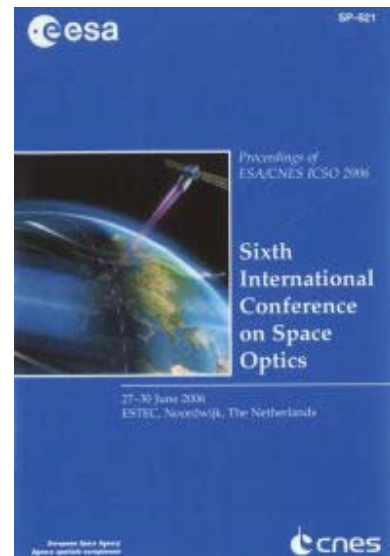


International Conference on Space Optics—ICSO 2006

Noordwijk, Netherlands

27–30 June 2006

Edited by Errico Armandillo, Josiane Costeraste, and Nikos Karafolas



Technological aspects and results from the DARWIN fringe sensor predevelopment

Hans Thiele, Stefan Hofer, Timo Stuffer, Frederic Cassaign, et al.



TECHNOLOGICAL ASPECTS AND RESULTS FROM THE DARWIN FRINGE SENSOR PREDEVELOPMENT

Hans Thiele⁽¹⁾, Stefan Hofer⁽¹⁾, Timo Stuffer⁽¹⁾, Frederic Cassaign⁽²⁾, Isabelle Mocoour⁽²⁾, Laurent Mugnier⁽²⁾, Marc Barillot⁽³⁾, Yves Salvadé⁽⁴⁾, Igor Zayer⁽⁵⁾

⁽¹⁾Kayser-Threde GmbH, Wolfratshausenstr. 48, D-81379 Munich, Germany, Email: hans.thiele@kayser-threde.com

⁽²⁾ONERA, 28, avenue de la Division Leclerc, F-92322 Châtillon, Email: frederic.cassaing@onera.fr

⁽³⁾ALCATEL SPACE, 100, bld du Midi BP 99, F-06156 CANNES LA BOCCA, Email: marc.barillot@space.alcatel.fr

⁽⁴⁾Institut de Micro-Technologie, Université de Neuchâtel, 2 Rue A.L. Bréguet, CH-2000 Neuchâtel, Switzerland, Email: yves.salvade@unine.ch

⁽⁵⁾ESA-ESTEC, Keplerlaan 1, Postbus 299, 2200 AG Noordwijk, The Netherlands, Email: igor.zayer@esa.int

ABSTRACT

The objective of the so-called fringe sensor DWARF - derived from **DARWIN AstRonomical Fringe Sensor** is to measure all relevant perturbations and to provide real time control data to achieve co-phasing of the free-flying telescopes of the DARWIN system. An overview of the design of the sensor Breadboard (BB), as it has been designed and built at Kayser-Threde as Prime with main partners ONERA and Alcatel Space under ESA contract 17012/03/NL/EC is presented. An extensive test campaign has been carried out at ONERA. The respective optical test setup is outlined and the achieved performances for retrieval of primary and higher order aberrations are presented. As final outcome of the BB study the essential elements to build a fringe sensor (FS) flight model are shortly characterized and the respective development roadmap is sketched.

1. INTRODUCTION – DWARF STUDY OVERVIEW

The DARWIN mission objective is to detect signs of earthlike life outside our solar system. In the original DARWIN configuration, 6 free flying telescopes and one center spacecraft where the light of the 6 telescopes should be interferometrically combined by nulling technology. Nulling interferometry requires in principle perfect opto-mechanical system stability, which however is impossible for such a system configuration. Displacements, thermal effects and vibrations etc. are degrading the system performance. The objective of the so-called fringe sensor DWARF - derived from DARWIN AstRonomical Fringe sensor is to measure all relevant perturbations and to provide the necessary information to achieve co-phasing of the free-flying telescopes. DWARF is thus a core component and the most critical real-time sensor in the DARWIN system.

Proc. '6th Internat. Conf. on Space Optics', ESTEC, Noordwijk, The Netherlands, 27-30 June 2006 (ESA SP-621, June 2006)

The DARWIN configuration is currently under reinvestigation, probably leading to a reduced set-up with only three free flying telescopes and one center spacecraft as shown in Fig. 1. The DWARF concept as investigated in the breadboard study is fully compliant with such a three telescope configuration.

