Eidgenössische Technische Hochschule Zürich (ETH), Switzerland

Cosmic background radiation at 200 MHz

Determination of the Allan-variance for several frequencies

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Created 10.08.2004

Abstract. The aim of this work was to prepare the CALLISTO spectrometer for the measuring of the 0.02 Kelvin step at 200 MHz resulting from the reionisation epoch. Therefore, the resolution of CALLISTO is determined for each channel.

Key words. Reionisation epoch, Allan-variance, CALLISTO

1. Introduction

One expects [e.g. in (8)] to find a sharp step in the cosmic microwave background (CMB) left from the reionisation of the Universe at $z \simeq 5 \dots 20$. At present epoch, this HI $21 - cm$ line emission is due to redshift expected at $70 - 240\,MHz$. We shall examine in this paper the possibility of measuring this step of about $0.02\,K$ with the CALLISTO spectrometer.

2. The Callisto spectrometer

The CALLISTO spectrometer (**C**ompound **A**stronomical **L**ow-cost **L**ow-frequency **I**nstrument for **S**pectroscopy and **T**ransportable **O**bservatory) is a double heterodyne receiver built at the Institute for Astronomy by the Group for Radio- and Plasma-Physics. It is based on two cheap standard cable-TV-tuners with a frequency-resolution of $62.5\,kHz$ in the range from 45 to 870 MHz. There are several different CALLISTO-Models (e.g. the Flight-Model, built for the Green Bank Observatory in West Virigina) with different specifications. We have used for our measurements one of the QM-Types, which is able to take 400 measurements at different frequency with both of the two receivers per second. This means a frequency of $800\,Hz$. The data are collected via a $RS232$ interface in a computer and stored in a raw-file. In this file, there are several informations about the time / type / mode of the observation and one byte (8 bit) for each channel/time saved. One has to take care to the fact, that the amplifiers used in CALLISTO are logarithmical and have to be unlogarithmised in the following way bevor using:

(1) Converting the 8bit *digits* to *Millivolts* using the reference voltage of $5\,V$:

$$data_{mV} = data_{digits} \frac{5000\,mV}{256}$$

(2) Translate the *Milivolts* to *Decibels* [dB]:

$$data_{dB} = data_{mV} \frac{1}{100}$$

(3) Unlogarithmise the *Decibels* to *Linear Power*:

$$data_{Linear} = 10^{\frac{data_{dB}}{10}}$$

The data of the two tuners have to be unlogarithmised prior to the summation. Further information to CALLISTO can be found in (2).

3. Allan-Variance

3.1. Definition

The variance σ^2 of a number of measurements $\{x_i\}_i = 1 \dots n$ is defined by

$$\sigma^2 = \frac{1}{n-1} \sum_{i=0}^{n} (x_i - \bar{x})^2$$

where $\bar{x}$ is the arithmetic mean of the data points x_i. The process of averaging several datapoints to one single data point is called *integration*. If the integration takes place in time (another possibility would be an integration over several channels), the corresponding averaging interval is called integration time T:

$$x(T, t) = \frac{1}{T} \int_{t-T}^{t} s(t')dt'$$

Radiometer equation

With increasing integration time or bandwidth of measurements, one expects the standard deviation to decrease in the following way:

$$\sigma_F = \frac{F}{\sqrt{\Delta\nu \cdot \Delta t}}$$

where F is the intensity of the signal, $\Delta\nu$ the bandwidth and Δt the integration time is. By the relation $\Delta\nu \cdot \Delta t \geq \mathcal{O}(1)$ one can interpret the term $\Delta\nu \cdot \Delta t$ in the Radiometer equation as the number of statistically independent points and for N independent values of measurements, the error decreases as $\frac{\Delta w}{w} = \frac{1}{\sqrt{N}}$.

Allan-variance

Out of the Radiometer equation, one expects to get more accurate results with longer integration time. Because of systemac errors (e.g. fluctions in the temperature of the receiver), the errors decreases after a certain integration time. Therefore, one is interested in the minimum t_min of *Allan-variance* $\sigma_A^2(T)$. The plot $(log(\sigma_A^2(T))|log(T))$ of $\sigma_A^2(T)$ on logarithmic scales is called Allan-plot and will be calculated for several different channels in the following paper.

3.2. Algorithm

For this section, we consider a single-channel-measurement with n data-points and equidistant time steps Δt. The measurement $c(t)$ is for this reason only defined at the points $t_i = \Delta t \cdot i$ with $i = 1 \ldots n$. In (6) it is suggested to primarily normalise the data-points over the whole time of measurement. We will not do this, because we lose the information of the minimal value of σ_A^2 at t_{min} with this normalisation.

