SOLAR RADIO EMISSION

太阳无线电发射

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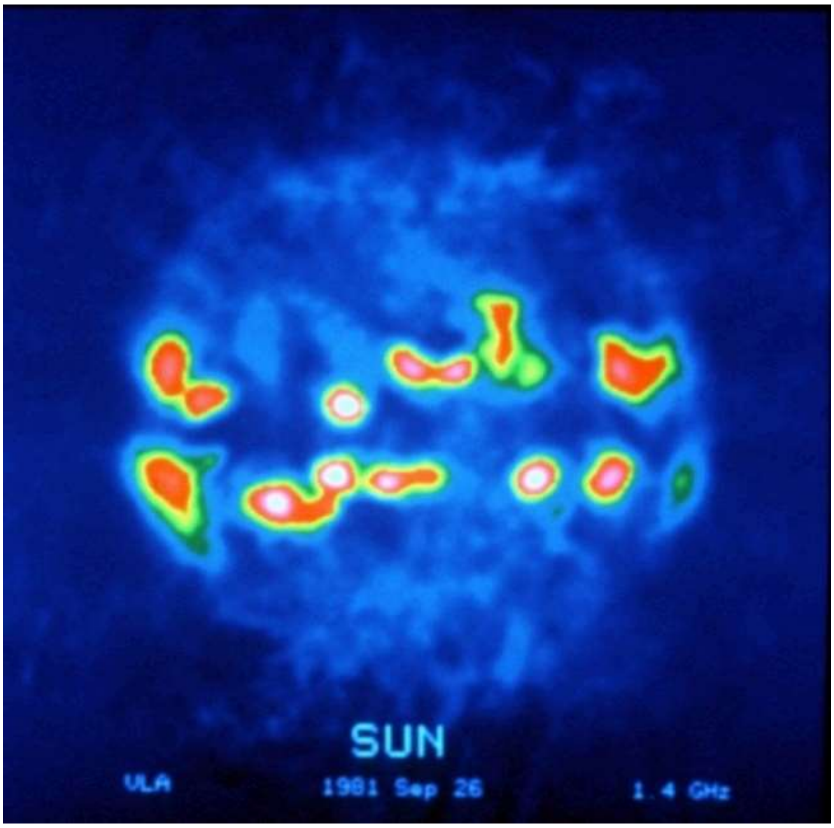


***Abstract** : Using the amateur radio telescope described in previous posts: A simple 11.2 GHz RadioTelescope (HW Part), A simple 11.2 GHz RadioTelescope (SW Part) we tried to make a quantitative detection of the radio emission of the sun at the frequency of 11.2 GHz. the measurements we made and the results obtained are described below.*

摘要： 使用前几篇文章中描述的业余射电望远镜：一个简单的 11.2 GHz 射电望远镜（硬件部分），一个简单的 11.2 GHz 射电望远镜（SW 部分），我们试图对太阳在 11.2 GHz 频率下的射电发射进行定量检测。我们所做的测量和获得的结果描述如下。

Introduction 介绍

The Sun is the easiest astronomical radio source to detect and measure. The surface of the Sun that we observe in the visible is called **photosphere**, but radio emissions also arise in the **chromosphere** and in the **solar corona** that make up the solar atmosphere. The photosphere has a temperature of about 6000 °K and, even if the plasma at this temperature emits more in the visible and ultraviolet range, thanks to the proximity of the sun we can also record its radio emission.

太阳是最容易探测和测量的天文射电源。我们在可见光中观察到的太阳表面称为光球层，但无线电发射也出现在构成太阳大气层的色球层和太阳日冕中。光球层的温度约为 6000 °K，即使该温度下的等离子体在可见光和紫外线范围内发射更多，但由于靠近太阳，我们也可以记录其无线电发射。

The radio emission of the sun is partly “**thermal**” and partly “**non-thermal**“. The thermal component follows the **black body** law and is predominant at high frequencies (f> 3 GHz) while the non-thermal component (**synchrotron radiation**) is predominant at lower frequencies (f <3 GHz).

太阳的无线电发射部分是“热的”，部分是“非热的”。热分量遵循黑体定律，在高频 （f> 3 GHz） 下占主导地位，而非热分量（同步辐射）在低频 （f <3 GHz） 下占主导地位。

The situations of **quiet Sun** and **active Sun** must then be distinguished. During the “quiet sun” phases, the emission is at a minimum, while in the phases of solar activity, characterized by many spots and solar flares, the emission can be considerably higher.

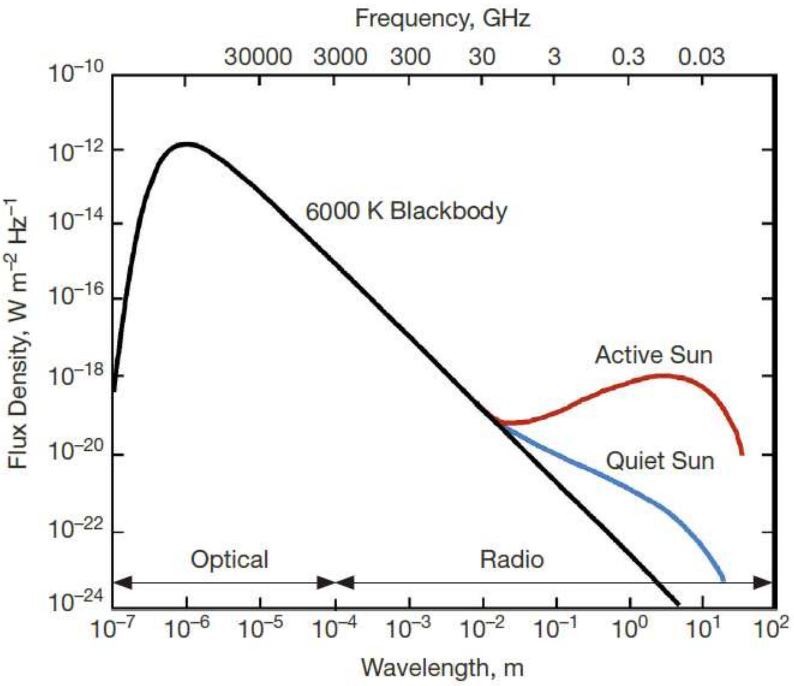
然后必须区分安静的太阳和活跃的太阳的情况。在“安静的太阳”阶段，发射是最小的，而在太阳活动阶段，以许多斑点和太阳耀斑为特征，发射量可能要高得多。

The solar radiation spectrum covers all frequencies from radio to optical (infrared, visible, and ultraviolet). In the optical range (100 nm to 1000 nm wavelength), the Sun can be treated with excellent approximation as a **blackbody** with a constant temperature of about **6000 °K**.

As shown in Figure below, the solar flux density is equal to that from a blackbody radiator at 6000 °K at wavelengths less than about 1.0 cm (a frequency greater than about 30 GHz), but the spectral density becomes **much greater** at longer wavelengths for both a **quiet and active Sun (solar flares)**. An active Sun has much larger flux density than does a quiet Sun in the frequency range between 100 MHz (3-m wavelength) and 30 GHz (1 cm wavelength). These elevated fluxes come mainly from the contribution of the **solar corona** and the **chromosphere**, a thin layer just above the visible photosphere.

太阳辐射光谱涵盖从无线电到光学（红外、可见光和紫外线）的所有频率。在光学范围（100 nm 至 1000 nm 波长）中，太阳可以很好地近似为恒定温度约为 6000 °K 的黑体。

如下图所示，太阳通量密度等于 6000 °K 时波长小于约 1.0 cm（频率大于约 30 GHz）的黑体辐射体的光通量密度，但对于安静和活跃的太阳（太阳耀斑），光谱密度在较长的波长下会变得更大。在 100 MHz（3 m 波长）和 30 GHz（1 cm 波长）之间的频率范围内，活跃的太阳比安静的太有更大的磁通密度。这些升高的通量主要来自太阳日冕和色球层的贡献，色球层是可见光球层上方的薄层。



From “Solar Brightness Temperature and Corresponding Antenna Noise Temperature at Microwave Frequencies” Christian Ho, Stephen Slobin,† Anil Kantak,* and Sami Asmar**

What we propose is to measure, with our DIY radio telescope, the radio emission of our sun at the frequency of 11.2 GHz which corresponds to a wavelength of 2.68 cm and to obtain the **brightness temperature**. From the graph above it appears that the emission spectrum deviate slightly from the black body curve, so we expect a brightness temperature a little higher than the temperature of 6000 ° K.

我们建议用我们的 DIY 射电望远镜测量太阳在 11.2 GHz 频率下的无线电发射，相当于 2.68 cm 的波长，并获得亮度温度。从上图可以看出，发射光谱似乎略微偏离了黑体曲线，因此我们预计亮度温度会略高于 6000°K 的温度。

Calibration of Radio Telescope

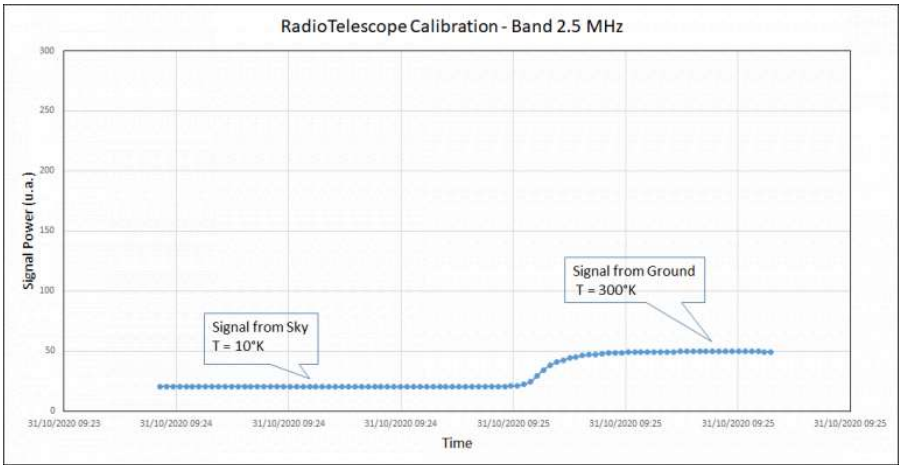
射电望远镜的校准

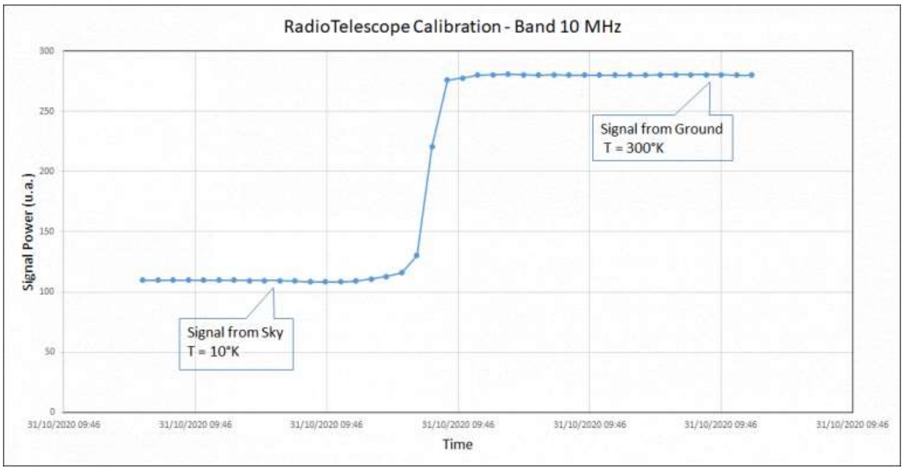
The first operation that must be performed before the observations is the calibration of the radio telescope. It is recommended to activate the system and keep it on for a while so that the operating temperature stabilizes. The calibration operation consists in pointing the antenna towards a “cold” source such as the clear sky and towards a “hot” source such as the ground. It is assumed that the brightness temperature of the clear sky is about 10 °K while that of the ground is about 300 °K. Take note of the power value returned by the system and enter these values in the radiometer GUI: at this point you can use the calibrated mode which directly returns the value of the **brightness temperature** of the source pointed to by the antenna (for details, see previous posts on amateur radio astronomy).

观测前必须执行的第一个操作是射电望远镜的校准。建议激活系统并保持开机一段时间，以使工作温度稳定。校准操作包括将天线指向“冷”源（如晴朗的天空）和“热”源（如地面）。假设晴空的亮度温度约为 10 °K，而地面的亮度温度约为 300 °K。 记下系统返回的功率值，并在辐射计 GUI 中输入这些值：此时，您可以使用校准模式，该模式直接返回天线指向的光源的亮温值（有关详细信息，请参阅之前关于业余射电天文的文章）。

The records below show the values obtained by alternately aiming for the clear sky and the ground. In the first graph we report the results for a band of **2.5 MHz**, while in the second the **10 MHz** band was used. As is correct and as we expect, with the 10 MHz band the power detected by the system is much greater.

以下记录显示了通过交替瞄准晴朗天空和地面获得的值。在第一张图中，我们报告了 2.5 MHz 频段的结果，而在第二张图表中，我们使用了 10 MHz 频段。正如我们预期的那样，对于 10 MHz 频段，系统检测到的功率要大得多。

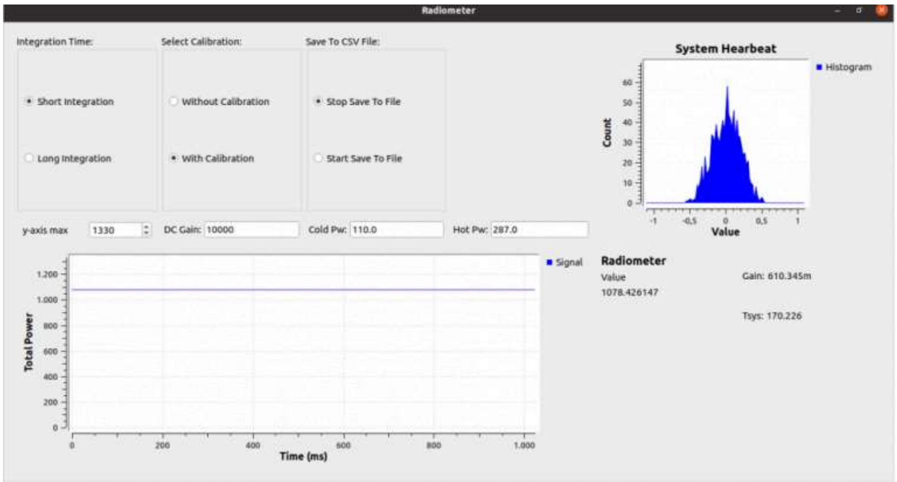




Sun Transit Sun Transit

After calibration, you can proceed with pointing the antenna towards the Sun. In our system, pointing is done manually. While orienting the antenna, the signal recorded by the radiometer is checked in order to obtain the maximum value: when the value is maximum, it means that the antenna is correctly pointed towards the Sun. At this point, saving data on file is started, in order to obtain the registration of the transit. The following image shows the graphic interface of our radiometer with the **Total Power** value graph.

校准后，您可以继续将天线指向太阳。在我们的系统中，指向是手动完成的。在确定天线方向时，检查辐射计记录的信号以获得最大值：当该值为最大值时，表示天线正确指向太阳。此时，将启动将数据存档，以获取传输的注册。下图显示了辐射计的图形界面和 Total Power （总功率） 值图。


Integration Time:
● Short Integration
○ Long Integration

Select Calibration:
○ Without Calibration
● With Calibration

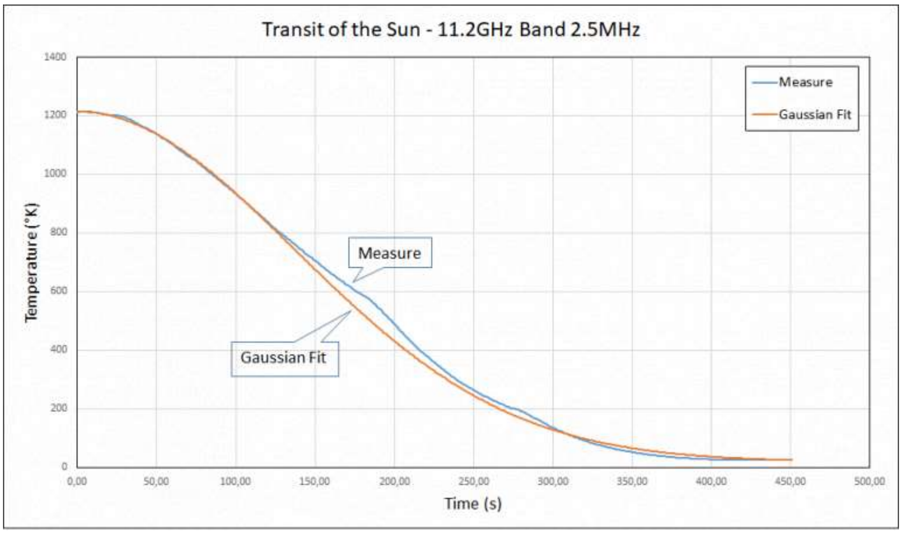
Save To CSV File:
● Stop Save To File
○ Start Save To File

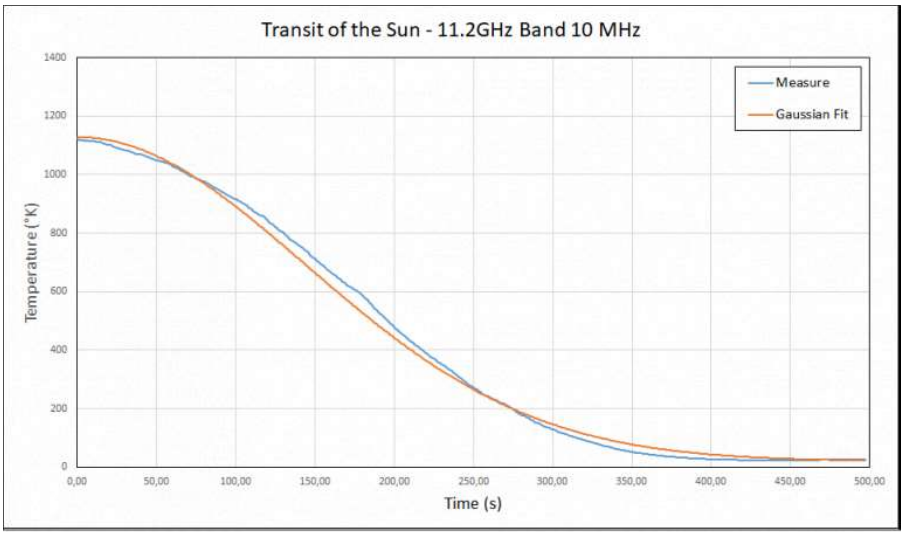
y-axis max: 1330
DC Gain: 10000
Cold Pw: 110.0
Hot Pw: 287.0

Radiometer
Value
1078.426147
Gain: 610.345m
Tsys: 170.226

Our solar transit record is “halved”. Given the difficulty of correct manual pointing of the antenna, it is easier to center it directly on the solar maximum and then follow the decreasing signal rather than point it towards a future position of passage of the Sun. The graphs below show the results obtained on a 2.5 MHz band. and on a 10 MHz band. The graphs show the time on the abscissa and the brightness temperature on the ordinate. The results are very similar to each other. Both record a maximum **brightness temperature of 1100 – 1200 °K** and a decreasing trend approximated quite well by a **Gaussian curve**.

我们的太阳能运输记录是"减半"。鉴于天线正确手动指向的难度，更容易将其直接置于太阳极大期的中心，然后跟随减弱的信号，而不是将其指向太阳的未来经过位置。下图显示了在 2.5 MHz 频段上获得的结果。和 10 MHz 频段。这些图表显示了横坐标上的时间和纵坐标上的亮度温度。结果彼此非常相似。两者都记录了 1100 – 1200 °K 的最大亮度温度和下降趋势，与高斯曲线相当接近。



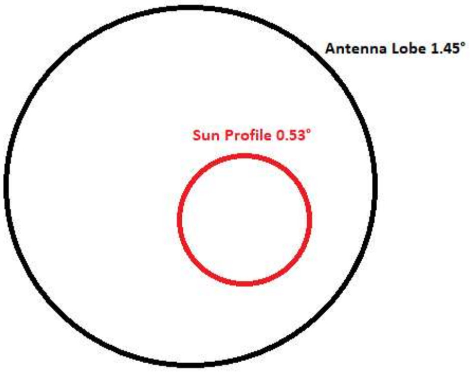


Sun Brightness Temperature

Sun Brightness Temperature

With the measurement data we want to try to derive the brightness temperature of the Sun. The first factor we must take into account is the solid angle subtended by the beam of our antenna. In the following drawing we compare the image of the Sun and the beam of our antenna: as you can see, the antenna lobe is much wider than the solar image. In practice, the value measured by our antenna is a sort of average over the whole beam width: the result is that the **solar radiation is diluted over a much larger surface** and the measured value is consequently much lower. Technically, the output signal produced by the system is the **spatial convolution** between the antenna diagram and the radiation diagram of the source.

利用测量数据，我们想尝试推导出太阳的亮度温度。我们必须考虑的第一个因素是天线波束所承受的立体角。在下面的图中，我们比较了太阳的图像和天线的光束：如您所见，天线瓣比太阳图像宽得多。在实践中，我们的天线测得的值是整个波束宽度的平均值：结果是太阳辐射在更大的表面上被稀释，因此测量值要低得多。从技术上讲，系统产生的输出信号是天线图和源辐射图之间的空间卷积。



We know that the angle subtended by the Sun's disk holds **0.53°** which correspond to a surface of **0.22 degrees^2**, the beam of our parabolic antenna is worth instead **1.45°** which correspond to **2 gradi^2**.

我们知道太阳圆盘的角度为 0.53°，对应于 0.22 度的表面2，我们的抛物面天线的波束值 1.45°，相当于 2 格拉迪2。

- **Sun Disk : 0.53° -> Ω_{sun} = 0.22 gradi^2**.

  太阳圆盘： 0.53° -> Ωsun = 0.22 gradi2.

- **Antenna Beam : 1.45° ->Ω_{ant} = 2 gradi^2**.

  天线波束： 1.45° ->Ωant = 2 gradi2.

The radiation pattern of the Sun and the radiation pattern of the antenna are graphically represented in the following image. The antenna diagram is calculated with the following formula:

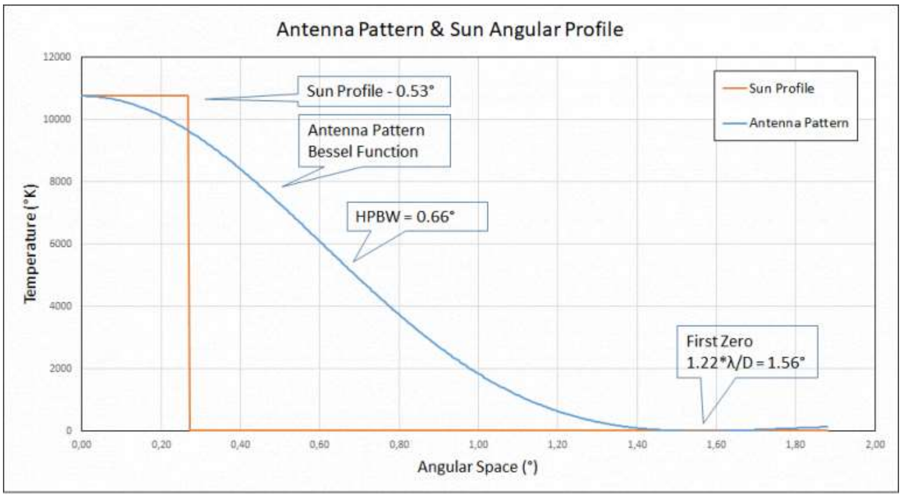
太阳的辐射图和天线的辐射图以图形方式表示在下图中。天线图使用以下公式计算：

$I = I_0*[\,2*J_1(\alpha)/\alpha]^2$ dove $\alpha=(\pi D/\lambda)*\theta$, J_1 is Bessel function of order 1

I = I0*[2*J1（α）/α]2 鸽子 α=（πD/λ）*θ， J1 是 1 阶的贝塞尔函数

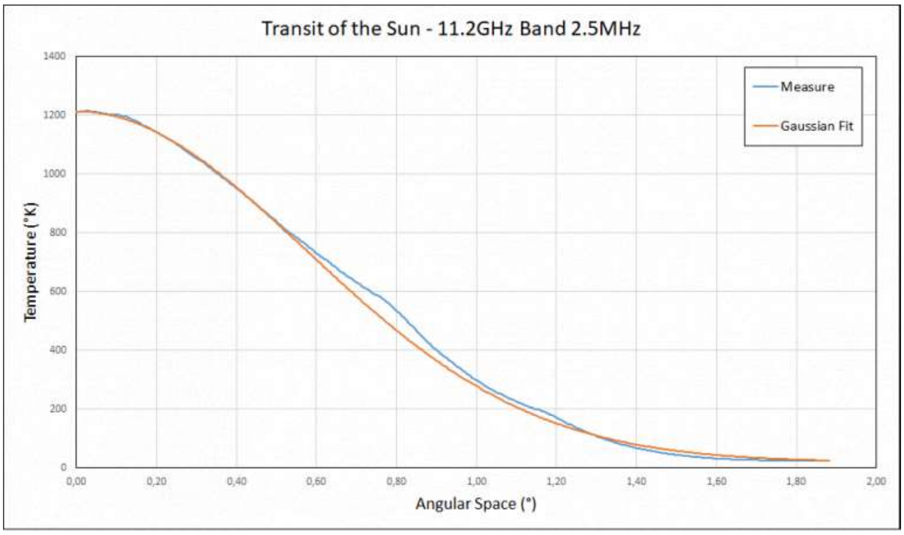
The angle **θ** is shown on the abscissa graph, while the intensity normalized to the arbitrary value is on the ordinate **I_0**

角度 θ 显示在横坐标图上，而标准化为任意值的强度位于纵坐标 I0 上



Since the radiation pattern of solar radiation is much narrower than the antenna pattern, the convolution of the two functions will be very similar to the somewhat enlarged antenna pattern. However, we have not done the calculation but the graph obtained from the registration of the transit, which we report below in "angular" terms instead of time, has the expected trend.

由于太阳辐射的辐射方向图比天线方向图窄得多，因此这两个函数的卷积将与略微扩大的天线方向图非常相似。但是，我们还没有进行计算，但从凌日登记中获得的图表（我们在下面以"角度"而不是时间术语报告）具有预期的趋势。



For the determination of the equivalent brightness temperature we can use the following relationship:

为了确定等效亮度温度，我们可以使用以下关系：

$$T_{ant} = T_{sun}*(\Omega_{sun}/\Omega_{ant}) + T_{sky}*(1-\Omega_{sun}/\Omega_{ant})$$

Tant = Tsun*(Ωsun/Ωant) + Tsky*(1-Ωsun/Ωant)

Where

Tant : equivalent antenna temperature (measured value)

Tsun : sun brightness temperature

Tsky : cold sky brightness temperature (measured value)

哪里
Tant： 等效天线温度（测量值）
Tsun： 太阳亮度温度
Tsky： 冷天空亮度温度（测量值）

Knowing, from the measurements made, **Tant = 1200 °K** and **Tsky = 20 °K**, we can solve the equation and getting Tsun

从所做的测量中知道，Tant = 1200 °K 和 Tsky = 20 °K，我们可以求解方程并得到 Tsun

Tsun = 10748 °K Tsun = 10748 °K

Comparing this value with the actual temperature of the solar surface, of 6000 °K, we can say that already at 11 GHz the behavior of the sun begins to deviate from the law of the black body, as mentioned in the introduction to this post.

将该值与太阳表面的实际温度 6000 °K 进行比较，我们可以说，正如本文引言中提到的，在 11 GHz 时，太阳的行为已经开始偏离黑体定律。

Conclusions 结论

We have seen that even with an amateur device you can make measurements of a certain accuracy. The big limitation of our radio telescope is the difficulty and poor pointing accuracy. With a source like the sun it is easy to center the antenna but with weaker sources it could be a problem.

我们已经看到，即使使用业余设备，您也可以进行一定精度的测量。我们射电望远镜的最大局限性是难度大，指向精度差。对于像太阳这样的光源，很容易将天线居中，但对于较弱的光源，这可能是个问题。

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