Giant Molecular Clouds

http://www.astro.ncu.edu.tw/irlab/projects/project.htm
→ Galactic Open Clusters → Galactic Structure → GMCs

The Solar System and its Place in the Galaxy

In Encyclopedia of the Solar System
By Paul R. Weissman
http://www.academicpress.com/refer/solar/Contents/chap1.htm

Stars in the galactic disk have different characteristic velocities as a function of their stellar classification, and hence age. Low-mass, older stars, like the Sun, have relatively high random velocities and as a result c an move farther out of the galactic plane. Younger, more massive stars have lower mean velocities and thus smaller scale heights above and below the plane. Giant molecular clouds, the birthplace of stars, also have low mean velocities and thus are confined to regions relatively close to the galactic plane. The disk rotates clockwise as viewed from "galactic north," at a relatively constant velocity of 160-220 km/sec. This motion is distinctly non-Keplerian, the result of the very nonspherical mass distribution. The rotation velocity for a circular galactic orbit in the galactic plane defines the Local Standard of Rest (LSR). The LSR is then used as the reference frame for describing local stellar dynamics.

The Sun and the solar system are located approxi-mately 8.5 kpc from the galactic center, and 10-20 pc above the central plane of the galactic disk. The circular orbit velocity at the Sun's distance from the galactic center is 220 km/sec, and the Sun and the solar system are moving at approximately 17 to 22 km/sec relative to the LSR. The Sun's velocity vector is currently directed toward a point in the constellation of Hercules, approximately at right ascension 18h 0m and dec-lination +3O°, known as the solar apex. Because of this motion relative to the LSR, the solar system's galactic orbit is not circular. The Sun and planets move in a quasi-elliptical orbit between about 8.4 and 9.7 kpc from the galactic center, with a period of revolution of about 240 million years. The solar system Is currently close to and moving inward toward "perigalacticon," the point in the orbit closest to the galactic center. In addition, the solar system moves perpendicular to the galactic plane in a harmonic fashion, with a period of 52 to 74 million years and an amplitude of ~49 to 93 pc out of the galactic plane. (The uncertainties in the estimates of the period and amplitude of the motion are caused by the uncertainty in the amount of dark matter in the galactic disk.) The Sun and planets passed through the galactic plane about 2-3 million years ago, moving "northward."

The Sun and solar system are located at the inner edge of one of the spiral arms of the galaxy, known as the Orion or local arm. Nearby spiral structures can be traced by constructing a three-dimensional map of stars, star clusters, and interstellar clouds in the solar neighborhood. Two well-defined neighboring structures are the Perseus arm, farther from the galactic center than the local arm, and the Sagittarius arm, toward the galactic center. The arms are about 0.5 kpc wide and the spacing between the spiral arms is about 1.2-1.6 kpc. The local galactic spiral arm structure is illustrated in Fig. 15.

The Sun's velocity relative to the LSR is low as compared with other G-type stars, which have typical velocities of 40-45 km sec-1 relative to the LSR. Stars are accelerated by encounters with giant molecular clouds in the galactic disk. Thus, older stars can be accelerated to higher mean velocities, as noted earlier. The reason(s) for the Sun's low velocity are not known. Velocity-altering encounters with giant molecular clouds occur with a typical frequency of once every 300-500 million years.

The local density of stars in the solar neighborhood is about 0.11 pc^-3, though many of the stars are in binary or multiple star systems. The local density of binary and multiple star systems is 0.086 pc^-3. Most of these are low-mass stars, less massive and less luminous than the Sun. The nearest star to the solar system is Proxima Centauri, which is a low-mass (M~ 0.1M), distant companion to Alpha Centauri, which itself is a double-star system of two close-orbiting solar-type stars. Proxima Centauri is currently about 1.3 pc from the Sun and about 0.06 pc (1.3 x l0~ AU) from the Alpha Centauri pair it is orbiting. The second nearest star is Barnard's star, a fast-moving red dwarf at a distance of 1.83 pc. The brightest star within 5 pc of the Sun is Sirius, an Al star (M ~2M) about 2.6 pc away. Sirius also is a double star, with a faint, white dwarf companion. The stars in the solar neighborhood are shown in Fig. 16.