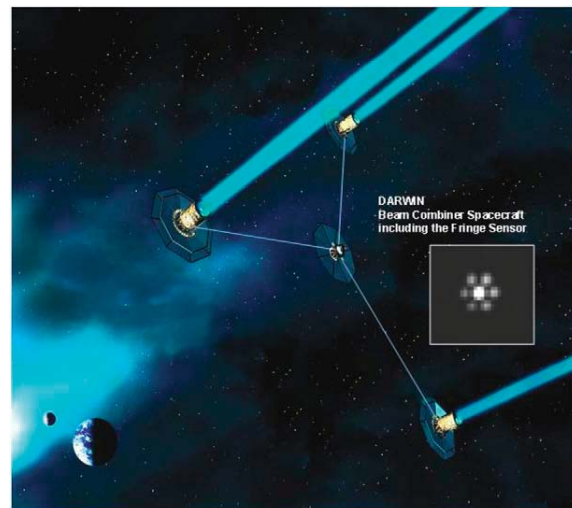


Fig. 1. DARWIN Formation flying telescopes with central hub satellite, which combines the individual beams. The small image in the right part of the illustration shows a typical measurement of the selected DWARF multi-axial focal-plane interferometer principle, which allows the calculation of the perturbations described by Zernicke coefficients from 1 to 11 in the optical configuration, respectively their input paths.

2. THE BREADBOARD DESIGN

As a result of an initial technology trade-off a multi-axial focal-plane interferometer concept has been

identified and selected as the most promising concept for the DARWIN fringe sensor [1], [2]. Fig. 2 shows the respective schematic design of the BB which mainly consists of a Schmidt-Cassegrain telescope which is used off axis, a defocus generator, a detector assembly, an optical bench and respective opto-mechanical parts and specific test equipment. The telescope receives light from the test bench on three sub aperture beams, which simulate the incoming DARWIN flight configuration, and it focuses these beams onto a CCD detector. A beam splitter setup (defocus generator) is used to generate a focused and a defocused spot on one detector as illustrated in Fig. 3. Focused and defocused images are needed to calculate the perturbations in the incoming beams by means of various algorithms which have been thoroughly investigated in the BB test campaign at ONERA.

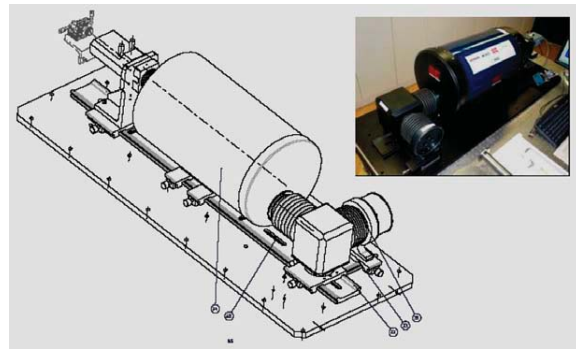


Fig 4. 3D sketch of the DWARF BB.



Fig. 2. Schematic diagram of the FS BB. A telescope focuses three incoming beams on the Fringe Sensor detector unit, where one focused and one defocused interference fringe are detected.

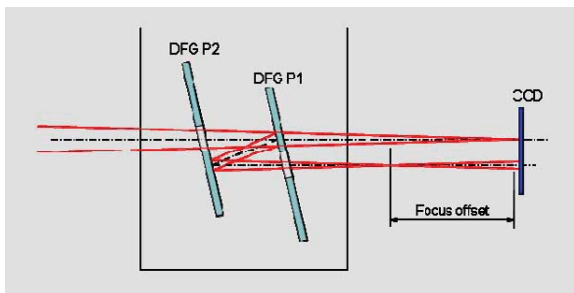


Fig. 3. The Defocus Generator allows generating a focused and a defocused image on just one detector

A 3D sketch of the BB showing the main elements is shown in Fig. 4.

3. THE BREADBOARD TEST CAMPAIGN

The BB test campaign has been performed at ONERA, using the so-called BRISE (Banc Reconfigurable d'Imagerie sur Sources Etendues) Optical Test Equipment (OTE). The block diagram in Fig. 5 shows the experimental configuration, with DWARF mounted on the BRISE test bench.

