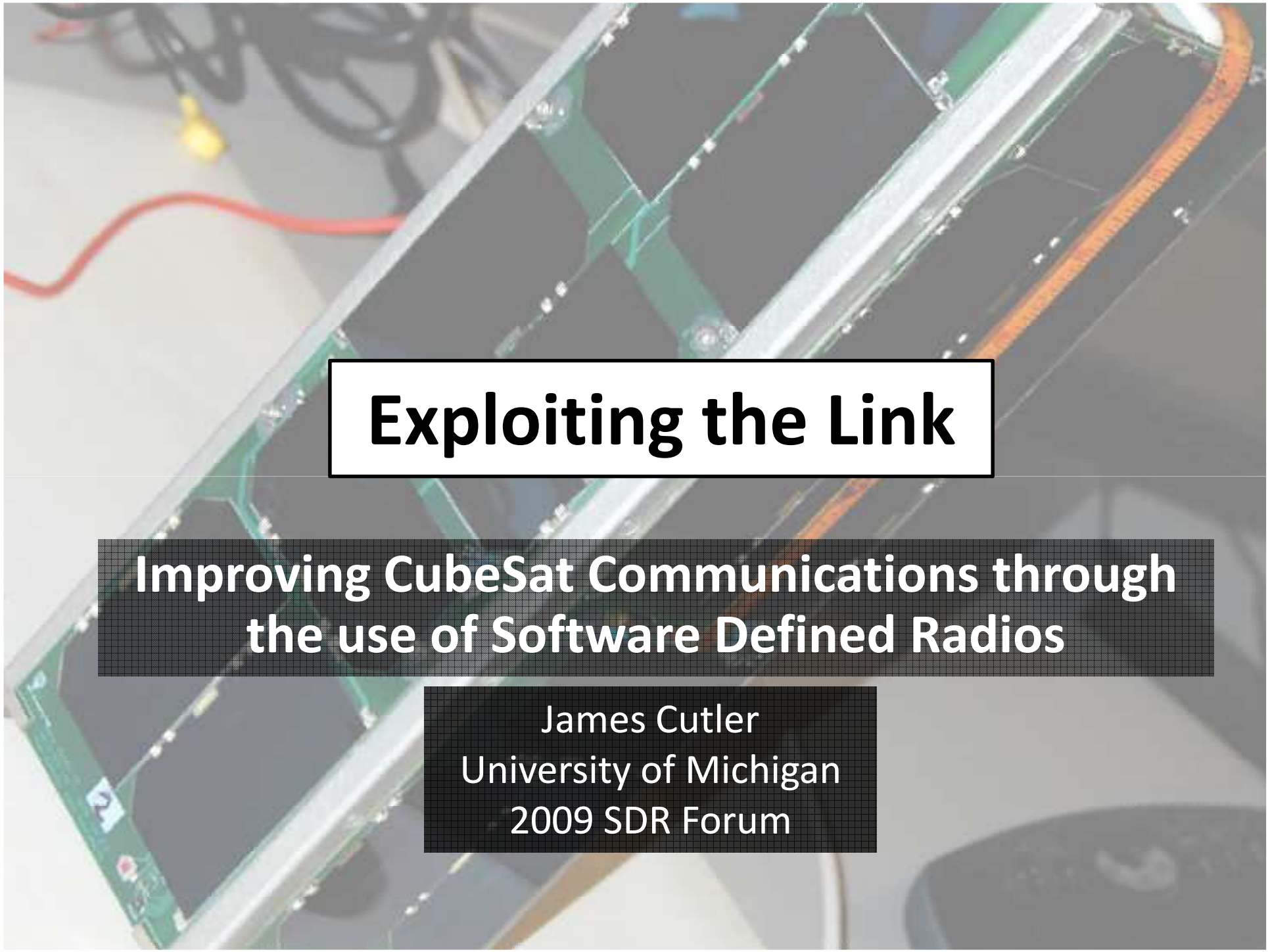


Exploiting the Link

Improving CubeSat Communications through the use of Software Defined Radios

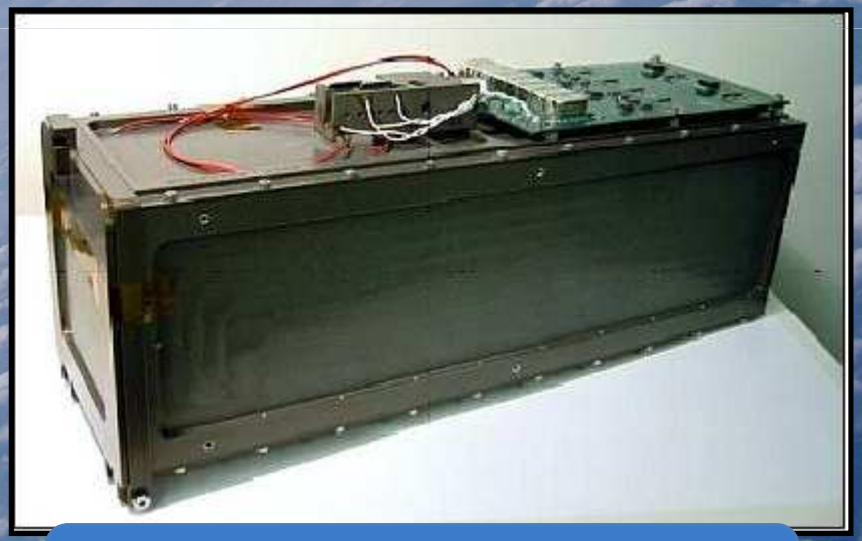
James Cutler
University of Michigan
2009 SDR Forum

What is a CubeSat?

