

MEO Satellite Dynamics

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Acknowledgments

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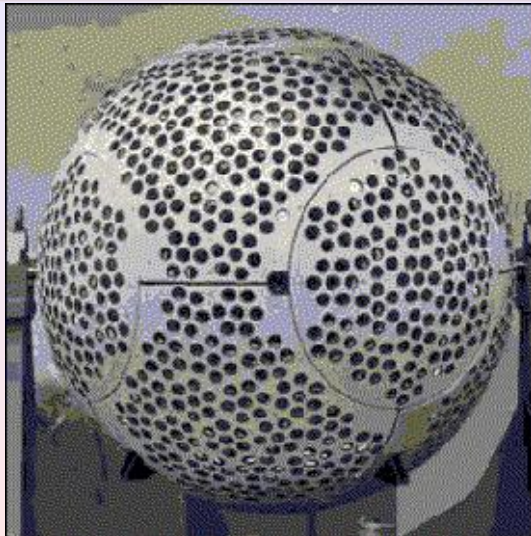
Agenda

- 1 Long term evolution of objects in GLONASS-like orbits
 - Orbital evolution
 - Orbital propagation
 - Orbital region survey
- 2 Conclusions

Orbital evolution MEO - ETALON

Etalon 1 and 2 are identical geodetic passive satellites of Russia (former USSR), for satellite laser ranging. They are spheres with diameter = 1.294 m, mass = 1415 kg. Etalon-1 and Etalon-2 were launched in 1989 in GLONASS-like orbits:

- 1 **E-1**: $a = 25\,498$ km,
 $e = 0.00061$, $i = 64.9^\circ$
- 2 **E-2**: $a = 25\,498$ km,
 $e = 0.00066$, $i = 65.5^\circ$



Orbital evolution MEO - ETALON

- The Etalon satellites are ideal test bodies to study the perturbations affecting the long term evolution of the navigation satellite orbits
- The Etalon satellites are ideal bodies to test the accuracy of the orbital propagators.
- The Tuned Inter-Range Vectors (TIRV) are state vectors of the Etalon satellites used to track them by the Laser stations.
- The accuracy of the TIRVs is about 1 m.
- ASI (Matera Station) provided also one year (2004) of fitted orbits with weighted RMS of a few cm.

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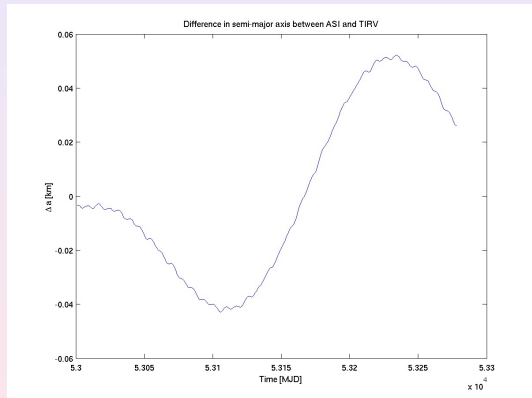
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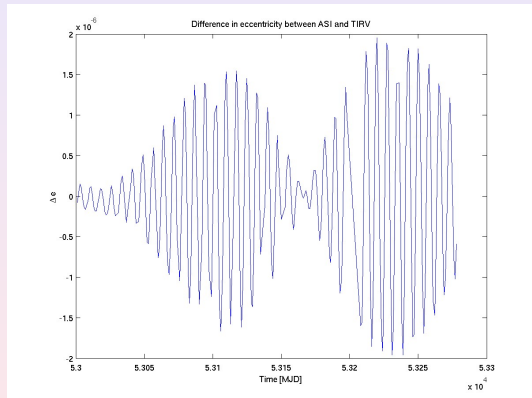
ASI vs. TIRV

The difference between the precise orbits and the TIRV elements is within a few tens of meters in a and a few parts in 10^{-6} in e .

