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## The Need for High Resolution for Polarization Studies of Galactic Background Radiation

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### Abstract

Polarization data at 390 and 826 MHz were obtained with the 300-foot telescope in February 1987. A survey of selected regions of sky planned for December 1988 had to be postponed. However, our limited data at 390 MHz show that the 30' beam detected polarization temperatures between four to six times larger than found in surveys with a  $1.^\circ3$  resolution. This was true in both the highly polarized region around  $l=140^\circ$  and in the North Polar Spur where polarization structures appear to be unresolved ( $<0.9$  pc at the distance of the spur). High resolution observations will be critical to our understanding of the interstellar magnetic field and the scale-length of depolarizing structures.

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## I. Preliminary Observations

In February 1987 preliminary polarizations observations at 390 MHz (beamwidth 30') and 826 MHz (14' beam) were made with the 300 foot radio telescope of the National Radio Astronomy Observatory in order to test the feasibility of performing large-scale surveys. The results were extremely encouraging and stressed the need for such data. Test scans across two regions of particular interest, the hole in the highly polarized patch around  $l=137^\circ$ ,  $b=+7^\circ$  and the north polar spur were made.

a) The Polarization hole at  $l=137^\circ$ ,  $b=+7^\circ$

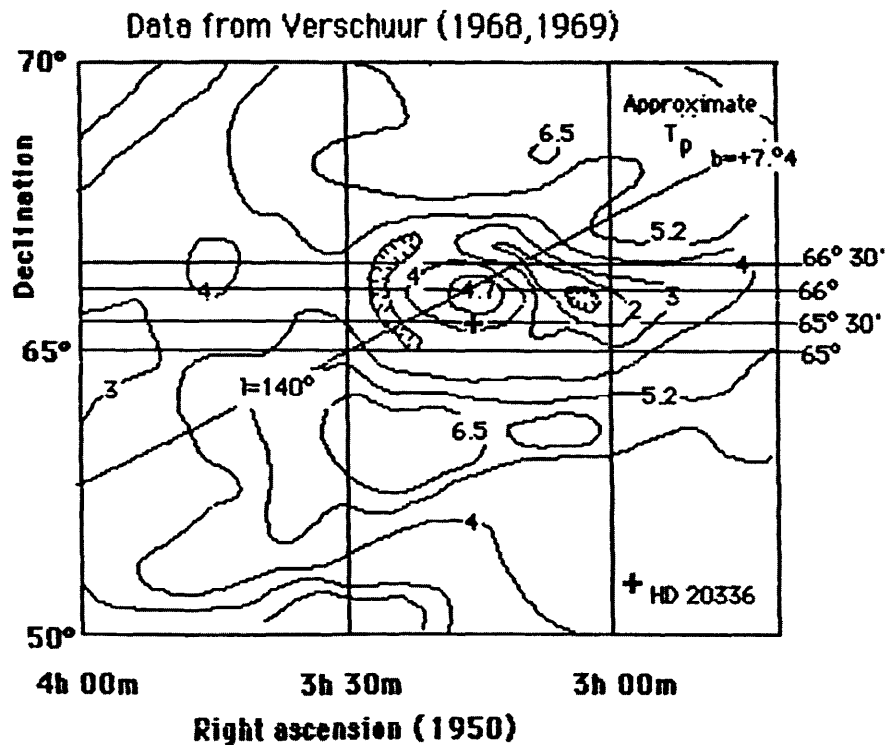


Figure 1. The hole in the region of high polarization around  $l=137^\circ$ ,  $b=+7^\circ$  as mapped at Jodrell Bank. Drifts were obtained with the 300-foot at the declinations indicated.

Figure 1 shows a sketch of the polarization hole based on the Verschuur (1968) Jodrell Bank data.

Figure 2 shows the values of one Stokes parameter obtained with the 300-foot telescope at the declinations indicated. Figure 3 shows a sample of the drifts across the same region made at 826 MHz.