We can rewrite the Allan-variance by using a Haar Wavelet (Fig. 1)

$$\psi_\tau(t) = \begin{cases} \frac{1}{\tau} & \text{for } -\tau \leq t < 0 \\ -\frac{1}{\tau} & \text{for } 0 \leq t < \tau \\ 0 & \text{everywhere else} \end{cases}$$

to simple convolutions

$$\sigma_A^2(\tau) = \langle (c(t_k) * \psi_\tau - \langle c(t_k) * \psi_\tau \rangle_k)^2 \rangle_k \quad .$$

Notice, the integration time τ has to be an integer multiple of the timestep Δt, i.e. $\tau = l\Delta$ with $l = 1 \ldots l_{max}$. After (6), l_{max} should be $\leq \frac{1}{3}\dot{n}$ for reliable results. With $C_k \equiv c(t_k) * \psi_\tau$, the above formula becomes

$$\sigma_A^2(\tau) = \langle (C_k - \langle C_k \rangle_k)^2 \rangle_k \quad .$$

We clearly see, that the problem is reduced to the calculation of a convolution and two averaging processes.

One can also estimate the error of the Allan-variance using convolutions:

$$\delta\sigma_A^2(\tau) = \sqrt{\frac{\langle (C_k - \langle C_k \rangle_k)^4 \rangle_k - \langle (C_k - \langle C_k \rangle_k)^2 \rangle_k^2}{n}} \quad .$$

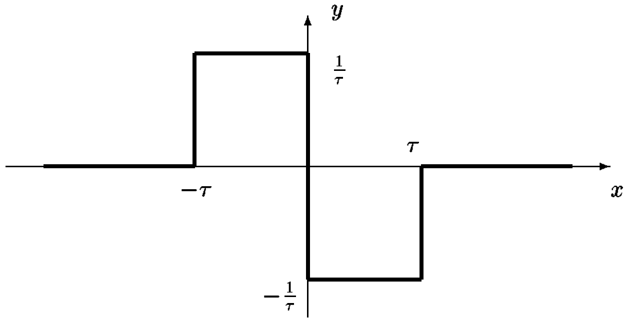

Fig. 1. Haar Wavelet $\psi_\tau(t)$

The most timeconsuming part to determine the Allan-variance is the calculation of the convolution C_k. Therefore, the following approximation was proposed by (6).

$$C_k = c(t_k) * \psi_\tau = S_k + T_k - S_{k+1} - T_{k+1}$$

with $\tau = l\Delta t$ and the two sums:

$$S_k = \frac{1}{l} \sum_{j=kl}^{(k+1)l} c(t_j) \text{ and } T_k = \frac{1}{l} \sum_{j=(k+\frac{1}{2})l}^{(k+\frac{3}{4})l} c(t_j) \ .$$

The idea behind this approximation is to leave out the calcultion of neighbouring values, since they are not statistically independent.

3.3. Implementation in C++

The above constructed algorithm was implemented in a C++ - program. To compare the approximation with the fully calculated convolution, we have written three different variations of the algorithm. The convolution after Ossenkopf is calculate by this code:

```
for(int k=0;k<K;k++){
   S[k]=Sum(data,l*k,l*(k+1)-1)/l;
   T[k]=Sum(data,l*k+l/2,l*(k+1)+l/2-1)/l;
}
for(int k=0;k<Conv;k++)
   C[k]=0.5*(S[k]+T[k]-S[k+1]-T[k+1]);
```

If we notice, that the full calculation of C_k is from the C_{k-1} only different by 4 values, we can optimise the full convolution-algorithm to be almost as fast as the approximation!

```
C[0]=(Sum(data,0,l-1)-Sum(data,l,2*l-1))/l;
for(int k=1;k<Conv;k++)
   C[k]=C[k-1]+
        (-data[k-1]+2*data[k+l-1]-data[k+2*l-1])/l;
```

To determine the minima of the Allan-variance, the algorithm looks for the first time, where the variance of two following points is increasing.

We have chosen the integration time l so that the points in the logarithmic scale are equidistant, i.e. $l = 10^{C \cdot j}$, $j = 1 \ldots j_{max}$ and C so that $l_{max} = 10^{C \cdot j_{max}}$

4. Data collection

Several sets of data were collected in order to determine the resolution of CALLISTO. For all measurements, we have used an equidistant frequency-program with $1\,MHz$ steps and 400 channels. The range of frequency is from $50.0\,MHz$ to $449.0\,MHz$. Despite the expected heavy interferences at around $150\,MHz$ of a nerby pager antenna, we have chosen not to make a gap in frequency in order to compare the Allan-variance with undisturbed channels.

4.1. Measurement at the 5 m - telescope in Bleien (Switzerland)

Unfortunaltey, there are 3 cell-phone and a pager station[1] in the enviroment of $1.5\,km$ around the observatory. In order to measure frequency below $500\,MHz$, we have replaced the standard antenna of the $5\,m$ dish with a dipol antenna. The 21 dipoles of the antenna have a length between $8\,cm$ and $3\,m$. By

$$f = \frac{c}{2l}$$

the antenna can be used for observations with frequency between $50\,MHz$ and $1.9\,GHz$. The main-boom length is $2\,m$. Because of this, it is not possible to put the whole antenna in the focus of the dish. The signal of the reionisation are expected around $200\,MHz$ and so, we have fixed the $75\,cm$ element in the focal point. For the first day of observation, the antenna was directd to the dish, then we have turned the antenna directly to the sky.

