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Small Satellites in the Michigan Exploration Laboratory
at the University of Michigan

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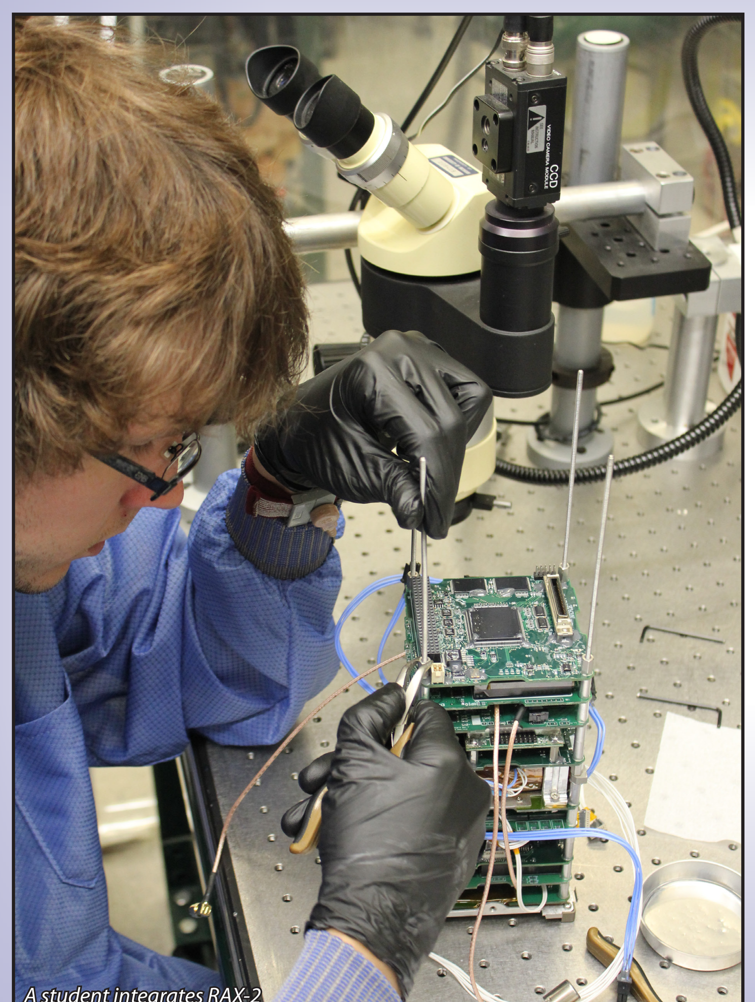
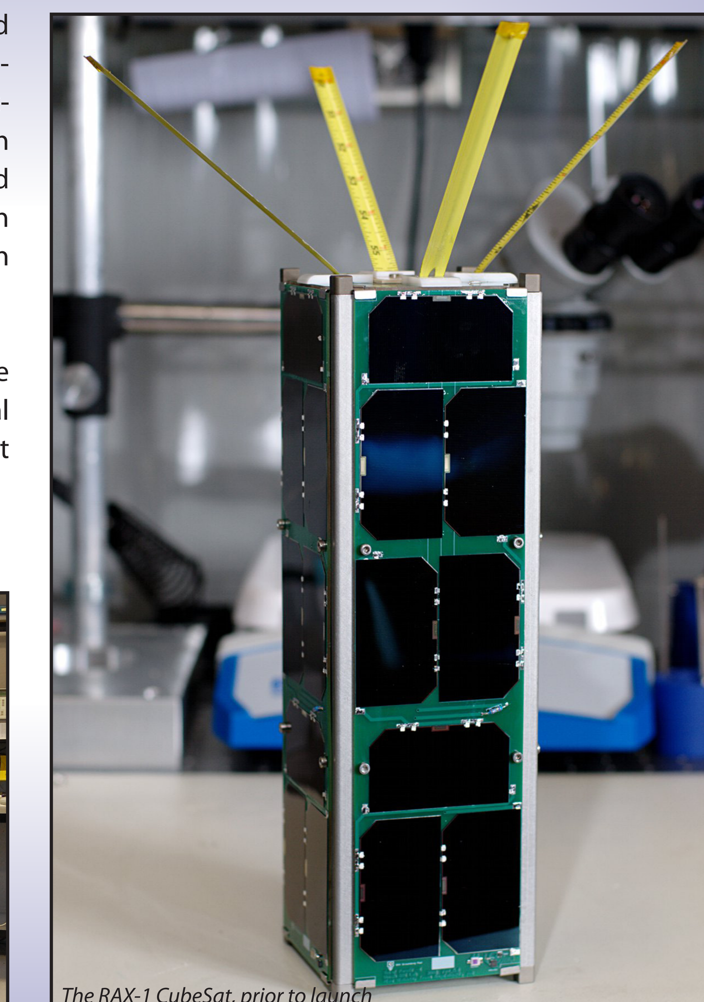
Michigan Exploration Laboratory (MXL) Overview


