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1ST ACT GLOBAL TRAJECTORY OPTIMISATION COMPETITION

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- **First team meeting for preliminary assessment of the problem**

- **Analysis of objective function**
  $\Rightarrow$ preferred impact conditions

  - Frontal impact at asteroid perihelion

  - Impactor in retrograde orbit, coplanar with the asteroid one

❍ Candidate trajectory concepts

- **Pure ballistic** trajectory
  - Coast arcs + planets swingby
- **Pure low thrust** trajectory
  - Thrust arcs + coast arcs
  - Without any planet swingby
- **Hybrid** trajectory
  - Thrust + coast arcs + swingby

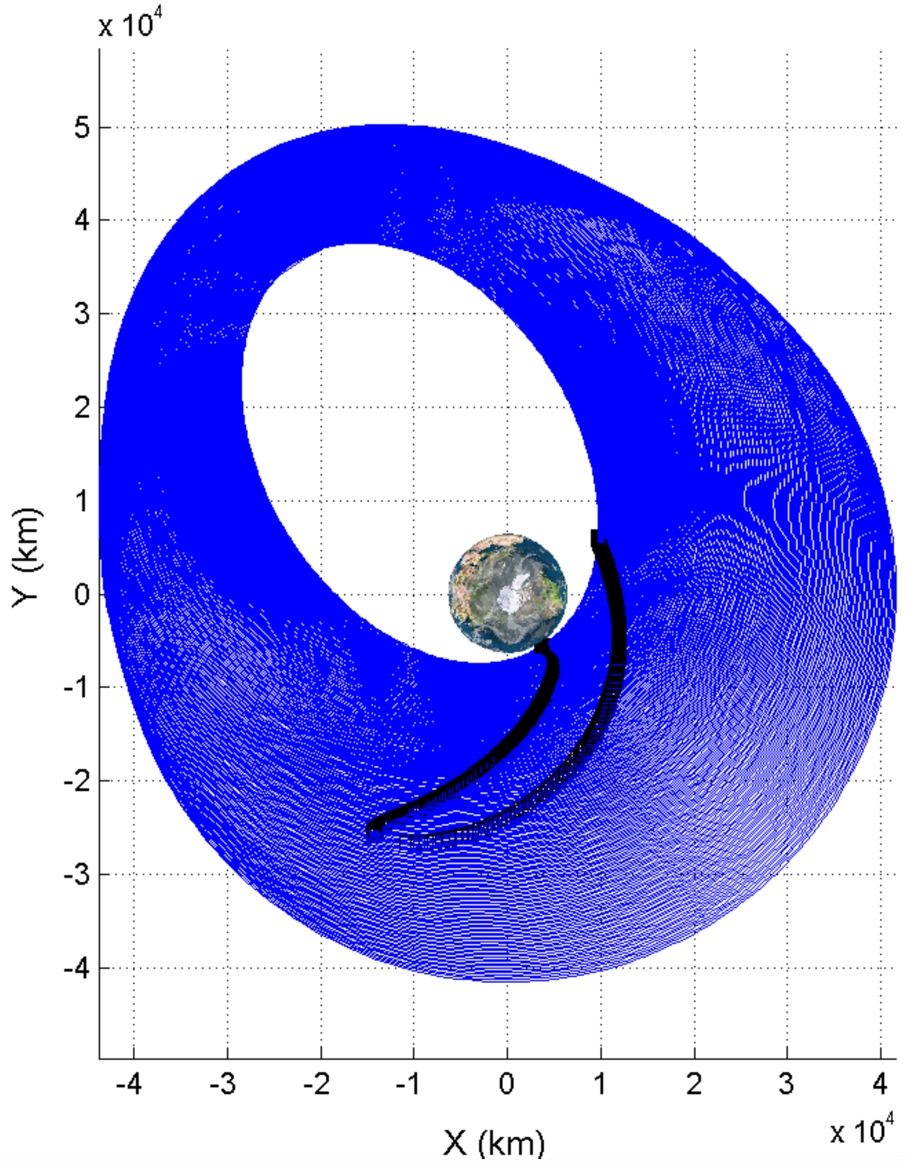
- **Pure ballistic trajectories**
  - Departure $\mathbf{v_\infty = 2.5\ km/s}$
    $\Rightarrow$ Do need low thrust to reach any planet other than the Earth
- **Pure low thrust trajectories**
  - Too much fuel to attain retrograde motion and fall back into the inner Solar System within 30 years
- **Hybrid trajectory**
  - Our choice

