SENSOR FUSION KALMAN FILTERING FOR STABILITY AND CONTROL OF SATELLITE SWARMS

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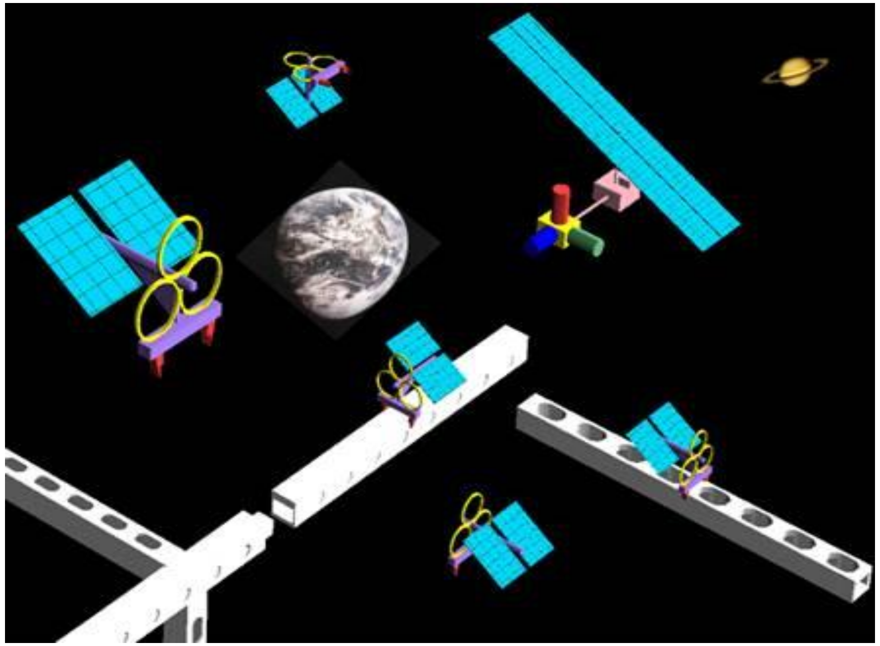
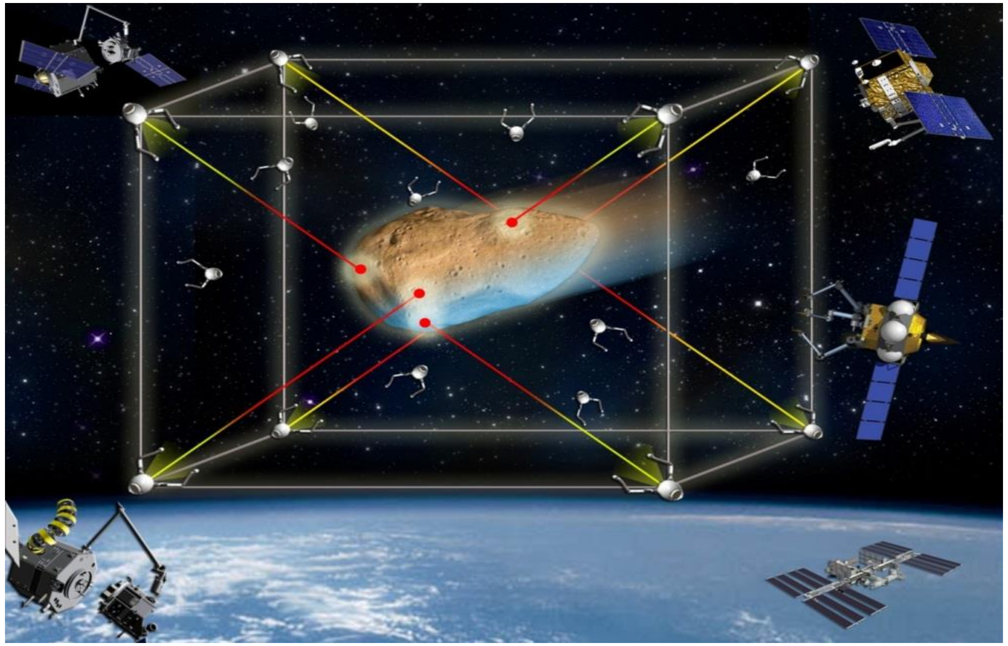
16th International Conference on Space Operations
Cape Town, South Africa
Virtual Conference Presentation

