Distinguishing Active Box-Wing and Cylindrical Geostationary Satellites using IR Photometry with NASA's WISE Spacecraft

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Abstract

Over 860 observations of 245 box-wing (BW) and 18 cylindrical (C) active geostationary satellites (GEOsats) have been extracted from the thousands of resident space objects (RSOs) serendipitously detected by NASA's Wide-field Infrared Survey Explorer (WISE). In 2010, WISE performed an all-sky infrared (IR) survey at 3.4, 4.6, 12, and 22 microns simultaneously from low Earth orbit (LEO). For GEOsats, these wavelengths are in the reflective and thermal IR regimes, and all observations were obtained near quadrature. From our unresolved IR photometry of GEOsats, we report and discuss a distinguishing characteristic between BW and C GEOsats using a unique combination of IR fluxes, along with generalizations of GEOsat photometry and colors as a whole based on our large sample size.

1 Introduction

An increase in space traffic over the past several decades has brought forth a multitude of encumbrances for space situational awareness (SSA) and space surveillance activities, such as increased inter-satellite collisional risk, an increase in the orbital debris population, as well as increased difficulty in satellite tracking. Particularly for geostationary satellites (GEOsats), given their cost and utility, proper characterization and monitoring of these satellites are imperative. For example, photometric characterization of satellites can help to rectify cross-tagging, since resolved imaging cannot be used to solve this problem or other satellite status related issues [1, 2].

Fig. 1: *(Images courtesy of Gunter's Space Page)* An example box-wing *(left)* and cylindrical *(right)* geostationary satellite.

In 2010, NASA's Wide-field Infrared Survey Explorer (WISE) was sent in a Sun-synchronous polar orbit to perform a simultaneous 4-band all-sky survey at 3.4 (W1), 4.6 (W2), 12 (W3), and 22 (W4) microns from low Earth orbit (LEO) with single exposures of ~8 seconds [3]. Its pointing was consistently kept perpendicular to the terminator to protect its IR optics from direct solar irradiation and scattered earthlight [3]. From this mission strategy, other resident space objects (RSOs) at larger orbital radii were captured in WISE images as streaked sources with each observation close to quadrature. The result is a large database of homogeneous space-based RSO observations.

For GEOsats, the near-quadrature observations result in the satellite photometry consistently representing the central bus of attitude-controlled box-wing (BW) satellites [4]. Since active cylindrical (C) satellites are spun for attitude control, WISE photometry likely reflects an integrated flux around the body of C satellites along with external appendages, such as antennae dish. Furthermore, for objects at 1 astronomical unit (AU) like GEOsats, the 3.4 micron passband primarily measures reflected sunlight. The 4.6 micron passband measures reflective and thermally emissive components depending on the temperature of the observed object. The 12 and 22 micron passbands primarily measure thermal emission. Finally, WISE can access the entire GEO regime since it is not geographically constrained to one ground-based location.

Although ground-based observations can provide deeper photometry in bluer passbands, WISE can perform a more comprehensive and uniform survey. This allows for large sample surveys of general GEOsat photometric properties that would be difficult to investigate with much smaller datasets. In particular, this analysis reports over 860 observations of 245 unique box-wing and 18 unique cylindrical GEOsats that were active during WISE's all-sky survey.

Preliminary analyses of a small subset of WISE GEOsat observations were previously reported [5], and updated color distributions using the current larger sample size agree with the preliminary reports. There is considerable overlap of WISE color distributions between active GEOsats and asteroids around 1 AU. Since the spectral energy distributions of GEOsats and asteroids are likely the result of similar physical characteristics (reflective in bluer passbands, thermal in redder passbands) it is also likely that GEOsat colors would similarly depend on heliocentric distance. Furthermore, GEOsat color distributions were found to be distinctly different from those of luminous astronomical sources. In particular, reflected sunlight color magnitudes were found to be redder than the Sun by an average of approximately 2.5 magnitudes.

