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Tenth anniversary of 51 Peg-b : Status of and prospects for hot Jupiter studies
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SOPHIE: the successor of the spectrograph ELODIE for extrasolar planet search and characterization

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Abstract. The SOPHIE echelle spectrograph is presently built at the Haute Provence Observatory (OHP). It will replace and upgrade the ELODIE spectrograph, well known for the discovery of the first hot Jupiter 51Peg-b ten years ago. This new spectrograph is going to be installed at the 1.93-cm telescope and be commissioned beginning of 2006. Primarily based on the experiment acquired on HARPS (3.6-m ESO), SOPHIE should be considered as its North counter part. Its main characteristics and expected performances are described. Some exoplanet programs which will be conducted these next years are presented.

1. Introduction

Radial velocity (RV) measurements have demonstrated these last ten years their efficiency and power for the detection and characterization of extrasolar planetary systems. Thanks to improvement in the Doppler techniques, radial velocity measurements continuously increased their accuracy and reached recently the level of 1 ms^{-1}. Far to be considered as an old-fashioned techniques, RV clearly offers for the next decade the possibility to complete the mass-period diagram of exoplanets, especially in the domain of Neptune-mass planets and hot big Earthes. Furthermore, RV appears to be a method fully complementary to photometry for characterizing the actual mass of transiting hot Jupiters. In this context and taking into account the limitation of the spectrograph ELODIE, it appeared that a new RV instrument had to be developed at Haute Provence Observatory.

2. ELODIE limitations

The ELODIE spectrograph (Baranne et al. 1996) is a fiber-fed cross-dispersed echelle spectrograph built on 1993 and installed on the 1.93-m telescope at Haute Provence Observatory. The 1k×1k CCD records 67 spectral orders which cover all the visible range from 391 to 681 nm with a spectral resolution of 42'000. Two optical fibers (100 μmm diameter) feed the spectrograph. The acceptance on the sky is 2 arcsec. One fiber is used for the stellar beam, the second one can be used for the sky background or the simultaneous Thorium-Argon calibration. The spectrograph is located in a thermally controlled room. ELODIE is working since 1994 and drove several discoveries and astrophysical breakthroughs. Its fame comes in a large part from the detection of the first extrasolar planet around the solar-type stars 51 Peg (Mayor & Queloz 1995). These last 11 years ELODIE led to the detection of up to 20 exoplanets. It also permitted significant progress in topics like stellar spectroscopic analysis, rotational velocity determination, discovery of very low mass stars, asteroseismology, vertical distribution of Galactic disk stars, etc. However ELODIE suffers from some limitations: 1) an overall efficiency of less than 1 %, 2) a spectral resolution of 42'000, 3) a fiber-to-fiber contamination and scattered light, and 4) a Doppler precision of 6-8 ms^{-1}. Taking into account these limitations and the performances achieved by the spectrograph HARPS installed two years ago at the 3.6-m ESO telescope (Pepe et al. 2002; Mayor et al. 2003), the development of a successor of ELODIE was decided.

3. SOPHIE project overview

Following the tradition at Haute Provence Observatory which consists in giving a woman name, the new spectrograph was called SOPHIE for Spectrograph for Observation of PHenomena in stellar Interiors and Exoplanets. The principal investigator is D. Gillet (OHP). S. Ilovaisky (OHP), M. Mayor (Genève), and J.P. Sivan (LAM) are Co-investigators. The project manager is L. Hill (OHP) and the instrument scientist is F. Bouchy (LAM/OHP). The Laboratoire d'Astrophysique de Marseille and the Observatoire de Genève are partners. One of the main science driver identified for SOPHIE is the search for extrasolar planets. The goal was to design an instrument based on the principle of HARPS but adapted for a 2-m class telescope. The requirements were to increase 3 factors compared to ELODIE: 1) the overall efficiency, 2) the spectral resolution, and 3) the Doppler accuracy.

4. Description of the instrument

Figure 1 shows the optical and mechanical design of the SOPHIE spectrograph. Table 1 gives the main characteristics of the optical components. The beam is collimated by a 200-mm spherical mirror and is folded by a pierced plane mirror. Such a configuration gives a quite compact instrument but introduces a central obstruction. Spherical aberration is corrected by a Schmidt plate used in double passage. The main dispersion is given by an R2 echelle grating and the cross dispersion is given by a prism. These two dispersive components are installed in a tank closed by the Schmidt plate. The tank is filled with N2 (dry air) and closed in order to be at constant pressure. This solution avoids the change of air optical index due to atmospheric pressure change which can typically introduce a RV instrumental drift of 90 ms^{-1} per mbar change. The CCD is installed just behind the plane mirror and is cooled at $-100°$ by liquid Nitrogen. The whole instrument is installed in a thermally controlled isolation box.

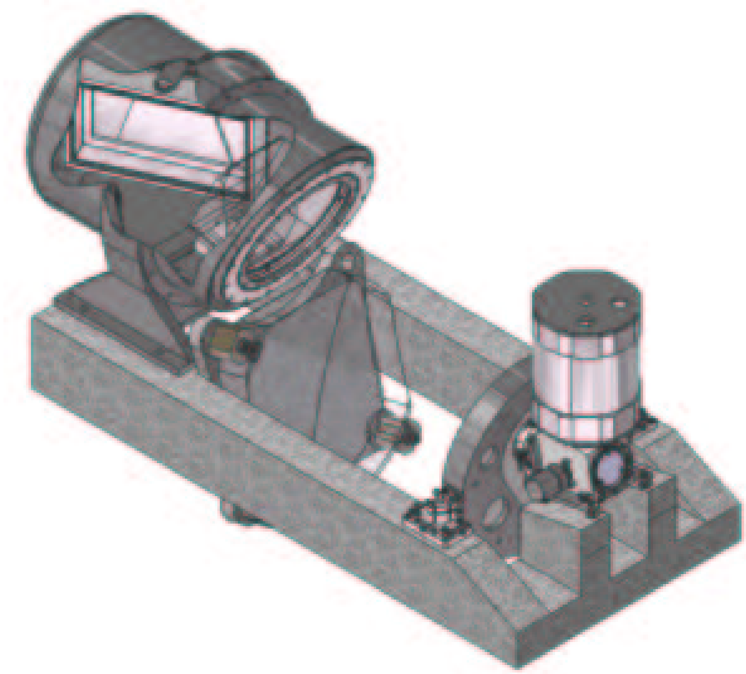

Figure 1. *Optical and mechanical design of SOPHIE spectrograph.*

In order to minimize the fiber length, the instrument is installed in the Coudé room of the 1.93-cm and is fixed in the telescope pillar. The ELODIE Cassegrain fiber adapter is used to feed the SOPHIE fibers (100 μmm diameter). The only difference is that SOPHIE fibers have an acceptance of 3 arcsec on the sky. Two set of fibers are installed for SOPHIE, the first one is called High Efficiency fibers, the second one is called High Resolution fibers. This last set of fibers includes two peculiarities : 1) a slit in front of the fiber at the spectrograph entrance in order to increase the spectral resolution and 2) a double scrambler in order to increase the homogeneity of the beam required for high RV precision. The Data reduction software is an adaptation of the HARPS one.

Table 1. *Main characteristics of SOPHIE optical components.*

Component	characteristics
Collimated beam	Ø = 200 mm
Collimator mirror	Ø = 540 mm
	f = 720 mm
	F/D = 3.6
Plane mirror	Ø = 440 mm
Schmidt plate	Ø = 320 mm
Prism cross disperser	angle = 31°
	280 × 220 mm
Echelle grating	blaze = 65°
	52.6 gr.mm^{-1}
	204 × 410 mm
Field lens	Ø = 90 mm
	R = 245 mm
CCD	EEV 44-82
	2048 × 4102 pixels
	pixel size 15 μm

The integration of the instrument will start in January 2006 with first light foreseen in March 2006. Several periods of commissioning and scientific verification will take place during spring and summer 2006. SOPHIE will be open to the community starting June 2006 on a "shared risk" basis. Documentations about SOPHIE project can be found in the OHP web page (http://www.obs-hp.fr/).

5. Expected performances

The expected performances for the two observation modes (High Efficiency and High Resolution) are given in Table 2. The overall efficiency includes CCD, spectrograph, fibers, Cassegrain adapter, telescope and atmosphere. The CCD detector records 40 spectral orders covering the spectral range from 383 nm to 693 nm. The expected S/N per pixel at 550 nm (0.025 Å) is given in Figure 2. The High Efficiency mode gives a gain of about 1 magnitude in efficiency.

Table 2. *Expected performances*

Observation Mode	Spectral Resolution	Overall efficiency at given λ [nm] 390	400	430	500	690
High Efficiency	34'000	0.046	0.059	0.082	0.104	0.083
High Resolution	68'000	0.019	0.025	0.034	0.043	0.035

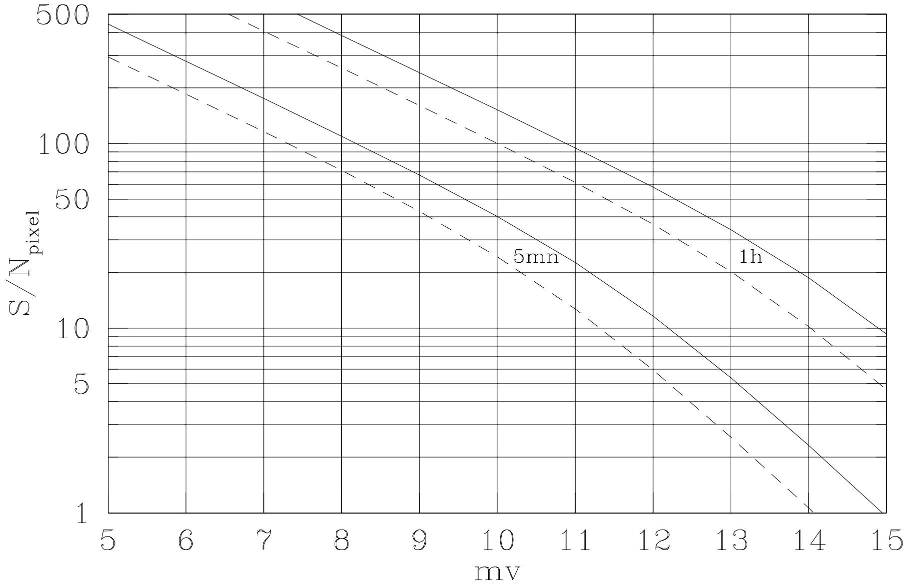

Figure 2. *Expected signal-to-noise ratio per pixel (0.025 Å) at 550 nm for a 5-mn exposure and a 1-hour exposure. The solid and dashed lines correspond respectively to High Efficiency mode and High Resolution mode.*

Radial velocity uncertainties due to photon noise were computed following Bouchy et al. (2001). RV uncertainties are given in Figure 3 versus visual magnitude in the case of a no-rotating K5V star which is the best stellar case in term of deep and numerous spectral lines. The High Efficiency mode is not optimized for high precision RV measurements and should be limited to the 5-10 ms^{-1} precision. However in case of faint stars and/or large rotating stars, this mode should be considered as more adapted than the High Resolution mode for RV measurements at the precision level of 10 ms^{-1}.

