Lessons Learned from the Development & Flight of the First Miniature Tethered Electrodynamics Experiment (MiTEE-1)

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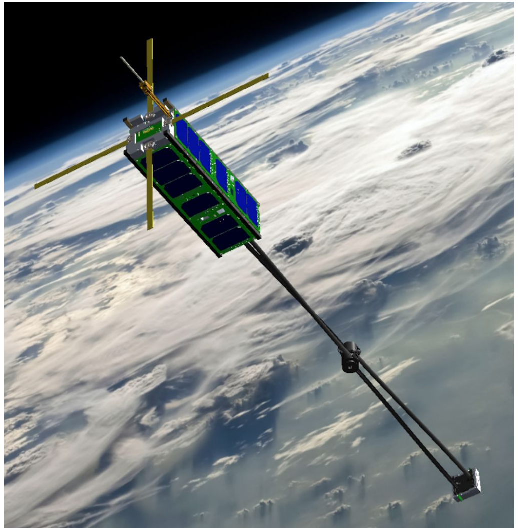
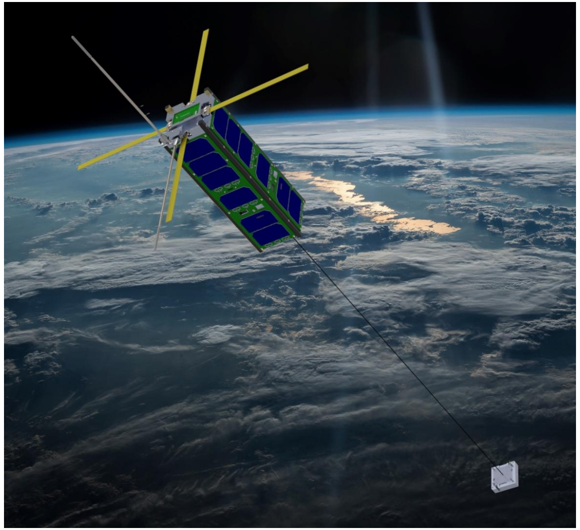
  - General System/Mission Overview

MiTEE Project Overview & Background

Project Overview



MiTEE-1



MiTEE-2

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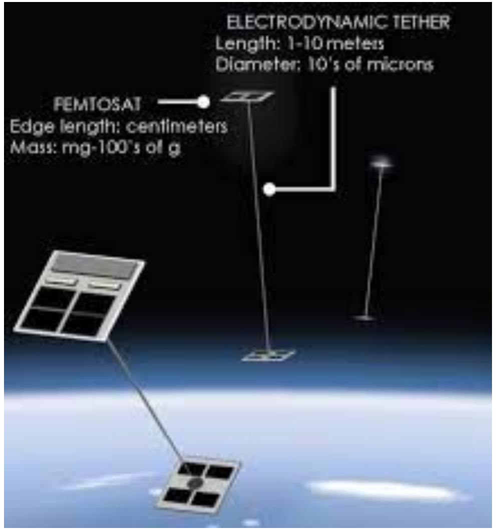
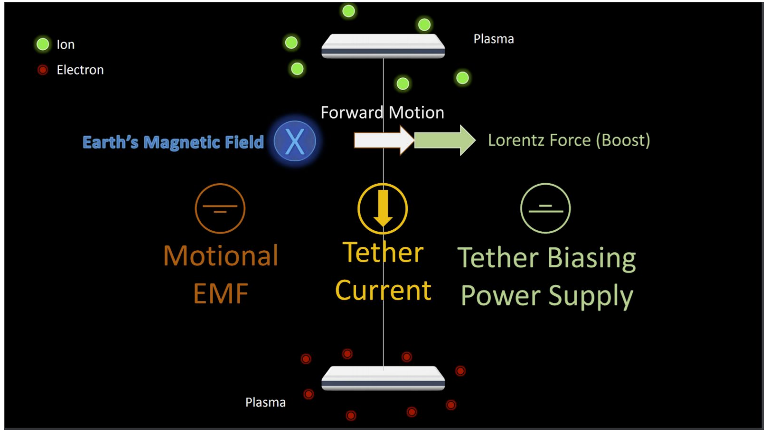


Project End Goal

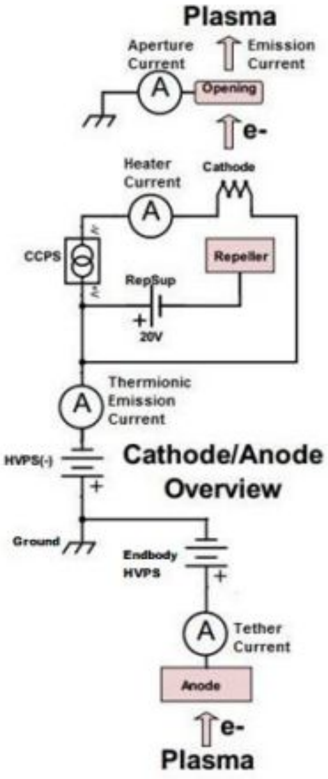
Electrodynamic Tethers (EDTs)

