CHAPTER 4
OBSERVING PROCEDURE AND DATA REDUCTION METHODS

General procedures for observation of radio spectral lines using different types of spectrometers and typical problems encountered have been discussed widely in the literature (see for example Ball, 1975, Williams 1976, Ball 1976). However in any attempt to measure weak spectral lines the problems encountered are peculiar to the telescope system being used. The recombination lines reported in this thesis are some of the weakest spectral lines in radio astronomy. In this chapter we discuss the observing procedures, data reduction methods and the difficulties involved which are peculiar to the ORT system

4. I THE NATURE OF SPECTRAL LINES:

A spectral line will appear as an increase in the system temperature over a narrow frequency range within the observable band of the telescope. The magnitude of the increase and the range of frequencies over which it occurs, depend on the intensity and width of the spectral line.

A typical recombination line expected in the ORT observing band is illustrated in figure 4.1 with the amplitude of the spectral line exagerrated for clarity. The spectral line appears at a centre frequency ν shifted by $\Delta\nu$ from the expected frequency ν_0 , because of the doppler shift due to the line of sight motion of the emiting region The ordinate of fig 4.1 represents the total system temperature T_{sys} when the antenna is pointed towards the source of interest. T_{sys} is made up of 2 parts T_R and T_s . T_R is the receiver temperature which includes the amplifier noise, losses in the system and spillover of the feed. T_s is the contribution fromthe sky which includes the

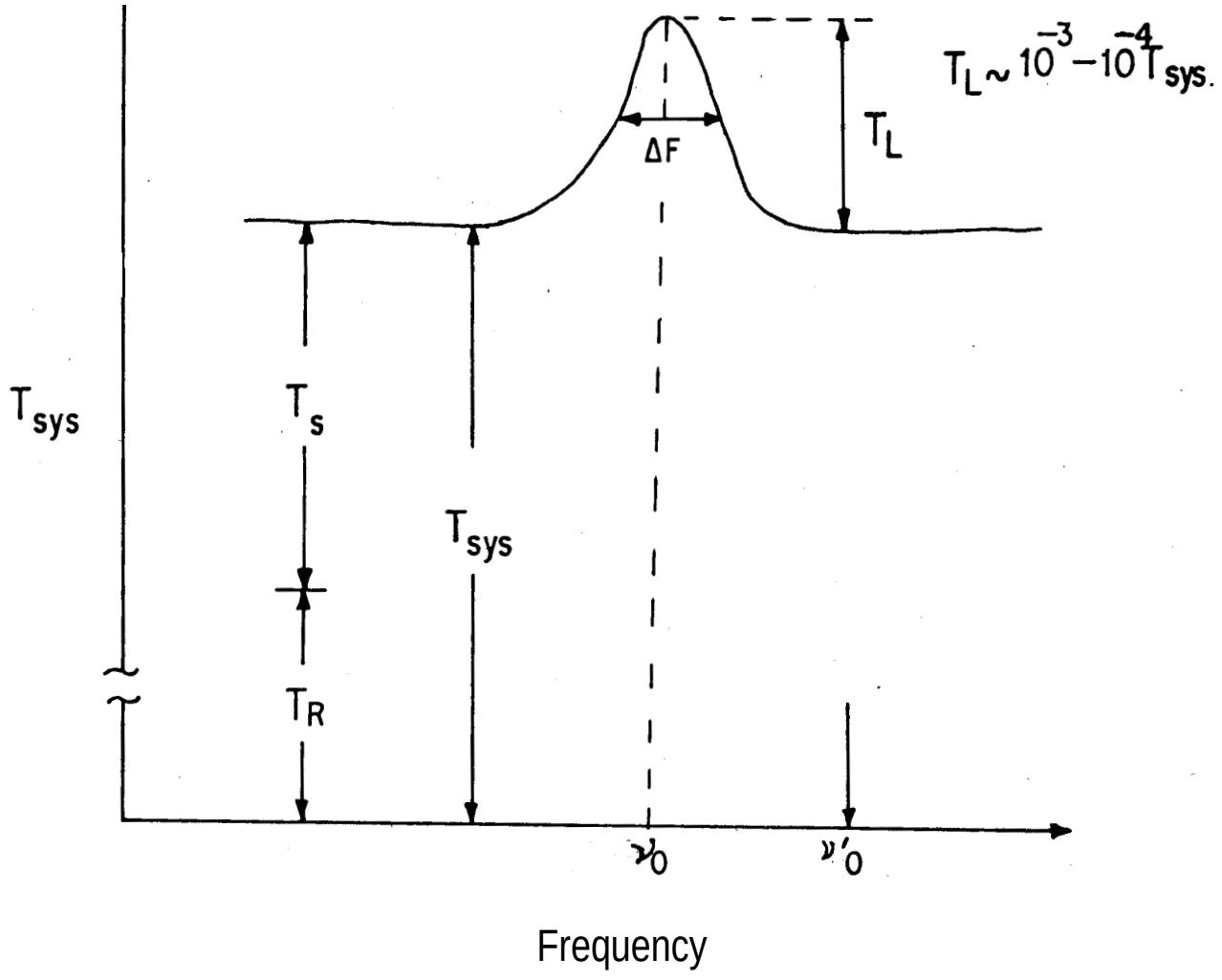


FIG. 4.1. A TYPICAL SPECTRAL LINE.

source and the underlying background. The spectral line increases the system temperature by T_L at the centre of the line which has a full width at half maximum (FWHM) of AF.

For a typical recombination line near the ORT observing frequency (328MHz) T_L / T_{sys} is of the order of (0.5-1.0) x 10^{-3} . The strongest line has $T_L / T_{sys} = 1.3 \times 10^{-3}$. Typically ΔF is 25-50KHz. It is clear that the recombination line will appear as a small perturbation in frequency space over the underlying continuum plus receiver temperature. It is therefore necessary to determine the response of the system as a function of frequency, in the neighbourhood of the spectral line to an accuracy better than 1 part in 10000 in order to be able to recognize the spectral line. However in general for any system, gain and freqency response variations with time, and departures from a flat response are orders of magnitude larger than this. Therefore in order to keep track of such variations and to take care of the departures from a flat response it is absolutely essential to adopt some kind of a switching scheme in which a reference spectrum (i.e. response of the system with the line absent) is continuously measured. The difference between the online spectrum (i.e response with the line present) and the reference spectrum would yield the required spectrum

An ideal switching scheme would be one in which the spectral line is switched on and off, keeping all the other parameters of the system same. A switching rate faster than the rate of gain and frequency response variations in the system should be used. In such an ideal case any desired accuracy can be obtained by simply choosing an appropriate integration time. However in practice such a scheme would not be available and one has to resort to some practical switching scheme.

4.2 THE SWITCHING SCHEME:-

There are many practical switching schemes suitable for spectral line observations like load switching, frequency switching, beam switching etc. The choice would depend on the

nature and frequency of the spectral line being observed, the telescope and receiver system being used and the accuracy desired. The scheme most suitable for spectral line observations with the ORT is the frequency switching scheme, in particular double frequency switching.

The frequency switching method is suitable when the bandwidth of the spectrum being measured is small compared to the total front end bandwidth and when there are no spectral lines in the adjoining bands. In the case of the ORT the mximum bandwith of the spectrum that needs to be analysed for galactic recombination lines is 500KHz, small compared to the RF amplifier bandwidth of >12MHz. The adjacent recombination lines at this frequency are separated by ~3.5MHz. The spin-flip (hyperfine) deuterium line, even if it is detectable, is at least 1.3MHz away from the nearest recombination line. Therefore the requirement for the suitability of frequency switching is easily met.

The double frequency switching method which is adopted for the recombination line observations reported here is illustrated in figure 4.2a The spectral line of interest occurs in the frequency window fl to f2 lying within the RF amplifier band. The N frequency channels of the spectrometer are effectively placed in this window by choosing an appropriate first LO frequency. In this setting, the spectrometer measures the online spectrum (ON). The spectrometer is made to measure two reference spectra (REF1 and REF2) on either side of the online window by switching the first LO frequency in the sequence shown in fig 4.2, and the cycle is repeated. It is easy. to see that best results are obtained when the observing time is equally split between online and reference measurements; the two spectra should be equally accurate for the effectiveness of switching.

