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The Radio Aurora Explorer (RAX)

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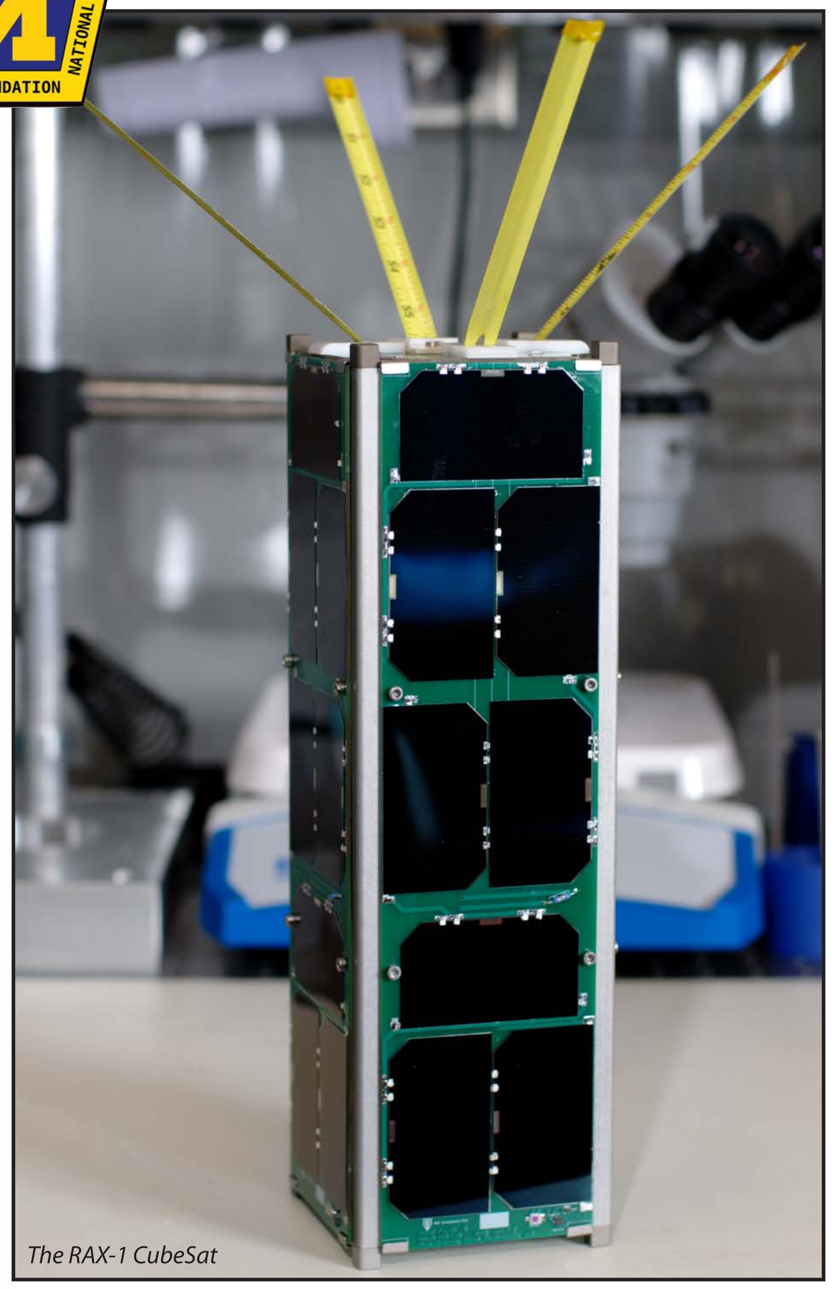
"The RAX radar echo discovery has convincingly proved that miniature satellites, beyond their role as teaching tools, can provide high caliber measurements for fundamental space weather research."