Cal Poly 1U Cubsat

- Formal specification satellite form factor and launch vehicle interface
  - Developed by Cal Poly (SLO) and Stanford in 1999
  - Simple, ~ 6 page document
  - International adoption of standard

- Basic Unit: 1U
  - Volume: 10x10x10cm
  - Mass: < 1kg
  - Power: 2W
  - Radios: amateur radio (U/VHF)
- Sizes
  - 1, 1.5, 2, 3 U
  - Power and capability scale



P-Pod – Flight qualified launch vehicle interface

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Why a CubeSat?

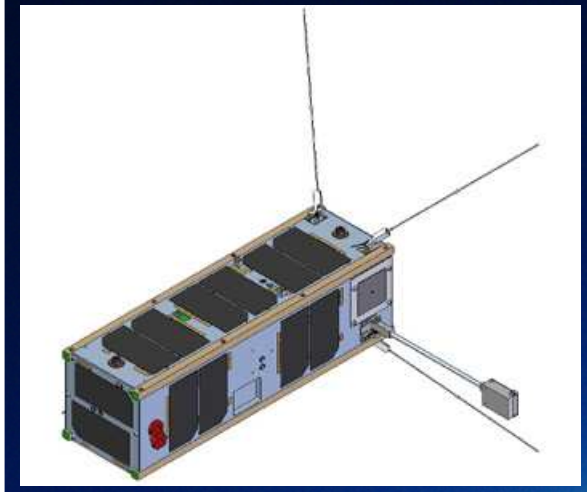
- Initially, an educational tool
  - Hands on training for next generation of engineers and space scientists
  - Design, built, and launched within a student generation (< 4 years)
- First missions discovered several benefits
  - Certified launch vehicle interface—we're in a "safe" box
  - Design space is constrained—innovation ensues
  - Lower cost and faster missions
- Current on-orbit mission types
  - Educational
  - Technology demonstration
  - Science (space weather and remote sensing)
  - Communication

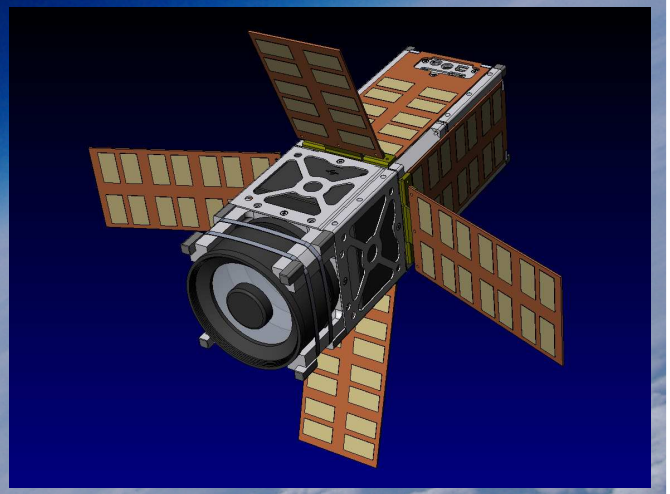
Numerous launches of Cubesats. Rockets from Europe, India, US, Japan

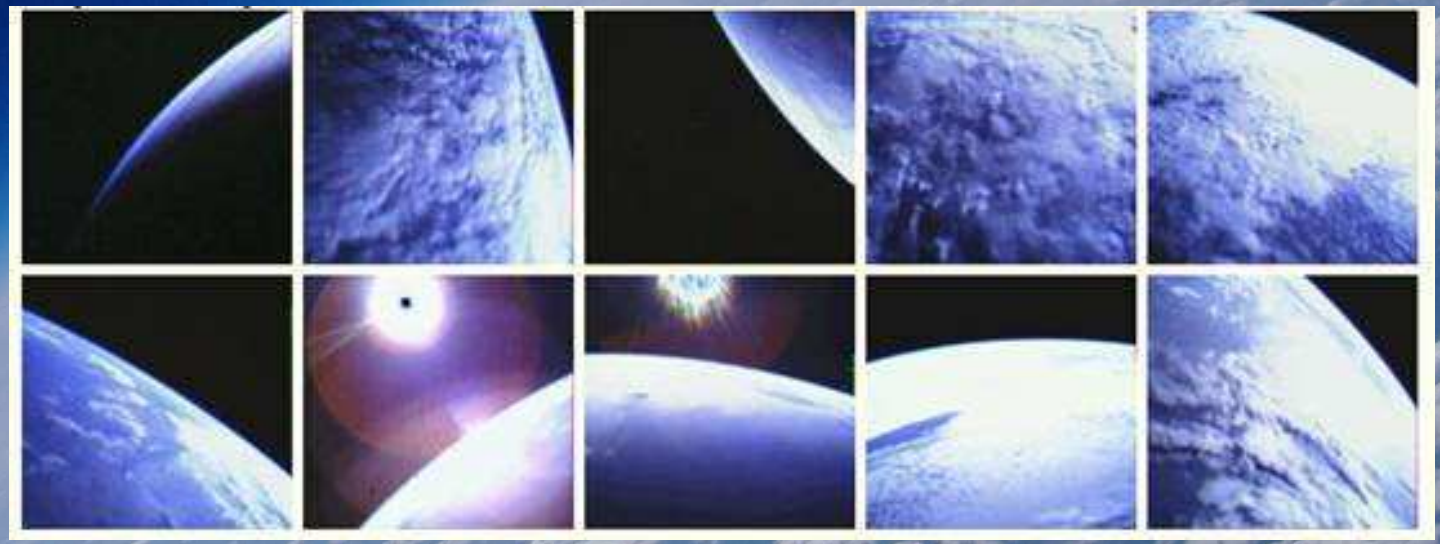
Who Uses Cubesats?