A student integrates RAX-2

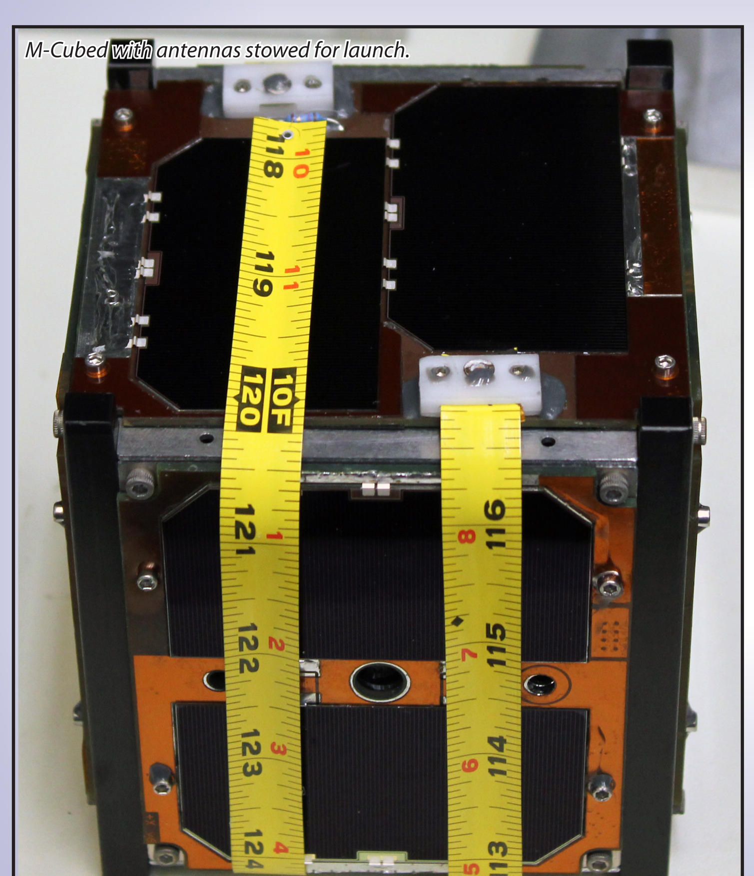
The Michigan Exploration Laboratory (MXL) works to achieve a comprehensive blend of education, research, and entrepreneurship within the University of Michigan College Of Engineering. The collaborative MXL environment has already yielded flight-proven achievements in small satellite design and high altitude ballooning, with even more innovations resulting from the analysis of flight data and completed missions. MXL is also pursuing fundamental research in the areas of satellite design and optimization, estimation and sensor calibration methods, and ground station network optimization and scheduling.

MXL aspires to foster new mission architectures, innovation in space, and to enable bold flight to extreme and remote environments. Through a variety of potential funding sources, MXL will sponsor projects that not only train future leaders, but also enhance the educational experiences of hundreds of engineering students.


Part of the RAX team with Prof. Cutler (top center)


The RAX-1 CubeSat, prior to launch

Michigan Multipurpose Minisat (M-Cubed)

