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A retrograde object near Jupiter's orbit

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ABSTRACT

Asteroid 2007 VW_{266} is among the rare objects with a heliocentric retrograde orbit, and its semimajor axis is within a Hill sphere radius of that of Jupiter. This raised the interesting possibility that it could be in co-orbital retrograde resonance with Jupiter, a second "counter-orbital" object in addition to recently discovered 2015 BZ_{509}. We find instead that the object is in 13/14 retrograde mean motion resonance (also referred to as 13/-14). The object is shown to have entered its present orbit about 1700 years ago, and it will leave it in about 8000 years, both through close approach to Jupiter. Entry and exit states both avoid 1:1 retrograde resonance, but the retrograde nature is preserved. The temporary stable state is due to an elliptic orbit with high inclination keeping nodal passages far from the associated planet. We discuss the motion of this unusual object based on modeling and theory, and its observational prospects.

1. Introduction

The best-known examples of co-orbital motion in the Solar System are the Trojan clouds of Jupiter (see Barucci et al. (2002); Emery et al. (2015) for a review of their physical properties, or Milani (1993); Stacey and Connors (2008) for a review of their dynamics). Trojans are now also known for planets Earth (Connors et al., 2011), Mars (Mikkola et al., 1994; Tabachnik and Evans, 1999; Connors et al., 2005), Uranus (Alexandersen et al., 2013) and Neptune (Chiang et al., 2003; Marzari et al., 2003; Brasser et al., 2004). Other types of co-orbital motion are horseshoe librators (first mentioned by Brown (1911)), quasi-satellites (Mikkola and Innanen, 1995, 1997), and compound orbits (first observed by Wiegert et al. (1997) and explained theoretically by Namouni (1999); Namouni et al. (1999)). In all heliocentric co-orbital motion known until recently, a small body moves under the control of the Sun and a planet in a prograde (counterclockwise viewed from above the north pole) sense, although the motion relative to the planet may appear to be retrograde.

Schubart (1978) computationally investigated certain cases of hypothetical retrograde 1:−1 mean motion resonance, in which a companion small object moves in a retrograde sense to the (assumed prograde) planet, noting that libration, an indicator of resonance, was possible. Dobrovolskis (2012) suggested that such motion by "counter-orbitals" could be stable. Morais and Namouni (2013b), Namouni and Morais (2015), and Morais and Namouni (2016) investigated this type of motion in detail, finding a new type of stable co-orbital motion that is retrograde (Morais and Namouni, 2017). Wiegert et al. (2017) recently identified the first such retrograde co-orbital object, 2015 BZ_{509}, associated with Jupiter. This raises the question of whether more objects exist in retrograde co-orbital resonance. 2007 VW_{266} has been known to be in retrograde motion since its discovery about ten years ago, and its semimajor axis a—less distant from that of Jupiter than the Hill sphere radius—made it possible that it was also in the 1:−1 resonance.

Recent interest in retrograde objects in the Solar System stems partly from exoplanet studies, and partly from the existence of over 80 retrograde asteroids[1] and thousands of retrograde comets. The JPL comet database[2] reports 1972 comets on retrograde orbits, but most (~1400) of these are Kreutz family comets, members of a split comet family that has been well-documented by the SOHO mission (Marsden, 2005) Some of our Solar System's retrograde bodies are in resonance (Morais and Namouni, 2013a; Wiegert et al., 2017) with planets.

The presence of retrograde objects within the present-day Solar System requires some explanation within current models of planet

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[1] Minor Planet Center, MPC Orbit (MPCORB) Database, http://www.minorplanetcenter.net/iau/MPCORB.html, retrieved Jan 12, 2017.
[2] http://ssd.jpl.nasa.gov/dat/ELEMENTS.COMET, Retrieved Mar 31, 2017.

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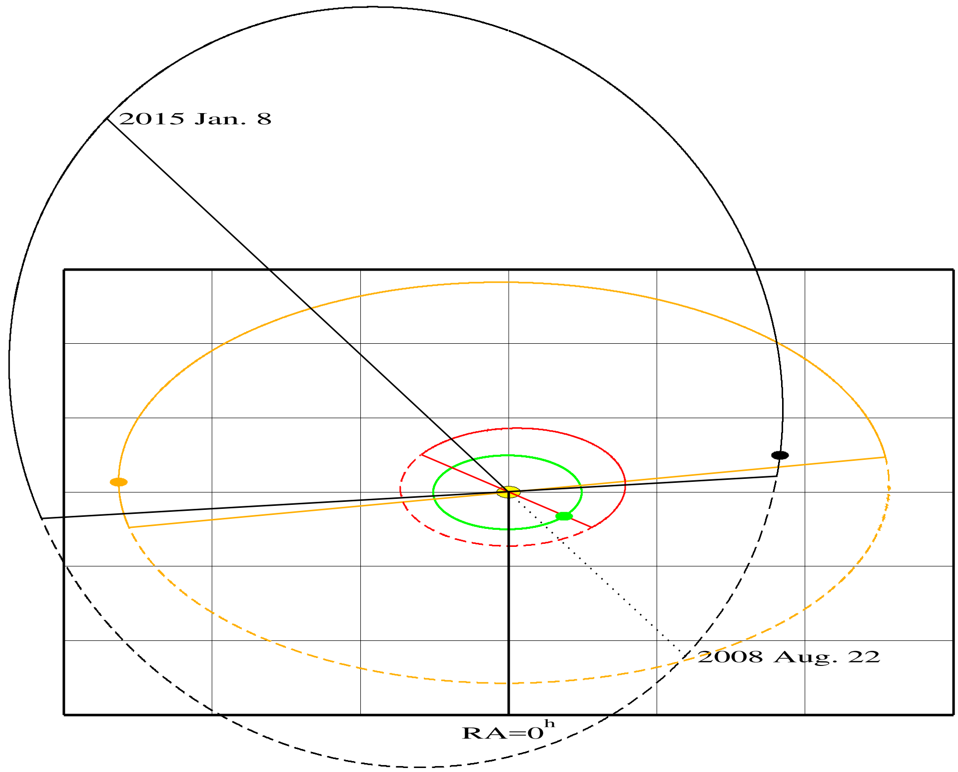

