Inside the Stars, IAU Colloquium 137
ASP Conference Series, Vol. 40, 1993
Werner W. Weiss and Annie Baglin (eds.)

MEASUREMENTS OF MASSES AND RADII OF ECLIPSING BINARIES

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ABSTRACT We report the detection of 10 new double–line eclipsing binary systems, with first measurements of masses and radii. These results are the preliminary outcome of an observational campaign for detecting new double–line eclipsing systems, carried out at the *Observatoire de Haute Provence (OHP)* in France, with the 1.52-m telescope and its CCD high–resolution spectrograph *Aurelie*.

THE SURVEY

It is well known that only binary systems, namely double–spectrum eclipsing binaries, may provide a *direct* determination of stellar masses and radii. The number of such stars, found in one century, hardly reaches a hundred.

The purpose is to enlarge the set of known double–spectrum eclipsing binaries, by detecting the secondary lines of those systems for which only the primary spectrum was observed up to now. Our survey extends in the whole northern celestial hemisphere, up to an uneclipsed magnitude V'=10.5 , providing a total set of 20 binaries (most *sd*–type) with a faint secondary component to be searched for (often $L_2/L_1 \simeq 1\%$) .

Orbital periods of these stars are short (few days or hours); so it is not possible to take long exposures (leading to undesired line broadening because of orbital motion). On the other hand, the secondary lines are often very faint, requiring large S/N ratios. This basic observational difficulty could be overcome in most cases, thanks to the high efficiency of *Aurelie*, combined with the technique of multiple exposures (taken on different epochs at the same orbital phase).

For searching the secondary spectrum, a special technique is used by comparing couples of observations performed at two opposite quadratures. So, a given secondary line appears at opposite sides of the strong primary feature (Fig.1). This method provides immediately the secondary orbital velocity, and it is suitable for applying our special mathematical treatment, which automatically separates the spectra of the two components.

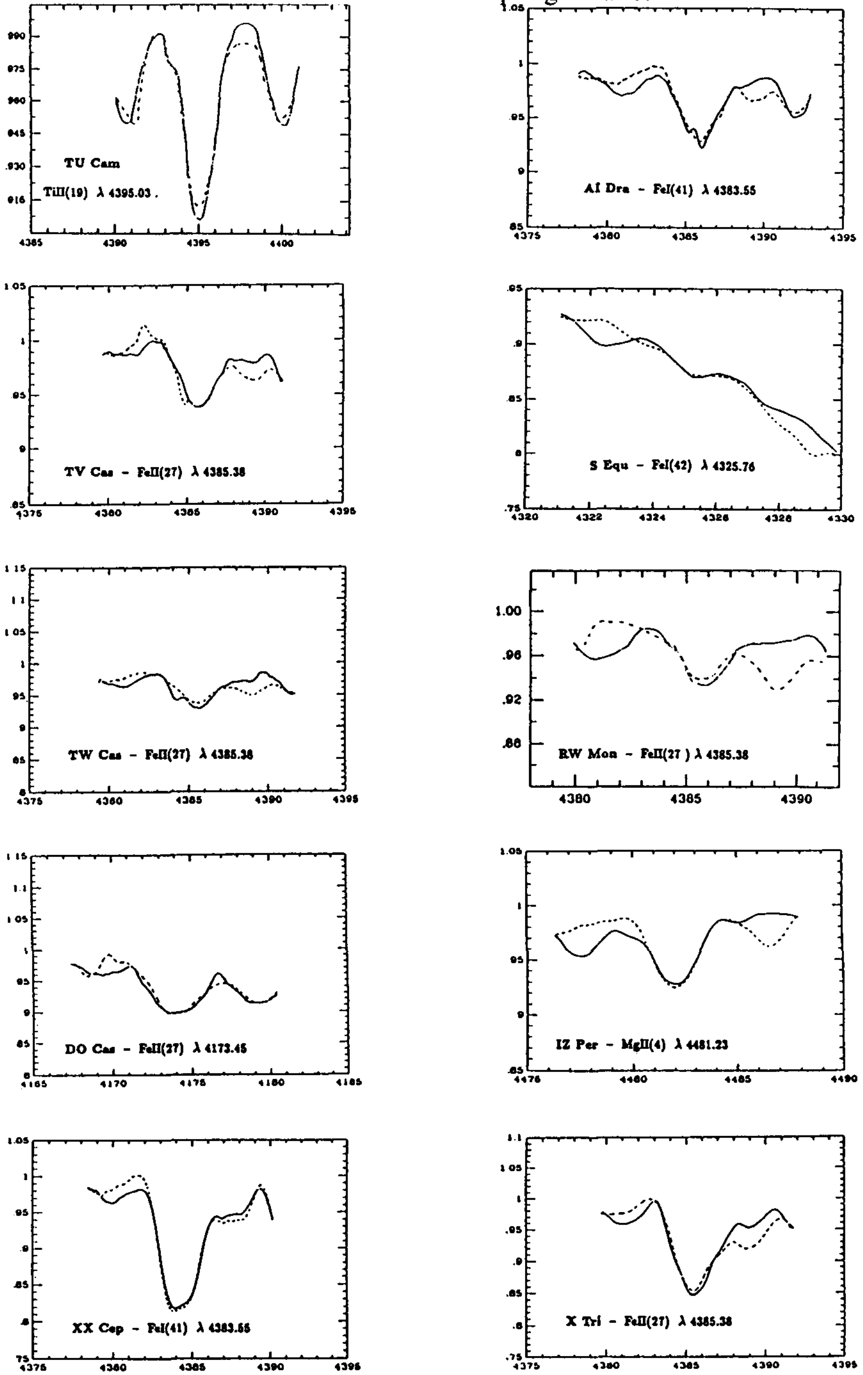

Figure 1. Secondary line detection. Continuum–normalized spectra taken at *1st* and at *2nd* quadrature (*dashed* and *solid* tracings, respectively) are shifted in wavelength, until the primary lines overlap; so the secondary contribution is revealed by difference (wavelength is in Å).

https://doi.org/10.1017/S0252921100018066 Published online by Cambridge University Press

Table 1. New measured masses $m_{1,2}$ and radii $r_{1,2}$, with 1-σ errors (solar units). Orbital period P is in days; V' and V'' are the visual magnitudes (uneclipsed and eclipsed, respectively); K_1 and K_2 are the radial velocity amplitudes in km·s^{-1}.