- Therese Moretto Jorgensen Ph.D.
NSF Geospace program director,
Division of Atmospheric and Geospace Sciences

"The recently collected radar echoes allow us to determine the root cause and to possibly predict future disturbances in the auroral ionosphere – disturbances that can severely compromise communication and GPS satellites."

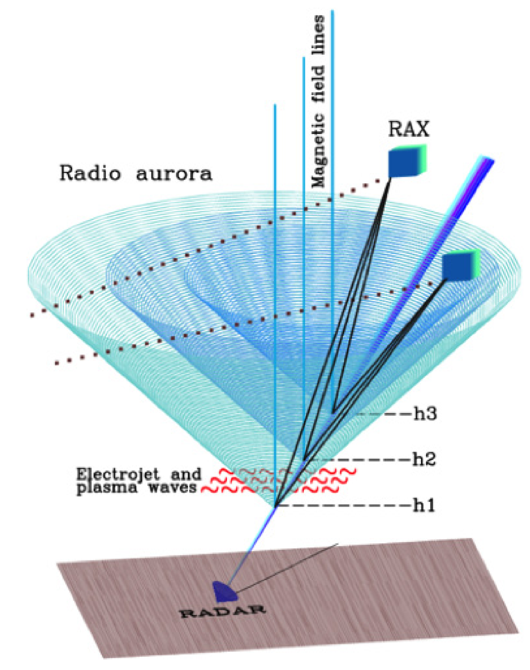
- Hasan Bahcivan, Ph.D.,
Co-principal investigator of the RAX mission



The RAX-1 CubeSat

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 the Michigan Exploration Laboratory (MXL), a research laboratory in the University of Michigan's Department of Aerospace Engineering

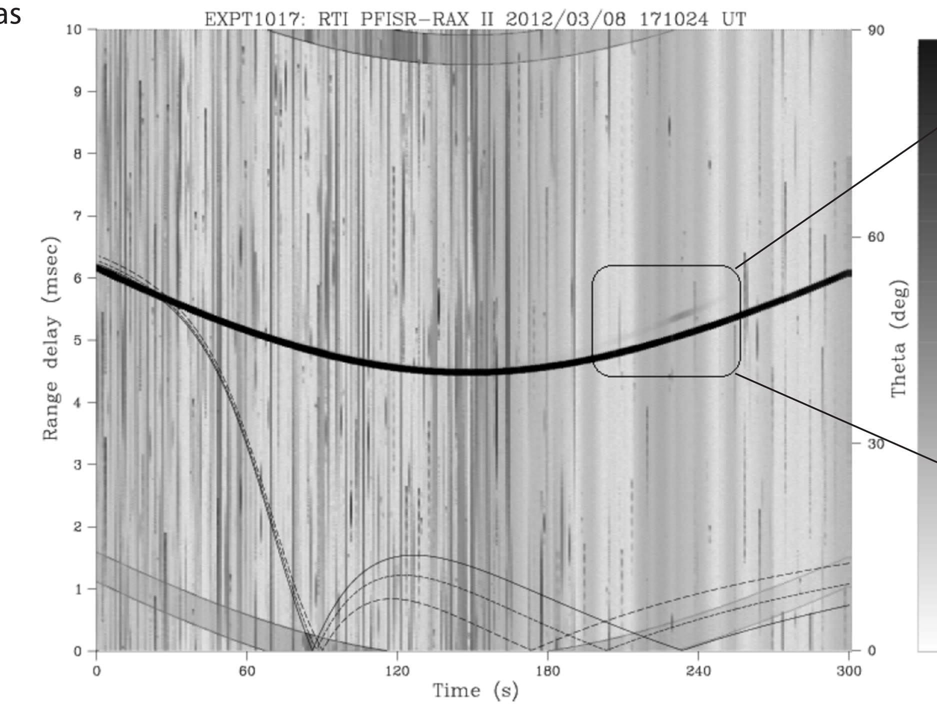
The RAX mission studies plasma instabilities that lead to field aligned irregularities (FAI) of electron density in the lower polar (80-300 km) ionosphere. These FAI are capable of scattering radio signals, disrupting critical space-based resources such as GPS and communication.