First observations showed very bad disturbation over the whole spectrum. The strong signal of the nearby pager and cell-phone-sender was able to saturate the amplifier in the Focale Plane Unit (FPU) and therefore we tried to attenuate the signal. [see (4)] Several measurements (passages around the sun) with attenuation between $-20\,dB$ and $0\,dB$ showed, that the quiet sun was only visble without attenuation. To test this, we have measured the voltage of a logarithmic detector ($50\,mV \cong 2\,dB$) attached to a single channel receiver at $450\,MHz$. The difference between sun $U_{Sun} = 1.14\,V$ and cold sky $U_{Sky} = 1.12\,V$ was unfortunately less than $1\,dB$. Therefore the first day ($15.25\,h$) of measurements was done without any attenuation despite the heavy interferences.

For the following $17\,h$ of takeing data on the next day, we tried to eliminate the interaction from the ADAM communication modules to the preamplifier. This module is measuring temperature, humidity and voltage in the FPU. The first impression of the spectrum with this setup were slightly better than before. The frequency below $100\,Mhz$ where not continuously disturbed and the quiet sun was even with an attenuation of $-10\,dB$ visible. Unfortunately, the spectrum taken in the measurments had a strange structure, (Fig. 2) repeated every $30\,s$. We couldn't figure out the source of this disturbance.

[1] See www.bakom.ch

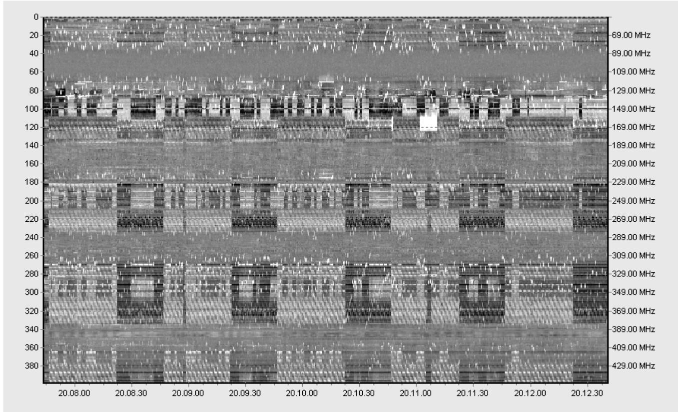

Fig. 2. Strange structure in the spectrum

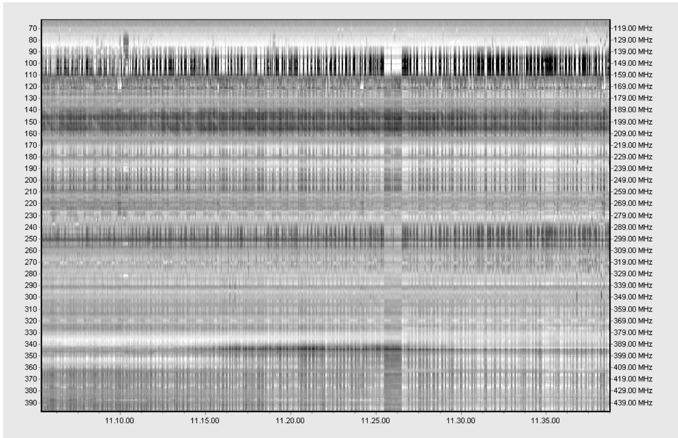

Fig. 3. Example for a very disturbed spectrum (19.3.2004)

On the last day of data collection at Bleien, we switched the preamplifier off. The result was not much encouraging: We were not able to see the quiet sun but there were as much interferences as before. We have taken 18.75 hours of data. In this measurement, another structure over the whole spectrum occured. (Fig. 4) In this case, a artifical source of interference can be excluded, because the lines can be observed over a range of $200\,MHz$. Either this disturbance couldn't be associated with a source, but it was visible over the whole time. It is therefore most likely a problem of the setup. (CALLISTO, the amplifier, maybe the power-supply?)

After this measurement, a test with a cell-phone-filter was done. The filter is installed between the antenna and the FPU and weaks down the frequency of about $1.8\,GHz$. This frequency is for our purpose to high and even higher as the range of the antenne. The spectrum showed therefore no much differenece to the prior measurements.

4.2. Measurement with several different amplifiers

Because of the heavy disturbance at the dishes in Bleien, we have made another group of measurements with 4 different preamplifiers attached to T_0, a resistance with

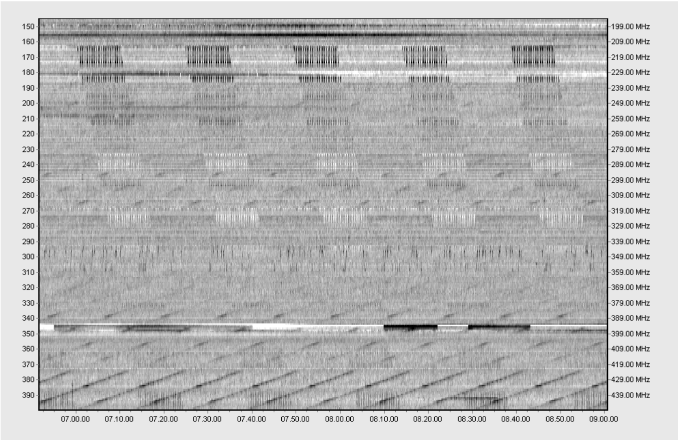

Fig. 4. Strange 13-minute structure (19.3.2004)

