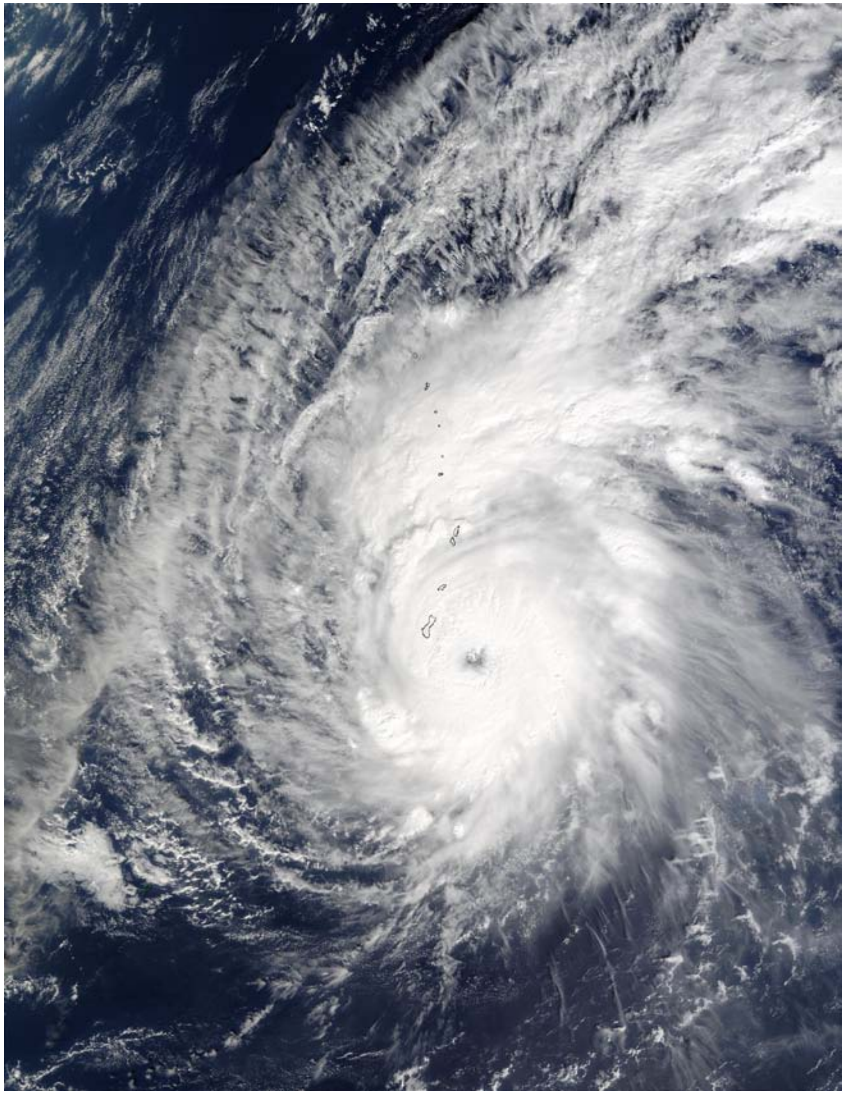
Microsized Microwave Atmospheric Satellite (MicroMAS)

K. Cahoy, R. Kingsbury, E. Peters, A. Marinan, M. Prinkey, E. Wise, P. Dave, S. Paek, C. Pong, D. Miller, D. Sklair, B. Coffee, L. Orrego, E. Main, K. Frey, R. Aniceto, P. Vaidyanathan

Overview

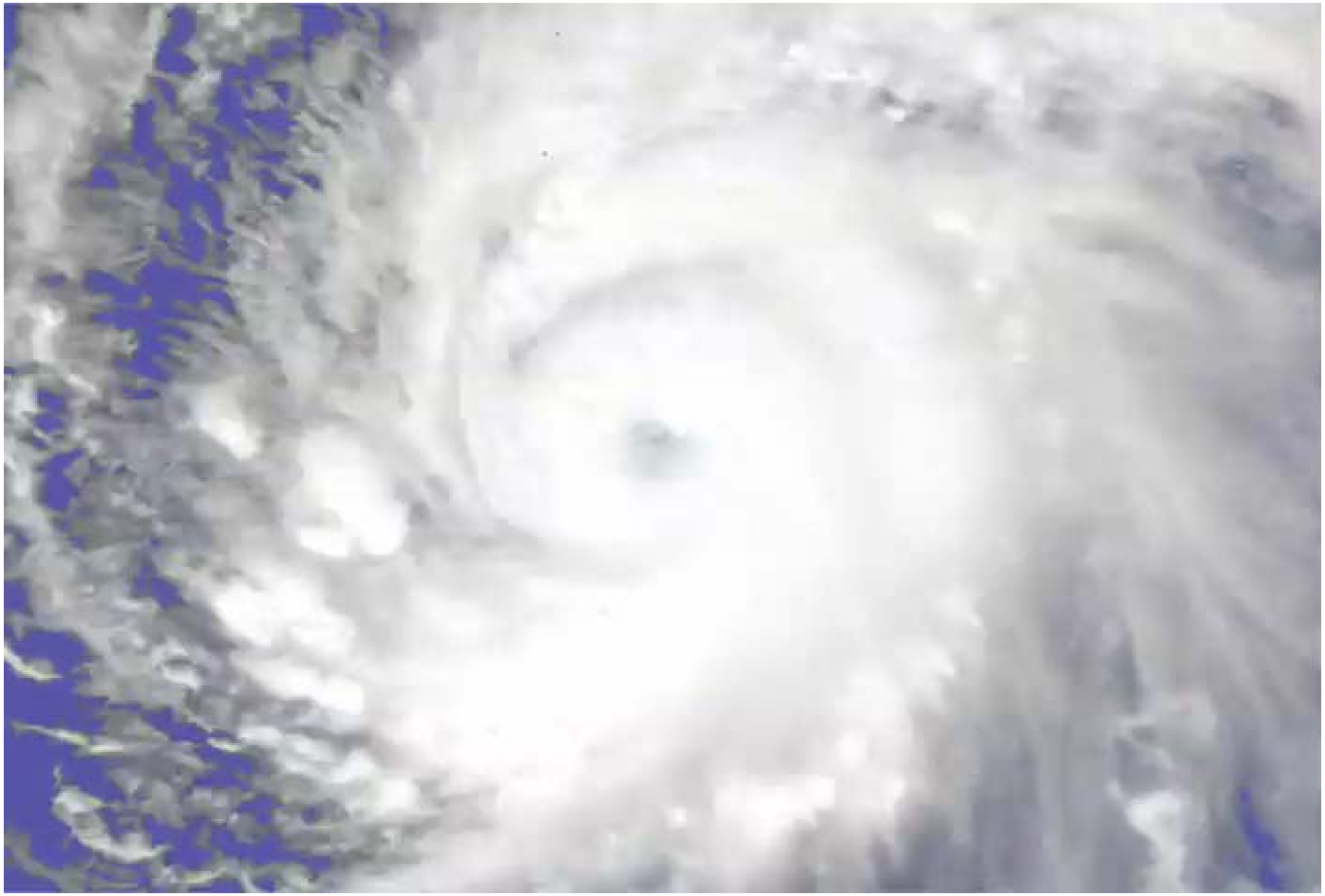
- About MicroMAS
- Movies
- Key design features
- Integration and test
  - Stack buildup
  - ADCS
  - Mass mockup
- Path forward
- Long term goal: constellation

Hurricanes, Tropical Storms, and Typhoons



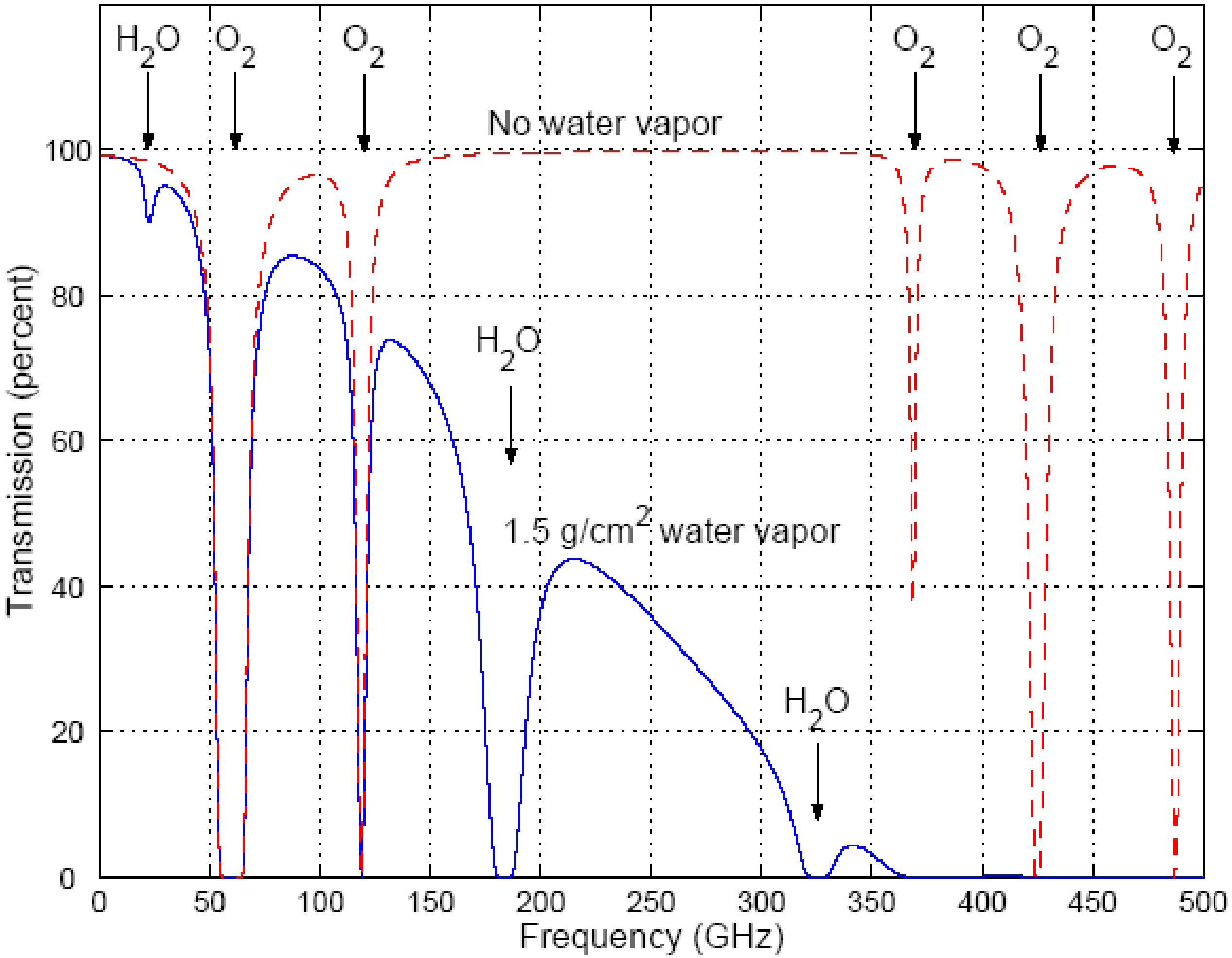
- Super Typhoon Pongsona (Dec 8, 2002)
  - MODIS image (Terra)
  - Want the core and water vapor with altitude
  - Microwave radiometers do this

“Looking them in the eye”



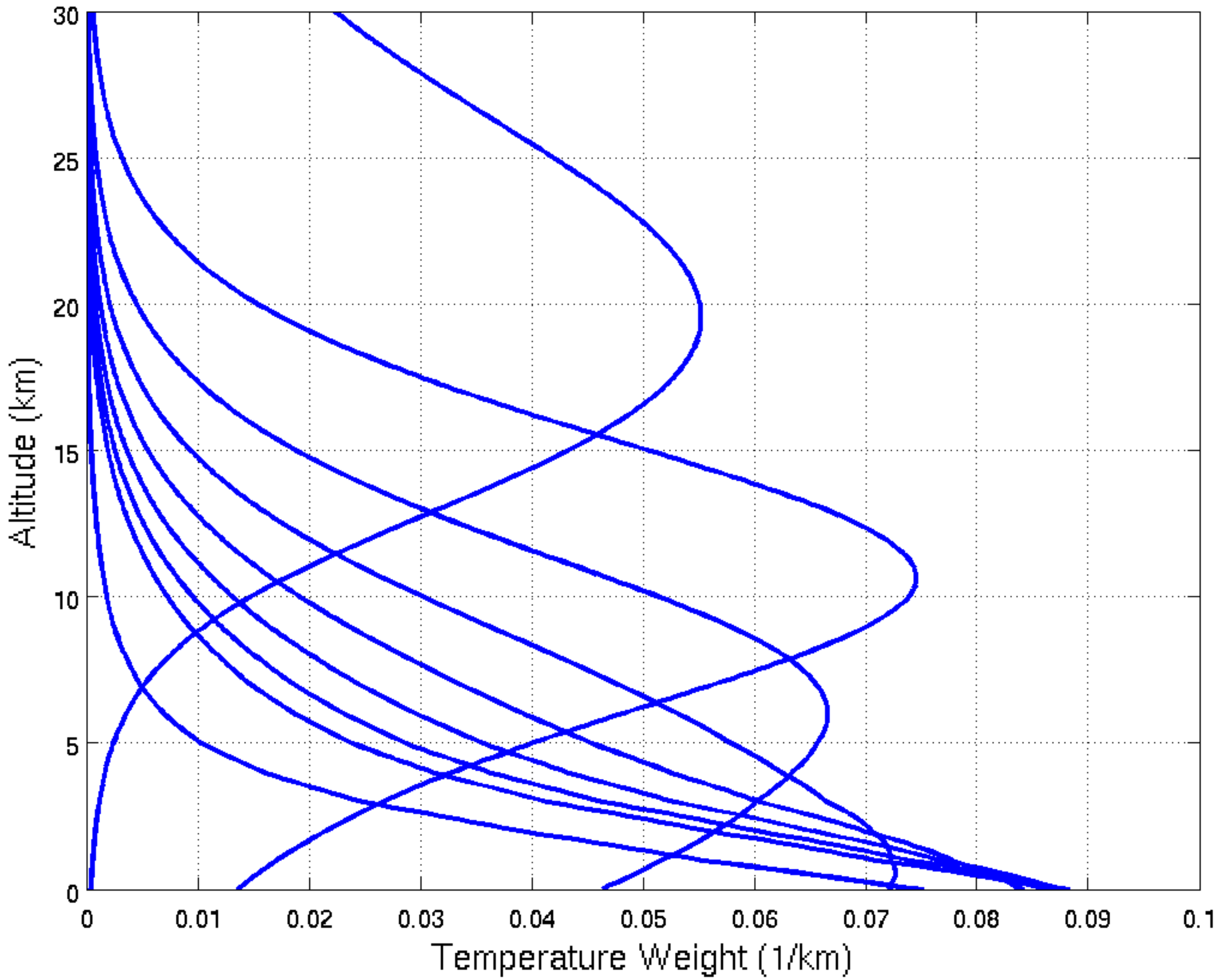
- Atmospheric Infrared Sounder (AIRS) with Advanced Microwave Sounding Unit (AMSU) on Aqua (Sun-synch)

