KIAM Astrodynamics Day - 2019

Quasi-Satellite Orbit as a Resonance Phenomenon

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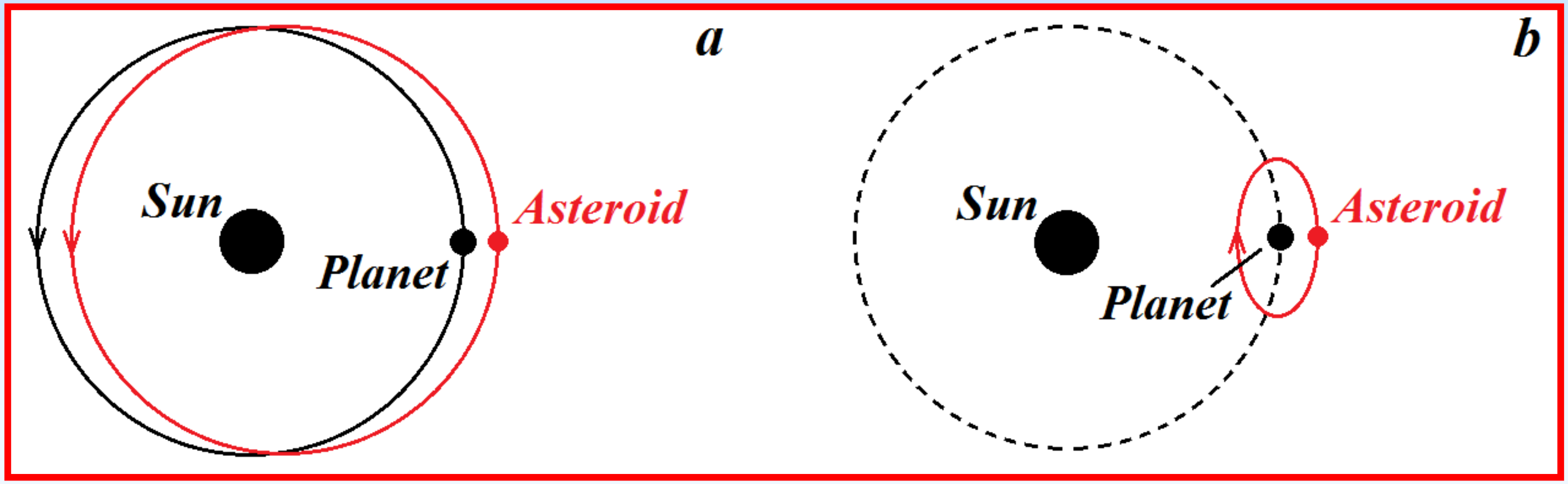
Based on publications

Sidorenko, V.V., Neishtadt, A.I., Artemyev, A.V., Zelenyi, L.M.: Quasi-satellite regime of motion of small celestial bodies: formation and destruction, Doklady Physics 58 (5), 207-211 (2013)

Sidorenko, V.V., Neishtadt, A.I., Artemyev, A.V., Zelenyi, L.M.: Quasi-satellite orbits in the general context of dynamics in the 1:1 mean motion resonance: perturbative treatment, CM&DA 120:131–162 (2014)

Quasi-satellite orbits

1:1 mean motion resonance!



a: Sun-centered reference frame with the orientation fixed in the absolute space. The quasi-satellite and the planet move around the Sun with the same orbital period in elliptic and in circular orbits respectively.
b: Sun-centered frame rotating with the mean orbital motion of the planet.

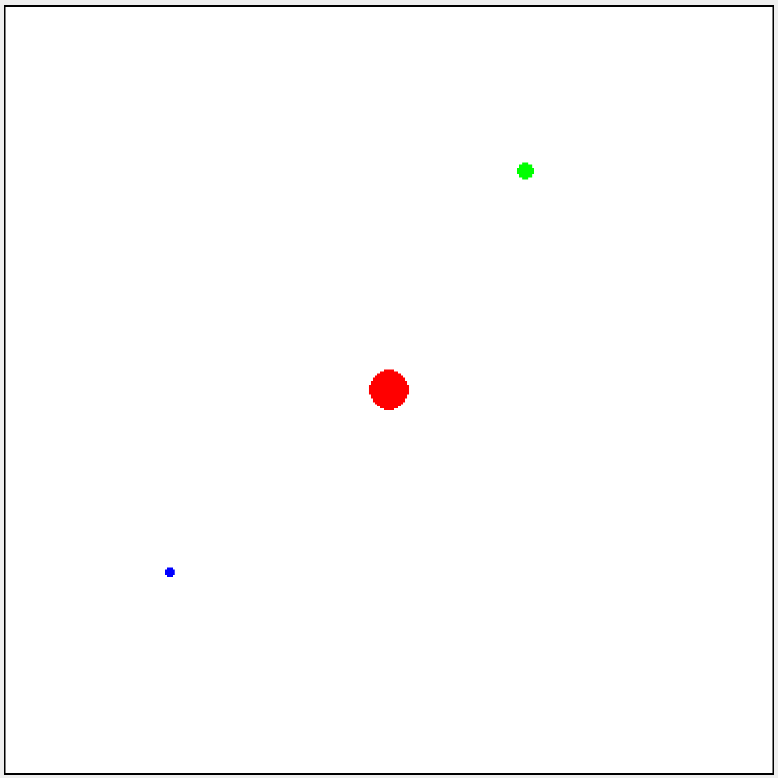
A.Yu.Kogan (1990): quasi-satellite orbits are the trajectories of restricted three-body problem which are (1) located far beyond the Hill's sphere surrounding the minor primary body and (2) much less distant from it than from the major primary

