Materials Research Proceedings 37 (2023) 270-273 https://doi.org/10.21741/9781644902813-59

A static, refractive and monolithic Fourier spectrometer for an HEMERA balloon flight

Fabio Frassetto[a1*], Lorenzo Cocola[b1], Paola Zuppella[1], Vania Da Deppo[1], Riccardo Claudi[2] and Luca Poletto[1]

[1] CNR-IFN Via Trasea, 7 – 35131 Padova, Italy

[2] Astronomical Observatory, INAF, Padova, Italy

[a]fabio.frassetto@cnr.it, [b]lorenzo.cocola@cnr.it

Keywords: Fourier Transform Spectroscopy, Space Instruments, Interferometry

Abstract. In this work we present the characteristics of a static Fourier transform spectrometer designed for a balloon flight and meant to test the instrument in an actual working environment. The flight campaign has been provided within the HEMERA Research Infrastructure. The interferometric assembly, the core of the instrument, is made with only refractive and reflective surfaces, without diffraction gratings. It is realized with four glass elements that are glued in a single monolithic structure with no spacers or framed supports. There are no hollow spaces, thus improving the mechanical stiffness. The spectral band accessible to the presented optical design is 450 – 850 nm and the working spectral region can be chosen to be either 550 – 850 nm or 450 – 550 nm. The spectral resolution is variable as it is driven by the refractive index of the used glasses in the considered spectral region. In this design, the resolution varies from 1500 at 550 nm to 200 at 800 nm and to 4000 at 450 nm. The total field of view of the instrument is 3 degrees. All the optical elements used to operate the spectrometer are installed on a 3D printed structure. This is possible due to the low sensitivity of the instrument to vibrations. The interferometric assembly has undergone thermal test to quantify the temperature range it can tolerate. We will present the instrument design and the first results of the flight campaign.

Introduction

Static Fourier transform spectroscopy is nowadays a well-documented technique [1-3], the interested reader is invited to start from the references for a description of the technique. Here is sufficient to recall that the technique is based on the recording, via a 2D detector, of an image signal, called interferogram, whose Fourier transform returns the spectrum of the light that has produced the interferogram itself. What we have tested in this flight campaign is the possibility to realize the interferometer as a monolithic optical assembly in which the beam-splitter and the retro-dispersive elements, two Littrow's prisms [4-6], are glued together forming a compact structure (hereafter the interferometric assembly, IA) with no hollow volumes in the optical path.

Being the IA realized by gluing together glasses with different coefficients of thermal expansion (BK7 and SF57), the proposed optical concept has been tested to evaluate the possible occurrence and effect of thermal stresses in the interferometric assembly. The spectrometer, with the indication of all its major parts, is shown in Fig. 1a; Fig. 1b shows the instrument, closed with its cover, during the pre-flight tests. The supporting base is realized via SLS 3D printing technology in Nylon 12.