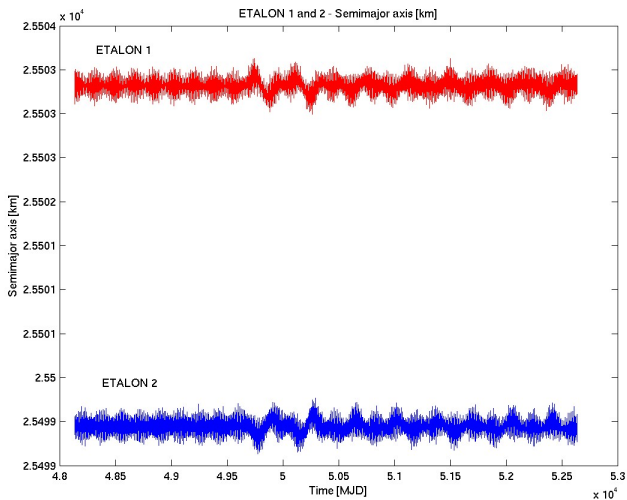


ASI vs. TIRV

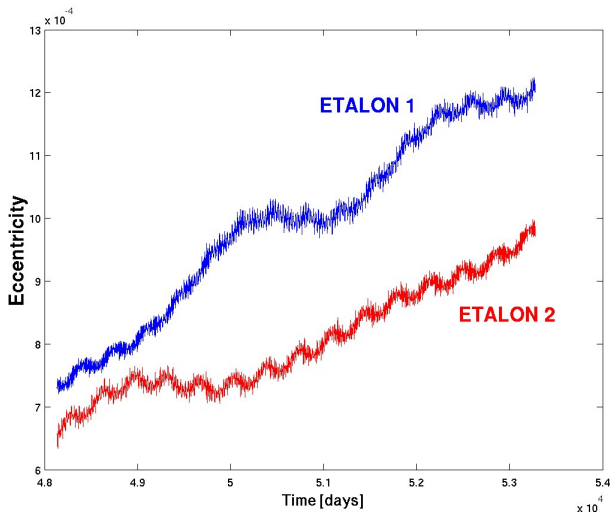
The difference between the precise orbits and the TIRV elements is within a few tens of meters in a and a few parts in 10^{-6} in $e \Rightarrow$ **use of TIRV correct for the study.**



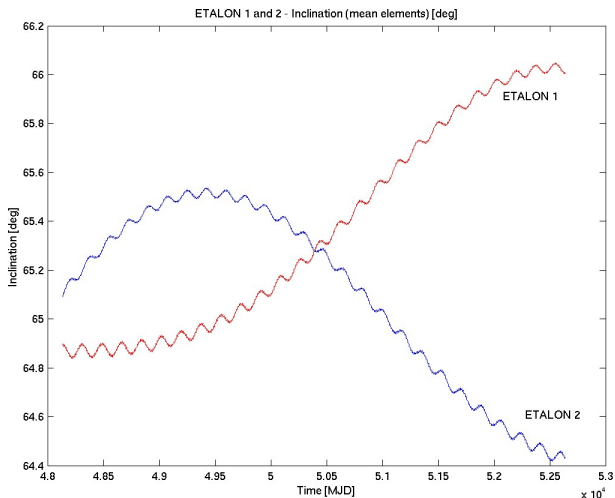
ETALONs orbital evolution from TIRVs- Semiaxis



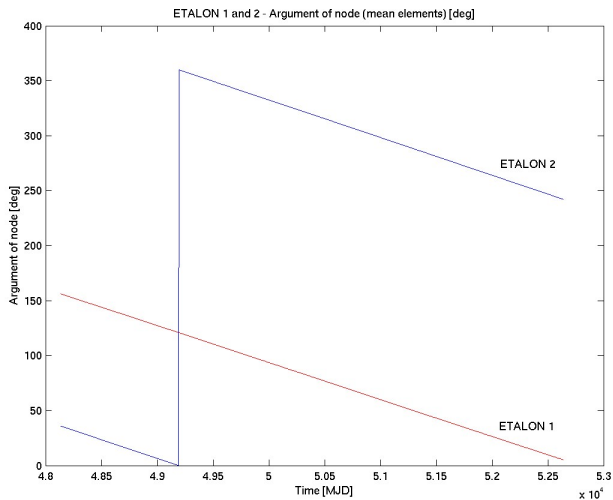
ETALONs orbital evolution from TIRVs - Eccentricity



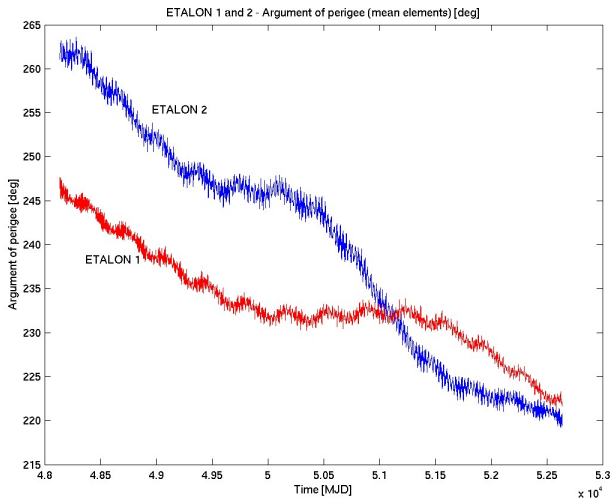
ETALONS orbital evolution from TIRVs - Inclination



