

University of Stuttgart  
Institute of Space Systems



# Modeling and Control of Orbital Perturbation Torques and Mass Distribution Impact on Libration Dynamics of Tethered Systems

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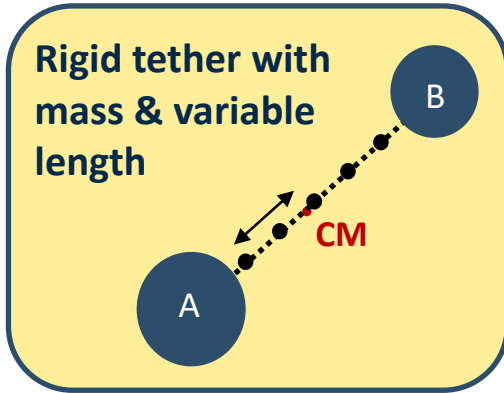
A Case Study of a 12U Tethered CubeSat System  
with a 100 m, Non-conductive, Rigid Space Tether on Sun-Synchronous Orbit

# Objectives and Methodology

## Phase 0/A study

- Libration analysis of two design concepts
- Definition of mission requirements on SSO at 400-600 km
- Gravity-gradient stability
- Control options and estimation of control torques

### Dumbbell model

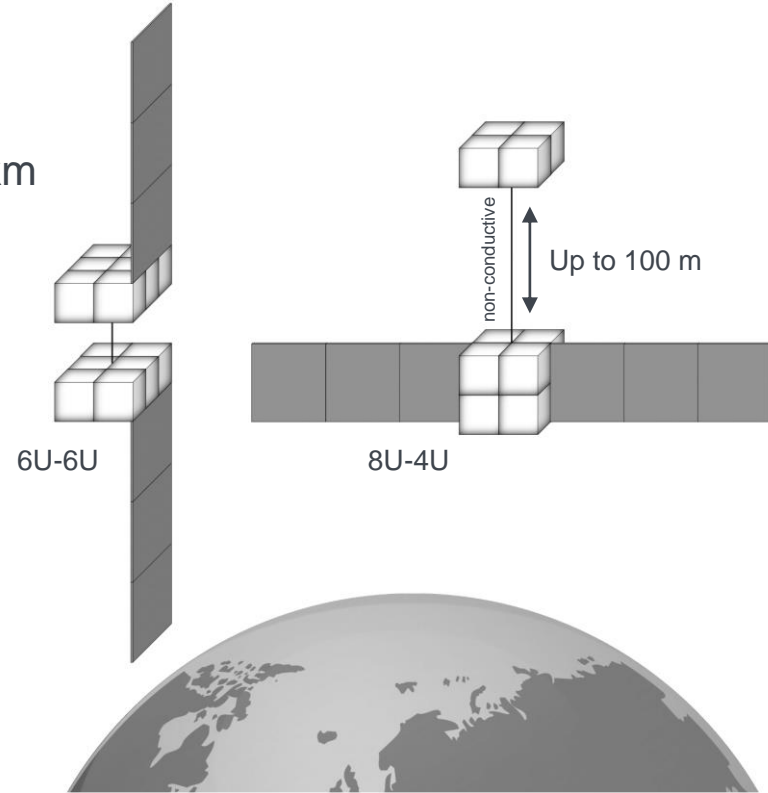


### Control strategies

Tether Tension

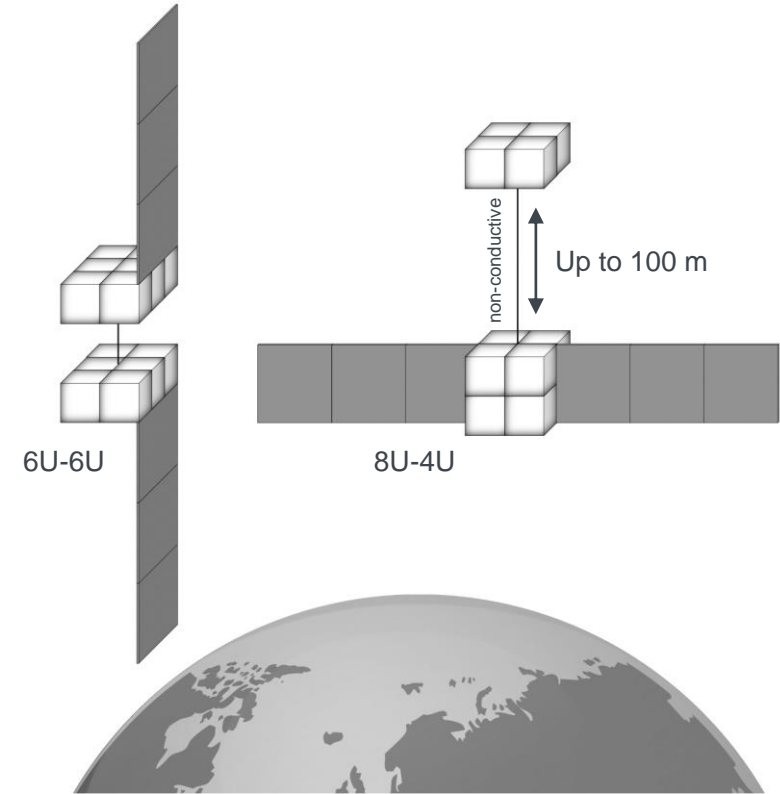
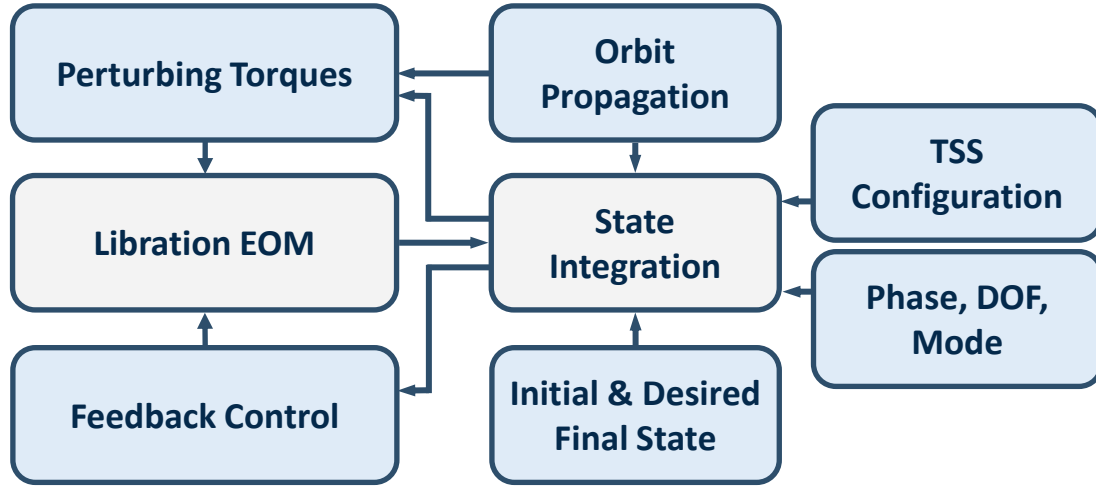
Thrusters

