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# **WISE IR OBSERVATIONS OF RESIDENT SPACE OBJECTS**

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**Final Report**

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# WISE IR Observations of Resident Space Objects

## Final Performance Report

FA9453-19-1-0079

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## Abstract

NASA's WISE (Wide Field Infrared Survey Explorer) conducted a simultaneous 4-band all sky survey in 2010 at 3.4, 4.6, 12, and 22 microns. In many of the images are streaks from Resident Space Objects (RSO). Measurements of these streaks provides fluxes which can be used to characterize the thermal and non-thermal characteristics of objects in orbit around the Earth. In this project we measured and analyzed the fluxes of different types of RSOs at geosynchronous orbit (GEO): uncontrolled satellites no longer station-keeping, SL-12 rocket bodies, and cataloged pieces of debris. An analysis was performed to see if infrared colors could be used to distinguish between various types of RSOs at GEO. In most cases the distributions overlap, and a unique identification cannot be made solely on the basis of infrared colors.

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# 1. Introduction

## 1.1 The WISE Mission

NASA's WISE (Wide Field Infrared Survey Explorer) conducted a simultaneous 4-band all sky survey in 2010 at 3.4, 4.6, 12, and 22 microns from low Earth orbit (LEO). In many of the images are streaks from Resident Space Objects (RSO). Measurements of these streaks provides fluxes which can be used to characterize the thermal and non-thermal characteristics of objects in orbit around the Earth.

The 3.4-micron band (W1) measures reflected sunlight, while thermal emission is dominant in the two longest wavelength bands 12 (W3) and 22 (W4) microns. The intermediate band at 4.6-microns (W2) is a mixture of both reflected sunlight and thermal emission depending on the temperature of the object.

The spacecraft tracked the stars, which appeared as point sources in the images. Streaks from objects at geosynchronous orbit (GEO) are short enough that both end points can be in one image, and thus we can measure the total flux of an object.

One of the strengths of the WISE dataset is that all observations were obtained at the same solar phase angle: roughly 90 degrees. No correction for phase angle needed to be applied. And the targets were never in Earth eclipse.

## 1.2 Previous Work

Our results to date are:

1. Colors of active, controlled satellites at GEO are the same as asteroids at 1 AU, but very different from astronomical sources like stars and galaxies [1].
2. Box wing and spin stabilized active GEO satellites have different but slightly overlapping distributions in the color W2-W3 [2]. If the color W2-W3 can be measured for an unresolved active satellite, then the probability of it being either box wing or spin stabilized can be estimated.
3. IR colors and magnitudes have been determined for uncontrolled Titan 3C Transtage rocket bodies at GEO and associated debris from the public catalog [3], and compared with active GEO satellites. The rocket bodies are bluer (and presumably hotter) in the color W3-W4 (both thermal). The spread in W2 (largely reflective?) is what one would expect if the rocket bodies are seen at different orientations.

A preliminary analysis has been done for Breeze M rocket bodies at GEO by Lee (2018, presented at COSPAR). These have a very different distribution than the Titan Transtages at GEO, and are more like active cylindrical satellites.

## 2. Methods, Assumptions, and Procedures

### 2.1 Sample Selection

The sample of RSOs to be studied was selected from the public catalog of RSOs maintained at [www.space-track.org](http://www.space-track.org). This catalog of orbits was used for all previous work outlined above.

Specifically, we searched the catalog for objects in circular or near-circular orbits (eccentricity < 0.1) near GEO (altitude 35,786 km). The catalog epoch ranged from 2010.04 to 2010.74 which is when WISE was operating with all four bands. Our particular interest was in objects which could be compared with our previous work:

1. Inactive satellites which have ceased functioning and are no longer station-keeping. They may have orbital inclinations up to 15 degrees due to perturbations from the Earth, the Moon, and the Sun.
2. SL-12 rocket bodies. This is the largest class of rocket bodies at GEO which we have not previously studied (see section 1.2).
3. Objects classified as debris in the catalog. We have previously studied debris associated with Titan Transtages (see section 1.2), and now which to study other pieces of debris at GEO.

The NORAD IDs for each sample are given in the Appendix.

### 2.2 Measurements

Once the list of objects to be studied had been generated, the following procedure was followed to measure magnitudes in all 4 WISE passbands, and produce results.

1. Obtain orbital elements for an object for the year 2010 when WISE was operational in all four bands from [www.space-track.org](http://www.space-track.org)
2. Identify which WISE images had this object in it.
3. Download those images from the WISE image server at the Infrared Processing and Analysis Center (IPAC).
4. Confirm the streaks and measure their total flux using software previously developed.
5. Put the measured magnitudes on a standard calibrated system using magnitude zeropoints determined previously by IPAC.
6. Colors were produced by taking the difference of two magnitudes, which is the same as the ratio of two fluxes.

