Space and Ground-Based New Tools for THz Solar Flare Observations


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Abstract—Recent sub-THz and 30 THz observations revealed an unexpected new spectral component, with fluxes increasing towards THz frequencies, simultaneously with the well-known 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 telescope photometric systems to observe solar flares at 3 and 7 THz from above the atmosphere, named SOLAR-T, and at 0.85 and 1.4 THz from the ground at a high altitude site, named HATS. The innovative optical setup allows observations of the full solar disk with high sensitivity to detect small burst transients (tens of solar flux units) with time resolution of less than one second. The SOLAR-T space experiment uses two Golay cell detectors at the focus of 7.6 cm 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. 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. SOLAR-T is being integrated to U.C. Berkeley gamma-ray GRIPS experiment to be flown on a long duration stratospheric balloon mission over Antarctica. The HATS telescope utilizes the same principles, with a 46 cm rough mirror Newtonian telescope, a Golay cell sensor preceded by low pass filter, and a double window chopper, each one with band pass filters at 0.87 and 1.4 THz. HATS now undergoes operational tests in Brazil, and is planned for operations in 2015 at a site to be selected in the Andes Cordillera, above 5000 m altitude.

I. 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 a 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.
II. THE 3 AND 7 THZ SOLAR-T SPACE EXPERIMENT

The THz solar photometers system, named SOLAR-T, is the result of more than 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 system to be flown on stratospheric balloon, 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-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, a limitation found in usual coherent optical configurations. The SOLAR-T will be flown together with U.C. Berkeley, SSL, gamma-rays experiment GRIPS [21] on long duration stratospheric balloon mission (one month) over Antarctica, scheduled for the southern summer 2015-2016. Fig. 3 illustrates the SOLAR-T design concept and the complete experiment with the data acquisition and Iridium telemetry modules (the aluminium lateral blocks), being assembled on GRIPS boom.
THz and 9.8 K/mV at 7 THz. Measured 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 $5 \times 10^{-2}$ mV, which corresponds to 0.5 K for both THz photometers. Neglecting the air attenuation 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.

Operational tests performed at SSL, U.C. Berkeley have confirmed SOLAR-T performance. Samples of data acquired with 256 ms time resolution were transmitted from SOLAR-T by the Iridium based Short Data Burst services and received without any data point lost.

IV. THE GROUND-BASED HATS EXPERIMENT

The terrestrial atmosphere presents transmission windows at sub-THz and THz frequency bands at high altitude sites for low precipitable water vapour content (PWV) [9,22]. Transmissions better than 50% at 0.67 and 0.85 THz bands and better than 15% at 1.3 and 1.5 THz bands can be attained at 5000m altitude with PWV < 1mm.

A telescope has been designed for photometry of solar flares at 0.87 and 1.4 THz. It utilises the same optical concept of SOLAR-T [12]. A short focal length 46 cm diameter mirror, producing a solar image smaller than the Golay cell detector input cone placed at its Newtonian focus, as shown in Figures 4 and 5. Band-pass metal mesh filters were fabricated with bandwidth of 20% of the central frequencies. They are placed at the separate chopper wheel windows. To account for the 40 ms Golay cell response time constant [23], the input radiation gets into the filter during 50 ms, then blocked along 250 ms for the cell return to the ground level, followed by the next frequency filter and blockage. A set of readings are recorded at the end of each phase. A synchronous detection firmware has been developed for the data acquisition of the two frequency photometric readings. The radiation input at each frequency is measured once every 600 ms.

![Ground-based two-frequency photometer](image.png)

Fig. 4 – Schematic diagram of HATS photometric telescope

Figure 5, left, show the complete HATS assembly. Right panels, top right: the case containing the Golay cell and chopper placed at the Newtonian focus; middle: the chopper wheel exhibiting the windows with metal mesh band-pass filters, one at 0.87 THz and another at 1.4 THz; lower panel shows the 46 cm rough surface mirror.

![HATS system assembly](image.png)

Fig. 5 – Left: the complete HATS system assembly undergoing operational tests. Right, top: the Golay cell and double window wheel front-end case at the Newtonian focus; middle: chopper wheel with 0.87 and 1.4 THz band-pass filter windows; bottom: the 46 cm rough surface reflector with three small polished mirrors for alignment adjustments.

The HATS system operational tests performed at Propertech facilities, Jacareí, SP. Brazil have demonstrated appropriate performance. The telescope was placed at a robotic Paramount polar mount [24]. The fine tracking corrections will be supported by a Hutech-Hinode sun-guider [25] installed on the telescope body, interfaced to the mount tracking software.

Preliminary measurements have shown that the system can detect three sigma excess temperature excess smaller than 0.5 K at each frequency. The three sigma solar burst detection sensitivity can be predicted for the aperture effective area taking into account all transmission factors at the two frequencies: (1) instrumental (a) physical blockage, 0.85; (b) low-pass filter rough mirror reflection, 0.90; (c) two 2 mm thick TPX windows 0.76 at 0.87 THz and 0.72 at 1.4 THz; (d) Tydex low-pass filter LPF23.1 membrane, 0.7 at 0.85 THz and 0.5 at 1.4 THz; and (e) band-pass filter, 0.9. Net transmissions due to instrumental losses: 0.37 and 0.25 at 0.85 and 1.4 THz respectively. (2) Atmospheric transmission of about 0.5 at 0.87 THz and 0.15 at 1.4 THz, in the zenith direction, might be assumed for a high altitude location exhibiting precipitable water vapour content < 1 mm [22]. For solar observations at an elevation angle of 45 degrees the net aperture effective areas become 0.023 m$^2$ at 0.87 THz and 0.003 m$^2$ at 1.4 THz, respectively. For three sigma $\Delta T < 0.5$ K the predicted minimum detectable flux densities become < 5 SFU at 0.87 THz and of < 40 SFU at 1.4 THz. A new data sampling
technique is being added to further improve the HATS response to small THz burst levels.

A site is being selected for definitive installation and operations in 2015. The atmosphere THz transmission conditions described before are attained at Chajnantor, Chile. Good transmission conditions are expected at Atacama plateau, at 5000 m altitude, for about 100 days each year [22]. Good transmission conditions are expected at Famatina Mountain, above 5200 m altitude, in Argentina La Rioja region.

V. CONCLUDING REMARKS

In the course of 2015-2016 it is expected to obtain the unprecedented solar flare spectral coverage at 45, 90, 212, 405 GHz (El Leoncito); 0.87 and 1.4 THz with HATS; 3 and 7 THz from space, and ground-based 30 THz in Argentina and Brazil. These observations, combined with other ground-based radio, visible, space EUV, X- and Gamma rays, will provide an unique extended spectral description of the solar flare emissions which shall bring new clues to understand the still mysterious energy conversion physical processes in the Sun.

ACKNOWLEDGMENT

These researches and developments are being partially funded by Brazil agencies FAPESP, CNPq Mackpesquisa, INCT NAMITEC and U.S. NASA and AFOSR.

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