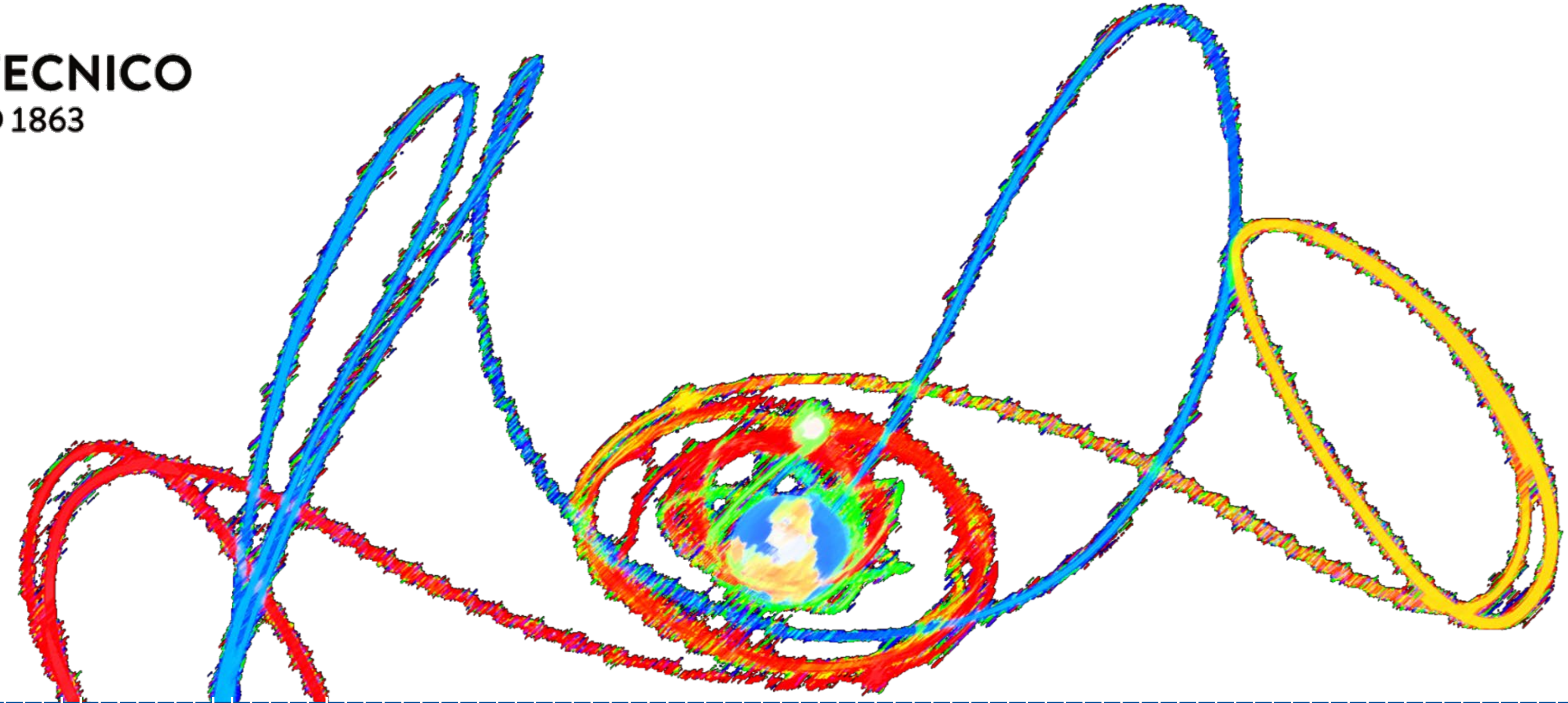
POLITECNICO
MILANO 1863



Orbital Mechanics
Lab Assignments

Andrea MUCIACCIA, Mathilda BOLIS, Francesca OTTOBONI, Giacomo BORELLI, Juan Luis GONZALO GOMEZ, Camilla COLOMBO

Department of Aerospace Science and Technology, Politecnico di Milano

Academic year 2025/26

Contents

Assignments 2

- **Assignment 2: Planetary Explorer Mission**
  - Mission requirements
  - Mission analysis outputs
- **General instructions**
  - Auxiliar functions available in WeBeep
  - Project deliverables and deadlines
    - Report
    - Code
  - References

