THE CASTOR "SPUTNIK 50TH ANNIVERSARY SATELLITE TRACKING BONANZA": PROJECT OVERVIEW AND PRELIMINARY ANALYSIS

By Michael A. Earl

INTRODUCTION

On October 4, 1957, the Soviet Union launched Sputnik 1, the Earth's very first artificial satellite. Today, fifty years later, nearly 13,000 individual man-made objects are orbiting the Earth in the form of payloads, spent rockets and an abundance of debris from both.

In the year 2007, Canadian Satellite Tracking and Orbit Research (CASTOR) celebrated this monumental anniversary by optically detecting and tracking over 2,000 of our artificial satellites. This would be the first time anyone independent of government or military had attempted such an ambitious project of this nature.

The project began on January 1, 2007 and concluded on December 31, 2007. In that time, 50,000 images containing 2,050 of our satellites were obtained with a single SBIG ST-9XE CCD camera.

This project was also conducted to be a preliminary survey of those satellites that could be detected with standard astronomical equipment: a goto telescope of 20 to 28 cm (8 to 11 inches respectively) in aperture and a CCD camera with a minimum quantum efficiency of 50 percent. Over 2008, all the images collected over 2007 will be analyzed for every possible piece of data that can be extracted.

This paper contains a project overview and the results of preliminary analyses carried out during the first quarter of 2008.

PROJECT OVERVIEW

TARGET SATELLITES

CASTOR detected and tracked satellites in the four critical orbit types:

Low Earth Orbit (LEO) satellites were tracked from January 1 to March 31, 2007. For this project, LEO satellites were defined to have a maximum average orbit altitude of 1,700 kilometres (a maximum orbit period of 2 hours). This orbit type includes all sun-synchronous (polar-orbiting) satellites.

Mid Earth Orbit (MEO) satellites were tracked from April 1 to June 30, 2007. For this project, MEO satellites were defined to have an average orbit altitude between 1,700 and 35,500 kilometres (orbit periods of between 2 hours and 24 hours). This orbit type includes all the semi-synchronous GPS and Russian Molniya-type satellites.

Geosynchronous satellites (GEO) were tracked from July 1 to August 31, 2007. For this project, GEO satellites were defined to have an average orbit altitude of between 35,500 and 36,500 kilometres (orbit period of nearly one sidereal day). This orbit type includes the satellite radio and satellite television satellites currently servicing the North, Central and South American continents.

High Earth Orbit (HEO) and new satellites of all previous orbit types defined above were tracked from September 1 to December 31, 2007. For this project, HEO satellites were defined to have a minimum average orbit altitude of 36,500 kilometres (an orbit period of greater than one sidereal day). This orbit type includes all of the super-synchronous satellites.

EQUIPMENT USED

HARDWARE

One “NexStar 11 GPS” 26 centimetre (11-inch) goto computer controlled telescope (2800mm focal length) was used as the main telescope of the project.

One “NexStar 8i SE” 20 centimetre (8-inch) goto computer controlled telescope (2100mm focal length) was used as the portable and backup telescope of the project.

One “Rikenon” 50mm camera lens was used for wide-field imaging.

One “SBIG ST-9XE” CCD camera (512x512 pixels of 20 microns each) was used for all imaging during the project.

The “Astro Power Cube” (built by CASTOR) housed all of the power supplies for the aforementioned hardware.

One Compaq Presario 2199CA notebook computer controlled all telescopes and the CCD camera.

SOFTWARE

TLESort (created by CASTOR) sorted all orbit elements of the candidate satellites into their corresponding orbit types (LEO, MEO, GEO and HEO).

Software Bisque’s “TheSky Version 5” software was used to predict satellite locations and control both telescopes.