http://adsabs.harvard.edu/abs/1990dres.iafcY....K

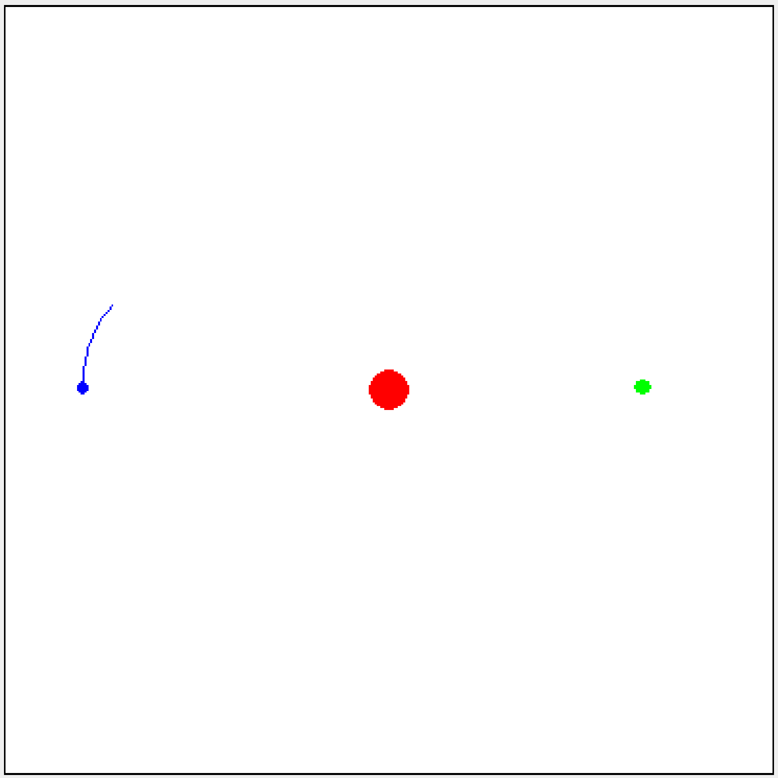
QS-orbits: the history (I)

J.Jackson (1913) – the first(?) discussion of QS-orbits

R.F.Broucke(1968), M.Henon(1969), A.D.Bruno(19??) – the investigation of periodic QS-orbits in RC3BP



Motion in non-rotating barycentric system of coordinates

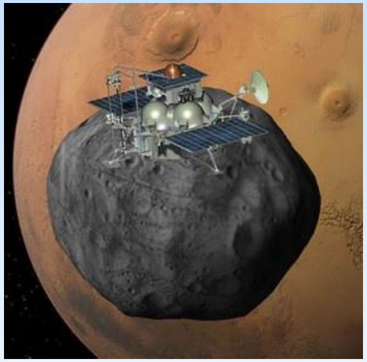


Motion in synodic (rotating) system of coordinates

QS-orbits: the history (II)

A.Yu.Kogan (1988), M.L.Lidov, M.A.Vashkovyak (1994) : the consideration of the QS-orbits in connection with the russian space project "Phobos"

A.G.Tuchin (2007): QS-orbits for "Phobos-Grunt"



S. Mikkola, K. Innanen (1997), F.Namouni (1999) & F.Namouni, A.A.Christou, C.D.Murray (1999): an application of the averaging procedure to study the long-term evolution of the QS-orbits

S.Mikkola, R. Brasser, P. Wiegert, K. Innanen, K. (2004): asteroid 2002VE68 is a quasi-satellite of Venus

M.Connors, C. Veillet, R. Brasser, P.Wiegert, P. Chodas, S.Mikkola, K. Innanen (2004): discovery of the first Earth's quasi-satellite

H.Kinoshita & H.Nakai, P.Wajer, Fuente Marcos & Fuente Marcos, Kortenkamp,...

Quasi-satellite orbits

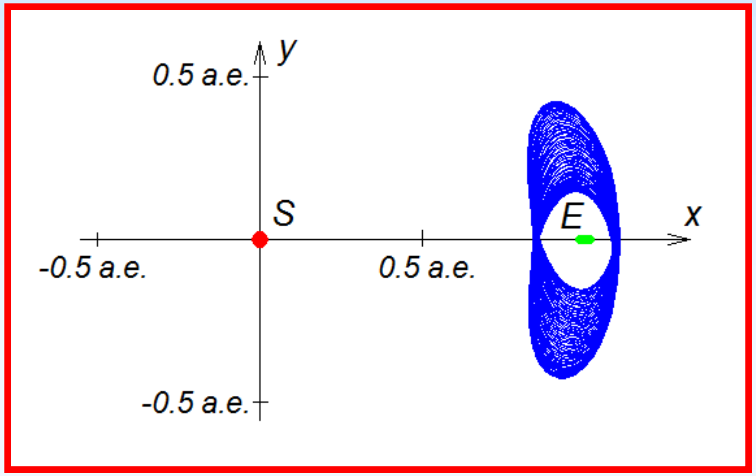
Real asteroids in QS-orbits:

2002VE68 – Venus QS;

2003YN107, 2004GU9,
2006FV35 – Earth QS;

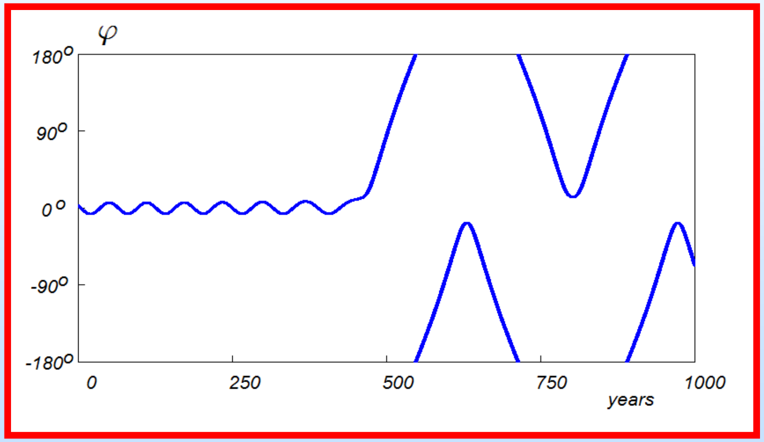
2001QQ199, 2004AE9
– Jupiter's QS

……………………



Trajectory of the asteroid 2004GU9

Variation of the resonant phase $\varphi = \lambda - \lambda'$ (λ and λ' are the mean longitudes of the asteroid and of the planet)



Nonplanar circular restricted three-body problem "Sun-Planet-Asteroid"

Time scales at the resonance

T_1 - orbital motions periods

T_2 - timescale of rotations/oscillations of the resonant argument (some combination of asteroid and planet mean longitudes)

T_3 - secular evolution of asteroid's eccentricity e, inclination i, argument of prihelion ω and ascending node longitude Ω .

$$T_1 << T_2 << T_3$$

Strategy: double averaging of the motion equations

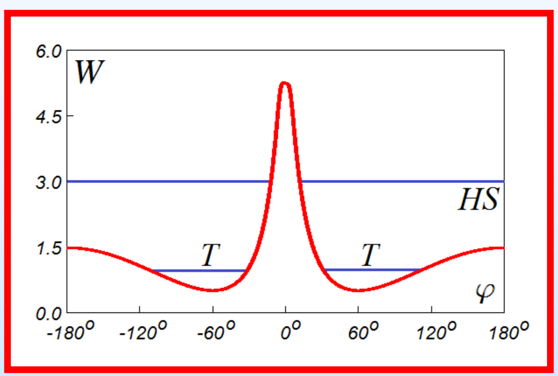
Resonant approximation (~N(1999)&NCM(1999))

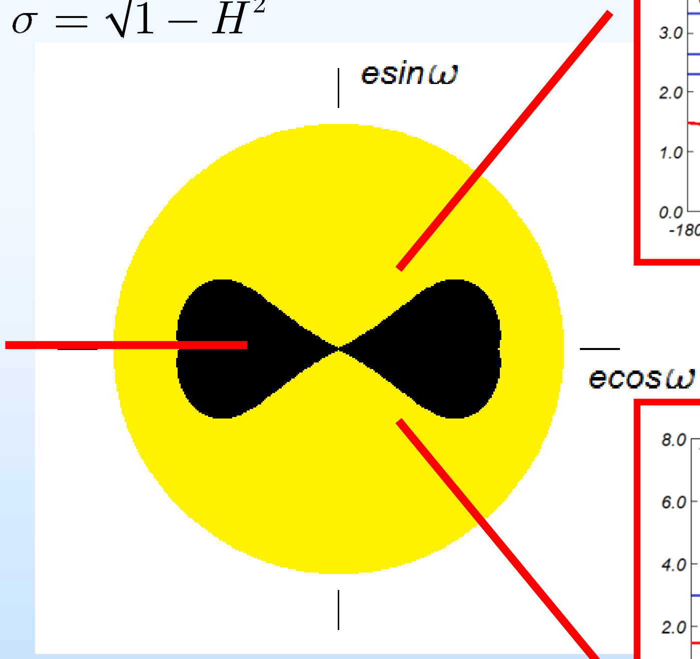
Variation of the resonant phase φ (e,ω are fixed)

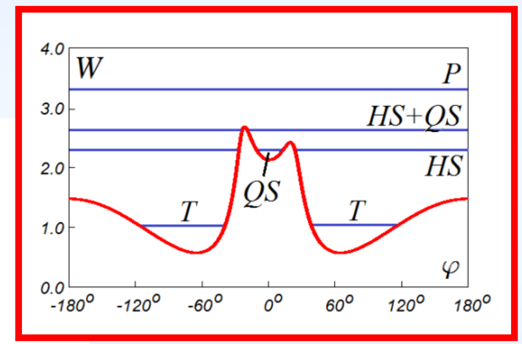
$$\Xi = \frac{3\Phi^2}{2} + W(\varphi, e, \omega, H)$$

