POLITECNICO
MILANO 1863

Orbital Mechanics

ASSIGNMENT PRESENTATION

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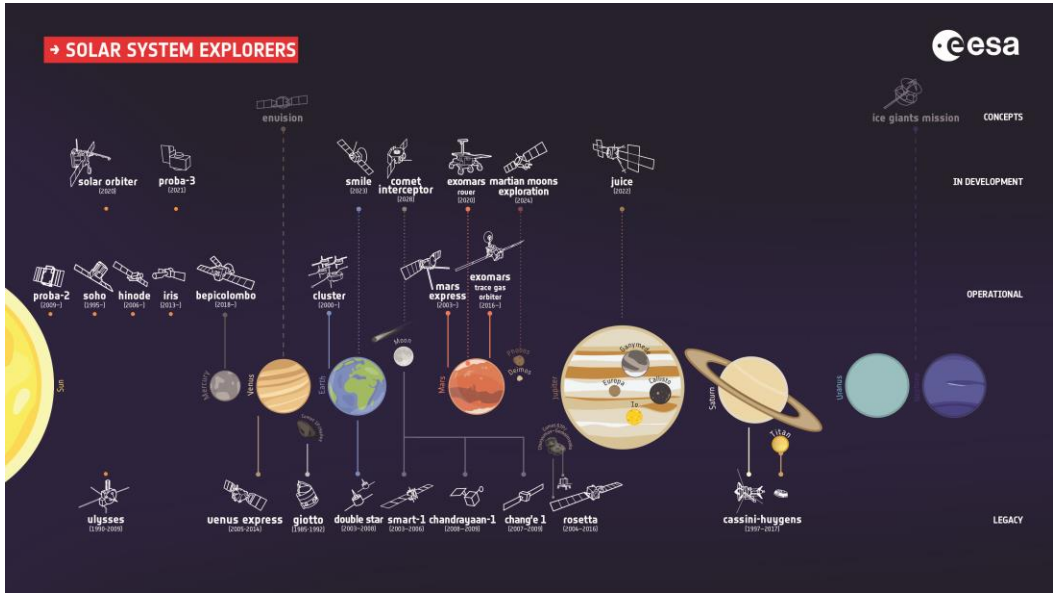
INTERPLANETARY EXPLORER MISSION



Solar System Explorers
Image from ESA

MISSION:

- Departure from Neptune
- Flyby at Mars
- Arrive at Earth

FIGURE OF MERIT:

- Δv_{tot}

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DESIGN PROCESS

CONSTRAINTS:

- Earliest Departure

  $1^{st}\ Jan\ 2020$

- Latest Arrival

  $1^{st}\ Jan\ 2060$

- Flyby Minimum Altitude

  $h_{min} = 250\ km$

Rosetta's flyby at Mars
Image from ESA

DESIGN PROCESS

ASSUMPTIONS:

- Patched Conics Method
- Other planets ignored
- SRP neglected
- Neptune departure and Earth arrival neglected

PRELIMINARY ESTIMATIONS

Planet	Orbital period in Earth years		Planets	Synodic Period in Earth years
Neptune	164,8		**Neptune & Mars**	1,90
Mars	1,88		**Mars & Earth**	2,13
Earth	1		**Neptune & Earth**	1,01

#	Neptune - Mars	Mars - Earth
Parabolic Transfer Time	$13.36\ years$	$24.14\ days$
Hohmann Transfer Time	$31.47\ years$	$258.87\ days$

Neptune-Earth Hohmann Transfer	$\Delta v = 15.71 \frac{km}{s}$

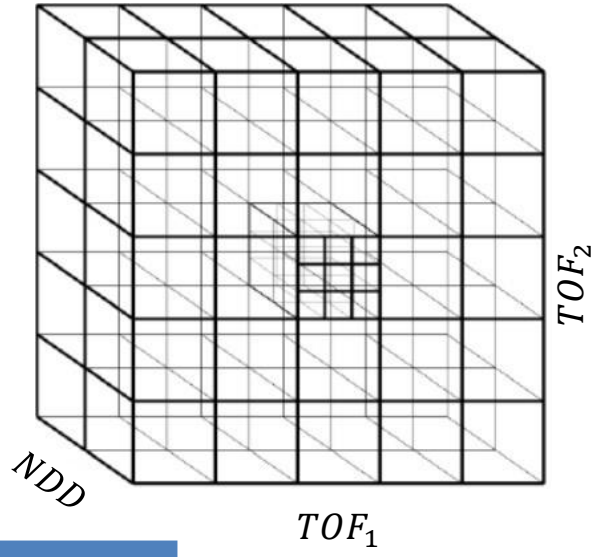
FIRST STRATEGY

GRID SEARCH

3 degrees of freedom:

- Departure time NDD
- First time of flight TOF_1
- Second time of flight TOF_2

3 nested loop cycles evaluate the Δv_{tot}

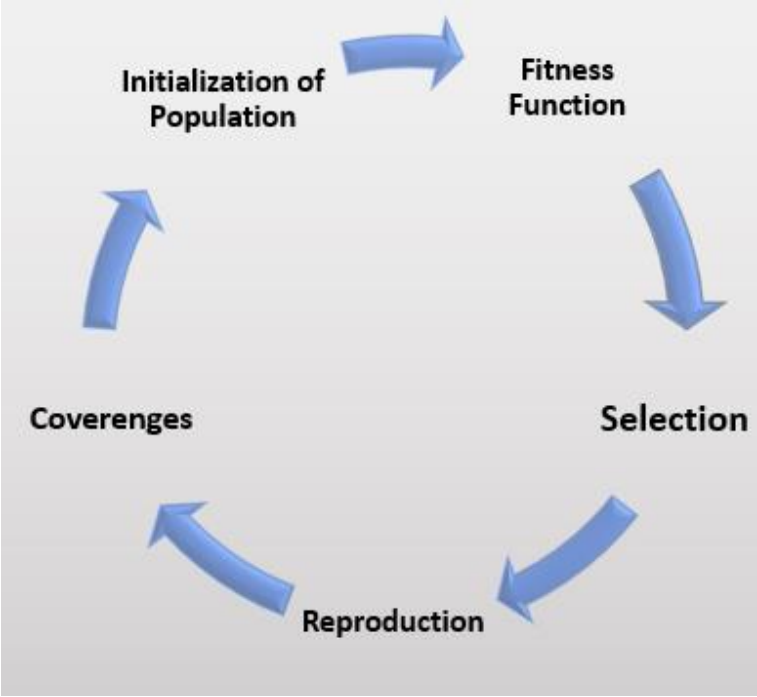


Cube grid
Image from Lab Notes
Orbital Mechanics

Array Boundaries

dof	Lower Boundary	Upper Boundary	Time Step [days]
$\boldsymbol{NDD}$	$Earliest\ Dep.$	$ED + T_{synME}$	165
$\boldsymbol{TOF_1}$	$TOF_{par}^{N\rightarrow M}$	$120\%\ TOF_{H}^{N\rightarrow M}$	1
$\boldsymbol{TOF_2}$	$TOF_{par}^{M\rightarrow E}$	$120\%\ TOF_{H}^{M\rightarrow E}$	1

SECOND STRATEGY



Genetic Algorithm scheme
Image from educba.com

GENETIC ALGORITHM

Heuristic approach applied to a wider domain:

- Number of runs $N_{runs} = 5$
- Populations $N_{pop} = 2000$
- Generations $N_{gen} = 300$
- Fitness function

