A Near Deterministic Method For Constructing the GTOC-11 Dyson Ring

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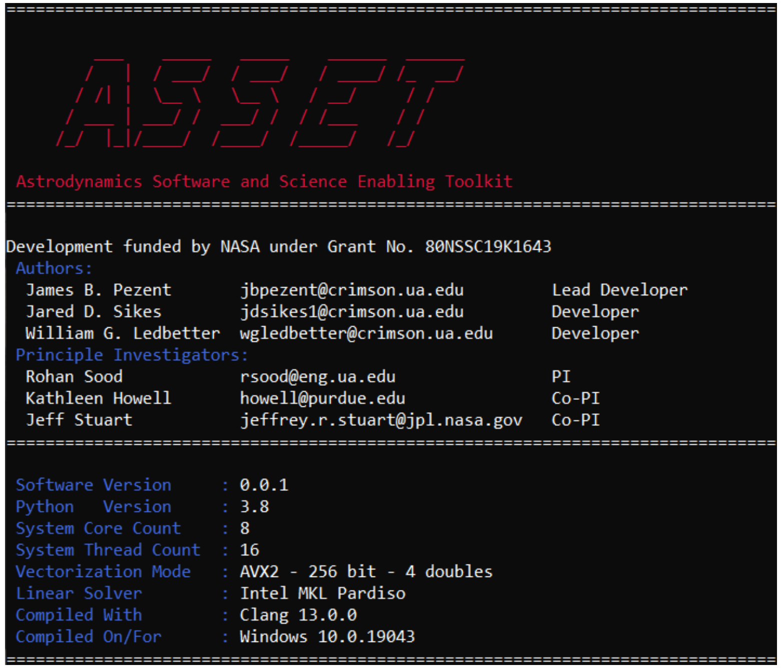
Overall Strategy

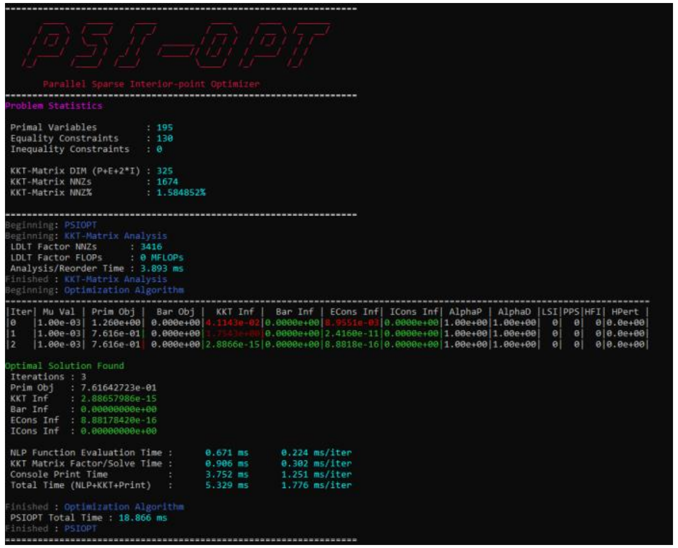
- Planar Dyson ring
- Construct many independent “Tours” wrt. fixed bins and radius
  - 1 Mothership flyby sequence
  - Transfers of all asteroids in sequence to at least one station
  - Sequential station build order
  - Equal build time for each station
- Combine 10 Tours in post processing
  - Bin-pack to increase minimum mass
- Full fidelity almost all the time

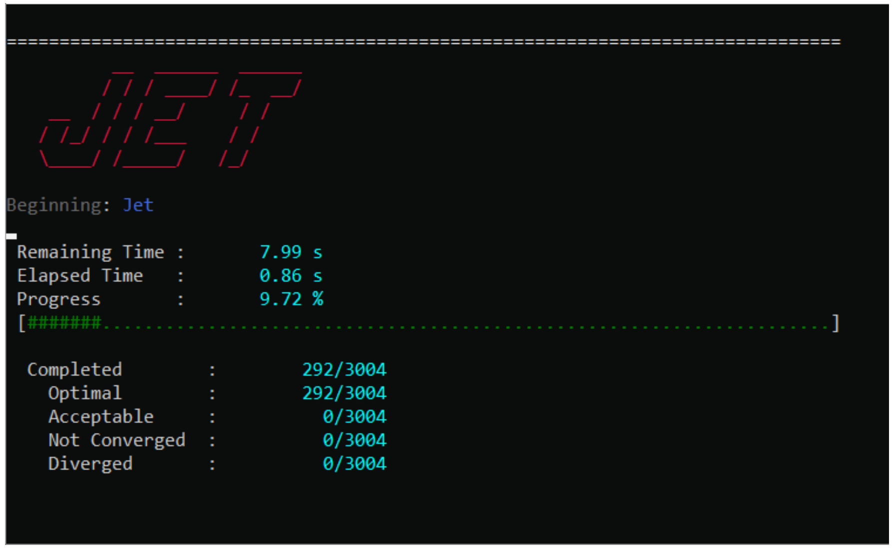
Tools

- ➢ Software
  - ➢ ASSET: Astrodynamics Software and Science Enabling Toolkit
    - ➢ Custom Sparse Non-Linear Optimizer (PSIOPT & Jet)
    - ➢ General Purpose Optimal Control
    - ➢ Spacecraft Trajectory Design
    - ➢ C++/Python
    - ➢ Developed at UA - Open source at EOY 2022

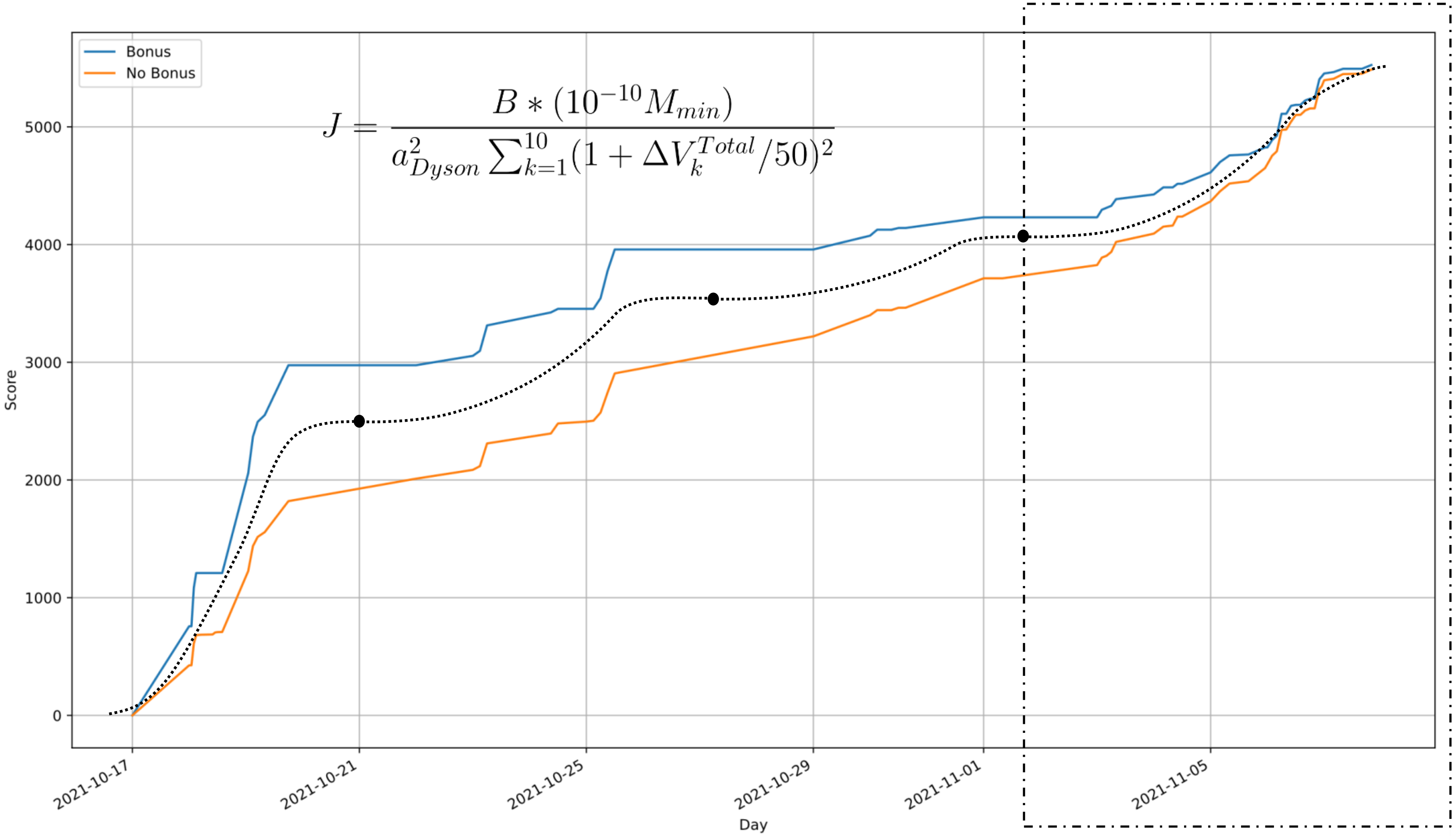


- ➢ Hardware
  - ➢ Two desktop computers
    - ➢ i9 9900k (8 Core)
    - ➢ i7 10700k (8 Core)





