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A thorough spectroscopic study of the very nearby triple system: 36 Ophiuchi*

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Summary. The three K-star components of the 36 Ophiuchi system have been analysed in detail on high resolution, high S/N ESO Reticon spectra. The atmospheric parameters of the stars: effective temperature, spectroscopic gravity, microturbulence, metal abundances and degree of chromospheric activity have been determined. The position of the observational ZAMS built up by the three stars has been compared with theoretical ZAMS. The agreement between the iron abundances, $[\mathrm{Fe/H}]^{*}_{\odot}$, is excellent for the three components. A discussion of the masses of the components is also given.

Key words: stellar evolution – K stars – chemical composition – internal structure models – mass – chromospheric activity

1. Introduction

The high S/N spectroscopic detailed analysis of the stars of the triple system 36 Ophiuchi is part of our observing program of a sample of very nearby G and K stars, lying within 10 parsecs of the Sun (Perrin et al., 1988). This sample contains a few double and multiple stars such as α Centauri and 36 Ophiuchi. Indeed the 36 Ophiuchi system can be considered as the nearest open cluster, with the advantage that its distance is accurately known.

For the knowledge of galactic structure and chemical evolution of the solar neighbourhood, double and multiple stars are a useful working tool. These stars do not only inform us about the kinematics and the chemical composition of the environment of the Sun, as do single stars, but, also about its spectrum of stellar masses. Furthermore if such systems are sufficiently near to the Sun, absolute magnitudes, M_V, can be determined with good accuracy, and, if their effective temperatures, T_{eff}, do not differ too much from that of the Sun as in the case of G and early K stars, bolometric corrections, BC, can also be determined accurately. Furthermore, if careful spectroscopic detailed analyses of unevolved or slightly evolved G and K components of nearby double or multiple systems do exist, we also know effective temperatures, spectroscopic gravities, metal abundances, degree of chromospheric activity, etc. of the components of the system. Once the effective temperatures and the bolometric magnitudes of each component are known, we can draw in a (log T_{eff}, M_{bol}) diagram a portion of an empirical ZAMS or a given isochrone. Such ZAMS can be compared with theoretical ZAMS's, computed with various helium contents, Y, or different metal contents, Z. If we know the metal content, Z, of the components, their helium content, Y, can be estimated (Perrin et al., 1977) from the position of a theoretical ZAMS having the same Z and Y fitting the best with the observational positions of the components. Also the comparison between observational and theoretical ZAMS's can give an estimation of the mass of each component. If a computation of the orbit of a multiple system exists, the masses of the components are known. These masses can then be compared with those determined with the help of theoretical (log T_{eff}, M_{bol}) diagrams based on stellar structure computations. In that case the abundance of helium can be determined much more accurately. In what follows we propose to apply the above described procedure to the well known system, 36 Ophiuchi.

2. Existing data of the three components 36 Ophiuchi A, B and C

The SIMBAD (Set of Identifications, Measurements, and Bibliography, for Astronomical Data, Edition:1988) catalog (Ochsenbein et al., 1988) contains up to 1988, 85 bibliography references for 36 Oph A, 72 for 36 Oph B, and 52 for 36 Oph C. Specialists in very different branches of astronomy and astrophysics have studied this very interesting triple system. Many of the references concern papers of photometric studies of red dwarfs in which photometric results of one or more components of 36 Oph have been reported (for example: Johnson et al., 1957; Clark and McClure, 1979; Olsen, 1984). The many papers of Eggen on intermediate band photometry of main sequence stars near the Sun contain results for 36 Oph: let us just quote Eggen (1986).

The research on rotation, convection and magnetic activity in lower main sequence stars, based on flux measurements of Ca II H and K emission contains results of the chromospheric activity of the stars of 36 Oph (Vaugham et al., 1981; Noyes et al., 1984; Marcy, 1984). The components A and B of 36 Oph have been included in a space observing program of stellar coronae with EXOSAT and have been published by Pallavicini et al. (1988). Photoelectric rotational velocities of 36 Oph A, B and C have been determined by Benz and Mayor (1984) with the CORAVEL. Speckle interferometric measurements of the same system have been made by Blazit et al. (1987).

We found only two references in the SIMBAD catalog (Ochsenbein et al., 1988) concerning high resolution spectroscopic research of the 36 Oph stars: Strohbach (1970) and Perrin (1975). Even less numerous are the references on the astrometric

Send offprint requests to: M.-N. Perrin orbits of the system. We have to go back to Brosche (1960) to find two possibilities of the orbit of 36 Oph B around 36 Oph A. One is characterized by $a=25''.5$ and $P=11547$ yr, and the other one characterized by $a=13''.9$ and $P=548.7$ yr. The distance of component C to the AB system being much larger, its orbit around AB cannot be determined. The first solution leads to a mass of 0.02 $\mathcal{M}_\odot$ for the AB system. This mass is much too low for a pair of K-type stars. The second orbit is much more realistic. It leads to $\mathcal{M}_{A+B}=1.46\ \mathcal{M}_\odot$. If we assume that the excentricity of the orbit is ≤ 0.90, the masses of components A and B have to be almost identical, i.e. $\mathcal{M}_A=\mathcal{M}_B=0.73\ \mathcal{M}_\odot$. We dwelt on the results of the astrometric mass computation by Brosche (1960) of the A and B components of 36 Oph, because, further on, we shall compare these astrometric masses with those obtained with the help of stellar structure computations.

To end this section we present in Table 1 the basic catalog data for 36 Oph A, B and C. They will be useful for further discussions in this paper.

3. Spectroscopic observations

Reticon spectrograms of the components of the 36 Ophiuchi system were obtained at the European Southern Observatory in April 1985 and March 1986. Moon or daylight have been taken as reference for the solar flux spectrum. The observations were obtained with the coudé echelle spectrograph (CES) fed by the 1.4 m coudé auxilliary telescope (CAT). The detector was a 1872 pixel linear Reticon array. The journal of observations is given in Table 2.