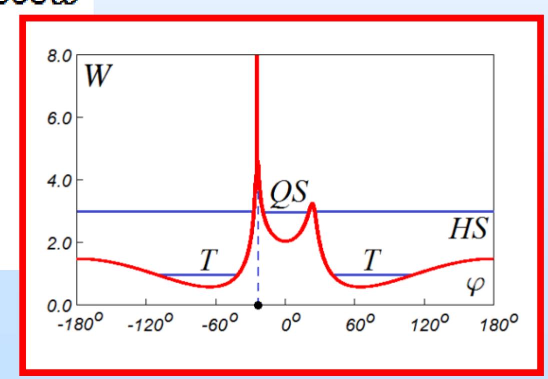
$W(\varphi, e, \omega, H) = \langle R \rangle,\ R = \frac{1}{|\mathbf{r} - \mathbf{r}'|} - (\mathbf{r}, \mathbf{r}'),\ \langle \cdot \rangle$ - averaging along the orbital motion taking into account the resonance

$$H = \sqrt{1-e^2}\cos i; \quad e_{\max} = \sigma = \sqrt{1-H^2}$$









NCM(1999): W - "ponderomotive potential

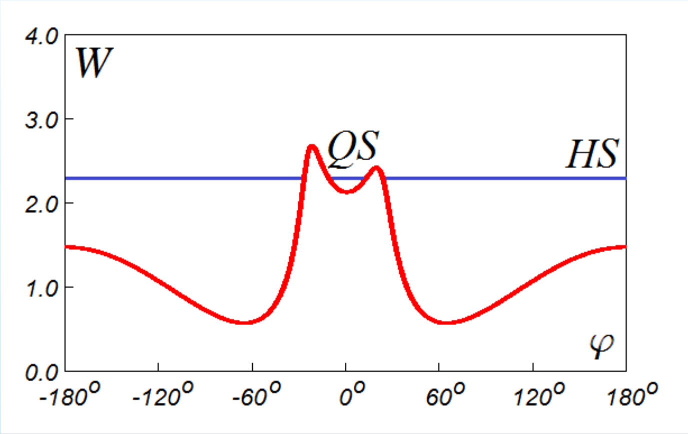
Evolutionary equations ($\Xi = \xi$) :

$$\frac{de}{d\tau} = -\varepsilon \frac{\sqrt{1-e^2}}{e}\left\langle \frac{\partial W}{\partial \omega}\right\rangle, \quad \frac{d\omega}{\partial \tau} = \varepsilon \frac{\sqrt{1-e^2}}{e}\left\langle \frac{\partial W}{\partial e}\right\rangle$$

$$\left\langle \frac{\partial W}{\partial \zeta}\right\rangle = \frac{1}{T(e,\omega,\xi,H)} \int_0^{T(x,y,\xi,H)} \frac{\partial W}{\partial \zeta}(e,\omega,\varphi(\tau,e,\omega,\xi,H),H))d\tau$$

