The *SOPHIE* northern extrasolar planets*

I. A companion close to the planet/brown-dwarf transition around HD 16760

Bouchy, F.1,2, Hébrard, G.1, Udry, S.3, Delfosse, X.4, Boisse, I.1, Desort, M.4, Bonfils, X.4, Eggenberger, A.4, Ehrenreich, D.4, Forveille, T.4, Le Coroller, H.2, Lagrange, A.M.,5, Lovis, C.3, Moutou, C.5, Pepe, F.3, Perrier, C.4, Pont, F.6, Queloz, D.3, Santos, N.C.7, Ségransan, D.3, and Vidal-Madjar, A.1

1 Institut d’Astrophysique de Paris, UMR7095 CNRS, Université Pierre & Marie Curie, 98bis Bd Arago, 75014 Paris, France
2 Observatoire de Haute-Provence, CNRS/OAMP, 04870 St Michel l’Observatoire, France
3 Observatoire de Genève, Université de Genève, 51 Ch. des Maillettes, 1290 Sauverny, Switzerland
4 Laboratoire d’Astrophysique, Observatoire de Grenoble, Université J. Fourier, CNRS, BP 53, 38041 Grenoble cedex 9, France
5 Laboratoire d’Astrophysique de Marseille, 38 rue Frédéric Joliot-Curie, 13388 Marseille cedex 13, France
6 School of Physics, University of Exeter, Exeter, EX4 4QL, UK
7 Centro de Astrofísica, Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal

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ABSTRACT

We report on the discovery of a substellar companion or a massive Jupiter orbiting the G5V star HD 16760 with the spectrograph *SOPHIE* installed on the OHP 1.93-m telescope. Characteristics and performances of the spectrograph are presented, as well as the *SOPHIE* exoplanet consortium program. With a minimum mass of 14.3 $M_{\text{Jup}}$, an orbital period of 465 days and an eccentricity of 0.067, HD 16760b seems to be located just at the end of the mass distribution of giant planets, close to planet/brown-dwarf transition. Its quite circular orbit supports a formation in a gaseous protoplanetary disk.

Key words. planetary systems – Techniques: radial velocities – stars: individual: HD 16760

1. Introduction

The vast majority of 350 known exoplanets have been found thanks to radial velocity measurements. Far to be an old-fashioned technique, Doppler measurements illustrated these last years their capabilities to extend the exoplanet search around a large variety of stars. The sensitivity of this technique continuously increases, opening the possibility to explore the domain of low-mass planets down to few Earth masses, to discover and characterize multiple planetary systems, to perform long term surveys to find true Jupiter-like planets, to establish the planetary nature and to characterize the transiting candidates of photometric surveys. Doppler surveys for exoplanet search require high-precision spectrographs and a significant amount of telescope time over a long duration.

The *SOPHIE* spectrograph (Bouchy et al. 2000, Perruchot et al. 2008) is in operation since October 2006 at the 1.93-m telescope of Observatoire de Haute-Provence. Benefiting from experience acquired on HARPS (Pepe et al. 2002) and taking into account the limitations of the ELODIE spectrograph (Baranne et al. 1996), *SOPHIE* was designed to obtain precise radial velocities with much higher throughput than its predecessor and to be operated as a northern counterpart of HARPS. This instrument is briefly described in section 2. The *SOPHIE* consortium started in October 2006 a large and comprehensive program of search and characterization of exoplanets described in section 3. We report in section 4 the detection of a substellar companion or a massive Jupiter around HD 16760 and we discuss in section 5 the properties and nature of this object located at the upper limit of the mass distribution of giant planets.

