Technical exploration of 800 GHz HEB

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ABSTRACT

The KOSMA telescope in Zermatt, Switzerland, has been equipped recently with a phonon-cooled ??? hot electron bolometer (HEB) operational at 800 GHz. The HEB is part of the Sub-Millimeter Array Receiver for Two frequencies (SMART), where it is part of a four pixel array of three 800GHz SIS mixers. This configuration gives an excellent opportunity to measure the technical properties of an HEB in comparison to SIS receivers.

1. Introduction

- HEB build by K. Jacobs and his group

- Initial lab tests of HEB

- HEB at KOSMA: Wir haben am Dienstag den SMART-Dewar geoeffnet und den HEMT-Verstaerker von Kanal 1 ausgetauscht, der widerspruechlichen Meldungen zufolge defekt ist. Gleichzeitig wurde zum erstenmal am Gornergrat ein 800 GHz- Hot-Electron-Bolometer (HEB) zu Testzwecken eingebaut. Der Empfaenger-Umbau ging sehr problemlos, Mittwoch vormittags war der Dewar wieder kalt.

Das HEB laesst sich im SMART-Dewar mit der normalen SIS-Bias- und ZF-Elektronik problemlos betreiben. Auch die LO-Versorgung ueber das vorhandene Fourier-Gitter funktioniert gut. Der HEMT-Verstaerker des HEBs muss allerdings bei sehr niedriger Spannung (0.65 - 0.7 V) betrieben werden, sonst heizt er ueber das ZF-Kabel das Bolometer auf. Wohl nicht zuletzt deshalb ist die Empfaenger-Rauschtemperatur des HEB-Kanal enttaeuschend hoch (ca. 5000 K gegenueber 2000 K im Labor). Mit dazu beitragen mag auch, dass das improvisierte 800 GHz-Horn sich gegenueber den Labortests noch verschlechtert haben koennte.

Das HEB ist weiterhin betriebsbereit und soll, wenn die Bedingungen gut sind, fuer spektroskopische Messungen eingesetzt werden. D.h. es soll eine starke Quelle (DR21, Orion o.ae.) damit gemessen werden. Eine Spektrallinie reicht. Dazu muss das HEB-ZF-Kabel an die Array-ZF-Box angeschlossen werden (z.B. Kanal 4 durch HEB ersetzen). Die Bias-Versorgung fuer das HEB kommt von der zweiten Array-Bias-Box, die wir auf dem Karussel neben dem Empfaenger-Rack aufgestellt haben. Das HEB liegt auf Kanal 9, Bias-Spannung ist 0.75 mV (siehe Aufkleber auf Bias-Box). Optisch liegt der HEB-Kanal neben Kanal 5 in der zweiten Reihe des Arrays. - Viel Spass und Erfolg damit!

2. Set-up

The HEB requires less LO power than the SIS mixers. Since only one LO is used and its power split equally to the four mixers, the beam to the HEB has to be attenuated. Currently, this is done with about 15 strips of millimeter paper (2cm wide) that are positions in the optical path between the LO and the HEB. From time to time additional pieces of paper were added to reduce the LO power further. Unfortunately, the attenuation does not depend only on the number of pieces of paper, but also greatly on their distance between them, which can be altered by changing the tension, as well as slightly by the position of the edges of the paper. Though this is not an ideal situation, we have not seen any flipping of the paper during observation, e.g. due to wind in the telescope dome. However, in the long run one should use a different method of attenuation.

The dewar temperature seems to be very stable around 4.63 K.

3. IV curves

4. Receiver Temperatures

We have measured the receiver temperatures of the HEB as a function of V_{bias} and local oscillator (LO) attenuation, which we altered by adding and removing paper within the LO beam to the HEB, in order not to affect the LO power to the three SIS mixers. The LO was locked to 807.885 GHz (Backshort 103, Tuner 81). For the data reduction we employed a little greg script called trec.graphic. In order to calculate the receiver temperature we subtracted the "zero", i.e. the signal from the IF and AOS chain, from the hot and cold counts and then used the standard formula ($T_{rx} = (T_{hot}$ - $YT_{cold})/Y$-1, where y=counts(hot)-counts(zero)/(counts(cold)-counts(zero))), with $T_{cold} = 77$ K, and $T_{hot} = 271$ K as measured by the temperature sensor on the hot load. A typical plot of the receiver temperature as a function of AOS channel is shown in Fig. 2, where one AOS channel as a width of 1 MHz and channel 0 lies at an IF frequency of 400 MHz ???.

In Tab. **??** we list the voltage bias (V_{bias}) of the HEB, the bias current, the minimum receiver temperature (where we insured that the minimum is part of a steady function and