Assignment 2

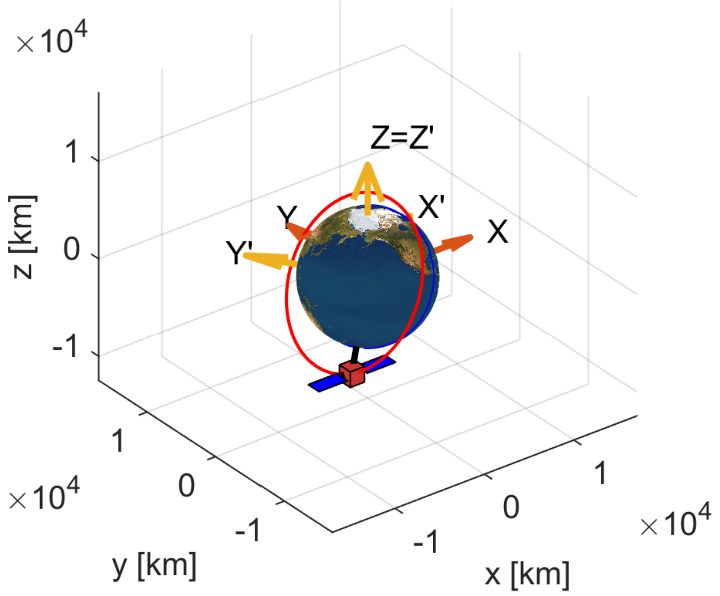
PLANETARY EXPLORER MISSION

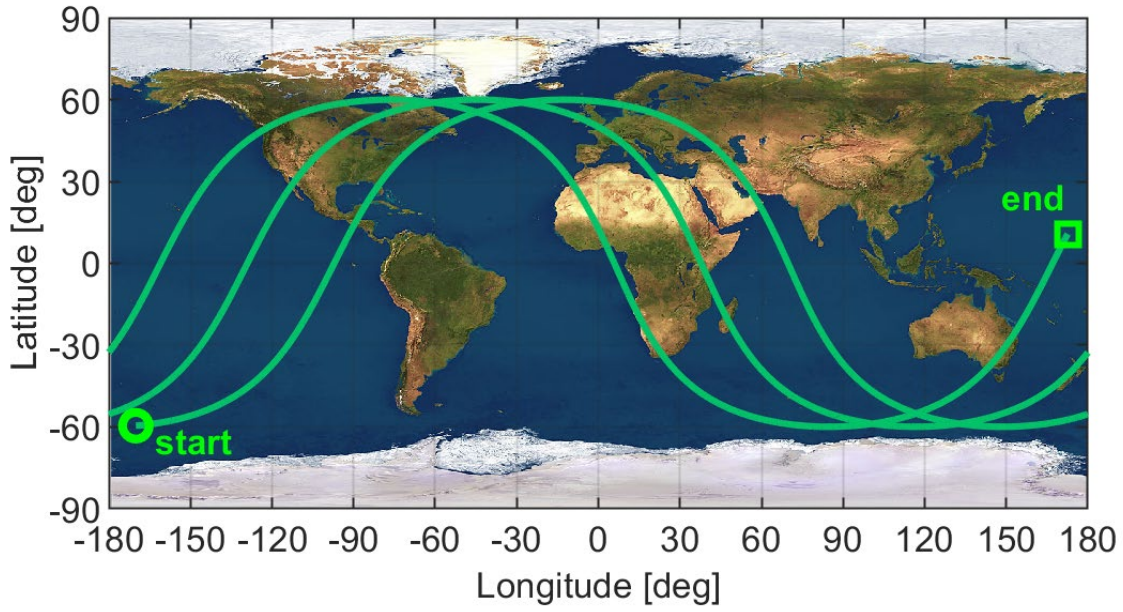
Planetary Explorer Mission

Second Assignment

The **PoliMi Space Agency** wants to launch a **Planetary Explorer Mission**, to perform planetary observations.

As part of the **mission analysis team**, you are requested to carry out the **orbit analysis and ground track estimation.** You have to study the effects of **orbit perturbations**, and compare different **propagation methods**. Also, you have to characterise the **ground track**, and propose an orbit modification to reach a **repeating ground track** (for better observation of the areas of interest).



