

Physical Questions Raised by Frequency-Increasing Sub-THz Solar Flare Emissions and a New Tool to Reveal THz Spectral Shapes

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Abstract

Important emissions at higher frequencies have been suggested by some of the earlier flare observations in the microwaves to mm-waves. Recent sub-THz and 30 THz observations revealed a new spectral component, with fluxes increasing towards THz frequencies, simultaneously with the well known spectral component peaking at microwaves, bringing challenging constraints for interpretation. The knowledge of the complete THz flare spectrum is the essential requirement for understanding the origin of this radiation. We present the concept, fabrication and performance of a double THz photometers system, named SOLAR-T. Its innovative optical setup allows observations of the full solar disk with enough sensitivity to detect small burst transients at the same time. It has been constructed to observe solar flare THz emissions on board of stratospheric balloons. SOLAR-T uses two Golay cell detectors preceded by low-pass filters made of rough surface primary mirrors and membranes, 3 and 7 THz band-pass filters, and choppers. Its photometers can detect small solar bursts (tens of solar flux units) with sub second time resolution. The system has been integrated to data acquisition and telemetry modules for this application. Tests comprised the whole system performance, on ambient and low pressure and temperature conditions. One artificial Sun setup was developed to simulate actual observations. The experiment is planned to be on board of two long-duration stratospheric balloon flights over Antarctica and Russia in 2014-2016.

1. GHz, Sub-THz and THz Flare Observations

A number of solar bursts observed at GHz, sub-THz and 30 THz frequencies indicate an emission spectral component at this range [1-4], distinct from the well known microwaves emission that maximizes at few to tens GHz. These results raise serious interpretation problems to explain both the sub-THz and the concurrent microwave component [5,6] (Figs. 1 and 2). The physical nature of the THz emission remains mysterious.

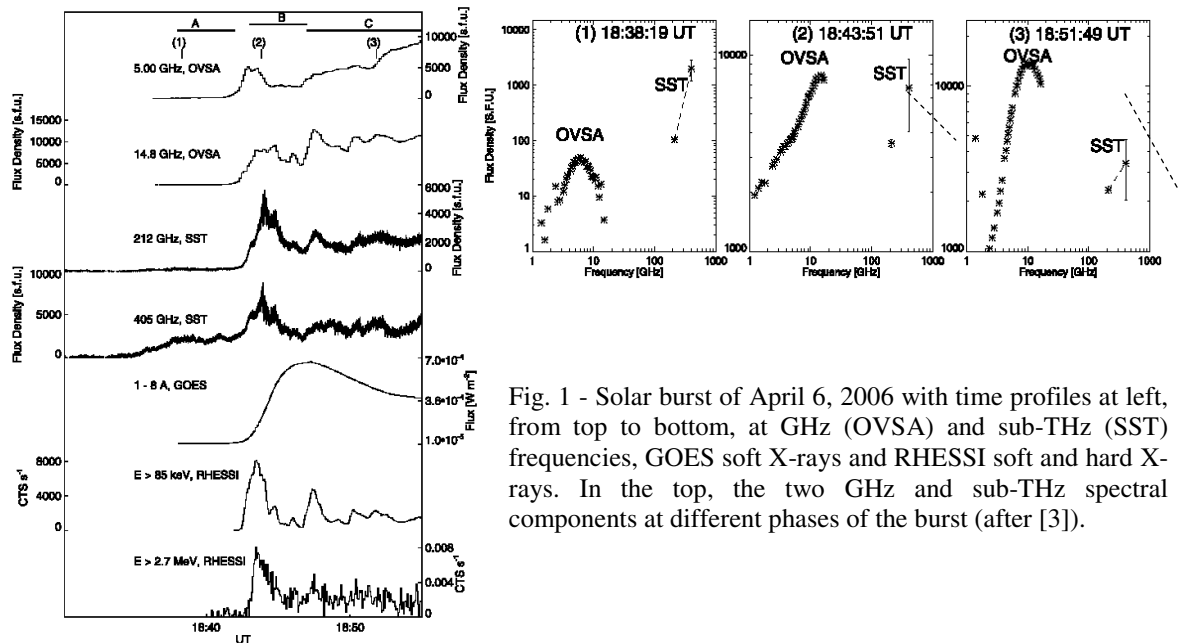


Fig. 1 - Solar burst of April 6, 2006 with time profiles at left, from top to bottom, at GHz (OVSA) and sub-THz (SST) frequencies, GOES soft X-rays and RHESSI soft and hard X-rays. In the top, the two GHz and sub-THz spectral components at different phases of the burst (after [3]).