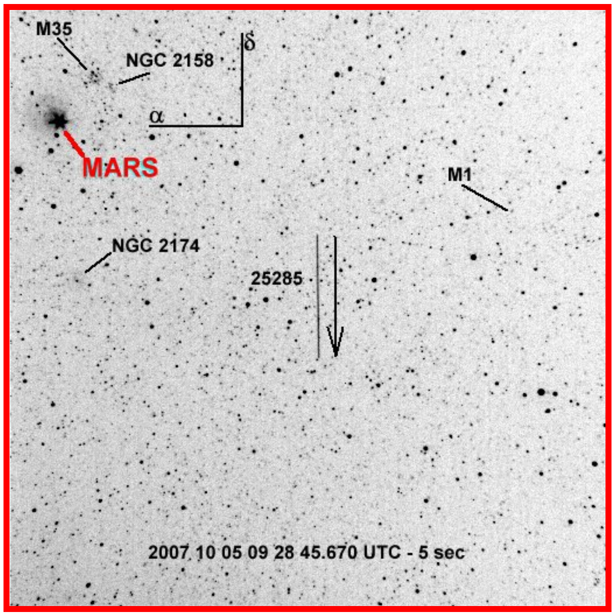
Software Bisque’s “CCDSoft Version 5” software was used to control the CCD camera and will be the main tool in performing astrometric and photometric analyses of all 50,000 images in 2008.

SATELLITE TRACKING LOGISTICS

All LEO satellites were tracked using the SBIG ST-9XE CCD fitted with the Rikenon 50mm lens. Both were piggy-backed onto the NexStar 11 GPS telescope. The resultant field of view (FOV) and angular resolution was 11.26 degrees and 1.32 arc-minutes per pixel, respectively. A CASTOR LEO image is illustrated in Figure 1.

All MEO and GEO satellites were tracked using both NexStar 8i SE and NexStar 11 GPS telescopes with the ST-9XE CCD at prime focus. The FOV and angular resolution for the NexStar 8i SE was 18.73 arc-minutes and 2.195 arc-seconds per pixel respectively. The FOV and angular resolution for the NexStar 11 GPS was 13.33 arc-minutes and 1.562 arc-seconds per pixel respectively. A CASTOR MEO image is illustrated in Figure 2. A CASTOR GEO image is illustrated in Figure 3.

All HEO satellites were tracked using the NexStar 11 GPS telescope with the ST-9XE CCD at prime focus. A CASTOR HEO image is illustrated in Figure 4.



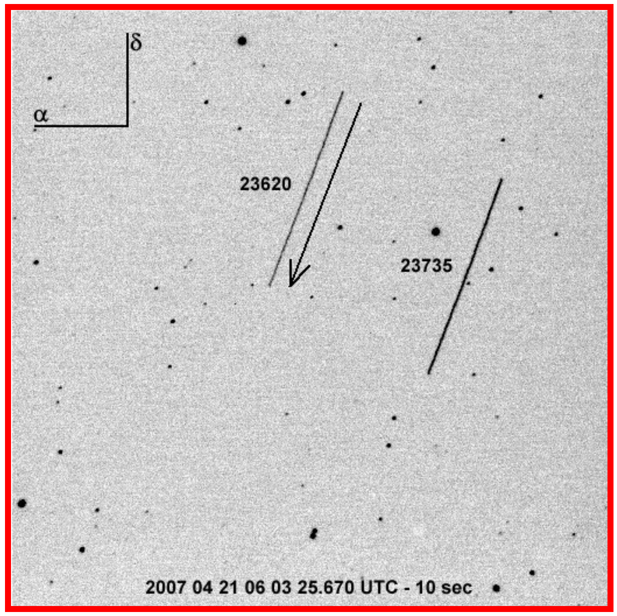
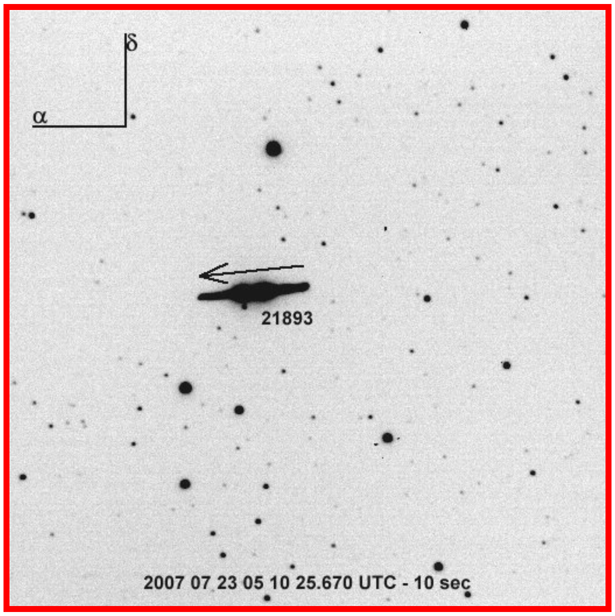


