Orbital States Keeping of the Floating Partial Space Elevator Using Reinforming Learning Method

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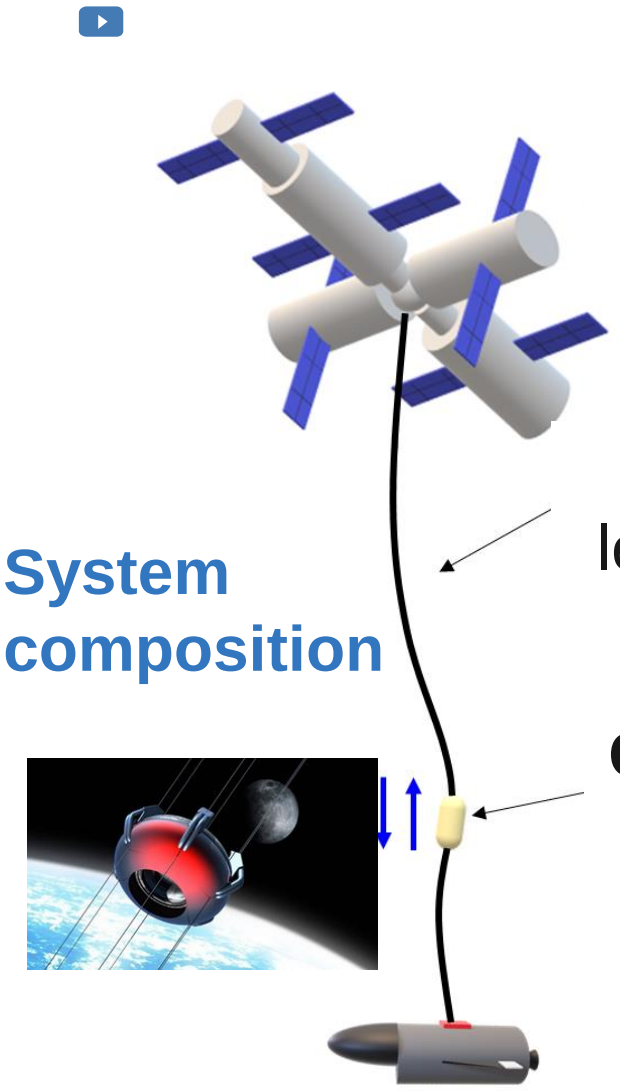
What is a Partial Space Elevator?

System composition



Main satellite:
(Ultra-large Spacecrafts, Space Stations and Moon base)

Tether
length: several - 10^4 *km*

Climber (carrying cargos)
Driven by electricity

End body
(transport spacecraft)

Low to

95% OFF

Technical positioning

- A space elevator **halfway**
- **Normalized auxiliary** cargo transportation technology in space

Advantages

- **Safe cargo transportation**
- **Save freight**

Partial Space Elevator is an Space Elevator Halfway

The Academic Times

dozens, their most recent achievement surrounds a protein molecule that targets the deadly virus Eastern equine encephalitis.

Genetic reason found for fatal cancer that affects popular dog breeds — and sometimes, their owners

By Monisha Ravisetti

Genetic analysis of several hun
sarcoma have corresponding g
this rare form of cancer, the fin
canines and people alike.

Far from science fiction, space elevators may be nearing deployment

By Monisha Ravisetti

With one end of a steel cable hovering in Earth's orbit and the other end somewhe
outer space, the concept of a futuristic floating "space elevator" promises to ampli
humans' ability to explore the universe — and scientists engineering an improve
on the 19th-century idea say the one-time fantasy is close to becoming a reality

Laser cooling of antimatter particles could rewrite modern physics

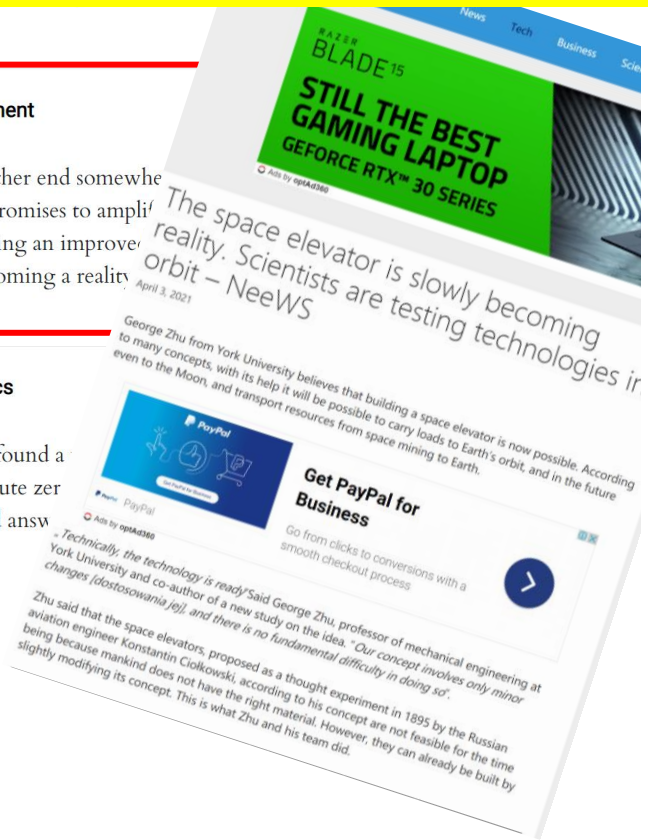
By Monisha Ravisetti

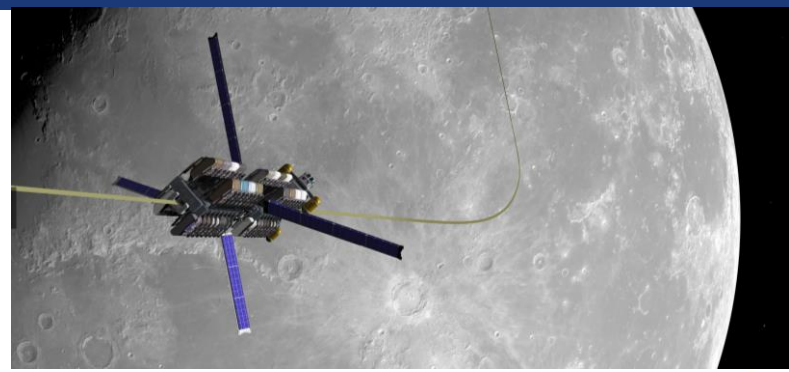
One of the few teams in the world with access to antimatter has found a
examine these mysterious particles by cooling them to near absolute zer
scientists close to finally understanding their elusive behavior and answ
the most pressing questions in modern physics.

