Aurora Flight Sciences CubeSat Cluster

Technologies and Mission

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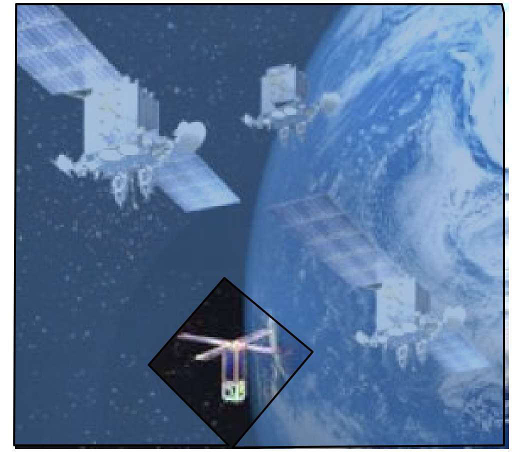
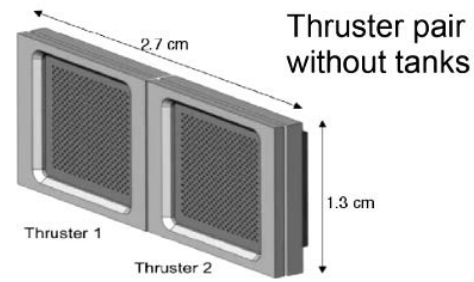
Agenda

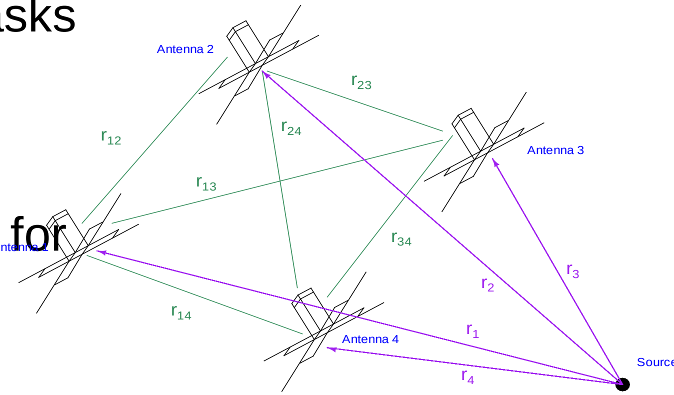
- Introduction
- Goals of Aurora SBIR effort
- CubeSat fractionation Architectures
- RF Cluster Mission
- The MotherCube Architecture
- Cluster Control enabling formation flight
- Key Technologies Enabling Clusters for LEO and Beyond
  - Electrospray Thruster Assembly
  - Multipurpose FPGA Payload and Telemetry Radio

Introduction

- What is the smallest form factor for cluster missions?
  - The CubeSat: Packaging challenges present opportunities for fractionation
- But can a CubeSat Cluster accomplish a useful mission for less cost than a monolith?
  - Aurora concept will demonstrate LEO RF signal measurement mission for under $3M
- What are the key enabling technologies in the CubeSat form factor?
  - Fractionation architecture to allow distribution of tasks
  - Propulsion, attitude actuators
  - Formation flight and cluster algorithms
- Clusters provide flexibility, scalability, and redundancy for interplanetary missions







Goals, objectives of Aurora Efforts

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Goal: Produce a networked CubeSat cluster taking advantage of distributed systems to execute a significant mission

A demonstration of a "minimalist" cluster architecture:

- Focus is on enabling technologies to create a lowest cost fractionated cluster as an existence proof of CubeSat fractionation
  - Develop streamlined algorithms to control cluster and attitude
  - Utilize electrospray propulsion for actuation, off-the-shelf GPS and sensors

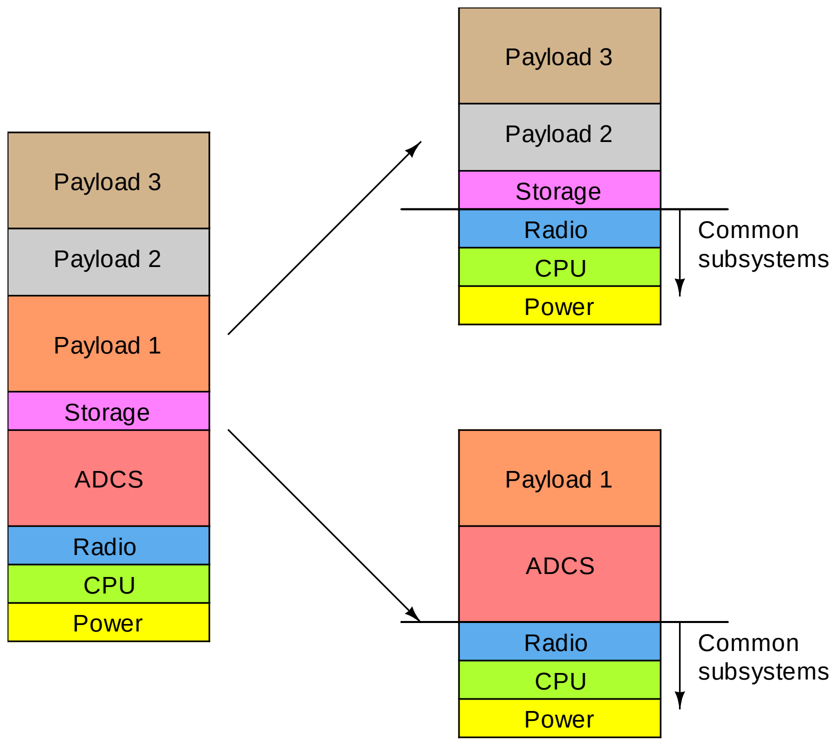
Technologies	Partners
MotherCube Architecture: - Processing and downlink node - Cluster control algorithms 3-Axis Electrospray Thruster Slice: - Positive attitude/position control DGPS corrections shared among cluster	MIT Space Propulsion Lab / Space Systems Lab - Novel propulsion concepts, ADCS software Espace Inc. - Payload & Telemetry System Southwest Research Institute - Mission and RF support

