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From brown dwarfs to exo-planets: ideas for a study of sub-stellar objects based on mid-infrared photometry at Dome-C

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Abstract. The installation of the InfraRed Antarctic Italian Telescope (IRAIT) at Dome-C will allow astronomical observations that could not be performed elsewhere. We consider here the search of cool objects around nearby stars. Starting from the importance of their emission at long wavelengths, we propose a purely photometric method to infer their fundamental properties such as radius and temperature. The method proves itself powerful also in disentangling the presence of planets from stellar variability. We analyze its feasibility and conclude that the best results are obtained at mid-infrared wavelengths. Therefore, we propose it as a science case for a future antarctic mid-infrared camera mounted at the focus of the IRAIT telescope.

Key words. sub-stellar objects - mid-infrared - Antarctica

1. Introduction

In the framework of the IRAIT collaboration for an infrared telescope on the antarctic plateau (Busso et al. 2002), we have started the study of the scientific applications that could be performed by fully exploiting its characteristics. Among these, we want to discuss in this paper the possibility to study the properties of sub-stellar objects around nearby stars with mid-infrared photometric measurements. This is indeed one of the most exciting scientific challenges of the current epoch. After the discovery of the first Jupiter-sized object around the sun-like star 51-Peg (Mayor & Queloz 1995), more than 100 extrasolar planets have been found (for a complete list, see *http://obswww.unige.ch/exoplanets*). In almost all cases, these planets are Jupiter-mass objects in very close orbits around their parent stars, sometimes closer than Mercury to the Sun, with very short orbital periods. While the large planetary masses are easily explained in terms of observational limits, which prevent us from detecting planets significantly smaller than Jupiter, the orbital parameters appear in contrast with the accepted theories of the formation of planetary systems, and new hypotheses, such as planet migration inward from the outer regions of the sys-

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tems, must be taken into account (Masset & Papaloizou 2003).

In order to test such hypotheses and to understand how such star-planet configurations may be formed, it is necessary first of all to increase their statistical sample: for this purpose, large optical surveys are currently working to detect new extrasolar planet candidates, such as the CORALIE network (Queloz et al. 2000). A second step should consist in the direct analysis of their physical properties: this task requires high-resolution far-infrared spectroscopy and is planned for future space-borne missions (e.g. the NASA's Terrestrial Planet Finder (Beichman 2001)). Purely photometric measurements can provide only indirect information about some physical parameters of the planet, as in the case of planetary transits, where the planet's radius can be inferred: on the other hand, they are much less demanding in terms of instrumental complexity and telescope size. Recently, the potential of infrared photometric observations of extrasolar planets has already been addressed by Richardson et al. (2000), which remarked the importance of the emission of cool objects at long wavelengths and computed infrared lightcurves for an extrasolar planetary transit in the range $2-5\ \mu m$. Based on the same fundamental assumption, we propose here a method to infer the fundamental properties of cool objects orbiting around stars, such as radius, temperature and chemical composition, based only on mid-infrared photometry.

In section 2 we shortly revise the methods of detection of extrasolar planets and their limits; the method we propose is explained in section 3; finally, in sections 4 and 5 we show that this method is particularly powerful in the mid-infrared and can be achieved only from an Antarctic observing site. We propose therefore this method as a science case for the mid-infrared camera that will be mounted at the focus of the IRAIT telescope (Busso et al. 2002).

2. Methods for detection and study of exo-planets and their limits

A direct detection of planets orbiting around distant stars is still beyond the observational limits with the present generation telescopes: large improvements are expected from space observations (NGST) and adaptive-optics-aided interferometry with very-large telescopes (VLTI, KECK, LBT). Extrasolar planets are normally detected in two ways: 1) via the perturbation they induce in the position of the parent star, that is recorded as a Doppler shift of the stellar lines; 2) via the transit behind the stellar disk, which causes a recordable magnitude fluctuation. The spectroscopic method allows only to estimate the orbital period of the planet and to put a lower limit on its mass; when also a transit is detected, the limit on its mass can be significantly constrained, its radius can be derived and, by using suitable atmospheric models (as that used in the case of HD209458, (Guillot et al. 1996)), a raw indication about its effective temperature can be inferred. Direct information about the planet's composition and temperature could be inferred only from spectroscopic observations of the transit, when the planetary spectrum is superimposed to the stellar one; this has been attempted in the case of HD209458, suggesting the presence of sodium in the planetary atmosphere (Rauer et al. 2000).

However, besides the "geometrical" probability of detecting a planet with the two methods (e.g. see Perryman (2000)), they suffer severe limitations due to the existence of microvariability phenomena on the surface of the parent star: indeed, stellar oscillations, spots, magnetic phenomena, via the stellar rotation, may simulate a Doppler perturbation or even the transit of a planetary companion. For this reason, very long observing runs are required in order to disentangle between the orbital influence of a planet and more or less periodic phenomena on the stellar surface, together with a careful analysis of the observable effect of a planet compared with the various kinds of variability. As a matter of fact, out of 105 extrasolar planets so far discovered, only one has been detected by observing its transit across the disk of the star HD209458 (Charbonneau et al. 2000): the others were only suggested by Doppler observations, and the identification of many of them is still under debate.

