COE CST Tenth Annual Technical Meeting

CubeSat Cluster Deployment Tracking

Task 367-CU

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Students: Laura Davies
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Agenda

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

Team Members

- People
  - Principal Investigator – Dr. Penina Axelrad
  - Students – Laura Davies
    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
  - Augment estimation methods to detect deployment anomalies
  - Integrate in-situ observations

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.

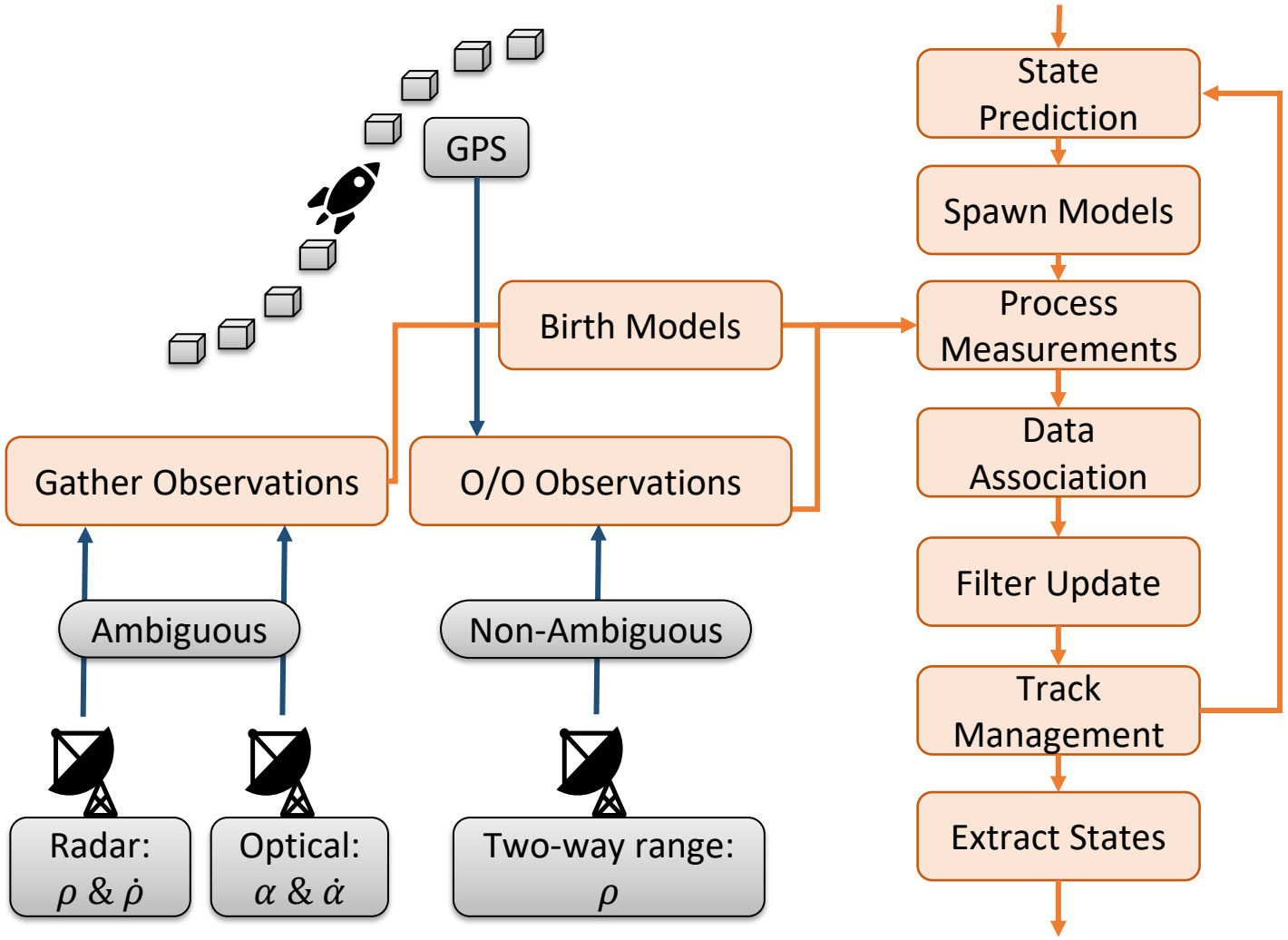
Relevance to Commercial Space Industry

- 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

Results

- Comparison of FISST Filter approaches: Generalized Labelled Multi-Bernoulli (GLMB) filter achieves accurate orbit estimation, correct cardinality, with few mis-tagged objects

- Range-Range based track initiation pairing UCT position estimates efficiently establishes 86/89 targets within 2 days of observations

- Identity management augmentation of GLMB integrating Owner/Operator tagged observations eliminates cross tagging and establishes all targets within 2 days of deployment

- Design of in-situ on-deployer measurement system to accelerate object tracking and identification.

