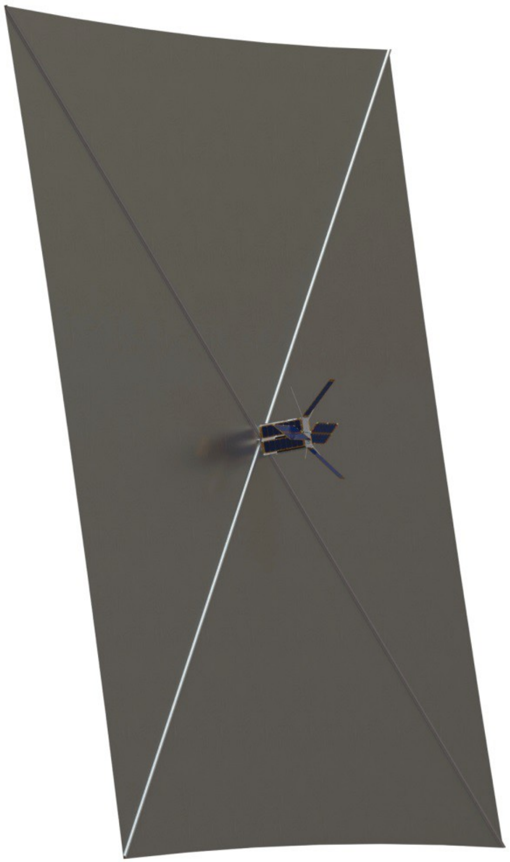
Lunar Flashlight: Finding Lunar Volatiles Using CubeSats



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Palo Alto, California

2013 November 13

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2NASA George C. Marshall Space Flight Center
3Morehead State University
4University of California, Los Angeles
5Stellar Exploration

Formulation funded by Advanced Exploration Systems
Human Exploration & Operations Mission Directorate.

This mission not approved for implementation at this time.

Lunar Flashlight

POC: Benny Toomarian – JPL,   Measurement Lead: Barbara Cohen - MSFC

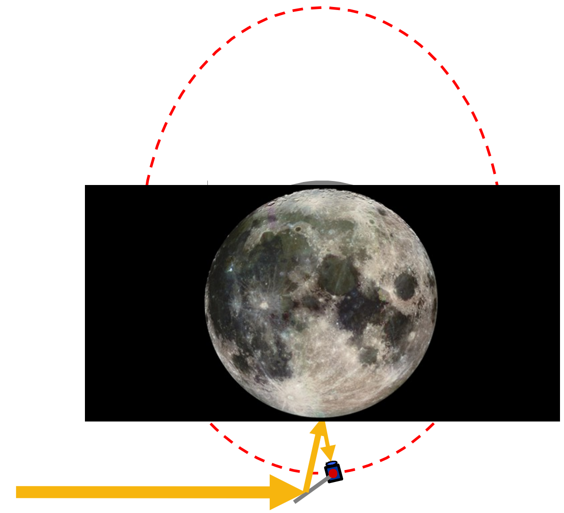
Finding Lunar Volatiles Using CubeSats

Objective:

- **Locating ice deposits in the Moon's permanently shadowed craters.**
  - Strategic Knowledge Gaps (SKGs): - Composition, quantity, distribution, form of water/H species and other volatiles associated with lunar cold traps.

Approach:

- **~50 kW of sunlight is specularly reflected off the sail down to the lunar surface in a ~1 deg beam. A small fraction of the light diffusely reflected off the lunar surface enters the spectrometer aperture, providing adequate SNR to distinguish volatile ices from regolith.**



Lunar Flashlight schematic illustration not to scale

Teaming:

- ***Lead: JPL***
- ***S/C: JPL, (6U) and Morehead State Univ. (MSU)***
  - ***Rad-tol Dependable Multiprocessor, (MSU, Honeywell)***
  - ***Rad-tol DSN compatible radio (no HGA)***
- ***Mission Design & Nav: JPL***
- ***Propulsion: MSFC, ≈78m2 solar sail***
- ***Payload: JPL, 3-band point spectrometer***
- ***I&T: JPL, MSU & MSFC***

Status:

- **SLS Secondary Payload Launch** – EM1
- **Launch:** Late 2017
- **Arrival**: 2018
- **Mission Concept Rev**: Summer 2014

