# On-orbit Servicing for Spacecraft Collision Avoidance Using Reinforcement Learning

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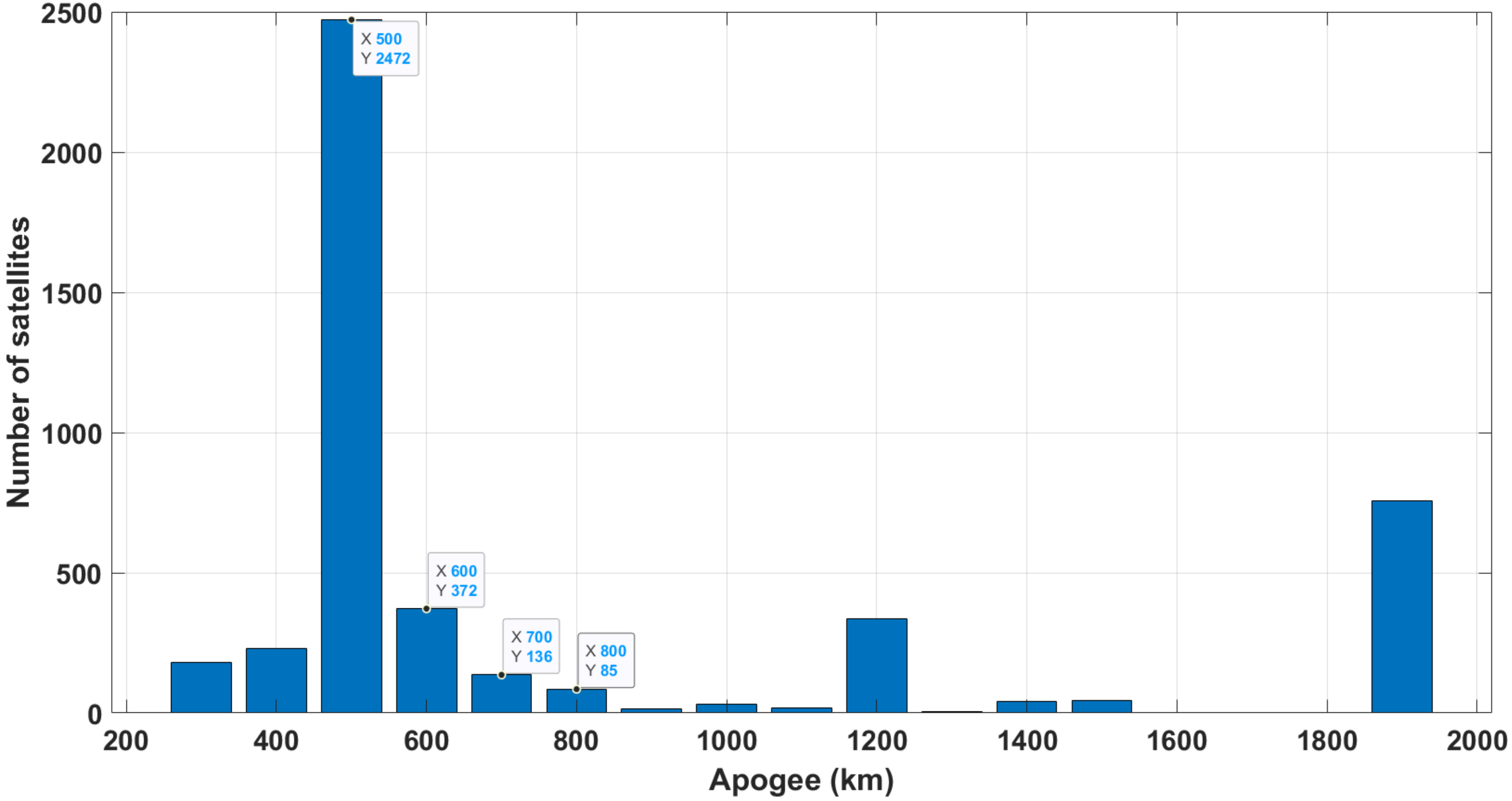
# SERVICER MISSION ARCHITECTURE -ONE TO MANY

