VI INTERMEDIATE HELIUM STARS

INTERMEDIATE HELIUM STARS:
ATMOSPHERIC PARAMETERS, OBLIQUE ROTATORS AND SHELLS

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1. INTRODUCTION

Intermediate helium stars are defined by

$$0.3 < n_{He}/n_H \lesssim 10$$

n_{He}/n_H being the number ratio of He over H. The upper bound which separates the intermediates from the extremes is well-defined (see Sect. 7), whereas the lower bound is rather soft.

The first intermediate helium star discovered was Sigma Ori E (Greenstein and Wallerstein, 1956). Since then, 23 intermediates with $V \lesssim 11^m$ have been found (see the list of Walborn, 1983 and also the Annex), mostly through surveys such as that by McConnell et al. (1970) and McConnell (1972). (To this list, the newly discovered object SB 939, Langhans and Heber, 1985, should be added.) It is anticipated that a substantial fraction has as yet escaped detection. The spectral type centres around B2V while n_{He}/n_H is typically of the order of unity.

Up to the mid-seventies, most of the work done on the intermediates was in photometry and spectral analysis of the photospheres. The results were reviewed by Hunger (1975) who gave a complete bibliography. In the following, mainly the period starting 1975 is reported. For the older literature the reader is referred to the above cited review. He is also referred to the reviews by Bolton (1983) and Hunger (1986).

The previous results (Hunger, 1975) indicate that the intermediates do not form a uniform class but are divided into 2 distinct subclasses, one with $M \lesssim 2\ M_\odot$, which may be linked to the extremes, and one with $M \gtrsim 2\ M_\odot$ which belongs to a young population, and which are often fast rotators with strong and variable magnetic fields and variable strengths of the absorption lines. In the former, He-enrichment would be the result of nuclear evolution while in the latter, He-enrichment may be brought about by diffusion (Osmer and Peterson, 1974, Vauclair, 1975). This subclass is considered to be the extension of the Ap-star sequence.

The existence of a low-mass component has been questioned by

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various authors (see the discussion in the paper by Walborn, 1983). In particular, the idea of a nuclear He-enrichment of a young star is hardly acceptable. Since the low masses are derived from low gravities, and these in turn from small equivalent widths, the calibration of (mostly ESO) photographic plates has also been questioned. As can be seen in Sect. 4, the disputed calibrations have been re-checked and found to be correct (Hunger, 1986). The small masses, hence, can only be ascribed to the distances being systematically underestimated. We concentrate on this important issue in Sect. 4. Clues as to whether we are dealing with nuclear enrichment or with diffusion will also come from the metal abundances (Sect. 3).

A major part of this review is devoted to the prototype Sigma Ori E as this is the best-studied object, both observationally and theoretically. The discussion covers atmospheric parameters, distance, mass (Sect. 4), He-variability, oblique rotator model (Sect. 5) and (partly) circumstellar material (Sect. 6).

The period 1978-1985 brought a wealth of data on the circumstellar matter around intermediates, mainly through IUE but also through ground-based IR, IRAS and VLA observations. For the variable component of the intermediates, the picture of a magnetic field modulated wind emerges which feeds circumstellar clouds. We have only briefly treated this interesting subject as it will be dealt with extensively in the review by Barker (this conference). Likewise, for the sake of space, we have not reported on the promising attempts to model magnetized stellar atmospheres (Madej, 1971; Carpenter, 1985) and also hot and windy magnetospheres (Nerney, 1980; Havnes, 1981; Havnes and Görtz, 1984; Nakajima, 1985).

2. STATISTICS, ROTATION

Among the intermediates listed by Walborn (1983), about one third (7 stars) are spectrum variables (Walborn, 1975; Bond and Levato, 1976; Pedersen and Thompson, 1977; Pedersen, 1979). Six of the seven stars have variable magnetic fields and one a static field (Landstreet and Borra, 1978; Borra and Landstreet, 1979; Borra et al. 1983;). Five have $v \sin i \approx 150$ kms^{-1}, with periods $P < 2$d, and three have $v \sin i \lesssim 30$ kms^{-1}, with $P \gtrsim 9$d (Walborn, 1983). All variables obey the (P, v sini)-relation for radii $R > 4 R_\odot$, i.e. all variables are considered as being oblique rotators. Four of them belong to the Orion aggregate, one to IC 2944. From these properties, the age τ is estimated to be: 10^6 a $< \tau \lesssim 10^8$ a. The stars are listed in Table I.

