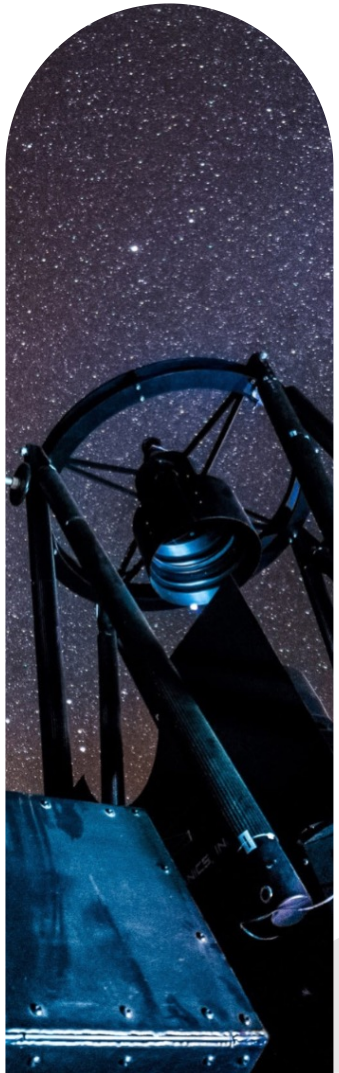
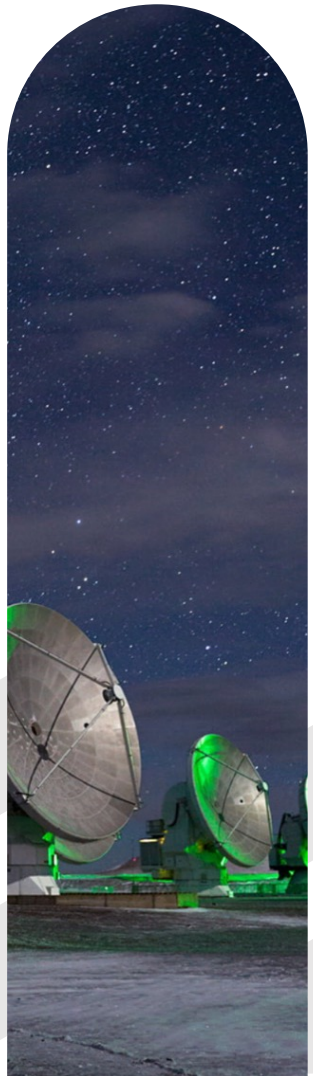
Initial Advances on Cislunar SSA Challenges

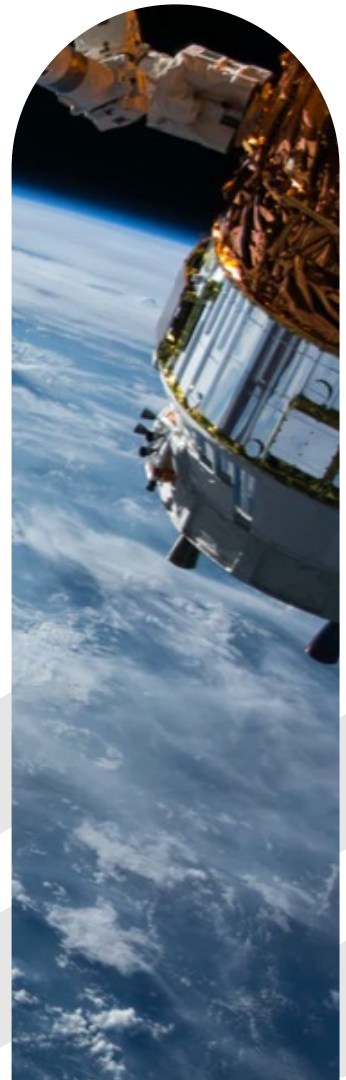
Inter-Agency Space Debris Coordination Committee

Inter-Agency Space Debris Coordination Committee Meeting

Bangalore, 16-19 April 2024







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OUTLINE

01 CONTEXT AND MOTIVATION

Features, potential and SSA/SST challenges of cislunar space.

02 RESEARCH OBJECTIVES

Areas where research is currently being conducted.

03 FIRST ITERATION

Ongoing and future research steps.

