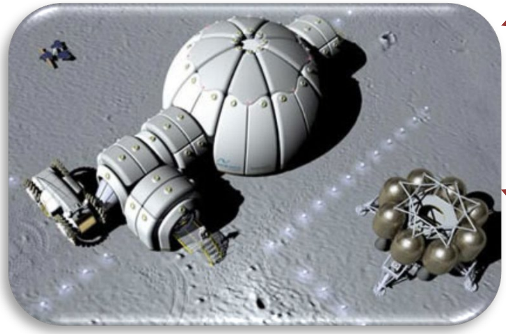


CREW CARGO

SURFACE TRANSFER

LUNAR BUGGY

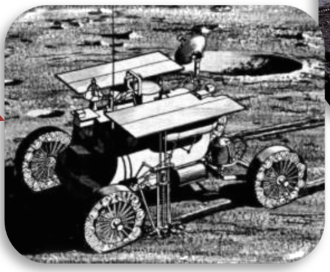
HABITAT



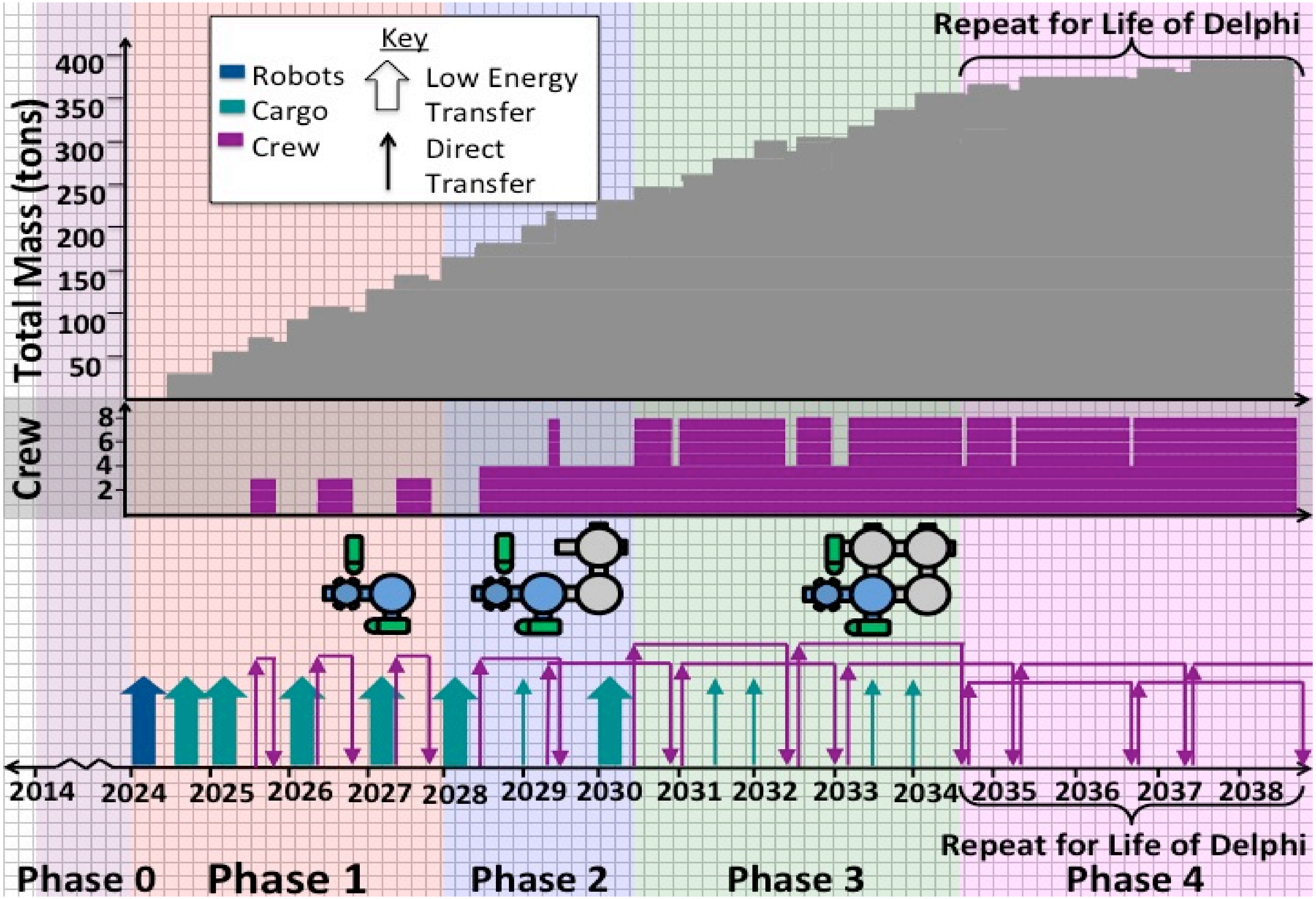
ABOVE GROUND

CONSTRUCTION

HYBRID
(Robot/EVA)