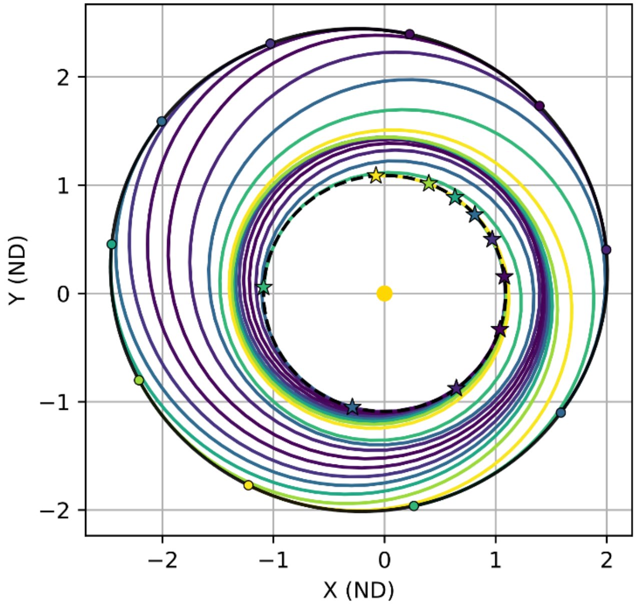
Development Cycle

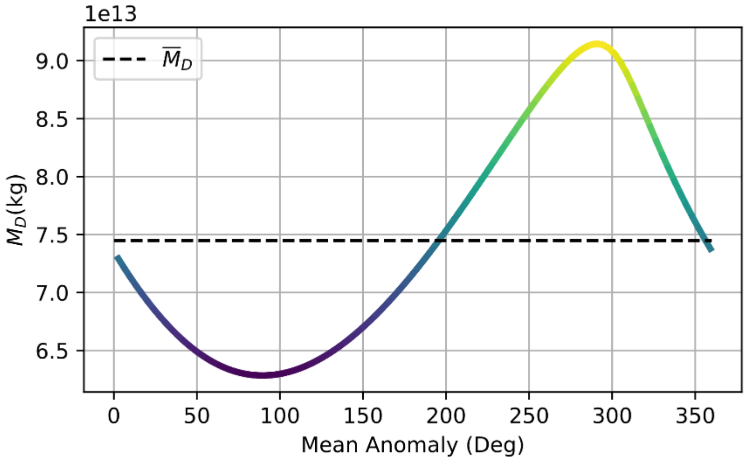


- Overhauled search 4 times
  - Restart when scores went logistic
  - Obtain old score as quickly as possible
  - Methods became simpler over time

- Focus on final strategy today
  1. Pre-Analysis
  2. Tour-Sequence Construction
  3. Tour-Transfer Construction
  4. Final Solution Construction

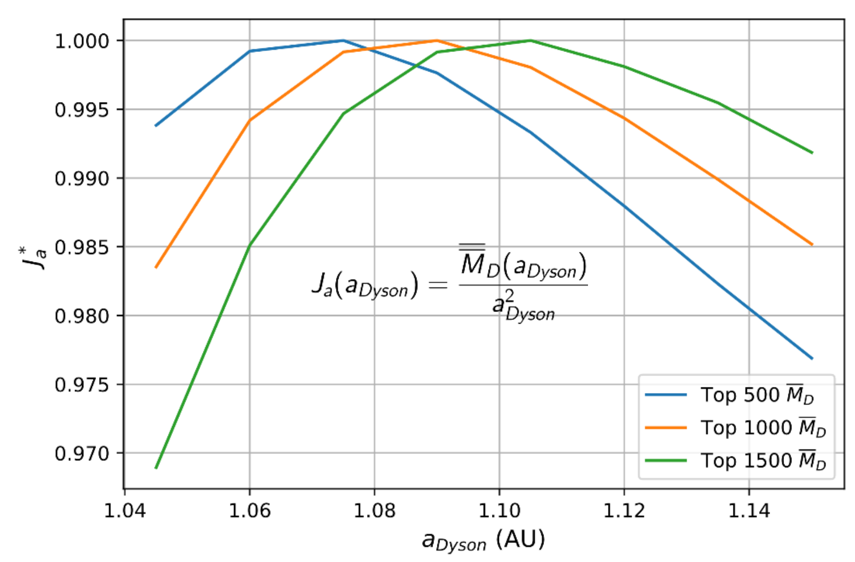
Pre-Analysis

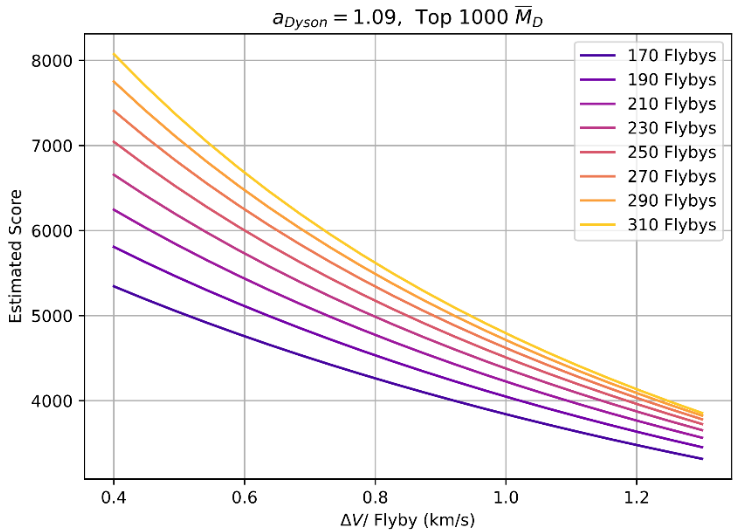




- Estimate best radius
- Estimate score for subsets of asteroids
- Compute mean mass delivered for highest mass asteroids
  - MEE Low-thrust model
  - Disregard phasing/rendezvous w/ station
  - Average over mean anomaly
- Repeat over range of station radii

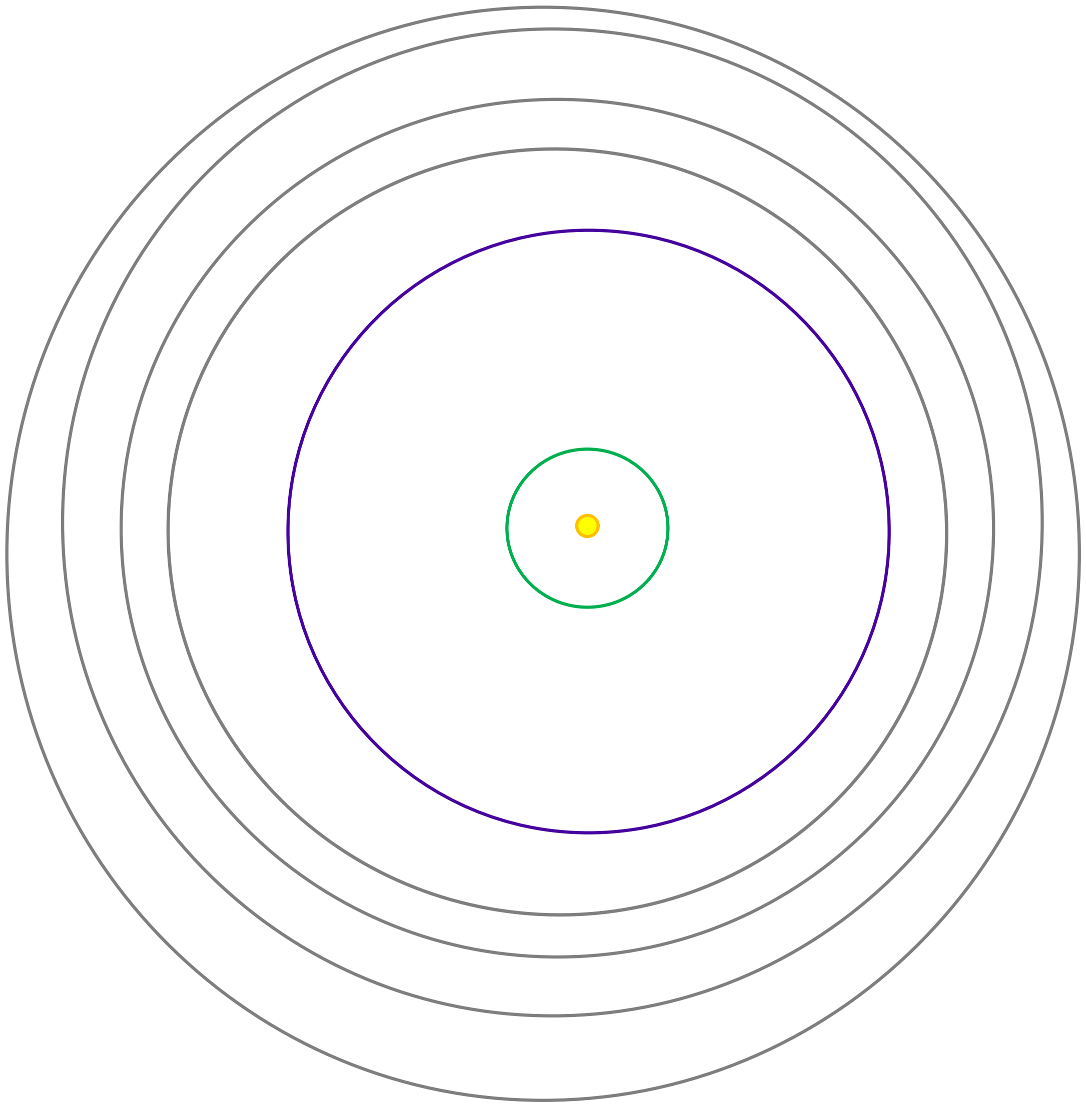
Pre-Analysis Results





- Best target radius depends on asteroid set
  - Target top 1000 average mass delivered ($\overline{M}_D$)
  - Chose 1.09 AU
- Derive upper bound on tour TOF
  - 15.5 years
- Derive acceptable ΔV targets to meet a desired score
- Target ΔV/flyby of .75 km/s and 190 – 230 flybys
  - Chosen due to time constraints
  - Should score 5000 or better

