

Data-Driven Identification of Spacecraft Transport Pathways in Cislunar Space

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Goal: Develop an adaptive and interpretable data-driven framework for extracting natural and controlled transport pathways governing the motion of a spacecraft in the Earth-Moon-Sun system.

Objective 1: Construct a data-driven framework that adaptively samples & summarizes the trajectory solution space

Prior work: Developed clustering framework to summarize trajectories in multi-body system

Approach:

- Adaptively select initial conditions of trajectories to be clustered by balancing:
 - Local exploitation
 - Global exploration
- Generate and update a data-driven summary of the evolving set of trajectories

An adaptive data-driven summary:

- Reduces reliance on pre-specified grids, parameters, tuning, expertise of environment
- Improves quality of data-driven summary

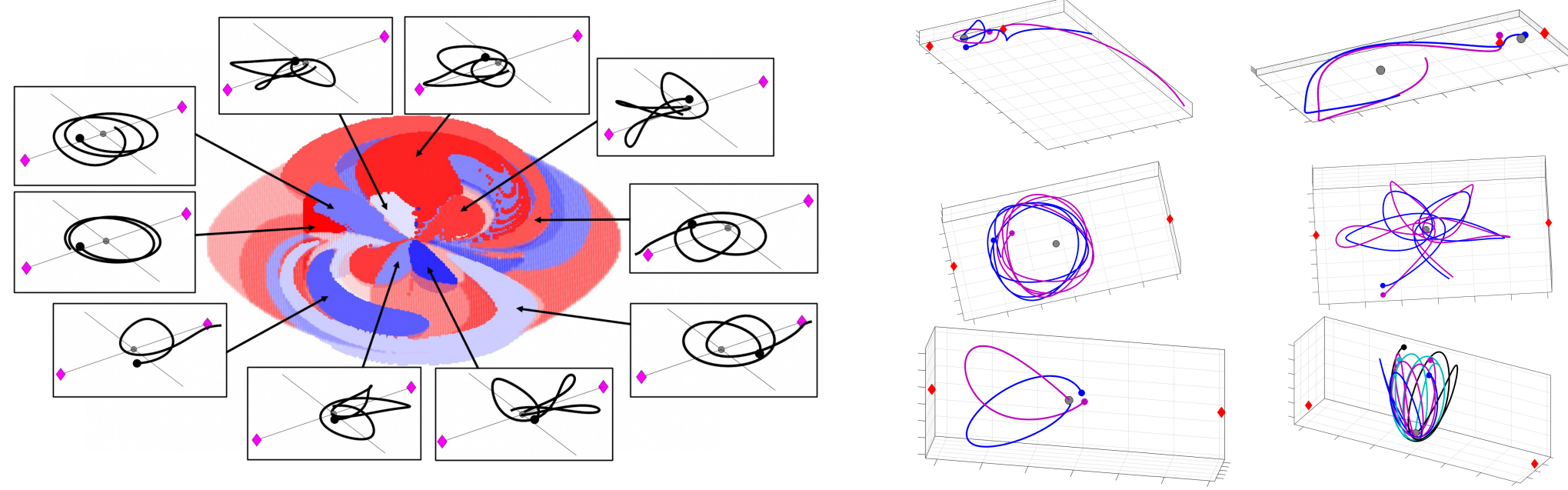


Image credit: first published in Bosanac and Bonasera CMDA, Vol. 133, No. 5, 2021 by Springer Nature

Image credit: Bosanac, N., "Data-Driven Summary of Natural Spacecraft Trajectories in the Earth- Moon System," August 2023.

