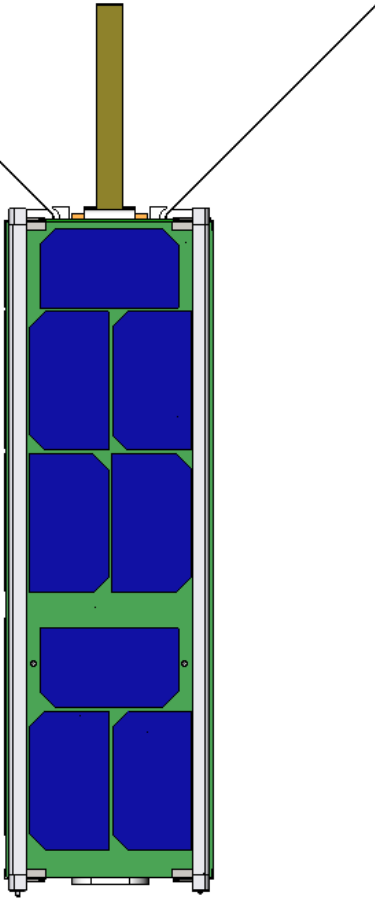
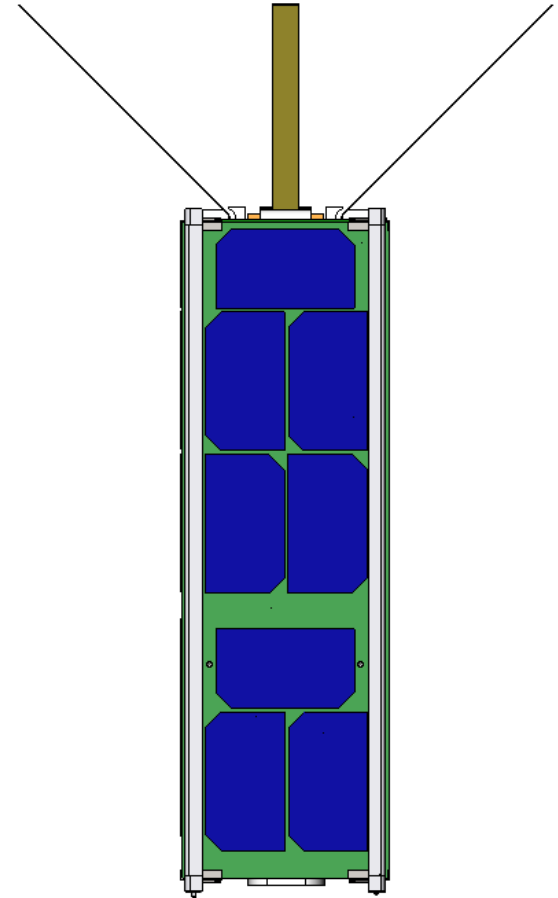


# In-Lab Testing for Attitude Determination and Control



Kiril Dontchev  
University of Michigan

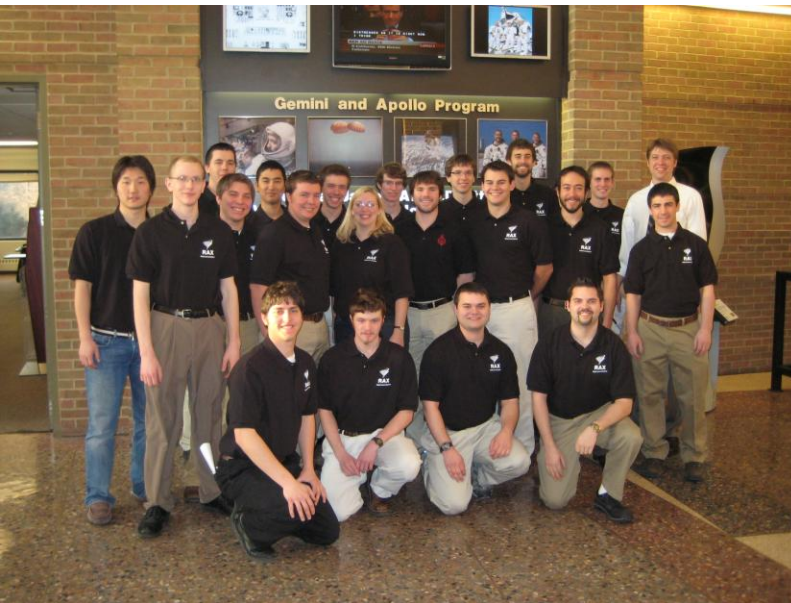
CubeSat Workshop  
Utah State University, Logan, UT  
Aug 9<sup>th</sup> 2009





# Background

- Sponsored by National Science Foundation
- University of Michigan and SRI International Collaboration
- Co-investigators:
  1. Prof. James Cutler, University of Michigan
  2. Dr. Hasan Bahcivan, SRI International