Cloud Penetration



- MicroMAS 118 GHz, 9 channels

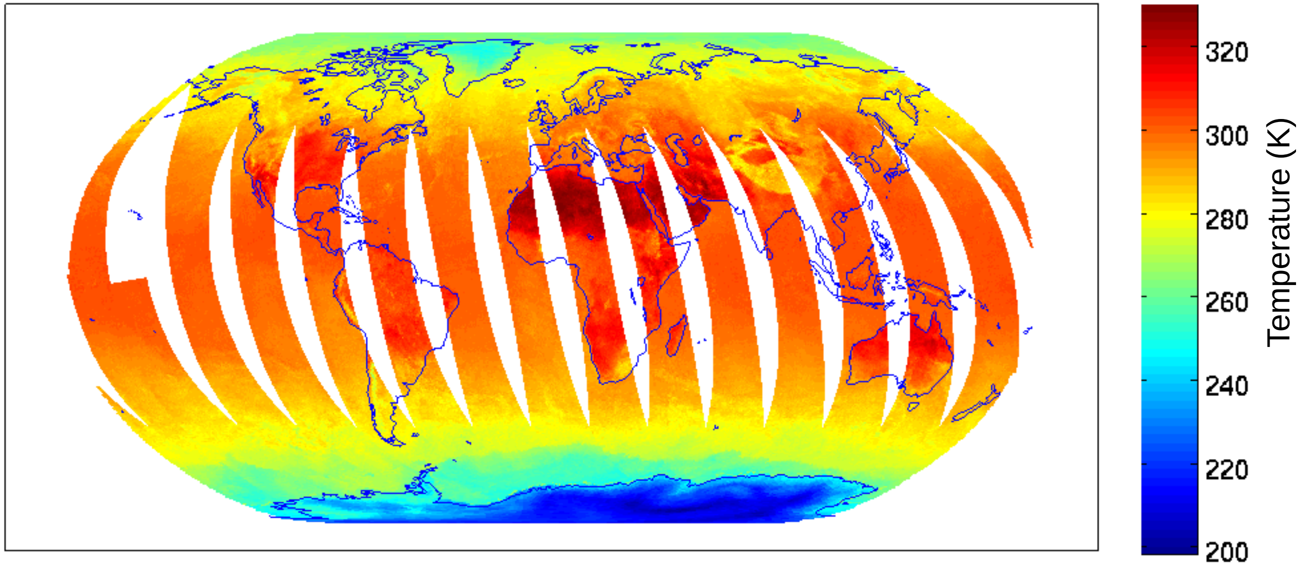
Temperature vs. Altitude



- Channels sample different altitudes

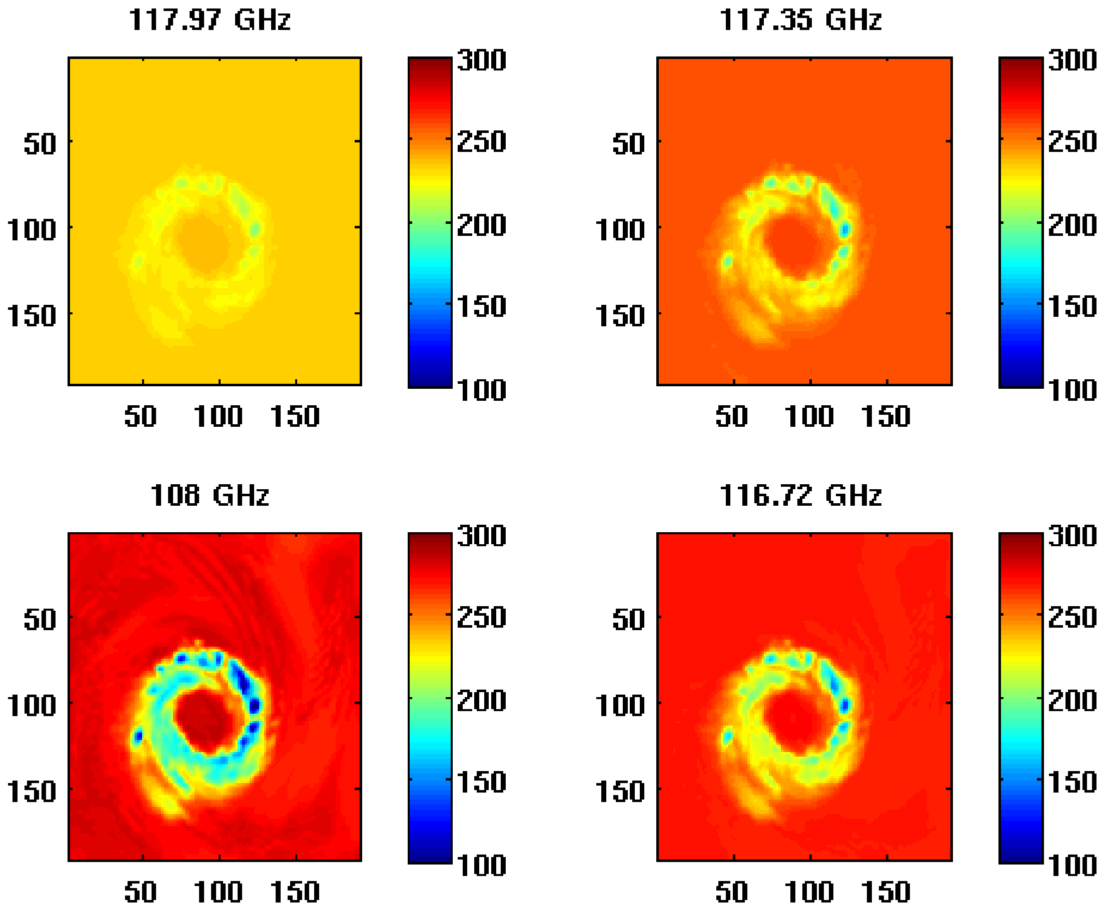
Why put radiometers on CubeSats?

- Currently in sun-synch orbits
  - Twice daily revisits
  - Better temporal coverage with LEO CubeSats (90 min)
  - Lower altitude, better signal + resolution
- Cost
  - $1B vs 1M
- Replaceable
- Distribute channels



AIRS/AMSU (NASA Aqua) Mosaic of Ascending Orbits on Sep 6, 2002

MicroMAS modeled performance



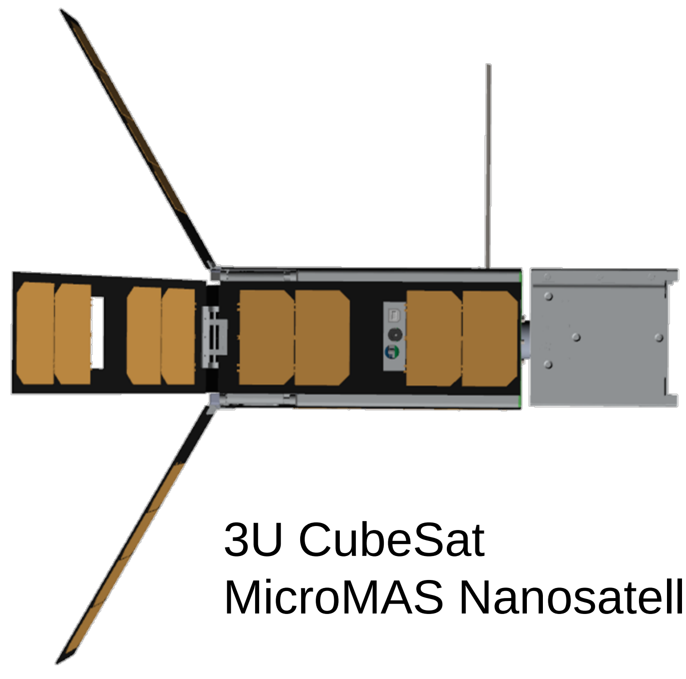
- Super Typhoon Pongsona (Dec 8, 2002)

MicroMAS

- http://www.youtube.com/watch?v=hY3YMs5ZIb0&feature=youtu.be

Objectives

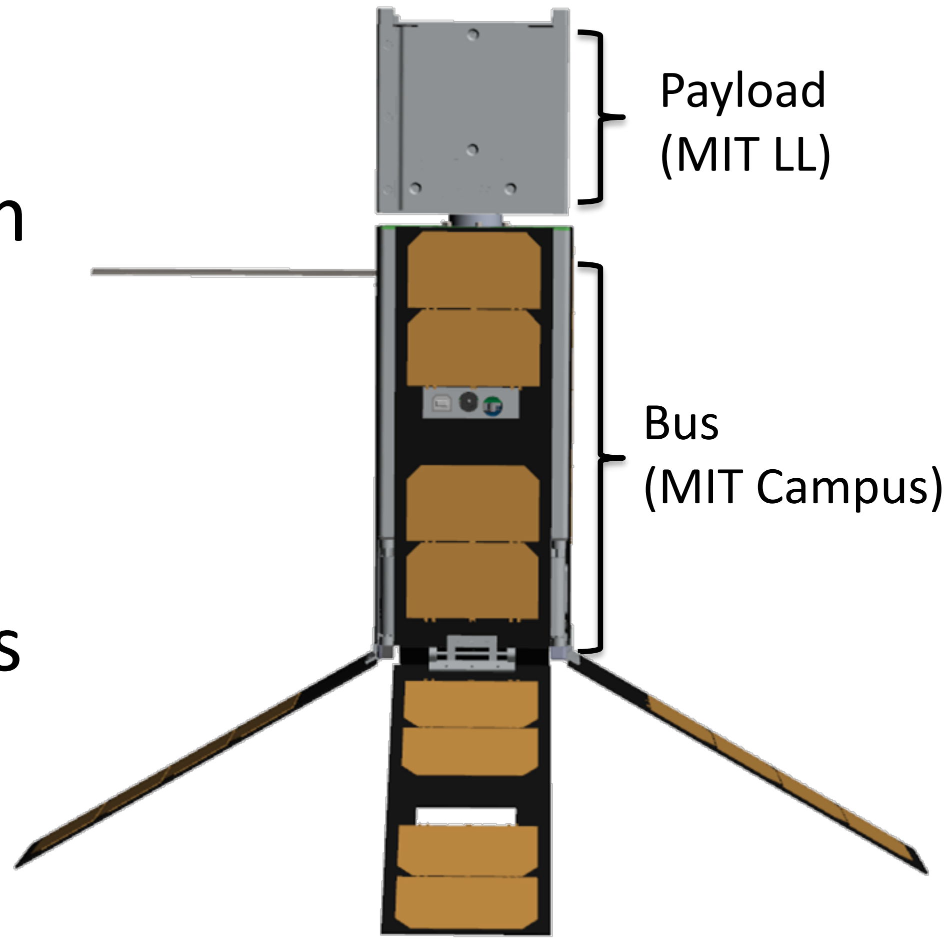
- Focus on hurricanes + severe weather
- 500-km orbit altitude
- 25-km pixel diameter at nadir (cross-track scan out to ±50°)
- 1 K absolute accuracy
  - 0.3 K sensitivity
- Geolocation error threshold 52 arcmin
  - 30% of 25 km pixel diameter at altitude of 500 km
- 20 kbps (avg) downlink
- 12 W (avg) power
- One year mission lifetime
- 2014 launch by NASA ELaNa



