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TURBULENCE IN HII REGIONS

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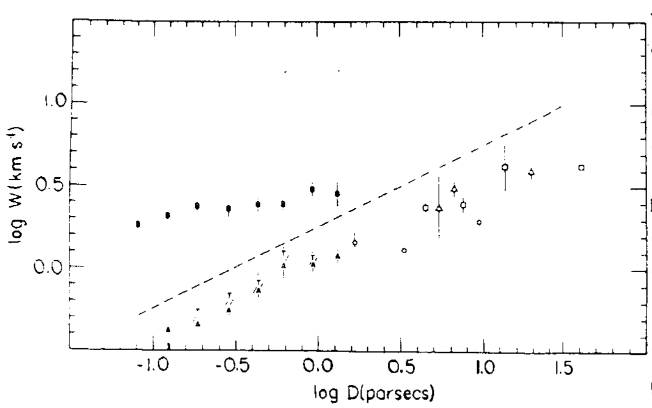
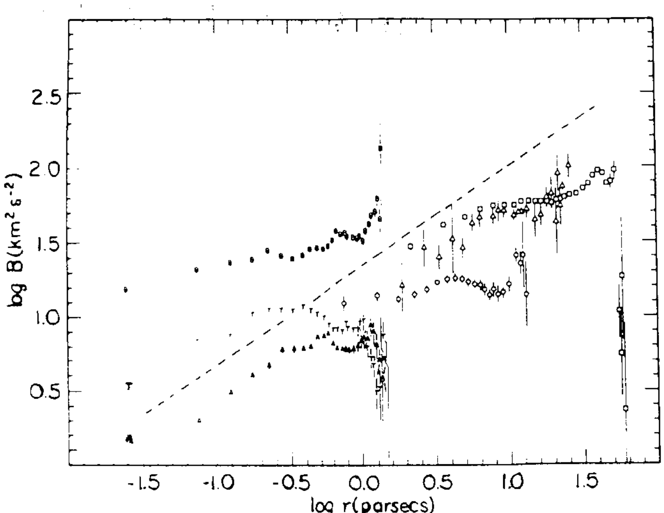
It has been known for many decades that the Reynolds number in HII regions must be very high and that the corresponding fine scale flow must be turbulent. Even though the theoretical relation between turbulent element separation and random velocity ($v \sim r^{1/3}$) was derived by Kolmogoroff over forty years ago, there have been only a few attempts to test this theory and its corresponding assumptions. An attempt by Münch for M42 with marginal velocity resolution lead to ambiguous results, although more recent studies by Jean René Roy and his colleagues have been more credible. My collaborators and I have been systematically studying the internal velocities of a number of HII regions and are now able to test the theory with considerable certainty. The results should be important for the determination of the energy balance of HII regions and the relation of small scale motion to the process of star formation.

Our observations were made with two spectrograph systems. Detailed spectral maps of the entire nebulae were made in the Hα line of NGC 7000 (□) NGC 1499 (o), and S252 (Δ) at an angular resolution of a few arcminutes using an echelle spectrograph, giving velocities accurate to a few km s^{-1}. The higher resolution coude feed system at K.P.N.O. was used to map the inner regions of NGC 6514 (T) and NGC 6523 in the intrinsically narrower [OIII] N1 line to an accuracy of about one km s^{-1} and an angular resolution of a few arcseconds. The data were analyzed by numerically fitting the digitized line profiles to Gaussian line profiles. This could be done for single or multiple line components, all of the above cited nebulae being single except for NGC 6523, which had two velocity systems (A and B). The resulting data for each spectral element was the radial velocity (V), the Full Width at Half Maximum (FWHM), and the intensity of each line. The resulting values are a unique data set of nebular velocities with accurately determined instrumental line widths and dispersions made over a wide dynamic range.

The data were analyzed using statistical methods. The first of these was to determine the r.m.s. dispersion of velocities in samples across the face of each nebula. The average dispersion was determined for that sample size (D) and from that, the most probably turbulent velocity (W). This process was then repeated for a larger sample size, until the entire area mapped was enclosed by a single sample. In its simplest form, where there is no averaging of velocity elements along a line of sight and optical depth effects are unimportant, Kolmogoroff theory would predict $W \sim D^{1/3}$. The results for the several nebulae are shown in the first figure, where a reference line of slope 1/3 is shown. The second method of analysis was to determine the structure function (B), which is $B(r) = \langle |V(r') - V(r'')|^2 \rangle$ where r is the distance between two points on the face of the HII region. Since B is calculated for all possible combinations of data points at each distance of separation, it gives a much more critical determination of the dependence of random motion upon velocity. The results for the structure function are shown in the second figure. The simplest model for the theory predicts that $B \sim r^{2/3}$ and a reference line of slope 2/3 is shown. Where error bars are not shown in either figure it means that the error was less than the symbol size.





The vertical displacement of W and B for various nebulae is what is expected, as the absolute scale of the dispersion of velocities should depend upon the rate at which energy is fed into the system. If the ultimate source of this energy is photoionization, then W should scale as the 1/3 power of the local gas density, so that object to object variations in absolute scale are to be expected.

The slope in all objects does not agree with the expectations of the simplest theories except over only very small portions. In general it is always flatter. A deviation in this direction is difficult to explain, as the effects of compressibility and non-turbulent motion would both produce slopes that are much steeper than the reference values. The most realistic models for HII regions are those of von Hoerner (1951), who predicted FWHM and B for several realistic models. Again, the predicted slope for B was always greater than or equal to 2/3. Another important discrepancy is that the rate of increase of W is such that including the entire HII region would still not reach a velocity sufficient to explain the FWHM, a result similar to that drawn by Münch (1958) for M42. The only published idea for a flat slope is that of Fleck (1983) who argues that such a slope would result from the source of energy entering through the smallest scale velocity elements, rather than the largest, as commonly assumed.

More complete presentations of this work appear in a recent publication (O'Dell 1986a) or papers in press (O'Dell 1986b, O'Dell et al. 1986).

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____________ 1986b, P.A.S.P., in press.

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