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

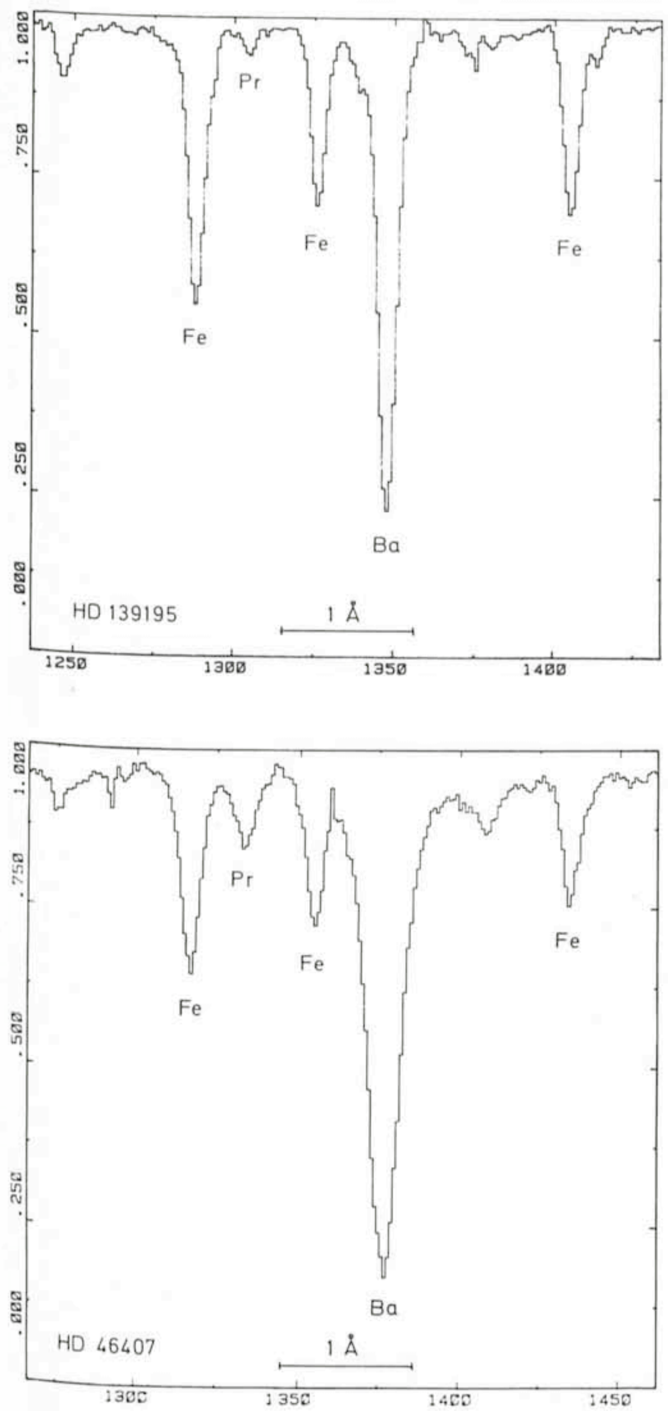

Fig. 1: *CES/reticon spectra of two barium stars, HD 139195 (m_v = 5.3) and HD 46407 (m_v = 6.2). A small section of the original spectrum is shown, extending from channel number 1240 to 1430. The spectrum is centred at the Ba^+ line 5853.69 Å and includes three iron lines and one due to the rare earth element praseodymium. In HD 139195 the Ba/Fe ratio is enhanced with respect to the solar value by a factor of three. HD 46407 is a more extreme Ba star: whereas the iron lines are of similar strength as in HD 139195, those of Ba and Pr are clearly enhanced.*

stellar line profiles. This is particularly important for red giants, where we want to take advantage of their enormously rich line spectrum. A resolving power of at least 10^5 is required; the ESO Coudé Echelle Spectrometer is ideally suited for this purpose.

Another crucial point is the linearity of the intensity scale. The reticon – although a linear detector – has a dark current whose contribution to the stellar signal may become sensible in long integrations at low light level. During my observing period in February 1983 the dark counts accumulated in 90 minutes corresponded to 1 % of the saturation level of the reticon. If your integrated stellar signal is only 5 %, say, of this level, you will have to be pretty sure about how many dark counts you subtract (the dark current was said to be unusually high at that time, and I found it was not sufficiently constant to permit scaling to very different exposures). Thus, if one wants to fully exploit the high photometric accuracy the reticon is capable of, one has to spend quite some time on dark integrations. Nevertheless, the CES/reticon system is very efficient and versatile, and it makes much fun to work with it.