- Academia, Government, and Industry—International
- Educational groups
  - 100+ universities world wide
  - High schools
  - Amateur radio clubs
  - Middle school science fair project
- NSF has sponsored 5 space weather missions
  - First launches in 2010
- DoD has purchased 20+ systems
- Norway using for communication and ship tracking.
- The community is growing…

Example Missions







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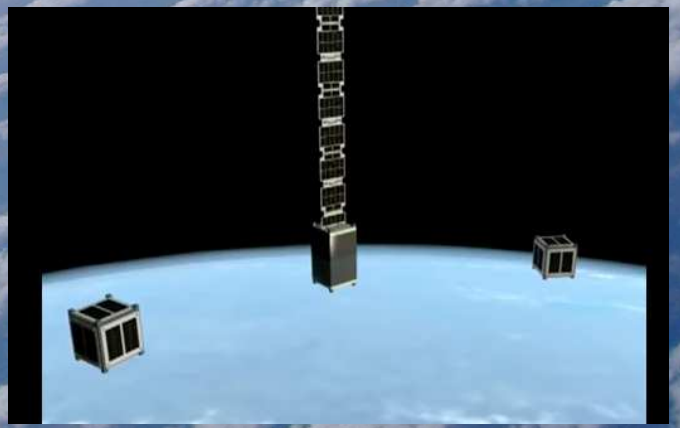
RAXLab Research Goals

Bold flight to extreme and remote environments.

- Removing Communication as a constraint.
  - Can we talk to our space vehicles as easily as we access Google?
- Novel near space and space vehicles
  - Small (nano), maneuverable, capable satellites
  - Cooperative and self assembling
  - Frequency flights



Flight Opportunities

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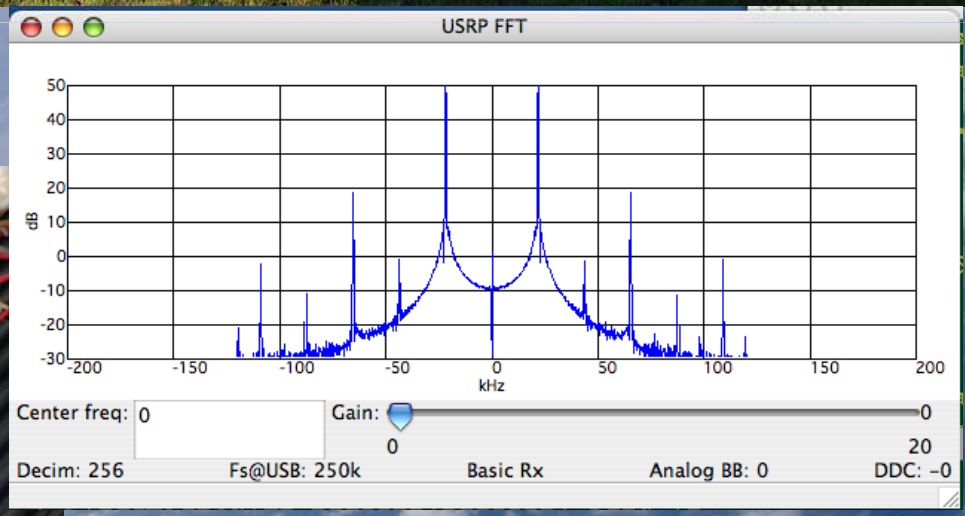
BioLaunch Field Work



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Easy Recovery

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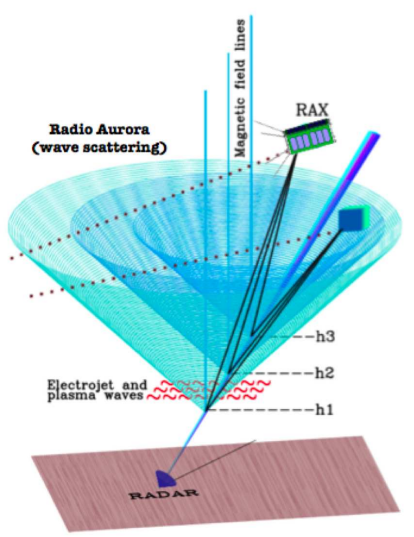
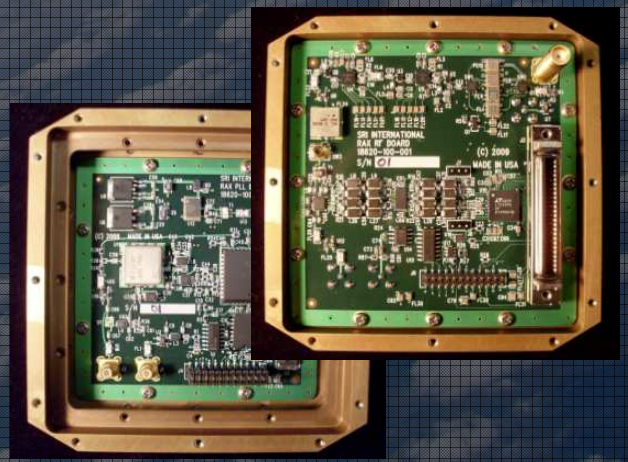
RAX—First NSF Sponsored Mission

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

RAX Mission Objective:

