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The Li overabundance of J 37: diffusion or accretion?

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Abstract. In September 2002 the discovery of a super Li-rich F-dwarf (J 37) in NGC 6633, an iron poor analogue of the better studied Hyades and Praecepe open clusters, was announced. This unique star was thought to be the smoking gun for the action of diffusion, models of which predict a narrow "Li-peak" at approximately the correct temperature. However, with more detailed studies into J 37's abundance pattern this star provides firm evidence for the accretion of planetesimals or other material from the circumstellar environment of new born stars.

Thanks to the specific predictions made about the behaviour of Be abundances, (the most striking of which being no Be in super-Li-rich dwarfs subject to diffusion) the opposing diffusion/accretion predictions can be tested.

Initial modelling of the Be line indicates that J 37 is as Be rich as it is Li rich; $\log N(\mathrm{Be}) = 2.25 \pm 0.25$, and so is broadly consistent with an accretion-fuelled enhancement. However, that both Li and Be are enhanced by much more than the iron-peak elements (as determined in previous studies) suggests that diffusion also plays a role in increasing the abundances of Li and Be specifically.

Furthermore, a new data set from the UVES/UT2 combination has allowed the elemental abundance of iron to be measured. The preliminary stellar parameters are; $T_{\mathrm{eff}} \sim 7340\,\mathrm{K}$, $\log g \sim 4.1$, microturbulence $\sim 4.3\ \mathrm{km\,s^{-1}}$, $[\mathrm{Fe/H}] \sim 0.50$. This again provides distinct evidence for the effects of accretion in J 37 and requires a new synthesis of the Be doublet.

Keywords. Accretion, diffusion, stars: abundances, stars: chemically peculiar, stars: individual: (J 37).

1. Introduction

The determination of Lithium and Beryllium photospheric abundances can reveal and improve the understanding of processes occurring in the stellar interior, with simultaneous measurements of both Li and Be being sensitive to mixing, diffusion and other poorly understood transport processes.

This investigation focuses specifically on the super Li-rich star, J 37, discovered in September 2002 which is a photometric, proper motion and radial velocity member of NGC6633 (Deliyannis *et al.* 2002). It is a late A or early F dwarf and as such should possess a very shallow convection zone as well as being a slow rotator for its spectral class at $29 \pm 2\,\mathrm{km\,s^{-1}}$ (Deliyannis *et al.* 2002). Its relatively thin mixing layer allows physical processes to produce observable effects that are mostly negligible in cooler dwarfs thus making J 37 susceptible to abundance concentrations that might otherwise be diluted by turbulence, convection and meridional circulation in the atmosphere.

Deliyannis *et al.* (2002) suggested that the high Li abundance could be explained by the theoretical diffusion models of Richer & Michaud (1993), as when internal mixing is insufficient to inhibit it, diffusion offers a viable mechanism for the Li overabundance. These diffusion models specifically predict an overabundance of Li in the very narrow $T_{\rm eff}$ range 6900-7100 K. In this $T_{\rm eff}$ range there is a substantial region below the extremely thin (model) surface convection zone where Li atoms retain one electron, and below this region are completely ionised and diffuse downwards (via gravitational settling and thermal diffusion) relative to hydrogen. By contrast, the electron retaining Li is radiatively accelerated upwards thus enriching the SCZ (surface convective zone). It should be noted that subsequent improvements to these models (Richer *et al.* 2000) results in them no longer showing a Li peak, but the reasons for this are unclear.

An alternative hypothesis comes in the form of accretion, with direct evidence for this process coming from either a correlation between metallicity and mass that could be explained in terms of decreasing CZ mass onto which the accreted material is mixed, or a correlation between the abundance enhancements of various elements and either the abundances found in planetesimals or the condensation temperature of each element (e.g., Gonzalez *et al.* 2001). Laws & Gonzalez (2003) suggested accretion as the cause of J 37's high Li abundance and concluded that, though neither diffusion or accretion of either type is in complete agreement with J 37's abundance pattern the elements in the CZ of J 37 were set by the composition of a) the primordial gas from the star's formation, b) subsequent accretion of both depleted circumstellar gas and planetesimal material, and c) evolution of its atmosphere through internal processes.

Despite this ambiguity one can, in principal, distinguish between stars exhibiting the effects of diffusion or accretion by looking simultaneously at other elements, such as Be, that burn at different temperatures or are stable in the stellar core. The Li/Be ratio is unlikely to be markedly changed by accretion processes, but because these are the lightest metals, they can behave in extreme and usually completely contrary ways, when subject to the effects of diffusion (e.g., Turcotte *et al.* 1998). Thanks to the specific predictions made about the behaviour of Be abundances in the models of Richer *et al.* (2000), the most striking of which being the excessive underabundance of Be in super-Li-rich dwarfs, the opposing diffusion/accretion predictions can be tested.

