CMBPOL AND THE MAGNETIC FIELD OF THE DIFFUSE INTERSTELLAR MEDIUM

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INTRODUCTION: SCIENCE GOALS FOR MICROWAVE POLARIZATION

The important tracers for magnetic fields associated with (i.e. frozen into) the diffuse ISM include

- Zeeman splitting of the 21-cm line ($B_{||}$: line of sight field strength).
- Faraday rotation ($B_{||}$)
- Linear polarization of syhnchrotron emission ($B_{\perp}$: "iron filings on the sky")
- Starlight polarization from aligned dust grains ($B_{\perp}$).

NONE PROVIDES ANYTHING OTHER THAN COARSE ($\sim$ 30 arcmin) ANGULAR RESOLUTION

Measurement of the polarization of dust emission gives $B_{\perp}$ with the angular resolution of the telescope. $B_{\perp}$ is particularly valuable for understanding the morphology of the magnetic field and its relation to the morphology of the gas structures. Gas structures range down to sub-arcminute sizes, which is well-matched to CMBPOL angular resolution at the higher frequencies.

POLARIZATION OF DUST EMISSION

Empirically, we find high polarization of absorbed starlight from magnetically aligned grains; grains must be easy to align. Theories of alignment are getting more sophisticated but not all details are yet understood.

Dust *absorbs* starlight, producing linear polarization of the starlight that lies parallel to the plane-of-the-sky projected field. When the dust *emits*, it will produce polarization that lies perpendicular to the projected field. CNM structures are clearly defined and we should be able to see clear association with polarized dust emission; we expect a clear morphological relationship between gas structure and field direction unless turbulence totally dominates.

The fractional polarization of diffuse dust emission is not known, but levels of a few percent are reasonaable to expect.

"PHASES" OF THE DIFFUSE GAS

Dust and diffuse gas are well mixed. the diffuse gas resides in three "phases". The phases probably affect the dust size distribution, so the dust emission properties probably differ among the phases.

Neutral Gas has two phases with roughly equal mass:

- CNM, the Cold Neutral Medium. $T \sim 50$ K, $n(HI) \sim 100$ cm^{-3}, volume filling factor a few percent. CNM is mainly responsible for the IR emitting "cirrus", which has small scale structure. This structure often appears to be *filamentary.* Heiles & Troland (HT; 2003: ApJ 586, 1067) find it is *sheets*, sometimes with very high aspect ratios (e.g. 150:1). Perhaps filaments are sheets seen edge on, or perhaps some of the gas is filaments and some sheets. The CNM pressure is probably domianted by turbulence and magnetism, which are thought to be in rough equipartition.
- WNM, the Warm Neutral Medium. $T \sim 2000$ K, $n(HI) \sim 2$ cm^{-3}, volume filling factor somewhere around 50% at z=0. Probably smooth spatial structure, but no observational data. We have essentially no direct knowledge of the magnetic field strength in the WNM. However, consistency arguments (volume-averaged field from synchrotron emissivity, field in the WIM from pulsars) suggest that its field strength is comparable to the CNM's.

CNM and WNM are considered, by many, to be quasistationary structures that result from thermal instability. And they are considered, also by many, to be transient structures that result from the vagaries of interstellar turbulence. If the former, magnetic fields should lie *parallel to filaments and perpendicular to sheets.* If the latter, the relative orientations should be *"random"*.

The Third Phase: Ionized Gas

WIM, the Warm Ionized Medium. $T \sim 8000$ K, $n_e \sim 0.3$ cm^{-3}. Lots of spatial structure given its low density, probably a result of the scarcity of ionizing photons, which have very short mean free paths in the neutral ISM.

ANGULAR RESOLUTION REQUIREMENTS

We can judge angular resolution requirements in two ways. One is by looking at available IR emission maps; the other is from statistical analyses of 21-cm line absorption data.

EMISSION MAPS

The diffuse ISM is resides in different types of environment, which are characterized by the degree of mechanical energy input (e.g. from supernovae), stellar UV photons, and others, some of which remain unknown. It's worth looking at three different regions as examples of the diversity.

• Figure 1: the North Celestial Pole. On a large scale it is a huge shell about 40 degrees in diameter. It must be old because there is no apparent energy source inside.