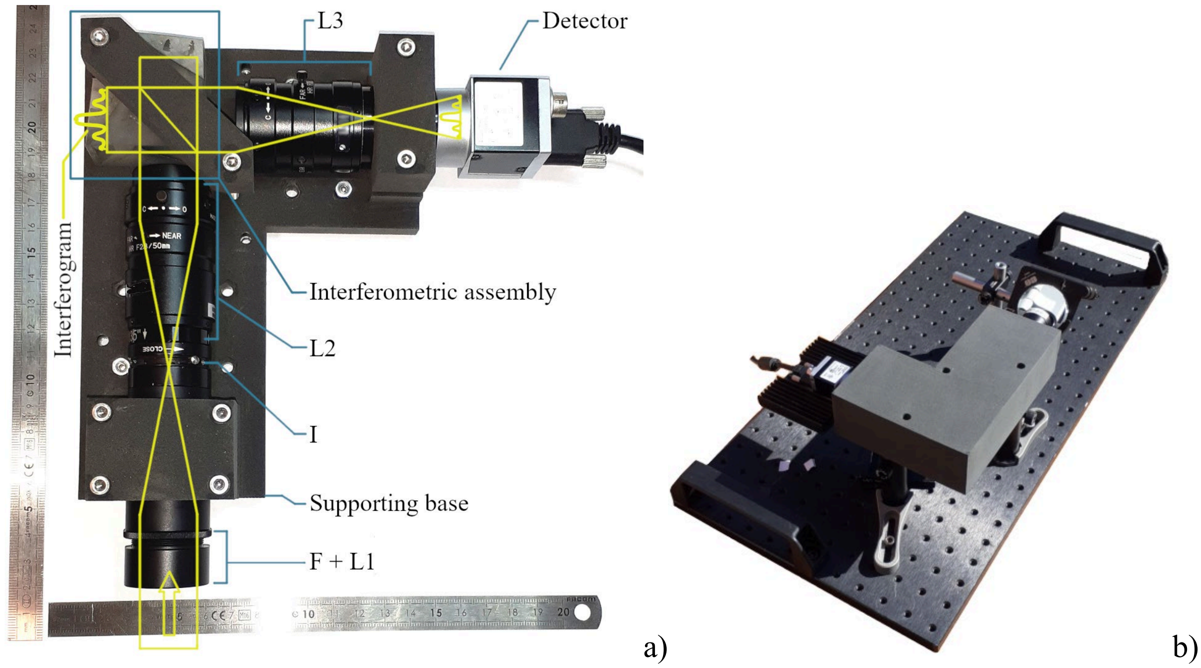


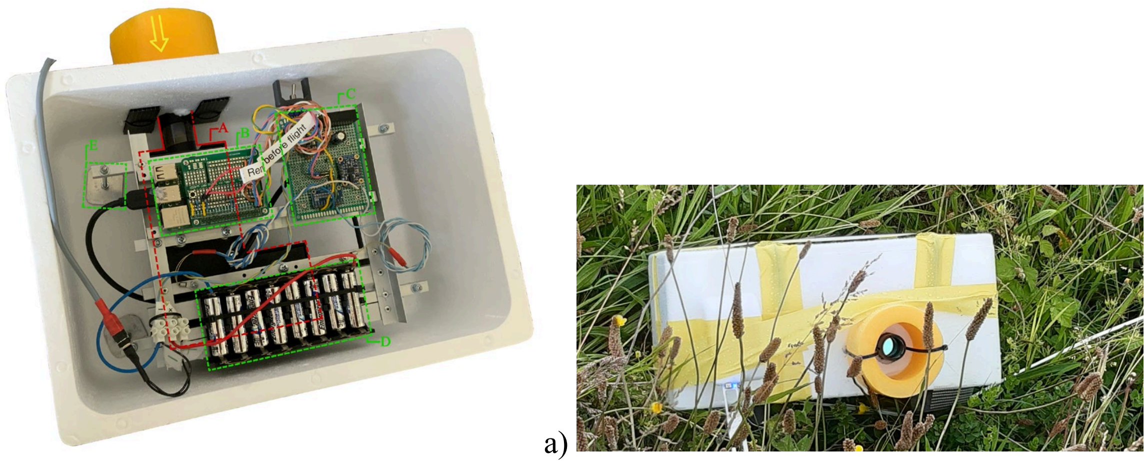
Fig. 1. Image of the realized instrument. a) The spectrometer without the cover and with all the main parts indicated. The yellow overlay mimics the light path and illustrates the imaging action of L3, which projects the interferogram on the detector focal plane. b) The spectrometer installed on a breadboard, during the pre-flight tests.

The flight

As in the first flight [7], the spectrometer, prepared for the flight campaign, has been installed inside a polystyrene box with 1 cm thick walls. The box contains also all the electronics and the power source, see Fig. 2 for details on the internal sub-assembly arrangement. The flight took place the 11th of May 2023 in the morning at the Aire-Sur-L'Adour "Centre d'Opérations Ballons" - CNES. The ascending phase lasted about 1 hour and 30 minutes and the descending one 50 minutes, for a total flight duration of about 2 hours and 20 minutes. The maximum reached altitude, as inferred from the internal sensor (Bosch BME680) with its default calibration curve, was 26 km. Pressure altitude and temperature as measured from the internal transducers are plotted in Fig. 3.

