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Coupled dynamics of large space structures in Lagrangian points

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Presentation overview

- Motivation
- Framework
- Coupled orbit-attitude periodic solutions
- Solar radiation pressure effect
- Spacecraft flexibility effect
- Conclusions

Motivation

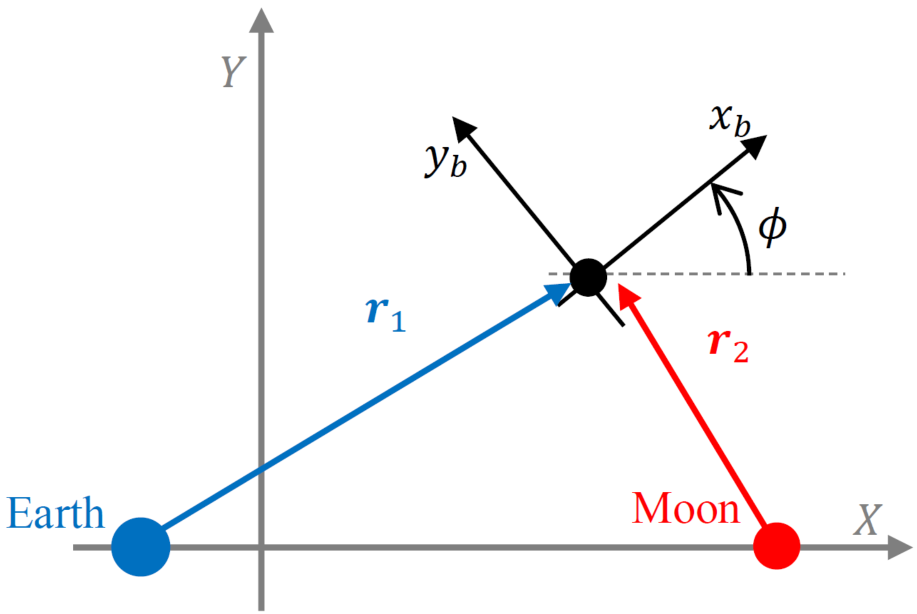
Growing interest in **Large Space Structures** (LSS):

- New manned station after ISS dismissal
- Orbiting infrastructure to support lunar soil activities
- Space station with modular architecture

LSS in multi-body gravitational environments (Earth-Moon) require a deeper analysis of the coupled orbit-attitude dynamics; ACS sizing requirements derive from the environmental torques, highly coupled with the orbital motion.

Framework (1)

Earth-Moon **Circular Restricted Three-Body Problem** (CR3BP). Planar orbit and attitude dynamics in the synodic frame.