The observations were made in three spectral ranges centered at λ6165, 6715 and 8520 Å. The component 36 Oph C has also been taken in the region centered at λ6560 Å. The 6165 and 6715 Å regions have been chosen because they contain weak or fairly weak metallic lines and are free of telluric lines. The infrared region at 8520 Å which contains two of the Ca II infrared triplet lines has been chosen in order to detect, at least qualitatively, the chromospheric activity of the stars. It is unfortunate that ESO Reticon spectra have a short spectral coverage, covering 57 Å at

Table 1. Photometric, spectral type and astrometric data

Star	36 Oph A HD 155886	36 Oph B HD 155885	36 Oph C HD 156026
V (mag.)	5.05 (1)	5.08 (1)	6.34 (1)
$B-V$	0.86J* (5)		1.16 (8)
$U-B$	0.49J (5)		1.07 (8)
$R-I$	0.44J (5)		0.61 (9)
$V-I$	1.14J (5)		1.54 (9)
$G-I$	0.15J (6)		0.64 (6)
B_2-V_1	0.538J (7)		0.730 (7)
$b-y$	–		0.667 (10)
Sp.T.	K0V (1)	K1V (1)	K5Ve (1)
$\pi'' \pm \epsilon''_\pi$	0.1884 ± 0.0078 (2)		0.1832 ± 0.0065 (2)
RV (kms^{-1})	−1 (3)	0 (3)	−1 (3)
U (kms^{-1})	8 (4)	9 (4)	8 (4)
V (kms^{-1})	−19 (4)	−18 (4)	−19 (4)
W (kms^{-1})	1 (4)	0 (4)	0 (4)

Notes and references :

* : J=joint colours

(1): Hoffleit and Jaschek (1982).
(2): Gliese (1986, private communication).
(3): Gliese (1969).
(4): The components U, V and W, relative to the Local Standard of Rest (Delhaye, 1965) have been computed using the Gliese (1986) parallaxes.
(5): Johnson et al. (1966).
(6): Kron et al. (1972).
(7): Rufener (1981).
(8): Nicolet (1978).
(9): Feinstein (1966).
(10): Olsen (1984).

Table 2. Journal of observations: continuum signal-to-noise ratios

Star	Date	S/N	Date	S/N	Date	S/N	Date	S/N
	6165(Å)		6560(Å)		6715(Å)		8520(Å)	
36 OphA	86 – 3 – 20	320	—	–	85 – 4 – 3	200	86 – 3 – 22	240
	86 – 3 – 19	150			86 – 3 – 21	300		
36 OphB	86 – 3 – 20	390	—	–	86 – 3 – 21	430	86 – 3 – 22	240
36 OphC	86 – 3 – 19	320	85 – 4 – 2	420	85 – 4 – 3	420	86 – 3 – 22	270
	86 – 3 – 20	370			86 – 3 – 23	490		

Table 3. Effective temperatures $T_{\rm eff}$ (K) derived from colour indices and from excitation and ionization equilibria

Star	36 OphA	36 OphB	36 OphC	Sources
$R-I$	5100	5100	4350	(1)
$V-I$	5100	5100	4500	(1)
$G-I$	5040	5040	4200	(2)
B_2-V_1	5160	5160	4585	(3)
$b-y$	–	–	4426	(4)
Exc.Eq.	5060	5025	4600	(5)
Ion.Eq.	5090	5120	4600	(5)
Adopted	5125	5100	4550	(5)

Sources: (1) : Johnson (1966); (2) : Rousseau (1968); (3) : Hauck (1985); (4) : Olsen (1984); (5) : This paper.

Hα, and therefore are too narrow to set correctly the continuum in the Hα region. The determination of the effective temperature of the three components from the comparison between the observed and the theoretical Hα wing-profiles, as done on CFHT-Reticon observations (Cayrel et al., 1985) was not possible, and therefore we have not continued to observe the Hα spectral region of the program stars.

From the journal of the observations we see that the Reticon spectra of the 36 Ophiuchi stars have all very good S/N ratios exceeding by factors of 5 to 10 the S/N ratios of former photographic spectra taken for the same stars (Perrin, 1975). For the CAT-ESO echelle spectrograph at λ6715 Å the effective dispersion was 28 mÅ per pixel (1.9Å/mm) and the spectral resolution 0.11 Å ($\lambda/\Delta\lambda \simeq 60\,000$).

4. Detailed spectroscopic analysis of the atmospheres of 36 Ophiuchi A, B and C

4.1. Determination of equivalent widths

The procedures we employed for the data reductions were essentially the same as described in detail in Cayrel et al. (1985), Perrin et al. (1988) and Cayrel de Strobel and Bentolila (1988). The continuum was determined by a polynomial fit through a set of carefully chosen "line free" windows. The equivalent widths, W, were determined with a detailed line profile fitting technique. The contamination by blends of weak lines, has been taken into account except for some unidentified very weak lines. The equivalent widths of the individual lines are given in Table 4.

