Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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Measuring spatially resolved gas-to-dust ratios in AGB stars

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Abstract. Gas-to-dust ratios in Asymptotic Giant Branch (AGB) stars are used to calculate gas masses from measured dust masses and vice versa, but can vary widely and are rarely directly measured. In this work, we present spatially resolved gas and dust masses for a sample of 8 nearby AGB stars, using JCMT CO-line and continuum observations, and compare them. This serves as a pilot study for the Nearby Evolved Stars Survey (NESS; PI: P. Scicluna) project which will provide similar observations of $\sim$ 400 AGB stars in a volume-limited sample.

Keywords. stars: AGB and post-AGB, stars: mass loss, (stars:) circumstellar matter

1. Background

AGB stars form significant circumstellar envelopes of gas and dust, and the gas-to-dust ratio across the envelope carries vital information about, e.g., the dust-condensation efficiency. A canonical value of 100 or 200 is often used for Galactic stars. Knapp (1985) measured gas-to-dust ratios in Galactic evolved stars – finding ratios around 160 for O-rich stars, and 400 for C-rich stars – which remains the only direct measurement of this ratio for evolved stars in the Solar Neighbourhood. The Nearby Evolved Stars Survey (NESS; PI: P. Scicluna) project will provide CO and continuum observations of $\sim$ 400 AGB stars within 2 kpc. The statistical robustness of a volume-limited sample will allow us to address a range of questions about mass return to the Galactic ISM and the physics of mass loss from evolved stars, including direct determination of the gas-to-dust ratio. Mapping of a subsample of the closest sources allows the determination of spatially resolved gas-to-dust ratios and an investigation of changes in mass-loss over time.

2. Data analysis

We have used JCMT jiggle maps of CO 3–2 (with HARP) and 850 μm continuum (with SCUBA-2) emission on an initial sample of 8 nearby AGB stars from the NESS sample. Azimuthal averaging of the surface brightness was used to create radial profiles, assuming the circumstellar envelopes are spherically symmetric. From these radial profiles we subtracted the telescope PSF (beam $\sim 14''$) profiles to quantify the amount of extended emission. The continuum results are taken from Dharmawardena *et al.* (2018) who use SED fitting (70 – 850 μm) at each radial point to find a dust surface density and then integrate over a given annulus to find a dust mass. We get a crude estimate of the gas masses by integrating the CO emission within the PSF and using the empirical formula from Ramstedt *et al.* (2008) to calculate a central mass-loss rate, which is then multiplied by the spatial extent of the PSF and the expansion velocity to get a central

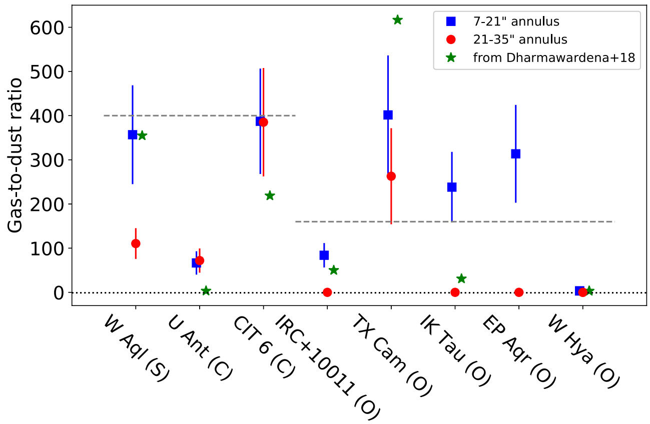

Figure 1. Gas-to-dust ratios integrated over radial annuli for each source, with uncertainties from the dust masses from Dharmawardena *et al.* (2018) plus 30%. Canonical values from Knapp (1985) are shown with grey dashed lines.

gas mass. This $I_{CO} - M_{gas}$ relation for each source is applied to the extended emission, integrated in beam-width annuli, to estimate the extended gas masses.

3. Results

Across our sample, the median dust extent is 1.5 times larger than the CO extent, and a median of 50% of the 850 μm flux and 30% of the CO flux is in the extended component. The gas-to-dust ratios are shown in Fig. 1, calculated in integrated annuli from 7–21$''$ and 21–35$''$. Most sources have smaller gas-to-dust ratios in the outer annuli, consistent with the smaller gas extent which is likely due to a decrease in temperature leading to less efficient CO 3–2 emission, or CO dissociation by the interstellar radiation field. However, we see some distinction between chemical types: the two C-rich AGB stars, U Ant and CIT 6, show no decline in the gas-to-dust ratio. Furthermore, our sources do not seem to follow the overall gas-to-dust ratios found by Knapp (1985), which are indicated by grey dashed lines in Fig. 1. Also plotted are the gas-to-dust ratios calculated for the entire envelope by Dharmawardena *et al.* (2018), based on their continuum observations and CO modeling from De Beck *et al.* (2010). These total gas-to-dust ratios can vary significantly from our measurements, showing the importance of spatially resolving the emission and measuring both gas and dust.

4. Further work

We will model the CO maps with the 1D radiative transfer code MLINE (Kemper *et al.* 2003) to better constrain gas masses, and eventually extend our analysis to the full NESS sample. Proposed follow-up interferometric observations will resolve both CO and continuum emission, revealing detailed variations in the historic gas and dust mass-loss and gas-to-dust ratio for both individual sources and a statistical sample of AGB stars.

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