A Fractionated Space Weather Base at L_5 using CubeSats & Solar Sails

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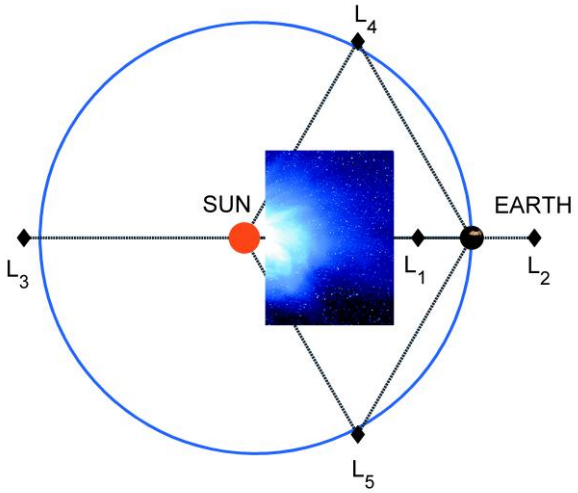
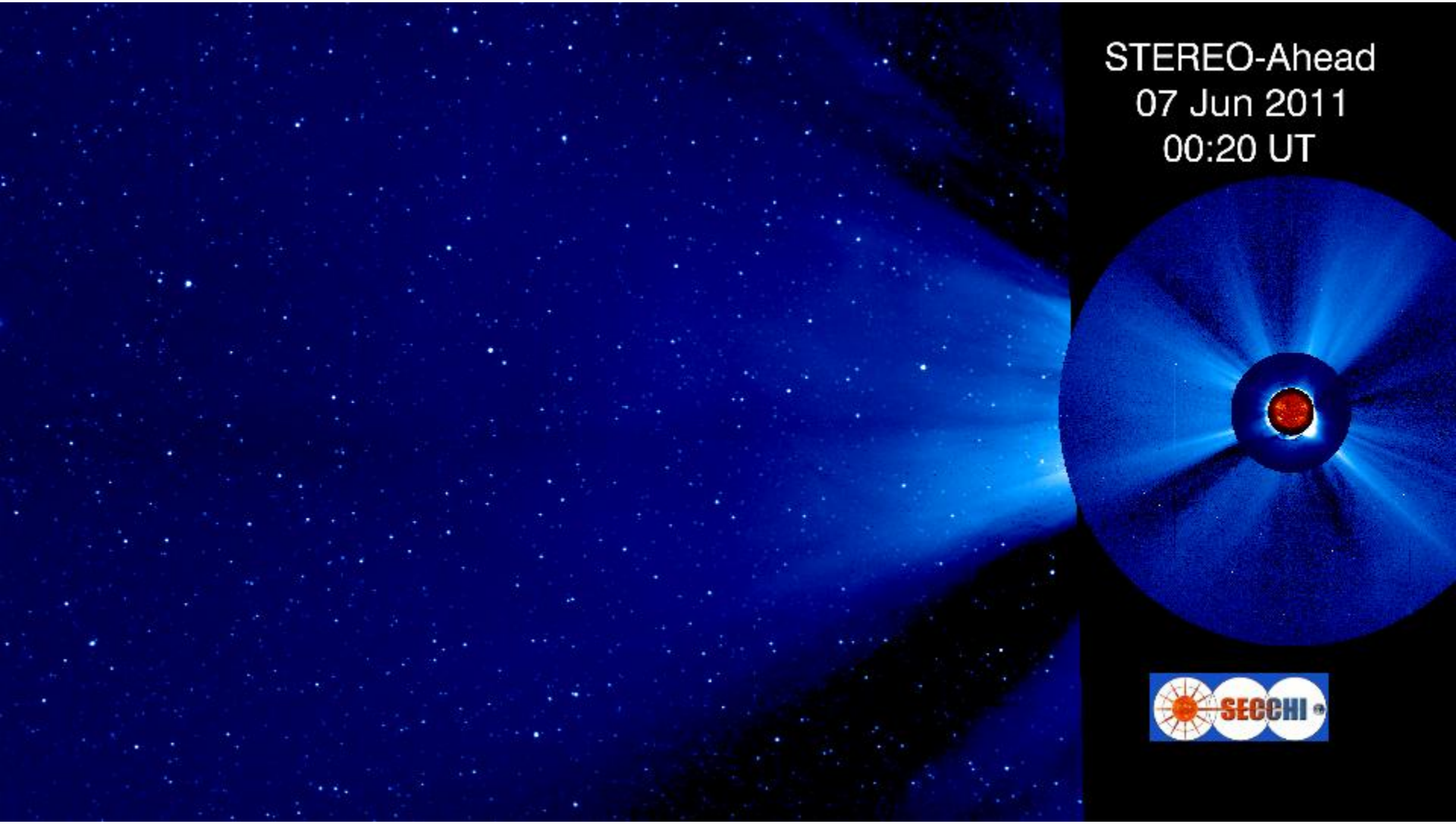


