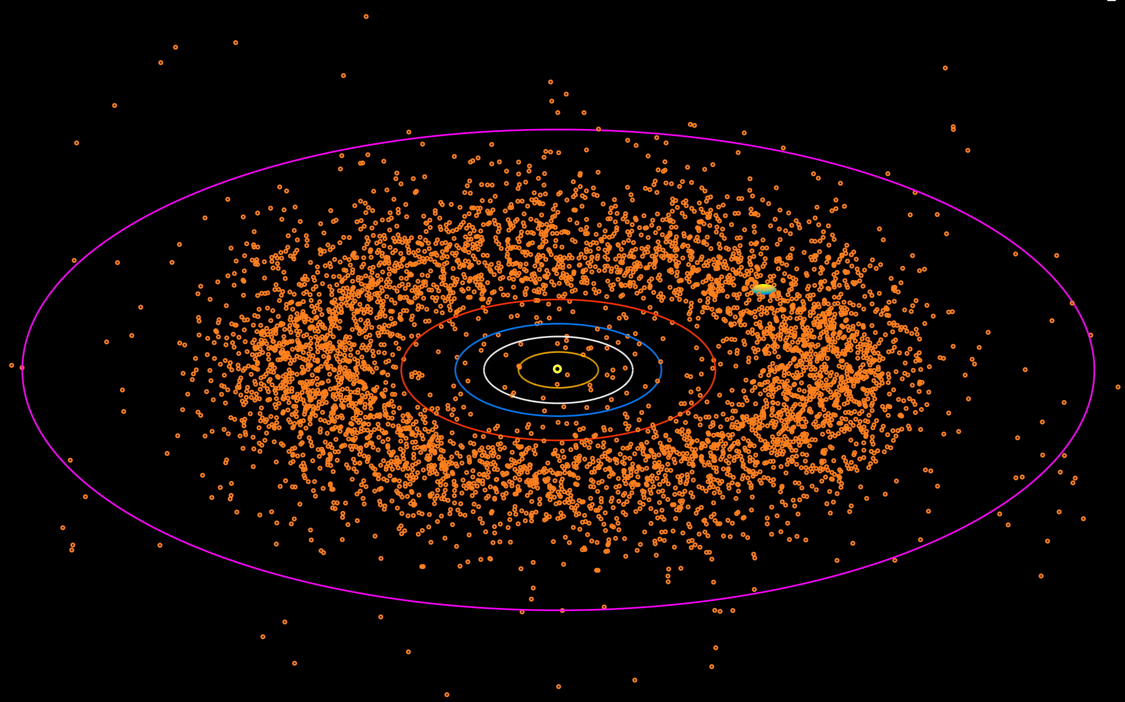
Evaluation of Mother-Daughter Architectures for Asteroid Belt Exploration



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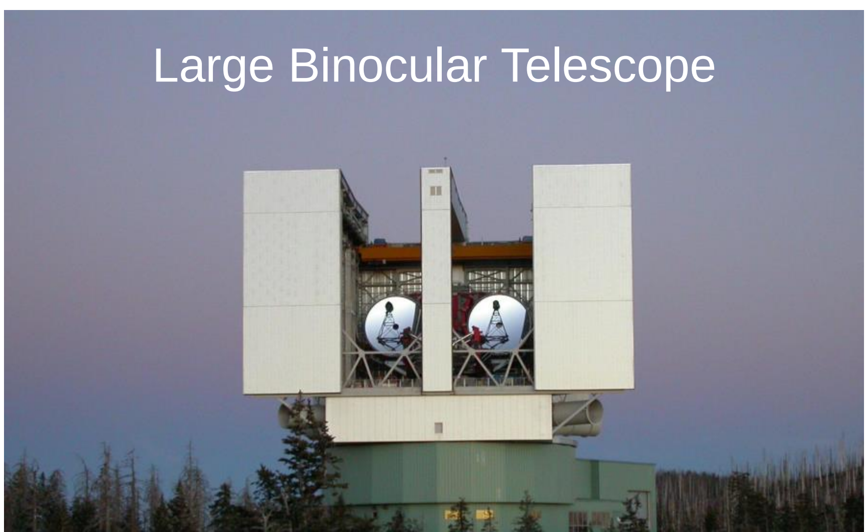
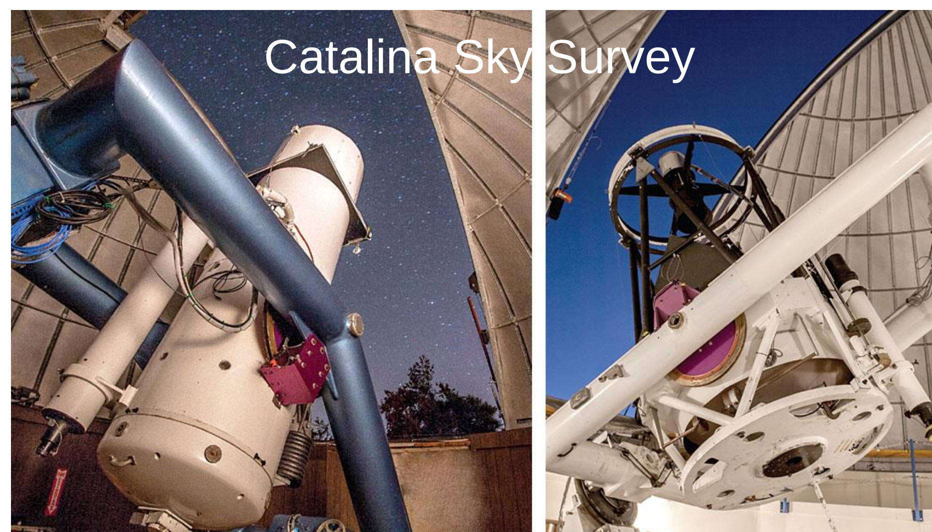
Over 700,000 asteroids are currently cataloged
- **Some as small as a few meters**

Each tracked asteroid represents a potentially large source of material for development.

Low gravitational potential reduces the cost of visitation.

