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S1242: a lithium-rich subgiant star in the open cluster M 67★

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ABSTRACT

Aims. We report the serendipitous discovery of a lithium-rich subgiant star, S1242. This object is member of a large eccentricity spectroscopic binary system in the solar-age open cluster M 67.
Methods. Using VLT/FLAMES-UVES observations and synthetic spectrum analysis, we derived for this star stellar parameters (temperature, gravity, metallicity and rotational velocity) and a surface Li abundance ($A_{\rm Li}$ = 2.7) larger than the higher abundance of M 67 stars near the turn-off.
Results. The high Li abundance we found in S1242 points to an excess of lithium at the subgiant stage. We discuss two possible explanations for this unusually high Li content in this binary system: a preservation of the Li at the turn-off stage due to tidal effects, or an efficient dredge-up of Li, hidden below the convective zone by atomic diffusion occuring in the post turn-off stage.

Key words. stars: binaries: general – stars: abundances – stars: fundamental parameters – stars: atmospheres – stars: evolution

1. Introduction

The star S1242, following the notation from Sanders (1977), is member of a wide eccentric binary system of the solar-age open cluster M 67, that lies on the subgiant branch. Its evolutionary status is well explained if a subgiant (M_1 = 1.25 $M_\odot$) has a faint ($V > 15$) dwarf companion of lower mass (0.14 $M_\odot < M_2 <$ 0.94 $M_\odot$, see Mathieu et al. 1990). These authors have determined an orbital solution with an eccentricity of 0.66 and an orbital period of 31.8 days. On the basis of observations with the ROSAT PSPC, this star is reported as an X-ray source (Belloni et al. 1998). For this star, chromospheric activity has been detected from emission features in CaII H & K and H_α lines (Pasquini & Belloni 1998; van den Berg et al. 1999). CCD photometry and a power spectrum analysis performed on M 67 stars by Gilliland et al. (1991) detected photometric variability for S1242, with a period of 4.88 days. van den Berg et al. (1999) have pointed out that such a photometric period corresponds to corotation with the orbit at the periastron. According to these authors, coronal and chromospheric activities for S1242 are due to rapid rotation induced by tidal interaction taking place at this specific orbital phase. In addition, van den Berg et al. (1999) have suggested that S1242 is a binary system in transition from an eccentric to a circular orbit.

In the present work we show that the binary S1242 has a very high lithium content, the largest one ever measured for an M 67 star evolving off the main-sequence. Our VLT observations and lithium abundance determination are described in Sect. 2. A discussion on the results is given in Sect. 3, and conclusions are drawn in Sect. 4.

★ Based on observations collected at ESO, Paranal, Chile (VLT/FLAMES program ID 072.D-0309).

2. Data and spectroscopic study of S1242

Figure 1 displays a color-magnitude diagram of M 67, with the photometry from Montgomery et al. (1993). The binary star S1242 is well located in the subgiant evolutionary stage, at $(B-V) = 0.683$.

2.1. Spectroscopic observations

In January 2004, observations of the binary subgiant S1242 of M 67 were carried out with the VLT/Unit 2 telescope (ESO, Paranal, Chile) and the FLAMES-UVES instrumentation (Pasquini et al. 2002). We used the UVES red arm standard set-up centered at 580 nm, covering the wavelength range 420–680 nm and with a resolving power of ~47 000 (1 arcsec sky aperture). The spectra were extracted using the standard ESO UVES pipeline with bias, flat-field and background corrections. Wavelength calibration was performed with ThAr spectra.

We have combined three exposures collected at different dates to obtain a good quality spectrum with a resulting signal-to-noise (S/N) ratio of 110 per pixel. We carefully checked that there was no variable nor composite spectroscopic feature (due to binarity) perturbing our analysis. For the three individual spectra, the measured radial velocities are compatible with the observations of Mathieu et al. (1990) for S1242. These values are shown in Table 1, with the log of observations. Hence, in our spectroscopic analysis, we have treated S1242 as a single

Table 1. Log of the spectroscopic observations of S1242.