$$\zeta = e,\omega$$

The accuracy of $O(\varepsilon)$ over time intervals $\sim 1/\varepsilon$



Problem: what solution of the fast subsystem

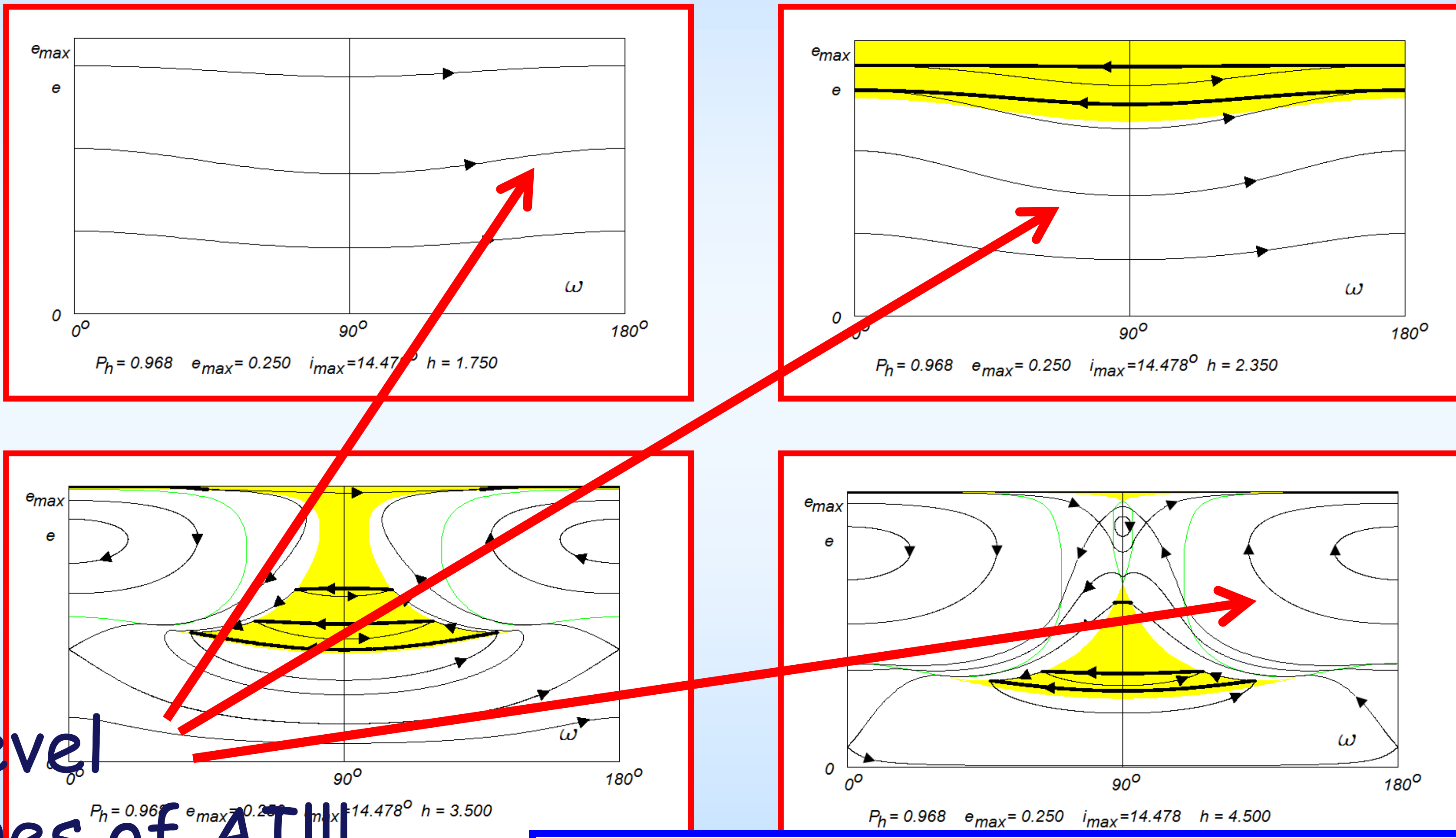
$$\frac{d\varphi}{d\tau} = 3\Phi, \ \frac{d\Phi}{d\tau} = -\frac{\partial W}{\partial \varphi}$$

should be used for averaging ?

QS-orbit or HS-orbit?

Nonplanar circular restricted three-body problem "Sun-Planet-Asteroid"

Secular effects: examples

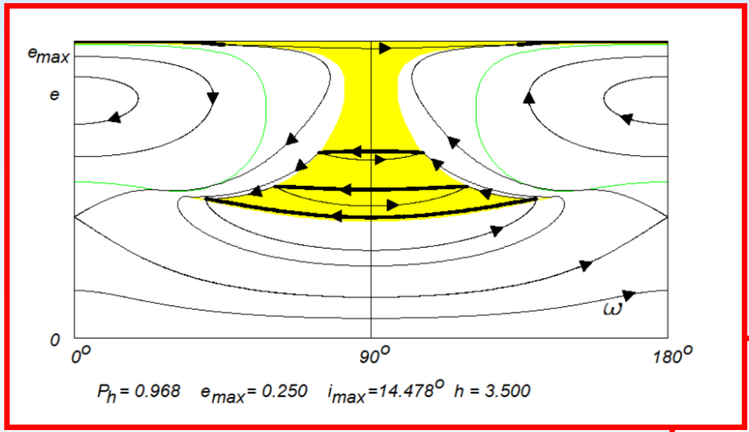


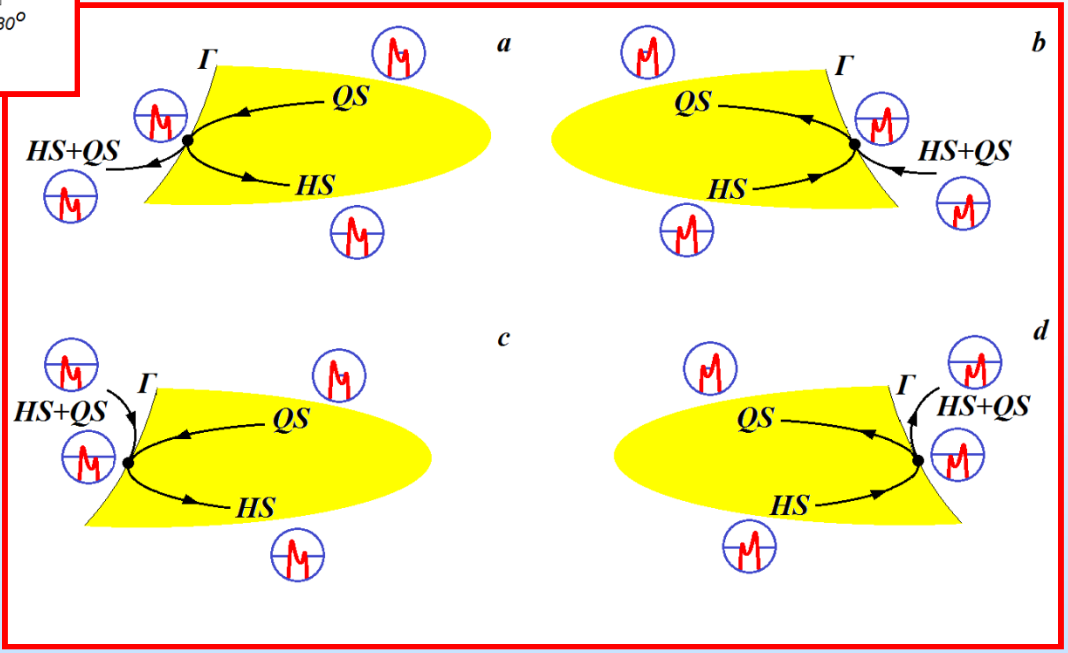
Level lines of AI!!!