During the observations, a switching time of 250ms was used. The switching waveform for the first LO is shown in fig 4.2b. A dead time of 10ms (when no data is recorded) is allowed immedietly after switching to allow the frequency synthesizer, used as the first LO, and the rest of the receiver system to

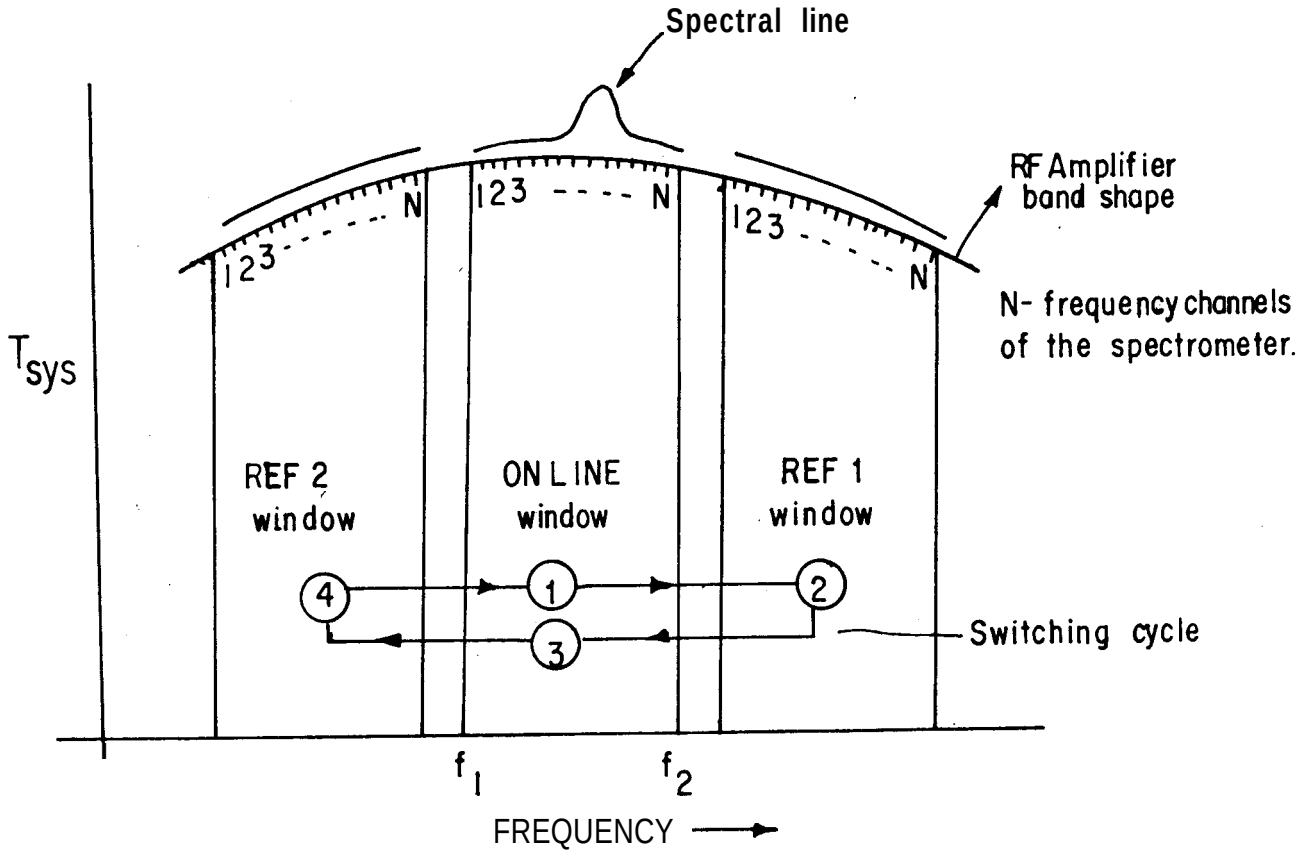


FIG.4.2a. DOUBLE FREQUENCY SWITCHING SCHEME.

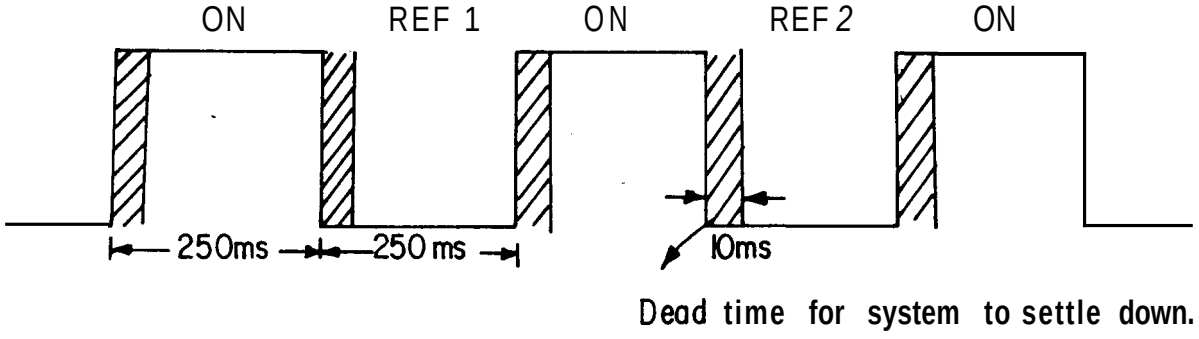


FIG.4.2b. FIRST LO SWITCHING SEQUENCE.

settle down. The required spectrum P(f) is obtained using the relation

$$P(n) = \frac{ON(n) - REF(n)}{REF(n)} \qquad (4.1)$$

$$REF(n) = \frac{REF1(n) + REF2(n)}{2}$$

The implicit assumption in the above way of calculating the spectrum is that the average of the two reference spectra REF1 and REF2, reprasents a reference spectrum at the position of the online window with the line absent. Any actual departure from this assumption will result in a non-zero or a curved baseline in the final spectrum obtained. Such departures are bound to occur because of the differences in the response of the system in the online and the reference bands. Since the frequency switching takes place close to the front end of the receiver, the only change. in the response between the online and reference window that must be considered is that ahead of the frequency switch, namely the RF amplifier and the antenna. This is because for both online and reference measurements the spectrometer receives the same IF band.

If the response of the system as a function of frequency, ahead of the frequency switch is of a simple mathematical form, then the effect of obtaining the spectra in the double frequency switched mode, as described above, is to cancel the first derivative of this response leaving only the higher order terms. For example, if the response is a parabolic function then only a linear baseline will be left.

4.3 THE BASELINE CURVATURE

In a perfect system observations employing a good switching scheme towards a source with no spectral lines should yield a spectrum which is truly zero at every point, except for noise fluctuations. However in any practical system such an observation will in general yield a non-zero curved spectrum This is known as baseline curvature which is one of the most

serious problems in any spectral line observation. A spectral line present in the direction of observation will be superposed on this curved baseline. In a surprisingly large number of observations the limits on the details of a weak spectral line are set not so much by the noise in the spectrum as by the presence of baseline curvature.

The nature and origin of the baseline curvature depend on the telesope system and the switching scheme employed. As mentioned above, in the double frequency switching scheme the baseline curvature will depend on the frequency response of the system ahead of the switch. In principle even changes in the gain of the system due to change in the LO frequency can contribute to the baseline curvature. However a one-bit correlation spectrometer is not sensitive to changes in the overall gain. Therefore in spectral line observations with the ORT using frequency switching, only the variation in the frequency response of the RF amplifier and the antenna feed system determine the baseline curvature.

The frequency response of the RF amplifier in the ORT system is a reasonably smooth function and it can be approximated by a parabolic function over the narrow frequency range of interest. Therefore the double frequency switching method will leave at the most a linear baseline. This was ascertained by making a number of measurements with the antenna pointed towards a cold region in the sky and tracking for several hours. However, higher order baseline curvature was noticed when observations were made towards strong continuum sources.

The major cause for baseline curvature is the beam shift that occurs when the frequency of the first LO of the ORT system is altered. This is explained below.

The ORT is a phased array in the north-south direction. The declination pointing of the beam is done by applying appropriate phases and delays at the IF before combining the signals fromthe 22 modules (see section 3.2). The IF phases and delays are

calculated for the effective frequency at RF given by $f_{RF} = f_{LO} + f_{IF}$. For the ORT system f_{IF} is fixed at 30MHz and the delay and phase cables are made at the wavelength corresponding to this frequency. A change in the FLO frequency will therefore systematically change the effective RF phases and delays thereby causing a shift in the beam For a change in the freqeuncy by Δf the magnitude of the beam shift in declination is given by

$$\Delta\delta = \frac{\Delta f}{f_{RF}} \tan\delta$$

where δ is the declination to which the antenna is pointed. Therefore when the FLO frequency is switched during observations the beam shifts alternately on either side of the source being observed. This causes a change in the system temperature between the online and reference measurements. A mere change in the system temperature will however not affect the baseline as the one-bit correlator is insensitive to such variations. But if one goes a step further it can be seen that the effective pointing of the beam is actually slightly different for the different frequency channels of the spectrometer. Further the beam shift that occurs due to frequency switching is slightly different for different channels. In other words there will be a differential change in the system temperature across the channels of the spectrometer due to differential shifts in the beams corresponding to the different channels when the FLO is switched. This results in a major contribution to the baseline curvature.

The nature of the baseline curvature will depend on the continuum strength and structure of the source being observed and the underlying background in its neighbourhood. The continuum distribution will determine the magnitude of the differential variation in the system temperature due to the beam shifts. Further the baseline will now also depend on the declination of the source as the magnitude of the beam shift depends on the declination. This being so it is not possible to observe an off-source region or another source with no spectral lines to get a reference baseline, as is usually done in many spectral line

observations using single dish telescopes.

The first thought that occurs is that it should be possible to solve this problem if we manage to stop the beam from shifting when the local oscillator frequency is altered. This of course is possible as we can calculate and set (through the computer) new IF phases and delays corresponding to the new LO frequency, for the beam to be pointed in the same direction. We made several measurements employing a scheme in which the IF phases and delays were switched at the same rate and sequence as the frequency switching so as to keep the beam pointed in the same direction.