The Sun's motion relative to the LSR, as well as the random velocities of the stars in the solar neighborhood, will occasionally result in close encounters between the Sun and other stars. Using the foregoing value for the density of stars in the solar neighborhood, one can predict that about 12 star systems (single or multiple stars) will pass within 1 pc of the Sun per million years. The total number of stellar encounters scales as the square of the encounter distance. This rate has been confirmed in part by data from the Hipparcos astrometrv satellite, which measured the distances and proper motions of 118,000 stars and which was used to reconstruct the trajectories of stars in the solar neighborhood.

Based on this rate, the closest stellar approach over the lifetime of the solar system would be expected to be at ~900 AU. Such an encounter would result in a major perturbation of the Oort cloud and would eject many comets to interstellar space. It would also send a shower of comets into the planetary region, raising the impact rate on the planets for a period of about 2-3 million years, and having other effects that may be detectable in the stratigraphic record on the Earth or on other planets. A stellar encounter at 900 AU could also have a substantial perturbative effect on the orbits of comets in the Kuiper belt and would likely disrupt the outer regions of that ecliptic comet disk. Obviously, the effect that any such stellar passage will have is a strong function of the mass and velocity of the passing star.

The advent of space-based astronomy, primarily through Earth-orbiting ultraviolet and x-ray tele-scopes, has made it possible to study the local interstellar medium surrounding the solar system. The structure of the local interstellar medium has turned out to be quite complex. The solar system appears to be on the edge of an expanding bubble of hot plasma about 120 pc in radius, which appears to have originated from multiple supernovae explosions in the Scorpius-Centaurus OB association. The Sco-Cen association is a nearby star-forming region that contains many young, high-mass 0- and B-type stars. Such stars have relatively short lifetimes and end their lives in massive supernova explosions, before collapsing into black holes. The expanding shells of hot gas blown off the stars in the supernova explosions are able to "sweep" material before them, leaving a low-density "bubble" of hot plasma.

Within this bubble, known as the Local Bubble, the solar system is at this time within a small interstellar cloud, perhaps 2-5 pc across, known as the Local Interstellar Cloud. That cloud is apparently a fragment of the expanding shells of gas from the supernova explosions, and there appear to be a number of such clouds within the local solar neighborhood.

Giant Molecular Clouds (L. Blitz in Protostars and Planets III)

Global properties of solar neighborhood GMCs

Mass	1-2 x 10^5 Msun
Average diameter	45 pc
Projected surface area	2.1 x 10^3 pc^2
Volume	9.6 x 10^4 pc^3
Volume averaged N(H2)	~50 cm^{-3}
Mean N(H2)	3-6 x 10^{21} cm^{-2}
Local surface density	~4 kpc^{-2}
Mean separation	~500 pc

- ✓ GMCs are discrete objects with well defined boundaries.
- ✓ GMCs are not uniform. They contain numerous dense clumps and small-volume filling factions.
- ✓ The CO and ^{13}CO line widths of the clumps are always wider than the thermal widths → bulk motions associated with turbulence and/or magnetic field.
- ✓ GMCs are gravitationally bound
- ✓ Cloud-to-cloud velocity dispersion of local GMCs is the same as that of small molecular clouds → so could not have been formed by collisional agglomeration of smaller independently moving clouds?
- ✓ No GMCs within 1 kpc are found without star formation (Dame et al. 1986, ApJ, 305, 892)
- ✓ Within 3 kpc of the sun, only 1 GMC is found without star formation (Maddalena and Thaddeus 1985, ApJ, 294, 231).
- ✓ Therefore GMCs could not survive for more than a few generations of massive star formation. Life time ~30 Myr (Blitz and Shu 1980, ApJ, 238, 148)
  Note: Blitz and Shu gave a derivation of collision time scale with clumps.

