# EUROPEAN SOUTHERN OBSERVATORY

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

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APPLICATION FOR OBSERVING TIME PERIOD: **74A**

To be submitted only to: proposal@eso.org
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 Panel: **C–7**
Mapping the Realm of Hot Jupiters

2. Abstract
As part of an international consortium aimed at identifying new hot Jupiters, we propose to measure precise radial velocities for a subsample of several hundred stars out of a bigger sample of 2000 stars not currently surveyed by ongoing Doppler searches. The sample stars have been selected based on Stroemgren photometry to have at least solar metallicity, in order to enhance the chances of finding new planets. The samples of currently on-going Doppler Surveys have already been culled from virtually all short-period gas giant planets, leading to a stagnant pool of about 20 hot Jupiters. In order to advance our understanding of planet structure, atmospheres, and orbital migration, additional short-period, multi-planet systems with observable non-Keplerian interactions or planetary transits have to be detected. Our observing strategy is exactly designed to fulfill this task, dropping any star from the list that does not show significant radial velocity variations during three consecutive nights.

3.

| Run | Period | Instrument | Time | Month | Moon | Seeing | Sky Trans. | Obs.Mode |
|---|---|---|---|---|---|---|---|---|
| A | 74 | HARPS | 6n | any | n | n | THN | v |
| B | 74 | UVES | 3n | any | n | n | THN | v |

4.

| Number of nights/hours | Telescope(s) | Amount of time |
|---|---|---|
| a) already awarded to this project: | | |
| b) still required to complete this project: | 3.6m/UT2 | 6n/3n |

5. Special remarks. (e.g., indicate here if this is a ToO proposal applying for RRM)
Minimum useful time allocation would be 3 half nights on either telescope.

6. Principal Investigator: A. Quirrenbach (Sterrewacht Leiden, NL, quirrenbach@strw.leidenuniv.nl)
CoI(s): S. Frink (Sterrewacht Leiden, NL), D. Fischer (San Francisco State University, USA)

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: Extrasolar Planet Searches and their implications are one of the hot topics in astronomy right now, gaining attention not only from scientists, but also from the wider public. One of the most surprising results of the early Doppler surveys was the discovery of hot Jupiters, gas giant planets of several Jupiter masses that orbit very closely to the parent stars, with orbital periods of only a few days (see e.g. the discovery paper of 51 Peg, Mayor & Queloz 1995, Nature 378, 355). These discoveries have spawned a whole new research field, including the development of theoretical arguments for the existence of such planets as well as new observational methods to detect and characterize such objects, including a number of space missions to be carried out in the coming decade. The planetary transit observed for HD 209458 has confirmed the gas giant hypothesis for this object (along with the astrometrically observed system GJ 876 the only two ones for which we have reasonably accurate planet masses), and lead to the first discovery of a planetary atmosphere by HST (Charbonneau et al. 2002, ApJ 568, 377).

Hot Jupiters provide:

- **High probability transit candidates:**
  The detection of a planet transiting HD 209458 (Charbonneau et al. 2000, ApJ 529, L45; Henry et al. 2000, ApJ 529, L41) has garnered about 200 citations in the literature and spawned 22 transit search projects (Horne 2003, ASP Conf. Ser. 294, 361). The quality of physical information about HD 209458b, made possible by the transit observation, far exceeds that of any other known exoplanet. The scientific yield from this transit was only possible because the intrinsic brightness of the host star enabled high temporal resolution HST photometry. The detection of 60 new hot Jupiters will statistically yield **three new transiting planets around bright, nearby stars**. These transits will provide high quality information about planet radii, densities, atmospheres, interior structure and heating.

- **Tracers of multiple planet systems with orbital periods short enough to exhibit non-Keplerian interactions:**
  Of the planet-bearing stars which have been detected with the Lick RV survey, over half appear to have at least one additional planet in the system (Fischer et al. 2001). Among these, the $\Upsilon$ And and 55 Cnc systems (which both have hot Jupiters) have greatly deepened and constrained our understanding of chaotic orbital evolution, disk migration, and the dynamics of resonances. A resonant configuration with an inner planet period of about three to ten days would show strong non-Keplerian interactions on easily observed timescales.

- **Constraints on tidal dissipation indicating the presence or absence of a core:**
  As more planets are discovered with periods between three and ten days, the free parameters in the tidal circularization theory will become over-constrained and reveal internal structure in hot Jupiters.

- **Statistical anomalies such as a pile-up in orbital periods at three days, systematically lower planet masses and higher stellar masses:**
  All of these statistical anomalies are in need of confirmation, which can only be provided by finding more short-period planets.

