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NEAR-EARTH ASTEROIDS AND THE KOZAI-MECHANISM

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INTRODUCTION

- I examine the Near-Earth Asteroids, due to how many of them show the Kozai-mechanism.
- When the argument of pericenter of an asteroid don't precess, but librate around 90°or 270°, while the inclination (*i*) and the eccentricity (*e*) is oscillate, we name this the Kozai-mechanism.
- More than 10 years ago, some astronomers examined this, but then they knew less than 500 Near-Earth Asteroids. Now we know more than 6500.

NEAR-EARTH OBJECTS (NEOs)

- **N**ear-**E**arth **O**bjects are comets and asteroids that have been nudged by the gravitational attraction of nearby planets into orbits that allow them to enter the Earth's neighborhood.
- In terms of orbital elements, NEOs are asteroids and comets with perihelion distance q less than 1.3 AU.
- Near-Earth Comets (NECs) are further restricted to include only short-period comets (i.e. Orbital period P less than 200 years).

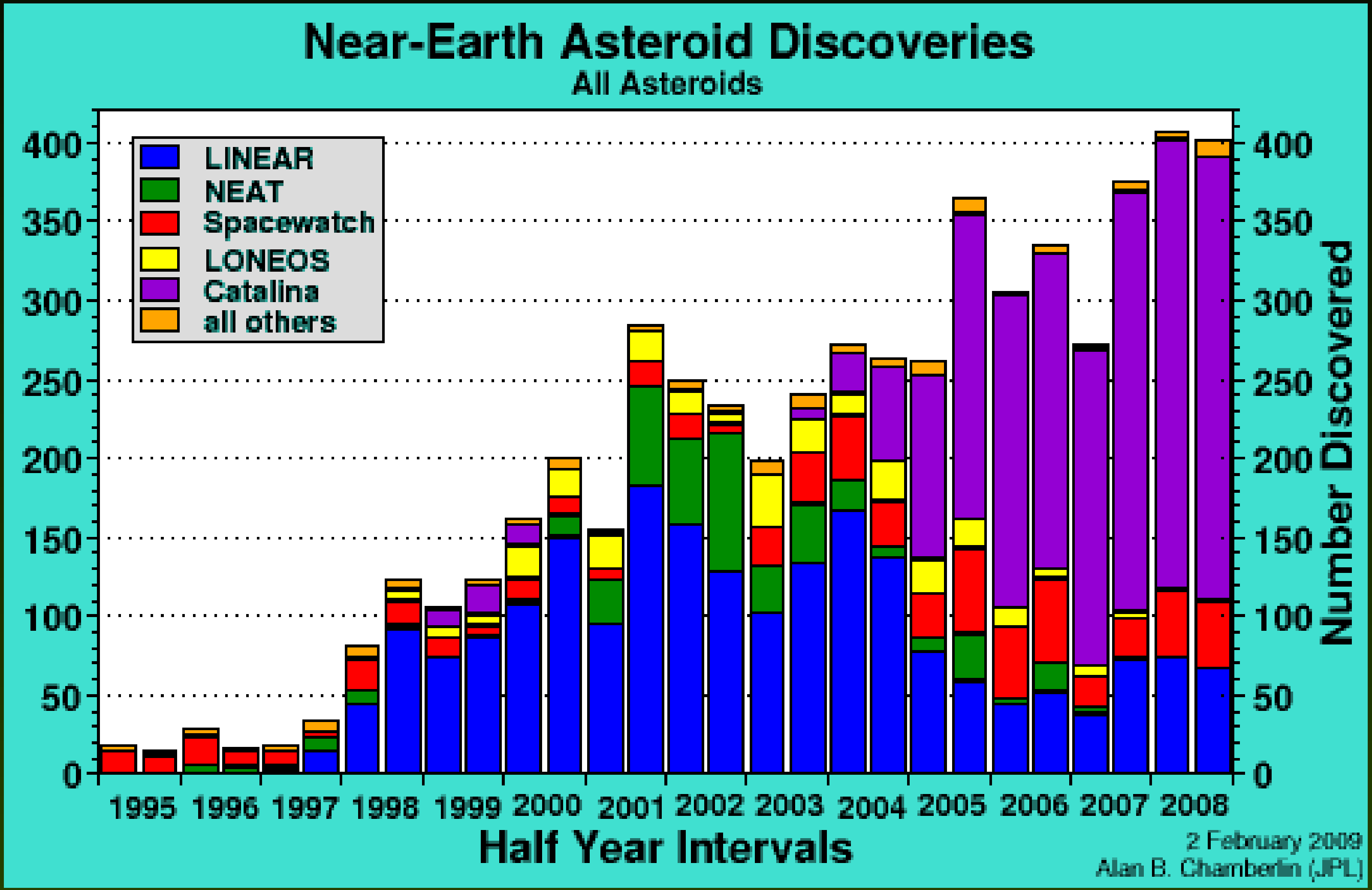
NEAR-EARTH ASTEROIDS (NEAs)

- The vast majority of NEOs are the asteroids, referred to as **N**ear-**E**arth **A**steroids (NEAs). NEAs are divided into groups (Apollo, Aten, Amor) according to their perihelion distance (q), aphelion distance (Q) and their semimajor axes (a).
- In 1998 NASA commenced its part of the „Spaceguard“ effort, with the goal of discovering and tracking over 90% of the NEOs larger than one kilometer by the end of 2008.

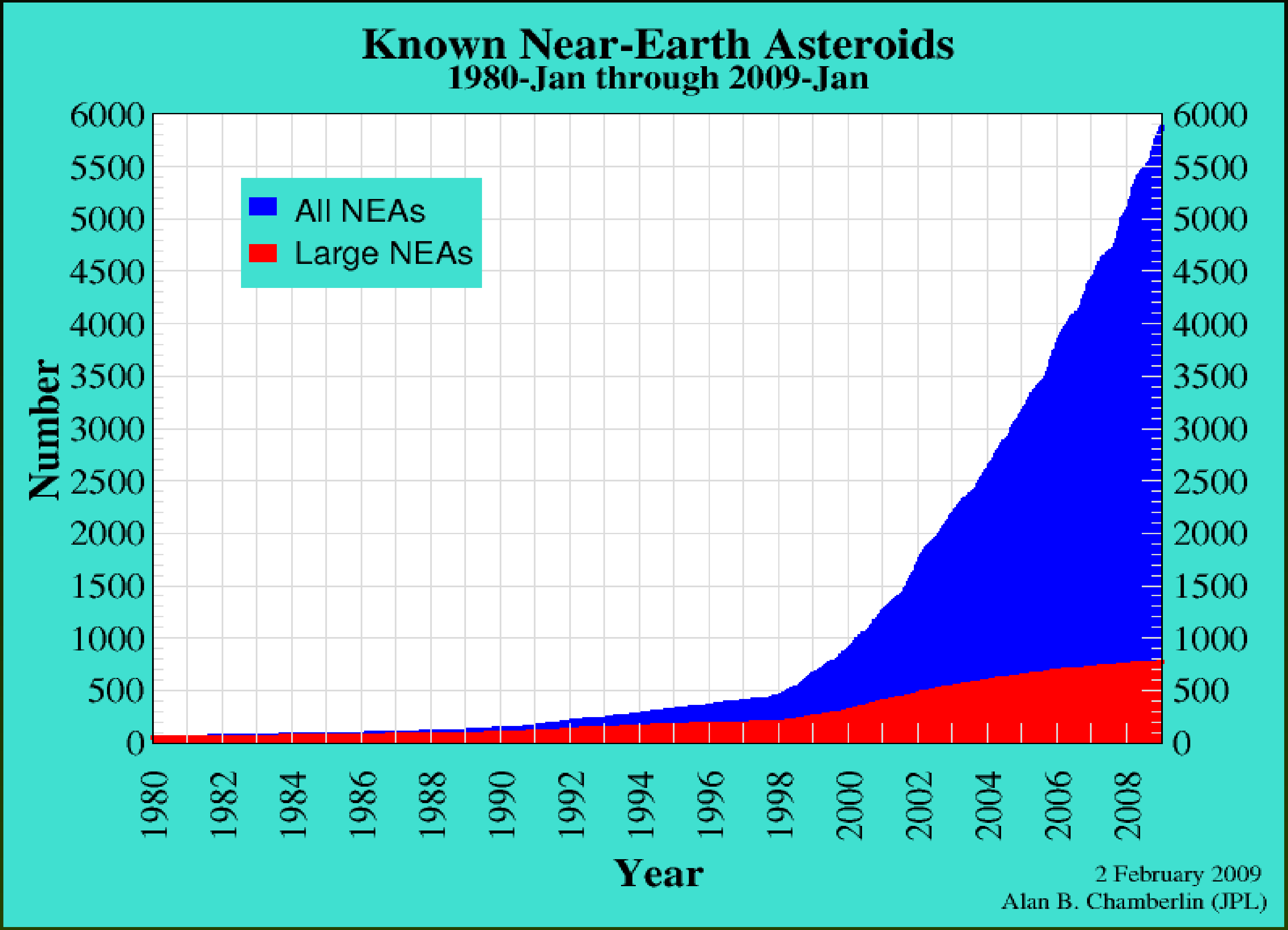
NEAR-EARTH ASTEROIDS (NEAs)

- There are several Near-Earth Object discovery teams:
  - LINCOLN NEAR-EARTH ASTEROID RESEARCH (LINEAR)
  - NEAR-EARTH ASTEROID TRACKING (NEAT)
  - SPACEWATCH
  - LOWELL OBSERVATORY NEAR-EARTH OBJECT SEARCH (LONEOS)
  - CATALINA SKY SURVEYS
  - JAPANESE SPACEGUARD ASSOCIATION (JSGA)
  - ASIAGO DLR ASTEROIDS SURVEY (ADAS)

NEAR-EARTH ASTEROIDS (NEAs)



NEAR-EARTH ASTEROIDS (NEAs)



NEAR-EARTH ASTEROIDS (NEAs)

- You can find these results in the Horizons System, or in the JPL Small-Body Database Search Engine.
- The JPL HORIZONS *on-line* solar system data and ephemeris computation service provides access to key solar system data and flexible production of highly accurate ephemerides for solar system objects.
- You can use JPL Small-Body Database search engine to generate custom tables of orbital and/or physical parameters for all asteroids and comets.

KOZAI-MECHANISM

- In 1962 Yoshihide Kozai examined the secular perturbations of asteroids with high inclination and eccentricity with analitical methods. He found that above of the critical inclination (39.2°) the argument of pericenter don't precess rather than librate around 90° or 270°, while the oscillations of *e* and *i* are coupled.
- In 1979 astronomers discovered the first asteroid, which showed this mechanism, the 3040 Kozai.

KOZAI-MECHANISM

- In 1995 Patrick Michel and Fabrice Thomas examined 10 NEAs by numerical and semi-analytical methods, whose semimajor axes smaller than 2 AU. They found 4 asteroids which showed the Kozai mechanism, but 2 of them has small inclination ($i<14°$) and the ω librate around 180°.
- An important effect of the mechanism is to protect the objects from encounters with the planets.
- Two types of protection mechanisms are possible:

KOZAI-MECHANISM

- 1. For bodies whose values of *a* and *e* are such that they could encounter the planets only near perihelion (or aphelion), such encounters may be prevented by the high inclination and the libration of ω about 90° or 270° (even when the encounters occur, they do not affect much the asteroid's orbit due to comparatively high relative velocities)

KOZAI-MECHANISM

- 2. Another mechanism for NEAs, is viable when at low inclinations when ω oscillates around 0° or 180° and the asteroid's semimajor axis is close to that of the perturbing planet: in this case the node crossing occur always near perihelion and aphelion, namly far from the planet itself provided the eccentricity is high enough and the orbit of the planet is almost circular.

