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DOUBLE FARADAY ROTATION TOWARD 3C 27

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ABSTRACT

From observations of the integrated flux of 3C 27 with the NRAO 140 foot (43 m) telescope at 40 frequencies between 1250 and 1445 MHz, we deduce rotation measures of 165 ± 15 and -104 ± 4 rad m^{-2}. Since the source (assumed to be a radio galaxy) has components 45″ apart, we conclude that the net magnetic field reverses between these directions. One explanation is that a large magnetic field surrounding the central galaxy of the distant source covers one component but not the other. Another explanation is that our Galaxy contains a dipole field with a scale of order 1 pc. One component of the distant source is seen inside the current loop associated with the dipole field, while the other is seen outside the loop.

Subject headings: galaxies: individual — interstellar: magnetic fields — polarization — radio sources: galaxies

I. INTRODUCTION

The strong radio source 3C 27 has a galactic longitude of 123°35 and a latitude of 5°50. It thus lies in a heavily obscured region and has no optical identification. Högbom and Carlsson (1974) found it to be a double source with spacing of 45″, while Kellerman, Pauliny-Toth, and Williams (1969) obtained a spectral index of 0.6–0.7. From these properties one assumes that 3C 37 is a radio galaxy. A recent study by Salter and Haslam (1980) suggests that the source is a member of a cluster of extragalactic radio sources extending over at least 1° × 3°.

We analyze linear polarization observations in a 20′ beam made simultaneously at 40 different frequencies between 1250.4 and 1445.4 MHz, seeking information on the distribution of Faraday rotation toward the source. Our methods have been previously described by Gauss and Goldstein (1973).

The most extensive survey of Faraday rotation observations toward extragalactic sources is that of Simard-Normandin, Kronberg, and Button (1981, hereafter SKB). Their measurements are calculated from observations of the position angle of linearly polarized emission at three to five widely spaced frequencies. They fit the observed position angles to the equation

$$\theta = \theta_0 + R\lambda^2 , \quad (1)$$

thus finding a single rotation measure and a single intrinsic polarization angle for each source.

Slysh (1965) noted a departure from equation (1) in the observed linear polarization of Cyg A, and fitted a two-source model to the data. He found large and distinct rotation measures (1170 and 100–200 rad m^{-2}) and attributed the larger rotation measure to a "magnetoionic region" surrounding the central galaxy of Cyg A and the smaller to our Galaxy.

We find for 3C 27 that a two-source model gives a good fit to the observations of position angle versus frequency and also to the observations of fractional polarization. The two rotations toward 3C 27 have opposite signs, a fact that is determined from the observations of fractional polarization.

Our observations are described in § II, and the model fitting and its errors are discussed in § III. Section IV contains information on Faraday rotations observed near 3C 27. In the final section we consider briefly the possibilities that the double Faraday rotation is produced in the solar system, and that Slysh's explanation for Cyg A applies to 3C 27. We then consider more fully a model with a local dipole field embedded in the general Galactic magnetic field.

II. OBSERVATIONS

The observations were made by S. J. G. and Ralph High in two sets of 10 scans between 19:30 and 21:04 EST on 1972 December 7. The NRAO[1] 140 foot (43 m) telescope scanned 1°5 in declination while tracking the source in right ascension, and at the end of each scan the antenna feed including the receiver box was rotated 36°. The receiver switched between a room-temperature load and the antenna 10 times per second. The input temperatures were matched with a gain modulator in the intermediate-frequency amplifier at the beginning of each set of scans. Each scan lasted 4 minutes, and the system noise temperature was about 340 K averaged over 200 MHz.

The 40 channel receiver employed 5 MHz filters spaced every 5 MHz with individual detectors. The data reduction was performed independently for each channel. A scan represented by 24 points gave for each channel, by least squares fitting, a parabolic response to the source and a linear baseline. The difference, calculated in terms of a calibration noise source, is obtained for each of the 10 orientations of the antenna feed.

