VLBA Scientific Memo 41

On S-band Observations with the VLBA

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Abstract

The VLBA has been operated with filters for S-band on 7 of the 10 telescopes suppressing signals outside of the range about 2.2 - 2.4 GHz. The current study is intended to determine whether these filters should remain in, or be removed from, the system. The results suggest that RFI makes the VLBA S-band system unreliable whether these filters are present or removed from the system.

1 Introduction

VLBA antennas have two sets of filters in the S-band system designed to limit the response of the telescope. The wide filters allow signals from about 2.0 to 2.8 GHz, while the narrow filters limit the observations to about 2.18 through 2.4 GHz. These narrow filters are present in 7 antennas, but are absent from FD, MK, and PT. It has been noticed that these filters select frequencies which include ubiquitous strong satellite broadcasts, prompting the usefulness of the filters to be questioned. Six data sets were obtained on the VLBA to study this question. The first TY040A was observed 15 October 2020 and included a single scan on 3C345 with 4 spectral windows ("SPWs") covering 2.076 - 2.528 GHz with filters present on all antennas except FD, MK, and the VLA (in Y1 mode). The second TS044A was observed on 10 December 2020 at the same frequencies and with filters in all but FD, MK, and PT. A total of 16 sources were observed over 140 minutes. The third and fourth data sets, called TS044B0 and TS044B1, were observed 1 April 2021 using 3 sources in strict rotation and alternating between 2 frequency setups. The lower frequencies covered 2.076 - 2.588 GHz in 4 spectral windows and the upper frequencies covered an overlapping 2.376 to 2.888 GHz. These data had the narrow S-band filters (at least) bypassed. The remaining data sets TS044C0 and TS044C1 were observed on 9 April 2021 with an identical setup but with the filters re-enabled.

Mark Claussen caused these data to be taken and wrote a report on the first two sessions. In general, he found that SPW 4 appeared to be usable with normal Tsys, but only when the narrow filter was not present. He was puzzled by the lack of fringes in SPW 1 on most baselines except those to PT. I have looked at the data from TS044B and TS044C and will describe what I have found in this memo. I will refer to the higher frequency SPWs as SPW 5 through 8 although SPW 5 actually starts in the middle of SPW 3. These SPWs are summarized in Table 1. I should note that these data were taken before the construction of a cell tower near PT, so that station will appear to be better than it is likely to be now.

2 The data

The data were taken on three sources, 3C345, J1648+4104, and J1651+4002 in a strict rotation. Thirty minutes (5 cycles of the sources) was spent on one set of frequencies followed by the second set of frequencies and then repeat. 3C345 is quite strong, J1648+4104 is easily detected, and J1651+4002 is rather weak. The observations with the filters bypassed shows strong fringes in SPWs 2 through 8. As was found by Mark, SPW 1 has almost no detected signal except for baselines between the antennas with no filters (FD, KP, PT).

SPW	F_{min} GHz	F_{max} GHz	Projects
1	2.076	2.203875	TS044B0, TS044C0
2	2.204	2.331875	TS044B0, TS044C0
3	2.332	2.459875	TS044B0, TS044C0
4	2.460	2.587875	TS044B0, TS044C0
5	2.376	2.503875	TS044B1, TS044C1
6	2.504	2.631875	TS044B1, TS044C1
7	2.632	2.759875	TS044B1, TS044C1
8	2.760	2.887875	TS044B1, TS044C1

Table 1: Spectral window definitions

Whatever was done to "remove" the narrow filters seems to have filtered out frequencies below 2.2 GHz. Curiously, when the filters are in, the fringes are detected clearly down to 2.18 GHz. The filters are quite effective at suppressing any response below 2.18 GHz and above 2.41 GHz.

Figures 1 through 4 are illustrative. Baselines between BR, KP, LA, and MK with PT are shown, illustrating 3 baselines affected by the filters and one (MK-PT) not so affected. Mark reports that there are actually 2 filters, the narrow band 2.2 - 2.4 GHz on 7 stations and a broader one 2.0 - 2.8 on all stations. It is not clear that the broad-band filter was bypassed at FD, MK, or PT. Mark was unsure about the filter at SC, but the data from TS044C suggests that the narrow-band filter is installed there.

3 RFI

In VLBI, local sources of RFI normally do not appear in the cross-correlation data either because the source of the RFI is not visible to both antennas or the RFI fringe rate differs from the target source fringe rate by a large amount. It is clear from Figures 1 and 3 that this does not always work. SPW 1 has significant RFI and almost no sensitivity to the astronomical signal. There are 3 general bands of RFI in the cross-correlations from 2.320 - 2.324, 2.328 - 2.336, and 2.342 - 2.345 GHz and RFI affecting KP baselines from about 2.352 - 2.358 GHz.

Unfortunately, calibration of VLBI data requires an accurate measure of the system temperature at each antenna. RFI that affects only one antenna can still ruin this measurement and thus make calibration difficult or impossible. The actual Tsys from these data will be examined in the next section. In the next paragraph, we examine the autocorrelation data from these observations to see what we expect from the single-station RFI.

Figures 5 through 10 illustrate the autocorrelation data from all 9 antennas (HN was absent) with the plots cut off below 0.0 and above 1.6. The plots are generated by `VBRFI` and are of the mean autocorrelation (in green), the mean rms in purple, and the mean of the rms divided by mean in cyan. The broad features in green are the bandpass shapes of the autocorrelation, whilst the narrow features are RFI. The rms plots reflect instability over time, a characteristic of many types of RFI. `VBRFI` combines the two polarizations although any difference in the two polarizations increases the rms. Note that there are significant frequency ranges free of obvious RFI, but that RFI is present in almost all SPWs. The RFI has similarities among the antennas, but also very significant differences. The plot scale causes a number of channels to be omitted; the numbers across the upper portions of the plots give the number omitted in each SPW. At the higher frequencies, some sites are relatively quiet (BR, FD, MK, PT) while others (KP, LA, NL, SC) have numerous sources of RFI. These are weaker than the RFI signals around 2.32 - 2.36 GHz which are dominant on most antennas in autocorrelation and even cross correlation.

Autocorrelation data are used in calibration only to make corrections for the digital samplers. The mean autocorrelation in each spectral window should be 1.0 and `ACCOR` adds gains to the calibration to insure this.

After a bandpass function is found, usually from cross-correlation data, ACSCL makes a further adjustment to insure that the bandpass-corrected autocorrelation averages 1.0. When the autocorrelation data are affected by strong RFI, this second correction will introduce gain errors when the bandpass shape is not ideal (which is the case here).

4 Tsys

The Tsys values in the TY table from TS044B0 are summarized in Table 2. Recorded values range from -2060000 to 941000 Dgrees Kelvin and there are only a few SPWs which appear entirely well behaved. SPW 1 is omitted to allow the table to fit on one page and since there is little interferometric sensitivity there. LA, MK, and PT appear more stable, but the last is certainly no longer true. The most unstable of the Tsys are not always correlated with the RFI seen in Figure 5.

Looking at SNPLT of the TY table, from TS044B0 and B1 and only for values from 0 to 110 degrees Kelvin, the following comments may be made. BR was questionable in SPW 3 and SPWs 5-8 seem too low, but the values are pretty stable. FD is poor-bad in SPWs 2L, 3R, 3L, 5R, 5L, and 8L; the rest are maybe okay. KP SPWs 2-4, 6, and 7 are too high; 5 and 8 maybe okay. LA had a bad scan in SPW 4 and was low but relatively stable in SPWs 5-8. MK was amazingly stable. NL was mostly off scale, SPWs 5-8 L perhaps okay. OV had SPW 3, 6R and 8R high; the rest perhaps okay. PT had 8L off scale, the rest (before the cell tower) quite okay. SC SPW 2, 4, 5, and 8 okay; rest bad. It is clear that a usable TY table may be produced by TYSMO if applied with a firm hand to flag extreme values and values differing from a median window filter by more than a little, replacing the flagged values with values from the filter.

Table 3 lists the statistics from TS044C0 for the two SPWs passed by the narrow filters. Plotting these SPWs along with the same ones from TS044B0, the following comments may be made. FD, MK, and PT lack filters and have quite similar Tsys in both data sets. NL and SC are also rather similar. The B0 Tsys are rather better for BR and LA and are also better in SPW 2 for KP and NL. For KP and NL SPW 3, the C0 Tsys are rather better. HN did not participate in the B0 observations. We should note that the 2.2 - 2.4 GHz filter suppresses about half of SPW 3 which may account for the KP and NL results.

For completeness, Tables 4 and 5 list the Tsys statistics for TS044B1.

5 Calibrating the data

One of the first tasks in the standard sequence of VLBA calibration is ACCOR which determines gain amplitudes to insure that the average autocorrelation is 1.0. Figure 11 shows a plot of the spectral average autocorrelation as a function of time for the TS044C0 data set with the input flag table and with an added clip operation to remove obvious RFI (> 5 Jy), and for TS044B0 with default flagging. It is clear that stable ACCOR gains are encouraged by the narrow filters (of the C0 data) and that RFI in the autocorrelation must not be deleted before ACCOR.

This figure brings out an aspect of calibration with ACCOR which is seen in many VLBA data sets. The first 6 - 12 seconds of data in each frequency session should probably be flagged while the system stabilizes.

Examining similar plots for all usable SPWs, we note that the average autocorrelation in TS044C0 is near 1.0 for all antennas in SPW 2 and near 1.6 to 2.0 for most antennas in SPW 3. Stations that are (or were) less plagued by RFI, MK and PT, had the average SPW 3 near 1.0 although PT was noisier in both SPWs. The two polarizations are quite similar. In the TS044B0 data set, the average autocorrelations are mostly relatively stable in each SPW and polarization, although those rough averages vary from 0.6 to 1.1 for some antennas. Again, MK has a very narrow range and SC SPW 2 R is very noisy. Finally, in TS044B1, looking at all 4 SPWS 5 - 8, we again see that the averages are generally relatively stable over time. The averages can be as low as 0.5 or as high as 1.1. PT in SPW 5 is noisy and LA and KP in SPW 8 show significant changes between scans.

