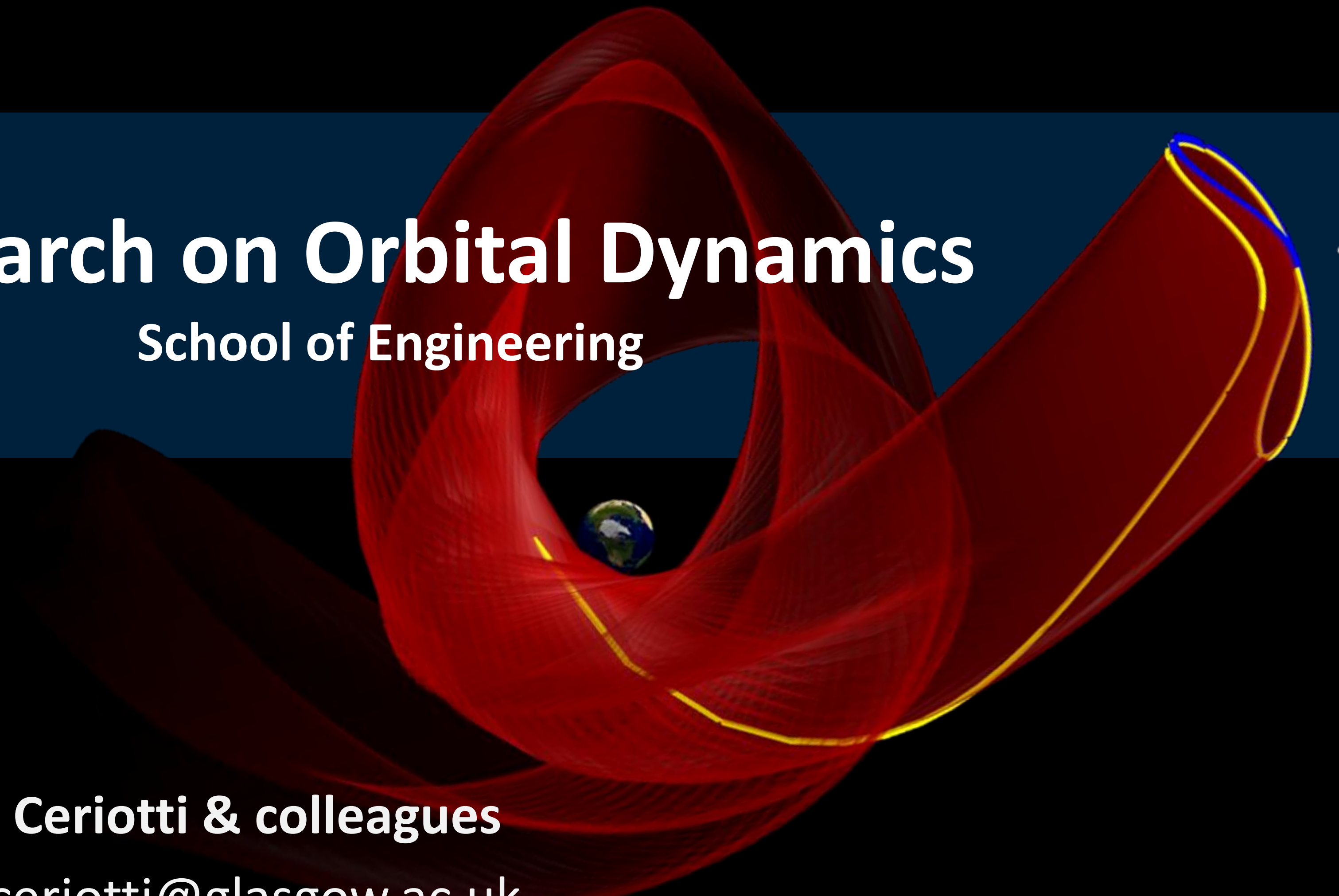
GrEAT GrEAT Network with China
University of Glasgow, 3 May 2019

Research on Orbital Dynamics

School of Engineering



Matteo Ceriotti & colleagues
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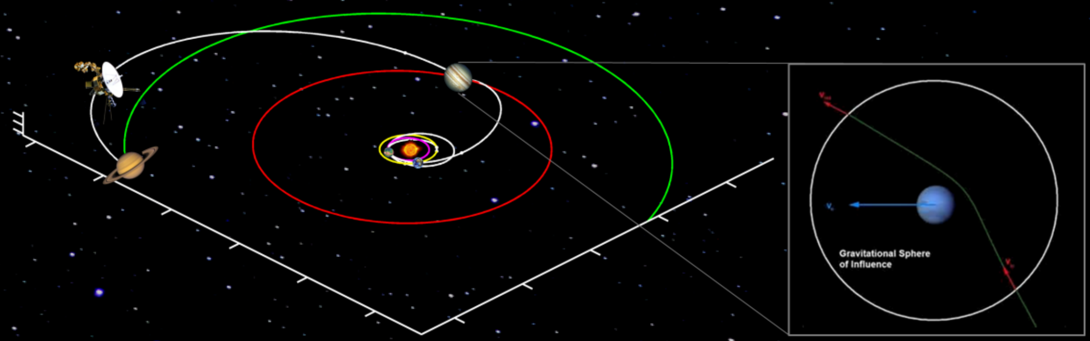
Expertise and interests

- Orbital dynamics
- Space trajectory design
- Local/global/combinatorial optimisation
- Dynamical systems

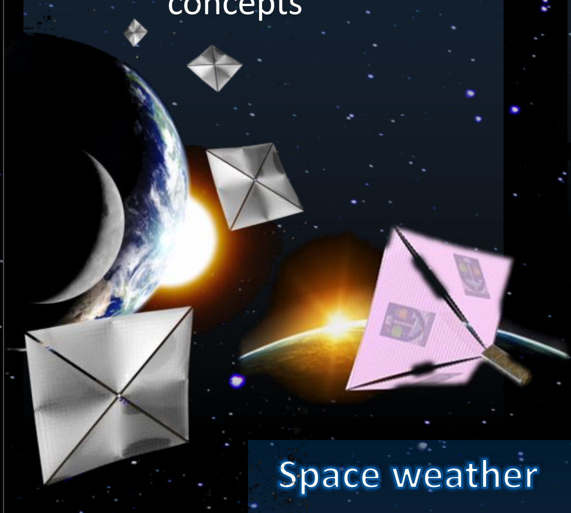


- Feedback control
- Swarming, multi-agent systems
- Artificial intelligence, decision making, tree search

Applications

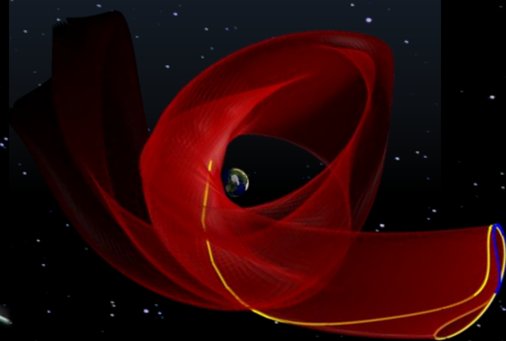
Solar sailing

- Travelling in space using the sunlight pressure
  - Advanced solar sailing concepts



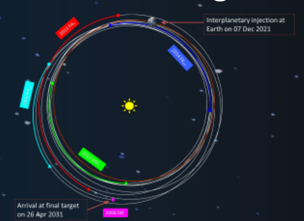
Orbital dynamics and Trajectory design

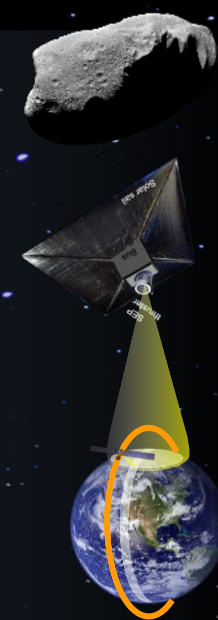
- Travelling in space in multi-body dynamics
- Hybrid propulsion



Asteroids and Future mission concepts

- How can we protect the Earth from hazardous asteroids?
  - Can we exploit asteroids?
- Multiple asteroid rendezvous mission with solar sailing



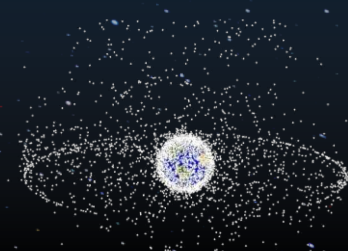


Space weather

- Can we predict and mitigate space weather phenomena?

Debris mitigation

- Can we accurately predict the orbit of lightweight, flexible debris?