α_{2000}	δ_{2000}	Date	Julian Day	UT	Exposure time (sec)	S/N	Rad. Vel. ($\mathrm{km\,s^{-1}}$)
08:51:36.04	11:46:33.70	Jan. 05, 2004	2453009.74	05:39	3000	91	37.6
		Jan. 07, 2004	2453011.77	06:21	1500	45	38.4
		Jan. 27, 2004	2453031.75	06:02	3000	93	33.6

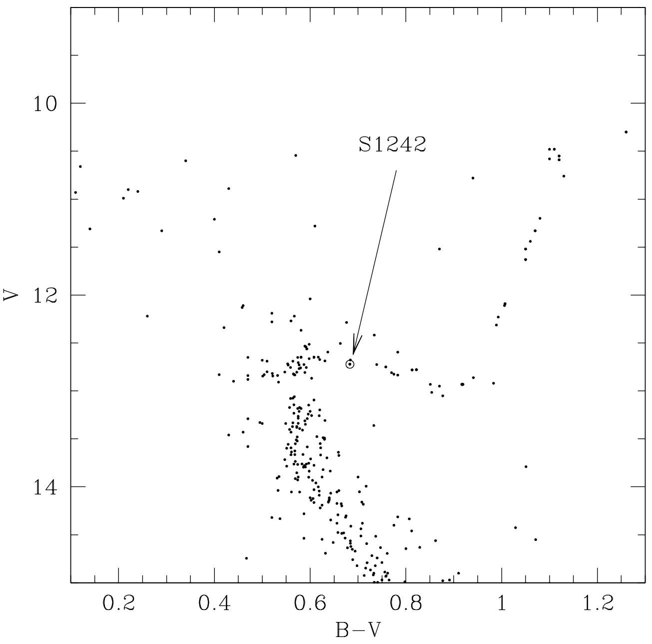

Fig. 1. Color–magnitude diagram of the open cluster M 67. (V, $B-V$) photometry is taken from Montgomery et al. (1993). The location of the Li-rich subgiant star (S1242) is indicated in this diagram.

star. We can safely ignore any contribution of the secondary and assume that the Li we are measuring is only from the primary. With an expected mass for the primary of 1.25 $M_\odot$ and considering the mass function of this binary system as in Mathieu et al. (1990), a typical mass of about 0.2 $M_\odot$, is obtained for the dwarf companion leading to a luminosity ratio proving that the contribution of the secondary is negligible. Even by considering the system in synchronization, a higher mass would be obtained for the secondary, but still with a negligible contribution.

2.2. Spectral analysis

A new generation of MARCS stellar atmosphere models (Gustafsson et al. 2006, in preparation), spectral synthesis tools (described in Alvarez & Plez 1998, and improved with further developments) and, when necessary, interpolation routines on model atmosphere were used. Solar abundances have been taken from Grevesse & Sauval (1998). As weak atomic (e.g., iron lines) and molecular features are known to blend the Li lines at 6707.78 Å (Israelian et al. 2003), it was first necessary to have a good precision on the measurement of the Fe abundance. Hence we have calibrated, on the high resolution spectrum of the Sun (Hinkle et al. 2000), the oscillator strength values ($\log gf$) of an atomic line list issued from the VALD database (Kupka et al. 1999) and covering 14 Å around the Li line. This atomic line list is displayed in Table 2, together with our improved values on $\log gf$ and our measured equivalent widths for the lines identified in this region. We have investigated the Li equivalent

Table 2. Atomic line list in the Li region 6703–6717 Å: element, wavelength, excitation potential, $\log gf$ (from VALD data base and adopted here), equivalent widths in S1242 for each identified line.

Element	λ(Å)	χ_{ex} (eV)	$\log gf$ VALD	$\log gf$ This work	EW_λ (mÅ)
Fe I	6703.57	2.758	−3.160	−3.080	35.9
	6704.48	4.217	−2.660	−2.680	6.5
	6705.10	4.607	−1.496	−1.138	47.2
	6707.42	4.610		−2.265	4.1
	6710.32	1.485	−4.880	−4.880	12.7
	6713.05	4.607	−1.448	−1.550	25.3
	6713.20	4.143	−2.560	−2.500	8.7
	6713.74	4.795	−1.600	−1.480	17.2
	6715.38	4.607	−1.640	−1.580	24.3
	6716.23	4.580	−1.920	−1.890	15.3
Li I	6707.78	0.000	−0.431	−0.431	98.7

widths for the three individual observations of S1242. They are all in good agreement, considering the S/N for each observation. To compute synthetic spectra we have also taken into account molecular line lists: TiO (Plez 1998), VO (Alvarez & Plez 1998), CN and CH (Hill et al. 2002), and finally, we convolved our outputs with a Gaussian to reproduce the instrumental profile of FLAMES (resolving power of 47 000).

