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Spatially Resolved H_2O Masers as Probes of Supersonic Turbulence

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Abstract. VLBI of the H_2O maser sources associated with outflows from young stars reveals, besides the regular velocity component (expansion and rotation), a random component suggestive of highly supersonic turbulence generated by the interaction of the star's jets with the quiescent ambient gas. Our analysis of the geometry and velocity statistics in Sgr B2(M)–H_2O demonstrates low fractal dimension of the turbulence and strong deviations of the velocity increments from Gaussian statistics—both indicating strong intermittency of the turbulent energy dissipation. These properties are discussed, along with the two-point velocity scaling law, and compared with the related properties of incompressible turbulence.

A new conception of H_2O masers in regions of star formation is proposed. It associates the smallest clusters of masers with the sites of ultimate dissipation of turbulent energy via shocks in gas surrounding a newly born star. Turbulence is produced by the star's wind or jets. We share the common point of view that the energy of supersonic turbulence dissipates in shock waves, but we hypothesize that in a highly supersonic turbulence (Mach number at the largest scale $\gg 1$), with proper boundary conditions, the bulk of dissipation occurs at some relatively small scale, analogous to the Kolmogorov dissipation scale for incompressible turbulence. We obtain an approximate expression for the dissipation scale η from physical and dimensional considerations:

$$\eta \sim \frac{L}{M_L^3},$$

where M_L is the typical value of the Mach number associated with the largest scale L. The observed size of the smallest H_2O clusters is close to this predicted dissipation scale. We thus suggest that H_2O masers are a by-product of small-scale, moderately supersonic random shocks dissipating turbulent energy. The pumping energy is not imparted to the masing gas blobs directly by the stellar wind, as is the case in most current models. Instead, energy is channeled, by an almost dissipationless turbulent cascade, from the largest scale (which receives energy from the stellar wind or jets) to the small-scale shocks, which pump the masers. If this hypothesis is correct, H_2O masers are an effective tool for studying geometric and kinematic properties of the spatial set on which supersonic turbulence dissipates.

We analyzed the geometry of supersonic turbulence using the VLBI maps of H_2O masers in Sgr B2(M). The distribution of maser emission demonstrates

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crude self-similarity (fractality) over four orders of magnitude in scale, although significant deviations from a single-fractal model are evident. Comparison of the observed maser distribution with homogeneous random model distributions of points supports the hypothesis that the former is fractal. Two measures of fractal dimension D are applied to the maser data set—the mass-radius and the box-counting measures. Although values obtained by these measures demonstrate a systematic difference, both approaches unambiguously show that the spatial set, on which the energy of supersonic turbulence dissipates, has low fractal dimension. We estimate a fractal dimension of $D \approx 0.6 \pm 0.5$, which is significantly lower than that of incompressible turbulence ($D \approx 2.6$). This indicates that supersonic turbulence is "more intermittent" than incompressible turbulence.