For comparison purposes, we concentrate on the TS044B0 and TS044C0 data sets. In each, the RFI is flagged at the high end of SPW 2 and lower end of SPW 3, using `UVFLG` after guidance from `FTFLG`. A single 3C345 scan was selected in each and `VLBAMPCL` was run to remove the overall delays. That worked well. Attempting `BPASS` over all times in each data set produced an over abundance of flagged channels. Using a single half-hour set of scans produced a more usable bandpass correction function.

As described previously, the input Tsys tables are a mess, requiring some editing. `TYSMO` was run to flag initially all Tsys outside the range 20 - 150 degrees Kelvin, to run a median window filter of width 15 minutes and flagging all points more than 25 degrees Kelvin away from the median, and finally replacing all flagged points with the values of the median filter. This produced some significant flagging of data, but a generally usable representation of Tsys for the rest of the data. The values of Tsys were similar in the two data sets. VLBAAMP was then run to apply `ACSCL` to change amplitudes due to the effect of bandpass on the autocorrelations and then `APCAL` to scale the data by the Tsys. Again, the two data sets had similar gain amplitudes. Finally, `FRING` was run over the data to remove any remaining phase slopes and the data written out by `SPLIT`.

The resulting time averaged spectra in each baseline looked pretty good except for NL in TS044B0 which was essentially zero with much noise. Each spectrum had both flat phase and amplitude over spectral channel. However, when one examined the average amplitude as a function of time for each baseline, it was clear that the C0 data set had much larger and better behaved fringe amplitudes. The B0 amplitudes are rather scattered in time and often an order of magnitude smaller.

Making images with `IMAGR` and self-calibrating with `CALIB` confirmed these differences. The C0 images reached a total flux density of about 3 Jy with a couple of rounds of phase self-cal. Following one round of phase and amplitude self-cal, the final image had a total flux density of 2.83 Jy and an rms noise of 8 mJy/beam. The B0 image never got above density 0.65 Jy. Note that 3C345 should probably have a flux density closer to 6 Jy at this frequency, so even the C0 result is problematical.

The TS044B1 data set was also processed in a similar fashion. The best total flux densities obtained were 1.4 Jy with an rms of 4 mJy/beam.

At Walter Brisken's suggestion, I have run `FRING` on J1648+4104 in both the B0 and C0 data sets. On the B0 data set, `FRING` found 692 solutions and failed on 388; on the C0 data set, `FRING` found 640 good solutions and failed on 260. These are rather high failure rates for a `SOLINT` of 2 minutes. The mean and rms of the SNRs reported by `FRING` are summarized in Table 6 and 7. SPW 2 is the only SPW fully sampled by the 2.2 - 2.4 GHz filters. The SNRs tend to be significantly higher with the filters for those antennas that have filters and similar for the antennas (2, 6, 9) without. The numbers for OV are an exception to this rule and the large number of blank cells attests to the significant amount of the data that ends up flagged during the calibration.

6 Conclusion

The "obvious" conclusion at the start of this project was to remove the narrow filters to make a much wider bandwidth available to the users. This was thought to be obvious in part because of the significant RFI found in the cross-correlations with those filters and not seen at other frequencies over the rest of S band. However, the failure to calibrate the data in SPWs 2 and 3 usefully when the narrow filters were removed suggests a quite different conclusion. It would appear that those filters, even though they are only on 7 antennas, reduce the RFI depressing and destabilizing the receivers in a significant fashion. The recent construction of a cell tower near PT suggests that adding a filter to PT and perhaps FD would be wise. MK appears to be safe from RFI so far. Even with the use of the narrow filters, the visibility amplitudes after calibration are less than satisfactory. Phase accuracy was not measured in the present study. Therefore, declaring S-band on the VLBA as "shared risk" would, I think, be justified. We certainly cannot guarantee good data for our users.

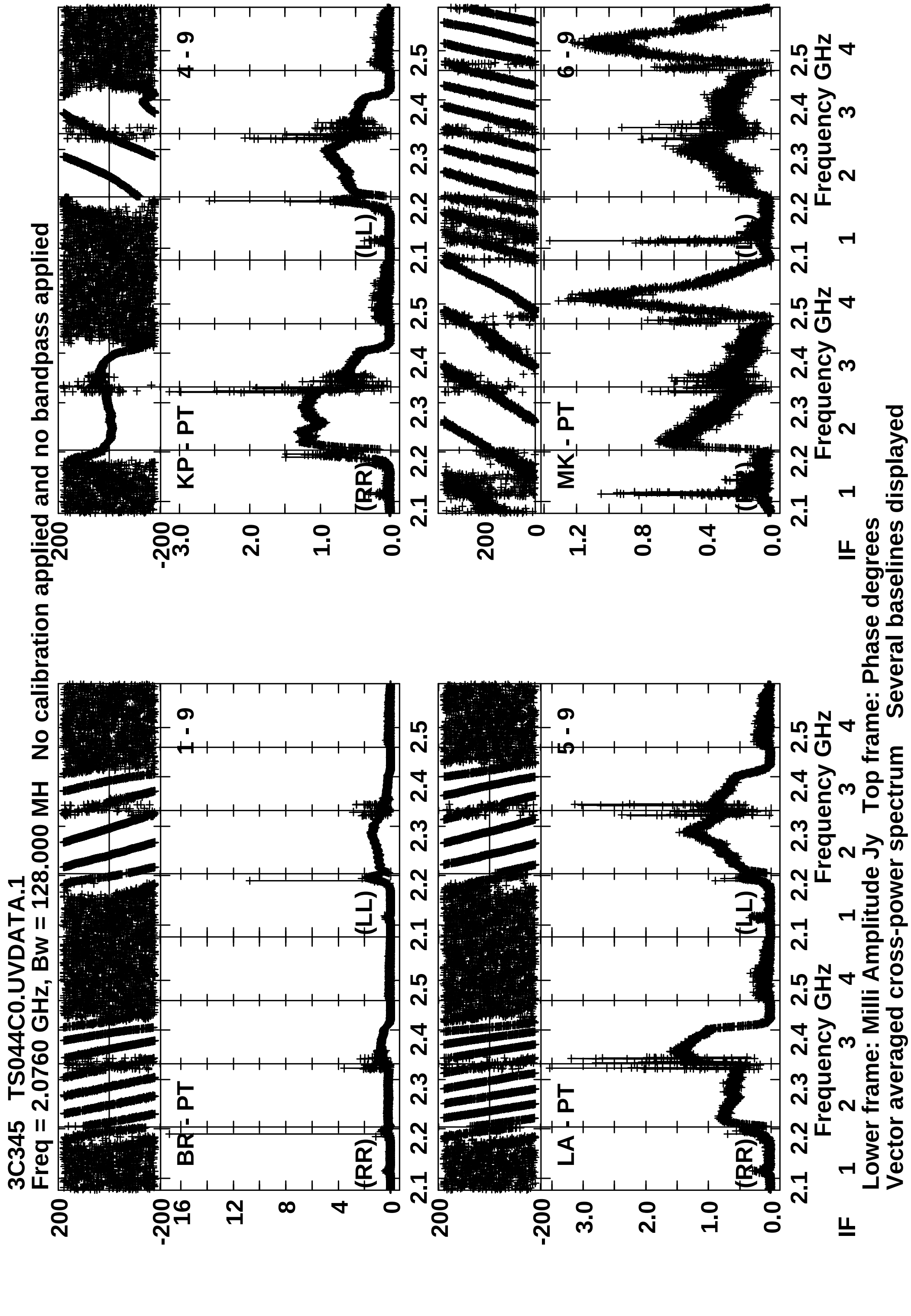

Figure 1: TS044C0 average spectrum of 3C345 for 4 baselines as labeled. The filters are in the usual antennas (BR, HN, KP here) and are quite effective in limiting the response to 2.18 - 2.41 GHz. SPW 1 shows fringes on the baseline with no filters (MK - PT). Note also considerable RFI in the cross correlations in SPW 1 and in the region between SPWs 2 and 3.