2. The *SOPHIE* spectrograph

*SOPHIE* architecture mainly benefits from ELODIE and HARPS experiences. A detailed technical description of this instrument is given by Perruchot et al. (2008). In this section we briefly describe the main properties of the spectrograph and its different observing modes. *SOPHIE* is a cross-dispersed, environmentally stabilized echelle spectrograph dedicated to high-precision radial velocity measurements. The detector (EEV-4482) is a thinned, back-illuminated, anti-reflection coated 4k x 2k 15-µm-pixel CCD cooled at -100°C, with slow- and fast-readout modes. It records 39 spectral orders covering the wavelength domain from 3872 to 6943 Å. The spectrograph is fed through a pair of 3”-wide optical fibers for the high-resolution mode ($R = 75000$, obtained from an extra slit), and another pair for the high-efficiency mode ($R = 40000$, allowing one magnitude gain). The high-resolution mode is equipped with a double fiber scrambler (Brown 1990) to homogenize and stabilize the illumination of the spectrograph entrance. For each fiber pair, one aperture is used for starlight whereas the other one, 2” away from the first one, can be used either on a Thorium-Argon lamp for tracking spectrograph drift ($thosimult$ mode), or on the sky to estimate background pollution, especially in case of strong moonlight ($objAB$ mode). Both aperture can also be simultaneously put on Thorium-Argon or tungsten lamps for wavelength or flat-field calibrations, respectively. Apart from thermal pre-
cautions, the key-point for stability is the encapsulation of the dispersive components in a constant pressure tank. This solution stabilizes the air refractive index sensitive to atmospheric pressure variations. With such a concept typical intrinsic drift of the spectrograph is less than 3 \( \text{m s}^{-1} \) per hour. The ELODIE front-end adaptor (Baranne et al. [1996], is still used for SOPHIE. It holds the calibration lamps, the atmospheric dispersion corrector and the guiding system. Compared to ELODIE, SOPHIE leads to 1) gain on photon efficiency by a factor of 10 in high-efficiency mode, 2) increase the spectrograph radial velocity stability by a factor of 3, and 3) increase spectral resolution from 42000 to 75000 for the high-resolution mode.

The spectra are extracted from the detector images and the radial velocities are measured online with the SOPHIE pipeline derived and adapted from the HARPS on[4]. The spectra extraction includes localization of the 39 spectral orders on the 2D-images, optimal order extraction, cosmic-ray rejection, wavelength calibration and spectral flat-field correction yielding a two dimension spectra (E2DS). The orders are then merged and rebinned after correction of the blaze function, yielding a one dimension spectra (S1D). The E2DS spectra are cross-correlated with numerical masks corresponding to different spectral types (F0, G2, K0, K5, M4); the resulting cross-correlation functions (CCFs) are fitted by Gaussians to get the radial velocities (Baranne et al. [1996] Pepe et al. [2002]).

Following the approach of Santos et al. (2002), we calibrated the CCF to determine the projected rotational velocity \( v \sin i \) and the metallicity index [Fe/H]. We also calibrated the CCF to compute the RV photon-noise uncertainty \( \sigma_{RV} \). Following the approach of Santos et al. (2000), we computed and calibrated the chromospheric-activity index \( R'_{HK} \) based on our SOPHIE spectra.

The SOPHIE radial velocity measurements were initially affected by a systematic effect at low signal-to-noise ratio, due to CCD charge transfer inefficiency, which increases at low flux level. This effect was calibrated and is now corrected by the pipeline, which reallocates the charge lost during the readout process on each extracted pixel (Bouchy et al. [2009]). Uncertainties on the radial velocity measurements include photon noise, uncertainties in the wavelength calibration, and systematic instrumental errors. The photon noise RV uncertainty depends on the signal-to-noise of the spectra, as well as on the spectral type and the rotation velocity \( v \sin i \) of the observed star. It can be approximated by the semi-empirical estimator \( \sigma_{RV} = A \times \sqrt{\text{FWHM}/(S/N \times C)} \), where FWHM is the full width at half maximum of the CCF (in same unit as \( \sigma_{RV} \)). \( C \) is its contrast (in percent of the continuum), \( S/N \) is the signal-to-noise ratio per pixel at 550 nm, and the scaling factor \( A = 1.7 \) or 3.4 in high-resolution or high-efficiency mode, respectively. For a non-rotating K-dwarf star, a \( S/N \) per pixel of 150 provides a photon-noise RV uncertainty of 1 \( \text{m s}^{-1} \). Such a \( S/N \) is obtained on 5-mm on a 6.5 magnitude star. The uncertainty of the wavelength calibration was estimated to 1 \( \text{m s}^{-1} \). Telescope guiding and centering errors in averaged weather conditions are typically of 0.3 - 1 arcsec. In high-resolution mode, these errors imply a RV jitter of 3-4 \( \text{m s}^{-1} \) due to the insufficient scrambling gain of the fiber. This corresponds to the dispersion obtained on the SOPHIE measurements around the orbit of HD 189733b, after correction of the stellar jitter (Boisse et al. [2009]). Uncertainties due to guiding errors are more than twice this level in high-efficiency mode due to the absence of scrambler in this instrumental setup.

