VLBA TEST MEMO NO. 27

Frequency Dependence of VLBA System Temperatures and Gains

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Version 1.1   14 December 1991

Abstract

We report measurements of system temperatures and gains across the 90, 50, 20, 13, 6, 4, and 1 cm bands for subsets of VLBA antennas Fort Davis, Kitt Peak, Los Alamos, and Pie Town. Related effects such as the base band converter anomalies, the IF band pass spectrum, and interference are also discussed.

Contents

I. Introduction

Multi-frequency synthesis may be an important technique for improving the (u, v) coverage of VLBA observations (*c.f.* Biretta *et al.* 1992 and Conway *et al.* 1992). The VLBA is especially well suited for this technique, since data can be simultaneously recorded at channels spread over a 500 MHz wide range of frequencies. Also, the single frequency (u, v) coverage has only small gaps, so that a ~10% range in frequencies is sufficient to completely eliminate gaps in the (u, v) coverage. As a prelude to the implementation of such techniques, we have investigated the spectral response and frequency limitations of the VLBA system.

The following section describes the measurement and analysis procedures in general terms. Details of the observations at each band, and the resulting T_{sys} and gain spectra, are presented in section III. Section IV summarizes the bandpass limits and features in tabular form. Finally, Section V discusses the results in terms multi-frequency synthesis, and summarizes possible problems discovered with the VLBA systems.

II. Measurements and Analyses

Measurements of system and antenna temperatures were made for standard flux calibrators at a wide range of frequencies spanning the nominal band pass of each RF system. Baars *et al.* (1977) calibrator sources were used, along with 3C84 (whose flux was determined against Baars calibrators within a few weeks of the measurements). The flux of 3C274 was corrected for source resolution using data from the US VLBI Network Handbook.

Each observation consisted of a sequence of pointings on source and at offsets ±1 and ±6 beam HWHM in azimuth, ±1 and ±2 beam HWHM in elevation. (The command procedures used for this were derived from procedures used by C. Walker for pointing tests.) During this sequence the system power was measured continuously relative to the calibration noise source. These measurements were made for each of the 8 BBC's, which were usually tuned to a range of different frequencies in the 500 - 1000 MHz IF bandpass. (In 1990 most stations had only a few BBC's available, so a single BBC was used for each of the LCP and RCP polarizations. Otherwise the 1990 and 1991 data were taken in the same manner.) The observation pointing sequence was typically repeated three times in rapid succession at a given LO setting, and then the LO setting was changed and the procedure was repeated at the new frequency. Each LO frequency setting was repeated several times, so there were typically six to twelve measurements per sky frequency.

These data were initially analyzed with the program "fitmon" written by C. Walker. For each observation this program computes the off-source system temperature (in °K) using a lookup table of temperatures measured in the laboratory for the calibrator noise sources; there is a separate look-up table for each antenna. Gaussian interpolation is used to estimate the maximum power contributed by the calibrator source from the sequence of pointing offsets. This is then converted to a source temperature, again using the look-up tables for the calibrator noise sources.

The resulting system and source temperatures were then sorted by sky frequency and station using UNIX utilities, and then fed to "bw" program for further analysis. For each station and sky frequency this program computes the mean and standard deviation of the measured temperatures. In cases where there is only a single of measurement the data are discarded. Polynomials describing the calibrator fluxes as a function of frequency are then used to derive the gain in °K/Jy from the source temperature, and finally the system temperatures in units of Jy were computed. In cases where anomalous results could be attributed to poor weather or equipment failure, the anomalous points were edited out by hand and the analysis was repeated. Where anomalous results could be attributed to interference or more permanent equipment properties, the anomalous data were left in place.

The results were then plotted vs. frequency. There are typically four plots per band - station. The first two plots show the system temperatures (in °K) plotted at different scales, the third plot shows the system temperature (in Jy), and the fourth plot shows the gain (in °K/Jy). In each case the LCP data are shown by the filled circles joined by the solid line; RCP data are shown by triangles joined by a dashed line. The plotted points represent the average of the measurements at a given frequency, and the error bar shows the standard deviation about the mean. In many cases the error bar is smaller than the plotting symbols, and cannot be seen.

There are a number of important uncertainties in our results. In analyzing our data we have assumed all the BBC's would, for a given input signal, report the same power. As tests show (see below) this is not the case. Different BBC's gave results varying over a range of up to 12% for a given input signal. At present, we do not know enough about this effect to make reliable corrections for it, and so none have been made. Hence the detailed shape of the temperature and gain curves are probably accurate to only 10% or so.

Another uncertainty is caused by poor knowledge of the calibrator noise source temperatures. Typically the laboratory measurements cover only the VLBA Project Book (1988, "Blue Book") frequency range, while our measurements cover a much broader range. At frequencies outside the range of the lab measurements, we merely used the closest available values for the same RF band. Errors in this extrapolation will effect the system temperatures in units of °K and the gains, but not the system temperatures in Jy.

We have made no effort to correct for gain variations with elevation, other than to discard data from low elevations. A limit of 20° was used at the lowest frequencies, and 40° was used at the highest. It is thought that gain variations should be only a few percent over the remaining elevation range.

The data are incomplete at some wavebands. This is partly because the measurements were made using "spare" telescope time when some antennas were not being used by VLBI observations, and also because of numerous hardware and on-line software failures. These situations made it impossible to obtain data for all wavebands and stations. Nonetheless, we present complete observations for at least one representative station at each waveband.

As a final "uncertainty," the reader is cautioned that our information regarding "bad" sky frequencies and settings is likely to be very incomplete. We have noted problems when they were found. But we have not tested all possible sky frequencies, nor have we tested all possible combinations of LO and BBC settings. It would be advisable to test non-standard frequencies before commencing VLBI observations, especially for frequencies near the ends of the bands.

In section IV. we summarize the important results in brief tabular form. We give frequency limits for several increases in the system temperature (in Jy) above the nominal value at band center. The narrowest limits (40% system temperature increase) are probably appropriate to multi-frequency synthesis observations. (A lower limit might be desirable, but the measurement uncertainties would begin to have a large impact.) The widest limits (10x increase in system temperature) might be appropriate to situations where a certain frequency must be used (*e.g.* spectral line observations). These limits are frequency ranges where all stations give performance equal to, or better than, the specification.

III. Results

Base Band Converter Consistency Test

For the 1991 measurements we used all eight base band converters (BBC's), each being tuned to a different frequency. Hence it is important to consider whether the BBC's give identical outputs when given identical inputs (*i.e.* whether some BBC's might give incorrect power measurements which would contribute artifacts to the measured response curves). We tested for consistent results among the different BBC's by measuring system temperatures when all BBC's were simultaneously set to the same frequency. This test was done at 328 MHz (FD, KP, PT), 610 MHz (KP, PT), 1651 MHz (FD), 2242 MHz (FD, PT), and 8309 MHz (FD, KP, LA, PT).

The system temperatures (°K) derived from the different BBC's typically covered a range of about 5%, with some measurements giving ranges as large as 12%. Fort Davis always showed the largest inconsistencies among the different BBC's; some frequencies gave ranges as large as 12%, while a range of 8% was more typical. Kitt Peak was slightly better; its BBC's gave ranges of values up to 10%, with 4% being typical. Los Alamos and Pie Town were better with the largest range of 5%, and 4% being typical. These effects may be caused by non-linearities in the BBC power meters. They might also be caused by differences in the shape the BBC bandpasses interacting with the spectrum of the incoming signals, but the effect is probably too large to be explained by this. We have not attempted to correct for these effects, since they are poorly understood. Because of these inconsistencies among the different BBC's, the detailed shape of the spectra we report are probably accurate only to about 10%. This effect must be studied further, if the VLBA is to give system temperatures accurate to better than 10%. (We note that derived values of T_{sys}(Jy) show nearly identical ranges of variation. Though, BBC's giving the highest T_{sys}(°K) values were not necessarily those giving the highest T_{sys}(Jy).)

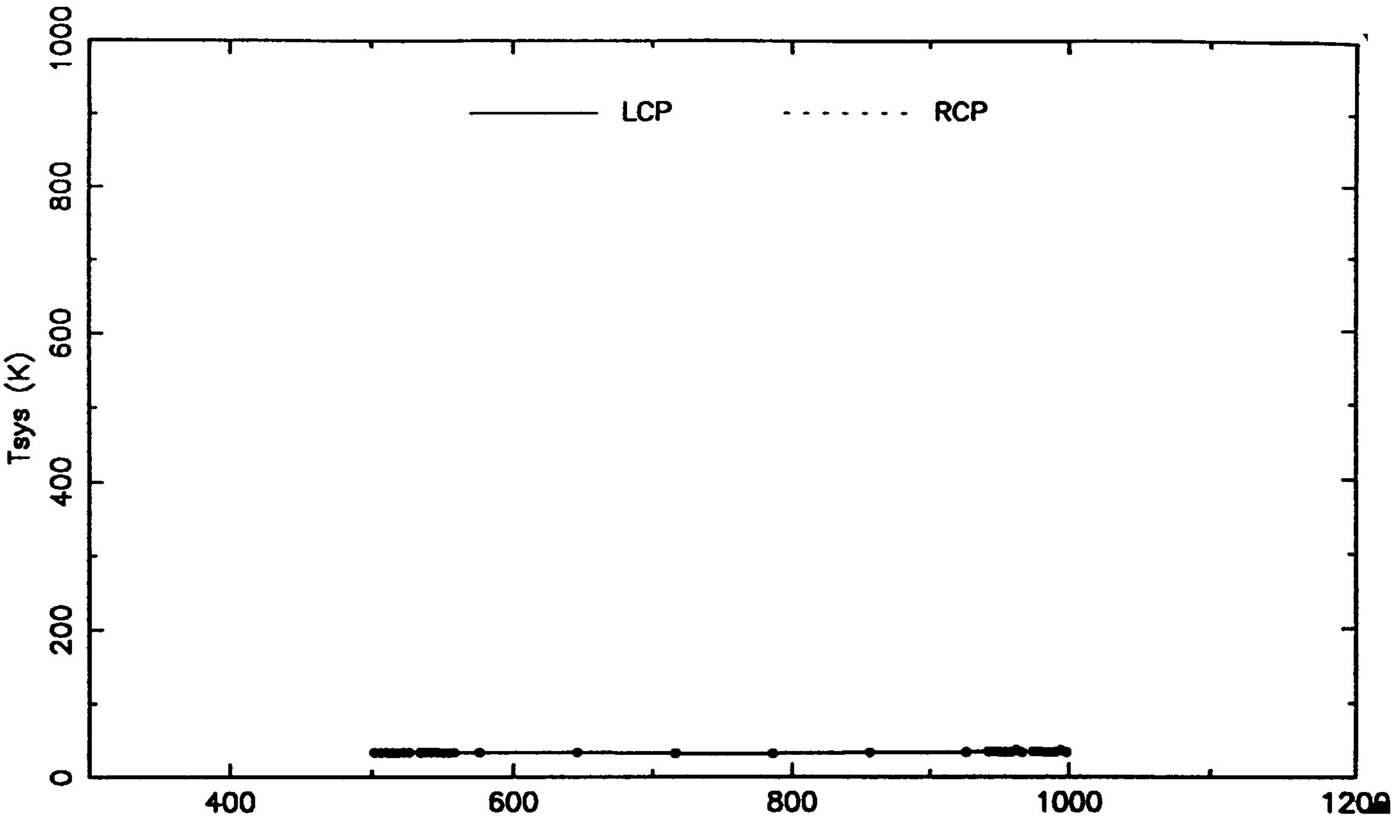
IF (500 - 1000 MHz) Bandpass

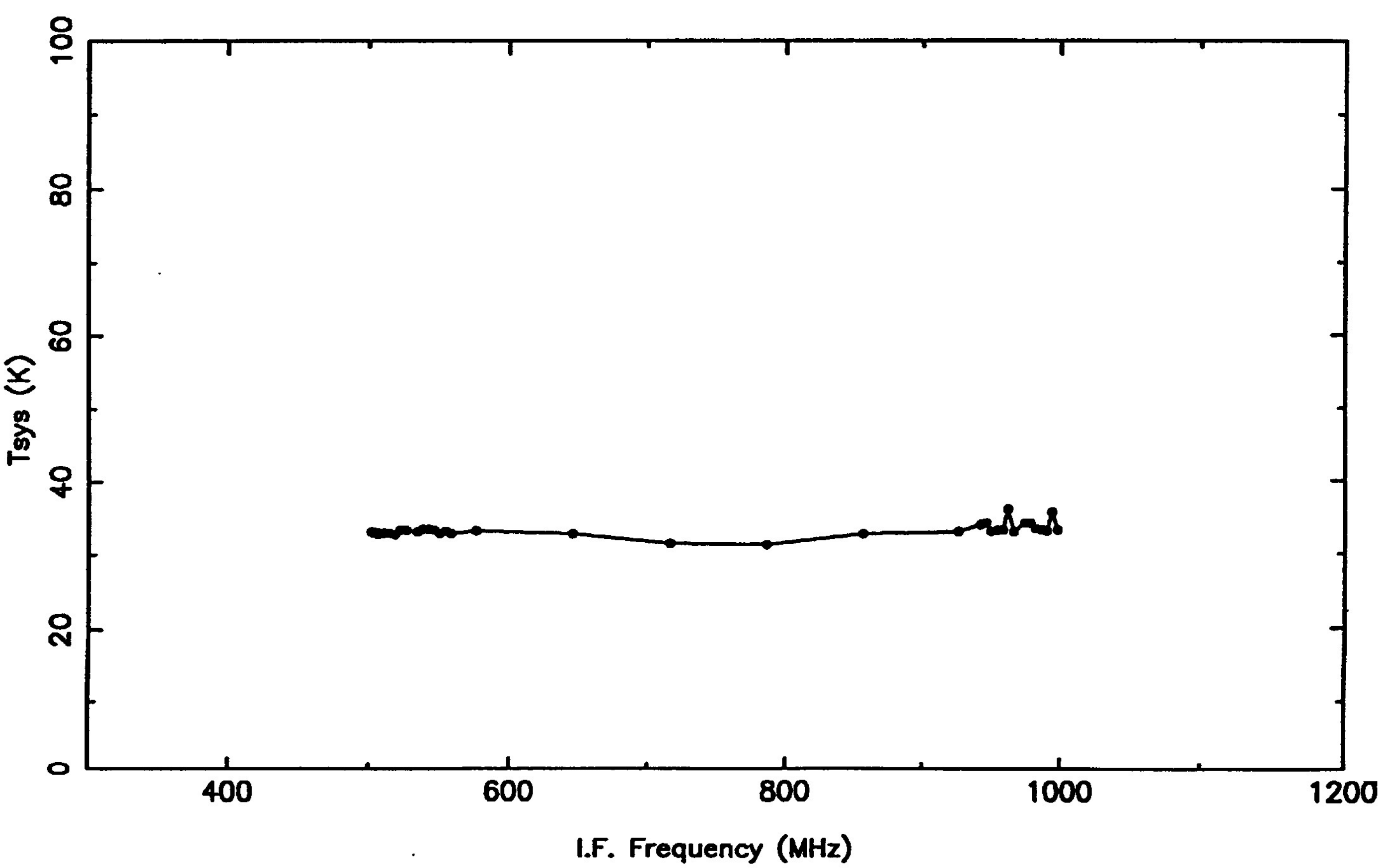
It is interesting to ask whether the IF filters contribute their own spectral effects to the RF spectra we are attempting to measure, and whether it is possible to tune the BBC's to frequencies outside the nominal 500 - 1000 MHz range.

This was tested by setting the LO to a single frequency (7.6 GHz), and observing the system temperature as the BBC's were tuned from 308 to 1192 MHz. We chose X band for this test, since the RF system temperature spectrum appeared to be extremely flat. The test was successfully completed only at Kitt Peak in LCP with the ellipsoid retracted. We used 4 MHz bands on source 3C274 at elevations $> 20°$.

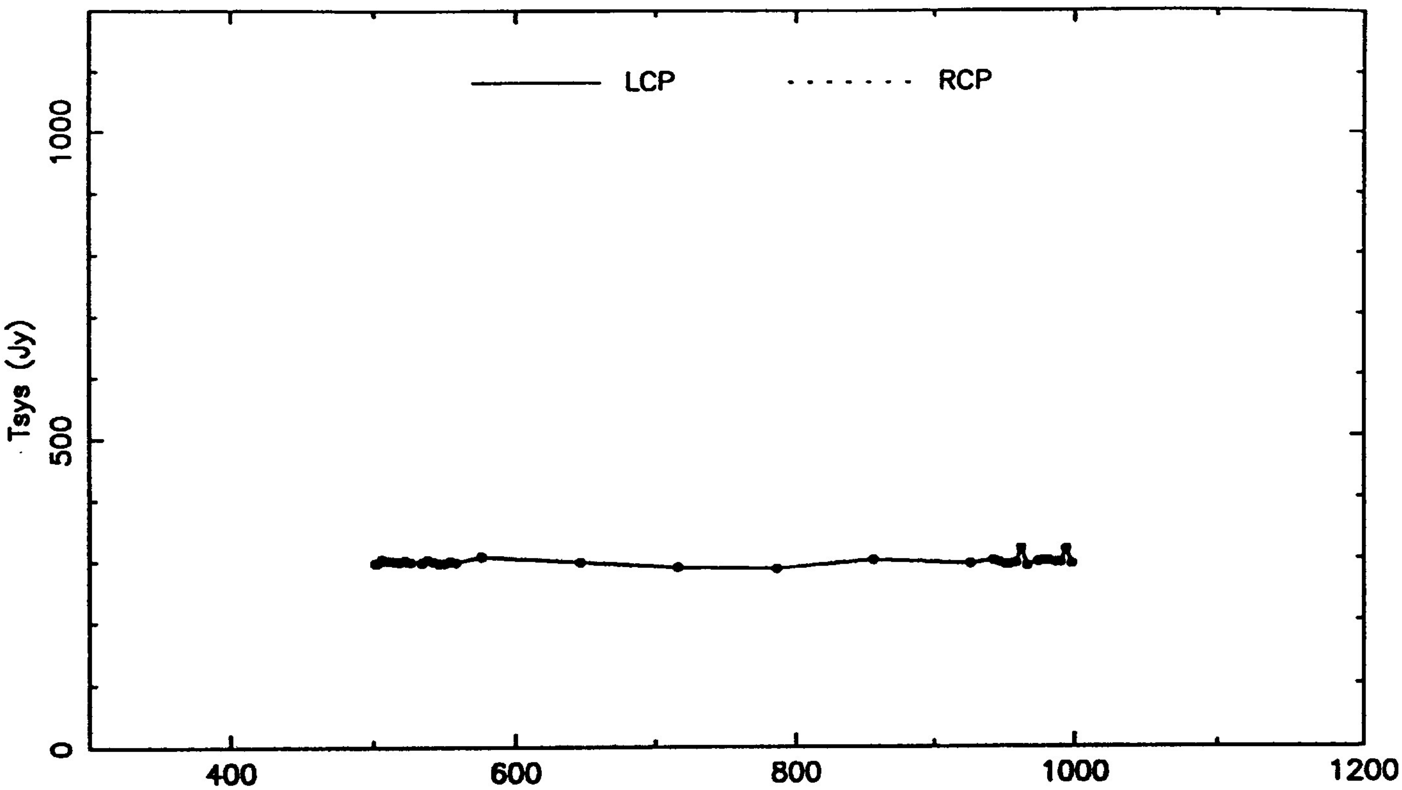
The shape of the 500 - 1000 MHz IF bandpass appears to be extremely flat. There is no evidence of any "turn up" at the ends of the nominal bands. We attribute the small fluctuations which are visible to inconsistencies among the different BBC's. We were unable to tune the BBC's to frequencies outside the range 500 - 1000 MHz; this appears to be caused by limits set in the on-line software. We also note that the SCHED scheduling program does not allow values outside the range 500.00 to 999.99 MHz (*i.e.* 1000.00 MHz cannot be scheduled).

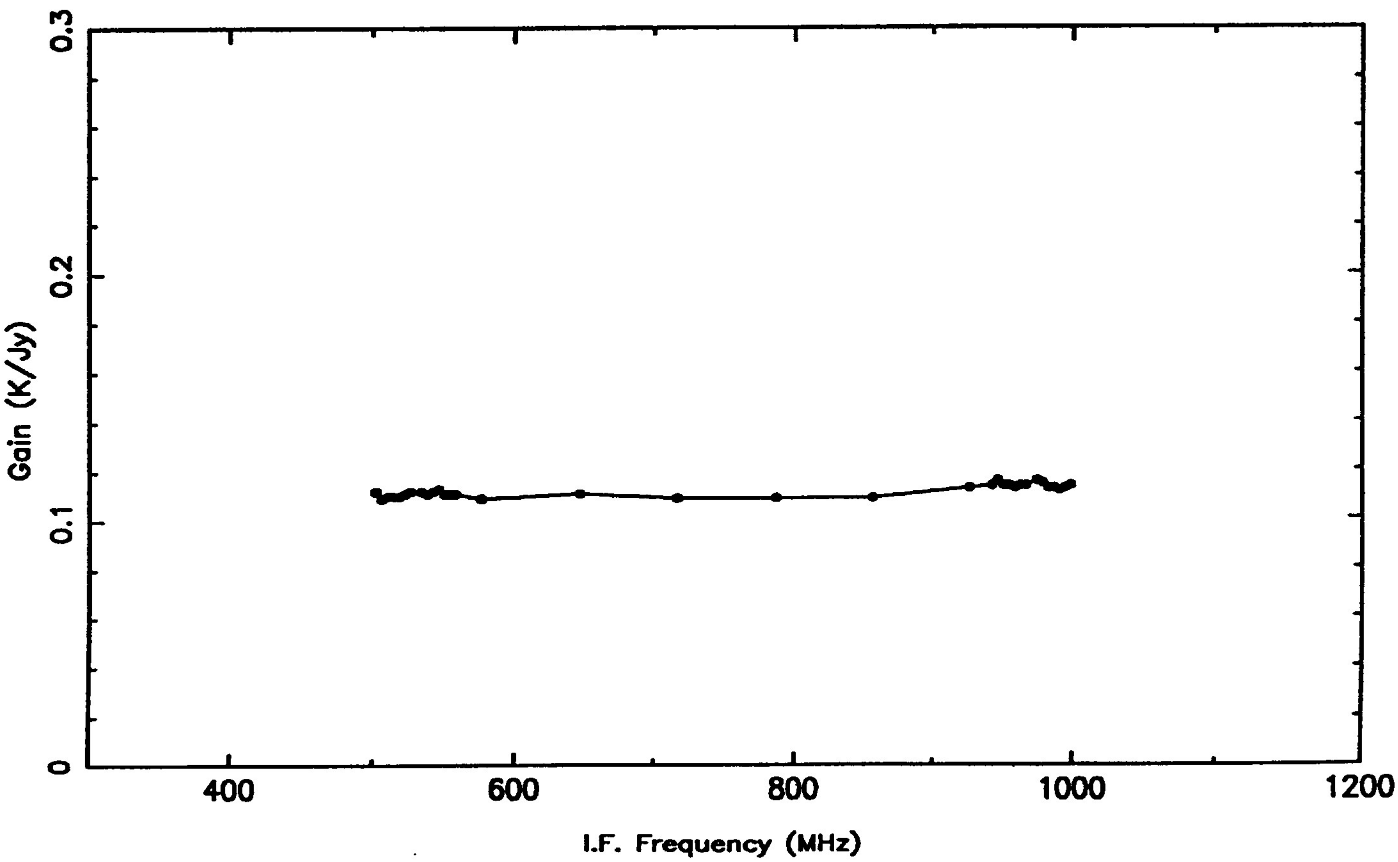
Kitt Peak X Band 500 – 1000 MHz I.F. Test





Kitt Peak X Band 500 – 1000 MHz I.F. Test





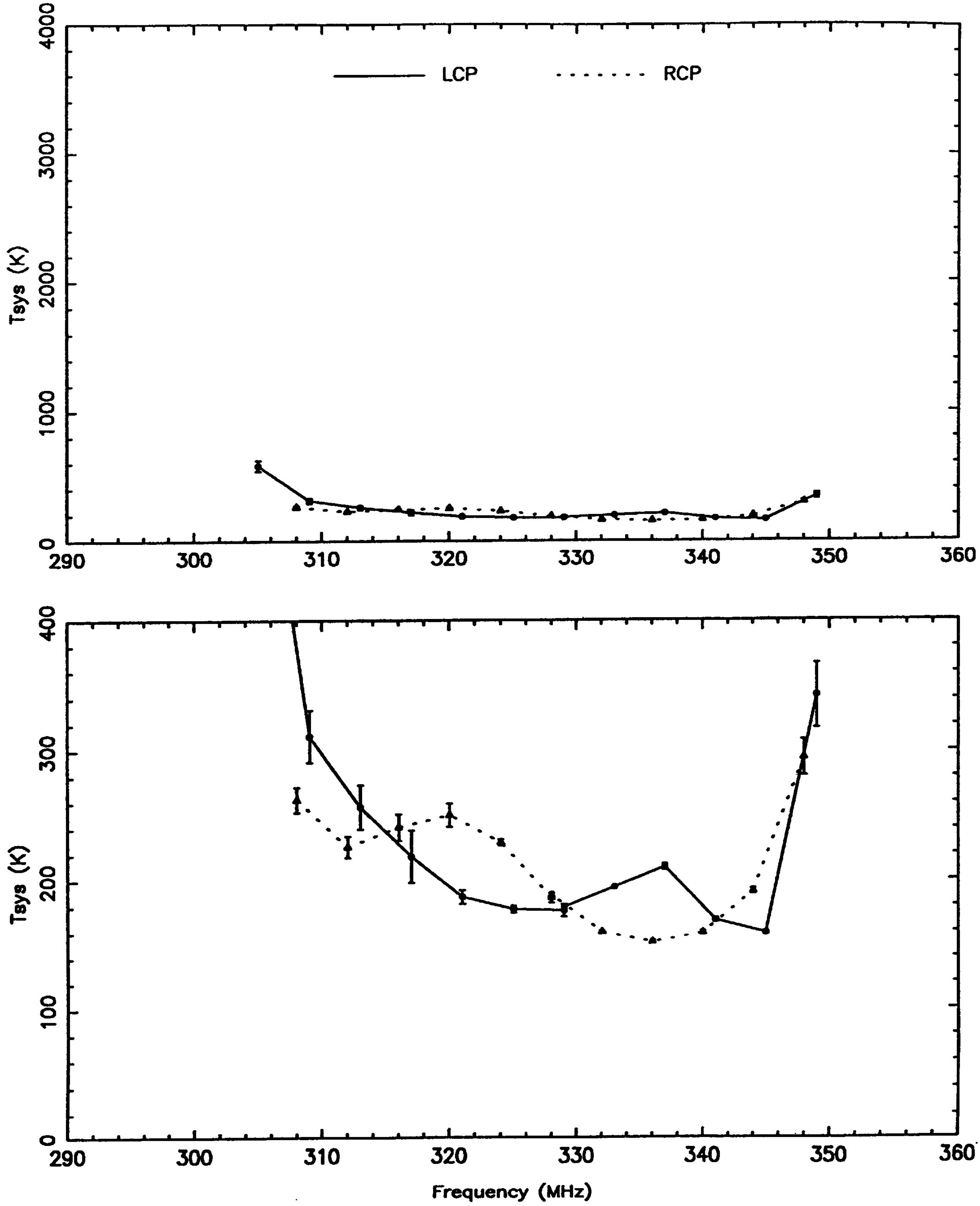
P Band

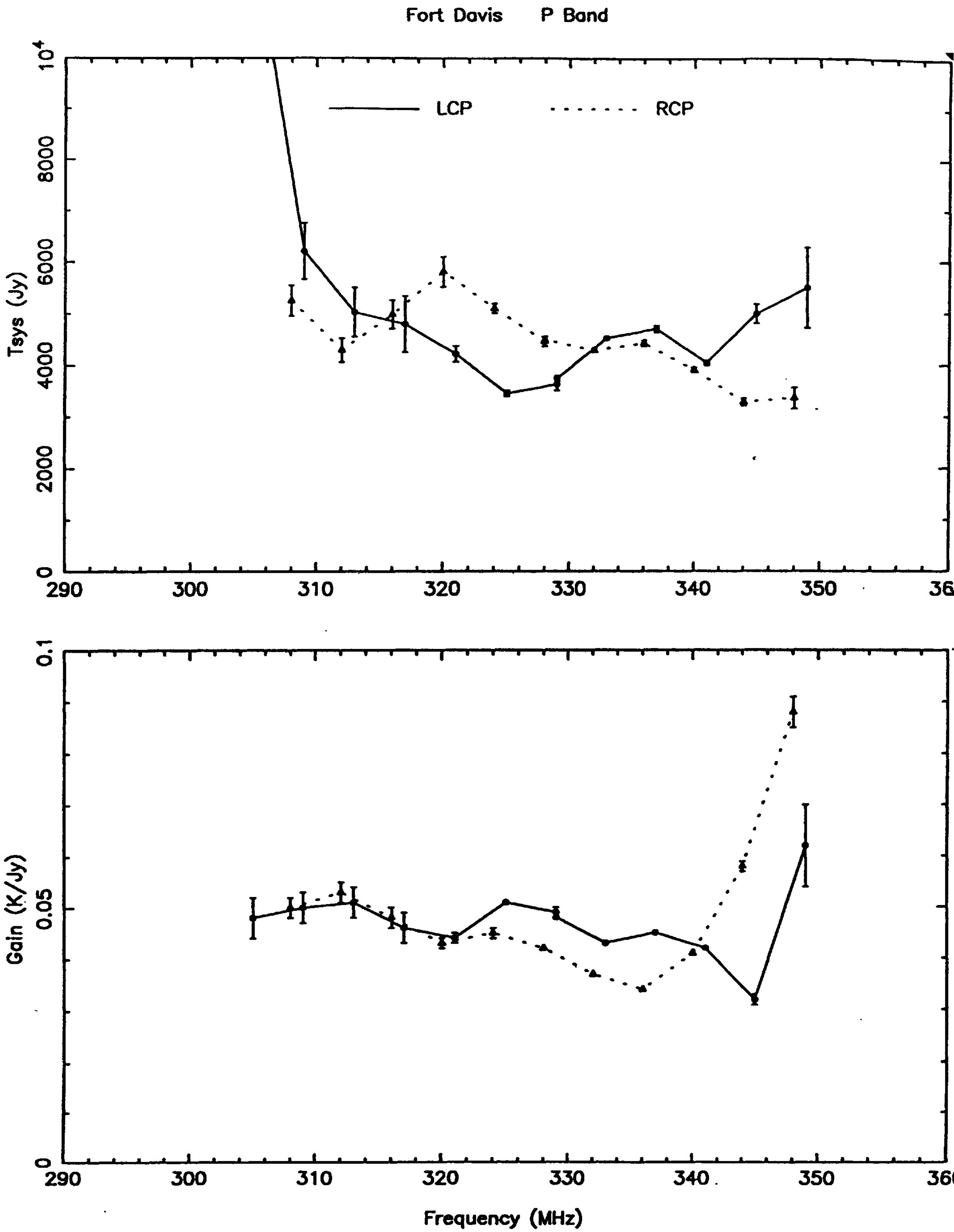
Data were taken at Fort Davis, Kitt Peak, and Pie Town in October 1991. Measurements were made between 290 and 380 MHz with 4 MHz channels. The source Tau A was used at elevations > 20°. The RCP and LCP data were observed at slightly different frequencies for clarity in the final plots.

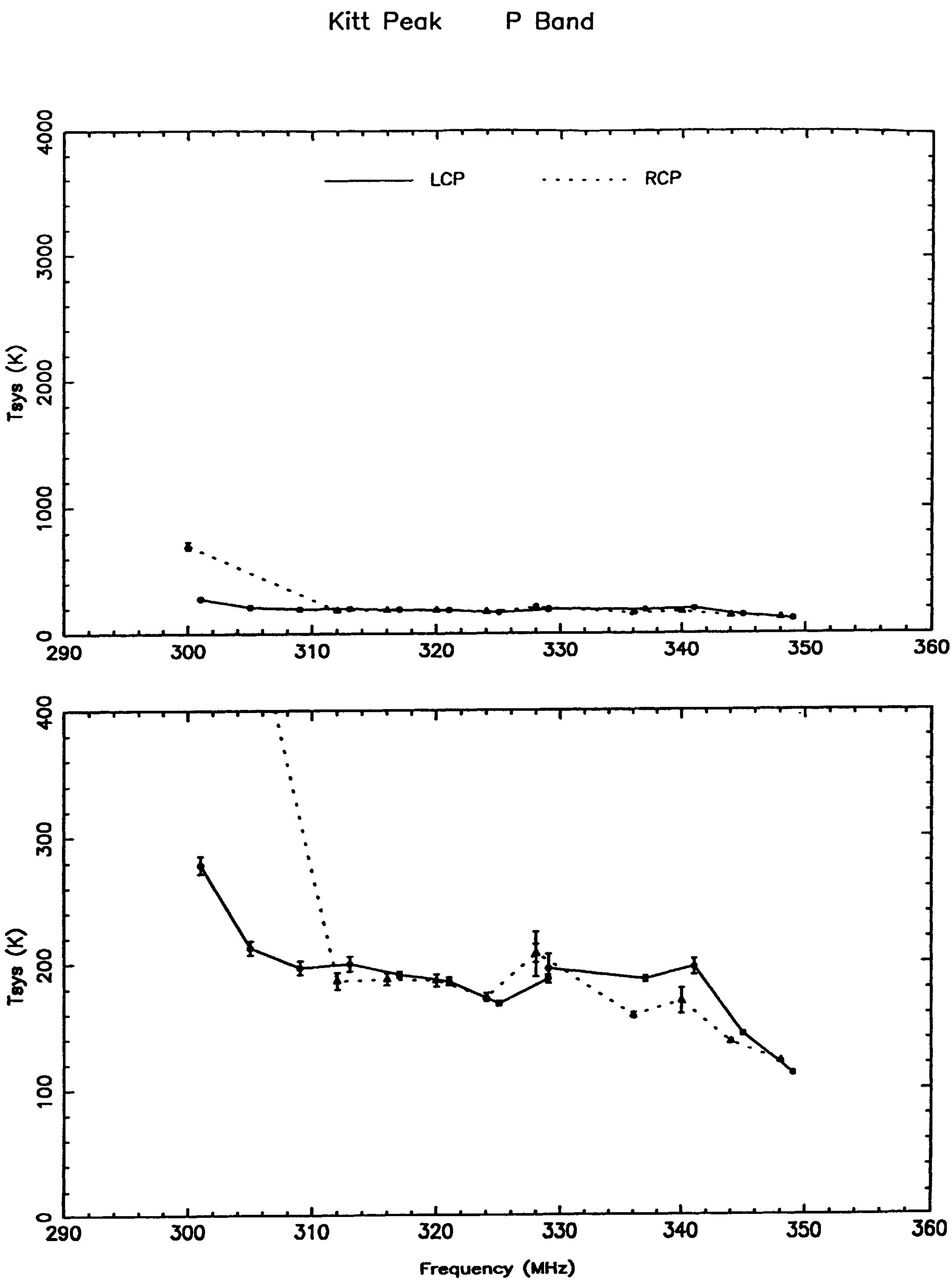
The lower frequency limit appears to be about 308 MHz; below this frequency the system temperature is more than twice the nominal value near the band center. The upper limit is 350 MHz; all observations above this frequency failed. This upper frequency limit appears to be caused by the on-line software, rather than a sudden increase in system temperature.

Fort Davis shows an increase in both T_{sys}(°K) and gain above 345 MHz, but not in T_{sys}(Jy). This may be caused by a weakening of the calibration signal at these frequencies. All observations for Kitt Peak at 332 and 333 MHz failed, suggesting a strong source of interference between 331 and 334 MHz. Similarly, most Kitt Peak RCP observations at 304 and 308 MHz failed, suggesting intermittent interference between 302 and 310 MHz. The missing data for Pie Town RCP at 313 and 345 MHz are caused by an intermittent failure in BBC#6.