Fig. 1. Orbits of the Earth (green), Mars (red), Jupiter (orange) and asteroid 2007 VW_{266} (black) over a 12.8 year period centred on the epoch of its discovery in 2007. The Sun is in the middle and a grid 2 AU square is shown in the ecliptic plane with positive X (vernal equinox) toward the bottom (axis marked by heavy line). Portions of objects' orbits which are below the ecliptic are shown dashed, and the nodes are joined by a straight line. The positions of Earth, Jupiter, and the asteroid on the date of discovery are shown by dots on the respective orbits. The line of apsides crosses at roughly a 45° angle from lower right to upper left, shown as dotted below the ecliptic and solid above. The motion of the asteroid is clockwise due to its retrograde nature. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Osculating orbital elements of asteroid 2007 VW_{266} from http://neo.jpl.nasa.gov/, cited 23/11/2013.

Element	Name	Value	Error
	Epoch	JD 2456600.5	
a	semimajor axis	5.454 au	0.0156 au
e	eccentricity	0.3896	0.00170
i	inclination	108.358°	0.0261°
q	perihelion distance	3.32901 au	0.000586 au
ω	argument of perihelion	226.107°	0.0501°
Ω	longitude of node	276.509°	0.00114°
M	mean anomaly	146.88°	0.604°

formation, but can be understood. A near-Earth asteroid population with retrograde objects was produced from main belt sources in models by Greenstreet et al. (2012), with the majority originating from 3:1 resonance. These authors stressed that an integrator having good numerical characteristics for close encounters was essential for matching even the small number of observed objects. On the other hand, the outer solar system Damocloids, which include a significant proportion of retrograde members, were proposed by Jewitt (2005) to originate from long-period comets, on both dynamical and compositional grounds. The long-period comets, coming from low angular momentum states in the Oort cloud, contain a high proportion of retrograde orbits due to interactions with passing stars and the Galactic tidal field e.g. Wiegert and Tremaine (1999); Morais and Namouni (2017).

The dynamics of nearly-coplanar ($i \approx 163°$) retrograde co-orbital 2015 BZ_{509} are essentially understood (Morais and Namouni, 2016) and show surprising stability. We find that 2007 VW_{266} — retrograde but far from coplanar ($i \approx 108°$) — does not share that stability, but displays a new form of retrograde temporarily protected orbit.

2. Configuration of the present orbit

Asteroid 2007 VW_{266} was discovered[3] on Nov. 12, 2007 (UT) by the Mt. Lemmon Survey, at a magnitude $m \sim 21.4$, with 60 subsequent observations spanning 38 days.[4] The result is a nominal orbit shown in Fig. 1. It is shown below that the behaviour over about 10,000 years is well described, but due to Jupiter encounters, not well known outside of that range. The osculating elements for epoch 2456600.5 (2013-Nov.-04.0) TDB, with standard errors, are summarized in Table 1. Since there have been no observations since that date, the only orbital change is due to interactions that are included in our models, and we have based our calculations on these initial conditions. The data arc is sufficient to determine the orbit with a well defined error model (Milani and Gronchi, 2010), allowing statistical investigations such as the clone orbits described below.

The eccentricity e of roughly 0.39 means that the orbit is elongated, while at roughly 108°, the inclination is large and motion is retrograde. Mean motion resonant interaction with Jupiter may be observed for cases where a is within roughly a Hill radius, or about 0.355 AU, of its semimajor axis $a_J \sim 5.2$ AU, and this criterion is met at about the one σ level. Due to the retrograde orbit, this may be regarded as suggestive of possible strong interaction, but not a mean motion resonance in the usual sense. It is thus useful to investigate the stability of the orbit and whether it has "counter-orbital" (Dobrovolskis, 2012; Morais and Namouni, 2016) stability. The large absolute value of the inclination $|i|$ and of the eccentricity suggest that the Kozai (1962) mechanism might operate. Use of the Kozai formulae (Connors, 2014) with $|i|$ suggests that it should, however numerical integration did not bear this out. This aspect is not

[3] http://www.minorplanetcenter.net/mpec/K07/K07W21.html, cited 1/12/2013.
[4] http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=2007+VW266&orb=1, cited 1/12/2013.