MULTIPLE ASTEROID MISSION WITH SOLAR SAILING

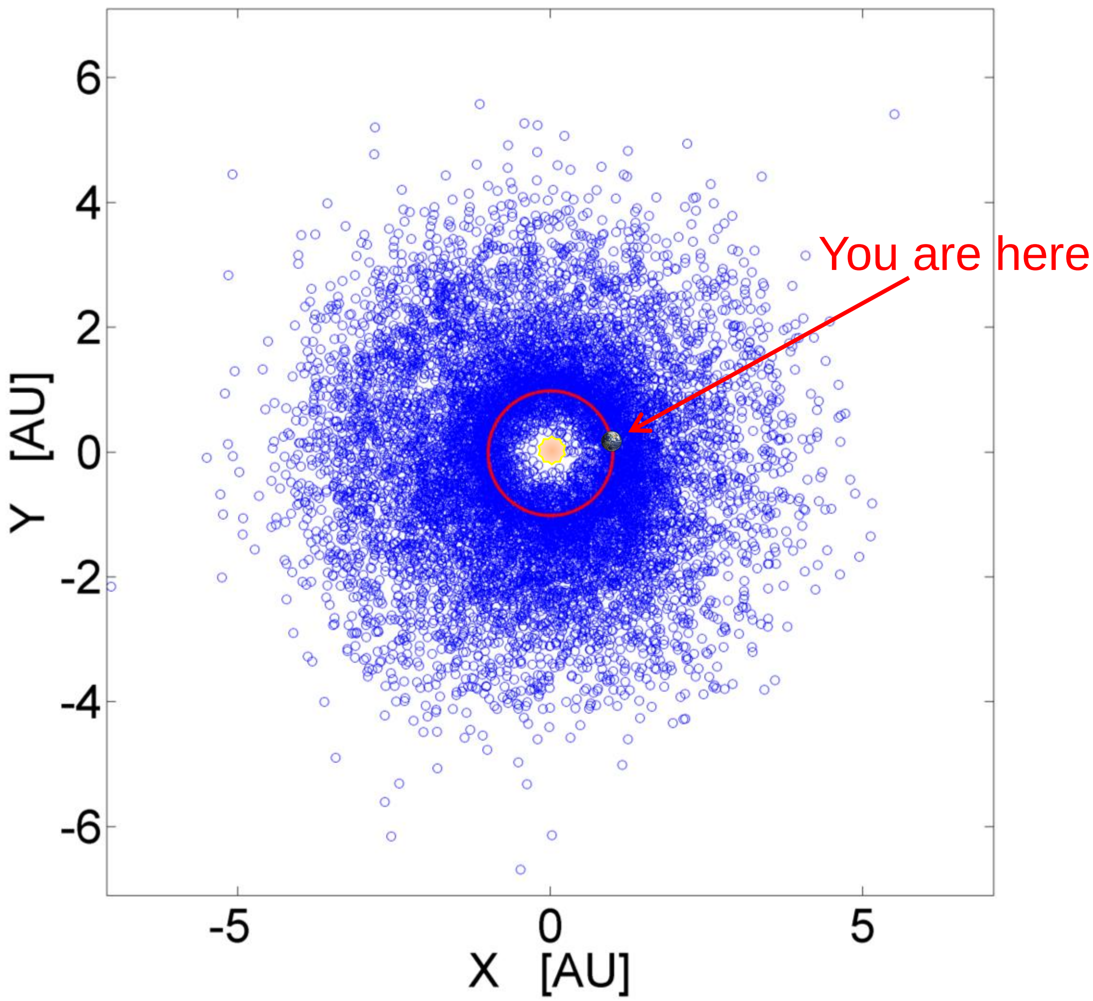
Giulia Viavattene

Alessandro Peloni

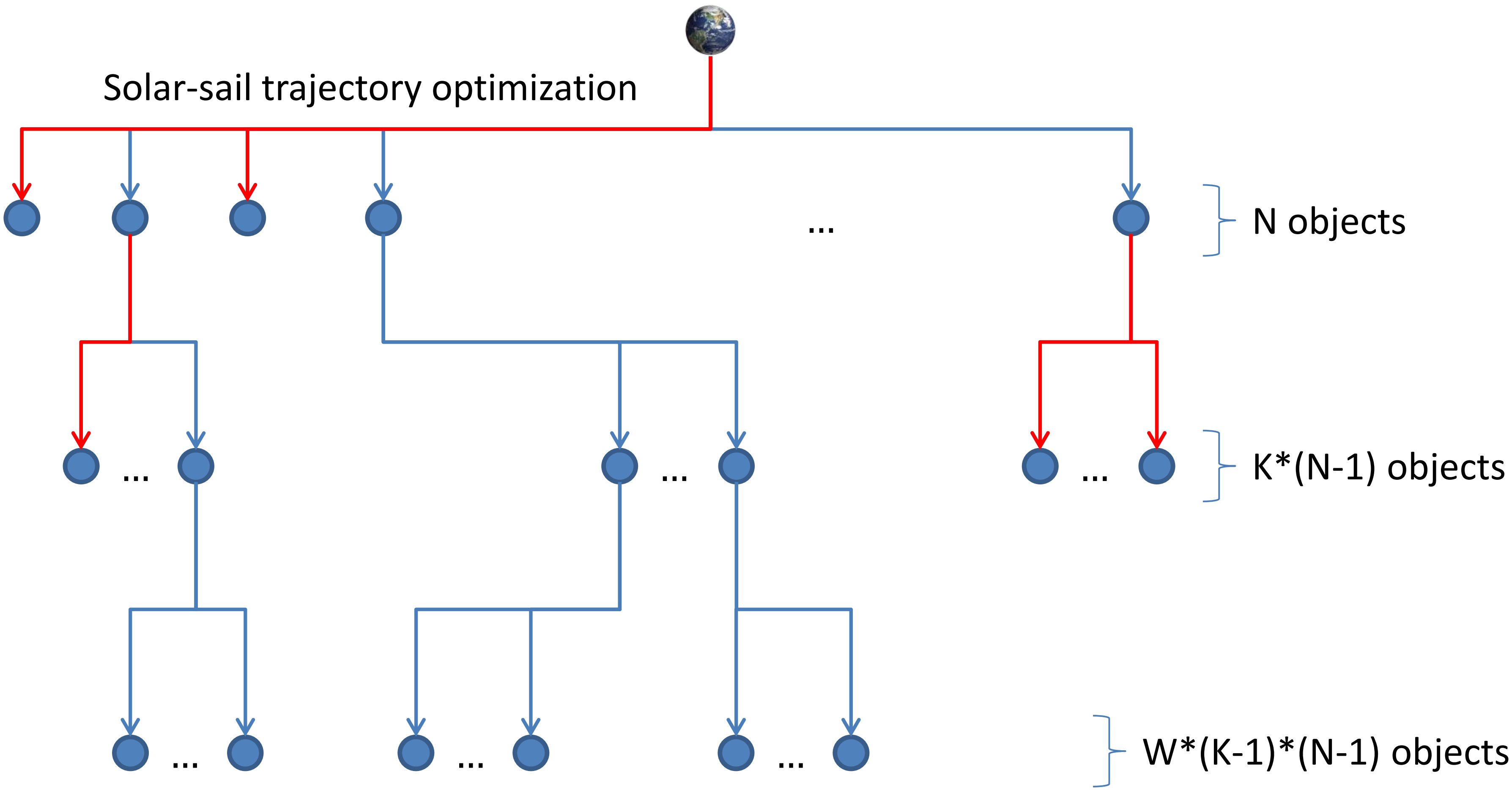
Matteo Ceriotti

Bernd Dachwald

Why NEOs?