High-quality spectra call for adequate analytical techniques. Most of the earlier analyses of Ba stars employed curve-of-growth methods. Furthermore, most oscillator strengths available at that time are now known to be highly unreliable. In view of this, and of the lower resolution necessitated by photographic spectroscopy, one is not surprised that grossly discrepant results have been reported for the same objects: heavy-element abundances sometimes differing by more than a factor of ten! Model-atmosphere techniques are indispensable, combined with use of solar f-values, and careful consideration of the departures from LTE recently found in red giants.

To my knowledge, heavy-element abundance determinations that conform to these standards are available for only two Ba stars: ζ Cap and HR 774 (Smith et al., 1980, *Publ. Astron. Soc. Pacific* **92,** 809; Tomkin and Lambert 1983, *Astrophysical Journal,* in press). With the ESO Coudé Echelle Spectrometer coming into operation in 1982, a European contribution to this field of research has become possible. In two periods of observation I have recorded reticon spectra of seven southern Ba stars with visual magnitudes ranging from 5.1 to 7.0. Spectral resolution was 100,000 throughout. Two examples are shown in Fig. 1.

One major disadvantage of the CES/reticon system – as opposed to photographic spectroscopy – seemed to me that only a small part of the spectrum can be recorded in one integration: about 40 to 80 Å, depending on wavelength. But now I am convinced that a detailed stellar analysis is nevertheless possible – and even preferable – on the basis of a moderate number of high-quality narrow-band spectra, provided the wavelength bands are carefully chosen to contain spectrum lines of strategic importance. On average, six wavelength bands were recorded for each star, distributed over the wavelength range 5180 to 10330 Å. Integration times were typically 80 min. for the Ba star HD 46407 (visual magnitude 6.24); somewhat larger exposures were needed in the near infrared, and the Sr^+ line at 10327 Å could be reached only in the brighter objects of my sample.

Model-atmosphere analysis of these spectra is currently carried out at Kiel. Dr. N. Kovács, who is engaged in this project, has already published results for two of the seven Ba stars, HD 65699 and HD 83548 (*Astronomy and Astrophysics* **124,** 63).

Selective Enrichment of Magic Nuclei

Six of the seven Ba stars of our sample show the typical enrichment pattern which other investigators have found among other objects of this type: overabundances relative to iron of all spectroscopically observable heavy elements that can be synthesized by slow neutron capture, e.g. Sr,Y, Zr, Ba and the rare earth elements La, Ce and Nd. Minor differences from star to star may be attributed to slightly different neutron irradiation which, in any case, must have been quite strong in order to convert iron "seed" nuclei into those heavy elements. The overall heavy-element content of these "ordinary" Ba stars requires only a small fraction of the stellar envelope to have