Table 4. Equivalent widths and logarithmic abundances with respect to the Sun

			36 OphA		36 OphB		36 OphC	
λ	Mult.	χ	W(mÅ)	$[M/H]^{*}_{\odot}$	W(mÅ)	$[M/H]^{*}_{\odot}$	W(mÅ)	$[M/H]^{*}_{\odot}$
Na I								
6154.230	5	2.10	38.0	−0.33	39.2	−0.32	70.6	−0.19
Al I								
6696.032	5	3.14	41.7	−0.19	41.8	−0.21	65.0	−0.13
6698.669	5	3.14	24.9	−0.23	23.9	−0.26	42.8	−0.16
Si I								
6142.494	30	5.62	22.3	−0.25	20.8	−0.29	8.9	−0.42
6145.020	29	5.61	22.1	−0.35	21.1	−0.37	8.8	−0.52
6721.844	38	5.86	27.8	−0.31	–	–	–	–
Ca I								
6166.440	20	2.52	85.6	−0.24	85.6	−0.26	–	–
V I								
6150.154	20	0.30	32.6	−0.12	33.1	−0.15	–	–
Fe I								
6147.834	1016	4.07	39.2	−0.33	39.2	−0.34	37.0	−0.39
6151.623	62	2.18	59.5	−0.36	59.0	−0.38	–	–
6157.733	1015	4.07	59.4	−0.38	–	–	59.2	−0.46
6159.382	1175	4.61	12.3	−0.27	11.7	−0.30	–	–
6165.363	1018	4.14	46.6	−0.26	46.3	−0.27	–	–
6696.322	1255	4.83	16.3	−0.19	16.2	−0.19	15.0	−0.14
6699.136	1228	4.59	7.2	−0.28	6.9	−0.31	5.9	−0.30
6703.576	268	2.76	44.8	−0.34	43.6	−0.38	50.0	−0.40
6704.500	1052	4.22	5.5	−0.32	5.6	−0.32	4.2	−0.41
6705.105	1197	4.61	43.3	−0.34	42.8	−0.36	36.6	−0.42
6710.323	34	1.48	25.9	−0.29	26.0	−0.31	34.6	−0.37
6713.044	1195	4.61	23.1	−0.31	23.5	−0.31	17.3	−0.40
6713.207	1013	4.14	11.4	−0.24	11.0	−0.26	8.9	−0.33
6713.745	1255	4.79	19.3	−0.30	18.8	−0.32	13.7	−0.39
6715.386	1174	4.61	26.7	−0.27	25.5	−0.31	–	–
6716.252	1225	4.58	15.2	−0.27	14.3	−0.31	–	–
6717.527	1194	4.61	12.4	−0.26	10.8	−0.33	–	–
6725.364	1052	4.10	19.8	−0.24	18.3	−0.29	14.9	−0.37
6726.673	1197	4.61	48.7	−0.27	46.0	−0.32	43.5	−0.32
6732.068	1225	4.58	–	–	7.4	−0.25	4.8	−0.37
6733.153	1195	4.64	26.6	−0.25	25.7	−0.28	20.7	−0.33
6737.978	1192	4.56	21.7	−0.28	–	–	15.3	−0.40
6739.524	34	1.56	22.4	−0.22	–	–	28.2	−0.34
mean				−0.29		−0.31		−0.36
$\pm\sigma$				0.05		0.04		0.07
Fe II								
6149.249	74	3.89	13.8	−0.32	14.3	−0.29	4.0	−0.31

Table 4 (continued)

λ	Mult.	χ	36 OphA W(mÅ)	36 OphA $[M/H]^*_\odot$	36 OphB W(mÅ)	36 OphB $[M/H]^*_\odot$	36 OphC W(mÅ)	36 OphC $[M/H]^*_\odot$
Ni I								
6175.370	217	4.09	42.1	−0.35	41.4	−0.36	33.9	−0.41
6176.816	228	4.09	55.3	−0.42	54.8	−0.43	42.1	−0.59
6177.253	58	1.83	19.1	−0.32	18.1	−0.36	20.1	−0.39
Ba II								
6141.727	2	0.70	131.6	−0.11	129.4	−0.14	142.2	−0.35

4.2. Determination of the physical parameters

The spectra have been interpreted with theoretical line computations using a grid of model atmospheres of various effective temperatures, gravities and metallicities suitable for F, G and K dwarfs, computed by Gustafsson (Gustafsson et al., 1975; Gustafsson, 1981, private communication). Good abundance determinations are based on very reliable effective temperatures, spectroscopic gravities and microturbulent velocities. The effective temperatures were inspired from photometry, ionization equilibrium and Boltzman excitation ratios. The surface gravity has been set to log $g=4.6$, for the two hotter components of 36 Oph, and log $g=4.7$ for the coolest component 36 Oph C. The microturbulence, ξ_t, has been obtained by fitting a theoretical curve of growth on the observational curve of growth of each of the three 36 Oph stars.

We have have also estimated the chromospheric activity of the three stars through the central depth of two of the Ca II infrared triplet lines.

4.3. Results

Table 3 contains a list of effective temperatures for the program stars, derived from colour indices and derived subsequently from the ionization and excitation equilibria. The last line of Table 3 gives the adopted effective temperatures. Table 4 gives the equivalent widths, *W*, and the corresponding logarithmic metal abundance, $[M/H]^*_\odot$, for each line. We restricted ourselves to lines with equivalent widths between 7 and 60 mÅ. Lines with equivalent widths smaller than about 7 mÅ can be heavily affected by uncertainties in the continuum position, lines with equivalents widths larger than 60 mÅ become unfit to pure Gaussian representation.

Table 5 summarizes the atmospheric parameters and the logarithmic abundances with respect to the Sun for the element of which lines are present in the spectral intervals centered at λ6165 Å and λ6715 Å. Three abundances values are given for each element. The central value is the abundance $[M/H]^*_\odot$ for the adopted atmospheric parameters of 36 Oph A, B and C respectively. The side values are $[M/H]^*_\odot$ abundances computed for $\Delta T_{\rm eff}=\pm 100$ K. These abundances columns will be useful in the discussion of the location of the components of 36 Oph system in an observational diagram. For the two hotter components the adopted effective temperature approaches the ionization equilibrium temperature. For 36 Oph C the adopted effective temperature is identical to the excitation temperature. Indeed, in a star in which iron is mostly ionized, the population of an excited neutral level is mostly controlled by the ionization temperature, whereas if iron is mostly neutral the population is controlled by the excitation temperature.

