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A Close Look at Our Closest Neighbor: High Resolution Spectroscopy of Alpha Centauri

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As most astronomers will tell you, most of the telescopes are in the northern hemisphere, and most of the interesting objects are in the south. The Magellanic Clouds, the largest globular clusters, and the center of our Galaxy are among the celestial objects that must be studied from south of the equator. Also in the deep south are the Sun's nearest neighbors – the α Centauri system. It contains three stars: (1) α Cen A has the same spectral type as the Sun, although it is slightly more massive; (2) α Cen B is a little less massive than the Sun and orbits α Cen A with a period of 80 years; and (3) Proxima Cen is a very low mass star that is slightly closer to us than either of the other two. Proxima Cen is moving through space in the same direction and at the same rate as α Cen A and B, but is very distant from them.

None of these three stars is particularly unusual – they certainly show none of the bizarre behavior of some astronomical objects. But it is their very ordinariness that makes them so interesting. Here are assembled three excellent examples of the lower main sequence, and they are much brighter than most stars, hence easier to observe. These stars, particularly α Cen A, bear a striking resemblance to our Sun, and so we naturally want to study them in great detail, in order to draw comparisons.

New astronomical instruments are designed to reach new frontiers. This often means being able to examine extremely faint objects at the edges of our Galaxy or the universe. But there is also an inward-facing frontier to be breached, a frontier in the quality of data for bright objects. Astronomical spectroscopy has traditionally used (and still does) photographic plates to record stellar spectra. Photographic emulsions are inefficient (only 1 in 1,000 photons gets recorded), and even for the best cases the data are mediocre. The quality of a spectrogram is measured by its signal-to-noise (S/N) ratio. An exposure with S/N = 100 means that there are random fluctuations of $\pm$ 1 % in the data. Such fluctuations prevent the detection of very weak absorption lines, and stronger lines do not get defined well enough to detect subtle but interesting phenomena. Photographic spectra rarely exceed a S/N of 100.

Technological advances in the last decade have produced the Reticon and the CCD. The Reticon is particularly well suited for high S/N spectroscopy of bright stars. It is better than 90 % efficient at many wavelengths – hardly any photons are wasted! A Reticon is capable of producing data with S/N $\gtrsim 10^4$. Obtaining such data is time consuming and difficult, but the efforts are rewarded by spectra of unprecedented detail.

Such a Reticon is in use on ESO's Coudé Echelle Spectrometer (CES), a high resolution stellar spectrograph that is fed by the Coudé Auxiliary Telescope (CAT). The CES is the best instrument of its kind in the southern hemisphere – no other can deliver the same combination of high S/N and high spectral resolution. Because it is unique, ESO has granted time on the CAT/CES to North American astronomers; indeed, one such person was involved with the design and testing of the instrument. Further, our National Science Foundation provides travel funds to use such instruments if they do not duplicate US facilities.

I therefore found myself on La Silla in April 1983, using the CAT/CES to observe α Centauri A and B. My objective was to compare these stars to the Sun in order to learn about several age-related properties of solar-type stars. All of these properties relate to the presence of a convective envelope. Convection mixes the surface material deep down into the star. One manifestation of this mixing is that lithium atoms are gradually destroyed because they undergo nuclear reactions at a temperature of about two millions degrees. Although the exact process is poorly understood, the convective envelopes of solar-type stars must reach such a temperature because we can see that their lithium is depleted. For example, meteoritic material contains about 200 times the lithium that is now present on the solar surface, and very young stars also have lots of lithium. Old stars have little or no lithium. Because of this gradual lithium depletion, a star's lithium abundance can be used to estimate its age.

Determining a star's lithium abundance is difficult. If one wished to observe, say, iron in a star, there are hundreds of absorption lines to measure, and so some of the errors of measurement cancel out. But there is only one lithium feature available, at 6708 Å wavelength. To make matters worse, no element in the Sun is less abundant than lithium (except for the heavy, radioactive elements). The only positive factor is that this lithium feature is well out in the red, where modern detectors like the Reticon are especially sensitive, and where other spectral lines are less of a problem.

The solar lithium feature is extremely weak, and because of this some observers have claimed that it is not even there at all. However, some observations of extraordinary quality, made about ten years ago at Kitt Peak, provide an accurate solar lithium abundance. The Sun is the only old star for which a good lithium abundance exists, and is therefore crucial for calibrating the lithium abundance-age relation. Therefore α Cen A provides a good test of whether or not the Sun has a lithium abundance that is typical for a star of its mass and age.