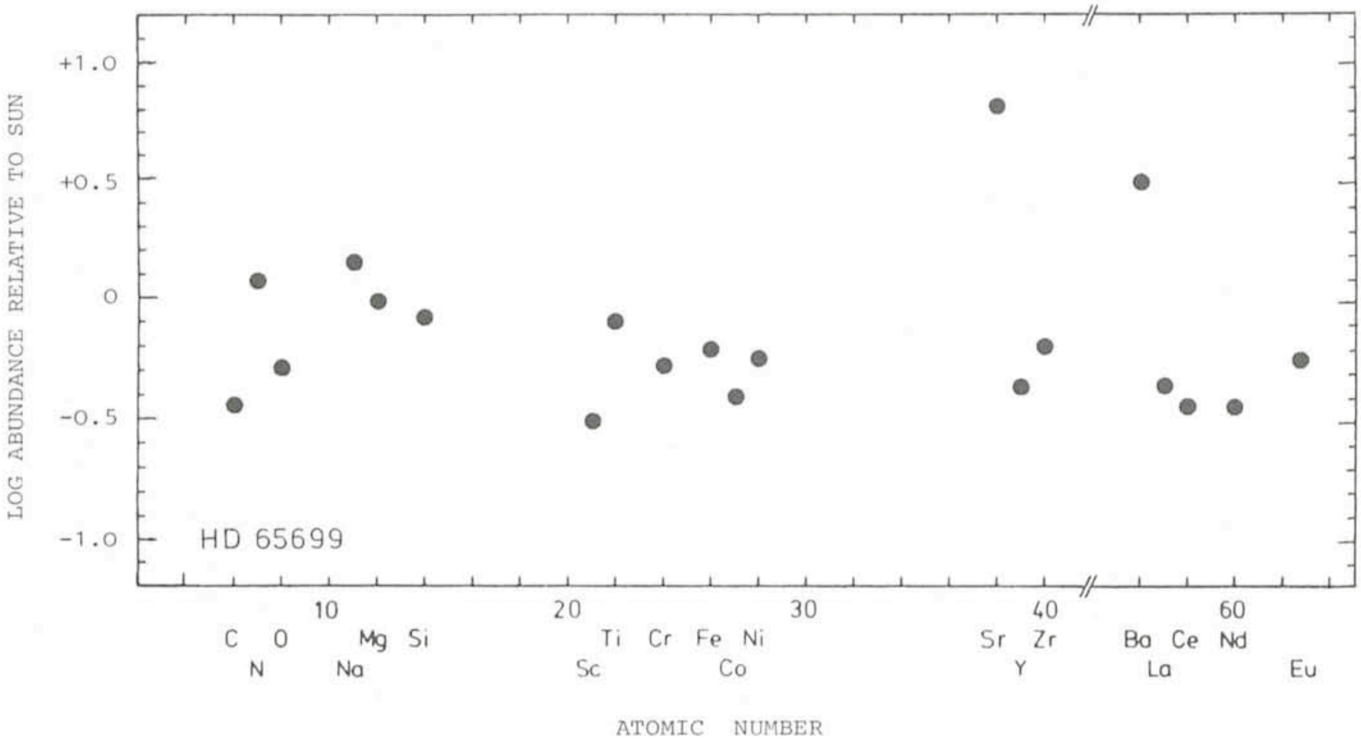

Fig. 2: *Elemental composition of the Ba star HD 65699 showing selective enhancement of strontium and barium (Kovács 1983).*

been processed. In the case of HR 774 quoted above, this fraction is of the order of 0.1%.

In contrast, one of the Ba stars – HD 65699 – exhibits a peculiar abundance pattern. Barium is enhanced by about a factor of four, and strontium even more, but the other observable heavy elements are virtually unchanged (Fig. 2). Interestingly, there seems to be a connection to normal giants. In recent years five bright red giants and a supergiant – all of spectral type K – have been analysed at Kiel on the basis of high-dispersion photographic spectra, including 3.3 Å/mm plates taken at the ESO 1.5 m telescope. According to Kovács (1983, *Astronomy and Astrophysics* **120,** 21), two of these evolved objects – α TrA (K4 III) and ε Peg (K2 Ib) – show a selective enrichment of Ba (the Sr abundance is not yet known). It seems to me that the high-quality CES/Reticon data of the Ba star confirm that a chemical peculiarity of this kind may occur among evolved objects.

The question arises which sort of slow neutron capture process is able to selectively enrich Sr and Ba. A clue to this puzzle may be found in the systematics of neutron capture cross-sections of the heavy nuclei involved. By far the smallest cross-sections occur at the "magic" nuclei ^{88}Sr, ^{138}Ba, and ^{208}Ba, possessing closed neutron shells with 50, 82, and 126 neutrons, respectively. Small cross-section means that the nucleus has only a small chance to capture a neutron, and thereby to increase its mass by one unit as required in order to proceed towards heavier elements. The traditional scheme assumes that there are so many free neutrons available that these barriers are easily overcome. A large range in mass is produced; the resulting abundance pattern depends on the individual cross-sections and on the details of the irradiation event(s). This process obviously has operated in the "ordinary" Ba stars, and is responsible for their general enrichment of heavy elements. However, there seems to be no way to produce only Sr and Ba, and leave elements like Y, Zr, La, Ce, and Nd unchanged.

