Cubesat for Detection of Dark Matter as Sterile Neutrino

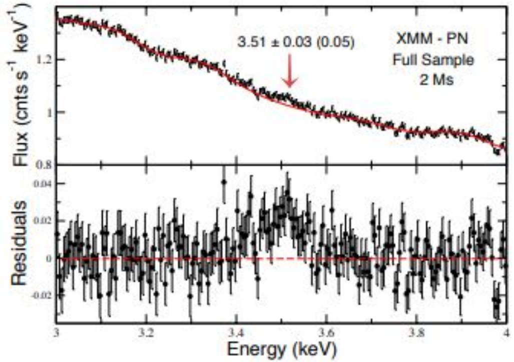
Eloise de Castelnau

Final Presentation

8-6-18

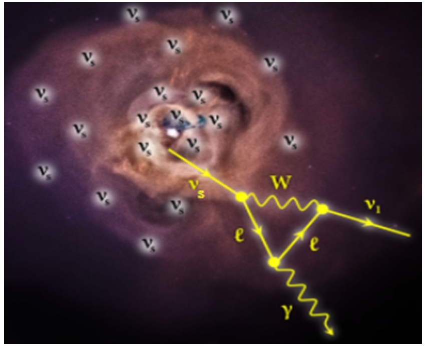
Motivation

- Satellite CHANDRA saw a 3.5 keV emission line while pointed at galaxies outside of our own
- This x-ray does not match the emission line of any known valence shell decay (although a potassium emission line has come close)
- Even if an atomic decay could produce 3.5keV, it is extremely unlikely that that element is prevalent enough throughout space to have caused such a strong signal
- Theory suggests that this emission line could result from the decay of a large sterile neutrino



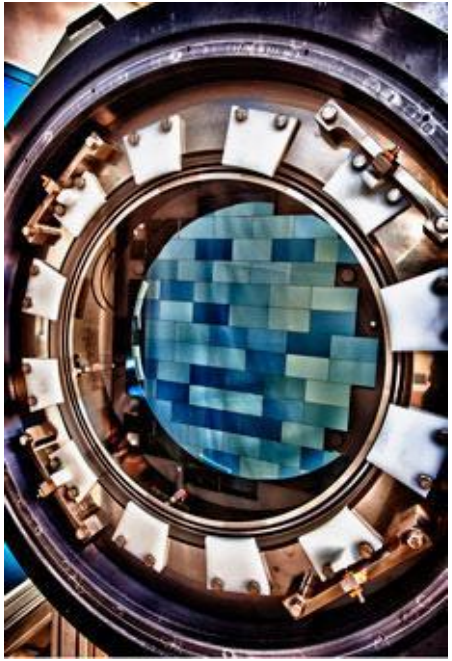
Motivation

- If this large sterile neutrino is the correct candidate for dark matter, we expect to see a certain distribution of it when looking in and out of our galactic plane
- If we can map the incidence of this 3.5 keV line throughout the cross section of the milky way, we can verify that it matches the predicted distribution of dark matter
- This would strongly suggest that the heavy sterile neutrino is a suitable candidate for dark matter



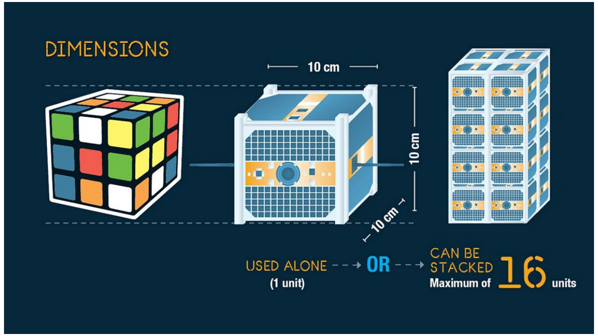
Approach

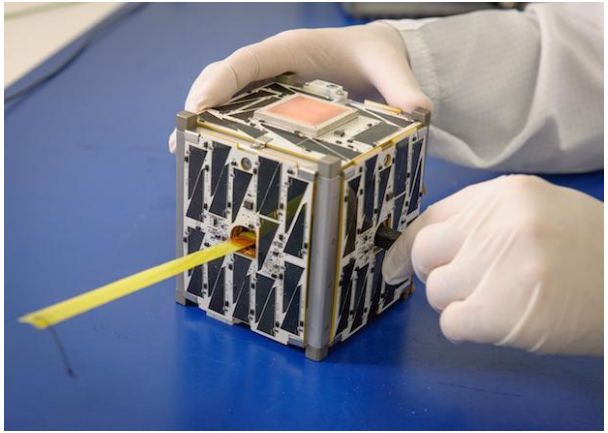
- To detect soft x-rays with very high resolution, we will use 2k x 4k CCD's and point along the normal to the galactic plane
- Since the earth's atmosphere would filter out the 3.5 keV signal, the CCD must at least be on a spacecraft in LEO
- A CubeSat will be employed for this purpose



What are CubeSats?