3. The Transit-Occultation Method (TOM)

The method we propose here is based on the assumption that the emission from a "cool" planet, that is a negligible fraction of the stellar one in the visible, becomes important at longer wavelengths. Indeed, a photometric fluctuation should be normally expected both when the planet passes behind its parent star, what we call a "transit", and beyond it, what we call an "occultation". We propose therefore to search for both occultations and transits, and we show that this method (that we call the Transit-Occultation Method - TOM) is as simple as powerful in getting information about the physical properties of the planet. Consider the simple model of figure 1, where a planet of disk area A_P and intensity I_P is orbiting around a star whose intensity is I_S and the disk area is A_S: neglecting the starlight reflected by the planet, the overall luminosity is the following in the three cases of star+planet (SP), transit (T) and occultation (O):

$$E_T = (A_S - A_P)I_S + A_P I_P \quad (1)$$

$$E_{SP} = A_S I_S + A_P I_P \quad (2)$$

$$E_O = A_S I_S \quad (3)$$

The relative fluctuations for the T and O cases are therefore

$$\Delta_T = \frac{E_T - E_{SP}}{E_{SP}} = -\frac{A_P I_S}{A_S I_S + A_P I_P} \quad (4)$$

$$\Delta_O = \frac{E_O - E_{SP}}{E_{SP}} = -\frac{A_P I_P}{A_S I_S + A_P I_P} \quad (5)$$

Taking the ratio of the previous two equations, we obtain the following expression,

$$\frac{\Delta_O}{\Delta_T} = \frac{I_P}{I_S} \quad (6)$$

which is independent on the stellar and planetary radii and on the orbital parameters and carries information about the effective temperatures and chemical compositions of the star and the planet. **Therefore, knowing these parameters for the star allows us to infer the temperature of the planet and possibly (when comparing data in different photometric bands) strong indications about its raw chemical composition.** This method proves itself powerful also in discriminating between the presence of a planet and variability phenomena: the fluctuations due to the transit and the occultation, indeed, must be opposite in phase, a behaviour that every variability phenomenon cannot have; moreover, by detecting both the transit and the occultation we can reduce by 50% the time required for the identification of a planet orbiting around the star.

4. Mid-infrared observation advantages

In order to apply the TOM, we must check its feasibility. For this reason, a preliminary estimation of the expected photometric fluctuations has been performed by considering the classical wide-band filters from the optical to the mid-infrared region of the spectrum. The results are shown in figure 2 for a variety of cases, taking into account the combinations of a star whose T_{eff} is 6000, 4000, 3500 and 3000 K and a planet whose radius and temperature are [70000 Km,125 K (Jupiter)] and [89000 Km, 1200 K (HD209458b)]. We can see that while a planetary transit produces nearly the same photometric fluctuation at every wavelength (figure 2, *left*), the effect of a planetary occultation is dramatically different (figure 2, *right*): this happens because the term Δ_T is dominated by the ra-

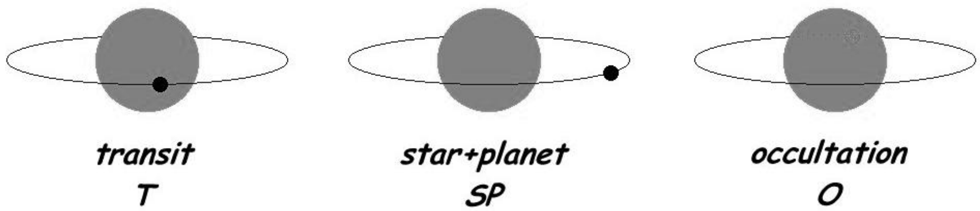

Fig. 1. Scheme of the simple model used to develop the Transit- Occultation Method (TOM)

tio of the radii R_P/R_S, while the term Δ_O depends only on the intensity ratio. The photometric fluctuation of a planetary occultation is very far from being detectable at optical wavelengths, but it could be observable in the M, N and Q bands, i.e. in the mid-infrared region of the spectrum. The amplitude of the fluctuation depends on the stellar and planetary radii and on the difference of their effective temperatures, and increases rapidly as this difference decreases (for cold Jupiters the magnitude fluctuation is still negligible, as shown in figure 2, *right*); the TOM is thus particularly suitable in searching and studying planets around M dwarfs. This is of fundamental importance, because M dwarfs are too faint in the optical bands to allow a reliable search for planets (both with transit observation and with Doppler techniques) and, on the other hand, they compose 80% of the main sequence stars: therefore the research of planetary companions around M dwarfs is crucial to increase and study the statistical sample of planetary systems.