# Orbitography

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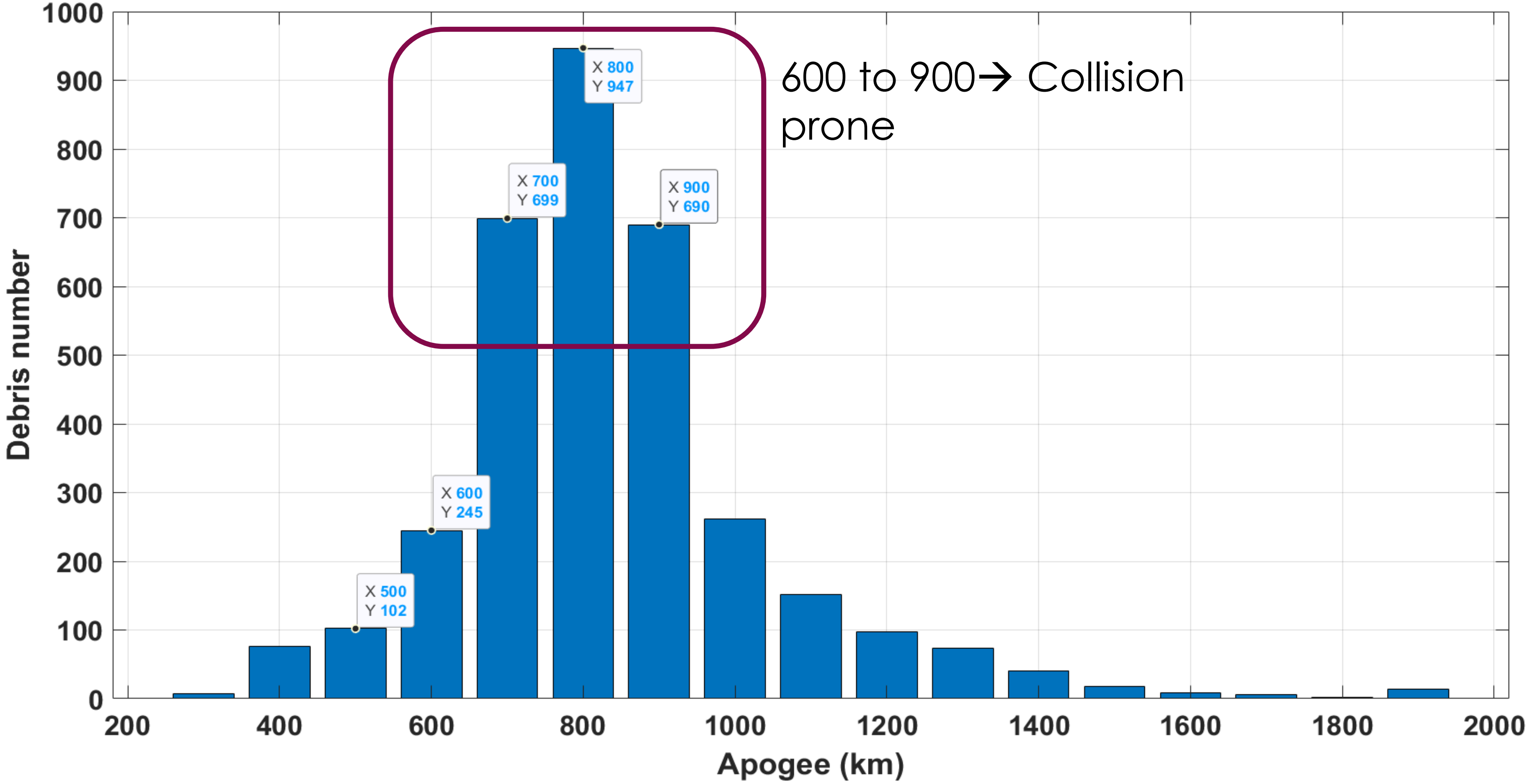
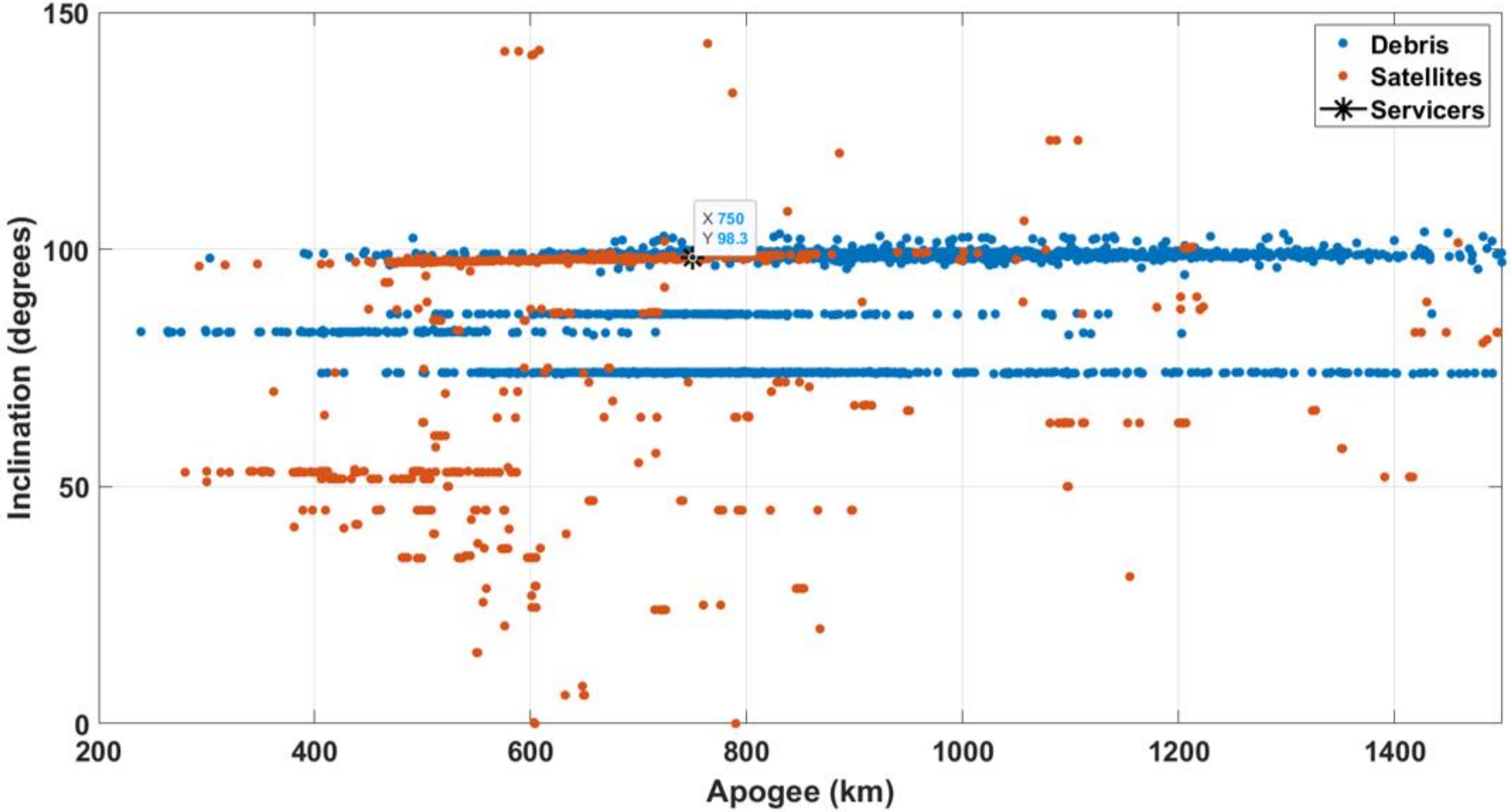
# Orbitography