Fig. 5. Picture of the 5m dish at Bleien with the low-frequency-antenna pointing to the mirror

known temperature. We have used a 0180A from Kuhne[2] (about 430. $-$ SFR), a LNA5000 (about 250. $-$ SFr) and two more expensive amplifiers from Miteq[3] (Miteq-1355 and Miteq-AMF2). LNA5000 is a cheap preamplifier also used by radio amateurs. The measurements were done in the basement of the institute in a temperature-stabilised box. It was not possible to put the whole apperature inside this box, but a measurement of the temperature of the preamplifier showed no difference over the time. We have taken about 10 hours of data for the two Miteq and the Kuhne amplifier and 35.75 h for LNA5000. At the begin of every data set, the resistance T_0 was replaced by a noise source to get a calibration (i.e. the conversion from Linear Power to Kelvin).

The large amout of 35.75 hours data (200 $MBytes$) had to be splitten up in 3 different files each 12 h long. It is suggested by (6) to maximaly use one third of the data-length to integrate for the Allan-variance and therefore

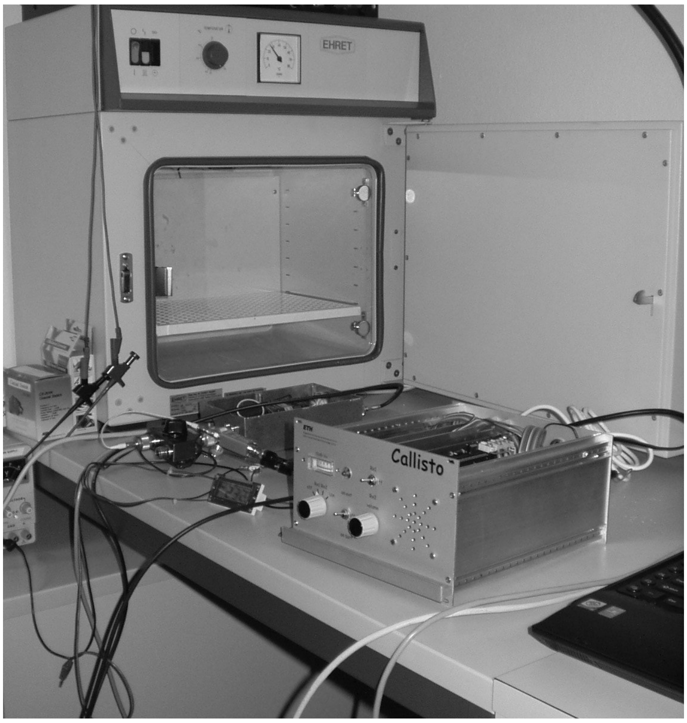

Fig. 6. Measuring T_0 with several different amplifiers

it is still possible to get accurate results for the Allan-variance up to about 4 h.

During the measurements, some interactions between the computer and CALLISTO were observed, although they were not on the same power feed. It was possible to disturb CALLISTO by moving the mouse of the notebook. We suspect the graphic card to be responsible for this interaction.

4.3. Measurement in an absorber room

To avoid any electromagnetic interference, a measurement in the absorber room of the Departement of Information Technology and Electrical Engineering was done. The absorber room acts like a faraday cage and it's walls are covered inside with foam, damping waves at least $-40\,dB$. Unfortunately, this room has been built for frequencies above $1\,GHz$ and it was not possible to use an absorber room for lower frequency[4]. We were approved to use the absorber room on one morning, so it was not possible to take longer data sets.

We have used the same antenna as for the measurements in Bleien, and for the calibration again a noise source was applied on to CALLISTO. We took data with two different configurations:

- Antenna, laptop and CALLISTO inside the absorber room. (1 h)
- Antenna inside the absorber room, laptop and CALLISTO outside. (0.5 h)