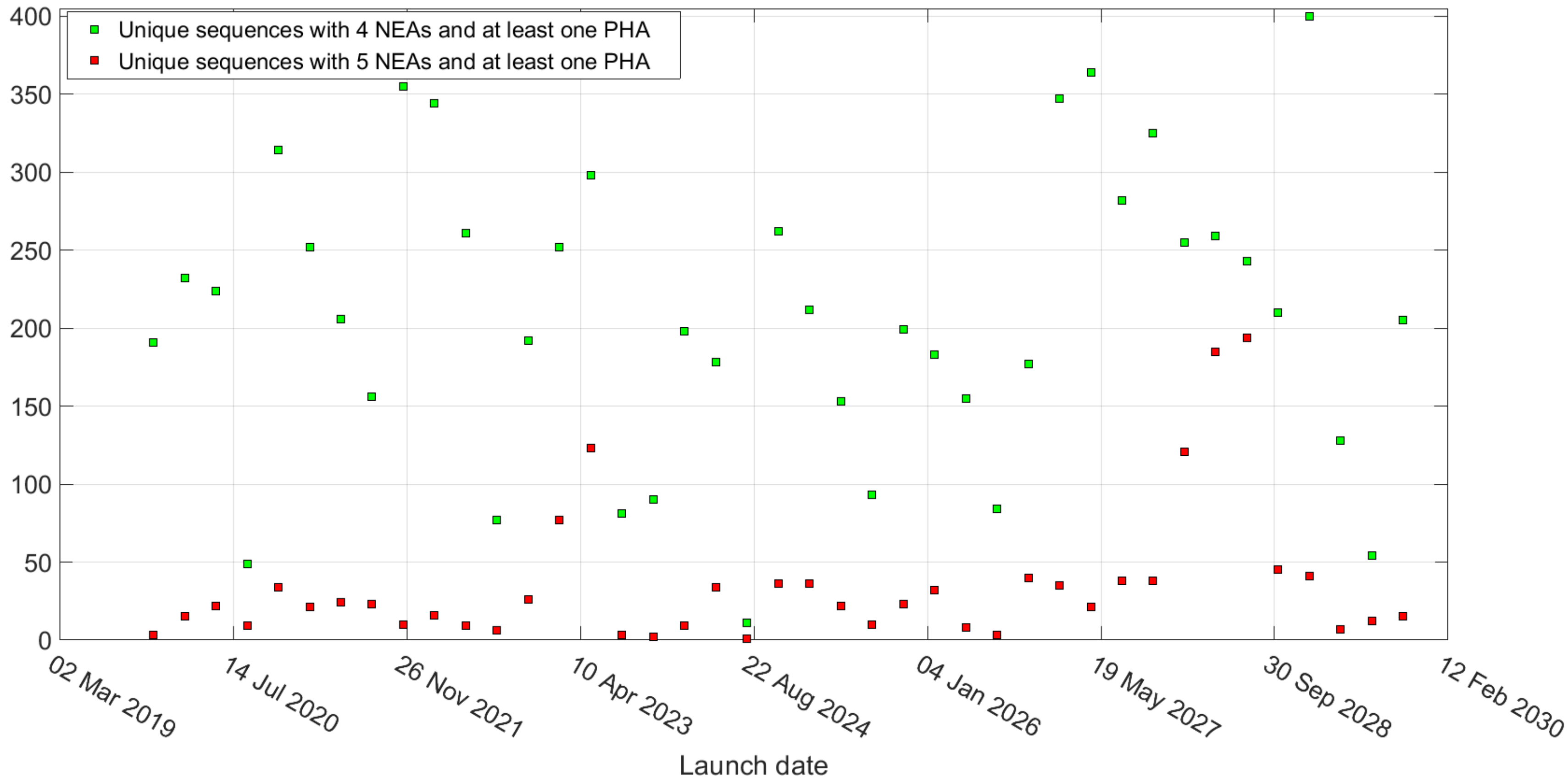
Visiting multiple asteroids



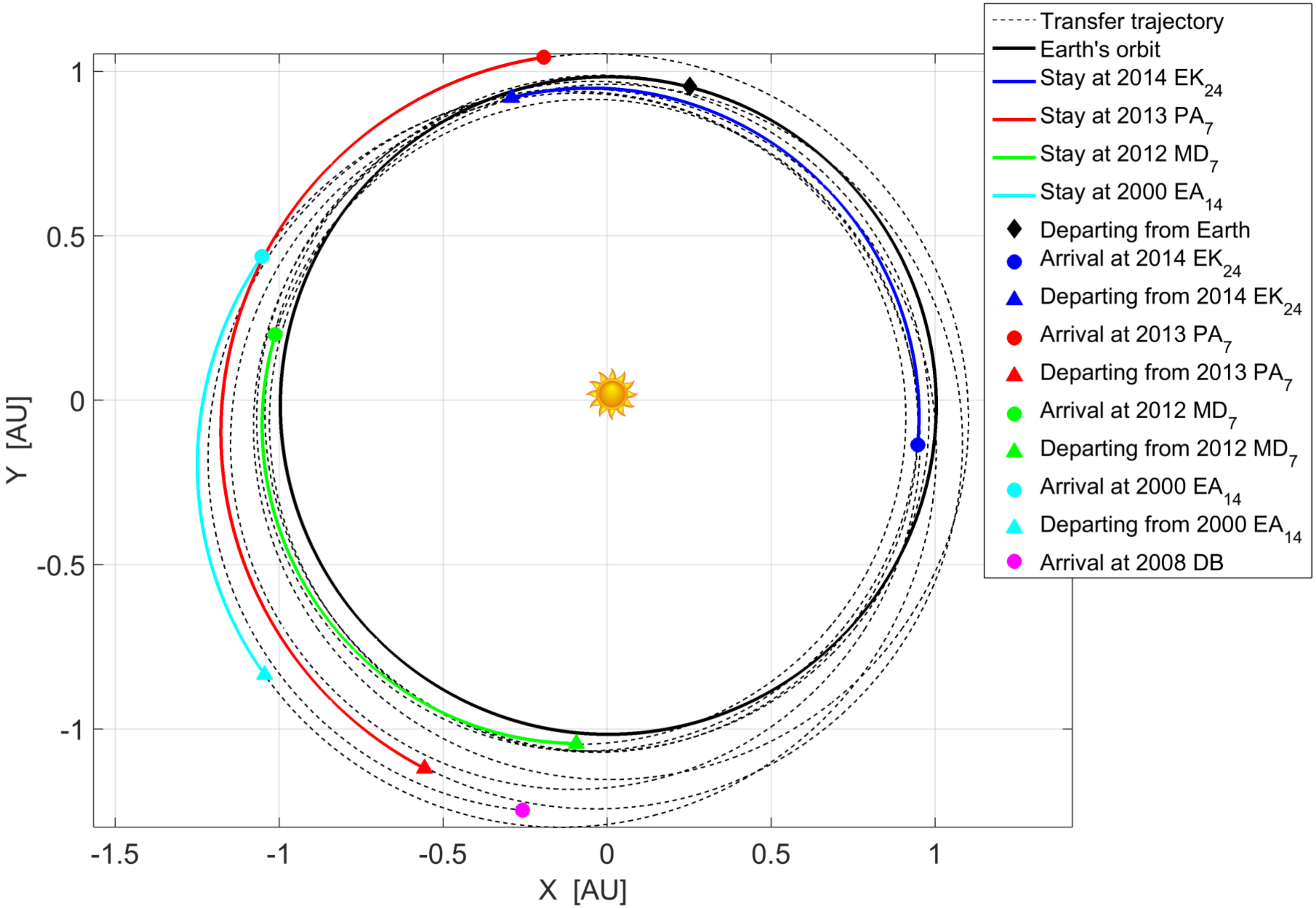
Sequence search

Characteristic acceleration: $a_c = 0.2\,\frac{\text{mm}}{\text{s}^2}$ $\left(\frac{A}{m} = 22\,\frac{\text{m}^2}{\text{kg}}\right)$

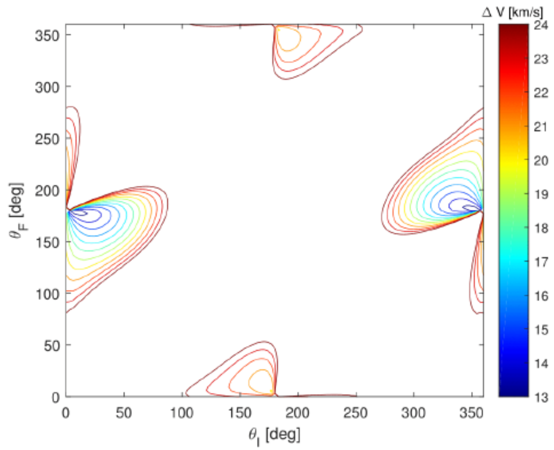
> 1,000 unique sequences made of 4 NHATS asteroids and 1 PHA!