Preliminary reductions established that there was no significant difference between the two sets; therefore, the two were averaged to make Table 1. Each row begins with a channel number c from which one calculates the operating frequency in MHz according to the formula

$$f = 1450.4 - 5.0c . \quad (2)$$

Each column after the column of channel numbers gives the receiver outputs for a different apparent position angle of the antenna, starting with 36°, and increasing in 36° steps to 360°. The true position angle in deg, determined from observations of 3C 270, is given in terms of the apparent position angle by

$$\theta_t = \theta_a - 39.6 . \quad (3)$$

The position angle of the electric vector of the polarized emission for each channel is found by least squares fitting of a double-frequency sine wave to the 10 responses in Table 1. We

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

TABLE 1

RESULTS OF 40 CHANNEL SCANS OF 3C 27

CHANNEL NUMBER	APPARENT POSITION ANGLE OF FEED (deg)									
	36	72	108	144	180	216	252	288	324	360
1......	406	395	351	379	379	414	407	363	334	417
2......	373	385	365	363	395	433	400	348	351	425
3......	395	232	358	391	404	406	385	331	384	412
4......	400	400	358	382	421	412	377	369	376	395
5......	386	380	354	358	411	442	356	391	384	411
6......	367	369	319	382	420	426	394	386	357	370
7......	394	398	376	396	390	427	406	388	391	390
8......	425	397	355	411	401	406	391	398	362	403
9......	408	400	373	371	406	408	388	398	369	403
10......	396	376	355	374	400	410	365	366	390	392
11......	395	376	365	364	395	404	378	362	370	399
12......	401	387	364	382	410	406	388	386	386	381
13......	391	388	356	388	403	412	374	386	378	396
14......	396	397	368	383	391	414	368	379	370	398
15......	403	373	361	381	395	409	369	384	382	397
16......	392	380	376	396	412	390	362	378	397	406
17......	399	375	362	405	429	417	388	392	395	402
18......	391	411	365	387	415	428	412	403	362	420
19......	411	407	381	397	432	430	408	394	383	433
20......	554	561	367	421	433	440	574	416	413	489
21......	653	710	365	405	418	446	705	421	433	538
22......	429	423	409	436	434	434	419	417	434	448
23......	425	415	419	429	424	432	409	420	447	451
24......	434	411	413	453	437	439	415	433	447	446
25......	440	412	432	463	437	452	424	448	459	445
26......	458	444	444	487	440	381	357	413	444	405
27......	477	458	451	506	439	354	348	408	448	389
28......	452	423	435	475	461	424	411	452	459	455
29......	446	429	446	477	448	450	428	456	469	458
30......	437	437	443	480	437	454	416	461	474	447
31......	433	437	448	471	453	445	383	478	467	441
32......	428	434	449	471	451	426	393	484	467	448
33......	428	432	456	482	433	427	402	451	469	449
34......	437	423	488	520	428	454	392	424	497	426
35......	927	427	490	597	71	656	142	410	558	730
36......	535	487	614	616	118	591	383	566	−3373	439
37......	555	471	604	594	119	600	607	550	412	436
38......	485	453	463	613	515	546	311	346	544	434
39......	450	425	512	547	418	475	381	423	510	439
40......	422	441	498	502	446	435	396	468	485	436

also calculate for each channel the ratio of the polarized flux to the total flux. As a measure of the uncertainty in the polarization angle we calculate the rms residual of the observed points from the best fitting double sine wave. These results are listed in Table 2.

To minimize the effects of man-made radio interference, we examine Table 2 to see which channels, if any, ought to be omitted from the model fitting. We assume that the spectrum of the source is smooth enough to be represented by $S \sim \lambda^a$, where a is constant over the observed range of frequencies. There are seven channels for which the amplitude of the polarized wave is above 0.45 (the units are approximately 2 K), all of which seem to be interference localized in frequency. These channels are 3, 20, 21, 35, 36, 37, and 38. We omit them from model fitting, noting that six of the seven would also be omitted if the criterion were to reject channels with residuals above 0.45.

