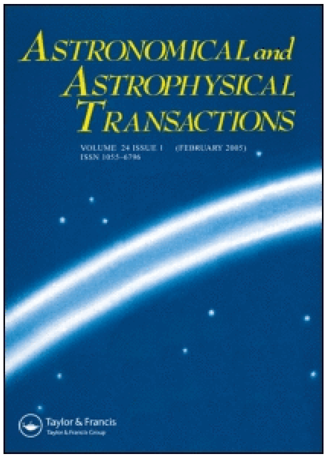

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SEARCH FOR RADIO RECOMBINATION LINES AT 408 MHZ WITH THE NORTHERN CROSS

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Spectral line search was carried out for the first time with the Northern Cross radiotelescope at Medicina (Italy). The total bandpass of the antenna was sampled and processed in real time with the high resolution digital FFT spectrometer. The radio recombination line of carbon C252α was reliably detected toward Cassiopeia A. The observed line profile is composed of 3 emission components at positions -47 km s^{-1}, -38 km s^{-1} and 0 km s^{-1} and relative intensities as 3:2:1. The detection of the component at zero velocity is of special importance since there has been only one measurement of such an emission made at 325 MHz.

KEY WORDS ISM, radio lines, HII regions, Cassiopeia A

1 INTRODUCTION

Low frequency radio recombination lines of carbon are a good diagnostic of photodissociation regions which form on outer surfaces of molecular clouds or in HI clouds exposed to external UV radiation. The lines turn from absorption at low frequencies into emission at frequencies above 150 MHz and reach a maximum of intensity at 300–500 MHz (Sorochenko and Walmsley, 1991; Kantharia *et al.*, 1998). The Northern Cross radiotelescope (Ficarra *et al.*, 1985; D'Amico *et al.*, 1996) operating at 408 MHz presents a good opportunity to probe the lines near the maximum. We undertook a radio recombination line search with the Northern Cross with the aim of accessing the capabilities of the instrument for spectral line investigations. Two well known objects: the supernova remnant Cassiopeia A and the HII region W51 were chosen as primary targets for the search. The present paper presents the first results obtained towards Cassiopeia A.

2 OBSERVATIONS AND DATA REDUCTION

We selected the North-South arm of the Cross for the present search because it provides longer integration time as compared to the East-West arm. We measured the transition time of Cassiopeia A through the North-South antenna beam to be about 13 minutes. The half power beam width in declination, $4'$, is just about the angular size $4.3'$ of Cassiopeia A (Rosenberg, 1970).

The spectral analysis was performed with a fast Fourier transform high resolution digital spectrometer (Montebugnoli *et al.*, 1996). The total frequency band of the antenna, 2.7 MHz, was sampled and processed in real time. The spectrometer was used in a total power mode with 8192 channels giving a spectral resolution of 397 Hz (or 0.3 km s^{-1}). Source spectra were recorded during the 20 minutes of the source transit. Reference spectra were recorded over 20 minutes starting 50 minutes prior to or 30 minutes after the culmination time. The spectra are stored in an output file in blocks of 2.5 minutes each of integration.

In contrast to the usual spectral line observations which are made with steerable antennae the present observations used a transit instrument. Therefore a data reduction technique must account for the system noise temperature varying substantially during source transit especially if the source is strong like Cassiopeia A. To account for such variations we did as follows. For each OFF block we extracted 512 points of a spectrum centered at the expected line frequency, fitted this extraction to a third order polynomial, and took a median value of the polynomial. Then we averaged the median values over all the OFF blocks. This average, $Y_{\rm OFF}$, is proportional to the system temperature at the line frequency for the reference position.

Similarly for each ON block i we extracted 512 points $S_i(f)$ and fitted to a polynomial, $Y_i(f)$. The difference between the median value Y_i of the $Y_i(f)$ and the $Y_{\rm OFF}$ is proportional to the source antenna temperature and we can calculate coefficients $k_i = Y_i/(Y_i - Y_{\rm OFF})$, which equal the ratio of the ON source system temperature to the source antenna temperature for this block.

An equation of transfer for the case of a strong background source and small optical depth which both hold true for Cassiopeia A at 408 MHz simplifies to $T_L = -\tau_L T_{\rm BG}$, where: T_L is the excess temperature at the line frequency, τ_L is the line optical depth, and $T_{\rm BG}$ is the temperature of the background source. Therefore a line optical depth spectrum for the ith block can be written as $\tau_i(f) = k_i(S_i(f) - Y_i(f))/Y_i(f)$ and its rms deviation as $\sigma_i = k_i\sigma_0$, where: $\sigma_0 = (\delta f t_0)^{-1/2}$, δf is the spectral resolution, and t_0 – the integration time of a single block.

