CubeSats for Geospace Science at Montana State University:

Tailored approaches to CubeSat Mission Implementation

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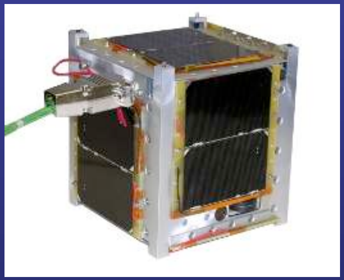
Space Science and Engineering Laboratory (SSEL)
Montana State University– Bozeman

A Montana State University program for undergraduates to conceive, design, build and operate sounding rocket payloads, small satellites, and spaceflight systems

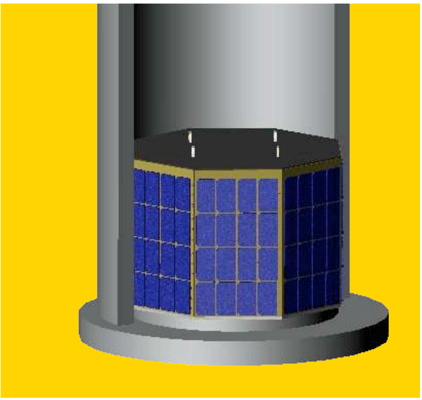
A center of expertise with faculty, staff, and facilities for space research and space technologies.



Montana Earth Orbiting Pico Explorer (MEROPE); a hand-held satellite

Student-focused management, design, and implementation, builds:

- Self-confidence
- Responsibility
- Decision-making capability
- Technical skills



Systems engineering, science, and emerging space technologies

Applying classroom learning to complex systems

SSEL Primary Capabilities and Interests

- Science and Operational Space
  - **Space Weather; Sun-Earth Connections**
    - **Ionizing Radiation (Plasmas to MeVs)**
    - **Radiation Belt variations**
    - **Ionosphere**
  - **Space Situational Awareness**
    - **Naturally occurring phenomena**
    - **Man-made unknowns**

- Education:
  - ‘Today’s students – Tomorrows Engineers and Scientists”
  - Hands-on training – develop professional skills by doing.

- Technical
  - Miniaturization technologies for space applications
  - 1 kg - 40 kg spacecraft systems (CubeSats and AFRL University “NanoSats”)
  - Plasma detectors
  - Ionizing radiation sensors (electrons and ions)
  - Space environment effects on COTS subsystems
  - Radhard reconfigurable electronics (with MSU and industry partners
  - Low power heterodyne lidar ranging and imaging systems for SSA (w/ partners)

Today’s messages

- Know what your objectives are
- Once your mission is specified, don’t deviate -- avoid requirements creep
- Tailor your implementation to your goals
  - Different goals required different approaches.
  - MSU Space Science and Engineering Lab CubeSat examples
- Lessons learned

First: Compose Your Mission Statement -- Write it down!!

- What is the primary purpose of the project? Three examples:
  - Student Hands-on training exercise
  - Science investigation
  - Technology development and demonstration