[2] www.kuhne-electronic.de
[3] www.miteq.com

[4] In fact, there is no such room to do this in Switzerland

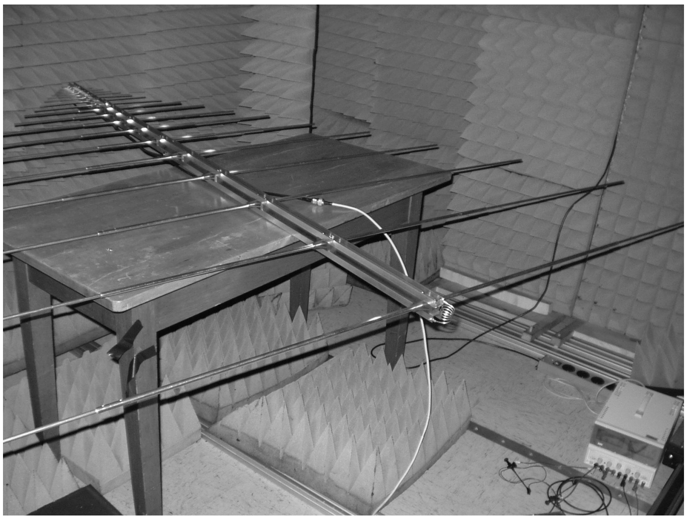

Fig. 7. The low-frequency-antenna in the absorber room at ETH-ETZ

A first look at the spectrum with all equipment inside the absorber showed much noise below and again a line structure like in Fig. 4 was observed, but this time with a $2\,min.$ interval between each line. There must have been some other problem with the software, because there is a discontinuity between the first and second data file, althougt it was a non-stop measurement and no parameter was changed. The noise level seems to decreases for frequencies above $150\,MHz$. The spectrum of the second setup had not much difference, but during $5\,min.$ there were regularly repeated peaks every 12 seconds.

During all measurements in Bleien and with the preamplifiers, the two tuners of CALLISTO were connected (i.e. tuner 0 received the same singal as tuner 1). The measurement with the second configuration was repeated without the connection between the two tuners to determine the mutual influence. The spectrum showed neither line structures nor peaks.

To test the effectiveness of the absorber room, we also made a measurement meanwhile the door of the room was opened. But on the recorded spectrum, we couldn't distinguish the area with opened and closed door.

4.4. Simulation

In order to test the algorithm, a program to simulate sinusoidal and linear signals was written. This tool generates data in the form

$$f(T) = \frac{T}{m} + b$$

or

$$f(T) = A\,sin(\frac{2\pi}{B} \cdot T) + C$$

and adds gaussian-, equally- or poisson-distributed noise. One can also chose the number of channels and the length in time of the produced raw-files.

Table 1. Parameters for the simulated signals

File Nr.	m	b	Sigma
1	1500	128	1
2	300	128	1
3	100	128	1
4	1500	128	5
5	300	128	5
6	100	128	5
7	1500	128	15
8	300	128	15
9	100	128	15

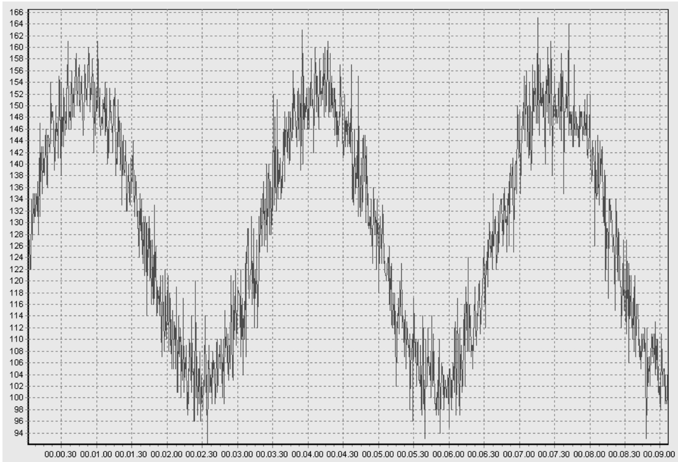

Fig. 8. A simulated sinusoidal lightcurve

For this work, we have generated 9 files with the linear formula $f(T) = \frac{T}{m} + b$ and gaussian-distributed noise (Tab. 1). Each file contained 3000 values (i.e. about half an hour with $0.5\,s$ steps.) and 100 channels. It's important not to unlogarithmise the simulated data before calculating their Allan-variance.

5. Results

Calibration

To determine the resolution in Kelvin, one has to convert the Linear Power into Kelvin. For solar data [e.g. in (4)], this can be done using the sfu[5] values published by the U.S. National Oceanic and Atmospheric Administration and the U.S. Air Force[6]. The difference in digits between sun and sky corresponds to the published sfu data. In the second step, one has to use Rayleigh-Jeans-Law:

$$data_K = data_{sfu} \frac{\lambda^2}{2k} \frac{G}{4\pi} 10^{-22} ,$$

where λ is the wavelength of the considered frequency, k Boltzmann's constant and G the gain of the antenna calculated by the gain formula [e.g. in (3)].

The data we have taken at Bleien are unfortunately so bad, that an accurate calibration is not possible: We

[5] $1\,sfu = 10^{-22} \frac{W}{m^2 Hz}$

[6] www.sec.noaa.gov

Table 2. Averaged data (in Linear Power) for some channels (16.3.04).