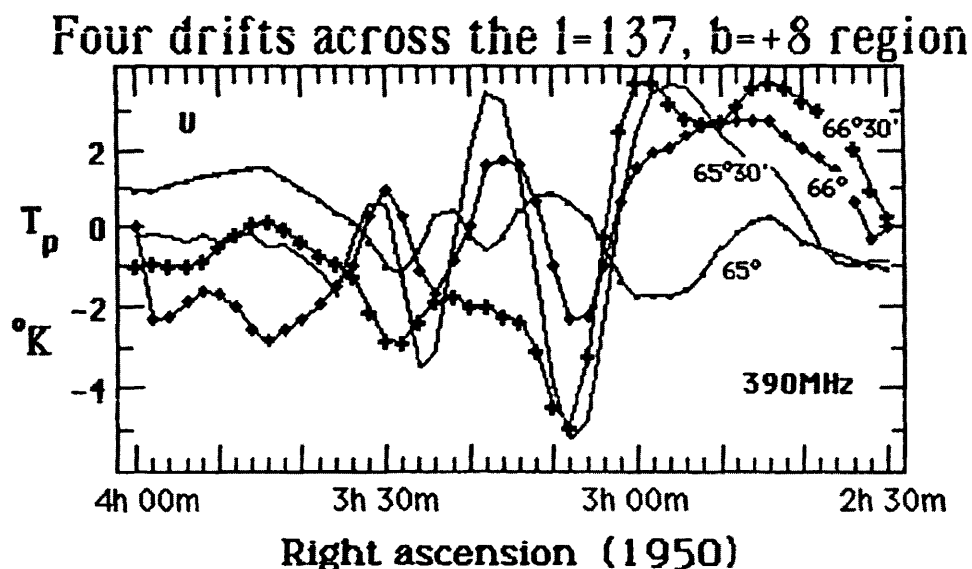


Figure 2. The antenna temperature indicating the magnitude of the Stokes parameter U as a function of right ascension across the region of the polarization hole shown in Figure 1.

For comparison Figure 4 shows the data of Baker and Smith (1971) in the forms of cuts across the same region, and Figure 5 shows the data of Baker and Wilkinson (1974).

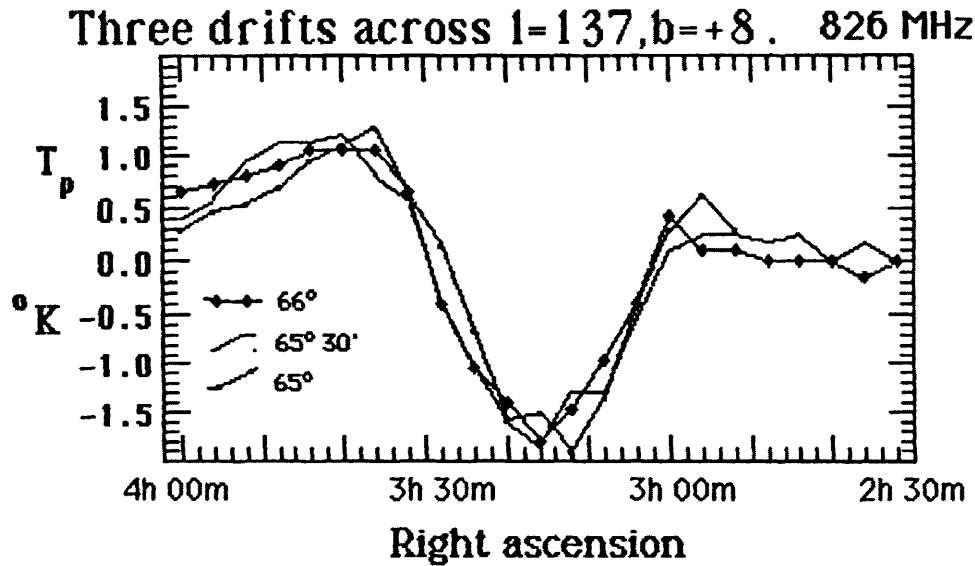


Figure 3. The 826 MHz data in the same region scanned in Figure 2. The systematic differences indicate the change in polarization structure due to depolarization as well as intrinsic field effects.

Table 1 shows the range in polarization temperature ( $T_p$ ) in the three sets of data across a limited RA range. Although the 300-foot data only measured one Stokes parameter we can assume that the other has a similar value in view of the large excursions which gives us a lower limit to  $T_p$ .

Table 1

300 foot telescope	30' resolution.	9 K in one Stokes parameter
Baker and Smith	46' resolution	4 K in total polarization .
Baker and Wilkinson	1.°3 resolution	2 K in total polarization.