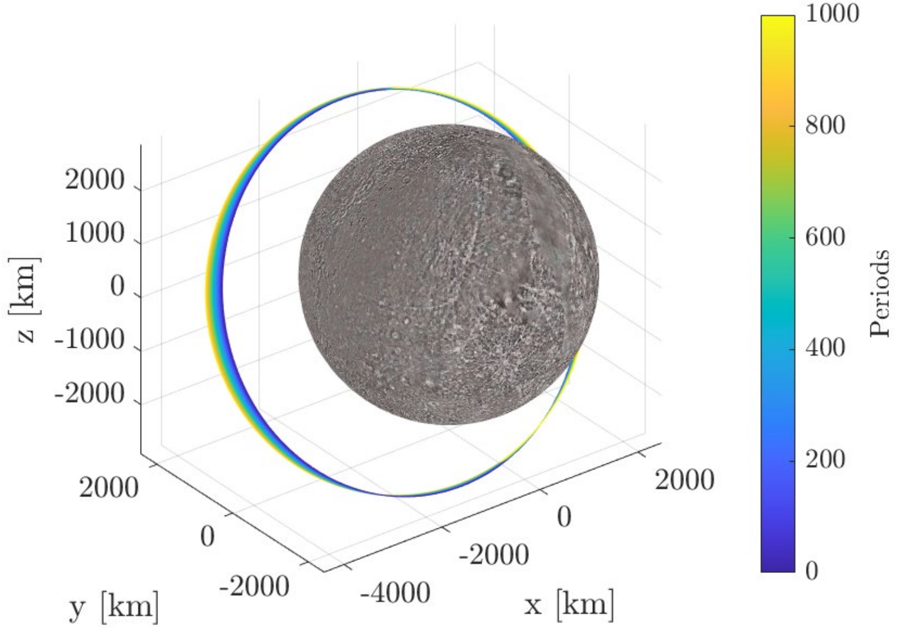


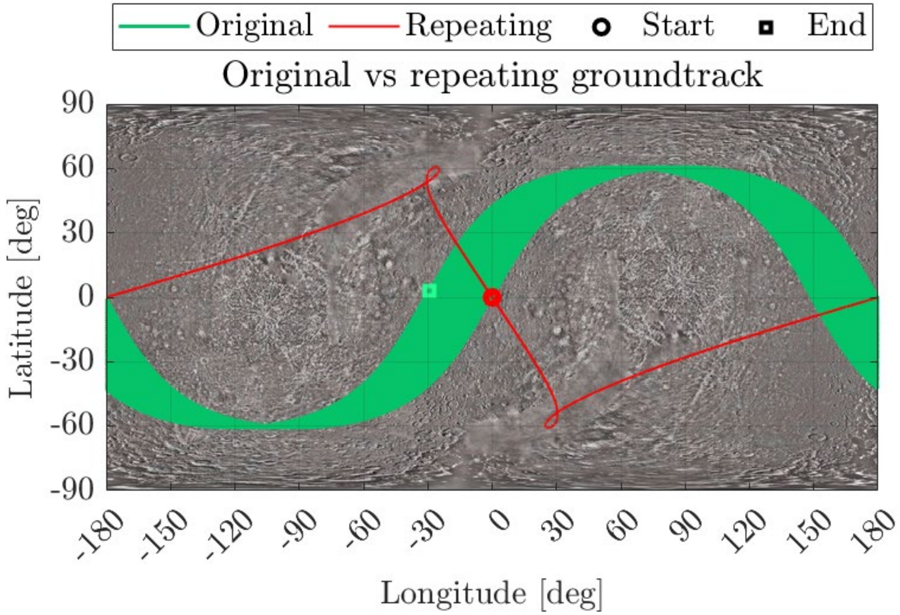
Planetary Explorer Mission

Second Assignment

The observations you are interested in could be conducted in one of the following scenarios:

1. **At the departure planet:** Before the start of the interplanetary mission, an observation campaign is conducted at the departure planet.
2. **At the fly-by planet:** During the fly-by, the spacecraft deploys an orbiter, having as mission objective to study the effect of orbit perturbations on the fly-by planet.

