

## VIII. RADIO ASTRONOMY\*

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### A. AN ATTEMPT TO MEASURE ZEEMAN SPLITTING OF THE GALACTIC 21-cm HYDROGEN LINE

#### 1. Introduction

The existence of a galactic magnetic field is presupposed by theories describing the polarization of starlight, the emission of galactic radio noise, and the behavior of cosmic rays. The magnitude of the field cannot be measured directly from these effects, although estimates of from  $10^{-5}$  gauss to  $10^{-6}$  gauss are common. These facts are discussed and referenced by Shklovsky,<sup>1</sup> and also in two papers<sup>2,3</sup> that describe previous attempts to measure the field by measuring the Zeeman splitting of the 21-cm hydrogen line. The experiment was first suggested by Bolton and Wild.<sup>4</sup>

A brief description of the Zeeman effect on hydrogen line radiation may be given as follows. The line-of-sight component of the galactic magnetic field causes a splitting of the radiation into left-hand and right-hand circularly polarized waves with a difference in frequency of 2.8 cps per  $10^{-6}$  gauss. The sharpest hydrogen lines found in absorption of the strong discrete sources are  $\sim 10$ -20 kc wide, and thus the expected splitting of 3-30 cps is quite difficult to measure. The procedure consists of alternately measuring the hydrogen profile with feeds that are receptive to circular polarization of opposite sense and recording the difference profile. This difference profile,  $\Delta T(f)$ , is related to the observed (either polarization) profile,  $T(f)$ , by the following relation which holds if the frequency splitting,  $\Delta f$ , is small compared with the width of the observed line:

$$\Delta T(f) = \Delta f \cdot T'(f) = 2.8 \times 10^6 H \cdot T'(f),$$

where  $H$  is the magnetic field, and the prime denotes derivative with respect to frequency. The observed profile and the expected difference profile for the two observed sources, Cas A and Taurus A, are shown in Figs. VIII-1 and VIII-2.

#### 2. Experimental Procedure

Observations of Cas A and Taurus A were performed with the use of the 85' Howard Tatel Radio Telescope at the National Radio Astronomy Observatory, Green Bank, West Virginia, in conjunction with a dual circular polarization feed built by Jasik Laboratories. Switching between polarizations was done at a 1/14 cps rate by using a

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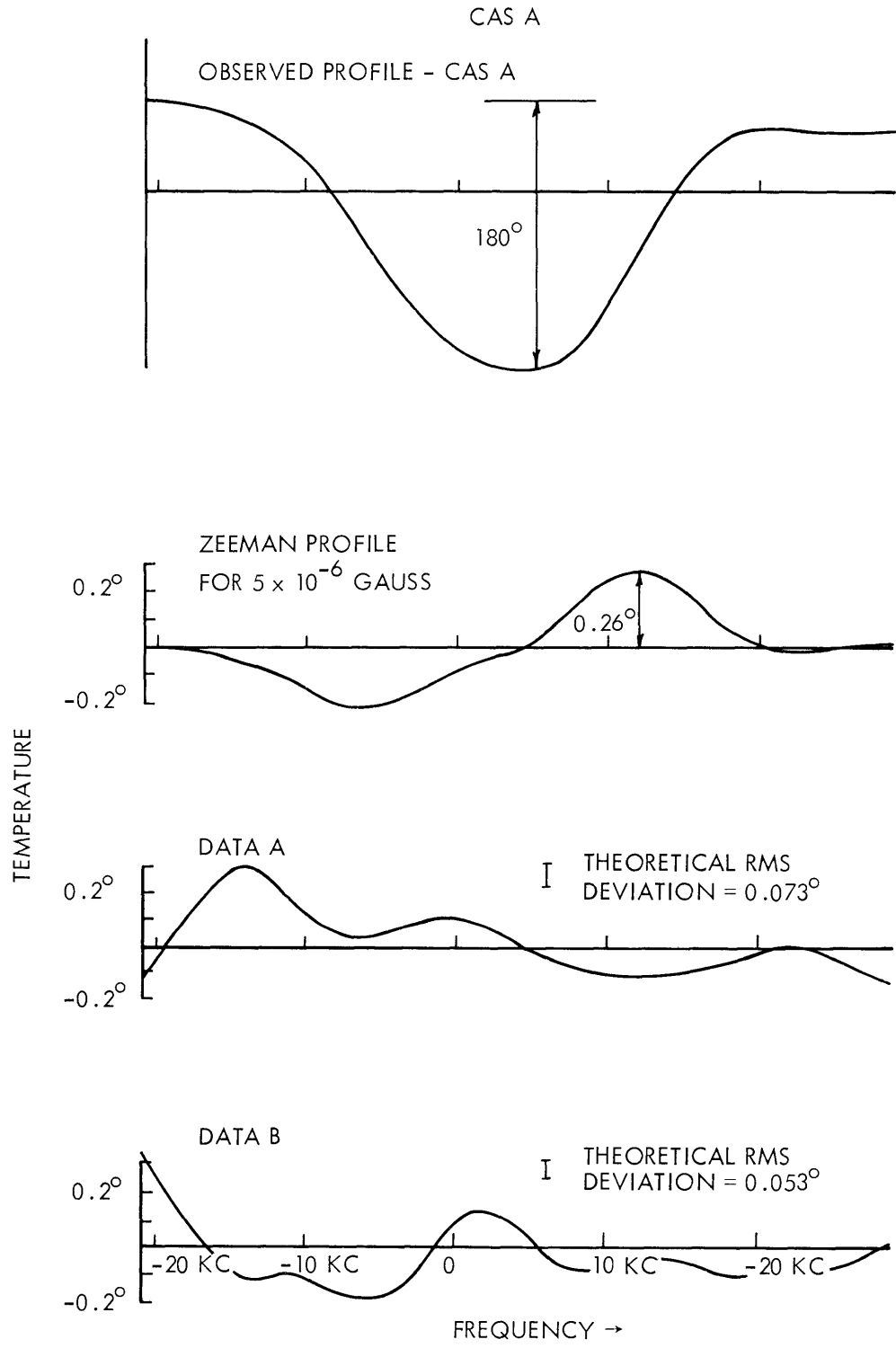