Sequence Construction



- **For each asteroid in high mass delivered set**
  - Find lowest ΔV Lambert solution from Earth
    - Must depart within first year
  - Converge full fidelity flyby
    - Two ΔVs per leg
- Loop
  - Estimate ΔV to all other asteroids in high mass set
    - Lambert solver
  - Select minimum n Lambert ΔV asteroids
  - Solve n full fidelity OCPs with these asteroids as next target
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  - Lowest ΔV solution becomes new sequence
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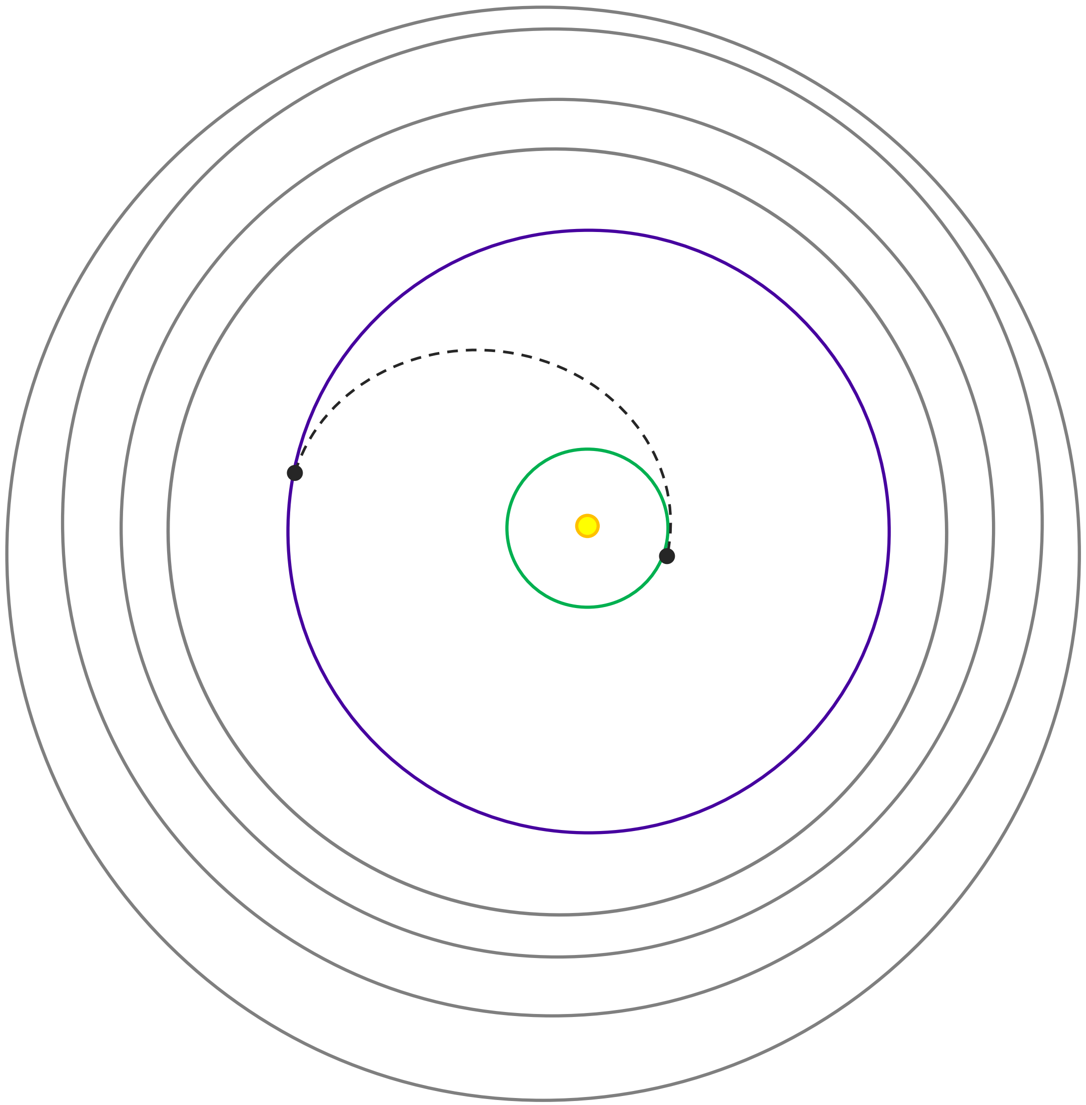

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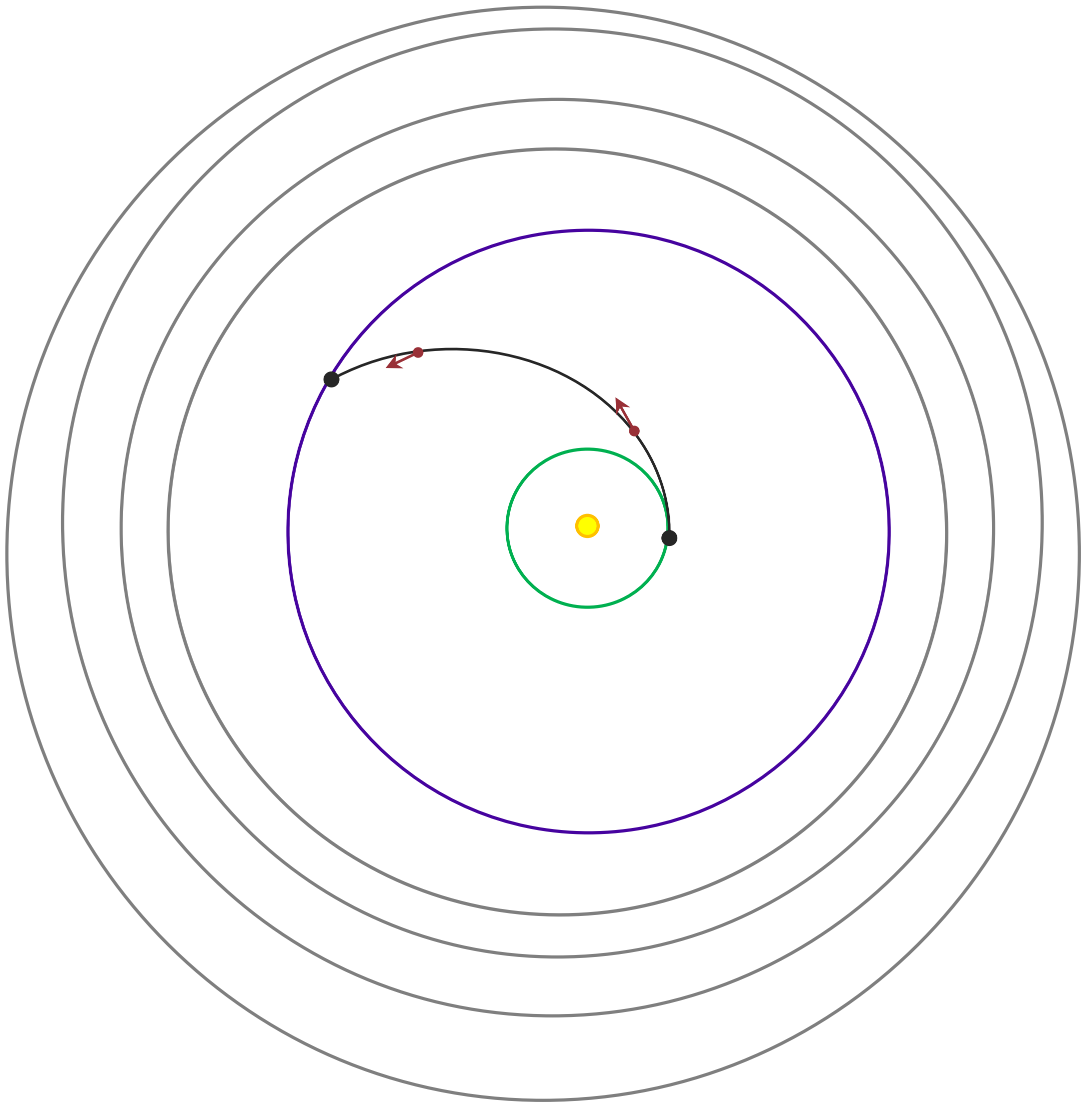