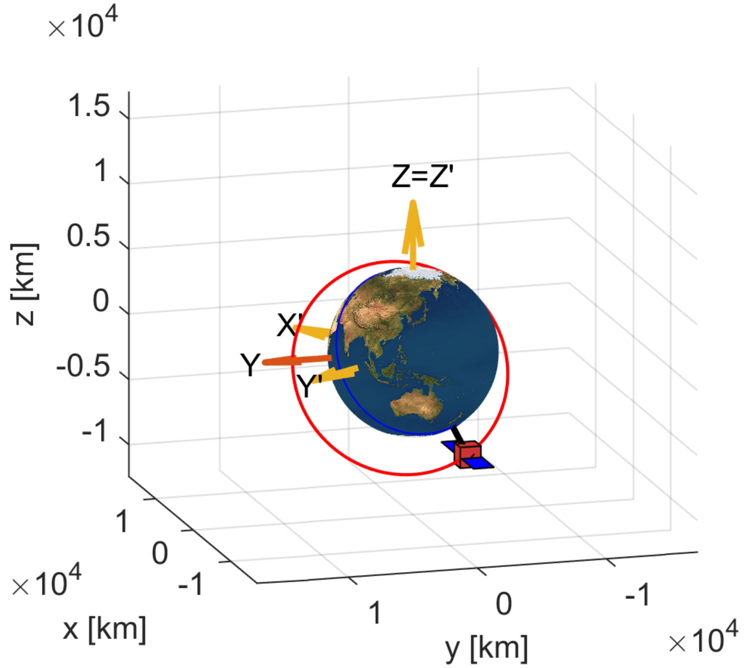




Planetary Explorer Mission

Mission requirements

- Each group has the following **mission requirements** (available in WeBeep):
  - Central planet,
  - Keplerian state of the spacecraft at a certain given time,
  - Orbit perturbations to be considered,
  - Ratio of satellite and planet revolutions for the repeating ground track.



NOTE: The reference frame to which the Keplerian elements of the nominal operational orbit are referred to is the planet centred inertial equatorial reference frame, and defined as follows:

- *The z-axis is perpendicular to the equatorial plane of the central planet.*
- *The x-axis points toward Earth's vernal equinox (coincides with the x-axis of the ecliptic plane, i.e. the γ-line)*
- *The y-axis completes the right-handed coordinate system.*

Moreover, approximate the Earth-Sun γ-line and each planet-Sun γ-line to always coincide.

Planetary Explorer Mission

Mission requirements

- Note that:
  - The nominal orbit you are given **IS NOT** related to the results you have found in the first part of the project (Assignment 1). The same is true for the initial date you are assigned.
  - Data on the physical characteristics of each planet are provided in `astroConstants`. For each planet, you are given:
    - J2 gravitational harmonic coefficient [-]
    - Planetary oblateness [-]
    - Sidereal rotation period [hours] → Suggestion: pay attention to units
    - Axial tilt (inclination of the equator with respect to the ecliptic) [deg]
    - Solar irradiance [W/m^2] → Suggestion: pay attention to units

Planetary Explorer Mission

Mission analysis outputs (1/4)

1. **Nominal orbit,** indicating its initial values and main characteristics. The initial true anomaly is always equal to zero.
   - Note that the "Initial date" data indicates the time instant at which the Keplerian state you are given has been retrieved.

2. **Ground track**
   a) ~~Plot the ground track of the nominal orbit for the unperturbed 2BP~~, over different times relevant to your orbit (e.g., 1 orbital period, 1 day, 10 days, pay attention to select times relevant for your orbit).
   b) ~~Modify the semimajor axis to obtain a repeating ground track, and plot it:~~
      - ~~For the unperturbed 2BP~~,
      - ~~Use the ratio for satellite and planet revolutions given in WeBeep.~~

IMPORTANT: The modified value of the semimajor axis should only be used for ground track analysis. For all other parts of the assignment, use the nominal value provided in WeBeep.
Not following this request will result in -1 point

Planetary Explorer Mission

POLITECNICO MILANO 1863

Mission analysis outputs (2/4)

c) Plot again the ground tracks for the nominal orbit and for the modified orbit in point **b)**, adding the assigned perturbations to the orbit propagation (J_2 + see table in WeBeep)
   - Does the repeating ground track solution from point **b)** still work under the presence of perturbations? Why?

IMPORTANT: If you are assigned a perturbation for a planet other than Earth, you should model it as on Earth (i.e., the equations are the same).
To know more about how to model perturbations, check Vallado [1], Chapter 8.6

3. ~~**Propagate the orbit with the assigned perturbations** (J_2 + see table in WeBeep), in:~~

a) ~~Cartesian coordinates,~~

b) Keplerian elements through Gauss's planetary equations.