Reaction Wheels



# Objectives and Methodology

## Simulation



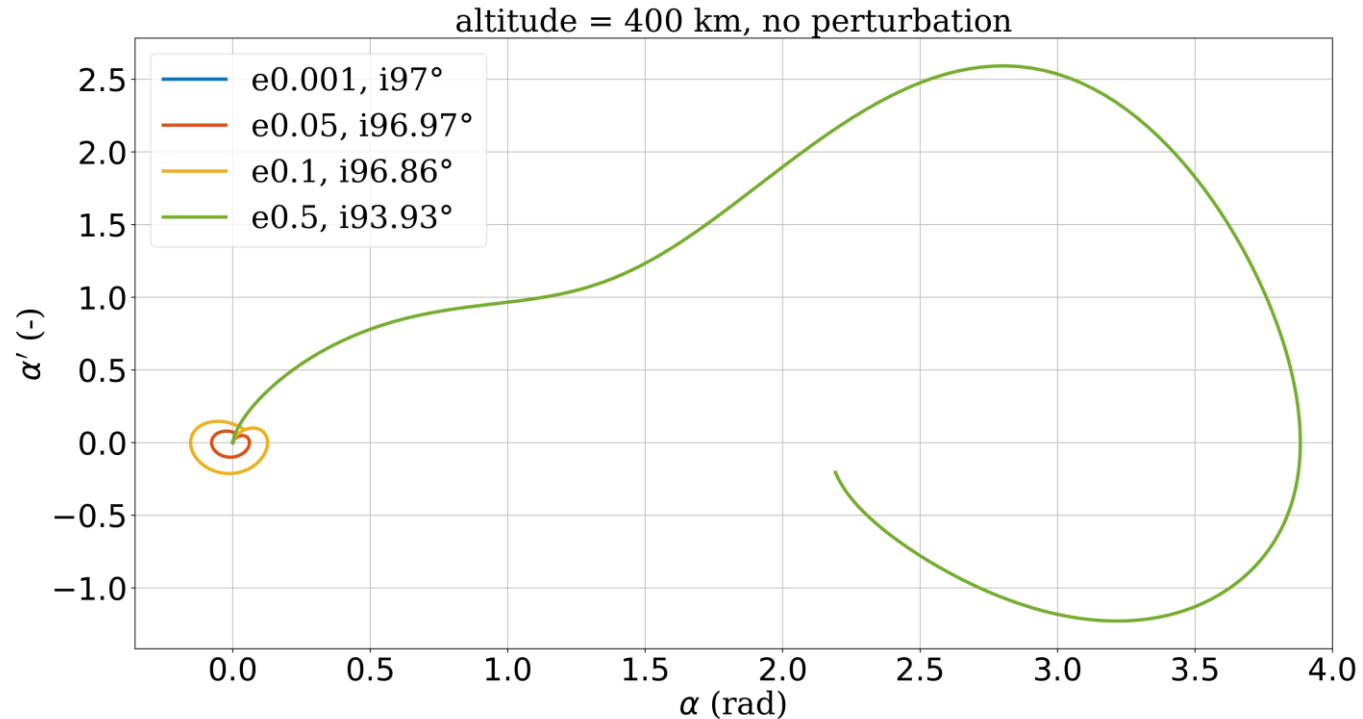
# Results: 1-DOF Planer Libration

## Assumptions

- Station-keeping at 100 m
- Without feedback control
- SSO at 400 km
- No perturbations
- 1 orbit period

## Key findings

- Negative effect of large orbit eccentricity



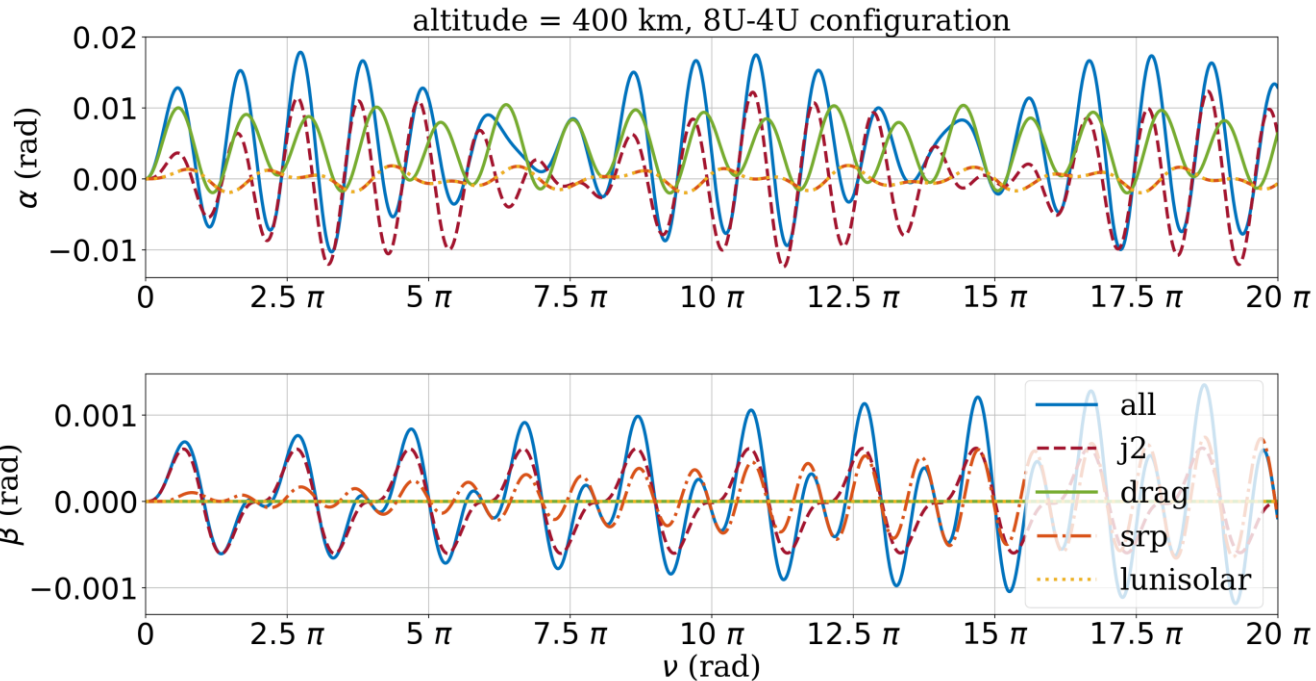
# Results: 2-DOF Coupled In-plane and Out-of-plane Libration