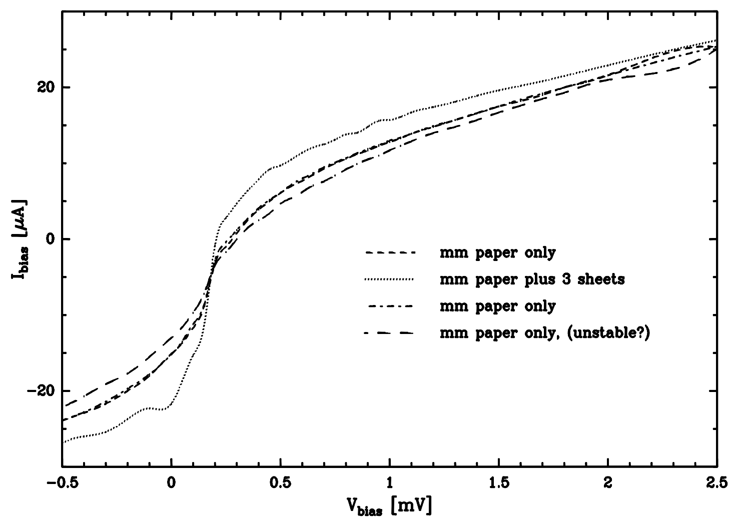

Fig. 1.— I/V curves of the HEB with the LO attenuated by some millimeter paper and with it further attenuated by additional 3 sheets of paper.
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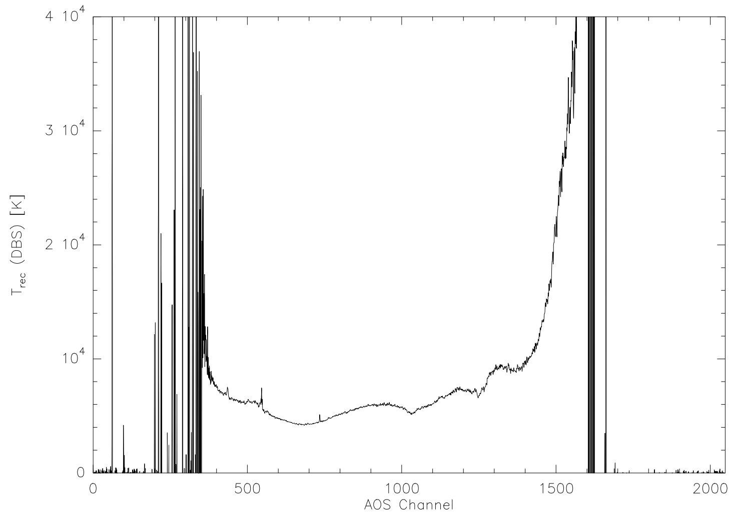


Fig. 2.— Receiver Temperatures with V_{bias}=75 mV and I_{bias}=15.0 μA, LO attenuated only with millimeter paper

not due to noise in the measurement) and the channel at which the minimum occurred.

In contrast to our expectation the bias current can vary by as much as 0.7 micro Ampere (0.3 micro amps rms???) for the same bias voltage and LO power setting. KARL, IS THIS NORMAL?

Conclusion from T_{rx}:

1. The receiver temperature is best (below 7500 K) from about channel 500 to 1200 and dramatically increases for channels smaller than 350 and larger than 1500.

2. The results are quite reproducible.

5. Allan variances

We have taken several Allan variance measurements in order to study the behavior of the HEB. In all of the variances measured the noise of the HEB first reduces however with a slope shallower than -1, which is expected pure thermal noise. The curve starts bending to even shallower slopes and reaches a minimum between 10 and 40 sec. After a short increase in noise there is usually a second minimum around 40 s - 300 s followed by a steady increase in noise. One possible explanation would be that we see the superposition of two Allan variance plots from two separate components in the chain (THINK ABOUT THIS, IS THIS A CORRECT HYPOTHESIS??)

The Allan variance taken with the moving telescope are significantly worse than with the telescope stationary in the HEB as well as in the SIS channels. Large spikes (up to 0.7 μA) are seen in the I_{bias} of the HEB whenever the carousel is readjusting to catch up with the telescope, but no spikes are seen when the telescope is moving without the carousel. The HEB bias box, which was originally positioned above the carousel motor was moved to a different location to the right of the SMART receiver, to avoid current being induced from the motor switching on. In addition we noticed that the bracket that holds the LO touches the electronics rack, which is located on the carousel. Pushing the bracket manually, changes the LO position slightly and alters the I_{bias}. When the carousel with the electronics rack moves, it is well possible that it deforms the LO bracket mounted on the telescope slightly and thus modulates the LO power. A piece of foam was removed from the LO bracket, such that the LO bracket no longer touches the rack.

A summary of all the Allan variances is given in the Appendix in Tab. 2 and the plots are depicted in Fig. 6 to 7.

Table 1: Receiver Temperatures

LO attenuated by millimeter paper plus 3 sheets (21Jan):					
V_{bias} [mV]	0.45	0.6	0.75	0.9	1.05
I_{bias} [μA]	12.6	13.8	15.0	15.9	17.0
T_{rx} [K]	4800	4280	4280	4460	4900
Channel	660	665	670	670	700
LO attenuated by millimeter paper only (21Jan) V_{bias} [mV]	0.45	0.6	0.75	0.9	1.05
I_{bias} [μA]	6.7	9.3	11.1	12.5	14.1
T_{rx} [K]	5000	4000	4300	4300	4470
Channel	650	660	670	680	690
LO attenuated by millimeter paper only (22Jan) V_{bias} [mV]	0.45	0.6	0.75	0.9	1.05
I_{bias} [μA]	4.6	6.9	9.0	10.5	12.5
T_{rx} [K]	4100	4800	4230	4900	4600
Channel	590	660	660	680	670
T_{mixer}[K]	4.64	4.64	4.63	4.64	4.63

Note. —

6. Astronomical Observations

On 25th Jan 2004 we have observed DR21 at an elevation of 60-80 degrees in CO 7-6 (806.651 GHz) and CI (809.341 GHz) by tuning the LO to 807.84 GHz, so that both the CO and the CI line appear in the same spectrum. The weather was fine, though not excellent, with -16C, 60% humidity, low wind, and a zenith τ of around 2.1 at 807 GHz ($\sim$8% transmission along the line of sight). The receiver temperature of the HEB were between 8000 and 10000 K (SSB) in the frequency band relevant for the observations (see Fig 3), whereas the SIS system temperatures lay between 1200 and 1700 K. We checked for the pointing and used offsets of 230", 150" to place the HEB on top of the source. The spectra were carefully calibrated taken the atmospheric transmission into account (assuming the same PWV for all receivers). One spectrum with very poor baselines was removed, the remaining 24 spectra were weighted corresponding to the noise in the data and averaged. Only a linear baseline was removed from the averaged HEB spectrum. The spectra thus obtained after 48 min of integration are shown on the top of Fig. 5, whereas the lower spectrum (shifted by -10 K)was obtained after 2 min of integration with the SIS (channel5). The CO 8-7 line at 120 km/s is detected with the HEB and there is also a hint of the CI line at -5 km/s. Fig. **??** shows the same two spectra, but plotted on top of each other.