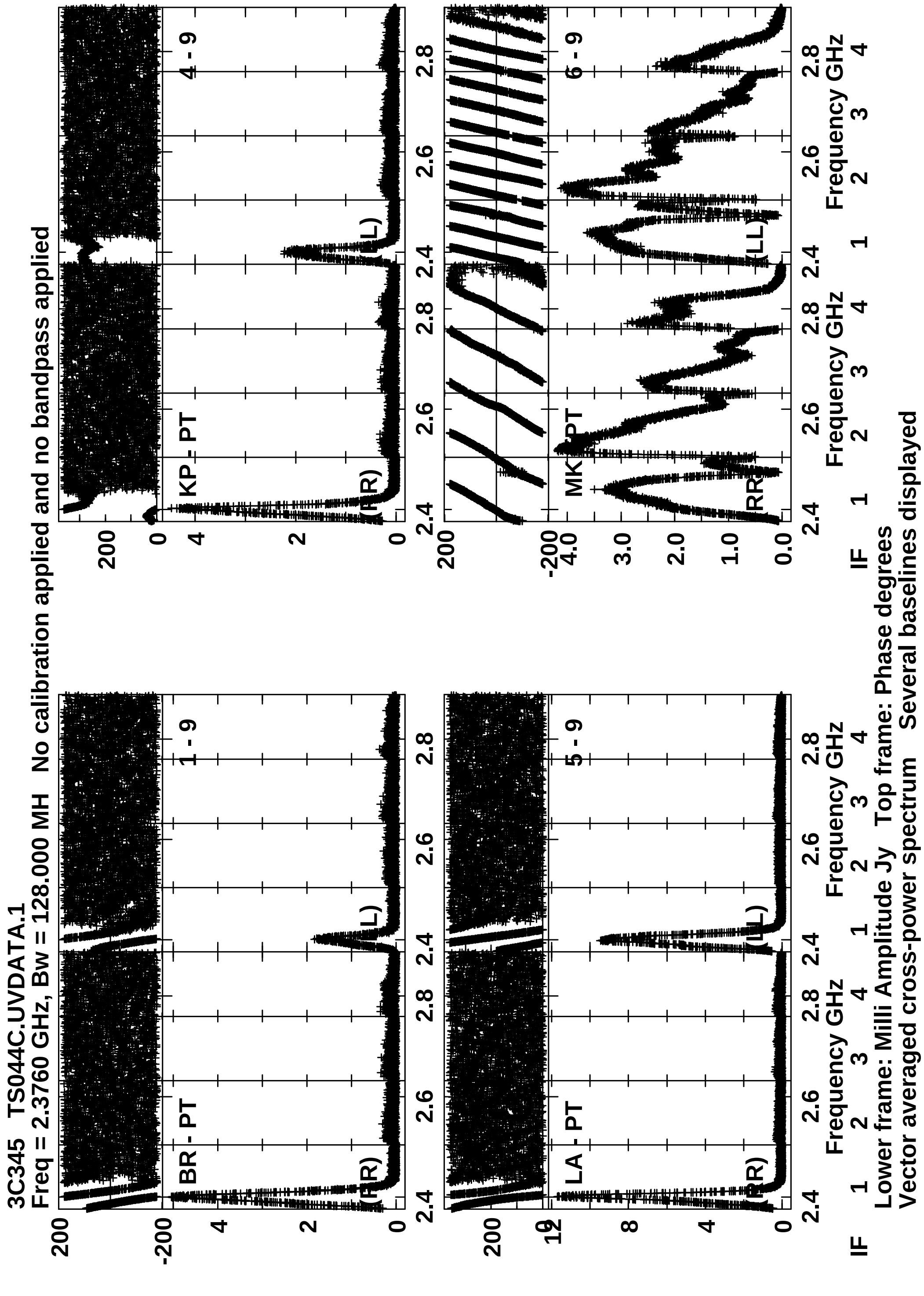

Figure 2: TS044C1 average spectrum of 3C345 for 4 baselines as labeled. The filters are in the usual antennas (BR, HN, KP here) and are quite effective in limiting the response to frequencies above about 2.41 GHz. Fringes are seen at all frequencies on the baseline with no filters (MK - PT). Note also the lack of RFI on that baseline.

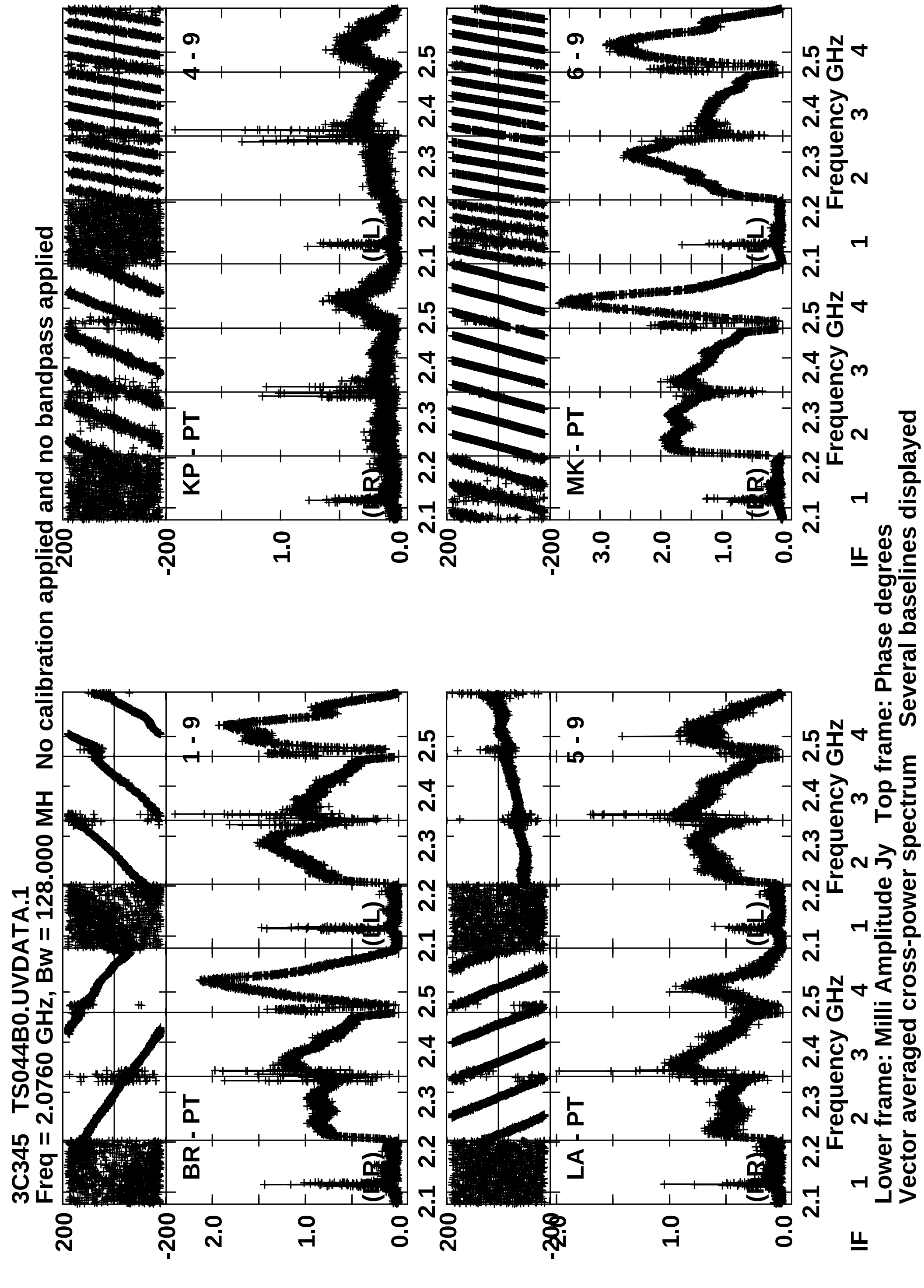

Figure 3: TS044B0 average spectrum of 3C345 for 4 baselines as labeled. The filters have been bypassed. SPW 1 does not show fringes in either polarization for antennas that have the bypassed filters. Note also considerable RFI in the cross correlations in SPW 1 and in the region between SPWs 2 and 3.

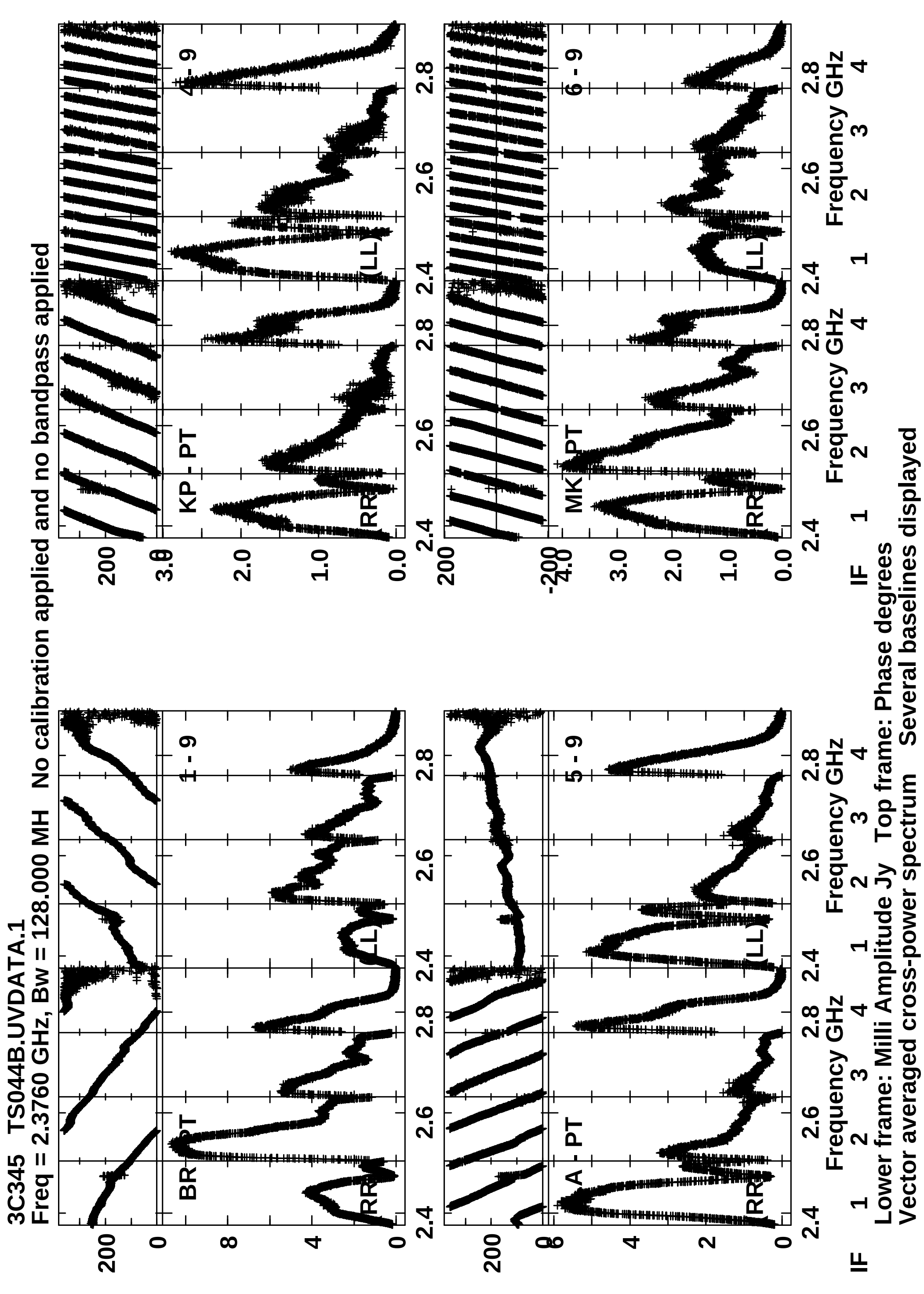

Figure 4: TS044B1 average spectrum of 3C345 for 4 baselines as labeled. The filters have been bypassed. All spectral windows show good fringes except at the high end of SPW 8, presumably because the sensitivity approaches zero. There is a wide-band filter 2.0 - 2.8 GHz which is probably in place at least for FD, MK, and PT. The cross-correlations do not show the serious RFI seen at lower frequencies.

