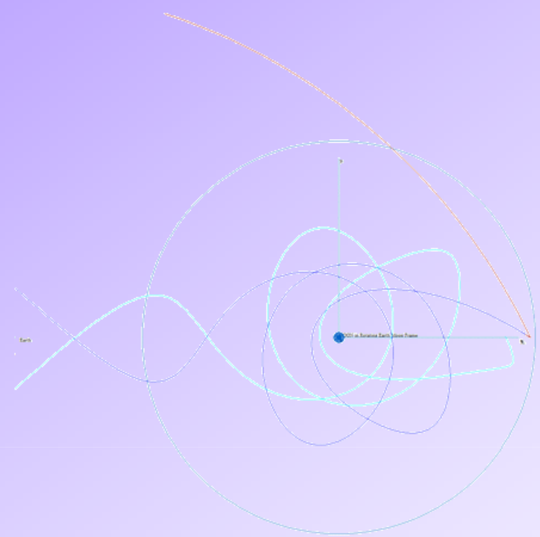
6th ICATT

Some Validation Checks of "Triaxorbital" Tool : Earth-moon L2 Orbit, Sun-moon Perturbations

Darmstadt, 14th to 17th March 2016



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Summary

- Introduction
- Modelling Tool For Orbital evolutions
- Examples of Orbital Manoeuvres
- Checks of TriaXOrbitaL: GEO case
- Powerful checks within the Earth-Moon system
- Application Earth to Moon L2
- Conclusions

1. Validation checks of TriaXOrbitaL, ICATT 6th , 14-17 March 2016, Darmstadt, Germany

Introduction

- Tools based on a more than 25 years history
- Early beginning: need to view the GPS constellation
  - TriaXOrbitaL was born with a 3 dimensional viewer relying for speediness on scalar and vector products instead of trigonometric routines.
- Need of delta-V (and losses) while thrusting during arcs
  - Integration routines with Runge-Kutta 5th order (auto adaptive time steps)
- North-South East-West station keeping maneuvers with EP
  - Integration in 3D, features dedicated for local analyses and understanding
- New tool with OpenGL libraries: 3D viewer interfaced with Excel
  - Improved for 3D Dynamic (= 4D) views
  - Fully compatible with the previous tool
- Finally, a multi-purpose tools is available for space propulsion engineers…

Modelling Tool For Orbital evolutions

- The multi-purpose tool "TriaXOrbitaL" is primarily a visualization tool
  - All outputs are shown in a three dimensional dynamic space.
  - The heart of the tool is based on the momentum equation

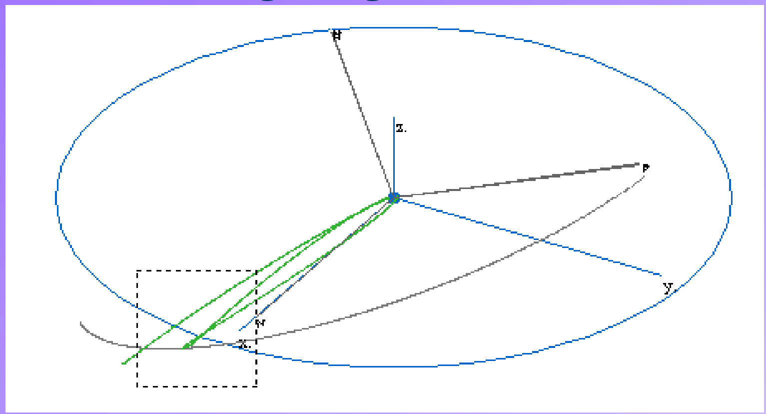
$$\frac{d\vec{\omega}}{dt} = \vec{\Omega} \qquad \vec{\omega} = \begin{pmatrix} \vec{r} \\ \vec{v} \\ m \\ t \end{pmatrix} \qquad \vec{\Omega} = \begin{pmatrix} \vec{v} \\ -GM_{focus}\,\vec{r}/r^3 + \sum\left(\vec{T}_{thrust} + \vec{P}_{perturb}\right)/m \\ \sum\left\|\vec{T}_{thrust}\right\|/(g_0.Isp) \\ 1 \end{pmatrix}$$

T_{thrust} thrust vectors
$P_{perturb}$ optional perturbing forces vectors coming from
- other bodies (Moon, Sun, etc.)
- from sun pressure
- from non-spherical potential terms (J2, equatorial ellipticity)