In conclusion it was possible to detect a bright source with the HEB around 810 GHz. Once the problem with the I_bias change due to the carousel motion is fully understood and resolved as well as the attenuation is achieved in a more reliable way, the functionality of the HEB should improve considerably. In addition changing the potter horn with a much less lossy potter horn, which is expected to reduce the receiver temperature from 5000 K to 1500 K, the HEB could be a valuable mixer suitable for astronomical research.

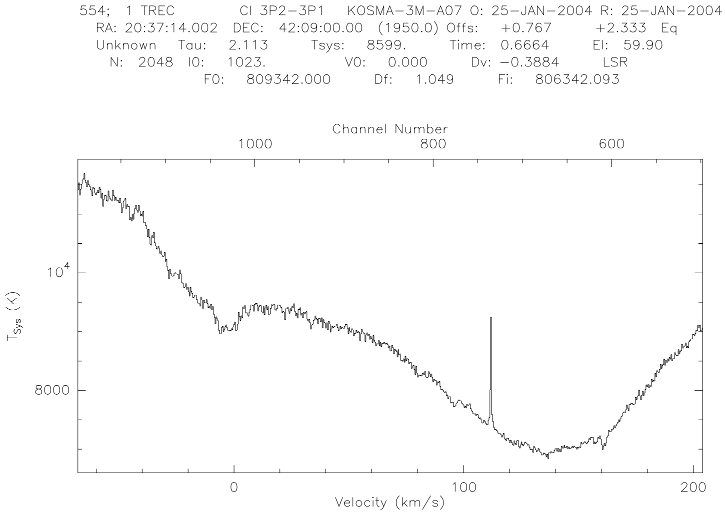


Fig. 3.— Single Side Band “system temperatre”, which does not take the atmosphere into account.

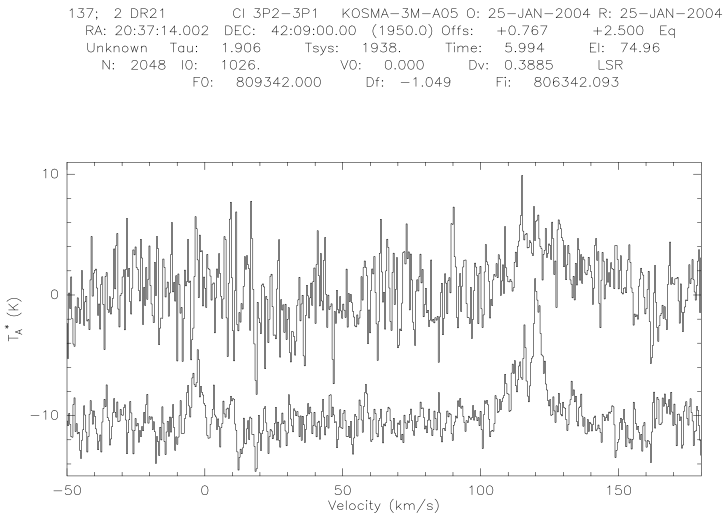


Fig. 4.— CO 7-6 and CI line in DR21. The top spectrum was taken with the HEB in 48 min of integration, the bottom spectrum (shifted by -10K) was observed with an SIS mixer (channel 5) in 2 min integration.

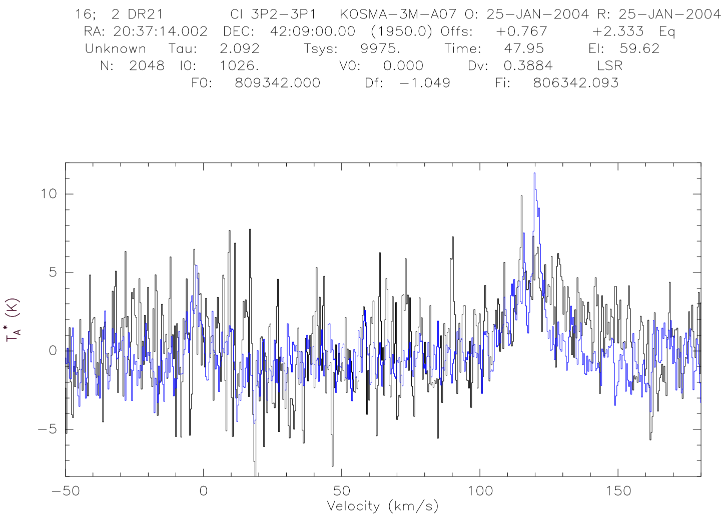


Fig. 5.— CO 7-6 and CI line in DR21. The black spectrum was taken with the HEB in 48 min of integration, the blue spectrum was observed with an SIS mixer (channel 5) in 2 min integration.

7. Appendix

All Allan variances measured are listed in Tab. 2 and displays in Fig. 6 to 7. The data have been reduced using software provided by the AOS team (Frank Schloeder).