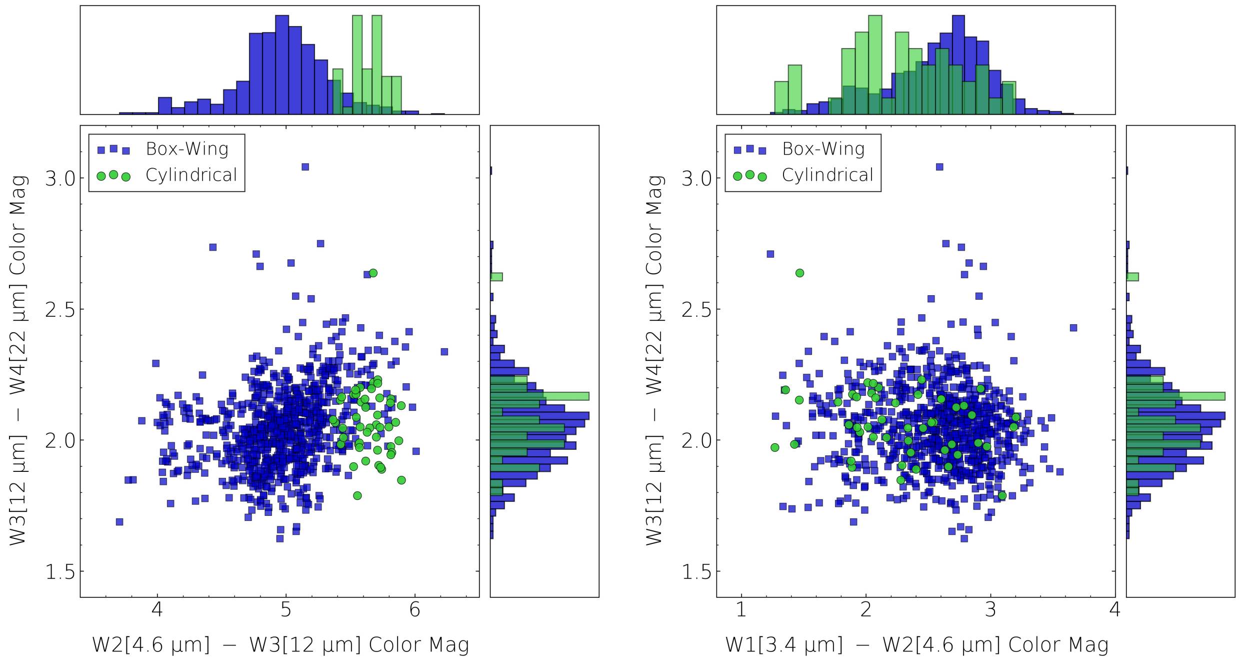


Fig. 2: Box-wing (blue) and cylindridal (green) satellite color magnitude scatterplots with marginal histograms. (a) W3−W4 vs W2−W3 color mag axes, (b) W3−W4 vs W1−W2 color mag axes. Errors are all roughly the plot marker sizes.

