Infrared Excess Emission From Asymptotic Giant Branch Stars in the Large Magellanic Cloud


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Abstract

We present empirical relations for infrared (IR) excess emission from evolved stars to the Large Magellanic Cloud (LMC) using data from the Spitzer Space Telescope SAGE (Surveying the Agents of a Galaxy’s Evolution) survey. Combined with the 2MASS survey and the optical Magellanic Cloud Photometry Survey (MCPS) catalog, these data enable multiband analysis of evolved stars, and can help probe the life cycle of dust in the LMC. Outflows from evolved asymptotic giant branch (AGB) stars and supergiants are the main producers of dust in a galaxy, and the aim of this work is to investigate the mass loss return by AGBs and supergiants to the interstellar medium (ISM) of the LMC. The spectral energy distributions (SEDs) of these stars are compared with plane-parallel (for carbon-rich AGBs) and spherical (for oxygen-rich AGBs) photosphere models to obtain the excess flux in the 8 and 24 μm bands, which is plotted against the total integrated flux. We show that this excess emission increases with total integrated flux, and that the 24 μm flux for heavily obscured AGNs is entirely due to excess emission from dust.

AGB mass loss and IR excess

Mass loss from AGB stars results in the formation of circumstellar envelopes (CSEs) that can efficiently absorb visible light from the central source. The subsequent re-emission of radiation is seen as an emission in the IR in excess of that expected from the star itself. Since the observed IR excess is a direct result of the mass-loss process, we expect it to increase with increasing central star luminosity (and hence increase injection pressure, which can drive the mass loss).

The SAGE survey of the LMC (Meixner et al. 2008) offers an ideal database for the study of AGB mass loss. In this work, we use stellar photosphere models to estimate the IR excess and the color temperature and optical depth of the circumstellar dust around AGB stars, and study the relationship between these quantities and the integrated luminosity. We also estimate the total rate of injection of processed matter into the ISM of the LMC.

The Sample

Based on their locations in different color-magnitude diagrams (CMDs), we identify carbon-rich and oxygen-rich (2MASS J-band and Ks colors, Blum et al. 2008) and heavily obscured ("extreme") AGB candidates (2MASS-IRAC and IRAC-IRAC colors, Blum et al. 2008) in the SAGE Epoch 1 Archive (Meixner et al. 2006). Our dataset consists of about 9000 C-rich, 35000 O-rich, and 1550 extreme AGBs. The figure above, from Blum et al. 2008, shows the location of these sources on a J vs. J-[3.6] CMD. The second figure shows an [3.6] vs [8.0]-[24] CMD for the three types of AGB sources. Blum et al. (2006) noted that the appearance of a faint, redder population of O-rich sources in the SAGE sample. We distinguish between the bright and faint populations with a magnitude cut at [8.0]=10.2 (x axis in the figure). The faint population makes up ~60% of our O-rich sources.

Computing The Excesses

Since we concentrate on obtaining general trends, a single model is used for all sources of one kind, instead of fitting a model to each source. The model that best fits the median SED for the blue/foreground sources (which are expected to have little or no excess) is used for this purpose. The model fluxes are then fitted to the optical UBVI, 2MASS JHKs, IRAC and MIPS filter response profiles. The resulting synthetic photometric fluxes are scaled to the flux of each source at the pivot band wavelength (the 2MASS H band) and the flux of the source in excess of the scaled model flux in each band is calculated. For the extreme AGB stars, the excess is taken to be equal to the flux in that band. An excess is considered to be "reliable" only if it is above a threshold of 3σ.

We calculate integrated luminosities and we also use the excesses to estimate the color temperature and the optical depth of the circumstellar dust.

Results: Excess

We find that the IR excess increases with luminosity in all four IRAC bands and the MIPS24 band for all three types of sources. The plot below shows the variation of the 8 μm excess for C-rich sources with luminosity (the light and dark gray circles correspond to the faint and bright populations, respectively). There is a large scatter in the trend, partly due to the fact that the variability has not been taken into account. These relations hint towards a similar rise of mass-loss rate with luminosity on the AGB.

Results: Dust Temperature and Optical Depth

We also find an increase in the [8]-[24] color temperature accompanied by a corresponding increase in the 24 μm optical depth. The calculated optical depths for all three types of sources rise with excess. Both these results are consistent with increasing MLR resulting in progressively higher obscuration of the central source. The plots below show these variations for O-rich sources. The dark and light gray circles correspond to the faint and bright populations respectively, indicating that the faint population consists of cooler, optically thinner CSEs.

Results: Total Injection Rate

By fitting a linear relationship to the mass-loss rates calculated for bright LMC AGB stars by van Loon et al. (1999) versus their corresponding 8 μm excesses, we are able to plot the relationship for sources with valid excesses and estimate the contribution to the ISM of the LMC as shown in the figure on the right. The injection rate (thick dashed line) from O-rich (thin solid line), C-rich (dashed line) and extreme (dot-dashed line) AGN rates is shown as a function of luminosity. We find that the total injection rate from all AGN stars in our sample is ~ 8 x 10^-3 M_⊙ yr^-1.