Table 6 shows, for both neutral and ionized iron lines, the variation of abundances $[Fe/H]^*_\odot$ when a variation of $\Delta T_{\rm eff}=\pm 100$ K or a variation of Δlog $g=\pm 0.20$ is applied to the adopted model. This does not mean that the observational error on the temperatures of the three stars is ± 100 K: we think that is twice as small, of the order of ± 50K for 36 OphA and B, and ± 75 K for 36 Oph C. We adopted for 36 Oph A and B Δlog $g=\pm 0.20$, and for 36 Oph C Δlog $g=\pm 0.30$. The estimated total standard error for iron is computed, taking into account the errors coming from the measures of the equivalent widths of Fe I lines only (± 0.05, ± 0.04 and ± 0.07 respectively for 36 Oph A, B and C, cf. Table 4). These total standard errors are given in the last column of Table 6 and are those given in Table 5.

Figure 1 shows the absolute curve of growth of iron for 36 Oph A, B and C respectively. Figure 2 shows the $\lambda\lambda$6690 −6740 Å spectral region for the three stars.

The chromospheric activity of the three components of 36 Oph has been estimated from the central depths of two lines of the Ca II infrared triplet λ8498.06Å and λ8542.14 Å. Table 7 reproduces these depths together with those of the sunlight (Moon), a K-type star and a G-type star. The star γLepB is the cooler component of the binary system γLep and has been analysed recently by Cayrel et al. (1988) using the same reduction procedure and model atmosphere technics than in this paper. The binary γLep belongs to the UMa stream which is relatively young ($\simeq 10^8$ yr). The star HD 115617 has also been analysed recently by Perrin et al. (1988). This latter is an old disk star. Clearly, the values of the central depths of the Ca II triplet lines of 36 Oph A, B and C are very similar to γLepB. This, at least qualitatively, indicates that the components of 36 Oph are young stars which have approximatively the same age than γLepA and B.

Figure 3 reproduces the ESO-Reticon spectra of two Ca II triplet lines Ca II λ8498.06 Å and Ca II λ8542.14 Å centered at λ8520 Å for the above-mentioned stars.

Table 5. Atmospheric parameters of the stars and elemental logarithmic abundances with respect to the Sun

Star		36 OphA			36 OphB			36 OphC	
$T_{\rm eff}$ (K)		5125 ± 50			5100 ± 50			4550 ± 75	
log g		4.6 ± 0.2			4.6 ± 0.2			4.7 ± 0.3	
ξ_t (kms^{-1})		1.0 ± 0.5			1.0 ± 0.5			1.0 ± 0.5	
Element					$[\mathrm{M/H}]^*_\odot$				
	$\Delta T_{\rm eff}$ (K) −100		$\Delta T_{\rm eff}$ (K) +100	$\Delta T_{\rm eff}$ (K) −100		$\Delta T_{\rm eff}$ (K) +100	$\Delta T_{\rm eff}$ (K) −100		$\Delta T_{\rm eff}$ (K +100
Na I	*−0.39*	−0.33 (1)	*−0.27*	*−0.38*	−0.32 (1)	*−0.26*	*−0.25*	−0.19 (1	*−0.11*
Al I	*−0.26*	−0.21 (2)	*−0.16*	*−0.28*	−0.23 (2)	*−0.19*	*−0.18*	−0.15 (2)	*−0.09*
Si I	*−0.26*	−0.30 (3)	*−0.33*	*−0.29*	−0.33 (2)	*−0.36*	*−0.37*	−0.47 (2)	*−0.54*
Ca I	*−0.31*	−0.24 (1)	*−0.17*	*−0.33*	−0.26 (1)	*−0.19*	–	–	–
V I	*−0.26*	−0.12 (1)	*−0.06*	*−0.28*	−0.15 (1)	*−0.02*	–	–	–
Fe I	*−0.30*	−0.29 (22) ±0.06	*−0.26*	*−0.32*	−0.31 (20) ±0.05	*−0.28*	*−0.32*	−0.36 (17) ±0.12	*−0.38*
Fe II	*−0.25*	−0.32 (1)	*−0.39*	*−0.21*	−0.29 (1)	*−0.36*	*−0.15*	−0.31 (1)	*−0.43*
Ni I	*−0.37*	−0.36 (3)	*−0.35*	*−0.39*	−0.38 (3)	*−0.37*	*−0.42*	−0.46 (3)	*−0.49*

Notes: Number of measured lines is given in parentheses.

Table 6. Errors on the Fe abundance determination

Star	$\Delta T_{eff} = \pm 100$		$\Delta \log g = \pm 0.20$		Total error estimate
	$\Delta[\frac{\rm Fe\,I}{\rm H}]^*_\odot$	$\Delta[\frac{\rm Fe\,II}{\rm H}]^*_\odot$	$\Delta[\frac{\rm Fe\,I}{\rm H}]^*_\odot$	$\Delta[\frac{\rm Fe\,II}{\rm H}]^*_\odot$	$\Delta[\frac{\rm Fe}{\rm H}]^*_\odot$
36 OphA, B	±0.02	∓0.07	±0.03	±0.10	±0.06
36 OphC	∓0.03	∓0.14	±0.06	±0.13	±0.12

Table 7. Chromospheric activity estimation from the central depth of two lines of the Ca II triplet

Star	Sunlight	36 OphA	36 OphB	36 OphC	γLepB	HD 115617
T_{eff}	5770	5125	5100	4550	4950	5585
λ(Å)						
8498.06	0.64	0.48	0.50	0.46	0.46	0.63
8542.14	0.76	0.62	065	0.61	058	0.75