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





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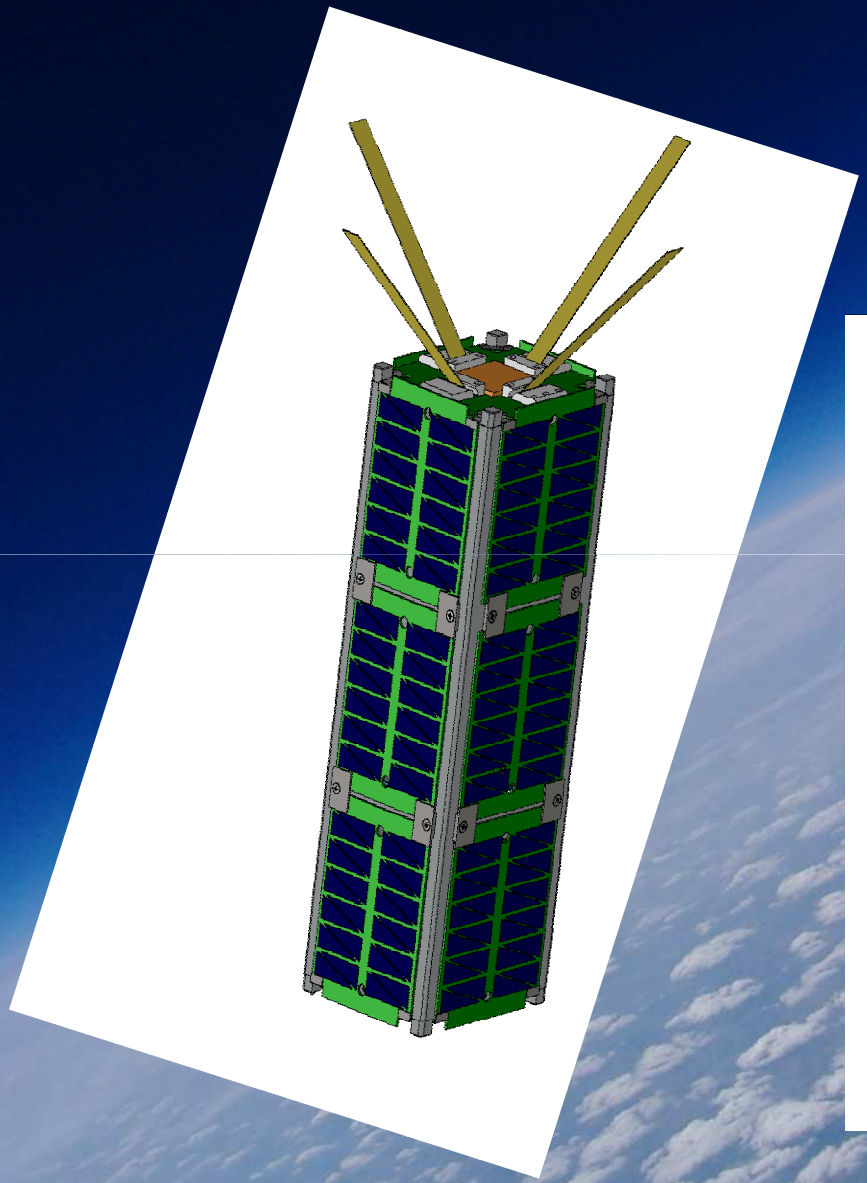
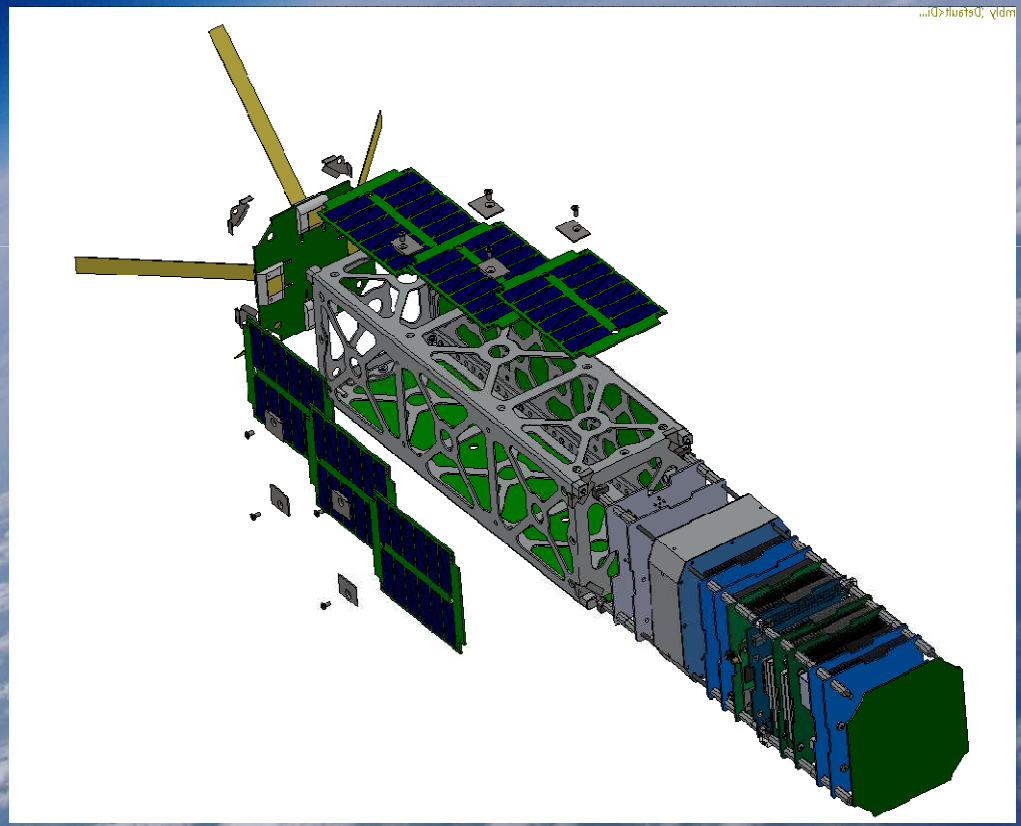
RAX System View





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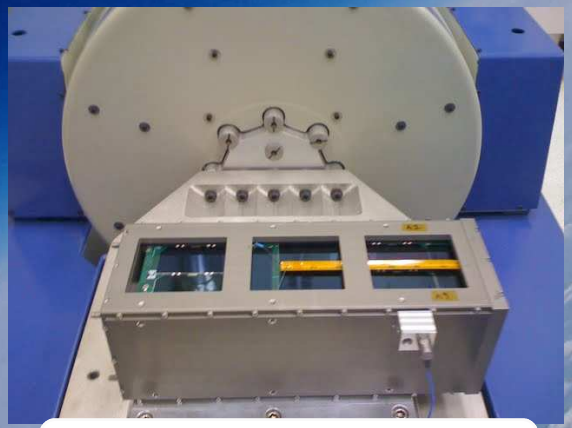
RAX Status

