# COE CST Eleventh Annual Technical Meeting

# TASK 327. RSO System Mechanics

Scheeres/Khatri/Greaves

# Agenda

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

# Team Members

- People
  - PI: Daniel Scheeres
  - GSRAs: Yashica Khatri & Jesse Greaves
- Organizations
  - University of Colorado Boulder
  - AGI

Jesse

Yashica

# Task Description

- Effective space situational awareness faces the challenge of bringing together observations from disparate sensors and sources, developing computationally efficient dynamic propagation schemes for orbits and their uncertainty distributions, and formulating accurate estimation methods for the purpose of quantifying and qualifying space-based activities.
  - Maximize the information extracted from usual sources of SSA data (minimize uncertainty)
  - Identify how data should be collected to maximize information content (maximize efficiency)
  - Recover and predict the space domain with more accuracy
  - Timely estimation of the space-based environment to create actionable information.

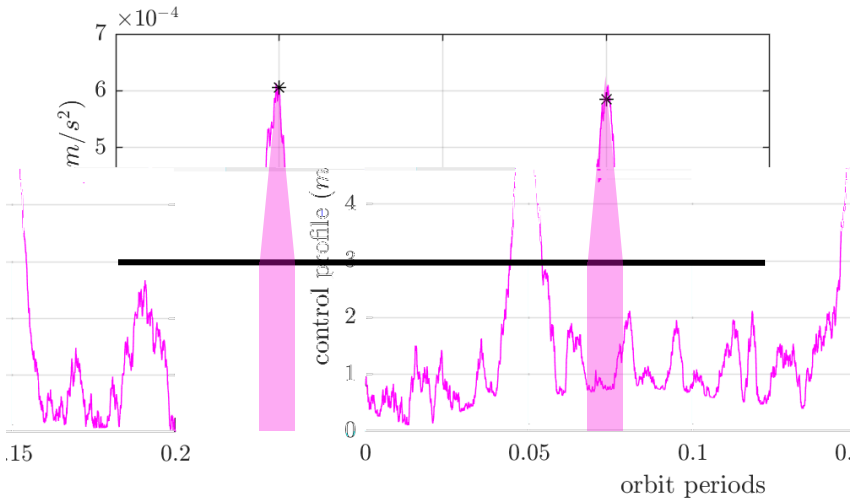
# Goals

- Specific tasks investigated over the last few years:
  - Relative state estimation between two space vehicles in cis-lunar space:
    - Utilizing Liaison Navigation, including maneuver detection and identifying opportunities for autonomous navigation
  - Conjunction analysis over long time periods using semi-analytical methods:
    - Enables rapid calculation of accurate collision probabilities, reducing computational costs by orders of magnitude while retaining accuracy and precision