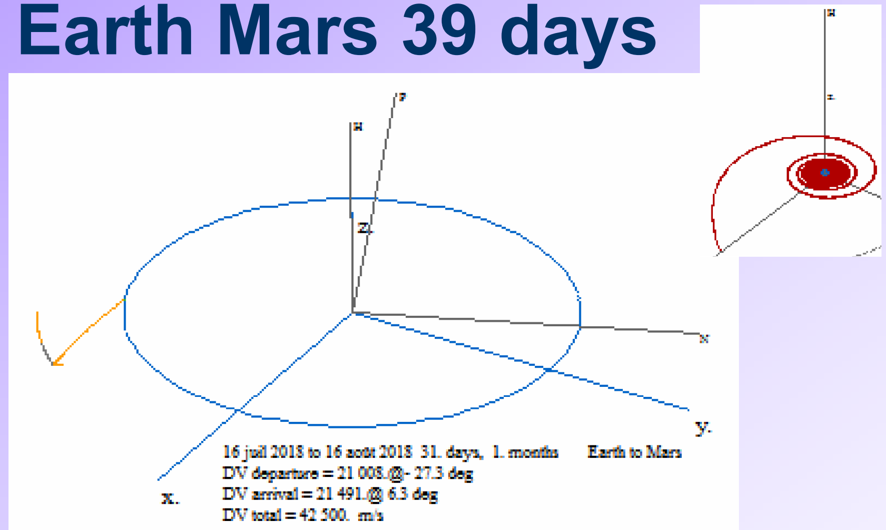
  - Yes, the time is also integrated: for some checks and simple RK
- Because the perturbation forces allows gravity of celestial bodies
  - The general equation allows trajectories/maneuvers between planets

Examples of Orbital Manoeuvres

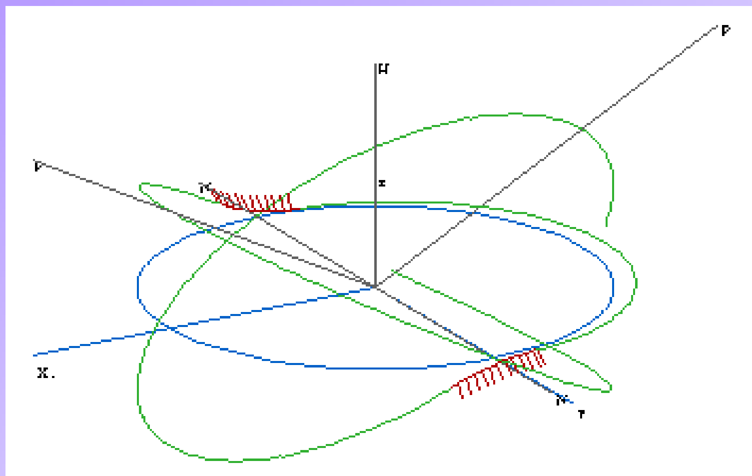
Moon fly-by (Apollo 11 back-up)