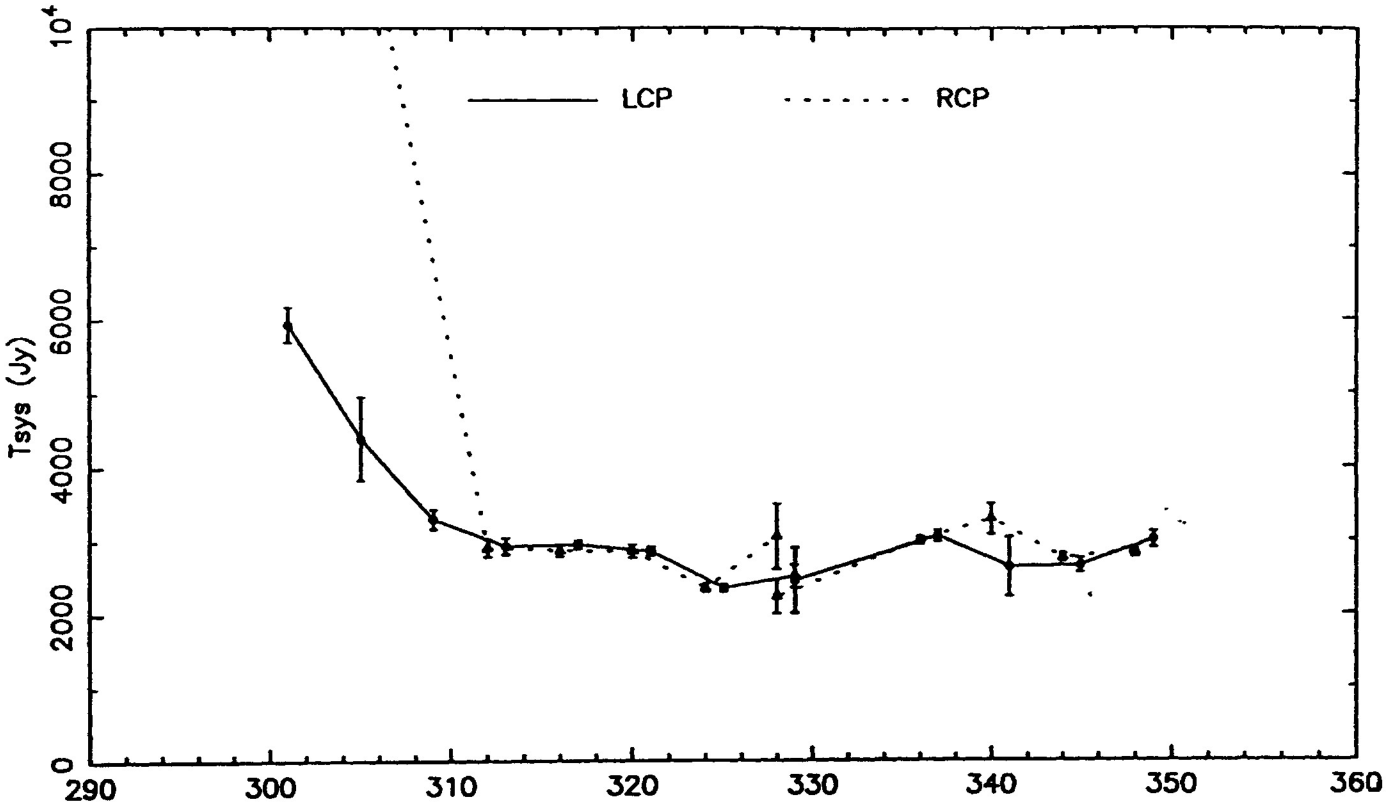
Fort Davis P Band

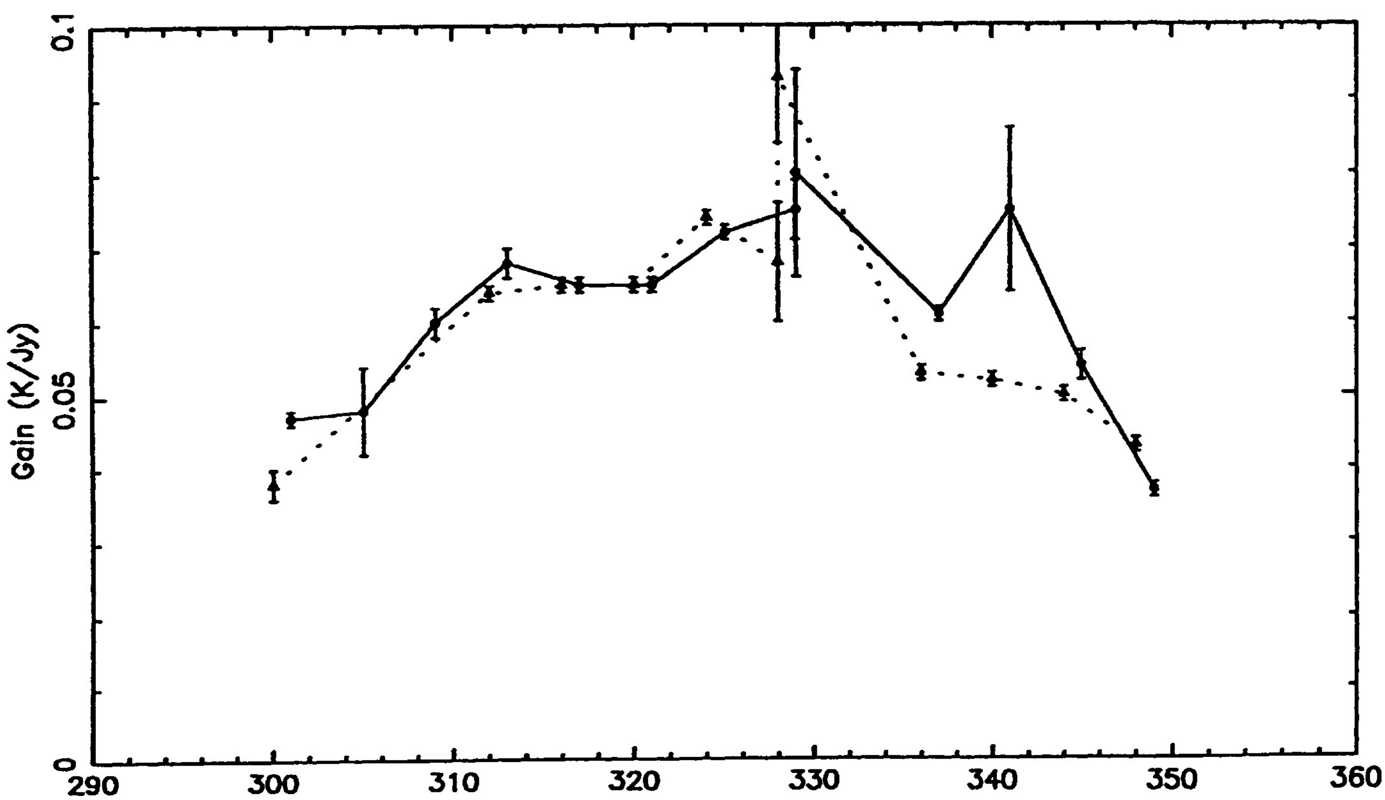



Fort Davis P Band
LCP
RCP
Tsys (Jy)
10^4
8000
6000
4000
2000
0
290
300
310
320
330
340
350
360
Gain (K/Jy)
0.1
0.05
0
Frequency (MHz)

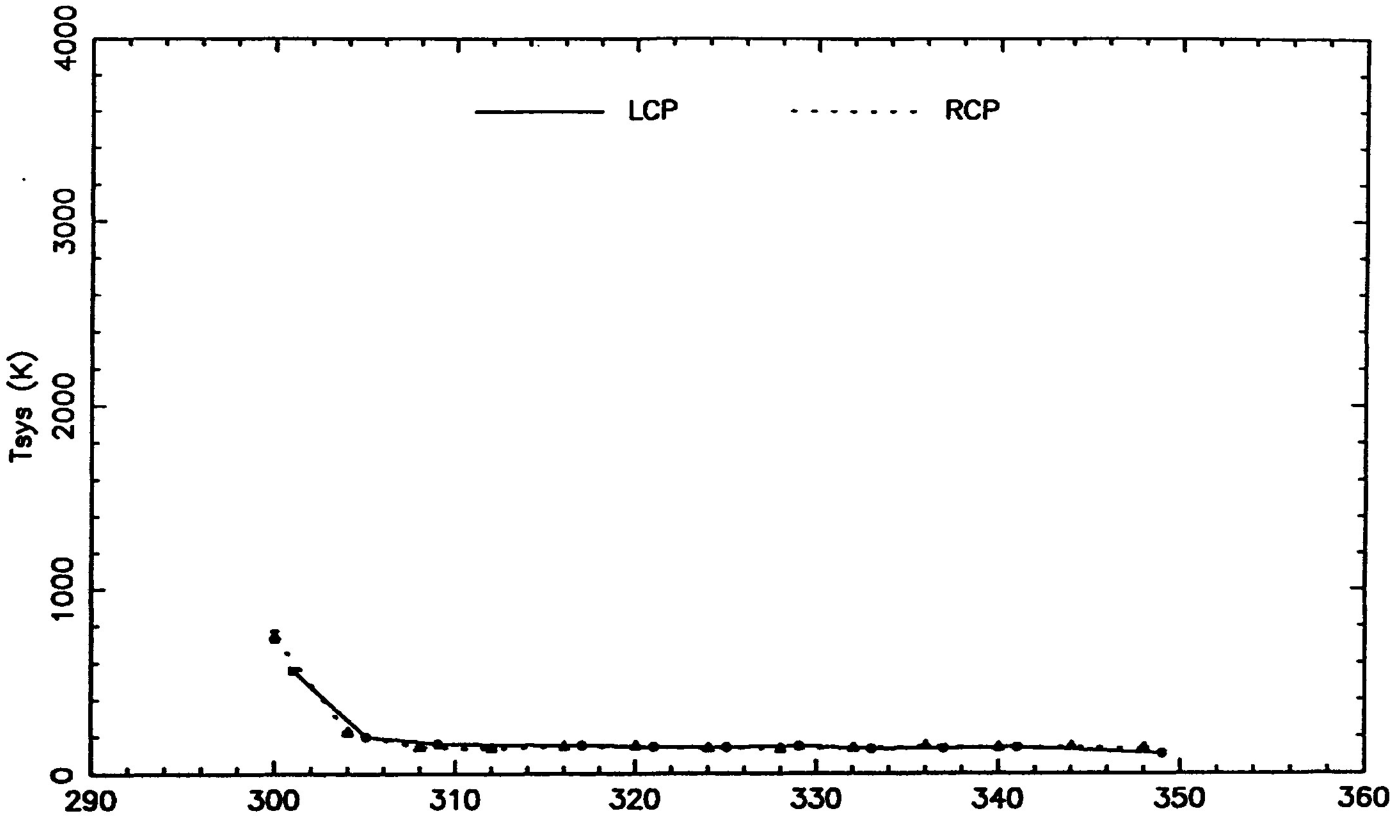

Kitt Peak P Band
LCP
RCP
Tsys (K)
0
1000
2000
3000
4000
290
300
310
320
330
340
350
360
Tsys (K)
0
100
200
300
400
290
300
310
320
330
340
350
360
Frequency (MHz)

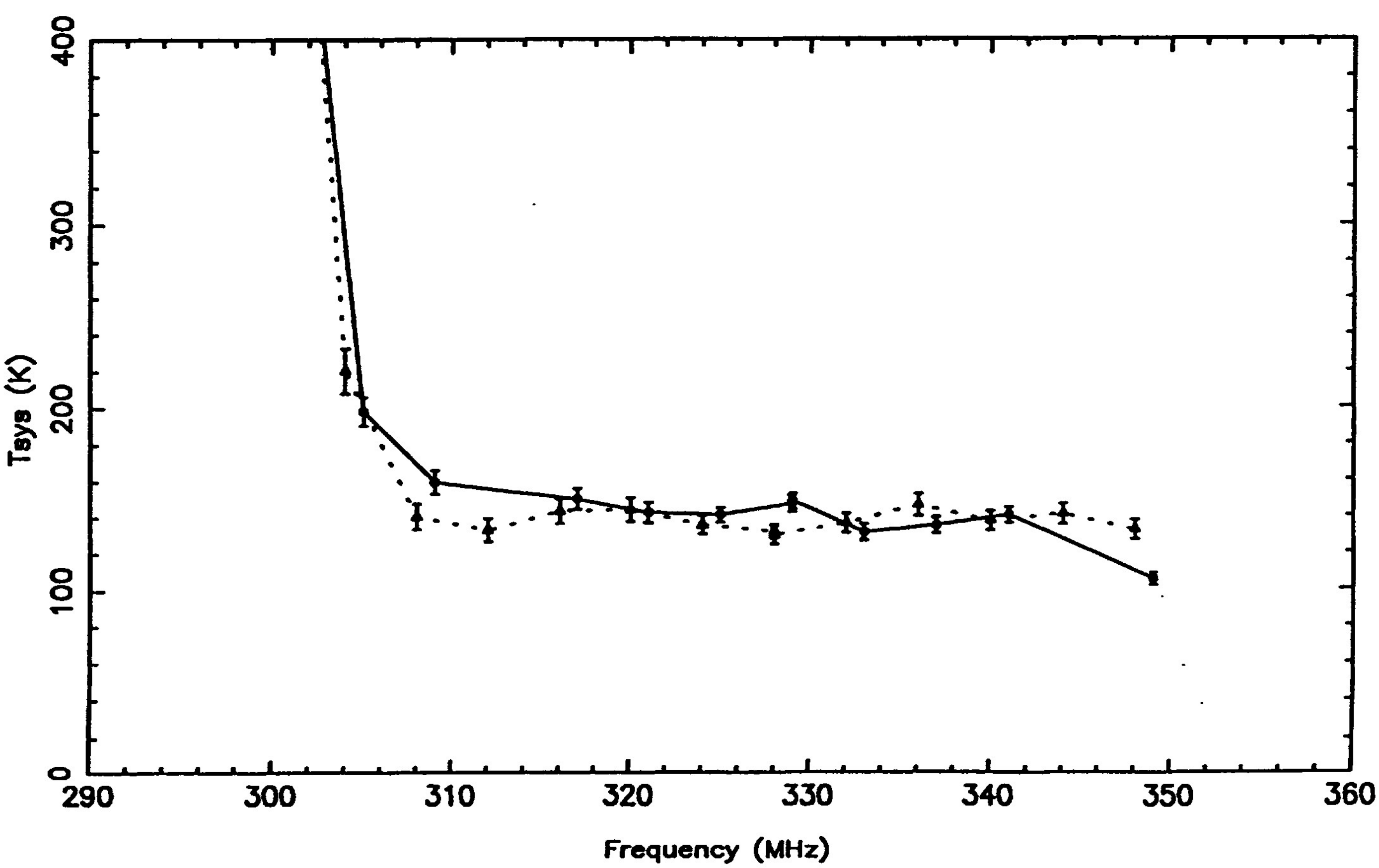
Kitt Peak P Band



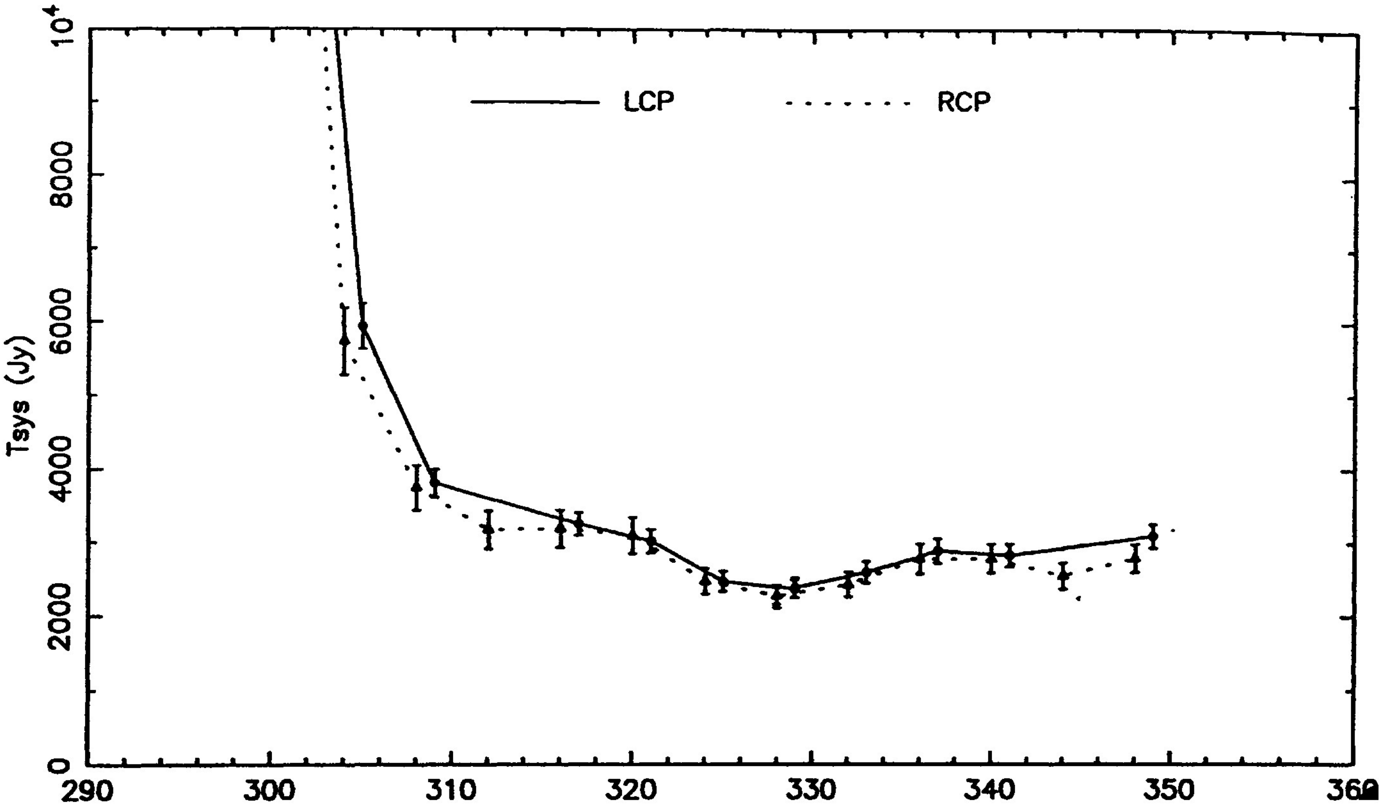


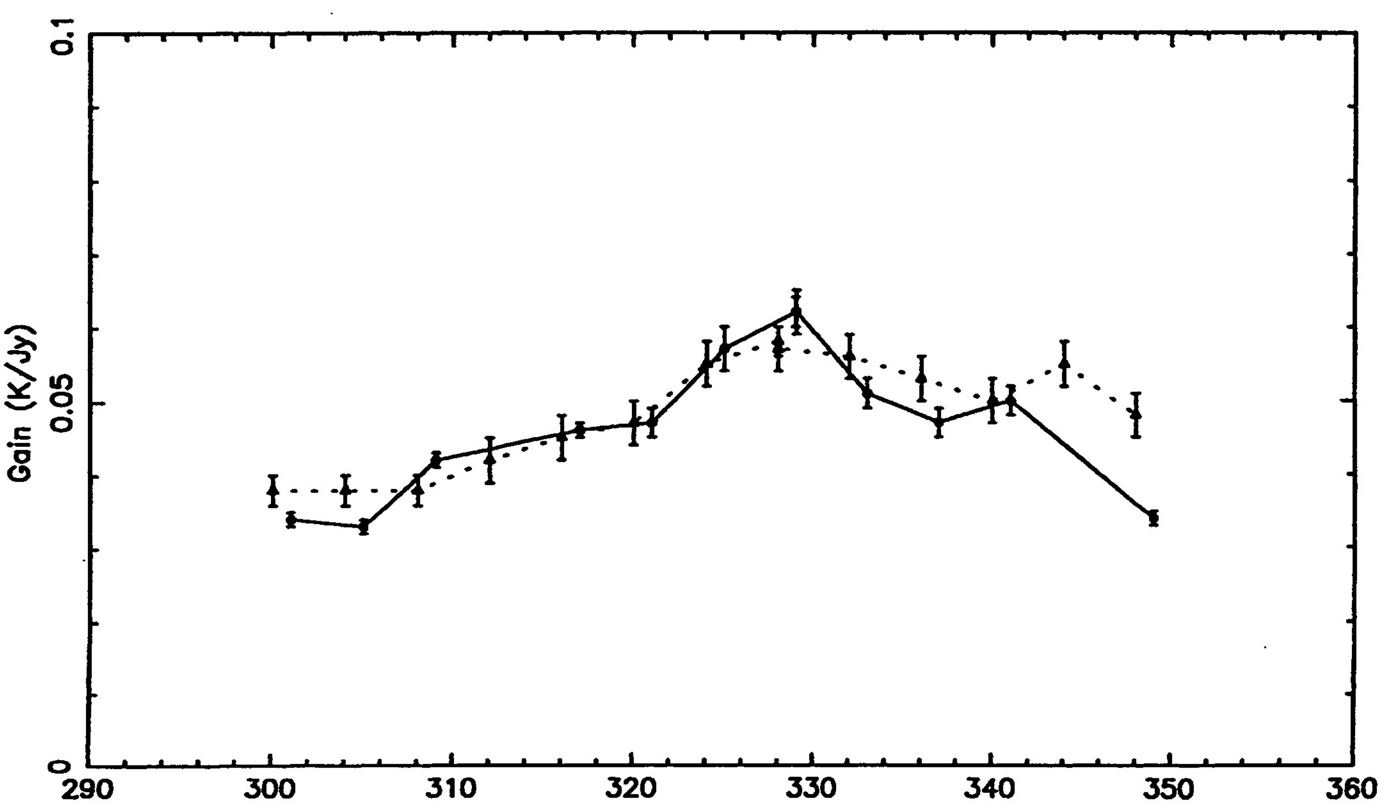
Pie Town P Band





Pie Town P Band





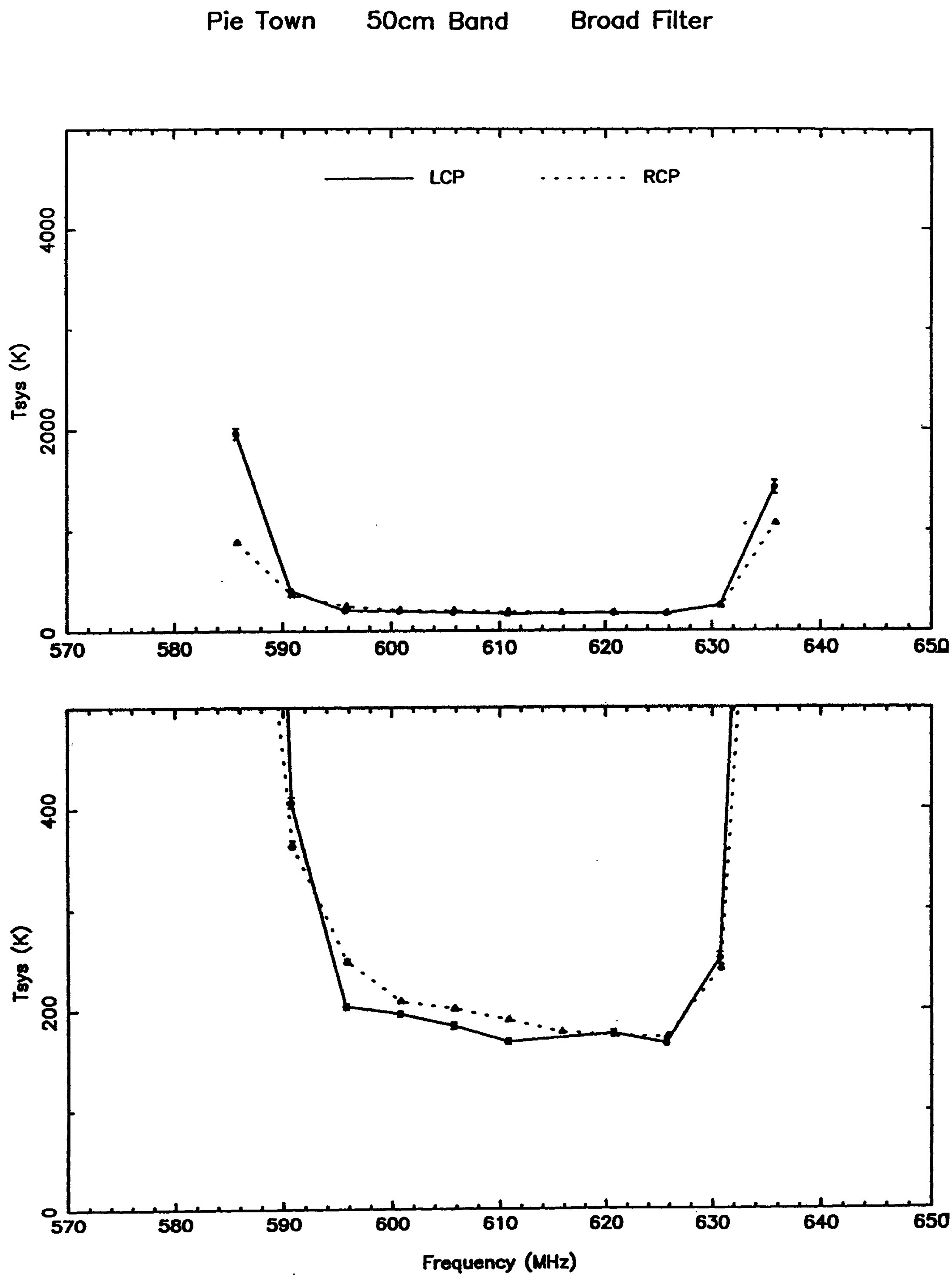
50cm Band

Data were taken at Kitt Peak and Pie Town in October 1991. Measurements were made with the 609 - 613 MHz filter both switched out (BROAD FILTER) and in (NARROW FILTER). The source Tau A was used at elevations > 20°. For clarity the RCP results are plotted 1 MHz higher than the true observation frequency.

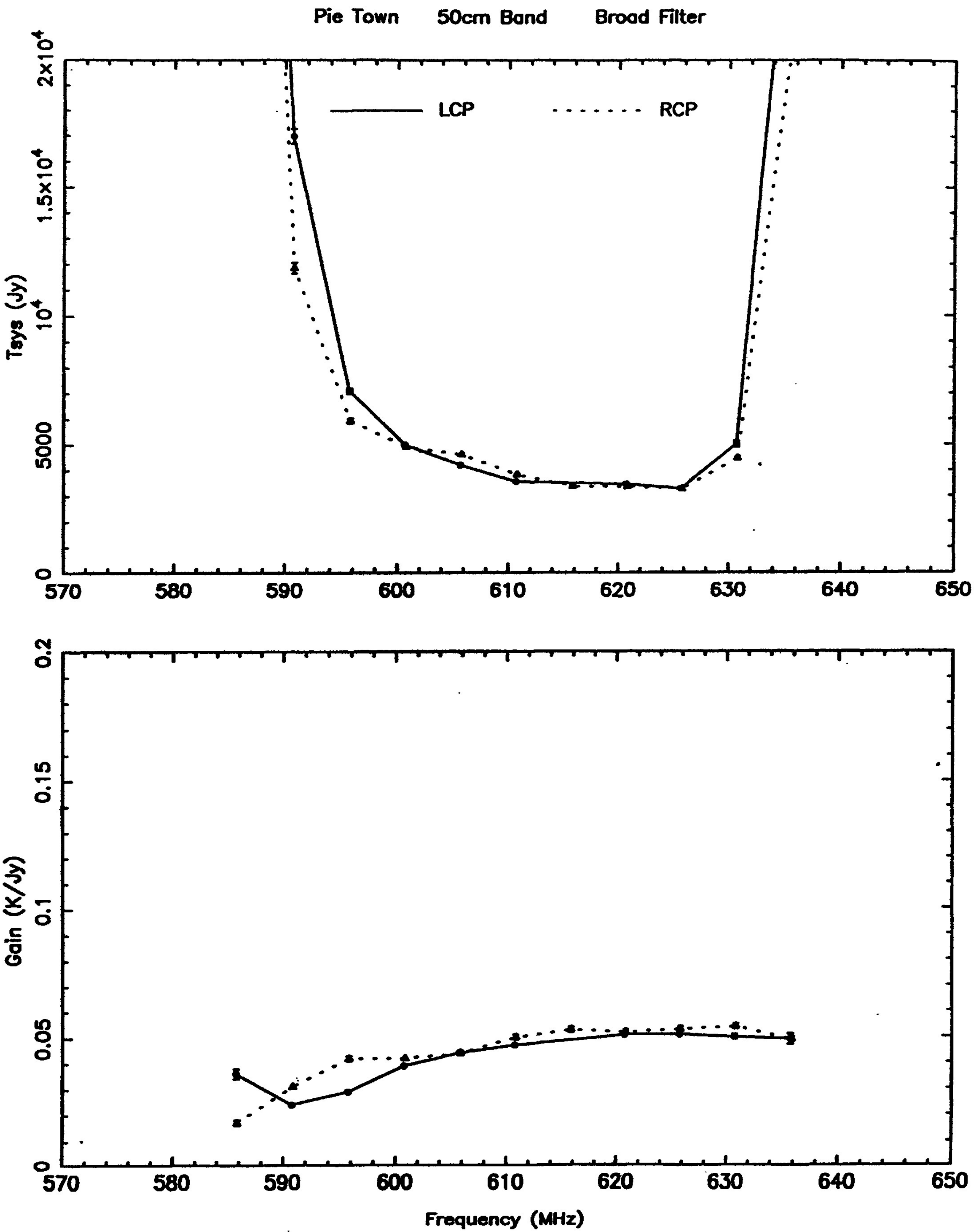
The BROAD FILTER observations were made between 550 and 705 MHz with 1 MHz channels. Pie Town shows a lower frequency limit near 594 MHz, and an upper limit near 630 MHz (limits defined as points where the system temperature is twice the nominal value). Missing Pie Town data at 615.7 MHz LCP are caused by an intermittent failure in BBC#6. Data for all frequencies at Kitt Peak were unuseable, presumably due to strong interference.

The NARROW FILTER observations were made between 606 and 616 MHz using 0.5 MHz channels. (Observations were also made between 603 and 619 MHz using 1 MHz channels but are not plotted.) The Kitt Peak data show a lower frequency limit near 608.5 MHz, and an upper limit near 613.5 MHz; outside this range both the T_{sys} and gain degrade rapidly. At Pie Town the filter appears to be disconnected; switching the filter "in" by commands in the observing schedule caused no change in the observed response. Missing Pie Town data at 608.9, 612.4, and 615.9 LCP are caused by an intermittent failure in BBC#6.

Finally, we note that the gain at Pie Town is, on average, half that at Kitt Peak. The cause of this is unknown.

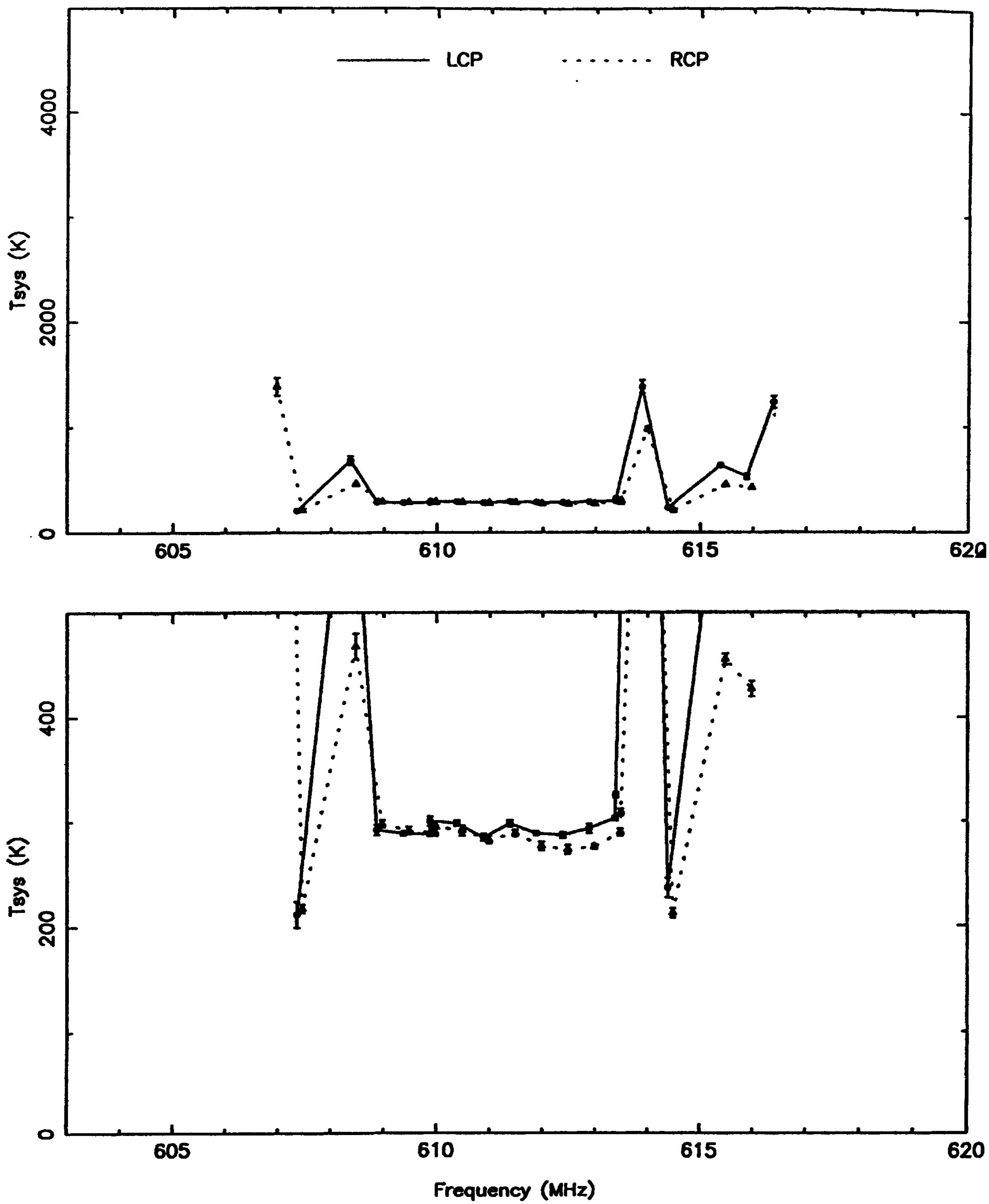


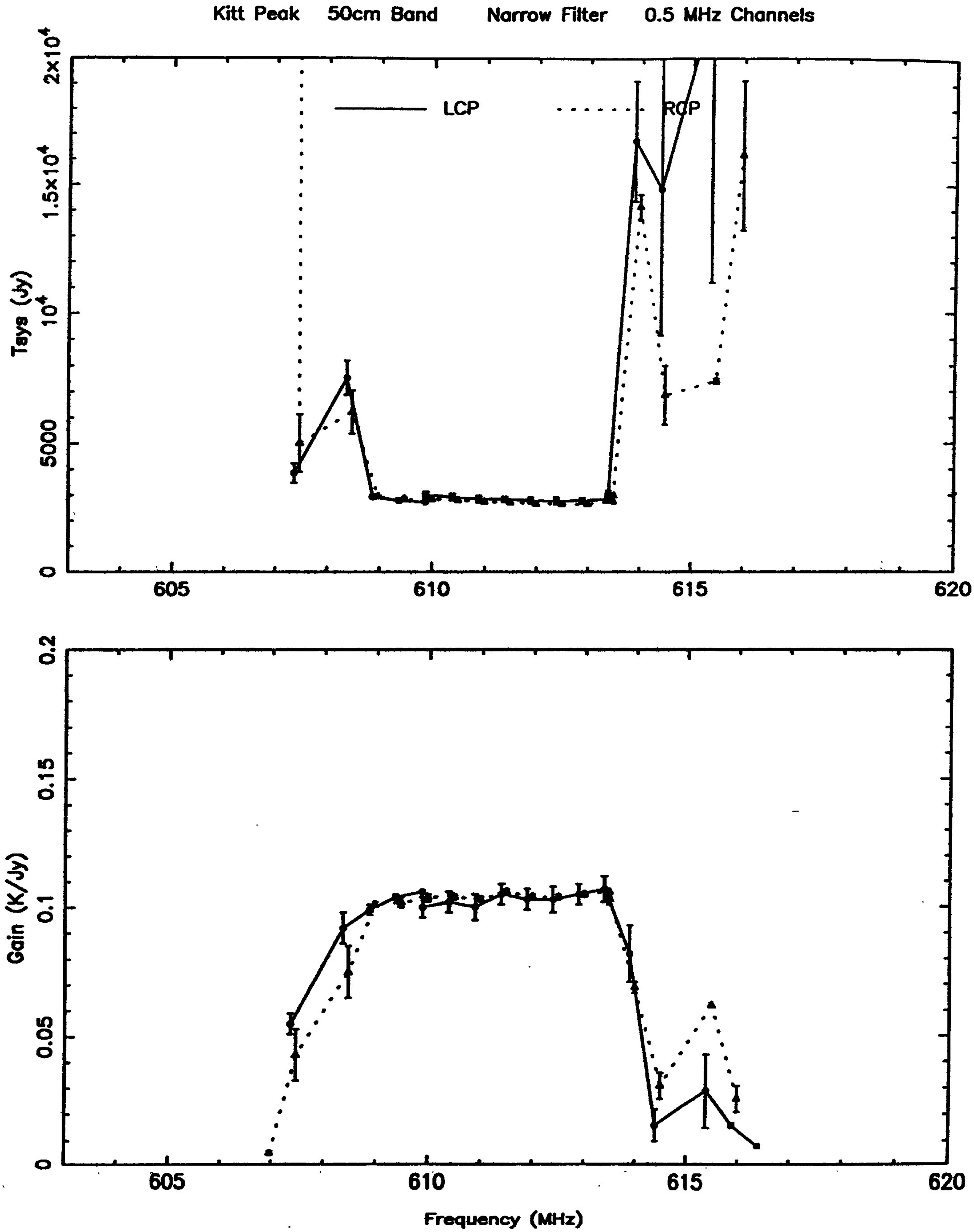
Pie Town 50cm Band Broad Filter
LCP
RCP
Tsys (K)
0
2000
4000
570
580
590
600
610
620
630
640
650
Tsys (K)
0
200
400
570
580
590
600
610
620
630
640
650
Frequency (MHz)