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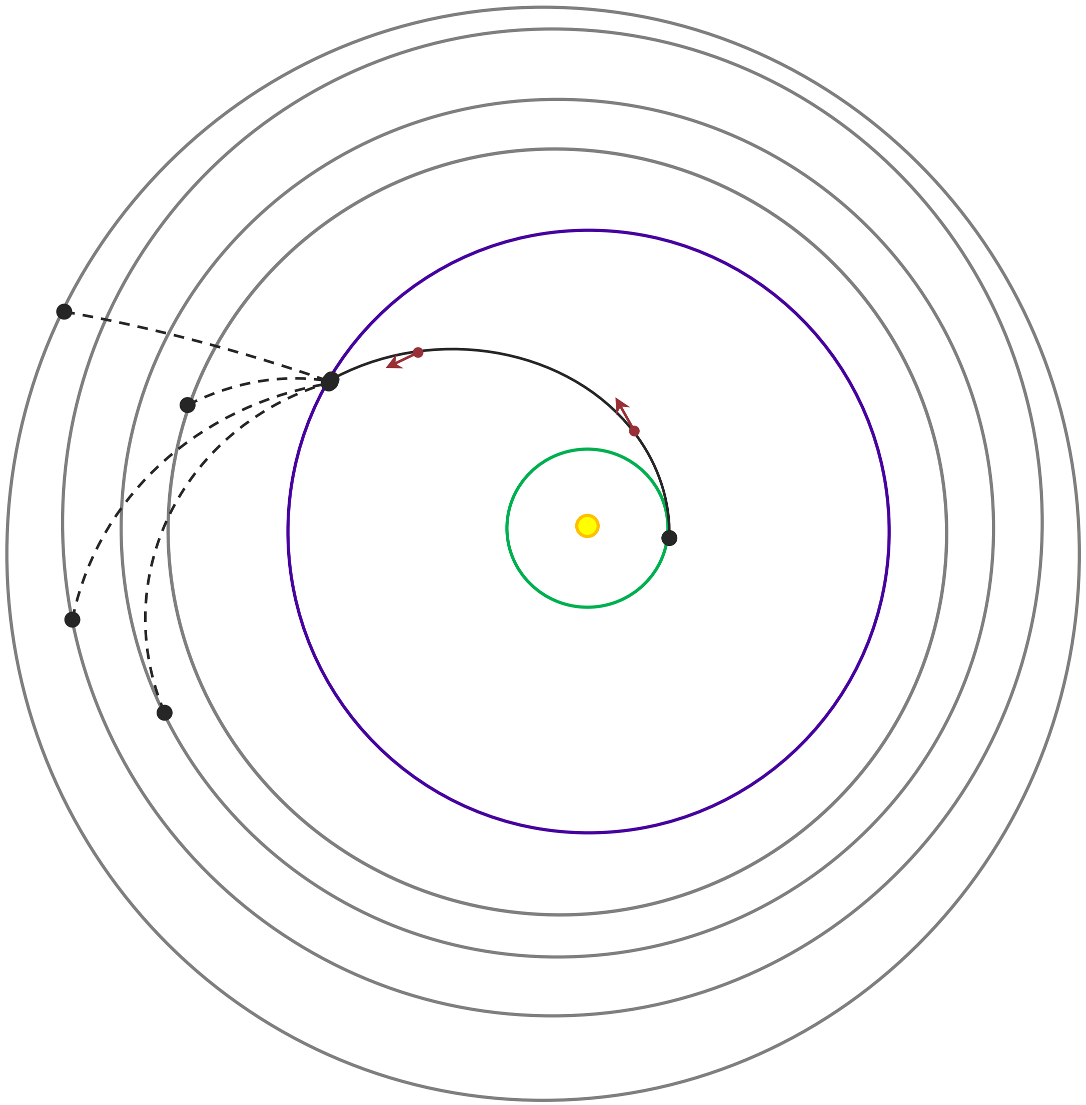

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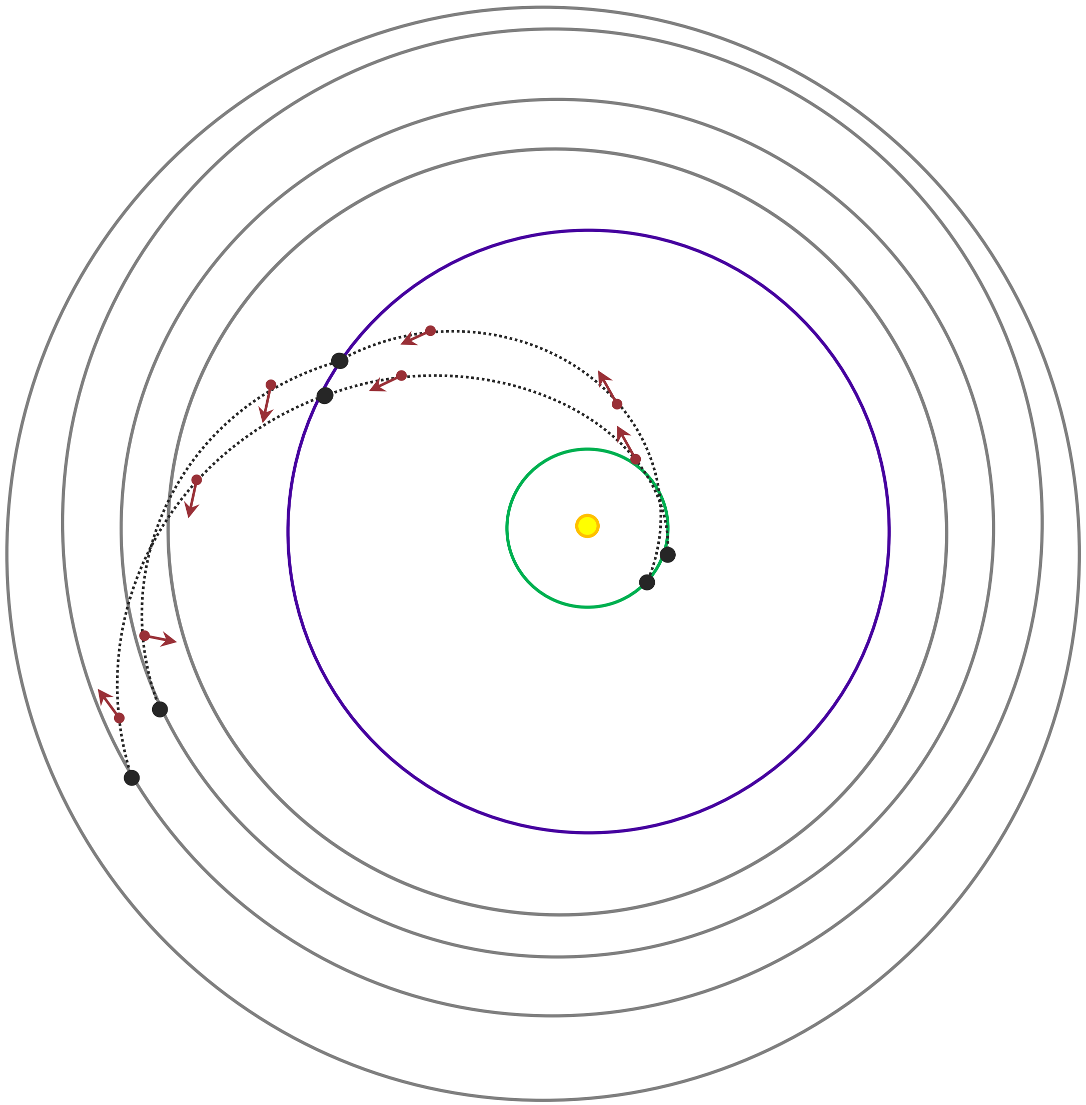