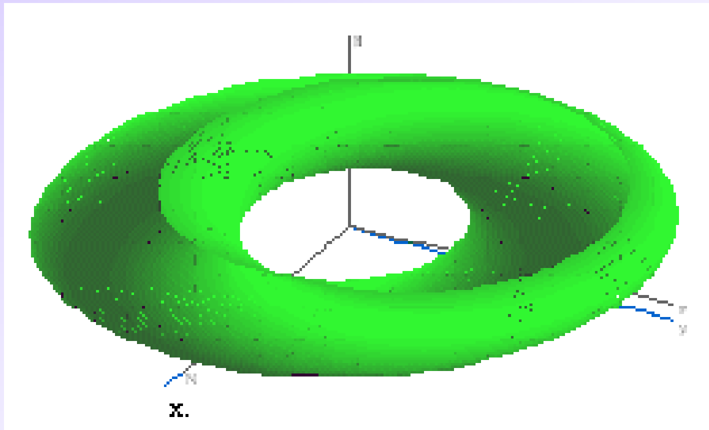
Earth Mars 39 days



NSSK with EP



Sun pressure perturbation



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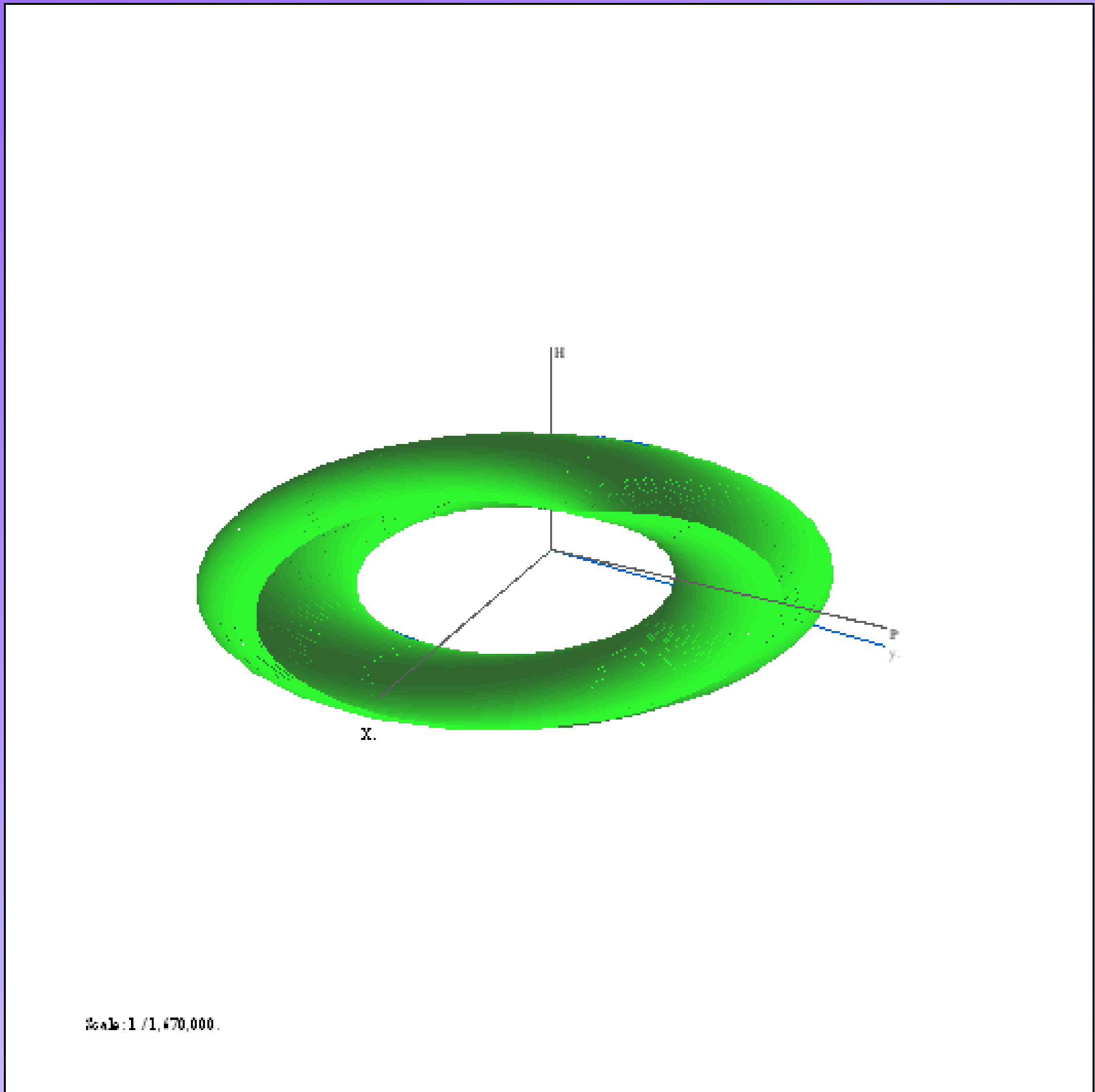
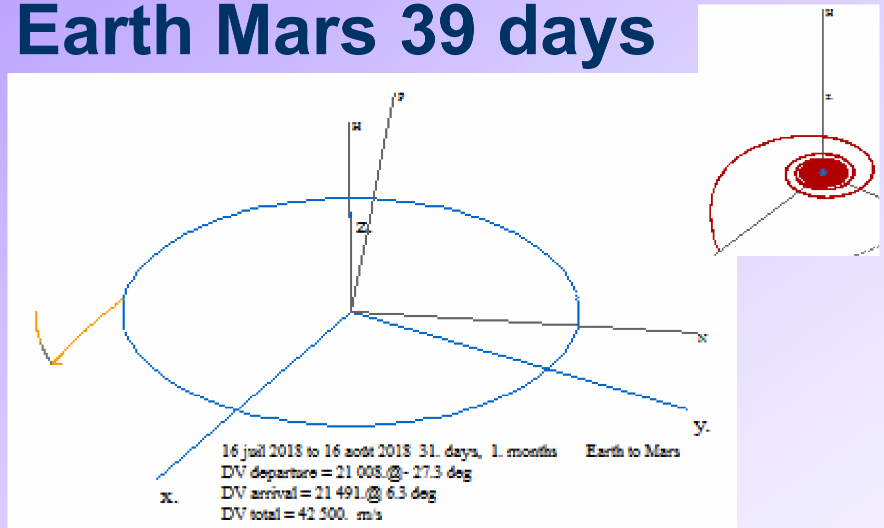
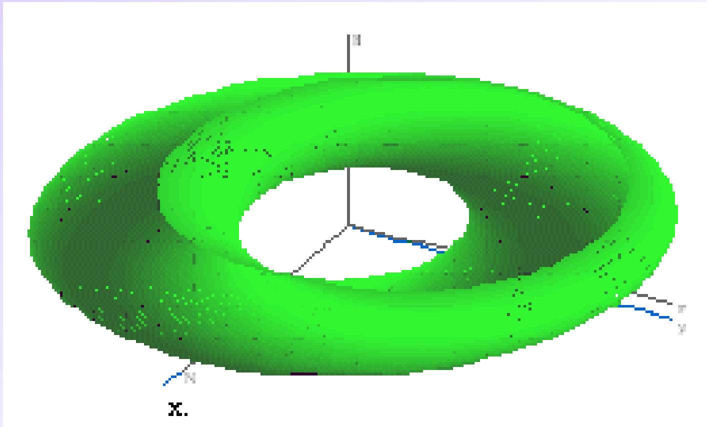
Examples of Orbital Manoeuvres