Space elevators could be getting closer and closer

3 MONTHS AGO · READ TIME: 9 MINUTES · BY MYRTLE FROST · LEAVE A COMMENT

A Space Elevator Halfway



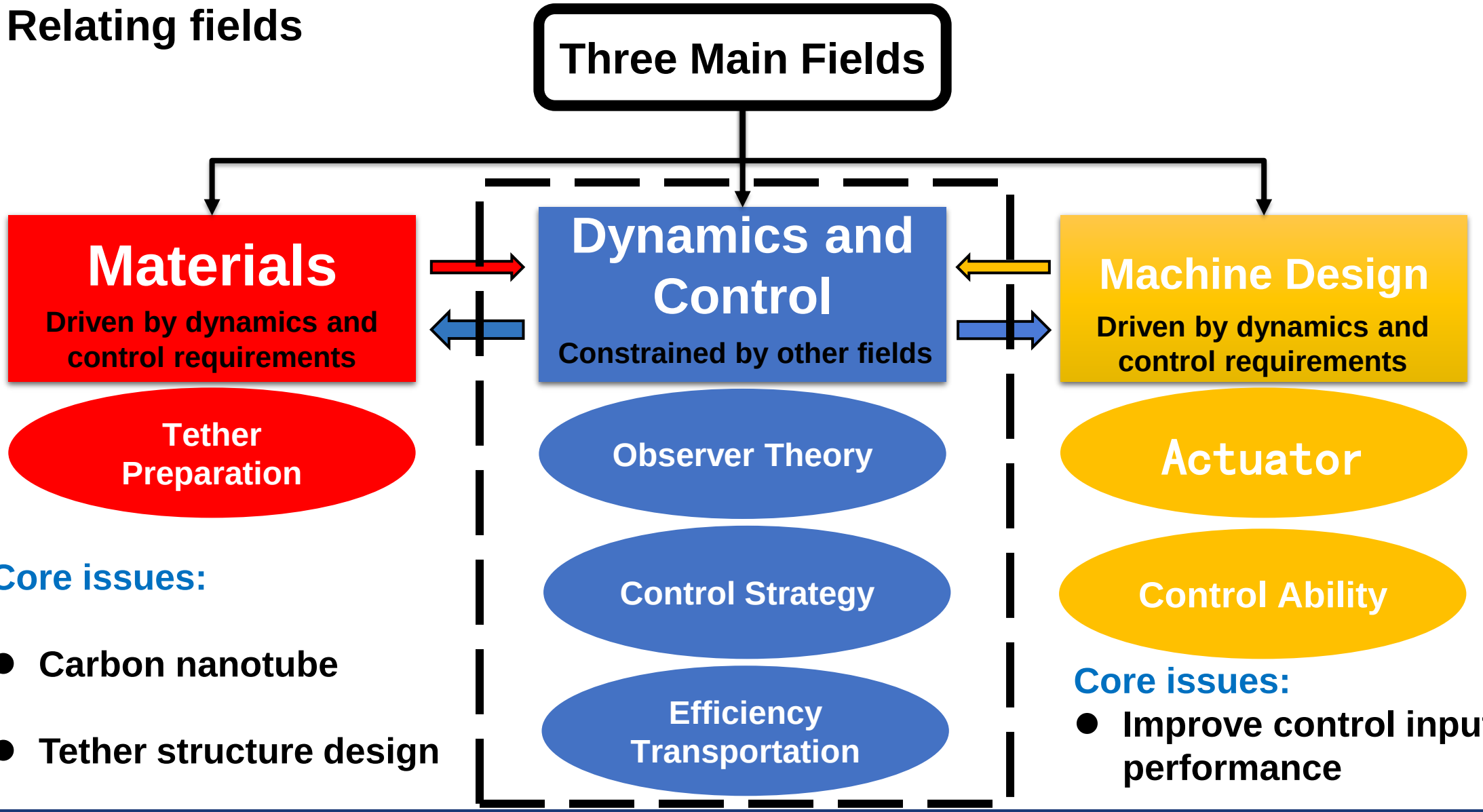


The idea of scientists from York University assumes the construction of a floating space elevator. The two ropes will not be attached to the surface of the Earth and the International Space Station, for example. It is about connecting two ropes with each other, but at the same time they are to float freely in space. One load will go up and the other will go down, so the forces will cancel each other out.

The tether proposed by Zhu can now be made of titanium and other types of steel used, for example, in rockets, and the length of the elevator can range from several meters to several thousand kilometers. Zhu's visions may seem absurd, but the scientist sent a microsatellite into orbit a few months ago, which confirmed that his concept was entirely feasible.

Problems of the Partial Space Elevator

- Relating fields



Core issues:

- Carbon nanotube
- Tether structure design

Core issues:

- Improve control input performance

Problems about Dynamics and Control

Dynamics and Control

- High-fidelity Dynamic Model
- States and disturbances observing
- **Control and Mission plan**

Libration Suppression

Orbit-Keeping
for
The main satellite

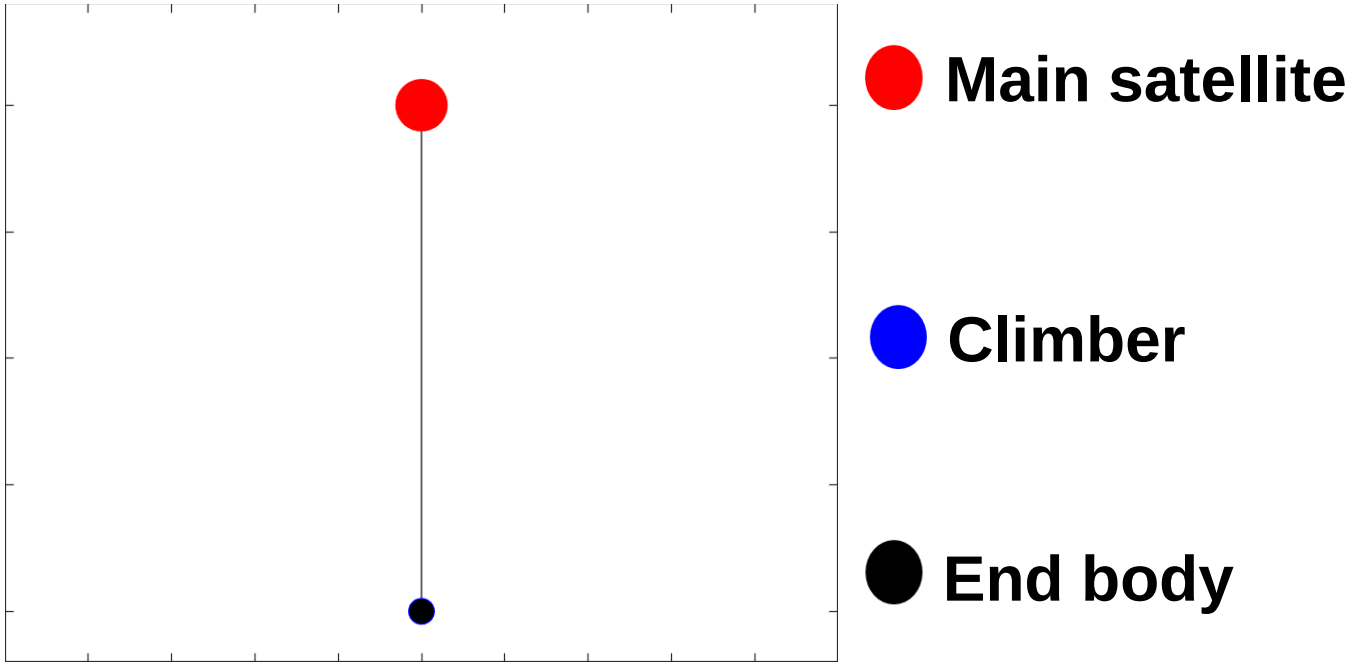
Research Introductions about PSE

- In the past decade, studies in the field of PSE have mainly focused on: **Modeling**, **Dynamic Calculations**, and **Libration Suppression**.