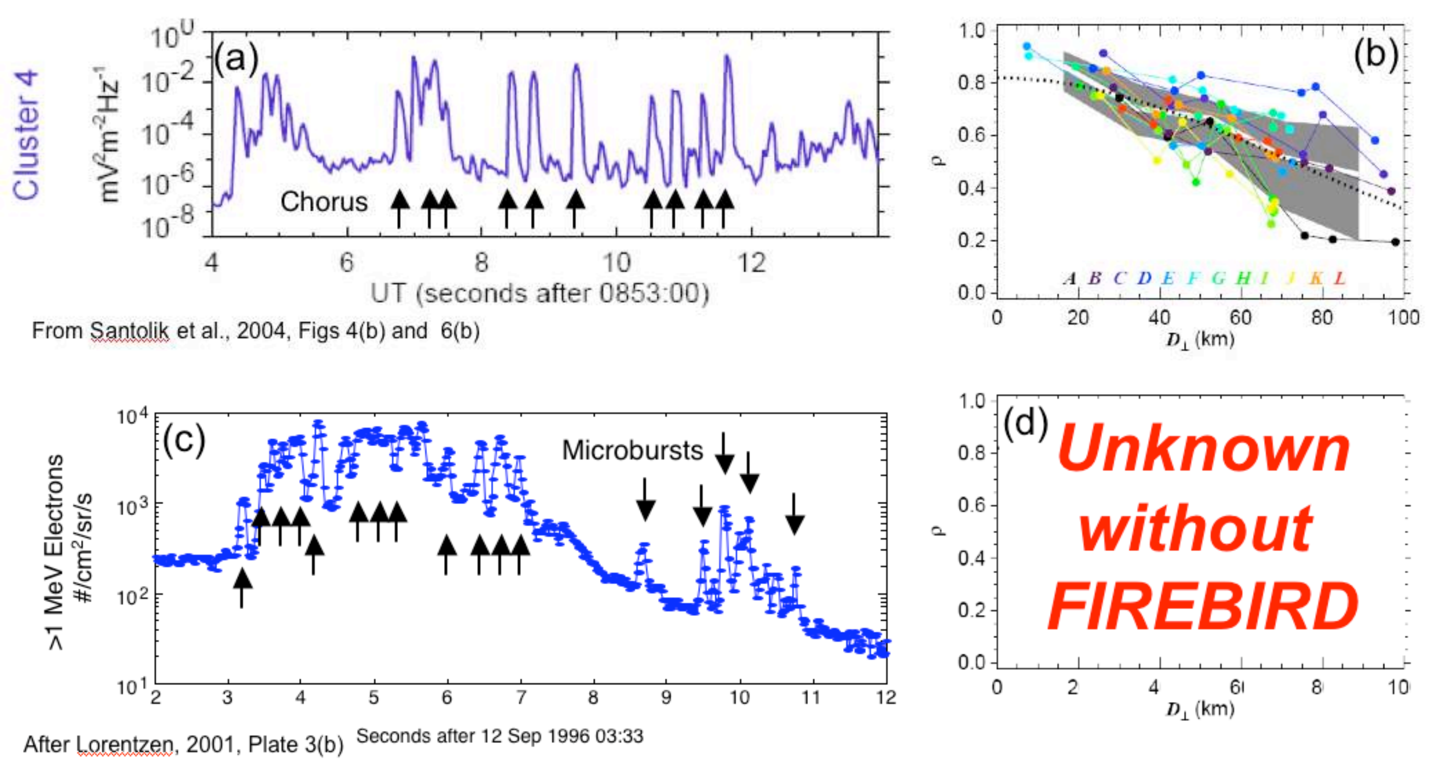
  - Prioritize, if all of the above (and more)
- Tailor your approach to maximize reaching your goals.
  - If, your primary goal is **student training** success will be measured by the quantity and quality of the experiential training.
  - If a **science investigation**, success will be measured by successful operation in space, retrieval of data, and its scientific interpretation and publication of results.
  - If **technology demonstration** the metric for success is successful demonstration of space operations leading to subsequent use of the technology. Your goal is to raise the TRL of the hardware to flight proven in the intended environment.

If a science investigation:

- The all important technical goal is 100% successful operation in space, retrieval of data, analysis and publication of results.
- Focus on the payload, the instrument calibration, and the concept of operations. Have a mission operations and data analysis plan and develop analysis software early.
- Minimize risk of mission failure by utilizing proven flight subsystems. Do not squander your resources by developing everything from the ground up.
- Involve professionals
- Secure adequate funding to complete the investigation.
- The mission duration might be many months or years -- design for longevity

MSU Science Example

- **The Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics * (FIREBIRD)**
- A National Science Foundation dual CubeSat mission to investigate spatial temporal ambiguities in energetic elec



From Santolik et al., 2004, Figs 4(b) and 6(b)

