EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

OBSERVING PROGRAMMES OFFICE • Karl-Schwarzschild-Straße 2 • D-85748 Garching bei München • e-mail: opo@eso.org • Tel.: +49-89-32 00 64 73

APPLICATION FOR OBSERVING TIME PERIOD: **89A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title Category: **C–7**

Uncovering the true frequency of close brown dwarf companions to Sun-like stars

2. Abstract / Total Time Requested

Total Amount of Time: 0 nights VM, 9.6 hours SM

We propose to use CRIRES to validate or refute the brown dwarf candidates presented recently by Sahlmann et al. (2011). The objective is to recover the spectra of the companion, an attempt made possible in the IR by the much higher contrast (relative to the visible) between a stellar host and a brown dwarf companion. We shown that it is within our capabilities to detect companions down to 80 M_{Jup} and thus exclude the companions in our sample from the stellar domain. This will lead to a re-evaluation of the number of brown dwarfs yielded by one of the most complete surveys up to date, and improve the statistics on the determination of the brown-dwarf desert limits. The change in frequency of brown dwarfs around main-sequence stars can go up to 45 %, from 0.66% to 0.36%, providing the most stringent constraints ever on the presence of such companions.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	89	CRIRES	9.6h	any	n	1.2	THN	s	

4. Number of nights/hours Telescope(s) Amount of time

a) already awarded to this project:

b) still required to complete this project:

5. Special remarks:

6. Principal Investigator: Pedro Figueira, pedro.figueira@astro.up.pt, P, Centro de Astrofisica da Universidade do Porto

6a. Co-investigators:

R.	Diaz	Institut d'astrophysique de Paris,F
J.	Sahlmann	Observatoire Astronomique de l'Universite de Geneve,CH
N.C.	Santos	Centro de Astrofisica da Universidade do Porto,P
I.	Boisse	Centro de Astrofisica da Universidade do Porto,P

Following CoIs moved to the end of the document ...

7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

8. Description of the proposed programme

A – Scientific Rationale: The absence of brown dwarfs at orbital distances smaller than 10 AU, when compared with the abundance of both planets and stars, remains largely unexplained. In contrast with the abundance of massive planets ($M > 50\,M_{\oplus}$, with $P < 10\,\mathrm{yr}$) around main-sequence hosts (14% according to Mayor et al. 2011, submitted to A&A, arXiv e-print:1109.2497) and the high-frequency of stellar binaries (60% by Duquennoy & Mayor 1991, A&A, 248 485), the very few brown dwarf detections correspond to a comparatively very small fraction; only 50 companions were detected through planetary surveys in the mass range of 13–80M_{Jup}(e.g. Bouchy et al. 2011, A&A, 525A,68). Marcy and Butler (2000, PASP, 112, 137) quoted a frequency of close-in brown dwarfs around main-sequence stars inferior to 0.5%, a number confirmed recently by the work of Sahlmann et al. (2011, A&A, 525, A95), who reached an upper limit of 0.6%. The work of Sahlmann et al. (2011) went further than many of its kind: it combined precise radial velocities with Hipparchos astrometry to detect low-mass companions, and increased by 20% the number of potential brown-dwarf companions. Moreover, it proposed a dividing line between the planet and stellar population based on the absence of companions in the mass range 25-45 M_{Jup}; this feature, even though based on small-number statistics, emerges as significant for the first time.

Of the proposed companions, 10 remain candidate brown dwarfs, since their true mass could not be recovered by the combination of radial velocity measurements and astrometry. The assessment of the true nature of these objects would allow to better constrain the frequency of brown-dwarfs around main-sequence stars and improve our knowledge on the diving line between the two classes of objects. This would provide highly valuable insight into the formation mechanisms of both stars and planets, who currently lack of observational constraints in what concerns allowed mass. The confirmation of a dividing line in mass would allow to constrain these formation models, which currently produce planet populations and stellar populations that overlap (e.g. Mordasini et al 2009, A&A, 501 1139).

B – Immediate Objective: We propose to use the CRIRES spectrograph to measure the IR spectra of 7 candidate brown dwarf companions and determine if they are of stellar nature. We show that it is possible to detect an object at the mass boundary of 80 M_{Jup} (= 0.076 $M_{\odot}$, or spectral type M7-M8) in the K band due to high contrast relative to the host star, depicted in the extreme V-K color indexes (>7.8).
Out of the 10 systems with putative brown dwarfs presented by Sahlmann et al. (2011), 6 are observable at less than airmass 1.5 from Paranal for Period 89. These are located at distances 20–50 pc which corresponds to an apparent K magnitude of 10–12 for an M8 companion. The last companion is located around HD 30501, for which an orbit was determined, locating the its mass at 90 M_{Jup}. Close to the boundary limit, this object will be used as a proof of concept for our study.
The removal of 5 candidates from the current statistics would change the final frequency from $11/1650 = 0.66\%$ to $6/1650 = 0.36\%$, providing the most stringent constraints on close brown dwarf frequency ever.

