aquila space

OPEN TECHNOLOGY FOR SPACE

Perseus-M On-Orbit Report and Corvus-BC Satellite Design

Michael Bertino, Brian Cooper 4/23/15

Introduction

aquila space
OPEN TECHNOLOGY FOR SPACE

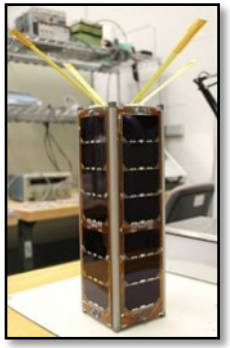
- Aquila Space
  - Silicon Valley start up founded in 2015
  - 16 employees
  - Focus on small remote sensing satellites
- Mission
  - Produce commercially viable satellite imagery data
  - Design, build and operate remote sensing satellites
  - Target agriculture and urban monitoring markets
- Carry out Our Mission
  - System integrators
  - Develop sub-systems and components when necessary
  - Partner with specialized companies for ground segment and image processing
  - Not vertically integrated
  - Targeting 22m and 2.5m GSD with high temporal revisit
  - Opening up our design to enable other missions

Our Background

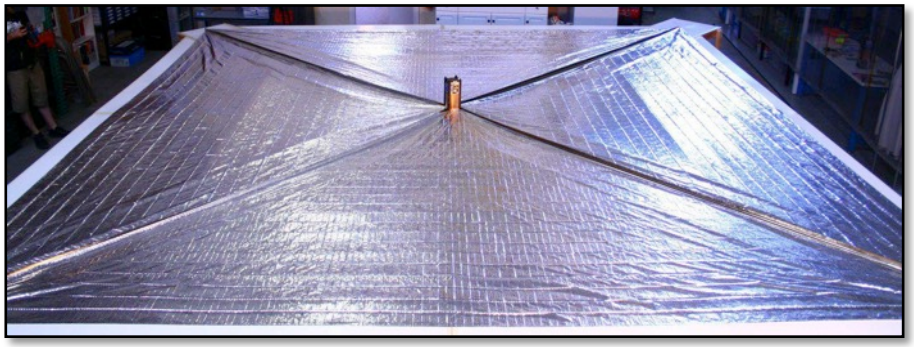
aquila space
OPEN TECHNOLOGY FOR SPACE

- Core engineering team worked at Canopus Systems
- 100% of current team completed Perseus-M mission
- Experience in satellite missions

