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Spitzer/IRAC Characterization of Galactic AGB Stars

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Abstract. The *Spitzer Space Telescope* and in particular its InfraRed Array Camera (IRAC) is an ideal facility to study the distribution of AGB stars in our own and other galaxies because of its efficiency in surveying vast areas of the sky and its ability to detect sources with infrared excess. The IRAC colors of AGB stars, however, are not well known because cool stars have numerous molecular absorption features in the spectral region covered by the IRAC photometric system. The presence and strength of these features depends on the chemistry of the stellar atmosphere and the mass loss rate and can change with time due to the star's variability. To characterize the IRAC colors of AGB stars, we are carrying out a *Spitzer* Guaranteed Time Observation program to observe a sample of AGB stars with IRAC. The results will be made available to the community in the form of template magnitudes and colors for each target with the goal of aiding the identification of AGB stars in already available and future IRAC surveys. We present here the first results of this project.

1. Mapping AGB Stars with *Spitzer*/IRAC

Asymptotic Giant Branch (AGB) stars, with luminosities exceeding $10^4 L_{\odot}$, are among the brightest stars in the galaxy. They are also among the reddest because of intense mass loss processes (up to $10^{-4} M_{\odot}/\text{yr}$) responsible for enshrouding AGB stars in dusty envelopes, which are the source of strong infrared excess. These characteristics of AGB stars make them very important tools to study the structure of our and other galaxies by mapping their distribution at infrared wavelengths. The *Spitzer Space Telescope* (Werner et al. 2004) is especially suited for this task. The telescope has very low background emission, which makes the InfraRed Array Camera (IRAC, Fazio et al. 2004) onboard *Spitzer* very sensitive and allows mapping large areas of the sky in a very short time. Several large area IRAC surveys, including GLIMPSE (Benjamin et al. 2003) covering 220 square degrees of the galactic plane and SAGE (Meixner et al. 2006), mapping a 50 square degrees area centered on the Large Magellanic Cloud, are already available. The four IRAC channels operating at 3.6, 4.5, 5.8, and $8.0 \mu\text{m}$ allow detection of both photospheric and dust shell emission. The IRAC colors of AGB stars, however, are not very well known.

AGB stars have numerous molecular absorption features in the spectral region covered by the IRAC photometric system (Waters et al. 1999), as demonstrated by observations with the Short Wavelength Spectrometer (SWS, Valentijn et al. 1996) aboard the *Infrared Space Observatory* (ISO). Features seen include H_2O , SiO , CO_2 , CO , and silicates in stars with atmospheric C/O ratio <1 , while C_2H_2 , HCN , CS , C_3 , and carbonaceous dust (SiC and amorphous carbon) have

been found in carbon stars, which have $C/O > 1$. The presence and strength of these spectral features depends on the chemistry of the stellar atmosphere (Sloan et al. 1998; Sloan & Price 1998) and the mass loss rate. The features can also change with time (Onaka et al. 2002) because AGB stars are long period variables of Mira, semi-regular, or irregular type.

As a result of these dust and molecular features, the IRAC colors of AGB stars can be quite different from the “reddened photospheres” that one would expect for mass losing giants of late spectral type. There is a need, in order to efficiently identify AGB stars among other red objects, for accurate measurements of IRAC colors of AGB stars. For this reason, we have started a program to observe a sample of nearby AGB stars with IRAC as part of Cycle-3 Guaranteed Time Observations (GTO). The program is in progress, and we present here the first results.

2. IRAC AGB Colors from ISO SWS and Models

As a first step in deriving IRAC colors for AGB stars, we computed synthetic colors for 87 O-rich AGB stars, 27 carbon stars, 8 S-stars, and 23 M-type supergiants (lists from Sloan & Price 1998; Sloan et al. 1998) by convolving their ISO SWS spectra with the IRAC bandpasses. We obtained the ISO spectra (212 in total, with some stars observed in multiple epochs) from Sloan et al. (2003) and the IRAC transmission profile from the *Spitzer* Science Center web site¹.

The distribution of the sources on two IRAC color-color diagrams is shown in Figure 1:

1. Sources with larger mass loss, as expected, have a larger infrared excess, especially in the $[3.6] - [8.0]$ color that is the most sensitive to the overall slope of the spectrum.
2. IRAC colors are not sensitive to the detailed dust composition because even the longest passband, centered around $8.0 \mu\text{m}$, only marginally includes the $10 \mu\text{m}$ silicate feature.
3. Carbon stars tend to have redder $[3.6] - [4.5]$ colors than O-rich stars having the same infrared excess. This is due to very strong C_2H_2 and HCN absorption within the $3.6 \mu\text{m}$ band in carbon stars and broad CO_2 and SiO absorption features in the $4.5 \mu\text{m}$ band in O-rich stars.
4. There is a population of carbon stars with very blue (-0.5 magnitudes below the model tracks) $[4.5] - [5.8]$ color due to strong C_3 absorption at $5.8 \mu\text{m}$. This feature is transient, as some sources observed by ISO at multiple epochs have this anomalous color only at some pulsation phases.
5. S-stars and M-type supergiants tend to have colors very similar to the colors of M-type AGB stars.