- Standardized picosatellite defined by CalPoly
- Low cost provides iterability and ability to be designed in house
- Standard configuration means there are many launch opportunities throughout the year
- 3 year project lifetime as opposed to 10+
- 50% success rate, not great, but pretty good for amateur/educational spacecrafts



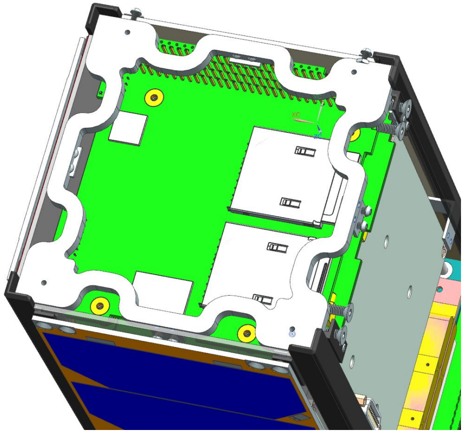


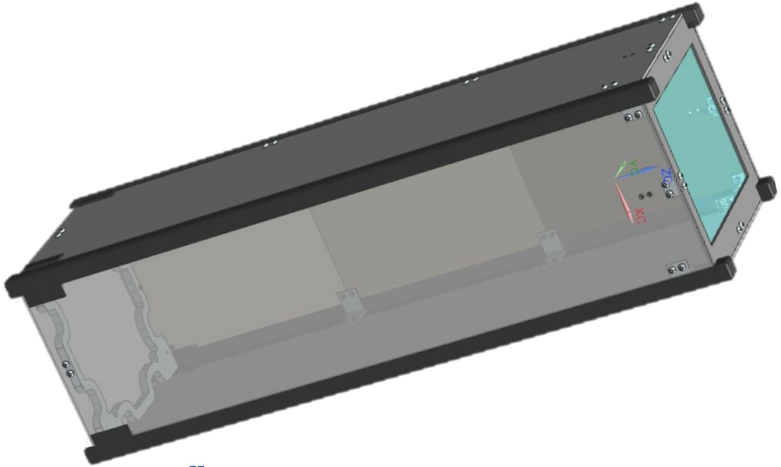
Challenges

- Since the CCD's are so sensitive, they are susceptible to noise and must be kept below 170 K for an acceptable signal to noise ratio
- The temperature of a CubeSat in LEO can vary from 200-400K across a 90 minute orbital period. This causes thermal strain.
- All onboard electronics must be space rated and/or have shielding from environmental radiation
- Redundancies must be built into the CubeSat so that a single failure doesn't compromise the entire mission
- High resolution can mean high data transfer and downlinking rates, how do we optimize this?
- Rigorous vibration, thermal bakeout, and COG testing must be passed.

Mechanical Design

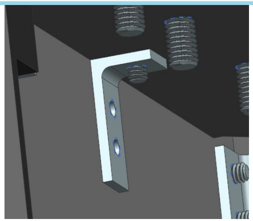
- A full mechanical assembly for the frame of the CubeSat was created in CAD to allow us to assess mounting challenges, fit issues, approximate mass, and more.
- Several iterations of rail/wall mounting configurations were examined before we decided on a modular bracket system

