SIO MASER SURVEY OF THE BULGE IRAS SOURCES

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ABSTRACT. SiO maser emission from the Bulge IRAS sources has been searched by the v=1, J=1−0 and v=2, J=1−0 transitions to investigate the kinematics of the Galactic Bulge, resulting in a sample of 124 line-of-sight velocities. The rotation velocity, velocity dispersion, and velocity offset at $l = 0°$ for the sample are found to be 9.3±1.4 km s^{-1} deg^{-1}, $75.8^{+6.6}_{-5.9}$ km s^{-1}, and −18.2±9.7 km s^{-1}, respectively (80% confidence interval). Furthermore we find trends for the rotation velocity and velocity dispersion to decrease with distance from the galactic plane. These trends are supported by a larger sample constructed by incorporating other available velocity data on the Bulge IRAS sources. The rotation velocity and velocity dispersion are expressed as $15.6-1.23\times|b(\mathrm{deg})|$ km s^{-1} deg^{-1} and $101-3.6\times|b(\mathrm{deg})|$ km s^{-1}, respectively. The implications of the observed quantities are discussed.

1. Introduction

The Galactic Bulge is a unique system for which we can investigate the kinematical properties in detail. So far several attempts were made to examine the motion of the Bulge at optical wavelengths (Menzies 1990 and references therein, Minniti et al. 1992). Most of them were, however, made toward some restricted regions because interstellar extinction hampers homogeneous sampling toward the Bulge. The success in IRAS mission changed this situation dramatically. As shown by Habing et al. (1985) it has become possible to extract the Bugle source candidates from IRAS Point Source Catalog with color and flux constraints (the Bulge IRAS sources). They are most likely mass losing AGB stars, hence SiO maser sources. SiO maser emission is one of the best tools to study stellar kinematics in distant and obscured regions

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like the Bulge (cf. Lindqvist et al. 1991). We have started a survey of SiO masers from the color-selected Bulge IRAS sources with the Nobeyama 45-m telescope (cf. Nakada et al. 1992).

2. Observations and Survey Results

The observations were made with the 45-m telescope of Nobeyama Radio Observatory from January 1990 to June 1992 (still continuing). We used a 4-K cooled SIS mixer receiver with T_{sys} around 200 K (SSB, Ta*) at the elevation angle of 25°. The beam size of the telescope is 39"(HPBW) at 43 GHz. We observed two SiO maser lines simultaneously: SiO v=1, J=1−0 (43.122027 GHz) and v=2, J=1−0 (42.820539 GHz). This dual line observation assures firm detection of the emission like conspicuous twin-peaks of OH masers. The velocity coverage in V_{LSR} is from −300 km s^{-1} to +300 km s^{-1}. The velocity resolution is 0.28 km s^{-1} at the observing frequencies. Pointing accuracy was better than 10", which is accurate enough for our observing beam size of 39".

The Bulge IRAS sources are extracted from the IRAS Point Source Catalog with the conditions of F12<10Jy, 0.0≤log(F25/F12)≤0.2, $-15° \leq l \leq 15°$, and $3° \leq |b| \leq 15°$. The upper limit to the 12μm flux and color range were determined so that the sources were distributed on the sky to delineate clearly the shape of the Bulge (cf. Habing et al. 1985) and by consulting the study by Whitelock et al. (1991). The region near the galactic plane was excluded because of the contamination and confusion by disk sources. We included sources which did not satisfy the above criteria but were assigned to the Bulge members by Whitelock et al. (1991). To the present 186 "Bulge" sources were observed at Nobeyama and the SiO maser emission has been detected in 124 (67%) of them. The distribution of the detected sources on the sky is shown in Figure 1 in the galactic coordinates. They seem to concentrate rather into the four strips, $4° \leq |b| \leq 5°$ and $7° \leq |b| \leq 8°$. This is because we gave a priority to these areas in extending our survey down to sources having 12μm fluxes smaller than 5Jy. The detection rate exceeds about 70% for the sources which satisfy the above color criterion but have 12μm flux greater than 10Jy (32 out of 44, 73%). The velocities between SiO masers and OH masers (te Lintel et al. 1991) agree well within ±3 km s^{-1} for commonly observed sources. These results are in good agreement with those by Jewell et al. (1991) on the sources in the solar neighbourhood and by Lindqvist et al. (1991) on the OH/IR stars close to the galactic center.