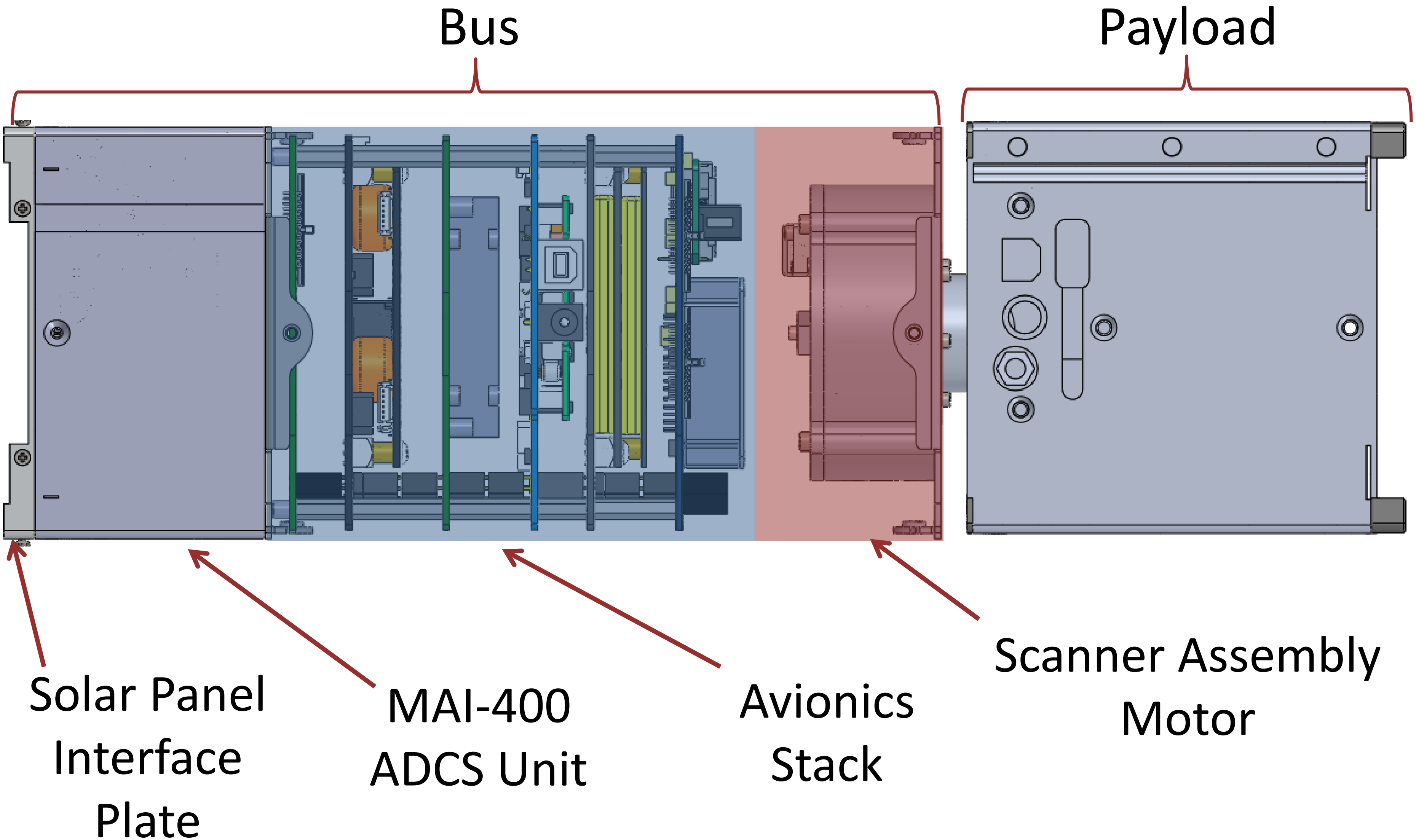
3U CubeSat
MicroMAS Nanosatellite

Design Overview

- 3U CubeSat
- 1U Payload + 2U Bus connected via custom scanner assembly
- 4, 2U double-sided deployed and body-mounted solar panels
- Deployed measuring tape antenna
- MAI 400 ADCS Module

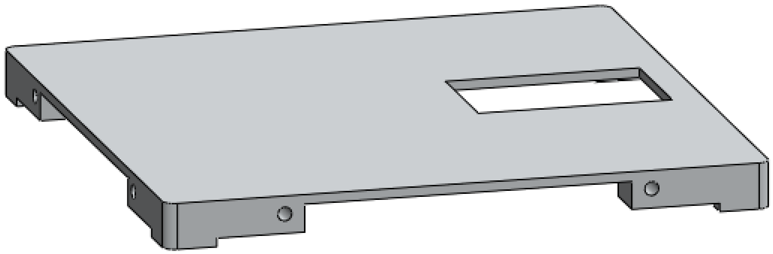


Design Overview



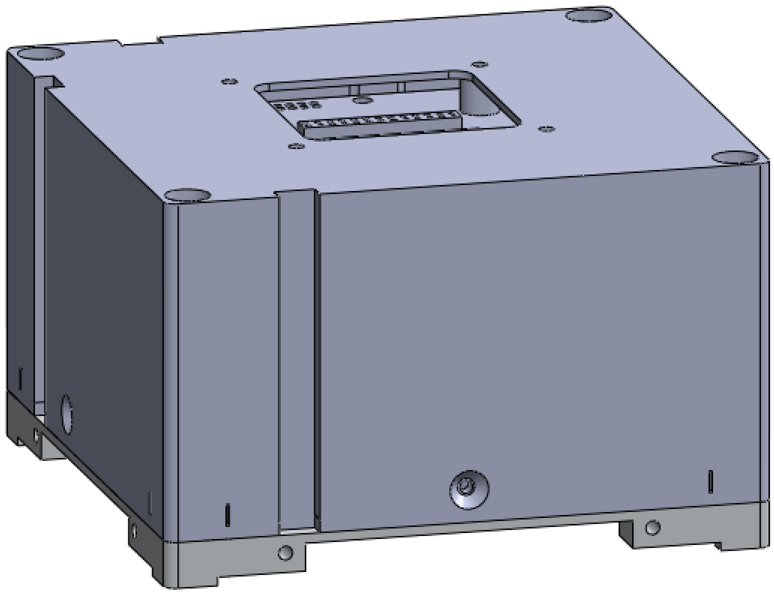
Systems Integration

- **Bottom Interface Plate**
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



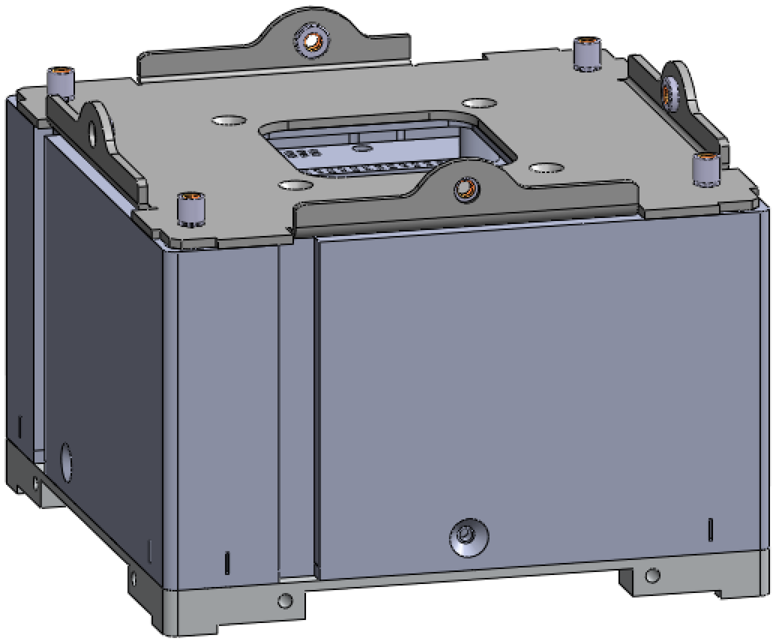
Systems Integration

- Bottom Interface Plate
- **MAI-400**
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



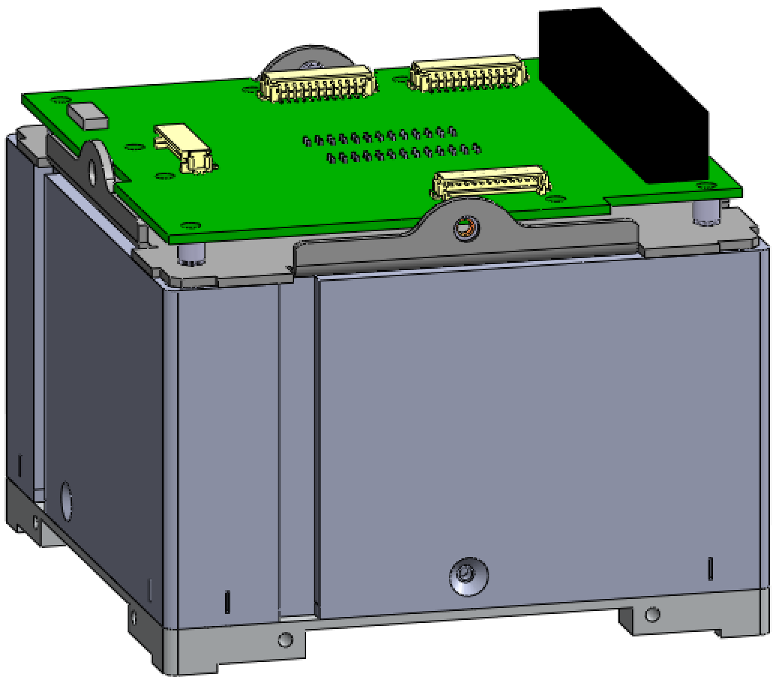
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - **Chassis Base Plate**
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



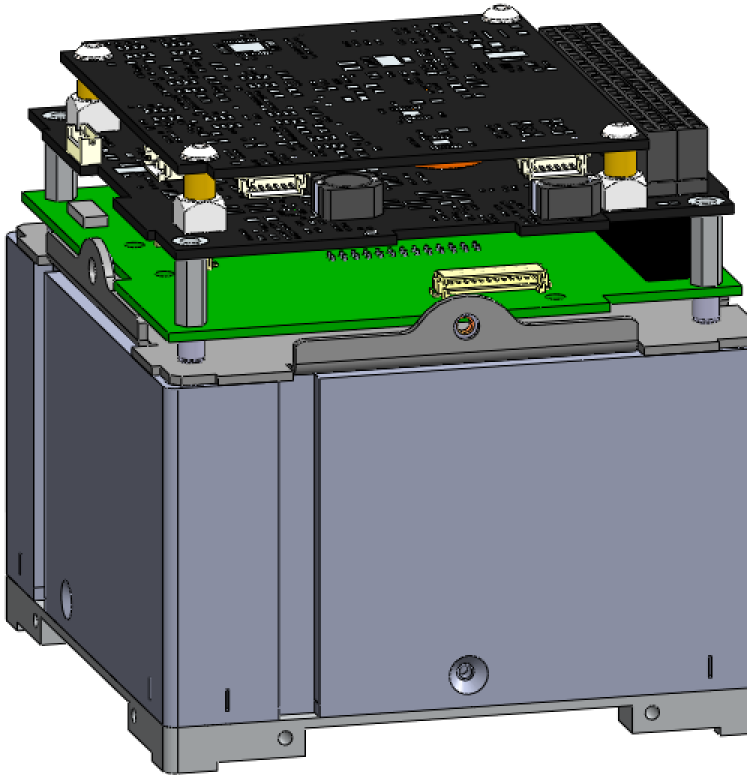
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - **Bottom Interface Board**
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



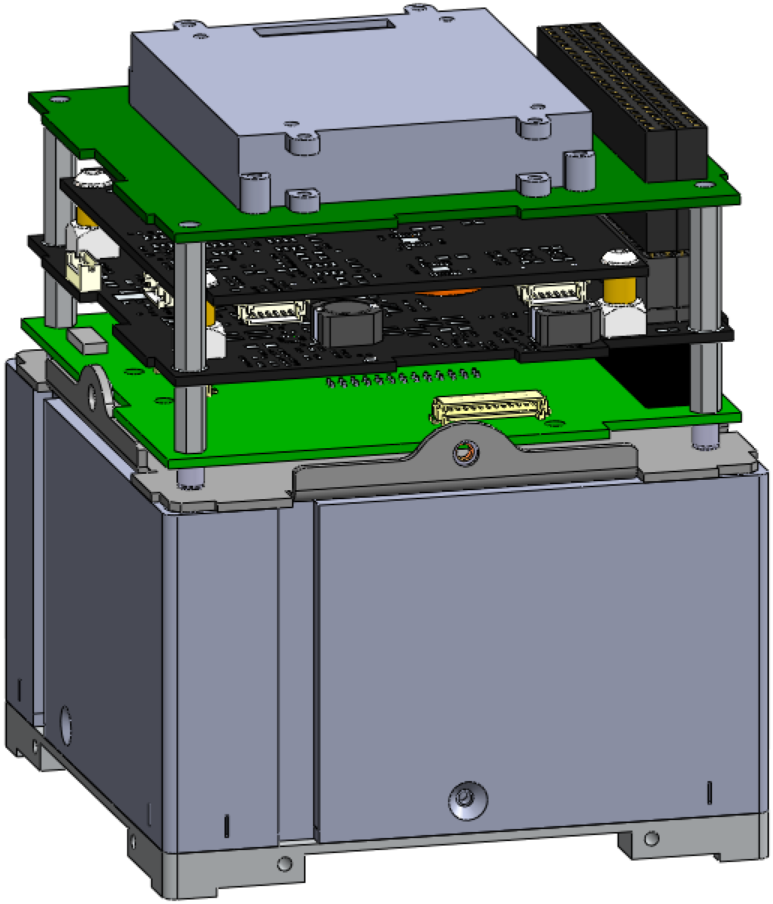
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - **EPS**
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



