National Aeronautics and Space Administration

Orbital Debris
Quarterly News

Volume 11, Issue 2

April 2007

Inside...

A publication of

The NASA Orbital Debris Program Office

United Nations Adopts Space Debris Mitigation Guidelines

During its annual meeting in February 2007, the Scientific and Technical Subcommittee (STSC) of the United Nations' (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) adopted by consensus a comprehensive set of space debris mitigation guidelines designed to curtail the growth of the Earth's orbital debris population. The new document culminates a multi-year work plan involving the review of space debris mitigation guidelines by the Inter-Agency Space Debris Coordination Committee (IADC) and the drafting of a similar set of guidelines for Member States of the UN and other international organizations.

Space debris has been a topic on the agenda of the STSC since 1994. After several years discussing the state-of-the-art of environment measurements and modeling, as well as debris mitigation measures, the STSC completed its *Technical Report on Space Debris* (A/AC.105/720, 1999). Special space debris subjects were then addressed during the annual STSC meetings in Vienna, Austria, for the three-year period of 2000-2002. Following a detailed examination of the IADC Space Debris Mitigation Guidelines during 2003-2004, the STSC undertook the challenge of preparing its own set of mitigation guidelines, leading to the completion of a draft document in February 2006 (*Orbital Debris Quarterly News*, 10-2, p. 2).

Final discussions on the draft document were held during 19-21 February 2007. The full STSC approved the guidelines on 21 February with only one minor revision. The document states that "Member States and international organizations should voluntarily take measures, through national mechanisms or through their own applicable mechanisms, to ensure that these guidelines are implemented, to the greatest extent feasible, through space debris mitigation practices and procedures."

The STSC document contains seven guidelines covering space system design, launch, operation, and disposal:

Guideline 1: Limit debris released during normal operations

Space systems should be designed not to release debris during normal operations. If this is not feasible, the effect of any release of debris on the outer space environment should be minimized.

Guideline 2: Minimize the potential for break-ups during operational phases

Spacecraft and launch vehicle orbital stages should be designed to avoid failure modes which may lead to accidental break-ups. In the case that a condition leading to such a failure is detected, disposal and passivation measures should be planned and executed to avoid break-ups.

Guideline 3: Limit the probability of accidental collision in orbit

In developing the design and mission profile of spacecraft and launch vehicle stages, the probability of accidental collision with known objects during the system's launch phase and orbital lifetime should be estimated and limited. If available orbital data indicate a potential collision, adjustment of the launch time or an on-orbit avoidance maneuver should be considered.

Guideline 4: Avoid intentional destruction and other harmful activities

Recognizing that an increased risk of collision could pose a threat to space operations, the intentional destruction of any on-orbit spacecraft and launch vehicle orbital stages or other harmful activities that generate long-lived debris should be avoided.

Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy

In order to limit the risk to other spacecraft and launch vehicle orbital stages from accidental break-ups, all on-board sources of stored energy should be depleted or made safe when they are no longer required

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for mission operations or post-mission disposal.

Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low Earth orbit (LEO) region after the end of their mission

Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the LEO region, should be removed from orbit in a controlled fashion. If this is not possible, they should be disposed of in orbits which avoid their long-term presence in the LEO region.

Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with geosynchronous (GEO) region after the end of their mission

Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the GEO region should be left in orbits which avoid their long-term interference with the GEO region.

The STSC Space Debris Mitigation Guidelines also contain information on application, rationale, and potential future revisions. The full COPUOS is expected to endorse the document at its annual meeting in June. Member States of STSC are encouraged to report annually on their efforts to implement the new UN guidelines. ♦

Chinese Anti-satellite Test Creates Most Severe Orbital Debris Cloud in History

The debris cloud created by a successful test of a Chinese anti-satellite (ASAT) system on 11 January 2007 represents the single worst contamination of low Earth orbit (LEO) during the past 50 years. Extending from 200 km to more than 4000 km in altitude, the debris frequently transit the orbits of hundreds of operational spacecraft, including the human space flight regime, posing new risks to current and future space systems. Moreover, the majority of the debris were thrown into long-duration orbits, with lifetimes measured in decades and even centuries.

The target of the test was an old Chinese meteorological spacecraft, Fengyun-1C (International Designator 1999-025A, U.S. Satellite Number 25730), residing in an orbit of 845 km by 865 km with an inclination of 98.6°. The 960-kg spacecraft was struck by a ballistic interceptor launched near Xichang, the southernmost launch complex in the People's Republic of China. Two months after the test, more than 1200 debris had been officially cataloged by the U.S. Space Surveillance Network (SSN), and nearly 400 additional debris were being tracked, awaiting permanent catalog numbers (Figure 1). While the final tally of large (> 5 cm size) debris could well exceed 2000, the number of objects with a size of 1 cm or more is estimated to be as large as 35,000. Both values represent an increase of more than 15% of the known debris environment at the start of 2007.

More than half the identified debris were thrown into orbits with mean altitudes in excess of 850 km. Consequently, the debris will remain scattered throughout LEO for many, many years to come. Initially confined to a disk about the Earth, the orbital planes of the debris are rapidly dispersing and will encircle the globe before the end

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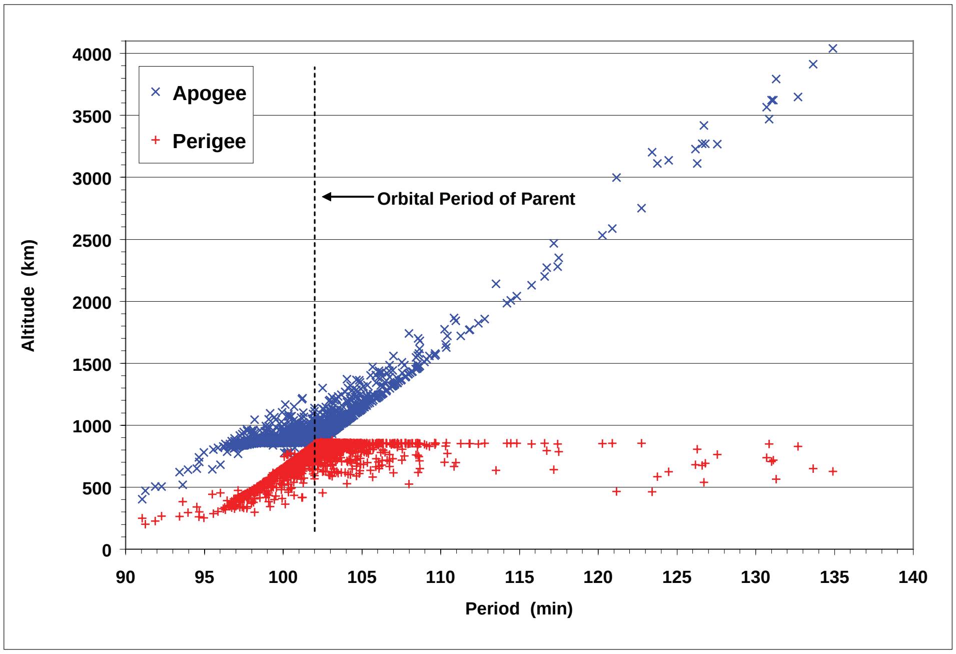

Figure 1. By 31 March 2007 more than 1600 debris from the Chinese ASAT test had been identified and were being tracked by the U.S. Space Surveillance Network.

