

# Training Period + PhD Proposal

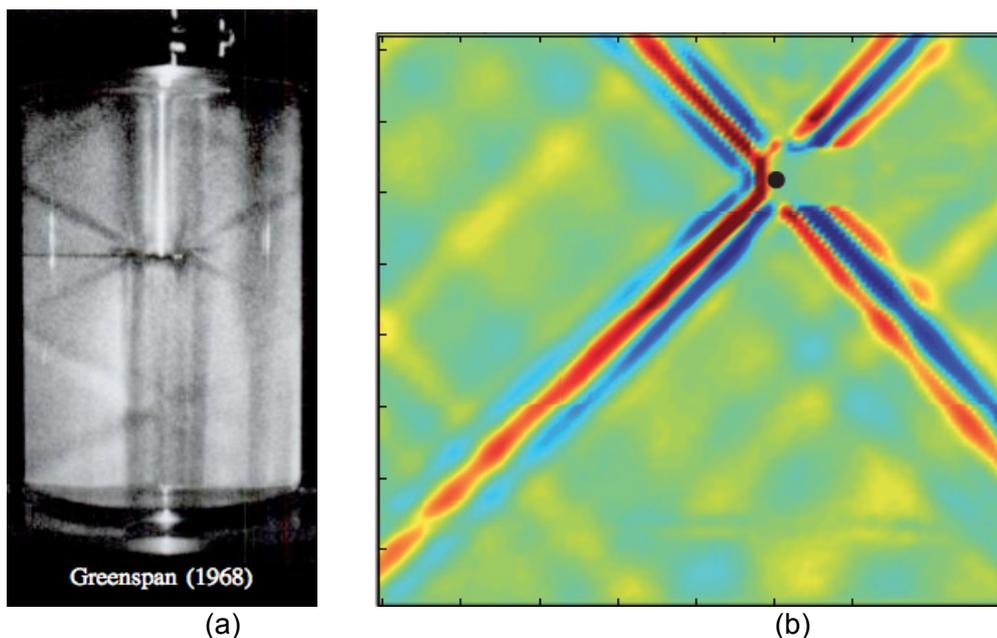
## Internal shear layers in rotating and stratified fluid

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Stratified and/or rotating fluids support waves that can transport and dissipate energy away from their sources. These waves are suspected to play an important role in atmospheric sciences, oceanography, and in the dynamics of stars and planets. In the atmosphere, they transport momentum from the convective regions to the high altitude regions where they break and create meanflow circulation. In the ocean, they are mostly generated by tide and winds and are expected to provide the missing contribution to the global energy budget of the ocean. In planets and stars, they are excited by gravitational effects or convection and could play a role in the generation of zonal flows [1] and in dissipative processes [2].

In a fluid, rotating with the rotation rate  $\Omega$  around the axis  $Oz$  and stably stratified with a constant buoyancy frequency  $N$  along the same axis, an harmonic forcing excites waves when its frequency  $\omega$  is in the inertia-gravity interval  $\min(N, 2\Omega) < \omega < \max(N, 2\Omega)$ . These waves propagate along cones (in 3D) or plane (in 2D) with a fixed angle  $\alpha$  with respect to the horizontal plane given by  $\sin^2\alpha = (\omega^2 - 4\Omega^2)/(N^2 - 4\Omega^2)$ . The cone (or the plane) tangent to the oscillating object or to a local topographical feature corresponds to a singular surface across which the wave field changes of nature. The singularity of the wave field across these surfaces if smoothed by viscosity gives rise to thin internal shear layers which possess some generic features [3,4]. These internal shear layers are for instance visible when oscillating a small object as they form the familiar St Andrews cross pattern (see figure).



**Figure:** St Andrews cross pattern obtained by oscillating an object in a rotating fluid. (a) is from [5], (b) is from [6].

So far, most of the asymptotical works have concerned open geometries. The goal of the thesis is to take into account the boundaries on which the internal shear layers are reflected. We shall first analyse the viscous structure of internal shear layers close to a boundary. Then, configurations where the internal shear layers form a close structure after several boundary reflections will be studied. Finally, we shall also consider the situation where the internal shear layer is an attractor [7]. In each configuration, both the harmonic structure and the meanflow corrections will be calculated using asymptotic methods.

Possibilities to pursue the work experimentally and/or numerically will be proposed.

#### **Références :**

- [1] TILGNER, A. 2007 Zonal wind driven by inertial modes. *Phys. Rev. Lett.* **99**, 194501.
- [2] OGILVIE, G. I. & LIN, D. N. C. 2004 Tidal dissipation in rotating giant planets. *Astrophys. J.* **610**, 477–509.
- [3] THOMAS, N. H. & STEVENSON, T. N. 1972 A similarity solution for viscous internal waves. *J. Fluid Mech.* **54**, 495–506.
- [4] LE DIZES, S. 2015 Wave field and zonal flow of a librating disk. *J. Fluid Mech.* **782**, 178-208.
- [5] GREENSPAN, H. P. 1968 *The Theory of Rotating Fluids*. Cambridge University Press.
- [6] CORTET, P.-P. LAMRIBEN, C. & MOISY, F. 2010. Viscous spreading of an inertial wave beam in a rotating fluid. *Phys. Fluids* **22** 086603.
- [7] MAAS, L. R. M., BENIELLI, D., SOMMERIA, J. & LAM, F.-P. A. 1997 Observation of an internal wave attractor in a confined, stably stratified fluid. *Nature* **388**, 557–561.

**The candidate should possess basic knowledge of fluid mechanics, a strong interest in fundamental research and a solid mathematical background. Applications should be sent to:**

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