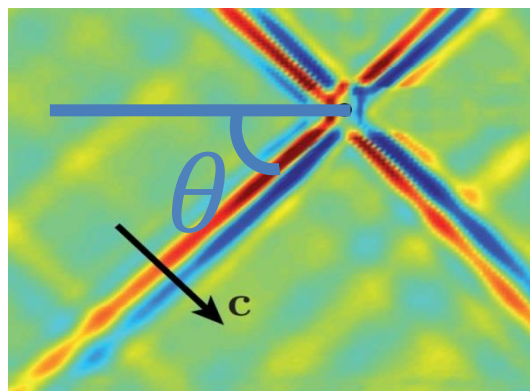


La turbulence en rotation est-elle une turbulence d'ondes?

A. Campagne, B. Gallet, F. Moisy, P.-P. Cortet

Une onde d'inertie

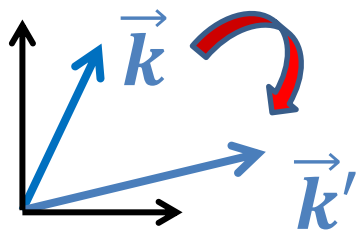


Modèles de turbulence d'ondes d'inerties

Superposition d'ondes d'inerties en interactions faiblement non-linéaire

$$\mathbf{u}(\mathbf{x}, t) = \sum_{\mathbf{k}, s_{\mathbf{k}}=\pm 1} B_{s_{\mathbf{k}}}(\mathbf{k}, t) \mathbf{h}_{s_{\mathbf{k}}}(\mathbf{k}) e^{i(\mathbf{k} \cdot \mathbf{x} - \sigma_{s_{\mathbf{k}}} t)}$$

Prédictions



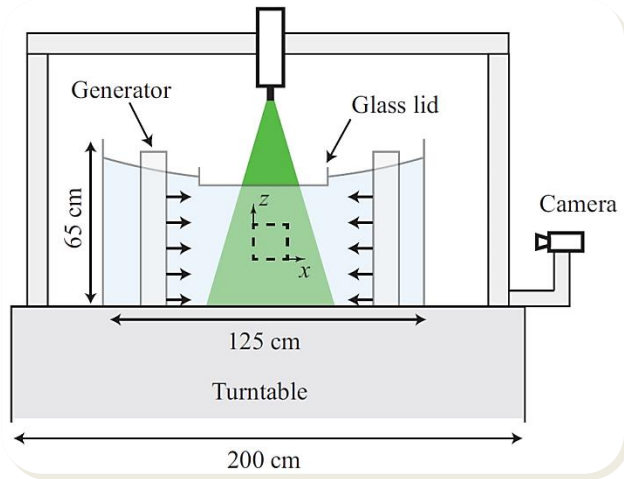
- Spectres d'énergies anisotropes $E(\vec{k}) \sim k_{\perp}^{-5/2} k_{\parallel}^{-1/2}$
- Transferts d'énergies anisotropes
- ...

La turbulence d'ondes est-elle un bon candidat pour décrire la turbulence en rotation fortement non-linéaire?

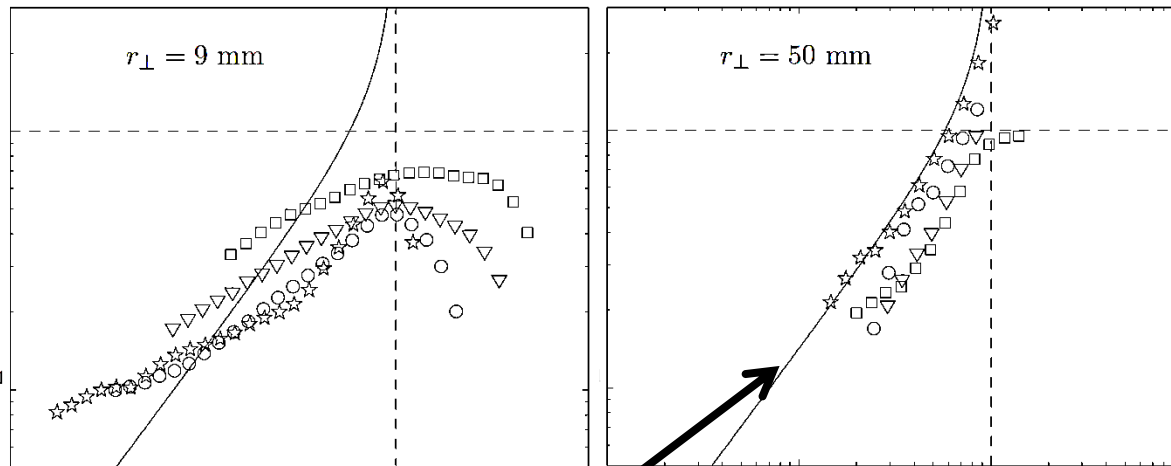
Turbulence forcée en rotation

Turbulence forcée en rotation

Mesure des 3 composantes de la vitesse dans un plan vertical
 => Analyse spatio-temporelle dans le but de détecter des ondes à travers leur relation de dispersion