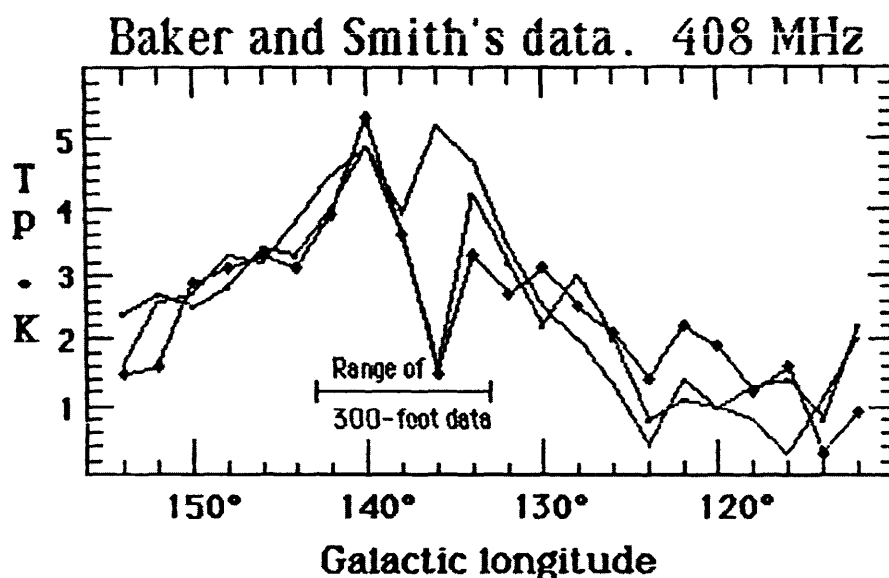


Figure 4. Reconstructed drift scans showing the variation in polarization brightness temperature across the polarization hole as measured by Baker and Smith (1971).

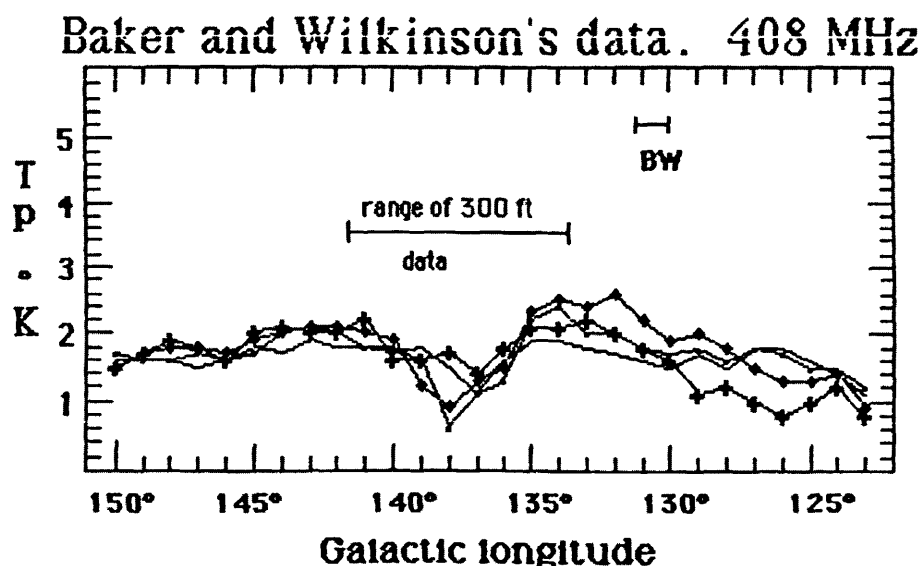


Figure 4. Reconstructed drift scans showing the variation in polarization brightness temperature across the polarization hole as measured by Baker and Wilkinson (1974).

b) The North Polar Spur.