Interplanetary Small Satellite Conference, Caltech, June 2013

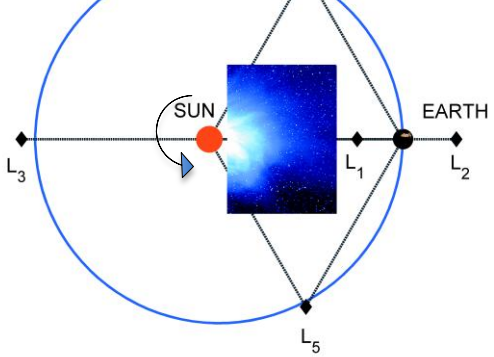
Coronal Mass Ejections (CMEs): Drivers of Space Weather



Images from 4 telescopes on STEREO A

Overview:

A Fractionated Space Weather Base at L_5 using CubeSats & Solar Sails



- Mission Goal: Provide early warning of Earth-directed solar storms (coronal mass ejections, shocks & solar energetic particles)
  - Such storms can damage power grids, spacecraft, communications systems and astronauts, but effects can be mitigated if early warning is received
- Sun-Earth L_5 Lagrange point - an ideal location for a space weather forecasting mission
  - Gives view of CMEs heading to Earth, give views of solar active regions not visible from Earth and samples solar wind conditions rotating towards Earth
- Proposed space weather missions at L_5 using conventional spacecraft & chemical propulsion cost hundreds of millions of dollars
- A fractionated Space Weather Base at L5 (SWBL5) could accomplish many of the goals at a much lower cost by dividing the payload among a cluster of 6U interplanetary CubeSats that reach orbits around L_5 using solar sails.

Space Weather Base at L_5 (SWBL5): Mission Overview

- Loose constellation of five 6U/~10kG CubeSats in ~1000 km diameter orbits around L_5
- Each carries its own solar sail, packaged in ~2U (derived from Lightsail-1™, but larger area)
- Each carries common engineering subsystems packaged in ~2U *(ADCS, avionics, solar panels ….)*
- Each also carries a unique payload in remaining ~2U
- Spacecraft 1 is Communications Hub – It collects science data from other four & relays it to Earth
  - Other four spacecraft only communicate low rate engineering/navigation data with Earth
- Other four S/C carry one or two science instruments