3. Kinematical Properties of the Bulge

We here show some results on the Bulge kinematics. We assume that the Local Standard of Rest moves with respect to the Galactic Center in a circular oribit at a velocity of 220 km s^{-1}. Velocities given here are refered to the Galactic Standard of Rest.

We first show radial velocities of the Bulge IRAS sources as a function of galactic longitude ($l-v$ diagram, Figure 2). Clear evidence is found for the rotation of the Bulge. We obtained the rotation velocity to be 9.3±1.4 km s^{-1} deg^{-1} (80% confidence interval) from a linear regression. This corresponds to 67.4 ±10.4 km s^{-1}

kpc^{-1} assuming Ro=8.0 kpc. The residual velocity dispersion is $75.8^{+6.6}_{-5.9}$ km s^{-1} (80% confidence interval). Minkowski (1964) first pointed out that the Bulge of our Galaxy slowly rotates in the same direction as the disk component does through the analysis of planetary nebulae near the Galactic Center region. Since then several works are made on the motion of the Bulge (Menzies 1990 and references therein, Minniti et al. 1992, Nakada et al. 1992). They are consistent with the present results on both the direction and speed of rotation of about 10 km s^{-1} deg^{-1}.

In Figure 1 a velocity offset at l = 0° of −18.2±9.7 km s^{-1} (80% confidence interval) is found. Similar offsets are observed for Baade's Window K-giants (Rich 1990) and planetary nebulae in the vicinity of the galactic center (Kinman et al. 1988). Some possible reasons can be thought of immediately:

· It is suffered from statistical fluctuations,

· Our survey is still too shallow to obtain a $l-v$ diagram symmetric with regard to the origin,

· There is another component about the motion of the Local Standard of Rest.

The second reason suggests a systematic velocity structure in the Bulge. It requires some relation between the distances to the sources and the radial velocities. Nakada et al. (1991) and Blitz and Spargel (1991) suggest existence of a bar-like bulge in the center of our Galaxy. In such a bar-like system, systematic streaming motion can be expected (cf. Freeman 1966). More observations in the $l \leq 0°$ region with higher sensitivity are necessary to discriminate one from these possibilities.

Second, we divided our survey region into areas of 1 degree width in $|b|$ and examined the dependence of the kinematical parameters on the distance from the galactic plane. We have found that the rotation velocity tends to decrease with distance. For the velocity dispersion a similar trend is discernible but less conclusive. To improve the statistics we have incorporated other available data on the radial velocities of the Bulge IRAS sources, i.e., the OH maser survey by te Lintel et al. (1991). The number of the sample is increased from 124 to 183. With the improved statistics the trends became more evident (Figure 3,4). The rotation velocity and velocity dispersion can be expressed as $15.6-1.23\times|b(\text{deg})|$ km s^{-1} deg^{-1} and $101-3.6\times|b(\text{deg})|$ km s^{-1}, respectively. Two possibilities are considered:

· Both quantities really depend on $|b|$,

· The contamination by disk sources decreases with distance from the galactic plane.

The former can be anticipated for kinematic studies, and if real, it is found observationally for the first time. The velocity dispersion is suggested to decline with distance from the galactic center (Minniti et al. 1992), which favours the former possibility. We expect the disk source contamination is low, however, we still cannot rule out completely the latter possibility at present. We are now exmamining influence by the contamination.

4. Summary

1). SiO maser emission has been searched for v=1 J=1-0 and v=2 J=1-0 transitions simultaneously toward 186 Bulge IRAS sources and detected in 124 sources.