The present radial velocity precision obtained on stable stars is about 4-5 \( \text{m s}^{-1} \) over several semesters. This limitation is mainly due to guiding and centering effects on the fiber entrance at the telescope focal plan and the insufficient scrambling provided by the fiber and the double scrambler. An upgrade of the Cassegrain fiber adapter is presently on-going, including new high-precision guiding camera and new double scrambler, with the goal to reach the precision level of 1-2 m/s.

3. The SOPHIE exoplanet program

The SOPHIE consortium program is devoted exclusively to the study and characterization of exoplanets, in continuation of a planet-search program initiated 15 years ago with ELODIE spectrograph (Queloz et al. [1998]) and in complement to the HARPS program performed in the southern hemisphere (Mayor et al. [2003]). We started on October 2006 a key program with the aims to cover a large part of the exoplanetary science and to bring constraints on the formation and evolution processes of planetary systems. Our observing strategies and target samples are optimized to achieve a variety of science goals and to solve several important issues: 1) mass function of planets below the mass of Saturn, 2) planetary statistical properties to constrain the formation and evolution models, 3) relationships between planets and the physical and chemical properties of their stars, 4) detection of exoplanets around nearby stars, allowing space and ground-based follow-up, 5) deep characterization of known transiting exoplanets including long term follow-up and spectroscopic transit analysis. All these aspects are treated through 5 complementary sub-programs discussed below and using an amount of 60 to 90 nights per semester allocated on SOPHIE at the 1.93-m telescope.

- High precision search for super-Earth

Only a few percents of the 350 detected planets have masses less than 0.1 M\(_{\text{Jup}}\), and due to the present precision of radial velocity surveys, the distribution of planetary masses is heavily biased against low-mass planets. Recent HARPS discoveries indicate that these low-mass exoplanets are not rare and suggest that 30% of non-active G and K dwarfs solar-type harbor Neptune or rocky planets with periods shorter than 50 days (Lovis et al. [2009], Mayor et al. [2009]). From the ELODIE survey and from our volume-limited sub-program, we pre-selected a sample of about 200 non-active bright solar-type stars to explore this domain of low-mass planets.

- Giant planets survey on a volume-limited sample

For a large volume-limited sample of 2000 stars, we perform a first screening to identify new Hot Jupiters and other Jovian-type planets orbiting near and bright stars. Increasing the list of Hot Jupiters offers a chance to find a transiting one orbiting a bright star appropriate for additional study of planetary atmosphere. This survey will also provide better statistics to search for new properties of the distribution of exoplanet parameters. We include on this sub-program the long term follow-up and the spin-orbit analysis – from the Rossiter-McLaughlin effect – of known transiting giant exoplanets to respectively detect additional companions and determine the spin-orbit angle of the system.

- Search for exoplanets around M-dwarfs

A systematic search for planets is made for a volume-limited sample of 180 M-dwarfs closer than 12 parsecs. Such a survey low mass stars will give us a chance to derive the frequency

\footnote{http://www.eso.org/sci/facilities/lasilla/instruments/harps/doc/index.html}
of planets as function of the stellar mass. The objectives are 1) to detect exoplanets of few Earth masses in the habitable zone, 2) to determine the statistics of planetary systems orbiting M-dwarfs in combining these 180-M dwarfs sample with 100-M dwarfs monitored with HARPS, 3) to identify new potential transiting Hot Neptunes.

