Extrasolar Planets in Multi-Body Systems: Theory and Observations
K. Goździewski, A. Niedzielski and J. Schneider (eds)
EAS Publications Series, **42** *(2010) 117-124*
www.eas.org

THE SARG PLANET SEARCH

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Abstract. We present the radial velocity planet search in moderately wide binaries with similar components (twins) ongoing at Telescopio Nazionale Galileo (TNG) using the Galileo High Resolution Spectrograph (Spettrografo Alta Risoluzione Galileo, SARG). We discuss the sample selection, the observing and analysis procedures, the main results of the radial velocity monitoring and the implications in terms of planet frequency in binary systems. We also briefly discuss the second major science goal of the SARG survey, the search for abundance anomalies caused by the ingestion of planetary material by the central star. Finally, we present some preliminary conclusions regarding the frequency of planets in binary systems.

1 Introduction

The frequency of planets in multiple systems has a strong impact on the global planet frequency, more than half of solar type stars being in multiple systems (Duquennoy & Mayor 1991). Furthermore, any difference in planet frequency and planet properties between single stars and multiple systems would make it possible to constrain the mechanisms of planet formation and evolution.

Most radial velocity surveys are biased against binaries. In spite of this selection effect, several planets in binary systems have been found (often the binarity was discovered after the planet detection). A few transiting planets are also in binary systems. Dedicated surveys looking for planets in binaries are also in progress.

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DOI: 10.1051/eas/1042010

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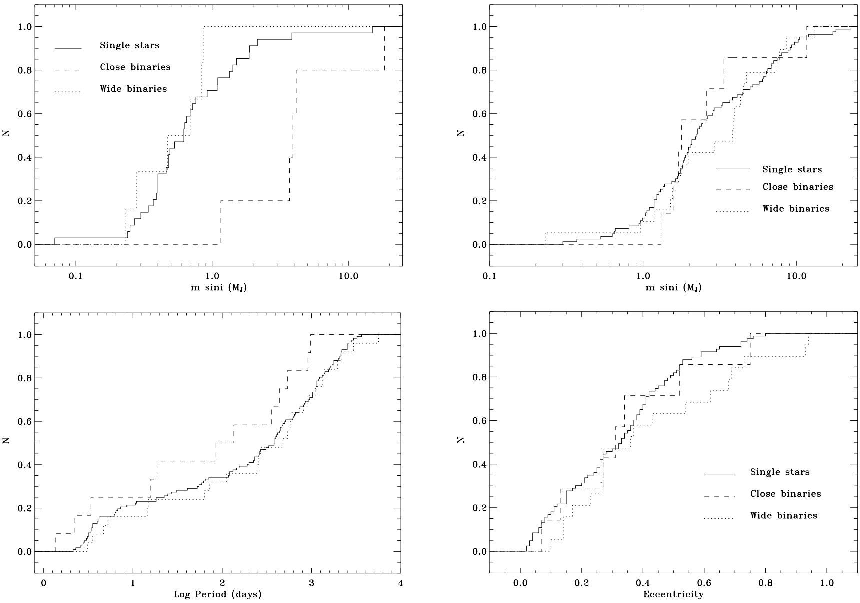

Fig. 1. Cumulative distributions of planet parameters for planets orbiting single stars (continuous lines); components of wide binaries (dotted lines); components of tight binaries (dashed lines). *Upper left panel*: mass distribution of planets with period shorter than 40 days. *Upper right panel*: mass distribution of planets with period longer than 40 days. *Lower left panel*: period distribution. *Lower right panel*: eccentricity distribution of planets with period longer than 40 days. Adapted from Desidera & Barbieri (2007).

Our project ongoing at Telescopio Nazionale Galileo (TNG) is presented here while other programs are described by A. Eggenberger in these proceedings.

Overall, a large variety of binary systems in terms of mass ratio and separation have been found to have planets. Statistical studies indicate that some planet parameters (*e.g.* the mass distribution) are different for planets in binary systems, in particular for those in rather close binaries (Desidera & Barbieri 2007, see Fig. 1).