TABLE I

List of He-variable and magnetic intermediates

	Period (days)	v sini (kms^{-1})
HD 37017	0.9[1]	170[2]
HD 37479	1.2	170
HD 37776	1.5	160
HD 58260	1.7	≤30
HD 64740	1.3	160
HD 184927	9.5[3]	≤ 17
CPD-46°3093	variable ?[4]	150
HD 96446	non-variable	≤30

[1] Pedersen (1979)
[2] Walborn (1983)
[3] Bond and Levato (1976)
[4] Groote et al. (1982)

The question of a bimodal distribution of the intermediates is also encountered in the statistics of rotational velocities (Walborn, 1983). From these statistics, the possibility that two classes of rotators exist, one with v sini < 80 kms^{-1} and one with v sini > 120 kms^{-1}, cannot be excluded. The statistics, however, depend largely on the way the data are presented. If a uniform binning of the data is used, then the histogram of rotational velocities flattens out and the distinction between slow and fast rotators is lost. In the same way, the differences between early main-sequence B stars and intermediates disappear. Furthermore, there is no correlation between v sini and galactic latitude so that, with this information, one has to conclude that the intermediates have essentially the same rotational velocities as main-sequence stars.

3. CNO ABUNDANCES

Walborn (1983) raised the question as to whether metal abundance anomalies can be seen in intermediates and whether they can clarify their evolutionary status. If helium enrichment were the result of nuclear burning, anomalies of the CNO elements would be present. Since no conspicuous anomalies could be found, Walborn concluded that all intermediates may be Population I main-sequence objects. One problem, however, at least with the helium variables, is that the metal lines are also variable (they vary in antiphase with the helium lines) (Hunger, 1974; Lester, 1979; Levato and Malaroda, 1979; Shore and Adelman, 1981; Walborn, 1982;). Analyses based on a few spectrograms may not be representative of the whole star.

The other problem is of a more general nature: abundance tables are often based on inhomogeneous sets of observations, on different model atmospheres, f-values and also on the way of presentation which renders direct comparison difficult. In addition to the analyses cited by Hunger (1975), the following abundance analyses have been published: HD 60344 (Kaufmann and Hunger, 1975), HD 64740 (Lester, 1976), HD 133518 (Gerlach, 1976), HD 120640 (as a result of the analysis now classified as a normal B star; Detz, 1977), HD 186205 (Lee and O'Brien, 1977) and CPD-46°3093 (Heber and Hunger, 1981; Groote et al., 1982).

A homogeneous table of abundances was published by Hunger (1975). It comprises 8 intermediates, 2 of which are helium variables and one (HD 144941) a border case between the extremes and the intermediates. If we leave out these 3 objects and adopt for hydrogen the normalization, $\log n_H = 12$, then we find a remarkable uniformity in the abundances of the (other) 5 stars: HD 168785, CPD-69°2698, HD 60344, HD 184927 and HD 96446. For the sake of space, we have quoted in Table II only the mean logarithmic abundances, plus the root mean square deviations. The latter proved to be smaller than the typically encountered ± 0.3 dex for the individual abundances, from which we conclude that there is practically only one single type of non-variable intermediate helium star. This statement also pertains to the helium abundances and to the metallicity Z. The range of effective temperatures and gravities is likewise very small, the differences, however, are probably real.

TABLE II

Logarithmic abundances (by numbers) of He, C, N and O, and the metallicity Z, for the average of 5 non-variable intermediate helium stars

	H	He	C	N	O
Intermediates	12.0	11.9 ± 0.05	8.4 ± 0.1	8.0 ± 0.2	8.4 ± 0.2
B-stars (Scholz, 1972)	12.0	10.95	8.6	7.9	8.9

	Z	T_{eff}	log g
Intermediates	0.01 ± 0.003	24600 K ± 2700 K	3.7 ± 0.3

The CNO abundances are essentially normal in the non-variable intermediates. The latter statement allows an important conclusion to be drawn, with regards to evolution. Even if only a very small fraction of helium is generated by nuclear processes, the very sensitive N/C ratio switches from < 1 to > 1 (Caughlan, 1965). Since N/C is found to be smaller than unity, it must be concluded that He enrichment in the non-variable intermediates cannot be the result of nuclear burning but must be due to a selective effect as with diffusion. This statement is not necessarily true for the variables as, according to analyses by Schacht (quoted by Hunger, 1975) and Lester (1976), nitrogen is significantly enhanced in HD 64740. There is also an example for a non-variable with nitrogen enhancement: HD 186205 (Lee and O'Brien, 1977).

