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Interferometric spectrophotometry of Pegasides: APISD the Antarctic Plateau Interferometer Science Demonstrator

V. Coudé du Foresto[1], M. Swain[2], J. Schneider[3] and F. Allard[4]

[1] LESIA – Observatoire de Paris, 5 place Jules Janssen, 92190 Meudon, France
e-mail: `vincent.foresto@obspm.fr`
[2] JPL, 4800 Oak Grove Dr., Pasadena CA 91109, USA
[3] LUTH – Observatoire de Paris, 5 place Jules Janssen, 92190 Meudon, France
[4] CRAL, 46 allée d'Italie, 69364 Lyon Cedex 07, France

Abstract. We propose a science demonstrator for the Antarctic Plateau Interferometer. It is a comparatively much simpler system than API but dedicated to the goal of obtaining the first low-resolution spectra in the thermal infrared of a few "hot Jupiter" type exoplanets. It would provide a unique platform to acquire operational experience on antarctic stellar interferometry, and build up an extensive database on the relevant site properties, as a preparation for API.

Key words. Exoplanets – Interferometry – Thermal infrared

1. Introduction

The Antarctic Plateau Interferometer (Swain et al., these Proceedings) will eventually be a complete interferometric facility at the Concordia station, dedicated mostly to the detection and characterization of extrasolar planets, using different advanced techniques such as differential phase, nulling, astrometry etc.... It will benefit from the exceptional properties of Dome C: coldness (low thermal emission), dryness (infrared transparency), anticipated weak and slow night time atmospheric turbulence (high performance for adaptive optical systems) with a very large isoplanetic angle (availability of bright reference stars), the combination of all the above making it the most space-like environment on Earth. In preparation to API, and as a way to demonstrate the unique qualities of the site for long baseline stellar interferometry in the thermal infrared, it appears necessary to build and operate a simple interferometer for at least one winter over. This would be used to accumulate a large database on the atmospheric turbulence parameters at Concordia and validate the implementation, commissionning and operational concepts for an antarctic stellar interferometer. We argue that even a simple interferometer, provided that it is well optimized for its science objectives, can provide significant results in extrasolar planet research.

Send offprint requests to: V. Coudé du Foresto
Correspondence to: vincent.foresto@obspm.fr

2. APISD definition

In a nutshell, the API Science Demonstrator (APISD) can be defined as *the simplest form of fully operational interferometer that can provide a unique (though focused) science result in the field of exoplanet study*. Three important points need to be stressed here:

- *Fully operational*: APISD is meant to demonstrate operational concepts (fully automated observing, remote maintenance etc…) and science potential, not a specific technology (all of the technology needed for API is supposed to be already available in the labs anyway). The only way to measure several atmospheric parameters relevant for long baseline interferometry, such as the outer scale of turbulence or the power spectrum of its piston mode (fringe jitter or random OPD fluctuations), is to use a two-pupil interferometer;
- *Simplicity*: in a remote site with limited support, simplicity is of paramount importance to ensure a quick success of the operation. It also makes it possible to concentrate the efforts on operational and scientific aspects, as opposed to engineering issues;
- *Focused science*: versatility (different observing modes, wavebands etc…) is a strong complexity driver for stellar interferometers. By pursuing a single and adequately chosen scientific objective it is possible to keep complexity at a strict minimum.

¿From all of the above it appears that the API Science Demonstrator has to be *single-field* (only one field of view, no use of off-axis reference star), *single-mode* (field of view limited to one Airy disk of the individual collectors), with *naturally diffraction-limited collectors* (individual pupil size smaller or equivalent Fried's parameter r_0 so that adaptive optics can be limited to tip-tilt correction and piston compensation). Such a platform is ideal for optimized on-axis V^2 science, precisely measuring the squared modulus of the coherence factor for the target sources, and needs no sophisticated metrology. Existing interferometers have been routinely performing mostly V^2 observations in the last decade, while prototyping more complex operation (such as, for example, astrometry, phase closure or nulling). This observing mode is mature, can provide high accuracy measurements (within a few parts in a thousand when using spatial filtering Coudé du Foresto et al. (1998), with room for improvement after fringe jitter stabilization) and even though it does not provide phase information (and ultimately the possibility to reconstruct images) it is well adapted to address scientific problems where useful information can be extracted from a small number of parameters. A typical example of such a problem is the characterization of binary star systems. In a snapshot observation, the binary can be described by only three parameters: separation, position angle and contrast ratio. A full orbit can be characterized by its inclination and orientation, maximum elongation, orbital period, excentricity, and ephemeris, with the last three parameters being know from radial velocity techniques in the case of spectroscopic binaries.

3. Science objectives

Giant planets are known to orbit in the near proximity ($\simeq 0.05\,\mathrm{AU}$) of a small percentage of nearby solar-type stars (such as 51 Peg, hence their nickname "Pegasides" Marcy et al. (2000)). Their existence is inferred from indirect observations with radial velocity techniques, which provide firm information on orbital parameters only (maximum elongation, period, excentricity and ephemeris). They revolve around a quasi-circular orbit within a few days. Their mass can be hinted at through the $M \sin i$ product, where i is the unknown orbital inclination with respect to the plane of the sky. They are expected to be hot because of their proximity to the parent star.

