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Orbital Debris Quarterly News

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Inside...

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Program Office (ODPO)

Two New Breakups with One Resulting in an ISS Maneuver

The Space Force's 18th Space Control Squadron (18 SPCS) announced the detection of the breakup of mission-related debris associated with a Japanese H-2A launch vehicle upper stage on 12 July 2020. The detection was made via data collected by the U.S. Space Command (USSPACECOM) Space Surveillance Network (SSN). The parent object of the breakup (International Designator 2018-084C, SSN# 43673) was an H-2A upper stage half-cylindrical fairing cover associated with the GOSAT-2 mission, which was launched on 29 October 2018. The orbit of 2018-084C at the time of breakup was 643 x 595 km, with an inclination of 97.89 degrees. Based on 18 SPCS' data and analysis, the GOSAT-2 mission released three mission-related debris during deployment of the payloads. They included the fairing adapter (2018-084E, SSN# 43675) and two identical cylindrical fairing halves (SSN# 43673 and 2018-084D, SSN# 43674). Another small fragment (2018-084A, SSN# 43671) was also detected, but it rapidly decayed and reentered in August 2019.

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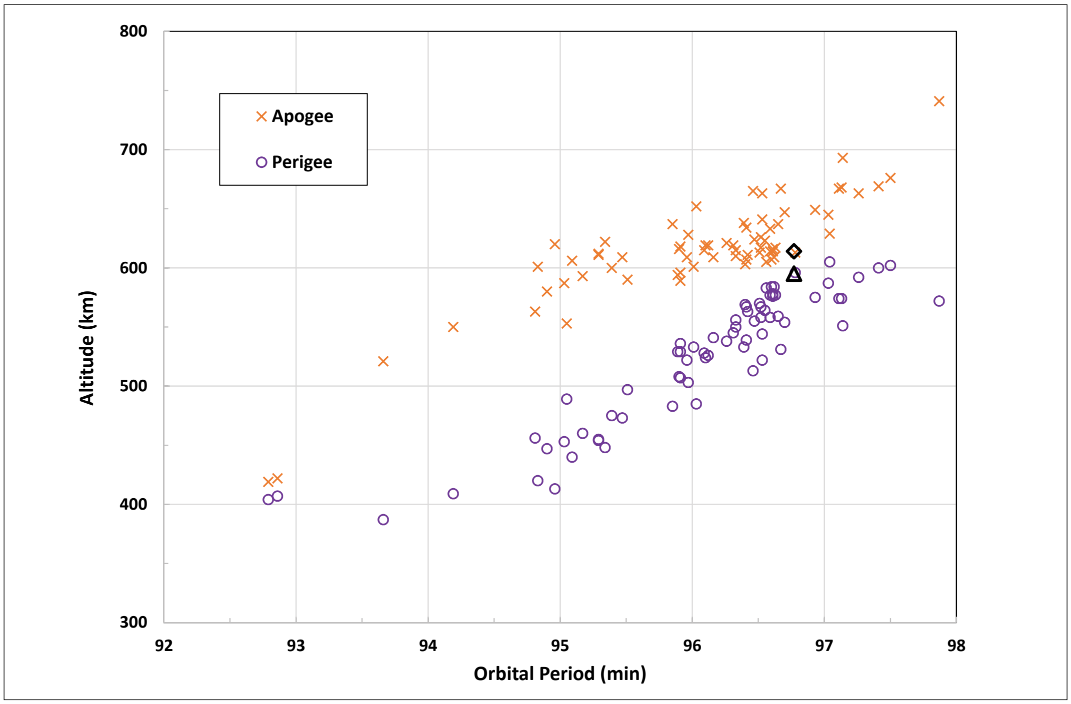

Figure 1. Gabbard diagram of the 2018-084C breakup fragments. Approximate epoch is the end of September 2020. The apogee (black diamond) and perigee (black triangle) altitudes of the parent object, 2018-084C, are also shown.

Breakups

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The fairing cover's mass is estimated to be more than 100 kg. It is made of aluminum alloy honeycomb with carbon fiber reinforced plastic skin. A total of 74 additional fragments from the breakup of 2018-084C had been cataloged by early October. Nine of them decayed and reentered in less than three months after the event. Figure 1 shows the Gabbard diagram of the fragments. The 18 SPCS conducted a detailed data analysis to screen all tracked objects near 2018-084C around the time of the breakup but could not identify any candidate for a likely collision with 2018-084C. Since the fairing cover did not appear to contain any energy sources, explosion was out of the question. A hypervelocity collision with an object below the SSN detection limit is a logical explanation for the breakup of 2018-084C.

The 18 SPCS also detected the breakup of the retired Russian Resurs-O1 spacecraft on 27 August 2020. The 1.9 metric-ton Resurs-O1 (1994-074A, SSN# 23342) was an Earth observation satellite launched in 1994. Its orbit at the time of the breakup was 660 x 633 km, with an inclination of 97.92 degrees. A total of nine new fragments had been cataloged by the end of September. Resurs-O1 was based on the Meteor-2 bus. Debris shedding events, producing one or more multiple debris objects with low separation velocities, and associated with several spacecraft using this same bus, have been documented before. However, fragments generated from this event seem to have somewhat higher separation velocities implying a minor, though energetic, event.

One of the fragments generated from the breakup of the H-2A fairing cover, 2018-084C, reached the operational altitude of the International Space Station (ISS) in September. As the fragment (2018-084CQ, SSN# 46477) approached that altitude, it had repeated high-risk conjunctions with the ISS. To mitigate the risk, the ISS conducted a debris avoidance maneuver on September 22. After passing the ISS altitude, object 46477 continued to decay and reentered on September 27. The ISS maneuvers to avoid potential collisions with tracked objects on a regular basis (ODQN, vol. 24, issue 1, pp. 1-2). The collision avoidance maneuver on September 22 was the third such maneuver in 2020. It brought the total to 28 collision avoidance maneuvers since 1999. ♦

PROJECT REVIEW

HUSIR Radar Measurements of the Orbital Debris Environment: 2018-2019

J. MURRAY AND T. KENNEDY

The NASA Orbital Debris Program Office (ODPO) performs regular observations of the orbital debris environment using the Haystack Ultra-wideband Satellite Imaging Radar (HUSIR). A summary of these measurements and analyses are published annually, with the most recent publication being the HUSIR Calendar Year (CY) 2018 orbital debris radar measurements report [1] and the HUSIR CY2019 orbital debris radar measurements report, in review for publication. The data collected is used in the development and validation of populations for the Orbital Debris Engineering Model (ORDEM). An overview of the radar data collected by HUSIR is given in this review article, which highlights recent developments from measurements taken in CY2018–2019.

For orbital debris radar measurements, HUSIR operates in a beam park mode in which the radar stares at a specific topocentric azimuth and elevation angle for the duration of the observation. Debris is then observed as it passes through the stationary beam of the radar. The fundamental measurements made by the radar for each detection are range, range-rate, and signal-to-noise ratio (SNR), from which radar cross section (RCS) can be inferred. Figure 1 shows a plot of the range and range-rate measured for all detections, in the case of HUSIR pointed at 75° elevation and due east (an azimuth of 90°), an observation geometry referred to as 75E, for both CY2018 and CY2019.