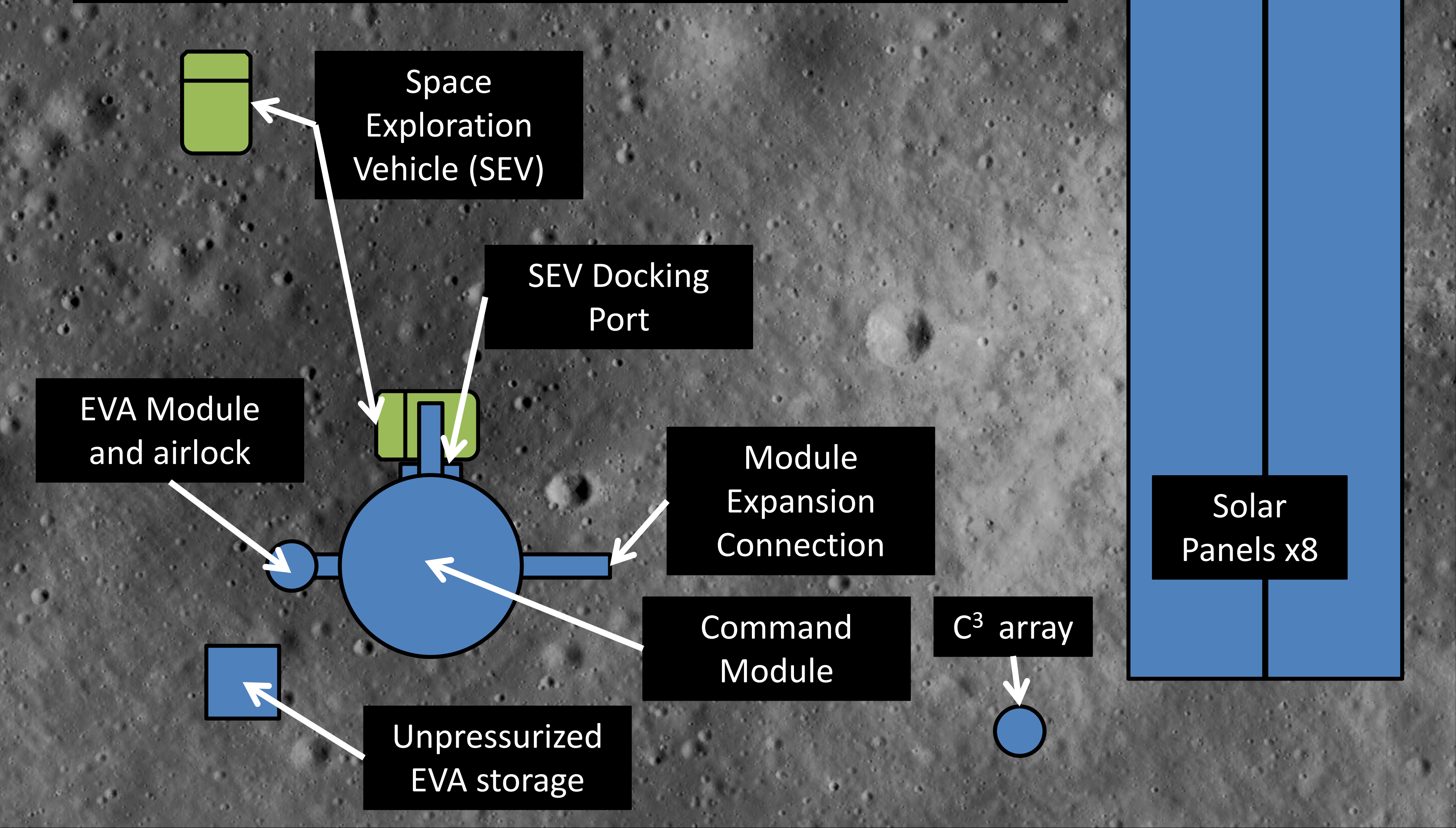
Design Reference Missions



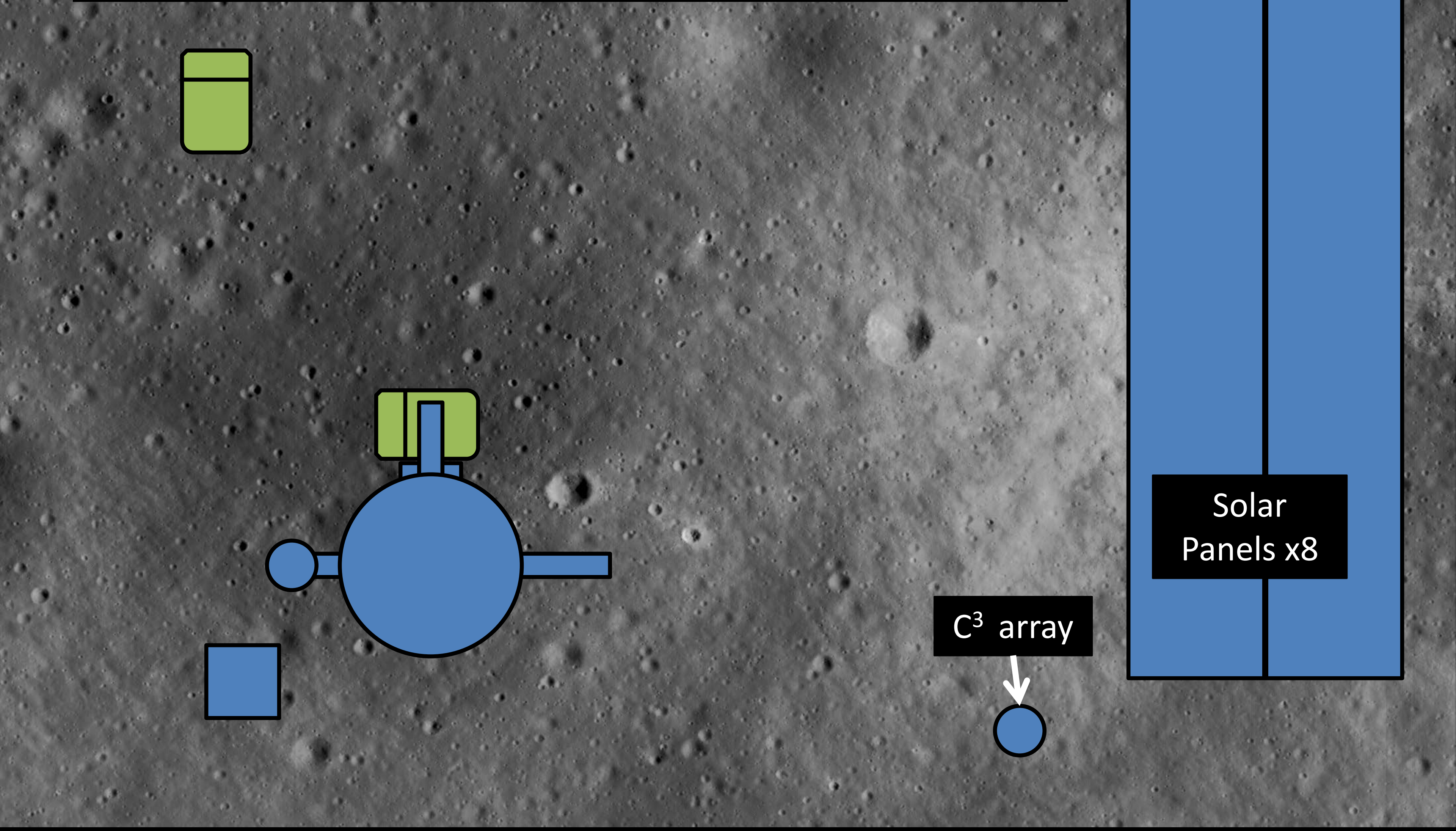
Habitat Design Overview

- Multi-phase buildup
  - Command module, EVA equipment, power systems, C^3
  - Crew, greenhouse module
  - Research module
- Vertical cylinder configuration
- Connection ports for expansion

Habitat Design and Buildup



Habitat Design and Buildup



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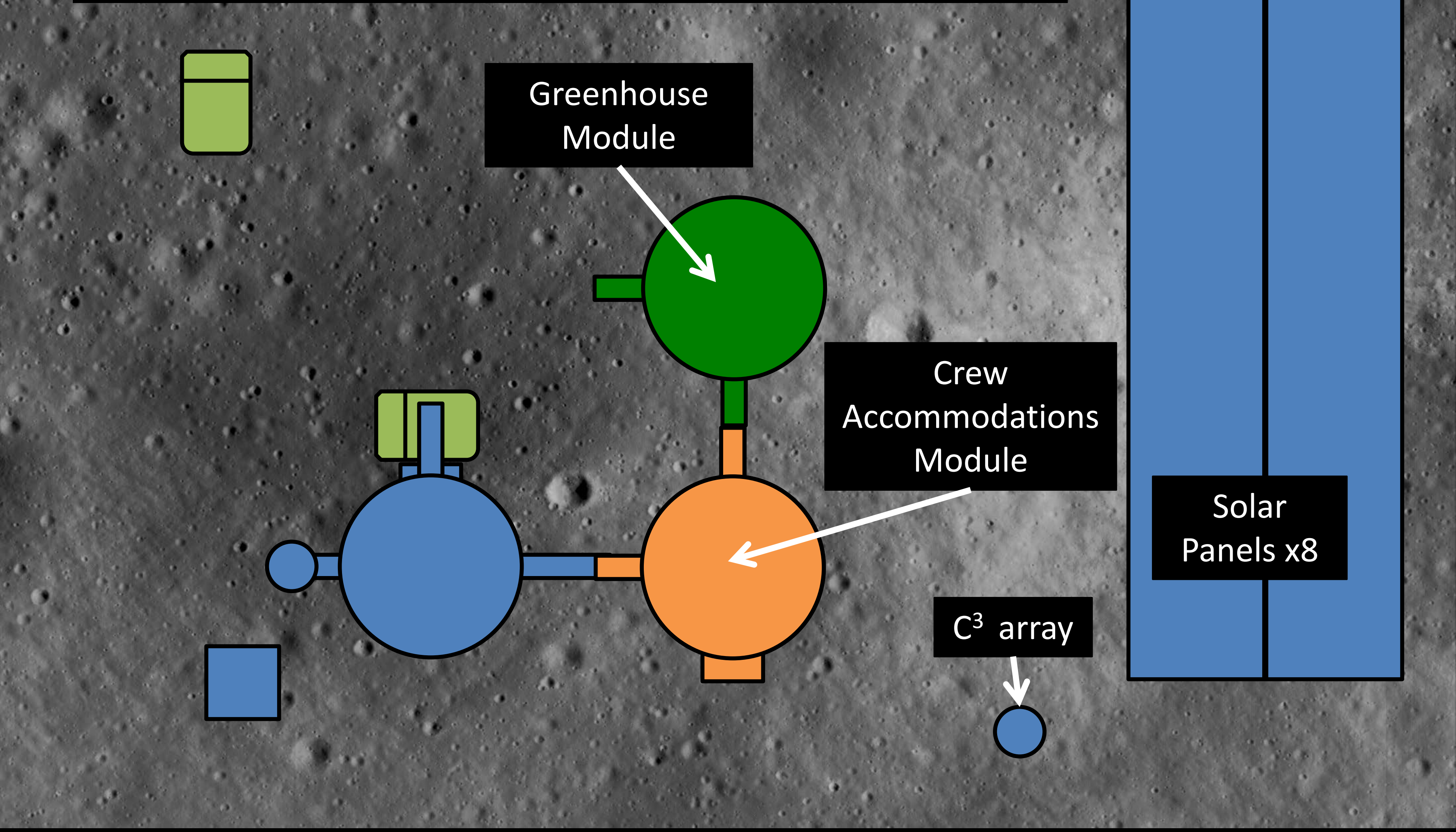

