

Solar Submillimeter Telescope next generation

C. Guillermo Giménez de Castro^{*(1)(2)}, Jean-Pierre Raulin⁽¹⁾, Adriana Valio⁽¹⁾, Emilia Correia⁽¹⁾⁽³⁾, Paulo J. A. Simões⁽¹⁾⁽⁴⁾ and Sérgio Szpigel⁽¹⁾

(1) Centro de Rádio Astronomia e Astrofísica Mackenzie, EE, UPM, São Paulo, Brazil; e-mail: guigue@craam.mackenzie.br; raulin@craam.mackenzie.br; avalio@craam.mackenzie.br, ecorreia@craam.mackenzie.br, paulo@craam.mackenzie.br; szpigel@craam.mackenzie.br

(2) Instituto de Astronomía y Física del Espacio, UBA / CONICET, Buenos Aires, Argentina

(3) Instituto Nacional de Pesquisas Espaciais, INPE, São José dos Campos, Brazil

(4) SUPA School of Physics and Astronomy, University of Glasgow, Glasgow, G12 8QQ, UK

Abstract

The Solar Submillimeter Telescope (SST) is an unique instrument that has been observing the Sun daily since 2001 bringing a wealth of information and raising new questions about the particle acceleration and transport, and emission mechanisms during flares. We are now designing its successor, the SSTNG, that will expand the scientific goals of the instrument, including non-solar source observations.

1 Introduction

Submillimeter-wave (submm) observations, here considered for $0.3 \leq \lambda \leq 3$ mm, allow us to study the solar low atmospheric layers, from the Transition Region to the Chromosphere [1]. During flares, the submm emission might be originated by synchrotron emission from relativistic particles [2]. Therefore, we can track the energy transport from the acceleration to the emission sites. Moreover, Kaufmann et al. [3] have shown that some flares have a second spectral submm component (Figure 1) with a still unknown origin [4].

Even though the immense wealth of information that submm observations may bring to the understanding of the solar atmosphere and its dynamics, there is a lack of regular observations to cover this wavelength range. First efforts were carried on with the James Clerk Maxwell Telescope (JCMT) [5]. The Swiss KOSMA telescope, also observed the Sun a few times in 2003/2004 before it was decommissioned [6, 7]. More recently, the Atacama Large Millimeter Array (ALMA) is revealing fine details of the quiet and quiescent solar behavior [8]. However, JCMT and KOSMA observed the Sun just a couple of times, and ALMA allocates a small portion of its observing time to the Sun and it is not the best instrument to catch fast transient phenomena, like solar flares.

Since 1999, the only solar dedicated submm instrument is the Solar Submillimeter Telescope (SST) [9], a single

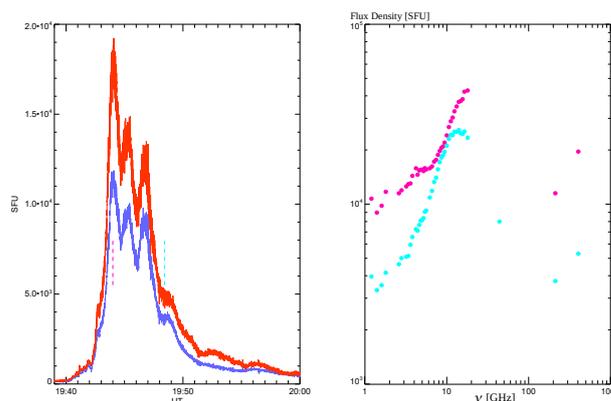


Figure 1. Left: Time profiles of the SOL2003-11-04T1945 solar event at 212 GHz (blue) and 405 GHz (red) observed by the SST. Spectra obtained at two different instants of the event (see vertical dashed lines on the left panel). Microwave data were obtained by the OVSA array. Observations at 44 GHz were carried out at Pierre Kaufmann Radio Observatory (ROPK) with its 14-m single dish antenna. This was the first event to show a second spectral submm component [3].

dish telescope with room temperature receivers operating at 212 GHz ($\lambda = 1.4$ mm) and 405 GHz ($\lambda = 0.7$ mm). After more than 20 years of excellent service, SST has to be updated in order to provide answers to the questions its observations have raised: what is the emission mechanism that creates a second spectral component > 100 GHz during flares? Does this component exist in “weak” flares? It may also bring more information about the 3–5 minute p-mode oscillations, the time evolution of the large scale chromospheric structures and its relationship with the magnetic field, the “slow” components at these frequencies, among other.