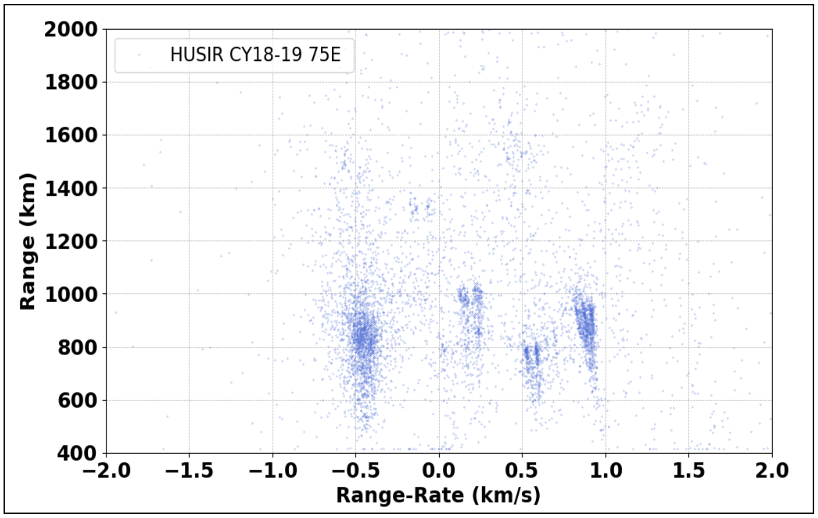

Figure 1. Range vs. range-rate observations of resident space objects, as measured by HUSIR in CY2018 and 2019.

Estimates of the orbital inclination of an object passing through the beam can be made using the known pointing of the radar and the measured range and range-rate, if one assumes a circular orbit [2]. This enables the transformation from range and range-rate to altitude and inclination, as shown in Figure 2. In doing so, several important orbital debris families become apparent. The geometry of northward-moving and southward-moving orbiting objects viewed with the 75E geometry creates the "twinning" effect visible for each grouping of objects. In particular, one can see debris associated with the sun-synchronous family of orbits clustered around the dashed black line that represents the sun-synchronous condition for circular orbits [3]. The well-known and documented family of liquid metallic sodium potassium (NaK) droplets is seen clustered around 65° Doppler inclination. Other notable on-orbit breakup events are indicated in Figure 2 with red circles, where the circle centers correspond to the altitude and inclination of the parent object at the time of the breakup [4].

The RCS of an object is calculated using the measured

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HUSIR 2018-2019

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power reflected from the object, polarization information of the returned signal, and the range of the object. From the RCS, the size of the debris is inferred using the NASA Size Estimation Model (SEM) [5]. A plot of altitude versus SEM size for HUSIR orbital debris observations is shown in Figure 3. The approximate data completeness to a given size is indicated by the dashed black curve shown in this plot, where the detection efficiency is observed to decrease rapidly to the left of this curve. The curve indicates a completeness of about 5.62 mm below 1000 km and 1 cm below 1600 km in altitude.

The cumulative count rate for objects of a given SEM-estimated size, for the U.S. Government Fiscal Years (FY) 2014–2017 and CY2018–2019 observation periods, is shown in Figure 4. Neglecting differences for small sizes due to fluctuations in radar sensitivity, the count rates are stable over FY2014–2017. In FY2017, the size distribution for objects > 20 cm appears lower than other years shown in Figure 4. Including Poisson uncertainties (2σ) for these larger-sized objects, however, the observations in FY2017 are statistically equivalent to other years shown. The reader is referred to Section 4.3.1 of [1] for further details that include the Poisson uncertainties for the cumulative count rate, as well as additional analysis indicating that when the distribution is limited to sizes < 1 m, similar results are obtained for FY2017 relative to other years for this size regime.

In CY2018, the size distribution for objects larger than 7 cm appeared higher than previous years. Nearly all detections greater than 10 cm correlated to objects in the Space Surveillance Network (SSN) public satellite catalog (SATCAT), where 10 cm is the generally accepted limiting size for the SATCAT in low Earth orbit (LEO). It was determined that the SEM size distribution was skewed higher in CY2018 by a handful of exceptionally large detections at the large end of the distribution. Continued monitoring of the environment has shown that this increase did not represent a persistent change in the debris environment, as the CY2019 distribution is statistically equivalent to that of FY2014–2017 for the larger SEM sizes.

In addition to the total cumulative count rate distribution, it is of interest to monitor the debris flux in altitudes of interest. Here, flux is defined as the number of detections through the lateral surface area of the radar beam, considering the 3 dB beamwidth of the main beam only, within a given period of time. From Figure 3, we should be approximately complete at 5.62 mm up to 1000 km altitude, a number which is consistent with estimates in previous years [6]. Figure 5 shows the flux of debris larger than 5.62 mm from 400 km to 600 km in altitude from FY2014–CY2019, where the error bars represent the Poisson 2σ uncertainties. The flux remains largely the same from FY2014 to CY2018. In CY2019, we see an increase in the flux from 400 km to 600 km. Figure 6 shows the flux of debris larger than 5.62 mm between 400 km and 600 km, where the data has been split by the quarter of year collected – referred to as Q1, Q2, Q3, and Q4. The increase occurs between Q1 and Q2 of CY2019 and persists through Q3. Although Q4 appears to show a decrease, continued monitoring of the environment is necessary to characterize

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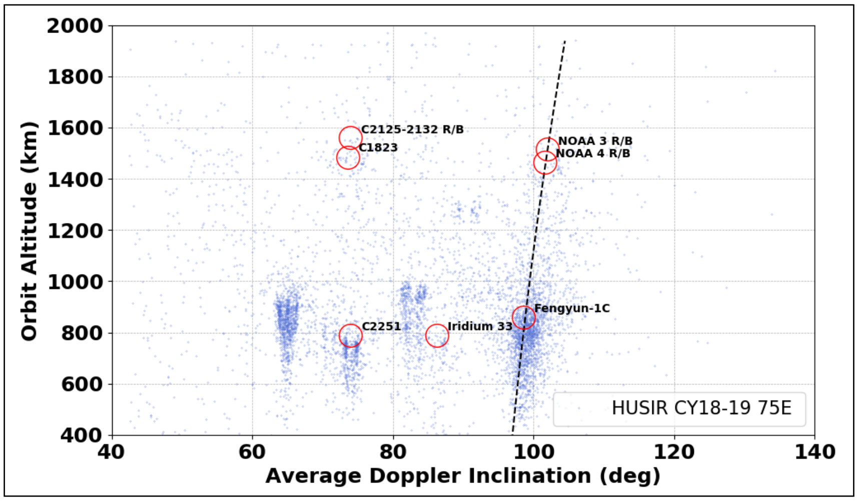

Figure 2. Conversion of HUSIR range and range-rate measurements into altitude and Doppler-derived inclination. The sun synchronous condition, assuming a circular orbit, is indicated by the dashed black line.

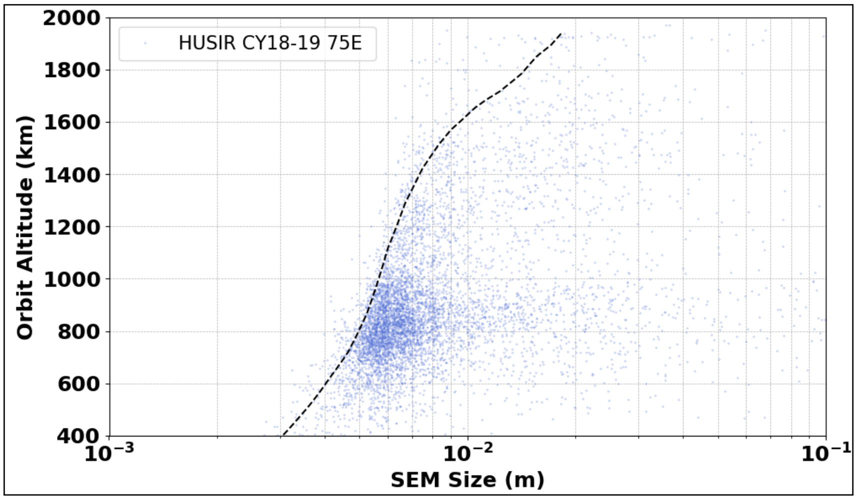

Figure 3. Orbital debris observations in altitude and SEM-size space for the HUSIR CY2018–2019 75E data.