## Assumptions

- 8U-4U
- Station-keeping at 100 m
- Without feedback control
- SSO at 400 km
- All perturbations

## Key findings

- Larger in-plane oscillations
- Dominant drag & J2 effects on in-plane motion
- SRP and eclipse effect on out-of-plane oscillations



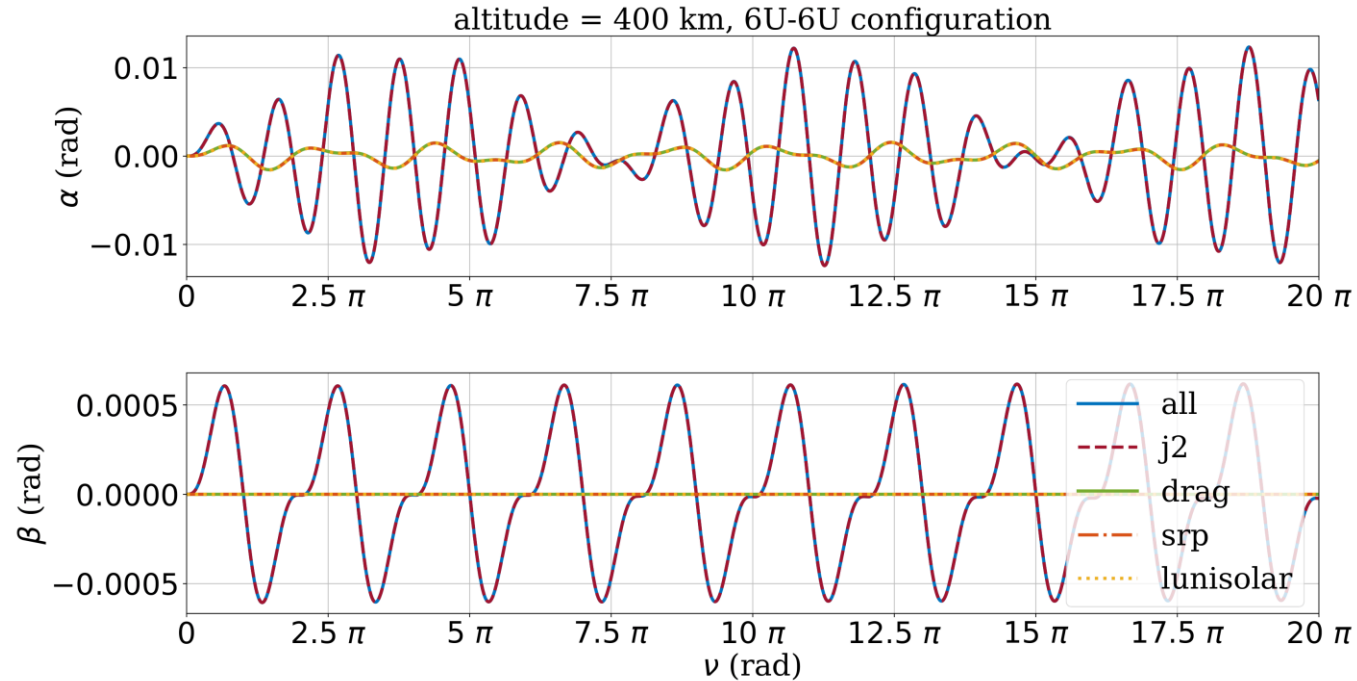
# Results: 2-DOF Coupled In-plane and Out-of-plane Libration

## Assumptions

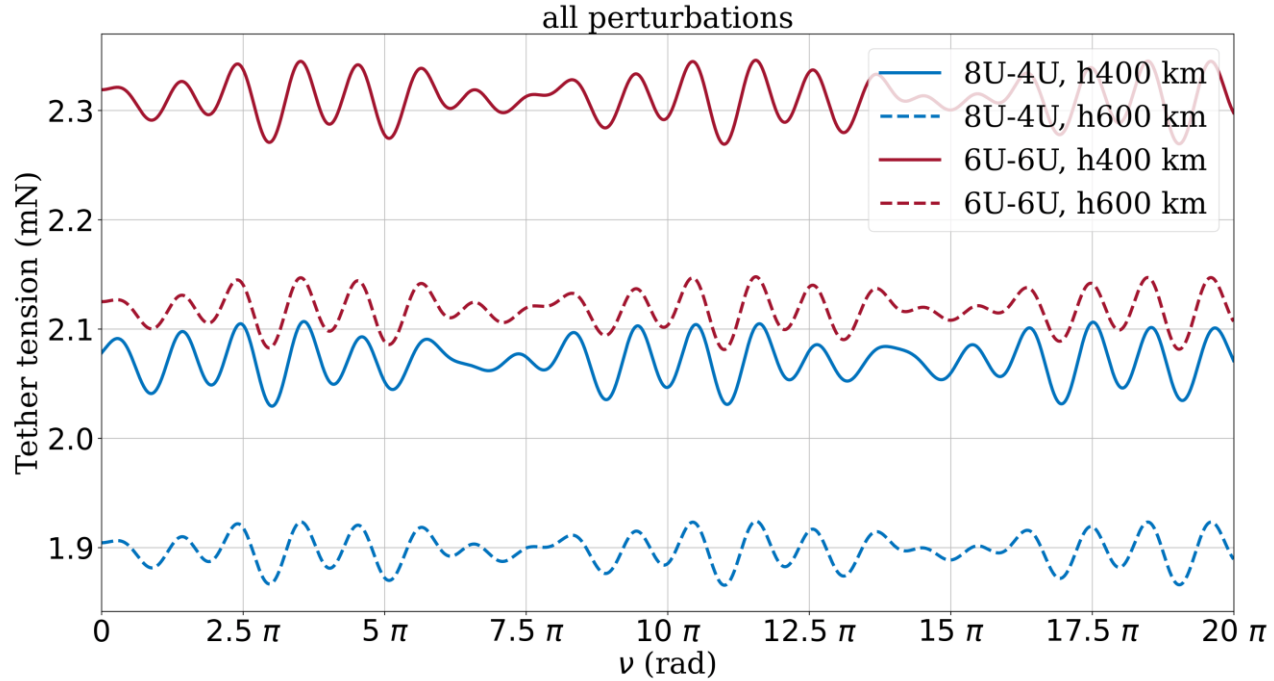
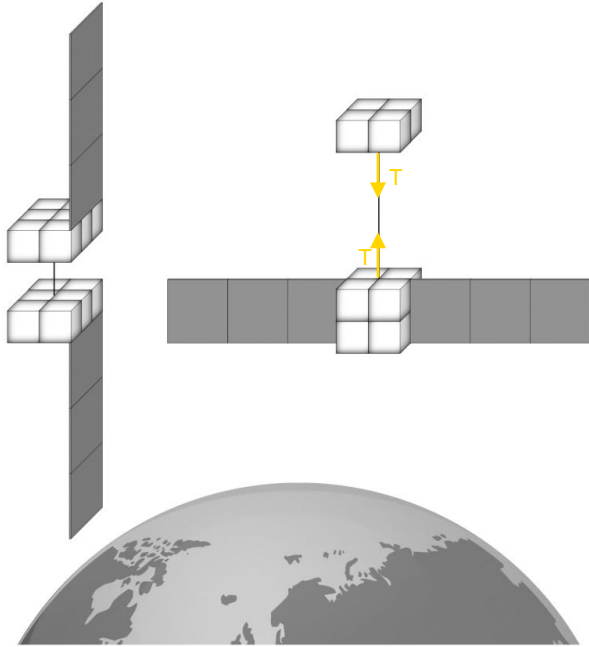
- 6U-6U
- Station-keeping at 100 m
- Without feedback control
- SSO at 400 km
- All perturbations