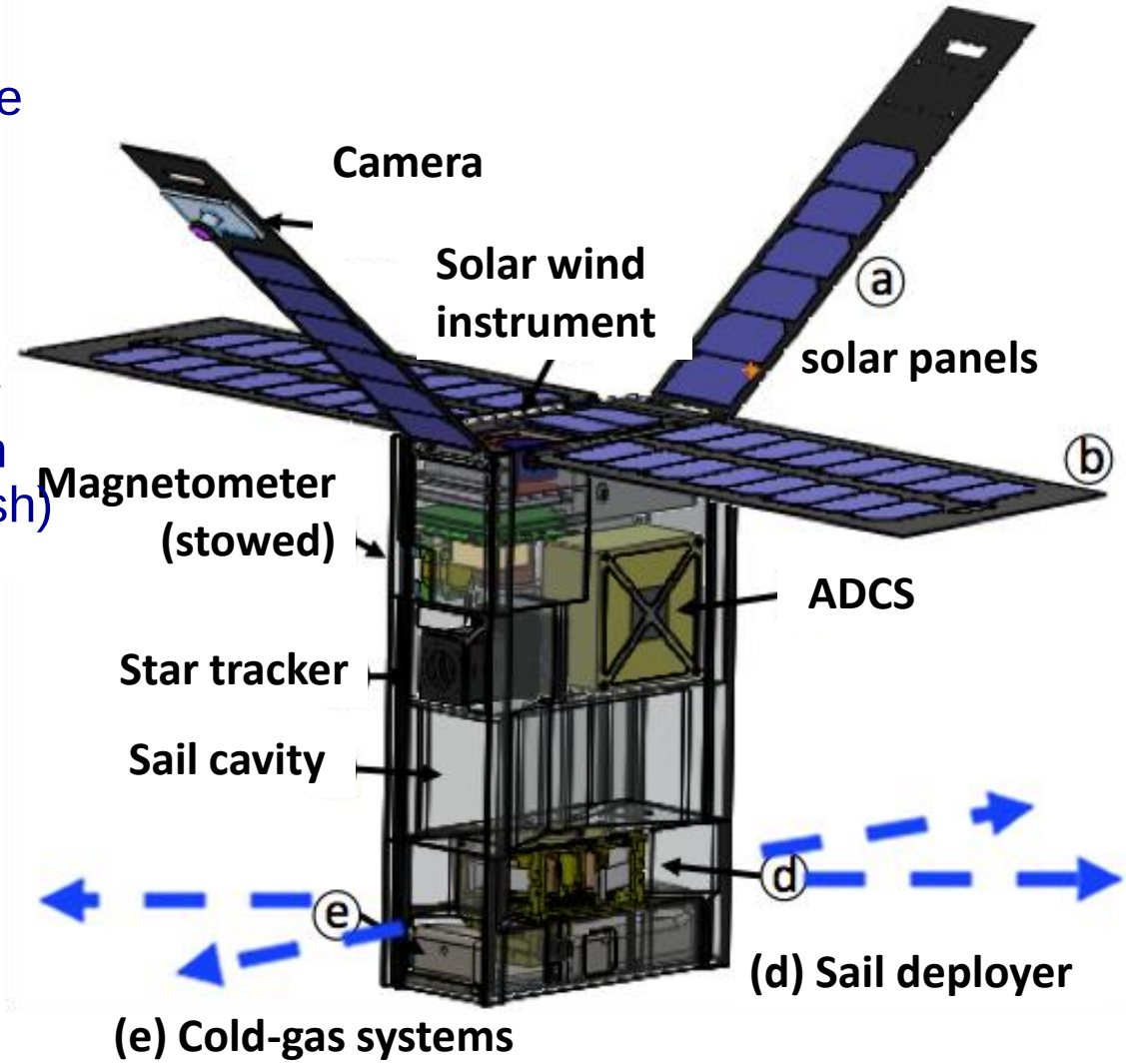
SWBL5: Concept Heritage

Conceived at KISS* workshop; draws on 3 other concepts

- Interplanetary 6U CubeSat NIAC study, led by R. Staehle
- Solwise 6U interplanetary CubeSat – unsuccessful Edison proposal, led by A. Klesh
- INSPIRE – 3U interplanetary CubeSat, selected for launch as early as 2014 (led by Klesh)

Right: The 6U SolWISE CubeSat shown after sail deployment (with sail, booms and sides hidden)