The effective temperature was determined from ($B-V$) color index (Montgomery et al. 1993) using improved color–temperature relations from Houdashelt et al. (2000). Then, with synthetic spectra, effective temperature was spectroscopically determined from three indicators providing rather good agreement: H_β and H_α Balmer Hydrogen lines and Fe I lines identified in the Li region (see Table 2). As already reported by Grupp (2004), the H_α line may be the best temperature indicator for stars of solar metallicity, the H_β line always pointing to a lower temperature (−200 K). Figure 2 presents the H_α line region observed in S1242, together with synthetic spectra computed at different effective temperatures. The best fit is found for $T_{\mathrm{eff}} = 5800$ K.

We have estimated the surface gravity ($\log g = 3.8$) using the Michaud et al. (2004) evolutionary models. The iron abundance was determined by fitting the Fe I lines identified in the Li region with synthetic spectra computed with a microturbulence velocity (v_{mic}) of 1.0 $\mathrm{km\,s^{-1}}$ and a rotational velocity ($v \sin i$) estimated by adjusting the FWHM of absorption lines. Table 3 provides the atmospheric parameters adopted to compute synthetic spectra used to derive A_{Li}. Figure 3 presents the observed Li region of S1242 together with synthetic spectra for different values of A_{Li}.

The adopted [Fe/H] value (−0.05 ± 0.1) is in good agreement with the metallicity obtained for the open cluster M 67 by Tautvaišien et al. (2000): [M/H] = −0.03 ± 0.03. We clearly find that a $v \sin i$ value of 2.6 $\mathrm{km\,s^{-1}}$, as proposed for S1242 by van den Berg et al. (1999), is not sufficient to reproduce a good line fitting, while our $v \sin i$ estimation (6.0 $\mathrm{km\,s^{-1}}$) is in very

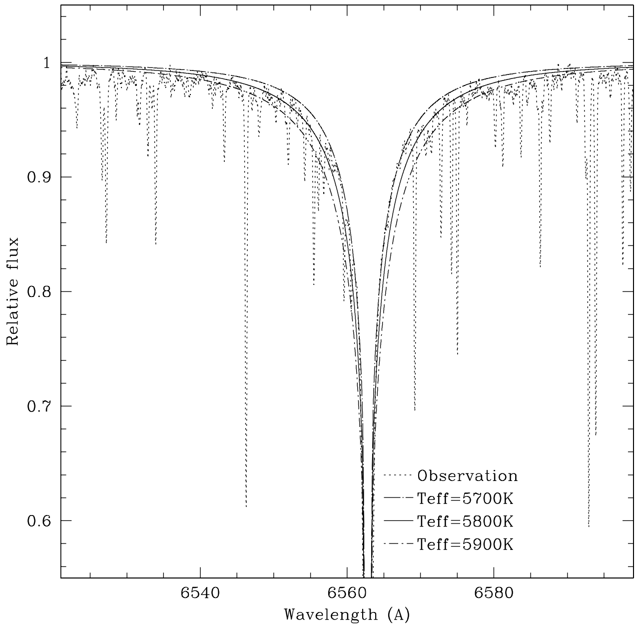

Fig. 2. Spectroscopic observation of S1242 (dotted line) in the H_α line region. Synthetic spectra have been computed at effective temperature of 5700 K (dashed-dot line), 5800 K (solid line) and 5900 K (long-dashed line). For S1242, we have adopted $T_{\rm eff}$ = 5800 ± 100 K.

Table 3. Adopted atmospheric parameters for S1242 and its lithium abundance derived from spectral synthesis method.