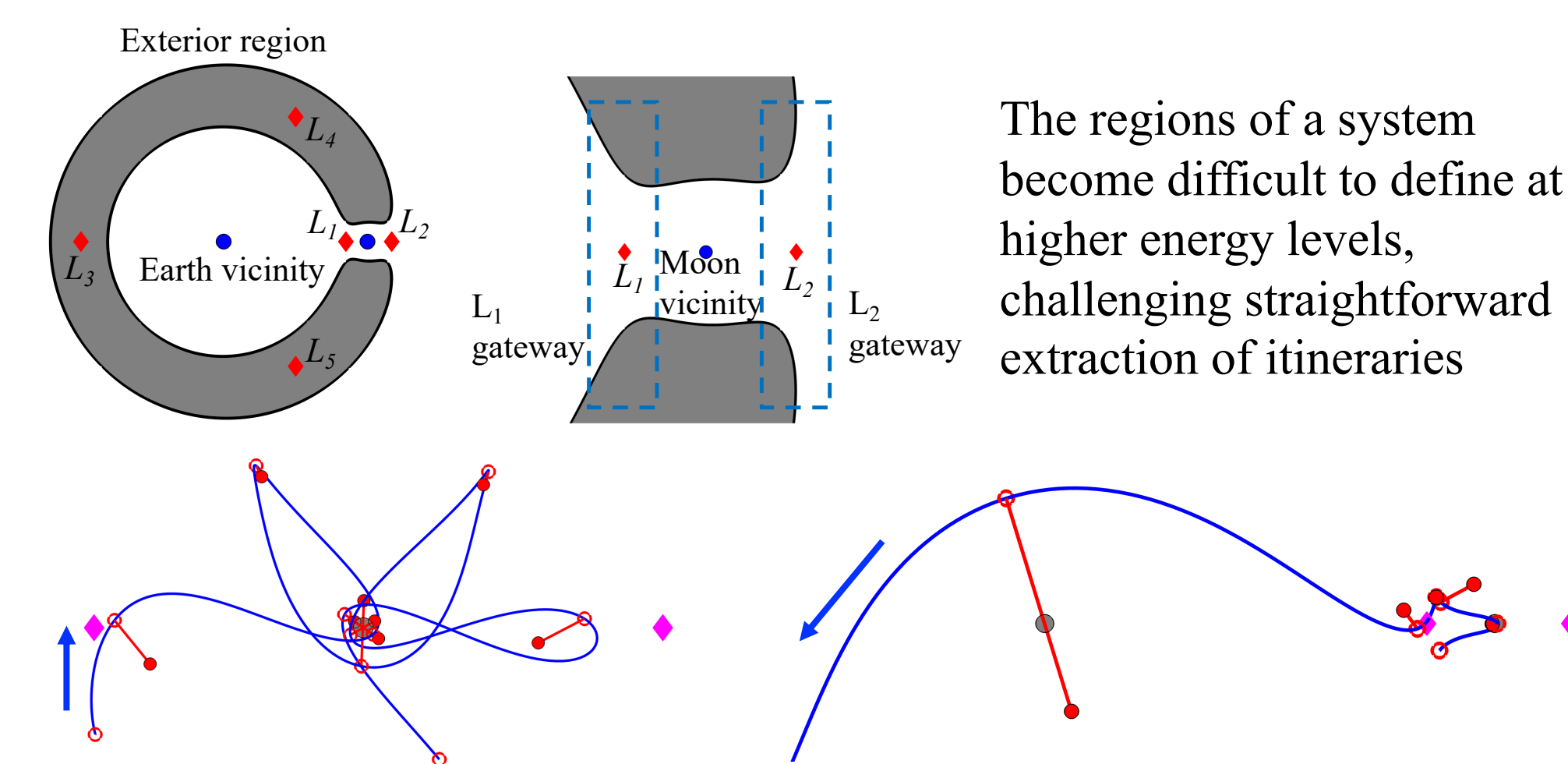
Objective 2: Construct an interpretable representation of the trajectories comprising the data-driven summary

Approach:

- Automatically extract itinerary using differential geometry and stay point detection
- Extract geometric characteristics similar to descriptions by trajectory designers

An interpretable description of trajectories:

- Supports extracting transport pathways
- Describes complex trajectories that are difficult to visualize or distinguish
- Supports decision-making or training



Itinerary: Pass through L_1 , loiter near Moon with high eccentricity

Itinerary: Transit from Moon vicinity with close pass, exit via L_1 gateway to Earth vicinity

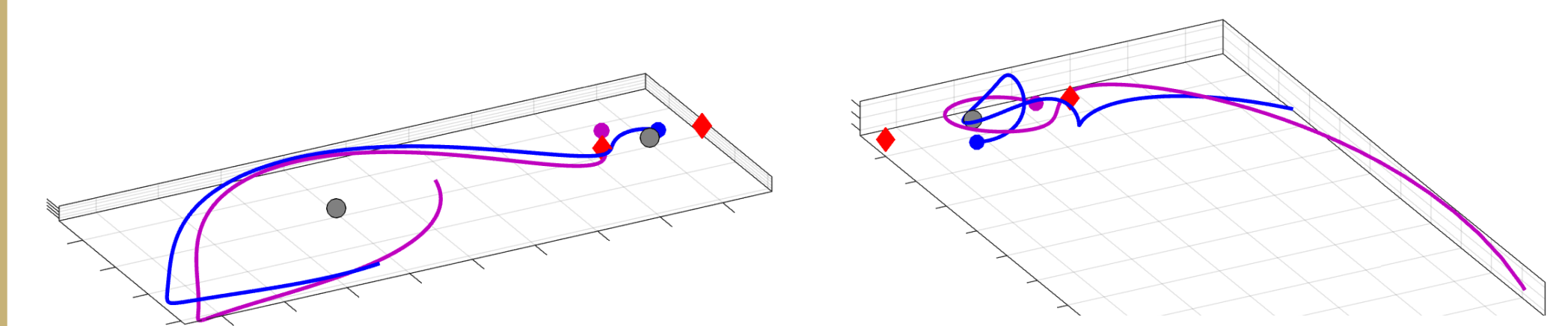
Objective 3: Generate natural & controlled transport pathways via the summary & assess the impact of model parameters

Approach:

- Transport pathway: groups of trajectories with similar itinerary
- Extract transport pathways from interpretable data-driven summary
- Repeat process across models of distinct fidelity, parameters, control profiles
- Aggregate geometrically similar transport pathways existing across distinct models

Spacecraft transport pathways support:

- Understanding global structure of a complex solution space and impact of model fidelity, governing parameters, or control profiles
- Knowledge discovery or verifying alternative methods for studying solution space



Transport pathway I : Moon vicinity to Earth vicinity via L_1 gateway

Transport pathway N : Moon vicinity to exterior region via L_2 gateway