Background

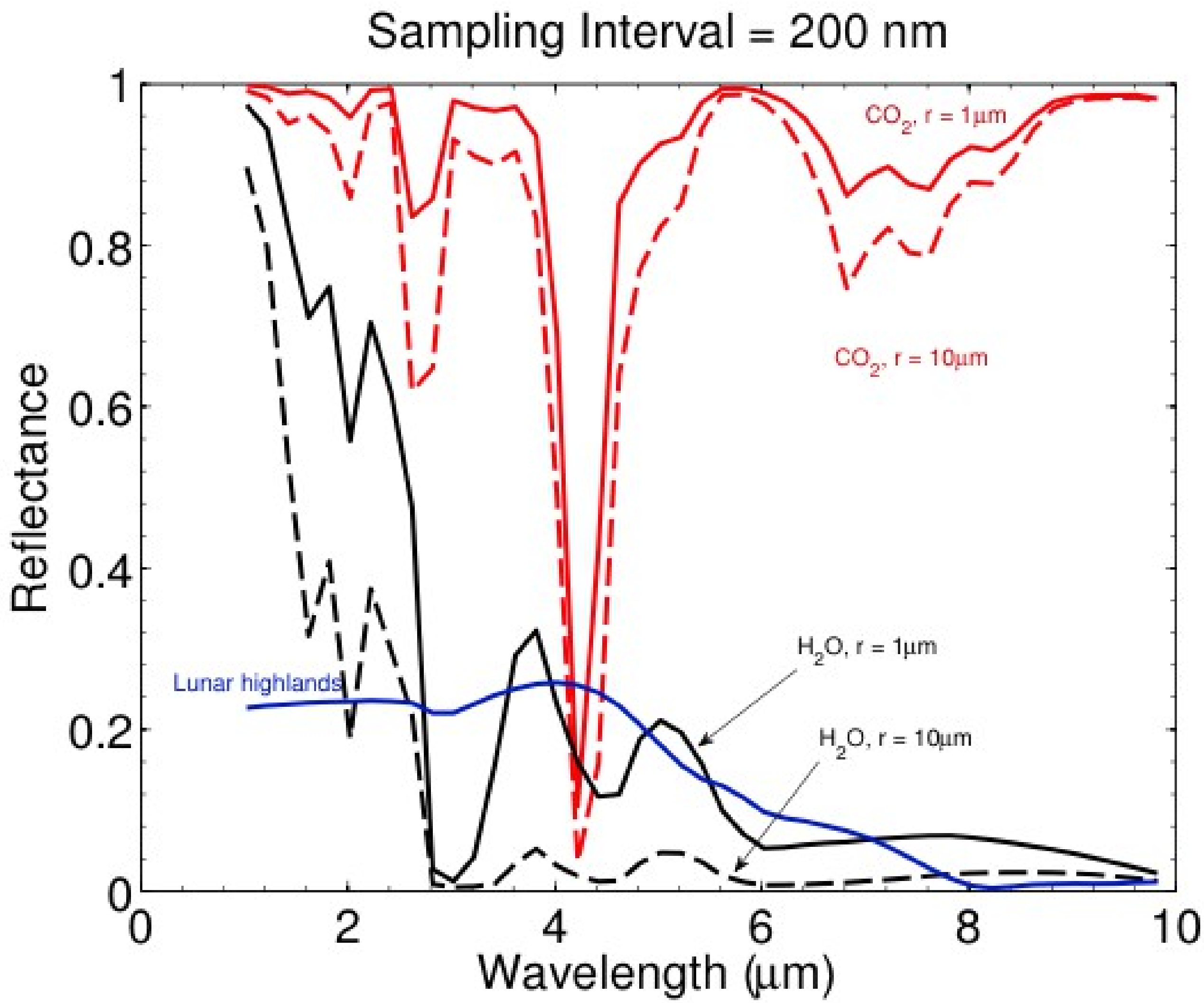
- **Idea that water (and other volatiles) should be cold-trapped at the lunar poles probably originated with Robert Goddard (1920)*, was advanced by Urey (1952), and quantified in the 1960's at Caltech (Ken Watson, Bruce Murray, and Harrison Brown)**
- **Radar backscatter from Mercury's shadowed craters strong evidence of ice in the upper ~meter (Harmon *et a*l., 1992; Paige *et al.*, 1992); Laser reflectivity from MLA consistent w/ water ice (Neumann *et al.*, 2012)**
- **Patchwork evidence for *lunar* ice:**
  - Lunar Prospector and LRO neutron spectrometers indicate hydrogen enrichment in polar regions (Feldman *et al*., 2001)
  - No definitive radar signature of ice at the Moon so far (Campbell *et al.*, 2003; Thomson *et al.*, 2012a)
  - M3 (+Cassini-VIMS, +Deep Impact) spectra in 3-µm region indicate presence of H2O or OH boded or adsorbed on mineral grains even in sunlit regions, possibly mobile on diurnal time scales (Pieters *et al.*, 2009; Clark 2009; Sunshine *et al*., 2009; McCord *et al*., 2011); could represent a source for accumulation of polar ice
  - Mini-RF on LRO suggests enhancement in ice-like scattering properties in polar craters (Spudis *et al*., 2010; Thomson *et al.*, 2012b)
  - Recent Diviner temperature measurements indicate large real-estate with favorable thermal environment for water ice and many other volatiles (Paige *et al*., 2010)
  - LCROSS excavated material from a single south-polar site, strong evidence for H2O ice, weaker evidence for H2S, NH3, SO2, C2H4, CO2, CH3OH, CH4 (Colaprete *et al*., 2010)
  - LOLA reflectivity of near-polar Shackleton crater unusually high, consistent with surface ice (Zuber *et al*., 2012)

***Robert H. Goddard 1920. In *Papers of Robert H. Goddard, Volume 1*, eds. E. C. Goddard & G. E. Pendray (New York: McGraw-Hill, 1970), pp. 413 – 430.**