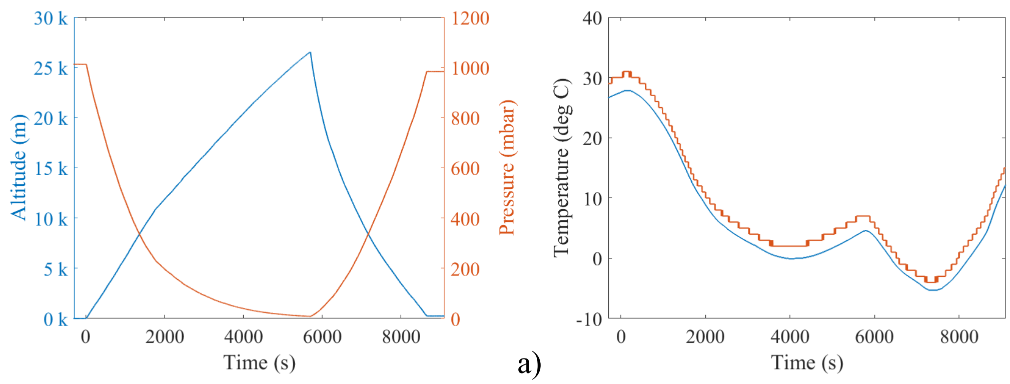
An interferogram has been acquired every second. Fig. 4a presents a 2D map of the acquired spectra during the entire ascending and descending phase. To obtain a spectrum, the interferogram is line by line multiplied with a "Blackman" window, then for each line the squared absolute value of the 1-D Fourier transform is calculated. The results are then averaged on the full frame. For each acquisition the spectrum is normalized to its maximum value. Fig. 4b shows in detail three spectra acquired after 1031 s, 3007 s and 5504 s.

Materials Research Proceedings 37 (2023) 270-273
https://doi.org/10.21741/9781644902813-59



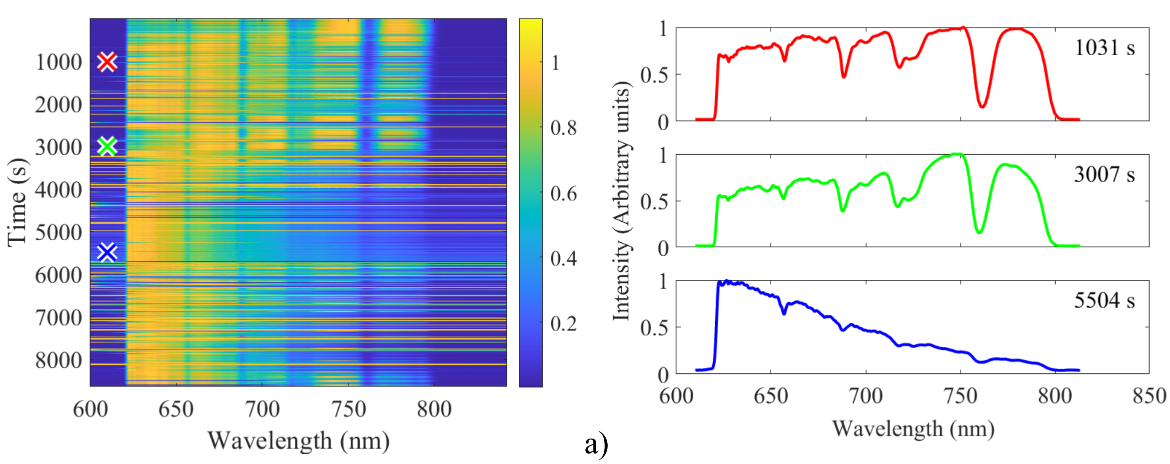
a) b)

Fig. 2. The instrument assembled for the flight campaign. a) Internal view: the arrow indicates the entering direction of the light. A) the instrument, partially hidden behind the two PCBs, B) the single board computer, C) the power and environmental sensing unit, D) the batteries, E) one of the four connecting pylons between the instrument and the external box in polystyrene. b) The instrument, landed in an open field, after the flight.



a) b)

Fig. 3. Environmental parameters acquired during the flight. a) Altitude and pressure from Bosch BME680. b) Temperature inside the polystyrene box measured by two distinct transducers.



a) b)

Fig. 4. Spectra acquired during the flight. A) 2D map: each spectrum is normalized to its maximum value. B) for the three horizontal cuts corresponding to the crosses in figure a), the corresponding spectra are plotted. The spectra are acquired after 1031, 3007, 5504 seconds from the beginning of the flight.

