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Assessment of DSN Communication Coverage for Space Missions to Potentially Hazardous Asteroids

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Abstract - *A communication coverage gap exists for Deep Space Network (DSN) antennas. This communication coverage gap is on the southern hemisphere, centered at approximate latitude of –47° and longitude of –45°. The area of this communication gap varies depending on the altitude from the Earth's surface. There are no current planetary space missions that fall within the DSN communication gap because planetary bodies in the Solar system lie near the ecliptic plane. However, some asteroids' orbits are not confined to the ecliptic plane. In recent years, Potentially Hazardous Asteroids (PHAs) have passed within 100,000 km of the Earth. NASA's future space exploration goals include a manned mission to asteroids. It is important to ensure reliable and redundant communication coverage/capabilities for manned space missions to dangerous asteroids that make a sequence of close Earth encounters. In this paper, we will describe simulations performed to determine whether near-Earth objects (NEO) that have been classified as PHAs fall within the DSN communication coverage gap. In the study, we reviewed literature for a number of PHAs, generated binary ephemeris for selected PHAs using JPL's HORIZONS tool, and created their trajectories using Satellite Took Kit (STK). The results show that some of the PHAs fall within DSN communication coverage gap. This paper presents the simulation results and our analyses.*

Keywords: DSN Communication gap, Deep Space Network, PHA simulation, Asteroids.

1 Introduction

In our recent work [1], we modeled the communication coverage gap within DSN and presented both 2D and 3D communication coverage profiles showing the location, size, and shape of the DSN communication coverage gap projected in space at various deep space altitudes. As the Earth rotates, the center of this DSN gap is rotating at approximate latitude of –47° and longitude of –45° (Figure 3 and 4) and stretches in space depending on the altitude from the Earth's surface [1]. There are no current planetary space missions that fall within the DSN communication gap because planetary bodies in the Solar system lie near the ecliptic plane. As illustrated in Figure 1 with the example of asteroid 2004 QY2, some asteroids' orbits are not confined to the ecliptic plane. In recent years, PHAs have passed within 100,000 km of the Earth. On March 2, 2009, the Apollo asteroid named 2009 DD45 (approximately 35 m in diameter) passed about 72,000 km above the Earth's surface, approximately twice the height of a geostationary communications satellite. Also, on March 18, 2004, a 30-m Aten asteroid identified as 2004 FH, passed about 43,000 km above the Earth's surface, about 0.1 of the distance to the Moon.

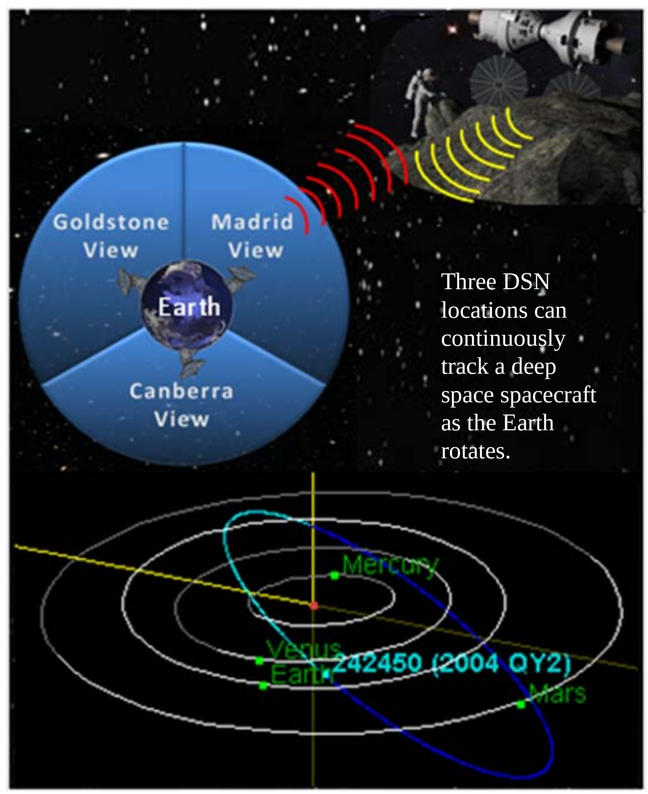


Figure 1. An artistic illustration of DSN supporting communication for a manned asteroid mission

NASA's future space exploration goals include both robotic and manned missions to asteroids. Asteroids with an Earth Minimum Orbit Intersection Distance (MOID) of 0.05 AU (7,480,000 km) or less and an absolute magnitude (H) of 22.0 or less are considered Potentially Hazardous Asteroids (PHAs) [2]. A manned mission to an asteroid (as depicted in Figure 1) would require redundant communication coverage at all times. This paper describes simulations performed to determine whether PHAs fall within the present DSN communication coverage and evaluate the capability of the current DSN to support an asteroid mission.