Channel	Cold Sky	Sun (16.3.)	Sun (17.3)
128 @ 177.000 MHz	175.1	168.0	171.5
129 @ 178.000 MHz	175.9	171.7	174.6
130 @ 179.000 MHz	175.8	176.2	176.2
131 @ 180.000 MHz	177.0	181.9	180.8
132 @ 181.000 MHz	177.8	182.5	181.5
133 @ 182.000 MHz	177.2	186.4	183.9
134 @ 183.000 MHz	174.0	176.1	178.0
135 @ 184.000 MHz	173.5	171.6	175.8
136 @ 185.000 MHz	173.4	172.3	178.0
137 @ 186.000 MHz	173.8	171.0	177.9
138 @ 187.000 MHz	173.1	171.5	179.3
139 @ 188.000 MHz	171.3	172.6	179.8
140 @ 189.000 MHz	170.0	174.1	180.0

have calculated the average of data take during the night and compared with the averaged data of the sun. The difference

$\Delta data = data_{Sun} - data_{Sky}$

should as above mentioned correspond to the sfu. But for some channels, the Linear Power for the Cold Sky is even higher as the value for the sun! We can anyway calculate the Allan-variance for this data sets, the time of the minimal Allan-variance will be the same, since the calibration for one channel is a linear transformation.

For data, collected with a resistance T_0, one has to know the temperature of the noise source T_{noise}. The difference $T_{noise} - T_0$ is equal to the Linear Power and leads to a relative calibration. In each of our data sets, the step between T_{noise} is clearly visible (Fig. 9). This calculation leads to a relative calibration, which is needed for the Allan-variance. We have used a resistance T_0 with temperature 290 K and a noise source T_{noise} with temperature 36′000 K.

Comparison of algorithms

In order to compare the three implemented algorithms, we have choosen a not very much disturbed channel (371 @ 420 MHz) and calculated the Allan-variance. The minimal point calculated by the algorithm is in this example not very different for the two methodes, but the Allan-plot calculated with full convolution (Fig. 11 vs. 10) is smoother and therefore less sensitive for outliers. Since the algorithm determins the minimum value of the Allan-variance by two sequent rising points, the big steps in the approximate algorithm can lead to a too low Allan-variance. In the decreasing part of the approximate plot, some times a hump was observed (e.g. in (4),Fig. 6-8)

In the following work we have used the full convolution algorithm since the data files are not longer than 12 h. For further enquiries with larger data sets, the approximate algorithm could be needed. A methode to insure the determination of the minimum point could be fitting of a function like $\sigma_A^2(T) = a/T + bT^\beta$ as suggested in (7).

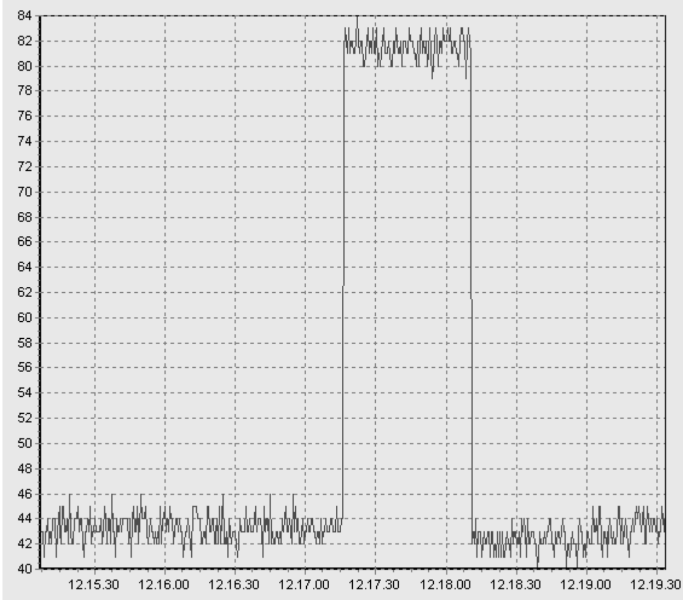

Fig. 9. Lightcurve for the calibration with T_{noise} (X-axis in digits and Y-axis in minutes)

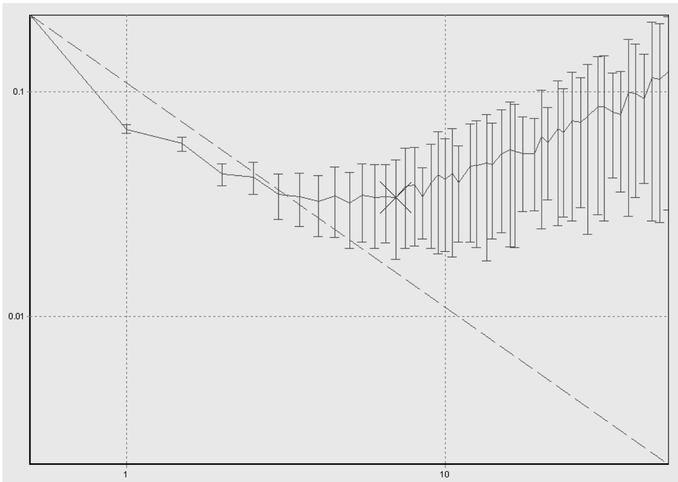

Fig. 10. Allan-variance calculated with the algorithm suggested by Ossenkopf (X-axis logarithmic in seconds and Y-axis logarithmic in digits)

Allan-Variance

Although the data of Bleien couldn't be calibrated, we have calculated the mean, variance and the Allan-variance for the unlogarithmised but not calibrated values. All calculations were done with the optimised full convolution algorithm, the maximal integration time was one half of the file length and we set $j_{max} = 200$ (cf. 3.3). In Tab. 3 we give an overview of the results. We refer T_{av} to the minimal Allan-variance