We have little understanding of their individual composition



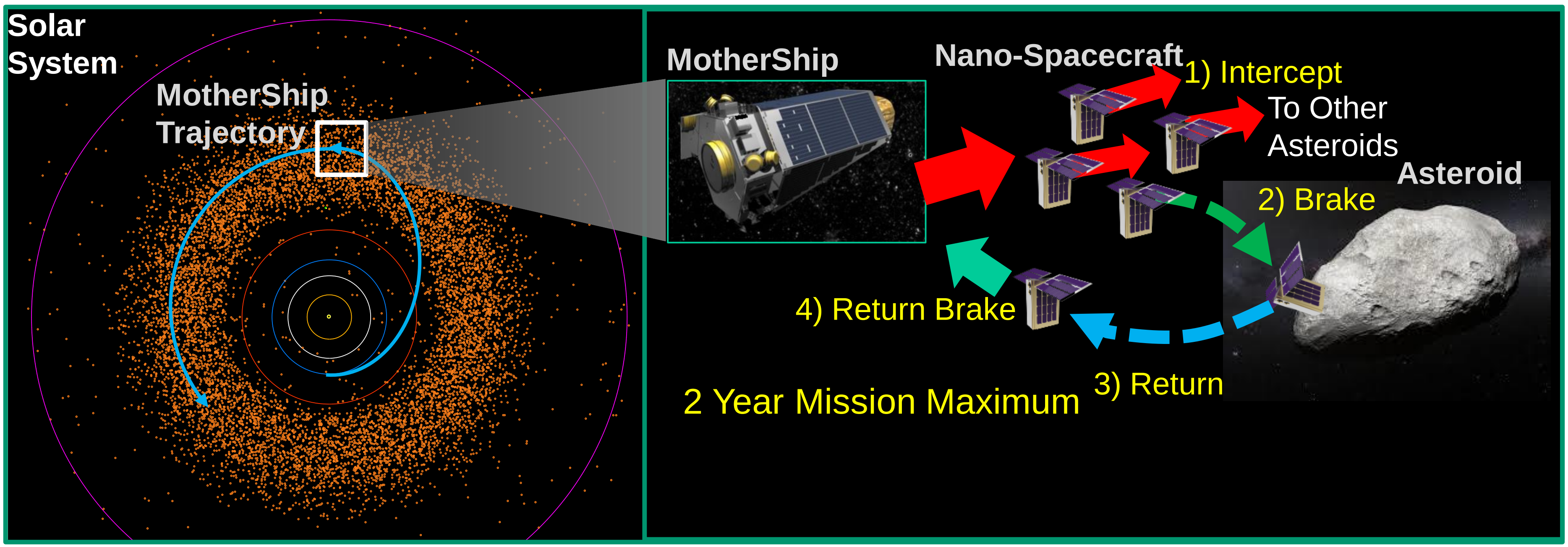


Individual sample and return missions from a significant number of asteroids allows us to understand the statistical make-up of the belt, improving in-situ resource development.

OSIRIS-Rex Sample Return Mission to to Near Earth Asteroid Bennu

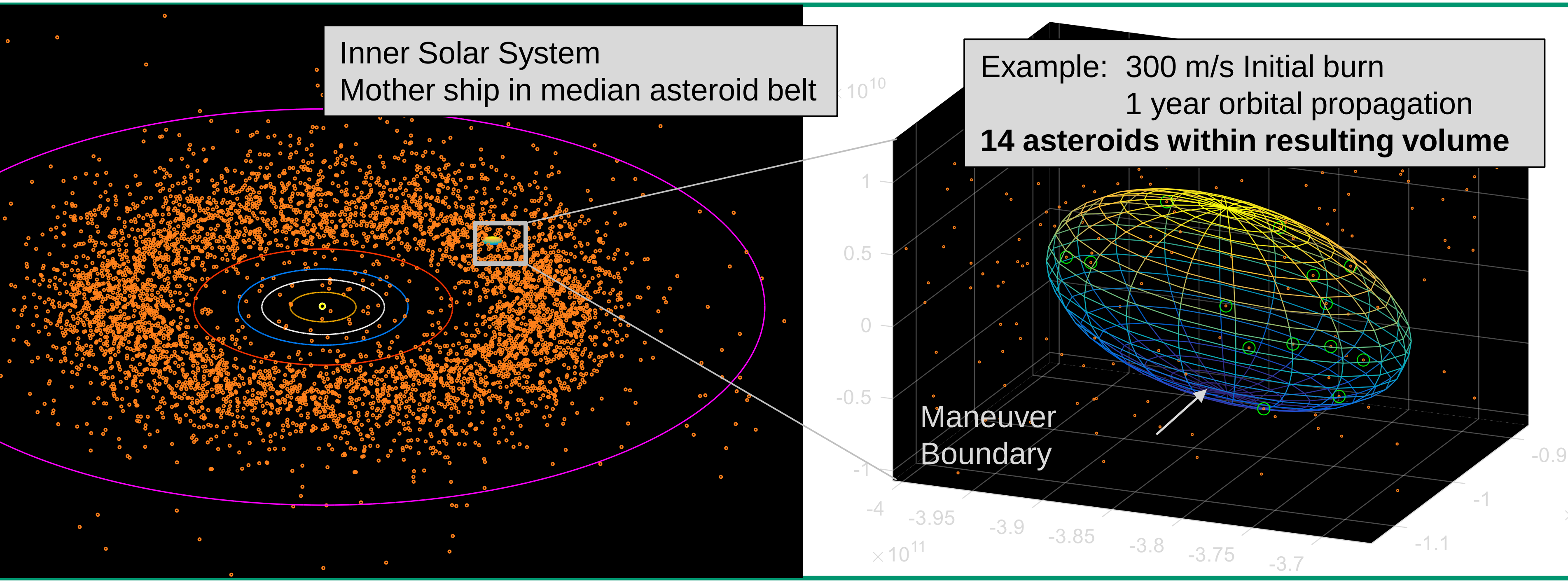
Mission Overview:

Multiple Nano-spacecraft are deployed from a mothership within the asteroid belt, each executing a sample and return from a known asteroid.