A weighted average over all the ON blocks, τ, was obtained with weights $w_i = c^2/\sigma_i^2$. We chose the arbitrary constant c to require $\sum_{i=1}^{N} w_i = 1$. Then we got very simple expressions for the rms deviation of the average line optical depth $\sigma_\tau = c = \sigma_0(\sum_{i=1}^{N} k_i^{-1/2})^{-1/2}$ and for the effective integration time $t_{\rm eff} = t_0 \sum_{i=1}^{N} k_i^{-1/2}$. The spectra of individual observing sessions j were averaged together with weights equal to their effective integration times t_j. In this way the total integration time was a simple sum of t_j.

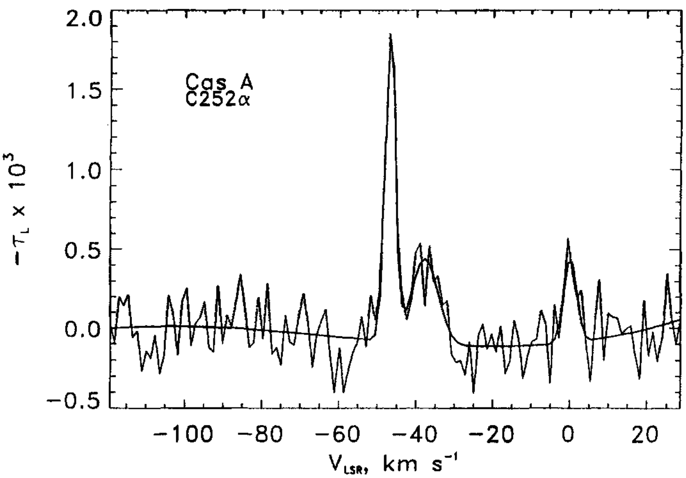

Figure 1 Carbon recombination line spectrum observed toward Cassiopeia A at 408.7 MHz. The vertical scale is in units of line optical depth and the horizontal one is in units of radial velocity. The original data were smoothed to a resolution of 1.2 km s^{-1}. The 3 best fitted Gaussian components and a polynomial are shown superimposed on the observed spectrum.

3 RESULTS AND DISCUSSION

We averaged the spectra obtained toward Cassiopeia A during 28 observing sessions in November – December 1999 and got a total effective integration time of 6.4 hours. It should be noted that the observed band was essentially free of interference and we did not discard any spectrum or channel when averaging. The average was fitted to a function composed of one Gaussian to represent the most prominent spectral feature and of a polynomial of 5th order and a sine function to represent a baseline. The sine term is due to DSP board hardware and is still observable even with a 50 Om match load at the spectrometer input. Fortunately it has a constant period of about 32 channels and can easily be removed from spectra. In our case it had a relatively small amplitude of 0.25×10^{-3} and a period of 31.8 channels. The final spectrum after subtraction of the fitted baseline and rebinning the residuals by 4 channels to smooth them is shown in Figure 1.

The figure clearly shows the presence of three spectral features in the C252α spectrum. The parameters of the Gaussian fit to the features are listed in Table 1. Rows 2–5 give for each of the three components the peak line optical depth, τ_L, multiplied by 10^3, the line velocity relative to the local standard of rest, V_{LSR}, the full line width at half maximum in km s^{-1}, ΔV, and in kHz, $\Delta\nu$. The last row gives estimates of integrated line intensity $I_L = 1.07\tau_L\Delta\nu$.

The components at velocities −47 km s^{-1} and −38 km s^{-1} are in good agreement with other high frequency measurements (e.g. Payne *et al.*, 1989; Kantharia *et al.*, 1998). They arise in cold ($T_e \simeq$ 50–70 K) gas located in Perseus spiral arm along the line of sight toward Cassiopeia A. The component at zero velocity detected here

Table 1. Parameters of the observed lines*.

Component	*1*	*2*	*3*
$\tau_L \times 10^3$	-1.97 ± 0.15	-0.54 ± 0.09	-0.54 ± 0.13
V_{LSR}, km s^{-1}	-46.8 ± 0.12	-37.7 ± 0.7	0.06 ± 0.4
ΔV, km s^{-1}	3.13 ± 0.28	8.0 ± 1.7	3.9 ± 1.1
$\Delta\nu$, kHz	4.27 ± 0.38	10.9 ± 2.3	5.3 ± 1.5
I_L, Hz	9.0 ± 1.0	6.3 ± 1.7	3.1 ± 1.1

*Errors quoted are 1σ values.

should be due to gas located in the Orion arm. There had previously been only one positive detection of such an emission component at 4σ level made by Payne *et al.* (1989) at 325 MHz while the most recent measurements at 560 MHz and 770 MHz (Kantharia *et al.*, 1998) failed to detect it. Further observations at 408 MHz with longer integration time could improve the accuracy of the data and allow reliable physical characteristics of the gas in the Orion arm to be derived.

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