$\sigma_A^2(T_{av}) = minimal\ .$

This table and the histogram 4 shows that we couldn't confirm the much better results of Andreas Knechts work (4). Tab. 3 and Tab. 4 were done with measurements

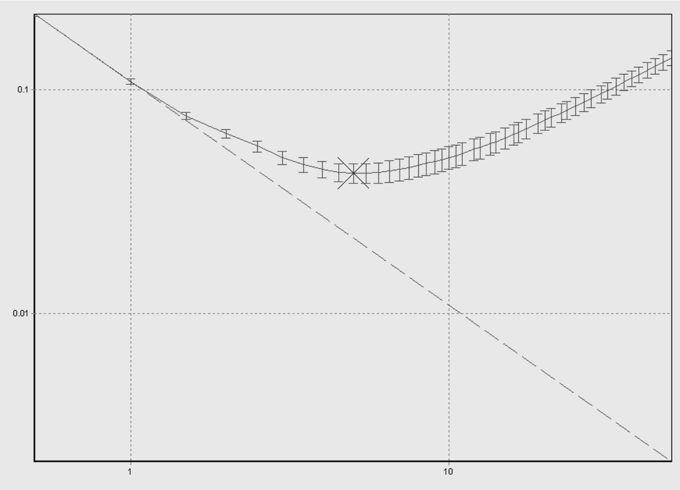

Fig. 11. Allan-variance by full convolution (X-axis logarithmic in seconds and Y-axis logarithmic in digits)

Table 3. Allan-variance for the first day of measurement (16.3.-17.3.). The unit of the σ_A^2-values is Linear Power

	Sun	Cold Sky	Hot Sky	Sun
T_{av} min.	$0.5\,s$	$0.5\,s$	$0.5\,s$	$0.5\,s$
T_{av} max.	$587.5\,s$	$746.0\,s$	$53.5\,s$	$460.0\,s$
$\bar{T_{av}}$	$24.20\,s$	$23.39\,s$	$9.92\,s$	$21.15\,s$
Best channel	373	76	204	191
Frequency $[MHz]$	422.0	125.0	253.0	240.0
σ_A^2 min.	0.047	0.097	0.071	0.047
$\bar{\sigma_A^2}$	5.02	4.95	4.09	18.59

Table 4. Number of channels with Allan-variance above T seconds. Data from 16.3.-17.3.

T	Sun	Cold Sky	Hot Sky	Sun
1	260	333	385	217
10	135	111	169	95
100	32	30	–	19
200	6	4	–	9
300	2	1	–	6
400	1	1	–	3
500	1	1	–	–
600	–	1	–	–
700	–	1	–	–

of tuner 0, calculations with tuner 1 show not much difference in the Allan-variance.

The calibration of data taken in the absorber room was also difficult. Because the difference between the measurement of T_0 and T_{noise} was only small, we got a very inaccurate calibration. For the first setup with CALLISTO inside the room, 64 channels had to be withdrawn, because the averaged data of T_0 than the one of T_{noise}. The Allan-variance of this measurements showed no useful results. The measurement with the CALLISTO outside the absorber, we had to remove 33 channels because of a bad calibration. As 35 channels reached the maximal integration time of $600\,s$, it would be necessary to take longer measurements in the absorber room. Using T_{noise} instead

Table 5. Results of the measurement in the absorber room

	CALLISTO inside	CALLISTO outside
T_{av} min.	$1\,s$	$1\,s$
T_{av} max.	$40.5\,s$	$600\,s$
$\bar{T_{av}}$	$6.8\,s$	$189.1\,s$
Best channel	290	several
Frequency	$334.0\,MHz$	
σ_A^2 min.	$1.6 \cdot 10^5\,K^2$	$11.4\,K^2$
$\bar{\sigma_A^2}$	$1.1 \cdot 10^{10}\,K^2$	$6.4 \cdot 10^8\,K^2$

Table 6. Allan-variance for the measurement with 4 different preamplifier

	MiteqAMF2	Kuhne
T_{av} min.	$276.0\,s$	$9.0\,s$
T_{av} max.	$7'362.0\,s$	$49.0\,s$
$\bar{T_{av}}$	$2'938.0\,s$	$19.5\,s$
Best channel	399	8
Frequency $[MHz]$	448.0	57.0
σ_A^2 min.	$0.1\,K^2$	$0.8\,K^2$
$\bar{\sigma_A^2}$	$244.9\,K^2$	$6.1\,K^2$
	Miteq1355	LNA5000
T_{av} min.	$379.0\,s$	$846.0\,s$
T_{av} max.	$3'769.0\,s$	$14'400\,s$
$\bar{T_{av}}$	$1'857.0\,s$	$7'104\,s$
Best channel	128,386	several
Frequency $[MHz]$	177.0,435.0	
σ_A^2 min.	$0.005\,K^2$	$0.068\,K^2$
$\bar{\sigma_A^2}$	$6.5\,K^2$	$40.12\,K^2$

of T_0 to make the measurements would maybe make a better calibration as seen in the measurement with 4 different amplifiers.