$T_{\rm eff}$ (K)	$\log g$	[Fe/H]	$v \sin i$ (km s^{-1})	$v_{\rm mic}$ (km s^{-1})	$A_{\rm Li}$
5800	3.8	−0.05	6.0	1.0	2.7
±100	±0.05	±0.1	±1.0	±0.5	±0.13

good agreement with rotational velocities measured in slightly evolved M 67 stars (Melo et al. 2001).

3. Results and discussion

3.1. Lithium abundance of S1242 and evolutionary stage

Our spectral synthesis analysis gives for this binary subgiant, S1242, an abundance of lithium $A_{\rm Li}$ = 2.7 ± 0.13. The total error on the Li abundance has been estimated by computing the quadratic sum of errors induced by errors on individual parameters. This detection reveals the largest Li abundance ever measured for a star of M 67 evolving off the main-sequence. To date, as mentioned by different studies, subgiant and giant stars in the open cluster M 67 show no significant lithium abundance (Balachandran 1995; Pilachowski et al. 1988), pointing to a severe Li depletion for stars having just left the main-sequence turn-off.

Deliyannis et al. (1996) also mentioned a subgiant star of M 67 (but without any identification) with an effective temperature of 5800 K and with a Li content very close to the theoretical predicted value for M 67 turn-off stars: $A_{\rm Li}$ ∼ 2.5 (Balachandran 1995; Sills & Deliyannis 2000). The binary subgiant S1242, with such a high lithium content ($A_{\rm Li}$ = 2.7 ± 0.13), also presents an abnormally high Li abundance for its evolutionary stage.

From CTIO and ESO observations, Deliyannis et al. (1994) and Pasquini et al. (1997) have also reported the detection of another Li-rich binary star in M 67, S1045. This object is a short-period tidally locked binary (SPTLB) lying on the Li peak region

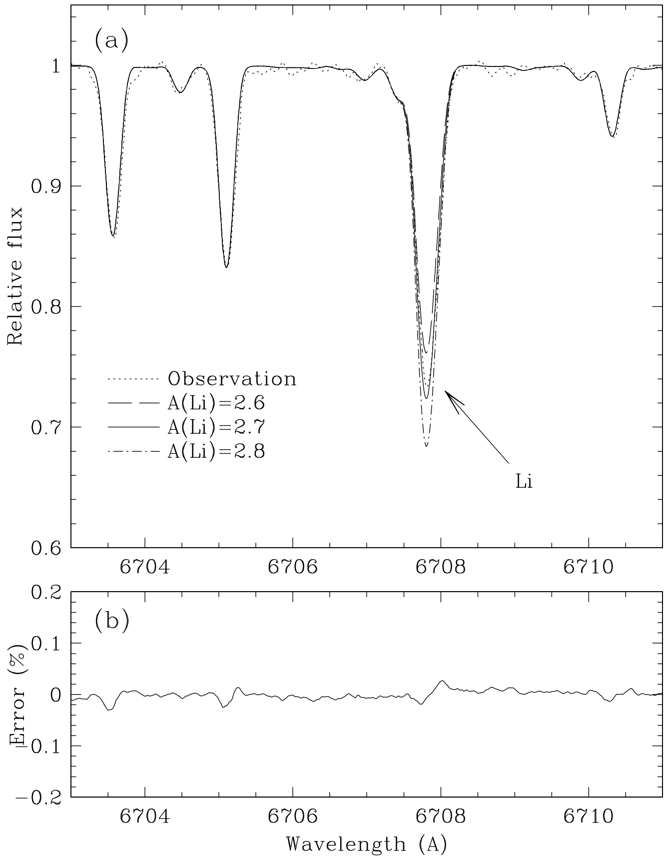

Fig. 3. a) Lithium line region of S1242 (dotted line) and synthetic spectra computed with the atmospheric parameters listed in Table 2, and with $A_{\rm Li}$ = 2.6, 2.7 and 2.8 dex (dashed, solid and dashed-dot lines respectively). The best synthetic spectrum is clearly the one computed with $A_{\rm Li}$ = 2.7. **b)** Residual difference between synthetic ($A_{\rm Li}$ = 2.7, best fit) and observed spectra.