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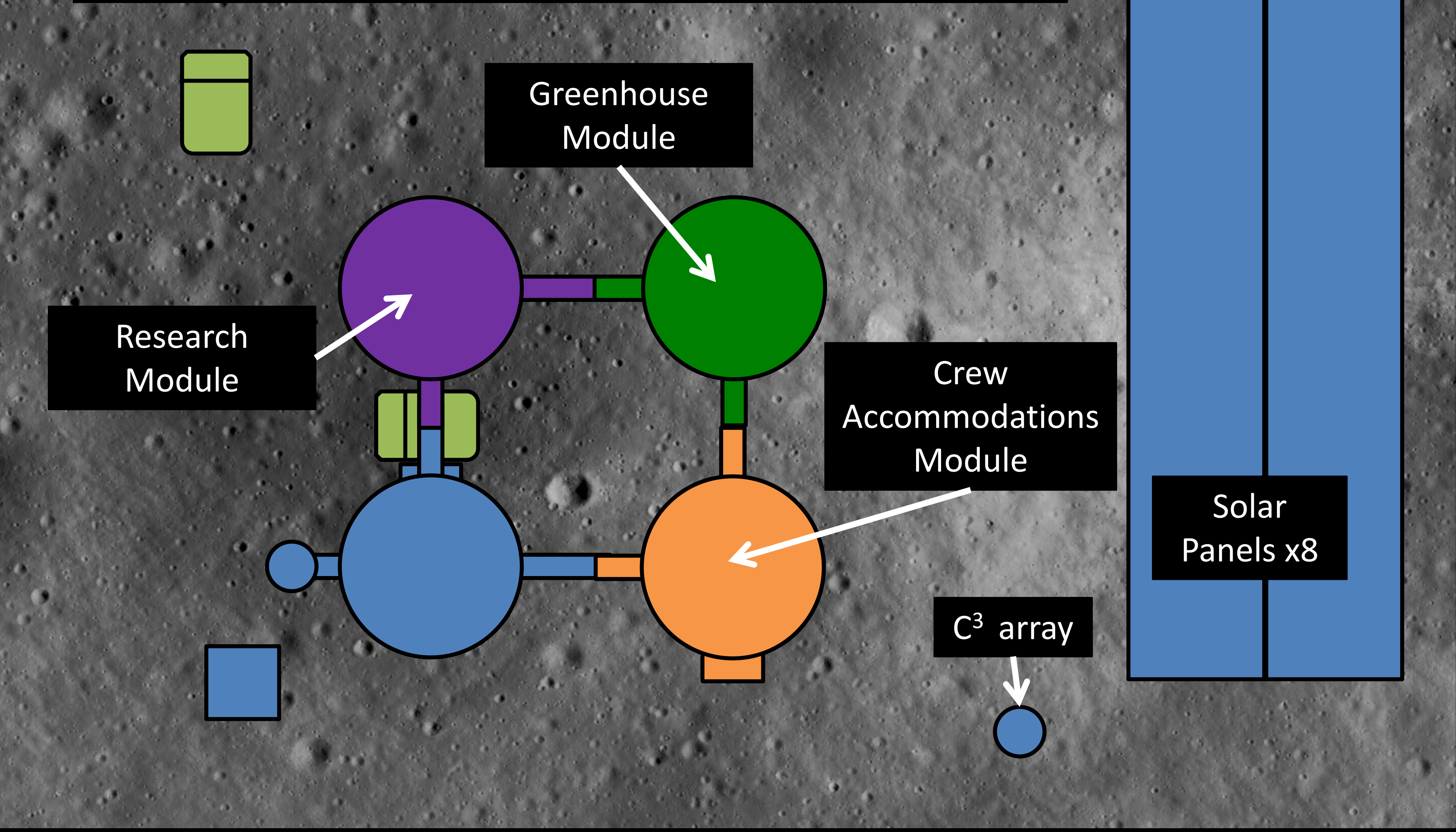
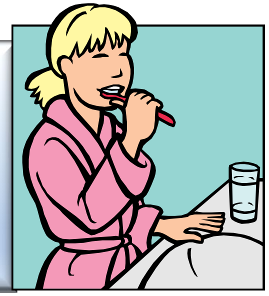


ConOps

Morning Time
Wake up, Bathroom, Drink water, Wash, Get Dressed, Eat Personal time (read, write, etc)



Do Work: A, B, C, D, E, F

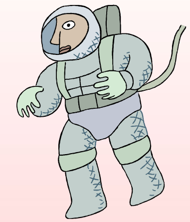
Lunch Time
Wash, Prepare lunch, Eat, Drink Water, Dispose Trash

Do Work: A, B, C, D, E, F

Evening Time
Bathroom, Drink water, Change clothes, Exercise, Prepare & eat dinner, Personal time, Wash