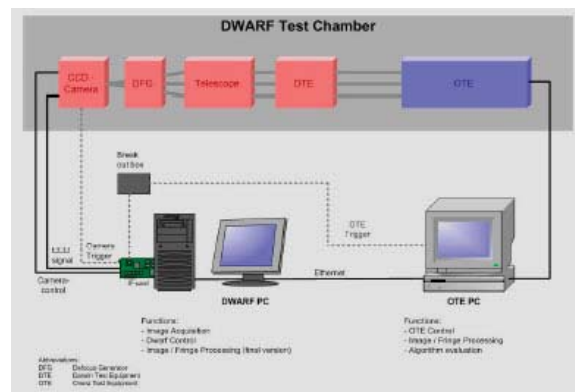


Fig. 5. DWARF – BRISE test setup block diagram.

BRISE allows to generate three collimated sub-aperture input beams with known piston, tip/tilt aberrations (PA, primary aberrations) between the beams by means of a precisely piezo-controlled folding mirror assembly as shown in Fig. 6.

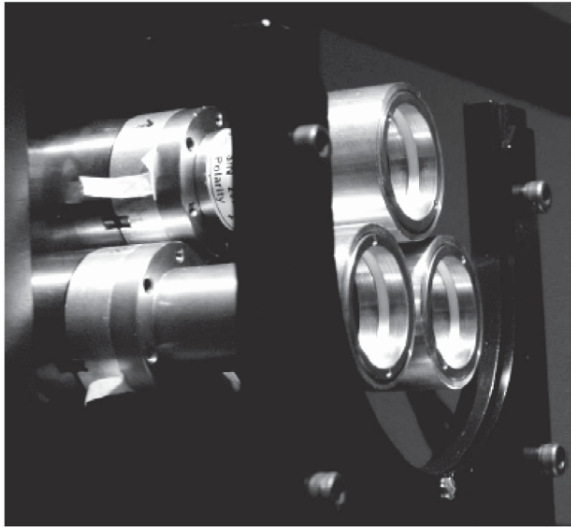


Fig. 6. Segmented deformable mirror mounted on BRISE.

The system therefore is capable to simulate three independent telescope input beams accordingly to the DARWIN system. Defocus and higher order aberrations (HA) can also be generated by introduction of distorted folding mirrors into the optical path in front of the DWARF FS telescope. An additional Zygo Interferometer, which is part of the BRISE test bench, allows to calibrate the BRISE output and also to calibrate wave-front errors (WFEs) of the optical train of the DWARF BB. The complete set-up is shown in Fig. 7.



Fig. 7. The DWARF BB is installed on the BRISE test bench ready for testing; the optical path is closed with baffles to suppress any stray light.

The raw images taken by the DWARF BB detector have been evaluated by phase retrieval and phase

diversity algorithms. An example for defocused and focused point spread functions (PSF) is given in Fig. 8.

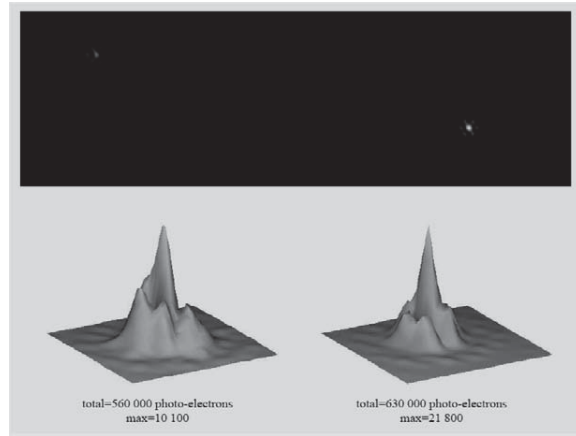


Fig. 8. Experimental PSF generated with the BRISE optical test bench and detected with the DWARF BB with its defocus generator: raw image (top) and 3D zoom (bottom) of the focal (right) and out-of-focus (left) images.

Focal-plane “phase retrieval” and as well as phase diversity algorithms and a new algorithm using only the out-of-focus images have been validated. For PA estimation the algorithm performance is nearly identical for the piston, whereas for tip/tilt the larger dynamic for the new out of focus algorithm is obtained at the expense of a worse repeatability. Nevertheless compliance with the requirement (0,05 arcsec respectively 1,21 nm RMS) has been demonstrated up to star magnitude 10. The PA modes can be acquired and estimated with at least 10 Hz update rate as required. For the BB the update rate is limited by the commercial camera performance, but for the FM (Flight Model) much faster acquisition rates would be feasible if required.

For the HA estimation, performance is as well satisfying for range, accuracy and repeatability. Surprisingly, the out of focus algorithm turns out to be more efficient than the phase diversity with respect to the repeatability. Compliance with the repeatability requirements has been demonstrated up to stars with mag 11.