• Figure 3: The Eridanus superbubble. The shell was formed by stellar winds and supernovae in the Orion star clusters. This superbubble is huge, larger than our image. Note the filaments, streamers, and blobs, formed by the interior hot gas pushing outwards.

• Figure 4: A quieescent region. The structure is much smoother, reflting a domiance of WNM over CNM. Among other things, this contains an extremely cold cloud: producing this low temperatures almost certaily requires that the tiny "PAH" grains have been destroyed. Microwave spectra of dust emission might peculiar in this cloud.

TYPICAL ANGULAR SIZE

Figure 2 shows a magnified version of Figure 1 to assess the angular structure scale. The pixel size is about 2 arcmin, one-third the angular resolution. Most of the CNM structure is unresolved by the 6 arcmin resolution. **THIS IS GENERALLY TRUE: IRAS RARELY RESOLVES CNM STRUCTURE!**

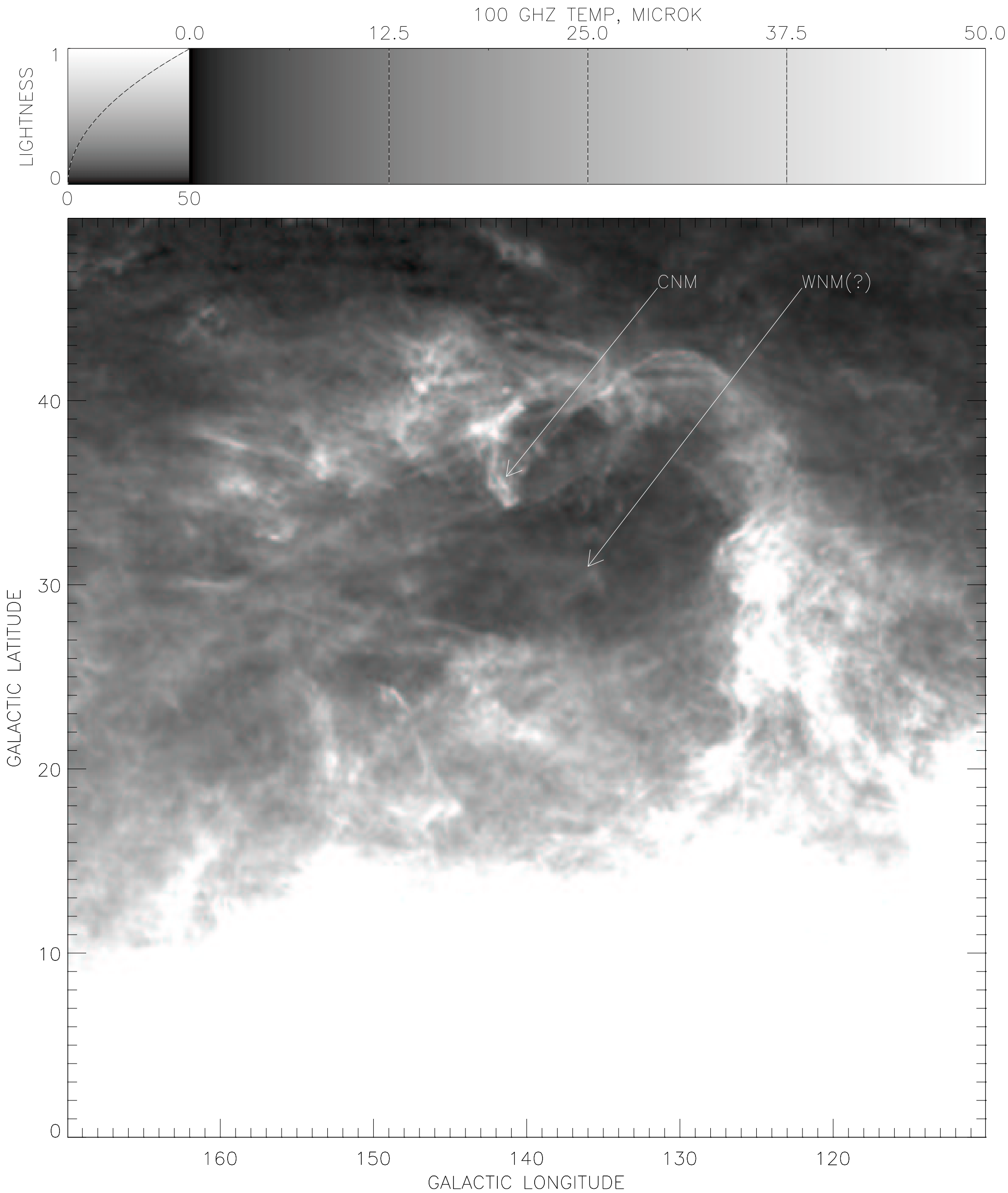

Fig. 1.— Predicted 100 GHz map of the NCP region, which is dominated on the large scale by a shell. The CNM exhibits prominent small-scale filamentary structure while the WNM is smoother.

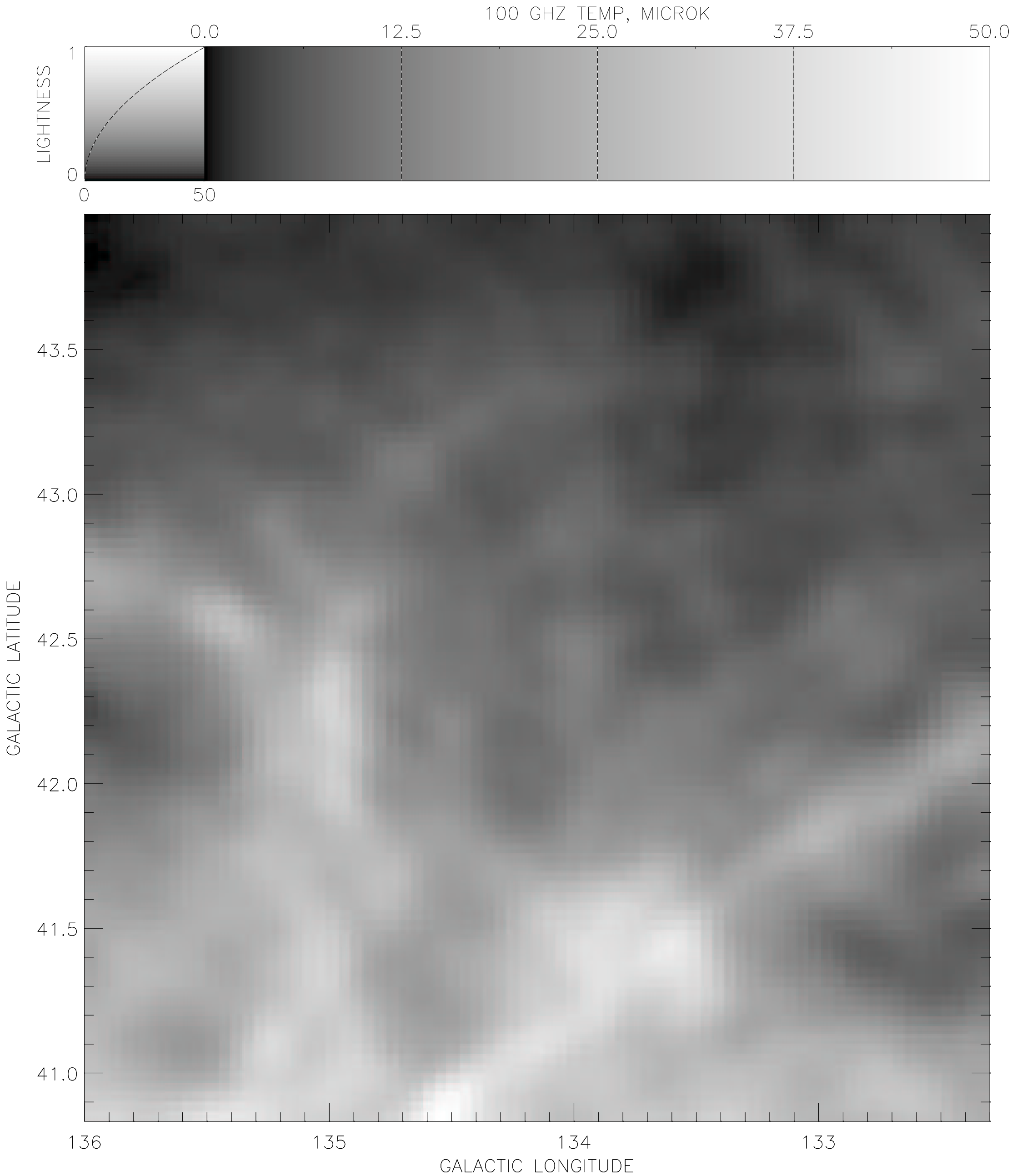

Fig. 2.— Magnified section of NCP region. The pixels are 2 arcmin square and the angular resolution is 6 arcmin. *Most of the structure is unresolved.*