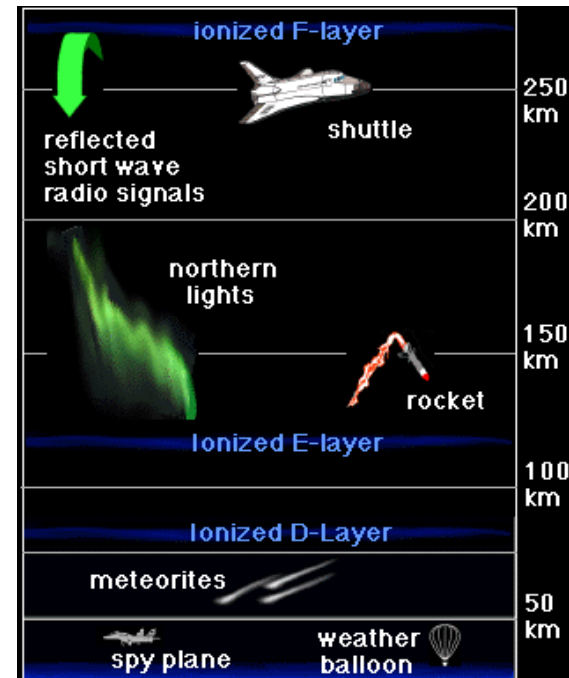
# Mission Science

## RAX Mission Objective:

Study formations and distribution of magnetic field-aligned plasma irregularities (FAI) located in the lower ionosphere

## What are FAI?

- Dense plasma structures forming between E and F layers of the ionosphere
- Sizes range from sub-meter to kilometer scales



Courtesy UCAR:  
[www.windows.ucar.edu/tour/link%3D/earth/Atmosphere/ion\\_regions.html](http://www.windows.ucar.edu/tour/link%3D/earth/Atmosphere/ion_regions.html)



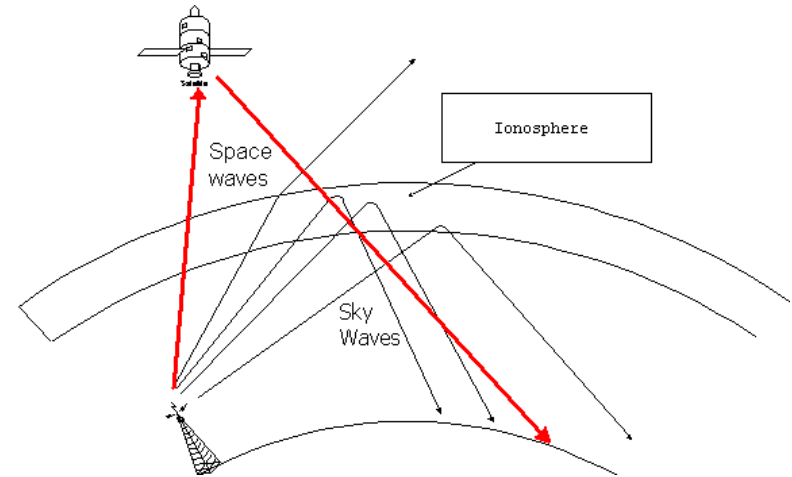
# Mission Science

## Why Study FAI?

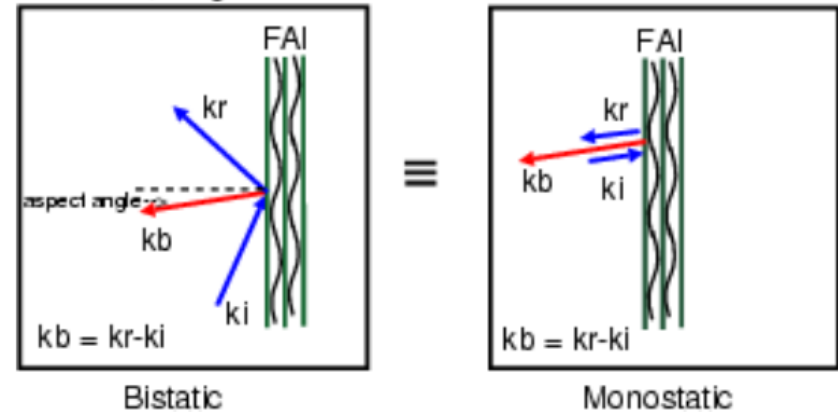
1. FAI are known to disrupt tracking and communications with spacecraft
2. Formation is not yet predictable, and there are no methods of mitigation
3. Understanding physics of formation will lead to forecasting models