Pie Town 50cm Band Broad Filter
LCP
RCP
Tsys (Jy)
0
5000
10^4
1.5×10^4
2×10^4
570
580
590
600
610
620
630
640
650
Gain (K/Jy)
0
0.05
0.1
0.15
0.2
Frequency (MHz)

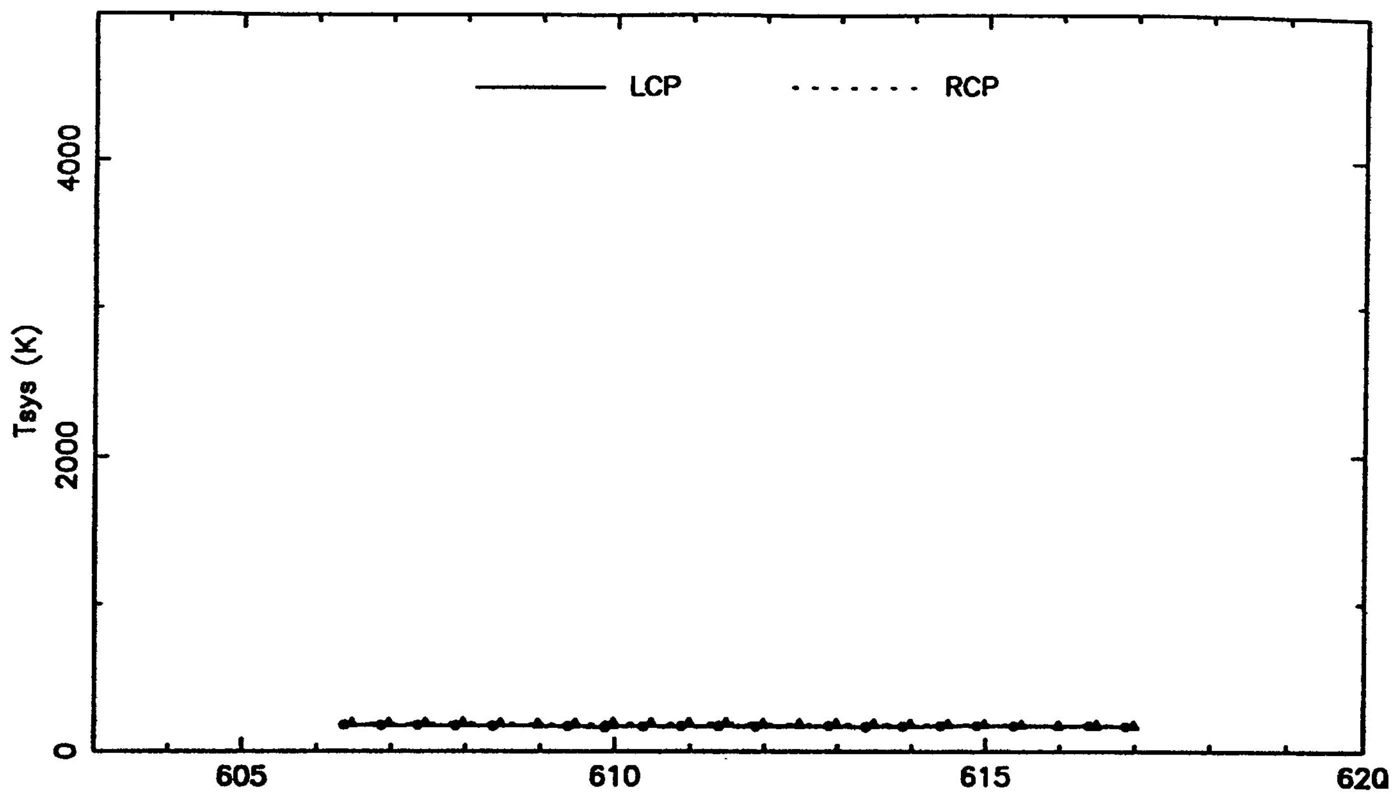
Kitt Peak 50cm Band Narrow Filter 0.5 MHz Channels

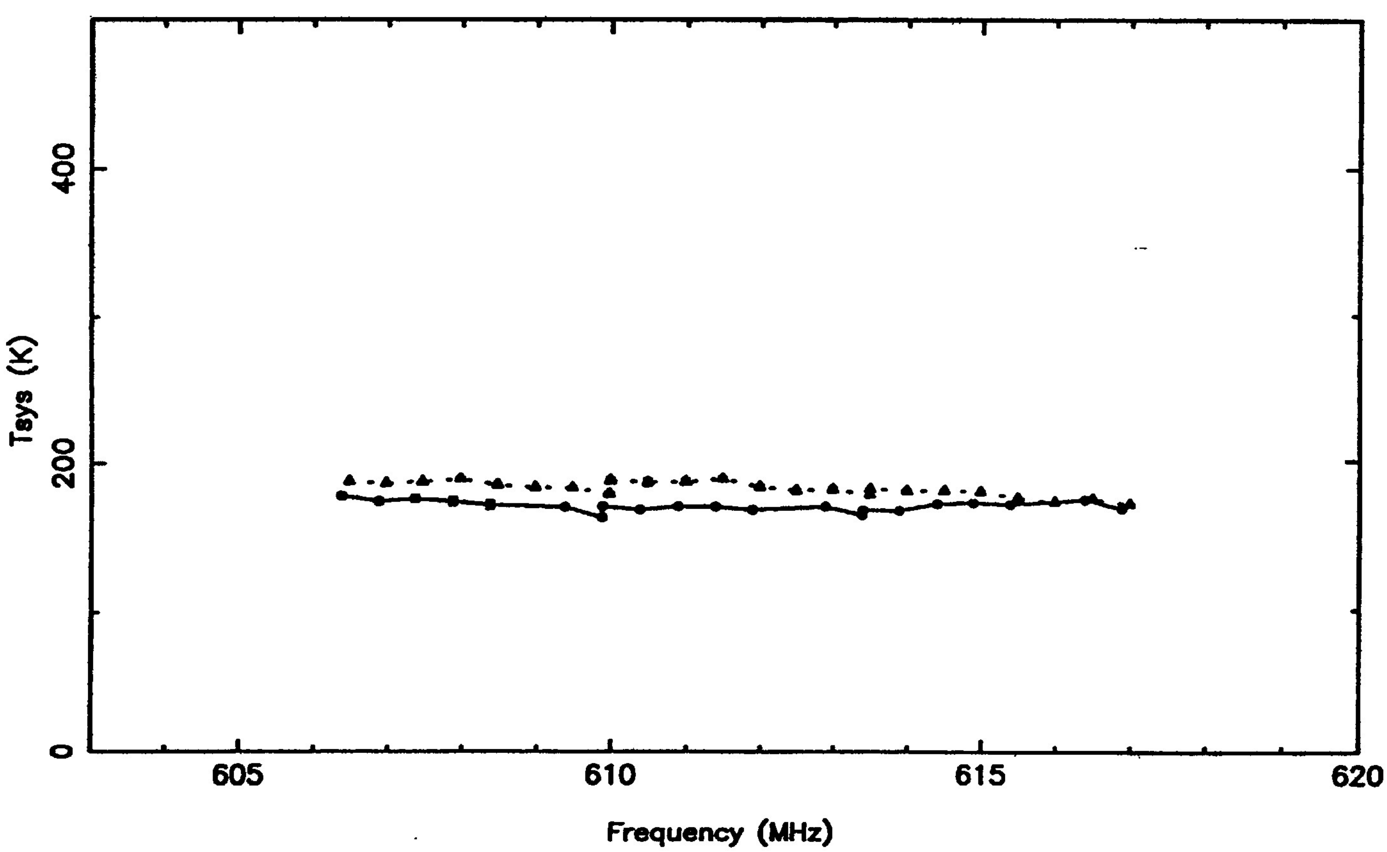


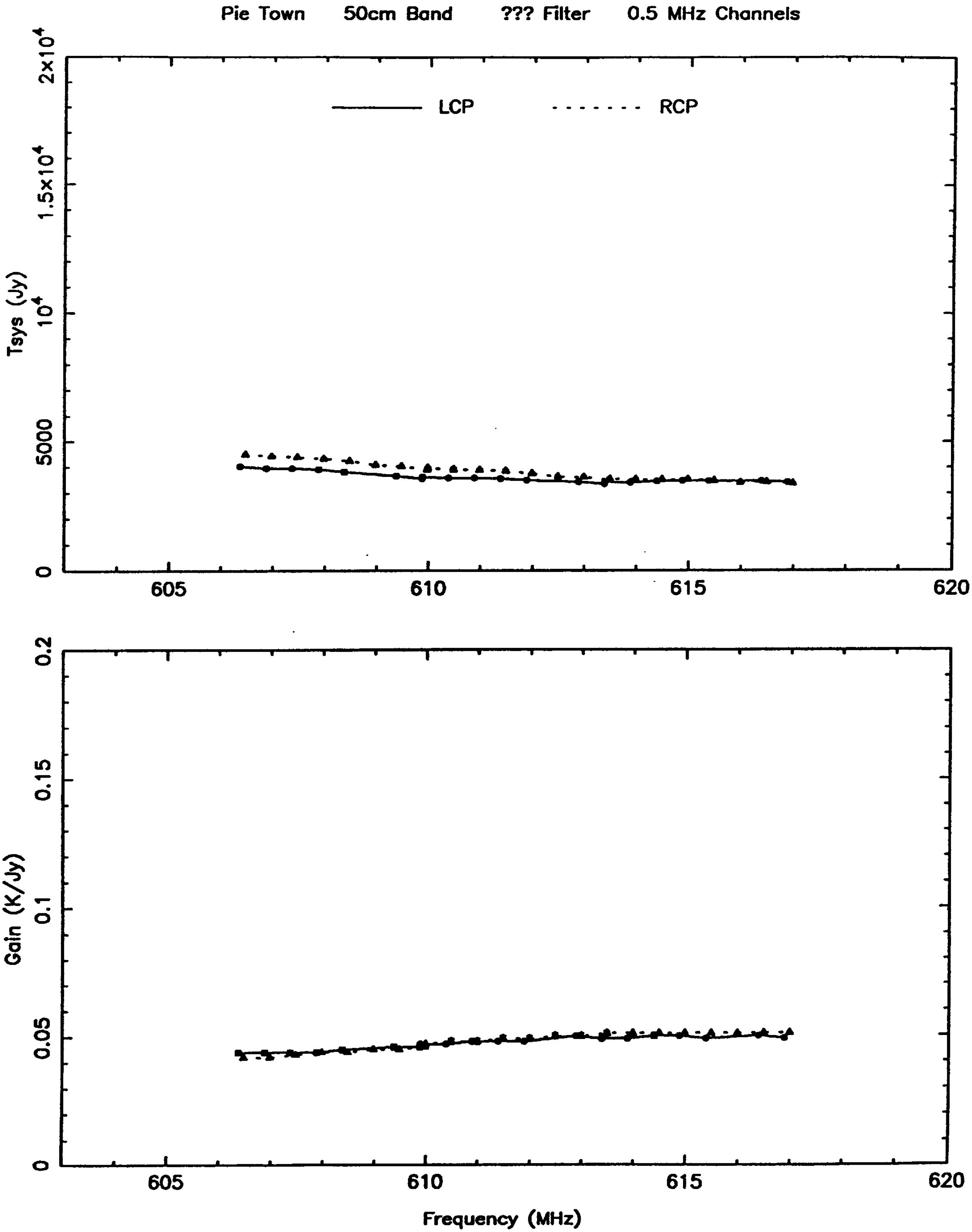


Kitt Peak 50cm Band Narrow Filter 0.5 MHz Channels
LCP
RCP
Tsys (Jy)
0
5000
10^4
1.5×10^4
2×10^4
605
610
615
620
Gain (K/Jy)
0
0.05
0.1
0.15
0.2
Frequency (MHz)

Pie Town 50cm Band ??? Filter 0.5 MHz Channels







Pie Town 50cm Band ??? Filter 0.5 MHz Channels
LCP
RCP
Tsys (Jy)
0
5000
10^4
1.5×10^4
2×10^4
605
610
615
620
Gain (K/Jy)
0
0.05
0.1
0.15
0.2
605
610
615
620
Frequency (MHz)

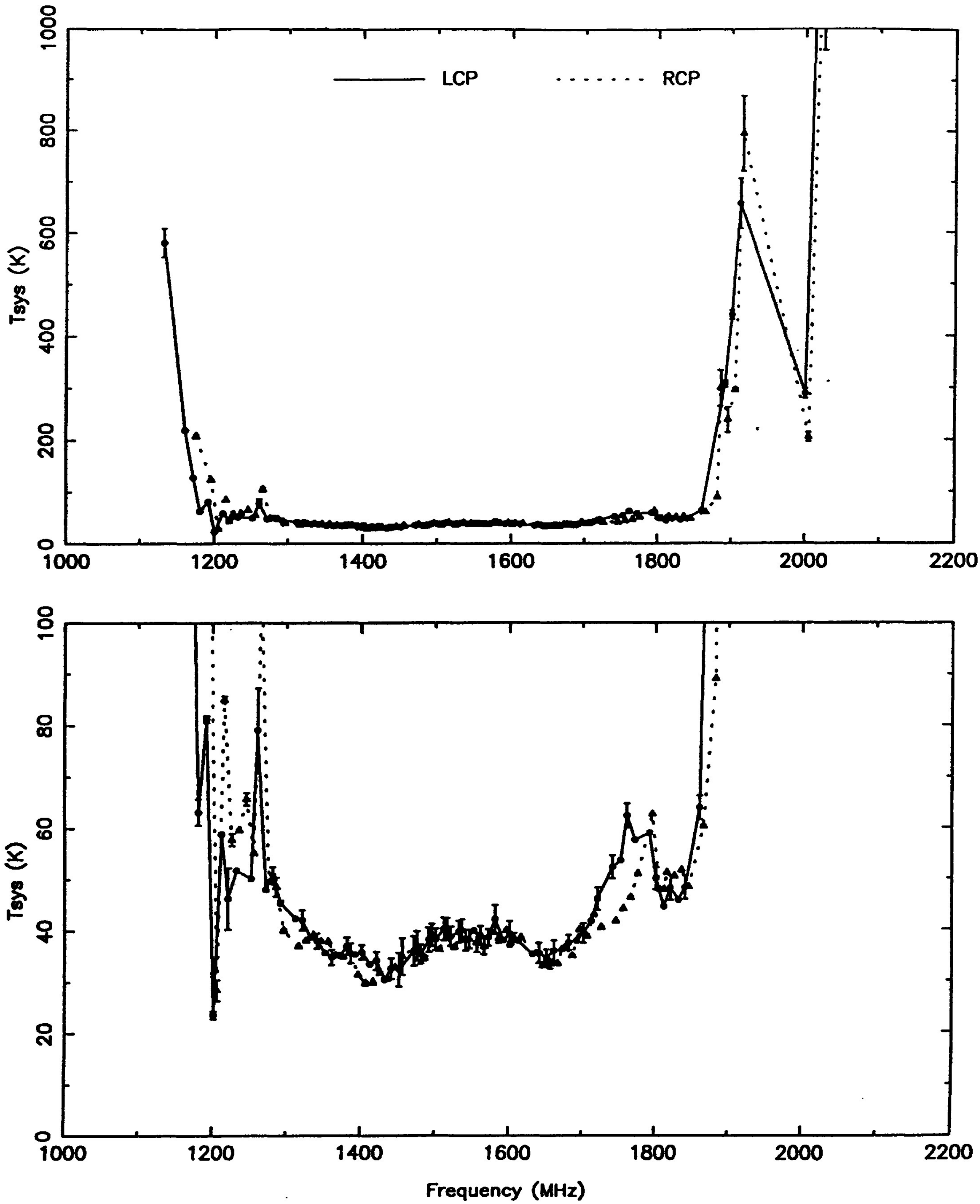
L Band

Data were taken at Fort Davis, Kitt Peak, Los Alamos, and Pie Town in May 1990 and October 1991. Measurements were made between 896 and 2050 MHz with 16 MHz channels. The sources 3C123, 3C274, and 3C353 were used at source elevations $> 20°$. For clarity the RCP results are plotted 4 MHz higher than the true observation frequency.

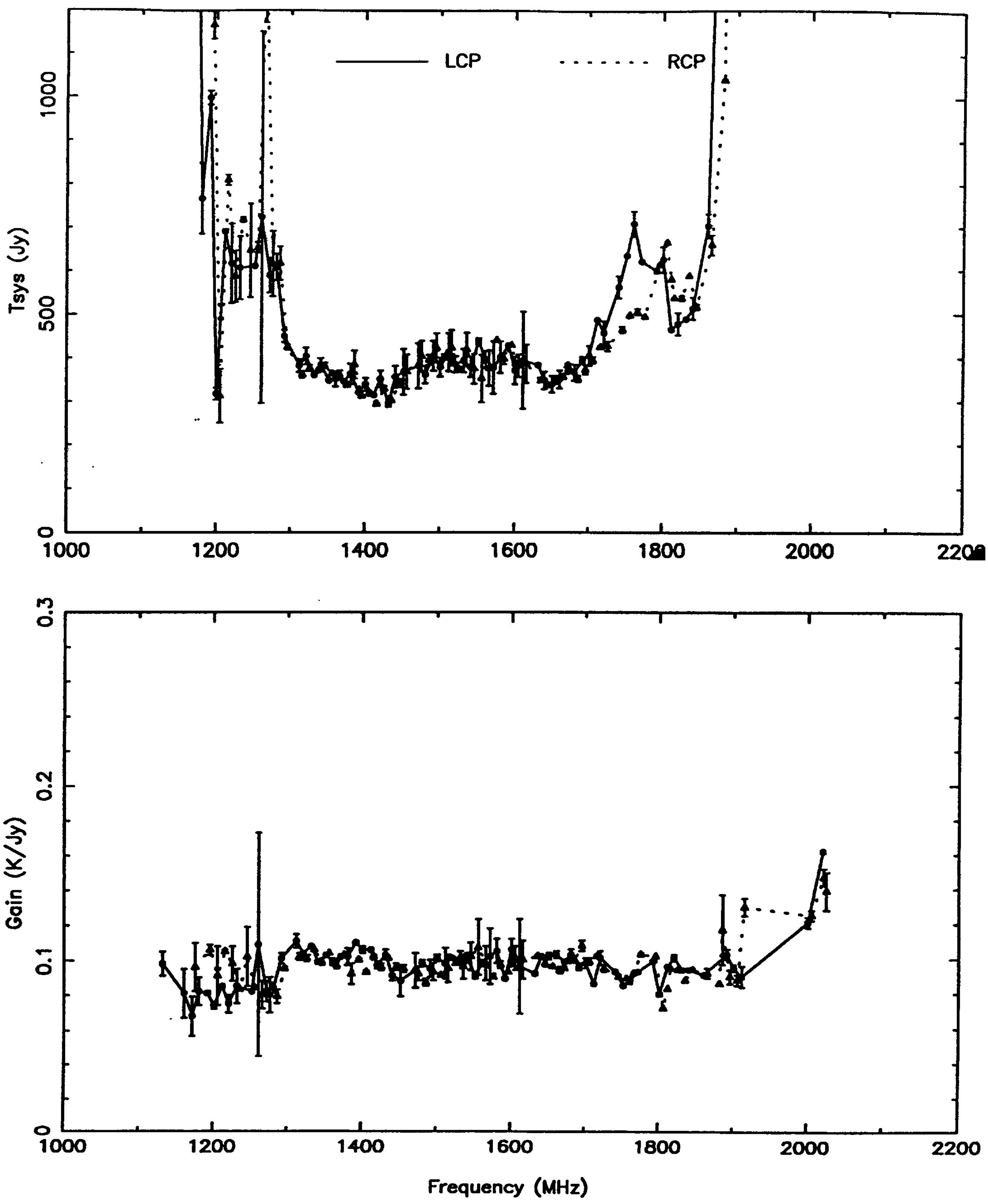
The lower and upper frequency limits are 1200 and 1850 MHz, respectively; outside this range the system temperature (in Jy) is more than twice the nominal value near the band center. The Fort Davis and Pie Town data also show narrow frequency ranges near 2000 and 2100 MHz where the system temperature decreases again, however the S band receiver gives better performance at these frequencies. Many of the data points have large "error bars" caused by a large dispersion among the individual measurements; this may be caused by variable interference.

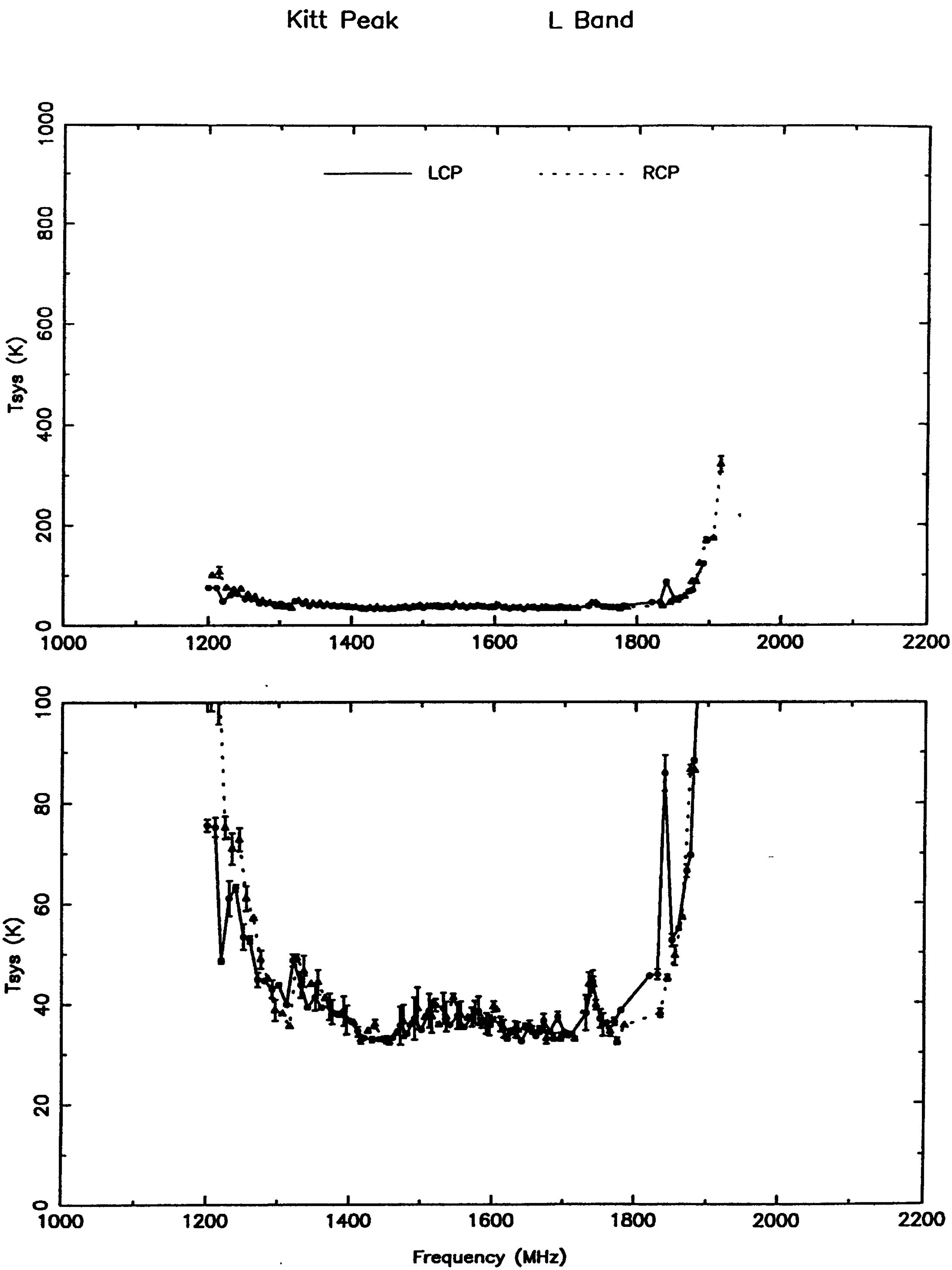
The missing Fort Davis data at 1302, 1462, 1622, and 1782 MHz are caused by a malfunction of BBC#3. Missing data 1801 MHz at Kitt Peak are probably caused by interference between 1793 and 1809 MHz. The high gain and system temperatures at 1841 MHz LCP are probably caused by interference; only two observations were made at this frequency. Los Alamos was unavailable for the Oct. 1991 tests, so its data are less complete. The high system temperature for Pie Town at 1501 MHz LCP was very consistent in 3 measurements made over 6 minutes; it is probably caused by interference between 1492 and 1509 MHz. Several of the stations show anomalous gain values exceeding 0.15 °K/Jy near the ends of the band; these may be caused by attenuation of the calibrator noise source.

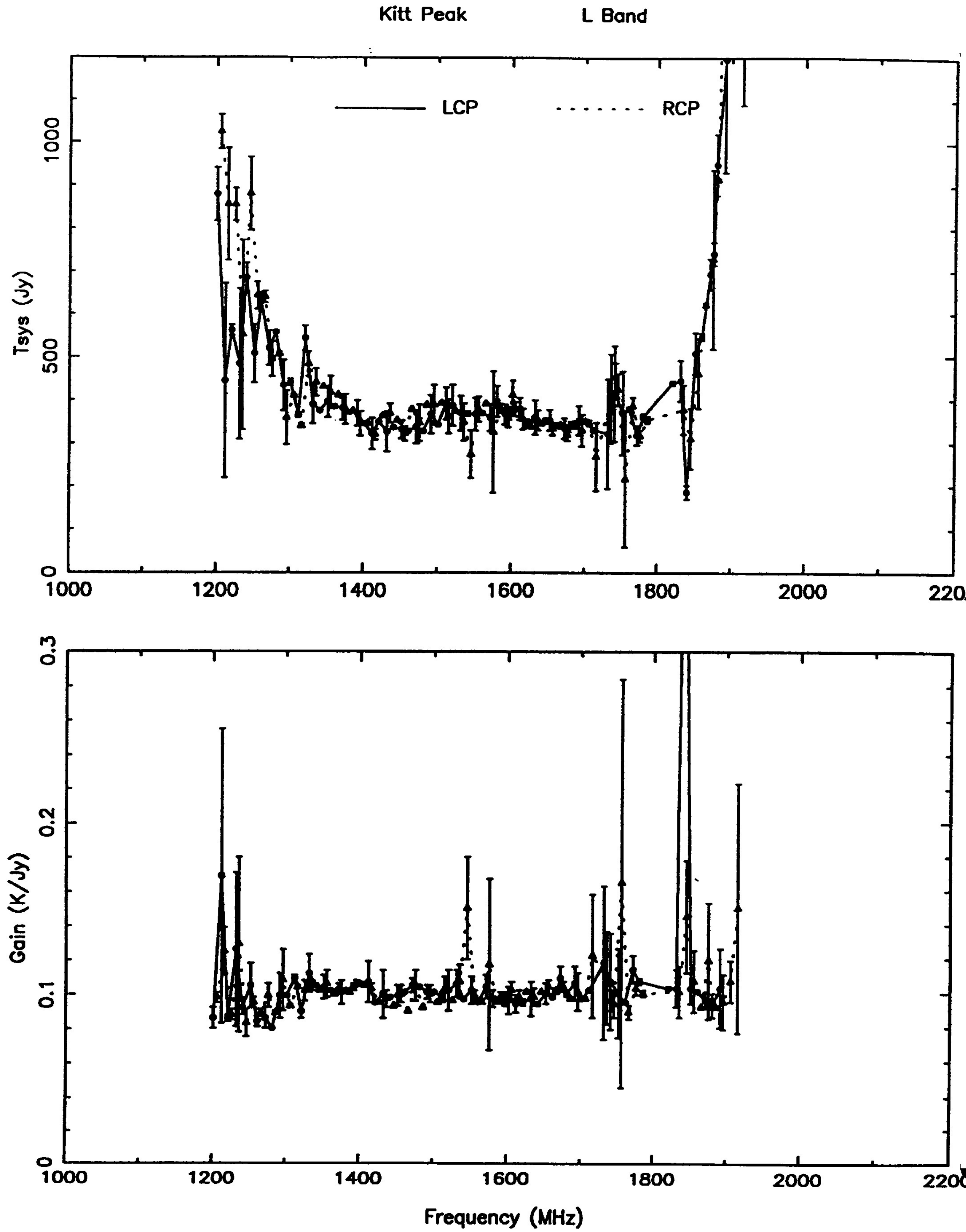
Fort Davis L Band



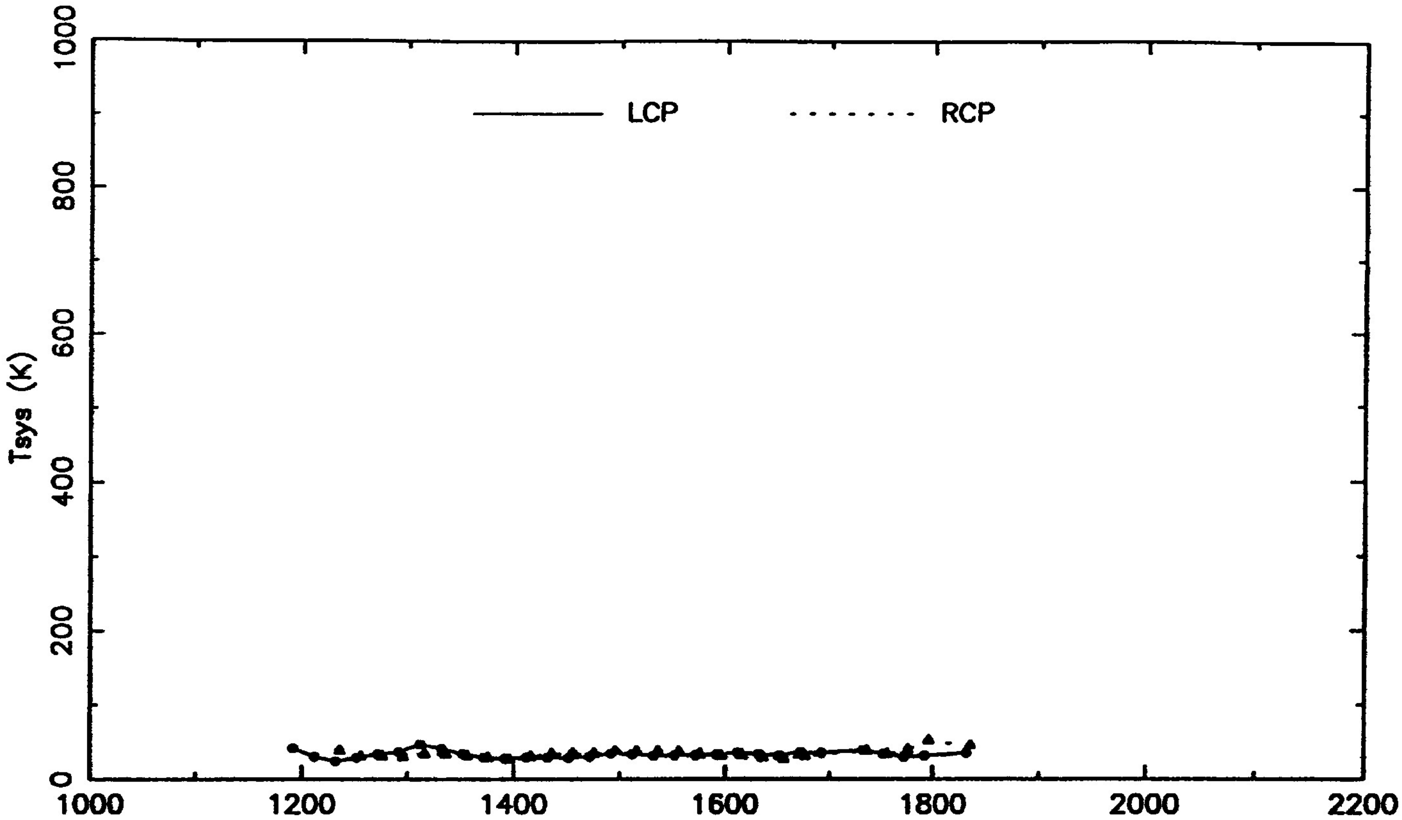
Fort Davis L Band

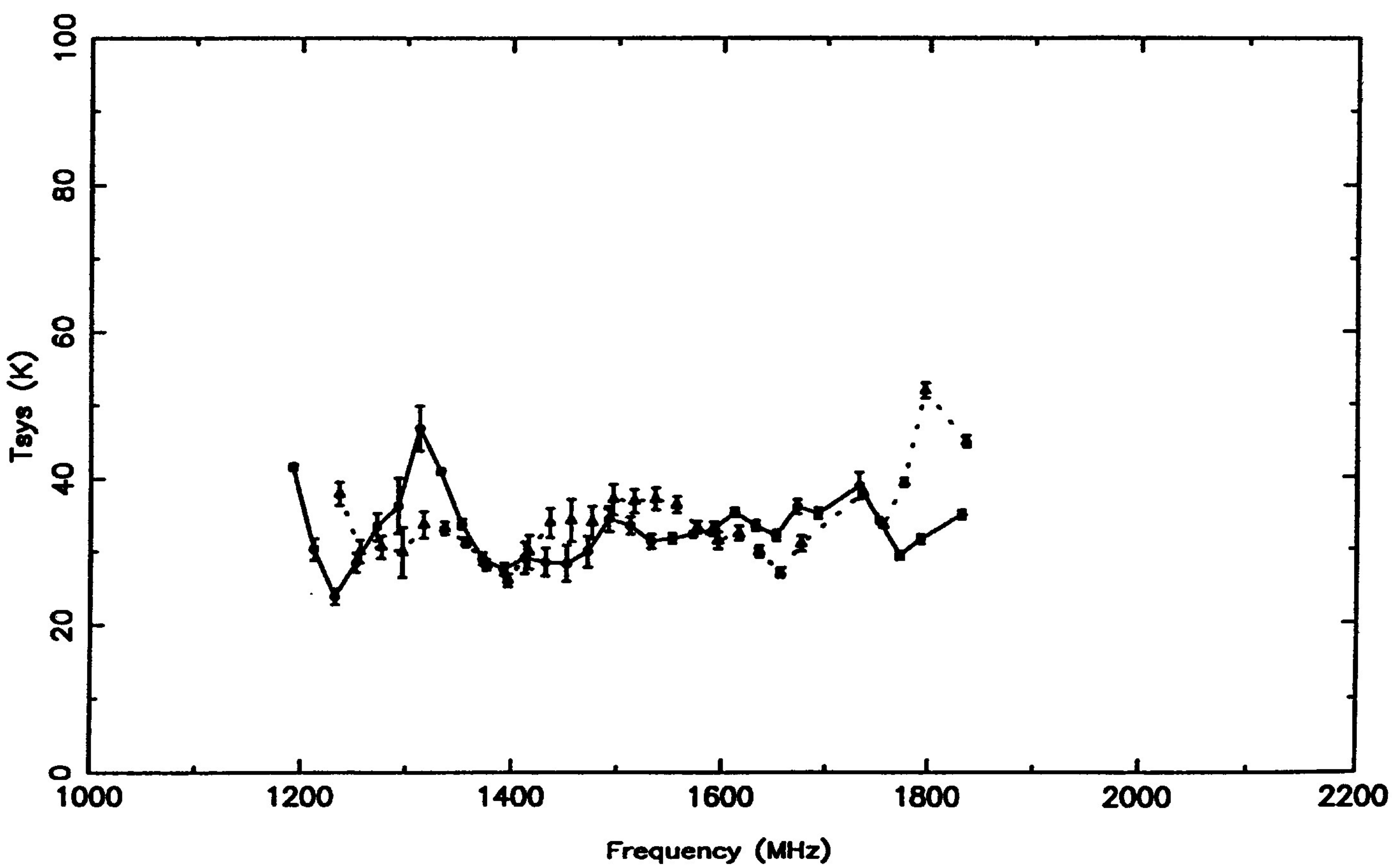


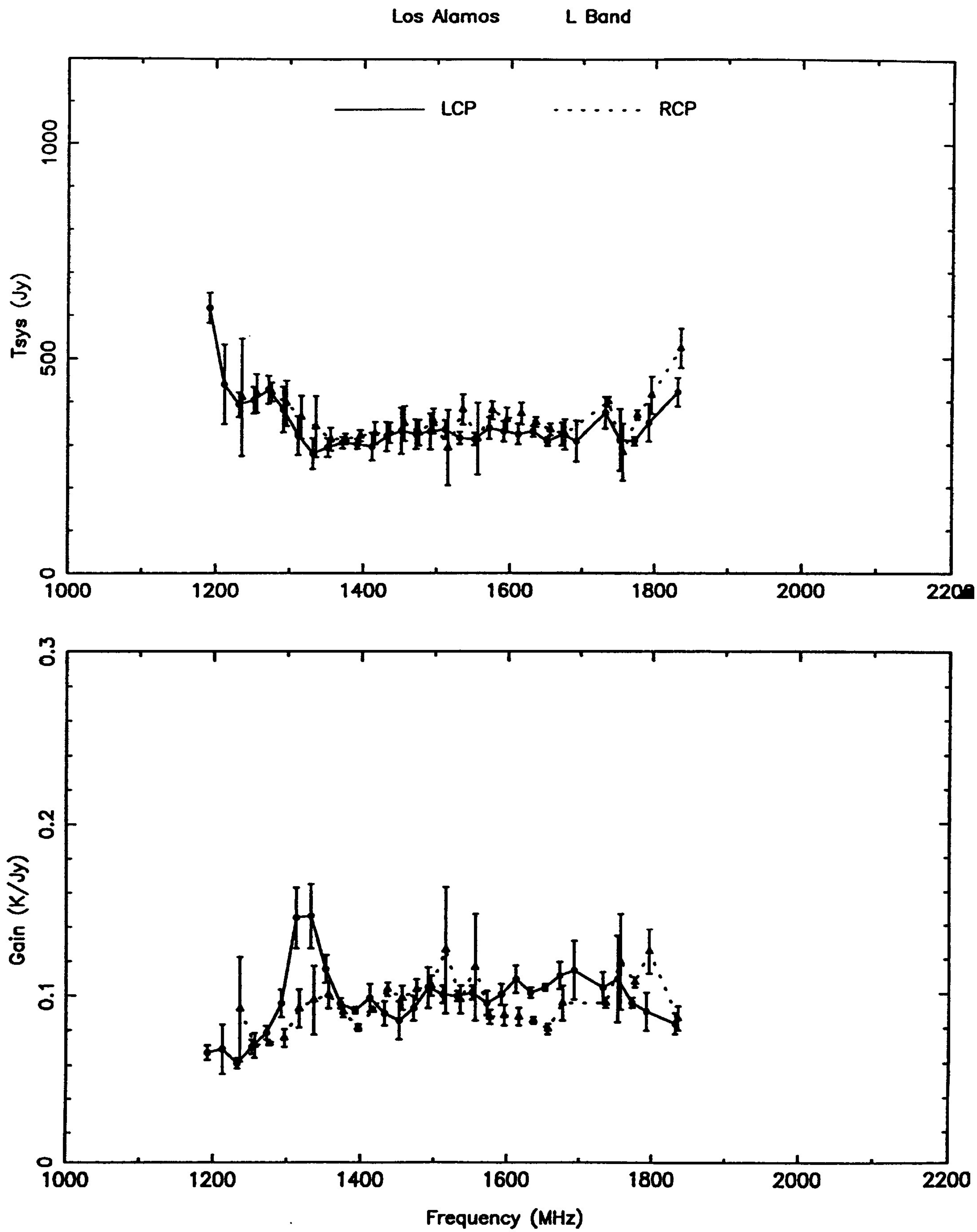

Kitt Peak
L Band
LCP
RCP
Tsys (K)
0
200
400
600
800
1000
1000
1200
1400
1600
1800
2000
2200
Tsys (K)
0
20
40
60
80
100
Frequency (MHz)