The 21 cm line from galactic neutral hydrogen is set to the middle of channel 6. Since the residual is slightly higher in this channel than in the adjoining channels, it is possible that structure in the galactic 21 cm emission has deteriorated the accuracy in this channel.

Figure 1*a* is the measured polarization angle plotted against channel number, corrected by equation (3). The points omitted from the model fitting are squares; those accepted are crosses. Figure 2*a* is the ratio of linearly polarized flux to the total flux. Again a square represents a point rejected for interference. Six of them are off scale and not plotted.

III. MODEL FITTING

First, we consider a single Faraday rotation and use equation (1) and the principle of least squares to find the rotation measure and the intrinsic polarization angle. The best fitting position angle curve is shown in Figure 1*a* superposed on the observations. The ratio of polarized flux to total flux (a straight line parallel to the frequency axis by hypothesis) is shown in Figure 2*a*.

The single Faraday rotation model gives a curve for the position angle that is low in channels 7–19 and is high in channels 25–34. Although there is large uncertainty for the ratio of polarized flux to total flux, another systematic deviation can be seen: the least squares line is low for the highest and lowest channels and is high for the central channels. The

TABLE 2

POSITION ANGLE OF ELECTRIC VECTOR OF POLARIZED FLUX AND RATIO OF POLARIZED-TO-TOTAL FLUX VERSUS CHANNEL NUMBER

Channel Number	Average	Ampl.	Resid.	Apparent Angle (deg)	Pol. Flux/ Total Flux
1..........	3.85	0.32	0.15	1.1	0.153
2..........	3.84	0.30	0.18	−6.5	0.145
3..........	3.70	0.49	0.38	−38.0	0.234
4..........	3.89	0.23	0.09	−14.1	0.112
5..........	3.87	0.27	0.19	−18.5	0.130
6..........	3.79	0.23	0.24	−11.8	0.114
7..........	3.96	0.11	0.10	4.7	0.054
8..........	3.95	0.18	0.15	−8.5	0.087
9..........	3.92	0.17	0.09	−0.6	0.083
10..........	3.82	0.22	0.07	−21.6	0.109
11..........	3.81	0.21	0.04	−11.9	0.104
12..........	3.89	0.14	0.08	−11.2	0.069
13..........	3.87	0.16	0.09	−18.5	0.079
14..........	3.85	0.17	0.08	−15.7	0.085
15..........	3.85	0.18	0.08	−20.7	0.089
16..........	3.89	0.19	0.04	−41.3	0.093
17..........	3.96	0.21	0.11	−30.4	0.100
18..........	3.99	0.21	0.16	−0.1	0.100
19..........	4.08	0.23	0.09	−13.2	0.107
20..........	4.67	0.73	0.46	14.1	0.270
21..........	5.09	1.32	0.84	19.0	0.412
22..........	4.28	0.14	0.05	−34.8	0.063
23..........	4.27	0.14	0.08	−47.2	0.063
24..........	4.33	0.17	0.07	−48.8	0.076
25..........	4.41	0.15	0.10	−58.8	0.066
26..........	4.27	0.26	0.31	−69.6	0.115
27..........	4.28	0.30	0.44	−74.8	0.131
28..........	4.45	0.24	0.09	−59.1	0.102
29..........	4.51	0.18	0.07	−63.4	0.077
30..........	4.49	0.19	0.12	−71.0	0.081
31..........	4.46	0.25	0.18	−71.2	0.106
32..........	4.45	0.29	0.14	−75.3	0.122
33..........	4.43	0.28	0.10	−74.4	0.119
34..........	4.49	0.37	0.28	−73.8	0.152
35..........	5.01	1.01	2.34	−23.6	0.336
36..........	0.98	7.72	10.30	21.3	1.775
37..........	4.95	1.18	1.16	49.3	0.385
38..........	4.71	0.76	0.69	−47.3	0.278
39..........	4.58	0.42	0.39	−72.6	0.168
40..........	4.53	0.40	0.17	−82.0	0.162

NOTE.—Units for Average, Amplitude, and Residual are about 2 K of antenna temperature.