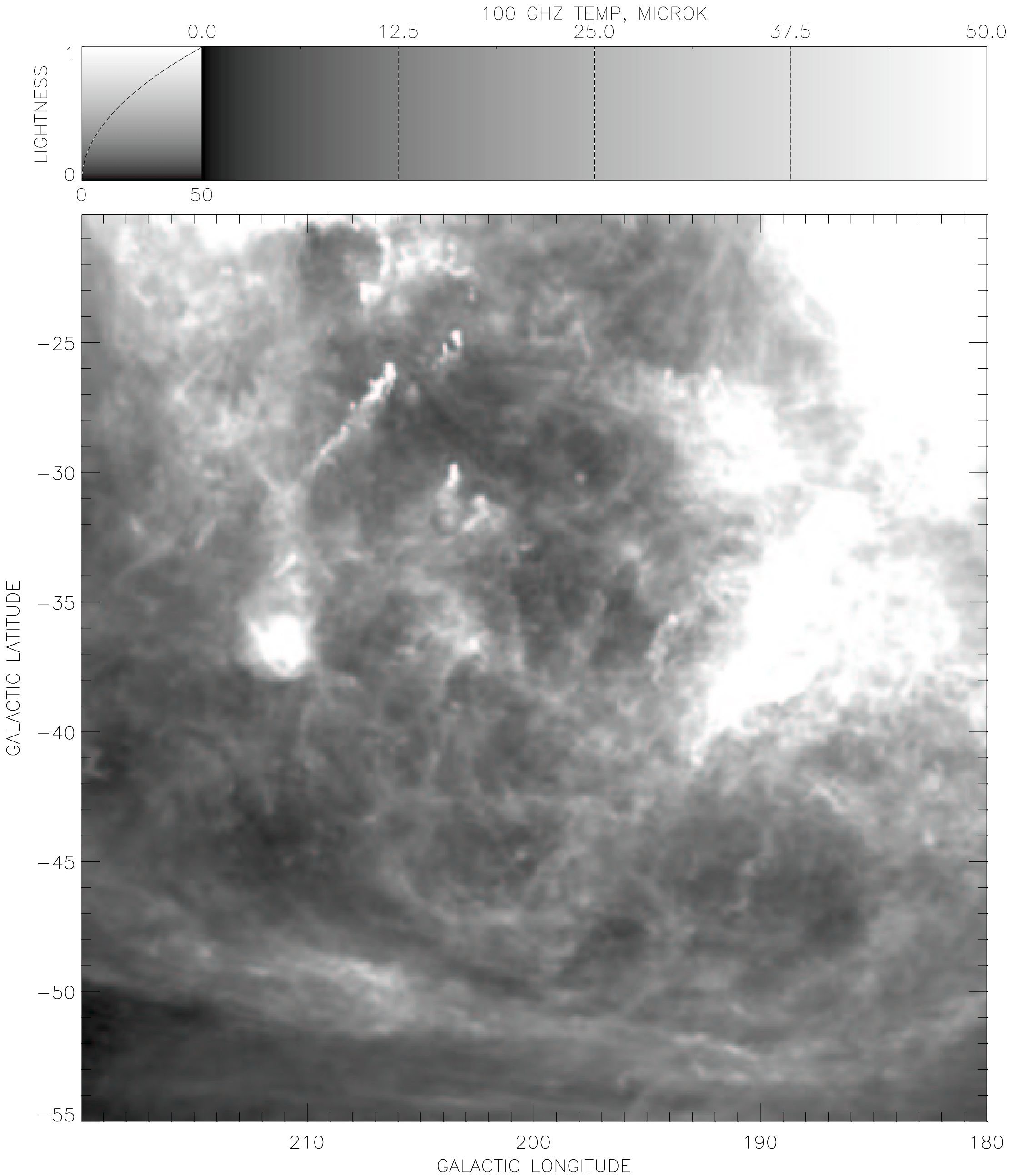

Fig. 3.— Predicted 100 GHz map of the Eridanus superbubble region, which is dominated by small-scale filaments, streamers, and blobs formed by the interior hot gas pushing outwards.