Dynamics

Based on previous works, Professor Z.H. Zhu and Gefei SHI et. al. have devoted on the **libration suppression** of the PSE **in the past 10 years**.

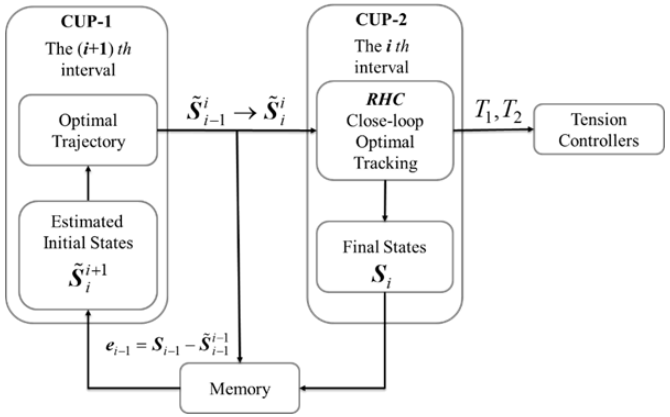
Control



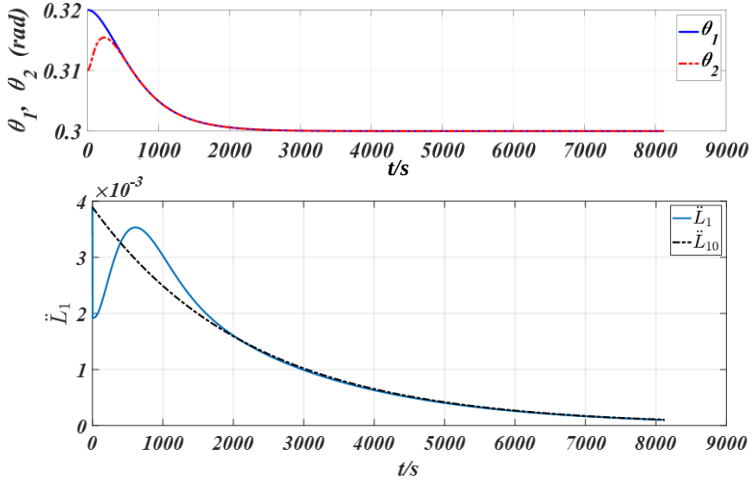
Libration motions

Research Introductions about PSE

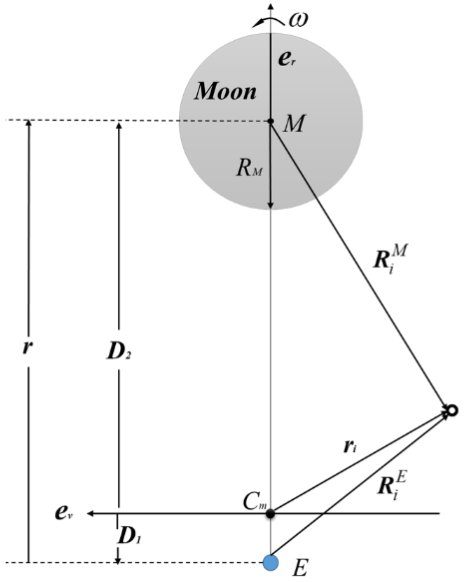
- **The main contributions of Professor Z.H. Zhu and Gefei Shi include:**
  - **New libration suppression control strategy (no thrust).**
  - **Online optimal control schemes of PSE.**
  - **Stable cargo transportation scheme using analytical speed function.**
  - **Multiple application modes of PSE.**
  - **Orbit-keeping methods.**

