COE CST Eleventh Annual Technical Meeting

CubeSat Cluster Deployment Tracking

Task 367-CU
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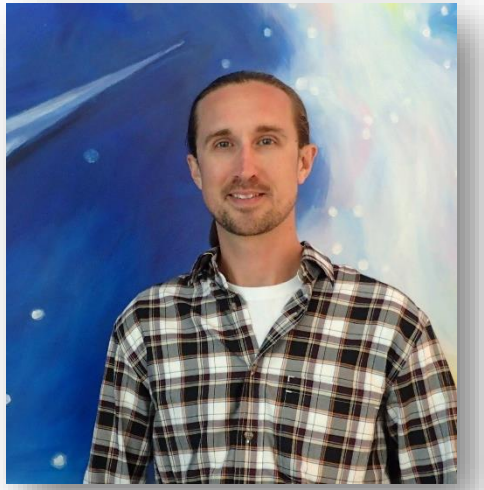
Students: Laura Davies
Shaylah Mutschler
John Gaebler, PhD

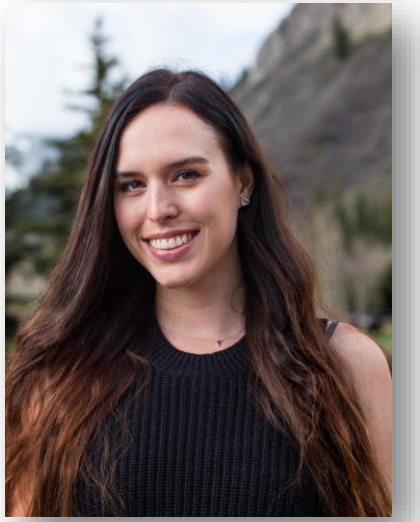
Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

- People
  - Principal Investigator – Dr. Penina Axelrad
  - Students – Laura Davies, Shaylah Mutschler
    John Gaebler (PhD 2020) – currently Research Aerospace Engineer, Air Force Maui Optical & Supercomputing Site
- Organizations: University of Colorado Boulder





Task Description

- Clustered CubeSat deployments, where dozens of CubeSats are released over a short time span, represent a relatively new and challenging problem for detection, tracking, and space traffic management.

- Space traffic surveillance and management requires timely, cost effective, and robust approaches to accurately tracking, tagging, and predicting the orbits of large groups of CubeSat class satellites.

- Our goal is to develop and demonstrate resilient strategies for the deployment, detection, and tracking of multiple CubeSats, that leverage, but are not entirely reliant on compliance or cooperation by CubeSat developers/operators.

Schedule

- **Completed prior projects**
  - Modeling of Planet 88 CubeSat deployment on PSLV-37
  - Implementation and comparison of filtering methods
  - Track initiation and identity management
  - Prototype deployer system for in-situ CubeSat observation
- **Current & Planned**
  - Recommend deployment strategies to aid tracking & identification
  - Estimate orbits using actual ground radar data*
  - Characterize data quality and realistic cross-tagging conditions*

Goals

- Maximize accuracy of orbit knowledge of each deployed CubeSat.
- Minimize time to correctly identify each CubeSat.
- Enable prediction of conjunctions with longest possible lead time.