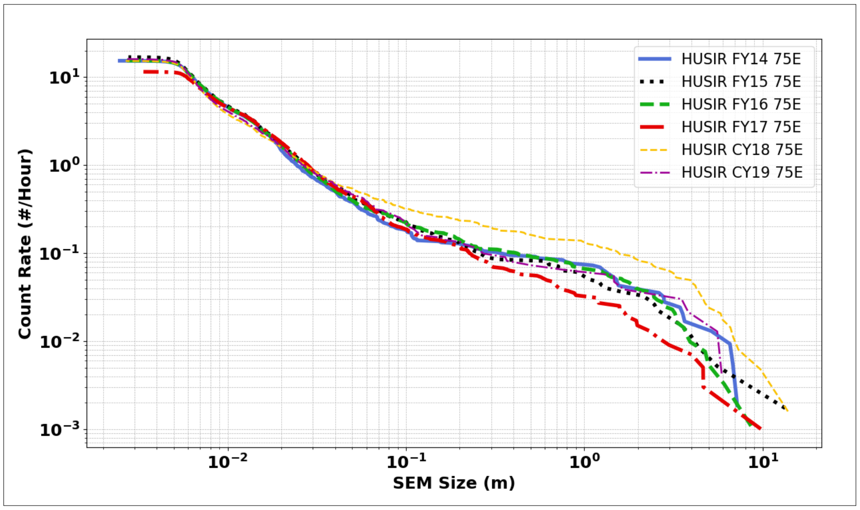

Figure 4. Cumulative count rate for orbital debris as a function of NASA SEM size for objects under 1000 km in altitude.

HUSIR 2018-2019

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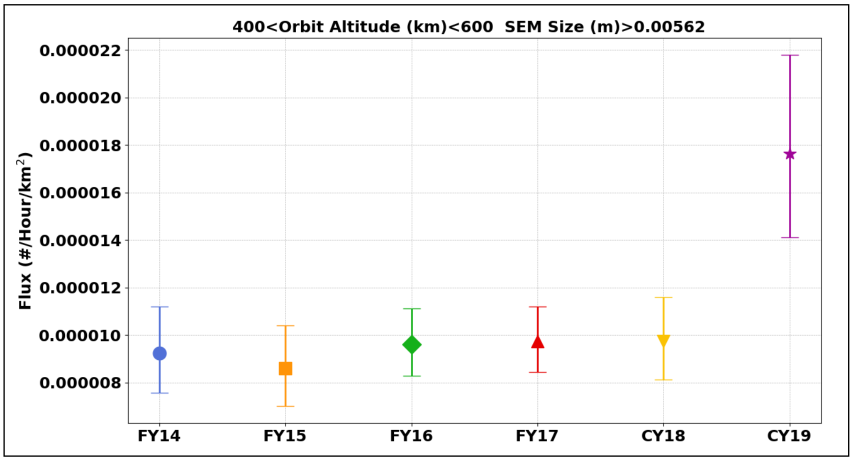

Figure 5. Surface area flux between 400 km and 600 km in altitude, limited to 5.62 mm for all 75E data by year. The error bars represent the 95% confidence intervals.

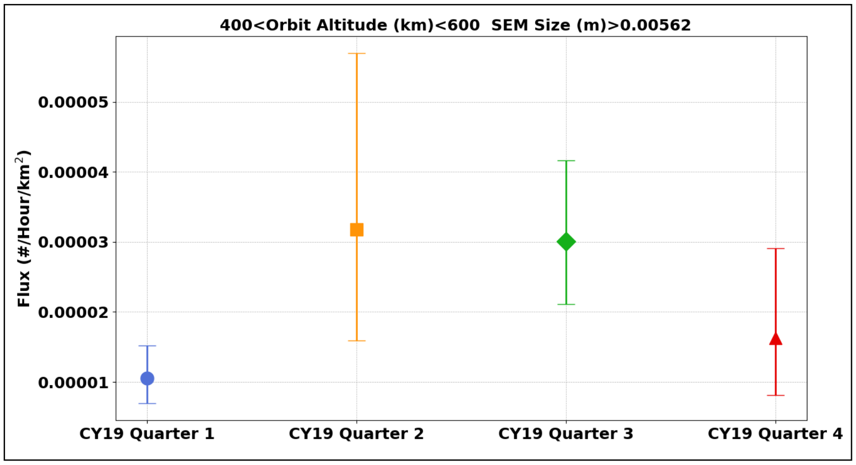

Figure 6. Surface area flux between 400 km and 600 km in altitude, limited to 5.62 mm for CY2019, and split into quarters. The error bars represent the 95% confidence intervals.

the persistence of this low-altitude flux increase in the orbital debris environment. Additional data and analysis regarding this increase is found in the forthcoming HUSIR CY2019 orbital debris radar measurements report.

This review has provided a brief overview of the orbital debris radar measurements taken by HUSIR in CY2018 and CY2019 in support of the NASA ODPO for the development and validation of populations for ORDEM. Analysis has shown that the data is generally complete down to 5.62 mm at 1000 km and 1 cm at 1600 km. A low-altitude flux increase was observed in CY2019, which occurred between Q1 and Q2. Although the increase shows signs of being short lived, the dynamic nature of the sub-centimeter debris environment in LEO necessitates continued observations for the development of accurate debris environment models.

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Updated Solar Cycle Predictions for Orbital Debris Modeling

A. MANIS AND M. MATNEY

Solar activity plays an important role in the evolution of the orbital debris environment. Orbital lifetimes of uncontrolled objects in or crossing through low Earth orbit (LEO) are typically driven by atmospheric drag, and atmospheric density is sensitive to the solar flux. Increased solar extreme ultraviolet (EUV) radiation causes an increase in the density of the exosphere, increasing atmospheric drag, and shortening orbital lifetimes. Conversely, decreased solar flux decreases atmospheric drag, which leads to longer orbital lifetimes. These effects help drive the evolution of the overall orbital debris environment as, during solar maxima, the increased atmospheric drag helps to "clean out" debris from the low altitude environment at a faster rate, while during solar minima the slower drag rates can allow LEO debris populations to build up.

The National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center develops predictions for solar activity, specifically in terms of the sunspot number and solar radio flux at 10.7 cm, known as the F10.7 index, which serves as a ground-based measurable proxy for the EUV. A 27-day forecast of daily values provides a near-term prediction, and monthly values are provided by NOAA for the approximately 11-year solar cycle prediction. Because environment modeling and space mission planning can require solar flux predictions on a longer time scale than the 11-year solar cycle, the NASA Orbital Debris Program Office (ODPO) uses the F10.7 and sunspot histories together with NOAA predictions to develop long-term F10.7 projections (100–200 years) in support of models for atmospheric drag and orbit evolution. These long-term solar flux predictions are released on a quarterly basis for use by the NASA Debris Assessment Software (DAS), which enables mission planners to assess their compliance with the NASA requirements for limiting orbital debris. Also, these predictions are used

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Solar Flux

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in the ODPO's LEO-to-GEO ENvironment Debris (LEGEND) model, which is used to statistically model the long-term evolution of the overall orbital debris environment.

The process to develop the long-term F10.7 projections begins with the NOAA 27-day forecast, which is concatenated with the remaining portion of the NOAA solar cycle prediction. NOAA provides the solar cycle predictions as monthly values, so these values are linearly interpolated to provide a smooth prediction of daily values. Finally, the end of the NOAA solar cycle prediction is merged into the longer-term ODPO solar activity prediction using a bridging function. This process creates a continuous daily prediction forecast starting from the current date and going out at least 100 years into the future.

The NOAA solar cycle predictions are released at long intervals – typically every 11 years at the beginning of each solar cycle. After the ODPO delivered the March 2020 solar flux table (announced in ODQN, vol. 24, issue 2, April 2020, p. 8), and prior to the delivery of the updated solar flux table in July 2020 (announced in ODQN, vol. 24, issue 3, August 2020, p. 13), NOAA released the data [1] for a new prediction of the next solar cycle (Solar Cycle 25). This prediction was developed by the Solar Cycle 25 Prediction Panel, an international group of experts co-chaired by NASA and NOAA. The Panel also recently announced the solar minimum to have occurred in December 2019, indicating the start of Solar Cycle 25, which is forecast to be a low cycle, similar to the previous Solar Cycle 24. While developing the July 2020 updated solar flux table to include this new prediction for Solar Cycle 25, it was determined that the ODPO procedure for fitting the historical F10.7 solar activity and bridging with the NOAA predictions needed to be updated.

