Lithium in the symbiotic Mira V407 Cyg

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ABSTRACT

We report an identification of the lithium resonance doublet LiI 6708Å in the spectrum of V407 Cyg, a symbiotic Mira with a pulsation period of about 745 days. The resolution of the spectra used was $R = \lambda/\Delta\lambda \approx 18500$ and the measured equivalent width of the line is $\sim 0.34$ Å. It is suggested that the lithium enrichment is due to hot bottom burning in the intermediate mass AGB variable, although other possible origins cannot be totally ruled out. In contrast to lithium-rich AGB stars in the Magellanic Clouds, ZrO 5551Å, 6474Å absorption bands were not found in the spectrum of V407 Cyg. These are the bands used to classify the S-type stars at low-resolution. Although we identified weak ZrO 5718Å, 6412Å these are not visible in the low-resolution spectra, and we therefore classify the Mira in V407 Cyg as an M type. This, together with other published work, suggests lithium enrichment can precede the third dredge up of s-process enriched material in galactic AGB stars.

Key words: Stars: AGB and post-AGB – Stars: variable – (stars:) binaries: symbiotic – stars: individual: V407 Cyg – stars: chemically peculiar

1 INTRODUCTION
1.1 Lithium in AGB stars

Lithium is one of the key elements related to stellar evolution and thermonuclear synthesis. It is both easily destroyed and easily produced at the temperatures found in stellar interiors. Lithium undergoes nuclear burning at temperatures above about $2.5 \times 10^6$ K and primordial lithium is therefore destroyed in the convective atmospheres of late-type giants. Fresh lithium can be produced and brought to the surface of AGB stars via the beryllium transport mechanism proposed by Cameron & Fowler (1971). While the detailed determination of lithium abundances in AGB star atmospheres is difficult, due to heavy line blanketing and non-LTE effects, AGB stars with unusually high abundances of lithium (lithium rich $\log \epsilon(\text{Li}) > 1.0$ and super lithium rich (SLR) $\log \epsilon(\text{Li}) > 4.0$ stars) are known both in the Galaxy and in the Magellanic Clouds; although the two environments seem to produce lithium enrichment in different types of AGB star (see below).

In the Magellanic Clouds Smith et al. (1995) found 35 lithium-rich stars. The majority of these are S-type stars while a small fraction are C stars; the paucity of C-type SLR stars in the LMC compared to the Galaxy was recently confirmed by Hatzidimitriou et al. (2003). Most of the lithium-rich stars in the Magellanic Clouds lie in the luminosity range $-6 > M_{bol} > -7$ mag and their enrichment can be explained as a consequence of hot bottom burning (HBB), in stars with initial masses of $4 < M_\odot < 6$, as described by Sackmann & Boothroyd (1992). These SLR stars have rather thin dust shells (possibly a selection effect) and those which are also large amplitude variables have periods over 400 days and are more luminous than the Mira period-luminosity relation would predict (Whitelock et al. 2003).

A rather small number of SLR S (e.g. RZ Sgr, T Sgr, VX Aql, He 166) and C (e.g. T Ara, IY Hya, WZ Cass, WX Cyg) stars are known in the Galaxy, a much larger fraction of them being C stars than in the Magellanic Clouds and some are J-type C stars (i.e. they have high $^{13}\text{C}/^{12}\text{C}$); see Catchpole & Feast (1971,1976) and Abia et al. (1991). The distances, and therefore the luminosities, of these galactic SLR stars are uncertain, but the evidence favours their evolving from lower mass progenitors than those of the HBB stars in the Magellanic Clouds. Abia & Isern (2000) discuss possible mechanisms for mixing lithium to the surface in low mass stars, but a full explanation for their enrichment remains elusive.