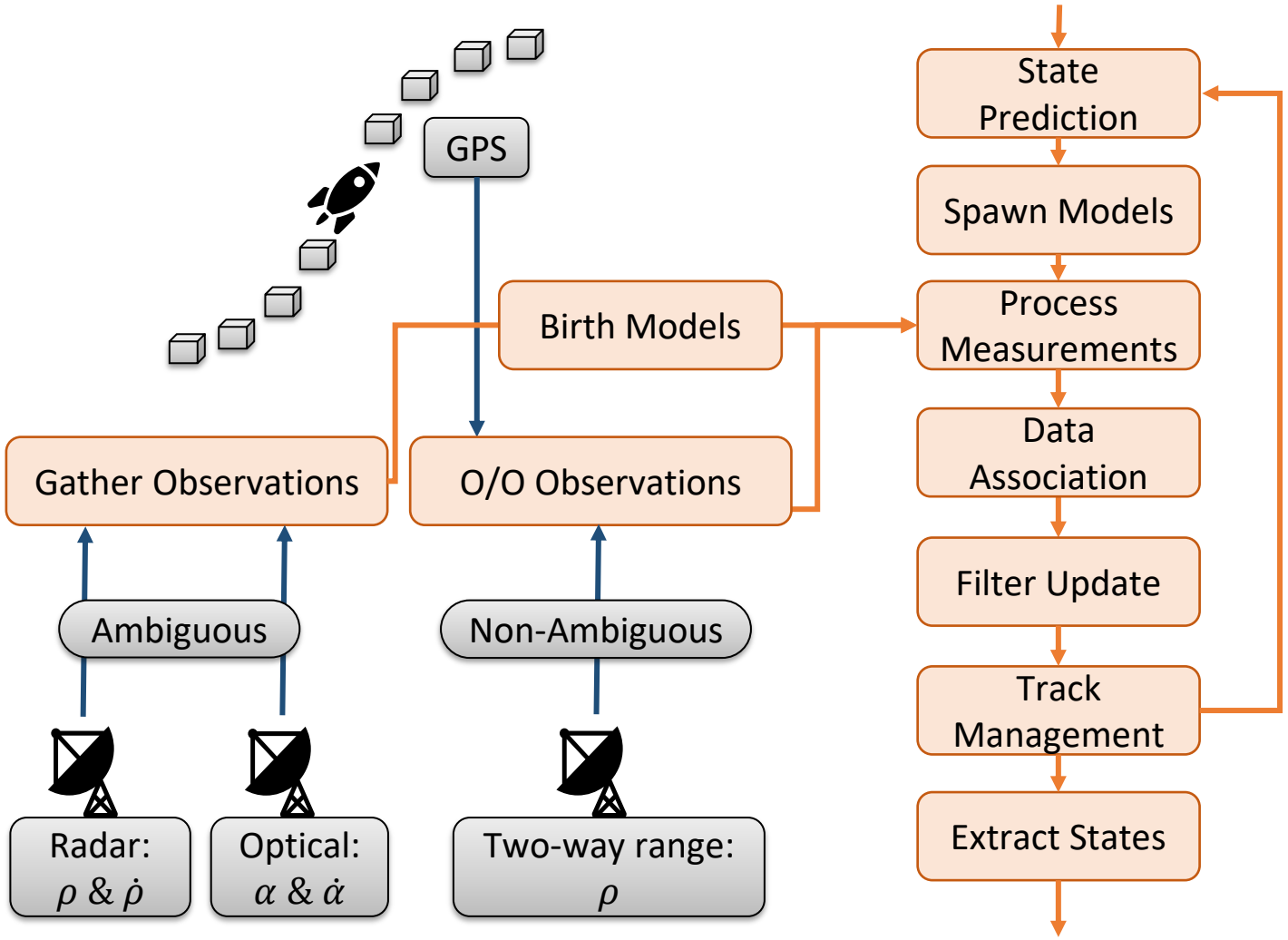
Relevance to Commercial Space Industry

- Reduced time to establish orbits/TLE's for CubeSats allows operators to more quickly begin their operational mission.
- Improved situational awareness enables monitoring agency to more quickly and precisely address anomalies.
- Improved orbit knowledge minimizes unnecessary collision avoidance maneuvers

Real World Challenge

- Planet Labs Flock-III Deployment
  - PSLV-C37 launched in Feb 2017
  - 88 CubeSats + 1 Deployer
- CubeSat initial conditions from Planet Labs
  - Deployer rotating
  - Two batches ejected in opposite directions every ~5 sec
  - Third batch ejected in cross-track

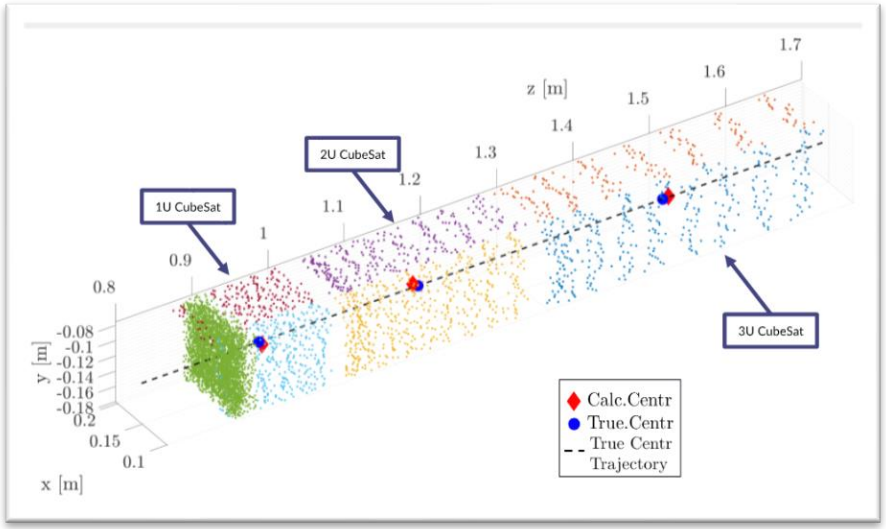
Necessary Components of Tracking Strategy