Figure 1 (Left): A CASTOR image of the Iridium 62 (LEO) satellite (CASTOR #1734; NORAD #25285). This image includes the planet Mars, clusters M35 and NGC 2158, nebula NGC 2174 and the Crab Nebula (M1). The compass directions indicate increasing Right Ascension (α) and increasing Declination (δ). The arrow indicates the satellite's apparent direction of travel. This is a negative of the original 5-second CASTOR image obtained at 09:28:45.670 UTC October 5, 2007. The limiting stellar magnitude is 10^{th}.

Figure 2 (Right): A CASTOR image of two Russian "Glonass" GPS (MEO) satellites (CASTOR #'s 0558 and 0559; NORAD #'s 23735 and 23620 respectively) obtained with the NexStar 8i SE telescope and SBIG ST-9XE CCD. The compass directions indicate increasing Right Ascension (α) and increasing Declination (δ). The arrow indicates both satellites' apparent directions of travel. This is a negative of the original 10-second CASTOR image obtained at 06:03:25.670 UTC April 21, 2007. The limiting stellar magnitude is 17^{th}.



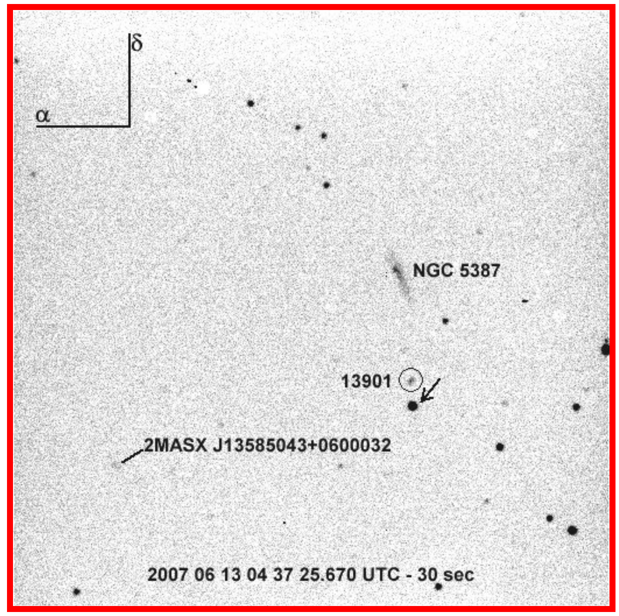


Figure 3 (Left): A CASTOR image of the Japanese Superbird B1 (GEO) satellite (CASTOR #1229; NORAD #21893) obtained with the NexStar 11 GPS telescope and SBIG ST-9XE CCD. This satellite was undergoing a brilliant sunlight reflection during the exposure. The compass directions indicate increasing Right Ascension (α) and increasing Declination (δ). The arrow indicates the satellite's apparent direction of travel. This is a negative of the original 10-second CASTOR image obtained at 05:10:25.670 UTC July 23, 2007. The limiting stellar magnitude is 18^{th}.

Figure 4 (Right): A CASTOR image of the Russian X-Ray Observatory Astron (HEO) satellite (CASTOR #0978; NORAD #13901) (circled) obtained with the NexStar 11 GPS telescope and SBIG ST-9XE CCD. This satellite was the furthest that CASTOR detected in 2007, with a range (distance) of nearly 196,000 kilometres. Galaxy NGC 5387 and a 2MASX survey galaxy also appear. The compass directions indicate increasing Right Ascension (α) and increasing Declination (δ). The arrow indicates the satellite's apparent direction of travel. This is a negative of the original 30-second CASTOR image obtained at 04:37:25.670 UTC June 13, 2007. The limiting stellar magnitude is 18^{th}.

PRELIMINARY ANALYSES

UNIQUE SATELLITES TRACKED PER MONTH

Figure 5 illustrates the number of unique satellites CASTOR detected per month of 2007. "Unique" refers to those satellites that were not already detected in any of the preceding months.