Question:
How effectively can a nano-spacecraft swarm explore the asteroid belt when limited to a 2 year lifespan?

Intercept Potential is established by determining inclusion within a nano-spacecraft maneuver boundary

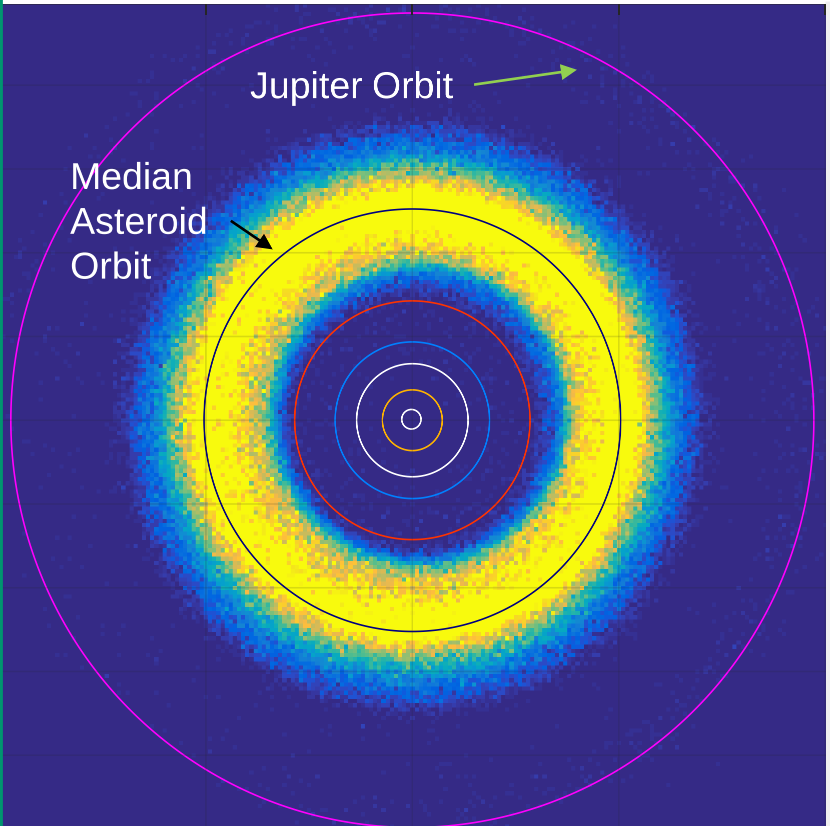


Multiple intercepts appear possible even using a small delta-V within the limited lifespan of a Nano-satellite

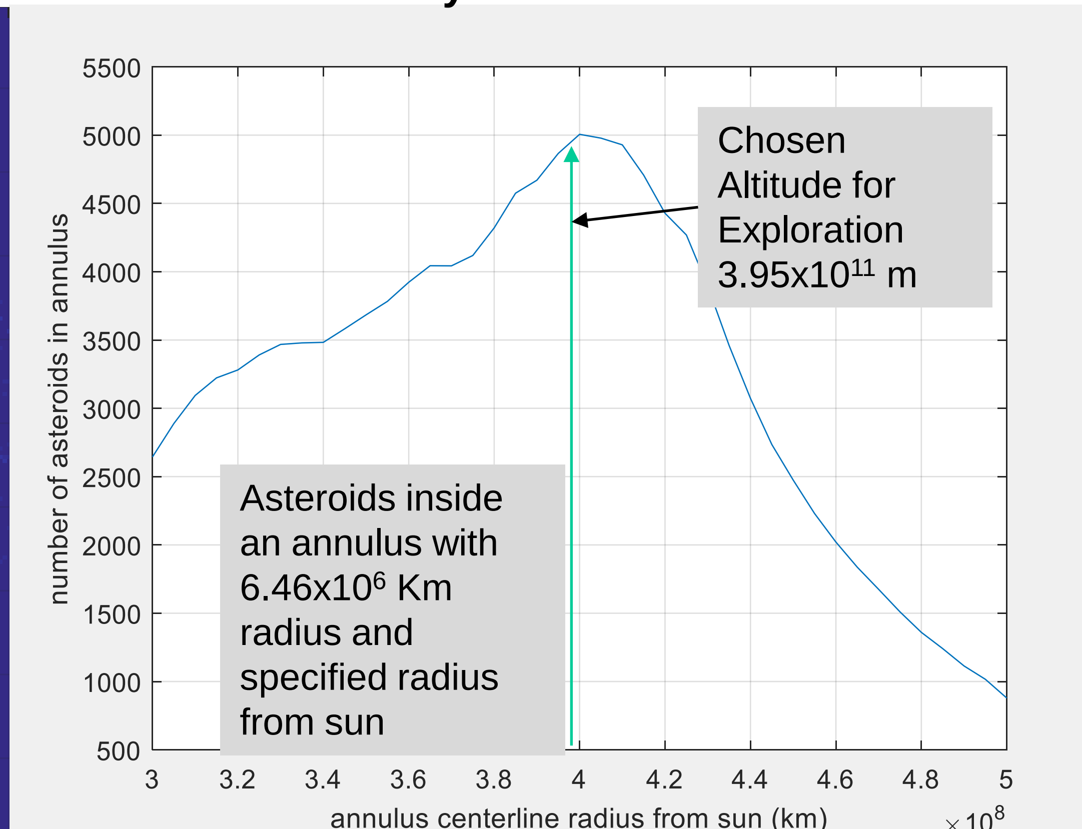
Next Question: What does an optimal initial orbit look like?