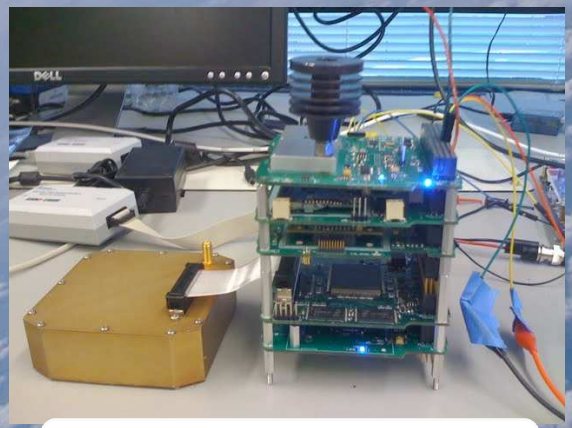
- Delivery date: ~2/2010

- Current RAX Work
  - Detailed characterization of engineering development units (EDU1 and EDU2)
    - Magnetic noise (attitude determination/control)
    - EMI and receiver noise
    - Attitude sensor calibration
  - Flight component fabrication
  - *Software, software, software*

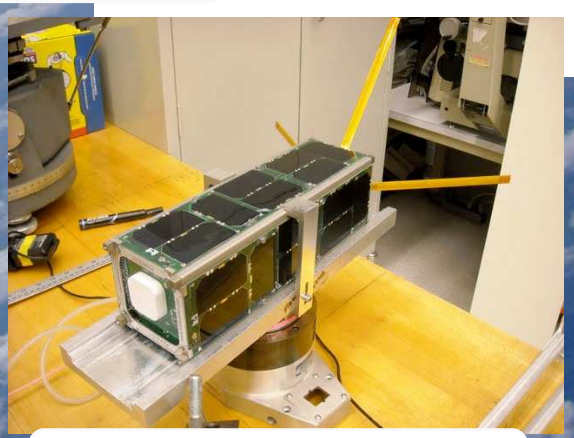
RAX EDU1 prior to shake



RAX EDU1 shake test



Mini stack for remote payload operation and testing



RAX inertia measurements @ 70rpm

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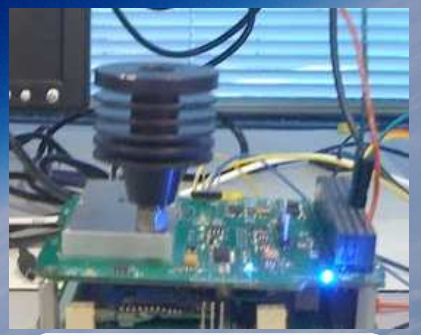
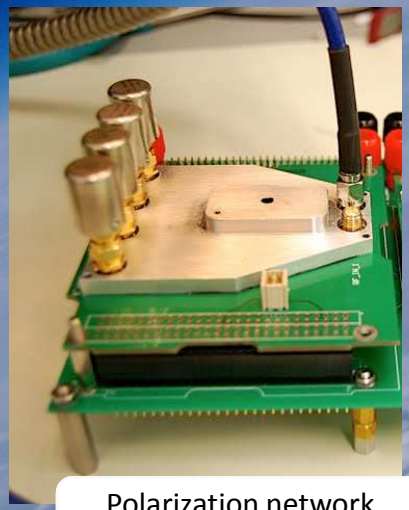
RAX Radios

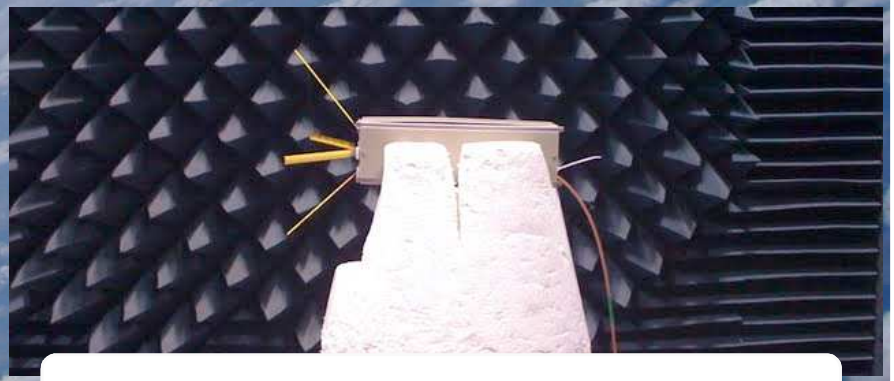
- Built our “own” UHF radio
  - Founded AstroDev with Kevin Brown while at Stanford.
  - Government funding to develop low-cost radios.
- Lithium-1 radio
  - ~140MHz – 600MHz.
  - Select 20MHz band at build time.
  - AX.25 packetization.
  - Configured for single band (dual possible).
  - Up to 40kbps like past AMSATs (though > 100kbps possible).
  - Independent of “bus” system architecture
- In House Antenna design
  - Turn stile with optimal orientation for radar signal reception.
- Polarization and antenna switch
  - Partnered with AstroDev to develop.
  - Polarization control: LHCP or RHCP
  - Antennas shared by both payload and transceiver.



Lithium integrated on our UHF and Watch Dog board



Polarization network and antenna switch



Initial anechoic chamber testing of the UHF antennas.

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Cubesat Community Needs

- In space – Resources constrained!
  - Low power, low mass, space environment
  - But large communication rates needed.
    - RAX is 1GB per day
- On the ground
  - Teams have limited stations
  - But there is a global network growing
- Specific needs and goals
  - ***Global ground station network*** with interoperable systems
  - Flexible communication systems to enable ***design operation***
  - ***Faster rates***
  - ***FCC Licensing***

Global Ground Stations

- Many ground stations, but little cooperation
- How do you measure and share capacity? How do you optimize schedule?