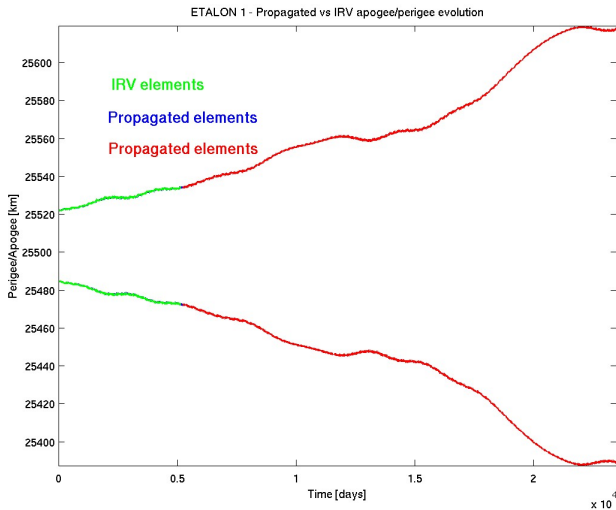
ETALONS orbital evolution from TIRVs - Node



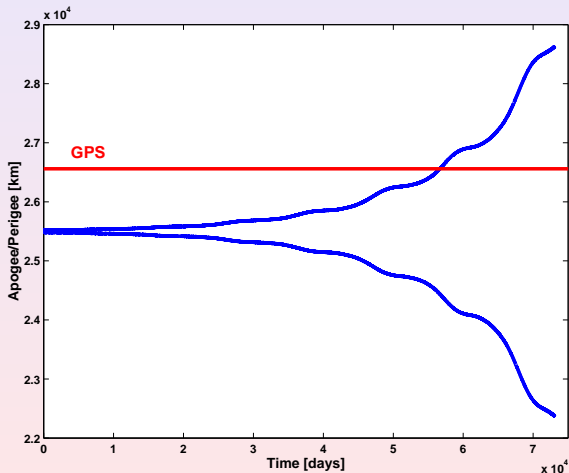
ETALONS orbital evolution from TIRVs - Node



TIRV vs. FOP (ETALON 1 - 63 y)

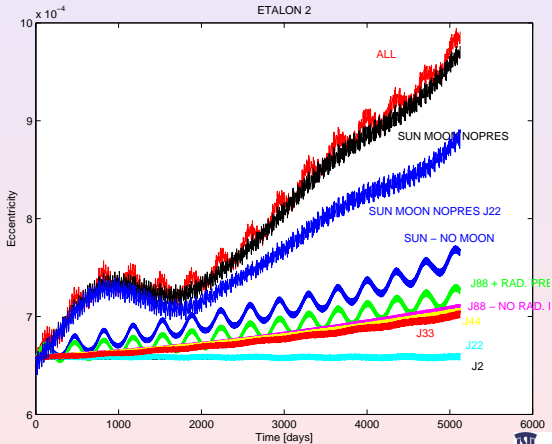


TIRV vs. SATRAP (ETALON 2 - 200 y)