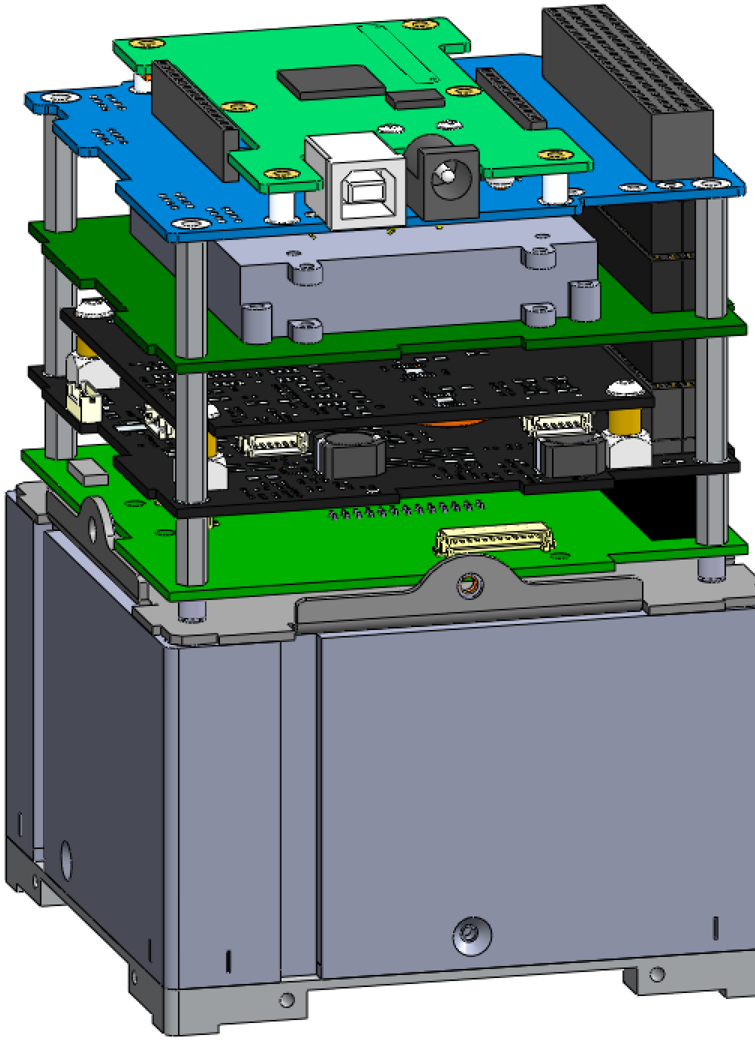
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - **Radio**
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



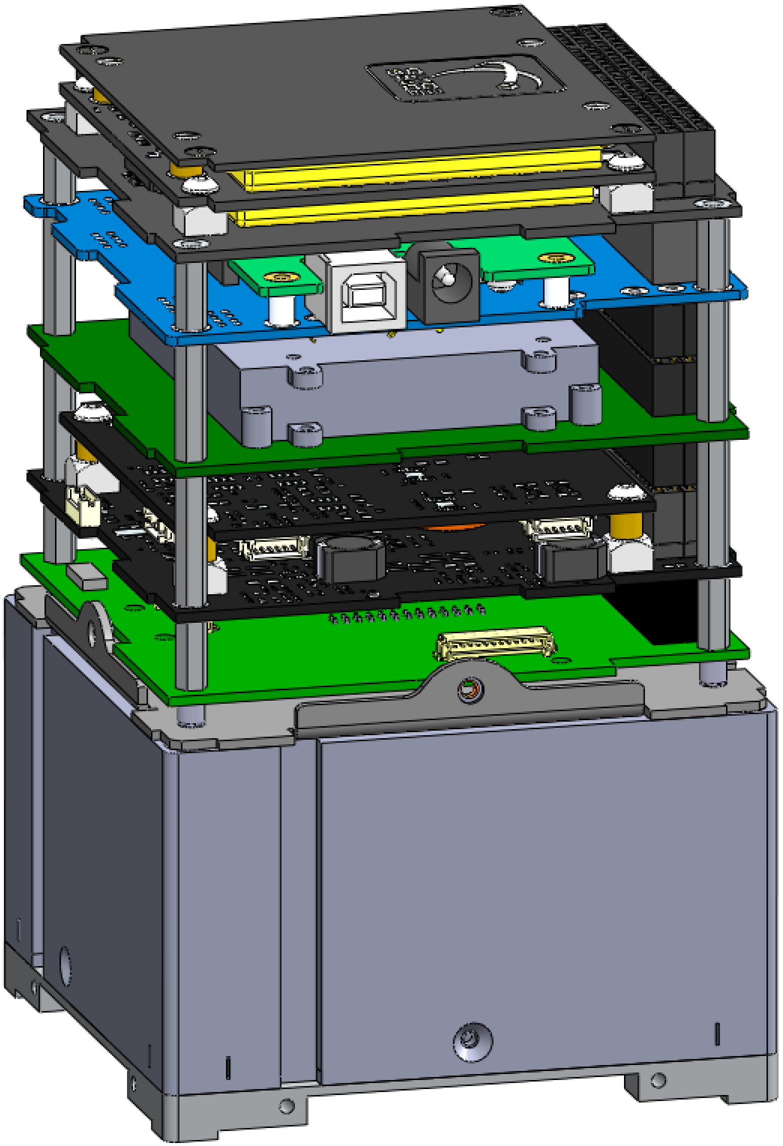
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - **Motherboard**
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



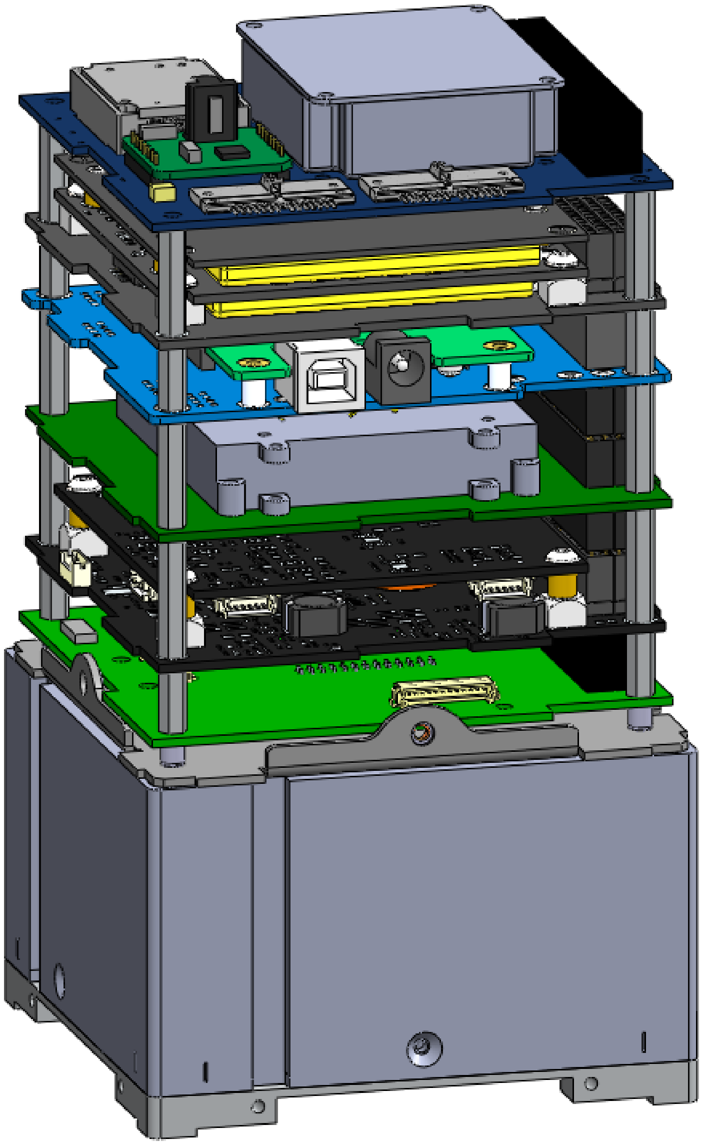
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - **Battery**
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



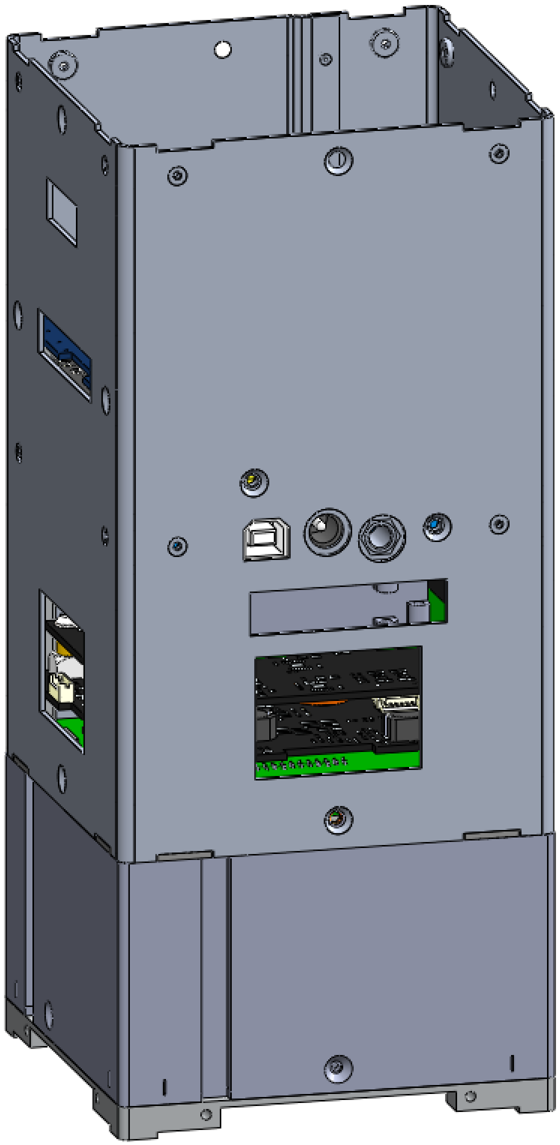
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - **Top Interface Board**
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels



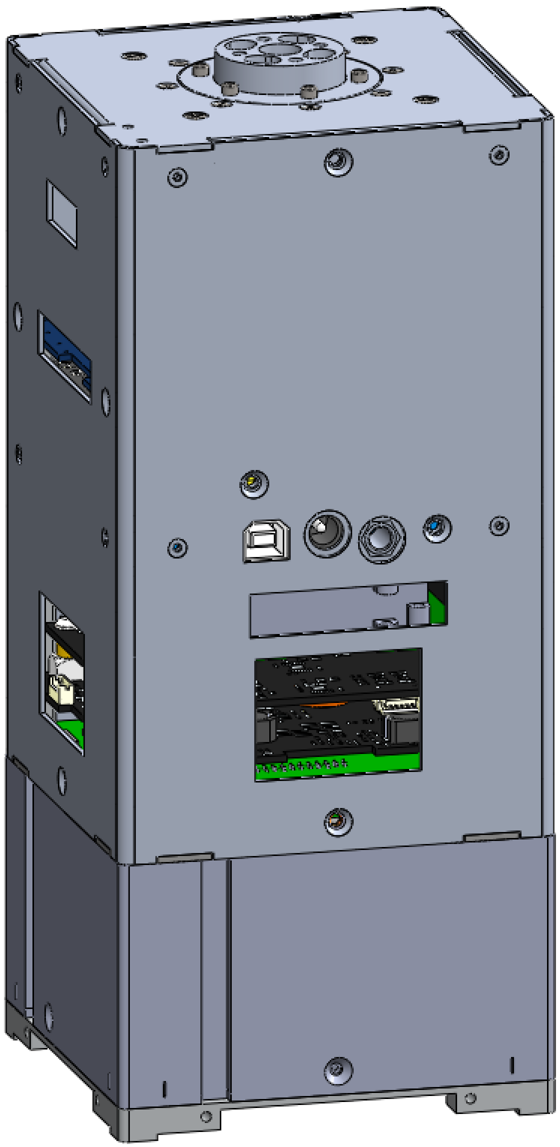
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- **Chassis**
- Scanner Assembly
- Antenna Assembly
- Solar Panels