4. Search for exoplanets around early-type main sequence stars

A systematic search for planets around a sample of 300 early-type main sequence stars (A and F stars) is performed to study the impact of the host star mass on the exoplanet formation processes. Such stars were previously not included in the exoplanet surveys due to their lack of spectral lines and high rotation broadening. A specific pipe-line was developed to compute radial velocity on these specific targets (Galland et al. 2005b) with an accuracy allowing the detection of planets from massive hot Jupiters to fast rotating A stars, and down to Neptune-mass planets for the slowest F stars.

- Long term follow-up of ELODIE long period candidates

The ELODIE program for exoplanet search which started on 1994 was performed on a sample of 320 G and K stars. About 40 of these stars present evidence of long term trends which may be due to giant planets with Jupiter or Saturn like orbit. A long term follow-up of these candidates is performed to explore the domain of long period (≥ 10 years) planets.

As part of the SOPHIE consortium programs, the detection of four exoplanets have been published up to now: HD 43691b and HD 132406b (Da Silva et al. 2008), HD 45652b (Santos et al. 2008), and θ Cygni b (Desort et al. 2009). These planets have respectively minimum masses of 2.5, 5.6, 0.5 and 2.5 M_Jup with a 37, 975, 44 and 154 day periods. Their velocities were first determined from the ELODIE or CORALIE survey then monitored by SOPHIE. Spectroscopic transits of the massive planets HD 147506b and XO-3b were also observed (Loeillet et al. 2008 and Hébrard et al. 2008) respectively, allowing a refinement of the parameters of the systems, and the detection of a first case of misaligned spin-orbit for XO-3 (recently confirmed by Winn et al. 2009). A study of the stellar activity of the transiting planet host star HD 189733 is also presented by Boisse et al. (2009). Recently the transit of the 111-day period exoplanet HD 80606b was established by Moutou et al. (2009).

Outside of the consortium programs, SOPHIE plays an efficient role in the Doppler follow-up of photometric surveys for planetary transits search. It allowed the planetary nature to be established for transiting candidates found by SuperWASP (e.g. Collier Cameron et al. 2007, Pollacco et al. 2008, Hebb et al. 2008), by HAT (Bakos et al. 2007) and by CoRoT space mission (e.g. Barge et al. 2008, Bouchy et al. 2008, Moutou et al. 2008, Deleuil et al. 2008, Rauer et al. 2009), as well as the parameters of these new planets to be characterized, including the measurement of the masses.

In the next section we present the detection of the substellar companion orbiting HD 16760 as part of our sub-program 2 “Giant planets survey on a volume-limited sample”.

4. The substellar companion of HD 16760

4.1. Stellar properties of HD 16760

HD 16760 (HIP 12638, BD+37 604) is a G5V star located 50 pc away according the Hipparcos parallax. Table 1 summarizes the stellar parameters. From spectral analysis of the SOPHIE data using the method presented in Santos et al. (2004), we derived \( T_{\text{eff}} = 5608 \pm 20 \text{ K} \), \( \log g = 4.51 \pm 0.10 \), \( [\text{Fe/H}] = -0.02 \pm 0.03 \), and \( M_\star = 0.86 \pm 0.06 \text{ M}_\odot \), which agrees with values from literature. For the temperature and the mass, the values we adopt in Table 1 are compromise values between ours and those obtained by Nordström et al. (2004) \( (T_{\text{eff}} = 5636 \text{ K} \) and \( M_\star = 0.91^{+0.06}_{-0.05} \text{ M}_\odot) \). We derive \( v \sin i = 2.8 \pm 1.0 \text{ km s}^{-1} \) from the parameters of the CCF using a calibration similar to those presented by Santos et al. (2002), in agreement with the value \( v \sin i = 3 \text{ km s}^{-1} \) from Nordström et al. (2004). The CCF also allows the value \( [\text{Fe/H}] = 0.06 \pm 0.05 \) to be measured, in agreement but less accurate than the metallicity obtained above from spectral analysis. This target has a quiet chromosphere with no emissions in the Ca λ lines (\( \log R'_{\text{HK}} = -5.0 \pm 0.1 \)), making it a favorable target for planets search from radial velocity measurements.