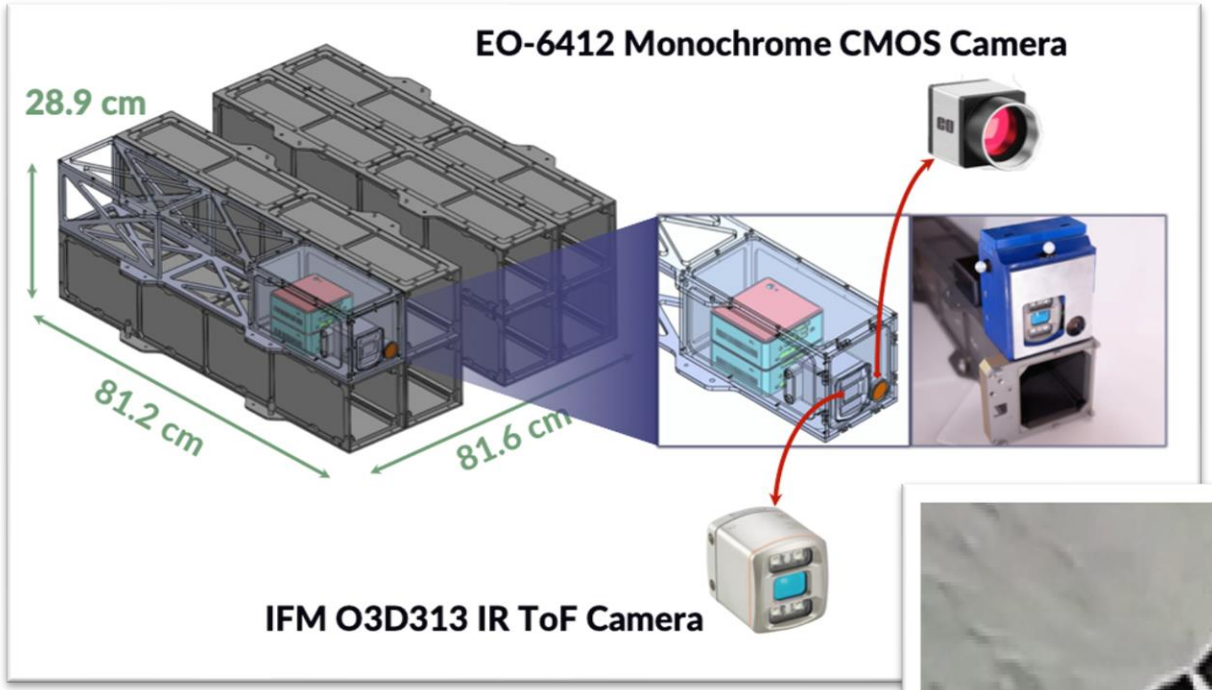


John Gaebler

In-situ Measurements

- Use images/observations of CubeSats from deployer to aid space surveillance
- Sr. Project teams VANTAGE (AY18-19), VISION (AY19-20), +ugrad researcher





Current Work

PSLV-C37 Deployment

- February 15, 2017
- Deployed 104 satellites in 10 minutes
- 1 medium satellite and 103 CubeSats

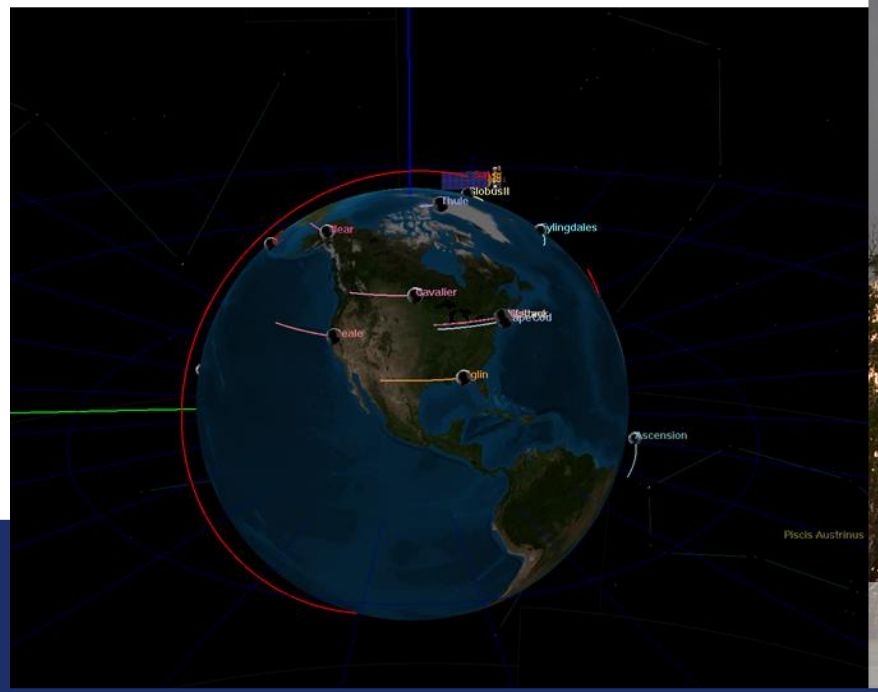


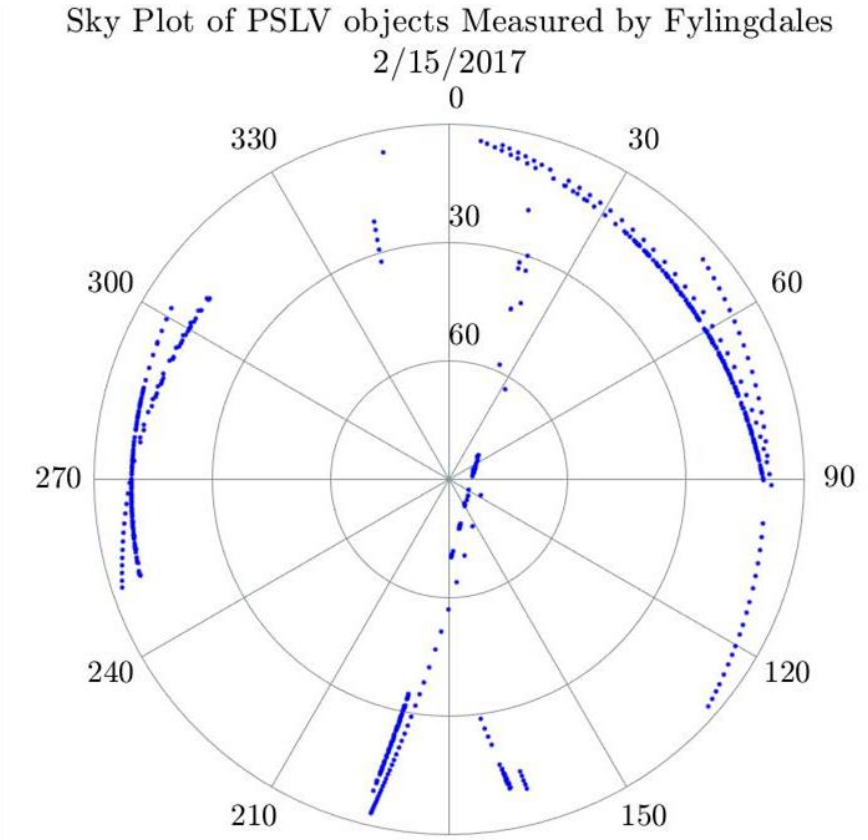
Image Source: ISRO
Gallery: https://www.isro.gov.in/pslv-c37-cartosat-2-series-satellite/pslv-c37-cartosat-2-series-satellite-gallery?page=1

