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Statistical properties of cold circumstellar envelops observed in NESS–NRO

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Abstract. We conducted CO J=1→0 emission line observations for nearby AGB stars using the Nobeyama 45 m telescope. Comparing our results with those from CO J=3→2 observations with JCMT, the circumstellar envelopes observed in CO J=1→0 look more extended than J=3→2. Thus, we could trace the outer, cold parts of the envelopes. We also found four stars in which the CO/^{13}CO ratio changes dramatically outward, but the change implies the effect of selective photodissociation by interstellar ultraviolet radiation, not the third dredge up in the stellar interior. We moreover found two unique stars with aspherical envelope morphology.

Keywords. stars: AGB and post-AGB, stars: mass loss, stars: winds, outflows, stars: carbon

1. Introduction

The asymptotic giant branch (AGB) represents the final stage in the evolution of low- and intermediate-mass stars. Inside the AGB stars, carbon is dredged up from the vicinity of the central core to the stellar surface by the convection (Third Dredge Up (TDU)) caused by thermal pulses (TPs, e.g. Herwig 2005). This repeated TDU process gradually changes the C/^{13}C abundance ratio in the circumstellar envelopes (CSEs). The issues of this TDU process are its efficiency and the mechanism determining the stellar mass-loss rate (MLR). Because the MLR is enhanced by TP, a detached shell-like gas (and dust) distribution with high C/^{13}C ratio is formed in CSEs (e.g. Olofsson et al. 1990). Therefore, these issues are expected to be constrained by determining the CO/^{13}CO ratio over the entire CSEs.

The Nearby Evolved Stars Survey (NESS) project addresses several issues with a volume-complete sample of ∼850 evolved stars within 3 kpc (Scicluna et al. 2022). These stars have been observed in the CO J= 2→1 and 3→2 emission lines, and the sub-mm continuum mainly using the James Clerk Maxwell Telescope (JCMT). In addition, we have conducted staring and mapping observations in CO J= 1→0 emission using the 45 m radio telescope of the Nobeyama Radio Observatory (NRO) to reveal more extended cold gas distribution.

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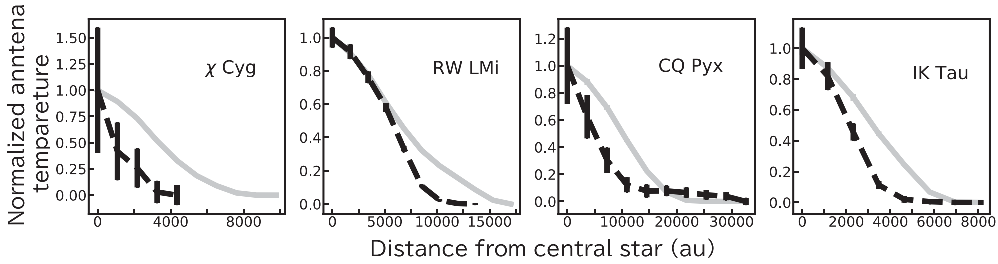

Figure 1. Radial profiles in CO and ^{13}CO J=1→0 emission lines for 4 stars with ^{13}CO intensity decreasing against CO intensity. Grey solid and black dashed lines show CO and ^{13}CO emission lines, respectively.

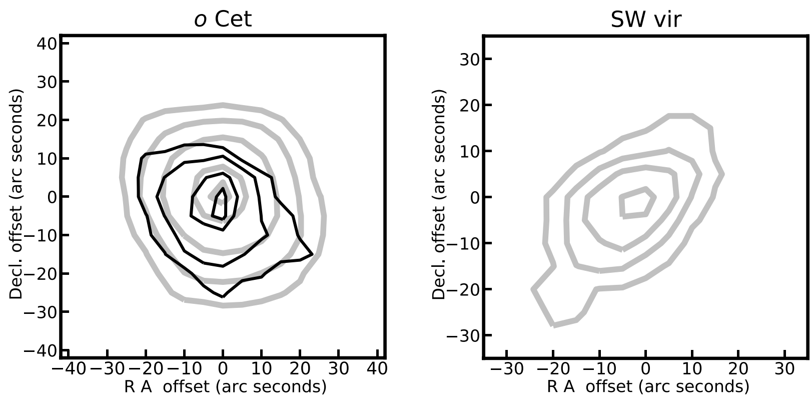

Figure 2. Velocity integrated maps of o Cet (left panel) and SW Vir (right panel). Grey and black lines show the CO and ^{13}CO emission line, respectively. Contour levels in CO and ^{13}CO are peak flux times (10, 20, 40, 80, 95) and (20, 40, 80, 95) in o Cet, (10, 40, 70, 95) in SW Vir.

2. Results of NESS–NRO

We carried out staring observations for 212 stars, and detected CO and ^{13}CO emission lines in 96 and 34 stars, respectively. For the stars detected in CO emission, MLR has been derived from the CO line profile, and the ranged from 10^{-9} to 10^{-5} $M_\odot$ yr^{-1}. However, it would be underestimated taking into account the derived MLR/dust-production rate ratio that is ∼5 times smaller than previously derived (Knapp 1985). This small ratio suggests that the beam could not cover the whole CSEs with the beam of the NESS–NRO observations smaller than those CSEs.

We conducted mapping observations for 27 stars, and detected CO and ^{13}CO emission towards 19 and 10 stars, respectively. Comparing the angular sizes of CSEs observed in the CO J=1→0 emission using NRO with those in the CO J=3→2 emission using JCMT (Scicluna et al. 2022), the CO J=1→0 appears to be 2–3 times more extended than the J=3→2 towards all the stars so as to trace outer, cold parts of the envelopes.

Through the radial profiles of the CO and ^{13}CO J=1→0 emission in the CSEs of 10 stars, we found four stars towards which the ^{13}CO intensity, or the CO/^{13}CO intensity ratio, decreases dramatically against the CO intensity outward (see Figure 1). This implies no evidence for TPs or TDUs within recent 2000–7000 yr when developing the present envelope. Note that the radial change in the intensity ratio is caused by a decrease in the ^{13}CO rather than the CO intensity. This suggests the effect of selective photodissociation for CO molecules by intersteller ultraviolet radiation (e.g. Saberi et al. 2020).

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We also found asymmetry in the CSEs of SW Vir and o Cet (see Figure 2). The CSE of o Cet appears to be formed aspherically by a bipor outflow and the selective photodissociation. However, the energy origin forming the SW Vir's CSE is still unclear.

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