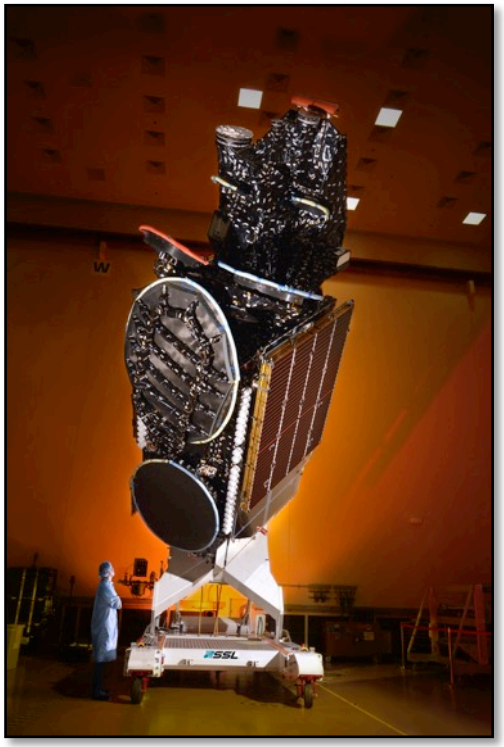
SRI –RAX 1



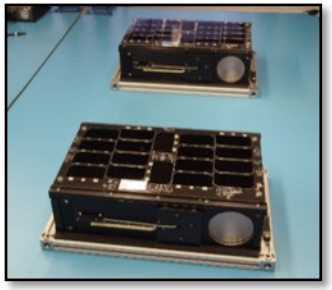
LightSail



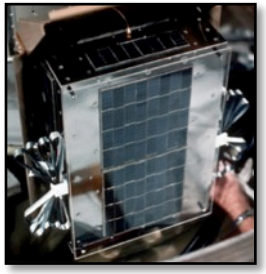
SSL-ABS2



Perseus-M



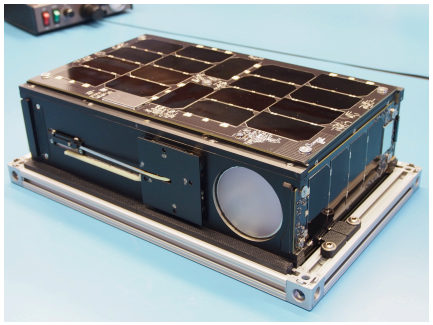
AmSat – Oscar Series



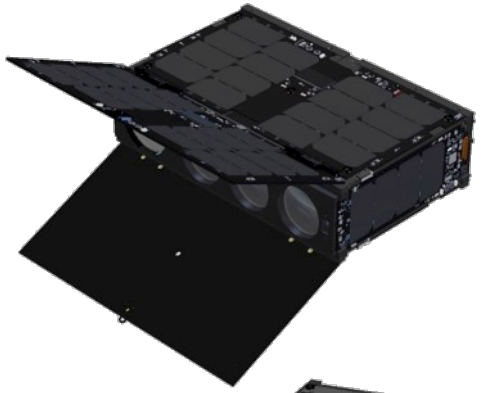
Current Projects

aquila space
OPEN TECHNOLOGY FOR SPACE

- **Perseus-M**
  - Launched in June 2014
  - 2x 6U Automatic Identification System (AIS) CubeSat
  - Extended commissioning phase
  - Characterizing AIS payload performance



- **Corvus-BC**
  - Launch Q1 2016
  - 4x 6U remote sensing CubeSat
  - Multispectral: Red, Green, NIR
  - 22 m GSD

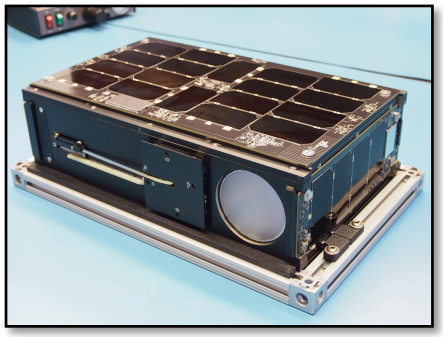


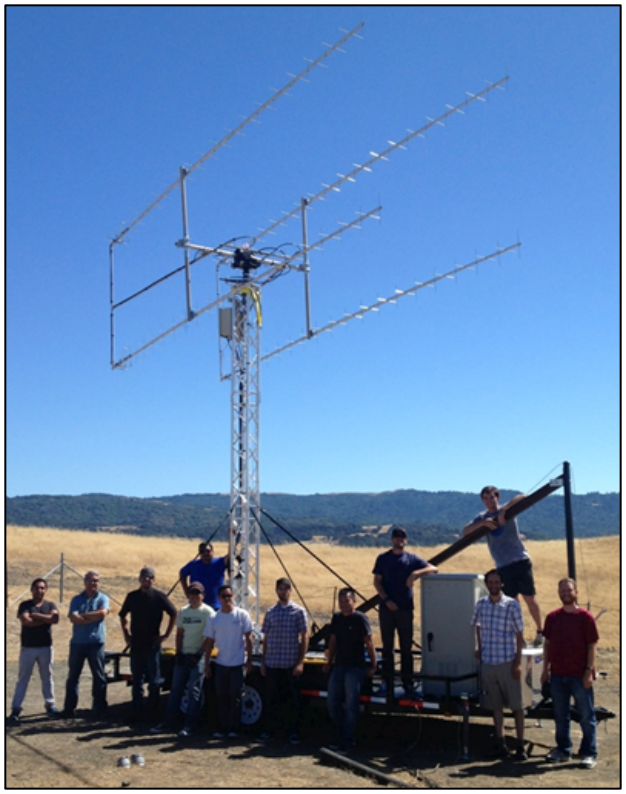
- **Corvus-HD**
  - Launch Q4 2016
  - 4x 16U remote sensing CubeSat
  - Multispectral: Red, Green, Blue, NIR, Red Edge
  - 2.5 m GSD

