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Memorie della

The SARG exo-planets search

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Abstract. We present the status of the SARG Exo-Planets search. This program started about 2.5 years ago. It consists in a search for planets in about 50 wide solar type binaries using high precision radial velocities gathered with SARG. We also perform a high precision abundance analysis of the two components of each system. We obtain differential radial velocities with typical accuracies of 2-3 m/s for bright standard stars, and of $\sim$ 5 m/s for the fainter program stars. Abundance differences between the two components have typical precision of about 0.016 dex. Preliminary results are presented, with emphasis on the case of HD219542, a binary for which we found a difference of about 0.09 dex in the Fe abundance between the two components. While no giant planet in close in orbit is found around the primary, we found radial velocity variations compatible with a Saturn mass orbiting the secondary on a Mercury-like orbit. However, we cannot still exclude that the observed small amplitude radial velocity variations are due to a moderate stellar activity.

Key words. stars: exoplanets – stars: binaries – stars: activity

1. Introduction

Since the first discovery by Mayor & Queloz (1995) of a planet orbiting 51 Peg, about 100 exo-solar planets have been discovered; all but two have been discovered using high precision radial velocities. These planets have unexpected properties. Giant planets have been found on close orbit, with period down to $\sim$ 1.2 days. While the observation of such systems is favoured by the technique used, the presence of such planets was totally unexpected from theories of planet formation. Also totally unexpected is the finding that planets on orbits with semimajor axis a larger than 0.05 AU have in most cases eccentric orbits, with an ec-

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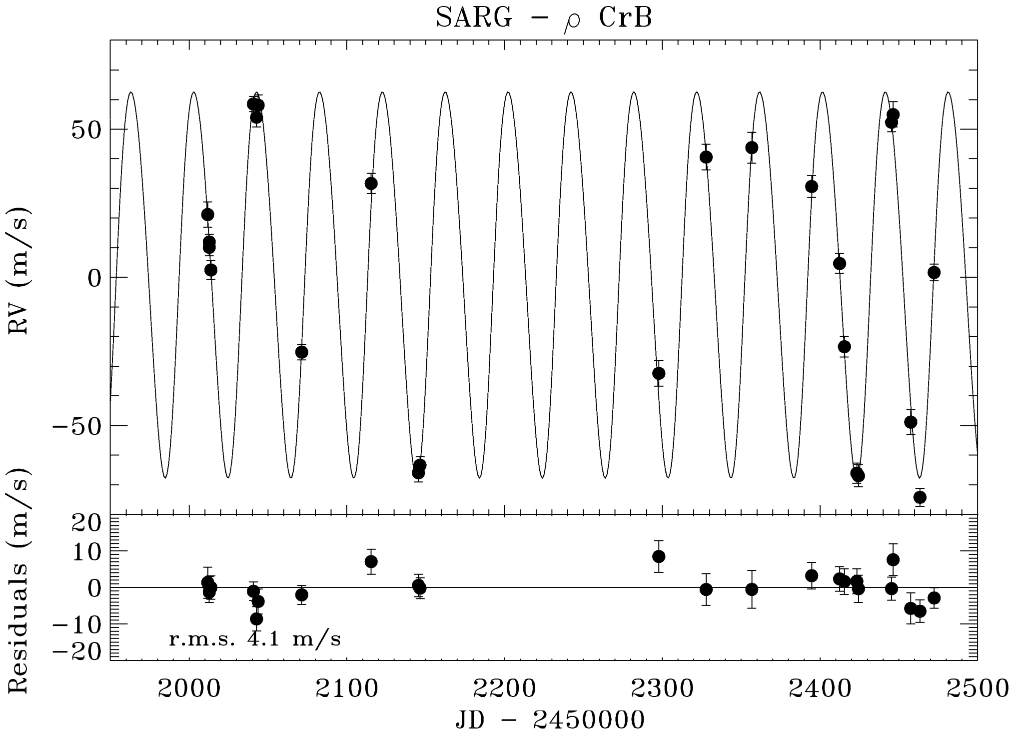

Fig. 1. Radial velocity data for ρ CrB. The radial velocity variations due to the planet discovered by Hayes et al. (1997) are clearly seen

centricity distribution not distinguishable from that of binary stars for planets with $a > 0.3$ AU. The separation between giant planets and brown dwarfs, that seems to be quite elusive when free floating objects are considered, is quite clear when considering objects orbiting around stars (the so called *Brown Dwarf Desert*). Various multi-planetary systems have been discovered; in a few cases, they show orbital resonances. Finally, in a couple of cases the planet has been observed to transit on the stellar disk: the best studied case is HD 209458 (Charbonneau et al. 2000). This allows the derivation of the planet mass, radius and density, confirming its planetary nature.