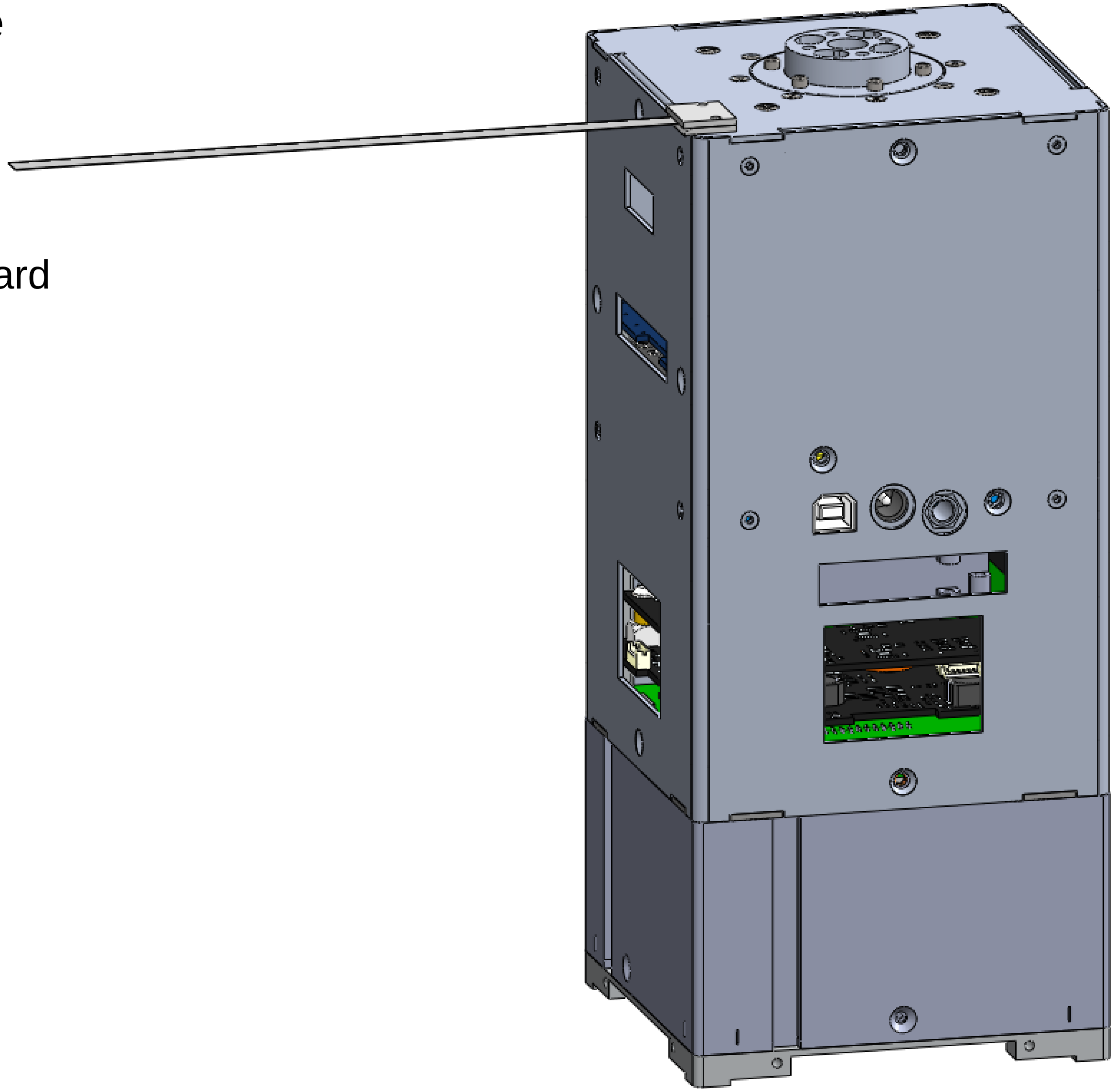
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- **Scanner Assembly**
- Antenna Assembly
- Solar Panels



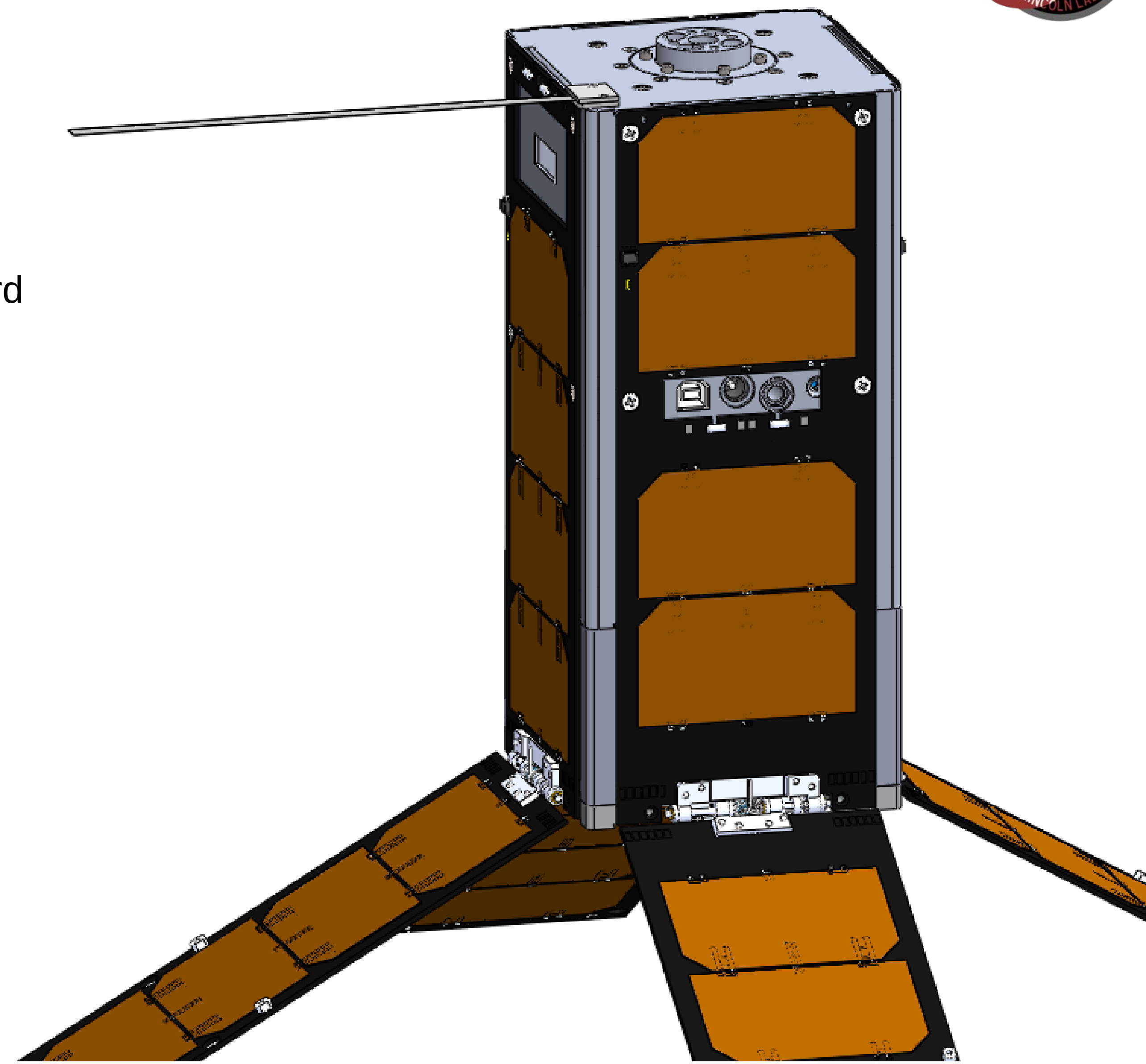
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- **Antenna Assembly**
- Solar Panels



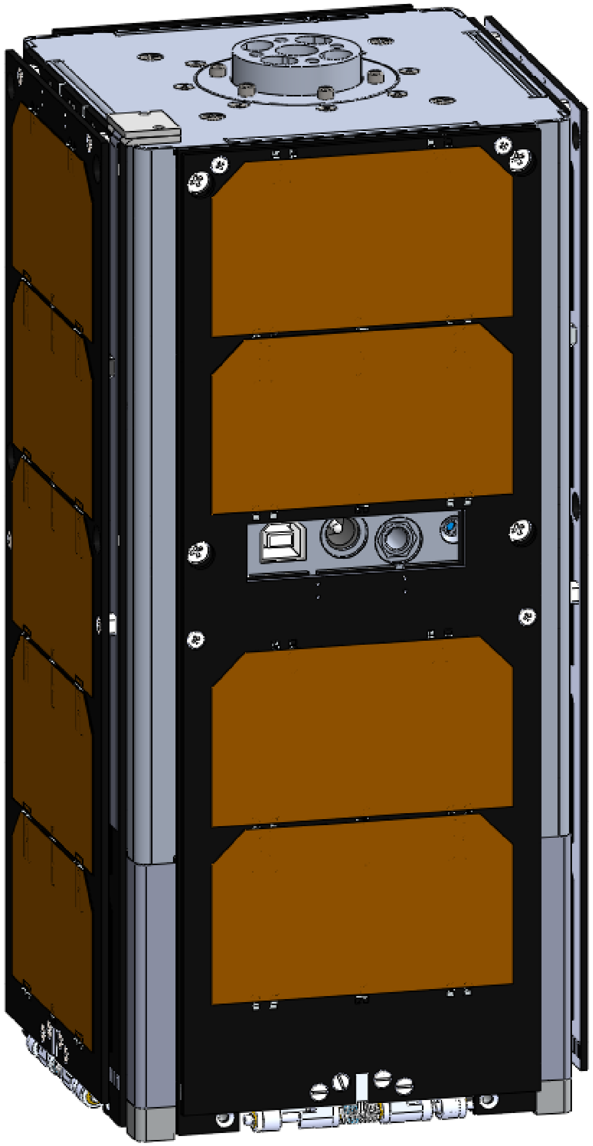
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- **Solar Panels**



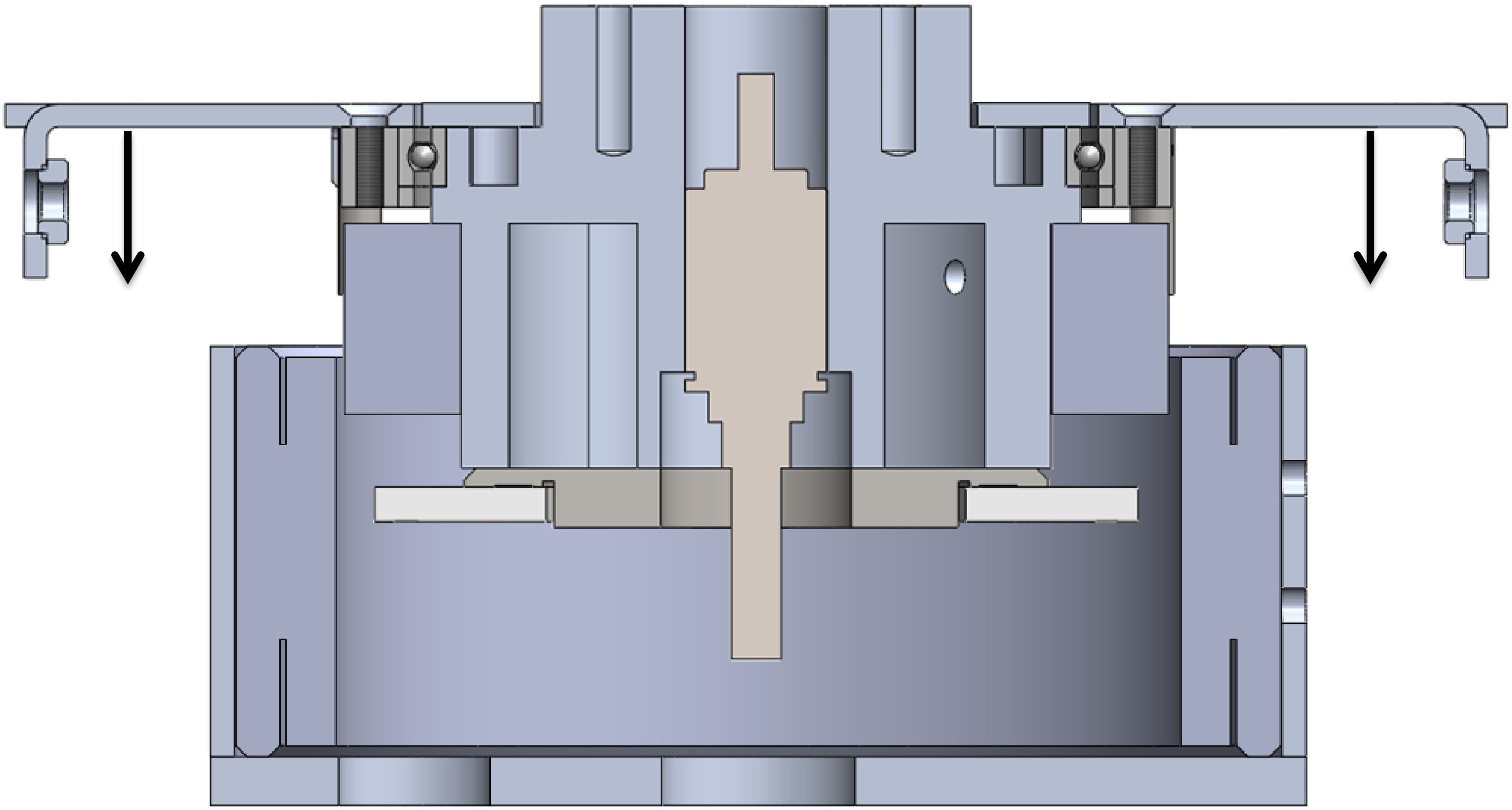
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- **Solar Panels (stowed)**



Getting it to spin

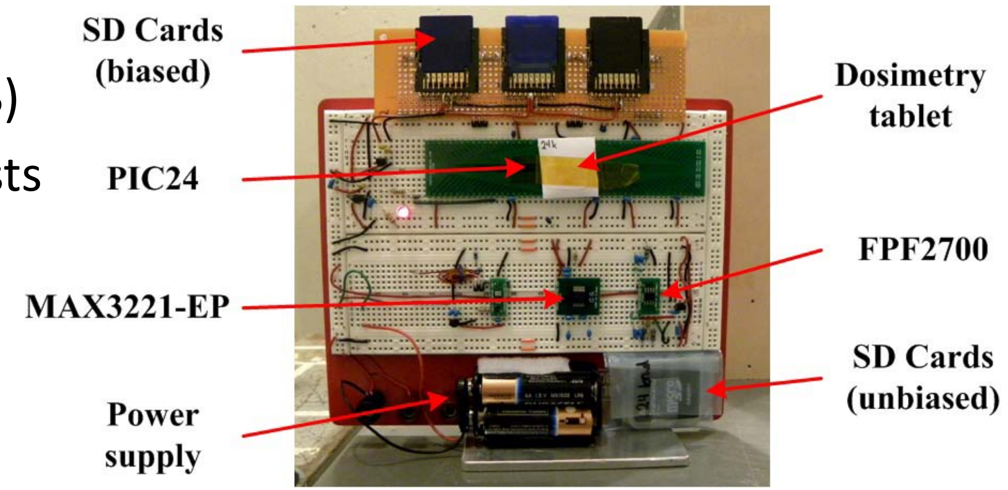
- Brushless dc zero cogging motor, controller
- Encoder



Scanner Assembly Movie

Radiation Testing

- Cobalt-60 TID testing of critical components.
- Mission dose: **1.2 krad** (SPENVIS)
- All devices passed functional tests after 8krad dose.
- Test limitations:
  - No SEL or SEU testing
  - Low sample sizes
- Upcoming test: TCXO, another PIC



Test jig

Part Number	Description	8 krad	24 krad
FPF2700	Current limit switch	PASS	PASS
MAX3221-EP	RS232 transceiver	PASS	FAIL
PIC24FJ256GA110	PIC24F microcontroller	PASS	FAIL
PIC24EP512GU810	PIC24E microcontroller (alt. CPU)	PASS	FAIL
SE02SAMHL-C1000-D	Industrial SD card (Delkin)	PASS	PASS
LT6003 + photodiode	Op-amp (sun sensor circuit)	PASS	PASS

Radiation Testing

TID Tolerance of Popular CubeSat Components

R. Kingsbury, F. Schmidt,
K. Cahoy and D. Sklair
Space Systems Lab
Massachusetts Institute of Technology
Cambr
http

Kingsbury, et al. NSREC 2013

Abstract—In this paper we report total dose test result
COTS components commonly used on CubeSats. We investi
a variety of analog integrated ciruits, a popular microcontro
(PIC24) as well as SD memory cards.