5. The absolute need for an Antarctic observing site

The application of the TOM requires of course a great photometric accuracy and special acquisition and reduction data techniques. On the other hand, mid-infrared observations are heavily affected by overall background emission and only complex observing procedures allow to achieve small photometric errors: currently, the main problem in performing such observations from temperate sites is still related to the low transmission and the poor stability of the atmosphere. For its significantly greater atmospheric transmission, much lower sky emission and particularly stable atmosphere at mid-infrared wavelengths (Chamberlain et al. 2000), the Antarctic Plateau represents the best ground-based observing site.

Therefore, for our purposes, this particular site is absolutely mandatory.

Antarctica provides also several advantages over a search of exoplanets conducted at lower latitudes: at -75^o latitude, all stars with $\delta < -15^o$ never rise and set, and can be observed without interruption. Also the excursion in the elevation angle is much smaller and therefore also the noise caused by the varying extinction will be strongly reduced. An experiment exploiting these properties to search for planetary transits is already working at South Pole (*Vulcan South*, see Borucki et al. (2001)): however, this research is performed at optical wavelengths and the stars are observed only during the three month-long winter nights. At mid-infrared wavelengths, on the contrary, there is not a significant difference between day and night and the stars can really be observed continuously.

6. Conclusions

In this paper we have discussed the possibility to study the fundamental properties of cool sub-stellar objects with simple

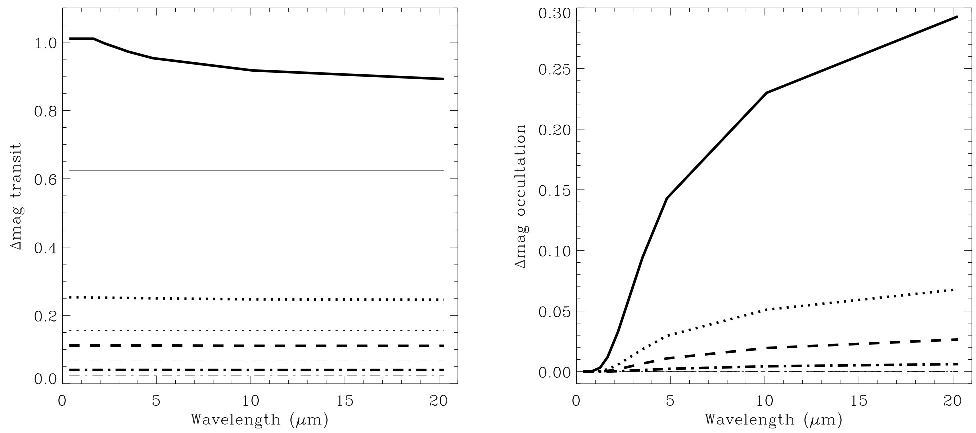

Fig. 2. Magnitude fluctuations for a planetary transit (*left*) and a planetary occulation (*right*). Stellar temperatures are indicated by the line type (*solid: 3000 K, dotted: 3500 K, dashed: 4000 K, dash-and-dot: 6000 K*), while its thickness refers to the planet (*thin: Jupiter, thick: HD209458b*)

photometric measurements at mid-infrared wavelengths. After having examined the classical detection methods and their limits, we have remarked the importance of the emission of such objects at long wavelengths and we have developed a method which permits:

1. to get information about the orbital parameters, radius, temperature and possibly raw chemical composition of the planet;
2. to disentangle between planetary perturbations and intrinsic stellar variability;
3. to reduce of 50% the time required for the identification of a planet.

The method has proven itself very powerful when applied to mid-infrared measurements; moreover, given the high photometric accuracy required, we examined the properties of the antarctic plateau and concluded that such a research can be conducted only from there. In conclusion, we suggest the application of this method as a science case for the mid-infrared camera that will be mounted at the focus of the IRAIT telescope on the antarctic plateau.

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References

Beichman, C., 2001 : AAS Meeting 198, 51.12
Borucki, W. J., et al., 2001 : PASP, 113, 439
Busso, M. et al., 2002: PASA, 19, 306
Chamberlain, M. A., et al., 2000: ApJ, 535, 501
Charbonneau, D. et al., 2000 : ApJ, 529, L45
Guillot, T. et al., 1996 : ApJ, 459, L35
Masset, F. S., Papaloizou, J. C. B., 2003: ApJ, 588, 494
Mayor, M., Queloz, D., 1995: Nature, 378, 355
Perryman, M.A. C., 2000: Rep. Prog. Phys., 63, 1209
Queloz, D. et al., 2000: A&A, 354, 99
Rauer, H. et al., 2000: AAS DPS meeting 32, 32.09

Richardson, L. J., Deming, D., Goukenleuque, C., 2000: in Planetary Systems in the Universe, International Astronomical Union. Symposium no. 202. Manchester, England, August 2000