Place nominal mothership orbit at the location of highest asteroid density

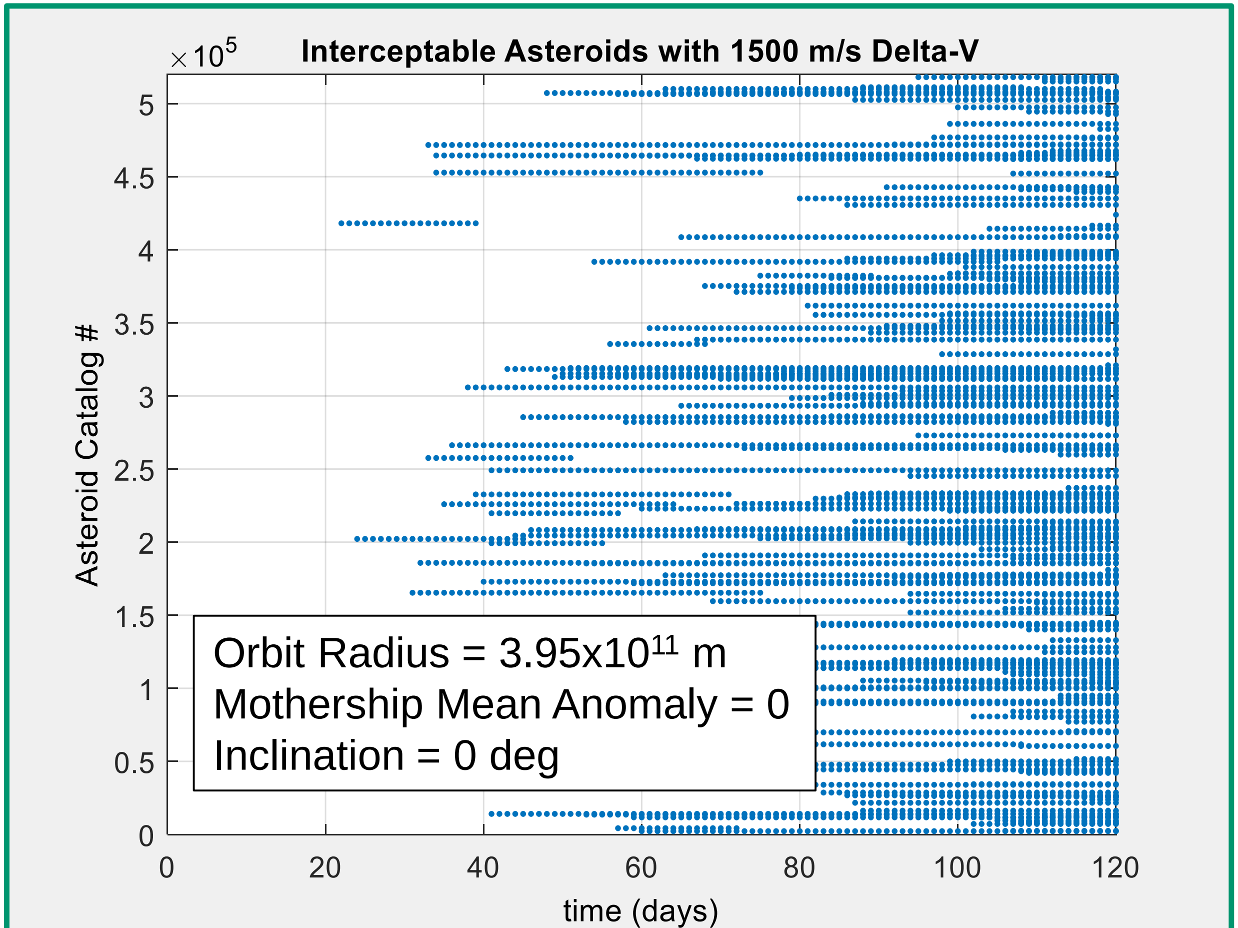
Asteroid Density in Solar System



Density afo Distance from Sun



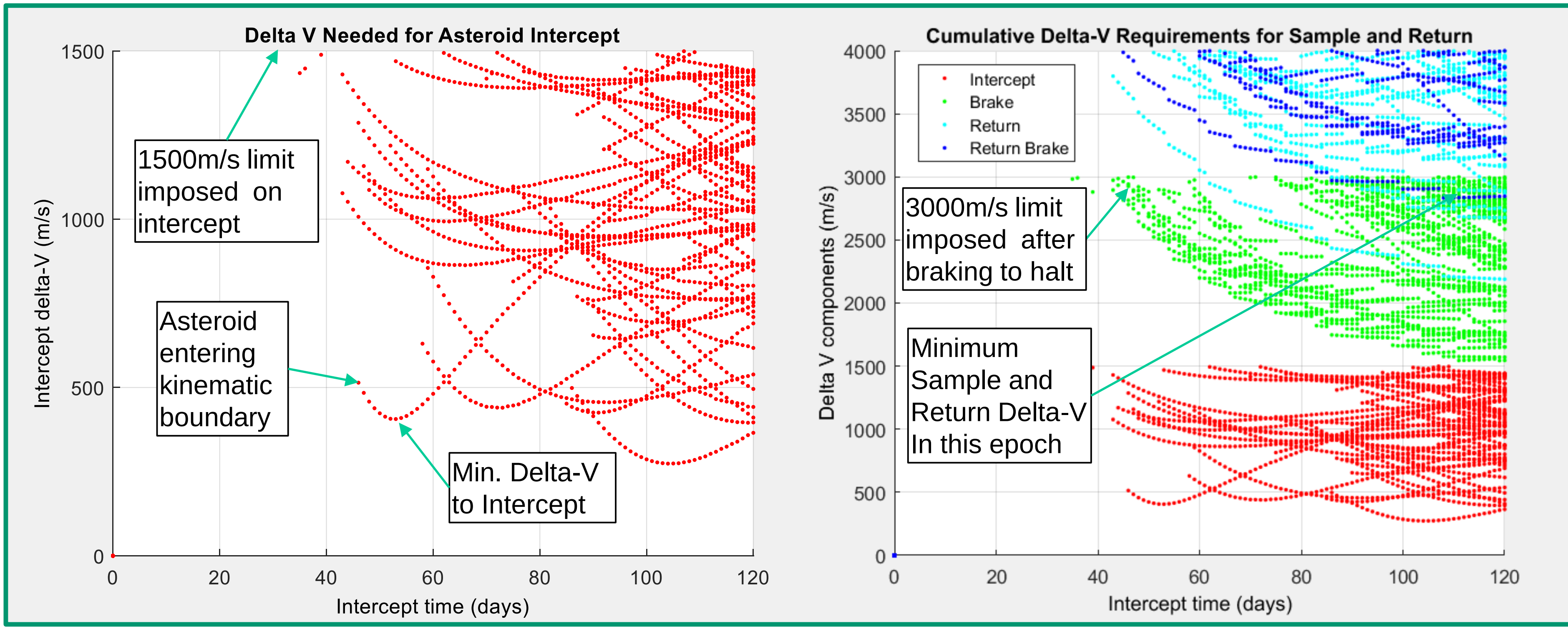
Many asteroids can be reached as nano-spacecraft flyout time increases