A rudimentary model, assuming the planet to be a grey body, gives their equilibrium temperature T_{eq}:

$$T_{eq} = \frac{T_\star}{\sqrt{2}}(1-A)^{\frac{1}{4}}(\frac{R_\star}{a})^{\frac{1}{2}} \qquad (1)$$

where $T_\star$ is the temperature of the parent star, $R_\star$ its radius, a the orbital radius and A the planet albedo. Beyond this, however, the physical nature of these objects remains elusive, even though since their discovery considerable theoretical work has been undertaken to model their structure and atmosphere. Only in one special case (the transit in edge-on system HD 209458) could an observational signature of the atmosphere be detected Charbonneau et al. (2002); Vidal-Madjar et al. (2003).

A direct spectrophotometric measurement of a Pegaside atmosphere would therefore represent a major breakthrough in extrasolar planet studies. Even low-resolution ($R = 20$) spectra in the 3 to 4 μm region (L band) would enable the detection, for example, of potential NH_3 bands and provide significant information on its constituents and the amount of thermalization in the irradiated atmosphere. Table 1 shows three very southern solar-type stars known to have a nearby planetary companion, which are observable from a site at -75 deg latitude. They are all fairly bright infrared sources with an L-band magnitude ranging between 5 and 6. With physical separations of $\simeq 0.04$ AU at 29–37 pc, the binary pairs separations range from 1.0 to 1.6 mas, an angular resolution which can be achieved only by long baseline interferometry.

¿From an observational point of view, a planetary system behaves like a spectroscopic binary: the visibility function is made of an Airy pattern corresponding to a primary, on which is superposed a visibility modulation which is the signature of the secondary. The amplitude of the modulation is twice the brightness ratio between the secondary and the primary. The main challenge, then, resides in the very large contrast between the solar-type star and its planetary companion. If the planet behaved like a greybody at equilibrium temperature, the contrast ratio would monotonously decrease with increasing wavelength. Event though the reality is probably more complex, it still suggests that the signature of the companion becomes stronger as the wavelength increases, and points towards the thermal infrared as the waveband of choice. In the infrared L band, for example, the contrast could be as low as 10^3 on the substellar point Allard et al. (2003). The drive for long wavelengths has to be mitigated, however, with the proportional increase of baseline in order to achieve the same spatial resolution, and the decrease of sensitivity when background shot noise becomes dominant.

4. Instrumental concept

The proposed instrumental concept for APISD is a pair of fully automated, 60 cm telescopes located on fixed stations, operating in the $\lambda = 2.8 - 4.2\,\mu$m range (extended L band), which corresponds to a transparency window at Dome C Hidas et al. (2000). The distance between the two telescopes is established so as to provide adequate angular separation ($\lambda/B = 1.5$ mas at $\lambda = 3.5\,\mu$m) for a $B = 500$ m baseline. The environment of Concordia provides an almost unlimited supply of flat real estate for very long baselines. Telescope optics are streamlined for on-axis, single-mode operation with a field of view corresponding to one Airy disk. Active optical systems are limited to on-axis fringe tracking for phase stabilization and tip-tilt correction at the telescopes which, given the large expected value of r_0 in the L band, will provide quasi diffraction limited imaging. The beams are transferred by free air propagation to the delay line and then the beam combining station, which contains a spatial filtering unit and a two-way beam combiner with a low-resolution ($R = 20$) spectrograph.

A key for a fast track implementation of APISD is that all of the elements de-

Star	$M \sin i$ (M_{Jup})	P (days)	a (AU)	a (mas)	T_{eq} (K)
HD75289 (G0 V – 29 pc)	0.98	3.09	0.040	1.59	1245
HD179949 (F8 V – 27 pc)	0.42	3.51	0.046	1.48	1160
HD73256 (G8/K0 V – 37 pc	1.85	2.55	0.037	1.01	1070

Table 1. Three very southern stars (declination < -20 deg) with nearby planetary companions. The effective temperature of the planet is based on a grey body of 0.5 albedo.

Telescope diameter	Location	SNR	Noise sources
0.6 m	Dome C	$1.7\,\sigma$	47% thermal, 40% detector, 13% shot noise
1.8 m	Temperate	$1.9\,\sigma$	100% thermal
1.8 m	Dome C	$42\,\sigma$	4% thermal, 3% detector, 92% shot noise

Table 2. Instantaneous (within one coherence time of 500 ms) signal to noise ratio on the detection of a companion 1000 times fainter than a $L = 5$ primary. Assumptions are: spectral resolution 200 nm, overall opticall transmission 1 %, overall emissivity 50 %, temperature: 293 K (temperate site) or 220 K (Dome C), detector: 5e$^-$ readout noise, 60 % quantum efficiency, interferometer point source response: 90 %.

scribed above (including their associated software) already exist and can be either duplicated or adapted for Antarctic operation. The beam collectors, transfer optics, active systems and delay lines are similar to those in use on the Palomar Testbed Interferometer Colavita et al. (1999), while a high precision beam combiner using single-mode fibers in the L band has already been demonstrated in the TISIS experiment Mennesson et al. (1999). Therefore, the development effort can be concentrated on integration and operational aspects rather than conceptual designs. The expected performance of such a platform is summarized in the first line of Table 2: the detectivity is as good as what can be obtained with 1.8 m telescopes on a temperate site, thanks to the very low thermal emission of the sky and the optical train at Dome C.

5. Conclusion

The intrinsic qualities of the Dome C site, which is probably the best ground-based location for thermal infrared interferometry, make it possible to consider the implementation in a short time frame of a simplified, dedicated interferometer that would still produce unique results in extrasolar planet science. This early platform, using proven solutions in a novel environment, would demonstrate the scientific value of the Concordia station in stellar interferometry and open the way to the Antarctic Plateau Interferometer.

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