A Massive Star Odyssey, from Main Sequence to Supernova
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CFHT Fabry-Perot 2D spectroscopy in Hα of the ejected Wolf-Rayet ring nebula M1-67: universal multifractal analysis and turbulent status

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Using CFHT-SIS Fabry-Perot interferograms of the Wolf-Rayet ring nebula M1-67, we present an investigation of the statistical properties of fluctuating gas motions using structure functions (SFs) traced by Hα emission-line centroid velocities. We consider the SFs $\langle|\Delta v(r)|^p\rangle$ of order p, *i.e.*, the spatially averaged moments of order p of the spatial velocity increments at projected spatial scale r of M1-67's velocity field: we test for (*i*) SF scaling, $\langle|\Delta v(r)|^p\rangle \propto r^{\zeta(p)}$, and (*ii*) nonlinearity of the observed scaling exponents $\zeta(p)$s, as expected for intermittent flows. We find that there is a clear correlation at scales 0.02 - 0.22 pc between the mean quadratic differences of radial velocities and distance over the surface of M1-67. The first and second order SFs are found to scale as $\langle|\Delta v(r)|\rangle \propto r^{0.5}$ and $\langle|\Delta v(r)|^2\rangle \propto r^{0.9}$ (Grosdidier *et al.* 2001). The former scaling law strongly suggests that supersonic turbulence is at play in M1-67, on the other hand, the latter scaling law agrees very well with Larson-type laws for velocity turbulence. Additionally, we can discuss the nature of the turbulence in terms of Universal Multifractals (UM), a continuous-scale limit of multiplicative cascades (Schertzer & Lovejoy 1987) and derive the level of intermittency in the nebula. The function $\zeta(p)$ is found to be nonlinear and well reproduced with the following UM parameters: $\alpha \simeq 1.91$ (the field is highly multifractal) and $C_1 \simeq 0.04$ (the field suffers small intermittency):

$$\zeta(p) = p \times \zeta(1) - C_1(p^\alpha - p)/(\alpha - 1).$$

Figure 1 shows the exponents $\zeta(p)$ along with the best UM fit. Our results on the planetary nebula NGC 40 (Grosdidier *et al.* 2002) led to the same level of multifractality ($\alpha \simeq 1.9$ - 2) but with larger intermittency ($C_1 \simeq 0.08$). On the whole, such a study provides a way to quantify turbulence in ejected nebulae (with potential implications for the estimation of temperature fluctuations) and give insight on astrophysical turbulence for its own sake.

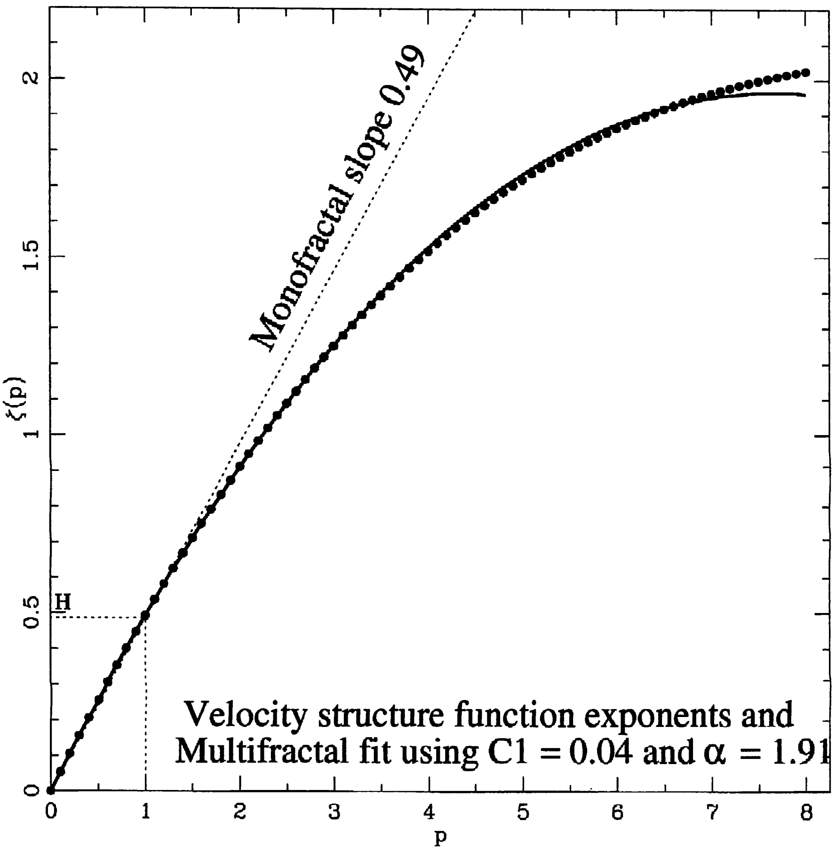

Figure 1. Velocity structure function analysis of the WR ring nebula M1-67. The corresponding $\zeta(p)$ function (dots) demonstrates the multiaffinity of M1-67's velocity field. A Universal Multifractal fit is also shown as a solid curve.

References

Grosdidier, Y., Moffat, A.F.J., Blais-Quellette, S., *et al.* 2001, ApJ 562, 753

Grosdidier, Y., *et al.* 2002, in: M. Dopita, S. Kwok & R.S. Sutherland (eds.) *Planetary Nebulae: Their Evolution and Role in the Universe*, Proc. IAU Symp. No. 209 (San Francisco: ASP), in press

Schertzer, D., Lovejoy, S. 1987, J. Geophys. Res. 92, 9693