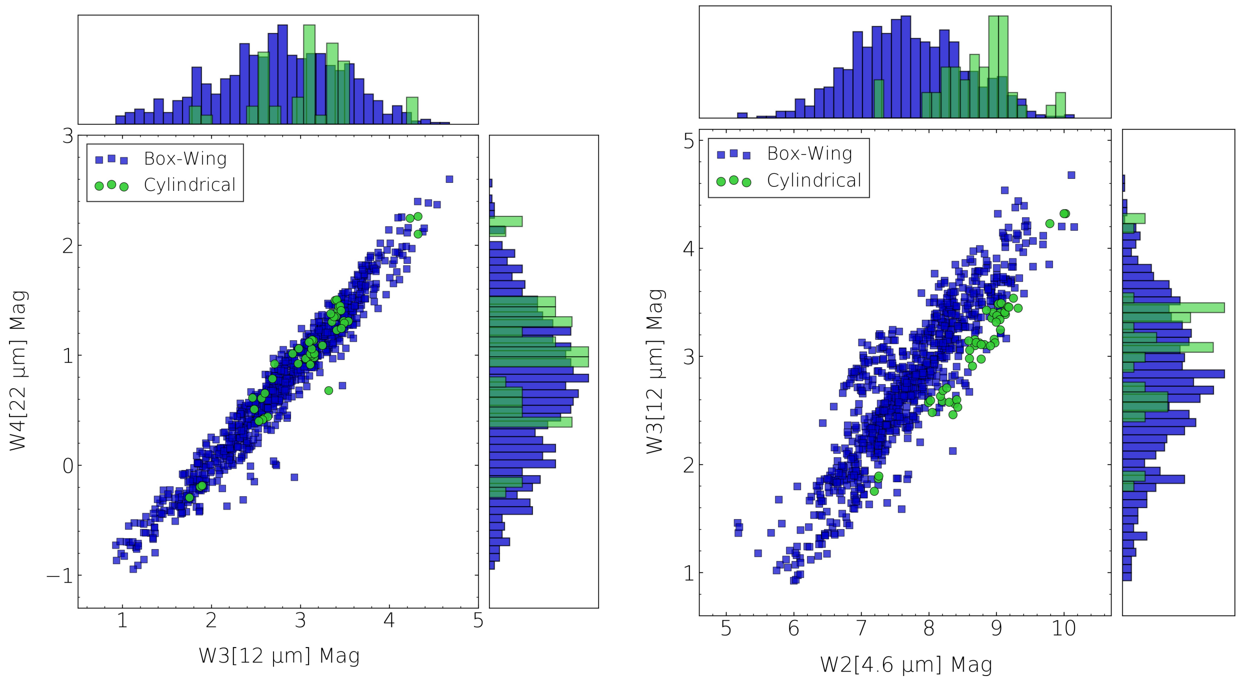
2 Obtaining GEOsat Photometry

Equatorial WISE images were downloaded from IPAC's WISE image data server, where image field centers must also have been 30° above or below the galactic plane to minimize contamination from stars in the aperture used for satellite photometry. Detected streak centers were then correlated with satellites using Analytical Graphics Incorporated's Systems Tool Kit and their database of publicly available two-line element sets (TLEs). Photometry was obtained using a custom streak aperture-fitting algorithm with fluxes calibrated as prescribed in the WISE Explanatory Supplement [6].

3 Distinguishing Box-wing and Cylindrical Satellites

Observations of active BW and C satellites reveal distinctly separate color distributions from a combination of fluxes that is not prevalently used. The W1−W2 color magnitude measures spacecraft reflective colors, the W3−W4 color magnitude measures spacecraft color temperature, and the W2−W3 color magnitude is a peculiar combination of reflective and thermal fluxes depending on the satellite's temperature. As shown in Fig. 2, the distinction in distributions is observed in this particular cross color but not in primarily reflective or emissive colors.

Although not explicitly shown, this distinction is also observed in the W2−W4 cross color and to a lesser extent in the W1−W3 and W1−W4 cross colors. The temperature-regulated GEOsats have a peak in their thermal emission within the W3 passband, and W3 and W4 fluxes are tightly correlated as shown in Fig. 3 likely due to their emission spectra. Therefore, it is unsurprising that distribution differences are observed for both W2−W3 and W2−W4. However, it is peculiar that less of a distinction is observed when the W2 portion of the cross flux is substituted with the more reflective W1 fluxes. This indicates that there may be some distinguishing feature in the unresolved photometry between BW and C satellites within W2 that is more thermally correlated, which is further supported by the offset in the W3 vs W2 magnitude



(a) (b)

Fig. 3: Box-wing (blue) and cylindrical (green) satellite color magnitude scatterplots with marginal histograms. (a) W4 vs W3 color axes, (b) W3 vs W2 color axes. Errors are all roughly the plot marker sizes.

scatterplots as shown in Fig. 3. Further investigation would require higher spectral resolution with another instrument. Fortuitously, the W2 and W3 passbands reside within IR atmospheric transmission windows, so more detailed photometry with ground-based observations is possible.

3.1 Miscellaneous Analyses

Apart from the color distinctions, there are other photometric characteristics that can be confidently inferred about the GEOsat population as a whole, since this sample contains most of the retrospectively active GEOsats with multiple observations for many of the satellites. The color temperature distribution likely depends on spacecraft thermal regulation, and the reflective color distribution likely depends on the variety of construction for different satellite types and slightly different viewing geometries between each observation. The range of reflective and thermal color variability for GEOsats due to these characteristics is shown in Fig. 2, which shows the spread of the reflective W1−W2 to be approximately 2 magnitudes and the thermal W3−W4 to be approximately 1 magnitude.

The sample size considered here allows for generalizations of GEOsat colors. Therefore, given similar observation parameters, photometry of an unidentified satellite that significantly deviates from these presented distributions may signify that the satellite is of very different construction and may warrant further surveillance. If observations are constrained to WISE-like passbands, these distributions can be a photometric reference for BW buses and C satellites.

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References

[1] Darryl J. Sanchez et al. Photometric Measurements of Deep Space Satellites. In *Proceedings Volume 4091, Imaging Technology and Telescopes*. Society of Photo-Optical Instrumentation Engineers (SPIE), 2000.

[2] Tamara E. Payne et al. Analysis of Multispectral Radiometric Signatures from Geosynchronous Satellites. In *2002 AMOS Technologies Conference Proceedings*. Maui Economic Development Board, 2002.

[3] Edward L. Wright et al. The Wide-field Infrared Survey Explorer (WISE): Mission Description and Initial On-orbit Performance. *The Astronomical Journal*, 140:1868–1881, 2010.

[4] Rita L. Cognion. Observations and Modeling of GEO Satellites at Large Phase Angles. In *2013 AMOS Technologies Conference Proceedings*. Maui Economic Development Board, 2013.

[5] Chris H. Lee et al. Infrared Photometry of GEO Spacecraft with WISE. In *2016 AMOS Technologies Conference Proceedings*. Maui Economic Development Board, 2016.

[6] IPAC. IV. WISE Data Processing, 3. Scan/Frame Pipeline, g. Photometric Calibration, 2011.