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Observations

of the

OWENS VALLEY RADIO OBSERVATORY

California Institute of Technology

Pasadena, California

1963

5. AN ATTEMPT TO MEASURE THE GALACTIC MAGNETIC FIELD

by

D. Morris, B. G. Clark, and R. W. Wilson

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I. INTRODUCTION

This paper describes measurements made in November, 1961, and February, 1962, in an attempt to determine the galactic magnetic field by the Zeeman splitting of the 21-cm line. This method of measurement was first proposed by Bolton and Wild (1957) and has been used previously by a number of observers (Galt, Slater, and Shuter 1960; Davies, Slater, Shuter, and Wild 1960; Davies, Verschuur, and Wild 1962; and by Weinreb 1962).

The present observations were confined to two absorption lines, one in the spectrum of Cas A (at a frequency of ≈ 0 kc/s with respect to the natural line frequency, after correction to the local standard of rest) and the other in the spectrum of the Crab Nebula (at a frequeny of $\approx$ -50 kc/s).

In the case of the Cas A line, Davies, Slater, Schuter, and Wild (1960) reported a field of $+1 \pm 4 \times 10^{-6}$ oersted directed away from the observer. Weinreb (1962), on the other hand, obtained an upper limit of 3×10^{-6} oersted. For the line in the spectrum of the Crab Nebula, Davies, Verschuur and Wild (1962) have recently reported a rather complicated situation. They find that the absorption line can be resolved into two distinct components, one of which shows evidence of a longitudinal field of $+2.5 \times 10^{-5}$ oersted. Weinreb's (1962) limit in this case was 5×10^{-6} oersted. However, this limit may need revision in view of the reported double nature of the absorption line (Davies, Verschuur and Wild 1962).

II. EXPERIMENTAL TECHNIQUE

For the present investigation the two 90' antennas at the California Institute of Technology Radio Observatory have been used with a single-channel, narrow-band interferometer (Clark, Radhakrishnan and Wilson 1962). Each dish was illuminated by a linearly polarized feed horn. When the two feeds are arranged with orthogonal electric vectors the system is sensitive to both linear and circular polarizations. However, the two types of polarization can be distinguished on the basis of the phase of the interferometer response they produce. In particular, the component of the interferometer response in phase quadrature with that produced with parallel feeds is proportional to one-half the difference between oppositely circularly polarized fluxes. Hence on scanning across an absorption line, this component will produce the familiar "S" shaped response in the presence of Zeeman splitting. When the feed horns are set with their electric vectors parallel, on the other hand, the system will respond to one-half of the total flux from an unpolarized source and thus provide a gain and phase calibration.

The measurements with orthogonal horns were made with the electric vectors of the feeds at position angles of 0° and 90°. With this choice of angles the response to the 1.5% linear polarization from the Crab Nebula (Morris and Radhakrishnan 1963) was completely negligible. In the case of Cas A, no linear polarization greater than 0.2% has been reported, and consequently its effects can be neglected for the present purpose.

Figure 1 is a schematic representation of our receiving equipment which was a simple superheterodyne. The local oscillator for each channel of the receiver consisted of a klystron which was phase-locked to a waveform of frequency equal to the difference in frequency between a tunable high-frequency oscillator and a 1 Mc/s reference signal. Lobe rotation was accomplished by phase shifting this 1 Mc/s signal and in practice a fringe rate of about one per minute was used. With conventional crystal mixers, the overall single sideband system temperature was about 1000°K. The line receiver had a nearly rectangular bandpass, the width of which was fixed at about 6 kc/s by crystal filters. Any instrumental polarization could be monitored by the wide band (5 Mc/s) continuum receiver. In correcting for instrumental polarization, we have assumed that the instrumental polarization does not differ over this bandpass from that in the narrow channel.

