Dynamics of possible Uranus Trojans

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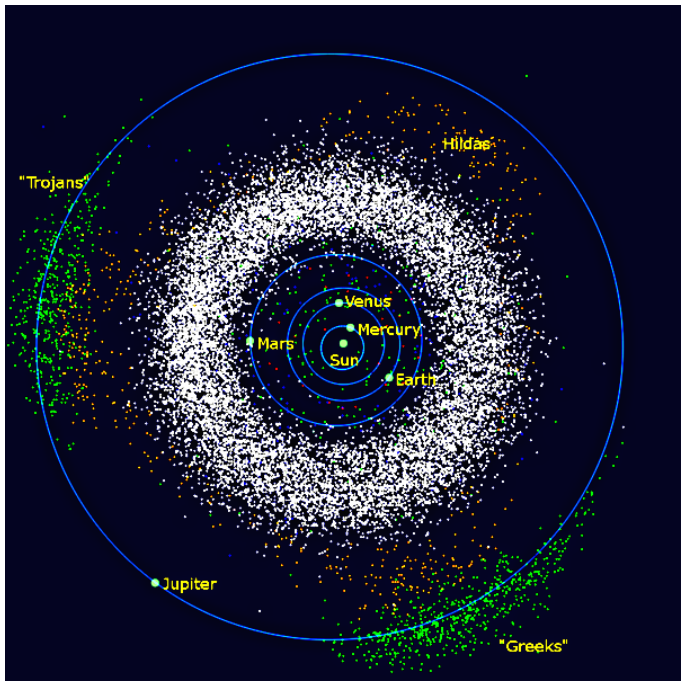
Outline

Trojans in the Solar System

Planets with known Trojan asteroids[a]:

- \+ Mars:
  $L_4 = 1$, $L_5 = 3$
- \+ Jupiter:
  $L_4 = 2603$, $L_5 = 1473$
- – Saturn: 0
- – Uranus: 0
- \+ Neptune:
  $L_4 = 6$, $L_5 = 0$



Jupiter Trojans (source from: Wikipedia)

[a] source: IAU Minor Planet Center, list dated from 2010 Feb. 12, http://www.cfa.harvard.edu/iau/lists/Trojans.html

Trojans in the Solar System
Goals for investigation

1. Dynamically stable zone for Uranus Trojans?

- Murray & Holman (1999): overlap of MMR in OSS
- Nesvorný & Dones (2002): population depleted by factor 100
- Zhou et al. (2009): Neptune Trojans at high inclinations

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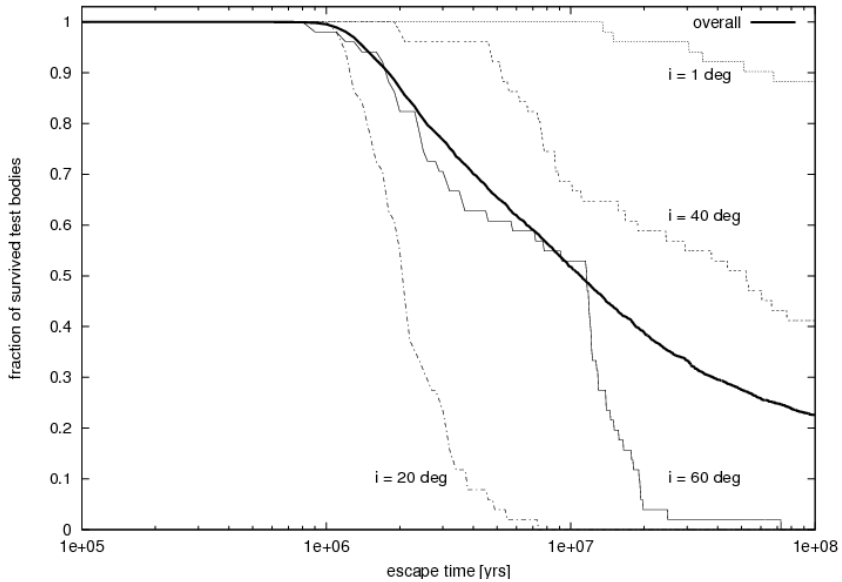
2. Timescale for stability?



Trojans in the Solar System

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3. Dependence on inclination?

Trojans in the Solar System

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2. Timescale for stability?
3. Dependence on inclination?
4. Perturbations by resonances?

Dynamical Model

- OSS: Sun – Jupiter – Saturn – Uranus – Neptune
- restricted problem: swarm of massless Trojan asteroids
- Newtonian framework
- equilateral triangle equilibrium points L_4, L_5 dynamically symmetric