The NASA long-term fit to the historical F10.7 data is done using a 13-term truncated Fourier series

$$F(t) = a_0 + \sum_{n=1}^{6}\left[a_n \cos\left(\frac{2n\pi t}{\tau}\right) + b_n \sin\left(\frac{2n\pi t}{\tau}\right)\right]$$

where t is the Julian date in days, τ is the solar cycle period, averaged over the historical record, in days, and F(t) is expressed in solar flux units. The ODPO uses the 70+ years of detailed F10.7 historical data, from 1947 up to the current date, to fit the amplitude parameters (a_n, b_n). However, this data only covers 6 solar maxima, and a much longer timeline of solar activity is required to better capture the variability in the length of the cycles. The long-term historical sunspot record represents more than 250 years of solar cycle data, providing insight into 24 full solar cycles. The sunspot data is used to determine an average cycle period τ, then a fit to the historical F10.7 data is calculated using this fixed period to determine the amplitude and phase of a "typical" cycle. The fit developed for the March 2020 solar flux table used a period of 3913.38 days (approximately 10.7 years), based on the historical sunspot data as of 2012. As seen in Figure 1, this fitted period was found to diverge from the phasing of the most recent observed and predicted solar cycles due to the recent low (and longer-period) cycle.

NOAA recently released a reanalysis of historical sunspot activity [2]. This updated sunspot record, including data from the low-amplitude Solar Cycle 24, now yields a period of 4014.0 days (approximately 11 years), as shown in Figure 2. Figure 3 shows the fit updated with this new period as compared to the historical F10.7 13-month weighted average. The longer period from the updated sunspot data better captures the average long-term F10.7 periodic behavior. Even with this new longer period, however, the timing of the long-term fit did not agree sufficiently well with the timing of the unusually low-amplitude, long-period Solar Cycle 25 prediction (see Figure 1). Thus, the fit was subsequently shifted

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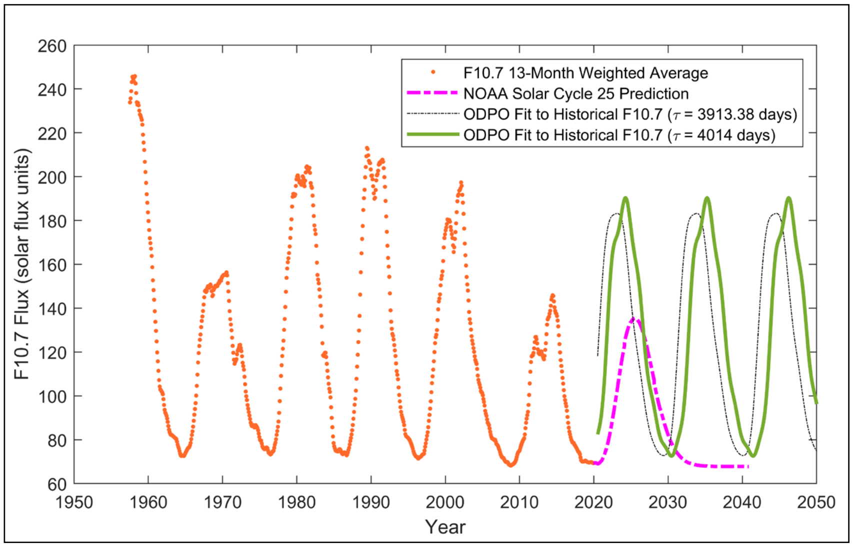

Figure 1. Historical F10.7 13-month weighted average, the NOAA solar cycle 25 prediction, and the ODPO long-term F10.7 fit with a fixed period (τ) based on the historical sunspot record of 3913.38 days and 4014 days, as used in the March 2020 and July 2020, respectively, solar flux table updates.

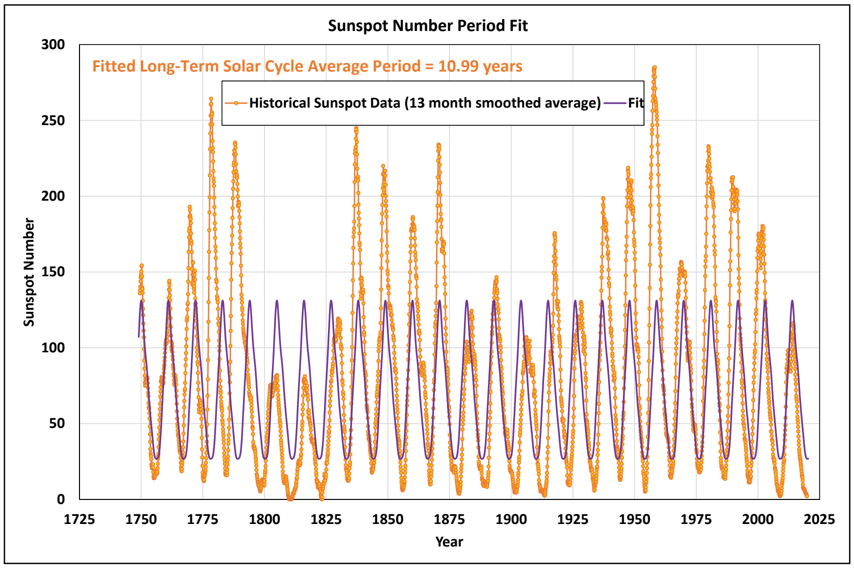

Figure 2. Historical 13-month weighted average of the sunspot number and fit. Note that the fit was intended to capture the period of the cycle, not necessarily the full range of amplitude or the phase of each individual cycle. Also there were years where the fit and the sunspot cycle were nearly 180° out of phase, yet the fit overall seems to capture the majority of the long-term periodic behavior.

Solar Flux

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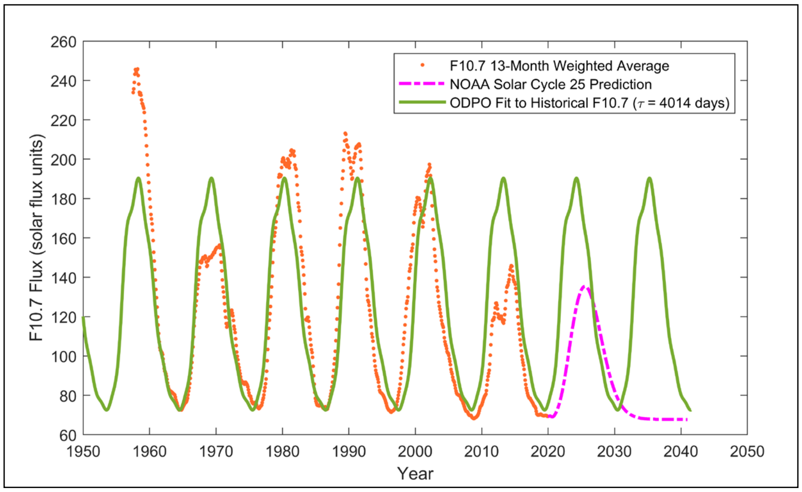

Figure 3. NASA long-term F10.7 fit using a fixed period of 4014 days, compared to the historical F10.7 13-month weighted average and the NOAA Solar Cycle 25 prediction. The long-term fit agrees well with the overall average F10.7 activity but requires shifting slightly to align with the timing of the Cycle 25 prediction.