It is necessary to integrate for some hours to measure any Zeeman splitting and, consequently, the interferometer fringes must be phase-detected and integrated. These operations were performed by the equipment in the lower half of Figure 1. The equipment within the box is an analogue computer, the output of which is a shift rotation whose instantaneous angle corresponds to the phase of the interferometer fringes. The receiver output can then be multiplied by the sine and cosine of this angle before integration. For this purpose the receiver output was chopped at 400 c/s, then passed through a resolver which performed the multiplication, and subsequently phase detected at 400 c/s. The resultant "D.C." output was then integrated by two "ball and disc" mechanical integrators.

All the observations were made at an antenna spacing of 200 feet N-S. Measurements of circularly polarized flux were taken with orthogonal feeds at a series of frequencies off the lines, at the points of maximum slope on the lines, and in the case of the Crab Nebula at the bottom of the line. Each integration with orthogonal feeds extended for a period of about 20 minutes during which time phase drifts in the equipment were judged to be negligible. For the purpose of establishing a phase and gain reference, each integration was preceded by a short observation with parallel feeds. Throughout all observations a broad-band continuum record was taken in order to monitor and adjust any instrumental polarization.

III. RESULTS

The Cas A Line at 0 kc/s

Our observations of Cas A are summarized in Table 1 and are displayed together with the line profile as observed with a 6 kc/s bandwidth in Figure 2.

Table 1

Summary of Results on Cas A After Correction for Instrumental Polarization

	Off Line Low	Negative Slope	Line Bottom	Positive Slope	Off Line High
Frequency (kc/s)	-85	-7.0	+1.6	+10	+102.0
Integration Time (hours)	10	16	0	16	10
Measured Circular Polarization $\frac{(\text{L.H.}-\text{R.H.})\times 10^3}{\text{Profile Depth}}$	-1.25 ±0.5	-0.36 ±0.65		-1.45 ±0.70	-1.0 ±0.9

In Figure 2a we show the absorption profile. In Figure 2b we show our raw data without correction for instrumental polarization. There we have plotted as the ordinate R.H. circularly polarized flux minus L.H. circularly polarized flux, expressed as a fraction of the profile depth as measured in one polarization (c.f. Davies, Verschuur and Wild 1962). We use the radio convention of defining R.H. and L.H. circular polarization as given in Pawsey and Bracewell (1955). During the observations the instrumental polarization was typically 2 parts per 1000, but of random phase. On the basis of the continuum records we have estimated the corrections necessary to allow for this. Figure 2c displays the resultant corrected values. The effective bandwidth used for these observations is about 6.5 kc/s.

The observed difference in circularly polarized flux between the two sides of the line corresponds to a longitudinal magnetic field of $+2 \pm 2 \times 10^{-6}$ oersted. In arriving at this figure we have assumed that the line is single and we have used the sign convention that a positive field is one directed away from the observer. The quoted errors are standard deviations.

We note that the above value for the field is not in disagreement with either the results of Davies et al (1962) or Weinreb (1962).

The Crab Nebula Line at -50 kc/s

In Figure 3 we present our observations as a function of frequency and uncorrected for instrumental polarization. Table 2 summarizes our observations of the Crab Nebula line.

Table 2

Summary of Results on Crab Nebula Line After Smoothing to 8 kc/s and Correcting for Instrumental Polarization

	Off Line Low	Negative Slope	Line Bottom	Positive Slope	Off Line High
Frequency (kc/s)	-99	-55	-49	-44	+39
Integration Time (hours)	16	29	5	33	5
Measured Circular Polarization $\frac{(\text{L.H.}-\text{R.H.})\times 10^3}{\text{Profile Depth}}$	+0.6 ±2.8	-1.5 ±1.5	-4.0 ±4.0	+1.3 ±1.9	+1.8 ±4.0

In Figure 4 we compare our measurements, after correction for instrumental polarization, with those of Davies, Verschuur and Wild (1962) and with those of Weinreb (1962). We have averaged our observations made on the sides of the absorption line so that the effective bandwidth of our observations is about 8 kc/s. Since Weinreb's bandwidth was 7.5 kc/s we have plotted his results directly, but the results of Davies, Verschuur and Wild (1962) have been smoothed to correspond to measures made with a rectangular bandpass of 7.5 kc/s width.