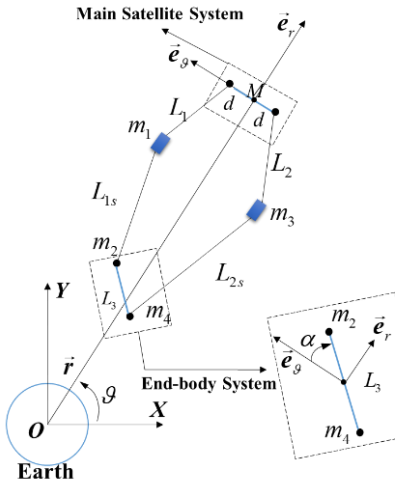


Parallel Optimization of Trajectory Planning and Tracking



Stable cargo transportation

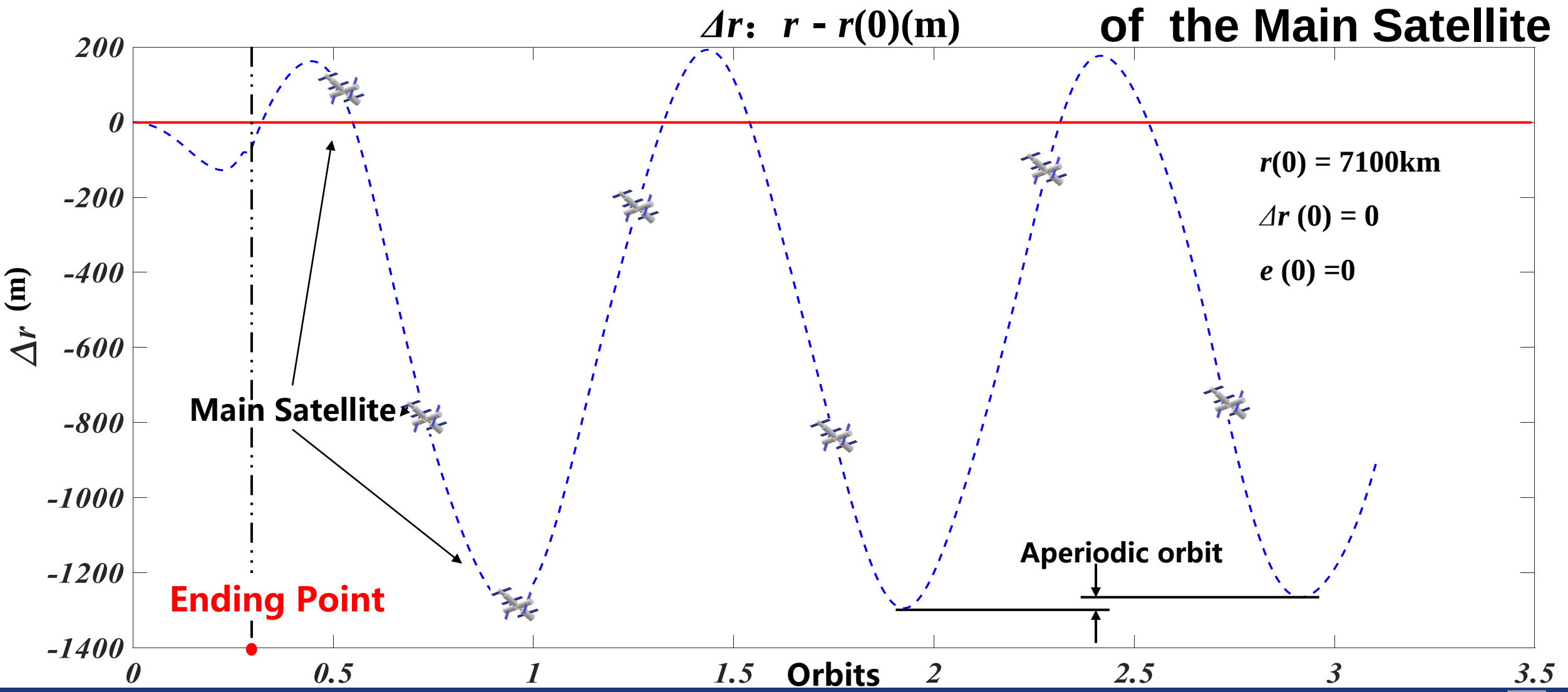




Moon-based PSE and Parallel PSE

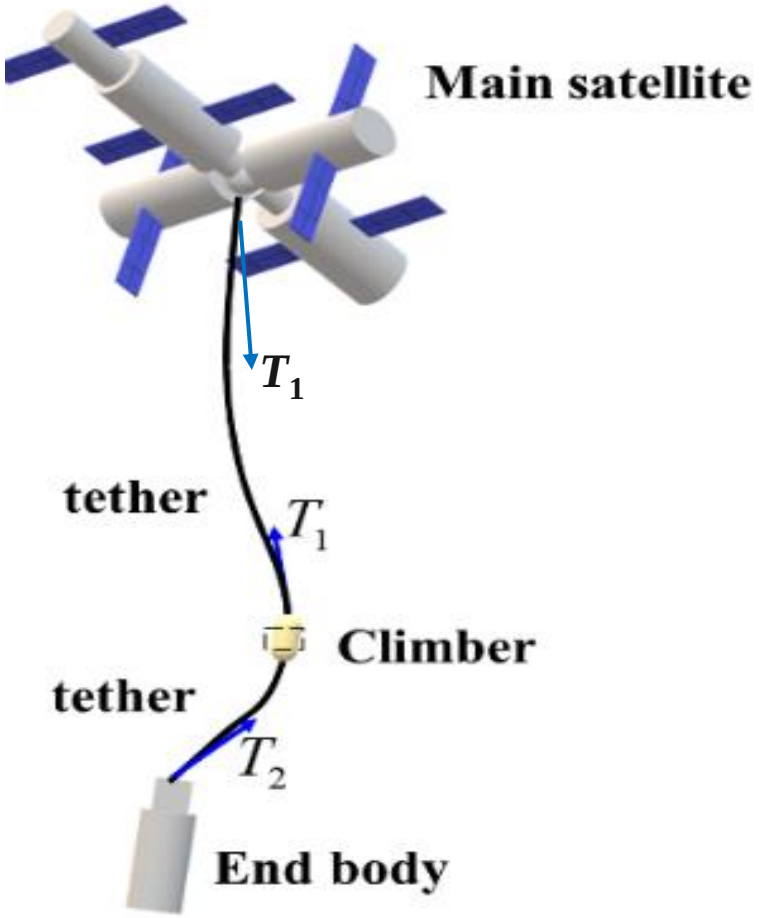
Orbit-Keeping issue

- Cargo transfer leads to the orbit change (radius)



What is Orbit-Keeping issue

- **To reduce the change of radius without using thrusters on the Main Satellite**

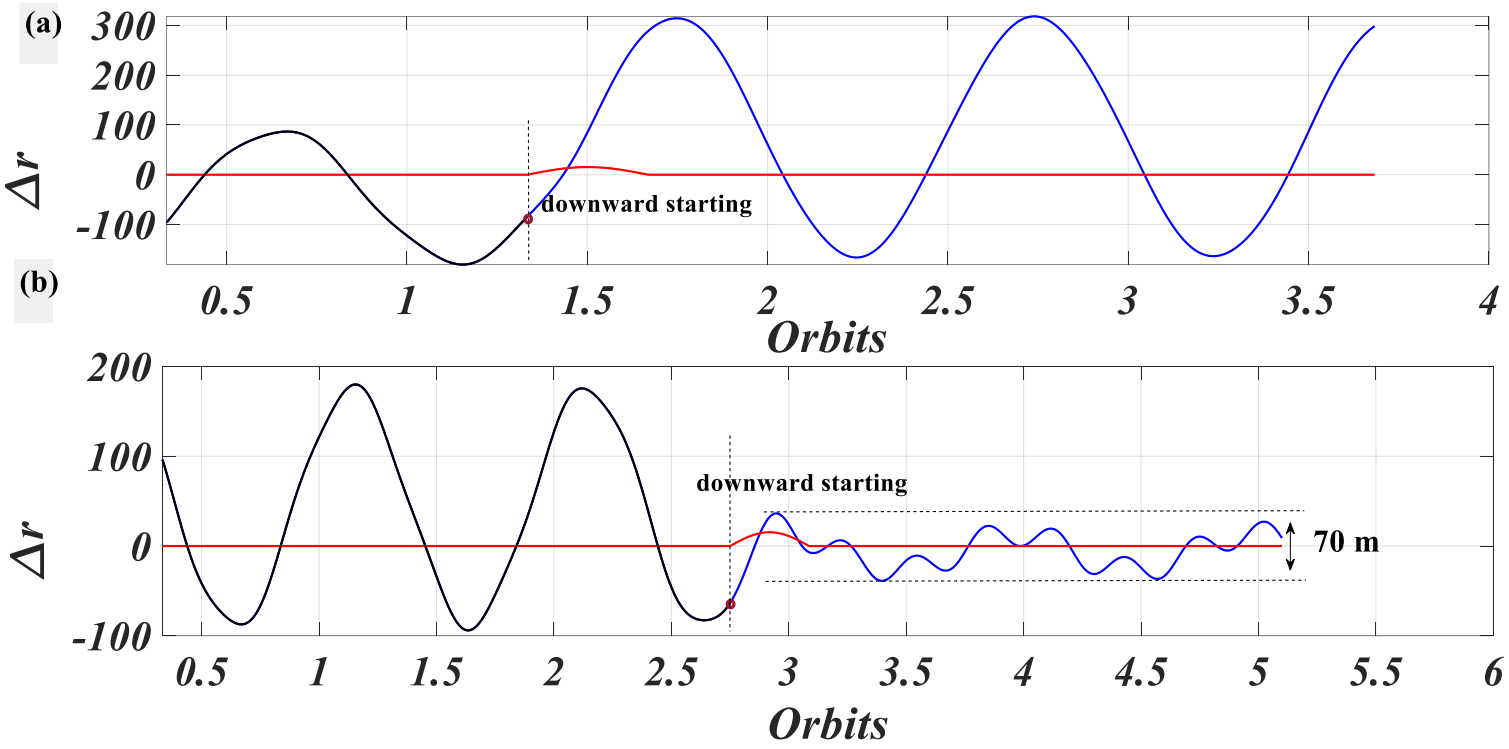


- **Modeling and Dynamic analyzing**

- **Mission-based Method**

Main Objective

- One reasonable condition after one transfer mission is that the changing magnitude of r is small, see blue lines in Figure.