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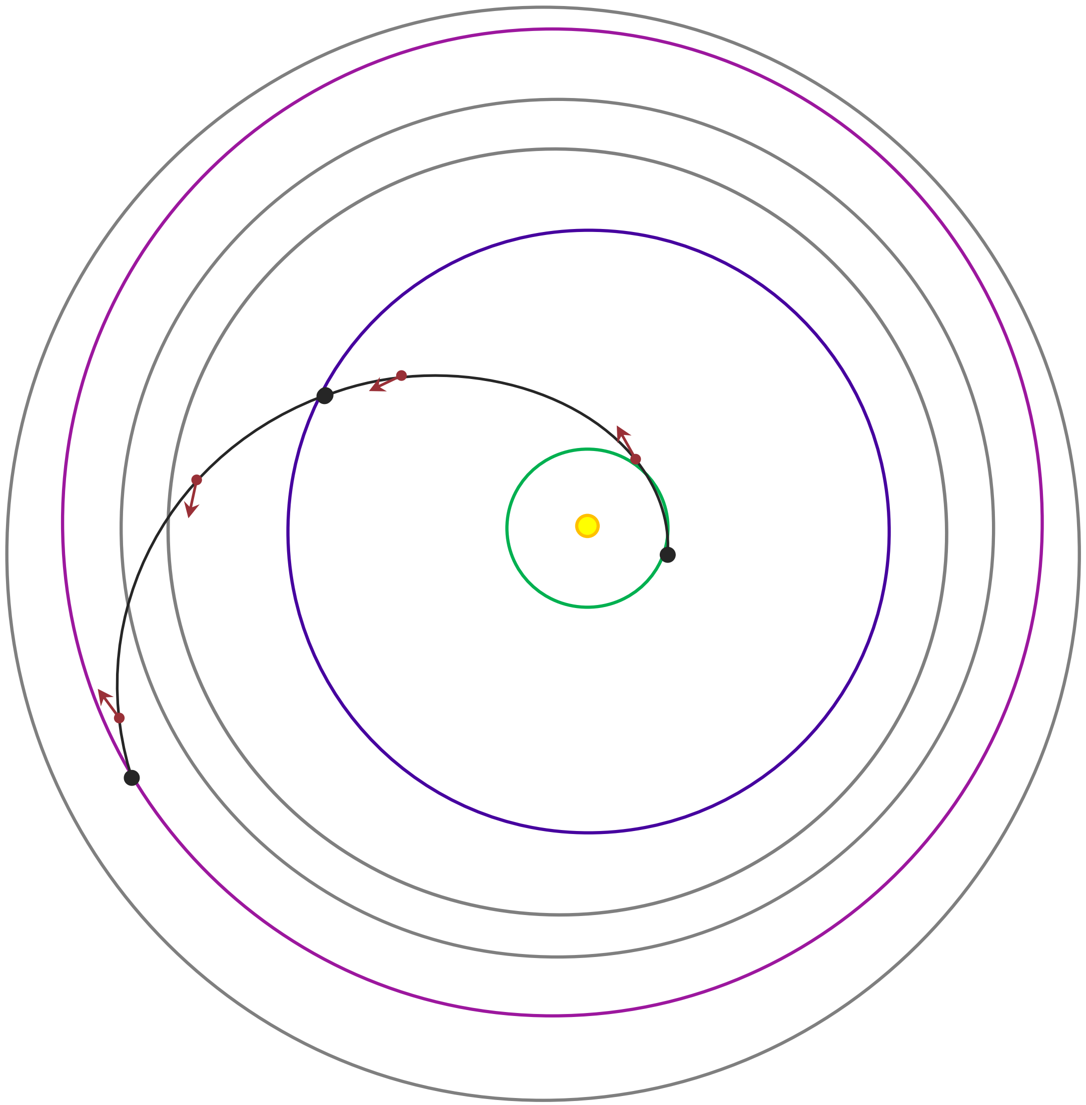

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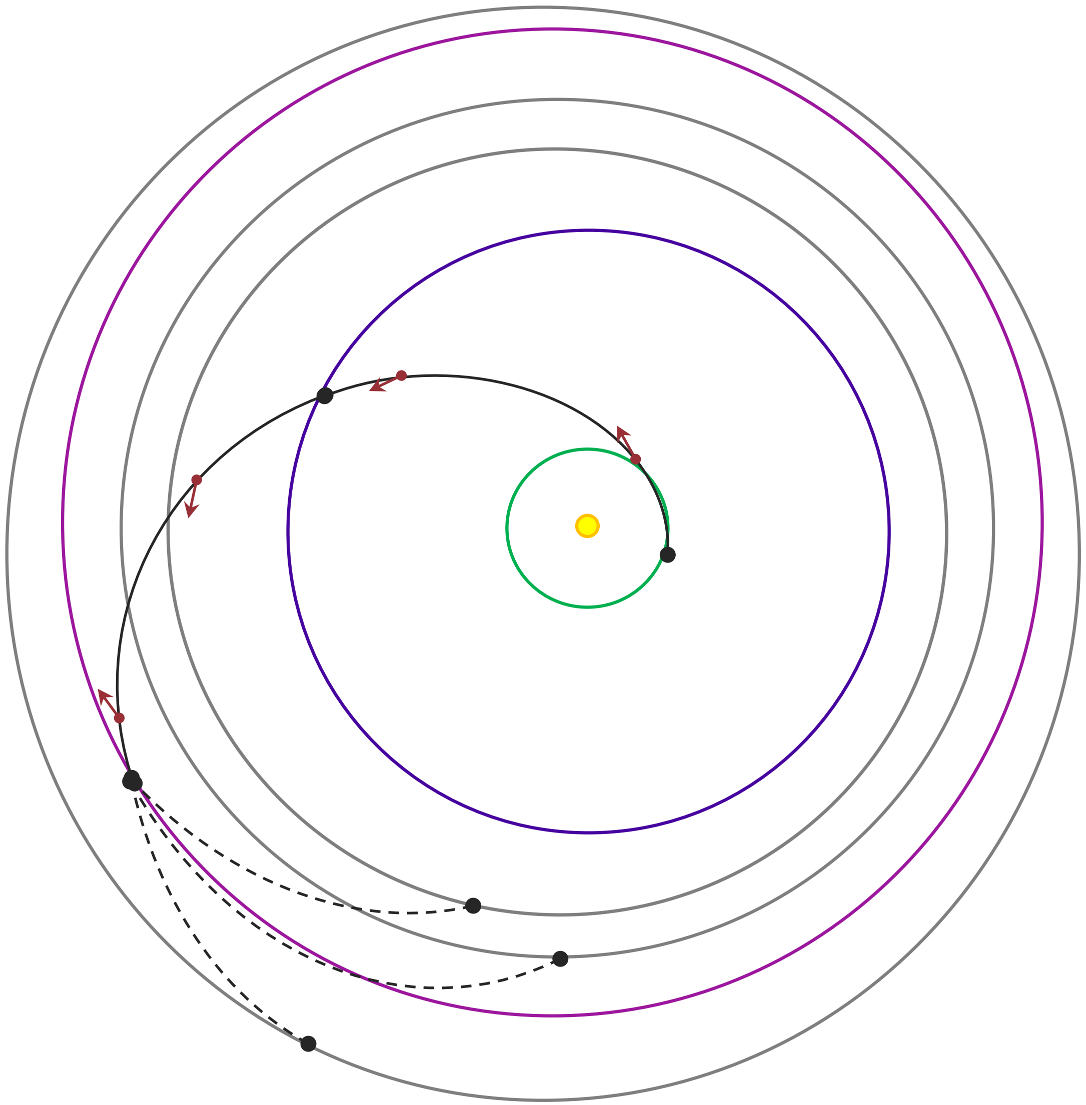

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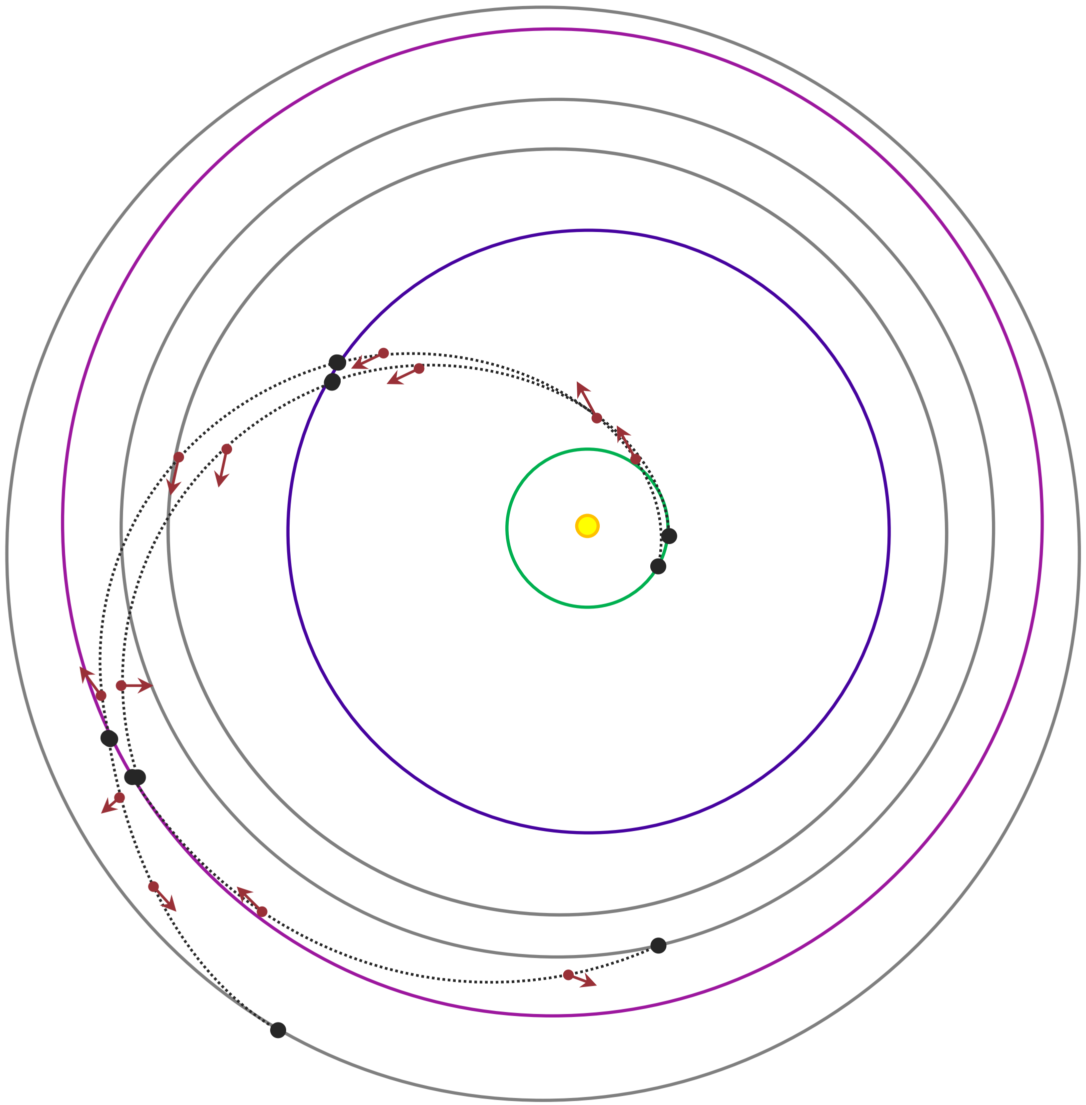

