SMA Technical Memo 155
Performance of the SMA during observations of BR1202-0725
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November 4, 2004

The observations of BR1202-0725, a faint high redshift galaxy of 20 to 40 mJy, did not meet the theoretical expectations for sensitivity by a factor of approximately 2 or 3. The proposal and scientific goals of the project indicate that these observations were designed for the highest possible sensitivity in order to detect faint galaxies at high red shift and were made in some of the best weather of the first semester. It was not clear at the time of the data reduction why the expected sensitivity was not obtained.

Understanding the limitations on sensitivity is critical for planning certain studies that would be of high scientific value such as the high redshift galaxies and debris disks around young stars. Objects in these classes are typically faint with fluxes of several to a few tens of mJy. The SMA should be able to image these objects at a noise level of about 2 mJy at 340 GHz in one track or roughly 8 hours of observing. However, if the actual sensitivity is a few times worse than expected, then the observing time increases by a factor of 4 to 10, and studies of faint objects are at an entirely different level of difficulty.

The expected sensitivity and the underlying assumptions are well summarized in a web page document and cgi script (a fill-in-the-blanks type of web page program) known as the the "SMA Beam Calculator & Sensitivity Estimator". This web page summarizes what is considered the current standard for the SMA. For example, the results of this calculator are required for proposals submitted to the SMA. Briefly, the assumptions include an SSB receiver noise temperature of $9h\nu/k$ or about 150 K at 345 GHz, and an atmospheric optical depth of 0.07 at the 225 GHz frequency of the CSO radiometer. The calculations take into account the efficiency of the dishes, the atmospheric emission from a model atmosphere, and time lost for system and calibration overhead. At the time of the observations of BR1202-0705, the 225 GHz optical depth was recorded to be around 0.07 – excellent weather. The receiver temperatures are not recorded for each observation, but a measurement made in the spring of 2004 (memo by Ray Blundell) indicated that all the receivers achieved noise temperatures of 150 K or better with the exception of the receiver in antenna 5. Thus the conditions should have allowed the observations to meet the expected sensitivity.

As a first step toward investigating the sensitivity, the system noise temperatures for each antenna and the 225 GHz optical depth were extracted from the SMA database for 10 minute intervals over the entire first semester

of 2004. For the time period covering the observations, the data shows that the lowest stable DSB system noise temperature, averaged over the 7 operating antennas, was about 400 K despite the excellent weather, and many of the 10 minute samples showed much higher noise (figures 1 and 2 for March 16 and April 5). Theoretically we expect an SSB (not DSB) system noise temperature of about 500 K. Since the difference between the SSB and DSB temperatures is a factor of 2, the excess system noise accounts in general for the poor performance noted in the observations.

Data for the individual antennas shows a wide variation in noise and stability (figures 3 and 4). The receivers in antennas 1,2, and 3 were generally performing the best, while those in antennas 5, 6, 7, and 8 were considerably worse. Antenna 4 was not operating at all. In addition, the system noise in antennas 6 and 7 appeared to be variable indicating some instability. In looking at figure 3 for March 16, I concentrate on the time period between 3.51 and 3.52 months where the system noise is the most stable.

Such large variations in noise between the individual antennas as well as the variations in time are not expected. For example, variations of about 20% are typical for the Owens Valley 1 mm receivers and for the Hat Creek 3 mm receivers according to James Lamb (OVRO) and Dick Plambeck (Hat Creek). Plots of the system temperatures with time for the duration of one observation (about 8 hours) are shown in figures 5 and 6 for the individual antennas those observatories. These data were obtained from my colleagues at the CFA who happened to have this data available because they were working on observations from these telescopes. In that sense these data from OVRO and Hat Creek are a random selection taken in weather that was at least good enough to permit observing. The single noisy receiver in the Hat Creek interferometer is an old Schottky diode receiver that is expected to have a much higher noise temperature than the other newer and lower noise SIS receivers. I do not know why one of the Owens Valley receivers is noisy in this particular observation, but both James Lamb and Dick Plambeck said that every so often an antenna develops a high noise temperature until the problem is determined and resolved. Similar plots for the SMA are shown in figures 7 and 8. These SMA plots contain exactly the same information as shown in figures 3 and 4, but plotted to match the data from OVRO and Hat Creek for comparison.

Clearly there were problems with the SMA performance in both stability and absolute sensitivity even allowing that the higher frequency receivers of the SMA will necessarily have a higher noise temperature and allowing that the atmosphere will have a higher emissivity at higher frequency despite the higher elevation of the SMA.