To see why this is so, we need to consider the age of the Sun and α Cen. We know the Sun's age by radioactive dating of solar system material. We can also use stellar structure theory to calculate what the present properties of the Sun *ought* to be, and then compare those to the real Sun. As the Sun has grown older, it has converted hydrogen into helium in its core – this produces the solar luminosity. The very center of the Sun

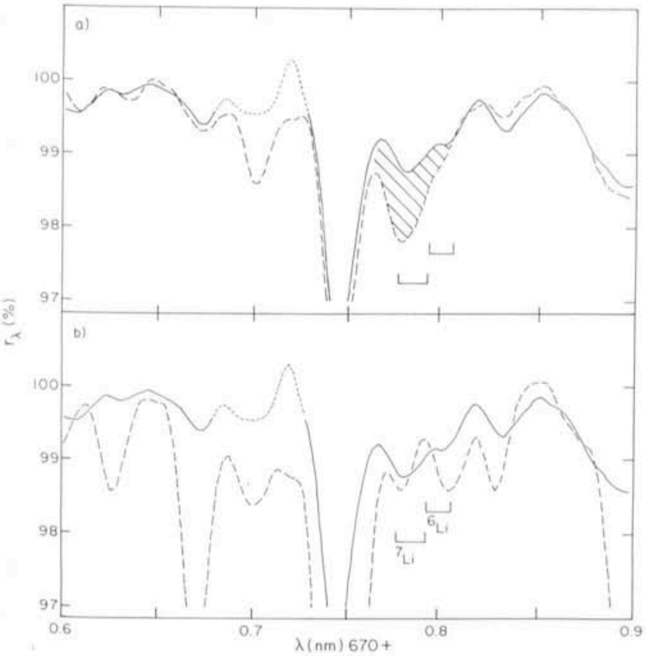

Fig. 1: *Data from the CAT/CES for lithium in α Centauri and the Sun. Note the vertical scale: only the top three percent of the spectrum is displayed. In both panels, the solid line shows a solar spectrum (the dotted section is a Reticon imperfection). Panel* a) *compares α Cen A to the Sun, while* b) *shows α Cen B. The expected wavelengths of the lithium lines are shown in the lower panel.* ^{6}*Li is rare – it constitutes less than 10 % of the total solar or terrestrial lithium. The* ^{7}*Li feature is a doublet, with the blueward component being twice as strong as the redward one. The shaded region in the upper panel shows the extra lithium absorption in α Cen A compared to the Sun.*

gradually runs out of hydrogen, and this causes the structure of the Sun to adjust in order to keep the nuclear reactions going. Because of all this, the Sun has grown a little warmer and larger over its main sequence lifetime.

We can use the same theory to determine the age of α Cen. The parallax and apparent magnitude together define the star's true luminosity. Determination of the temperature is then needed to get the age, since we know the mass (because it is a binary). This sounds straightforward, but is in reality difficult and uncertain. Because α Cen is in the south, it has not been as thoroughly observed as nearby stars that are in the north. Therefore the parallax and masses are not as well determined as we would like. The age one calculates depends on the composition of the star, and that is not known very well either. The best present estimates place α Cen at about 6 billion years old, just a little older than the Sun's 4.6 billion years.

For the purpose of understanding the lithium, it is sufficient to just compare α Cen A to the Sun. A great deal of effort is saved because it appears that they have the same temperature. Carefully determined spectral types for α Cen A and the Sun are identical. Comparing the spectra does not suffer from the usual problems of comparing the Sun to other stars: an excess of light that stellar equipment cannot handle. Another way of comparing temperatures is to compare Hα profiles. Again, α Cen A and the Sun appear to be indistinguishable.

If we assume that α Cen A and the Sun have exactly the same temperature, getting a lithium abundance is easy; we just need good measurements of the line strengths. An example of the lithium spectral region is shown in Fig. 1. You can see that the lithium spectral feature is a good deal stronger in α Cen A than it is in the Sun, but lithium is probably absent from α Cen B. These data indicate that α Cen A has about twice the solar lithium abundance. D. Dravins of Lund Observatory has also observed lithium in these stars, during the commissioning of the CAT/CES, and his data give the same result.

What does this mean? Remember that α Cen A is slightly more massive than the Sun (10 % more), while α Cen B is 9 % less massive. The depth of the convective envelope is extremely sensitive to a star's mass, so α Cen A should have a thinner convective zone than the Sun does. Therefore the lithium depletion will be slower, and α Cen A's greater lithium abundance is reasonable. Similarly, a star like α Cen B depletes lithium much faster than the Sun does, and it has none left.

There are other age-related properties that are being studied in these stars, such as the strength of their chromospheres and their rotation rates. They will have to be discussed another time.

The staff of ESO make observing there a real pleasure. I would particularly like to thank Sr. José Véliz for his help.

Ca II in HD 190073 Revisited

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In 1933, Paul W. Merrill, of the Mount Wilson Observatory, published, with the collaboration of Cora Burwell (Merrill and Burwell, 1933), a Catalogue of such attractive objects as the B and A stars that display emission lines in their spectra.

The classical model for the Be stars suggests that we are dealing with evolved (off the main sequence) objects and that the emisson arises because of a geometrical effect in the flat, extended envelope that surrounds them. This envelope would result from the shedding of matter through the equatorial bulge because of instability generated by the large rotational velocities that seemed to characterize our group of objects. Such a model is, however, vulnerable in many aspects, as recent studies, particularly those that cover the satellite ultraviolet wavelength region, have disclosed. Indeed, the apparent correlation of rotational velocity and emission is no longer an established fact, the mass loss rate does not seem to be related with velocity of rotation, and it does not seem to be necessarily true that the emission is observed because of a geometrical effect. The investigation of Be and Ae stars, in as an extended a wavelength range as possible is, therefore, most desirable if we wish to reach a full understanding of their nature and of the structure and extent of their gaseous envelope.

One of the particularly interesting stars of the group is the one listed under number 325 in Merrill and Burwell's (or Mount Wilson) Catalogue and known as MWC 325, or, more gener-