DARWIN FRINGE SENSOR (DWARF): BREADBOARD DEVELOPMENT

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ABSTRACT

The current DARWIN design is based on six telescopes located on free-flying spacecrafts, interferometrically combined on a central hub with free space propagation. Perfect mechanical stability of the system configuration is impossible, i.e. displacements, thermal effects and vibrations etc. are degrading the system performance. The purpose of the fringe sensor is to measure all relevant perturbations and to provide the necessary information to achieve co-phasing of the free-flying telescopes. This implies the measurement of differential piston/tip/tilt between the telescopes and selected higher-order aberrations on each pupil. The fringe sensor is thus a core component and the most critical real-time sensor in the DARWIN system. The goal of the current study is to identify and validate a high-precision fringe detection and tracking sensor called DWARF (DARWIN Astronomical Fringe Sensor) by setting up, characterising and testing a respective sensor breadboard. This paper summarises the requirements and the technological trade-off and describes the conceptual breadboard design and testing scheme. Another paper of this conference 'DARWIN Fringe Sensor (DWARF) Concept Study' by F. Cassaing et al. describes the concept selection.

1. DWARF - STUDY OVERVIEW

DWARF is one of several preparatory activities for the DARWIN Infrared Space Interferometer (IRSI). The background of this mission and the outcome of the concept and feasibility study is given in [1].

The DWARF study is performed under a contract of the European Space Agency in the Technology Research Programme. Kayser-Threde is prime contractor and major contributors are the subcontractors ONERA and Alcatel Space. The main study goals are:

- The identification and validation of the best high-precision fringe detection and tracking sensor concept to measure all relevant perturbations and to provide the necessary information to achieve co-phasing of the free-flying DARWIN/IRSI telescopes
- The definition, preliminary and detailed design of a demonstration breadboard
- Manufacturing, characterisation and performance testing of a representative breadboard
- The consideration of space technological issues in order to allow a direct derivation of a space-compatible design
- The set up of a development planning for DWARF (SMART-3 pre-curser flight)

2. REQUIREMENTS

The development of the DWARF sensor is based on the set of requirements summarised in Table 1. The sensor will be implemented on the DARWIN central hub spacecraft (subsystem temperature: 40 K). The allowed wavelength range covers the visible range up to 4 µm. The magnitude range of the stars to be considered is broad, including very faint stars (see [2]). Zernike coefficients up to Z10 have to be measured to a very demanding accuracy. A detailed requirements analysis is given in [3], included in these proceedings.

Table 1: DWARF Requirements

Parameter	Specification
Temperature	40 K
Spectral type of targets [m_v range]	G (3.5-11.1) K (2.0-17.3) M (5.8-19.7)
Wavelength	∈[0.4;4] µm
Modes to measure	Z1 to Z10
Piston range in rms WFE	10 µm
Piston accuracy in rms WFE	0.75 nm
Tip-tilt range in rms WFE	18 µm
Tip-tilt accuracy in rms WFE	1.21 nm
Beam diameter	20 mm

In addition to the here presented quantitative requirements, the ability of the sensor to withstand the harsh space environment is important. The issues to be taken into account are:

- Radiation hardness
- Preference for space qualified components and technologies
- High reliability
- No mechanism

- Inherent robustness
- Redundancy
- Mass to be minimised
- Power dissipation to be minimised

There is also one programatical impact to be considered: The here presented requirements are derived from a Pre-Phase A study and are therefore to be seen as preliminary. Consequently, the proposed concept has to be sufficiently flexible and should allow some margin for future detailing of requirements. The selection of a concept that is already at its performance limits is not recommended.

3. DARWIN-DWARF Interface

The DWARF sensor is fed from the DARWIN optical train by dichroic beam splitters. Fig. 1 gives a simplified DARWIN block diagram, showing how the six beams are led towards the DWARF sensor.

4. TECHNOLOGICAL TRADE-OFF

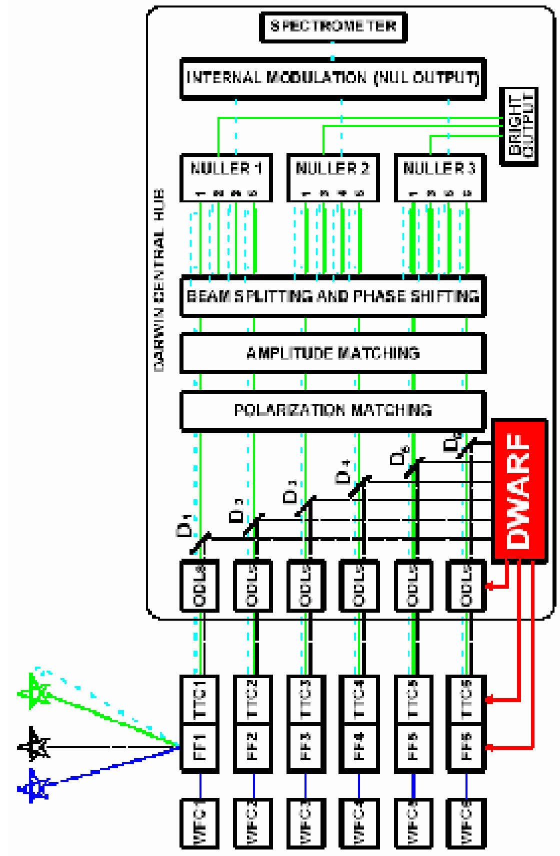
A thorough trade-off between the potential candidates has been performed. The options reviewed in detail are:

- Combination of wave front sensor and interferometer
- Interferometer in pupil plane with 2D detector
- Focal plane interferometer

The preferred DWARF sensor concept is a focal-plane interferometer as shown in Fig. 2.
For further details of the selection process refer to [3]. It covers the detailed results of the concept study.