Giant planets in close orbits ($a <$ 3.5 AU) are present in about 8% of the stars: however, this frequency is a strong function of the star metallicity. Planets (at least, giant planets in close orbits) are rare among stars with [Fe/H]< 0.1, while they are present in more than 10% of the metal-rich stars. This result is also quite unexpected, since giant planets are mainly made of H and He, and their formation was then expected to be rather unsensitive to the initial composition of the proto-planetary disk.

These results raise a number of still unanswered questions. What is the origin of the giant planets in close-in orbits? Did they form where they presently are, or rather formed in outer regions of the system and later migrated inward due to some dynamical perturbation? What is the origin of the large eccentricities? The high metallicity of the star is the cause or the effect of the presence of planets? The answers to all of these questions have important consequences on the frequency of habitable planets around stars, and are basic

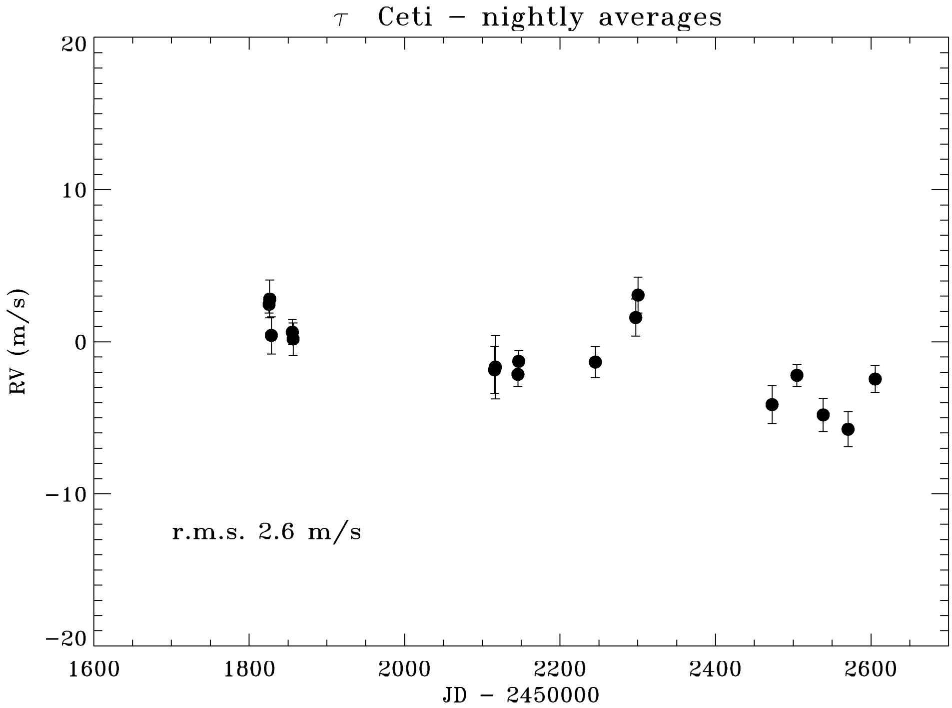

Fig. 2. Radial velocity data for τ Cet

in our understanding of the formation and evolution of planetray systems.

Binary systems are important laboratories to test these issues. First, binaries make up a large fraction of the stars in the solar neighborhood. Second, in the case of binaries there are clear sources of dynamical perturbations: a systematic study of the incidence of planets in both components of binary systems, as well as of their dynamical properties, may provide basic test on the impact of dynamical perturbations. Third, in the case of binaries of similar mass, we may perform high precision differential determinations of the chemical composition, unveiling the possible pollution of one of the two components by planetary or proto-planetary material.