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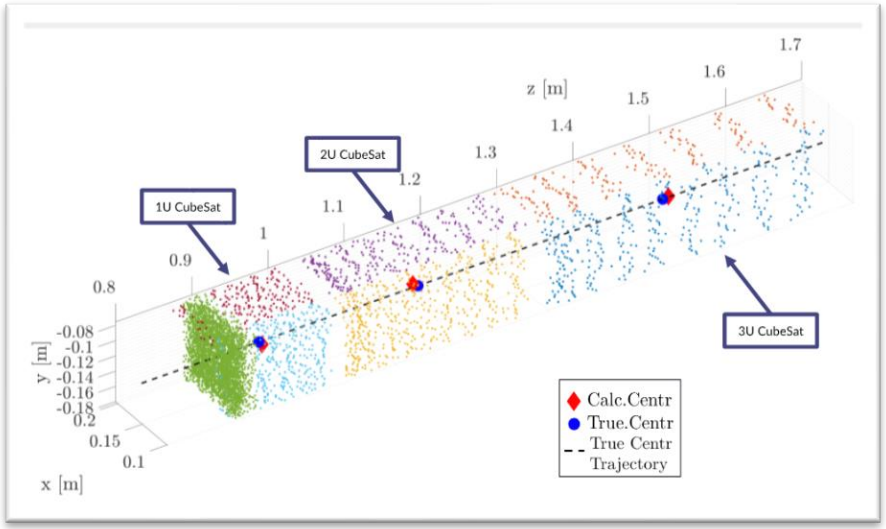
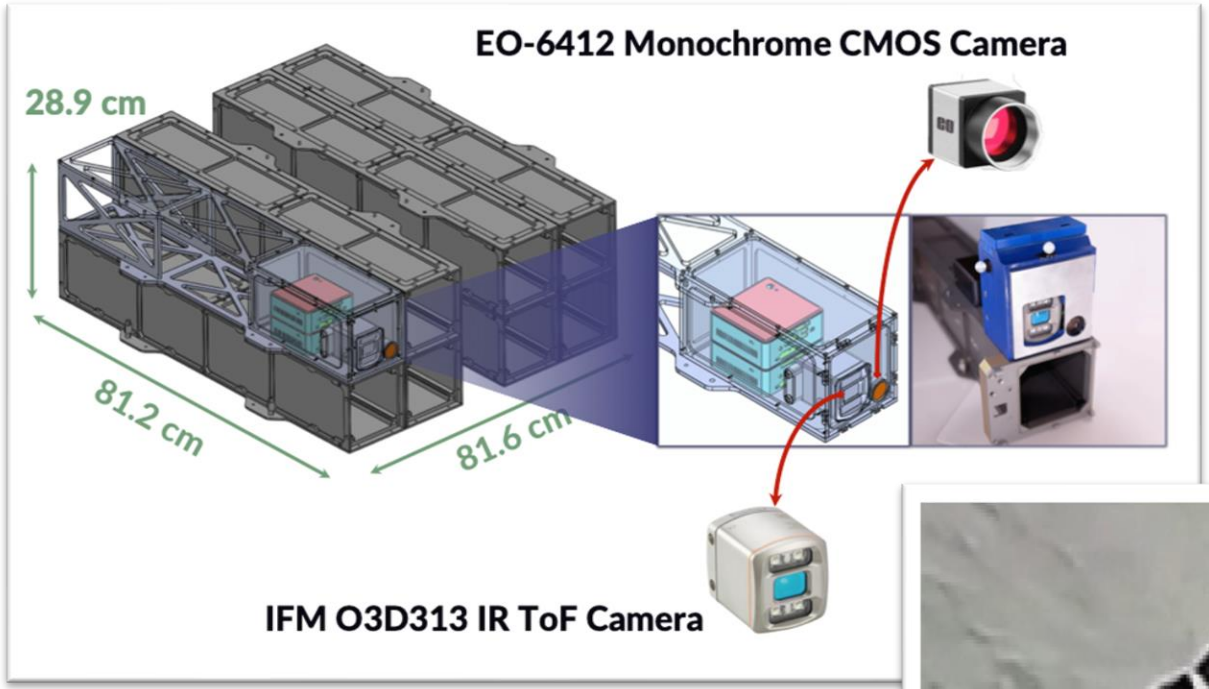
In-situ Measurements

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





Clustered CubeSat Deployment Tracking Impact

Simlation results demonstrate:

- **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.