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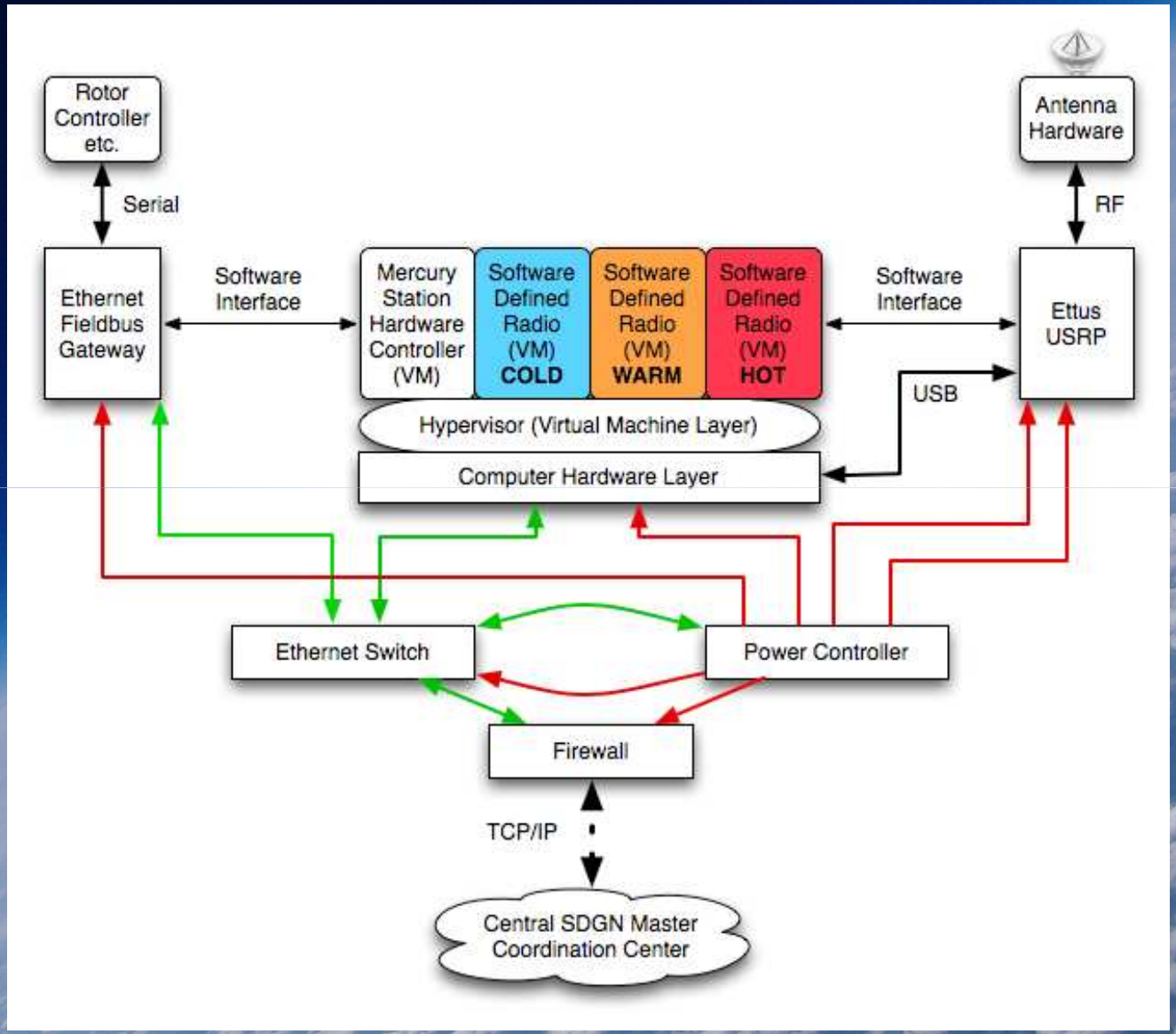
SDGS – Software Defined Ground Station