2 DSN Communication Coverage Gap

The current NASA Deep Space Network (DSN) consists of 13 ground antennas located at three Deep Space Communications Complex (DSCC) facilities: Goldstone in USA, Canberra in Australia, and Madrid in Spain (Figure 2). These DSN antennas are required to provide continuous communication coverage for deep space flights and interplanetary missions. Each DSCC has at least one 34-m beam wave guide antenna, one 34-m high efficiency antenna, one 70-m antenna, and a signal processing center (Figure 2). The three DSCC facilities are not separated by exactly 120 degrees, and some DSN antennas are located in the bowl-shaped mountainous terrain to shield against radiofrequency interference resulting in a coverage gap in the southern hemisphere for the current DSN architecture.

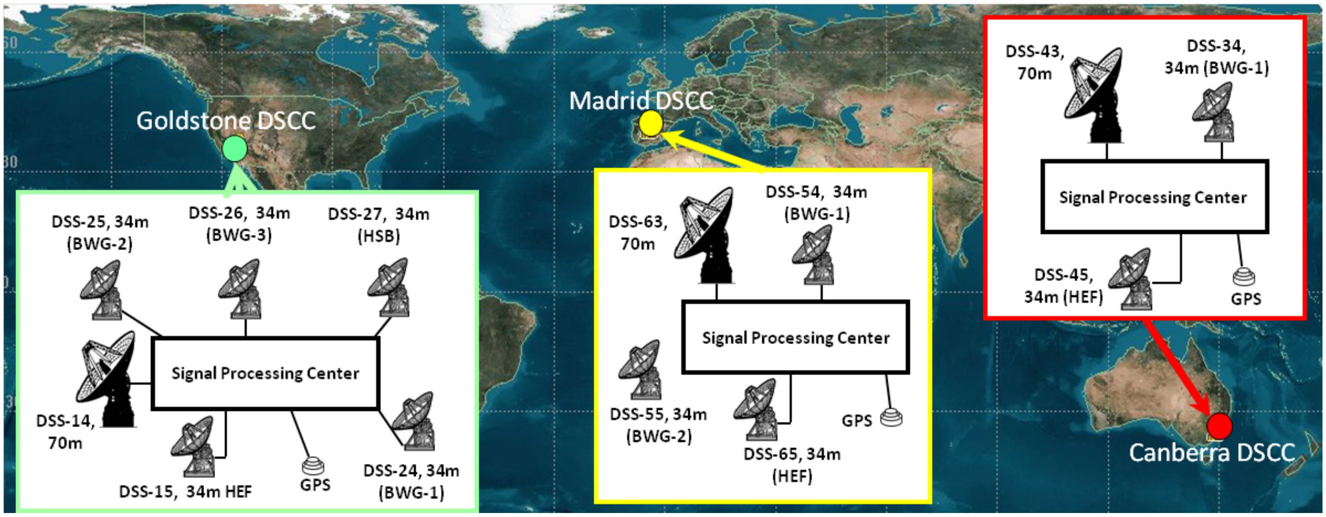
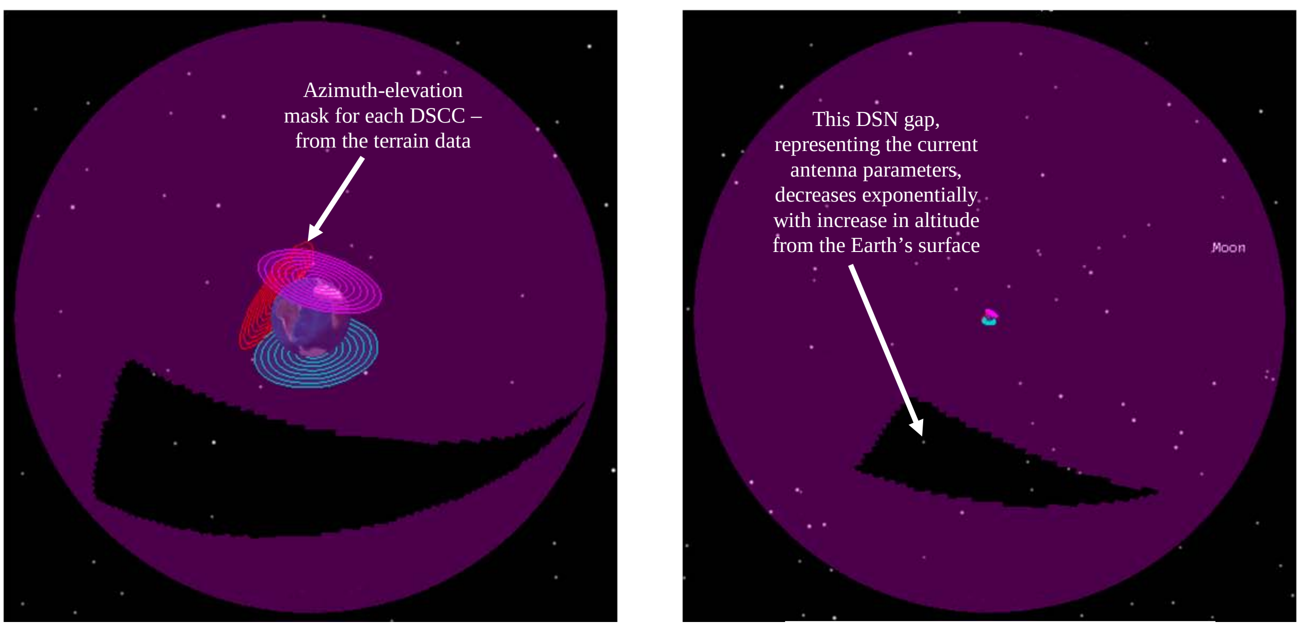