GMCs has a mass function index so that most mass is concentrated in the most massive clouds.

Kokubo and Ida (1992, PASJ, 44, 601) studied scattering of disk stars by GMCs including vertical motion to the Galactic disk → heating rate reduced

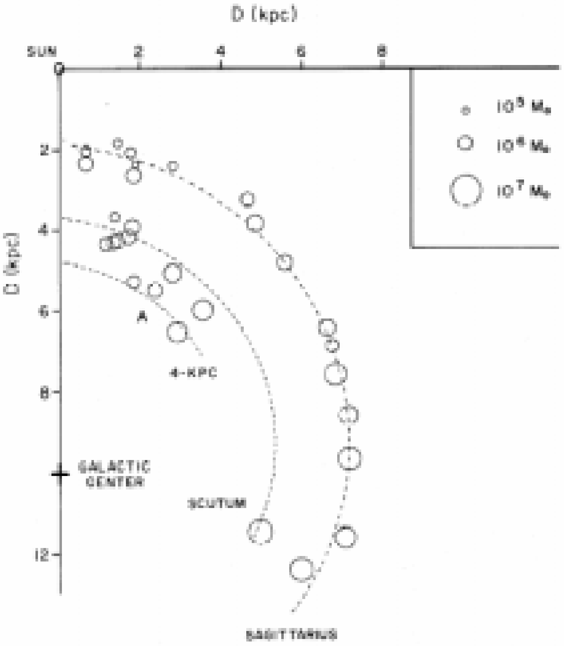

FIG. 9.—The locations in the Galactic plane of the large complexes listed in Table 7; the four clouds with masses less than $10^5\ M_\odot$ are not shown. The circle sizes are proportional to the cube roots of the cloud masses. For *A*, see § III.

The Sagittarius spiral, an unweighted least-squares fit to the positions of the 17 complexes that outline the arm, has a pitch angle of 5°3 and crosses the Sun–center line at $R = 8.24$ kpc. The Scutum and 4 kpc spirals were not fitted through the clouds but taken directly from the 21 cm analysis of the inner Galaxy by Shane (1972). The Scutum spiral has a pitch angle of 7° and crosses the Sun–center line at $R = 6.39$ kpc; the 4 kpc spiral has a pitch angle of 10° and crosses the Sun–center line at $R = 5.28$ kpc.