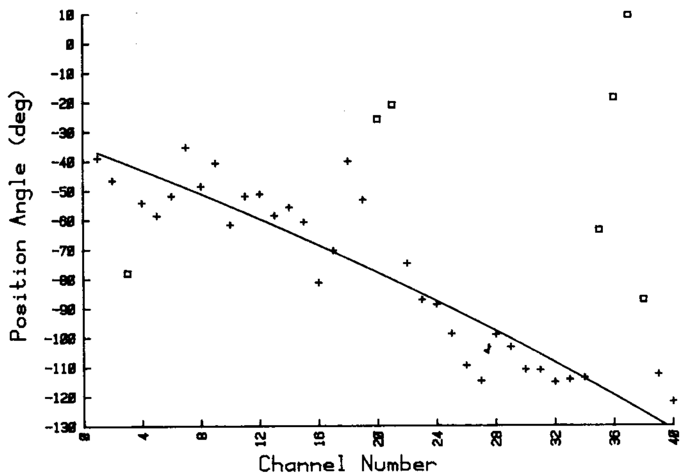

FIG. 1*a*

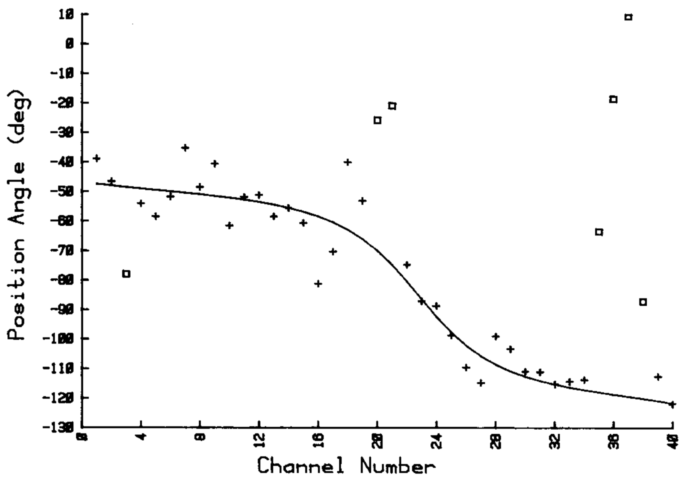

FIG. 1*b*

FIG. 1.—(*a*) Observations of the true position angle of the electric vector of the polarized emission from 3C 27 plotted against channel number. The line represents a one-source model. (*b*) Same observations with a two-source model. Calculated errors for the position angles have an average value of 14°.9. Channel 1 corresponds to 1445.4 MHz; channel 40 to 1250.4 MHz.

sources studied by Gauss and Goldstein (1973) were free of these systematic deviations. Therefore, let us consider that there are two distinct Faraday rotations toward 3C 27, one for each of the components.

A two-source model has five constants to be determined: two intrinsic polarization angles (θ_{01} and θ_{02}), two Faraday rotations (R_1 and R_2), and the ratio of the polarized fluxes (k). We assume that the ratio of polarized to unpolarized flux is the same for both components. The position angle of the polarized flux of a two-source model may be calculated from the superposition property of the Stokes parameters. The result is

$$\tan 2\theta = \frac{\sin 2\theta_1 + k \sin 2\theta_2}{\cos 2\theta_1 + k \cos 2\theta_2}, \tag{4}$$

where θ_1 and θ_2 are the position angles of the electric vector of the individual sources at the frequency under consideration, and source 2 is weaker than source 1 ($k < 1$). The polarized flux for the two-source model is

$$s = s_1[1 + k^2 + 2k \cos(\theta_1 - \theta_2)]^{1/2}, \tag{5}$$

where s_1 is the polarized flux of the stronger source.

We found an approximate value of the constant k from the maximum and minimum values of s (Fig. 2*a*), and approximate values for θ_{01} and R_1 from the one-source model. Then by differentiating equation (4) with respect to frequency and evaluating the maximum and minimum slopes (Fig. 1*b*) we calculated approximate values θ_{02} and R_2.