Observing strategy: We will schedule two observations per star in order to obtain two different and clearly separated radial-velocities for the secondary; clearly separated means with a relative shift much larger than the width of its lines, i.e., of several km/s. Due to the close projected separation in the sky between each star and each companion ($\lesssim 0.2$ arcsec), the light of the companion will enter the CRIRES slit and be superimposed with the main spectrum.

Data reduction strategy: The observation in two different epochs will allow o disentangle the different components of the spectra. The observations will be performed in an atmospheric window in the K band in order to reduce absorption introduced by our own atmosphere (2.120-2.174 μm, for details see Barnes et al. (2008, MNRAS, 390 1258). We will use LBLRTM (Clough et al. 2005, J. Quant. Spectrosc. Radiat. Transfer, 91, 233) forward model to correct for the telluric absorption; the main-sequence spectra will be removed by shifting the two (corrected) spectra back to the same referential and subtracting one by the other. This will cancel the stellar lines and leave a spectra with the double of the photon noise but on which the signature of an M8 star will be apparent. Our calculations, considering the difference in photon noise introduced by the subtraction of the spectra and the increased photon noise due to the primary, show that the final spectra will have a $S/N > 7$ for integration times of 30 min (see *Time Justification* box for more). This signal can be easily recovered by correlating it with a M8 binary mask derived from atmospheric models (e.g. Barman et al. 2005, ApJ, 632, 1132).
This project is particularly interesting because it will pave the way to direct detection of emission of massive planets in the IR, a domain largely unexplored. While all attempts so far resulted in non-detections (e.g. Barnes et al. 2008) we propose to approach the extreme ratios from the stellar side, a domain in which the contrast is by far more favorable.

8. Description of the proposed programme and attachments

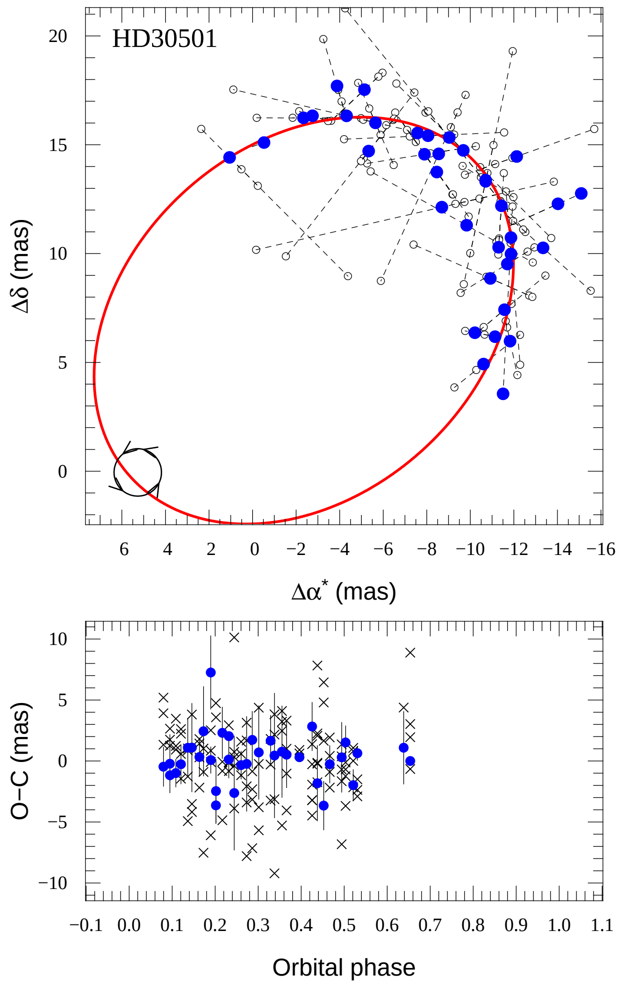

Fig. 1: Top panels: Astrometric stellar orbit of HD301501 projected on the sky. North is up and east is left. The solid red line shows the orbital solution and open circles mark the individual Hipparcos measurements. Bottom panels: OC residuals for the normal points of the orbital solution (filled blue circles) and of the standard 5-parameter model without companion (black crosses). From Sahlmann et al. (2011), for details check original reference.