Because the observations of BR1202-0705 were intended to be of the highest sensitivity to detect the faintest sources yet attempted by the SMA, one would suppose that at the time of the observations, the observers were not aware of the performance they were getting. Otherwise, these observations would or should not have been attempted with this level of performance.

One probable cause of noise includes poor tuning of the receivers. Ant Schinckel and Ray Blundell suspect that this may be part or all of the problem. The data show that each receiver often has a very different noise temperature on individual nights. In other words, it seems that each receiver may show good or poor performance on any particular night, and this would be consistent with a tuning rather than an intrinsic problem with the receivers. The receiver tuning is not a complex operation, but there are a number of settings that need to be optimized including phase lock loops, magnetic fields for dark current suppression, oscillator settings, bias voltages, etc. A certain amount of training and experience is helpful in optimizing receiver performance. Among other possible causes, Dick Plambeck offered that at Hat Creek they often find problems caused by moisture, either condensation on the reflecting surfaces or more dramatically water that leaks onto the components following bad weather. Dick also suggested that stability problems can occur if the refrigerator is not maintaining a constant temperature. In the Hat Creek receivers, the setting of the bias voltage across the SIS junction is particulary sensitive to the receiver temperature. Thus the receiver will appear to be unstable if the temperature is changing. According to Ed Tong, incorrect setting of the magnetic field strength or changing conditions within the receiver or surroundings that change the optimization of the magnetic field can also lead to instability in the high frequency SMA receivers.

In order to check on the more recent performance of the SMA, data was extracted for the month of September, 2004. For most of the month, there were problems with the database or the array was observing with the low frequency, 230 GHz receivers. Two observations are available, and the weather was excellent on both nights. The atmospheric optical depth at 225 GHz was about 0.1 on both nights.

The plots of the average system temperature in figures 9 and 10 still show high average system temperatures. The plot of the noise of the individual antennas during the observations at the beginning of the month, figure 11 again shows variability between the antennas with excellent sensitivity from antennas 2 and 3. Antennas 1, 4, and 5 appear stable, but the system temperatures are too high. Antenna 7 looks unstable and noisy.

Finally antenna 8 was not operating. During the observations at the end of the month, figure 12, again antennas 2 and 3 were performing well. Antennas 1, 5 and 8 are noisier, and antennas 4 and 6 are unstable and very noisy. In these observations at the end of the month, one can see how the poor performance of two antennas, 4 and 6, completely changes the character of the average system temperature as shown in the difference between the noise in figures 9 and 10. The differences in the performance in the two September observations again suggest operational problems such as tuning of the individual receivers. The September observations are in general encouraging indicating that the noise might immediately be improved simply by improving the observing procedures.

Motivated by the data presented in this memo, a review of the receiver operations is scheduled for this fall and preparations for more rigorous testing of the receiver performance are already underway. These preparations include new software for recording total power or Tsys measurements at very rapid time scales.

