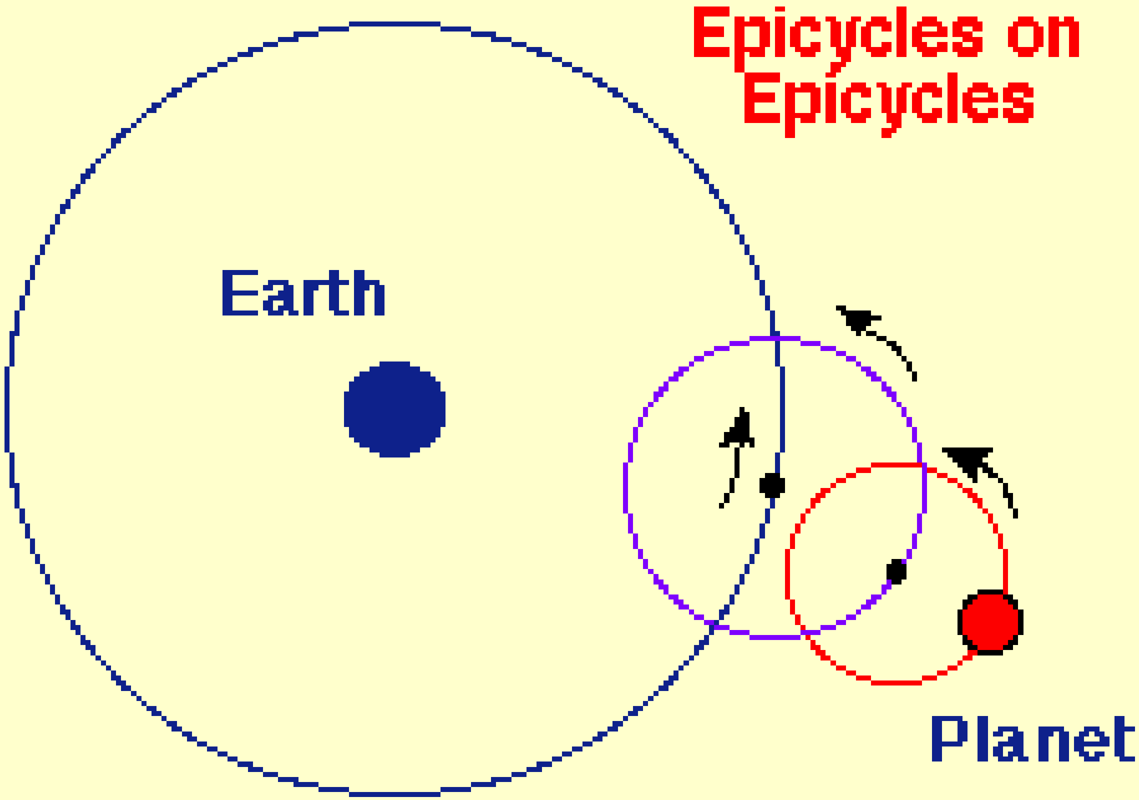
ASTRONOMIA DINÂMICA
ou
MECÂNICA CELESTE

Sylvio Ferraz Mello
Universidade de Sao Paulo

23h00m
22h30m
22h00m
-5°
-10°
-15°
-20°
φ Aqr
λ Aqr
θ Aqr
ψ3 Aqr
ECLIPTIC
σ Aqr
τ2 Aqr
ι Aqr
♂
δ Aqr
66 Aqr
88 Aqr
89 Aqr
2003-06-15