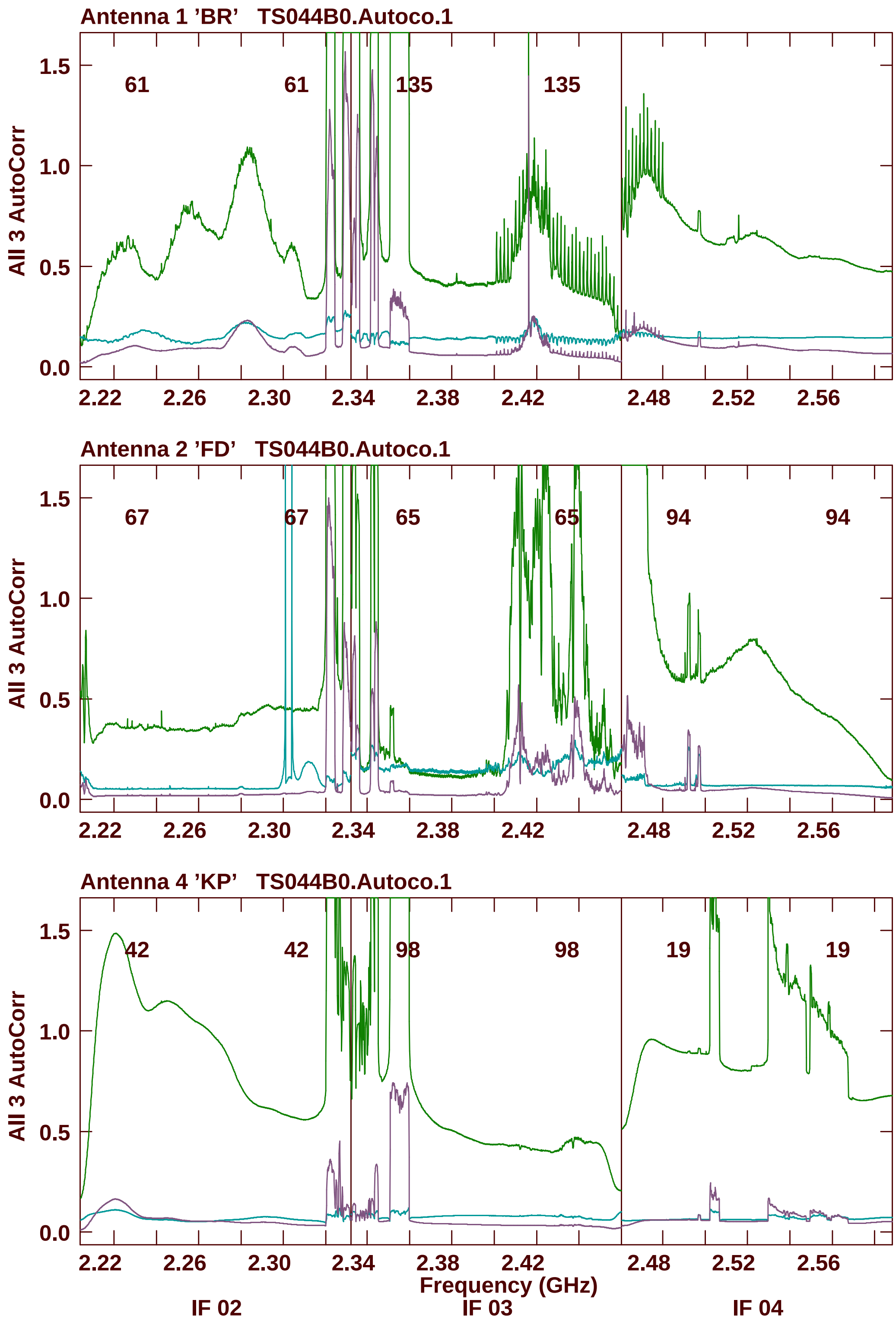

Figure 5: TS044B0 average autocorrelation spectrum of 3C345 for 3 antennas in green. The mean rms/mean in cyan and the rms is purple. The filters have been bypassed. Data points outside the range 0 to 1.6 or so have been omitted.

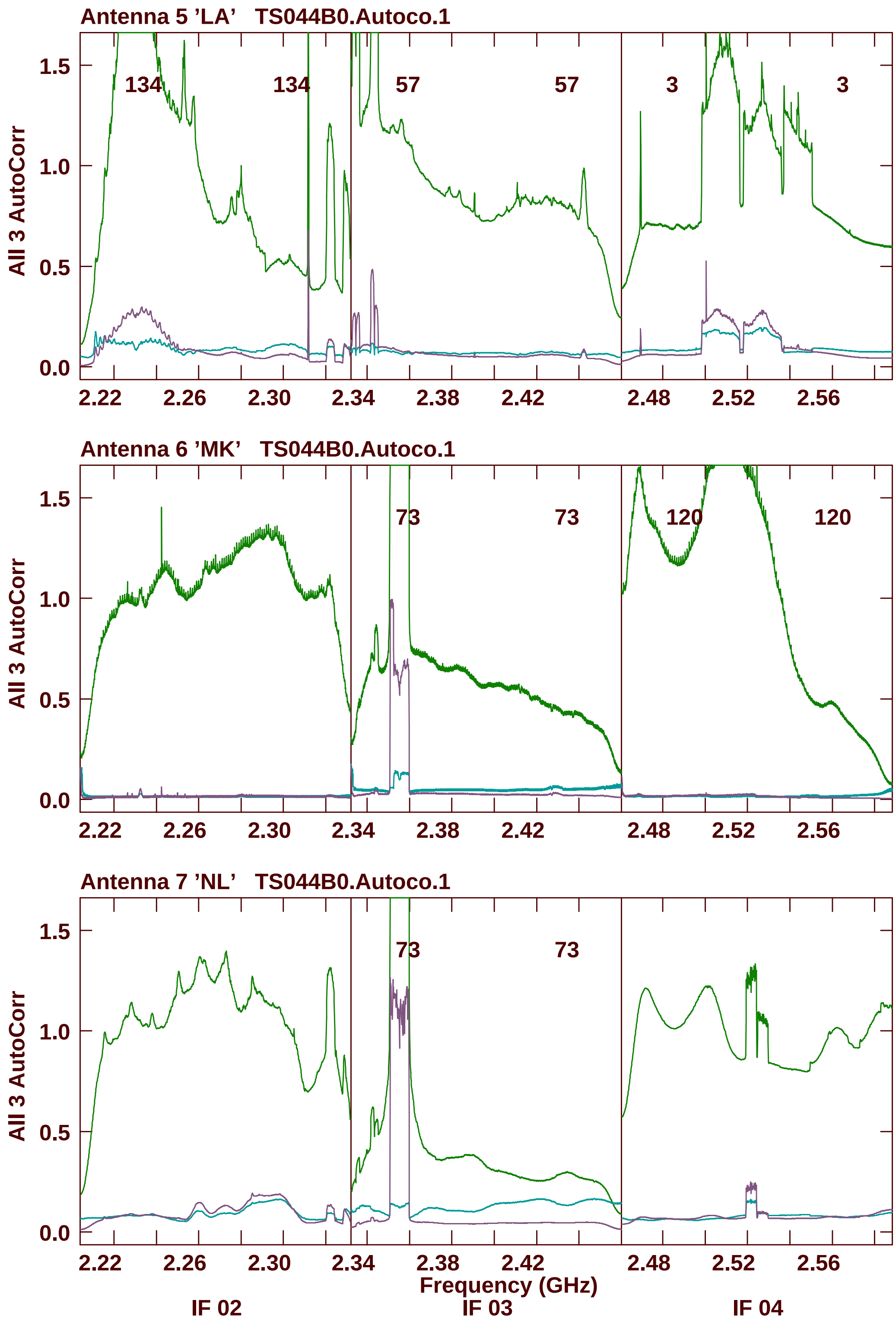

Figure 6: TS044B0 average autocorrelation spectrum of 3C345 for 3 antennas in green. The mean rms/mean in cyan and the rms is purple. The filters have been bypassed. Data points outside the range 0 to 1.6 or so have been omitted.