Figure 2. Overview of antennas and facilities for each Deep Space Communications Complex (DSCC)



(a) Altitude of 40,000 km

(b) Altitude of 400,000 km

Figure 3. 3D profile of DSN communication coverage gap

The DSN communication gap (Figure 3 and 4) is based on the line of sight for each antenna computed using the current DSN antenna parameters [3-6], and Azimuth-Elevation masks that were computed from the terrain data for each antenna [1]. As shown in Figure 3, the area of this communication gap varies depending on the altitude from the Earth's surface. This communication coverage gap on the southern hemisphere is centered at approximate latitude of –47° and longitude of –45° (Figure 3 and 4). At an altitude of 10,000,000 km, the gap stretches from longitudes of –75° to 2° (Figure 4).

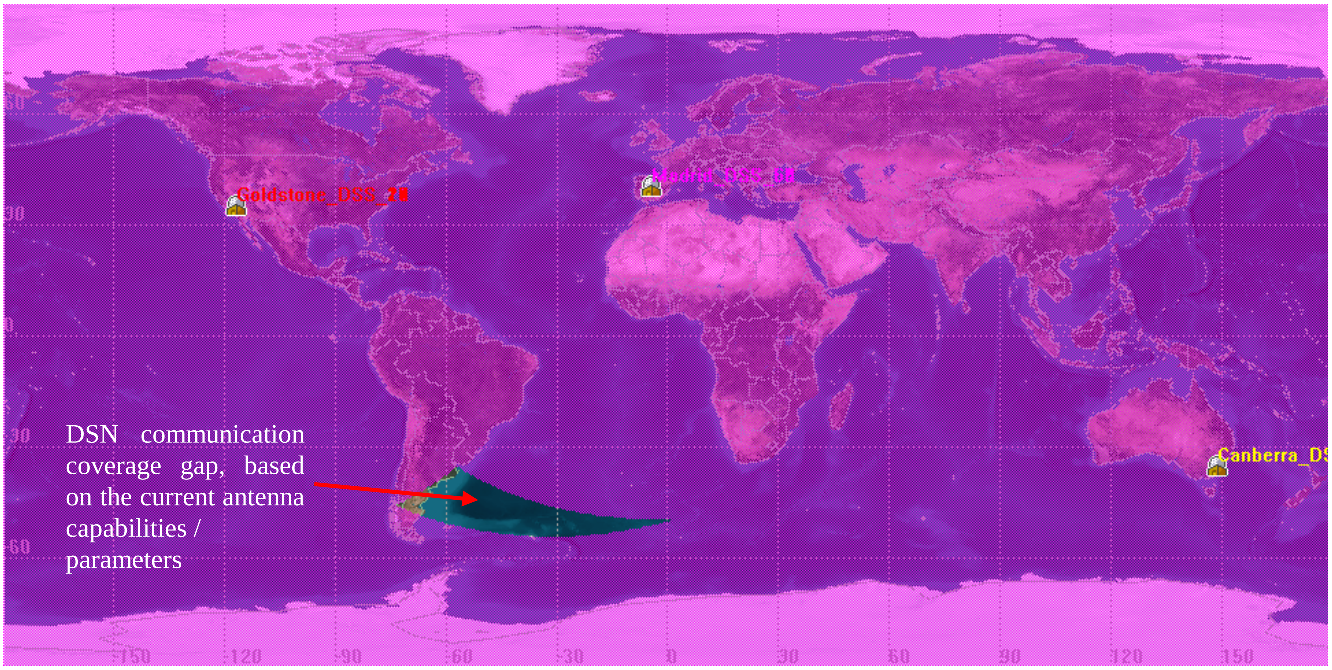


Figure 4. 2D profile of DSN communication coverage at an altitude of 10,000,000 km

3 PHAs Simulations and Analysis

The objective of these simulations was to determine whether the current DSN antennas are capable of supporting a PHA mission. A number of publications have shown the need for PHA mitigation planning to protect life on Earth from the potential future catastrophic consequences of a PHA colliding with Earth. Mitigation planning would first require a space mission to carry out fundamental science investigations that will lead to designing deflection or mitigation schemes. Such missions would study the mineralogical and chemical compositions of PHAs, physical characteristics, and impact hazards. Whether they will be sample return missions or remote sensing science orbital payload, navigation and communication back to Earth will be required. Authors of [7], [8], and [9] have suggested mission lengths ranging from 180 to 365 days.

