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The properties of the PDS Li-rich giant stars [1]

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Abstract. In the Pico dos Dias Survey (PDS), devised to search for young stellar objects, we found also K giants presenting moderate to strong Lithium lines associated with IRAS sources. But there are some gK with weak or absent Li lines too. There is a dichotomy in the distribution of the IRAS spectral indices between both kinds of K stars. A model of an expanding shell with a mass-dependent velocity may explain this behavior, if the photospheric Li depletion takes only ~2500 yrs.

1. Introduction

In spite of the infrared spectral criteria used in the the Pico dos Dias Survey (PDS), conceived to search for young stellar objects (Gregorio-Hetem et al., 1992), we found about 40 K giants in the direction of the selected IRAS sources, more than 20 of them presenting moderate to strong Lithium lines. A preliminary result was presented by de la Reza et al. (1997). To explain this result, de la Reza et al. (1996) developed a model where an internal Li enrichment during the red giant branch stage is followed by a prompt mass-loss event, responsible for the infrared excesses.

As the PDS was recently finished (Torres, 1998), we present now a more complete analysis of the K giants found.

2. The K giants of the PDS

To clarify the infrared properties of the K giants we restrict the sample by including giants in only two cases, taking into account the possibility of chance coincidences of the fairly abundant K stars with the IRAS sources within the positional error ellipses:
a) gK with Lithium equivalent widths (W_{Li}) larger than 0.07 Å and being the most probable optical counterpart of the IRAS source.

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b) gK with very weak or absent Li line having no other obvious possible counterpart of the IRAS source.
Actually, most of the IRAS sources eliminated in this way show H_α and forbidden line emissions in the sky spectra and are thus probably associated with HII regions. We retained 17 and 11 stars of cases (a) and (b), respectively. They are presented in Tables 1 and 2, with some of their properties, where [12] means the IRAS flux in the 12 μm band, in Jy. The spectral indices are defined as $\alpha = \log\lambda F/\log\lambda$, α_1 being between 12 and 25 μm and α_2 between 25 and 60 μm. Two of the stars in Table 1 belong to an unpublished extension of the PDS, using the IRAS Faint Source Catalog.

Table 1. Properties of the PDS K giants with the Li I line λ6707

PDS	IRAS	W_{Li}	V	[12]	α_1	α_2	SpT	A_V
003	03062-6538	-0.49	9.4V	0.30	0.31	-1.27	K0III	0.39
[a]	F04376-3238 [b]	-0.4:	10.37	0.26	-0.73	-1.65	K0III:	0
132	07227-1320	-0.25	12.59	2.47	-0.04	-1.69	K8III	1.46
258	07419-2514	-0.10	12.32	0.19	-0.02	0.73	K2III	2.36
135	07456-4722	-0.19	11.01	2.11	-0.58	-1.76	K2III	1.23
260	07577-2806	-0.50	14.62	0.60	1.13	-1.74	K0Ib/III	2.96
[c]	F08359-1644 [b]	-0.45	14	0.10	1.04	-1.38	K0III	-
354	12236-6302	-0.37	12.30	0.95	1.01	1.37	K1III	0.94
355	12327-6523	-0.28	10.40	8.60	-1.24	-0.54	K1III	4.6
365	13313-5838	-0.46	13.15	1.88	0.59	-1.69	K1III	1.46
068	13539-4153	-0.60	12.81	0.48	-0.26	-1.28	K2II-III	1.74
410	16086-5255	-0.15	13.83	5.70	0.85	-1.15	K1IIIp	1.84
432	16514-4625	-0.51	11.48	2.60	0.14	0.35	K2III	1.23
485	17596-3952	-0.20	12.10	0.48	0.13	-1.71	K1III	1.26
524	18334-0631	-0.14	12.50	7.86	0.29	0.21	K0II	4.8
562	19083+0119	-0.16	9.4V	2.34	1.58	-1.10	K2III	0.28
100	19285+0517	-0.33	10.45	4.74	-0.56	-1.75	K0III	1.87