PRE-NEWTONIAN KINEMATICS

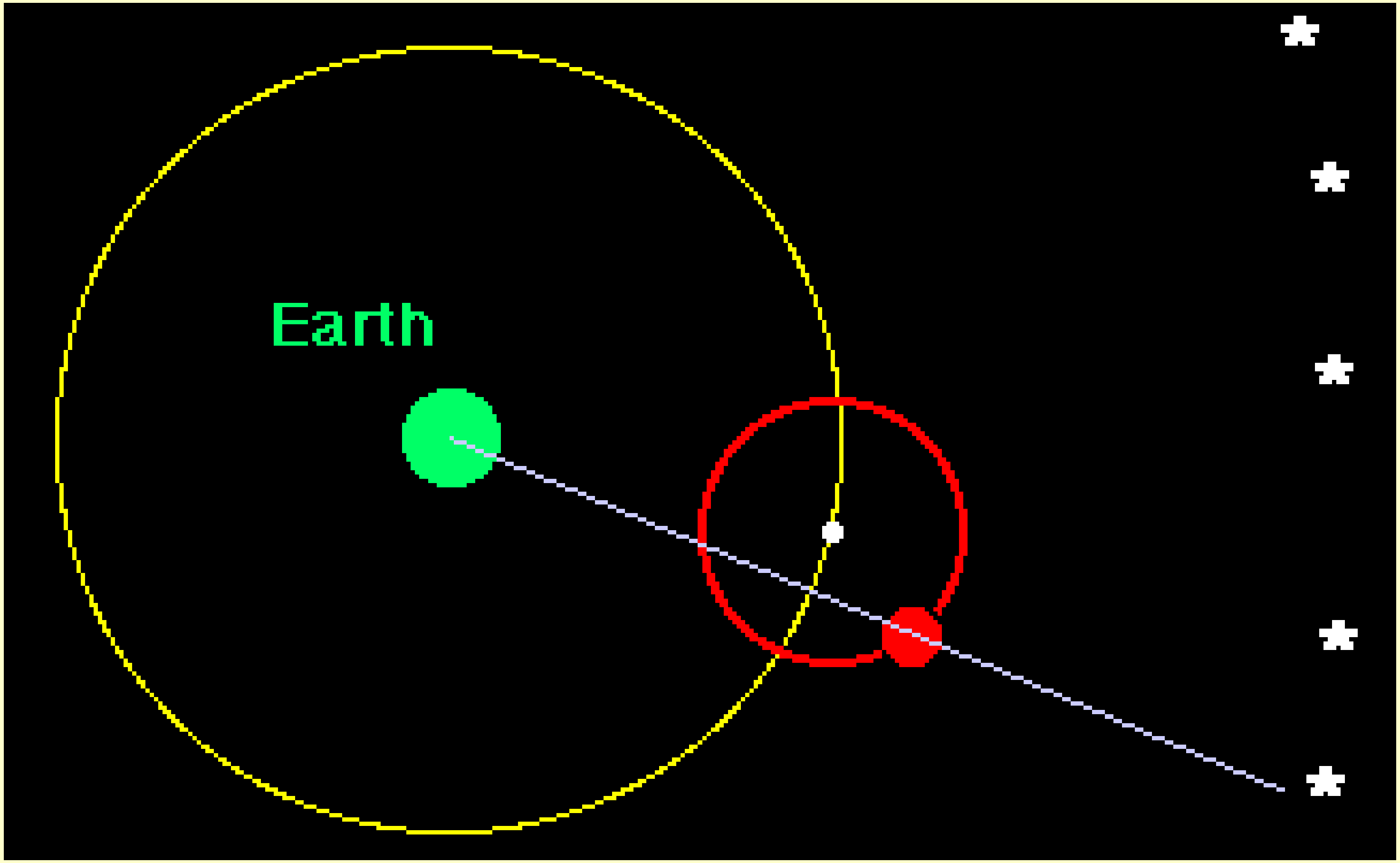


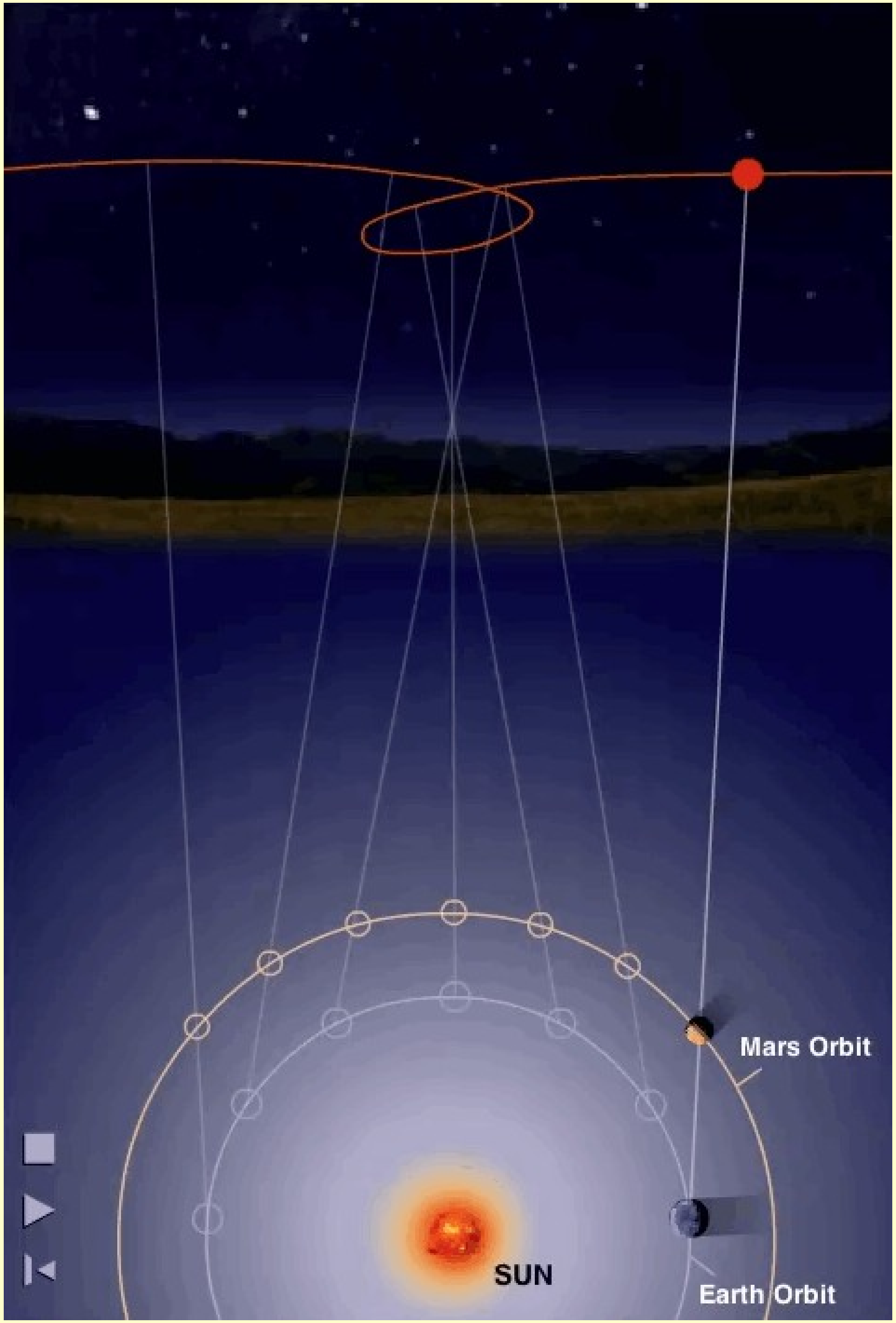
Apolonius of Perga

Ptolemy