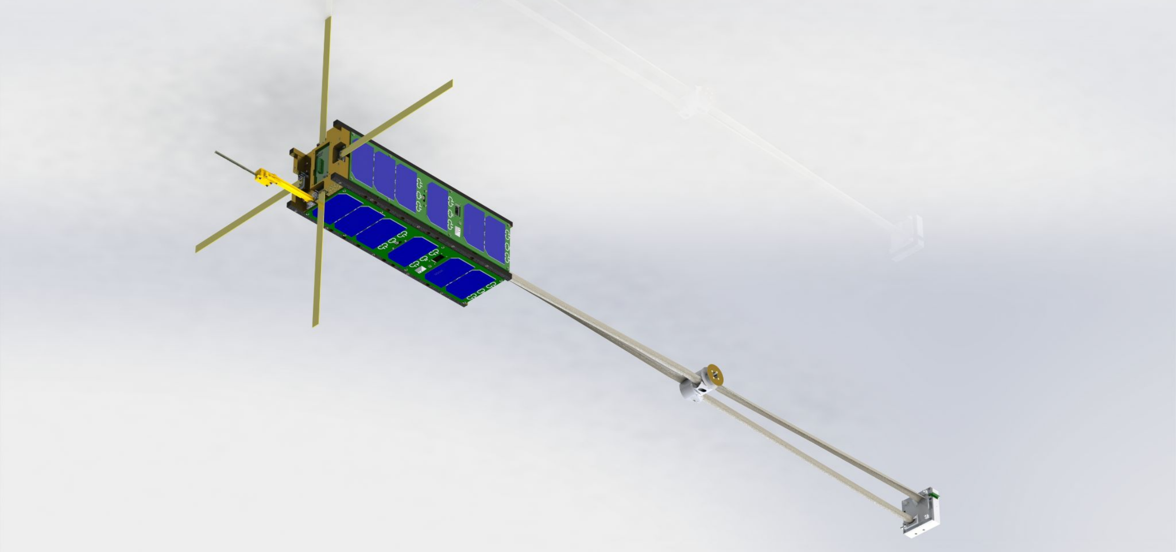
- Current flows along long, thin, conductive tethers connecting two endbodies
  - Induced magnetic field interactions add or remove energy from orbit
  - System interacts via the Lorentz Force equation: F = IL x B
- Enable propellantless propulsion on small satellite systems
  - Indefinite mission lifetime of LEO satellites
  - Controllable quick deorbit solution to eliminate “space junk”
- Deployable Earth-Satellite communications antenna
  - Greater communications capabilities with smaller volume & mass requirements



MiTEE-1 Plasma Circuit

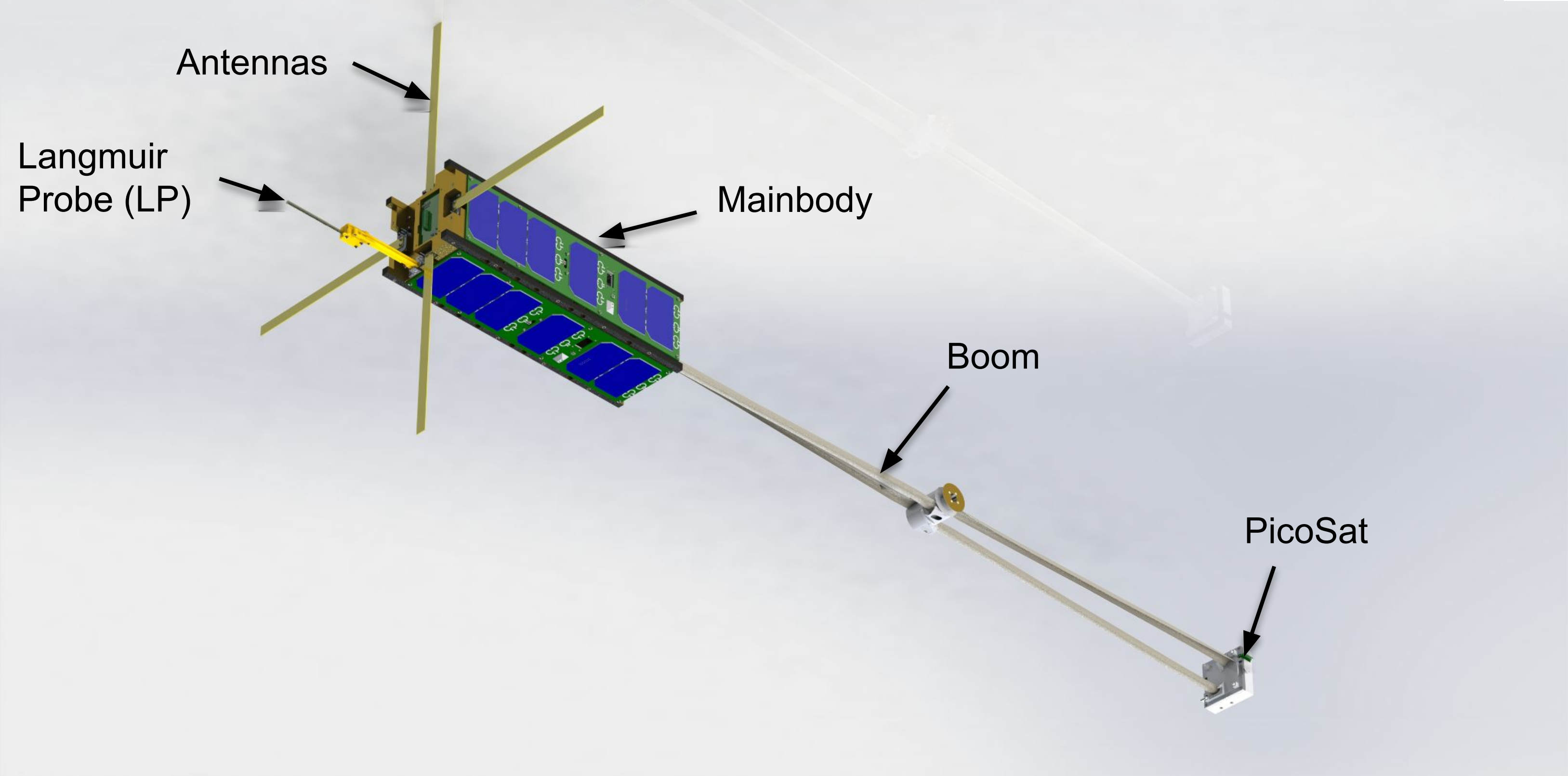
- Electrons are collected from a positively biased picosat
- Current runs through tether to HVPS and CCPS
- Thermionic cathode (electron emitter) completes circuit
- Langmuir probe (LP) provides information about electron temperature, plasma density, and plasma potential in Low Earth Orbit (LEO)