- Earth Mars 39 days

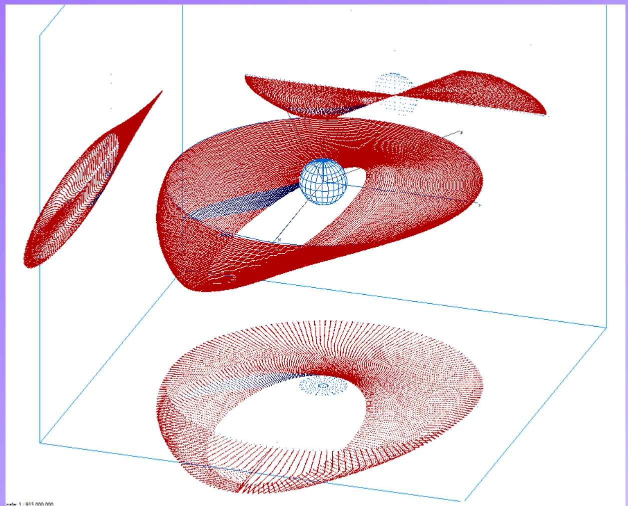


- Sun pressure perturbation



Examples of Orbital Manoeuvres

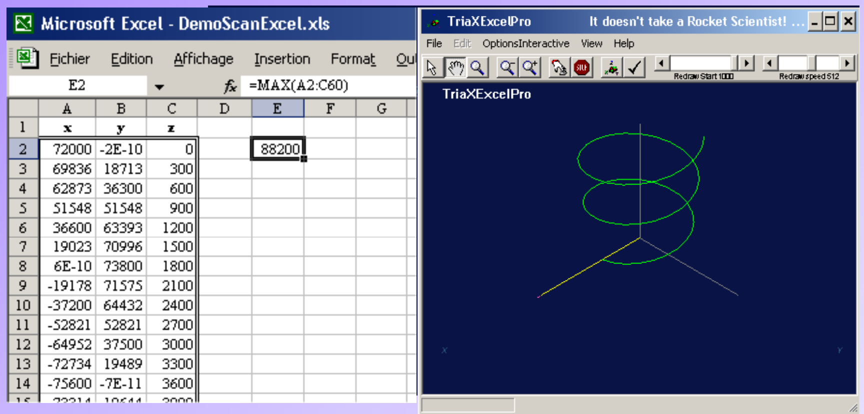
- **Continuous Thrust to GEO** with eclipses



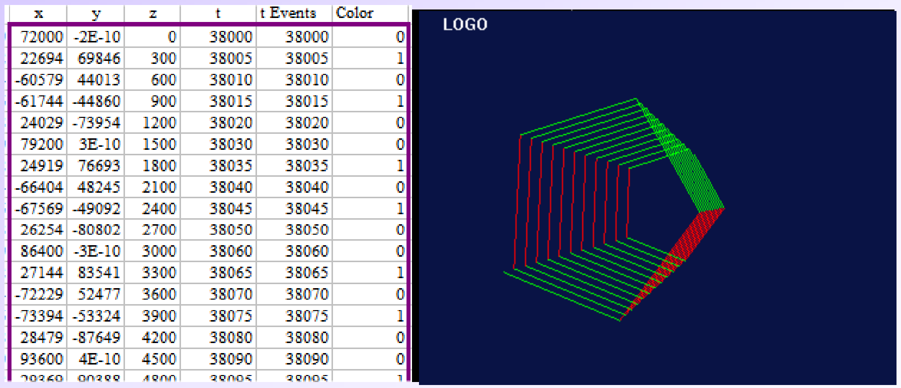
- **Synthesis of the modelling with "TriaXOrbitaL"**
  - **Non limited range of applications**
  - **Adapted to multi-purpose studies**
  - **Many improvements can be added: more fly-by, more useful input data, more traceability up to a** "self sustainable traceability"

A 3D, 3DD=4D multi-purpose Viewer tool for Excel

- User-friendly engineering tool : based on an Excel sheet
- Without any add-in, without link with Excel: totally independent
- More than a 3D viewer because it includes
  - Reactions to time events
  - Sun light, planets can be included
  - NED frames (North, East, Down)
- Examples