Hundreds of asteroids can be reached given reasonable delta-Vs and flyout times

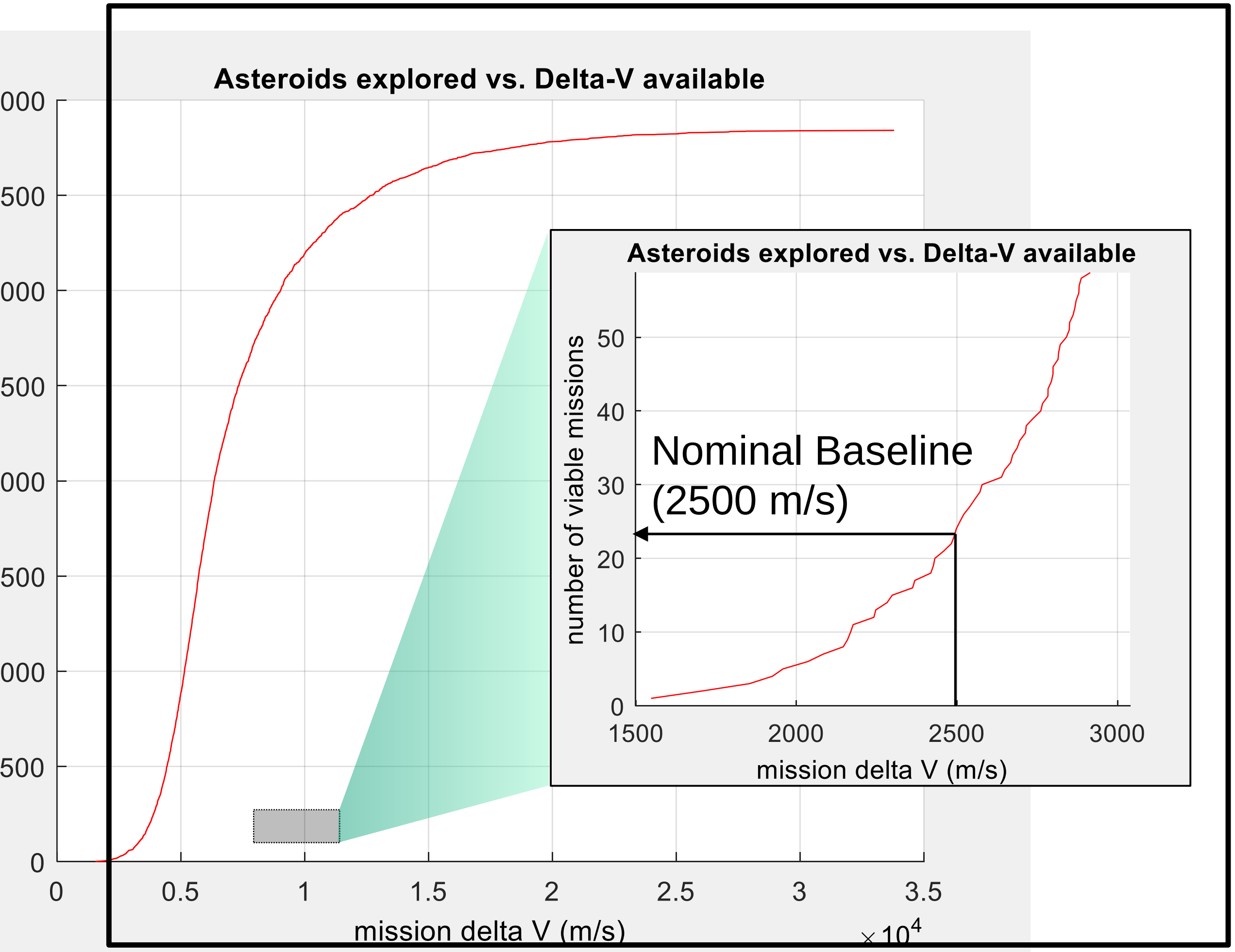
Next Question: How much delta-V does it then take to stop and return to the mothership?

