

High Resolution Stellar Spectrometry: Application to the Li Isotope Problem

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Background

From the beginning of the ESO 3.6 m telescope project, a high-resolution coude spectrograph had high priority on the list of auxiliary instruments. Inspired by the results obtained with the high resolution, low-noise spectra from the Tull coude scanner and Reticon spectrometer at the 2.7 m telescope of McDonald Observatory, the project underwent a metamorphosis from the very classical design foreseen at the start in 1973 to the present highly efficient echelle instrument, the Coude Echelle Spectrometer (CES). At the same time, the siderostat feed of the early plans was replaced with a real 1.4 m telescope – fondly known as the CAT – of original and very efficient design, thus turning the CES, from a full moon pastime for the 3.6 m, into a full-time powerful facility. Readers of the *Messenger* are already familiar with the instrument from Enard's descriptions (No. 11, p. 22, No. 17, p. 32, and No. 26, p. 22).

A strong argument for this type of spectrometer was the fact that there was – and still is – no other instrument in the southern hemisphere with comparable capabilities. At the same time, several groups in the ESO countries were working actively on problems in stellar atmospheres and stellar and interstellar abundances which required high-resolution spectra of the best possible spectral purity and S/N, such as can be obtained with the electronic detectors of the CES. The expected large demand for observing time on the instrument has not failed to materialize.

With the CES having become a reality, one of us has long wanted to continue his McDonald programmes on some of the many interesting stars that can only be reached from a southern observatory. Another had followed the CES project throughout as a Review Team member and consultant from its inception, and now looked forward to do some real astronomical work of the kinds that were now finally possible. Thus, entering the control room of the CES and CAT to start the first observing run by visiting astronomers on this instrument made us feel much like children on Christmas Eve. That feeling became of course even more vivid when, two nights later, it actually was Christmas Eve (1981)! The gifts turned out to be some 25 nights of perfect weather and excellent seeing.

Programmes

One of the purposes of our observing run was to review the performance of the CES on the background of the experience from the McDonald instrument. For this purpose we had chosen a number of different programmes within the field of high resolution spectrometry which were well suited to test the instrument performance, and which at the same time addressed significant astrophysical problems. Among these programmes, we shall mention here those concerning the element lithium. As is well known, Li is a key element in the observational study of stellar evolution, as it is rapidly destroyed in the stellar interior at rather low temperatures. Hence, if convection mixes matter from the surface to sufficiently deep layers, one expects Li to become depleted in the stellar atmosphere, the ${}^6\text{Li}$ isotope more rapidly than the much more abundant ${}^7\text{Li}$. Consequently, one expects stars to contain less Li the older they are

and the more efficient convection and other mixing processes are. Recent extensive work on these problems was done by Duncan (*Astrophysical Journal* **248**, 651, 1981) and Spite (*Astronomy and Astrophysics* **115**, 357, 1982).

However, the agreement of this simplified picture with observations is only very approximate, with several conspicuous discrepancies. Obviously, we also need to understand better by which mechanisms Li can be produced in stars, and to investigate further the connection between atmospheric Li abundance and the degree of mixing of the stellar envelope. Such tests are provided by measurements of the ${}^6\text{Li}/{}^7\text{Li}$ isotopic abundance ratio, and of the Li abundance in evolved stars, such as the "weak G-band" stars whose chemical composition suggests that their atmospheres are mixed with large amounts of CNO-processed material from their interiors. But in spite of this evidence for large-scale mixing, some of them show quite strong Li lines, a puzzling behaviour. Our observations nearly doubled the number of "weak G-band" stars with Li observations, and thus considerably enlarged the observational basis for attempts to understand the conditions under which these stars may preserve or produce their Li during their evolution.

We hope to return with a report on these observations before long; in the following, we shall describe our results on the Li isotope ratio.

The ${}^6\text{Li}/{}^7\text{Li}$ Isotopic Abundance Ratio

The ratio between the two Li isotopes plays a crucial role in answering the question whether Li may be produced as well as destroyed in stars. Primordial matter should contain a negligible fraction of ${}^6\text{Li}$ (see Wallerstein and Conti, 1969, *Annual Review of Astronomy and Astrophysics* **7**, 99), and the terrestrial and meteoritic ratio is about ${}^6\text{Li}/{}^7\text{Li} = 0.08$. However, the most likely of the proposed processes which could possibly produce Li in main-sequence and subgiant stars, primarily spallation of CNO nuclei by collisions with energetic protons in the envelope, would produce ${}^6\text{Li}/{}^7\text{Li}$ ratios of the order 0.4–0.5. Hence, if a star has a ${}^6\text{Li}/{}^7\text{Li}$ significantly greater than the cosmic value, this is evidence that Li has been freshly produced in that star, with obvious consequences for the interpretation of Li strengths in terms of stellar age and convection progresses. In fact, Herbig (*Astrophysical Journal* **140**, 702, 1964) and later both Conti (*Ap. J.* **155**, L 167, 1969) and Feast (*Monthly Notices* **134**, 321, 1966; *MN* **148**, 489, 1970) interpreted their measurements of the effective wavelength of the blended Li I feature at 670 Å to indicate that at least some stars have ${}^6\text{Li}/{}^7\text{Li}$ as high as 0.4–0.5, and Feast speculated that perhaps stars could synthesize Li during their subgiant evolution.