Other considerations

- Gravity assists with giant planets promise high ΔV
  - Constraints on mission duration & periapsis altitude
    $\Rightarrow$ only Saturn may produce retrograde motion
- Venus and Earth swingbys needed to reach Jupiter
- Expected impact velocity (approx. 50 km/s) exceeds $g_0 \cdot I_{sp}$
  - No thrust in the last trajectory leg
- Last swingby close to a node of the giant planet with the asteroid

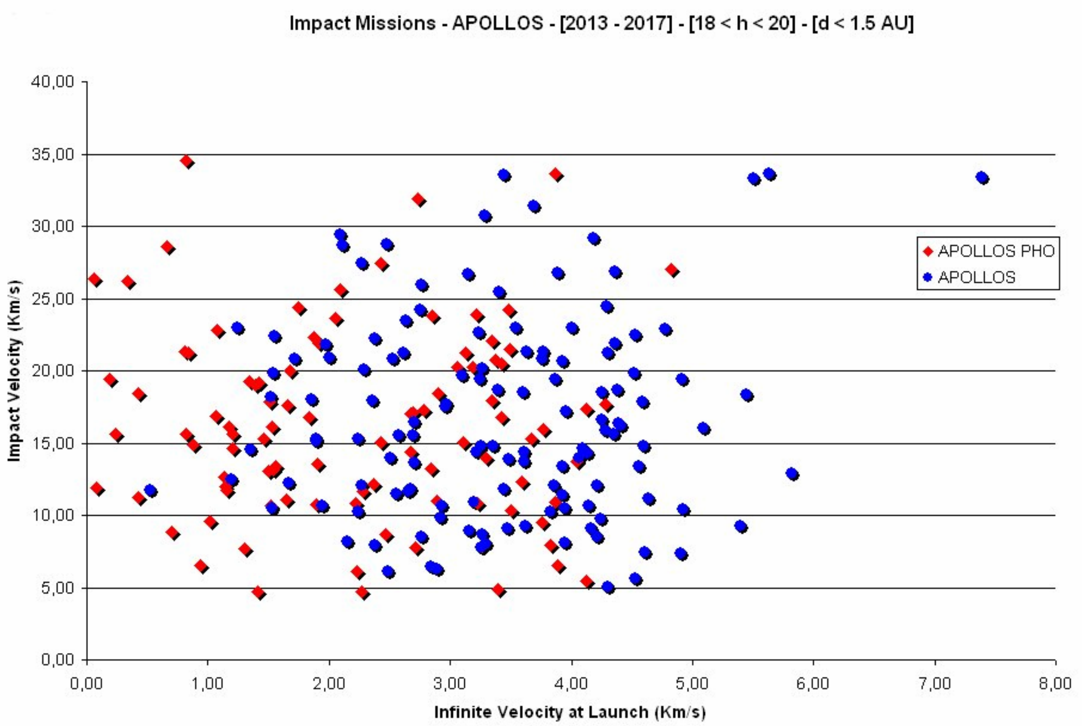
❍ GeoExpress

- Low-thrust transfers
- Optimal control (Pontryagin) in the inner (fast) loop
- Optimisation of the guidance profile in the outer (slow) loop
- Applied to the GTO-GEO transfer of ConExpress