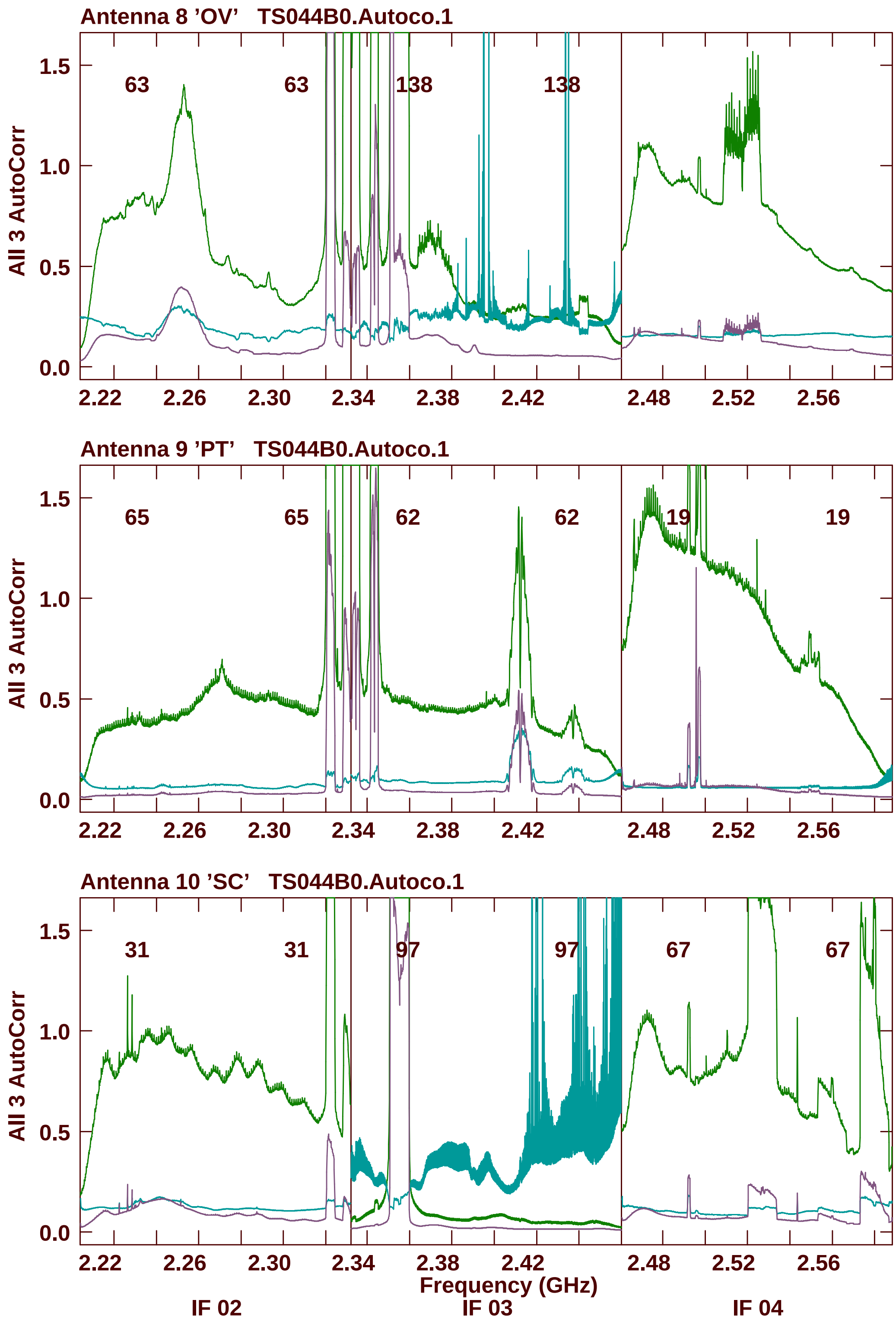

Figure 7: TS044B0 average autocorrelation spectrum of 3C345 for 3 antennas in green. The mean rms/mean in cyan and the rms is purple. The filters have been bypassed. Data points outside the range 0 to 1.6 or so have been omitted.

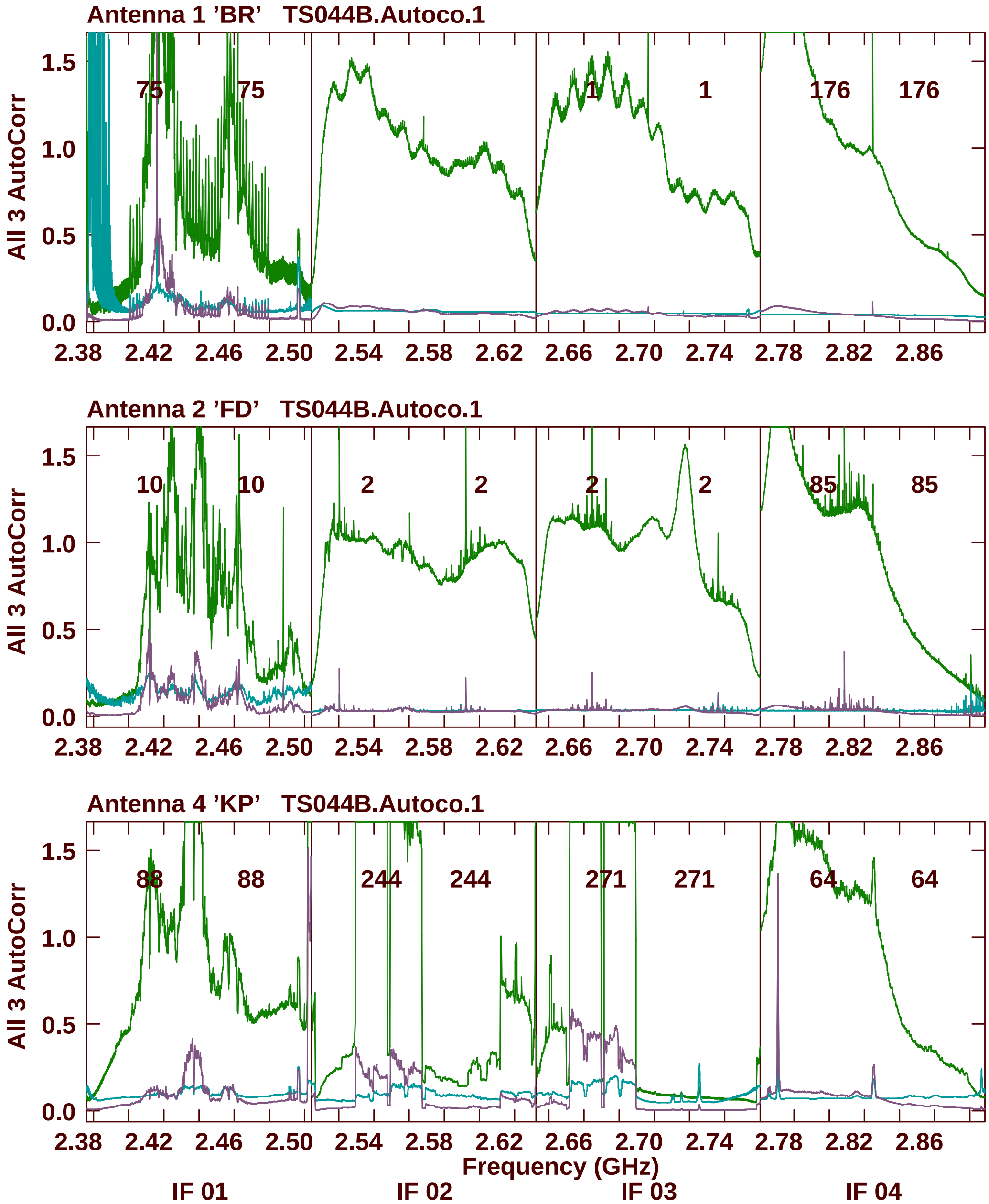

Figure 8: TS044B1 average autocorrelation spectrum of 3C345 for 3 antennas in green. The mean rms/mean in cyan and the rms is purple. The filters have been bypassed. Data points outside the range 0 to 1.6 or so have been omitted.

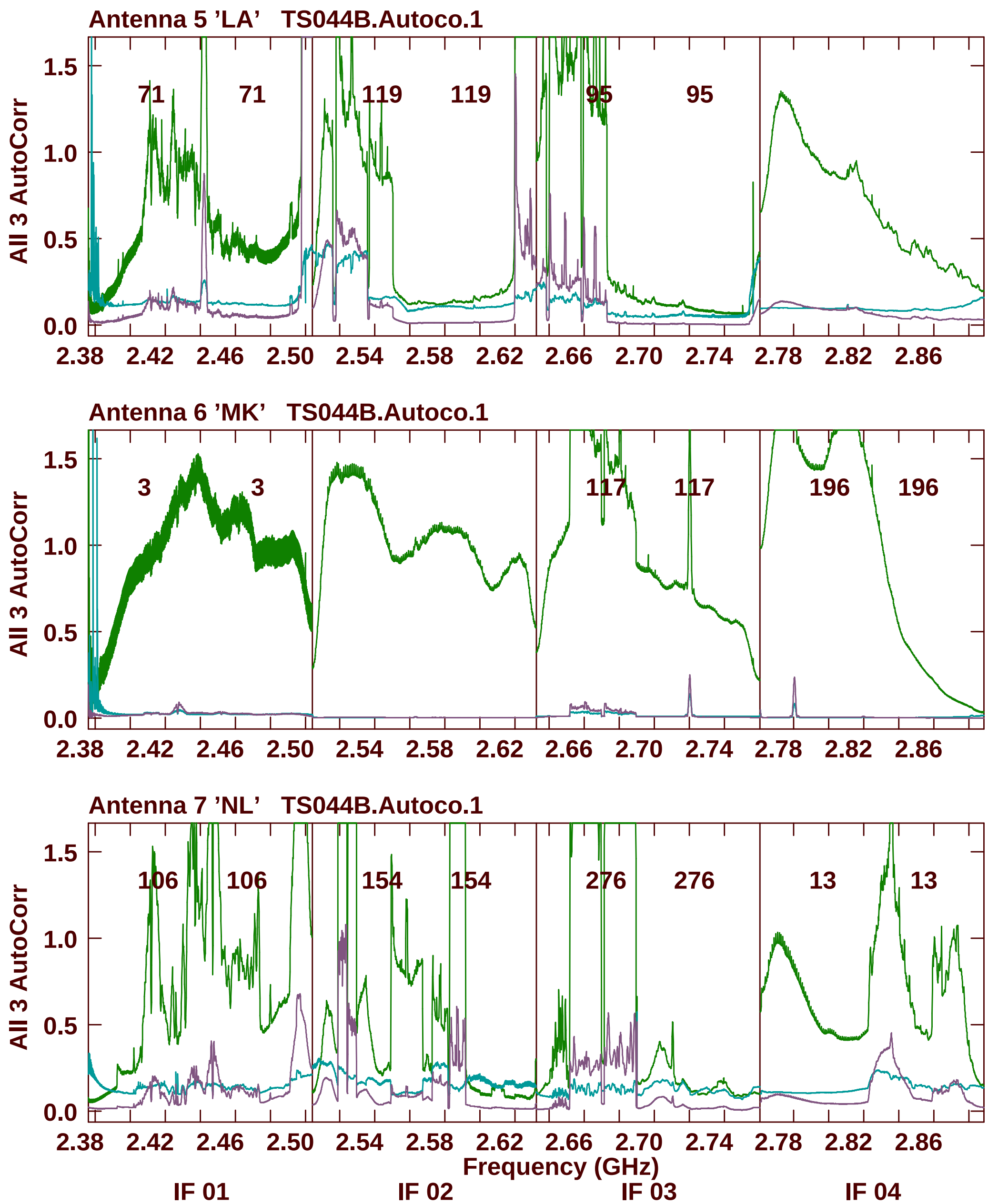

Figure 9: TS044B1 average autocorrelation spectrum of 3C345 for 3 antennas in green. The mean rms/mean in cyan and the rms is purple. The filters have been bypassed. Data points outside the range 0 to 1.6 or so have been omitted.