SERC

Swarm Operations in Orbit



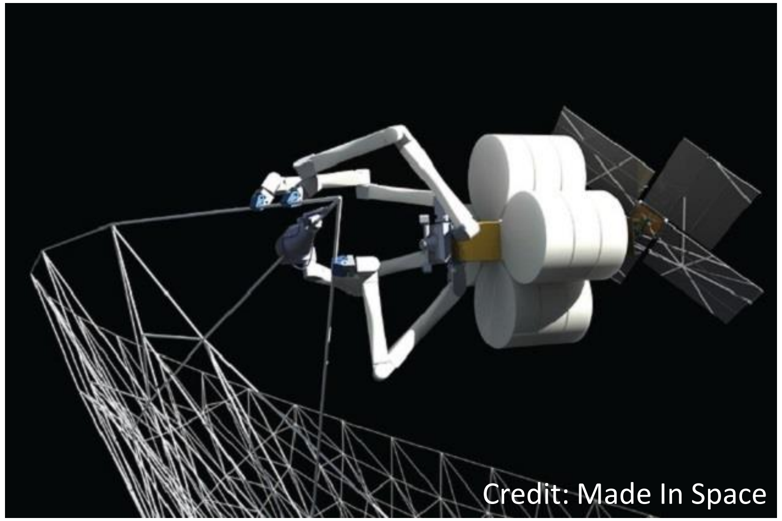
On-orbit assembly

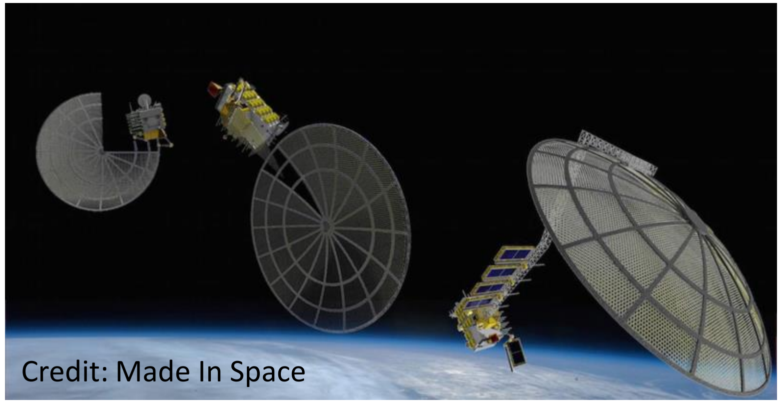


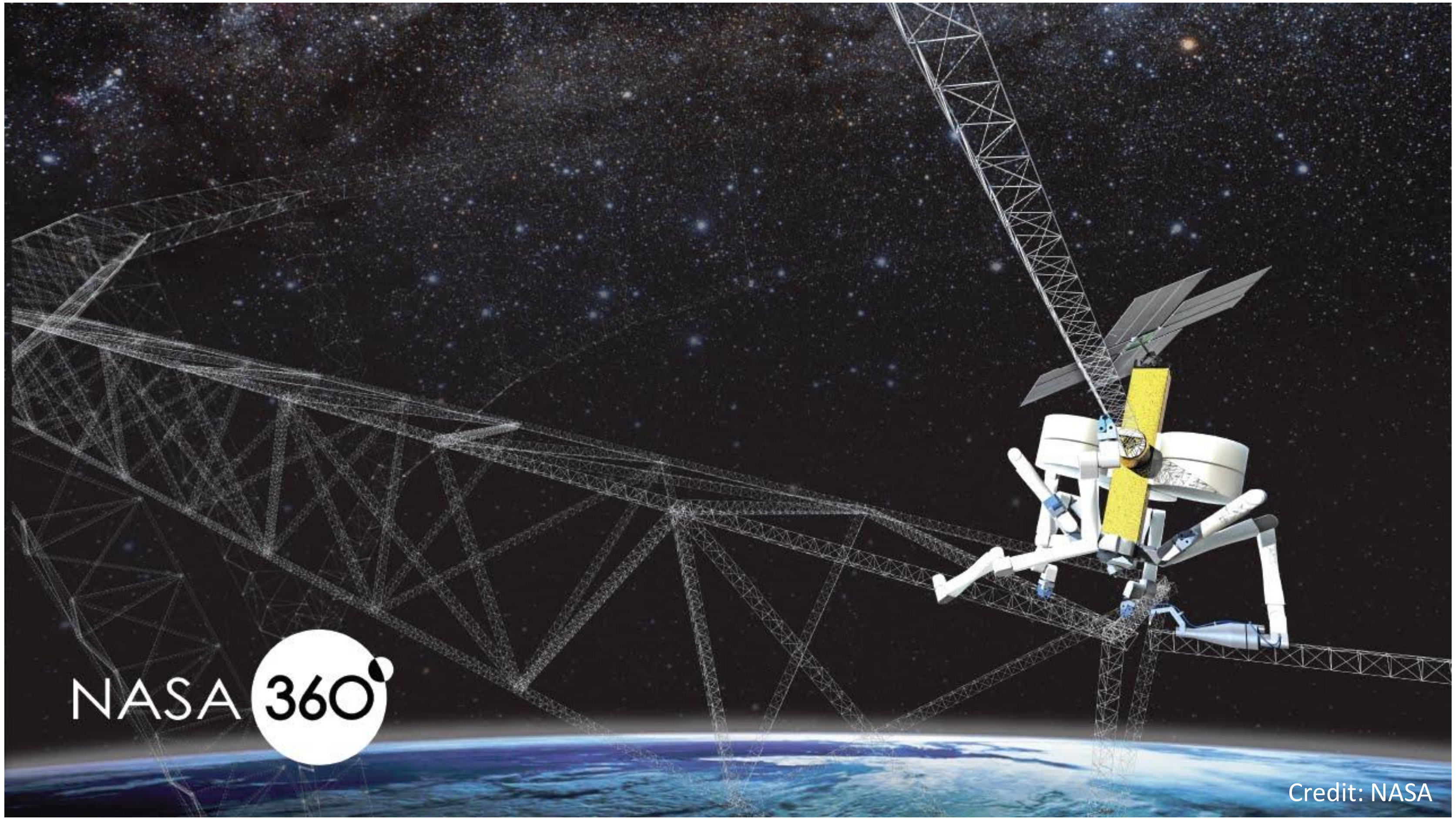
Cooperative Proximity Operations

- Enables construction of complex orbital assets, and repair of existing assets.
- Redundant nature of swarm and large number of spacecraft allow for higher autonomy and reliability