SECOND STRATEGY

Boundaries

dof	Lower Boundary	Upper Boundary
$\boldsymbol{NDD}$	ED	$ED + T_{synME}$
$\boldsymbol{TOF_1}$	TOF_{par}^{NM}	$120\%\ TOF_{H}^{NM}$
$\boldsymbol{TOF_2}$	TOF_{par}^{ME}	$12\ years$

Constraints:

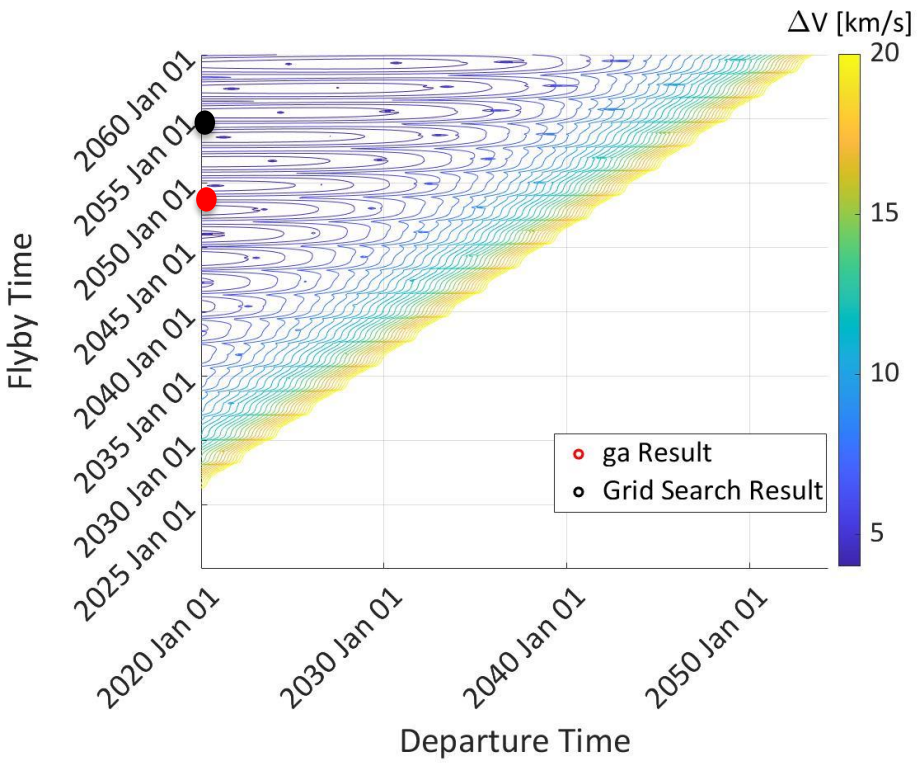
- $NDD + TOF_1 + TOF_2 < LA;$
- $r_p(NDD, TOF_1, TOF_2) > R_{Mars} + h_{min}$

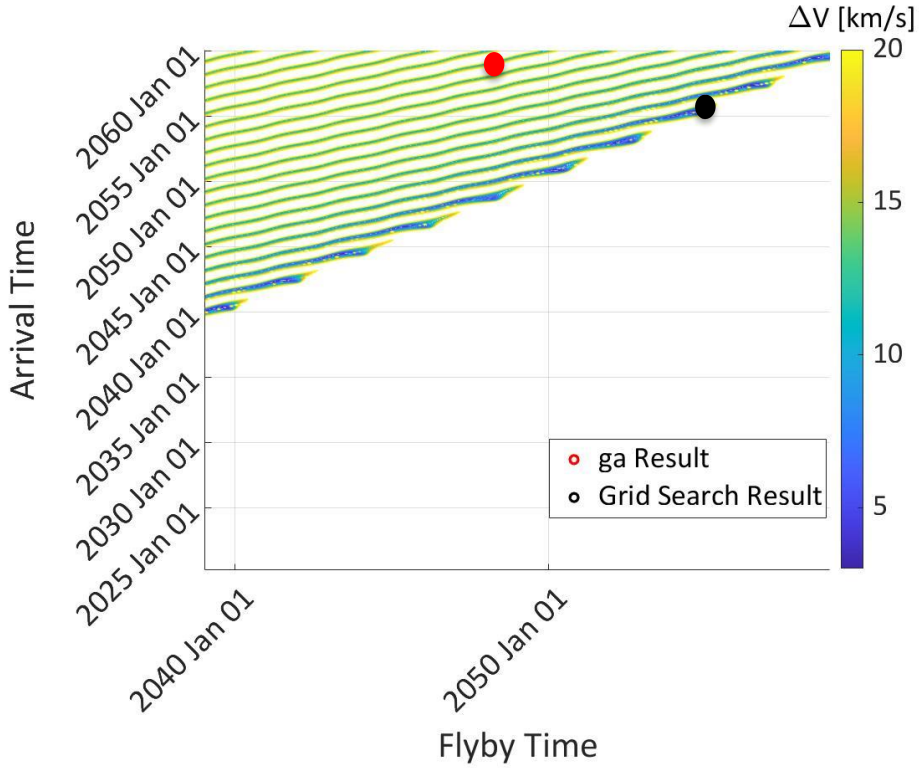
RESULTS

#	$NDD[MJD]$	$TOF_1[days]$	$TOF_2[days]$	Normalised comp. time
Grid Search	7304,50	12777	85,1	0,66
G.A.	7401,07	10257	3952	1,00

#	$\Delta v_1\ [km/s]$	$\Delta v_2\ [km/s]$	$\Delta v_3\ [km/s]$	$\Delta v_{tot}\ [km/s]$
Grid Search	4,199	0,071	12,569	16,840
G.A.	4,098	1,705	10,092	15,895

PORKCHOP PLOTS





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FINAL TRAJECTORY CHARACTERIZATION

Departure	Flyby	Arrival
2020 *April* 06 *at* 13: 40: 10,30	2048 *May* 07 *at* 13: 14: 25,53	2059 *March* 03 *at* 18: 37: 05,26