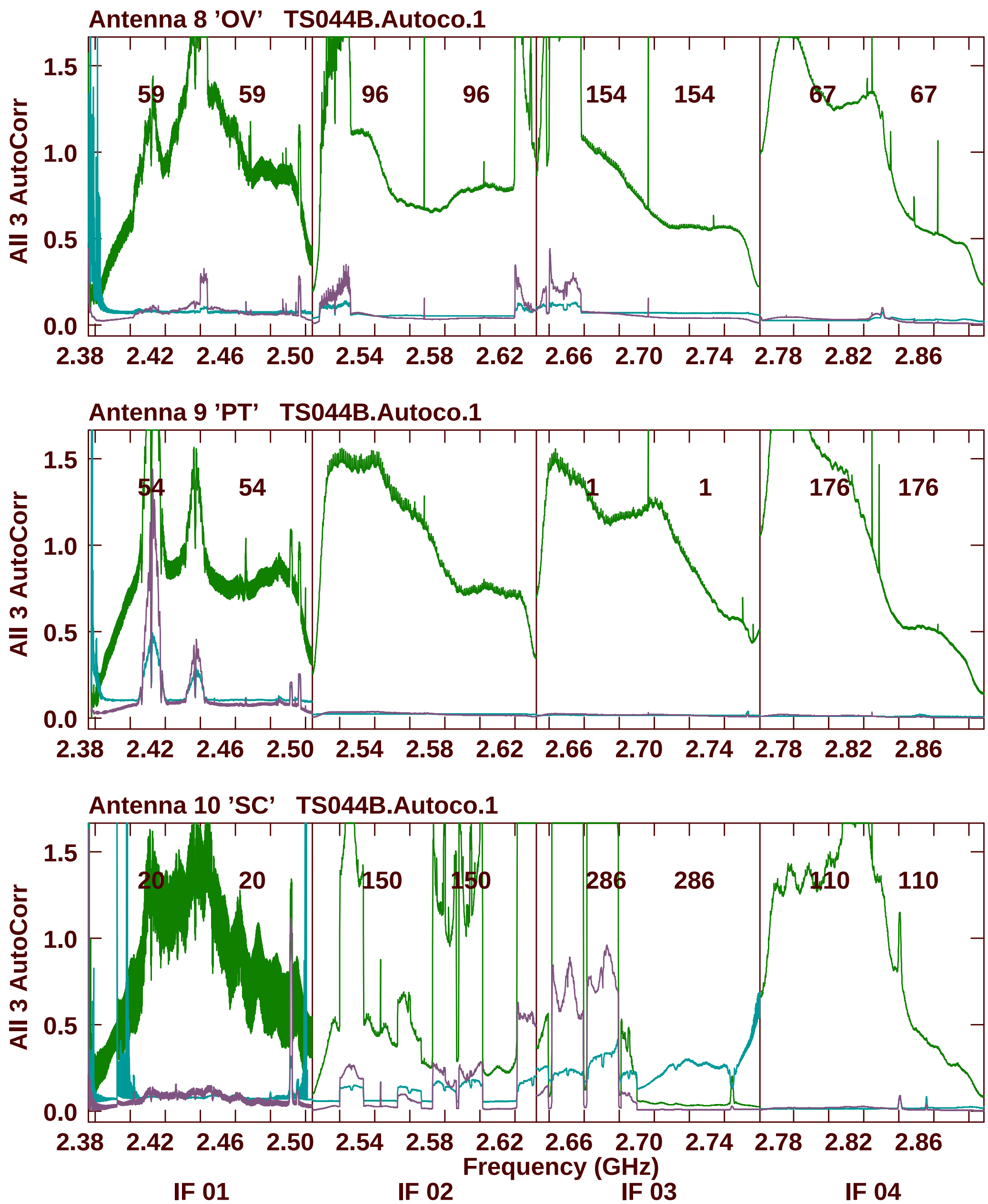

Figure 10: TS044B1 average autocorrelation spectrum of 3C345 for 3 antennas in green. The mean rms/mean in cyan and the rms is purple. The filters have been bypassed. Data points outside the range 0 to 1.6 or so have been omitted.

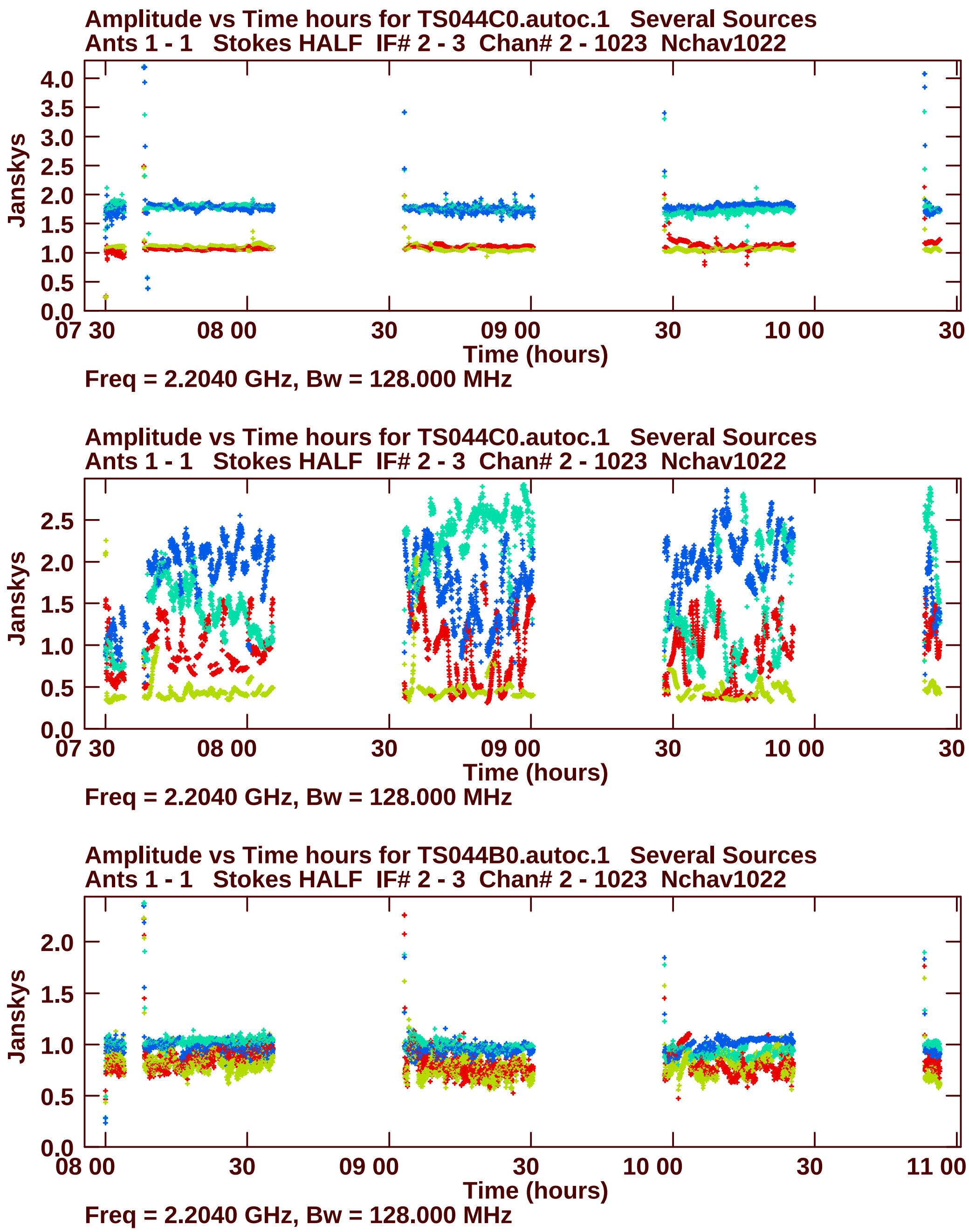

Figure 11: TS044 BR autocorrelation averaged over spectral channels as a function of time for SPWs 2 and 3. Top for C0 data with standard flagging, middle for C0 data with a clip applied to the data, and bottom for B0 data with standard flagging. The red color is SPW 2 R polarization, yellow-green is SPW 2 L polarization, blue-green is SPW 3 R polarization, and blue is SPW 3 L polarization.