Likely Ices in Lunar Cold Traps

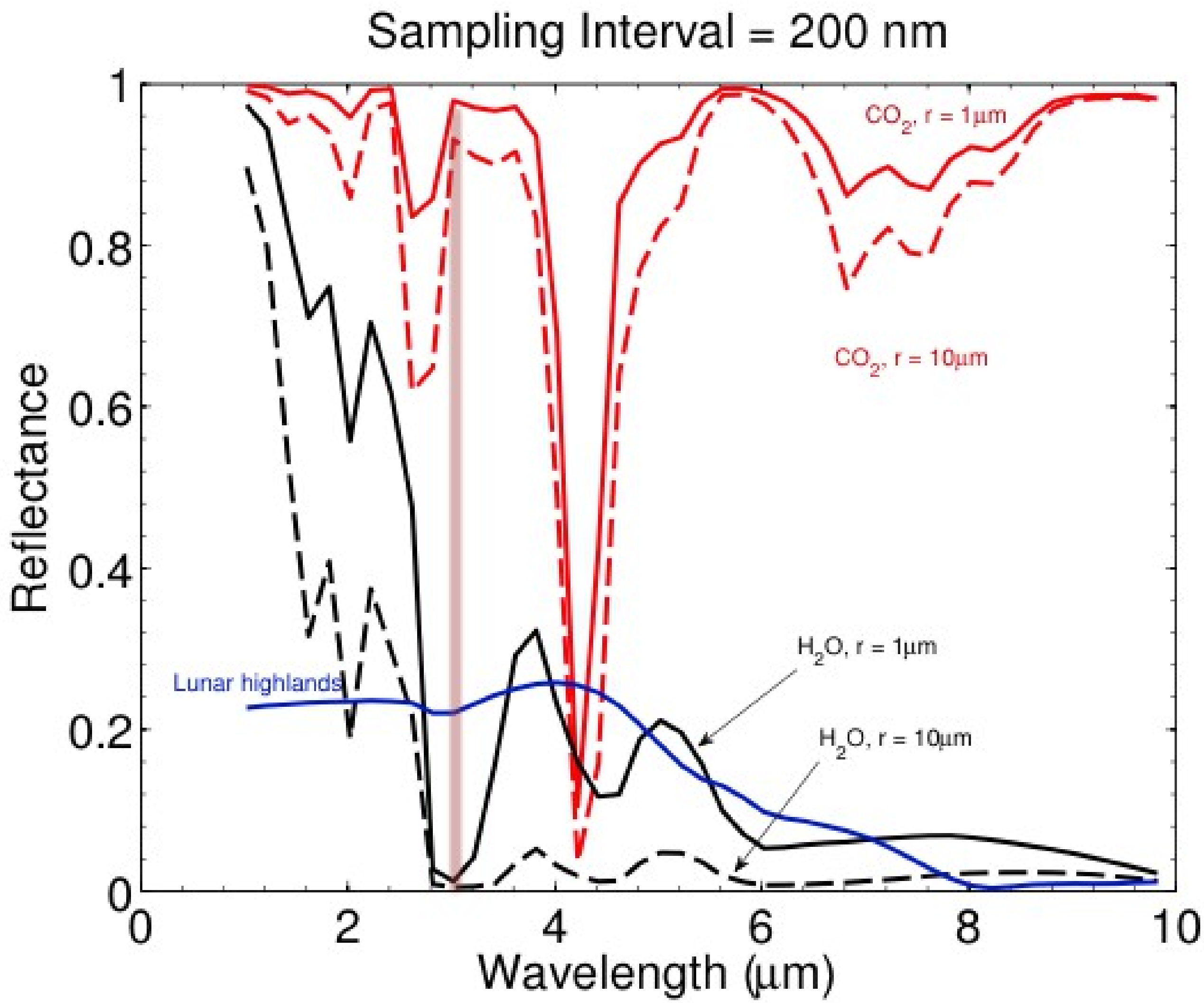
	Abundance (%)		Sublimation		
pecies	Comets	LCROSS	Temp. (K)	Likelihood	Opt. Const. Ref.
I2O	100	100	112	x	Warren and Brandt (2008)
O2	3 - 30	2.17	55	x	Hansen (1997)
O	0.4 - 20	?	18	x	Elsila et al. (1997); Ehrenfreun
H3OH	0.2 - 6	1.55	90	x	Hudgins et al. (1993)
I2S	0.2 - 2	16.75	50	x	Ferraro and Fink (1977)
IH3	0.3 - 1.5	6.03	66	x	Howett et al. (2007)
H4	0.2 - 1.5	0.65	22	x	Martonchik and Orton (1994);
H2O	0.15 - 1.5	?	57		
O2	~0.2	3.19	62	x	Wiener (1956); Hapke et al. (1
2H2	0.1 - 0.5	?	?		
CS	0.1 - 0.4	?	45		
	0.001 - 0.3 (S2)	?	245	x	
2H4	?	3.12	?		
S2	?	?	72		
Ia	?	?	201		
unar highlands*	-	2000	-	x	

Inventory of compounds with scientific interest.
Arrows indicate volatiles considered in this preliminary study
Co2 and H2o are most important for HSF



r is the ice grain size

At 3 μm, we can easily distinguish between three different item



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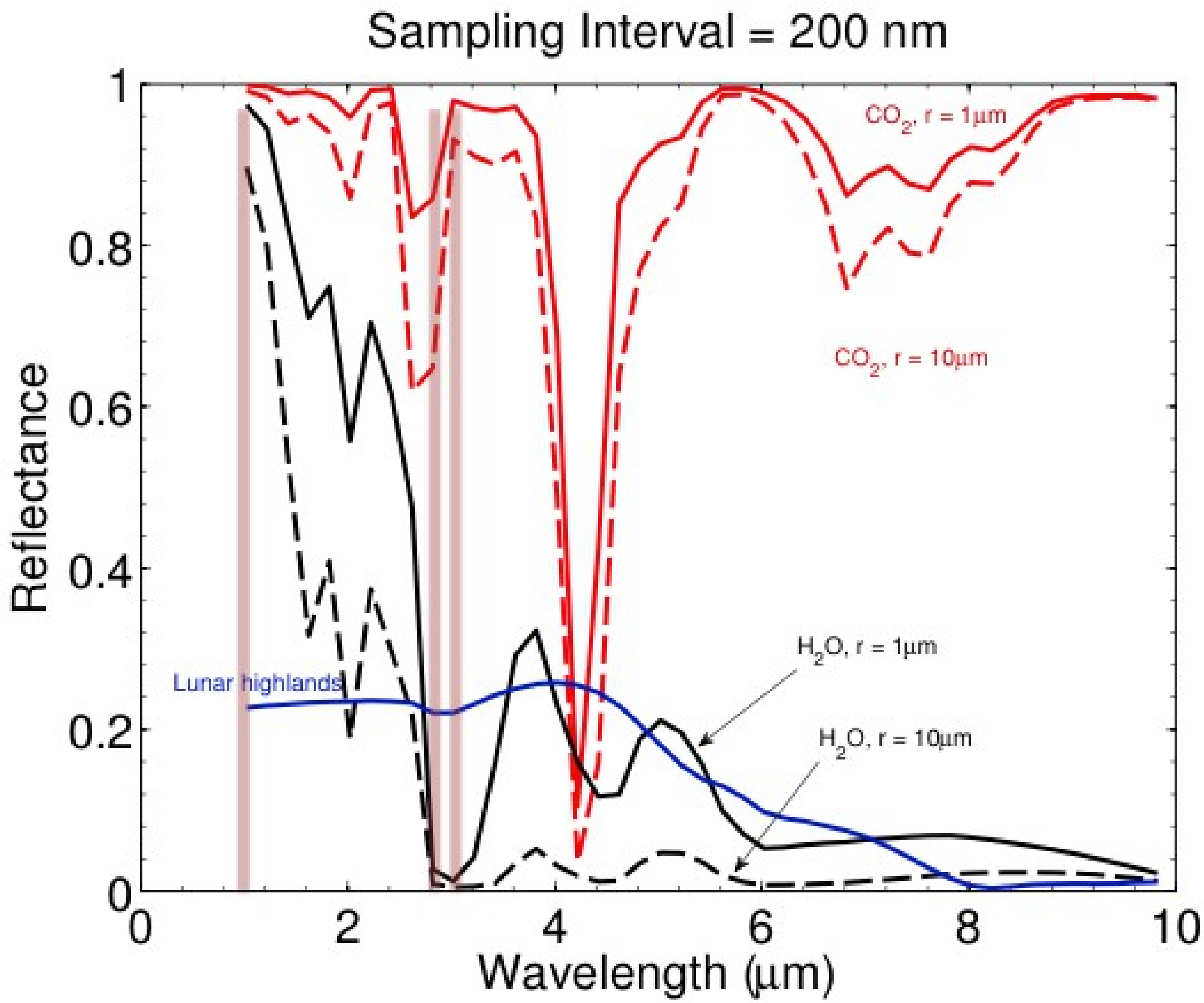