Drivers of Architecture Selection:
CubeSat Form Factor

- 3U CubeSat specifications limit size and mass
  - 3U: 30 x 10 x 10 cm, 4 kg
  - Limited 10-30 W power generation
- Meeting this specification is very desirable:
  - Lower cost ($50k-100k materials, $50k launch)
  - Simpler and more frequent launch opportunities

Distributing tasks is a key enabler

- Components can be bulky
  - Optics to achieve desired focal length
  - Antennas (esp. high-gain directional)
  - Reaction wheel attitude control systems
  - Star cameras
- Allow each Cube to specialize



Splitting up a satellite can ease size/weight constraints and realize functions not previously possible within the CubeSat standard

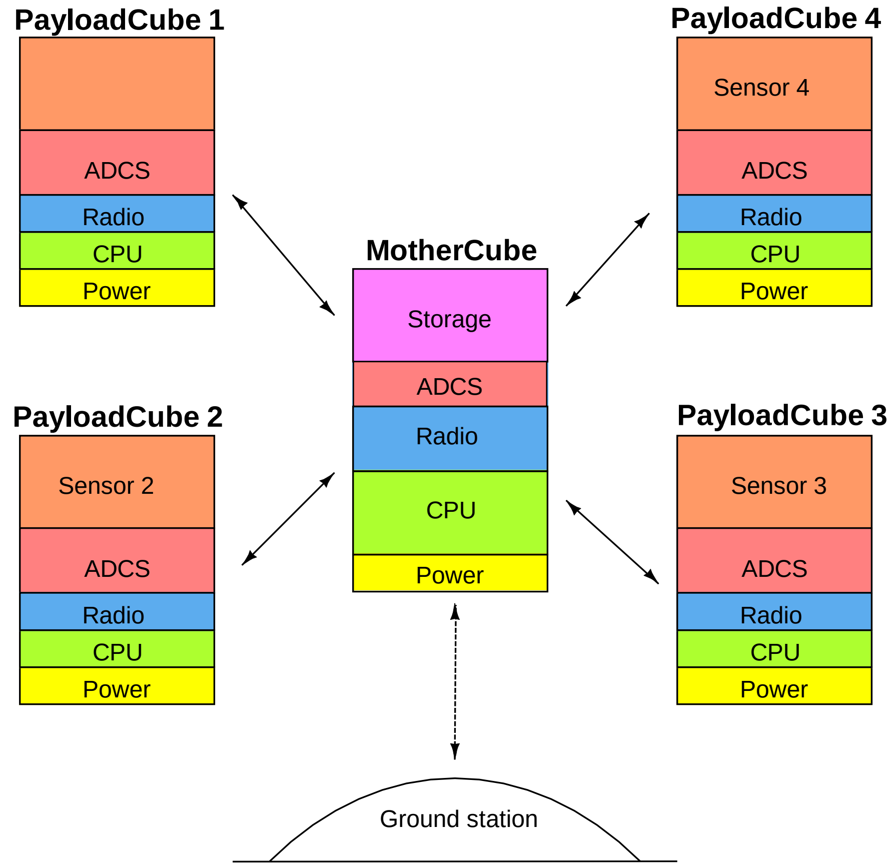
Drivers of Architecture Selection:
Distributed Sensing

Most missions benefit from *Distributed* architecture (e.g. star or mesh topology)

- Large effective apertures
  - Radio telescope
  - Radar synthetic apertures
  - Multiple-camera vision
- Distribute tasks to meet CubeSat form factor
  - MotherCube: Storage, processing and downlink

    (free up SWaP on PayloadCubes)
  - PayloadCubes : more resources devoted to payloads, scalable

- Optimized ADCS capability
- Redundancy, scalability, and survivability for minimal cost