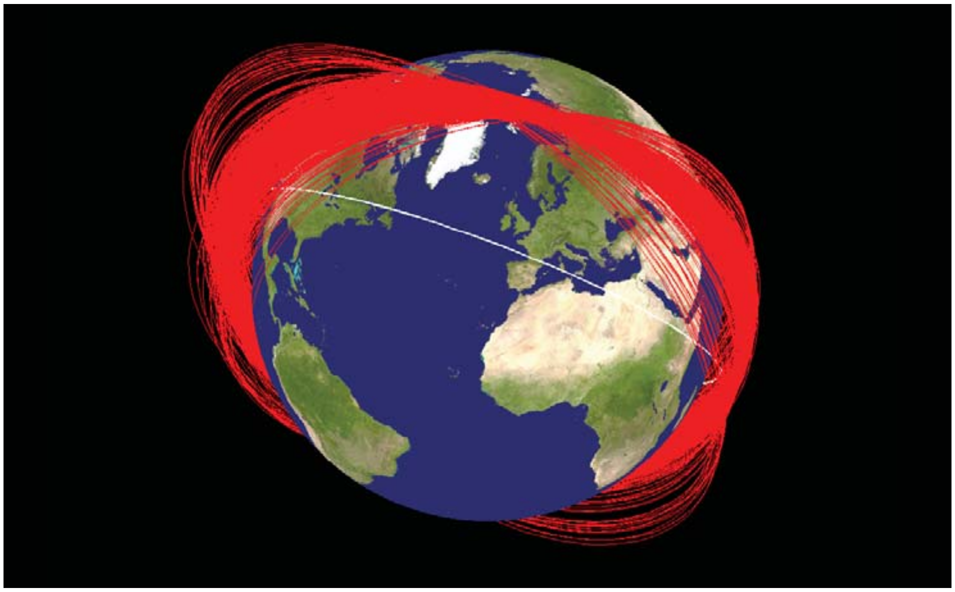

Figure 2. Known orbit planes of Fengyun-1C debris one month after its disintegration by a Chinese interceptor. The white orbit represents the International Space Station.

Chinese Anti-satellite Test

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of the year.

The test directly conflicts with Guideline 5.2.3 of the Space Debris Mitigation Guidelines of the Inter-Agency Space Debris Coordination Committee (IADC), which were officially accepted by the China National Space Administration (CNSA) in October 2002, and represents the breaking of a more than 20-year-old moratorium on orbital debris generation from ASAT testing. The sole impact test of a U.S. ASAT system was conducted in 1985, and no debris from that test remains in orbit today. During 1968-1982, the former Soviet Union conducted 20 ASAT tests, resulting in the creation of more than 700 cataloged debris of which 301 still circle the Earth. The new space debris mitigation guidelines adopted by the Scientific and Technical Subcommittee of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS) also strongly discourage the intentional destruction of spacecraft which could result in the generation of long-lived debris (see article on page 1).

The NASA Orbital Debris Program Office is analyzing debris data from the SSN and from special debris observations by the Haystack radar, which can detect debris as small as 5 mm in diameter. Of particular interest are the comparison of the debris cloud with existing satellite breakup models and the long-term effects of the debris on the near-Earth space environment. (See related chart on the back page of this issue.) ♦

Four Satellite Breakups in February Add to Debris Population

Following the severe, deliberate fragmentation of the Fengyun-1C spacecraft in January (see related article on page 2), additional blows to the near-Earth space environment resulted from the breakup of four satellites in less than three weeks during February. These four latest events involved two Chinese spacecraft and two Russian launch vehicle components. Unlike the destruction of Fengyun-1C, the February breakups appear to have been accidental.

On 2 February the People's Republic of China launched the fourth in a series of geosynchronous navigation satellites under the name Beidou 2A (International Designator 2007-003A, U.S. Satellite Number 30323). Beidou 2A was the first of a series of improved Beidou spacecraft, following the Beidou 1 series launched during 2000-2003. A Long March 3A launch vehicle successfully placed the spacecraft into a geosynchronous transfer orbit of approximately 195 km by 41,775 km with an inclination of 25°.

The spacecraft, with a dry mass of about 1100 kg and 1200 kg of propellant, appears to have suffered a failure at about the time of its first apogee late on 2 February, when the spacecraft's liquid-propellant main engine would be expected to ignite. The U.S. Space Surveillance Network (SSN) detected 70-100 debris soon after the breakup; however, the development of orbital data for each fragment was hampered by the nature of the debris orbits (highly eccentric) and the extensive efforts then underway by the SSN to identify and to track debris from the Fengyun-1C breakup. Later, China reported that the failure had not been catastrophic, and the spacecraft eventually reached geosynchronous Earth orbit.

A 7-year-old Earth observation spacecraft, jointly developed and operated by China and Brazil, suffered an unexpected fragmentation on 18 February. At the time the CBERS-1 (China Brazil Earth Resources Satellite -1) spacecraft was in an orbit of 770 km by 780 km with an inclination of 98.2°. The spacecraft had been retired in August 2003 after exceeding its design lifetime of two years by another two years. The apogee of CBERS-1 was raised slightly at the time of its decommissioning, but the degree of passivation of the spacecraft is unknown.

Approximately two dozen debris from CBERS-1 were detected by the SSN. The first fourteen debris were officially cataloged in early March (U.S. Satellite Numbers 30779-30792). Debris were ejected in both posigrade and retrograde directions, although the more energetic debris appear to have been thrown into lower orbits with perigees up to 200 km below that of CBERS-1 prior to the breakup.

Four days before the breakup of CBERS-1, another ullage motor from a Russian Proton launch vehicle fourth stage broke-up in a decaying geosynchronous transfer orbit. The propulsion unit (International Designator 1997-070F, U.S. Satellite Number 25054) had been used in the successful launch of the Kupon spacecraft in November 1997. The breakup, the 36th of its kind since 1984, occurred on 14 February in an orbit of 260 km by 14,160 km with an inclination of 46.6°.

The SSN detected an estimated 60 debris soon after the breakup. Remarkably, an observer in Finland captured about 20 of the debris by accident with two CCD cameras less than 24 hours after the event. The debris were too faint to be seen with the naked eye. The cause of the breakup is assessed to have been related to residual propellants.

The last satellite breakup of February was also apparently the most severe by far. In February 2006 a Briz-M (also known as Breeze-M) fourth stage of a Russian Proton launch vehicle was used to insert the Arabsat 4A spacecraft into a low altitude parking orbit. About 50 minutes after orbital insertion, the Briz-M stage was reignited in the second of four planned burns. However, due to a malfunction, the stage shut-down early and failed to restart again. The spacecraft, which could not be lifted into the desired geosynchronous operational orbit, was separated and later commanded to a controlled reentry.