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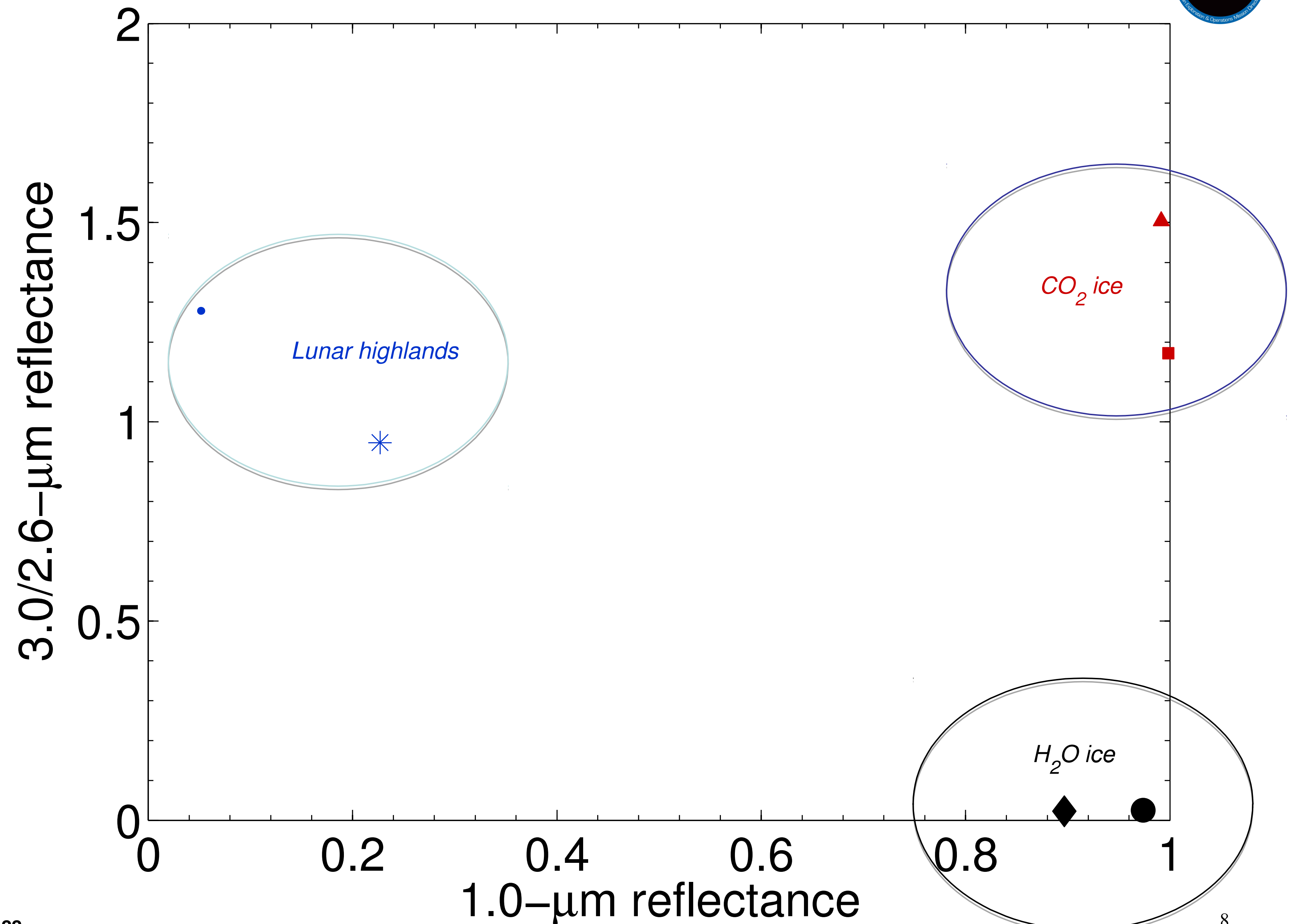
Sampling Interval = 200 nm



