# LLAMA SUB-THZ HIGH CADENCE CAMERA FOR SOLAR FLARES


## Abstract

New solar flare diagnostics at different electromagnetic bands are needed to allow a better understanding of the emission component found at sub-THz frequencies, extending to THz or far infrared ranges. The results recently obtained brought new constraints for the interpretation of physical mechanisms at the origin of the flaring process. There are unquestionable evidences that sub-THz flare emission have clear association to particle acceleration to ultra-relativistic energies also producing tens MeV gamma rays. Solar flare sub-THz radiometry and imaging from the ground will bring the unique opportunity to obtain new unprecedented information, essential to understand the origin of the flare accelerators. This objective can be accomplished with the development of ground-based sub-THz photometer/imager coupled to a large antenna located at a high altitude site. These measurements will be complemented by planned space observations at THz frequencies.


## 1. <u>The scientific case</u>

### 1.1. Synchrotron radiation components

Figure 1 shows the characteristic electromagnetic spectrum for flare emissions in the radio band, from metric to submillimeter wavelengths. The new spectral component discovered (Kaufmann *et al.* 2004), structure C in Figure 1, suggest the existence of another synchrotron emission component involving larger electron energies (> tens of MeV) and intense magnetic fields (1000 Gauss). The two superimposed spectral components (B and C, in Figure 1) may correspond to electrons injected into magnetic arches at different heights and different magnetic field strengths (according to the classical Wild & Smerd cartoon 1972; Silva *et al.* 2007). Another possibility involves the excitation of Langmuir waves by electron or proton beams in solar atmosphere denser regions (Sakai & Nagasugi 2007). The possibility of synchrotron emission by high energy positrons has been discussed (Silva *et al.* 2007; Trottet *et al.* 2008). The T-ray emission component has been detected in large and small events as well (Silva *et al.* 2007; Cristiani *et al.* 2008, Kaufmann *et al.* 2009a).

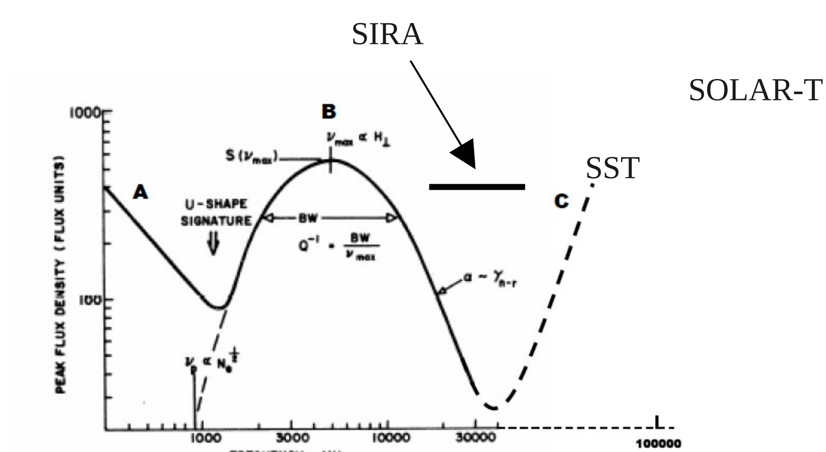


**Figure 1 - (up to 30 GHz, after Castelli 1972)**

Solar flare GHz emissions (spectral structure B in Figure 1) are usually attributed to gyrosynchrotron produced by mildly relativistic electrons (energies upt to few MeV in magnetic fields of few hundred Gauss), exhibiting typical maximum fluxes at about 10 GHz (Dulk 1985; Bastian, Benz & Gary 1998). The emission regime is optically thin for higher frequencies. Their intensity and spectral indices bring information on the energies of the accelerated electrons. Other researches have found that more than half of larger bursts exhibit emission maxima in the frequency range 25-30 GHz (Correia, Kaufmann & Magun 1994), often extending up to 80 GHz (Ramaty *et al.* 1994; Nita, Gary & Lee 2004; Bastian, Fleishman & Gary 2007; Altyntsev *et al.* 2008). The GHz component (structure B in Figure 1) might eventually be the result from broadband coherent synchrotron radiation originated from wave-particle instability known as “microbunching”, occurring in beams of ultrarelativistic electrons accelerated, these ones producing the observed THz component (Williams 2002; Kaufmann & Raulin 2006; Klopf 2008).