Equivalent to modern trigonometrical series

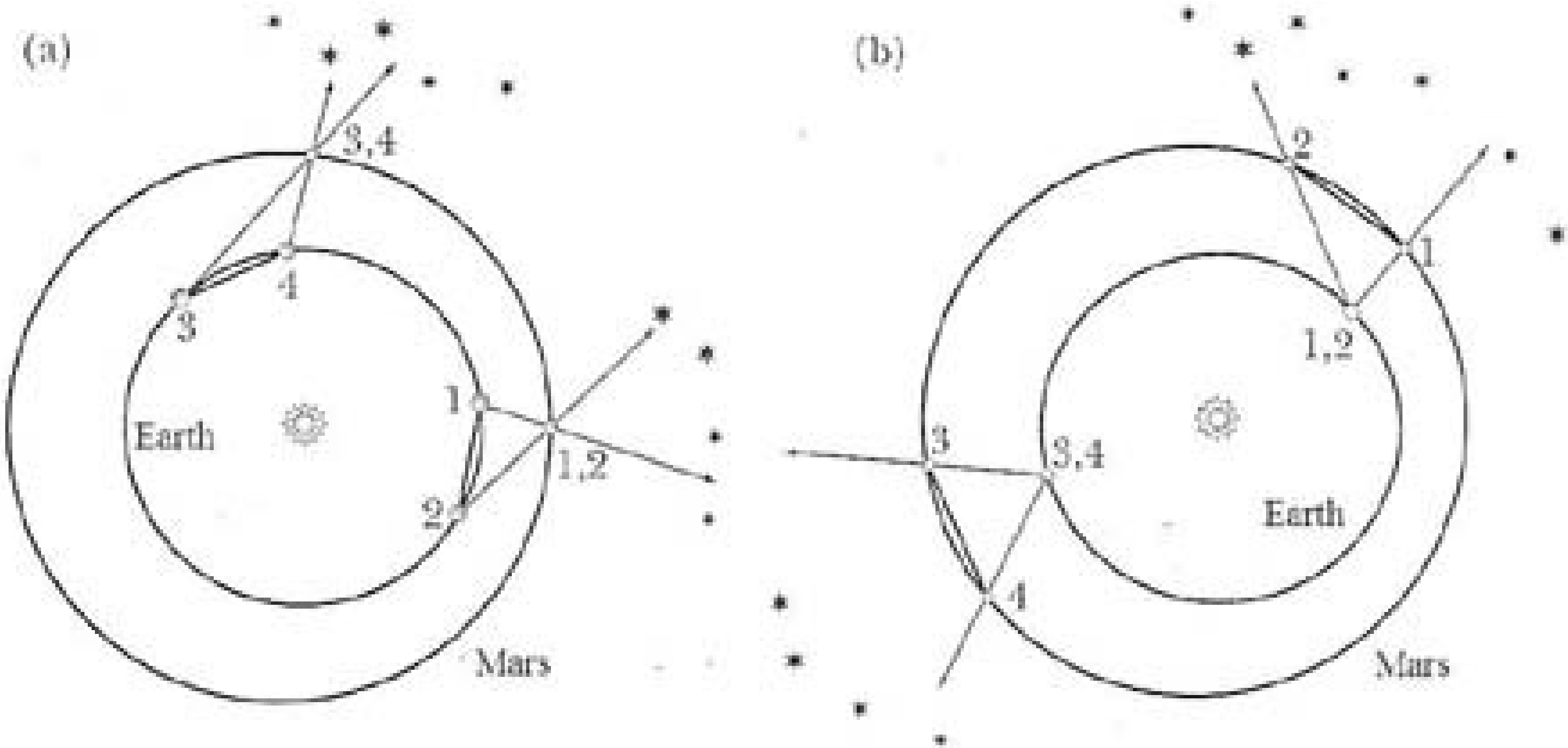
$$F = \sum_{i=0}^{n} A_k \begin{matrix} \sin \\ \cos \end{matrix} f_k t$$