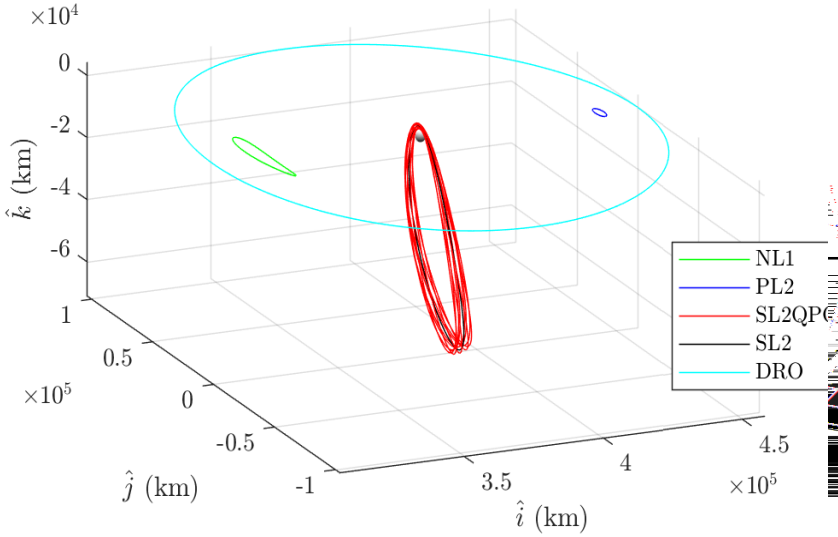
# Maneuver Detection in Cis-Lunar Space

- Analysis of maneuver detection for a vehicle in a Halo Orbit near the moon

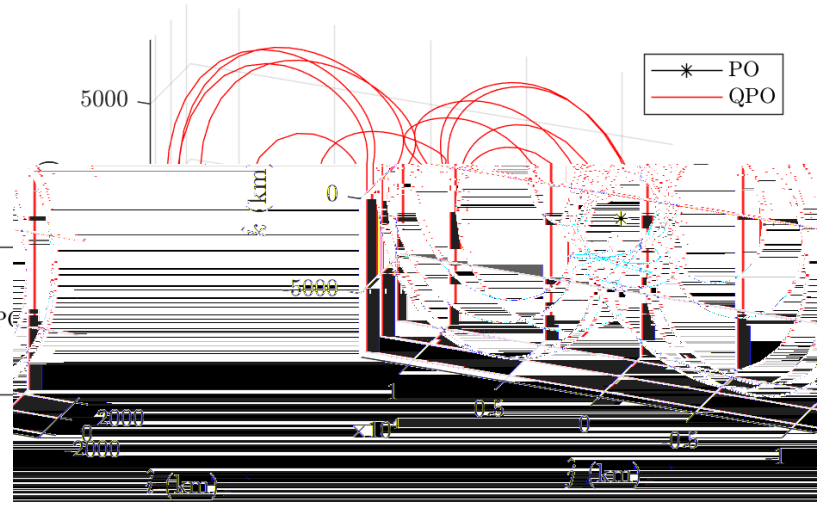
Automatic Detection of Events

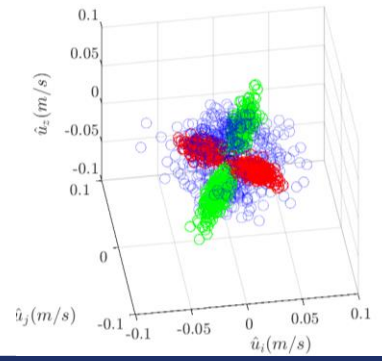



Examined Orbits