The complete diagnostic of the flare processes require measurements at unexplored spectral bands in the THz range of frequencies. Some solar events may present ambiguities in the characterization of the GHz and THz spectral mixed-up components in the millimeter (GHz) band between 20 GHz (the highest Owens Valley Solar Array-OVSA frequency) and 200 GHz (the lowest Solar Submillimeter-wave Telescope- SST frequency) due to the lmissing observations in the 20- 200 GHz range (Lüthi, Lüdi & Magun 2004; Raulin *et al*. 2004). Therefore, space observations in the THz range, complemented by the GHz and sub-THz ground based observations, are essential to set the boundary conditions relative to accelerated electrons energies and on their distribution. They will characterize completely the GHz and the THz spectral components, and discriminate them when superimposed, bringing the necessary information for the interpretation of the physical mechanisms at the origin of solar flares.

Recently project SIRA has been approved by Brazil São Paulo State research agency FAPESP, assuring the full operation of the sub-THz SST (at 200 and 400 GHz) together with high cadence Mid-infrared solar telescope (30 THz) at the El Leoncito observatory, in the Argentina Andes, within cooperation with the Complejo Astronomico El Leoncito, from Argentina research agency CONICET (Melo *et al.* 2006; Kaufmann *et al.* 2008; Marcon *et al.* 2008). Current plans include the construction of new high sensitivity (few solar flux units) and high time resolution (10 milliseconds) solar patrol circular-wave polarimeters at 45 and 90 GHz. These telescopes will contribute to distinguish emission components producing the spectral components B and C in Figure 1, helping to establish the causal relationships between the two.

### 1.2. Pulsating mechanisms

The emission diagnostics will be extended for the analysis of rapid pulsations in the THz range. They are present in the two spectral components, B and C (Figure 1), with distinct characteristics that needs to be better understood (Gaizauskas & Tapping 1980; Kaufmann *et al.* 1985; 2004; Correia & Kaufmann 1987; Qin *et al.* 1996; Nakajima 2000, Makhmutov *et al.* 2003; Raulin *et al.* 2004, Kaufmann *et al.* 2009b). This process might be associated to discrete pulsating energy release mechanisms related to the plasma instabilities that give origin to the bursts, or to modulations of flare generated confined plasma emissions. The onset of pulsating bursts at sub-THz frequencies seem to be associated to the onset of coronal mass ejections (CMEs) (Kaufmann *et al.* 2003). The analysis of burst-associated pulsations requires enough sensitivity and time resolution. The SOLAR-T photometer is planned to be sensitive to about 100 sfu (1 sfu = $10^{-22}$ W m$^{-2}$ Hz$^{-1}$) at 20 ms time resolution.

### 1.3. Filling the missing spectrum of continuum flare emissions

The spectral coverage of solar flare emissions in the continuum is strikingly poor. In Figure 2 we show the 4 November 2003 large flare emission from microwaves to the gamma rays. Continuum emission fluxes are unavailable along about five decades in frequencies, from the submillimeter range, at the higher SST frequency (400 GHz) to X-rays.