2 The SARG Planet Search

The SARG planet search started in 2001, to survey a sample of about 50 moderately wide pairs looking for planets, using SARG, the TNG high resolution spectrograph (Spettrografo Alta Risoluzione Galileo) (Gratton *et al.* 2001). Only pairs with similar components ($\Delta V \leq 1$) were selected. Both components were put under radial velocity monitoring (Fig. 2). With a time allocation of 6−10 nights/semester, about 20 spectra per star were obtained on average. The general monitoring has now been completed and we are performing additional observations of

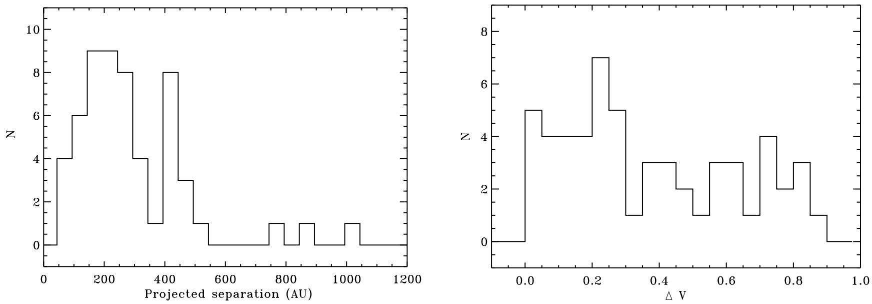

Fig. 2. *Left panel*: distribution of the projected separation in AU of the binaries in the sample of the SARG survey. *Right panel*: distribution of the visual magnitude difference of the binaries in the sample of the SARG survey.

the most interesting systems. High-precision radial velocities were obtained exploiting the iodine cell technique, using the AUSTRAL code by Endl *et al.* (2000). A radial velocity precision of 2–3 m/s was achieved for bright stars, and 3–10 m/s for the program star (V = 8–10). Complementary observations with AdOpt@TNG (Cecconi *et al.* 2006) were performed on planet candidates (see below) and on stars with long term RV trends. Some results of the adaptive optics observations are described in the contribution by Martinez Fiorenzano *et al.* (these proceedings). The whole project is presented in more detail in Desidera *et al.* (2008).

3 Differential Abundance Analysis

The second goal of our project is the search for abundance anomalies due to the ingestion of metal-rich planetary material. Binary systems with similar components are very useful for this type of study, as high-precision line-by-line differential abundance analysis can be performed with errors as small as 0.02 dex (Desidera *et al.* 2004b, 2006, Fig. 3). Only one pair was shown to have a large (>0.1 dex) difference of Fe abundances (HD 113984). However, the primary of this system is a blue straggler, and the observed abundance anamalies may not be linked to the evolution of a planetary system (see Desidera *et al.* 2007). For warm pairs (with thin convective zones), the limits on the amount of accreted material are similar to the estimates of accretion by the Sun during its main sequence lifetime (0.4 $M_{\rm Earth}$ of iron, Murray *et al.* 2001). These results suggest that the occurrence of large abundance alterations are not common. This is further confirmed by the abundance analysis of stars with planets in binary systems with components suitable for abundance analysis (see Desidera *et al.* 2008).

4 Planet Candidates

We search for periodicities using a Lomb-Scargle periodogram coupled with bootstrap simulations for evaluating statistical significance. In our sample, there are no

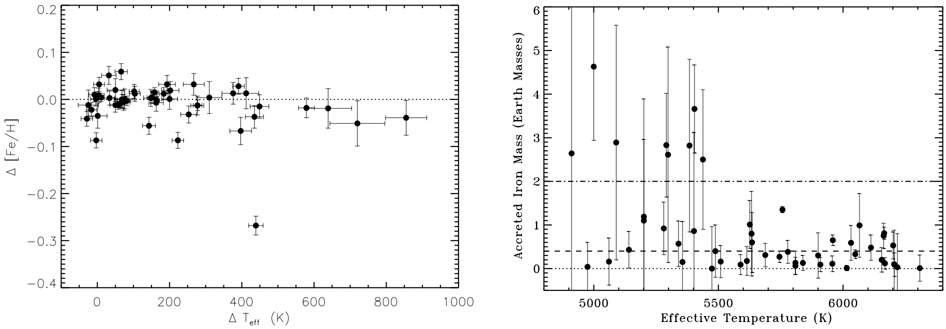

Fig. 3. *Left panel*: iron abundance difference between the components of pairs as a function of temperature difference for the pairs studied in Desidera *et al.* (2004b, 2006). *Right panel*: estimate of iron accreted by the metal-rich component of each pair as a function of its effective temperature, taking into account the mass of the mixing zone as in Murray *et al.* (2001). The less severe limits at lower effective temperatures are mostly due to the more massive convective zone in cool stars. The horizontal lines show the amount of iron expected to have been accreted by the Sun during the main sequence lifetime (0.4 $M_{\oplus}$: Murray *et al.* 2001), and the amount of iron corresponding to the upper limit on the abundance difference between the inner and outer regions of the Sun according to helioseismology (2 $M_{\oplus}$: Winnick *et al.* 2002). The mass of meteoritic material is assumed to be about 5.5 times the mass of iron. From Desidera *et al.* (2006).

short-period planet candidates with false alarm probability smaller than about 3%. The most interesting candidates have rather long periods or low radial velocity amplitude. A couple of examples are shown in Figure 4. Some additional stars are characterized by radial variability. In most cases this can be explained by stellar activity jitter and residual contamination of the spectra from the companion (see below). The low-amplitude radial velocity variations of HD 219542B were shown to be due to stellar activity and not to a planet (Desidera *et al.* 2003, 2004a).