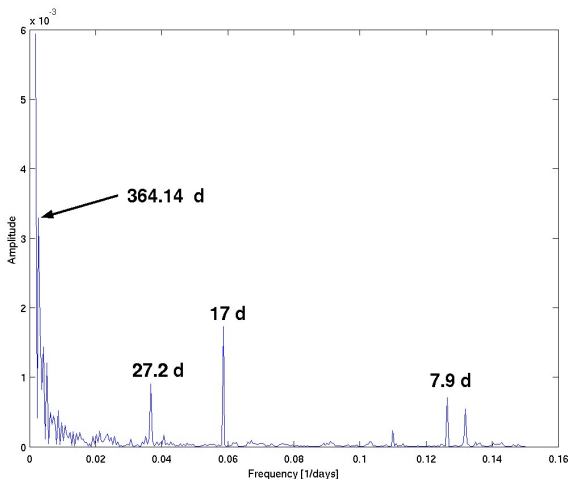


ETALON 2 Ecc. evolution 1990–2004 w. SATRAP

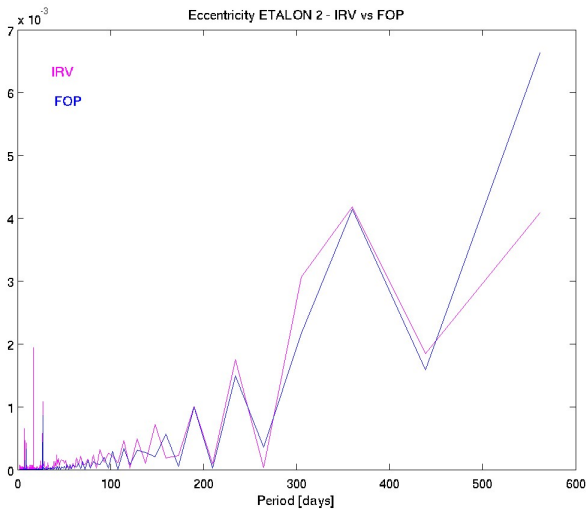
- There is a secular growth of the eccentricity caused mainly by the third body perturbations.



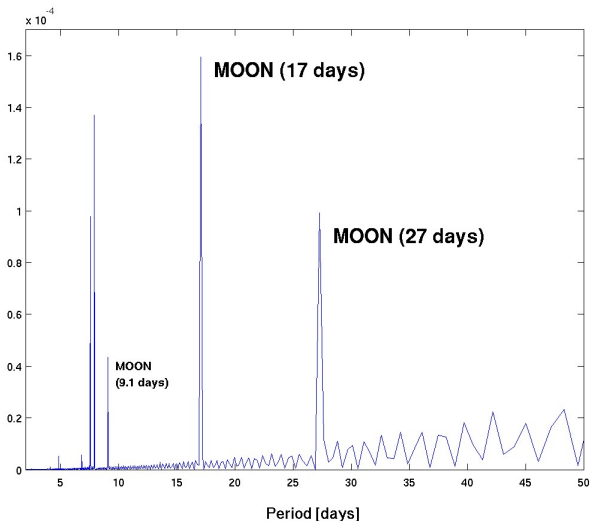
Spectrum of the ETALON 2 Eccentricity perturbations



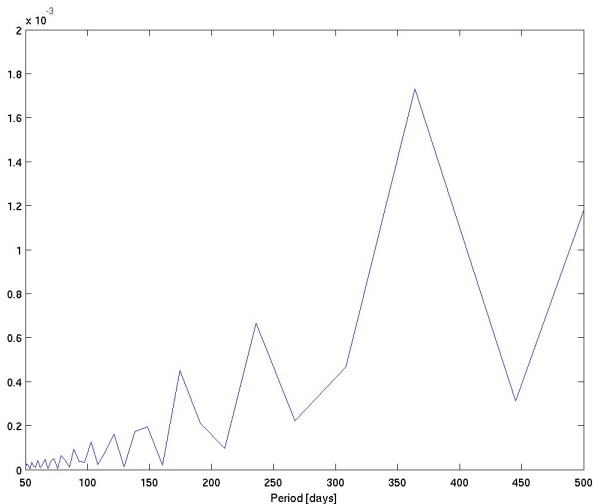
TIRV vs. FOP - Eccentricity Spectrum



SATRAP - Eccentricity Spectrum



SATRAP - Eccentricity Spectrum (long period)

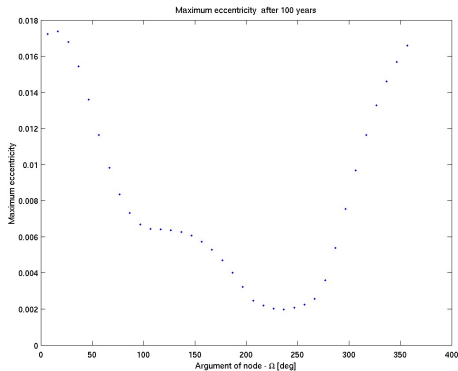


Exploration of the MEO region

The influence of the node and semimajor axis on the eccentricity growth of the orbits is explored by propagating, for 100 years with FOP and SATRAP, a large set of ETALON clones.