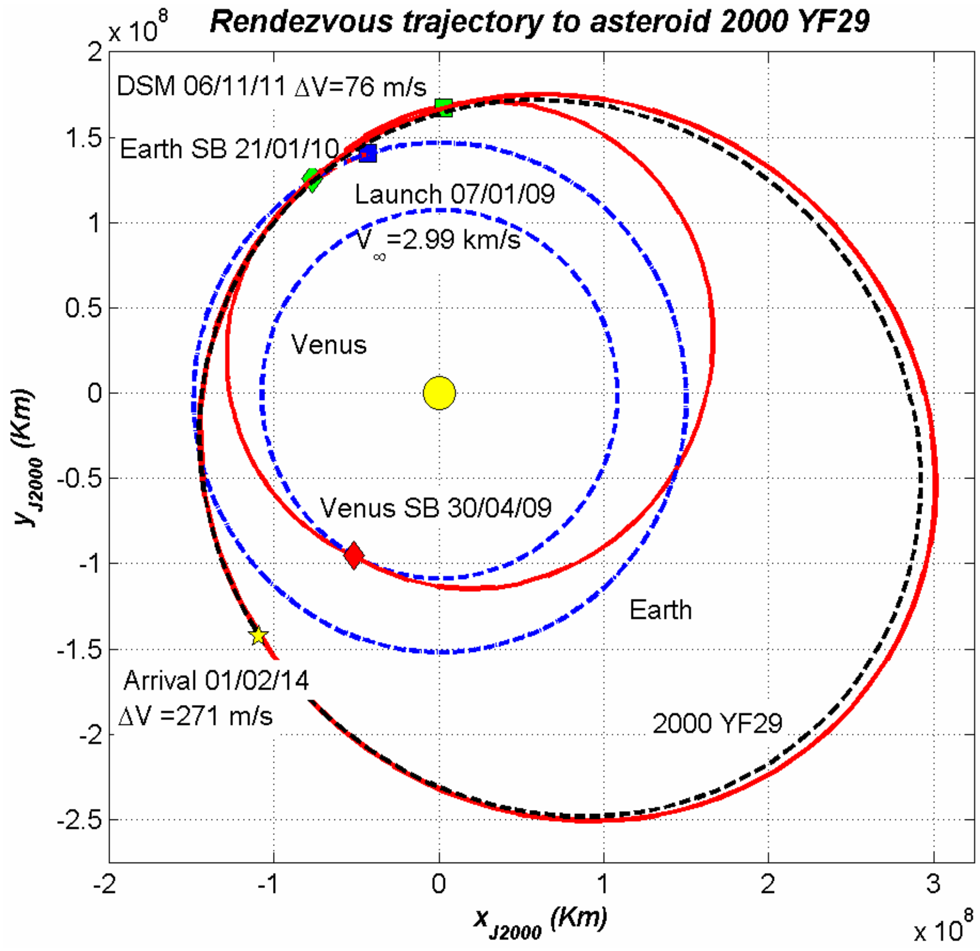
❍ GlOptImp

- Global search (GA) of ballistic trajectories within the Solar System
- Includes
  - planet swingbys
  - minor body flybys
  - impulsive deep space maneuvers



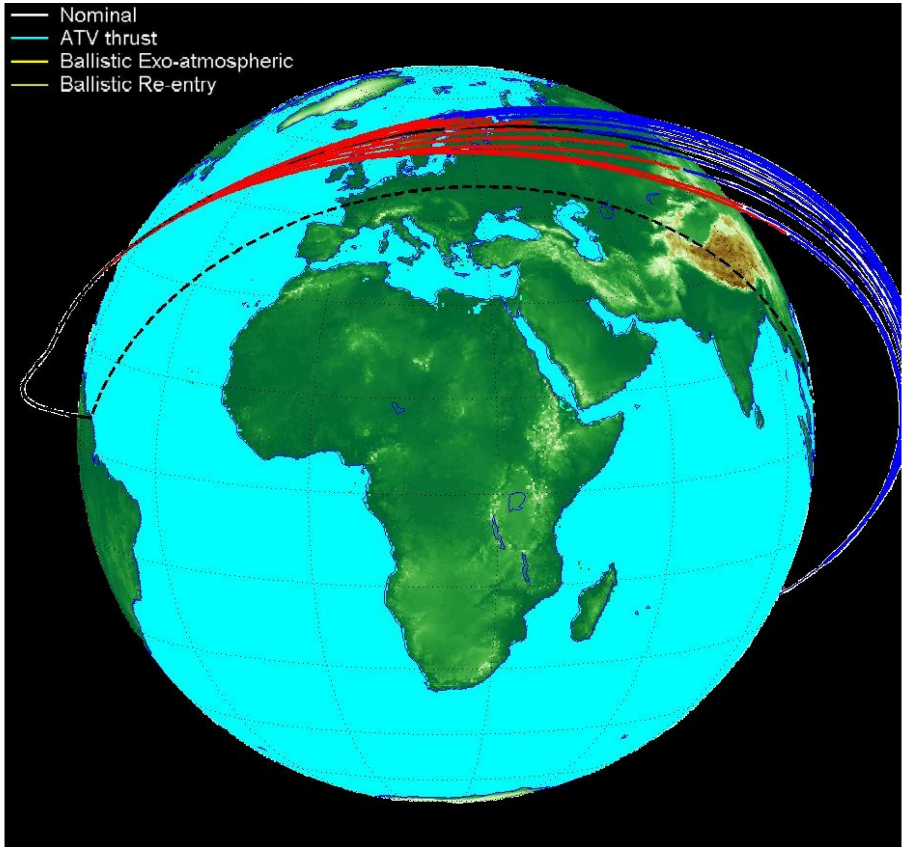
❍ Mitrades

- Interactive design and optimization of interplanetary ballistic trajectories in MATLAB
- Phase-free transfers, resonant orbits, multiple DSM
- Applied to NEO mission design