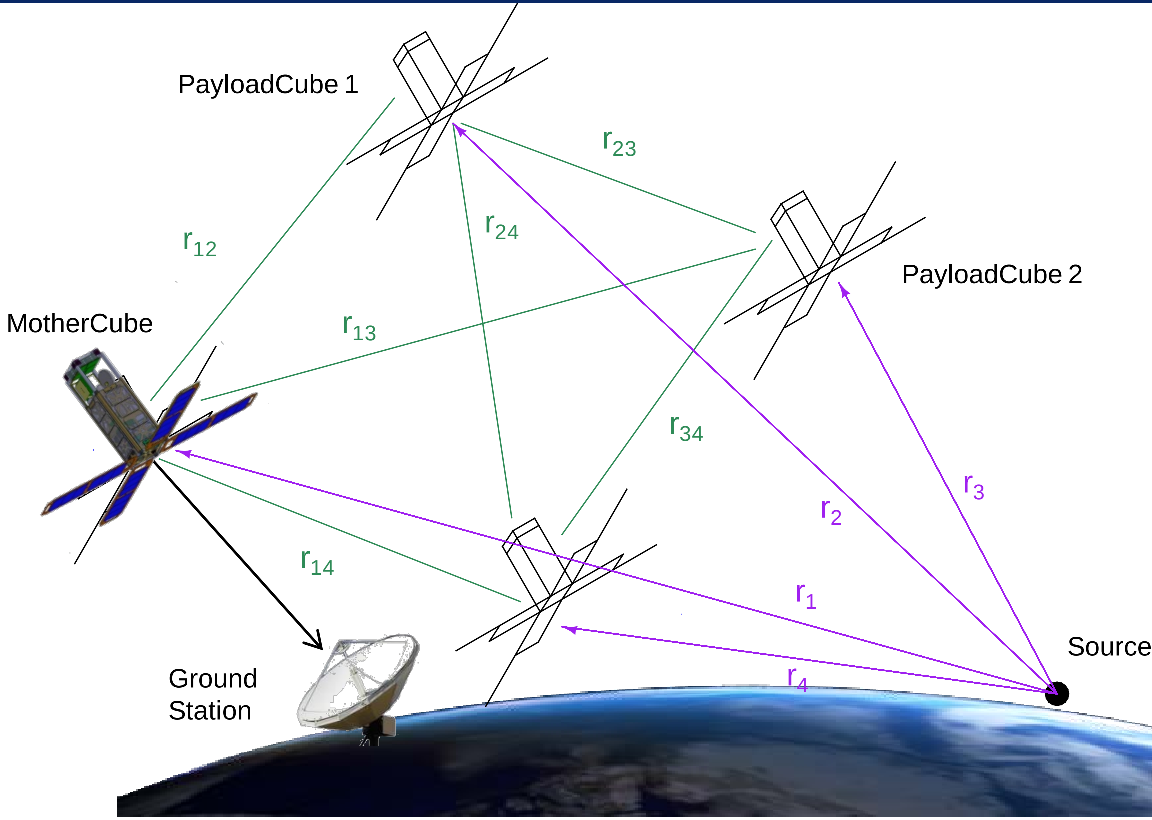


The central node, MotherCube, enables distribution of tasks among platforms enabling fractionation on the CubeSat scale

Current Effort: RF Measurement Cluster

Selected as target mission following Phase I studies

- Detect and locate signals of interest
  - Accomplish basic on orbit demonstration ability to detect VHF sources on ground during flyover and downlink for additional processing
- Instruments on PayloadCubes
  - Antennas
    - Multiple directional and omnidirectional antennas
  - Electronics
    - Reconfigurable FPGA radio
    - GPS-derived timing used to tag signals
    - 3-Axis thruster slice
- MotherCube Serves as combiner and downlink

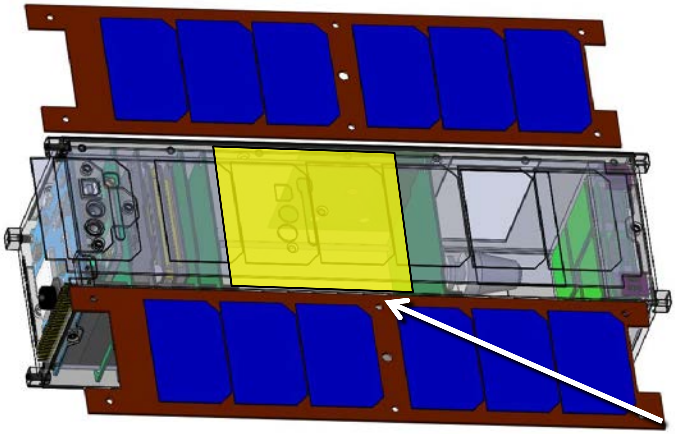


- Mission Demonstration
  - On-orbit proof of fractionated CubeSat cluster
  - Useful mission: locate an RF source
  - Flight heritage for propulsion concept