I. Introduction

In this paper we present the results from total ioniz
dose (TID) testing that was completed for components u
in the MicroMAS satellite. MicroMAS, the Micro-sized
crowave Atmospheric Satellite, is a 3U CubeSat under
development by the Space Systems Lab at MIT and Linc
Laboratory [1]. This three-axis stabilized CubeSat will c
a state of the art passive microwave radiometer. In orde

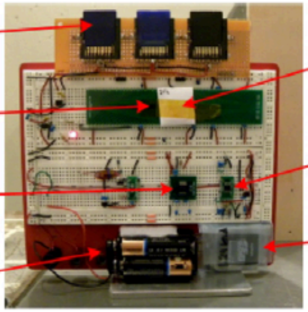


Fig. 1. Test jig used for TID tests

TABLE I
FPF2700 Measurement Data

DUT	Dose	I_{trip} (A)	R_{ON} $(m\Omega)$	V_{OFF} (mV)	I_Q (μA)
#1	0 krad	0.447	162	2.1	92
#1	8 krad	0.442	90	0.8	89
#2	0 krad	0.509	156	1.6	92
#2	24 krad	0.505	77.2	1.5	105

TABLE II
MAX3221-EP Measurement Data

DUT	Dose	I_S (mA)	V_{open} (V)	V_{load} (V)	t_{HL} (ns)	t_{LH} (ns)
#1	0 krad	0.36	L: -5.579 H: +5.578	L: -5.331 H: +5.429	560	400
#1	8 krad	0.43	L: -5.420 H: +5.484	L: -5.248 H: +5.344	620	430
#2	0 krad	0.33	L: -5.516 H: +5.517	L: -5.316 H: +5.363	580	440
#2	24 krad	0.70	L: +0.140 H: +0.047	L: +0.004 H: +0.000	N/A	N/A

B. MAX3221-EP RS232 Interface

The MAX3221-EP is a TIA/EIA-232 compliant line transceiver that can be powered from a 3.3V power supply. This device contains a charge pump circuit that is used to produce the necessary RS-232 signalling levels. The following device parameters were selected for TID characterization:

- No-load supply current (I_S)
- Driver output voltages without load (V

- Want to test PIC24FJ256GB210 (new option 98 vs. 16 kB RAM) and TCXO (FOX924B-16.000)

Integration & Test I

Elmo Hornet motor controller

Image from Elmo

- Test in vacuum over varying temps
- Test on Elmo development board
- Test with Pittman motor connections
- Read telemetry

Perkin Elmer thermopiles

- Test in vacuum over varying temps
- Test varying FOVs of a hot plate
- Characterize sensor data

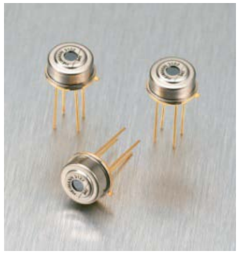


Image from Perkin Elmer

MicroE Encoder (disk + sensor)

Image from MicroE

- Test in thermal oven over varying temps
- Characterize failure modes and criteria
- Characterize sensor data

Clyde Space batteries

- Test internal thermostatically controlled heaters

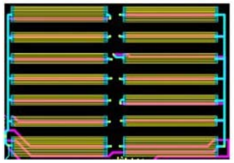


Image from Clyde Space

RTD thermal sensors

- Test functionality and range in vacuum
- Characterize sensor data

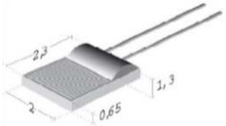
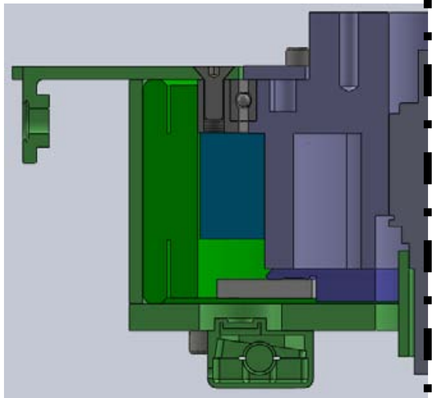


Image from Farnell

Integration & Test II

Scanner assembly

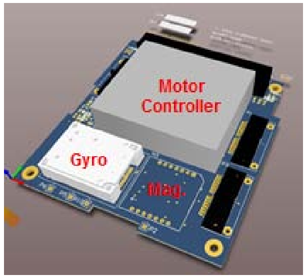


CAD image: E. Peters

- Test encoder + sensor functionality in vacuum
- Test CTE mismatches between bearing + shaft
- Test conductance and radiance to payload
- Test workmanship and alignment in vacuum over varying temperatures

Image from MicroE

Top interface board

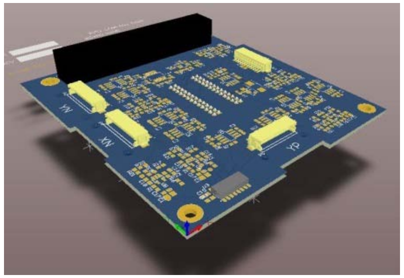


Design image:
R. Kingsbury

- Test connections in vacuum over varying temperatures
- Test with motor controller, gyroscope, and magnetometer
- Characterize data output

Bottom interface board

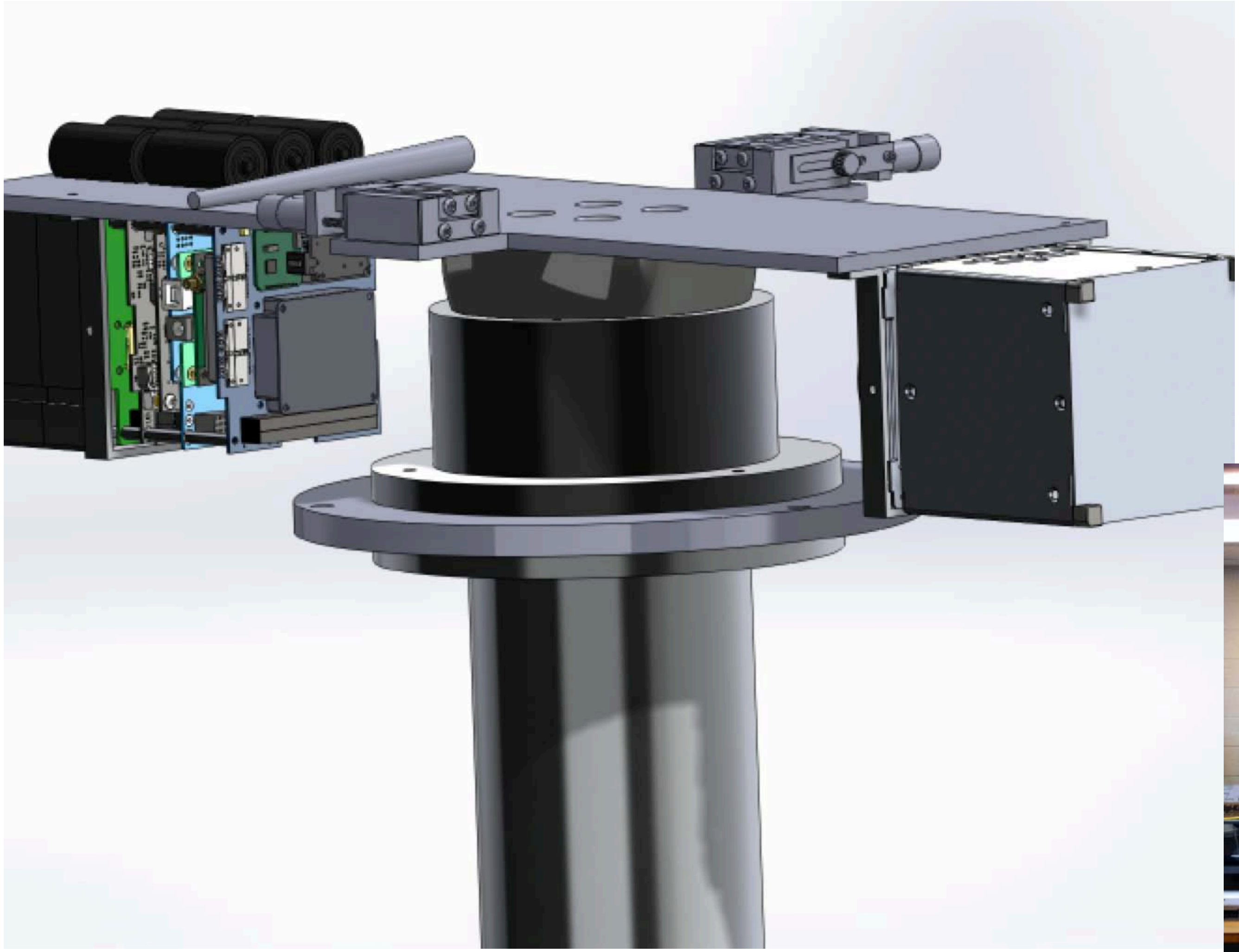
- Test connections in vacuum over varying temperatures
- Characterize data output



Design image:
R. Kingsbury

Detailed Mass Mockup

ADCS Test Rig

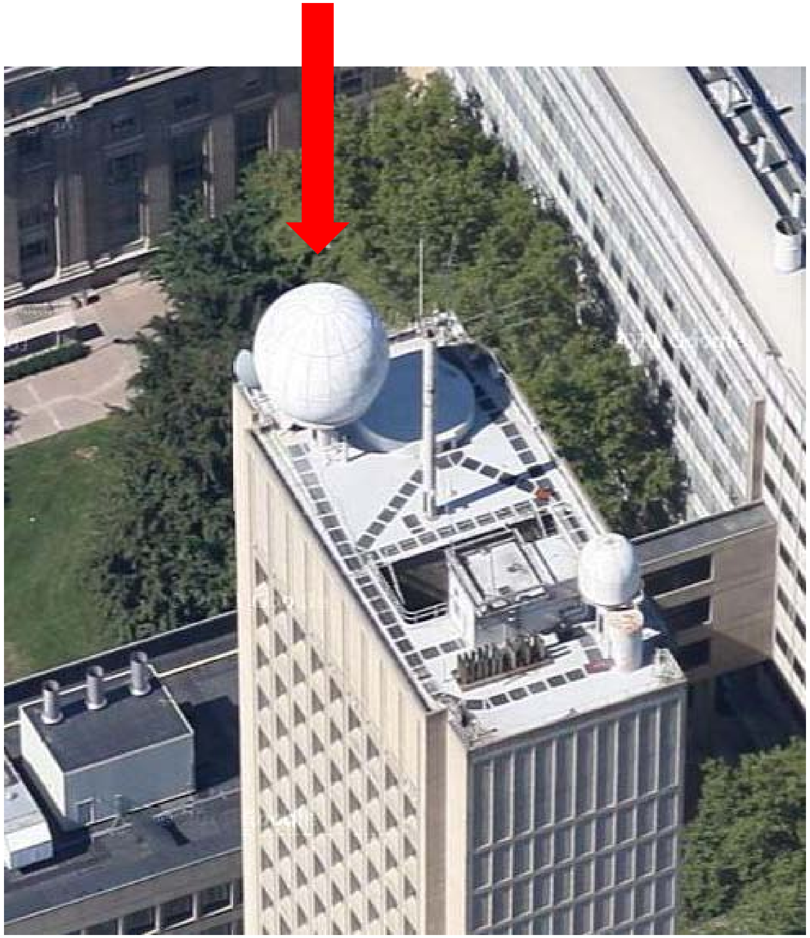


MIT Ground Stations

- UHF/VHF Station
  - MIT Radio Society is assembling a “standard” UHF/VHF station
  - Two az-el steerable yagi antennas
  - Approximately 100W of
  - Undergoing final integration this spring
- S-Band Station
  - A much bigger project…