Kitt Peak
L Band
LCP
RCP
Tsys (Jy)
0
500
1000
1000
1200
1400
1600
1800
2000
2200
Gain (K/Jy)
0
0.1
0.2
0.3
1000
1200
1400
1600
1800
2000
2200
Frequency (MHz)

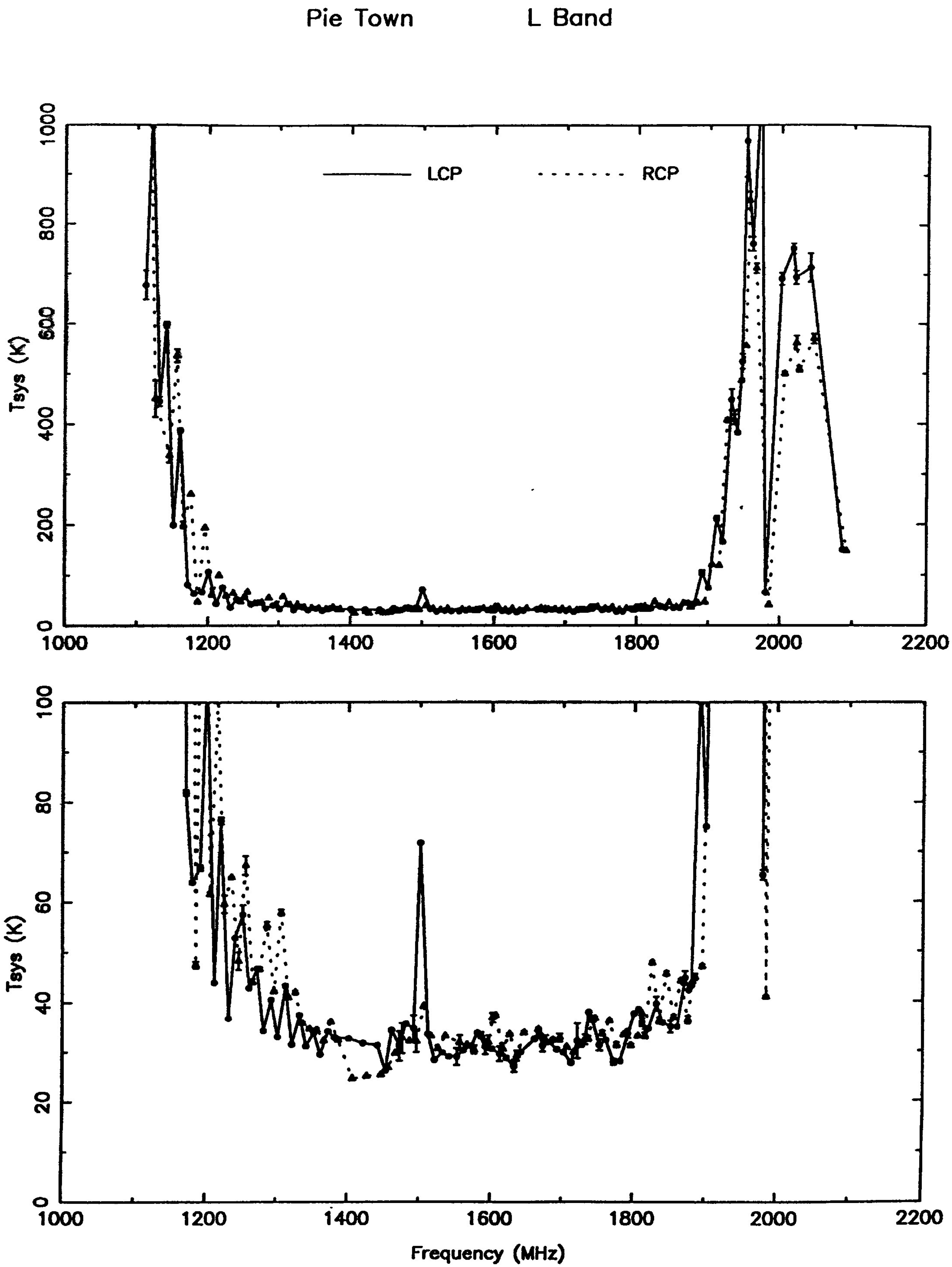
Los Alamos L Band

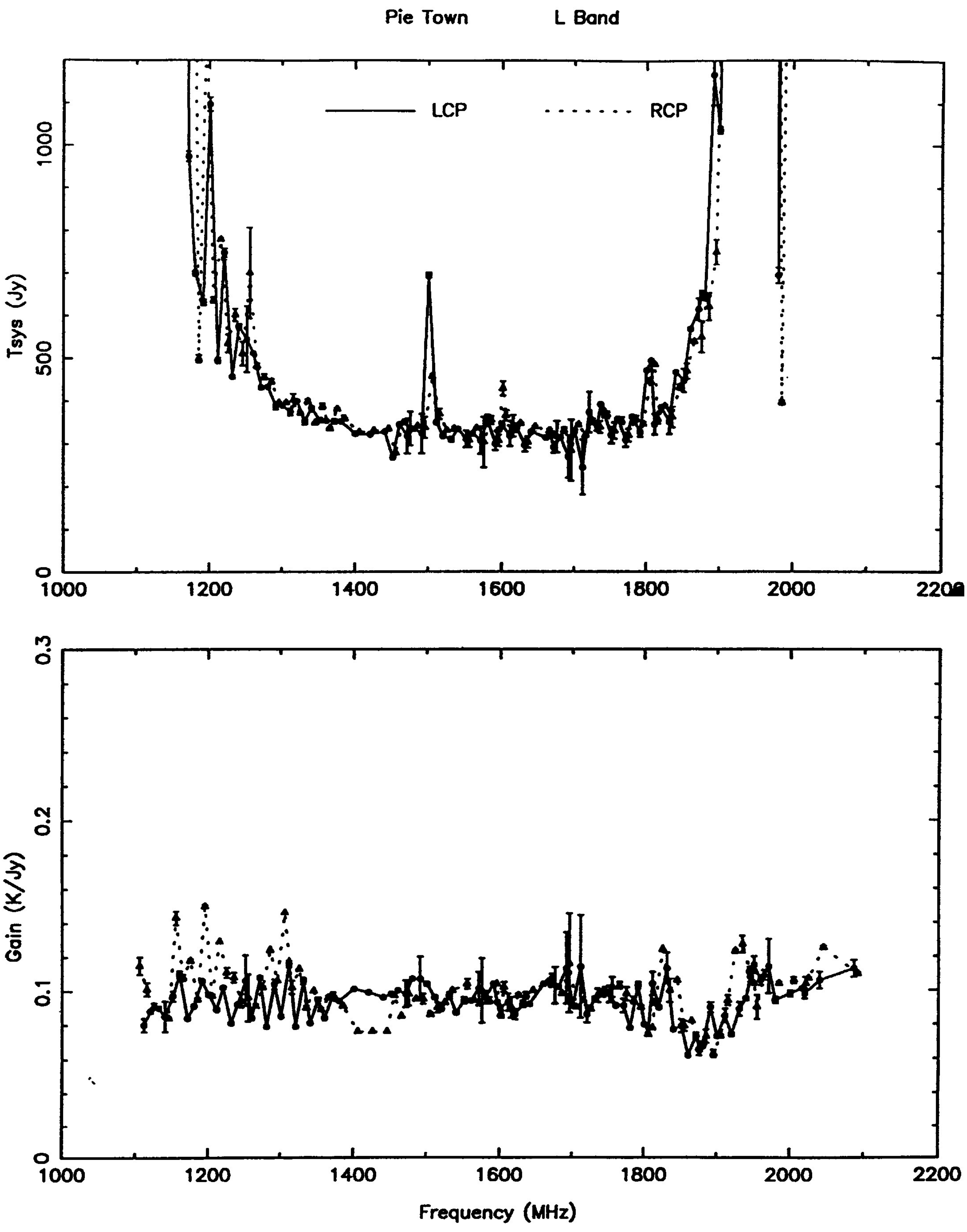






Los Alamos L Band
LCP
RCP
Tsys (Jy)
1000
500
0
1000
1200
1400
1600
1800
2000
2200
Gain (K/Jy)
0.3
0.2
0.1
0
1000
1200
1400
1600
1800
2000
2200
Frequency (MHz)


Pie Town L Band
LCP
RCP
Tsys (K)
Frequency (MHz)
0
200
400
600
800
1000
20
40
60
80
100
1000
1200
1400
1600
1800
2000
2200


Pie Town
L Band
LCP
RCP
Tsys (Jy)
0
500
1000
1000
1200
1400
1600
1800
2000
2200
Gain (K/Jy)
0
0.1
0.2
0.3
Frequency (MHz)

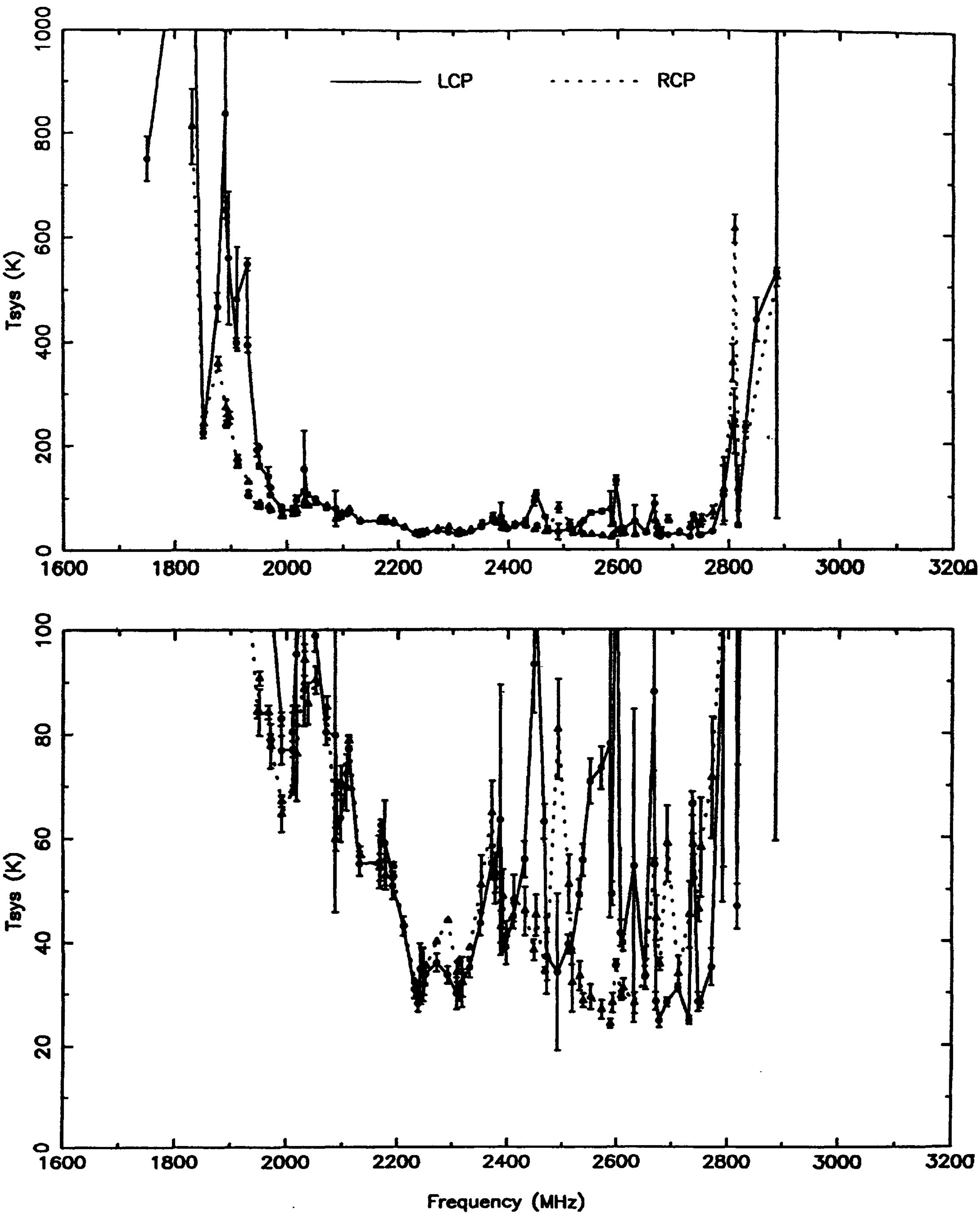
S Band

Data were taken at Fort Davis, Kitt Peak, and Pie Town in October and November 1991. Measurements were made between 1606 and 3100 MHz with 16 MHz channels. The sources 3C123, 3C274, and 3C353 were used at source elevations $> 20°$. The RCP data were observed at 1 MHz higher frequency than the LCP data in order to give greater clarity in the final plots. The optimum focus for S band was used (as opposed to the X band optimized focus used in S/X mode).

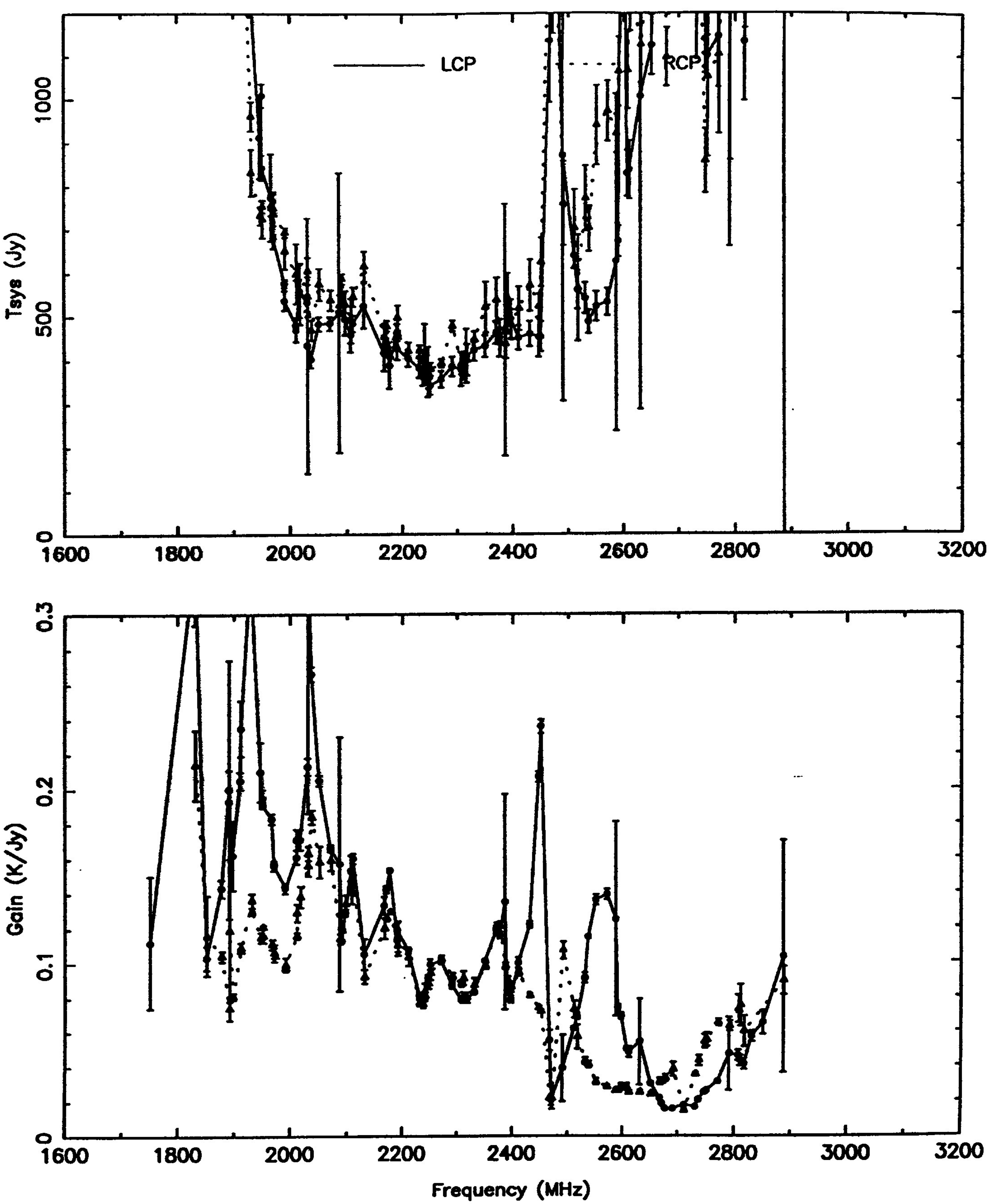
The observed spectra are extremely complicated. The plots of system temperature in units of Jy have the simplest behavior, and we begin by discussing these. All the stations show system temperatures within a factor of two of the nominal band center value over most of the range from about 1960 to 2600 MHz. Within this range, all stations have a narrow range from 2450 to 2500 MHz with system temperatures several times the nominal value; the cause of this is unknown. Above 2600 MHz the system temperature increases in an erratic fashion, and reaches ten times the nominal value between 2800 and 2900 MHz.

The plots of system temperature in °K, and gain in °K/Jy, both show large fluctuations below 2000 MHz, and above 2400 MHz. In many cases these fluctuations are highly repeatable as indicated by the small error bars, suggesting they are not caused by interference (*e.g.* Pie Town gain in °K/Jy near 2570 MHz). Such effects might be accounted for by frequency dependent variations in the output of the calibration noise source. Other points with very large error bars might be caused by variable interference (*e.g.* Pie Town gain at 2170 MHz). It seems possible that the dichroic beamsplitter might also play some role in these effects.

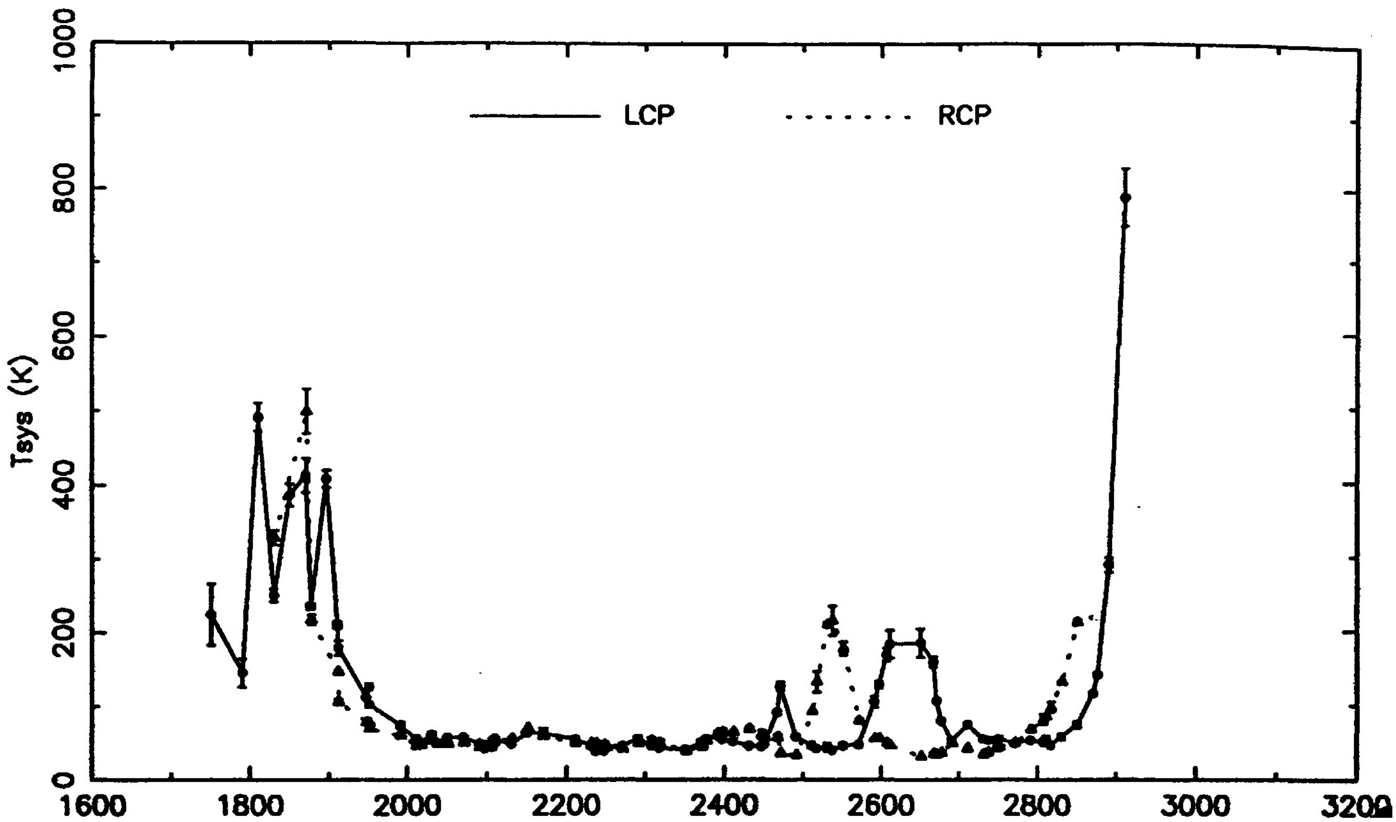
Fort Davis S Band S Band Optimized Focus

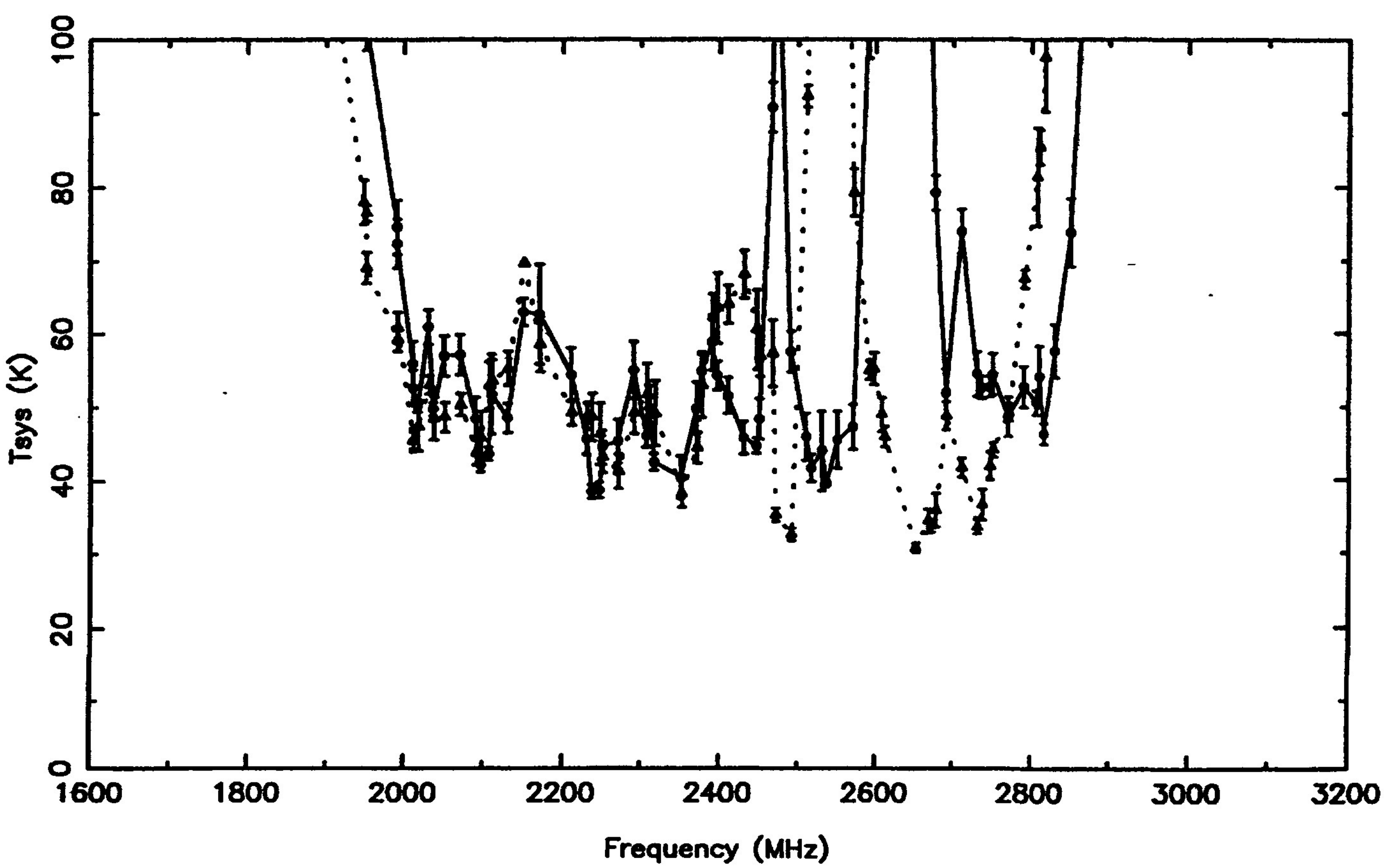


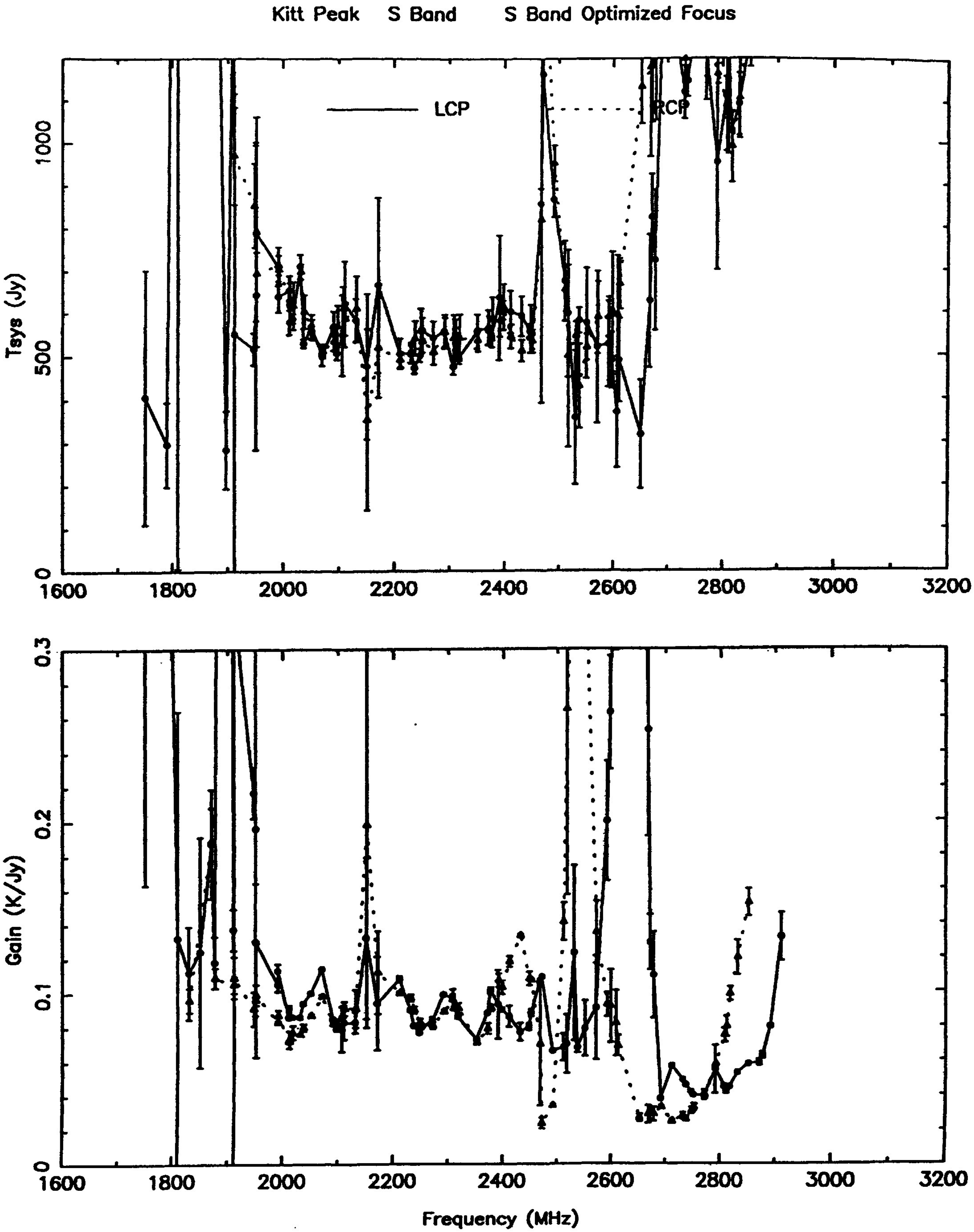
Fort Davis S Band S Band Optimized Focus