Earth



Copérnico

TYCHO BRAHE > KEPLER



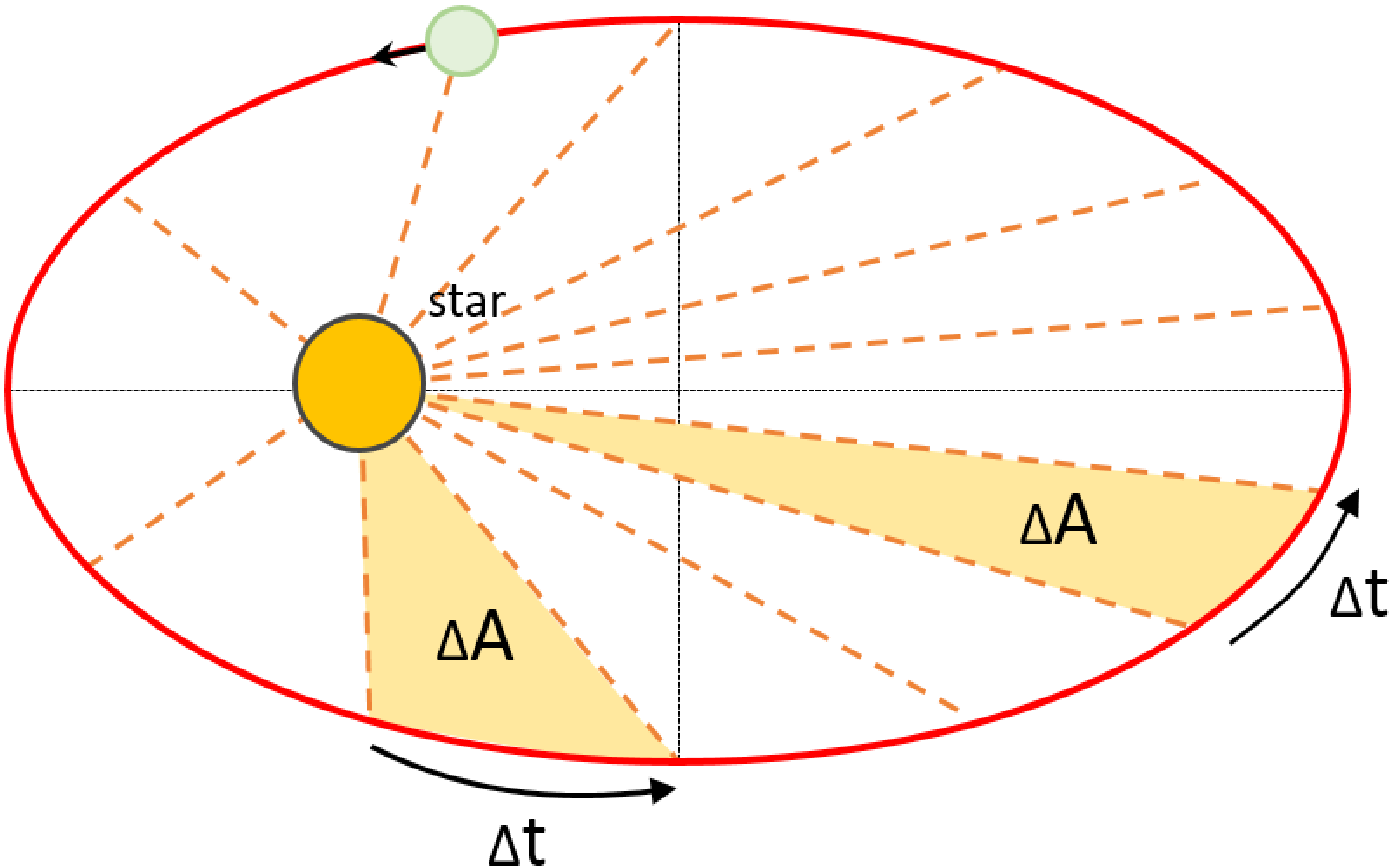
KEPLER LAWS

First Law (1609):

The planets move on ellipses with one focus in the Sun.

Second Law (1609):