9. Justification of requested observing time and observing conditions

Lunar Phase Justification: Bright targets and near-IR observations: no particular lunar phase required. Ephemerides will be used to make sure that targets lie at more than 60° from the Moon, but this will provide no stringent constraints due to the wide period in which observations are feasible.

Time Justification: (including seeing overhead) When we observe these objects we get an increased photon noise because we are collecting the photons from the parent star too. In order to calculate the true photon noise we compared the photon noise we will have with that of a single star (the companion). If we take into account that we are subtracting two stellar spectra and, assuming that the photon noise of the sum is well approximated by that of the primary, one gets:
$Noise(B)/Noise(A) = sqrt(2) * sqrt(F_A/F_B) = sqrt(2) * sqrt(100^((m_B - m_A)/5))$
Fro Hipparcos parallax one can calculate the apparent magnitude of these M dwarfs and considering as reference m_A=7.0 and m_B=10.5 we have N(B)/N(A) = 7.09.
This means that we reduce the S/N obtained for the spectra by this factor. For an observation with slit width of 0.4″ and NoAO (DIT=600 s, NDIT=3) one will have: 52.7/7.09 = 7.43 of S/N in the secondary. Note that a magnitude difference of 3.5 corresponds to a flux ratio of 1/25, much more favorable that those usually attempted in most direct detection campaigns. The different primary target K magnitudes lead to an adjustment to different final integration times.

9a. Telescope Justification:

CRIRES is the only available high resolution near-IR spectrograph in the southern hemisphere.

9b. Observing Mode Justification (visitor or service):

Visitor mode better suited given the proposed observing schedule.

9c. Calibration Request:

Standard Calibration

10. Report on the use of ESO facilities during the last 2 years

184.C-0639 'Characterization of the unique transiting exoplanets detected from the CoRoT space mission' (PI Bouchy)

086.C-0680, 087.C-0567, and 088.C-0679: Exploring planetary and substellar companions of L dwarfs. (PI Sahlmann)

10a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

No.

10b. GTO/Public Survey Duplications:

11. Applicant's publications related to the subject of this application during the last 2 years

Sahlmann, J.; Sgransan, D.; Queloz, D. et al., 2011, A&A, 525A, 95: "Search for brown-dwarf companions of stars"

Sahlmann, J., Lovis, C., Queloz, D., Segransan, D., 2011, A&AL, 528: HD5388 b is a 69 M_{Jup} companion instead of a planet

Díaz R F, Santerne A, Sahlmann J, et al., 2011, submitted to A&A: "The SOPHIE search for northern extrasolar planets IV. Massive companions in the planet-brown dwarf boundary"

Figueira, P.; Pepe, F.; Melo, C. H. F. et al. 2010, A&A, 511A, 55: "Radial velocities with CRIRES. Pushing precision down to 5-10 m/s"

Bouchy F, Bonomo A, Santerne S, et al., 2011, A&A, 533, 83: "SOPHIE velocimetry of Kepler transit candidates. III. KOI-423b: an 18 MJup transiting companion around an F7IV star"

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	HD 30501	04 45 38.5	-50 04 27.2	1.2	5.53		K band magnitude	
A	HD 4747	00 49 26.8	-23 12 44.9	1.2	5.31		K band magnitude	
A	HD 162020	17 50 38.4	-40 19 06.1	1.8	7.03		K band magnitude	
A	HD 167665	18 17 23.8	-28 17 20.3	1.2	5.04		K band magnitude	
A	HD 168443	18 20 03.9	-09 35 44.6	1.2	5.31		K band magnitude	
A	HD 202206	21 14 57.8	-20 47 21.2	1.4	6.47		K band magnitude	
A	HD 211747	22 19 15.6	+08 45 06.5	1.4	6.37		K band magnitude	

13. Scheduling requirements

This proposal involves time-critical observations, or observations to be performed at specific time intervals.

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
89	CRIRES	A	no-AO	K band: 2.120-2.174 μm

6b. Co-investigators:

...continued from box 6a.

F.	Bouchy	Institut d'astrophysique de Paris,F
G.	Hebrard	Institut d'astrophysique de Paris,F
F.	Pepe	Observatoire Astronomique de l'Universite de Geneve,CH
D.	Segransan	Observatoire Astronomique de l'Universite de Geneve,CH