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," *Journal of Guidance, Control, and Dynamics*, Vol. 43, No. 10, p. 1927-1934, doi.org/10.2514/1.G005139, October 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

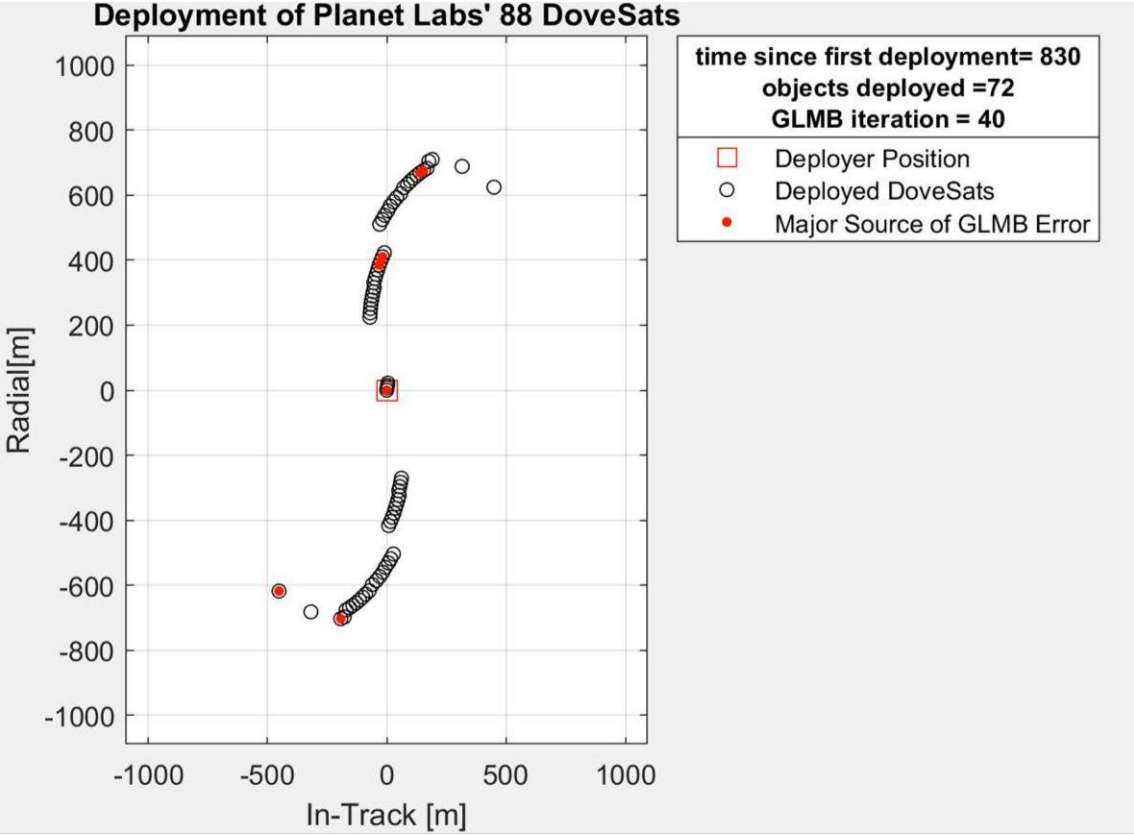
- Gaebler, J.A. and P. Axelrad, "Label Assignments in CubeSat Cluster Deployment Tracking," AAS/AIAA Space Flight Mechanics Meeting, Ka'anapali Maui, AAS 19-540, 15 pages, January 2019.
- Gaebler, J.A. and P. Axelrad, "Improving Orbit Determination of Clustered CubeSat Deployments using Camera-Derived 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.

Current Work

- Complete MATLAB simulation of CubeSat cluster deployment and propagation over the course of several days



- Ability to modify original Planet Labs deployment
  - Tune GLMB filter to new deployment scenarios
  - Recommend cluster deployment strategies for optimal tracking