## Why Study FAI from orbit?

1. Ground radars beams do not always meet perpendicularity condition
2. Bi-static configuration required



FAI, magnetic field lines and radar wave vector



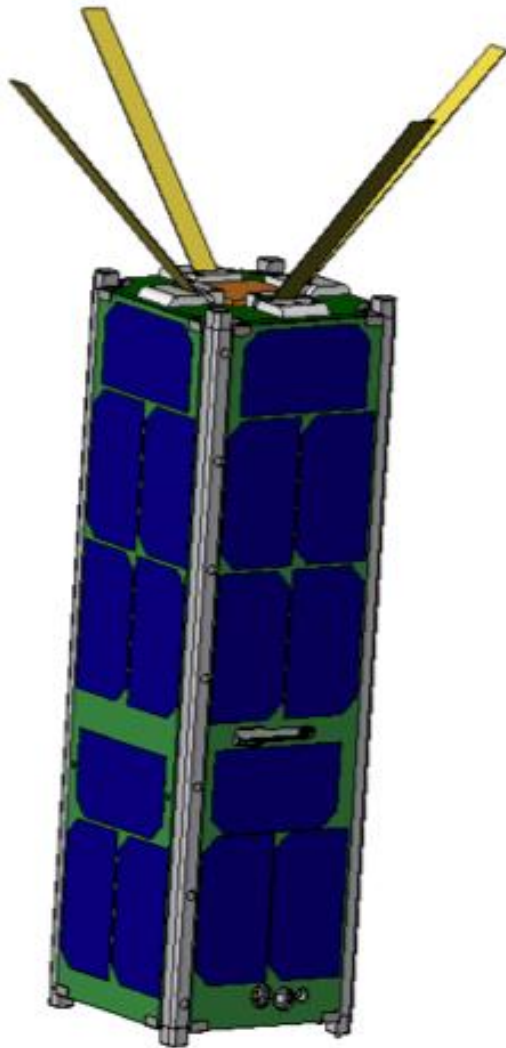


# Poker Flats Advanced Modular Incoherent Scatter Radar (PFISR)





# RAX System Overview



**Dimensions:** Standard 3U CubeSat

**Mass:** < 3 kg

**Attitude Determination:**

- Magnetometers (internal and external)
- Inertial measurement unit
- Sun sensors