Résultats



Relation de dispersion

Is rotating turbulence a wave turbulence?
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1. Motivations:

- Turbulence
- Rotation
- Stratification
- Magnétisme
- Thermal convection

Geo/astrophysical flows =

$\partial_t \vec{u} + (\vec{u} \cdot \nabla) \vec{u} = -\frac{1}{\rho} \nabla p - 2\vec{\Omega} \times \vec{u} + \nu \nabla^2 \vec{u}$

$Ro = \frac{U}{\Omega L} \sim \frac{(\vec{u} \cdot \nabla) \vec{u}}{2\vec{\Omega} \times \vec{u}} \quad Re = \frac{UL}{\nu} \sim \frac{(\vec{u} \cdot \nabla) \vec{u}}{\nu \nabla^2 \vec{u}}$

2. Inertial Wave turbulence theory $Ro \rightarrow 0$

Inertial Wave $\sigma_i = \frac{\sigma}{2\Omega} = \frac{k_z}{|k|} = \cos \theta$

Superposition of 3D inertial waves in weakly non-linear interaction

- Predictions for energy spectra $E(k) \sim k^{-5/2} k^{-1/2}$
- Direct anisotropic energy cascades that brings energy towards more vertically invariant modes
- No transfer towards an exactly 2D mode

Real flows: $Ro \sim 10^{-2}$ to 1

- Inertial waves + coherent classical turbulent structures
- Growth of an energetic 2D mode
- Interaction between 2D mode and 3D waves

Is wave turbulence relevant to describe rotating turbulence?

3. Experimental setup

We generate a stationary turbulence on a turntable:
 $\Omega \in [2, 16] \text{ rpm}$
 $Ro \in [0.07, 0.3]$

We measure the vorticity field in a vertical plane of the rotating frame

4. Spatio-temporal analysis

$R(\vec{x}, \sigma) = \frac{2\pi}{T} (\vec{u}_i(\vec{x}, \sigma) \cdot \vec{u}_i^*(\vec{x} + \vec{R}, \sigma))_{\vec{x} \perp \vec{e}_z} + c.c.$

$\vec{u}_i(\vec{x}, \sigma) = \frac{1}{2\pi} \int_0^T \vec{u}_i(\vec{x}, t) dt$

$\Omega = 16 \text{ rpm}$

$\sigma = 0.1 \text{ rad s}^{-1}$
 $\sigma = 0.041$
 $\sigma = 2.4 \text{ rad s}^{-1}$
 $\sigma = 3.3 \text{ rad s}^{-1}$
 $\sigma_0 = 0.06$
 $\sigma_0 = 0.06$

Anisotropy factor

$A(\sigma) = \frac{r_{\perp}}{l_i(r_{\perp}, \sigma)}$ with $R(l_i, \vec{u}_i, \sigma) = R(\vec{r}_i, \vec{u}_i, \sigma)$

Prediction for an assembly of inertial wave $A = (\frac{r_{\perp}}{r_{\perp}^2 - l_i^2})^{1/2}$

Theoretical prediction

Prediction fails at small scales

5. Sweeping effect

Wave with intrinsic frequency $\sigma_i \Rightarrow \sigma = \sigma_i + \vec{k} \cdot \vec{U}$

Wave with large scale flow \vec{U}

Dimensional analysis gives $\sigma \approx \frac{2\Omega}{\sqrt{1+2A^2}} + C \frac{U_{rms}}{r_{\perp}}$

We obtain $N = \frac{2\Omega r_{\perp}}{U_{rms} \sqrt{1+2A^2}} \approx \frac{1}{2} + C$ with $S = \frac{U_{rms}}{\sigma_i r_{\perp}}$

Waves of small scale and frequency are subjected to an intense sweeping by the large-scale 2D mode.

The growth of a large-2D vortex mode is a robust feature of rotating turbulence

\Rightarrow Sweeping is inevitable and not considered by wave turbulence