Conclusions

The proposed optical design proved to operate in a real flight environment showing negligible thermal drift effects. Moreover, compared to the previous spectrometer design [7] which featured separate prisms and beam splitter on an aluminum optical bench, this new layout showed an improved mechanical stability. Despite the lightweight 3D printed supporting base, the new design enabled operation with longer integration times without any spectral degradation due to loss of contrast in the interferogram.

Acknowledgments

We desire to thank all the people from CNES, ASI and INAF that supported us during the realization of the instrument and the flight campaign. In particular, and knowing we are mentioning just a few, André Vargas, Cruzel Serge, all the CNES operation team, Angela Volpe, Lorenzo Natalucci, Pietro Ubertini and all the HEMERA community.

Fundings

This work has been supported by ASI, Agenzia Spaziale Italiana, Agreement n. 2019-33- HH.0, for the payload realization and the flight opportunity has been provided by the European Commission in the frame of the INFRAIA grant 730790-HEMERA.

References

[1] J. M. Harlander, Spatial Heterodyne Spectroscopy: Interferometric Performance at any Wavelength Without Scanning, Thesis (Ph.D.) University of Wisconsin, Madison, 1991, https://ui.adsabs.harvard.edu/abs/1991PhDT........62H

[2] J. Harlander, F. Roesler, J. Cardon, C. Englert and R. Conway, Shimmer: a spatial heterodyne spectrometer for remote sensing of Earth' middle atmosphere, Appl. Opt. 41, 1343-1352 (2002). https://doi.org/10.1364/AO.41.001343

[3] M. Kaufmann, F. Olschewski, K. Mantel, B. Solheim, G. Shepherd, M. Deiml, J. Liu, R. Song, Q. Chen, O. Wroblowski, D. Wei, Y. Zhu, F. Wagner, F. Loosen, D. Froehlich, T. Neubert, H. Rongen, P. Knieling, P. Toumpas, J. Shan, G. Tang, R. Koppmann and M. Riese, A highly miniaturized satellite payload based on a spatial heterodyne spectrometer for atmospheric temperature measurements in the mesosphere and lower thermosphere, Atmos. Meas. Tech., 11, 3861–3870. https://doi.org/10.5194/amt-11-3861-2018

[4] F. Frassetto, L. Cocola, V. Da Deppo, L. Poletto and P. Zuppella, High signal-to-noise ratio spectrometer based on static Fourier transform interferometer (for hemera balloon flight), Italian Association of Aeronautics and Astronautics, XXV International Congress, 9-12 September 2019, Rome, Italy

[5] F. Frassetto, L. Cocola, R. Claudi, V. Da Deppo, P. Zuppella and L. Poletto, Low noise Fourier transform spectrometer for a balloon borne platform, Italian Association of Aeronautics and Astronautics, XXVI International Congress, 31 August -3 September 2021, Pisa, Italy. https://doi.org/10.5194/egusphere-egu22-11428

[6] F. Frassetto, L. Cocola, P. Zuppella, V. Da Deppo and L. Poletto, High sensitivity static Fourier transform spectrometer, Opt. Express 29, 15906-15917 (2021). https://doi.org/10.1364/OE.422645

[7] F. Frassetto, L. Cocola, R. Claudi, V. Da Deppo, P. Zuppella and L. Poletto, Report on a refractive static Fourier transform spectrometer flown on a stratospheric balloon for the HEMERA program, ICSO International Conference on Space Optics 3-7 October 2022, Dubrovnik, Croatia. https://doi.org/10.5194/egusphere-egu22-11428