Conjunction Risks of Near-Earth Objects to Artificial Satellites: The Case of Asteroid 2015 VY_{105}

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ABSTRACT

The close approach of near-Earth object 2015 VY_{105} on November 15, 2015 occurred less than 24 hours after discovery by the Catalina Sky Survey (located in Tucson, AZ). Based on the discovery metric information and follow up data from Magdalena Ridge Observatory (MRO) observations, it was clear that this asteroid would pass through the geostationary satellite belt. In particular, data indicated that although 2015 VY_{105} would come within approximately 200 km of the *DirectTV 11* and *14* satellites, it would not impact either. The details of this analysis as well as characterization results acquired are presented. Further, examples of various other asteroids that have made close approaches within geostationary distances in the past (with both long and short lead times) are included for risk context.

1. INTRODUCTION

Since the early 1990's, potentially hazardous asteroids have been monitored and catalogued through NASA's Spaceguard program. Based on current population models, objects 1 km and larger have an average impact interval on the order of about a million years. However, this population model has a power law behavior resulting in the prediction that meter-sized asteroids have impact intervals on the order of just one year. Fortunately, the Earth's atmosphere filters its surface from most objects less than ~25 meters in diameter. However, resident space objects (RSOs) do not benefit from this protective layer.

Current observation statistics reveal that asteroids passing in close proximity (but not on an impact trajectory) to the Earth are a common occurrence. Several asteroids typically pass within lunar distances (384,402 km) of the Earth on a monthly basis. As ground based monitoring facilities and techniques are improved, the frequency of detection of such events has increased. Moreover, observational facilities have been better able to capitalize on these close (and non-threatening) flybys by acquiring valuable scientific data such as orbit metrics, spin rate, composition, size, and rough shape.

Although the risk to RSOs from these close approaches is low, it is not zero. Currently, there are procedures in place for NASA's Planetary Defense Office to inform *JSpOC* of any asteroidal bodies that have been identified to pose a risk to artificial objects [1]. However, this procedure is still in development for recently discovered objects whose orbits have not been fully characterized. Unfortunately, many of the smaller objects that have impact intervals on the order of years fall into this category and are only discovered days or even hours before their closest approach. It would be beneficial to have appropriately streamlined communication protocols and software in place to prepare for both long and short lead-time potential conjunction events.

2. EVENT FREQUENCY

Table 1 shows how often objects pass within the geosynchronous (GEO) satellite zone, coming to within at least 42,000 km of the Earth. In 2016 to date, five such close approaches have occurred. The asteroids in Table 1 highlighted in green have been observed and characterized by researchers at the Magdalena Ridge Observatory's (MRO's) fast-tracking 2.4-meter telescope (see Figure 1). Such characterization efforts help narrow down important parameters such as the object's size (via spectra) which constrains the nature of the threat for Earth-impacting objects, and better defines the conjunction profile for possible satellite collisions.

Although we focus on analysis of close-flyby asteroid 2015 VY_{105} in this paper, in the larger context, other similar events have occurred and will continue to occur on a regular basis.

Approach Distance to Earth (km)	Date (UT)	Asteroid	Absolute Magnitude (H)	Diameter (meters)
6,433	2008 Oct. 7	2008 TC_3	30.4	2 - 5
6,433	2014 Jan. 2	2014 AA	30.9	2 - 4
11,818	2011 Feb. 4	2011 CQ_1	32.1	1
13,464	2008 Oct. 9	2008 TS_{26}	33.2	1
14,361	2016 Feb. 25	2016 DY_{30}	30.5	2 - 5
18,700	2011 June 27	2011 MD	28.0	10 - 14
20,345	2009 Nov. 6	2009 VA	28.6	3 - 14
20,794	2012 May 29	2012 KT_{42}	29.0	4 - 10
30,069	2016 Jan. 12	2016 AH_{164}	29.7	3 - 7
30,817	2008 Oct. 20	2008 US	31.6	3
35,754	2013 Dec. 23	2013 YB	31.5	3
37,250	2016 Jan. 14	2016 AN_{164}	30.4	2 - 5
38,895	2010 Nov. 17	2010 WA	30.0	2 - 6
38,895	2011 Feb. 6	2011 CF_{22}	30.9	3
39,195	2015 Feb. 17	2015 DD_1	30.4	2 - 5
39,494	2015 Nov. 15	2015 VY_{105}	29.0	3 - 4
39,643	2016 Mar. 11	2016 EF_{195}	25.5	16 - 31
39,943	2014 Sept. 7	2014 RC	26.8	11 - 25
40,541	2014 June 3	2014 LY_{21}	29.1	4 - 8
41,139	2013 Feb. 15	2012 DA_{14}	24.0	20 - 40
41,139	2015 Sept. 22	2015 SK_7	28.9	3 - 14
42,336	2016 Sept. 7	2016 RB_1	28.2	4 - 13