Just nine days shy of its first anniversary in space on 19 February 2007, the approximately 2-metric-ton Briz-M stage (International Designator 2006-006B, U.S. Satellite Number 28944) exploded into perhaps more than 1000 detectable debris while in an orbit of 495 km by 14,705 km with an inclination of 51.5°. By sheer luck, the breakup was observed by at least three astronomers in separate locations in Australia and recorded photographically. Several images clearly showed the expansion of a faint cloud around the stage. The cause of the breakup is assumed to be related to the propellants remaining on board the stage after the engine failure the previous year. Again, due in part to the large number of debris generated by the previous four satellite breakups during 11 January – 18 February, the process of developing orbital data for each of the Briz-M debris was delayed. The full extent of the breakup should be better understood in the coming months.

Whereas the four satellite breakups of February appear to have been accidental, at least three of them could have been prevented. As recommended by many national and international orbital debris mitigation guidelines, spacecraft and launch vehicle components should be passivated at the end of their useful lives. Even in the case of the Briz-M malfunction, a backup command to vent unused propellants in the event of a propulsion system failure could have prevented the subsequent explosion. ♦

Publication of *An Assessment of the Role of Solid Rocket Motors in the Generation of Orbital Debris*

A two-year research initiative evaluating the behavior of Solid Rocket Motors (SRMs) and the possible contribution of their effluent to the orbital debris environment has resulted in a NASA Technical Publication entitled *An Assessment of the Role of Solid Rocket Motors in the Generation of Orbital Debris* (NASA/TP-2007-213738). Analysis of optical and IR data collected from SRMs operating in low pressure environments (either sub-orbital or ground-based vacuum) has supported and amplified the contention of other researchers that significant quantities of Al_2O_3 are ejected as large (0.01-5 cm) particulates during the lower pressure tail-off phase of an SRM burn. These particles are believed to be formed by the rapid expansion, dissemination, and solidification of the molten Al_2O_3 slag pool accumulated during the main burn phase of those SRMs that utilize immersion-type nozzles. Representing up to 0.65% of the initial propellant mass, the emissions are of sufficient quantity to warrant assessment of their contribution to the orbital debris environment. To this end an approximate number-size-velocity distribution was proposed which has since been incorporated by other authors into various models describing the orbital distribution and time evolution of SRM ejecta. Coupled with historical launch data – these models indicate that the ejecta may be a significant component of the current and future population. ♦

PROJECT REVIEWS

The NASA Liquid Mirror Telescope

M. MULROONEY

The NASA 3.0 m diameter Liquid Mirror Telescope (NASA-LMT) was a low-cost, large aperture telescope dedicated primarily to observing orbital objects. During its eight year (1995-2002) operational lifetime it enabled NASA to better fulfill its mission to promote space exploration via a more thorough characterization of the orbital environment and thereby provide a more accurate assessment of the potential hazard to spacecraft from collisions. Over time the telescope's role became multi-fold - evolving to include comprehensive observations of astronomical objects as well as a limited survey of near Earth objects (NEOs).

The impetus for the NASA-LMT began inauspiciously in 1989 when Johnson Space Center (JSC) contractor David Talent attended a conference at which Ermanno Borra of Laval University presented results of recent experiments involving laboratory liquid mirrors. Talent reported his impressions to NASA JSC Branch Chief Drew Potter who was intrigued at the possibility of building an inexpensive, wide-field, large-aperture optical telescope to perform observations of orbital debris. To further explore the prospects, Potter and Lockheed Engineering Sciences Corporation (LESC) engineer Terry Byers arranged a visit to Quebec, Canada to tour Borra's Laval laboratory. Borra described in detail the construction and operation of the 1.5 m liquid mirror test bed in place at that time and provided interferograms quantifying the excellent (diffraction-limited) performance of the mirror. Potter and Byers returned to NASA JSC convinced of the viability of the LMT concept and funds were allocated for early development of what was initially called the Liquid Metal Mirror Telescope (LMMT) project. Via the synergistic efforts of Canadian astronomer Paul Hickson and the NASA-LESC team, by May 1994 the aptly renamed NASA-LMT had achieved first light at JSC – producing images of such high quality that relocation to a remote mountain observatory was justified. By April 1995, the LMT's second light was achieved at the new NASA Orbital Debris Observatory (NODO) located at an altitude of 9000 ft near Cloudcroft, New Mexico (Figure 1). It remained among the top twenty largest telescopes in the world and the largest LMT throughout the duration of its mission (Figure 2). Clear skies permitting, the LMT operated nightly until June 2002 when funding cutbacks resulted in closure of NODO.

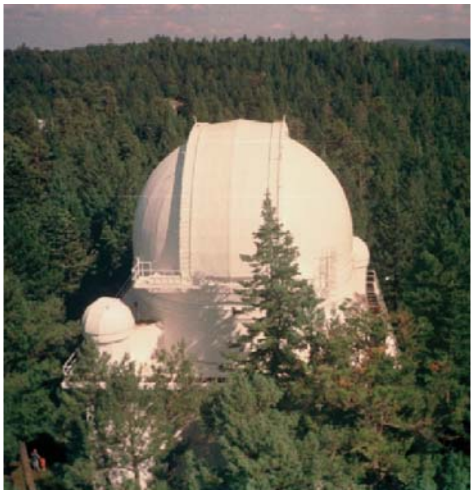
Figure 1. NASA Orbital Debris Observatory, Cloudcroft, New Mexico.


Figure 2. The 3.0 m NASA-LMT inside the NODO dome. The mirror is rotating at 10 rpm and the mercury (Hg) is fully oxidized.

From the outset it was desirable that the new orbital debris telescope be able to detect objects smaller than the ostensible 10-15 cm SATCAT diameter size limit. For a minimum detection diameter, 1 cm was selected because research performed on shielding for the International Space Station (ISS) indicated that layered (Whipple) bumpers offered protection from objects smaller than this. Since the ISS would be constructed in low Earth orbit (LEO) at approximately 500 km altitude, the NASA-LMT would focus on providing information on the LEO debris population in the critical 1 to 15 cm diameter size regime. The LMT would also help quantify the statistical accuracy of the SATCAT by comparing the observed and predicted flux of objects larger than 10 cm diameter at LEO and middle Earth orbit (MEO) altitudes. By necessity, direct observations below 1 cm were relegated to Radar such as Haystack operated by Massachusetts Institute of Technology's (MIT) Lincoln Labs at Millstone Hill, Massachusetts.

