THz Solar Observations on Board of a Trans-Antarctic Stratospheric Balloon Flight

P. Kaufmann, *Member IEEE,* A. Abrantes, E. C. Bortolucci, A. Caspi, L. O. T. Fernandes, G. Kropotov, A. S. Kudaka, G. Laurent, N. Machado, R. Marcon, A. Marun, V. Nicolaev, R. F. Hidalgo Ramirez, J.-P. Raulin, P. Saint-Hilaire, A. Shih, C. M. Silva, and A. Timofeevsky

***Abstract*— A new system of two photometers was built to observe the Sun at 3 and 7 THz from space, named SOLAR-T. It has been flown coupled to U.C. Berkeley GRIPS experiment on a NASA stratospheric balloon flight over Antarctica, 19-30 January 2016. The mission was successfully accomplished. We describe the system performance, solar brightness determination and the first THz impulsive burst detected.**

***Index Terms*— Solar flares, solar brightness, THz measurements from space, THz solar photometers.**

I. Introduction

Sub-THz and 30 THz solar burst observations revealed a new spectral component, with fluxes increasing towards THz frequencies, simultaneously with the well known component peaking at microwaves, bringing challenging constraints for interpretation [1-3]. The THz flare spectra can be completed with measurements made from space. A new system of two photometers was built to observe the Sun at 3 and 7 THz, named SOLAR-T [4]. An innovative optical setup allows observations of the full solar disk and detects small bursts with sub-second time resolution. The photometers use two Golay cell detectors at the foci of 76 mm Cassegrain telescopes. The incoming radiation undergoes low-pass filters made of rough surface primary mirrors and membranes, 3 and 7 THz band-pass filters, and choppers (Fig. 1).

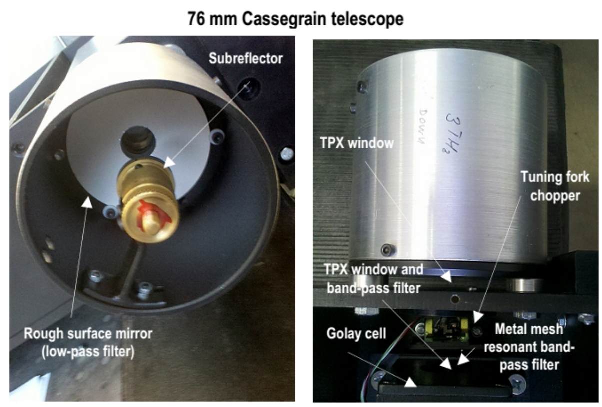


Fig. 1 – One SOLAR-T 76 mm telescope (left) has a rough surface primary to diffuse visible and near IR. Radiation is fed into the Golay cell, preceded by TPX windows, TydexBlack low-pass filter membrane, resonant metal mesh 3 and 7 THz band-pass filters, and resonant tuning fork 20 Hz chopper.

The system carried redundant data acquisition system and Iridium telemetry for monitoring during the flight. SOLAR-T has been flown coupled to U.C. Berkeley solar hard X-ray and gamma-ray imaging spectro-polarimeter GRIPS [5] experiment launched on a NASA CSBF stratospheric balloon from U.S. McMurdo base on January 19, 2016, on a trans-Antarctic flight. The mission ended on January 30. The SOLAR-T on-board computers were recovered from the payload that landed in the Argentina Mountain Range, nearly 2100 km from McMurdo.

II. SOLAR-T performance and results

The SOLAR-T performance was successfully attained, with full space qualification of instrumentation. Fig. 2 shows SOLAR-T under tests at McMurdo base and installed at the top of GRIPS boom.

The THz optics forms a solar disk image smaller than the photometers input cones. A small halo surrounds the disk due to spherical aberration. In actual GRIPS tracking conditions SOLAR-T input cones observed partially the eastern part of

This work was partially supported by Brazilian agencies FAPESP (Proc. 2013/24155-3), Mackpesquisa, CNPq, CAPES, NAMITEC, US NASA, AFOSR, Argentina CONICET.