Diffusion leading to He enrichment apparently acts only in a narrow range of effective temperatures ($22000 \text{ K} < T_{eff} < 27000 \text{ K}$), and in an even narrower range of gravities ($3.4 < \log g < 4.0$). According to gravity, intermediates have already evolved away from the main sequence or have not yet reached it. The metallicity ($Z = 0.01$) points to the former interpretation.

Hunger (1975) quoted also the masses for the above-described sample of non-variable intermediates. The masses are determined spectroscopically (see Sect. 4) and, hence, depend quadratically on the assumed distances. The mean mass proved to be $2.4 \pm 1.5 \text{ M}_{\odot}$ which is more than a factor of 3 smaller than the mass of a normal composition star. Hence, if one wants to restore the normal B2-star mass ($8 \text{ M}_{\odot}$), one must assume distances which are a factor 1.8 larger than hitherto determined.

Because of the importance of the mass problem (see also Odell, 1974), the atmospheric parameters and the distance of Sigma Orionis E shall be discussed in some detail in the following section.

4. ATMOSPHERIC PARAMETER AND MASS OF Sigma Ori E

As the mass is of crucial importance when one wants to find out whether helium-enrichment is due to diffusion, and hence only a surface effect, or whether it is due to evolution, as is the case with the extreme helium stars, we shall now discuss the mass of Sigma Ori E, the so far best-studied example of an intermediate.

The masses of the intermediates are determined spectroscopically as there are no binaries known in this class, except for HD 37017. The principle of the method is as follows: spectral analysis yields T_{eff} and gravity g while photometry yields apparent magnitudes. If the distance is known and hence the absolute magnitudes, then from $L = 4 R^2 \pi \sigma T_{eff}$ the radius R can be determined, and from $g = GM/R^2$ finally the mass M. The 3 quantities that determine the mass, hence, are T_{eff}, gravity and distance.

T_{eff} is determined from the IUE-flux plus V-magnitude (Remie and Lamers, 1982). As most of the flux of a B star is carried in the IUE band, T_{eff} is determined with a high precision, namely with $\pm$ 2.5%. (This method is largely independent of gravity and chemical composition in the parameter range under consideration.)

Once T_{eff} is known, gravity and helium content can be determined from the profiles of the Balmer and helium lines. (This has to be done simultaneously - see the paper on Sigma Ori E by Groote and Hunger, 1982.) Up to the present paper, only photographic spectrograms have been used. Since gravity depends sensitively on the profiles, the calibration of the photographic plates is important. The ESO calibration, which yields small equivalent widths and hence uncomfortably small gravities and masses, has been questioned (see Walborn, 1983). To settle the dispute, ESO CASPEC spectrograms have been taken from Sigma Ori E. (This spectrograph employs a linear CCD detector.) The result is shown in Figure 1, where the profile of H_{γ} is

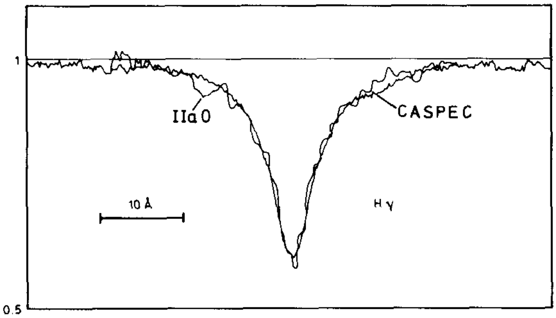

Fig. 1 The profiles of H_γ (Sigma Ori E) obtained photographically (IIa O) and with CASPEC.

reproduced. It fully confirms the photographic profile and, hence, clearly demonstrates the reliability of the ESO calibration. Gravity indeed comes out as small as quoted in the paper by Groote and Hunger (1982): log g = 3.85, again with good precision (Δ log g = ± 0.15), which means that Sigma Ori E is not on the main sequence but is evolving either to or away from it. (In the derivation of T_{eff} and log g, a slight inconsistency is introduced, in as much as for the continuous flux distribution (Kurucz, 1979) normal composition models are employed, while for the line profiles, He-rich models are used. The latter do not account for metal line blanketing. Consistent He-rich metal line blanketed models may lead to gravities which are larger by Δ log = 0.1.)