García-Lario et al. (1999) have reported preliminary results from a lithium survey of IRAS selected AGB variables which shows that lithium is preferentially found in stars with long periods, $P > 400$ d, large expansion velocities, $V > 6 \text{ km s}^{-1}$, and relatively thin dust shells, $[12] - [25] < 0$ (although this is largely a selection effect as most of those with thicker shells could not be observed spectroscopically). Furthermore these are all oxygen-rich, although not S-type stars, and could be related to the HBB stars in the Magellanic Clouds. However, insufficient information is presented to judge their luminosities and or the level of their lithium enrichment.

Lithium is also found in the close binary systems HD 172481 and HD 190390 (Reyniers 2002) where its origin is not understood.
In this note we report on the LiI 6708 Å doublet identification in the spectrum of the symbiotic Mira V407 Cyg.

1.2 Symbiotic Miras

The symbiotic Miras are binary systems in which an asymptotic giant branch variable interacts with a white dwarf; these are rare objects, fewer than 28 are known in the Galaxy and LMC (Whitelock 1987, 2003). The AGB star loses mass to the white dwarf via its stellar wind, while a circumbinary nebulae reaches ionization levels comparable to those found in planetary nebulae. Their binary periods are assumed to be long, in excess of 10 years, while the pulsation periods of the AGB stars range from 275 to 745 days.

V407 Cyg was identified as symbiotic Mira by Munari, Margoni & Stagni (1990); at 745 days its pulsation period is the longest known in a symbiotic Mira. Most symbiotic Miras suffer from strong and variable circumstellar extinction. V407 Cyg is an exception, it has surprisingly low circumstellar extinction given its long period and symbiotic character. According to the intensity of the TiO 7055 Å band the Mira can be classified as M6-M7. VO absorption bands are also present in its spectrum. Therefore the cool component of V407 Cyg is oxygen-rich (Kolotilov et al. 1998).

Note that if we accept that the late-type giant in V407 Cyg is a Mira variable then we must also accept that it is an AGB star. Mira variables obey a period-luminosity relation (e.g. Whitelock et al. 2003 and references therein) and even the short period Miras, found in globular clusters, have luminosities above the tip of the first giant branch (e.g. Feast & Whitelock 1987).

The kinematics of AGB variables shows that their pulsation periods are a function of the population to which they belong, with longer period stars being younger (e.g. Feast & Whitelock 2000). Not much is known about stars with periods over 700 days, but periods are a function of the population to which they belong, with first giant branch variable interacting with a white dwarf; these are rare objects, fewer than 28 are known in the Galaxy and LMC (Whitelock 1987, 2003). The AGB star loses mass to the white dwarf via its stellar wind, while a circumbinary nebulae reaches ionization levels comparable to those found in planetary nebulae. Their binary periods are assumed to be long, in excess of 10 years, while the pulsation periods of the AGB stars range from 275 to 745 days.

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The region around the LiI 6708 Å line in the spectrum of V407 Cyg obtained on 30 July 1997.

Table 1. Radial velocities for V407 Cyg

| sp.no. | date         | RV(star) | RV(LiI)  | RV(CeII) | Mira phase |
|-------|--------------|----------|----------|----------|------------|
| 25577 | 30 July 97   | −40.7    | −43.7    | −56.5    | 0.120      |
| 32948 | 8 June 99    | −47.1    | −49.9    | −62.7    | 0.030      |
| 37219 | 9 Sept 01    | −38.0    | −40.6    | −53.3    | 0.136      |

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The region around the LiI 6708 Å line in the spectrum of V407 Cyg obtained on 30 July 1997.

2 LITHIUM IDENTIFICATION

High-resolution spectra \( R = \lambda/\Delta \lambda \approx 18500 \) of V407 Cyg have been obtained with the Echelle spectrograph mounted at the Cassegrain focus of the 1.82m telescope which is operated by the Padova and Asiago Astronomical Observatories on Mt. Ekar (Asiago, Italy). The detector was a Thomson THX31156 CCD with 1024×1024 19 µm pixels, and the slit width was set to 1.8 arcsec. The spectra cover the 4500-9000 Å range. The reduction and analysis of the spectra was performed in the standard fashion under IRAF.

