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New Trends in Disentangling the Spectra of Multiple Stars

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Abstract. The method of spectra disentangling has been applied in many studies of different stellar systems up to the distance of Andromeda Galaxy. In some of these applications the underlying assumptions are not precisely satisfied. This is why new generalizations of the method are needed. Ways to overcome these problems are discussed here.

Keywords. techniques: spectroscopic, (stars:) binaries: spectroscopic

1. Introduction

The method of spectra disentangling developed using different approaches by Simon & Sturm (1994) and Hadrava (1995) enables the simultaneous determination of the orbital parameters of a system as well as the spectra of individual component stars. It proved to be very useful for various studies, including several presented in this volume. However, an improper application of the method as a black box without understanding to systems which do not satisfy the underlying assumptions is risky. A review of the method together with discussion of related techniques and practical hints is available at Hadrava (2004c). In this abbreviated version of the present contribution, only the basic, sometimes misunderstood, principles of disentangling are reviewed and recent developments towards a generalization of the method are summarized.

2. Disentangling = decomposition of spectra + fitting of parameters

In the classical treatment, orbital elements of spectroscopic binaries are obtained by subsequent measurement of radial velocities (RVs hereafter) and their fitting preferably together with light curves and other data (cf. Wilson 1979; Kallrath & Milone 1999; Hadrava 2004b, 2005). To measure the RVs for blended lines, special techniques (cf. Hill 1993, Zucker & Mazeh 1994, Rucinski 1992) requiring the knowledge of component spectra are needed. Special techniques have been developed (e.g. by Bagnuolo & Gies 1991) to separate the component spectra if RVs are known.

In disentangling, the observed spectra $I(x,t)$ are decomposed into spectra $I_j(x)$ of n component stars assuming that (in the logarithmic wavelengths $x = c\ln\lambda$) they are a linear combination

$$\sum_{j=1}^{n} I_j(x) * \delta(x - v_j(t,p)) = I(x,t), \qquad (2.1)$$

and simultaneously the orbital parameters p (or RVs $v_j(t)$) are fitted (cf. Figure 1 in the full version of this contribution).

3. Disentangling of spectra or Spectral disentangling?

Some users incorrectly denote the method of disentangling by adjective "spectral", what reveals misunderstanding of its principle. Spectral methods are generally a mathematical treatment of functions as a linear vector space, while for the spectra disentangling in astrophysics is essential that the treated functions represent some observed parts of electromagnetic spectrum radiated by the stellar system. The spectra decomposition can be performed either by the method of Singular Value Decomposition in the x- representation (Simon & Sturm 1994), or using the Fourier transform method, which reduces the set of Equations (2.1) into n- dimensional systems for each Fourier component (Hadrava 1995). Recently a kind of iterative procedure for the decomposition was also demonstrated by Gonzáles & Levato (2006).

4. Disentangling with line-profile variability

The standard disentangling does not impose any restriction on the component spectra I_j apart from their invariability in time. However, in real systems I_j may change because of proximity effects, eclipses and circumstellar matter, or from intrinsic line-profile variations arising from oscillations, rotation or secular changes of the component stars. In some systems, we can neglect these effects in the first approximation, and study them from $O-C$ residuals as higher-order perturbations only. But there is a danger of systematic errors e.g. in the disentangled orbital parameters. Moreover, the solution by standard disentangling may fail completely in extreme cases.

The relevant effects should thus be involved directly into the procedure of disentangling by generalization of Equation (2.1) to the form

$$\sum_{j,k} I_j^k(x) * \Delta_j^k(x,t,p) = I(x,t), \tag{4.1}$$

where the spectrum of each component star j can be a superposition of several functions I_j^k corresponding e.g. to different limb-darkening modes, each one broadened by appropriate broadening function Δ_j^k (cf. Hadrava 1997, 2004c).

The first such step consists of involving line-strength factors $s_j(t)$ into Equation (2.1), as done in the KOREL04 code (Hadrava 1997, 2004c). This enables the measurement of eclipses of (not too fast rotating) stars from their spectra, but also to disentangle telluric lines (cf. Hadrava 2006a). More tricky possibilities are to disentangle the rotation of ellipsoidal components (Hadrava & Kubát 2003), rotational effects in eclipsing binaries (Hadrava 2006c), or oscillations and pulsations — either radial (Hadrava 2004a, 2004c) or non-radial. Other models of line-profile variability, like spots etc. could be included using a proper model of the stellar disc like in light-curve models (Hadrava 2005).

5. Disentangling with constraints

It is generally advantageous to solve all types of data (spectroscopy, photometry, astrometry etc.) simultaneously, as it is enabled, e.g., by FOTEL code (cf. Hadrava 2004b). The previous versions of KOREL provided RVs of individual components at each exposure, which could be subsequently included into FOTEL solution with other RVs (e.g., from the literature), photometry etc. However, the information available in the additional data is not then utilized in the disentangling itself, which can result in a false solution, or, at least, its convergence may be more difficult. In a case of disentangling with LPVs caused by eclipses, the solution of radii or inclination would be safer to perform

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simultaneously with light-curve solution (despite a possibility of different photospheric and chromospheric radii should be considered). Such constraints of parameters can be, in some cases, taken into account by their fixing to values found from the additional sources. However, more generally, we need to search for a minimum of $(O-C)^2$ bound by some conditions $F_k(p) = 0$ to a subspace of the parameter space. This can be performed by minimization of the sum

$$S = \sum_t \int |I - \sum_j I_j * \Delta_j|^2 dx + \sum \lambda_k F_k^2(p) \tag{5.1}$$

with some Lagrange multiplicators λ. Because, in practice, the constraints obtained from the additional data have also some uncertainty, the additional terms F_k^2 can be the $(O-C)^2$ for those data and we thus arrive at the problem of simultaneous disentangling and solution of the other data with λs determining their relative weights, like it is done in FOTEL and other similar codes (cf. Holmgren 2004; Hadrava 2004b, 2006b).

Also, information about a component spectrum (e.g., from known spectral type or for the telluric lines) may help the convergence and to avoid instabilities (especially of low Fourier modes). The new version of KOREL thus permits the selection of some component spectra to be restricted by templates J_j given on input and to disentangle the others (Hadrava 2006b, cf. Figure 2), i.e., to solve the equation

$$\sum_{j=1}^{m} I_j(x) * \Delta_j(x,t,p) = I(x,t) - \sum_{j=m+1}^{n} J_j(x) * \Delta_j(x,t,p). \tag{5.2}$$

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