2. Observations & data reduction

High resolution spectroscopy was obtained for J 37 and nine other stars in NGC 6633 with the UV-Visual Echelle Spectrograph (UVES) mounted on the UT2 8.2 m VLT telescope at Cerro Paranal, Chile, on the night of 2003 June 12 − 13. The standard DIC1/346/580 template with a 1.2 arcsec slit was used with 2×2 and 1×1 binning on the blue and red arms of the instrument respectively. This provides the wavelength range 3050 − 6820 Å (orders 152 − 90) at a resolution of 35000, with an exposure time of 3000 seconds.

The blue arm of UVES was used to measure the Be abundance while the red arm provided very high signal spectra allowing great improvements in the stellar atmospheric parameters (particularly $T_{\rm eff}$ and microturbulence), by detailed consideration of many (unblended) lines of neutral/ionised Fe and fitting the Balmer line profiles.

Due to problems with UVES's automatic data reduction pipeline, data reduction and extraction were carried out using the LINUX computing facilities at Keele University and the ECHOMOP data reduction package. CCD frames were debiased, flat-fielded and sky-subtracted before the extraction of individual orders from the images. These extracted spectra were then wavelength calibrated using Thorium-Argon arc spectra taken on the same night.

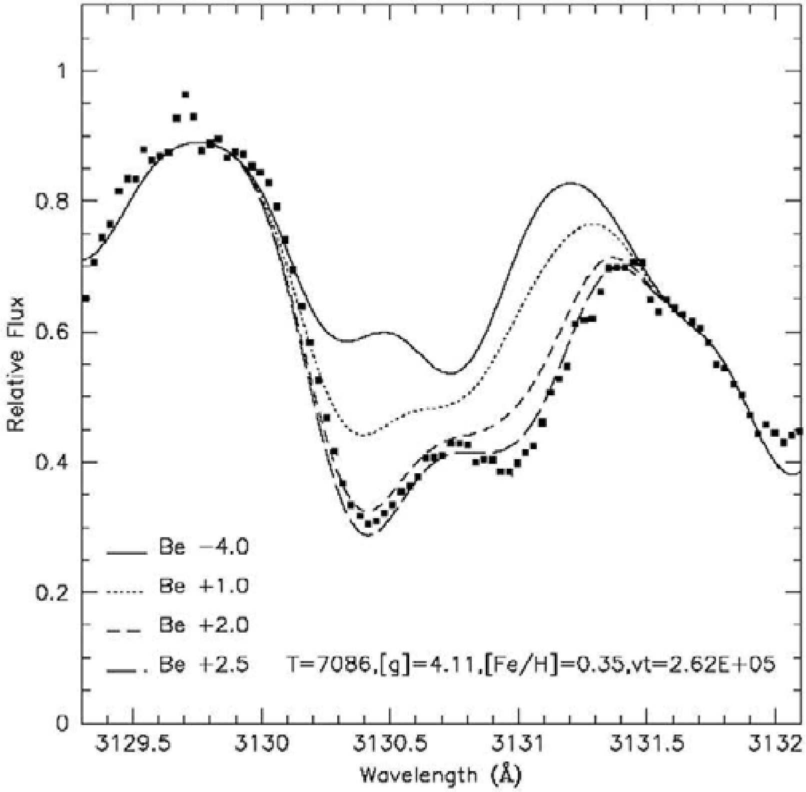

Figure 1. An initial spectra synthesis of the region around the Be II doublet (3130.4 Å and 3131.1 Å) in J 37. The dotted trace shows the original data and the four syntheses show varying Be abundances, from $\log N(\mathrm{Be}) = -4.0$ dex (negligible Be) to $\log N(\mathrm{Be}) = +2.5$ dex (super solar). The currently favoured solution is $\log N(\mathrm{Be}) = 2.25 \pm 0.25$ dex suggesting J 37 is as Be rich as it is Li rich.

3. Preliminary results & conclusions

Initial synthesis of the Be line using the parameters of Deliyannis *et al.* (2002) appears to favour the accretion hypothesis. As mentioned in the introduction if diffusion is the correct solution for the Li overabundance there should be a very low Be abundance. An initial spectral synthesis of the Be II doublet (3130.4 Å and 3131.1 Å) region is shown in Figure 1, and the favoured result is currently $\log N(\mathrm{Be}) = +2.25 \pm 0.25$ dex suggesting the Be overabundance is almost as great at the Li overabundance. However, although the studies of iron peak elements carried out by Laws & Gonzalez (2003) and Deliyannis *et al.* (2002) show their overabundances are not as great as those for Li and Be, diffusion may also be playing a role in increasing the abundance of these particular elements.