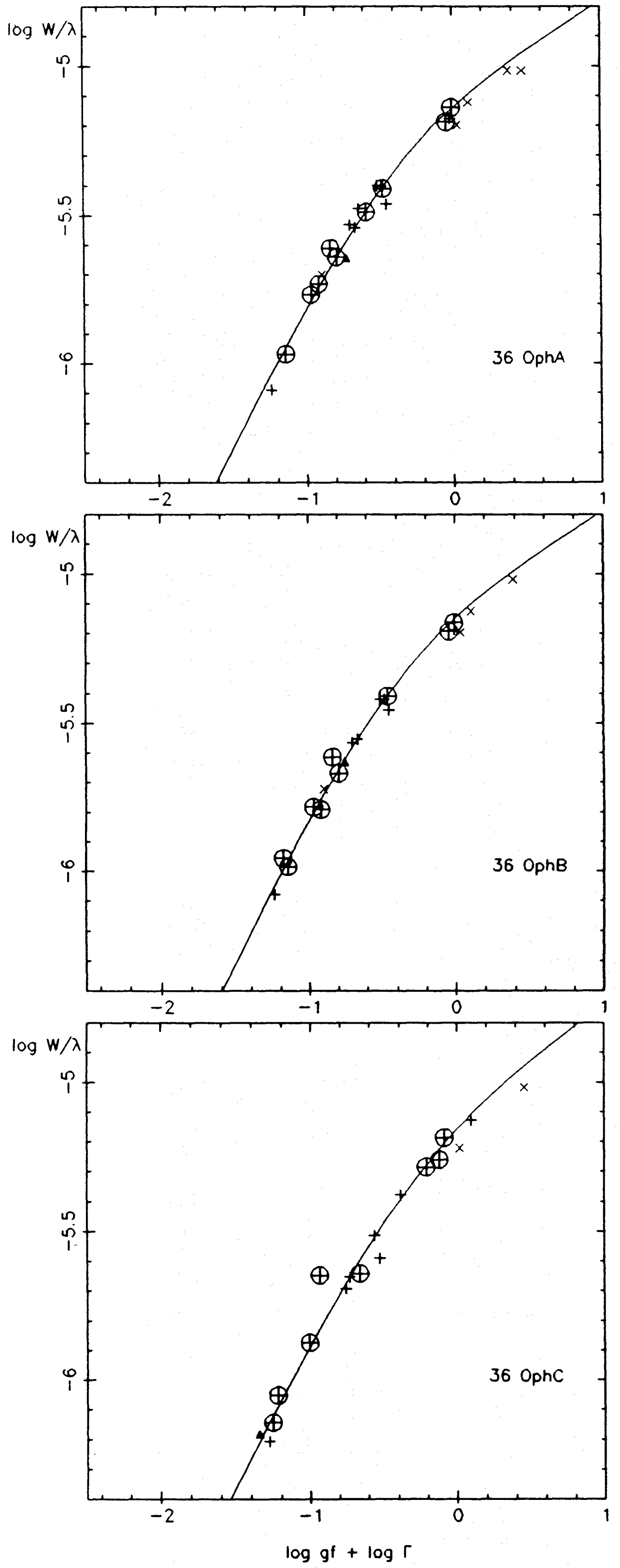

Fig. 1. Absolute curve of growth of Fe for 36 OphA, B and C. The Fe I lines with absolute oscillator strengths *gf* from May et al. (1974) and Rutten & van der Zalm (1984) have been plotted. The symbols are: points for the 6165 Å region and crosses for the 6715 Å region. The Fe I lines with relative *gf* read from the solar curve of growth have the same symbols by spectral region but are circled. One Fe II line lying in the 6165 Å region are represented by triangle (relative *gf* only). The continuous curve represents the theoretical curve of growth computed with the final atmospheric model

5. Discussion

The atmospheric parameters (i.e. effective temperature, spectroscopic gravity, microturbulent velocity and chemical composition) have been determined with great care for the triple system 36 Ophiuchi. These parameters are reproduced in Table 5. For the elements whose lines were present in the studied spectral ranges, only iron is determined with high redundancy, but it seems that the abundances of the other analysed elements vary in lock-step with iron. The abundance of baryum has been omitted: the only measurable line was too strong in the three stars for gaussian fitting. The $[Fe/H]^{*}_{\odot}$ abundance value of 36 Oph C is slightly lower, but not significantly lower than that of the two hotter components. The higher deficiency of iron in 36 Oph C could be spurious and a consequence of its higher chromospheric activity (see for instance Cayrel et al., 1985).

The comparison between the new detailed spectral analyses of the components of the system 36 Ophiuchi and the old spectral analyses of Perrin (1975) and Strohbach (1970) is given in Table 8. If effective temperatures and gravities agree quite well between old and new analyses, not as well do agree the abundances. This probably comes from the difficulty that the authors had in measuring accurately on former photographic low S/N spectra equivalent widths of very weak lines, which are essential in the determination of the abundance of a given element.

Eventually we will discuss the observational segment of the ZAMS formed by the three components of 36 Oph. A similar discussion has already been made in Perrin et al., (1977), but it is interesting to see if our conclusion remains the same one, with the new Reticon results, and having at our disposal newly computed grids of internal structure models (Green et al., 1987; Lebreton, 1988, private communication). The grid of evolutionary models of VandenBerg (1983) has not been taken into consideration because it does not extend to low enough mass. We recall that the conclusion made by Perrin et al. (1977) was that the small portion of ZAMS formed by the three components of 36 Oph satisfied a theoretical ZAMS calculated by Hejlesen (1980) normal in metals but enriched in helium.