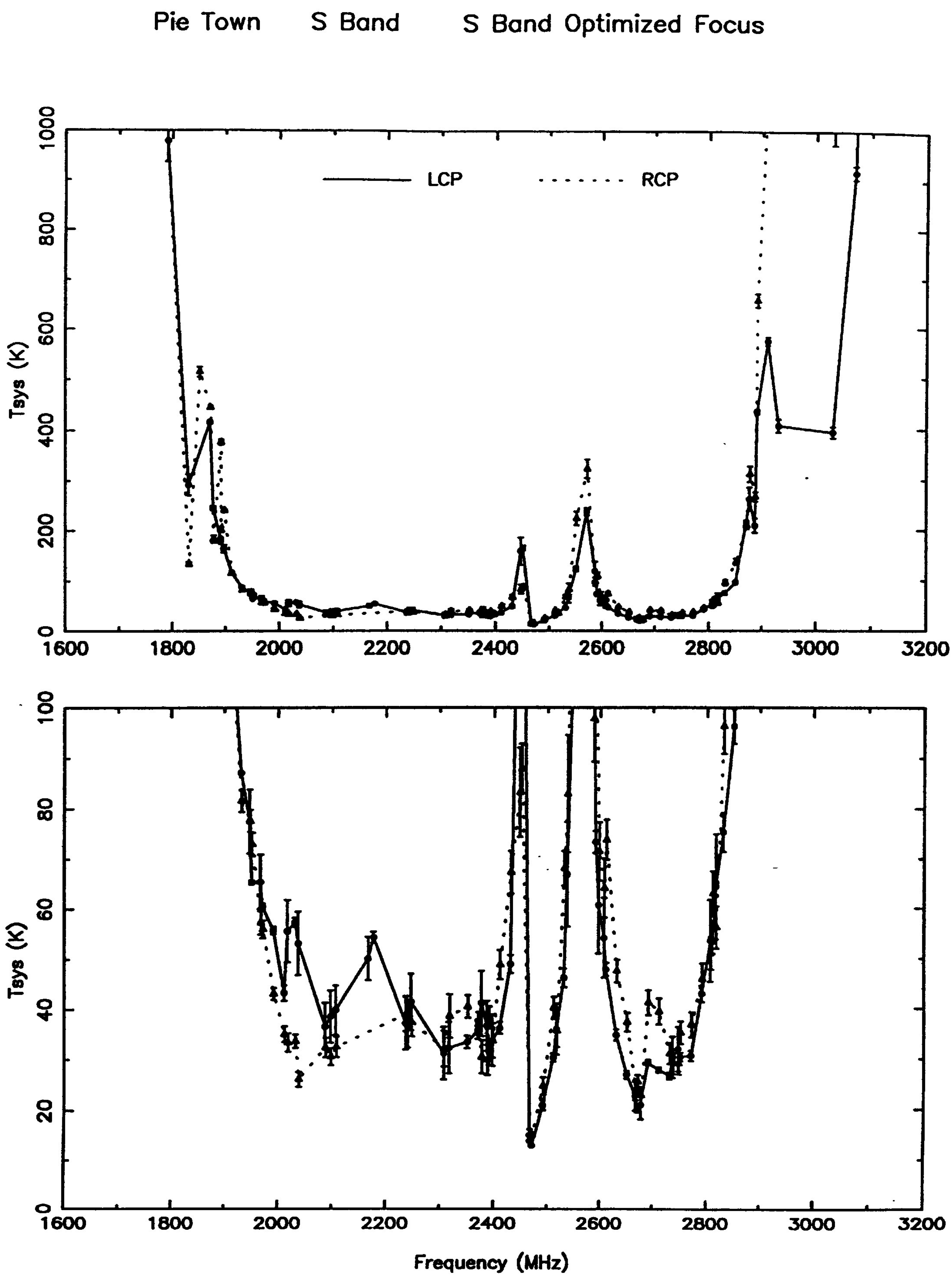
Kitt Peak S Band S Band Optimized Focus





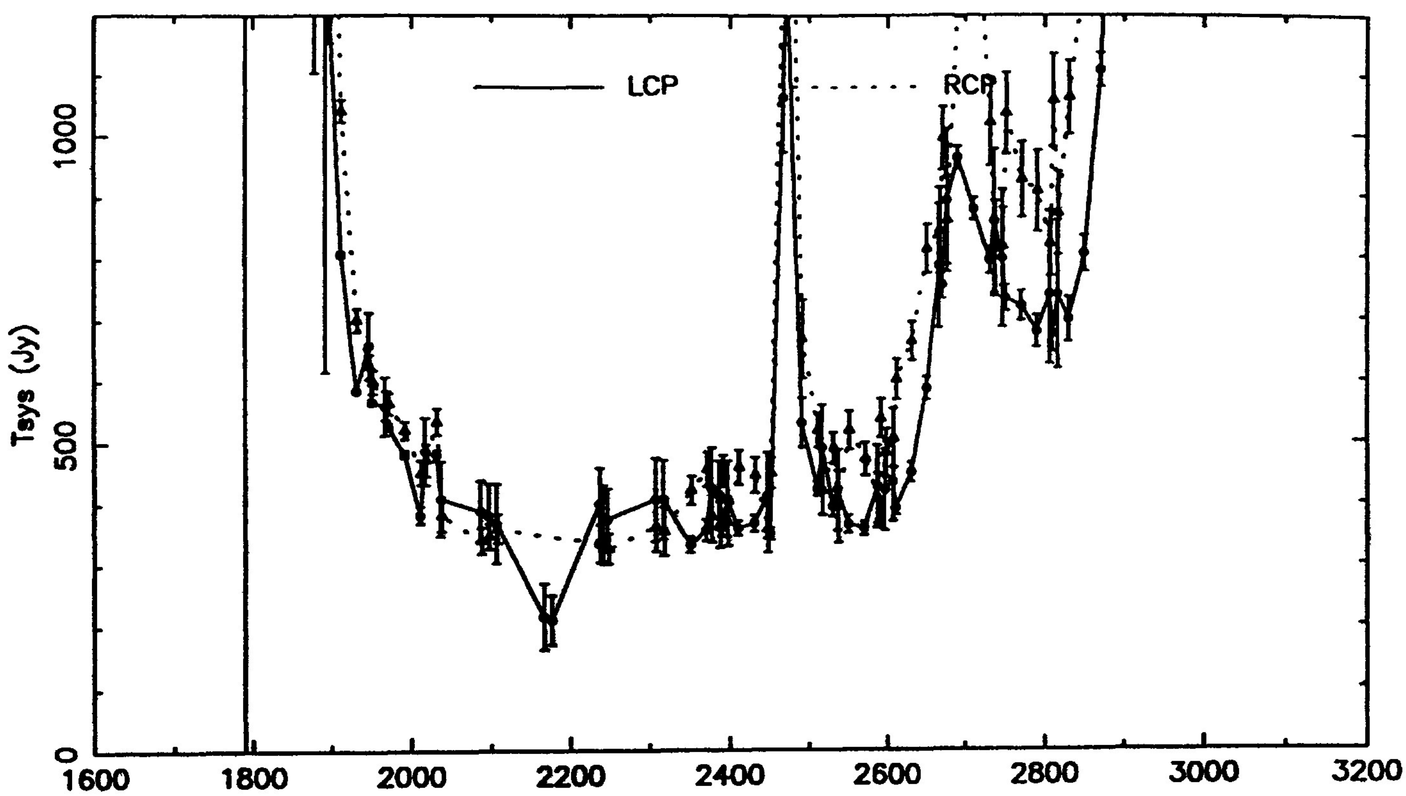


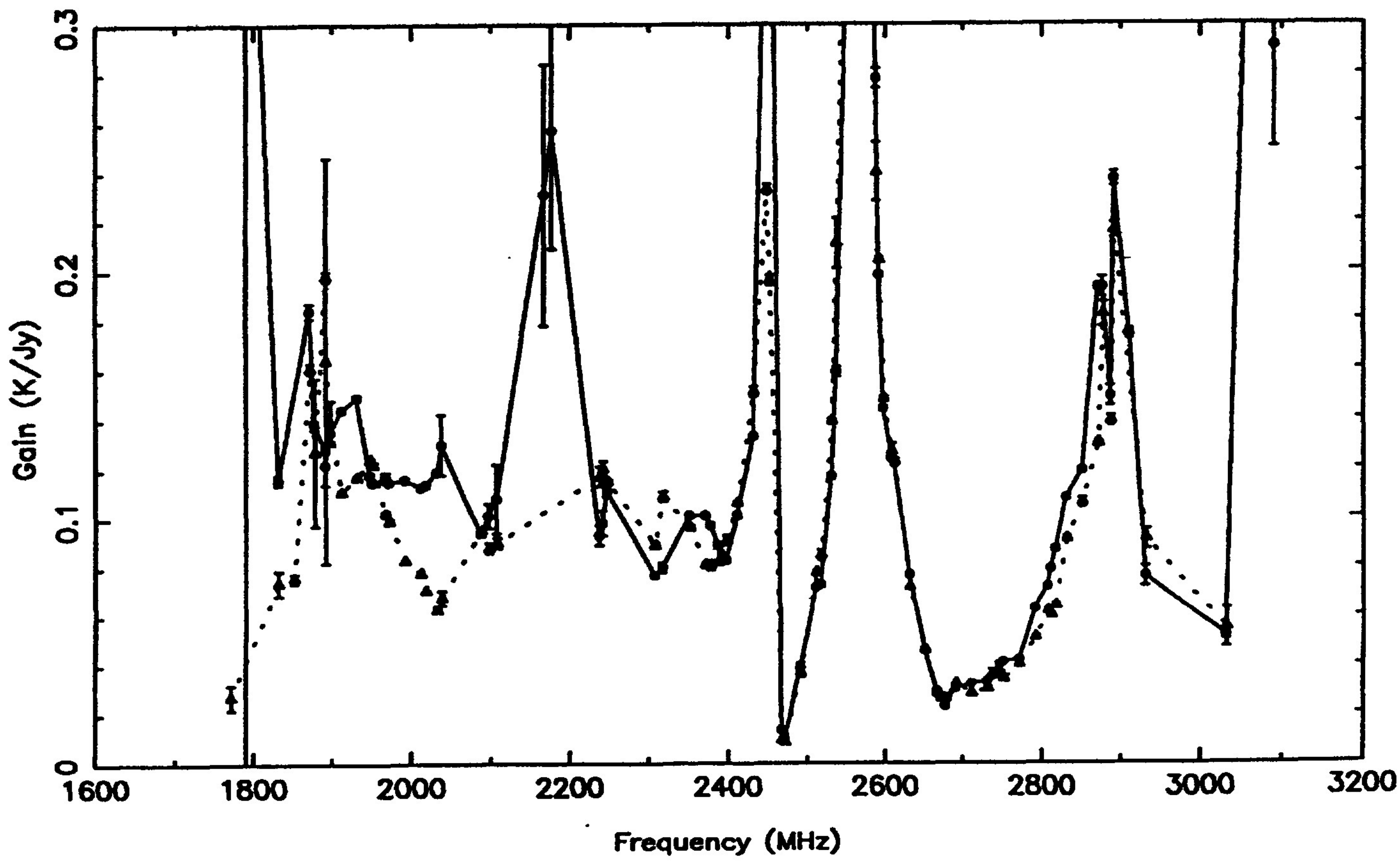
Kitt Peak S Band S Band Optimized Focus
LCP
RCP
Tsys (Jy)
0
500
1000
1600
1800
2000
2200
2400
2600
2800
3000
3200
Gain (K/Jy)
0
0.1
0.2
0.3
Frequency (MHz)



Pie Town S Band S Band Optimized Focus
LCP
RCP
Tsys (K)
0
200
400
600
800
1000
1600
1800
2000
2200
2400
2600
2800
3000
3200
Tsys (K)
0
20
40
60
80
100
Frequency (MHz)

Pie Town   S Band   S Band Optimized Focus



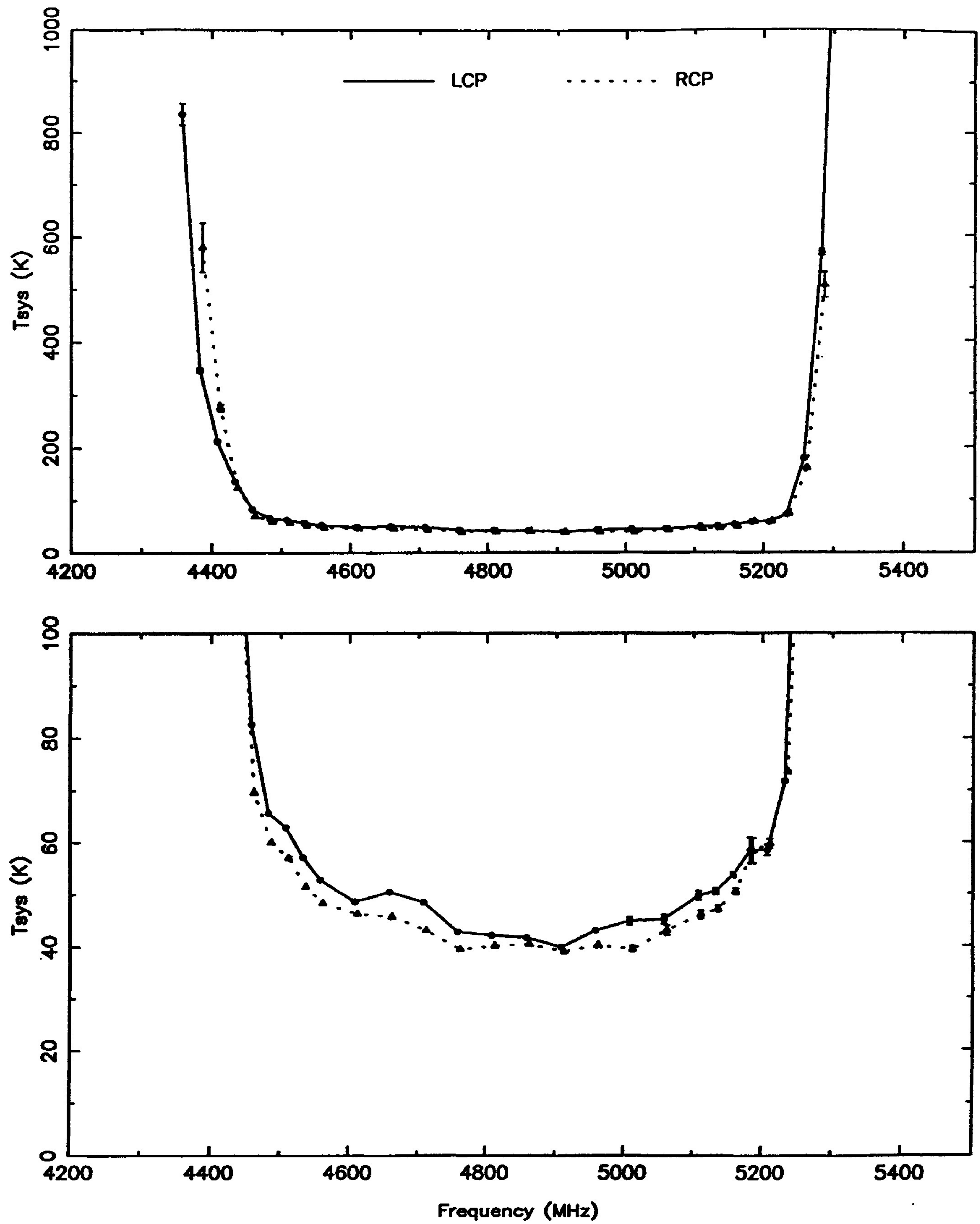


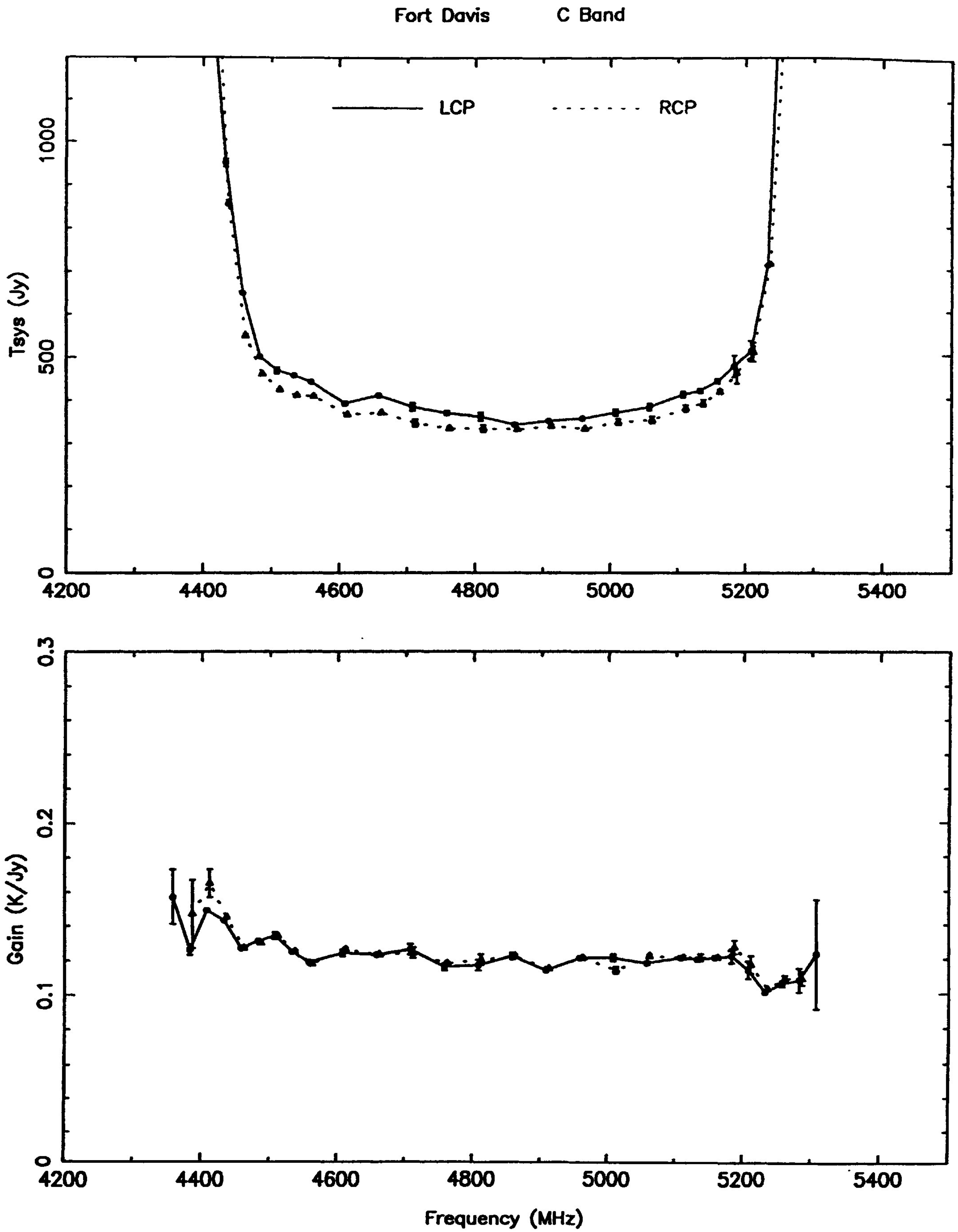
C Band

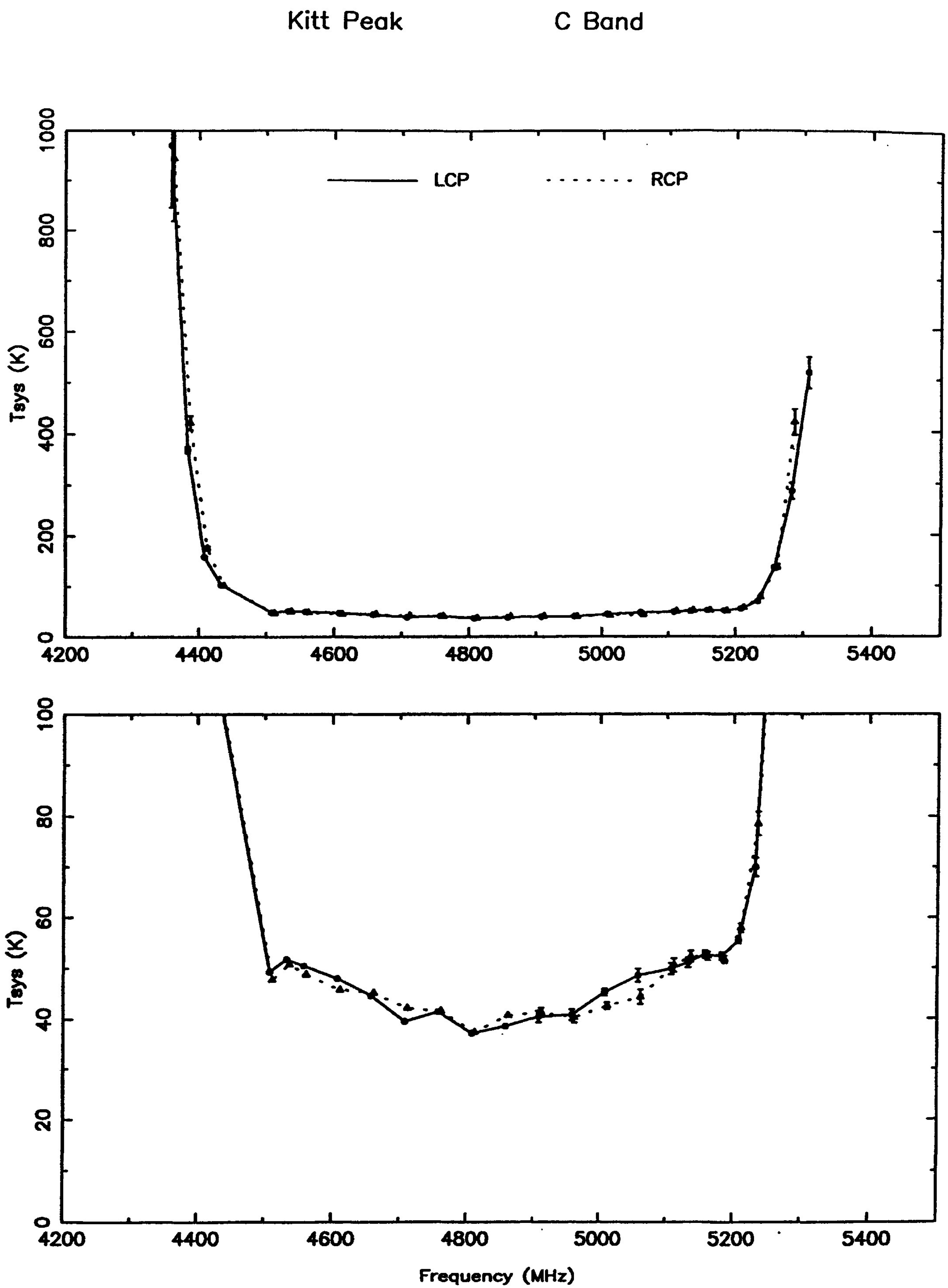
Data were taken at Fort Davis, Kitt Peak, Los Alamos, and Pie Town between January and May 1990. Measurements were made between 4000 and 5650 MHz with 16 MHz channels. The sources 3C123, 3C274, 3C353, and NGC7027 were used at elevations $> 30°$. For clarity the RCP data are plotted at 4 MHz higher than the true observation frequency.

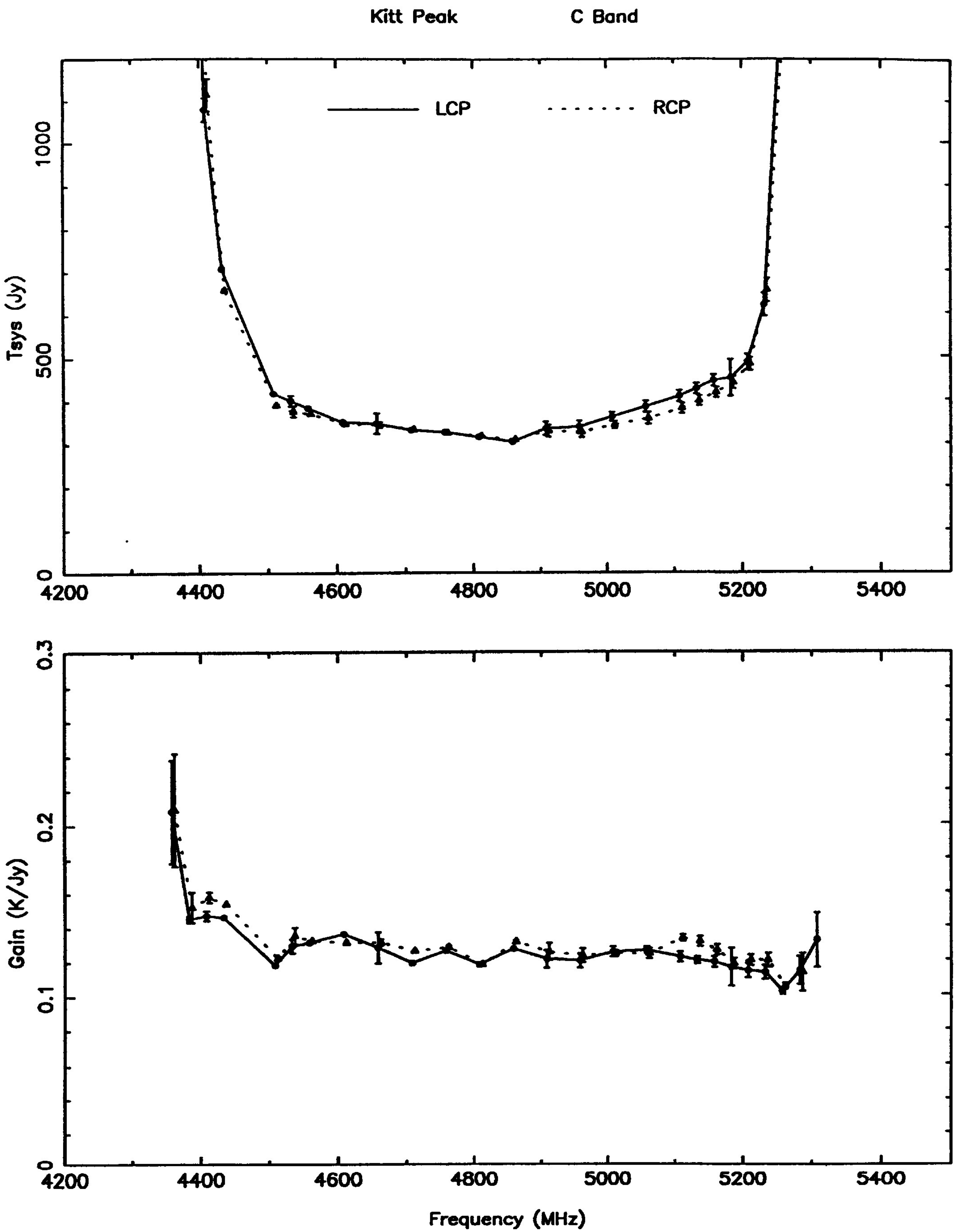
The lower and upper frequency limits (defined as points where the system temperature in Jy has doubled) are about 4450 and 5220 MHz, respectively.

Fort Davis C Band



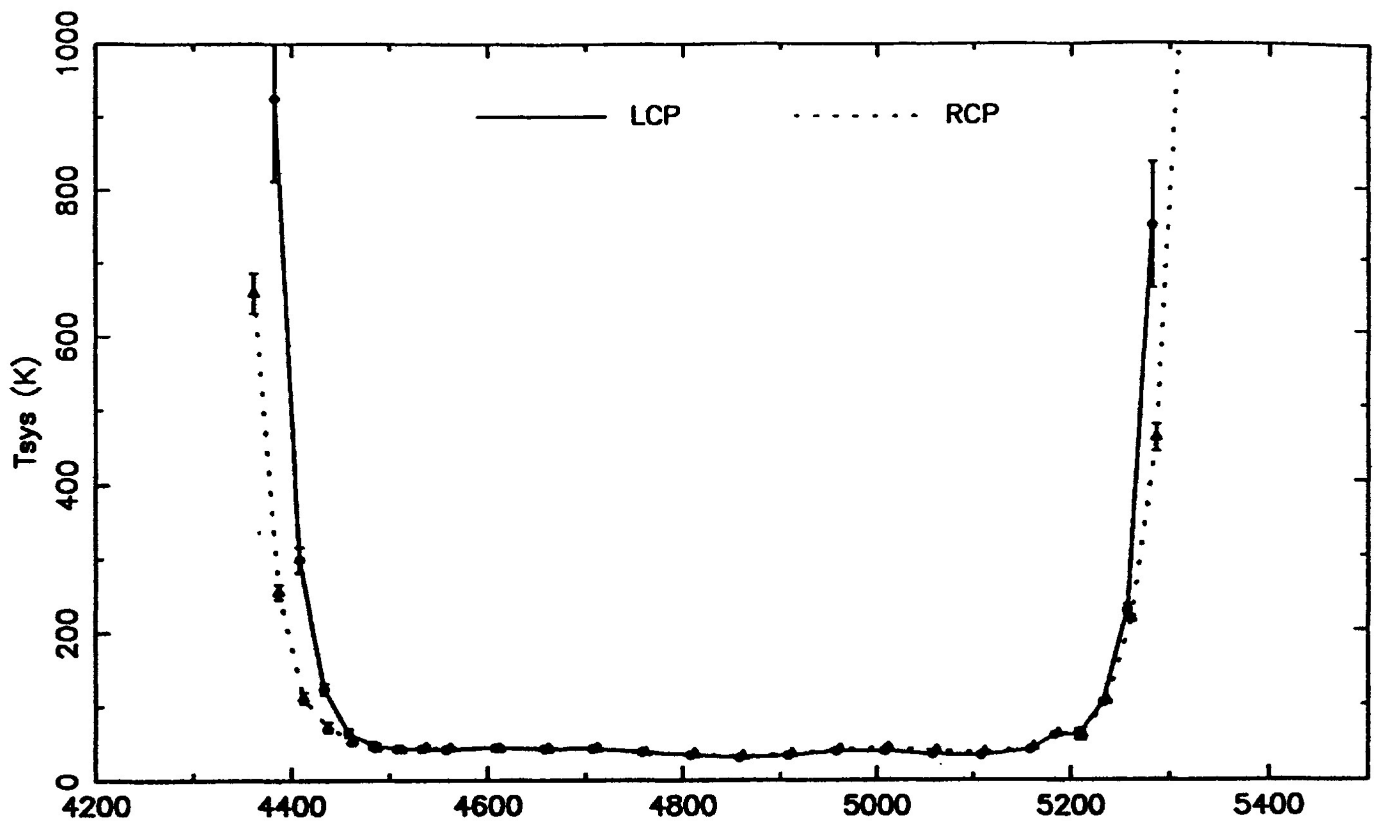

Fort Davis C Band
LCP
RCP
Tsys (Jy)
0
500
1000
4200
4400
4600
4800
5000
5200
5400
Gain (K/Jy)
0
0.1
0.2
0.3
4200
4400
4600
4800
5000
5200
5400
Frequency (MHz)

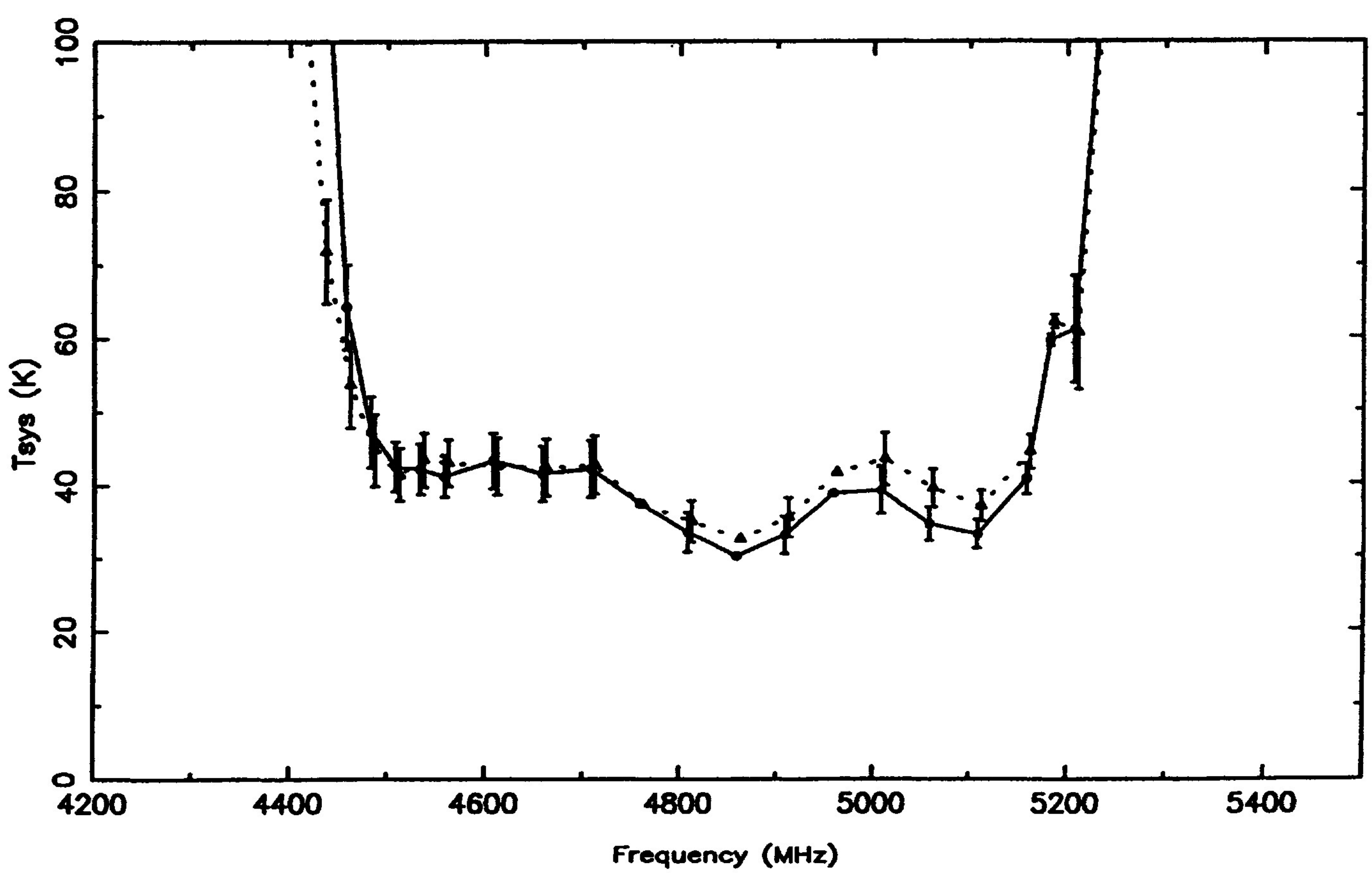

Kitt Peak
C Band
LCP
RCP
Tsys (K)
Tsys (K)
Frequency (MHz)

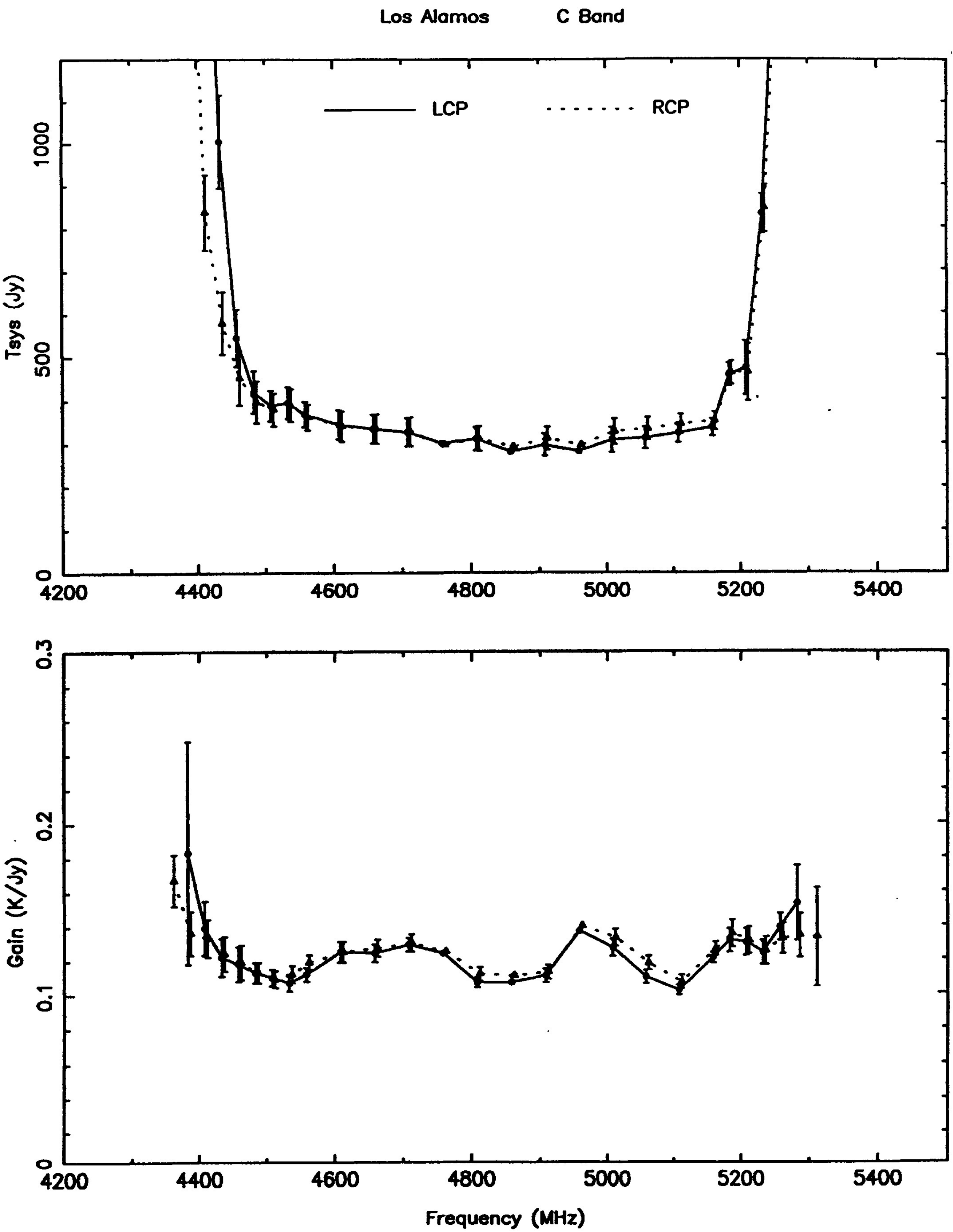


Kitt Peak
C Band
LCP
RCP
Tsys (Jy)
1000
500
0
4200
4400
4600
4800
5000
5200
5400
0.3
0.2
0.1
Gain (K/Jy)
Frequency (MHz)