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

The RAX mission provides data to study the formation of FAI with the ultimate goal of enabling short-term forecasting to predict FAI.

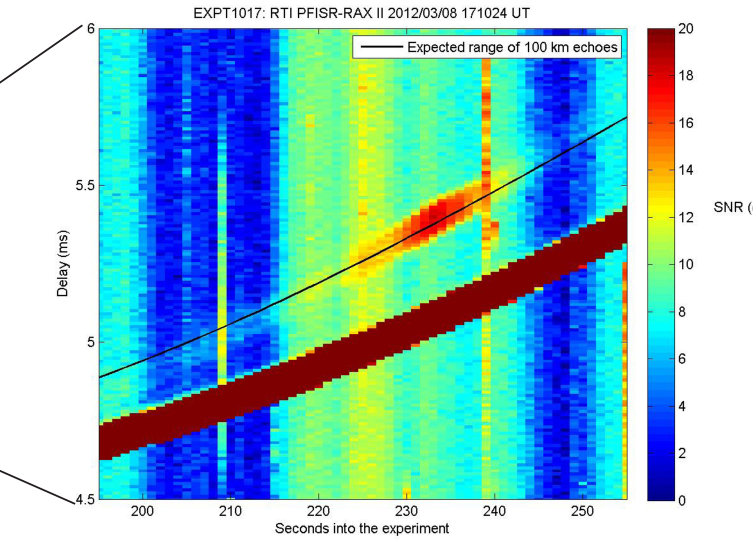
RAX utilizes a novel bi-static radar configuration, where the transmitter is a ground-based incoherent scatter radar station and the receiver is the RAX payload. Pulses from the ground-based radar illuminate the ionosphere as RAX passes overhead, and the satellite measures the radar echo from the FAI.