We obtained sample drift scans across a section of the North Polar Spur at declination  $+21^\circ$  and the data at 390 and 826 MHz are compared in Figure 6

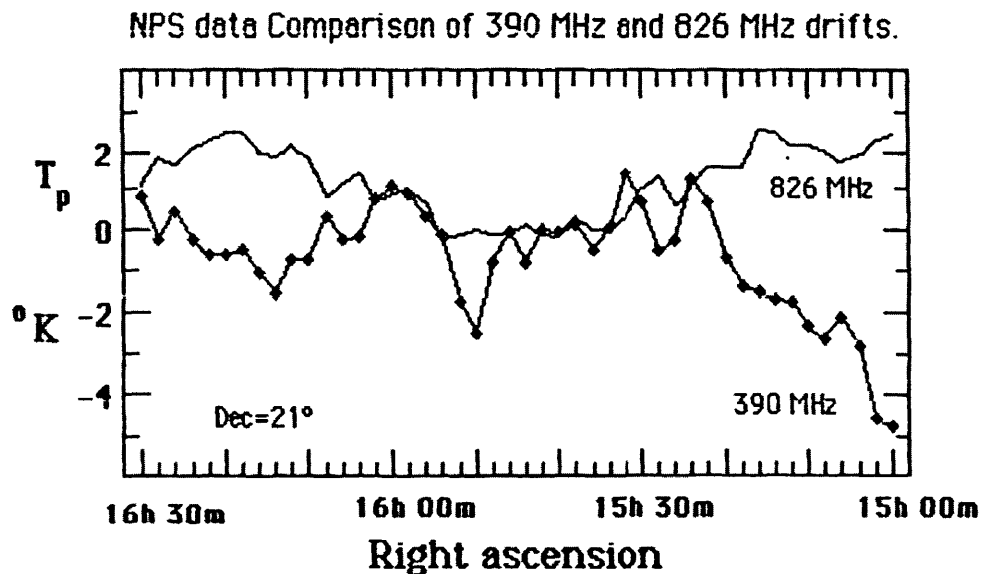


Figure 6. Average of several drift scans at declination  $+21^\circ$  which cuts the North Polar Spur.

The structure we see in the NPS is comparable to the beamwidth and this implies that high resolution studies will reveal a lot more information about Faraday rotation and the intrinsic polarization structure. Again, the peak-to-peak variation in polarization signal within the limits of the scan we made is far larger in our data than in the low resolution survey of Spoelstra ( ). We observed a range of  $> 5\text{K}$  in one Stokes parameter while the  $1.3''$  resolution survey showed only  $1\text{ K}$  changes.

Clearly higher resolution observations are required to discover

what the typical scale of the polarization structure is. These will, in turn, allow us to estimate the magnitude of the physical parameters involved. A first-order attempt to do is outlined next.

## II. Depolarization

Following Spoelstra (1984) we re-examine the theoretical work of Burn (1966) regarding the nature of the depolarizing medium. Depolarization may be due to differential polarization (a) along the line of sight and/or (b) across the beam, differential Faraday rotation (c) across the beam or (d) across the bandwidth. In galactic background studies we may neglect (d). Spoelstra smoothed his multi-frequency data to the largest beam (at 408 MHz) in an attempt to learn about (b) and (c), although his surveys were not fully sampled. We require full sampling in future studies. Since the coherence scale in the 1411 MHz polarization in the galactic loops was larger than the beam he concluded that the primary source of depolarization was due to (a), structures along the line of sight.

Some year ago Burn (1966) developed a theoretical approach which allows high resolution polarization data to be interpreted in order to obtain the scale length in the depolarizing medium. In summary, the maximum degree of polarization,  $\Pi$ , that can be expected is given by

$$\Pi = \frac{3\beta+3}{3\beta+1} \quad (1)$$

With the spectral index  $\beta = -2.7$ ,  $\Pi = 72\%$ . Depending on the field strength,  $B$ , in  $\mu\text{G}$ , and variations in  $B$  and  $N$  (the electron density),  $\Pi$  is reduced to  $p_0$ , the "zero rotation percentage" (i.e. at  $\lambda=0$ ). Then  $q(\nu) = p(\nu)/\Pi$  which Spoelstra (1971) called the "regularity coefficient", a

measure of the regularity of the properties of the magnetic-ionic medium. He noted that  $q$ , like  $p$ , is wavelength dependent and applies only at frequencies where Faraday rotation is insignificant. In this case a "zero rotation measure regularity coefficient" can be defined as

$$q_0 = p_0 / \Pi \quad (2)$$

which, according to Burn (1966), is given by,

$$q_0 = \frac{B_u^2}{(B_r^2 + B_u^2)} = \frac{\text{energy in uniform field}}{\text{energy in total field}} \quad (3)$$