[1] D. Vallado, Fundamentals of Astrodynamics and Applications, 4th Edition, Springer, 2007, ISBN-13 978-0387718316.

Planetary Explorer Mission

Mission analysis outputs (3/4)

4. ~~**Plot the history of the Keplerian elements:**~~
   a) ~~Choose an adequate and reasoned propagation time based on the assigned perturbations (that is, long enough to observe the effect of all the perturbations you are assigned),~~
   b) ~~Choose proper units for time, use degrees for angles,~~
   c) **Compare and analyse** the evolution of each element,
   d) Compare both propagation methods (in terms of relative error, computational time, etc).

5. ~~**Represent the evolution of the orbit** (image or movie)~~

6. **Filtering of high frequencies:**
   a) ~~Use a low-pass filter (e.g., `movmean`) to remove high frequencies in the orbital elements, retrieving the long-period and/or secular evolution. You can do more than one filter (i.e., with different cut-off frequencies) for the different time scales.~~
   Suggestion: Select the cut-off frequencies based on the specific perturbation assigned to you.
   b) Plot the results (you can plot together filtered and unfiltered evolution)

Planetary Explorer Mission

Mission analysis outputs (4/4)

To conclude your assignment, you are required to **focus on the evolution of two real satellites orbiting around Earth**. You have modelled the dynamics of the two-body problem with perturbations for a planet in the Solar System and verified that the resulting dynamics are consistent with the theory. However, **in the real world, things can be more complex**. Therefore, an additional task is necessary to ensure that the theory you studied can be applied to a real-case scenario.

7. **Real data analysis:**
   a) ~~Select two objects, preferably uncontrolled, located in two different orbital regions around the Earth (e.g., LEO and MEO), and download their orbital elements for a significant time.~~
   b) ~~Plot the evolution of the orbital elements for both objects over time.~~
   c) Comment on how the data you downloaded aligns with the theoretical model. Specifically: from the plotted graphs, you will observe the evolution of the orbital elements of the two objects over time. In the chosen orbital regions, one or more perturbations should dominate over others. Does the real data behaviour align with the theoretical predictions? If not, why?

IMPORTANT: You are asked to carry out this analysis considering ***the Earth as the central body*** *(whichever one was assigned to you in the previous part of the assignment). Furthermore, you are* ***NOT ASKED*** *to compare the evolution of the orbital elements propagated with the dynamics you have implemented and the real ones.*

POLITECNICO
MILANO 1863

GENERAL INSTRUCTIONS

Project

Auxiliar functions available in WeBeep

- For the assignments, you may use the auxiliary MATLAB functions **available in WeBeep**:
  - `astroConstants`: Use it to retrieve common astrodynamics constants (both assignments).
  - `lambertMR`: Use it for solving each Lambert arc (Assignment 1).
  - `uplanet`: Planets' ephemeris (do not propagate the planets' orbits yourself)
    - In Assignment 1, use it to compute the ephemerides of departure and flyby planets.
    - In Assignment 2, use it to compute the Sun-Planet position vector for SRP evaluation.
  - `ephMoon`: Analytical ephemeris of the Moon.
    - In Assignment 2, use it to compute the Moon position for third-body perturbation evaluation.
  - `ephAsteroids`: Ephemerides of several asteroids.
    - In Assignment 1, use it to compute the ephemerides of the arrival asteroid.
  - **timeConversion.zip**: Compressed folder with several time conversion routines

Teamwork

As in a **Mission Analysis team** at **ESA**, you will also work in a group:

- Members of the group must **cooperate**: you are advised to share the work among the team, but **everyone is responsible for all the work done in the project**. This means the work of the team must be checked by the whole team.
- Make decisions towards design solutions based on numerical/analytical/physical evidence and analyses: you must always be able to **motivate your design choices**. *You are supposed to perform the preliminary mission analysis of a real mission*.
- During the final review (oral exam), **any team member can be questioned about any part of the work**.