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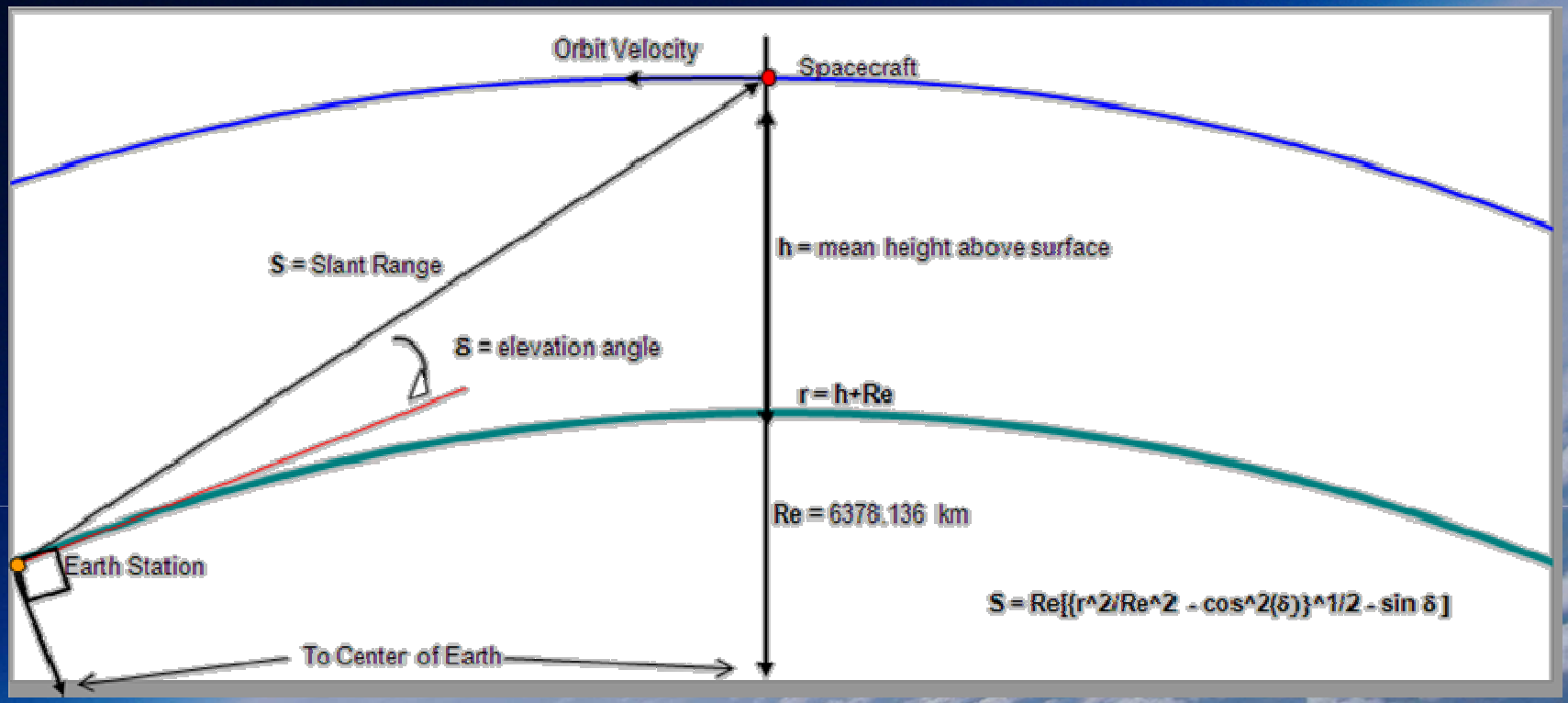
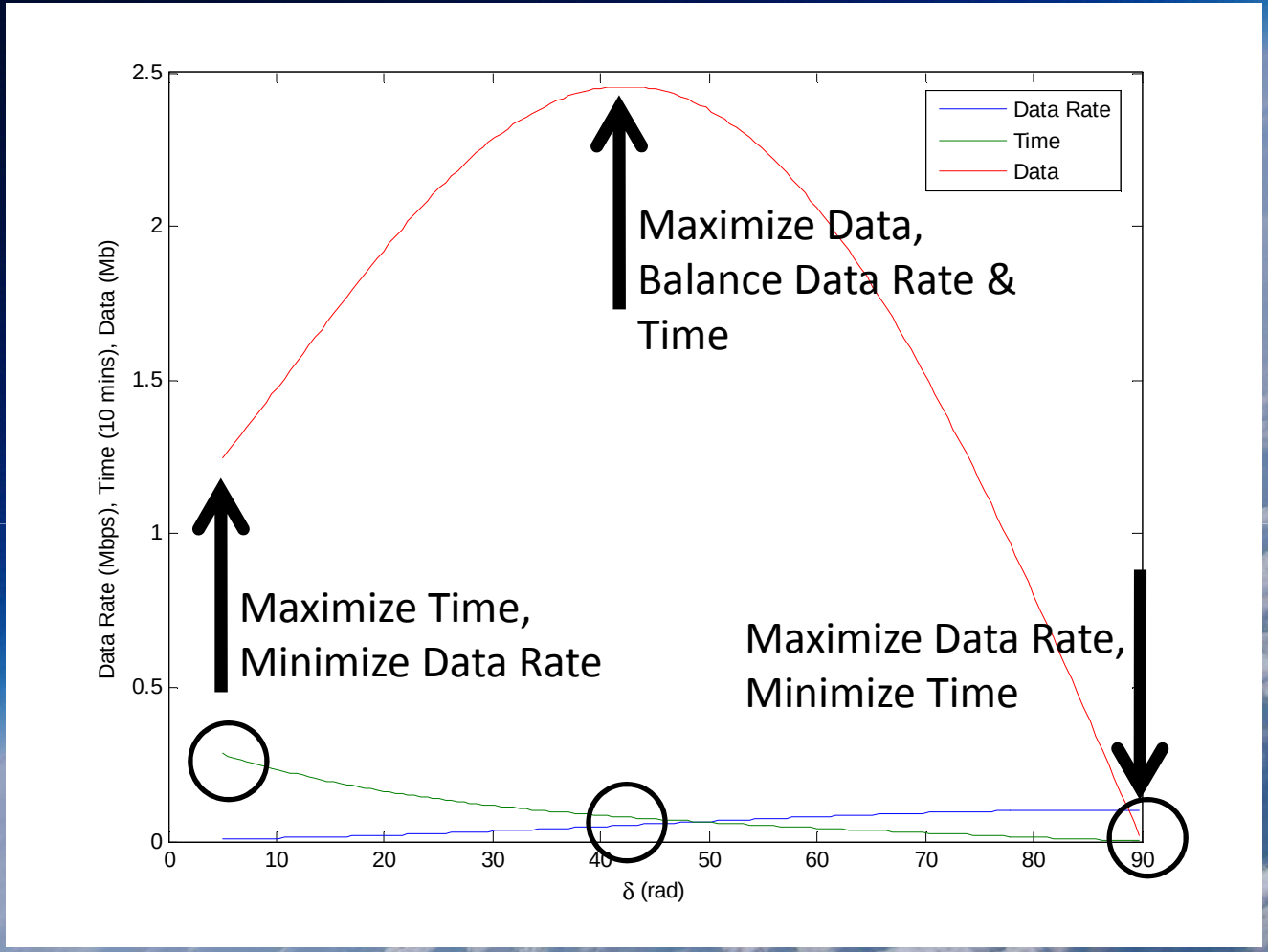
Communication Constraints



$$E_b/N_o = P + L_l + G_t + L_{pr} + L_s + L_a + G_r + 228.6 - 10\log T_s - 10\log R \qquad (13\text{-}13)$$

