Finding Warm Debris Disks with *WISE* Around Bright Stars

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Abstract. The WISE All-Sky Survey Catalog presents an opportunity to expand the number of detections of warm (>100K) circumstellar dust in asteroid belt-analog regions. Such detections are useful to statistically constrain the occurrence rate of dusty systems, and imaging campaigns aiming to characterize the morphology of the dust populations can choose their targets form the nearest (< 75 pc) dust detections. Unfortunately, *WISE* bands saturate at relatively bright magnitudes, effectively removing bright stars from WISE excess searches. However, for the first time, we are able to detect small excesses even around bright solar neighborhood stars by deriving and applying corrections to the fluxes of saturated stars in *WISE*. In this study we identify 214 Hipparcos stars within 75 pc with mid-infrared excesses arising from warm optically thin circumstellar dust at the W3 (12 μm) and W4 (22 μm) bands. For optimal sensitivity, we use the stars contemporaneously measured shorter-wavelength fluxes at $W1$ (3.4 μm) and $W2$ (4.6 μm) to identify excesses at $W3$ and $W4$. These systematic corrections, together with careful inspection of other possible sources of contamination, enable us to increase by 45% the number of stars with warm dusty excesses within 75 pc of the Sun, even in the light of several recent studies on *WISE*. Our findings include five new stars with tenuous but significant $W3$ excesses, adding new members to the small population of known exozodi within 75 pc. Altogether, we have expanded the number of known debris disks (with excess at any wavelength) within 75 pc of the Sun by 29%. As a result of our WISE study, the number of debris disks with known 10–30μm excesses within 75 pc (379) has now surpassed the number of disks with known > 30μm excesses (289, with 171 in common), even if the latter have been found to have a higher occurrence rate.

1. Introduction and Cross-Match Overview

Numerous surveys have been conducted to search for dusty circumstellar debris disks around main-sequence stars in the last few decades by IRAS, the Spitzer Space Telescope and ISO (e.g., Rhee et al. 2007; Bryden et al. 2009; Chen et al. 2006; Su et al. 2006; Habing et al. 2001)). As of now, roughly 330 debris disk hosts are known with 75 pc, detected by the excess IR thermal emission produced by the dust in the system, above the expected photospheric flux of the star. The majority of these are long wavelength excesses ($> 30\mu$m), attributed to cold Kuiper-belt analogs.

Warm circumstellar dust (100—400 K) is more challenging to detect. Stars with this type of dust are interesting because the dust spans the frost line and habitable zone around a star. The Spitzer Space Telescope is responsible for detecting the majority of known warm dusty disks (e.g., Rhee et al. 2007; Bryden et al. 2009; Su et al. 2009; Beichman et al. 2006), though like all pointed surveys, their limited coverage leads to biases in the overall completeness of the survey. The Wide-Field Infrared Survey Explorer (*WISE* Wright et al. 2010) is particularly powerful in detecting these warm disks given its all-sky coverage at $W1$, $W2$, $W3$, and $W4$ bands (3.4, 4.6, 12 and 22μm respectively). The contemporaneous coverage provides uniform 3–30μm photometry, which allows precise estimtes of the stellar photospheres and hence detections of tenuous excesses from warm dust. Our study takes advantage of this, and we provide an unbiased and complete sample of stars with excess emission at $W3$ and $W4$ for main-sequence Hipparcos stars within 75 pc by only using *WISE* colors to search for these excesses.

2. Infrared Excess Identification

2.1 Sample Selection

We initially cross-matched all Hipparcos main-sequence stars within 120 pc and outside the galactic plane ($|b| > 5°$) to WISE sources. We used this 120 pc sample as a parent sample to accurately determine the photospheric behavior of stars in the *WISE* bands. We only used stars with Tycho $B_T - V_T$ color between -0.17 and 1.4 mag. We also discarded objects with *WISE* flags indicating confusion, extended sources, inconsistent variability across *WISE* bands, scattered moonlight contamination and stars with contamination from interstellar cirrus. This ensured a clean sample of stars without any major systematic biases. We report detections for a subset of stars that are within 75 pc.