The best results of our measurements were achieved with the 4 different amplifier. The calibration was done by the same procedure, but this time we have measured T_{noise} instead of T_0. There is a much larger gap between the averaged T_0 data and the T_{noise} and therefore, the calibration is better. In the series of measurements with LNA5000, we had to remove channels 6 and 7 because of some problems with the calibration. The maximal integration time was choosen to one third of the file length and so we can accurately calculate the Allan-variance up to about $3.5\,h$. The results are quite encouraging: In the measurement with Miteq1355, we have a minimal Allan-variance of $0.005\,K^2$, which leads to an Allan-standard deviation of $0.07\,K$. This is in the same dimension as the needed resolution to detect the 0.02 Kelvin step!

Simulated data

The simulated data sets (Tab.1) were also evaluated with a maximal integration time of one half of the file-length (Tab.7). The time of minimal Allan-variance $T_a v$ min. was averaged over the 100 channels and the variance shows the distribution between the channels. As we have used arbitrary units, no calibration is needed. One would expect a bigger T_{av} min. for smaller sigma but the achived results

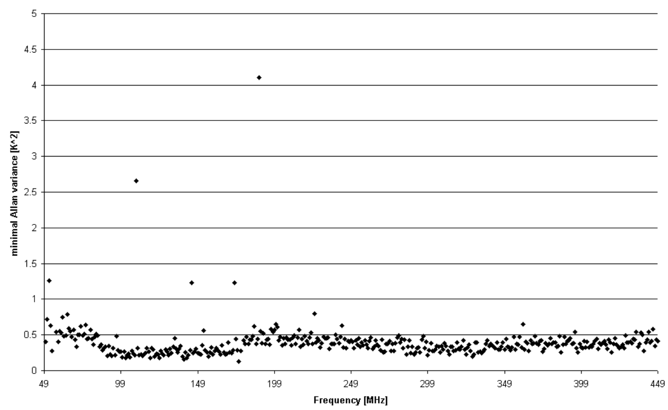

Fig. 12. Plot of the minimal Allan-variance subject to the frequency. (Data with MiteqAMF2)

Table 7. Results of the evalution with the simulated data

File.Nr	T_{av} min.	$\sigma_{T_{av}min.}$	σ_A^2 min.
1	349.7	215.1	0.0035
2	431.0	229.5	0.0026
3	394.3	243.0	0.0038
4	332.4	225.0	0.0904
5	409.5	241.6	0.0723
6	397.0	227.5	0.0721
7	380.0	227.8	0.6793
8	393.3	245.1	0.6994
9	379.4	218.3	0.6226

shows similar times for all data sets. The minimal Allan-variance follows the expectation: σ_A^2 changes in the order of one magnitude between the first three sets with sigma 1 and the next group with sigma 5 resp. sigma 15.

6. Problems and suggestions

The main problem of our work were heavy terrestrial disturbances: A cell-phone and a pager transmitter close to the observatory in Bleien. Oberservations in our specific frequency range should therefore be done in radio quiet zones, such as remote valleys. As we have also seen interferences of the laptop to CALLISTO, a further improvement would be a better shielding of its case.

7. Conclusion

There is still a lot of work to be done on CALLISTO to detect the $0.02\,Kelvin$ step in the CMB left by the reionisation epoch, but the measurement with 4 different amplifiers is encouraging. It shows clearly, that a detection of this $0.02\,K$ trace is not impossible. A first step towards it would be a measurement in a less disturbed zone and a better shielding of CALLISTO.

Acknowledgements. I would like to thank Christian Monstein and Hansueli Meyer for their help with the observations and Arnold O. Benz for the theoretical explanations and the possibility to work in his group. Other thank is going to Departement of Information Technology and Eletrical Engineering for using the absorber room.

References

[1] Burke B.F., Graham-Smith F.: *An Introduction to Radio Astronomy* 2^{nd} *Edition* Cambridge University Press (2002)

[2] Homepage of CALLISTO http://www.astro.phys.ethz.ch

[3] John D. Kraus *Radio Astronomy 2nd edition*, Cygnus-Quasar Books, 1986

[4] Knecht. A: *Cosmic background radiation at 200 MHz*, http://e-collection.ethbib.ethz.ch (2003)

[5] Krüger A.: *Introduction to Solar Radio Astronomy and Radio Physics*, D. Reidel Publishing Company (1979)

[6] Ossenkopf V.: *A unified Allan-variance computation scheme*, not yet published (2003)

[7] Schieder R. and Kramer C.: *Optimization of heterodyne observations using Allan-variance measurements*, Astronomy and Astrophysics 373, 746-756 (2001)

[8] Shaver P.A. et al.: *Can the reionization epoch be detected as a global signature in the cosmic background?*, Astronomy and Astrophysics 345, 380-390 (1999)

[9] Weinmann S.: *ALLEN-variance for the ARGOS spectrometer*, http://e-collection.ethbib.ethz.ch (2002)