Transfer Arcs

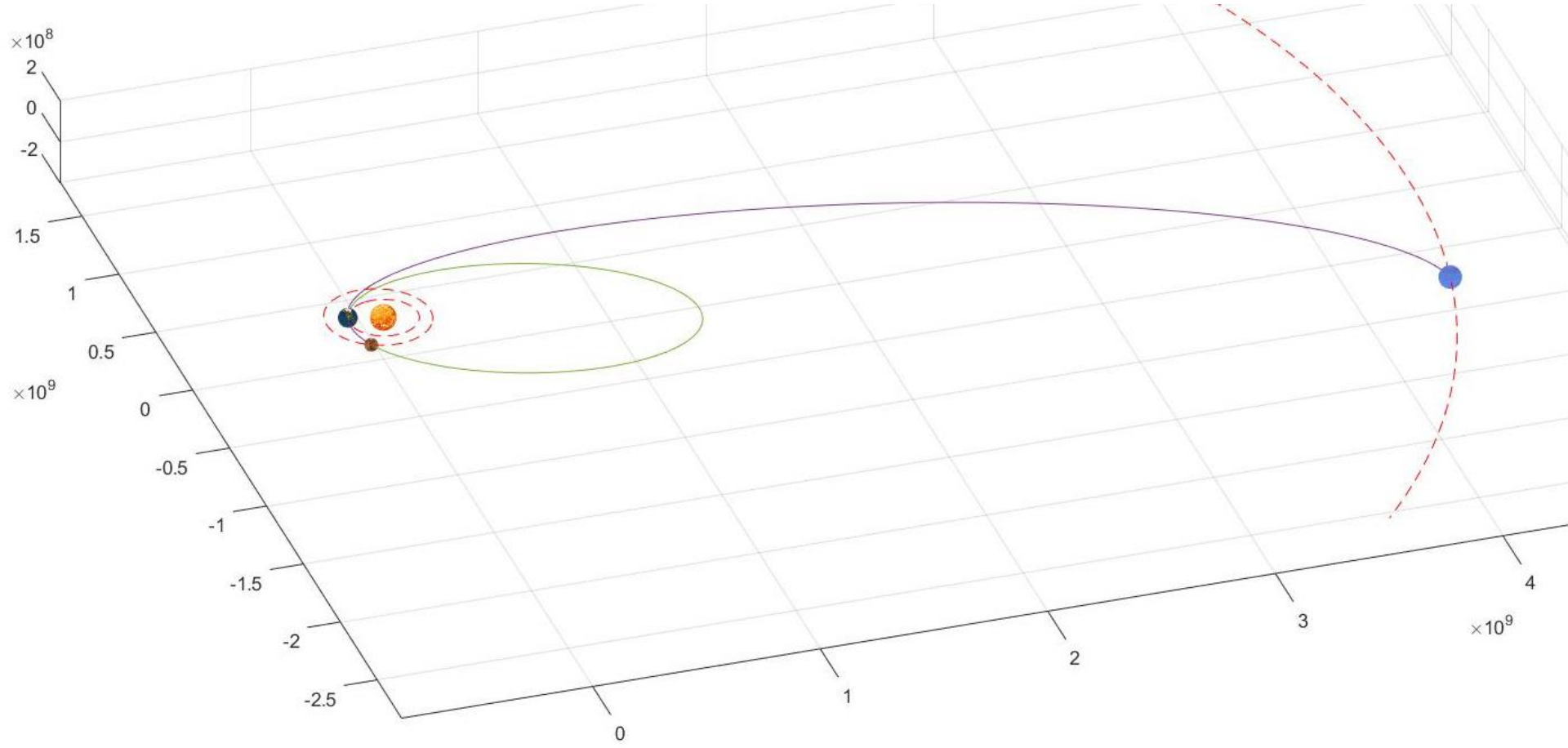
#	$a\ [km]$	$e\ [-]$	$i\ [deg]$	$\Omega\ [deg]$	$\omega\ [deg]$	$\theta_i\ [deg]$	$\theta_f\ [deg]$
Neptune - Mars	$2{,}33 * 10^9$	0,935	1,236	45,18	121,23	181,58	72,93
Mars - Earth	$7{,}42 * 10^8$	0,800	0,311	343,19	178,16	77,99	1,84

Flyby Hyperbolas

#	$h_p\ [km]$	$v_p\ [km/s]$	$v_\infty\ [km/s]$	$e\ [-]$	$TOF_f [h]$
Incoming	250,006	22,109	21,571	40,545	7,455
Outgoing	250,006	20,404	19,819	34,384	8,113

$V^- = [13{,}6593 \quad -30{,}2687 \quad -0{,}6695]'$	$V^+ = [13{,}4802 \quad -28{,}2751 \quad -0{,}1260]'$

FINAL TRAJECTORY



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DISCUSSION

- Mars not ideal for gravity assist
- Mission time/cost trade-off
- Improvement Possibilities
  - Alternate flybys
  - Earth aero-capture

Spacecraft	Flyby Planet	Planet Earth Masses	Flyby Altitude $[km]$	Δv_f $[km/s]$
Voyager	Jupiter	318	570000	16
Cassini Huygens	Venus	0,82	250	7
PoliMi	Mars	0,11	250	2*

PLANETARY EXPLORER MISSION

Initial Keplerian Elements:

$a\ [km]$	$e\ [-]$	$i\ [deg]$	$\Omega\ [deg]$	$\omega\ [deg]$	$\theta\ [deg]$
18302	0,6158	71,5679	20	70	0

Orbital Period: $6.8447\ hours$

Spacecraft Data:

- $C_d = 2.2$
- $\frac{A}{m} = 0.06$

Groundtrack repetition:

- $m = 2$
- $k = 7$

Perturbations:

- J_2
- Drag

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DRAG

Atmospheric Density

Wertz exponential model:

$$\rho(h,t) = \rho_0 \exp\left[-\frac{h-h_0}{H}\right]$$

Maximum altitude considered: $1700\ km$

- Machine epsilon cutoff

Upper atmosphere
Image from NASA

INTEGRATION METHODS

Integration in Cartesian Coordinates

$$\frac{d}{dt}\begin{Bmatrix}\vec{r}\\ \vec{v}\end{Bmatrix} = \begin{Bmatrix}\vec{v}\\ -\frac{\mu}{r^3}\vec{r} + \vec{a}_{pert}\end{Bmatrix}$$

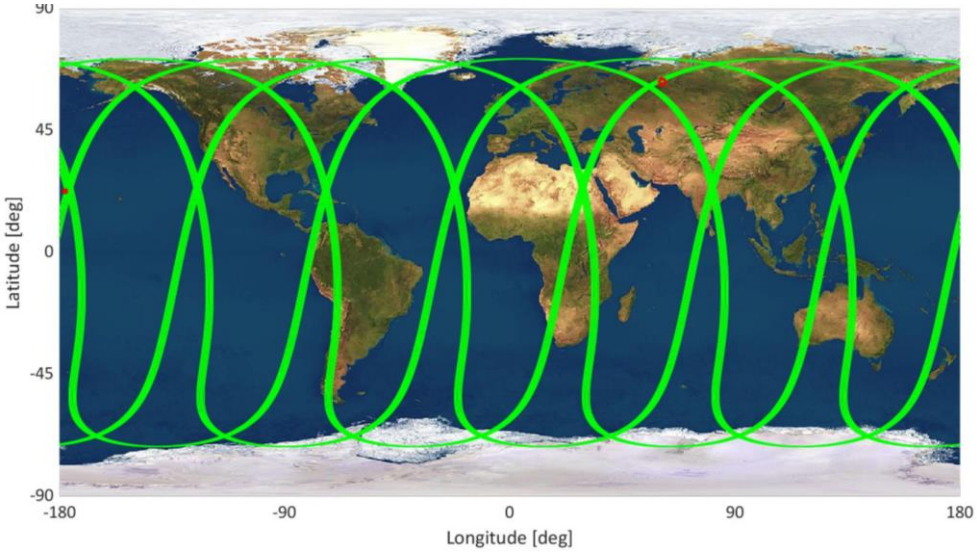
Integration of Gauss Planetary Equations