To obtain a numerical comparison of the results we have fitted the results of Davies, Verschuur and Wild (1962) to our measurements as shown in Figure 3b by the method of least squares. We choose a relation of the form

$$\text{C.I.T.} = A(\text{Davies et al}) + B(\text{profile shape}).$$

This last term allows for an unknown instrumental polarization. We obtain

$$A = -0.36 \pm 0.29$$

$$B = 5.0 \pm 2.4 \times 10^{-3} .$$

Hence we conclude that both the present measurements and those of Weinreb would suggest a considerably smaller field than has been proposed by Davies, Verschuur and Wild (1962).

Acknowledgments

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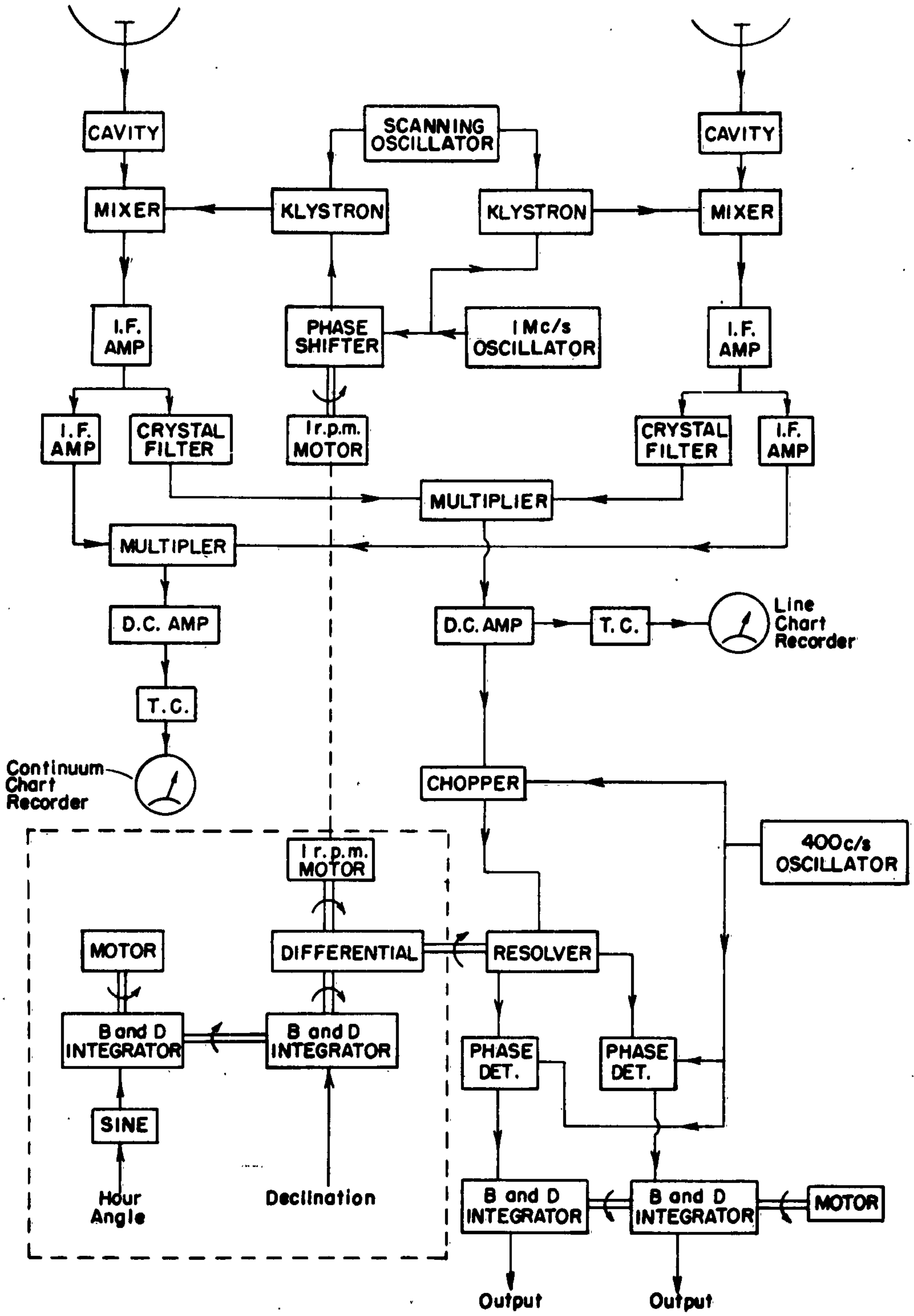

Figure 1. Block diagram of receiving equipment.