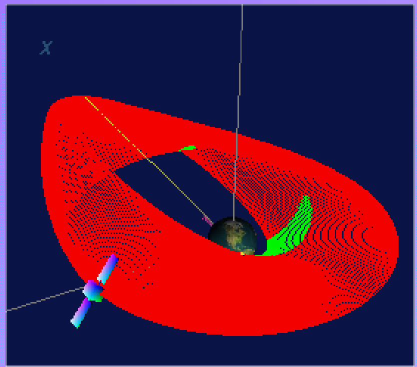
	A	B	C
1	x	y	z
2	72000	-2E-10	0
3	69836	18713	300
4	62873	36300	600
5	51548	51548	900
6	36600	63393	1200
7	19023	70996	1500
8	6E-10	73800	1800
9	-19178	71575	2100
10	-37200	64432	2400
11	-52821	52821	2700
12	-64952	37500	3000
13	-72734	19489	3300
14	-75600	-7E-11	3600



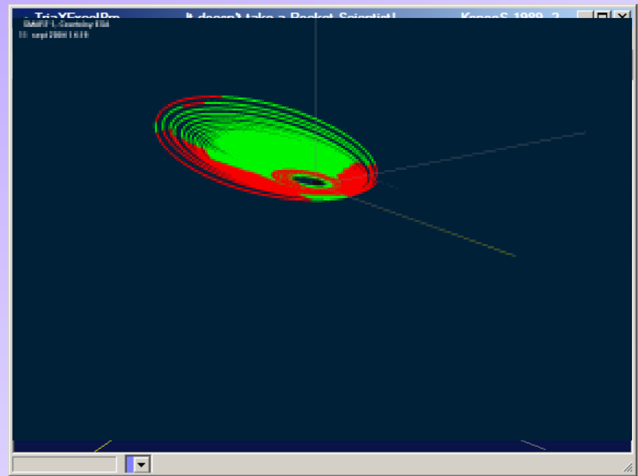
x	y	z	t	t Events	Color
72000	-2E-10	0	38000	38000	0
22694	69846	300	38005	38005	1
-60579	44013	600	38010	38010	0
-61744	-44860	900	38015	38015	1
24029	-73954	1200	38020	38020	0
79200	3E-10	1500	38030	38030	0
24919	76693	1800	38035	38035	1
-66404	48245	2100	38040	38040	0
-67569	-49092	2400	38045	38045	1
26254	-80802	2700	38050	38050	0
86400	-3E-10	3000	38060	38060	0
27144	83541	3300	38065	38065	1
-72229	52477	3600	38070	38070	0
-73394	-53324	3900	38075	38075	1
28479	-87649	4200	38080	38080	0
93600	4E-10	4500	38090	38090	0

A 3DD Viewer with Excel interface : Examples

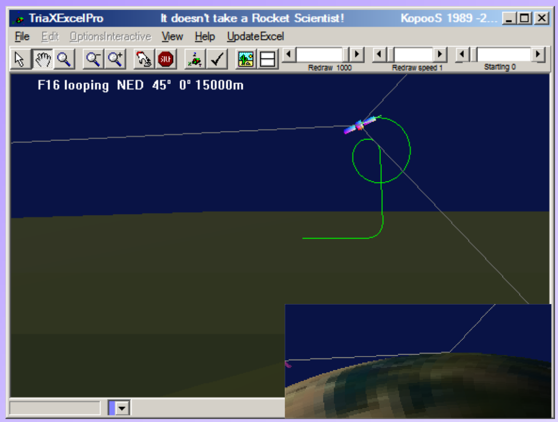
- **Continuous Thrust to GEO**
  TriaXOrbitaL report => Excel => 3DD



- **SMART-1 in flight Trajectory**
  DDS Esoc=>Excel=>3DD



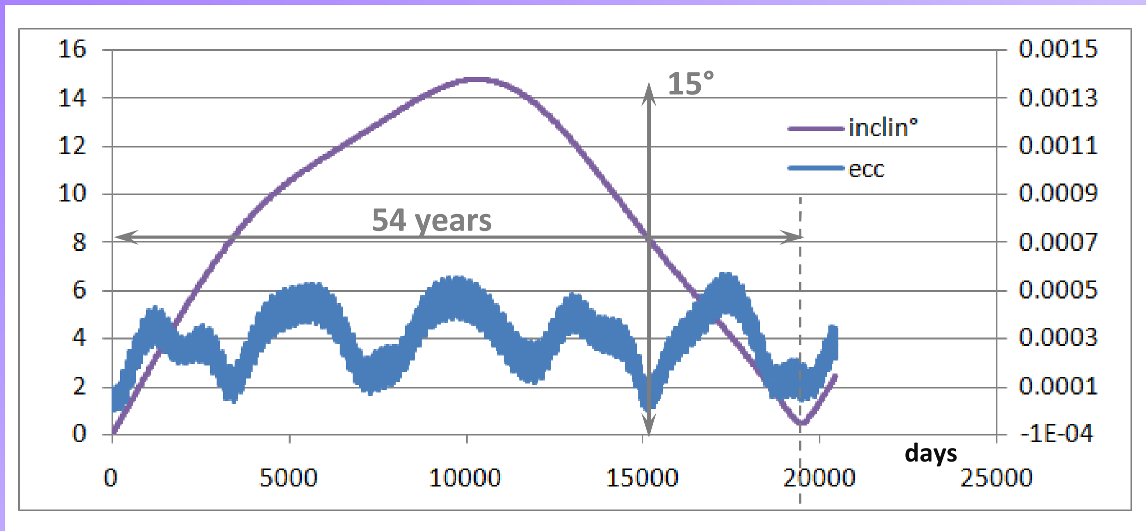
- **F16 looping**
  EcosimPro=>Excel=> 3DD