In the following lines we will present the general characteristics of the SST and introduce the SST next generation (SSTNG) which is being designed at the Center for Radio Astronomy and Astrophysics Mackenzie (CRRAM) in São Paulo (Brazil).

2 SST



Figure 2. The SST with the radome open for maintenance.

SST (Figure 2) is a product of *state-of-art* technologies of the 1990s. It has a 1.5 m, $f/D = 8$, radome-enclosed single-dish aluminum reflector built at the Steward Observatory, University of Arizona, Tucson, USA. Its frontend has six room temperature radiometers that operate simultaneously: four receivers operate at 212 GHz and two at 405 GHz, with nominal beam sizes of 4 and 2 arc minutes, respectively. The six beams form two arrays separated by approximately 6 arc-minutes. The first array has three 212 GHz beams arranged in an equilateral triangle, in the center of this triangle, there is one 405 GHz beam. The

receiver horns have a taper that allows the beam intersection at 50% level (-3 dB). Although the taper reduces the efficiency and increases the spill over, it allows the use of the *multibeam* method to instantly localize the emission centroid of point-like sources and to correct the flux for offset pointing [10, 11]. The second array has one 212 GHz and one 405 GHz beam with the same center and is used for reference. The radiometers have a $\Delta\nu = 8.5$ GHz bandwidth, temperatures of around 2000–3000 K and were custom made by RPG-Radiometer GmbH, Meckenheim, Germany. The backend output signal is converted to 2-byte integer numbers. SST has an Alt-Azimuth mount with 3.6 milliarcsec resolution and maximum speed of 3° s^{-1} . The output data is recorded in three different file structures: *sub-integrated* with 5 ms time resolution, *integrated* with 40 ms time resolution and *auxiliary* with 1 s time resolution.

The telescope is installed in the El Leoncito Astronomical Complex (CASLEO, in Spanish) at 2550 m above sea level in the Argentinean Andes, Province of San Juan. First light was in July 1999 and since April 2001 does daily observations. During the past 20+ years we refined the measurement of the atmospheric optical depth with different techniques and gathered a large statistics to understand the atmospheric transmission on the site at both frequencies [12, 13]. Median values of the opacity are 0.16 and 1.1 for 212 and 405 GHz, respectively [14]. That means that for more than 50% of the time, the atmosphere is nominally optically thick at 405 GHz.

3 SSTNG

The SSTNG will be more sensitive. Indeed, the SST noise flux density, when observing the Sun, is 1 and 7 SFU¹ for 212 and 405 GHz, respectively, considering 40 ms integration time, the median values of the atmospheric opacities and a mean elevation angle of 60° . With this sensitivity, the weakest flares we have observed are of GOES class M. By changing the receiver frequencies to 150 and 300 GHz we gain a factor > 2 in opacity: from our statistics and using the relationship obtained in [13] we derive median values of 0.07 and 0.4 for the atmospheric opacities at 150 and 300 GHz, respectively. In Figure 3 we show the histograms of the observed zenith opacities obtained between 2008 and 2012 using the skydip method. The same figure presents the expected histograms for 150 and 300 GHz showing an expressive reduction.

We also want to keep the same beam sizes, therefore we plan to substitute the present reflector by a new one of 3-m diameter. Moreover, today receivers have lower temperatures and larger bandwidths. For the present work we assume temperatures around 1000 and 2500 K for 150, and 300 GHz, respectively, and $\Delta\nu = 16$ GHz for both

¹ Solar Flux Unit $\equiv 10^4$ Jy.

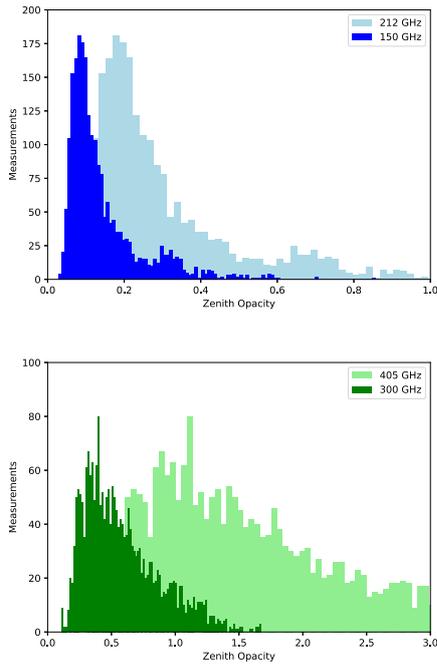


Figure 3. Top panel: Observed atmospheric opacity histogram at 212 GHz and expected opacity at 150 GHz. Bottom panel: Observed opacity histogram at 405 GHz and expected opacity for 300 GHz. The observed opacities were determined with skydips between 2008 and 2012.

frequency bands. Everything combined, lower opacities, larger reflector surface and receiver bandwidth, and smaller temperature, shall yield noise fluxes of 0.06 and 0.12 SFU, i.e. **SSTNG** will be 15 and 55 times more sensitive when compared with SST 212 and 405 GHz observations. In terms of flares, this gain means that events of GOES class C, and maybe, class B, will be detected, dramatically increasing the number of events to analyze. In terms of quiet sun behavior, it will certainly be possible to detect the 3-5 minute oscillations, and faint structures.

Polarization is key to discriminate the origin of the emission and to study the ambient magnetic field, however it was not yet explored at submm wavelengths during flares. **SSTNG** will be the first solar telescope to have circular polarization detectors for both frequency bands. And we plan to have a spectrometer to make studies of the yet to be observed large n Rydberg hydrogen lines at these frequencies. On the other hand the multibeam system will be maintained with three receivers at 300 GHz and one at 150 GHz in a triangular array similar to SST.

SSTNG will be able to make observations of non-solar objects like H II regions and QSOs. Indeed, for 1-min integration time, the noise flux density of **SSTNG** will be 3 and 12 Jy for 150 and 300 GHz, respectively, making possible night surveys.

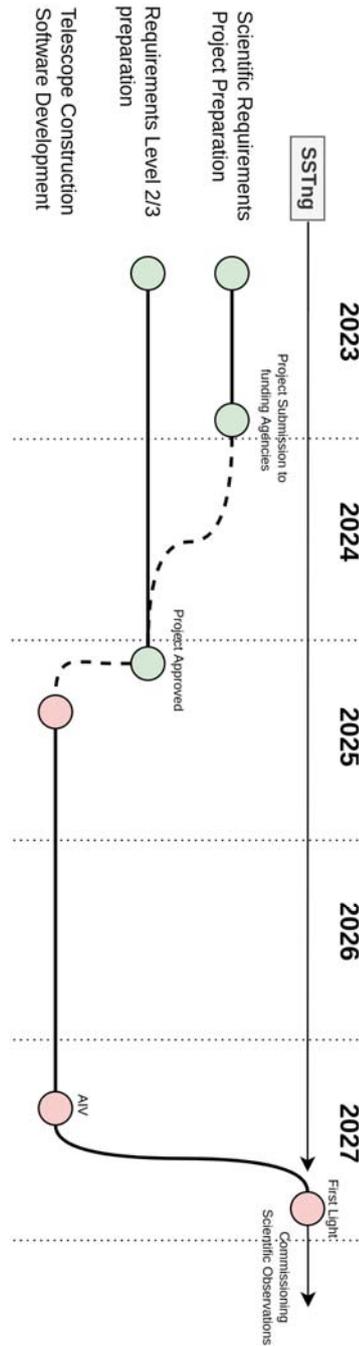


Figure 4. Provisional project schedule.

4 Final remarks

As we said above, **SSTNG** is more than an update of the 1990s technology. It intends to be a new instrument, based on our experience in this frequency range that will enlarge the original scientific goals. At the present time we are finishing the scientific requirements, afterwards we will start to identify possible contractors for the different subsystems. By the end of 2023 we will submit projects to our funding agencies to obtain financial support. Construction should start early 2025 and by 2027 it should have its first light,

starting the commissioning and the scientific observations (Figure 4).

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References

- [1] S. Wedemeyer, T. Bastian, R. Brajša, H. Hudson, G. Fleishman, M. Loukitcheva, B. Fleck, E. P. Kontar, B. De Pontieu, P. Yagoubov, S. K. Tiwari, R. Soler, J. H. Black, P. Antolin, E. Scullion, S. Gunár, N. Labrosse, H.-G. Ludwig, A. O. Benz, S. M. White, P. Hauschildt, J. G. Doyle, V. M. Nakariakov, T. Ayres, P. Heinzel, M. Karlicky, T. Van Doorselaere, D. Gary, C. E. Alissandrakis, A. Nindos, S. K. Solanki, L. Rouppe van der Voort, M. Shimojo, Y. Kato, T. Zaqarashvili, E. Perez, C. L. Selhorst, and M. Barta, “Solar Science with the Atacama Large Millimeter/Submillimeter Array—A New View of Our Sun,” *Space Sci. Rev.*, vol. 200, pp. 1–73, Apr. 2016.
- [2] R. Ramaty, R. A. Schwartz, S. Enome, and H. Nakajima, “Gamma-ray and millimeter-wave emissions from the 1991 June X-class solar flares,” *Astrophys. J.*, vol. 436, pp. 941–949, Dec. 1994.
- [3] P. Kaufmann, J.-P. Raulin, C. G. G. de Castro, H. Levato, D. E. Gary, J. E. R. Costa, A. Marun, P. Pereyra, A. V. R. Silva, and E. Correia, “A New Solar Burst Spectral Component Emitting Only in the Terahertz Range,” *Astrophys. J. Lett.*, vol. 603, no. 2, pp. L121–L124, Mar. 2004.
- [4] S. Krucker, C. G. Giménez de Castro, H. S. Hudson, G. Trotter, T. S. Bastian, A. S. Hales, J. Kašparová, K.-L. Klein, M. Kretschmar, T. Lüthi, A. Mackinnon, S. Pohjolainen, and S. M. White, “Solar flares at submillimeter wavelengths,” *Astron. Astrophys. Rev.*, vol. 21, p. 58, Mar. 2013.
- [5] C. Lindsey and G. Kopp, “Submillimeter Radiometry of Sunspots,” *Astrophys. J.*, vol. 453, p. 517, Nov. 1995.
- [6] T. Lüthi, A. Magun, and M. Miller, “First observation of a solar X-class flare in the submillimeter range with KOSMA,” *Astron. Astrophys.*, vol. 415, pp. 1123–1132, Mar. 2004.
- [7] T. Lüthi, A. Lüdi, and A. Magun, “Determination of the location and effective angular size of solar flares with a 210 GHz multibeam radiometer,” *Astron. Astrophys.*, vol. 420, pp. 361–370, Jun. 2004.
- [8] S. Wedemeyer, M. Szydlarski, S. Jafarzadeh, H. Eklund, J. C. Guevara Gomez, T. Bastian, B. Fleck, J. de la Cruz Rodriguez, A. Rodger, and M. Carlsson, “The Sun at millimeter wavelengths. I. Introduction to ALMA Band 3 observations,” *Astron. Astrophys.*, vol. 635, p. A71, Mar. 2020.
- [9] P. Kaufmann, H. Levato, M. M. Cassiano, E. Correia, J. E. R. Costa, C. G. Giménez de Castro, R. Godoy, R. K. Kingsley, J. S. Kingsley, A. S. Kudaka, R. Marcon, R. Martin, A. Marun, A. M. Melo, P. Pereyra, J.-P. Raulin, T. Rose, A. Silva Valio, A. Walber, P. Wallace, A. Yakubovich, and M. B. Zakia, “New telescopes for ground-based solar observations at submillimeter and mid-infrared,” in *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, vol. 7012, Aug. 2008.
- [10] C. G. Giménez de Castro, J. P. Raulin, V. S. Makhmutov, P. Kaufmann, and J. E. R. Costa, “Instantaneous positions of microwave solar bursts: Properties and validity of the multiple beam observations,” *Astron. Astrophys. Suppl.*, vol. 140, pp. 373–382, Dec. 1999.
- [11] J. E. R. Costa, E. Correia, P. Kaufmann, A. Magun, and R. Herrmann, “A Method for Arc-Second Determination of Solar Burst Emission Centers with High Time Resolution and Sensitivity at 48 GHz,” *Solar Phys.*, vol. 159, pp. 157–171, 1995.
- [12] M. M. Cassiano, D. Cornejo Espinoza, J.-P. Raulin, and C. G. Giménez de Castro, “Precipitable water vapor and 212 GHz atmospheric optical depth correlation at El Leoncito site,” *J. Atmos. Solar Terr. Phys.*, vol. 168, pp. 32–36, Mar 2018.
- [13] J. F. Valle Silva, C. G. Giménez de Castro, C. Pasarelli, D. Cornejo Espinoza, M. M. Cassiano, J.-P. Raulin, and A. Valio, “Optical depth measurements at 45 and 90 GHz in CASLEO,” *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 199, p. 105214, Mar. 2019.
- [14] D. C. Espinoza, J.-P. Raulin, J. F. Valle Silva, C. G. Giménez de Castro, and M. M. Cassiano, “Submillimeter atmospheric opacity over “el leoncito” site,” in *2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science*, 2020, pp. 1–4.

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