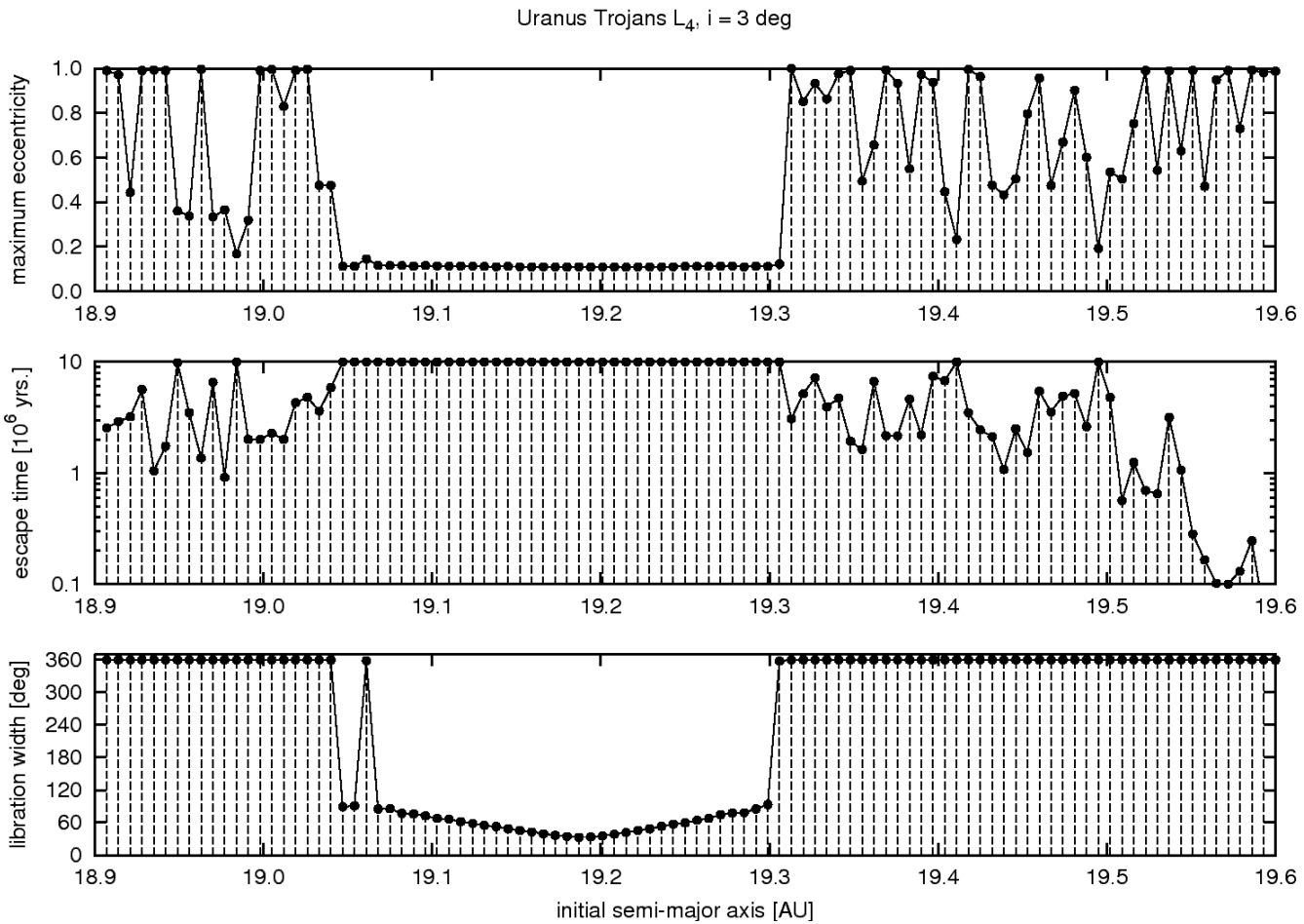
Methods

- numerical integration of equations of motion: Lie Integrator
- integration time: $10^6 - 5 \times 10^9$ years
- grid of initial conditions:
  - changed $a = a_U \pm m \times 0.007$ AU $(1 \leq m \leq 50)$
  - changed $i_U \leq i \leq 60°$
  - $\omega_T = \omega_U \pm 60°$
- (e, Ω, M) identical to Uranus
- cuts through equilibrium points (supposed values)

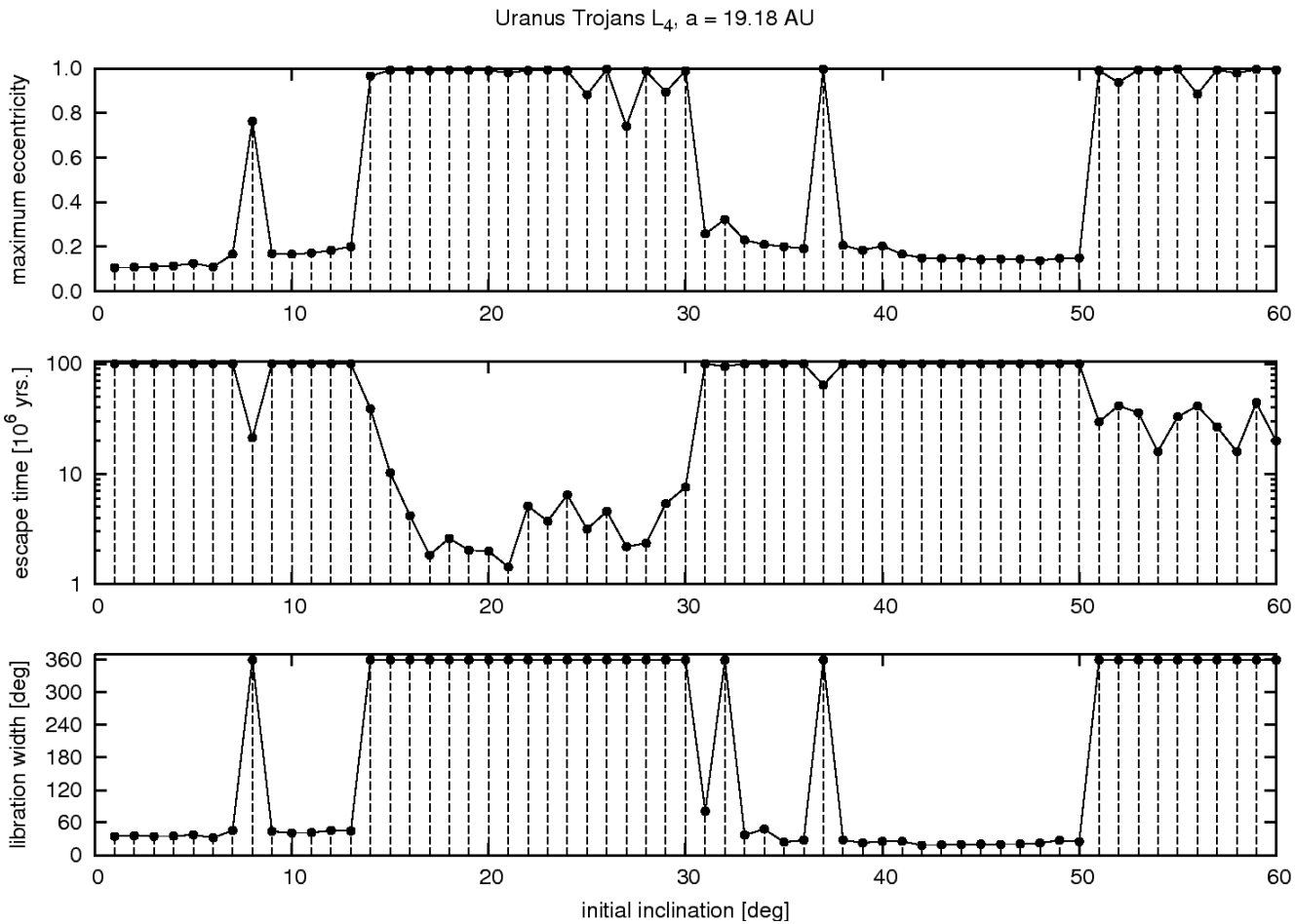
Tools for analysis

1. maximum eccentricity: $e_{\max}$
2. libration width: $\sigma = \lambda - \lambda_U$
3. escape times
4. frequency analysis: proper frequencies