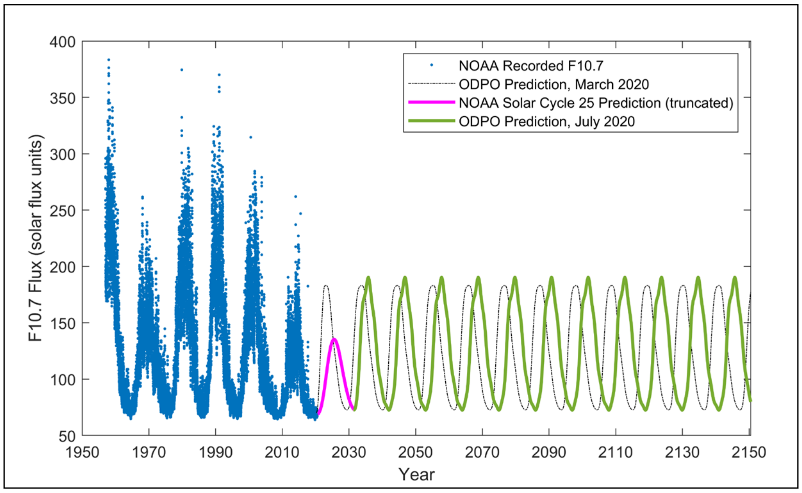

Figure 4. Historical F10.7, ODPO long-term prediction from March 2020, and ODPO long-term prediction from July 2020. The July 2020 prediction was the first to include the new NOAA Solar Cycle 25 Prediction.

slightly to the right by 200 days to better align the timing of the predicted minimum from the long-term fit with the Solar Cycle 25 prediction.

Figure 4 shows the updated ODPO long-term prediction from July 2020, incorporating the new longer period from the sunspot data and the NOAA Solar Cycle 25 prediction, compared to the ODPO long-term prediction from March 2020. It is worth noting that since the March 2020 solar flux table did not include the prediction for Solar Cycle 25, it transitioned directly from the measured data into the long-term average cycle prediction, which is higher in amplitude and occurs sooner than the Cycle 25 prediction released by NOAA. The update significantly changes the predicted F10.7 behavior over the next 5–10 years. Note also that the NOAA prediction for Solar Cycle 25 extends through 2040 but does not predict the onset of the next cycle. The NOAA prediction was truncated at June 2031 and connected to the long-term ODPO prediction with a bridging function from 1 June 2031 to 1 February 2033.

These updates capture the timing of the new NOAA prediction as well as the overall average long-term solar cycle behavior. However, the new prediction for a low solar cycle immediately following a previous low cycle has exposed some unanticipated issues with the ODPO fitting and prediction procedure – specifically how to capture the observed correlation between solar cycle magnitude and cycle length. The adjustments made for the July 2020 update to the solar flux table appear to adequately capture the effects of the new NOAA Solar Cycle 25 prediction while maintaining the ODPO's overall procedure to fit and predict long-term solar activity without significant changes.

References

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DAS 3.1 NOTICE

Attention DAS Users: DAS 3.0.1 has been updated to DAS 3.1. Previous versions of DAS should no longer be used. NASA regulations require that a Software Usage Agreement must be obtained to acquire DAS 3.1. DAS 3.1 requires the Windows operating system and has been extensively tested in Windows 10.

To begin the process, click on the Request Now! button in the NASA Software Catalog at https://software.nasa.gov/software/MSC-26690-1. Users who have already completed the software request process for earlier versions of DAS 3.x do not need to reapply for DAS 3.1. Simply go to your existing account on the NASA Software portal and download the latest installer.

An updated solar flux table (created 29 September 2020) can be downloaded for use with DAS 3.1.

CONFERENCE AND MEETING REPORTS

The 34th Annual Small Satellite Conference, 1-6 August 2020, Logan, Utah, USA (Virtual)

The 34th Annual American Institute of Aeronautics and Astronautics/Utah State University Conference on Small Satellites was conducted virtually at www.SmallSat.org. The theme of this year's conference was "Space Mission Architectures: Infinite Possibilities," and many presentations focused on the emerging problems and opportunities as individual small satellites proliferate, large constellations deploy, and launch opportunities expand, notably with simultaneous deployments of large numbers of dissimilar small satellites. The conference keynote from National Reconnaissance Office Director, Dr. Christopher Scolese, narrated the agency's use of small satellites over the past 50 years and the special attributes that small satellites possess, including the capability to quickly deploy new technologies, lower initial costs, and having a wide experience base that now includes universities and non-traditional vendors. A total of 22 technical sessions were held, including the pre-conference workshop, complemented by 6 poster sessions with 106 posters presented. Many of the conference topics focused on recently developed or upcoming small satellite technologies, with limited discussions on the short or long-term effects of smallsats on the orbital debris environment.

Representatives from the NASA Orbital Debris Program Office (ODPO) presented an overview of the 2019 U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP), which also included focused discussions for small satellite operators to consider in preparation for potential future flight requirements when implementing documents finalized by NASA, the Federal Aviation Administration, the Federal Communications Commission, and other organizations. Provided this focus on ODMSP for small satellite operators, several commercial exhibitors advertised their products were designed to meet NASA OD mitigation requirements. Although robust, commercial off-the-shelf spacecraft subsystems and buses are evolving, historically only 25% of small satellite missions have performed 100% of their mission requirements, and comparable numbers fulfill none of them, raising the apprehension that many small satellite missions could add to the worsening orbital debris problem. ♦

The 21st Advanced Maui Optical and Space Surveillance Technologies Conference, 15-18 September 2020, Maui, Hawai'i, USA (Virtual)

The 21st Advanced Maui Optical and Space Surveillance Technologies Conference was held virtually 15-18 September 2020. This year's virtual event hosted 808 participants, including representatives from 26 countries. The opening keynote speaker was Major General Stephen N. Whiting, Commander, Space Operations Command, United States Space Force. Maj. Gen. Whiting discussed the need for dependency on robust space domain awareness (SDA), the explosive growth in space capabilities, and the SDA contributions to national defense. Next, invited speaker Mr. Kevin O'Connell, Director of the Office of Space Commerce at the U.S. Department of Commerce discussed the resiliency of the space industry when faced with a global pandemic. He also provided details on Space Policy Directive-3 and National Academy of Public Administration support for the Department of Commerce leading non-military space traffic management.

Five papers were presented during the Orbital Debris session, co-chaired by representatives of the University of Warwick and the NASA Orbital Debris Program Office (ODPO). Representatives from ODPO provided a paper giving an overview on optical characterization of DebriSat fragments in support of orbital debris environmental models and a poster summarizing ES-MCAT nearing Full Operational Capability (FOC). Other papers in this session included a discussion about large constellations of low Earth orbit satellites and astronomy, University of Michigan; the contribution from Space Situational Awareness (SSA) data to the definition of a Space Sustainability Rating, Space Enabled Research Group, MIT Media Lab; the U.S. Air Force compliance with the Orbital Debris Mitigation Standard Practices, University of Tokyo; and a discussion on whether international law can provide a basis for actively removing space debris, The Open University.

The Non-Resolved Object Characterization session, co-chaired by representatives of L3 Harris and Applied Optimization, Inc., focused on characterization of resident space object states using functional data analysis; radar and optical studies of defunct GEO satellites; multicolor and spectral characterization of space objects in the near-IR; hyperspectral unmixing for remote sensing of unresolved objects; calculating photometric uncertainty; and light curve analysis using Kalman filtering and small telescope capabilities.

A new session was introduced this year on Cislunar Space Situational Awareness, a topic that garnered much attention across all sessions. ♦

The NASA-DOD Orbital Debris Working Group Meeting, 22 September 2020 (Virtual)

The 23rd annual NASA-DOD Orbital Debris Working Group (ODWG) meeting was conducted virtually on 22 September 2020. The goal of this ODWG is to provide a framework for cooperation and collaboration between NASA and DOD on OD activities such as measurements, modeling, mitigation, and policy development.

After the opening remarks, DOD provided an update on the status and future plans for the Space Fence, an S-band phased-array space surveillance radar which became operational in March 2020. Participants from the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) provided updates and analysis from Space Fence data collected to date as well. DOD and MIT/LL also provided updates on the status of the Space Surveillance Telescope (SST) program, now relocated to Australia. The SST achieved first light in March 2020 and is expected to reach initial operational capabilities in 2022.