2.2 Saturation Corrections and Consistency Checking

In some cases, we found that certain stars in the *WISE* All-Sky Survey Catalog (ASC) had photometric measurements discrepant from the mean of the profile-fit photometric measurements from the Single Exposure Source Table. This discrepancy affects only a tiny fraction of the photometry in the *WISE* $W1$–3 bands (∼0.4%–0.9%) and ∼10% of the $W4$ photometry. Since the goal of this study is to search for outlying photometric measurements due to debris disk emission, spurious outliers are a problem that must be addressed. We chose to retain the ASC fluxes as they are reliable in the majority of cases. However we opted to reject from our sample all stars with $> 2\sigma$ discrepancies between the two flux estimates.

One of our aims was to search for excesses around the closest and brightest Hipparcos stars, which would allow for characterization of the dust distribution in followup imaging surveys. However, $WISE$ bands saturate at relatively faint magnitudes ($W1 < 8.0$ mag and $W2 < 6.7$ mag) and display a systematic trend when compared to the 2MASS K_s magnitudes of the same stars. To incorporate stars with saturated photometry int our sample, we corrected for the biases in the $K_s - Wi$ versus Wi color-magnitude distributions. We fit polynomials to the two-sigma clipped $K_s - Wi$ versus Wi distributions and add the fitted values to correct the Wi measurement for each star and use these corrected values for the remainder of our study. An example of the fitted polynomial and systematic saturation trend can be seen for $W2$ in Figure .1.

3. Excess Selection

We searched for excesses using only $WISE$ colors: $W2 - W3$ and $W1 - W3$ for $W3$ excesses and $W1 - W4$,$W2 - W4$ and $W3 - W4$ for $W4$ excesses. We also searched for potential hot dust > 400 K around our stars in the form of $W2$ excesses by using the $W1 - W2$ colors. The photospheric colors of main-sequence stars vary over the $WISE$ bands as a function of stellar tempertaure. We calibrated this dependence by determining the trimmed mean of $WISE$ colors as a function of $B_T - V_T$, which traces the photospheric $WISE$ colors. The left hand panel of Figure .2 shows the $W2 - W4$ color of stars in our sample plotted as a function of $B_T - V_T$, with green circles tracing the mean photospheric color in 0.1 mag wide bins.

Then we create a color SNR ($\Sigma_{E[Wi-Wj]}$), which is the color excess of a star weighted by the quadrature sum of the individual photometric uncertainties and the uncertainty in the photospheric $WISE$ color. The right hand panel of Figure .2 shows the $\Sigma_{E[W2-W4]}$ distribution of stars in our sample. These distributions were used to calculate the 99.5% confidence level (green dotted line), above which stars were chosen as candidate debris disks.

4. Results and Discussion

We detect 214 unique IR excesses within 75 pc from our $WISE$ color excess search. The total number of new excesses never previously reported at any wavelength is 106. The total number of new 10–30μm excesses is 116. This constitues a 29% expansion in the number of debris disks at any wavelength within 75 pc.

The incidence rates we derive for 12 and 22μm excesses exceed previous determinations from $WISE$ studies by virtue of our precise photometric calibration. Our incidence rates for 12μm excesses agree with the most sensitive results from Spitzer, while our incidence rates for 22μm excesses are 1.5–3× less sensitive to Spitzer's estimates. The spectral type breakdown of these incidence rates are shown in Figure .3.