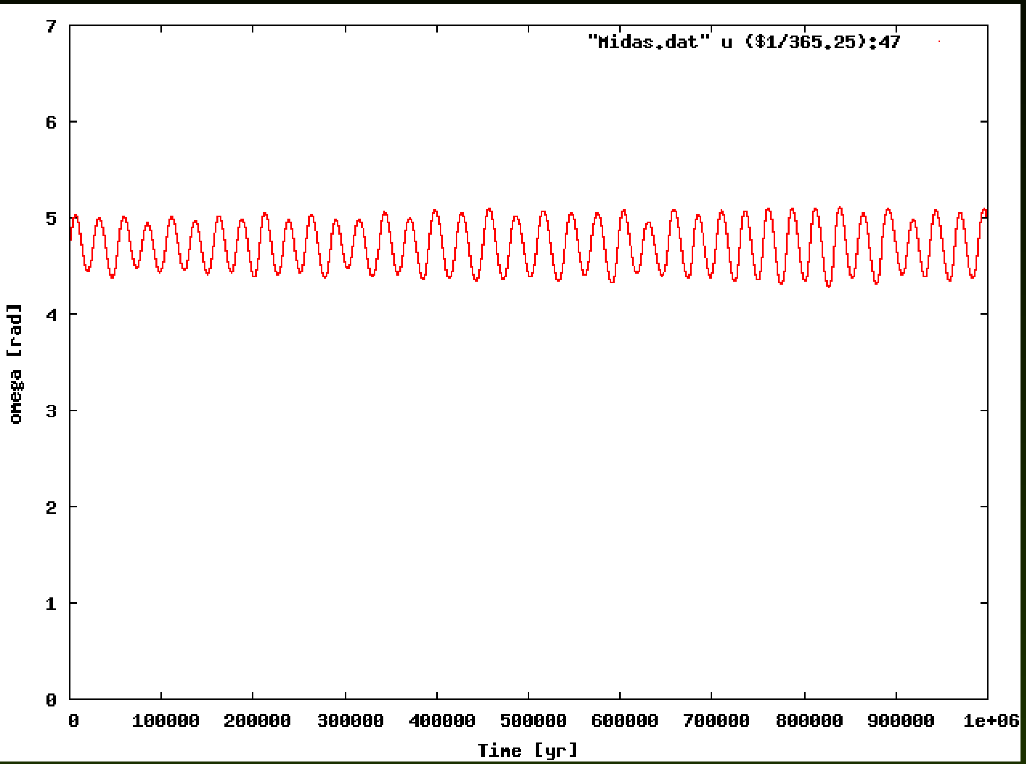
KOZAI-MECHANISM

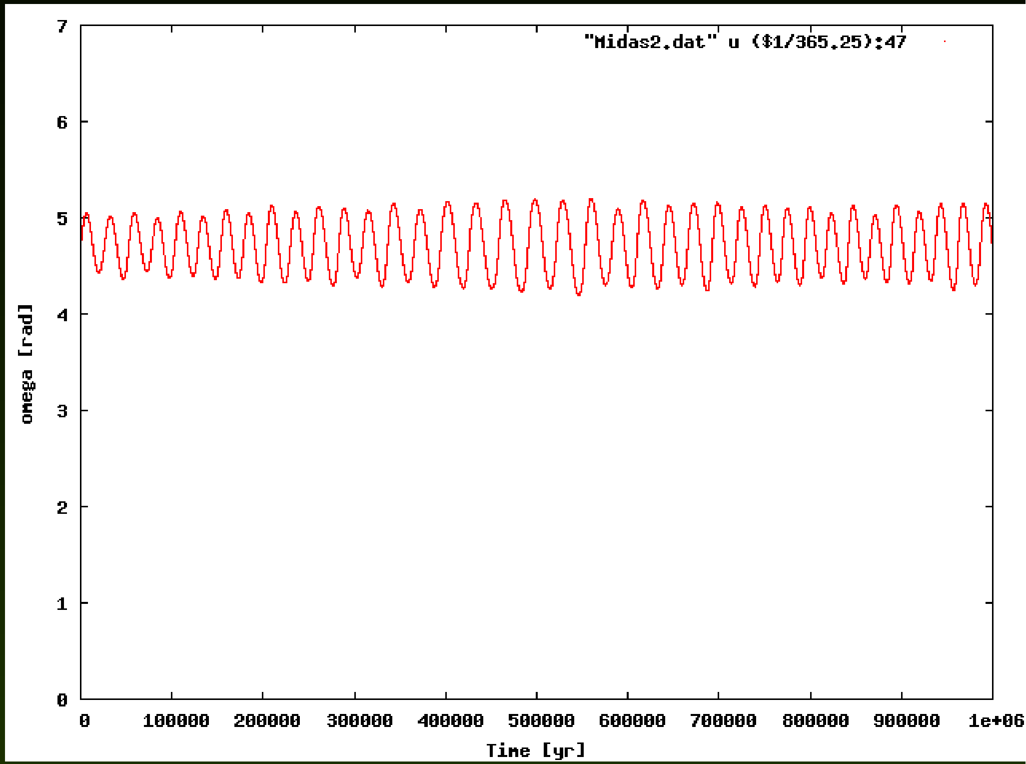
- For main-belt asteroids (a>2 AU) only the former mechanism can work, while among NEAs both are possible.
- With both protection mechanism, during the stay inside the mechanism there are no drastic changes of *a* and the orbits behave as if they were in a meta-stable state.

CALCULATIONS

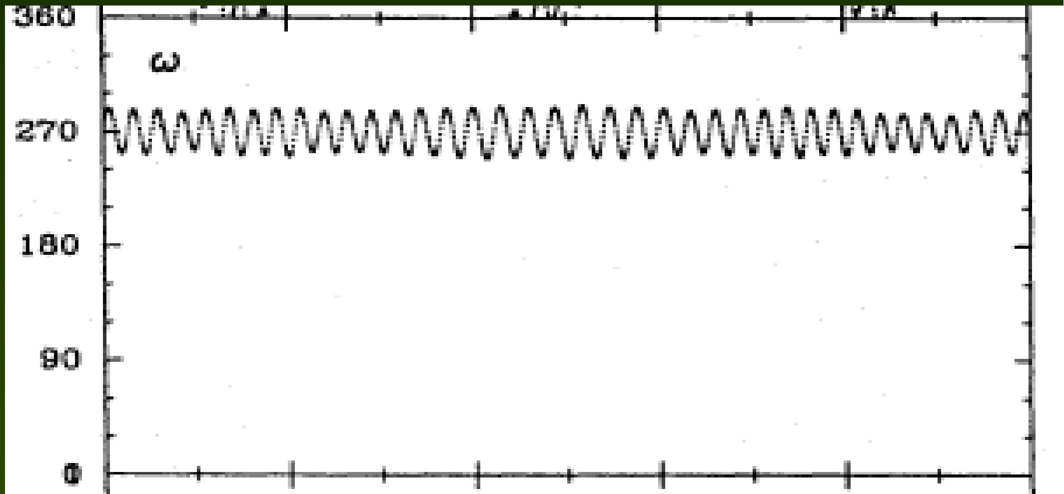
- I use the Bulirsch-Stoer integrator.
- First I examined the same asteroids, which was examined by F. Thomas and P. Michel.
- After that I calculated the orbital elements of other NEAs.
- From the JPL Small-Body Database I found 308 NEAs, whose inclinations are larger than 39.2° and the perihelion distance (*q*) less than 1.3 AU, and 4148 NEAs, whose inclinatons are smaller than 14°.

THE RESULTS OF THE MIDAS

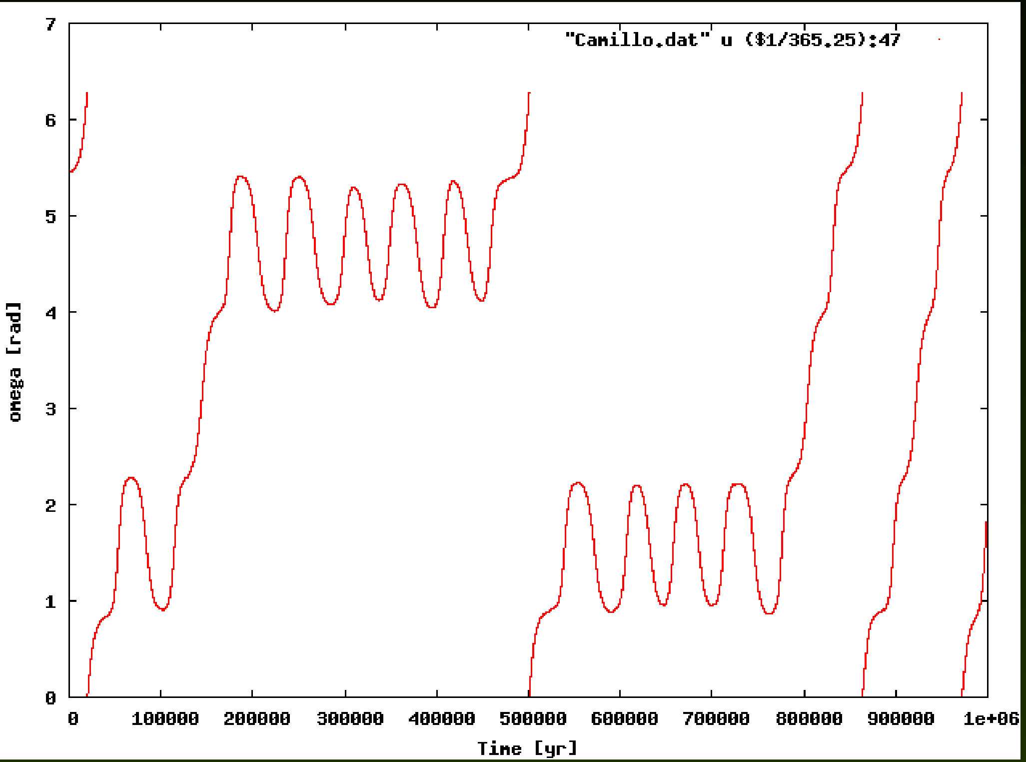


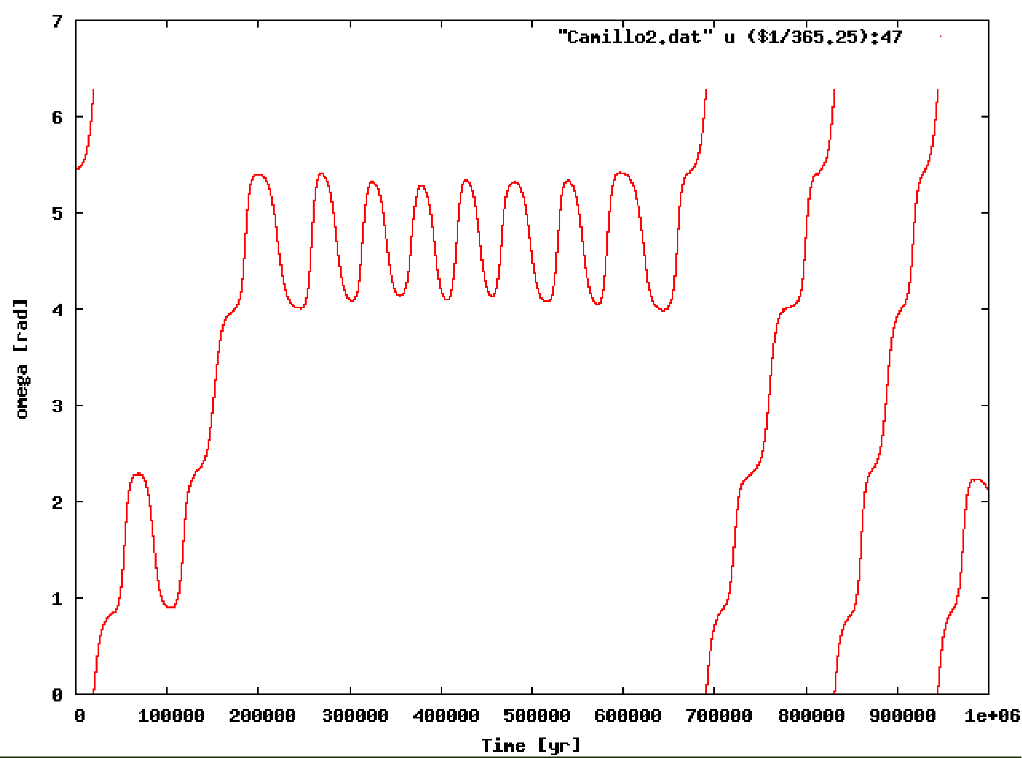


NAME	a [AU]	eccentricity	i [degrees]
Midas	1.776595022845237	0.6498599909312371	39.84193586342156
Midas2	1.7765951	0.6498599	39.83566

