The Development of THz Photometers to Observe Solar Flares from a Stratospheric Platform

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The Development of THz Photometers to Observe Solar Flares from a Stratospheric Platform

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Abstract— **The newly found solar flare spectral component with intensities increasing for larger sub-THz frequencies, brings challenging constraints for interpretation. Higher THz frequencies observations are needed to understand the nature of the mechanisms involved. A two-frequency THz photometer system was developed to observe outside the terrestrial atmosphere on stratospheric balloons. Two 76 mm diameter telescopes were designed to observe the whole solar disk detecting small relative temperature changes caused by flares at localized positions at 3 and 7 THz. Golay cell detectors are preceded by low-pass filters to suppress visible and near IR radiation, band-pass filters, and choppers. It can detect temperature variations smaller than 1 K with time resolution of a fraction of a second, corresponding to small burst intensities. The photometers are assembled in a thermal controlled box to which data acquisition and telemetry systems are coupled. A laboratory THz photometer prototype was developed. The SOLAR-T flying model has been completed. It is planned to fly on board of long-duration stratospheric balloon flights in 2013-2015. One will be coupled to the GRIPS gamma-ray experiment in cooperation with University of California, Berkeley, USA with one test flight in US, and a 2 weeks flight over Antarctica during local summer. Another flight over Russia (one week) is planned in cooperation with the Lebedev Physics Institute, Moscow, during local summer.**

Keywords - THz photometers; solar flares; stratospheric balloon platform; THz detectors; THz filters

I. THz CONTINUUM PHOTOMETRY

To fully understand the nature of the high frequency emission in flares it is necessary to measure the complete continuum spectra at higher THz frequencies. This requires observations with detectors placed outside the terrestrial atmosphere, as it has been done at far IR for non-solar experiments on SOFIA high altitude aircraft [1], PACS experiment on HERSCHEL satellite [2], a solar scanning experiment on a stratospheric balloon [3], or through few atmospheric THz transmission "windows" at exceptionally good high altitude ground based locations [4].

A THz photometer prototype to measure transient temperature bursts in the continuum has been successfully assembled, together with an "artificial Sun" calibration source [5]. The difficulty to observe the whole solar disk with sufficient sensitivity to detect flares subtended by much smaller sizes was solved with an innovative photon concentrator [6] that combines the formation a full solar image size d at the focal plane, according to the well known relationship f tan θ = d, where f is the aperture focal length and θ is the angular size of the Sun, with another well known relationship relating the minimum detectable flux ΔS of a small source to the observed excess temperature transient ΔT inversely proportional to the aperture area A_e, $\Delta S = 2\,k\,\Delta T/A_e$, where k is the Boltzmann constant.

The response to temperature variations and stability was derived from 23.7 minutes measurements response to a steady temperature increase from 600 to 1300 K.

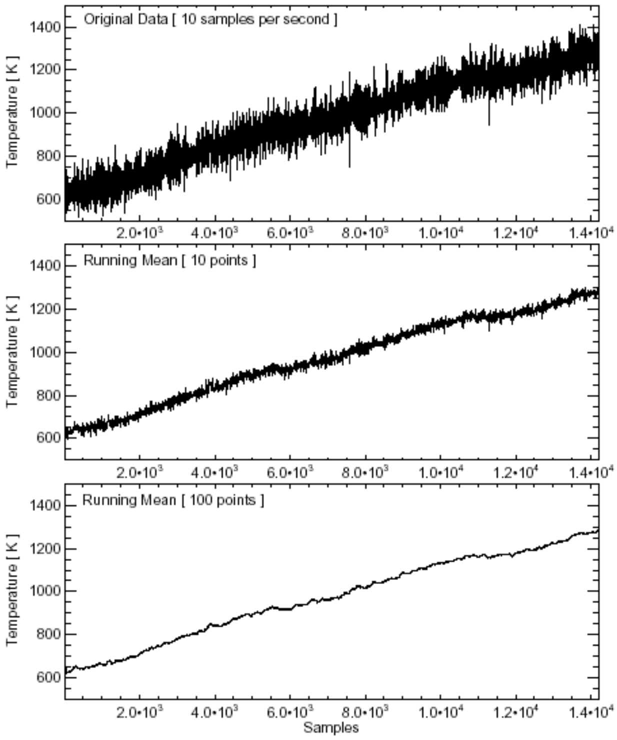

Figure 1**.** The 2 THz prototype measured output for temperatures ranging 600-1300 K for three smoothing times (after [5]).