Perseus-M Overview

aquila space
OPEN TECHNOLOGY FOR SPACE

- The Perseus-M spacecraft serve as a pathfinder mission, helping to develop skills, processes, and technology at Aquila
- Initially slated as an imaging mission, but payload was exchanged when an AIS receiver payload was made available from LuxSpace
  - More time to spend on bus development this way
- Perseus-M software is highly customizable on-orbit (Embedded Linux, new python scripts uploaded regularly)
- Many lessons learned through this development
  - Design
  - Assembly, Integration, & Test
  - Ground Segment
  - Flight Operations

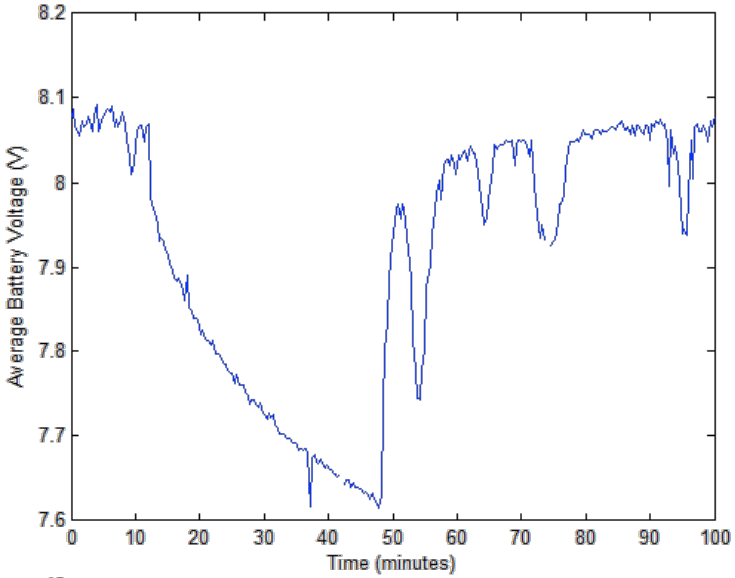


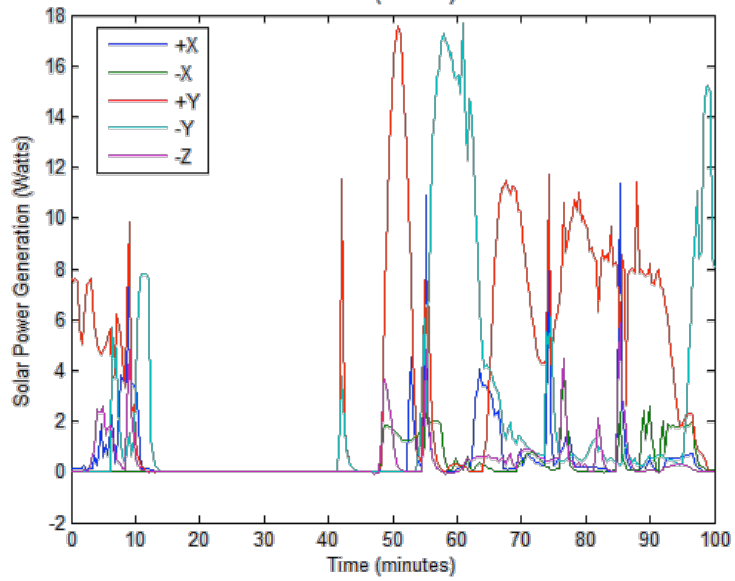


Health and Status – EPS

aquila space
OPEN TECHNOLOGY FOR SPACE

- This data shows battery voltage and solar power input over one orbit
- Taper charge voltage is ~8.08 Volts
- Discharge through eclipse to ~7.62 Volts
  - 10% of battery capacity used