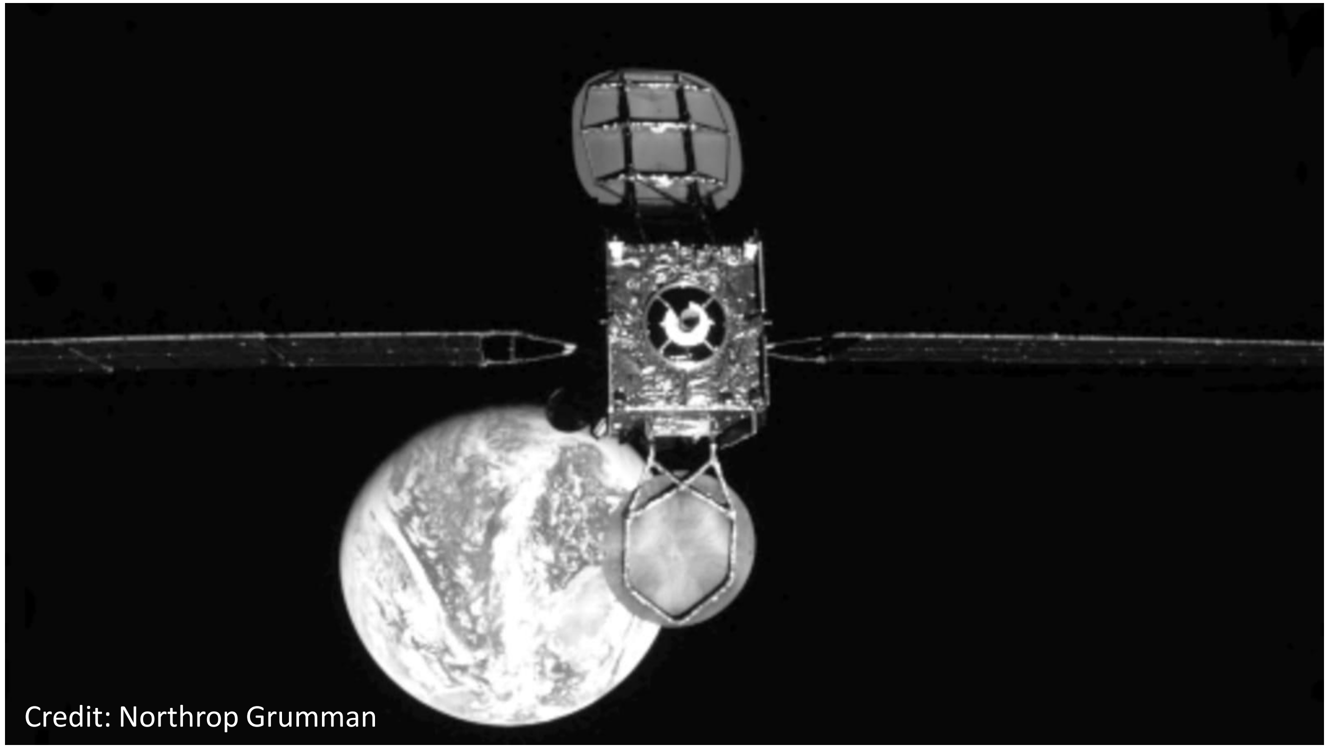
On-Orbit Construction



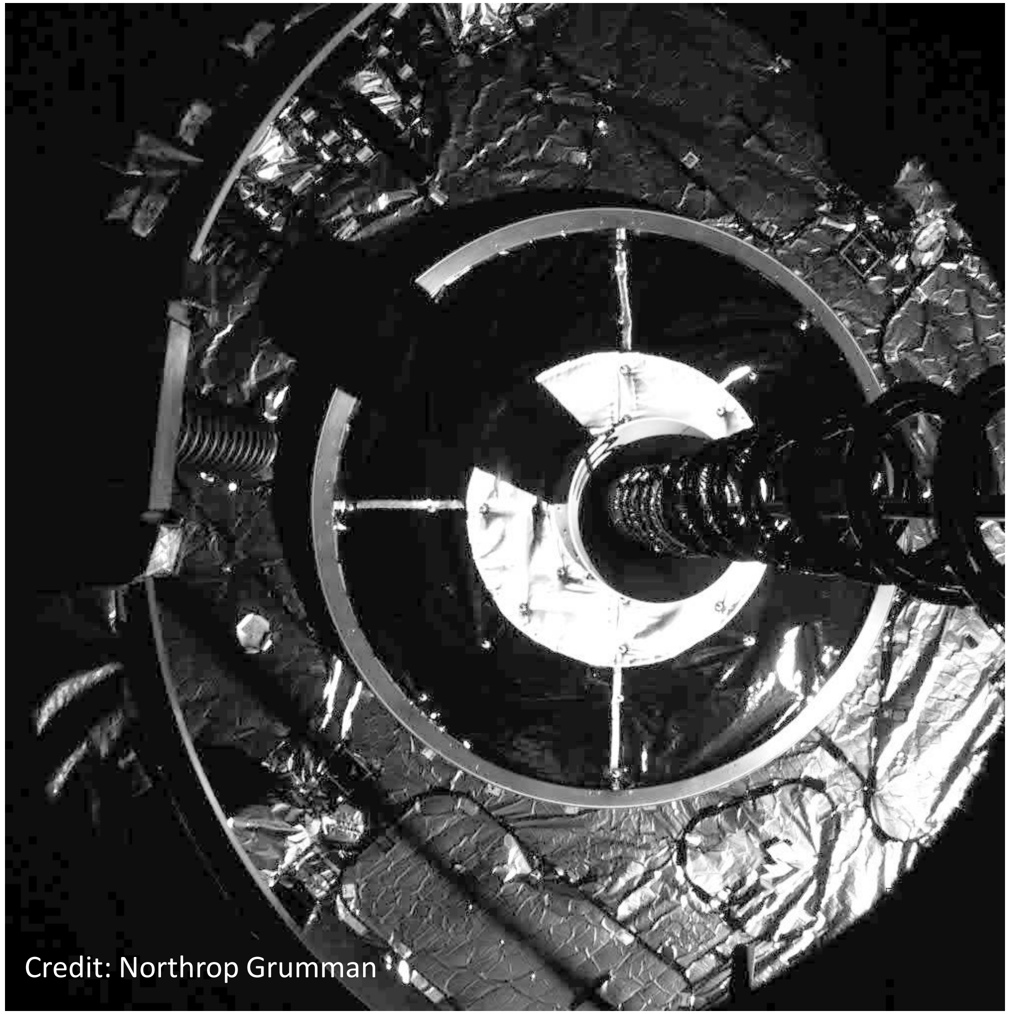




Current State-of-the-Art



- MEV-1 successfully docked to a retired GEO spacecraft to provide mission extension services [1]



MEV-1 docks with Intelsat-901

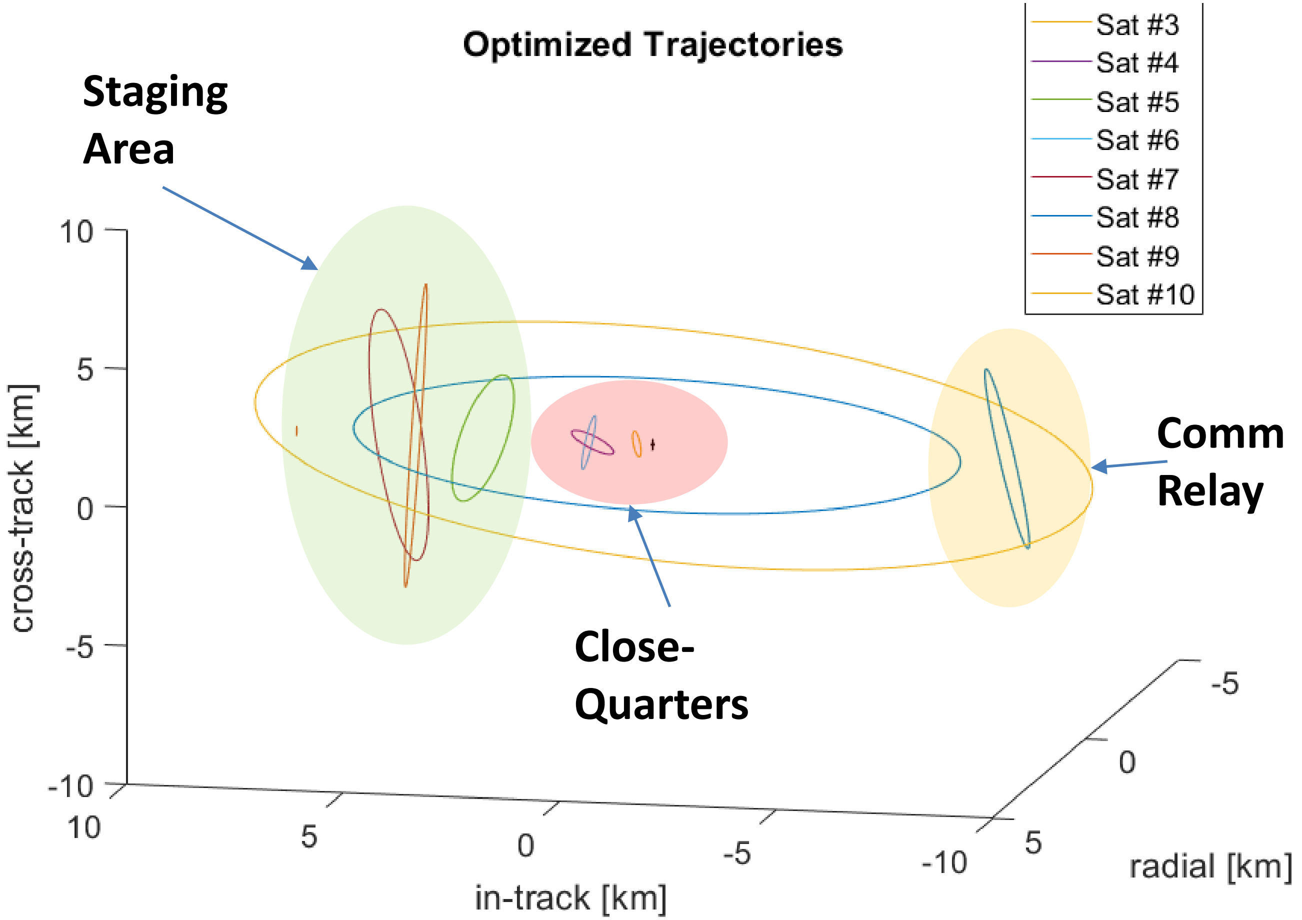
Research Goal

Advance the state-of-the-art for spacecraft swarm operations to enable large-scale in-space manufacturing in the not-too-distant future

Credit: Jack Olson / Getty Images

Swarm Example (10 Spacecraft)

- Trajectory on right shows example of 10-spacecraft swarm for in-space manufacturing
- Swarm roles split up into the staging area, a comm relay, and close-quarters robotic operations