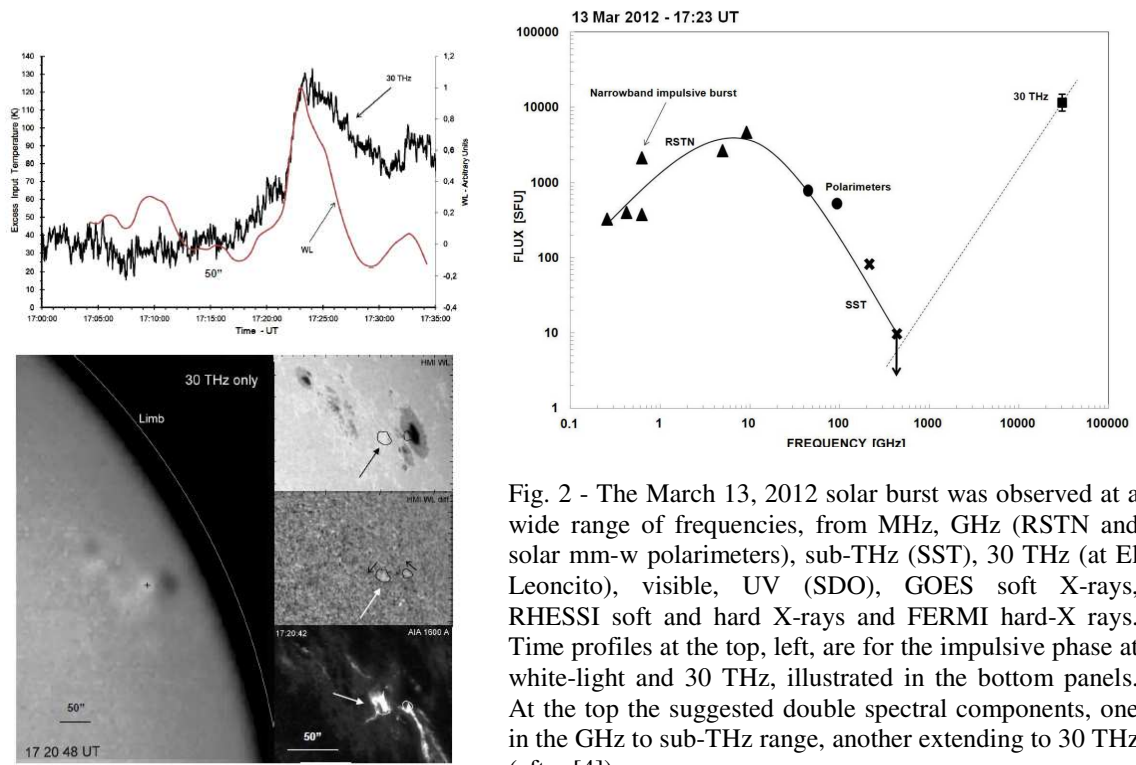


Fig. 2 - The March 13, 2012 solar burst was observed at a wide range of frequencies, from MHz, GHz (RSTN and solar mm-w polarimeters), sub-THz (SST), 30 THz (at El Leoncito), visible, UV (SDO), GOES soft X-rays, RHESSI soft and hard X-rays and FERMI hard-X rays. Time profiles at the top, left, are for the impulsive phase at white-light and 30 THz, illustrated in the bottom panels. At the top the suggested double spectral components, one in the GHz to sub-THz range, another extending to 30 THz (after [4]).