$x_b y_b$ = principal body frame

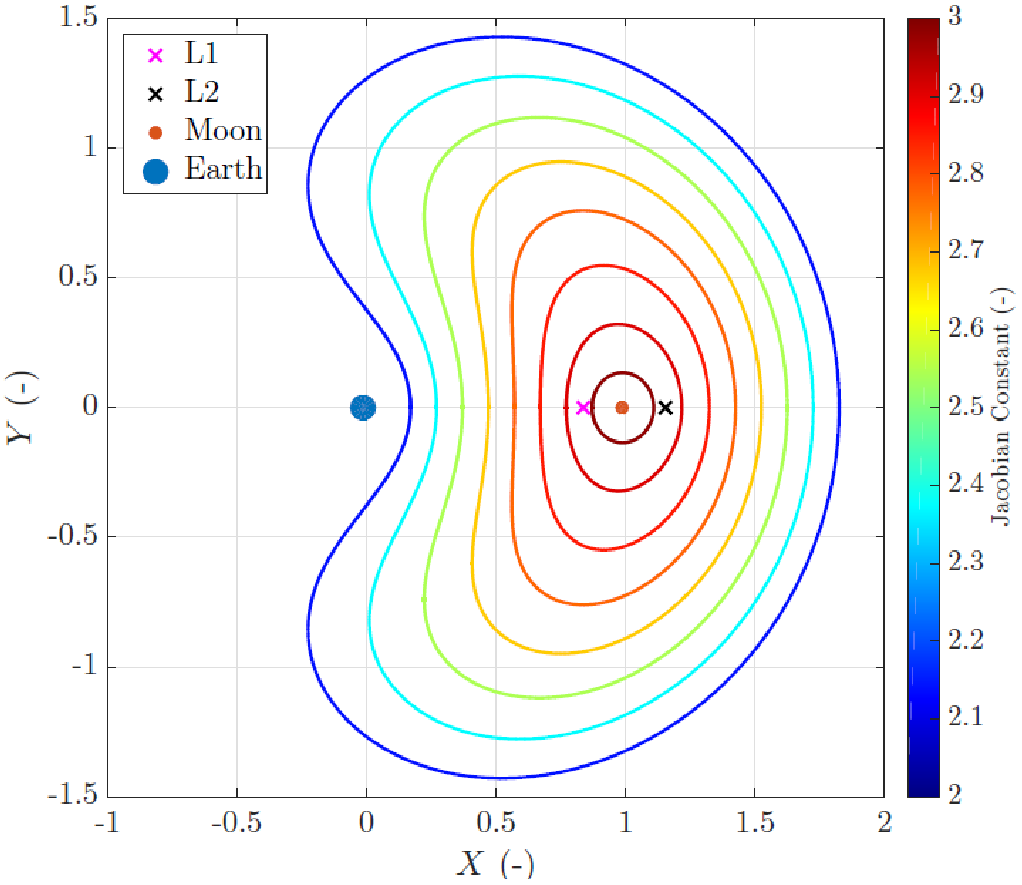
XY = rotating synodic frame

ϕ = rotation angle

Framework (2)

Investigation focused on **Distant Retrograde Orbits** (DRO).

- High stability (4 stable and 2 center manifolds up to Earth's vicinity)
- Possible location for asteroid boulder (ARM)
- Suitable for lunar support infrastructure



Coupled orbit-attitude periodic solutions (1)

The combined **gravity gradient torque** of the two primaries creates peculiar attitude behaviors, strongly coupled with the orbital motion

$$[I]\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times [I]\boldsymbol{\omega} = -3\frac{1-\mu}{r_1^5}[I][A]\boldsymbol{r}_1 \times [A]\boldsymbol{r}_1 - 3\frac{\mu}{r_2^5}[I][A]\boldsymbol{r}_2 \times [A]\boldsymbol{r}_2$$

$[I]$ = principal inertia tensor; $[A]$ = rotation matrix; $\boldsymbol{\omega}$ = body angular velocity

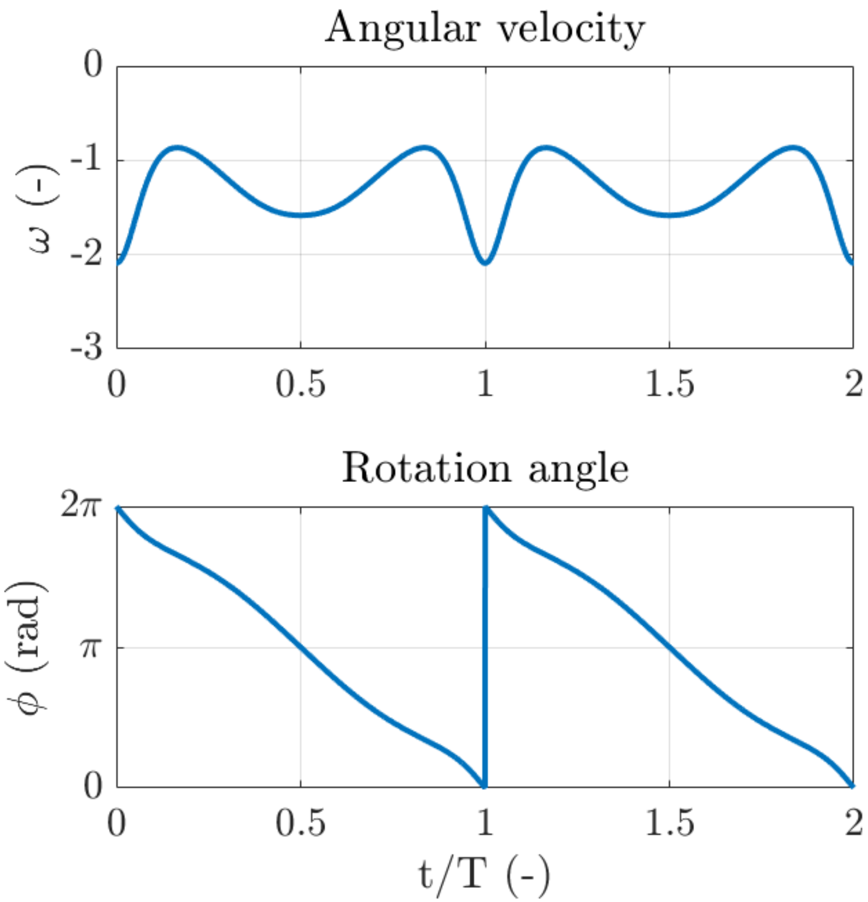
Coupling term: gravity gradient torque, depending both on orbital position and body attitude.