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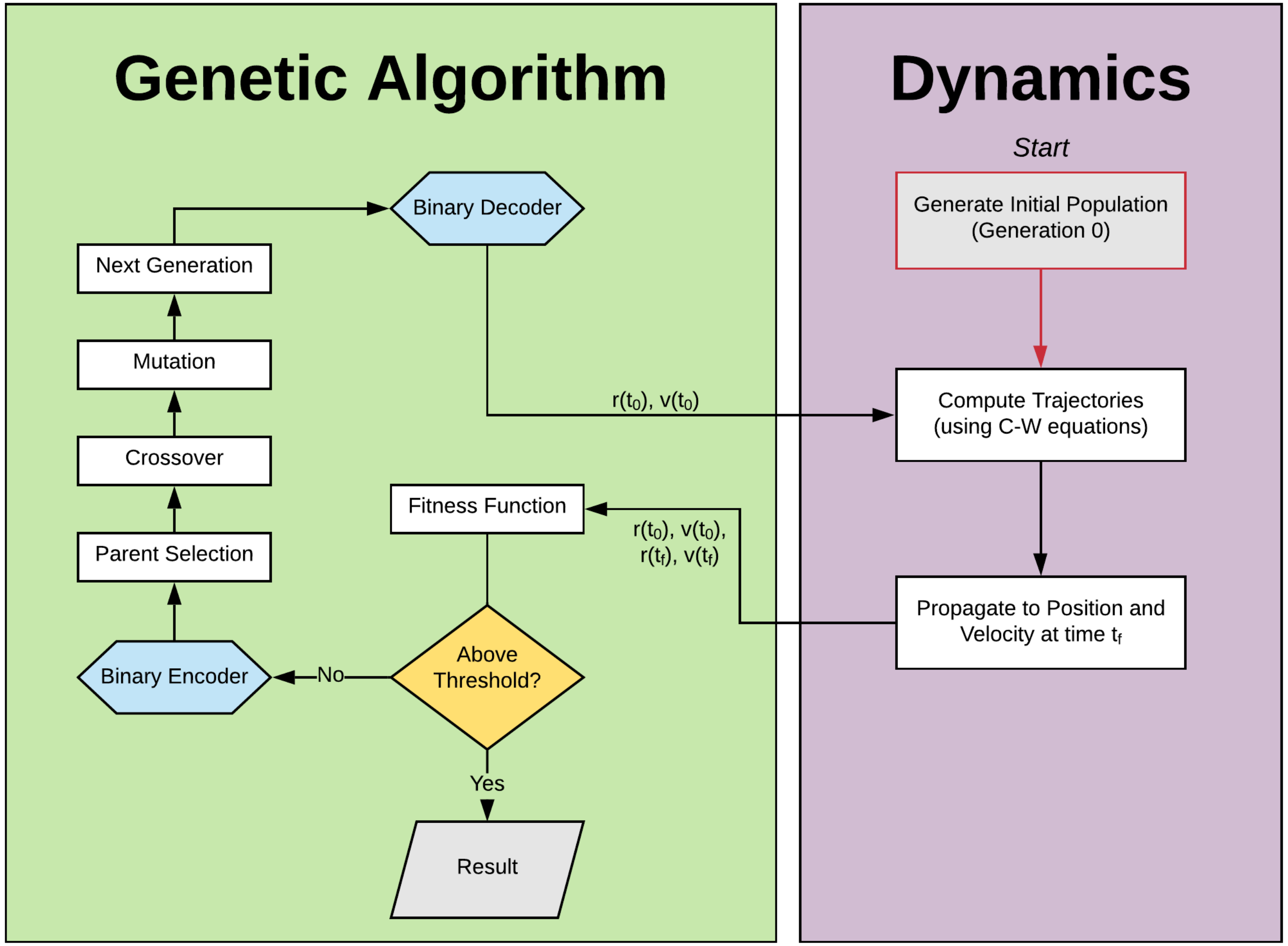
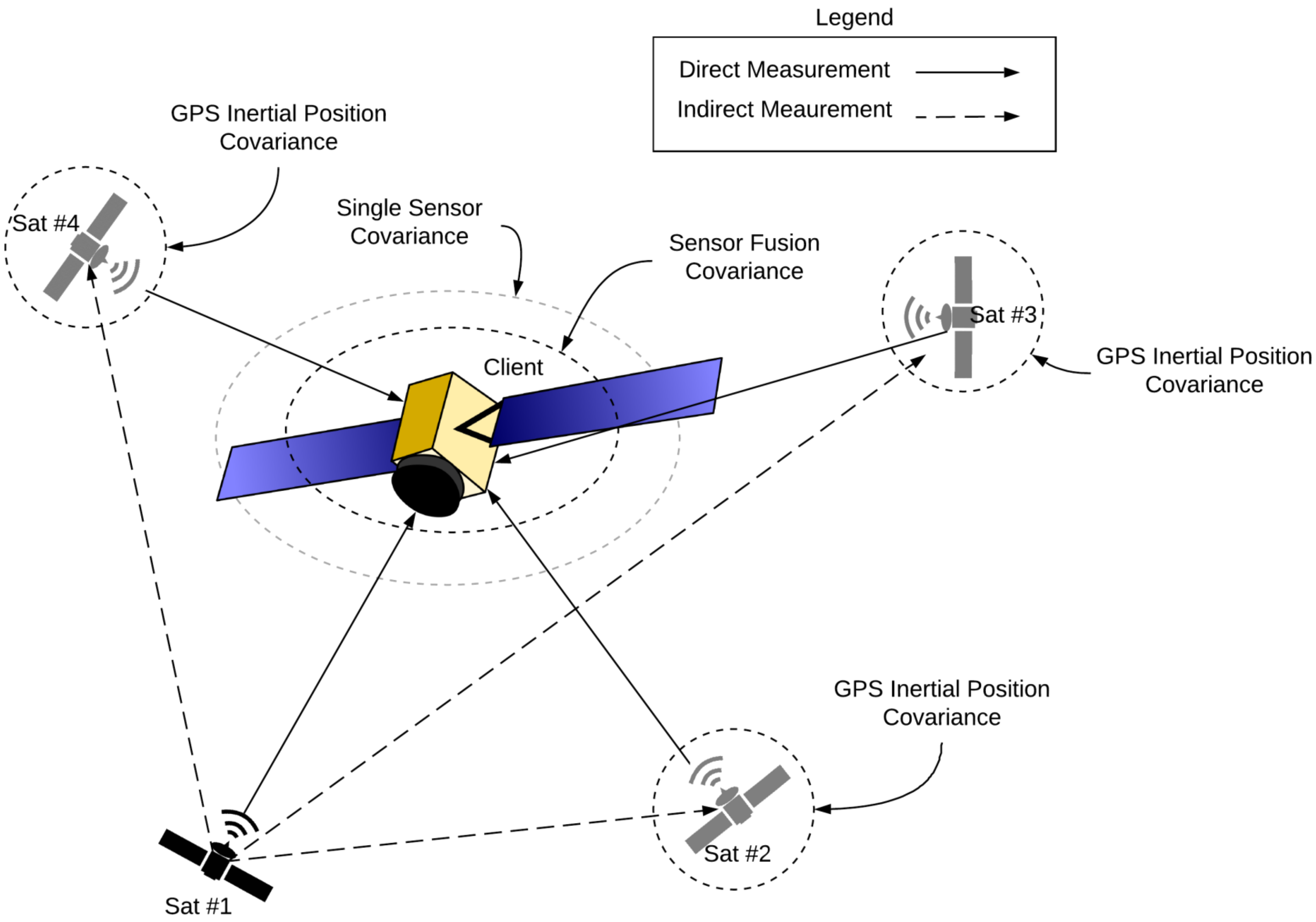
Trajectory Generation