P. Kaufmann, L.O.T. Fernandes, A.S. Kudaka, R.F.H. Ramirez, J.-P. Raulin are with Escola de Engenharia, CRAAM, Universidade Presbiteriana Mackenzie, São Paulo, SP, Brazil (e-mail:pierrekau@gmail.com).

A. Abrantes and N. Machado are with Propertech Ltd., Jacarei, SP. Brazil (e-mail:nelson@propertech.com.br).

E.C. Bortolucci and P. Kaufmann are with Centro de Componentes Semicondutores, Universidade Estadual de Campinas, Campinas, SP, Brazil (e-mail: emiliocb@unicamp.br).

A. Caspi and G. Laurent are with [4]Southwest Research Institute, Boulder, CO, USA (e-Mail: amir@boulder.swri.edu).

G. Kropotov, V. Nicolaev and A. Timofeevsky are with Tydex LLC, St. Petersburg, Russia (e-mail: grigorykropotov@tydex.ru).

R. Marcon is with [6]Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Campinas, SP, and Observatório Solar "Bernard Lyot", Campinas, SP, Brazil (e-mail: rmarcon@mpcnet.com.br).

A. Marun is with Instituto de Ciencias Astronomicas, Tierra y Espacio, Conicet, San Juan, Argentina (e-mail: amarun@icate-conicet.gob.ar).

P. Saint-Hilaire is with Space Science Laboratory, University of California, Berkeley, CA, U.S.A. (e-mail: shilaire@ssl.berkeley.edu).

A. Shih is with NASA, GSFC, Greenbelt, MD, U.S.A. (e-mail: albert.y.shih@nasa.gov).

C. M. Silva is with Neuron Ltda., São José dos Campos, SP, Brazil (e-mail: cmsilva@bighost.com.br).

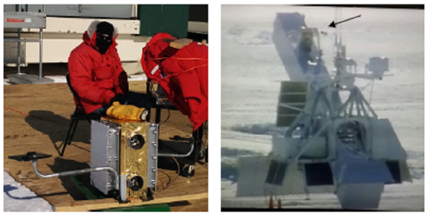


Fig. 2 –SOLAR-T under tests at U.S. McMurdo base in Antarctica (left) and at the top of GRIPS on pre-launch phase (right)..

the solar disk with constant gain over it. This is illustrated in Fig. 3. Tracking variations produced changes in exposed areas and respective signal levels. 3 THz telescope observed nearly 60-70% of the disk all time, while the 7 THz telescope observed 5-70 % of the disk, depending on tracking fluctuations.

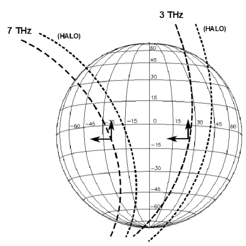


Fig. 3 –Solar disk as approximately observed by SOLAR-T 3 and 7 THz photometers, at a period of time on January 28, 2016.

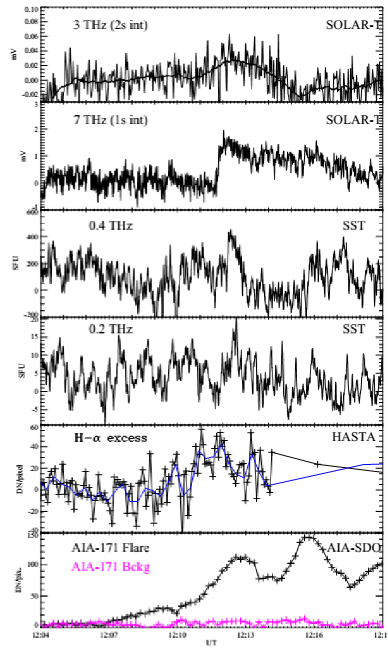
Full solar disk to sky scans were obtained as the GRIPS pointing and tracking was set earlier in the mission. Solar disk brightness temperatures were estimated as 5300K at 3 THz and 4700K at 7 THz. These values are within the range of temperatures found by other authors [6]. The result also demonstrates that both SOLAR-T photometers performed according to pre-calibrations measurements.