$$\frac{d}{dt}\vec{K} = f\left(\vec{K}, \vec{a}_{pert}{}^{(tnh)}\right)$$

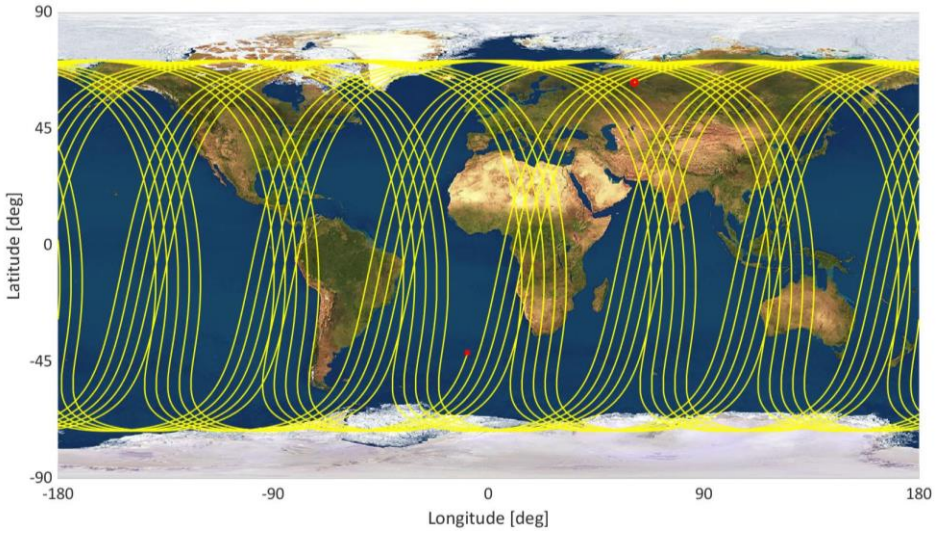
GROUND TRACK

After 10 Days

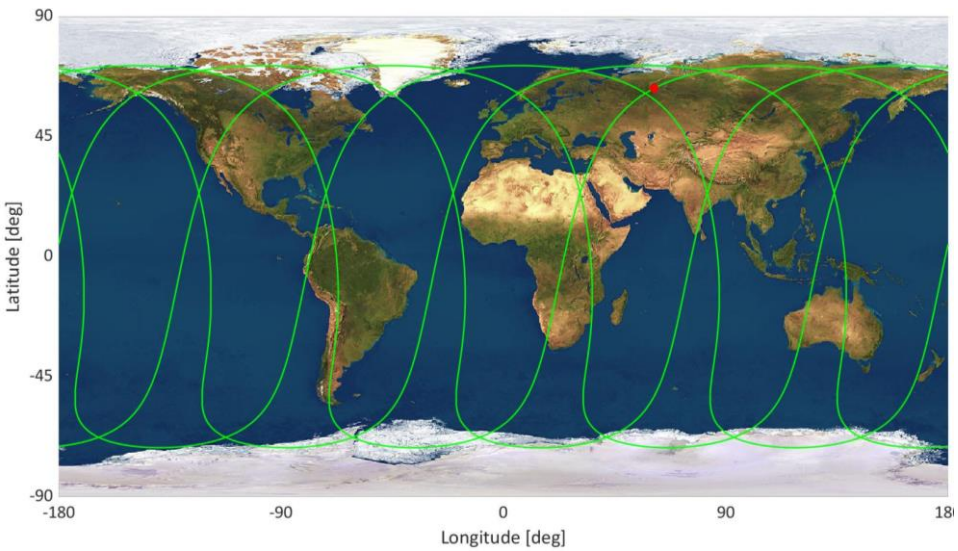
Unperturbed

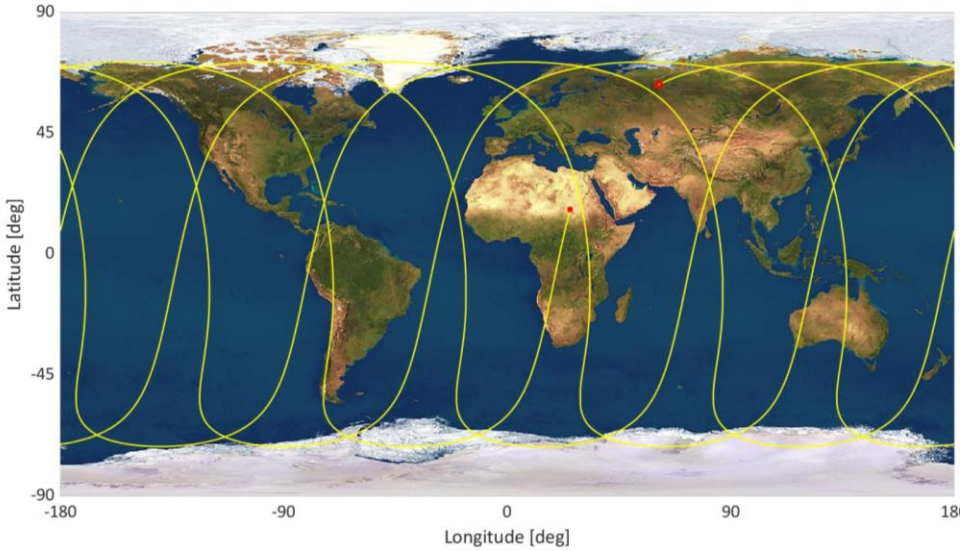


With J2 effects



REPEATING GROUND TRACK





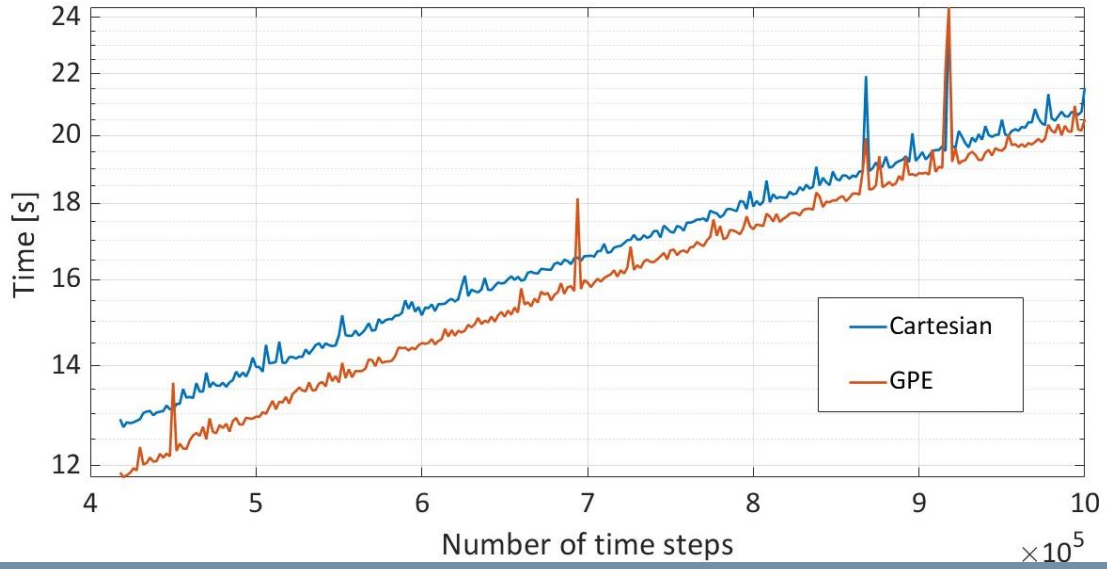
#	Original Orbit	Unperturbed orbit	J_2 perturbed orbit
$a\ [km]$	18302	18284	18290

METHOD COMPARISON

After 100 orbit, 500 sec. time steps

$a\ [km]$	$e\ [-]$	$i\ [deg]$	$\Omega\ [deg]$	$\omega\ [deg]$	$\theta\ [deg]$
$2{,}0019 \cdot 10^{-4}$	$4{,}2074 \cdot 10^{-9}$	$2{,}2819 \cdot 10^{-8}$	$4{,}7728 \cdot 10^{-8}$	$3{,}0187 \cdot 10^{-7}$	$9{,}4882 \cdot 10^{-5}$