DOD participants provided an update on the status of the transition of the satellite catalog (two-line elements) to a nine-digit catalog number, necessitated by increasing space traffic and improved sensor capabilities. Representatives of the USSF/18th Space Control Squadron (SPCS) provided updates on the conjunction assessment process and recent improvements to catalog accuracy following the Space Fence becoming operational. DOD participants presented a briefing on the on-orbit breakups since October 2019, including a lessons learned summary based on these events. ♦

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NASA-DOD Orbital Debris Working Group - Cont.

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The NASA ODPO then provided updates on the status of the Eugene Stansbery Meter Class Autonomous Telescope as it nears full operational capability, as well as ongoing geosynchronous Earth orbit survey data collection activities. NASA ODPO also provided an update on its other measurement activities, including the status of radar data collection conducted by the Haystack Ultra-wideband Satellite Imaging Radar; major findings are presented elsewhere in this issue. ODPO provided an update on the Orbital Debris Engineering Model 3.1 (ODQN, vol. 24, issue 1, p. 3), the recent release of the Debris Assessment Software 3.1 (ODQN, vol. 24, issue 3, p. 3), and an updated status on data processing, measurements, and analysis activities for the DebriSat project. The final ODPO presentation summarized the update on Orbital Debris Mitigation Standard Practices (ODMSP; ODQN vol. 24, issue 1, p. 1 & pp. 4-8) and activities associated with international engagement.

The ODWG concluded with a special presentation by the USSF/18 SPCS on the process to monitor and track large constellation spacecraft from launch, deployment, through reentry, and the challenges to improve the process as the trend of large constellation deployment continues in the coming years. ♦

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

14-16 January 2020: 2nd IAA Conference on Space Situational Awareness (ICSSA), Washington, D.C., USA

Recent Radar Observations of the Sub-Centimeter Orbital Debris Environment

T. KENNEDY, J. MURRAY, AND R. MILLER

The NASA Orbital Debris Program Office (ODPO) has conducted radar observations of the orbital debris environment since the early 1990's to provide measurement data that supports orbital debris models and risk mitigation activities in support of NASA mission objectives. Orbital debris radar observations are a unique mode for radar operation, employing a fixed beam configuration to statistically sample the environment. An advantage of conducting operations in this fashion is that it enables observations of smaller classes of orbital debris than would otherwise be available from the same sensor operating in a traditional tracking mode. Orbital debris-mode radar observations are used to fill in the gaps, which exist in the currently available data from the Space Surveillance Network (SSN), on small size orbital debris populations that represent significant risk to NASA programs. These gaps have typically covered orbital debris with characteristic sizes less than approximately 10 cm down to approximately 3 mm in low Earth orbit (LEO) – depending upon the altitude and sensor configuration.

The value of orbital debris radar measurements lies in the ability to extract partial orbital element information about orbital debris in the centimeter to several millimeter size regimes in low Earth orbit – which are not available from other measurement sources. This paper will discuss observations of this smaller class of orbital debris observed in recent years from the radars at the MIT Haystack Observatory in Westford, Massachusetts, and the Goldstone Solar System Radar near Barstow, California. The former radar is able to observe orbital debris down to approximately 5 mm, and the latter, orbital debris with characteristic sizes near 3 mm – at altitudes less than 1000 km. The characteristics and inferences about the current LEO orbital debris environment, and the different subpopulations that are identifiable in the observations are highlighted. ♦

The 34th Annual Small Satellite Conference, 1-6 August 2020, Logan, Utah, USA (Virtual)

The 2019 U.S. Government Orbital Debris Mitigation Standard Practices

J. B. BACON AND J.-C. LIOU

The rapid expansion of space traffic enabled by the SmallSat revolution has enabled unparalleled opportunity for commercial, educational, and national interests. However, it is an ongoing truth of space operations that the number of functioning spacecraft in orbit is vastly exceeded by non-functional orbital objects that can destroy them. As with any other environment, orbital space is easily polluted by human activities, and at some point, the pollution can significantly degrade the usefulness of that environment. Today, there are more threats to more spacecraft than ever before, and the current accelerated growth of space activity consequently accelerates the growth of its risks.

As early as 1988, U.S. national space policy established the priority to protect the space environment. Subsequently NASA and the U.S. Department of Defense made first efforts on formal standard practices to control space debris as early as 1993. Their work was expanded with the participation of all involved U.S. agencies in the publication of the first US Orbital Debris Mitigation Standard Practices (ODMSP) document in 2001. That document mandated minimum design and operations practices to best preserve the orbital environment with prudent, low-cost, mandatory steps. Subsequently, global coordination through the Interagency Debris Coordination Committee (IADC) has propagated many of these practices to all space-faring powers with varying levels of success and has elevated orbital debris mitigation to be a global concern. Each U.S. agency implements the standard practices within their own official regulatory/safety documents, such as NASA's Standard 8719.14 and DOD's Directive 3100.10, and others. ♦

continued on page 9

2019 OD Mitigation Standard Practices - Cont.

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In the last decade innovative new practices, concepts, and massive constellation proposals have opened "future space" to realities not envisioned in the 2001 standard practices document. Therefore, under Presidential Space Policy Directive #3 (June 8, 2018) all U.S. space-related agencies were directed to coordinate a major revision to the ODMSP to reflect expected best practices for this new era in space. This revised document was approved by the National Space Council in December 2019 and is reprinted here. All U.S. agencies with any certification or development authority over space launchers and/or spacecraft are now working to assure compliance of their internal standards with these practices. In addition, a 2025 list of recommendations (non-mandatory) from the 18th Space Wing at the Central Space Operations Center introduces addition details of design and operations that are all useful in reducing the risks in small satellite operations. This document is proposed for revision as well.

No matter the intended function of a space object or launch vehicle, its certification for flight by any U.S. agency will now depend upon meeting the minimum set of debris mitigation practices of the 2019 ODMSP. Additionally, good recommended practices are embodied in the 2015 Recommendations for Optimal CubeSat Operations. Both documents are included with this presentation. The attached presentation slides highlight all ODMSP requirements, especially key new expected practices for large constellations, active debris removal, and un-trackable or minimally trackable swarms. ♦

The 21st Advanced Maui Optical and Space Surveillance Technologies Conference, 15-18 September 2020, Maui, Hawai'i, USA (Virtual)

Optical Characterization of DebriSat Fragments in Support of Orbital Debris Environmental Models

H. COWARDIN, J. HOSTETLER, J. MURRAY, J. REYES, AND C. CRUZ

The NASA Orbital Debris Program Office (ODPO) develops, maintains, and updates orbital debris environmental models, such as the NASA Orbital Debris Engineering Model (ORDEM), to support satellite designers and operators by estimating the risk from orbital debris impacts on their vehicles in orbit. Updates to ORDEM utilize the most recent validated datasets from radar, optical, and *in situ* sources to provide estimates of the debris flux as a function of size, material density, impact speed, and direction along a mission orbit. On-going efforts within the NASA ODPO to update the next version of ORDEM include a new parameter that highly affects the damage risk – shape. Shape can be binned by material density and size to better understand the damage assessments on spacecraft. The *in situ* and laboratory research activities at the NASA ODPO are focused on cataloging and characterizing fragments from a laboratory hypervelocity-impact test using a high-fidelity, mock-up satellite, DebriSat, in controlled and instrumented laboratory conditions. DebriSat is representative of present-day, low Earth orbit satellites, having been constructed with modern spacecraft materials and techniques.

