Small Satellite Research Laboratory

Franklin College of Arts and Sciences

UNIVERSITY OF GEORGIA

How UGA is Helping Develop the Next Generation of Systems Engineers for the State of Georgia

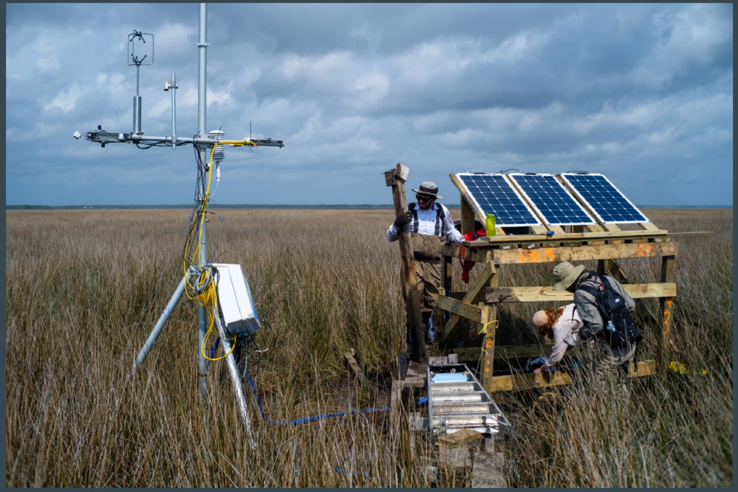
Dr. David L Cotten

Principal Investigator – SSRL
Assistant Research Scientist – Center for Geospatial Research
Department of Geography

Background

- Physics BS from Louisiana State University: 2005
- Physics and Astronomy PhD from University of Georgia: 2011
- Post Docs in Micro Meteorology and Environmental Physics: 2011-2014
    - Eddy Covariance method for carbon storage in terrestrial ecosystems
- Research Scientist (Center for Geospatial Research – Geography Department) : 2015 - Present
    - Combining Eddy Covariance and Remote Sensing to measure carbon storage as a function of tides in wetland ecosystems

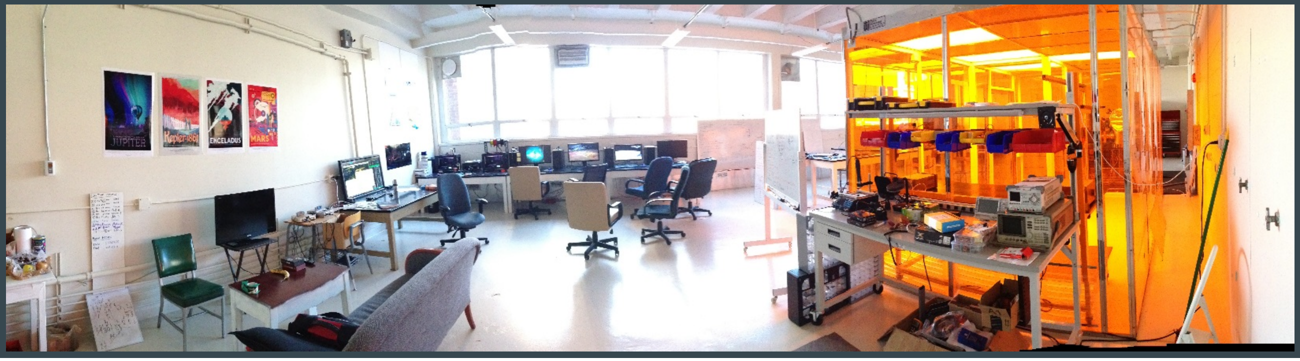
View from the boat at the Bayou Sauvage, LA eddy covariance site.



Eddy Covariance flux tower in Grand Bay, MS.

Small Satellite Research Laboratory

- Founded in 2016
    - 2 Cube satellites under development
- Over 40 undergraduates work in the lab
- 12 faculty advisors, mentors, and researchers from all over campus



Our Missions

MOCI

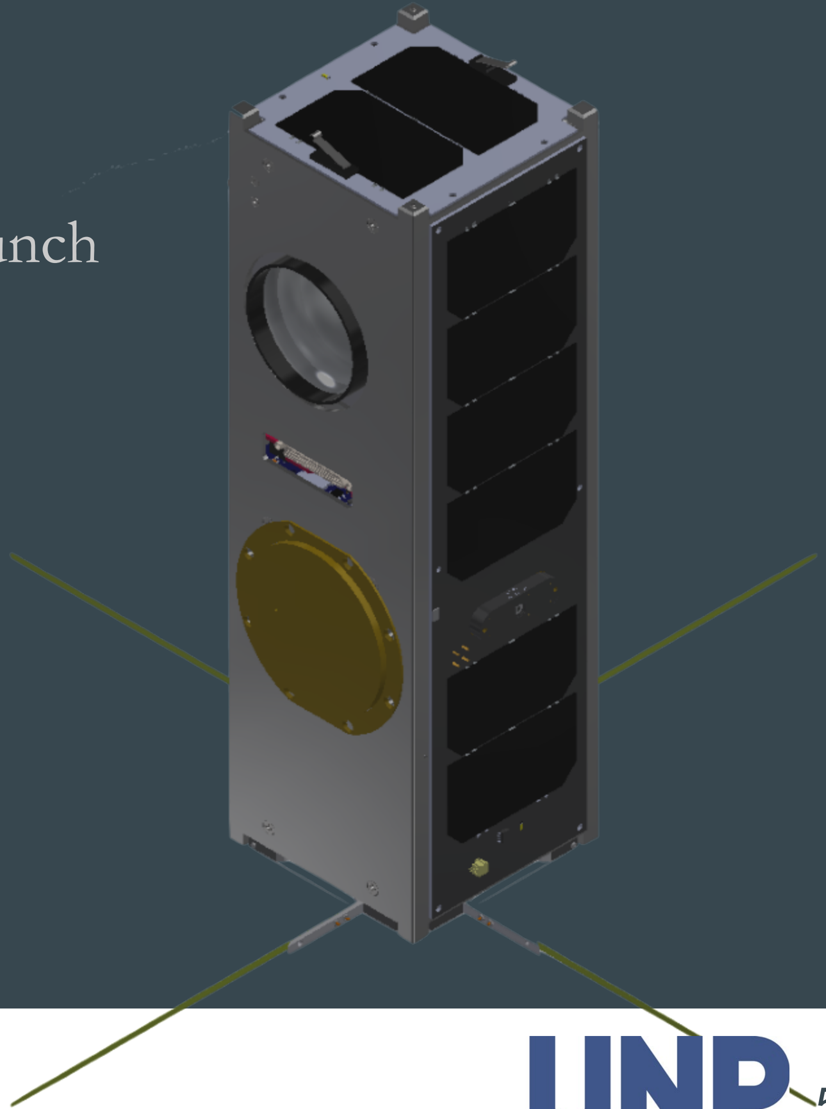
- *Multi-view Onboard Computational Imager*
- Funded through the Air Force (AFRL)
- Use images to create 3D point clouds
- Create high performance computational units for use in space

SPOC

- *SPectral Ocean Color Satellite*
- Funded through NASA
- Measure coastal, oceanic, and environmental productivity
- Adjustable multi spectral payload

MOCI: Multi-view Onboard Computational Imager

- Part of the 9th University Nanosatellite Program
- Competed against 9 schools for a chance to full build and launch
  - UGA WON!
- Was a 3U
  - Now a 6U
- Launch in late 2020

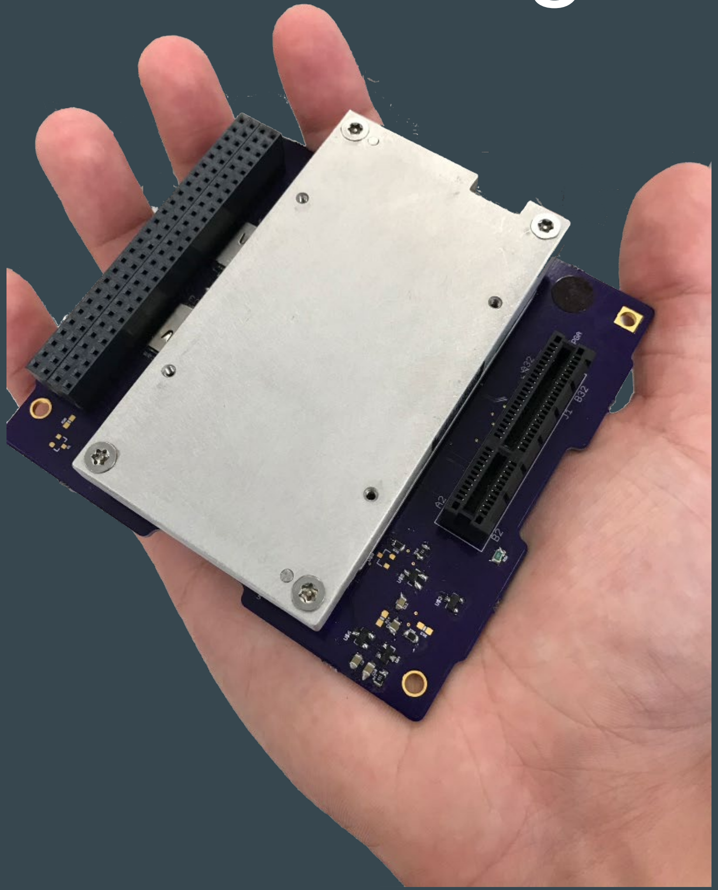


MOCI: Multi-view Onboard Computational Imager

- Use GPU's to increase on board processing abilities
- Utilize computer vision and neural networks to identify and track Earth based objects from an orbiting platform

MODIS image of Lake Erie 20160516

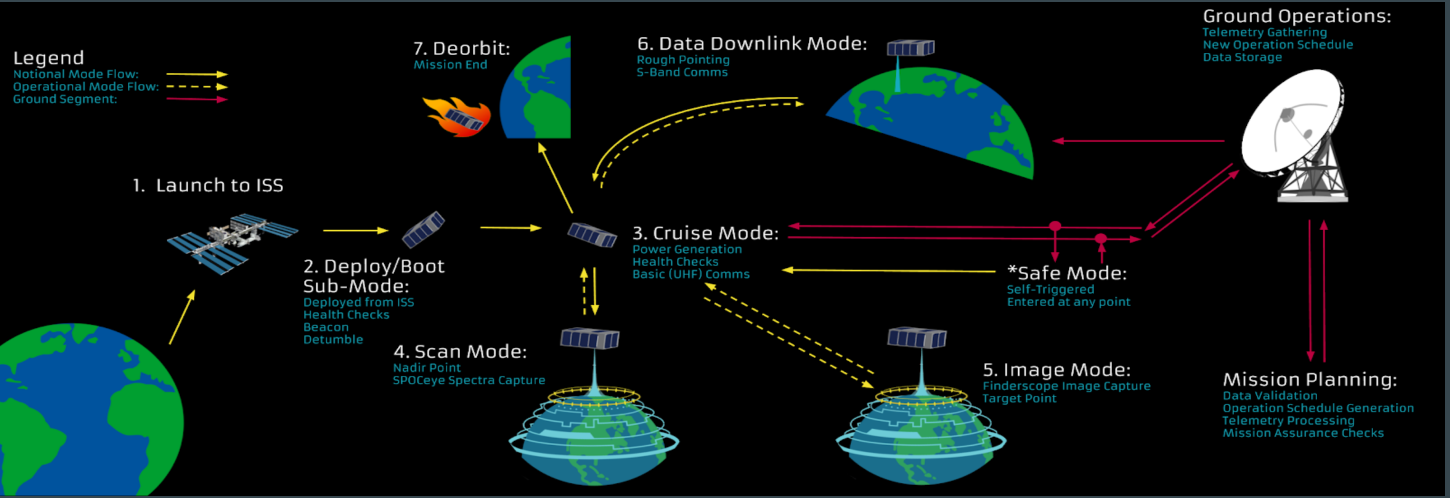
Simulation of the tracking of objects over the red sea from an ISS nadir video.