Meeting these criteria required that certain conditions be met regarding primary mirror size, focal length, detector quantum efficiency, band width, plate-scale, and total system throughput. Detection sensitivity calculations indicated

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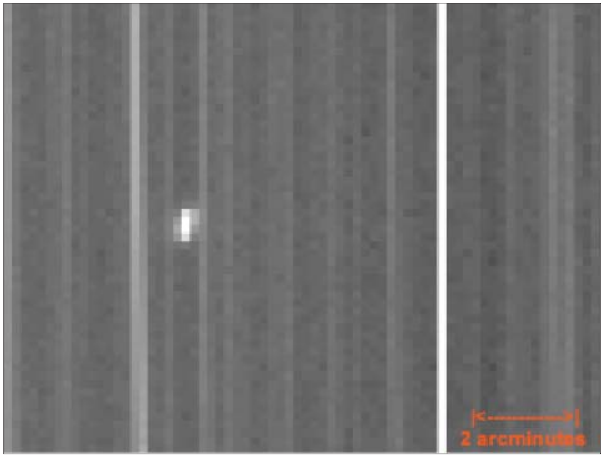

Figure 3. LMT TDI image of SAT NO 19667 - a 12.1 cm object at 1117 km.

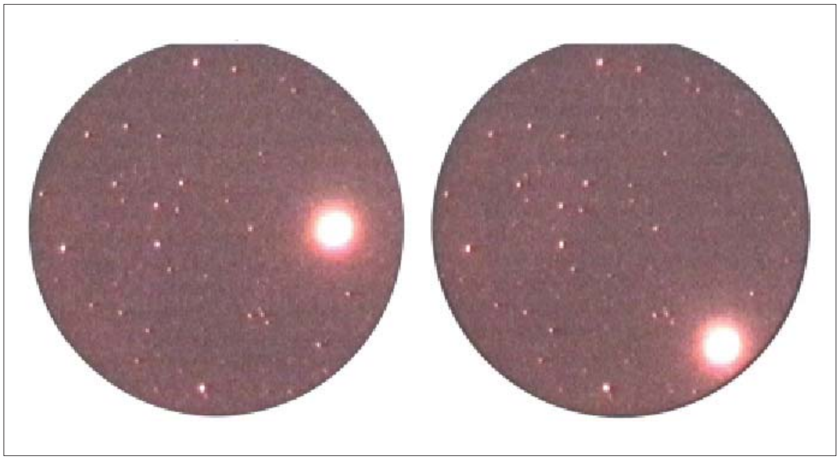

Figure 4. LMT MCP video frames of a bright satellite at 410 km. FOV is 0.44°.

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that if located at a dark site with minimal (21.5 VMag) sky brightness, a 78% reflective mercury telescope with a 3.0 m diameter primary mirror, a 4 element corrector, and a 4.5 m focal length (f/1.5), coupled to a 2048x2048 (2K) 15 um pixel CCD with 35% V Band quantum efficiency (QE) could detect, at a signal-to-noise ratio (SNR) of 6.3, a solar illuminated 1 cm diameter specular phase function sphere with 0.1 albedo at an altitude of 1000 km. This performance at LEO was only possible with a drift-scanning, or time–delay-integration (TDI) mode, CCD set to read at a rate and direction which exactly matched the angular velocity and position angle (PA) of motion of the orbiting object. In this way all the signal photons accumulate on a few pixels to maximize the SNR, rather than streak across the detector as is normal for a fixed telescope and a framing or sidereal scanning CCD. Figure 3 shows an LMT drift-scan of a 12.1 cm catalogued object at 1117 km.

In actual practice the LMT TDI sensitivity was less (2.5 cm versus 1 cm) than that predicted due primarily to enhanced background (shot) noise levels from the smeared light of background stars. This fact coupled with poor detection efficiency for orbital debris objects moving at rates or PAs other than the TDI settings, led to the use of alternative detectors operating at NTSC video rates (30 fps) which could more efficiently sample the orbital phase space – albeit at reduced sensitivity relative to TDI (16th vs. 19th magnitude). All published LMT orbital debris data was acquired using these video detectors employing two different micro-channel-plate (MCP) image intensifiers – a wide field (0.444°) 2nd generation unit (Oct 1997 – Dec 1999) and a narrower field (0.27°) slightly more sensitive 3rd generation unit (January 2000- December 2001). Using these detectors the optical orbital environment above

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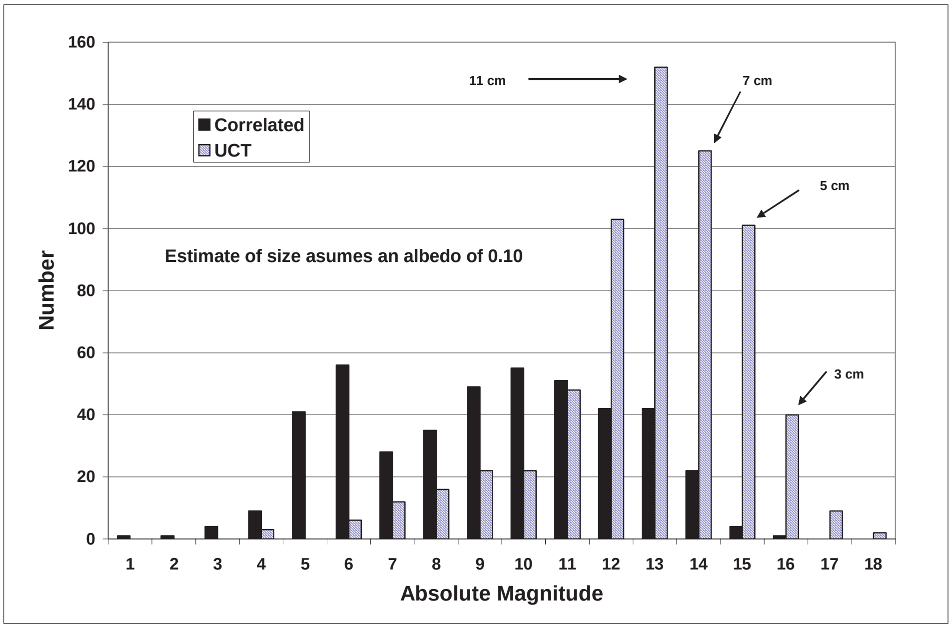

Figure 5. LMT uncorrelated target (UCT) and correlated target (CT) observations. UCTs dominate (Africano et al, 1999).

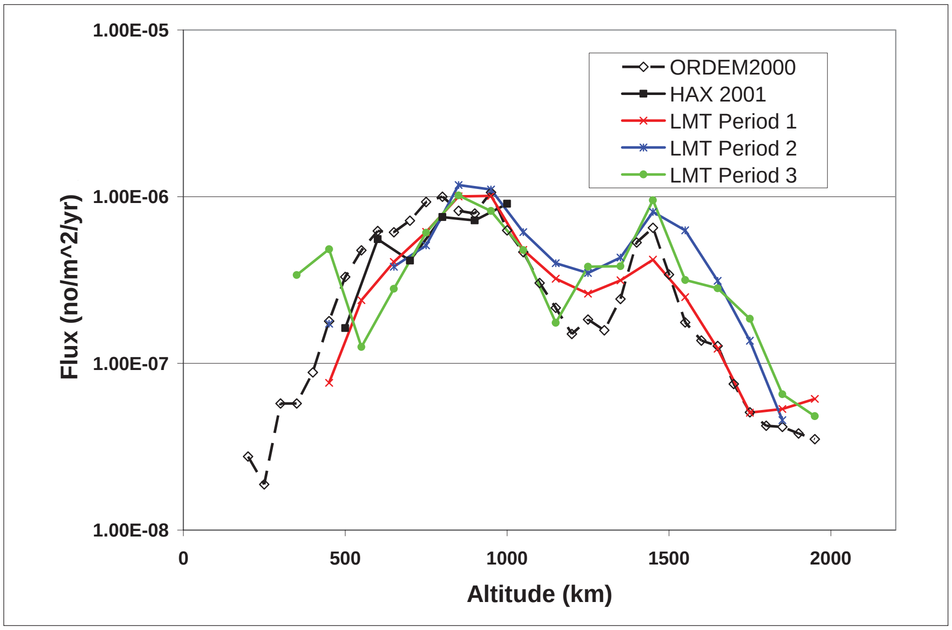

Figure 6. Flux estimates (> 10 cm) for LMT, Haystack Auxiliary (HAX) and ORDEM2000, showing overall agreement.