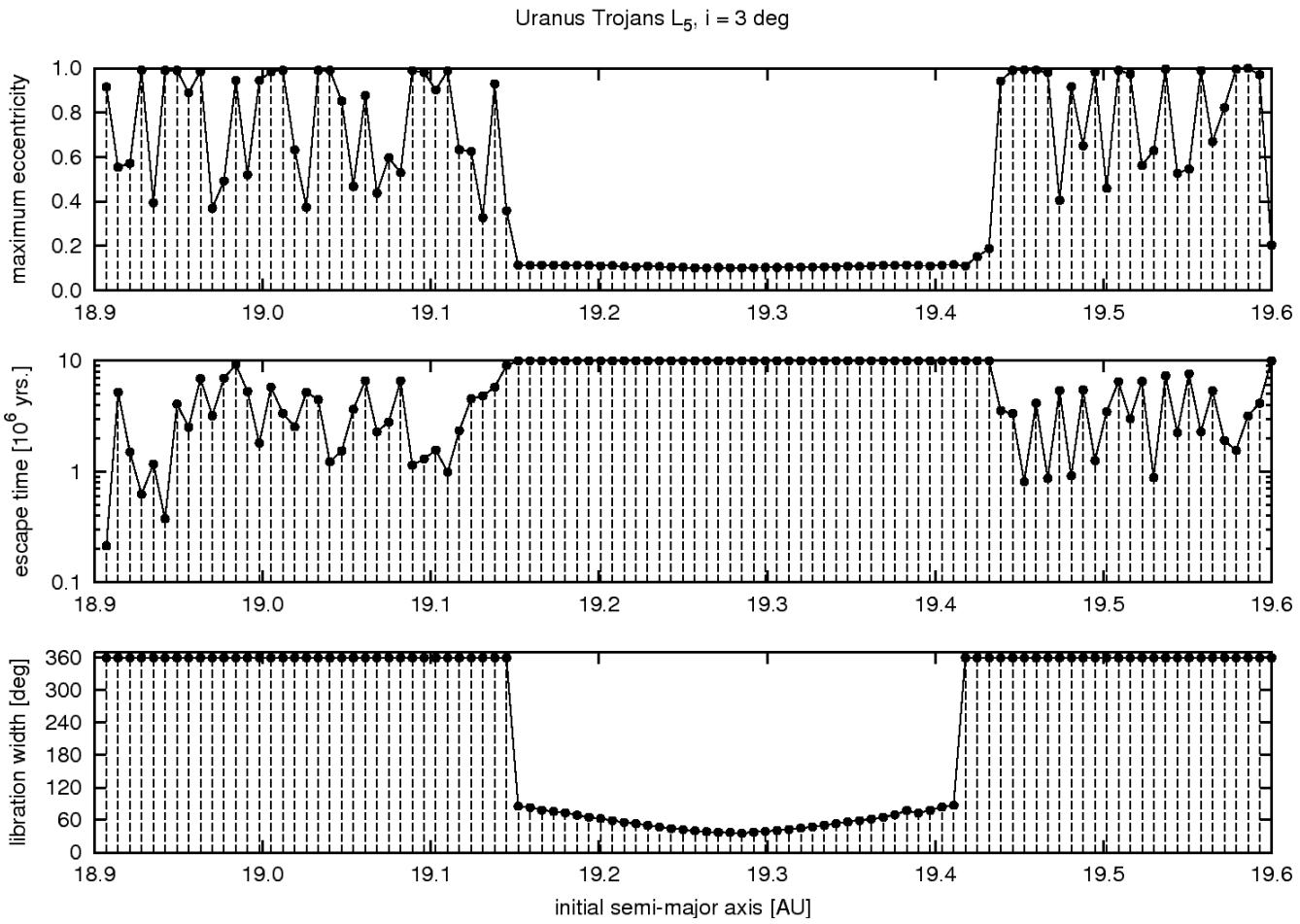
Stability of L_4
cut in semi-major axis



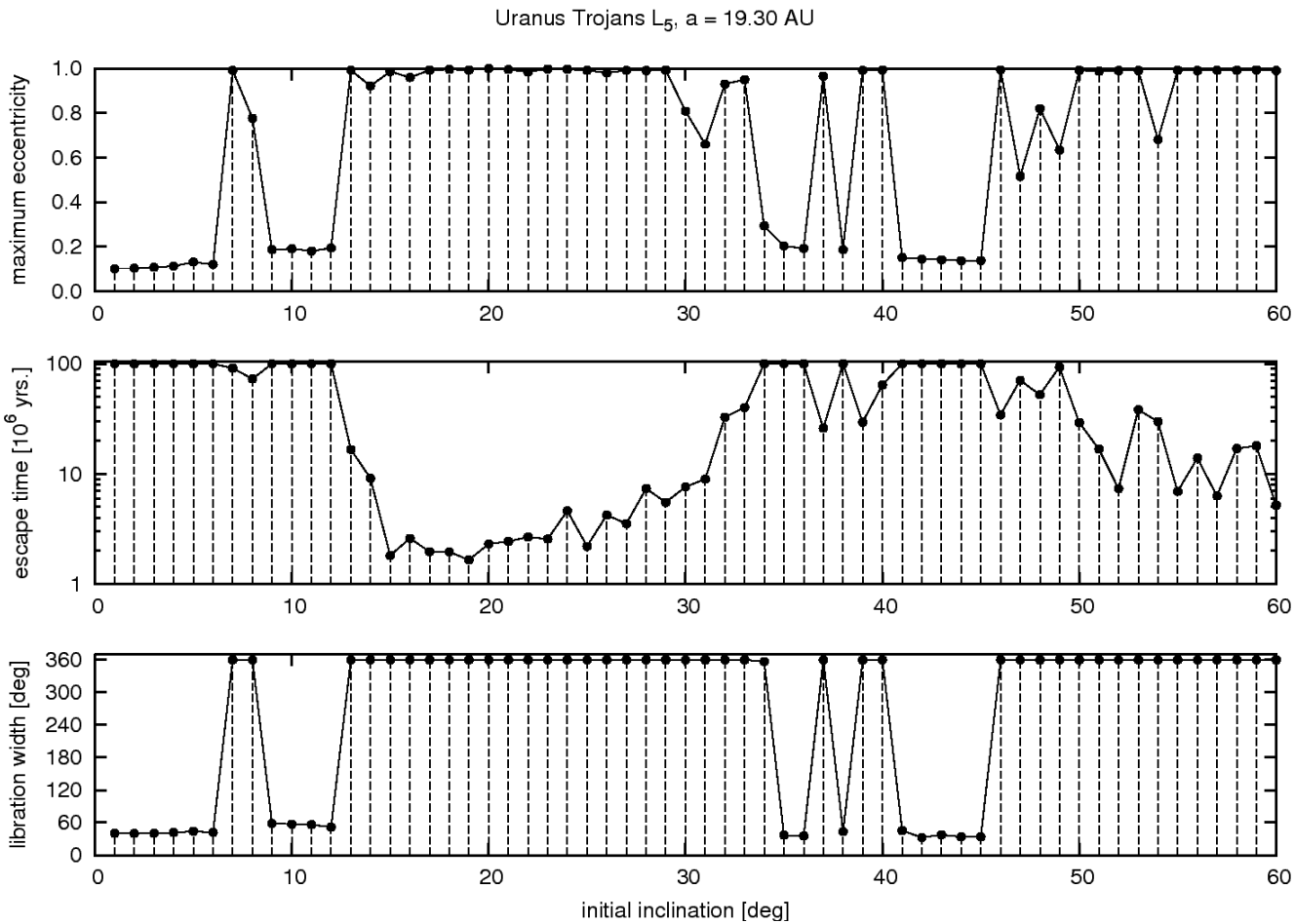
Stability of L_4
cut in inclination



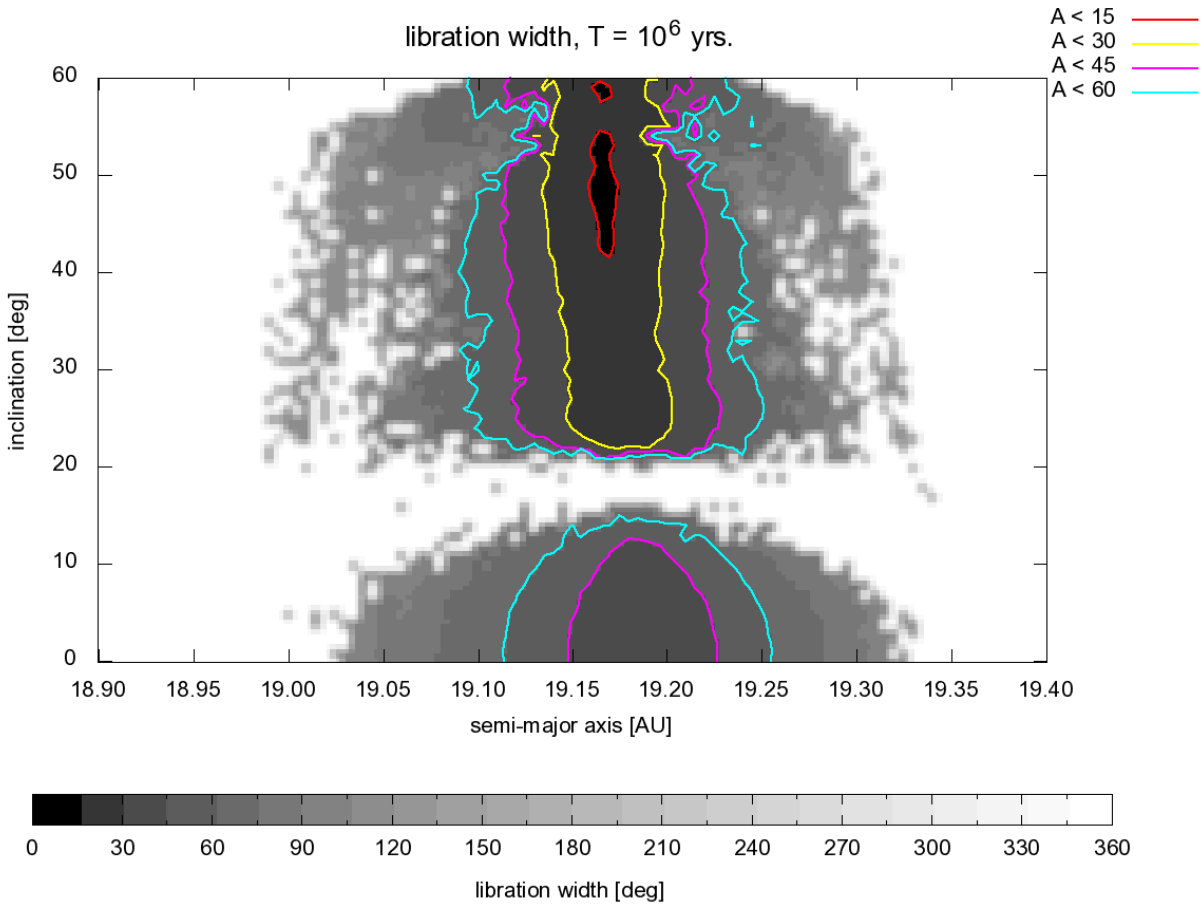