A few exo-solar planets have been already discovered in wide binaries. The most famous case is that of the planet around 16 Cyg B (Cochran et al. 1997); remarkable is the case of the planet in the γ Cep system, which have a periastron of only 12 AU (Hatzes et al. 2003). These findings show that planets can indeed form and survive in binary systems. However, no systematic search for planets in binaries have been done insofar. The SARG exo-planet search (www.pd.astro.it/new_sites/ESP/) propose to fill this gap.

2. The sample

The SARG sample consists of about 50 pairs taken from the Hipparcos Double and Multiple System Catalogue (Perryman et al. 1998). Only binaries having a separation larger than 2 arcsec were selected, to avoid contamination between the components. We also limited ourselves to main sequences pairs with a magnitude difference of < 1 mag (in V): this allows a careful comparison between the composition of the two stars. Additional criteria included apparent magnitude ($7 < V < 9.5$) and spectral type of the primary (F7-K), as well as a parallax larger than 10 mas. Finally, we eliminated a few stars that revealed to be spectroscopic binary, rapidly rotating or active stars from analysis of first epoch spectra. Analysis of available data showed that for the projected separation typical of our pairs ($\sim 200 - 300$ AU), the critical semiaxis for dynamical stability of planets computed following Holman & Weigart (1999) is a few tens of AU.

3. The observations

We are searching for planets around stars in our sample looking for radial velocity variations. To this purpose, we are using SARG at TNG (Gratton et al. 2001a). SARG is equipped with an iodine absorbing cell. This technique provides most accurate radial velocity variations, with errors below 3 m/s in best cases (see Butler et al. 1996). SARG is well suited to high precision radial velocities, thanks to its high spectral resolution ($R = 144,000$), large spectral coverage in a single exposure, to the thermal and mechanical stabilization, and of the high efficiency.

Spectra obtained with the iodine cell results from the superposition of the reference iodine and stellar spetra. This provides the possibility to remove instrumental shifts. The iodine spectrum is characterized by a forest of very narrow lines, blended even at very high spectral resolution. A full modelling of the instrumental profile is needed to analyze the composite spectrum: in fact spurious shifts between the narrow iodine lines and the much broader spectral lines can be introduced when the instrumental profile is not adequately considered. Simultaneous model of the instrumental profile (using the iodine lines themselves) is mandatory to reach a radial velocity precision below 10 m/s. The software we use, a basic element in our work, is the AUSTRAL code developed by Endl et al. (2000); it has been used in the discovery of several exo-solar planets at ESO and McDonald (ι Hor, ϵ Eri, γ Cep).

4. Search status

The SARG Exo-planet Search is a five years program (88 nights). It started in January 2001. After about 28 months, we have completed slightly more than a third of the survey using about 30 nights, acquiring 50% of the template spectra, and on average 6.5 spectra for each star (out of a planned 20 spectra).

SARG radial velocity precision has been estimated using three standard stars: two stars known to host exo-solar planets (51 Peg and ρ CrB), and a star whose radial velocity is considered to be constant (τ Cet). Figures 1 and 2 show our radial velocity data for ρ CrB and τ Cet. These data show that radial velocities accurate at 2-3 m/s and stable over > 2 yrs are achieved with SARG.

5. HD 219542: A pair with different chemical composition

The high S/N template spectra needed in the radial velocity measurements can be used to derive accurate abundances. The most critical issue in abundance analysis is the derivation of accurate temperatures. Exploiting the fact that the two components of a binary system are at the same distance from us, and that magnitude difference between the two components (as well as mass ratios) can be accurately estimated, Gratton et al. (2001b) showed that temperature differences with errors ≤ 15 K can be derived for the components of the binaries of our sample using the Fe ionization equilibrium, *provided that a strictly differential line-by-line analysis is adopted.*

Errors in these differential abundances are typically 0.016 dex, a value confirmed by the observed spread. Figure 3 shows the run of the differential abundances as a function of the difference in temperature between the two components for 22 pairs in our sample. In most cases we