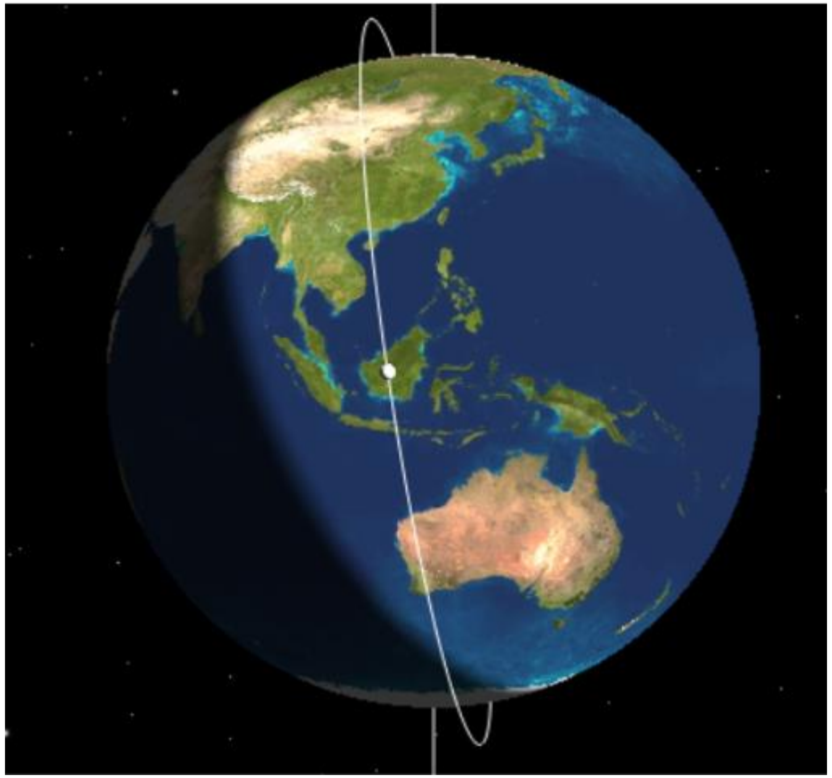

600 to 900→ Collision prone

# Orbitography

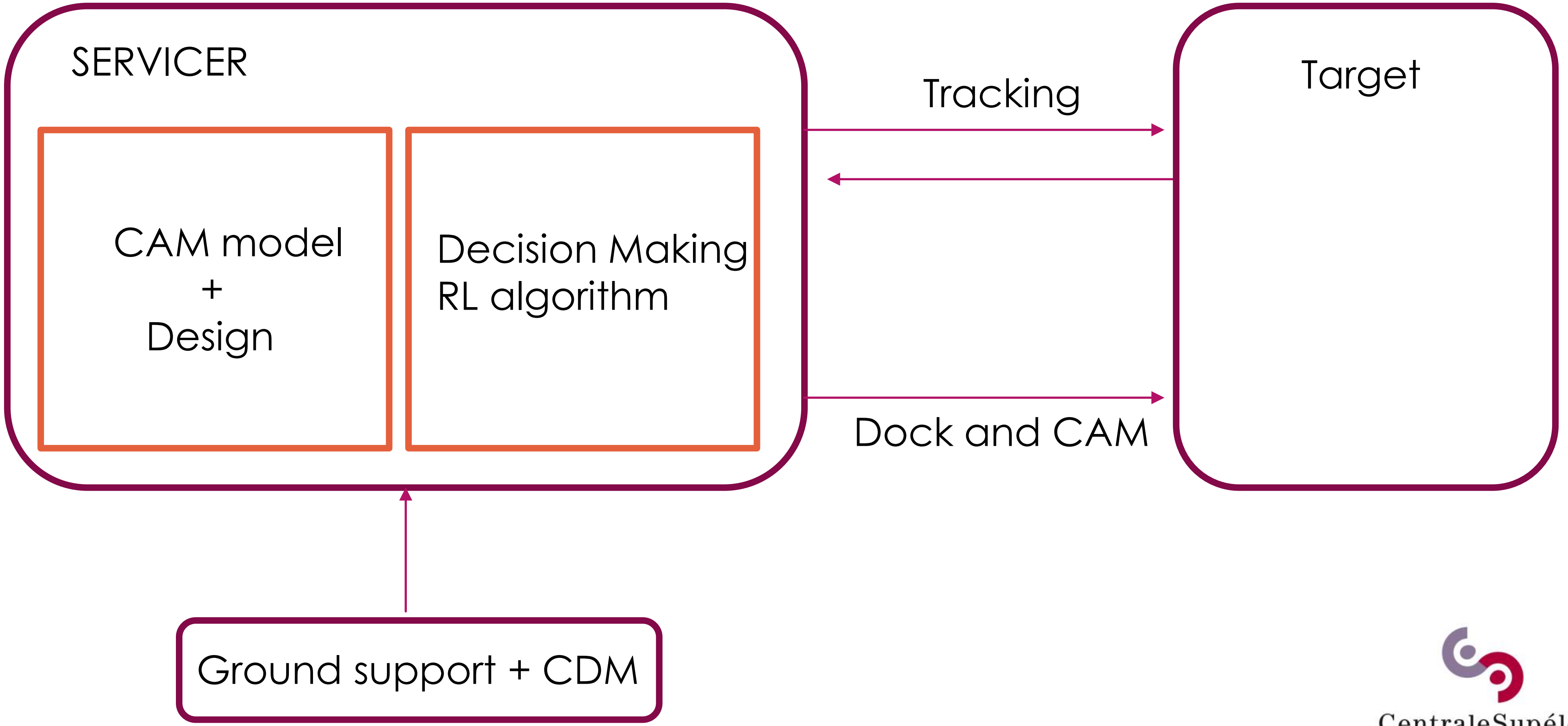


# Orbitography

- Parking orbit in LEO at 750km
- Sun-synchronous orbit
- Inclination ~ 98°

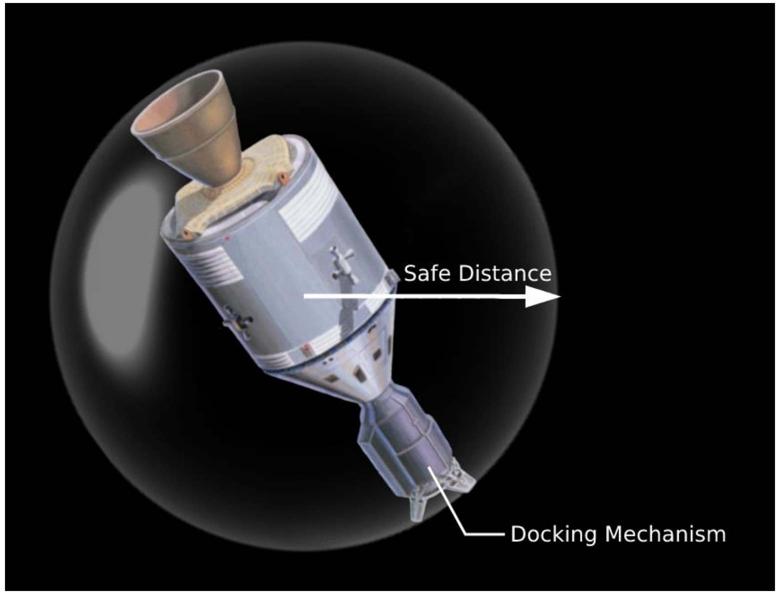


# Servicer Collision avoidance architecture



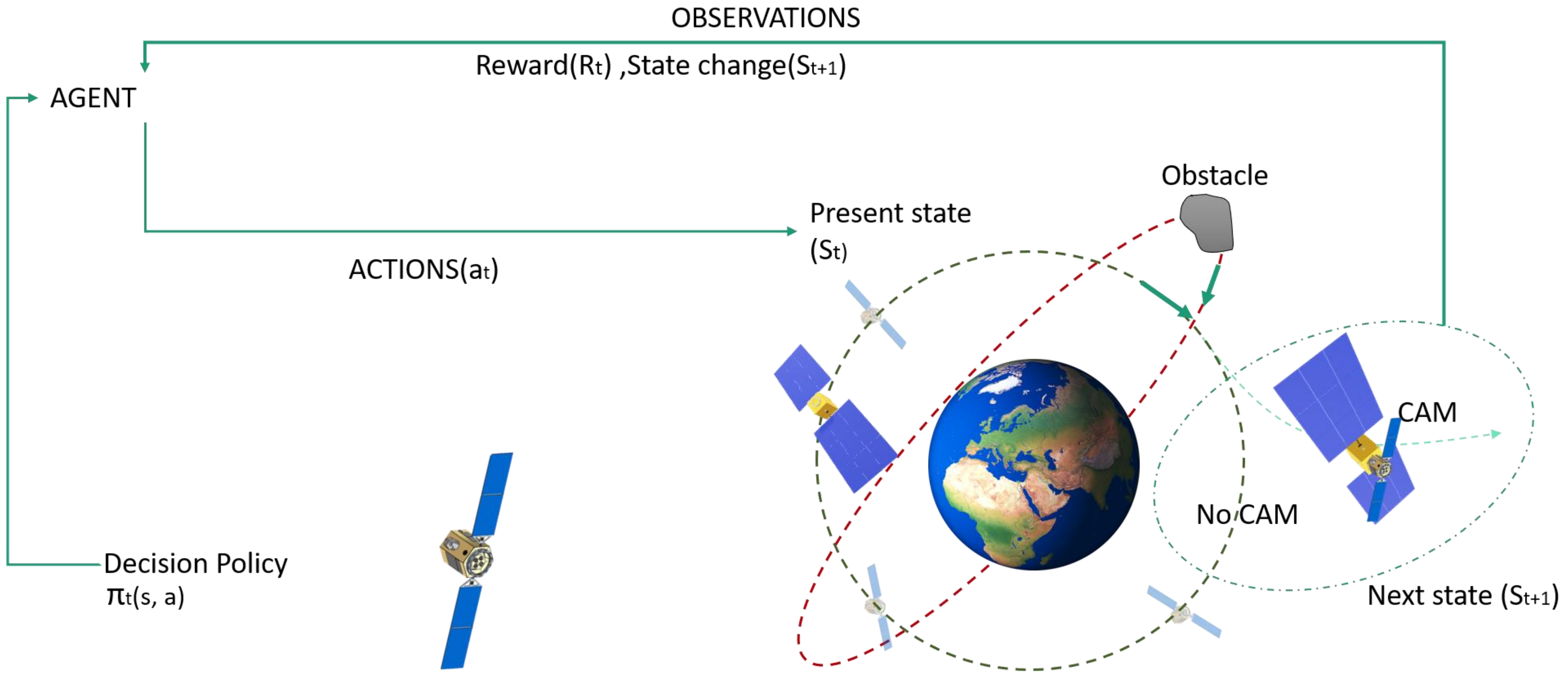
# Mission parameters

| Mission parameters | Value |
|---|---|
| Orbit | Circular SSO at 750km |
| Inclination | 98.38deg |
| No. of servicers | 1 servicers |
| No. of missions per servicer | [3-n] |
| No. of planes | 1 |
| Satellites per plane | 1 |
| Range of RAAN/I (deg) | [-1.5,+1.5] |
| Range of altitude (km) | [-150,+150] |