Paramet

$$AI: \quad I(e,\omega,\xi,H) = \frac{3}{2\pi} \int_0^{T(e,\omega,\xi,H)} \Phi^2(\tau,e,\omega,\xi,H)\, d\tau$$

Phase portrait of the slow motion: mathching of the trajectories on the uncertainty curve



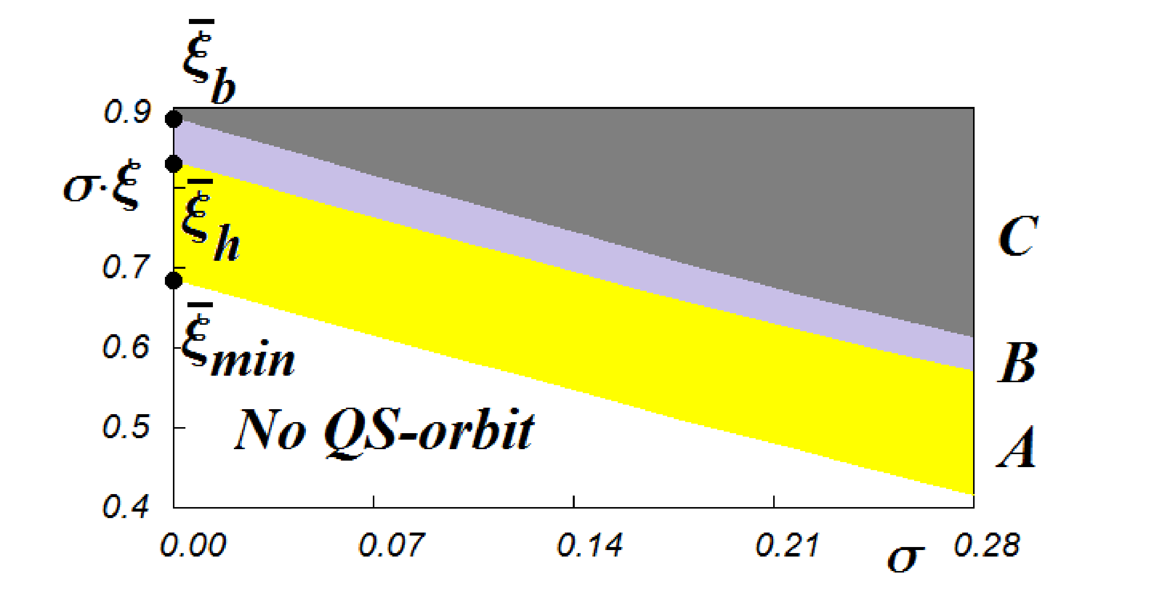


Scaling

$$\sigma = \sqrt{1 - H^2}$$

If $\sigma << 1$ then

$$\sigma \sim \sqrt{i^2 + e^2}$$



A – the motion in QS-orbit is perpetual
B – the abundances of the perpetual and temporary QS-motions are more or less comparable
C- the motion in QS-orbit is mainly temporary

Asteroid 164207 (2004GU9)

Orbital Elements at Epoch 2456000.5 (2012-Mar-14.0) TDB
Reference: JPL 36 (heliocentric ecliptic J2000)

Element	Value	Uncertainty (1-sigma)	Units
e	.1362904920360489	8.3981e-07	
a	1.001056350821795	4.9789e-09	AU
q	.8646218882124806	8.388e-07	AU
i	13.64944749947083	6.626e-05	deg
node	38.74489028357296	4.6936e-05	deg
peri	280.6255989836612	6.4544e-05	deg
M	217.2153150601352	5.9363e-05	deg
t_p	2456145.599308084731 (2012-Aug-06.09930808)	6.0018e-05	JED
period	365.8358102796718	2.7293e-06	d
	1.00	7.472e-09	yr
n	.9840480070138283	7.3414e-09	deg/d
Q	1.137490813431109	5.6574e-09	AU

Orbit Determination Parameters

# obs. used (total)	169
data-arc span	3612 days (9.89 yr)
first obs. used	2001-05-11
last obs. used	2011-04-01
planetary ephem.	DE405
SB-pert. ephem.	SB405-CPV-2
condition code	0
fit RMS	.59148
data source	ORB
producer	Otto Matic
solution date	2011-Dec-04 00:56:01