Table 2. Allan Variance Data

Filename	V_{bias} [mV]	I_{bias} [μA]	T_{dewar} [K]	T_{rx} [K]	Paper	Channels #	t [min]	Comment
20JAN								
040120_lo_opt	0.75	13.5	4.64	4800	mm+3sheets	50-1500	60	
21JAN								
040121_075_150.75	15	?	4280	mm+3sheets	50-1200	15		SIS3 B not ok
040121 _060_085.6	8.5	?	4000	mm only	50-1200	15		SIS3 B not ok
040121 _060_071.6	7.1	?	4000	mm only	50-1200	15		SIS3 B not ok, good HEB Allan
22JAN								
020122_075_273_lo_off	0.75	27.3	4.63	–	mm only	50-1200	15	Lo off, but Vbias too low not stable → does not look like Allan variance → chuck data
020122 _250_294_lo_off	2.5	29.4	4.63	–	mm only	50-1200	15	Lo off, but SIS1-3 not in resistive Range → HEB Allan variance ok, but comparable to pumped Variance B-field of SIS 3 was now adjusted
040122 _350_353_lo_off	3.5	35.3	?	–	mm only	50-1200	15	SIS in resistive mode, i.e. Vbias 4mV, B1 21mA, B2 66.8mA, B3 68mA (B1= Current setting of B-field of SIS1) → Allan variance ok, except for SIS1
040122 _350_353_lo_off_narrow	3.5	35.3	?	–	mm only	60-700	15	SIS in resistive mode, i.e. Vbias 4mV same B as above → Allan variance ok, except for SIS1
23JAN								
040123_500_471_lo_off	5.0	47.1	4.65	–	mm only	50-1200	15	Lo off, all in resistive mode, SIS all at 5mV bias and around 68mA Bfield
040123 _500_471_lo_off_narrow	5.0	47.1	4.65	–	mm only	60-700	15	Lo off, all in resistive mode, SIS all at 5mV bias and around 68mA Bfield
040123 _075_176_tel_moving	0.75	17.6	4.61	?	mm + 2bands	50-1200	15	telescope tracking, beam rotator on
040123 _075_176_tel_off	0.75	17.6	4.61	?	mm + 2bands	50-1200	15	telescope still, beam rotator off
040123 _075_116_tel_off	0.75	11.6	?	?	mm + 2bands?	50-1200	15	telescope still, beam rotator off
24Jan								
040124_075_096_tel_moving	0.75 9.6	?	?	mm only	50-1200	15		telescope tracking, beam rotator on

Table 2—Continued

Filename	V_{bias} [mV]	I_{bias} [μA]	T_{dewar} [K]	T_{rx} [K]	Paper	Channels #	t [min]	Comment
040124_075_096_tel_notmoving	0.75	9.6?	?	?	mm only	50-1200	15	telescope standing, beam rotator off
040124_075_088_tel_off	0.75	8.8	?	?	mm only	50-1200	15	telescope standing, beam rotator off I_{bias} changes a lot when caroussel moves, but not when tel moves in az or el. HEB bias box was moved left next to SMART
040124_075_095_tel_off	0.75	9.5	?	?	mm only	50-1200	15	telescope standing, beam rotator off Bias had been switched off and on 10 min ago, I_{bias} might still drift as HEB warms up
040124_075_095_tel_moving	0.75	9.5	?	?	mm only	50-1200	15	telescope moving, beam rotator on
040124_075_102_tel_off	0.75	0.12	4.62	?	mm only	50-1200	15	telescope standing, beam rotator off When caroussel moves, the polstering below the LO support touches the electronics rack, this might bend the LO support and move the LO and hence modulate the LO power. → The foam was removed, SMART no longer touches the Rack.
040124_075_090_tel_moving	0.75	9.0	4.62	?	mm only	50-1200	15	telescope moving, beam rotator on

Note. —

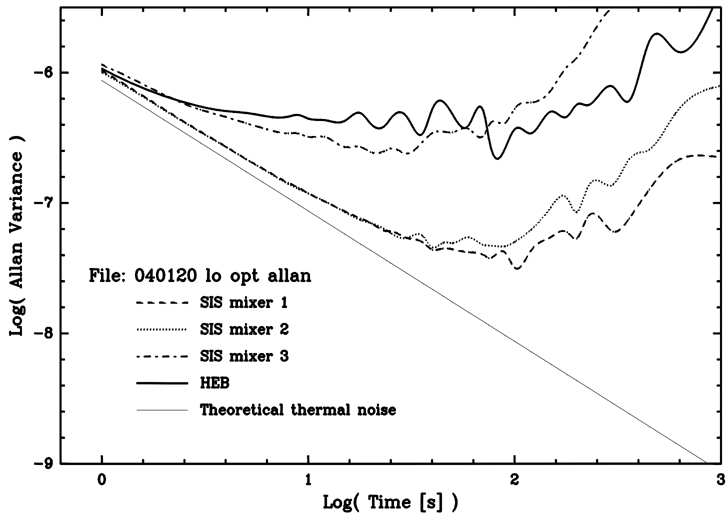


Fig. 6.— Allan variance with V_{bias}=0.75 mV and I_{bias}=13.5 μA, LO attenuated with millimeter paper plus 3 sheets of white paper.

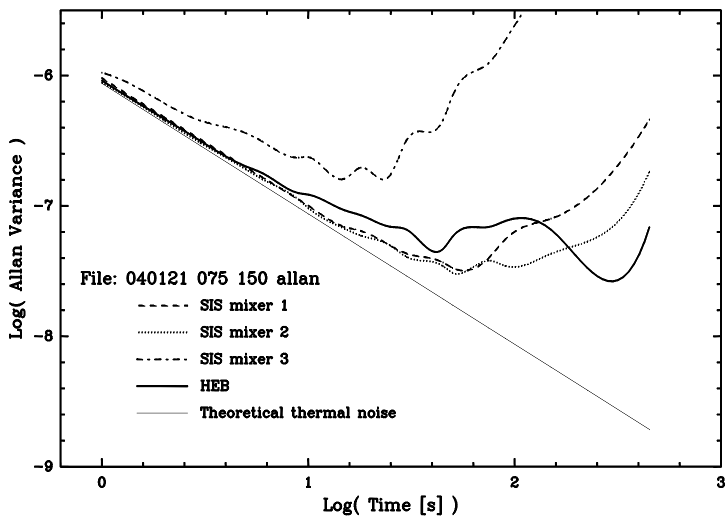


Fig. 7.— Allan variance with V_{bias}=0.75 mV and I_{bias}=15.0 μA, LO attenuated with millimeter paper plus 3 sheets of white paper.