The only quantity left which could be blamed for the small mass of our prototype object is the distance. If one employs the dynamical parallax of Sigma Ori AB, d = 400 pc (Heintz, 1984), then with T_{eff} = 22500 K and log = 3.85 the mass M = 3.0 $M_\odot$ results, which is roughly a factor 3 too small for a normal composition near main- sequence star (8 $M_\odot$) but in agreement with the mass of a fully mixed star with equal amounts of hydrogen and helium (Röser, 1975) (see Fig. 2). To avoid this conclusion, one must postulate a distance of 700 pc which would simply mean that Sigma Ori E is not a physical member of the quintuplet system Sigma Orionis, but a background star. Whether this is true must be checked by a differential study of the UV interstellar lines and the lambda 2300 feature of the system Sigma Orionis.

5. HELIUM VARIABILITY AND THE OBLIQUE ROTATOR

Since a substantial fraction of the intermediates, i.e. those whose masses are well in excess of 2 $M_\odot$, are helium variables (see Sect. 2), we have to discuss the surface distribution of the chemical elements and possible implications on the outer structure.

The most direct access to the oblique rotator model is offered by the cap model of Mihalas (1973) (see also Hensler, 1979). In this

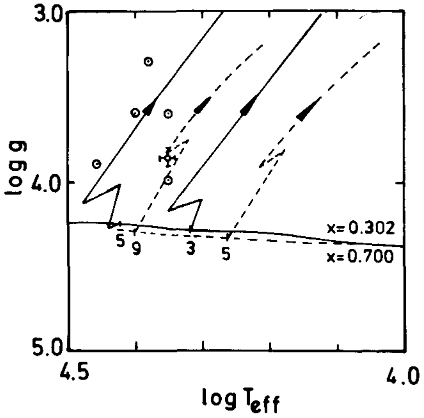

Fig. 2 (g, T_{eff})-diagram. Fully drawn: zero age main sequence and evolutionary tracks for mixed stars with X = 0.302. Dashed: the same as before, for normal composition stars. Circles correspond to non-variable intermediates, the error bars to Sigma Ori E.

simple approach, the helium-enriched surface area is approximated by one or two circular caps which are defined by the diameter, orientation and chemical composition. The 3 parameters can be extracted from the observed phase variations of the equivalent widths W_λ (ϕ) of the helium lines and their variable radial velocity shifts Δ $v_R(\phi)$. The latter play an important role as roughly the same W_λ (ϕ) variations result for a small cap with a large amount of He as for a large cap with a medium amount of He. The radial velocities, however, will tell us which model is appropriate: the small and He-strong cap produces large amplitudes of Δ v_R, while the large cap produces small amplitudes of Δ v_R because the radial velocities are smeared out. The problem with the intermediates is that, so far, no radial velocity shifts have been observed, though efficient cross-correlation techniques have been employed. For Sigma Ori E the radial velocities are constant within 2 kms^{-1} while the equivalent width of He I 4471 varies by as much as a factor of 1.5 (Hunger, 1974; Bolton, 1974; Groote and Hunger, 1977).

A way out of the dilemma of the missing R.V. variations is saturation (Landstreet and Borra, 1978; Groote and Hunger, 1982). In the intermediates, both in the spectrum of the cap and in the disk, the strong He lines are saturated. Figure 3 shows the unrotated profiles of HeI 4471, for the number fractions of Helium ε_{He} = 0.90 (cap) and ε_{He} = 0.35 (disk). It appears that, due to a slight difference in the temperature structure, the helium "poor" disk produces a core that is even slightly deeper than that of the helium rich cap. From this example, one would expect the cores of strong He lines to be stationary while the wings of the strong lines and the cores of unsaturated (faint) He lines would, at least partially, reflect the motion of the helium-rich cap. The theory based on the method developed by Stoeckly and Mihalas (1973) and applied by Gruschinske (1982) to HeI 4471 yields, however, the surprising result that, when the cap is approaching the observer, the core is shifted to the red and, when the cap is receding, the core is shifted to the blue (Fig. 3). This means that, in the core, we see predominantly the helium "poor" disk while, in the wings, we see mainly the helium-rich cap. This strange behaviour is due to the combined effect of saturation and rotation: it can be shown by series expansion, that the intensity of a rotated line profile at a given $\Delta\lambda$ is the sum of the intensity of the unrotated profile at this wavelength plus 3/8 x λ/c x v sini times the wave length derivative of the unrotated profile. As the profile of the disk line is sharper than that of the cap line, and accordingly the derivative of the disk line larger than that of the cap line, the former dominates in the core of the rotated line. Consequently, the strong line cores exhibit an inverse shift while the weak lines are shifted directly; the medium-strong lines are practically unshifted. A cross-correlation method (Groote and Hunger, 1977) is hence bound to find near zero velocity amplitudes. This situation exists as long as the helium lines are core-saturated. In the helium-weak variable stars, with their unsaturated lines, radial velocity shifts indeed are observed.

