Nulling interferometry: performance comparison between the PEGASE space mission and ground-based sites

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1. Introduction

Nulling interferometry is the core technique of future life-finding space missions such as ESA's **Darwin** and NASA's Terrestrial Planet Finder (**TPF**). Observing in the thermal infrared, these missions could enable the spectroscopic characterisation of the atmosphere of habitable extrasolar planets orbiting nearby main sequence stars. This ability to study distant planets strongly depends on the density of exozodiacal clouds around the stars which can overwhelm the planetary signal. Assessing the level of circumstellar dust around nearby main sequence stars is by consequent a necessary pre-requisite to prepare the observing program of Darwin/TPF but also very useful to get information about the planetary system formation. Several ground-based concepts have already been considered in that respect; **GENIE** [3], a nulling instrument for the VLTI and **ALADDIN**, a nulling interferometer project for Dome C, on the high Antarctic plateau [2]. Recent results [2] show that, using 1-m collectors, ALADDIN would have an improved sensitivity with respect to GENIE working on 8-m telescopes, provided that it is placed above the turbulence boundary layer (about 30m at Dome C). ALADDIN would enable the detection of circumstellar discs 20 times as dense as our local zodiacal cloud for typical Darwin/TPF targets in an integration time of few hours. The purpose of this poster is to present the results to be expected from PEGASE [5], a space nulling interferometer dedicated to the study of extrasolar giant planets, and compare them to the expected performances of ground-based instruments.

Fig. 1: ALADDIN and PEGASE concepts

	GENIE-AT	GENIE-UT	ALADDIN	PEGASE
Baselines [m]	16-128	47-130	4-30	50-500
Telescope diameter [m]	1.8	8	1	0.4
Science waveband [μm]	3.5-4.1	3.5-4.1	3.1-4.1	2.5-5
Fringe sensing waveband [μm]	1.5-1.8	1.5-1.8	2.0-2.4	1.25-1.75
Tip-tilt sensing waveband [μm]	1.15-1.40	1.15-1.40	1.15-1-3	0.75-1.25

Tab. 1: Main instrumental parameters

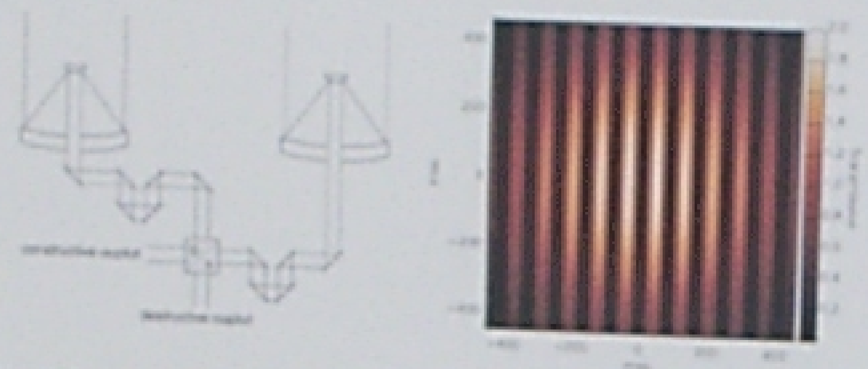

Fig. 1: Left: Beam-combining system of a two-telescope nulling interferometer. A destructive interference is produced on a line of sight by applying an achromatic π phase shift to one of the two input beams. **Right:** Monochromatic transmission map representing the parts of the field that are transmitted and those that are blocked by the interference process.

2. The instrumental concepts

- **GENIE** (Ground-based European Nulling Interferometer Experiment - [3]) is a nulling interferometer concept which has been studied by ESA at the phase A level. It is conceived as a focal instrument for the VLTI and dedicated mainly to the study of the exozodiacal dust around nearby solar type stars.
- **ALADDIN** (Antarctic L-band Astrophysics Discovery Demonstrator for Interferometric Nulling - [2]) is a nulling interferometer concept consisting in a 40 m long rotating truss installed on top of a 30 m tower, on which are placed two moveable 1-m diameter siderostats.
- **PEGASE** [4] is a two-aperture near-infrared (2.5-5 μm) interferometer formed of three free flying spacecrafts planned orbit at the Lagrange point L2. The main scientific goal is the spectroscopy of hot extrasolar giant planets and brown dwarfs. It has been proposed in the framework of the 2004 call for scientific proposals from Centre National d'Etudes Spatiales (CNES) for its formation flying demonstrator mission. A Phase 0 study was performed by CNES in 2005 [4].