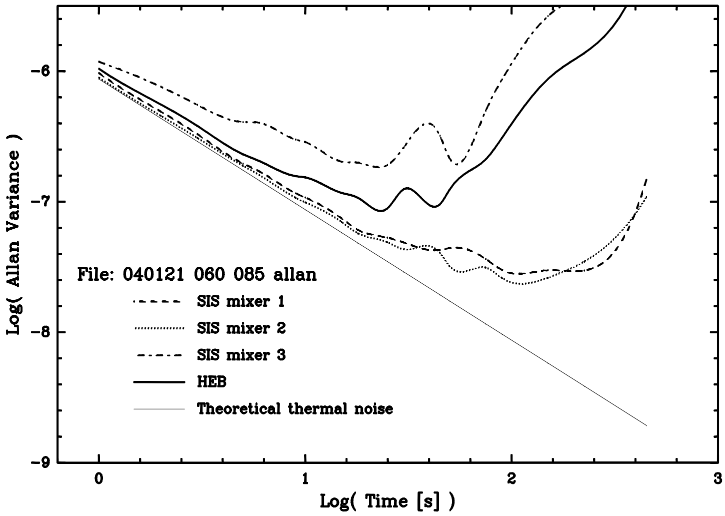


Fig. 8.— Allan variance with V_{bias}=0.60 mV and I_{bias}=8.5 μA, LO attenuated with millimeter paper only.

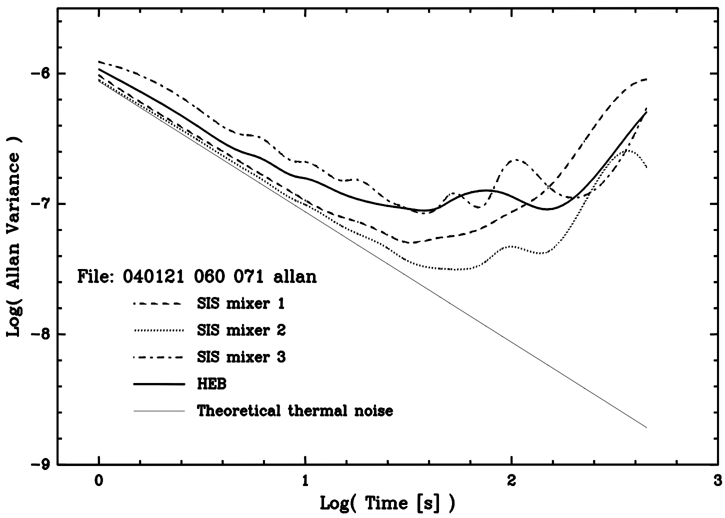


Fig. 9.— Allan variance with V_{bias}=0.75 mV and I_{bias}=15.0 μA, LO attenuated with millimeter paper plus 3 sheets of white paper.

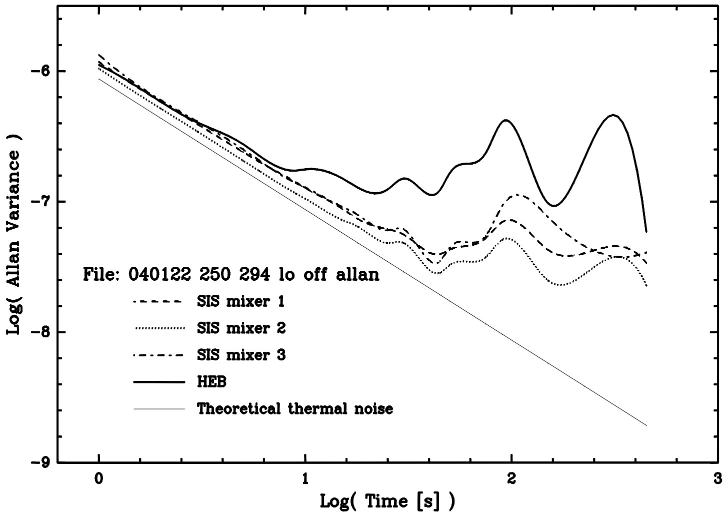


Fig. 10.— Allan variance with LO turned off and V_{bias}=2.5 mV and I_{bias}=29.4 μA, SIS mixers NOT biased to resistive range.

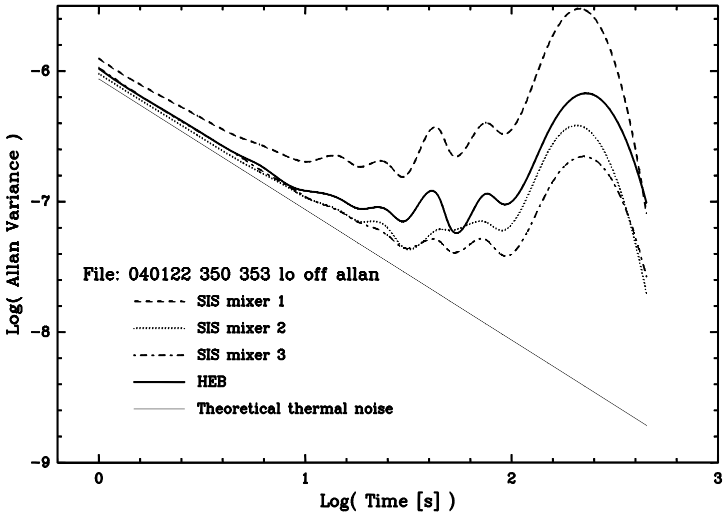


Fig. 11.— Allan variance with LO turned off and V_{bias}=3.5 mV and I_{bias}=35.3 μA, SIS mixers in resistive range with V_{bias}=$\sim$4 mV, magnetic fields using currents of 21mA, 66.8mA and 68mA, respectively.