Coupled orbit-attitude periodic solutions (2)

Search for periodic orbit-attitude behaviors:

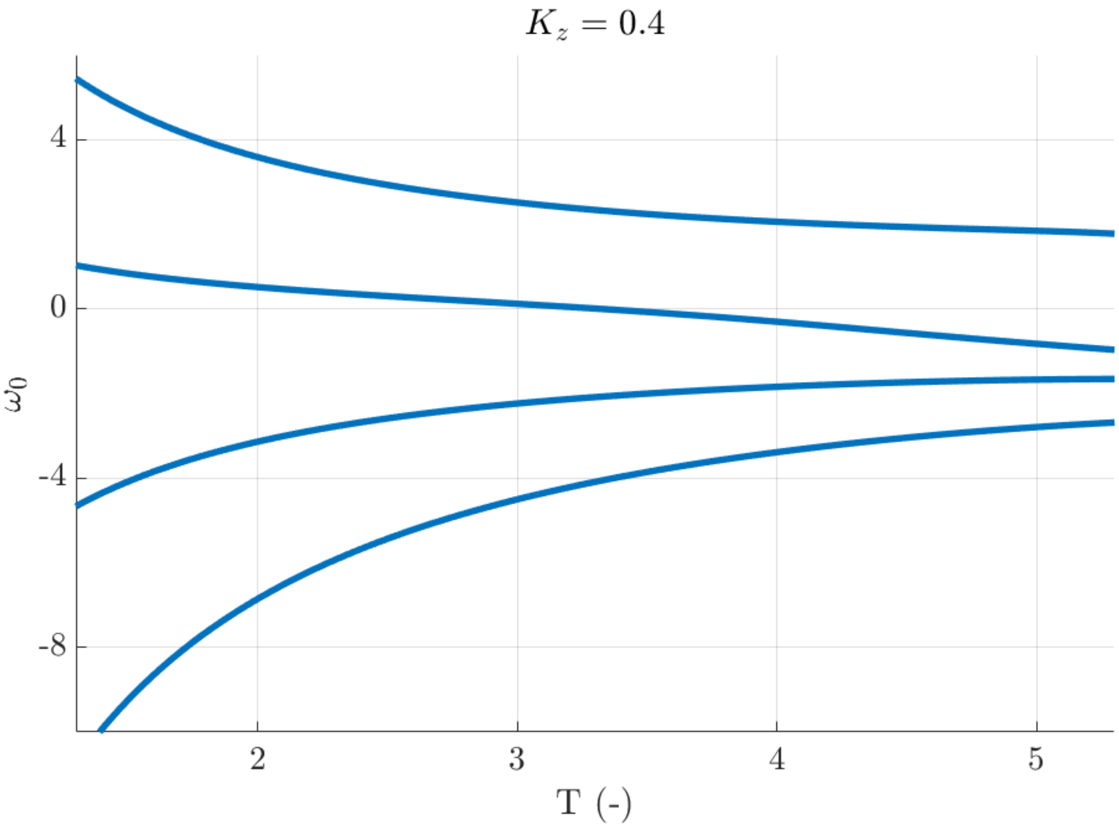
- **Benefit for ACS**, reducing control effort
- Satisfy coarse pointing requirements
- Provide insight on the **dynamical structure** of the problem