Absolute error between Cartesian and GPE integrations



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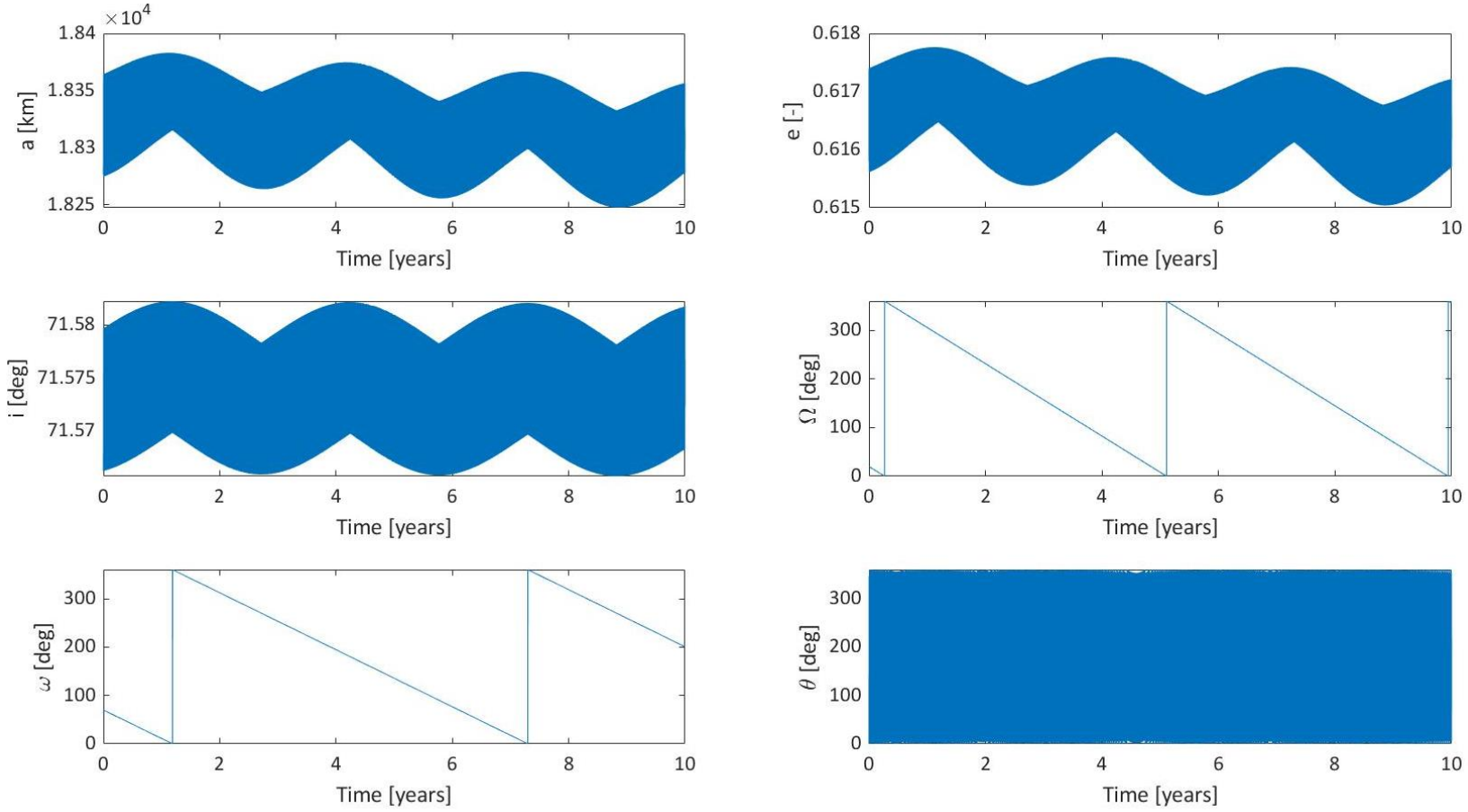
TIME EVOLUTION

10 year propogation, 500 sec. time steps



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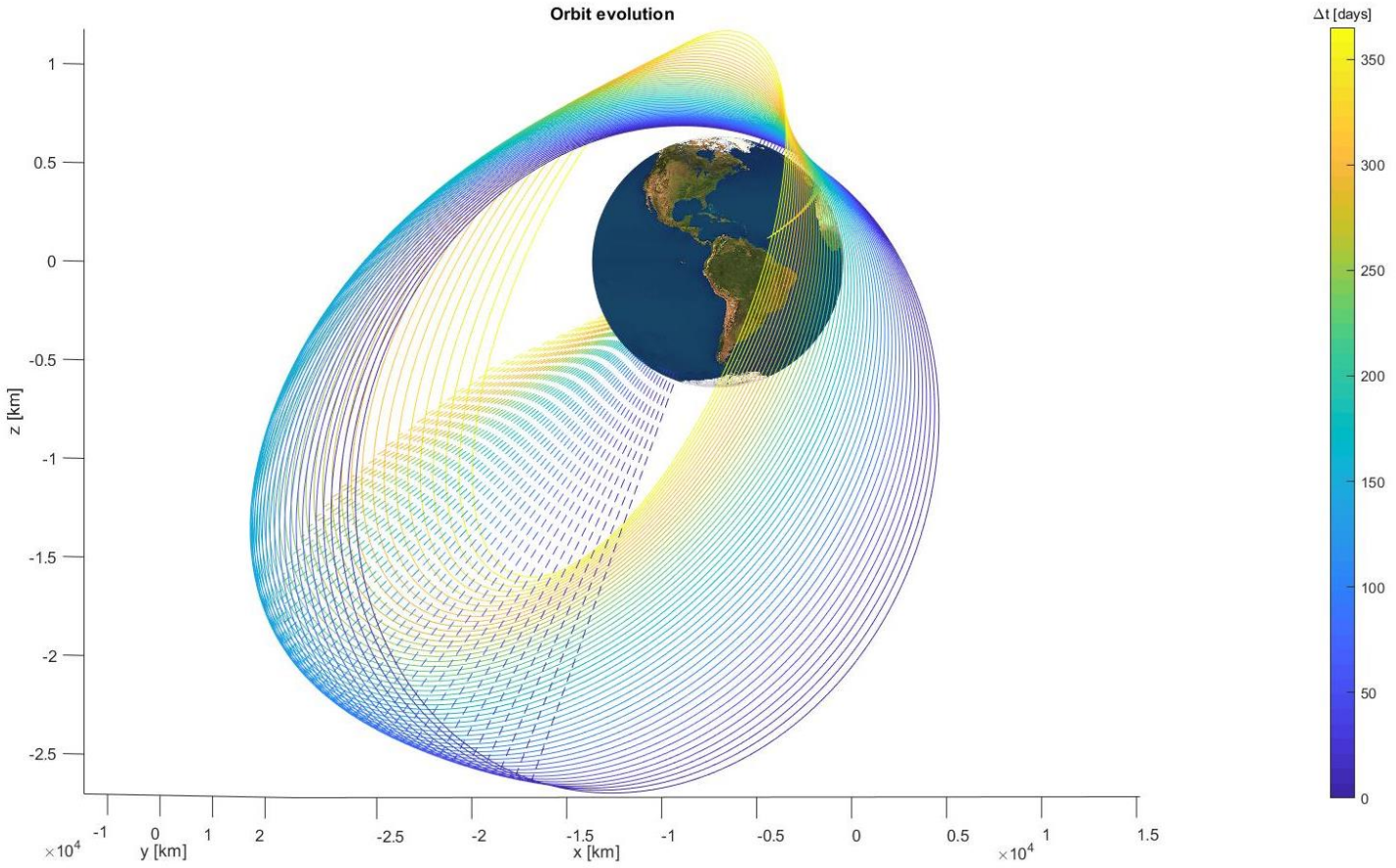
TIME EVOLUTION