Equal areas are swept in equal times

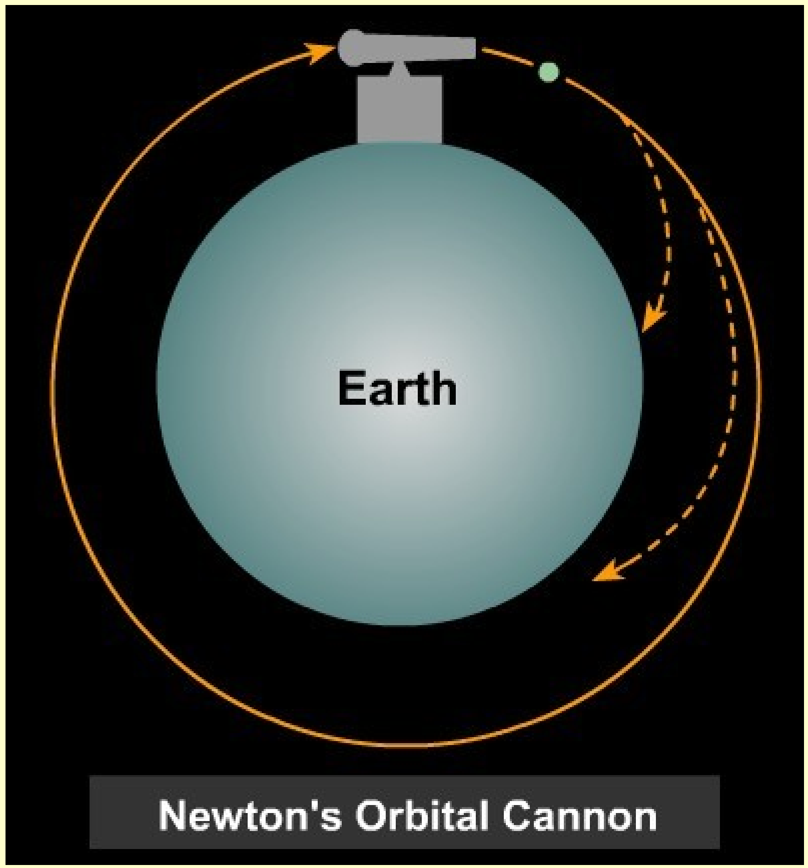

star
ΔA
ΔA
Δt
Δt

KEPLER'S THIRD LAW (1619)

The ratio of the cube of the semi-major axes of the ellipse to the square of the periods of the planetary motions is constant and the same for all planets.

$$\frac{a_1^3}{T_1^2} = \frac{a_2^3}{T_2^2} \qquad \text{alias} \qquad \frac{a^3}{T^2} = \frac{G(M+m)}{4\pi^2}$$

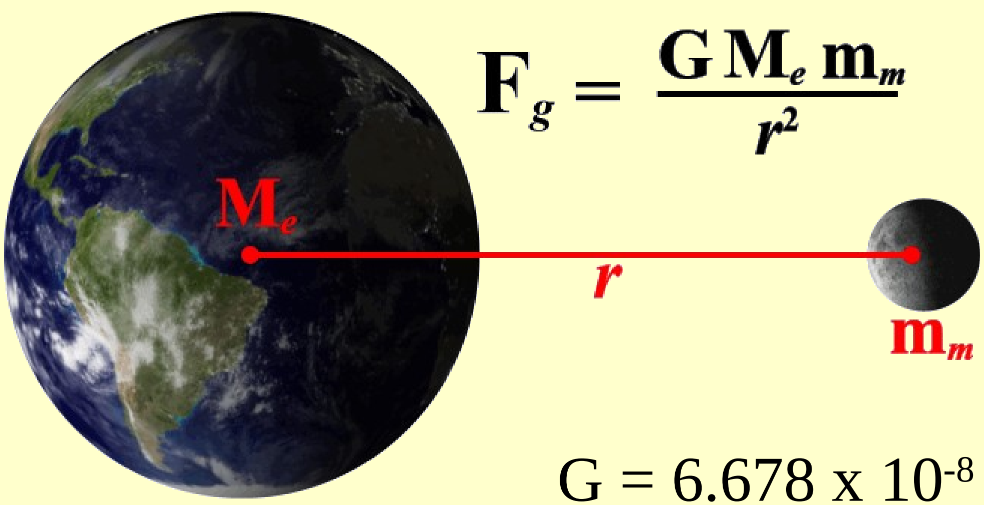
NEWTONIAN CELESTIAL MECHANICS



<u>Law of Universal Gravitation (1687)</u>

Bodies attract themselves mutually with a force proportional to their masses and inversely proportional to the square of the distance between them.

$$F_g = \frac{G M_e m_m}{r^2}$$



G = 6.678 x 10^{-8} (cgs)

Applications

Newton: Moon, Polar flattening of the Earth
Halley comet (1531, 1607, 1682) => 1758
Lagrange, Laplace, ...
Leverrier: Inequalities in the motion of Uranus and prediction/discovery of Neptune.

Celestial Mechanics after EINSTEIN

What was known at the end of the XIXth century

Motion of Mercury's perihelion:

- due to Venus .... 277 arcsec/cy
- due to Jupiter..................................... 153 arcsec/cy
- due to the Earth.................................. 90 arcsec/cy
- due to Mars .... 10 arcsec/cy

sum .... **530** arcsec/cy

Observed .... **570** arcsec/cy

General Theory of Relativity (1915)

The planetary ellipses precessions

Mercury .... 42.98 arcsec/cy
Venus 8.62
Earth 3.84
Mars 1.35

Schwarzschild solution (1916)

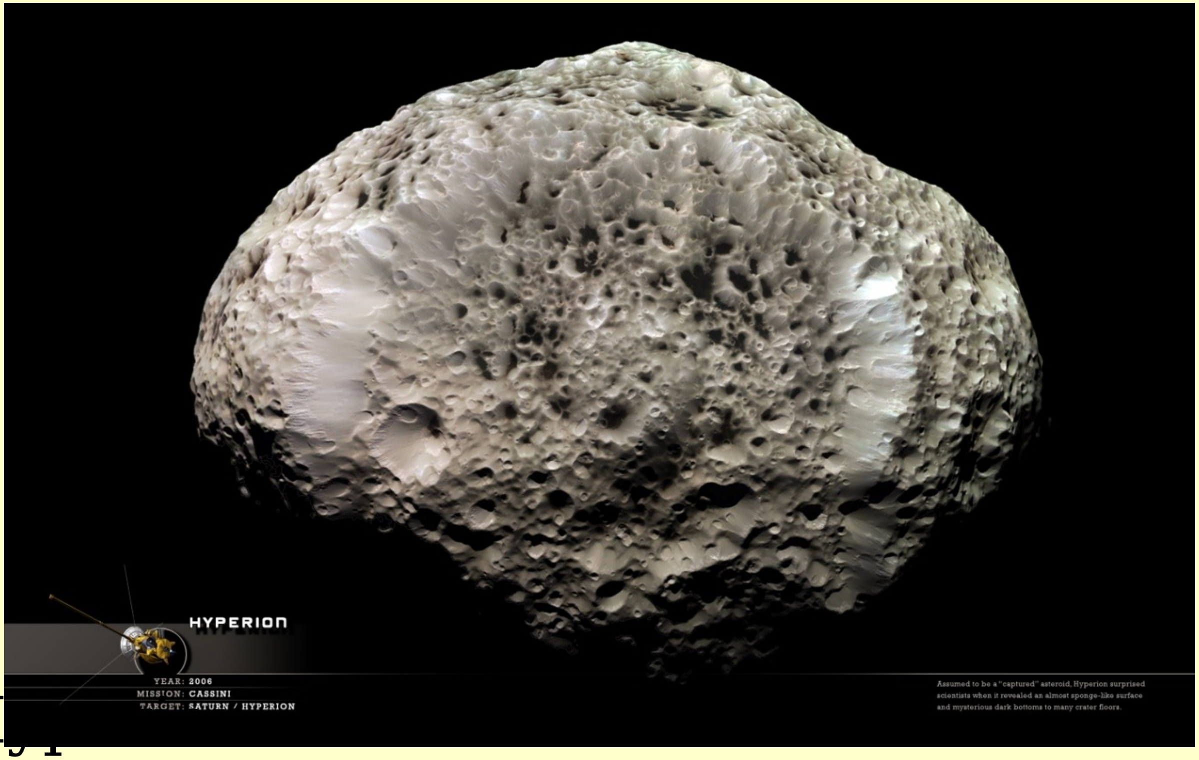
N-body: De Sitter, Eddington (1938), Einstein,Infeld,Hoffman (id.)

