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PLANET DETECTION AROUND M DWARFS: NEW CONSTRAINTS ON PLANET FORMATION MODELS

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Abstract. The dependence of planetary statistics on the physical conditions during the initial stages of the system (i.e. in the proto-planetary disk) represent an essential constraint on planetary formation mechanisms. The planets orbiting M dwarfs were formed in a lower-mass disk, with an ice boundary much closer to the star, and a longer orbital period (for the same separation) than the planets formed around solar-type stars. Planetary formation is extremely sensitive to all three parameters, and the relative statistical properties of planets around G dwarfs and very low mass stars therefore represent a very sensitive diagnostic. In this talk we will present the first results of a very sensitive search for planets around southern M dwarfs with the HARPS spectrograph (as part of the HARPS GTO program). The northern counterpart of the survey will be conducted with SOPHIE at OHP, within the SOPHIE Exoplanets Consortium. These first results suggest that planets around M dwarfs have lower mass than around solar type stars.

1 Introduction

The compared statistical properties of exoplanets around host stars with different masses provide quantitative constraints on models of planet formation. The physical conditions in the proto-planetary disk during the initial stages of the planetary system depend strongly on the central star. Changing the central star directly affects:

- the central gravity, and thus the orbital period at a given separation, which influences the accretion rate of the proto-planet,
- the temperature in the disk, and therefore the sound speed, which affects planetary migration, and the position of the ice boundary,
- most likely the mass of the disk, and thus the quantity of material available for planet formation,
- ...

Each step of the planetary formation process (core growth, accretion rate, migration, etc...) therefore depends directly or indirectly on the central star, and the relative statistical properties of planets around G dwarfs and very low mass stars represent a very powerful diagnostic.

The two leading candidate mechanisms for planet formation, core accretion and disk instabilities, have different sensitivities to this control parameter, and observations could thus discriminate them. Core accretion models (initial formation of solid core, followed by gas accretion) predict than Jupiter mass planets are rare around M dwarfs (Laughlin et al. 2004; Ida & Lin 2005) but that Neptune mass planets at small orbital separations could be numerous (Ida & Lin 2005; Kornet et al. 2006). By contrast disk instability models seem unable to form Neptune mass planets (except in very particular environments; Boss 2006a) but readily form Jupiter mass (and above) planets (Boss 2006b)

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2 Planets around M dwarfs

Radial velocity surveys have to date unveiled about 170 planetary systems. They were initially searched for, and thus found, around solar-type stars (e.g. Mayor & Queloz 1995). As consequence of this bias, the vast majority were detected around late-F, G and K dwarfs stars.

To date 6 planets around M dwarfs have been detected by radial velocity surveys: 1.9 M_{Jup}, 0.6 $M_{Jup}$and 0.42 M_{Nep}around Gl 876 (Delfosse et al., 1998; Marcy et al., 1998, 2001; Rivera et al., 2005); 0.8 M_{Jup}around Gl 849 (Butler et al, 2006); 1.2 M_{Nep}around Gl 436 (Butler et al. 2004) and 0.97 M_{Nep}around Gl 581 (Bonfils et al. 2005).

Figures 1 and 2 respectively plot the planet mass versus separation and planet mass vs mass of the host stars for all extrasolar planets detected by radial velocity. A strong observational bias must be taken into account, since the parent samples only contain 200 or 300 M dwarfs, compared to a few thousands of solar type stars. With due account for this, these first detections suggest that planets around very low mass stars have rather distinct characteristics:

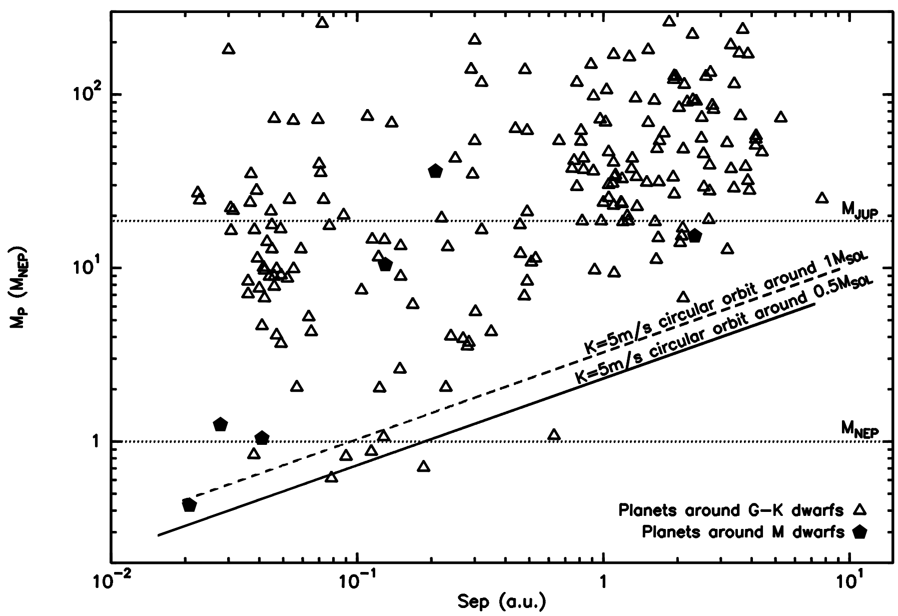

Fig. 1. Planet mass versus orbital separation. Dark pentagons represent planets around M dwarfs while open triangles represent planets around solar type stars. The two lines represent a a radial velocity semi-amplitude $K_1 = 5m.s^{-1}$ for respectively 1 and 0.5 $M_\odot$central stars.

- A large fraction (∼30%) of all currently known Neptune mass planets orbit M dwarfs (Fig. 1),
- None of the large population of hot-Jupiter planets (with separation around 0.04 a.u.) orbits an M-dwarf,
- planets with mass from 7 earth mass (Gl876d; Rivera et al. 2005) to 2 Jupiter mass (Gl876b; Delfosse et al. 1998) are formed around M-dwarfs.

Montecarlo simulations of the observational biases confirm that the hot Jupiter deficit is intrinsic (Bonfils et al. 2006)

3 Our HARPS and SOPHIE programs

To pinpoint the statistical characteristics of planets around M-dwarfs we monitor over 200 very low mass stars with an accuracy of a few meters per seconds. Since 2003 (as part of the HARPS GTO program) we measure 100

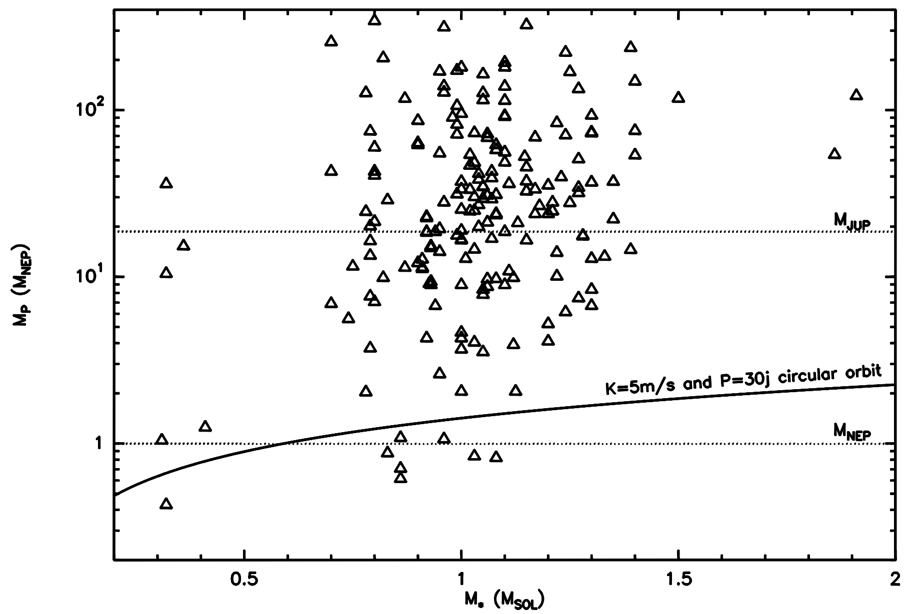

Fig. 2. Planet mass vs mass of the host star for all currently known planets. A large fraction of all M<0.01M_{Jup}planets know to date orbit M dwarfs, while a vast majority of the Jupiter-mass planets orbits solar type stars.