The detection rate is 67% for the present sample and exceeds 70 % for the bright sources. Further it was found that the SiO maser emission gave the stellar systemic velocities as accurately as OH masers. Thus the SiO masers have been proved to be one of the best tools to probe line-of-sight velocities of the Bulge IRAS sources.

2). The mean rotation speed and velocity dispersion of the Bulge were obtained to be 9.3 $\pm$1.4 km s^{-1} deg^{-1} (67.4 km s^{-1} kpc^{-1}, Ro=8.0 kpc) and 75.8 $^{+6.6}_{-5.9}$ km s^{-1}, respectively.

3). The velocity offset at $l = 0°$ is -18.2 ± 9.7 km s^{-1}. This may suggest existence of a systematic velocity structure in the Bulge or that of an additional velocity component in the motion of the Local Standard of Rest. However, statistical fluctuations cannot be ruled out.

4). Both the rotaion velocity and velocity dispersion tend to decrease with distance from the galactic plane, and are expressed as $15.6-1.23\times|b(\text{deg})|$ km s^{-1} deg^{-1} and $101-3.6\times|b(\text{deg})|$ km s^{-1} , respectively, for the sample including OH data.

Our survey is still on its way. We will be able to discuss the above issues with greater confidence and to understand the origin and kinematics of the Bulge in conjunction with the rest of the Galaxy in near future.

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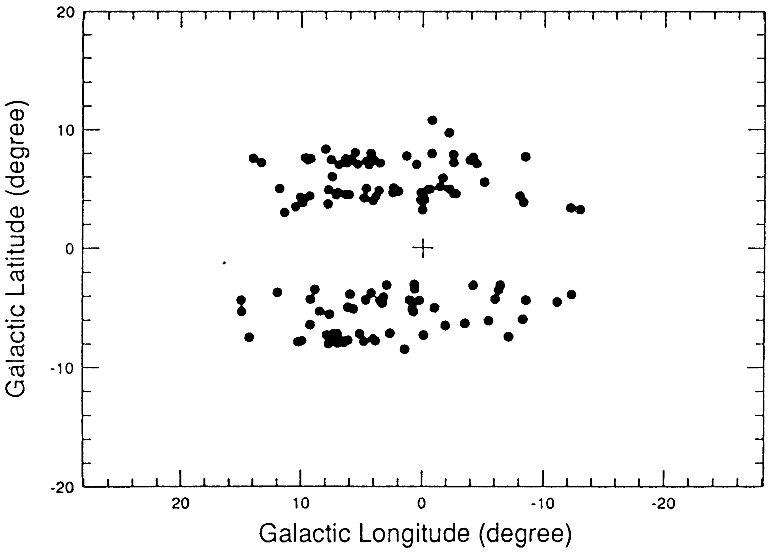

Figure 1: The distribution of 124 Bulge IRAS sources associated with SiO maser emission. The region of $|b| < 3°$ is excluded in our survey.