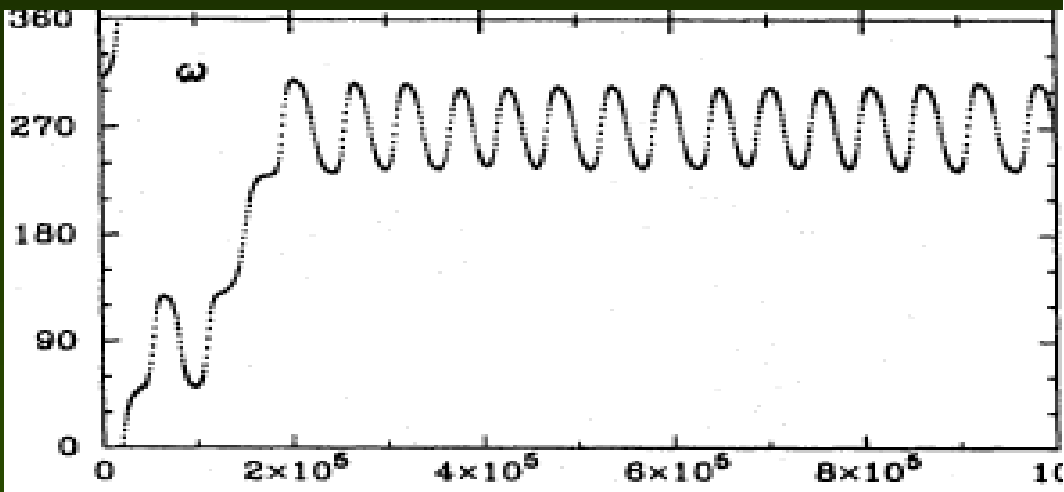


THE RESULTS OF THE CAMILLO

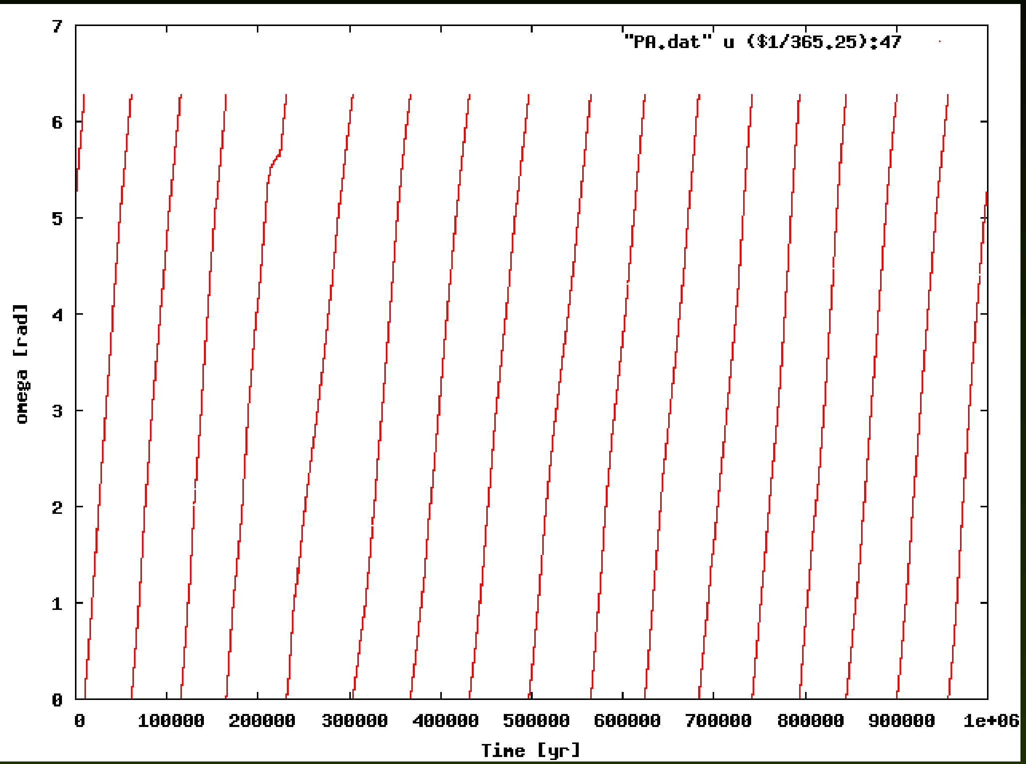


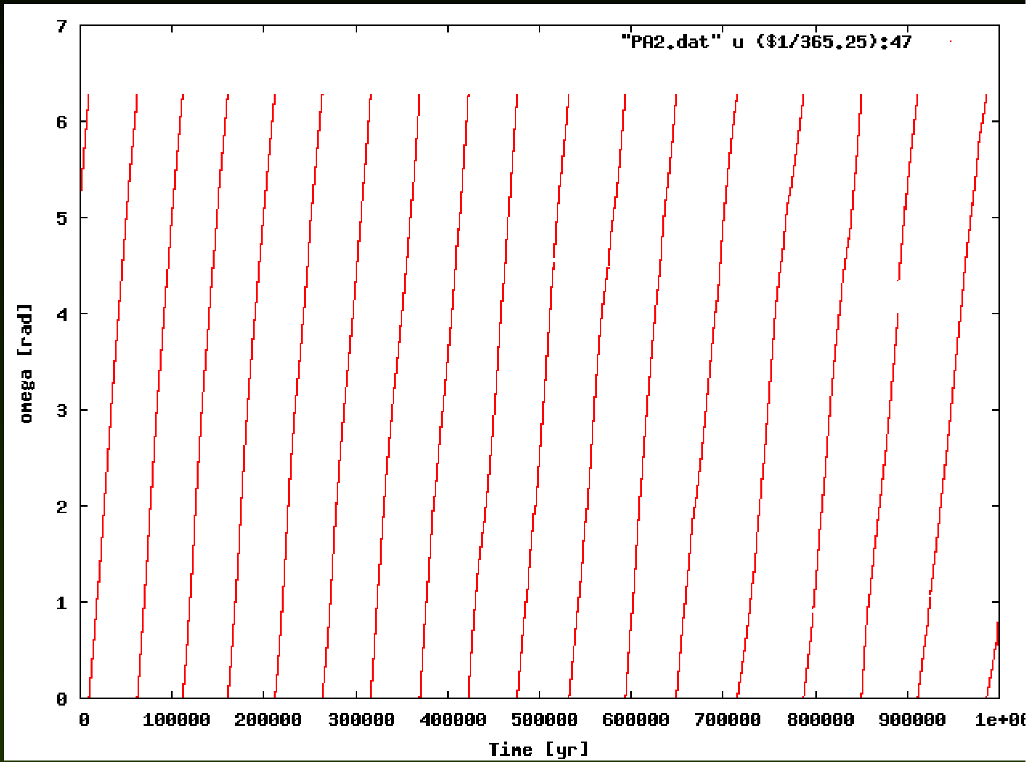


NAME	a [AU]	eccentricity	i [degrees]
Camillo	1.413591762956653	0.3024917085671500	55.54910918690051
Camillo2	1.4135920	0.3024920	55.55464