The DebriSat fragment ensemble provides a variety of shapes, bulk densities, and dimensions. Fragments down to 2 mm in size are being characterized by their physical and derived properties. A subset of fragments is being analyzed further in NASA's Optical Measurement Center (OMC) using broadband, bidirectional reflectance measurements to provide insight into the optical-based NASA Size Estimation Model. Additionally, pre-impact spectral measurements on a subset of DebriSat materials were acquired for baseline material characterization. This paper provides an overview of DebriSat, the status of the project, and ongoing fragment characterization efforts within the OMC. ♦

NASA's Orbital Debris Optical Program: ES-MCAT Nearing Full Operational Capability (FOC)

S. LEDERER, C. CRUZ, B. BUCKALEW, P. HICKSON, AND R. ALLISS

The NASA JAO/Eugene Stansbery Meter Class Autonomous Telescope (ES-MCAT) Facility is nearing Full Operational Capability, or FOC. ES-MCAT is now fully capable of autonomously running all observations, including: (a) monitoring weather and closing when conditions are not safe, as well as halting observations when conditions are not suitable (*e.g.*, too cloudy) for operations, (b) start-up/shut-down nightly tasking, (c) collecting calibration data and survey or TLE-tracked data, and (d) processing all collected data, including on-chip photometry and astrometry calibrations using the GAIA star catalogue. The processed data are then further analyzed at NASA Johnson Space Center to correlate detections with known objects in the Space Surveillance Network (SSN) catalogue.

ES-MCAT can collect data of specific objects with known orbits or can search for objects with orbits similar to those of spacecraft or rocket bodies that have recently broken up. However, the primary goal for ES-MCAT is to survey the geosynchronous (GEO) belt to provide a statistical sample of the GEO debris environment for both engineering models for spacecraft designers and long-term environment evolutionary purposes. The approach for sweeping the sky to statistically survey GEO has been investigated and updated from past surveys taken by NASA and will be reported, herein referred to as the Candy Cane method.

ES-MCAT's optical performance and the limiting magnitude for the full optical system will be discussed. An analysis used to determine which filter to use for GEO surveys (SDSS r') includes combining the reflectivity of the primary and secondary mirrors, transmission of the field corrector and CCD window, and the quantum efficiency of the CCD detector, resulting in throughput of the full optical path. This throughput is then combined with the expected typical transparency of the atmosphere at ES-MCAT's altitude/location for the Sloan Digital Sky Survey (SDSS) g'r'i'z' and Johnson/Kron-Cousins BVRI filters to yield expected relative throughput. ♦

UPCOMING MEETINGS

These events could be canceled or rescheduled due to the COVID-19 pandemic. All information is current at the time of publication. Please consult the respective websites for updated schedule changes.

2 December 2020: Virtual 5th Space Debris Re-entry Workshop

The European Space Operations Centre (ESOC) will host the 5th Space Debris Re-entry Workshop virtually this year. This half-day workshop aims to address the side effects of the increased traffic to orbit, namely a renewed interest in the practicalities of having objects, large and small, re-entering uncontrolled after the end of mission. Among the objectives of the workshop are linking space surveillance, astrodynamics, and re-entry physics to cover all aspects of the problem. The abstract deadline date passed on 12 October, but registration has been extended to 27 November. Detailed information, including the registration procedure, is available at https://reentry.esoc.esa.int/home/workshop.

8-9 December 2020: Virtual 2020 Space Systems Anomalies and Failures (SCAF) Workshop

The 2020 SCAF Workshop will be hosted by the Centauri Corporation and co-sponsored by NASA and the U.S. National Reconnaissance Office. The SCAF Workshop, organized in moderated discussions between community participants, has three primary goals: establishing enduring relationships between stakeholders that might not normally interact; improving the anomaly root cause attribution processes; and solving complex case studies in cause and effect. Attendees must be U.S. citizens to attend the workshop, and additional details are provided at the registration site. Registration deadline is 1 December 2020. Registration is available at https://www.eventbrite.com/e/2020-space-systems-anomalies-and-failures-scaf-virtual-workshop-tickets-120243925819?ref=estw.

28 January-4 February 2021: Hybrid COSPAR 2021, Sydney, Australia

Due to the worldwide COVID-19 pandemic, the 43rd Assembly of the Committee on Space Research (COSPAR) Scientific will convene both in the Sydney International Convention Center and in a virtual format, hence the Hybrid appellation. The COSPAR panel Potentially Environmentally Detrimental Activities in Space (PEDAS) will conduct a program entitled "The Science of Human-Made Objects in Orbit: Space Debris and Sustainable Use of Space." PEDAS.1 sessions will include advances in ground- and space-based measurements of the orbital debris environment, micrometeoroid and orbital debris environment modeling, end-of-life concepts, and solutions to fundamental operational challenges. The abstract submission period closed on 11 October 2020; however, early registration has been extended until 31 December 2020. Please see the COSPAR PEDAS.1 session website at https://www.cospar-assembly.org/admin/session_cospar.php?session=953 and the Assembly website at https://www.cospar2020.org/ for further information.

20-23 April 2021: Virtual 8th European Conference on Space Debris

The European Space Agency's European Space Operations Centre, Darmstadt, Germany, will host the 8th European Conference on Space Debris in virtual format. This quadrennial event will address all fundamental, technical areas relevant to the orbital debris community, including measurement techniques; environment modelling theories; risk analysis techniques; protection designs; mitigation and remediation concepts; and standardization, policy, regulation & legal issues. The deadline for abstract submission passed on 15 November. Additional information about this conference is available at https://space-debris-conference.sdo.esoc.esa.int/.

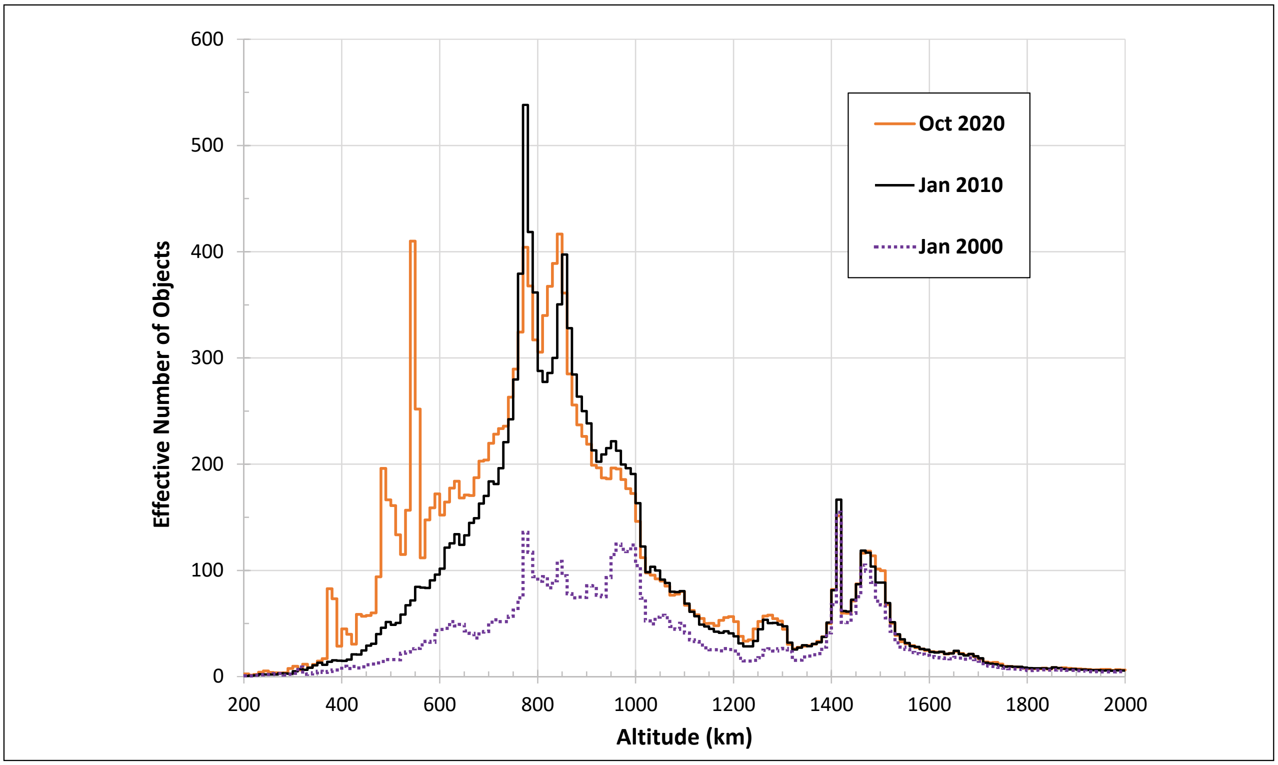
5-11 June 2021: 33rd International Symposium on Space Technology and Science (ISTS), Beppu, Ōita Prefecture, Japan

The 33rd ISTS will be convened in June 2021 and will be conducted jointly with the 10th Nano-Satellite Symposium & 13th IAA Low-Cost Planetary Missions Conference. ISTS will feature a dedicated session on Space Environment and Debris, including modeling, measurements, mitigation and protection, remediation, international cooperation, space weather, space situational awareness, space traffic management, and associated topics. Online abstract submission closes on 27 November 2020. Additional information about the conference is available at https://www.ists.or.jp/.