We then searched for improved values in five-dimensional space by minimizing the mean squared difference between the observed and calculated position angles. The formal errors can be evaluated by perturbing each constant individually from its least squares value to produce a standard increase in the rms

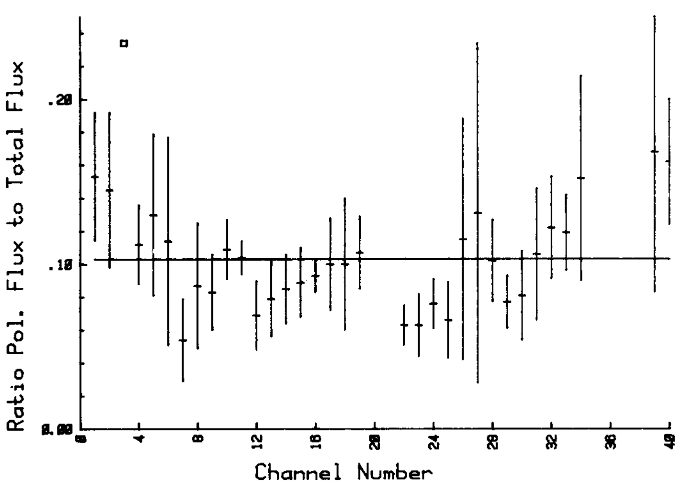

FIG. 2*a*

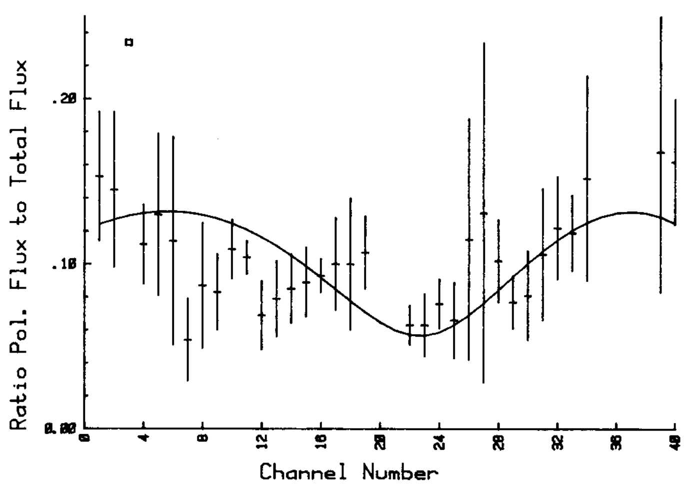

FIG. 2*b*

FIG. 2.—(*a*) Ratio of polarized flux to total flux plotted against channel number. The line represents a one-source model. (*b*) Same observations with a two-source model. Channel 1 corresponds to 1445.4 MHz; channel 40 to 1250.4 MHz. The ratio should be multiplied by 0.5.

residuals, 41.4% in this paper. A rigorous definition of the errors requires that all of the constants be perturbed together to make the departure of an individual constant maximum. For linear problems the rigorous errors and formal errors coincide when the off-diagonal elements of the normal equations are very small. Also, for linear problems it is easy to calculate the rigorous errors (see, for example, Brosche, Wade, and Hjellming 1973).

The one-source model is linear, and we have calculated rigorous errors, listed in Table 3, at the 2 σ level. For the two-source model, only formal errors are given for R_2, θ_{02}, and R. To estimate the errors for R_1 and θ_{01}, we have removed the second source from the data and calculated rigorous errors for Table 3 with the same method as used with the one-source model.

The intrinsic polarization angles are not well determined from our observations between 1250 and 1450 MHz because very small differences in the rotation measure make an appreciable difference in the angle. (There is no substitute for very high frequency observations when an accurate intrinsic polarization angle is required.) However, the rotation measures are free of the possible ambiguities resulting from missed half-turns between widely spaced observing frequencies.