¹http://ssc.spitzer.caltech.edu/irac/spectral_response.html

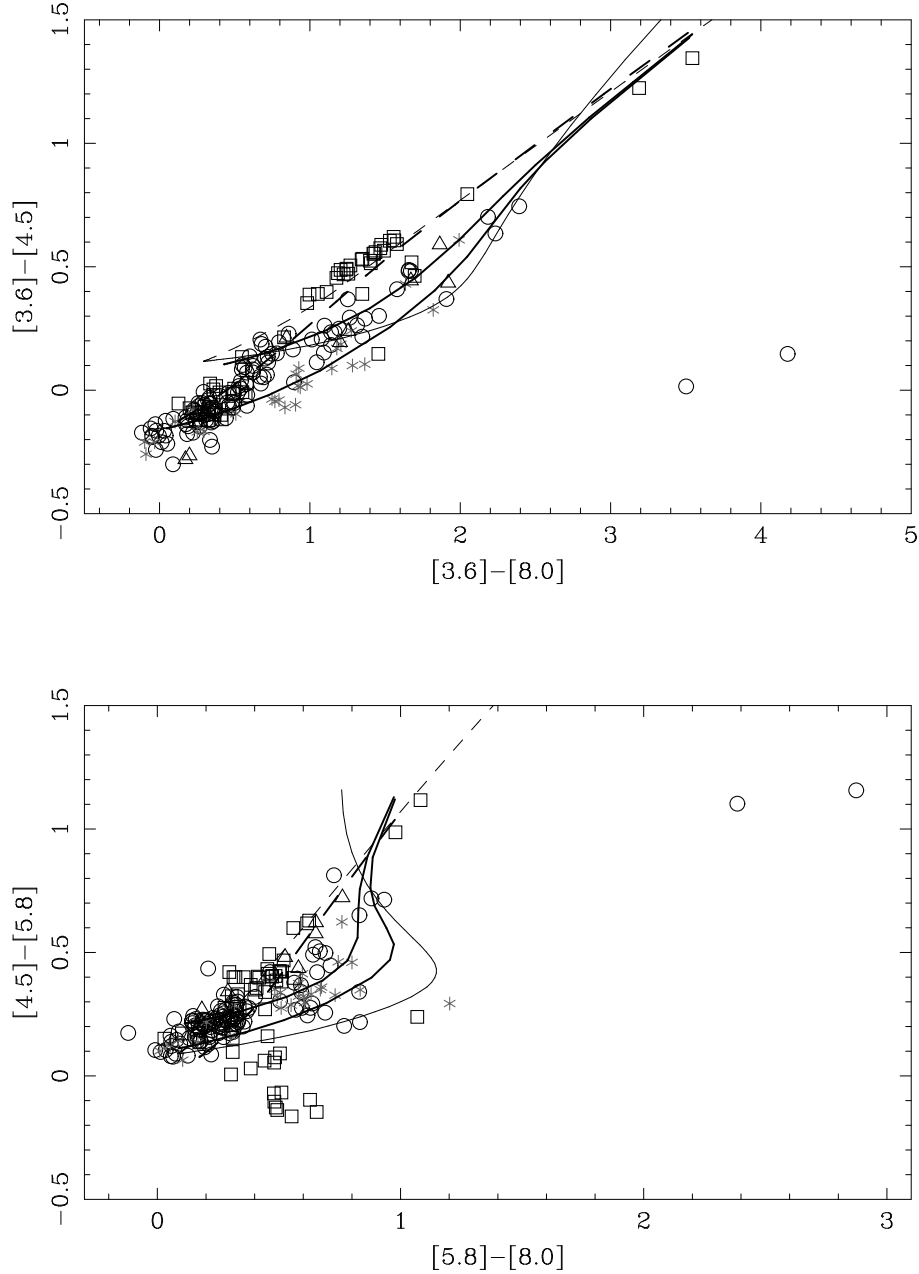


Figure 1. IRAC synthetic color-color diagrams of O-rich AGB stars (circles), carbon stars (squares), S-stars (triangles), and M-type supergiants (asterisks) derived from ISO SWS spectra. The tracks are models of circumstellar envelopes with silicate (solid lines) and amorphous carbon (dashed lines) dust. Thin lines are DUSTY models using a black body as central source, and the thick lines are models computed by Groenewegen (2006) using realistic stellar atmosphere models. The two O-rich outliers are two-epoch measurements of V354 Lac, an AGB star with a very thick envelope.