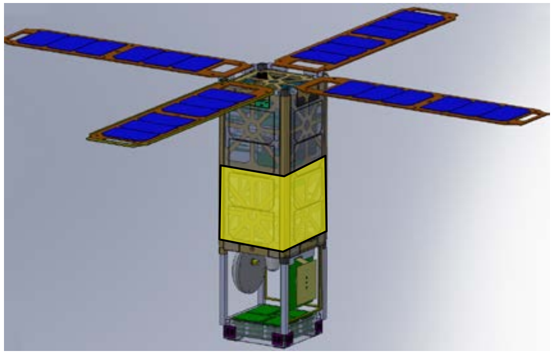
Aurora MotherCube Concept

A CubeSat cluster's primary 3U node

LEO SUN-SYNC CONFIGURATION



~1U available for processing, Comms, Storage, etc



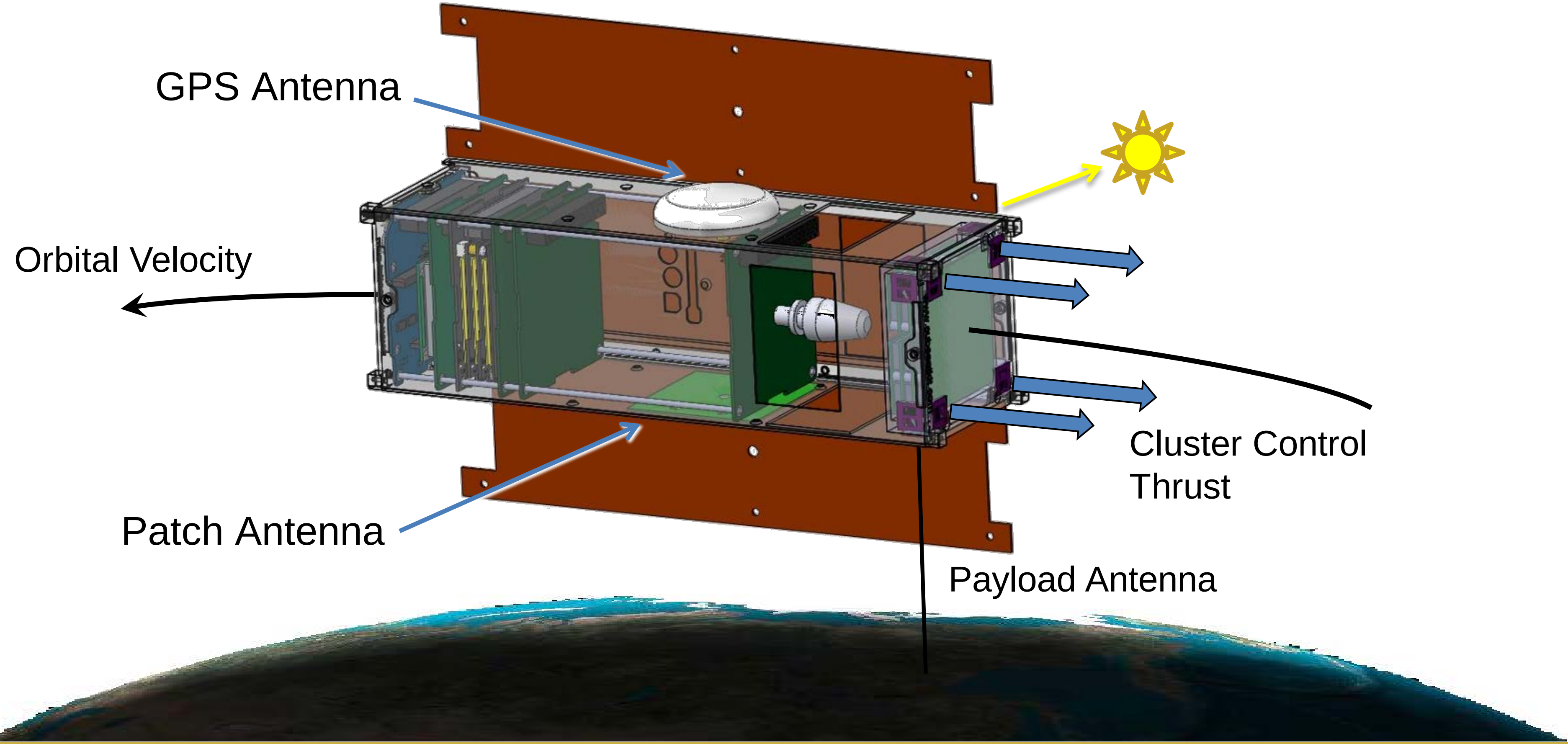
Alternate Flower Petal Configuration

- Central "hub" of distributed mission
  - Handles downlink burden
  - Secondary higher performance processor architecture proposed
- Adaptable to other roles
  - Modular design with ~1U available

Payload Power:	15 W (burst, LEO)
	7 W (continuous, LEO)
Payload Mass:	1 kg
Attitude:	3-Axis stabilized
Pointing:	+/- 5 degrees
	(finer pointing possible)

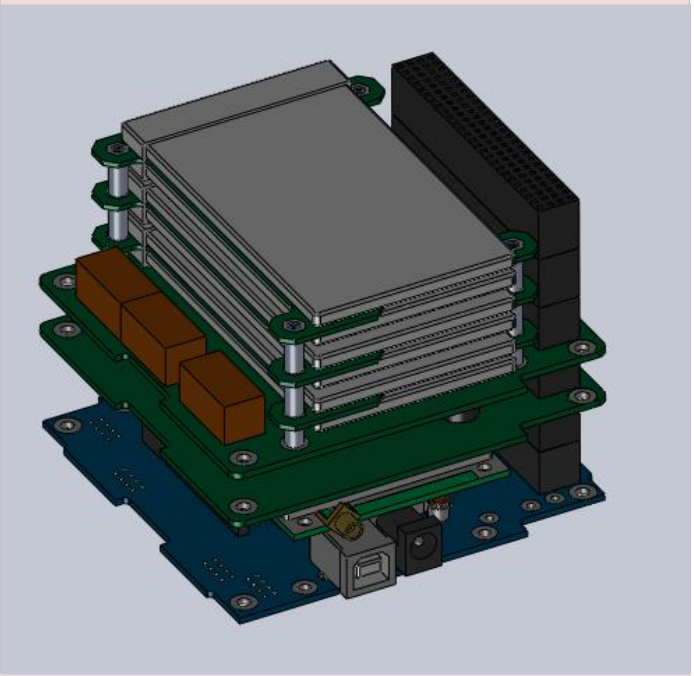
Sun-synchronous (Dusk-Dawn) Concept

- Dusk-Dawn Orbit lines up thrusters with velocity vector
  - Scalable delta-V capability for spiral orbit transfers
  - RF interposition, attitude and ranging possible for interplanetary