M-dwarfs with HARPS, the new ESO high-resolution (R = 115 000) fiber-fed echelle spectrograph. HARPS has proved by far the most precise spectro-velocimeter to date, reaching an instrumental RV accuracy significantly better than 1 m s^{-1} (Mayor et al. 2003). The M dwarfs are typically too faint to reach the stability limit of HARPS, but the median rms dispersion (left part of figure 3) which we obtain for M dwarfs remains excellent: ∼2 m/s. Because K (semi-amplitude of radial velocity variation) varies with stellar mass as $M_*^{2/3}$, a 3 m/s accuracy for a 0.3$M_\odot$ M dwarf can detect the same planet than a 1.5 m/s accuracy for a solar type star. Our accuracy is this sufficient to detect planets of a few earth masses on short period orbits around M dwarfs.

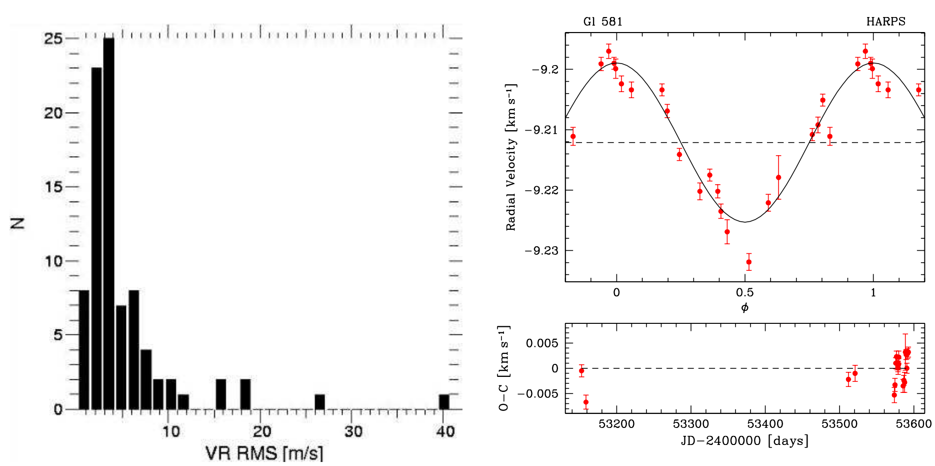

Fig. 3. Left: rms dispersion of our HARPS radial velocity measurements. Right : *Upper panel:* Phased radial velocities for Gl 581; *Lower panel:* Residuals of the fitted solution versus time.

The 0.97 M_{Nep}planet around Gl 581 (Bonfils et al. 2005, cited above) is the first planet discovered during this program and illustrates this capability. The right part of Fig. 3 shows our phased radial velocities, and shows that radial velocity orbits with a semi-amplitude half of that of Gl 581 would be fairly easily detected.

Such detections however need good temporal coverage, and the HARPS observations are just now starting to deliver their first candidates.

At the end of 2006 we will start a new program with SOPHIE at 1.93-m OHP telescope (see Loeillet et al. 2006, in these proceedings). 150 additional M-dwarfs will be monitored with an accuracy better than 3-4 m/s. With ∼250 M-dwarfs monitored with such radial velocity accuracy we will obtain good statistics on the frequency of Jupiter-mass planets around very low mass stars for all periods under a few years, and of super-earth planets with periods under ∼ 50 days.

4 Habitability and transits

Discovering habitable planets is another important motivation in searching for planets around M-dwarfs: the habitable zone is much closer to the star around an M-dwarf, and a planet in that zone therefore produces a larger velocity variation than around a solar type star. An 8 earth-mass planet in the habitable zone of a $1M_{\odot}$stars (1 a.u.), for example, produces a radial velocity semi-amplitude of 0.7 m/s, while the same planet habitable around an M2 dwarf ($0.4M_{\odot}$) will be at 0.1 a.u. and cause a 3.5 m/s semi-amplitude radial velocity variation. This amplitude is detectable today with HARPS.

Finally, the radius ratio between the planet and its star makes transits much deeper across M dwarfs. A Neptune mass planet eclipsing an M3 dwarf produce a deeper transit than a Jupiter mass planet eclipsing a solar-type star. Ground telescope can detect a Neptune radius planets eclipsing an M-dwarf fairly easily, when space-based observation are needed to detect the same event around solar type stars. The hot Neptune discovered by radial velocity around very low mass stars are clearly strong candidates for photometric monitoring.

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