| Propulsion | Electrical |
| ISP | 1650s |
| Dry mass(kg) | 240 |
| Propellant mass(kg) | 120 |
| Total mass(kg) | 360 |
| Lifetime | 10-15 years |

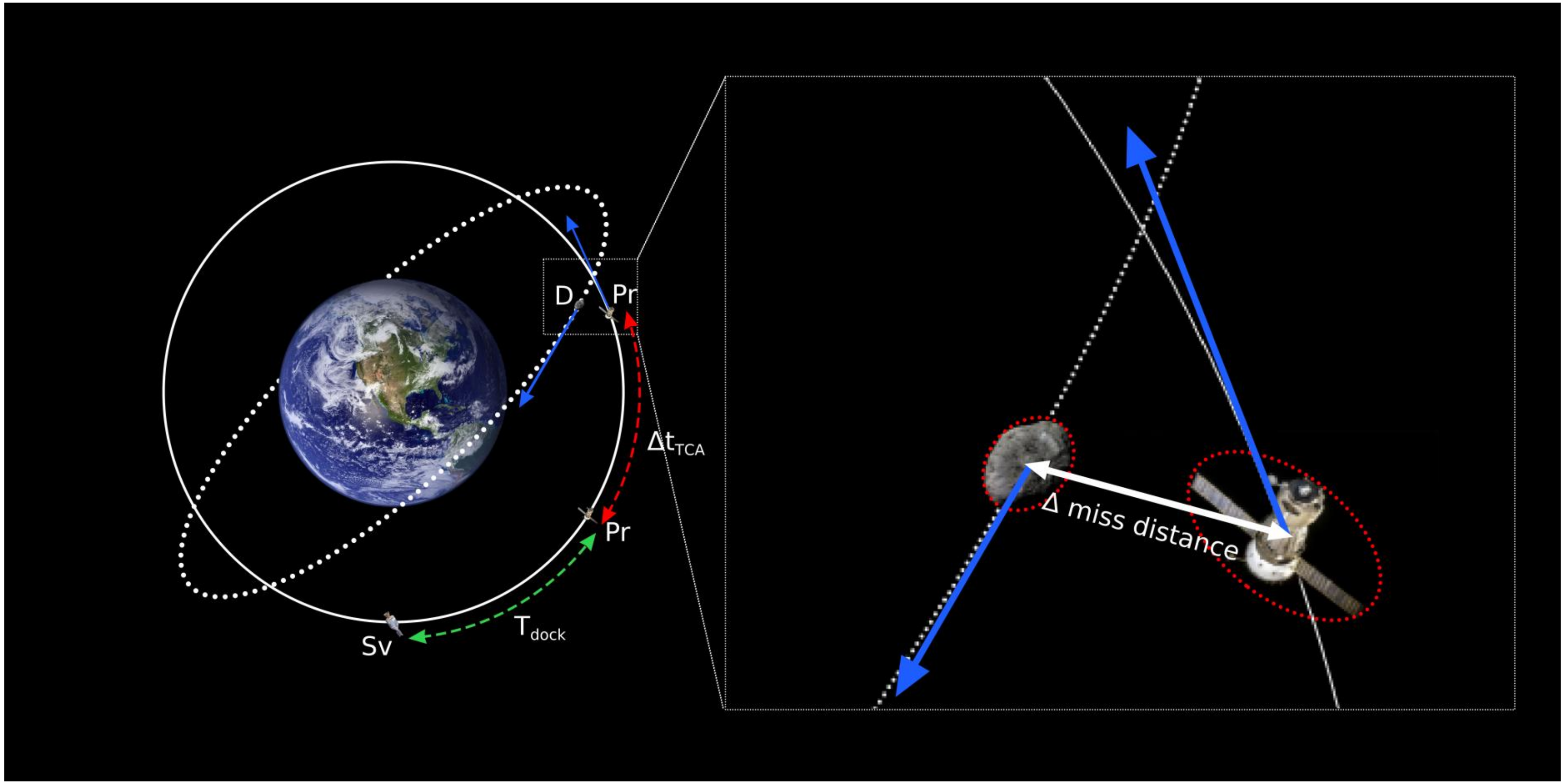


# AI Decision support model

# RL framework



# Schematic of a collision situation



# State and action space

- ***S*** = {positions and velocities of Protected, Servicer, Debris, epoch, fuel}
- ***a*** =

| $V_X$ | $V_Y$(direction of satellite) | $V_Z$ | Time to request next maneuver |
|---|---|---|---|
| 0 | 0 | 0 | Time for servicer to move: Phasing(Ts) |
| ±Δvx | ±Δvy | ±Δvz | T_dock |
| ±Δvx | ±Δvy | ±Δvz | TCAM=T_orb/2 |
| +Δvx | +Δvy | +Δvz | T_orb |
| -Δvz | -Δvz | -Δvz | T_undock |