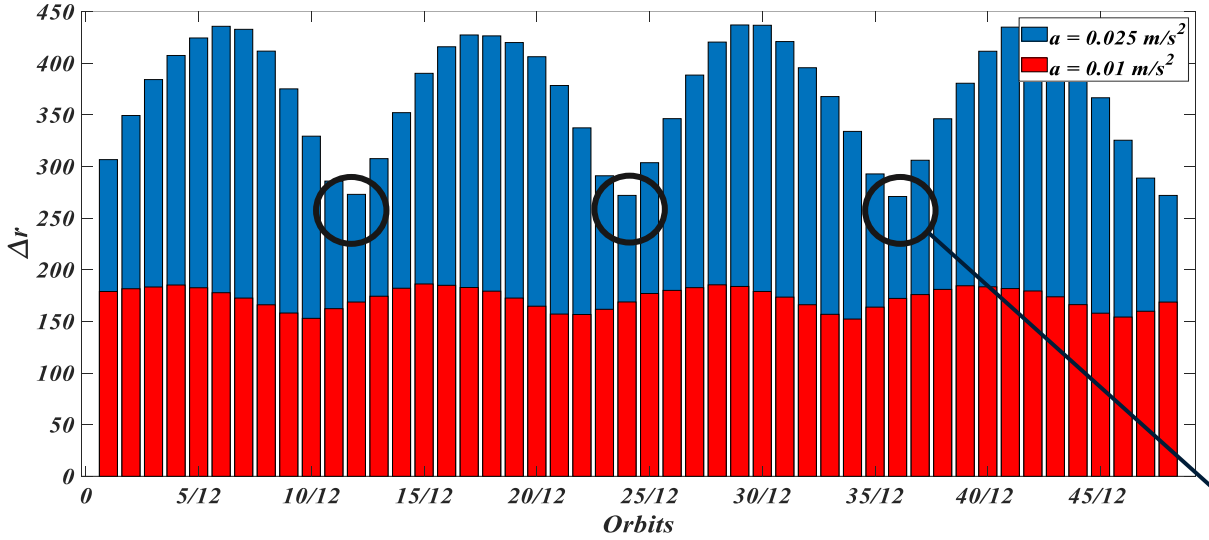


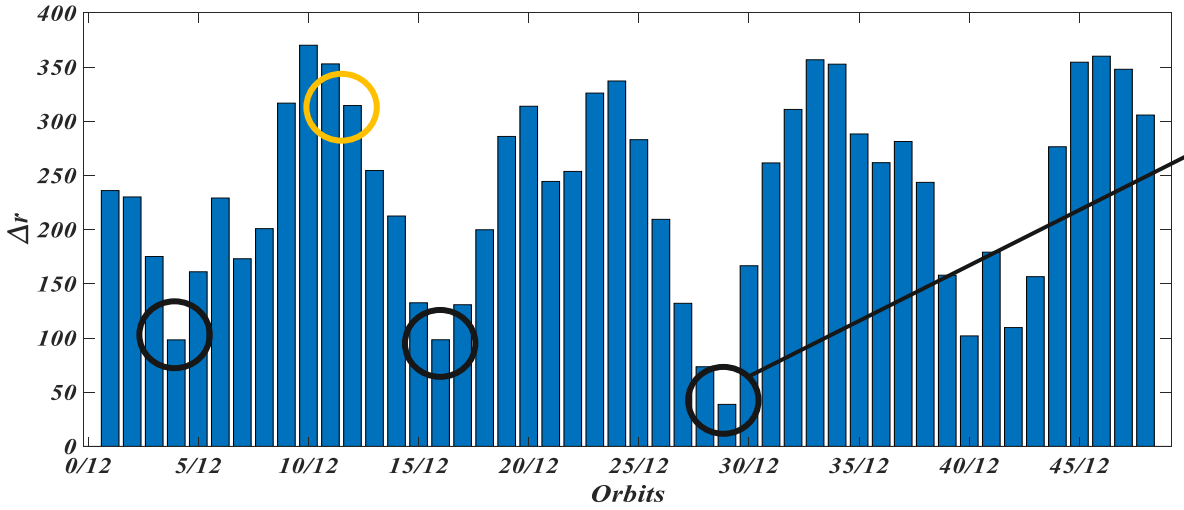
The orbital states after the transfer mission in (b) are better than those in (a).

The expected goal to be achieved after the cargo transportation

How to Achieve the Orbit-Keeping Objective

Dynamics: Effects of Cargo Transportation on the Radius





The minute Δr can be approached **after a waiting period** between the upward and downward movements of the climber

Dynamic Conclusions:

- After **a desired waiting period**, the changing magnitude of the main satellite's radius (Δr) **can be reduced obviously**.
- The appearing of the desired Δr presents some periodicity.

How to Achieve the Orbit-Keeping Objective

- **The problem becomes:**

Determining a transporting time point for the climber's downward movement

to make the final Δr small in a limited future period

Mission-based Method

How to Make the Decision

- **Yet** it is difficult to obtain the optimal beginning time by conventional quadratic planning:

A single **transportation mission** is a **time sequence** that includes a state trajectory, while the **orbital dynamics** of the main satellite focus on **the state at a particular moment**.

Response correlation

t_0 ⟶ K_2

Initial time point

Orbital characteristics of the main satellite after the transposition

Mission-based Method

- **Mission Planning using Reinforcement Learning Method**

RL Method:

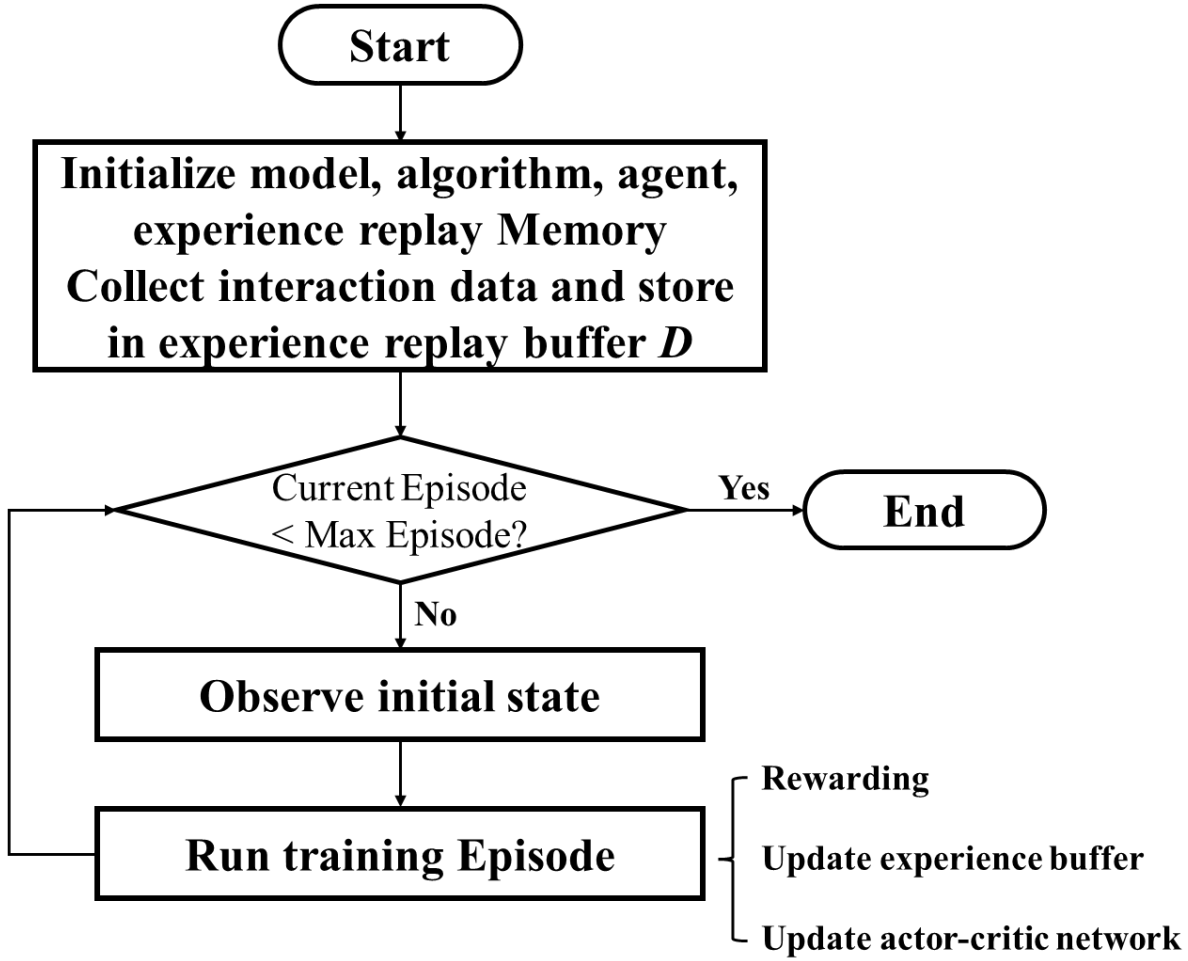
Deep Q-Network Learning Algorithm (DQN)

Why DQN:

1. **Match the issue well:** The decision for the mission-based method is one discrete action space.
2. **Train faster and easier:** DQN training algorithm is simpler and easier to operate than the algorithms with continuous action space like DDPG.

Mission-based Method

Mission Planning using Reinforcement Learning Method



Flow chart of DQN algorithm

State space:

$$(\theta_1, \dot{\theta}_1, \theta_2, \dot{\theta}_2, L_1, \dot{L}_1, r, \dot{r}, \vartheta, \dot{\vartheta}).$$

Action space:

Waiting interval: h

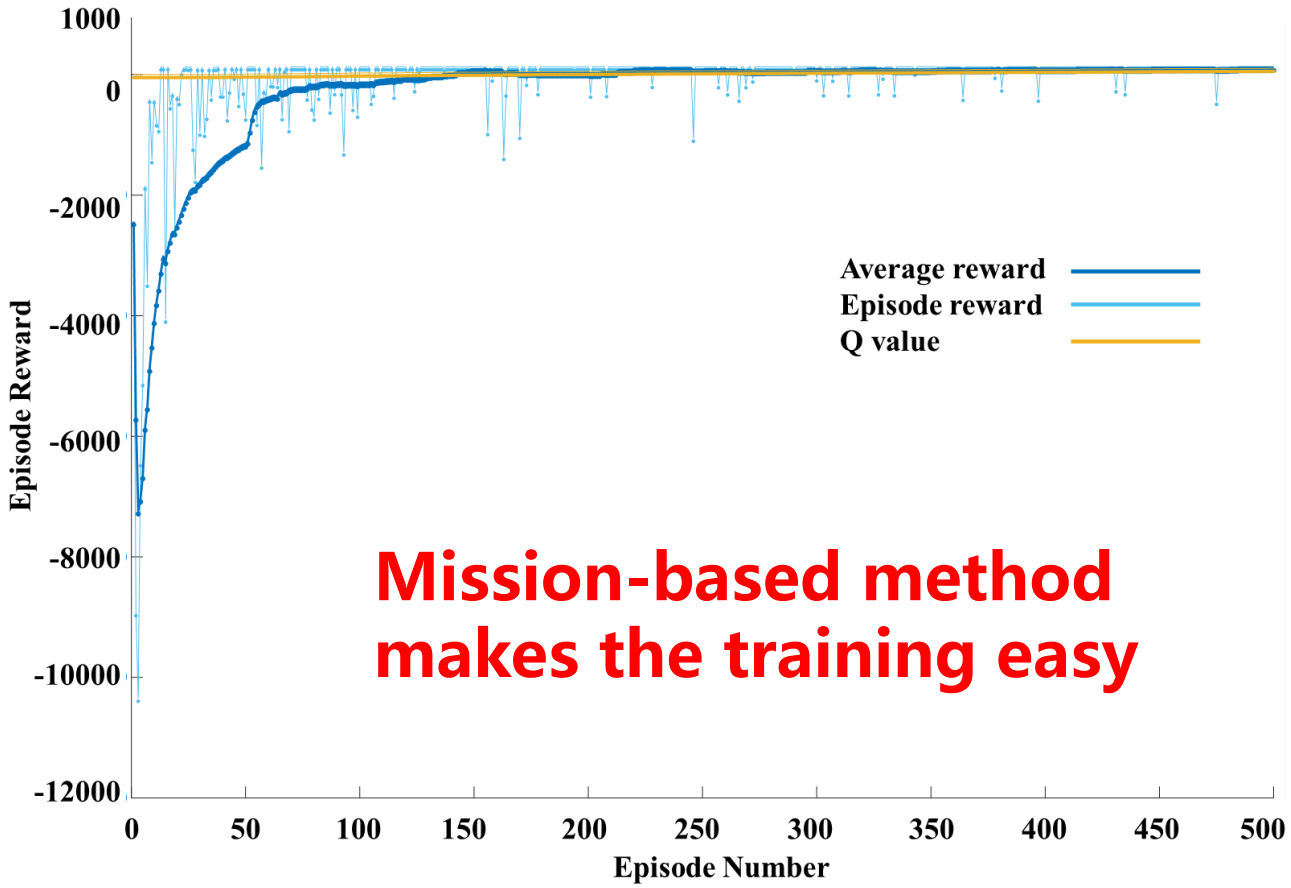
Reward function:

$$Reward = \Delta\bar{r} - \left(\max|r|_n - \min|r|_n\right) - \lambda \max|\dot{r}|_n$$

Each episode has only one action.