Stability of L_5
cut in semi-major axis



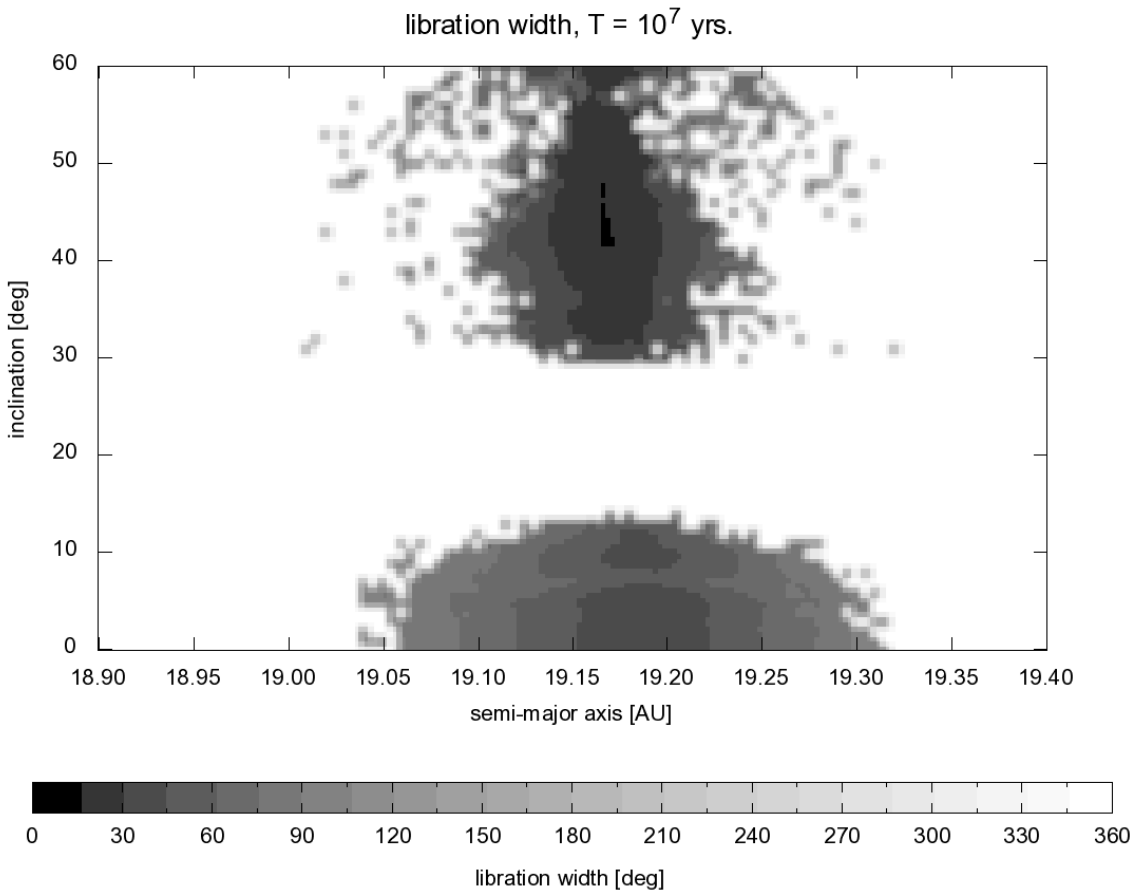
Stability of L_5
cut in inclination



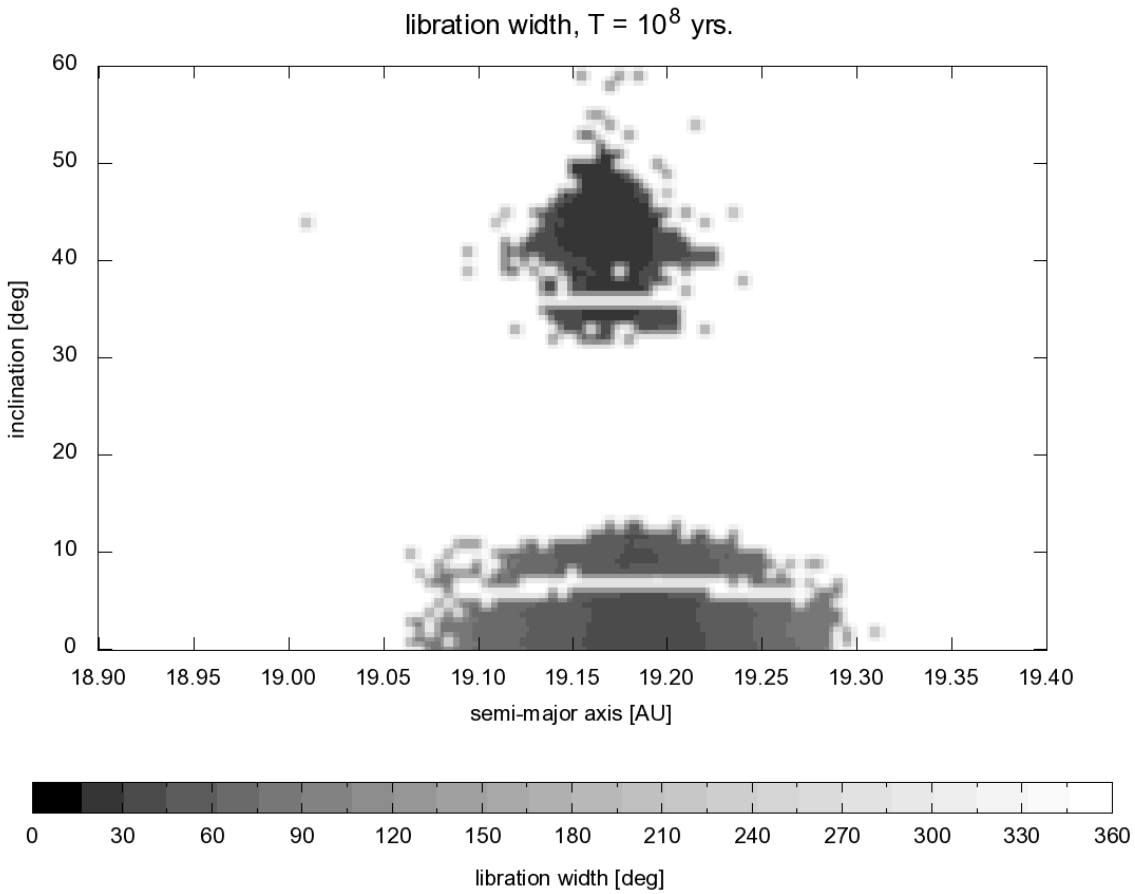
Libration Width (1/3)