**Attitude Control:** Passive magnetic

**Position and Time:** GPS receiver

**Power system:** Triple-junction solar panels  
Li-ion batteries

**Processing power:** Up to 520 MHz for payload

**Communications:**

- 38.4 kbps UHF transceiver
- 115.2 kbps, 2.4 GHz transceiver

**Antennas:** UHF Turnstile and 2.4 GHz patch

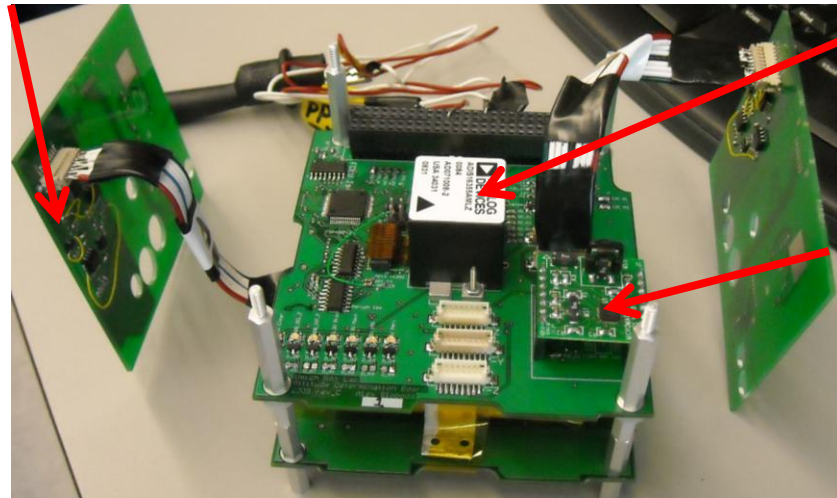


# Subsystem Highlights: Position & Attitude

**GPS Receiver**  
Novatel OEMV-1



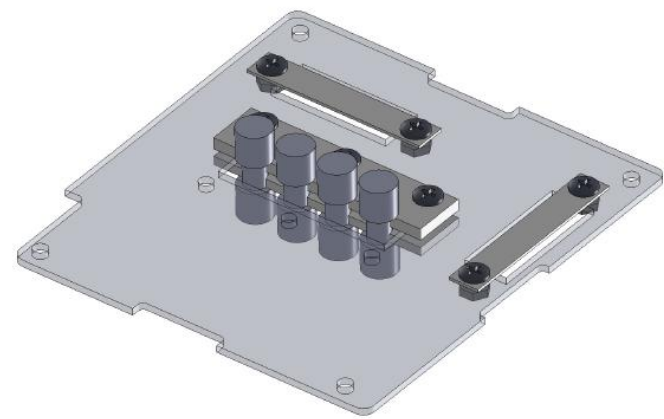
Sun Sensors



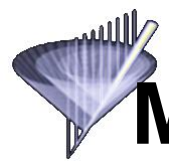
ADIS 16405  
IMU

PNI MicroMag3  
Magnetometer

**Attitude Determination Board**

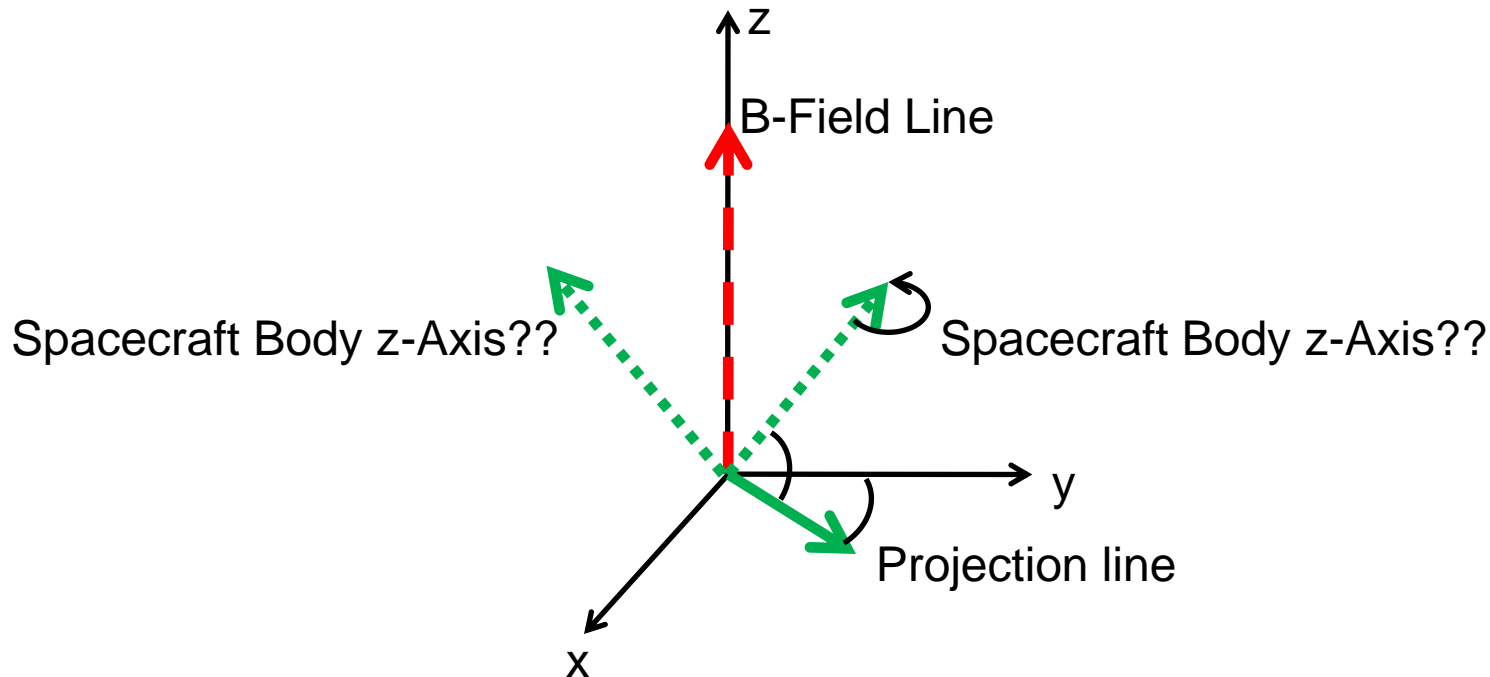


**Attitude Control Board**



# Magnetic Attitude Determination

- A single 3-axis measurement sample will only provide 2-axis determination



- The yaw of the spacecraft is unobservable





# Magnetic Attitude Estimation

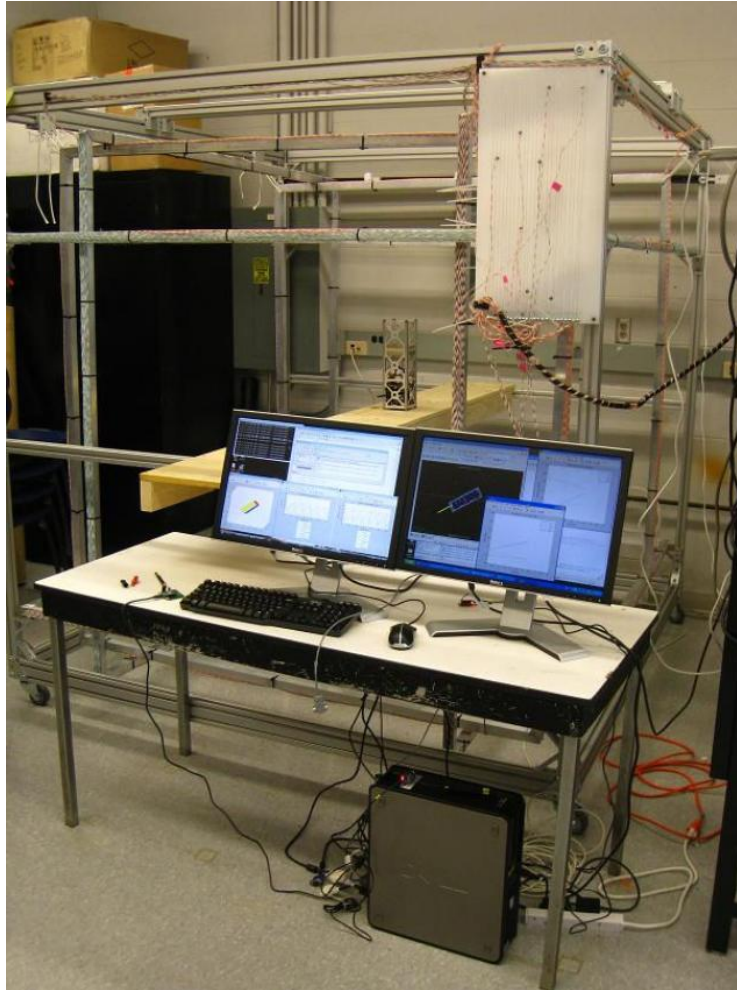
- Kalman Filtering with multiple measurements

M. Psiaki, F. Martel, P. Pal, “Three-axis attitude determination via Kalman filtering of magnetometer data,” *Journal of Guidance, Control and Dynamics*, vol 13, no 3 1990

- Requires multiple **changing** samples for accurate determination or **additional** (different) onboard sensors



# Helmholtz Cage

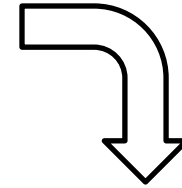
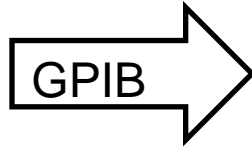