PHAs were selected for simulations based on the following criteria: (i) Earth-close-encounter mission opportunity occurring between 2015 and 2040, (ii) Earth MOID of less than 0.05 AU, and (iii) the absolute magnitude (H) of less than 22. H corresponds to the diameter and the albedo of the asteroid

$$D = \frac{1329}{\sqrt{\alpha}} 10^{-0.2H} \qquad (1)$$

where α is the geometric albedo of a minor planet or asteroid, and D is the diameter in km [8].

Using the above criteria, ephemeris (trajectory) data for each PHA selected was obtained by using the HORIZONS tool that was provided by the JPL Solar System Dynamics Group. These ephemeris data files were used to create simulation scenarios for each PHA using Satellite Tool Kit (STK) software. In Figures 5 – 11, the ground tracks of trajectories of PHAs that fall outside the DSN communication coverage gap during close Earth approach are highlighted in blue, whereas the PHAs that cross the DSN communication coverage gap are shown in red.

3.1 Simulations of 99942 Apophis

Figure 5 shows the ground tracks of the trajectories for 99942 Apophis (2004 MN4) from April 01, 2028, to April 01, 2030. On April 13, 2029, Apophis (about 350 m in diameter) will pass 37, 399.5 km (0.10 Lunar distances) closer to earth, which is very close to the geostationary satellite orbit (~35,786 km). This closer approach will provide an opportunity for delivery of a science payload to the PHA 99942 Apophis. Several sources have proposed 99942 Apophis as a good candidate for a test mission. During the 2029 closer approach, Apophis will be gravitationally perturbed to an orbit that may increase the chances of impacting Earth in 2036 [7]. As seen from the simulations in Figure 5, 99942 Apophis' trajectory is within DSN communication coverage.