Libration Width (2/3)

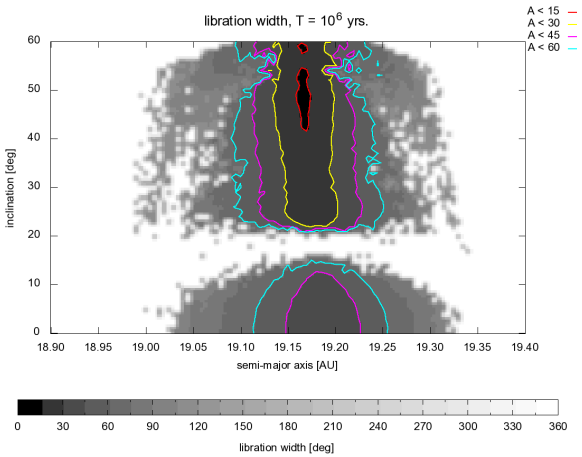


Libration Width (3/3)

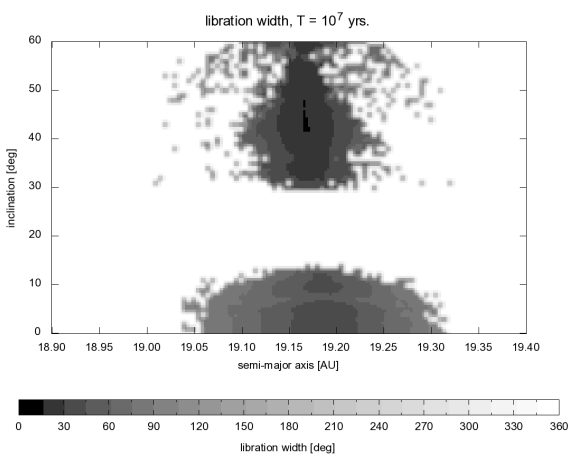


Comparison of Libration Widths

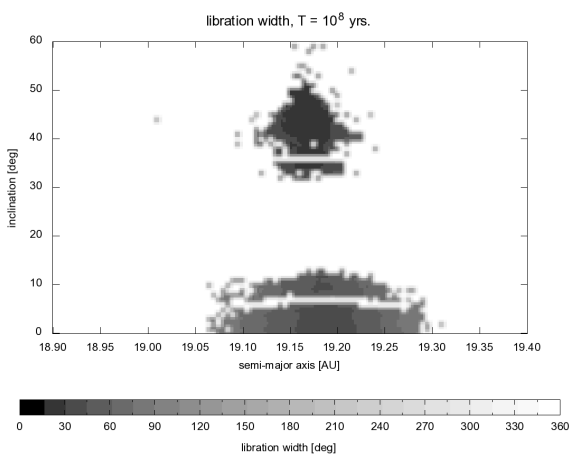
$T = 10^6$ yrs.



$T = 10^7$ yrs.

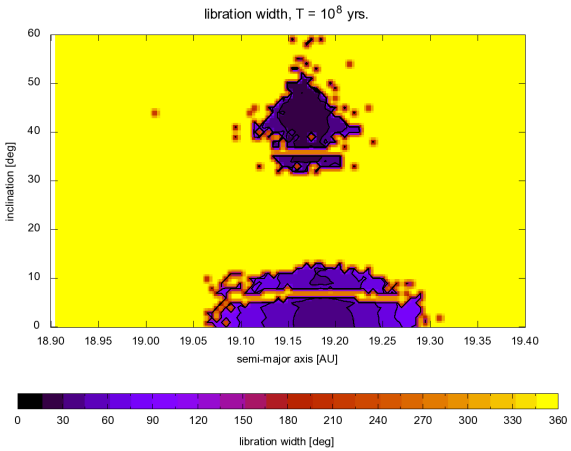


$T = 10^8$ yrs.

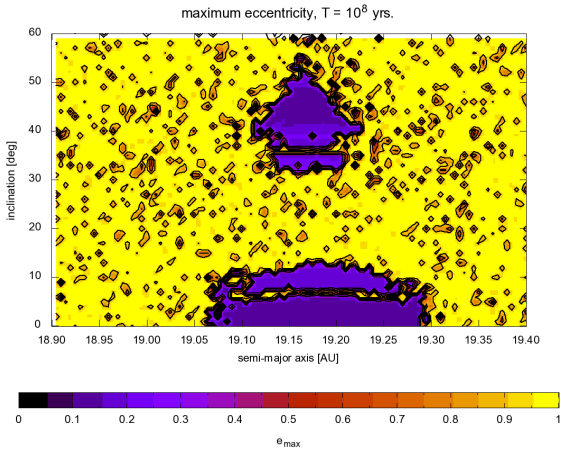


Comparison of Methods for $T = 10^8$ yrs.