01 CONTEXT AND MOTIVATIONS

Context and motivations

There is a growing interest for the development of suitable solutions for cislunar space:

Lunar resources exploration

Facilitate *In Situ* and cislunar activities, and importation back to Earth

Deep space exploration

Use the Moon and lunar orbits as a base for future interplanetary missions

Expansion of human activities in the cislunar regime:

- Shall we assess our capabilities to acquire and process measurements in the cislunar environment?
- Shall we identify and fill gaps to prepare for an intensive prospective exploitation of the cislunar environment?
- Need to explore challenges of new application scenarios, enabled by cislunar activities?

CHALLENGES: Near-Earth vs Cislunar

Different dynamical model

- Three-body problem (full ephemerides, CR3BP, etc…).
- TLEs are no longer applicable
- Trajectories are no longer easy to geometrically describe

Chaotic environment

- Highly nonlinear dynamics
- Gaussian distributions quickly enlarge and fail to describe propagated uncertainties
- Trajectories in this domain tend to be unstable

Ground operations issues

- Large distances and limited coverage
- Moon/Sun interferences
- Strong limitation on the measurements accuracy

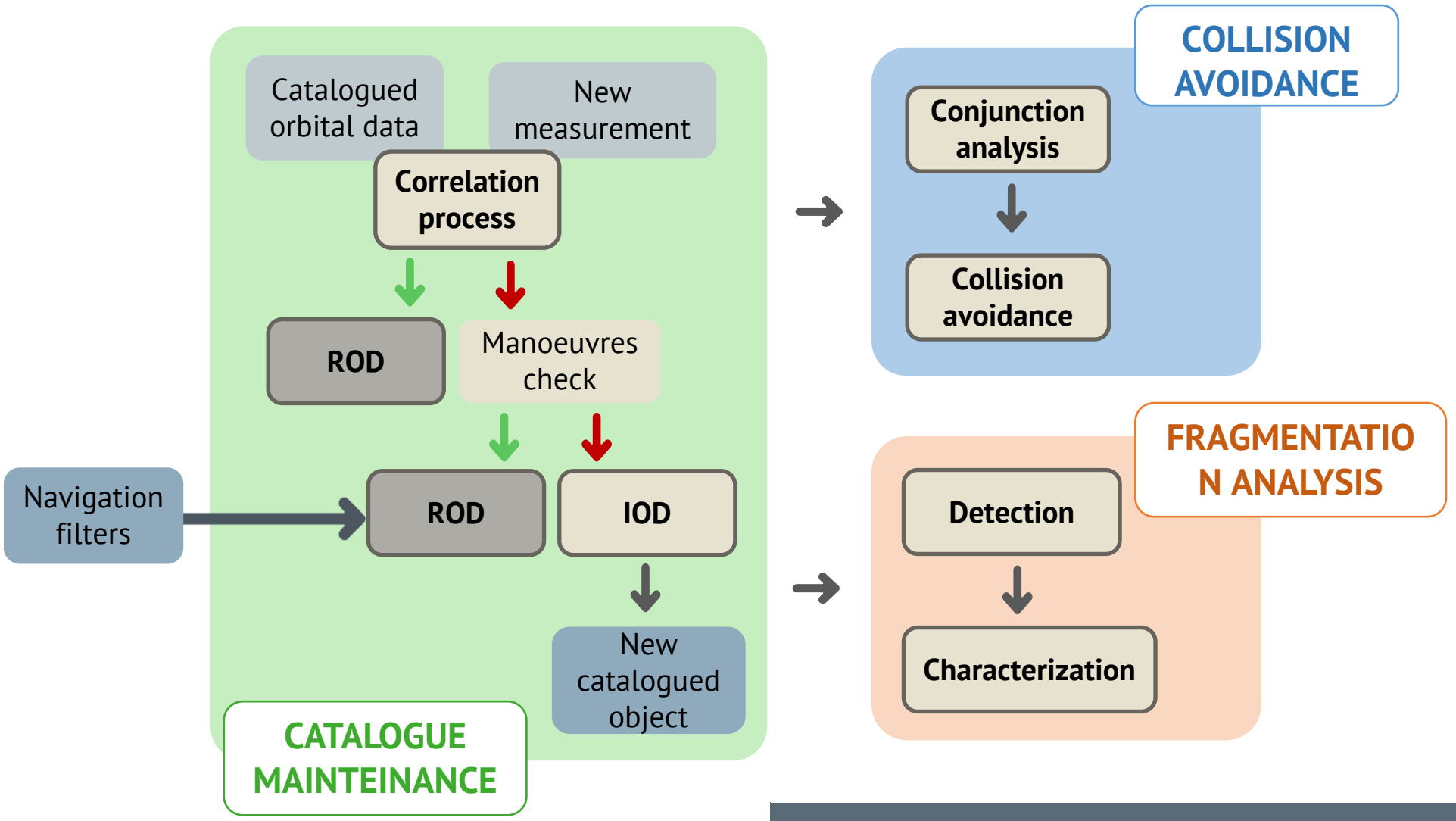
Possible future sensor locations

- Space-based and Moon-based
- Radars capabilities limited by power constraints

02 RESEARCH OBJECTIVES

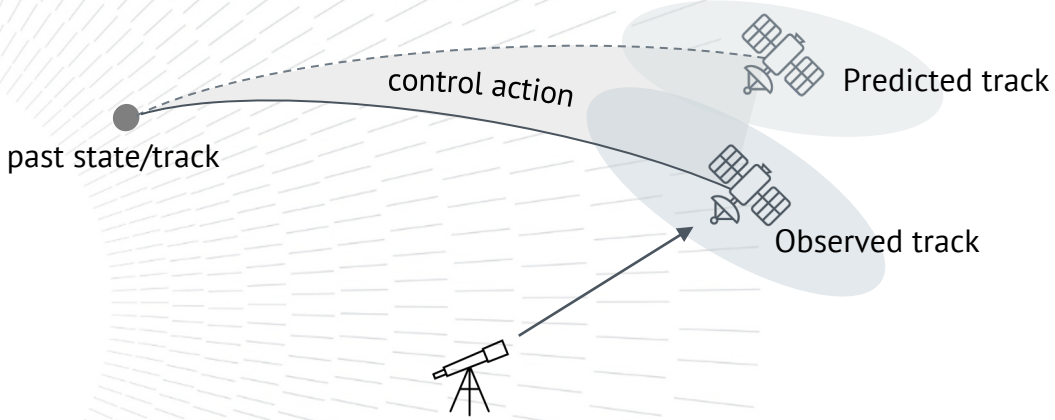
RESEARCH OBJECTIVES

Extend SST services to the cislunar domain, adapting existing techniques and developing new ones



03 FIRST ITERATION

CORRELATION



CHALLENGES

CURRENT RESEARCH

- **Optimal control problem** used to link boundary conditions, changing according to **correlation type** (track-to-orbit, track-to-track)
- **Minimum control energy** spent to connect a new track to a known state or to a different track
- The formulation can be applied to **any kind of controlled and ballistic dynamics**

FUTURE RESEARCH

- Integration of **maneuver detection** methods to the **correlation** pipeline
- Retrieve and compare past **orbit maintenance maneuvers** with **detected** ones