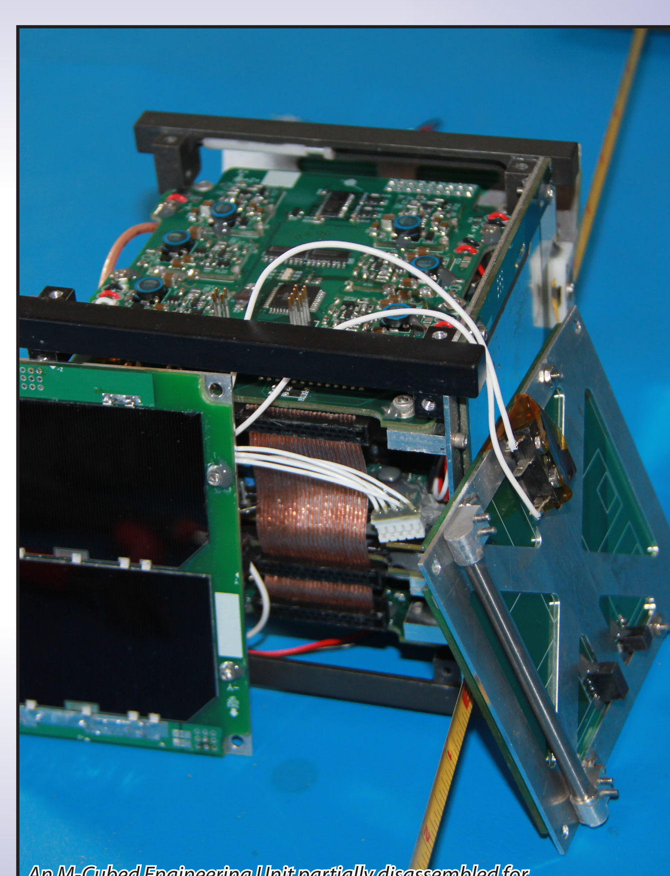

M-Cubed with antennas stowed for launch.

The Michigan Multipurpose Minisat (M-Cubed) is the first spacecraft developed by the University of Michigan's Student Space Fabrication Lab (S3FL) in collaboration with MXL. M-Cubed has partnered with the Jet Propulsion Lab (JPL) and NASA's Earth Science Technology Office (ESTO) to demonstrate an on-board processing system that is planned for the ACE Decadal Survey Mission.

M-Cubed's payload is an imaging system comprised of a 2 MP CMOS sensor and a Xilinx Virtex-5 FX130T rad-hard-by-design (RHBD) Field Programmable Gate Array (FPGA) coprocessor. The camera will take an image from low earth orbit with a resolution better than 200 meters per pixel. On-board processing results and original image data will be downlinked to ground stations for verifications against ground tests. The mission goal is to advance the TRL for MSPI camera development and the ACE mission.

MCubed launched in October 2011. The satellite is operational, but communication is difficult due to interference with another CubeSat deployed from the same P-POD, E1P. MCubed and E1P re-contacted and unexpectedly docked after launch, most likely due to interaction between their passive magnetic control systems. Because of this, communication with MCubed has been difficult, and the performance of the payload has not yet been verified.

M-Cubed 2 is being developed to refly the image processing system. The rebuild is scheduled to be completed in nine months.