A simple variant of the traditional scheme appears more promising. In a forthcoming paper together with N. Kovács we report calculations – employing recent neutron capture cross-sections – which show that selective enhancement of Ba can indeed be obtained if the neutron irradiation is weak, shifting pre-existing heavy nuclei of normal population I matter by only a few mass units. This mild irradiation piles up excess abundances at the magic nuclei, at the expense of the elements immediately preceding Ba. Among those, Sb, Te and Xe are predicted to show the largest depletion; unfortunately we cannot check this observationally because these elements are not accessible to spectroscopy. But Ba and some of the rare earth elements following Ba are accessible. Our model predicts

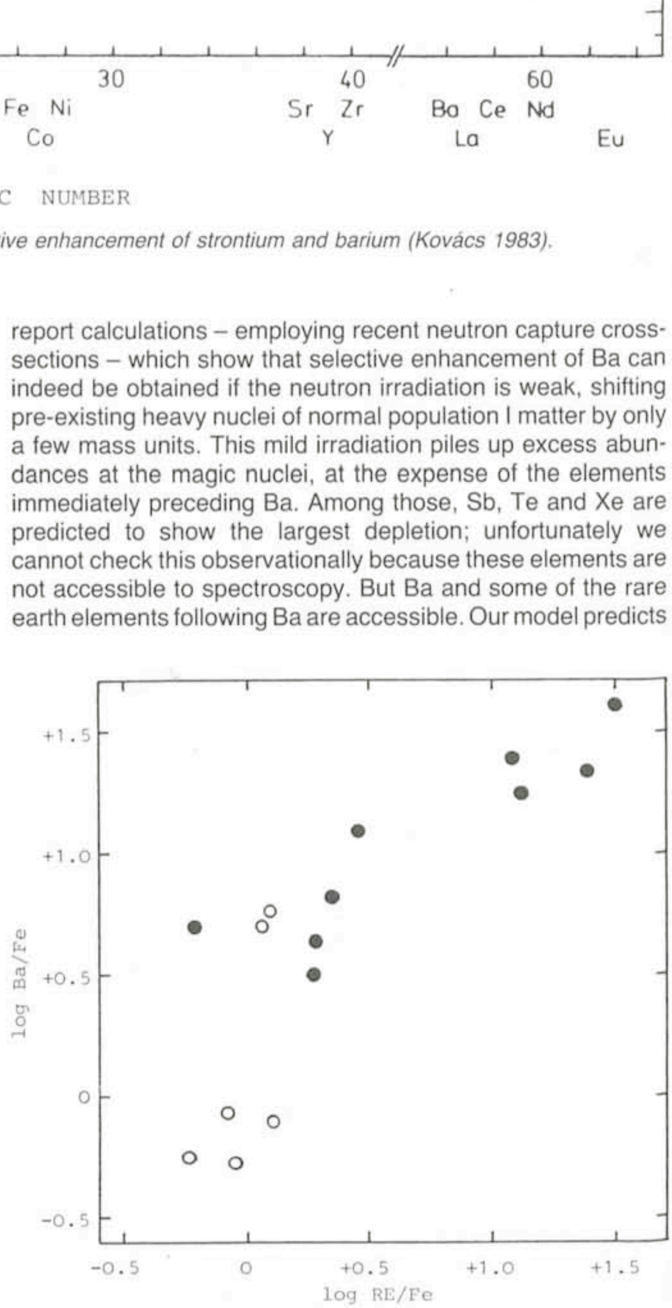

Fig. 3: *Enhancement of barium versus enhancement of rare earth elements (La, Ce, Nd) in Ba stars (filled circles) and "normal" red giants (open circles).*

an increase of the barium abundance by a factor of three, whereas La and Ca change by less than 15 % – in agreement with what we find in HD 65699, α TrA, and ε Peg.

The distinguishing feature of this alternative scheme is that it involves weak processing, yet of a large fraction of the stellar envelope. HD 65699, α TrA, and ε Peg appear to be extreme cases. The data so far obtained from high-resolution spectroscopy of K-type giants and Ba stars are collected in Fig. 3, which also includes the analyses of ζ Cap and HD 774 by Smith et al., and by Tomkin and Lambert cited above. Fig. 3 suggests that a whole sequence of combinations of neutron irradiation and mixing exists – while standard theory of stellar evolution does not predict any production of heavy elements at the relatively high effective temperatures and low luminosities of our objects!

The Optical Pulsar H 2252-035 (AO Psc)

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The optical counterpart of the pulsating X-ray source H 2252-035 appeared to be an interesting object for optical astronomers also. In the X-ray domain it shows the same characteristics as other pulsars. Its X-ray emission is modulated with a period of about 805 s, the pulse amplitude being about 25 % in the energy range 5–15 keV, 50 % in the range 2–5 keV and almost 100 % between 0.1 and 4 keV. The increase of pulse amplitude with decreasing energy is the only feature distinguishing this object from the other neutron star pulsars.