[a] *CD -32 1919*
[b] *IRAS faint souce catalogue*
[c] *GSC 6015-2379*

3. The biases on the sample

In any analysis we must carefully take into account the observational limits of the sample. For the observed stars we imposed a magnitude limit in the GSC of 14 (Torres, 1998). As these stars are red and the GSC magnitudes are, in general, blue ones, the visual limit is ~13. Although some stars in Tables 1 and 2 are somewhat fainter, this limit represents fairly well our sample. For an unreddened giant with M_V ~0 this means a limit in distance of ~4 kpc. The measured interstellar extinctions (A_V) show that this is essentially correct, assuming an average extinction of 1 mag/kpc. On the other hand, the limit on IRAS fluxes is ~0.25 Jy. We can establish a spectral index between the visual

Table 2. Properties of the PDS K giants with weak or absent Li I line

PDS	IRAS	V	[12]	α_1	α_2	SpT	A_V
299	09553-5621	12.85	0.74	-0.67	1.31	K0III	2.13
071	14422-8021	12.67	0.45	-0.16	-1.56	K0III	1.98
419	16227-4839	11.86	2.94	-1.17	0.63	K3III	0.77
434	16552-3050	13.46	2.46	0.97	-1.10	G7III	1.25
462	17399-3100	13.58	3.43	-0.76	-0.59	K5III	4.05
466	17442-2441	13.78	3.30	-0.27	-0.75	K1III	2.76
533	18397-0400	11.43	7.54	-0.92	0.22	G7III	2.59
542	18454-0731	12.89	0.60	-1.17	0.36	K0III	1.22
552	18559+0140	12.05	1.40	-1.18	1.50	K0III	0.54
573	19210+1715	10.86	0.59	-0.01	0.73	K0III	3.11
583	19365+2557	13.62	0.34	-0.33	0.93	G7III	1.79

and the 12 μm band (β). The mean de-reddened β index is ~-0.5. Thus, the IRAS flux limits imply a mean de-reddened visual limit of ~12.

This means that both, V-magnitude and infrared flux, impose quite similar limits. The selected PDS sources and their gK counterparts are close to these limits as a result of their low galactic density (we found ~ 1 star/kpc^3). Therefore, we detected mainly stars with shell infrared fluxes relatively strong compared to the photospheric ones.

4. Comments on some individual objects

PDS 258 – This star has the weakest Li line in Table 1 and may be considered an intermediate case between the two kinds of gK. In Figure 1, it is the open circle nearest to the upper left corner. The CO cloud WB 1046 may be another identification for this IRAS source (Wouterloot & Brand, 1989).
PDS 354– This star, with the highest α_2 value, has a strong H_α emission in the background sky. This position on the diagram is typical for HII regions and the infrared fluxes of the star may be, at least, contaminated. It is near PDS 355.
PDS 355– It is behind the Coalsack and, as the reddining comes from it and the star may be as near as 200 pc. The infrared fluxes may be contaminated.
PDS 434–Hu et al. (1993) classified it as G9III and found a compact reflection nebula wich reinforces the association with the IRAS source. Its position in Figure 1, the asterisk nearest to the lower right corner, is peculiar. This star may remind us that, in evolved stars, mass loss not only occurs during the Li enrichment process.

5. Discussion

In Figure 1 we plot the infrared spectral indices of the stars of both tables. We can see that there is a dichotomy in their distribution with respect to the Li abundance. In fact, almost all stars in Table 2 are at the left of the diagram. We explain this distribution as being the result of Li depletion in the stellar photospheres after the shell expulsion. There are some difficulties to explain