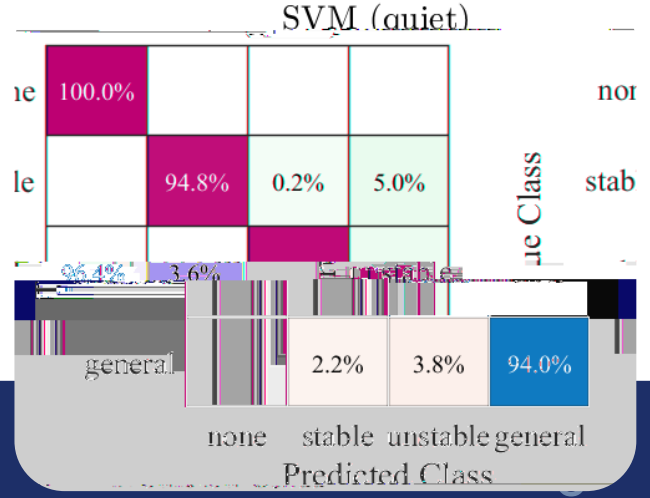

QPO to SL2 Relative Motion



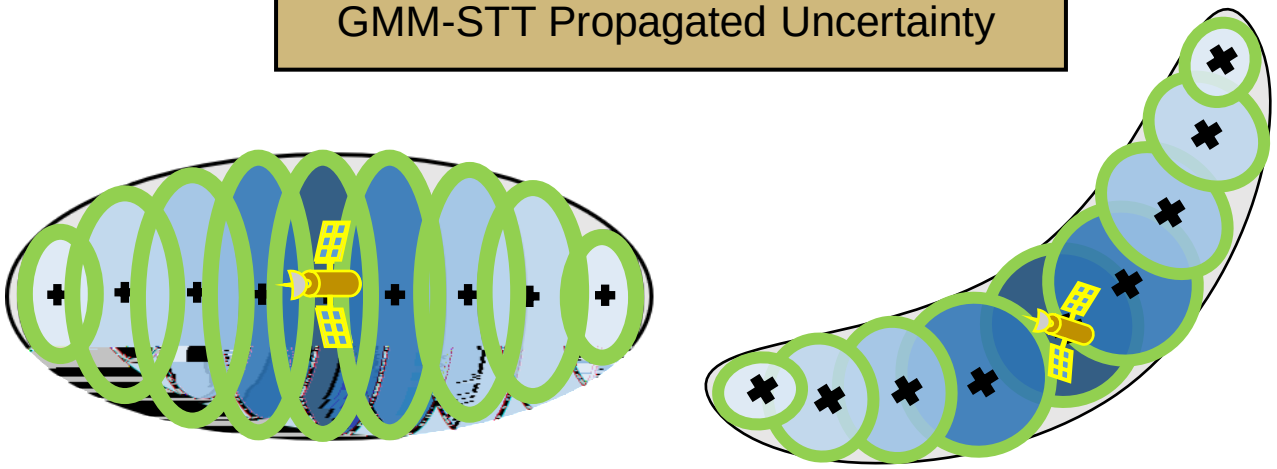

Projection of maneuver estimates onto stable and unstable manifolds

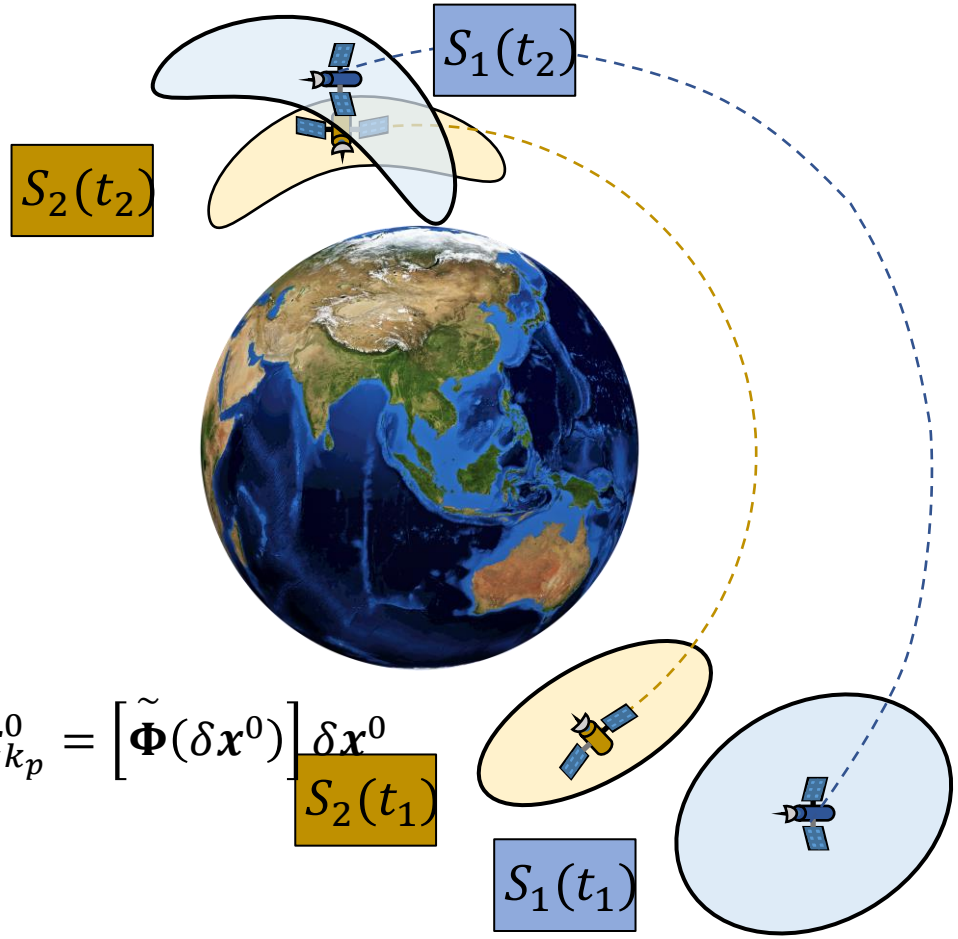
Method is able to identify and classify maneuvers