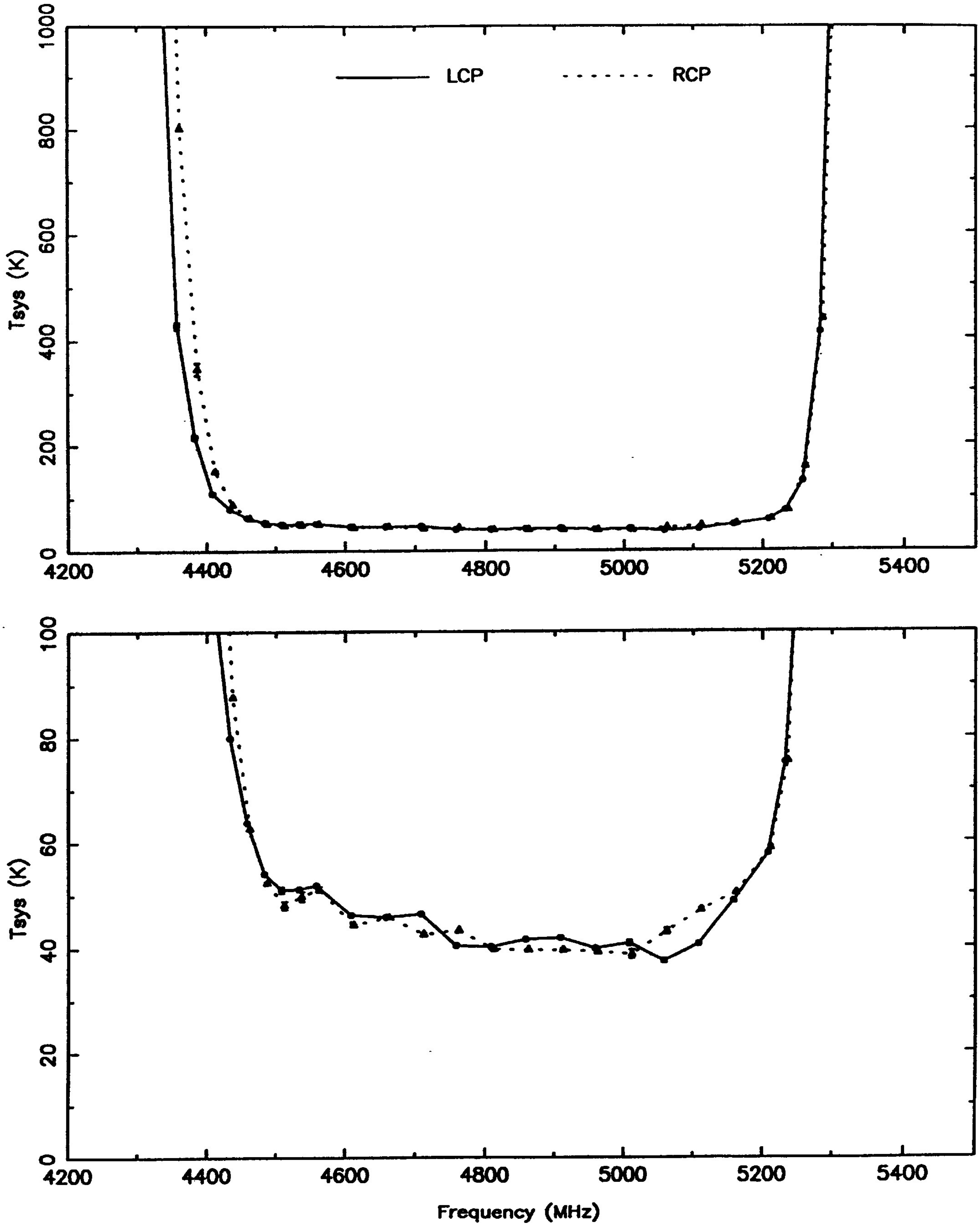
Los Alamos C Band

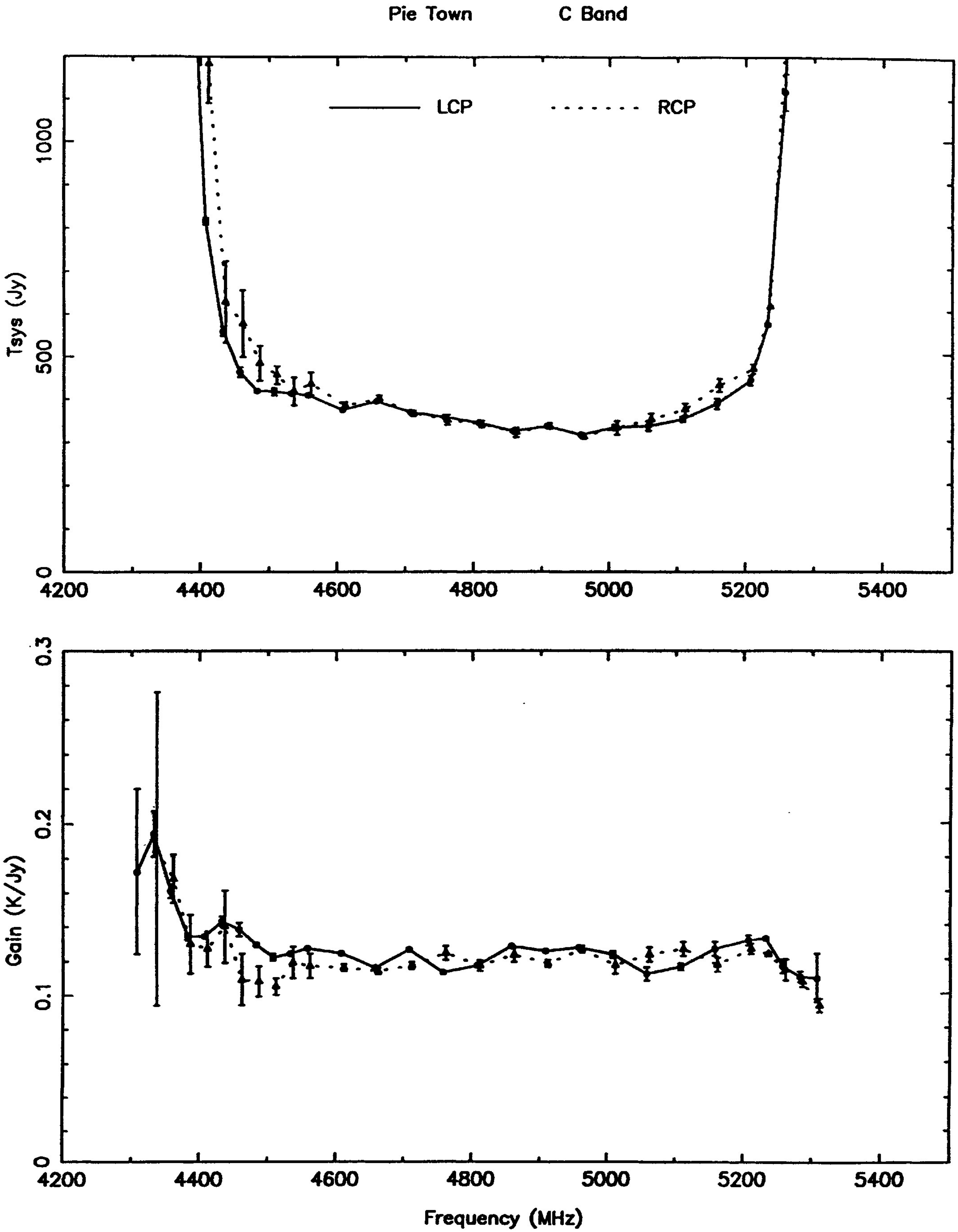





Los Alamos C Band
LCP
RCP
Tsys (Jy)
0
500
1000
4200
4400
4600
4800
5000
5200
5400
Gain (K/Jy)
0
0.1
0.2
0.3
4200
4400
4600
4800
5000
5200
5400
Frequency (MHz)

Pie Town C Band





Pie Town C Band
LCP
RCP
Tsys (Jy)
0
500
1000
4200
4400
4600
4800
5000
5200
5400
Gain (K/Jy)
0
0.1
0.2
0.3
4200
4400
4600
4800
5000
5200
5400
Frequency (MHz)

X Band

Data were taken in both the "Ellipsoid Retracted" and "Ellipsoid Extended" modes. The "Ellipsoid Retracted" mode data were taken at Fort Davis, Kitt Peak, Los Alamos, and Pie Town in October and November 1991. Measurements were made between 7400 and 9400 MHz with 16 MHz channels. The sources 3C274 and DR21 were used at elevations $> 30°$. For clarity in the final plots, the RCP and LCP observations were made at an offset of 1 MHz from each other.

The lower and upper frequency limits appear to be 7800 and 9000 MHz, respectively (points where T_{sys}(Jy) is twice nominal). The response below 7660 MHz is more complex than the plots suggest; measurements at 7448 MHz (FD), 7482 MHz (KP, LA), 7517 MHz (KP), 7623 MHz (FD, PT), and 7658 MHz (FD) failed completely.

An LO setting of 9900 MHz appears to be problematic. This setting is responsible for the large system temperatures for Los Alamos at 8898, 8933, 8968, 9002, and 9038 MHz, and also for persistent failures for Kitt Peak and Pie Town at these same frequencies. Yet this setting seems o.k. at Fort Davis. We note that this LO setting is outside the nominal bandpass (7150 - 9650 MHz) of the LO filter.

Similarly an LO setting of 6900 MHz causes problems for the LCP channel at Kitt Peak. This is evidenced by high system temperatures at 7798, 7833, and 7868 MHz, and by persistent failures for all other sky frequencies using this LO setting. This LO setting seems fine for the RCP channel at Kitt Peak, and for all other stations. Again, this LO setting is outside the nominal bandpass (7150 - 9650 MHz) of the LO filter.

Both Fort Davis and Kitt Peak have slightly high system temperatures at 7903, 8103, 8403, and 8603 MHz. These are always associated with BBC#8, but it would be surprising for BBC#8 to have problems at two different stations. The cause of this effect is unclear.

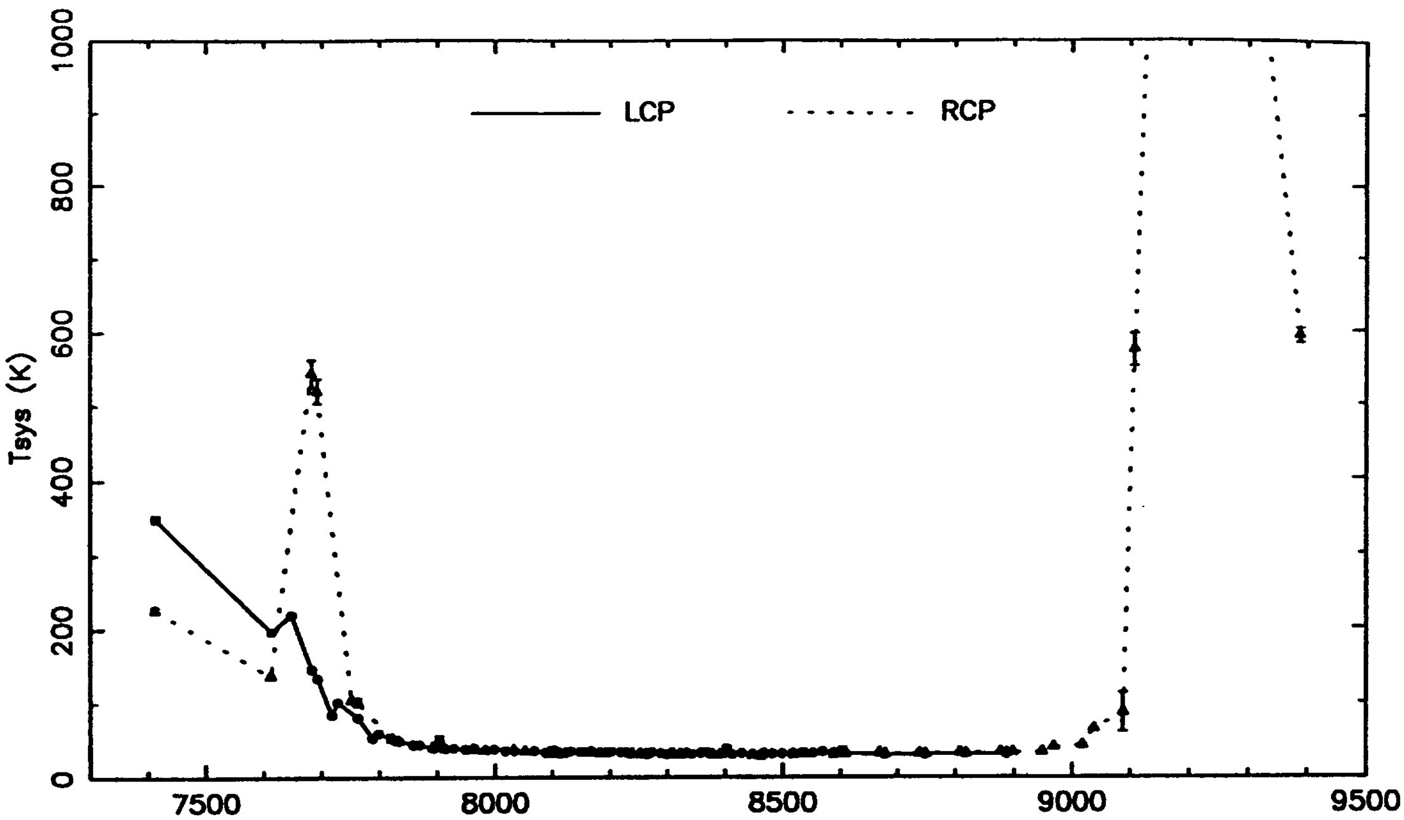
The Pie Town data show LCP system temperature spikes at 7963 and 8446 MHz, which were seen in all observations made over a few hours; these are probably caused by interference. In addition, observations at 8463 MHz had persistent failures, again suggesting interference. The large error bar at 8309 MHz LCP is thought to be caused by sporadic problems with BBC#6; perhaps this data should have been edited out.

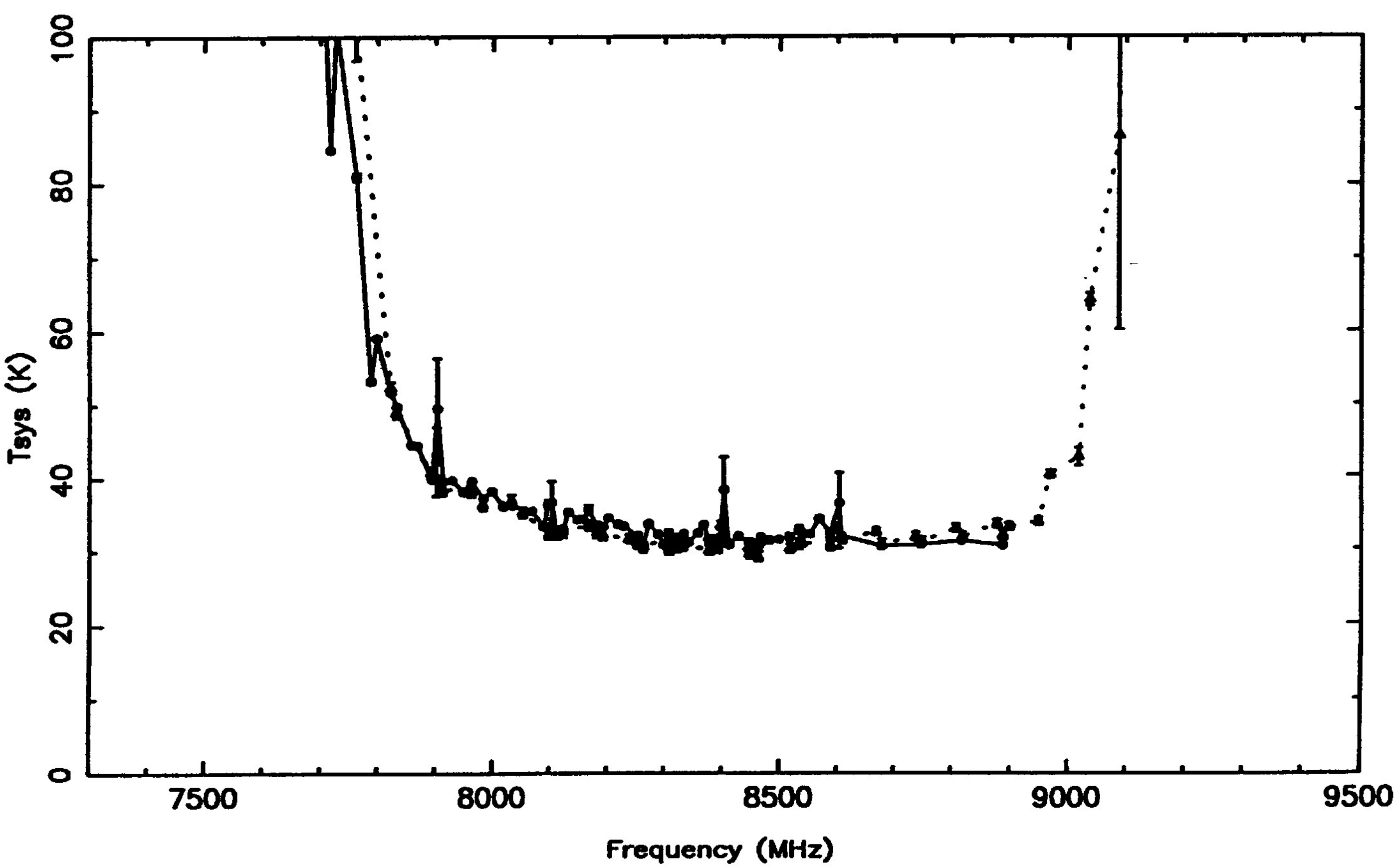
The Fort Davis measurements are less incomplete above 8600 MHz, and no LCP measurements were made above 8900 MHz.

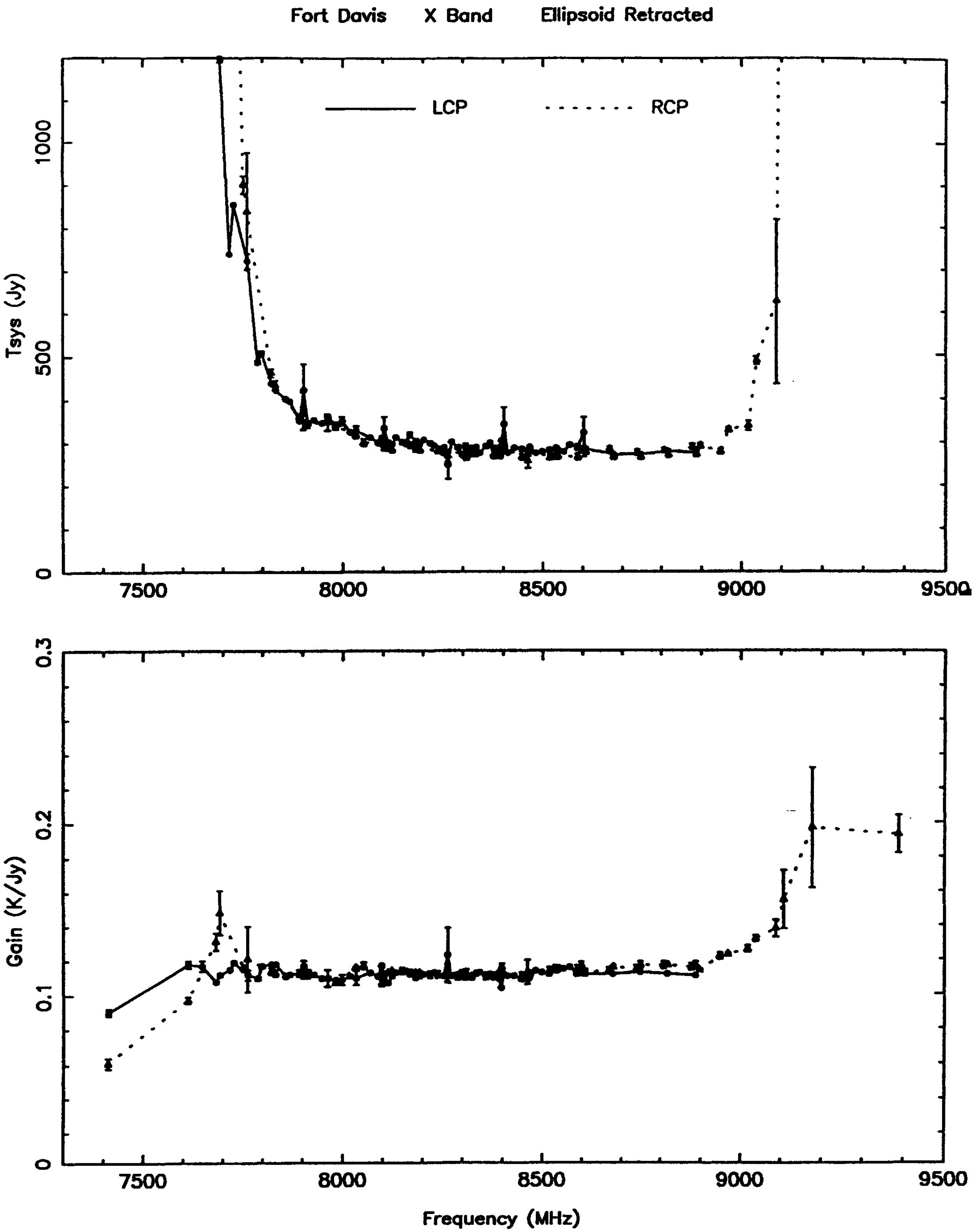
Data for the "Ellipsoid Extended" mode were taken only at Pie Town using 3C84. The flux of 3C84 was determined from pointing observations taken during Oct. and Nov. 1991; these gave a mean flux of 31.5 Jy, and a dispersion of 0.5 Jy. (Ideally, the sources used for the "Retracted" mode would have been used, but the observing schedule did not allow this.) The observation method was otherwise identical to the "Retracted" mode data.

The measured bandpass shape is identical for the "Extended" and "Retracted" modes. The only major difference is that the system temperature in °K is ~8% higher when the ellipsoid is "Extended." The gain also appears perhaps ~2% lower when the ellipsoid is "Extended," but this difference is close to the uncertainty on our flux for 3C84.

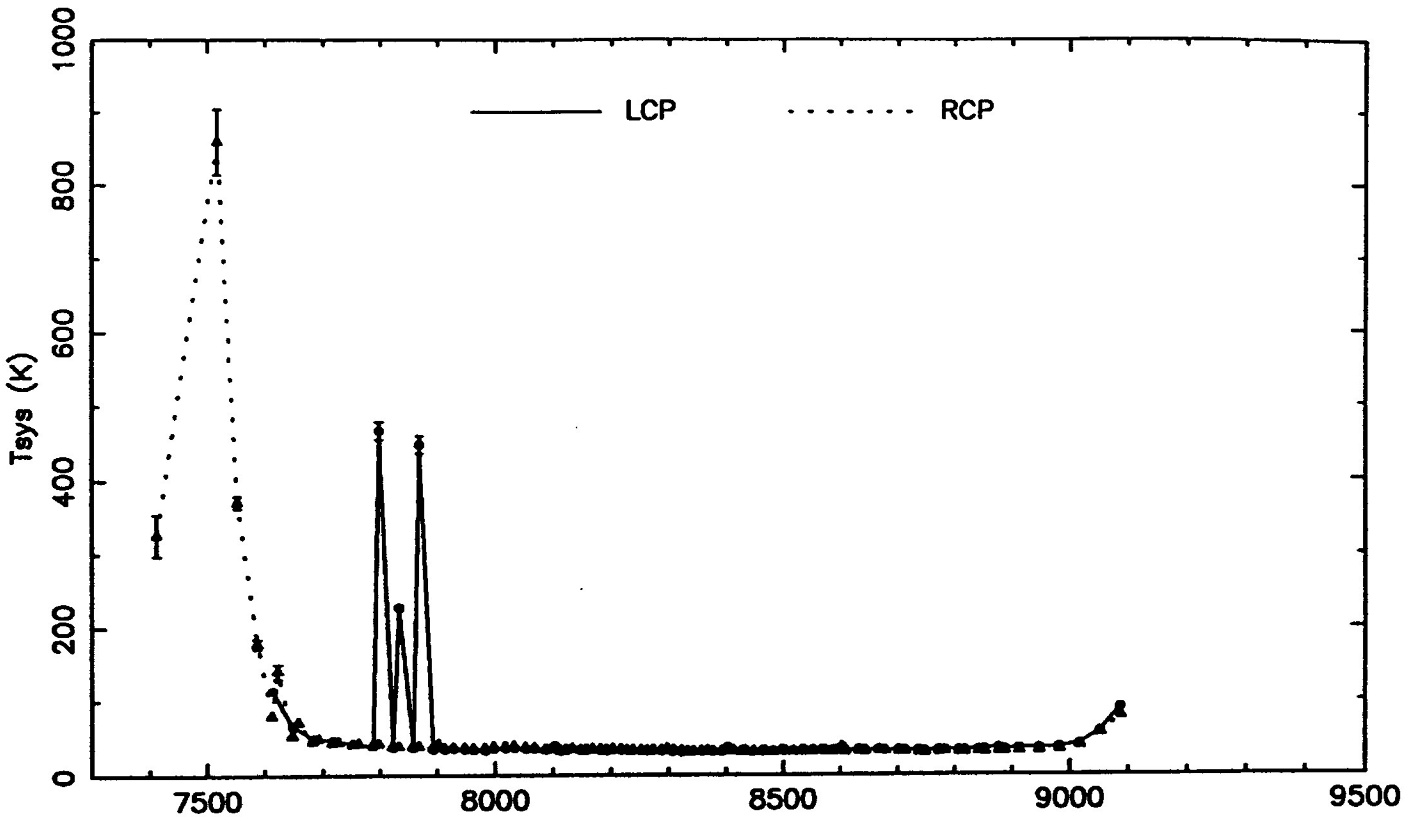
Fort Davis X Band Ellipsoid Retracted

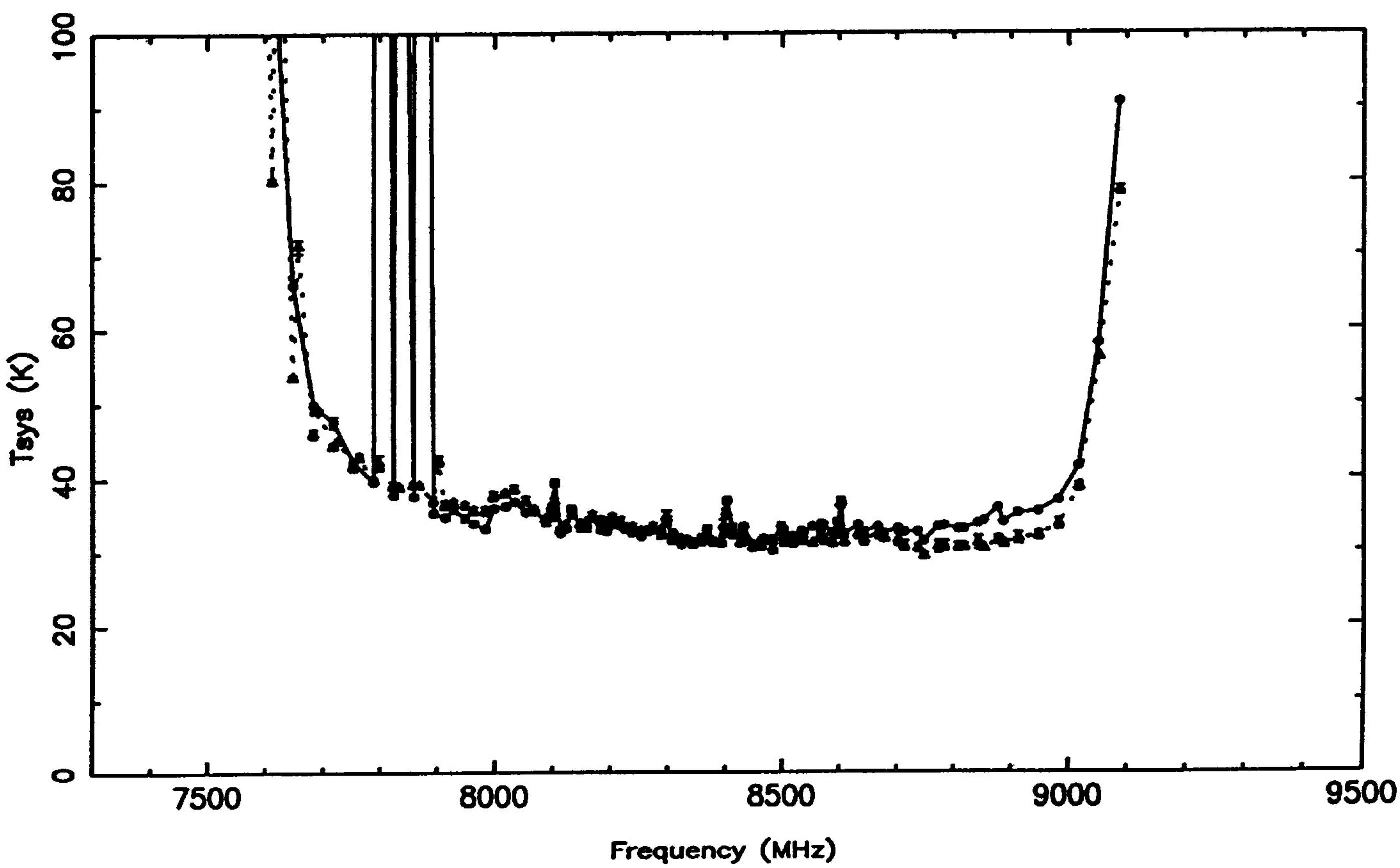


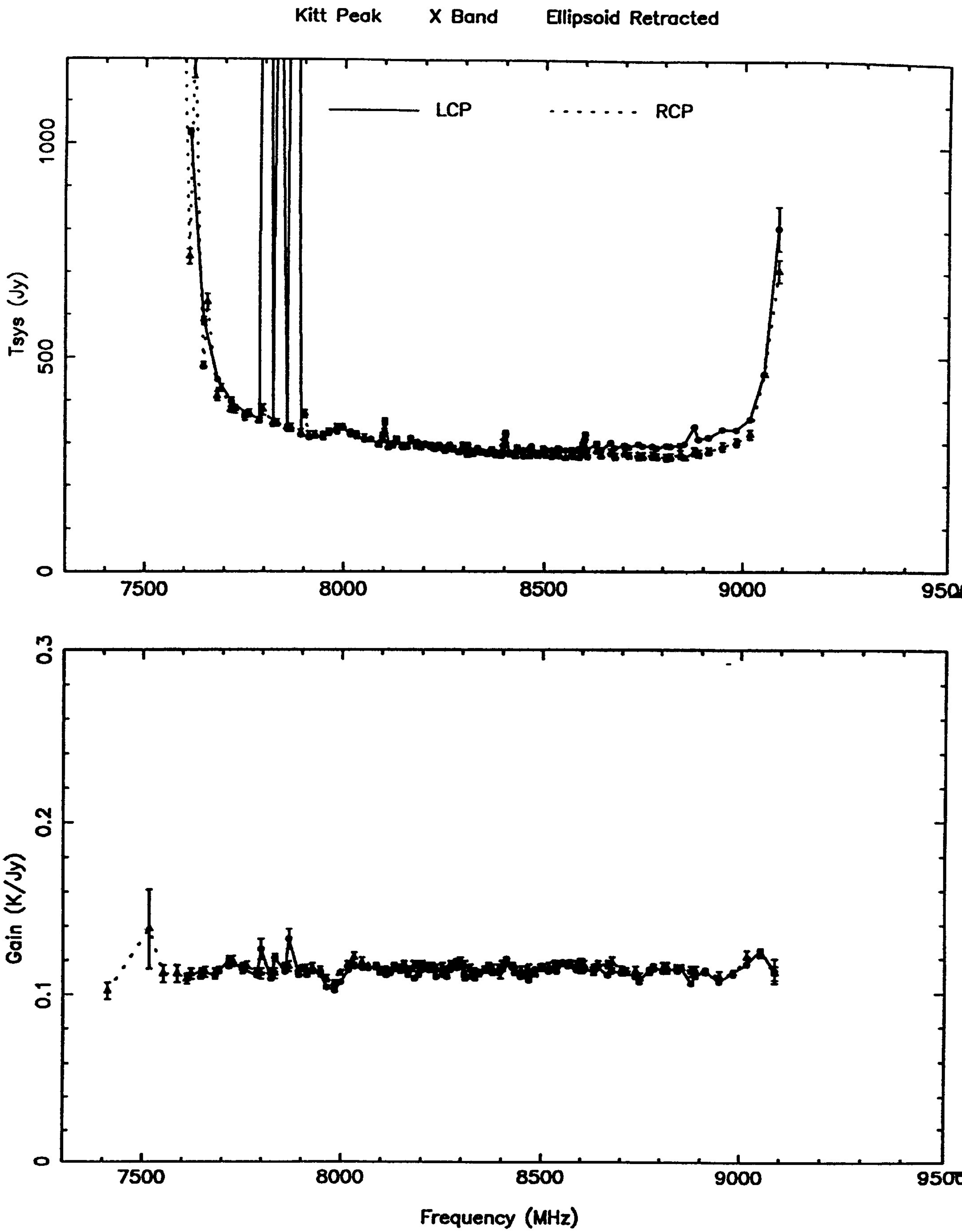



Fort Davis X Band Ellipsoid Retracted
LCP
RCP
Tsys (Jy)
0
500
1000
7500
8000
8500
9000
9500
Gain (K/Jy)
0
0.1
0.2
0.3
7500
8000
8500
9000
9500
Frequency (MHz)