New insights on the physical processes involved need the complete THz spectral description. This requires observations with detectors outside the terrestrial atmosphere. Experiments SIRE [7] and DESIR [8] have been proposed to observe solar flares in the THz range from space. Solar activity may also be observed through few atmospheric THz transmission “windows” at exceptionally good high altitude ground based locations [9].

2. The 3 and 7 THz SOLAR-T space experiment

The THz solar photometers system, named SOLAR-T, is the result of nearly ten years of research on detecting devices, development and characterization of materials, filters and systems. Several prototypes have been built and tested for their performances [10-11]. The definitive flight system has been built at Tydex LCC, Saint Petersburg, Russia, integrated to data acquisition and telemetry modules developed for this application, and tested at Propertech Ltda. and Neuron Ltda. in Brazil [12]. It utilizes two modern versions of Golay cell detectors [13,14] preceded by low-

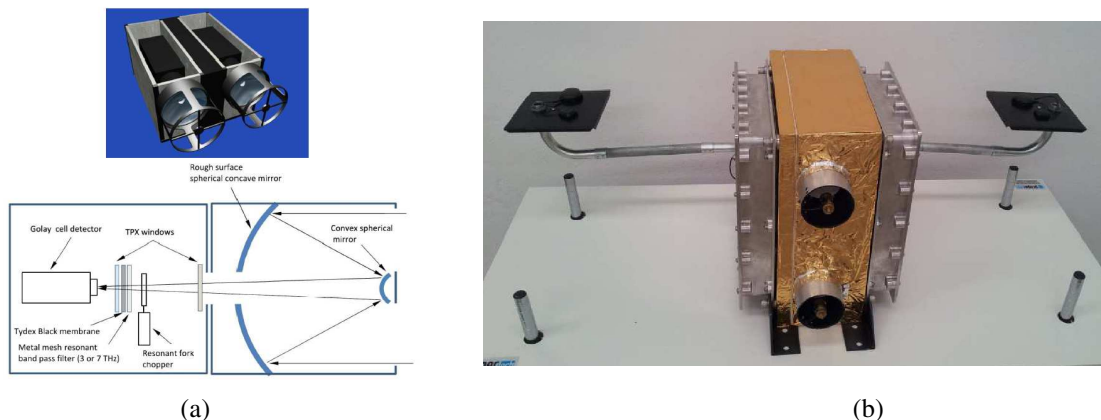


Fig. 3 – (a) The SOLAR-T photometers assembly concept. The diagram in the left bottom panel shows the Golay cell detector, preceded by TydexBlack low-pass filter membrane, a resonant metal mesh band-pass filter, and a resonant tuning fork 20 Hz chopper. The 76 mm Cassegrain telescope on the right has a rough surface to further diffuse the visible and near IR radiation. (b) The complete experiment integrated to the data acquisition and telemetry modules.

pass filters made of rough surface primary mirrors [15,16] and membranes [17] to suppress visible and near IR radiation, 3 and 7 THz metal mesh band-pass filters [18,19], and choppers. One innovative photon concentrator [14, 20] combines the formation of a full solar disk image at the focal plane with size smaller than the size of the surface of the detecting element with the primary aperture. It becomes possible to use apertures large enough to detect small solar bursts without the need to point at a particular location on the solar disk with narrow beams, as in usual coherent optical configurations. Fig. 3(a) illustrates the SOLAR-T design concept. Fig. 3(b) shows the complete experiment integrated to the data acquisition and Iridium telemetry modules (the aluminium lateral blocks).

3. SOLAR-T tests and performance

The Golay cells have two relevant characteristic response properties for the observations proposed here: (1) the noise fluctuations is constant and the same for the whole range of input temperatures and (2) the voltage outputs are proportional to the input temperatures. The calibration produced characteristic photometer output response of 9.8 K/mV at 3 THz and 4.2 K/mV at 7 THz. Samples of 30 minutes output system stability in response to a hot source input, with data points every 256 ms, smoothed over 11 points, exhibited peak-to-peak fluctuations of about $5 \cdot 10^{-2}$ mV, which corresponds to 0.5 K for both THz photometers. Neglecting the air transmission above the atmosphere, the aperture efficiencies obtained were of 0.2 and 0.15 at 3 and 7 THz, respectively. The three sigma detectable flux densities for $\Delta T \approx 0.5$ K correspond to less than about 150-200 SFU at 3 and 7 THz respectively.