1 year propogation, plotted weekly



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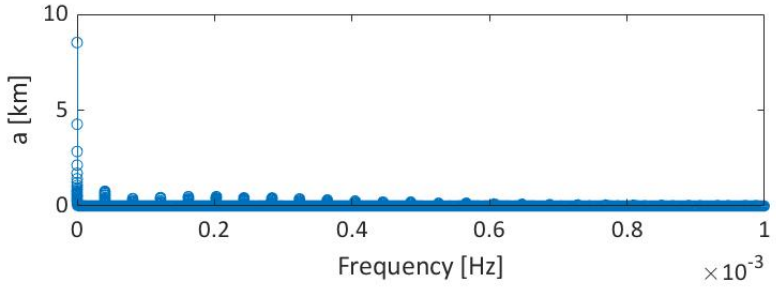
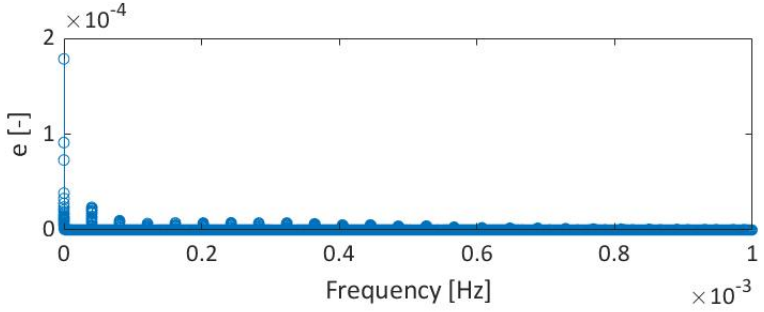
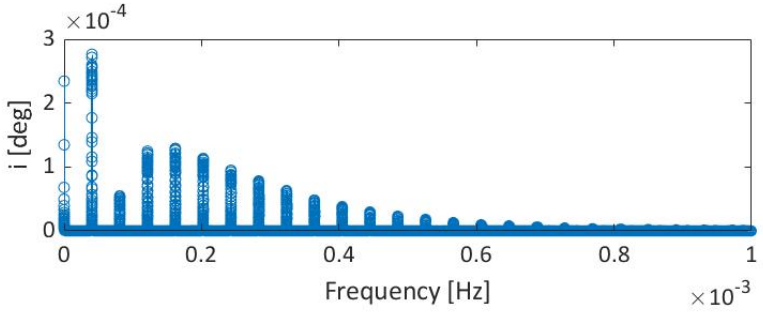
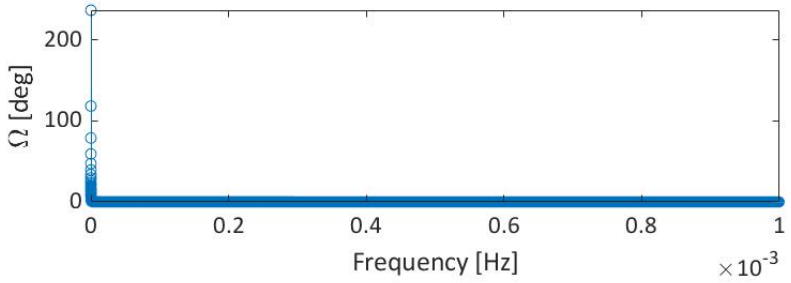
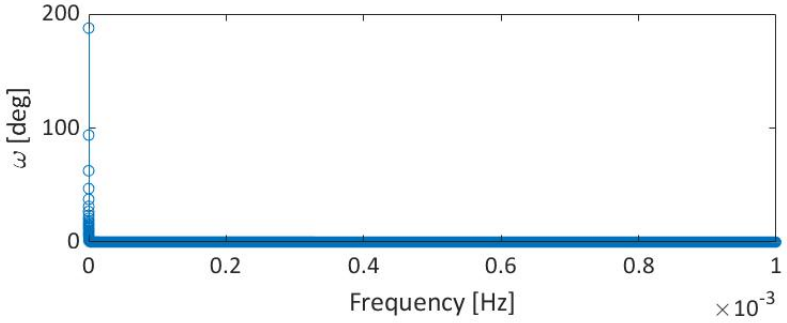
FREQUENCY ANALYSIS











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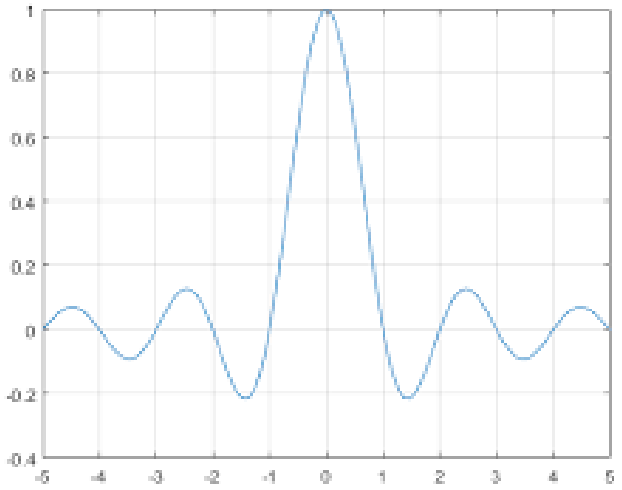
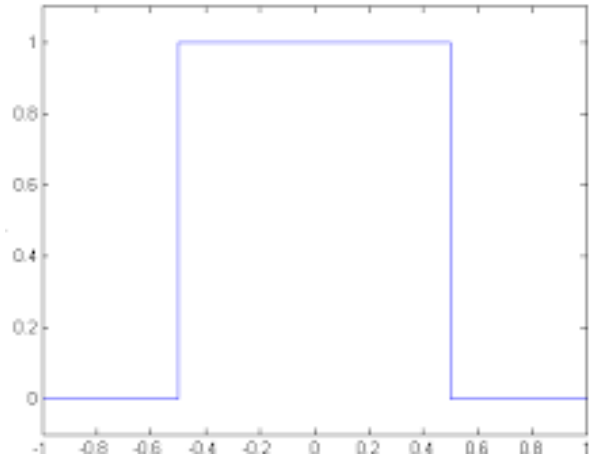
FILTERING METHODS

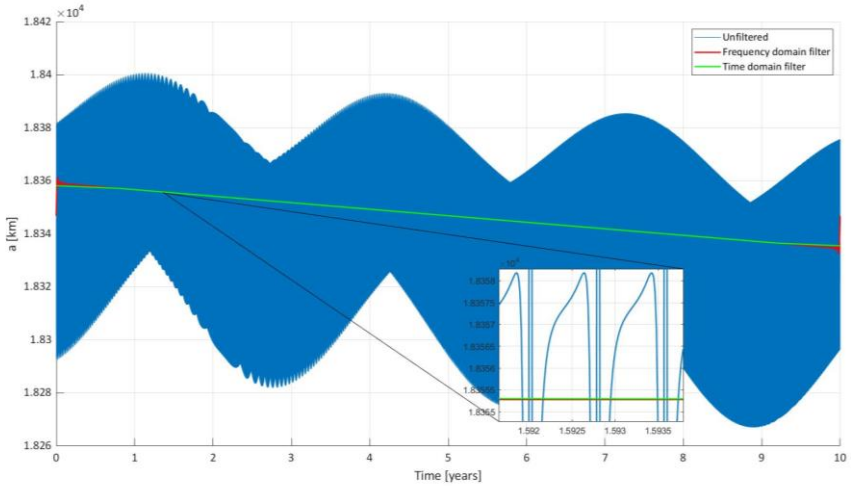
- Time domain filter
  - Centred moving mean