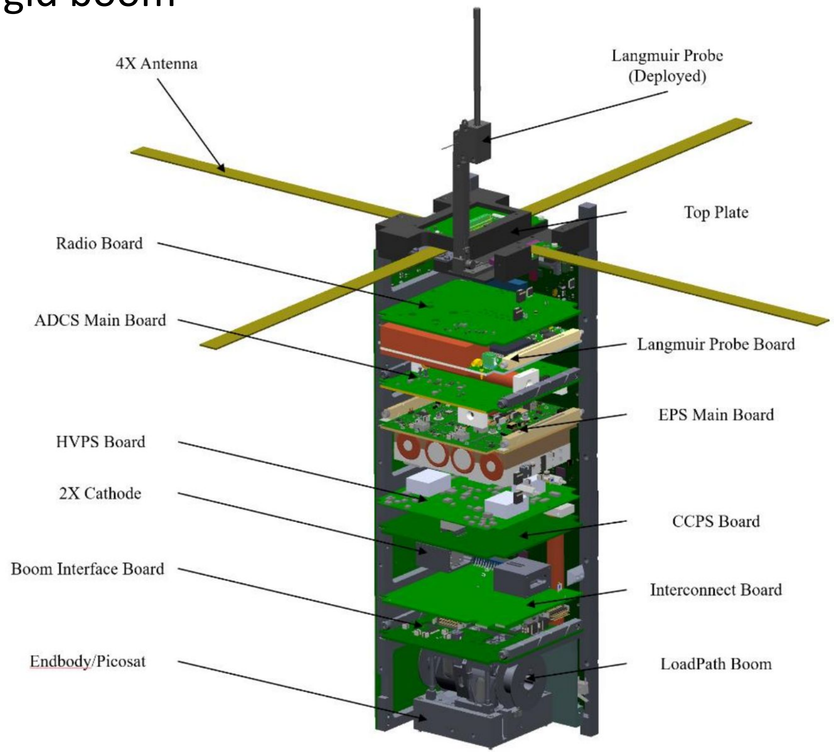

MiTEE-1 Payload Summary & Mission Overview

System Terminology



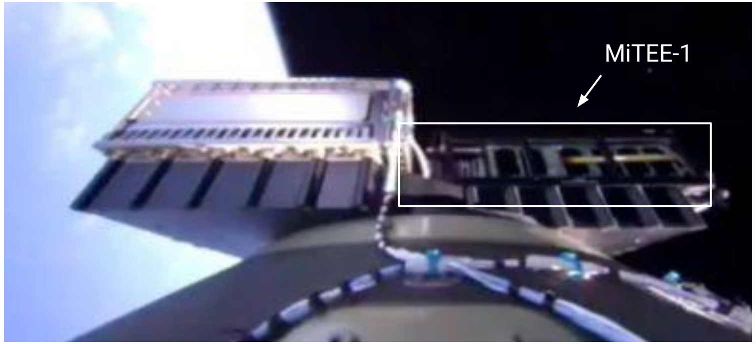
MiTEE-1 System Overview

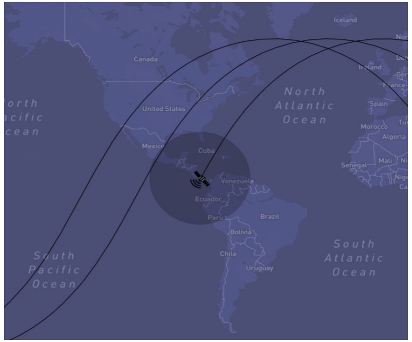
- 3U CubeSat with a deployable 1-meter LoadPath rigid boom
  - Connects mainbody to picosat endbody
  - Picosat used as current-collection device
- Electron-emitting Cathode
  - Used in current-measuring circuit
- Langmuir Probe (LP)
  - Used to characterize ambient plasma
- Omnidirectional antenna array
  - Increases chance of reliable communication regardless of current attitude
- Magnetorquer Attitude Control
  - Provides gyroscopic rate control in all 3 axes
- Onboard battery & solar panels
  - Used for power generation & storage