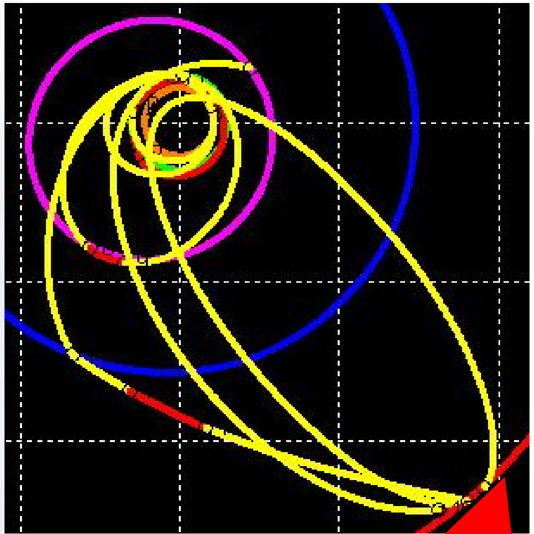


MerPro

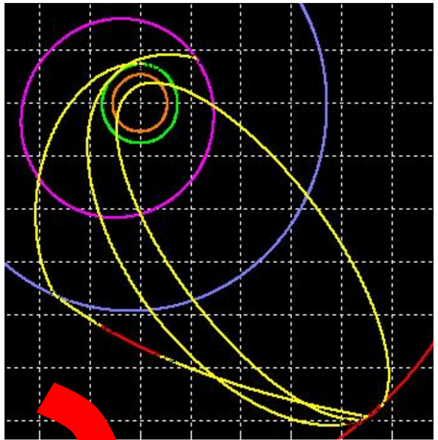
- Constrained optimization of multi-arc finite-thrust trajectories
- Global search (GA) + local optimizer
- Applied to abort trajectories, orbit transfer and launch and interplanetary missions



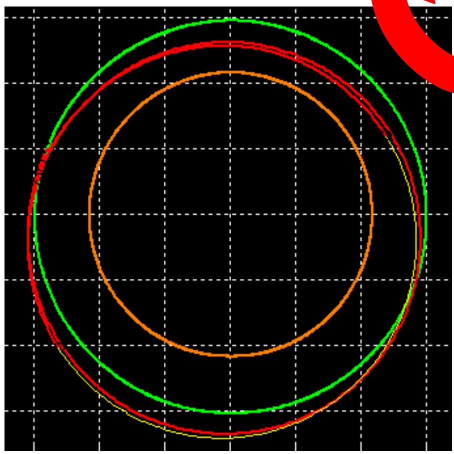
4. Merge phases



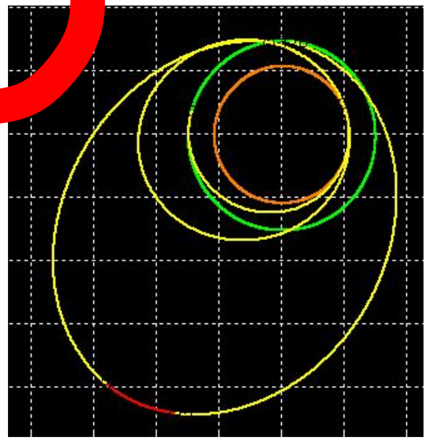
1. GlOptImp
EJSA tour by the giant planets