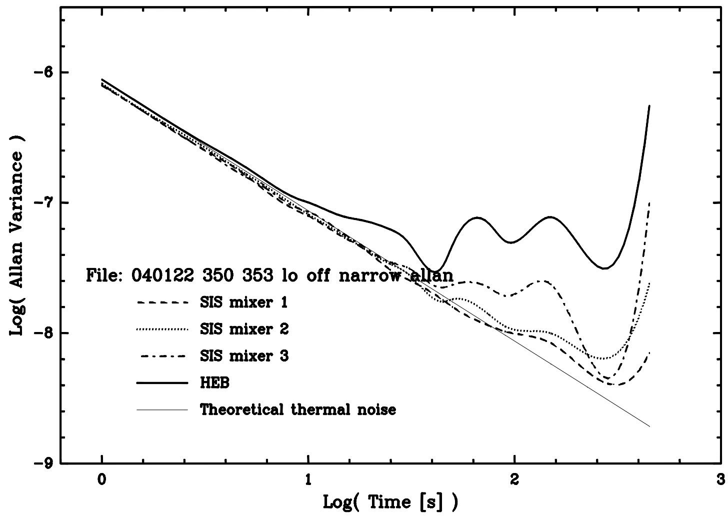


Fig. 12.— Same as above, but the Allan variance was calculated averaging only over 100 channels (rather than 700). Allan variance with LO turned off and V_{bias}=3.5 mV and I_{bias}=35.3 μA, SIS mixers in resistive range with V_{bias}=$\sim$4 mV, magnetic fields using currents of 21mA, 66.8mA and 68mA, respectively.

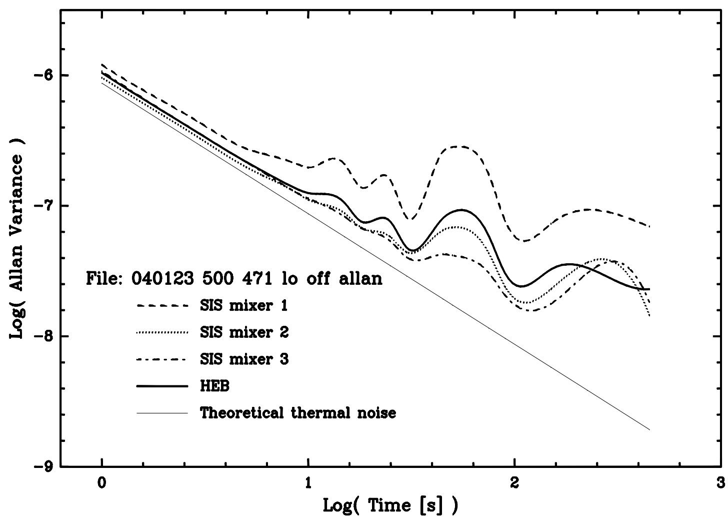


Fig. 13.— Allan variance with LO turned off and V_{bias}=5 mV and I_{bias}=47.1 μA, SIS mixers all have V_{bias}=5 mV and a current of I_{mag} $\sim$70mA for the magnetic field.

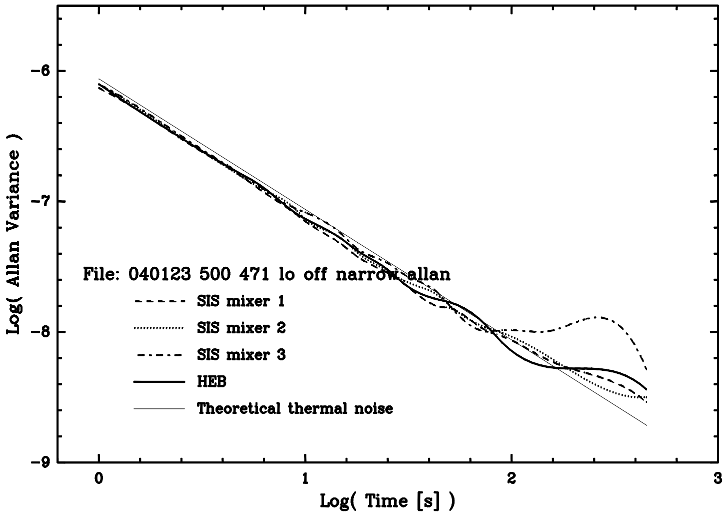
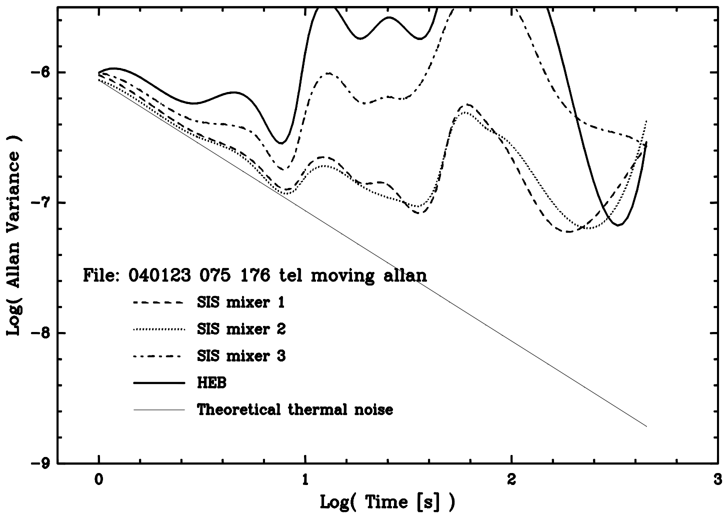
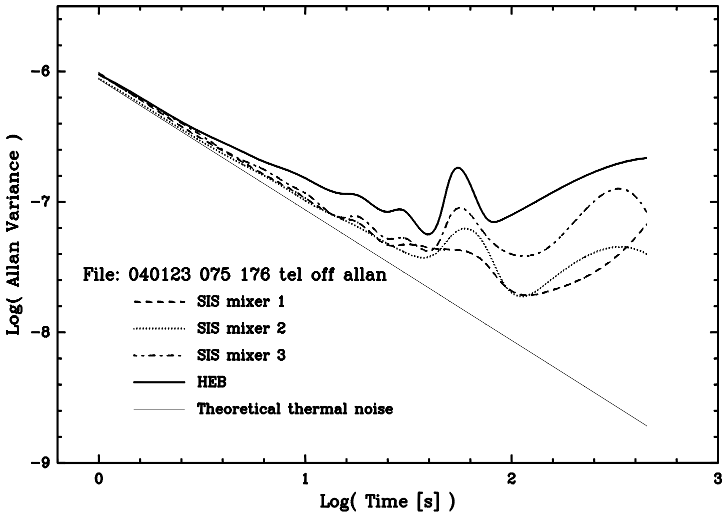


