"CO LINE BROADENING BY SATURATION EFFECT IN MOLECULAR CLOUDS"

Jacques R.D. Lépine
Instituto Astronômico e Geofísico
Universidade de São Paulo, Brazil

Abstract

A new discussion of the evidences for turbulences in molecular clouds, taking into account line broadenning by saturation at large optical depths, shows that the generally accepted power law dependence of turbulent velocity with cloud size must be revised.

I. Introduction

After the publication of a paper by Larson (1981), several authors have strengthened the conclusion that molecular clouds exhibit a turbulent behaviour with a power law dependence of the turbulent velocity σ on the size L of the cloud (eg. Leung et al., 1982, Myers, 1983; Henriksen and Turner, 1984). According to Larson, the relation is:

$$\sigma\,(\mathrm{km}^{-1}) = 1.1\ L^{0.38}\ (\mathrm{pc}) \tag{1}$$

We show that although the CO line width data can be fitted by the equation above, this result should not be interpreted as a Kolmogoroff spectrum of turbulence, since line broadenning by saturation must be taken into account.

II. The Model

We consider molecular clouds with constant density and temperature, and a beam filling factor equal to 1. In LTE the profile of a CO line expressed as a function of velocity is given by:

$$T_a(v) = (T - 2.7)\ (1 - \exp(-\tau\ (v))) \tag{2}$$

where T is the kinetic temperature and the optical depth $\tau(v)$ is proportional to the CO column density N:

$$\int \tau\,(\nu)\ d_\nu = \frac{8\ \pi^3 \nu\ \mu^2}{3\,h\,c}\ \frac{[\ 1 - e^{-h\nu/kT}]}{Q}\ N \tag{3}$$

where Q is the partition function, and μ the electric dipole matrix element of the transition. Adopting a gaussian profile, we have:

$$\tau\,(v) = \tau_0\ e^{-(v/\Delta v)^2} \tag{4}$$

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and

$$\int \tau(\nu)\, d\nu = \frac{\nu}{c} \int \tau(v)\, dv = \frac{\nu}{c}\, \pi^{1/2}\, \Delta v\, \tau_0 \qquad (5)$$

where τ_0 is the optical depth at the center of the line and Δv is the Doppler width, which includes the thermal width and microturbulence:

$$\Delta v = \left(\frac{2\,kT}{m} + V_t^{2}\right)^{1/2} \qquad (6)$$

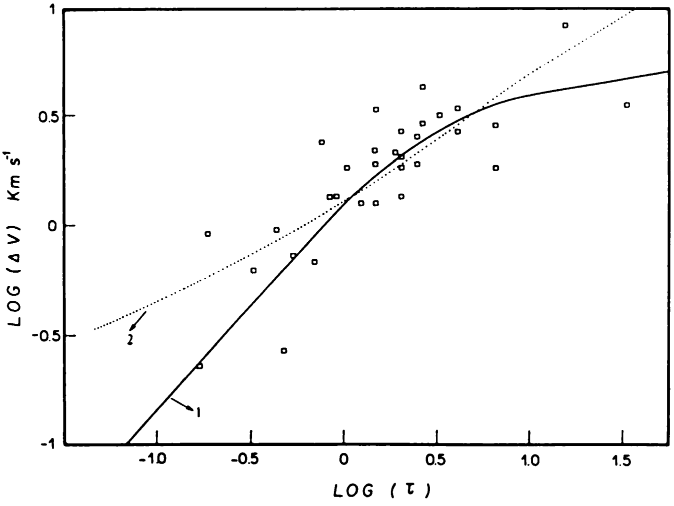
One must pay attention to the distinction between the Doppler width of the absorption coefficient, Δv, and half-linewidth at half-maximum of the line, σ, which includes broadenning by saturation.

In figure 1 we show $\sigma(C^{13}O, j=1-0)$ as a function of optical depth. The data points are the same data collected in the literature by Larson (1981), except that we only keep the $C^{13}O$, data, since different species have different optical depths and thus do not show the same amount of broadenning. We used a density of $5\ 10^3$ H_2 cm^{-3}. in order to scale cloud sizes to optical depths. A single value of the Doppler width does not fit correctly the data (not shown). However if we use a Δv law which first increases linearly with τ and then saturates, such as:

$$\Delta v\ (\mathrm{kms}^{-1}) = 2.5\ (1 - e^{-\tau_0}) \qquad (7)$$

then a good fit can be obtained (curve 1). For comparison we show (curve 2) a fit of the data with a power law of index 0.38.

Figure 1



III. Discussion

We conclude that line broadenning due to saturation cannot explain alone the observed increase of the $C^{13}O$ (J = 1-0) linewidth with the size of the clouds; however, if this broadenning is taken into account, and if for consistency only the $C^{13}O$ data is examined, the turbulence is better described by an expression like equation (7) than a power law. In other words, the Doppler width seems to reach a constant value for large clouds. This is not an unexpected result, if, for instance, the turbulence is produced by localized sources like the winds from embedded young stellar objects. Our result is in better agreement with the regular pattern of the magnetic field often observed in molecular clouds than the Kolmogoroff spectrum interpretation.

References

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