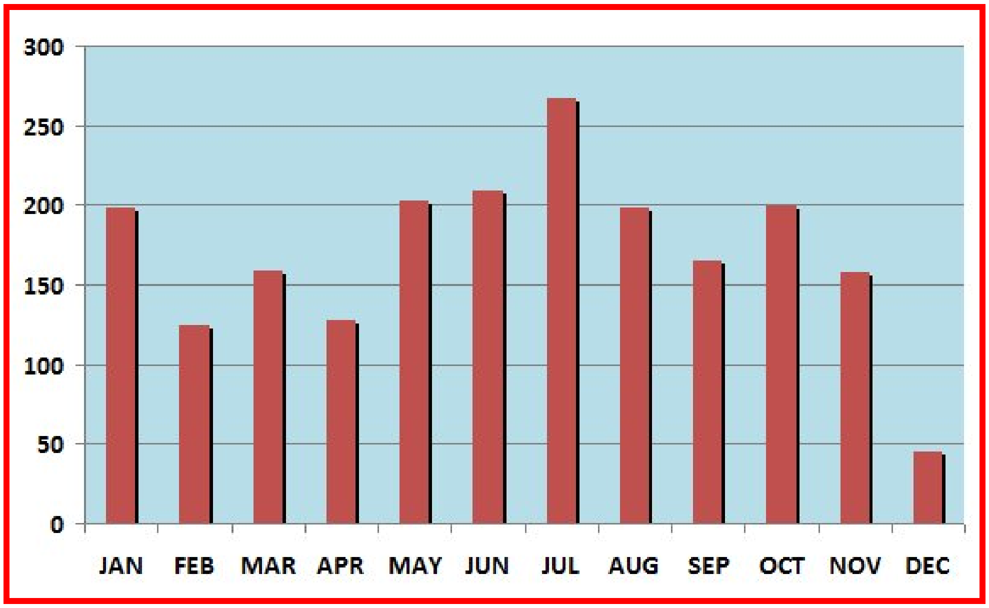


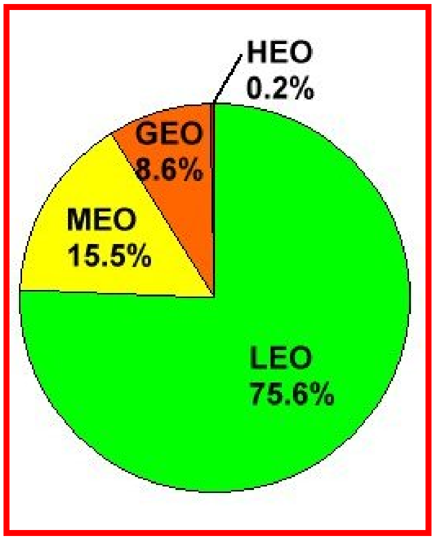
Figure 5: The number of unique satellites CASTOR detected per month in 2007. The low number in December was caused by highly inclement weather.

TOTAL AND DETECTED SATELLITES BY ORBIT TYPE

Figure 6 illustrates the percentage of total satellites in each orbit type with respect to the estimated total number of satellites currently in orbit (12,800).

Figure 7 illustrates the percentage of the number of detected satellites in each orbit type with respect to the total number of detected satellites (2,050).

Figures 8 through 11 illustrate the percentage of detected satellites in each orbit type with respect to the total number of satellites in each respective orbit type (LEO, MEO, GEO and HEO respectively).