Figure 1*b* gives the position angle from our two-source model superposed on the observations; while Figure 2*b* gives the polarized flux divided by the total flux for the model. The agreement between the model and observations now seems good for the position angles and slightly improved for the ratios.

There is another two-source model that fits the position angle measurements (albeit with minimum residuals slightly higher), having Faraday rotations of -104 and -373 rad m^{-2}. The second model has the same difference in rotation measures as the first, but it does not simultaneously minimize the residuals of the polarized flux ratio as the first model does. Hence, only the two-source model given in Table 3 is acceptable.

We accept the two-source model with rotation measures -104 and $+165$ rad m^{-2} for it substantially improves the agreement between observations and theory. See Table 3.

IV. ROTATION MEASURES OF OTHER SOURCES

To interpret our measurements toward 3C 27 it is desirable to consider the rotation measures of other sources. Only 61 of the 555 sources studied by SKB have values numerically greater than 100 rad m^{-2}. We list in Table 4 the rotation measures from SKB of 3C 27 and the five nearest sources. Note that for 3C 27 their value -91 ± 1 and our value for the stronger component -104 ± 13 agree within the uncertainties. The model of Sofue, Fujimoto, and Kawabata (1979) gives a fair prediction for only two of the six observations. The earlier model by Vallée and Kronberg (1975) is even less accurate as a predictor of these observations. Although there is some correlation between the rotation measures of these nearby sources, the existing models are not satisfactory for predicting rotation measures of individual sources. Either structure in the galactic magnetic field or large Faraday rotations in or near the extragalactic source may be responsible.

TABLE 3

LEAST SQUARES SOLUTIONS

One-Source Model	
Intrinsic polarization angle	$64° \pm 49°$
Rotation measure	-114 ± 17 rad m^{-2}
rms residual angle	11°4
rms residual ratio	0.030
Two-Source Model	
Intr. polar. angle: source 1	$35° \pm 37°$
Rotation measure: source 1	-104 ± 13 rad m^{-2}
Intr. polar. angle: source 2	$70° \pm 30°$
Rotation measure: source 2	165 ± 15 rad m^{-2}
rms residual angle	8°6
rms residual ratio	0.029
Ratio	0.4

TABLE 4

FARADAY ROTATIONS NEAR 3C 27 (rad m^{-2})

Source	Angular Dist. (deg) from 3C 27	Observations SKB 1981	Model SFK 1979
3C 27	...	−91	−109
3C 33.2	1.6	11	−90
3C 33.1	5.0	−15	−56
0224+67	8.7	−36	−91
2248+712	11.1	−49	−56
3C 69	14.3	−180	−610

What do we know about Faraday rotation in extragalactic sources? Gardner and Davies (1966) used the Parkes 210 foot (64 m) telescope to conclude: "An analysis of the scatter in rotation measure observed at high latitudes and in double sources indicates that the mean rotation measure arising in the sources themselves is less than 5 rad m^{-2}." From eight strong northern double sources Gauss and Goldstein (1973) set upper limits between 7 and 70 rad m^{-2} for the difference between the components. (These are corrected values; their eq. [3] should have for its left-hand side, tan $2\theta_T$, and the final column of their Table 2 should be divided by 2.) However, Seielstad and Weiler (1969) have reported on two double sources with substantially different rotation measures: Pic A with rotation measures of 50 and -34 rad m^{-2} and Cen A, for which the outer two components have rotation measures of -55 and -323 rad m^{-2}. They measured only the east-west structure.

Interferometer observations with high resolution may eventually give definitive data on the range of Faraday rotations in double sources. So far, the data are limited. Davis, Stannard, and Conway (1983) examined 18 sources but report two rotations for only three. The differences are 61, 0, and 3 rad m^{-2}. Conway *et al.* (1983) observed 37 double radio sources with no difference greater than 50 rad m^{-2}.