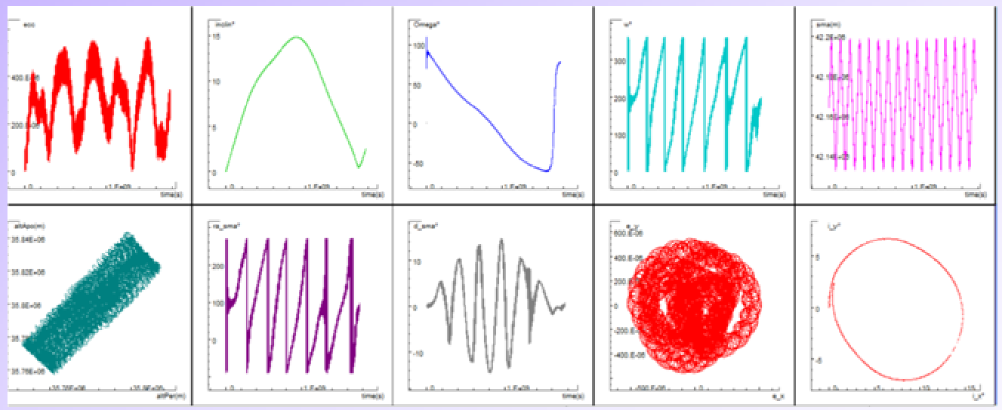


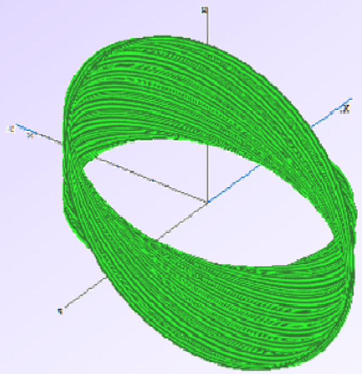
- **Synthesis: "TriaXExcelPro" a tool improving Excel**
  - **3DD much more than a simple 3D viewer**
- **Many improvements can be still added to the tool**
  - **Adding automatically much more bodies**
  - **Adding airplanes objects with their texture**
  - **Setting up other point of views.**

Checks of TriaXOrbitaL: GEO case

- A very well known behaviour of the GEO is the evolution of a free spacecraft under perturbations occurring from Moon, Sun and Earth flatness.
- Those induce the inclination to change and to culminate at 15 ° in a cycle of 54 years







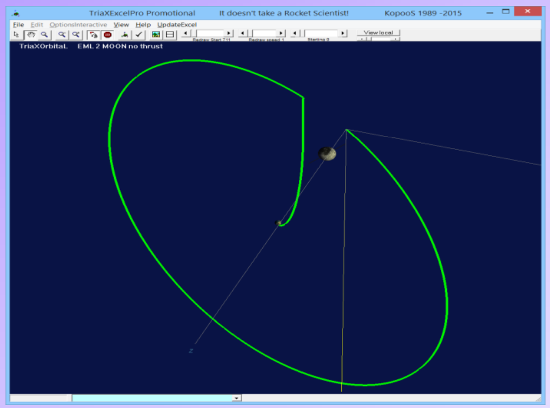
- Confirmed in 1 h.

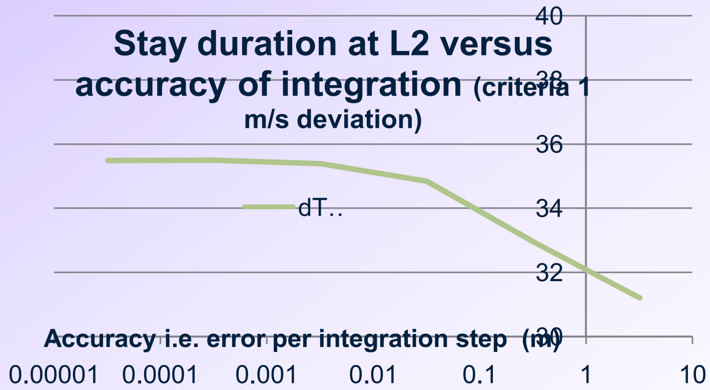
Powerful checks within the Earth-Moon system