Fig. VIII-1. Results of attempt to measure Zeeman splitting of 21-cm galactic hydrogen line observed in absorption of Cas A radio source.

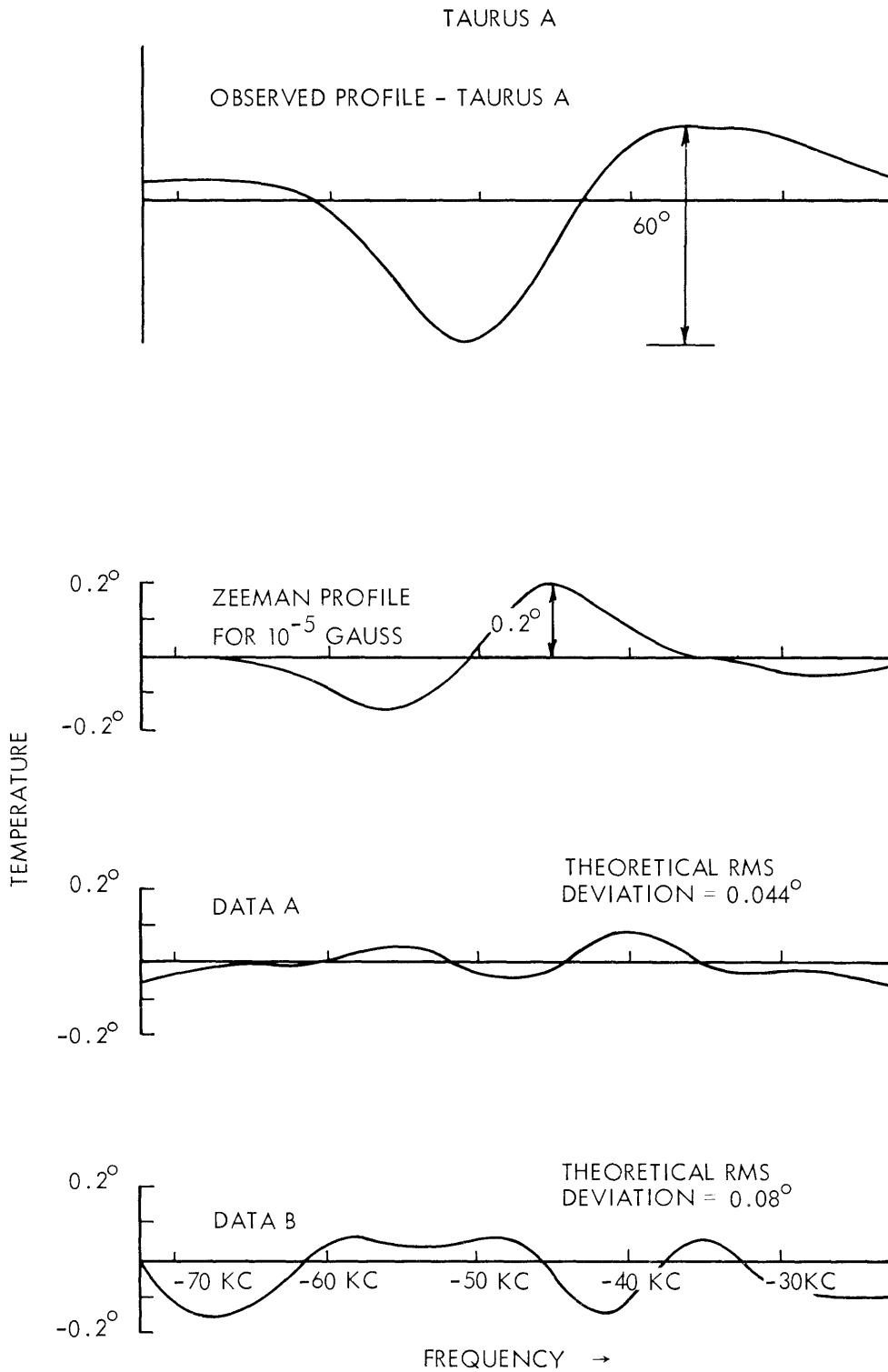


Fig. VIII-2. Results of attempt to measure Zeeman splitting of 21-cm galactic hydrogen line observed in absorption of Taurus A radio source.