- Operation:
  - Matlab driven power supplies
  - 60,000 feet of copper wire
  - Loops generate magnetic field
- Capability:
  - Calibration and characterization of magnetometers
  - Analogue-Orbit simulator with IGRF referenced magnetic fields
  - Verification of magnetic attitude determination

**“Dynamically Driven Helmholtz Cage for Experimental Magnetic Attitude Determination”, AAS 2009**

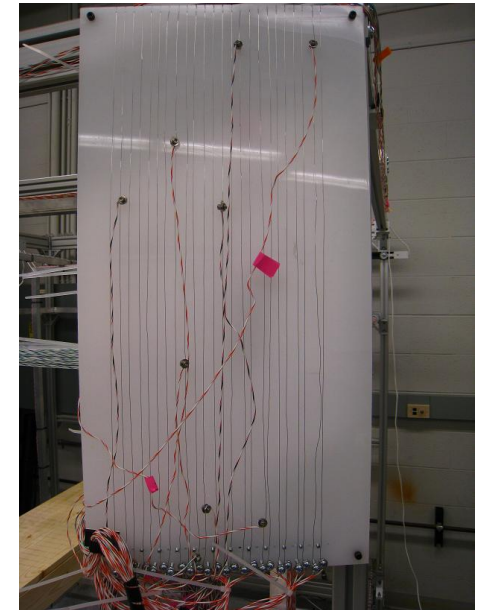
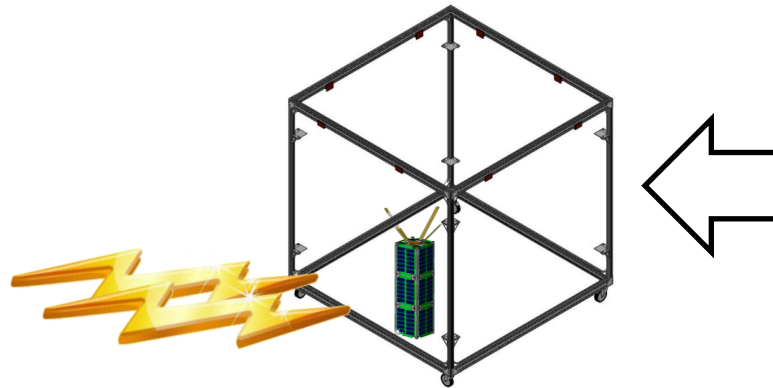