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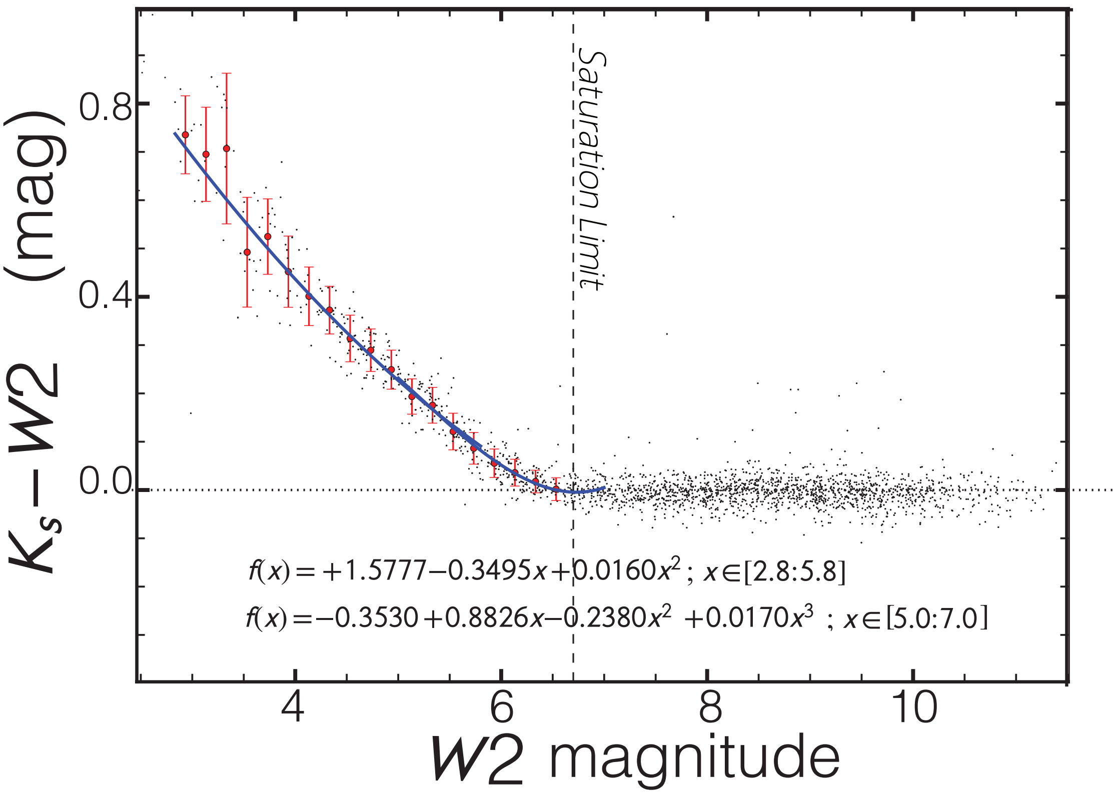

Figure .1: We show the 2MASS $K_s - W2$ vs $W2$ relations that are used for correcting systematics in saturated $W2$ photometry. These empirical distributions are a combination of B8–A9 dwarf stars within 75 pc, along with fainter $B - V < 0.10$ mag A0 stars from the Tycho-2 Spectral Type Catalog (Wright et al. 2003). The saturation limit for $W2$ is shown as a vertical dashed line. We also corrected for $W1$ saturation, which is not disapleyd here. Two overlapping polynomials were fit to the saturated $W2$ data to account for the knee between 5.4 mag adn 6.7 mag: a quadratic — fit between 2.8 mag $\leq W2 \leq$ 5.8 mag and applied between 2.8 mag $\leq W2 \leq$5.3 mag — and a cubic — fit between 5.0 mag $\leq W2 \leq$ 7.0 mag and applied between 5.3 mag $\leq W2 \leq$ 6.7 mag. No corrections were applied to the $W3$ and $W4$ photometry.