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33° inclination was completely sampled to 10 cm (0.13 albedo, 1000 km range normalized) below which sensitivity roll-off began. Figure 4 illustrates a typical orbital object detection among multiple video frames.

Processing and analysis of the prodigious quantities of LMT data (tens of terabytes) was conducted at NASA JSC initially under the guidance of John Africano and later by Jarvis and Barker. End products (Figure 5; Africano et al 1999) showed the range-albedo normalized detection sensitivity met the original 1 cm LMT design criteria and, significantly, demonstrated a large uncorrelated (un-catalogued) population of objects below 15 cm diameter. Later work (Jarvis et al 2007) - completing an exhaustive LMT data reduction and analysis, including a more rigorous brightness-albedo-size conversion - showed excellent overall agreement with the Haystack Radar data sets and ORDEM2000 model predictions (Figure 6).

As part of its evolving mission, in 2000 the LMT was retro-fitted to enhance its NEO detection capability. The prime focus array was redesigned and the astronomical CCD camera was upgraded to a 2K 24 um pixel backside illuminated device operating near liquid nitrogen temperatures (-130 C) and yielding a 32 arcminute field-of-view (FOV). Refinements yielding image quality improvements had continued steadily since 1995 and these were fully realized with the new wide-field camera and its enhanced blue sensitivity. Figure 7 shows the new array, while Figure 8 illustrates the progression in image quality from 1996 to 2000 - made primarily via improvements in mirror angular speed regulation, optical alignment, wave suppression via a reduction in mercury layer thickness, and thermal control. As familiar testaments to the quality of the LMT imagery Figure 9 shows an LMT field (right) compared with a common fiduciary – a Palomar Sky Survey (PSS) print

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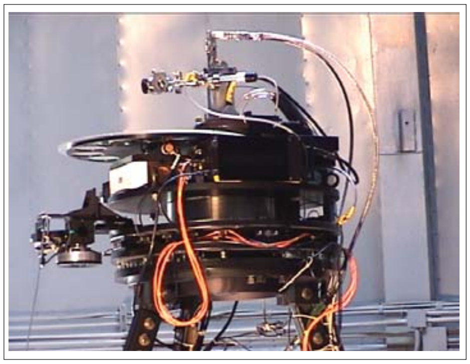

Figure 7. LMT Prime Focus Array - upgraded.

Figure 8. LMT image quality improvements obtained via prime focus array upgrades and better mirror control and alignment.

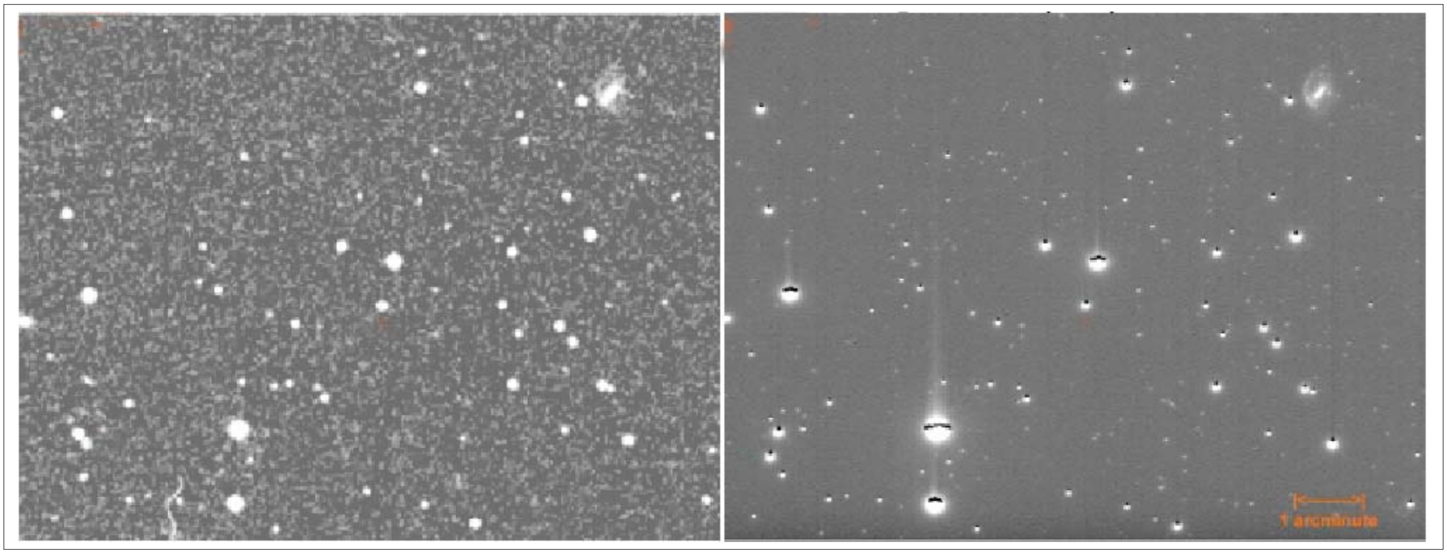

Figure 9. Palomar Sky Survey print (left) and LMT image of the same field (right) - a testament to the quality of LMT imagery.

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of the same field. Figure 10 is an LMT–Hubble Space Telescope (right) comparison of the Ring Nebula in Lyrae (Messier 57).