Table 1. Asteroid close approaches to within the GEO belt from 2008 – Sept. 2016. Highlighted asteroids were observed with the MRO 2.4-meter telescope.

Fig. 1. The Magdalena Ridge Observatory 2.4-meter fast-tracking telescope (left) and support facility (right) located outside of Socorro, NM on Magdalena Ridge. The observatory performs target-of-opportunity scientific research including near-Earth object asteroid studies (as a NASA-Spaceguard funded facility) and work in the area of space situational awareness.

3. ASTEROID 2015 VY_{105}

Asteroid 2015 VY_{105} made its close approach to the Earth on November 15, 2015. Data taken using the MRO 2.4-meter telescope showed that although 2015 VY_{105} would come within approximately 200 km of the *DirectTV 11* and *14* satellites, it would fortunately not impact either [2]. Figure 2 captures this asteroid in the same frame as another satellite (*TDRS 3*) on its incoming (not yet closest approach) trajectory. It was only 24 hours after discovery that this asteroid would make its closest approach to the Earth and pass through the GEO belt.

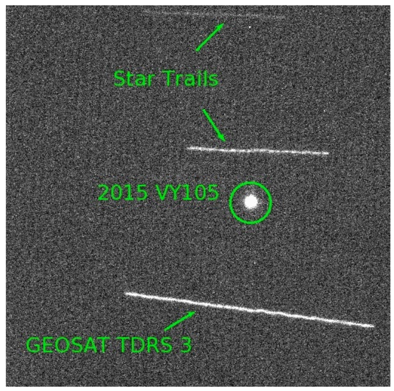


Fig. 2. Asteroid 2015 VY_{105} came within 0.1 Lunar distances (39, 494 km) of the Earth, and passed within the geosynchronous satellite belt. The image was taken using the MRO 2.4-meter telescope; the telescope is tracking on the asteroid such that stars appear trailed as does the satellite path.

The orbital path of 2015 VY_{105} as it made its way through the GEO belt is shown in Figure 3. Figure 4 displays its lighcurve, which indicates that it is a very fast rotator in a tumbling state with a primary period of ~133 seconds. Photometric measurements of the periodic light variation were obtained at MRO using an Andor iKon 936 CCD camera with a *2Kx2K* EEV CCD42-40 array and 13.5 micron pixels thermoelectrically cooled to -85ºC. The images were taken through a Bessel VR filter, and exposure times were adjusted based on the asteroid's brightness. Typical realized seeing was on the order of one arc-second, and the CCD was binned 4x4 resulting in approximately 2 pixels per seeing width. Photometry was extracted from the images using the IRAF *phot* task from which the sequential lightcurves were derived. Trial periods were identified using the IRAF *pdm* task. These possible periods were then used as input into custom software that modeled the tumbling nature of the asteroid using a 2-dimensional Fourier series.