of M 67 (i.e, 5950 K to 6350 K, corresponding to the late-F and early-G main-sequence stars). This double-line spectroscopic binary has an orbital period of 6.7 days (Latham et al. 1993). This system, exhibiting a lithium abundance of $A_{\rm Li}$ ∼ 3.0 dex and an effective temperature of ∼6100 K, is composed of very similar components both located near the turn-off (Deliyannis et al. 1994). For main-sequence and some turn-off stars of M 67, a Li dispersion was also observed (Deliyannis et al. 1994; Pasquini et al. 1997; Jones et al. 1999; and Randich et al. 2002). Concerning S1045, Deliyannis et al. (1994) have established that its high Li abundance (lying above the Li peak value in M 67) is well supported by the Zahn tidal circularization and rotationally induced mixing theories (Zahn & Bouchet 1989; Pinsonneault et al. 1990). Therefore, S1045 must have suffered little, if any, Li depletion during its main-sequence lifetime. Deliyannis et al. (1994) have also argued that such a high Li abundance measured in a SPTLB may indicate that the Li peak in M 67 (set at $A_{\rm Li}$ ∼ 2.5 dex) has been depleted from a higher initial abundance at least as high as $A_{\rm Li}$ ∼ 3.0 dex (close to the initial value for the solar system and also to the maximum value measured for the Pleiades, Hyades and Praesepe).

3.2. Lithium abundance of S1242 and binary status

For field solar-type subgiants, De Medeiros et al. (1997) have pointed out that Li abundances of single stars drop at $(B - V)$ ∼ 0.55. These authors also found that subgiant stars in synchronized binary systems, namely those with an orbital period lower than about 50 days located on the cool side of the drop in Li seem to retain their original lithium more than the subgiants in unsynchronized binary systems, and also more than their single subgiant counterparts. For the star S1242, with a color index $(B - V) \sim 0.68$, this binary system is located on the right side (or equivalently, on the cool side) of the drop in abundances of Li observed by De Medeiros et al. (1997). The high lithium abundance we measured for this binary system is clearly unusual relative to other M 67 subgiants.

Following the above scenario, one explanation for such a high Li content in S1242 can be directly related to its binary status. Consistent with Li determination in M 67 turn-off stars (Deliyannis et al. 1994), tidal effects may have contributed to the preservation of its Li abundance from the turn-off stage, following the scenario proposed by Zahn (1994). According to this author, tidally locked binary systems on the ZAMS also experience a tidal torque, which tends to synchronize their rotational and orbital motions. As a result, these binary stars exchange less angular momentum than their single counterparts, and thus retain more of their original lithium. This scenario is now also well supported by the determination of Li abundances in binary stars at different evolutionary stages and luminosity classes (Costa et al. 2002; De Medeiros et al. 1997; Barrado y Navascues et al. 1988).

For S1242, tidal effects may be acting at least at the periastron stage, leading the system to a pseudo-synchronization (Hut 1981) and therefore producing a spin-up. This is reflected by the enhanced coronal and chromospheric activities. The presence of this spin-up is also reinforced by the rotational velocity estimated for this system. Considering that the rotational period of S1242 is the same as the photometric period, our measured $v \sin i$ (6 km s^{-1}) corresponds to a rotational velocity of about 23 km s^{-1} (assuming a radius of $\sim$2.2 $R_\odot$) leading to an inclination angle of about 15°. This rotational velocity value is at least three times larger than the mean rotational velocity of single subgiants and unsynchronized binary systems with subgiant components (De Medeiros et al. 1996). With this high rotation and with an orbital period of 31.8 days, in spite of the large eccentricity of 0.66 (Mathieu et al. 1990), S1242 is a binary system that follows the trend for the Li behavior observed by De Medeiros et al. (1997) in field binary systems with a subgiant component. Further, as suggested by van den Berg et al. (1999), S1242 appears to be in transition from an eccentric to a circular orbit. However, if significant tidal effects are occuring in S1242, the scenario proposed by Zahn (1994) may explain the abnormally high Li content we have observed in this system.

3.3. Lithium abundance of S1242 and non standard theoretical predictions

In spite of the fact that tidal effects seem to be acting at the periastron of S1242, is the spin-up efficient enough in strength and duration to preserve Li? Because it is very difficult to assess the efficiency of the tidal effects occurring in this binary system, we have investigated an alternative explanation for the abnormally high lithium content in S1242, independent of tidal action.