With its High Resolution mode, SOPHIE was designed to reach the same level of RV precision than HARPS (1-2 ms^{-1}). As shown in Figure 3, a photon noise uncertainty of about 1 ms^{-1} should be obtained on a 7 magnitude K5V star within a 5-mn exposure or on a 9.5 magnitude K5V star within a 1-hour exposure.

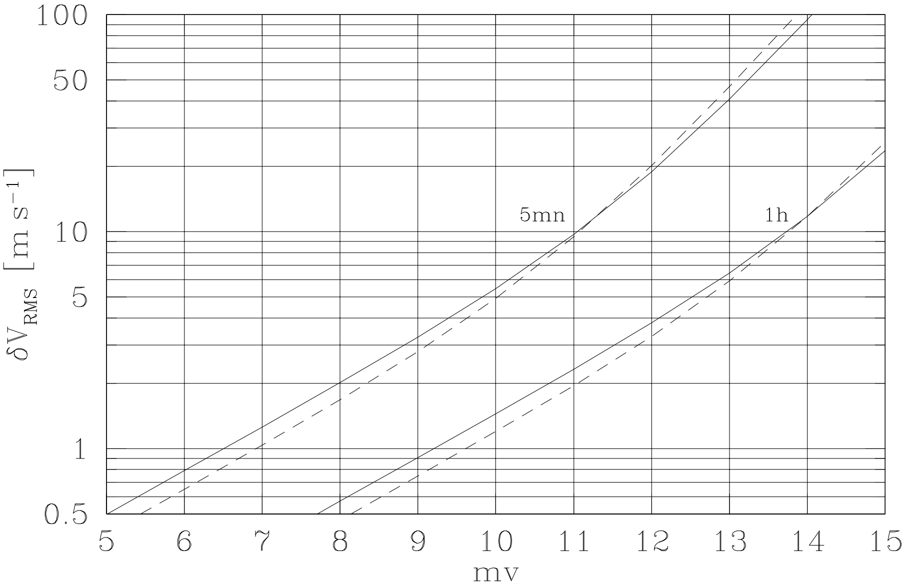

Figure 3. *Expected RV uncertainty due to photon noise for a no-rotating K5V star versus visual magnitude for a 5-mn exposure and a 1-hour exposure. The solid and dashed lines correspond respectively to High Efficiency mode and High Resolution mode. The expected systematic errors for the HE mode (solid curves) are 5-10* ms^{-1}. *The expected systematic errors for the HR mode (dashed curves) are 1-2* ms^{-1}.

6. Exoplanet programs

SOPHIE offers at least 3 main advantages for exoplanet search programs: 1) a high availability (about 180 nights per year will be dedicated for such programs), 2) a high Doppler precision (1-2 ms^{-1}) and 3) a real-time data reduction (in order to adapt the observation strategy in real-time). Exoplanet programs conducted with SOPHIE will be able to focus on :

- Searching for very low-mass planets (Neptune-mass planet and hot big Earths),
- Detection of Hot Jupiters coupled with photometric follow-up with the 1.20-m OHP telescope,
- Exploration of the HR diagram from A to M type stars,
- Follow-up of the long period (≥10 years) candidates found by ELODIE,
- Follow-up of the transiting candidates of the photometric ground-based survey,
- Follow-up of the transiting candidates of the COROT space mission.

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NAHUAL: a cool spectrograph for planets of ultra-cool objects

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Abstract. We present the status of an ongoing study to built a a high resolution near infrared Echelle spectrograph (NAHUAL) for the 10.4-m-Gran Telescopio Canarias (GTC) which will be especially optimised for planet searches by means of high precision radial velocity measurements. We show that infrared radial velocity programs are particularly suitable to search for planets, very low mass stars and brown dwarfs, as well as active stars. The goal of NAHUAL is to reach an accuracy of the radial velocity measurement of a few m s^{-1}, which would allow the detection of planets with a few earth-masses orbiting low-mass stars and brown dwarfs. It is planed that NAHUAL covers simultaneously the full wavelength range in the J, H, and K-band, and will also serve as a general purpose high resolution near infrared spectrograph of the GTC. The planed instrument will have a resolution of $\lambda/\Delta\lambda = 50,000$ with a 0.175 arcsec slit, and an AO-system. An absorption cell will serve as a simultaneous wavelength reference.

1. Introduction

In this contribution, we will present a study for a high-resolution spectrograph which is especially designed for high precision radial velocity

(RV) measurements at near infrared (IR) wavelengths. The instrument is called NAHUAL [1] for Near-infrAred High-resolUtion spectrogrAph for pLanet hunting, and will be operated at the 10.4-m-GTC telescope (Gran Telescopio Canarias). The GTC will see first light in 2006. NAHUAL will also serve as a high-resolution spectrograph IR spectrograph for general use (Martín et al. 2005). In Section 2, we discuss the benefits if RV-planet search programs are being carried out at IR-wavelength. In Sections 3 and 4, we discuss the requirements and present the conceptional design of the instrument.

2. The benefits of high-resolution NIR spectroscopy for exoplanet research

2.1 Planets of brown dwarfs and very low-mass stars

Most of the efforts for detecting extra-solar planets have been concentrated on main sequence F,G,K stars. These surveys show that while a large fraction of the stars are binaries and many have massive planets, there is a lack of close-in brown dwarf (BD) companions. This result has often been used as an argument that there are two distinct formation tracks: one leading to planets, and the other to stellar companions. In the standard model massive planets form by core accretion: In the first step a solid core of about 0.01 to 0.03 $M_{Jupiter}$ forms, which subsequently accretes gas from the disk in order to form a massive planet. The core accretion scenario is supported by the fact that stars with an overabundance of heavy elements also have a higher frequency of massive planets (Santos, Israelian, & Mayor, 2004). The discovery of HD 149026 b, which has 0.21 $M_{Jupiter}$ core composed of elements heavier than helium also supports the core accretion scenario (Sato et al. 2005).

What would be expected, if we go to stars of lower mass? According to Laughlin et al. (2004), stars of lower masses had also disk of lower masses and thus should also have planets of lower masses. This idea is in good agreement with the observations, as Butler et al. (2005) estimate that the fraction of Jupiter-mass planets of M-stars is at least a factor of 5 smaller than of FGK-stars. However, up to now it is not yet clear whether this is solely a result of the lower masses of the protoplanetary disks, or at least partly due to evaporation due to the strong UV radiation of young M-stars.

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[1] A NAHUAL is also a kind of shaman in Mexican mythology that is a person in daytime but a hunter at night time.

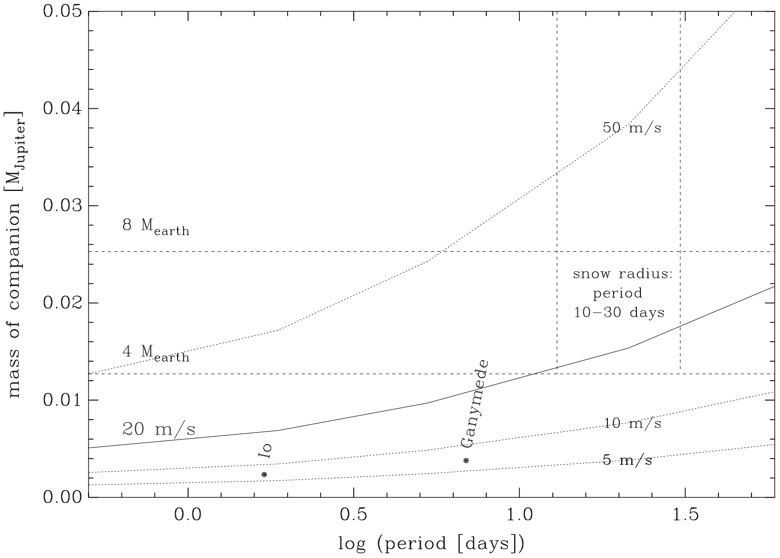

Figure 1. *The figure shows the semi-amplitude of the RV-variations caused planets orbiting a 40* $M_{Jupiter}$ *brown dwarf (BD). Planets of only a few earth-masses could be detected if an accuracy of 20* $m\,s^{-1}$ *is achieved. An accuracy of 5* ms^{-1} *is required in order to detect objects analogue to Io and Ganymede. In the case of the disk of a BD the ice-line would correspond to an orbital period of only 10 to 30 days.*

What would we expect, if we go to even lower masses, planets of brown dwarfs (BDs) and very low mass stars (VLMSs)? For BDs the evaporation due to the strong UV radiation is certainly irrelevant. If planets can only form by core accretion, one would expect to find only planets of very low mass ($\sim 0.01\ M_{Jupiter}$ or a few M_{earth} in this case). Likewise, one may argue that BDs resemble Jupiter and we might expect to see only Io or Ganymede-type objects. Again this implies that BDs should have planets of only a few M_{earth} (Desidera 1999). However, even such planets could be detected with an accuracy of RV-measurements of 5 to 10 ms^{-1} (Fig. 1). On the other hand, one may argue that BDs and VLMSs should have massive planets, simply because there are many BD-BD binaries and the mass-ratio between a BD and a massive planet is only $\sim$ 1:10. Since for field objects there is no break in the initial mass function at 13 $M_{Jupiter}$, such "BD-planet binaries" could be possible. Of course, the best evidence for the existence of such objects is 2MASSW J1207334-393254 (Chauvin et al. 2005). If BDs have massive planets, we would thus expect that there is no correlation with metallicity, as these planets would not have been formed by core-accretion.

