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FULL CHARACTERIZATION OF BINARY SYSTEMS WITH A HIGH DYNAMIC RANGE

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Abstract

Radial velocity measurements of binary systems lead to an incomplete set of orbital parameters. As a consequence, only minimum values for the masses of the two components can be determined. With the advent of long baseline stellar interferometry, it has become possible to resolve binaries with separations as small as a few mas. The latter technique yields the relative position of the secondary with respect to the primary, as well as the luminosity ratio between the two components. For systems observed with both techniques, a joint processing of the two kinds of data allows to retrieve all orbital parameters and thus to compute unambiguous estimates of the masses. We review this method and discuss to what extent it could be applied to systems with low mass companions, such as brown dwarfs and extrasolar giant planets.

1 Introduction

The long-term goal of this work is to use long baseline stellar interferometry (LBSI) in order to achieve a direct detection of *Pegasides* (51 Peg-like planets or "hot jupiters") already identified by radial velocimetry (Coudé du Foresto 2000). It appears as very challenging as the contrast (or luminosity) ratio of a Pegaside to its parent star is $r \approx 10^4$ in the near infrared. LBSI would make it possible to measure r as well as to remove the ambiguity on the planet mass by determining the inclination of the system on the sky. With some added spectral resolution ($r = r_\lambda$), the spectral features of atmospheric components like the methane would allow to discriminate between existing model atmospheres. Such high-dynamic observations require that the interferometric observable, the visibility, be measured with a very high precision during several orbits. Since the method we propose is general and can be applied to any binary system, we have undertaken an observing

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program with gradual steps that consists in studying spectroscopic binaries with companions of increasing differences in magnitude. First observations have been carried out with the FLUOR instrument (Coudé du Foresto *et al.* 1998) on the IOTA array (Traub *et al.* 2000) in fall 2000 and 2001, and will be resumed on the CHARA array (McAlister *et al.* 2000) in fall 2002. In parallel, we plan to use the VLTI/VISA array (Glindemann *et al.* 2000) as soon as possible.

In the following sections, we review the proposed method and present preliminary simulated observations of high contrast systems with the VLTI.

2 Observables

A binary system is usually described by a set of 7 orbital parameters: the semi-major axis a, the eccentricity e, the orbital period P, the epoch of periastron passage T_0, and the three Euler angles: the inclination i, the position angle of the ascending node Ω, and the argument of the periastron ω.

A radial velocity survey of the system already yields $a \times \sin i$, e, P, T_0, and ω. Above all, it provides the observer with a precise epheremis $\phi = \phi(t)$, where ϕ is the orbital phase. We do not advocate here a planet detection method and are only interested in systems for which this ephemeris is available.

LBSI happens to be a complementary technique by allowing the measure of i and Ω (with an uncertainty of 180° on the latter). Unfortunately, it also introduces new unknowns: the contrast ratio r and in a lesser extent the angular diameters of both components. In a first approximation, these diameters can be estimated using the spectral types as the visibility is not too sensitive to them.

Thanks to the knowledge of the ephemeris, visibilities need not to be grouped per night and turned into the familiar couples (ρ, θ) of separations and position angles. All measurements are recorded with their corresponding phase ϕ for the purpose of a global data processing.

3 Data processing and state of the art

Data processing consists in fitting a non-linear keplerian model to the data using for instance the Levenberg-Marquardt algorithm (Press *et al.* 1997). Although it is possible to fit independently spectrocopic and interferometric data, it is more efficient to perform a joint fit, as proved by Pourbaix and Eichhorn (1999) and applied for some time by several authors (*e.g.* Hummel *et al.* 1998 or Boden *et al.* 2000). This idea is not new as it originates in a paper by Morbey (1975) who proposed to combine visual and spectroscopic measurements to improve the quality of double star orbits. The main difficulty resides in finding the global minimum of the cost function that measures the distance between the model and the data. Either a global search followed by a local refinement of the solution (Pourbaix 1998, 2000), or a series of local searchs with a grid of initial conditions (*e.g.* Boden *et al.* 2000) can be undertaken.

Although a number of LBSI groups have determined very accurate orbits of spectroscopic binaries, the highest contrast ratio measured so far is, to our knowledge, $r \approx 28$ on Mizar (Hummel *et al.* 1998), well below the needed value for Pegasides ($r \approx 10^4$) or even for brown dwarfs ($r \approx 10^2 - 10^3$). Current performances are hampered by the atmospheric turbulence that limits the accuracy on the visibility measurements.

4 Simulated observations with the VLTI

We have simulated the observation of a high contrast binary system with the VLTI/VISA array to show the potential of this observational method. We report in Table 1 preliminary results for the inclination i, the position angle of the ascending node Ω, and the contrast ratio r in three cases. Let us assume that the 51 Peg system is observed for 8, 16 or 32 nights, beginning September, 1st, 2002. A given interferometric baseline is used 4 consecutive nights, and the target is interleaved with a reference star during 6 h centered on the transit of 51 Peg. The chosen sampling, rather sparse and easy to manage, covers a substantial part of the 4.11-day orbit each night. As for the precision on the visibility, 0.3% corresponds to the best statistical precision ever achieved by FLUOR, with spatial filtering by single-mode fibers but without fringe tracking (Perrin *et al.* 1999). The same figure can be expected from VLTI/VINCI (Kervella *et al.* 2000), whereas 0.1% is the predicted precision for VLTI/AMBER (Petrov *et al.* 1998).

Model	A	B	C
i	60°	60°	60°
Ω	45°	45°	45°
r	100	1000	10 000
Observations			
Precision	0.3%	0.3%	0.1%
# measures	64	128	512
# nights	8	16	32
baselines	A0M0, J2J6	A0M0, J2J6 B5J6, A0J2	A0M0, J2J6 B5J6, A0J2
Reduction			
i	$62° \pm 2°$	$64° \pm 7°$	$60° \pm 10°$
Ω	$45° \pm 2°$	$45° \pm 8°$	$54° \pm 10°$
r	95 ± 5	970 ± 135	10400 ± 2300
S/N on r	19	7.2	4.5

Table 1. Simulated observations of 51 Peg with the VLTI/VISA array, assuming three different contrast ratios for the companion, and different instrumental characteristics. "A" could be a faint stellar companion, "B" a brown dwarfs and "C" the actual giant planet in close orbit.

These simulations show that faint companions down to $r = 10^3$ (or $\Delta m = 7.5$) are already within reach of existing instruments in a reasonable observing time. Pegasides still require a large number of nights and a precision on the visibility that remains to be demonstrated. However, it is noteworthy that these nights need not to be consecutive, since all observations are phased with the ephemeris before their global processing.

5 Conclusion

Orbit reconstruction of spectroscopic binaries using interferometric visibilities and radial velocities jointly has proven to be very successful. However, the highest contrast ratio achieved so far is well below what is needed for Pegasides or even brown dwarf companions. Our preliminary simulations show that it should possible to measure the inclination as well as the contrast ratio of a Pegaside with a S/N of 4, using the VLTI/VISA array for 32 nights, provided a 0.1% precision on the visibility can be reached.

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