Kitt Peak X Band Ellipsoid Retracted

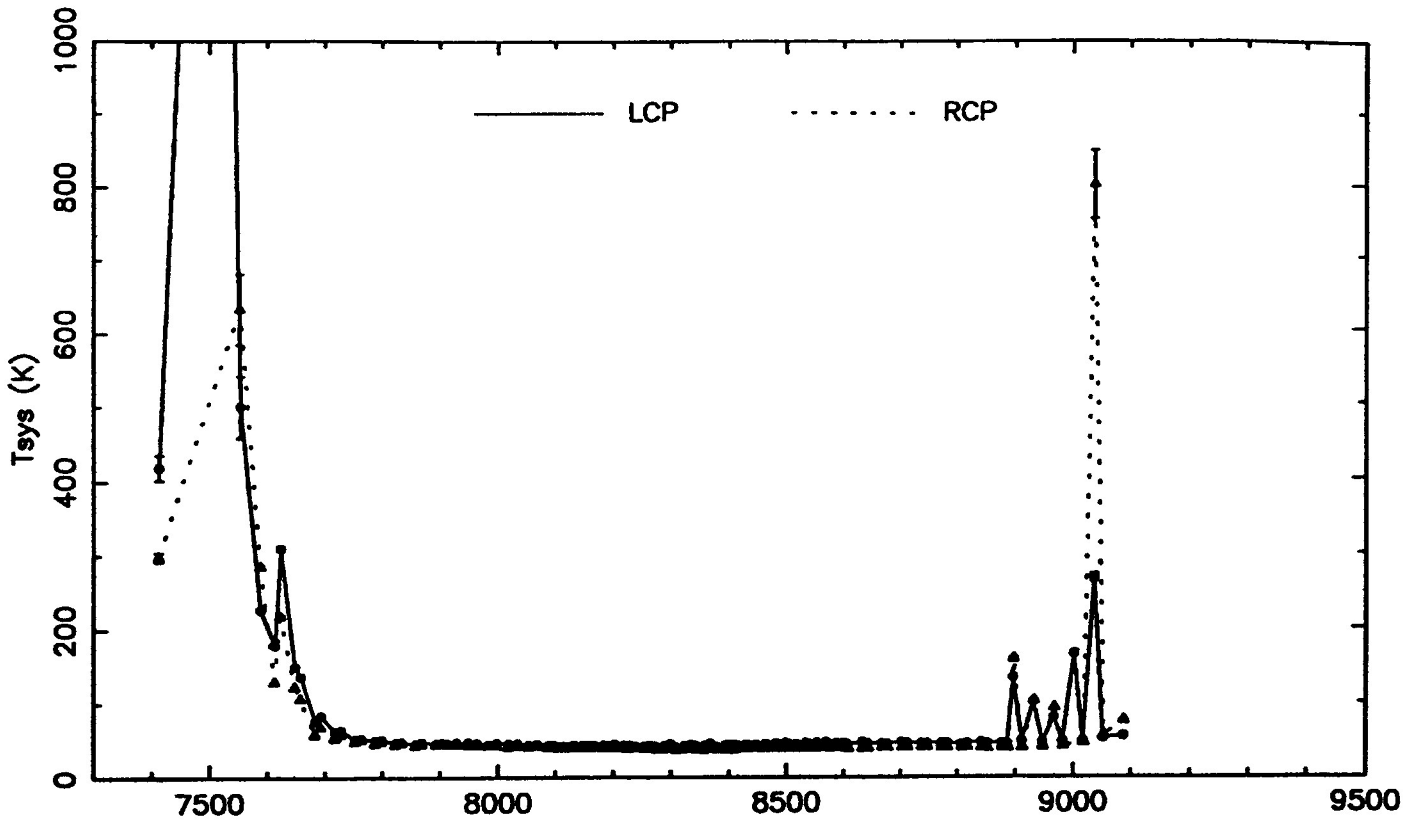


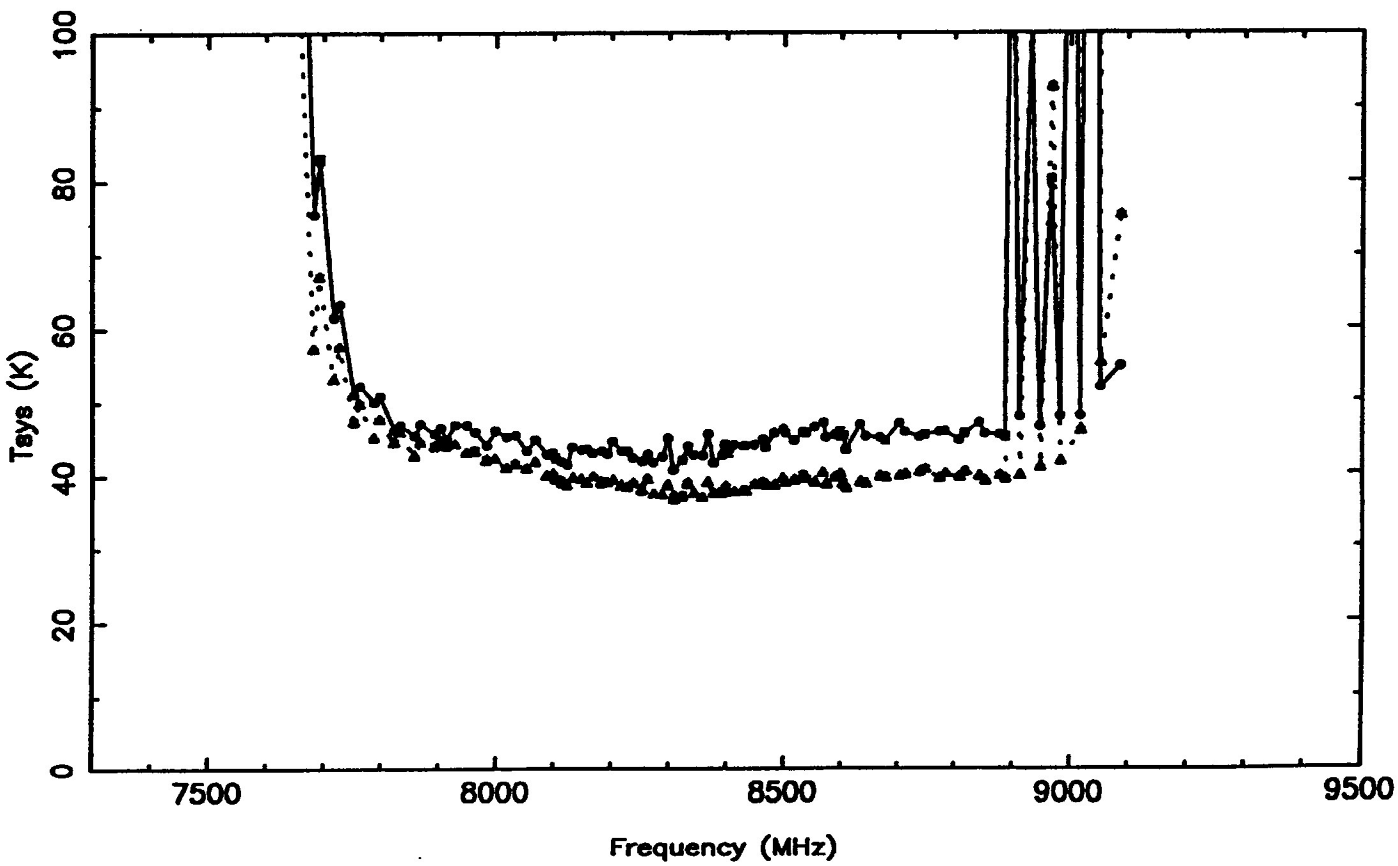


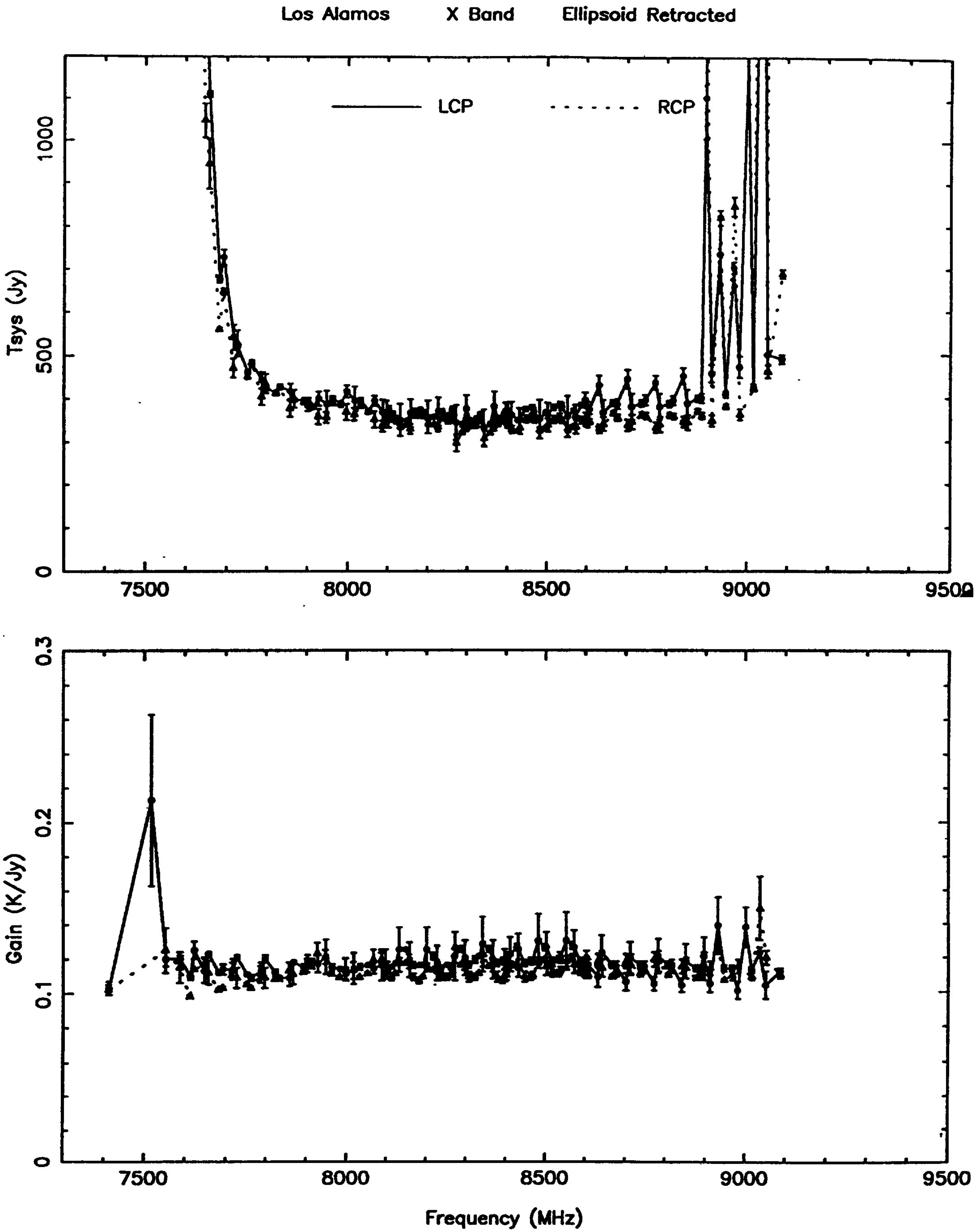


Kitt Peak
X Band
Ellipsoid Retracted
LCP
RCP
Tsys (Jy)
1000
500
0
7500
8000
8500
9000
9500
Gain (K/Jy)
0.3
0.2
0.1
0
7500
8000
8500
9000
9500
Frequency (MHz)

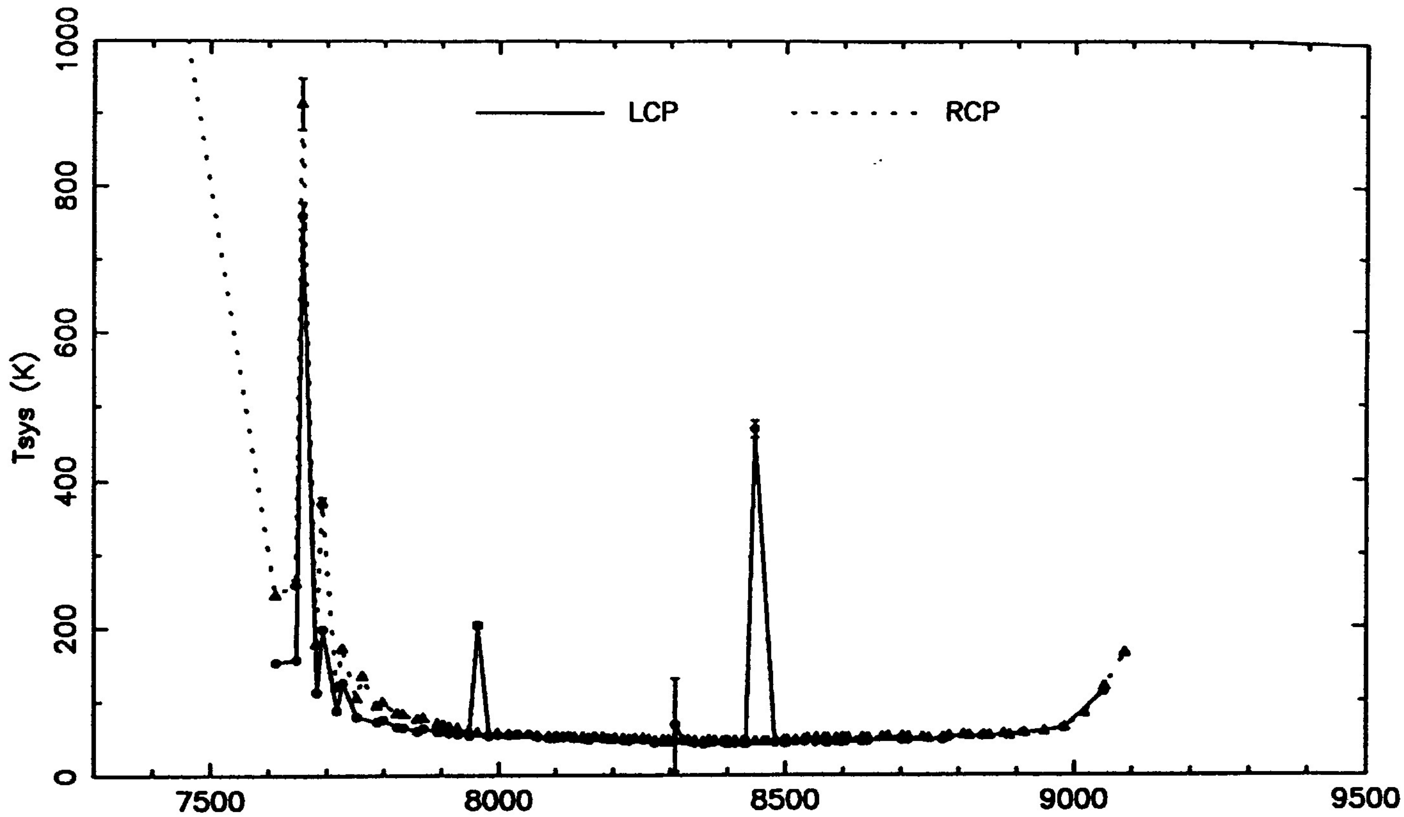
Los Alamos X Band Ellipsoid Retracted

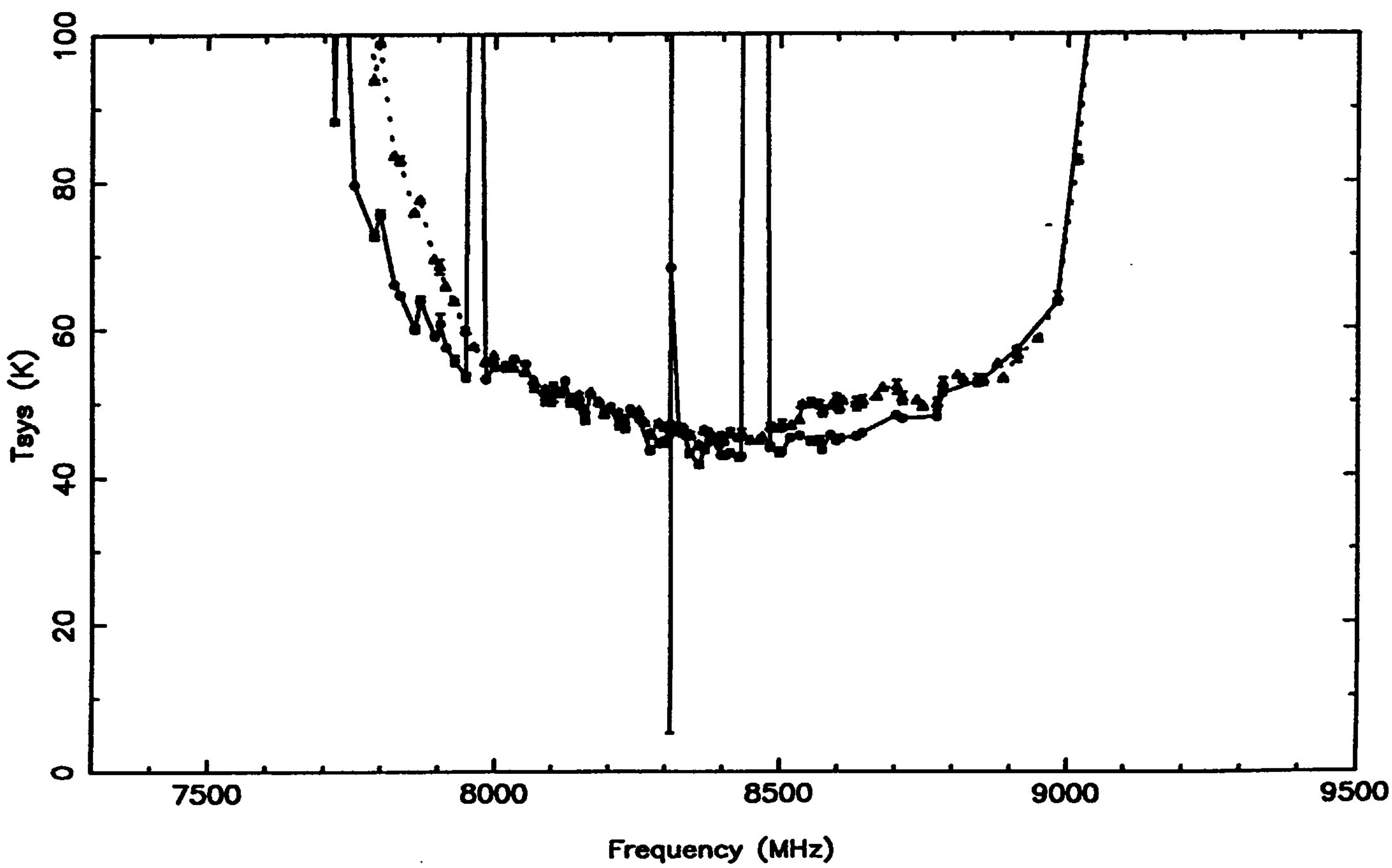




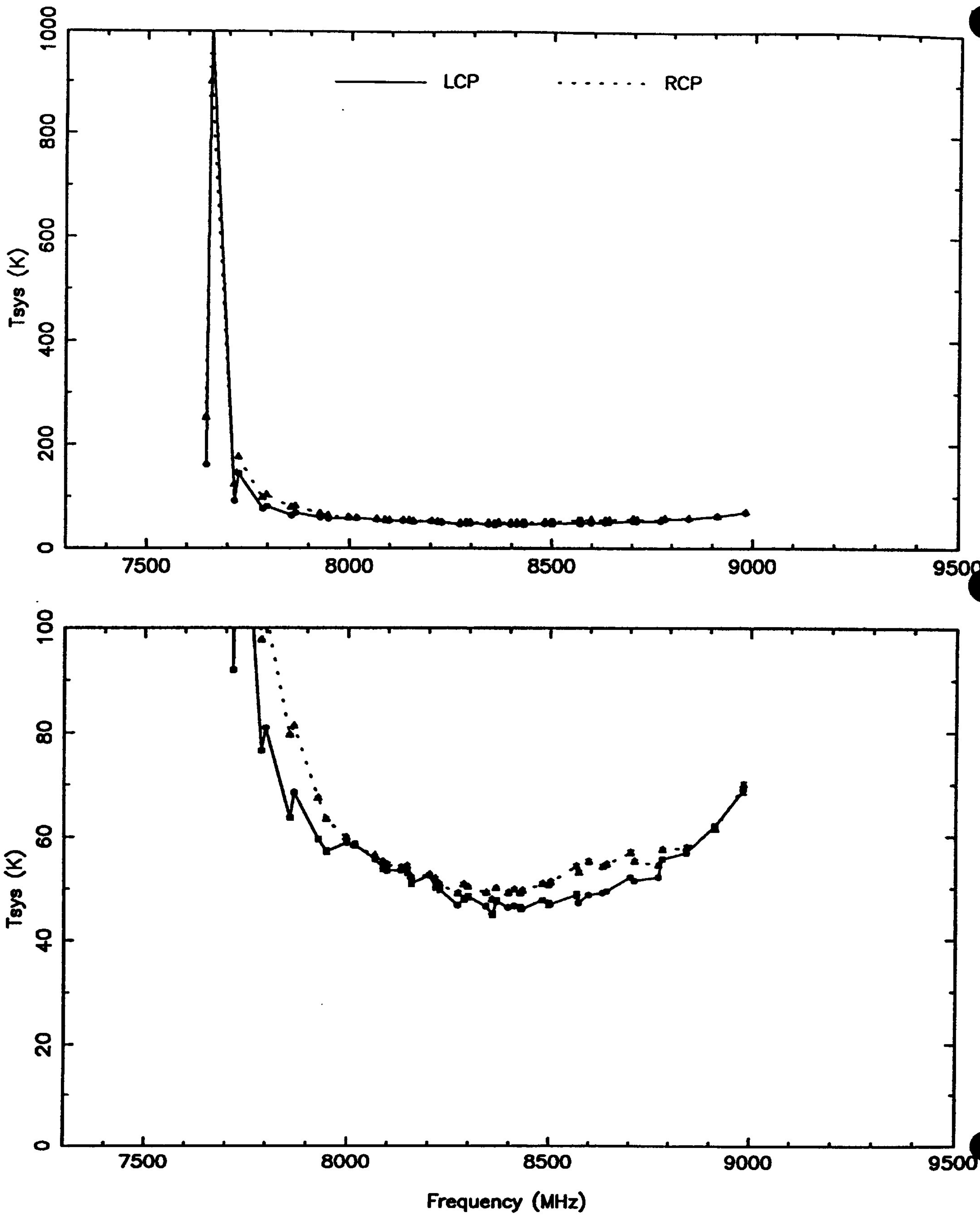

Los Alamos X Band Ellipsoid Retracted
LCP
RCP
Tsys (Jy)
0
500
1000
7500
8000
8500
9000
9500
Gain (K/Jy)
0
0.1
0.2
0.3
7500
8000
8500
9000
9500
Frequency (MHz)

Pie Town X Band Ellipsoid Retracted

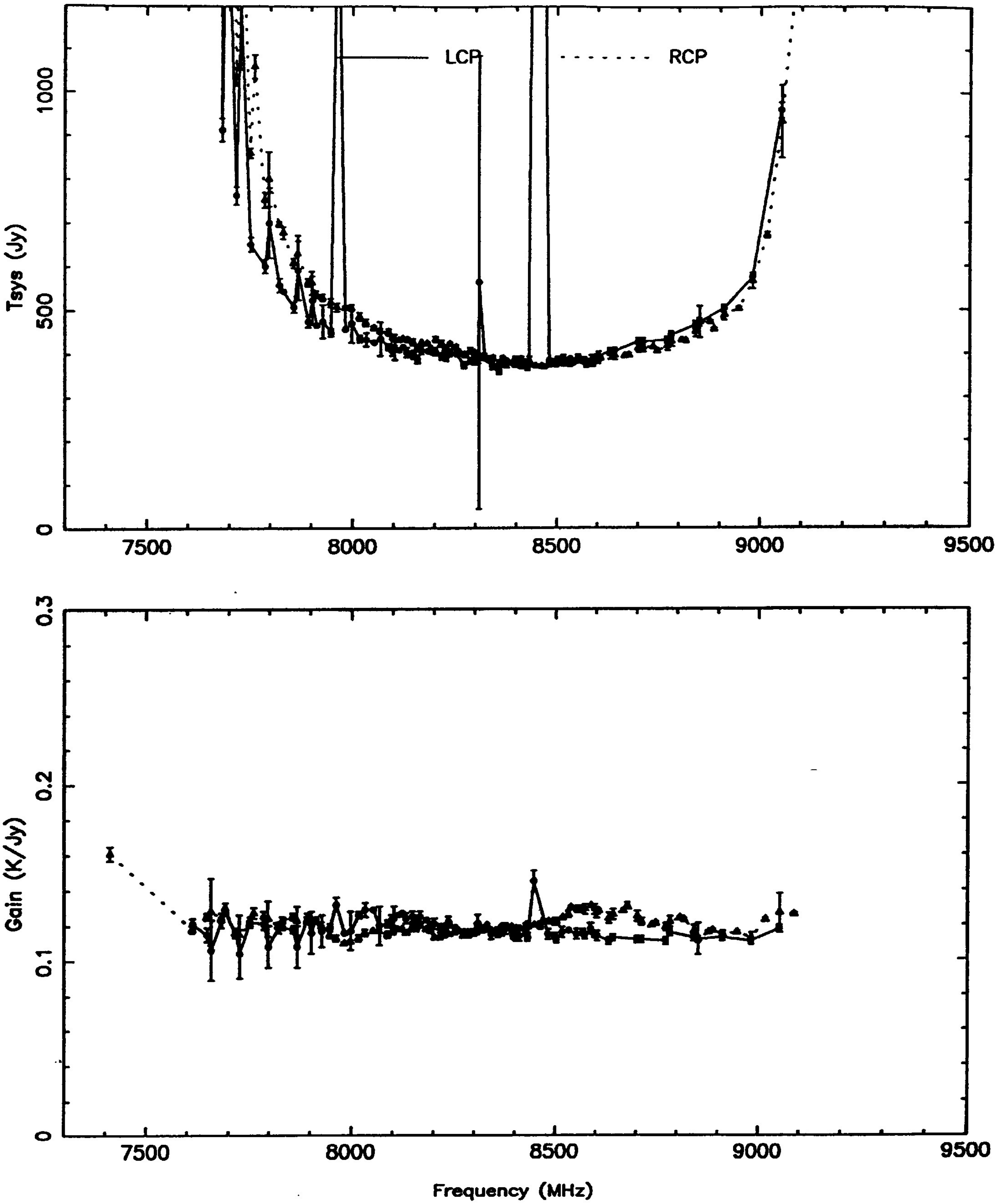


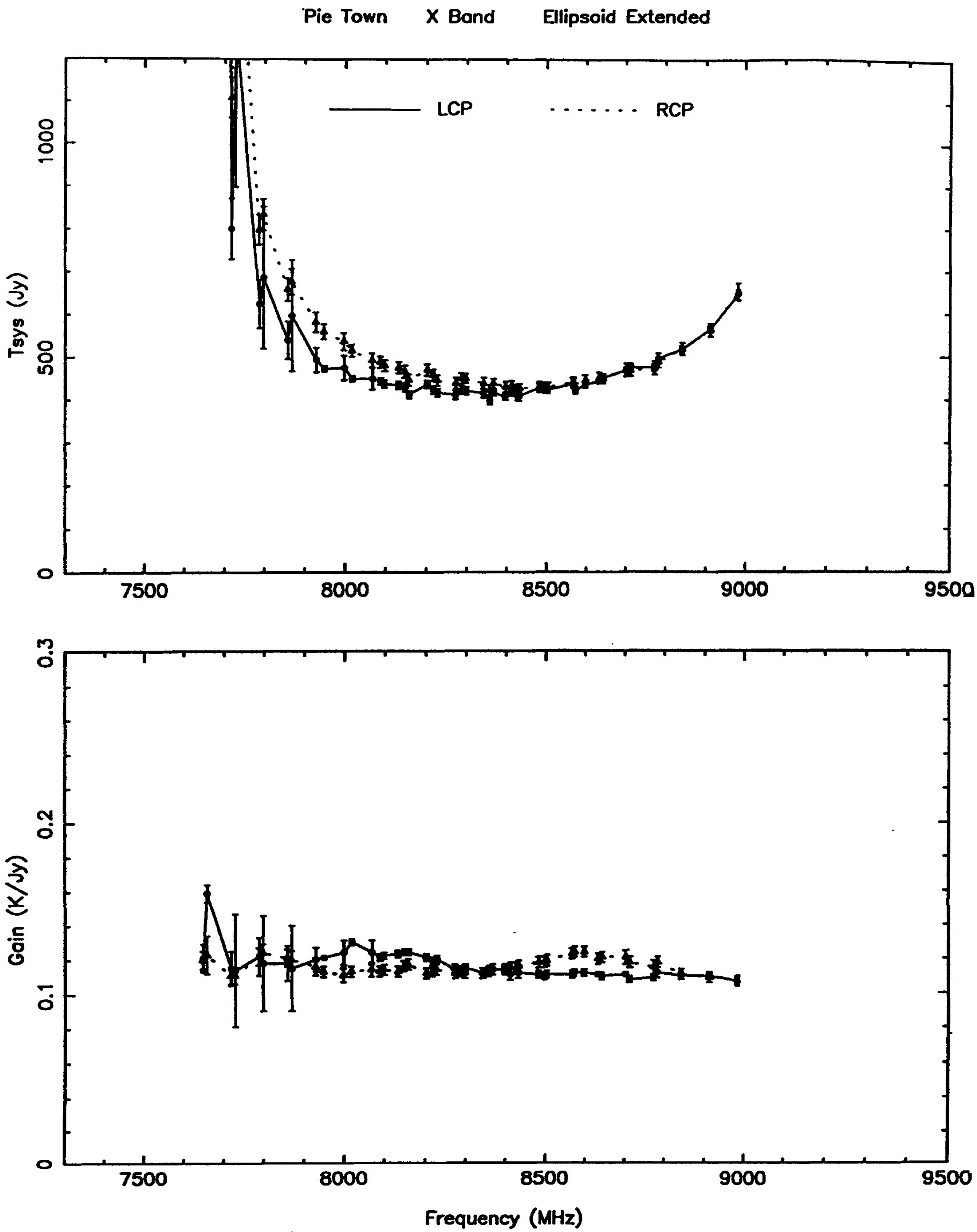


Pie Town X Band Ellipsoid Extended



Pie Town X Band Ellipsoid Retracted




Pie Town X Band Ellipsoid Extended
LCP
RCP
Tsys (Jy)
0
500
1000
7500
8000
8500
9000
9500
Gain (K/Jy)
0
0.1
0.2
0.3
7500
8000
8500
9000
9500
Frequency (MHz)

K Band

Measurements were made at Fort Davis, Kitt Peak, and Los Alamos. in March and April 1990 between 20000 and 25800 MHz with 16 MHz channels. The sources 3C84, 3C274, 3C345, and DR21 were used at elevations $> 40°$. For clarity, the RCP data are plotted at 20 MHz higher than the true observation frequency. The fluxes of 3C84 and 3C345 were determined relative to the other calibrators by observing all the sources at several frequencies at similar elevations. We adopted fluxes of 41.3 and 6.6 Jy, respectively, for 3C84 and 3C345.

The lower and upper frequency limits (T_{sys}(Jy) increase by factor of two) are 20500 and 24800 MHz, respectively for most of data sets. The RCP bandpass at Los Alamos has an anomalous upper limit of 24300 MHz.

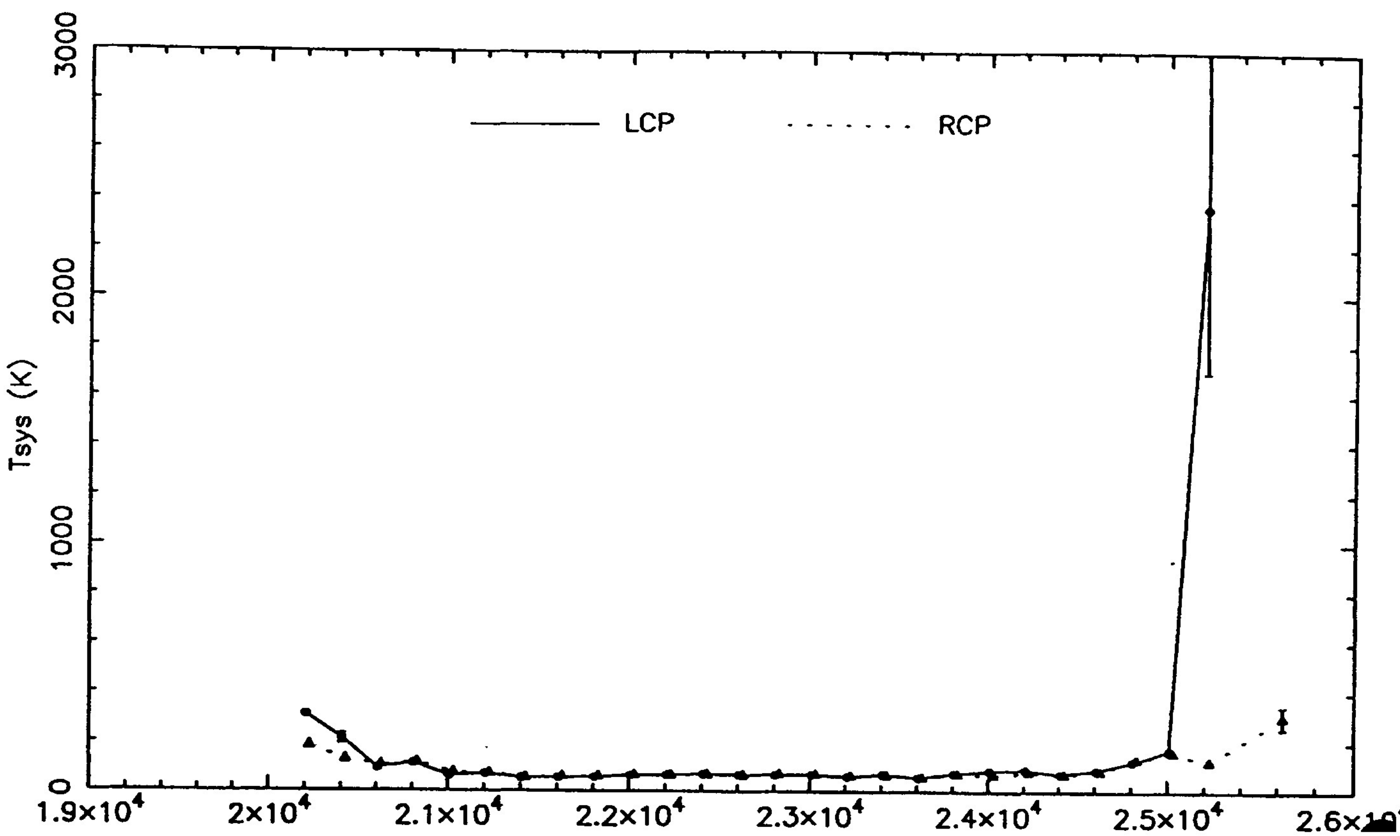
The Los Alamos RCP bandpass is anomalous in that the system temperature increases rapidly above 23000 MHz, whereas the other systems show a flat system temperature curve until about 24500 MHz. This effect was seen for several different sources for observations made over 16 hours. It seems likely to be caused by attenuation or other problem in the RCP RF system.

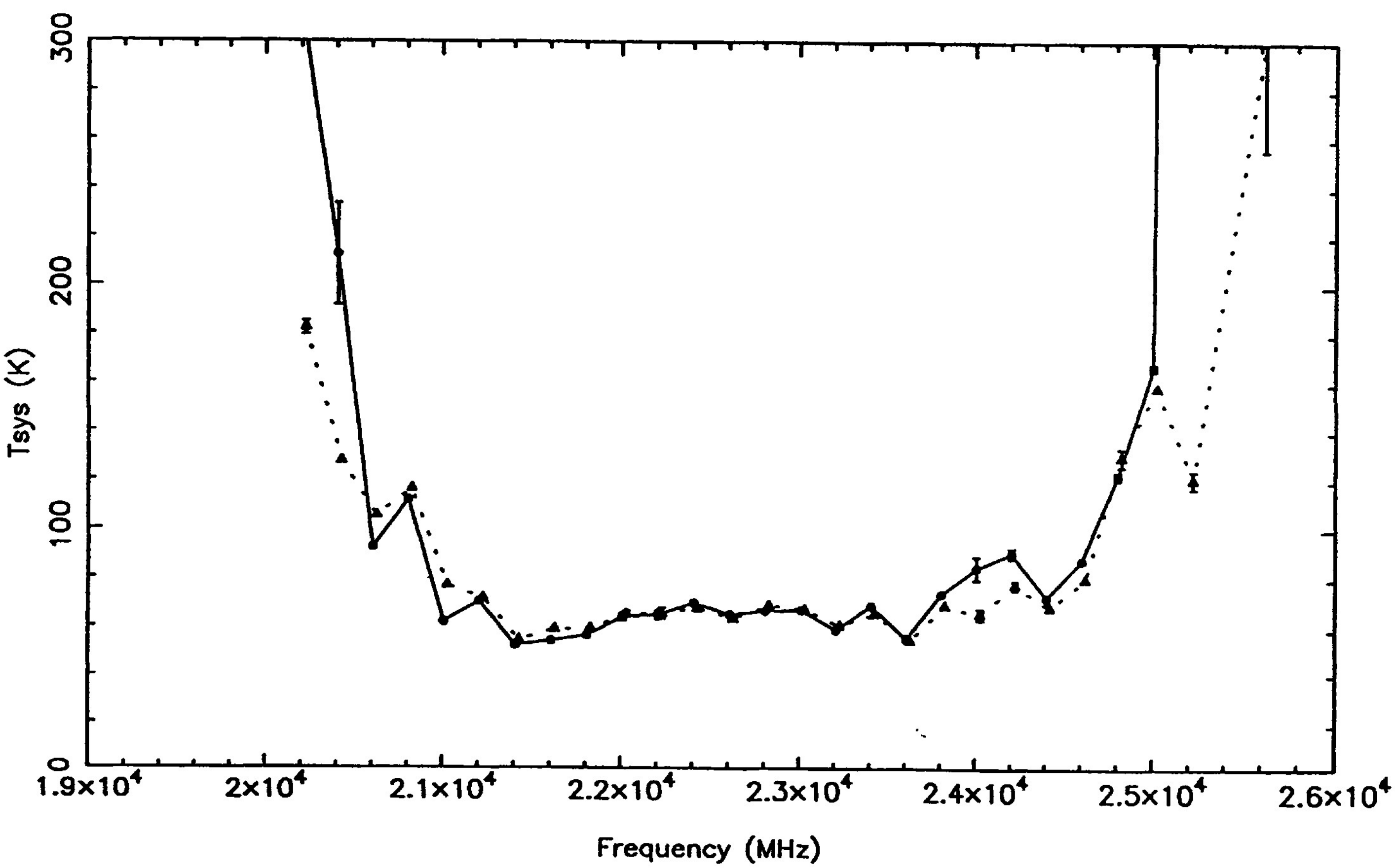
Kitt Peak shows high LCP system temperatures at 23608 and 23808 MHz. This effect was seen for all observations of several sources over several days. It might be a problem with the RF system, or interference.

(Missing Los Alamos data at 24008 MHz are caused by the elevation limit imposed on the data.)

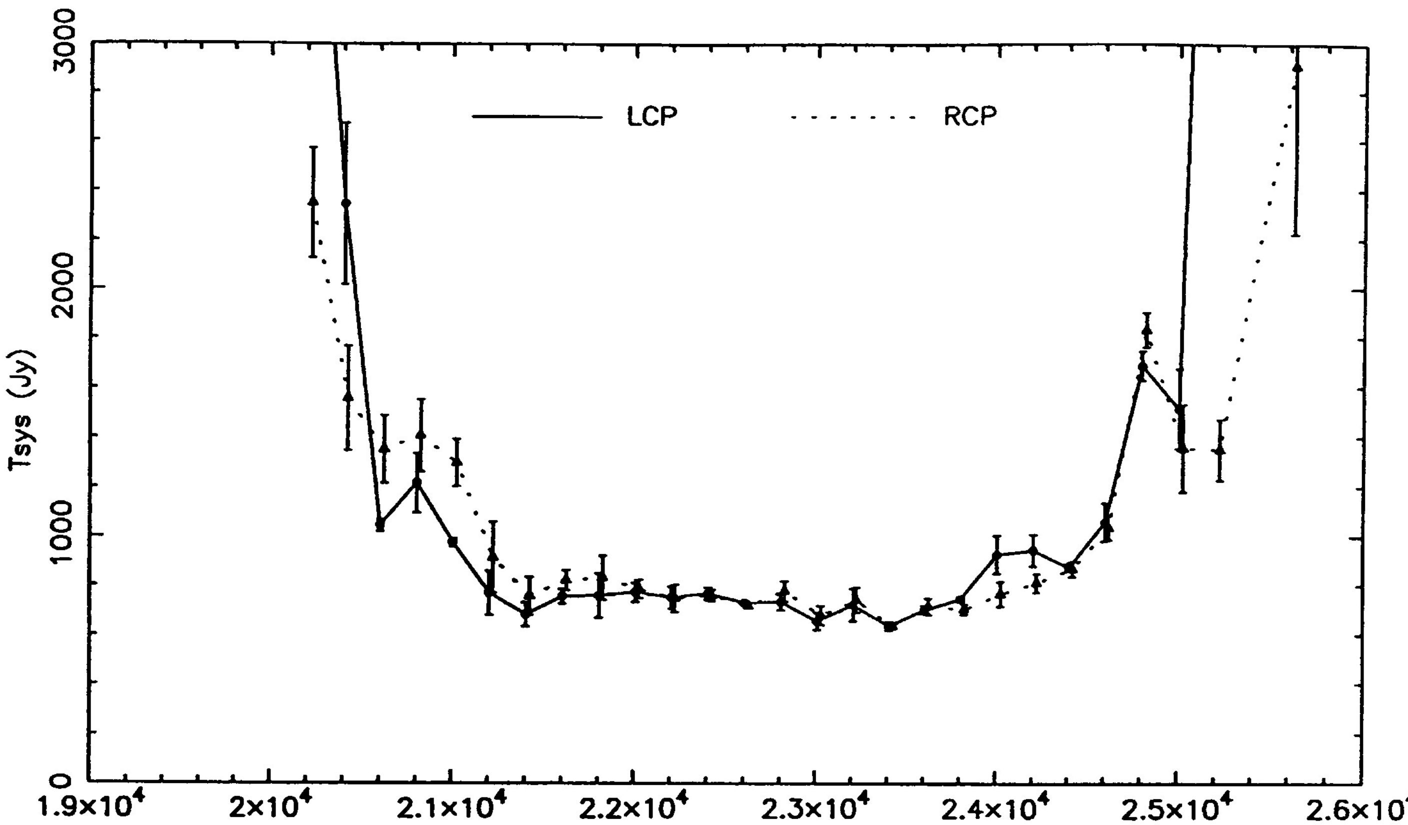
All three stations show an abrupt increase in the gain above ~25000 MHz; this might be caused by attenuation of the calibrator noise signal.