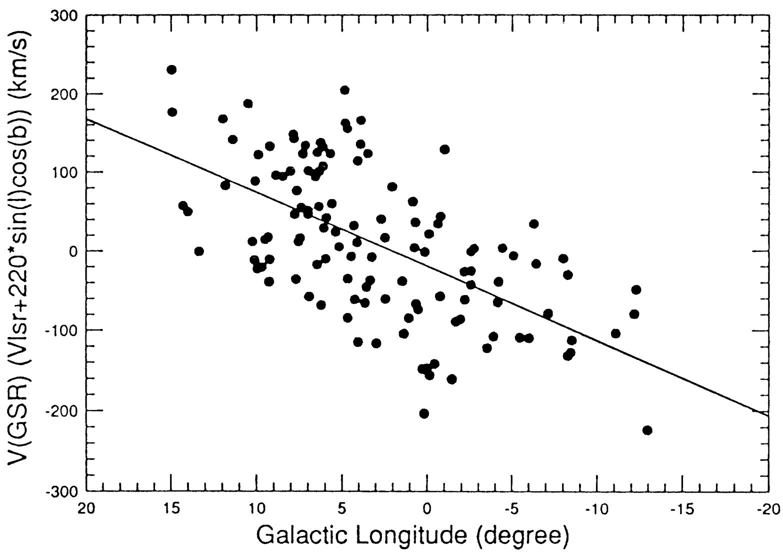

Figure 2: The radial velocities of the Bulge IRAS sources as a function of galactic longitude. A linear regression gives the rotation velocity, velocity dispersion, and velocity offset at $l = 0°$ to be 9.3 ± 1.4 km s^{-1} deg^{-1}, $75.8^{+6.6}_{-5.9}$ km s^{-1}, and -18.2 ± 9.7 km s^{-1}, respectively.

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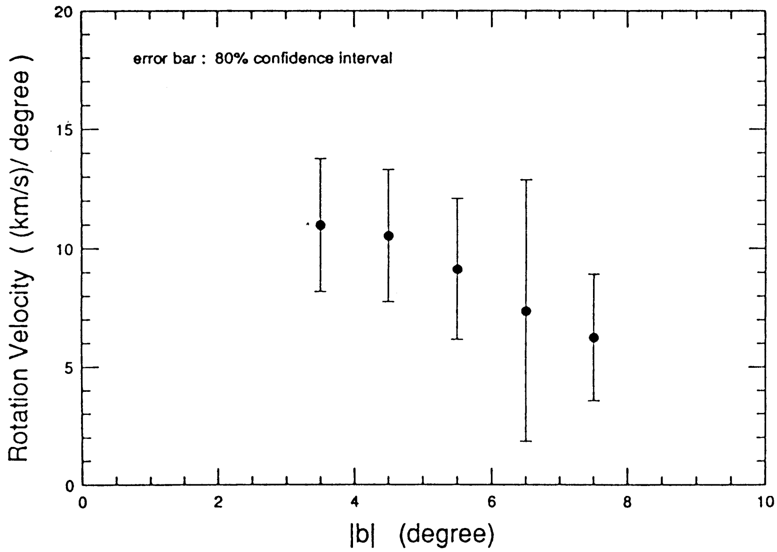

Figure 3: The dependence of rotation velocity on galactic latitude for a sample of 186 sources in which OH data are also included. The error bars express 80% confidence intervals. The least squares fit to a straight line gives a slope of -1.23 km s^{-1} deg^{-2}.

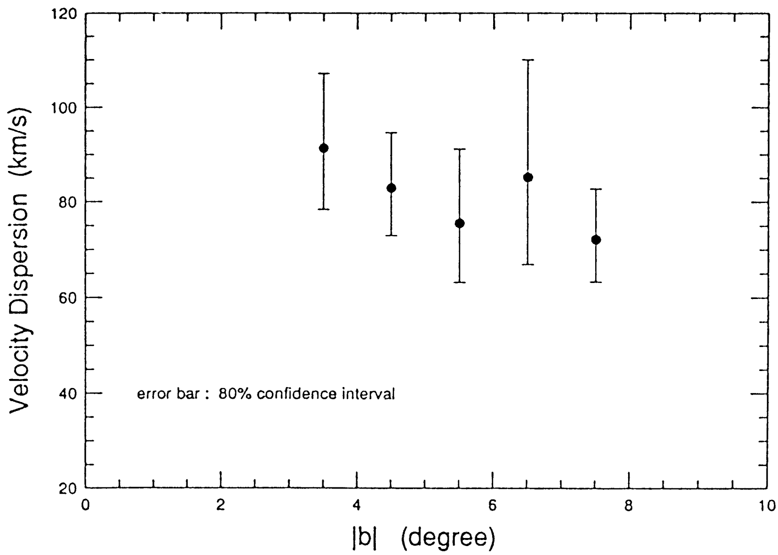

Figure 4: Same as in Figure 3 but for velocity dispersion. The slope is found to be -3.6 km s^{-1} deg^{-1}.

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