An M-Cubed Engineering Unit partially disassembled for

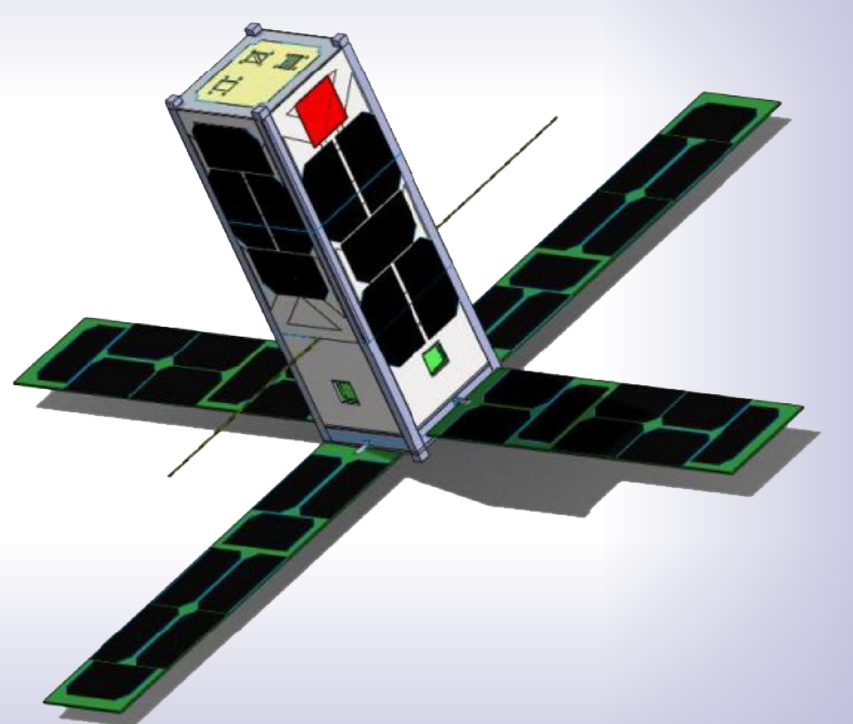
CADRE

The CubeSat-investigating Atmospheric Density Response to Extreme driving (CADRE) is the next space weather mission to be sponsored by the National Science Foundation. Instruments on CADRE will measure the in-situ density, temperature, and composition of the Earth's thermosphere, as well as winds and ion flows. This mission is a precursor for a constellation of CubeSats that will provide regional and global assessment of thermospheric feature scales.

CADRE's mission objectives include:

- Deploy a University of Michigan CubeSat housing the Wind Ion Neutral Composition Suite (WINCS)
- Flight-test low-cost dual-frequency GPS to measure atmospheric and ionospheric total electron content
- Advance CubeSat capabilities to enable Armada and other NanoSat missions

CADRE will operate WINCS in low earth orbit and advance capabilities of CubeSat class spacecraft as a test for Armada, and will launch with the NASA ELaNa program. The satellite is currently in development with a planned delivery for launch in late 2013.


A conceptual rendering of the CADRE CubeSat

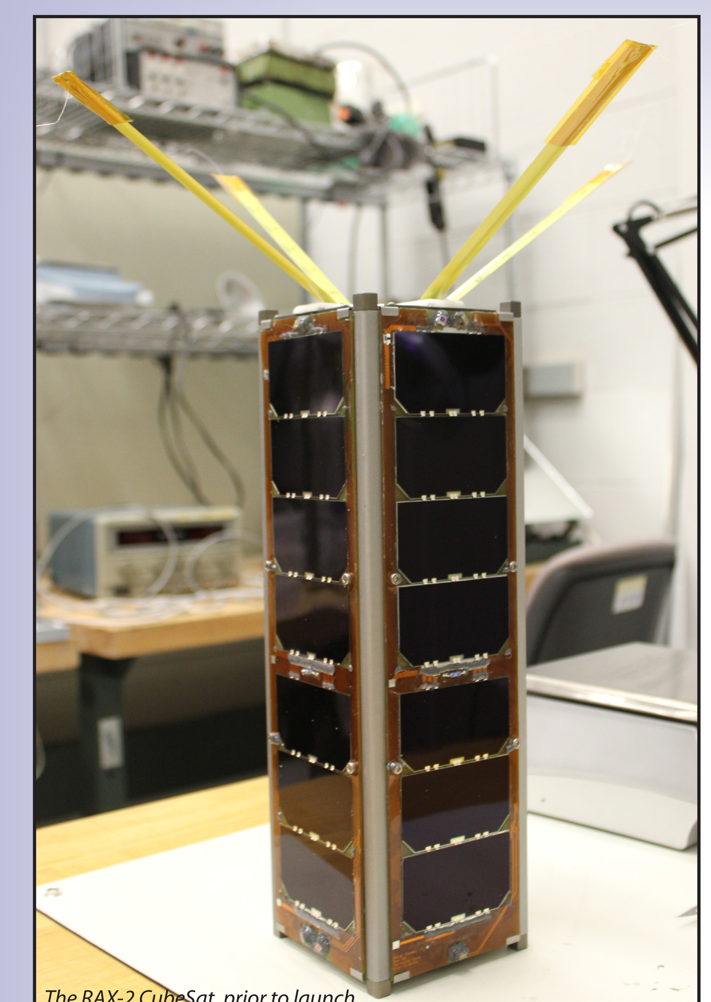
GRIFEX

In partnership with NASA ESTO and JPL, we are developing GRIFEX, the GEO-CAPE ROIC In-Flight Performance Experiment. GRIFEX will provide an on-orbit verification of a high performance focal plane array (FPA) consisting of an innovative in-pixel analog-to-digital (ADC) readout integrated circuit (ROIC) hybridized to a silicon detector array.

This high throughput digital FPA dramatically reduces the size, power, mass, risk, and cost of the FPA and signal chain electronics for Earth observing measurements. Its high throughput capacity will enable the Earth Science Decadal Survey Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission.