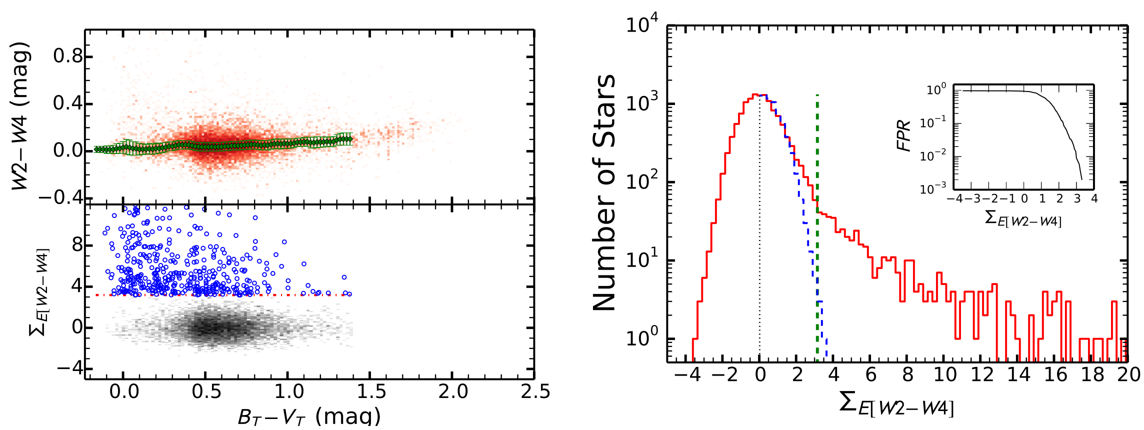

Figure .2: The left hand panel shows the $W2-W4$ vs. Tycho-2 $B_T - V_T$ color-color diagram. The green diamonds follow the running mean of the parent sample. The bottom half of the left hand panel plots the significance $\Sigma_{E[W2-W4]}$ of the color excess as a function of $B_T - V_T$. These are residuals of the subtraction of the photospheric running mean. The open blue circles are stars selected as excesses. The right hand panel shows the distribution of the significance of the color excess. The blue dashed histogram is the uncertainty distribution created by reflecting the negative excesses about the mode of the full distribution. The vertical dashed line indicate the false-positive rate threshold for this particular distribution, above which we identify a star as an excess. We perform a similar analysis for the other five $WISE$ colors used to search for excesses.

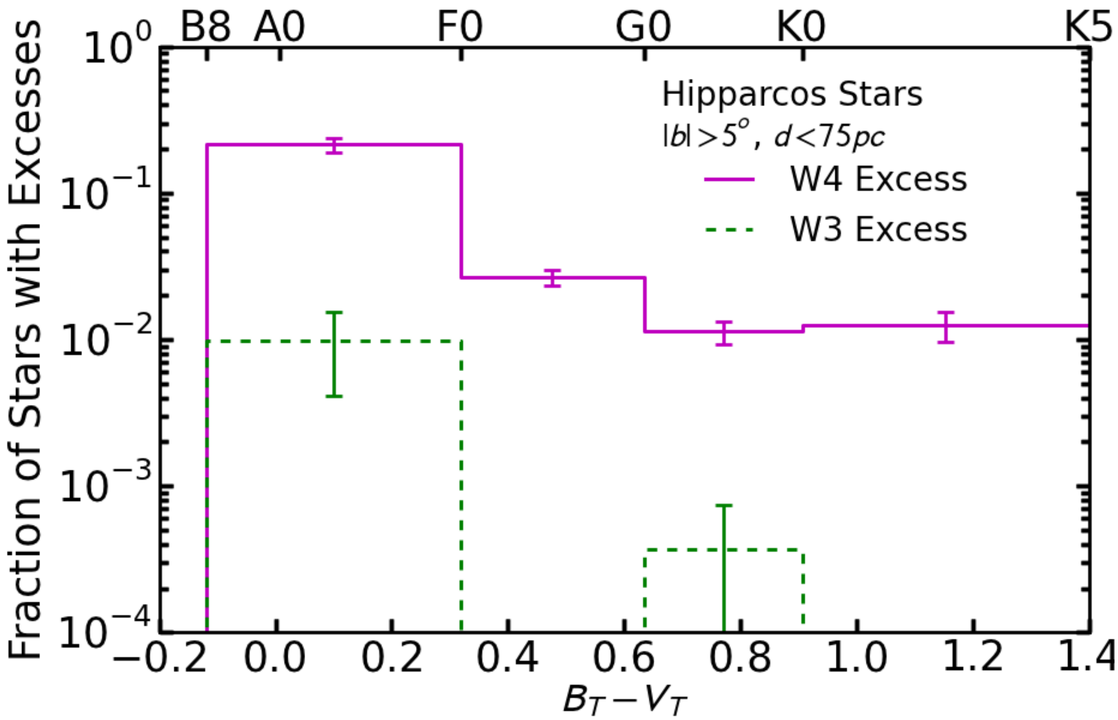

Figure .3: Fraction of WISE excesses detected in this survey as a function of spectral type from our science sample.