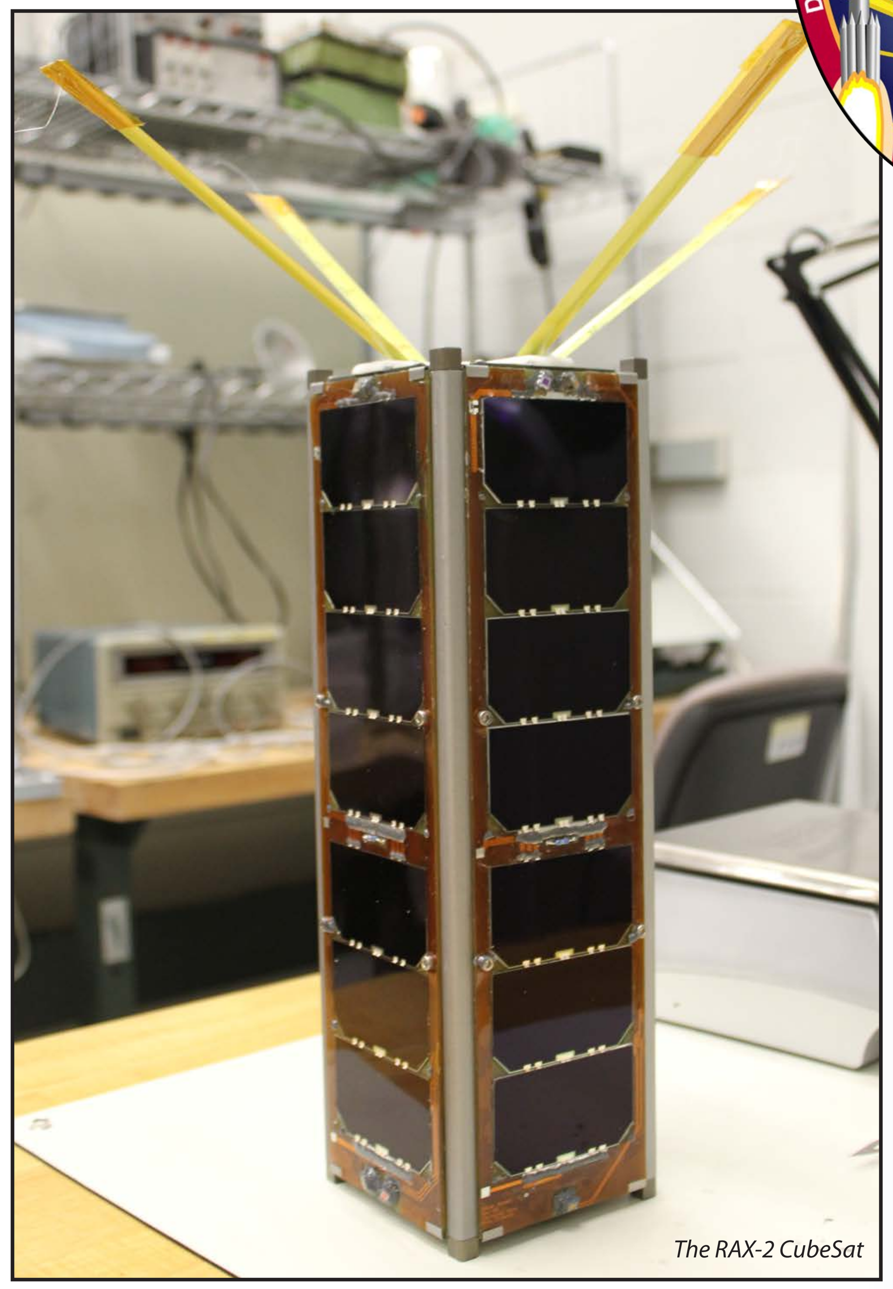
A range-time-intensity plot of RAX-2 radar measurements taken March 8, 2012. The horizontal axis is time into the experiment (5 minutes as RAX-2 passes over the radar station) and the y-axis is delay between radar transmission and receipt by RAX. The shading indicates signal strength. The black (saturated)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

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.

RAX has provided unprecedented measurements, which to our knowledge, are the highest resolution (in altitude and aspect angle) UHF radar measurements ever made in the auroral region.

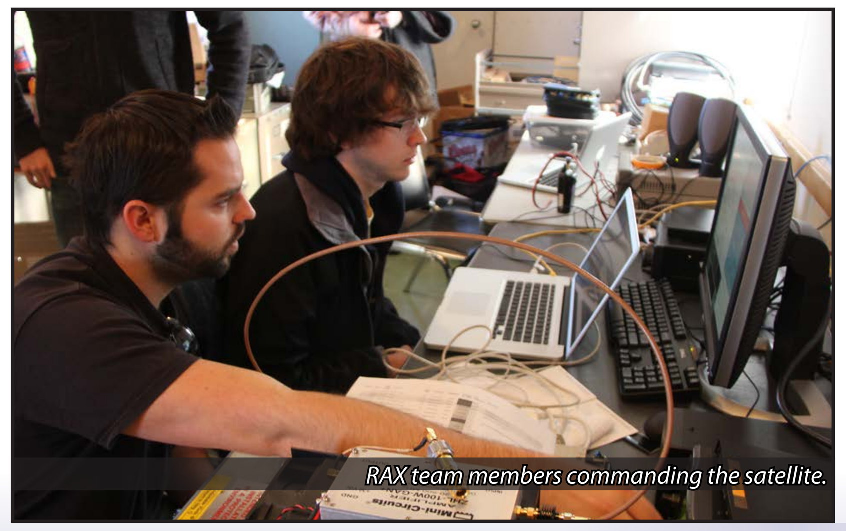


A zoomed in portion of radar echo. In this measurement, RAX detected echo from irregularities between 90 and 300 km. From preliminary analysis, this data shows that the magnetic-field-alignment of plasma irregularities is less pronounced than previously thought. Thorough data analysis is currently underway.



