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# THE DYNAMICAL STRUCTURES OF DENSE MOLECULAR CLOUDS IN THE GALACTIC CENTER REGION & THEIR IMPLICATIONS

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## ABSTRACT

We have studied the response of molecular clouds in the Galactic disk to a rotating bar by conducting Smoothed Particle Hydrodynamics (SPH) simulations for the Galaxy in order to understand the dynamical structures of the Galactic Center (GC) molecular clouds, and their implications. In our study it was found that the structures of GC molecular clouds could be induced by the combined effects of rotating bar potential, the hydrodynamic collisions and gravitational miss collisions between the clouds.

*Key Words :* he Galaxy: center - clouds: structures : SPH: gas dynamics

## I. INTRODUCTION

The dynamics of the molecular clouds in the Galactic Center is being well known from numerous molecular line observations ($^{12}$CO; Dame *et al.* 1987, $^{13}$CO and CS; Bally *et al.* 1988, $H_2CO$; Zylka *et al.* 1992; HCN; Lee 1996) and theoretical approaches (Binney *et al.* 1991, Wada & Habe 1992, Friedly & Benz 1992, Gehard 1995, Fux & Friedli 1996). But these studies are not focused in examining the detailed structures of small scale within about 6 degree from the GC region.

In this report, we make numerical simulations using Smoothed Particle Hydrodynamic (SPH) method for the response of molecular clouds under the time-dependent potential generated by various Galactic components: three axisymmetric components (massive halo expressed with the logarithmic potential, exponential disk and a compact bulge represented by a Plummer model) and one non-axisymmetric bar component. Initially, in our models SPH particles are uniformly distributed and follow their evolution under the influence of assumed potential.

The models with four different values for bar's axial ratio, 2:1, 2.5:1, 3:1, and 4:1 are considered. In these models we obtain runs of particles (about 8000 SPH particles) with hydrodynamic pressures. In case of a model of the bar's axial ratio of 4:1 we also obtain a run of a mixture (about 19,000 SPH particles) of (collisional) particles with hydrodynamic pressures and (collisionless) particles effected by only gravitational potential, without the hydrodynamic pressures.

We compare kinematic structures made by response of bar potential with ones appeared in HCN (Lee 1996; Fig. 1) and CO (Bitran 1987; Fig. 2) observations to discuss the dynamical structures of the molecular clouds in the GC and their implications.

## II. CONCLUSIONS & DISCUSSIONS

A comparison between observations (Fig. 1 & Fig. 2) and simulations (Fig. 3) informs us what the structures of GC clouds are like.

In the collisional models some observed kinematic structures of the GC molecular clouds could be fairly well explained. The $l = 5°.5$ complex is found to be consisted with two spiral arm components and x1 family, and the $l = 3.°.2$ complex to be consisted with x1 family, x2 family, and two spiral arm components. We suggest that the very wide line width of the $l = 3.°.2$ complex (Lee 1996) may be due to a combination of above three kinds of components.

The emissions in the Galactic nuclear disk ($|l| \leq 2°$) seems to be mostly x2 orbit family. Moreover a noticeable feature is the gas depleted region which is well shown in the CO map (Bitran 1987). From comparison of the collision model with the collisionless model, these gas-depleted regions are known to be the structures suppressed by the presence of the hydrodynamic collisions.

Although the collisional models are fairly successful for reproducing above structures, we should note that there are ones hard to explain, features such as a parallelogram in CO map and forbidden velocity components with $V_{LSR} \approx 100$ km s$^{-1}$ at negative longitude in CO map. So we made a model with a mixture of collisional particles and collisionless particles. It should be noted that the collisionless particles experience only their gravitational miss collisions and thus can get high velocity dispersions. Therefore these collisionless particles successfully reproduce the puzzling two features hard to be explained from only the collisional model. Fig. 3 is $l - V$ diagram of the mixture of the collisional particles (70%) and the collisionless particles (30%), which gives better reproduction of kinematic structures of the GC clouds.

From these considerations, it is suggested that two types of clouds such as clouds which have been in hy-