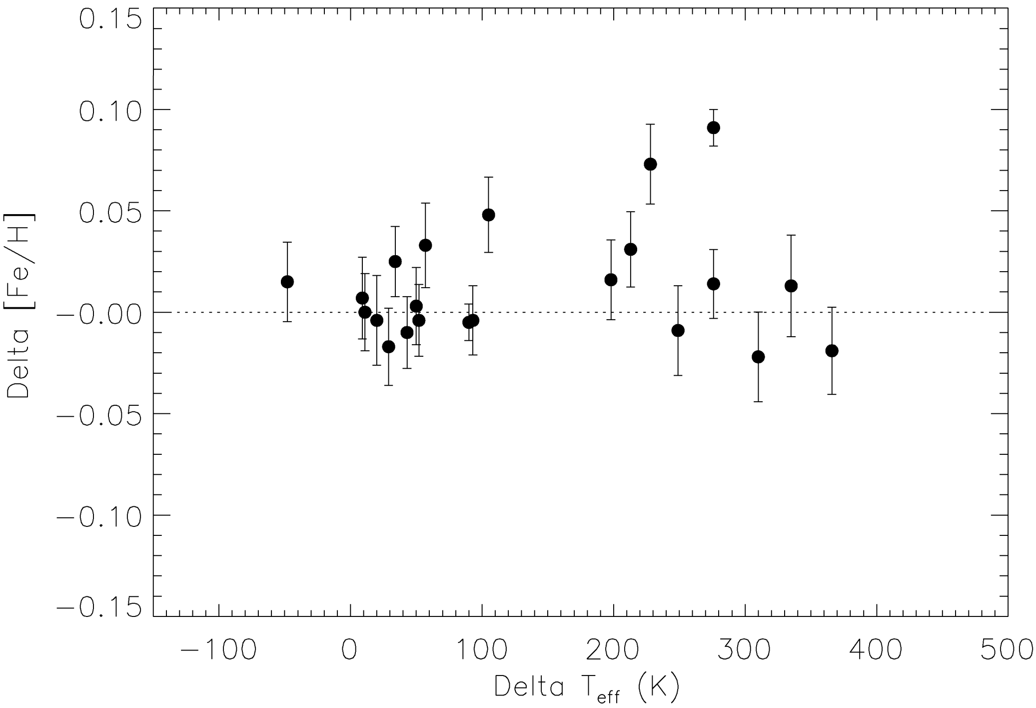

Fig. 3. Run of the differential abundances as a function of the difference in temperature between the two components for 22 pairs in our sample

found no significant difference between the two components. In three cases the difference is larger than twice the internal error; however only one case (HD219542) is indeed highly significant (0.09 dex, about 9 times the internal error; the primary resulting more metal rich than the secondary). We found no spurious trend of the differences with excitation potential, line strength or wavelength. Furthermore, both components of HD219542 do not show signs of a high activity level, so that the abundance difference cannot be attributed to anomalies in the atmospheres. Both stars are still close to the Zero Age Main Sequence, and there is no indication of binary interaction. Short period stellar companions can be clearly excluded from our radial velocities. Finally, there is some hint in the data that this difference is only limited to rocky elements, with no evidence for a variation in volatile ones. We then suggested that these data might be interpreted as due to engulfing of planetary material. The ingestion of 3-5 earth masses of rocky material (planets and/or parts of a protoplanetary disk) by the primary of the system can explain the observed differences.

In the last two years both components of HD219542 were intensively observed, looking for variations in the radial velocities. The radial velocity curves of the two components are shown in Figures 4 and 5 (Desidera et al. 2003). No massive close-in planet could be found around the primary. We computed the limits on the mass of possible planetary companions (see Figure 6), both for a circular and for an eccentric orbit using an innovative MonteCarlo procedure that allows for the first time to derive significant limits on eccentric orbit too. A part from the peak around 1-yr (due to visibil-