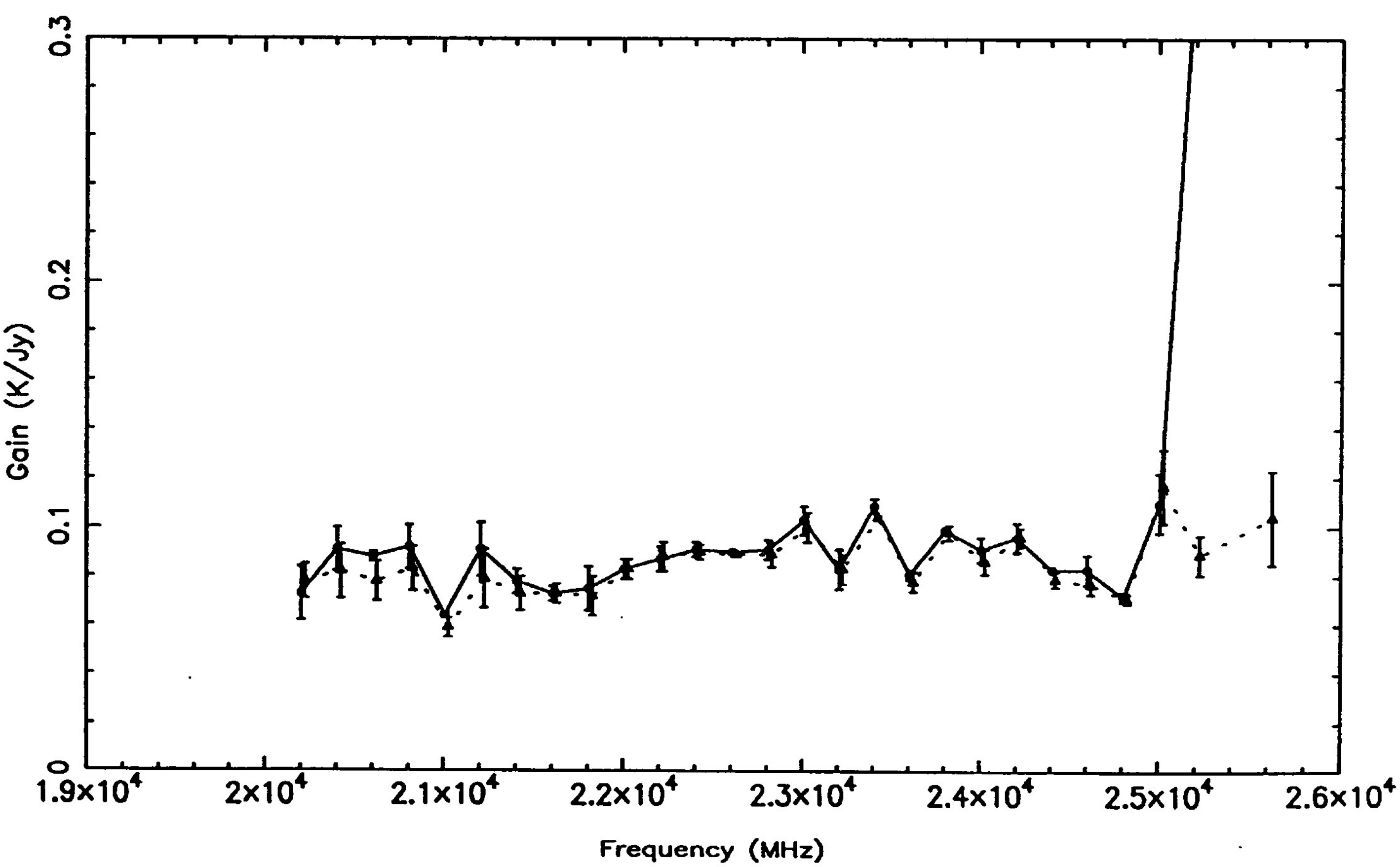
Fort Davis K Band



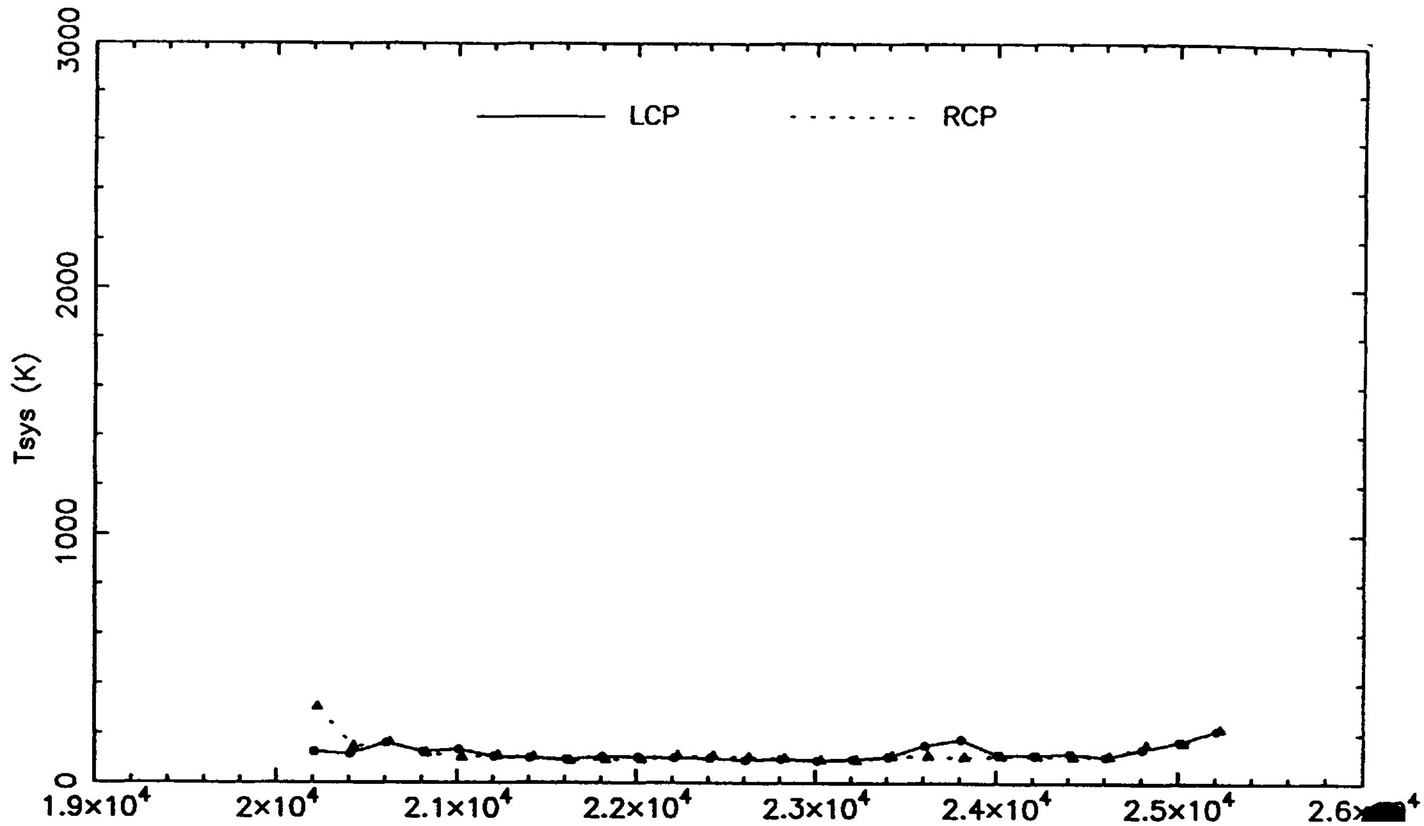


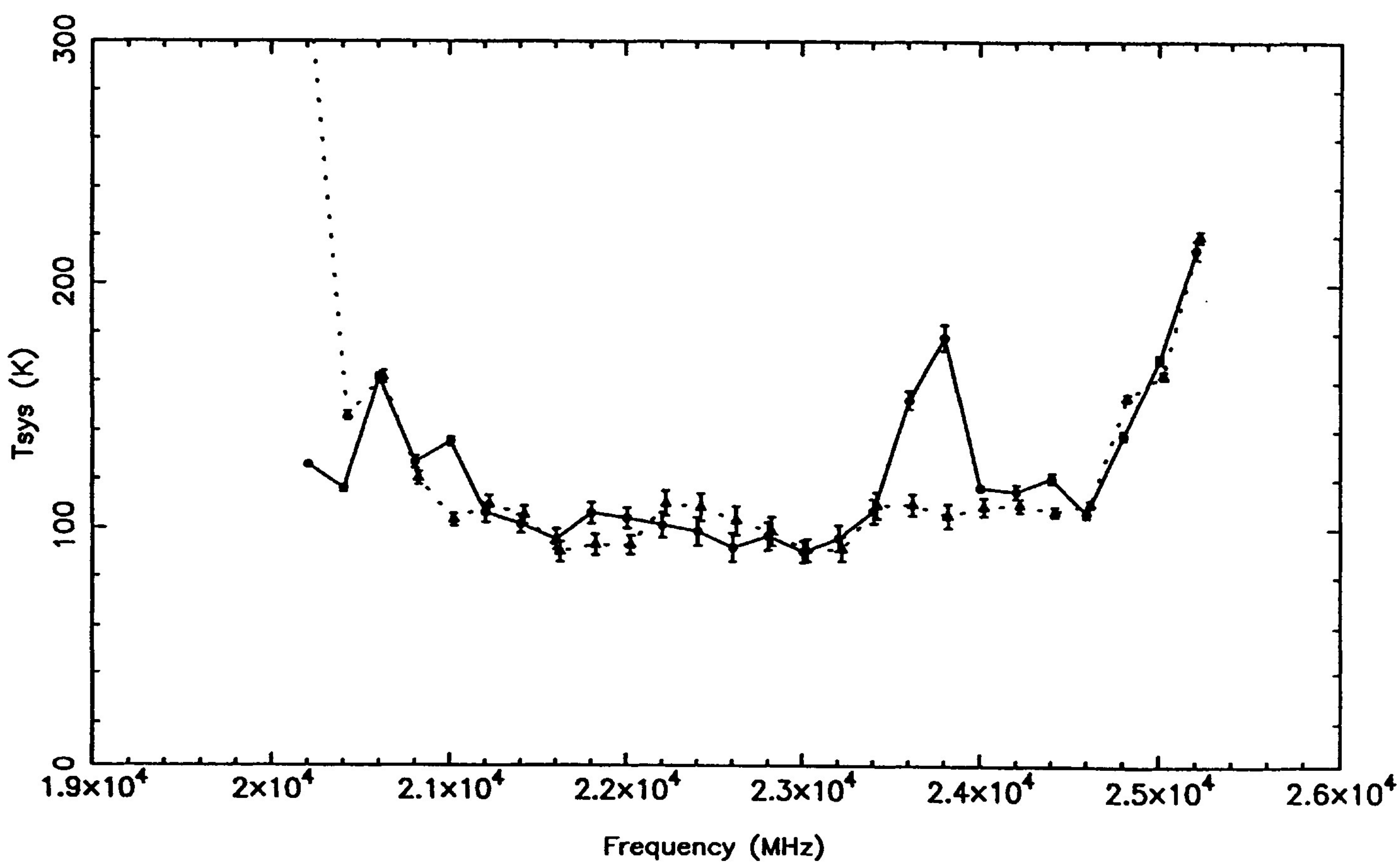
Fort Davis K Band

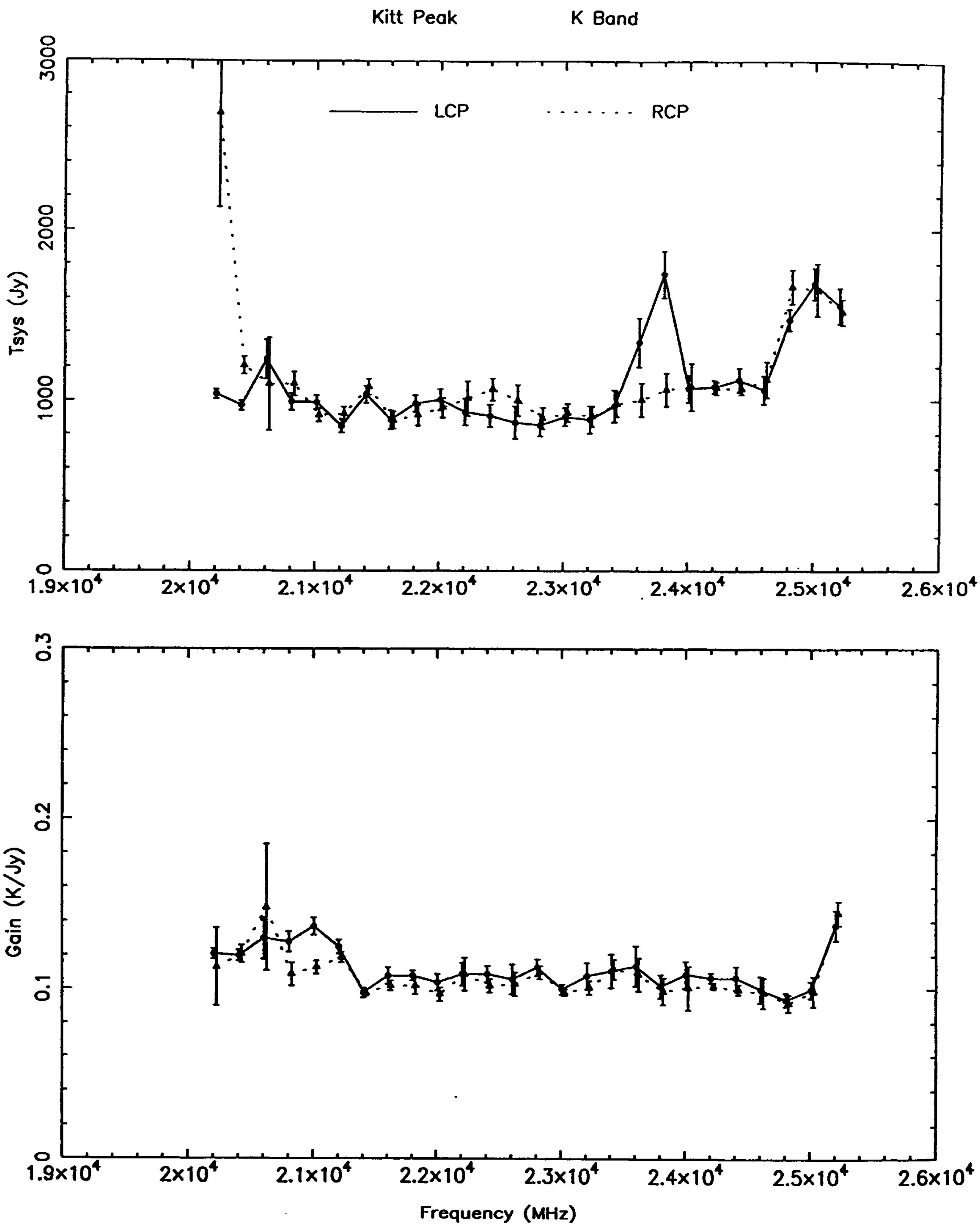




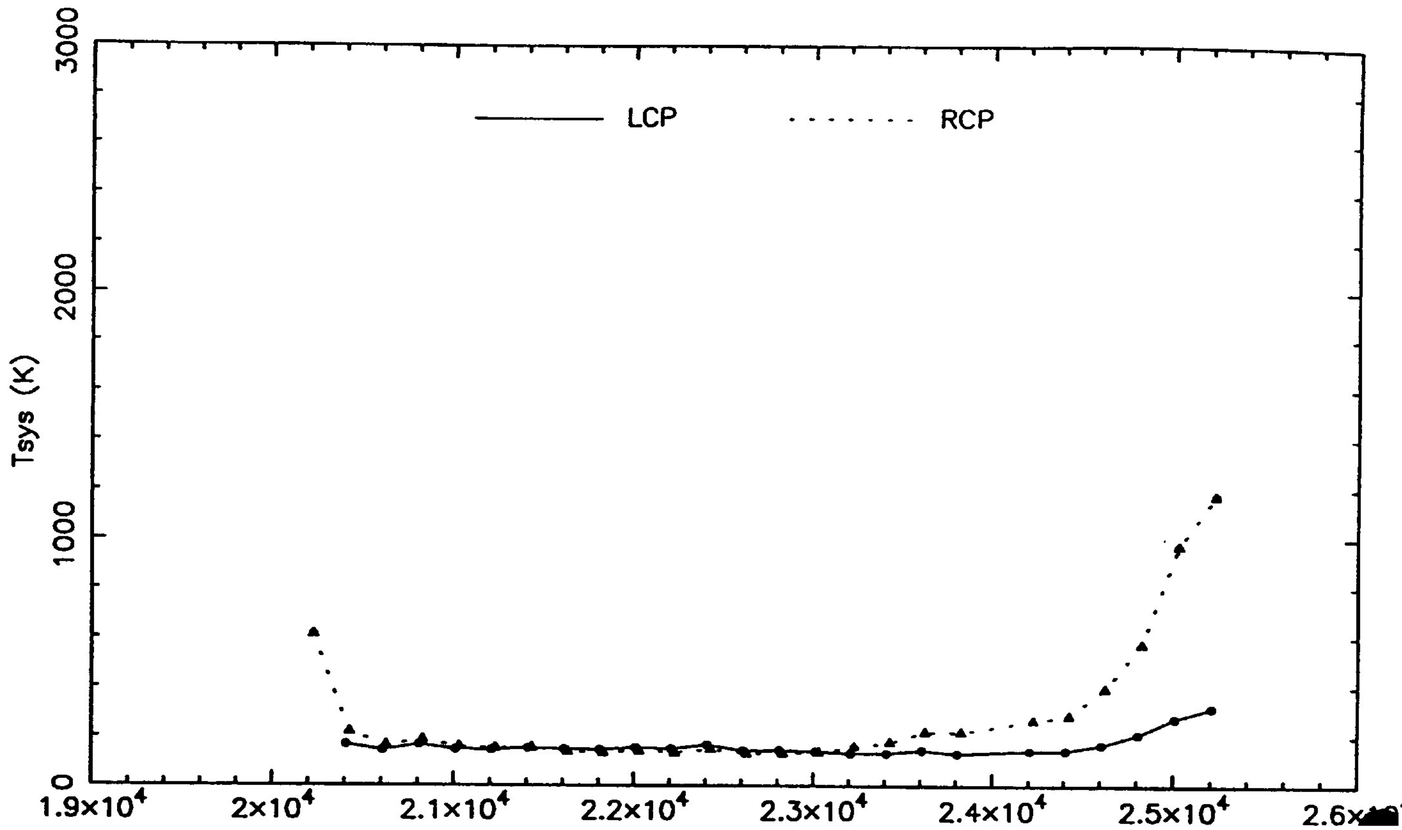
Kitt Peak K Band

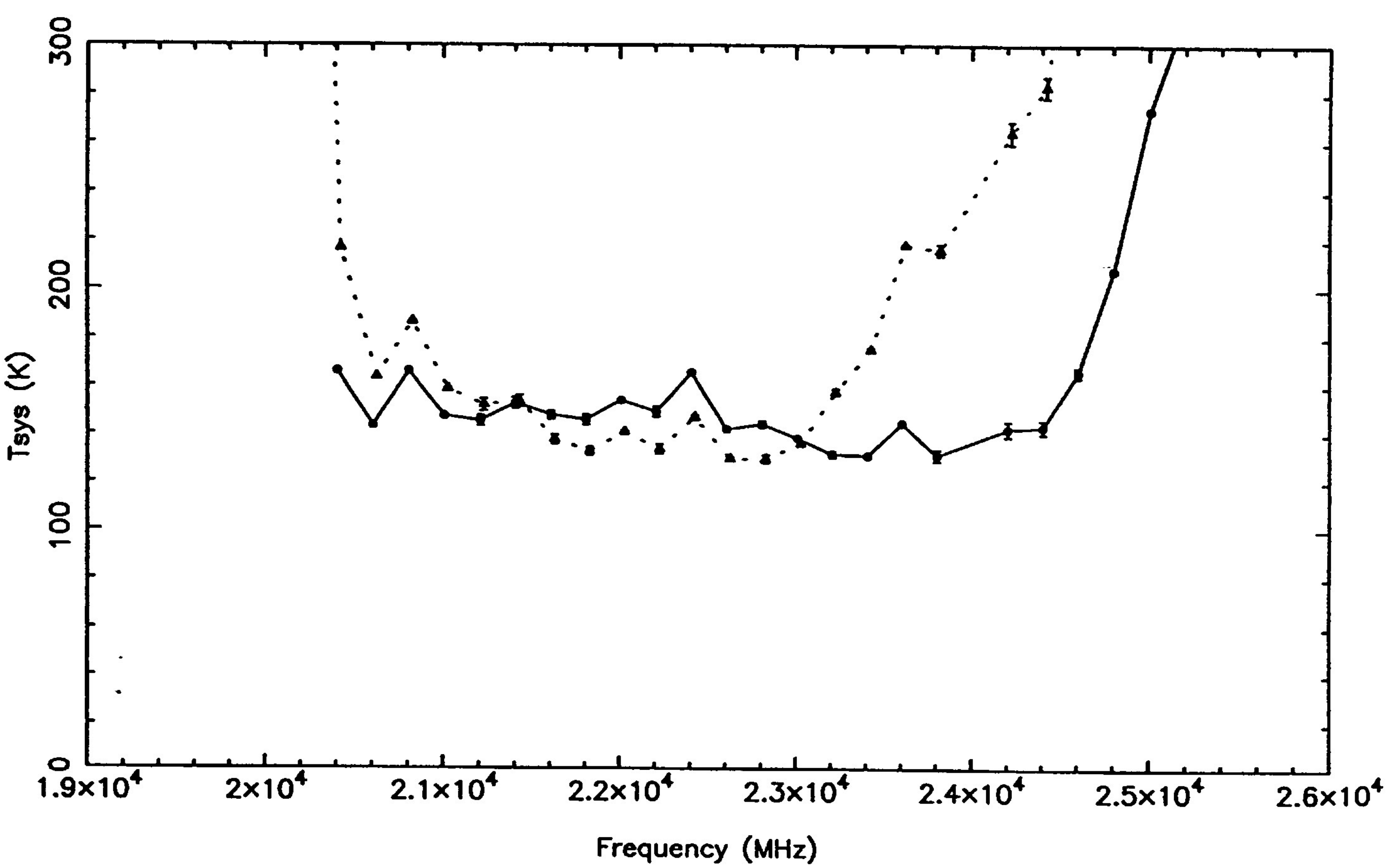


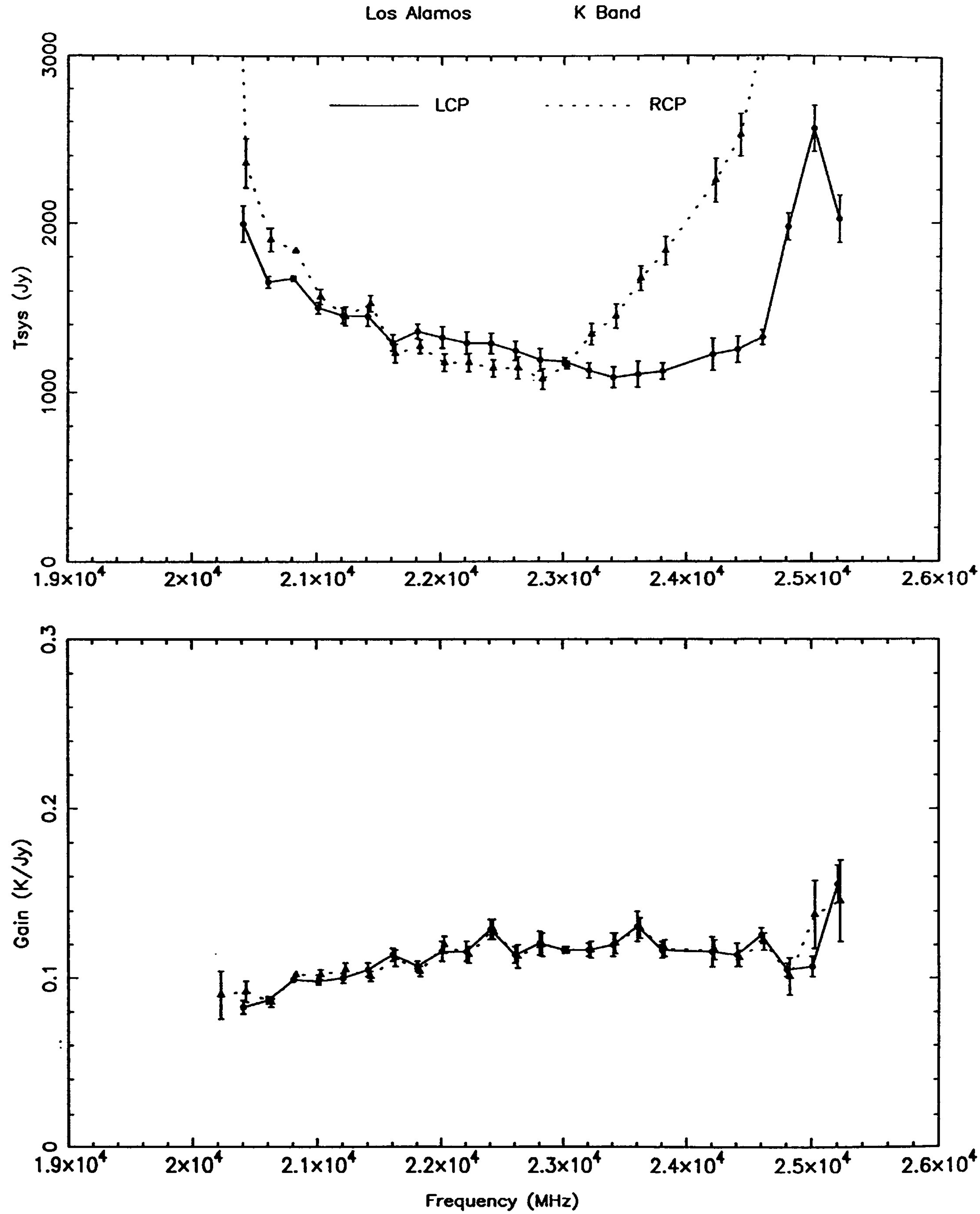



Kitt Peak
K Band
LCP
RCP
Tsys (Jy)
3000
2000
1000
0
1.9×10^4
2×10^4
2.1×10^4
2.2×10^4
2.3×10^4
2.4×10^4
2.5×10^4
2.6×10^4
Gain (K/Jy)
0.3
0.2
0.1
0
Frequency (MHz)

Los Alamos K Band






Los Alamos
K Band
LCP
RCP
Tsys (Jy)
3000
2000
1000
0
1.9x10^4
2x10^4
2.1x10^4
2.2x10^4
2.3x10^4
2.4x10^4
2.5x10^4
2.6x10^4
Gain (K/Jy)
0.3
0.2
0.1
0
Frequency (MHz)

IV. Summary of Band Limits and Features

Frequency (MHz)	Station	Limit or Feature
P Band		
302	FD, KP, PT	lower limit (10x nominal T_{sys}(Jy))
302-310	KP	persistent failure (strong interference?)
308	FD, KP, PT	lower limit (2x nominal T_{sys}(Jy))
312	FD, KP, PT	lower limit (1.4x nominal T_{sys}(Jy))
312	-	lower limit specification in VLBA project book
331-334	KP	persistent failure (strong interference?)
342	-	upper limit specification in VLBA project book
>345	FD	high T_{sys}(K) (cal. signal problem?)
350	FD, KP, PT	absolute upper limit (on-line software?)
50cm Band (BROAD FILTER)		
580	-	lower limit specification in VLBA project book
586	PT	lower limit (10x nominal T_{sys}(Jy))
594	PT	lower limit (2x nominal T_{sys}(Jy))
600	PT	lower limit (1.4x nominal T_{sys}(Jy))
630	PT	upper limit (1.4x nominal T_{sys}(Jy))
631	PT	upper limit (2x nominal T_{sys}(Jy))
636	PT	upper limit (10x nominal T_{sys}(Jy))
640	-	upper limit specification in VLBA project book
Note:	KP	all observations failed (interference)

Frequency (MHz)	Station	Limit or Feature
50cm Band (NARROW FILTER)		
606.5	KP	lower limit (10x nominal T_{sys}(Jy))
608.5	KP	lower limit (2x nominal T_{sys}(Jy))
608.6-609.1	KP	all observations failed
609.0	KP	lower limit (1.4x nominal T_{sys}(Jy))
613.5	KP	upper limit (1.4x, 2x nominal T_{sys}(Jy))
614.6-615.2	KP	all observations failed
616.9	KP	upper limit (10x nominal T_{sys}(Jy))
Note:	PT	narrow filter unavailable.
L Band		
1150	FD, KP, LA, PT	lower limit (10x nominal T_{sys}(Jy))
1200	FD, KP, LA, PT	lower limit (2x nominal T_{sys}(Jy))
1300	FD, KP, LA, PT	lower limit (1.4x nominal T_{sys}(Jy))
1350	-	lower limit specification in VLBA project book
1492-1509	PT	high T_{sys} (interference?)
1700	FD, KP, LA, PT	upper limit (1.4x nominal T_{sys}(Jy))
1750	-	upper limit specification in VLBA project book
1793-1809	KP	persistent failure (strong interference?)
1833-1849	KP	high T_{sys} and gain (interference?)
1850	FD, KP, LA, PT	upper limit (2x nominal T_{sys}(Jy))
1900	FD, KP, LA, PT	upper limit (10x nominal T_{sys}(Jy))

Frequency (MHz)	Station	Limit or Feature
S Band		
1940	FD, KP, PT	lower limit (10x nominal T_{sys}(Jy))
1960	FD, KP, PT	lower limit (2x nominal T_{sys}(Jy))
2130	FD, KP, PT	lower limit (1.4x nominal T_{sys}(Jy))
2150	-	lower limit specification in VLBA project book
2350	-	upper limit specification in VLBA project book
2350	FD, KP, PT	upper limit (1.4x nominal T_{sys}(Jy))
2450-2500	FD, KP, PT	very high T_{sys}(Jy)) (cause unknown)
2500-2600	FD, KP, PT	T_{sys}(K) and gain high (cal. signal problem?)
2600	FD, KP, PT	upper limit (2x nominal T_{sys}(Jy))
2800	FD, KP, PT	upper limit (10x nominal T_{sys}(Jy))
C Band		
4410	FD, KP, LA, PT	lower limit (10x nominal T_{sys}(Jy))
4450	FD, KP, LA, PT	lower limit (2x nominal T_{sys}(Jy))
4500	FD, KP, LA, PT	lower limit (1.4x nominal T_{sys}(Jy))
4600	-	lower limit specification in VLBA project book
5100	-	upper limit specification in VLBA project book
5140	FD, KP, LA, PT	upper limit (1.4x nominal T_{sys}(Jy))
5220	FD, KP, LA, PT	upper limit (2x nominal T_{sys}(Jy))
5260	FD, KP, LA, PT	upper limit (10x nominal T_{sys}(Jy))

Frequency (MHz)	Station	Limit or Feature
X Band		
7730	FD, KP, LA, PT	lower limit (10x nominal T_{sys}(Jy))
7800	FD, KP, LA, PT	lower limit (2x nominal T_{sys}(Jy))
7880	FD, KP, LA, PT	lower limit (1.4x nominal T_{sys}(Jy))
<7908	KP	LO=6900 MHz gives high T_{sys} or fails on LCP
7955-7971	PT	high T_{sys} (interference?)
8000	-	lower limit specification in VLBA project book
8438-8454	PT	high T_{sys} (interference?)
8800	-	upper limit specification in VLBA project book
>8892	KP, LA, PT	LO=9900 MHz gives high T_{sys} or fails
8930	FD, KP, LA, PT	upper limit (1.4x nominal T_{sys}(Jy))
9010	FD, KP, LA, PT	upper limit (2x nominal T_{sys}(Jy))
9100	FD, KP, LA, PT	upper limit (10x nominal T_{sys}(Jy))
Note:		Extending ellipsoid increases T_{sys}(°K) ~8% and decreases gain by ~2%.
K Band		
20200	FD, KP, LA	lower limit (10x nominal T_{sys}(Jy))
20500	FD, KP, LA	lower limit (2x nominal T_{sys}(Jy))
21100	FD, KP, LA	lower limit (1.4x nominal T_{sys}(Jy))
21700	-	lower limit specification in VLBA project book
23600-23816	KP	high T_{sys} (problem? interference?)
23700	LA	upper limit (1.4x nominal T_{sys}(Jy))
24100	-	upper limit specification in VLBA project book
24300	LA	upper limit (2x nominal T_{sys}(Jy))
24600	FD, KP	upper limit (1.4x nominal T_{sys}(Jy))
24800	FD, KP	upper limit (2x nominal T_{sys}(Jy))
>25000	FD, KP, LA	high gain (cal. signal attenuation?)
25200	FD, KP, LA	upper limit (10x nominal T_{sys}(Jy))

V. Discussion

We have presented RF bandpass data for several VLBA antennas at each band. In most cases the different stations are quite similar, suggesting that our results will probably be applicable to the completed array.

Most bands allow observations over a frequency range of 10 to 15% (defined as 1.4x T_{sys}(Jy) increase), which is sufficient for multi-frequency synthesis techniques to give a large improvement in (u, v) coverage. The 50 cm band is narrower, only 5% wide. L band is the widest, and allows a frequency range of 27%. Interesting possibility is multi-frequency synthesis utilizing both the L and S bands; this affords coverage from 1300 to 2350 MHz, with a ~400 MHz gap in the middle.

In most case the measured bandwidths (defined as 1.4x T_{sys}(Jy) increase) are 20 to 30% broader than the VLBA "Blue Book" specifications. The only exception is the 50cm band; we find 600 - 630 MHz while the specification is 580 - 640 MHz. The difference is academic, however, since interference will require use of the 608 - 613 MHz filter at some stations.

Our observations have uncovered (or re-discovered) a number of possible problems in the hardware. We now list these:

(1) P band T_{sys} higher than "Blue Book" (FD, KP 100% high; PT 40% high) and gains about 30% lower than "Blue Book" values.

(2) 50cm T_{sys} three to five times higher than "Blue Book" specification. Pie Town 50 cm gain factor of 2 too low (factor 2 lower than Kitt Peak).

(3) L band T_{sys} 30 to 40% higher than "Blue Book."

(4) C band T_{sys} ~ 30% higher than "Blue Book."

(5) X band T_{sys} ~ 25% higher at Pie Town than other stations.

(6) Los Alamos K band RCP system temperature high above 23000 MHz.

(7) Different BBC's give different power reading for the same IF input and same frequency. This seems most serious at Fort Davis and Kitt Peak where values had a range of ~10%.

(8) Pie Town BBC#6 has intermittent failure.

(9) Fort Davis BBC#3 intermittent failure.

Several limitations were also found which appear to exist in the software: (1) P band cannot be tuned above 350 MHz. (2) the BBC's cannot be tuned outside the range 500 - 1000 MHz. (3) SCHED does not allow BBC's to be scheduled at 1000.00 MHz.

We suggest that the these measurements be repeated after all the VLBA antennas are complete. This would verify the frequency limits we have obtained, and would serve as a test for various problems which might not be discovered at the usual VLBI continuum frequencies.

The interference spectrum should also be measured at all stations, so that a set of "clean" frequencies can be established for multi-frequency synthesis work with the array. Such measurements should be made by recording the BBC output, correlating the data, and computing the auto-correlation spectrum. This would allow much greater frequency resolution than can be obtained with the BBC filters.

We thank C. Walker for assistance with scheduling the measurements and contributing analysis software.

VI. References

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