5 The Contamination Issue

For a radial velocity survey targeting binary systems, the issue of contamination of the spectra by the light of the companions is crucial. Errors due to contamination are typically not included in the internal errors as estimated by the AUSTRAL code, because all the chunks on which the spectrum is divided and analyzed independently deviate by a similar amount, leading to formally significant but spurious radial velocity variations. During the observations, the slit was usually oriented perpendicularly to the separation of the components to minimize the contamination of the spectra by the companion. For the closest pairs in our sample (projected separation about 2–3 arcsec) contamination might be significant in spite of the fact the we observe these objects only in good seeing conditions. We use the seeing

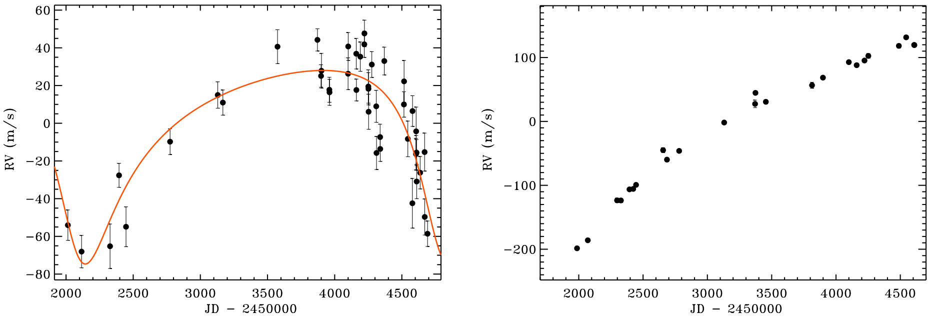

Fig. 4. *Left panel*: a long period planet candidate from the SARG survey. The formal best fit solution corresponds to $m \sin i$ about 4 $M_{\rm Jup}$ and $a \sim 4$ AU, but a longer period and larger masses are possible. Stellar companions more massive than 0.3 $M_{\odot}$ beyond 10 AU are excluded from images taken with AdOpt@TNG. *Right panel*: another long period candidate. A mass in the planetary regime is possible only for a particular combination of the orbital parameters. Therefore the companion is more likely to be a brown dwarf or a very low mass star. The companion was not detected in adpative optics images.

measured on the spectra images, coupled with a model of expected contamination and the analysis of line bisectors (see Martinez Fiorenzano *et al.* 2005) to identify contaminated spectra.

The analysis of line bisectors is also used to study activity-induced changes and to disentangle tertiary components in the spectra (see Martinez Fiorenzano *et al.*, these proceedings).

6 Binary Orbits

For the interpretation of the results of our survey, it is important to constrain the binary orbits as much as possible. The combination of radial velocity trends (observed with similar amplitude and opposite sign in the two components) coupled with visual observations from the literature enables the derivation or refinement of the orbits for 5 pairs (Fig. 5). For the remaining pairs, we use the radial velocity difference between the components coupled with available astrometric data (binary motion is typically detected) to constrain the binary orbit (as in Desidera *et al.* 2003).

7 Upper Limits

The null detection for planets with periods comparable to the survey duration and moderate radial velocity amplitude can be used to constrain the planet frequency in the kind of binaries we are observing. Limits for planets that are compatible or excluded by our data were derived on a star-by-star basis, including eccentric