Figure 1 illustrates a fraction of the V407 Cyg spectrum around the line we suspect to be lithium. Mindful of the possible confusion of the LiI doublet at 6707.76 Å and 6707.91 Å with CeII (assuming a negligible contribution from \( ^7 \)Li). If, however, the line is identified with CeII the difference in radial velocity with the Mira is 15.6 km s\(^{-1}\). This indicates that the LiI identification is to be preferred over CeII. The absence of any strong s-process lines in the spectrum (see below) also supports this conclusion.

The table shows a constant difference of 3.0 km s\(^{-1}\) between the radial velocity of the Mira and of the line, if the line is produced by the blended \( ^7 \)Li doublet (assuming a negligible contribution from \( ^6 \)Li). If, however, the line is identified with CeII the difference in radial velocity with the Mira is 15.6 km s\(^{-1}\). This indicates that the LiI identification of the line from CeII supports this conclusion.

The equivalent width of LiI 6708 Å is about 0.34 Å, relative to the line-blanked local continuum. This is in the spectrum obtained on 30 July 1997, when the hot component was in an inactive state and the equivalent width of the H\( \alpha \) emission line was only \(~ 3 \) Å. The intensities of the absorption bands TiO 5448 Å and 7125 Å suggest a spectral type of M6-M7. Therefore, it is clear that, at least in this spectral region, the V407 Cyg radiation was dominated by the cool component. On other dates the hot component was in an active state which is reflected in a reduced equivalent width for the lithium line. Although, an intrinsic variability of the lithium line in the Mira atmosphere, depending, for instance, on the pulsation phase, cannot be excluded.

A rough estimate of the abundance of lithium may be obtained from the ratio of the equivalent widths of LiI 6708 Å to Ca I 4227 Å with \( V = −25.8 \) km s\(^{-1}\); a few telluric lines were masked out. The measurements are accurate to about 0.2 km s\(^{-1}\).
A strong lithium LiI 6708 Å line has been identified for the first time in a symbiotic Mira. It is only the second identification of lithium in a Galactic Mira with a period of over 700 days, García-Lario et al. (1999) having already found lithium in an unnamed variable of comparable period.

There are three possible origins for the lithium which are discussed briefly below. First it could have been produced by the hot star when it was on the AGB, and deposited onto the surface during the mass-loss process which left it as a white dwarf. This would require the hot component to have undergone its AGB to white dwarf transition within about 10^4 years of the present epoch; this being the time scale on which the lithium would be destroyed as convection takes surface material close to the high temperature core. This seems much less probable than the alternative explanations explored below.

Secondly, the lithium might have been produced more recently, as a product of the binary interaction, and deposited onto the surface of the AGB star. Arnould & Nørgaard (1975) and Starrfield et al. (1978) predict the formation of large quantities of lithium during hydrogen-burning thermonuclear runaways, and Hernanz et al. (1996) have predicted significant lithium production from some nova models, although it is not at all clear that these calculations will be applicable to symbiotic systems such as V407 Cyg. As mentioned in section 1.1 lithium is detected in binary systems where its presence is not understood.

Thirdly, we suggest that V407 Cyg is actually an intermediate mass star, and that the lithium originates from hot bottom burning, as it does in the long period S-type Miras in the Magellanic Clouds. Although we cannot rule out other mechanisms until our understanding of the production of lithium in galactic low mass AGB stars and in interacting binaries is on a much firmer footing. We also note that, if our explanation is correct, the surface enrichment of lithium apparently precedes the dredge of s-process elements in V407 Cyg as it does for the AGB variables discussed by García-Lario et al. (1999).

This discovery that a significant fraction of long period IRAS Miras are lithium rich, García-Lario et al. (1999), together with finding lithium in an example of the rare class of symbiotic Miras, suggests that surveys for lithium should be extended to more long period variables, both in the Galaxy and in the Magellanic Clouds.

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