Definition: *given a periodic orbit in the CR3BP, find the initial condition that establishes a periodic attitude motion.*



Coupled orbit-attitude periodic solutions (3)

Solution space visually portrayed in periodicity maps.



Inertia ratio $K_z = \frac{I_y - I_x}{I_z}$

Different curves define **families of solutions**, classified according to the number of body revolutions per orbit.

SRP effect (1)

Solar radiation pressure (SRP) perturbs both attitude and orbital motion.

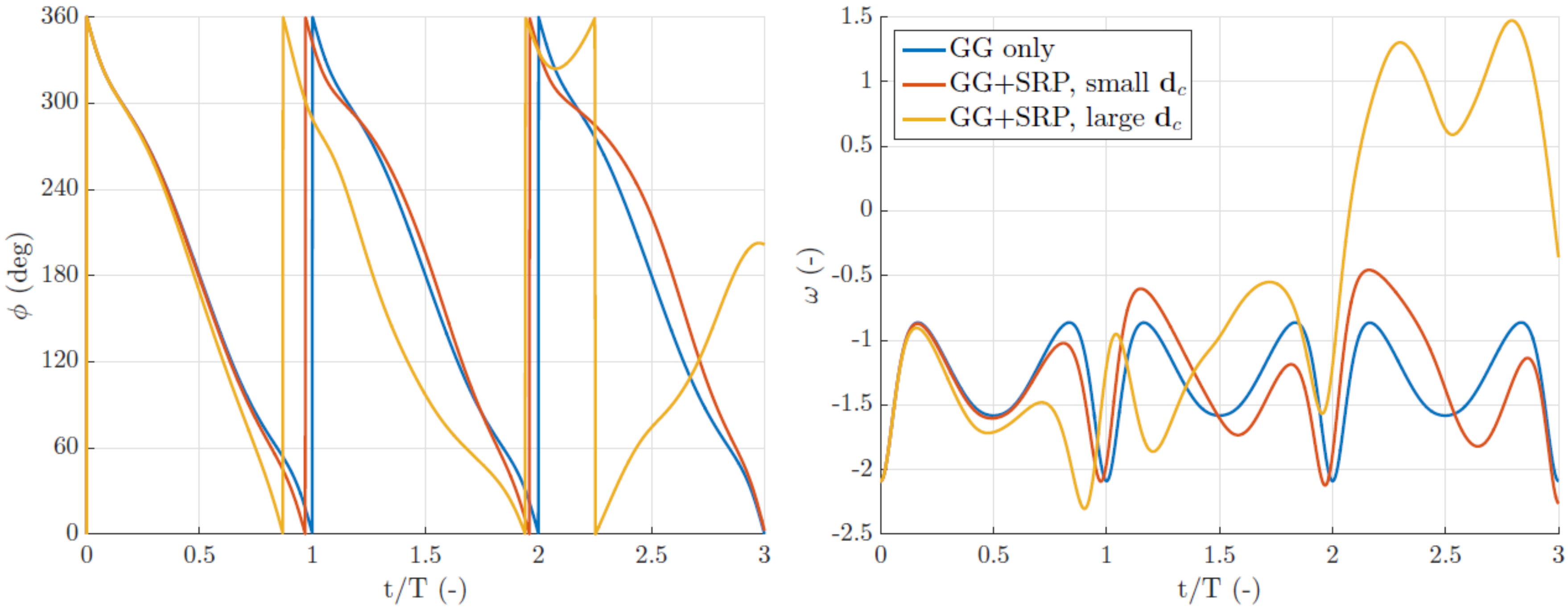
- **Acceleration** component: long period orbital deviation
- **Torque** component: focus of the study, may lead to large perturbations

SRP torque depends on the surface **reflectivity coefficients**, on the illuminated **area**, and on the position of the **center of pressure**.