The booms deploy in the direction of the blue arrows

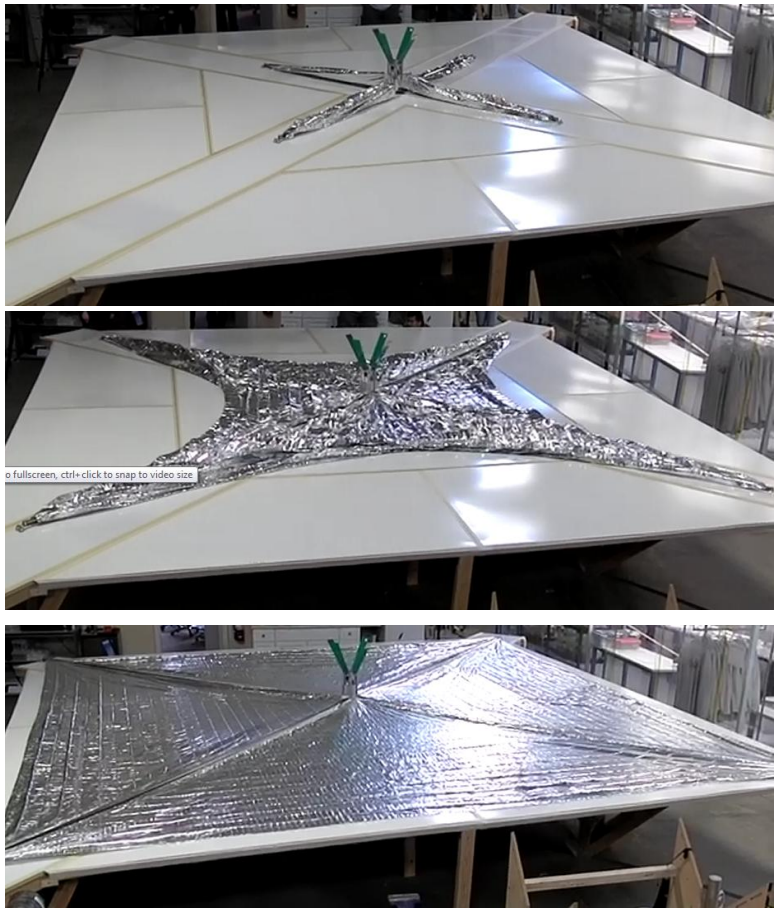


*Keck Institute for Space Studies

Deployments

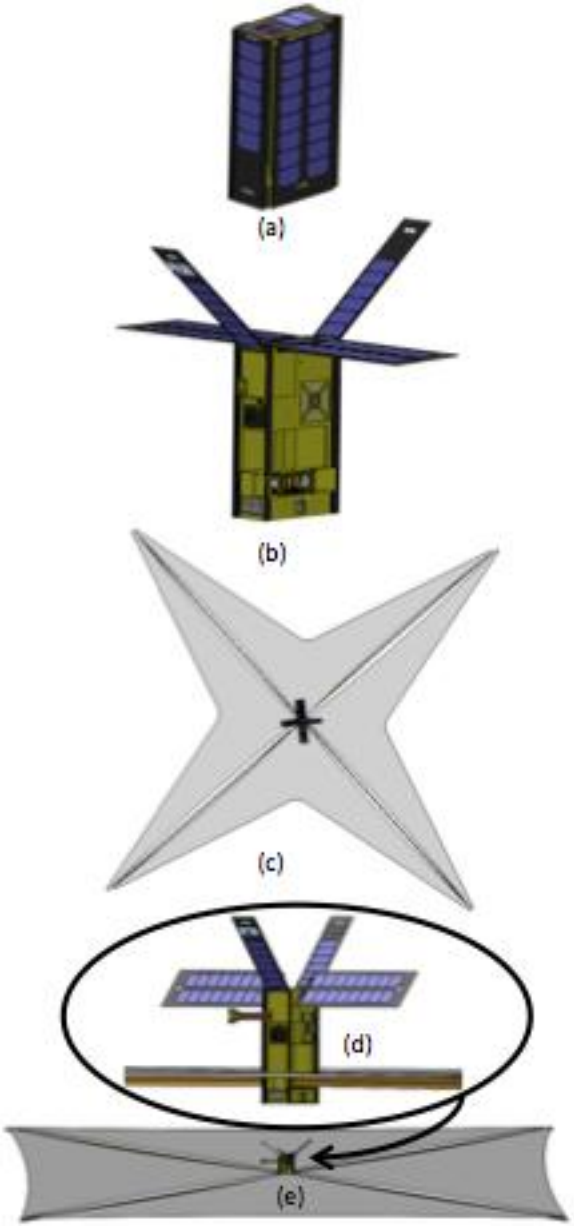
Stellar Exploration Lightsail-1™

3U CubeSat with 32m^2 sail membrane in a 2U package



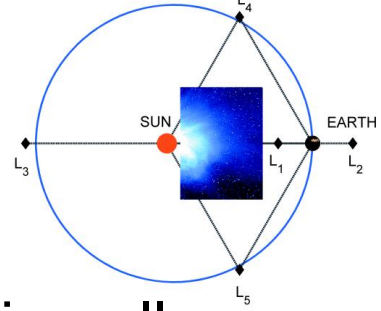
Date: 3/23/11 -- Deployment Time ~35sec

6U SolWISE



Spacecraft & Unique Payloads

~2U allocated to unique payload



① Commhub – Communication system for relaying all science data to Earth (high gain antenna, radio, etc.)