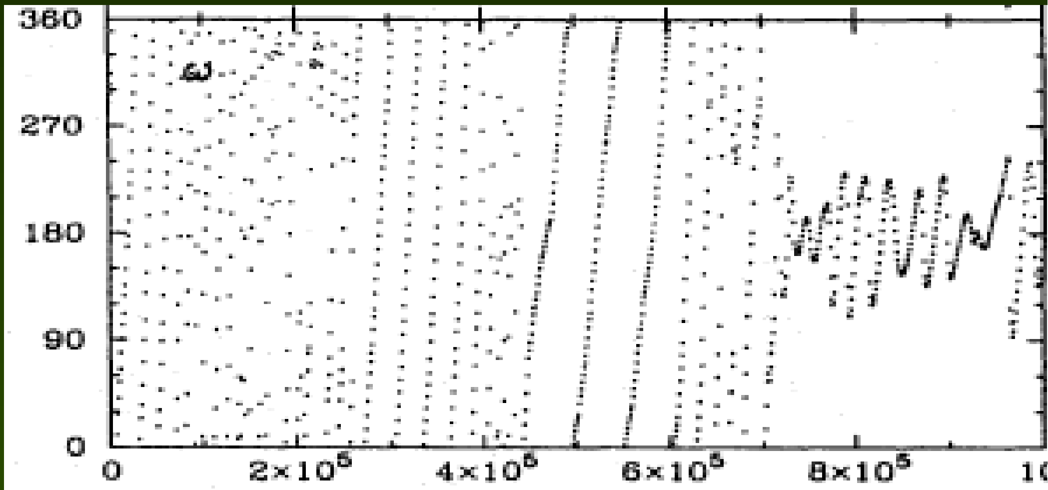


THE RESULTS OF THE PA

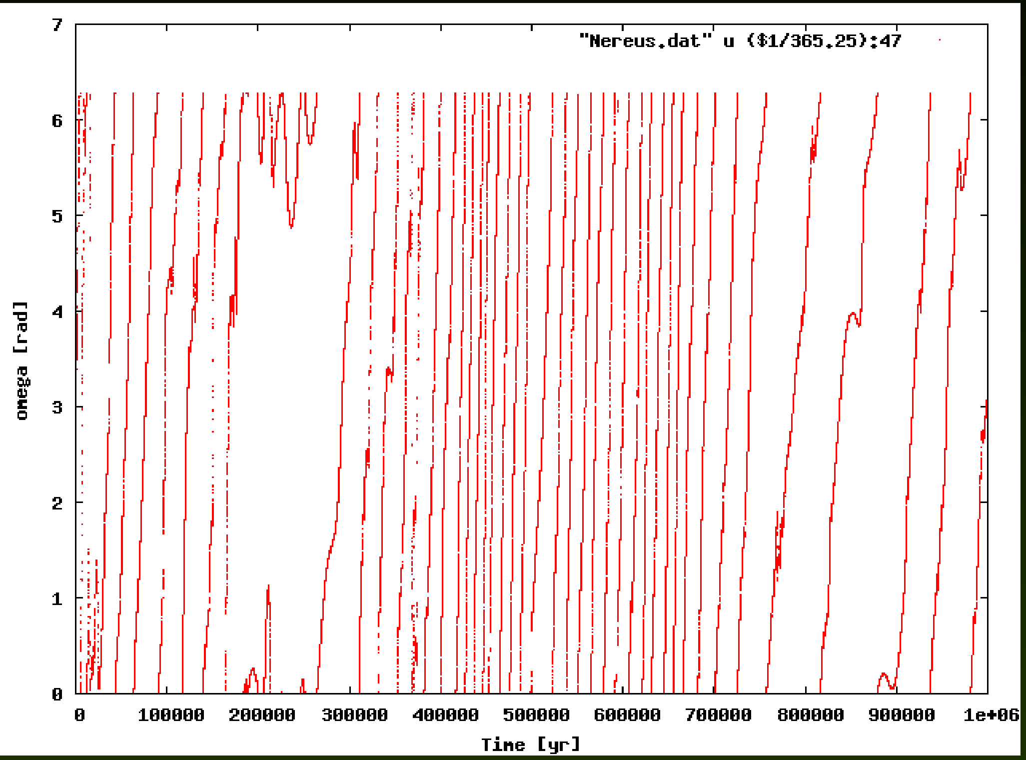


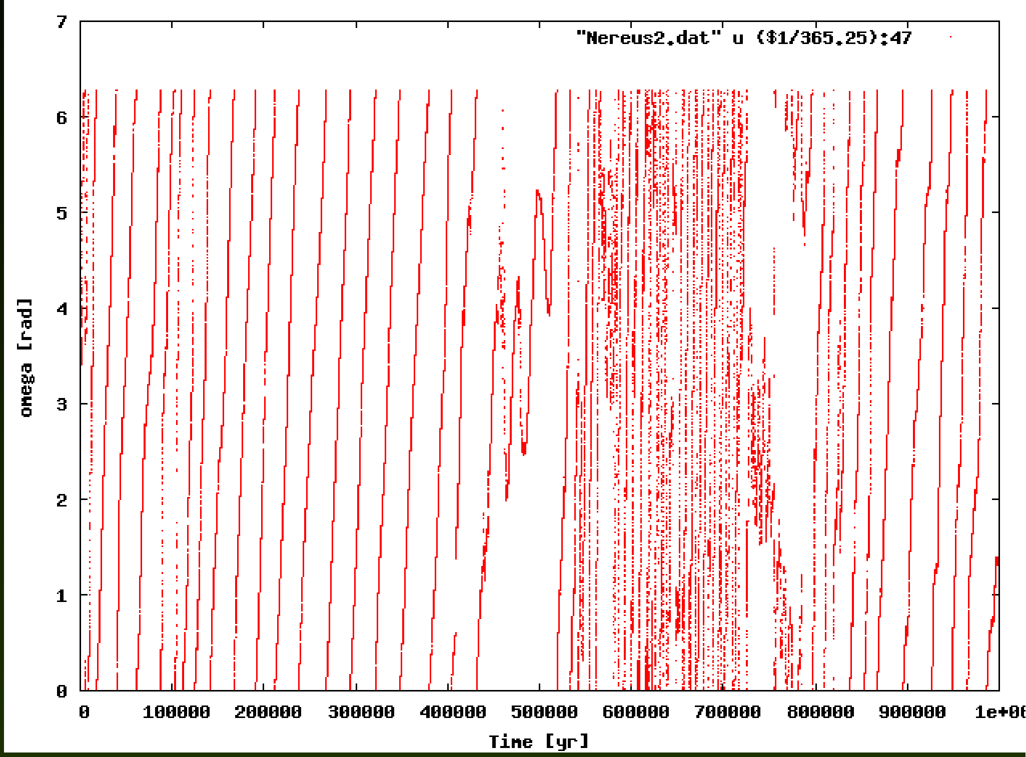


NAME	a [AU]	eccentricity	i [degrees]
PA	1.059992185546568	0.4440767869470404	11.16639099227798
PA2	1.0599923	0.4440787	11.17259

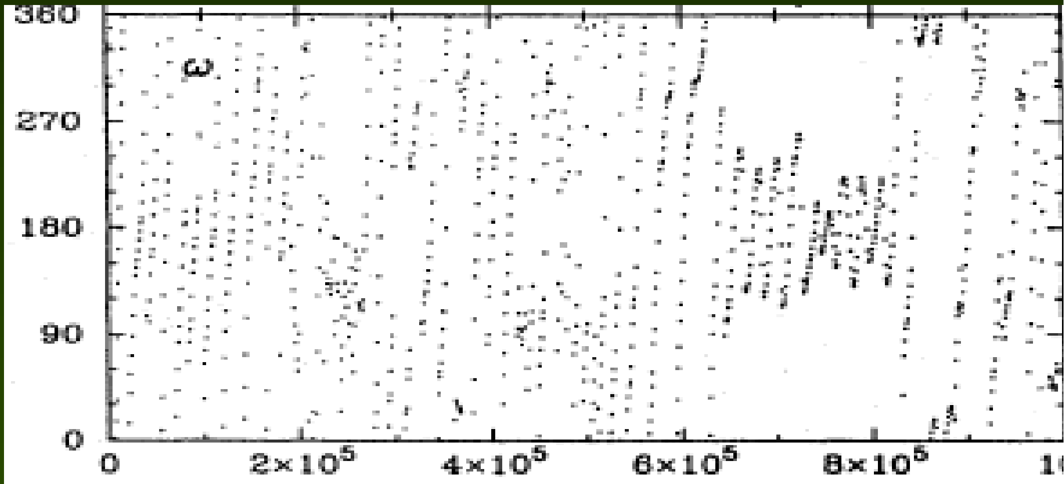


THE RESULTS OF THE NEREUS

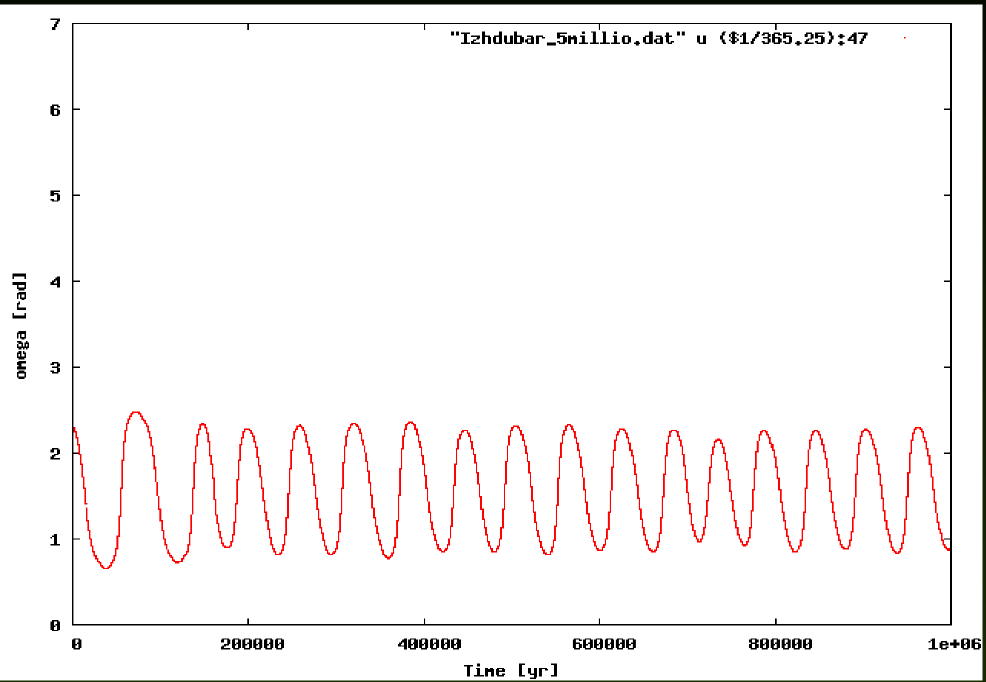


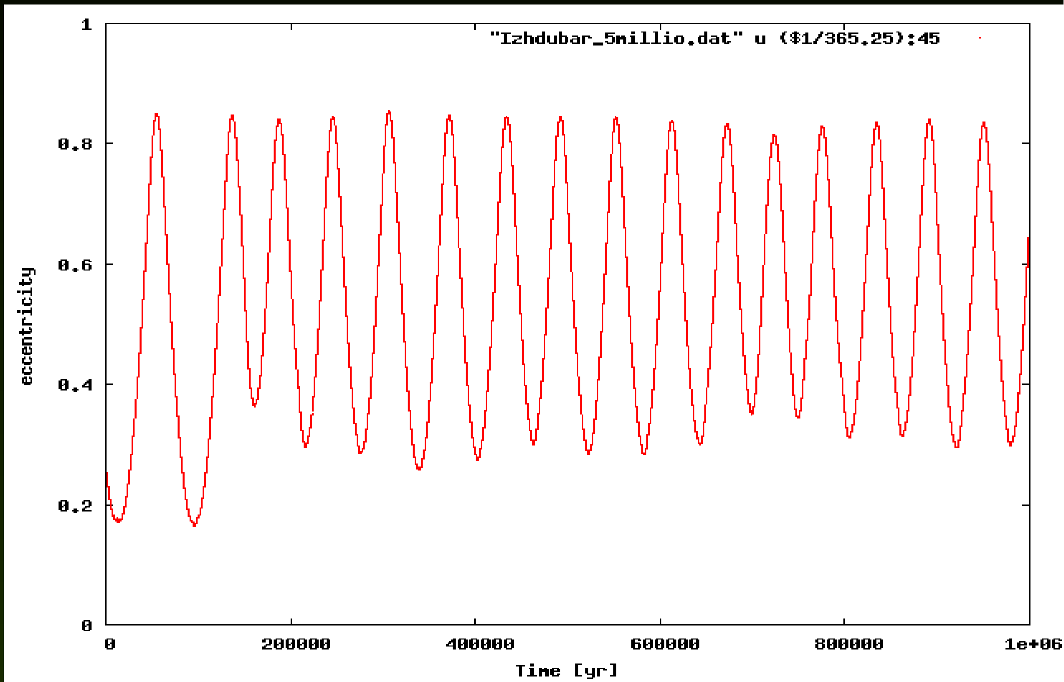


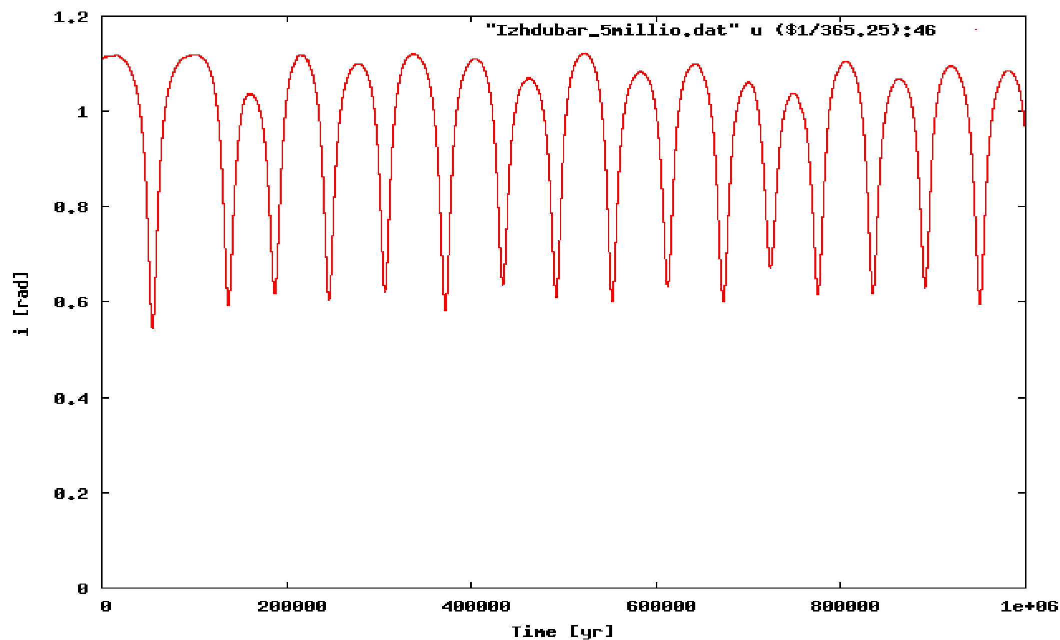
NAME	a [AU]	eccentricity	i [degrees]
Nereus	1.489601251363717	0.3602629191491443	1.424906420011550
Nereus2	1.4896013	0.36022636	1.42495