# Helmholtz Schematic



Computer with STK and Matlab  
Use "Connect" Interface

Power Supplies  
with GPIB Interface

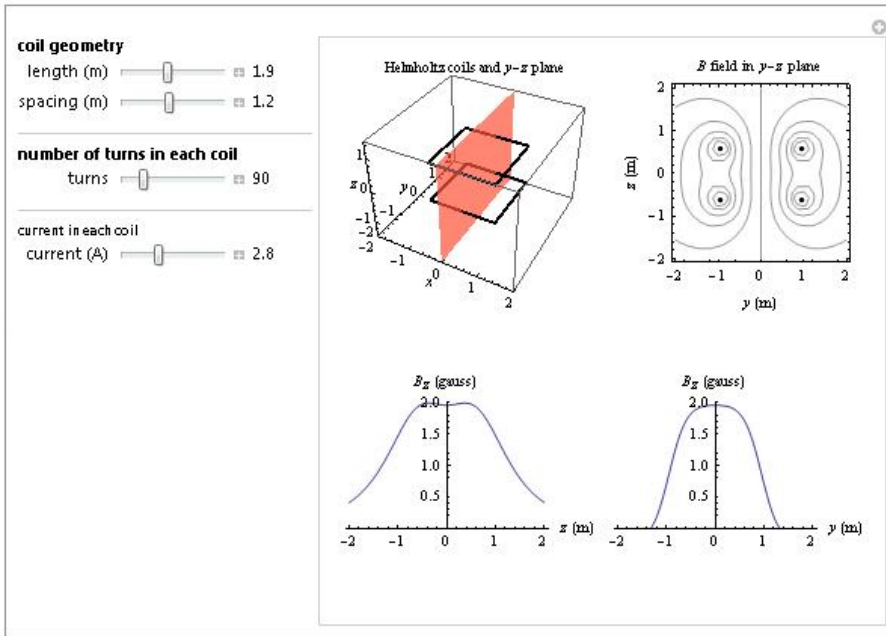


Computer with Matlab  
Compare truth to measurements

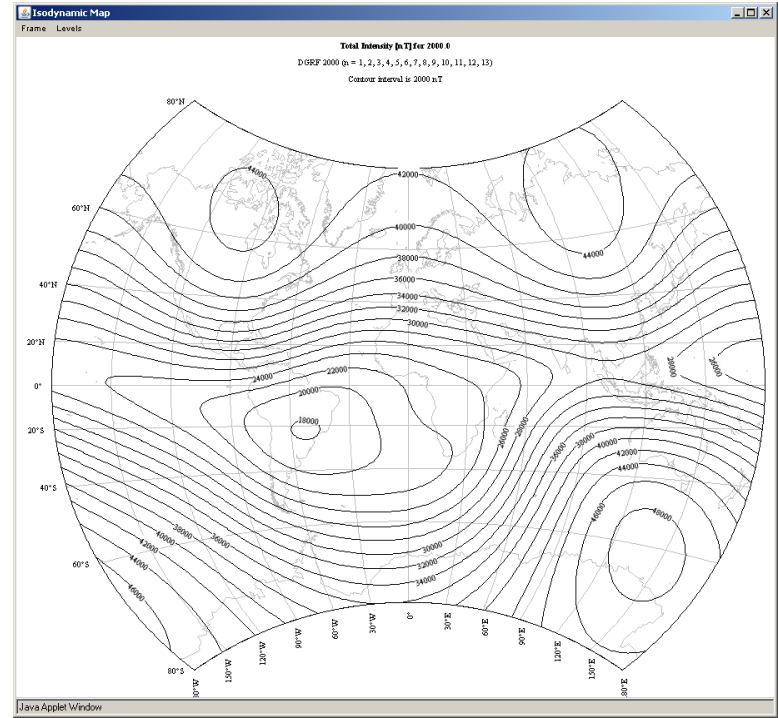
Impedance Matching  
(Nichrome Wire)



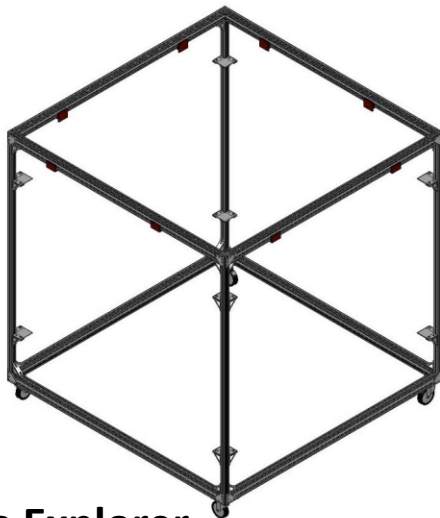
# Helmholtz Design



<http://demonstrations.wolfram.com/SquareHelmholtzCoils/>



International Geomagnetic Reference Field Database



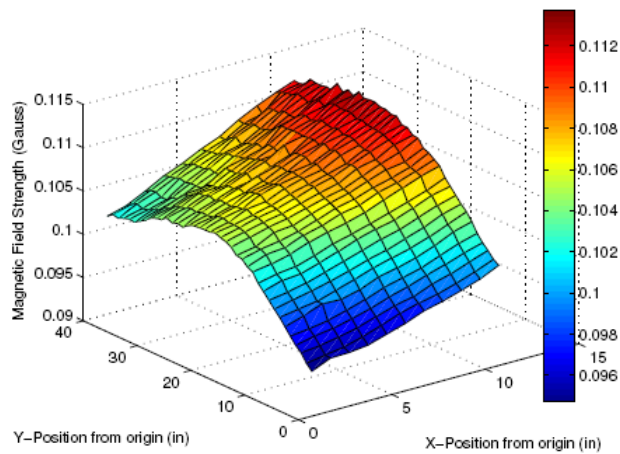
“DELFI-C3: Delft University of Technology’s Nanosatellite,” Delfi University