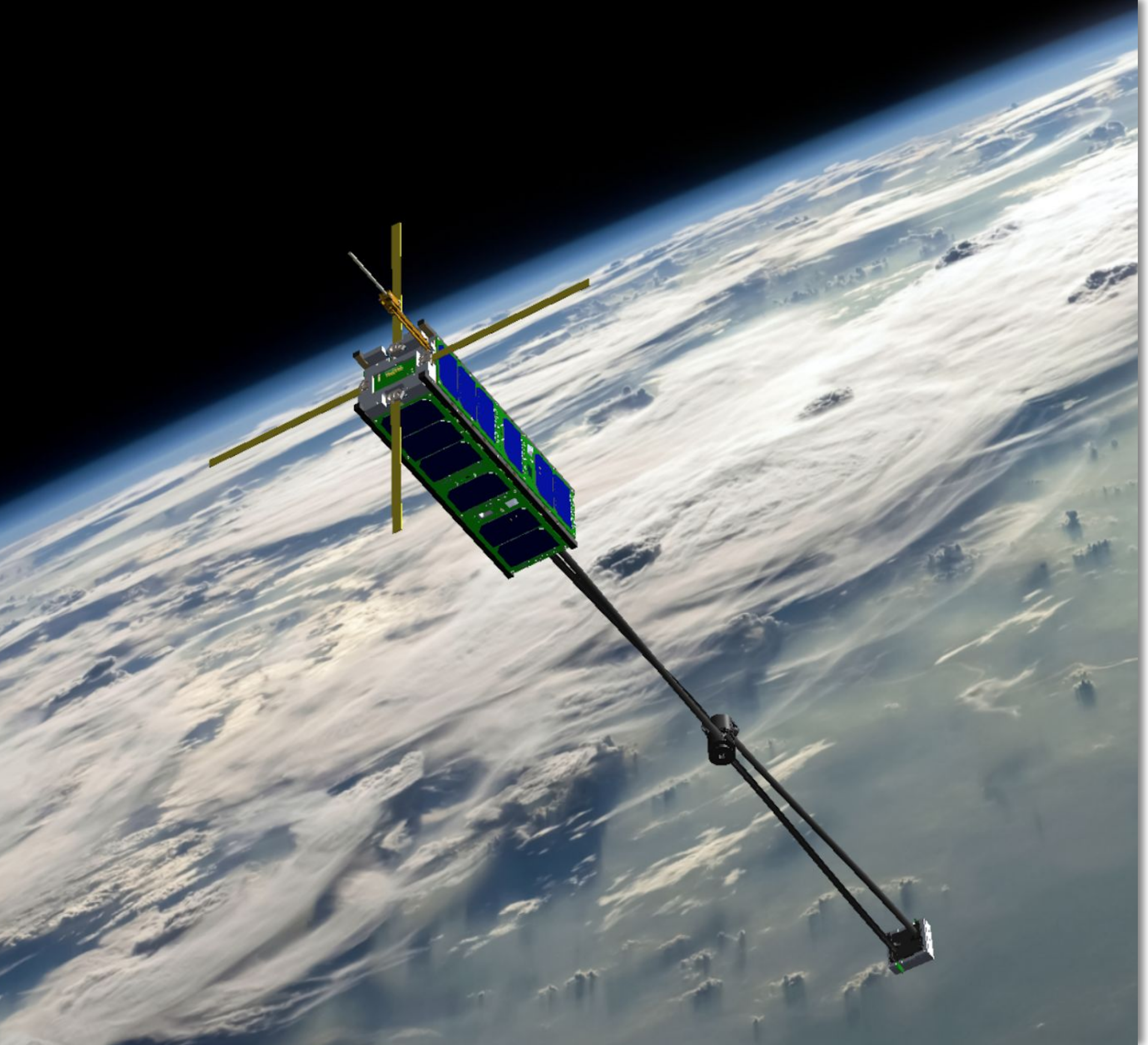


MiTEE-1 Mission Overview

- Goal: Measure the current-collection capabilities of a small deployable picosat in LEO & characterize the ambient plasma environment
  - Data collection mission to advise the development of an EDT system on MiTEE-2
- MiTEE-1 launched to space aboard Virgin Orbit's LauncherOne rocket January 17th, 2021
  - Received mostly nominal health data through periodic data beacons
  - Persisting issues in communications implementation
  - Recent license extension to December 1st of 2021







Lessons Learned

Categorization of Lessons Learned

- Technical
  - Specific component selection
  - System/Subsystem testing, validation, and verification
- Logistical
  - Transfer of knowledge & onboarding processes
  - Requirement definition and communication
  - Documentation and formal presentations/design reviews
  - Team organization and hierarchical structure
- Operational*
  - Full pre-flight mission simulation
  - Failure modes & effects analyses