THE RESULTS OF THE IZHDUBAR

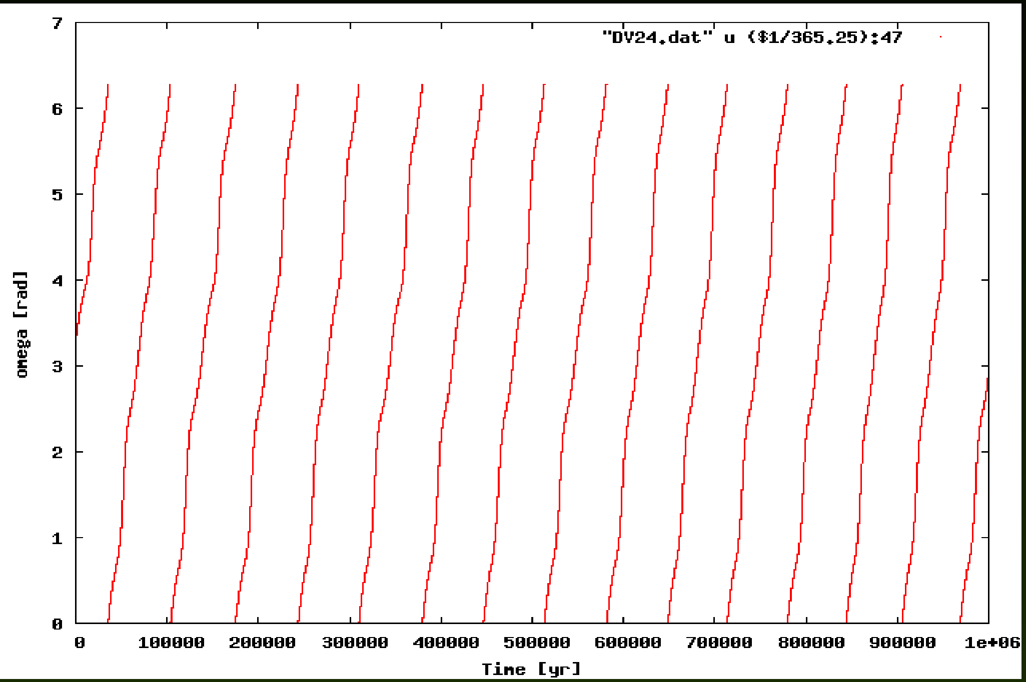


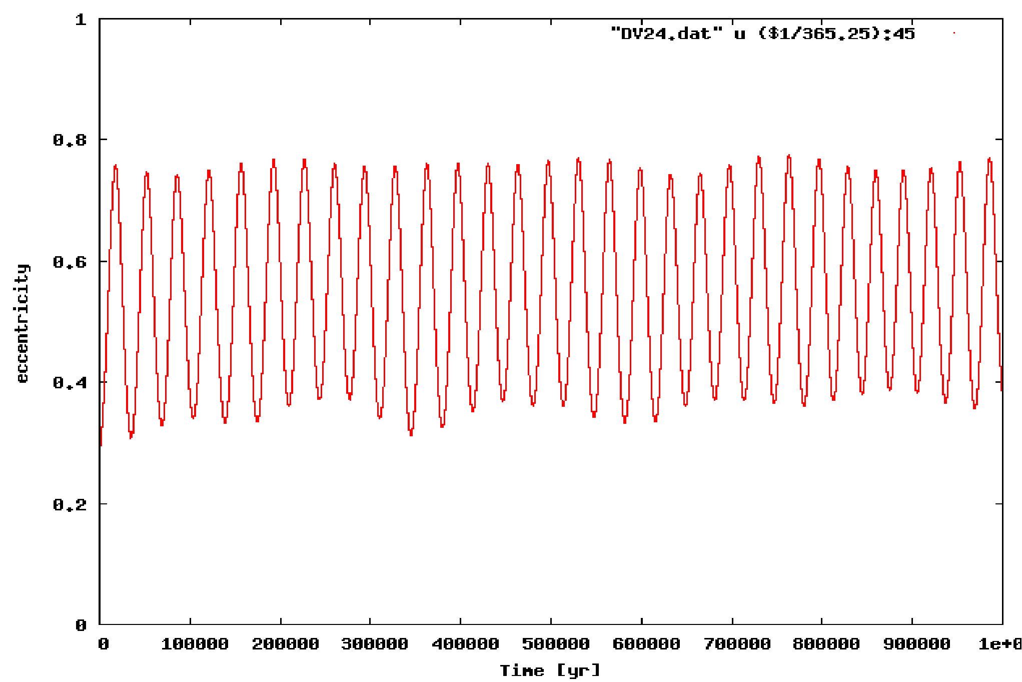


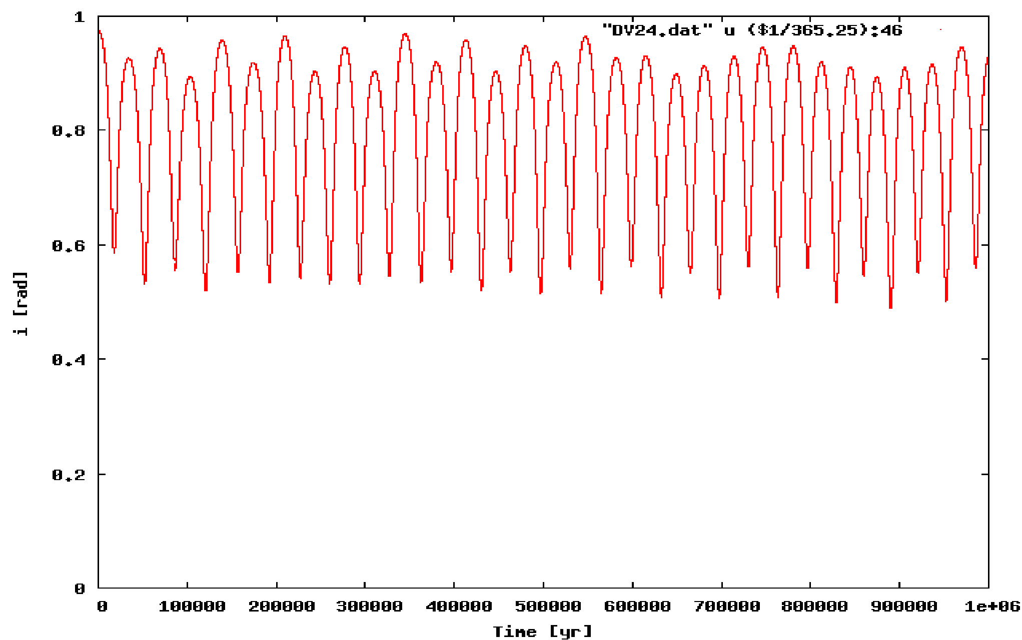


NAME	a [AU]	eccentricity	i [degrees]
Izhdubar	1.006834525734709	0.2664425906880701	63.46087473524871