Fig. 14.— Same as above, but with a very narrow channel range of 50MHz (channels 650 - 700). Allan variance with LO turned off and V_{bias}=5 mV and I_{bias}=47.1 μA, SIS mixers all have V_{bias}=5 mV and a current of I_{mag} $\sim$70mA for the magnetic field.

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SIS mixer 1
SIS mixer 2
SIS mixer 3
HEB
Theoretical thermal noise
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Log(Time [s])
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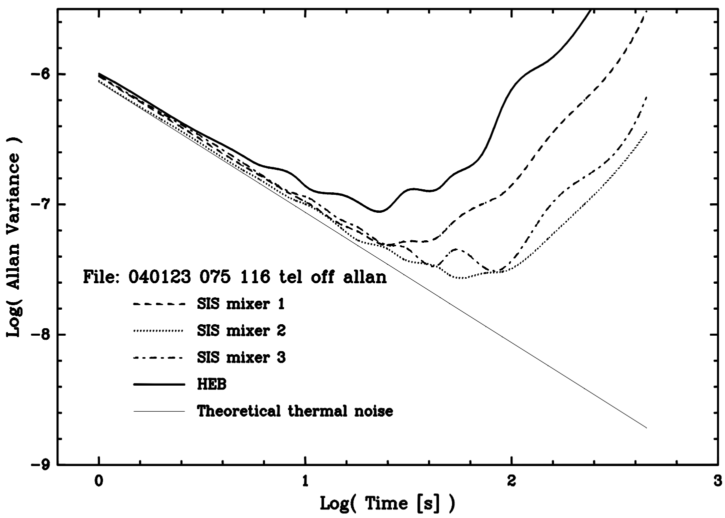
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SIS mixer 2
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HEB
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Log(Allan Variance)
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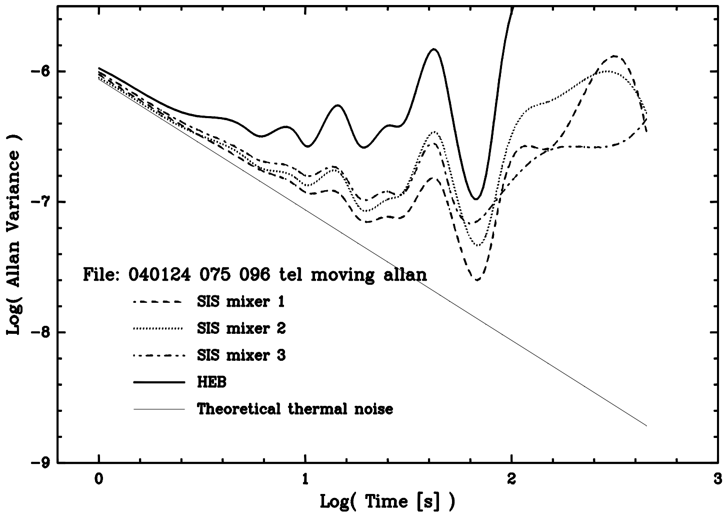