Radio Aurora Explorer

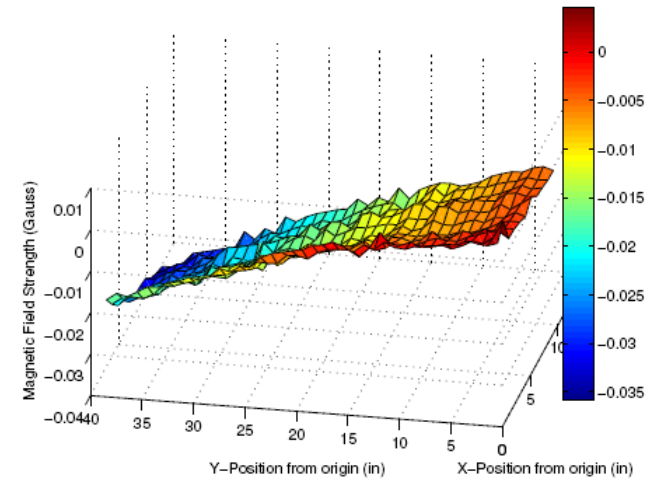
K. Dontchev



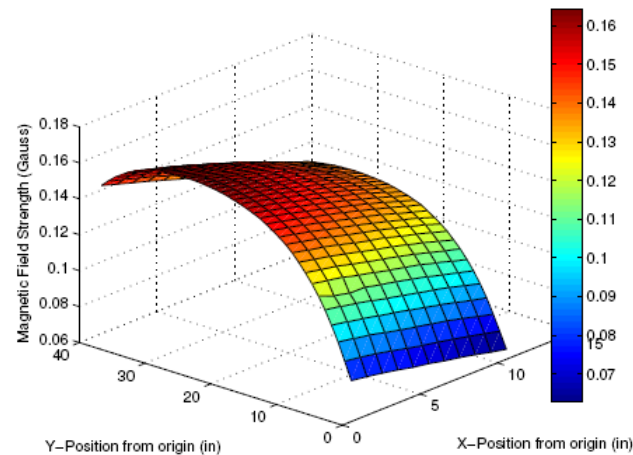
# Helmholtz Accuracy



(a)  $B_x$  Magnitude



(b)  $B_y$  Magnitude

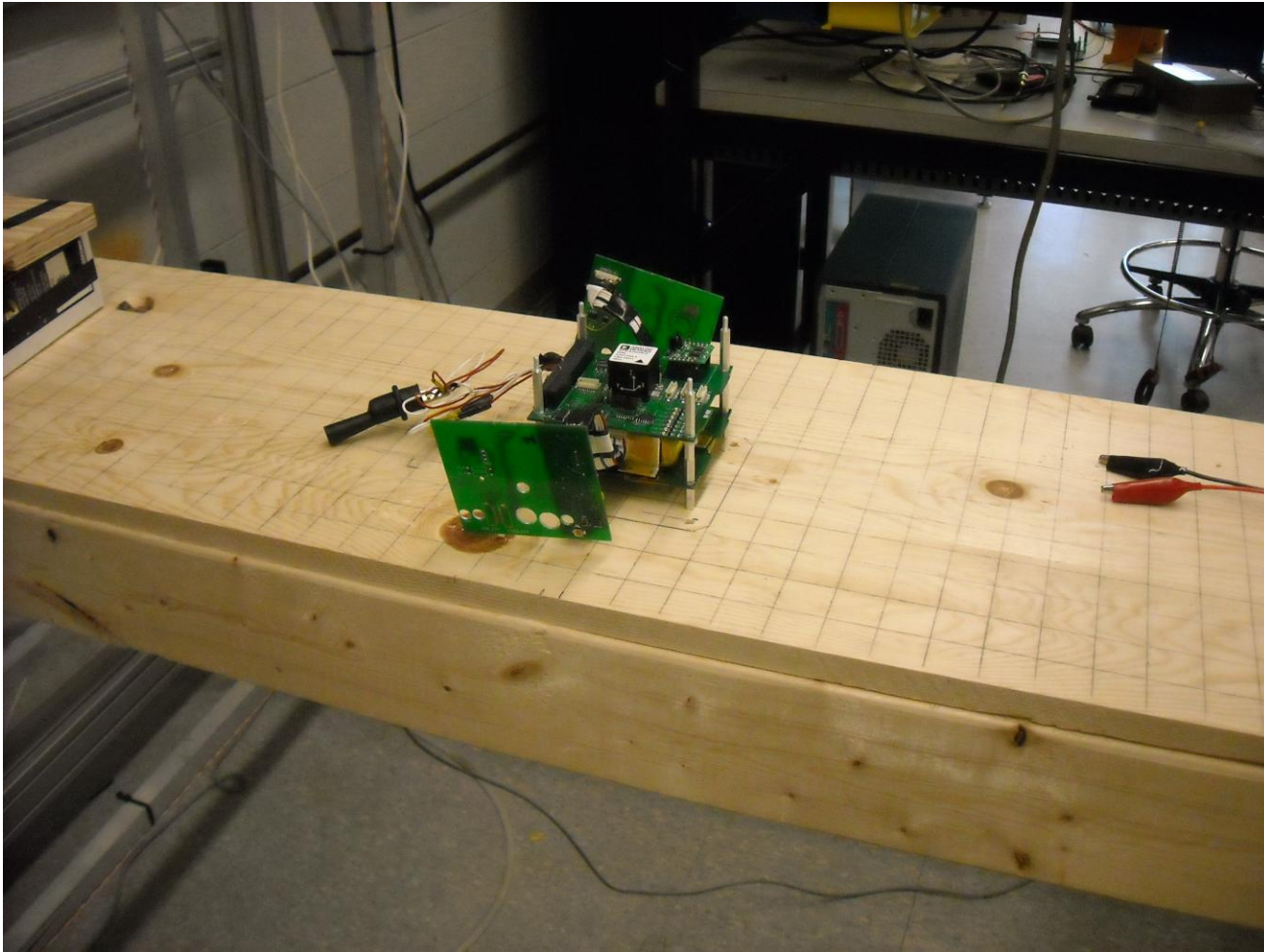


(c)  $B_z$  Magnitude

“Calibrating a triaxial accelerometer-magnetometer-using robotic actuation for sensor reorientation during data collection,” IEEE Control Systems Magazine