- **TriaXOrbital is fully featured with the possibility to make the Moon orbit real (using Bouiges formulae) or circular.**
  - This last case enable simulations in the so called CR3BP (circular restricted 3 body problem.
- **TriaXOrbitaL is not using any special frame in barycentric rotating coordinates for the integration of the dynamic equations**
  - neither any normalization, neither backward time integration This is contrast with most of other tools in CR3BP
  - For Earth-Moon trajectories, TriaXOrbitaL is integrating forward time with respect the Earth in Centered Inertial frame (ECI) with of course the full perturbations from the Moon.
  - Hence important to show that the results from TriaXOrbitaL do not provide any deviation with respect to some known results

First relevant check: Stability at L2

- It is well known that once the spacecraft is placed at L2 with the same velocity of L2 wrt Earth,
  - it must stay there indefinitely (CR3BP, no perturbations).
- Such test has been performed
  - First a two impulses Transfer Trajectory is performed (Farquhar).
  - Then a delta V at L2 is added to the spacecraft for staying at L2.
  - But because L2 is unstable, the spacecraft is ejected from L2
  - Ejection in about 1 month (depends slightly on accuracy chosen)





  - Check OK

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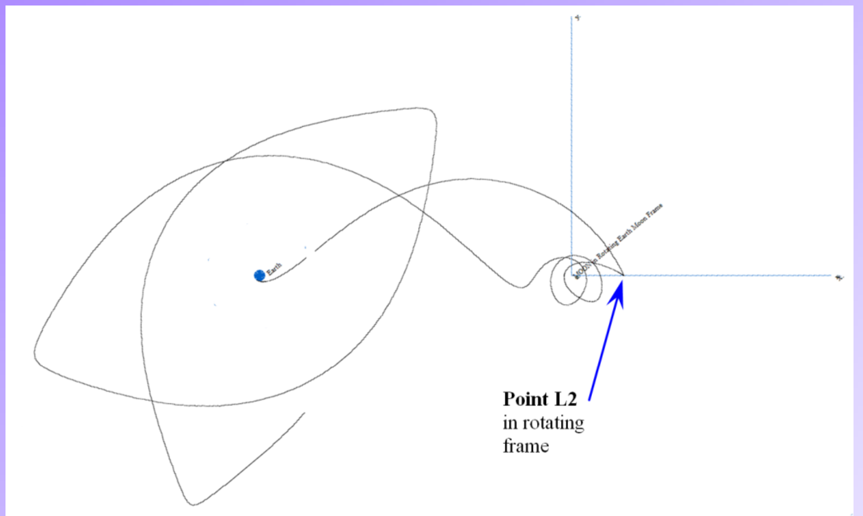
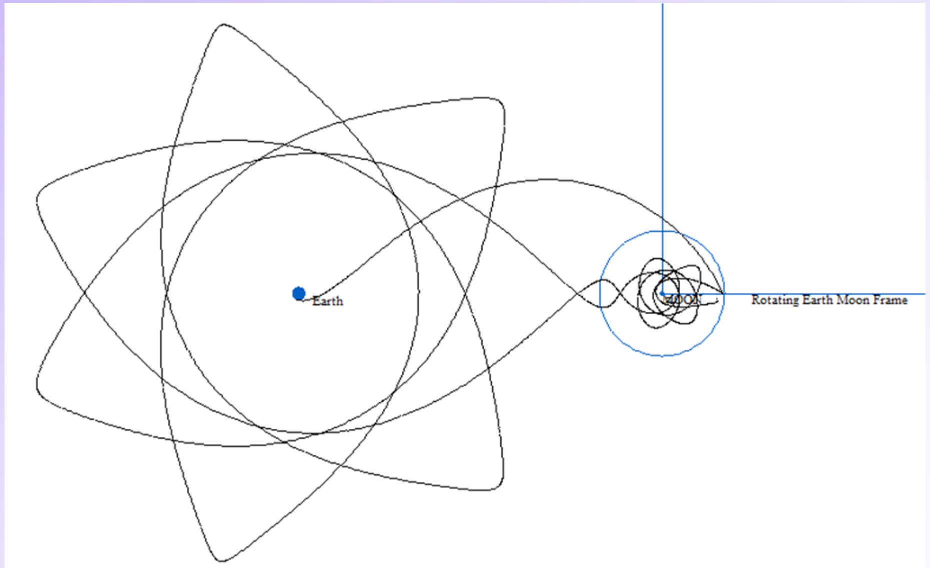
Second relevant check: Unstable manifold from L2

- **It is well known that once the spacecraft L2 is unstable**
  - **A spacecraft follows the unstable manifold (CR3BP).**
- **Such test has been performed nd compared with ref.**
  - **Natural perturbations due to integration errors provides indeed systematically the same trajectory out of L2**