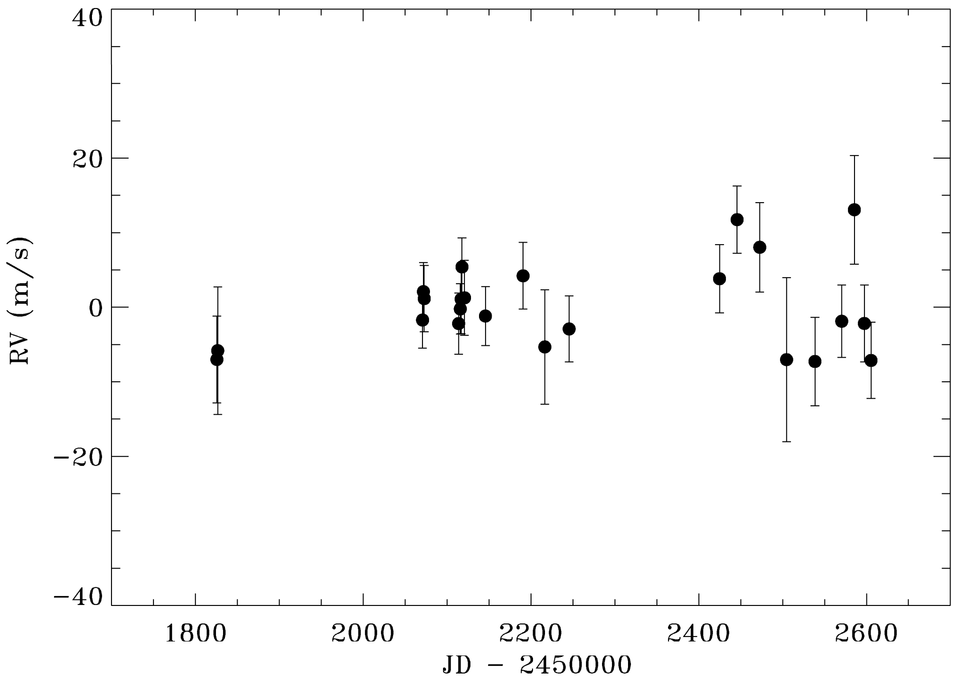

Fig. 4. Radial velocity data for HD219542A

ity of the system) there is no evidence for a massive planet in a close orbit. On the other side, we detected low amplitude radial velocity variations for the secondary. These may be interpreted as due to a slightly eccentric ($\sim$ 0.3) keplerian motion: in this case, the period would be about 112 d, and the velocity semi-amplitude of 13 m/s. If indeed caused by a planet, this would have a mass of $M \sin i = 0.3\ M_J$ (that is, the mass of Saturn), and the orbital semiaxis would be $a = 0.42$ AU. The significance of the proposed orbit is about 97%; this is a quite large value, but still lower than the generallay accepted lower limit of 99%, so that the confirmation of this detection must wait for further observations.

An alternative interpretation for the radial velocity variations of HD219542B is stellar activity. Stellar activity (spots, plages, flares) can induce spurious radial velocity variations, as shown for instance by the case of HD166435 (Queloz et al. 2001). Both components of HD219542 are certainly not very active: they have low chromospheric mission, slow rotation, and maybe some coronal x-ray emission. The activity induced velocity variations for HD219542A are about 4 m/s (using the relation by Saar et al. 1998), and may explain the small observed scatter. However, the activity level required to explain the radial velocity scatter of HD219542B is low, and cannot be easily excluded by the data. In order to test this issue, we measured the line bisector (a useful indicator of spurious radial velocity variations: see Queloz et al. 2001), and found no correlation of the bisector span with radial velocity. Unfortunately, also this test is not sensitive enough for the present case.