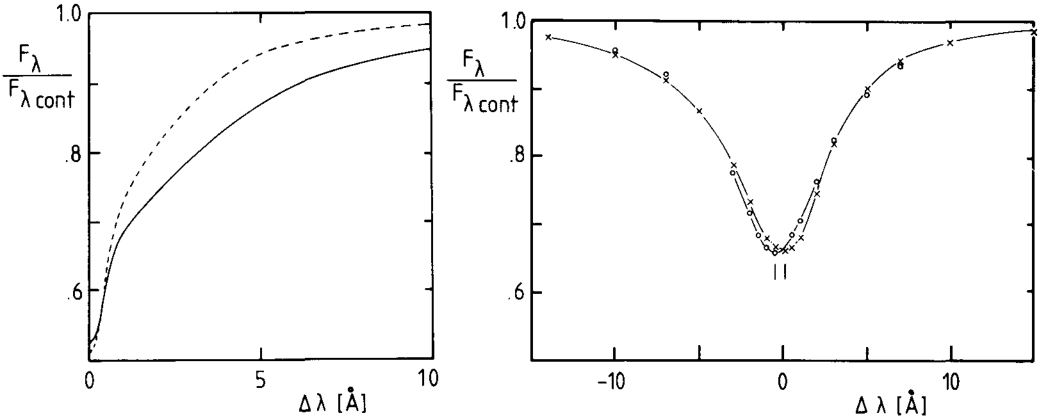

Fig. 3 Left panel: Unrotated profile of He 4471 (red wing only). He "poor": dashed, He rich: fully drawn. Right panel: The (symmetrisized) profile of He 4471, in two phases: xxx He cap is approaching, ooo cap is receding. The core is shifted inversely by 40 kms^{-1}.

For most of the strong variables, models with 1 or 2 He caps seem to be the rule. One example of a banded geometry is HD 37776. It represents the first case of a stellar magnetic quadrupole with current loops (Fig. 4) (Thompson and Landstreet, 1985). According to Groote and Kaufmann (1981) and Shore and Adelman (1981), helium is distributed in bands across the surface. It appears to be the only intermediate with variable Balmer absorption lines. (Recent CASPEC spectrograms, however, prove that also in Sigma Ori E Balmer lines are slightly variable - the variability apparently being correlated with the magnetic field.)

Surface enrichment in spots and bands is undoubtedly due to diffusion whereas the cause of the overall enrichment is still a matter of debate (see Sect. 4). The non-uniform surface distribution is probably the result of a complicated interplay of wind and magnetic braking, which acts differently on the different ions according to

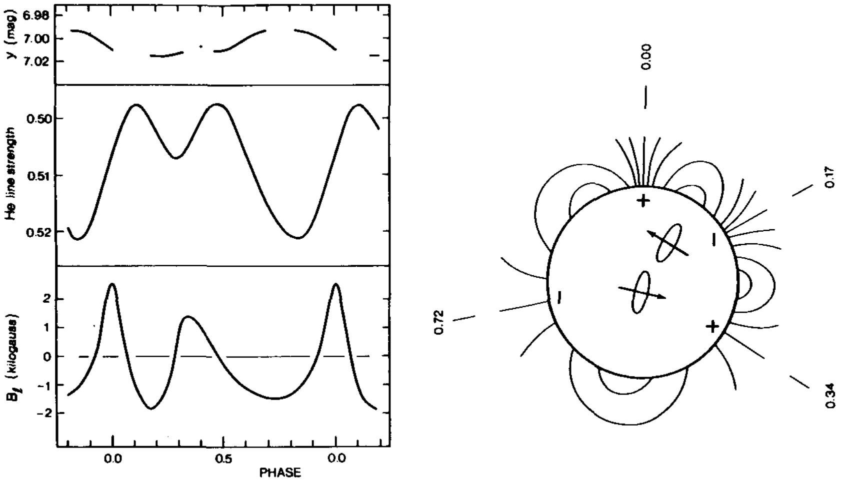

Fig. 4 Phase variation of the y-magnitude, He line strength and magnetic field of HD 37776. This variability is best explained by a banded helium distribution which is tied to a magnetic quadrupole field (right panel) (Thompson and Landstreet, 1985).

their charge to mass ratio (see, for instance, Shore, 1977). This not only leads to caps of helium but also to caps of the various metal ions which, as a rule, seem to vary in antiphase to helium (see Sect. 3).