THE RESULTS OF THE DV24

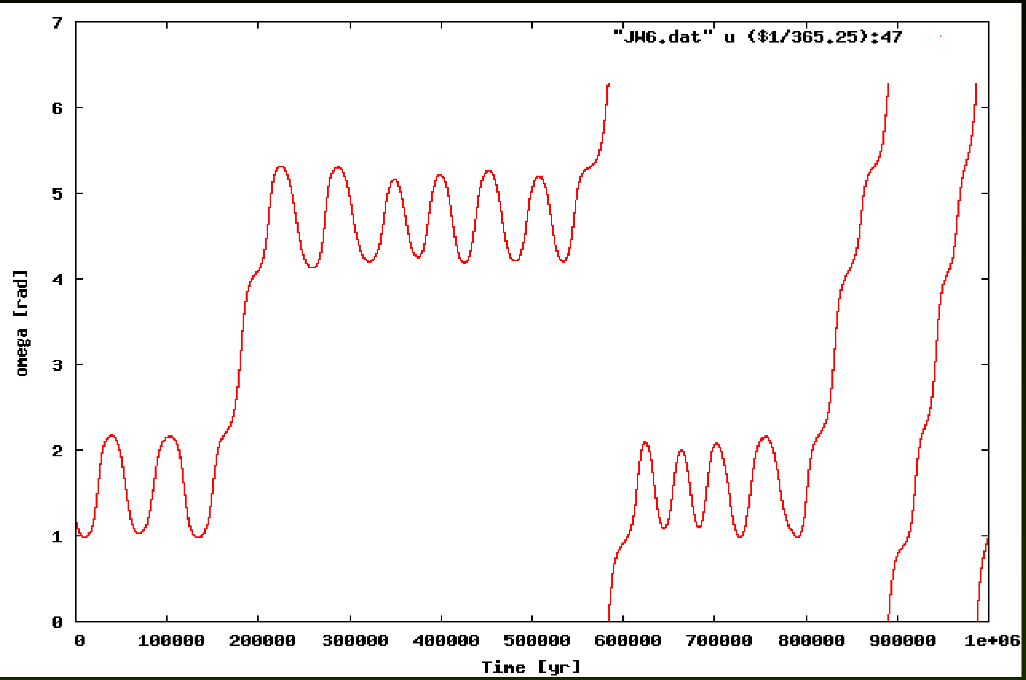


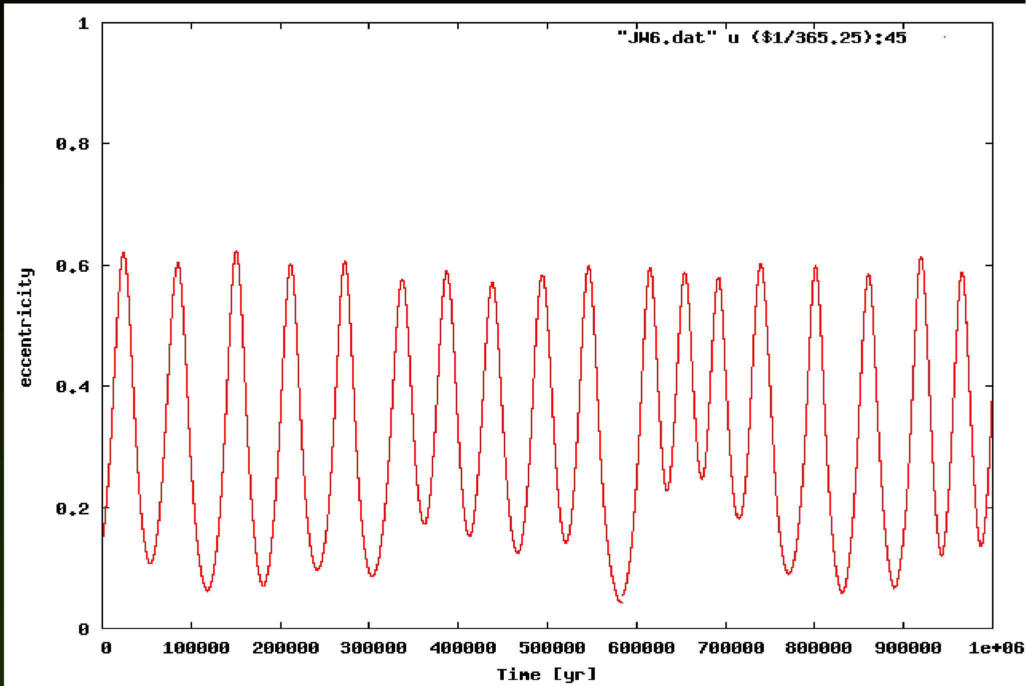


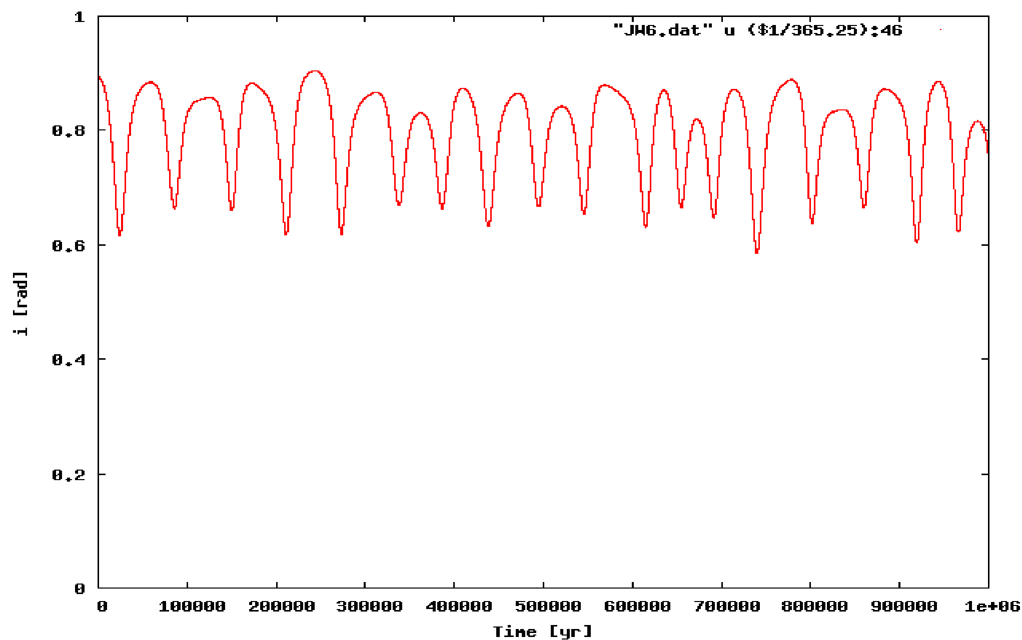


NAME	a [AU]	eccentricity	i [degrees]
DV24	1.422578254365016	0.2896151710046383	55.89939817545726

THE RESULTS OF THE JW6

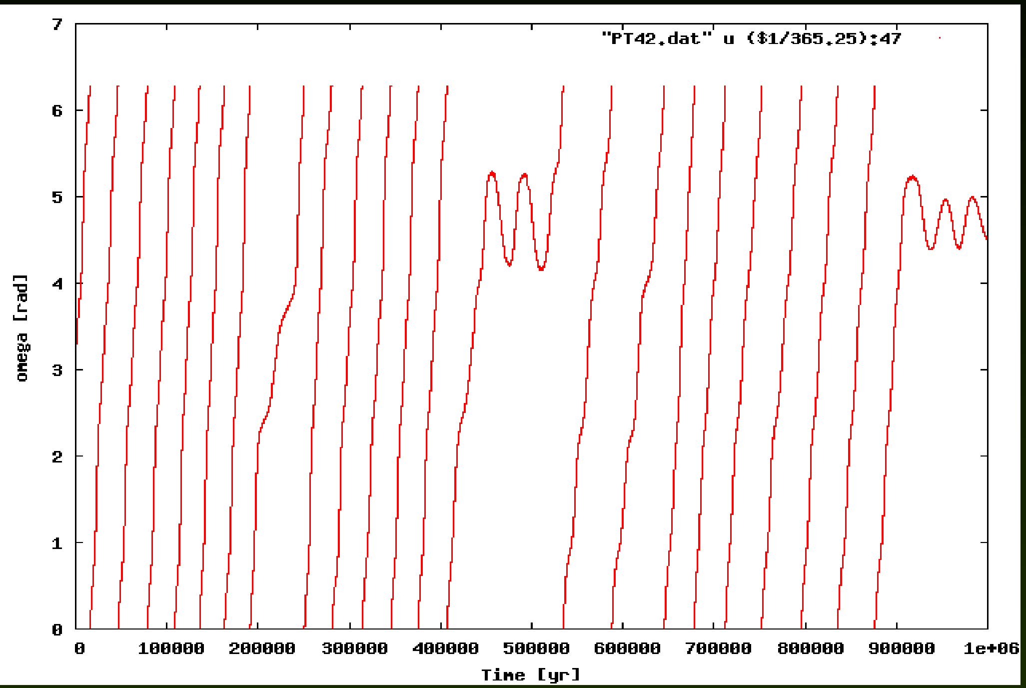


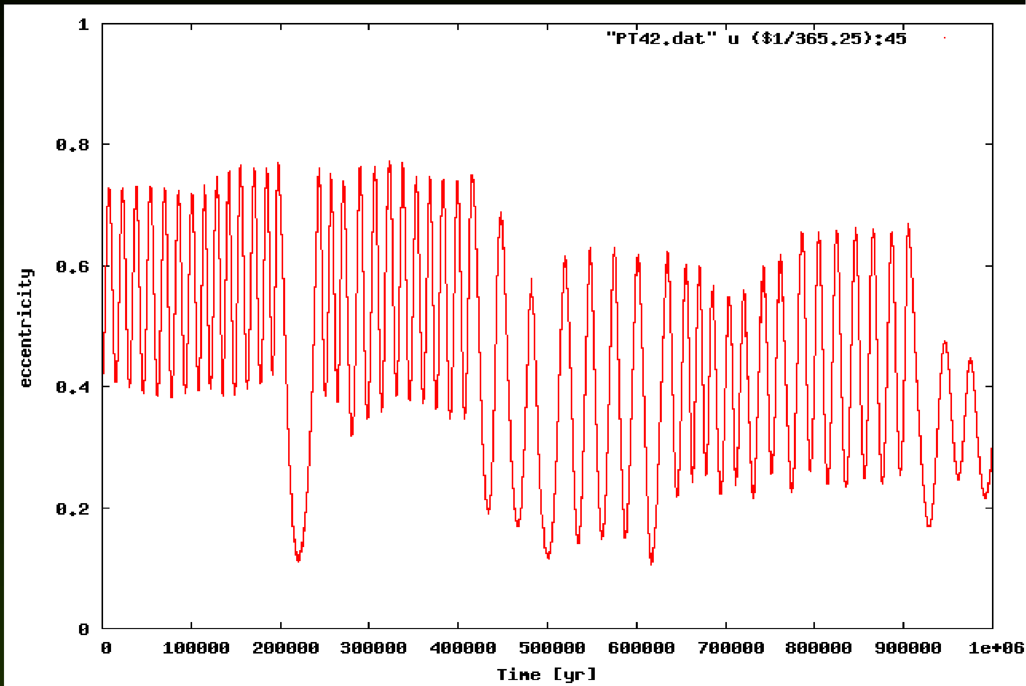


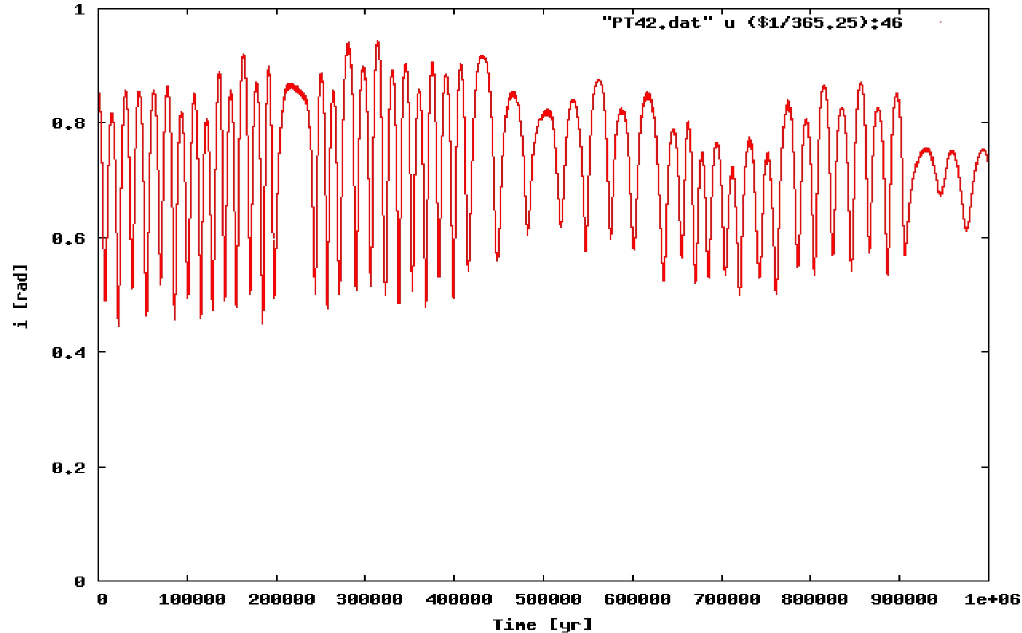


NAME	a [AU]	eccentricity	i [degrees]
JW6	1.507556461473791	0.1432431155972179	51.31061663864608