3. MerPro
EEE low-thrust transfer

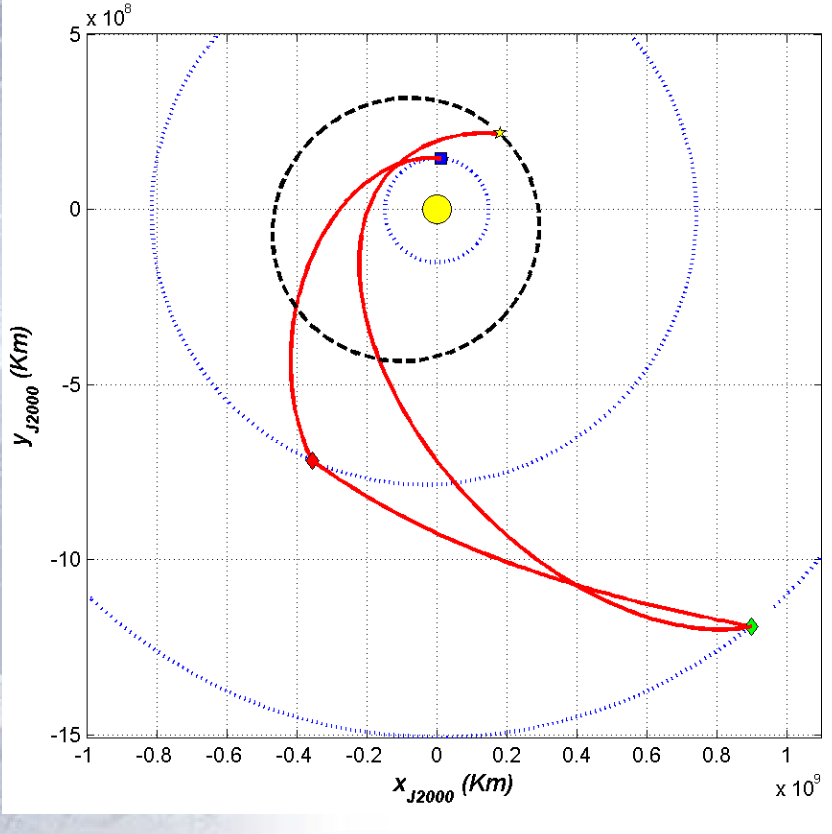


2. Mitrades
EVEE transfer

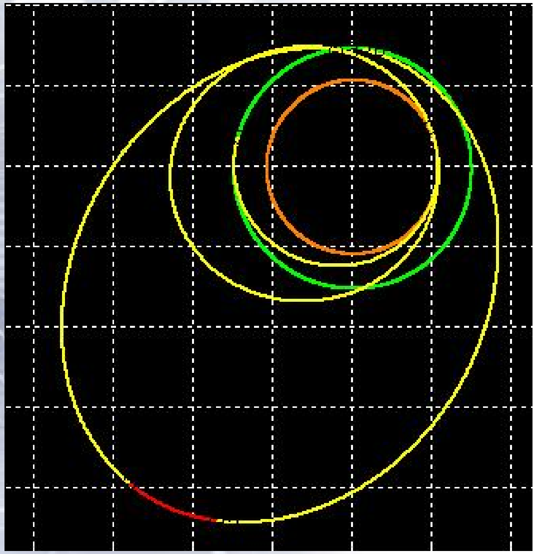


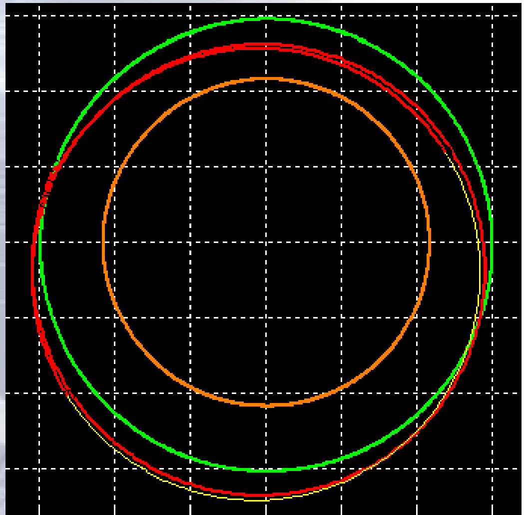
❍ Our first guess

- GlOptImp used to find best EJSA trajectory



- EJSA
  - ➢ Earth departure in December 2016 (< 7 years to get V_∞=9.2 km/s)
  - ➢ DSM between Jupiter and Saturn
  - ➢ Asteroid impact in December 2026 (48.5 km/s)