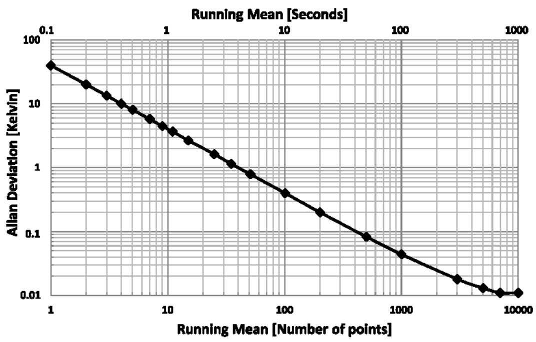

Figure 2. The Allan Deviation statistics for various smoothing times shows that □ 1 K is detectable for running mean of 4 seconds (after [5]).

The results are shown in Fig. 1, for three different running means. The photometer system has a linear voltage response to temperatures, and the system temperature noise fluctuations remain the same for the whole range of temperatures.

The system stability is better described using Allan statistics. The Allan Deviation is shown in Fig. 2. It indicates that the system is very stable and suitable for relative variations in temperature. Temperature variations of the order of ± 1 K can be detected for running means along or larger than 4 seconds (for data sampled at 10/s rate).

The noise equivalent power (NEP) for the whole system might be estimated. For signal-to-noise ratio equal to one, NEP $\approx \Delta P_S\,(\tau)^{0.5}$ [7], where $\Delta P_S = 2\,k\,\Delta T\,\Delta f$ is the noise equivalent power fluctuations measured within a band-pass Δf, and k the Boltzmann constant. The 2 THz metal mesh filter band pass Δf is of about ± 10 percent or 4 10^{11} Hz. With integration time of $\tau = 0.2$ s it has been measured $\Delta T \approx 40$ K at the RC integrator output. We obtain NEP ≈ 2 10^{-10} W $Hz^{-0.5}$. This approximate estimate is twice the nominal Golay cell specification using 20 Hz chopper [8].

II. THE 3 AND 7 THZ PHOTOMETERS FOR STRATOSPHERIC BALLOON PLATFORM

A THz dual frequency photometer system to operate outside the terrestrial atmosphere is currently being built. It has been designed accordingly to the prototype, duplicated to operate at two central frequencies, 3 and 7 THz, with modification in the optics and mechanical assembly, to be

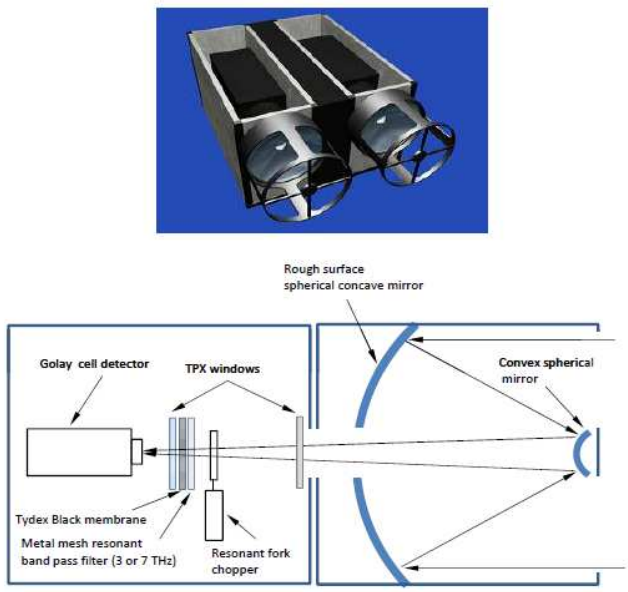

Figure 3. The SOLAR-T photometers assembly concept, above. The diagram in the bottom panel shows at right the Golay cell detector, preceded by TydexBlack low-pass filter membrane, a resonant metal mesh band-pass filter and a resonant fork 20 Hz chopper. The 76 mm Cassegrain telescope at right has a rough surface to further diffuse the visible and near IR radiation.

operated on board of long-duration stratospheric balloon flights. The experiment has been labeled SOLAR-T. Fig. 3 shows the schematic diagram for one photometer with the upper panel giving a possible two channel concept configuration.

Two 76 mm Cassegrain telescopes have been fabricated at "Bernard Lyot" Solar Observatory. They have 76 mm focal length, 25 mm secondary convex mirror with -25.8 mm focal length. The overall effective focal length of the Cassegrain is related to the system magnification, which depends of the secondary distance from the primary (see for example [10]). The two mirrors have been adjusted optically to produce a 500 mm focal length, before the primary reflector has been roughened. This setup produces a solar disk image of 4.4 mm at the system focal plane, smaller than the Golay cell 10 mm

Figure 4. The two 76 mm SOLAR-T Cassegrain telescopes, with roughened primary reflectors.

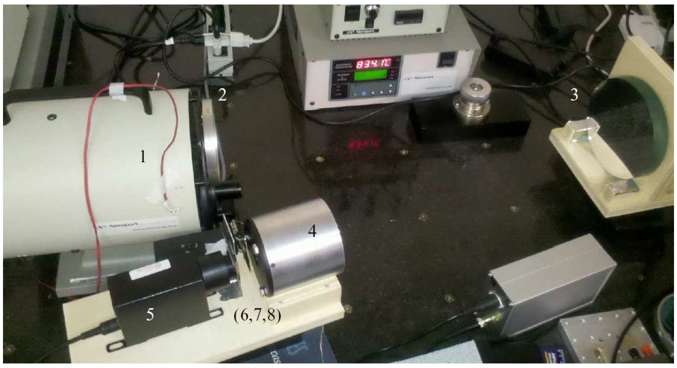

Figure 5. The laboratory setup to test the SOLAR-T telescopes: (1) the blackbody source, (2) diaphragm to set an "artificial" Sun diameter at the focus of (3) concave mirror, (4) one 76 mm telescope, (5) Golay cell, (6,7, 8): the BlackTydex low-pass filter, the 2 THz resonant metal mesh band pass filter, and the resonant fork chopper, respectively.

photon trap cone placed in front sensitive surface. The solar disk image on the focal plane may be displaced by about 5 mm from the center and still have all radiation photons reaching the detector. The resulting tolerance angular

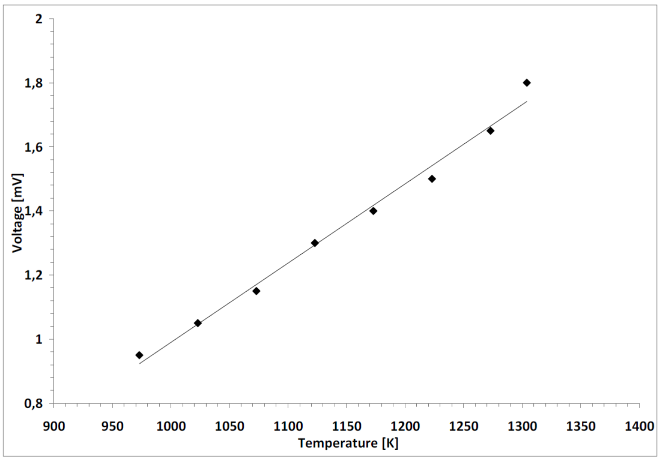

Figure 6. The 2 THz radiometer system response to temperature variations from the "artificial" solar disk source, shown in Fig. 5

displacement is equivalent to an accepting angle up to 0.6 degrees, through which all photons are detected.

The Cassegrain telescopes are shown in Fig. 4. Each telescope has been successfully tested for visible and near-IR diffusion effectiveness, and for their response to temperature changes, using the setup shown in Fig. 5.

The system response for temperatures is plotted in Fig. 6. It was nearly identical for both Cassegrain telescopes.

III. The SOLAR-T Assembly

The telescopes and the metal mesh 3 and 7 THz band-pass filters (fabricated at CCS/Unicamp, in Brazil) were sent to Tydex, in St. Petersburg, where they were integrated to the complete photometers thermalized box. The power supplied by external source (such as the GRIPS experiment) and will be regulated at the SOLAR-T unit.

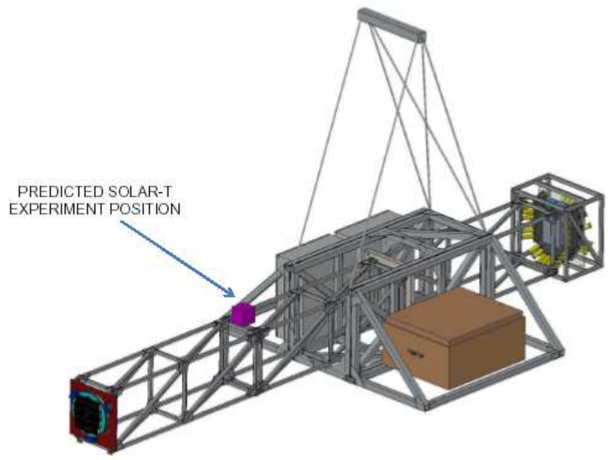

Figure 7. The SOLAR-T location on the boom of the GRIPS gamma-ray experiment. The experiment points to the Sun, to the left. It will be lifted at the altitude of 30-40 km in the stratosphere

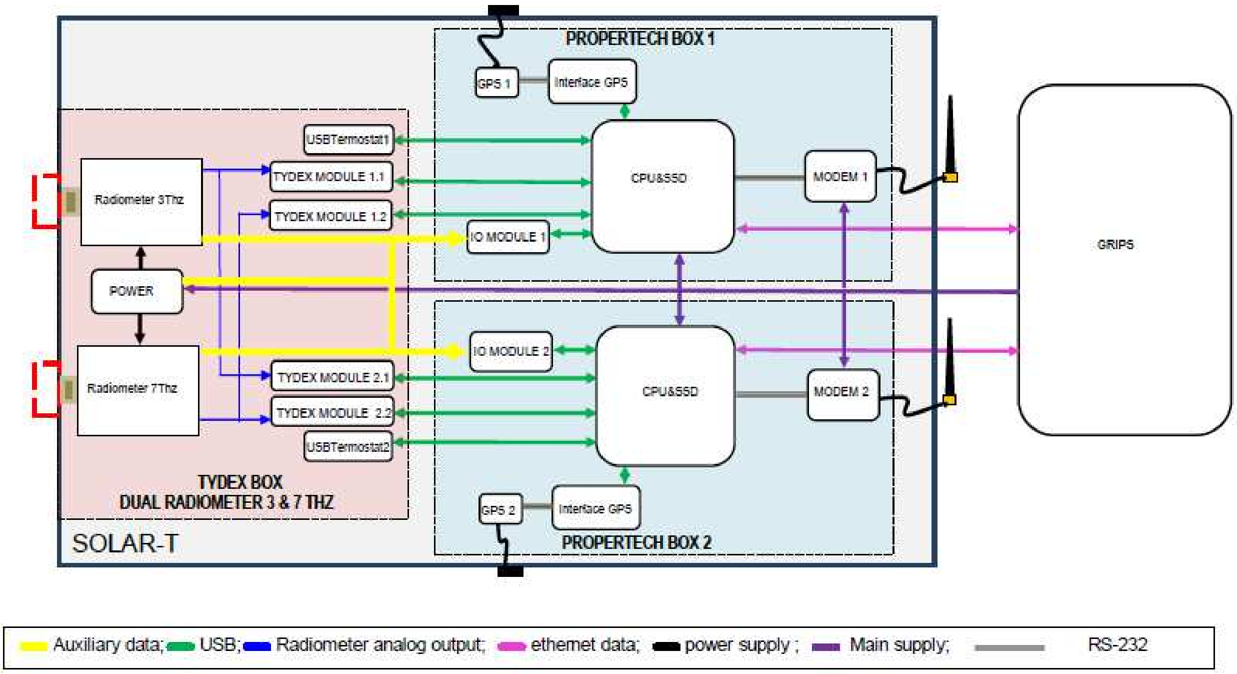

Figure 8. . SOLAR-T data acquisition block diagram (Propertech)

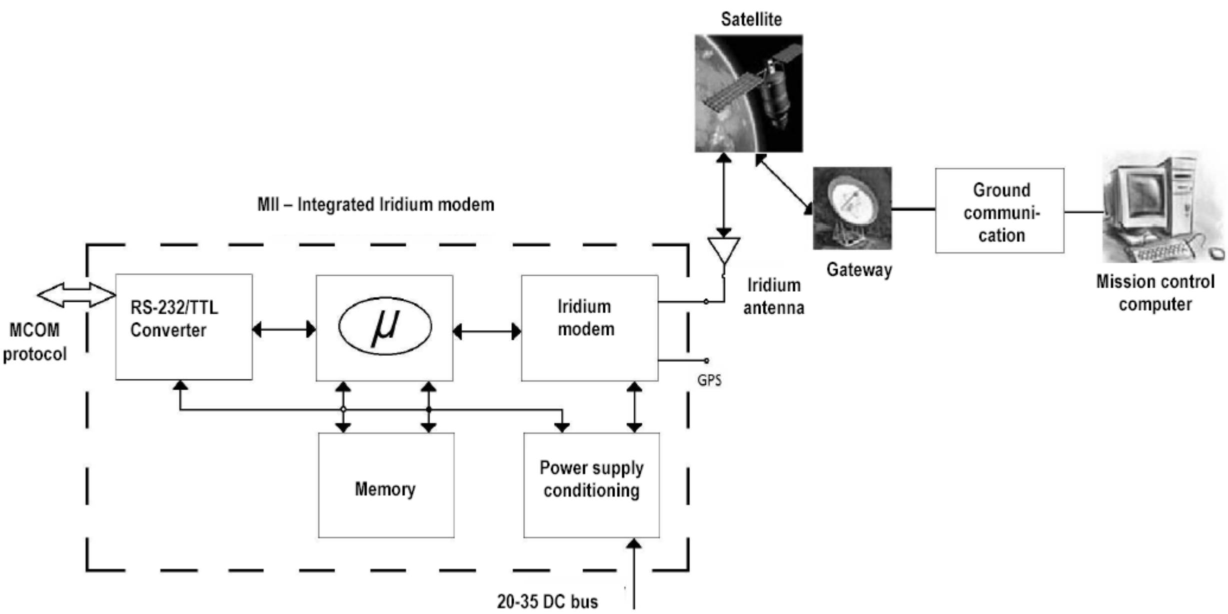

Figure 9. The Iridium communication module for SOLAR-T (Neuron)

The SOLAR-T data acquisition and conditioning subsystem and the telemetry unit are being developed and fabricated in Brazil by Propertech (Jacareí, SP) and Neuron (São José dos Campos) companies, respectively. Figure 7 shows the SOLAR-T location on the boom of the huge GRIPS experiment. The data acquisition block diagram is shown in Fig. 8. It shall be able to operate independently from GRIPS, with it own GPS clock. The system consists in two CPUs that read output signals from the two Golay cells, with an arrangement of four data reading modules, to assure a redundancy, in the case one of them fails. Other box parameters will be read at slower rates (voltages, temperatures). After first processing the radiometers's data rates will be 10/second. Data will be stored on board for the whole mission.

Compacted data, clock and auxiliary data to be transmitted is interfaced to the telemetry system, based on Iridium satellite network. The Iridium network is the best suited for communications from Antarctica, The block diagram for the telemetry subsystem is shown in Fig. 9. It is composed by a model 9602 Iridium modem [11] and an electronic circuitry which main components are a microcontroller, memory chip, linear regulator and a DC/DC converter. The modem transmits and receives digital data packages through the Iridium SBD – Short Burst Data – service [12]. Data packages transmitted to ground have the maximum size of 340 bytes and those received from ground of 270 bytes.

Actual Iridium network latency for transmitting and receiving data packages as well as modem heating during each transmission burst will eventually establish the maximum data package transmission rate and, consequently, the telemetry channel capacity. A preliminary figure for one-direction latency is 20 seconds maximum.

The telemetry subsystem functions are: a) to control 9602 modem to establish communication with the Iridium network satellites and monitoring of communication status; b) to control the interface of 9602 modem and Propertech data acquisition module to allow transmission and reception of data packages to and from ground; c) to condition the balloon power bus to generate the required subsystem secondary voltages; d) to generate telemetry subsystem voltage and temperature telemetries to allow monitoring and safe operation of 9602 modem.

IV. Concluding Remarks

The SOLAR-T experiment with the 3 and 7 THz photometers has been completed and tested at Tydex under vacuum and low temperature conditions. The sealed box is shown in Fig. 10. Fig. 11 shows the complete setup with the data acquisition and telemetry modules added. It is planned to fly on board of a long-duration stratospheric balloon flights somewhere in 2013-2015. One of them will be coupled to the GRIPS gamma-ray experiment [9] in cooperation with University of California, Berkeley, US. One engineering flight is scheduled in USA, and a 2 weeks flight over Antarctica during local summer. Another long duration stratospheric balloon flight over Russia (one week) is planned in cooperation with Lebedev Physics Institute, Moscow (during northern hemisphere summer).

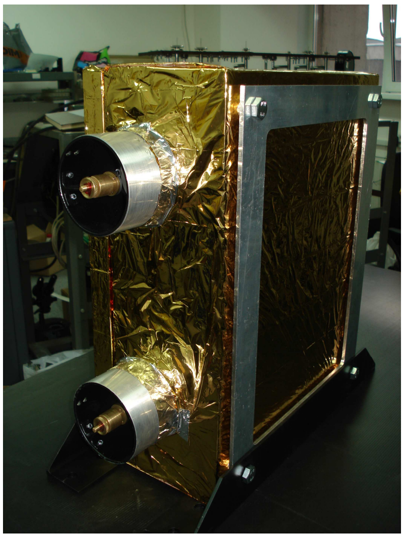

Figure 10. The SOLAR-T 3 and 7 THz photometers completed at Tydex, Saint Petersburg, before shipment to Brazil.

The SOLAR-T full integration to the data acquisition and telemetry are being carried out in Brazil, with the participation of the three companies. They include complete simulations of data acquisition, down link and telecomands as well as tests of operations under balloon environmental conditions. Tests under vacuum conditions are scheduled to be carried at "Bernard Lyot" Solar Observatory, Campinas, Brazil, and under low temperature environment (-60 C) at Centro de Tecnologia da Informação Renato Archer - CTI, Campinas, Brazil. The integration of the experiment before flight will be carried out together with the stratospheric balloon teams at before the respective missions.

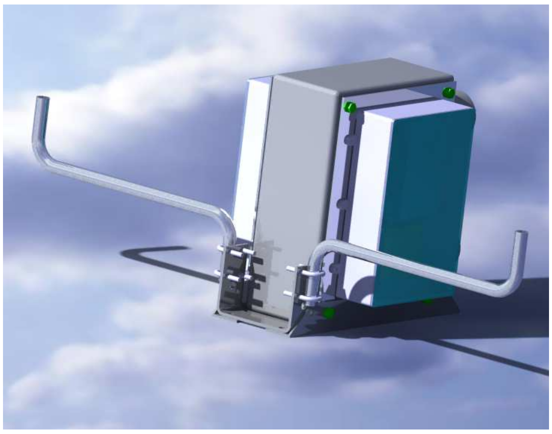

Figure 11. The complete SOLAR-T experiment with the data acquisition and telemetry modules added. The arms hold the two Iridium antennas.

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REFERENCES

[1] E.F. Erickson, “SOFIA: the next generation airborne observatory”. Space Sci. Rev., vol 84, pp. 91-100, 1985.

[2] A. Poglitsch *et al.*, “The photodetector array camera and spectrometer (PACS) on the Herschel space observatory” Astron. Astrophys., vol. 518, L2, pp. 1-12, 2010.

[3] C.G. Degiacomi, F.K Kneubühl, D. Huguenin, “Far-infrared solar imaging from a balloon-borne platform”, Astrophys. J., vol. 298, pp. 918-933, 1985.

[4] J.S. Lawrence, “Infrared and submillimeter atmospheric characteristics of high Antarctic plateau sites”, Publ. Astron Soc. Pacific, vol. 116, pp. 482-492, 2004.

[5] R. Marcon *et al.*, “Terahertz photometer to observe solar flares in continuum”, J. Infrared, Millimeter and Terahertz Waves, vol. 33, 192-205, 2012.

[6] R. Marcon, P. Kaufmann, “Método para maximizar ganho na detecção simultânea de radiação de fontes pequenas em campo extenso de visão” Brazil Patent Application, Universidade Estadual de Campinas and Instituto Presbiteriano Mackenzie, March 30, 2011.

[7] T.G. Phillips, “Techniques of submillimeter astronomy, in Millimetre and submillimetre astronomy” (Ed. by R.D. Wolstencroft and W.B. Burton), Lectures at Summer School, Stirling, Scotland, June 21-27, 1987 (Kluwer Academic Publishers, Dordrecht, NL) , pp. 1-25, 1988.

[8] http://www.tydexoptics.com/pdf/Golay_cell.pdf

[9] A.Y. Shih *et al.*, “The Gamma-Ray Imager/Polarimeter for Solar Flares (GRIPS)”. American Geophysical Union, Fall Meeting, abstract SM11B-1602, 2008.

[10] J. Texereau, How to make a Telescope, 2th English Edition (Wilmann-Bell Inc., Richmond, VA). pp. 139 – 175, 1984.

[11] http://www.satrunner.com/en/iridium-9602-sbd-modem.html

[12] http://www.wcclp.com/SBD.asp