THE RESULTS OF THE PT42

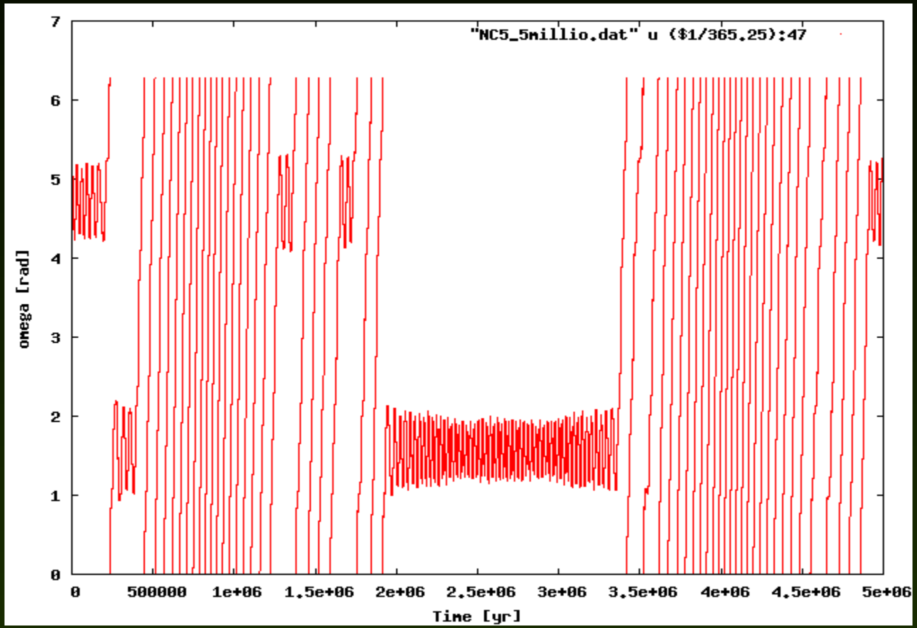


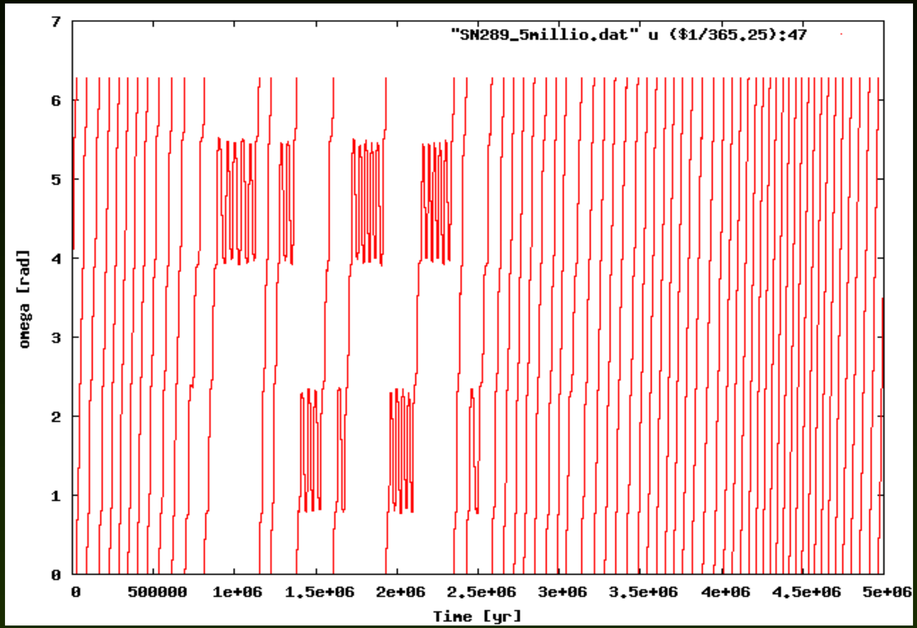


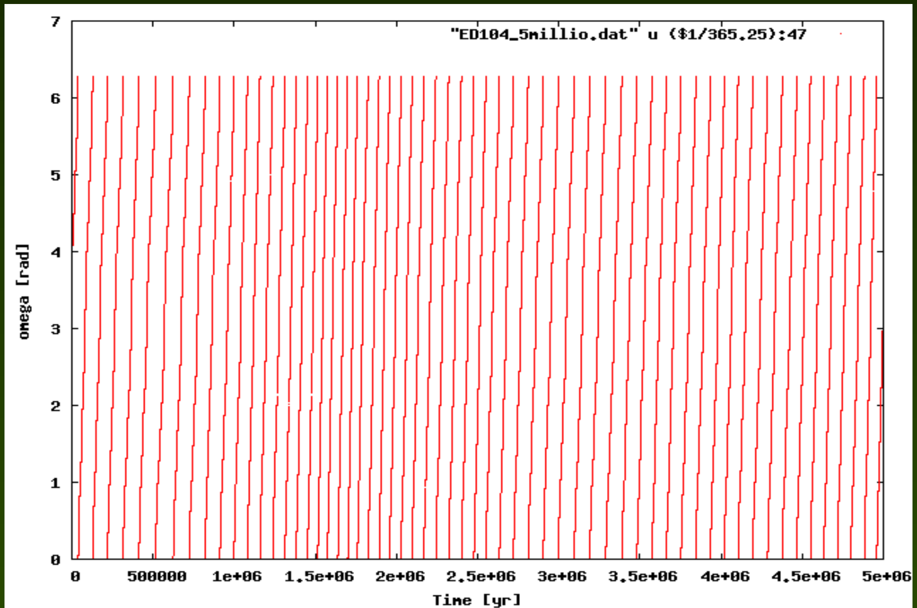


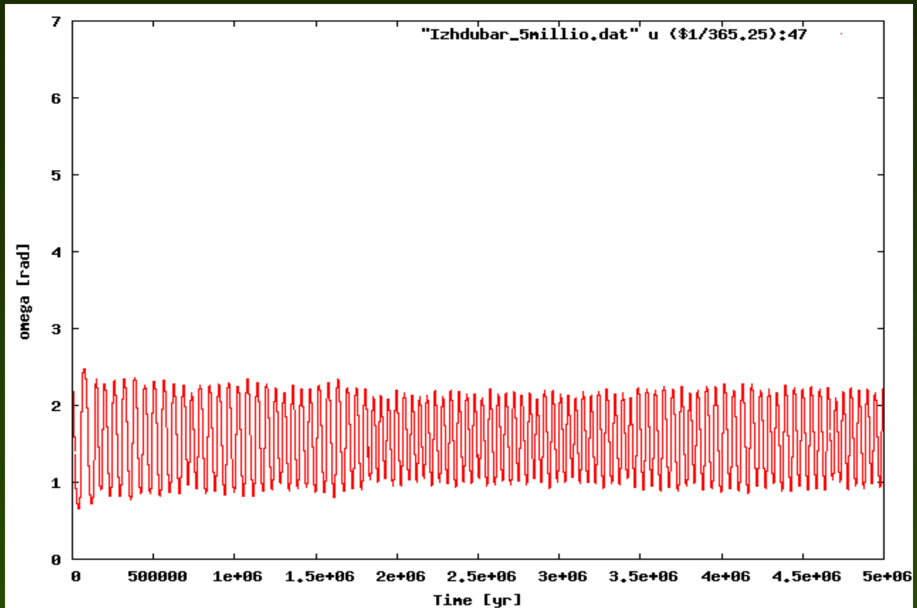
NAME	a [AU]	eccentricity	i [degrees]
PT42	2.012641572257746	0.4160378928428576	48.90147721364274