The determination of a new set of atmospheric parameters started with the measurement of the equivalent widths of 44 unblended Fe I and Fe II between 4900 and 6800 Åusing the default gf-values of the UCLSYN code (Smith 1992). The equivalent widths were measured by direct integration below a continuum that was estimated by fitting a low-order polynomial to line free regions of the surrounding spectrum. Initially working from the parameter set of Deliyannis *et al.* (2002) this line list was used to determine [Fe/H] via calculation of the mean abundance. The microturbulent velocity was then fixed by eliminating trends in Fe I abundance with expected equivalent width following the determina-

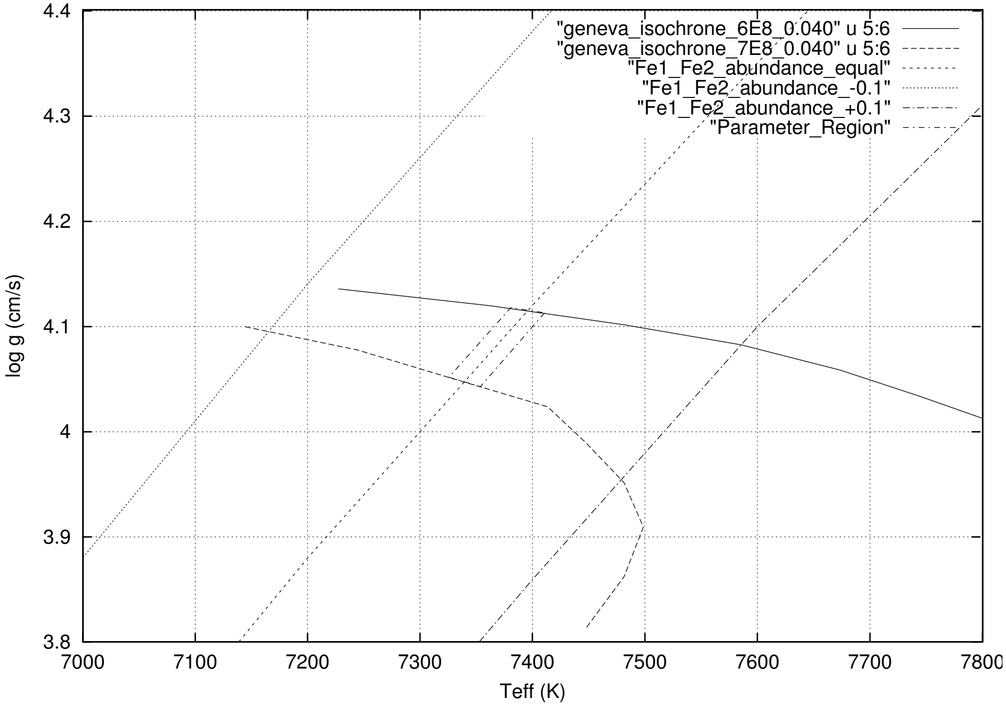

Figure 2. Determination of J 37's initial parameters via balancing the Fe I and Fe II abundances and limiting the balance to within ±0.1 dex. These possible combinations of parameters are limited via 600 My and 700 My Geneva stellar evolution isochrones. Finally, the upper limit of the region of $1\,\sigma$ variation in the gradient of excitation potential vs abundances of the Fe lines from zero was calculated, all of which limits the initial parameter set to the boxed region.

tion techniques of Magain (1984). These quantities were then used in the determination of $T_{\rm eff}$ and $\log g$ values by balancing the mean Fe I and Fe II abundances using the UCLSYN code. Selections of parameter sets from along the locus were then taken and these new sets synthesised, with new [Fe/H] and microturbulence values calculated. This process was iterated (focused on a constant $\log g$-value) until the parameters settled. With several possible combinations of parameter sets possible; and in theory infinite numbers in between, a plot of $T_{\rm eff}$ against $\log g$ was produced.

The next stage, requiring the possible parameter sets to be limited, was to minimise the gradient via a least squares fit of excitation potential vs abundance with the Fe line list. Any gradient which fell within $1\,\sigma$ of a zero gradient was conservatively deemed a reasonable threshold, and thus restricted the available parameter sets. It should be noted at this stage that none of the techniques utilised so far incorporates stellar evolution theory, and to this end the Geneva stellar evolution isochrones (Schaerer *et al.* 1993) are incorporated at this stage. The [Fe/H] for J 37 is clearly super solar and thus Z=0.040 isochrones were chosen (the highest metallicity available), with no convective overshoot and standard mass loss at ages 600-700 My. The resulting parameter range for J 37 is marked in Figure 2 as dictated by these three analysis techniques. From this first analysis the parameters are believed to be, $T_{\rm eff} \sim 7340\,{\rm K}$, $\log g \sim 4.1$, microturbulence $\sim 4.3\,{\rm km\,s^{-1}}$ and $[{\rm Fe/H}] \sim 0.50$.

These initial parameters agree well with the results of Laws & Gonzalez (2003) and moves J 37 off the predicted Li peak as predicted by Richer & Michaud (1993). Therefore, this also provides evidence for the accretion process as the cause of J 37s high Li abundance.

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