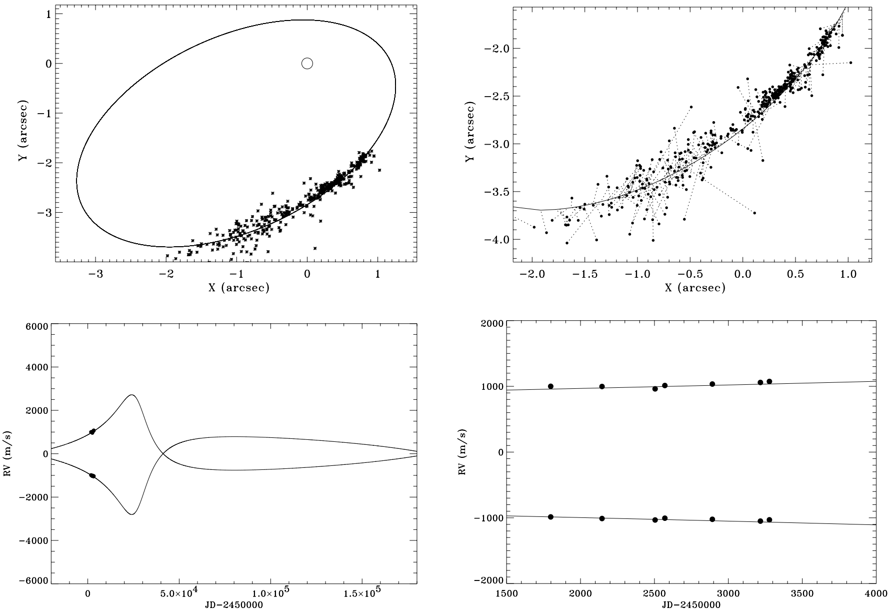

Fig. 5. Binary orbit of one pair for which radial velocity trends due to the binary motion are detected in SARG data. From top: a) full visual orbit and data from the Washington Double Star Catalog (Mason *et al.* 2001). b) Zoom in the region with visual data; residuals are plotted as dotted lines. c) Full radial velocity orbit plotted on top of the SARG radial velocity data. d) Zoom of central panel in the region with SARG radial velocity data

orbits, following the approach described in Desidera *et al.* (2003). Figure 6 summarizes the results.

8 Frequency of Planets in Binary Systems

The null results of the SARG planet search suggest a lower frequency of planets in the kind of binary we are exploring. A more general study of the frequency of planets in binaries was performed using the Uniform Detectablity sample by Fischer & Valenti (2005). The original analysis is described in Bonavita & Desidera (2007), with updates in Bonavita *et al.*, these proceedings. We use the critical semimajor axis for dynamical stability ($a_{\rm crit}$, Holman & Weigert 2001) to explore the dependencies of planet frequency with binary parameters. In fact, $a_{\rm crit}$ is a more relevant quantity than the separation to explore the effects of a companion on planets, as it includes the dependency on both the orbital parameters and the mass ratio.

For the Fischer & Valenti sample, binaries with $a_{\rm crit}$ smaller than 20 AU (corresponding to separations of about 50–100 AU depending on the mass ratio) have

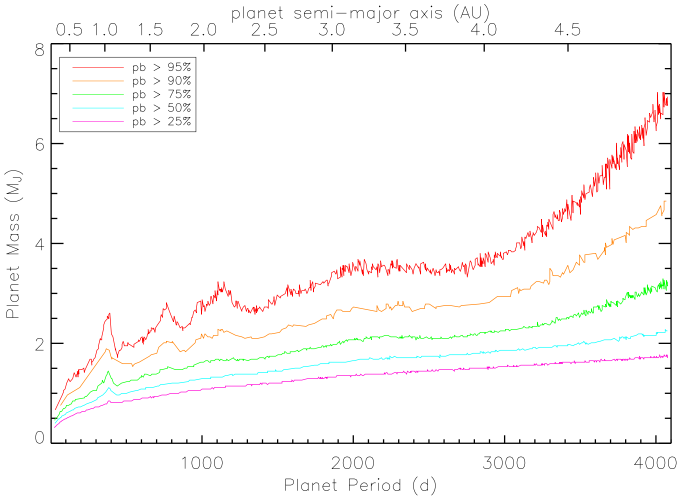

Fig. 6. Summary of estimates of exclusion/compatibility of planets in the SARG sample with current data for the stars with at least 10 observations. For each period, the mass corresponding to the exclusion of (from top to botton) 95%, 90%, 75%, 50%, and 25% of the planets (with planet eccentricity up to 0.99) is shown. The results of individual stars were averaged to produce the plot.

a planet frequency significantly lower than that of single stars and components of wider binaries. At the typical separation of the SARG survey binaries, there are no significant differences. This is probably due to the incompleteness of binary detection at intermediate separations in the Fischer & Valenti sample (adaptive optics observations are needed to detect low-mass companions at such separations, see *e.g.* Eggenberger *et al.* 2007, while dynamical signatures are more difficult to see than at closer separations). When merging the binaries in the SARG and Fischer & Valenti samples, the paucity of planets in binaries extends up to $a_{\rm crit}$ smaller than about 50–80 AU. This is similar to the limit adopted in Desidera & Barbieri (2007) to define their sample of tight binaries with planets, and the anomalies of the planet mass distribution appear to occur for these objects. This suggests some difference in planet formation and/or migration in moderately close binaries with respect to wide binaries and single stars. The details of the change of planet frequency with binary properties require larger and complete samples for detection of both planets and binaries. From available results, there is some indication of a bimodal distribution, with several planets with $a_{\rm crit} < 10$ AU and between 10 to 30 AU a less populated region compared to $a_{\rm crit} < 10$, but this might be due to selection effects and needs confirmation. We conclude that the search for planets in binaries and the study of their properties in comparison to planets orbiting single stars and components of wide binaries is indeed very important for our understanding of the processes of the formation and evolution of planetary systems.

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