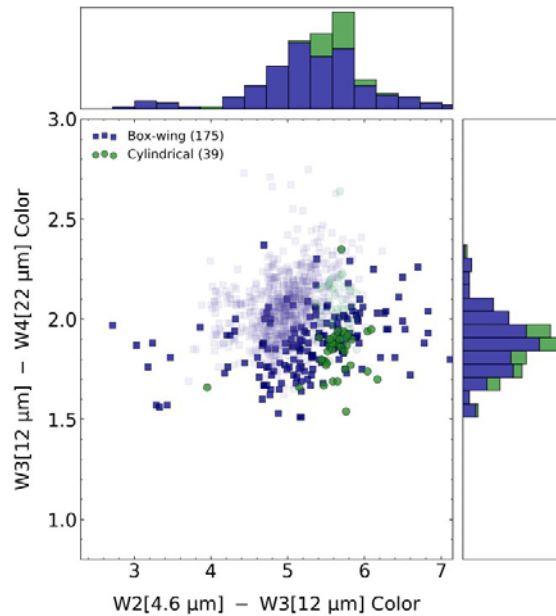
The above procedure was repeated for every object. In some cases, multiple observations at different times of the same object were obtained.

### 3. Results and Discussion

#### 3.1 Inactive GEO satellites

Inactive satellites are those which have ended their mission and have ceased functioning. At GEO, this also means that they have ceased station-keeping to keep them in a small box at GEO. Station keeping requires active maneuvering using on board thrusters (and fuel). Once station-keeping ends, the satellite will start to drift due to orbital perturbations from the non-spherical components of the Earth's gravity field, and the gravity of the Moon and Sun. The combination of these effects causes the satellite to drift East or West, and the orbital inclination to increase up to a maximum of 15 degrees and then back to zero with a period of 54 years.

Figure 1 shows the distribution in color space of inactive satellites (bright symbols) overlaid on the distribution of active satellites (faint symbols). Two different types of satellites are common: box wing with long solar panels and cylindrical.



**Figure 1: Color-Color plot of inactive satellites (bright symbols) overlaid on active satellite distribution (faint symbols)**

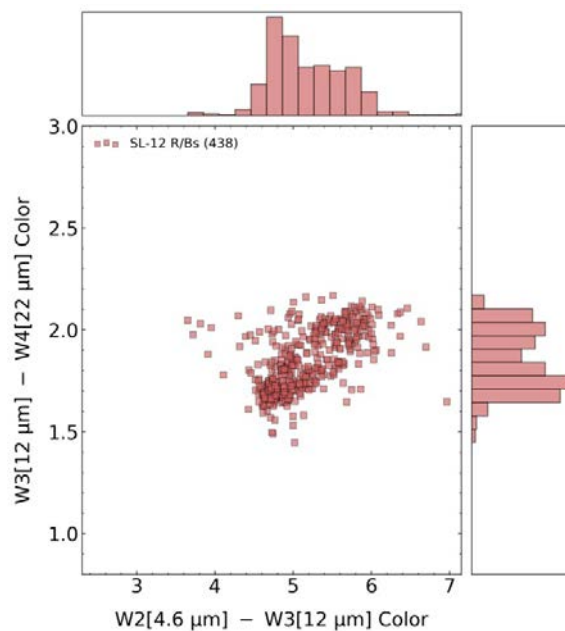
175 measurements were possible of box-wings satellites, and 39 were made of cylindrical satellites (which are less common). Results:

1. The color W3-W4 should measure temperature, since both should be dominated by thermal emission from the spacecraft. The inactive box-wing satellites have a much broader distribution than active ones and appear to be slightly bluer (warmer?) in this color.
2. The inactive box-wing satellites now have a much broader distribution in W2-W3. W2 measures a mixture of reflected solar flux and thermal emission from the object. Which dominates depends on the temperature of the object.

3. The inactive cylindrical satellites are still mostly redder in W2-W3 than box-wing satellites and are also bluer in W3-W4.
4. The distributions overlap to such a degree that infrared measurements alone cannot uniquely determine whether an object is active or inactive, box-wing or cylindrical. Only a probability estimate can be made. We did not make a quantitative statistical analysis of the differences.

### 3.2 SL-12 Rocket Bodies

The SL-12 is a Soviet/Russian last stage used for launches to GEO. Figure 2 shows the color-color distribution of the SL-12s that we were able to measure in the WISE dataset.



**Figure 2: Color-Color Distribution of SL-12 Rocket Bodies at GEO**

The distribution here is mostly elliptical, with evidence of a possible hole or gap in the center. We have no idea of what physical effect or systematic measurement error could cause this. The distribution overlaps considerable with the distribution of inactive satellites – thus identification of a rocket body would not be possible solely using these infrared colors.