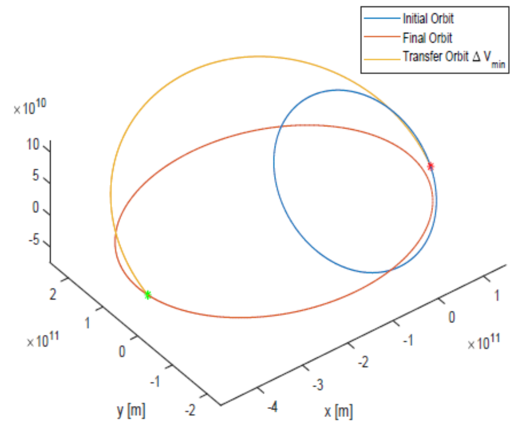


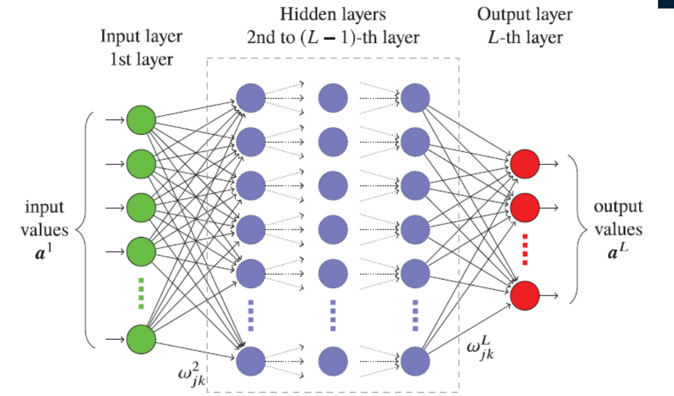
Solution using a solar sail

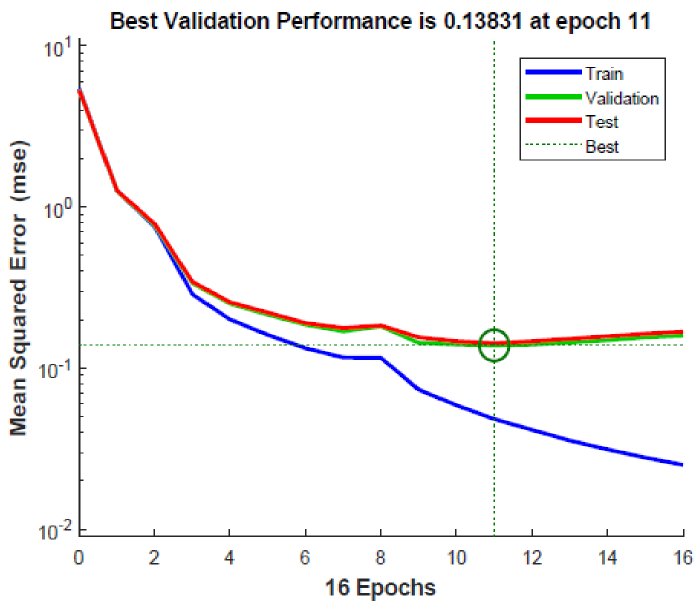


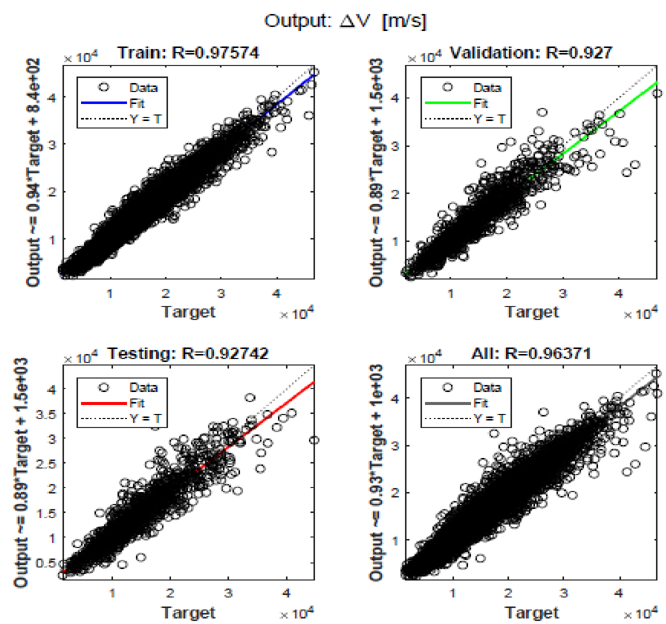
Trajectory design using ANN



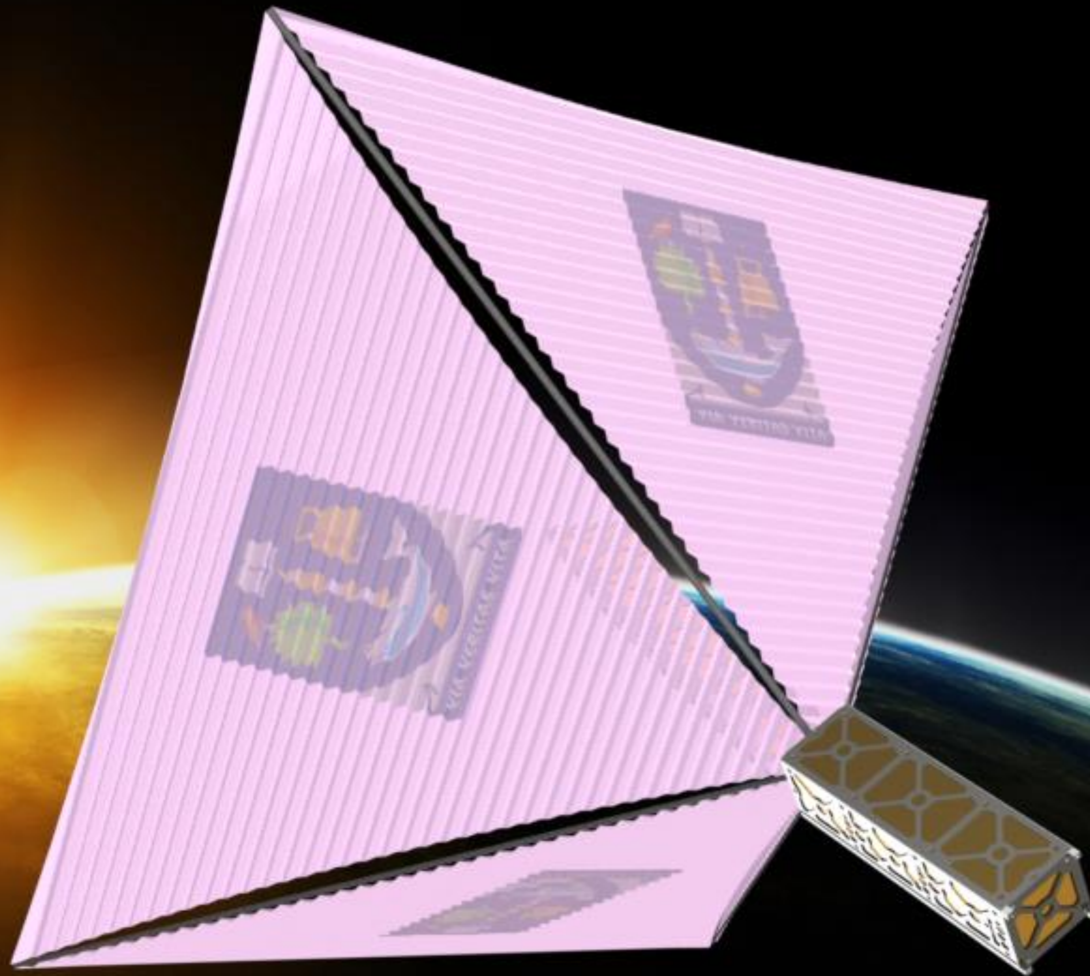








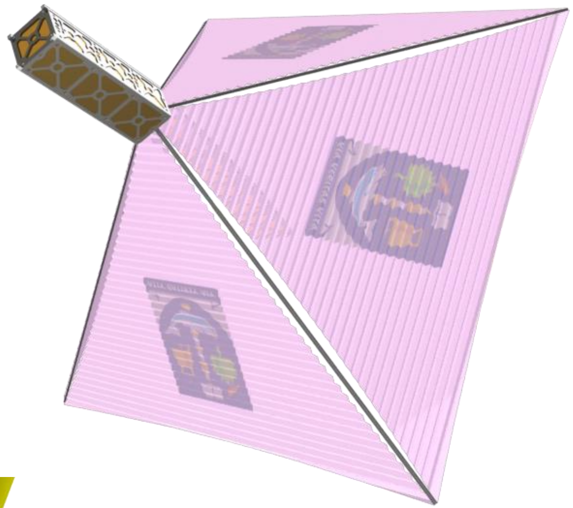
NEW SOLAR SAIL CONCEPTS

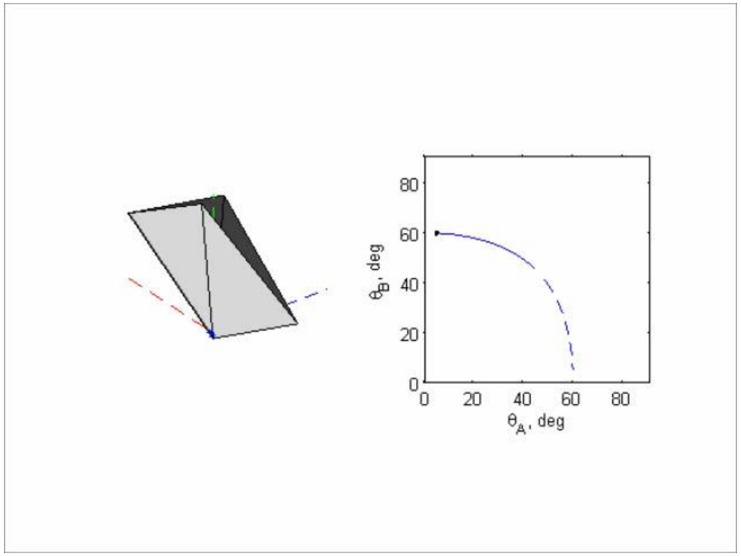


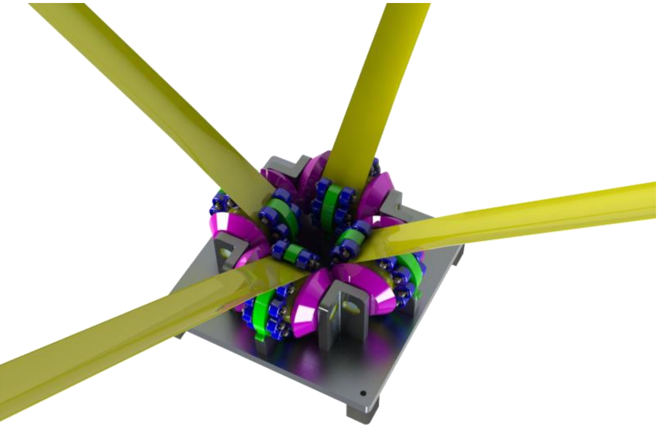
Ceriotti, McInnes, Harkness
McRobb, Heiligers, Borggraefe

