The New Submillimeter-wave Solar Telescope©

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***Resumo* — Um novo e inédito telescópio solar para ondas submilimétricas (SST) foi instalado no sítio de El Leoncito, nos Andes argentinos. Ele tem uma antena cassegrain de 1,5 m, dentro de redoma, e conjuntos focais de quatro receptores de 212 GHz e dois de 405 GHz. Apresentamos uma breve descrição técnica dosistema, resultados preliminares do seu desempenho, a opacidade atmosférica medida no sítio, e a detecção das primeiras emissões de explosões solares em ondas submilimétricas.**

***Abstract* — A new and unique solar submillimeter telescope (SST) was installed in the El Leoncito site, Argentina Andes. It has a 1.5 m radome-enclosed cassegrain antenna, and arrays of four 212 GHz and two 405 GHz radiometers placed in the focal plane. We present a brief technical description of the system, preliminary results on its performance, the atmospheric opacity measured at the site, and the first detection of solar flare submm-w emissions.**

***Palavras-Chave* — antenas submilimétricas, rádio-telescópios, radiômetros submilimétricos, opacidade atmosférica, explosões solares.**

***Index Terms* — Submm-w antennas, radio-telescopes, submm-w radiometers, atmospheric opacity, solar flares.**

I. INTRODUCTION

The solar submillimeter-w telescope project (SST) is the first instrument conceived to study the still unexplored submm-IR spectrum of solar emissions in quiet, quiescent and explosive conditions [1]-[2]. The project began in 1994. The complete instrument was assembled in El Leoncito site, operated by CASLEO, located at 2550 m altitude, Province of San Juan, Argentina Andes, in April 1999 (Fig. 1). "First light" was obtained in May 1, 1999 [3]. Since then SST is being operated in short campaigns, undergoing a number of tests, adjustments, while also being used in solar activity and atmospheric transmission measurements. The main SST subsystems are as follows:

(a) 1.5 m reflector, f/D = 8, aluminum surface and backstructure, built using a new "slumping" technique to mold the sheet before machining [4] by Steward Observatory, University of Arizona, Tucson, AZ, USA. Final mechanically measured surface r.m.s. was of 20 µ. (the required overall r.m.s. should be better that 50 µ). Fig. 2 shows the antenna on its final installation at CASLEO.

Fig. 1. The SST 3-m radome installed at CASLEO El Leoncito site

(b) All room temperature mixer total power receivers were built and assembled by RPG-Radiometer Physics, (Meckenheim, Germany: four 212 GHz radiometers, one fed by conical horn with 8 dB tapering, three with 3 dB tapering, and two 405 GHz radiometers with 8 dB tapering horns See Fig. 3). Radiometers' IF are 0.5-1.5 GHZ with DSB system temperatures of the order of 3000 K. Time resolution is of 1 ms. One SSB IF 14.3-14.7 GHz is available for planned experiments of atmospheric chlorine monoxide line (390 GHz) detection [5]. The arrangement is shown in Fig. 3. Feed-horns were displaced in the focal plane to produce beams separated in space by several HPBWs, except for three 212 GHz which are partially overlapping , used to find sources location with the multiple beam technique ([5] and references therein).

(c) El-Az positioner, inductosyns angular readings with 3.6" accuracy, built by Orbit, Netanya, Israel.

(d) 3-m Gore-Tex™ radome, built by ESSCO, Concord, MA, USA. Measured transmission of

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Fig. 2. The 1.5 -m submm-w cassegrain antenna seen through the radome maintenance door opening.

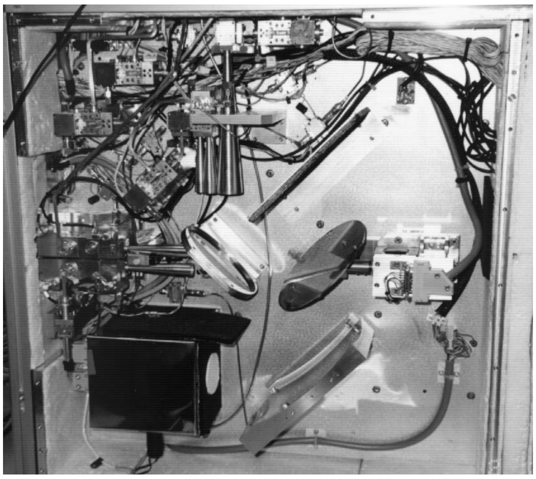

Fig. 3. The SST radiometers' box, as seen from the subreflector. Reflected signals are sent to the focal plane, after first reflection in the flat mirror (center right), directing them to a polarizing grid (center left). One plane of polarization pass through to the two 405 GHz horns, further at left. The other plane of polarization is reflected by the grid and directed to the four 212 GHz horns at the top. A hot load (black box below) and room temperature load (above the flat mirror), serve as calibration references by rotating the flat mirror. Gunn oscillators, mixers and IF strips are in the box which is kept stable in temperature within 1^o Celsius.

membrane plus metal frame blockage of 92% at 212 GHz and 96% at 405 GHz.

(e) Antenna position and drive digital controls, data acquisition, developed in a joint effort between CRAAE and the Institute of Applied Physics, University of Bern, Bern, Switzerland[7].

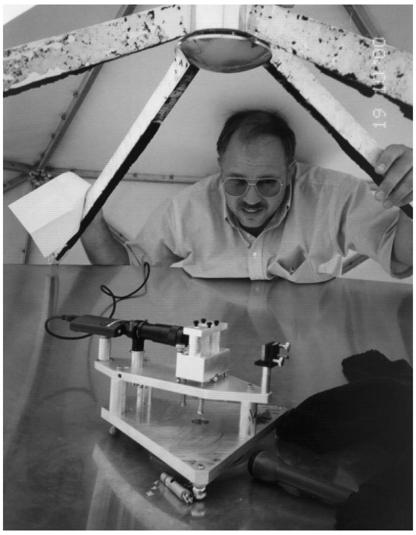

Fig. 4. The coalignment tool built specifically to adjust the SST cassegrain optics, without removing the reflector [9], installed at the vertex of the main dish.

II. TRACKING AND ANTENNA PERFORMANCE

Several campaigns were carried out in El Leoncito for instrumental tests, improvements and to optimize the system performance together with solar and atmospheric opacity measurements. The pointing and tracking parameters were determined using a well known method [8]. The absolute pointing accuracy attained so far is of about 0.5 arcmin, r.m.s., and has to be further improved.

Special attention was given to optimize the antenna performance at the site. A new co-alignment device has been designed to allow the Cassegrain optics alignment without having to remove the reflector from the mount (see Fig.4). It was used together with other new procedures for a complete SST system survey and adjustment, which results will be published in near future [9].Antenna patterns and efficiencies are being determined using planets as standard sources, with angular sizes small compared to the beamwidths. Fig. 5 shows examples of the SST beam patterns at 212 and 405 GHz obtained from azimuth and elevation scans on Venus, displayed in observed antenna temperatures, not corrected for atmospheric transmission. The HPBW angular sizes (i.e. 3.9' at 212 GHz and 2.0' at 405 GHz) are close to the nominal expected for the main reflector diameter). Approximate beam efficiencies of about 80% were obtained at the two frequencies, for the 8 dB tapered beams, derived from the ratios between observed and brightness temperatures for the Sun. Measurements of aperture efficiencies are in progress. They are time consuming because of long integration times needed for each one of the six antenna beams, each time under good sky transmission conditions. Provisional aperture efficiencies obtained for the two beams using 8 dB tapered feed horns are of the order of 15% at 405 GHz and 36% at 212 GHz, which is close to the best value expected for the original surface r.m.s. required specifications. For an overall r.m.s $< 50\ \mu$, taking into

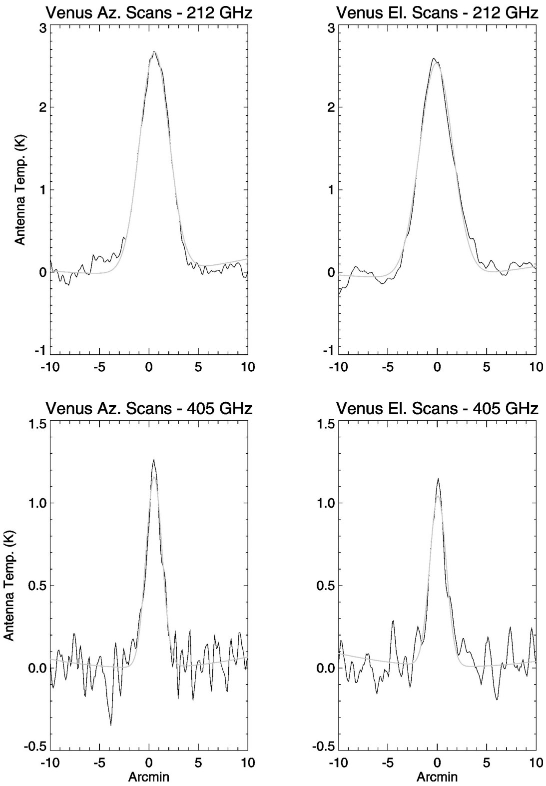

Fig. 5. SST main beam patterns derived from Venus drift scan observations in elevation and azimuth, obtained in April 2001, at 212 GHz above, and at 405 GHz below, plotted in observed antenna equivalent noise temperatures. Side lobes are smaller than the noise on these observations.

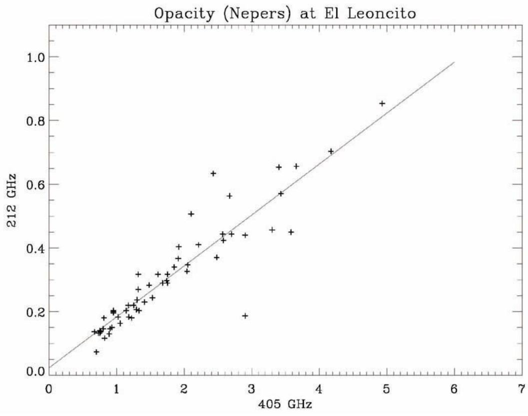

Fig. 6. Atmospheric zenith opacity at El Leoncito at the two submm-w frequencies. Optical depth at 405 GHz is nearly 6.2 times the optical depth at 212 GHz, which compares to results obtained at higher altitude sites [13][14].

account the other efficiencies for spillover, phase, polarization and tapering, it can be predicted an optimum aperture efficiency of about 28% at 405 GHz and of 38% at 212 GHz[10][11]. However further improvements in efficiencies are expected when the system focusing is completed, since we know the SST reflector surface is considerably better than original specifications[4].

III. SUBMM-WAVE ATMOSPHERIC OPACITY

A large number of measurements were made of the atmospheric transmission at El Leoncito site, during every campaign. A partial sample has been obtained for all seasons of the year. Two methods were used, and compared to each other [12]. The direct method allows the absolute derivation of attenuation from the measurement of variations in the solar level with respect to the sky level taken at various elevation angles. The other method estimates the zenith optical depth from sky temperatures at different elevation angles. Fig. 6 shows the correlation between atmospheric attenuation in the direction of zenith, in nepers, at the two frequencies, 212 and 405 GHz, using the direct method.

It was found that El Leoncito is a good submm-w site most of the time. For the sample measurements made so far, 75% of the time we have optical depth smaller than 0.4 at 212 GHz and less than 2.0 at 405 GHz.

IV. SOLAR SUBMM-W ACTIVITY

While SST was undergoing tests and adjustment works, we carried out several solar observations, tracking selected active regions.

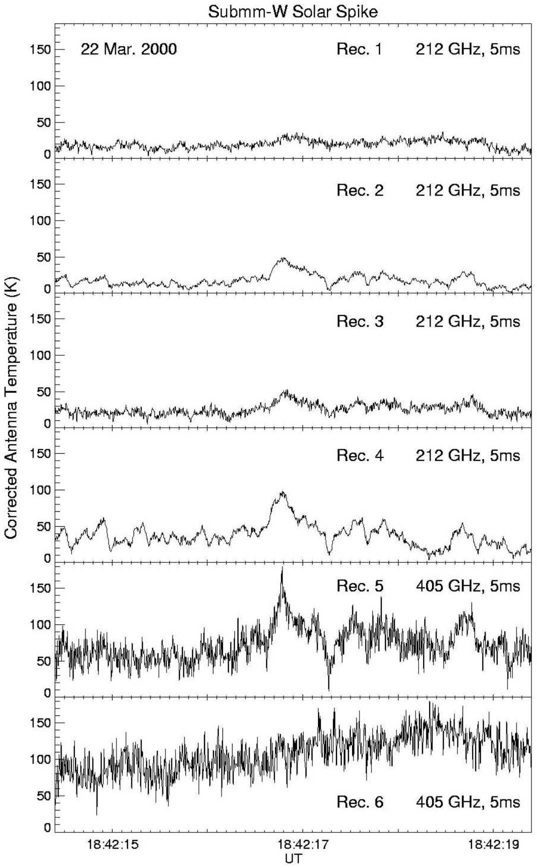

Fig. 7. Example of a fast submm-w solar brightening, observed simultaneously with the six SST beams. The burst source is located within beams 2, 3, 4 (212 GHz) and 5 (405 GHz), and consequently is undetected by distant beams 1 and 6.

Most of data obtained are currently being reduced and inspected. An important major discovery was the detection of rapid spikes (100-300 ms) during a large solar flare, which produced a X1.1 class GOES X-rays event[15]. Fig. 7 shows an example of such submm-w. brightening. The largest occur at rates exceeding 20 per minute, in good association to the flare light curves at X-rays and in the optical H-α line. Converting the antenna temperatures, corrected for atmospheric transmission, into solar flux units (1 sfu = 10^{-22} w m^{-2} Hz^{-1}), fluxes are larger for the larger frequency (405 GHz), suggesting a positive spectral index of about 2.0. This spectral trend might be attributed to short- lived optically thick sources, which might be produced by thermal or non-thermal processes. These results bring great impact in field of studies of fast elementary processes in solar flares, of waves, shocks, quakes, with possible implications in the mechanisms of solar coronal heating

REFERENCES

[1] P. Kaufmann, N.J. Parada, A. Magun, M. Rovira, H. Ghielmetti and H. Levato, "The new solar submillimeter-wave telescope project (SST)," in Proc. Kofu Symposium "New look at the Sun with emphasis on advanced observations of coronal dynamics and flares", ed. by S. Enome and T. Hirayama, Kofu, Japan, Sept. 6-10, 1993, NRO Report, no. 360, pp. 323-326, 1994.

[2] P. Kaufmann, J.E.R. Costa, E. Correia, A. Magun, K. Arzner, N. Kämpfer, M. Rovira and H. Levato, "Recent developments of the Solar Submm-wave Telescope (SST)", in Proc. CESRA Workshop "Coronal physics from radio and space observations", ed. by G. Trottet, Nouan le Fuzelier, France, 3-7 June 1996, *Lecture Notes in Physics*, Springer, pp. 202-206, 1997

[3] P. Kaufmann, J.E.R. Costa, E. Correia, C.G. Giménez de Castro, J.-P. Raulin, A.V.R. Silva, H. Levato, M. Rovira, A. Magun, N. Kämpfer and A. Lüdi, "Multiple high energy injections at the origin of solar flares", in Proc. High Energy Solar Physics - Anticipating HESSI, ed. by R. Ramaty and N. Mandzhavidze, College Park, MD, USA, 18-20 October 1999, *ASP Conference Series*, vol. 206, pp. 318-322, 2000.

[4] R.N. Martin; J.S. Kingsley; and R.K. Kingsley. "A new technique for submillimeter wave reflector construction", in Int'l Symposium on Astronomical Telescope Instrumentation, ed. by T.G. Phillips, Kona, Hawaii, USA, 20-28 March 1998, *Proc. SPIE Advanced Technology MMW, Radio and Terahertz telescopes*), vol. 3357, pp. 721-727, 1998.

[5] N. Kämpfer, A. Magun, D. Feist, K. Arzner, P. Kaufmann, J.E.R. Costa, M. Rovira and H. Levato, "A new instrument for the investigation of the atmosphere of the Sun and Earth", in Proc. 6th International Symposium on Recent Advances of Microwave Technology, ed. by B.S. Rawat and Z. Siyong, Beijing, China, Publ. House of Electronics Industry, pp.3-6, 1997.

[6] C.G. Giménez de Castro, J.-P. Raulin, V.S. Makhmutov, P. Kaufmann and J.E.R. Costa, *Astron. Astrophys.,* vol. 140, pp.373-382, 1999.

[7] C.G. Giménez de Castro, J.E.R. Costa e A. Magun, "Modularidade na integração de um sistema de processos de controle em tempo real para aplicações rádio astronômicas", XXVIa Reunião Anual da Sociedade Astronômica Brasileira, Mangaratiba, RJ, Brasil, 23-27 julho 2000, *Boletim da SAB*, vol 20, no. 1, p.76, 2000.

[8] M.L. Meeks, J.A. Ball and A.B. Hull, Pointing calibration of the Haystack antenna, *IEEE Trans.Ant.Propagat.,* vol AP-16, pp.744-751, 1968.

[9] J.S. Kingsley, R.K. Kingsley, P. Kaufmann, J.E.R. Costa, C.G. Giménez de Castro, Y.R. Hadano, H. Levato, A. Marun and M. Rovira, in preparation, 2001.

[10] R.E. Collin, "Antennas and radiowaves propagation", McGraw-Hill Series in Electrical Engineering, 119-215, 1985.

[11] T. Rose, private communication.

[12] J.-P. Raulin, A.M. Melo, A.V.R. Silva and P. Kaufmann, "Métodos de determinação de opacidade submilimétrica: primeiros resultados para El Leoncito", XXVIa Reunião Anual da Sociedade Astronômica Brasileira, Mangaratiba, RJ, Brasil, 23-27 julho 2000, *Boletim da SAB*, vol 20, no. 1, p.79, 2000.

[13] C. Masson, "Atmospheric opacity and water vapor", NRAO Memo. Nr. 12, April 12, 1990.

[14] H.S. Liebe, *Radio Science*, vol. 16, pp. 1183-1199, 1981.

[15] P. Kaufmann, J.-P. Raulin, E. Correia, J.E.R. Costa, C.G. Giménez de Castro, A.V.R. Silva, H. Levato, M. Rovira, C. Mandrini, R. Fernandez-Borda and O. Bauer, *Astrophys.J.Letters*, vol. 548, pp. L95-L98, 2001.

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