Up to now, only two programs to search for planets by means of RV-measurements have been carried out. Joergens (2005) monitored 7 young BDs in the Chameleon cluster, and found one companion candidate. Additionally, she found that the RV-variations caused by activity decreased with the mass of the object. Guenther & Wuchterl (2003) monitored the 26 VLMSs and BDs, and found apart from three binaries one object which showed significant RV-variations: LP944-20. Unfortunately, it is not yet clear, whether these are caused by surface features, or by an orbiting planet.

A search program for planets of VLMSs and BDs with NAHUAL will thus show, whether BDs and VLMSs have planets or not, and if so whether these planets formed by core-accretion or not.

2.2 Calibrating evolutionary tracks and the atmospheres of BDs

The lack of knowledge of the true masses of VLMSs and BDs at young age is a severe problem for this field of research. A dedicated search program for eclipsing BD-BD, or BD-planet binaries should solve the problem. Eclipsing systems could best be found with NAHUAL in a survey in which many BDs are observed but each BD is observed only three times.

NAHUAL will also allow to study the atmospheres of low-mass objects in detail, because it is possible to obtain spectra covering simultaneously J, H, and K-band at a resolution of $\lambda/\Delta\lambda = 50,000$. Such observation would allow to determine T_{eff}, log(g) and the abundances, for example.

Young BDs show clear signs of accretion. The presently available optical data seems to indicate that $\dot{M} \sim M_*^2$ (Mohanty et al. 2005). Because the disk mass $M_d \sim M_*$, one would deduce that VLMSs and BDs should take much longer than solar-like stars to form. Since the flux of the Bracket γ line is well correlated with the accretion rate, observations with NAHUAL will shed more light on to this question.

2.3 Planets of active stars

One problem of the RV-technique is that not only orbiting planets but also stellar spots, plage regions, changes of the granulation pattern, and oscillations can also lead to RV-variations. However, the only effect that causes RV-variations that does not depend on wavelength is an orbiting object. Thus, be carrying out RV-measurements at optical and

IR wavelengths, it is possible to distinguish between orbiting planets and other effects.

An interesting question is, whether the RV-scatter caused by stellar activity becomes larger or smaller when going from optical to IR wavelengths. Paulson et al. (2002) used their precise RV-data of the Hyades stars in order to investigate the cause of the RV-scatter. They find that the scatter is mainly caused by spots. Plage regions are less important. This result is confirmed by RV-monitoring of the very active star EK Dra (König et al. 2005). The main effect is that the 90 to 95% light deficit of a spot causes a hump in the profile of a spectral line which moves across it with the rotation of the star. We modeled this effect and find that it is reduced by a factor of 10 at IR wavelength, because the difference in brightness between a spot and the photosphere is smaller in the IR.

3. Scientific requirements

In order to achieve the highest possible accuracy for the RV-measurements, the top requirements are:

- Large spectral coverage: This requirement calls for a cross-dispersed Echelle spectrograph and a 2048x2048 HAWAII-2 PACE HgCdTe detector. NAHUAL will cover the whole region from 0.9 to 2.4 μm, with only some small gaps in the K-band.
- High signal-to-noise ratio: This requirement implies a high throughput and a big telescope, the GTC. Additionally, the instrument will be cooled to 70 K.
- A resolution that is high enough to resolve the spectral lines: Given the $v\,sin\,i$-values of VLMSs and BDs, this implies a resolution of $\lambda/\Delta\lambda \geq 50,000$.
- An absorption cell for the wavelength-self reference.
- AO-system to allow for a narrow slit, and for stabilising the star on the slit.
- Stable environment: The instrument will be place at the Nasmyth platform, evacuated, and temperature stabilised. Kjelsen et al. (2005) has demonstrated that an amazing accuracy of 0.44 $m\,s^{-1}$ can be achieved with UVES, which is also placed at the Nasmyth platform, and also uses an absorption cell as a wavelength self-reference.

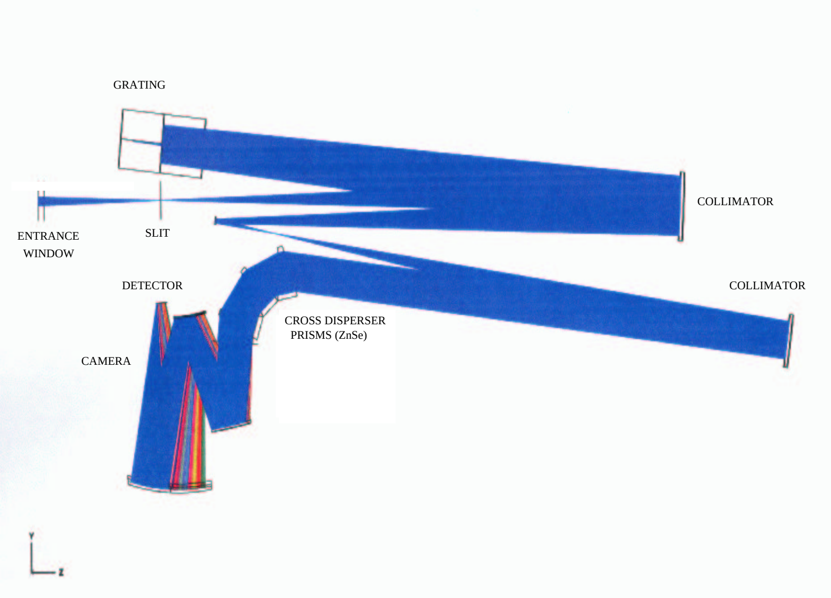

Figure 2. *The figure shows the conceptual optical design of NAHUAL*

4. Conceptual design of NAHUAL

The resolution of the spectrograph per arcsec is given by $R\varphi = 2(d/D)\tan\alpha_B$ where R is the resolution, φ the slit width on the sky, d the diameter of the collimated beam, D the telescope diameter and α_B the blaze angle. The first thing to discuss is whether a grating with $\tan\alpha_B = 4$, or 2 should be used. While a $\tan\alpha_B = 4$ grating gives a higher resolution, it requires a spectrograph camera of very short focal length with a large field of view. Unfortunately, we studied several possibilities but all of them suffer from vignetting at the edge of the field. This essentially is because a 3-mirror system has to be used. We thus have to choose a $\tan\alpha_B = 2$ grating. We also studied instrument concepts with collimated beam diameters of 200 and 100 mm but finally decided for the smaller beam diameter in order to keep the instrument manageable (Fig. 2). Forseen is a gold coated grating of 23.2 gr mm^{-1} with $\alpha_B = 63^o$.

These parameters already fix the slit-width to 0.175 arcsec for a resolution of R=50000. NAHUAL will thus work with an AO-system. A natural seeing mode with an image-slicer is also being studied. By placing a flat mirror in front of the Echelle grating, NAHUAL will also allow to take spectra with R $\sim$ 300, using only the three ZnSe prisms of the cross-disperser. Because the AO-system will not change the f-ratio

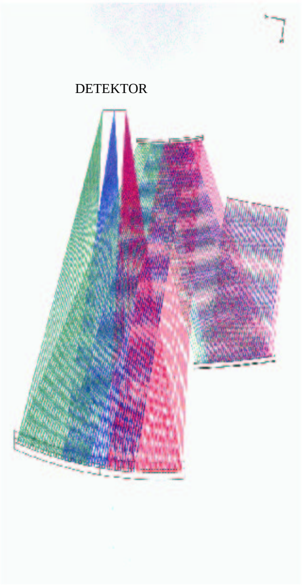

Figure 3. *The figure shows the three mirror design of the camera of NAHUAL in more detail.*

of the GTC, the focal length of the two collimators are fixed to 1700 mm. Given the pixel size of the 2048x2048 HAWAII-2 PACE detector, we designed a three-mirror camera of 420 mm focal length, which has no vignetting even at the edge of the 40x40 mm field of view (Fig. 3). It is interesting to note that for designing the instrument we used the GIANO (http://www.bo.astro.it/giano/) concept as a starting point but then finally came up with a design that is closer to HARPS. In the conceptual design NAHUAL is 2.5 m long and 1.2 m wide.

5. The absorption cell laboratory

In order to achieve a high accuracy of the RV-measurements, an absorption cell has to be placed in front of the spectrograph. The cell produces a large number of absorption lines recorded simultaneously with the object spectrum during the observation (self-reference spectrograph). While an I_2-cell is commonly used in the optical regime, the best choice of gases for an infrared cell still has to be found. As part of the NAHUAL study, we have started a laboratory experiment to try out various gas mixtures. The gases are mixed in a controlled vacuum chamber and the spectra are measured with a spectrophotometer which is available in the IAC optical laboratory. Promising is the mixture of N_2O (30%), H_2C_2 (27%), He (25%), and CH_4 (18%).

6. Schedule and Conclusions

We have outlined the potential of NAHUAL for surveys of planets of VLMSs and BDs. We would like to give one example of the expected capability of NAHUAL. With UVES and the VLT it is possible to achieve an RV-accuracy of 500 m s^{-1} with an exposure time of 20 minutes for the BD LP944-20. With NAHUAL it will be possible to achieve 5 m s^{-1} with an exposure time of only 5 minutes. Thus, we hope that NAHUAL will open up an entirely new window for planet research. The plan is to finish the design study of NAHUAL in 2006, and to have the first light by 2010.

Acknowledgements. We would like to thank the whole NAHUAL team, especially those that participated in the first and second NAHUAL meeting in the paradores nationales in La Gomera (2004), as well as Segovia (2005). Funding for this work has been provided by the Spanish Ministerio de Educación y Ciencia through Acción Complementaria AYA2004-22113-E.

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PLANETPOL: polarimetry of hot Jupiters at the parts per million level

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Abstract. We summarize the preliminary results from 3 observing runs with PLANETPOL, a polarimeter designed to achieve sensitivities of order 10^{-6} in fractional polarization for nearby hot Jupiter systems. We also describe some of the problems associated with measuring very small fractional polarizations and the solutions we have adopted. These observations were conducted at the 4.2-m William Herschel Telescope.

1. Introduction

Polarimetry has the potential to be a very powerful method for obtaining data on hot Jupiter planets. The basic premise is that the direct light from the central star has little or no linear polarization (LP), while reflected light from the planet will in general be polarized, perhaps at the level of tens of per cent. Hence by measuring the polarized flux from a hot Jupiter system we expect to remove the stellar flux and observe only the planet, thereby circumventing the contrast problem without using a high resolution imaging system.

PLANETPOL is a polarimeter built at the University of Hertfordshire specifically to attempt this type of observation. In section 2 we outline the information that can potentially be extracted from polarimetry of hot Jupiter planets. In section 3 we describe the principles upon which the design of the instrument is based. Section 4 contains preliminary results of 3 observing campaigns and outlines the practical observing issues which arose during them. Conclusions are given in section 5.