② Heliospheric Imager to image and track CMEs from the Sun to Earth

- CMEs and their shocks are the biggest space weather danger

③ Magnetograph to measure fields on Sun's surface

- Gives early warning of the appearance of solar active regions before they become visible from Earth
- Active regions are the source of the big solar storms

④ Solar Wind instrument

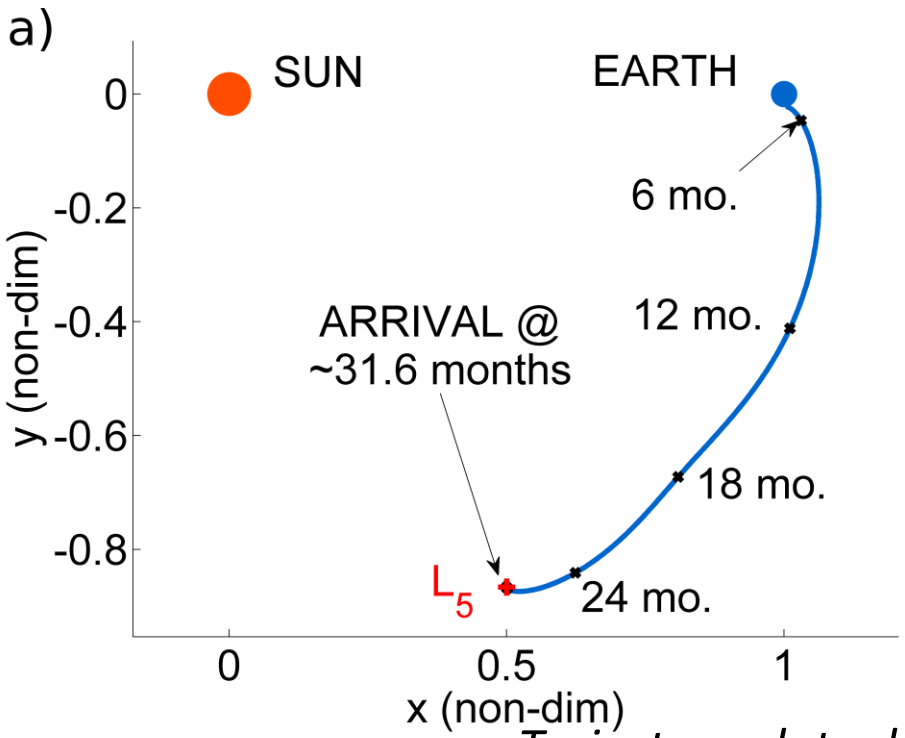
- Measures solar wind structures rotating towards Earth