Overview of Nano-Spacecraft Delta-V components for Asteroid Sample and Return



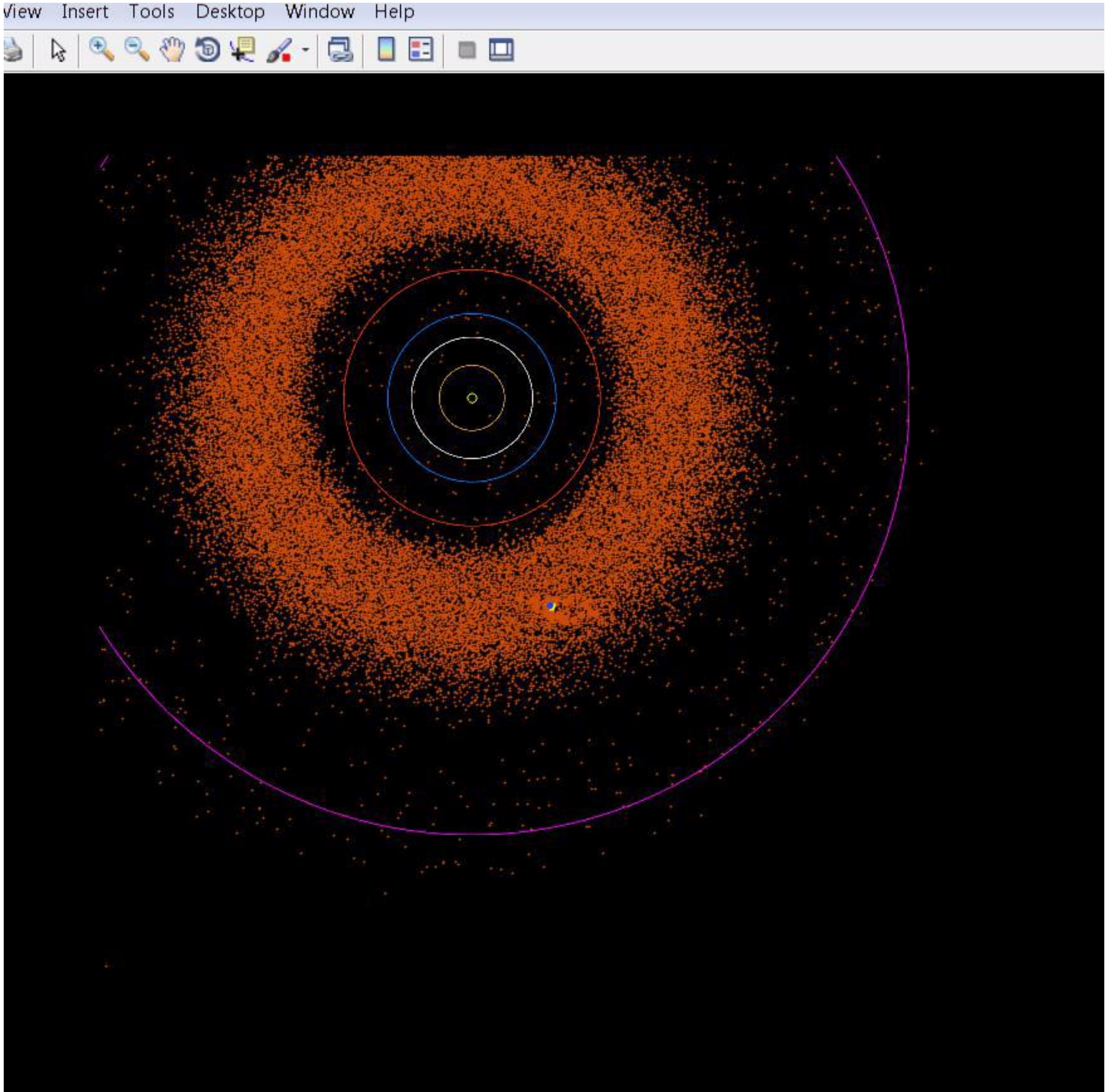
Combining elements of the sample and return flight provides an initial assessment of the total Delta-V necessary

Number of viable missions rise quickly as nano-spacecraft delta-V increases above 2000m/s



A cutoff at 2500 m/s total mission delta-V provides 23 mission opportunities

Nano-spacecraft limited to 2 year lifespan



Mission Example:

2 year lifespan limit

2.5 km/s delta-V per spacecraft

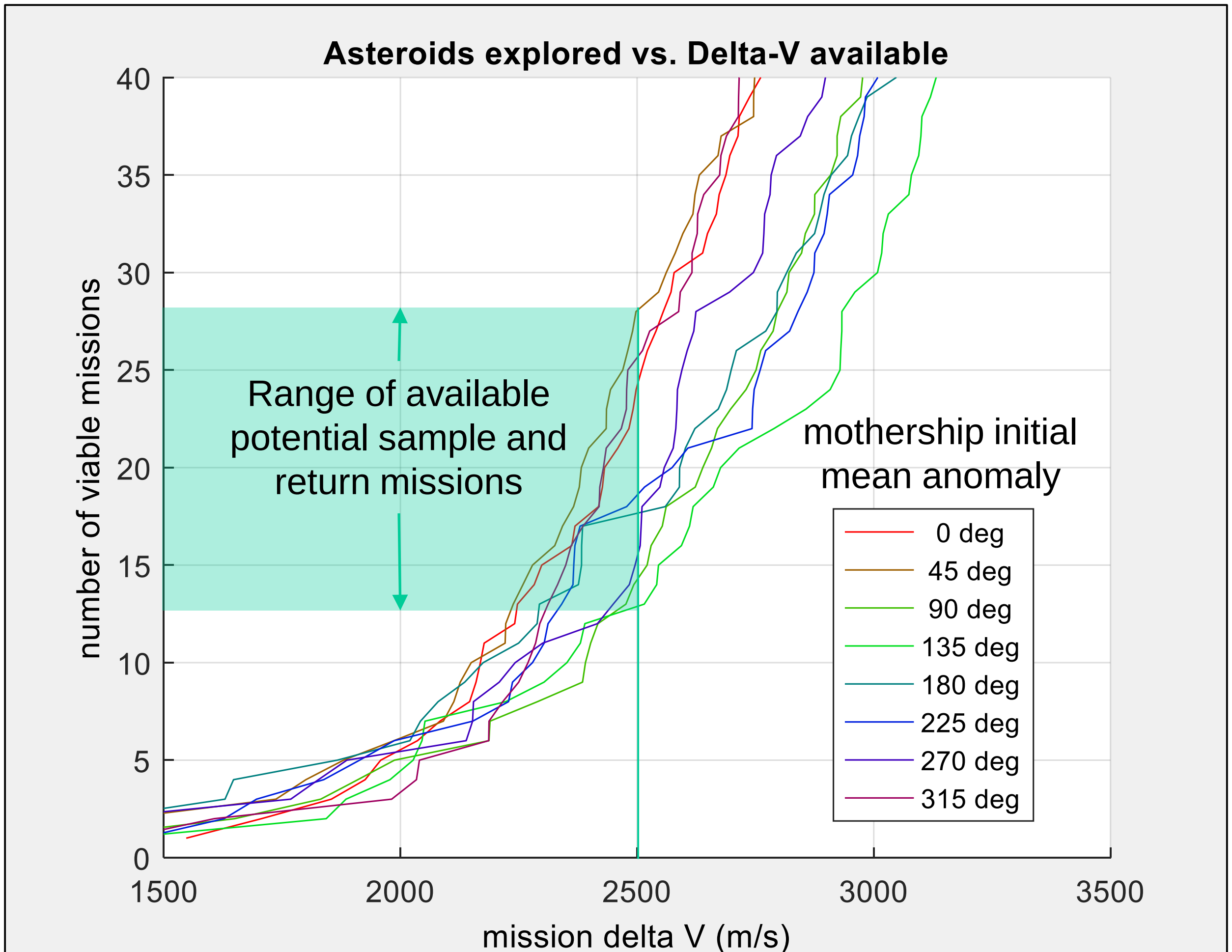
Mothership in median Asteroid orbit (yellow)

All nanospacecraft launched at beginning of epoch (Blue)

All nanospacecraft return at two years

23 Asteroids sampled

Choice of initial orbit anomaly can significantly effect mission opportunities



A factor of two difference depending upon the choice of initial phase of orbit.