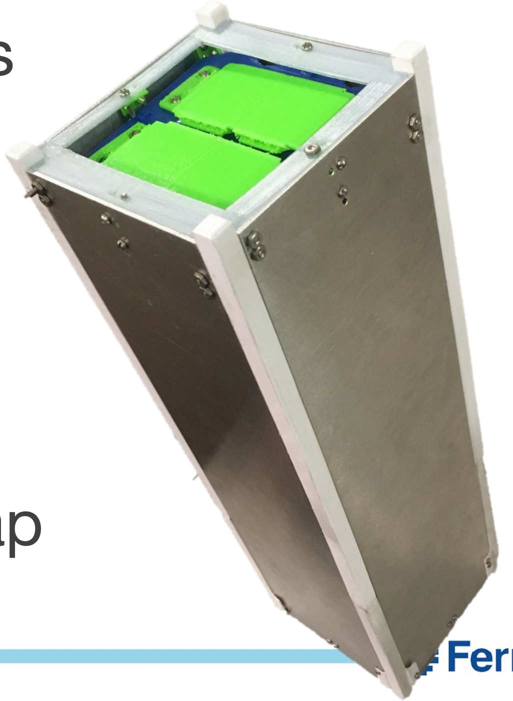


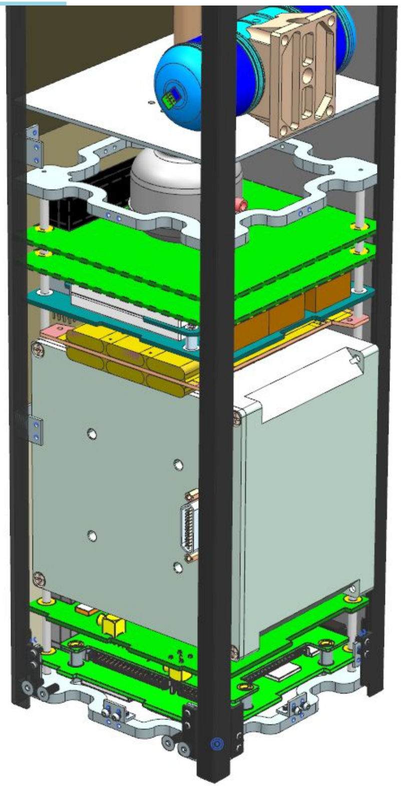


Mechanical Design

- Three standardized custom brackets can be used to mount any irregular part to the walls of the CubeSat
- All off the shelf electronics conform to a PC-104 mounting configuration, where the parts sit on rails and snap together