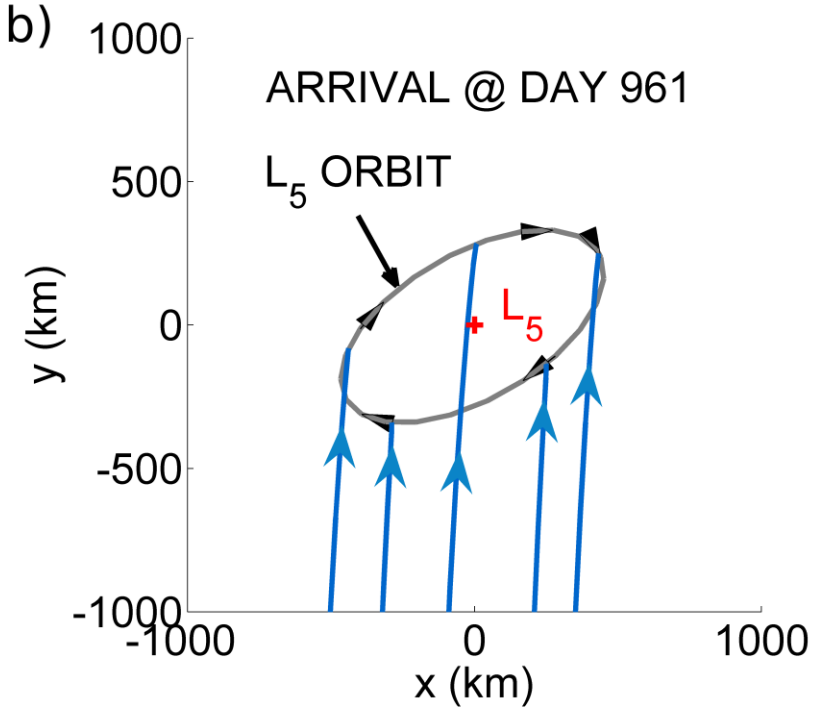
⑤ Energetic Particle instrument

- Measures energetic particle conditions rotating towards Earth

Solar Sailing to L_5

- Calculations by Anderson & Lo show can sail ~10kg CubeSat to L_5 in <3 years from Earth-escape using a commercially available ~76 m^2 sail packaged in ~2U
  - Each in a ~1000 km diameter stable orbit around L5
  - Easy to assemble constellation from single or multiple launches





Trajectory plots shown in rotating frame

Technology Status

Many technologies need to be matured

- Multiple CubeSat Missions in next few years should lead to rapid development and maturation of many relevant technologies

- INSPIRE (2 3U Interplanetary CubeSat Mission) will help mature
  - Iris radio with X-band inter-spacecraft communication (JPL)
  - Avionics – modified RAX-2 (UMich)
  - Electrical power – RAX-2 (UMich)
  - Attitude Determination and Control (ADCS) – U Texas/Austin
  - Compact Helium Magnetometer ~1/2 U size (JPL)
  - Launch in 2014-15

INSPIRE: Design Overview

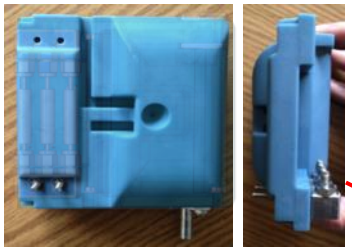
CubeSat Overview:
Volume: 3U (10x10x30cm)
Mass: 3.8 kg
Power Generation: 20 W
Data Rate: 62-64000 bps

Software:
Developed in-house

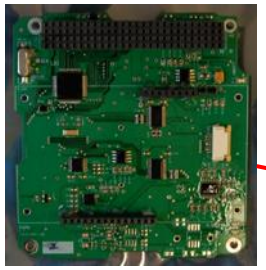
I&T:
In-house S/C I&T, CalPoly P-Pod/Launch Integration

Operations:
DSN, DSS-13 (JPL), & Peach Mountain (U. Michigan)

