THz Solar Telescope for Detection Flare Synchrotron Radiation

Pierre Kaufmann[1,2]***, and J. Michael Klopf*** [3]

[1]Escola de Engenharia, Centro de Rádio-Astronomia e Astrofísica Mackenzie - CRAAM, Universidade Presbiteriana Mackenzie, São Paulo, SP, Brazil (pierrekau@gmail.com)
[2]Centro de Componentes Semicondutores, Universidade Estadual de Campinas, Campinas, SP, Brazil

[3]Jefferson Lab, 12000 Jefferson Ave., Newport News, VA 23606, USA

Abstract

Recent solar flare observations have shown the existence of a spectral component exhibiting fluxes increasing with frequency in the sub-THz spectrum simultaneously with the well known spectral component peaking at microwaves bringing challenging constraints for interpretation. This double spectral feature cannot be well explained by existing models. One possibility is to associate the high frequency emissions to incoherent synchrotron radiation (ISR) produced by flare accelerated beams of high energy electrons with intensity peaking at THz frequencies. Certain wave-particle instabilities may set in the electron beam, giving rise to bunching of the electrons which could radiate powerful broadband coherent synchrotron radiation (CSR) in the microwave spectrum peaking at wavelengths comparable to the size of the bunching. Although this CSR process has been observed in laboratory accelerators, only now has its association to solar flare physics been explored. Simulations have shown that the mechanism may be extremely efficient and highly localized in solar flares. To demonstrate the high energy ISR emission in flares it is necessary to measure the complete continuum spectra at higher THz frequencies, outside the terrestrial atmosphere. A THz telescope has been developed with a 75 mm primary reflector with rough surface to diffuse part of the incoming visible and near IR radiation. Golay cell detectors are preceded by low-pass membranes and band-pass metal mesh resonant filters tuned at 3 and 7 THz.

1.The Nature of Solar Flare High RF Continuum Emissions

A number of solar bursts observed in the whole range of GHz to sub-THz frequencies have exhibited two unexpectedly distinct spectral components: one corresponds to the well known microwave emissions maximizing at few to tens of GHz, and another with fluxes increasing for larger sub-THz frequencies. Early solar burst observations made up to 0.1 THz did suggested high frequencies "double-spectral" features [1-3]. Recent observations carried out at higher frequencies (0.2 and 0.4 THz) by the Solar Submillimeter Telescope, SST, have further characterized the sub-THz flux component increasing with frequency [4-6]. Fig. 1 shows the first and best example of a two spectral component solar burst in the GHz to sub-THz range of frequencies. These results raise serious problems to explain both the sub-THz and the concurrent microwave component. A number of emission processes proposed to explain the sub-THz spectral

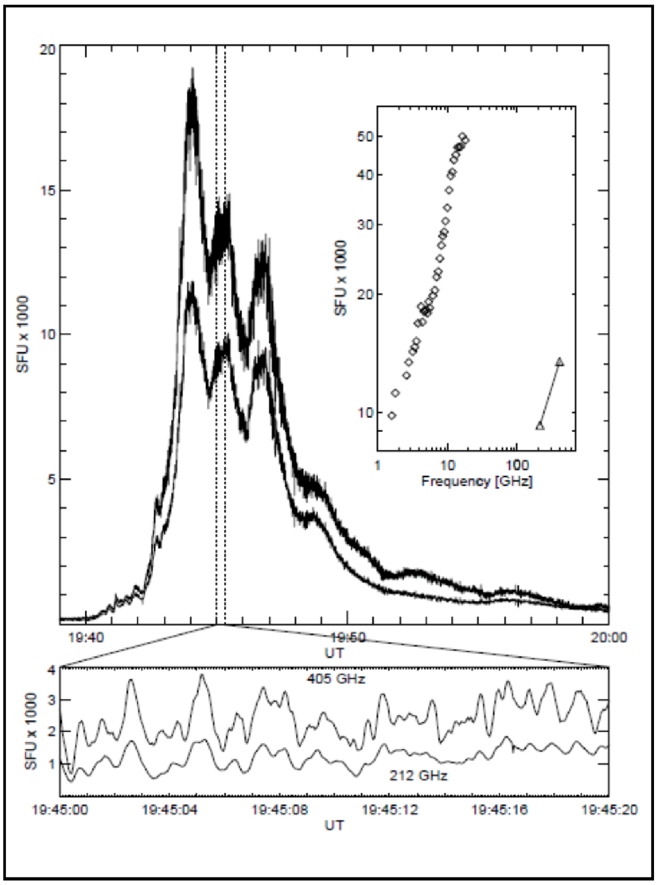

Fig. 1 – The solar burst of November 4, 2003 was the first event observed to produce a sub-THz spectral component with fluxes considerably larger at 0.4 THz than at 0.2 THz [4]. The first and the fourth peaks were simulated applying the microbunching instability mechanism in Fig. 2.