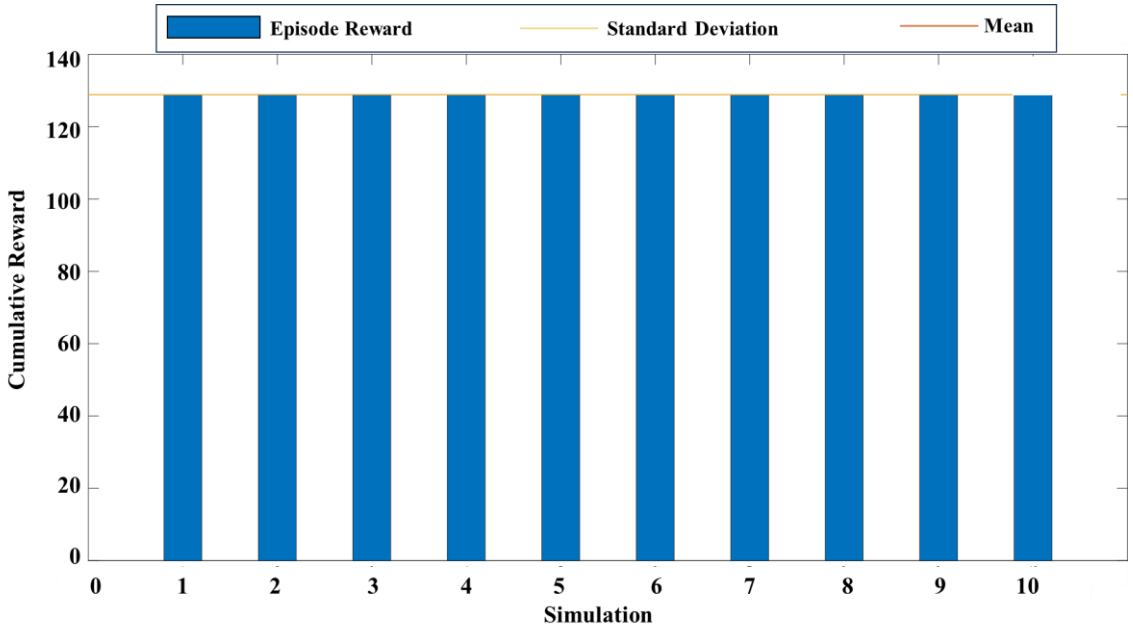
Simulation and Discussion

Training results



Training episodes mean reward

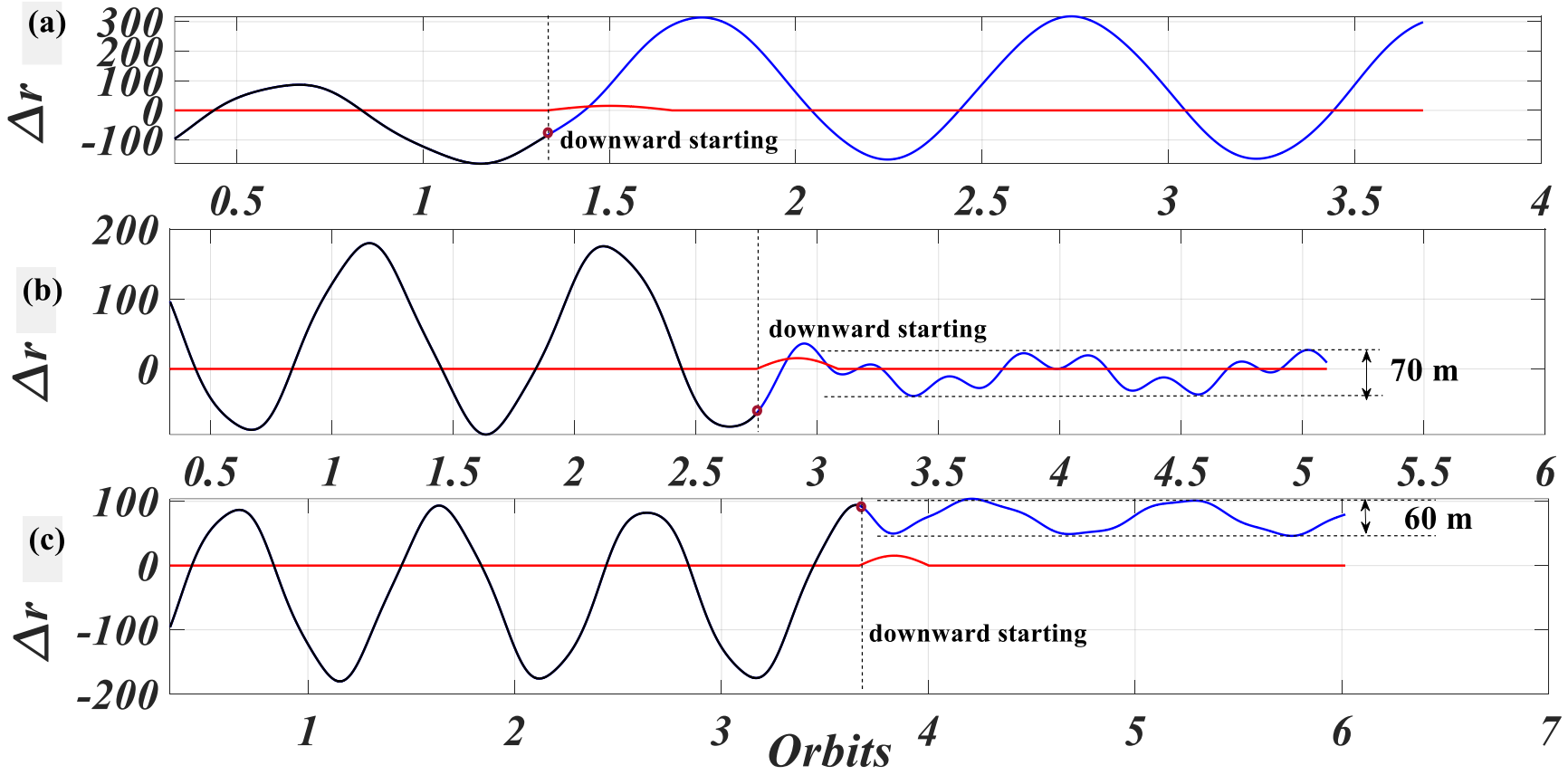
After 200 episodes of learning, the algorithm converged, and the reward value remained stable near 128.79.



