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Asteroid 2002 VE68, a quasi-satellite of Venus

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ABSTRACT

The asteroid 2002 VE68 is currently a quasi-satellite of Venus, the first object of this dynamical class to be discovered, and is also the first known co-orbital companion to Venus. Our computations show that it has been in its present orbital state for about seven millennia and will stay there for five more centuries to come. It has a high eccentricity (≈ 0.4) and inclination ($\approx 9^\circ$). Consequently the maximum distance of the asteroid from the Sun is near that of the Earth and the minimum distance is smaller than the aphelion of Mercury. Very close approaches with Venus and Mercury are excluded within the interval of time of reliable numerical computation of the orbit, but repeated encounters with the Earth do occur. From the evolution of the orbit of this object, we conclude that it may have been a near-Earth asteroid, which, some 7000 yr ago, was injected into its present orbit by the action of the Earth.

Key words: celestial mechanics – planets and satellites: individual: Venus – Solar system: general – minor planets, asteroids.

1 INTRODUCTION

There are essentially three kinds of trajectories possible for co-orbital objects: tadpole Trojan motion, horseshoe motion and retrograde quasi-satellite (QS) motion. For orbits with large enough eccentricity and/or high inclination, transitions between these orbit types, as well as compound horseshoe–QS orbits, are possible (Namouni 1999; Namouni, Christou & Murray 1999). Hundreds of Jovian Trojans, six Martian, and one of Neptune are known today. The Earth has one temporary co-orbital object, 3753 Cruithne (Wiegert, Innanen & Mikkola 1997), and one horseshoe object, 2002 AA29 (Connors et al. 2002). There are no known Trojan asteroids of the other planets, although Tabachnik & Evans (2000) and Brasser & Lehto (2002) have shown that Venus and Earth Trojans would be stable in low-inclination orbits.

Both of the above-mentioned Earth co-orbitals make transitions between horseshoe and QS behaviour, as found by numerical integrations of the orbits, but thus far QS objects have not been directly observed. In this Letter, we confirm that the asteroid 2002 VE68 is at this time a Venus QS, the first known QS presently ‘in action’.

2 NUMERICAL EXPERIMENTS

The orbital elements and other data for 2002 VE68 were taken from the Lowell observatory data base (astorb.dat).[1] As the orbital elements, given in Table 1, have uncertainties, a cluster of 50 orbits was also generated using the elements and covariance matrix C from the AstDys pages.[2] The variations in the element vector $\boldsymbol{q}$ were computed using $\delta\boldsymbol{q} = \sum_{k=1}^{6} \xi_k \sqrt{\lambda_k} \boldsymbol{X}_k$, where λ_k and $\boldsymbol{X}_k$ are, correspondingly, the eigenvalues and eigenvectors of the covariance matrix C, while ξ_k are random numbers with a nearly Gaussian distribution: $\langle \xi_k^2 \rangle = 1$. The orbit computations were done using a modified Wisdom–Holman algorithm (Wisdom & Holman 1991; Mikkola & Palmer 2001) with a time-step of 0.1 d for a few thousand years forward and backward.

3 ORBIT BEHAVIOUR

A QS orbit is one in which the asteroid orbits the Sun in an approximate ellipse with the same (mean) period as the planet and with nearly the same mean longitude. Such motion is stabilized by the mother planet with a mechanism resembling that of Trojan motion (Jackson 1913; Mikkola & Innanen 1997). Thus the asteroid moves around the Sun in a weakly perturbed elliptic orbit, while in the rotating coordinate system, where the planet is in a fixed position, the trajectory is a retrograde elongated orbit around the planet, thus the name ‘QS’.

In Fig. 1 we plot the motion of 2002 VE68 for the next 150 yr. The illustration is given in the coordinate system that rotates with Venus. One can see that the asteroid could also be classified as a near-Earth asteroid (NEA), for its maximum solar distance is at about the distance of the Earth. Also, at perihelion, the orbit moves in an area where an encounter with Mercury is potentially possible. Thus one cannot expect the orbit to be stable indefinitely.