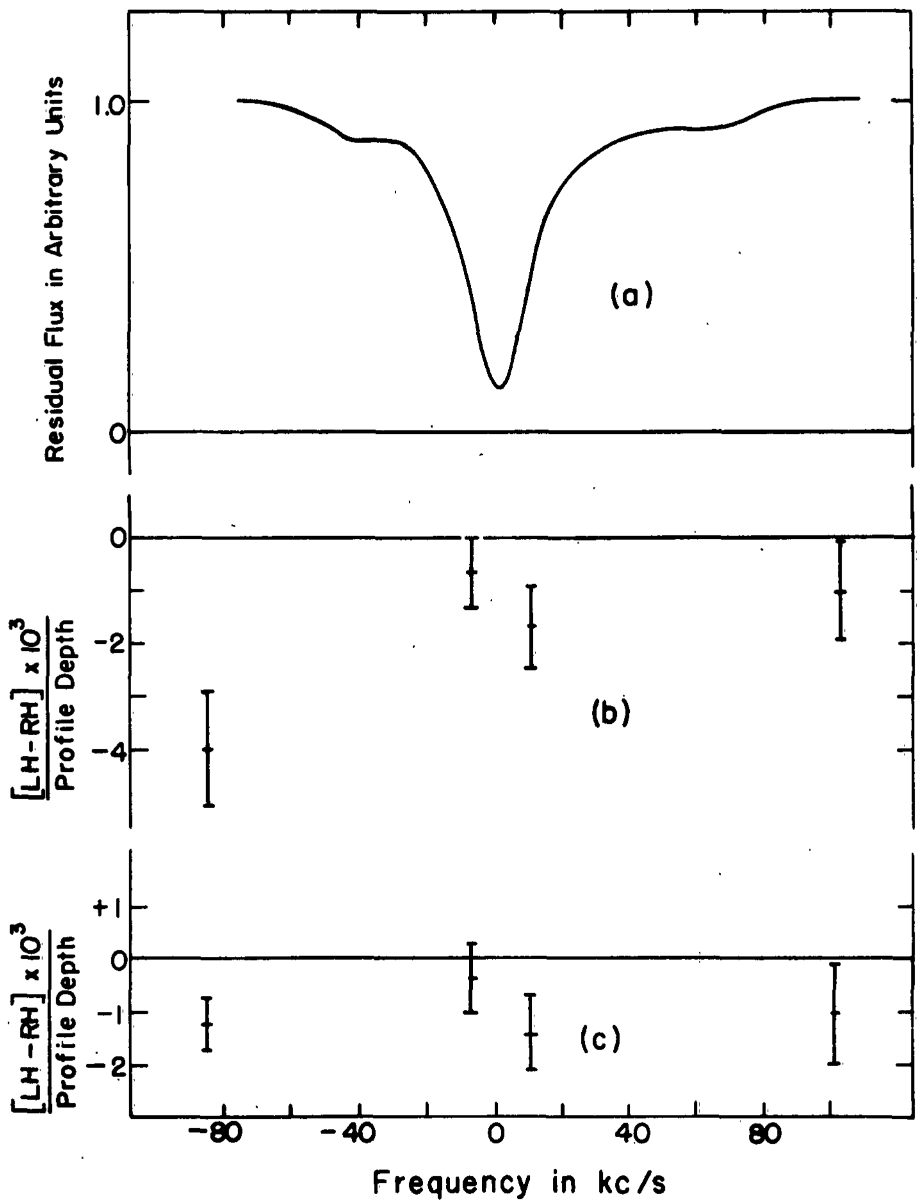

Figure 2. Measurements of the Cas A absorption line.