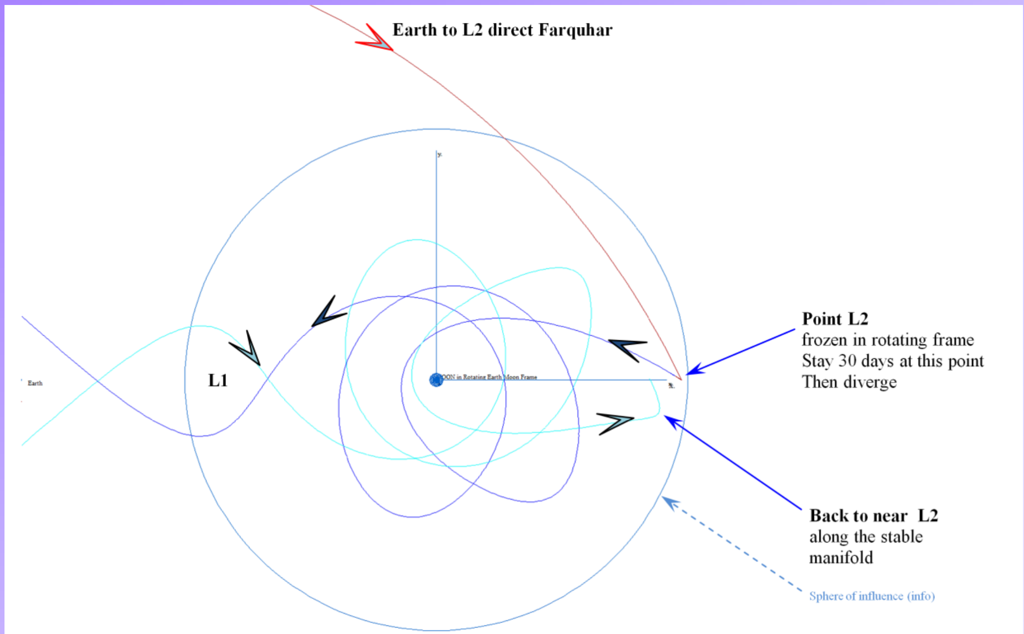


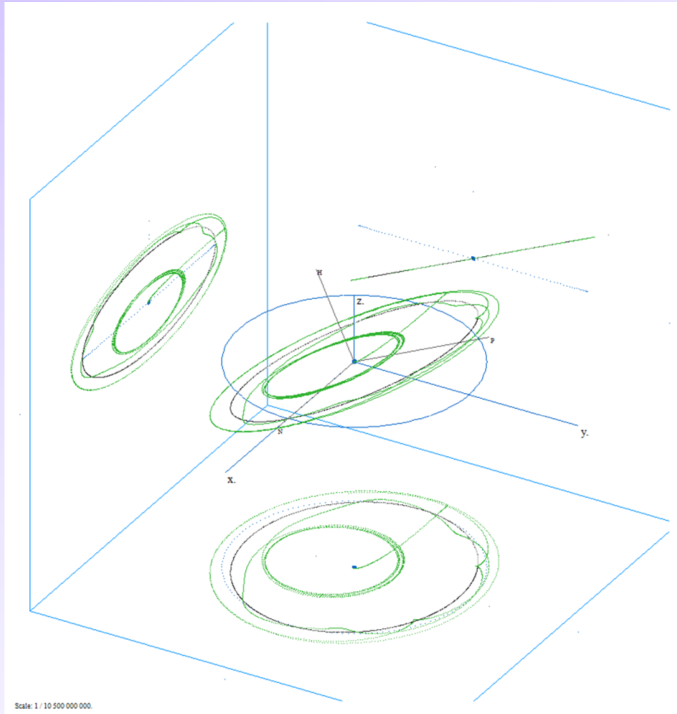


  - **Check OK**

Application Earth to Moon L2

- The last check exhibits some specific star shapes
  - From L2 to L1 neck and before going back again to near L2 through proximity with L1 neck
  - Actually 6 "elliptic orbits" around the Earth: same inclination as the Moon, similar perigee 125 000 km and apogee 290 000 km.





  - Such orbits are very well suited for EP

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Conclusion

- The paper has presented in simple words the tool TriaXOrbitaL.
  - The major checks performed with the tool can give a good confidence in the results of the simulations.
- Several interesting applications of the tool have been presented
  - those make the single tool a multipurpose tool for orbit evolution problems with or without thrust.
- The last application presented shows that this simple tool allows to simulate quite complex problems sometimes better known in the rotating synodic frame
  - but with the capability for the user to understand what happens in more conventional inertial frame.
  - The output of a free orbit transfer from elliptical orbit around the Earth to the point L2 seems to be valuable for the Electric propulsion.
- The tool TriaXOrbitaL "as is" is freely distributed.

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Thanks for your attention

Questions?

Ackowledgments

- The research leading to these results is a KopooS funding