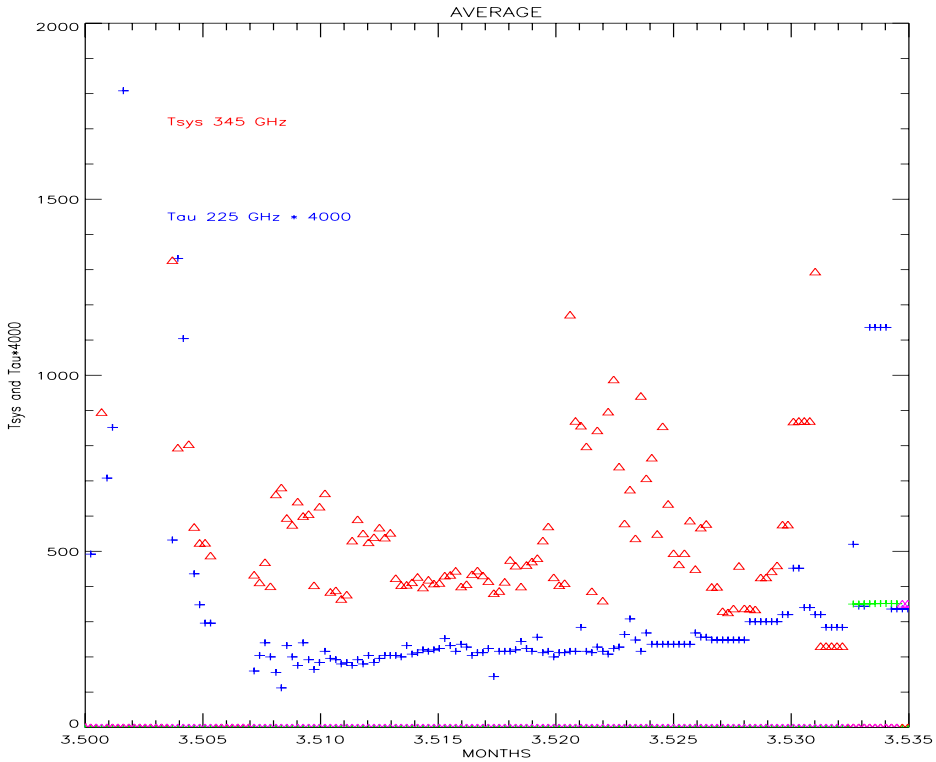

Figure 1: The DSB system noise in the SMA, Tsys, at 345 GHz (triangles) and the 225 GHz Tau * 4000 (crosses) on March 16, one of the two dates of the observations of BR1202-0725.

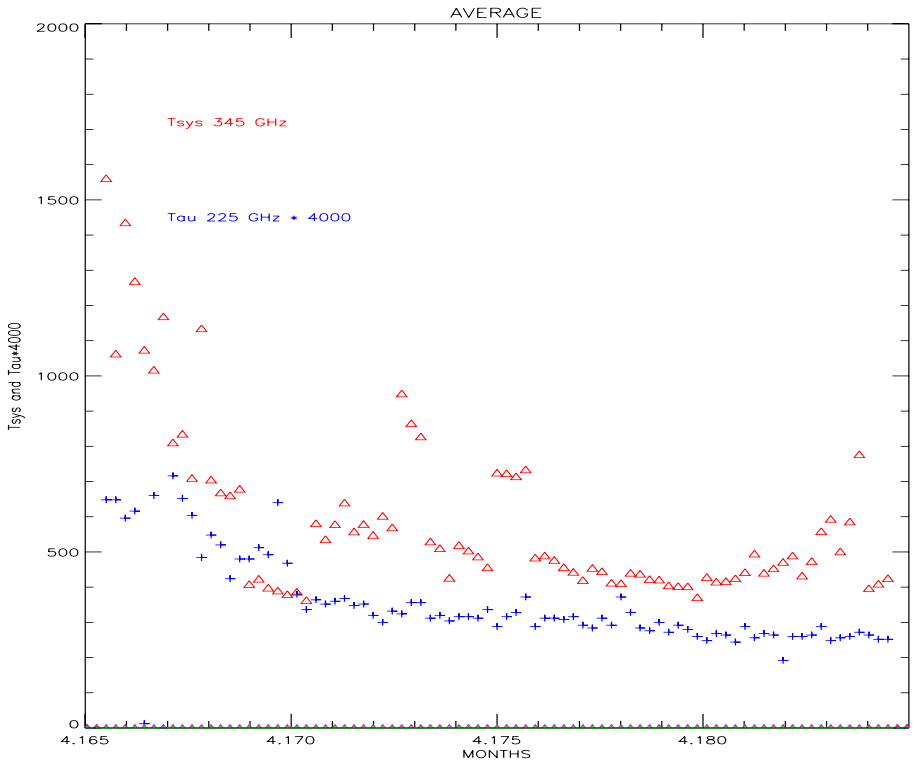

Figure 2: The DSB system noise in the SMA, Tsys, at 345 GHz (triangles) and the 225 GHz Tau * 4000 (crosses) on April 16, one of the two dates of the observations of BR1202-0725.

Figures 3 and 4 on the next two pages: System temperatures during the observations of BR1202-0725. The DSB system noise in the SMA, Tsys, at 345 GHz (triangles) and the 225 GHz Tau * 4000 (crosses) on March 16 (figure 3) and April 5 (4) for each individual antenna. The figures show the excellent performance of receivers on antennas 1,2, and 3, (Tsys $<$ 250 K), and how the poor performance of 5,7, and 8 (Tsys $>$ 500 K) degrade the sensitivity of the array. Antenna 4 was not working on this date.