Additional Information

Earth MOID = .000469824 AU
T_jup = 6.042

[show covariance matrix]

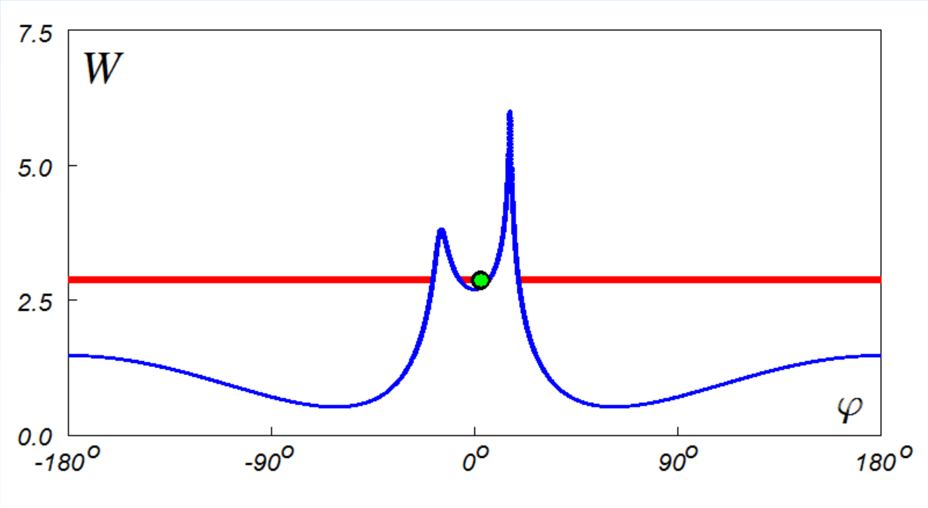
[Ephemeris | Orbit Diagram | Orbital Elements | Physical Parameters | Discovery Circumstances | Close-Approach D

Physical Parameter Table

Parameter	Symbol	Value	Units	Sigma	Reference	Notes
absolute magnitude	H	21.145	mag	.54469	36	autocmod 2.5a

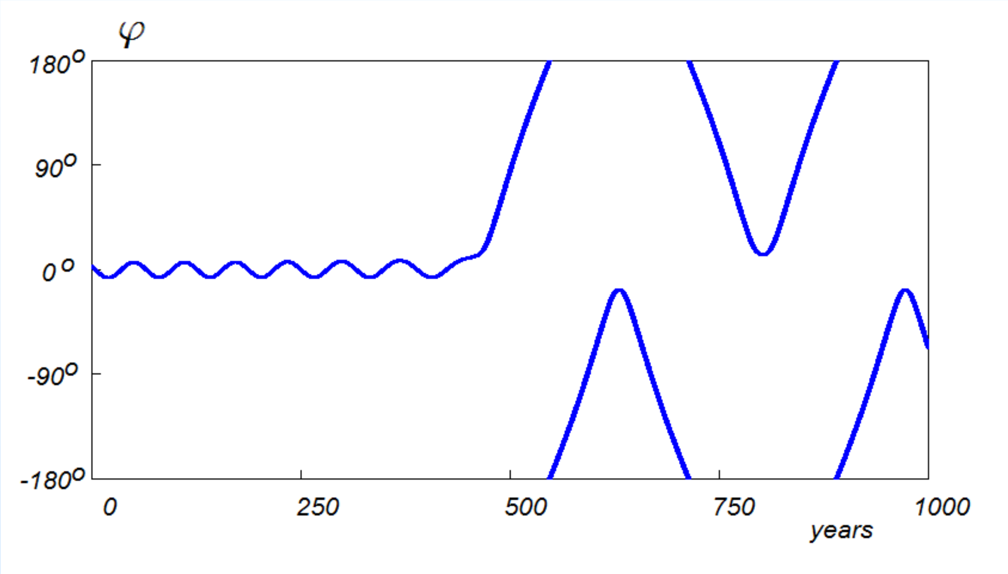
No close encounters with Venus or Mars!

Asteroid 164207 (2004GU9)