*new operational lessons learned will arise as MiTEE-1's mission continues

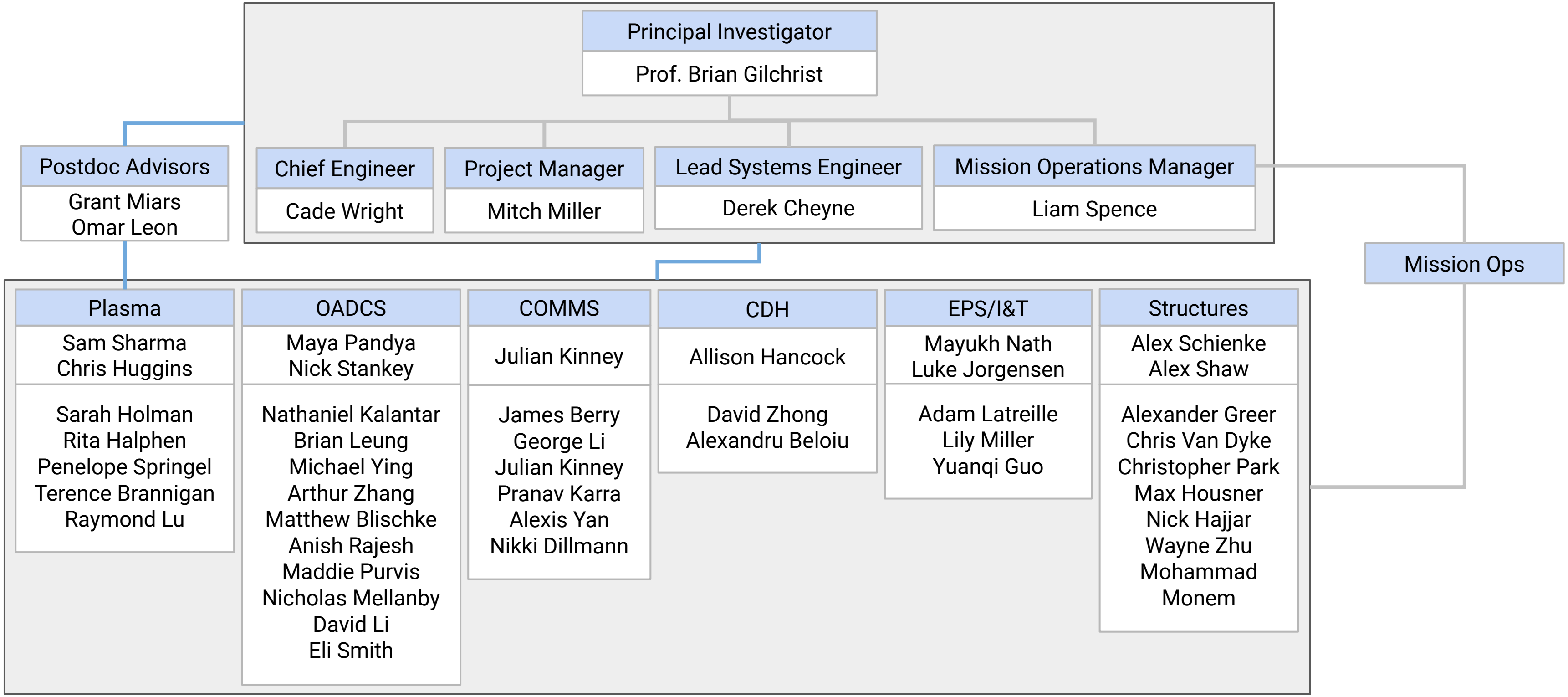
Technical Lessons Learned

- Full system testing must be achieved early in the development process
  - Component/subsystem testing performed regularly
  - Groundstation-satellite communications established early in system testing
- Drastically simplified flight computer hardware/software architecture needed
  - Accessible to anyone with basic programming knowledge (ex: EECS 280)
- Need more precise & responsive ADCS hardware & software
  - Current attitude determination method loses accuracy in Earth's shadow
  - Quick & precise control required to prevent tangling of a tethered spacecraft

Logistical Lessons Learned

- Need standardized, regularly-updated team documentation
  - Formal testing templates & team-wide testing schedule keeps progress moving
  - Process so team knowledge doesn't leave with graduating students
  - Consistent onboarding materials across subteams to get new students contributing ASAP
- Formal design reviews greatly aid the development and iteration of system designs
  - Clearly communicate all system and mission requirements across the team
  - Participation in formal presentations increases student participation & experience
  - Feedback from reviewers helps direct the continued development of MiTEE-2