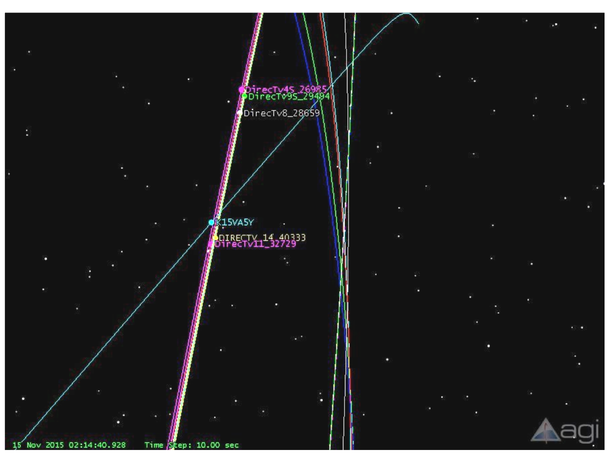


Fig. 3. Orbit trajectory of 2015 VY_{105} (blue line) on November 15, 2015. Also shown are *DirectTV* satellites' paths in purple and white. (image generated by the authors using *AGI-STK 11* software)

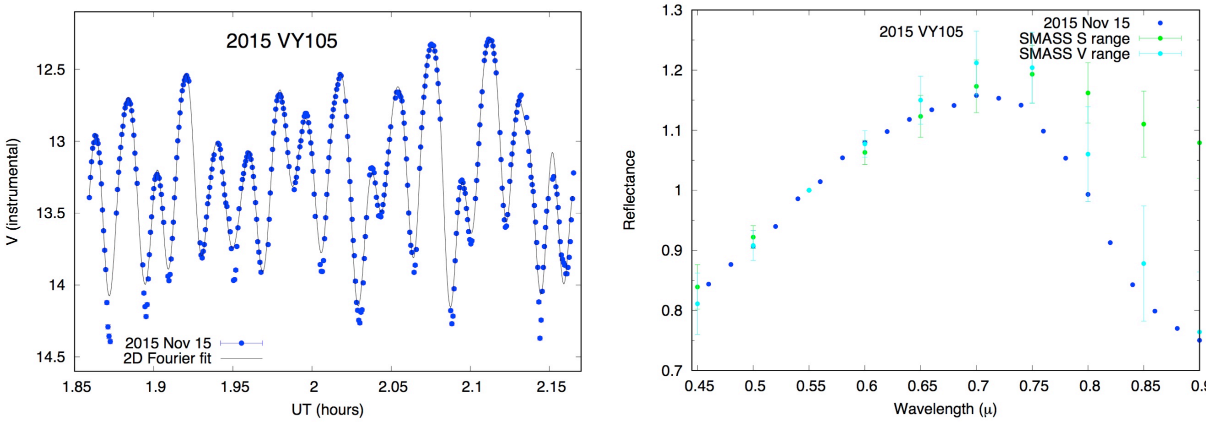
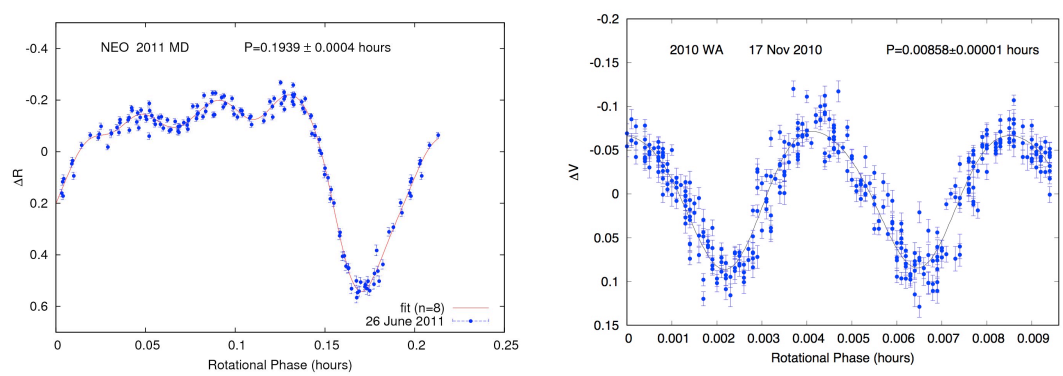


Fig. 4. (Left) Lighhtcurve obtained for 2015 VY_{105}; the asteroid was found to be tumbling with the primary spin period of 0.037 hours using a 3rd order 2D Fourier fit. (Right) Spectra (which helps pin down a size of ~4 m) for 2015 VY_{105}, indicating it may be of V-type composition (SMASS match shown in light blue symbols), a basaltic body similar to main-belt asteroid Vesta.