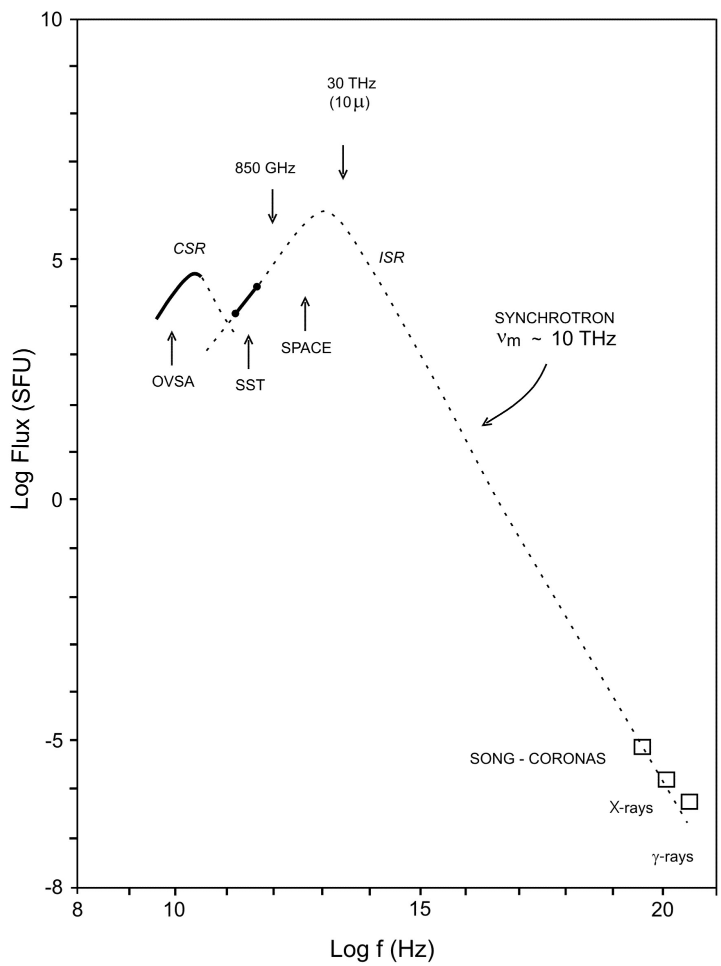


**Figure 2 – The known complete solar flare emission in the continuum, from microwaves to gamma rays, obtained for the November 4, 2003 event**.

Although there are many well known measurements carried out with photometers, spectrographs, imagers in the visible and UV, it is rather surprising to verify that continuum flux information are hardly available from about 4 $10^{11}$ Hz (sub-THz) to $10^{17}$ Hz (EUV). This might be explained by the existence of a number of instrumental limitations set by the solar telescopes designs. The ground-based and space telescopes optical setups were not designed for the purpose of broadband calibrated intensity measurements, often needing integration over angular sizes considerably larger than the instruments high resolution.

The new evidence showing that non-thermal continuum flare emission is likely to extend into far IR, visible and EUV require flux measurements in the whole range – particularly in the largely unexplored THz range of frequencies. New observing concepts are needed to obtain calibrated fluxes, with sufficient sensitivity even if in prejudice of the quality of space resolution.

It is proposed the development of a sub-THz flare imaging radiometer "camera" for focal plane of large aperture (Llama Project) applied to solar flare observations. These observations will be complemented by existing sub-THz continuum solar measurements (the SST Project) and planned solar flare emission at THz frequencies in space.

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## THE PROPOSED PROGRAM

Solar flare ground-based photometry and imaging at sub-THz frequencies

To obtain essential solar flare sub-THz flux measurements together with spatial information on bursts location at the active centers it is proposed to develop and construct a multiple beam camera to be placed at the focal plane of a large ALMA-like radio telescope able to point and track the Sun.

This proposal addresses specifically as an application for the Argentina-Brazil LLAMA joint project. It consists in an ALMA category 12-m single-dish radio telescope to be installed in a high attitude site located in the Argentina Andes, near the city of Salta.

At the LLAMA high altitude good transmission is expected at the atmosphere "windows" centered at 0.67 THz and 0.85 THz for a considerable number of days.

The camera should have a number of beams extending over a typical solar active region, say of about 2 arc-minute. The diffraction limited field of view, or the Airy angular size, is $\lambda$/D (rd) diameter or roughly about 6". Therefore, the camera might have, for example, 20x20 contiguous detectors to cover the whole solar AR. A simpler option may consider the use of arrays of pyroelectric detectors. This approach, however, will limit the flare observations time resolution to hundreds of milliseconds, considerably longer than the expected shorter bursts time scales of tens of milliseconds.

Since the room-temperature microbolometer arrays technology is not readily available at THz frequencies, the focal plane scale size for the 12-meter LLAMA reflector may limit the physical installation of larger size sensors, either horns feeding heterodyne receivers or far-IR detectors such as Golay cells.

Technical solutions to overcome this problem include the development of a sub-THz lens, the placement of one array of flat mirrors, or a combination of both, to widen the beam incoming from the sub-reflector over a wider angle, and thus extending the scale size at the focal plane.

The multiple “pixel” input calibration, data recording, storage, processing will be developed following well known technologies.

The time scale required for this development is of about 3 years. Rough estimate of costs: 1.5 MUSD.

**Institutions currently involved:** UP-EE-CRAAM Mackenzie, CCS-Unicamp, INPE-INATEL, CASLEO-Argentina, Observatoire de Paris