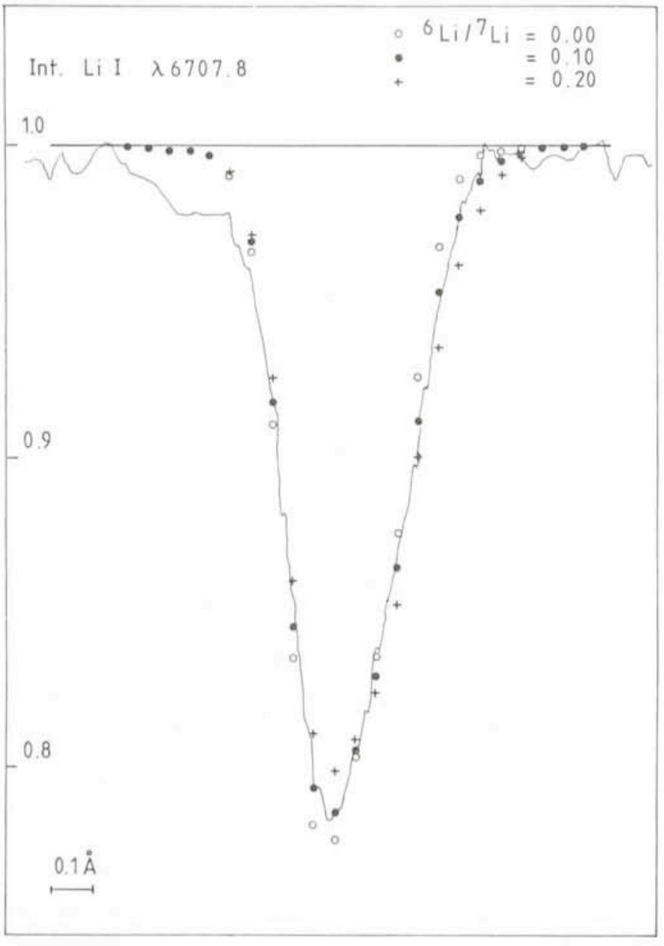

Fig. 2: *The observed spectrum of β Hyi and theoretical Li line profiles (dots) for three isotope ratios. The (VI ?) line at λ 6707.43 in the violet wing of the Li line was not included in the theoretical profiles.*

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 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.

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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Vibrations of Be Stars

D. Baade, ESO

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 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.

Be Stars Do it Faster

The problem with Be stars is, however, even more basic: The fundamental properties of the central stars, like mass, temperature, radius, luminosity, and evolutionary status, are only known with little accuracy. Many Be stars are members of star clusters (e.g. the Pleiades), and so it is well documented that Be stars are lying above and to the right of the zero-age main sequence. But evolutionary effects, a companion, the influence of the shell, and the rapid rotation can *each* account for most of this observation. Even a relative calibration is therefore difficult. The only well-established fact is that classical Be stars rotate faster than "normal" B stars (but it is no longer believed that Be stars are rotating at the break-up velocity and only for that reason losing mass to their envelope). The angular momentum transfer in an interacting binary can spin up a star, but the present statistics do not support the idea that this holds for all Be stars. Thus, we are still left with the question why the phenomenon of superrotation is so much more abundant among B-type stars than within any other class of stars (while binaries are about equally frequent over a wide range of spectral types).

Drilling Holes into Stars

If one wants to look for an explanation, it is probably inevitable to investigate the internal structure of Be stars and to compare it to "normal" B stars. The only means to observationally probe the interior of a star (a Be star in this particular case) whose surface properties are not too different from better known objects (here: "normal" B stars) but ill defined in the individual case, are stellar oscillations. (A very prominent example is the sun whose recently discovered oscillations will probably disclose much about its internal mass and angular momentum distribution.) In the case of the Be stars, oscillations might additionally be involved in the mass loss mechanism. And they permit an interesting speculation: Recent investigations show that rotation and nonradial oscillations can interact with one another so that rotational energy is converted into pulsational energy and vice versa. Should oscillations even be able to explain the rapid rotation of Be stars (which would then only be a surface phenomenon)? – So far, so good. But who said that Be stars are pulsating?

