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Candidate VLTI Configurations for the GENIE Nulling Experiment

Olivier Absil
IAGL, University of Liège, B5C, 17 Allée du 6 Août,
B-4000 Sart-Tilman, Belgium

Philippe Gondoin, Christian Erd, Malcolm Fridlund, Roland den Hartog, Lucas Labadie, Nicolas Rando
ESA-ESTEC, Postbus 299, NL-2200AG Noordwijk, The Netherlands

Vincent Coudé du Foresto
LESIA, Observatoire de Paris-Meudon, 5 place Jules Janssen,
F-92195 Meudon, France

Abstract. The European Space Agency (ESA) and the European Southern Observatory (ESO) initiate a definition study for a Ground-based European Nulling Interferometer Experiment (Darwin-GENIE). The experiment will use the Very Large Telescope Interferometer (VLTI) operating on Mount Paranal (Chile). The objective of GENIE is to gain experience in the manufacture and operation of a nulling interferometer using a design concept and technology representative of the ESA IRSI-Darwin space mission. GENIE will prepare the IRSI-Darwin science program through a systematic search for exozodiacal dust clouds around IRSI-Darwin candidate targets. GENIE also aims to perform IRSI-Darwin related science achievable from ground including the detection of low-mass companions (if possible, hot jupiters) around nearby stars. Among the variety of telescope sizes and positions on the VLTI site, candidate interferometric configurations have been identified for GENIE, taking into account the limitation imposed by the Earth's atmosphere. They include a Bracewell interferometer for exozodiacal clouds detection in the N band and a double Bracewell configuration with internal modulation for extrasolar jupiter detection in the L' band. The present paper presents the prospective performance of these configurations in light of current specifications of major VLTI subsystems.

1. Introduction

Darwin is one of the most challenging space missions ever considered by the European Space Agency (ESA). Its main objectives are to detect Earth-like planets orbiting nearby stars and to characterize their atmospheres by means of low resolution spectroscopy (Léger et al. 1996). Infrared nulling interferometry proposed by R. Bracewell in 1978, has been selected by ESA as a baseline for the Darwin mission. This technique achieves both a high angular resolution and a high dynamic range by adjusting the phases of the beams coming from various telescopes to produce a fully destructive interference on the optical axis.

In the context of the Technical Research Program leading to ESA's IRSI-Darwin, a major issue is the development of a ground-based nulling interferometer to test the IRSI-Darwin technologies in an appropriate environment. The Very Large Telescope Interferometer (VLTI) at ESO (Paranal, Chile) will provide the infrastructure for the Darwin-GENIE experiment. This nulling interferometer will combine two or more of the VLTI telescopes, using all optical functions foreseen into the future Darwin Infrared Space Interferometer. The overall performance of the instrument will heavily depend on the performance of all VLTI subsystems and in particular on the adaptive optics and co-phasing subsystems. Besides its main technological and scientific objectives, GENIE will also be a general-user instrument, scientifically useful for spectroscopic studies of any faint cool object located in the immediate environment of a bright astrophysical source. It will help develop data reduction and interpretation applicable for the Darwin mission.

2. Nulling Configurations at the VLTI

Thanks to the large number of telescopes at the VLTI—four 8-m Unit Telescopes (UTs) and three/four 1.8-m Auxiliary Telescopes (ATs)—many configurations can be found to achieve the on-axis destructive interference. The simplest one is the Bracewell configuration (Bracewell 1978), formed of two UTs. This configuration has a central transmission proportional to θ^2 along the interferometer baseline, which is not very deep. Therefore the shortest baseline (46 m between UT2 and UT3) is preferable to cancel the stellar light as much as possible with a wide central fringe.

In order to achieve a deeper null, linear configurations with three or four telescopes are also considered. These configurations make use of the ATs, because there are not three aligned UTs. They include the Degenerate Angel Cross and the OASES configurations, as shown in figure 1. These configurations are useful to reduce the stellar leakage in the output signal of the nuller, but are not very sensitive because of their smaller collecting surface.

In the case of low-mass companion detection, GENIE could be used to validate internal modulation, a technique for fast signal chopping developed for the Darwin interferometer, which extracts the planetary signal from other spurious signals (infrared background, stellar leaks, etc.). Internal modulation between two Bracewell interferometers, each one formed of two UTs, has the potential to detect a few hot jupiters around nearby stars.

3. Main Limitations to Ground-based Nulling Interferometry

The performances of a nulling interferometer are degraded by two main sources: stellar leakage and infrared background. These are two unwanted signals from which the exozodiacal or planetary signal has to be extracted. Moreover, these signals are two important sources of noise through their unavoidable photon noise and their fluctuations.