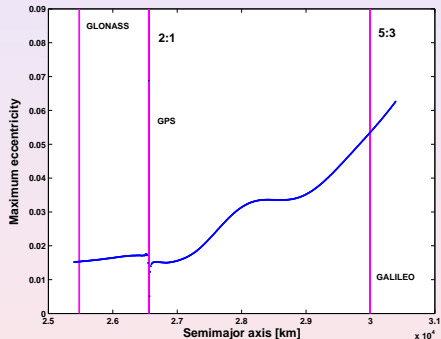
Node clones

- 36 Etalon 2 like orbits, with $\Omega_i = 36.69^\circ + (i \times 10^\circ)$ $i = 0, 35$
- Maximum eccentricity growth after 100 years.

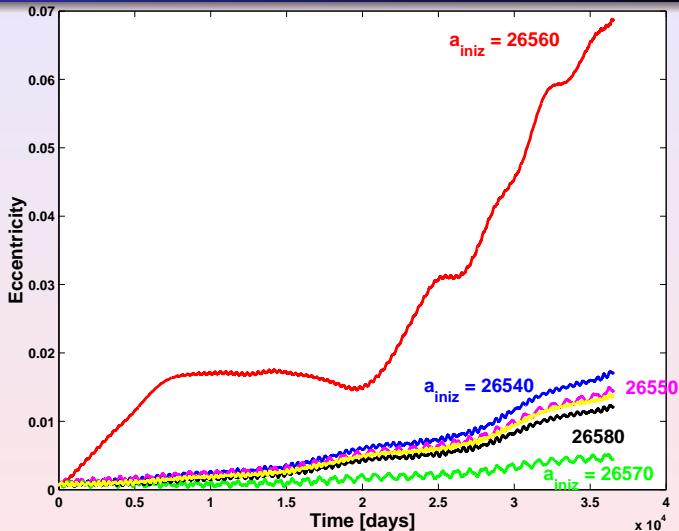


Semimajor axis clones

- 500 Etalon 2 like orbits
 $a_i = 25400 + (i \times 10)$ km,
 $i = 0, 459$
($25400 < a < 29990$).
- Maximum eccentricity growth after 100 years.

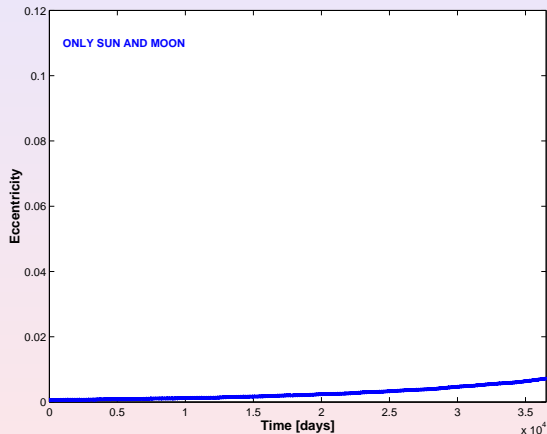


Semimajor axis clones - Ecc. evolution near resonance



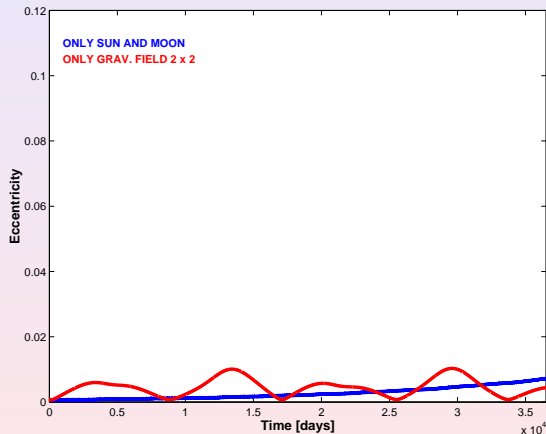
Resonance onset

Only Luni-Solar
perturbations (no
gravity
harmonics)



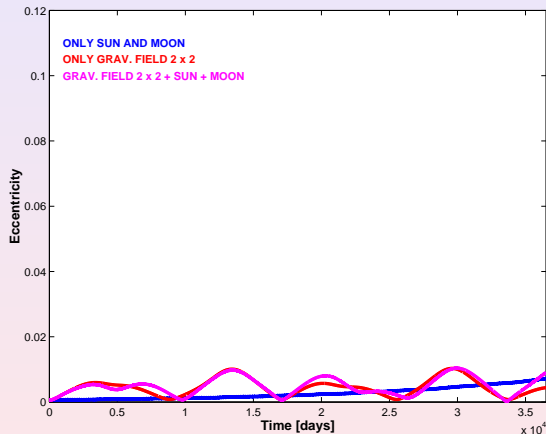
Resonance onset

Only gravity harmonics up to degree $\ell = 2$ and order $m = 2$.