Included currently in all ephemerides of the Solar System bodies.

Kerr solution (1943) [rotating body]

CHAOS

The solutions of the equations of CM show great sensitivity to initial conditions: very close initial conditions may lead to totally different evolutions.

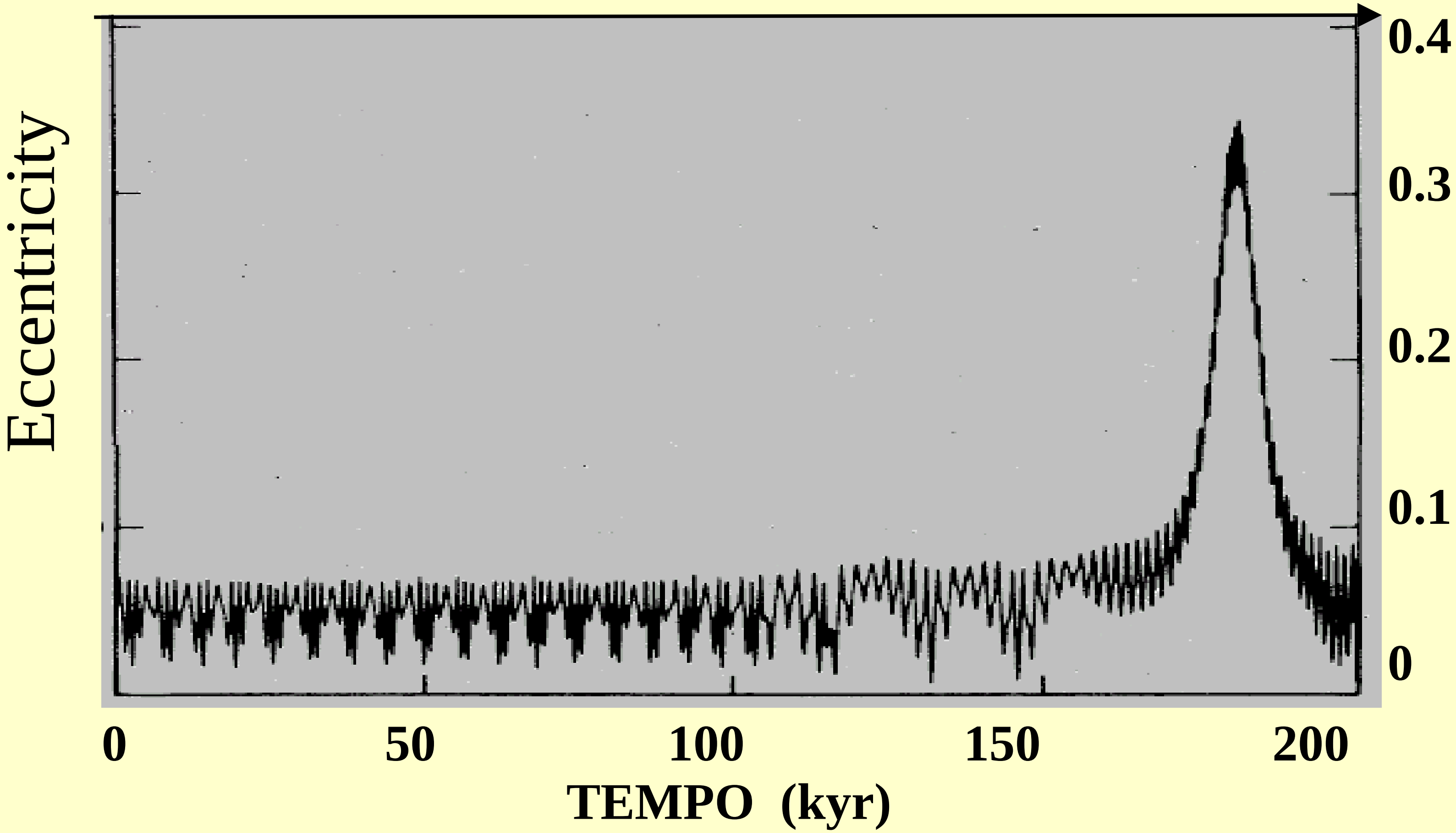


Ex:Hyp

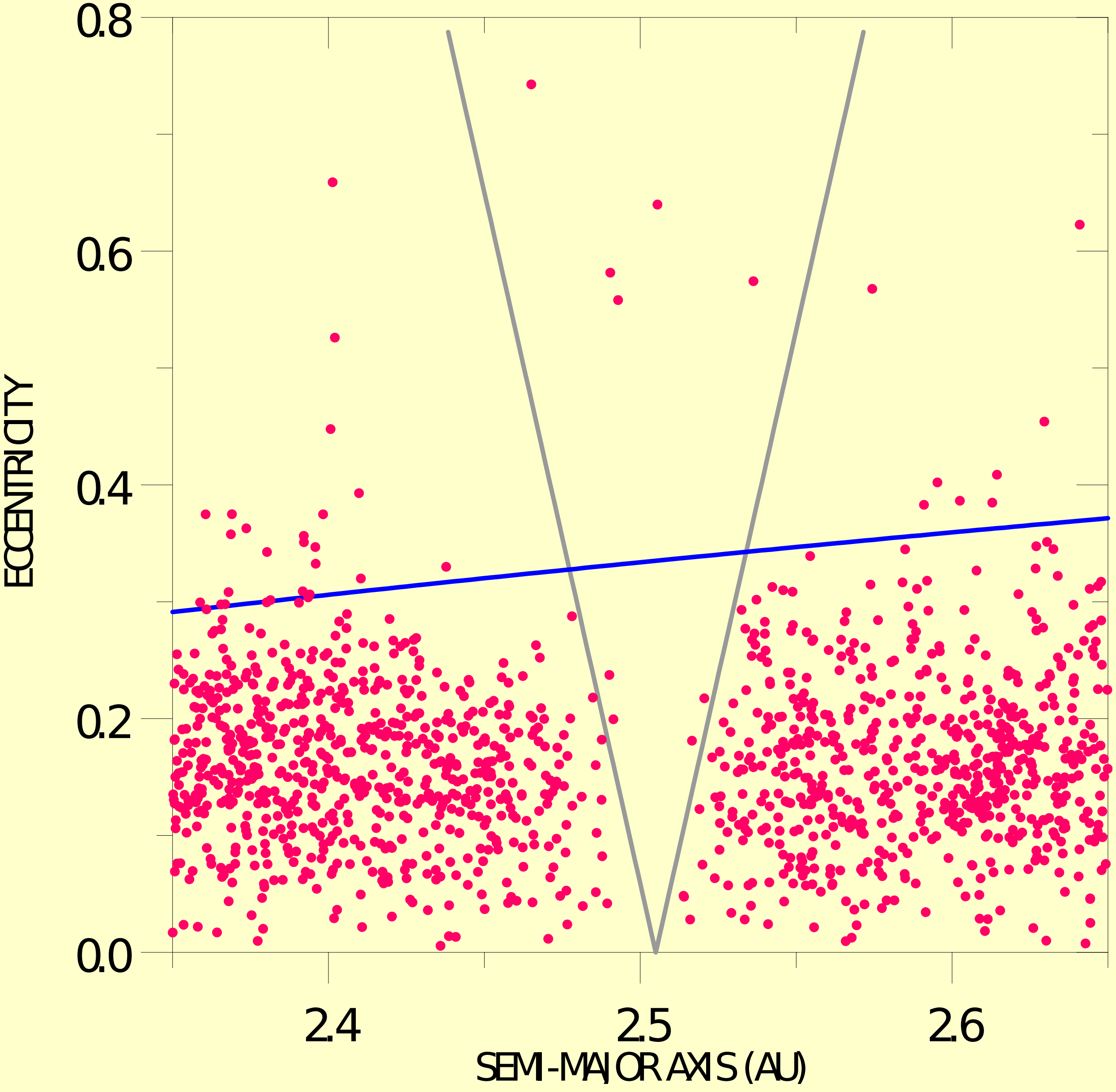
NOT New Physics! Just

An Example:
Asteroids in mean-motion resonance.
Paradigm: The 3/1 resonance (Wisdom, 1982)

J.Wisdom, Astron. Journal 85 (1982)



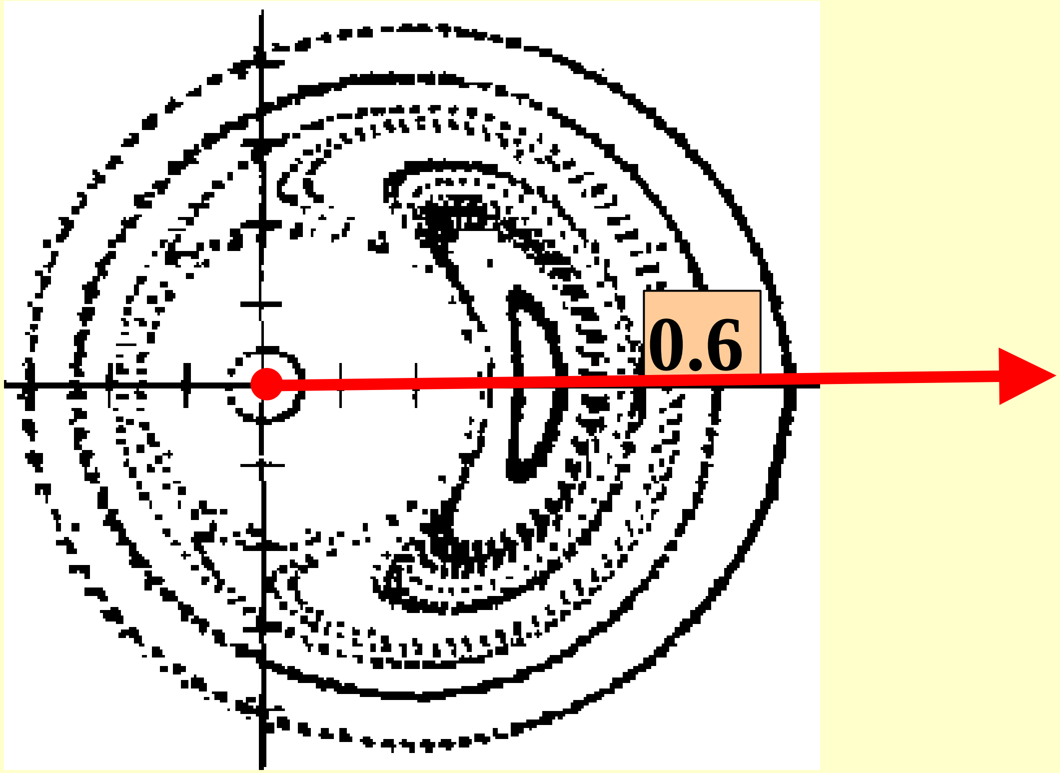
Asteroids distribution in the neighborhood of the 3/1 resonance



--Mars crossing line

Not enough to empty the gap

Section showing the low and medium-eccentricity modes of motion and their confinement by regular tori.
(cf SFM & Klafke, 1991)