Logistical Lessons – MiTEE-1 Team Breakdown



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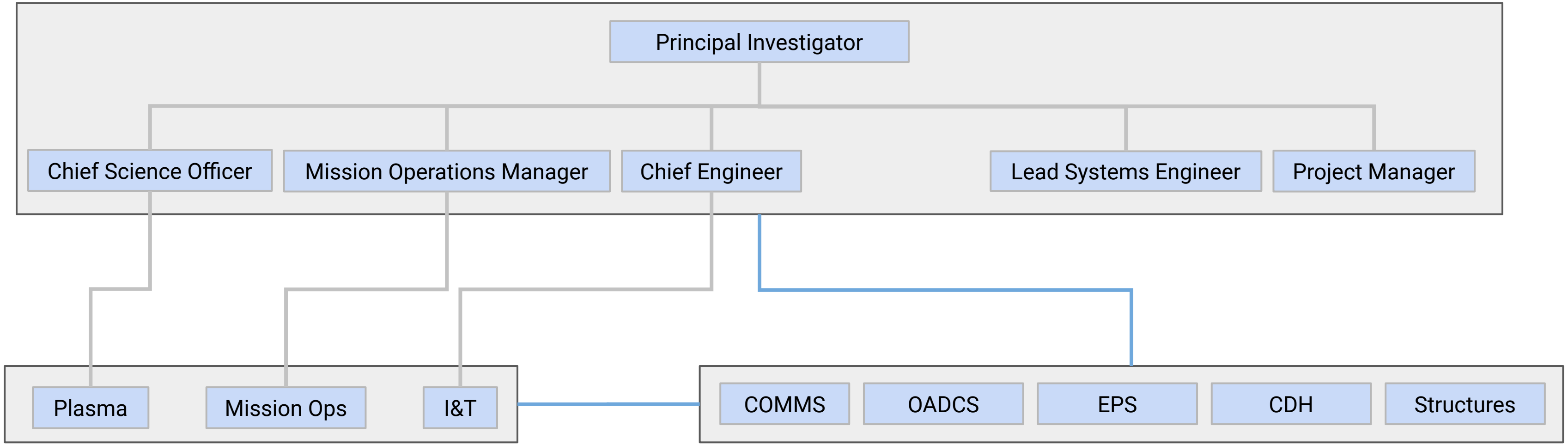
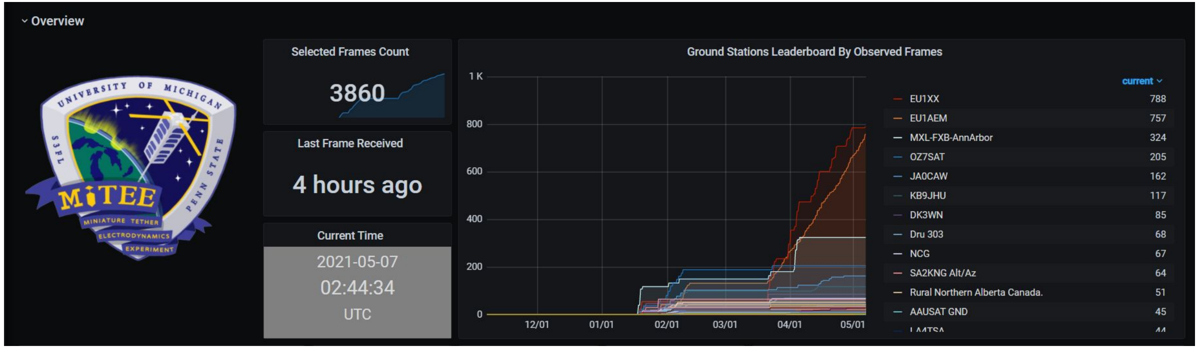
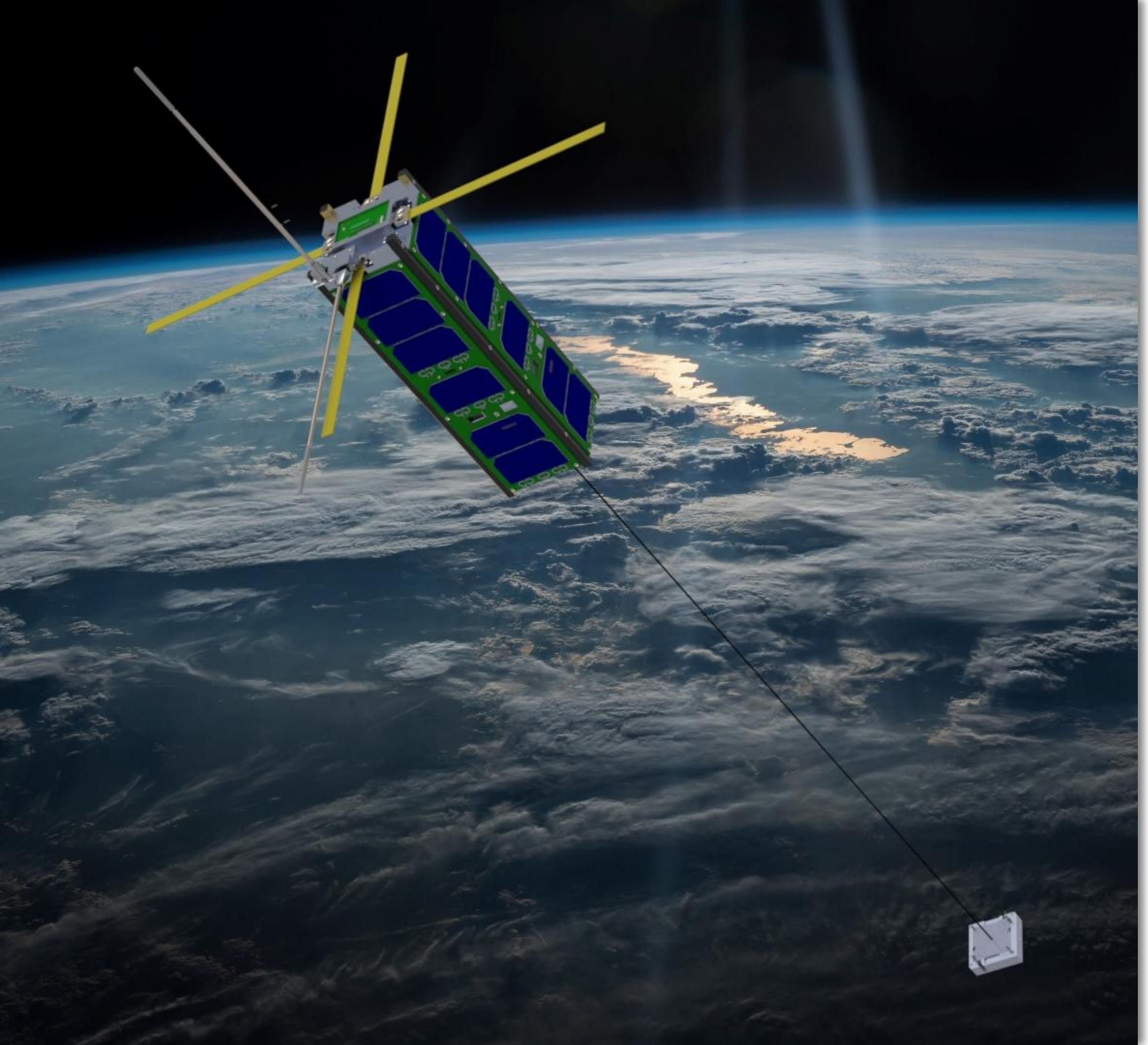
Logistical Lessons – MiTEE-2 Team Breakdown