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component include synchrotron emission produced by high energy electrons [4,6], synchrotron from relativistic positrons [6,7]; emission by Langmuir waves [8,9] and inverse-Compton effect on the field of synchrotron electrons [10]. Some of these mechanisms were recently reviewed by Fleishman and Kontar [11] who have added two other possibilities: the inverse-Compton effect on field of photons produced by Langmuir waves and the Vavilov-Cherenkov emission by high energy electrons on an assumed partially ionized chromospheric gas.

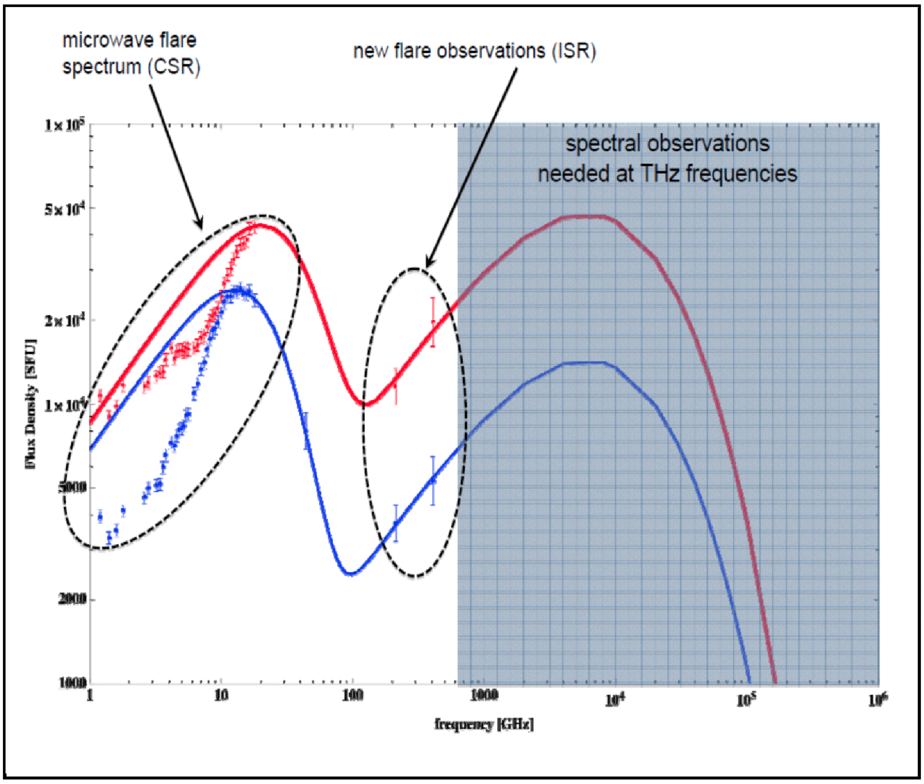

Fig. 2 – Simulation of emission from the proposed bunching mechanism fit to the two time structures the November 4, 2003 solar burst [14]. This bunching could radiate powerful broadband coherent synchrotron radiation (CSR) in the microwave spectrum at wavelengths comparable to and larger than the size of the bunching (3 cm here). The observed steeper spectral indices at lower frequencies is attributed to Razin effect and propagation in the active region medium while simulations are for vacuum conditions.

One method for producing very high power coherent broadband microwave to THz radiation has been demonstrated in laboratory accelerators, where relativistic bunches of electrons are compressed and accelerated using specially designed magnetic structures. The resulting synchrotron emission from suitably compressed electron bunches exhibits a coherent enhancement for wavelengths approximately equal to or longer than the bunch length [12]. This produces a modified synchrotron spectrum with a second peak at lower frequency associated with the coherent synchrotron radiation (CSR), with power proportional to the square of the number electrons undergoing the process. The CSR spectrum can also be produced from microbunching that is self-induced in larger bunches as a result from the interaction of the high energy electrons with the coherent component of their own radiation field. In either case the CSR peak occurs at a frequency related to the spatial charge density of the high energy electrons. The CSR mechanism may operate as a source to explain the spectral features identified in the microwave to sub-THz emission of solar flare events [13-14].

Utilizing estimates for active region magnetic field structures and solar flare plasma parameters, the CSR and the ISR spectral components have been simulated. These results were successfully compared to the anomalous spectrum observed from microwaves to sub-THz frequencies during the November 4, 2003 flare as shown in Fig. 2. The physical parameters used in simulations have shown that the mechanism may be extremely efficient to reproduce the emissions observed. Assuming about 10^{29} ultra-relativistic electrons/s accelerated, only a small fraction of electrons (about 10^{16} electrons) undergoing the microbunching process are necessary to produce the observed CSR emission flux at microwaves.

The crucial requirement to fully demonstrate the high energy ISR emission in flares is to measure the complete continuum solar flare spectra at higher THz frequencies. To attain this objective a radiometer system has been developed to perform measurements at discrete THz frequencies outside the terrestrial atmosphere, to be used in stratosphere balloons or satellite missions.