The RAX-2 CubeSat

Michigan and SRI team members at SRI headquarters



RAX team members commanding the satellite.

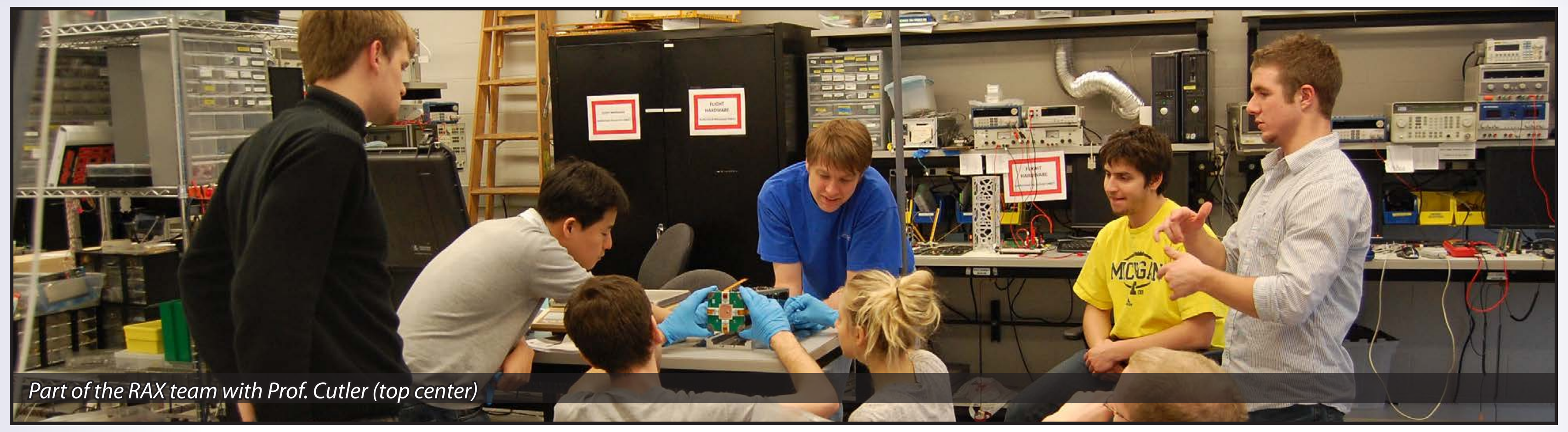
There are currently two CubeSats in the RAX mission: RAX-1, launched November 2010, and RAX-2, launched October 2011. RAX-1 successfully performed measurements with ground-based radar incoherent scatter radar, but the mission ended prematurely after two months of operation due to a solar panel failure. 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 lead by SRI international in Menlo Park, California.

Testing subsystems in a variety of environments

The SRI 60-foot dish in Palo Alto, California

Educational Impact



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

The RAX mission provides a comprehensive blend of education, research, and entrepreneurship opportunities at the University of Michigan College of Engineering.

Based in the department of aerospace engineering, RAX brings together students from across a multitude of academic engineering disciplines in order to create a finely tuned and well-balanced engineering design and development team.

By working with such a diversely populated team on real missions, students are afforded the opportunity to cultivate their own strengths and interests while learning key teambuilding and communication skills.

RAX was designed, built, and tested by students; it continues to be operated daily by a team of student researchers.

The relatively short time needed to develop a CubeSat allows students to contribute in all phases, from initial subsystem design to on-orbit operations and data analysis.

The structure of the RAX team is exceptional among student engineering groups at Michigan in that it contains diversity not only in skill, but also in management. Students take on serious leadership roles, such as project manager and subsystem leaders. These roles prepare students to not only excel at their own tasks, but to learn how to delegate responsibility to the appropriate skill and leadership level. There are currently 6 full-time students manning the mission.