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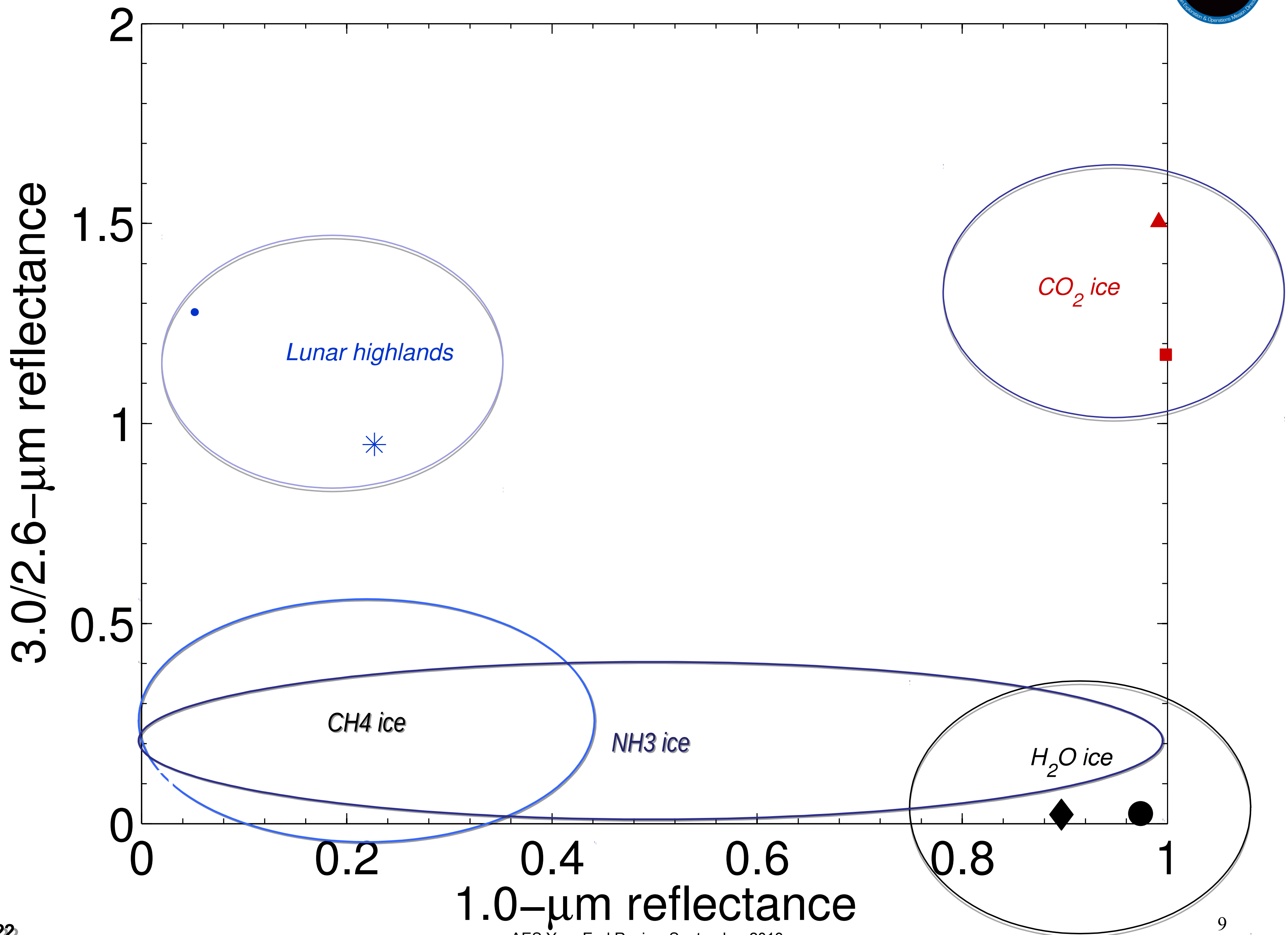
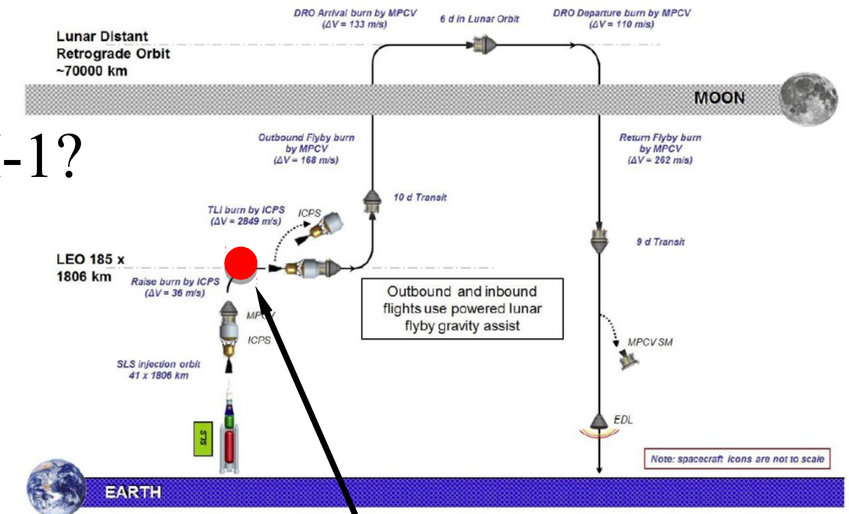
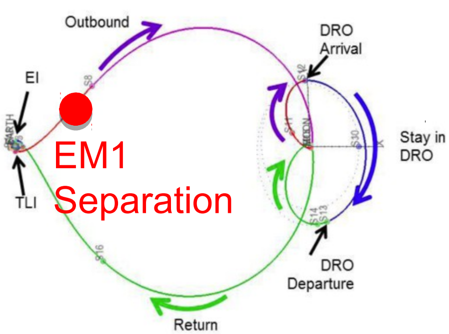


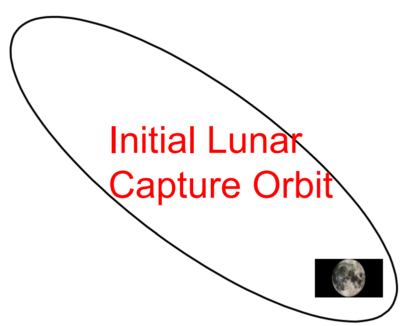
Mission/Navigation Design

- **Baseline: HEO, 20 km over S. Pole**
- **Key Trades:**
  - When to be dropped off from EM-1?
    - Right after TLI burn, To Be Confirmed.
  - How to achieve lunar capture?
    - Need Multiple Lunar Gravity Assists
    - Use Backflip Orbit to raise inclination & capture
    - Not sure we can/should use Earth gravity assist
    - Spiral down altitudes
  - Attitude Control?
    - Attitude control with Solar Sail is new, need to update models

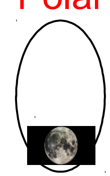


EM1 Separation
Launch + 1 Day
To Be Confirmed





Final
20xTBD (1000- 5000?) KM
Polar Orbit



Design Overview

CubeSat Overview:

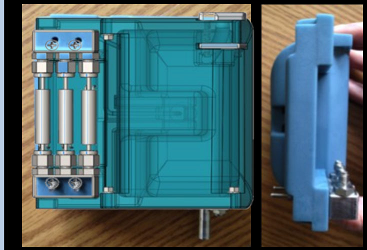
Volume: 6U (10x20x30cm3)
2U: Solar Sail and deploy mechanism
2U: Instrument
1.5U: ADACS, C&DH, Power, other
0.5U: Telecom (Iris)
Mass: ~12 kg
Propulsion: 78m2 solar sail

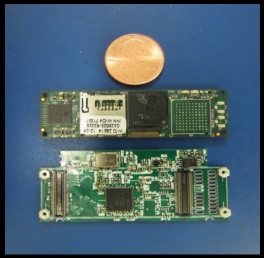
(aluminized Kaptontm)
Power Generation: ~50W
Data Rate: >10 kbps
ACS: 3-axis RWs, solar torq
CPU: Rad-Tol Dependable Multiprocessor
Radio: Iris to DSN, MSU

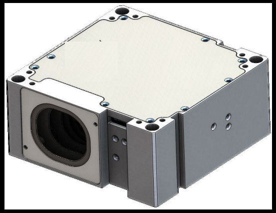
Will leverage INSPIRE
E. I. duPont & Co. trademark

Technology Demonstration Objectives:

1. **First ~80 m2 solar sail**
2. **First CubeSat to the Moon**
3. **First to use solar sail as reflector for observation**

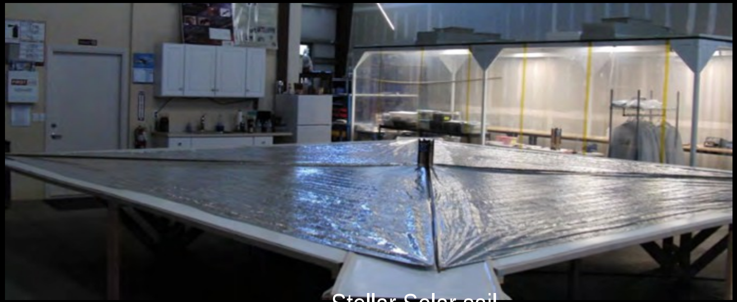

Cold-Gas ACS (U. Texas)


MSU DM


BCT XACT ADACS Module


Example Instrument JPL's NanoSat Spectrometer

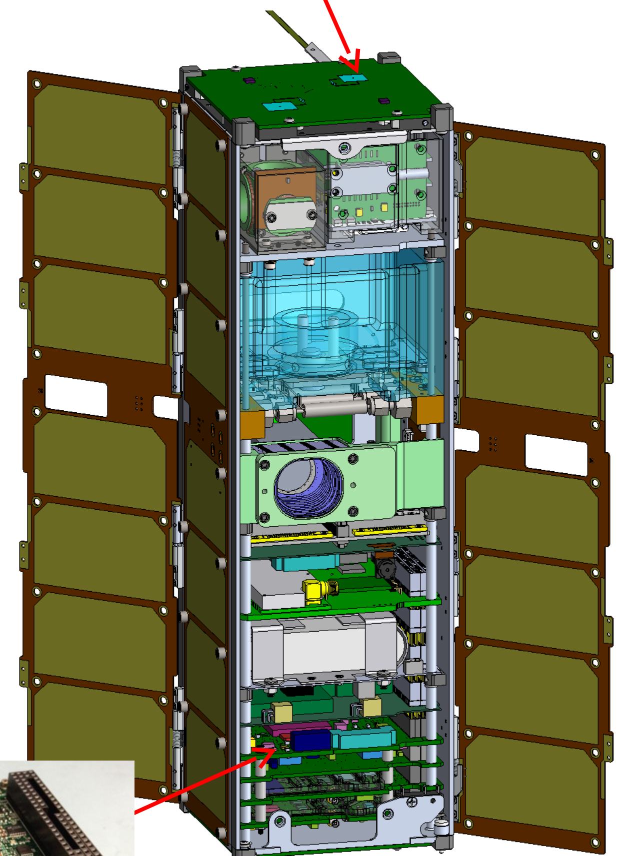

JPL X-Band IRIS Radio


Stellar Solar sail

Communications - Iris

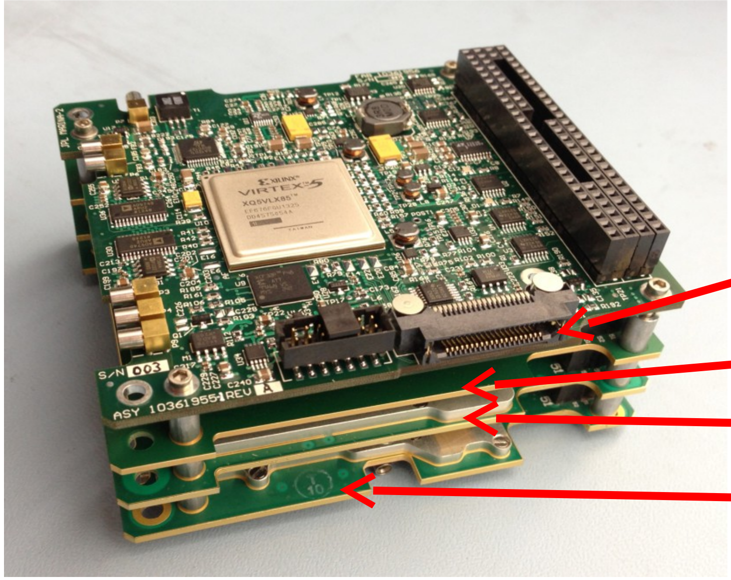
- **CubeSat Compatible / DSN Compatible Transponder**
  - Comparable and compatible to JPL UST and Electra
  - Addresses need for low mass, low power, low cost DSN compatible radio that can support Navigation
- **First Iris prototype for INSPIRE (shown), launch 2014**
  - X-Band (8.4/7.2 GHz), 1.5 M km range required
    - CCSDS, standard DSN protocols
    - Doppler / Ranging / DOR Tones
  - PC 104 stack
    - Virtex V "Marina 2" backend, UST derived FW
    - Exciter, Receiver, and power supply boards
  - 0.5U, 0.5 Kg, 10 W
  - FM delivery to INSPIRE November '13