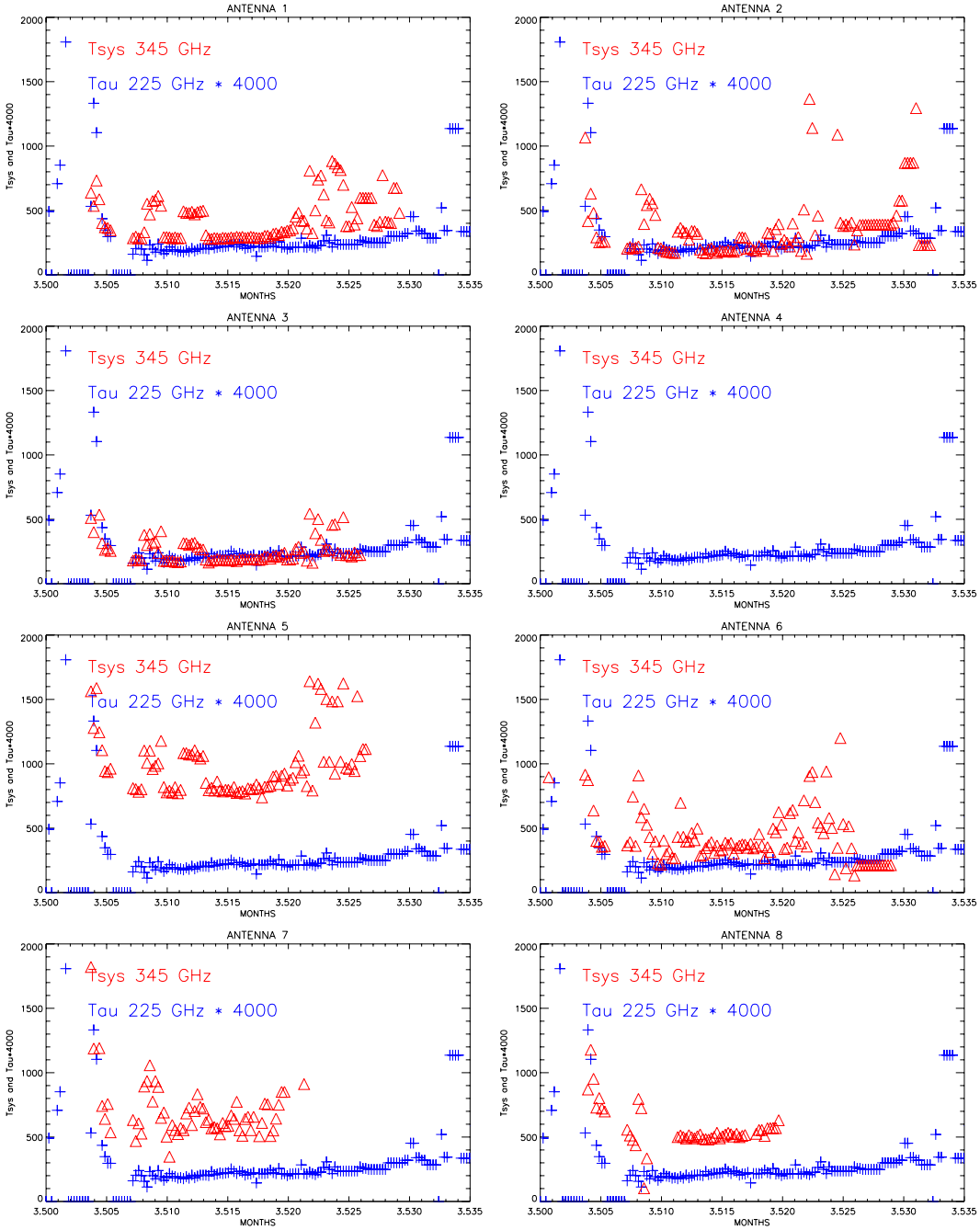
ANTENNA 1
ANTENNA 2
ANTENNA 3
ANTENNA 4
ANTENNA 5
ANTENNA 6
ANTENNA 7
ANTENNA 8
Tsys 345 GHz
Tau 225 GHz * 4000
Tsys and Tau*4000
MONTHS
0
500
1000
1500
2000
3.500
3.505
3.510
3.515
3.520
3.525
3.530
3.535

Figure 3:

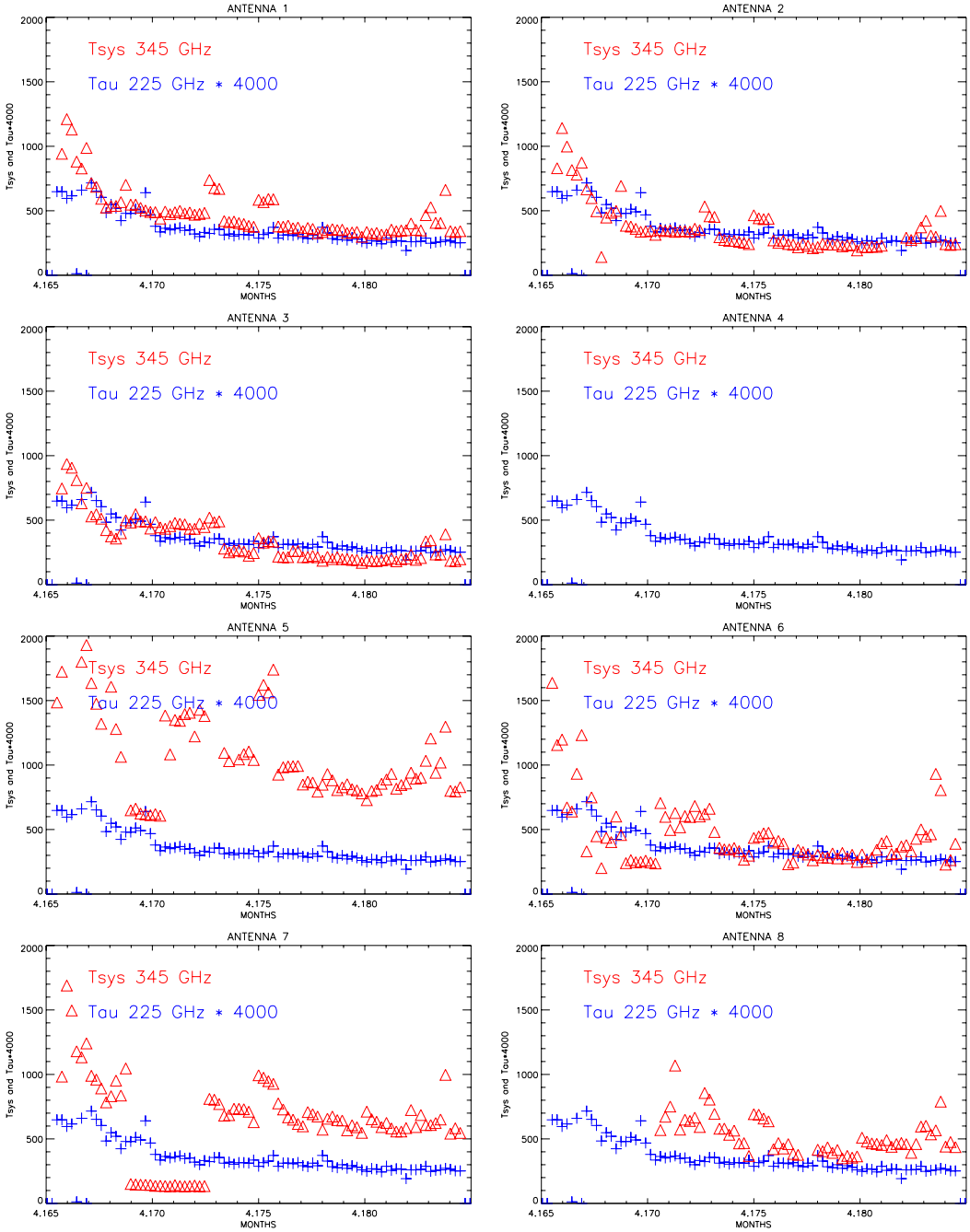
ANTENNA 1
ANTENNA 2
ANTENNA 3
ANTENNA 4
ANTENNA 5
ANTENNA 6
ANTENNA 7
ANTENNA 8
Tsys 345 GHz
Tau 225 GHz * 4000
Tsys and Tau*4000
MONTHS
0
500
1000
1500
2000
4.165
4.170
4.175
4.180

Figure 4:

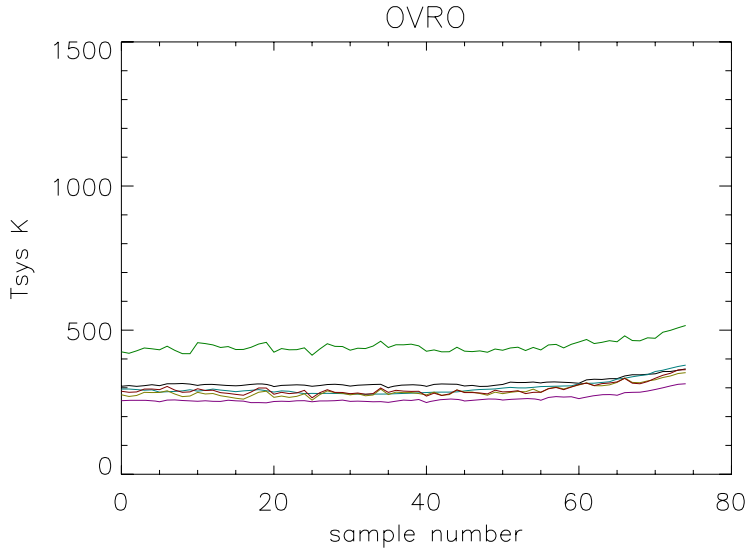

Figure 5: The DSB system noise for each antenna at OVRO during one observation.

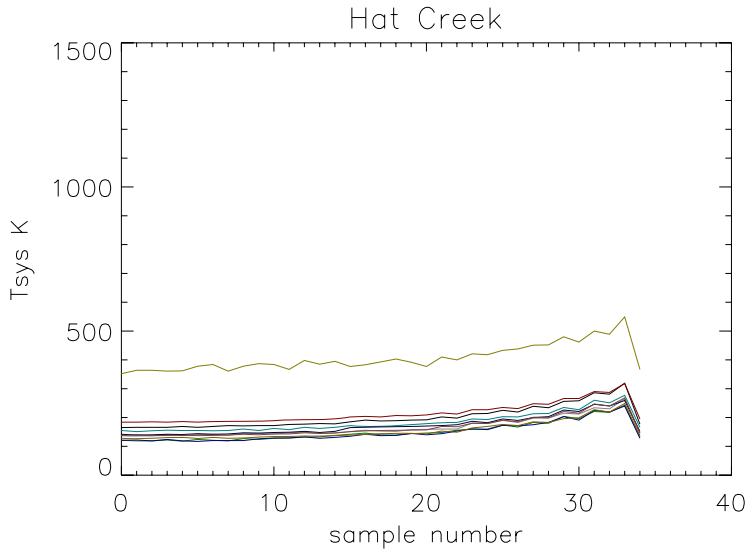

Figure 6: The DSB system noise for each antenna at Hat Creek during one observation.

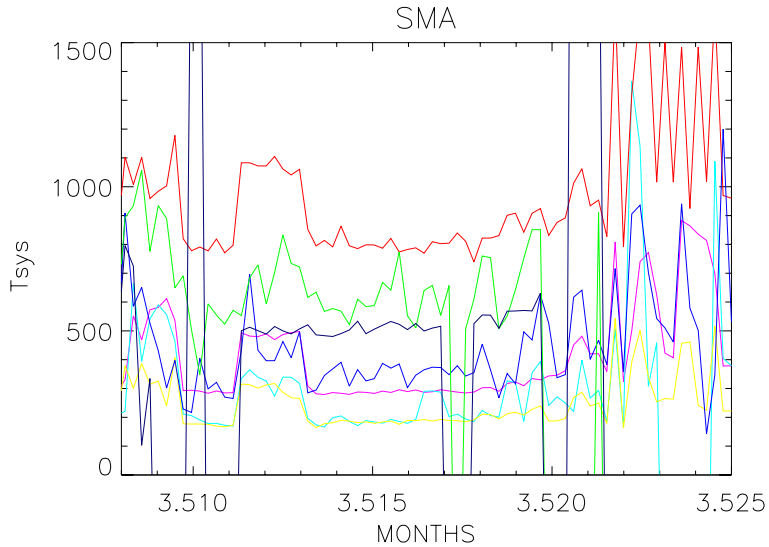

Figure 7: The DSB system noise for each antenna at the SMA during the observation of BR1201-0725 on March 16.