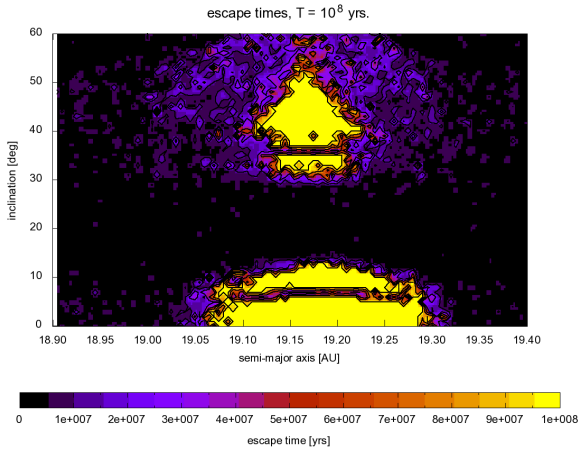
libration width



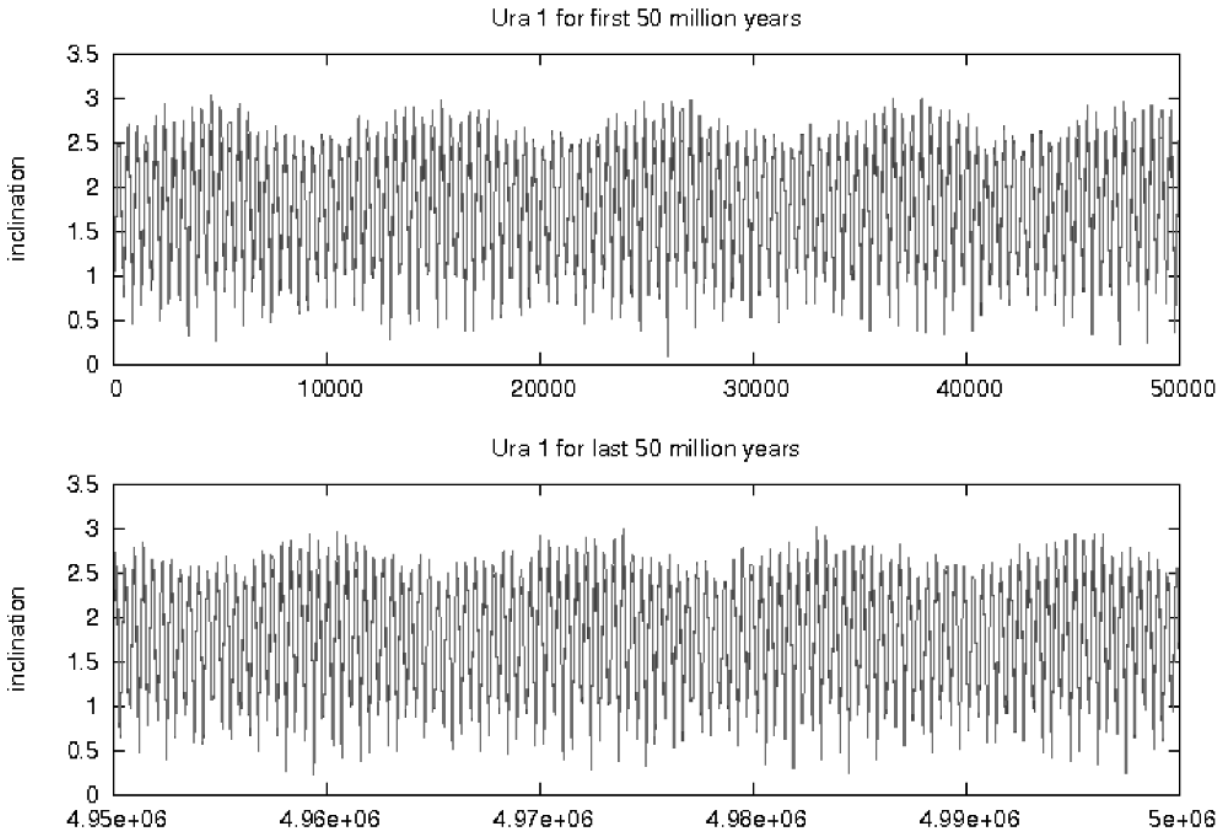
maximum eccentricity



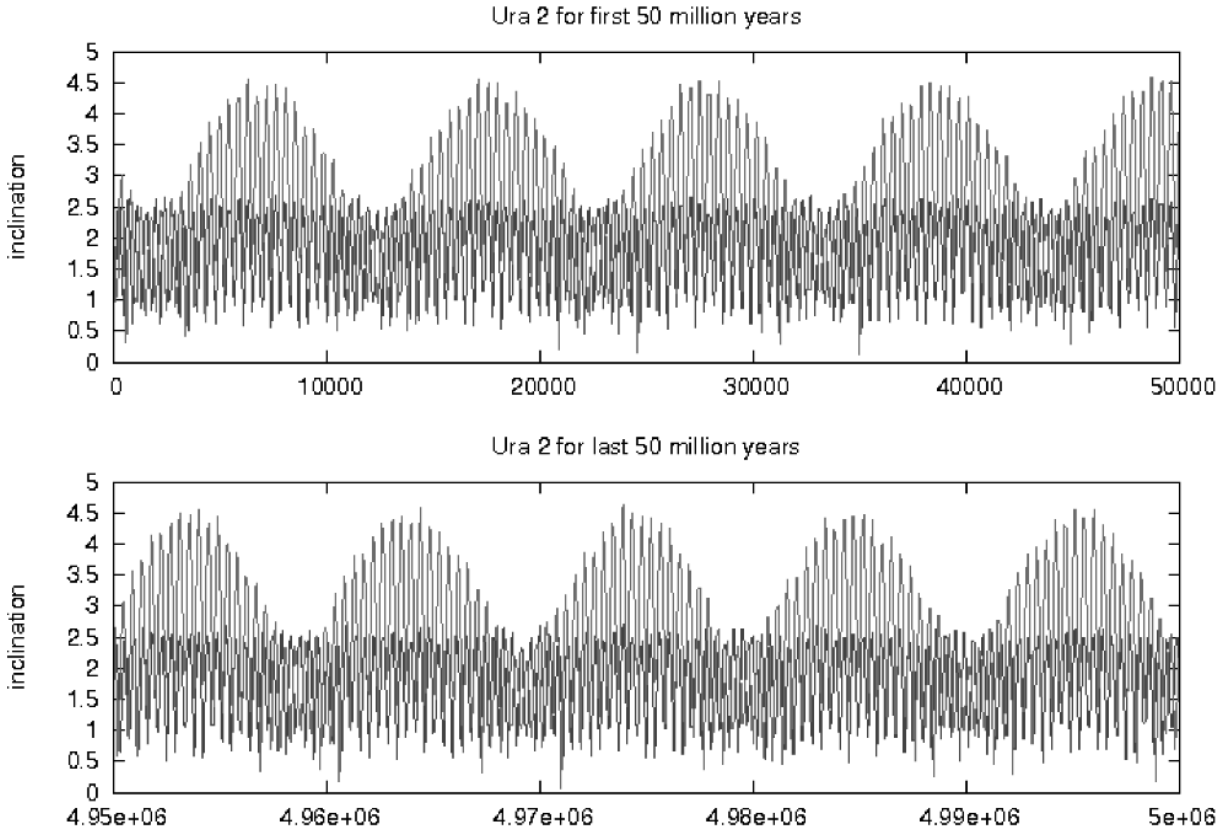
escape times



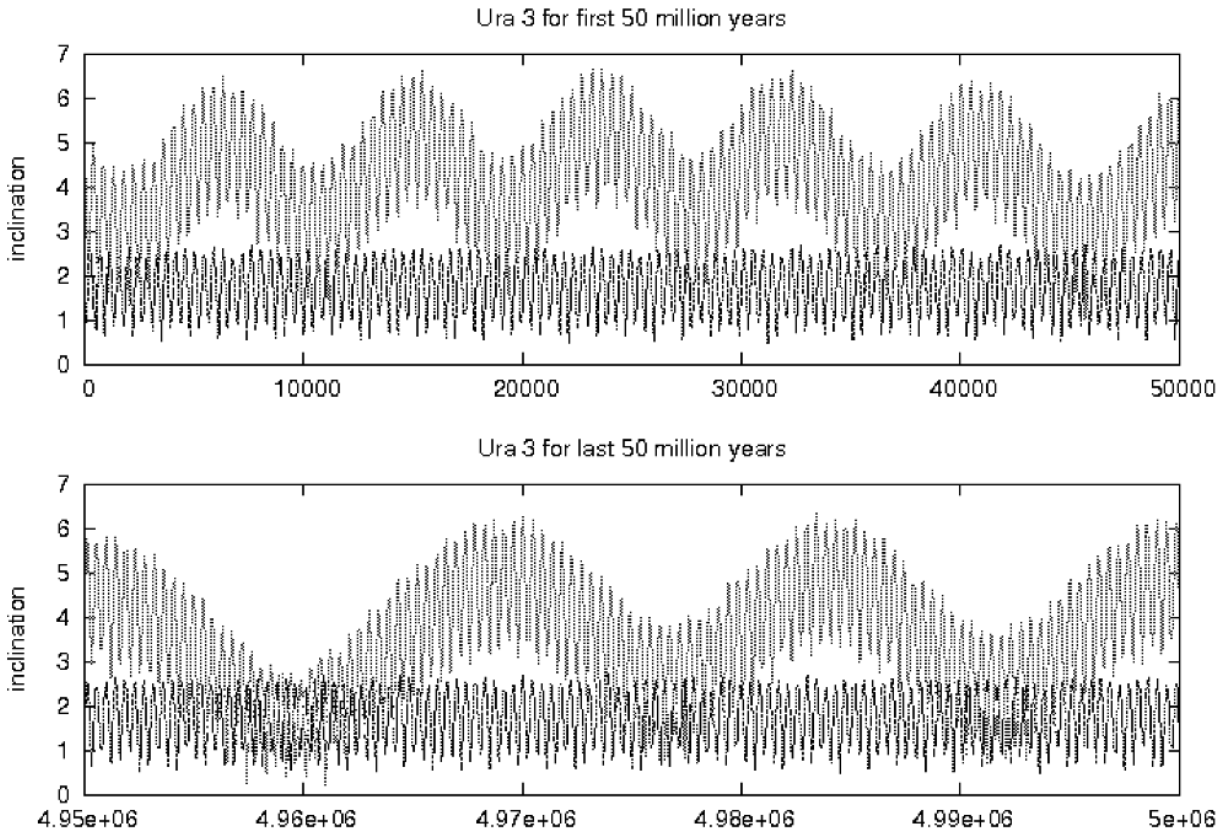
Trojan for 5 Ga (1/3)



Trojan for 5 Ga (2/3)



Trojan for 5 Ga (3/3)



Frequency Analysis (1/4)
About SIGSPEC

- Author: P. Reegen, A&A 467, 2007
- time series analysis by DFT