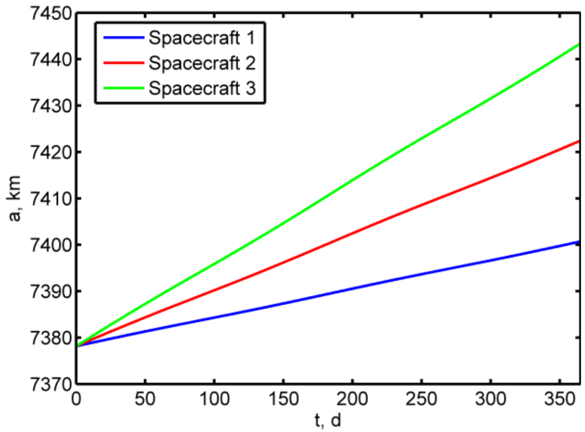
New solar sail concepts

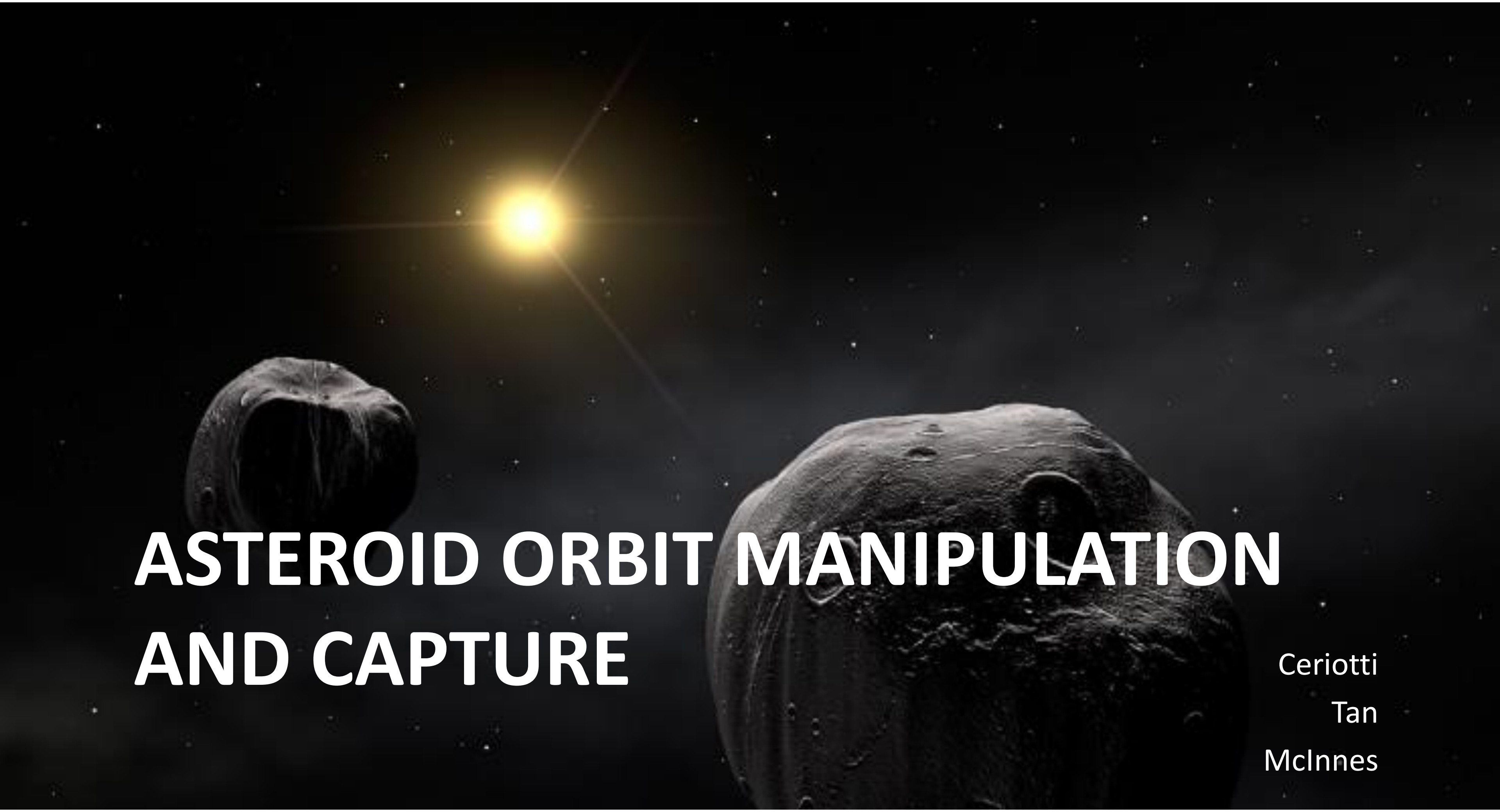
Quasi-rhombic pyramid







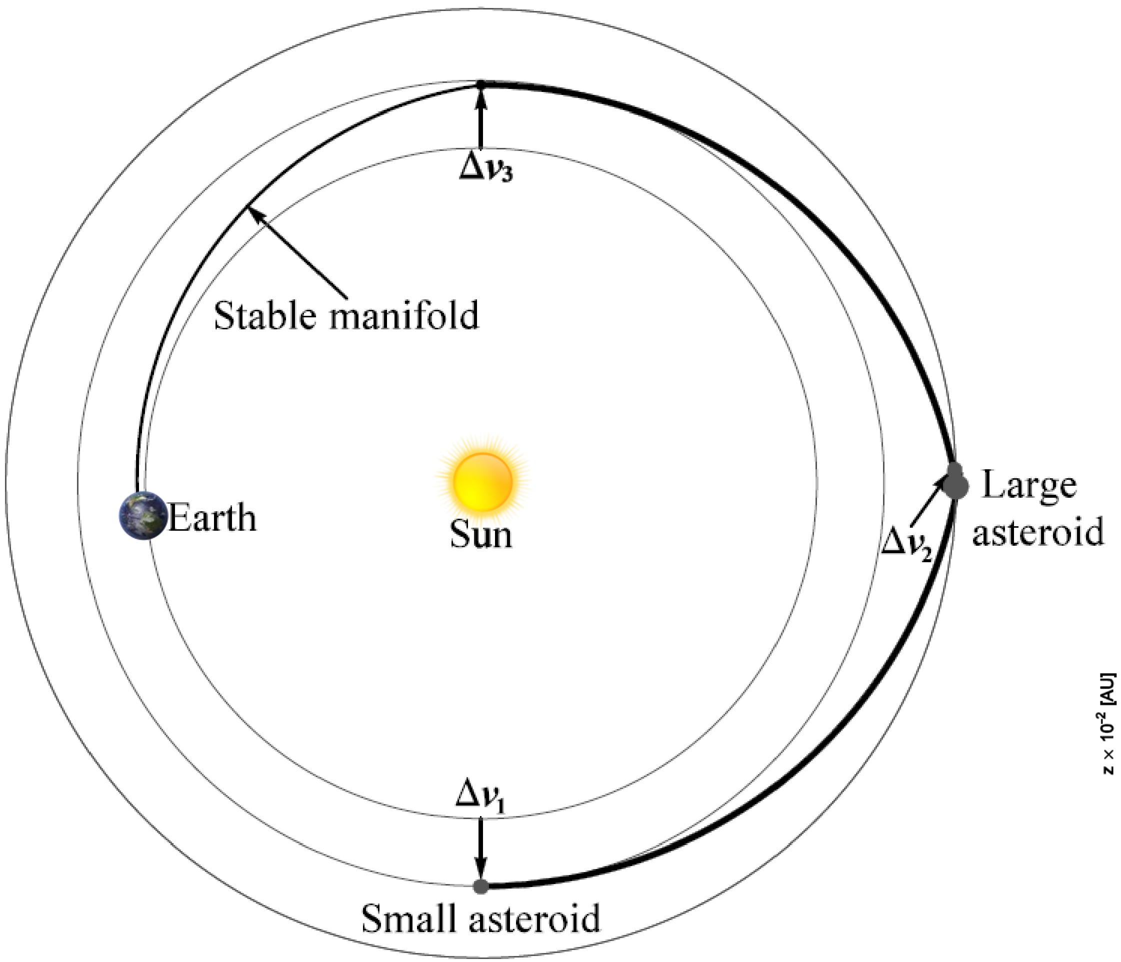


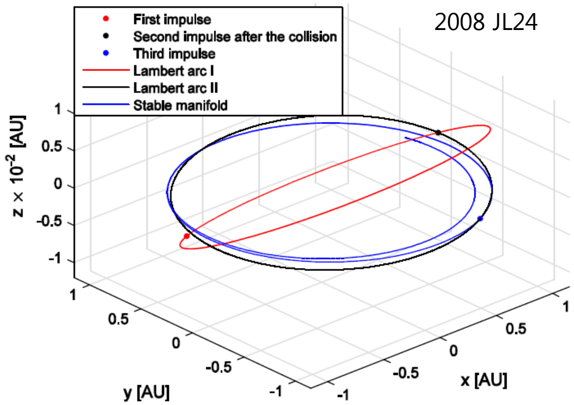


ASTEROID ORBIT MANIPULATION AND CAPTURE

Ceriotti
Tan
McInnes

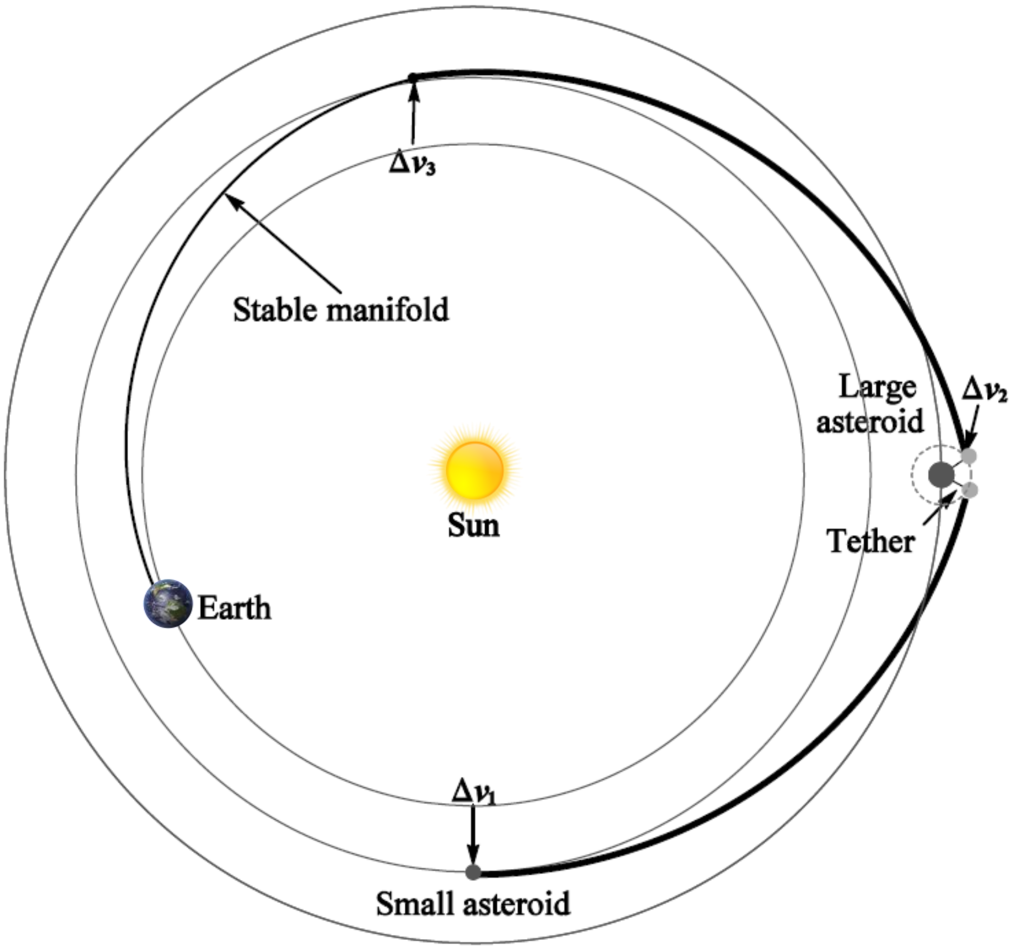
Collision with larger asteroid

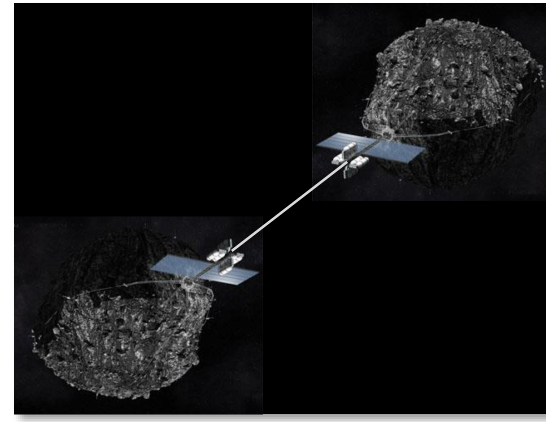




M. Tan, C. R. McInnes, M. Ceriotti, "Low-energy near-Earth asteroid capture using momentum exchange strategies", *Journal of Guidance, Control, and Dynamics*, vol. 41, n. 3, p. 632-643, 2018. DOI: 10.2514/1.G002957

Tether-assisted fly-by





2008 JL24 tethered by 2015 KE

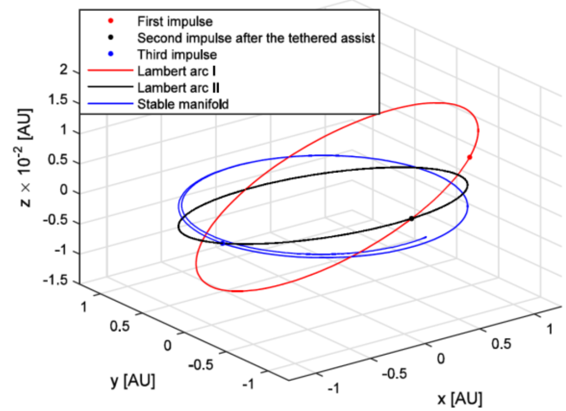
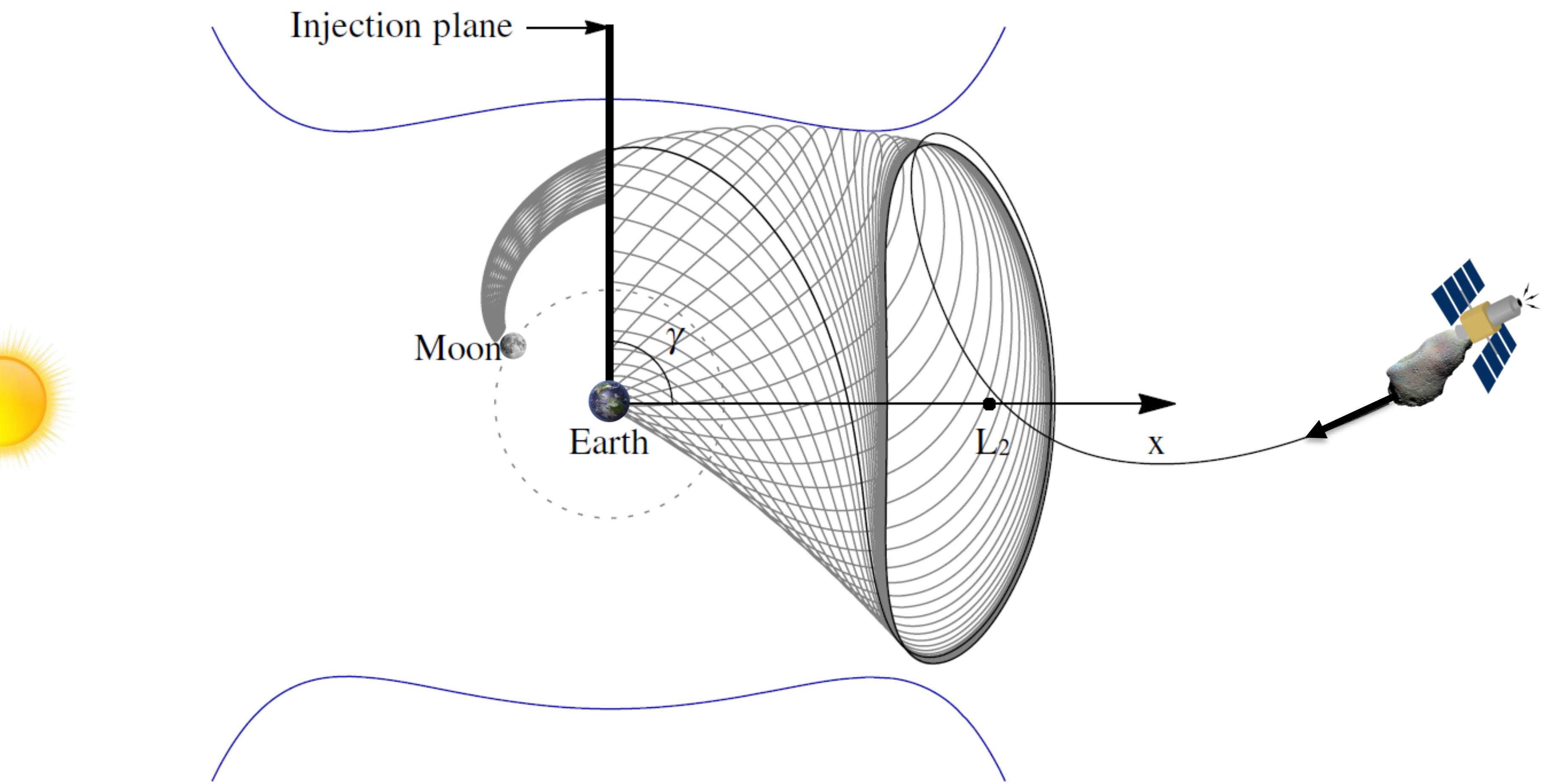