Nonradial Euphoria – Somewhat Damped

The first observations that were interpreted this way were published in the 1979 December issue of the *Messenger*. On photographic spectrograms obtained with the coudé spectrograph of the ESO 1.5 m telescope it had been found that in the Be star 28 CMa all (stellar) absorption lines (except for the hydrogen lines) were asymmetric and variable with a period of 1.37 day. At that time, this was by far the shortest stable spectroscopic period of a classical Be star. By eliminating all other models rather than by strong positive arguments it was concluded that this star is a nonradial pulsator. The crux of this model is that it can explain the unusual lenght of the period (the period of the fundamental radial mode would be just a few hours) the easiest if the pulsation waves are travelling in the direction opposite to the rotation. Theorists, however, had independently found that these so-called retrograde modes are much less likely excited than prograde modes.

Alpha Clavis?

Because of their extreme rotationally caused shallowness, the study of absorption lines in Be stars is quite difficult.The situation is actually even worse since almost all reasonably strong lines are due to hydrogen or helium which, owing to the Stark effect, are mostly useless for the investigation of locally confined velocity variations on the stellar surface (the example of 28 CMa and Fig. 1 illustrate this clearly). But with ESO's new Coudé Echelle Spectrometer (CES) it became eventually possible to discover more Be stars of the same type as 28 CMa. The new data confirmed most of the previous argumentation, the proof of the nonradial pulsation model was nevertheless still pending. Only during my latest observing run at La Silla last June, I had the luck to discover what may be the key star to this problem and, if correct, to some others, too (see above).

Eureka

Fig. 1 shows two sets of four and five profiles, respectively, of the lines He I λ 4471 and Mg II λ 4481 in μ Centauri. The variability of the magnesium line belongs to the most complex ones ever observed in stars. We can see that each profile contains a number (three to four on average) of absorption features. With time, they move from positive to negative velocities across the entire line profile. In addition, the over-all shape of the profile is of variable asymmetry (note that in the helium line only this variation is clearly visible) which evolves the same way. Either variation shows that something is moving on the stellar surface *opposite* to the direction of motion of the rotation! Analysis of a larger number of observations shows that this "something" repeats periodically every 0.101 day for the small absorption features and every 0.505 day for the asymmetry. The period ratio is thus five and means that both patterns are moving with the same angular velocity on the stellar surface because the small absorption components are five times as many as the "asymmetry features".

A Star Like a 20-Bit Orange?

In order to test the nonradial pulsation hypothesis, I have developed a computer programme to calculate model line profiles of a nonradially pulsating star. I could reproduce the

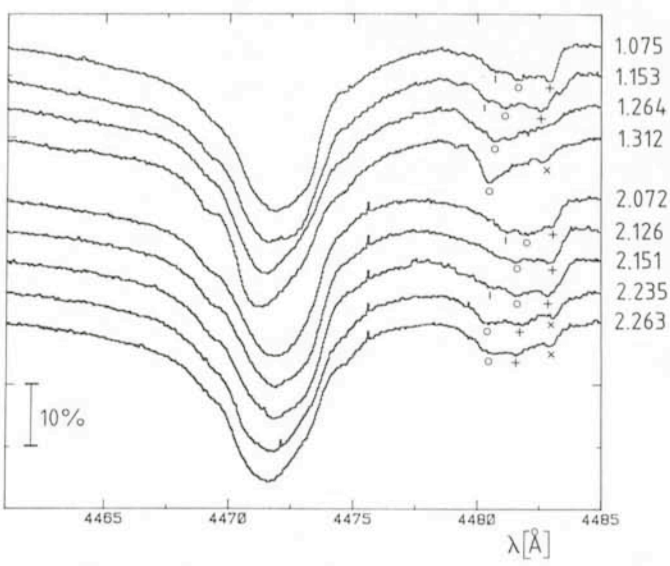

Fig. 1: *Series of 4 (top) and 5 (below) CES spectra of He I λ 4471 and Mg II λ 4481 in μ Centauri, observed with the CAT in two consecutive nights in June 1983. Note the difference between the two lines: The magnesium line is of variable asymmetry with several secondary absorption features superimposed; in the helium line the latter are almost undetectable. The time of the observations (in days, arbitrary zero point) is given on the right. In either group of spectra the secondary components of the magnesium line are identified with different symbols.*

observations of Fig. 1 quite well if and only if a (10, +10) plus a (2, +2) mode were assumed. The meaning of the notation is the following: The first number denotes the number of waves travelling around the star. The equality of the two numbers says that each wave occupies one sector extending from one pole to the other while the azimuthal width of the sector is determined by the number of the travelling waves. (A velocity map of the star would look like an orange whose peeling has been cut into pieces along an according number of great circles.) Finally, the plus sign means that the waves are travelling opposite to the direction of the rotation. In this model, the (10, +10) mode is responsible for the small absorption features in each line while the (2, +2) mode produces the variable asymmetry.