- **Telemetry error in eclipse: No I²C buffers + "long" distance connection**
- Spacecraft tumbling causes voltage sag during charge
- Note: Amperage readings in general have proven to have substantial errors. **Don't count on current monitors for critical tasks.**
- Spectrolab solar cells generate ~1 Watt per cell max, as expected

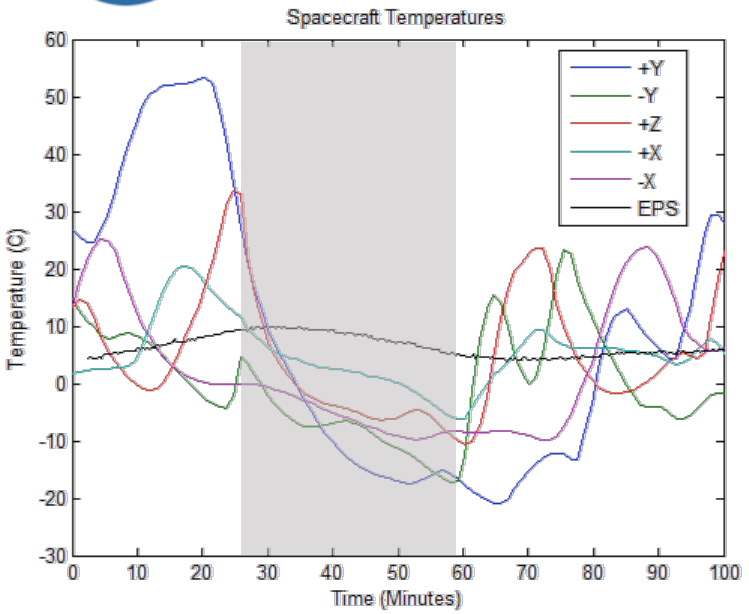


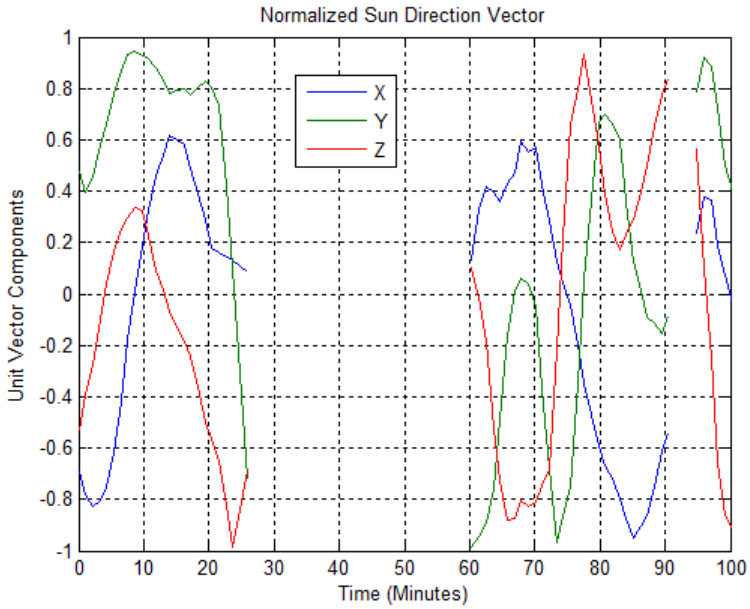


Health and Status Continued

aquila space
OPEN TECHNOLOGY FOR SPACE

- **Extensive use of machined aluminum structures**
  - Excellent heat conduction
  - High thermal inertia
  - Improved radiation shielding
  - Structure grounding
- External temperatures vary widely, but internal remains steady
- Sun sensor data shows how quickly panels heat up with sun exposure
- Sun sensors and magnetometers show a tumble rate of one per 15 minutes
  - **Elmos E910.86 sun sensor is compact and accurate (but discontinued!)**