# Reward and threshold

- Each component has a predefined threshold, and the agent receives a negative reward proportional to its distance from the desired value if the threshold is exceeded.

| Parameter | Threshold |
|---|---|
| Collision Probability | 10e−4 |
| Fuel Level | 500 units(negative reward for each action) |
| Trajectory Deviation (a) | 100 |
| Trajectory Deviation (e) | 0.01 |
| Trajectory Deviation (i) | 0.01 |
| Trajectory Deviation (Ω) | 0.01 |
| Trajectory Deviation (ω) | 0.01 |
| Docking Position | 500m |
| Docking Velocity | 5m/s |

# Collision probability computation and docking criteria



- The Chenbai[2] method is used to compute collision probability.
- Docking criteria: Overlap of radii of two objects or reaching within 500m radius

# Data formats

## Two Line Elements (TLE)

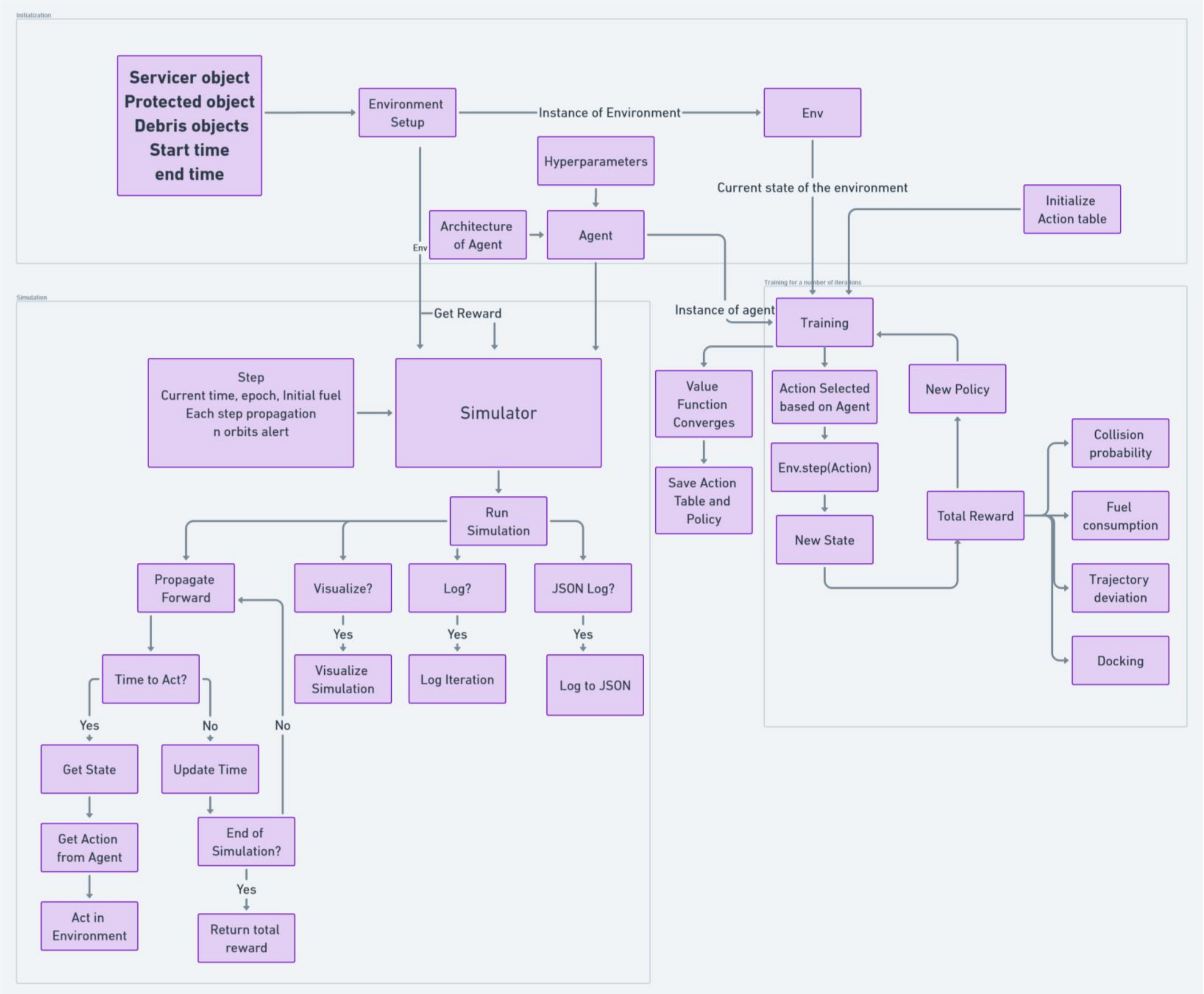
- Datasets providing information about the orbital elements of an object.
- Maintained by the United States Air Force
- Object's position, velocity, and orbital elements.
- Accuracy is influenced by various factors; update frequency can vary.

## Conjunction Data Messages(CDM)

- Standardized message formats for estimating potential collisions.
- Consultative Committee for Space Data Systems (CCSDS)
- State vectors of satellite and debris, collision probability, and method details.
- Designed for precise conjunction analysis.