While this scheme reduced the overall change in the system temperature between the online and reference settings it failed to improve the baseline. In fact it was noticed that the baseline curvature is actually aggravated when this scheme is employed. A possible reason for this is the inability of the system to precisely compensate the phases to prevent any beamshift. Further we would also be losing in this scheme one of the biggest advantages of frequency switching, namely that the IF response is automatically cancelled. This would no longer be true as the IF delay and phase cables are changed in going from online to reference frequency setting. If as a result there are any changes in the standing wave patterns in the cables it will contribute to worsening of the baseline curvature.

The scheme that was finally adopted for these observations is the simple double frequency switching scheme as explained in the previous section. The baselines obtained are tolerable if not the most desirable. A few examples of the observed baselines are shown in fig 4.3 and 4.4. These examples cover the extreme and typical baseline curvatures encountered during these observations. A polynomial function is fitted to the baselines, in a least square sense and removed from the observed spectrum as shown. Most case could be fitted with a maximum of a third order polynomial. In one or two cases it was necessary to use a 4th order polynomial.

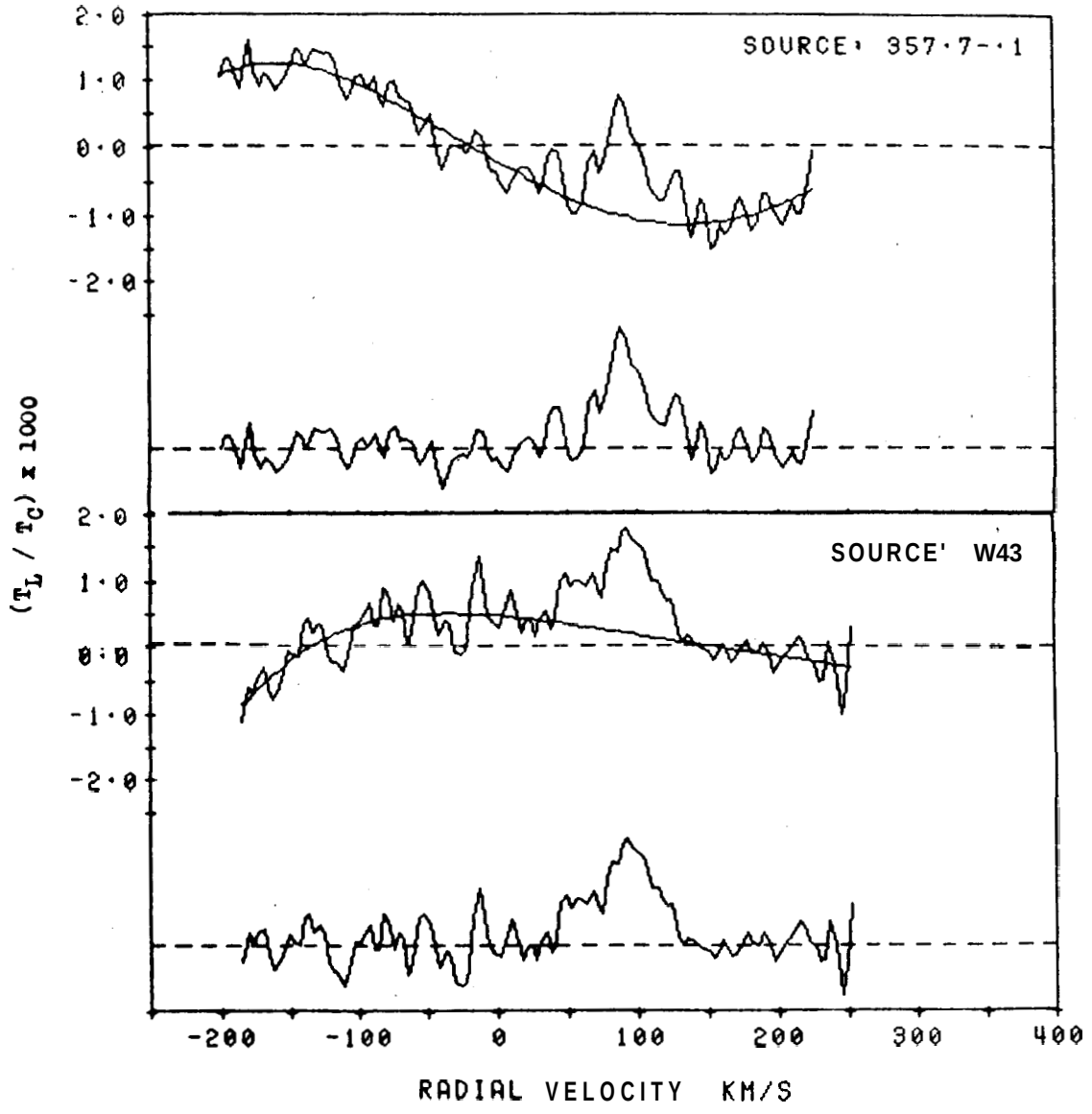


Fig. 4.3 Baseline curvature observed towards two sources. Second order polynomial in one case (W43) and third order in the other is fitted to the baseline. These can be considered as typical baselines. The final spectrum after baseline removal is also shown.

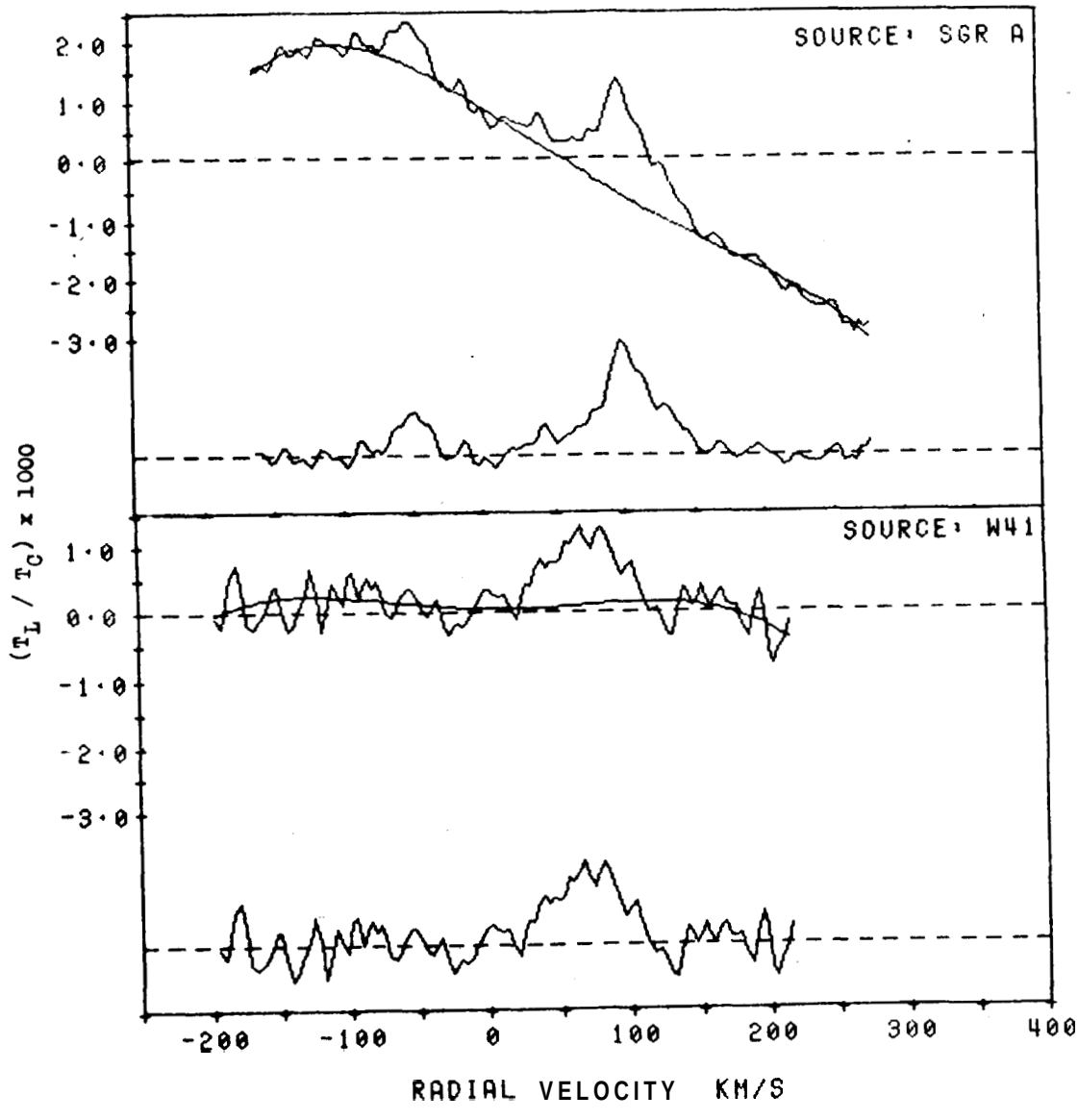


Fig. 4.4 Baseline curvature in the spectra observed towards Sgr A and W41. A polynomial of order 4, fitted to the baseline is also shown. The spectra at the bottom of the two frames are obtained after subtracting the baseline. These can be considered as extreme cases of 'baseline curvature'.