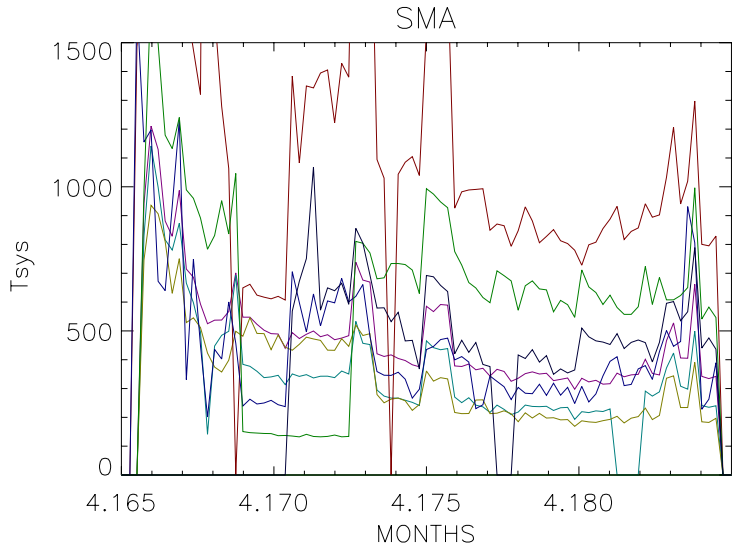

Figure 8: The DSB system noise for each antenna at the SMA during the observation of BR1201-0725 on April 5.

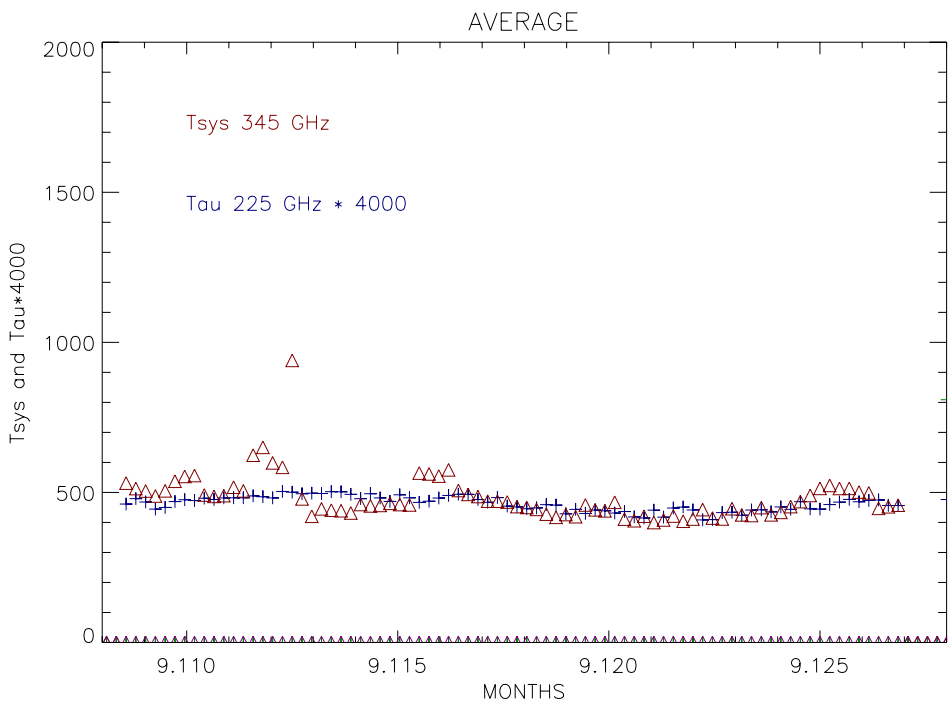

Figure 9: The DSB system noise in the SMA, Tsys, at 345 GHz (triangles) and the 225 GHz Tau * 4000 (crosses) at the beginning of September.