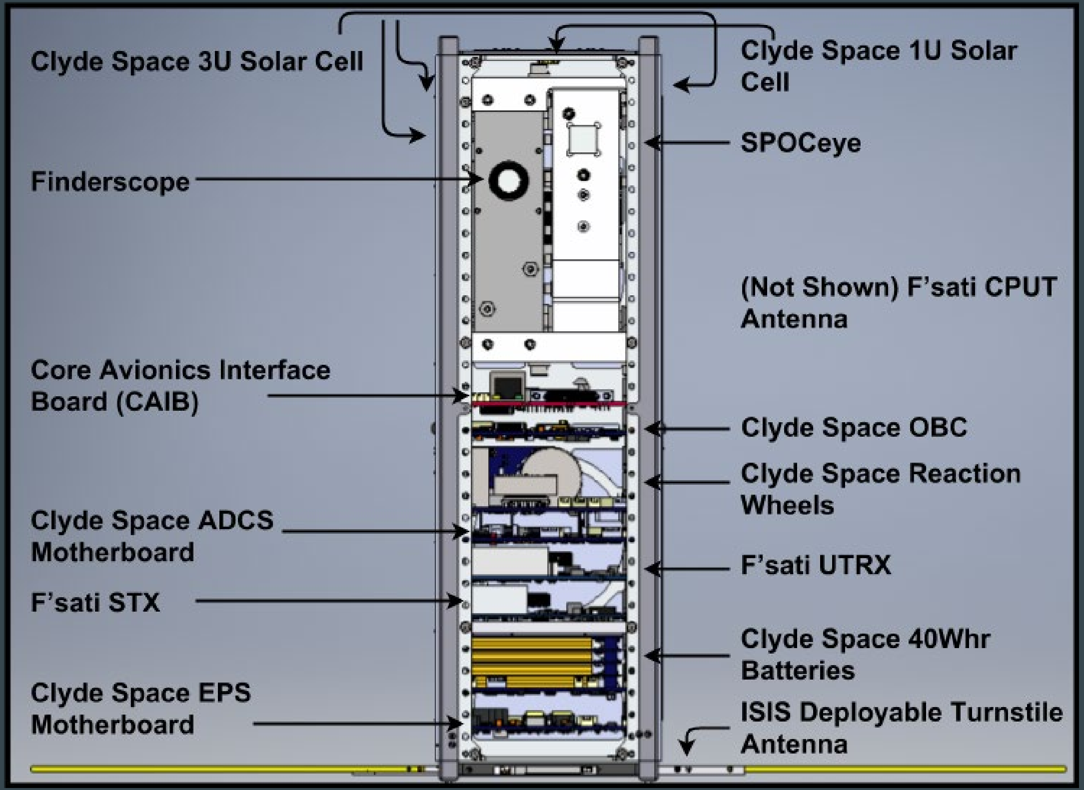


The UGA SSRL's miniaturized high performance computation unit developed around the Nvidia TX2i for the MOCI satellite

SPOC: Spectral Ocean Color Satellite

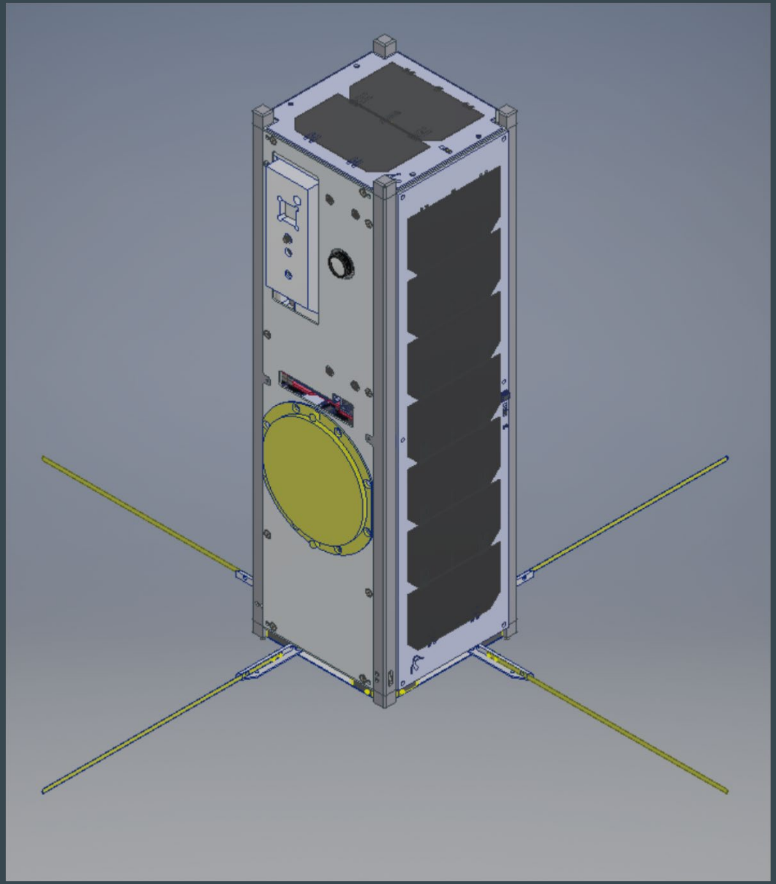
- 3U CubeSat
- Adjustable Multispectral Imager
  - 16 bands
  - ~433 nm - ~822nm
  - 130m resolution





SPOC: Spectral Ocean Color Satellite

- Delivery July 2019
  - Expected launch October 2019
- ISS orbit
  - ~450km altitude
  - 51.6º inclination



CAD of final SPOC design

Difficulties at Non Technical School

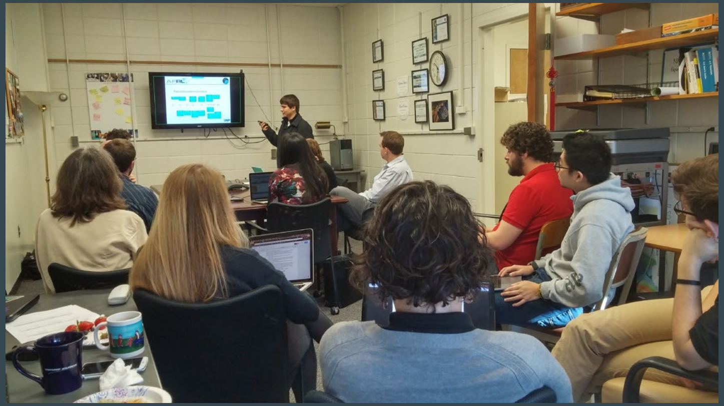
- Finding appropriate facilities and expertise in satellite integration
- More expensive to start a program

Old lab space used for storage

New lab space with 7 desktops, cleanroom, and ESD area

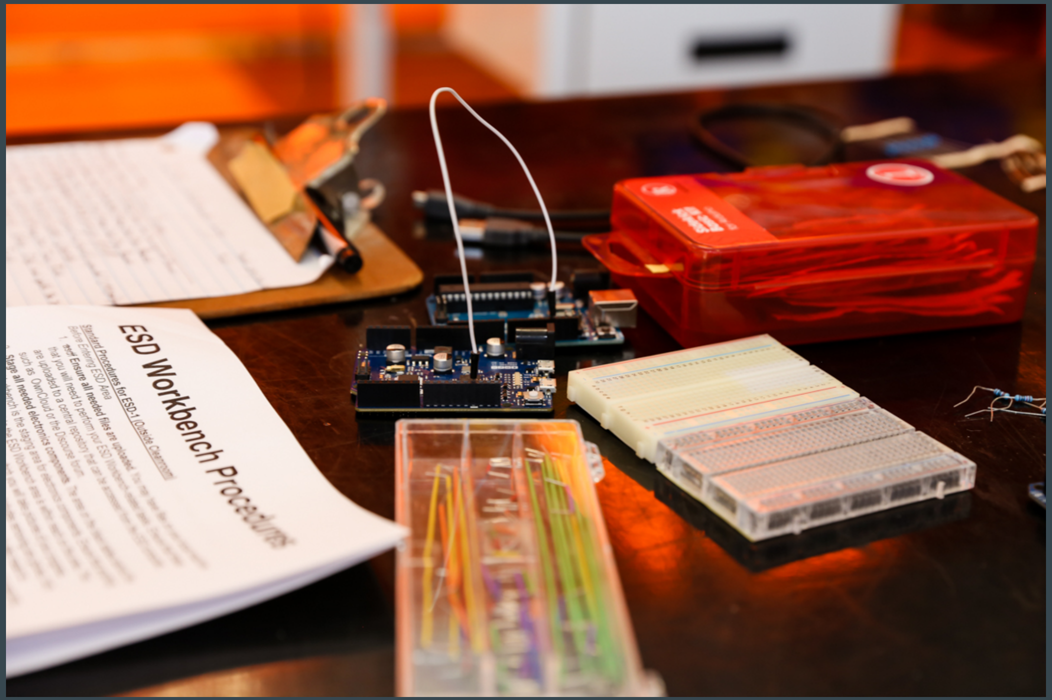
Difficulties at Non Technical School

- Missing a strong engineering mentoring component
- Having to rely heavily on independent research
- Getting departments to work together



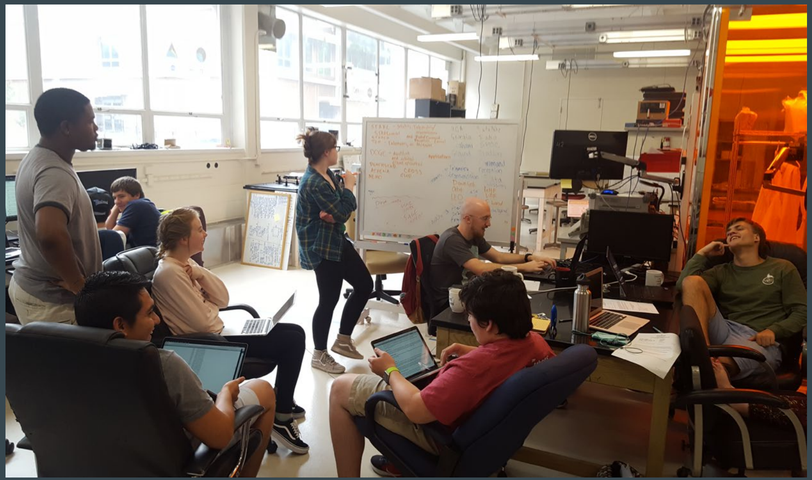
MOCI PDR, January 2017

Students working on deliverables, March 2017

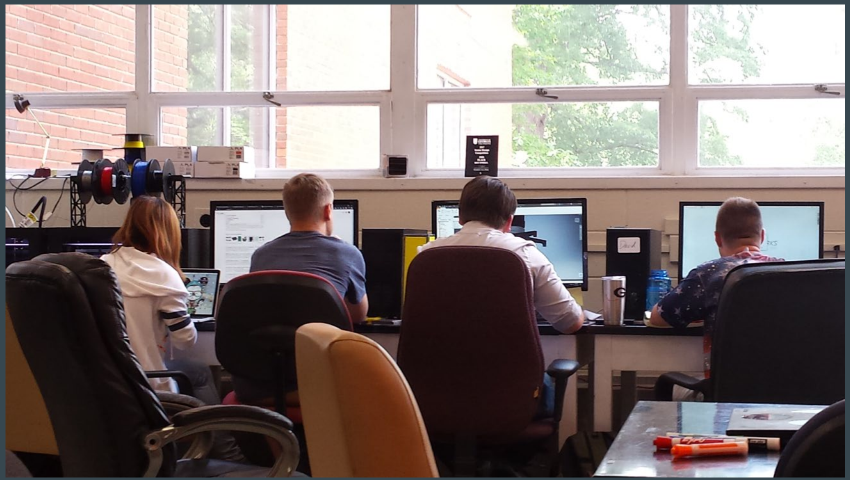


Advantages at a Non Technical School

- Students directly involved in designing/choosing equipment and components
- Entire student team is involved in every aspect of the project including: Proposal writing, reviews, outreach, etc.



Team meetings discussing ConOps

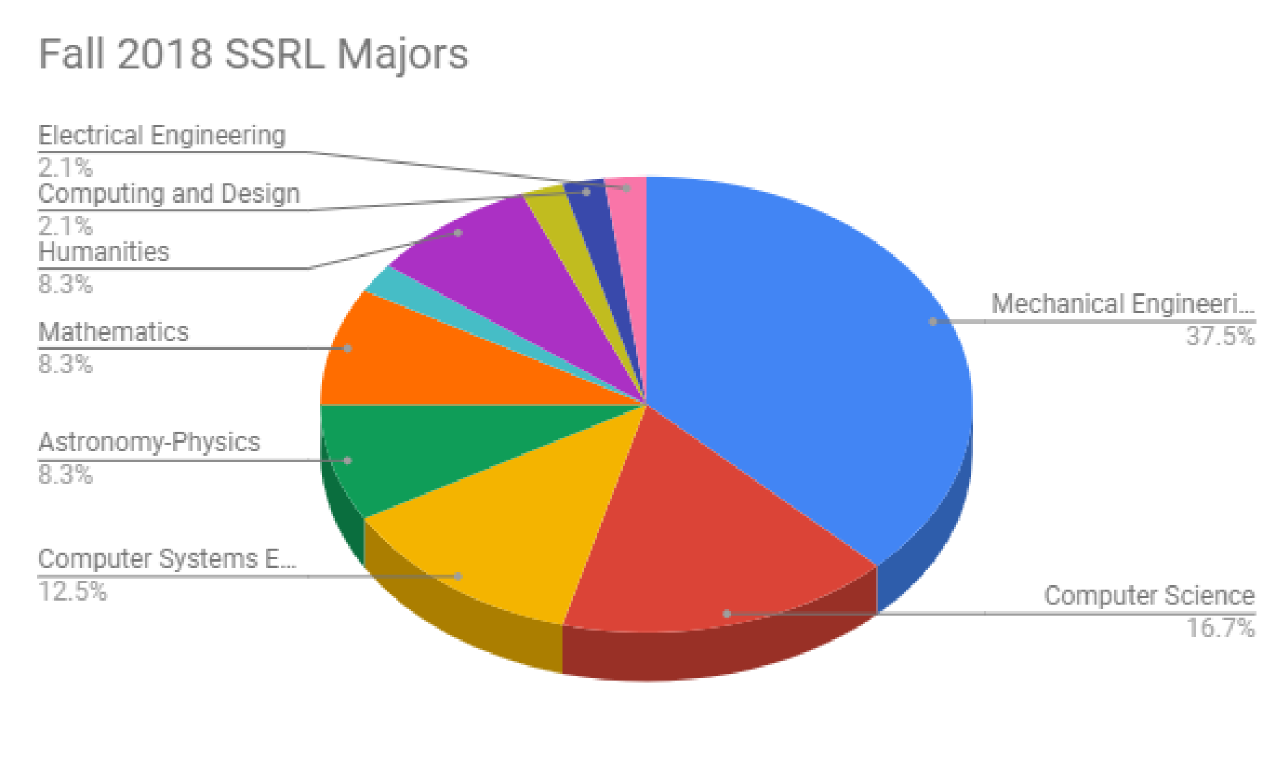


Group mechanical analysis

Students performing acceptance testing

Advantages at a Non Technical School

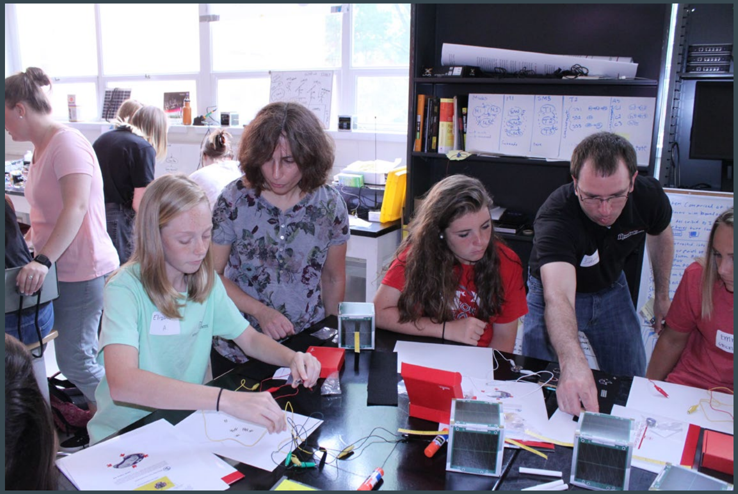
- "Outside the box" approaches to problem solving
- Numerous non-STEM majors involved in space based projects
- Easier to attract highly motivated and intelligent students from all majors not just engineering, less intimidating



Advantages at a Non Technical School

- Students involved in immersive/experiential learning opportunities that cannot be found else where around campus
- Using gained knowledge to create new courses, provide internships for high school students, and create outreach material

SSRL students learning soldering techniques.