The rotational velocity of about 23 km s^{-1} for S1242 (see previous section) can be compared to the rotational velocity distribution of more massive AmFm stars. They are mainly binary objects and slow rotators (compared to other stars of similar masses and spectral types) with $v \sin i < 80$ km s^{-1}. AmFm stars represent about 20% of A and F stars, and in these objects, atomic diffusion and mixing play an important role in their surface abundance anomalies and structure (Richer et al. 2000). We have investigated the stellar evolution (for stars with masses around that estimated for S1242) taking into account the effects of atomic diffusion, as already established for M 67 single stars (Michaud et al. 2004).

Figure 4 displays the evolution of $A_{\rm Li}$ for three stellar models at 1.33 $M_\odot$ (see Michaud et al. 2004 for the description of the models), in order to reach agreement with the age of the cluster (3.7 Gyr according to Michaud et al. 2004) and the required $T_{\rm eff}$ in the subgiant stage (5800 K). The initial lithium abundance has been set to 3.0 dex, according to the minimal estimation provided by Pasquini et al. (1997) from the observations of the SPLTB S1045 (see Sect. 3.1). No Li destruction in the Pre-Main Sequence has been considered, however such Li destruction is expected to be small for a star of 1.32 $M_\odot$ (D'Antona & Montalbán 2003). The three different curves correspond to models taking into account atomic diffusion and different parametrization of the mixing, according to models presented and discussed in Richard et al. (2002):

1. the dashed line shows the decrease of the Lithium in a model with a turbulence high enough to bring the lithium into its burning zone;
2. the dot-dashed line shows the evolution for a model with a turbulence that stops the surface lithium decrease due to atomic diffusion, but not enough to bring the Lithium to its burning zone. Hence, the behavior of Li abundance is quasi-constant (and at a high value) during the main-sequence evolution;
3. the solid line shows the surface Lithium evolution when only atomic diffusion is taken into account.

In the models 1 and 2 (dashed and dot-dashed lines in Fig. 4), we have only used a parametric formulation for the turbulence in order to take into account the rotational mixing. In Fig. 4, the model represented by the dashed line has similar Lithium evolution than the 1.5 $M_\odot$ model in Palacios et al. (2003), a rotating low mass stellar model taking into Account a consistent transport of angular momentum and chemicals under the effects of rotation-induced mixing and element segregation.

During the main-sequence evolution, atomic diffusion reduces the surface lithium by a maximum of $\sim$0.2 dex at around 2 Gyr when the surface convective zone reaches its thinest size. The lithium abundance profile constructed by diffusion increases from the surface to the depth where nuclear reaction rates are high enough to significantly burn the lithium (Sills & Deliyannis 2000). Deeper in the star the lithium rapidly decreases. When the star evolves, its surface convection zone deepens and dredges up lithium until the convection zone reaches the depth where the lithium abundance is at its maximum. This happens on the subgiant branch at a $T_{\rm eff}$ close to that of S1242 (e.g.: Sills & Deliyannis 2000; and Michaud et al. 2004). Afterwards, Li starts to decrease again. Thus, as it can be seen in Fig. 4 (solid line track), atomic diffusion may help to reproduce the rise in $A_{\rm Li}$ occurring close to our $T_{\rm eff}$ estimation for S1242. As a result, a high lithium content in the subgiant stage may be due to the combination of the variation of the depth of the surface convective zone and atomic diffusion.

Following the above approach, the high lithium content of S1242 suggests that this star has experienced less mixing than other stars of the same $T_{\rm eff}$ at the same evolutionary stage.