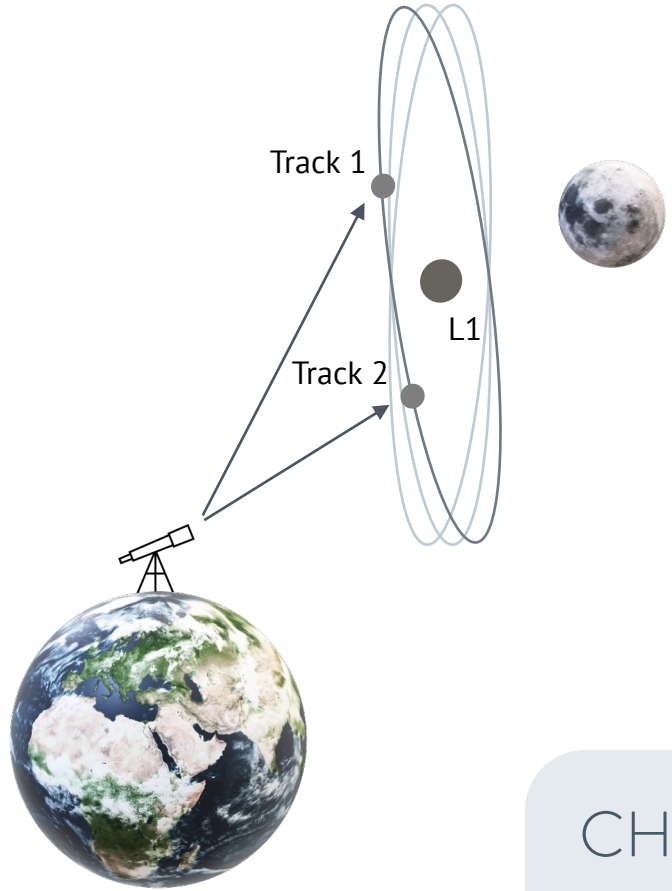
INITIAL ORBIT DETERMINATION

CURRENT RESEARCH

- Link **optimal control-based linkage** used for correlation to **extract a first estimate** if track-to-track correlation is successful
- **Extension of two-body integral method** to the CR3BP
- **Multi-hypothesis** method targeting **stable**, soon-to-be **operational orbits** that are expected to be the most crowded

FUTURE RESEARCH

- **Extend** the planar orbit **state estimation method** to other **operational CR3BP orbital families**
- **Test approaches** with space-based observations within the **ASI/ESA LUMIO mission**



CHALLENGES

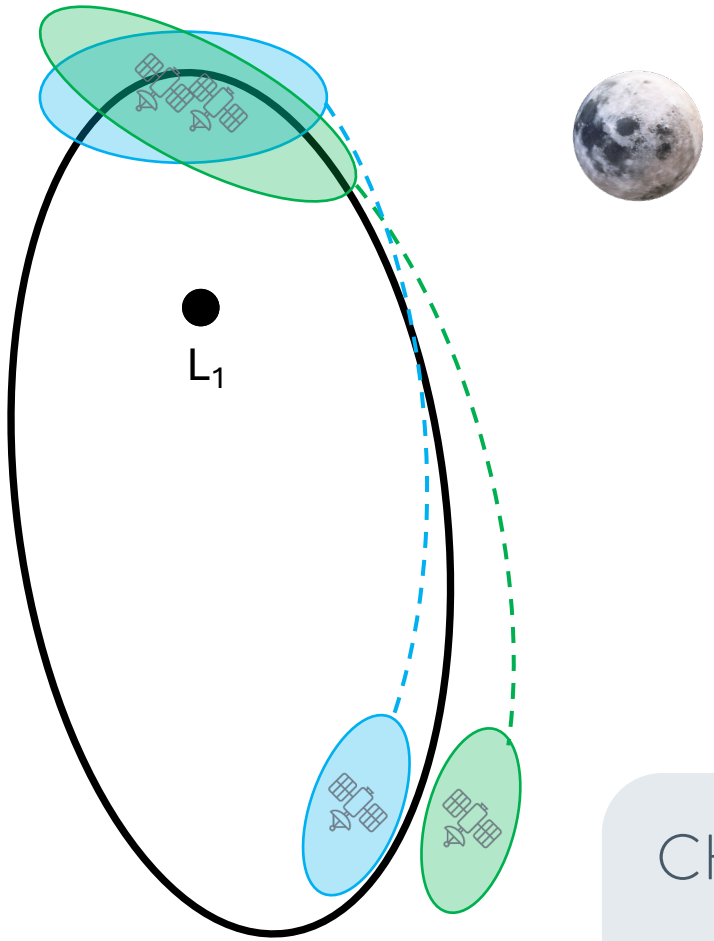
CONJUNCTION ANALYSIS

CURRENT RESEARCH

- Development of **conjunction test-case** scenarios
- State-of-the-art **rapid PoC computation** techniques applicability assessment
- **Analysis of uncertainty levels and behaviors** considering **long propagation times** and **nonlinear dynamics**