## Key findings

- Small & near-zero amplitudes
- Dominant J2 effect



# Results: 2-DOF Coupled In-plane and Out-of-plane Libration



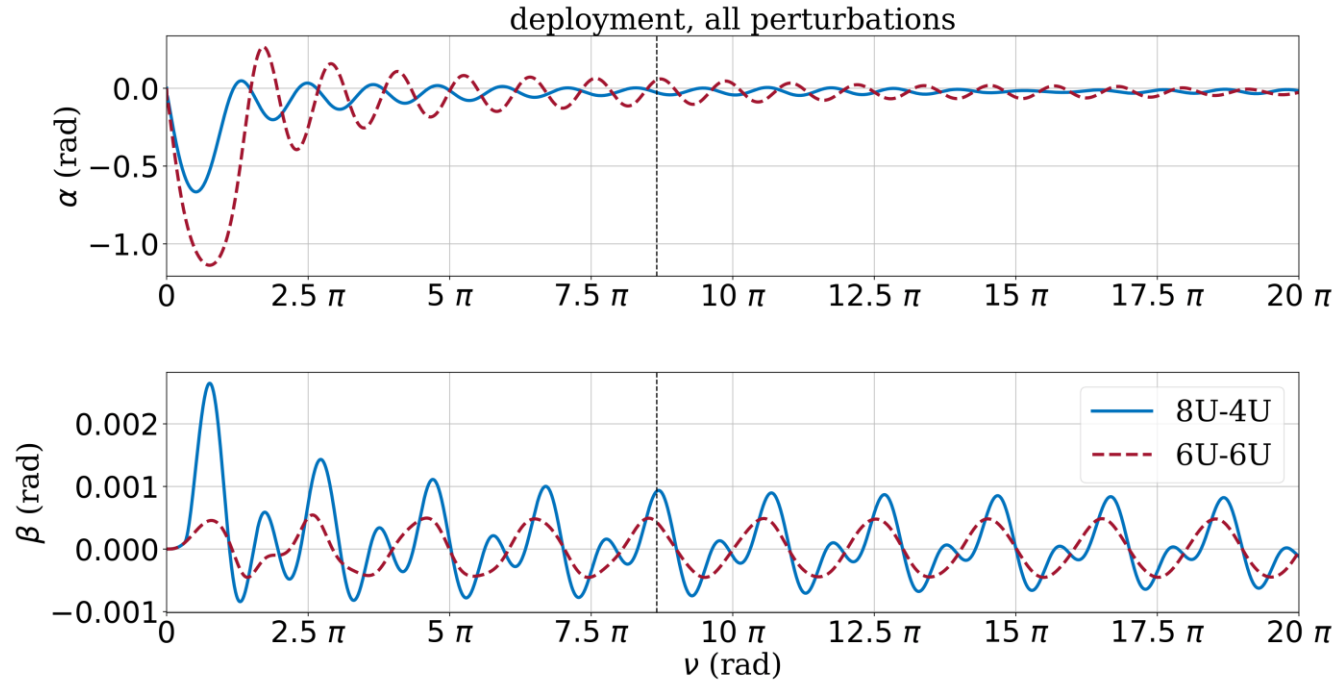
# Results: 3-DOF Deployment Libration

## Assumptions

- Deployment to 100 m
- Constant release rate
- 8U-4U vs. 6U-6U
- Without feedback control
- SSO at 400 km
- All perturbations

## Key findings

- Relatively stable after an initial increase in angles





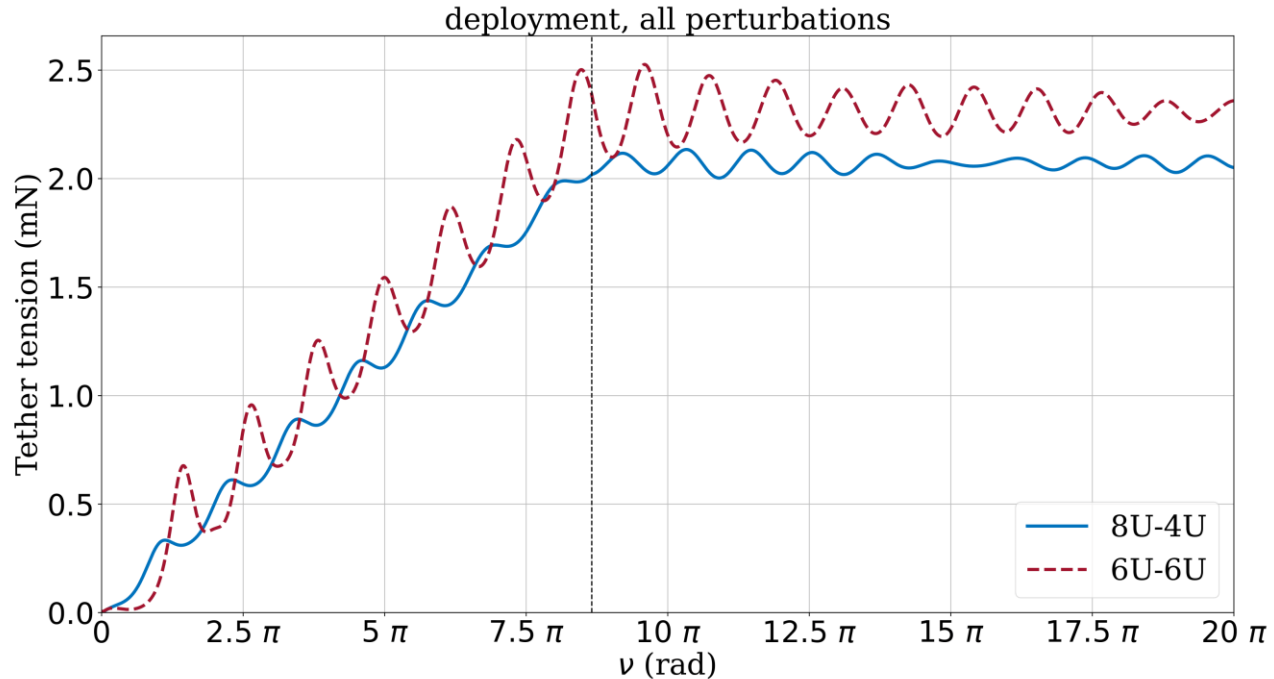
# Results: 3-DOF Deployment Libration

## Assumptions

- Deployment to 100 m
- Constant release rate
- 8U-4U vs. 6U-6U
- Without feedback control
- SSO at 400 km
- All perturbations

## Key findings

- Tension increase
- Larger oscillations in 6U-6U



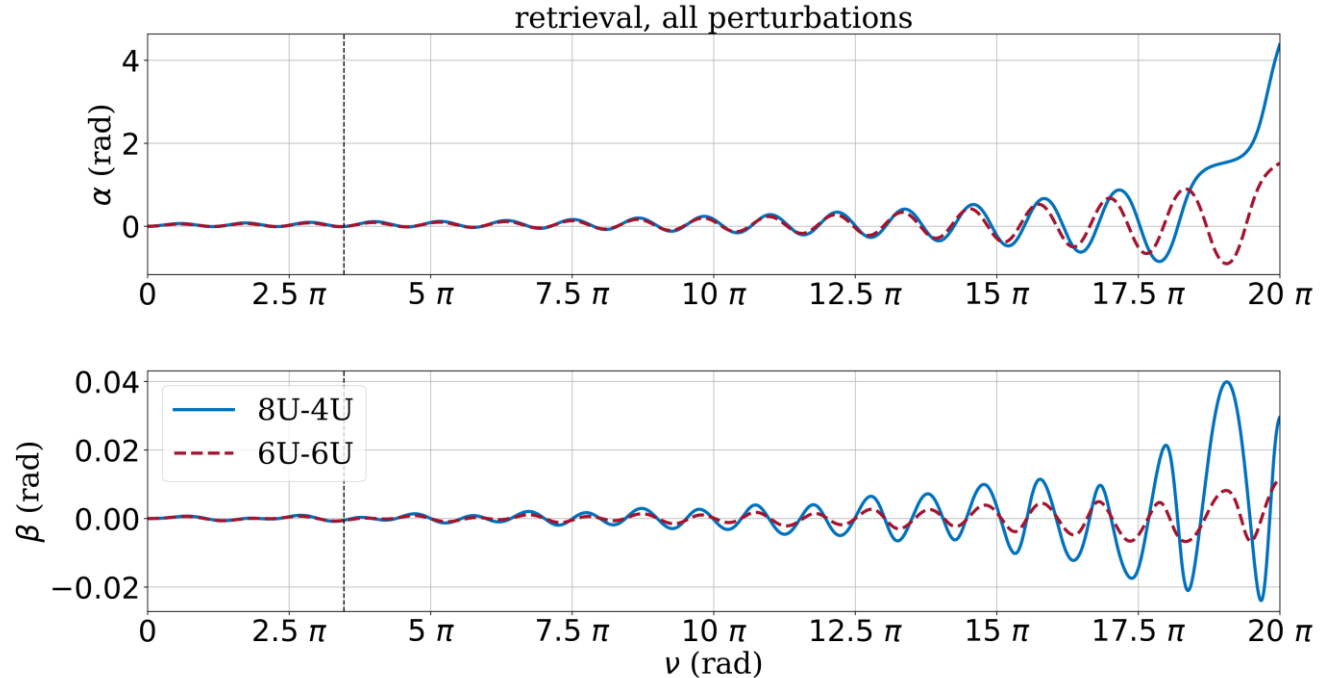
# Results: 3-DOF Retrieval Libration

## Assumptions

- Retrieval 100 m to 60 m
- Constant retrieve rate
- 8U-4U vs. 6U-6U
- Without feedback control
- SSO at 400 km
- All perturbations

## Key findings

- Very large libration angles
- Inability to stabilize



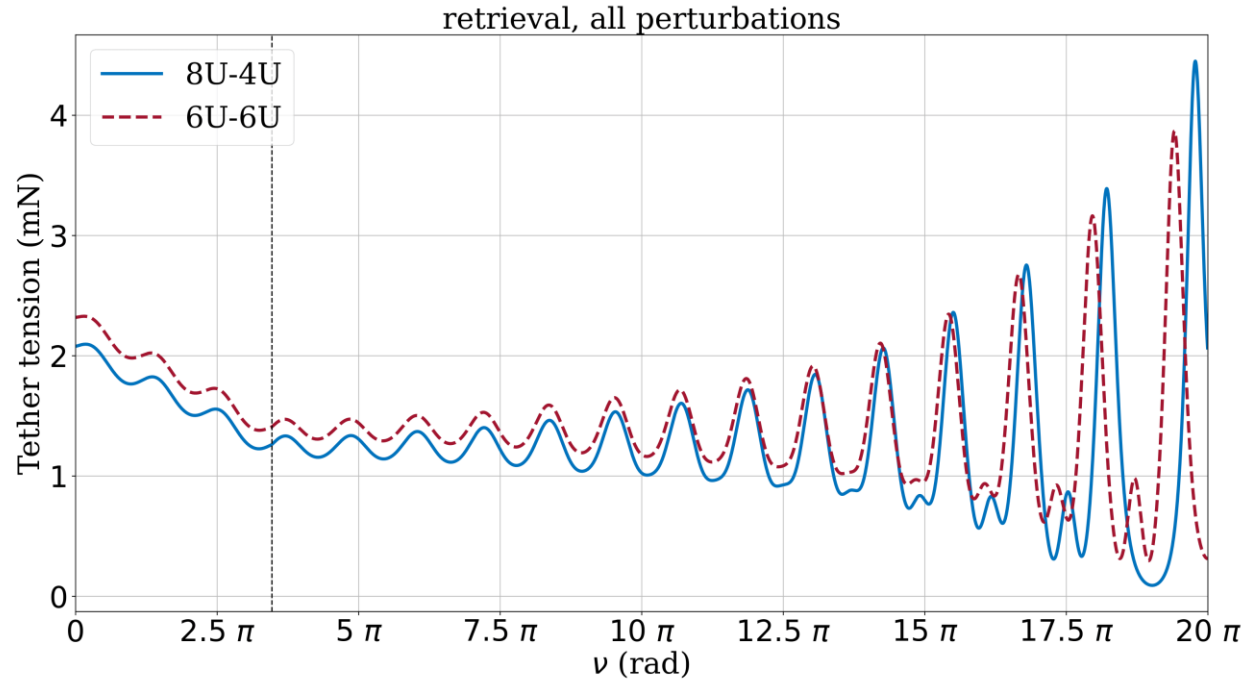
# Results: 3-DOF Retrieval Libration

## Assumptions

- Retrieval 100 m to 60 m
- Constant retrieve rate
- 8U-4U vs. 6U-6U
- Without feedback control
- SSO at 400 km
- All perturbations

## Key findings

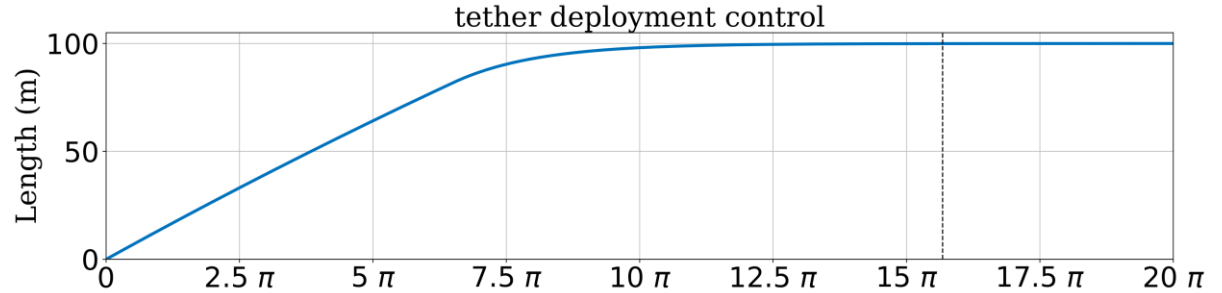
- Initial tension decrease
- Very large oscillation amplitudes



# Results: Deployment Control

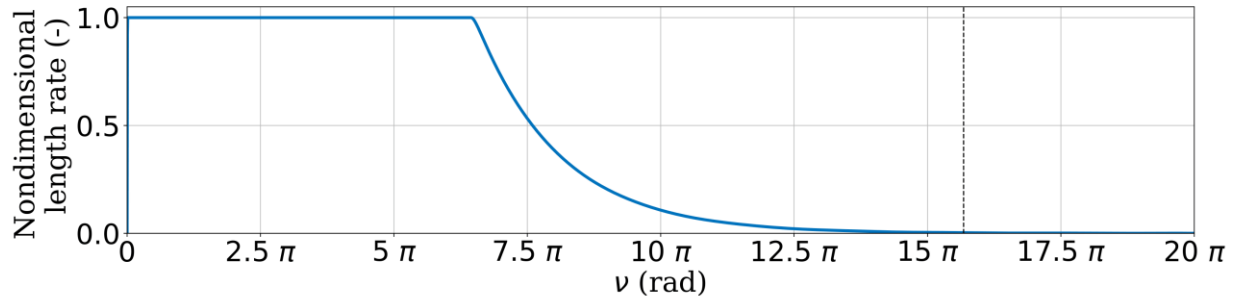
## Assumptions

- With feedback control
- Deployment to 100 m
- 8U-4U
- SSO at 400 km
- All perturbations



## Key findings

- Release rate regulation



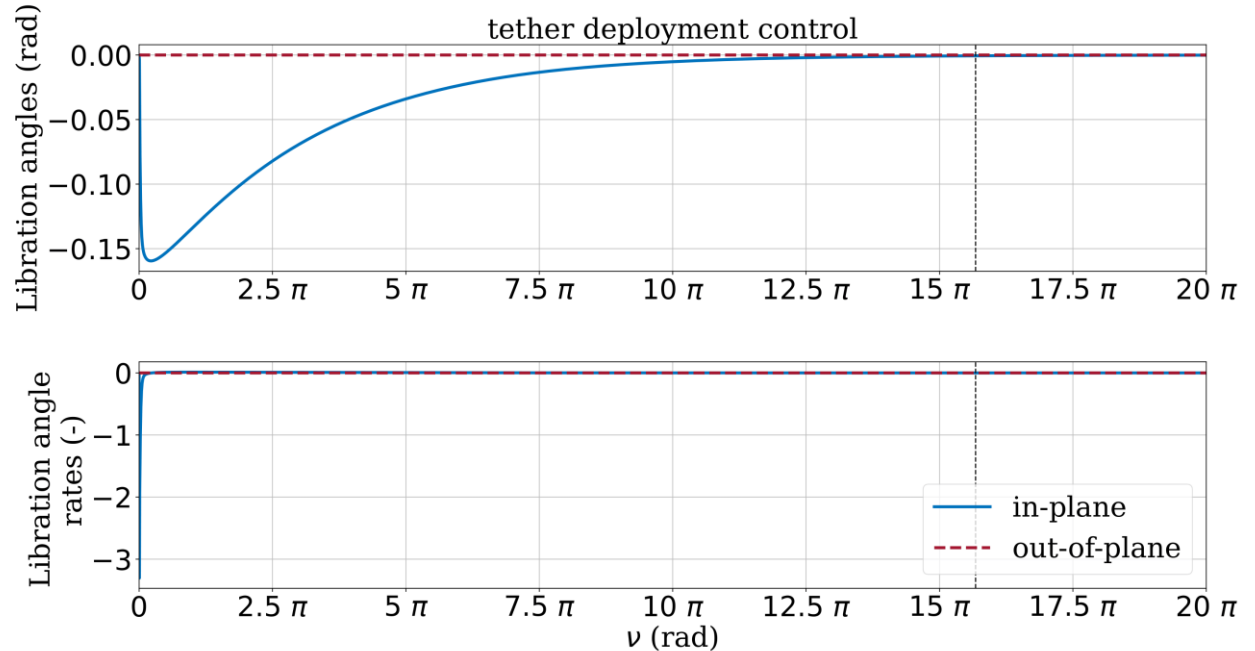
# Results: Deployment Control

## Assumptions

- With feedback control
- Deployment to 100 m
- 8U-4U
- SSO at 400 km
- All perturbations

## Key findings

- Release rate regulation
- Small in-plane angle variation



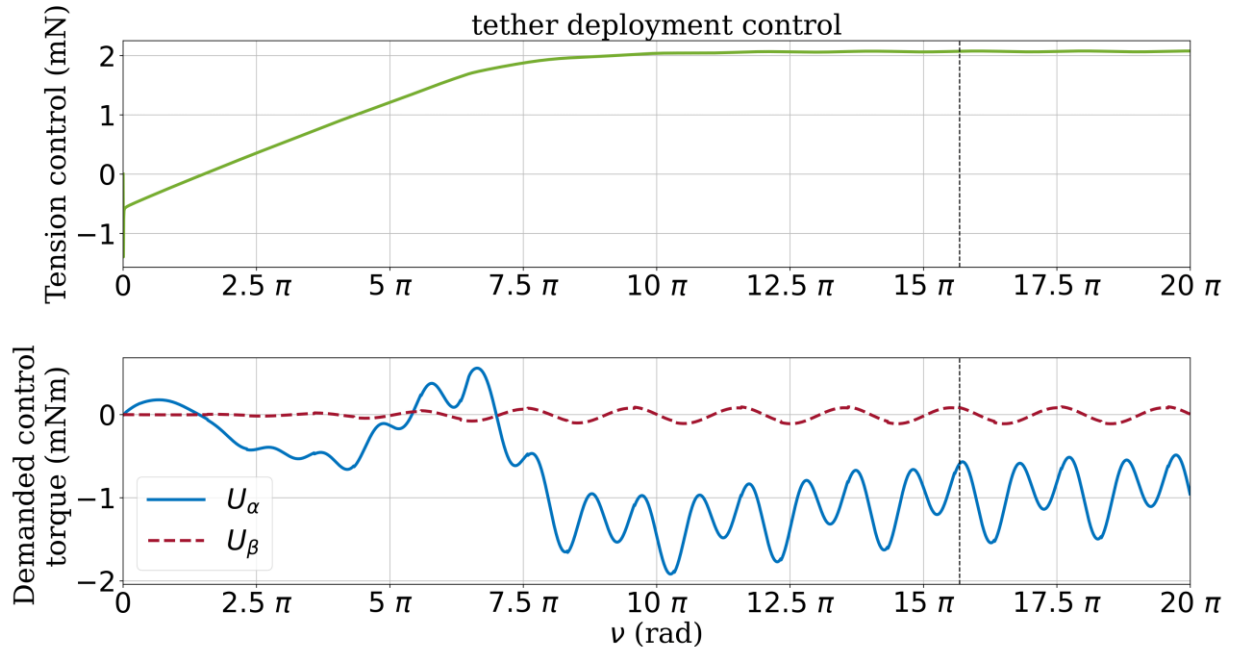
# Results: Deployment Control

## Assumptions

- With feedback control
- Deployment to 100 m
- 8U-4U
- SSO at 400 km
- All perturbations

## Key findings

- Release rate regulation
- Small in-plane angle variation
- Small but continuous control torque



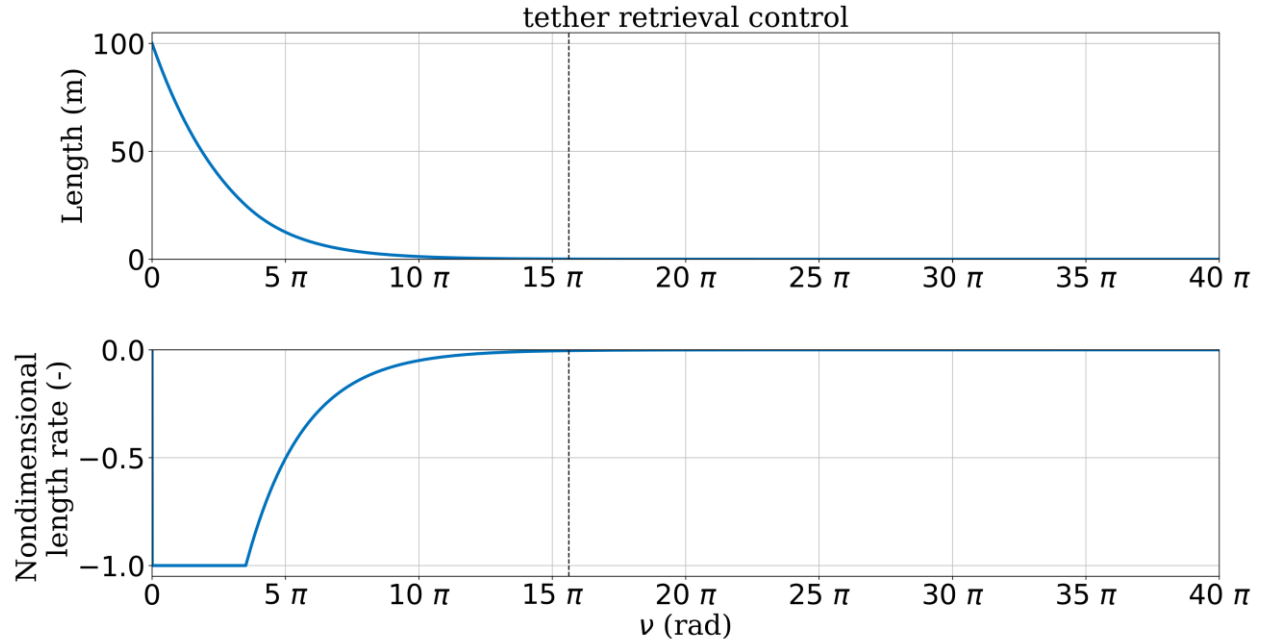
# Results: Retrieval Control

## Assumptions

- With feedback control
- Retrieval 100 m to 1 cm
- 8U-4U
- SSO at 400 km
- All perturbations