(a) The absorption profile as observed with 6 kc/s bandwidth.

(b) Uncorrected measurements of Zeeman profile.

(c) Measurements of Zeeman profile corrected for instrumental polarization.

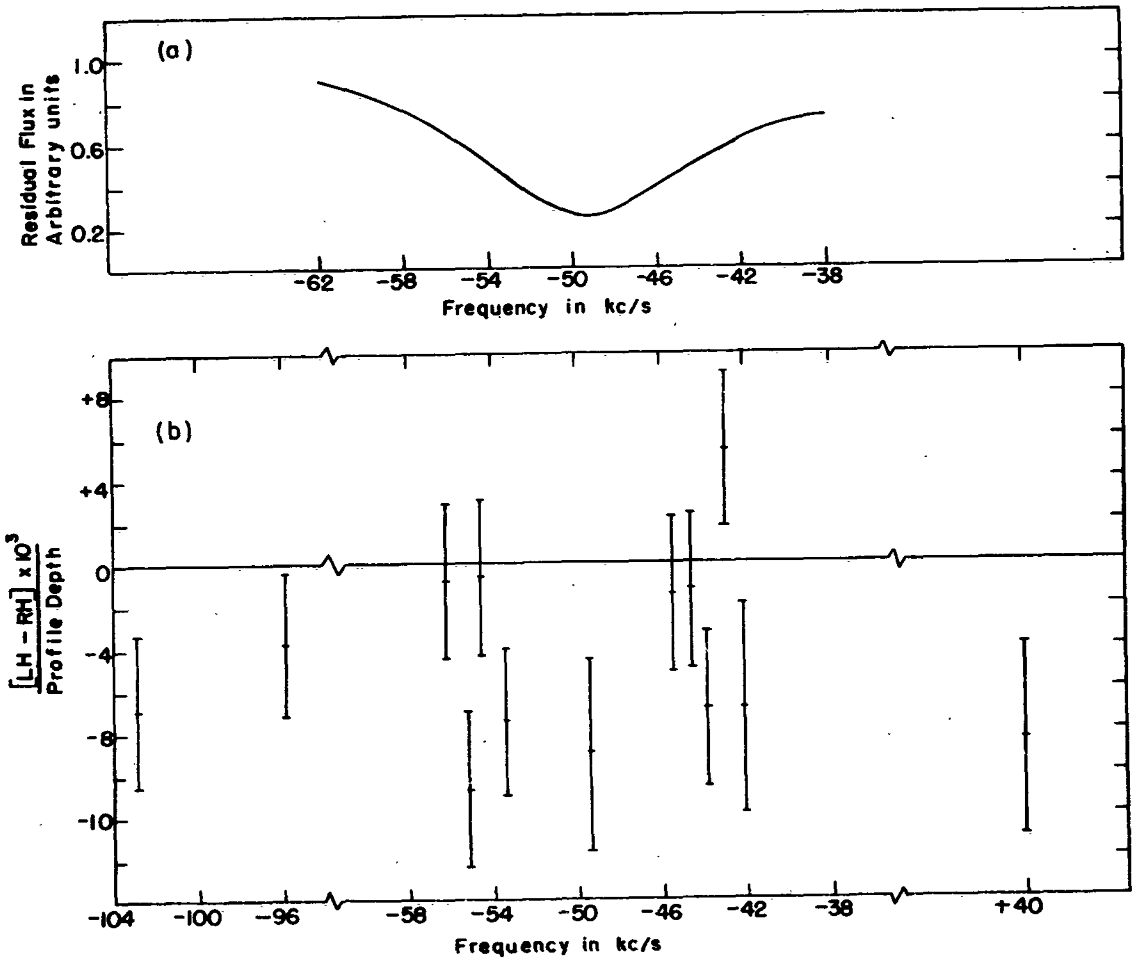

Figure 3. Measurements of the Crab Nebula absorption line.

(a) The absorption profiles observed with a 6 kc/s bandwidth.

(b) Measured circularly polarized flux, uncorrected for instrumental polarization.