Burn called  $p_0$  the intrinsic degree of polarization but it is not to be confused with  $\Pi$  which is an intrinsic value at the source while  $p$  takes into account the polarization in the beam projected on the sky. Lacking data for the frequency dependence of  $p(\nu)$  at every point on the sky, Spoelstra averaged data over all longitudes at  $10^\circ$  latitude intervals and assumed that  $p(1411)$  was close to the value of  $p_0$ . He then found that  $0.1 \leq q_0 \leq 0.4$ , which means  $B_u \leq B_r \leq 3B_u$ . In other words, the random field component is of the order of the uniform component and/or the distribution of the thermal electrons is patchy.

Following Burn we represent the emission region as a slab of linear depth  $L$  along the line-of-sight. Internal Faraday rotation along the line of sight then follows the relation

$$p(\nu) = p_0 \frac{1 - e^{-s}}{s} \quad (4)$$

where  $s = r\lambda^4 - \ln\lambda^2$ ,  $r = (0.81 N B_r)^2 L d$ ,  $n = 1.62 N B_{\parallel} L$  and  $B_{\parallel}$  is the component of the magnetic field along the line of sight.  $L$  is in pc and  $d$  is the typical scale (in pc) of the variations in the magneto-



ionic properties of the medium and has an imaginary part. Physically  $n$  refers to the rotation measure and  $r$  is a random depolarization parameter.

Spoelstra fitted relation (4) to the observed wavelength dependence of the polarization data averaged over longitude at several latitude intervals and derived values for  $r$  and  $n$ . The details do not concern us but we will show what the available data indicate and how the  $H\alpha$  data now supplement the Spoelstra analysis. Future high resolution studies will make it possible to apply this type of analysis to specific areas so as to study the detailed nature of the depolarizing structure.

Using the above expressions for  $r$  and  $n$  we find that

$$d = \frac{2.47rB_{\parallel}}{nNB_r^2} \quad (5)$$

$B_{\parallel}$  can be written as  $0.7 B_r + 0.7 B_u$ . Then, for  $B_r = 3 B_u$  (above)

$$d = \frac{0.768r}{nNB_u} \quad (6)$$

For  $B_r = B_u$ , the other limit found by Spoelstra,

$$d = \frac{3.458r}{nNB_u} \quad (7)$$

Spoelstra averaged data at 13 latitude intervals derived values of  $r$  that ranged from 60 to 140 and for  $n$  that ranged from 65 to 70. By assuming  $N (=0.03 \text{ cm}^{-3})$  and  $B_u = 3 \text{ } \mu\text{G}$  he found that  $d$  varied from 10 to 75 pc.

The availability of the  $H\alpha$  emission measure now remove one assumption uncertainty, the value of  $N$ , because the background polarization as well as the significant fraction of the  $H\alpha$  emission

(Reynolds, Roesler, and Scherb 1974) both appear to originate in the same depth of space, that is about 300 pc. Spoelstra found values of 300 to 500 pc by comparing optical and radio polarization data which compares well with the results of Verschuur (1967) for a specific direction where the depolarization effect of a Strömgren trail due to a star at 300 pc distance was clearly stamped on the data, while Reynolds, Roesler and Scherb (1974) showed that the  $H\alpha$  emission is well correlated with the existence of the Gould's belt stars which lie within 300 pc of the sun.

Following Spoelstra's longitude averaging approach, we have estimated the typical emission measures from the  $H\alpha$  maps at two latitudes. At  $b=+20^\circ$  the emission measure is about  $<2 \text{ cm}^{-6} \text{ pc}$  (Reynolds private communication) and along the equator of Gould's belt is in the range 6 to  $10 \text{ cm}^{-6} \text{ pc}$ . These reduce to give  $N = 0.08$  and  $0.16 \text{ cm}^{-3}$  respectively, whereas Spoelstra assumed  $0.03 \text{ cm}^{-3}$ . Using his values for  $r$  and  $n$  the typical value of  $d$  ranges from 6 to 25 pc at  $b=+20^\circ$  and 1 to 5 pc along the equator of Gould's belt, for which Spoelstra's data at  $b= +10^\circ$ ,  $0^\circ$ , and  $-10^\circ$  were averaged to obtain a first order estimate for the parameters. The ranges depend on the relative importance of the random and uniform field components.