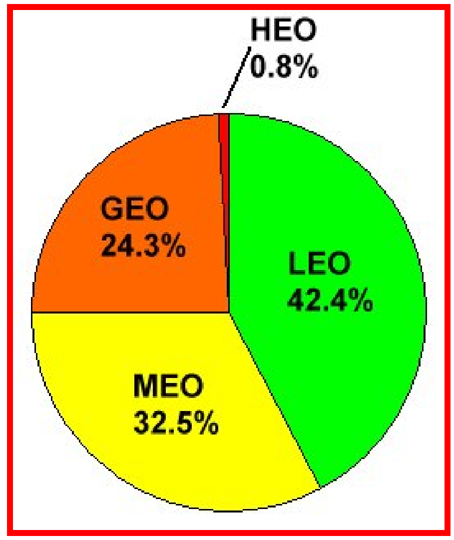
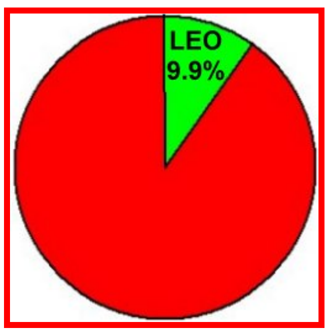
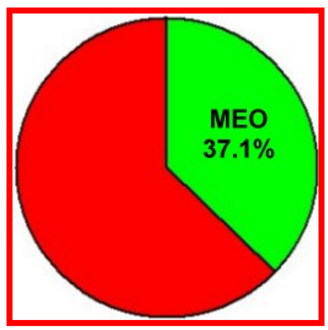
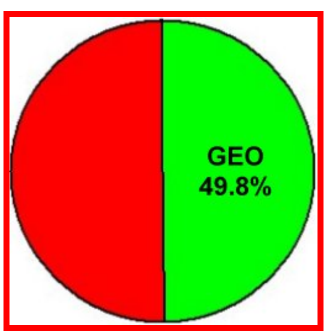


Figure 6 (Left): The percentage of total satellites in each orbit type with respect to the estimated total number of satellites currently in orbit (12,800). Note the dominant LEO percentage.

Figure 7 (Right): The percentage of the number of detected satellites in each orbit type with respect to the total number of detected satellites (2,050).







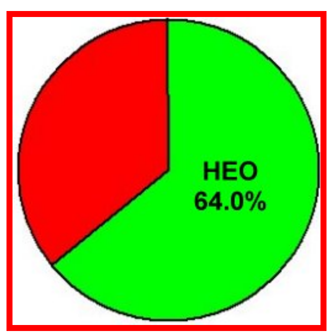


Figure 8 (Top Left): The percentage of the total number of LEO satellites detected.

Figure 9 (Top Right): The percentage of the total number of MEO satellites detected.

Figure 10 (Bottom Left): The percentage of the total number of GEO satellites detected.

Figure 11 (Bottom Right): The percentage of the total number of HEO satellites detected.

DETECTED SATELLITES BY COUNTRY

Figure 8 illustrates the percentage of detected satellites from each country with respect to the total number of satellites detected (2,050).

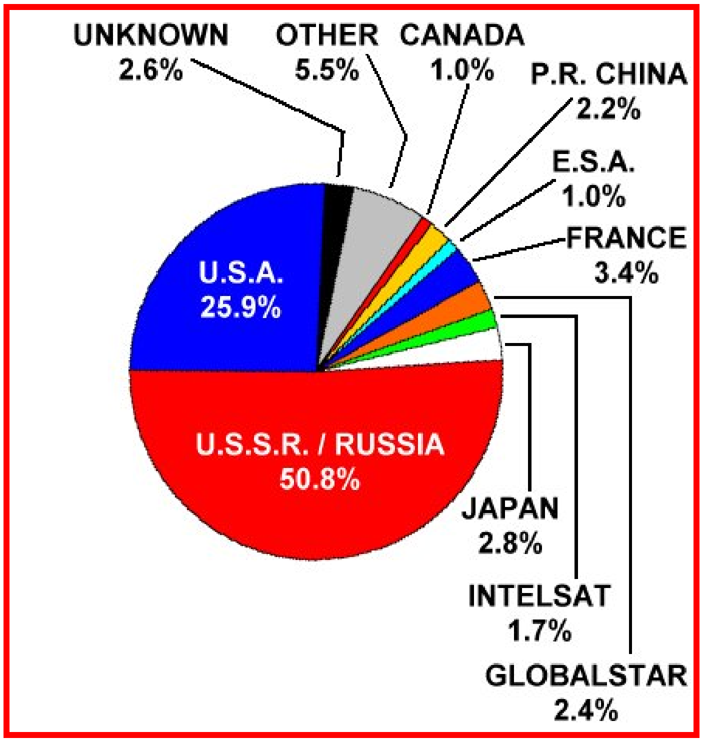


Figure 12: Percentages of the satellites detected by country of origin with respect to the total number of satellites detected (2,050). In several instances, private companies (Globalstar and Intelsat) are indicated. “Other” refers to the remaining countries that represented less than one percent of the overall number detected. “Unknown” refers to those detected satellites that could not be positively identified.