| Parameters       | Values   | References                  |
|------------------|----------|-----------------------------|
| \( m_\star \)    | 0.86 \text{ M}_\odot | Nordström et al. (2004) |
| Spectral type    | G5V      | Hipparcos catalog           |
| \( B - V \)      | 0.71 ± 0.02 | Hipparcos catalog          |
| Distance [pc]    | 50 ± 7   | Hipparcos catalog           |
| pmRA [mas/yr]    | 82.8 ± 3.1 | Hipparcos catalog          |
| pmDEC [mas/yr]   | −110.6 ± 3.1 | Hipparcos catalog       |
| \( v \sin i \) [\text{km s}^{-1}] | 2.8 ± 1.0 | this work                 |
| \( \log R'_{\text{HK}} \) | −5.0 ± 0.1 | this work                 |
| \([\text{Fe/H}]\) | −0.02 ± 0.03 | this work                 |
| \( T_{\text{eff}} \) [K] | 5620 ± 30 | Nordström et al. (2004) & this work |
| \( \log g \) [\text{cgs}] | 4.51 ± 0.1 | this work                 |
| Mass [\text{M}_\odot] | 0.88 ± 0.08 | Nordström et al. (2004) & this work |

HD 16760 has a stellar companion, HIP 12635 (Apt 1988 Sinachopoulos 2007), located 14.562 ± 0.008 arcsec in the North and 1.521 ± 0.002 mag fainter. From Hipparcos catalog (Perryman et al. 1997), HIP 12635 has similar distance (45 ± 17 pc) and similar proper motions (pmRA=107 ± 17, pmDEC=102 ± 12) with HD 16760, making them a likely physical system, with a separation > 700 AU and an orbital period > 10 000 years. This would induce tiny radial velocity variations on the stars, below 0.2 m s\(^{-1}\)yr\(^{-1}\).

4.2. Radial velocity measurements and Keplerian fit

We acquired with SOPHIE 20 spectra of HD 16760 within \( \text{objAB} \) mode between December 2006 and October 2008 under good weather conditions. Two of these 20 spectra were polluted by significant Moon contamination. The velocity of the CCF due to the Moon was far enough from those of the target to avoid any significant effect on the radial velocity measurement. We did not use these two spectra however for the spectral analysis presented in §4.1.

The derived radial velocities are reported in Table 2 together with the journal of the observations. Their typical accuracy is around 6 m s\(^{-1}\), which is the quadratic sum of three sources of noise: photon noise (3 m s\(^{-1}\)), guiding (4 m s\(^{-1}\)), and spectrograph drift (3 m s\(^{-1}\)). The radial velocities, shown in Fig. 1, present clear variations of the order of hundreds m s\(^{-1}\), without significant variations (\( \sigma < 10 \text{ m s}^{-1} \)) of the CCF bisector (Fig. 2), thus in agreement with the reflex motion due to a companion. We fitted the data with a Keplerian model. The solution is a 465-day
period oscillation with a semi-amplitude $K = 408$ m s$^{-1}$, corresponding to a substellar companion, with a minimum mass $m_p \sin i = 14.3$ M$_{\text{Jup}}$. The derived orbital parameters are reported in Table 5 together with error bars, which were computed from $\chi^2$ variations and Monte Carlo experiments.

The standard deviation of the residuals to the fit is $\sigma(O-C) = 10.1$ m s$^{-1}$. This is higher than the 6-m s$^{-1}$ estimated uncertainty on the individual measurements. Although about 23% of gaseous giant planets are in a multiple planetary system, we do not identify yet an indication for a second body orbiting HD 16760. With a maximum semi-amplitude of 20 m s$^{-1}$, the residuals of the fit do not exhibit structures, denoting a possible inner planet with a $m_p \sin i \geq 0.7$ M$_{\text{Jup}}$. A longer period planet may induce a drift lower than 20 m s$^{-1}$yr$^{-1}$ during our observational period.