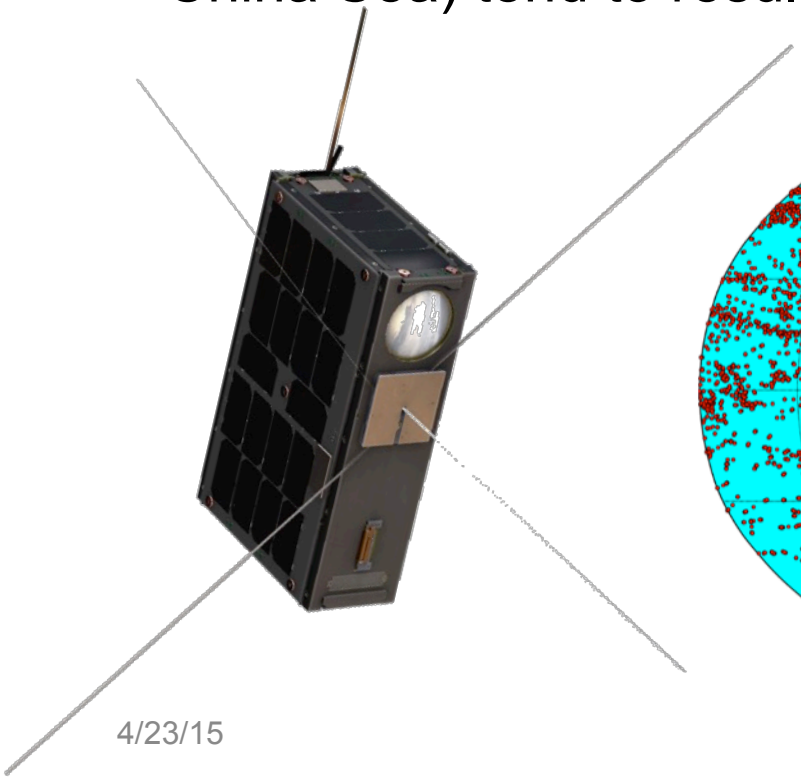


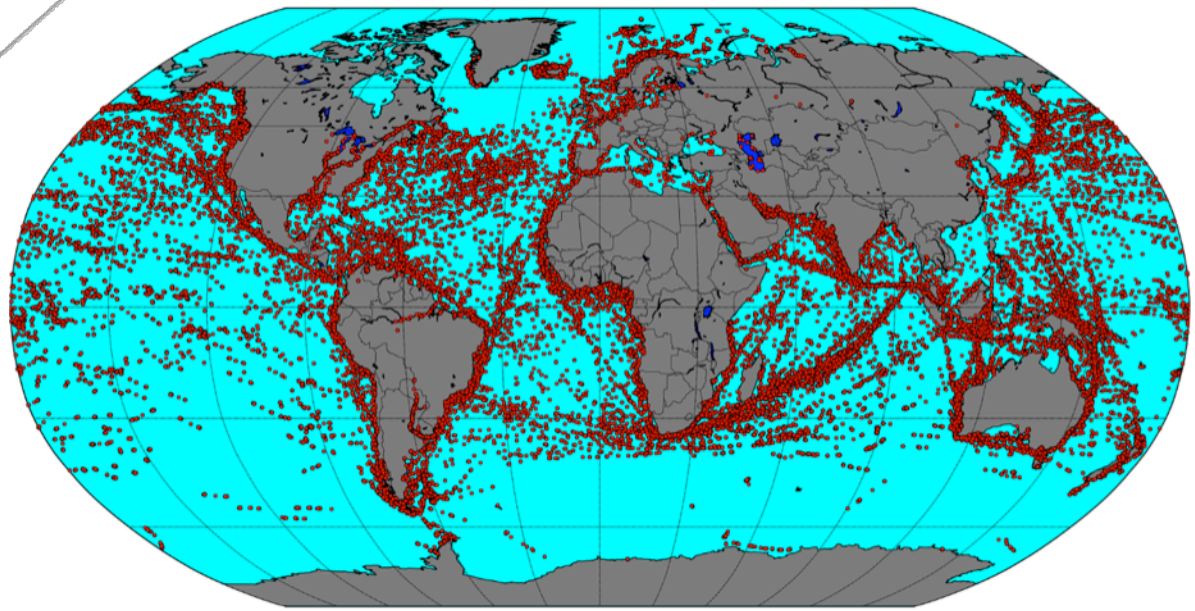


AIS Payload

aquila space
OPEN TECHNOLOGY FOR SPACE

- Operations have focused heavily on commissioning the AIS receivers
- Two ¼ wave crossed dipoles feed into redundant receiver on 162.0 MHz and 156.8 MHz AIS channels **(Performance is heavily dependent on the antenna)**
- Message collision in high density areas (Mediterranean, China Sea) tend to result in less messages received





Perseus-M Summary

aquila space
OPEN TECHNOLOGY FOR SPACE

- External HMC5983 magnetometers and E910.86 sun sensors have not experienced any failures over 9 months (20 each per S/C)
  - Shielded panel processors still working as well
- On-board SD Card still fully functional (1 per S/C)
- Ability to test and develop software on-orbit has been extremely useful
  - Short development cycles can be extended past the launch date, and performance improvements can be made
  - Downside: extends the time to full operational status
- Perseus-M “BenchSat” has proven extremely valuable for vetting code prior to upload
- Linux, TCP/IP, Python, C, have all proven useful and allow for relatively rapid software development
- We realized we needed the ability for more specific hardware customization in some areas

Corvus-BC Overview

aquila space
OPEN TECHNOLOGY FOR SPACE

- Imaging solution: 22 m GSD at 600 km, Red, Green, NIR spectral bands
- Flight computer: ARM A8 running linux
- Power system: scalable 48Wh Li-Ion
- Communication: UHF transceiver running at 19.2 kbps for TT&C. Payload data is downlinked through Ka-band at 40 Mbps
- Solar panels: ARM M0+ processor, temperature, magnetometers sun sensors and magnetorquer coils
- Control: 3-axis with three reaction wheels, star tracker, GPS and gyro
- Memory: 1 TB
- Imaging capability: 7.5 minutes per orbit assuming data downlink in 11 minute pass