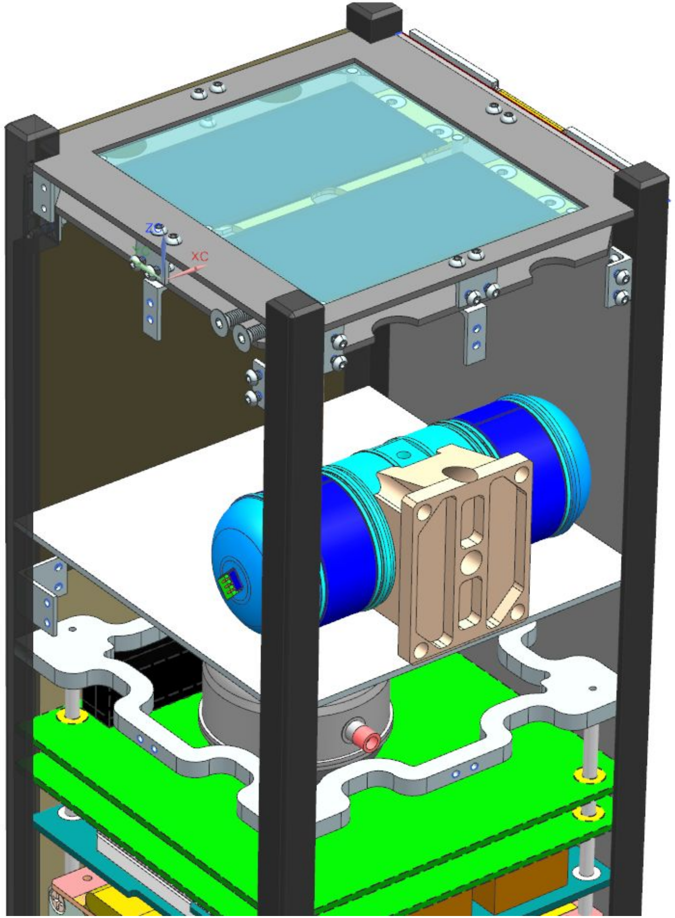






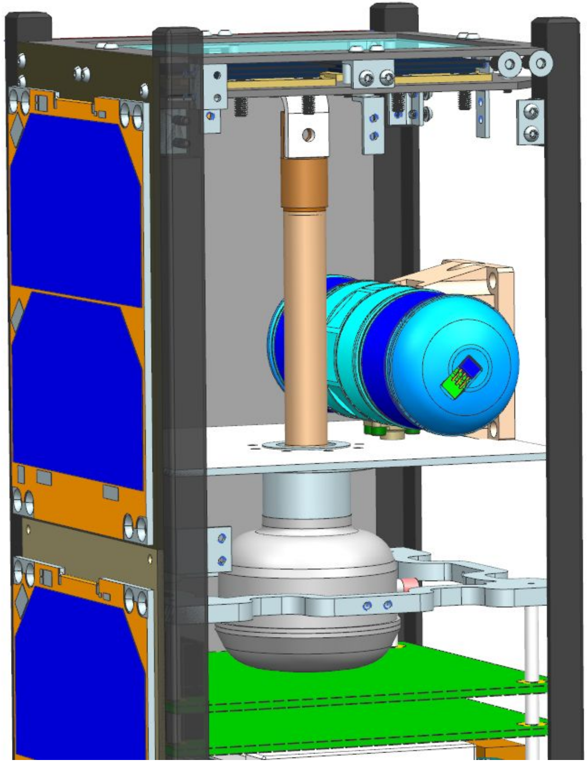
Payload Components

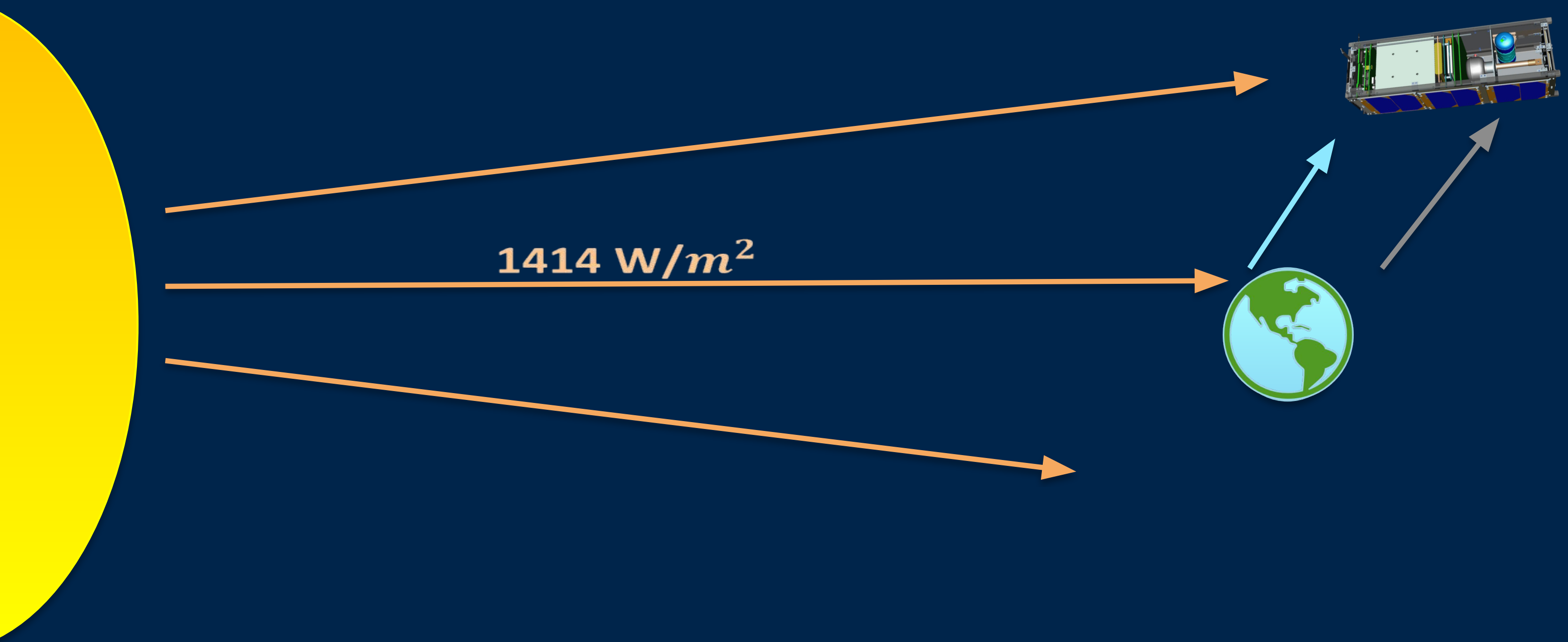
- 2 CCD's
- Beryllium Window
- Cooling system (passive/active)
- Readout boards



Active Cooling

- Requires input power to actively move heat
- Best option for active cooling is a microcryocooler, which keeps the CCD's at temp. by cooling an Al cold plate
- Very expensive, both in terms of power and monetarily
- Thermal strain leads to deteriorated contact and poor cooling performance
- Consumes significant volume





Plain heat flux does not accommodate emissivity/absorptivity of satellite!