Image adapted from NASA

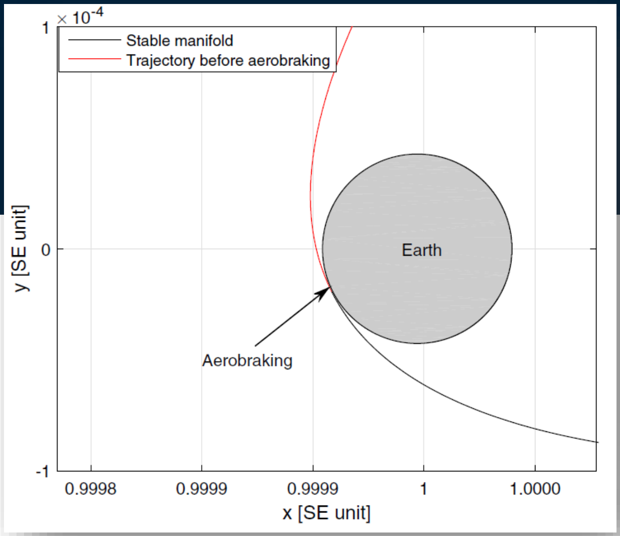
M. Tan, C. R. McInnes, M. Ceriotti, "Low-energy near-Earth asteroid capture using momentum exchange strategies", *Journal of Guidance, Control, and Dynamics*, vol. 41, n. 3, p. 632-643, 2018. DOI: 10.2514/1.G002957

Direct capture to the Moon



Minghu Tan, Colin McInnes, Matteo Ceriotti, "Direct and indirect capture of near-Earth asteroids in the Earth–Moon system", Celest Mech Dyn Astr (2017) 129:57–88, DOI 10.1007/s10569-017-9764-x

Aerobraking



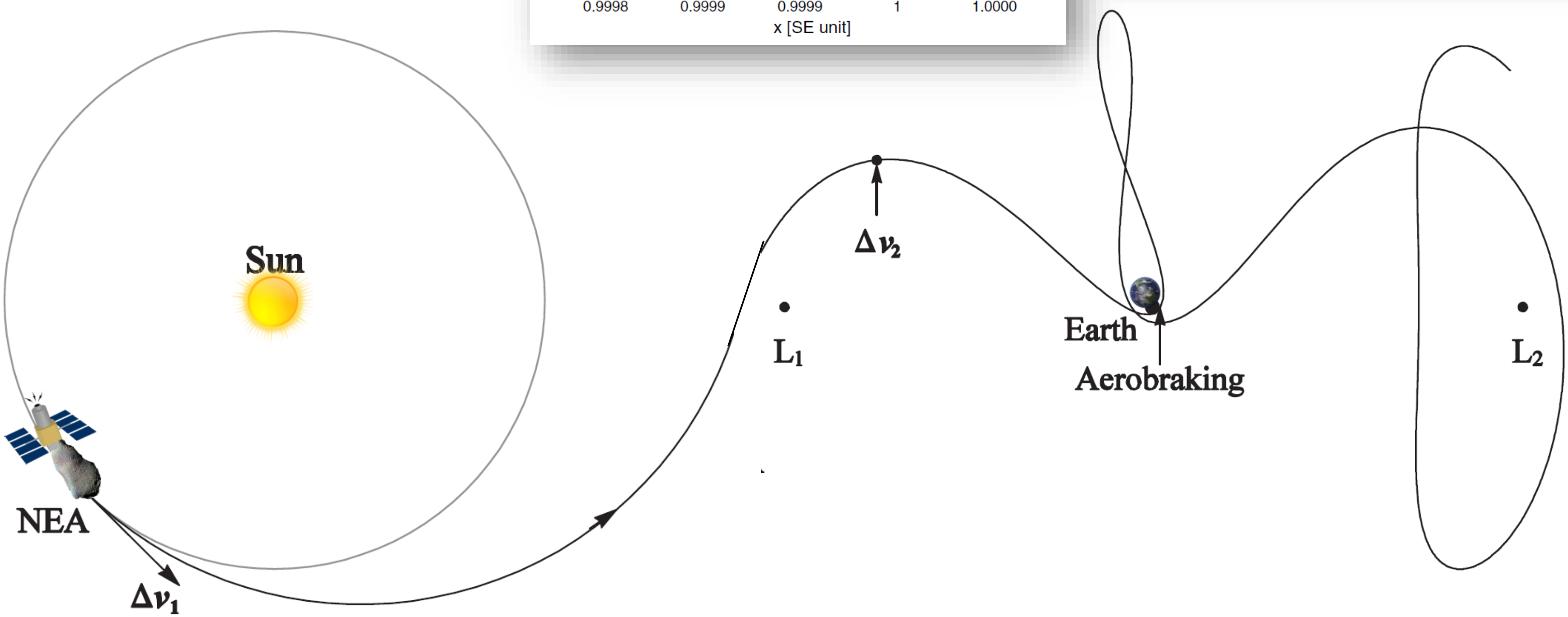


Image: Kerbal Space Program

M. Tan, C. R. McInnes, M. Ceriotti, "Low-energy near Earth asteroid capture using Earth flybys and aerobraking", *Advances in Space Research*, vol. 61, n. 8, p. 2099-2115, 2018. DOI: 10.1016/j.asr.2018.01.027

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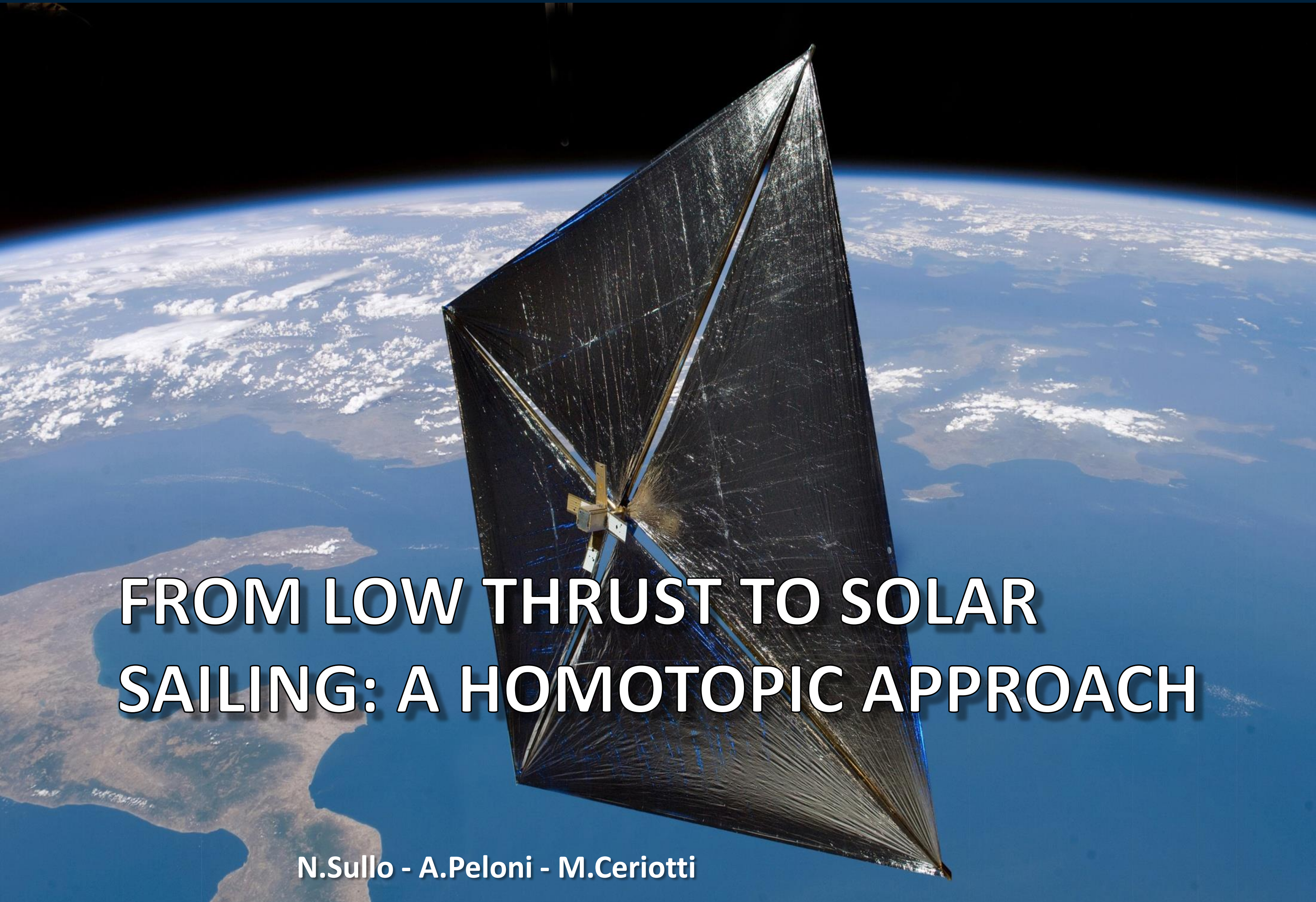