2. Hot Jupiter science with a polarimeter

The polarization signal from an extrasolar planet is expected to vary periodically in magnitude and position angle with the orbital period of the planet. The period and timing of the target planets is usually well measured by the radial velocity method, and will also be known for planets detected by the transit method. Hence it should be straightforward to confirm the planetary nature of any polarization signal which is detected from a hot Jupiter system by testing for repeatability.

The position angle of the polarization is always centrosymmetric with respect to the star to planet radial vector. Hence measurement over a full orbit will yield the orbital inclination, i. In combination with the $M.sin(i)$ measured by radial velocities this yields the exact mass, M, so polarimetry of a large sample could in principle be used to improve measurements of the hot Jupiter mass function.

The amount of fractional polarization can also be used to estimate the radius, R_P, of the planet with precision comparable to that provided by transit surveys, since the reflected signal will always be proportional to $p\phi(\alpha)R_P^2$, where p is the geometric albedo and $\phi(\alpha)$ is the phase function at phase angle α. The latter two terms can be determined by constructing a model atmosphere and comparing the predicted polarization as a function of orbital angle with the observations. Detailed models of this kind can be found in Seager, Whitney, & Sasselov (2000) and Stam, Hovenier, & Waters (2004).

In addition, polarimetry as a function of orbital phase can be used to determine the composition of the planet's atmosphere. Reflection due to Rayleigh scattering, sub-micron dust grains or larger dust grains all vary with orbital phase in a different manner, as shown in the papers referenced above. Observation as several different wavelengths would maximize the amount of information extracted on the size distribution and refractive index of reflecting particles. It may then also be possible to infer the chemical composition of different types of dust grain (Seager et al. 2000) or identify broad absorption features due to atomic and molecular gas (Stam et al. 2004).

3. Principles of PLANETPOL design

The design of PLANETPOL is described in Hough et al.(2001). Here we list some of the key features which allows us to reach a sensitivity of 1 part per million (ppm) for bright stars. Note that Kemp et al.(1987) achieved a sensitivity of $\sim$1 part in 10^7 in observations of the full solar disk, but these observations did not require a telescope to gather the light. Previous night time polarimetry has generally not achieved a sensitivity better than 10^{-4} in fractional polarization.

PLANETPOL uses photo-elastic modulators (PEMs) supplied by Hinds optics as the modulating element, not a conventional half-wave retarder. The light passes through the PEM, and then a Wollaston prism. The PEMs are composed of a silica glass which is piezoelectrically stressed at their natural frequency ($\sim$ 20 kHz), producing a sinusoidally varying retardance of the orthogonal planes of polarization with a tunable amplitude which is set to half of the desired wavelength. The PEM+Wollaston optical train causes the linearly polarized component of the light to oscillate in intensity at harmonic overtones of the fundamental frequency. The light from the 2 beams exiting the Wollaston is detected by single element low noise avalanche photo-diodes (APDs), which are sensitive to DC and high frequency signals. Lock-in amplifiers are then used to pick out the first harmonic at 40 kHz and filter out noise at all other frequencies.

The key feature of such a PEM-based system is that the polarized flux is separated from the unpolarized flux by being converted to a high frequency signal. Hence very small fractional polarizations can be measured without the need for high precision. The high frequency also removes the effects of the earth's atmosphere. Such systems are not truly differential since the two beams produce first overtone signals with identical amplitude, the only difference being a phase difference of pi radians. Each beam separately measures the same Stokes parameter.

Conventional dual beam polarimeters (half-wave plate + Wollaston) can remove the effects of the Earth's atmosphere by providing a differential measurement of orthogonal planes of polarization. However, they cannot measure fractional polarizations at the 10^{-6} level because the polarized signal is not separated from the much larger unpolarized signal, so that an unachievable absolute precision of 10^{-6} would be required in the measurements with each detector.

Other important elements of the PLANETPOL design are: as follows. (1) A Fabry lens, which images the telescope primary mirror on to the APDs. This is preferable to imaging the star, which might move about within the detector area on the atmospheric seeing timescale and cause problems due to non-uniform sensitivity. (2) A completely separate sky channel, offset by a few arcminutes on sky from the star channel (which is on the telescope axis). This is used to measure any polarized flux from the night sky within a 6 arcsecond detector aperture, which can then be subtracted from the planetary signal. (3) The APDs and the Wollaston (in both the star and sky channel) are mounted in rotatable housings which are used to change the angle between the axes of the PEM and the Wollaston from $+45°$ to $-45°$ every few minutes. This '2nd stage chopping procedure' removes the effect of any drifts in the electronics. (4) Absolute encoders with a step size of 0.009° are used to measure the rotation angles used in 2nd stage chopping and the rotation angle of the whole instrument. The instrument is rotated back and forth through 45° to measure the Stokes Q and U parameters. This permits high precision measurements, so that small planetary polarization signals can be detected despite the presence of other polarization signals such as telescope polarization, which can be large at some telescopes.

4. Results

Three observing campaigns were carried out at the 4.2-m William Herschel Telescope (WHT) at Roque de los Muchachos Observatory in La Palma in April 2004, October 2004 and April-May 2005. The first run aimed to detect τ Boo b, the second to detect υ And, and the third was a double run observing τ Boo b and starting an unbiased survey of nearby bright stars. All observations used a broad 590-950 nm bandpass, limited at the long end by detector response. In this section we briefly summarize the results.

The precision achieved is photon noise limited, declining with the square root of stellar flux. Sky polarization is only occasionally significant (eg. during conditions of bright moonlight illuminating thin cloud). For bright stars a precision slightly better than 1 ppm in fractional polarization has been achieved. However the noise is $\sim 2\times$ higher than expected, which is presently attributed to an additional source of photon shot noise arising in the APDs. The majority of the nearest bright stars show very little polarization. The observed signal from these stars is often dominated by the polarization of the telescope, which is typically 10-20 ppm at the WHT, with variations only on a timescale of months. This low telescope polarization (TP) can only be achieved at a Cassegrain focus or prime focus where there are no off-axis reflections. It appears to be due to spatial variations in the reflectivity of the mirror surface rather than any asymmetry in the mirror figure (which might change with zenith distance in a poor quality telescope) or any effect of the secondary mirror support spider. The WHT is an alt-azimuth telescope, so the Cassegrain focus is rotated to keep the image from rotating during observations as the telescope tracks. Hence the TP in each Stokes parameter is a function of telescope parallactic angle.

Figure 1 shows the data from April 2004. Three Tinbergen unpolarized standards were observed several times (the points without error bars) and the close fit to the curve indicates that any interstellar or intrinsic stellar polarization is at a level of 0-3 ppm in both Stokes parameters. By contrast the Tau Boo data in Stokes Q (data with error

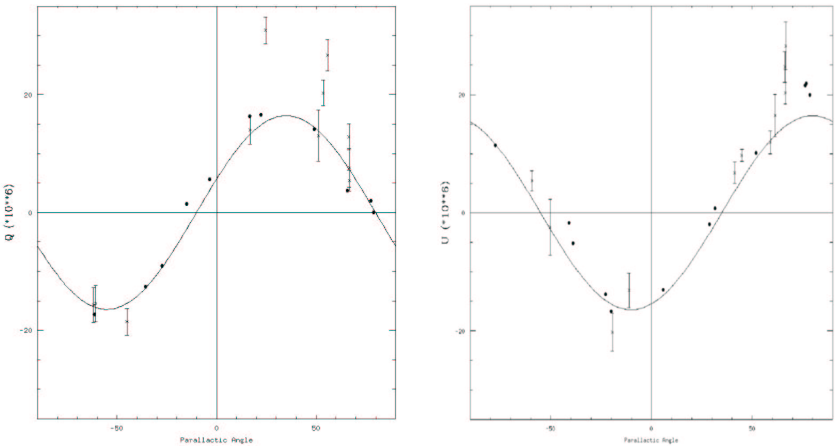

Figure 1. *Measurements from the April 2004 run plotted against telescope parallactic angle. (left) Stokes Q; (right) Stokes U. The curve in each plot shows the best fit telescope polarization. Points without error bars are for bright nearby stars with near zero polarization. Points with error bars are data for τ Boo.*

bars) agrees with the curve at some points and disagrees at other points. This indicates a variable polarization at the 10 ppm level due to either the planet or the star itself. There was insufficient good weather in April 2004 to make clear statements about this apparent signal.

Figure 2 shows the Tau Boo residual polarization from the longer run in April-May 2005, after the TP has been fitted and subtracted from each Q and U point and these have been combined in fractional polarization P. We plot P=$\sqrt{Q^2 + U^2 - \sigma_P^2}$ against orbital angle for the planet (orbital data courtesy Geoff Marcy, private comm.) There appears to be a great deal of scatter at a level of up to 10 ppm or more at all orbital angles for which several data points were obtained. The inconsistencies became apparent when data from 7 and 8 May were added to data from 25-30 April, after an interval of other observing programs and bad weather. This scatter is not seen for any of the several Tinbergen unpolarized standards which we have observed.

This scatter suggests that either we are observing a planet with a signal which varied strongly over an interval of 3 orbits, eg. due to weather, or that the star τ Boo itself has a significant variable polarization. Recent results from the MOST micro-satellite (Walker et al. 2005) show strong semi-regular photometric variability in this rapidly rotating star, apparently with the same period as the planetary orbit (3.3 days). (The star is believed to have been spun up by this unusually

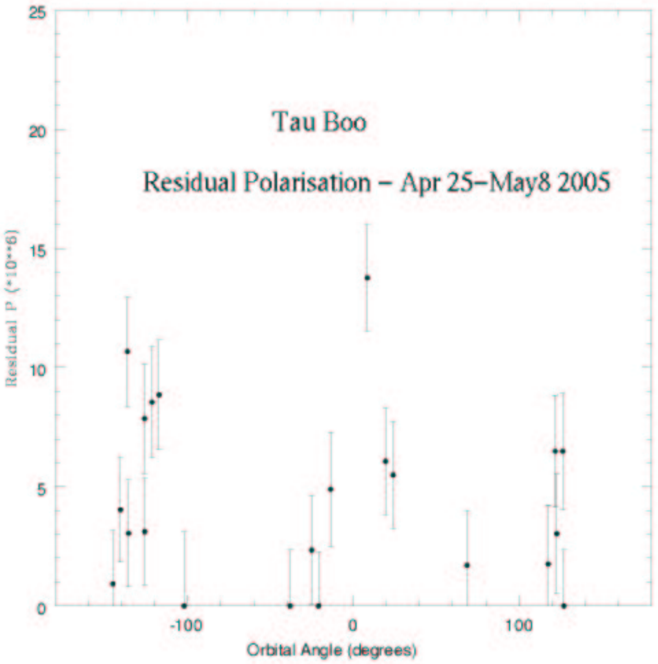

Figure 2. *Residual fractional polarization of Tau Boo in 2005. Scatter in the points at each orbital angle is attributed to the effect of the massive planet on the rapidly rotating star. Polarization variability is not seen in unpolarized standards at similar distances* ~ 15 *pc*

massive planet). Hence it appears likely that the observed polarization variation is caused by the star (eg. a very large star spot), rather than the planet.