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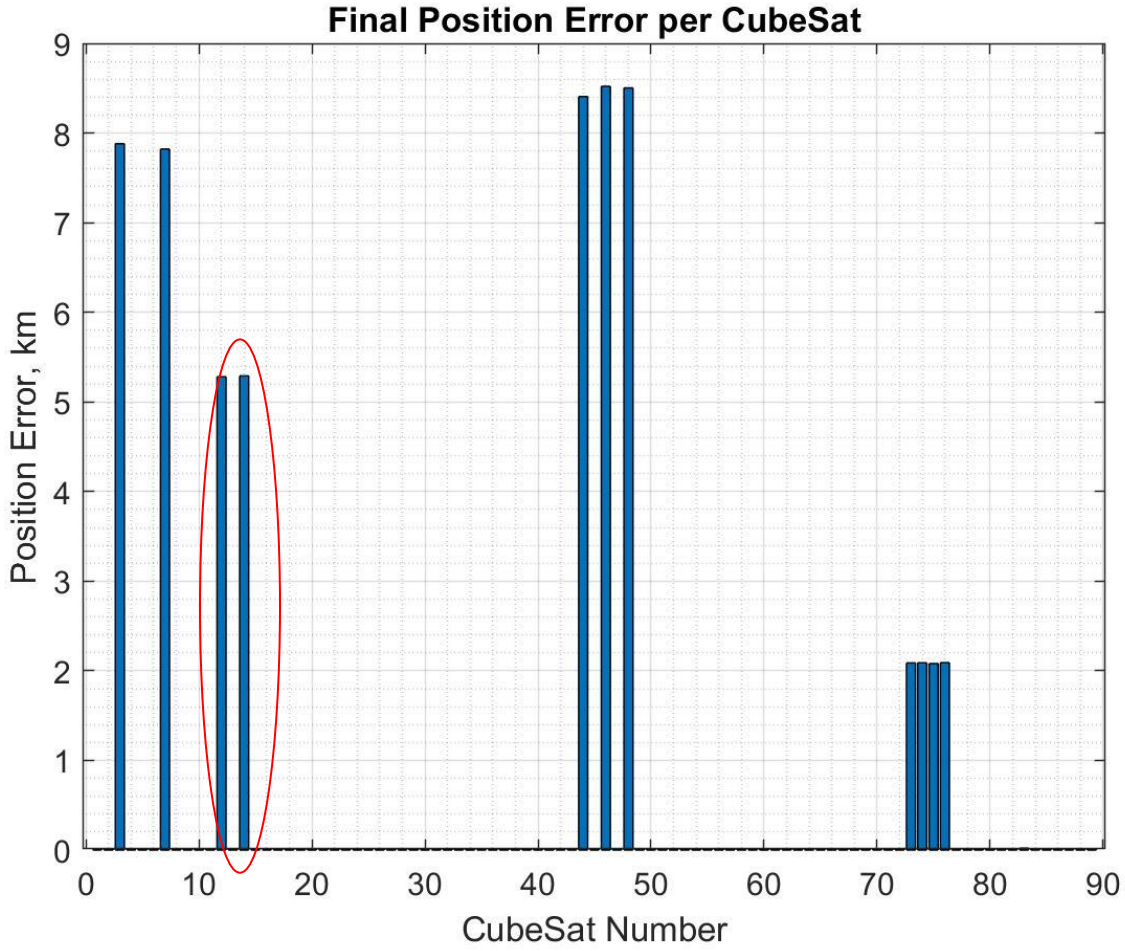
Current Work

