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Interstellar Scattering in the Galactic Anticenter

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Abstract. Interstellar scattering dictates the limiting resolution for many pulsars and OH masers and some extragalactic sources, a limit made more important by the advent of space-based VLBI. Scattering observations have been biased toward the inner Galaxy, leaving largely unconstrained basic parameters such as the scattering medium's extent in the outer Galaxy. Ionized gas at ~ 50 kpc is suggested by the appearance of H I in nearby galaxies and models of low-redshift quasar absorption systems. We combine multiwavelength, VLBA observations of twelve extragalactic sources with previous scattering measurements of extragalactic sources and pulsars in the anticenter and constrain the radial extent of the scattering medium to 20 kpc, comparable to that of massive star formation. The H II disk does not display significant flaring or warping, though this conclusion may reflect the coarse sampling.

Exterior to the solar circle the Galaxy's H I layer is warped systematically from its midplane in the inner Galaxy and extends to Galactocentric distances of $R \gtrsim 25$ kpc (Burton 1988). A similar morphology and extent is observed for other disk constituents such as molecular gas (Wouterloot et al. 1990).

A recent model for the Galactic distribution of free electrons adopted an e^{-1} scale length of $A_1 = 20$ kpc for the H II disk, though $A_1 \approx 50$ kpc was also allowed by the data (Taylor & Cordes 1993). The radial extent of H II may exceed that of the H I: 1) C IV absorption at $R \approx 25$ kpc is seen towards H1821+643 ($\ell = 94°, b = 27°$; Savage, Sembach, & Lu 1995). 2) H I disks of nearby galaxies are truncated at radii of 25–50 kpc, where they become optically thin to the intergalactic ionizing flux (Corbelli & Salpeter 1993). Some low-redshift Lyα absorption systems may be due to residual H I in extended disks of spiral galaxies (Charlton, Salpeter, & Hogan 1993).

Angular broadening measurements of extragalactic sources can constrain A_1, Fig. 1. The line of nodes of the H I disk is at $\ell \approx 170°$, so anticenter sources provide the longest path lengths through the H II disk. If the H II disk flares or warps like the H I disk, angular broadening could be non-negligible at higher latitudes ($|b| \approx 30°$), thereby limiting the resolution of space VLBI near 1 GHz, viz. Fig. 1.

We have conducted multifrequency VLBA observations of twelve anticenter sources, seven with $|b| < 0\overset{\circ}{.}5$ (Lazio & Cordes 1997a). Lines of sight with $|b| < 0\overset{\circ}{.}5$ remain within one scale height of the H II disk (0.88 kpc) for path lengths of 100 kpc.

We detected eleven sources at one or more of our observation frequencies—0.3, 1.6, and 5 GHz. We combined the scattering diameters from our survey with those in the literature for other extragalactic sources and pulsar scintillation bandwidths. We modified the Taylor-Cordes model, allowing the H II disk to flare and warp exterior to the solar circle. We used a likelihood analysis to constrain the model parameters (Lazio & Cordes 1997b).

Figure 2 shows the likelihood as a function of A_1 for an unwarped, nonflaring disk. We assume that the Perseus spiral arm, which is exterior to the solar circle

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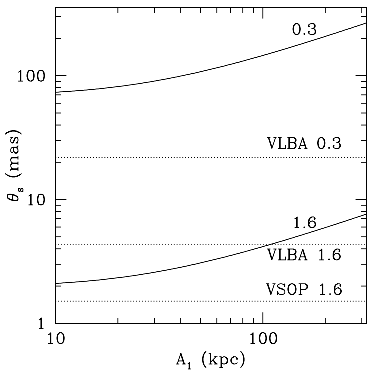

Figure 1. Anticenter angular broadening, for an extragalactic source, as a function of A_1, the radial scale length of the H II disk. Curves are labeled by observing frequency (GHz). Dotted lines show resolutions of the VLBA and an array including VSOP .

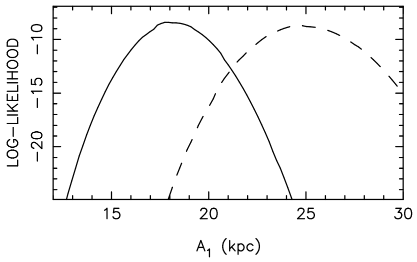

Figure 2. Likelihood estimates of A_1 for an unwarped, nonflaring disk. The solid line shows the likelihood for a disk with a gradual radial decrease in the electron density, the dashed line for a truncated disk. The Perseus spiral arm is assumed to contribute no scattering.

in the anticenter, contributes no scattering; including it decreases the allowed A_1 values. The large values, $A_1 \approx 50$ kpc, that were allowed by the Taylor-Cordes analysis are disfavored. Our analysis favors an unwarped disk, though, this may reflect our sparse (20 sources) and nonuniform anticenter coverage.

We favor an electron density distribution truncated at 20 kpc, because this is comparable to the radial extent of massive star formation (Wouterloot et al. 1990); scattering would then trace massive star formation, as in the inner Galaxy. We also find that scattering decreases more rapidly with R than does the H I. However, the H II disk could extend to $R \gtrsim 100$ kpc, comparable to that inferred from Lyα absorption systems (Charlton et al. 1993), if the extreme outer disk is quiescent and contributes little scattering.

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