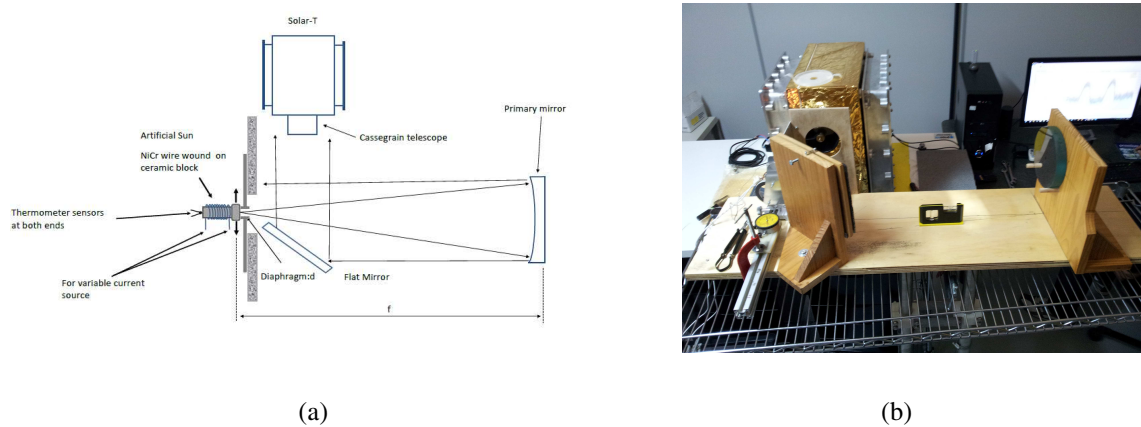


Fig. 4 – (a) The “artificial Sun” setup to simulate scans of disk radiation in front of the THz photometers. (b) The “artificial” Sun setup installed in front of one of the SOLAR-T telescopes for practical disk scans measurements.

An “artificial Sun” setup was constructed to confirm the SOLAR-T THz photometers actual performance to solar disk scans observations in laboratory, simulating realistic conditions in outer space (Fig. 4 (a) and (b)). The artificial Sun blackbody temperature was set at 743 K. Drift scans across the 3 and 7 THz photometers telescopes confirmed the spatial response predicted by the experiment new optics [11, 20]. The disc image size (of about 4.3 mm) was smaller than the Golay cell input cone (10 mm), producing an acceptance angle of about 50 arcminutes. Therefore the requirement for pointing and tracking accuracy is of about 20 arcminutes. The observed flux density was accurate to less than one order of magnitude compared to the calculated. In outer space SOLAR-T observations shall refer to scans of brighter disks, of about 4500 K (± 500 K) [21]. The three sigma solar flare flux density detectability was confirmed for both THz photometers (i.e. 150-200 SFU). In operational conditions, the solar scans will provide the flux density scale calibration for flares, as done by usual full Sun patrol radio telescopes.

Finally the Iridium based Short Data Burst services was successfully tested. Samples of 20 minutes data acquired, with 256 ms time resolution, were transmitted from SOLAR-T and received without any data point lost.

4. Final remarks

The SOLAR-T experiment shall fly on two long duration stratospheric balloon missions (2014-2016). One coupled to the gamma ray experiment GRIPS [22] of University of California, Berkeley, USA, over Antarctica (two weeks), and another over Russia (7-10 days) in cooperation with the Lebedev Physical Institute, Moscow, Russia, on an autonomous automatic Sun tracking gondola under development.

Acknowledgments: This program was partially funded by Brazil agencies FAPESP (Proc.2010/51861-8), CNPq INCT-NAMITEC, CNPq, and Mackpesquisa, Argentina CONICET and US AFOSR.

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