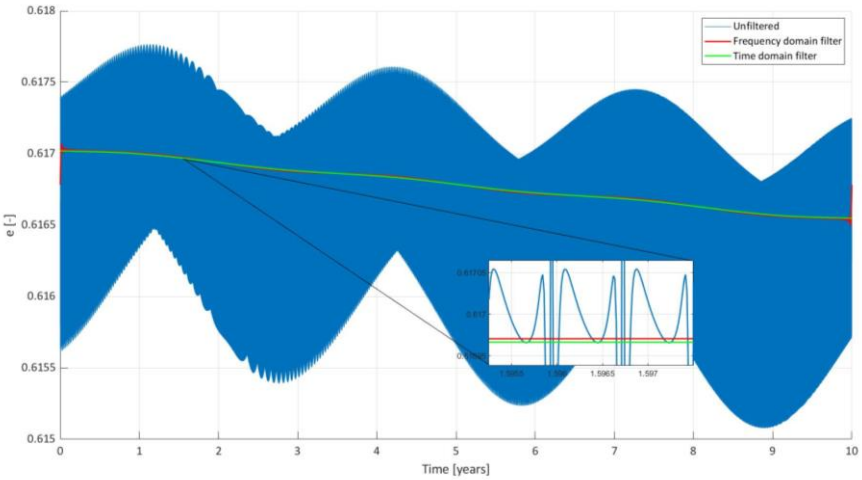


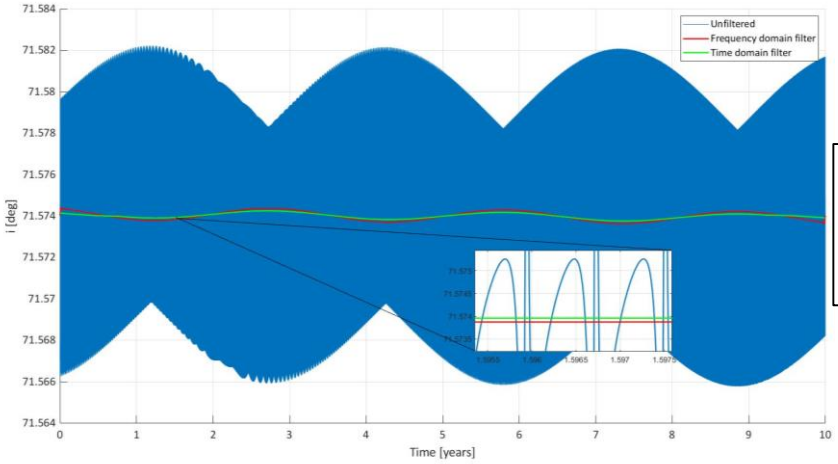
- Frequency domain filter
  - Rectangular low-pass filter



FILTERING RESULTS







Unfiltered

Frequency domain filter

Time domain filter

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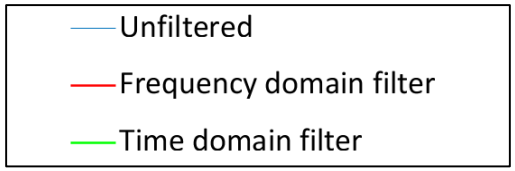
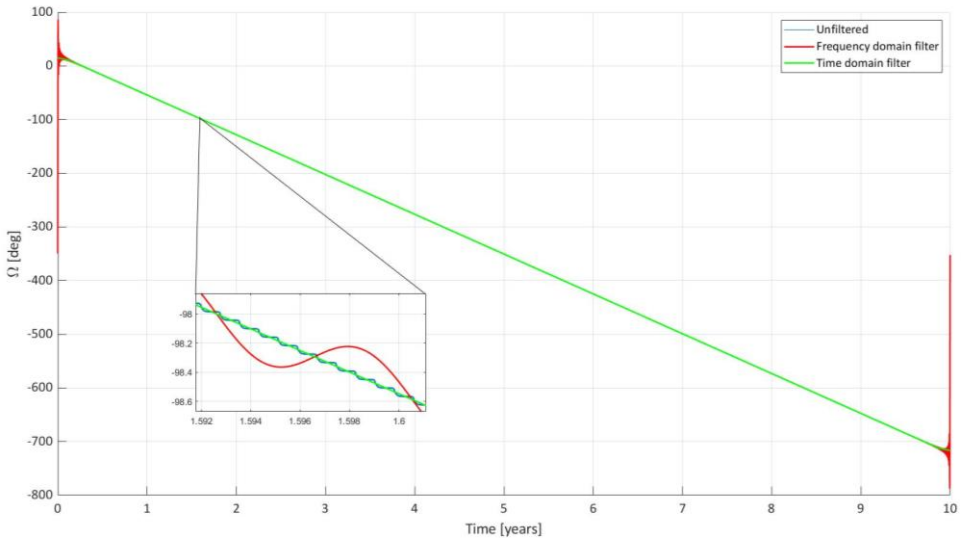
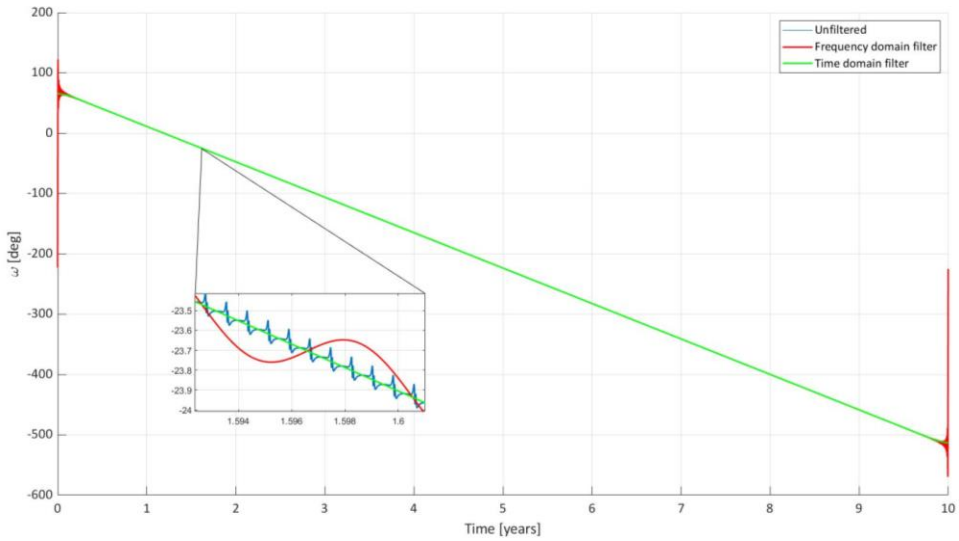
FILTERING RESULTS