$T_{SRP} = \boldsymbol{d}_c \times \boldsymbol{f}_{SRP}$ $\quad \boldsymbol{f}_{SRP} = f(A, C_d, C_a, C_s)$ $\quad \boldsymbol{d}_c$ known in body frame

SRP effect (2)

Major attitude disturbance for LSS; with $m = 500\,ton, A = 1000\,m^2$, an offset of $10\,cm$ between barycenter and center of pressure is sufficient to obtain **large deviations** from the nominal attitude.

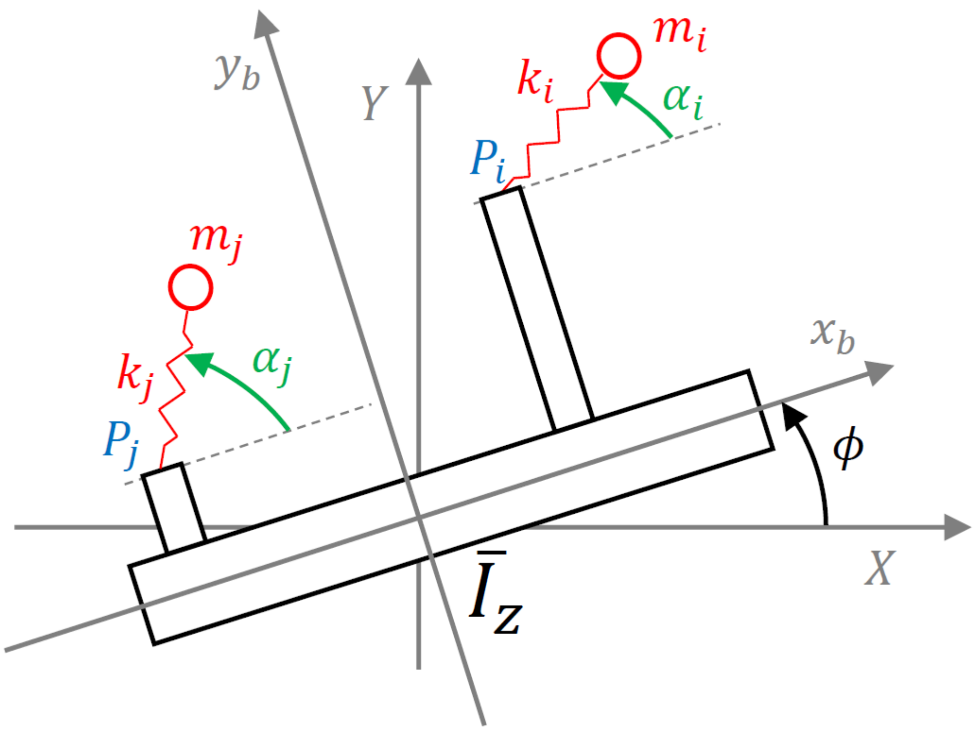


Spacecraft flexibility (1)

Coupling effect between structural vibrations and attitude dynamics.

Assumptions:

- Lumped parameters model
- Structural frequencies much higher than attitude's ones
- Spacecraft composed by a rigid section and flexible parts
- Orbital motion not perturbed by flexibility



Spacecraft flexibility (2)

- Under the assumption of high frequency structural vibrations, the flexible response is **statically excited** by the attitude motion.
- In turn, the attitude dynamics is perturbed by an **equivalent torque** due to flexural vibrations.
- The non-linear coupling terms may be dropped under the presented assumptions.

Conclusions

Presentation of a **tool** to investigate coupled orbit-attitude behaviors in the CR3BP

- Algorithm for periodic solutions in a purely gravitational environment
- Model enhancing with **solar radiation pressure** and spacecraft **flexibility**

Future works:

- Search for periodic solutions with SRP, both acceleration and torque components
- Refine flexible spacecraft model