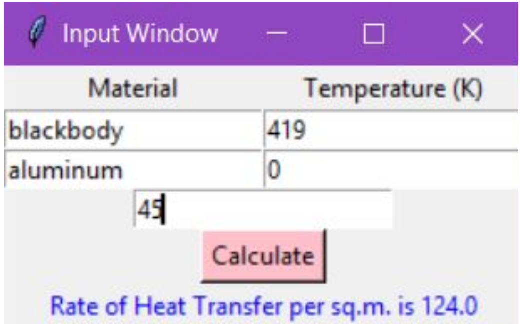
Solar Flux	**1414 W/m²**
Incident Albedo	0.35·1414·0.15 = **74.2 W/m²**
Earth Flux	**260 W/m²**

Active Cooling Thermal Analysis

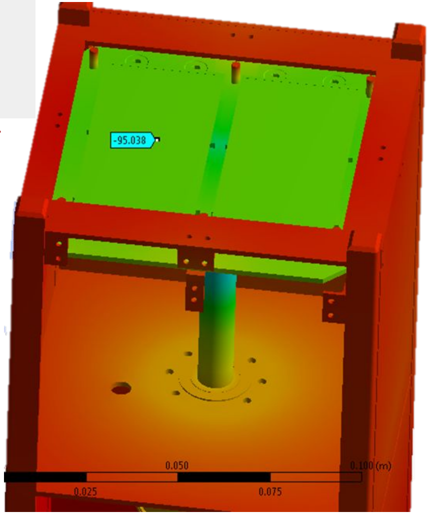
- Assuming full heat flux due to Albedo, Planetary IR, and Sun, CCD's are only 5K above desired temp with cryocooler cold tip held at 120K

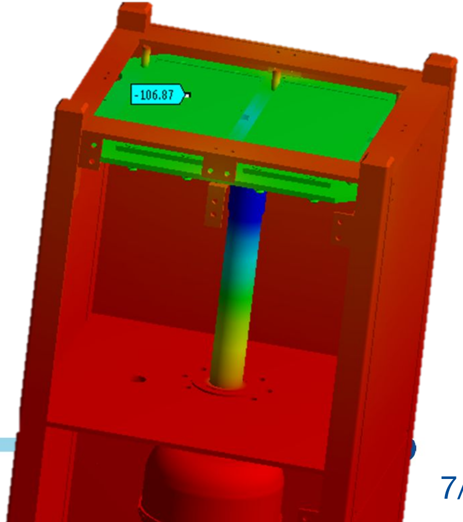
$$\dot{Q}_{12,\text{ no shield}} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

- Accounting for reflected heat due to emissivities (PyRad), the CCD's reach a peak temp of 165K