The lithium isotope ratio may be deduced from wavelength measurements as follows: The Li I resonance line is a close doublet. For ${}^7\text{Li}$, the two components have wavelengths 6707.761 Å and 6707.912 Å, while for ${}^6\text{Li}$ the wavelengths are 6707.921 Å and 6708.072 Å. For each isotope, the ratio between the strengths of the components is 2 : 1, the weaker ${}^7\text{Li}$ component nearly coinciding with the stronger ${}^6\text{Li}$ component. When changing the composition from pure ${}^7\text{Li}$ to pure ${}^6\text{Li}$, the centre-of-gravity wavelength $\lambda_{1/2}$ of the blend changes from 6707.811 Å to 6707.971 Å. Thus, the ${}^6\text{Li}/{}^7\text{Li}$ ratio may be

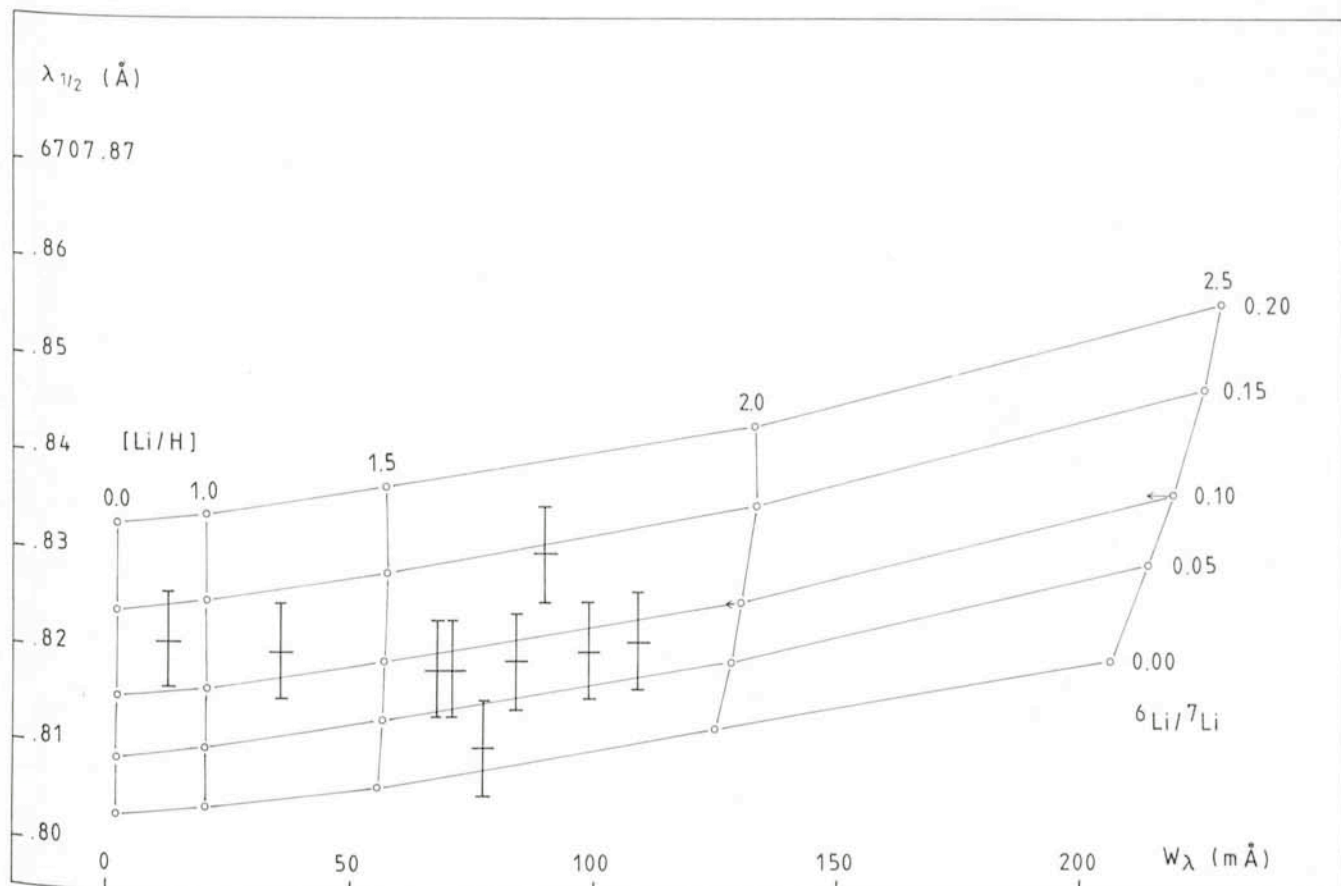


Fig. 1: Plot of the centre-of-gravity wavelength $\lambda_{1/2}$ of the lithium resonance line vs. total line strength. The grid (fine lines) shows the result of theoretical computations for various Li abundances and isotope ratios while the crosses (heavy lines) show the observed values. The latter have been corrected by -0.005 Å for the combined effects of gravitational redshift and convective blueshift on the solar wavelengths of the (mostly Fe I) stellar lines used to establish the wavelength scale. The small arrows show the effect of decreasing the microturbulence parameter from 2 to 1 km s^{-1} in the models.

computed from an accurately measured centre-of-gravity wavelength of the Li I line. Measurements on high-dispersion coude spectrograms were the basis of the results by Herbig and others referred to above.

However, by obtaining high-resolution photoelectric spectral scans and analysing the detailed line profiles, Cohen (*Ap. J.* **171**, 71, 1972) showed that in none of the northern stars considered by Herbig to have high ${}^6\text{Li}/{}^7\text{Li}$ was the ratio in reality significantly larger than zero ($0.0-0.1 \pm 0.1$). With the purpose of extending this check to the southern stars with reported high ${}^6\text{Li}/{}^7\text{Li}$ ratios, we have obtained high-resolution, low-noise CES Reticon spectra ($R = 100,000$, $S/N > 100$) of nine southern main-sequence and subgiant stars in which Li is less depleted from the cosmic value than in the Sun. In the analysis, we have used both $\lambda_{1/2}$ values and detailed line profiles from the CES spectra, compared with synthetic spectrum calculations.