Some of the Tinbergen "unpolarized standards" do show measurable polarization. Figure 3 shows the Stokes Q data as a function of parallactic angle from the October 2004 run. 4 Tinbergen unpolarized standards are included (large points). The left hand plot shows that they all display obvious scatter away from the best fit TP curve, at a level of 5-12 ppm. The right hand plot shows the same data after subtracting a different best fit constant Stokes Q from each star. (The TP amplitude and phase and a constant Q and U for each star are derived simultaneously by fitting all the data for unpolarized standards). The points then all lie close to the curve. It thus appears that interstellar polarization can be observed even toward these nearby stars (all within

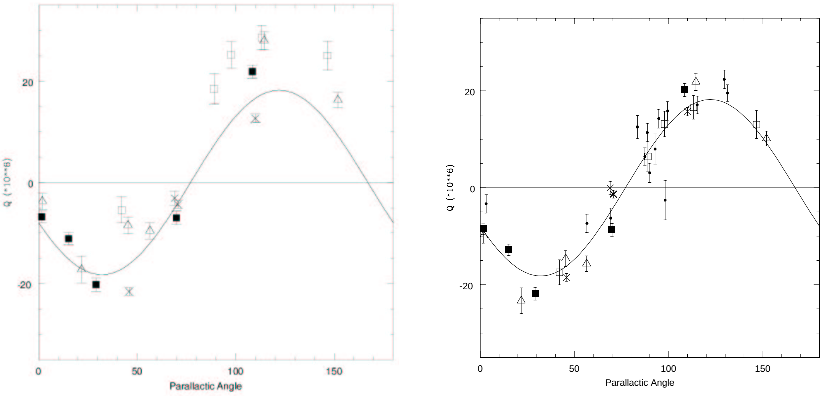

Figure 3. *A low interstellar polarization is seen toward some "unpolarized (standards". These lie off the TP curve in the raw Stokes Q data (left) but lie on the curve after fitting and subtracting a constant interstellar polarization for each standard (right).* υ *And data were taken near phase of minimum illumination (right plot, small filled circles).*

$\sim$ 25 pc). The amount appears to be a strong function of direction on the sky. The right hand plot in Figure 3 includes the data for υ And (small filled points). These show little departure from the curve, which is unsurprising since weather constraints allowed data collection only near the phase of minimum illumination.

5. Note on Saharan Dust

Part of the period of bad weather in early May 2005 was due to large grey particles of Saharan dust, a not uncommon occurrence in La Palma in the summer months. This introduced a polarization signal at the level of up to 40 ppm, which seriously interfered with our observations. The dust reduces throughput by $\approx$25% when the polarization effect is 40 ppm. The dust polarization, P_D, is attributed to dichroic extinction, and appears to be a strong function of zenith distance, ζ, declining to near zero at $\zeta < 20°$. If the effect is due to dichroic extinction we would expect that (i) $P_D = C(1 - cos(\zeta))$ (C being a function mainly of dust column density) and (ii) an orientation in the azimuthal plane or the altitudinal plane. The data appear to bear this out, though analysis is presently at an early stage. Hence it should be possible to minimize this effect when it occurs by observing science targets only near the zenith (reducing the effect to 1-4 ppm) and subtracting the calculated P_D. The difficulty is that the parameter C is likely to have some temporal and directional variability even within each night, so the error bars on any science data of bright science targets will be noticeably increased. This analysis will be attempted for the affected data, which was not included above.

6. Conclusions

We have shown that it is possible to observe nearby bright stars with a precision of parts per million in fractional polarization. Data for τ Boo appear to be affected by stellar variability, which may be a consequence of magnetic disturbance of the stellar photosphere by the massive planet, or simply the rapid rotation of the star (apparently spun up by the planet).

Nevertheless the low level of the observed polarization variation indicates that τ Boo b has a low geometric albedo ($p < 0.2$ perhaps, yet to be modeled). We can hope that the other bright hot Jupiter systems (υ And, 51 Peg) do not suffer from this stellar polarization variability problem since they rotate more slowly and the planets are 10× less massive than *tau* Boo b. Observation of the newly discovered class of hot Neptune planets (eg. 55 Cnc e) may also be possible with PLANETPOL.

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CoRoT searching for hot planets

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Abstract. The european space mission CoRoT will be partly dedicated to the search for planets with the photometric transit method. It is optimized for the detection of planets in the period range 1 to 50 days, and sensitive to planet size over 2 Earth radii, i.e. focused on hot Jupiters down to hot Neptunes. After a brief description of the instrument, the paper gives the status of the scientific preparation to CoRoT: fields and targets selection, performance tests and limitations.

1. Introduction

The transit method is one of the most promising tool for exploring future extrasolar planets, as it could be the first one to permit the detection of terrestrial planets. This challenge requires dedicated photometric observations from a space telescope and the monitoring of several tens of thousands stars. The follow-up photometry of known transiting planets from the HST has proven extremely accurate, at the level of putting constraints on the presence of terrestrial satellites to the main transiting body (Brown et al. 2001). Other space-based photometry of extrasolar planetary systems are performed by MOST and reported in this volume (Walker), aiming at the detection of the starlight reflected by the planet surface. The next instrument dedicated to obtaining light curves of stars and planets from space is CoRoT, which is presented in the following sections. Finally, the NASA mission Kepler is foreseen for a couple of years after CoRoT and will be optimized for the search for extrasolar Earth sisters.

2. CoRoT

The core science objectives for CoRoT (Baglin 2003) are asteroseismology and transit searches (Figure 1). Both require long and continuous stellar light curve series and a very accurate photometry. Observations for both programmes will be performed simultaneously on contiguous stellar fields.

CoRoT has a low polar inertial orbit at an altitude of 896 km and orbital period of 1h43min. The impacts of such an orbit on the light curve are: periodic gaps in the data (less than 5% of a total light curve) due to the South Atlantic Anomaly crossing, and periodic bell shapes due to the variation of the light scattered by Earth during the satellite revolution. To efficiently remove the contamination of light scattered by the Earth, a long baffle is located at the top of the telescope. Its specification is to let a residual flux on the CoRoT CCD of 1 photon per pixel and per second. The baffle behaves almost as specified so far (its actual performance will be known only from space), and the observation cone was reduced from 10° initially to 7° radius, since the impact of the Earth limb is more visible towards the field's edges.

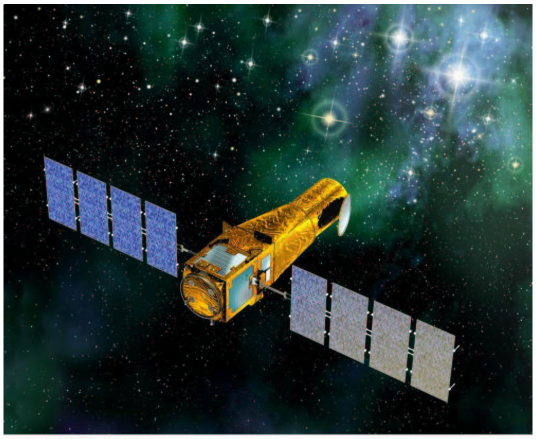

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Figure 1. *Artist view of the CoRoT telescope in space.*

The focal plane of CoRoT is divided into two sections of similar size. The field of view for planet search is 3.9 square degrees. It is located East (West) of the asteroseismology field during winter (summer resp.) observations.

For planet searches, a biprism is included in the light path. It allows to get chromatic information in the light curve on most of the targets (80%). Initially, it was foreseen that the non-chromatic characteristics of the planetary transits would be easily discriminated from the chromatic stellar variability with such a device. But as simulations show (see Section 4), it is now believed that the chromatic information will be more useful in discriminating planetary transits from the numerous background eclipsing binaries polluting the PSF of the main target. The extension of the star mini-spectrum on the CCD is about 15 to 30 arcsec (80-pixel area as average, with pixel size of 2.3 arcsec). A 3-colour light curve will then be obtained for 10,000 stars per field. For the 2,000 faintest stars, the colour information will not be available because of the low signal-to-noise ratio.

The photometry will be performed on board and downloaded to Earth every day. Only for approximately 40 stars per field will the corresponding small images be fully retrieved. In most cases, predefined photometric apertures will be used. The possibility to oversample the light curve by a factor of 16 (32 sec exposures) exists; it will be triggered on selected detected transit candidates.

CoRoT will be in operation during at least 2.5 years, starting mid-2006 with a launch from Baikonour by a Soyouz rocket. Each of the main stellar fields will be observed during 150 days without interruption. Every 6 months, the satellite must be rotated by 180°. A transition period of 20 to 30 days is then used for observations before a new long run starts. These exploratory runs will allow to enlarge the science objective ("additionnal science" call for proposals) and they will also permit the search for hot jupiters (i.e. the ones deep enough to be identified with 3 transit events only). In total, with the minimal observing period of 2.5 years, these are 60,000 stars that will be observed during 150 days and 120,000 stars during the shorter exploratory runs.

3. Fields and targets selection

CoRoT will observe within two cones, located around the Galactic plane at right ascensions 18h50 (so-called "summer fields") and 6h50 ("winter fields"). The asteroseismology main targets are situated at less than 10° from the cone center. A dozen of fields were preselected inside the two cones, taking into account constraints from both asteroseismology and planet searches. The criterion for planet search is a number of dwarf stars with V magnitude in the range 11 to 16, between 1000 and 5000 per square degree.

The first fields to be observed by CoRoT have been selected in May 2005. The planet search zones are located in the vicinity of the asteroseismology star HD181555 for the first summer field, and HD49933 and its neighbour HD49434 for the first winter field. Various preparatory observations are currently being performed for the targets located in both first fields to be observed.

