Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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Are the silicate crystallinities of oxygen-rich evolved stars related to their mass loss rates?

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Abstract. A sample of 28 oxygen-rich evolved stars is selected based on the presence of crystalline silicate emission features in their ISO/SWS spectra. The crystallinity, measured as the flux fraction of crystalline silicate features, is found not to be related to mass loss rate that is derived from fitting the spectral energy distribution.

1. Introduction

Crystalline silicates are identified through a series of sharp spectral lines between 10-70 micron by the ISO and Spitzer space observations (Henning 2010). They are detected in various types of objects, from solar system objects – comets, to pre-main sequence stars, evolved stars and distant quasars. The spectral features of crystalline silicates are detected in every stage of evolved stars: AGB stars, post-AGB stars and planetary nebulae (e.g. Jiang *et al.* 2013). The degree of crystallinity, i.e. the mass percentage of crystalline silicate in all silicate dust, is found to range from a few percent to $>90\%$. What determines crystallinity has long been debated (Liu & Jiang 2014). Mass loss rate is thought to be an important factor. Theoretical calculations have shown that amorphous silicates cannot be crystallized in stars of low mass loss rate because the dust cannot be heated to temperatures high enough for crystallization, and that crystalline silicates can only be formed in stars undergoing substantial mass-loss with a critical value of $\dot{M} > 10^{-5}\,M_\odot\,yr^{-1}$ and having high dust column densities (e.g. Gail *et al.* 1999). Jones *et al.* (2012) analyzed the Spitzer/IRS spectra of 315 evolved stars and found that the mass-loss rates of the stars exhibiting the crystalline silicate features at 23, 28 and 33 μm span over 3 dex, down to $10^{-9}\,M_\odot\,yr^{-1}$. They investigated the possible correlation between $\dot{M}$ and the silicate crystallinity by examining the relation of $\dot{M}$ with the strengths of the 23, 28 and 33 μm features measured by their equivalent widths, but found no correlation. Kemper *et al.* (2001) performed an extensive radiative transfer calculation of the model IR emission spectra for O-rich AGB stars of mass-loss rates ranging from $10^{-7}\,M_\odot\,yr^{-1}$ to $10^{-4}\,M_\odot\,yr^{-1}$ and of a wide range of crystallinities up to 40 percent. They also found that crystallinity is not necessarily a function of mass-loss rate.

2. Data and method

We selected a sample of nearby 28 oxygen-rich evolved stars (mainly AGB stars and red supergiants) which show prominent spectral features of crystalline silicate as well as amorphous silicate in their ISO spectra. The mass loss rate is calculated by fitting the spectral energy distribution from (ultraviolet-)optical to far-infrared based on the

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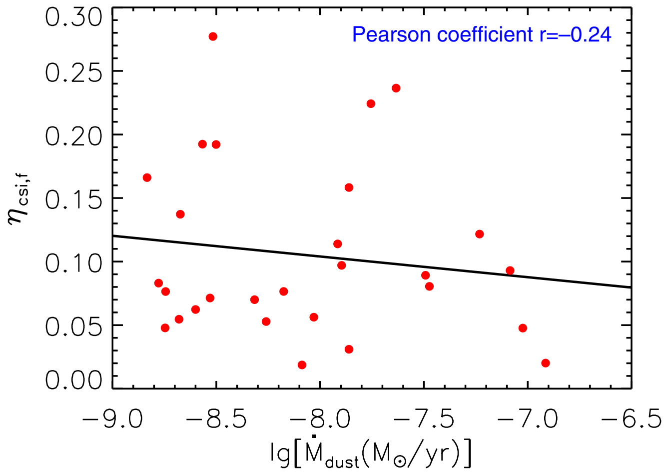

Figure 1. Relation between mass loss rates and silicate crystallinities of O-rich evolved stars.

photometry in the UBVRI, 2MASS/JHK, WISE and IRAS bands. The '2-DUST' radiative transfer code (Ueta & Meixner 2003) is used to derive the mass loss rate and other stellar and circumstellar parameters.

The silicate crystallinity ($\eta_{\rm csi,f}$) is characterized with the flux ratio of the emission features of crystalline silicates to that of all (crystalline + amorphous) silicates. This measure of crystallinity differs from the common measure of the mass ratio of crystalline to total silicate. The calculation of silicate mass suffers generally significant uncertainties from dust temperature in addition to the opacity since the species is not clearly identified. The flux ratio would represent the mass ratio if the UV/V/IR opacities of crystalline and amorphous silicates are comparable. The flux of crystalline and amorphous silicate is calculated with the PAHFIT code by decomposing the ISO spectrum into continuum and spectral features of amorphous and crystalline silicate.

3. Result

The derived mass loss rate and crystallinity have a Pearson correlation coefficient of -0.24 (Figure 1), which indicates that the silicate crystallinities and the mass-loss rates of these oxygen-rich evolved stars are not correlated (Liu *et al.* 2017). A further check also found no relation of crystallinity with stellar luminosity or effective temperature.

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