Cumulative reward

Simulation and Discussion

Orbital changing



Waiting 1 orbit

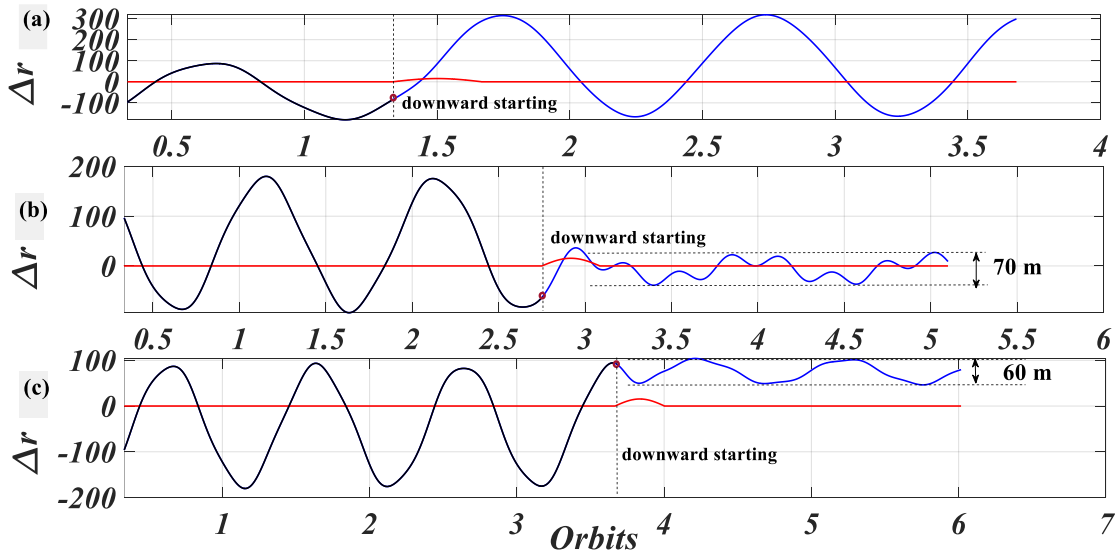
Exhaustion result

Waiting 3.67 orbits
Obtained by RL method

Comparison

Simulation and Discussion

Effects of mission-based method



Comparison

Waiting 1 orbit

Exhaustion result

Great online calculation burden

Obtained by RL method

Δr reduced 88%

Compared with non-planning case

The waiting interval generated by the proposed RL method reduces the orbital radius changing magnitude after the mission by **over 88%**.

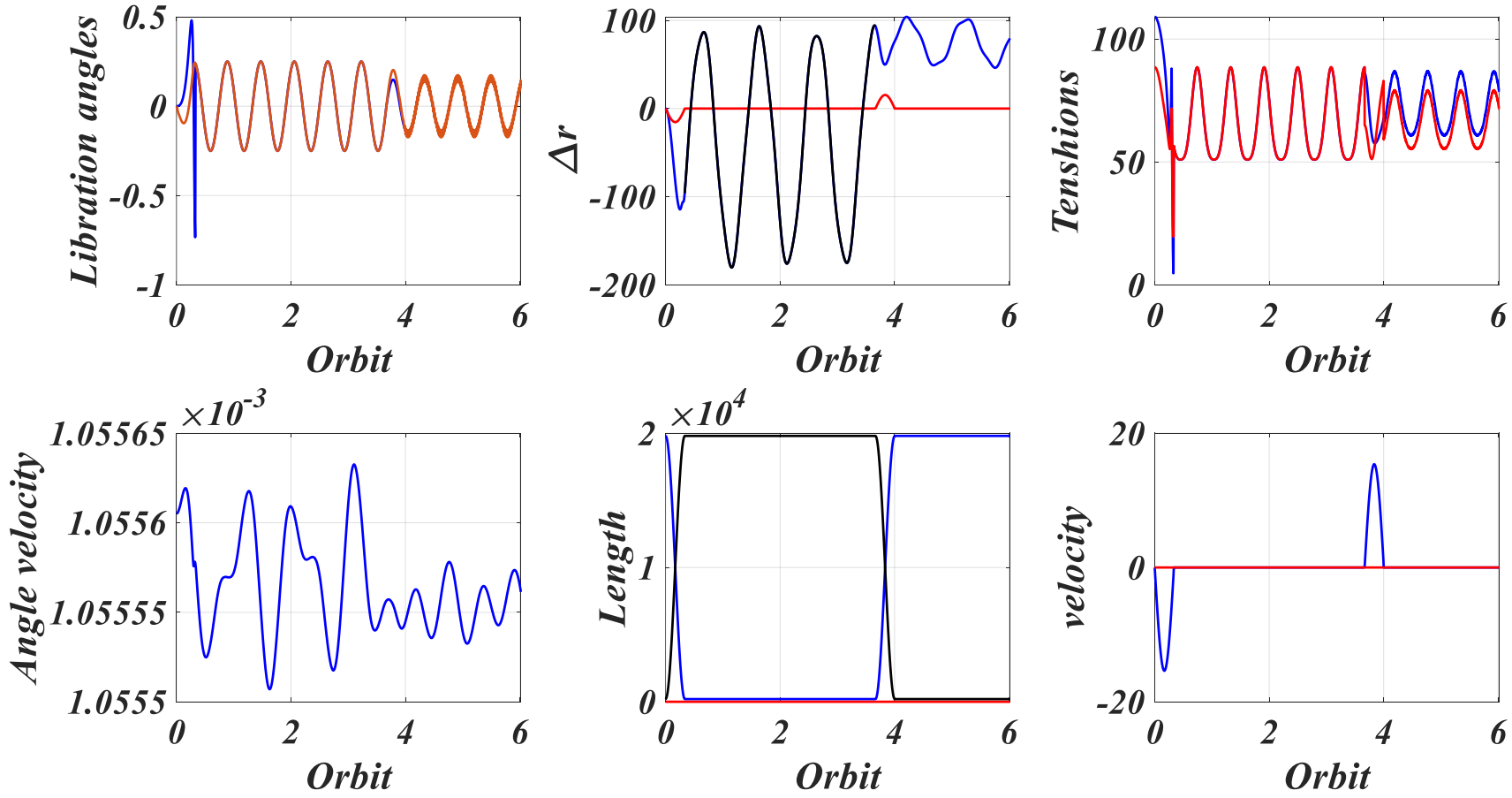
Exhaustion result's amplitude of the orbital radius is 70m, which is greater than that in the case in which the waiting interval is generated by the RL method. Due to the searching step of the exhaustion is not small enough to achieve the optimal waiting interval.

Simulation and Discussion

- **Disadvantages**

1.Libration suppression is not considered

2.Climber speed function is preset.



States of the PSE using RL method

Conclusions and Prospects

Conclusions

1. A Mission-based method has been proposed to address the main satellite's orbital keeping of the PSE implemented by DQN-based Algorithm.
2. The new method focuses on planning the waiting interval between two transfer missions from a mission planning perspective
3. The proposed mission-based method is effective in orbit radius keeping.

Conclusions and Prospects

- **Current Issues**

1. The current RL method lacks robustness.

2. The current method cannot balance the issue of libration suppression during the process.

Conclusions and Prospects

- **Prospects**

1. Establishing a mapping **relationship between the orbital dynamics of the main spacecraft** and the load transportation mission, in order to provide a specific mathematical description of the impact of the transportation mission on the orbital parameters of the main spacecraft after the transportation is completed.

2. Provide a cargo transportation mission planning method for maintaining the orbit of the main spacecraft, establish an integrated mission planning framework that **coordinates multiple objectives and constraints, and takes into account both "local" mission planning and "global" sequence planning**.

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