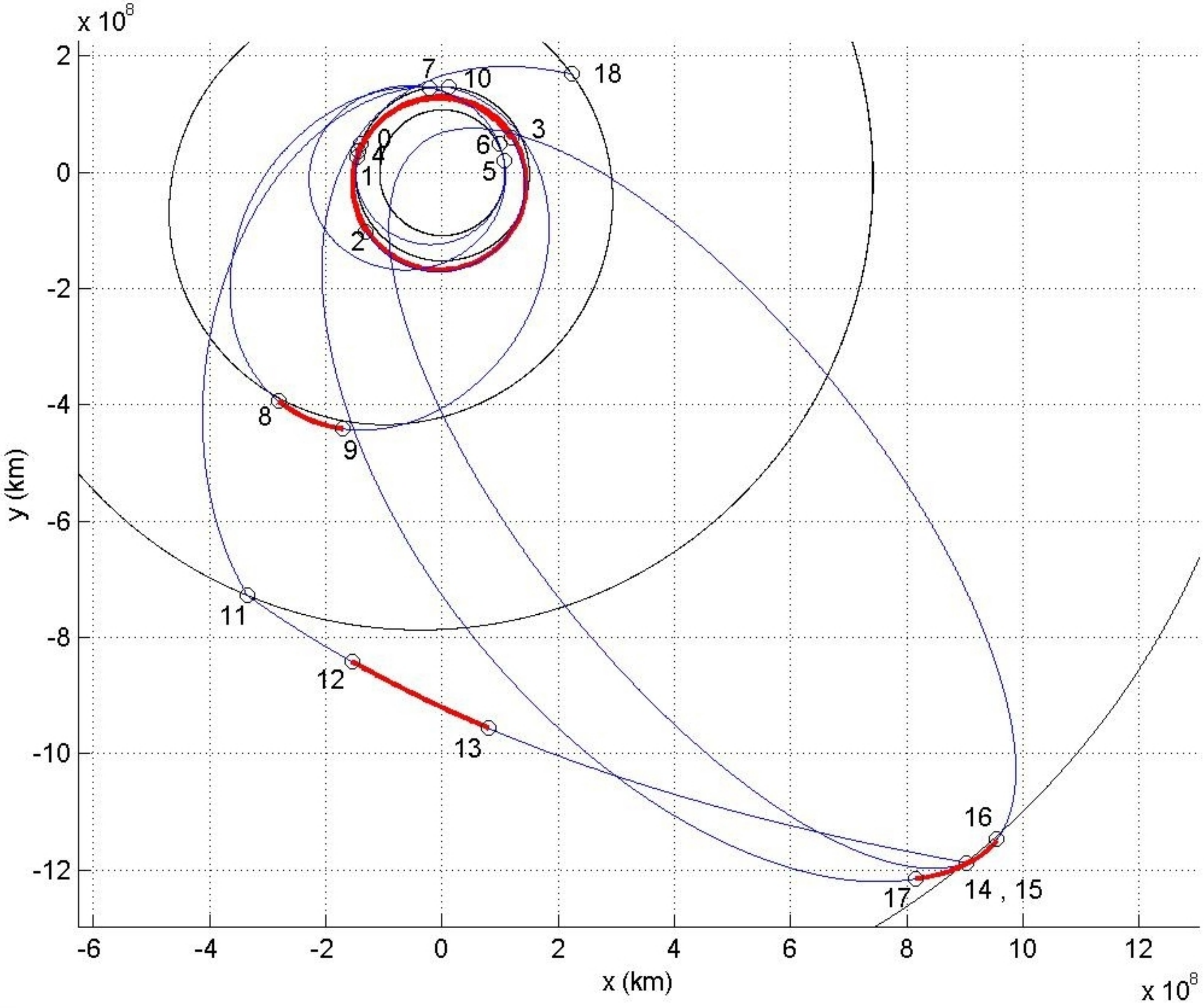




- Mitrades used to match the Earth swingby conditions
  - **EVE-DSM-E**
    - Earth departure March 2012 (2 years to get V_∞=4.5 km/s)
- Merpro used to compute the low-thrust transfer
  - **EEE**
    - Launch in March 2010
- Objective function
  - **1 283 000** km^{2}kg/s^2

Improvements

- Optimize dates and maneuvers
  - Objective function: 1 417 000 km^2kg/s^2
- Wait one extra revolution in the last arc and apply a DSM at aphelion to improve impact geometry and velocity
  - Objective function
    - **1 456 000 km^2kg/s^2**
  - Arrival
    - **June 15th, 2039**
    - **49.1 km/s**
    - **1306 kg**


x 10^8
2
0
-2
-4
-6
-8
-10
-12
y (km)
-6
-4
-2
0
2
4
6
8
10
12
x (km)
x 10^8
0
1
2
3
4
5
6
7
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17
18

- Focus in obtaining a feasible, good trajectory (not the global optimum)
  - Search for initial guess was not exhaustive
- Method to build and improve the complete trajectory worked successfully
  - Hybrid trajectory: low-thrust + swingbys
  - Difficult to satisfy constraint in launch date (due to initial guess)
- Tools require deep understanding of the problem to find a good solution
- GMV is continuously improving and extending the tools and algorithms for trajectory design and optimization