# Framework of simulator

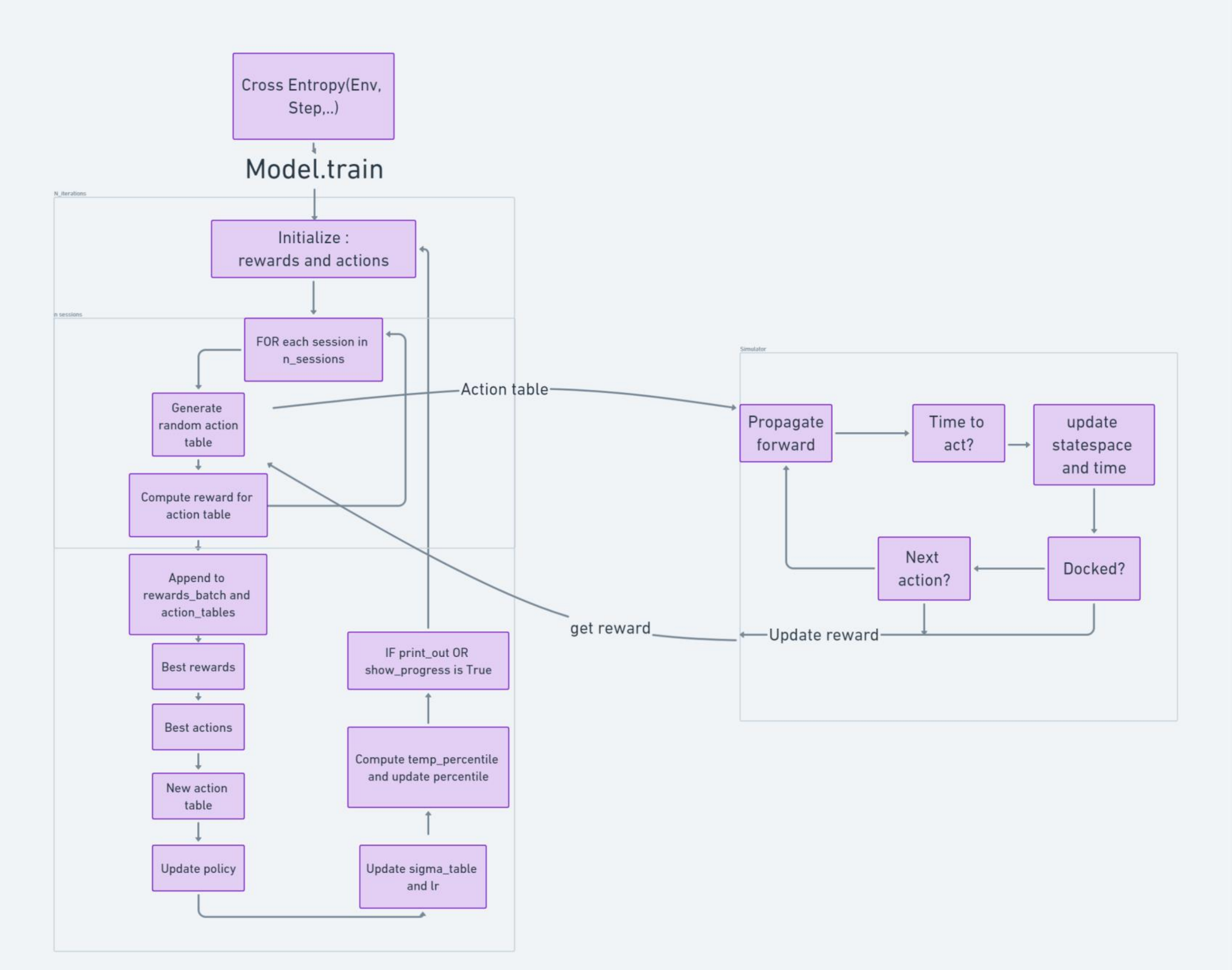





Model extracted and extended from the available simulator [1]

# RL algorithm: Cross Entropy(CE)





# Training and analysis of the solution

# Experiment description

Time resolution

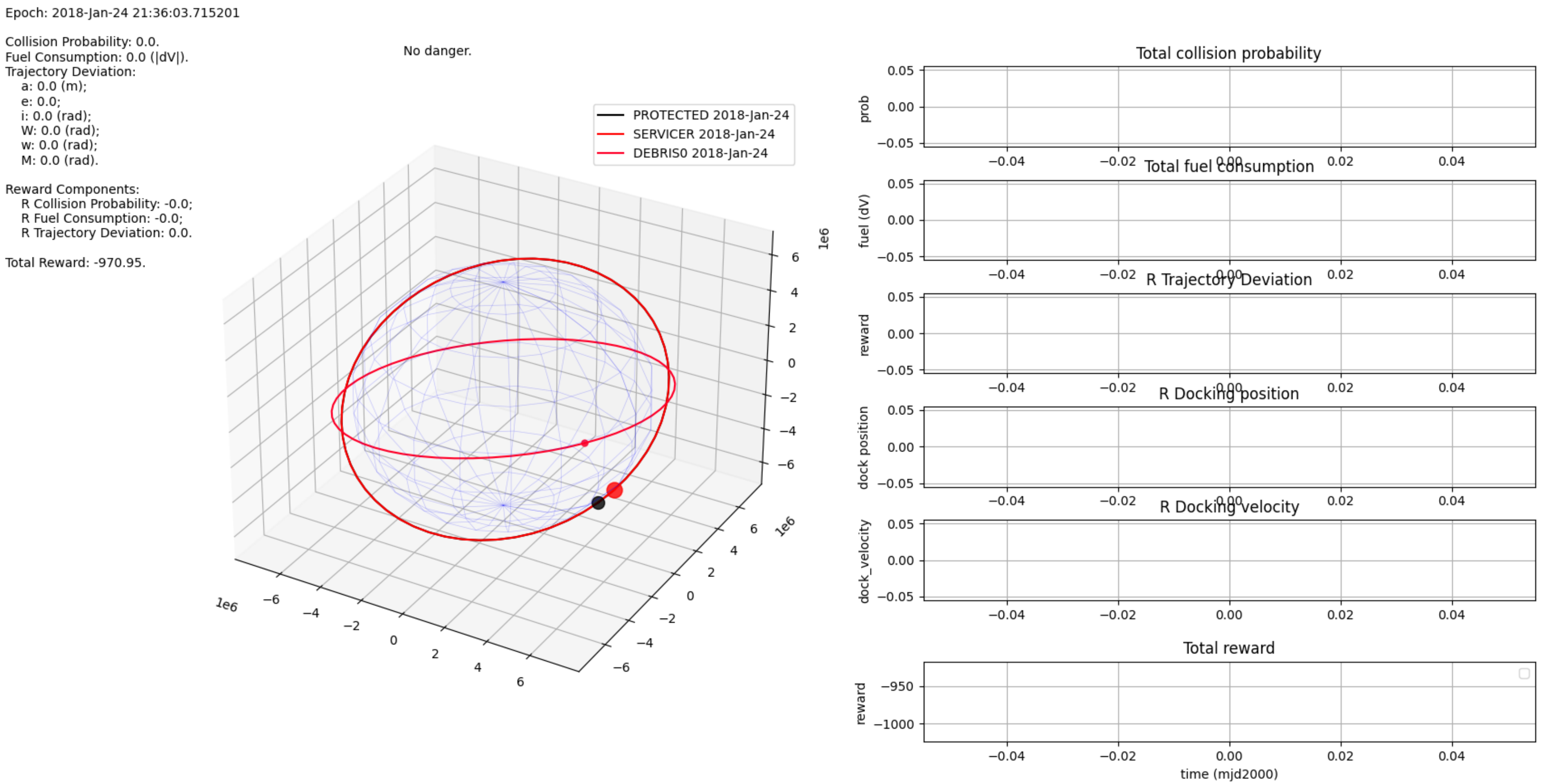
Fine grid: *about every 0.08 seconds*

Coarse grid: *captures the moments only before maneuvers and collisions.*

- Simulation time: two days, during which we have a potential collision with debris generated.
- The start time of the experiment is "2018-Jan-24 21:35:59" and the end time of the simulation is "2018-Jan-27 02:24:00".