FROM LOW THRUST TO SOLAR SAILING: A HOMOTOPIC APPROACH

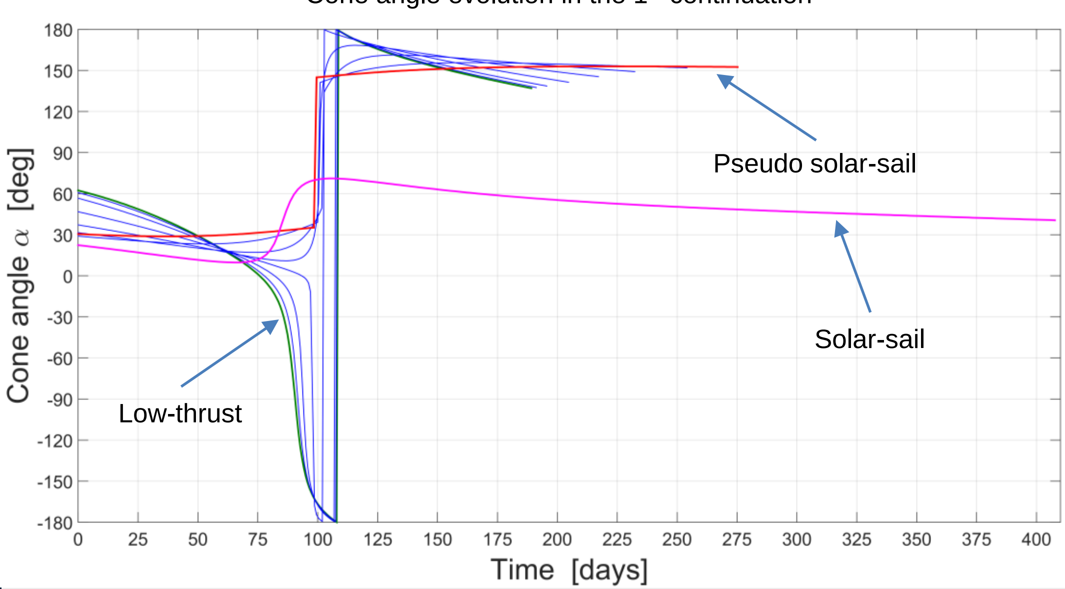
N.Sullo - A.Peloni - M.Ceriotti

Homotopic approach

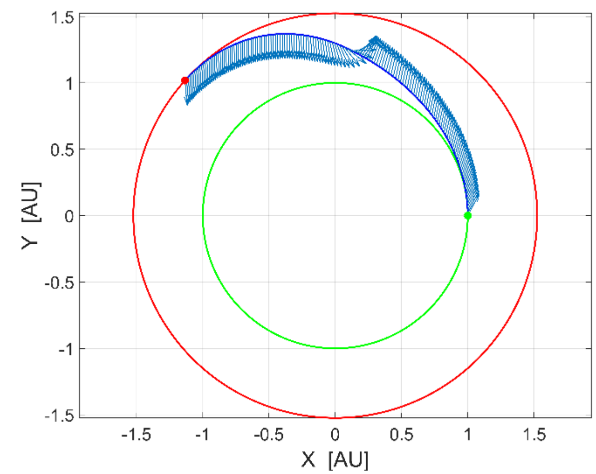
- Homotopies transforms a low-thrust solution into a solar sail solution

$$\boldsymbol{a}_{LTSS} = a_{\max}\left[(1-\varepsilon)u + \left(\left(\frac{r_\oplus}{r}\right)^2 \cos^2\alpha\right)\varepsilon\right]\cdot\begin{bmatrix}\cos\alpha\\ \sin\alpha\end{bmatrix},\quad \alpha\in[-\pi,\pi]$$

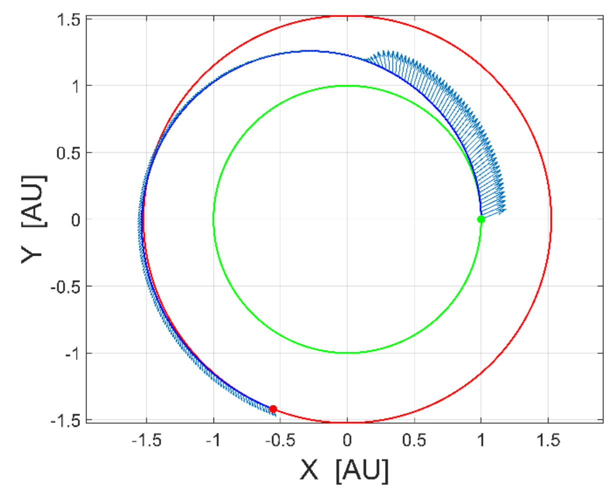
Cone angle evolution in the 1st continuation



Low-thrust transfer



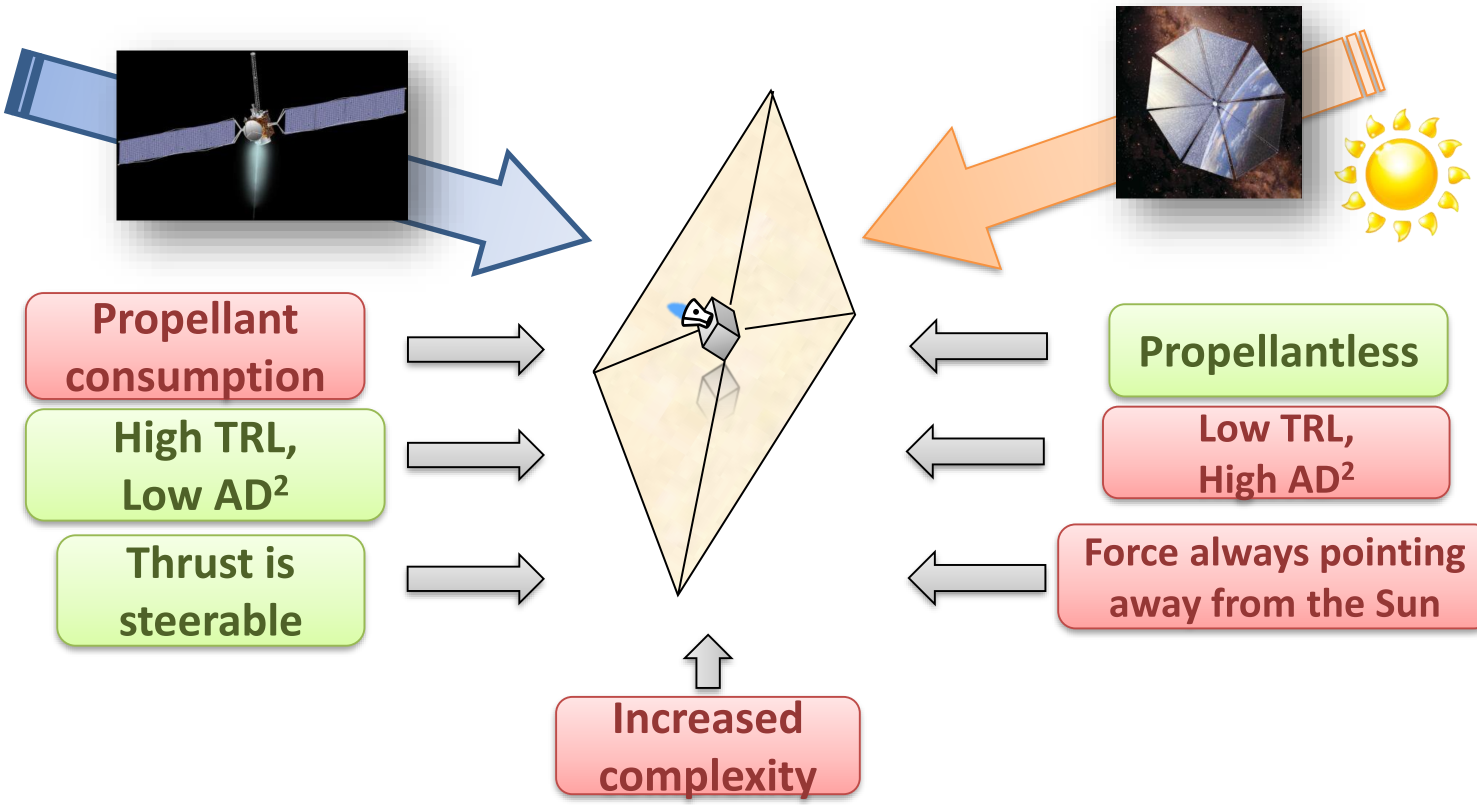
Solar-sail transfer



Hybrid Propulsion

How to take advantage of both SEP and sail?