Workshop for middle school students to learn about CubeSat's and simple circuits

Statistics

- Over 70 undergraduates have participated in the lab
- 130 applicants per semester

Team Meeting March 2016

Team Meeting December 2016

Team Meeting February 2018

Statistics - Outreach

- 8 high school interns
- Over 250 K-12 students reached this year

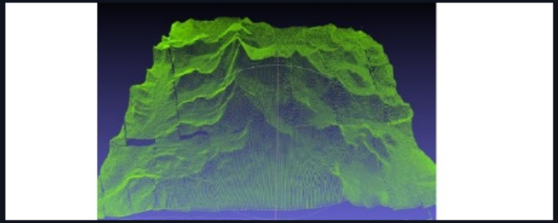
Women in Technology Workshop hosted by SSRL, 2017

NSF LISSIL B community outreach with the help of SSRL, 2017

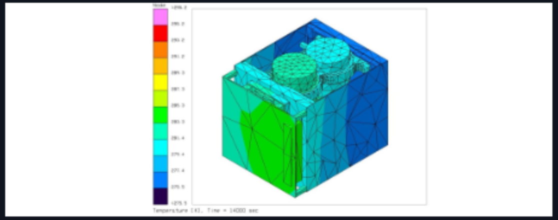
Middle School Students get a lab tour and holding a 3D model of our satellite, 2018

Statistics - Student Development

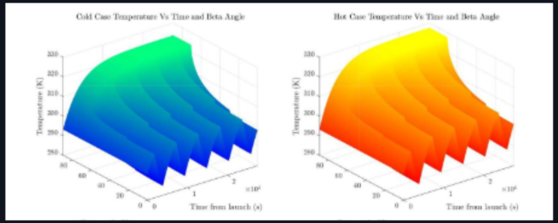
- Posters/Presentations
  - 2016 – 4
  - 2017 – 19
    - 14 unique authors
  - 2018 – 25
    - 26 unique authors



Caleb Adams and David L. Cotten PhD
A Near Real Time Space Based Computer Vision System for Accurate Terrain Mapping
32nd Annual AIAA/USU Conference on Small Satellites, August 2018



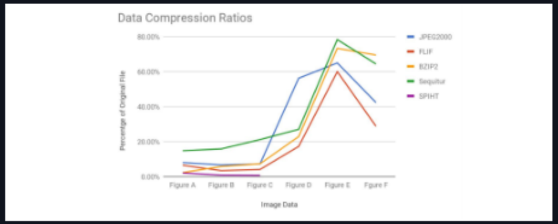
Casper Versteeg and David L. Cotten PhD
Thermal Management and Design of High Heat Small Satellite Payloads
32nd Annual AIAA/USU Conference on Small Satellites, August 2018



Casper Versteeg and David L. Cotten PhD
Preliminary Thermal Analysis of Small Satellites
AIAA Region II Student Conference, April 5th 2018

Nicholas Heavner and David L. Cotten PhD
The Multi-view Onboard Computational Imager (MOCI) Mission: A 3U Sized Supercomputer Floating in Space
2018 NASA Laboratory for Astrophysics Workshop, April 9th, 2018

Megan Arogeti and David L. Cotten PhD
Pseudo Invariant and Coastal Target Feasibility
UGA Center for Undergraduate Research Symposium, April 9th, 2018



Ethan Barnes and David L. Cotten PhD
Compression and Encryption Methods for Small Satellite Communications
UGA Center for Undergraduate Research Symposium, April 9th, 2018

Statistics - Job placement

- Internships
  - 2017 – 4
  - 2018 – 15
  - 2019 – 2
- Jobs
  - 12 jobs aerospace related around the country

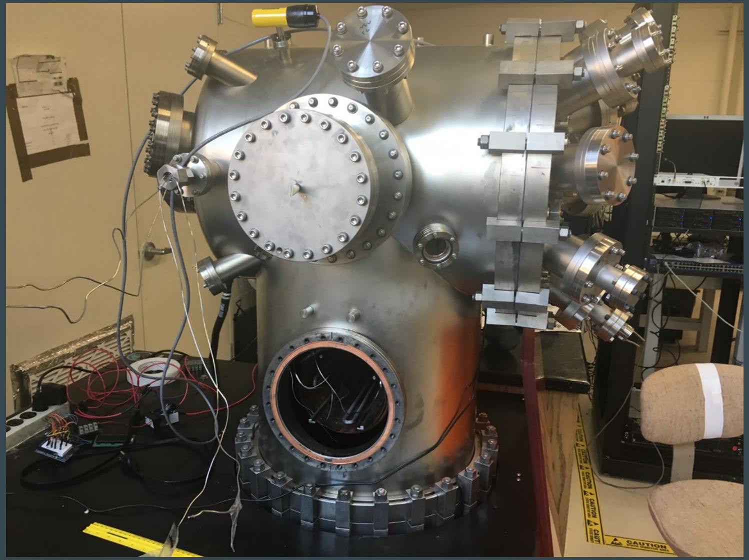
Location of internships in 2017 and 2018

Small Satellite Research Laboratory
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA

Future Goals

- Work more with Georgia industry
  - Try to get students to stay in Georgia
  - Provide new source of employees
  - Help grow the UGA SSRL

Students meeting with UGA Board Members



Nearly complete T vac chamber

Nearly complete Sband, UHF, and VHF ground station

Acknowledgments

NASA

Ames Research Center

AFRL
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

UNP
UNIVERSITY NANOSATELLITE PROGRAM

GEORGIA Space Grant Consortium

UNIVERSITY OF GEORGIA

Georgia®
INNOVATION | AEROSPACE

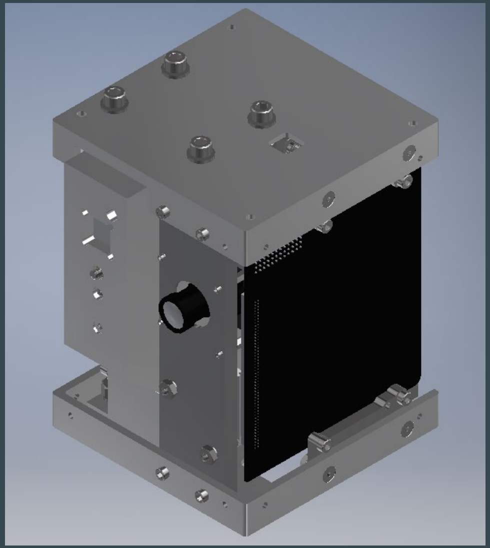
Marine Extension and Georgia Sea Grant
UNIVERSITY OF GEORGIA
Sea Grant

College of Engineering
School of Electrical and Computer Engineering
UNIVERSITY OF GEORGIA

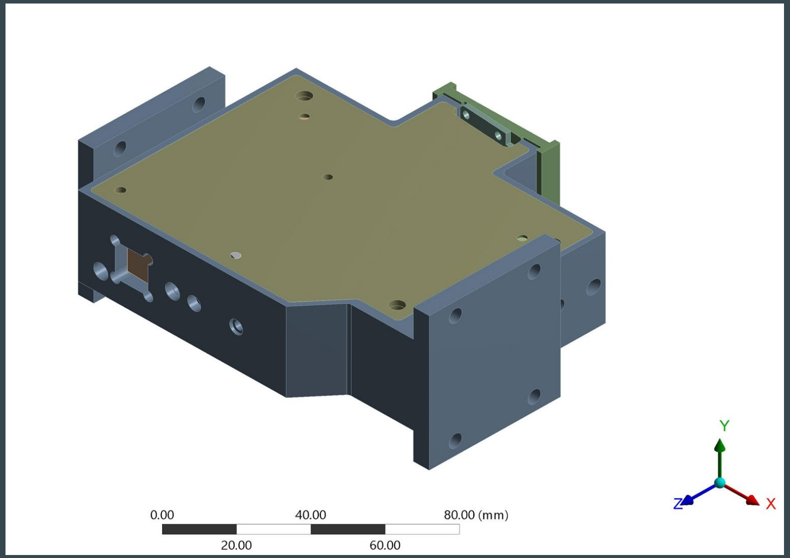
• EXTRAS

SPOC: Payload Housing

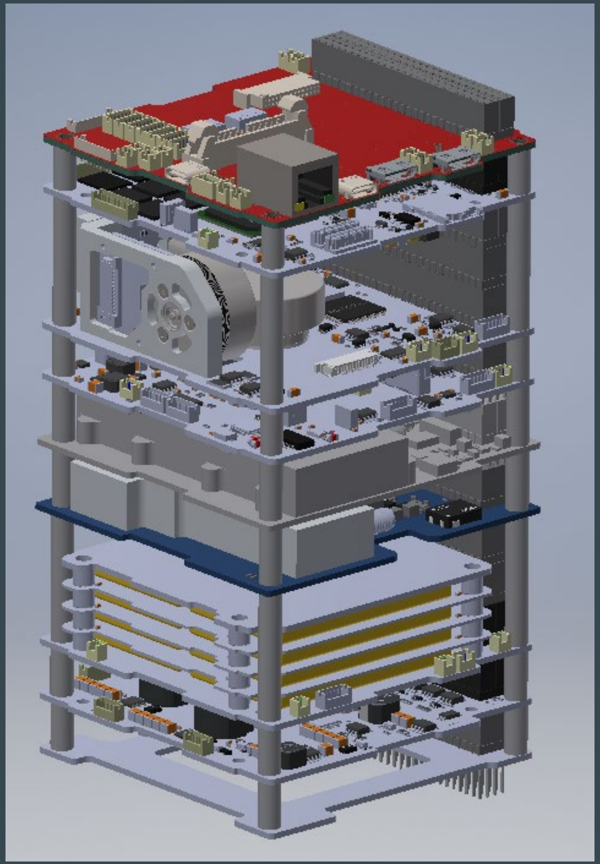
- Three main components:
  - SPOCeye (Camera)
  - Finder scope 1km GSD
  - Electronics/housing



SPOC Payload housing



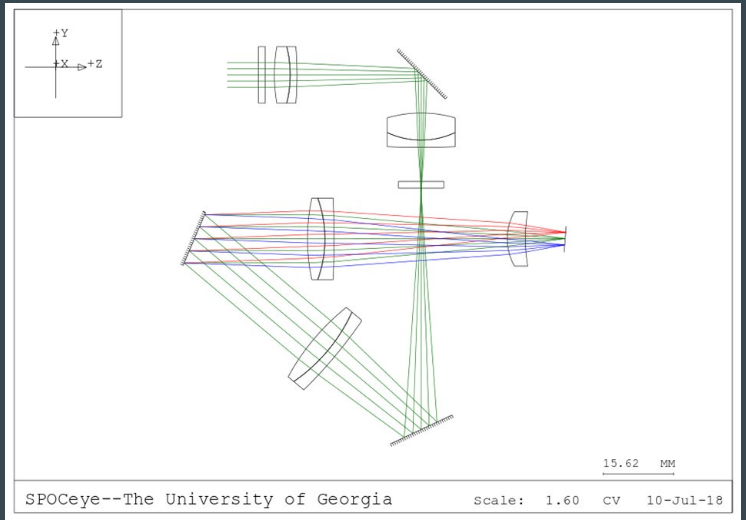
UGA “shoe box” to hold optical design



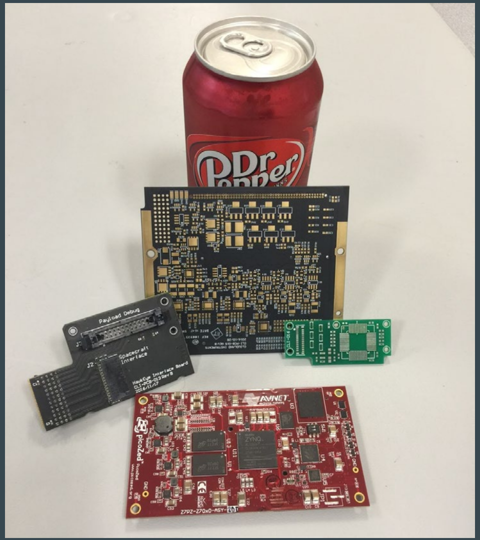
UGA SPOC core avionic stack with SSRL boards