Whatever lastly the theory for the horizontal surface abundance gradients may be, one must be aware of vertical abundance gradients which may be present in the atmosphere and which may influence the profiles (see also Bolton, 1983). For instance, He may float above a sea of hydrogen. This situation is opposite to what is known from White Dwarfs, where H floats above the DAs. However, from parameter studies of DA-model atmospheres and corresponding line formation calculations (Jordan, 1985), we can draw conclusions as to our helium variables: as long as the transition depth τ_{tr} , i.e. the depth where the helium content varies drastically with depth, is either very small or very large, normal profiles will result. However, when τ_{tr} is in the range $10^{-2} < \tau_{tr} < 1$, a temperature inversion may occur and hence strange profiles result.

So far, only one object has been found with unusual line profiles, the helium-weak variable HD 49333. The observed profiles of the strong helium lines in HD 49333 are far too shallow for any conceivable classical model and any reasonable v sini. Fig. 5 shows the example of He I 4471. According to Groote et al. (1985), the photosphere has a helium-poor surface layer atop a helium-normal bottom, the transition occurring at $\tau_{tr} = 0.4$. Because He is a poor absorber, the temperature stratification remains unaffected and hence no temperature inversion occurs, which explains why no emission is seen.

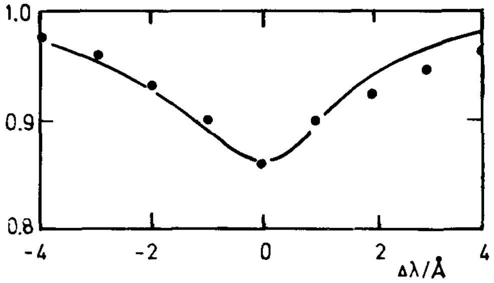

Fig. 5 He 4471 of HD 49333. The unusually shallow profile is formed in an atmosphere where the helium content varies drastically at $\tau_{4000} = 0.4$, from helium poor at the surface ($\varepsilon_{He} = 0.001$) to approximately helium normal at the bottom (... observed profile).

6. CIRCUMSTELLAR MATTER

Circumstellar matter seems to be present around all or most of the helium-strong variables. It may be the result of mass loss. Other hypotheses are that the clouds are a relict of protoplanetary matter, or that they are accreted from interstellar space. There have also been attempts to identify the helium-strong variables as Be-stars (Bolton, 1983; Harmanec, 1984). Mass loss is observed, for instance, in Sigma Ori E: 10^{-9}-10^{-10} $M_\odot y^{-1}$ (Hamann, 1981), which makes the first hypothesis plausible. The circumstellar matter is responsible for all observed variability, e.g. in Sigma Ori E, except for the variable He and metal lines, and the magnetic field.

Since probably all of the helium-strong variables also have strong magnetic fields (see Sect. 2), the wind is modulated by the magnetic field: it is funnelled from the polar caps and stored in clouds near the magnetic equator, i.e. the circumstellar matter around the variable intermediates occurs mostly in the form of localized clouds. In Sigma Ori E, the clouds become manifest by strong absorption in the U-band (Hesser and Ugarte, 1976; Hesser et al., 1976, 1977), by H_α-emission (Walborn, 1974; Walborn and Hesser, 1976), by additional Balmer absorption lines (Groote and Hunger, 1976, 1977), by polarization (Kemp and Herman, 1977), by IR excess (Groote et al., 1980; Groote and Kaufmann, 1981; Groote and Hunger, 1982) and by CIV UV lines (Shore and Adelman, 1981). All features are variable, with a common period of 1.19080 days which is the period of rotation. (In the new CASPEC spectrograms, also H_β-emission is seen.)