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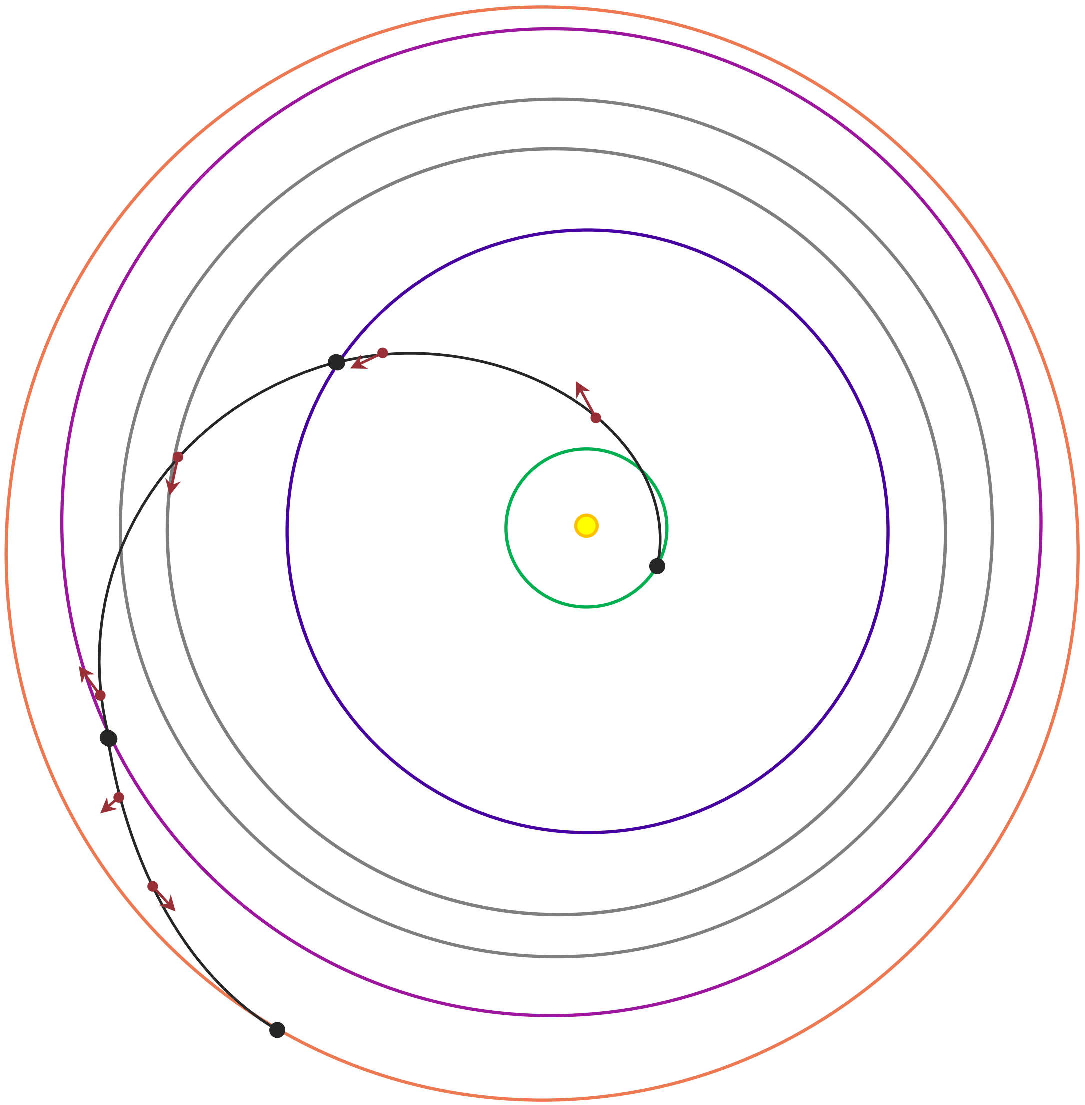

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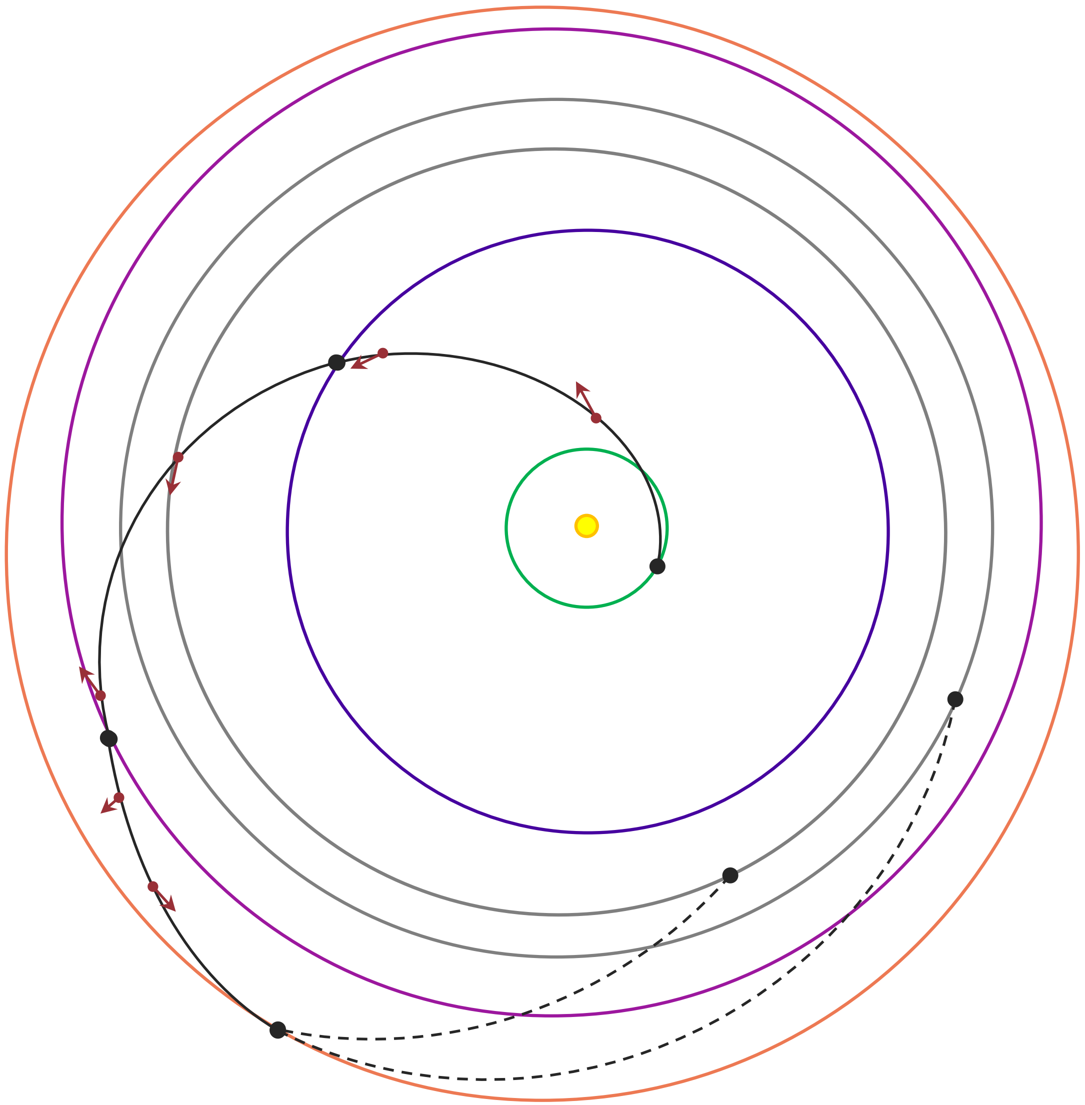