Imager Payload

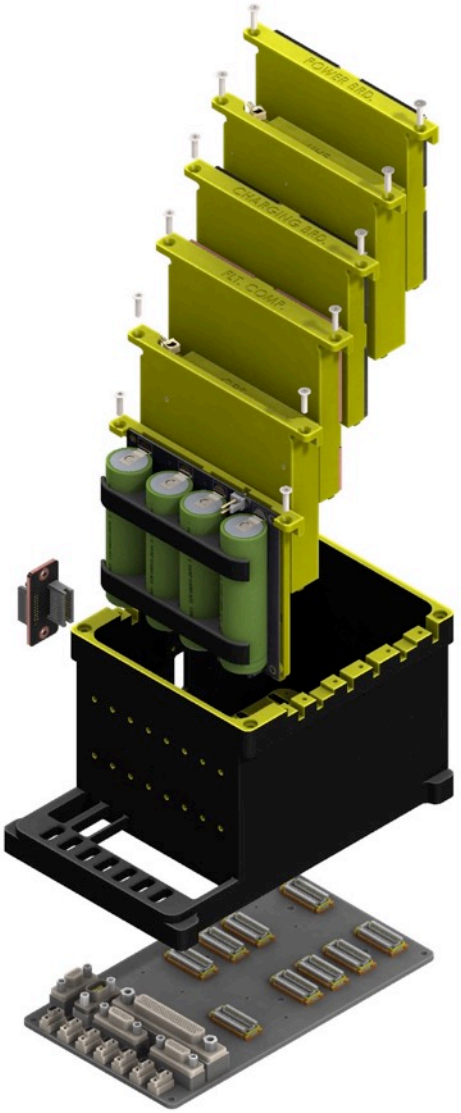
aquila space
OPEN TECHNOLOGY FOR SPACE

- 3x Spectral Bands: Green (520-600 nm), Red (630-690 nm), and NIR (770-900 nm)
- GSD: 22 m at 600km
- Swath width: 220km
- MTF: 0.10 at Nyquist frequency
- Single image SNR: ~70
- Frame Rate: 0.5 frames per second
- Single frame 70 Mega-Pixels per band
- IFOV: 7.6 arcseconds = 37 μradians
- Instrument FOV: 21.0 x 14.9 degrees
- Data Storage: 1 TB
- FPGA: Opalkelly FPGA
- Sensor(x 3): CMOSIS CHR70M

Data Power Module

aquila space
OPEN TECHNOLOGY FOR SPACE

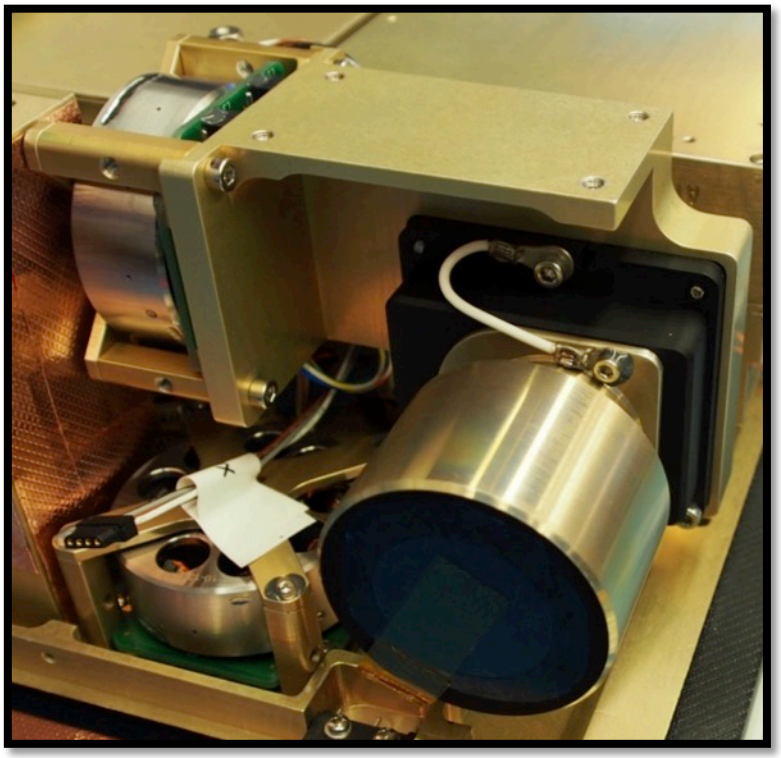
- Card, rack style design
- Electrical Power System
  - Battery Board: 4x 18650 Li-Ion batteries
  - Charging Board: Micro-Python processor
  - Power Board: Vbatt (3.6-4.0V), 5V, 8V and 12V
- Flight Computer
  - COTS ARM A8 SOM with daughter board
  - Running Linux with Python and C
- UHF radio
  - Astro-Dev Li-1 radio
  - Daughter card
  - 19.2 kbps
- GPS
  - Novatel OEM615
  - Daughter card