Combine them on the same spacecraft:



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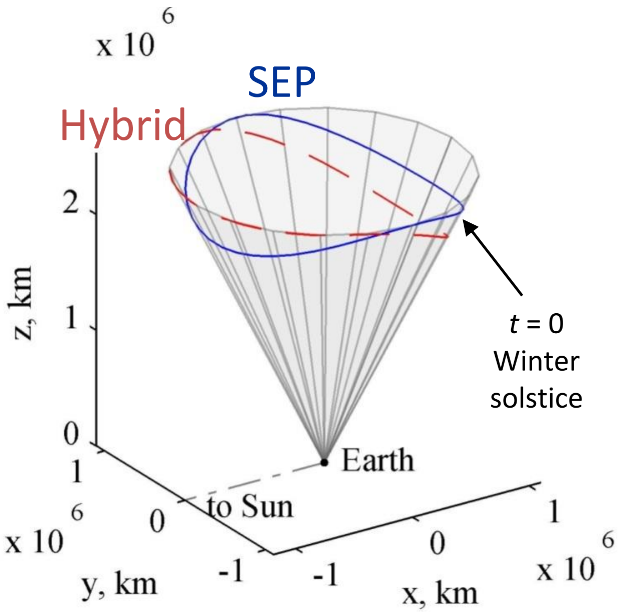
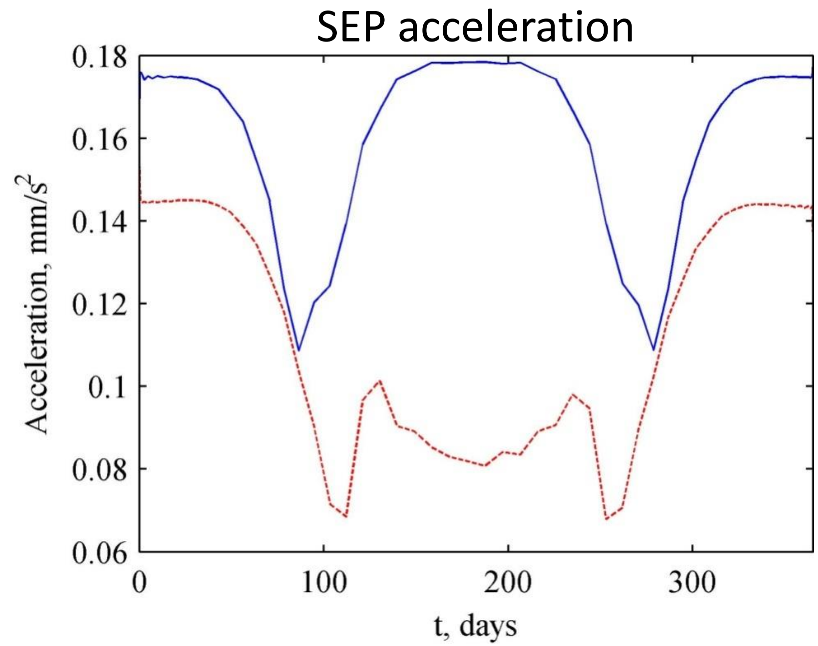
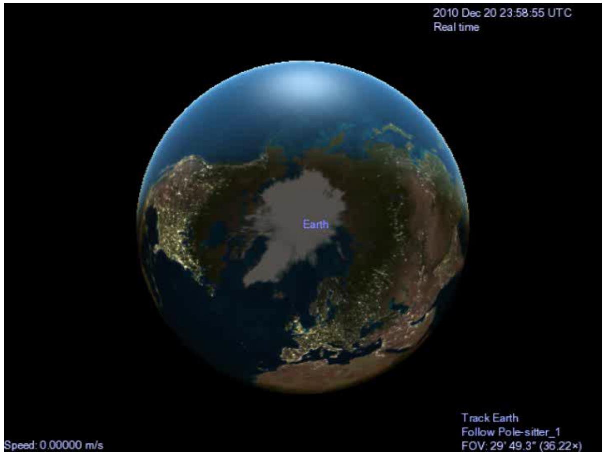
Optimal pole-sitter orbits



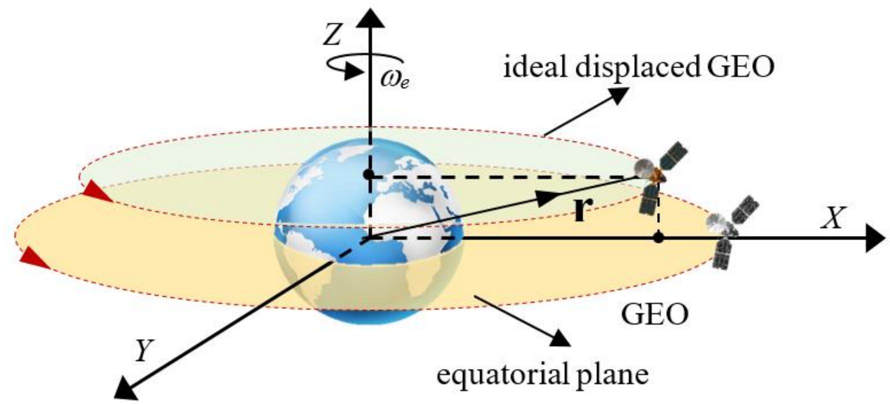


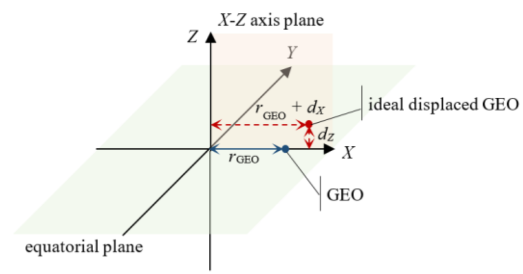


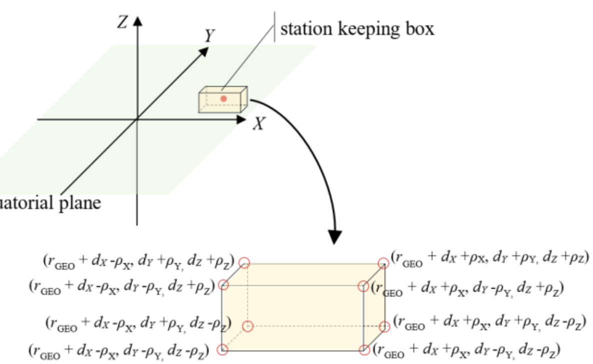
YouTube https://www.youtube.com/watch?v=-PFyq5zek0Q

Displaced Geostationary orbits

- Increase the capacity of the GEO ring
- Continuous thrust required
- Hybrid (sail+SEP) propulsion allows to save fuel
- Loose stationkeeping box enables further savings



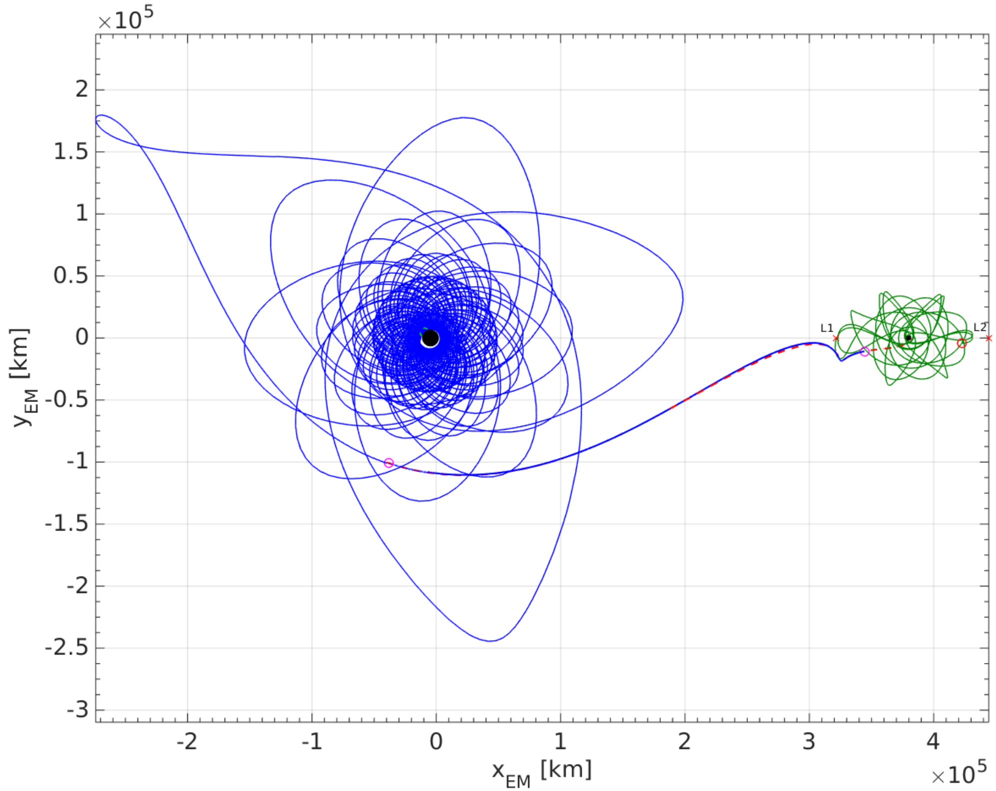




Interplanetary transfers

- Earth-Moon transfers with hybrid propulsion
  - High thrust (chemical)

    \+
  - Low thrust (SEP)

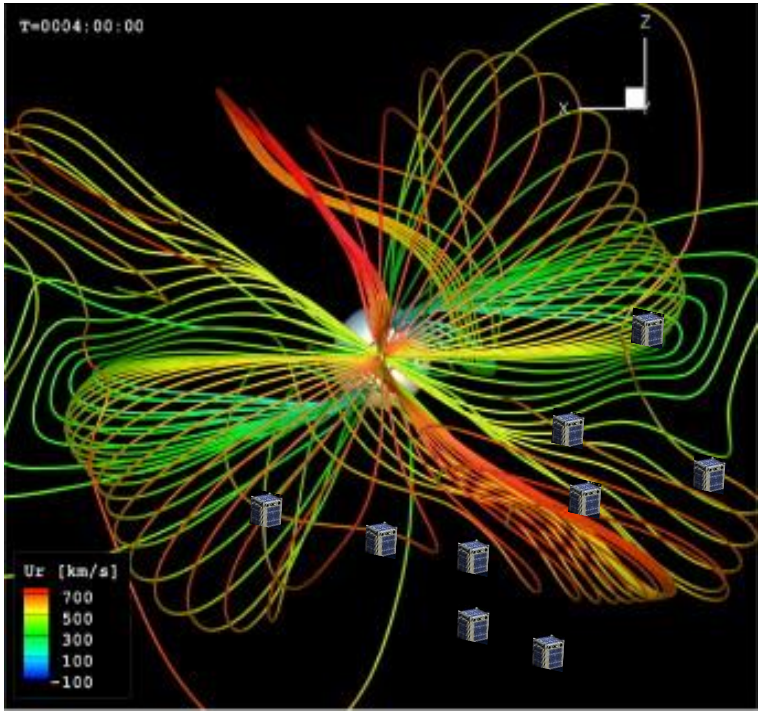


SPACE WEATHER MONITORING

Qingying Shu
Marian Scott
Lyndsay Fletcher
Matteo Ceriotti
Peter Craigmile

Space weather monitoring

- At present, we have very few space-weather sample points, limited to a small number of scientific (rather than operational) satellites
- Satellite resources are always at a premium



- What are the best strategies for sampling space weather data to give robust forecasts?
  - Locations
  - Sampling frequencies
  - Redundancy
  - Communication options
  - Achievable orbits
- How to predict E/M storms?


Thank you!
Questions?
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