Current Work

PSLV-C37 Deployment Real Radar Obs

- Obs from 22 radar sites across the globe
- Range and Angles
- 11,820 total obs

Image of Fylingdales N, SW, and SE Phased Array Radar (Wikipedia)
https://en.wikipedia.org/wiki/RAF_Fylingdales#/media/File:RAF_Fylingdales_Radar.jpeg



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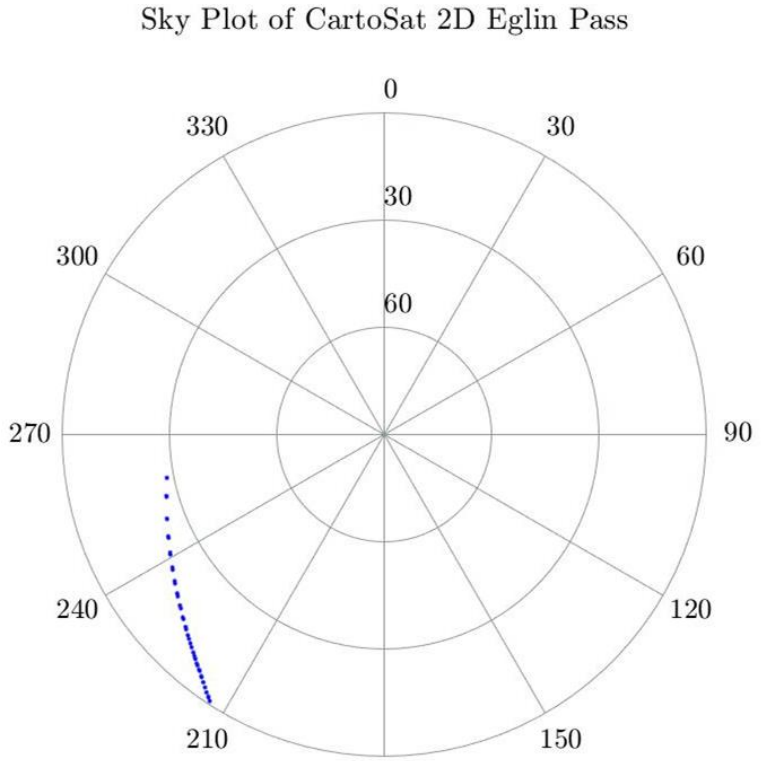
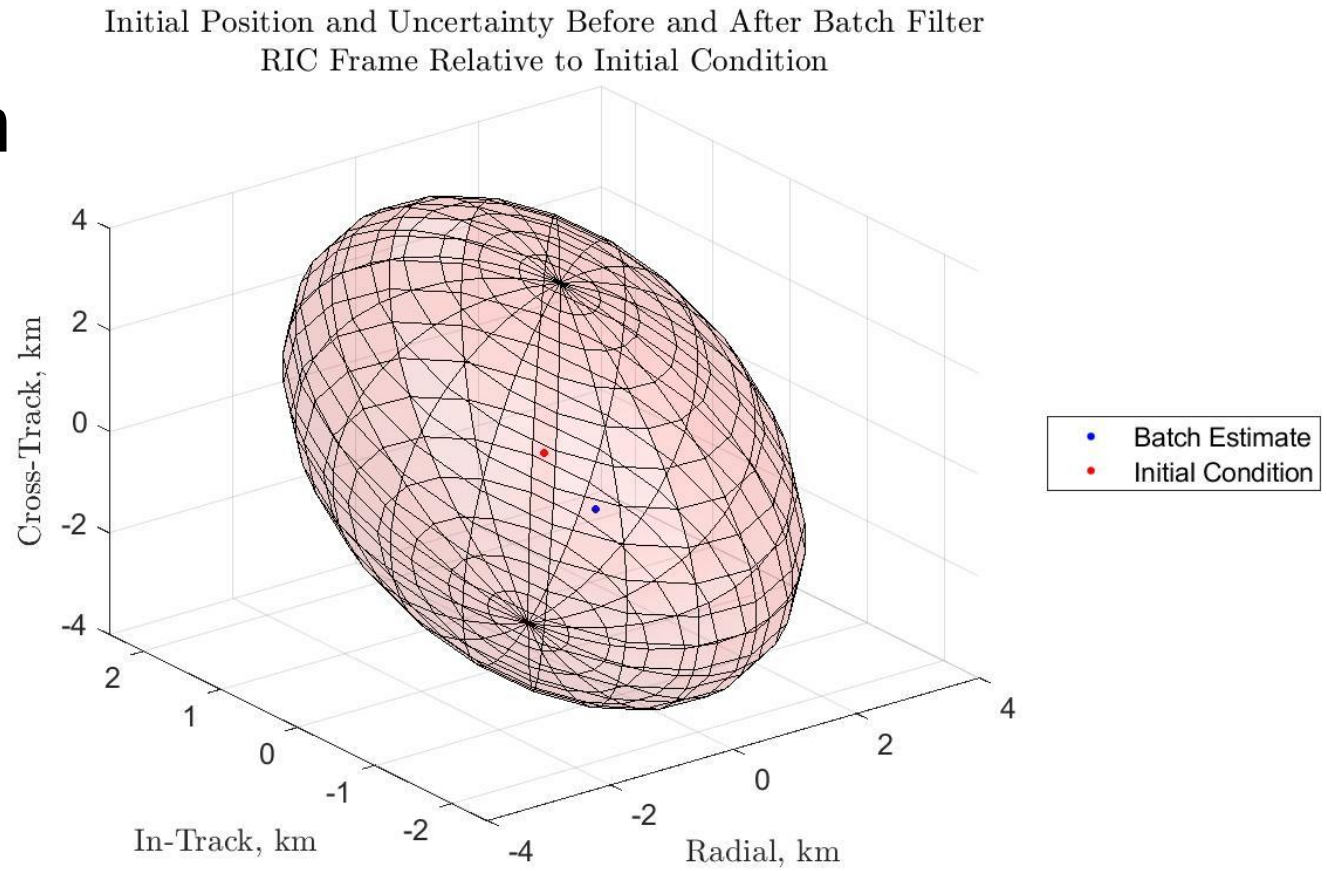
Current Work