Having significantly enhanced NASA's understanding of the orbital debris population, the NASA-LMT further distinguished itself by demonstrating to the astronomical community the viability of liquid mirror telescopes as a low-cost alternative to conventional glass mirrors. A consortium of universities and non-profit foundations including University of British Columbia, SUNY–Stony Brook, Columbia University, and the University of Oklahoma capitalized upon the NASA-LMT success to fund the now fully operational 6 m Large Zenith Telescope (LZT) and have received initial funding for a 60 m diameter LMT array – the Large Astronomical Mirror Array (LAMA). The NASA-LMT represented an engineering triumph for NASA and a further demonstration of how low-budget initiatives can result in technologically sophisticated instruments that benefit the scientific community at large. ♦

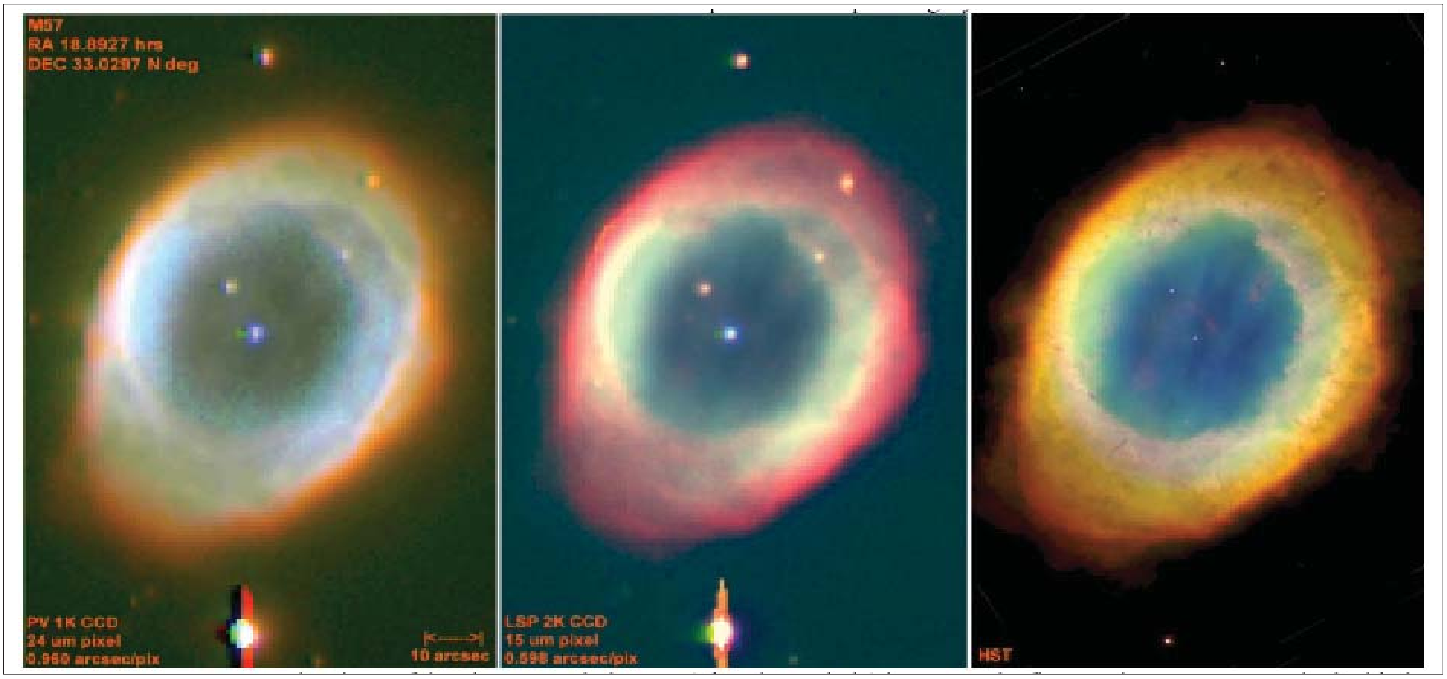

Figure 10. Messier 57 (Ring Nebula) imaged in BVR filters by the LMT with two different CCDs (enhanced B sensitivity, 0.96 arc-sec/pix, left; normal sensitivity, 0.598 arc-sec/pix, center) compared to Hubble Space Telescope image (right).

Strategy for Detection of Eccentric Objects In or Near the Geosynchronous Region

T. YANAGISAWA

Detection of eccentric objects with an orbital period near 24 hours is a very important issue. However, extremely narrow fields-of-view (FOVs) of optical telescopes hinders us from identifying eccentric objects. A new observation strategy to systematically detect these objects and determine their orbits precisely with one telescope is outlined in this article. Basically, one specific inertial position around geosynchronous orbit (GEO) altitude (not one specific celestial position) is observed on two nights. Objects which pass through that location in the first night must pass through that location again in the second night. By identifying the same objects from two nights of data, rough orbits for those objects are determined. A third night is needed for precise orbital determination.

The current observation strategy for MODEST (Michigan Orbital DEbris Survey Telescope) is to observe a few celestial positions for one night and detect as many objects (in, near, or crossing GEO) as possible. These objects have different motions from the celestial motion which limits the observable time for each object to about five minutes. From a five-minute orbital arc, it is difficult to determine the precise orbit of an object. Therefore, circular orbits are assumed for all detections. This assumption makes it possible to calculate their semi-major axes, inclinations, and the right ascensions of ascending node (RAAN). Various applications, such as the average distributions of GEO objects, and identifications of some groups in the RAAN-inclina-

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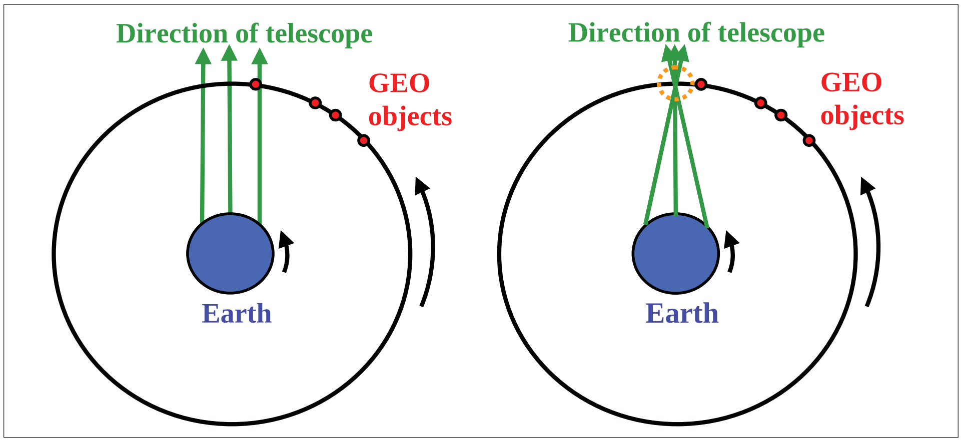

Figure 1. Difference between the current observation strategy of MODEST (left) and the new strategy. While the current strategy observes a specific celestial coordinate, the new strategy covers a specific GEO longitude to detect same objects two times in two nights of observation.

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tion phase space, are possible using these data. However, more precise orbit determinations are needed for other applications, such as long-term tracking and impact hazard analysis. A reliable orbital determination requires at least three observations with a long arc.

However, narrow FOVs of optical telescopes make it difficult to re-acquire the same objects after a few hours, especially in the case of eccentric orbits. To obtain a long arc, a telescope has to follow one target for a long period of time. Determining precise orbits of many GEO-crossing objects is time intensive , and not an efficient use of telescope time.

The proposed new observation strategy has the ability to cope with this situation to determine precise orbital elements of many objects in relatively short observation time. It utilizes a fundamental principle of orbital mechanics – neglecting higher order perturbations an object in bound orbit always returns to the same orbit location after one complete revolution. This means if a telescope observes one specific inertial position around GEO altitude for two nights, an object which passed through the FOV of the telescope in the first night must pass through the FOV again in the second night. (Of course, some observations may not be possible because the Sun could be above the horizon at the time of the second passage). For a given detector FOV the strategy covers an extended spatial volume (not one position). In the case of MODEST, its 1.3×1.3° FOV covers 800×800 km of sky area at the GEO altitude and about ±3000 km radially (relative to the GEO altitude).