System *type* P	V' V''	sp_1 sp_2	$K_1 \pm \Delta K_1$ $K_2 \pm \Delta K_2$	$m_1 \pm \Delta m_1$ $m_2 \pm \Delta m_2$	$r_1 \pm \Delta r_1$ $r_2 \pm \Delta r_2$
TUCam *d* 2.9	5.0 5.2	A2V F0	78.0 ± 1.4 108 ± 12	$1.21 \pm .28$ $0.88 \pm .11$	$3.52 \pm .23$ $1.13 \pm .08$
TV Cas *sd* 1.8	7.3 8.4	B9V G	87.9 ± 2.3 179 ± 7	$2.54 \pm .24$ $1.25 \pm .08$	$2.65 \pm .15$ $2.80 \pm .15$
TW Cas *sd-d* 1.4	8.3 8.9	B9V G2	87.0 ± 1.8 181 ± 3	$2.03 \pm .08$ $0.98 \pm .03$	$2.32 \pm .04$ $1.83 \pm .05$
DO Cas *c* 0.7	8.6 9.2	A5V F2	80.0 186 ± 7	$0.96 \pm .09$ $0.41 \pm .02$	$1.81 \pm .05$ $1.07 \pm .03$
XX Cep *sd* 2.3	9.1 10.3	A7V G4	28.0 ± 3.7 273 ± 20	5.70 ± 1.2 $0.58 \pm .12$	$3.41 \pm .28$ $3.03 \pm .42$
AI Dra *sd-d* 1.2	8.0 8.9	A0V G2	93.5 ± 1.1 177 ± 6	$1.76 \pm .13$ $0.93 \pm .04$	$2.02 \pm .07$ $1.82 \pm .09$
S Equ *sd* 3.4	8.0 10.8	B8V F9III	23.4 ± 0.7 189 ± 2	$2.87 \pm .06$ $0.36 \pm .01$	$2.78 \pm .05$ $3.07 \pm .12$
RWMon *sd* 1.9	9.1 11.9	B9V F9IV	74.4 ± 6.7 210 ± 2	$3.41 \pm .18$ $1.21 \pm .17$	$2.41 \pm .10$ $3.02 \pm .25$
IZ Per *sd* 3.7	7.8 9.0	B8 A4IV	52.9 ± 4.7 255 ± 7	$9.15 \pm .69$ $1.90 \pm .24$	$7.09 \pm .21$ $6.49 \pm .23$
X Tri *sd* 1.0	8.9 11.5	A5V G0V	110.0 ± 4.1 158 ± 10	$1.15 \pm .16$ $0.80 \pm .08$	$1.41 \pm .06$ $1.60 \pm .07$

20 NEW MASSES AND RADII

The 10 new detected systems provide absolute elements for 20 individual stars. Using a resolution of about 0.5Å in the range 4100–4500Å, we could generally achieve positive results for binaries up to the uneclipsed magnitude V'=9.5 . The selected spectral region includes H_δ, H_γ and MgII λ4481Å, which are often our first-detected secondary lines. Moreover in this range there are many strong metallic lines (mainly Fe and Ti), which can be detected in the secondary spectrum (usually of F or G type).

Program stars were selected among those having spectroscopic elements of the primary orbit well determined in the literature (Batten *et al.*, 1989): mass function $f(m)$, orbital semiaxis $a_1 \sin i$, radial velocity amplitude K_1. At the same time, photometric parameters should be known from numerical light–curve synthesis (Cester *et al.*, 1979): inclination i, fractional radii r_1/a and r_2/a.

The shift of the secondary lines at quadratures provides radial velocity amplitude K_2, giving the semiaxes ratio $a_2/a_1=K_2/K_1$ and the mass ratio $m_2/m_1=K_1/K_2$. So the orbital separation $a=a_1+a_2$ is known, providing absolute radii r_1 and r_2. Finally, the masses m_1 and m_2 are computed from the mass function $f(m)$. Results are reported in Table 1.

EXTRACTION OF THE SECONDARY

The high quality of the spectra obtained makes it possible to go beyond the simple recognition of the presence of the secondary lines. in particular, the stability of the instrumental response allows us to compare quantitatively the spectra of a given binary system at opposite quadratures, dealing with variations of about 1% of the continuum. From these variations, it has been possible to reconstruct mathematically the complete spectrum of the secondary star.

The procedure, which uses an iterative method, succeeds in putting in evidence some features that otherwise would be unrecognizable by visual inspection (Ferluga *et al.*, 1991). In principle this method of extraction could be applied to all spectroscopic binaries, provided they do not show intrinsic variability. The positive results of our survey, and the encouraging first applications of the extraction technique, suggest an extension of this research program to spectroscopic binaries in general.

ACKNOWLEDGMENTS

The authors are particularly grateful to J.P. De Greve, for invaluable suggestions.

ERRATUM – Values in Table 1 replace those reported in the *Abstract* booklet (Ferluga *et al.*, 1992: *Communic. Asteroseismol.* **43**, 4/2).

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