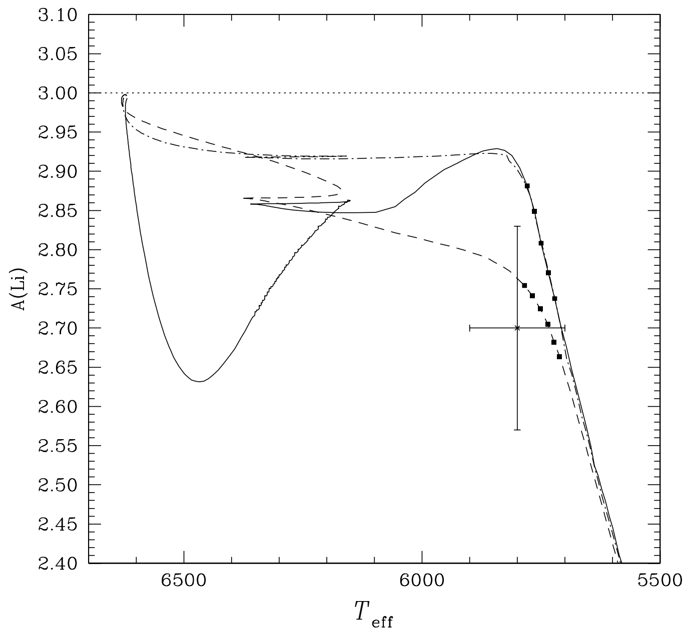

Fig. 4. $A_{\rm Li}$ evolution for three stellar models of 1.33 $M_{\odot}$. The reader is referred to Michaud et al. (2004) for a full description of the models. The dotted line is the initial $A_{\rm Li}$, set at 3.0 dex at the beginning of the main sequence, as no Li destruction on the pre-Main Sequence has been considered. The three different curves correspond to different models, taking into account atomic diffusion (solid line) and two different parametrizations of the mixing (dashed and dot-dashed lines, see text). Black dots represent the surface Li abundances predicted by our models from 3.6 to 3.8 Gyr (i.e., the expected age for M 67).

4. Conclusion

We report the detection of an exceptionally high Li abundance ($A_{\rm Li}$ = 2.7 dex) for the binary star, S1242, in the open cluster M 67. This star is known to have significant chromospheric and coronal activity, and it lies on the subgiant branch of M 67 (with $T_{\rm eff}$ = 5800 K). S1242 presents the highest $A_{\rm Li}$ ever measured in an M 67 star evolving off the main-sequence.

The binary status of S1242 may explain this high $A_{\rm Li}$ if tidal effects produce a pseudo-synchronization at the periastron, with a spin-up large enough in strength and duration to play an important role in the preservation of lithium abundance present in the previous turn-off stage. In addition to the high level of activity, the presence of tidal effects in this system is reinforced by its enhanced rotational velocity. Nevertheless, one question remains: are these effects strong enough to induce Li preservation?

Atomic diffusion also can explain the high lithium abundance observed at this evolved stage. When considering the theoretical evolution of a 1.33 $M_{\odot}$ star, we show that a dredge-up of Li can occur at the subgiant evolutionary phase, under atomic diffusion. Along an evolutionary path, this scenario helps to reconcile the Li abundance value at the turn-off stage ($A_{\rm Li}$ = 2.5, low compared to the initial Li abundance in M 67) to the Li enhancement observed in the binary subgiant S1242, studied here.

The $A_{\rm Li}$ previously measured in S1045, a binary star at the turn-off, helped to assess the initial Li abundance in M 67 ($A_{\rm Li}$ > 3.0 dex), indicating that stellar depletion (rather than Galactic Li enrichment) is acting in M 67 single and binary stars. The two assumptions we proposed here in order to explain the anomalously high Li abundance in S1242 (tidal effects and atomic diffusion) are both in agreement with the lithium behavior in M 67.

Moreover the combination of atomic diffusion and rotational mixing can explain the $A_{\rm Li}$ dispersion observed in main-sequence and turn-off stage stars in M 67. Away from the main sequence, the dredge-up of Li, explained in the framework of atomic diffusion, is predicted to occur over a very short period. Hence it appears very unlikely to observe, among the poorly populated evolved branch of M 67 (and more generally in younger open clusters), several evolved objects with such puzzling high $A_{\rm Li}$ as good constraints to this peculiar internal phenomenon. S1242 may be one such object.