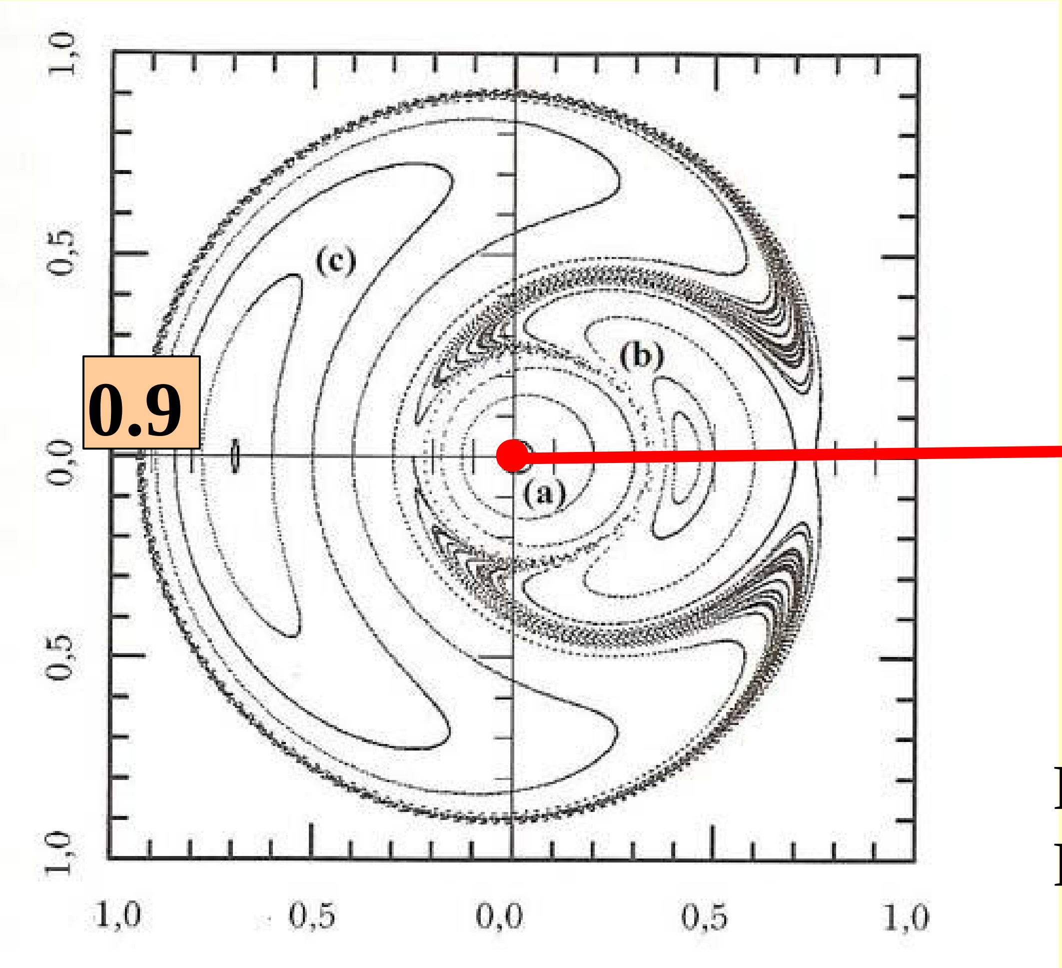


Radius vector = eccentricity
Polar angle = perihelion

New very high-eccentricity theory

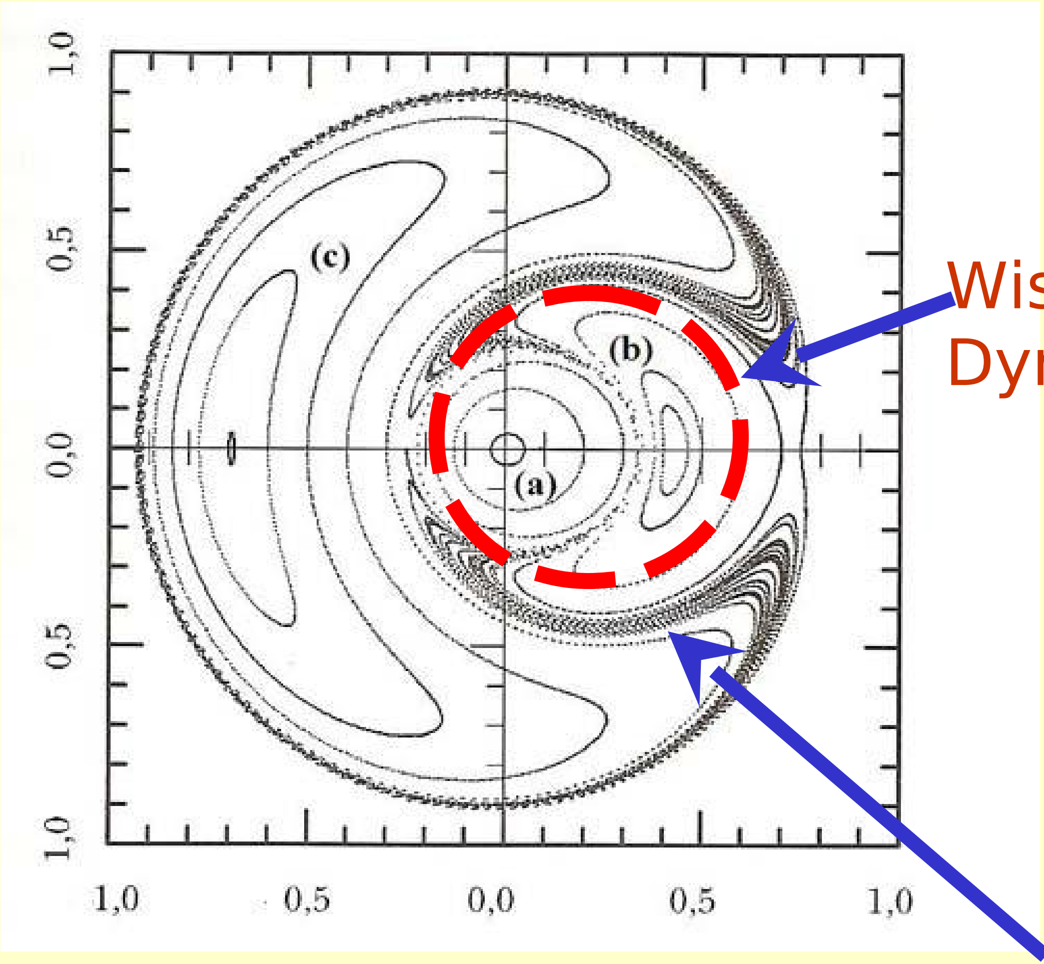
(**S.F.M. and Klafke,** NATO-ASI Proc. **1991**)