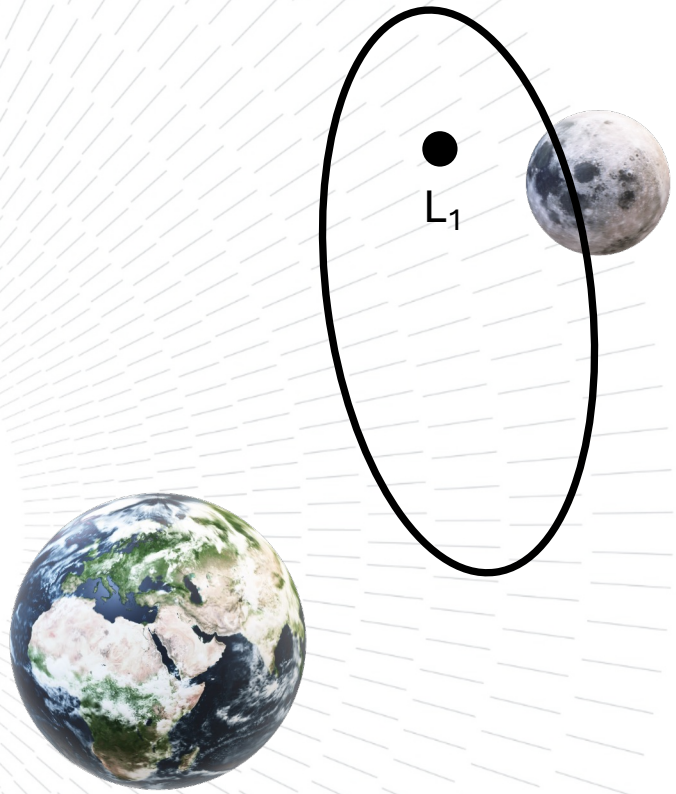
FUTURE RESEARCH

- **Long term PoC rapid computation** methods
- **Apply** conjunction analysis in **different orbital families**



CHALLENGES

COLLISION AVOIDANCE



CHALLENGES

CURRENT RESEARCH

- Devised **Analytical Collision Avoidance** (CAM) routines in the cislunar environment for both **impulsive** and **low-thrust** maneuvers

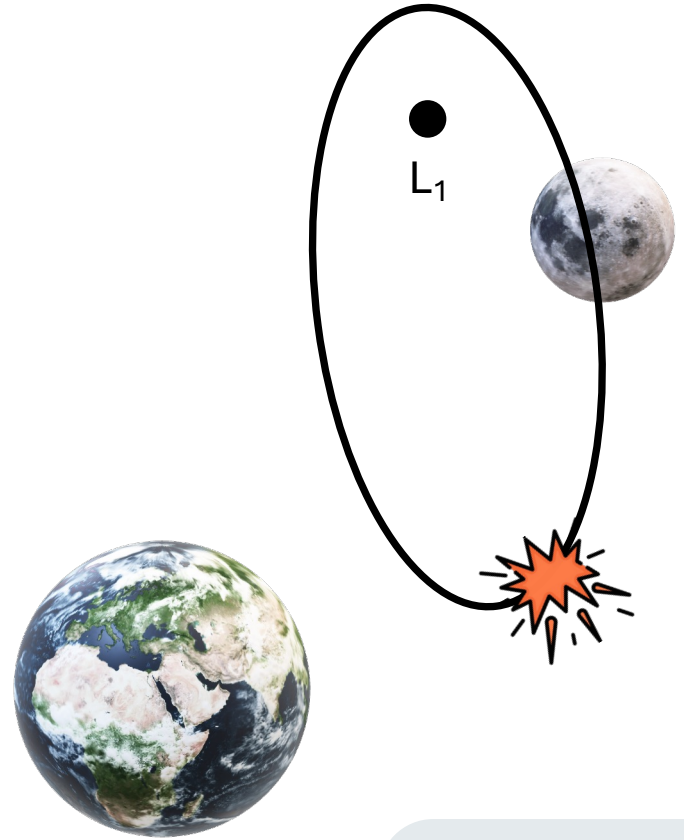
FUTURE RESEARCH

- Study Collision Avoidance effects on **stability** of **reference orbit**
- Embed **Station-Keeping** with CAM for **fuel consumption reduction**
- Apply **analytical propagators** within the analytical Collision Avoidance Framework (Koopman operator)

FRAGMENTATION ANALYSIS

FUTURE RESEARCH

- Study evolution of cloud of fragments in the cislunar domain
- Implement **fragmentation epoch detection** algorithm
- Develop tool to **characterize an in-orbit break-up** exploiting either measurements or OD results
- Develop tool to **associate** an observed fragment to the original event
- Identify **updates needed for current sensor networks** to better characterize fragmentations



CHALLENGES

THANK YOU

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