- spectral significance: accurate peak detection
- using secular variables:
  $k = e\cos(\omega + \Omega)$, $q = \sin i \cos\Omega$

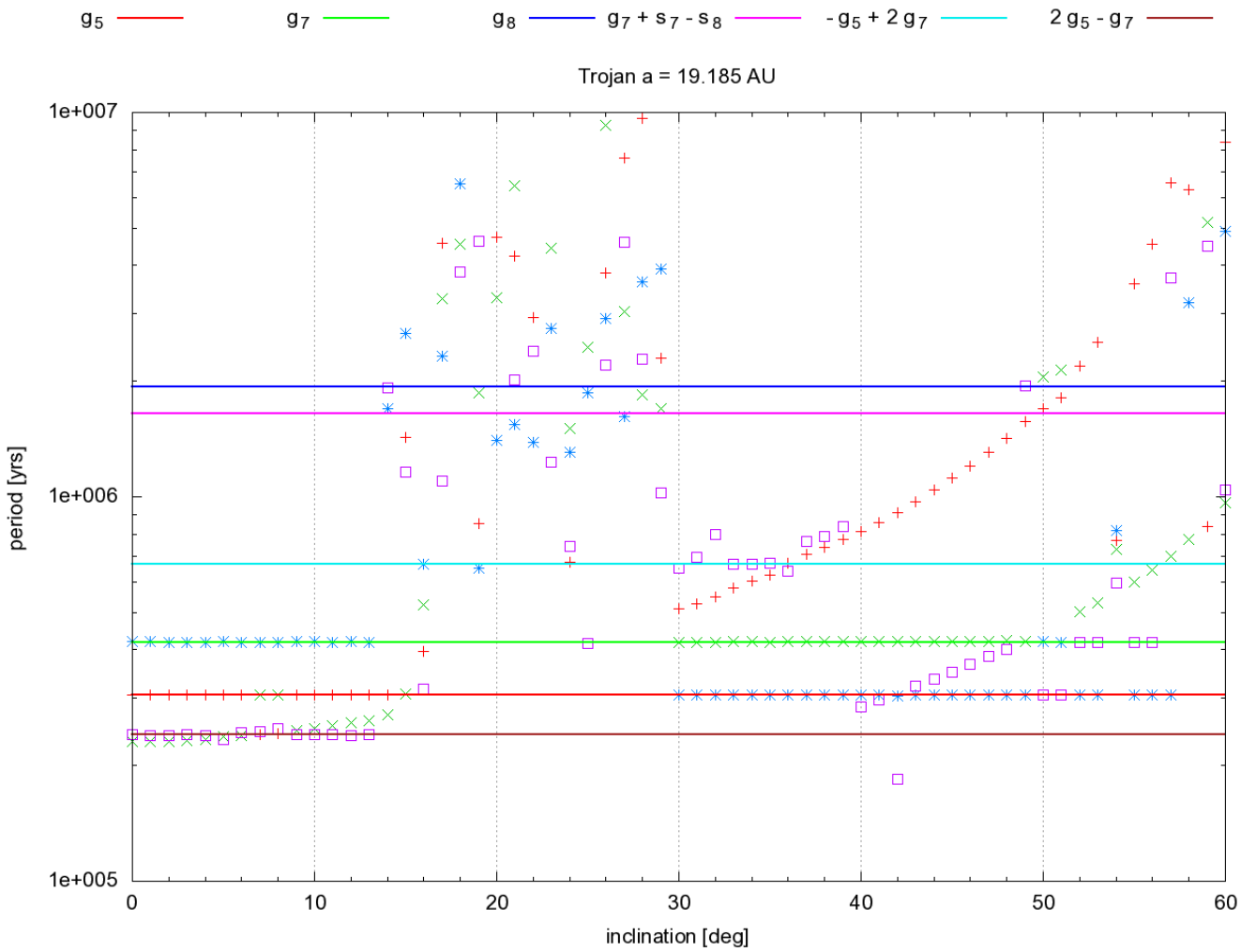
Frequency Analysis (2/4)

Common frequencies in dynamical spectrum of Uranus

combination	periods [$\times 10^3$ yrs]
g_5	305.2
g_6	45.7
g_7	419.2
g_8	1928.0
$g_7 + s_7 - s_8$	1650.6
$-g_5 + 2g_7$	666.8
$2g_5 - g_7$	240.1
MMR 2:1 U/N	4.236