Fig. 1. Top: Radial velocity SOPHIE measurements of HD 16760 as a function of time, and Keplerian fit to the data. The orbital parameters corresponding to this fit are reported in Table 3. Bottom: Residuals of the fit with 1-$\sigma$ error bars.

### Table 2. Radial velocities of HD 16760 measured with SOPHIE.

| BJD       | RV              | $\pm 1\sigma$ | exp. time | S/N p. pix. |
|-----------|-----------------|---------------|-----------|-------------|
| -2400000 | -3.6736         | 0.0055        | 300       | 62.5        |
| 54126.3439 | -3.7916        | 0.0058        | 300       | 52.1        |
| 54127.2914 | -3.8085        | 0.0068        | 480       | 36.2        |
| 54133.2541 | -3.8478        | 0.0055        | 225       | 61.4        |
| 54138.3414 | -3.8366        | 0.0054        | 673       | 67.1        |
| 54148.3393 | -3.8898        | 0.0071        | 224       | 35.1        |
| 54151.3375 | -3.9150        | 0.0092        | 225       | 30.0        |
| 54155.2737 | -3.9168        | 0.0063        | 180       | 43.5        |
| 54339.6353 | -3.3666        | 0.0053        | 512       | 78.7        |
| 54352.6607 | -3.2786        | 0.0058        | 380       | 52.0        |
| 54367.6375 | -3.2481        | 0.0055        | 300       | 61.2        |
| 54407.4733 | -3.1806        | 0.0053        | 500       | 79.5        |
| 54434.4444 | -3.1703        | 0.0054        | 620       | 64.2        |
| 54502.2489 | -3.3798        | 0.0057        | 443       | 54.5        |
| 54513.2880 | -3.4358        | 0.0059        | 464       | 53.4        |
| 54546.2900 | -3.5725        | 0.0061        | 1304      | 47.3        |
| 54683.6329 | -3.9680        | 0.0058        | 393       | 51.4        |
| 54705.6646 | -3.9045        | 0.0058        | 379       | 51.2        |
| 54739.5899 | -3.7242        | 0.0059        | 350       | 50.1        |
| 54755.5295 | -3.6488        | 0.0058        | 270       | 51.2        |

5. Discussion and Conclusion

Our RV measurements indicates that a substellar companion with a projected mass $m_p \sin i = 14.3$ M$_{\text{Jup}}$ is orbiting HD 16760. With the degeneracy of inclination angle $i$, it is difficult to conclude about the exact nature of this companion. It may correspond to a massive planet, formed in a gaseous protoplanetary disk, or a brown dwarf, issued from collapse in a giant molecular cloud.

Figure 3 shows the mass distribution of massive planets ($m_p \sin i \geq 3$ M$_{\text{Jup}}$) and light brown dwarfs ($M_C \sin i \leq 30$ M$_{\text{Jup}}$) found by radial velocity surveys. From the Extrasolar Planets Encyclopedia list, we completed with HD 137510b (Endl et al. 2004), HD 180777b (Galland et al. 2005), and HD 16760b (this paper), totaling 89 objects including 10 with mass between 15 and 30 M$_{\text{Jup}}$. The dashed curve corresponds to the relation $M^{-2}$ (dN/dM=M$^{-1}$). The black shaded histogram corresponds to the transiting planets with true masses (excluding non-confirming objects SWEEPS-11 and SWEEPS-04). It is worthwhile to notice that, although based on a small number of object, the mass distribution of transiting planets is following the same trend than non-transiting planets. Indeed, the ratio of transiting planets over non-transiting planets is about the same : 9.2, 9.5 and 10 for the bins 3-6, 6-9 and 9-12 M$_{\text{Jup}}$ respectively. In this histogram, HD 16760b seems to be located just at the end of the mass distribution of giant planets. Although based on small num-