From the 8 independent variables observed, a unique solution has been found for the models of the photosphere and shell of Sigma Ori E (Fig. 6) (Groote and Hunger, 1982). The angle between the axes of rotation and magnetic field is large, which may be typical for the variable intermediates. The clouds are located near the intersection of the magnetic and rotational equators. They radiate mainly ff-emission, with a temperature of 15000 K, which accounts for the infrared excess observed in the bands J, H, K and L (Fig. 7). The density is of the order of 10^{12} cm^{-3}, and the total mass 10^{-10} $M_\odot$, which means that the clouds are replenished by the stellar wind within one year.

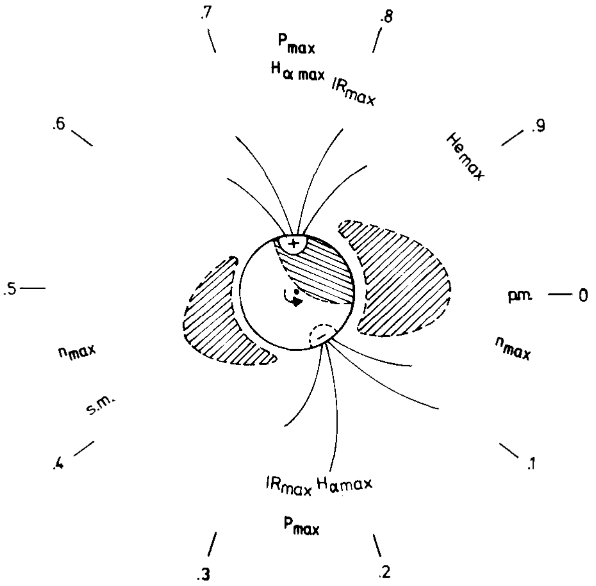

Fig. 6 Pole on model of Sigma Ori E. The line of sight rotates in the plane. The phases are given by numbers on the periphery. The phases of maximum H_α emission, IR emission, helium line strength, shell absorption and polarization, and minimum of light curves are indicated. The (cross-section of the) belt, helium cap and magnetic poles are shown.

The (variable) M-band excess has not been confirmed (Bonsack and Dyck, 1983; Odell and Lebofsky, 1984). If it were real, it would mean that there are corotating grain clouds, this being rather unlikely in view of the proximity of the hot star. Another explanation could be synchroton radiation from energetic electrons. The presence of energetic particles is considered to be typical in rotating magnetospheres (Havnes, 1981). In this case, Sigma Ori E would also be a strong radio-emitter. Radio-emission was searched for by Altenhoff and Wendker (1978) but the resolution of the 100 m Effelsberg telescope proved to be insufficient. Sigma Ori E was finally discovered with the VLA, at the wave lengths of 2 and 6 cm, by Drake et al. (1985). (This was a serendipitous discovery, as the literature on Sigma Ori E was apparently not known). IRAS also detected an excess of several magnitudes (Walker, 1985). From the 12 mμ/25 mμ ratio, a black body temperature of 200 K is determined which confirms the temperature of 270 K derived from Fig. 7.

The only other helium variable source found with VLA is the binary HD 37017. However, this source was too faint for detection with IRAS. This discovery once again opens up the question as to the M-band excesses of intermediates. It also makes the helium-strong variables interesting objects for observations in the far infrared.

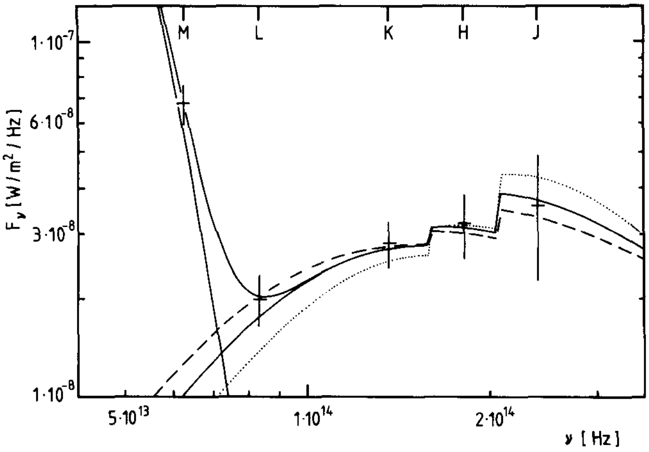

Fig. 7 The infrared excess of Sigma Ori E. Observations are marked by (long) crosses. The fully drawn curve (lower part of the diagram) corresponds to free-free emission with T = 15000 K. The M-band excess corresponds to a black-body temperature of 270 K.