## Key findings

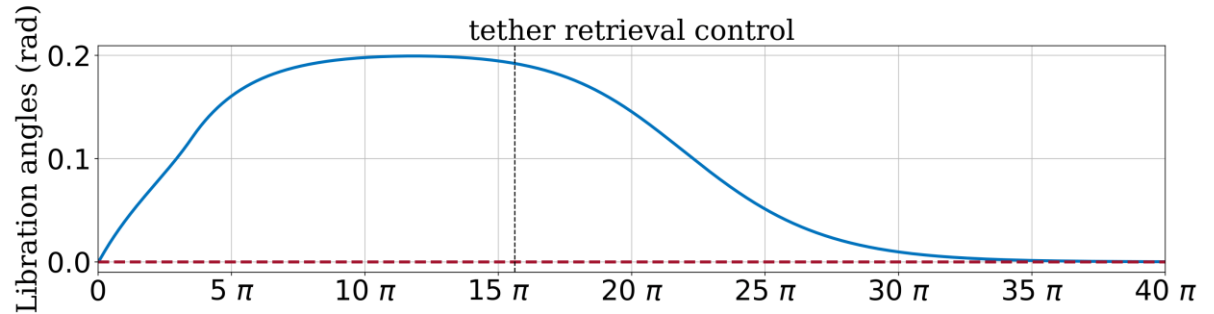
- Retrieve rate regulation



# Results: Retrieval Control

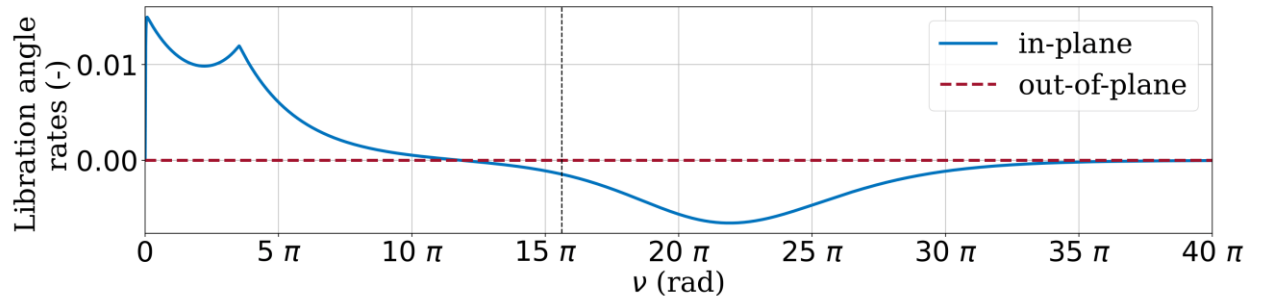
## Assumptions

- With feedback control
- Retrieval 100 m to 1 cm
- 8U-4U
- SSO at 400 km
- All perturbations



## Key findings

- Retrieve rate regulation
- Small in-plane angle variation
- Tumbling after retrieval





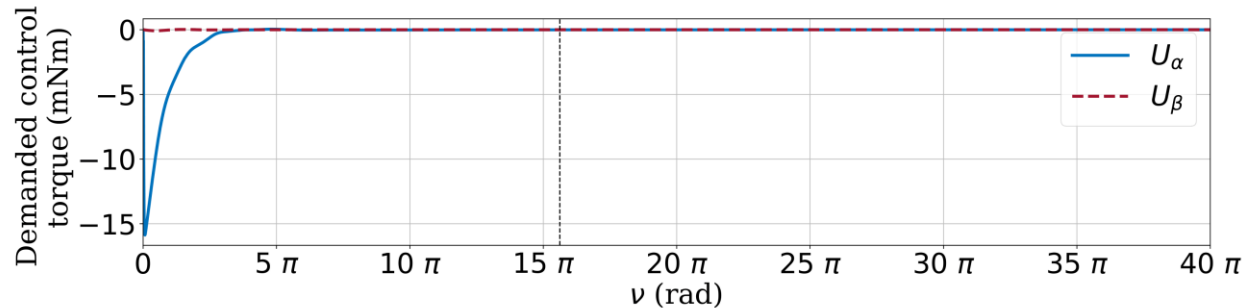
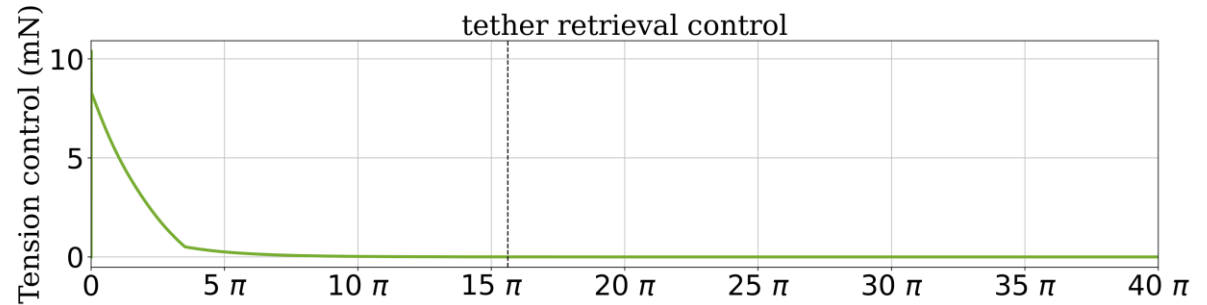
# Results: Retrieval Control

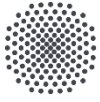
## Assumptions

- With feedback control
- Retrieval 100 m to 1 cm
- 8U-4U
- SSO at 400 km
- All perturbations

## Key findings

- Retrieve rate regulation
- Small in-plane angle variation
- Tumbling after retrieval
- Diminishing control terms





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**Thank you!**



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