In the case of the North Polar Spur, where the  $H\alpha$  emission measures are clearly distinguished from the background, electron densities are of order  $0.5 \text{ cm}^{-3}$  for a distance of 100 pc to the spur. We do not yet have specific values for  $r$  and  $n$  in the spur.

### III. The source of the depolarizing electrons.

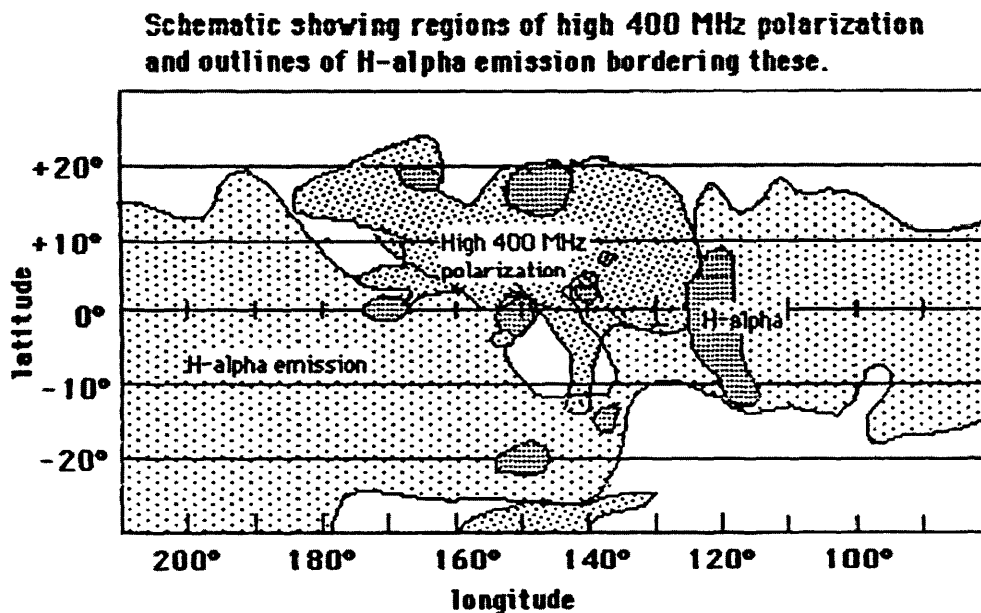


Figure 7. A schematic illustrating the relationship between regions of H $\alpha$  emission and the patch of high background polarization that shines through between the H $\alpha$  sources.

A direct comparison of the location of regions of high and low background polarization with the distribution of H $\alpha$  emission shows a high degree of correlation as is shown in Figure 7. Verschuur (1979) already alluded to the fact that high polarization at 408 MHz occurs in directions which lacked nearby B stars, clusters and HII regions, and suggested that the influence of Gould's belt stars, in particular, was instrumental in defining the morphology of the observed polarized emission. He suggested that regions of high polarization were holes in the depolarizing medium. This appears to be born out by the H $\alpha$  maps produced by Reynolds, Roesler, and Scherb (1974), as well as the more detailed studies by Reynolds and his coworkers on specific regions of the sky. In all cases the signature of the H $\alpha$  emission can be recognized in background polarization maps

as relative minima in polarization, especially the higher resolution data of Baker and Smith (1971). At low latitudes ( $b < 20^\circ$ ) from  $l=100$  to  $180^\circ$  every  $H\alpha$  emission patch is located at a polarization minimum while the well-known "fan shaped" region of high polarization (so named because of the way the polarization vectors on either side of  $l=140^\circ$  fan away from being oriented normal to the plane) lies in a region of very low  $H\alpha$  emission. The boundaries of the highly polarized region are clearly associated with  $H\alpha$  emission that follows the axis of Gould's belt.

#### IV. Conclusion

In future high resolution polarization and  $H\alpha$  studies will allow the scale lengths of the depolarizing medium,  $d$ , and the relative values of  $B_T$  and  $B_L$  to be found in specific regions of the sky. The influence of the individual Gould's belt stars, clusters and HII regions should become identifiable in the data. Together such studies will allow detailed interpretation to give values for scale lengths, electron densities, and magnetic fields in interstellar space.

#### References

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