Ant	SPW	S	Ngood	Max	Min	Avg	Rms	Median	Madrms	Nblank	Station
1	2	1	134	149.520	21.930	40.890	17.956	37.990	10.438	0	BR
1	2	2	134	71.730	18.870	30.363	8.592	27.530	7.250	0	BR
1	3	1	134	949.510	-3253.350	6.492	334.802	14.210	61.899	0	BR
1	3	2	134	4388.810	-4050.770	17.982	567.254	16.260	53.299	0	BR
1	4	1	134	2355.500	-2154.250	16.764	302.871	23.150	17.361	0	BR
1	4	2	134	293.010	-764.730	10.832	88.453	17.200	10.690	0	BR
2	2	1	134	178.200	31.410	73.354	31.748	62.560	23.069	0	FD
2	2	2	126	511.340	58.780	217.933	102.033	212.980	125.309	8	FD
2	3	1	134	11670.710	-2725.190	291.378	1594.979	79.780	360.168	0	FD
2	3	2	126	3102.470	-48395.520	-577.128	4485.779	45.940	299.159	8	FD
2	4	1	134	9033.990	-1426.790	173.560	814.452	80.730	42.269	0	FD
2	4	2	126	3235.810	-2754.710	83.071	553.547	57.550	34.218	8	FD
4	2	1	134	263.090	64.610	116.520	32.404	111.920	28.244	0	KP
4	2	2	134	293.290	66.220	139.878	44.838	125.670	36.561	0	KP
4	3	1	134	4565.790	-17155.600	15.204	1791.005	229.990	136.429	0	KP
4	3	2	134	26497.609	-6725.880	662.307	2821.418	352.570	821.197	0	KP
4	4	1	134	1147.380	70.110	172.508	116.649	139.130	45.545	0	KP
4	4	2	134	9879.580	68.750	231.289	843.336	139.650	49.296	0	KP
5	2	1	134	1437.070	24.540	54.830	120.703	42.830	12.350	0	LA
5	2	2	134	578.660	30.870	52.711	47.282	45.650	10.215	0	LA
5	3	1	134	208.770	21.500	36.302	17.091	32.190	6.983	0	LA
5	3	2	134	299.060	23.490	43.594	24.324	38.780	6.449	0	LA
5	4	1	134	1982.530	-1624.390	42.842	283.319	44.570	23.188	0	LA
5	4	2	134	735.340	-8216.730	-23.297	773.409	54.340	22.565	0	LA
6	2	1	134	57.060	34.920	44.378	6.139	42.950	7.650	0	MK
6	2	2	134	54.860	35.420	44.443	5.973	43.160	7.710	0	MK
6	3	1	134	98.910	47.710	67.209	9.660	66.260	9.385	0	MK
6	3	2	134	116.130	47.000	63.680	11.599	61.450	9.044	0	MK
6	4	1	134	46.870	31.810	38.491	4.487	37.190	5.041	0	MK
6	4	2	134	45.900	31.160	36.811	4.106	35.720	4.196	0	MK
7	2	1	129	5311.180	58.490	141.717	457.907	95.060	26.687	0	NL
7	2	2	129	206.150	53.550	81.701	21.531	77.380	14.930	0	NL
7	3	1	129	-315.060	-2731.450	-654.798	267.782	-604.790	191.522	0	NL
7	3	2	129	-82.870	-3716.280	-183.445	318.061	-141.000	35.123	0	NL
7	4	1	129	9.412E+05	-2.206E+06	-9.465E+03	2.115E+05	1.459E+03	1.043E+03	0	NL
7	4	2	129	24273.971	-24755.971	347.085	3420.463	287.970	218.224	0	NL
8	2	1	134	85.630	21.180	43.123	15.071	38.250	11.683	0	OV
8	2	2	134	167.050	19.890	55.276	28.049	48.510	18.132	0	OV
8	3	1	134	77989.219	-6256.920	435.466	6795.648	96.350	358.967	0	OV
8	3	2	134	151321.609	-4792.410	1244.146	13031.237	126.960	207.742	0	OV
8	4	1	134	65.270	23.320	33.057	6.562	32.840	5.589	0	OV
8	4	2	134	57.610	11.450	22.001	6.316	22.160	5.975	0	OV
9	2	1	134	174.980	36.200	81.281	31.670	75.950	37.421	0	PT
9	2	2	134	157.330	29.830	81.384	25.983	78.990	23.084	0	PT
9	3	1	134	3278.430	-3838.720	92.725	448.116	67.270	31.431	0	PT
9	3	2	134	209302.609	-211.520	1699.512	18002.785	92.760	39.630	0	PT
9	4	1	134	36.190	18.440	27.555	3.807	27.750	4.729	0	PT
9	4	2	134	44.360	19.370	33.588	4.733	33.840	3.736	0	PT
10	2	1	134	363.820	-11369.390	-8.745	986.713	54.990	20.919	0	SC
10	2	2	134	76.240	27.740	40.509	6.562	39.680	5.263	0	SC
10	3	1	134	1.153E+04	-4.069E+05	-2.578E+03	3.509E+04	3.072E+02	2.158E+02	0	SC
10	3	2	134	1159.400	-9455.390	138.612	845.155	169.360	78.607	0	SC
10	4	1	134	242.360	46.450	78.831	30.995	67.970	20.089	0	SC
10	4	2	134	102.550	29.560	44.000	10.559	39.960	5.575	0	SC

Table 2: `SNRMS` output for `TY` table from TS044B0

Ant	SPW	S	Ngood	Max	Min	Avg	Rms	Median	Madrms	Nblank	Station
1	2	1	134	858.250	-8972.320	256.807	817.623	279.020	138.119	0	BR
1	2	2	134	219.340	48.850	122.502	36.738	117.020	42.521	0	BR
1	3	1	134	3066.900	-4017.100	-12.646	555.631	64.170	130.973	0	BR
1	3	2	134	3072.230	-2171.230	51.719	447.837	55.050	137.215	0	BR
2	2	1	134	155.040	33.180	71.081	26.982	64.610	26.791	0	FD
2	2	2	134	398.580	58.110	207.063	98.281	192.030	129.905	0	FD
2	3	1	134	63321.398	-35854.898	213.902	6346.721	50.810	234.221	0	FD
2	3	2	134	1599.700	-19768.400	-154.944	1739.686	35.900	254.800	0	FD
3	2	1	134	1259.530	60.390	517.712	261.662	519.770	271.390	0	HN
3	2	2	134	566.830	54.780	210.274	126.373	167.730	113.552	0	HN
3	3	1	134	3036.070	30.430	207.468	375.899	120.960	55.212	0	HN
3	3	2	134	1380.710	-1324.480	109.191	213.016	76.850	41.231	0	HN
4	2	1	134	340.360	57.360	133.176	55.835	125.450	54.337	0	KP
4	2	2	134	18426.920	-13701.480	446.198	2555.539	263.510	156.385	0	KP
4	3	1	134	2945.640	-1818.850	170.965	341.562	125.680	46.480	0	KP
4	3	2	134	1373.620	-12993.390	82.259	1147.469	146.220	56.176	0	KP
5	2	1	134	251.050	44.080	101.606	43.139	91.940	31.995	0	LA
5	2	2	134	166.080	58.180	91.181	18.706	90.550	16.175	0	LA
5	3	1	134	246.250	58.580	134.413	47.099	135.370	62.269	0	LA
5	3	2	134	374.590	123.240	222.171	52.320	213.140	49.356	0	LA
6	2	1	134	56.730	33.990	43.455	6.058	42.220	7.502	0	MK
6	2	2	134	78.370	34.400	43.961	6.438	42.610	7.695	0	MK
6	3	1	134	100.410	47.620	64.891	10.775	64.510	11.683	0	MK
6	3	2	134	81.880	46.460	61.541	8.522	61.730	9.963	0	MK
7	2	1	129	578.040	48.530	123.418	82.726	91.690	38.844	0	NL
7	2	2	129	433.880	66.580	140.580	68.928	117.790	38.503	0	NL
7	3	1	129	103812.148	745.970	2426.815	9007.223	1350.320	505.329	0	NL
7	3	2	129	2529.710	172.720	552.088	411.870	408.540	155.910	0	NL
8	2	1	134	415.760	38.440	166.740	87.438	140.150	59.378	0	OV
8	2	2	134	526.390	79.790	219.488	101.978	200.050	79.364	0	OV
8	3	1	134	319.700	36.180	107.028	55.039	92.420	41.201	0	OV
8	3	2	134	2280.170	37.740	145.043	224.392	86.400	46.643	0	OV
9	2	1	134	210.750	33.830	81.703	34.149	76.880	41.394	0	PT
9	2	2	134	174.770	30.560	78.762	26.222	76.890	21.616	0	PT
9	3	1	134	1737.570	34.380	120.139	205.629	65.550	31.313	0	PT
9	3	2	134	3304.940	-2448.060	85.441	372.008	81.430	33.522	0	PT
10	2	1	134	54.640	34.170	42.974	5.148	42.090	5.604	0	SC
10	2	2	134	49.350	31.010	37.238	4.078	37.340	4.685	0	SC
10	3	1	134	631.850	120.140	208.691	72.845	190.030	39.496	0	SC
10	3	2	134	239.270	77.510	122.504	29.861	118.560	24.329	0	SC