Work Activities

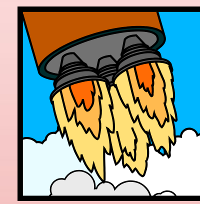
A: EVA



D: Research

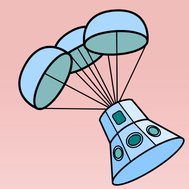
B: Day Off

E: Ascent Day

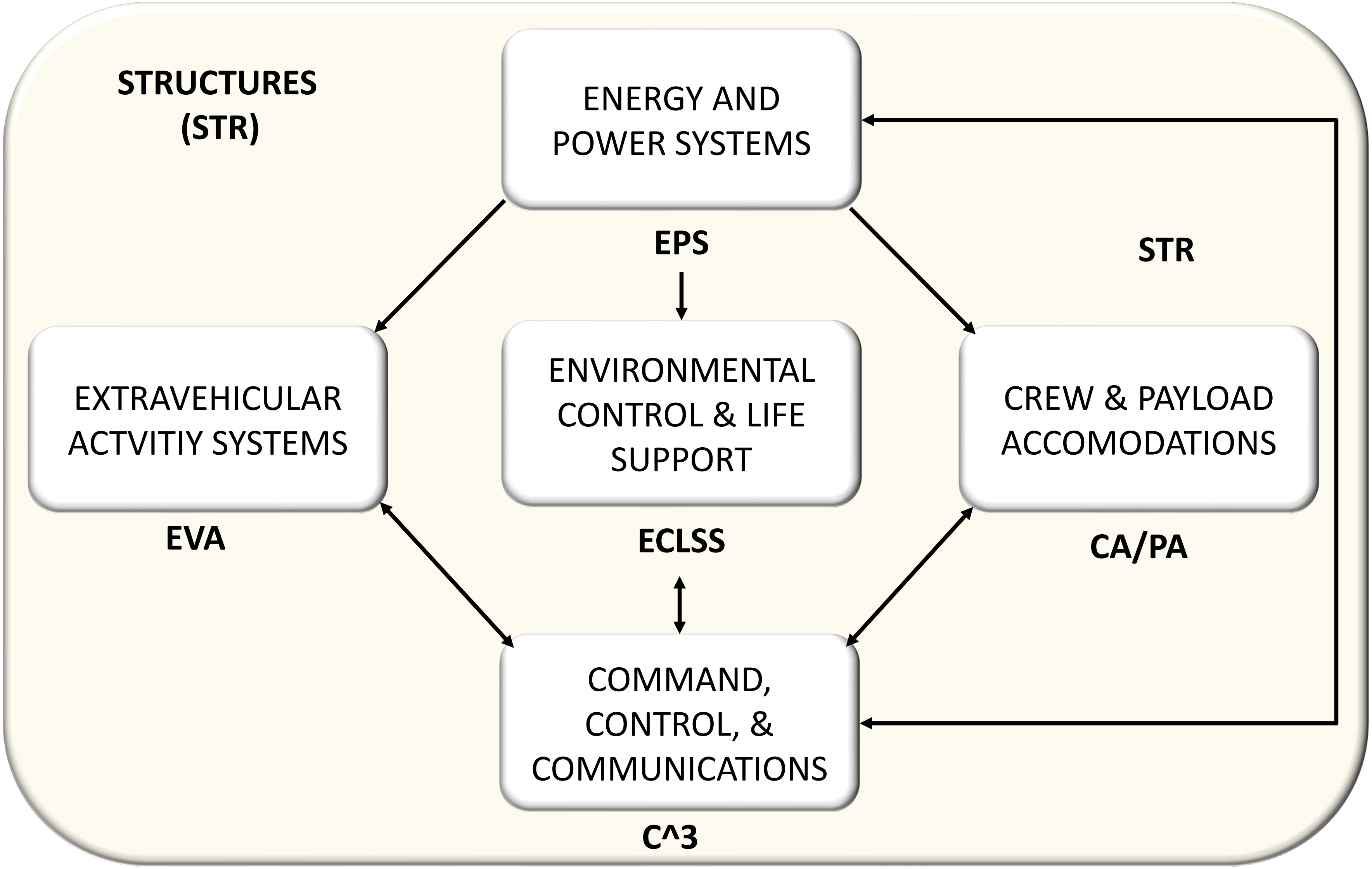


C: Maintenance

F: Descent Day

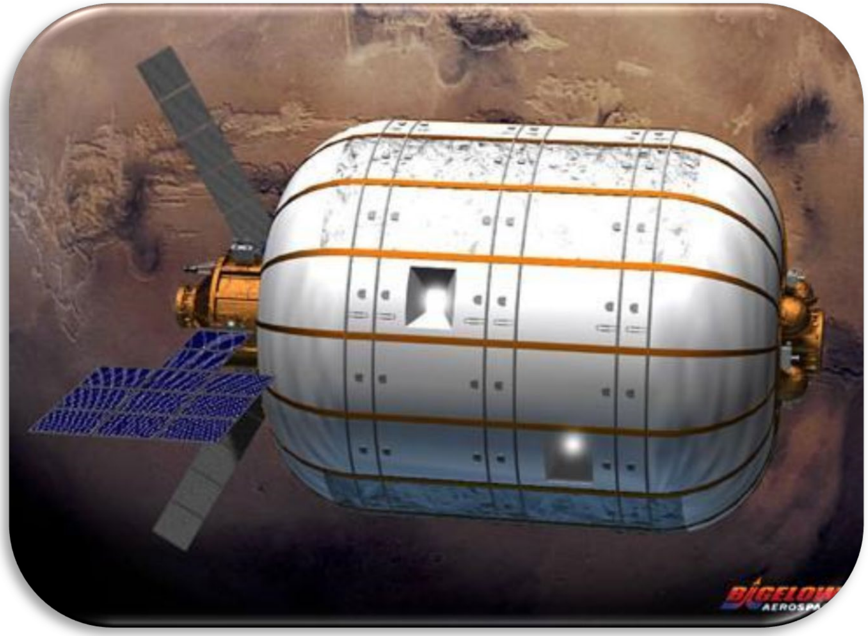


Subsystem Overview



Subsystem Overview - Structures

- Structure has rigid end caps with an inflatable center portion.
- Rigid end caps allow for pre-installation of infrastructure.



Bigelow's BA-330 module served as a reference

Component	Mass (kg)	Volume (m^3)
All Structures	99,420	2,427

Subsystem Overview - ECLSS

Provide Food

- 160 m^2 Greenhouse* (BVAD)
- Backup 90 day supply of packaged food (BVAD)
- Supplemental CO_2 (75% recovered from waste)
- Closed water loop (3-days Priming Volume)
- Galley Supplies

Provide Potable Water: 90 day recycled supply for hydration, food rehydration, personal hygiene, and medical use, including storage tanks (HIDH)

Phase 3, 1 Year w/ 90 Day Backup	Mass (kg)	Volume (m^3)	Phase 1	Phase 2	Phase 3
Food Provision	27k	31	All Earth Supplied	Supplement with Crops	Self-Sustaining
Water Management	7.1k	6.8	Supplied & Fuel Cells	Fuel Cells /Recycled	Self-Sustaining

* All mass/volume estimates are from the textbook unless otherwise noted.

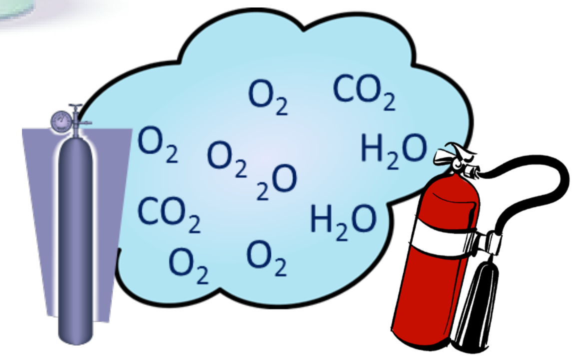
Subsystem Overview - ECLSS

Waste Management:

- Metabolic & Decomposable Liquids Storage
- Water & Solid Recovery
- Solid Metabolic Waste Storage
- Trash Compactor and bags

Atmospheric Management:

- 4BMS CO2 removal
- O2 from greenhouse
- Large storage for excess O2 (used for fuel and power)
- Fire Detection & Suppression (BVAD)



Phase 3, 1 Year w/ 90 Day Backup	Mass	Volume (m^3)	Phase 1	Phase 2	Phase 3
Waste Management	1.9k	2.1	Store & Return	Storage/Recycling	Recycling
Atmosphere Management	2.7	65	Supplied, Phys-Chem Regenerative	In Situ/Phys-chem Regenerative	Bio-Regenerative

* All mass/volume estimates are from the textbook unless otherwise noted.

Subsystem Overview - CA/PA

- Happy and Productive: long duration
- Based on class text and heuristics for:

  CA-8 Crew for 2 years on Moon

  PA- 3 full time and 2 part time Researchers

Component	Mass (kg)	Volume (m^3)
Health Care	895	3.5
Housekeeping	451	3.0
Hygiene	535	1.4
Maintenance/Repair	361	3.4
Recreational Equipment /Personal Storage	200	3.0
Sleep	72	1.0
Research Resources	1250	6.3
Total	**3,770**	**21**

Subsystem Overview - EVA Equipment

- Suit and Human Interface
  - Suit port feature desired for operational simplicity
  - External unpressurized storage shed
- Vehicle and Interface
  - Docking ability

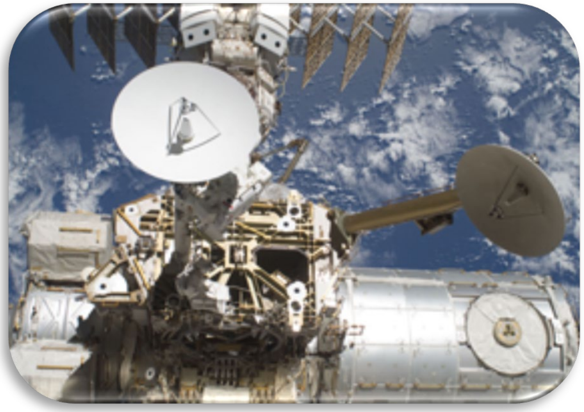
Component	Mass (kg)	Volume (m^3)
Suits	280	1.1
Rover	6,000	108
Airlock + Extra	10,060	-
Total	**16,340**	**110**

NASA Z-1 suit prototype testing

NASA Space Exploration Vehicle

Subsystem Overview- C^3

- ISS Heritage Architecture
  - SASA, ACRFG, SGANT units – 894 kg
  - Three embedded computers per module for core control and monitoring functionality – 10 kg
  - Five Thinkpads per module for user GUIs – 70 kg
  - Communications relayed to satellites in lunar orbit back to Earth (and vice versa)



ACRFG System

Subsystem Overview- Electrical Power Subsystem (EPS)

- ISS Baseline
- South Pole of Moon
- Focusing on Primary Power

Component	Mass (kg)	Volume (m^3)
Solar Panels	1,455	490
Batteries	45	5
Distribution	3,400	20
Total	**4,900**	**515**