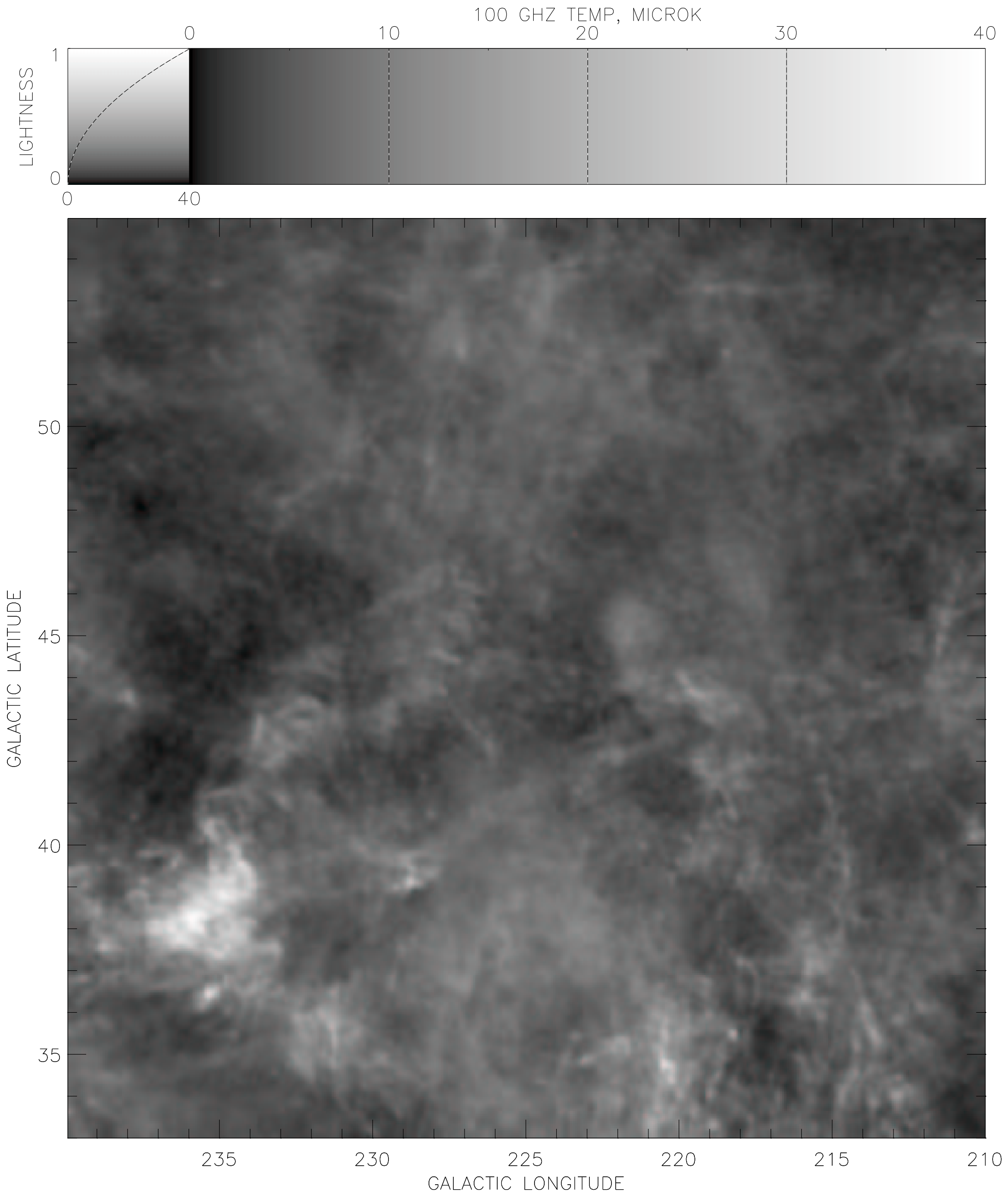

Fig. 4.— Predicted 100 GHz map of a quiesecent region. The structure is much smoother, reflting a domiance of WNM over CNM. And it contains a very cold cloud (not easily visible) which should have anamolous grains.