X-Band Patch Antennas (JPL)
[two sets]



Nav/Comm
X-Band Radio (JPL)

Communications - Iris



Marina-2
FPGA
Modem
Processor

Power
Supply Board

X-Band Receiver

X-Band Exciter

Not pictured: X-Band Patch Antennas (x2)

- **JPL Iris** (daughter of Electra) **radio for communications and navigation.**
- **Pair of patch antennas, one on each end of the S/C; mostly insensitive to pointing.**
- **Downlink rate ~20 kbps @ lunar distance**
- **~10 W DC input.**

Spacecraft Bus Trades

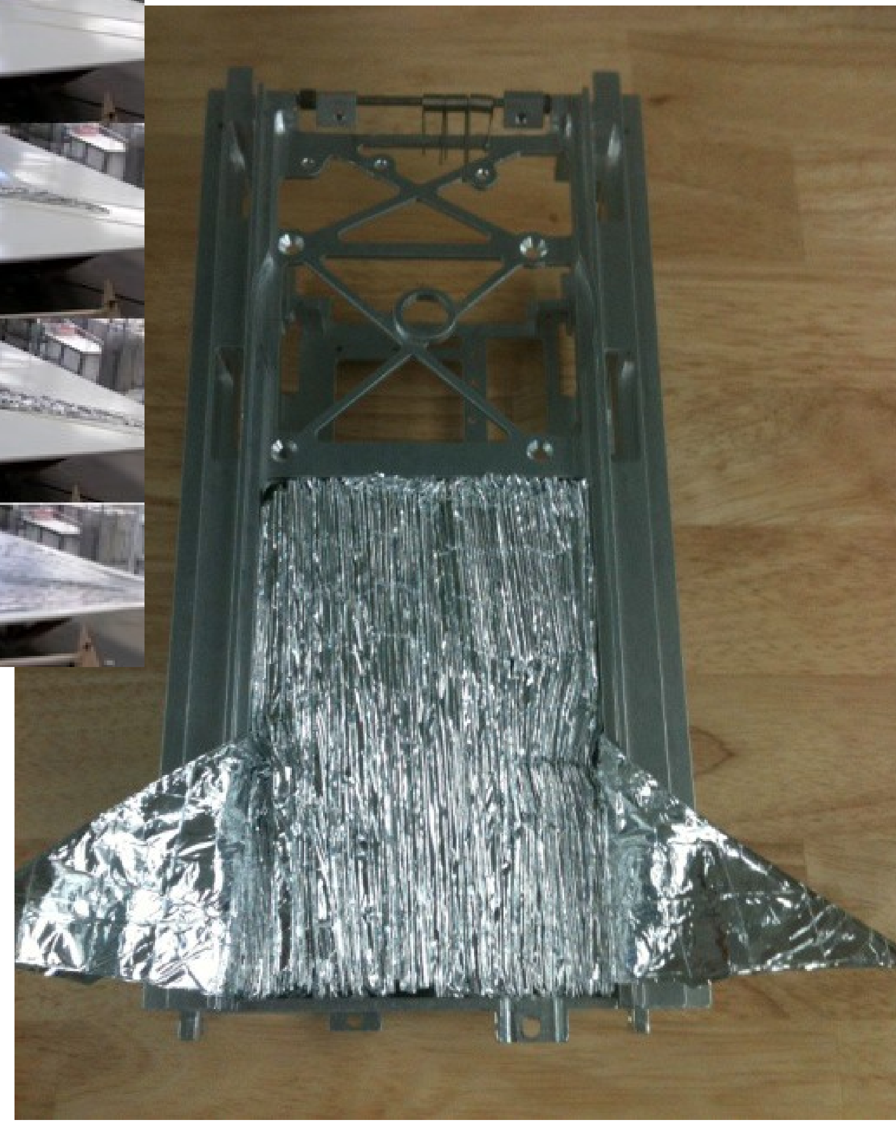
Bus: Commercial off-the-shelf (COTS) vs COTS + Custom with Flight Heritage

- **EPS/Power**: <13 Solar panels of 7.3W Each (<100W)
  - Battery Chemistry/Number/Sizing/Cycling/Capacity
  - Power System Architecture Trades:
    - Peak Power Tracking (PPT), Peak Current Tracking (PCT), Direct Energy Transfer (DET)
- **C&DH/Main Board:**
  - Distributed Architecture vs. Integrated Main Board
  - PowerPC vs Dependable Multiprocessor (DM) vs MARINA-derivative
- **Radiation Hardening vs Shielding**
  - GEANT Modeling of expected levels and induced upsets
  - Modeling of Graded-Z Material shielding of C&DH, EPS, Payload Electronics
  - Graded Z shielding vs use of hardened components
  - Software architecture to accommodate single event upsets
- **Deployer**:
  - Commercial 6U Deployer (Planetary Systems CSD, GAUSS PEPOD) vs. Ames/WFF 6U Deployer

LightSailtm-1 Eng. Model Successfully Deployed

(2011/3/4 and later tests)

http://www.youtube.com/watch?v=YMMA6bk7Kp4

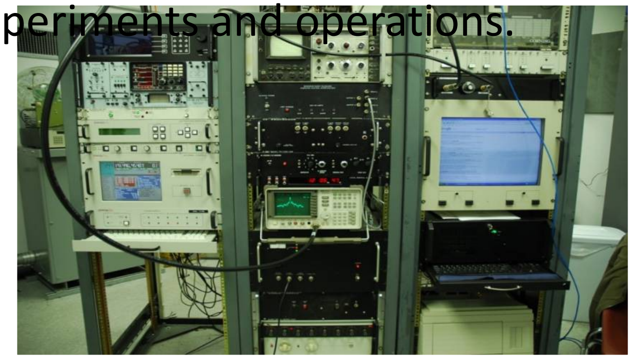


Stellar Exploration's 5.6 m on-a-side sail built for The Planetary Society can be scaled up to 8.7 m on-a-side (and perhaps as large as 10X10 m) using a somewhat more expensive boom material and thinner Kaptontm.