DETECTED SATELLITES BY CATEGORY

The detected satellites were binned into three categories: “Payloads”, “Rocket Bodies” and “Debris”. “Rocket Bodies” mainly refers to spent rockets in orbit. “Debris” refers to small fragments of payloads or rocket bodies. “Payloads” refers to those satellites not considered rocket bodies or debris.

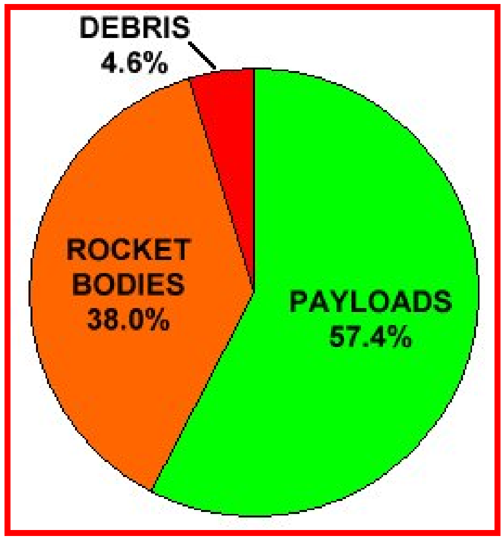


Figure 13: Percentages of the detected payloads, rocket bodies and debris with respect to the total number of detected satellites (2,050). Note the small percentage of debris that was detected.

NOTABLE SATELLITES DETECTED

Of the 2,050 unique satellites that were tracked by CASTOR in 2007, there were some that were of special interest:

The International Space Station (ISS; Alpha; CASTOR #0026; NORAD #25544): The first internationally constructed space station of the Earth;

Fengyun 1C Debris (CASTOR #0141; NORAD #29933): One single piece of the more than 2,000 pieces of debris left over from the intentional destruction of a Chinese weather satellite by a Chinese “anti-satellite” missile;

Telstar 1 (CASTOR #0466; NORAD #00340): The first satellite to transmit live transatlantic television broadcasts from North America to Europe and vice-versa;

Giove-A (Jupiter-A; CASTOR #0467; NORAD #28922): The first GPS satellite by the European Space Agency (ESA);

Westford Needles (CASTOR #0575; NORAD #02364): One of the many pieces of debris left over from the Westford Needles project. This 1960’s project involved placing millions of tiny copper needles into space to serve as an artificial ionosphere;

CXO (Chandra X-Ray Observatory; CASTOR #0976; NORAD #25867): One of the “Big Four” space observatories launched by NASA, including Hubble, Compton and Spitzer;

Anik A1 (Telesat 1; CASTOR #1170; NORAD #06278): The first GEO satellite for domestic (non-military) use. Built by Telesat Canada;

Celestis 2 (Ad-Astra; Taurus Rocket; CASTOR #1454; NORAD #25160): The second memorial spaceflight satellite that contained the cremated remains of loved ones; and

RadarSat 1 (CASTOR #1982; NORAD #23710): Canada's first Earth observation satellite. Built by MacDonald, Dettwiler and Associates, Canada.

CONCLUSIONS

The 2,050 satellites detected by CASTOR constitute 16 percent (nearly 1/6th) of the estimated 12,800 satellites currently in Earth orbit. This project shows that commercial-off-the-shelf (COTS) small aperture telescopes and CCD cameras can be utilized to detect and track a significant portion of our current satellite population.

Nearly one tenth of the total number of LEO satellites were detected (Figure 8). There were several factors which prevented the detection of many of the satellites in this type of orbit:

1) LEO satellites orbit very quickly over the Earth's surface. Most of these satellites can cross the observer's sky in 20 minutes or less. In many cases, as one LEO satellite is being tracked, many others are also accessible at the same time but can become inaccessible quickly. Additional CCD cameras and larger fields of view would be two solutions to this particular problem. A second survey planned for 2009 will attempt to detect more unique LEO satellites;

2) Many LEO satellites are very small debris only several centimetres in size. The apparent angular velocity of a LEO satellite is very fast and therefore travels across the CCD chip very quickly, thus allowing very little integration time per pixel. Many LEO satellites would invariably have a brightness (signal) below the CCD detector's background noise;

3) Many LEO satellites are sun-synchronous, meaning they orbit nearly along the Earth's terminator (night-day divide). Most of these LEO satellites can only be optically detected within the first two hours after sunset or the first two hours before dawn. Some LEO satellites will be within, or in close proximity to, the twilight (or dawn) glow, thereby rendering them nearly invisible to optical equipment; and

4) Many LEO satellites are simply eclipsed by the Earth. Once the Earth blocks the sunlight to a LEO satellite, it is undetectable by optical means. This invariably reduces the amount of available time that these satellites are accessible by CASTOR.