Reduced data allows the detection of intensity excess of the order of 1 % of the full solar disk emission level at both frequencies. The first THz impulsive burst was detected on January 28, 2016, at 3 and 7 THz, shown in Fig 4 (a). It peaks at a time coincident with bursts detected at 0.2 and 0.4 THz by ground-based Solar Submillimeter Telescope, SST, in Argentina, in Hα by HASTA (Argentina) and in EUV by AIA SDO on solar active region NOAA 14289 (N10E25). Spectral trends in the sub-THz and THz bands indicate fluxes increasing with frequency at both ranges, with a possible break in intensity somewhere between 0.4 and 3 THz (Fig. 4 (b)).

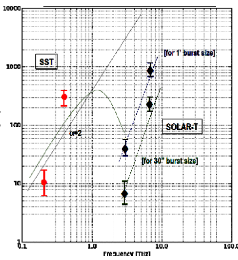
The burst time coincided to the time of collision at the eastern footpoint of an EUV bright "falling blob", formed earlier at the top of an arch, as shown in Fig. 5.

Acknowledgments

We acknowledge C. Francile (UNSJ) for providing the high cadence Hα HASTA observations.



(a)



(b)

Fig. 4 – (a) The first THz burst detected (left top two panels) on January 28, 2016, peak at 12:12 UT, simultaneous to ground-based SST observations (middle two panels), HASTA Hα and AIA-SDO, shown in the 171 Å wavelength on January 28, 2016. (b) Spectral trends derived from observations at sub-THz (SST) and THz frequencies (SOLAR-T).

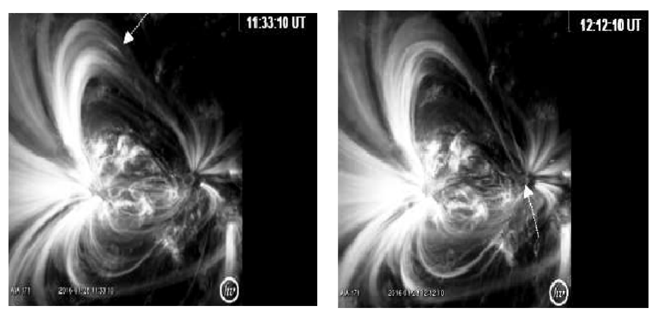


Fig. 5 – AIA SDO 171 Å images of AR14289, shows the earlier sudden formation of a bright blob at the top of the northern arch, that "falls" forming a new arch, hitting the footpoint at the same time of the THz burst peak.

References

[1] P. Kaufmann *et al.* "A new solar burst spectral component emitting only in the terahertz range", *Astrophys.J.,* vol. 603, pp. L121-L124, 2004.

[2] P. Kaufmann *et al*.: "Bright 30THz impulsive solar bursts, *J. Geophys. Res. (Space Phys.),* vol.120, pp. 4155-4163, 2015.

[3] G.D. Fleishman, E. Kontar, "Sub-THz Radiation Mechanisms in Solar Flares, *Astrophys. J.,* vol. 709, pp. L127-L132, 2010.

[4] P. Kaufmann *et al.,* "SOLAR-T : Terahertz Photometers to Observe Solar flare Emission on Stratospheric Balloon Flights", *Proc. of SPIE*, vol. 8442, pp. 8442L1-8442L9, 2012,

[5] N. Duncan *et al.,* "Detector and imaging systems for the gamma ray imager/polarimeter for solar flares (GRIPS) instrument", *SPIE Proc.,* vol. 8862, pp. 8862OW-1-8862OW-11, 2013.

[6] K. Shibasaki *et al.,* "Radio emission of the quiet Sun and active regions (Invited Review)", *Solar Phys*., 273,.309-337, 2011.