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### Table 3. Fitted orbit and planetary parameters for HD 16760b.

| Parameters | Values and 1-$\sigma$ error bars | Unit |
|------------|---------------------------------|------|
| $V_r$      | $-3.561 \pm 0.004$              | km s$^{-1}$ |
| $P$        | 465.1 $\pm$ 2.3                | days |
| $i$        | 0.067 $\pm$ 0.10               | $^\circ$ |
| $\omega$   | $-128 \pm 10$                 | $^\circ$ |
| $K$        | 408 $\pm$ 7                  | m s$^{-1}$ |
| $T_0$ (periastron) | 2454723 $\pm$ 12  | BJD |
| $\sigma(O-C)$ | 10.1 $\pm$ 0.66  | m s$^{-1}$ |
| reduced $\chi^2$ | 2.0                      |      |
| $N_{\text{obs}}$ | 20                        |      |
| $m_p \sin i$ | 14.3 $\pm$ 0.9$^\dagger$    | M$_{\text{Jup}}$ |
| $a$        | 1.13 $\pm$ 0.03$^\dagger$ | AU |

$^\dagger$: using $M_\ast = 0.88 \pm 0.08$ M$_\odot$
bers, sub-stellar companions with minimum mass greater than 17 $M_{\text{Jup}}$ do not seem to follow the $M^2$ relation.

Figure 4 shows the eccentricity - period diagram of massive exoplanets and light brown dwarfs. The size of circle is function of the mass (3-5, 5-10, 10-15 $M_{\text{Jup}}$). Hexagonal points corresponds to objects with mass greater than 15 $M_{\text{Jup}}$. Black filled symbols correspond to transiting companions. HD 16760b confirms the observed trend that more massive companions are found for longer period planets (Udry & Santos 2007). We also notice that all companions with mass greater than 15 $M_{\text{Jup}}$ have an eccentricity greater than 0.2 except CoRoT-exo-3b (Deleuil et al. 2008) and HD 41004Bb (Zucker et al. 2004) in very close-in orbit (with periods of respectively 4.2 et 1.3 days) tidally circularized. The properties of HD 16760b make it an interesting sub-stellar companion. With a mass greater than the Deuterium burning limit (13 $M_{\text{Jup}}$), it may be defined as a brow-dwarf. However its quite circular orbit supports a formation in a gaseous protoplanetary disk. On another way, Halbwachs et al. (2005) studied the eccentricity distribution for exoplanets and binary stars with a mass ratio smaller than 0.8 (non twin binaries). They found that exoplanets have orbits with eccentricities significantly smaller than those of the non-twin binaries, reinforcing the hypothesis that planetary systems and stellar binaries are not the products of the same physical process.

HD 16760b is in a visual and physical binary system. However, in the mass-period and eccentricity-period diagrams, HD 16760b is located in a region not much populated by planets in binary systems. The discovery of this long-period low-eccentricity planet thus adds to the growing evidence that contrary to short-period planets, long-period ($\geq$100 days) planets residing in binaries possess the same statistical properties as their counterparts orbiting single stars (Eggenberger et al. 2004; Mugrauer et al. 2005; Desidera et al. 2007).

HD 16760b would induce a motion of its host star of at least $\pm$0.35 milli-arcsec. The future Gaia ESA space mission scheduled for launch in late-2011, should be able to detect this system from astrometry, and thus would allow the inclination of the system to be measured and the true mass to be determined. Detailed characterization of this sub-stellar companion close to planet/brow-dwarf transition will help to distinguish the differences of formation processes between these two populations.

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Fig. 4. Eccentricity - period diagram of massive exoplanets and light brown dwarfs. The size of circle is function of the mass (3-5, 5-10, 10-15 $M_{\text{Jup}}$). Hexagonal points corresponds to objects with mass greater than 15 $M_{\text{Jup}}$. HD 16760b, with $P = 465$ days and $e = 0.067,$ is identified by the red circle. Black filled symbols correspond to transiting companions.

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