SOLAR POWER AS A TEST SIGNAL FOR RADIO ASTRONOMY

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At a recent technical, discussion at Table Mountain the sun was mentioned as a useful (albeit bright) calibration source. It so happens that I have a few pertinent plots in my dusty piles of files and I thought it might be useful to share them.

THE BASIC CHARACTERISTICS OF SOLAR RADIATION

The first figure shows the optical and radio frequency continuum spectrum of blackbody radiators and the sun.

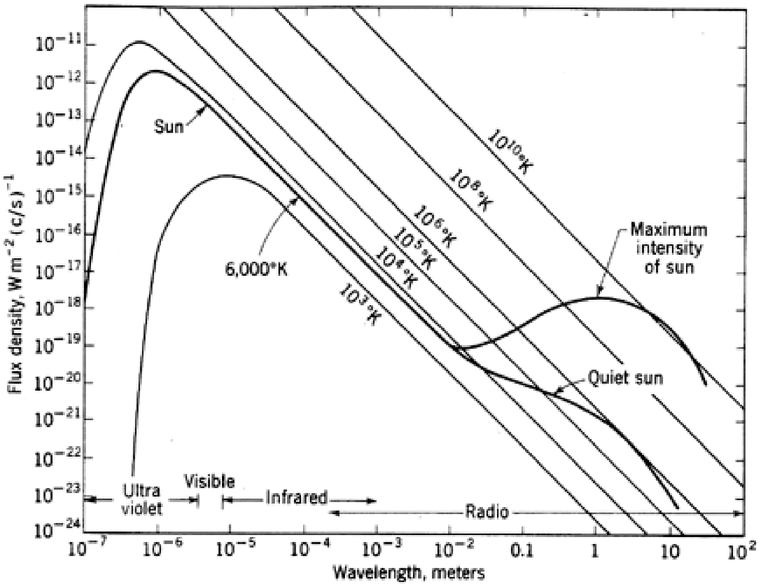

Fig. 7-6 The optical and radio-frequency continuum spectrum of the sun. On this figure the flux-density spectrum that would be received from a black body with the dimensions of the solar disk has been graphed for different temperatures. It is seen that in the optical region the sun radiates approximately like a black body at 6000°K; but it radiates at a much higher temperature on radio wavelengths, where its apparent diameter is larger and the emission originates in much hotter layers. Some radio bursts correspond to much higher equivalent temperatures still, but in such cases the emission is not thermal.

As noted in the legend, the sun appears as a blackbody radiator in the infrared, visible, and ultraviolet regions. However, at radio wavelengths longer than ~10^{-2} m its emission deviates significantly from this pattern. Measurements like these have been instrumental in understanding the structure of our local star but that topic is outside the scope of this note. In the figure's data we have an absolute power reference that can be used to calibrate our own instrumentation.

At a wavelength of 0.21 m (1.4 GHz) the sun radiates with a flux density between 10^{-20} and 10^{-19} W m^{-2} $(c/s)^{-1}$. Let's take a look at those units: "Watts per meter squared per cycles-per-second". Cycles-per-second is an older (ancient?) unit for frequency. The SI unit for frequency is Hertz, abbreviated Hz (remember the capitalization please, uppercase "H", lowercase "z", always). It was officially adopted around 1960 and found predominant use after 1970.

Now, what is needed is to calculate how much power will appear at the terminals of the feed line as it enters the shack at T-22.

An eighteen-meter diameter parabolic dish (you know which one(s) I mean) have a projected area of about 250 m^2. If the dish in question is lossless and the feed antenna is one hundred percent efficient (we could only hope) then a power of 2.5 $x10^{-17}$ to $2.5x10^{-16}$ W Hz^{-1} will appear at the antenna terminals. The "per Hz" part of the relation describes the fact that the energy emanating from the sun is broadband rather than narrowband and that it is carried by EM (electromagnetic radiation) of varying frequencies or wavelengths. The frequency width over which the power measurement is made must be specified. This is highly dependent on the measurement tool being used but a spectrum analyzer that would be used to perform this measurement would typically be set to a bandwidth of 10000 Hz. That means that limited by that bandwidth a power of $2.5x10^{-12}$ to $2.5x10^{-11}$ W would be available at the antenna terminals.

Typically, (perhaps on a good day) the LNA (Low Noise Amplifier) positioned at the feed offers a power gain of one-thousand (termed +30dB to the *cognoscenti*) and the large diameter transmission line leading from the feed to the shack will pass only one-third (termed -5dB to those same folk) of our precious signal (this might seem wasteful but it is exceptionally good considering the length of transmission line and the operating frequency). This results in a power of roughly $8x10^{-11}$ to $8x10^{-12}$ making its way into the shack. This is feeble amount of power indeed.

That this signal is so weak is made even more remarkable by the fact that when the power emitted by the sun and received on the surface of the earth <u>and integrated over all frequencies</u> is measured it is a whopping 1 kW m^{-2} (note the lowercase "k" for kilo which means 1000, not 1024 and the uppercase "W" for Watt) This is because each photon of infrared, visible, and especially ultraviolet light carries so much more energy than does each radio frequency photon.

Anyway, although 8 to 80 µW (1 µW <=> 10^{-6} W) is weak it is measurable and we look forward to performing this measurement (most likely not for the first time at Table Mountain) to see what we get and calibrate our gear.

THE APPEARANCE OF THE RADIO SUN

Another interesting feature of solar measurements can be seen in the following figure.

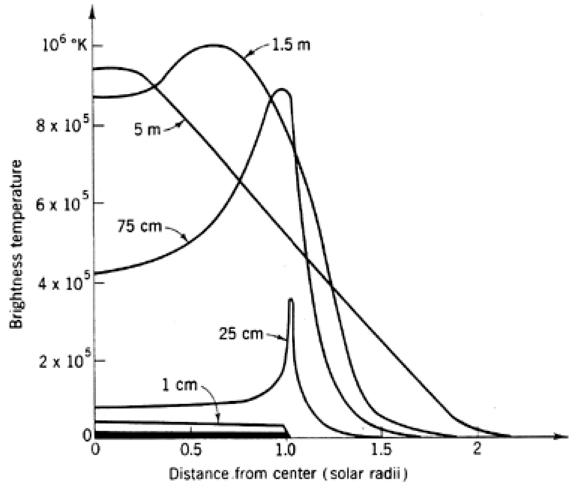

Fig. 7-5 Appearance of the radio sun on different wavelengths of observation. The visible sun is indicated by the heavy line.

This figure shows the radial dependence of the brightness as a function of position across the sun's face and shows the astonishing factoid that the sun does not look the same (not in the least) at different radio and visible frequencies. At a wavelength of 0.21 m (1.4 GHz) the sun "looks" like a bright ring with a significantly dimmer center. One solar radius is roughly 0.25° and the beam width of one eighteen-meter diameter dish is closer to 1.0° so a map made with such a dish would be rather blurry although the effect should be observable. Two of these dishes separated by a few hundred meters and operating together as a Michelson interferometer (see below) would be quite able to resolve structures of this size. It's not hard to predict that this measurement will be made at Table Mountain also.

THE QUIET AND ACTIVE RADIO SUN

The next figure shows some rather ancient data taken of the sun.

As the figure legend says, it consists of the superposition of many individual interferograms (that is position-dependent measurements made with an interferometer) with a very fine 0.066° resolution. The difference between the quiet sun and individual active centers can be readily seen as can the advance of these active centers across the face of the sun. The difference between the quiet and active sun is apparent.

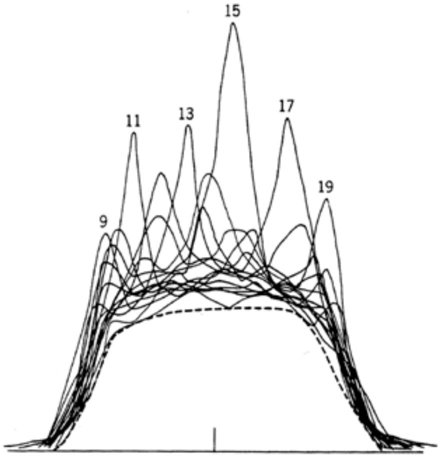

Fig. 7-7 Superposition of 15 solar interferograms taken on 3 cm in July 1959 with the 16-element interferometer at Nançay with a resolution of about 4 minutes of arc. The lower envelope of these curves in principle represents the contribution of the quiet sun, but the number of records is here insufficient and a slight asymmetry without physical significance remains. Note the rotation and evolution of the intense active center as followed at 2-day intervals.

Once again measurements such as these have been pivotal in gaining an understanding of the structure and dynamics of the sun.

AN INTERFEROMETER

In the last figure, a rough schematic of the aforementioned Michelson stellar interferometer is shown.

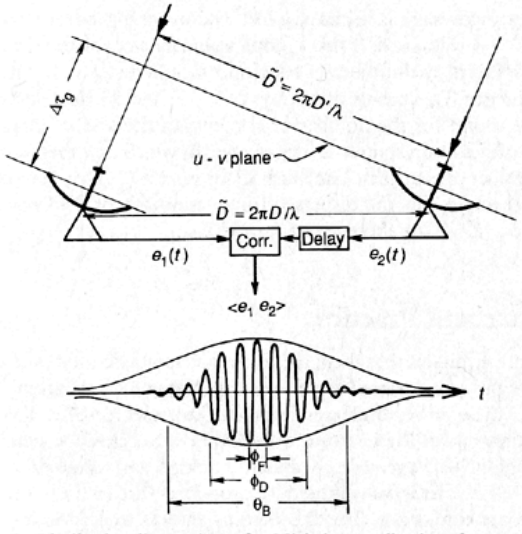

Fig. 2. Idealized radio version of a Michelson stellar interferometer. The angular spacing ϕ_F of the fringes is determined by the projected spacing $\tilde{D}'$, and the modulation in angle is determined either by the coherence length (the inverse bandwidth) or by the diffraction pattern θ_B; e_1, signal from antenna 1; e_2, signal from antenna 2; $\Delta\tau_g$, arrival time delay.

This figure neatly presents the important geometric parameters that give rise to and govern interferometric signals. Depending upon the physical configuration of the several antennas that make up the interferometer, the variation in arrival time delay can be affected by the use of an experimenter-controlled delay line or phase shifter or the earth's slow and steady rotation. We'll get to this type of measurement also.

At the same discussion it was noted that the sun is too bright for certain measurements and that the moon is a weak reflector of the very same solar radiation, hence, a dependable source for other experiments.

So, what is the albedo of the moon at radio frequencies?