MotherCube Components

Components stack up neatly (CubeSat Kit bus)



COTS CubeSat components offer low risk. Questionable radiation tolerance above LEO

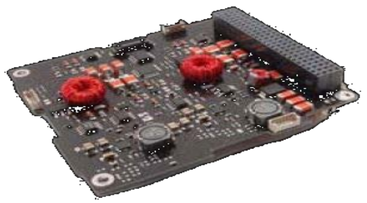
COTS

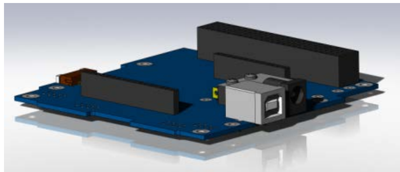
- Pumpkin, Inc.
  - Chassis and hardware
  - Flight computer with PIC24 processor module
- Clyde Space
  - Solar panels
  - Batteries
  - EPS board with MPPTs
- Other assorted components
  - Novatel OEMV-1G differential GPS receiver
  - L-com and Haigh-Farr antennas
  - AeroAstro coarse sun sensor

Under Development

- Espace: Payload & Telemetry Subsystem
- MIT SPL: Electrospray Thruster slice

EPS - $10k





Computer - $2k

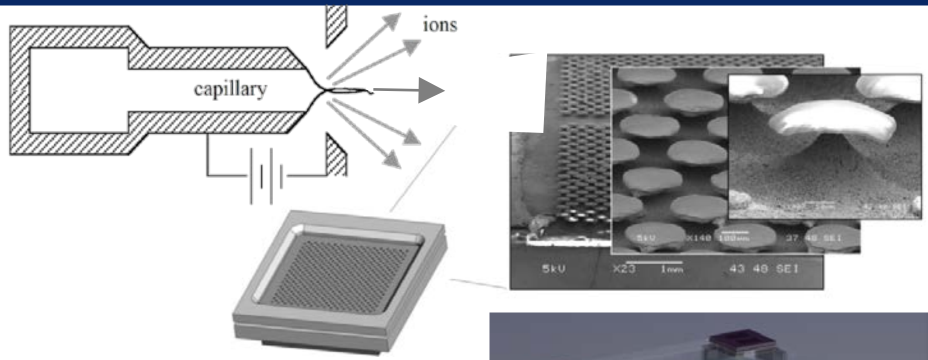
Novatel GPS -

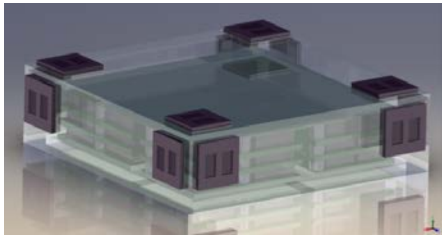
AeroAstro Sun Sensor - $5k

Solar panels - $40k

Enabling Technology

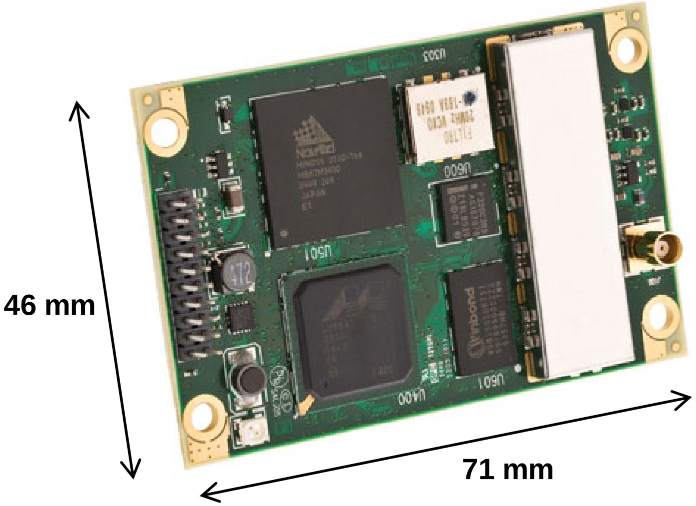
- Electrospray Thruster Concept (MIT SPL, Espace)
  - Very fine thrust control: ~1 μN
  - Low noise: 0.001 μN/sqrt(Hz)
  - High I_{sp}: 1000 to 4000 sec
  - Approx. <0.5 kg propellant for escape velocity





- Novatel OEMV-1DF GPS Receiver
  - Utilizing Novatel's RT-2 real-time kinematic corrections
  - MotherCube receiver crosslinks GPS corrections to PayloadCubes in cluster

RF interpositioning and star cameras required for interplanetary

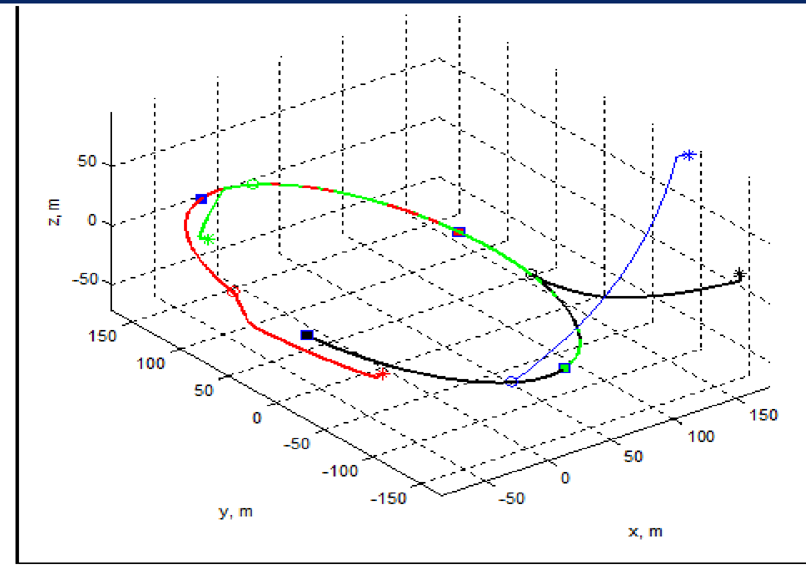


Cluster Control

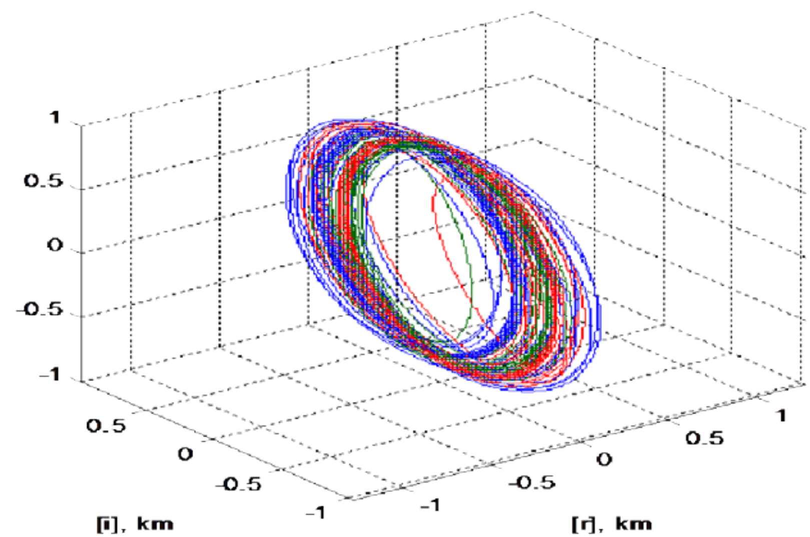
Challenge:

- Hold cluster geometry despite differential drag, gravitational disturbances
- Reduce propellant usage

- Linear Programming Strategy
  - ➢ Reduces computational burden
  - ➢ Guarantees convergence to a solution
- Larger bounding box when possible
  - ➢ Reduce propellant usage when tight control not required
- Thrusters allow tight control of cluster formation
  - ➢ Mixing of thrusters allows steering of thrust vector



Orbits Relative to Geom Center



Summary

- Fractionation and distribution of operations
  - Most applicable to volume/mass constrained platforms: CubeSat is at the extreme
- Aurora’s efforts focus on developing cluster flight & ACS algorithms, bus architecture, and mission utility
- Several key technologies enabling CubeSat clusters are applicable to interplanetary missions
  - MotherCube/PayloadCube architecture for fractionation
  - Low power thrusters for delta-V and precise attitude/position control
  - Radios, processing electronics
- Aurora’s CubeSat Cluster demonstration: affordable existence proof for fractionation and of the utility of CubeSat cluster missions paving the way for CubeSat clusters to leave LEO

Questions?

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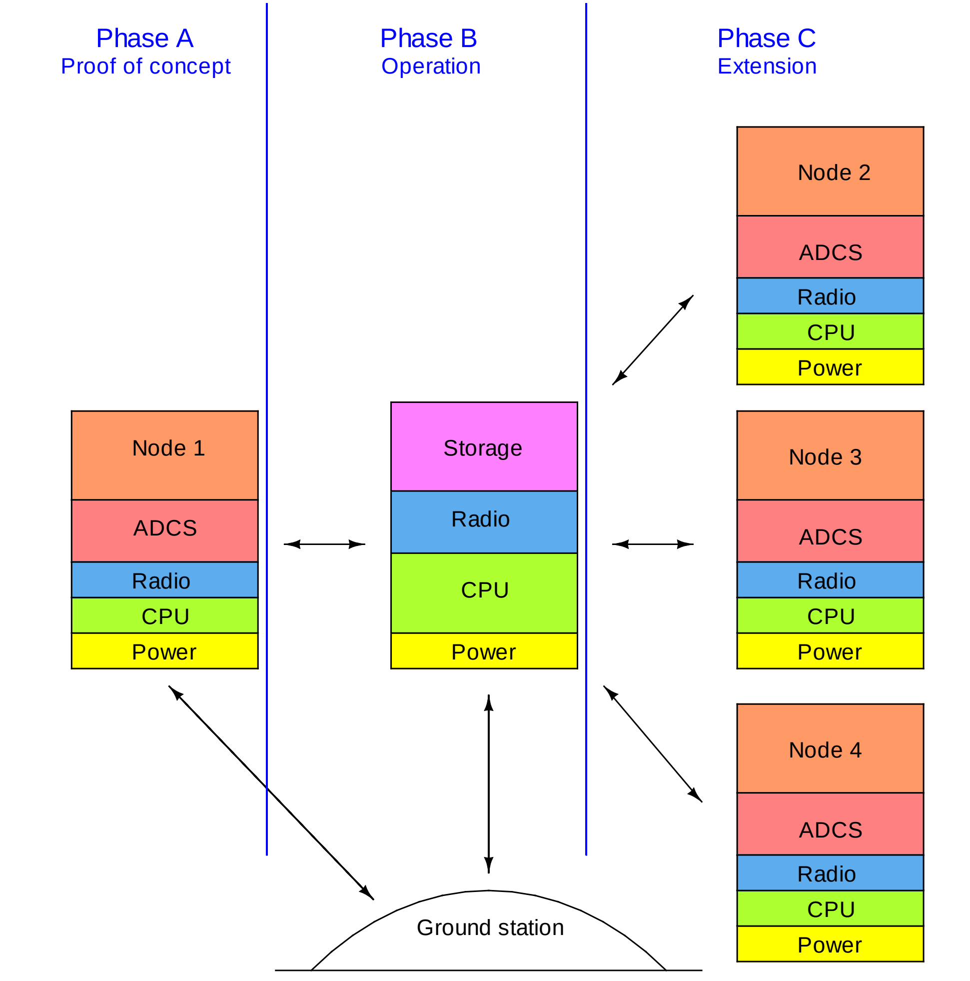
Backup, Additional Information

Risk reduction and responsiveness

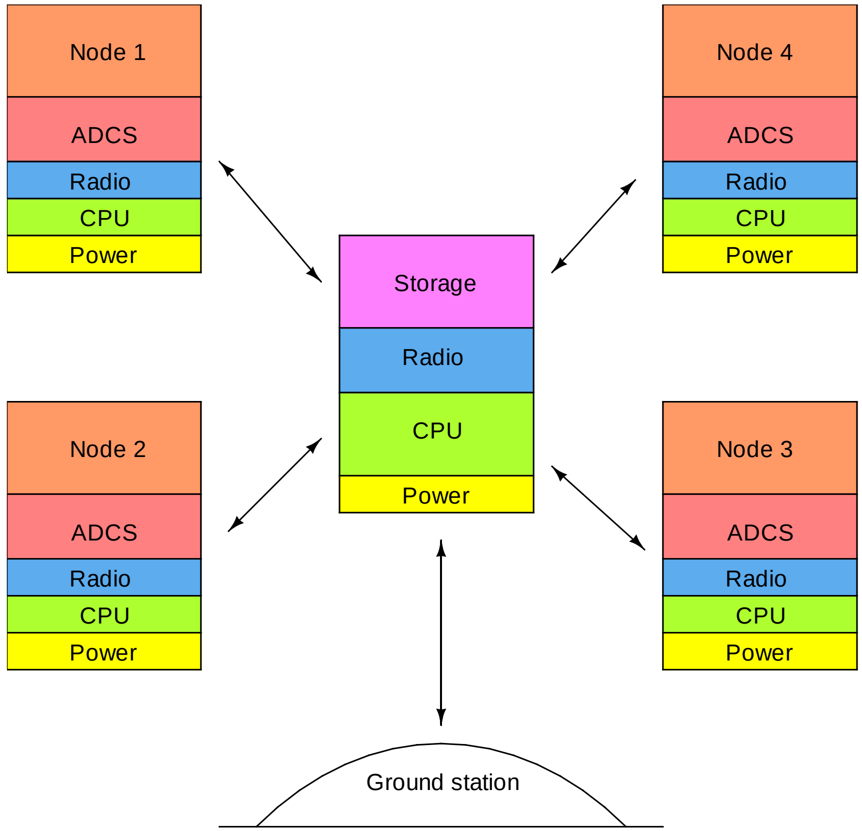
- Funding for high-risk activities is limited
  - Feasibility demonstration required
  - CubeSat platform may be viable not just for proof of concept, but for attaining entire mission
- Use *incremental* architecture



Building a CubeSat cluster incrementally allows data collection capability to scale with confidence and funding

Distributed sensing needs

- Large effective apertures
  - Radio telescope
  - Radar
  - Stereo vision
- Parallelizable tasks
  - Communications on different channels
  - Photometry of multiple stars
- Use *distributed* architecture (e.g. star or mesh topology)