These fundamental discoveries confirmed the gas-giant nature of the first Doppler-detected planets, revealed and deepened our understanding of orbital migration, allowed the detection of orbital resonances and demonstrated non-Keplerian interactions. However, a stagnant sample of about 20 hot Jupiters now serves as the test cases for theory. Significant advances in our understanding of planet formation, migration and evolution require many new hot Jupiters. The only way to find these planets is to survey a fresh sample of stars.

B) Immediate Objective: Here we propose to measure precise radial velocities of a sample of about 200 FGK stars, pre-selected to exclude stars of low metallicity as well those stars already routinely observed by ongoing Doppler surveys, with an observing strategy designed to efficiently identify the hot Jupiters in such a sample. Monte Carlo simulations (see **Fig. 1**) show that RV measurements obtained on three consecutive nights with a precision of 7 m/s will identify $> 3\sigma$ RV velocity scatter in virtually all stars hosting planets more massive than 0.5 $M_{\rm Jup}$ with orbital periods between 1.25 and 14 days. Velocity trends for more massive planets with orbital periods up to one year and double- and single-lined spectroscopic binaries will also be identified. The rate of occurrence of extrasolar planets with periods less than 14 days is about **1.5%**. Note that this rate is higher than the usual 0.75% (e.g. Butler et al. 2001, ApJ 555, 377) because the orbital period range to which we are sensitive here extends beyond three to five day orbits. These numbers hold for a parent sample of stars which is not selected according to metallicity. Our detection rate of hot Jupiters should even be somewhat **higher** than those numbers because we preferentially selected stars of approximately solar or higher metallicity, based on a photometric *uvby* calibration (Martell & Laughlin 2002, ApJ 577, L45). This calibration is accurate to 0.1 dex, more than sufficient for our purpose of rejecting the more metal-poor stars. Reddening is not taken

8. Description of the proposed programme (continued)

into account, since our stars are typically closer than 100 pc where any reddening is only a small correction. Since we are not interested in the highest possible accuracy metallicities here, it is completely negligible.
**Figure 2** quantifies the planet-metallicity correlation: stars with solar or higher metallicity are far more likely to host Doppler-detectable planets than metal-poor stars.
Thus, if our detection rate of hot Jupiters was around 3%, we would be able to identify of the order of **60 fresh hot Jupiters** in a parent sample of 2000 stars pre-selected for metallicity, observed by our consortium. The same detection rate would yield about six new hot Jupiters for the sample of about 200 stars we propose to observe in the framework of this proposal.
We would like to stress again that we do not propose to perform a full radial velocity monitoring campaign for those stars, but rather a fast test as to whether those systems might harbor hot Jupiters or not. If any given star observed during three consecutive nights does not show radial velocity jitter at a level larger than 3 $\sigma$, we will drop this star from our lists and never observe it again.
The success of the current proposal as well as that the whole consortium critically depends on whether we manage to observe a large enough sample in order detect a statistically significant number of new hot Jupiters. The consortium members consists of observers from the US (Keck), Chile (Magellan) and Japan (Subaru). While our first ESO proposal for this project was rejected, the proposals of all other consortium partners were accepted, resulting in four nights of Keck time, three nights of Magellan time, and four nights of Subaru time (all of what was requested). So this project is definitely going ahead, with or without ESO participation. While the majority of the observing time is still to come, the first five hot Jupiter candidates have already been identified (see **Fig.3** for one example), and follow-up radial velocity observations as well as photometry is now underway.
As mentioned earlier, our goal as a consortium is to observe a sample of about 2000 stars within a few years. Our list for the current proposal contains about 300 targets. Most of them are suitable for HARPS, but since fast troughput is essential for our program, it is not efficient to observe stars with HARPS for which integration times would be larger than about 5 minutes (which occurs at about 8 mag for a target S/N of larger than 100, which should give us radial velocities with 7 m/s precision). However, since we pre-selected according to metallicity, some of our stars lie in the magnitude range between 8 and 10 mag, and those can only be efficiently observed with UVES.

C) Telescope Justification: We require a high resolution spectrograph which is capable of producing radial velocities with a precision of 7 m/s. The only available choices are therefore HARPS at the 3.6m and UVES at the UT2. We decided to divide the observing program between those two spectrographs, using HARPS whenever possible to reduce the observing load at the VLT. However, many of our stars are too faint to be efficiently observed with HARPS, so that we also require UVES time for a successful execution of this program.

D) Observing Mode Justification (visitor or service): We propose to perform these observations in visitor mode, since our target list is very large and might require ad-hoc decisions about which stars to observe. Furthermore, we definitely want to use the output of the pipeline reduction mode for HARPS, which is currently only accessible in visitor mode. Similarly, iodine cell observations with UVES are also best performed in visitor mode.