SENSITIVITY REQUIREMENTS

In the first three the prominent CNM filaments have typical CNM column density $N(HI) = 4.5 \times 10^{20}$ cm^{-2}. Using this together with the microwave spectrum of Finkbeiner, Davis, & Schlegel (FDS: 1999, ApJ 524, 867) model 8 we predict the equivalent excess CMB temperature T_{CMB}. This forms the calibration represented in all of our Figures. This column density provides (from FDS)

$$N(HI) = 4.5 \times 10^{20} \text{ cm}^{-2} \Longleftrightarrow T_{CMB,100GHz} = 15 \ \mu\text{K}$$

We use this, together with the FDS spectrum, to calculate the required sensitivity versus frequency in Table 1.

Column 2 is the one-year mission noise per beam and Column 3 is T_{CMB}; Column 4 is the ratio S/N for the total intensity. This is high, even below 100 GHz,

but not high enough to detect polarization at the level of a few percent except at the highest frequency bands.

Assuming we want to detect 2% linear polarization at the 1σ level, we must pixel average; Column 6 gives the square root of the number of pixels required. For circular areas, this averaging degrades the angular resolution for polarization mneasurements. Column 7 gives the effective angular resolution $FWHM_{pol}$ for polarization measurements at this level.

Finally, not all CNM structures are so strong. The median CNM column density from HT provides

$$N(HI) = 6 \times 10^{19} \text{ cm}^{-2} \Longleftrightarrow T_{CMB,100GHz} = 1.4 \ \mu\text{K}$$

which is about ten times smaller: sensitivity *does* become an issue for polariztion, even at 500 GHz.

TABLE 1:
CMBPOL AND CNN DUST EMISSION

(1) GHz	(2) NOISE	(3) MICROK	(4) S/N	(5) FWHM	(6) $N_{pol}^{1/2}$	(7) FWHM_{pol}
30	1.2	1.9	1.5	10.3	34	350
45	0.8	3.7	4.3	6.9	12	80
70	0.6	7.9	13	4.4	4.0	17
100	0.6	15	25	3.1	2.0	6.3
150	0.8	38	46	2.1	1.1	2.3
220	1.7	110	64	1.4	–	1.4
340	10	670	67	0.9	–	0.9
500	100	7600	76	0.6	–	0.6

Table 1:
(2): Noise per beam for one-year mission.
(3): Signal for CNM having $N(HI) = 4.5 \times 10^{20}$ cm^{-2}. This is representative of strong filaments, but *ten times larger* than the median CNM cloud.
(4) $\frac{SIG}{NOISE} = \frac{Col(3)}{Col(4)}$.
(5) Angular resolution (FWHM), arcmin
(6) If linpol=2%, N is the nr of beam areas we must average to detect the polarizataion with S/N=1.
(7) The effective angular resolution after averaging a circular area over N beam areas.

CONCLUSIONS

The first three statements apply to morphologically obvious CNM structures.

1. Above 100 GHz, the angular resolution for polarization $FWHM_{pol}$ is better than currently available from IRAS or Planck, so is a big improvement.

2. Above 150 GHz, $FWHM_{pol}$ is not limited by sensitivity, so is equal to $FWHM$ of CMBPOL.

3. What's required to resolve the CNM angular structure? Unknown! Any improvement in $FWHM$ is a plus—the more the better. But we cannot state any definite "requirement".

4. The above statements are valid for the mrphologically obvious filaments shown in our Figures, which have $N(HI) \sim 4.5 \times 10^{20}$ cm^{-2}. The median CNM column density is about ten times smaller (HT). Polarization of such weak structures will require pixel averaging, which will probably cause them to be unresolved.

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5. *The absolute bottom line*: as currently spec'd, and even if the higher frequencies are somewhat degraded from current specs, CMBPOL's sensitivity and angular resolution will provide revolutionary capability regarding mapping of IR emission from diffuse ISM dust, both in total intensity and polarization.