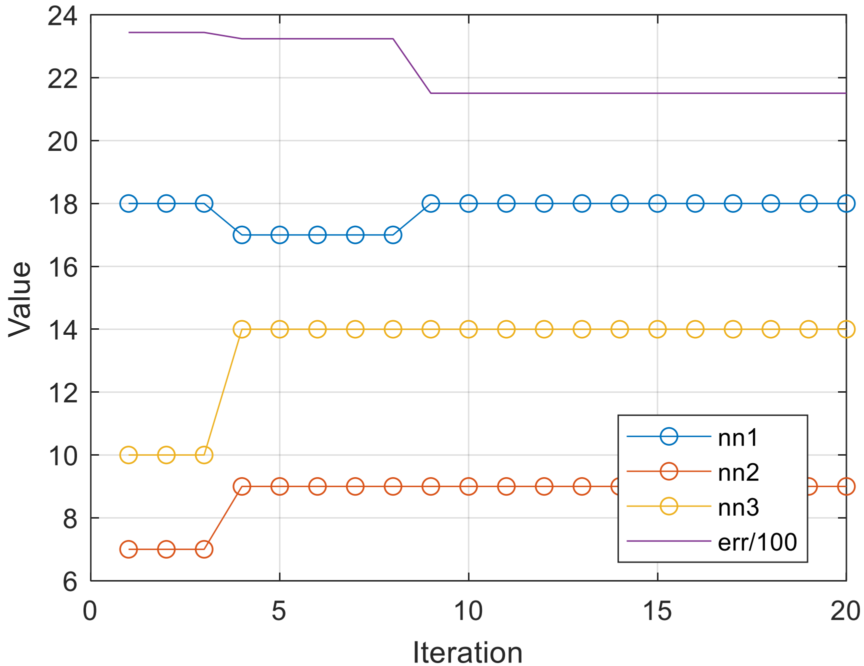
2 year lifetime assumed

- **Establishing number of missions for each location is computationally intensive**
    - **Only 8 points derived for 6 hours of CPU work**
- **Use of a neural network to approximate delta-V calculations could significantly improve speed**

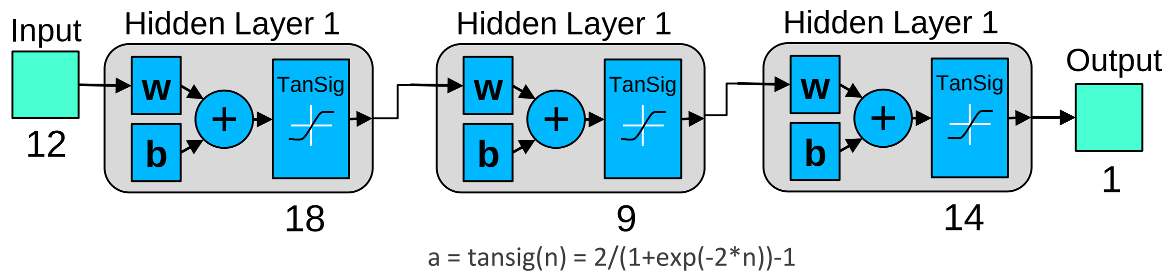
Process:

- Sample random asteroid pairs
- Throw out pairs which are more than 1 AU apart
- Bootstrap until 500,000 pairs are selected
- Use conventional Computation to calculate sample and return Delta V for each of those 500,000 pairs
- Provide this database as input to a Neural Net for supervised training
- Run trades on number of hidden layers and nodes in each layer to establish best performance

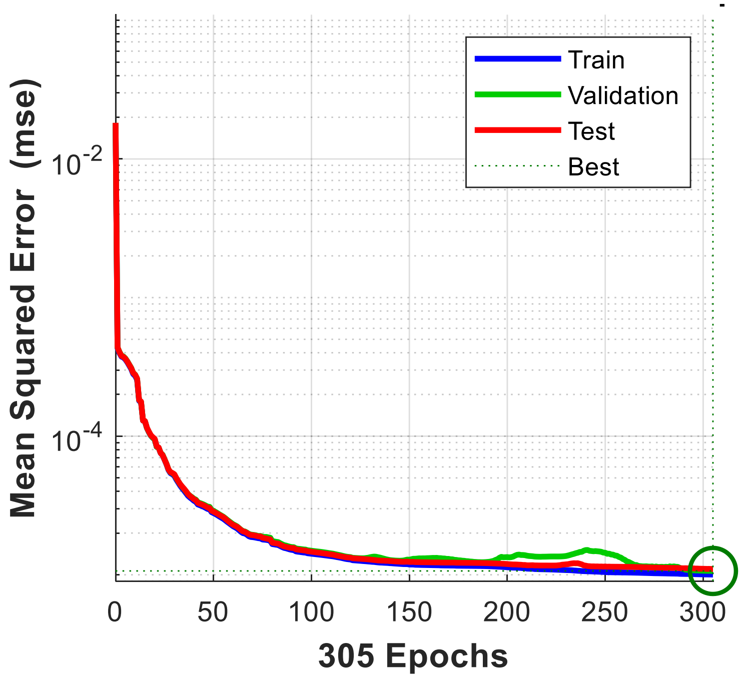
Optimization of Number of Nodes for a 3 layer Configuration