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mechanical coaxial switch. Double stub tuners were inserted between each arm of the switch and the feed, and were adjusted so that the standing-wave ratio of each polarization feed was less than 1.01 when measured through the switch.

An electron-beam, traveling-wave, parametric amplifier was used for all observations except for those of Taurus, Data B, for which a crystal mixer was used. The single-channel noise temperature, including switch and stub losses, was  $600^\circ$  for the parametric amplifier, and  $1080^\circ$  for the crystal mixer.

Through conventional means a 50-kc portion of the band is filtered out and shifted down to low frequencies at which its autocorrelation function is found by a digital correlator.<sup>5</sup> A computer Fourier transform of the autocorrelation function then gives the power spectrum. This system is analogous to a multichannel radiometer having 7.5-kc wide filters spaced over the 50-kc band.

The observational procedure consisted, first, of making a 10-minute observation of the absorption profile, with the use of the right-hand circular polarization feed. Typical results are the top curves in Figs. VIII-1 and VIII-2. A loss in sensitivity or a frequency error could be found in this manner. Next, after this run, a 5-hour run for measuring the difference profile was made. The local oscillator was reset every half hour to correct for Doppler shift resulting from the earth's motion. One or two 5-hour runs were made on Cas A and Taurus A each day for approximately 35 days.

### 3. Results

A difficulty that arises in performing the Zeeman experiment is due to small differences in gain between the right-hand and left-hand circular polarization feeds. If the gain of one feed is  $1 + a$  times the gain of the other feed, then the difference profile,  $\Delta T(f)$ , will contain a term  $a \cdot T(f)$ ; the absorption profile will appear in the data. Since the absorption profile is known, it may be removed from the difference profile. However, care must be taken that the correction is not shifted in frequency, for this would cause a false Zeeman effect. It is easily seen that if an unbalance signal,  $a \cdot T(f)$ , is corrected by subtraction of a profile,  $a \cdot T(f + \delta f)$ , then the result is the same as that which would be found for a Zeeman splitting of value  $a \cdot \delta f$ .

Approximately 20 per cent of the data that were taken showed values of  $a$  less than 0.003 (Data A); 40 per cent had  $a$  between 0.003 and 0.03 (Data B); and the rest had  $a$  greater than 0.03 and were not used. The variations in  $a$  are probably due to temperature effects on the feed, stubs, and switch, and to tracking errors and flexure of the telescope. The largest error in the local oscillators was less than 100 cps; thus even with  $a = 0.03$ , the largest spurious Zeeman effect would be 3 cps, or  $\sim 10^{-6}$  gauss.

The average of the Data A and Data B runs for Cas A and Taurus A are plotted in the figures. The Data A runs require no correction for feed unbalance, while the

Table VIII-1. Zeeman results.

	Theoretical RMS Fluctuation*	Actual RMS Fluctuation†	Total Noise Temperature T	Profile Depth	Observed Time $\tau$ (sec)	Treatment of Data
Cas Data A	.073° 1.4	.099° 1.9	1060°	180°	$1.2 \times 10^5$	No correction to data
Cas Data B	.053° 1.0	.12° 2.3	1060°	180°	$2.1 \times 10^5$	Absorption profile of 1.37° peak subtracted from raw data
Taurus Data A	.044° 2.2	.04° 2.0	850°	60°	$2.2 \times 10^5$	Small slope correction of 0.12°/10 kc
Taurus Data B	.08° 4.0	.05° 2.5	1330°	60°	$1.6 \times 10^5$	Absorption profile of 1.15° peak subtracted from raw data

\*  $\Delta T = 2.1 T / \sqrt{B\tau}$ , where T = Antenna + Receiver Noise Temperature,  $B = 7.5 \times 10^3$ , and  $\tau$  is the Observation Time. (The quantity below  $\Delta T$  is the magnetic field in units of  $10^{-6}$  gauss which will give a peak signal =  $\Delta T$ .)

†  $\Delta T'$  = rms value of data, with the mean taken over frequency.

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Data B runs have been corrected as indicated in Table VIII-1. Our conclusion is that the line-of-sight component of the magnetic field is less than  $3 \times 10^{-6}$  gauss in Cas A, and less than  $5 \times 10^{-6}$  gauss in Taurus A.

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