Full flux:
Max 256 K



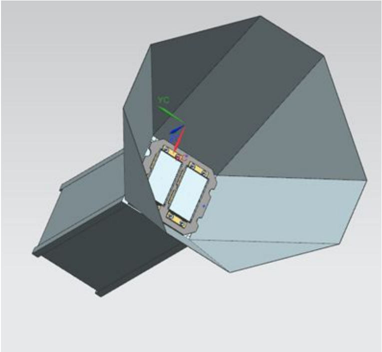


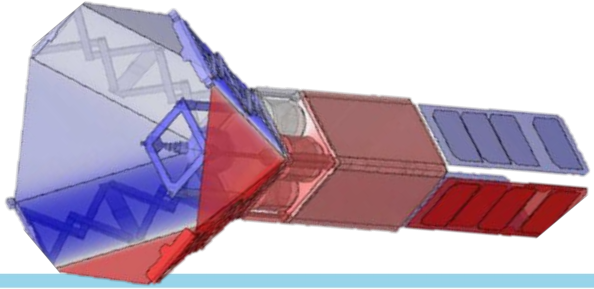
CCD temp:
165-175K

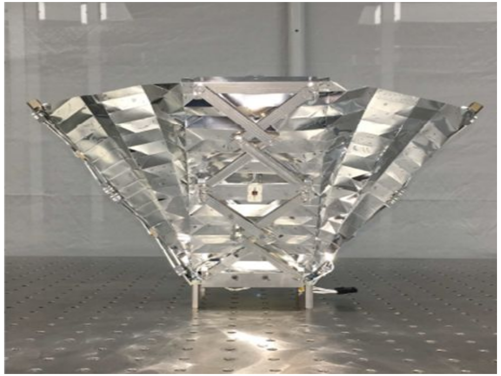
Reflected:
Max 226 K

Passive Cooling

- Uses shielding and material properties to prevent the CCD's from getting too warm in the first place
- Cheaper and does not require input power
- Limits ability to point in vicinity of sun/earth due to incident heat
- Unreliable and difficult to model

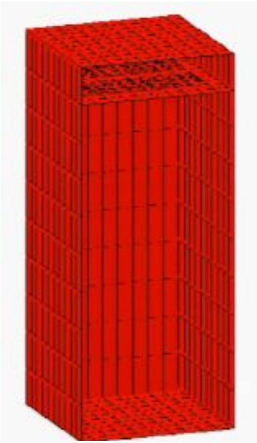


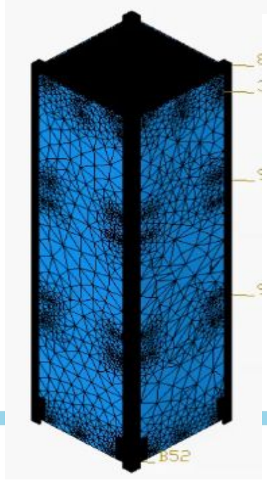


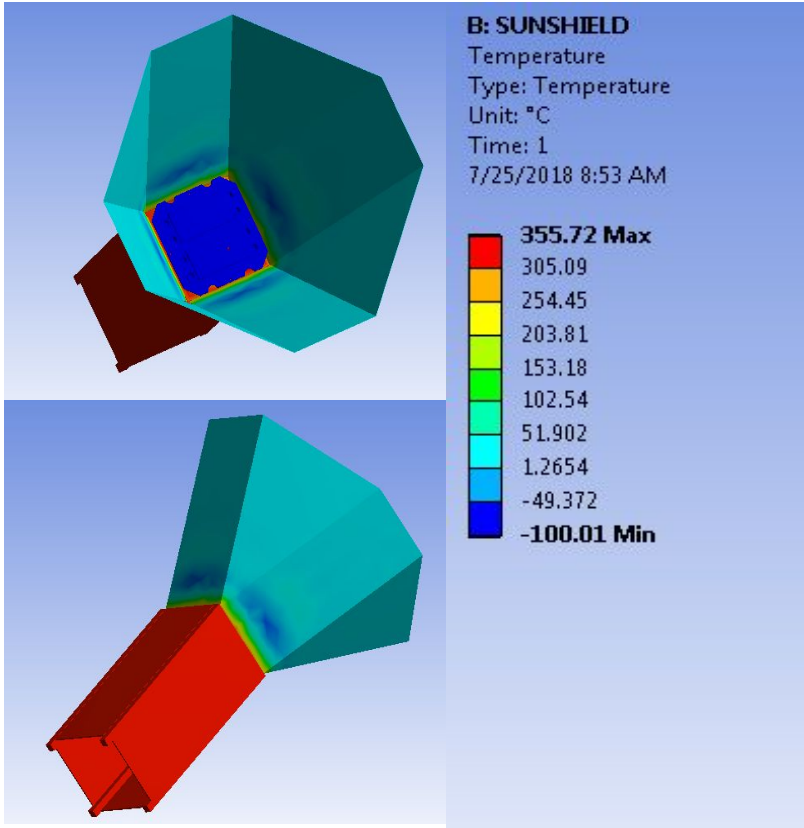


Passive Cooling Thermal Analysis

- Analysis was pursued at steady state (ANSYS mechanical) and through orbit (RADCad/Thermal Desktop)
- Both softwares rely on a predicted “initial temperature”, significantly throws off results if guessed
- Thermal desktop is highly incompatible with model level input (STEP/IGES)