2. THz Solar Radio Telescope

Considerable efforts have been made to develop photometry and imaging at THz frequencies. We have investigated the performance of low pass filters to prevent the income of visible and near infrared radiation, room temperature sensors sensitive to THz radiation and band pass filters to improve the sensitivity of the instrument [15]. The photometry of temperature enhancements above a pre existent bright level - as it is the case of flare radiation excess over the solar disk intense emission – brings special measuring requirements. One of them is the effective suppression of the incoming visible and near-infrared (NIR) radiation. This has been accomplished with the use of a combination of THz low-pass filters, consisting of rough surface mirrors and commercially available membranes [15]. Band-pass filters have been developed and tested, using a resonant metal mesh technique [16]. They allow a band larger than 20% the central frequency. The performance of the system assembly using distinct un-cooled sensors (microbolometer array, pyro-electric module, and Golay cell) response to black body THz radiation was investigated. It has been found that the Golay cell has a superior performance with much lower noise power level

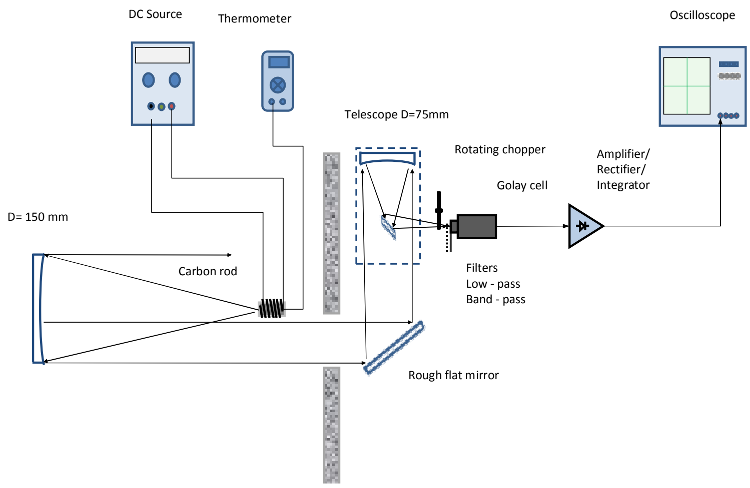

Fig. 3 – The THz radiometer assembly at right, uses a 75 mm Newtonian telescope to feed the Golay cell, preceded by the low-pass, band-pass filters and the chopper. Part of the incoming visible and NIR is diffused by a flat rough surface mirror placed at 45 degrees. A black body radiator assembly is at the left, with the heated source at the focus of a concave mirror, exhibiting an angular size comparable to the solar disk. See technical details at paper presented in this URSI GA [17].

The diagram for one prototype is shown in the diagram of Fig. 3. Tests using band-pass mesh filters have shown that the system can detect 1 K with about 0.2 s time integration [17]. For a 75 mm aperture, assuming 50% losses, it corresponds to about 60 10^{-22} w m^{-2} Hz^{-1}, or 60 solar flux units (a small solar burst).

3. THz Solar Observations from Space

A double THz solar radiometer system is currently being developed to operate at center frequencies of 3 and 7 THz, which concept design is shown in Fig. 4. It was provisionally named SOLAR-T [19].

The Golay cell sensor is preceded by sandwich made of a plate with good THz transmission , a low pass membrane filter ($\lambda \geq 20$ µm), resonant metal mesh band-pass filters with center frequencies at 3 and 7 THz (± 10% bandwidth), and a tuning fork resonant chopper. The incoming solar signal is collected by Cassegrain telescopes which reflectors' surfaces are roughened in order to diffuse most of the visible and near IR thermal radiation. SOLAR-T system is planned to be flown in long duration flights in USA and Antarctica (about two weeks circumnavigation), in 2012 and 2013, respectively, in cooperation with University of California, Berkeley, together with their GRIPS gamma-ray experiment [19], and over Russia (about one week) sometime between 2013-2016, in a cooperation with Moscow Lebedev Physics Institute.

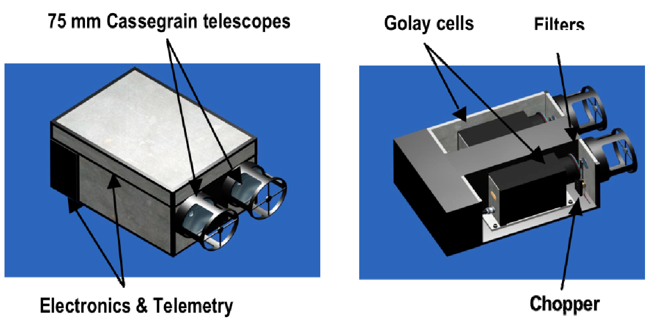

Fig. 4 – The dual 3 and 7 THz solar telescope concept design carrying two 75 mm Cassegrain telescopes.

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