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Gravity-capillary wave turbulence

Turbulence d'ondes de gravité-capillarité

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ABSTRACT

We study wave turbulence of capillary-gravity waves nonlinearly interacting at the surface of a fluid layer. The statistical properties of the deformation of the interface are analyzed and compared to theoretical predictions. We report the phenomenon of intermittency and study the fluctuations of the energy flux driving the waves. Experiments in parabolic flights are performed in order to study the pure capillary regime without being perturbed by the effect of gravity.

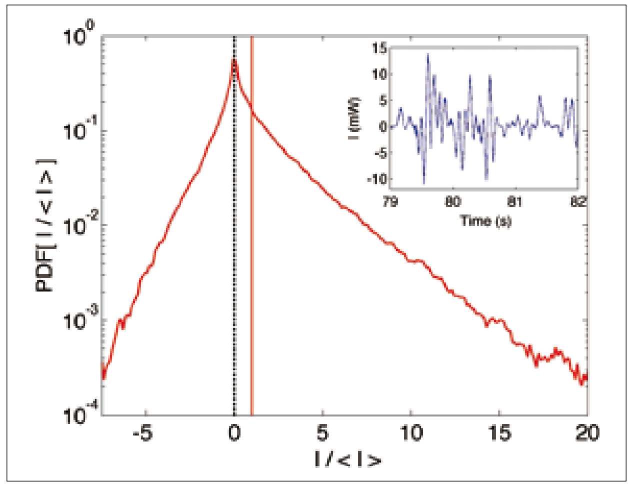
Nous étudions la turbulence d'ondes résultant de l'interaction non linéaire entre ondes de gravité-capillarité à la surface d'un fluide. Les propriétés statistiques de la déformation de la surface sont analysées et comparées aux prédictions théoriques. Le phénomène d'intermittence est mis en évidence ainsi que les fluctuations du flux d'énergie alimentant les ondes. Des expériences en vol parabolique permettent d'étudier le régime d'ondes capillaires sans l'effet parasite de la gravité.

Wave turbulence concerns the dynamical and statistical properties of an ensemble of weakly interacting nonlinear waves. Examples involve, waves on the ocean, Alfven waves in the solar wind, radar waves in the ionosphere, spin waves in solids, etc. The first analytical studies of wave turbulence have been performed in order to predict the spectrum, i. e., the distribution of the energy of the fluctuations as a function of wavenumber or frequency. It has been understood since the early seventies, that besides equilibrium spectra (similar to the blackbody spectrum in statistical physics for instance) nonlinearly interacting waves also involve spectra that correspond to the transfer of a finite energy flux from large scales to small ones. These stationary out-of-equilibrium solutions are similar to the Kolmogorov description of hydrodynamic turbulence. However, in the case of interacting waves, they can be computed analytically using perturbation methods. A lot of data obtained by remote sensing of the atmosphere or the ocean as well as satellite measurements in astrophysics, have thus been analyzed using the framework of wave turbulence. However, very few laboratory experiments have been performed on the subject so far.

We have studied capillary-gravity wave turbulence. A disturbance of the interface between a liquid and air propagates as a wave because of the restoring forces due to gravity and capillarity. The former is dominant at large scales and the later at small ones. Microgravity experiments allow the study of pure capillary waves on the whole range of scales of the experiment. They have been performed using parabolic flights. A reduced gravity environment also allow to study a spherical geometry with a layer of fluid on which waves can propagate without being reflected by lateral boundaries *(see fig. 1)*. The spectra of the wavy fluctuations have been measured both in microgravity and in laboratory experiments. A good agreement with theory has been observed for capillary waves but not for gravity waves. It has been also found that gravity waves are intermittent, i. e. the statistics of velocity increments of the interface are strongly non Gaussian at small scales.

The key governing parameter of wave turbulence is the energy flux that drives the waves, cascades to small scales through nonlinear interactions and is dissipated by viscosity. It has been measured for the first time in laboratory experiments. Fluctuations much larger than the mean value have been observed *(see fig. 2)*. In addition, instantaneous negative energy flux events (for which the waves give back energy to the driving device) occur with a fairly large probability. Taking into account these fluctuations in theoretical models of cascades remains an open problem.

(Fig.1) Surface waves generated inside a spherical container made of glass during a parabolic flight. The fluid inside the sphere wets the surface and forms a layer along the inner boundary of the sphere. Waves are generated by vibrating the container.



(Fig.2) The time recording of the energy flux, I, driving the waves is shown in the inset. Its probability density function displays two exponential tails. Their asymmetry is related to the mean flux <I> (full vertical line). Note that the fluctuations are much larger than the mean.

There are several issues for carrying further research on wave turbulence: first at the fundamental level, where a statistical description of out-of-equilibrium systems is still missing, wave turbulence is a domain where a lot can be understood by using the tools of both statistical and nonlinear physics. Second, many technological devices are concerned with transport properties of waves. It is known for instance that one of the problems to solve in order to operate nuclear fusion devices is related to the high transport associated with turbulent waves. At much smaller scales, transport of carriers in semiconductor lasers has been also handled using theoretical tools of wave turbulence transposed to quantum statistics. Third, transport of energy is also mediated by waves in many astrophysical and geophysical situations: Alfven waves in the solar wind, Rossby waves in the Earth atmosphere, or internal waves in the ocean, etc. A better understanding of these processes is necessary to develop more accurate climate models or marine renewable energy such as ocean wave energy for instance. In addition, satellite measurements of the Earth and other planets provide more and more data that need to be analyzed and the concepts and tools of wave turbulence that are widely used, need to be developed further.

• References :

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