ODPO Celebrates ISS20

The NASA Orbital Debris Program Office (ODPO) and NASA's International Space Station (ISS) program celebrate the 20th anniversary of crewed operations and the many technical and scientific accomplishments of human spaceflight aboard the ISS. While the ISS was still on the drawing board, the ODPO was working to characterize the debris environment at ISS altitudes. Orbital debris was recognized as one of the top risks to the ISS, and the NASA Hypervelocity Impact Technology (HVIT) team used the ODPO's models and measurements to develop the ISS debris shields to minimize that debris risk. Since then, the ODPO and HVIT teams have worked closely with the ISS Program Office, including the Trajectory Operations & Planning Officer, to continue protecting the ISS from orbital debris. These efforts include regularly updated orbital debris environment modeling to improve the ISS probabilistic risk assessment, improving ISS impact protection shielding requirements for new modules and visiting vehicles, and defining the risk from breakup events to the station, visiting vehicles, and extravehicular activity operations. The ODPO and HVIT teams will continue this ISS support to ensure the safe operations of the ISS, including its U.S. National Laboratory, for many years to come.

The Tracked Objects in Low Earth Orbit: 2000–2020



Effective numbers of objects per 10 km altitude bin between 200 and 2000 km altitude at three different epochs. These are objects, approximately 10 cm and larger, tracked by the Space Surveillance Network. The increase from 2000 to 2010 was dominated by fragments generated from the Fengyun-1C antisatellite test conducted by China in 2007 and the accidental collision between Cosmos 2251 and the operational Iridium 33 spacecraft in 2009. The increase from 2010 to October 2020 was driven by the on-going build-up of the Starlink large constellation and the proliferation of CubeSats below about 650 km altitude.

SATELLITE BOX SCORE

(as of 04 October 2020, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Spacecraft*	Spent Rocket Bodies & Cataloged Debris	Total
CHINA	431	3748	4179
CIS	1546	5576	7122
ESA	92	57	149
FRANCE	69	510	579
INDIA	100	121	221
JAPAN	187	179	366
USA	2588	4898	7486
OTHER	1066	125	1191
TOTAL	6079	15214	21293

* *active and defunct*

Visit the NASA

Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS

01 June – 31 August 2020

Intl.* Designator	Spacecraft	Country/ Organization	Perigee Alt. (KM)	Apogee Alt. (KM)	Incli. (DEG)	Addnl. SC	Earth Orbital R/B	Other Cat. Debris
1998-067	ISS dispensed CubeSats	USA	414	417	51.6	4	0	0
2020-035B	STARLINK-1441	USA	549	550	53.0	59	0	4
2020-036A	HAIYANG 1D	CHINA	770	785	98.5	0	1	0
2020-037A	USA 301	USA	581	590	97.7	0	2	0
2020-037B	USA 302	USA	585	605	97.7			
2020-037C	USA 303	USA	586	604	97.7			
2020-037D	ANDESITE	USA	583	601	97.7			
2020-037E	M2 PATHFINDER	AUSTRALIA	586	602	97.7			
2020-038A	STARLINK-1461	USA	549	551	53	60	0	6
2020-039A	GAOFEN 9 03	CHINA	488	502	97.3	0	0	4
2020-039B	ZHEDA PIXING 3A	CHINA	485	502	97.3			
2020-039C	HEAD-5	CHINA	484	501	97.3			
2020-040A	BEIDOU 3 G3	CHINA	35755	35816	2.9	0	1	0
2020-041A	NAVSTAR 79 (USA 304)	USA	20160	20204	55.1	0	0	0
2020-042A	GAOFEN DUOMO (GFDM)	CHINA	630	650	98.0	0	1	0
2020-042B	BY70-2	CHINA	634	648	98.0			
2020-043A	SHIYAN 6 02 (SY-6 02)	CHINA	686	708	98.2	0	0	0
2020-044A	OFEQ 16	ISRAEL	NO ELEMS. AVAILABLE			0	1	0
2020-045A	APSTAR 6D	CHINA	35782	35796	0.0	0	1	0
2020-046A	USA 305	USA	570	581	54.0	0	1	0
2020-046B	USA 306	USA	565	581	54.0			
2020-046C	USA 307	USA	565	581	54.0			
2020-046D	USA 308	USA	565	581	54.0			
2020-047A	AL-AMAL (HOPE)	UAE	EN ROUTE TO MARS			0	0	0
2020-048A	KOREASAT 116	SOUTH KOREA	35781	35794	0.0	0	0	1
2020-049A	TIANWEN-1	CHINA	EN ROUTE TO MARS			0	0	0
2020-050A	PROGRESS MS-15	RUSSIA	419	421	51.6	0	1	0
2020-051A	OBJECT A	CHINA	492	512	97.5	0		
2020-051B	OBJECT B	CHINA	481	499	97.5			
2020-051C	OBJECT C	CHINA	481	500	97.5			
2020-051D	OBJECT D	CHINA	279	481	97.6			
2020-051E	OBJECT E	CHINA	458	512	97.6			
2020-052A	MARS 2020	USA	EN ROUTE TO MARS			0	0	0
2020-053A	OBJECT A	RUSSIA	EN ROUTE TO GEO			0	1	1
2020-053B	OBJECT B	RUSSIA	EN ROUTE TO GEO					
2020-054A	GAOFEN 9 04	CHINA	485	506	97.5	0	0	0
2020-054B	TSINGHUA SCIENCE	CHINA	481	507	97.5			
2020-055A	STARLINK-1522	USA	549	550	53.0	58	0	5
2020-056A	BSAT-4B	JAPAN	35773	35800	0.1	0	1	1
2020-056B	MEV-2	USA	EN ROUTE TO GEO					
2020-056C	GALAXY 30	USA	35782	35792	0.0			
2020-057A	STARLINK-1585	USA	374	386	53.0	60	0	5
2020-058A	OBJECT A	CHINA	481	507	97.5	0	0	0
2020-058B	OBJECT B	TBD	481	506	97.5			
2020-058C	OBJECT C	TBD	481	506	97.5			
2020-059A	SAOCOM 1-B	ARGENTINA	609	613	97.9	0	0	0
2020-059B	GNOMES-1	USA	600	609	97.9			
2020-059C	TYVAK-0172	USA	598	609	97.9			
2020-060A	RLFL14	USA	530	545	45.1	0	1	0
2020-060B	CAPELLA-2	USA	532	545	45.1			

* *Intl. = International; SC = Spacecraft; Alt. = Altitude; Incli. = Inclination; Addnl. = Additional; R/B = Rocket Bodies; Cat. = Cataloged*

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www.nasa.gov
https://orbitaldebris.jsc.nasa.gov/

The NASA Orbital Debris Photo Gallery has added high resolution, computer-generated images of objects in Earth orbit that are currently being tracked. They may be downloaded. Full instructions are at the webpage:

https://orbitaldebris.jsc.nasa.gov/photo-gallery/