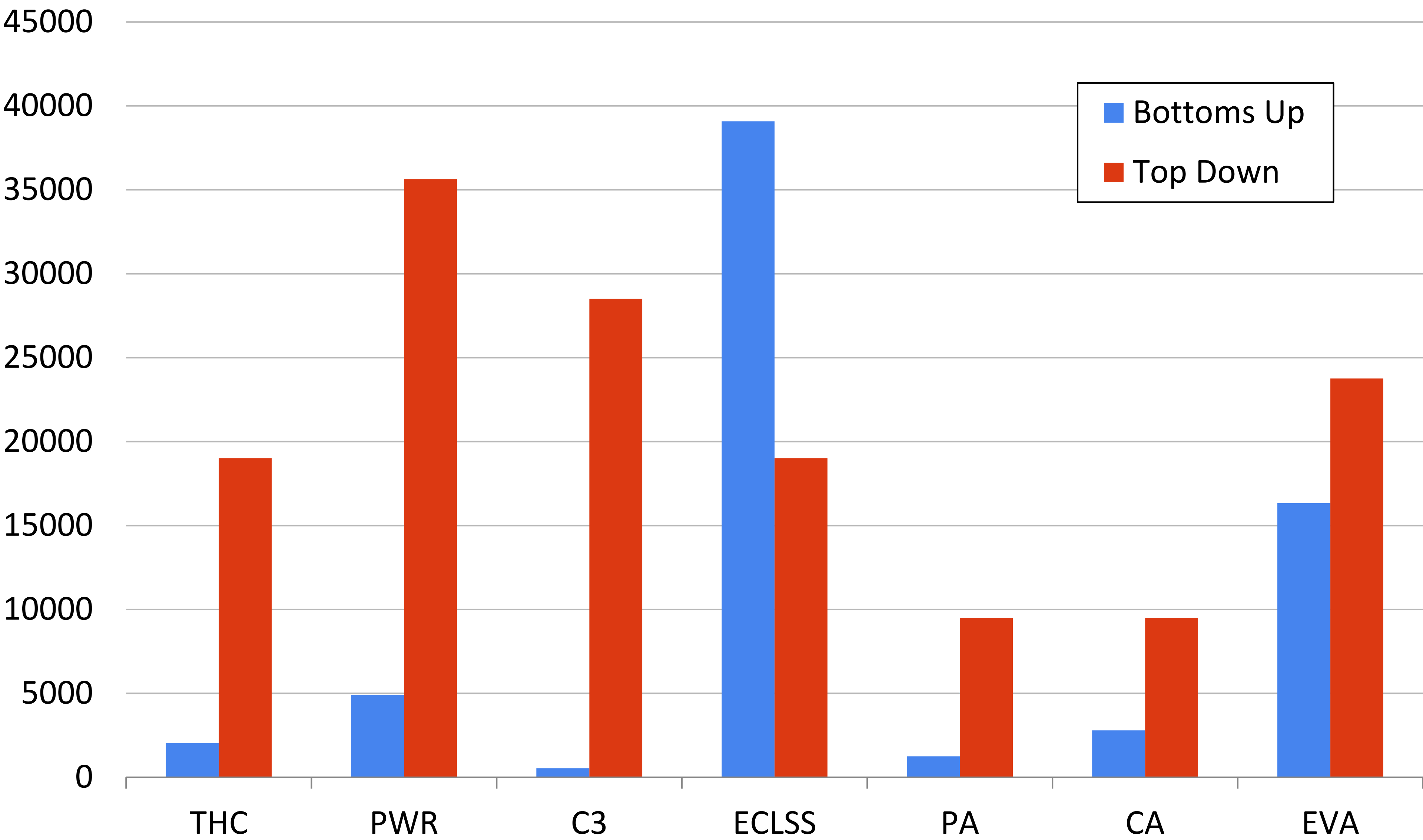
Subsystem Overview- Thermal

- High TRL Components
- Active and Passive Systems

Component	Mass (kg)	Volume (m^3)
MLI	1,980	Integrated in Structure
Heat Pump	44	2.0
Plumbing	7	7.0
Controls	2	0.5
Fluids	2	In plumbing
Total	**2,035**	**9.5**

ISS External Active Thermal Control System Pump Module

Mass Graphics – Comparison



Mass Analysis: Top Down Approach

For first-order Mass estimate, use Burnout Mass Equation

$$m_{bo} = 592 \times (number\ of\ crew \times mission\ duration \times pressurized\ volume)^{.346}$$

Estimate habitable volume of primary modules from academic references

Module	Volume (m^3)
C3/Primary Module	450
Sleeping Quarters	130
Dust Lock	10
Research	450
Kitchen	450
Recreation/Exercise	450
Connecting "Hallways"	40
Greenhouse	450
Total	2,430

Sub-system mass estimates from historically-derived heuristic proportions

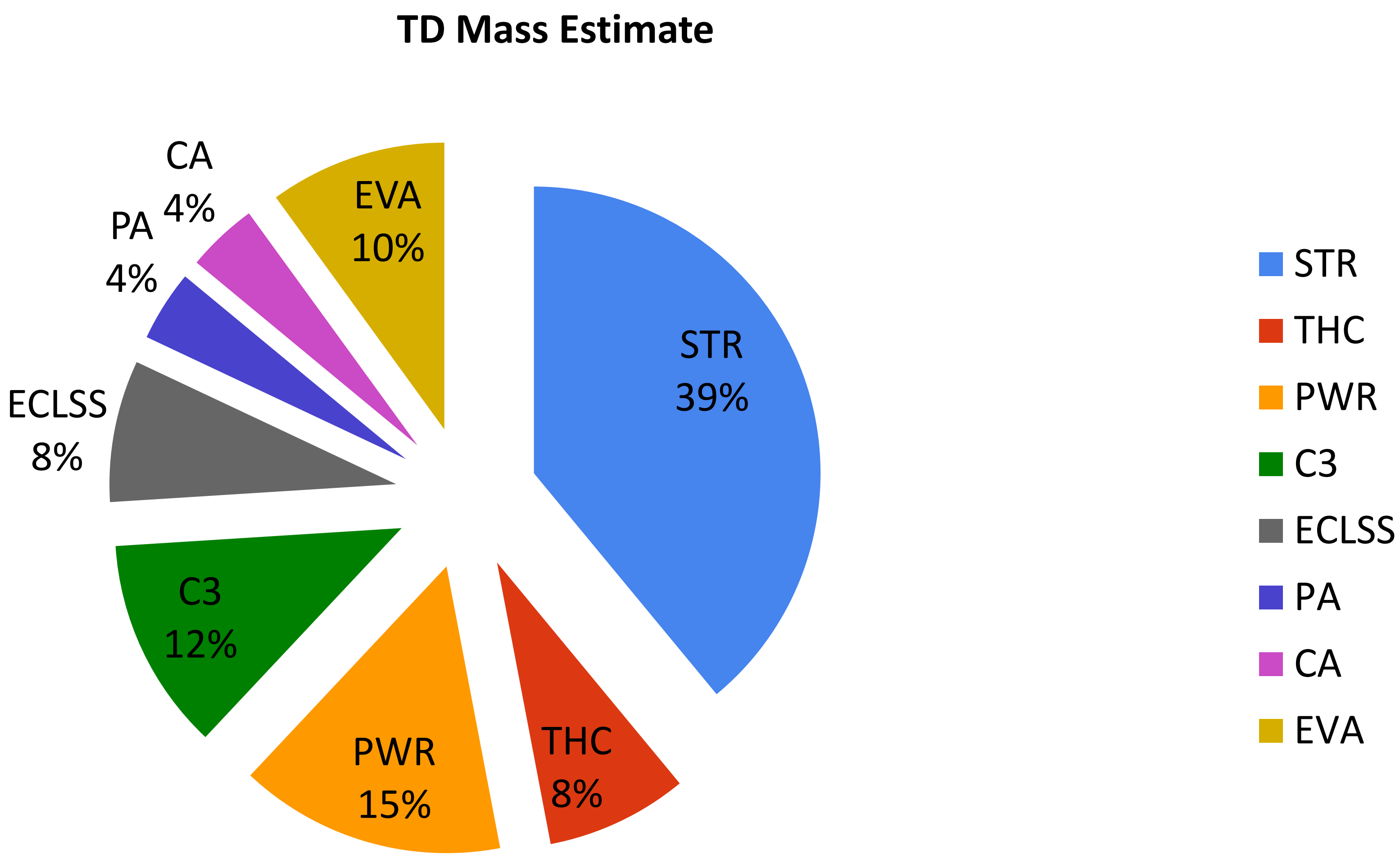
Subsystem	Mass Percent	Mass (t)
STR	39	93
THC	8	19
PWR	15	36
C^3	12	29
FOOD	2	4.8
WSTE	2	4.8
WTR	2	4.8
ATM	2	4.8
PA	4	9.5
CA	4	9.5
EVA	10	23
TOTAL	100	238

Habitable Volume * ISS Factor = Pressurized Volume

$2430m^3 * 2.3 = 5730m^3$

$$\boldsymbol{m_{bo} = 592 \times (8\ crew \times 2\ years \times 5730m^3)^{.346}}$$ = **238 Tons**