4.4 CALIBRATION OF THE SPECTRUM

The one-bit autocorrelation spectrometer looks only at the zero-crossings of the input signal and therefore only measures a normalized spectrum The ordinate of the spectrum comes out in arbitrary units. It is necessary to convert this ordinate into, units of line brightness temperature.

The fourier transform of the autocorrelation functions measured in the online and reference windows essentially gives effective video bandshapes. The effective video bandshape is a product of the online or reference window response (which includes the beam response discussed in the previous section) and the IF response. The IF response is same for both the online and reference measurements. The normalized spectrum from the two measurements is obtained using equation 4.1 namely

$$P(n) = \frac{ON(n) - REF(n)}{REF(n)} \quad ; \; n \text{ is the channel no.}$$

The division by REF(n) compensates for the response of the system over the video band.

If T_{BSys} is the total system temperature in brightness temperature units when the antenna is pointed towards the source under observation then the line brightness temperature at any point in the spectrum is given by

$$T_{BL}(n) = P(n) \times T_{BSys} \qquad (4.2)$$

A measurement of T_{BSys} is essential for calibrating the spectrum in line brightness temperature units. This measurement using the total power beam of the ORT can be made as illustrated in fig 4.5.

First a measurement is made on a calibration source of known flux S at a declination as close as possible to that of the

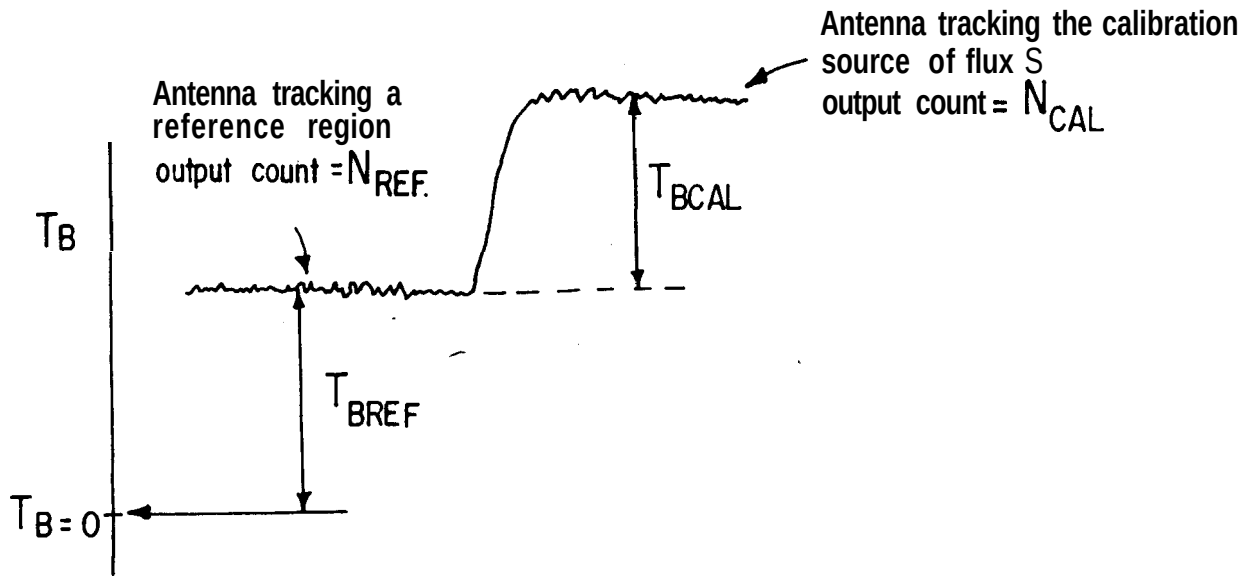


FIG. 4.5a. Measurement on a calibration source.

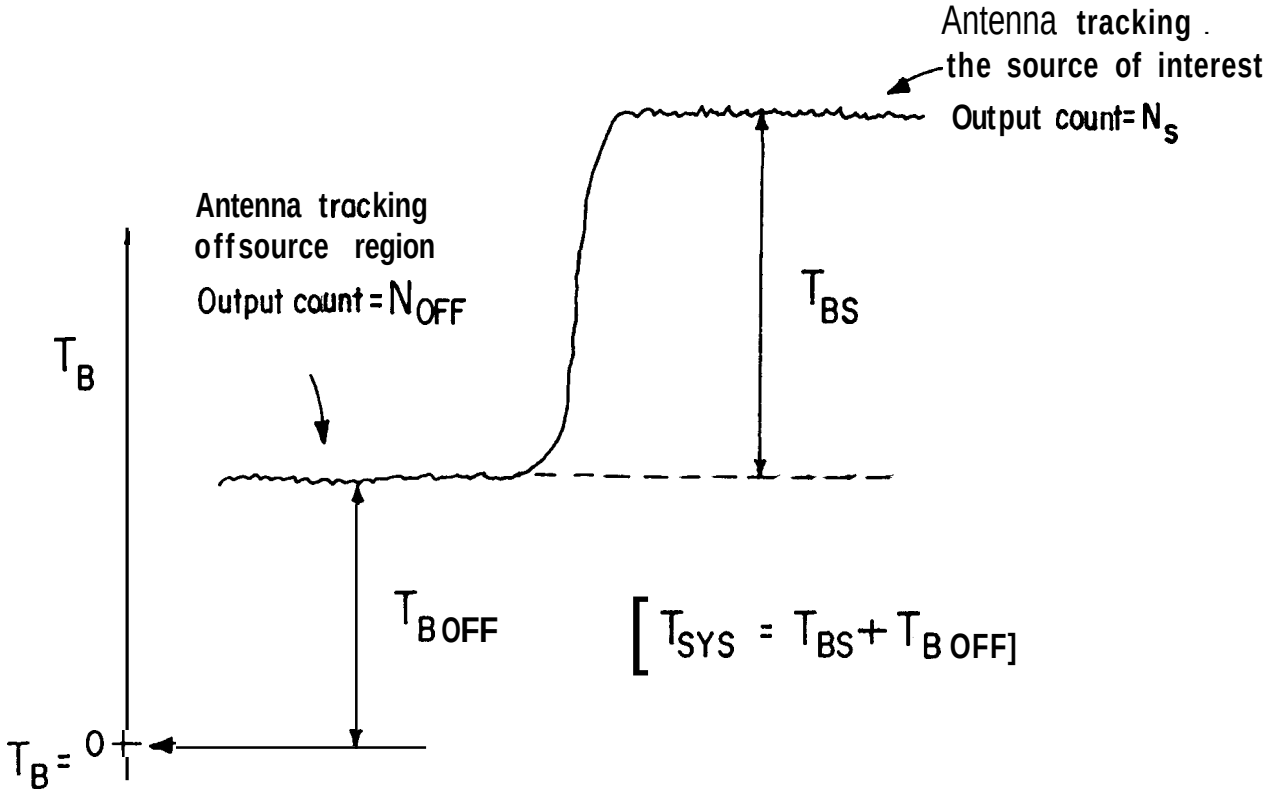


FIG. 45b. MEASUREMENT ON THE SOURCE OF INTEREST

source from which the spectral line is being observed. The calibration source should be small compared to the antenna beam so that it can be considered as a point source.

A nearby reference region shifted only in right ascention (essential as the system parameters change with declination) which represents the typical cold sky (for eg. far away from the galactic plane) is tracked. The TP beam will record N_{REF} counts. Then the antenna is moved to the position of the calibration source and tracked. The total power beam will now record N_{CAL} counts.

Let T_{BREF} be the system temperature in brightness temperature units when the antenna is pointed towards the cold sky. Then the increase in system temperature in the same units due to the calibration source is given by

$$T_{BCAL} = \left[\left(\frac{N_{CAL}}{N_{REF}}\right)^m - 1\right] T_{BREF} \qquad (4.3)$$

where m is the correction for the departure of the TP detector from a true square law. If Ω_B is the beam solid angle of the antenna then

$$T_{BCAL} = \frac{2k}{\lambda^2} \cdot \frac{S}{\Omega_B} \qquad (4.4)$$

Knowing Ω_B, which can be separately measured, or calculated, for the antenna, T_{BREF} can be obtained from 4.3. and 4.4.

A similar measurement is made (fig4.5b) on the source of interest yielding counts N_{OFF} and N_S for the offsource and source position respectively. The increase in system temperature in brightness temperature units due to the source is given by

$$T_{BS} = \left[\left(\frac{N_s}{N_{off}}\right)^m - 1\right] T_{Boff} \qquad (4.5)$$

If the reference and the offsource regions are properly chosen, then it is reasonable to assume that

$$T_{BREF} = T_{BOFF} \qquad (4.6)$$

From the value of T_{BREF} calculated earlier and using equations 4.5 and 4.6 we can calculate T_{BS}. The total system temperature in brightness temperature units (as in section 3.3.5) is given by

$$T_{Bsys} = T_{BS} + T_{Boff} \qquad (4.7)$$

Now equation 4.2 can be used to calibrate the observed spectrum in line brightness temperature units.