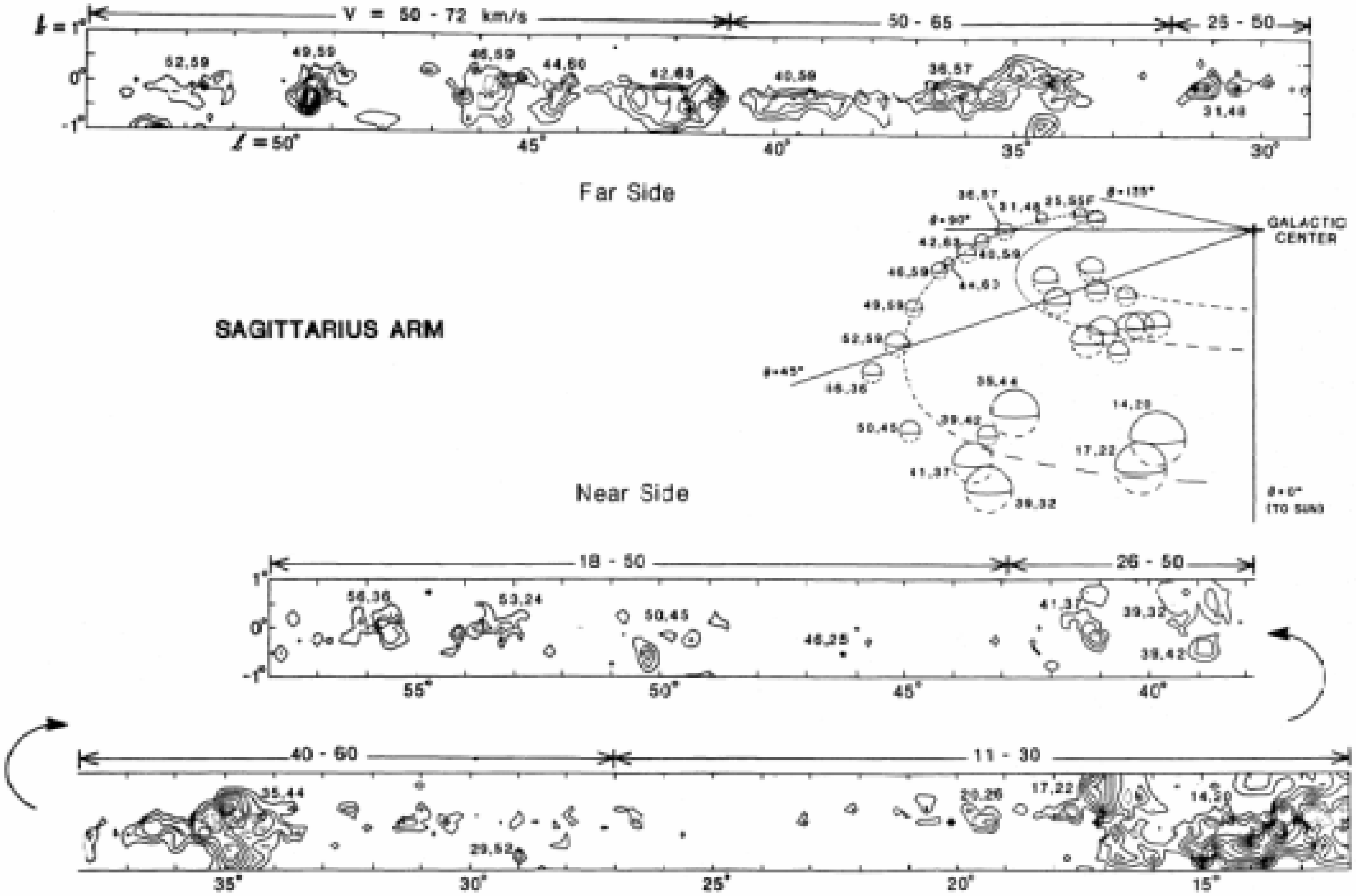

Fig. 10a

Fig. 10.—Spatial maps of the molecular clouds discussed in the text and listed in Table 2. Clouds in (a) the Sagittarius arm; (b) the Scutum and 4 kpc arms. The maps were produced by setting all spectral channels with $T < 2$ K to zero before integrating over velocity. The velocity integration limits change by discrete steps along the maps, in (a) to follow the velocity of the Sagittarius arm and in (b) simply to distinguish individual complexes in the crowded inner Galaxy. In every map the contour interval is 9.8 K km s^{-1}.

The figures between the maps show the distribution of the clouds in the Galactic plane viewed from the perspective of an observer located 2 kpc above the Sun. The circle diameters are proportional to the cube roots of the cloud masses and to the inverses of the cloud distances, and all the clouds are assumed to lie in the Galactic plane. Straight lines from the Galactic center at galactocentric longitudes of 0°, 45°, 90°, and 135° are shown in perspective. The four clouds with masses less than 10^5 $M_\odot$ which are not shown in the figure appear labeled in the spatial maps. The dotted curves are logarithmic spirals shown in perspective; the parameters of the spirals are the same as in Fig. 9.