For the optical astronomers the source looks like a typical cataclysmic variable, most probably consisting of a compact object (magnetic white dwarf or neutron star) and a low mass star orbiting with a period of about 3.6 h, revealed by both photometric and spectroscopic observations. What makes, however, the object particularly interesting is the presence of additional light modulations with periods of about 805 and 859 s. The first period corresponds exactly to the period of X-ray flux modulation; the second one, however, is not independent from the two others: the difference of frequencies corresponding to the 805 and 859 s periods is equal to the frequency of the orbital motion. As all three periods are real and can be observed as independent light modulations, this means that the 859 s period is connected with radiation emitted originally with an 805 s period and "reflected" somehow from an element of the system taking part in (prograde) orbital motion.

Thus, we can adopt the following working model of the system (J. Patterson and Ch. Price, 1981 *Astrophysical Journal,* Letters, **243,** L83): A close binary contains a compact object – the pulsar – fed by the matter being lost by a dwarf secondary and accreted via a disk by the magnetized compact primary. A moderately strong magnetic field of the primary channels the accretion at the polar regions, giving rise to intense X-ray and optical radiation emitted mainly within a cone the aperture of which depends on the details of the emission mechanism. Rotation of the compact star modulates the X-ray and optical emission with the period of 805 s. A part of the X-ray flux is reprocessed – in the secondary's atmosphere or somewhere in the accretion disk – and observed by an external observer as the 859 s modulation in the X-ray emission.

In order to enlarge somewhat our knowledge of the optical characteristics of the system, H 2252-035 was observed on five nights, between 3 and 10 October 1982, with the standard UBV

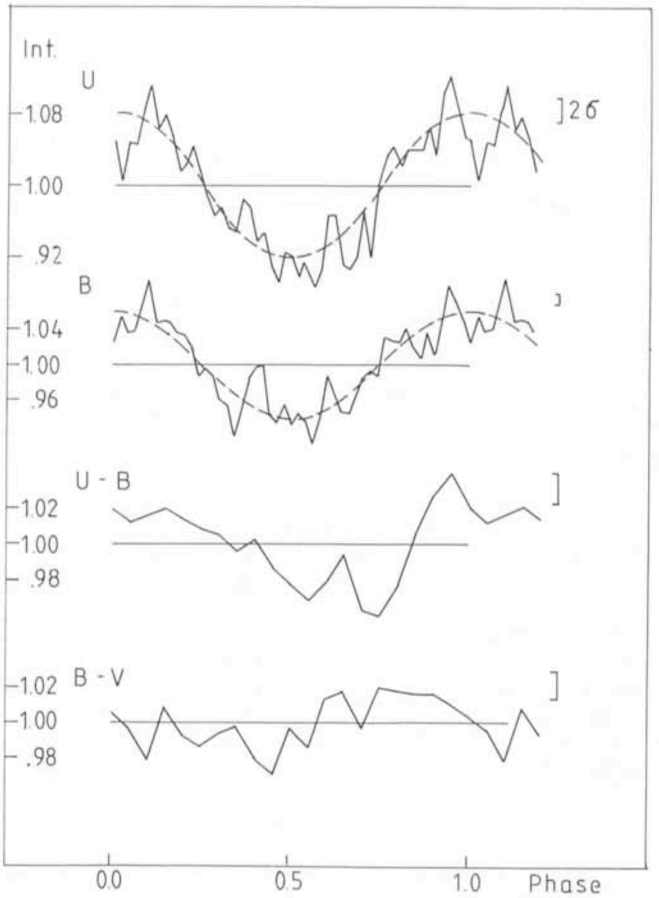

Fig. 1: *Mean brightness and colour changes with orbital period (in intensity scale). Broken curves – sinusoids resulting from periodogram analysis.*

Table 1. Results of periodogram analysis

Periodicity	U amp	U Φ	B amp	B Φ	V amp	V Φ	U – B amp	U – B Φ	B – V amp	B – V Φ
orbital	0.083	– 0.19	0.062	– 0.02	0.047	0.19	0.025	0.36	0.016	– 1.19
reprocessed	0.044	– 1.50	0.036	– 1.62	0.021	– 1.93	0.013	– 1.97	0.008	– 0.98
pulsar rotation	0.025	1.29	0.012	1.51	0.013	0.15	0.011	1.38	0.007	2.69