There are also measurements for "knots" in the jets of 3C 274 by Owen, Hardee, and Bignell (1980) and by Dennison (1980). Dennison, from X-ray observations and radio observations at 1.3, 3.7, 6, and 11.1 cm, obtains "RM $\approx$ 460 rad m^{-2}" for the entire jet region; while Owen, Hardee, and Bignell find "a rotation measure $\sim$200 rad m^{-2}" for just one knot using observations at 2 and 6 cms.

V. INTERPRETATION

a) Interplanetary Medium

Let us consider the possibility that the Faraday rotation occurred in the solar system and was therefore a transient event. Levy *et al.* (1969) observed several transient Faraday rotations in the 13 cm emission of the *Pioneer 6* spacecraft.

These events expressed in terms of rotation measure had a peak of about 41 rad m^{-2} and had durations of about 2 hr, with considerable structure measured in minutes. They were observed between 1°.6 and 2°.9 from the Sun. By contrast our observations did not change on two occasions an hour apart, had two substantially different rotation measures, and were observed between 121°.0 and 122°.0 from the Sun.

There is recent evidence of flux loops in the solar corona associated with X-ray bright points and with the solar wind according to Mullan and Ahmad (1982) and Pneuman (1983). Whether or not these loops persist to a distance of more than an astronomical unit from the Sun is an open question. It appears unlikely that our results could be produced by open or closed flux paths in the interplanetary medium.

b) *Region of the Distant Galaxy*

Following the analysis of Slysh for Cyg A, let us suppose that the numerically smaller rotation measure, -104 rad m^{-2}, is due to our Galaxy, and that the net difference 269 rad m^{-2} is caused by the large magnetic field and thermal electrons of the invisible central Galaxy.

Inserting the latter rotation measure and a path length of 10^4 pc into the formula

$$R = 8.1 \times 10^5 \int nBdl \,, \tag{6}$$

where n is the electron density in cm^{-3}, B is the line-of-sight component of the magnetic field in gauss, and dl is the path length in pc, we obtain the average product

$$nB = 3.3 \times 10^{-8} \,. \tag{7}$$

For example, if the mean magnetic field is 10^{-5} gauss, the mean electron density is 3.3×10^{-3} cm^{-3}. These are plausible values. A mild objection to this model arises from Cyg A, where the optical diameter of the central galaxy is an order of magnitude less than the spacing of the components. Thus the central magnetic field must extend a large distance to cover the more distant component (36 kpc for $H = 75$).

However, Salter and Haslam (1980) have observed the 10 cm continuum radiation surrounding 3C 27 and concluded that the source lies in a cluster of extragalactic radio sources. Thus the Faraday rotation might come from another galaxy in the cluster or from the intergalactic medium of the cluster.

c) *A Current Loop in Our Galaxy*

Since Cyg A, at galactic latitude 5°.8, and 3C 27, at latitude 5°.5, both have large double Faraday rotations, it seems necessary to consider that our Galaxy may be responsible. The conventional view of the local galactic magnetic field may be obtained from the work of Manchester (1974). With the Faraday rotations of 38 pulsars he concluded that there is a longitudinal component (assumed to be in the galactic plane) "of 2.2 ± 0.4 microgauss toward $l = 94° \pm 11°$, together with superposed irregularities of comparable field strength."

Michel and Yahil (1973) have postulated cell structure in the galactic magnetic field and argued that stars are a possible source of the cells. See also the comments by Parker (1974) and Michel (1974).

Let us consider a specific model, a dipole field whose axis coincides with the direction to the source with larger rotation measure. The associated current loop is then perpendicular to the line of sight. The polarity of the magnetic field changes sign for paths outside the current loop, and the field is weaker there. We will fit our model only to the larger rotation measure and assume that the Galaxy and the dipole fields combine to give the smaller rotation measure. We thereby avoid a long analysis with elliptical integrals (which might be appropriate for a case with data in more than two directions). Choose a path length of 1 pc. Then the radius of the current loop, found by integrating the dipole field along its axis (Jackson 1962), is $2^{1/2}/\pi$ times the path length, or 0.45 pc.