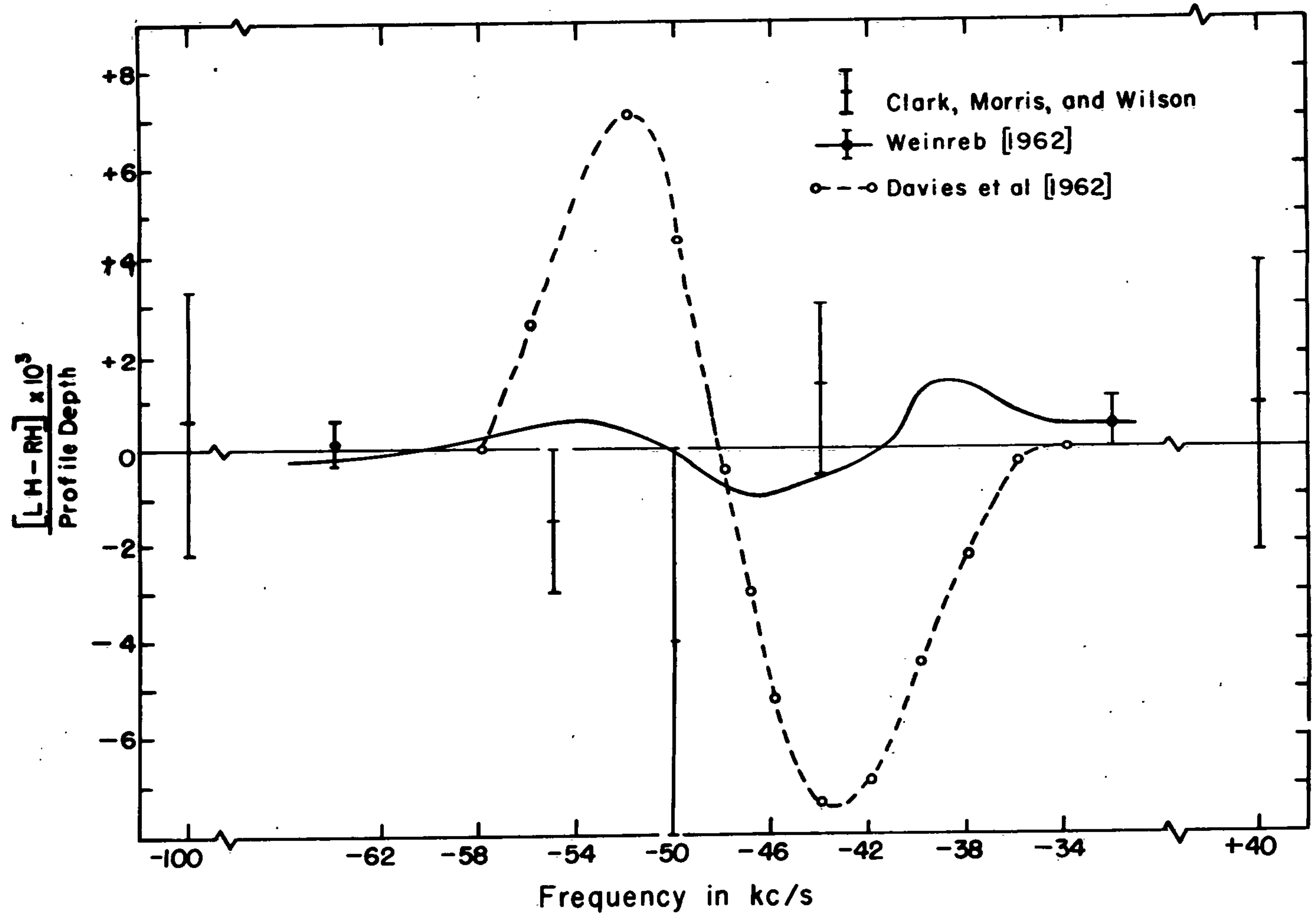

Figure 4. The present measurements of the Crab Nebula, after correction for instrumental polarization, together with those of Davies et alia (1962) and Weinreb (1962).