If a source is to be observed on several days in differrent sessions it would be .sufficient to make the above measurement only once to calibrate the integrated spectrum in brightness temperature units. This is explained below.

The quantities T_{BL} and T_{BS} are properties of the sky and therefore in general they do not vary from one day to another if the same beam solid angle Ω_B is used. On the otherhand T_{Boff} includes the parameters of the telescope and the receiver system, or in otherwords the sensitivity. Therefore the quantity T_{Boff} can be different on different days depending on the phase and amplitude errors in the system which can change from day to day. The ratio T_{BL}/T_{BS} is independent of T_{Boff} and if this quanitity is measured during each observation then the integrated spectrum can be calibrated with a single measurement of T_{BS} as explained above.

The spectrum of each day can be calibrated in units of (T_{BL}/T_{BS}) by making a single measurement of T_{BS} in units of T_{Boff} at the begining of each observation. This is illustrated in figure 4.6. When the telescope is moved from the offsource position to the onsource position the system temperature increases from T_{Boff} to $\alpha T_{Boff} (= T_{Bsys})$. The factor α can be

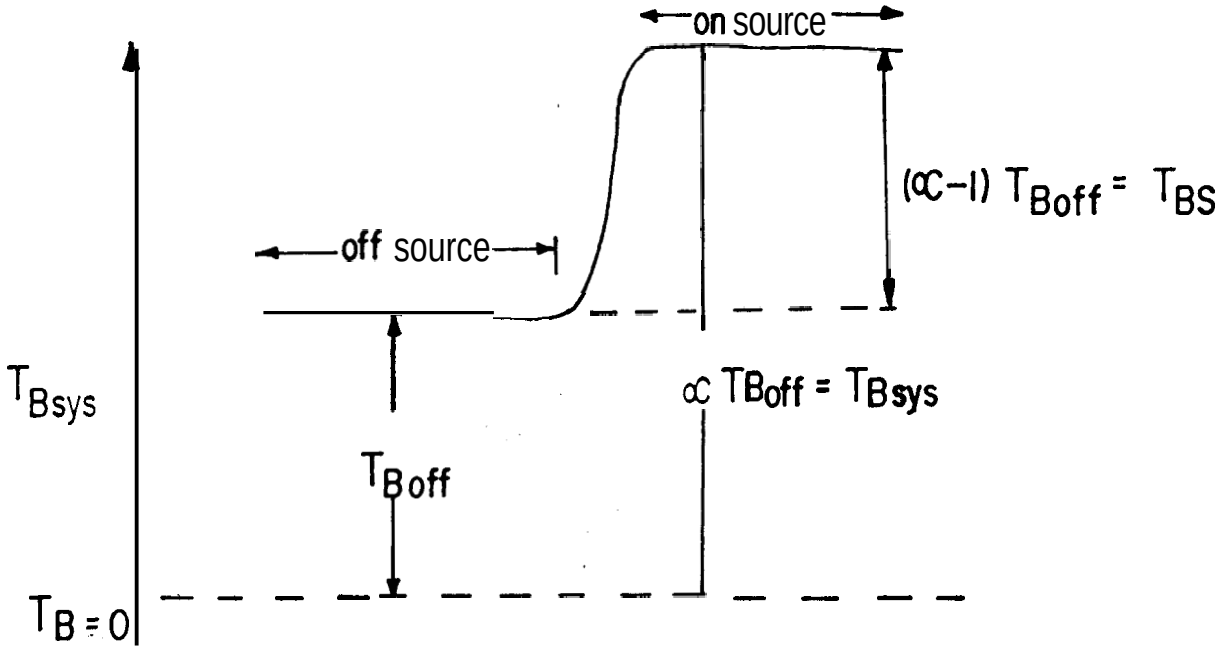


FIG.4.6. MEASUREMENT OF T_{Bsys} AND T_{BS} IN UNITS OF T_{Boff}.

measured using a calibrated attenuator. An appropriate attenuation is introduced in the system (before the detector) to bring the output level on the chart recorder back to that of the offsource position. The value of the attenuation gives the factor α. For example for a attenuation of 3dB, $\alpha = 2$. We have therefore

$$T_{BSys} = \alpha\, T_{Boff} \qquad (4.8)$$
$$T_{BS} = (\alpha - 1)\, T_{Boff}$$

From equation 4.2

$$\frac{T_{BL}(n)}{T_{BS}} = P(n)\,\frac{\alpha}{\alpha - 1}$$

4.5 THE OBSERVING PROCEDURE:

All the observations reported in this thesis were carried out using the procedure described here. A bandwidth of 500KHz, sampling frequency of 1MHz and total power mode was used for all the observations. The different steps during the observations were as follows

1. Set an appropriate online frequency (f_{LO}) for the first LO, depending on the expected frequency of the spectral line. The frequency synthesizer is set to the double frequency switching mode (mode 4, see section 3.6.3) in which during each cycle the frequency changes in the sequence ON-REF1-ON-REF2-ON-etc, where ON = f_{LO}, REF1 = $f_{LO} + \Delta f_{LO}$ and REF2 = $f_{LO} - \Delta f_{LO}$. A Δf_{LO} of 510KHz, which is slightly larger than the spectral bandwidth of 500KHz is used.

2. The declination of the ORT is set to that of the source. The IF phases and delays are calculated for the observing frequency given by $f_{RF} = f_{LO} + 30\text{MHz}$.

3. The factor α by which the system temperature increases (eqn 4.8) in going from an offsource region to the source position is measured using the total power beam The offsource region is shifted only in right ascension with respect to the source and chosen to be far away from the galactic plane (by about 1^h30^m)

4. With the antenna tracking the source position data is acquired from the autocorrelator by the Varian 620i computer using the data acquistition software described in section 3.6.5.

The autocorrelator is used in the external (EXT) integration mode where the computer decides the interval between readouts. Data is read out from the autocorrelator every 250ms. This is also the time spent on the online and reference frequencies in each switching cycle. The computer sends out a switching pulse of the form shown in fig 2b to the frequency synthesizer. Thus the computer reads the online and reference autocorrelation functions during alternate readouts.

These autocorrelation functions are averaged over 1 minute and written on a magnectic tape after applying the clipping correction (Van-Vleck correction, eqn 3.11). Usually the data was acquired in continuous stretches of 60 to 90 minutes and written on the magnetic tape as a file containing 60 to 90 records. At the begining of each file a legend containing information like date, source, synthesizer setting, declination etc is written. At the end of each such observing stretch the computer plots the integrated online and reference autocorrelation functions, their fourier transform and the normalized spectrum (eqn 4.1) for immediate inspection. At the end of an observing session for the day, an integrated normalized spectrum is also plotted.

Further processing of the data written on tape is carried out offline to obtain an integrated and calibrated spectrum

4.6 DATA REDUCTION

Some preliminary processing of the data stored in magnetic tapes was done in the Varian computer. This data was then transferred to the PDP 11/70 computer for further processing.

The normalized spectrum (equation 4.1) corresponding to each 1 minute data read from the tape was first examined for the presence of spectral interference or malfunctioning of the equipment. Any bad stretch of data so discovered was flagged so that it was not included in further processing. The online and reference autocorrelation functions corresponding to each stretch of 60-90 minutes data were averaged separately leaving out the bad records. These autocorrelation functions which have integration times in minutes equal to the number of records averaged, were transferred to the PDP 11/70 computer.

The online and reference autocorrelation functions were multiplied by Hanning weighting functions (equation 3.9) and fourier transformed to obtain the online and reference spectra. A standard 256 point FFT algorithm was use'd for the transform Since the autocorrelation function is real and symmetric ($R(\tau)=R(-\tau)$), its fourier transform is also real. This allows us to transform two autocorrelation functions simultaneously with a single pass through the FFT program The two autocorrelation functions were used as the real and imaginary parts of the input to the FFT program The real and imaginary parts at the output then correspond to the fourier transform of these two autocorrelation functions. Thus 'the online and reference autocorrelation functions are simultaneously transformed using the FFT program

For each stretch of data (60-90 minutes) the averaged spectrum calibrated in units of (T_{BL}/T_{BS}) given by (see eqn 4.9)

$$\frac{T_{BL}(n)}{T_{BS}} = \frac{ON(n) - REF(n)}{REF(n)} \cdot \frac{\alpha}{\alpha - 1} \qquad (4.10)$$

was calculated and written into a single file of 3 records on the PDP 11/70 disk. The first record contains a legend with information like date, source, online and reference frequencies, the value of V_0, the velocity with respect to LSR for the 0th channel, number of minutes of integration etc. The second and third records contain the unsmoothed (uniform weighting for the autocorrelation function) and the Hanning smoothed spectrum Each such file is called a SCAN. A SCAN thus contains the integrated spectrum calibrated in units of (T_{BL}/T_{BS}) for one stretch of data with integration time ranging from 60 to 90 minutes. All subsequent processing of the data from a given source was done using the SCANs corresponding to that source.