| | $a(m)$ | $e$ | $i(°)$ | $\Omega(°)$ | $\omega(°)$ | $\nu(°)$ |
|---|---|---|---|---|---|---|
| Protected | 7208006 | 7.5e-05 | 324.51 | 177.65 | 174.32 | 127.9 |
| Servicer | 7208006 | 7.5e-05 | 324.51 | 177.65 | 174.32 | 134.9 |
| Debris | 7,213,238 | 7.7e-05 | 13.37 | 234.33 | 330.8 | -15.08 |

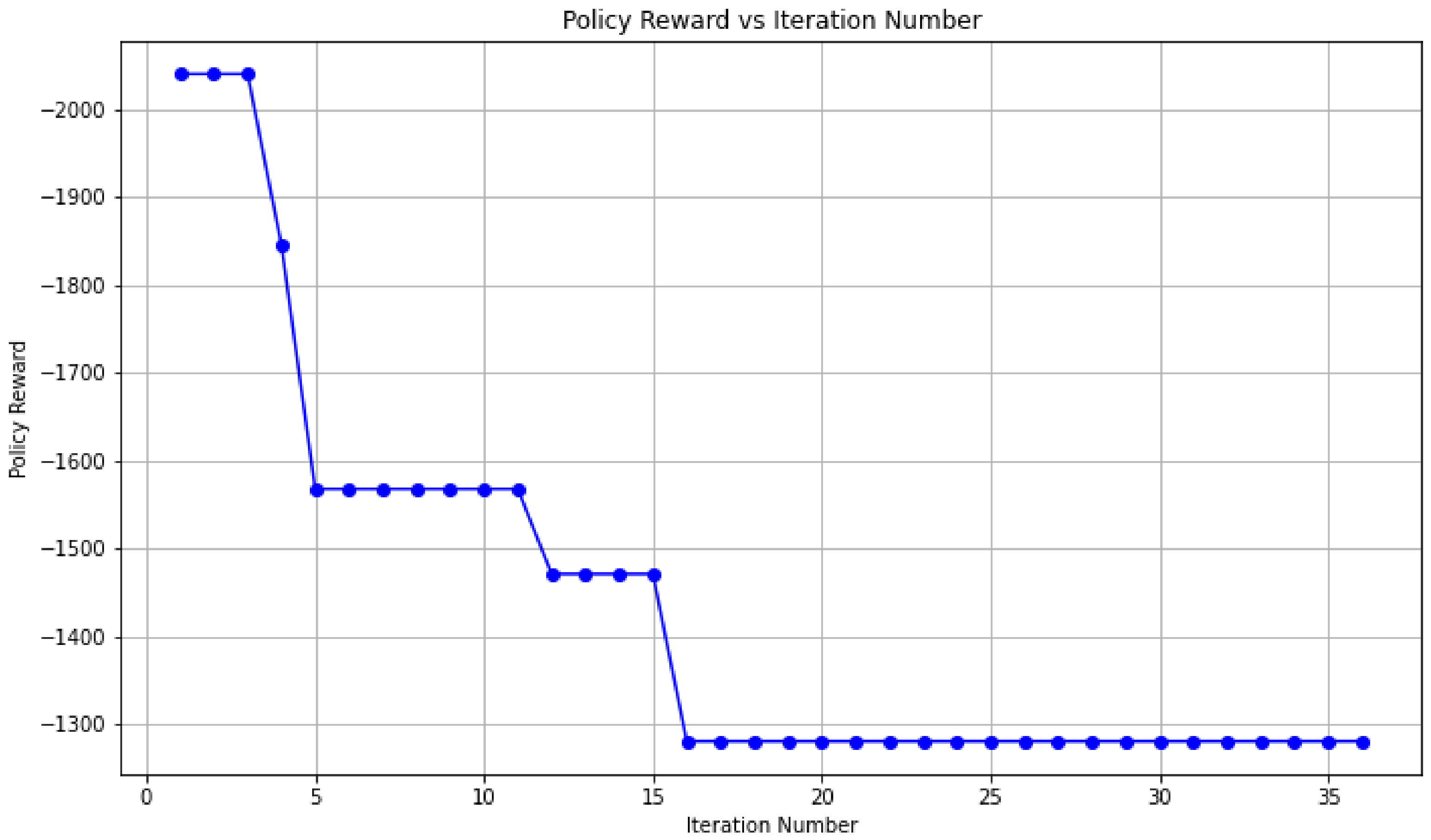
# Experiment description



# Model parameters and tools

- Initialize with 70 iterations and 50 sessions each
- Collision alert before 5 orbital periods
- First maneuver time: early
- Reverse maneuver is performed after CAM
- Total number of maneuvers: 4
- Pykep library [3] is used for the propagation of objects

