EXCESS LINE BROADENING IN VARIOUS OBJECTS
- A CASE FOR WEAK MAGNETIC EFFECTS

(Letter to the Editor)

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Abstract. I present updated compilations of both observational data and theoretical predictions concerning excess line width and sizes in astrophysical bodies. After removing two well-known broadening mechanisms (thermal width and width due to large scale motions such as expansion), I analyse statistically the excess line width $W_{\text{excess}}$. The excess line width shows a changing behavior with object size $R$, of the form $W_{\text{excess}} \sim R^q$. Taking all objects together, I find that $q = 0.55$ with s.d. = 0.05. This result extends previous studies to cover 5 decades in sizes, from 0.01 pc up to 1000 pc. Taking only objects with $R < 1$ pc, I find that $q = 0.7$ with s.d. = 0.1, while taking only objects with $R > 1$ pc gives $q = 0.5$ with s.d. = 0.1; thus a steeper (not flatter) value of $q$ at small $R$ may be possible. Previous claims to derive a law for objects of sizes $R > 1$ kpc are discussed, in relation to the problem of removing obvious large scale motions from the observed line width. Thus several models with predicted $q$ values between 0 and 1 can be eliminated, and the remaining ones could allow weak magnetic effects on the line widths.

1. Introduction

One of the most important signatures of small scale turbulence is the presence of a spectral line width in excess of (i) the thermal width expected from the gas temperature and of (ii) line broadening due to large scale motions such as expansion. Theoretical attempts have been made since the 1950s to interpret observed excess line widths in terms of small scale turbulence of one kind or another (magnetic or not).

Since the gaseous objects observed are at different temperatures, from cold (10 K) to hot (10$^7$ K), the thermal line broadening differs greatly (0.1 to 130 km s$^{-1}$), and this thermal line width must be removed from the observed line width before the small scale turbulence can be obtained. Similarly, gaseous objects undergoing large scale motions such as expansion have a component of line width due to this motion, which must be removed from the observed line width before the small scale turbulence can be obtained.

The presence of a power-law relation of the form $W_{\text{excess}} \sim R^q$, where $W_{\text{excess}}$ is the excess line width from small scale turbulence, and $R$ is the object size, has been known since the 1970s in both radio molecular cloud studies and in optical H II regions. Discrepancies in the $q$ values arose because of distance uncertainties, limited data sets, limited object sizes $R$, different frequency resolutions, and noise.
The aim of this note is to take a statistical look at this problem, since more recent observations have yielded data with improved quality (increased data sets, better distance determinations, higher resolutions and less noise), and because recent observational data extends to smaller scales. A look is made on recent data on objects with small sizes $R$, which seem to show differences in the exponent $q$, i.e. $q = 0.4 \pm 0.1$ (Falgarone et al., 1992) and $q = 0.7 \pm 0.1$ (Fuller and Myers, 1992).

Section 2 presents a compilation of the observed, thermal, and turbulent line widths in various groups of objects. A statistical analysis follows in Section 3. Section 4 gives a compilation of the predicted model behavior of the excess line width, for various sizes, and a discussion is presented in Section 5.

2. Observational Data on Excess Line Width

2.1. DATA SELECTION

Attempts have been made to find general laws applicable to various types of objects covering many scales in sizes, such as the magnetic field $B$ versus gas density $n$, i.e. $B \sim n^k$, from maser spots to clusters of galaxies (e.g., Vallée, 1990), or the excess line width $W_{\text{excess}} \sim R^q$ from clumps to extragalactic H II regions (e.g., this paper). Gaseous astrophysical objects can be separated according to whether they primarily contain ambient thermal gas (type A) or primarily gas undergoing large scale motions such as expansion (type S). Objects containing primarily large scale motions (type S) have been excluded here, because they contain an additional, identified, line broadening which could be difficult to take out entirely from the observed width (i.e., expanding stellar envelope or interstellar bubble, rotating and expanding ultracompact H II region or disk, moving maser spot, etc).

Various groups of astrophysical objects have been selected here, provided that they contain primarily ambient thermal gas (type A), whose excess line width remains to be identified.

2.2. OBSERVED AND DERIVED WIDTHS

The thermal line widths are obtained from the relation:

$$W_{\text{thermal}} = \left[ \frac{8 \ln 2 k T_k}{(m_a/m_H)} \right]^{1/2} = 0.214 \left( \frac{T_k}{(m_a/m_H)} \right)^{1/2} \text{km s}^{-1},$$

where $T_k$ is the kinetic temperature in kelvins, and $m_a/m_H$ is the atomic mass (in units of the hydrogen atom) of the atom or molecule exhibiting a line width $W_{\text{observed}}$.

The small scale turbulent (= excess) line width is given by the relation:

$$W_{\text{excess}} = \left[ W_{\text{observed}}^2 - W_{\text{thermal}}^2 \right]^{1/2} = \left[ \frac{8 \ln 2 \langle V_t^2 \rangle}{3} \right]^{1/2},$$

where $V_t$ is the equivalent turbulent rms speed; then $V_t = 0.736 W_{\text{excess}}$. The line widths from optical extragalactic H II regions are often given as e-folding widths.