3. Method and control loop performance

The GENIEsim software [2], used for the GENIE and ALADDIN studies, has been adapted to enable the simulation of a space-based nulling interferometer. In particular, the expected vibrations of the telescopes along the optical path in the space environment have been implemented (a stability level of 1 μm/s has been considered [4]) and all atmospheric effects disabled. Results are reported in **Tab. 2** and show the improvement of the nulling performance of PEGASE with respect to ALADDIN and GENIE.

	GENIE-UT	ALADDIN	PEGASE	Goal
Piston	17 nm-20 kHz	14 nm-3 kHz	5 nm-200 Hz	< 4nm
Inter-band disp.	17 nm-200 Hz	7.0 nm-0 kHz	0 nm-0 kHz	< 4nm
Intra-band disp.	4.1 nm-200 Hz	7.4 nm-0 Hz	0 nm-0 kHz	< 4nm
Tip-tilt	11 mas-1 kHz	7 mas-1 kHz	17 mas-1 kHz	(see intensity)
Intensity mismatch	4%-1 kHz	1.2%-0 Hz	0.03%-0 kHz	< 1%
Total null	9.7×10^{-4}	2.9×10^{-4}	5.9×10^{-5}	f(baseline)
Instrumental null	5.0×10^{-4}	2.0×10^{-4}	2.6×10^{-5}	10^{-5}
rms null	5.8×10^{-4}	1.3×10^{-4}	2.2×10^{-5}	10^{-5}

Tab. 2: Control loop performance and optimum repetition frequencies simulated for a 100 sec observation sequence. The observations are carried out for a Sun-like G2V star located at 20 pc using either the 47-m UT2-UT3 baseline at the VLTI (waveband: 3.5-4.1 μm), a baseline length of 20 m for ALADDIN (waveband: 3.1-4.1 μm) or a 50-m baseline length for PEGASE (waveband: 2.5-5 μm).

Star	0.25%	0.5%	1%	1.5%	Instrument
K0V - 5pc	83	110	185	266	GENIE - AT
	107	215	430	645	GENIE - UT
	18	31	53	77	ALADDIN
	196	392	784	1176	PEGASE
G5V - 10pc	140	147	174	212	GENIE - AT
	29	56	112	167	GENIE - UT
	14	22	34	47	ALADDIN
	43	86	172	258	PEGASE
G0V - 20pc	338	339	344	351	GENIE - AT
	23	37	69	102	GENIE - UT
	18	22	32	41	ALADDIN
	14	29	58	87	PEGASE
G0V - 30pc	714	714	717	721	GENIE - AT
	38	48	77	109	GENIE - UT
	47	48	51	54	ALADDIN
	7	13	26	39	PEGASE

Tab. 3: Performance comparison of GENIE, ALADDIN and **the linear PEGASE** expressed in detectable exozodiacal disc densities as compared to the solar zodiacal disc (for different uncertainties on the stellar angular diameter and an integration time of 30 min).

4. Estimated sensitivity of Pegase

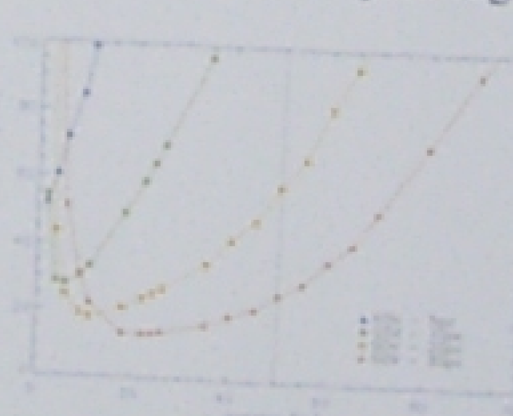

Fig. 2: Simulated performance of PEGASE for four typical Darwin targets with respect to the baseline, assuming 1% uncertainty on the stellar angular diameter and an integration time of 30 min.

