UNRAVELING MYSTERIES IN LATE STAGES OF STELLAR EVOLUTION: THE ENIGMA OF THE S-TYPE STARS

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Abstract. We report the results of an ongoing survey of S stars within 1 kpc of the Sun for emission from the $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ lines of CO. We derive mass loss rates from the CO emission and compare with other estimates. We find that S stars are losing copious amounts of mass at rates comparable to that of the carbon stars. There are indications that the gas-to-dust ratio is *higher* than for carbon stars. To aid in determining the evolutionary status of the S-type stars, we are also searching the brightest CO stars for $J = 1 \rightarrow 0$ HCN and $J = 2 \rightarrow 1$, $v = 0$ SiO emission. We use our results to estimate the chemical composition of the circumstellar envelopes. Comparison is made with thermodynamic equilibrium models for the formation of these and other species under photospheric conditions.

1. Introduction

Nearly seventy-three years ago a new spectral type called S was added to the Harvard system of spectral classification (Merrill 1922). At the time little was known about these unusual stars. Recently, the situation has been improving. Today we have the tools required to address some of the fundamental properties of the S-type stars.

S stars are a relatively rare class of luminous red giants undergoing evolution along the asymptotic giant branch (AGB). (We consider here

only the "intrinsic" S stars, not the "extrinsic" S stars whose abundances are believed to have been altered by mass transfer effects – cf. Jorissen and Mayor 1992.) Their distinguishing features are a C/O abundance ratio which is unity (to within 5%); and evidence of strong enrichment in s-process elements. Together these properties suggest that the S stars have undergone mixing of the products of nucleosynthesis from the interior to the photosphere. They might be transition objects between the O-rich M giants, with C/O < 1, and the carbon stars, with C/O > 1. If so, their rarity could indicate a short timescale during which the surface C/O ratio switches from O-rich to C-rich. The details of how this transition occurs, or even if it occurs has been the subject of much debate.

We have undertaken a program to survey as completely as possible the the nearest S-type stars for their mass-loss and chemical properties using single-dish and interferometric techniques. The first results of this work have been reported (Bieging & Latter 1994). A study of CO emission and mass-loss from S stars has been presented by Sahai & Liechti (1995). Dust properties have been studied by Chen & Kwok (1993) and Skinner et al. (1990).

2. The study

The goals of our initial survey (Bieging & Latter 1994), and our continued study is 1) to determine the time-averaged mass-loss rates for a complete sample of S stars within 1 kpc of the Sun, by observing emission from the CO molecule as a mass-loss tracer; and 2) to use observations of key molecular species, namely HCN and SiO, as indicators of the C/O ratio in the present envelope gas in order to constrain the possible evolutionary sequence of the surface C/O abundance for the detected stars. To achieve these goals, we are combining data from the NRAO 12-m, SEST, and BIMA.

Chemical models of AGB envelopes with C/O ≈ 1 are also being developed. Currently, our models only assume photospheric-type conditions (local thermodynamic equilibrium), which is where formation of HCN and SiO is believed to occur. These calculations indicate that HCN and SiO abundances are extremely sensitive to the C/O ratio (see, for example, Fig. 9 of Bieging & Latter 1994).

Our observational results so far suggest that S star circumstellar envelopes have abundances consistent with a chemistry at photospheric densities, C/O ≈ 1, and gas temperatures $T_{\rm gas} < 1500$ K. Also, the S stars detected appear to have been losing mass for timescales $\tau > 10^4$ years. There is evidence that S stars have a "dust deficit" in that the typical gas-to-dust ratio is ~ 2 times larger than the typical gas-to-dust ratio found

for carbon stars (see also Sahai & Liechti 1995).

3. Implications

The results obtained have several important implications to understanding the evolution of AGB stars in general and suggest further study –

• S stars have been identified as such by observations of photospheric abundances. This means that no fully enshrouded S stars are known. Yet, measured mass loss rates are comparable to the carbon stars, implying heavily obscured objects could exist. If fully enshrouded S stars are present, then they can be identified by observations of both HCN and SiO.

• Observations and modeling show that the chemistry within S star envelopes is extremely sensitive to the C/O ratio. This can give insight into dust formation and other fundamental chemical problems.

• Of key importance is the evolutionary status of the S stars. Are they in transition to C-rich, or are they a stable phase in the evolution of some AGB stars? Molecular abundances found in the envelopes of S stars are consistent with those observed at the photosphere, implying that the S star phase is long-lived and might be the terminal phase of their AGB evolution.

Further studies are required to fully understand the status of S stars in AGB evolution, and are being conducted or planned. These include interferometric mapping of key molecular species in the nearest S star envelopes. Improving the size of the single-dish sample, especially the HCN and SiO detections, is necessary to complete the statistical analysis. Modeling of the molecular and dust contents in circumstellar envelopes with C/O ≈ 1 is required to fully understand the observations.

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References

Bieging, J. H., & Latter, W. B. 1994, ApJ, 422, 765
Chen, P.S., & Kwok, S. 1993, ApJ, 416, 769
Jorissen, A., & Mayor, M. 1992, A&A, 260, 115
Merrill, P. 1922, ApJ, 56, 457
Sahai, R., & Liechti, S. 1995, A&A, 293, 198
Skinner, C. J., Griffin, I., & Whitmore, B. 1990, MNRAS, 243, 78