E) Strategy for Data Reduction and Analysis: Data reduction is straightforward. For HARPS, the pipeline directly outputs science grade radial velocities, which we plan to use for this project. For UVES, we will follow a different measurement and data reduction philosophy. In order to be able to measure precise radial velocities with UVES, we plan to use the iodine cell technique. After standard flatfielding and extraction of the spectrum, which is done by the ESO pipeline, the reduced data will be fed into the radial velocity pipeline developed by Marcy & Butler, which is available to us for the purpose of this project. A synthetic template will be used, eliminating the need for an additional template observation of each star and thus reducing the observing load by 25%. The resulting velocity precision is sufficient for our project flagging hot Jupiters, which can then be followed up with a traditional template yielding higher precision radial velocities.
An additional pipeline for spectral synthesis was developed by Fischer & Valenti and will also be used for this project. In addition to $T_{\rm eff}$, [Fe/H] and $v \cdot \sin i$, problematic double-lined spectroscopic binaries as well as chromospherically active stars will be readily identified.
All investigators have experience with high precision radial velocity work, and facilities and computers to conduct the data reduction are available at all participating institutes.

8. Attachments (Figures)

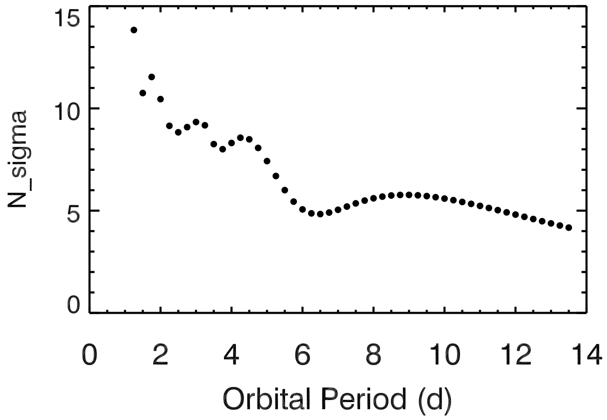


**Fig.1:** The mean number of sigma (in RMS velocity scatter) is plotted as a function of the orbital period. Different phases of theoretical Keplerians for a 0.5 $M_{Jup}$ companion were tested with a Monte Carlo simulation of observational data, assuming 7 m/s Doppler precision. Chromospherically quiet stars with more than $3\sigma$ RV scatter are strong candidates for harboring hot Jupiters.

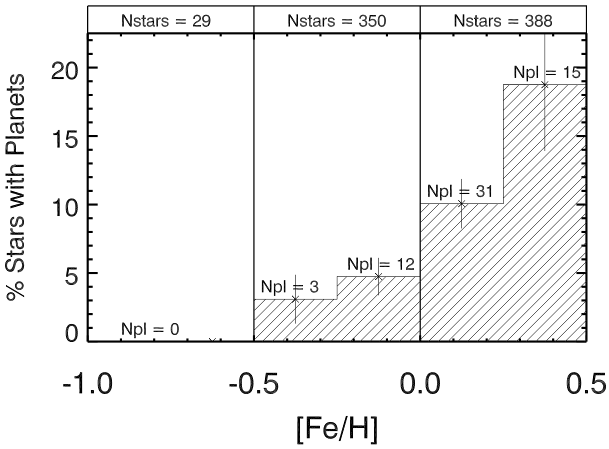


**Fig.2:** Abundance analysis of FGK stars on the Keck, Lick and AAT planet search projects, quantifying the planet-metallicity correlation (Fischer & Valenti 2003, ASP Conf. Ser. 294, 117). The subset of 767 stars represented here have sufficient observations to rule in (or out) the presence of a gas giant planet with an orbital period less than 2 years.

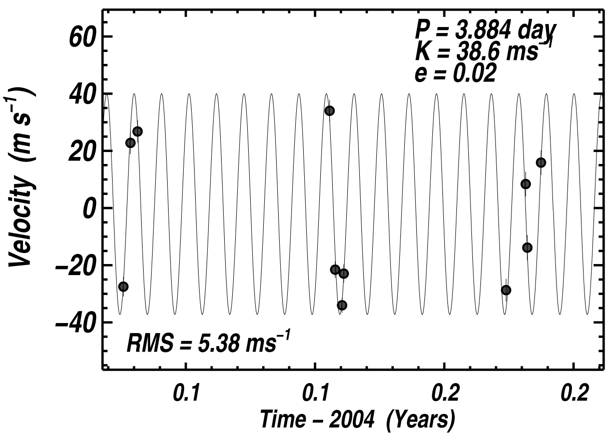


**Fig.3:** One out of five new hot Jupiter candidates that have been identified with Keck time to this project so far. Follow-up radial velocities as well as photometry to search for possible transits are underway.