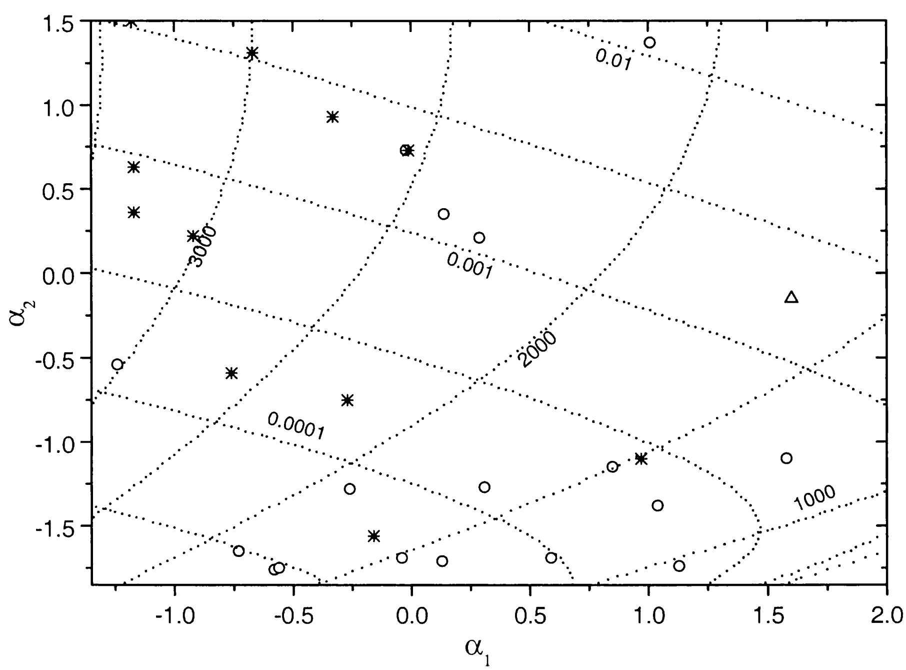

Figure 1. Diagram of IRAS spectral indices within the limits used in the PDS. Circles represent the stars with moderate to strong Li lines (Table 1) and asterisks those with weak to absent Li lines (Table 2). The triangle represents HDE233517, discovered by Fekel et al. (1996), that would belong to the PDS if it were extended to the northern hemisphere. Lines represent the expanding mass-dependent shell model. Isochrones are labeled with 1000 to 3000 yr and the evolutionary tracks for equal shell masses are labeled with 0.01 to 0.0001 $M_{\odot}$. This model was computed for a star with $R_* = 20R_{\odot}$ and $T_{eff} = 4500$ K. As real stars may deviate from the above average parameters, individual positions relative to the model must be taken with caution. The dichotomy between the samples may be explained in this model by a Li depletion in the stellar photosphere in $\sim$2500 yr.

this by the model of de la Reza et al.(1996) as its isochrones are almost parallel to the α_1 axis. There are, of course, a lot of simplifying hypotheses in the model, one of them being the independence of the velocity of expansion of the shell on its mass. If we suppose that there may be such a dependence, we can find an empirical law that could explain the observational behavior. For example, it could be fairly well explained with a power law of the kind:

$$V = V_0 (M/M_0)^{1/4}$$

where V and M are the velocity of expansion and the mass of the shell. This is the model presented in Figure 1. According to this one the Li in K giants is depleted in ~2500 yr if the normalization parameters are: $V_0 = 0.5$ km/s and $M_0 = 10^{-6}\, M_\odot$.

The fact that the Li depleted stars have, apparently, larger shell masses may be qualitatively explained by bias: first, the model forsees that the shell stays longer in the region of the graph where the Li depleted stars are and, second, the sample is biased towards more massive shells, because an evolved less massive shell has weaker infrared emission and would not have been selected in the PDS.

The Li-rich K giant stars are more concentrated in the lower part of the diagram. This represents the expected distribution in the diagram as it means only that low mass shells are more frequent than more massive ones. But it should be noted that the lack of stars older than 2000 yr, in the lower part of the diagram, may be the result of both the Li depletion and the weaker emission of the shell.

The semi-empirical expanding shell model presented here seems to describe quite well the behavior of the PDS K giants. Any model that attempts to explain the physical reasons of the shell ejection should reproduce the law (or a similar one) found by us.

The Li-rich giants are difficult to detected (in the PDS we found ~ 1 star/kpc^3). But considering the short time-scale of this phenomenon, it is probable that all gK will pass through this phase at least once. It may be one of the most important Li sources of the interstellar medium.

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