First, we have calculated $\lambda_{1/2}$ for a variety of Li abundances and ${}^6\text{Li}/{}^7\text{Li}$ ratios for a range of atmospheric parameters corresponding to our programme stars. As Fig. 1 shows, $\lambda_{1/2}$ does in fact depend both on isotope ratio and line strength: For weak lines, we essentially confirm the Herbig relation, but for stronger lines $\lambda_{1/2}$ shifts towards the red due to saturation of the stronger components of the line. The observed $\lambda_{1/2}$ values are also shown in Fig. 1, and it is clear that they are all consistent, with some scatter, with a single value of ${}^6\text{Li}/{}^7\text{Li}$ of about 0.10, close to the terrestrial and meteoritic value. There are clearly no cases of the high values indicated by the older photographic observations, but it is interesting to note that also the value ${}^6\text{Li}/{}^7\text{Li} = 0.00$ seems excluded for most of our stars. This is

astonishing and interesting, since the present interstellar ${}^6\text{Li}/{}^7\text{Li}$ ratio is claimed to be significantly lower than 0.10 (Ferlet, *The Messenger* No. 30, p. 9), and the slow mixing processes suggested to deplete Li in main-sequence stars would also lower the isotope ratio.

We are currently working to refine these results by direct comparison of the observations with detailed synthetic line profiles. Fig. 2 shows the comparison for one of our stars, β Hyi. This figure demonstrates the kind of results that can be achieved with really high quality spectra: The isotope ratio can be determined rather accurately from the line profile itself.

It still remains to carry out similar observations on the last few cases of reported high ${}^6\text{Li}/{}^7\text{Li}$ values, e.g. ν And. However, all previous detections having now been disproved whenever subjected to reexamination on high-quality material, one might expect the remaining cases of high ${}^6\text{Li}/{}^7\text{Li}$ in dwarfs and subgiants to also disappear under closer scrutiny.