Another field of specific interest for the planet searches is the one including the star HD52265. This bright solar-type star is one of the main targets for asteroseismology and in addition, it is known to harbour a planet (a =0.49 AU, $Msini$ =1.15 M_{Jup}, ecc =0.29, Butler et al. 2000). It is still plausible that a low-mass planet orbits the star at closest distance without being detected by radial-velocity surveys. And in any case, getting a photometric light curve of a sun-like star with a planet at the level of accuracy expected in the asteroseismology channel is of great interest. The acquisition rate is much higher than in the exoplanet field (1 sec exposures) and the photometric accuracy is expected 6 times better.

Systematic preparatory observations have been performed towards the CoRoT exoplanet fields. This represents a total of more than 100 square degrees, on which we carried multi-colour wide-band photometry, at Isaac Newton Telescope in La Palma. The objectives of such observations were to settle the astrometry for the positionning of CoRoT photometric masks, to get first estimates on the stellar spectral classification and to estimate the background contamination of individual targets. The catalogs are complete up to R magnitude of 18 to 20. Deeper observations were also carried at CFHT for a selection of fields and an extended program of multi-object spectroscopy is foreseen for the brightest targets. The full stellar database EXODAT is maintained at Laboratoire d'Astrophysique de Marseille and a subset of it is accessible to all CoRoT CoIs through the CNES facility *Corotsky*.

A preliminary stellar classification has been performed on the stars up to V= 16. It consists in the best comparison between the UBVri (INT) + JHK (2MASS) magnitudes and a library of templates for the spectral energy distribution of dwarf and giant stars (Hatziminaoglou et al. 2002, Moutou et al. in prep.). The infrared colours, less sensitive to interstellar reddening, are used to separate dwarfs and giants in a first place. This leads to 10 to 20% errors due to reddening effects. Statistical results of this preliminary classification are nevertheless in good agreement with the stellar population model of Besancon (Robin et al. 2003).

The stellar population of CoRoT exoplanet fields is biased towards F and G stars due to the limit in magnitude. In summer fields, in the direction of the centre of the Milky Way, the proportion of giants

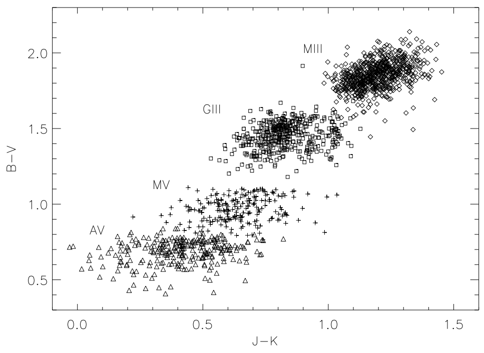

Figure 2. Results of stellar classification of one summer field presented in a colour-colour diagram. For clarity, only few classes are represented: from blue A dwarfs (triangles) to red M giants (diamonds). Summer fields have the largest counts of giants.

is large and fields are crowded. In winter fields, the star counts per square degree are lower, but the dwarf/giant ratio is more favourable (Figure 2). Very few M dwarfs are present as they evidently belong to the faintest targets, where the stellar classification is more tidious. Finally, our classification tool includes the templates for binary stars and according to the results, about 40% of CoRoT potential targets would be binaries. The spectroscopic validation of this first step is necessary; it is in progress for one winter field. Multi-object, medium-resolution spectra of more than 600 stars were obtained last February with VLT/GIRAFFE and their analysis will allow refining the large-scale spectral classification.

4. Performance tests

Another important aspect of the scientific preparation for CoRoT is the correct simulation of its performance in detecting planetary transits. After theoretical estimations have been obtained from a stellar population model and an ideal transit detectivity (Bordé et al 2003), a more realistic test had to be done. It started with the creation of 1000 CoRoT-like light curves. They include all instrumental noises that CoRoT will suffer (Auvergne et al. 2003), a variety of stellar micro-activity patterns, polluting events such as grazing eclipsing binaries and background variables, and a small number of planetary transits (Figure 3). These data were then distributed blindly to five teams which independently executed an optimized detrending and transit detection. The comparison of their results turned to be very interesting and the limit towards non-detected events allowed to extract an estimate of CoRoT performance in terms of the smallest detectable planetary radius.

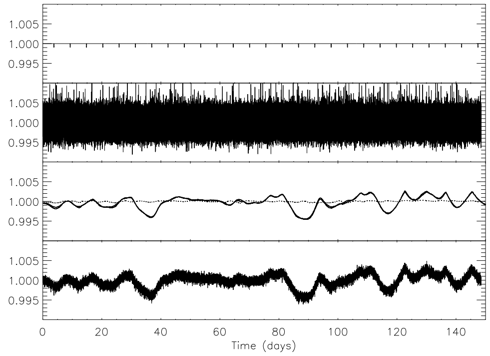

Figure 3. One of the light curves included in the performance blind test. From top to bottom: the short-period, low-depth planetary transits, the instrumental noises, the stellar micro-activity, and the final combined light curve.

The blind test is fully described in Moutou et al. (2005). Here we list the lessons learned from this performance exercise:

- Over the 20 hidden planetary transits, 9 were found by all teams, 5 by one or a few teams, and 7 by none.
- False alarms (9 announced) always occurred on different light curves, from one team to another. This means that we could in principle rely on a set of different detection teams to disentangle true candidates from false alarms, since the methods are not all sensitive to the same systematics in the data.
- The detrending technics based on harmonics fitting, coupled with the Box-fitting Least-Squared detection algorithm (Kovács et al. 2002) appeared to be the most performant transit detection tool, as it is sensitive to faint events without producing false alarm.
- Stellar micro-activity, as we simulated it, does not appear to be a source of errors in the detection. The amplitude of variations were in the range 0.01 to 4% but at frequencies well distinguishable

from planetary transit events. Similarly, highly variable background stars do not produce false detections of transits.

- As expected, it is in most cases difficult to disentangle a planetary transit from a background eclipsing binary from the light curve alone and all teams had false positive events (true stellar transits at a depth compatible with planetary transits).
- The smallest radius to be detected by CoRoT depends on the planetary orbital period and on the star radius. For a G-type star and period 10 days, if this test is realistic, it is about 2 Earth radii (see Figure 4 for more values). The detection niche of CoRoT thus appears to be "hot Neptune" planets. The recent discoveries of radial velocity programs tend to prove that their frequency could be much higher than the frequency of hot Jupiters (for recent reviews see Udry et al. and Fischer et al., this volume).

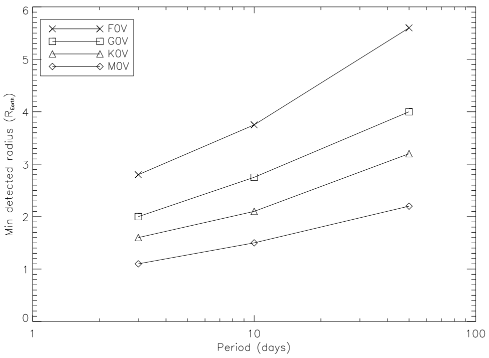

Figure 4. Smallest planetary radius detected by CoRoT following the performance test (Moutou et al. 2005) in Earth radii. It depends on the orbital period (number of transits in the light curve) and on the star type (transit depth). Note that M0 dwarfs are rare in our magnitude-limited sample.

5. Conclusion

In a year from this meeting, the CoRoT satellite should have been launched and started observations. The telescope is being integrated at Alcatel in Cannes and scientific preparation is still ongoing. Next steps will include: 1) another blind exercice to test our ability to use the colour information in CoRoT for the distinction of planetary transits and background eclipsing binaries or other "impostors", 2) the completion of the EXODAT data base at least in 7-colour photometry and the link to various observing data bases (e.g. BEST light curves, see Rauer et al. this volume), 3) more spectroscopic and radial-velocity observations in CoRoT fields to settle the spectral classification and search for spectroscopic binaries and hot Jupiters. All these tasks will allow a better scientific impact at the time the first CoRoT data will arrive.

CoRoT will discover many new planetary systems, especially if "hot Neptunes" are significantly more frequent than hot Jupiters. Combined with radial velocity follow-up observations, we will get an accurate estimate for the radius and the mass of the planet. It will then change our view of the exoplanetary science, for instance regarding the mass-radius diagram, of great importance for the theories of planetary internal structure. Statistics on the mass (or radius) versus orbital distance will give refined constraints on the formation and migration scenarii, with probably less observational bias. It should be emphasized that CoRoT transit candidates will require a large effort in follow-up observations, in order to 1) confirm the planetary origin of the transit, 2) measure the planet mass (radial-velocity), 3) get precise estimates for the star mass and radius (high S/N spectroscopy) and 4) get light curves for faint neighbours of a CoRoT target for eclipsing binary identification. Finally, the strategies developed for CoRoT will in many cases be also usable for the more ambitious transit mission Kepler (Borucki et al. 2003) in pursuing the way to terrestrial planets...

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RATS: Radial Velocities and Transit Search

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Abstract. RATS project, started in February 2005, is a collaboration between several INAF Observatories (Padova, Catania, Napoli, Palermo), the Astronomy Department and Physics Department of the University of Padova and ESA, devoted to search for extrasolar planets exploiting the transit photometric technique together with spectroscopic follow up strategy for reconnaissance of false alarms. The photometric survey will conduct with the 67/92 Schmidt Telescope of M.^{nt} Ekar equipped with the EDDINGTON frame transfer CCD. The spectroscopic follow up will be made using the echelle spectrograph (modified for fiber feeding) at the Copernico Telescope (1.82 m) at the same site. The aim of the project is twofold. The first aim is to find almost 10 (goal 20) new giant planets in 5 years and the second is to test the observing mode, the data reduction and data archiving of a transit search space mission.

1. Introduction

Since 1995, when the Jupiter-like planet 51 Peg b (Mayor & Queloz 1995) was discovered, identification and study of extrasolar planets are between the main goals of the international astronomical community. The final aim will be the discovery of other habitable planets and/or the confirmation of existence of life on them. Up to day 136 planetary systems (18 are multiple systems) for a total number of 160 planets are listed in the Extrasolar Planets Encyclopedia (vo.obspm.fr/exoplanetes/encyclo/catalog.php). Most of these planets have been discovered using the radial velocity method however a small fraction of them have been detected thanks to their transit in front of the host star. The detection of transit allows to unveil information on the radius, the mass and hence the density of the planet that cannot be obtained through the radial velocity analysis. Unfortunately the geometric probability of a transit is generally low. This means that to have a high probability of detecting a transit one has to sample a large number of stars. Furthermore the photometric accuracy of the observations has to be of the order of < 0.01 mag for giant planets transiting a solar type stars. Last but not least there are several phenomena that can mimic a planetary transit, e.g. eclipsing M dwarves, grazing eclipses, etc. (Brown 2003). This means that to disentangle these other effects each candidate transiting planet has to be observed spectroscopically. In this framework RATS project will have a duration of five years during which the detection of at least ten new extrasolar planets is expected.