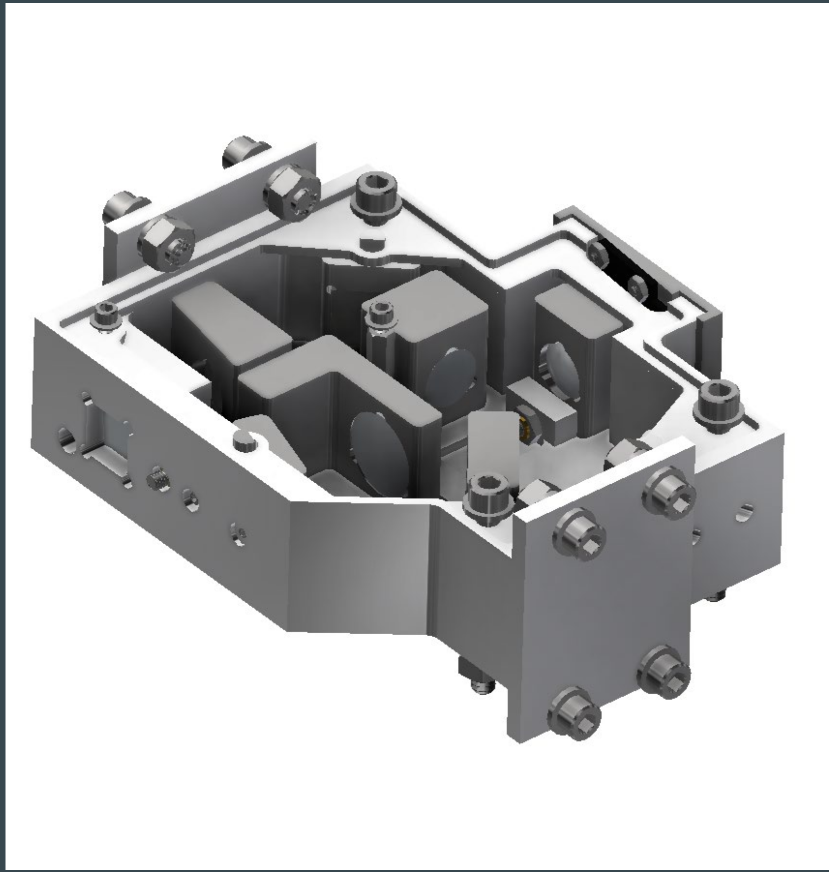
SPOC: Payload Specifics

- Optical layout designed by Cloudland Instruments
  - Focus on coastal wetlands status and near-coastal ocean productivity
  - Diffraction style hyperspectral sensor from 432 nm - 866 nm



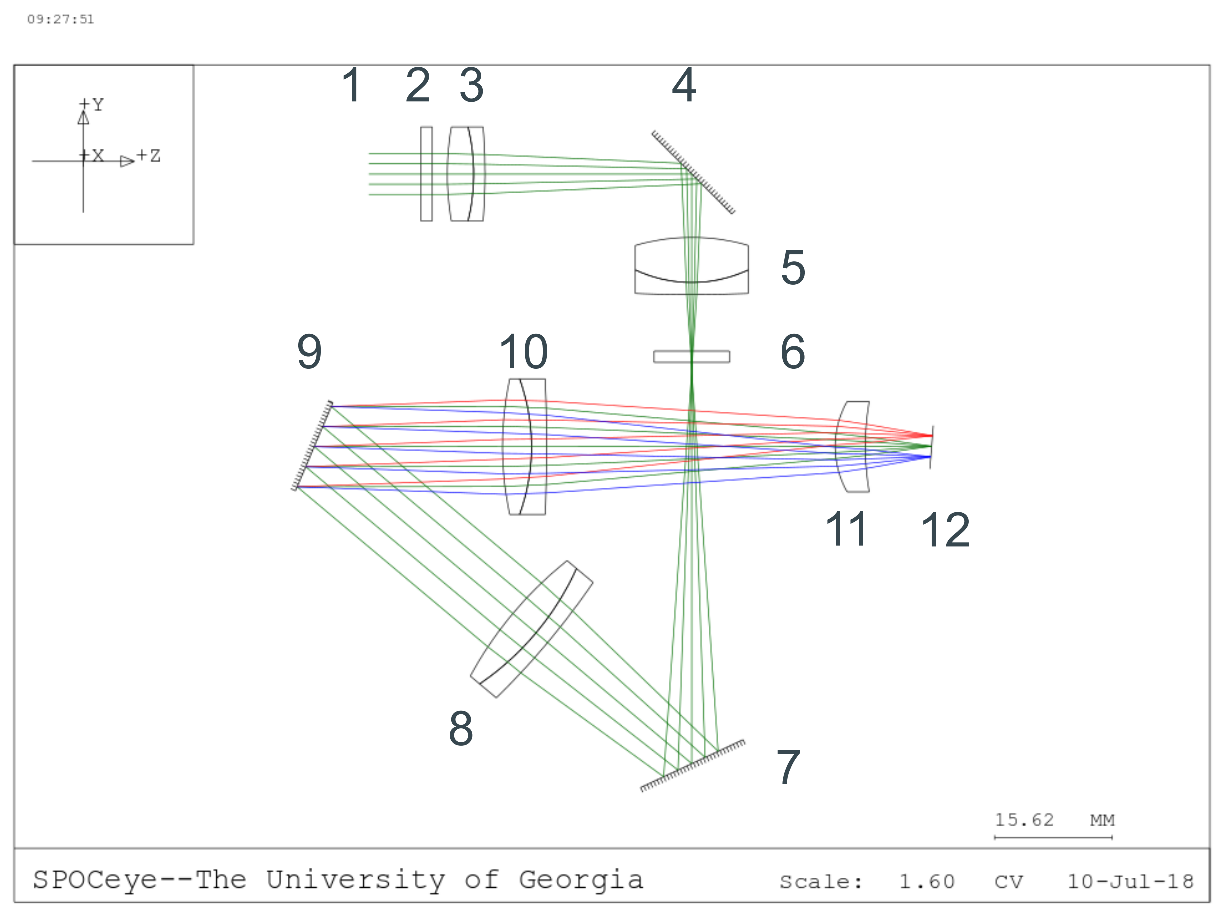
Cloudland Instruments compact optical design


Cloudland Instruments board and sensor for SPOCeye


Optical housing with adjustable lens mounts

SPOC: Payload Optics

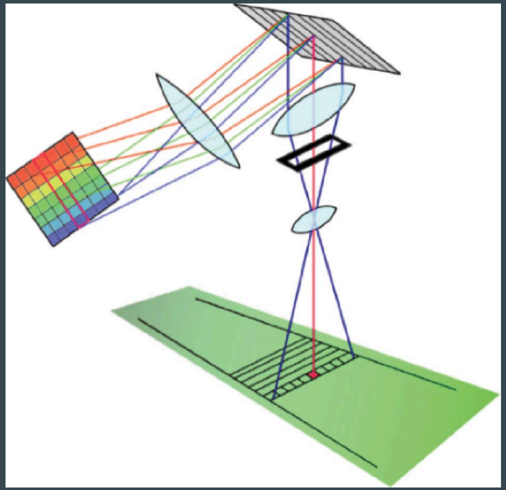
1. Polarization scrambler
2. Longpass filter (10.5 mm diameter)
3. Primary telescopic lens
4. First mirror fold
5. Secondary telescoping lens
6. Custom optical slit
7. Second mirror fold
8. Collimator lens
9. Diffraction grating fold
10. First camera lens
11. Focusing camera lens
12. CMOS Sensor



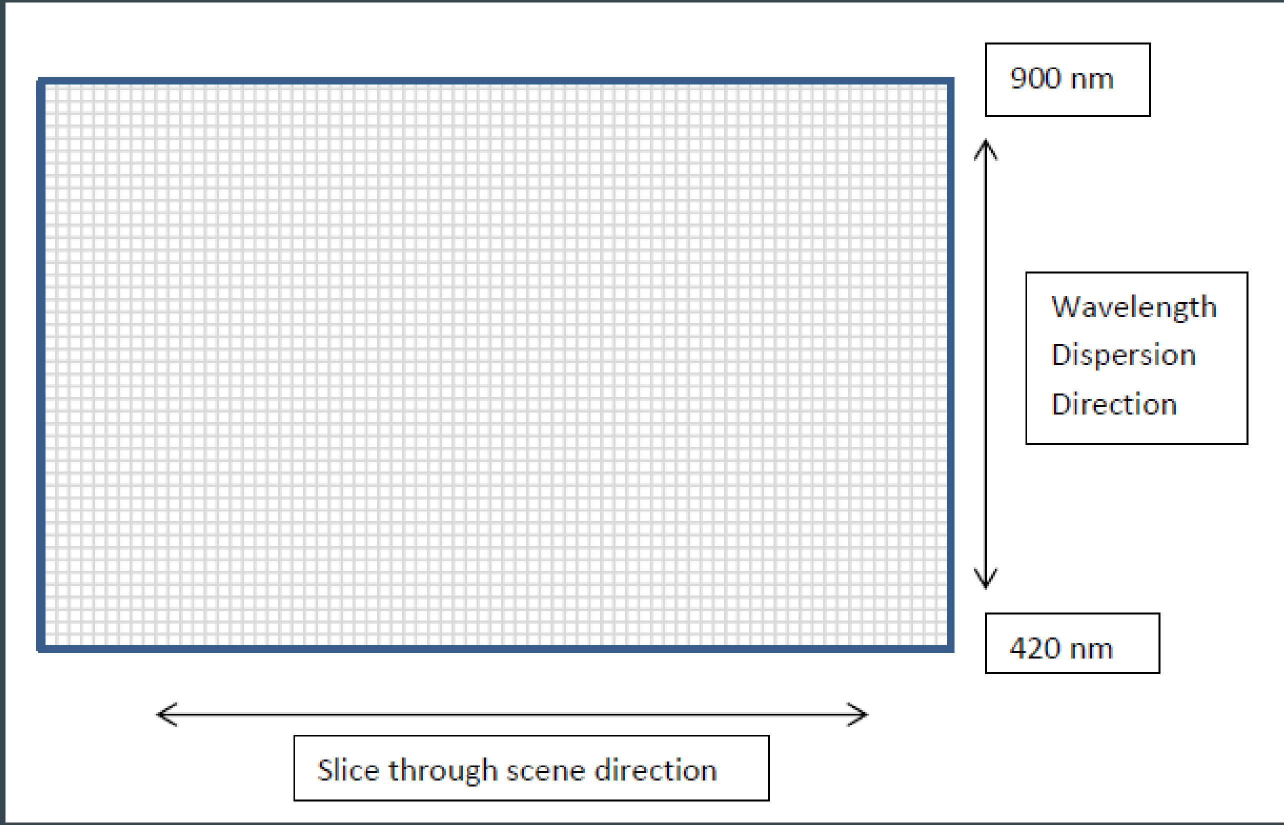
Small Satellite Research Laboratory
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA

SPOC: Sensor

- 752 x 480 pixel CMOS array
- 98km x 130m Capture
- 1.042 nm per pixel
- 130x130 m pixel for 18 ms exposure



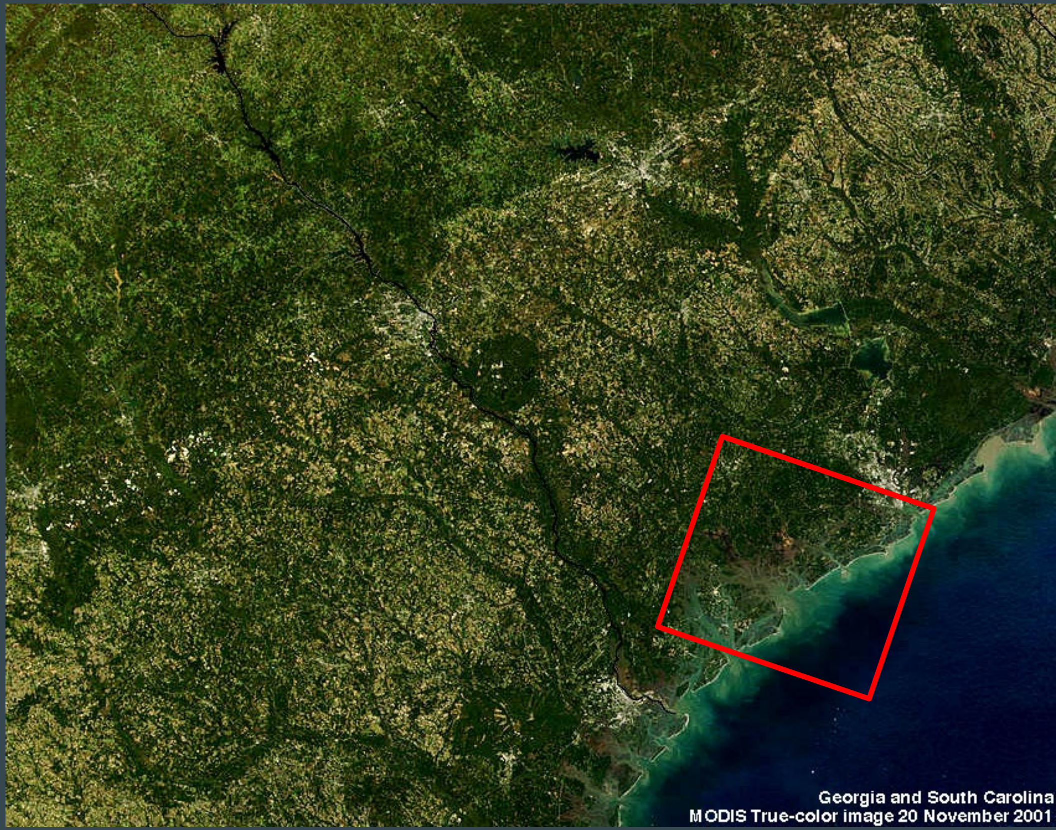
Example of SPOCs push broom scan orientation



CMOS Sensor orientation and pixel configuration

SPOC: Payload Problem

- Hyperspectral Sensor from 433 nm - 866 nm
- 750 frames ~9,500km^2 area
- Data Size?
  - Data downlink rates = 1Mb/s
    - 19 minutes of data for a year of science data 840,606 km^2
- SNR?
  - Is the signal to noise useful at that resolution?



140,000 km2 area, red insert represents ~9,500km2

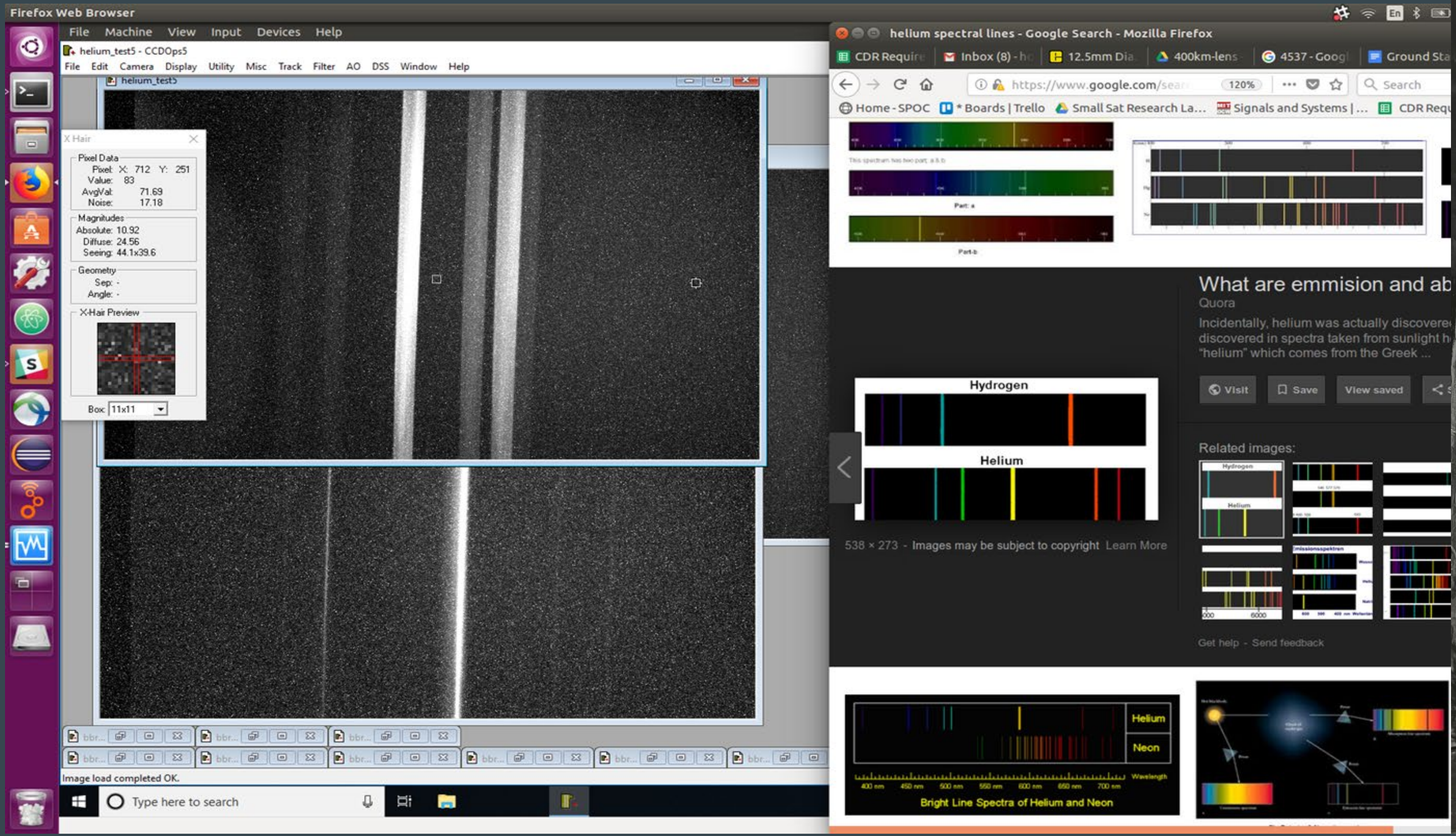
SPOC: Payload Solution

- "Smart" Multi Spectral Imager
  - 16 bands
  - 433 - 866 nm
  - Minimum 130 m spatial and 4nm spectral resolution
- Data rates
  - Area covered increased to 5,500,000km^2 per year
- SNR
  - Increased to >100 for most bands

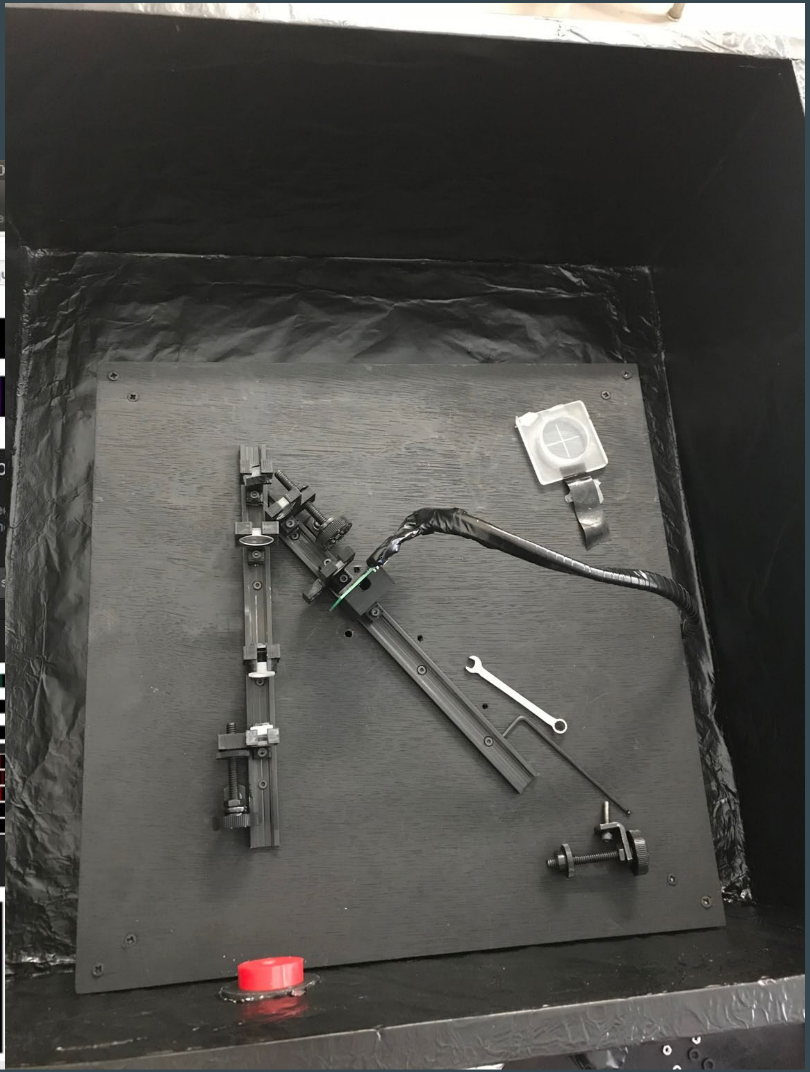
Wavelength (nm)	Bandwidth (nm)	SNR per 20 pixels
443	20	181
490	20	185
510	20	171
555	20	157
670	20	139
750	20	83
865	20	63

Estimated SNR of corresponding SeaWiFS bands

Test Results



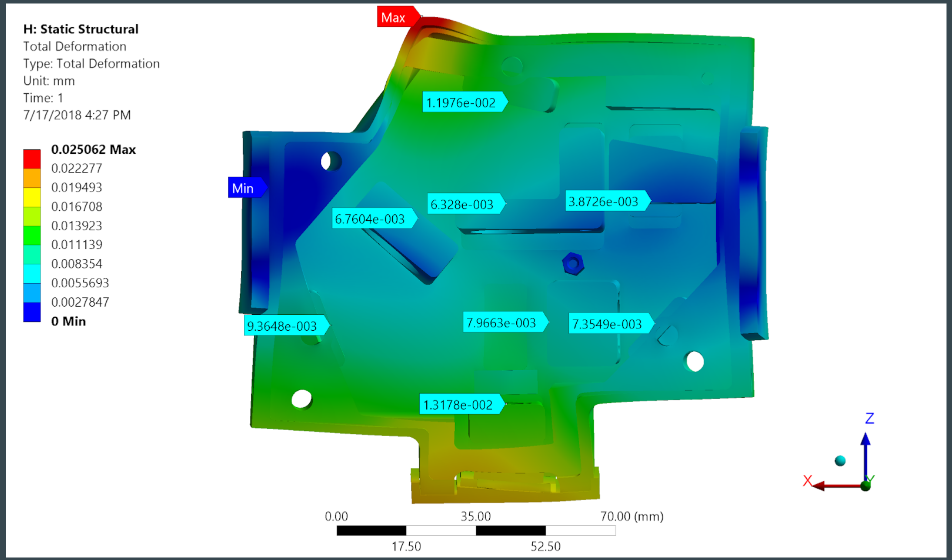
Spectral lines observed with SPOCeye August 2018



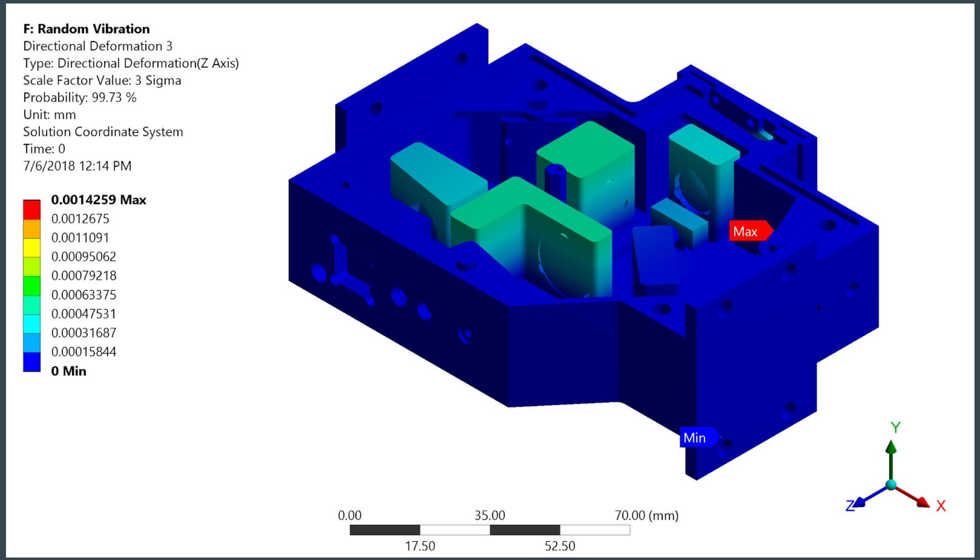
Optical test bench setup

Lab Based Calibration

- Engineering model is nearing completion
- Flight model is currently being machined
- Working with Brandon Zimmerman at NASA Goddard for lab based calibration and characterization
- Lock down mounts once optimal configurations are met



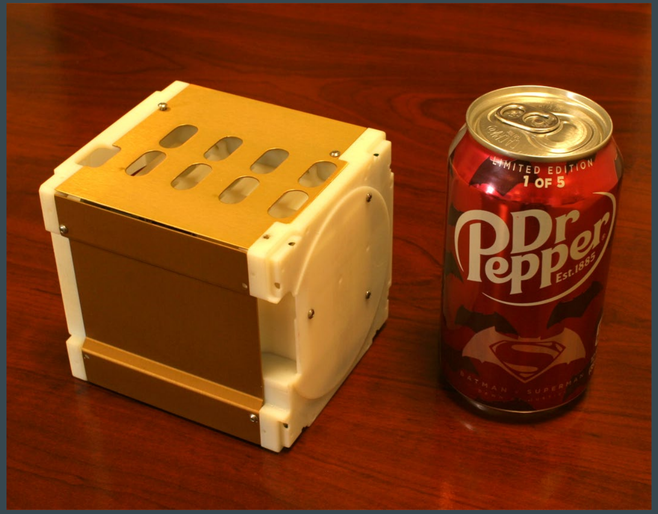
SPOC payload housing thermal simulations



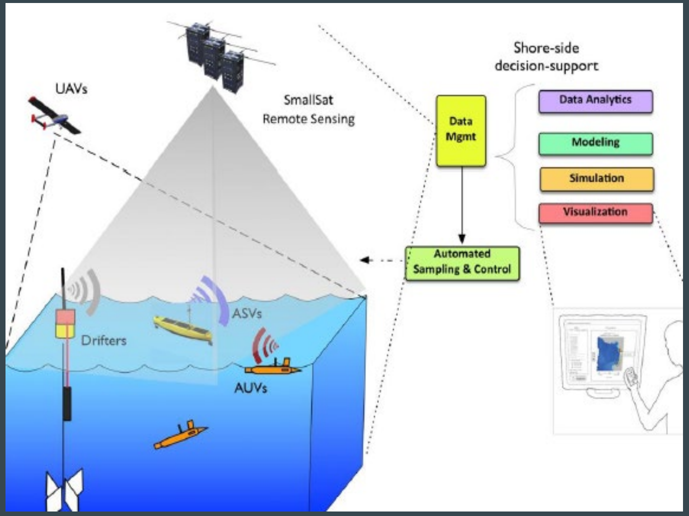
SPOC payload housing vibration simulations

On orbit calibration

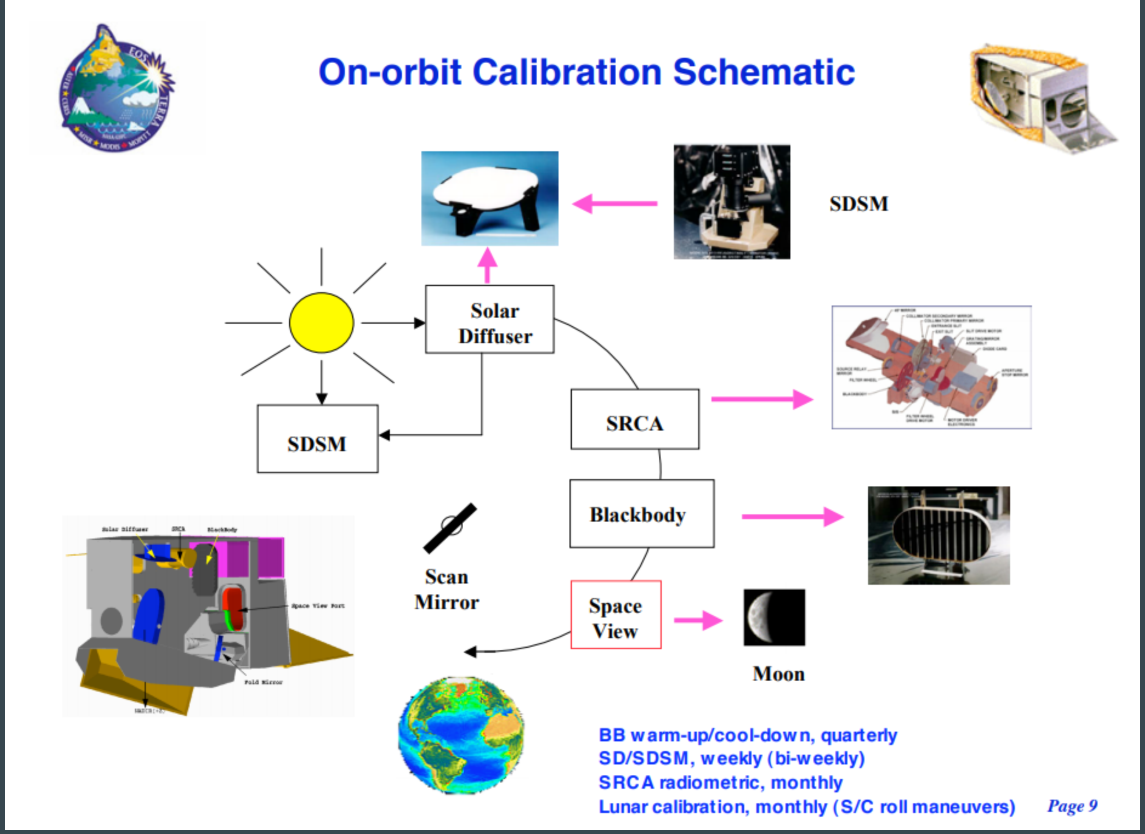
- Pseudo invariant targets
- Vicarious calibration with MODIS, SeaHawk, and Norwegian University of Science and Technology (NTNU) hyperspectral imaging small sat mission



Hawkeye payload for SeaHawk



NTNU Small Sat plattform



MODIS On-orbit Calibration Methodologies (Xiong and Barnes CEOS-IVOS at ESA / ESTEC, Noordwijk, Netherlands (12-14 October, 2004))

SPOC: Data

- Primary targets
  - Sapelo Island LTER
  - Grand Bay NERR
- Intense field campaigns synced with over pass times

MONITORING-PAM chlorophyll fluorometer at Grand Bay site

Bayou Sauvage research site

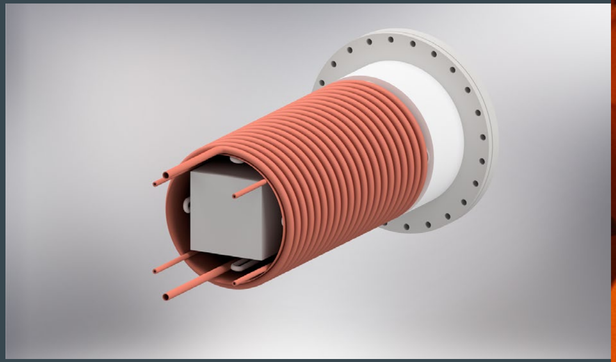
Sapelo Island LTER eddy covariance tower

Small Satellite Research Laboratory
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA

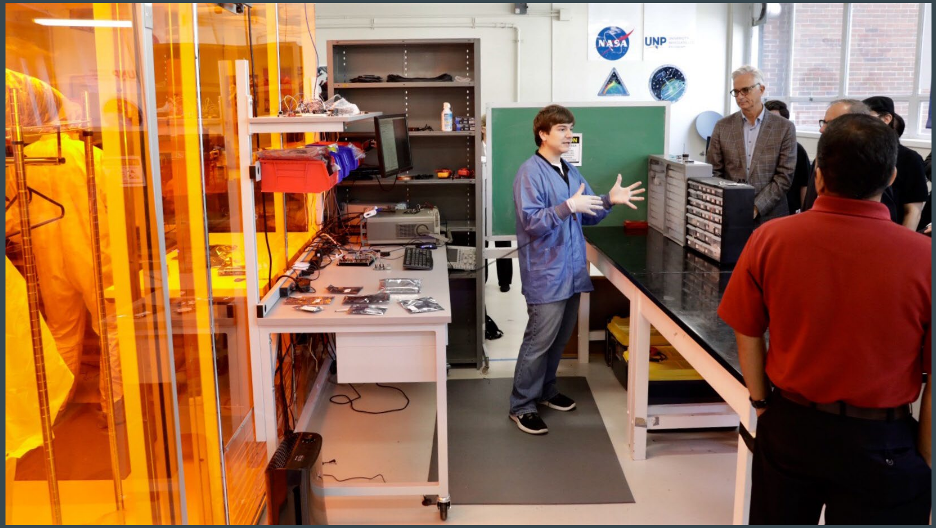
SSRL Facilities

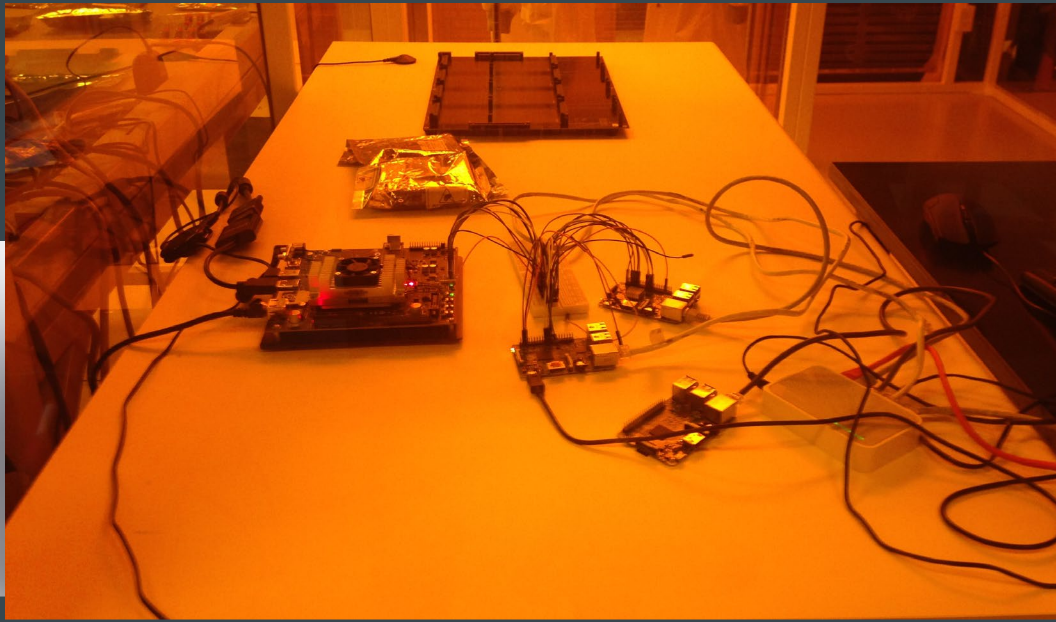
- Clean room
  - ISO 6 and 7
- T-Vac Chamber
  - 10^{-6} Torr
  - -100 K – 150 K
- Ground Station

T-Vac Chamber from an old MBE



Thermal shroud for CubeSats

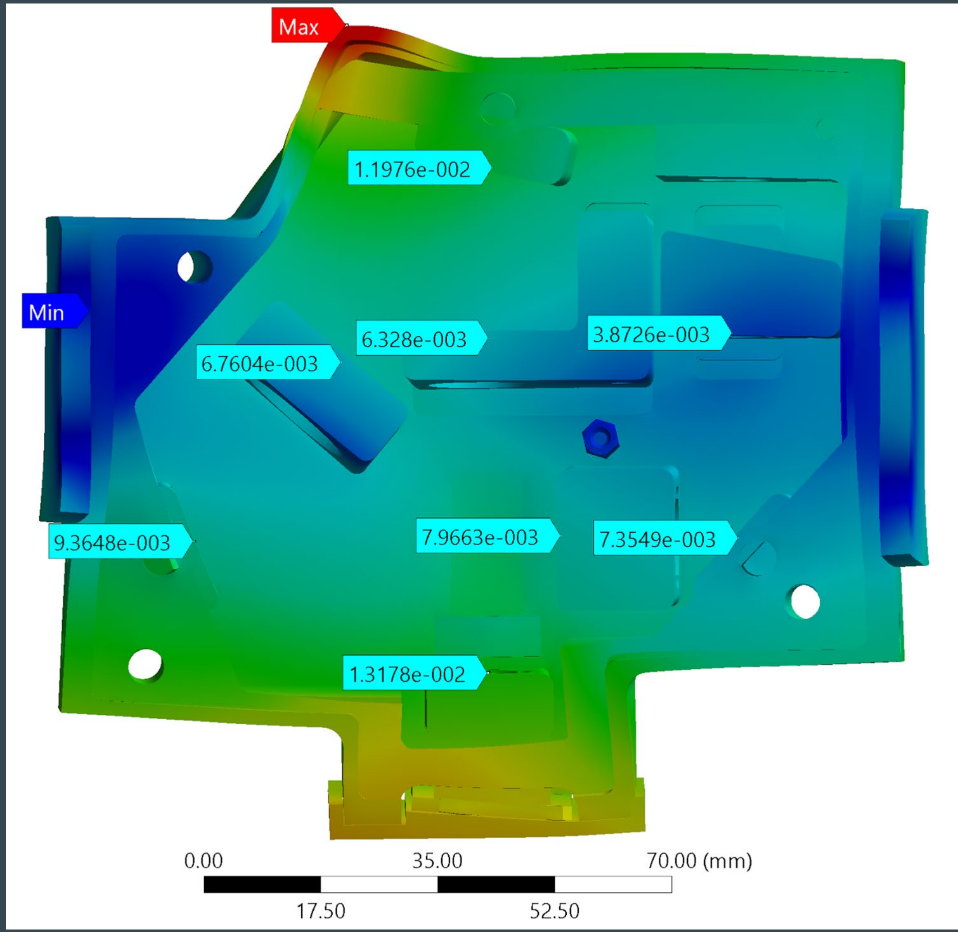




Engineering level components undergoing testing

Payload Thermal Simulation

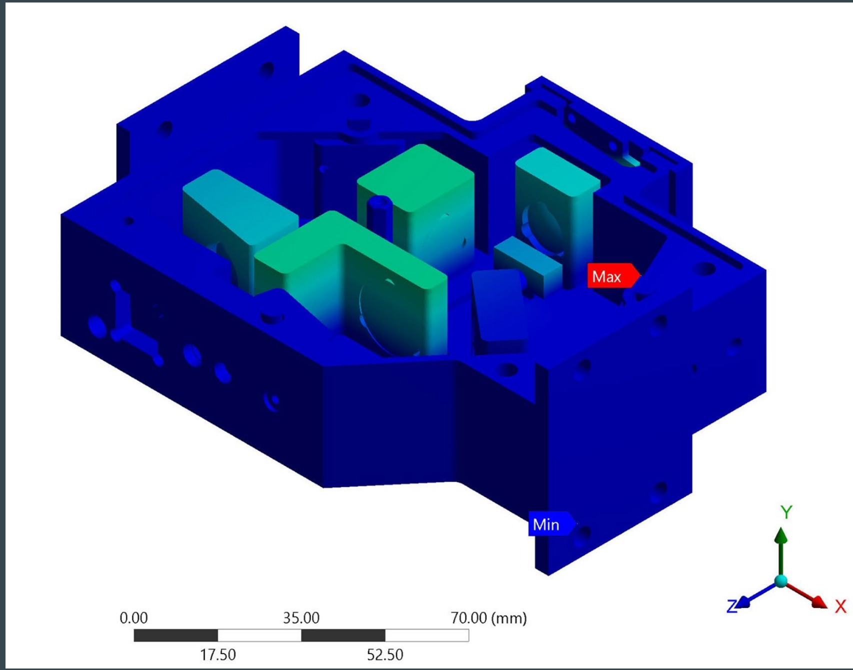
- ANSYS 18.2 Thermal Simulation of Camera Assembly to determine relative displacement and total stress of optics in a heat soaked environment
  - -10º C - 30º C
- Calculated total displacement of optics subassemblies to ensure minimal movement
- Results present possible movement of optic focal points while in orbit



Small Satellite Research Laboratory
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA

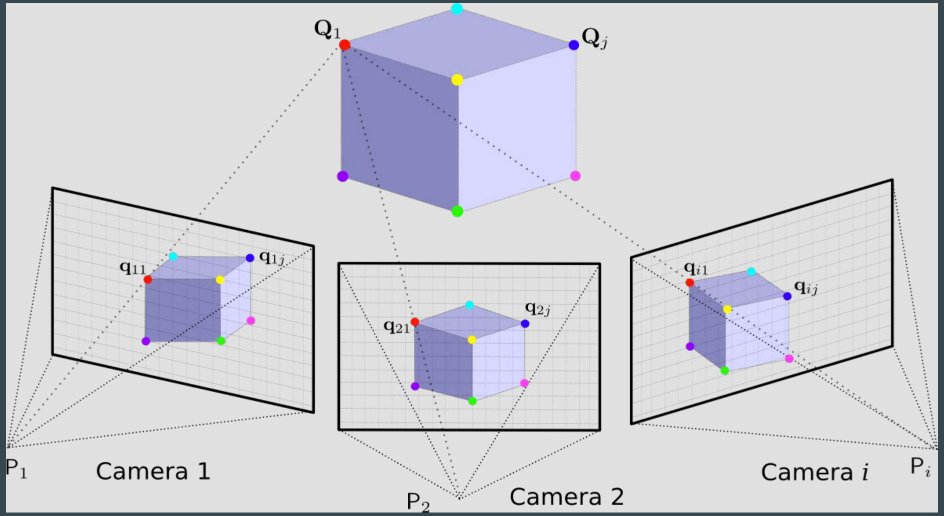
Payload Structural Simulation

- Modal analysis, inertial loading, response spectrum analysis, and a random vibration analysis.
- Analysis executed on Camera Assembly and individual SPOCeye subassemblies
- Camera Assembly first mode: 2022.0 Hz
- Inertial acceleration of 42Gs, or 412.02 m s^{-2}
    - Calculated FOS of ~32.905 from results
- Response Spectrum maximum displacement of 0.52341 mm
- Random Vibration maximum deformation is 9.0161E-3 mm with a statistical probability of 99.73%.
    - Occurs on Camera Assembly in +YY orientation



MOCI: Structure from Motion

- Input is a set of 2D images, output is a 3D structure
- Generates a point cloud from multiple images from multiple angles
- Sort of like saying "cloud computing" or "Big Data", it's really just a buzz word with lots of complicated parts



Small Satellite Research Laboratory
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA
Credit: Caleb Adams

MOCI: Simulating SfM

```
./main.py config.json
```

- Takes in the .json as an arg
- Runs through workflow
    - Workflow can be stopped at discrete steps
- Outputs:
    - DEM/DSM
    - Feature Set
    - Dense/Sparse Point Cloud
    - GeoTiff (Raster)

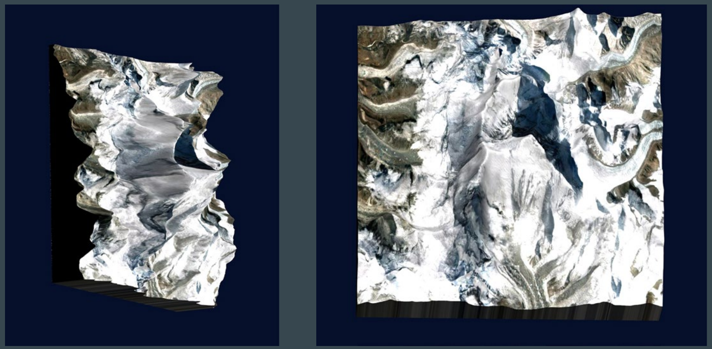
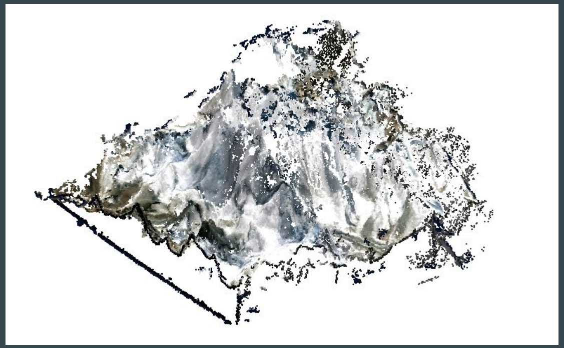
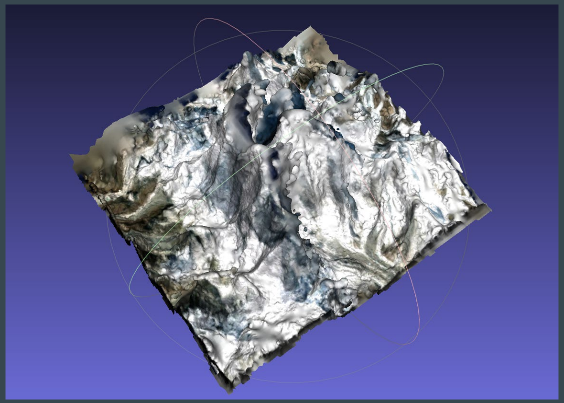


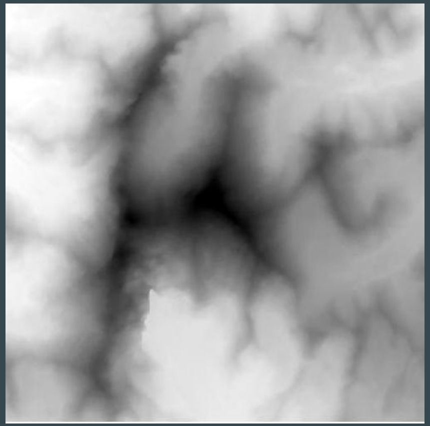
image acquisition



point cloud generation



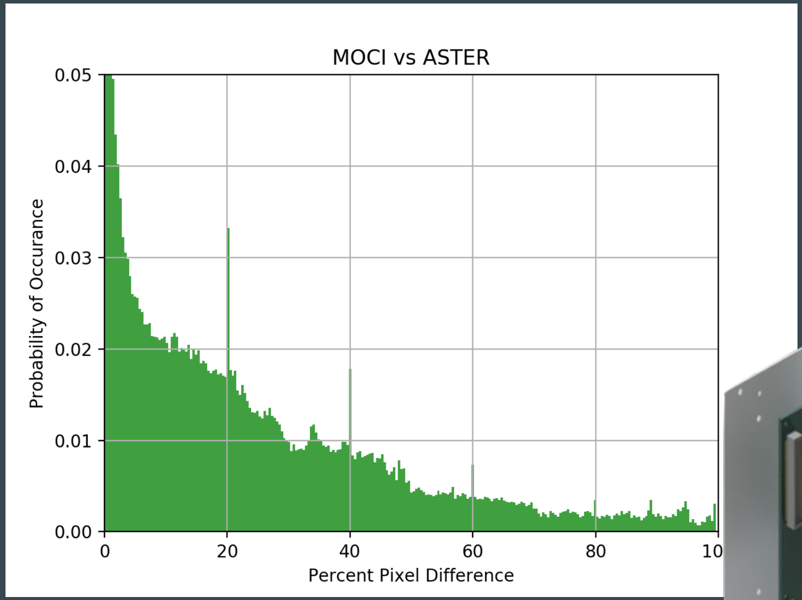
surface reconstruction



GeoTiff Generation (Rasterization)

Current Results

- After 500+ tests…
- Testing with a custom 6.4 m GSD camera
- Comparing DSM/DEM's with ASTER data (15m GSD data)
- Allows for better reconstructions!
- Simulations defined, finalized, confirmed our hardware!
  - Custom 6.4m GSD camera
  - Integrated FPGA (Opal Kelly XEM7310)
  - Integrated GPU (TX2)