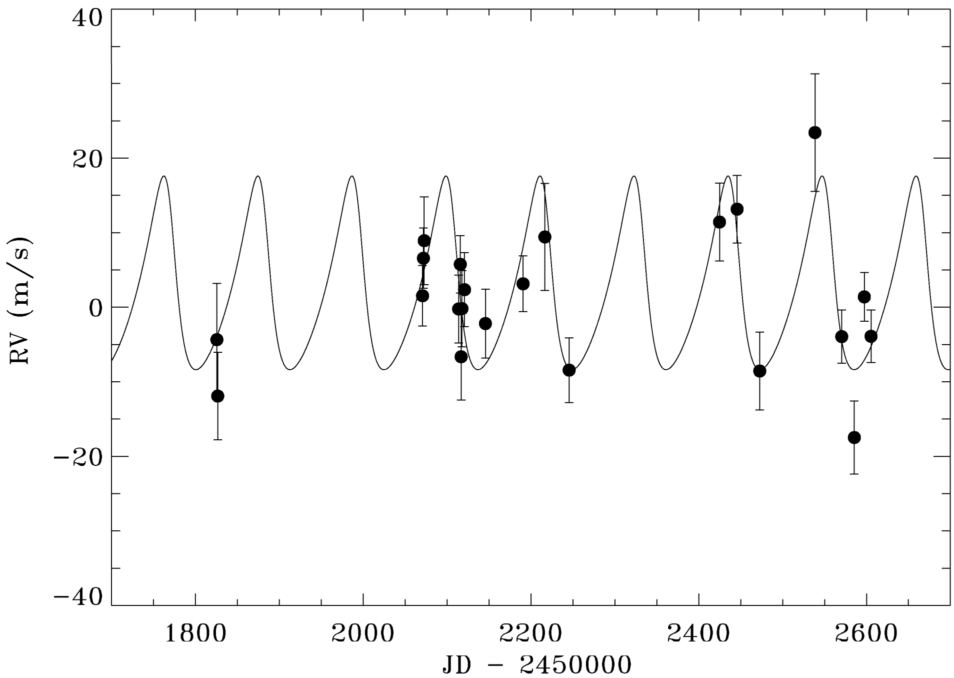

Fig. 5. Radial velocity data for HD219542B. Overplotted is the best orbital solution of the planet candidate

6. Conclusions

The present results are only preliminary ones from the SARG Exo-planets Search. However, after little more than two years, we have found a good planet candidate in the special binary HD219542. If confirmed, this would be one of the planets with lowest velocity amplitude. This makes difficult to exclude the presence of activity-induced variations. At least another observing season should be required to confirm the presence of this planet.

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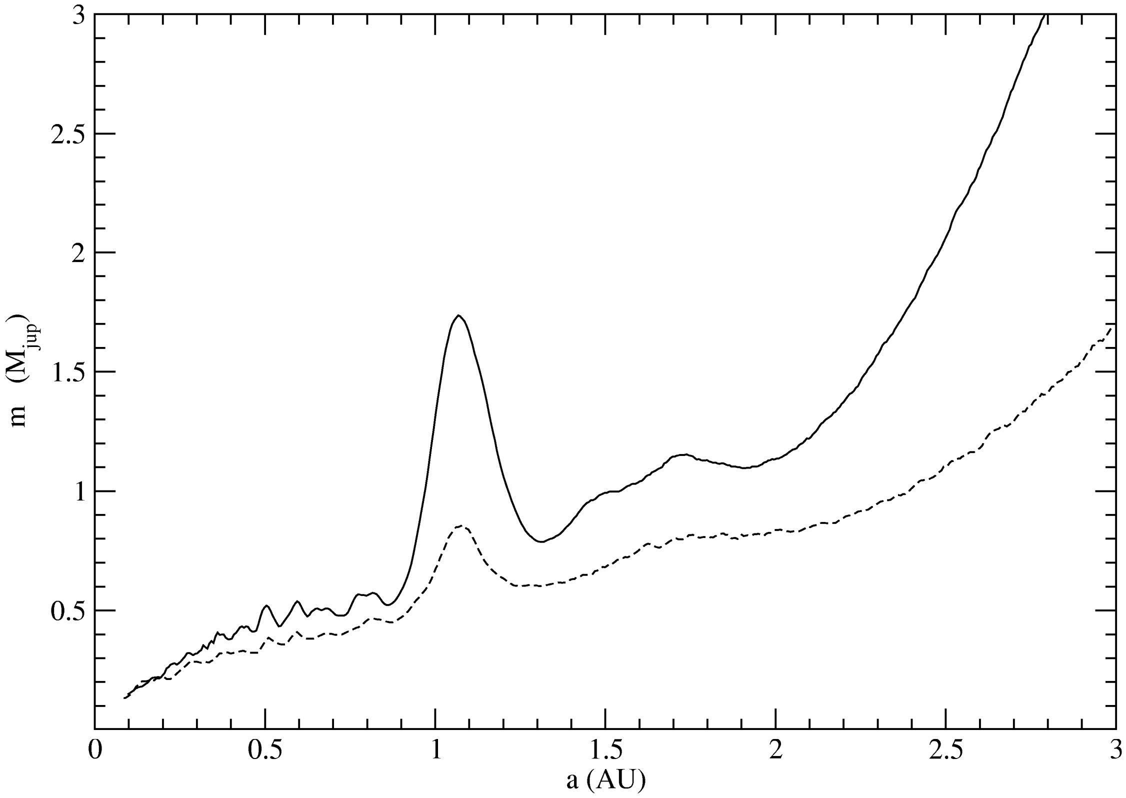

Fig. 6. Limits on the mass of a possible planetary companion around HD219542A