Over one third of the total MEO satellites were detected (Figure 9). In most cases, the undetected satellites were either too small or too dim to be detected by CASTOR's optical equipment.

Nearly one half of the total GEO satellites were detected (Figure 10). Although many GEO satellites are very large and bright, there are several factors which can still render them optically undetectable:

1) Many GEO satellites reside on the opposite side of the Earth from the CASTOR observing site in Brockville Ontario, Canada. Since the orbit period of all GEO satellites is

nearly one orbit per day (nearly the same period as the Earth's rotation), they will be orbiting over the same position over the Earth's surface for long periods of time. As a result, the Earth is regularly in the way of some GEO satellites, rendering them undetectable by CASTOR. One solution to this problem is to employ a second CASTOR facility on or near the opposite side of the Earth from Canada to access the remaining detectable GEOs; and

2) Some GEO satellites are either too small or simply too dim to be optically detected by CASTOR. These mainly come in the form of very small debris from old payloads or rocket bodies. This debris would be about 36,000 kilometres in altitude and therefore would be approximately 500 times (6.8 magnitudes) dimmer than a satellite of the same size at the outer edge of a LEO orbit (1,700 km).

Nearly two thirds of the total number of HEO satellites was detected. This result is not surprising given that most of these satellites are very slow-moving and are large in size. The main reason why Astron (Figure 4) was detected at a range of 196,000 km was mainly due to its large size and slow apparent angular velocity which translated into a large pixel integration time on the CCD chip.

The large proportion of Russian and American satellites detected was not surprising as both nations were the most prolific in satellite launches in the past 50 years. What is surprising is the difference in the percentages of the two countries, despite the fact that at present both countries have nearly the same amount of orbiting satellites (approximately 4,400 each). This discrepancy might be explained by the fact that the Soviet Union launched extremely massive payloads and rockets, while the Americans launched much more compact (and less reflective?) payloads and rockets during the Space Race of the latter 20th century. A good example of this is the difference in size between Sputnik 1 (58 cm) and Vanguard 1 (16 cm). CASTOR tried but failed to detect Vanguard 1.

The third largest number of satellites binned by country (not including "Other") originated in France (Figure 8). This is mainly due to France's successful Ariane rockets. There is no doubt that the Chinese percentage would have been much greater had CASTOR been able to detect a larger amount of debris from the Fengyun 1C weather satellite.

The small amount of debris that was detected by CASTOR (Figure 9) is not surprising. CASTOR utilizes small-aperture telescopes and as a result, most debris will certainly be missed. It is possible that a future analysis will determine possible cross-section (size) limits based on the faintest satellites detected. This data could possibly be used to establish a correlation between the satellites' detected brightness and their radar cross-sections, although there will be numerous factors and variables involved.

The next CASTOR publication will feature the final results of the photometric and astrometric analyses of all 2,050 satellites CASTOR detected in 2007.

Plans are underway for a second year-long CASTOR survey of our Earth-orbiting satellites to begin on the evening of January 1, 2009. This second survey is expected to provide a supplementary CASTOR satellite catalogue in addition to the preliminary 2,050 satellites already detected.

REFERENCES

"Space Track – The Source for Space Surveillance Data - www.space-track.org": All up-to-date orbit elements for all 2,050 satellites CASTOR detected and tracked in 2007;

"Chris Peat's Heavens Above – www.heavens-above.com" – Preliminary predictions for the naked eye LEO satellites; and

"Mike McCants' Satellite Tracking Web Pages - www.io.com/~mmccants" – Orbit elements for the notable satellites CASTOR detected and tracked in 2007.

ACKOWLEDGEMENTS

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CASTOR WEB SITE

To learn more about the CASTOR project and its goals, please visit the CASTOR web site at www.castor2.ca.