All the individual SCANs corresponding to a source are first examined by plotting (T_{BL}/T_{BS}) aginst V_{LSR}, the doppler velocity with respect to the local standard of rest. All the good SCANs (viz., those free of interference and instrumental malfunctions if any) are averaged with weighting factors proportional to their integration times. During the averaging, 4 channels on either end of the spectrum in each SCAN are deleted. The channels are deleted at the upper end because of the possible aliasing if the input video band extends further than $f_S/2$, where f_S is the sampling frequency, and at the lower end because of insufficient rejection of the lower sideband in the SSB unit of the front end analog system (see section 3.6.2). Further, during the averaging the channels of the different SCANs are aligned such that their velocity V_{LSR} match with each other. If the velocity corresponding to channel 0 is different for the SCANs averaged, then one gets an integrated spectrum having more channels than in each SCAN. The end channels therefore may have somewhat smaller integration times and consequently a higher noise level.

An example of different SCANs corresponding to a source, and the integrated spectrum is shown in fig 4.7. As can be seen in this figure, a baseline curvature is usually present in the integrated spectrum This is instrumental in origin as discussed in section 4.3. A polynomial of appropriate order is fitted to the baseline in a least squares sense using only the channels

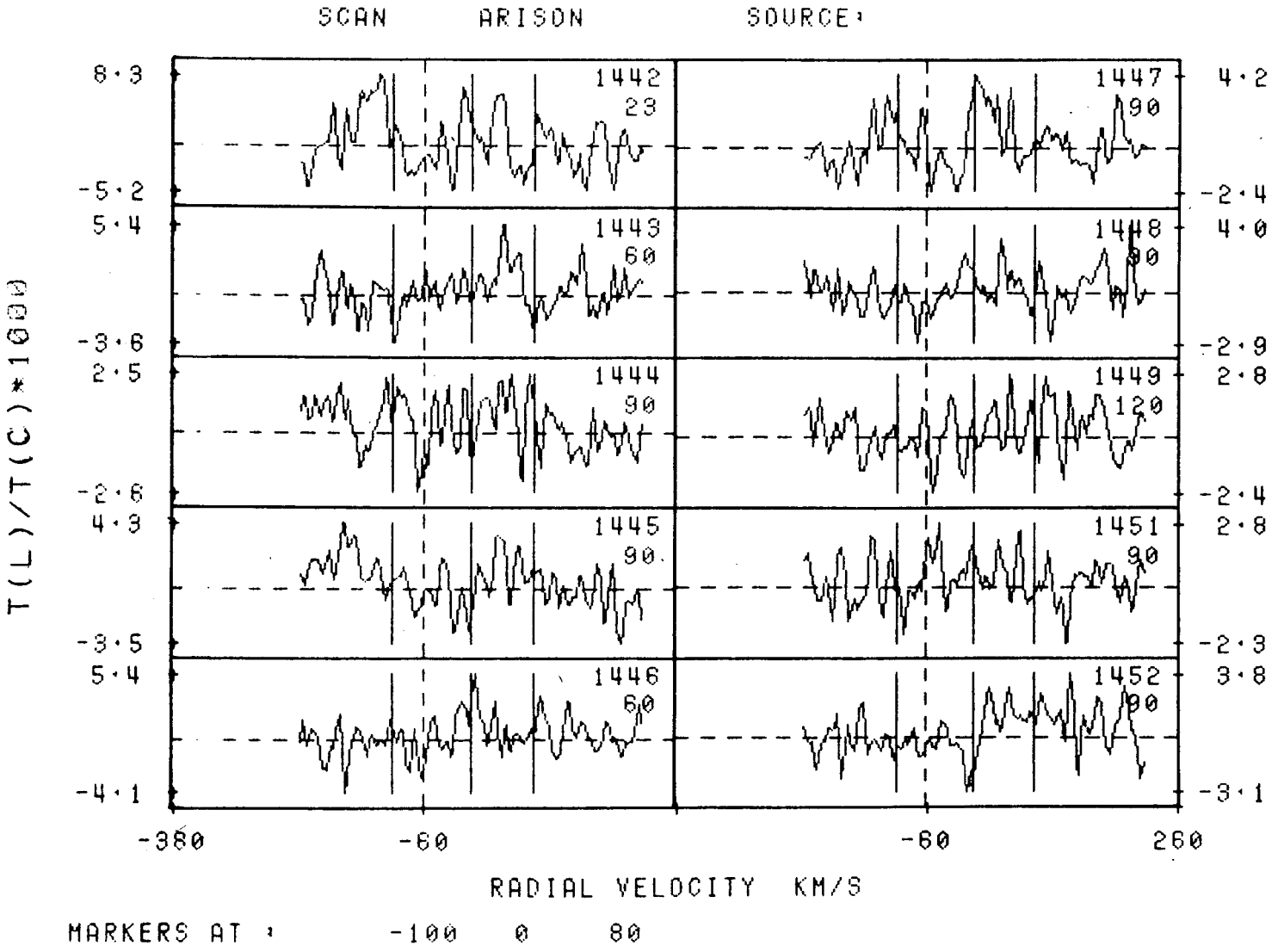


Fig. 4.7 The individual SCANs of source W48 (see text). The numbers on the top right corner indicate the scan numbers and integration time in minutes.

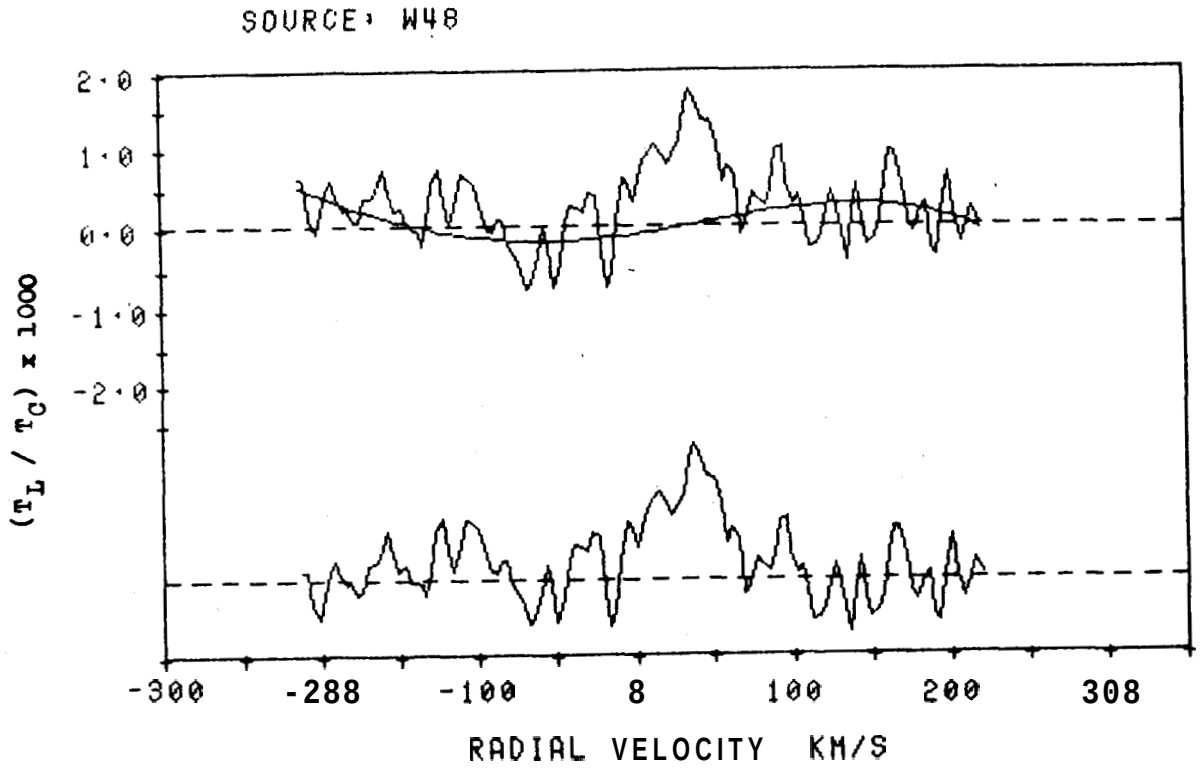
where the spectral line is not present. This polynomial is removed from the integrated spectrum to obtain the final spectrum In general, it was necessary to fit polynomials of up to 3rd order. The danger of fitting a baseline is that there is a possibility of losing any broad component that might be present in the spectrum If a very high order polynomial is used it is even possible that spectral components are modified due to the baseline fit. Only in one or two cases was it necessary to use a polynomial of order 4. An example of the baseline fit and the final spectrum after baseline removal is shown in figure 4.8

The next step in the data reduction (which is optional) is to smooth the final spectrum to the required velocity resolution. This is done in order to increase the signal to noise ratio in the spectrum without losing any spectral information or smearing the spectral profile. It is clear that the best signal to noise ratio is obtained when the resolution of the spectrum is comparable to the width (FWHM) of the spectral line present. Obviously, the final velocity resolution is determined by the width of the narrowest line present in the spectrum

In principle, any required frequency resolution (with the restriction that it be not better than $1/\tau_{max}$) can be obtained using a appropriate weighting for the autocorrelation function. However, the same result can be obtained by convolving the unsmoothed spectrum with a new function of appropriate width. Here the latter method is adopted. The Hanning smoothed final spectrum obtained as described above is convolved with a gaussian function whose width (FWHM) is calculated as follows.