PSLV-C37 Deployment

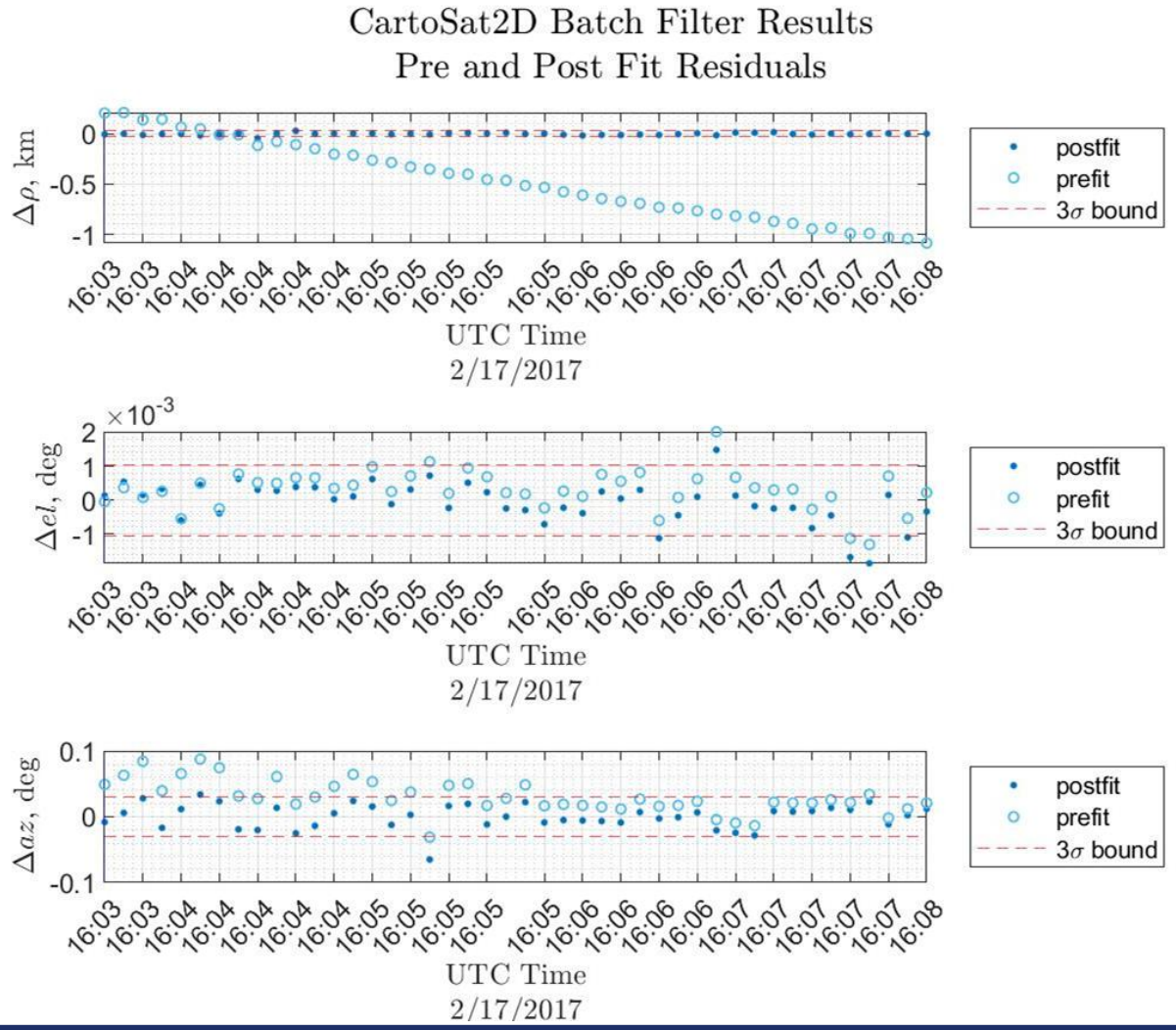
- Successful orbit results from single radar passes