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[1] ftp://ftp.lowell.edu/pub/elgb/astorb.html
[2] http://hamilton.dm.unipi.it/astdys/

Table 1. Orbital elements of 2002 VE68 used in this investigation. (Epoch = JD 245 2900.5; J2000.0 ecliptic and equinox.)

a (au)	e	i (°)	Ω (°)	ω (°)	M (°)
0.723 688 70	0.410 427	8.9766	231.674	355.528	318.875

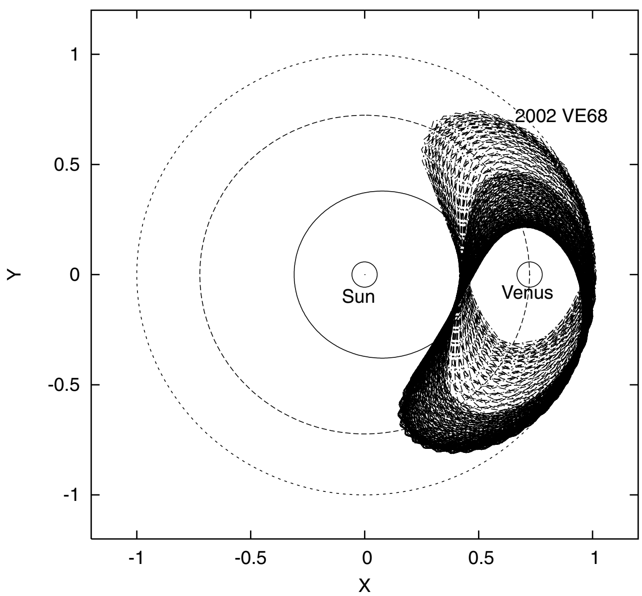

Figure 1. The motion of 2002 VE68 for the next 150 yr. The coordinate system rotates with Venus. Orbits of Mercury, Venus and Earth are also (schematically) illustrated.

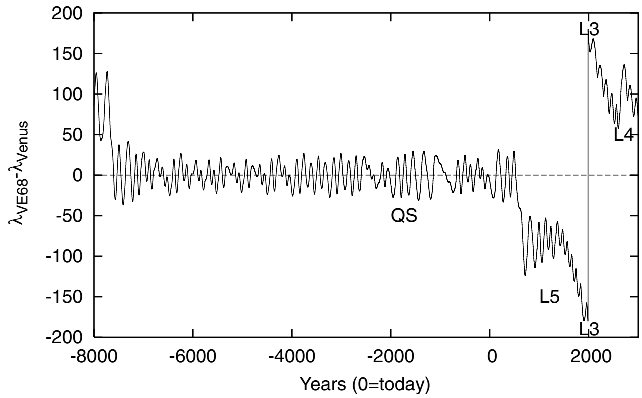

Figure 2. The mean longitude difference of 2002 VE68 and Venus.

In fact, all our simulations suggest that the present state of the orbit has lasted for about 7000 yr. In the future the asteroid will become a Venus Trojan around the L_5 Lagrangian point. This will happen about 500 yr from now. The simulations with the cluster of orbits (50 altogether) suggest that we can, reliably, compute the motion in the time interval −7000 to +1000 yr from now. In the past this corresponds to the period of time when 2002 VE68 remains a QS, while in the future the motion as an L_5 Trojan is included.

In Fig. 2 the difference of the mean longitudes of the asteroid and Venus, $\lambda_{\rm VE68} - \lambda_{\rm Venus}$, is illustrated ($\lambda = M + \Omega + \omega$; standard notation). The figure was computed using the orbital elements referred to in Table 1; however, the other simulations gave very similar figures, over the interval of reliability mentioned above, but diverge outside that period of time.

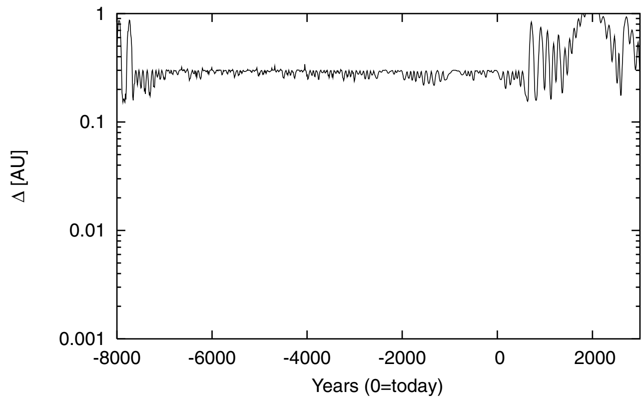

Figure 3. The distance of 2002 VE68 from Venus. The plot gives minima over consecutive 10-yr periods.

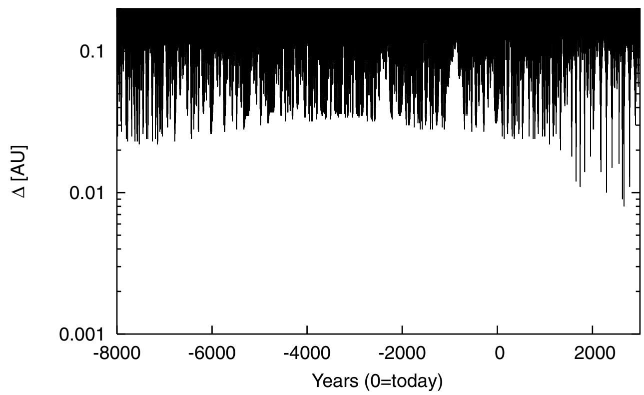

Figure 4. The distance of 2002 VE68 from the Earth.