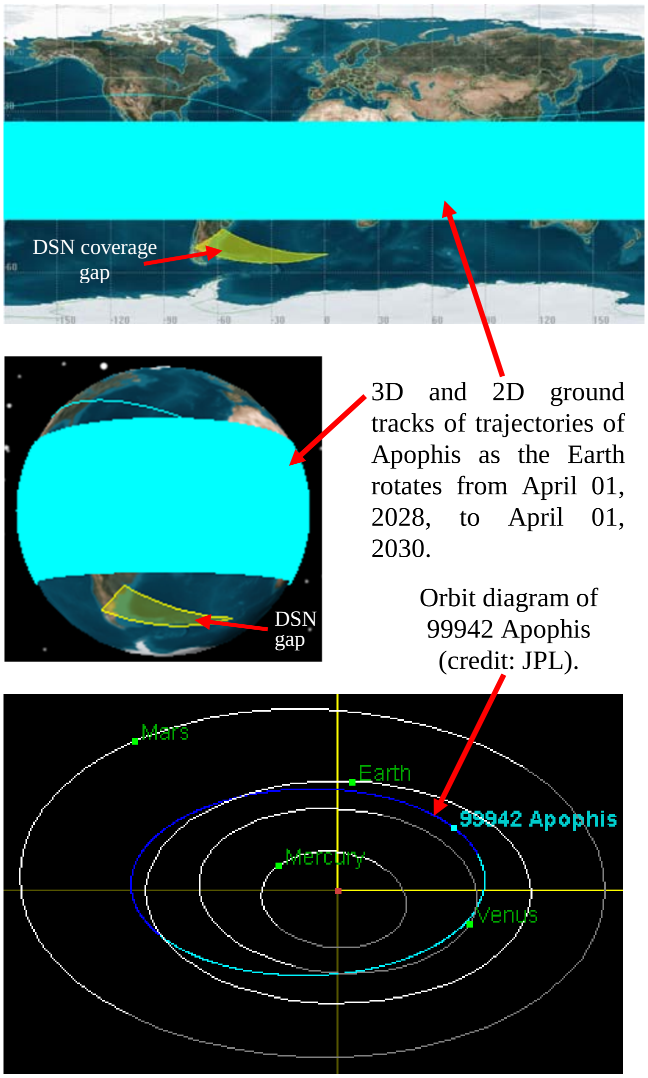


Figure 5. Simulations of 99942 Apophis

3.2 Simulations of 1998 OR2

On April 29, 2020, asteroid 1998 OR2, which has a diameter of 3.3 km, will make a close approach to Earth within 0.04205 AU (6,298,070 km or 16.4 Lunar distances). Figure 6 shows the simulations of the trajectories of 1998 OR2 from October 29, 2019, to October 29, 2020. These simulations show that 1998 OR2 passes into the DSN communication coverage gap during the simulation period. However, on April 29, 2020 (close approach date), 1998 OR2 is above the DSN communication coverage gap, but descending down to the gap (Figure 6). The simulations show that 1998 OR2 starts crossing the gap at simulation time "2 May 2020 00:35:53.818," crosses the gap 8 times, and leaves the gap at simulation time "9 May 2020 01:29:53.818."

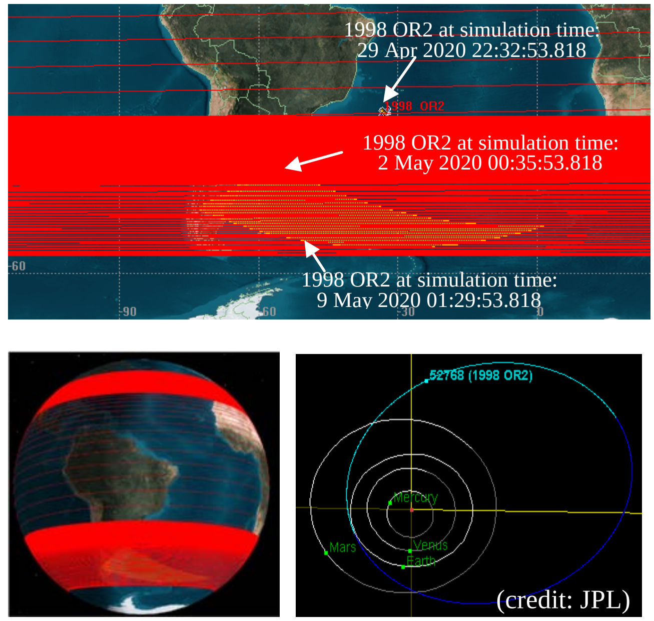


Figure 6. Simulations of 1998 OR2

3.3 Simulations of 2004 QY2

Asteroid 2004 QY2 will make a close approach of 0.0471 AU (7,046,060 km or 18.3 Lunar distances) to Earth on July 15, 2029. Figure 7 shows the trajectories of 2004 QY2, starting from January 06, 2029, to December 06, 2029.