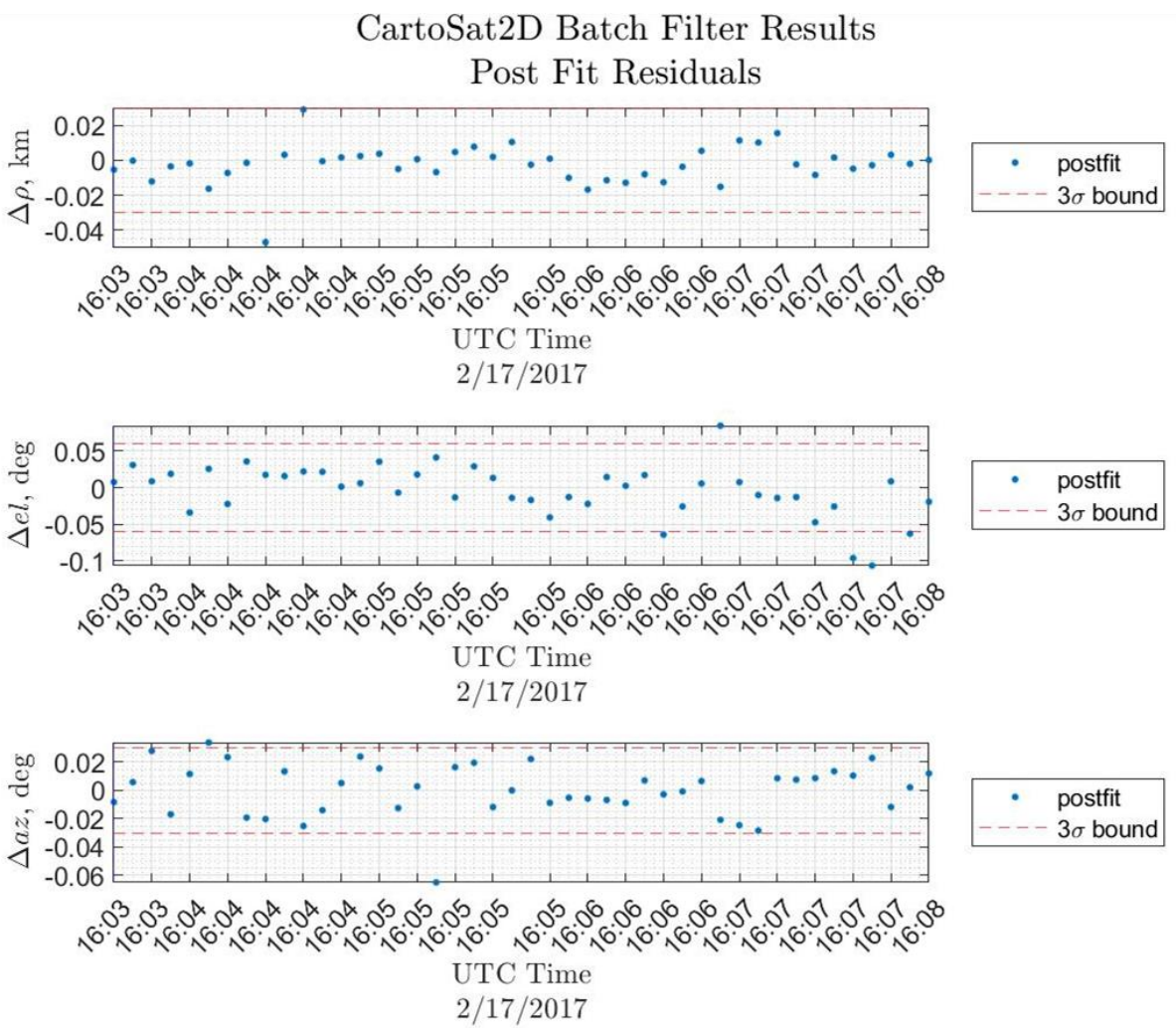




Laura Davies

Current Work: Single pass pre & post fit residuals

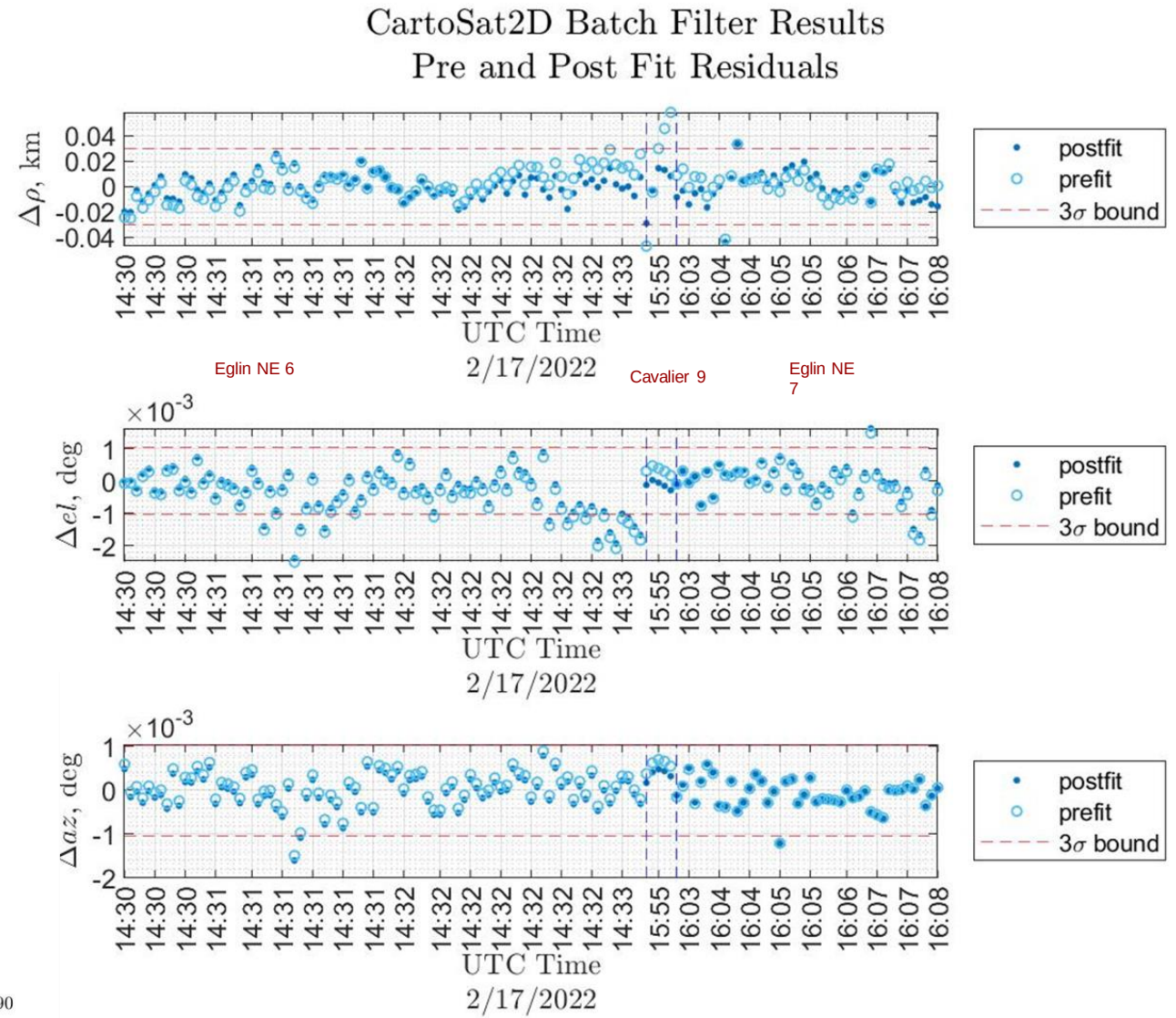


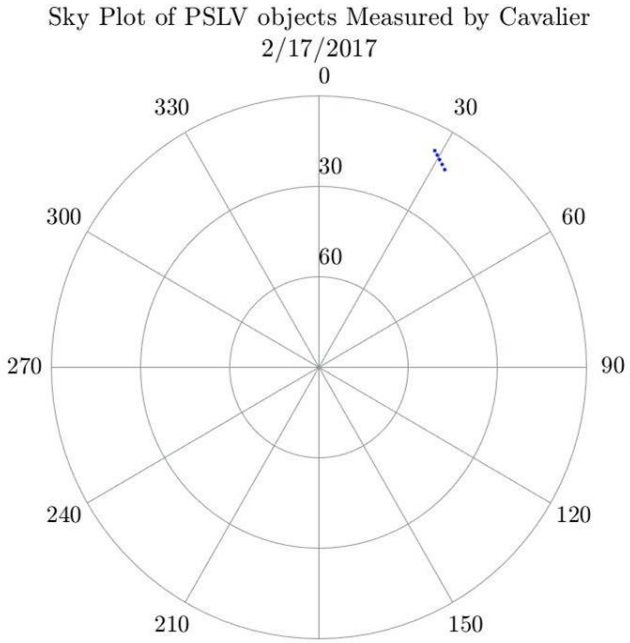


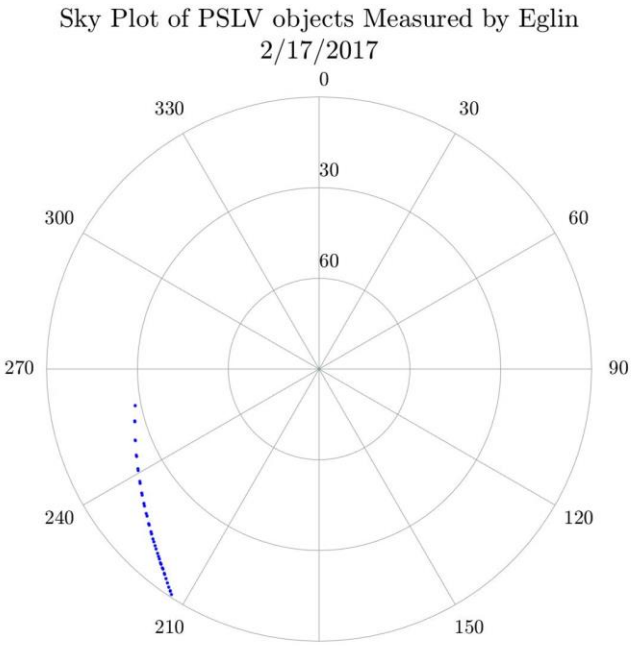
Current Work

Combining multiple passes

Compare meas fit between passes to detect cross-tagging

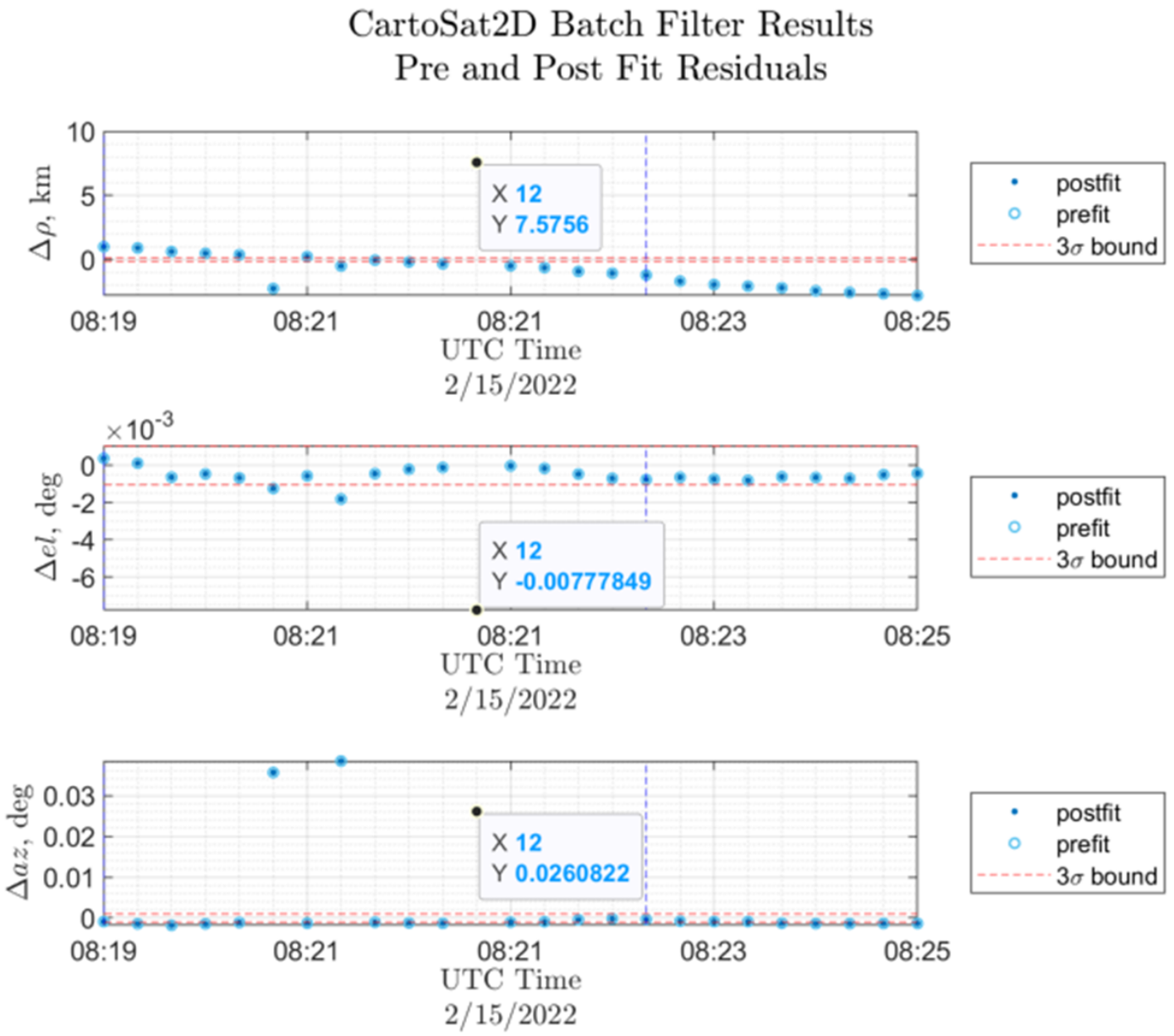






Current Work

Example of cross-tagged measurements in a radar pass



Clustered CubeSat Deployment Tracking Impact

- **GLMB filter** – efficiently estimates states of ~100 target objects to average absolute error of ~50m with observations & clutter from 4 ground stations.
- **Identity management** – correctly identifies all CubeSats within 2-3 days with data from O/O tracking site (serially observing targets)
- **Track initiation** – enables all targets to be found within 2-3 days based on ground tracking with no prior information.
- **Prototype in-situ hardware and software** – use these measurements to initialize GLMB and evaluate impact on multi-target estimates & identity.
- **Analysis of radar data from Combined Space Operations Center** – provides realistic assessment of initialization process and cross-tagging risk