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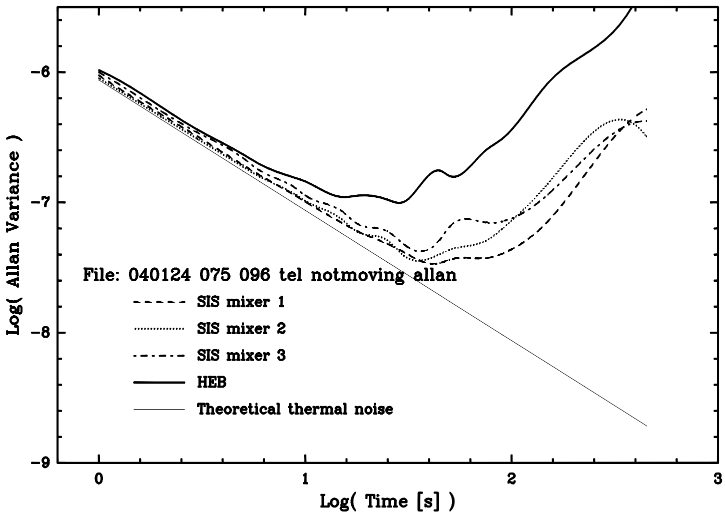
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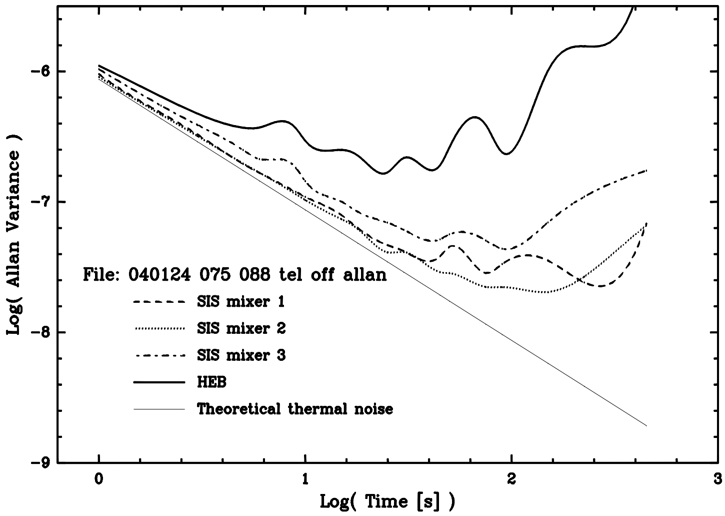
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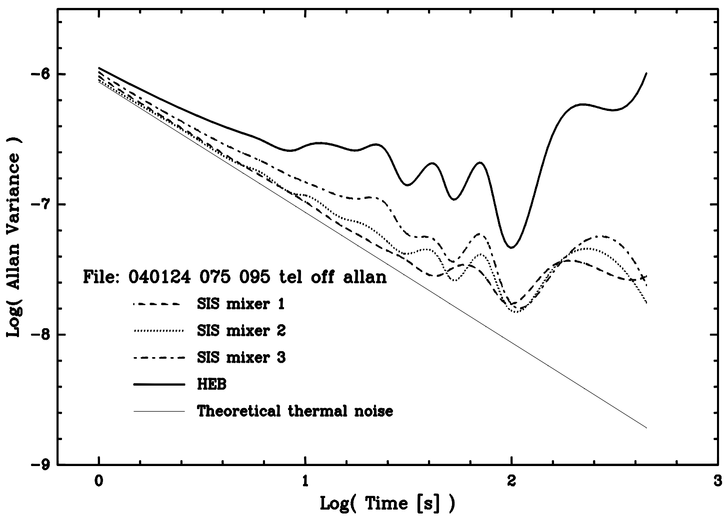
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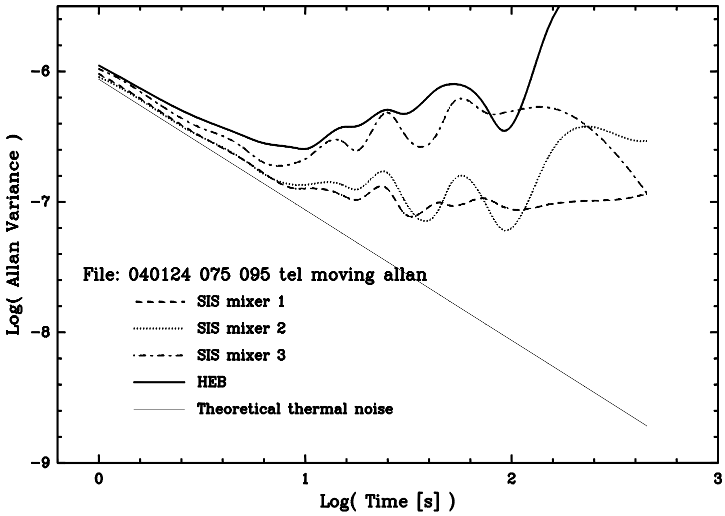
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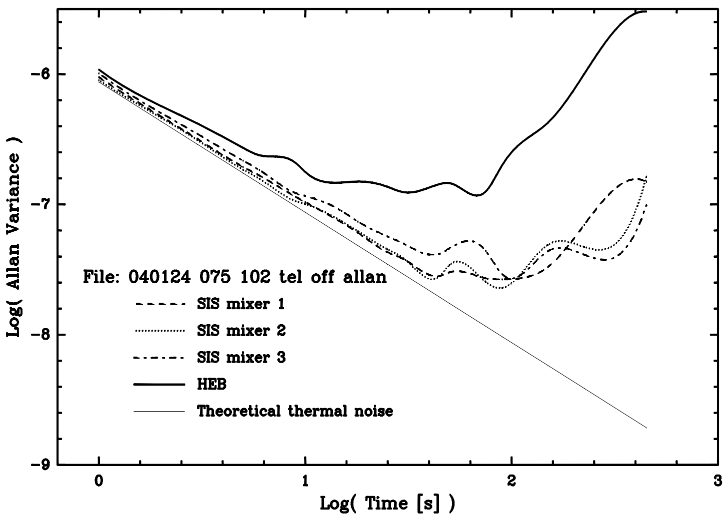
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HEB
Theoretical thermal noise
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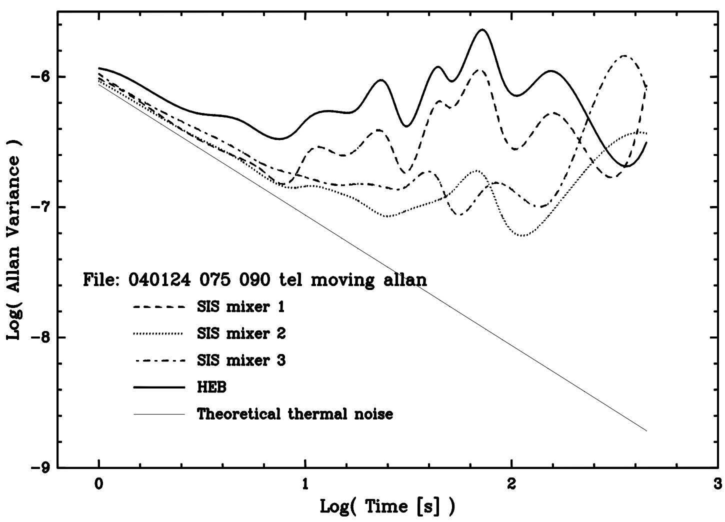
Log(Allan Variance)
Log(Time [s])
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File: 040124 075 090 tel moving allan
SIS mixer 1
SIS mixer 2
SIS mixer 3
HEB
Theoretical thermal noise