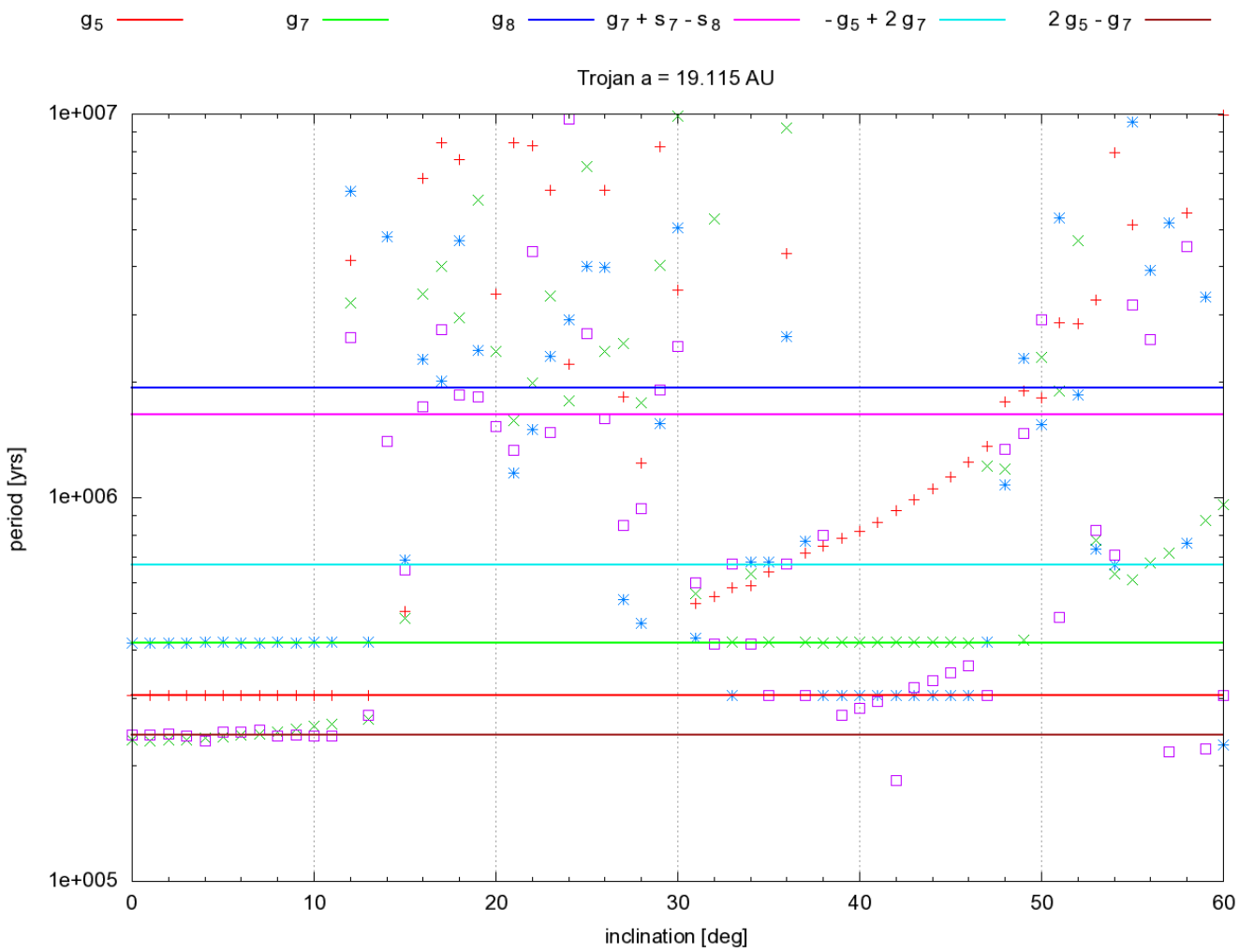
Frequency Analysis (3/4)

Secular frequencies acting on Trojans

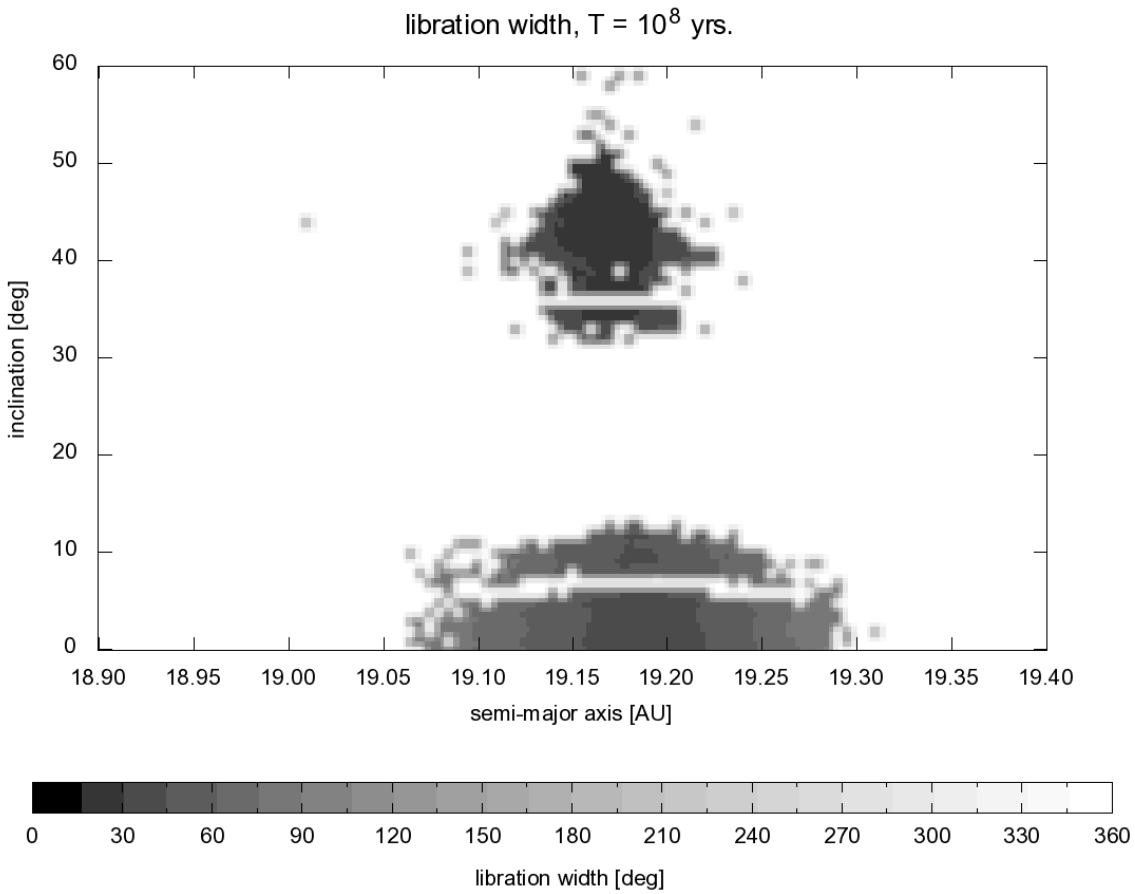


Frequency Analysis (4/4)

Secular frequencies acting on Trojans



Comparison


libration width, T = 10^8 yrs.
inclination [deg]
60
50
40
30
20
10
0
18.90
18.95
19.00
19.05
19.10
19.15
19.20
19.25
19.30
19.35
19.40
semi-major axis [AU]
0
30
60
90
120
150
180
210
240
270
300
330
360
libration width [deg]

Conclusions

- detected stable zones for at least up to 5×10^8 years
- lifetime for selected (low inclination) orbits 5 Ga
- secular resonances shaping stability zone