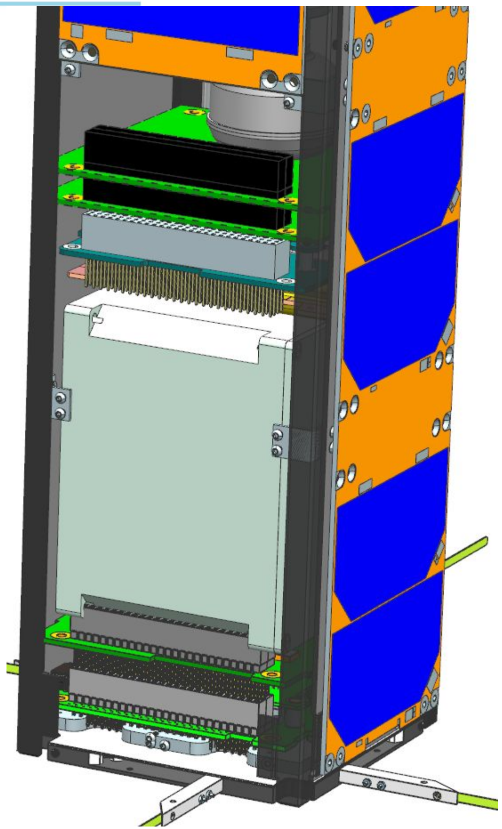






Bus Components

- Readout Boards
- Batteries
- Attitude Determination and Control
  - Magnetorquers
  - Reaction Wheels
- Energy and Power System
- Transceiver
- Antennae
- Main Computer

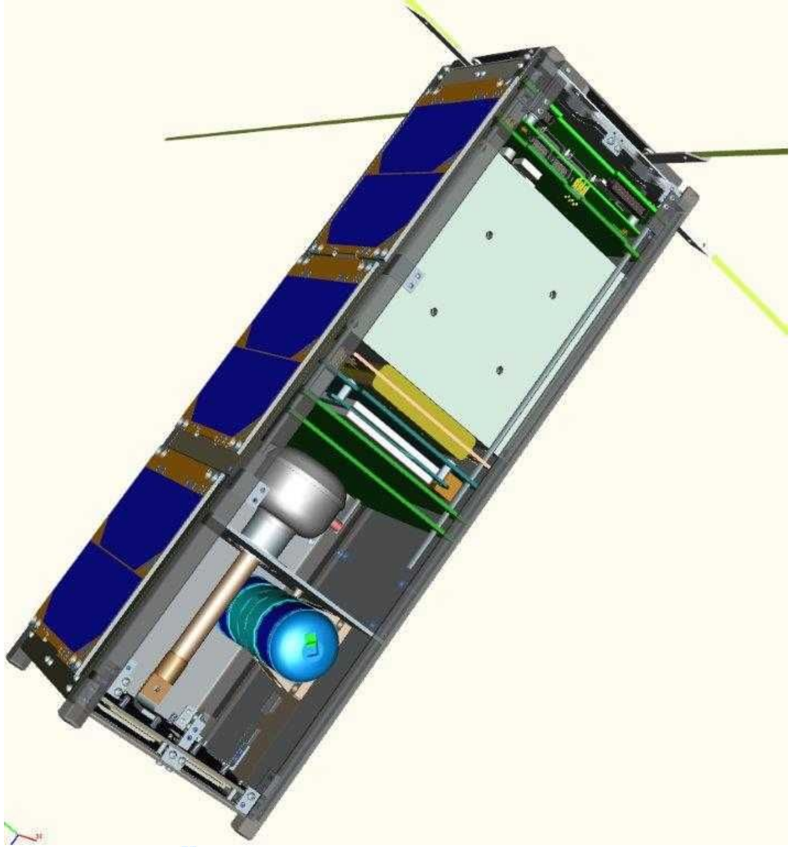


Each of these components have functional operational temperature ranges, as well as heat productions/losses.

Fermilab

Moving forward

- Component analysis of the thermal effects of the bus
- Vibration simulation to verify frame integrity
- More passive cooling feasibility analyses
- Integrated thermal simulation and experimental validation



Acknowledgements

- Sincerest thanks to my supervisor, Stephanie Timpone
- Everyone on the CubeSat project; Juan Estrada, Katie Chennault, Amanda Joseph, Venetia Colon.
- My mentors, Donovan Tooke and Javier Mauricio Duarte
- The SIST committee, Sandra Charles, Judy Nunez, Laura Fields.