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A CS J = 2 → 1 Survey of the Galactic Center Region

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We present a CS map of the galactic center region consisting of 15,000 spectra covering $-1.^\circ < \ell < 3.^\circ 6$, $-0.^\circ 4 < b < 0.^\circ 4$, each having an rms noise of 0.15 K in 1 MHz filters. CS is a high-excitation molecule, meaning that it is excited into emission only when the ambient density $<n> \gtrsim 2\times 10^4 \mathrm{cm}^{-3}$. CS emission in the inner 2° of the galaxy is nearly as pervasive as CO emission, in stark contrast to the outer galaxy where CS emission is confined to cloud cores. Galactic center clouds are on average much more dense than outer Galaxy clouds. This can be understood as a necessary consequence of the strong tidal stresses in the inner galaxy.

In a roughly spherical cloud, of radius r_0, at a distance R_0 from the galactic center, consider the gravitational forces on a parcel of gas at a distance r_0 from the cloud center along a line towards the galactic center. If this parcel of gas is bound to the cloud, so that it follows a circular trajectory around the galactic center at a slower-than-orbital velocity, the cloud must exert a gravitational acceleration on it equal to Tr_0, where

$$T \equiv - \frac{\mathrm{d}}{\mathrm{d}R}\left(\frac{v_{circular}{}^2}{R}\right)\Bigg]_{R_0} + \frac{v_{circular\,0}^2}{R_0^2} \approx 2\,\frac{v_{circular}{}^2}{R_0^2}$$

(the rotation velocity $v_{circular}$ is approximately independent of R when 10pc $\lesssim R \lesssim$ 20Kpc). This acceleration is caused by the gravitational pull of the cloud, so that

$$\frac{GM_{cloud}}{r_0^2} \gtrsim Tr_0 \quad .$$

and

$$<\rho_{cloud}> \equiv \frac{M_{cloud}}{(4/3\ \pi r_0^3)} \gtrsim \frac{3T}{4\pi G} \approx \frac{3}{2\pi G}\,\frac{v_{circular}{}^2}{R_0^2} \approx 3.5\times 10^3\ \mathrm{a.m.u.\ cm^{-3}}\left[\frac{500\ \mathrm{pc}}{R_0}\right]^2 \ .$$

The minimum average density of a cloud is a strong function of galactic radius, and clouds near the galactic center must be many times more dense than clouds in the solar neighborhood. Gravitationally bound clouds within about 200 pc of the galactic center must be dense enough to excite the CS J=2→ 1 line.

The virial theorem relates cloud density to cloud size and to the internal pressure. The dominant pressure term is turbulent pressure characterized by a mean square velocity $<v^2>$. Define a mean gravitational radius $<r>$ such that the potential energy $W_{cloud} \equiv -\,GM_{cloud}^2/<r>$. For a spherical cloud where $\rho \propto r^\alpha$, with a sharp edge at r_0, the gravitational radius is related to the outer radius $\frac{r_0}{<r>} = \frac{\alpha+3}{2\alpha+5}$. The virial theorem can then be written as a requirement on the minimum internal velocity dispersion:

$$<v^2> \approx \frac{GM_{cloud}}{<r>} = \frac{4\pi G}{3} <\rho_{cloud}> \left(\frac{r_0}{<r>}\right) r_0^2 \gtrsim 2\ v_{circular}{}^2 \left(\frac{r_0}{<r>}\right)\left(\frac{r_0}{R_0}\right)^2 ,$$

where for ρ_{cloud} we have substituted the tidal limit. This inequality does not impose a very stringent limit on the random velocities internal to outer-galaxy clouds. Most clouds in the outer galaxy have velocities 2 or 3 times bigger than this minimum. For the dense, large clouds in the galactic center, however, it says that a 30 pc cloud 300 parsecs from the galactic center must have a FWHM linewidth of at least 37 km s^{-1} — a typical linewidth for a galactic center cloud. Clouds as large as those we find in the galactic center must have large linewidths, or they will not be in equilibrium and bound against the galactic tide.

Figure 1 — The CS Survey spectra, integrated over 100 km s^{-1} wide velocity ranges, and displayed as evenly spaced contours at 10 K·km s^{-1} intervals. The Sgr A cloud is at $\ell = 0.^{\circ}0$, Sgr B2 is at $\ell = 0.^{\circ}66$, and Clump 2 is at $\ell = 3.^{\circ}0$, $b = 0.^{\circ}4$.