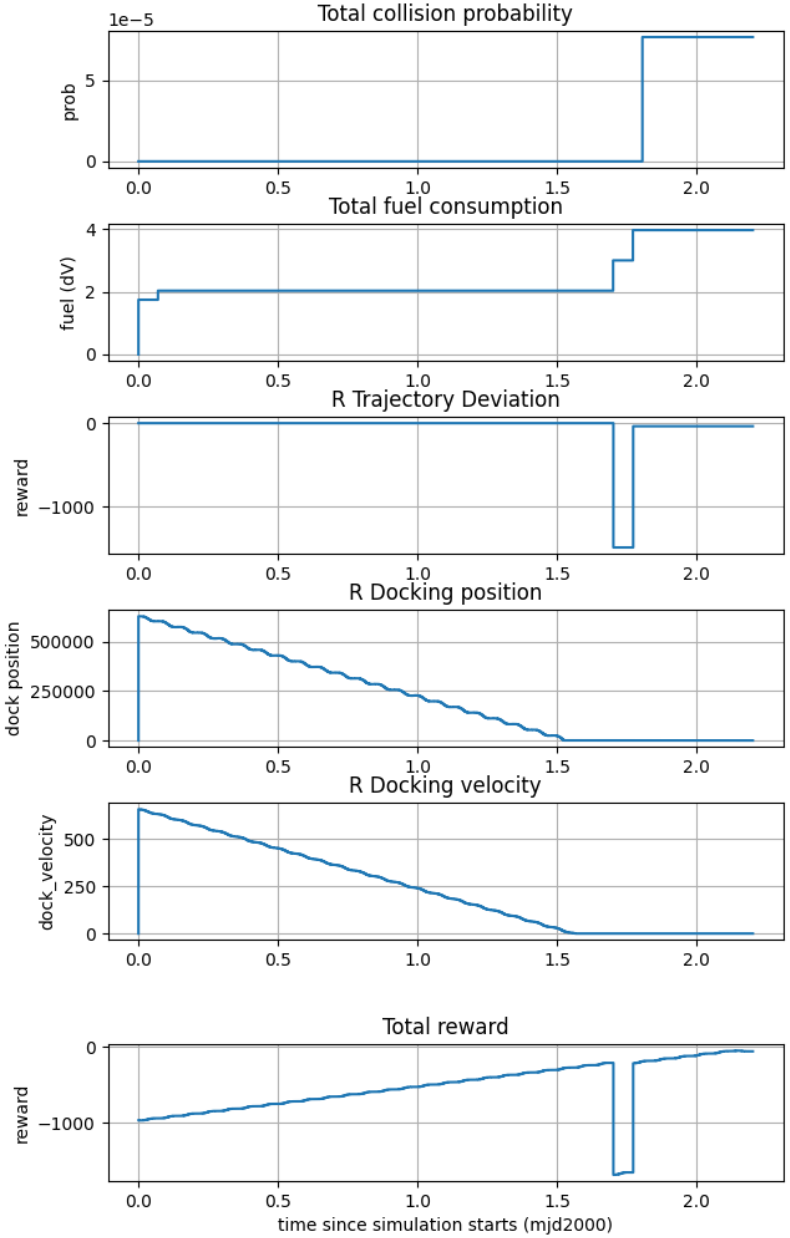
# Results with random guess




Decreasing policy reward with iterations.

# Results with a random guess






Training with *coarse grid* and visualization with *fine grid*

| | dVx (m/s) | dVy (m/s) | dVz (m/s) | time (mjd2000) |
|---|---|---|---|---|
| 1 | 0.990560 | 1.427529 | -0.151943 | 6598.900000 |
| 2 | 0.192450 | 0.036808 | 0.212797 | 6598.970489 |
| 3 | 0.935751 | -0.235568 | -0.059789 | 6600.600560 |
| 4 | -0.935751 | 0.235568 | 0.059789 | 6600.671043 |

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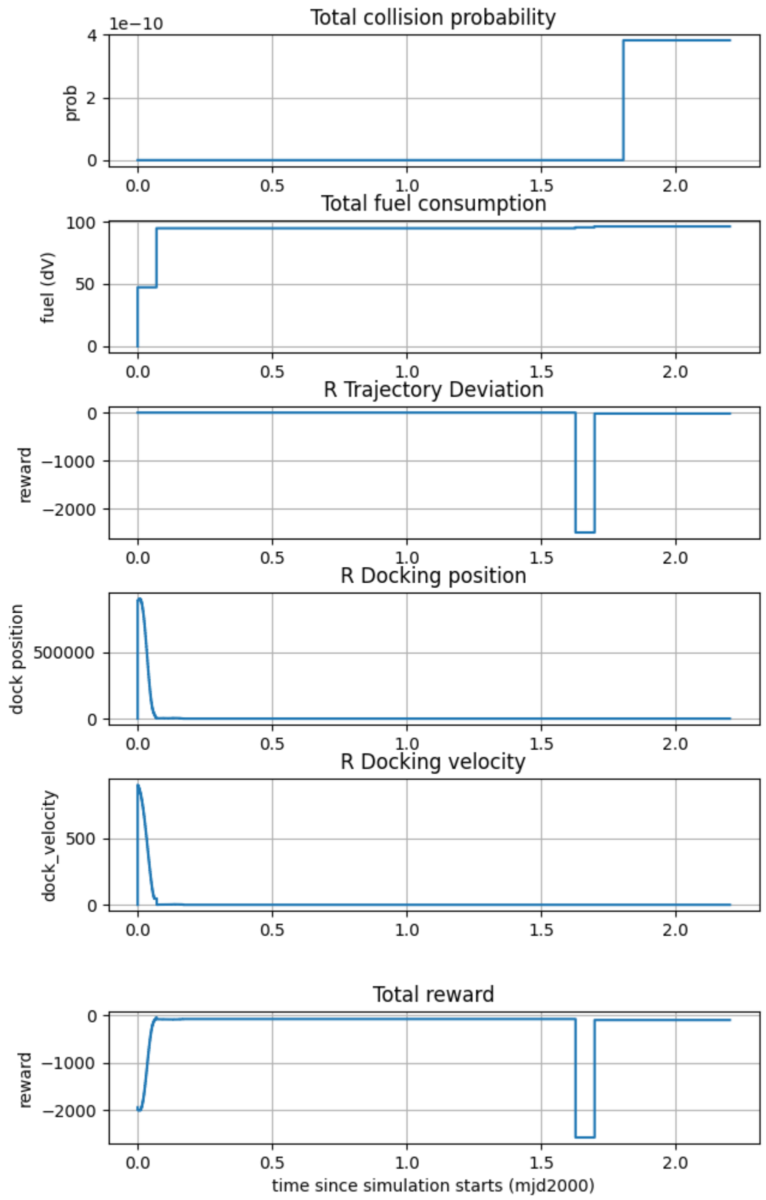
# Results with Lambert's[4] solution as guess




Training with *coarse grid* and visualization with *fine grid*

| No. | dVx (m/s) | dVy (m/s) | dVz (m/s) | Time (mjd2000) |
|---|---|---|---|---|
| 1 | 23.90 | 32.94 | 24.16 | 6598.90 |
| 2 | −18.82 | −35.11 | −25.56 | 6598.97 |
| 3 | 0.00 | −0.69 | 0.22 | 6600.53 |
| 4 | −0.00 | 0.69 | −0.22 | 6600.60 |

# Animation of the simulation

- Put an alert at jan 26th 10oclock

# Conclusions

- The preliminary results look promising in terms of using an on-orbit servicing for collision avoidance maneuvers.
- Docking + CAM are different on following aspects: propellant required and time resolution needs
- The solution obtained can only be thought of as suboptimal.
- The optimality for docking occurs in two ways: one is to find the time stamps where we are going to initialize the phasing. The second one is to find an optimal trajectory joining these points using the least possible fuel.

# References


1. Gremyachikh, Leonid, et al. "SPACE NAVIGATOR: A tool for the optimization of collision avoidance maneuvers." *arXiv preprint arXiv:1902.02095* (2019).

2. L. Chen, X. Z. Bai, Y. G. Liang, and K. B. Li, Orbital Data Applications for Space Objects, p. 166. 2017.

3. D. Izzo, dariomm098, A. Mereta, C. I. Sprague, dhennes, K. Nowak, C. Andre, N. Guy, T. G. Badger, J. Willitts, J. Simon, and A. Babenia, “esa/pykep,” 11 2017. Version 2.0.

4. Izzo, Dario. "Revisiting Lambert’s problem." *Celestial Mechanics and Dynamical Astronomy* 121 (2015): 1-15.