FOR 5 MILLIO YR: NC5, SN289, ED104, IZHDUBAR

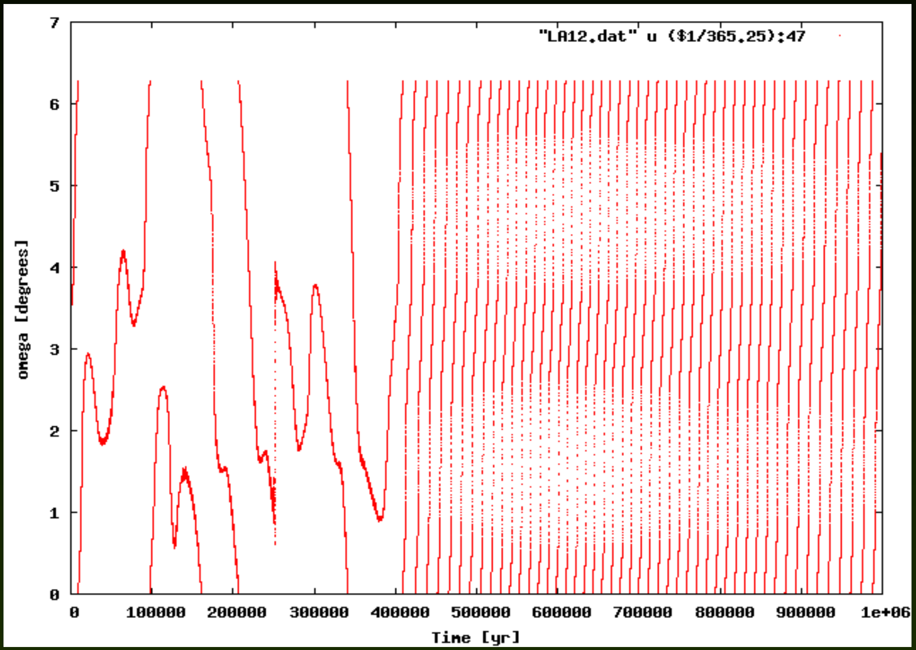


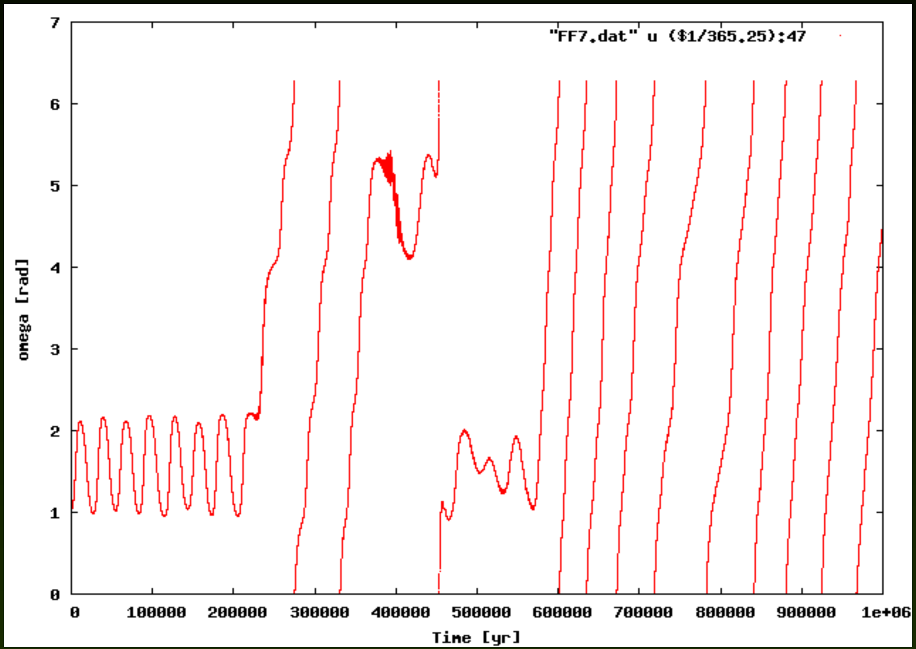


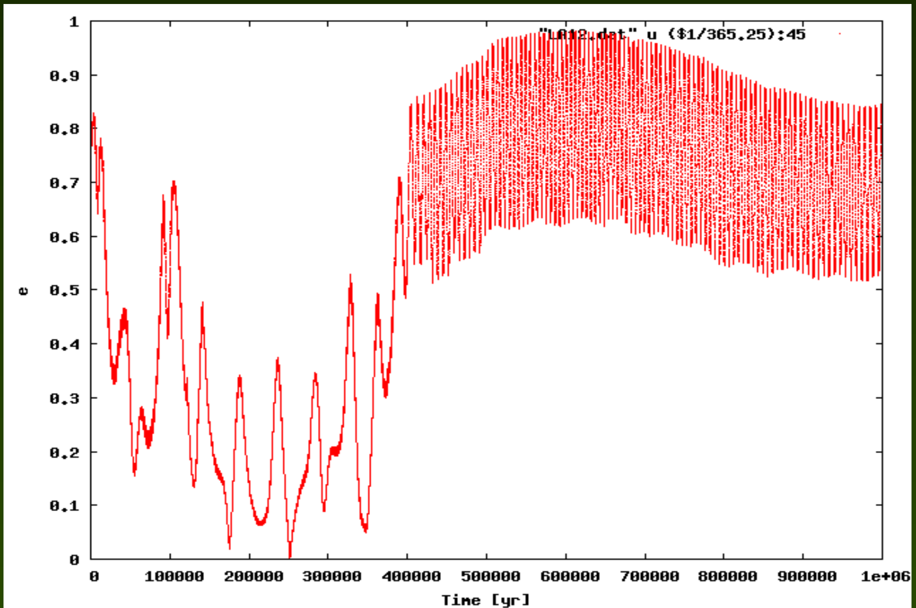


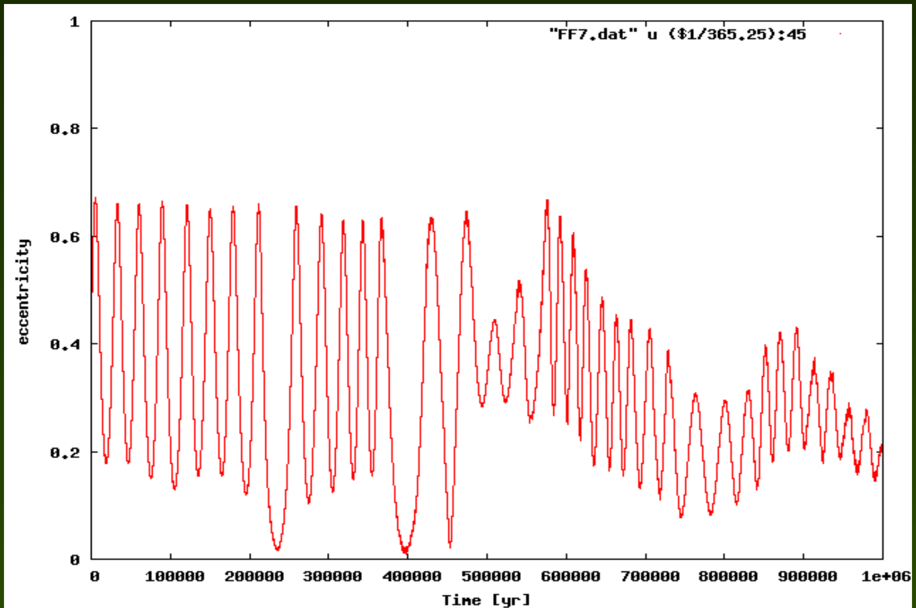


INTERESTING RESULTS: LA12, FF7



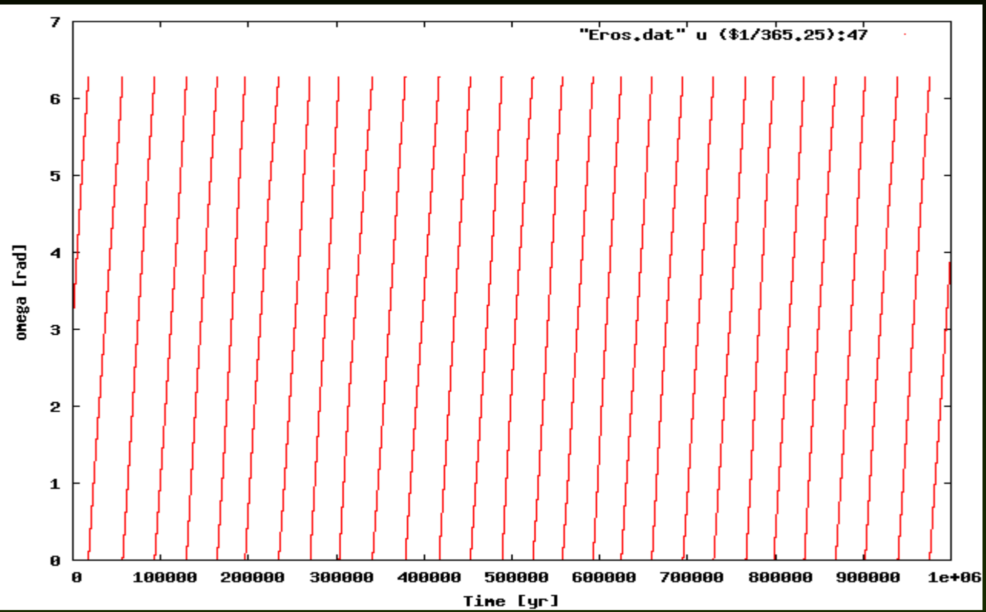


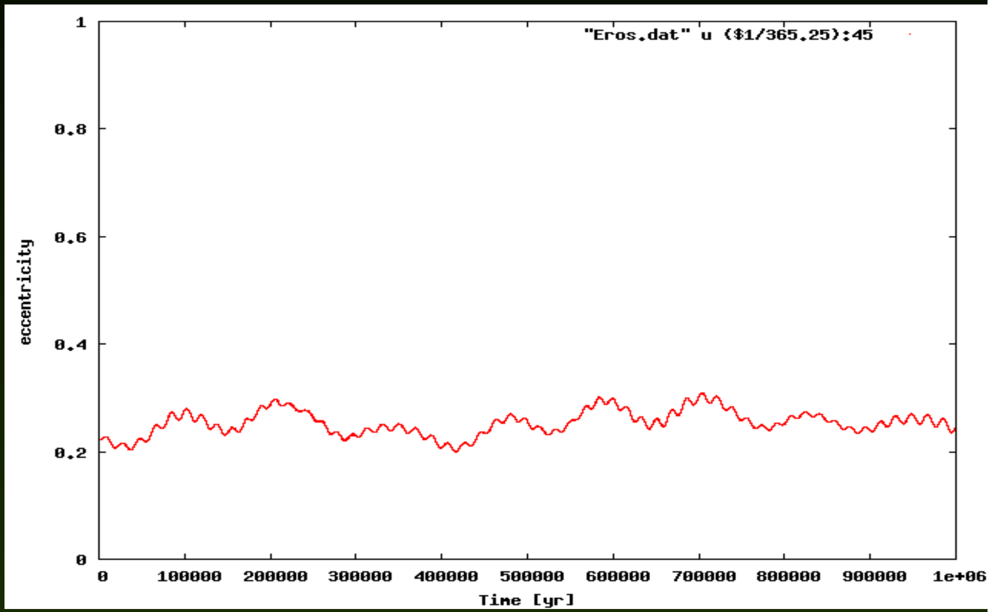




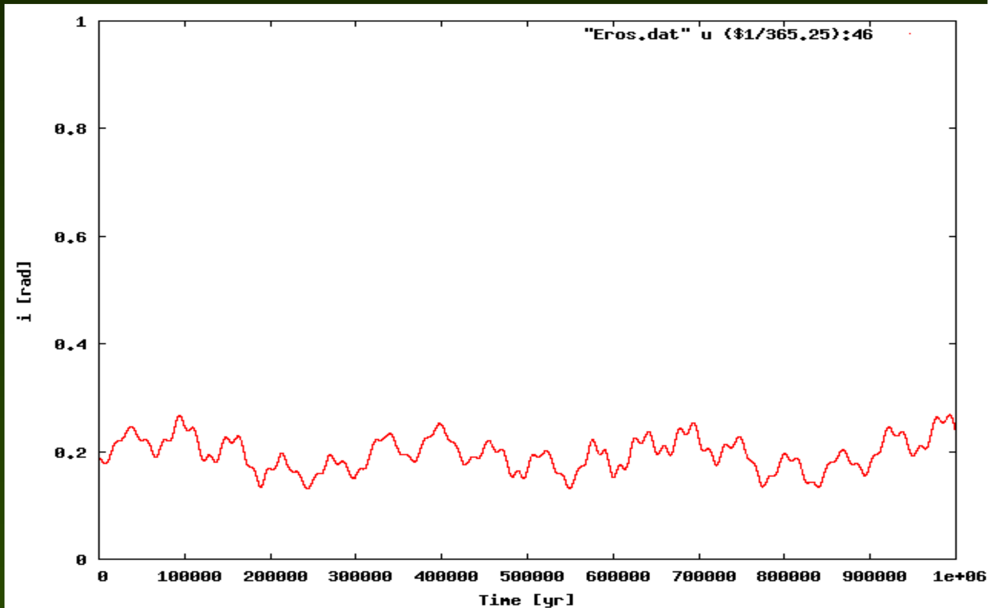
Thank you for your attention!

WHEN THE INCLINATION IS SMALLER THAN 14°



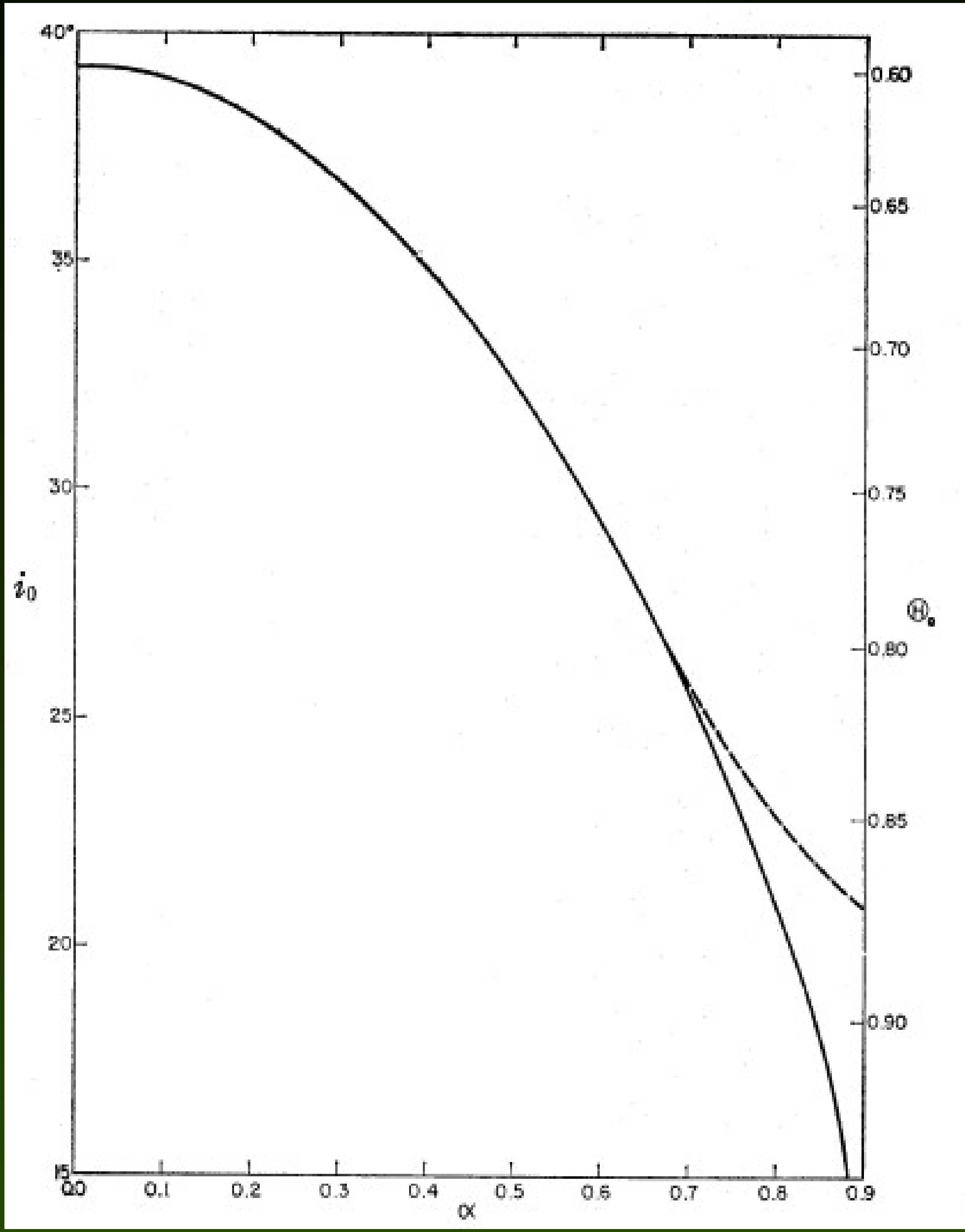


NAME	a [AU]	eccentricity	i [degrees]
Eros	1.458104555229334	0.2227892848124254	10.82931703593923



Critical inclination: 39.2°

- The equation of motion has a stacionary solution when H is equal to or smaller than a limiting value H_0.
- The corresponding inclination is derived by H_0=L*cosi_0.
- Both H_0 and i_0 depend on α and are derived by numerical harmonic analysis of ∂W*/∂G*.



The FF7 asteroid: