Making Lunar Scans with the ESA-Dresden radio telescope

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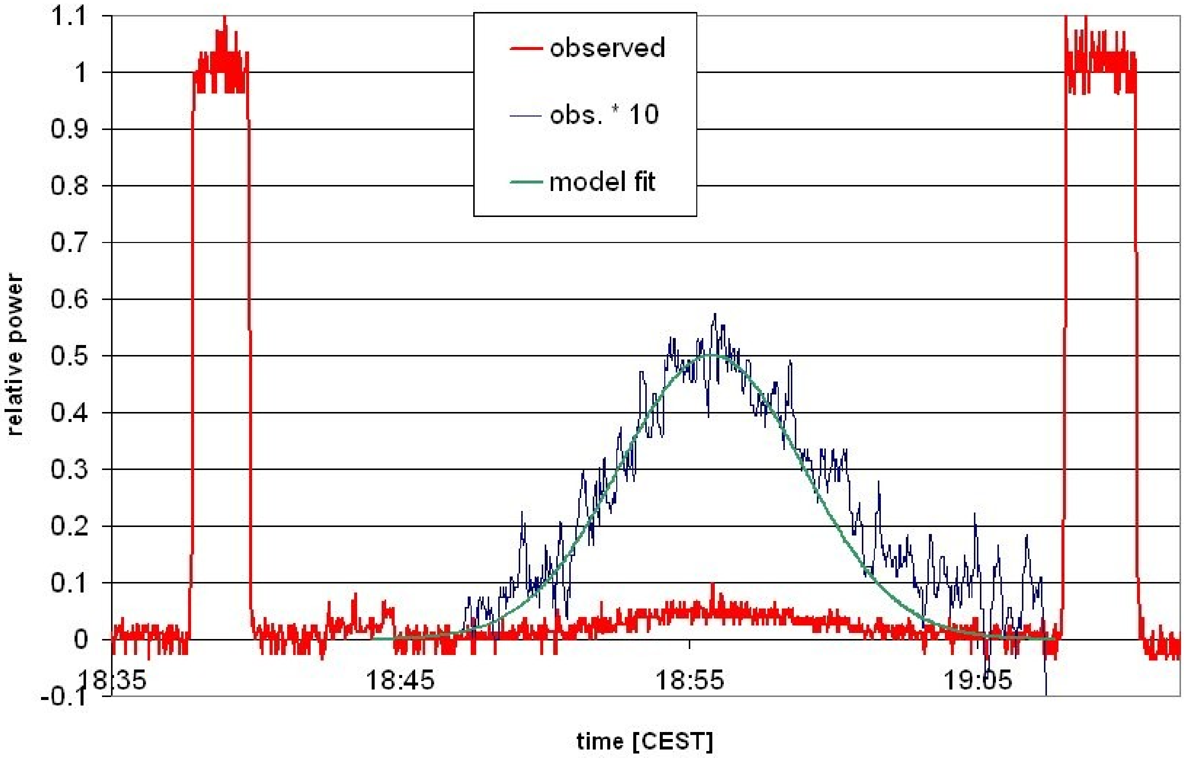
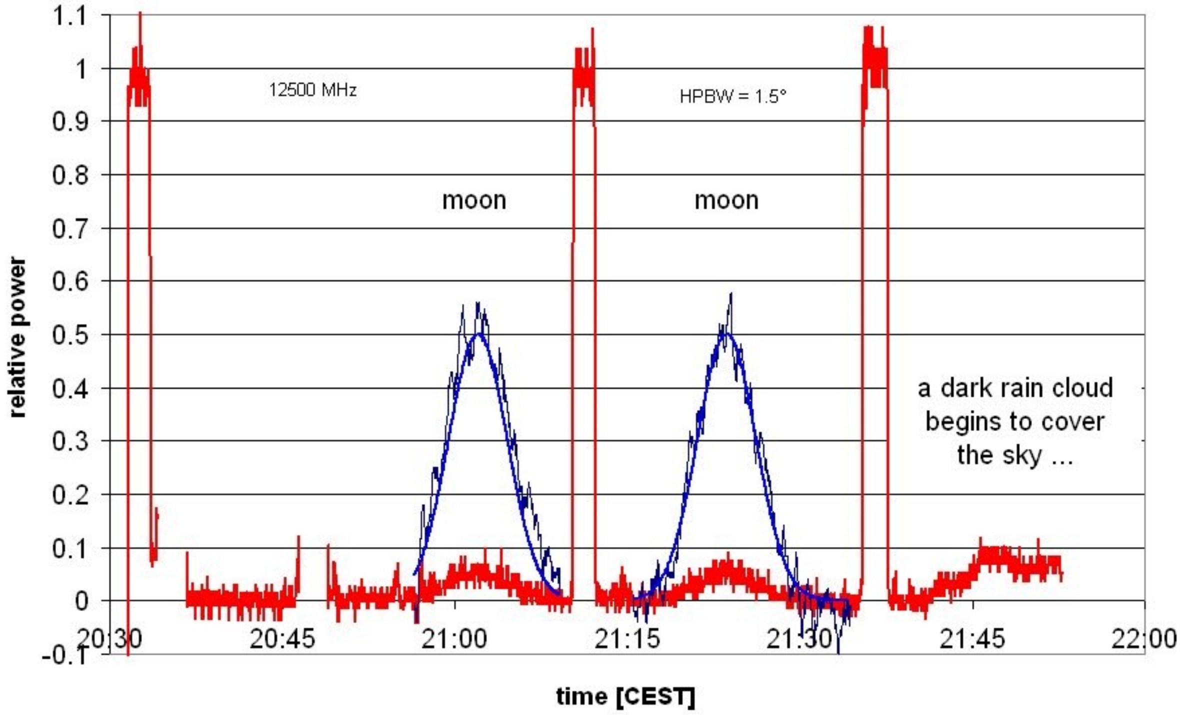
First tries

The first fully successful lunar scan was done on 26 April 2007 (lunar age 9.8 days): The profile is matched with a HPBW of 1.88°; the antenna temperature is 16.5 K, giving a lunar temperature of 233 K. However, the HPBW is significantly larger than the 1.5° we always obtain from the solar scans! The enhanced signal just before 18:45 is due to a search for the Moon near the predicted position prior to shifting the telescope slightly to the west in anticipation of the scan.



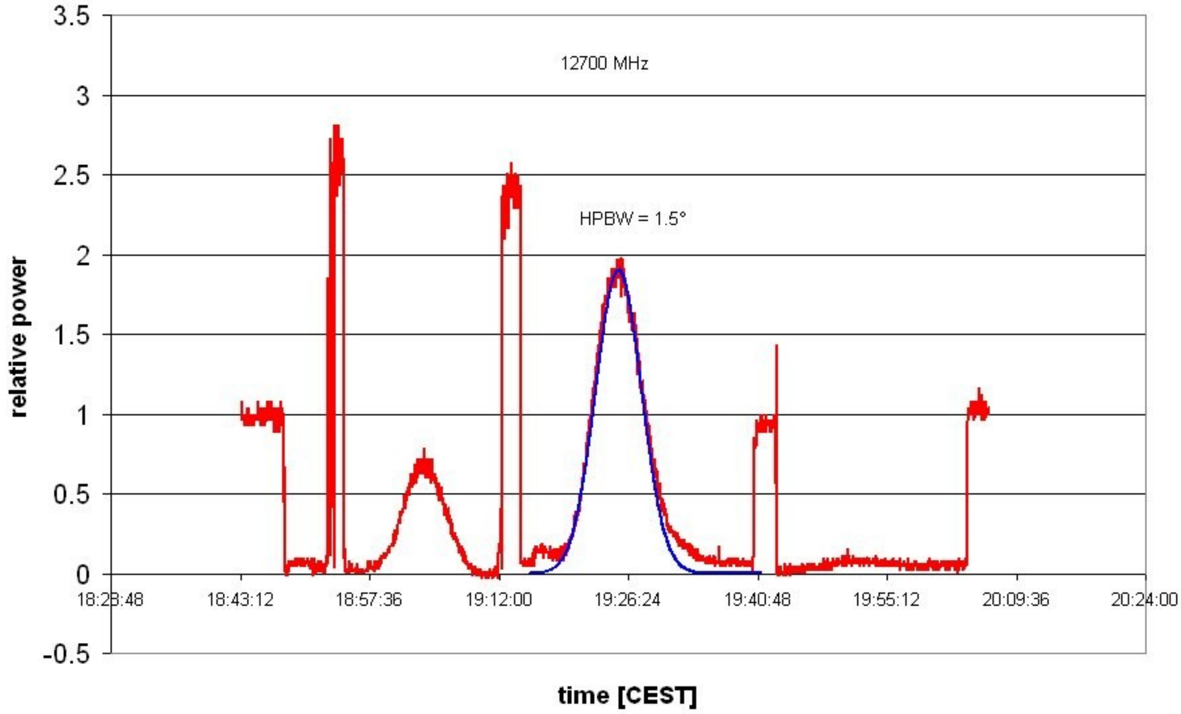
Of Moon, Rain Clouds, and the HPBW

The next scans were obtained on 24 June 2007 (lunar age 9.4 days). Here we got two nice complete profiles of the moon at first quarter, as the moon passed close to the meridian, and thus at constant elevation. This was particularly helpful, because it removed the difficulties due to the limited accuracy and stability of the positioning system.

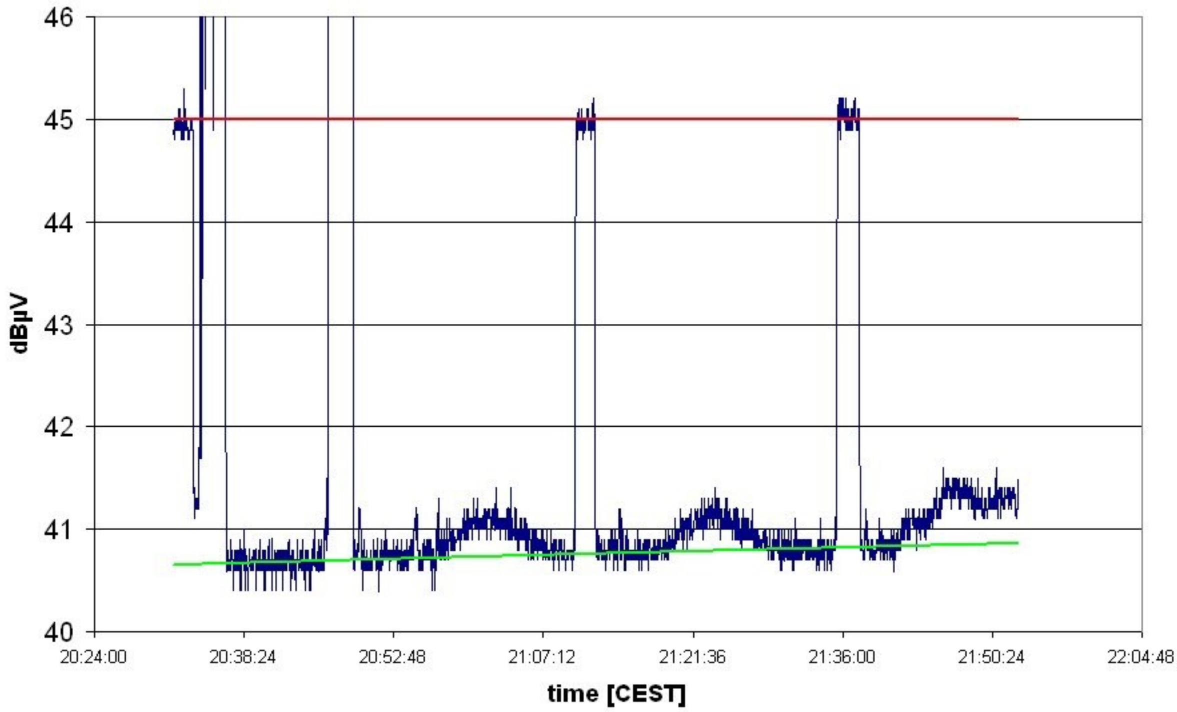


These successive scans were helpful in confirming that establishing that we do observe the moon, but we also could identify the failure of a third scan with a dark rain cloud passing over that region of the sky. In the first two scans, the sky contained a thin veil of clouds which apparently did not affect the observations, giving a very constant background signal. The rain cloud's signal is comparable with the lunar signal, and even exceeds it.

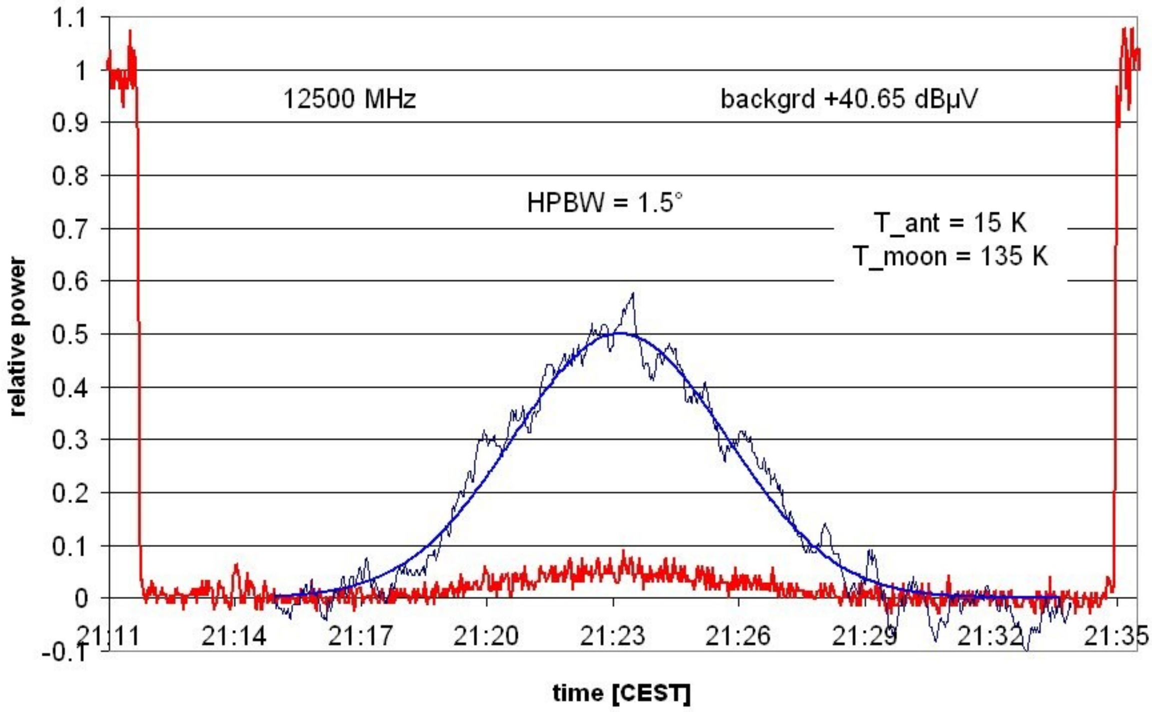
The question of the HPBW remained. The first interpretations of the data also pointed towards a high value of 1.88°. However, solar scans of the same day (and on the same frequency) definitely favoured 1.5°, as shown in the scan below:



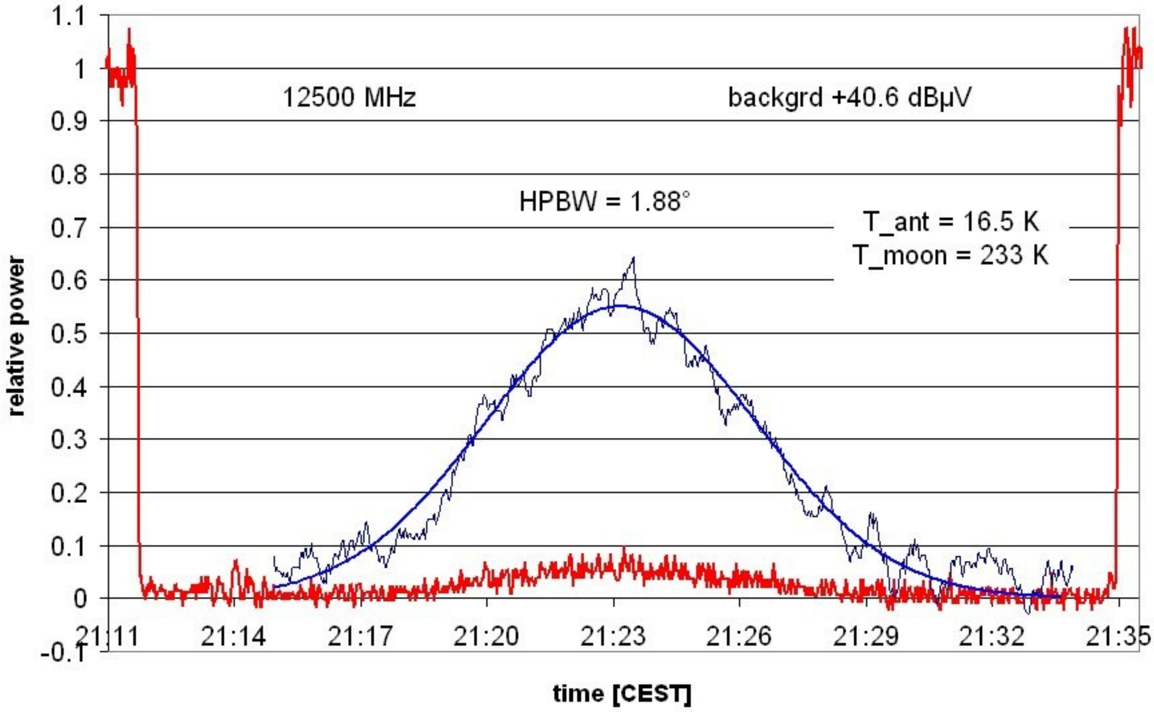
Finally, it was found that the setting of the background level is rather crucial for the shape of the subtracted lunar profile. The figure below show the fit of background and calibration levels during the lunar scans:



If one sets the background level as shown above, so that it passes through the average background signal, the reduced lunar profile may have negative values far away from the position of the peak, one can indeed match this profile well with a HPBW of 1.5°, as shown below:



However, in the first analyses, the background level had been set very slightly lower – by only 0.05 dB – and the resulting lunar profile was broader, and needed a HPBW of about 1.88°:

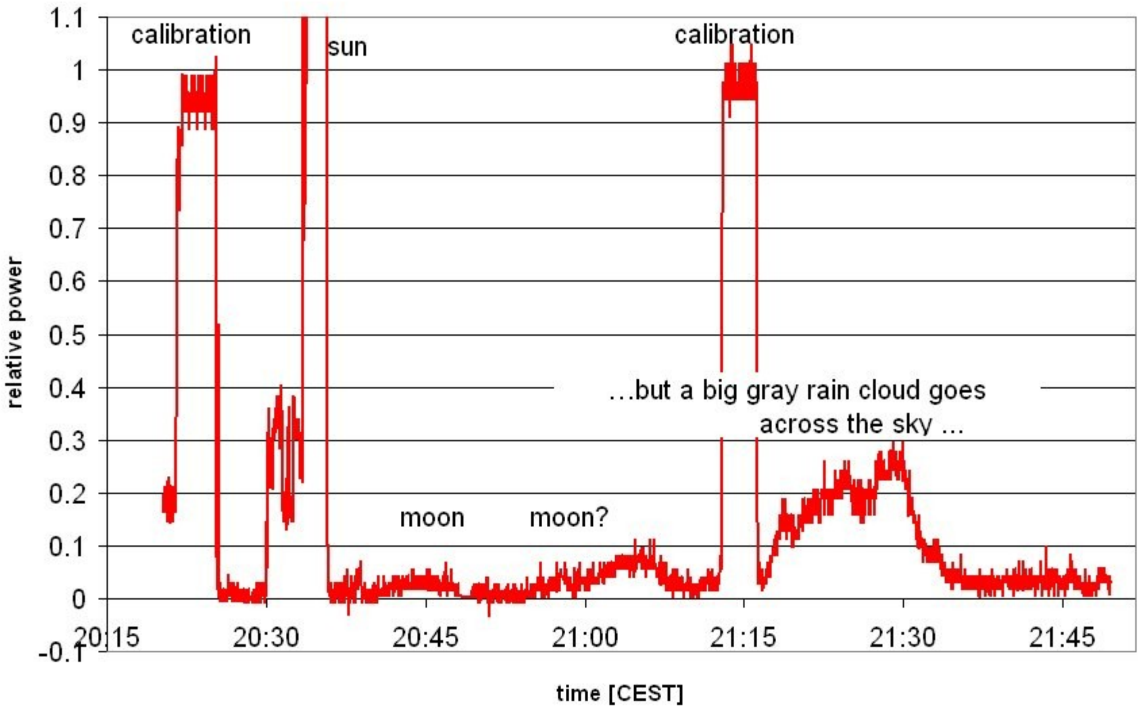


This demonstrates that a good background subtraction is of crucial importance for the interpretation of weak signals, such as from the moon. This affects the antenna temperature and hence the deduced source temperature: The lunar temperature came down from 233 K to 135 K. One must emphasize that this large change in the absolute value is mainly due to the different value for the HPBW, which enters quadratically in the antenna filling factor. However, for a determination of the absolute value of the temperature other factors also enter, such as the accuracy of the flux calibration and the transparency of the atmosphere (see Monstein, 1987).

On the other hand, the antenna temperature – determined from the peak of the profile – changes only by 10 %, even if the background is not overly well determined. Thus, if one compares data from different days, one may well expect to be able to measure temperature differences on the moon of about 20 K, about its average value of 200 K (see below).

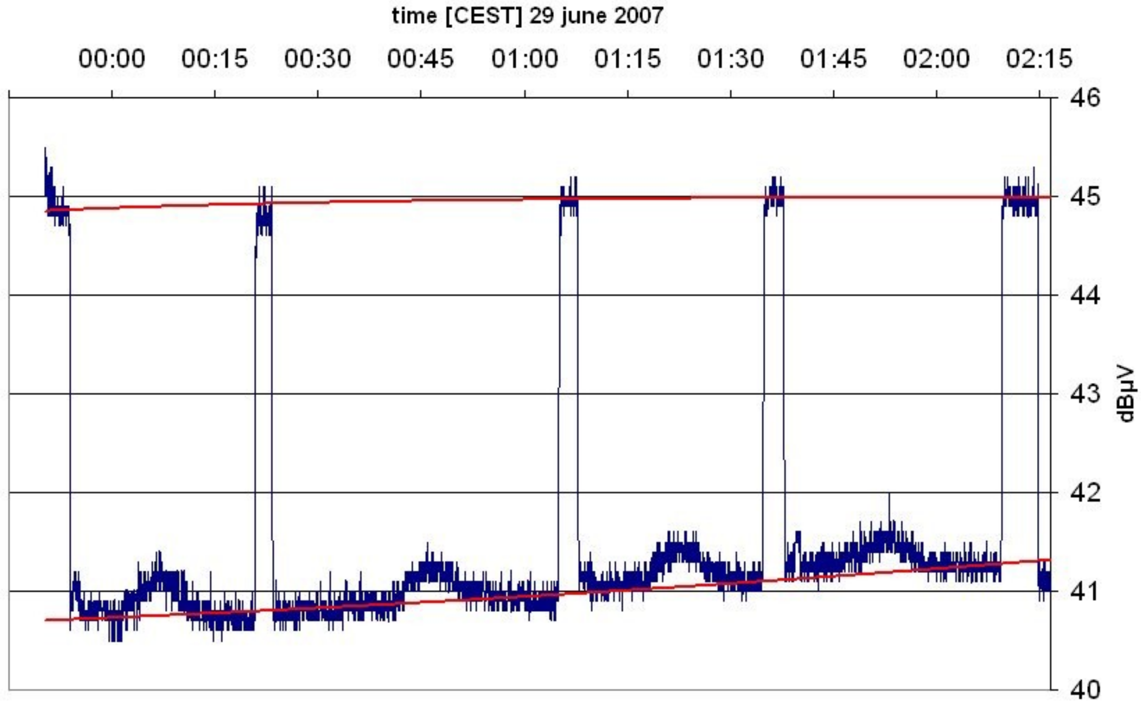
Effects of Rain Clouds

The observations also showed that lunar scans should better not be done in rainy weather or with a thick cover of dark, rain-loaded clouds. In an earlier attempt, on 22 June, we had two rather uncertain lunar observations – partly due to the uncertainties of the positioning system – when the arrival of a thick black rain cloud dispersed all the doubts about the source of radio emission. As depicted below, the signal became five times stronger as that of the moon. After the cloud passed over, the observations were abandoned in view of more rain clouds coming in from the west. It goes without saying that the observer made good use of his umbrella on the way home.

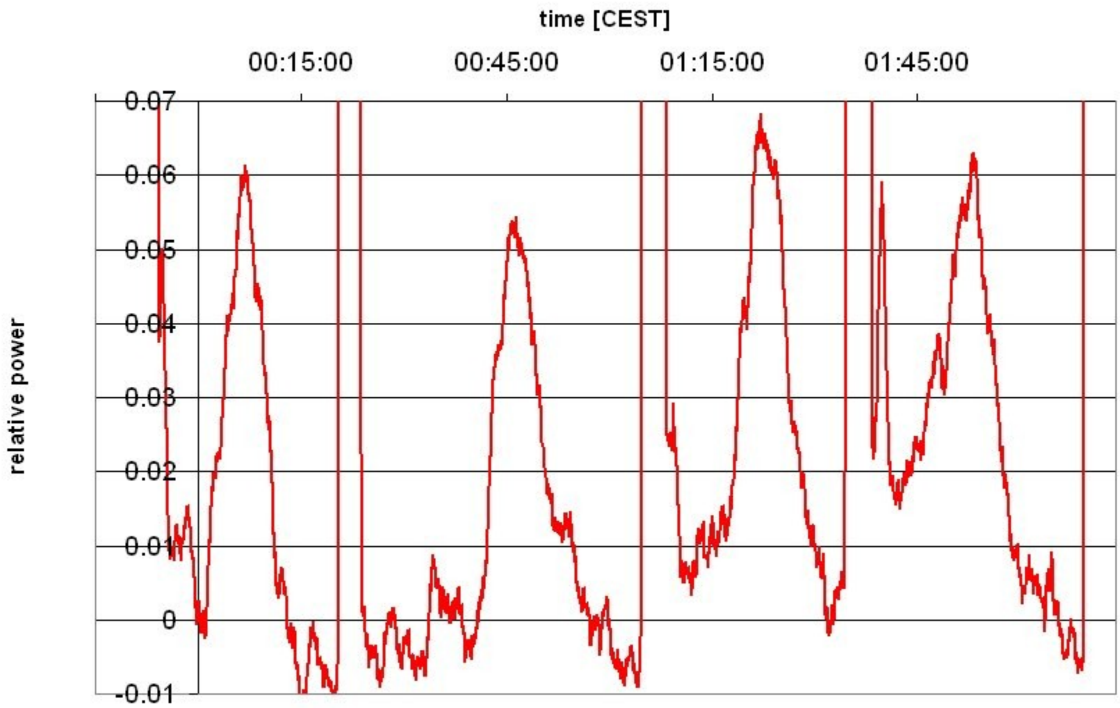


Multiple Scans

The clear skies on 28/29 June (lunar age: 12.2 days) gave the following data were obtained, shown as raw data:



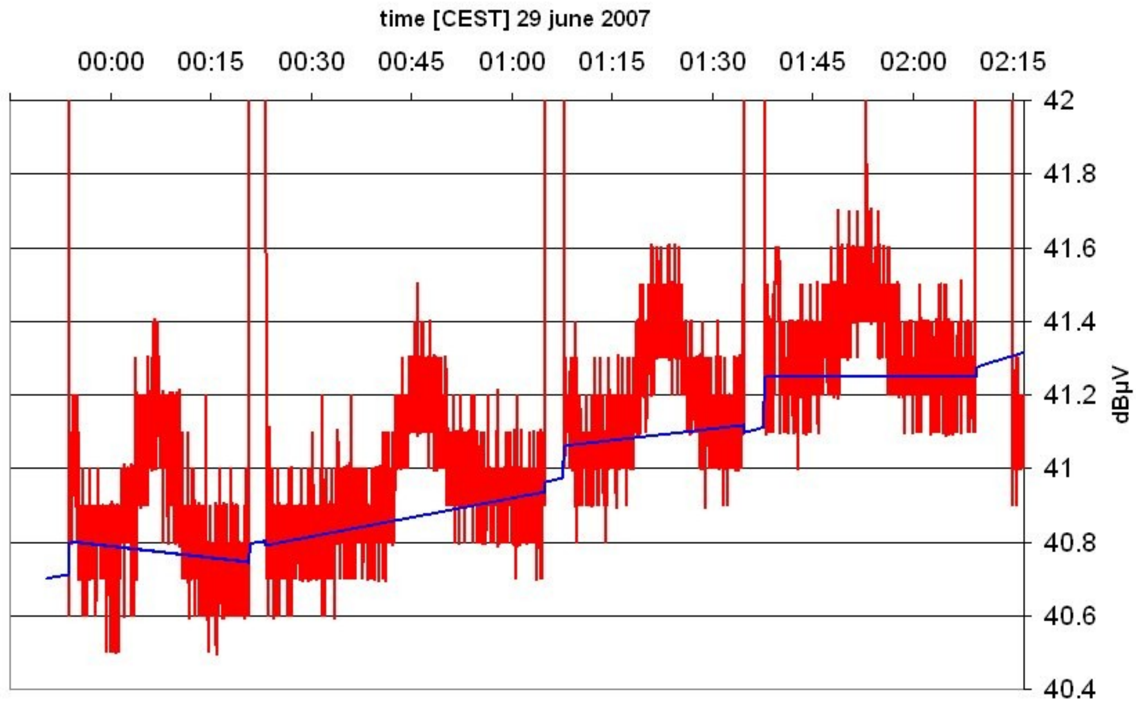
As the moon passed over the meridian at nearly constant elevation, it was especially easy to position the telescope and to lay in wait for the transit. For transits were observed, with the calibration observations at the Holiday Inn hotel placed in between. On notes a slight variation of the calibration level, which most probably is because of the warming up of the receiving system after switch on. The red curve is the adopted fit by a simple analytical expression, which obviously could be improved somewhat further. But also, one notes a substantial increase of the background level over the observational period. A simple analytical fit (as shown as a red curve) is insufficient. Below are shown the data, subtracted with this approximate background and flux-calibrated:



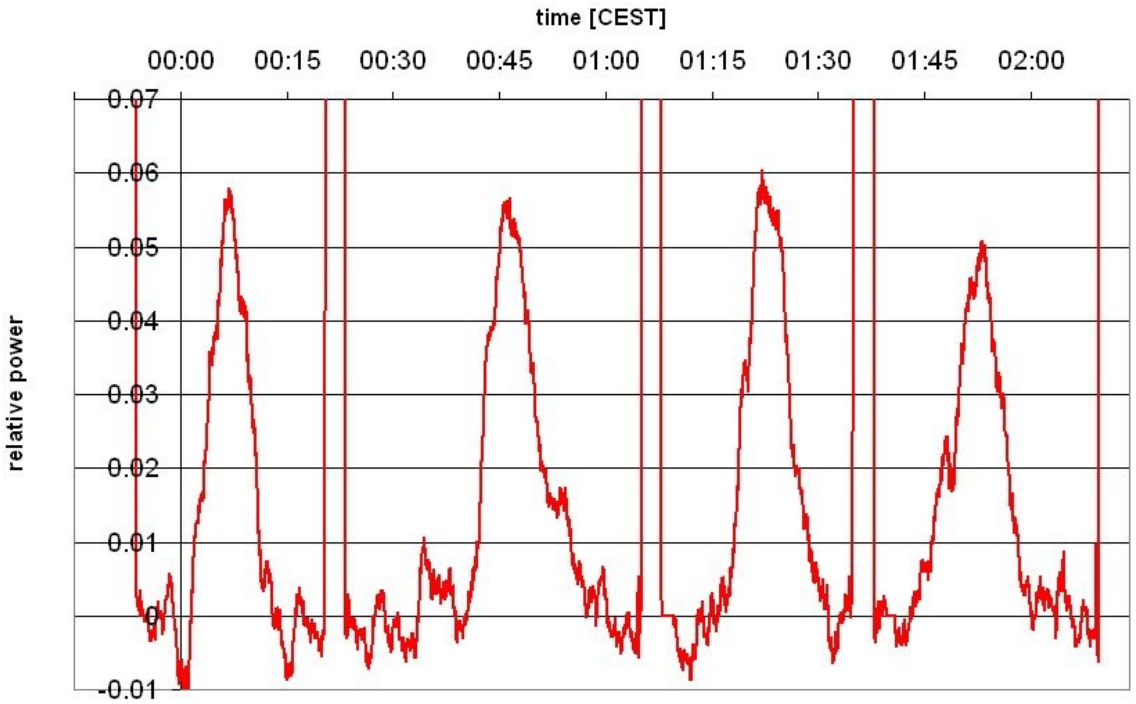
The origin of this increase seems to be the arrival of what appeared to be a thin layer of clouds. Since a simultaneous close watch of the sky could not be executed, the presence of a complete coverage of the sky was only noticed after the end of the observational period. However, in the second transit it was noticed that the right hand part of the profile showed some enhancement. This could have been due to the presence of a thin cloud, although a quick look at the moon at that time (00:45) did not reveal any obvious obscuration.

The above data was smoothed with a box-car function extending 25 points below and above the datum of interest. Thus the transitions from calibration and transit data are slurred. As can be seen in the raw data, at the start of each scan section, there is a short stretch of data with a level as high as the peak value: These are quick searches for the moon around the approximate position, followed by setting the azimuth a couple of degrees to the west and wait for the transit. This technique is absolutely necessary because of the limited accuracy and stability of the positioning system. But this simple measure gives a good guarantee for a successful and reliable scan.

It was evident that the background needed to be adjusted for each transit separately. The adopted linear fits for the backgrounds are depicted here:

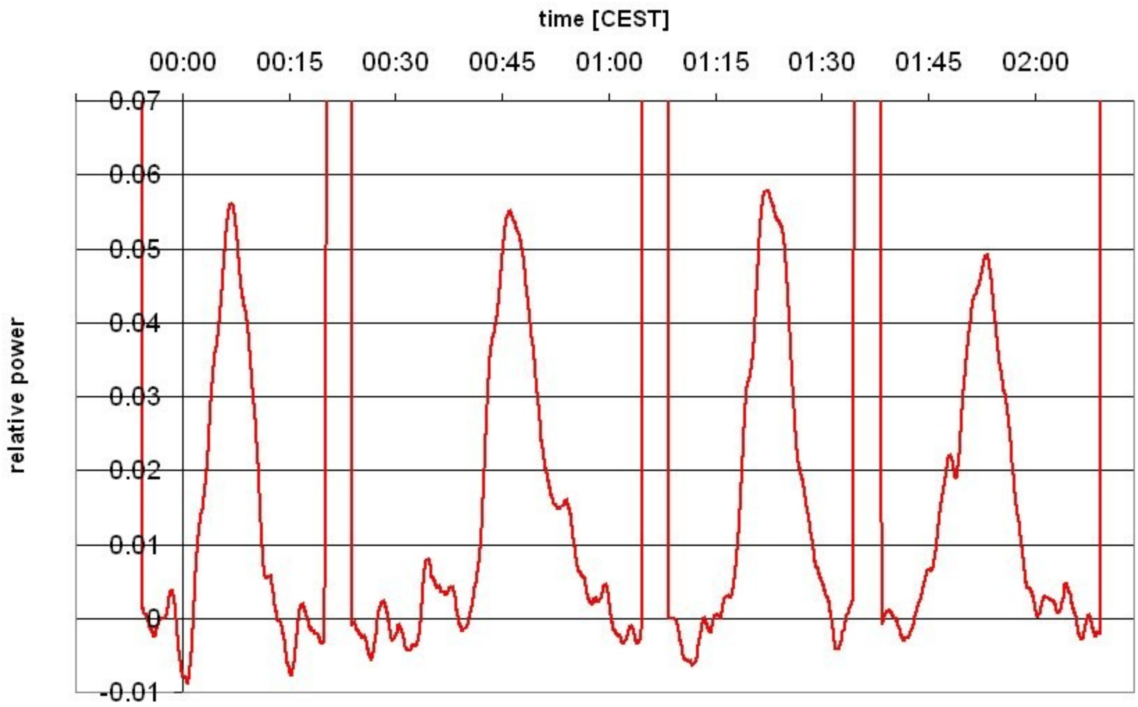


Reducing the data with the above backgrounds and using the analytical fit to the calibration data, and smoothing the reduced data with a box-car average of about 50 points gave these results:



The four scans show a satisfactory background subtraction and that the peaks have the same values. We must except the fourth scan, which suffered from either the arrival of the cloud cover or a non-central passage through the antenna lobe.

If one applies another box-car smoothing, one obtains the following profiles. Note that the averaging applies separately to each interval of lunar observations and calibration, thus near the edges the averaging is not symmetric about the datum of interest.



Perspectives

- The detection of rain clouds by the telescope should be done in a more systematic way, by observing the same part of the sky (preferentially nearly overhead) in the radio region as well as by direct visual inspection. The aim would be to correlate the signal strength with the type of cloud. For the latter a simple descriptive classification should suffice.

- The observations of 28/29 June demonstrate that if one observes the moon near the time of its culmination, and obtains several good scans, it is possible to determine the peak antenna temperature with quite a good accuracy: perhaps about 10 %. Since the peak is about 0.3 dB above the background, this corresponds to about 0.03 dB. Thus averaging due to matching of the entire profile (which is composed of about 1000 data points), or obtaining it by mere smoothing of the data has already lead to an improvement by a factor of 10. Perhaps this can be further increased. Because the peak and the background should be well defined, a full scan or a half-scan starting before the peak must be aimed for. This requires about half an hour for a single scan. Perhaps one can optimize this.

- As pointed out, if one is content with measuring variations of the temperature, it is clear that with such a value of the error for the peak antenna temperature, one could well measure with the ESA-Dresden telescope the variation of the lunar surface temperature with the lunar phase. Its viability has already been proven by Monstein

(1987) who used a smaller dish (80 cm) and a LNB with a higher noise figure of 0.9 dB, and whose results taken over two lunar phases are depicted below.