- Free-flight trajectories, combined with conjunction analysis, used to build safe swarms
- Optimization performed using genetic algorithms to find solutions satisfying a set of criteria [2,3]
  - Minimize insertion Δv
  - Trajectories with no collision risk for a set period of time



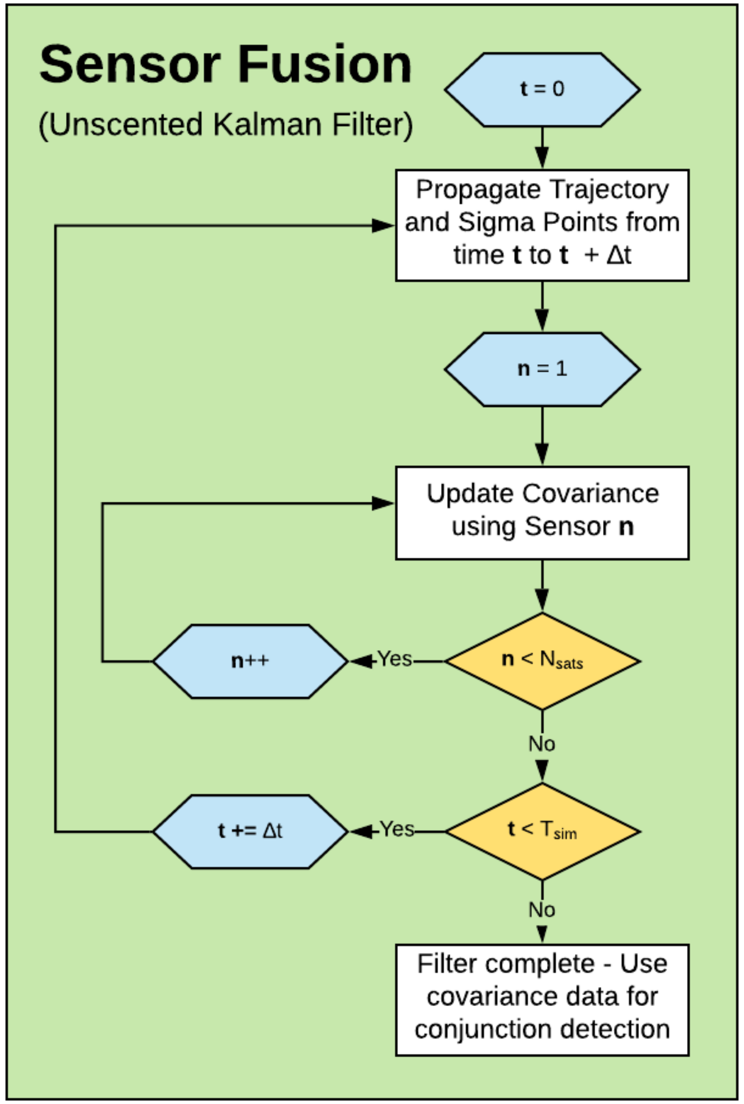
Swarm Sensor Fusion

- Sensor Fusion combines inputs from multiple sensors, spread across the swarm
- Using a Kalman filter, this shared data can be used to pinpoint the relative positions of each spacecraft more accurately, reducing their covariances