- Analyzing major sources of filter error to improve filter performance



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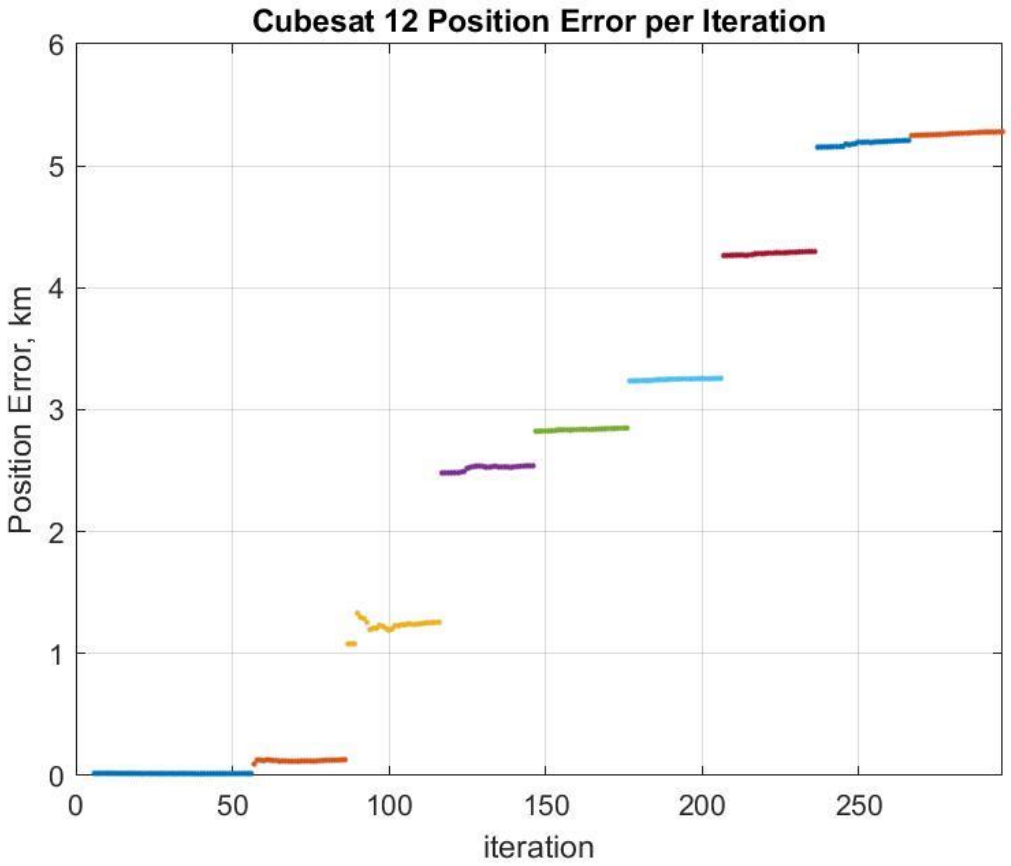
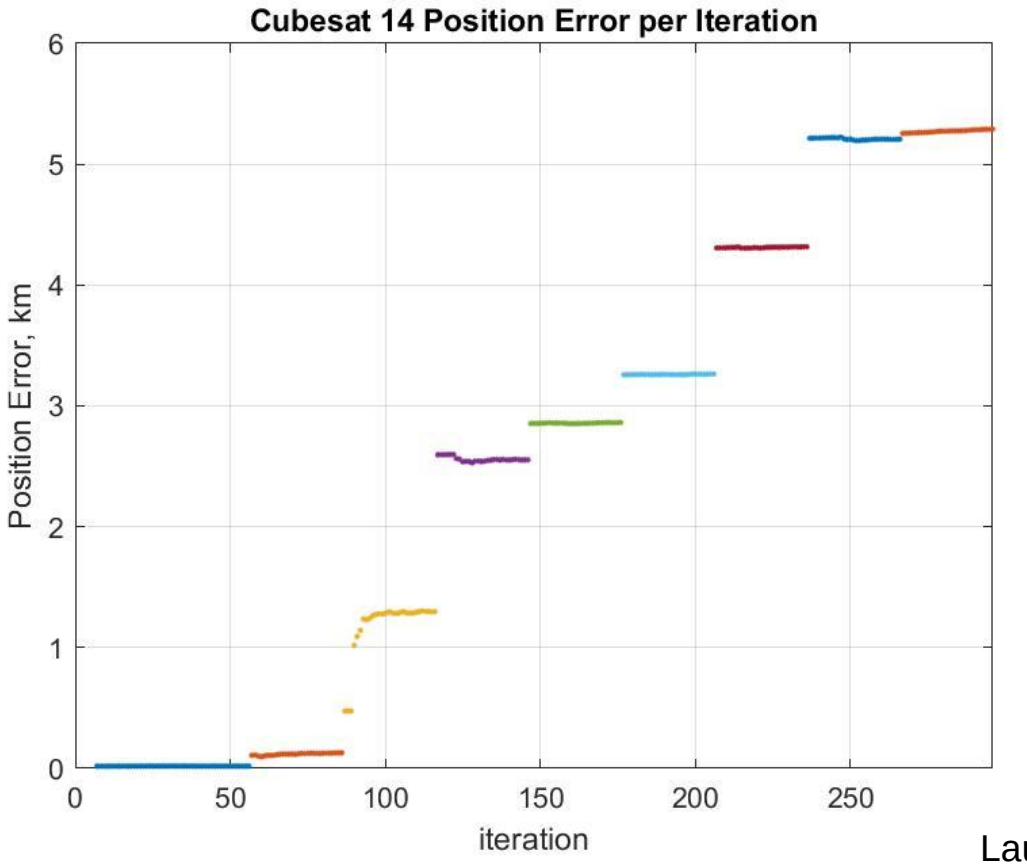
Current Work

- Dominant errors come from CubeSats in close proximity at end of observation site pass





Laura Davies

Conclusions and Future Work

- Orbit determination and identification of clustered small targets from ground sensors is challenging
- We have tools that work well for most objects

Next Steps – change the ground rules to improve performance

- Add in-situ measurements
- Characterize and recommend modification to features of rapid deployment that produce largest errors & mis-tagging
- Extend algorithms to identify anomalies in deployment