Mass Graphics – Top Down



Mass Analysis: Bottom-up Approach

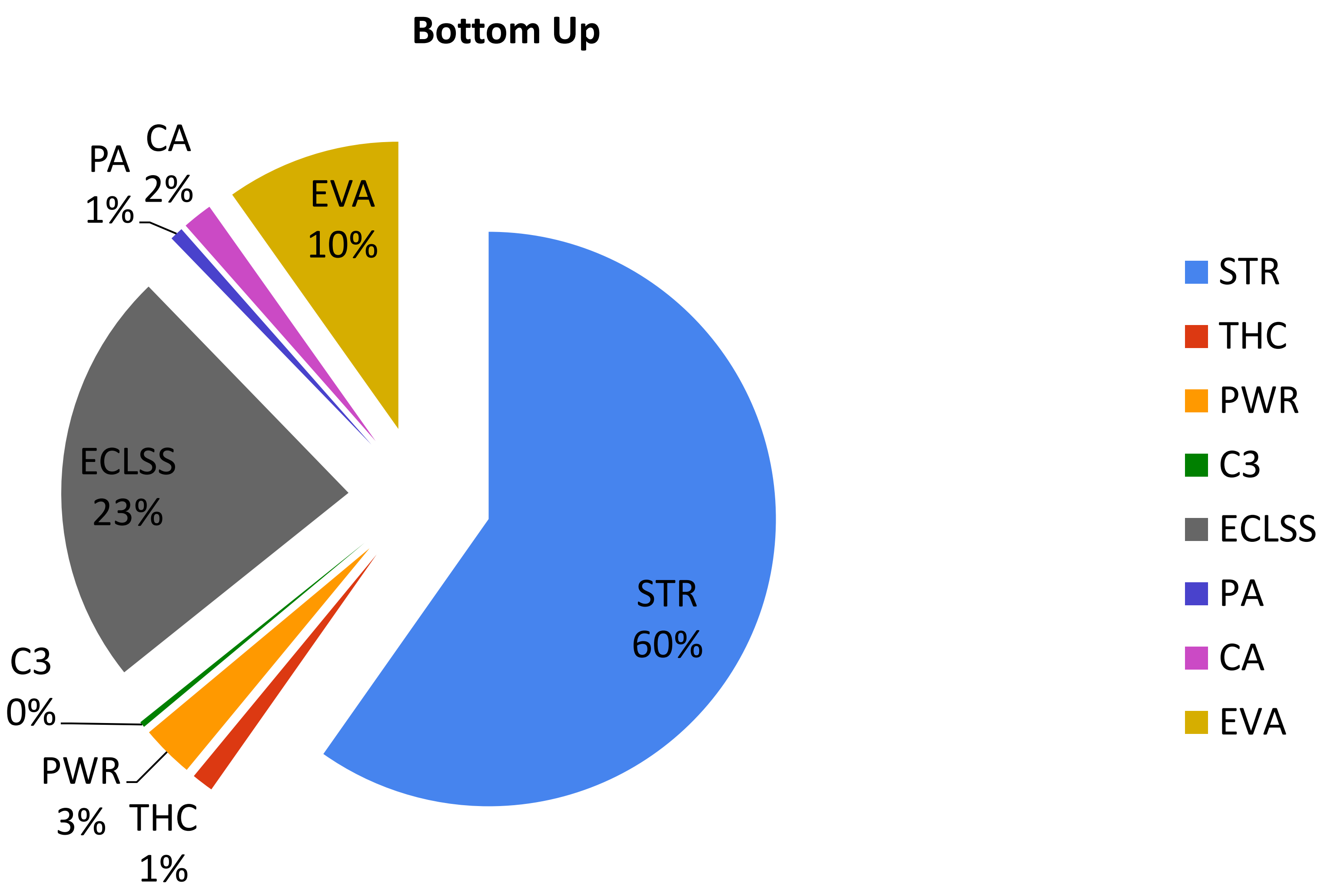
Estimate mass of each subsystem from historically-derived heuristics, add 25% FOS

Description	Acronym	Bottom- Up Mass (kg)	Bottom-Up Mass Ratio	Bottom-Up Mass+25% (kg)	Top-Down Mass Ratio	Top-Down Mass (kg)
Habitat Structure	STR	99,420	0.598	124,275	0.39	92,656
Thermal and Humidity Control System	THC	2,031	0.012	2,539	0.08	19,006
Power Management System	PWR	4,912	0.030	6,140	0.15	35,637
Command, Control, and Communications System	C^3	545	0.003	681	0.12	28,510
Food Provision	FOOD	27,359	0.164	34,198	0.02	4,752
Waste Management	WSTE	1,893	0.011	2,366	0.02	4,752
Water Management	WTR	7,118	0.043	8,898	0.02	4,752
Atmospheric Management	ATM	2,712	0.016	3,390	0.02	4,752
Payload Accommodations	PA	1,250	0.008	1,563	0.04	9,503
Crew Accommodations	CA	2,798	0.017	3,498	0.04	9,503
Extra-vehicular Activity Systems	EVA	16,335	0.098	20,418	0.10	23,758
TOTALS [kg]		166,372	1.0	207,970	1.0	237,580