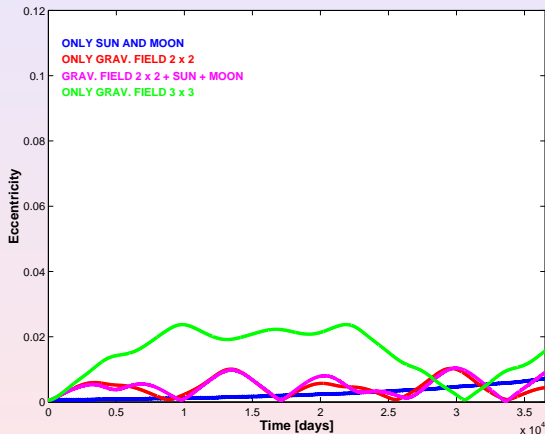
Resonance onset

Gravity harmonics up to degree $\ell = 2$ and order $m = 2 +$ Luni-Solar perturbations



Resonance onset

Only gravity harmonics up to degree $\ell = 3$ and order $m = 3$ (No Luni-Solar perturbations).



Resonance theory

Given the expansion of the gravity field in terms of spherical harmonics, the resonance argument for a $J_{\ell m}$ coefficient is:

$$\psi_{lmpq} = [(\ell - 2p + q)n - m\dot{\theta}]t + (l - 2p)\omega + m(\Omega - \theta_0)$$

where: $0 \leq p \leq \ell$, $-\infty < q < +\infty$

n = mean motion

Ω , ω : argument of node and pericenter

$\theta = \theta_0 + \dot{\theta}t$ = right ascension of the Greenwich meridian

Large perturbations occur when:

$$\dot{\psi}_{lmpq} = [(\ell - 2p + q)n - m\dot{\theta}]t + (l - 2p)\dot{\omega} + m\dot{\Omega} \simeq 0$$

Resonance theory

For MEOs we have:

$$\dot{\omega} \simeq 10^{-5}, \quad \dot{\Omega} \simeq -10^{-4}, \quad n \simeq 2, \quad \dot{\theta} \simeq 1$$

So that:

$$2 \simeq \frac{n}{\dot{\theta}} \simeq \frac{m}{\ell - 2p + q}$$

Therefore the main resonant coefficients are:

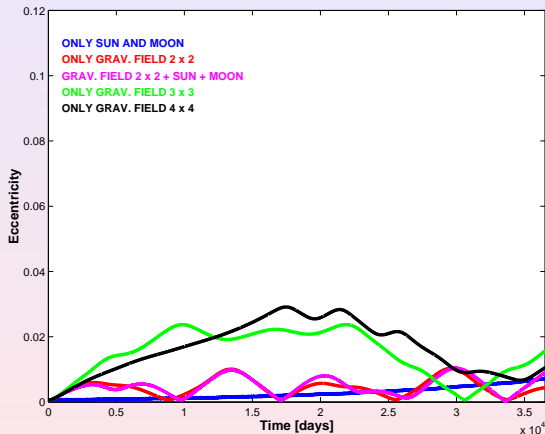
$$\ell = 3, \quad m = 2 \text{ for } p = 1 \text{ and } q = 0$$

$$\ell = 4, \quad m = 4 \text{ for } p = 1 \text{ and } q = 0$$

$$\ell = 2, \quad m = 2 \text{ for } p = 0, 1 \text{ and } q = \pm 1$$

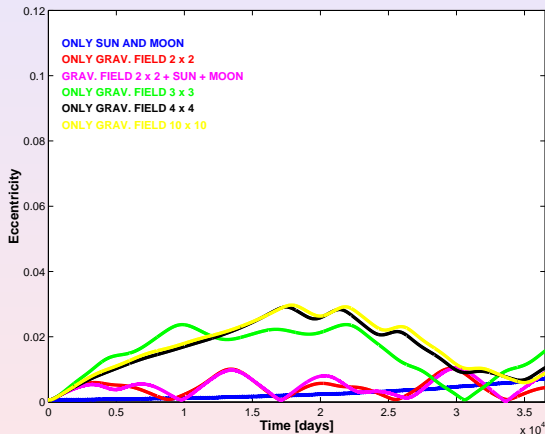
Resonance onset

Only gravity harmonics up to degree $\ell = 4$ and order $m = 4$ (No Luni-Solar perturbations).