Figure 4 represents a ($\log T_{\rm eff}$, $M_{\rm bol}$) diagram constructed with new theoretical and observational material. In this diagram, the dotted lines represent two ZAMS's interpolated in the grid of Green et al. (1987), the thin lines correspond to two ZAMS's calculated by Lebreton (1988, private communication). The interpolation in the grid of Green et al. (1987) has been made for two different helium content values ($Y=0.247$ and $Y=0.287$) and the same Z-value ($Z=0.01$). The low helium content gives the best fit for the solar isochrone in the Green et al. grid. The two ZAMS's of Lebreton correspond to $Z=0.02$ and $Z=0.01$ and $Y=0.287$. The value, $Y=0.287$, corresponds to the initial helium abundance of the solar models of Lebreton et al. (1988).

The segment of the observational ZAMS composed by the three components of 36 Ophiuchi is indicated in Fig. 4 as a thick line. The positions in the ($\log T_{\rm eff}$, $M_{\rm bol}$) diagram of the stars have been established with the help of Table 9. The bolometric corrections are a mean of the empirical ones of Johnson (1966) and theoretical ones of Gustafsson and Bell (1979).

The two ZAMS's of Green et al. (1987) are interpolated from "The revised Yale isochrones and luminosity functions" published by Yale University Observatory. A magnetic tape of these

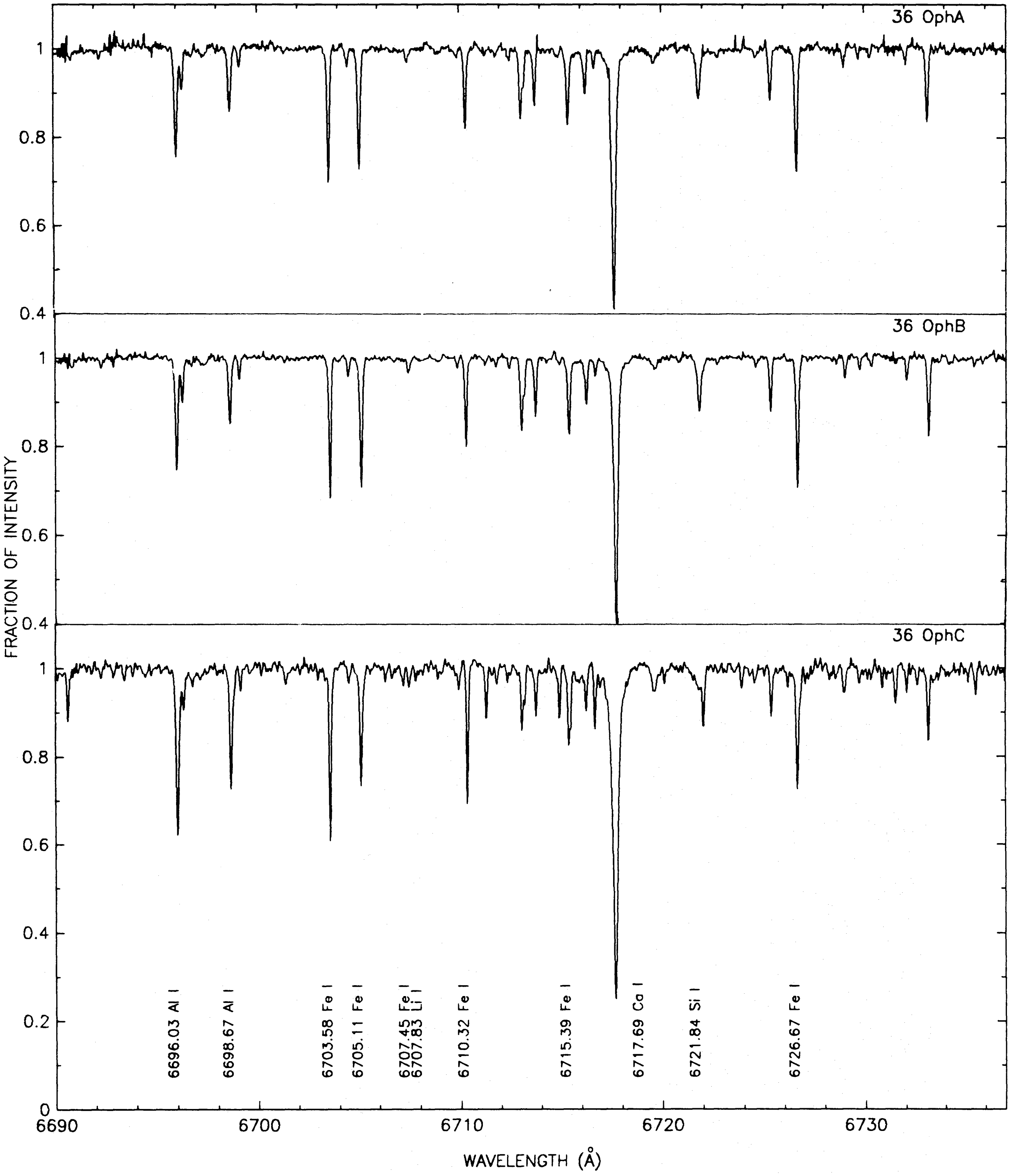

Fig. 2. Spectrum of the region of the 6715 Å for 36 OphA, B and C

isochrones has been kindly sent to the authors by Dr. Warren (World Astronomical Center of Maryland). The two ZAMS's calculated by Lebreton come from the Geneva evolution code developed by A. Maeder and collaborators (Lebreton and Maeder, 1988). The stellar models obtained by Lebreton include: i) the most recent reaction rates for the proton-proton chain (Parker, 1987), ii) the opacity tables of Huebner et al. (1977), iii) and molecular absorption coefficients at low temperatures (Cox, 1981, private communication). These low-temperature opacity tables are of great importance in the study of low-mass stars.