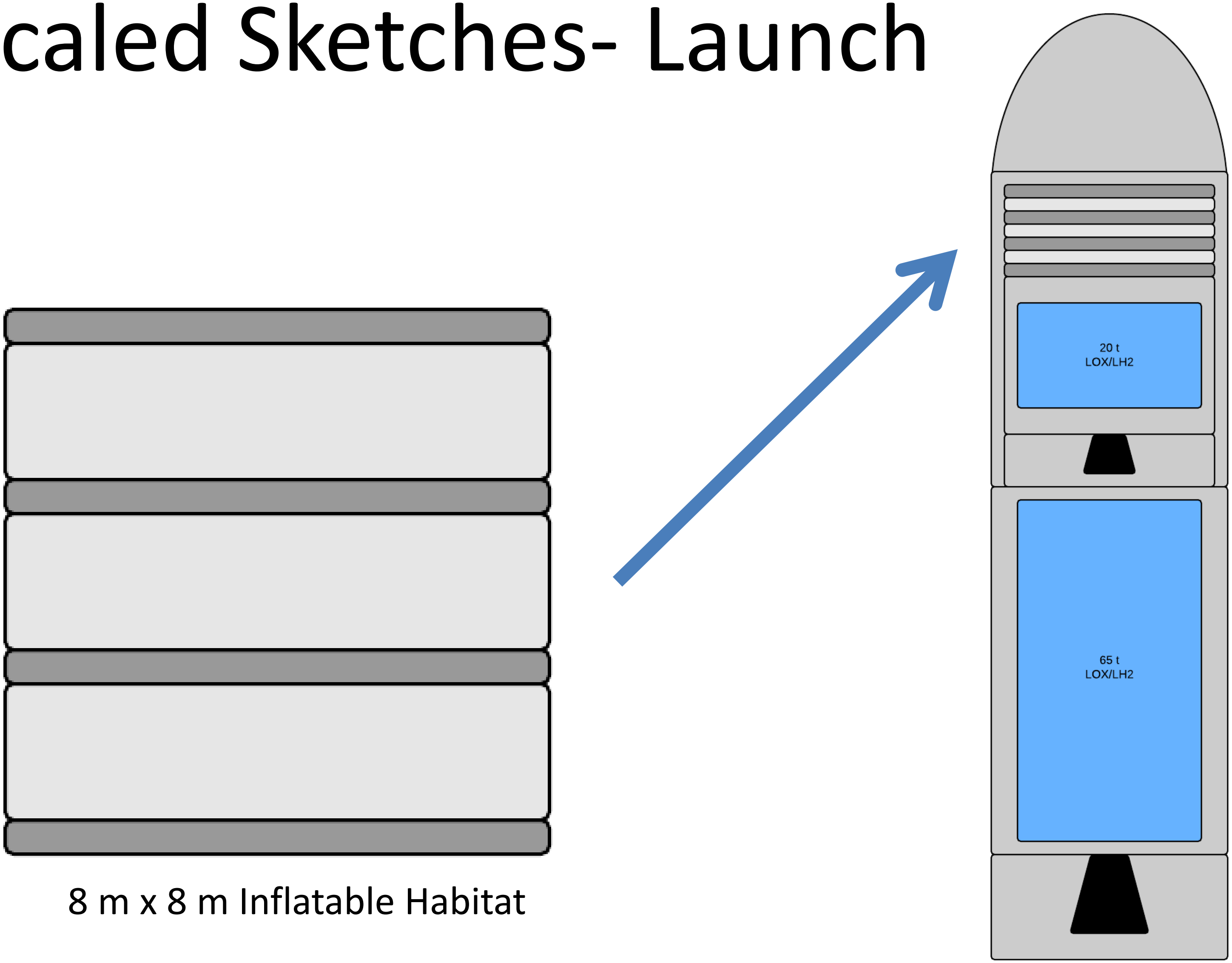
Estimates differ by 12%

Initial Mass Estimate: 223 ± 15 Tons

Mass Graphics – Bottom Up



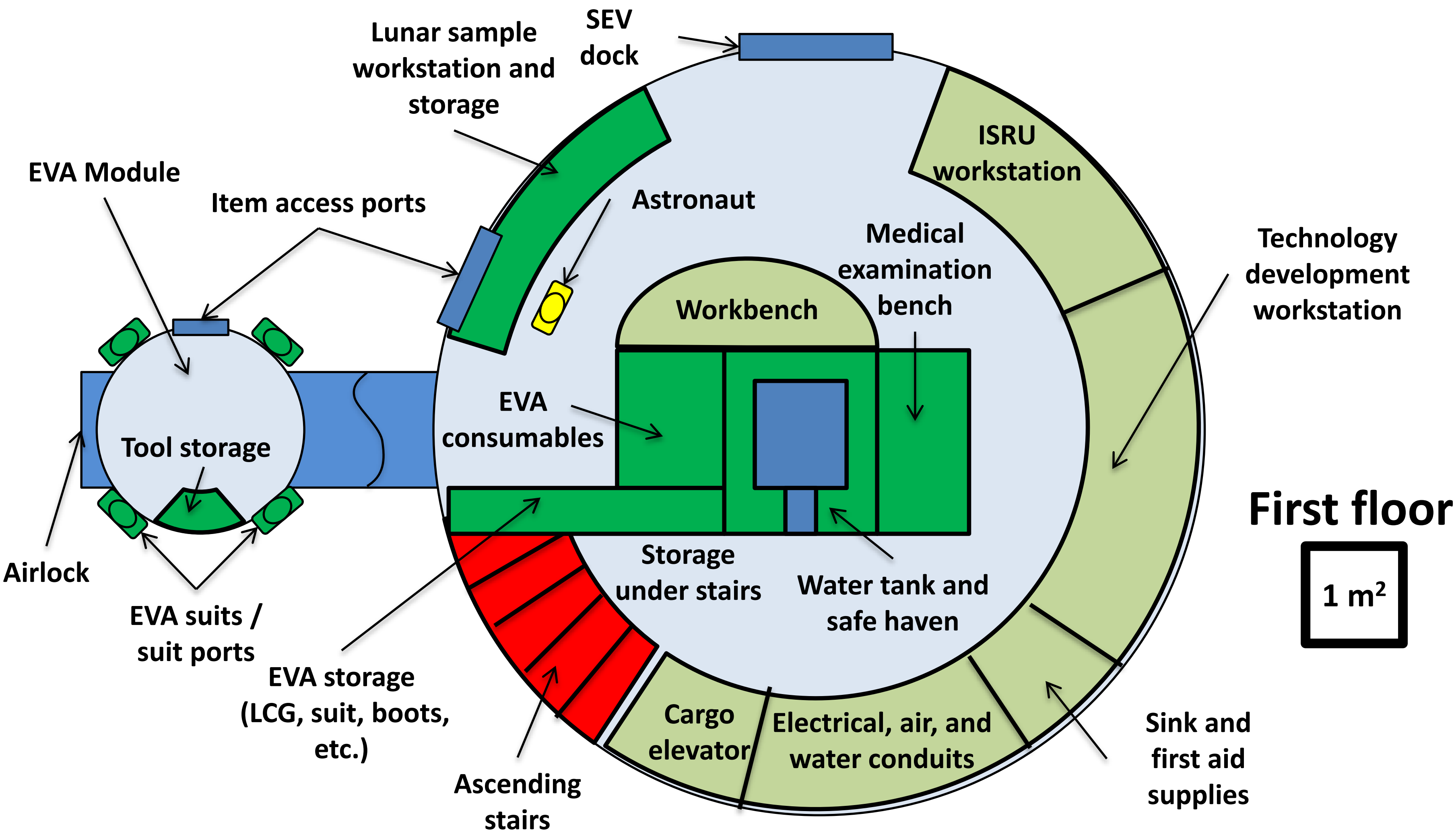
Scaled Sketches- Launch



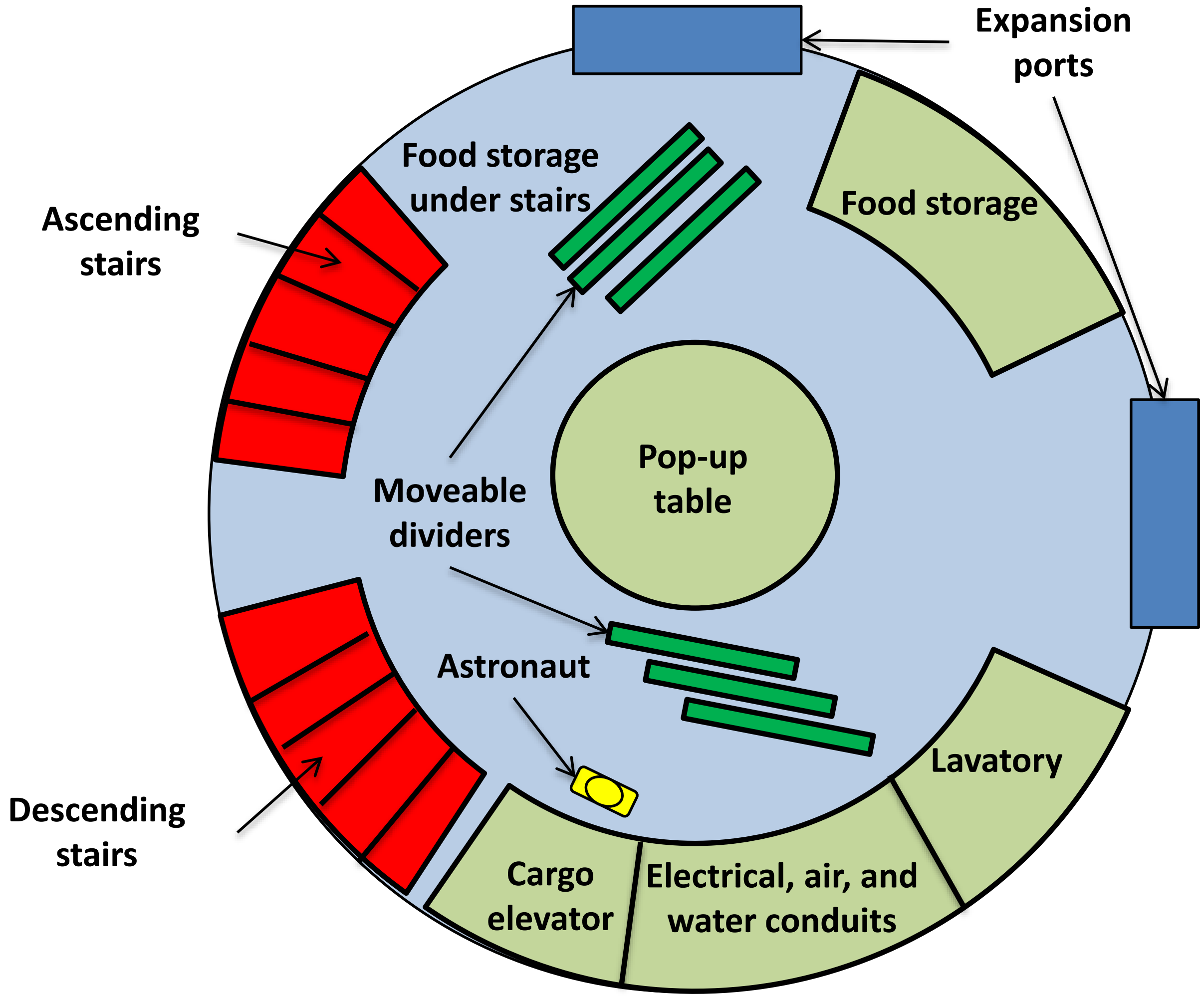
8 m x 8 m Inflatable Habitat

8.4 m x 36 m Launch Stack

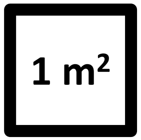
Scaled Sketches - Command Module



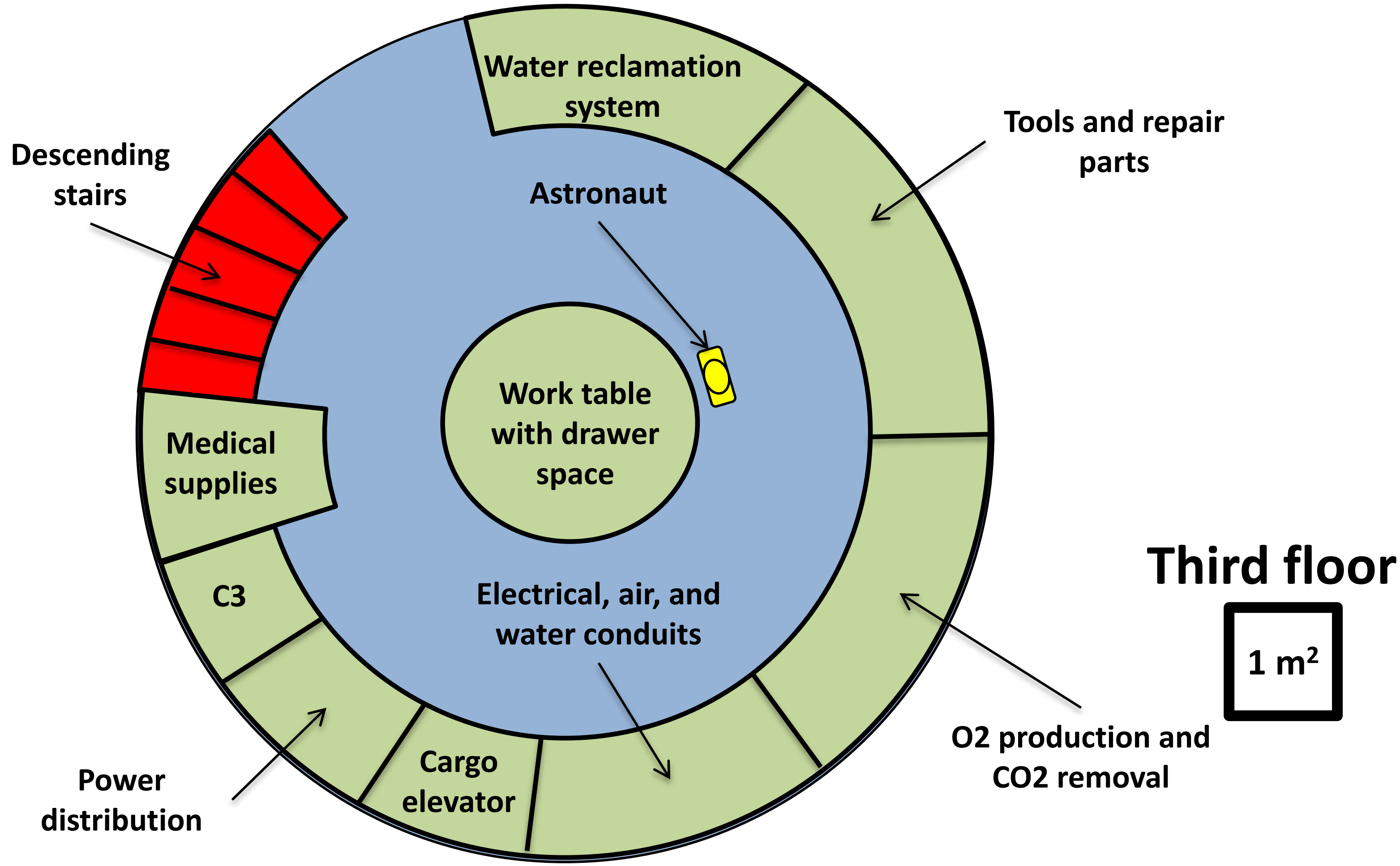
Scaled Sketches - Command Module



Second floor

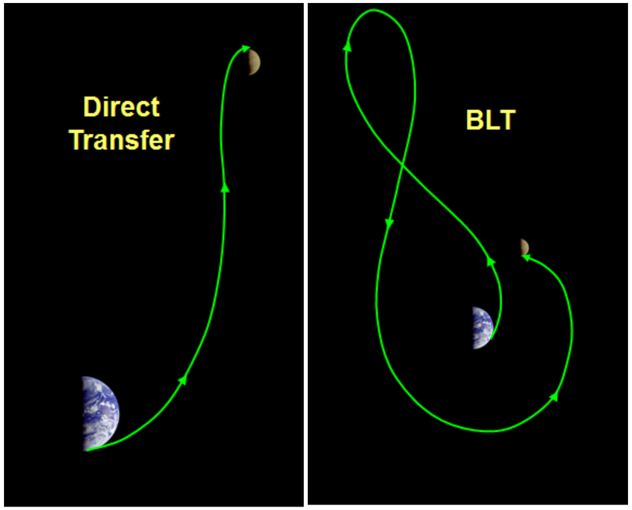


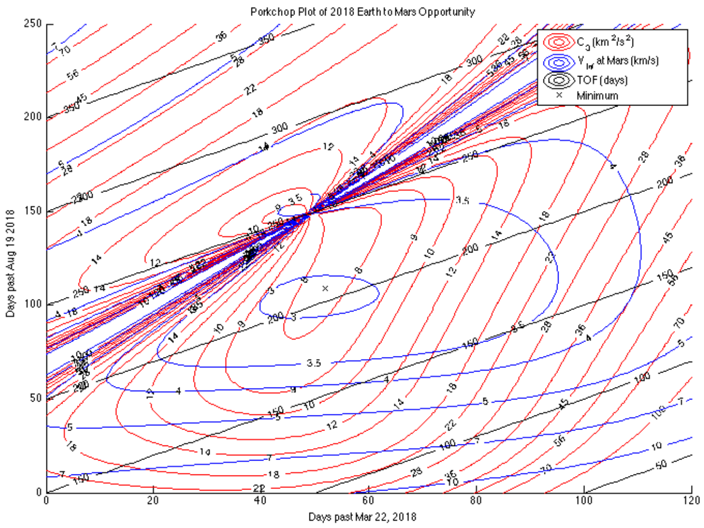
Scaled Sketches - Command Module



Launch Vehicle - Earth to LLO

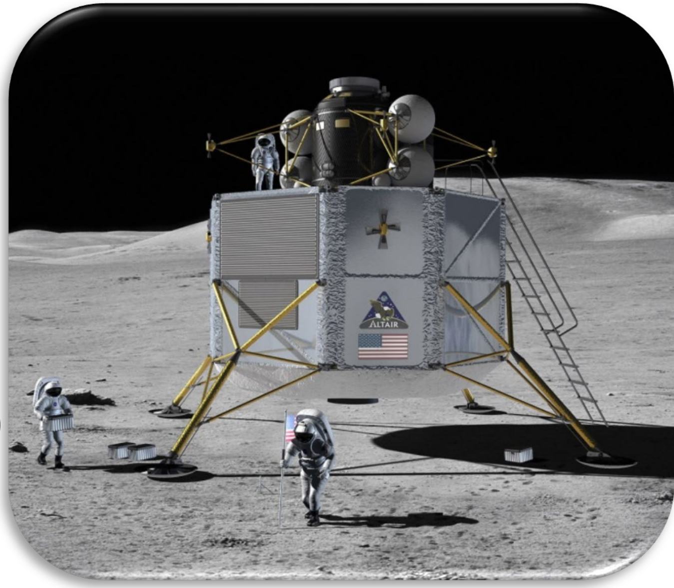
- SLS Lower and Upper Stage
  - **Build Up**: Low Energy
  - **Crew**: Direct Transfer
- Mass to LLO
  - **DT:** 39.4 tons
  - **LE:** 50.4 tons





Landing Vehicle

- Altair-derived landing vehicle
- Apollo-derived descent and landing sequence
  - Descent orbit (100 km to 15 km)
  - Powered descent (15 km to touchdown)
  - Budgeted ΔV from LLO to surface of 2.12 km/s
  - 24.5 t to lunar surface from 50.4 t in LLO



Altair Lander Concept

'Take Homes' (golden nuggets)

Low energy transfers take longer, but give an extra 25% mass. That's 5 extra metric tons we can take to the surface.

Hybrid rigid/inflatable structures integrate the best aspects of both technologies with an acceptable weight penalty.

Technology hasn't changed dramatically from Apollo. The mass constraints are nearly the same and things haven't become that much lighter.

Next Steps

- Expound on design of remaining systems for RASC-AL
  - C3, Navigation, etc.
  - Landing habitat on lunar surface
  - Moving habitat into place on lunar surface
  - Design floor plans of all modules
- Iterate design to reduce system mass and cost
- Clarify goals and requirements after 2034
- RASC-AL Competition
  - Submit Abstract 1/11/2015
  - Finalists Announced 2/2/2015
  - Report Due 5/30/2015
  - Forum 6/14 - 6/17/2014

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Photo Citations

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Questions?