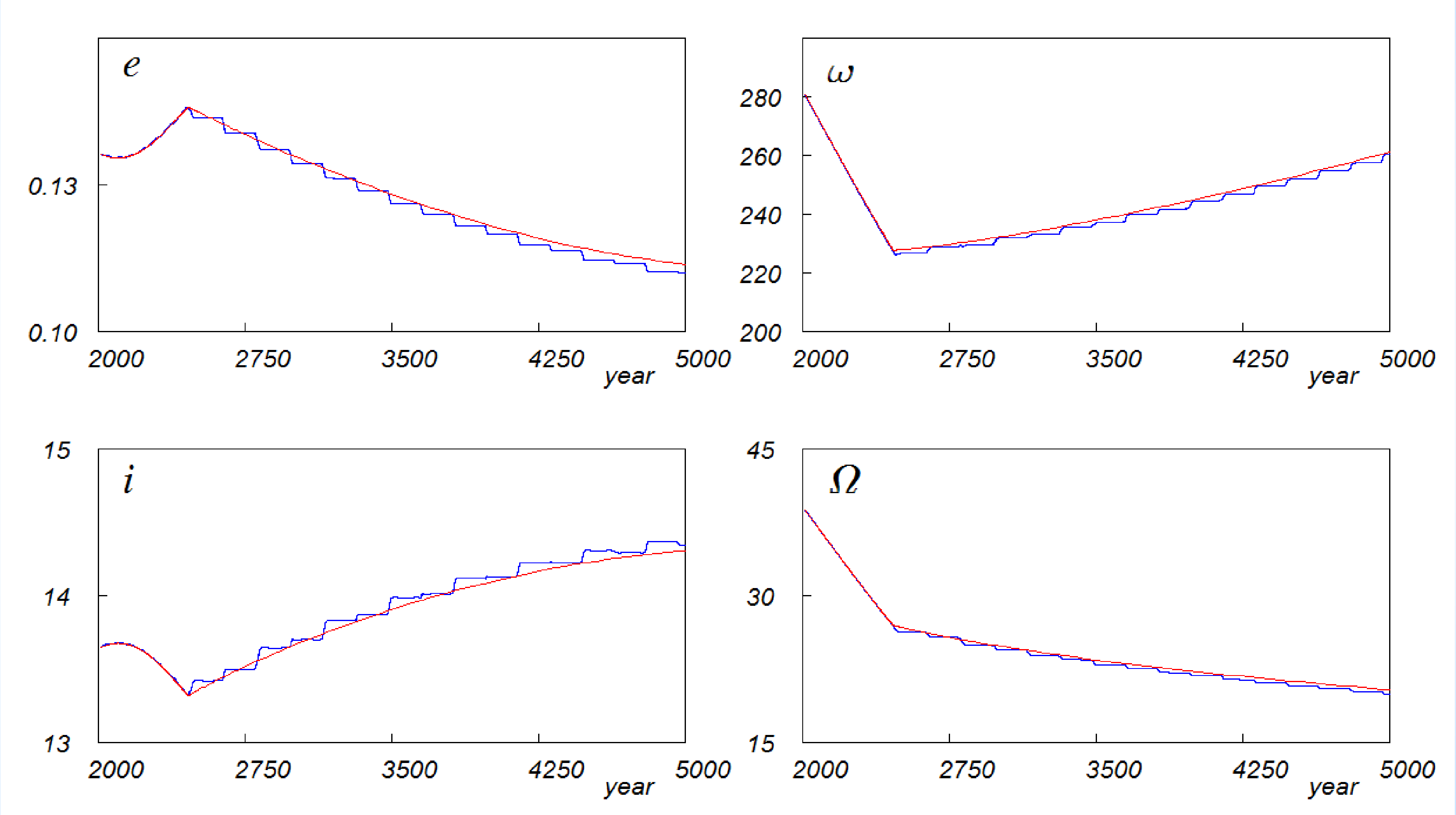


Current φ and W

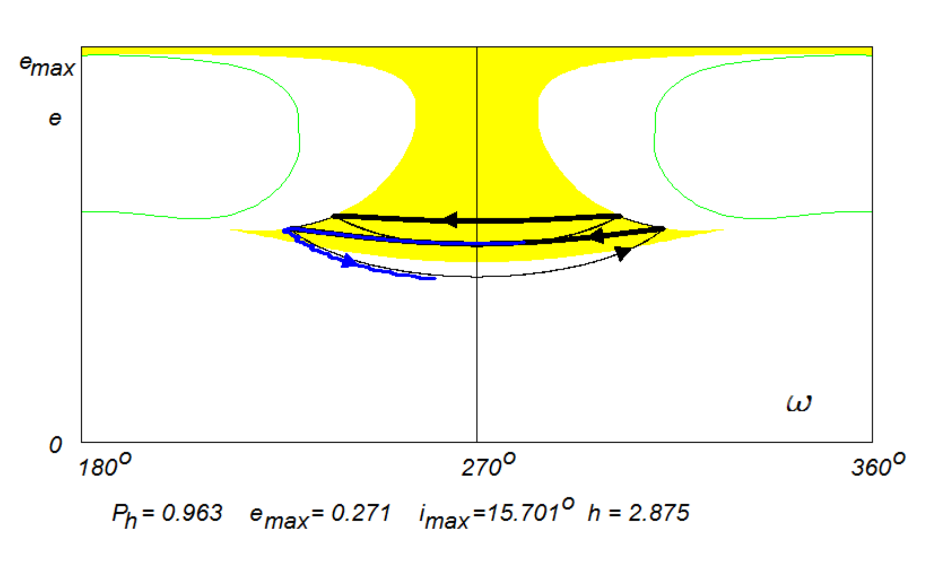
Variation of the resonant phase



Asteroid 164207 (2004GU9)



The evolution of the orbital elements (CR3BP!)



Asteroid 164207 (2004GU9)

Conclusions:

- Row classification of slow evolution scenarios is presented;
- The criterion to distinguish between the perpertual and temporary motion in QS-orbit is established (in CR3BP)