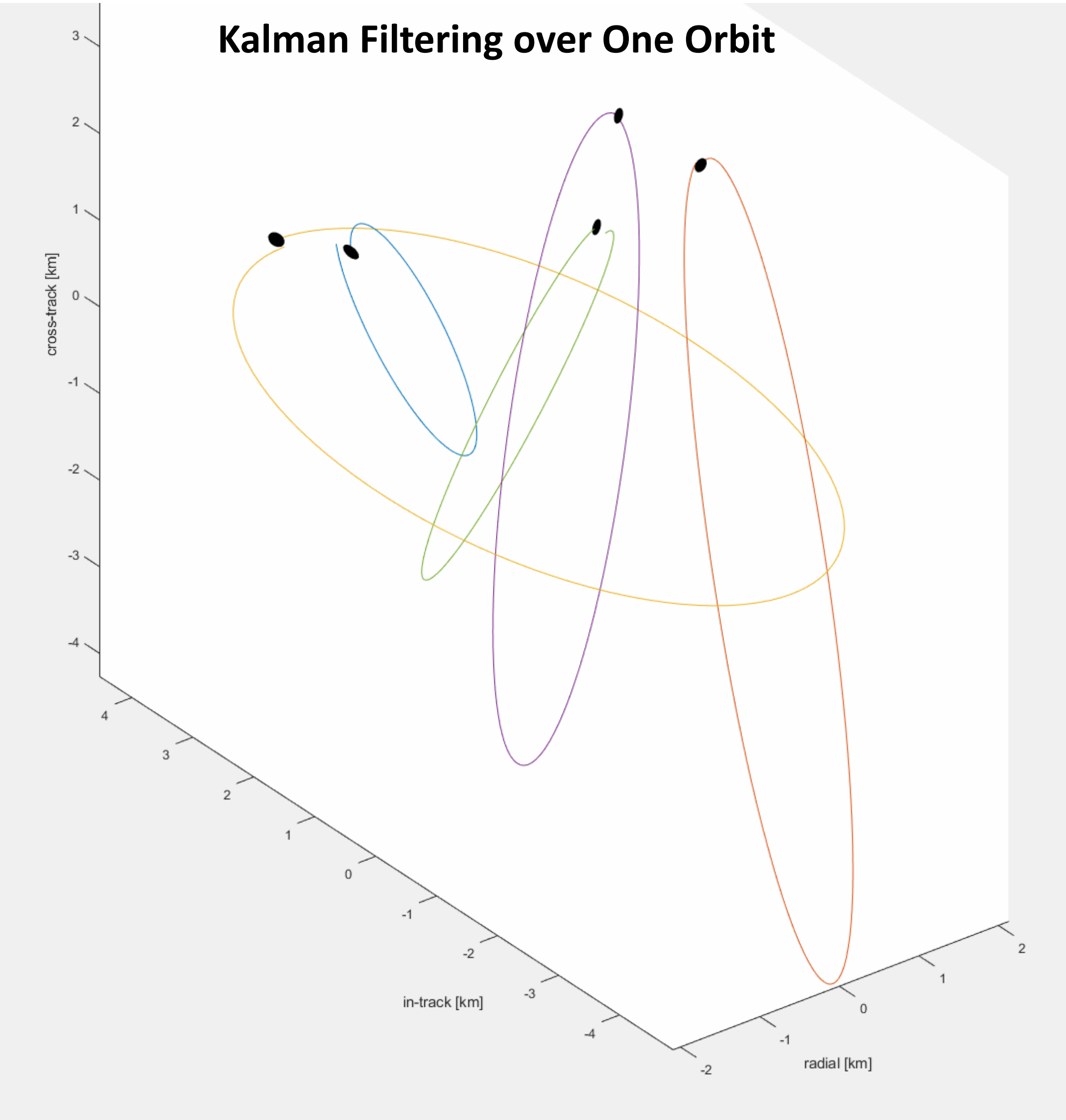


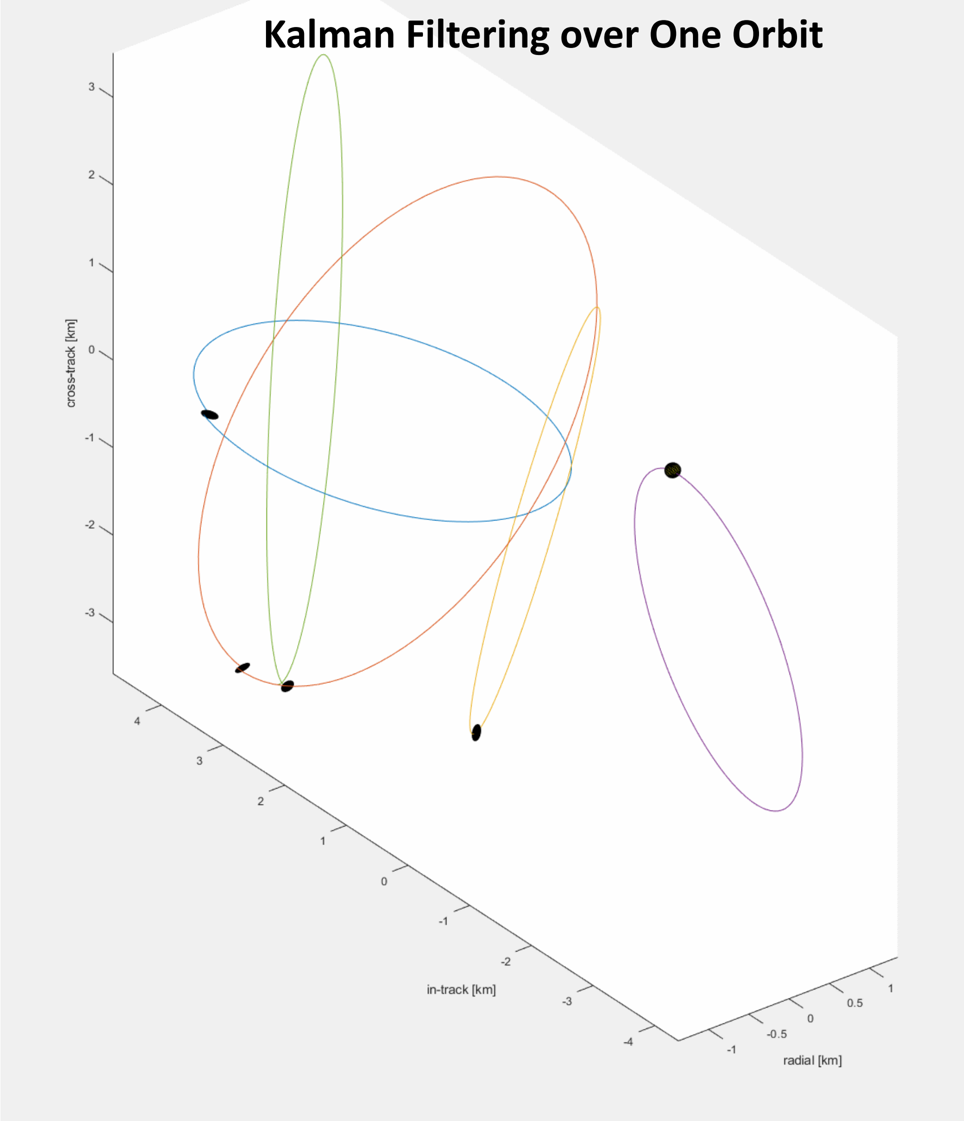
Sensor-Fusion Kalman Filtering

- Sensor fusion can be applied to Kalman filters
  - Simulation uses the Unscented Kalman Filter since the perturbed 2-body problem is a non-linear problem
- Similar to a standard Kalman filter, except the update step is repeated for each sensor in the shared swarm sensor net
  - Adds very little computational overhead, as most of the wall-time is spent on the propagation step of the UKF