Operational

- Full early-mission simulations are crucial for a successful launch & spacecraft checkout events
  - Team should be ready for mission operations months before launch
- Pre-flight analyses and characterization of possible failure modes are crucial
  - Allow the team to quickly diagnose and address any off-nominal events once on-orbit
- Using the SmallSat enthusiast community greatly increases the amount of health data received
  - Earlier integration with SatNOGS groundstation network benefits the entire community
  - Open-source data collection networks provide crucial health & status data

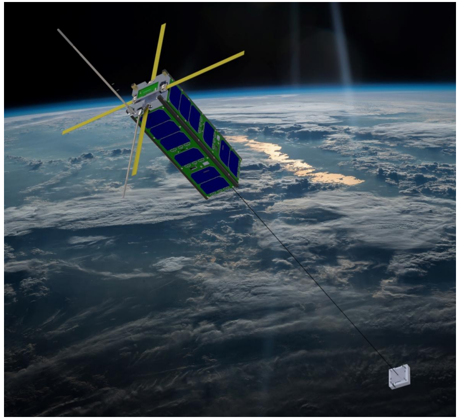




Planned Development of MiTEE-2

General Mission Concept

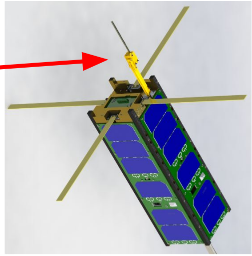
- MiTEE-2 is a 3U CubeSat that will deploy an EDT to study the physical and electrical dynamics of operating an electrodynamic-tether-based spacecraft in LEO
  - Propellantless propulsion system
  - Deployable communications antenna
- Main changes from MiTEE-1
  - Rigid boom to electrodynamic tether
  - Additional Langmuir Probe (LP) for mainbody bias measurement
  - Additional tether-based Earth communications radio
  - More capable ADCS design (addition of reaction wheels)
  - Sat-to-sat communications between mainbody & picosat



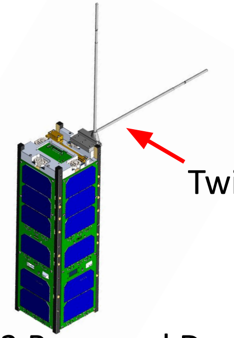
Updated Plasma Subsystem

- Utilization of rigid 1-meter boom for MiTEE-1
  - MiTEE-2 transitioning to 10-30 meter thin conductive tether
- Single LP used for plasma characterization on MiTEE-1 alongside high impedance measurements
  - Twin-LP's more preferable for MiTEE-2 to account for variability of spacecraft potentials but requires storage and deployment changes

Single-LP



MiTEE-1

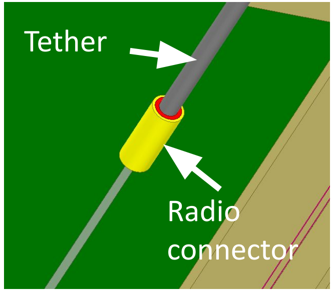


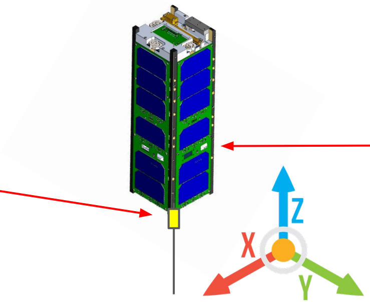
Twin-LP Design

MiTEE-2 Proposed Design

Subsystem Design Changes

- More advanced Communication subsystem design
  - Additional radio attached to tether to use as to-Earth antenna
  - Disruptive coiling inductance from partially undeployed tether circumvented with capacitive radio connector to the deployed length
  - Satellite-to-satellite local communication between mainbody/picosat
- More capable ADCS needed for MiTEE-2 Nadir-direction pointing requirement
  - MiTEE-1's had rotation rate control, not absolute attitude control
  - MiTEE-2 will add a z-axis reaction wheel to mitigate torsional loads on the tether