Let us also assign an electron density $n = 1$ cm^{-3} to the region of the dipole field. Then the measured rotation measure and equation (6) give a flux density $B = 20.4 \times 10^{-5}$ gauss. The flux density times the area of the current loops is the flux of the loop, $\Phi = 1.24 \times 10^{25}$ webers (1.24×10^{33} maxwells).

A simple way of calculating the energy of the dipole field is to evaluate the inductance of the current loop. From Ramo and Whinnery (1953), the inductance is

$$L = a\mu\left[\ln\left(\frac{8a}{b}\right) - 2\right], \tag{8}$$

where a is the radius of the loop, b is that of the conductor, and μ is the permeability of free space, $4\pi \times 10^{-7}$ hy m^{-1}. Let $b = 10^{14}$ cm. Then $L = 1.68 \times 10^{11}$ hy. The loop current follows from $I = \phi/L = 7.38 \times 10^{13}$ amps; while the energy stored in the dipole is $W = \frac{1}{2}LI^2 = 4.6 \times 10^{45}$ ergs.

Let us calculate the energy in the entire galactic magnetic field for comparison. Adopt Manchester's (1974) mean flux density of 2.2 microgauss and take the Galaxy to be a uniform disk 400 pc thick and 15 kpc in radius. The energy is 5.1×10^{53} ergs; thus the energy in our hypothetical dipole field is less than 10^{-8} of the total.

Although a general discussion of the stability of this field is beyond the scope of the present paper, some comments are in order. The loop current is shielded by its field from charged particles passing by and maintained by the field in accordance with Lenz's[2] law. The resistivity of the loop current can be evaluated from the work of Spitzer (1968) insofar as losses are due to collisions of electrons and ions. With an electron temperature of 10^4 K, we obtain a time constant (diffusion time) of 4×10^{21} s, a value much greater than the age of the universe. Collisions between electrons and neutral hydrogen atoms are no doubt more important in controlling the diffusion time of the dipole field.

Suppose that the current loop contains electrons gravitationally bound to a central star. The positive ions that are also present would circulate in the opposite direction. The mass of the star can be calculated from Kepler's third law. Let the density of the current-loop electrons be the same as the Faraday rotating electrons, 1 cm^{-3}, and let the electrons and ions have the same orbital velocity. Then the orbital period is 3.8×10^7 yr, and the mass of the star is $0.57\ M_\odot$. Since stars of this mass are common in the Galaxy, we have additional reason to expect that current loops might be long lived. Pressure equilibrium with the surrounding medium offers another method for arresting the natural expansion of an interstellar inductor.

Could there be existing observations of other current loops of comparable size in the Galaxy? The diameter selected for our model subtends an angle of 45″ at a distance of 4.1 kpc. It would subtend an angle of 2° at 26 pc. Thus only rather nearby

[2] If the net magnetic flux enclosed by a current loop is perturbed, there will be a voltage induced in the loop, which acts to eliminate the perturbation. (See, for example, Feynman, Leighton, and Sands 1964.)

current loops of this size would be discernible in the SKB catalog, where the minimum spacings are of order 2°. From a Mercator plot of this Faraday rotation data for the latitude range $-70°$ to $+70°$ we counted 27 pairs with spacings of 2° or less. These are well scattered in galactic latitude. Four of these pairs (one triple is counted twice) have strong reversals in the rotation measure and lie between latitudes $+1°$ and $-19°$. In 26 directions were we can search for a nearby current loop, there may be three, and an unknown number may be attributed to the extragalactic source. We did not find any nearby stars in these directions. The presence of many other current loops is not ruled out by energy considerations or by existing observations.

Michel and Yahil (1973) have proposed supernova remnants, pulsars, and T Tauri stars as possible sources of field cells with scales of 100 pc. These or other stars might be able to produce the smaller cells considered here, and a process of reconnection from a large general field might also be responsible.

We conclude that a dipole magnetic field with a current loop diameter of order 1 pc offers a satisfactory explanation to our Faraday rotation observations of 3C 27.

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