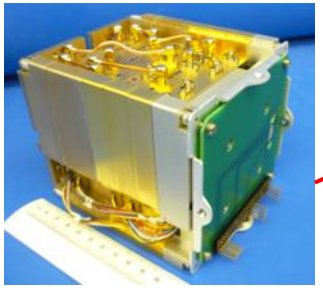
S/C components would provide ***the basis for future high-capability, lower-cost-risk missions*** beyond Earth expanding and ***providing JPL leadership in an emergent domain***



Cold-Gas ACS (U. Texas)



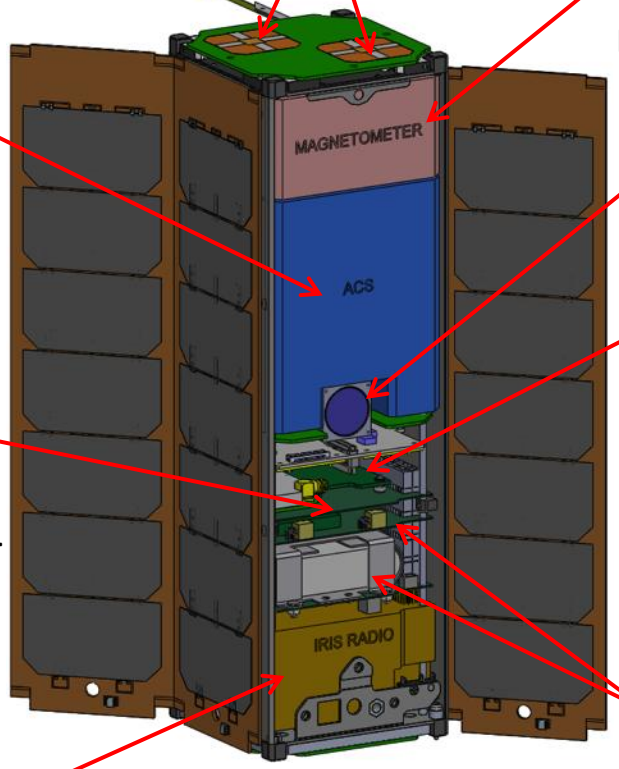
C&DH + Watchdog Board + Lithium UHF (U. Michigan)



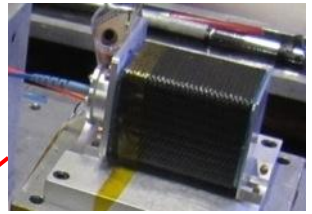
Nav/Comm X-Band Radio (JPL)

UHF Antenna

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



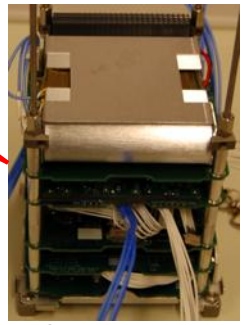
Deployable Solar Panels + Structure (Pumpkin)



Magnetometer (JPL)

Star Tracker (Blue Canyon)

Processing Board (CalPoly)



Electrical Power System + Battery Board (U. Michigan)

Technology Challenges for SWBL5

- Sail System
  - Lightsail™ flight demonstration – now ready to fly
- Attitude control with solar sail – especially for Heliospheric Imager CubeSat
  - Pieces of ADCS system exist, but need to test them together with the solar sail
- Communications System
  - Requirements/design concept for navigation and communication for all constellation members
  - Deployable ~1m antenna and more for CommHub in ~2U
- Avionics: Fault tolerance to last 5+ years in deep space
- Compact instruments (Heliospheric imager, energetic particle, solar wind)

Advantages of Fractionated Approach

- Existing solar sails are sufficient for propulsion, reaching L_5 in < 3 years
- Spacecraft requirements eased when *in situ* fields and particle (F&P) instruments on different spacecraft. F&P instruments prefer spinners & imaging instruments require 3-axis stabilization; Instruments can interfere with each other
- Integration and testing is much easier and cheaper for several simple small spacecraft than one large spacecraft with many instruments with conflicting requirements
- Cluster can be built up incrementally; different agencies or institutions could contribute their own CubeSat
- Fractionation allows incremental upgrading of capabilities or replacement of degraded/failed spacecraft at much lower cost
- The Space Weather Base could be expanded later by adding other (perhaps larger) spacecraft with new instruments (solar coronagraph, solar EUV and X-ray imagers and spectrometers) to address additional science goals