MIT Green Building Dish

- 5.5 meter (18 ft) dish
- Originally installed for weather radar research
- Pedestal is WW2 surplus SCR-584
- Modified in 1960s
  - Increased dish size
  - Added radome
  - Waveguide feed

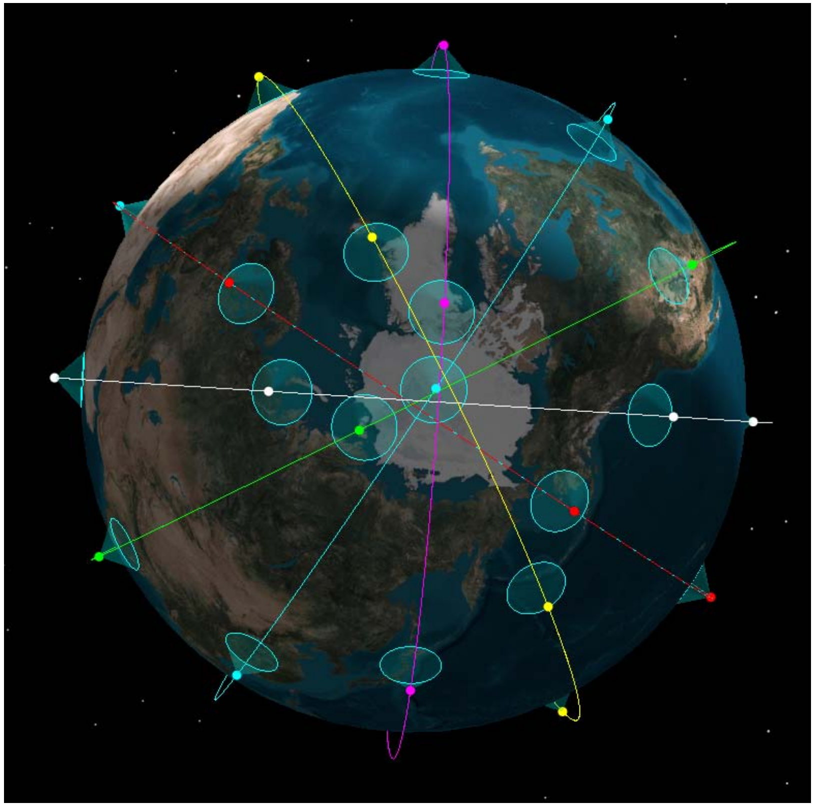


Path forward

- Waiting to get manifest
  - Ready for early 2014
- Flight motor integration and test
- MAI-400 delivery, ADCS testing
  - Helmholtz cage, air bearing testing
- Additional radiation tests
- Software: linear algebra on PIC24
- Solar panel assembly delivery, integration
- Antenna fabrication, integration, tuning, characterization
- Ground station simulator, testing → MIT ground stations

RAX-2 and M-Cubed launch on Delta II
28 Oct 2011

Future: Constellation of Microwave Radiometers



Marinan, Nicholas and Cahoy, "Ad hoc CubeSat Constellations." IEEE Aerospace 2013

One satellite per plane

Case	Revisit Time (Avg, hrs)	Response Time (Avg, hrs)	Hours to 100% Coverage
Walker	8	12	10
Ad Hoc 1	12	23	22
Ad Hoc 2	6	13	12

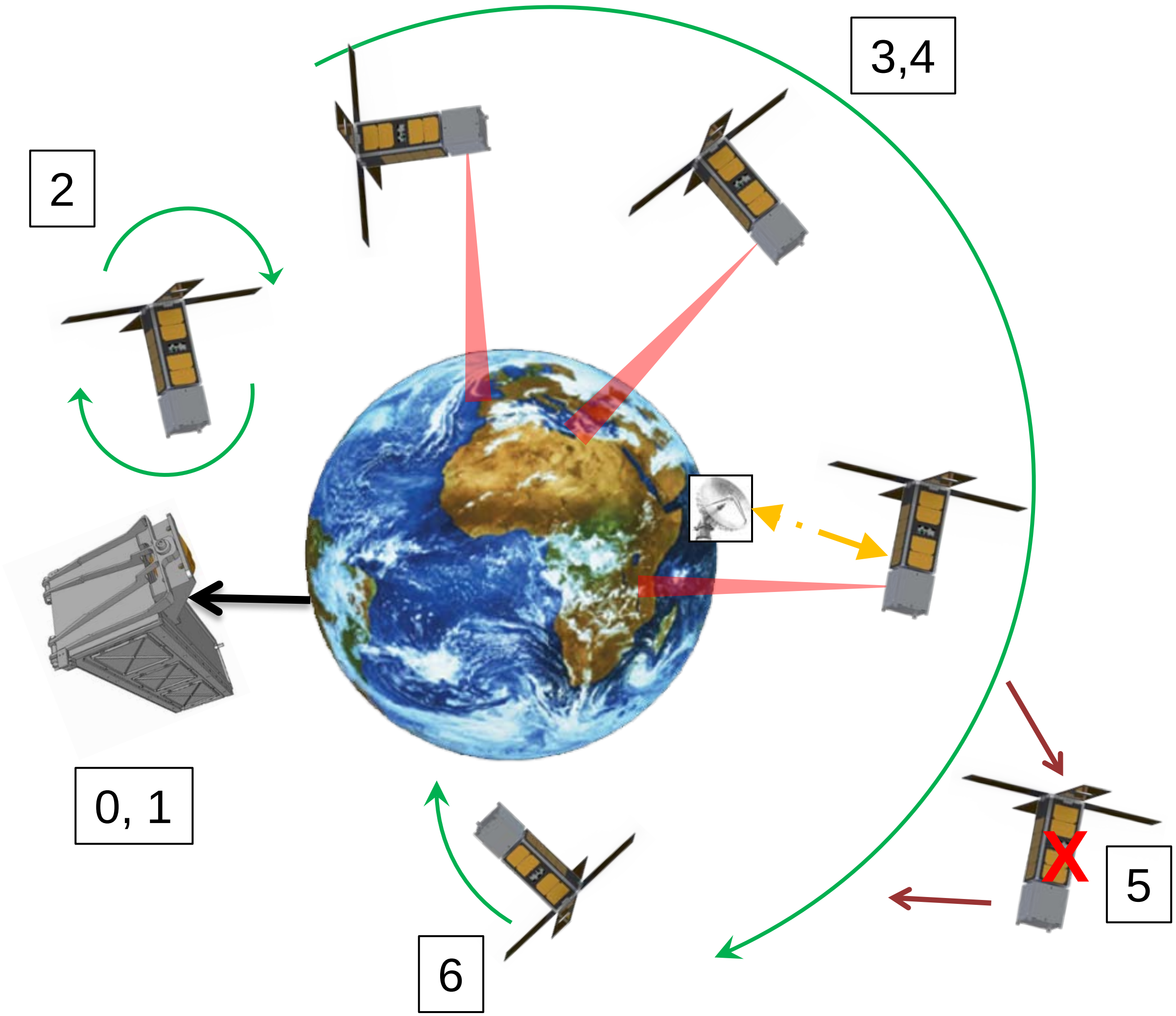
Six satellites per plane

Case	Revisit Time (Avg, hrs)	Response Time (Avg, hrs)	Hours to 100% Coverage
Walker	0.8	2	2
Ad Hoc 1	1.0	16	15
Ad Hoc 2	0.7	9	8

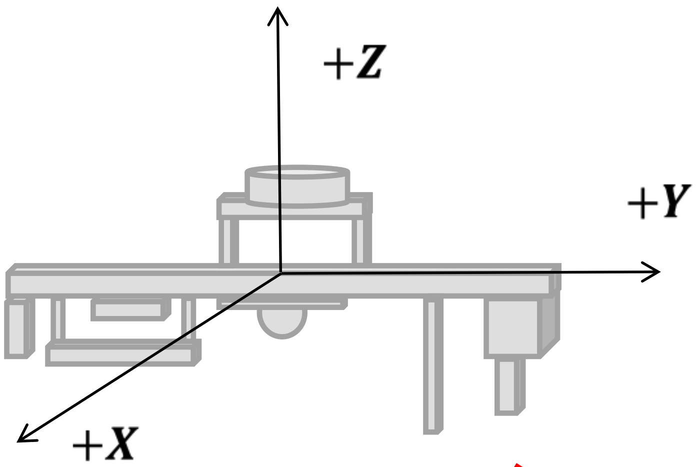
Backup

Operational Overview

0	Mission Planning/Pre-Launch Integration
1	Launch as secondary payload
2	On-orbit deployment and initialization
3,4	Mission Ops - 6 months nominal
5	Fault Recovery/ Limited Ops
6	Mission Termination

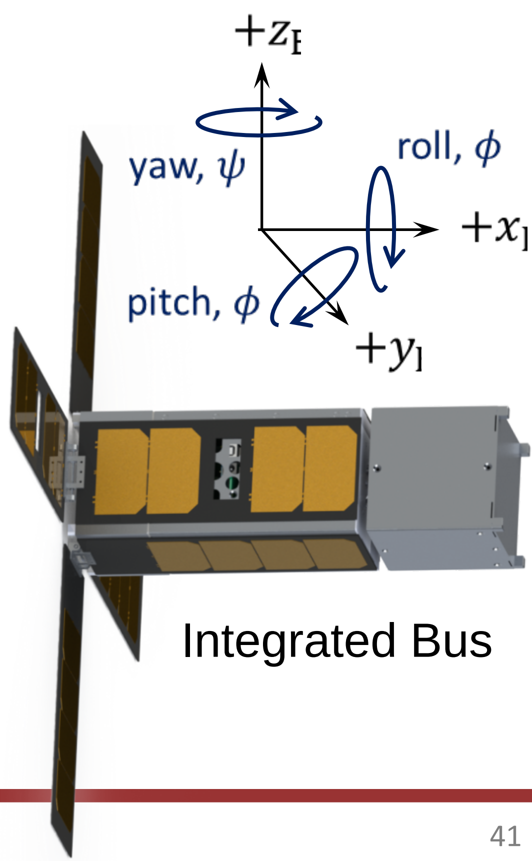


Subsystem Integration



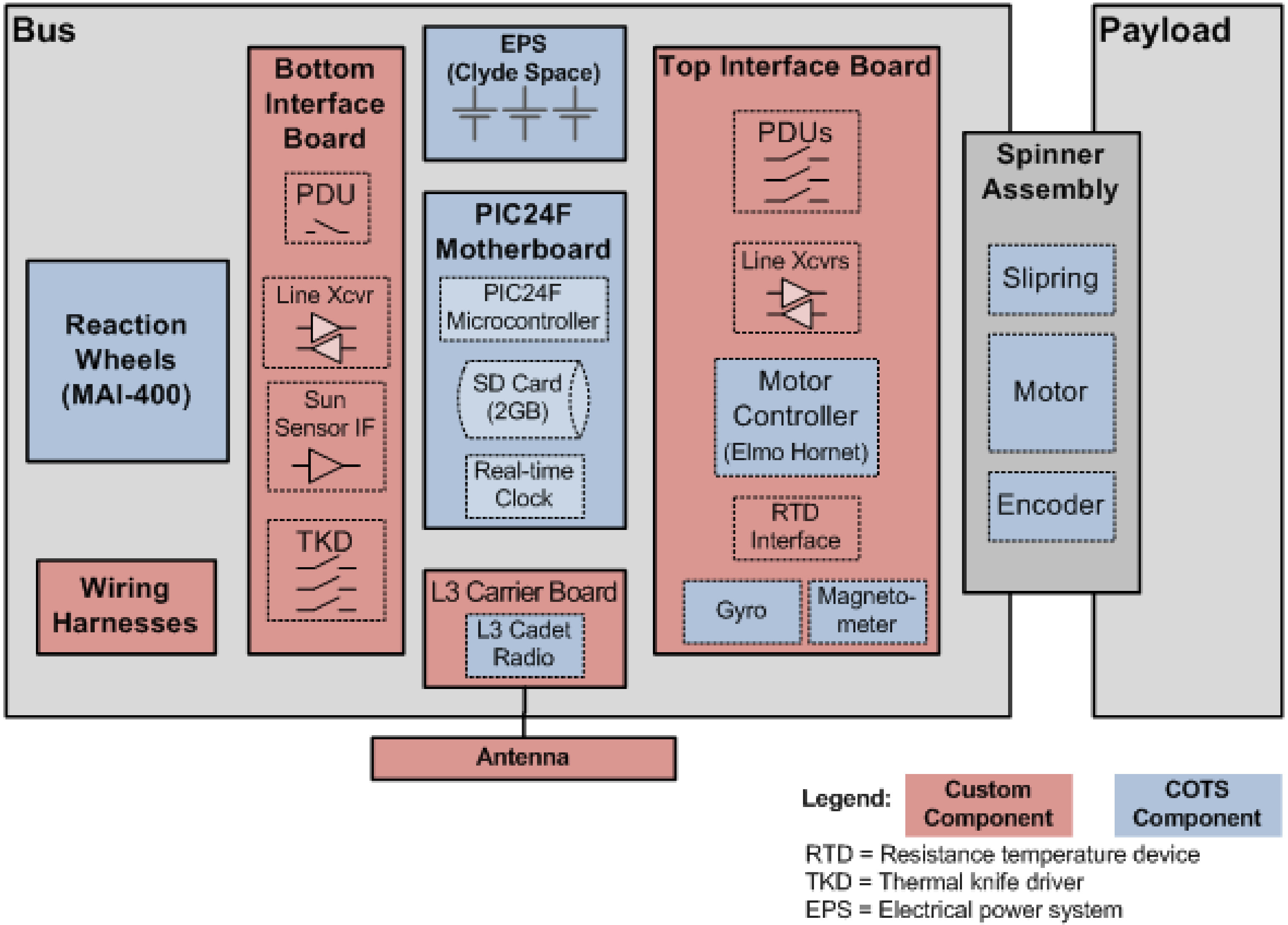
“Flat Sat”
Engineering Model

ADCS Testbed Platform:
Precision design with mass mock-ups, designed for repeatable tests of ADCS modes
(currently in design phase)