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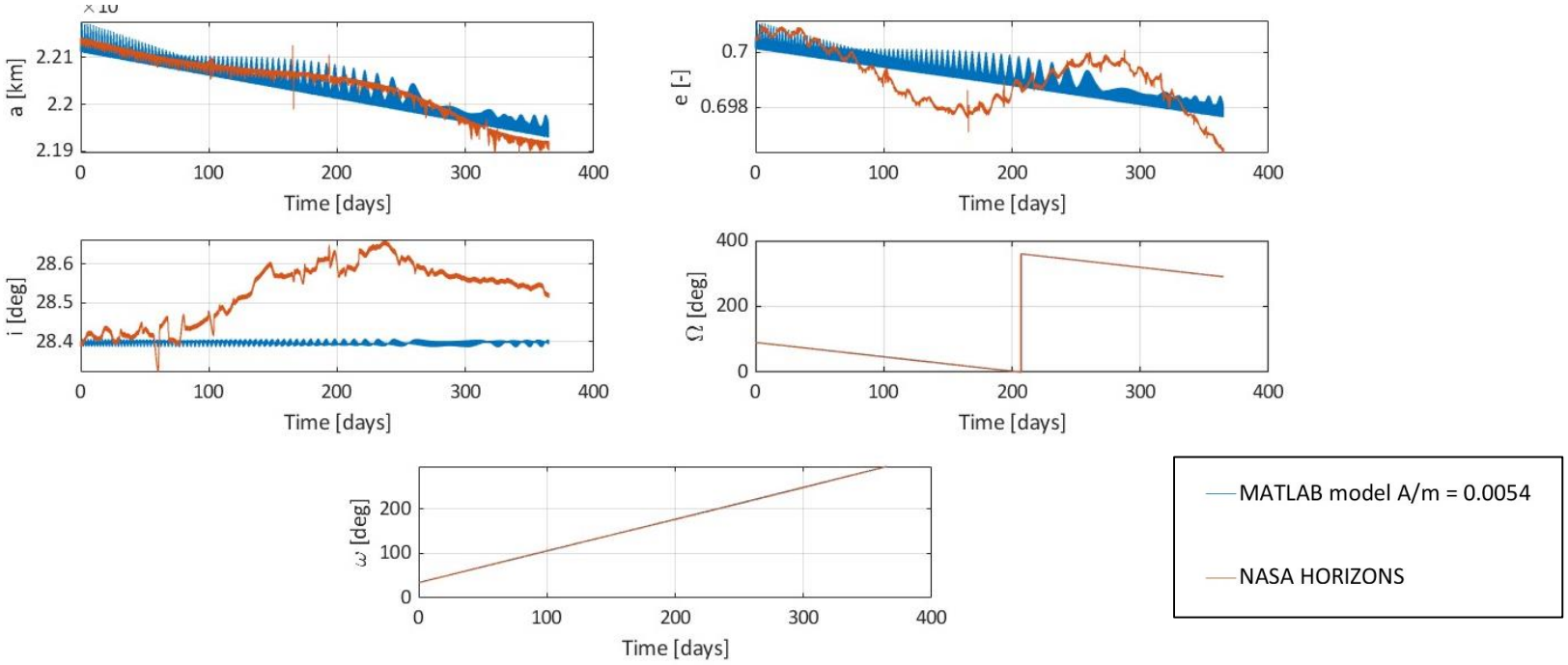
REAL SATELLITE COMPARISON

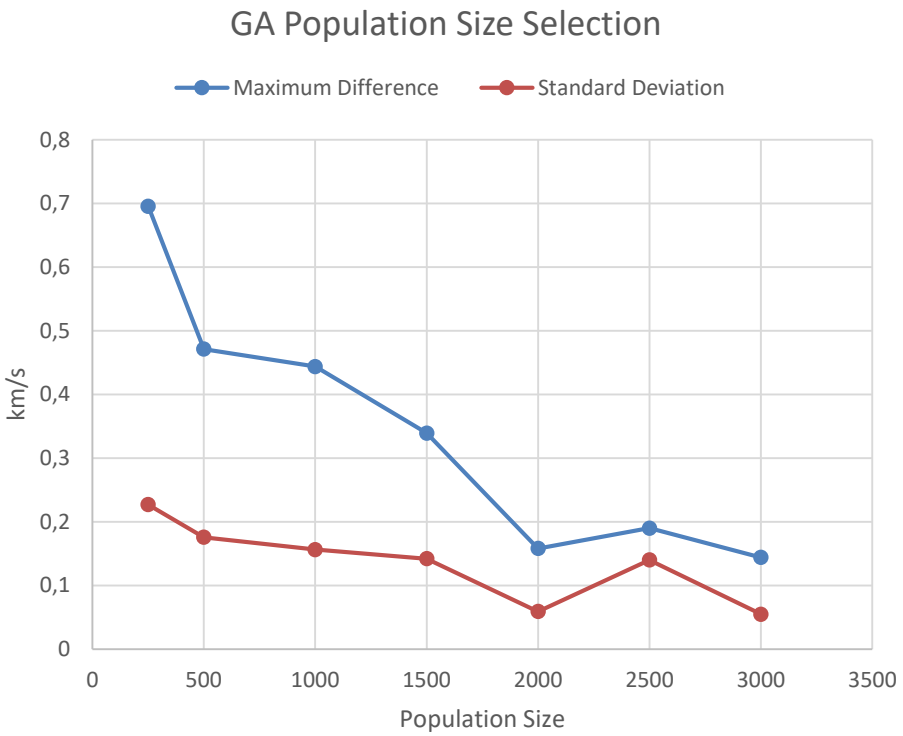
Satellite KIKU-3(ETS-IV)

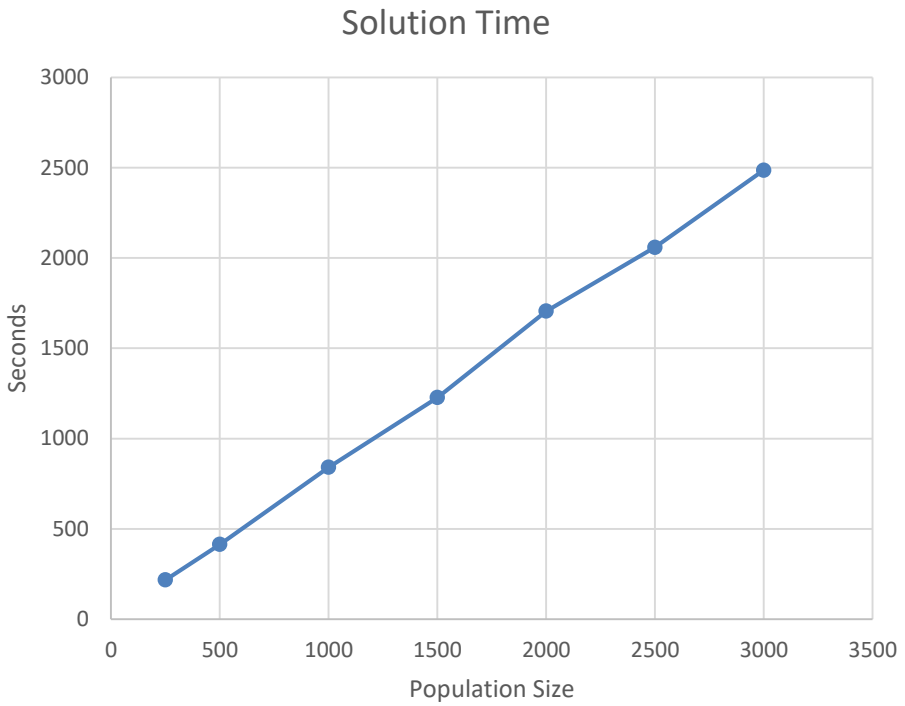
h_p	h_a	i	D	$Mass$	A/m	c_d
$225\ km$	$36000\ km$	$28{,}5°$	$2{,}1\ m$	$638\ kg$	$0{,}0054\ m^2/kg$	$2{,}2$



QUESTIONS

QUESTIONS





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