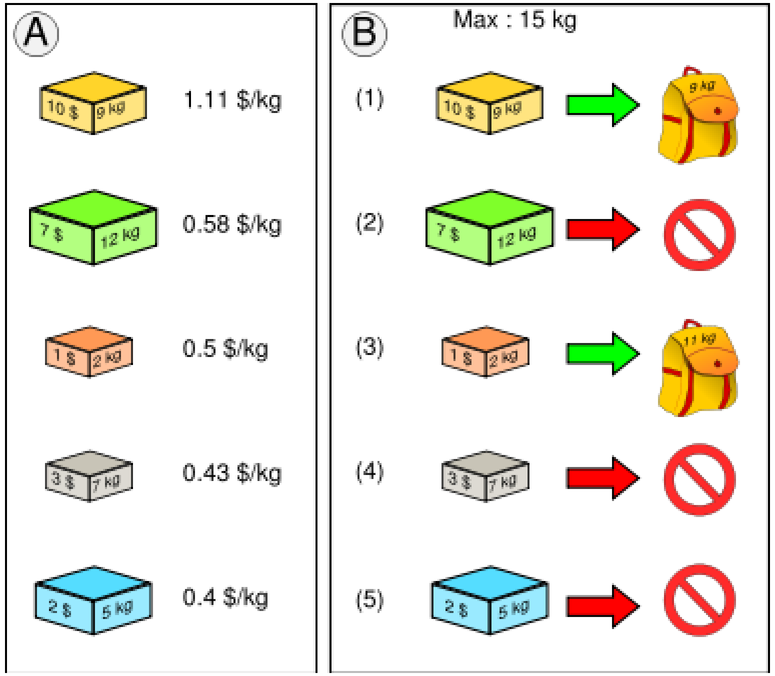
Example of Real-Time Kalman Filtering





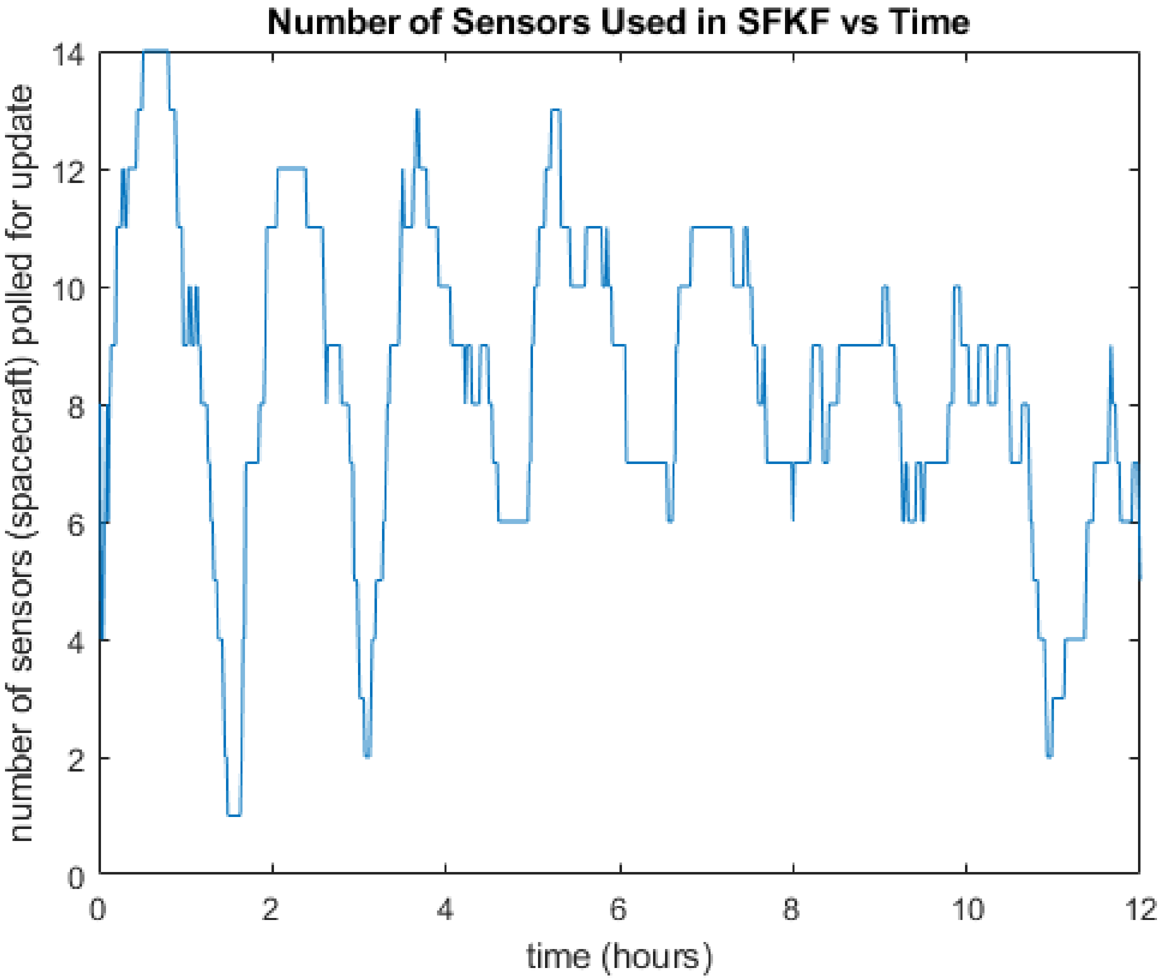
Greedy Optimization

- Not all sensors will be useful to improve the covariance at a given point in time
- Choosing the right ones is a complex problem, similar to the classic “Knapsack problem”
  - Greedy optimization is used to find a quick solution that is not necessarily the most optimal solution, but will satisfy the required parameters
  - This is done by sequentially selecting the measurement with the largest improvement (discard those that do not improve the state)



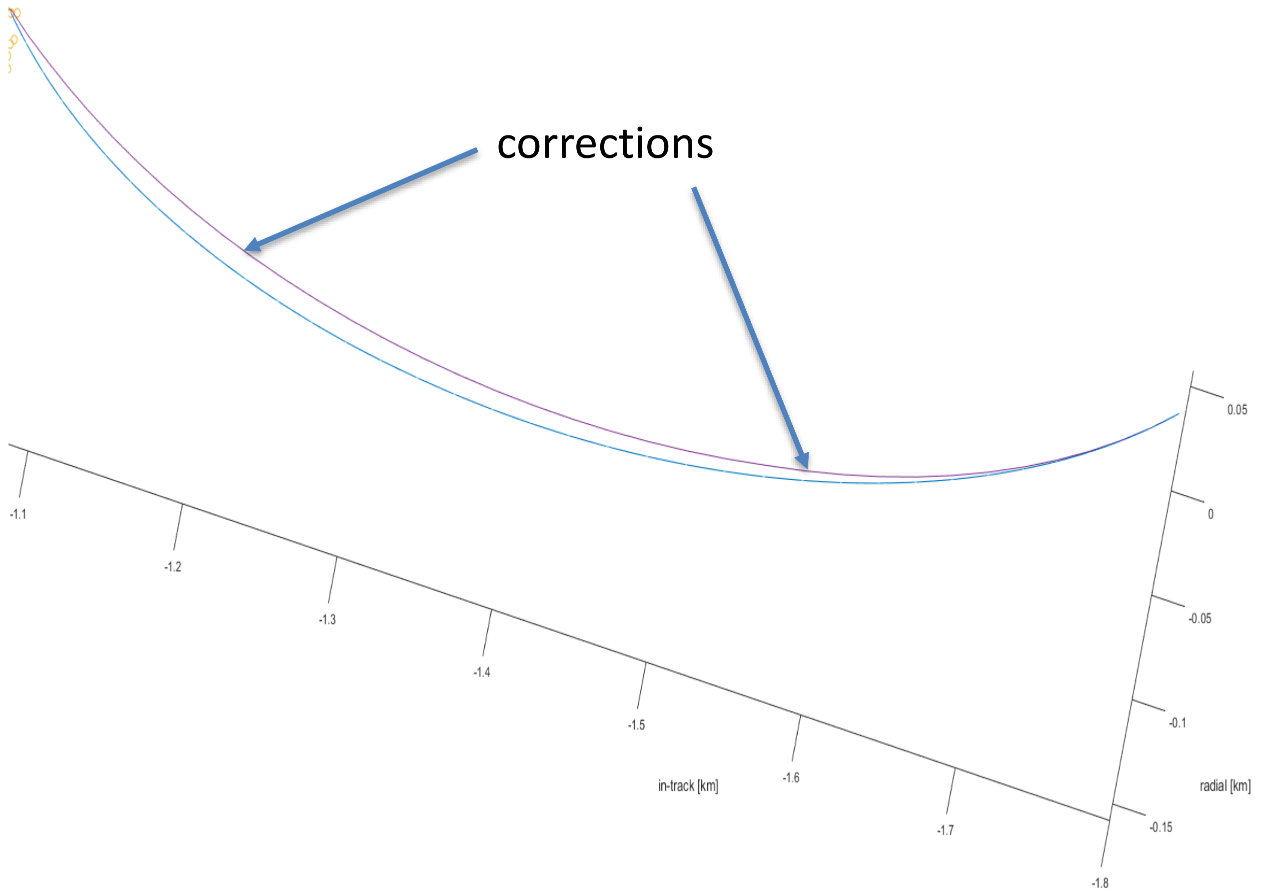
Greedy Optimization Example

Sensor Usage over Time



Trajectory Maintenance

- A Sensor Fusion Kalman Filter can be used to maintain GA generated swarm trajectories over time by tracking deviations from the initial trajectory and compensating with periodic correction burns
  - Each spacecraft is assigned a corridor and can deviate within that corridor without risk of collision with other SC (50m in these simulations)