2. Instrumentation

The project will use the telescopes of the Padua Astronomical Observatory at Cima Ekar. In particular the refurbished Schmidt telescope will be used for the wide field photometric survey while the 182 Copernico telescope equipped with a fiber fed echelle spectrograph will be used for the spectroscopic follow up. Wide field imaging will be performed using one of the CCDs manufactured by e2v for the EDDINGTON mission. The necessity for a spectroscopic follow up limits the range of magnitudes that we can sample during the survey. In fact, the limiting magnitude to reach a precision in the radial velocity measurements of 10 m/s using the echelle spectrograph at the Copernico Telescope in one hour exposure is about 14. On the other side the brighter magnitude is set by the observational strategy. A 15 seconds exposure (as foreseen for the Eddington mission) at the Schmidt of Cima Ekar taken in integrated light easily saturates a star with visual magnitude of 13. The solution adopted to avoid CCD saturation is to defocus the telescope. In order to guarantee high S/N ratio for the fainter magnitude and also an adequate number of stars per square degree with brightest magnitude, a limit value of $m_V = 9$ seems a good compromise.

3. Fields selection

A selection of the survey stellar field (Claudi et al., 2005) has been performed in order to maximize the number of solar – like dwarves taking into account the geographical position of the telescope and the defocussing of the telescope.

4. Observational Strategy

From stellar counts one finds that the number of stars per square degree with $9 \leq m_V \leq 14$ and spectral types F,G,K is about 200. With three fields selected and a CCD field of view of about 0.8° the total field of view covered by the survey would be 2.4°. This means that the total number of possible candidates is about 480 stars. The probability of having a hot Jupiter is about 1% while the probability of observing a hot Jupiter transit is 10% so in total the probability to observe a transit is 0.1%. This number has to be reduced by a factor that take into account the observing conditions (temporal coverage, duration of transit, period of transit etc). Using typical numbers for observing conditions at Cima Ekar we obtain a total number of detected transits during the whole survey of 2. This number can be increased only increasing the sky coverage of the survey by, for instance, a suitable number of adjacent pointings. In order to define this number we have to make a reasonable compromise between the number of adjacent pointings and the number of expected false alarm the recognition of which required several observing nights to the spectrograph. Assuming a spectrographic telescope usage of 40%, a compatible number of successive pointings is 7. An increase in the sky coverage by a factor of 7 will increase the number of detected transits per year to 2.8 and the total number to 14.

5. Conclusions

The new discoveries are expected to give some insight in the mechanism of planetary formations, in the properties of the environmental conditions, the hot Jupiter problem. Parallel science in the fields of stellar variability (pulsating stars, magnetic activity, eclipse variables etc) and spatial variability (minor bodies of the solar system) will be pursued.

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A "Planet Finder" instrument for the VLT

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Abstract. Direct detection and spectral characterization of extrasolar planets is one of the most exciting but also one of the most challenging area in modern astronomy. For the second generation instrumentation for the ESO VLT, we propose a "Planet Finder" instrument including a powerful extreme adaptive optics system, various coronagraphs, a differential imaging camera, an integral field spectrograph and a dual imaging polarimeter.

1. Introduction

The prime objective of a “Planet Finder” instrument for the VLT (VLT-PF) will be the discovery and study of new extra-solar giant planets orbiting stars by direct imaging of the circumstellar environment. The challenge consists in the very high contrast between the star and the planet, larger than 12.5 magnitudes (10^5 in flux), at very small angular separations, typically inside the seeing halo (Mouillet et al. 2001).

2. Scientific requirements

The key scientific requirements for the design of the VLT-PF include the capability to: i/ gain up to 5 magnitudes in contrast as compared to present instrumentation, allowing to detect planets with magnitudes up to 21 to 25 around bright nearby stars; ii/ explore the separation range from 0.1” to 3”, corresponding to planet distances from 0.5 to 150 AUs; iii/ study a large enough target sample (typically 500 targets), including low mass stars and young stars; iv/ perform spectral characterization with a typical resolving power R $\sim$ 30 to 50, in the range 0.96 to 2.32 μm; v/ perform polarimetric measurements.

3. Instrument concept

The main features of the proposed instrument are given below:

- A common path optics, transmitting the telescope beam via the various correcting elements of the adaptive optics system and via the coronagraphs to the adaptive optics wavefront sensor and to the three science channels.
- An extreme AO system which will deliver expected Strehl ratios of 90% in H band under reasonably good seeing conditions.
- A coronagraphic unit, including a classical Lyot device as well as one or two phase mask devices, allowing to reach very small separations between the host star and the planet candidates.
- An Infra-Red Dual Imaging Spectrograph dedicated to IR imaging in one or two simultaneous spectral bands or two orthogonal polarizations as well as low resolution long slit spectroscopy.
- An Integral Field Spectrograph, working in the IR and providing low spectral resolution (R $\sim$ 30) over a limited, 3” × 3”, field of view.

- A visible dual imaging polarimeter achieving polarimetric precisions better than 10^{-5}.

End-to-end simulations of the instrument show that contrasts between 10^5 and 10^6 can be reached depending of the characteristics of the host stars and the foreseen separation.

4. Project organization

The current development plan foresees a first light for VLT-PF by the spring of 2010. The consortium includes several European institutes, namely the Laboratoire d'Astrophysique de Grenoble (P.I. institute), the Laboratoire d'Astrophysique de Marseille, the Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique in Paris, ONERA, Geneva Observatory, the Max-Planck Institute for Astronomy in Heidelberg, Padova Observatory, the Institute of Astronomy of the Zurich College of Technology, the Astronomical Institute "Anton Pannekoek" of the University of Amsterdam, with contributions from Observatoire de Haute-Provence, Laboratoire Universitaire d'Astrophysique de Nice, Naples Observatory and ASTRON.

5. Conclusions

The proposed instrument, optimized for the very high contrast imaging around an extensive sample of stars, and its operation model including in particular a large public survey strongly supported by the building consortium will make possible the direct detection of a sample of giant planets in a variety of conditions. Such a return in the proposed schedule (first light in 2010) provides a timely and critical contribution to the highly competitive research on extra solar planets: formation, evolution and characterization. This observational approach provides specific information, nicely complementary to other observational techniques (radial velocities, transits, thermal IR, etc.) and absolutely necessary to the preparation of the foreseen next generation challenges.

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Jupiter-mass planet hunting in the galactic bulge by gravitational microlensing

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Abstract. In this work we propose the use of a Schmidt-Cassegrain telescope equipped with a CCD dedicated to the search for microlensing events. An event can reveal an Earth-mass planet near its star.

1. Introduction

Detection of extrasolar planets is becoming today one of the leading fields of astronomy. Since the discovery of the first exoplanet orbiting a normal star (Mayor & Queloz 1995), more than 155 planets have been confirmed. In particular, the interest of microlensing as a reliable technique for planet detection is growing very fast (Paresce & Renzini 1997). A planet orbiting a star modifies the gravitational lens profile of the star itself and creates a distortion of a background sources light curve: if the planet lies in the lensing zone of its parent star, regions able of high amplification are generated and a background source passing in the line of sight of the observer behind these regions exhibits a short-lived deviation or anomaly in its microlensing light curve. This particular lightcurve allows to extract some valuable data on the lensing objects, as the mass ratio between the star and its (possibly planetary) companion. This technique is also very sensitive to reveal Earth-mass planets near the host star and/or Jupiter-mass planets placed at average distances similar to those found in our own solar system (Udalski 2003). In April 2004, OGLE III team announced that they had found a

Jupiter-mass planet orbiting a red-dwarf star located 15,000 light-years away (Udalski et al. 2005). It was the first detection using this revolutionary technique and an elegant confirmation of Einstein's Theory of Relativity. For a microlensing event to occur, the intervening object must pass extremely close to the line of sight of the background star, and this happens very rarely. However, computerized monitoring of rich fields of the Milky Way has made feasible tracking these odd events. To elaborate a reasonable theory of planetary systems formation, new observations are needed, aiming the detection of exoplanets in a wide range of masses and distances. And it is exactly on this gap that our observational proposal takes place.

2. Discussion

For this work, we will use a Schmidt-Cassegrain telescope (D = 406mm; f/10) equipped with a good resolution imaging detector (CCD). The instrument will be dedicated to the search for microlensing events. The instrument has been equipped with auxiliary devices: a f/5 focal reducer to extend the field of view, an adaptive optics system (AO) and an automated filter wheel (for Cousin-Bessel photometry).

The detection of one single event requires to observe thousands of stars down to the limit magnitude, covering a relatively large area of the sky. Automated observing and real-time data-processing programs are developed in order to extract lensing events among all detected stellar variabilities. There is a very low probability to have a favorable alignment. We thus observe toward the galactic bulge. Of course, as we face very dense star fields here, difficulties to follow photometrically the tiny magnitude variations increased.

The instrument is being installed in a good quality astronomical site, near the small town of Itacuruba, northeast of Brazil, probably one of the driest places on this continental country. This site guarantees reasonable seeing averages, providing the necessary conditions to achieve accurate photometry measurements. Once the installation completed, the whole system will be commissioned. Our team hopes to obtain preliminary science results just a few months after commissioning. The telescope will be fully accessible over long uninterrupted periods of time. This is one of the most important factors to allow the successful completion of these time-consuming observations. The detection of microlensing events caused by suspected exoplanets constitutes the first step and requires subsequent spectroscopic investigation on larger telescopes.

3. Conclusions

Several space missions will be launched in the next years, for exoplanets search and related research fields (asteroseismology). However, this does not mean that ground-based observations are going to become obsolete. In the case of microlensing events search, ground-based observations are still extremely relevant, since this technique is actually the most promising to detect Earth-mass planets. Real-time alerting capability would also be of crucial importance: the earlier an event is observed, the better the characterization of the detected object. As mentioned before, this would allow spectra of the event to be taken throughout the short-lived anomaly in the star's light curve. Observations from only one site decreases the probability of successful planet detection. So partnership between research groups is highly recommendable. We are thus confident that the ongoing microlensing hunts will find more planets very soon, and that cooperation between research teams could be very helpful to confirm detections and allow a better events follow-up.