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References

Alvarez, R., & Plez, B. 1998, A&A, 330, 1109
Balachandran, S. 1995, ApJ, 446, 203
Barrado y Navascues, D., de Castro, E., Fernandez-Figueroa, M. J., Cornide, M., & Garcia Lopez, R. J. 1998, A&A, 337, 739
Belloni, T., Verbunt, F., & Mathieu, R. D. 1998, A&A, 339, 431
Costa, J. M., da Silva, L., do Nascimento, J. D., Jr., & De Medeiros, J. R. 2002, A&A, 382, 1016
De Medeiros, J. R., do Nascimento, J. D. Jr., & Mayor, M. 1997, A&A, 317, 701
De Medeiros, J. R., da Rocha, & C., Mayor, M. 1996, A&A, 314, 499
Deliyannis, C. P., King, J. R., Boesgaard, A. M., & Ryan, S. G. 1994, ApJ, 434, 71
Deliyannis, C. P., King, J. R., & Boesgaard, A. M. 1996, in Proc. Second Conf. of IAU Comission 9, Wide Field Spectroscopy, ed. M. Kontizas (Dordrecht: Kluwer), 201
D'Antona, F., & Montalbàn, J. 2003, A&A, 412, 213
Gilliland, R. L., Brown, T. M., Duncan, D. K., et al. 1991, AJ, 101, 541
Grevesse, N., & Sauval, A. J. 1998, SSRv, 85, 161
Grupp, F. 2004, A&A, 426, 309
Gustafsson, B., Edvardsson, B., Eriksson, K., et al. 2006, in preparation
Hill, V., Plez, B., Cayrel, R., et al. 2002, A&A, 387, 560
Hinkle, K., Wallace, L., Valenti, J., & Harmer, D. 2000, Visible and Near Infrared Atlas of the Arcturus Spectrum 3727–9300 Å (San Francisco: ASP Publisher)
Houdashelt, M. L., Bell, R. A., & Sweigart, A. V. 2000, AJ, 119, 1448
Hut, P. 1981, A&A, 99, 126
Israelian, G., Santos, N. C., Mayor, M., & Rebolo, R. 2003, A&A, 405, 753
Jones, B. F., Fischer, D., & Soderblom, D. R. 1999, AJ, 117, 330
Kupka, F., Piskunov, N. E., Ryabchikova, T. A., Stempels, H. C., & Weiss, W. W. 1999, A&AS, 138, 119
Latham, D. W., Mathieu, R. D., Milone, A. A. E., & Davis, R. J. 1993, in Binaries as Tracers of Stellar Formation, ed. A. Duquennoy, & M. Mayor (Cambridge University Press), 132
Mathieu, R. D., Latham, D. W., & Griffin, R. W. 1990, AJ, 100, 1859
Melo, C. H. F., Pasquini, L., & De Medeiros, J. R. 2001, A&A, 375, 851
Michaud, G., Richard, O., Richer, J., & Vandenberg, D. A. 2004, ApJ, 606, 452
Montgomery, K. A., Marschall, L. A., & Janes, K. A. 1993, AJ, 106, 181
Palacios, A., Talon, S., Charbonnel, C., & Forestini, M. 2003, A&A 399, 603
Pasquini, L., Randich, S., & Pallavicini, R. 1997, A&A, 325, 535
Pasquini, L., & Belloni, T. 1998, A&A, 336, 902
Pasquini, L., Avila, G., Blecha, A., et al. 2002, The Messenger, 110, 1
Pilachowski, C., Saha, A, & Hobbs, L. M. 1988, PASP, 100, 474
Pinsonneault, M. H., Kawaler, S. D., & Demarque, P. 1990, ApJS, 74, 501
Plez, B. 1998, A&AS, 337, 495
Randich, S., Primas, F., Pasquini, L., & Pallavicini, R. 2002, A&A, 387, 222
Richard, O., Michaud, G., Richer, J., et al. 2002, ApJ, 568, 979
Richer, J., Michaud, G., & Turcotte, S. 2000, ApJ, 529, 338
Sanders, W. L. 1977, A&AS, 27, 89
Sills, A., & Deliyannis, C. P. 2000, ApJ, 544, 944
Tautvaišiene, G., Edvardsson, B., Tuominen, I., & Ilyin, I. 2000, A&A, 360, 499
van den Berg, M., Verbunt, F., & Mathieu, R. D. 1999, A&A, 347, 866
Zahn, J.-P., & Bouchet, L. 1989, A&A, 223, 112
Zahn, J.-P. 1994, A&A, 288, 829