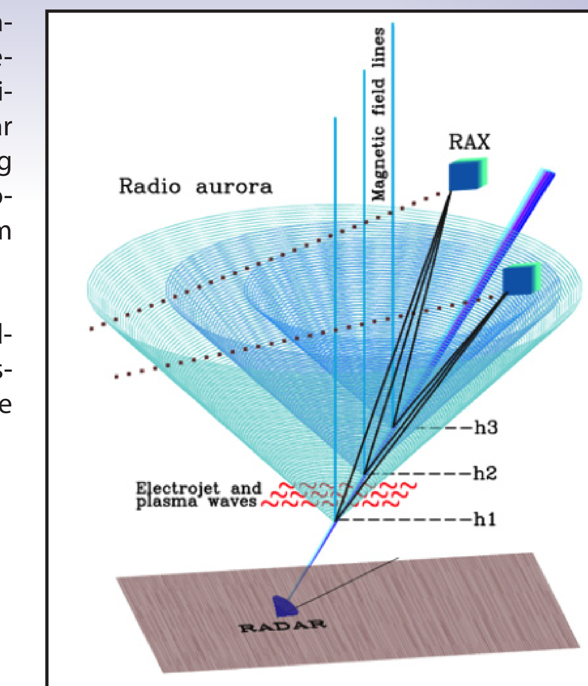
GRIFEX is currently in development and has been selected to launch with NASA's ELaNa program.

The Radio Aurora Explorer (RAX)

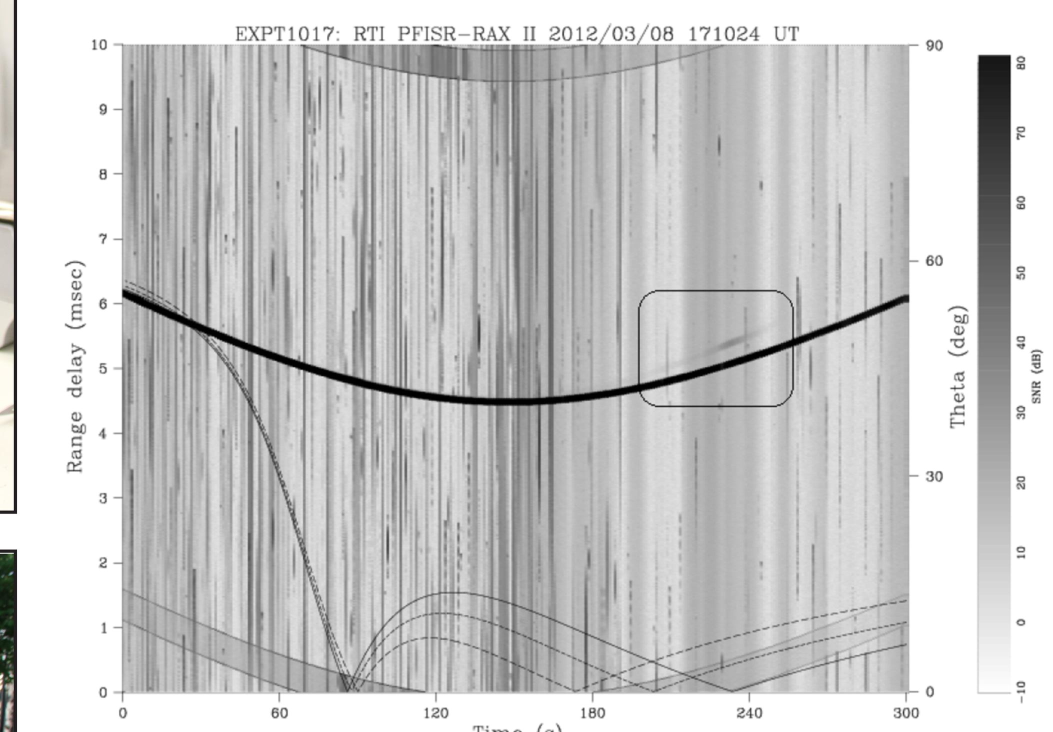

The RAX-2 CubeSat, prior to launch

The Radio Aurora Explorer (RAX) is the first of several CubeSats sponsored by the National Science Foundation to study space weather phenomena. The satellite was developed jointly by SRI International and MXL. The RAX mission studies plasma instabilities that lead to field aligned irregularities (FAI) of electron density in the lower polar (80-300 km) ionosphere. These FAI are capable of scattering radio signals, disrupting critical space-based resources such as GPS and communication. The RAX mission provides data to study the formation of FAI with the ultimate goal of enabling short-term forecasting to predict FAI.