Table 3: `SNRMS` output for `TY` table from TS044C0

Ant	SPW	S	Ngood	Max	Min	Avg	Rms	Median	Madrms	Nblank	Station
1	1	1	133	486.390	-103.830	0.117	46.369	-2.870	12.306	0	BR
1	1	2	133	610.600	-104.680	3.400	55.387	2.090	9.652	0	BR
1	2	1	133	3767.160	-339.910	59.209	331.418	23.270	12.587	0	BR
1	2	2	133	79.230	26.420	36.233	5.650	36.270	2.891	0	BR
1	3	1	133	991.730	-938.860	46.752	175.107	19.090	16.590	0	BR
1	3	2	133	37.780	18.930	21.324	2.598	20.840	1.038	0	BR
1	4	1	133	432.940	-390.860	9.410	74.318	9.720	29.860	0	BR
1	4	2	133	1690.350	30.620	84.000	141.653	66.670	16.323	0	BR
2	1	1	133	5980.480	-10983.970	-164.590	1440.362	86.580	327.788	0	FD
2	1	2	133	1527.510	-4977.400	-97.150	818.480	48.920	250.930	0	FD
2	2	1	133	164.950	-36495.988	-225.798	3157.176	47.620	12.899	0	FD
2	2	2	133	425.710	14.150	38.901	39.506	29.980	10.719	0	FD
2	3	1	133	172.070	22.400	46.781	19.138	42.530	7.457	0	FD
2	3	2	133	36.210	14.270	21.946	3.643	21.380	3.158	0	FD
2	4	1	133	425.730	-387.570	94.596	80.573	85.330	28.229	0	FD
2	4	2	133	3303.320	-3933.270	79.580	683.965	76.840	179.825	0	FD
4	1	1	133	460.160	22.890	47.039	40.870	37.660	9.948	0	KP
4	1	2	133	472.200	-674.130	54.074	89.745	44.990	14.455	0	KP
4	2	1	133	5246.000	-1821.400	163.404	823.218	79.030	124.761	0	KP
4	2	2	133	1233.870	-6555.090	-37.150	695.923	56.330	224.036	0	KP
4	3	1	133	22131.510	-5375.670	-32.697	2062.787	-69.330	68.096	0	KP
4	3	2	133	320769.000	-7770.350	2296.783	27742.697	-73.160	48.481	0	KP
4	4	1	133	3777.170	20.660	58.035	324.626	24.520	2.936	0	KP
4	4	2	133	538.900	-576.460	27.812	85.464	26.280	3.336	0	KP
5	1	1	133	338.670	13.070	38.891	41.903	29.630	12.839	0	LA
5	1	2	133	101.640	-100.580	33.567	17.777	30.590	8.792	0	LA
5	2	1	133	38.290	7.630	14.814	7.083	12.130	3.959	0	LA
5	2	2	133	55.820	10.080	18.136	7.467	16.780	6.049	0	LA
5	3	1	133	25.680	7.170	9.077	1.878	8.750	1.379	0	LA
5	3	2	133	32.760	8.900	11.851	2.466	11.730	2.254	0	LA
5	4	1	133	61.450	9.480	18.865	11.363	14.560	5.041	0	LA
5	4	2	133	205.700	11.500	31.362	24.284	26.270	17.406	0	LA
6	1	1	133	106.720	55.830	61.718	7.424	59.520	3.425	0	MK
6	1	2	133	70.330	41.530	46.813	3.984	45.160	2.713	0	MK
6	2	1	133	41.160	28.770	33.076	3.359	32.310	4.107	0	MK
6	2	2	133	43.130	30.920	35.173	3.259	34.580	4.151	0	MK
6	3	1	133	48.090	32.600	37.725	4.078	36.640	4.077	0	MK
6	3	2	133	45.510	30.930	36.214	3.869	35.380	4.359	0	MK
6	4	1	133	47.190	33.720	38.280	3.772	37.050	3.914	0	MK
6	4	2	133	47.840	34.310	39.390	3.825	38.190	4.107	0	MK
7	1	1	133	2871.330	194.420	425.436	362.693	324.830	71.565	0	NL
7	1	2	133	270.800	27.710	62.329	27.534	56.170	11.624	0	NL
7	2	1	133	334.280	115.230	175.241	40.760	170.170	42.684	0	NL
7	2	2	133	156.020	25.710	42.291	16.847	38.380	8.406	0	NL
7	3	1	133	142.840	82.720	99.039	11.769	95.900	9.251	0	NL
7	3	2	133	43.370	21.820	25.830	2.853	25.330	2.224	0	NL
7	4	1	133	13963.790	-2040.290	465.708	1412.190	255.310	99.646	0	NL
7	4	2	133	194.140	-1670.810	12.871	147.523	22.610	3.025	0	NL

Table 4: `SNRMS` output for `TY` table from TS044B1

Ant	SPW	S	Ngood	Max	Min	Avg	Rms	Median	Madrms	Nblank	Station
8	1	1	133	405.390	-356.610	111.281	52.678	107.960	5.323	0	OV
8	1	2	133	131.980	-462.000	45.360	45.448	46.990	6.390	0	OV
8	2	1	133	486.520	-216.560	128.320	55.566	125.970	25.782	0	OV
8	2	2	133	43.670	19.080	29.529	4.580	29.140	3.899	0	OV
8	3	1	133	1035.300	-172.110	115.839	114.352	106.640	31.238	0	OV
8	3	2	133	32.210	17.750	21.841	2.484	21.510	1.883	0	OV
8	4	1	133	1358.400	-244.790	1176.833	218.202	1222.240	72.410	0	OV
8	4	2	133	124.890	54.650	86.811	8.252	86.200	7.057	0	OV
9	1	1	133	3281.230	-4416.040	17.362	594.042	48.900	18.903	0	PT
9	1	2	133	6780.890	-139.390	97.535	582.616	41.090	9.415	0	PT
9	2	1	133	25.370	19.910	21.411	1.122	21.400	1.468	0	PT
9	2	2	133	44.360	34.870	37.034	1.664	36.960	2.120	0	PT
9	3	1	133	33.890	24.800	26.281	1.194	26.090	1.201	0	PT
9	3	2	133	43.820	31.380	32.594	1.284	32.460	1.127	0	PT
9	4	1	133	92.260	63.660	86.288	3.530	86.610	2.891	0	PT
9	4	2	133	156.790	105.450	147.410	5.315	147.380	4.300	0	PT
10	1	1	133	165.750	48.150	64.551	11.524	60.450	3.766	0	SC
10	1	2	133	127.570	47.300	56.888	8.000	55.110	2.639	0	SC
10	2	1	133	9465.670	-4807.610	231.671	1197.899	135.640	65.783	0	SC
10	2	2	133	396.880	38.950	104.166	55.061	97.090	45.605	0	SC
10	3	1	133	52194.039	-37766.551	634.646	6072.357	297.210	577.250	0	SC
10	3	2	133	12425.740	-9572.640	65.026	2209.293	164.450	701.018	0	SC
10	4	1	133	47.040	37.360	41.582	1.489	41.230	1.705	0	SC
10	4	2	133	40.010	31.540	35.268	1.348	35.160	1.972	0	SC

Table 5: `SNRMS` output for `TY` table from TS044B1

			TS044B0			TS044C0		
Ant	SPW	S	Mean SNR	rms SNR	Number	Mean SNR	rms SNR	Number
1	1	1				2.7	2.0	15
1	1	2				4.0	2.0	15
1	2	1	41.6	5.7	14	106.4	74.6	7
1	2	2	63.5	10.6	15	113.2	39.7	15
1	3	1	29.3	6.0	13	35.9	26.5	14
1	3	2	50.2	7.1	15	51.9	17.7	15
1	4	1	30.8	4.1	14			
1	4	2	55.7	4.7	15			
2	1	1				47.5	11.7	13
2	1	2				45.8	21.6	7
2	2	1				164.0	31.4	14
2	2	2	138.5	37.0	10	128.8	41.3	5
2	3	1				105.3	15.3	14
2	3	2	90.7	13.3	15	81.9	20.7	9
2	4	1						
2	4	2	111.9	11.2	15			
3	1	1				2.6	1.1	13
3	1	2				3.9	0.8	15
3	2	1				86.1	29.1	10
3	2	2				116.7	12.7	13
3	3	1				31.9	11.6	15
3	3	2				49.0	9.3	14
4	1	1				3.7	0.5	15
4	1	2				3.4	1.2	15
4	2	1	21.9	2.0	15	115.6	20.2	15
4	2	2	62.9	6.7	15	102.9	23.3	10
4	3	1	16.2	3.9	6	43.0	8.4	15
4	3	2				36.3	10.7	15
4	4	1	17.6	2.1	10			
4	4	2	50.7	3.2	15			
5	1	1				4.1	1.5	15
5	1	2				3.9	1.1	15
5	2	1	26.4	3.7	14	135.3	32.4	14
5	2	2	28.4	3.7	15	130.0	36.0	15
5	3	1	23.8	3.0	14	74.5	21.5	14
5	3	2	24.3	2.4	15	59.0	13.6	12
5	4	1	22.6	1.1	3			
5	4	2	25.0	3.1	9			

Table 6: `FRING` SNR ratios for lower frequency SPWs

			TS044B0			TS044C0		
Ant	SPW	S	Mean SNR	rms SNR	Number	Mean SNR	rms SNR	Number
6	1	1	28.3	2.9	15			
6	1	2				27.9	5.5	15
6	2	1	72.6	5.0	15	103.1	30.6	15
6	2	2	84.2	7.8	15	63.5	6.6	15
6	3	1	49.6	4.1	15	69.3	21.1	15
6	3	2	65.9	3.2	15	48.8	6.4	15
6	4	1	49.0	4.2	15			
6	4	2	71.4	2.9	15			
7	1	1				2.8	0.8	15
7	1	2				1.8	0.5	14
7	2	1				87.8	23.0	15
7	2	2				59.7	16.9	15
8	1	1				2.5	0.6	15
8	1	2				3.7	0.7	15
8	2	1	98.9	7.0	15	85.9	22.4	15
8	2	2	72.4	8.0	15	107.2	19.9	15
8	3	1	71.0	11.4	15	40.4	10.0	15
8	3	2	55.4	6.7	13	52.3	9.3	15
8	4	1	83.0	7.2	15			
8	4	2	67.6	5.3	15			
9	1	1	86.5	21.1	10	37.0	7.3	2
9	1	2				54.5	10.5	7
9	2	1	201.0	18.3	15	104.4	26.3	2
9	2	2				135.9	20.5	8
9	3	1	131.0	13.4	15	69.3	15.9	2
9	3	2				86.3	15.0	7
9	4	1	142.3	16.6	15			
9	4	2						
10	1	1				3.5	0.5	15
10	1	2				2.7	0.5	10
10	2	1	41.3	12.6	15	113.0	20.3	15
10	2	2	67.9	8.2	15	83.0	10.7	15
10	3	1	22.4	8.2	8	31.5	7.3	14
10	3	2	30.6	6.1	14	25.8	3.6	15
10	4	1	25.7	6.2	15			
10	4	2	43.9	2.9	15			

Table 7: `FRING` SNR ratios for lower frequency SPWs