The Hanning smoothed spectrum has a frequency resolution of $\Delta f_h = f_s/N$, where f_s is the sampling frequency and N is the number of autocorrelation channels. If the final frequency resolution required is Δf, then the width of the gaussian function Δ_4 to be used for convolution is given to good accuracy by

$$\Delta f^2 = \Delta f_h^2 + \Delta f_g^2$$



1442 1443 1444 1445 1446 1447 1440 1449 1451 1452

INTEGRRTIDN TIME	:	803	MINUTES
NUHBER OF CHRNNELS	:	120	
ORDER OF THE POLYNOMIRL	:	4	
VELOCITY RANGES SKIPPED	:	-130	-10
		-80	78

Fig. *4.8* The integrated spectrum and baseline fit for the source W48. The baseline removed spectrum is shown below. The baseline is fitted by leaving out the velocity ranges where line is present.

An example of the smoothing of the final spectrum is shown in figure 4.9.

The last step in the data reduction is the fitting of gaussian profiles to the spectral lines present in the final spectrum A gaussian profile is not always a good representation of the shape of a spectral line observed, but it is useful in defining the parameters of the observed line. Gaussian profiles are fitted to the final spectrum by using a least squares method. The residuals left after removing these gaussian profiles from the final spectrum should have pure noise like charecteristics. Two examples of a gaussian profile fit to the final spectrum are shown in figure 4.10.

4.6.1 Software for Data Reduction

The data reduction procedure described above was carried out using a number of computer codes developed to run on the PDP 11/70 computer at the ORT. The functions of each of these codes is briefly described below.

1. CODE 1: This program converts the integrated online and reference functions transferred from the Varian computer to the PDP format and writes it into a file on the disk. The program accepts information like date, source, T_{Bsys}, declination, LO frequencies, velocity of channel 0 etc and writes it as a legend record in the same file

2. CODE 2: This program is used to fourier transform the online and reference autocorrelation functions contained in the file created by CODE 1 after applying both uniform and Hanning weighting. The program uses a standard FFT algorithm The two normalized spectra with different weighting functions are computed and written into a file which is designated as a SCAN. These files are refered to by their SCAN numbers during further processing. Each SCAN also contains a legend.

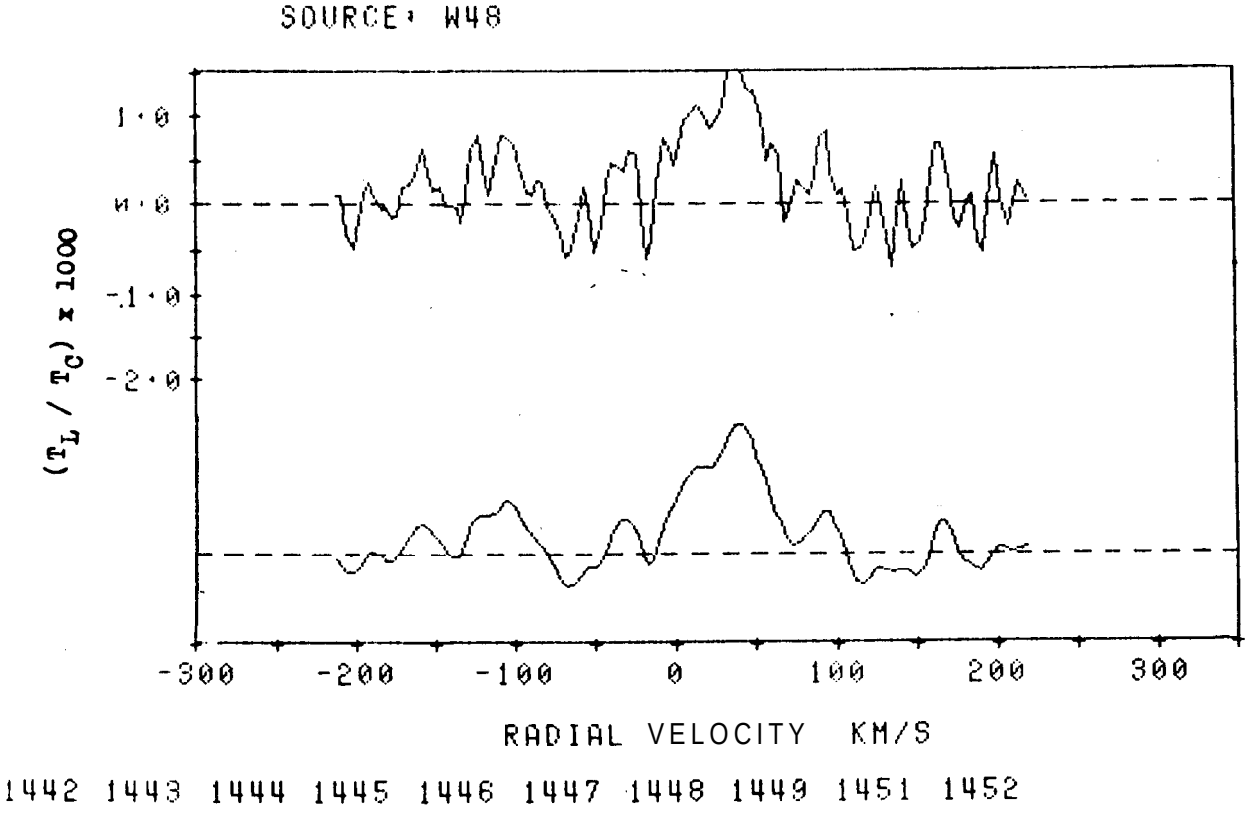
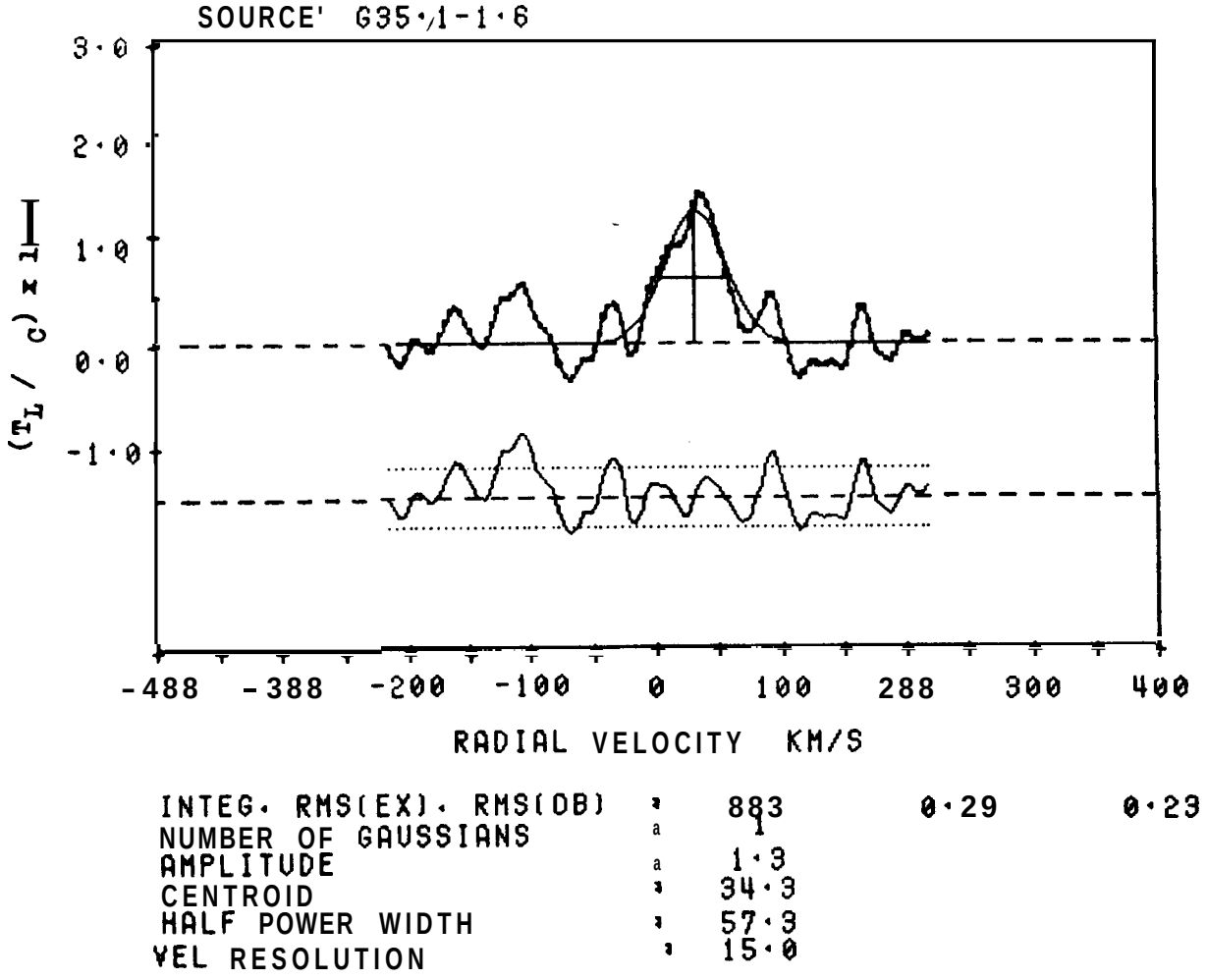


Fig. 4.9 Smoothing' of the baseline removed spectrum observed towards W48. The spectrum is smoothed to a resolution of 15 km s^{-1} and is shown in the lower part of the diagram.