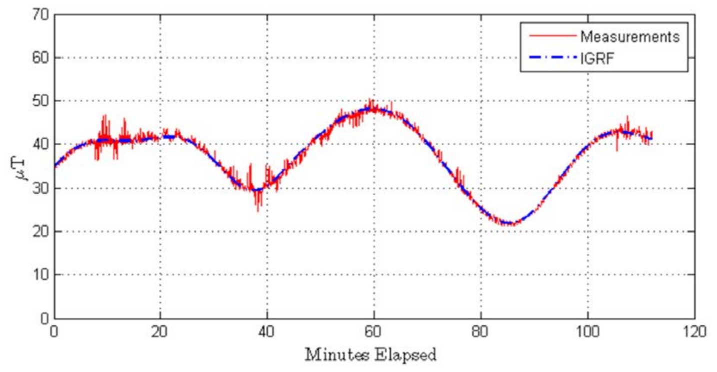
Alumni include 3 doctoral graduates and 36 bachelor's and master's degree students. These former team members are now contributing at leading-edge engineering companies and government laboratories, including the Jet Propulsion Laboratory, Applied Physics Laboratory, Orbital Sciences, SpaceX, Space Systems Loral, and Department of Defense research labs

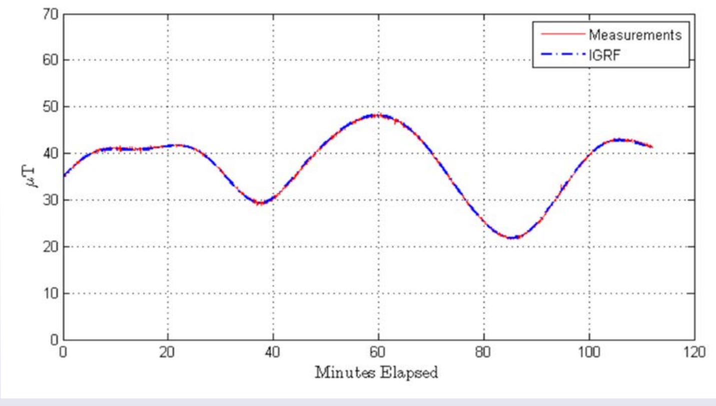
Engineering Research to Advance Space Systems

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 intgration with high tolerances to ensure sensor alignments. This reduces the development time and costs of satellite integration, and increases 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.





The plots show one orbit of 1 Hz magnetometer data taken by the RAX-1 spacecraft. The magnitude of the measurements are overlayed wih the expected magnitude using the IGRF model. The magnetometer is embeded within the satellite and subject to magnetic fields due to nearby electronics. On the top, existing calibration algorithms are applied to correct the measurements, but remaining errors are due to time-varying effects of on-board electornics. On the bottom, we've corrected the data using a new calibraion algorihtm that accounds for time-varying magnetometer bias.

Optimization of Space Network Scheduling

There is a growing population of highly constrained small satellites seeking to download large amounts of science, observation, and surveillance data. The constraints of these missions, coupled with the limitations of the existing ground station infrastructure, lead to significant operational and scheduling challenges.

To assess and optimize mission returns, we have developed analytic models and simulation tools that capture on-board satellite energy and data dynamics, as well as interactions with the realistic external space environment. We use these models and tools to formulate and solve space network optimization problems to maximize the amount of data downloaded from small satellites to Federated Ground Station Networks (FGSNs).

Initial results highlight the importance of developing globally distributed FGSNs and the advantages of higher data rate and variable data rate communication. Current research centers on developing scheduling algorithms that take into account realistic sources of problem stochasticity, such as inefficient communication links and the uncertainty in opportunities to perform science experiments and collect power. We are also working to extend and apply our foundational models and tools to multiple-satellite constellation missions, such as the NASA CubeSat Launch Initiative, and interplanetary applications.

Above: Schematic of communication between low Earth orbit space vehicles and a globally distributed Federated Ground Station Network.