CONCLUSIONS, PROBLEMS

The central problem of the intermediates is whether He-enrichment is a surface phenomenon or whether the entire envelope of an intermediate has been transformed by nuclear processes. An N/C ratio below unity definitely rules out the latter alternative. A ratio close to 0.4 is found in all non-variable intermediates, except for HD 186205 (which may be a candidate for variability). This ratio, hence, can be used to define the boundary between the intermediates and evolved extreme helium stars. With this definition the border case HD 144941, for instance, having $n_{He}/n_H = 15$ and N/C = 3, cannot be considered as intermediate.

The low gravities of the non-variable intermediates (log g = 3.7 ± 0.3), confirmed by recent CCD-spectrograms, mean that the intermediates are <u>not</u> on the main sequence. Whether this also implies that the intermediates have low masses, depends critically on the distances assumed. Distances published so far lead to masses which are by a factor of 2-3 too small for stars with normal composition. In view of the small N/C ratios observed, the distances must be regarded with scepsis.

A further problem not yet thoroughly discussed is: what is the distinction between the non-variables and variables among the intermediates, apart from the variability? Most of the variable features observed in Sigma Ori E, for instance, are caused by corotating clouds. Why do some intermediates have clouds and others not? Is it a matter of wind or accretion? The localization of the clouds, undoubtedly, is related to magnetic fields. Why, then, do some variables have strong magnetic fields - and these in turn are related to the non-uniform surface distribution of the chemical elements - and others not? The simple discrimination "rotation" apparently does not apply. Is it then the mass or the N/C ratio? From the foregoing, it is clear that we are still far away from completely understanding the intermediate helium stars.

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DISCUSSION

HILL: When you look at the helium lines with phase, do you find that the inverse shift problem for the strong lines goes away when all the lines are weak?

HUNGER: Even in the phase when the disk is shown, the strong He lines are saturated.

VARDYA: You have talked about He at the top and with a H and He mixture below. How does this fractionation take place?

HUNGER: Fractionation takes place by diffusion in the presence of wind and magnetic field. You have to play with the two things, wind and magnetic field. When the wind is braked down by the magnetic field to a certain value, then you might have all the He ions transported upwards where they recombine to neutral helium. Thus, He can accumulate in the region of optical depth 0.3. This effect you get only for a definite velocity determined by the wind and also by the magnetic field. This led people to believe that He-enrichment is latitude-dependent, with respect to the magnetic equator. This model, however, leads to bands rather than spots.

MICHAUD: What do you believe to be the effective temperature range of the helium-rich stars?

HUNGER: The He-rich oblique rotators cluster around T_{eff} = 22000 K. The hottest known object is HD 37771 (T_{eff} = 27000 K).

MICHAUD: How well-known is that?

HUNGER: 27000 is by Kaufman, I think. Do you think it is too high?

MICHAUD: I am not saying that. It has an important effect on the separation mechanism.

KILAMBI: What is the observed variation in the strength of the magnetic field in these stars?

HUNGER: Of the order of ΔB = 5000 G typically.

KILAMBI: In your model, you have said that the He is concentrated in a spot. What would be the size estimates of these spots?

HUNGER: In σ Ori E, He in the spot is enriched up to He = 0.90. The spot covers some 30% of the surface.

DESHPANDE: If σ Ori E has a synchrotron component in its radiation, then polarimetric observations will help in proving this. Have any such observations been made?

HUNGER: Yes. Polarization measurements have been taken. They are difficult to perform as one has amplitudes of the order of only 0.1% which led us to assume that the clouds are not full but are truncated van Allen belts. The polarization, hence, is not connected with sychronoton radiation.

WEHLAU: In your model of the He spots, is the He distribution assumed to be uniform within the spots?

HUNGER: Yes.

GARRISON: You mentioned that you have a problem with the mass for σ Ori E. I notice that you have assumed 400 parsecs. However, I prefer 500 pc to the Ori group from the results of unpublished work I have done on the cluster. I believe this will help to relieve the mass problem.

HUNGER: That changes in the right direction. However, you need 600 pc in order to bring it up to the normal main sequence mass. Our estimate of 400 pc comes from Heintz which should be reliable.

GARRISON: The other comment is that I really like the models that you are coming up with because, for a long time, even at low dispersion, I think one has seen structures and strange profiles in the hydrogen and helium lines. The previous models have not really addressed this problem.

MICHAUD: Have other anomalies been observed?

HUNGER: Anomalies in metal abundances are hard to detect because weak lines are washed out by rotation.