Figure 1 shows the difference between the current observation strategy of MODEST and the new strategy. The figure illustrates the orientation of the Earth, a near-GEO object and its orbit, and observational directions for each case. Readers are looking down at the Earth from the North Pole. The Earth is rotating counter-clockwise and the objects are also moving around the Earth counter-clockwise. While the current MODEST survey strategy observes a specific celestial right ascension and declination, the new strategy observes a specific inertia position around GEO altitude to detect the same object twice in two nights of observation. After two nights of observation, the correlation between objects detected from the first and second nights is conducted. The inclination and RAAN are calculated, based on simple geometry, for each detection. These two elements, together with other criteria, such as magnitude, are used to pair detections from the two nights of data. Once a pair is identified, the true semi-major axis is automatically calculated from its orbital period, which is the time interval between the two detections. Even with the semimajor axis, inclination, and the RAAN determined from the two detections, there still exist a family of orbits with different eccentricities and arguments of perigee that can fit the data. The red, orange, and blue orbits shown in Figure 2 are just some examples. Therefore, a third night's observation is required to determine a precise orbit.

To achieve this objective, a different region from the one observed on the first and second nights should be covered on the third night, as illustrated with the black dotted arrow in Figure 2. From the arrival time of the object at the third night's region, its eccentricity and argument of perigee are determined. Figure 3 shows an example of the third night's observation. For example, a 30° separated region from the first and second night's region is illustrated. Trajectories of three objects with each color representing the same color's orbit in Figure 2 are illustrated. The X- and Y-axis show the right ascension and the declination of the celestial coordinates, respectively. The black dotted line indicates the FOV of the MODEST telescope. The arrival time of each object to the FOV depends on its eccentricity and argument of perigee. It takes about five minutes to pass the colored line for each object. Therefore, if a telescope observes the FOV for 20 minutes, the telescope can detect the object of any cases. By combining three nights of data that contain almost a 48-hour arc, precise orbital elements are calculated. The required observation time for each object is about 30 minutes (5 minutes for the first and second night, and 20 minutes for third night), which is postulated to be very effective. If two telescopes are available, one is used for the first and second night observations and the other is used for the third night observation, which means the first telescope is ready to start the process again on a new inertial position on the third night. The observation of three consecutive nights is ideal for this strategy. However, a few nights interruption due to bad weather conditions are manageable. Of course, in such cases, the probability that some objects with significantly larger or smaller semi-major axes than that of the geostationary orbit escape from the observable time (dark enough to observe) increases.

This new strategy will be tested with future observations. Once the technique is validated, it will provide a new and efficient way for observers to better define the debris populations in the GEO region. ♦

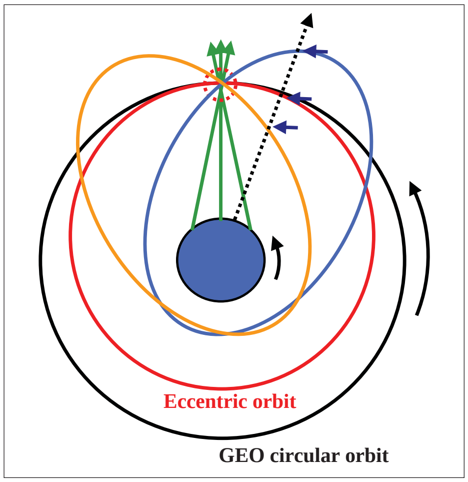


Figure 2. Three possible orbits based on two nights' observations. The red, orange, and blue solid lines represent three orbits with the same semimajor axis, but different combinations of eccentricity and argument of perigee. The black dotted arrow shows an example of observation direction for the third night. A GEO circular orbit is also shown for comparison.

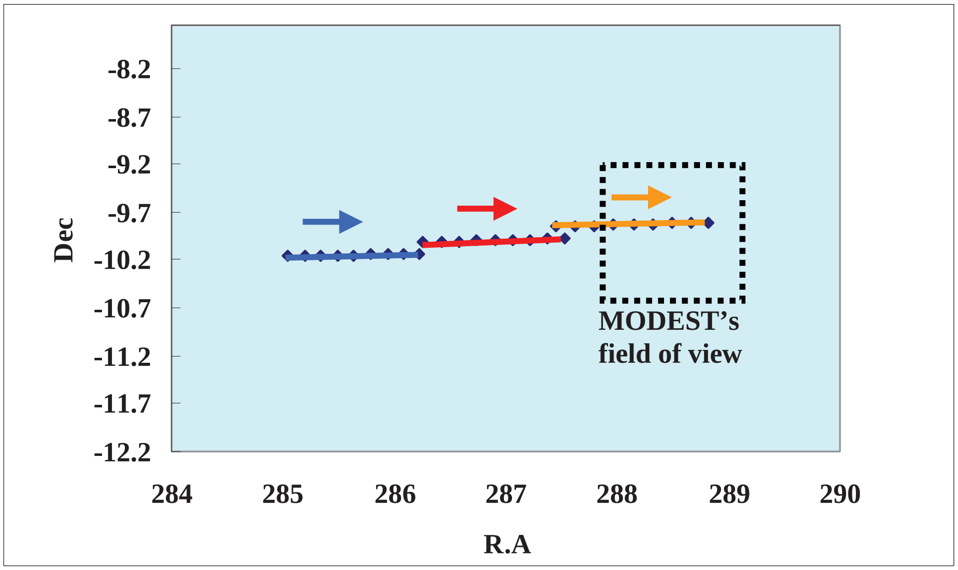


Figure 3. An example of the third night's observation. Trajectories of three GEO objects with each color representing same color's orbit in Figure 2 are illustrated. The X- and Y-axis show the right ascension and the declination of the celestial coordinates, respectively. The black dotted line indicates the field of view of the MODEST telescope.