Figure 1 also shows the tracks of simple radiative transfer models in the IRAC colors. The DUSTY² models, which use a cool black body for the spectrum of the central source, cannot fit the colors of sources with little or no infrared excess because the models are missing the molecular features responsible for blue IRAC colors. The models computed by Groenewegen (2006) using realistic spectra for the central AGB star fit the data much better. On the whole, the model tracks intercept the synthetic colors for most of the sources with the exception of the carbon stars that show strong C₃ absorption features.

3. The *Spitzer*/IRAC GTO Program

The nearby AGB stars selected for IRAC observations are ones for which accurate parallax or interferometric distances and reliable determinations of their mass loss rates are available. The observations target 22 O-rich stars, 7 intrinsic S-stars, 19 carbon stars, and 4 M-type supergiants. The supergiants have been added as a comparison sample of mass-losing stars outside the AGB. The mass loss rates of our target stars range from 10^{-8} to 10^{-4} M_{\odot}/yr in each category (Guandalini et al. 2006). The sample contains Mira, semi-regular, and irregular variables.

The goal of the program is to measure accurate IRAC photometry for all stars in the sample in order to validate and cross-calibrate the ISO SWS spectra for this class of sources. This is particularly important because the absolute photometric calibration of IRAC is based mainly on A-type primary calibrators (Reach et al. 2005) and because of the uncertainties in the ISO SWS absolute calibration resulting from the splicing of the different spectral segments. Each star will be observed in two epochs two months apart in order to evaluate the change in color at different variability phases. (The timing of the observations is constrained by the orbit of the spacecraft).

Nearby AGB stars are of course among the brightest objects in the infrared sky. This makes the IRAC photometry very difficult because all sources will be heavily saturated even with the shortest available frame times. To solve this problem, we have developed a technique to derive the Vega magnitudes of saturated stars by fitting the low level features of the saturated PSF (diffraction spikes and PSF wings) with a model of the IRAC PSF derived from a sample of bright stars (Marengo et al. 2006). Figure 2 shows the $4.5 \mu\text{m}$ image of SZ Car (SRb carbon star), one of the first objects observed in our program, before and after PSF subtraction. The stability of the *Spitzer* optical system allowed us to create a very accurate model of the IRAC PSF. The PSF is directly normalized to the actual image of Vega, which is one of the stars used in its construction. By fitting the observed saturated sources with this PSF, we can derive their magnitudes with an accuracy within 1 – 3% independently of the standard IRAC flux calibration (Schuster, Marengo & Patten 2006).

The program is in progress. As of 2006 November, 33 stars have been observed in their first epoch. Preliminary results show that the photometry is consistent with the synthetic colors derived from ISO SWS. The program will

²<http://www.pa.uky.edu/~moshe/dusty>

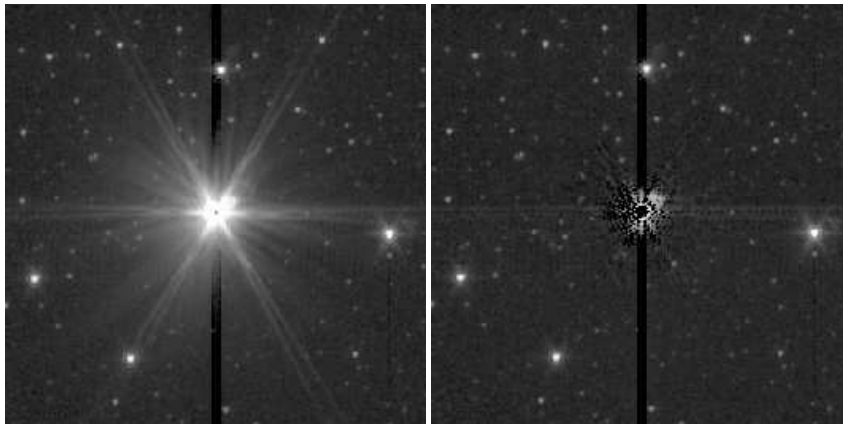


Figure 2. IRAC 4.5 μm image of SZ Car (SRb carbon star with $m_{[4.5]} = 1.18$). Left panel is the mosaic resulting from the co-addition of 5 individual 2-second frame time exposures. The saturated star occupies almost all the IRAC field of view (5×5 arcmin). The right panel shows the same image after PSF subtraction. The PSF fitting determines the magnitude of the AGB star with an accuracy of 1 – 3% in flux.

be completed within one year, after which we will release the complete catalog to the community.

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