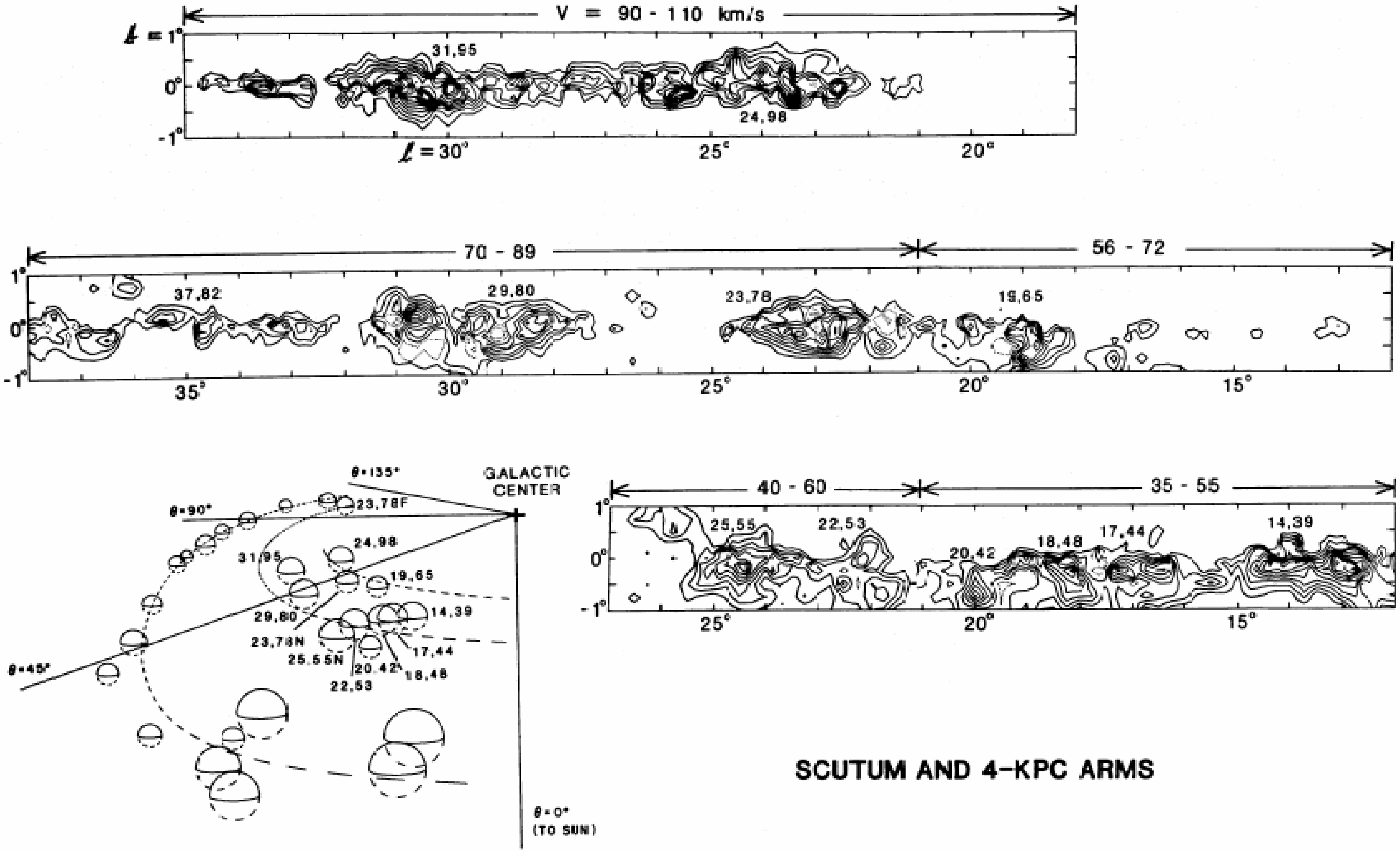
V = 90 - 110 km/s
ℓ = 1°
0°
-1°
31,95
24,98
ℓ = 30°
25°
20°
70 - 89
56 - 72
37,82
29,80
23,78
19,65
35°
30°
15°
40 - 60
35 - 55
25,55
22,53
20,42
18,48
17,44
14,39
θ=135°
GALACTIC
CENTER
θ=90°
23,78F
24,98
31,95
19,65
29,80
14,39
23,78N
25,55N
20,42
17,44
18,48
22,53
θ=45°
θ=0°
(TO SUN)
SCUTUM AND 4-KPC ARMS

FIG. 10b