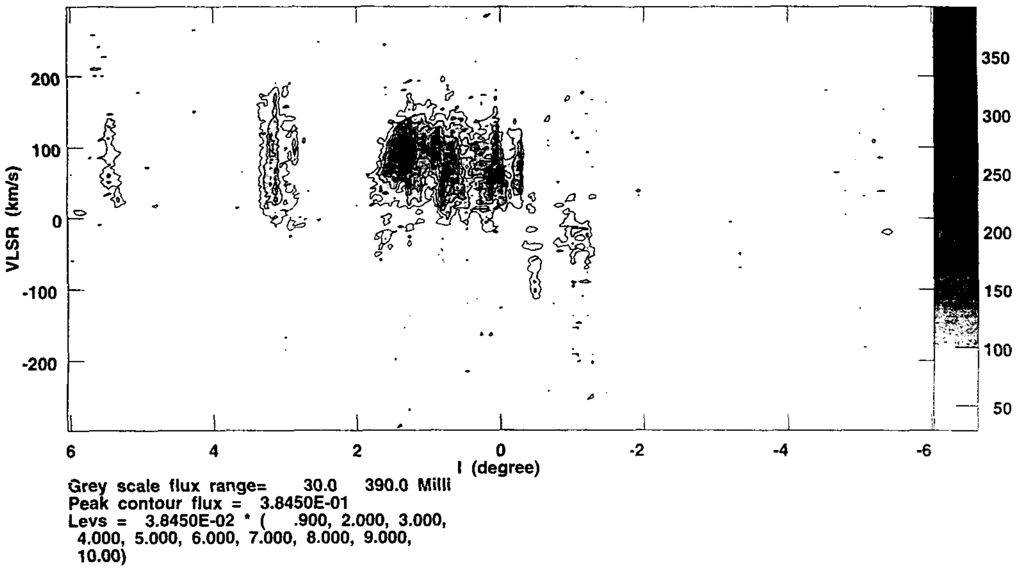


**Fig. 1.**— The HCN $l - V$ map averaged over $b = -0^{\circ}.8 \sim 0^{\circ}.85$ (Lee 1996).

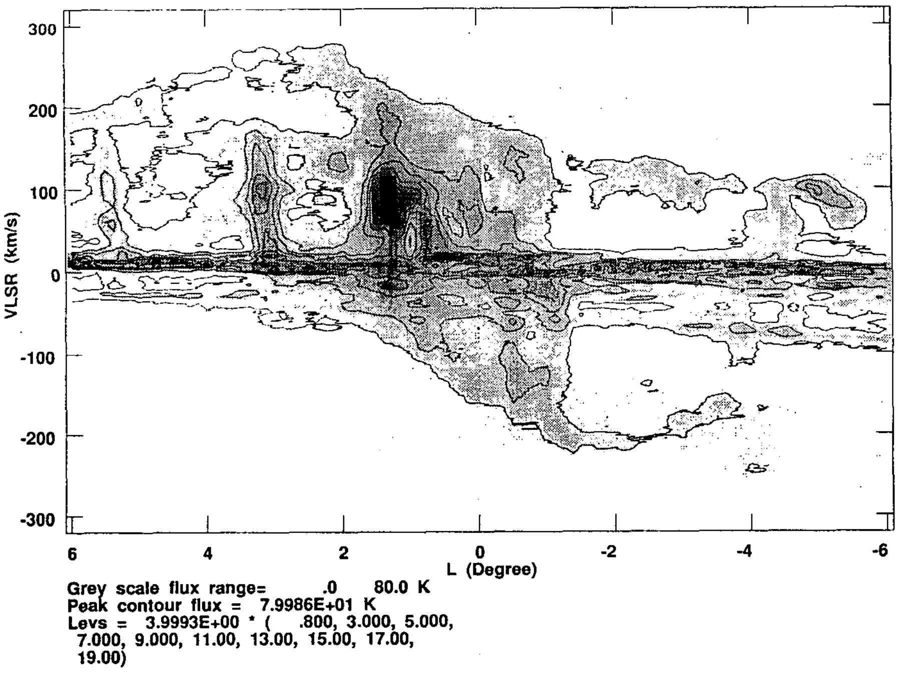


**Fig. 2.**— The $^{12}$CO $l - V$ map averaged over $|b| = 2^{\circ}$ (Bitran 1987).

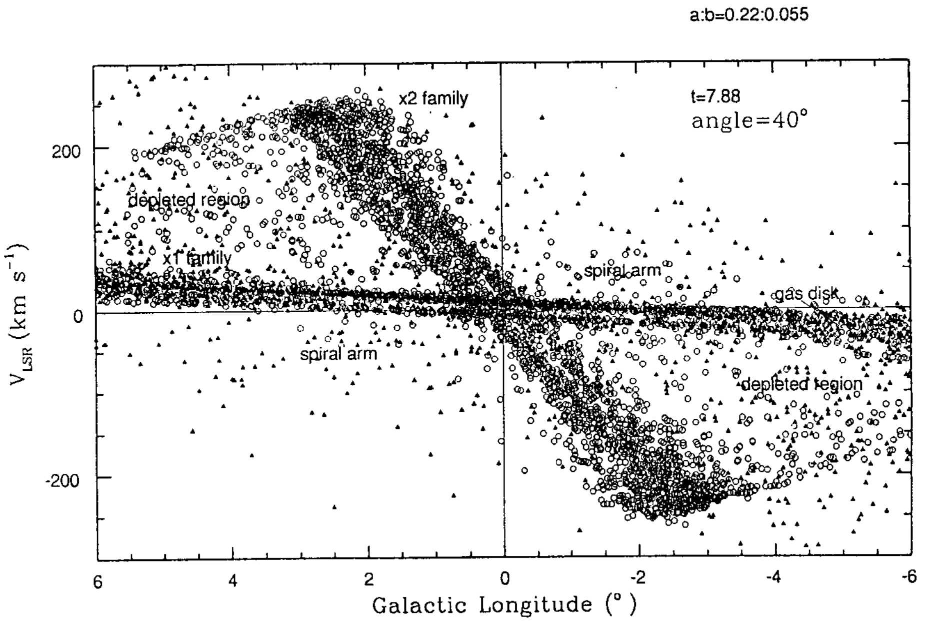


**Fig. 3.**— The $l-V$ map of the B4-1 model containing the collisional particles (70%) and the collsionless particles (30%).

drodynamic collisions and clouds which have been in gravitational miss collisions, not in hydrodynamic collisions may exist simultaneously in the GC.

In our short report, we discuss what the forbidden components known in molecular line observations could be like. It is shown that in our calculations the forbidden components could be made by both of the hydrodynamic collision and the gravitational miss collision. Hence, as the candidates of the forbidden components, we suggest the infalling spiral arm components due to the hydrodynamic collision or components with high velocities due to the gravitational miss collision.

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