## 9. Justification of requested observing time and lunar phase

**Lunar Phase Justification:** For radial velocity observations there are no restrictions regarding lunar phase.

**Time Justification: (including seeing overhead)** In order to detect a significant number of new hot Jupiters, a large parent sample of stars has to be observed. Our parent sample to be observed by the international consortium as a whole thus consists of about 2000 stars, out of which we expect to detect around 60 new hot Jupiters. We propose here to observe a subsample of 200 stars out of those 2000 stars in total, so that we can expect to detect about 6 new hot Jupiters. Smaller numbers of nights would be possible, for example half-nights instead of full nights, but the main aim of the proposal - detecting a **statistically significant** sample of new hot Jupiters - would be somewhat compromised. Note that is critical to our scientific goals to obtain measurements at 3 different epochs (3 continuous nights are preferred). We expect to observe between 50 and 100 stars per full night at each telescope. Once integration times become larger than 5 minutes in order to reach a S/N of at least 100 (for a radial velocity precision of 7 m/s), we will observe it with UVES instead HARPS; that implies that stars which are fainter than $V \approx 8$ mag will have to be observed with UVES.

**Calibration Request:** Standard Calibration

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

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


Fischer, D.A., Marcy, G.W., Butler, R.P., Vogt, S.S., Walp, B., Apps, K., 2002, PASP, 114, 529: Planetary Companions to HD 136118, HD 50554, and HD 106252

Fischer, D.A., Marcy, G.W., Butler, R.P., Laughlin, G., Vogt, S.S., 2002, ApJ, 564, 1028: A Second Planet Orbiting 47 Ursae Majoris

Fischer, D.A., Marcy, G.W., Butler, R.P., Vogt, S.S., Henry, G.W., Pourbaix, D., Walp, B., Misch, A.A., Wright, J.T., 2003, ApJ, 586, 1394: A Planetary Companion to HD 40979 and Additional Planets Orbiting HD 12661 and HD 38529

Fischer, D.A., Butler, R.P., Marcy, G.W., Vogt, S.S., Henry, G.W., 2003, ApJ, 590, 1081: A Sub-Saturn Mass Planet Orbiting HD 3651

Fischer, D.A., Valenti, J.A., 2003, ASP Conference Series, 294, 117: Metallicities of Stars with Extrasolar Planets

Frink, S., Mitchell, D.S., Quirrenbach, A., Fischer, D.A., Marcy, G.W., Butler, R.P., 2002, ApJ, 576, 478: Discovery of a Substellar Companion to the K2 III Giant $\iota$ Draconis

Mitchell, D.S., Frink, S., Quirrenbach, A., Fischer, D.A., Marcy, G.W., Butler, R.P., 2004, submitted to ApJ: Sub-Stellar Companions to K Giant Stars $\tau$ Gem, HD 59686, $\nu$ Oph, and 91 Aqr

12. List of targets proposed in this programme

| Run | Target/Field | $\alpha$(J2000) | $\delta$(J2000) | ToT(hrs) | Mag. | Diam. | Additional info | Reference star |
|---|---|---|---|---|---|---|---|---|
| A | HIP 58579 | 12 00 48 | –12 09 27 | 0.2 | 7.96 | | [Fe/H]=0.19, G0 | |
| B | HIP 59077 | 12 06 55 | –38 06 23 | 0.2 | 9.35 | | [Fe/H]=–0.01, G8/K0 | |

Target Notes: Our target list for this proposal consists of about 300 stars and did not fit entirely onto the one page limit. We therefore provide the first few stars of each of the lists for HARPS (run A) and UVES (run B) as an example. The stars span the whole range right ascension range accessible during the months from October to March, and have all southern declinations. For HARPS, the stars are brighter than 8.5 mag in V, and brighter than about 10 mag for UVES. The last column gives our derived **metallicity** as well as the spectral type.

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

13. Scheduling requirements

**1. Run Splitting**

| Run | splitting |
|---|---|
| A | 3,100w,3 |
| B | 3 |

14. Instrument configuration

| Period | Instrument | Run ID | Parameter | Value or list |
|---|---|---|---|---|
| 74 | HARPS | A | spectro-Thosimult | |
| 74 | UVES | B | RED | Iodine cell standard setting: 600 |
| 74 | UVES | B | Iodine cell | yes |