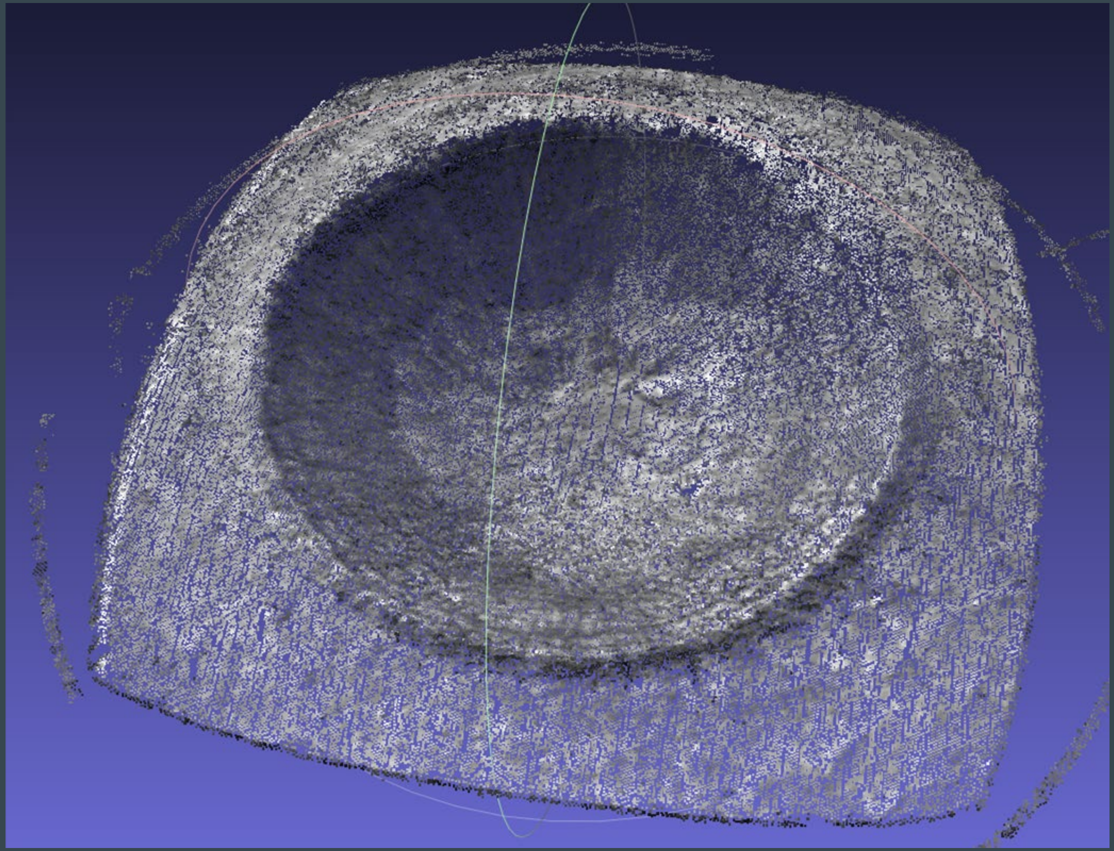


MOCI's accuracy relative to ASTER data

The MOCI 1U bionicle payload

MOCI Optimization & Future Plans

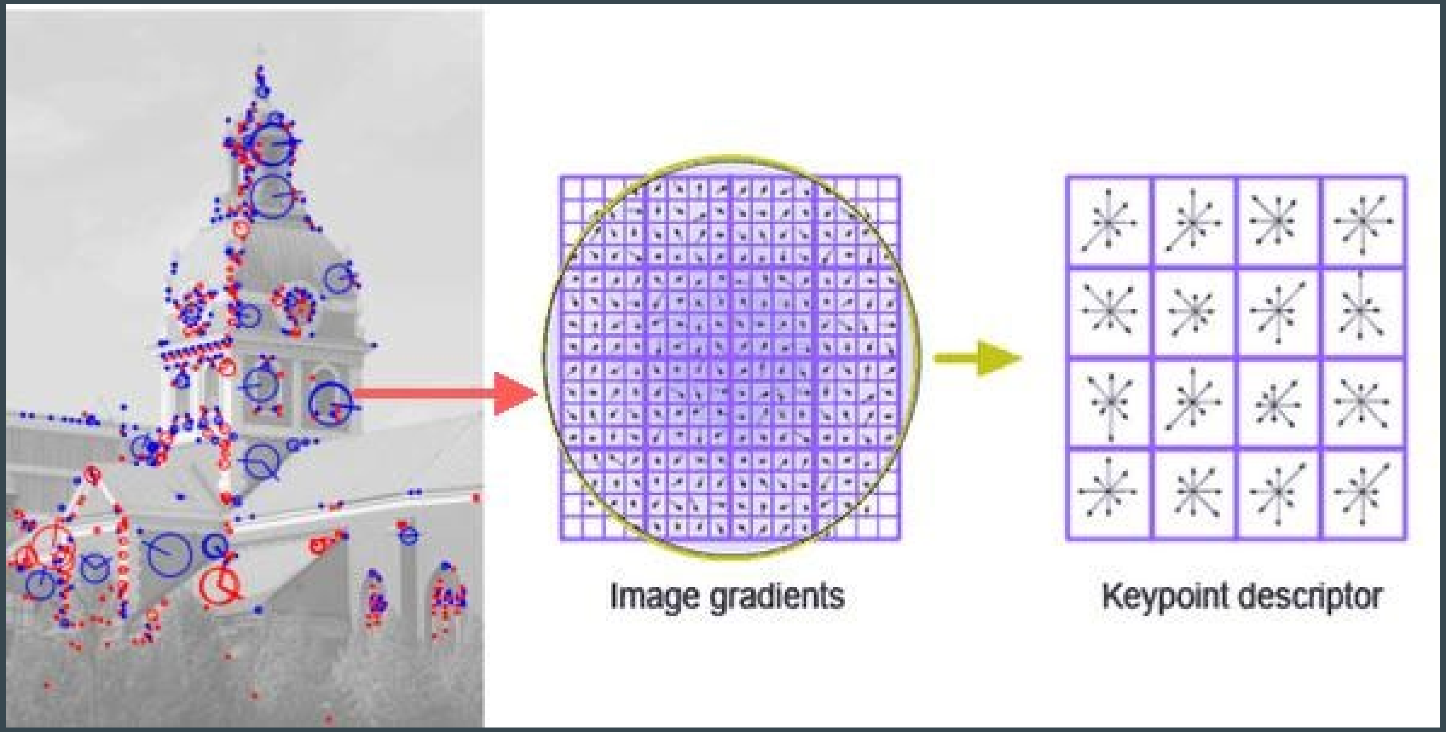
- Now that we have proven feasibility…
- Use constrained geometry advantageously
- AI & neural nets to get better workflows
- Can be used on other satellites
  - Onboard image analysis
  - Autonomous space operations



Dense point cloud of Lenne crater on the moon, using MOCI & simulations

Simulating SfM - Feature Extraction

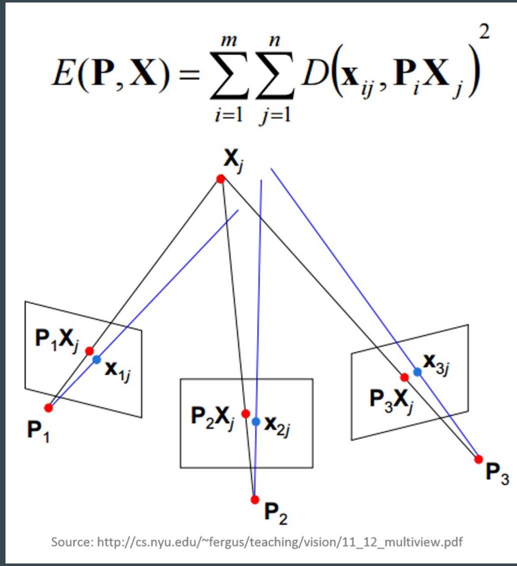
- Scale Invariant Feature Transform (SIFT) Algorithm
  - Implemented on an FPGA
  - Also CUDA implementation
- Features then need to be matched (we're glossing over that step here, may be added in the future)



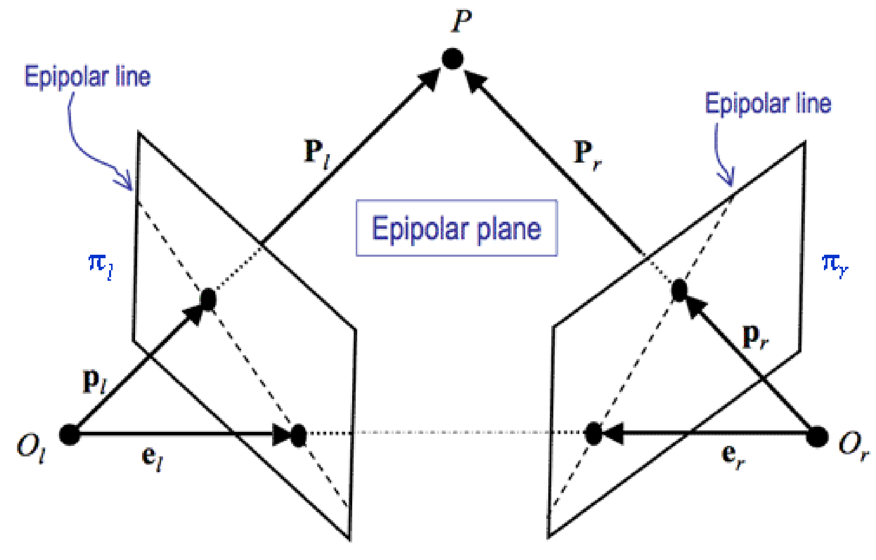
http://www.codeproject.com/KB/recipes/619039/SIFT.JPG

Simulating SfM - Bundle Adjustment

- Addition of the Epipolar Constraint may remove Bundle Adjustment
  - Camera position is known
  - Center of rotation is known
- Given the set of image coordinates xji find the set of camera matrices, Pi, and the points Xj such that PiXj = xji This is known as project reconstruction
- With known Pi, the epipolar constraint could be used to make a sparse point cloud generation faster than a pure bundle adjustment approach



bundle adjustment

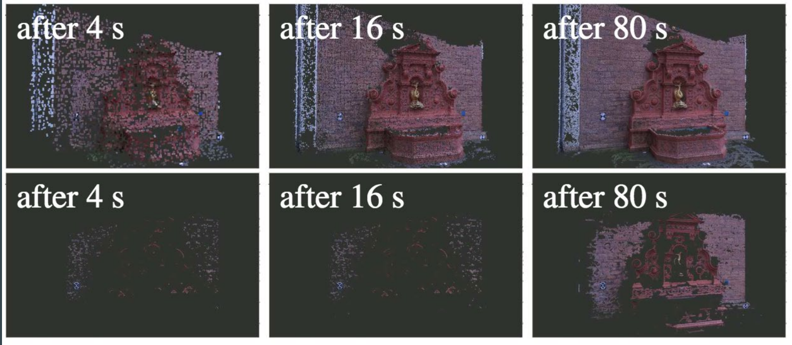


Epipolar constrained reconstruction
https://www.cs.auckland.ac.nz

Simulating SfM - Point Cloud Reconstruction

- Patch-based Multi-View Stereo (pmvs)
- Hierarchical Progressive Multi-View Stereo (hpmvs)
- Runs a dense reconstruction from the sparse reconstruction
  - after a sparse bundle adjustment
  - after an epipolar constrained reconstruction

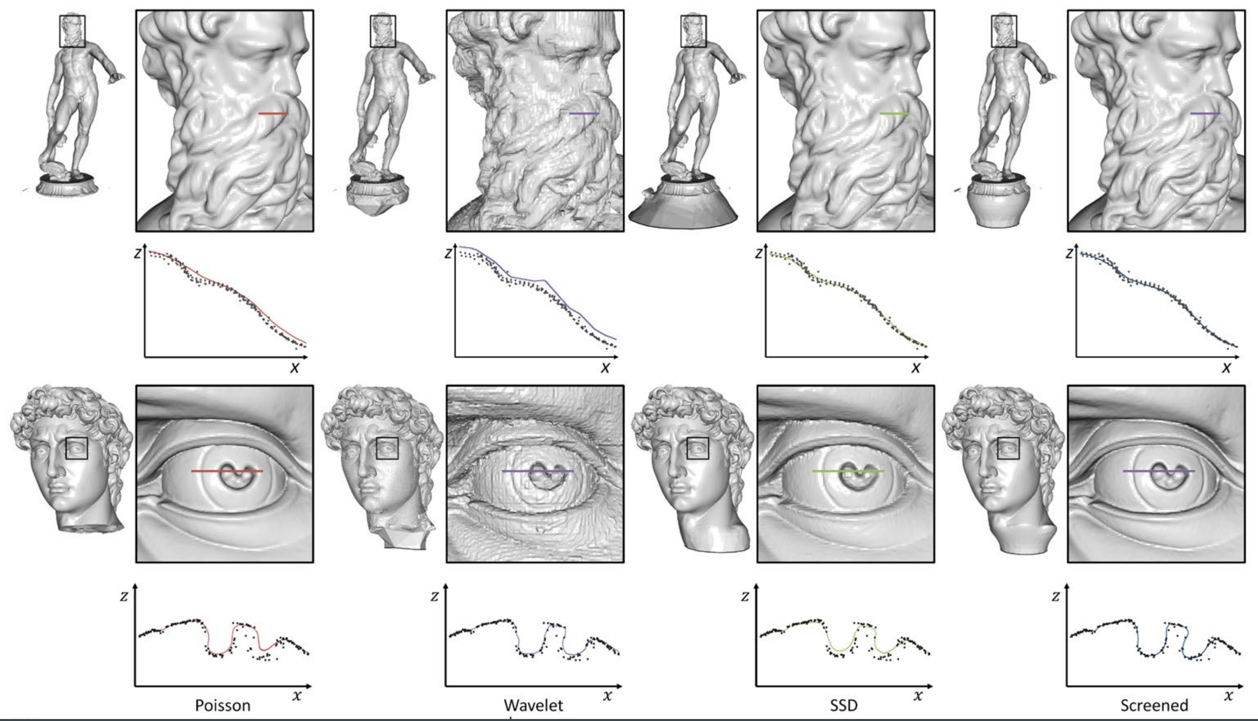
pmvs - https://www.di.ens.fr/pmvs/pmvs-1/images/overflow.jpg



hpmvs - https://www.cv-foundation.org/openaccess/content_cvpr_2016/papers/Locher_Progressive_Prioritized_Multi-View_CVPR_2016_paper.pdf

Simulating SfM - Surface Reconstruction

- Given a set of oriented points, build a 3D model from those points to approximate the original model
- Screened Poisson Surface Reconstruction
- Texturing post-reconstruction

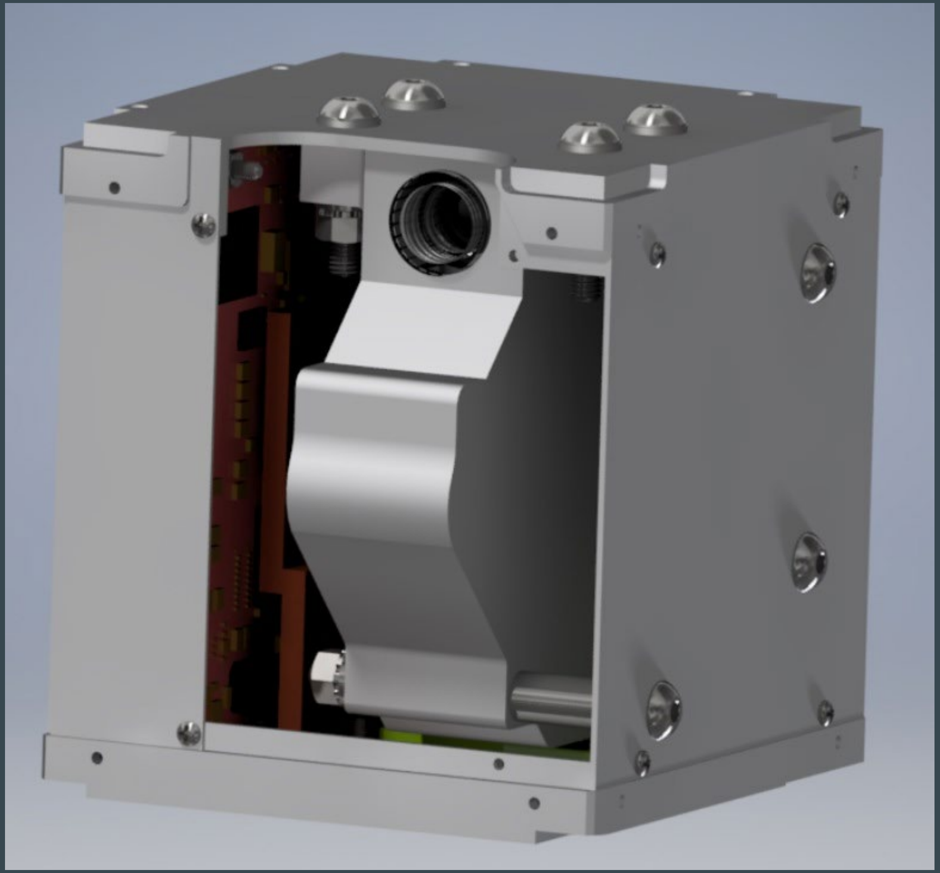


http://www.cs.jhu.edu/~misha/MyPapers/ToG13.pdf

Satisfaction of Mission Requirements

Still in the building and testing phases but have thus far been successful in:

- Optics Design
    - 131 meter ground resolution
    - Images acquired will be between 400 and 850nm
- Mechanical Design
    - Approx. mass (+10% contingency): 0.713 kg
    - 105mm x 96 mm x 97 mm
    - Three adjustable lenses and diffraction grating for ground calibration



Future Goals

- Expand missions beyond Earth Observations
  - Interferometry
  - Planetary atmospheres
- Design missions to accompany traditional satellites