We expect these contributions can support future civil & military space domain awareness.

Publications, Presentations, Awards, & Recognitions

PUBLICATIONS (JOURNAL)

Gaebler, J., P. Axelrad, P. Schumacher, "CubeSat Cluster Deployment Track Initiation via a Radar Admissible Region Birth Model," *J. of Guidance, Control, & Dynamics*, Vol. 43, No. 10, p. 1927-1934, doi.org/10.2514/1.G005139, 2020.

Gaebler, J. and P. Axelrad, "Identity Management of Clustered Satellites with a Generalized Labeled Multi-Bernoulli Filter," *AIAA Journal of Guidance, Control, and Dynamics,* doi.org/10.2514/1.G004725, Online June 2020.

CONFERENCE PAPERS & PRESENTATIONS

- Axelrad, P., "Tracking Clustered CubeSat Deployments," Invited Talk Stanford Center for Position, Navigation & Time (SCPNT) Symposium, October 27, 2021.
- Gaebler, J.A. and P. Axelrad, "Label Assignments in CubeSat Cluster Deployment Tracking," AAS/AIAA Space Flight Mechanics Meeting, Ka'anapali Maui, AAS 19-540, 15 pages, January 2019.
- Gaebler, J.A. and P. Axelrad, "Improving Orbit Determination of Clustered CubeSat Deployments using Camera-Derived Observations," Proc 42nd AAS Guidance & Control Conference, Breckenridge, CO, AAS 19-041, Feb 2019.
- *Boylston, A., J.A. Gaebler, and P. Axelrad, "Extracting CubeSat Relative Motion Using In Situ Deployment Imagery," Proc 42nd Annual AAS Guidance & Control Conference, Breckenridge, CO, AAS 19-016, Feb 2019.
- **Aboaf, A., N. Renninger, and L. Lufkin. 2019. "Design of an In-Situ Sensor Package to Track CubeSat Deployments," Proceedings of the Small Satellite Conference, FJR Student Competition (2nd Prize Winner), SSC19-VIII-06, https://digitalcommons.usu.edu/smallsat/2019/all2019/141/

AWARDS

- Boylston (*) 2nd Place Student Paper (2019)
- Aboaf (**) 2nd Prize Frank J. Redd Student Competition (2019)
- Vantage Senior Project Team (2020) Department Award for Best Technical Understanding.

Conclusions and Future Work

- Orbit determination and identification of clustered small targets from ground sensors is challenging
- We have multi-target tools that work well for most objects in simulation
- We are able to initiate orbit estimates from actual radar data

Next Steps

- Add deployer in-situ obs (GPS & images) to simulation
- Characterize and recommend protocols for rapid deployment that reduce errors & risk of mis-tagging