# Semi-analytical conjunction analysis

GMM-STT Propagated Uncertainty






$$\delta \boldsymbol{x}(t) = \frac{\delta \phi}{\delta \boldsymbol{x}} \Big|_{x^0} . \delta \boldsymbol{x}^0 + H.O.T.$$

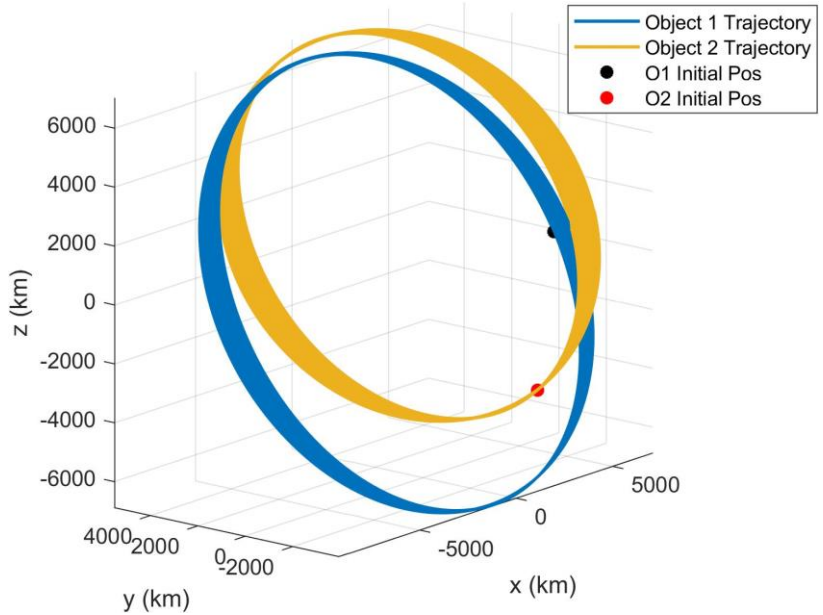
$$\delta \boldsymbol{x}_i(t) = \sum_{p=1}^{m} \frac{1}{p!} \boldsymbol{\Phi}_{i,k_1 \ldots k_p} \delta \boldsymbol{x}_{k_1}^0 \ldots \boldsymbol{x}_{k_p}^0 = \left[\tilde{\boldsymbol{\Phi}}(\delta \boldsymbol{x}^0)\right] \delta \boldsymbol{x}^0$$

$$\boldsymbol{\Phi}_{i,k_1 \ldots k_p} = \frac{\delta^p \boldsymbol{x}_i}{\delta \boldsymbol{x}_{k_1}^o \ldots \delta \boldsymbol{x}_{k_p}^0}$$

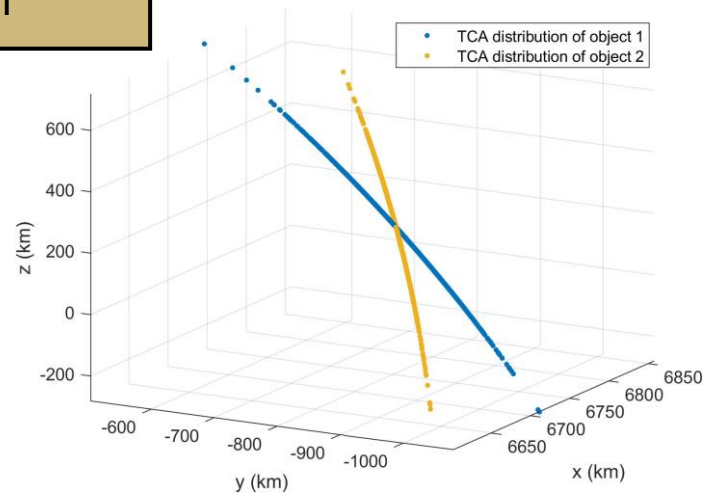
$$\boldsymbol{m}_i(t) = \sum_{p=1}^{m} \frac{1}{p!} \boldsymbol{\Phi}_{\mathrm{i,k_1 \ldots k_p}} \mathrm{E}\left[x_{k_1}^0 \ldots x_{k_p}^0\right]$$