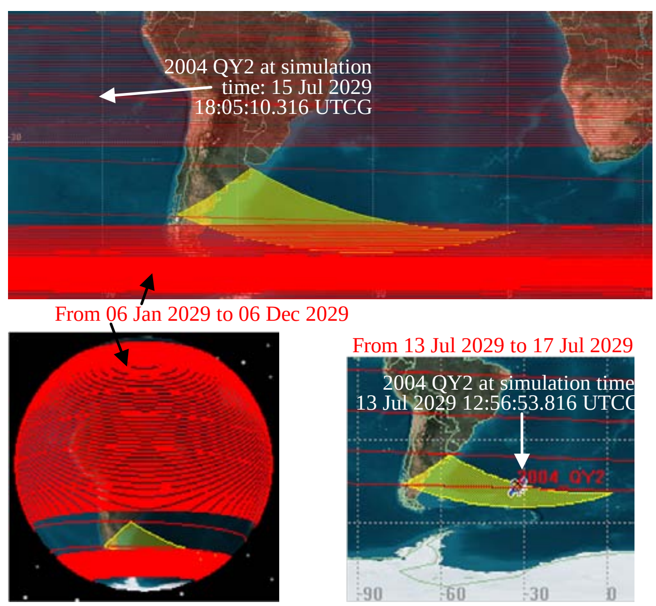


Figure 7. Simulations of 2004 QY2

The orbit diagram of 2004 QY2 is shown in Figure 1. From the simulations in Figure 7, we can see that 2004 QY2 passes into the DSN communication coverage gap about two days before its close encounter (on July 15, 2029).

3.4 Simulations of 2001 WN5

2001 WN5, an Apollo PHA will pass within 254,316 km (~ 0.6 Lunar distances) from the Earth on June 26, 2028. 2001 WN5 is estimated to be 700 to 1500 m in diameter (http://neo.jpl.nasa.gov).

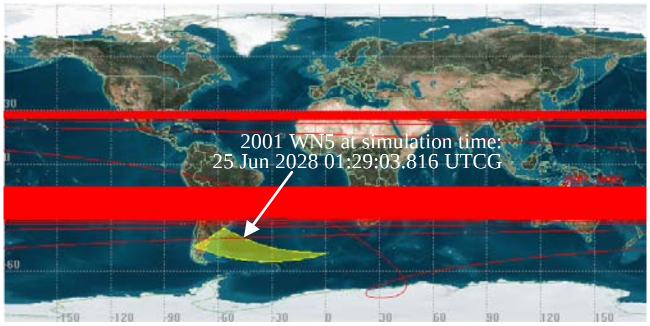


Figure 8. Simulations of 2001 WN5

Figure 8 shows the simulations of the trajectories of 2001 WN5 from January 01, 2028 to December 01, 2028. Simulations show that on June 25, 2028, 2001 WN5 crosses into the DSN communications gap and stays in the gap for about 1.5 hours.

3.5 Simulations of 2004 BL86

The PHA named 2004 BL86, which has an estimated diameter of 0.5 to 1.1 km, will make the next close approach to Earth of 0.008 AU (1,196,783 km or 3.1 Lunar distances). Figure 9 shows the simulations of the trajectories of 2004 BL86 from June 24, 2014, to June 24, 2015. During its close encounter (January 26, 2015), 2004 BL86 orbit falls within the region without DSN communication coverage.

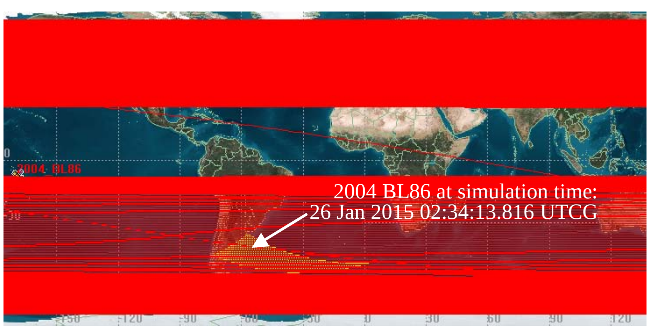


Figure 9. Simulations of 2004 BL86

3.6 Simulations of 2006 SU49

On January 28, 2029, asteroid 2006 SU49, which has a diameter of 0.38 km, will make a close approach to Earth within 0.0082 AU (1,226,703 km or 3.2 Lunar distances). Figure 10 shows the simulations of the trajectories of PHA 2006 SU49 from June 01, 2028, to June 01, 2029. From the simulations in Figure 10, 2006 SU49 passes into the DSN communication coverage gap during its close encounter (on January 28, 2029).

