Self-similar regimes in Unstably Stratified Homogeneous Turbulence

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In many problems, the initial distribution of energy at large scale influences the late time dynamics of turbulent flows. A classical illustration of this phenomenon is the self-similar decay of homogeneous isotropic turbulence (HIT) in which the decay rate, as shown first by [1], depends on the properties of large scale eddies. This effect has been also identified in more complex flows such as buoyancy induced turbulence [2]. Quite recently in [3], these ideas were transposed to a new problem, how to evaluate the growth rates of self-similar regimes in unstably stratified homogeneous turbulence (USHT). Therefore, assuming that the infrared spectrum representing large scale properties in the kinetic energy spectrum $E(k)$ scales as $\sim k^s$, the kinetic energy $\mathcal{K}(t)$ evolves self-similarly at late time t as $\sim e^{\beta N t}$ with N the buoyancy frequency (similar to Brunt-Väisälä frequency in stably stratified flows). A strong result of the theory is that the growth rate coefficient β is related to the infrared slope as:

$$\beta = \frac{4}{s+3} \text{ for } s \leq 4. \tag{1}$$

Unfortunately, it is hard to confirm these predictions as the self-similar states of USHT are generally difficult to observe. For instance, an important characteristic of USHT is the growth of the integral scale which at late time generally induces confinement effects in experiments [4] and direct numerical simulations [5]. In order to deal with this issue, we propose to follow [7] idea for HIT by employing an EDQNM model to explore the dynamics of USHT. Still, the context of USHT is quite different from HIT, particularly because the turbulence is strongly anisotropic. This requires a significantly more complex EDQNM model which in this work follows the formalism introduced for axisymmetric turbulence. It has been successfully compared to various USHT direct numerical simulations (DNS) at moderate Reynolds number with different initial conditions accounting for intensity of mixing and strength of the acceleration [6]. By studying self-similar states of USHT, we expect to gain a better insight into buoyancy induced turbulence which has many practical applications such as Rayleigh-Taylor mixing.

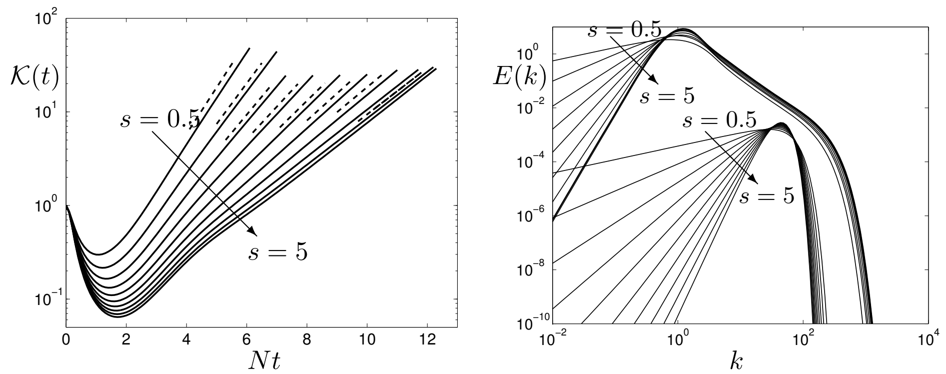

Fig. 1: (Left): Time evolution of the kinetic energy. Each curve corresponds to different initial infrared exponent s. The slopes for the different dashed straight lines corresponds to the theoretical β of Eq. (1). (Right) Spectra of kinetic energy at initial time and at a given turbulent Reynolds number ($\simeq 46000$). Initial conditions have been divided by a factor 10 to fit correctly in the figure.

References

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