$$\boldsymbol{P}_{ij}(t) = \left( \sum_{p=1}^{m} \sum_{q=1}^{m} \frac{1}{p!\, q!} \boldsymbol{\Phi}_{\mathrm{i,k_1 \ldots k_p}} \boldsymbol{\Phi}_{\mathrm{j,l_1 \ldots l_p}} E\left[x_{k_1}^0 \ldots x_{k_p}^0 x_{l_1}^0 \ldots x_{l_q}^0\right] \right) - \boldsymbol{m}_i(t)\, \boldsymbol{m}_j(t)$$

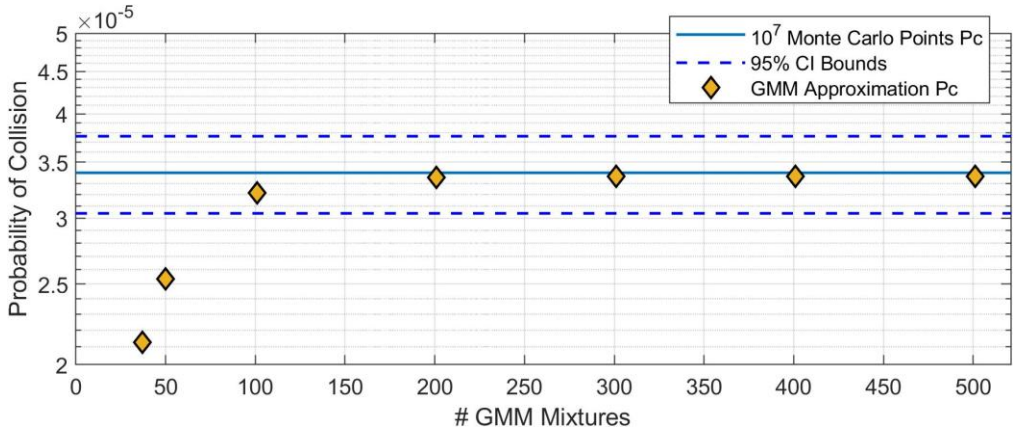
## Orbits




## Distribution




## GMM-STT Pc vs MC Pc



# Publications, Presentations, Awards, & Recognitions

**PUBLICATIONS & PRESENTATIONS**

1. J. A. Greaves and D. J. Scheeres. 2021. “Observation and Maneuver Detection for Cislunar Vehicles,” Journal of the Astronautical Sciences 68: 826-854.

2. Jesse Greaves, D.J. Scheeres Relative Estimation in the Cislunar Regime using Optical Sensors. AMOS Conference, September 15-17, 2021. To be submitted to JGCD.

3. Y. Khatri, D.J. Scheeres Nonlinear Semi-Analytical Uncertainty Propagation for Conjunction Analysis. IAC Conference, October 25-29, 2021. Paper IAC-21,C1,3,12,x64896. Submitted to Acta Astronautica.

**AWARDS**

J.A. Greaves: Best paper award from 2020 AMOS meeting.

Y. Khatri: Amelia Earhart Fellowship (2021), Tau Beta Pi Fellowship (2022)

# Conclusions and Future Work

- Final Remarks: Significant appreciation for the support that the FAA COE has provided our SSA-focused research over the life of the center!
- Alternate sources of support are being leveraged for the research that Yashica and Jesse are pursuing
  - Expected graduate dates are:
  - Jesse — 2023
  - Yashica — 2023