=> 3 modes of motion instead of 2



To Jupiter's Perihelion

Radius vector = eccentricity
Polar angle = perihelion

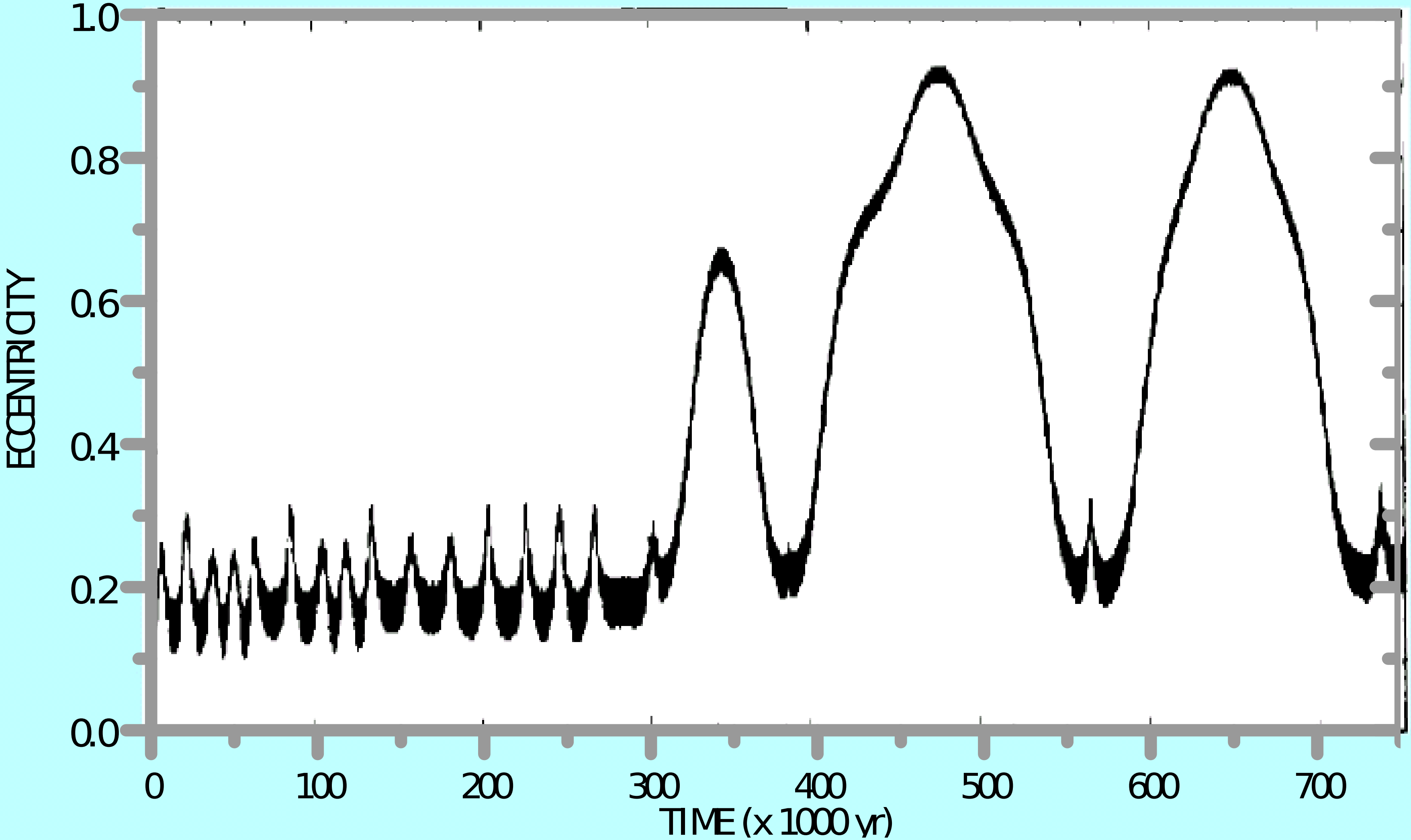


Wisdom
Dynamics

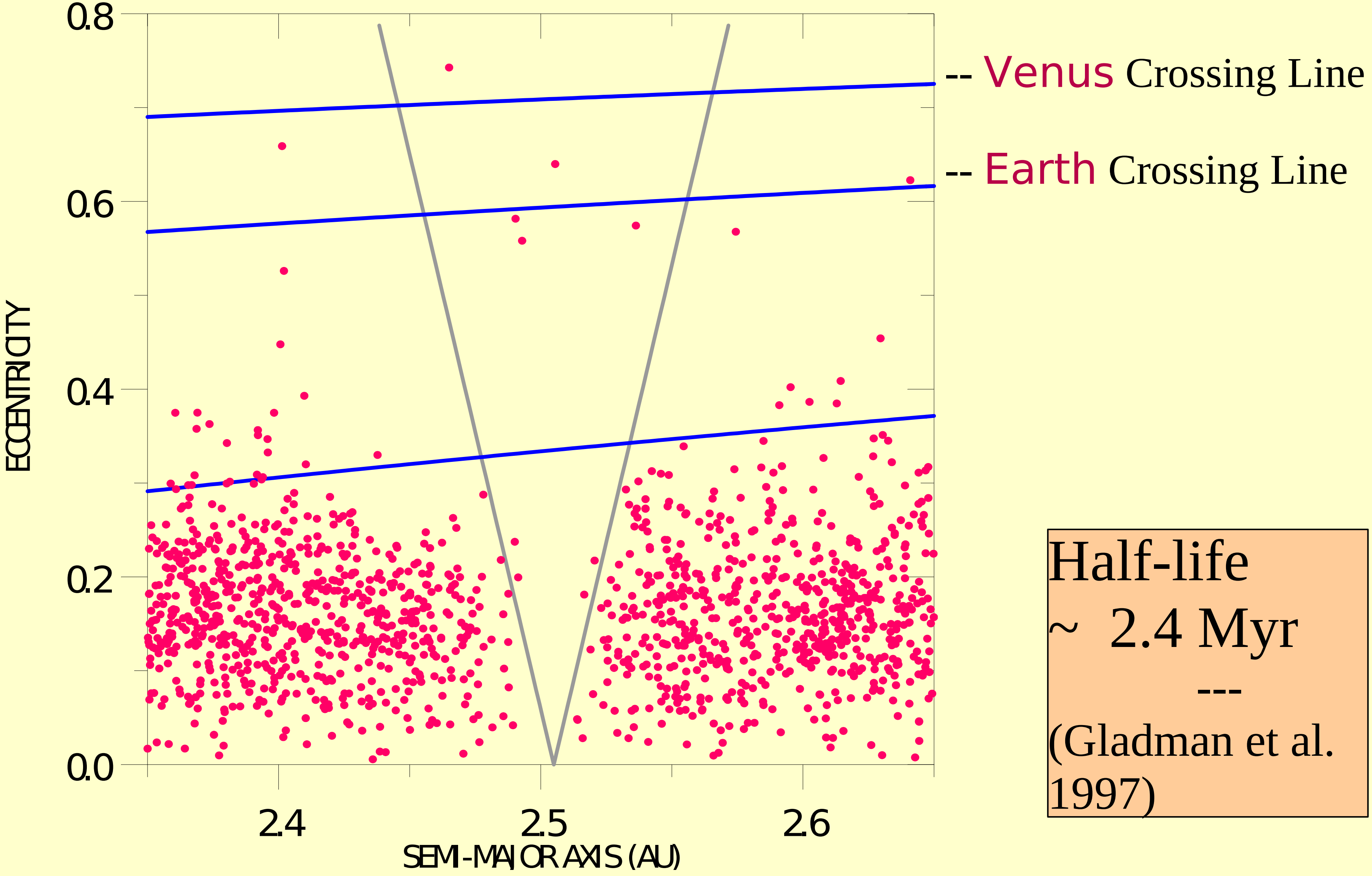
Heteroclini
Bridge

@SFM & Klafke (1991)

Eccentricity Jumps (VHE theory)



Asteroids in the neighborhood of the3:1 resonance



Half-life
~ 2.4 Myr

(Gladman et al. 1997)

TOUTATIS

(1.9 x 2.4 x 4.6

Aug 12, 1992
(at 3.6 million
km from Earth)

KT extinction event
sudden mass extinction of some three-quarters of the plant and animal species

Chicxulub impact

KT boundary @ Gubbio

> 10 km


000000000 TEXET
~20m
000km/h
2013/02/15 09:20:06

FIM
Obrigado!