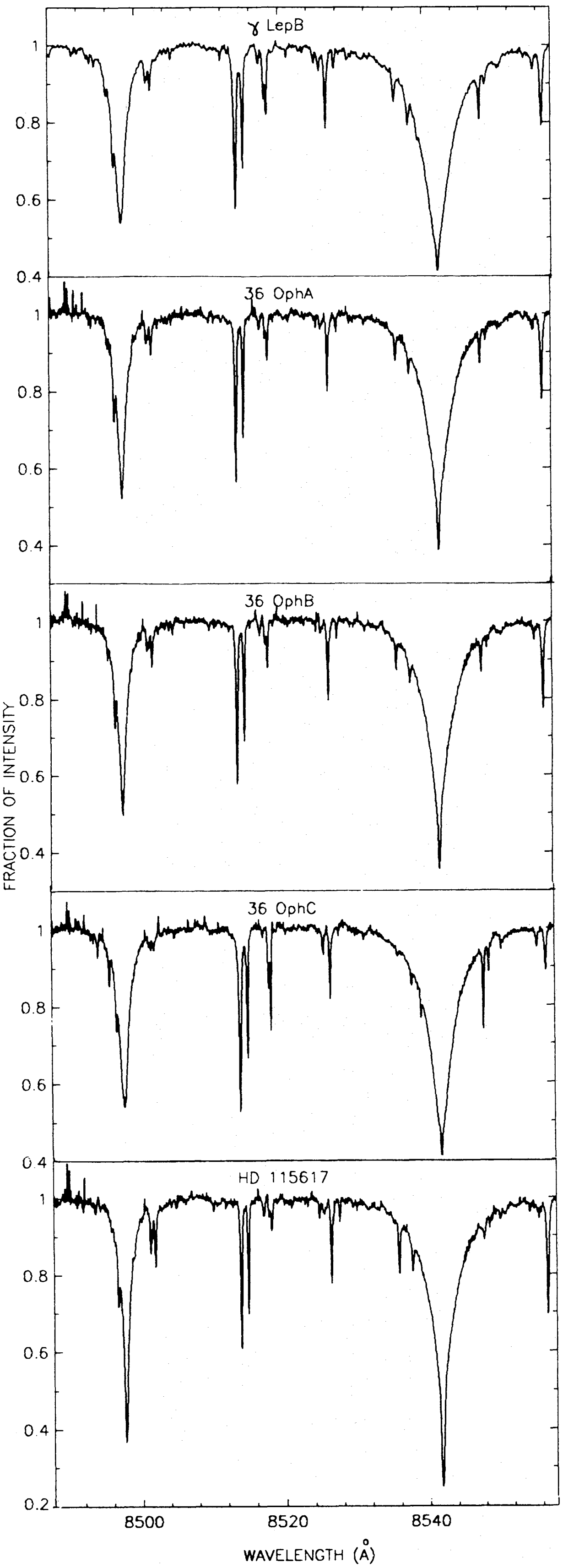

Fig. 3. Spectrum of the 8520 Å region for 36 OphA, B and C. At the top and the bottom are the spectrum of γLepB and HD 115617. Two of the calcium triplet infrared lines are visible: Ca II 8498.06 Å and Ca II 8542.14 Å

Unfortunately similar low temperature opacity tables were not available for $Z=0.01$ and Y. Lebreton is not yet able to calculate a ZAMS with the $Z=0.01$ which corresponds to the metallicity $[M/H]^*_\odot=-0.30$ of the 36 Oph stars. Therefore, the $Z=0.01$ isochrone has been obtained by applying to the $Z=0.02$ a δ log T_{eff} correction equal to the shift found between $Z=0.02$ and $Z=0.01$ isochrones computed with "old" opacity tables (Cox and Stewart, 1970a, 1970b) which do not include molecular opacities. It is interesting to note that the grid of Green et al. (1987) has been calculated with the mixing-length parameter $\alpha=1.5$ and the ZAMS's of Lebreton (1988, private communication) with $\alpha=2.18$.

The slope of the observational ZAMS defined by the 36 Oph stars is somewhat steeper than the theoretical ones, but marginally compatible with that of Lebreton (see error bars). Lebreton and Däppen (1988) have examined the effects of the new equation of state developed by Hummer and Mihalas (1988), Mihalas et al. (1988) and Däppen et al. (1988) on the position of a star in the H-R diagram. They note that for masses lower than about 0.7 $\mathcal{M}_\odot$ this new equation of state leads to a steepening of the slope of the ZAMS. It would be interesting to introduce the use of observational ZAMS's for correcting the input physics of new stellar evolutionary models, as those of Green et al. (1987) or Lebreton (1988, private communication) and will becomes necessary when very accurate observational ZAMS's become available with Hipparcos data.

Taking into account the disagreement between theories, and between theories and observations we have tried to make a rough estimation of the masses of the three components with the help of the Green et al. models and successively with those of Lebreton. The values of these masses are given in Table 9. Also are given in the beginning of this table the values of the most important physical parameters of the stars. Furthermore two other mass determinations have been added in this table. The first one by Perrin (1988, private communication) from the IRAS 12 μm fluxes. Indeed, the infrared observations of IRAS for 36 Oph A B and C stars permit to use the infrared flux method originally developed by Gray (1967) and applied by Perrin and Karoji (1987) for radius determination of the G- and K-type dwarfs with reliable parallaxes. The last mass determination comes from a classical orbital computation by Brosche (1960) of the three 36 Oph components. Because of the two great number of free parameters, the mass determination derived with the internal structure models of Green et al. (1987) and Lebreton are not very accurate although they are not dissimilar to the other mass determinations. Nevertheless, the result of this comparison is that the stars belonging to the 36 Oph system definitively seem to be small mass stars, with masses spanning between 0.8$\mathcal{M}_\odot$ and 0.6$\mathcal{M}_\odot$.