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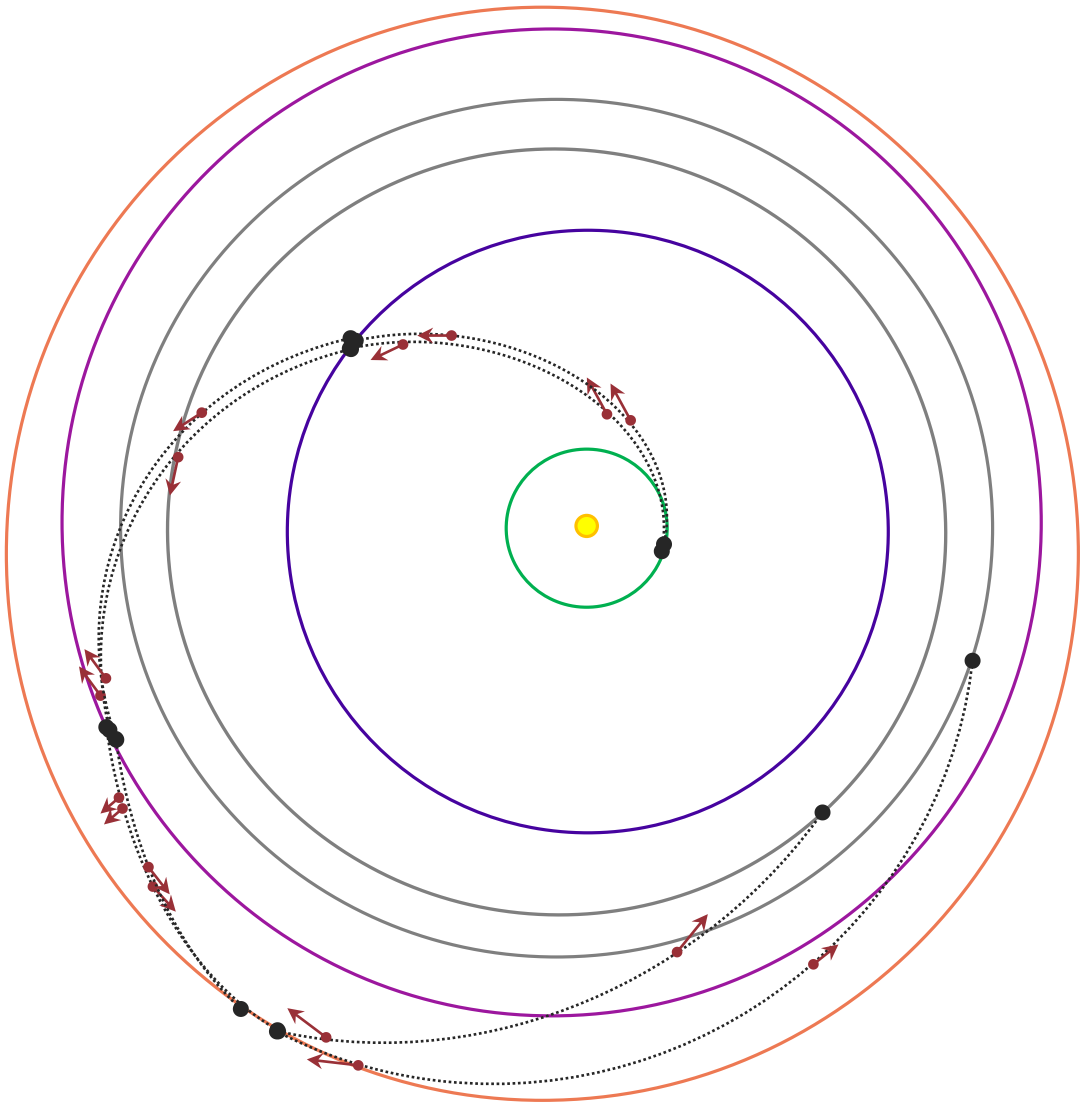

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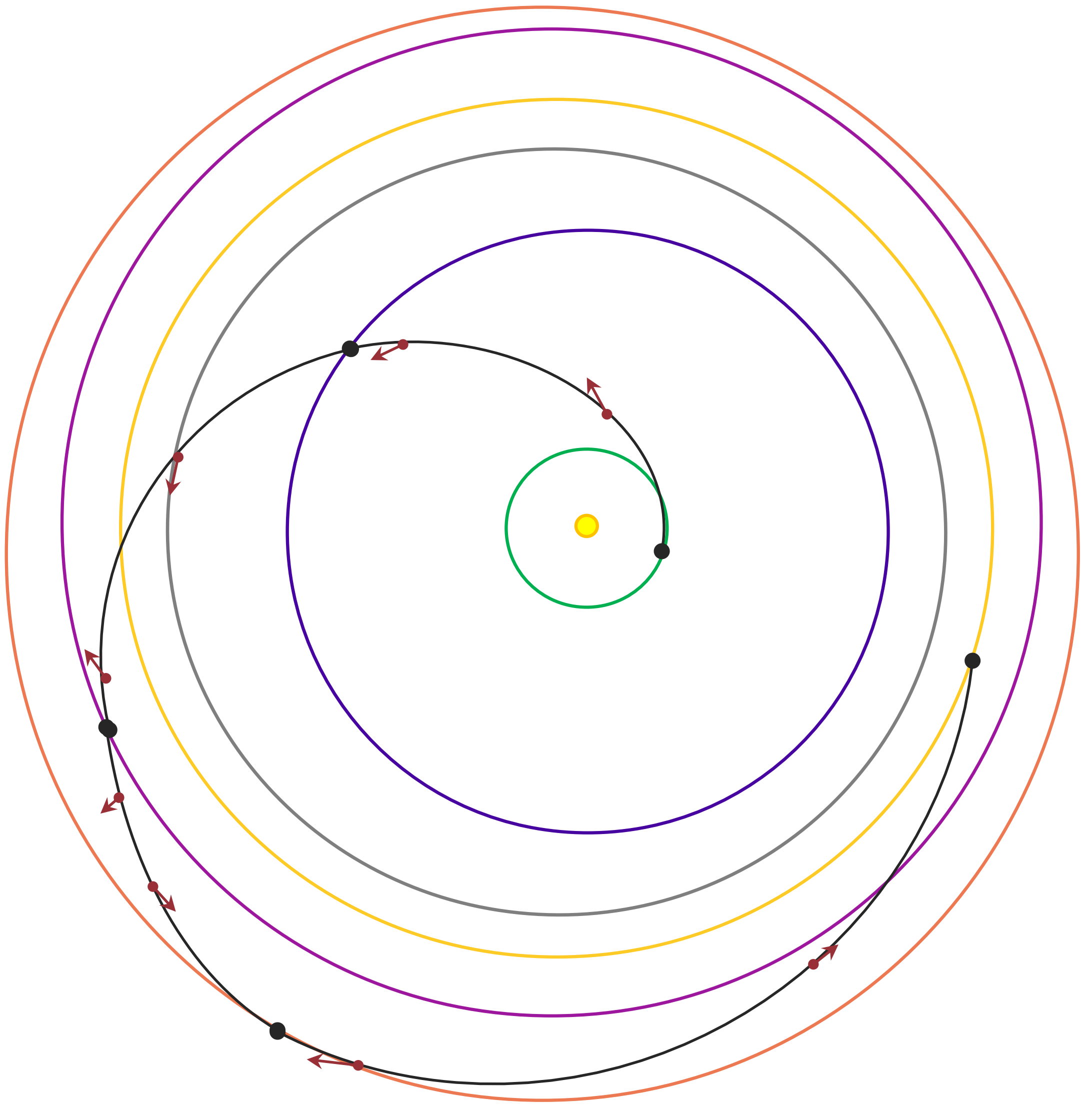