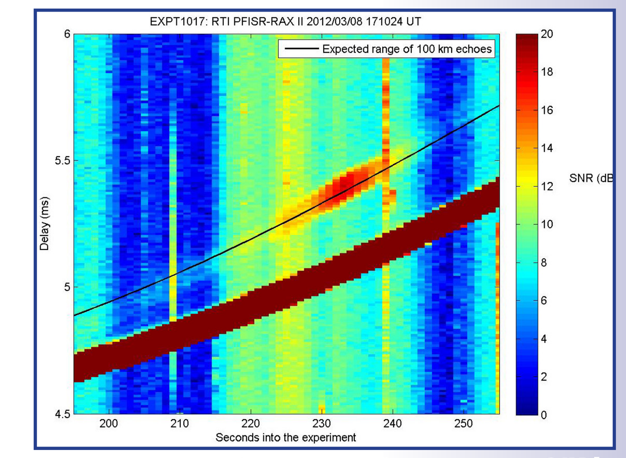
RAX utilizes a novel bi-static radar configuration, where the transmitter is a ground-based incoherent scatter radar station and the receiver is the RAX payload. Radar pulses illuminate the ionosphere as RAX passes overhead, and the satellite measures the radar echo from the FAI.



A schematic of the RAX radar measurements. Radar pulses are reflected off the magnetically aligned plasma disturbances and are measured by RAX orbiting overhead.



A range-time-intensity plot of RAX-2 radar measurements taken March 8, 2012. The horizontal axis is time into the experiment (5 minutes as RAX-2 passes over the radar station) and the y-axis is delay between radar transmission and receipt by RAX. The shading indicates signal strength. The black (saturated) strip is the direct radar pulses, and echo from FAI, highlighted by the box, is seen just above the direct beam.

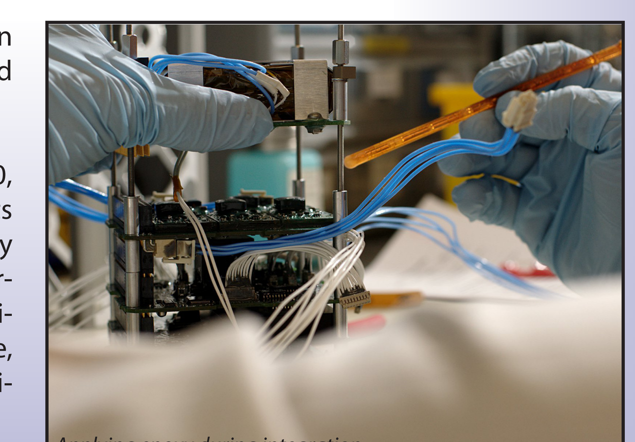


A zoomed in portion of radar echo. In this measurement, RAX detected echo from irregularities between 90 and 300 km. From preliminary analysis, this data shows that the magnetic-field-alignment of plasma irregularities is less pronounced than previously thought. Thorough data analysis is currently underway.


Students conducting tests on RAX-1

The primary RAX data product is irregularity intensity, measured by RAX, as a function of convection electric field, electron density, electron and ion temperatures (measured by the incoherent scatter radar), altitude, and magnetic aspect angle.

There are currently two CubeSats in the RAX mission: RAX-1, launched November 2010, and RAX-2, launched November 2011. RAX-1 successfully performed measurements with ground-based radar incoherent scatter radar, but the mission ended prematurely after two months of operation due to a solar panel failure. RAX-2 was developed to correct the solar panels and is currently operating on-orbit. RAX-2 has performed experiments with incoherent scatter radar stations located in Poker Flat, Alaska, and Resolute, Canada. RAX-2 is operated by MXL using ground stations located at the University. Scientific operations and analysis are led by SRI international.