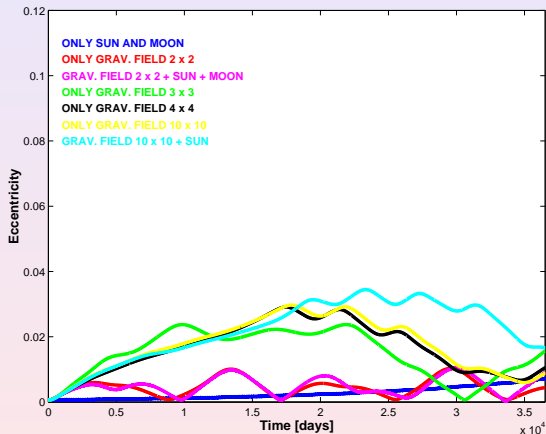
Resonance onset

Only gravity harmonics up to degree $\ell = 10$ and order $m = 10$ (No Luni-Solar perturbations).



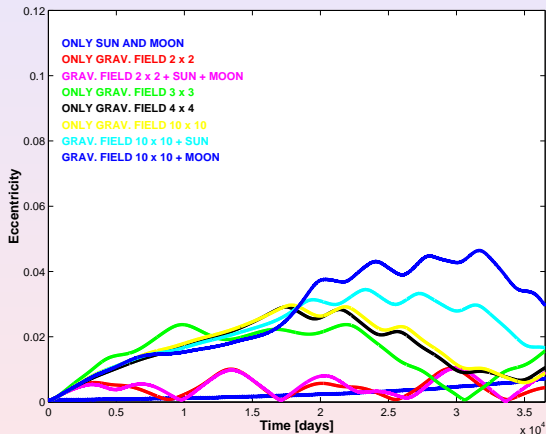
Resonance onset

Gravity harmonics up to degree $\ell = 10$ and order $m = 10$ + Solar perturbations (i.e., no Moon).



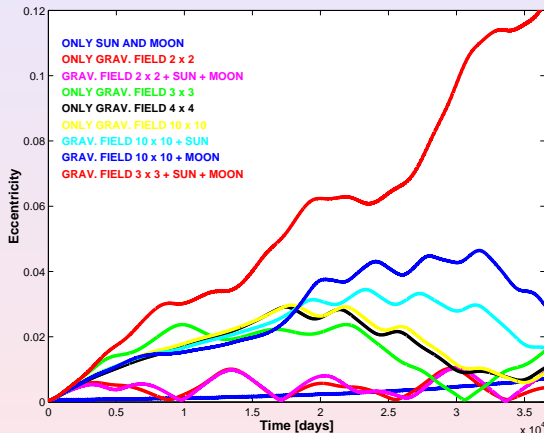
Resonance onset

Gravity harmonics up to degree $\ell = 10$ and order $m = 10 +$ Lunar perturbations (i.e., no Sun).



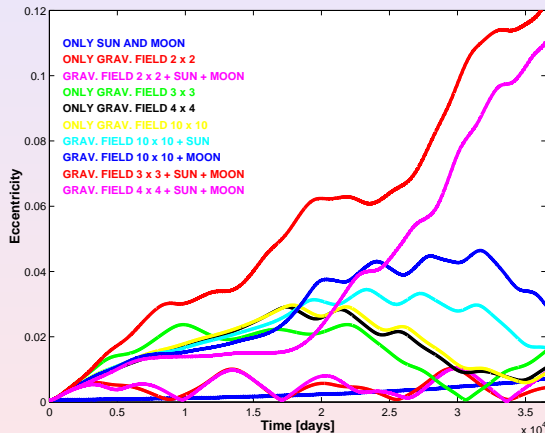
Resonance onset

Gravity harmonics up to degree $\ell = 3$ and order $m = 3$ + Lunar and Solar perturbations



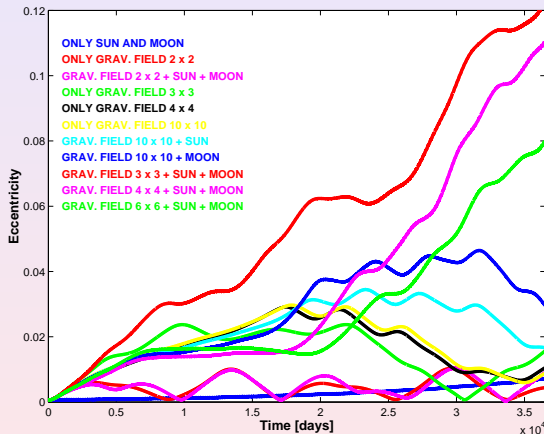
Resonance onset

Gravity harmonics up to degree $\ell = 4$ and order $m = 4$ + Lunar and Solar perturbations