Also shown in Figure 4 is the asteroid's spectrum, acquired via the grating method originally developed for space situational awareness applications [3] and later utilized for the study of near-Earth asteroids [4]. The spectrum suggests a basaltic composition, similar to main-belt asteroid Vesta. Having obtained a spectrum of the object enabled a rough composition to be determined, which in turn constrained the asteroid's size by providing a better estimate of its likely albedo. Without this constraint size can vary by a factor of 2 or greater. Assuming a typical V-type albedo for 2016 VY_{105} yields a diameter of 3-4 meters.

3. CHARACTRIZATION OF OTHER CLOSE FLYBYS

Other asteroids in Table 1 for which we have acquired data are shown in Figure 5. Both 2011 MD and 2010 WA, have fast rotation rates (11.6 minutes and 31 seconds, respectively). Asteroid 2012 DA_{14} is tumbling as it revolves around the sun, and is rotating much more slowly at 9 hours. Orbit details were known months in advance of the flyby for 2012 DA_{14}, confirming it would miss any RSOs (or Earth).



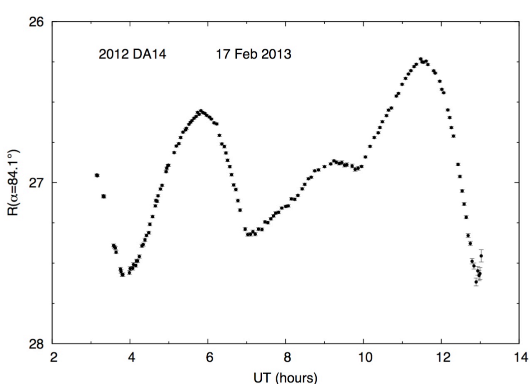


Fig. 5. Lightcurve (Top left) of 2011 MD; its rotation period is 0.194 hrs. (Top Right) Lightcurve for 2012 DA_{14}; this asteroid is tumbling with a primary rotation period of 9 hours. (Bottom) Lightcurve for 2010 WA, revealing a rotation rate of about 31 seconds.

With the long lead time (nearly a year) before the close approach of 2012 DA_{14}, detailed characterization data were acquired by ground based telescope facilities. This was a more unique situation in that such a close encounter was known, and able to be planned for, more than a few days or hours in advance. Radar observations provided images that suggested the body was an ellipsoid with a size of 40 x 20 meters. This would be a considerably large threat if on a collision course with Earth or its artificial satellites, but observational data confirmed it would safely miss both the Earth and all major satellite clusters.

4. SUMMARY

The journey of 2015 VY105 through the GEO-belt reminded us of the fact that a few-meter sized asteroids do travel through the neighborhood where RSOs reside. To date in 2016, five asteroids came to within GEO distances of the Earth and as ground based observational techniques improve, discovery statistics will likely increase. Understanding the long-term behavior of these bodies is important, as is establishing a notification protocol between NASA and *JSpOC* for communication of their orbit metrics. This would help ensure that low probability, but easily mitigated, conjunction events with asteroids that are a few meters in size or larger can be avoided.

5. REFERENCES

[1] Lindley Johnson, NASA Planetary Defense Officer, personal communication.

[2] Paul Chodas, NASA NEO Program Office at JPL, personal communication.

[3] Dao, P., P. McNicholl, A. Dentamaro, E. Ryan, and W. Ryan (2013). Unmixing Space Object's Moderate Resolution Spectra, Proceedings of the *2013 AMOS Technical Conference*, Maui, Hawaii.

[4] Ryan, W.H., and E.V. Ryan (2014). Diagnostic Comparisons of Near-Earth Object Identification using Slit Spectroscopy and Slitless Grating Methods, Proceedings of the *2014 AMOS Technical Conference*, Maui, Hawaii.

6. ACKNOWLEDGEMENTS

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