INTERNATIONAL SPACE MISSIONS
01 January 2007 - 28 March 2007

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2007-001A	LAPAN-TUBSAT	INDONESIA	619	639	97.9	1	0
2007-001B	CARTOSAT 2AT	INDIA	632	635	98.0		
2007-001C	SRE-1	INDIA	486	643	97.9		
2007-001D	PEHUENSAT 1	ARGENTINA	620	641	97.9		
2007-002A	PROGRESS M-59	RUSSIA	326	346	51.6	1	0
2007-003A	BEIDOU 2A	CHINA	184	41471	25.0	1	1
2007-004A	THEMIS A	USA	463	87305	15.6	2	0
2007-004B	THEMIS B	USA	463	87287	15.6		
2007-004C	THEMIS C	USA	461	87055	15.6		
2007-004D	THEMIS D	USA	571	87136	15.5		
2007-004E	THEMIS E	USA	444	87545	15.5		
2007-005A	IGS 4A	JAPAN	NO ELEMS. AVAILABLE			1	4
2007-005B	IGS 4B	JAPAN	NO ELEMS. AVAILABLE				
2007-006A	OE (ASTRO)	USA	491	498	46.0	1	0
2007-006B	MIDSTAR 1	USA	495	498	46.0		
2007-006C	OE (NEXTSAT)	USA	492	498	46.0		
2007-006D	STPSAT 1	USA	558	560	35.4		
2007-006E	FALCONSAT 1	USA	559	559	35.4		
2007-006F	CFESAT	USA	559	562	35.4		
2007-007A	INSAT 4B	INDIA	35782	35792	0.1	1	1
2007-007C	SKYNET 5A	ESA	35784	35793	0.1		

ORBITAL BOX SCORE
(as of 28 MAR 2007, as cataloged by U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	58	1507	1565
CIS	1361	2896	4257
ESA	37	35	72
FRANCE	45	314	359
INDIA	33	105	138
JAPAN	102	71	173
USA	1061	3106	4167
OTHER	368	42	410
TOTAL	3065	8076	11141

Technical Editor
J.-C. Liou

Managing Editor
Sara Portman

Correspondence concerning the ODQN can be sent to:
Sara Portman
NASA Johnson Space Center
Orbital Debris Program Office
Mail Code JE104
Houston, TX 77058

sara.a.portman@nasa.gov

UPCOMING MEETINGS

14-16 May 2007: The 2nd International Association for the Advancement of Space Safety (IAASS) Conference, Chicago, Illinois, USA.

The conference is an invitation to reflect and exchange information on a number of topics in space safety that are of national and international interest. Among the topics to be discussed are space debris environment and spacecraft reentry. Additional information is available at http://www.congrex.nl/07a02/.

10-14 September 2007: 2007 Advanced Maui Optical and Space (AMOS) Surveillance Technologies Conference, Wailea, Maui, Hawaii, USA.

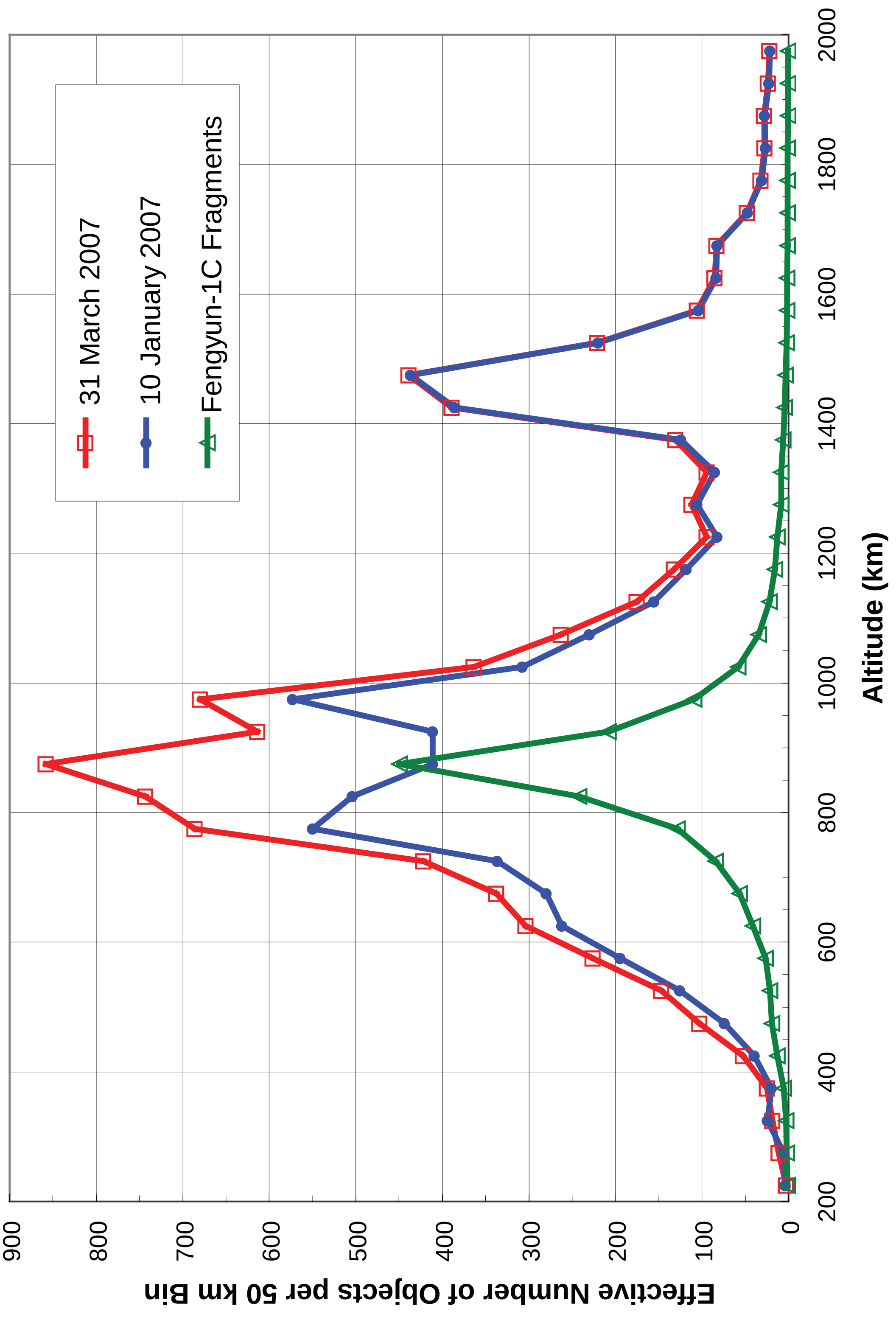
The 2007 AMOS Conference will cover various topics in adaptive optics, astronomy, imaging, lasers, metrics, non-resolved object characterization, orbital debris, Pan-STARRS, SSA programs and systems, and telescopes and sensors. Additional information on the conference is available at http://www.amostech.com.

23-27 September 2007: Hypervelocity Impact Symposium (HVIS), Wiliamsburg, Virginia, USA.

This biennial symposium is dedicated to enabling and promoting an understanding of the basic physics of high velocity impact and related technical areas, including spacecraft shielding design and orbital debris environment. More information can be obtained at http://hvis.org/HVIS_07/index.html.

24-28 September 2007: The 58th International Astronautical Congress (IAC), Hyderabad, India.

A Space Debris Symposium is planned for the congress. The four scheduled sessions will address the complete spectrum of technical issues of space debris, including measurements and space surveillance, modeling, risk assessment, reentry, hypervelocity impacts, protection, mitigation, and standards. Additional information on the Congress is available at http://www.iac2007.org.



Distributions of the Catalog populations in the low Earth orbit on 10 January 2007 (blue), and on 31 March 2007 (red). As of 31 March 2007, a total of 1613 fragments from the 11 January Fengyun-1C breakup had been identified and were being tracked (green). These fragments contribute to most of the difference between the red and blue curves.

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, TX 77058

www.nasa.gov