Retrograde in Resonance: A Step Forward

The common angular velocity of the two pulsation velocity patterns strongly suggests a resonant coupling of the two modes. The mutual stabilization could perhaps explain why against theoretical predictions retrograde modes are excited. Independent of the direction of the travelling waves, the ratio of their number in the two modes should be 5 if only surface conditions for the coupling are considered (it remains to be investigated if this means that the observed oscillations are mainly a surface phenomenon). This is indeed found in μ Centauri. Some simple considerations furthermore show that the postulated resonant coupling is much more likely in rapidly rotating stars. This is a nice result since Be stars are the fastest rotators on the right of the zero-age main sequence in the H-R diagram.

Simulations with the above-mentioned computer programme demonstrate that (not surprisingly) the multiple components caused by high-order modes cannot be observed in spectral lines of stars with low v sin i (like 28 CMa) because the intrinsic width of each component is too large to be resolvable. In the past, my observations focused on "slow" rotators because the asymmetry variations due to low-order pulsations which I had been looking for are most pronounced in stars with low v sin i. This (and perhaps also the better performance of the new Reticon array by which the previous one was replaced at the beginning of my last observing run) explains why I missed the unexpected high-order pulsation modes in earlier observations.

Loss of Harmony and Mass

It is tempting, but presently not justified to speculate that all Be stars are pulsating. However, my own observations of a few other Be stars clearly show that the phenomenon is not infrequent in early spectral subclasses (because I was searching for objects related to β Cephei and 53 Persei stars I did not observe later types). This is in line with observations by a group at the University of British Columbia in Vancouver of other early-type Be stars which could be the prograde counterparts to μ Cen (as may be some of the other stars, too, that I observed). This may justify the question if there is a relation between the episodal mass loss of Be stars and their pulsation: Suppose that the coupling of the modes is relatively weak (surface phenomenon?); could it then be that the mass loss is strongly enhanced (shell ejection) when the two pulsations get (temporarily) out of phase?

Bugs in a Pink Sky?

The *Messenger* is a forum where observers may occasionally paint the sky in pink. I should therefore stress that the model for μ Centauri still needs to be tested more extensively. However, if it should pass these tests successfully, the shells of Be stars will become a bit more transparent.

Barium Stars Observed with the Coudé Echelle Spectrometer

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Barium Stars: Nuclear Accidents that Should Not Have Occurred

Synthesis of heavy elements – by neutron irradiation of iron group seed nuclei – is generally believed to take place during advanced evolutionary stages of red giants and supergiants. Standard theory of stellar evolution suggests that thermal pulses occurring in the helium shell of stars with two active shells provide the mixing and thermal processing required to supply the neutrons. Stars in this stage of evolution are expected to be luminous cool giants and supergiants, with effective temperatures well below 3,500 K and luminosities of $10^3 - 10^4\ L_\odot$ and more. Indeed, some of the stars which are found in this part of the H-R diagram – the peculiar giants of type S, including the technetium stars – show freshly synthesized heavy elements mixed to their surface.

In contrast, there is another group of red giants – the barium stars – which also show enhanced heavy elements, but who have too low luminosities ($\approx 100\ L_\odot$ and less) and too high effective temperatures (4,600 – 5,200 K) to be in the shell flash stage (Scalo 1976, *Astrophysical Journal* **206,** 474). Most probably these stars are less evolved red giants in the helium core burning phase. The elements H, He, and C required to provide the free neutrons are indeed available in such stars, but they occur in different zones well separated by convectively stable layers. Standard evolutionary theory does not predict extensive mixing earlier than in the double-shell phase.

Virtually all Ba stars have low-mass companions (McClure, 1983, *Astrophysical Journal* **268,** 384). Although separations appear too large for any close interaction to have occurred, their binary nature must be related somehow to the abundance peculiarities.

Barium stars are not exotic objects, but make up at least 1 % of all red giants. Our theoretical knowledge of red giant evolution will be incomplete unless we understand why, and how, unorthodox mixing events and release of neutrons can occur in the lower red giant branch. We may hope to learn more about this by studying, in a reasonable sample of stars, the detailed record of this neutron irradiation as provided by the abundance pattern of the various heavy elements.

Analysis of Barium Stars Based on CES/Reticon Spectra

On the observational side, a prerequisite for reliable abundances will be spectra of sufficiently high resolution to yield true