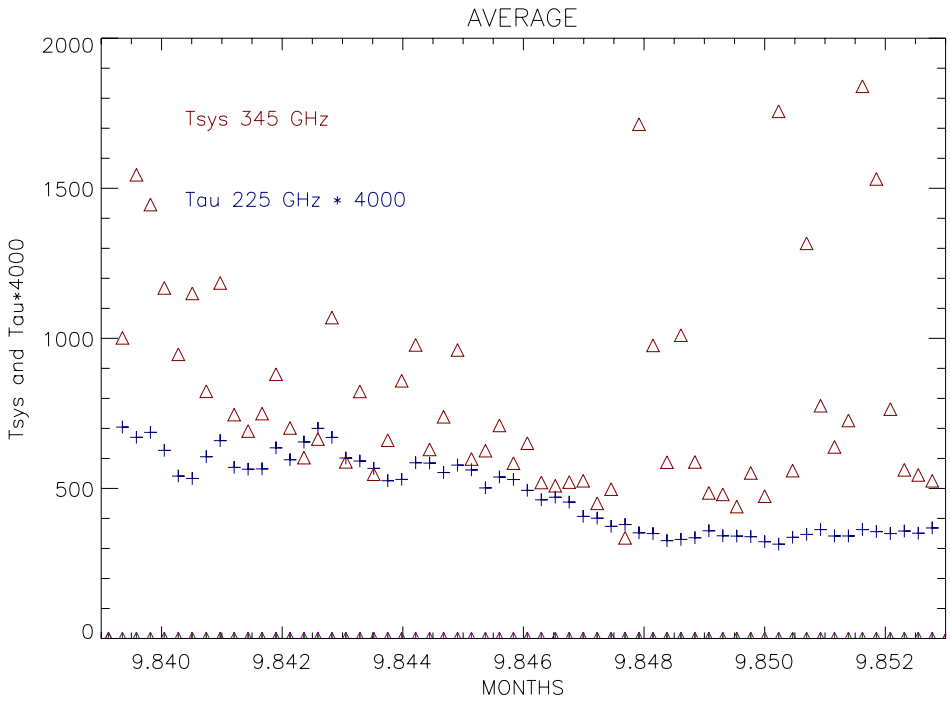

Figure 10: The DSB system noise in the SMA, Tsys, at 345 GHz (triangles) and the 225 GHz Tau * 4000 (crosses) at the end of September.

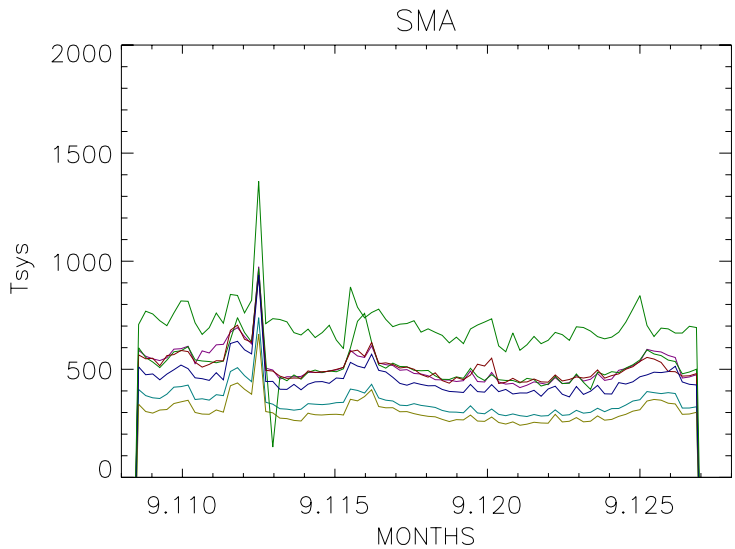

Figure 11: The DSB system noise for each antenna at the SMA during an observation at the beginning of September.

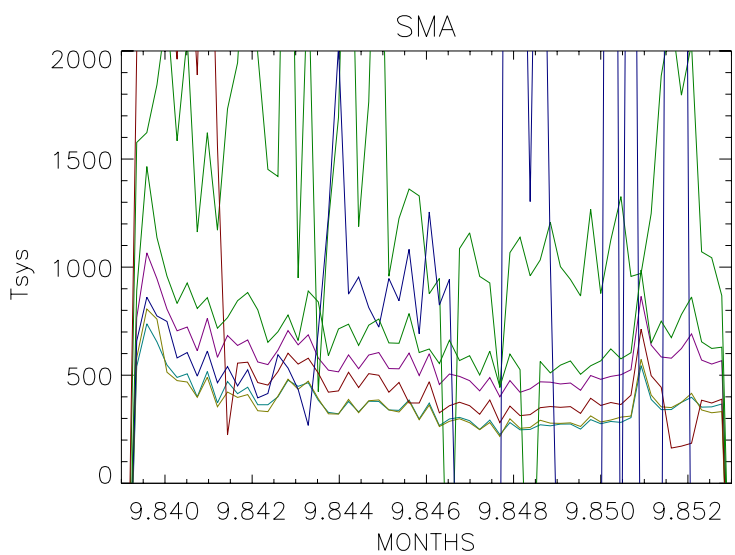

Figure 12: The DSB system noise for each antenna at the SMA during an observation at the end of September.