6. Conclusion

The highly precise spectroscopic Reticon observations of the components of the very nearby (distance = 5.3 pc) triple system of 36 Ophiuchi have been performed with a twofold purpose. The first one was to obtain very precise atmospheric parameters for the stars (T_{eff}, log g, $[M/H]^*_\odot$, etc . . .), and to compare them with the previous photographic results existing in the literature. In such a way we have been able to correct the value of their metal content: from a solar metallicity as found in Perrin (1975), the 36 Ophiuchi stars moved down to a mild metal deficiency by a factor of two with respect to the Sun. The slightly higher

Table 8. Comparison between the previous and present results

Star	36 Oph A HD 155886		36 Oph B HD 155885		36 Oph C HD 156026	
Source	Perrin (1975)	This paper (1988)	Perrin (1975)	This paper (1988)	Strohbach (1970)	This paper (1988)
$T_{\rm eff}$ (K)	5090 ± 120	5125 ± 50	5090 ± 120	5100 ± 50	4550 ± 120	4550 ± 75
$\log g$	4.6 ± 0.3	4.6 ± 0.2	4.6 ± 0.3	4.6 ± 0.2	4.7 ± 0.3	4.7 ± 0.3
$[{\rm Fe/H}]^*_\odot$	$+0.10 \pm 0.25$	-0.29 ± 0.06	-0.02 ± 0.25	-0.30 ± 0.05	-0.13 ± 0.25	-0.36 ± 0.12

Table 9. Estimation of the masses of the stars from different criteria

Star	36 Oph A	36 Oph B	36 Oph C
$T_{\rm eff}$ (K)	5125	5100	4550
$\log T_{\rm eff}$	3.710	3.708	3.658
$\log g$	4.6	4.6	4.7
M_V	6.43	6.46	7.65
BC	-0.20	-0.21	-0.53
$M_{\rm bol}$	6.23	6.25	7.12
$\mathcal{M}_*/\mathcal{M}_\odot$			
Green et al. (1987)	0.72 – 0.77	0.72 – 0.77	–
Lebreton (1988, private communication)	0.76 – 0.79	0.76 – 0.79	0.64 – 0.67
Perrin (1988, private communication)	0.69	0.69	0.60
Brosche (1960)	0.73	0.73	0.69

deficiency of 36 Oph C is attributed to the higher chromospheric activity of this very low-mass star. The second purpose was centered on a comparison between a relevant portion of the observational ZAMS, constituted by the three stars and two recently computed grids of ZAMS (Green et al., 1987; Lebreton, 1988, private communication). We have seen that these two grids differ significantly and we have found that the observational segment of ZAMS composed by the three components of 36 Ophiuchi is similar to the metal deficient ($Z = Z_\odot/2$) and normal helium ($Y = 0.287$) ZAMS, computed with the evolutionary models of Lebreton. Note that the observational ZAMS is somewhat steeper than the theoretical one.

The evolutionary masses obtained from the 36 Oph A B components are in quite good agreement with the astrometric

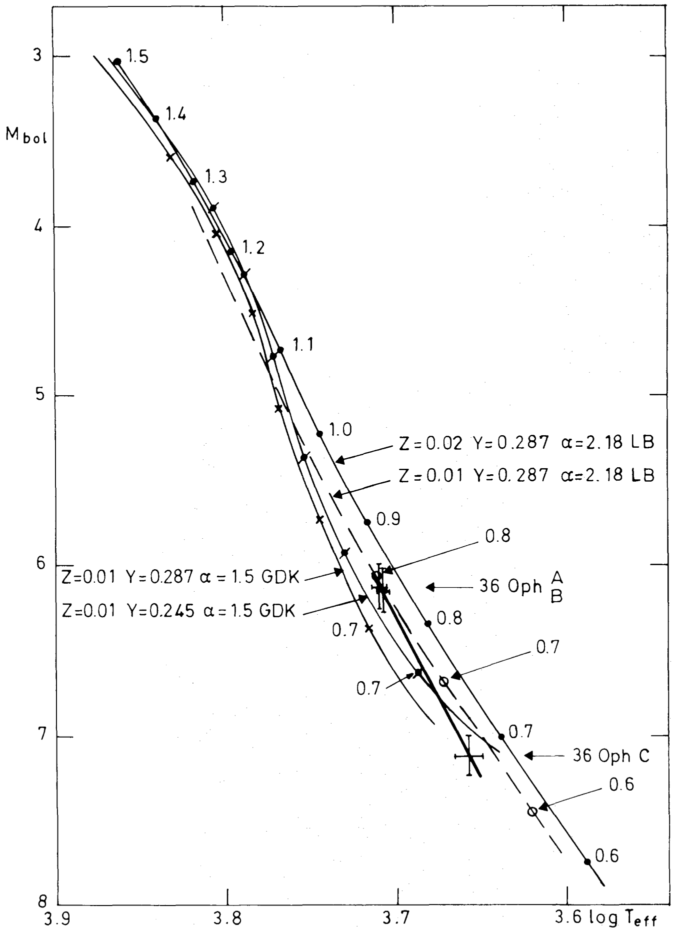

Fig. 4. Comparison between recently computed ZAMS's and an observational ZAMS constituted with the stars of the 36 Ophiuchi system. The two ZAMS's labelled GDK come from Green et al. (1987). The two ZAMS's labelled LB have been calculated by Lebreton (1988, private communication). The thick line represents the observational ZAMS which fits the best Lebreton's metal deficient and helium normal ($Z=0.01$, $Y=0.287$) ZAMS. Note the smallness of the error bars

masses of Brosche (1960). Let us emphasize that a more accurate determination of the astrometric masses for 36 Oph A B would be of great significance as a test of stellar interior theory.

We have seen that the data coming from ESO-CAT-CES observations have given very reliable results, especially in the case of effective temperature and abundance determinations. The bolometric magnitudes are also well determined thanks to the excellent parallaxes of the stars of 36 Ophiuchi. If we want to apply this technique to other more distant binaries or multiple systems, Hipparcos data will be of invaluable help.

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