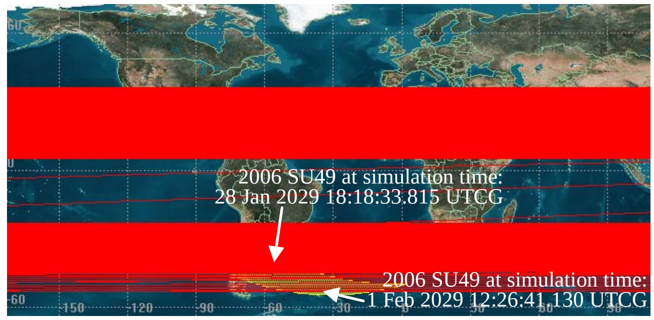


Figure 10. Simulations of 2006 SU49

3.7 Simulations of 2010 DM56

On September 12, 2030, the PHA 2010 DM56, which is about 360 m in diameter, will make a close approach to Earth within 0.0097 AU (1,451,099 km or 3.8 Lunar distances). Figure 11 shows the simulations of the trajectories of PHA 2010 DM56 from March 01, 2030, to March 01, 2031. As seen in Figure 11, on September 09, 2030, 2010 DM56 crosses the region without DSN communication coverage.

Figure 11. Simulations of 2010 DM56

4 Summary and Conclusions

This study evaluated the current DSN communication coverage to support space missions to PHAs. As of December 2011, there were 1274 known PHAs (http://neo.jpl.nasa.gov/neo/groups.html). The selection of PHAs for this simulation was based on Earth-close-encounter occurring between 2015 and 2040, MOID of less than 0.05 AU, and the absolute magnitude (*H*) of less than 22.

The PHA ephemeris data was obtained by using the HORIZONS tool that was provided by the JPL Solar System Dynamics Group. Then, using PHA ephemeris, scenarios for each PHA selected were created and simulated using STK software. Table 1 gives a summary of all the 13 PHAs that were simulated in this study.

Table 1. Summary of Selected PHAs Simulations

PHA Name	Close Approach Date yyyy-mmm-dd	Miss Distance (AU)	V (km/s)	H (mag)	With 100% DSN Coverage
99942 Apophis	2029-Apr-13	0.00025	7.4	19.7	Y
1998 OR2	2020-Apr-29	0.0421	8.7	15.8	N
1990 MU	2027-Jun-06	0.0308	23.8	14.1	Y
2004 QY2	2029-Jul-15	0.0471	23.3	14.7	N
2004 LJ1	2038-Nov-16	0.0198	17.2	15.4	Y
2004 BL86	2015-Jan-26	0.0080	15.7	18.8	N
1999 AN10	2027-Aug-07	0.0026	26.3	17.8	Y
2001 WN5	2028-Jun-26	0.0017	10.2	18.2	N
1997 XF11	2028-Oct-26	0.0062	13.9	16.9	Y
2006 SU49	2029-Jan-28	0.0082	4.9	19.5	N
2010 DM56	2030-Sep-12	0.0097	15.2	19.5	N
2002 NY40	2038-Feb-11	0.0073	20.6	19.2	N
2003 AF23	2021-Jan-03	0.0359	15.4	20.6	Y

As seen from Table 1, 7 out of 13 PHAs simulated cross the DSN communication coverage gap within the period of their close encounters with Earth. PHA mitigation planning to protect life on Earth from the potential future catastrophic consequences of a PHA colliding with Earth is a very necessary task. Mitigation planning would require a space mission to carry out fundamental science investigations that will lead to designing a deflection or mitigation scheme.

The OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) mission is under development and targeted for launch in 2016 [10]. The OSIRIS-REx mission will intercept asteroid 1999 RQ36, study the asteroid, return samples to provide more knowledge about the solar system, and provide knowledge that may guide in deflecting future asteroids [10]. 1999 RQ36 was not included in this assessment since its next close Earth-close-encounter within 0.05 AU will be on September 30, 2054 (0.039 AU).

For any PHA mission (observation, sample return, detonations, deflection, or manned), efficient communication to Earth is very critical and essential for a successful mission. The maximum period without communication coverage if a mission crosses the DSN gap is formulated in [1] as 5.12 hours. For the 7 PHAs that cross the communication coverage gap, communication to Earth can be limited to as little as 19 hours in a 24-hour period. This would be unacceptable for a crewed mission. Therefore, additional communication infrastructure would be required to provide 24-hour coverage for PHA missions.

Acknowledgment

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