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Results

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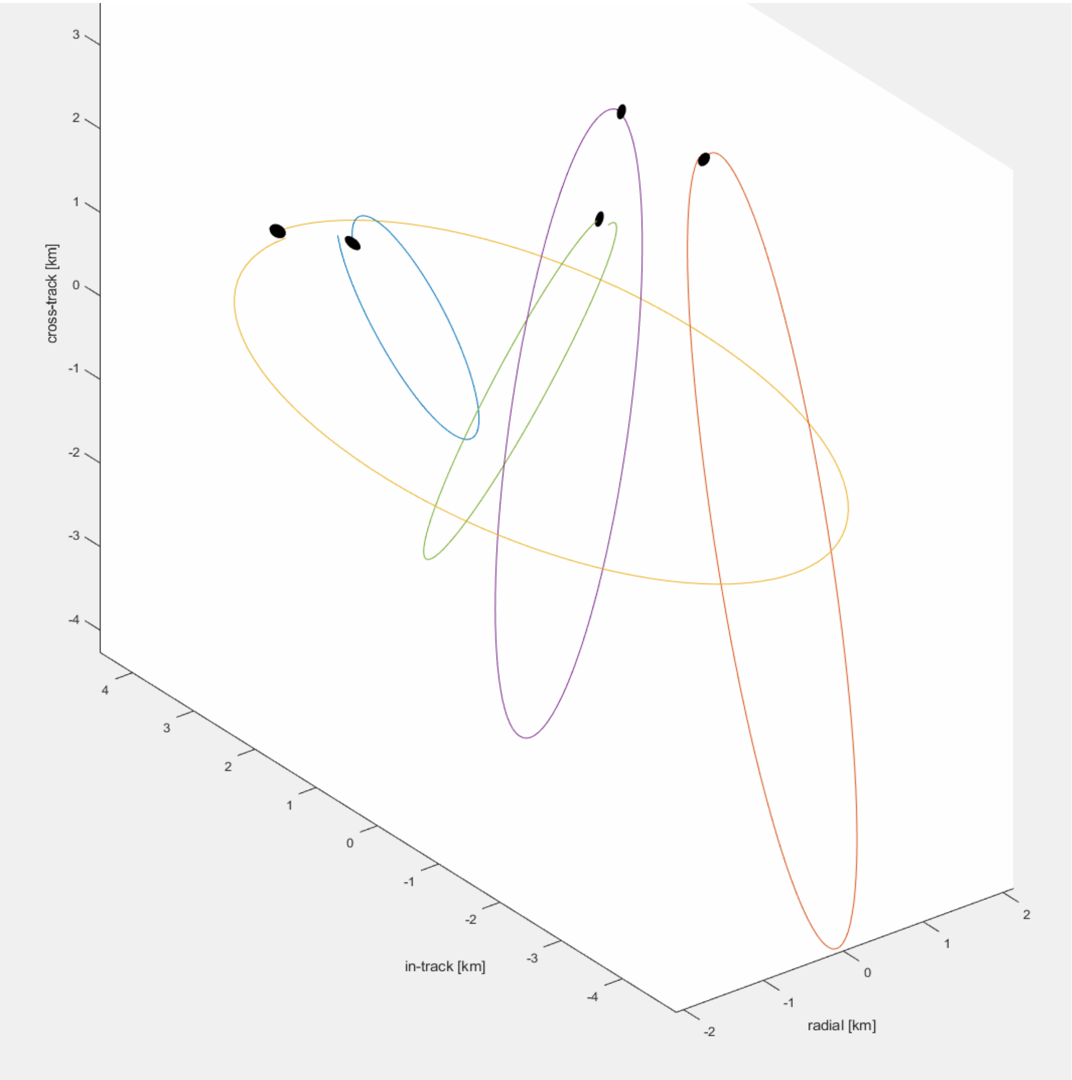
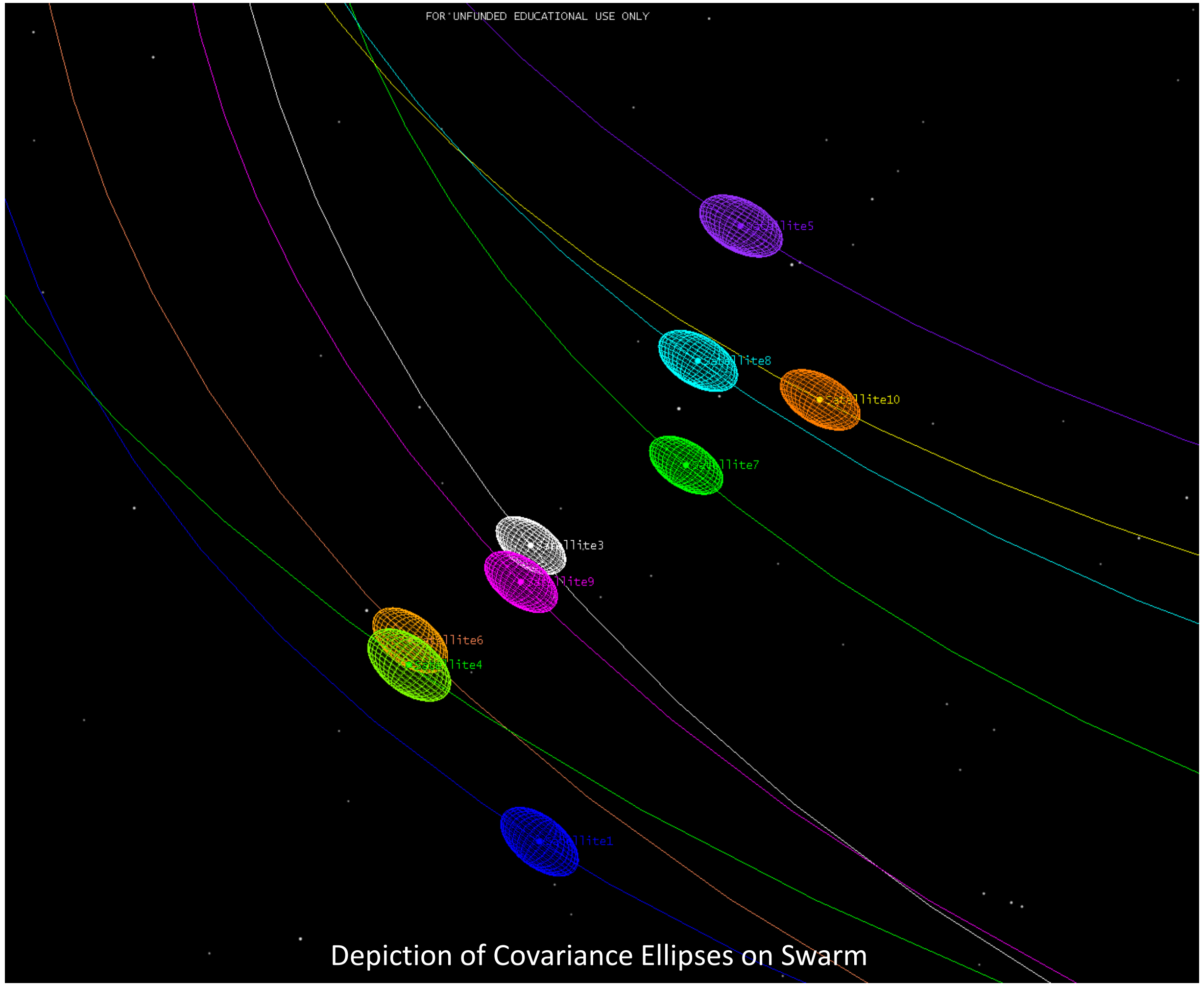


- Simulation shows SFKF can provide position estimates with 10m accuracy
  - Significant improvement over GPS alone, which is limited to 25m accuracy in LEO

Conclusion

- With swarms of spacecraft, there is an abundance of data available
  - Its necessary to build autonomous systems to sort and analyze this data in real-time, such as the SFKF
- Future research will test this system on a hardware testbed, such as an Air Bearing Platform



Depiction of Covariance Ellipses on Swarm