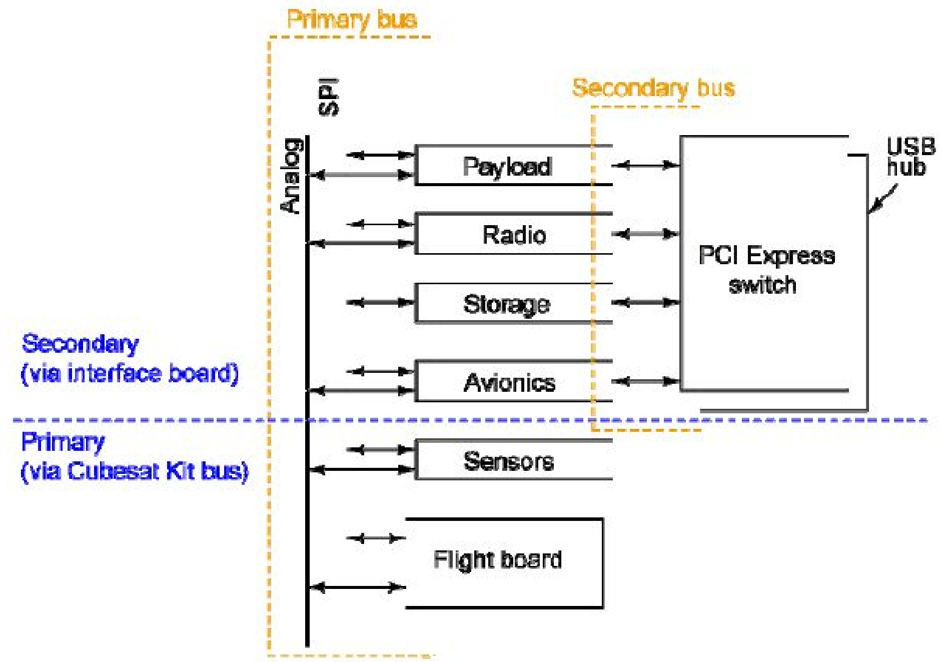


A distributed CubeSat cluster enables large aperture sensing functions that were previously infeasible

Secondary Processing Architecture

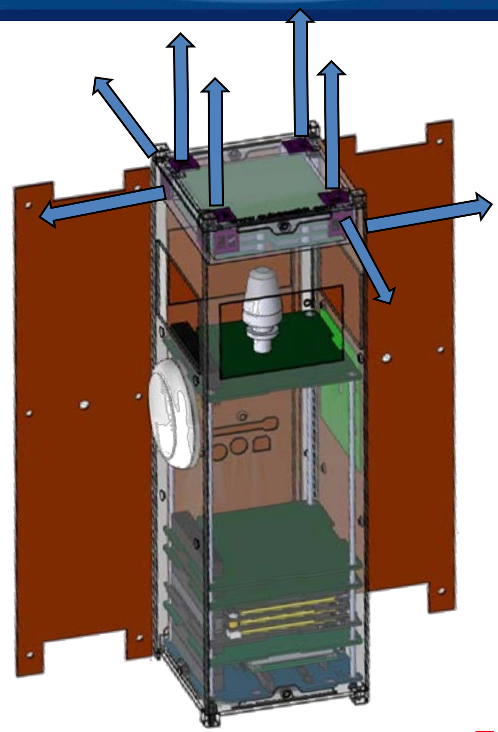
- Proposed secondary avionics architecture to augment primary avionics and add greater processing power
  - OMAP, Atom, or PowerPC processor
  - FPGA signal processing
  - PCI-Express switch
    - 250 MB/s full-duplex transfers between peripherals
  - Support for Wi-Fi and WiMAX

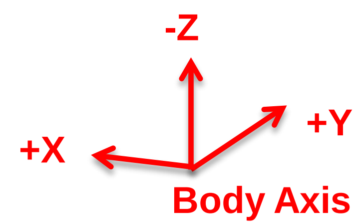
Dual-bus architecture
for adding high-bandwidth components
and additional processing

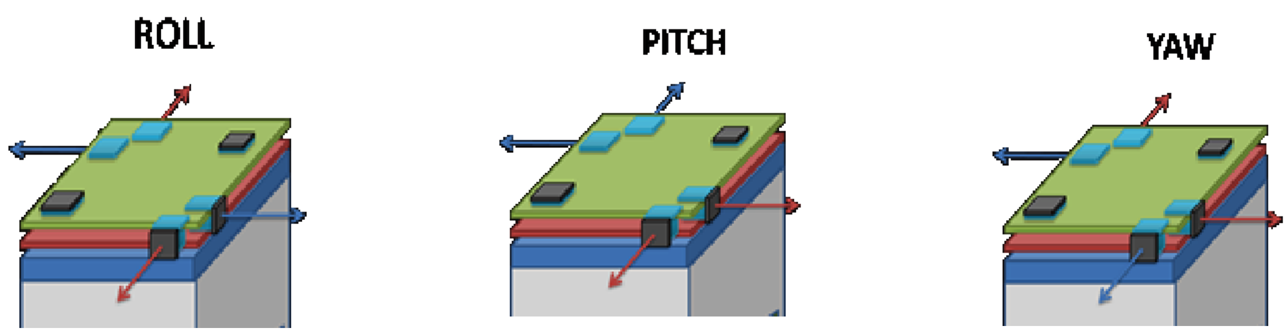


Thrust Mixing and Torques

- Algorithms designed to run quickly with limited resources
  - LRQ approach, penalizing use of off-axis thrusters
- String of Pearls, Circular Concentric ellipses
- Offset thrusters mixed with torque coils
  - Limited use of non-Z axis thrusters for simplicity
  - Torque coils for attitude control and attitude stiffness.







Cluster Mission Possibilities

Possible missions and variations	Potential Transition Customers
• MicroMAS ➢ May cover additional bands with additional PayloadCubes ➢ May perform onboard data reduction in MotherCube	• NASA ➢ Funding MicroMAS instrument development • DoD ➢ MicroMAS weather mission
• ExoplanetSat ➢ Additional payload cubes can monitor multiple stars in parallel	• NASA ➢ Potential scientific mission
• RF Sparse Array ➢ Scalable PayloadCubes to cover additional frequencies ➢ Perform processing on MotherCube	• US Army ➢ Interested in augment existing assets
➢ Cloud Cover Imager ➢ Cluster PayloadCubes to carry various wide swath imagers ➢ Perform storage, downlink on MotherCube	• Intelligence Agencies ➢ Low cost mission to augment and queue higher value assets