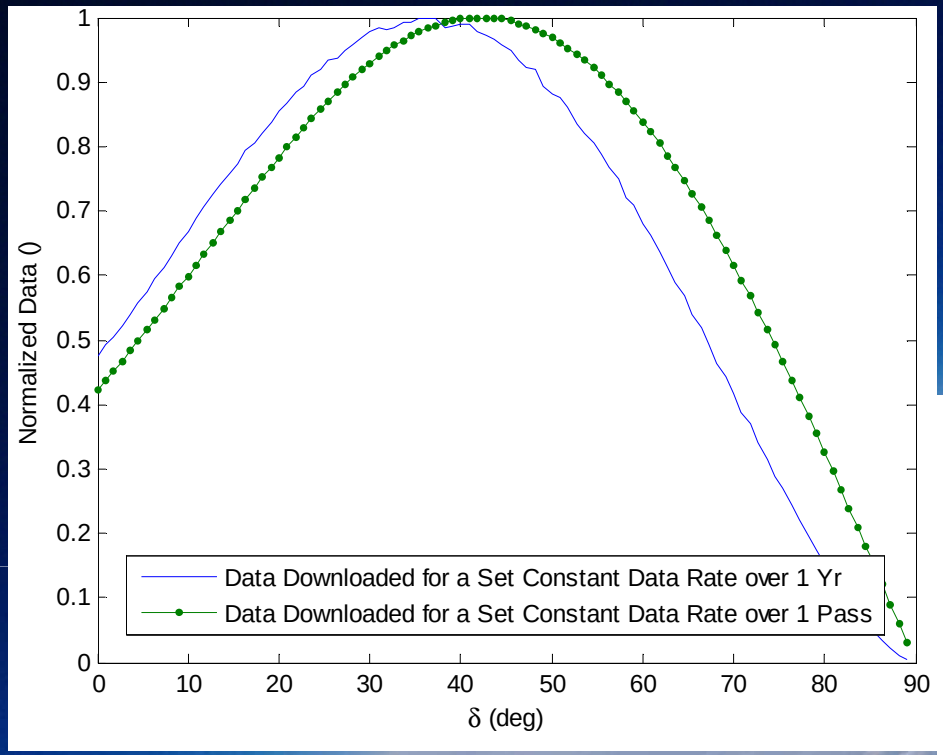
- Maximum data rate is proportional to range
- Lack of power constrains total data downlink
- Lack of radios available – especially small SDR

Better Design

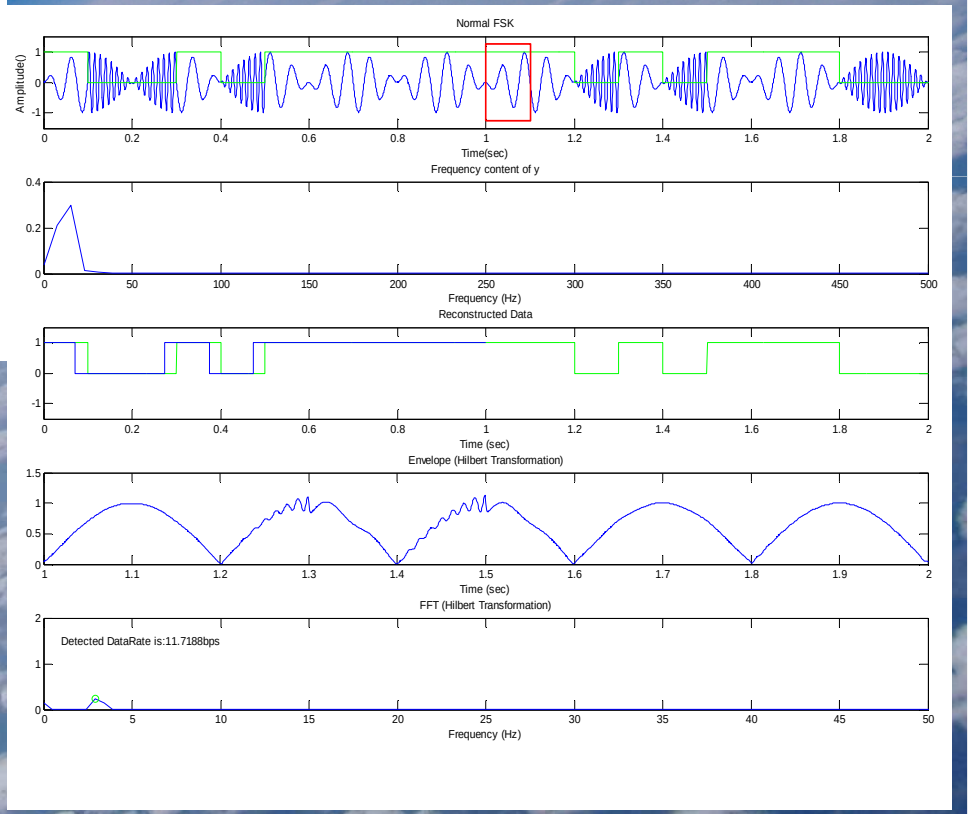


- Typical spacecraft use a fixed data rate for each pass that optimizes time
- What if we maximize data downloaded?

Better Utility



Optimize data rate dynamically (self-clocking signals)



Optimize data rate based on pass characteristics (pre-set)

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Frequency Licensing and Coordination

- In the past…
  - Most university and experimental missions have been classified as amateur radio satellites.
- Not a viable option as we move forward…
  - Government sponsored missions
  - Private industry
- So, what next?
  - Looking for spectral options
    - Possible 10MHz band 460 – 470 MHz. Low power density.
    - ISM – 2.4GHz
  - Other options? Share spectrum with existing satellite systems
- This will drive the radio technology selection and implementation

Conclusions

- CubeSats numbers are quickly growing
  - Exciting new missions
- Extremely constrained – Communication is challenging
  - We want to eliminate this constraint…
- Moving forward
  - FCC licensing
  - Groundstation networks
    - Optimal scheduling
    - Future proof…interoperability
  - Radios can be improved
    - Choose a smarter data rate
    - Extend **Software Defined Radios** to CubeSats
    - Choose dynamically changing data rates

Questions or Comments?

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