### 3.3 Debris

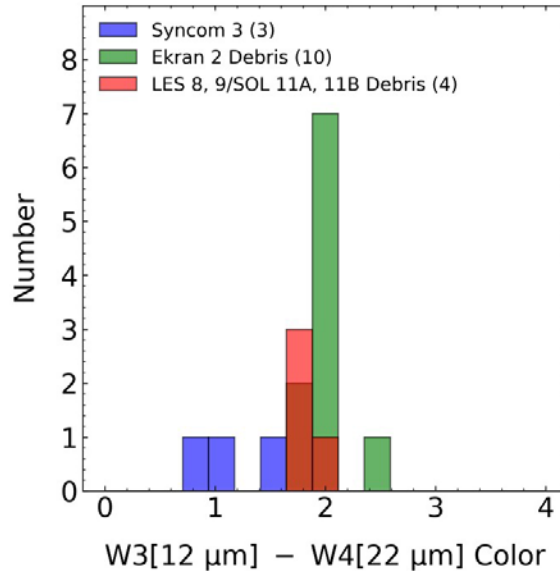
Debris can result from a number of sources:

1. The fragmentation of a larger body.
2. A collision of two RSOs.
3. Mission related such as the release of a mirror or baffle cover.

Our previous work studied debris resulting from Titan Transtage fragmentations. This sample was the largest number of debris pieces in the catalog.

In addition, we measured the WISE data for Syncom 3, which is the earliest geosynchronous satellite in the catalog, dating from the early 1960s. It is now inactive.

Unfortunately, these objects were too faint in the two bluest bands where the signal is dominated by reflected sunlight. Thus, they could only be measured in the two reddest bands and the color W3-W4 measured. This histogram is shown in Figure 3.



**Figure 3: Histogram of W3-W4 colors for Syncom 3 and GEO Debris**

Syncom 3 is slightly bluer (warmer?) than the debris pieces. It is also bluer than most of the active and inactive satellites, and SL-12 rocket bodies presented above. The colors of the debris pieces overlap well with satellites and rocket bodies. It appears that one could not distinguish debris from larger pieces on the basis of W3-W4 colors. This may not be too surprising, given that they may all be in thermal equilibrium with no heat (or cooling) systems active.

## 4. Conclusions

Infrared colors from the WISE dataset were measured for three different classes of RSOs at GEO:

1. Inactive satellites of two subtypes:
  - a. Box-wing
  - b. Cylindrical
2. SL-12 rocket bodies
3. Pieces of GEO debris and the Syncom 3 early GEO communications satellite (now inactive).

All of these classes show a broad distribution in both colors studied.

Our primary conclusion is that it is not possible to use infrared observations in the 4 WISE bands alone to uniquely classify an object into any of the above classes: satellite (active or inactive, box-wing or cylindrical), rocket body, or debris. Additional information would be required.

Our previous work showed that if one knew the object was an active satellite at GEO, then one could make a probabilistic estimate that the object was either box-wing or cylindrical [2].

## 5. References

- [1] Lee, C.H., et al. (2016) *AMOS Technologies Conference Proceedings*, Maui Economic Development Board, Maui, Hawaii.
- [2] Lee, C.H., et al, (2017) *AMOS Technologies Conference Proceedings*, Maui Economic Development Board, Maui, Hawaii.
- [3] Seitzer, P., et al. (2018) *International Astronautical Conference*, Adelaide, Australia.

## Appendix – List of NORAD IDs

Inactive box wing satellites:

13969 21047 21056 21139 21222 21227 21726 21803 21813 21814 22087 22096 22253  
22723 22930 22931 23192 23227 23413 23461 23581 23598 23649 23651 23730 23781  
23865 24313 24748 24786 25134 25642 25897 25913 26038 26056 26298 26378 26578  
26936 28218 28234 29230 30323 31395 32708 33460

Inactive cylindrical satellites:

3029 12309 17561 20570 20667 20872 21653 23016 23185 23943 25312

SL-12 Rocket Bodies:

11569 11571 11676 11684 12447 12471 12851 13630 13899 13900 13983 14086 14114  
14115 14117 14193 14195 14548 14943 14948 14951 15139 15181 15487 15581 15630  
15693 15963 16214 16732 17125 17705 17872 17873 17874 17875 17939 17972 18331  
18387 18446 18578 18634 18718 19076 19094 19347 19400 19686 20110 20266 20394  
20502 20662 20696 20836 20926 21019 21129 21135 21536 21703 21762 21792 21824  
22115 22213 22248 22272 22624 22839 22883 22910 22966 23013 23111 23171 23270  
23322 23330 23429 23451 23656 23683 23720 24438 24897 25048 25318 25339 25465  
25645 25900 26101 26246 26381 26397 26480 26895 26939 27444 27780 28119 28139  
28240 28256 28466 28634 28704 29233 33111 34265

GEO Debris objects:

858 11581 12996 13753 29014

## List of Acronyms

GEO	Geosynchronous Orbit
IPAC	Infrared Processing and Analysis Center
RSO	Resident Space Object
WISE	Wide Field Infrared Survey Explorer

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