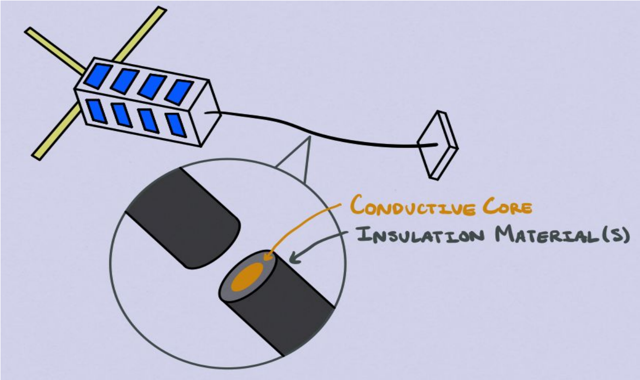
COTS Reaction Wheel

Preliminary EDT Physical Requirements

Rigid Boom (1 m) → Electrodynamic Tether (10 - 30 m)

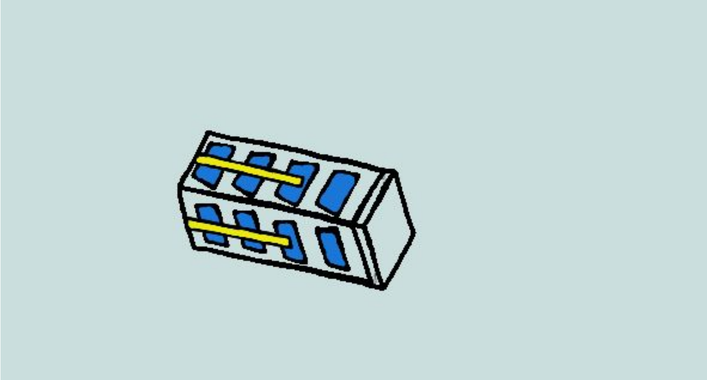
EDT Physical Requirements

- Conductive core
  - Induces current throughout the EDT with safety factor of 2 (400 V)
- Insulation Material(s)
  - Resistant to Low Earth Orbit (LEO) corrosive environmental conditions



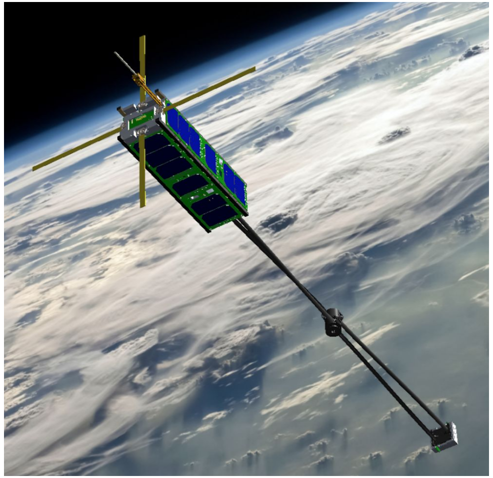
EDT Deployment Requirements

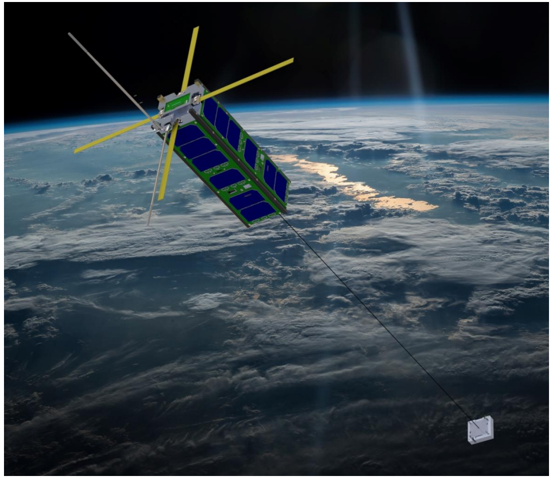
- Must be deployed to the greatest extent possible
  - Final velocity of the picosat must be mitigated to prevent kickback of the picosat
- Must prevent spinning of the satellite due to coil winding of the EDT during deployment



MiTEE-2 Future Prospects

- MiTEE-2 is the next step in achieving our project goal of operating a coordinated constellation of EDT-enabled MiTEE picosats
  - Explore the feasibility of novel uses for EDTs on future SmallSat platforms
  - Provide students with valuable experiential learning opportunities





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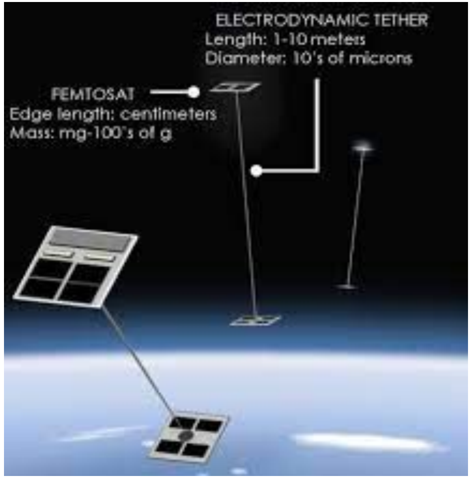

Thank You!

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Research reported in this publication was supported in part by funding provided by the National Aeronautics and Space Administration (NASA), under award number **80NSSC20M0124**, Michigan Space Grant Consortium (MSGC). Additionally, the NASA Undergraduate Instrument Program (USIP), **NNX116AI92A.**

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