5. REPRESENTATIVE BREADBOARD

The DARWIN breadboard is defined to be representative for the latter flight model. It is a focal plane interferometer as shown in Fig. 2 and performs all DWARF measurements (piston, tip, tilt as well as higher aberrations). Two beams are combined in a configuration that allows the extension to a higher number of beams. The set-up works at ambient environment in the visible spectral range. No moving parts are implemented, already anticipating the latter use in space. Fig. 3 shows a schematic sketch of the DWARF test set-up.



- Main star (nulling)

- - Planet (nulling)

- - OPD reference: on-axis main star (nulling) or off-axis (imaging)

-·- Off axis star used by FF WFC

-·→ Real-time control

FF: Telescope Free Flyers
ODL: Optical Delay Lines
WFC: Wide Field Camera,
TTC: Tip/Tilt Corrector)

Fig. 1. Simplified DARWIN Block Diagram

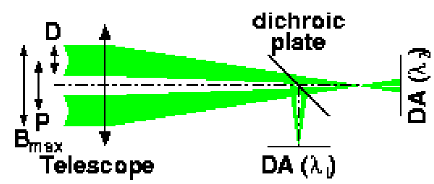


Fig. 2. Focal Plane Interferometer for DWARF

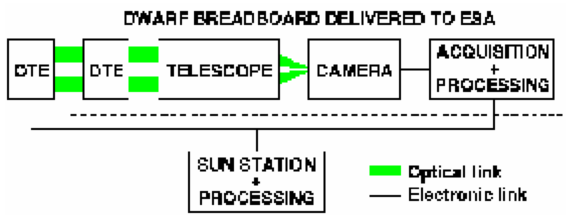


Fig. 3. DWARF Breadboard Block Diagramm

It consists of:

- The ONERA test equipment (OTE) which is a bench dedicated to the accurate characterisation of OPD or wavefront sensors, and available for the tests. It will be used as a beam generator for the DWARF breadboard, delivering two beams with required characteristics: diameter, spectral band, magnitude and calibrated piston and tip/tilt aberrations.
- The DARWIN test equipment (DTE) for the introduction of calibrated aberrations
- A beam combining telescope to form the focal plane image
- A two-dimensional detector for recording the focal plane image
- An acquisition subsystem for image acquisition and preprocessing
- A workstation for processing

The breadboard is assembled in a compact arrangement on a separate baseplate (DWARF Breadboard Optical Bench, see Fig. 4), allowing final delivery to the customer.

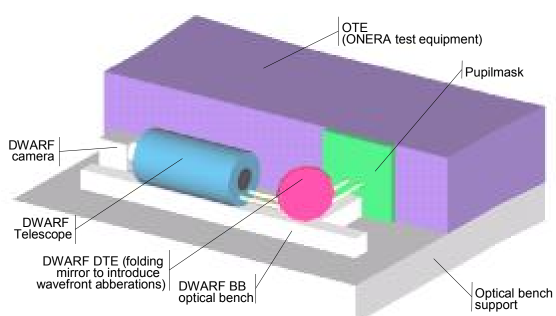


Fig. 4. DWARF Breadboard Perspective Sketch

6. TESTING SCHEME

In the course of the concept study and the detailed design phase, extensive performance simulations have been performed and are still ongoing. It is the goal of the breadboard activities to confirm the theoretical results by experiments. This guarantees the reliability of the DWARF simulation models and forms the basis for the performance prediction and design of the flight hardware. Of special interest is the prediction of the limiting magnitude.

The test program includes:

- Fringe visibility measurements
- Accuracy of aberration measurements
- Repeatability of aberration measurements

For a good validation of the theoretical model, several parameters have to be varied during the test sequence:

- Source brightness
- Spectral band
- Wave front error

To ensure the validity of the results, a proper alignment and calibration of the test set-up is crucial.

7. CONCLUSION

The required performance of the DARWIN fringe sensor is demanding (measurement accuracy in the nm rms range). To achieve securely the performance goals in a latter space hardware development, a breadboard study has been initiated. The first step, being the identification of a suitable concept, led to the selection of a focal plane interferometer. Based on this concept, a representative breadboard is being built. Already carried out model simulations are promising. This activity forms therefore a very good basis for a future cryogenic development.

8. REFERENCES

1. A. Karlsson et. al., *DARWIN The InfraRed Space Interferometer. Concept and Feasibility Study Report*, ESA-SCI(2000)12, ESA, April 2002.

2. L. Kaltenegger, *DARWIN Target List*, March 2002.

3. DARWIN Fringe Sensor (DWARF): Concept Study' by F. Cassaing, F. Baron, E. Schmidt, S. Hofer, L. Mugnier, M. Barillot, G. Rousset, T. Stuffler, Y. Salvadé, in *Towards other Earths*, Volume SP-539;ESA, 2003.

9. ACKNOWLEDGEMENT

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