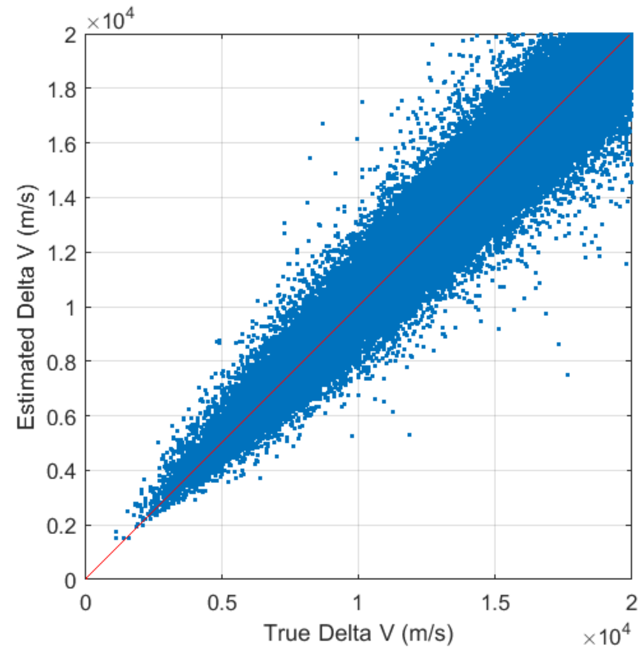
The chosen 3 layer configuration provides a respectable estimate of sample and return delta-V



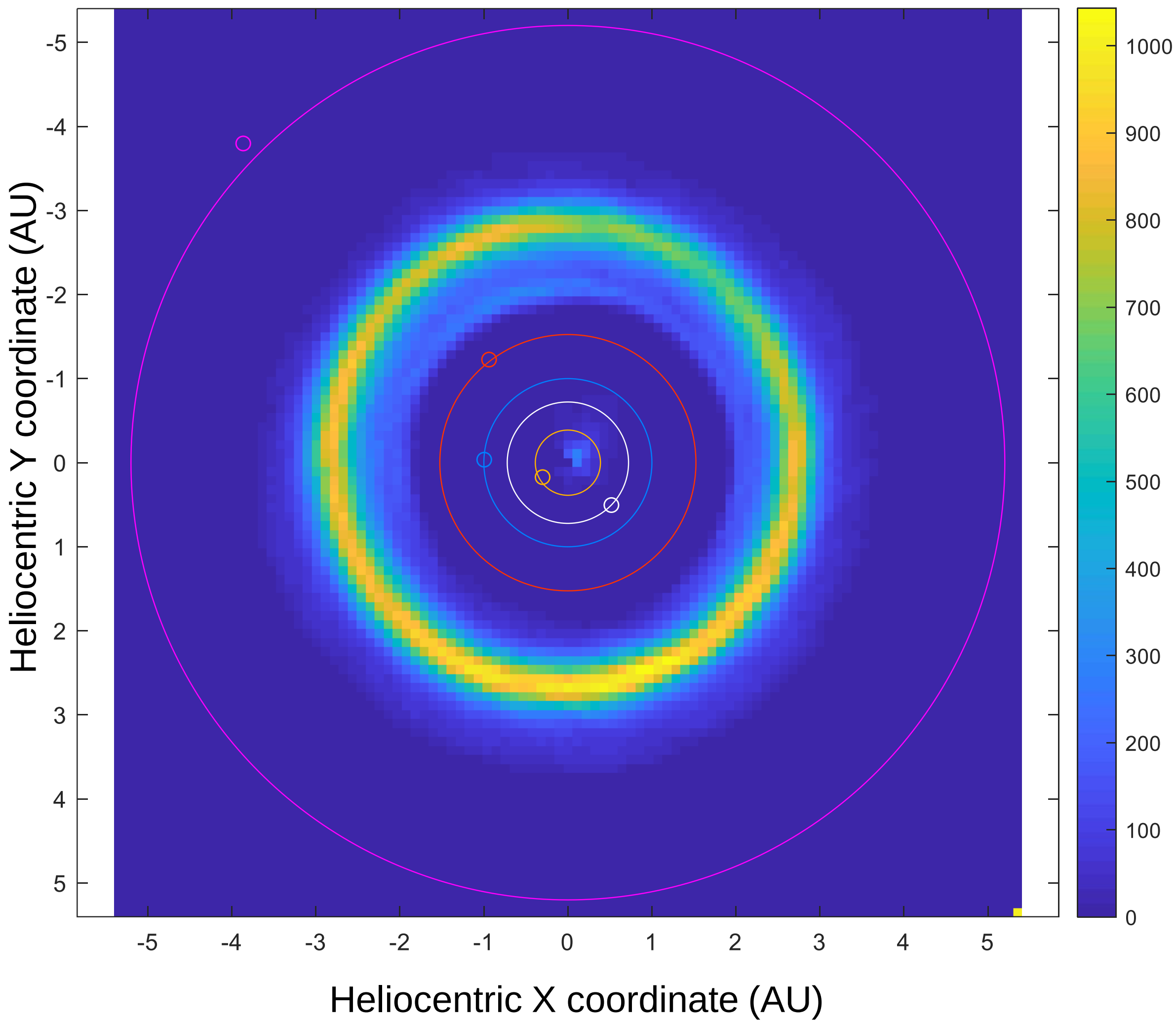
Training Error History



Actual vs. Estimated Delta-V



Sample and Return Missions Available



Neural Network Delta-V approach increases calculation speed by over 1000x

Sample and Return opportunities from a Mothership can now be mapped over the entire solar system

2 year nano-spacecraft lifetime

5 km/s delta-V per spacecraft

Assume mothership circular orbit

Julian epoch 2458200.5 (March 2018)

Conclusions and Summary

The large number of tracked asteroids suggests use of swarms for exploration

The Delta-V required to enable large scale sample and return from a single mothership is approximately 2.5 km/s

A two year nano-spacecraft lifespan is adequate for this approach

Large scale sample and return exploration of asteroids is plausible with nano-spacecraft utilizing single stage propulsion