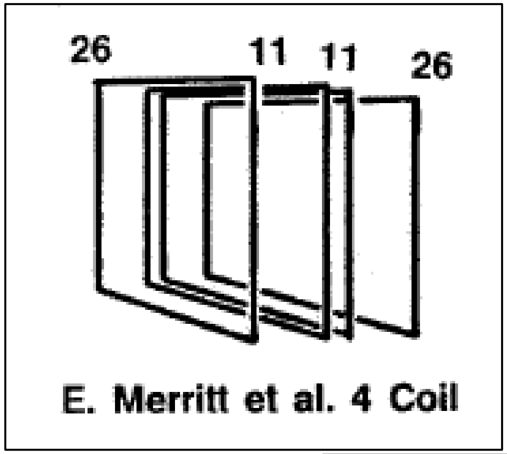
Integrated Bus

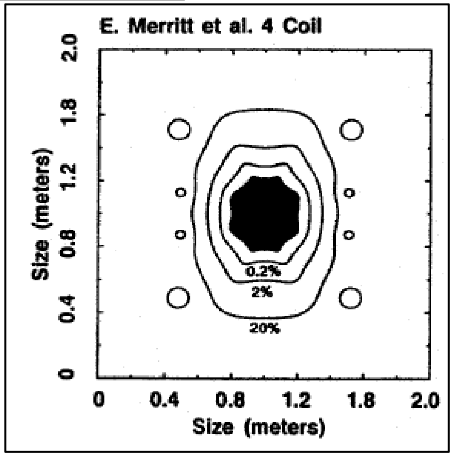
Design Overview

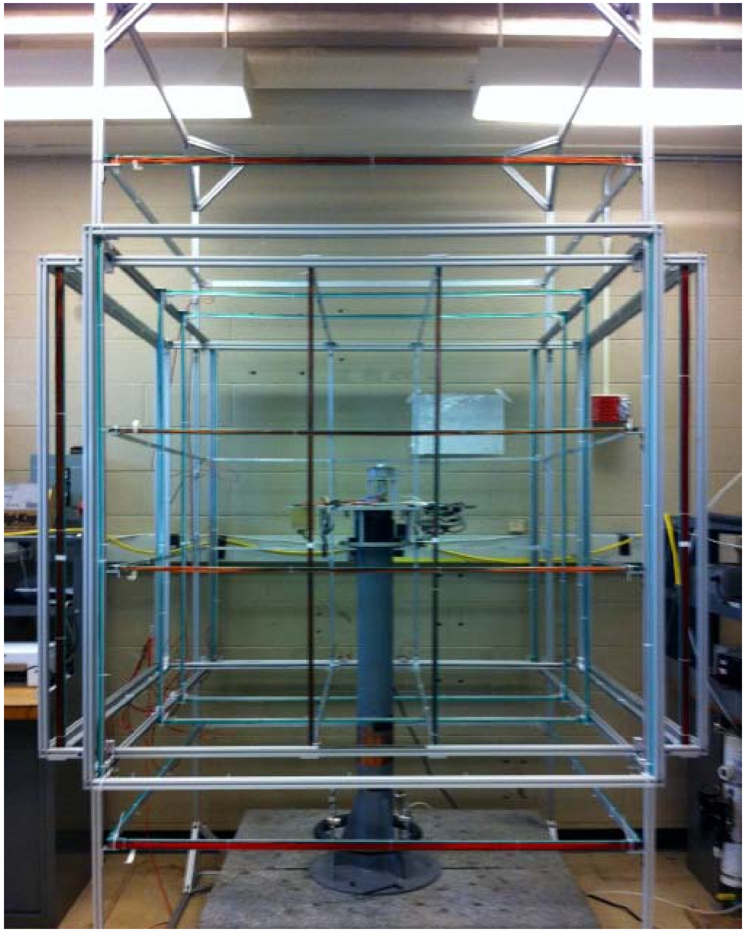


Air Bearing/Helmholtz Cage

- Air bearing encased in Helmholtz coil
- Plan to add hot plates for EHS stimulus

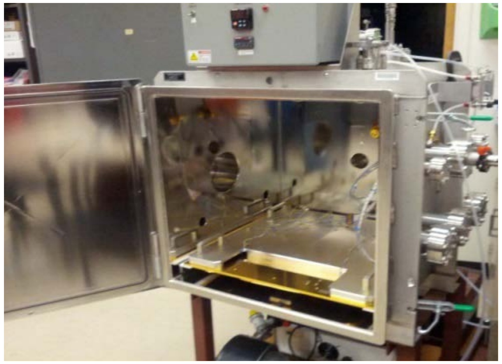


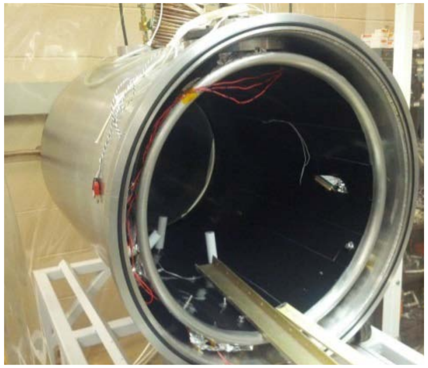


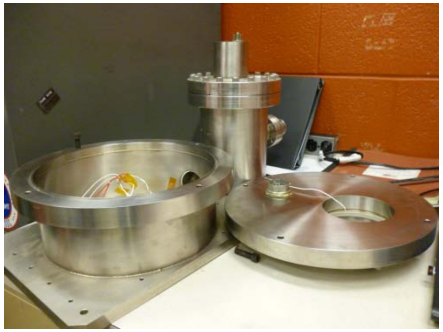


Thermal Vacuum Chamber

- SSL Chamber
  - Plan to use as clean chamber for integrated system testing
- Kavli Small and Large Chambers
  - Component-level testing, bake-outs
- SSL 'Desktop' Chamber
  - Component-level testing, bake-outs







Electronics Laboratory

- Board-level testing and assembly
  - Pumpkin CubeSat development board

Clean Room

- ISO Class 8
- ESD mats and straps
- Integrated Thermal-Vacuum chamber (TBD)

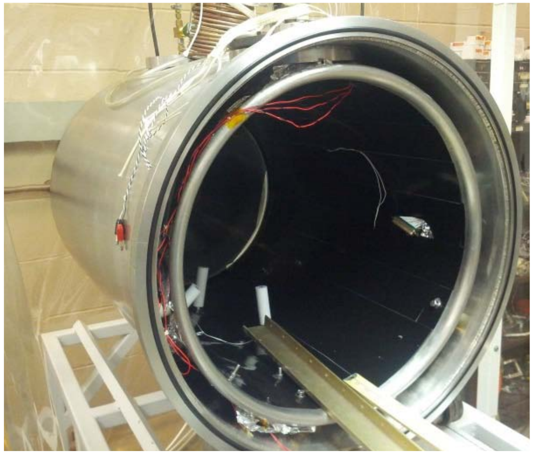
Testing Facilities

Kavli Small Chamber

- Size: 8.25” I.D. x 15” L
- Pressure: < 1E-05 torr
- DAQ: Currently borrowing Agilent 34970A and PC from AA Gelb Lab

Status: READY

Kavli Large Chamber



- Size: 20” I.D. x 26” L
- Pressure: < 1E-05 torr
- DAQ: Integrated with Agilent 34970A and remote desktop PC

Status: READY

SSL Clean Chamber

- Size: 2’ x 2’ x 2’
- Pressure: < 1E-05 torr
- DAQ: **TBD**

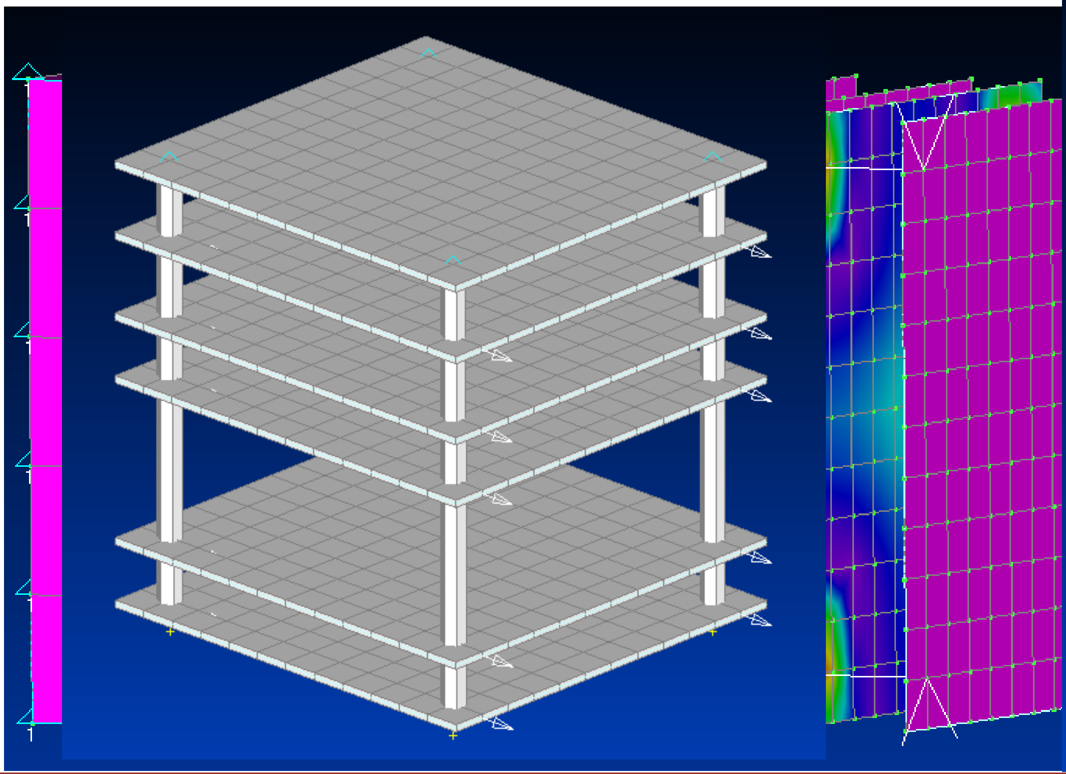
Work Needed:

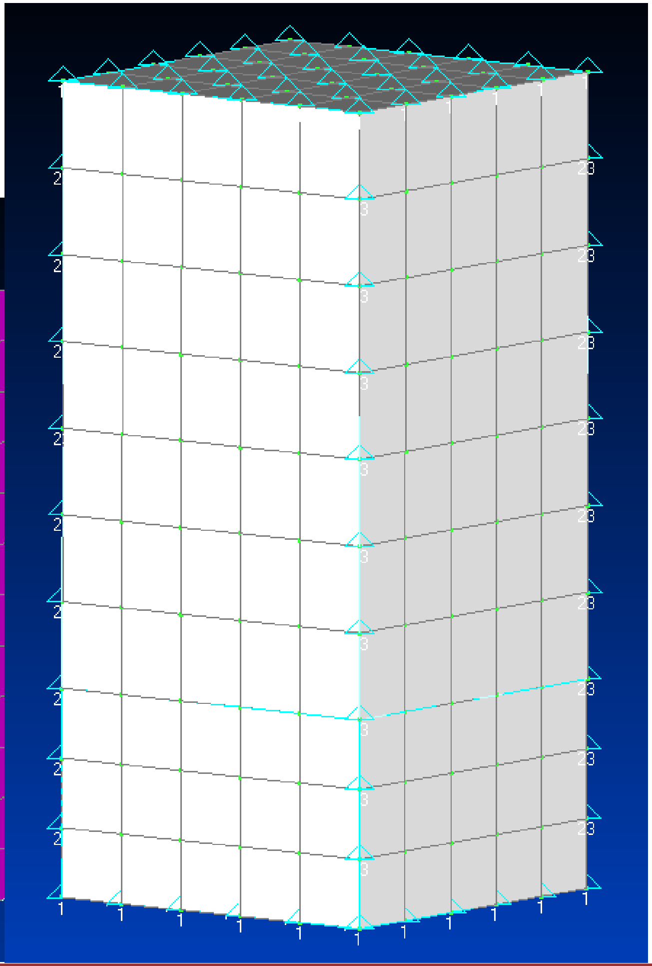
- Move into final location
- Supply with 220V power
- Replace O-ring, few parts
- Procure DAQ and PC

02/26 – 05/19/13

Finite Element Modeling

- Created finite element models of chassis, circuit board stack, and integrated assembly
- Lowest system mode: 189 Hz
  - Well above 70 Hz requirement





MIT Ground Stations

- UHF/VHF Station
  - MIT Radio Society is assembling a “standard” UHF/VHF station
  - Two az-el steerable yagi antennas
  - Approximately 100W of
  - Undergoing final integration this spring
- S-Band Station
  - A much bigger project…

MIT Green Building Dish

- 5.5 meter (18 ft) dish
- Originally installed for weather radar research
- Pedestal is WW2 surplus SCR-584
- Modified in 1960s
  - Increased dish size
  - Added radome
  - Waveguide feed