Applying epoxy during integration

Advancing the State-of-the-Art Through Fundamental Reasearch

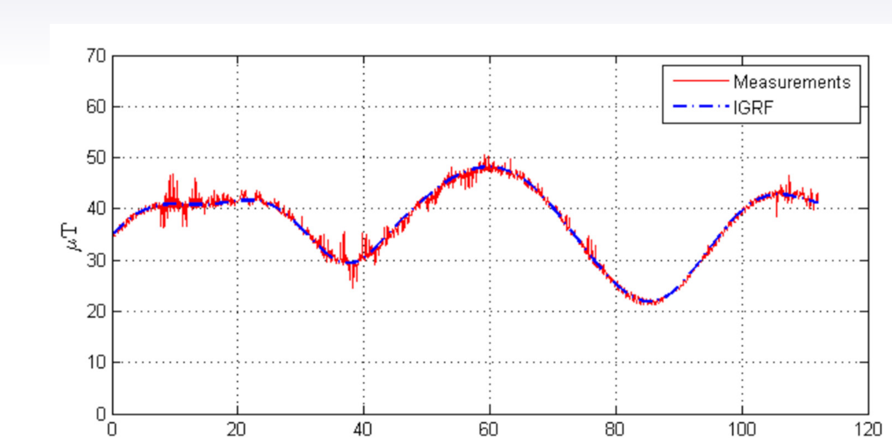
In addition to work in the design, integration, testing, and operation of small satellites, MXL is pursuing fundamental research related to increased capabilities of small satellite systems. Two examples are discussed below.

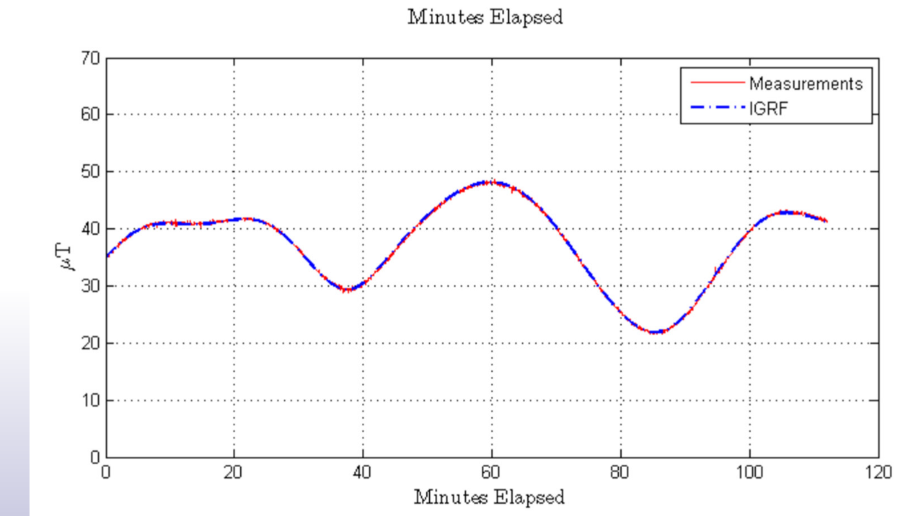
On-orbit sensor calibration

We are developing new, attitude-independent, on-orbit sensor calibration techniques to increase the accuracy of attitude determination sensors. The algorithms reduce the need for careful pre-flight calibration and integration with high tolerances to ensure sensor alignments. This reduces satellite development time and costs while increasing the performance of relatively cheap, commercially-available sensors that are common on small satellite missions.

In work with magnetometers, we have mitigated the effect of the satellite-induced magnetic field on the sensors. This is especially useful for small satellite missions, where volume constraints prevent physical separation and booms are often avoided due to cost and complexity.

(RIGHT) The plots show one orbit of 1 Hz magnetometer data taken by the RAX-1 spacecraft. The magnitude of the measurements is overlaid with the expected magnitude using the IGRF model. The magnetometer is embedded within the satellite and subject to magnetic fields due to nearby electronics. In the upper plot, existing calibration algorithms are applied to correct the measurements, but remaining errors are due to time-varying effects of on-board electronics. In the lower plot, we've corrected the data using a new calibration algorithm that accounts for time-varying magnetometer bias.





Assessment and Optimization of Constellation Missions and Federated Ground Station Networks

Motivated by the growing community of small satellites and various proposed constellation missions, such as QB50 and Armada, we are developing the analytical models, simulation tools, and optimization algorithms to maximize the data returns of existing and planned small satellite missions. This work is crucial for both single satellites and constellations seeking to download large amounts of data to distributed ground station networks.