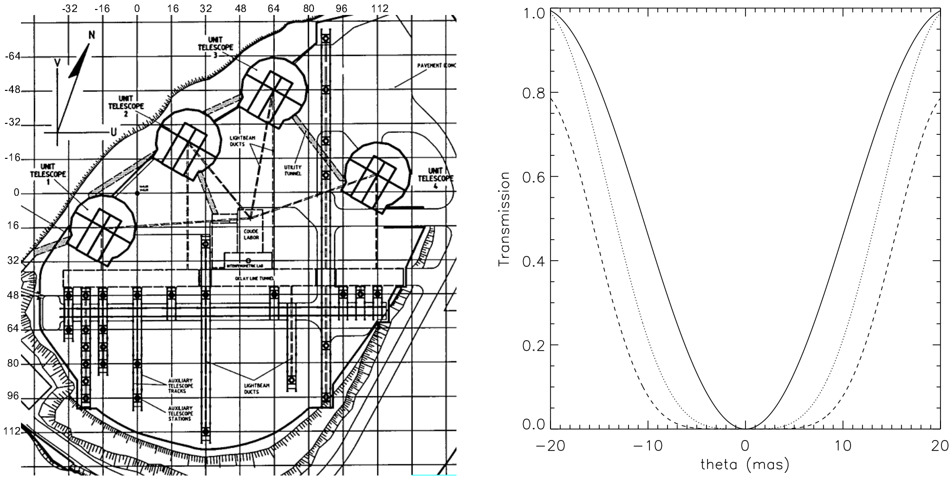

Figure 1. Left: Map of the VLTI site, with the four UTs and the stations for the ATs (filled circles). There are many ways to find three (or four) aligned AT stations. Right: Transmission along the baseline for a Bracewell interferometer (θ^2 transmission, solid line), a Degenerate Angel Cross (θ^4 transmission, dotted line) and an OASES interferometer (θ^6 transmission, dashed line).

3.1. Infrared Background

An important source of noise for any ground-based infrared observation is the thermal emission from the sky and from the telescope itself. The background flux exceeds the exozodiacal emission by several orders of magnitude in the thermal infrared. Appropriate chopping schemes will be used to isolate the useful signal from this huge incoherent source. However, the photon noise associated with the background remains and will set a lower limit to the integration time. Moreover, fluctuations of the background emission are expected because of emissivity and temperature fluctuations. In order to monitor and cancel these fluctuations, the chopping process needs to be done at a high enough frequency.

3.2. Atmospheric Turbulence

The destructive interference produced by a nulling interferometer is only perfect on the axis of the interferometer. Due to the finite extent of the stellar disk, a part of the starlight leaks through the null, producing another spurious signal. Assuming that the mean stellar leakage can be removed by an appropriate calibration method, only its associated noise remains. This noise can be divided into two parts: the photon noise associated with the mean stellar leakage, and the "transmission noise" due to the fluctuations of the stellar transmission. These fluctuations are produced by three main sources: differential optical path delay between the arms of the interferometer, intensity mismatches due to unequal coupling efficiencies into the fibers for the two telescopes, and phase fluctuations due to water vapor dispersion. These three effects will be reduced by means of control subsystems:

- The PRIMA Fringe Sensing Unit will reduce the differential optical path delay induced by the atmosphere down to about 50 nm RMS. This is sufficient to reduce the transmission noise below the unavoidable background noise for N band observations (around 10 μm).
- The MACAO adaptive optics system will reduce the fluctuations of the signals coupled in the two arms of the interferometer. An additional intensity matching device will be required to reach a low enough level of fluctuations.
- A feedback loop to control the chromatic dispersion due to air and water vapor. An adjustable thickness of ZnSe could be used in both arms of the interferometer to compensate for dispersion.

4. Expected Performances

Prospective performances of the GENIE instrument have been computed, taking into account the noise sources discussed above. The infrared background is the dominant source of noise in the N band. The chopping scheme will thus have a decisive influence on the N band performances. Internal chopping could be the best way to monitor the background fluctuations at a high frequency. In the L' band, the transmission noise due to stellar leakage becomes the main contributor. Therefore a second (more accurate) stage of OPD control will probably be needed if the L' band is selected for the GENIE experiment.

In any case, detection of zodiacal clouds 10 times as dense as our local zodiacal cloud around nearby stars with a Bracewell interferometer is a realistic goal, within less than one hour of integration time. Due to their smaller collecting surface, the DAC and OASES interferometers cannot operate in the N band: the huge infrared background would make the integration time too long. At short wavelengths (K and L bands), their performances are not really better than the Bracewell's, because the atmospheric turbulence degrades their deep null.

Hot jupiter detection in the L band should be possible with a double Bracewell within a few minutes for the brightest targets (tau Boo b, 51 Peg b). A 100 m baseline is sufficient to resolve the star-planet system. The N band is not really appropriate for hot jupiter detection at the VLTI, because the typical angular distance between the star and the planet is of 5 mas, while the angular resolution is limited to 20 mas in the N band.

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