Project deliverables and deadlines

Overview

- Project evaluation includes:
  - **Deliverables** (1 submission per group)
    - **Project report**: A single PDF report on the assignments, of maximum **15 pages (total, no exceptions)**
    - **Simulation codes and results**
    - **Numerical results**, to be submitted via a form
  - **Peer evaluation**
  - **Oral exam** (both on theory and project)
  - **See Slide Lectures Chapter 0 for rules!!**

Project deliverables and deadlines

Submission procedure and deadlines

- The deliverables must be submitted through **WeBeep**
  - Submit a **single ZIP file** with **report and code**, named "`OrbitalMech_group_nnnn.zip`", where `nnnn` is the group ID (e.g., `OrbitalMech_group_2542.zip`).
  - WeBeep **submission file limit is 250MB**. Larger submissions sizes are not allowed (nor needed).
  - **Numerical results for specific questions** and **peer review** submitted via activities in WeBeep.
  - Submissions via any other means will not be considered.
  - Changes to the deliverables after the deadline will not be considered.
- Deadlines:
  - **Deliverables must be submitted by 7 January 2026**.
    - Delivering the project is a must condition for the oral exam and to pass the course.
    - The delivery activity in WeBeep closes automatically on 7 January 2026 at 23:59.

Project deliverables and deadlines

Report

- **Single PDF (both assignments in the same report)**
- Include a **front page** with:
  - Title,
  - Group number, academic year,
  - For each member: full name, matriculation number, and person code.
- The report should contain **explanations, data, figures, and tables supporting your design process and final solution.**
  - You may follow the structure described in the previous slides.
  - **Properly indicate the units of all numerical data**.
  - **Include labels, legends and titles/captions in all figures**. Also, ensure that all figures are appropriately sized, allowing readers to interpret them clearly without requiring excessive zooming.
  - **No need to include theory**, but properly introduce/reference all the formulas and models you use.
  - Include a *References* section with a list of all the sources you consulted and cite them in the text where appropriate.
  - Properly credit all images taken from other sources including lecture notes and slide.
  - Improper use of references will be considered in the mark
  - Provide comments and explanations of your results, with a **PARTICULAR FOCUS ON THE UNDERLYING PHYSICS OF THE PROBLEM**.

Project deliverables and deadlines

Code

- The codes for both assignments must be included inside a folder named `Code`, with **two separate subfolders for each assignment** as follows:
  - ~~**Assignment 1**: Subfolder `Code\Assignment1\`~~
  - ~~**Assignment 2**: Subfolder `Code\Assignment2\` containing:~~
    - ~~`PlanetaryMission_group_N.m`: main script that reproduces your results (`N` is the group ID).~~
    - ~~`Code\Assignment2\functions\`: subfolder with **all the other functions you developed** for the second assignment.~~
- No need to upload the functions we provide to you in WeBeep, unless you modified them.

Project deliverables and deadlines

Code headers

- Each code file must include a **header** detailing:
  - Inputs and outputs (specify dimensions and units),
  - Authors,
  - Basic usage information

```
function dy = ode_2bp( t, y, muP )
%ode_2bp ODE system for the two-body problem (Keplerian motion)
%
% PROTOTYPE:
%   dy = ode_2bp( t, y, mu )
%
% INPUT:
%   t[1]         Time (can be omitted, as the system is autonomous)  [T]
%   y[6x1]       Cartesian state of the body ( rx, ry, rz, vx, vy, vz ) [ L, L/T ]
%   muP[1]       Gravitational parameter of the primary [L^3/T^2]
%
% OUTPUT:
%   dy[6x1]      Derivative of the state  [ L/T^2, L/T^3 ]
%
% CONTRIBUTORS:
%   Student 1
%   Student 2
%
% VERSIONS
%   2020-11-19: First version
%
```

References

- Lecture notes and lab slides.

- Spacecraft orbital elements available at:
  - Space-Track: https://www.space-track.org
  - Celestrack: https://celestrak.com/NORAD/elements/
  - NASA/JPL's HORIZONS: https://ssd.jpl.nasa.gov/horizons/app.html

- Books:

  - D. Vallado, *Fundamentals of Astrodynamics and Applications, 4th Edition*, Springer, 2007, ISBN-13 978-0387718316.
    Chapters 8 and 9 (very detailed).
  - R. H. Battin, *An Introduction to the Mathematics and Methods of Astrodynamics, Revised Edition*, AIAA Educational Series, Reston, 1999.
    Chapter 10 (Gauss and Lagrange equations derivation).
  - H. Curtis, *Orbital Mechanics for Engineering Students, Second Edition*, Butterworth-Heinemann, 2009, ISBN-13 978-0123747785.
    Chapter 12 (introduction to orbit perturbations).