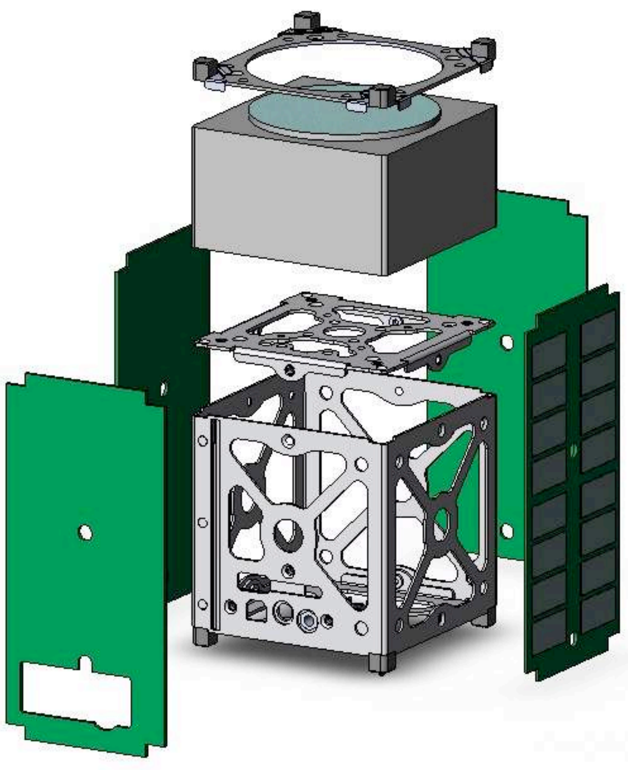
After Lorentzen, 2001, Plate 3(b)

Unknown without FIREBIRD

MSU Examples: Primarily scientific research

Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics (FIREBIRD)

- student involvement/training important, yet secondary to science return
- Imposed schedule requirement: 3-year mission plan (Phase B,C,D,E)
- funded externally (NSF) -> A real customer
- student participation with heavy professional mentoring and oversight
- Professional documentation
- Publication of results required for success
- Multiple institutions: Montana State University, Boston University, Aerospace Corporation



FIREBIRD Approach: Primarily a Science Investigation <u>yet student training is also important</u>

- Minimize technical and management risk
  - Acquire commercial, proven subsystems where available.
  - A significantly involved student team closely mentored by professional managers, scientists and engineers
  - Payload involvement by instrumenters who have developed and flown similar instruments. Adopt existing designs.
  - Back-up Ground station
- Our baseline is to buy commercially produced subsystems and design/manufacture only mission unique hardware.

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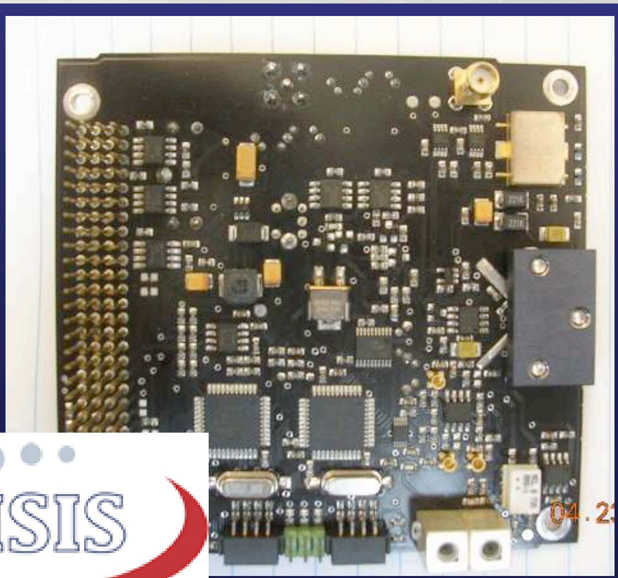
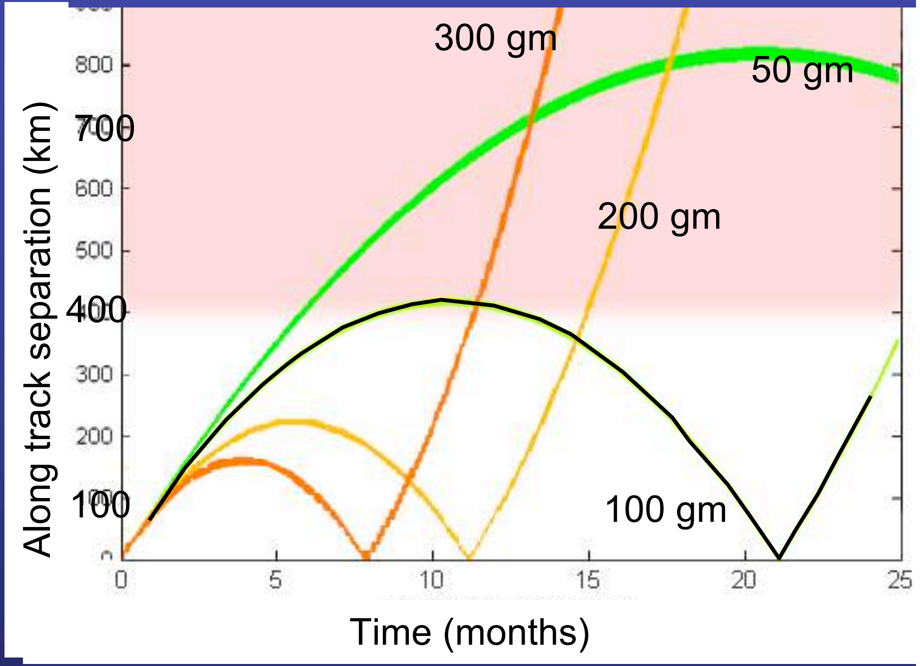


Above right: Pumpkin Kit
direct right: ISIS UHF/VHF Transceiver

FIREBIRD: Student involvement example

- The science requires two identically instrumented 1.5 U CubeSats separated by 10 to 400 km to resolve spatial from temporal variations in relativistic electron microbursts from the Van Allen Radiation Belts.
- With typical intersatellite separation velocities, expected mission duration is 1-5 months.
- 10-week undergraduate student project: Investigate prolonging the mission by carefully controlling separation velocity and ballistic coefficient.
- <u>Result:</u> A 26-month mission is possible with intersatellite separation never exceeding 400 km



- 1 cm/sec initial separation velocity.

- leading satellite less massive.

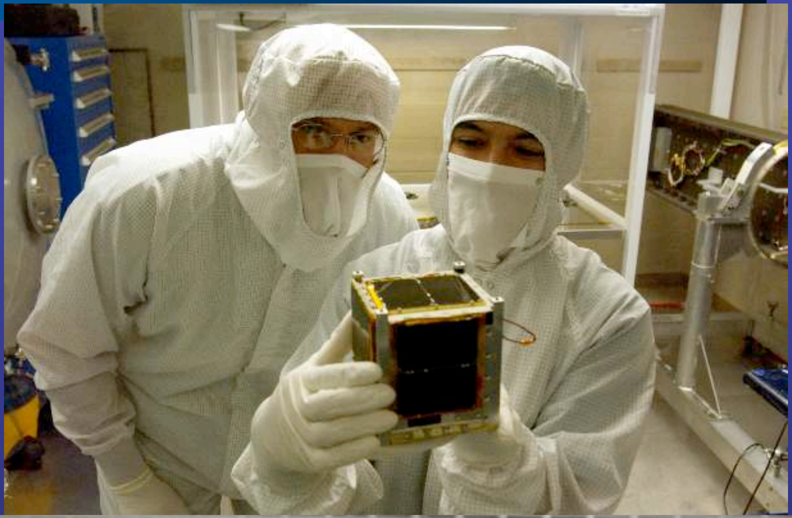
RESULT: with delta-v = 1 cm/sec, lead satellite moves 400 km ahead for ~10 months, then begins to close on the 100 gm more massive satellite, passing under it after 21 months.

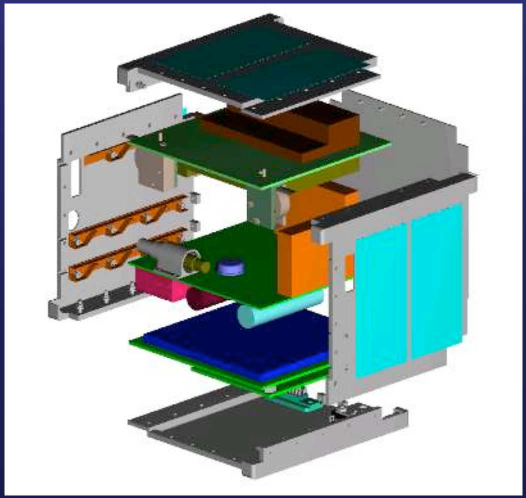
If, your primary goal is student training:

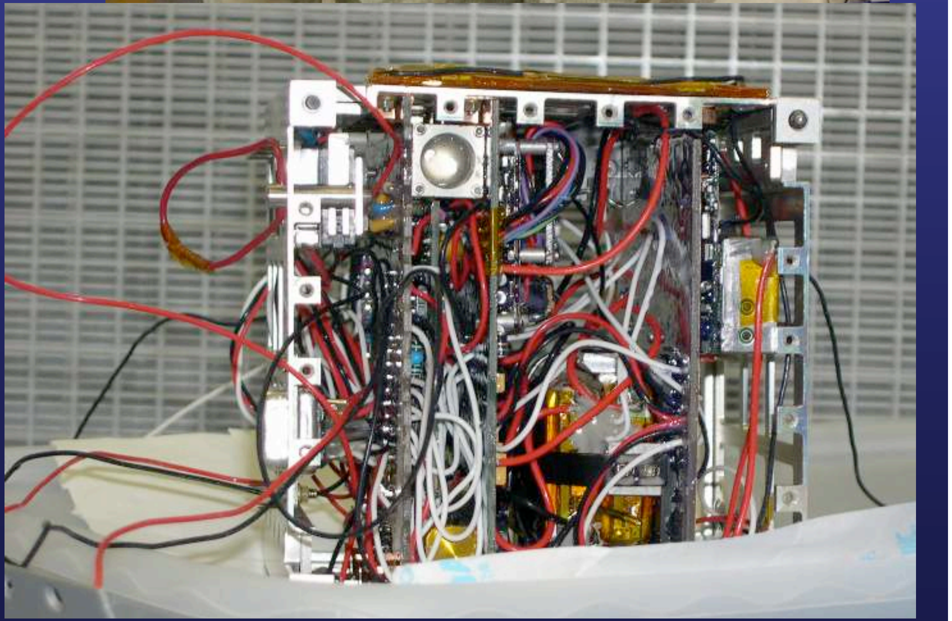
- Successful operation in space is frosting on the cake. 98% of the goal is achieved when the students deliver the flight qualified article to the launch pad.
- Process is more important than in-space data. Learning proper aerospace practices, documenting the process and the product, iterating the design, testing, retesting and qualifying the satellite for flight
- Maximize student learning by designing and building most of your hardware from scratch.
- Design and develop your own ground station.
- Students manage the project, test and integrate the hardware and operate the satellite after launch.
- There are multiple flight (e.g. near-space) opportunities preceding delivery of the flight model.

Student training example: MEROPE

- So;nsored by Montana Space Grant Consortium (with lots of other sources of support)
- Therefore, an in-house program with no real deadline
- We thought we would have it built in 12-months …. we finished it 5 years later.







MSU Examples: Primarily for student training

The Montana Earth Orbiting Pico Explorer (MEROPE)

- student designed and built “from scratch”
- 5-years in development
- funded internally (Space Grant) -> no real customer
- students do virtually everything, with some professional guidance
- minimal documentation (bad!)
- No schedule requirement, no fixed launch date
- scientific payload incidentatl to primary objective of student training.

If technology demonstration:

- A successful flight of the technology is required for success
- Ultimate success: Subsequent to the demonstration mission, the technology is widely used across the community.
- Focus on the development and testing of the technology.
- Utilize commercial subsystems for support functions. Do not reinvent proven subsystems.
- The mission duration might be short -- just long enough to demonstrate successful and durable operation in the space environment.

Lessons Learned

- Write down and know your mission statement.
- Write down your success criteria.
- Always keep your objectives clearly in mind.
- Avoid “creeping requirements”.
  - Once you have frozen your mission avoid the temptation to change the objectives. *Death statement: “Hey, wouldn’t it be cool if we just add ……”*
- Tailor your mission to meet your chosen objectives.
- The design effort, before you ever touch hardware, should take half of your timeline.
- It will always take longer than you initially thought. Even when you tell yourself “it is almost done” -- IT ISN’T
- Watch out for software development -- it is the most difficult subsystem on your mission and will NEVER be finished. (right, Ehson?)

Our contact information and acknowledgements

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    - Mr. Ehson Mosleh

…and the Several hundred MSU undergraduate students who have participated in SSEL over the last 10 years

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