The test campaign also revealed that for PA and HA calculation, the proper calibration of the fringe sensor is the most critical task. Therefore a sophisticated on-board calibration system for the flight model will be required and respective preliminary concepts have already been worked out as a result of the BB test campaign.

Another important result is the optimum spectral bandwidth for fringe acquisition. Increasing the

bandwidth increases the repeatability performance as the number of photons increases, but on the other hand reduces accuracy as the chromaticity of diffraction is not considered in the direct model. Results achieved with the BB demonstrate that the 40 nm or 80 nm bandwidth is well suited for PA when operating at 650 nm 40 nm width is sufficient to reach the specification and should therefore be considered as a conservative solution even if the repeatability is a bit worse. The linearity begins to be affected at 80 nm bandwidth.

4. FLIGHTMODEL ROADMAP

As a result of the design, simulation and experimental activities performed during the DWARF BB study, the conclusion is, that the focal-plane multi-axial concept selected for DWARF is perfectly suited to DARWIN needs as long as the DARWIN system concept will consist of at least three free flying telescopes. A preliminary concept for the optical design of the FM has been already derived in the course of the BB study. A sketch of the envisioned fringe sensor off-axis telescope is shown in Fig. 9.

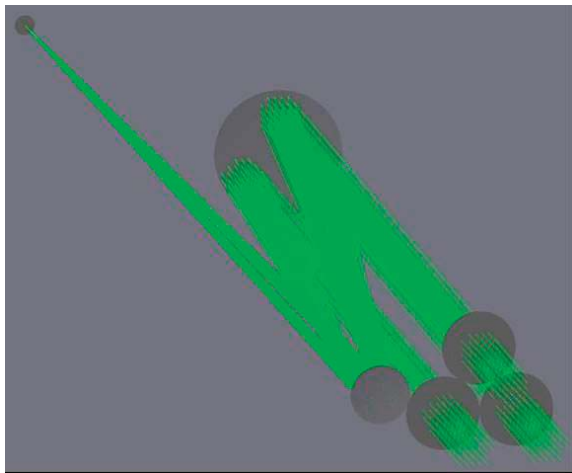


Fig. 9. Ray-trace of the FS telescope.

Nevertheless and in order to improve the maturity of the proposed fringe sensor concept, some further investigation are proposed to be carried out prior to a straight forward FM development. These activities comprise:

- Investigation of the performance for PA measurement while higher order aberrations are present.
- Detailed investigation of the accuracy for HA measurements.

- Implementation and test of fast, real time algorithms to be able to provide PA results faster than 10 Hz (System requirement is still tbd).
- Work out and test of a flight-representative internal calibration concept and verification at cryogenic temperatures. Several solutions have been identified and need to be compared and tested.
- Start detector, respectively focal plane assembly predevelopment. Detector development will be a main schedule driver.
- Clarification and investigation of new or updated requirements which may result from ongoing DARWIN system studies.

Based on the currently defined, preliminary system assumptions and the results of this TRP study the development time needed until delivery of a DWARF FM has been estimated to about 4 to 5 years including the mentioned predevelopment activities.

5. SUMMARY AND OUTLOOK

DWARF is a representative BB for a future FM for DARWIN. Performance tests carried out on the BRISE optical test bench at ONERA have demonstrated the validity of the all-in-one focal plane approach to accurately measure aberrations of the multiple-aperture instrument. For PA modes, both the focal-plane “phase retrieval” and a new out-of-focus algorithms have been validated. For HA modes, performance is satisfying. It turned out that calibration of DWARF is one of the most critical issues and has to be addressed with high priority during the FM development. As an outcome of the TRP study preliminary FM concepts have been derived.

6. ACKNOWLEDGEMENT

The DWARF BB study has been funded by ESA under contract 17012/03/NL/EC.

7. REFERENCES

1. Cassaing F., Baron F., Schmidt E., Hofer S., Mugnier L., Barillot M., Rousset G., Stuffer T., Salvadé Y., Zayer, I., *DARWIN FRINGE SENSOR (DWARF): CONCEPT STUDY*, Darwin Congress, Heidelberg 2003.
2. Schmidt E., Cassaing F., Hofer S., Barillot M., Baron F., Mugnier L., Rousset G., Stuffer T., *DARWIN FRINGE SENSOR (DWARF): BREADBOARD DEVELOPMENT*, Darwin Congress, Heidelberg 2003.