Conclusion

In the *Guidelines to Authors*, the Editor recommends that authors enliven the presentation with amusing stories about the difficulties experienced during the observations. Having had the first visitor run on a new instrument, we must almost apologize for not being able to entertain the reader with dramatic accounts of spectacular breakdowns, smoking circuits, and floods of tears and liquid nitrogen. We simply sat peacefully night after night at our computer terminals, quietly observing one star after the other, studying already the results

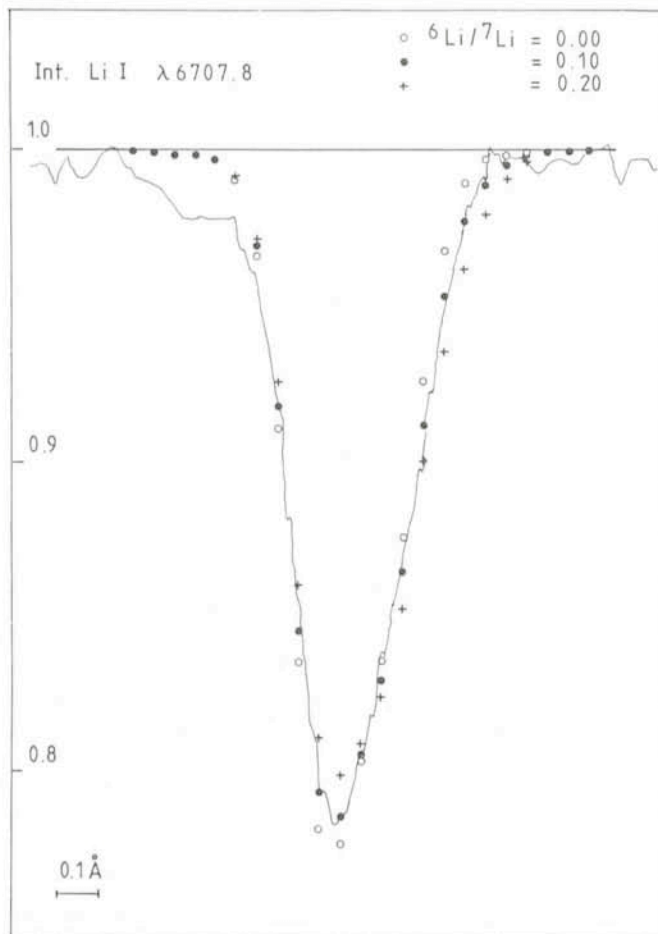


Fig. 2: The observed spectrum of β Hyi and theoretical Li line profiles (dots) for three isotope ratios. The (VI ?) line at λ 6707.43 in the violet wing of the Li line was not included in the theoretical profiles.

of the last observation while integrating on the next star, and trying occasionally to remind ourselves what a disgusting place the smelly interior of a darkroom used to be in the old days. On

Vibrations of Be Stars

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Be Stars – Observed for More than a Century...

Two well-attended IAU symposia in 1975 and 1981 (in the respective proceedings the interested reader may find all relevant references) and an IAU colloquium being planned for the mid-eighties, all three devoted exclusively to Be and shell stars, show that stellar astronomers take a very active interest in these strange objects. The first Be star, γ Cas, was identified as such by Secchi as early as 1866, and today 2–3% of all stars in the Bright Star Catalogue are known to belong to this class. The amount of observational data that has been accumulated is therefore vast, and at all times it has been of the best technical quality. For this reason we are now at a stage where for more and more of these stars it becomes possible (or tempting) to search for periodicities in the (sometimes spectacular) spectroscopic variability exhibited on time scales of years by many Be stars. The idea is that these stars might be binaries and that the mass exchange between the two components is the origin of the line emitting shell around the B-type primary. But for many objects it may well take a few more

ANNOUNCEMENT OF AN ESO WORKSHOP ON

“THE VIRGO CLUSTER OF GALAXIES”

to be held in GARCHING, September 1984

A large amount of observational and theoretical work has been done on this cluster. The workshop is intended to bring together people with a wide range of experience in an attempt to resolve some of the important controversies such as the membership definition, distance estimates, or the density contrast to the local environment, etc.

Both review papers and short contributions will be given, and there could be two panel discussions (if there is enough interest) on (a) dependence of conclusions on membership assignment to individual galaxies, and (b) differences between Virgo cluster galaxies and “field” galaxies: signs of different evolution or different formation?

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the whole, our run was a very convincing demonstration of the quality and efficiency of this new facility, and Daniel Enard and his colleagues are to be cordially congratulated on this achievement. We trust that our readers will, in the end, share our preference for the kind of excitement derived from new, interesting results rather than from ever so picturesque disasters.

decades to distinguish with some certainty between true and spurious periods. So far, there is no indication that the binary frequency of Be stars is any higher than the one of “normal” B stars which itself is roughly the same as for O through G type stars.

...and Still Not Understood

In the past couple of years, the discovery of a hot superionized wind with the COPERNICUS and IUE satellites, ground-based polarimetry and extensive model calculations have enormously improved our understanding of the dynamics, structure, dimensions, and thermodynamics of the circumstellar shell. But all this does not help explaining why some B stars, namely the Be stars, possess a shell and the others do not. Up to now, only the binary model can offer an inherent and plausible answer (mass exchange) to this question. But in view of the relatively small number of confirmed binaries, one should not too readily take a possibility for the fact.