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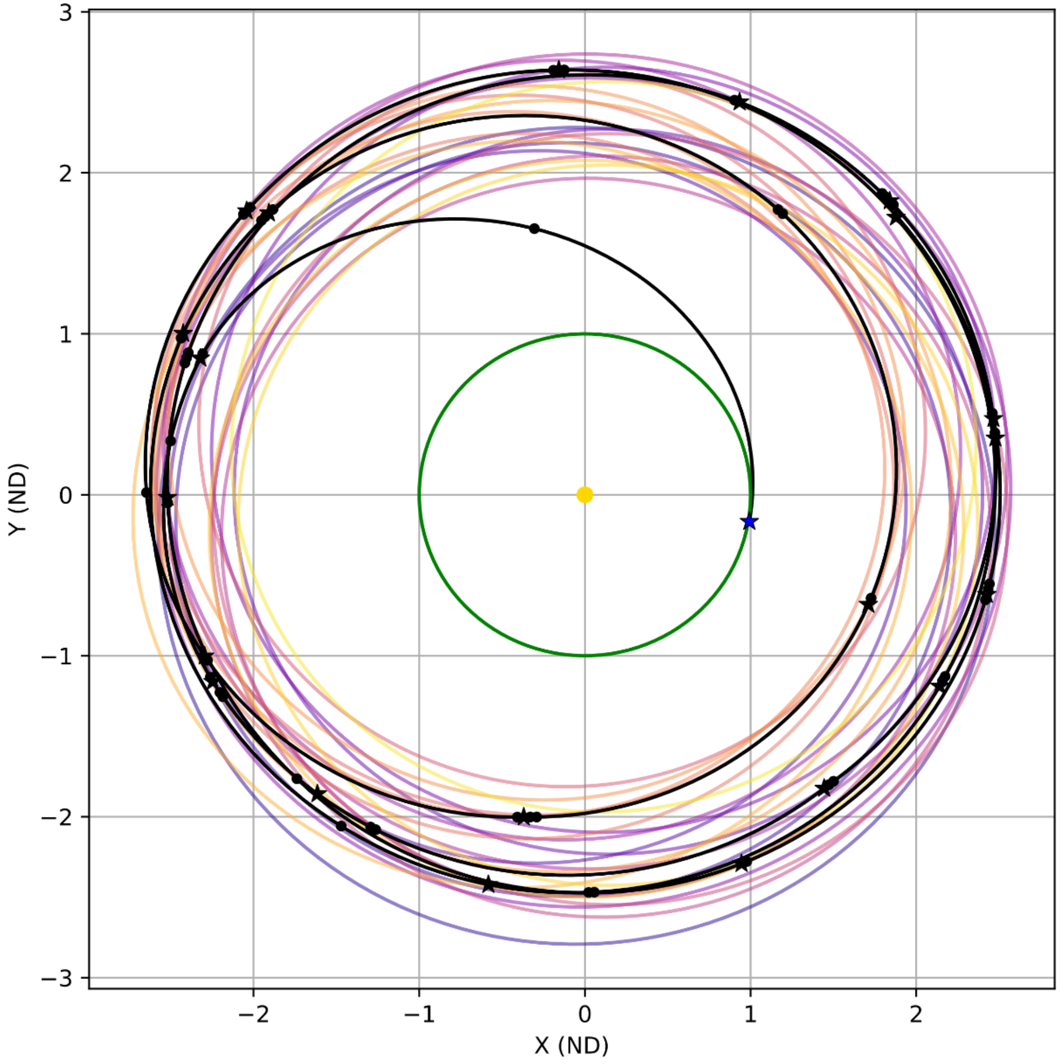
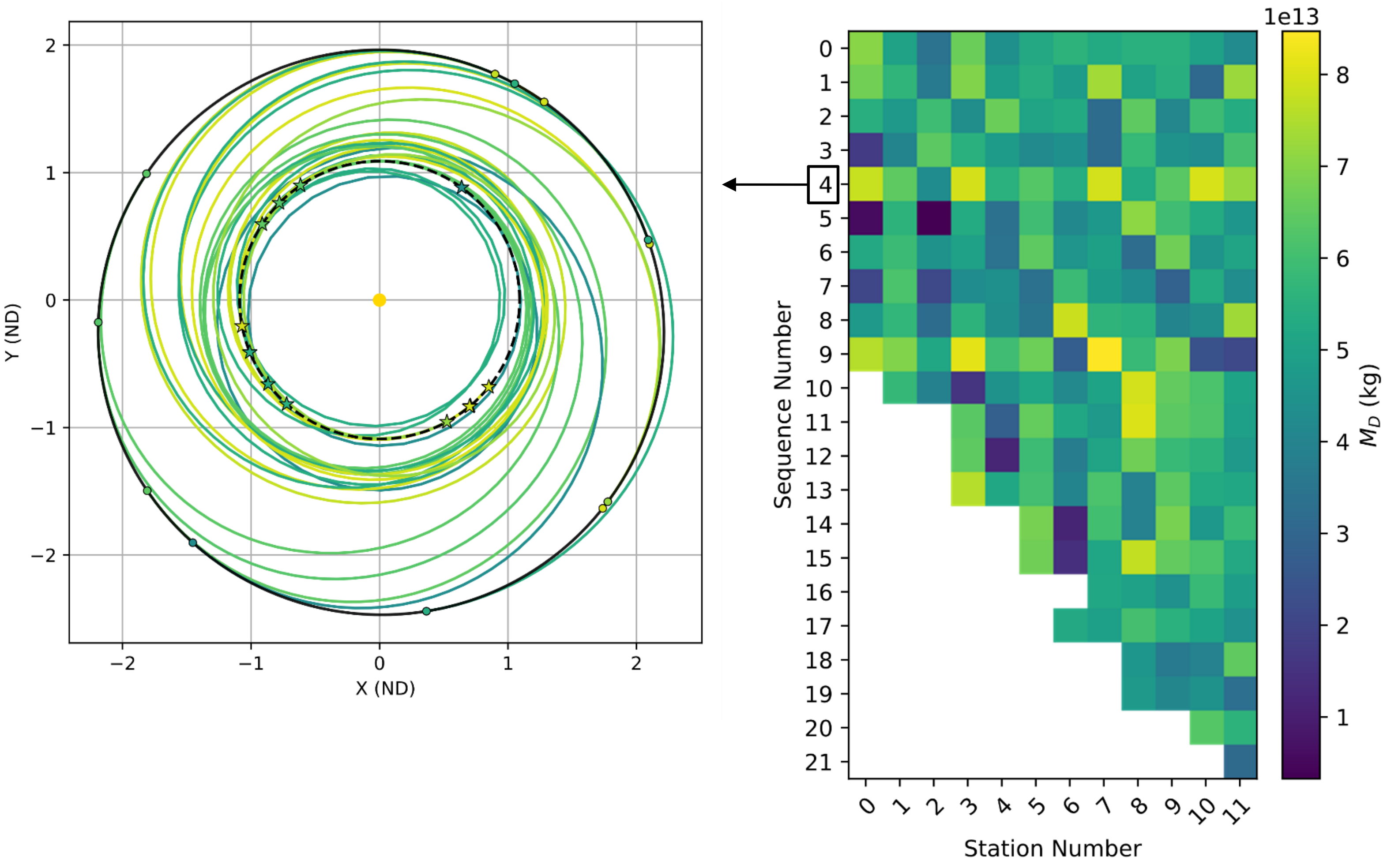
  - **Repeat until TOF limit reached**
- Deterministic wrt: target # flybys, asteroid set, TOF limit, n
  - Calculate all possible solutions

Sequence Construction Results



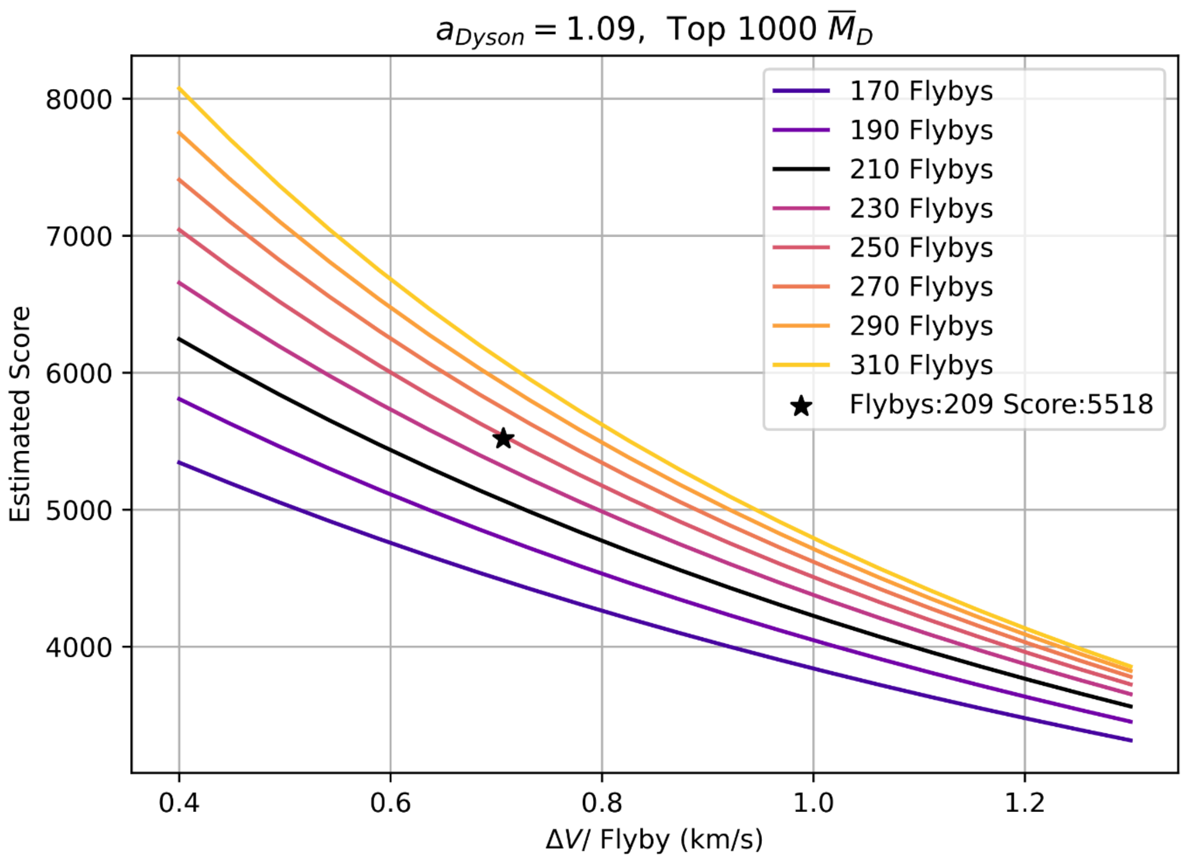
- Computed 1000s of sequences through high-mass sets
  - Targeted 20 – 24 flybys per tour
  - *n*=8 breadth at each stage in beam search
  - 6-10 search instances running on 2 desktops
    - 16-20 full solutions per minute at peak throughput
      - Approx. 3000 OCPs per minute (170-180 per full solution)
- 20% met *ΔV* target of .75 km/s per flyby
  - Pass on to transfer construction phase

Transfer Construction



- For each asteroid in sequence compute transfers to as many stations as possible
  - Evenly spaced build times over final 9 years
  - Maximize bin-packing mobility of asteroids in solution construction phase

Solution Construction



- Combine 10 tours into final solution
  - Delete least efficient duplicate asteroid (if any)
  - Select-best station for each asteroid
    - Bin-pack to increase minimum station mass
- Final solution scored better than estimated
  - Better than average mass delivered

Final Solution / Conclusion

Video Removed due
to size restrictions

- Final score 5525 w/ bonus
  - 209 asteroids delivered
  - 1.10e15 kg minimum mass
- Possible improvements to our solution
  - Increase the length of lambert sequences in tour search
    - More asteroids per tour at same ΔV
  - Add in light asteroids that almost encounter a mothership
- Really enjoyed the competition, can’t wait for GTOC 12