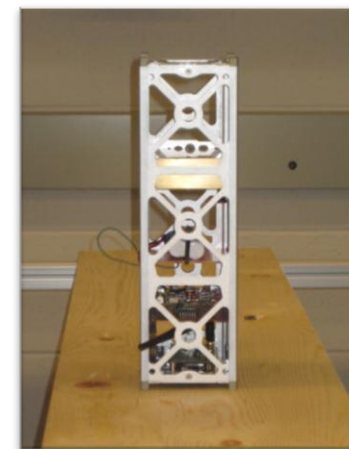
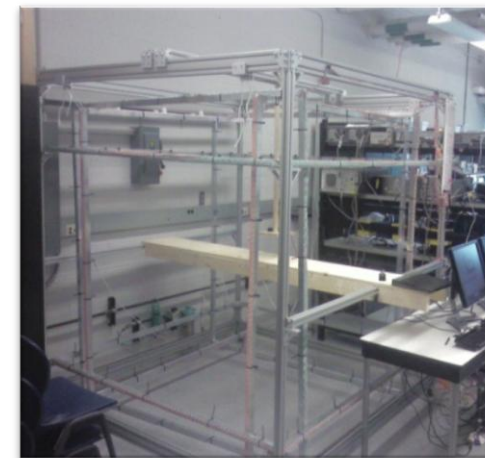
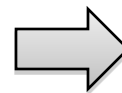
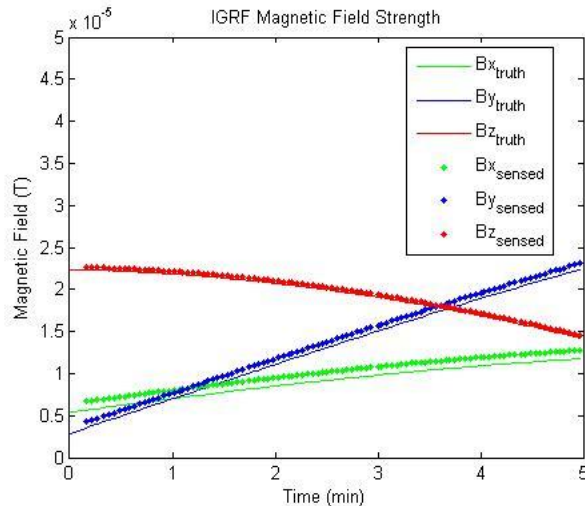
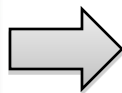
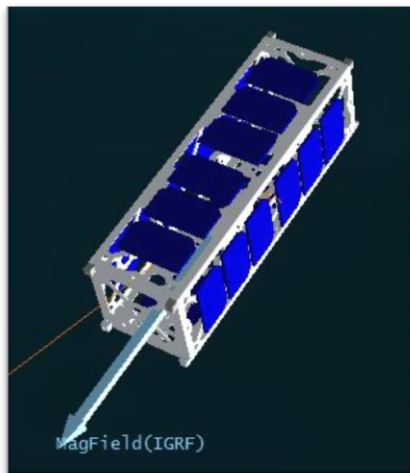


# Integrated Testing



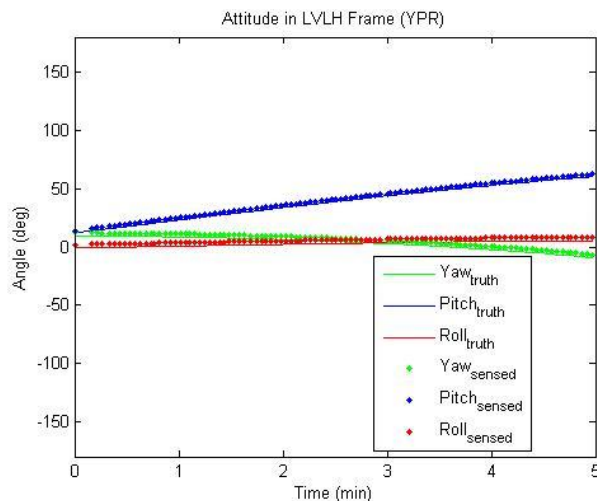
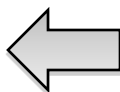


# Magnetic Determination Testing



```

Editor - (U:\storage.adroot.ftcs.umich.edu)\home\windet\V2\Desktop\RAX Demo Miles\HeimHoltz_Demo.m
File Edit Text Cell Tools Debug Desktop Window Help
-----
207 %-----Propagation Loop-----
208 % for runs=1:10
209 %   atKPropagate('*/Satellite/RAX', 0, 300);
210   time=atKAnisTime;
211   Bmat=[];
212   RAXmat=[];
213   Bfake=[];
214   RAXfake=[];
215   ttp=atKConnect('conid','animate','Scenario/RAX_Demo','Start');
216   while time<=300
217     %Get reference magnetic field vector from IGRF model
218     BfieldAnisTime = GetBref(time);
219     disp(['Magnetic Field: ', num2str(BfieldAnisTime) ' at ', num2str(time) ' s'];
220     %Get Attitude data referenced to Earth-Centered-Inertial frame
221     [AtTime, quats, ch] = atKAttitudeCBI('*/Satellite/RAX', 1,time,time+1);
222     q1=quats(1);
223     q2=quats(2);
224     q3=quats(3);
225     q4=quats(4);
226     %Convert from Quaternion to YPR angles
227     phi = atan( 2*( q1*q1 + q2*q2 ) / ( 1 - 2*( q1^2 + q2^2 ) ) );
228     theta = asin( 2*( q1*q2 - q3*q1 ) );
229     psi = atan( 2*( q1*q3 + q1*q2 ) / ( 1 - 2*( q2^2 + q3^2 ) ) );
230     %Convert to LVLH frame
231     [pos,vel]=atKPosVelCBI('Scenario/RAX_Demo/Satellite/RAX', time);
232     R=ECIL2LVLH(pos,vel);
  
```





# Air Bearing

- Acrylic sphere on non-magnetic air bearing
- Allows for full attitude determination and control testing
- Can be utilized **inside** the Helmholtz cage







# Conclusions

- Magnetic determination must be done with multiple samples or multiple sensors
- In-house testing is difficult, but a dynamically driven cage is very useful
- Matlab and STK control add significant flexibility



# Future Work

- Full integrated testing
- Total attitude estimation error measurement
- Sun sensors and solar cells
- Integrated GPS Simulator

**Objective:** A total position and attitude determination test facility within the RAX lab environment



# Questions?

**Contact us for more information!**  
**Andy Klesh – [aklesh@umich.edu](mailto:aklesh@umich.edu)**