Trademarks belong to The Planetary Society and DuPont, respectively.

Ground Segment: Morehead 21 M

- Full-motion, high precision Dish.
- Designed and built with NASA assistance.
- Operational in 2006.
- Replaceable feeds including L-band, S-band, C-band,and Ku-band.
- Provides Experimental and IOAG Compatible TT&C services.
- Mission support includes LRO Mini-RF calibration, university and commercial smallsats.
- High gain and extreme accuracy enable telecom link with small, low power, distant S/C.
- Ideal for LEO and lunar spacecraft experiments and operations.



Solar Sail Thrust Control...to raise orbit energy

- Thrust off when moving toward Sun
- Thrust on when moving away from Sun

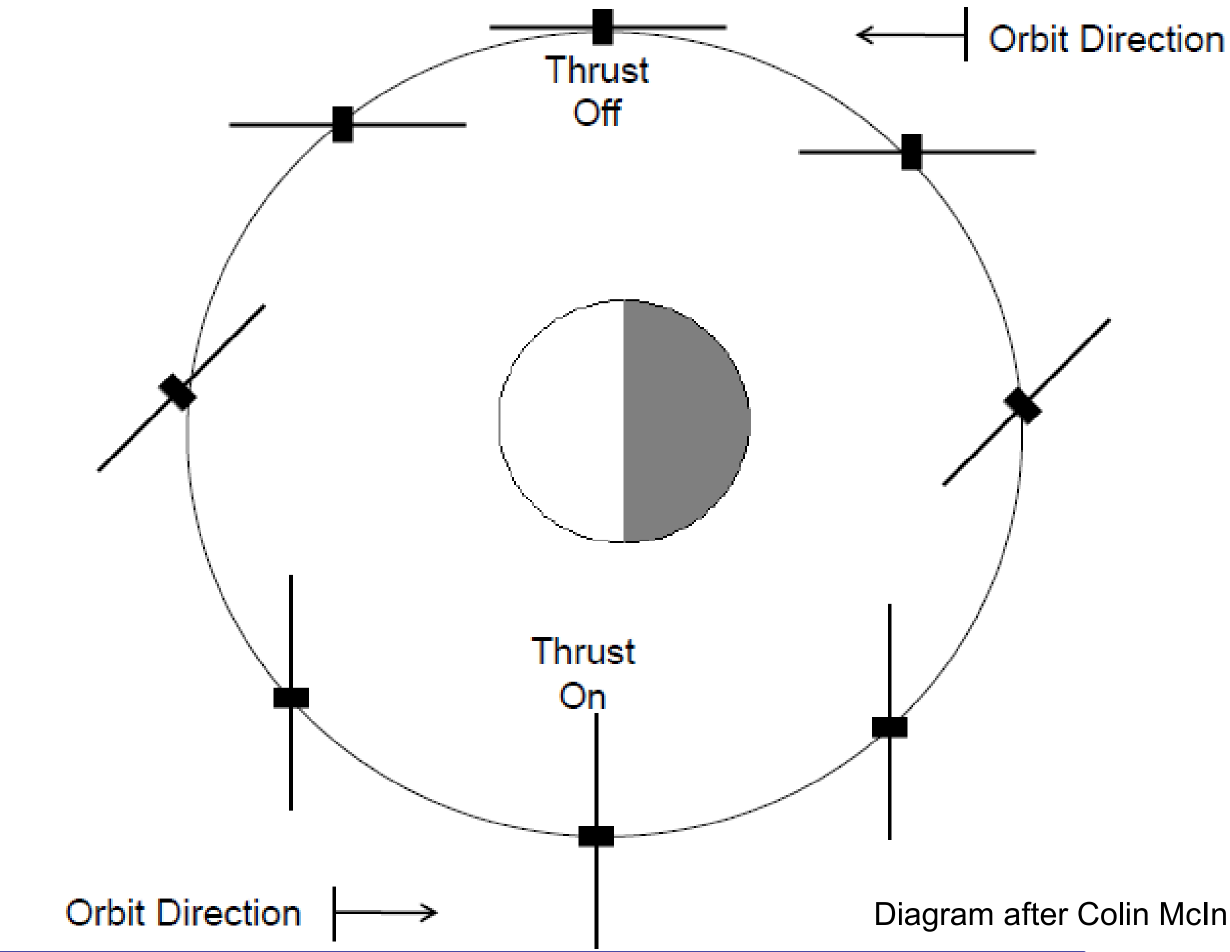
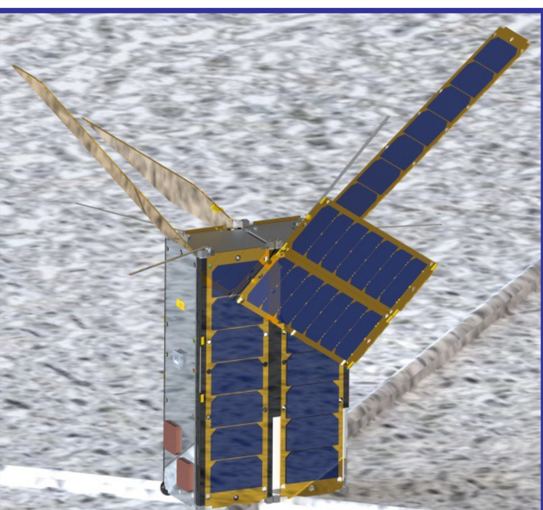


Diagram after Colin McInnes



JPL SolWISE (2012 proposal by Andrew Klesh) configuration.

Some Other Mission Challenges

- **Longevity**
  - Operational life
  - Battery life
- **Environments**
  - Radiation - not in LEO anymore
  - Thermal cycling in Lunar orbit

?Questions?

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