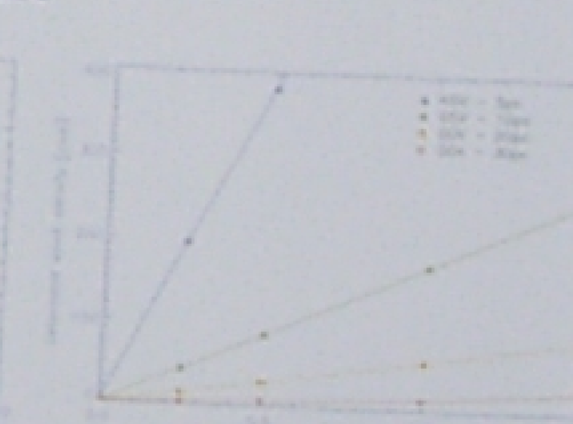

Fig. 3: Simulated performance of PEGASE for various assumptions on the uncertainty on the stellar angular diameter and for an integration time of 30 min.

Fig. 2 and **Fig. 3** show the simulated performances of PEGASE for exozodiacal dust detection, using the parameters listed in **Tab. 1** and taking into account the usual calibration procedures (i.e. background subtraction, geometric leakage calibration and instrumental leakage calibration - see [1]). The performances of PEGASE are compared to ground-based instruments in **Tab. 3** for four targets representative of the Darwin catalogue. Because baseline lengths smaller than 50 m are not available, PEGASE is not adapted for the observation of exozodiacal discs around the closest stars of the Darwin/TPF catalogue. PEGASE exceeds nevertheless the GENIE and ALADDIN sensitivities for the most distant targets. By example, PEGASE is more sensitive than GENIE (even on the UTs) for G0V stars located at 20 pc and 30 pc and more sensitive than ALADDIN for the G0V star at 30 pc. Considering a triangular configuration for PEGASE could boost significantly the performances as illustrated by **Fig. 4**.

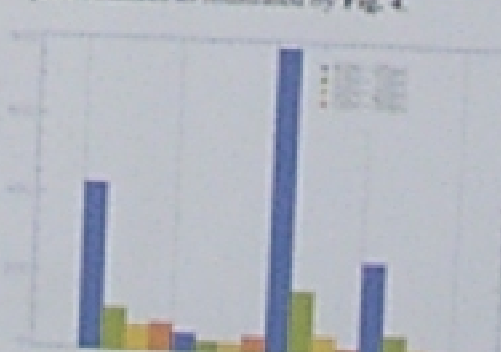

Fig. 4: Expected performance for the **triangular PEGASE** compared to the other concepts considering a 25-m nulling baseline (for 30 min integration time and 1% uncertainty on the stellar angular diameter).

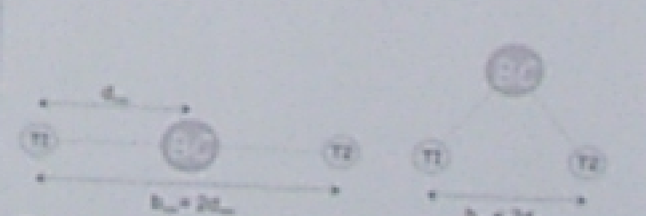

Fig. 5: A triangular configuration gives access to smaller baselines, more suited for exozodiacal dust detection.

5. Conclusions

Despite relatively small telescopes (40 cm diameter), the space-based nulling interferometer **PEGASE** presents very attractive capabilities for the exozodiacal disc detection. In its nominal linear configuration, **PEGASE** is not well adapted for the circumstellar dust detection around Darwin targets because the baselines smaller than 50 m are not available. Considering a triangular configuration boosts significantly the sensitivity, with performances largely exceeding those of **GENIE** and competing with the 1-m telescope nulling interferometer for Antarctica **ALADDIN**. Remaining the best instrument for the closest stars, **ALADDIN** is outperformed by **PEGASE** for the most distant targets. Even if it has not been designed for that, PEGASE could be very valuable for the exo-zodiacal dust detection around the Darwin/TPF targets.

References

[1] Absil et al., A&A, 3516, 2006.
[2] Absil et al., A&A, submitted, 2007.
[3] Gondoin et al., SPIE proc., 5491, 2004.
[4] Le Duigou et al., SPIE proc., 6258, 2006.

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