The distance of 2002 VE68 from Venus remains larger than ∼0.2 au as illustrated in Fig. 3. This suggests that encounters with Venus do not cause the asteroid to depart from the QS trajectory in either direction of time. Similarly, considerations of distances to Mercury convinced us that this planet is not of importance here: the closest distances are well outside the Hill sphere of Mercury.

On the other hand, the asteroid experiences repeated close encounters with the Earth as seen in Fig. 4. The smallest distances between 2002 VE68 and the Earth are 'dangerously' close to the Hill distance [$(m/3\,{\rm M}_\odot)^{1/3} \approx 0.01$ au]. Similarly, Fig. 5 shows the

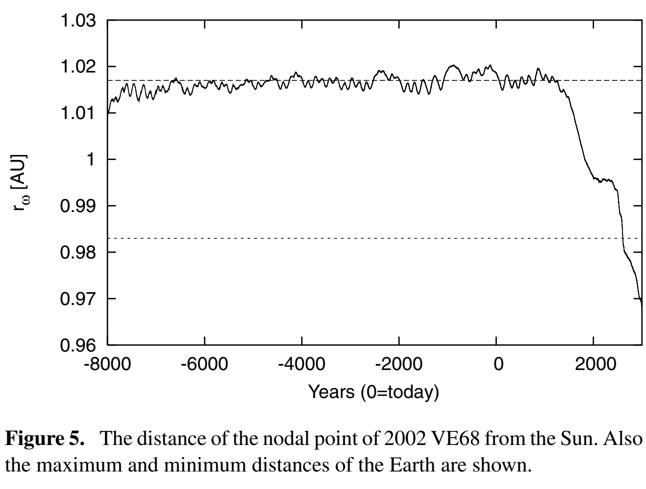

Figure 5. The distance of the nodal point of 2002 VE68 from the Sun. Also the maximum and minimum distances of the Earth are shown.

distance of the upper nodal point $r_{\rm node} = a(1 - e^2)/[1 - |e \cos(\omega)|]$ in the Earth's orbital plane. The importance of this is that a close approach can only occur at this point. One observes that this distance coincides quite accurately with the maximum distance of the Earth from the Sun. This state of affairs seems to last during the period of stability of the QS motion. From this fact one forms the impression that 2002 VE68 may have originated as an NEA and that some close encounter, perhaps about 7000 yr ago, has injected the asteroid into its present orbit. Also it is probable that the repeated close fly-bys with the Earth are the reason for the forthcoming transition to a different type of motion.

During the computations, the sensitivity of the orbit to initial values was studied by using the tangent map (Mikkola & Innanen 1999) to determine the Lyapunov times of the trajectories. As is usual with asteroids in the terrestrial planet region, the trajectory of 2002 VE68 turned out to be fairly chaotic: during the quasi-satellite period, the e-folding time was found to be $\tau_{\rm e} \sim 300$ yr, while outside this period the values suggested by the calculations are significantly smaller ($<$100 yr).

4 CONCLUSIONS

We have announced the existence of a Venus quasi-satellite, 2002 VE68. This asteroid has occupied its present orbit for about 7000 yr and will stay in that type of orbit for about 500 more years to come. The asteroid is also a near-Earth object and, quite likely, was injected into its present orbit by the Earth.

This asteroid is the first QS actually seen, and recognized as such, in action at the current epoch. At the same time it is the first known companion body to the planet Venus.

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REFERENCES

Brasser R., Lehto H. J., 2002, MNRAS, 334, 241
Connors M., Chodas P., Mikkola S., Wiegert P., Veillet C., Innanen K., 2002, Meteoritics Planet. Sci., 37, 1435
Jackson J., 1913, MNRAS, 74, 62
Mikkola S., Innanen K., 1997, in Henrard J., Dvorak R., eds, Proc. Fourth Alexander von Humbolt Colloq. on Celestial Mechanics, The Dynamical Behaviour of Our Planetary System. Kluwer, Dordrecht, p. 345
Mikkola S., Innanen K., 1999, Celest. Mech. Dyn. Astron., 74, 59
Mikkola S., Palmer P., 2001, Celest. Mech. Dyn. Astron., 77, 305
Namouni F., 1999, Icarus, 137, 293
Namouni F., Christou A. A., Murray C. D., 1999, Phys. Rev. Lett., 83, 2506
Tabachnik S., Evans N. W., 2000, MNRAS, 319, 63
Wiegert P., Innanen K., Mikkola S., 1997, Nat, 387, 685
Wisdom J., Holman M., 1991, AJ, 102, 152