Flight Control System

aquila space
OPEN TECHNOLOGY FOR SPACE

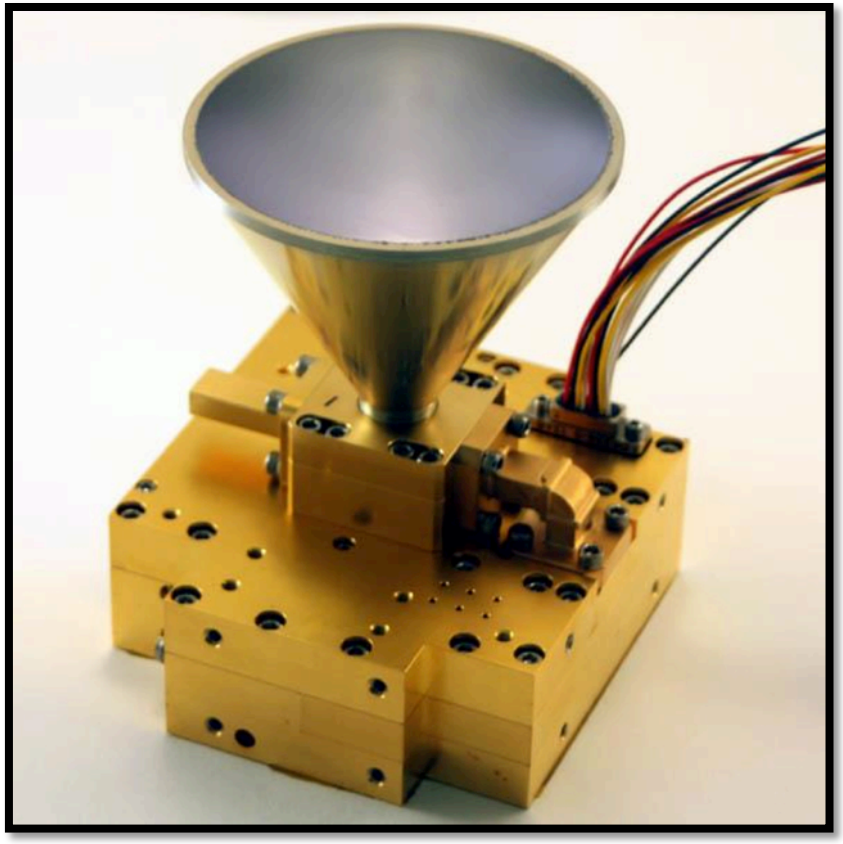
- Utilizing Sinclair hardware
- 3x 30 mNms Reaction Wheels
- 1x ST-16 Star Tracker
- Custom enclosure



Ka-band

aquila space
OPEN TECHNOLOGY FOR SPACE

- Approximately 1U size
- ~1kg
- 10 and 40 Mbps
- 10.2° beamwidth
- +28 dBm output power
- DVB-S2 MODCOD
  - Steps 1-12
  - Contains QPSK Modulator
  - Contains DVB-S2 FEC Coder
- 13 W consumption



Imaging Constellations

aquila space
OPEN TECHNOLOGY FOR SPACE

- LandMapper BC
  - Constellation of 8 Corvus-BC satellites for daily revisit of medium resolution imagery of all arable land in the world
  - Delivery raw data to partners
  - First partner is Astro-Digital
  - Applications include: Disaster monitoring, precision agriculture, land classification, forest management, etc.

- LandMapper HD
  - Constellation of 20 Corvus-HD satellites for daily revisit of medium resolution imagery of all arable land in the world
  - Applications include: precision agriculture, urban planning and business intelligence

aquila space

OPEN TECHNOLOGY FOR SPACE

Questions?

Ground Station

aquila space
OPEN TECHNOLOGY FOR SPACE

- 23 dBiC circularly polarized quad Yagi antenna
- Rotor controller steered with Gpredict
  - Some challenges with this interface
- Having “Mission Control” in our engineering work area has been helpful
  - Faster on-orbit software development
  - Lessons learned from operations are immediately available to the engineering team