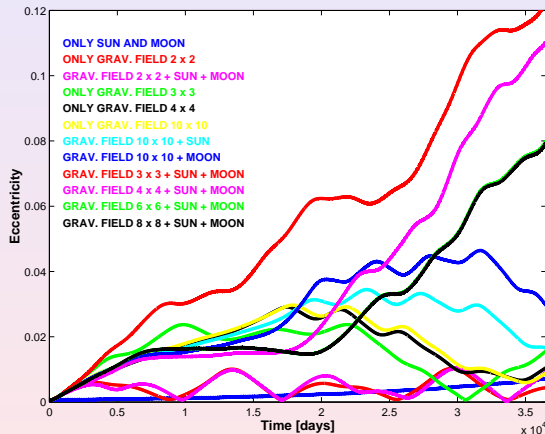
Resonance onset

Gravity harmonics up to degree $\ell = 6$ and order $m = 6$ + Lunar and Solar perturbations



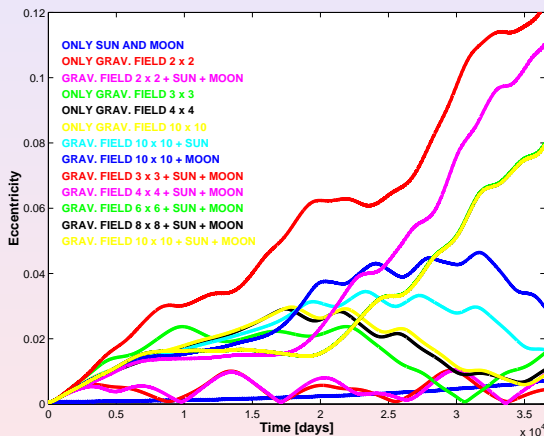
Resonance onset

Gravity harmonics up to degree $\ell = 8$ and order $m = 8$ + Lunar and Solar perturbations.



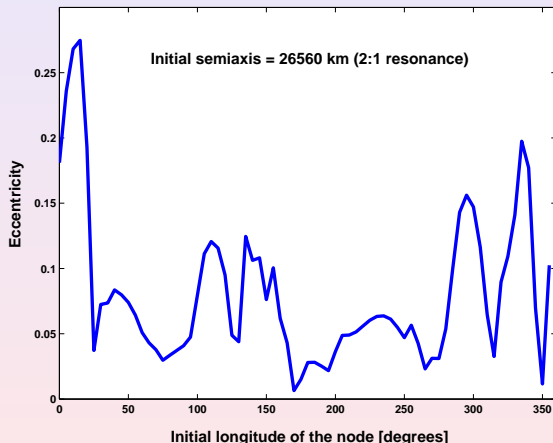
Resonance onset

Gravity harmonics up to degree $\ell = 10$ and order $m = 10$ + Lunar and Solar perturbations.



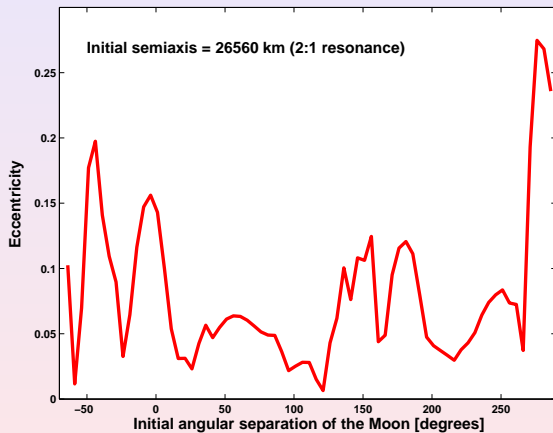
Node dependence at resonance

Maximum eccentricity growth as a function of initial longitude of the node, at the resonance semiaxis.



Node dependence at resonance

Maximum eccentricity growth as a function of initial Moon angle (difference between initial longitude of the node and initial longitude of the Moon), at the resonance semiaxis.



Agenda

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 - Orbital evolution
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- 2 Conclusions

(No) conclusions and Future work

- Analytical theory of the resonance (from Kozai *et al.*)
- Disposal of spacecraft
- Collision risk