Fig, 4.10a Gaussian fit to the observed spectrum towards W48. The residuals after subtracting the fitted gaussian is shown below. The dotted lines indicate the expected rms noise. The amplitude and width of the gaussian is indicated by the cross,

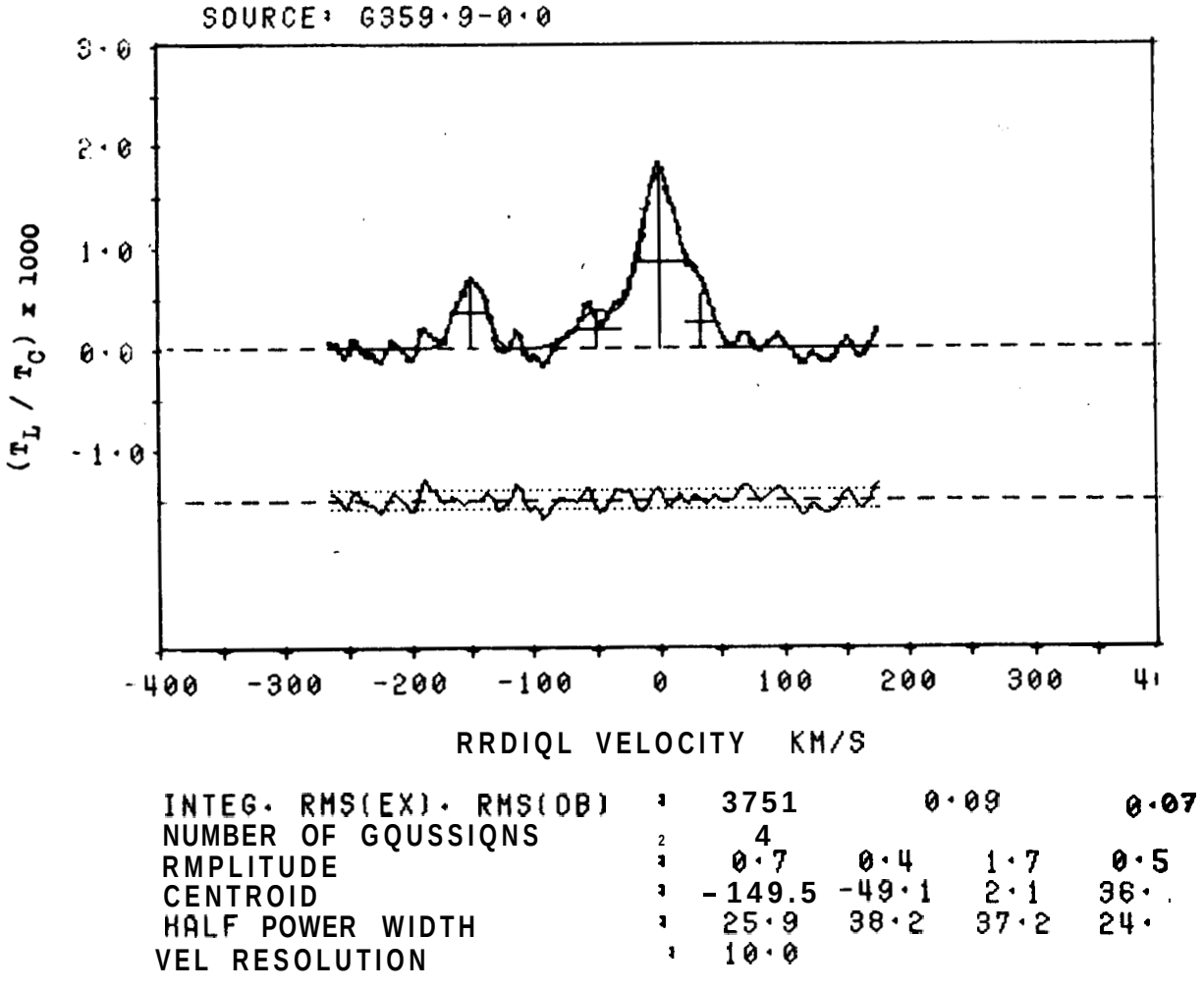


Fig. 4.10b Gaussian components fitted to the spectrum observed towards Sgr A. The residuals are shown below. The dotted lines indicate the expected rms noise.

3. CODE 3: This program can average different SCANS corresponding to a source and produce an integrated spectrum The SCANs are shifted and alligned so that their velocities match before integration is carried out. For any source this program creates an output file containing the integrated spectrum with both uniform and Hanning weighting. It records in the legend, the integration time and the total number of points in the spectrum

4. CODE 4: This program can fit and subtract a polynomial baseline of given order from an integrated spectrum. The velocity ranges to be skipped during the fitting process can be specified. The baseline 'removed spectrum is written into a file. The values of the coefficients of the polynomial are recorded in the legend. The program displays (on an interactive graphics terminal), the integrated spectrum, the polynomial function and the baseline subtracted spectrum for visual inspection. If the fit is unsatisfactory, the program allows for further trials with new parameters for fitting.

5. CODE 5: This program can smooth any baseline subtracted final spectrum, to any given velocity resolution by convolving the spectrum with a gaussian function of appropriate width. The unsmoothed and the smoothed spectra are displayed for visual inspection. The smoothed spectrum with the velocity resolution information is written into a file.

6. CODE 6: This program is for fitting gaussian profiles, to the final baseline removed spectrum or a smoothed version of it. Initial guesses for the parameters of the gaussian components should be given as inputs. The fit is obtained using a least squares method in which the residuals are minimized. The gaussian components and the residuals are displayed for visual inspection. The program also computes the expected rms noise of the

residuals and compares it with the observed rms noise.

7. CODE 7: This is a program for displaying the data as plots on a graphics terminal or a printer/plotter. Individual SCANs can be displayed one below the other with their velocity scales aligned for comparison. The program can display for any source the integrated spectrum, the baseline removed spectrum, the smoothed spectrum, the fitted baseline, gaussian components and the residuals. It also displays the information of the legend in each of the processed data files so that one knows what has been done or what is to be done.

4.7 THE INTERFERENCE PROBLEM

One of the major difficulties in spectral line observations at low frequencies is the presence of man made CW interference. Low level CW interference from equipment in the laboratory or even in the receiver room, low level oscillations in one of the RF amplifiers, harmonics of transmissions in the communication bands from nearby ground based transmitters and satellites can all affect the quality of the data seriously. The interference usually manifests itself as an increase in the rms noise in the spectra or as sharp spikes in either one minute data or the averaged spectrum depending on its strength and duration. The lines due to interference can generally be distinguished easily from those due to astronomical sources by their peakiness and confinement to one or two channels only. For nearby interference sources, the strength of interference would depend heavily on the hour angle and declination of the antenna.

The instruments in the laboratory which are most likely to cause spectral interference are those having fixed or variable frequency oscillators, like signal generators, crystal oscillators, clock generators' in digital circuits etc. For example, it was noticed that the digital delay line correlator which was used for interferometric observations with the ORT used

to cause CW interference in one of the bands used for recombination line observations. It was necessary to make sure that this equipment was switched off during spectral line observations; failing to do so usually required discarding of the whole stretch of data. A clock frequency generator based on a 5MHz quartz crystal oscillator located at the nearby Cosmic Ray Observatory used to cause strong CW interference at 325MHz corresponding to the 60th harmonic of the oscillator'frequency. All observations carried out when the Cosmic Ray Laboratory was operational had to be discarded due to this and other interference. For some time during the period of the observations reported here, CW interference from geostationary satellite used to come through the image band of the ORT receiver system(267.5MHz). We had to switch over from the recombination line at 328.6MHz to the adjacent one at 325MHz to avoid this interference. Because of this interference, additional filters were introduced following each of the RF amplifiers to provide enough rejection at the image band frequencies.

It is therefore necessary to take special precautions during spectral line observations, and to keep track of such interfering signals. At the begining of each day's observation a spectrum was first obtained by integrating for about 5 minutes, using the same LO setting as for the actual planned observation. The spectrum was examined for the presence of interference and if any was detected an attempt was made to locate its source (if it was within the observatory), and to switch .off the offending equipment. Failing to locate the source usually resulted in abandoning the day's observations.

During the data reduction, it was essential to examine the individual stretches of data carefully to make sure they were free of interference. It was sometimes necessary to discard several SCANs (60-90 minutes data) corresponding to a source during the data reduction. It was usually easy to detect and discard bad stretches of data. In the observations reported here, it was possible to obtain reliable spectra, free of interference, after discarding in some cases nearly 30% of the

total data.

Interference which is broad band in nature does not usually affect spectral line observation made using a 1-bit correlator. This is true only if the interference is noise-like in character and occupies a band larger than the total online and reference bands used for the observations. Interference due to atmospheric lightening, automobile spark plugs, and ionospheric scintillations which affect seriously continuum observations are not so detrimental to spectral line observations.