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The Karhunen-Loève Transform for bioastronomy and SETI

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Abstract. I present here a short description of the Karhunen-Loève Transform (KLT) used to detect very weak radio signals over narrow-band and wide-band extraterrestrial telecommunications out of the cosmic background noise. It appears that the KLT is more appropriate than the well known Fourier Transform (FT).

1. Introduction

Bioastronomy and SETI searches consist of the extraction of very weak radio signals out of the cosmic background noise. When SETI was born in 1959, it was natural to attempt this extraction by the Fourier Transform (FT) or since 1965 by the Fast Fourier Transform (FFT). SETI radio astronomers considered that a candidate extraterrestrial (ET) signal would necessarily be a sinusoidal carrier, i.e. a very narrow-band signal. Over such a narrow band, the background noise is necessarily white. Biraud (1983) argued that we only can make guesses about ETs telecommunication systems, and that the shifting trend on Earth was from narrow-band to wide-band telecommunications. Thus, a new transform was needed that could detect signals over both narrow and wide bands, regardless of the colored noise distribution over this finite bandwidth. Such a transform had actually been pointed out in 1946 by the mathematicians K. Karhunen and M. Loève, and is named KLT for them. Biraud (1983) suggested to look for the unknown in SETI by adopting the KLT rather than the FFT. The same was done, independently, by Dixon & Klein (1993) and Maccone (1990; 1994). One difficulty comes from the huge amount of computations (order of N^2) requested by the KLT. By the year 2000 the advent of programmable cards and efforts made by the Italian CNR SETI facilities at Medicina (Italy) made the KLT for SETI become a reality.

2. A Heuristic introduction to the KLT

The Karhunen-Loève Transform (KLT) is a rather recent mathematical tool capable of improving our understanding of physical phenomena, and it is superior to the classical Fourier Transform (FT). By adding random noise to a deterministic signal one obtains what is called a "noisy signal" or, in case the power of the signal is much less than the power of the noise "a signal buried into the noise". Since the (signal+noise) is a random function of the time, denoted hereafter by $X(t)$, one can describe it well by a statistical quantity called autocorrelation (or simply correlation), defined as the mean value of the product of the values of $X(t)$ at two different instants t_1 and t_2, and formally written $E\{X(t_1)X(t_2)\}$. This correlation, obviously symmetric in t_1 and t_2, can by described by a symmetric matrix. If one firstly seeks for the eigenvectors of the correlation, and then changes the reference frame over to this new set of vectors, the simplest possible description of the (signal+noise) is achieved. The next step is the rearranging of the eigenvalues in decreasing order of magnitude and, consequently, also the rearranging of the eigenvectors corresponding to each eigenvalue. It can be proved that there is no degeneracy. Also, all eigenvalues are positive, and so, once rearranged, they form a decreasing sequence whose first eigenvalue is the largest one, called the "dominant" eigenvalue. The new set of eigenvectors of the autocorrelation correspond to a new representation of the signal+noise and is just the direct KL Transform of the older signal+noise. So, the KLT is just a linear transformation of axes. Since the eigenvalues also are the variances of the zero-mean set of data, this really means that we are ordering the axes according to their decreasing order of statistical importance. In other words, the first eigen-axis is the one around which the variance is largest. The second eigen-axis is the one with second largest variance, and so on. In other words still, the more eigenvectors one takes into account, the more one "grabs" out of the statistically significant part of the data. Since the variances around the axes decrease as long as one takes into account more and more axes, one is really "grabbing" less and less statistically significant stuff. In fact, the KLT filtering simply consists in only taking a small, finite number of eigenvectors out of the set of all eigenvectors, and then declare the part of the data spanned by this smaller set of eigenvectors as the "statistical bulk", or the "signal", out of the original signal+noise. The "noise" is then automatically the cutaway part. Finally, in order to recover the signal out of the noise, one has simply to back-transform, or inverse KLT, the small set of data that has been regarded as the statistically "significant" part of the original (signal+noise).

3. KLT expansion and integral equation

The signal+noise $X(t)$ can be represented as the infinite series (called KLT expansion):

$$X(t) = \sum_{n=1}^{\infty} Z_n \, \phi_n(t) \tag{1}$$

where Z_n are just random variables (i.e. they are not stochastic processes) and the the $\phi_n(t)$ are just ordinary (i.e. deterministic) time functions. K. Karhunen and M. Loève proved, both at about the same time (1946) and independently, that the series (1) is convergent. Assuming that the signal+noise autocorrelation $E\{X(t_1)X(t_2)\}$ is a known function of t_1 and t_2, it can be proved that the functions $\phi_n(t)$ are the eigenfunctions of the correlation. In other words, the correlation is treated as an operator acting on the time variable, and the its eigenfunctions are the solutions to the integral equation:

$$\int_0^T E\{X(t_1)X(t_2)\} \, \phi_n(t_2) dt_2 = \lambda_n \, \phi_n(t_1) \tag{2}$$

These $\phi_n(t)$ form an orthonormal basis in the Hilbert space, and they actually are the best possible basis to describe the signal+noise, better than any classical Fourier basis. One can thus say that the KLT adapts itself to the shape of the signal+noise, whatever it is. Since the constants λ_n are both the (positive) eigenvalues and the variances of the random variables, the KL expansion, when truncated to keep only the first few terms, may be proved mathematically to be the best approximation to the full KL expansion in the mean square sense.

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Some elements for the history of astrobiology

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Abstract. Even being a young scientific field, astrobiology has an interesting and unexpected history. We study how the concept of astrobiology has been progressively defined, and its meaning precised. Studies of astrobiology, such as search for the detection of vegetation on the planet Mars, were already carried out several decades ago. The problematic and the method of some studies sometimes appear astonishingly similar to contemporary ones.

1. Introduction

The quest for extraterrestrial life exists for a very long time and numerous references about this subject, from Greek philosophers to eighteen century scientists, can be found for example in Dick (1982). More recently, astrobiology corresponds to the search for the life in Universe, by associating astronomical and biological studies. This word is not generally used for the research of communication with extraterrestrial civilizations. Words "astrobiology", "bioastronomy", "exobiology" and more rarely "cosmobiology" are generally used with the same meaning (unfortunately, the word "cosmobiology" is also used by astrologers). Actually, in the domain of science, it is very rare that several words exist with the same meaning. The fact that three or four existing words designate one science field is an indication of its multiple origins, in various epochs and in various places. We use here the word "astrobiology", which is the most frequently used. Astrobiology is generally considered as a young science, but actually it is older than often believed. Many studies were carried out seldom at a very high level, and they were forgotten later. It is quite interesting to discover them again.

2. Some early studies

The problematic similar to the one used today for the research of extraterrestrial life exists in fact for a long time, and some old papers can be found with a surprisingly modern method of reasoning. We give here some striking examples. A study about life in the Universe in a French journal of popular science as early as 1935 (Sternfeld 1935) questioned over what the origin of life could be, detailed the extreme forms of life then known, and reviewed physical conditions favourable or not to life in the various planets. The word "astrobiology" was not used, but the method was very similar to the one used today. As early as 1941 the word "astrobiology" was defined by Lafleur as "the consideration of life in the universe elsewhere than on Earth" in a paper entitled "astrobiology". En 1945, Tikhov, a Russian astronomer, created the word "astrobotany" that he used for the search of a vegetation on Mars. He used at the same time the word "astrobiology" and a little later the word "cosmobiology". He created a section of astrobotany in Alma-Ata (Kazakhstan) to search and study the behavior and the radiation of plants growing in conditions as similar as possible to Mars conditions and which spectra correspond to Mars observations (see, for example Briot, Schneider, & Arnold 2004). However, the section of Astrobotany of Alma-Ata was dismantled after the death of Tikhov in 1960. The first American symposium in astrobiology was held in 1957 (Wilson, and following papers, 1958), but the sense of the word "astrobiology" was not as restricted as its present meaning, and the papers of this symposium concerned not only life in other celestial bodies, but also all the problems common to astronomy and biology, among them, for example, physiological problems of astronomical observations. In 1965 Mamikunian attributed to Joshua Lederberg the creation of the word "exobiology".

3. Importance of astrobiology in the scientific literature along to various epochs

As to estimate more accurately the importance of astrobiology and the importance which was attached to this science in different times, we used books of astronomical bibliography edited at the same times. In the volumes of Astronomische Jahresbericht, the word "astrobiology" appeared as a keyword as early as 1953, but only this year, whereas the word "astrobotany" appeared as a keyword in 1949, and again from 1951 to 1954. Papers about astrobotany were mostly written by Tikhov or by scientists of the section of astrobotany in Alma-Ata. The phrase "Leben in Kosmos" i.e. "Life in Universe", was a keyword as early as 1949, but these papers were classified under the heading "Schriften allgemeiner Art" which corresponds to "Miscellanea". At the end of the forties, and during the fifties, the papers concerning this subject were still rare but became slowly more and more numerous. Many papers came from Soviet Union or close countries. Let us note that life and vegetation on Mars was the subject of many papers and their number decreased when it appeared more and more clearly that there is no vegetation on Mars. In 1959, item "Leben im Universe" gained some importance and became a rubric, instead of being classified indiscriminately in "Schriften allgemeiner Art" like "Astronomy and Philately" for example. In 1969, Astronomische Jahresbericht were replaced by Astronomy and Astrophysics Abstracts, which lasted until the year 2000. Surprisingly, papers corresponding to the search of extraterrestrial life were debased : they were classified in "Miscellanea". The keywords "Extraterrestrial intelligence" and "Extraterrestrial life" could be found in the Author and Subject Indexes volumes. None of the words "astrobiology", "bioastronomy", or "exobiology" appeared among the keywords, even in the last volume of Astronomy and Astrophysics Abstracts in 2000. Astrobiology was really treated as a marginal science. However papers about extraterrestrial life became more and more numerous and often classified as well under scientific headers.

4. Conclusions

Astrobiology is not a science as young as generally thought. It is old enough to have its own history. However, this history is not linear and because of that appears even more interesting. The present paper is a preliminary study and will be followed by a more detailed study. We have to emphasize that the real and much more exciting history of astrobiology will really begin when we shall get the answer to the question : is there some life elsewhere in the Universe ?

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