Conclusions

A Fractionated Space Weather Base at L_5 using CubeSats & Solar Sails

- Even with the technology development and flight testing needed, a mission like SWBL5 could be ready for launch before the next Heliophysics decadal review in ~2022
  - Because CubeSat technology development time scale is very short compared to conventional space technology

- SWBL5 could represent a beginning for a permanent Space Weather Forecasting Base at L_5

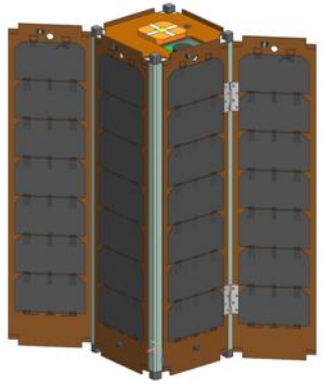
- SWBL5 is also on development path for a fractionated Solar Polar Imager mission – which explorers the polar regions of the Sun using a ~0.5 AU polar orbit around the Sun

Backup

INSPIRE: Fact Sheet

INSPIRE would enable a new class of interplanetary explorer, while providing components to reduce the size and cost of traditional missions

Mission Objectives

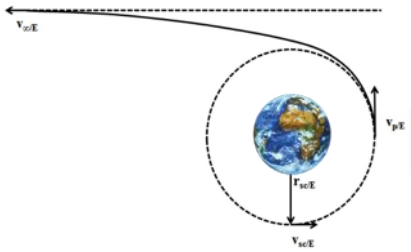


- Demonstrate and characterize key nano-spacecraft telecommunications, navigation, command & data handling, and relay communications for mother-daughter
- Demonstrate science utility with compact science payload (1/2U Helium Magnetometer and combination Star-Tracker/Imager)
- Demonstrate ability to monitor and power cycle COTS/university processing systems

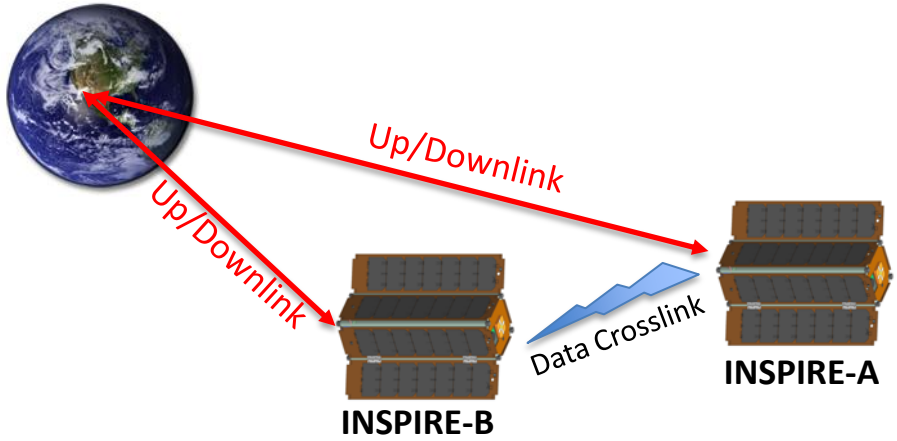
Mission Concept

- JPL-built spacecraft; collaborative partnerships with Michigan, Texas, and CalPoly/Tyvak for COTS processing systems. Ground stations at U. Michigan and Goldstone with DSN compatibility

Nominal:
CLI Launch:
Ready by
Summer 2014



Nominal:
Deploy to Escape



RAX-1

- CubeSat technology has advanced incredibly rapidly
- RAX-1: A successful 3U CubeSat Science Mission