Département de Physique
École normale supérieure

Normale Physics Review

Fights Bohr-dom

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Édito N_9: La newsletter physicienne pour Normaliens confinés

Chères physiciennes, chers physiciens, chers lecteurs curieux,
Voici la 9ème édition de la Normale Physics Review ! Je dédie mes premiers mots à tous ceux (enseignants, chercheurs, doctorants, étudiants) qui ont un jour participé à l'écriture de la NPR. Un grand merci à vous pour votre partage ! J'en profite pour lancer un appel à tous ceux qui voudraient également contribuer à ce projet, n'hésitez pas à nous contacter, nous accueillerons votre aide avec grand plaisir ! Cette newsletter ayant pour but de mettre à l'honneur l'esprit de groupe du département, l'effet n'en sera que meilleur s'il est issu d'un effort collectif. Aux M1 partis vers d'autres horizons et qui manquent tant au département, nous espérons que vous prenez du plaisir en stage ! Aux phy20 qu'aucun confinement n'arrête et qui cette semaine n'auront pas la chance de visionner les vidéos du célèbre Youtuber F. Chevy, ni celle de se faire prendre sur son téléphone en physique du solide, nous souhaitons de merveilleux partiels ! Enfin je finirai par un hommage à cette brave Conf IV au tableau rebelle (qui avait l'avantage de réveiller les étudiants les moins matinaux). Celle-ci va être complètement rénovée avec une bonne partie du département à compter des vacances. Bonne semaine, bonnes vacances d'avril et bonne lecture à tous !
(E.Foucher)

[Announcements]

- The M1 are currently updating their trombinoscope. If you want to update your picture please tell **Guillaume de Rochefort** by email at : guillaume.de.rochefort@ens.psl.eu
- **Photo d'intrication :** Que se passerait-il si tous les élèves de L3 apparaissaient en même temps sur une seule photo ? Tentez l'expérience pour élucider ce mystère !
- Congratulations to Stéphane Perrard for his new position at CNRS.

[Class' life]

Online lectures

Last year, French Universities knew a revolution. Since Mid-March and for at least 4 Month, students leaved halls and get full lectures online. This situation was obviously novel for everyone, including teachers who had to convert themselves in a hurry to new format of teaching. Newness of the thing gave us funny sequences bringing a glow of happiness in this particular times. Among foolish set-up, crazy moments or remarkable adaptation we would like to share you some schoolboy anecdotes !

First online lecture and the scallop shell dance

Our first physics online lecture was hydrodynamics, taught by M. Frédéric Moisy. Maybe to pursue the feelling of a "real" lecture, he chose to film himself writing on a blackboard. Seemed to be a great idea. Nevertheless the bandwidth was not right with this and just grant the student pixelated hieroglyphs. Another detail : ENS blackboards are really nice for their huge size. This was not the case this day. To represent how we suffered the image of the teacher making the brush following the chalk, leaving a span of a few second to see what was writing.

But they were funny -unexpected- moments. We were working on low Reynolds number flows. More precisely we discussed about questions of reversibility and how it should impact the motion of micro-organism in this kind of fluid. As you might know, Purcell gave the *Scallop theorem* claiming that in such fluids, time-symmetric motion could not achieve net movement. And the motion of the scallop which close and open during one period is not sufficient time-symmetric (so is not sufficient to perform motion in low Reynolds number flows). In order to give a clear representation of the scallop motion the teacher grant us a great (-I mean, the greatest-) mimicry of the scallop's motion ! In front of this surprise we were many to laugh uncontrollably !

Thank you M.Frédéric Moisy for all your investment during this particular period !

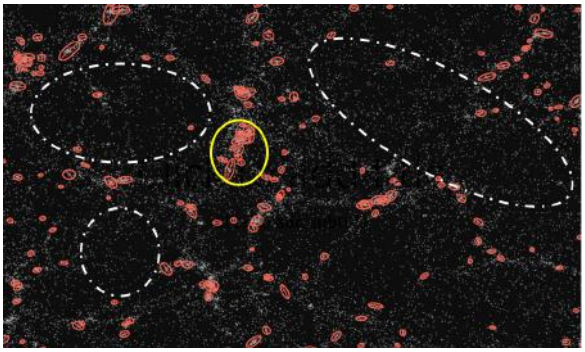

Figure 1 – *Large scale structure of the Universe from the Horizon simulation. Red ellipses : galaxies and their shapes. White dash : cosmic voids, almost no galaxy inside. Yellow : clusters of galaxies.*

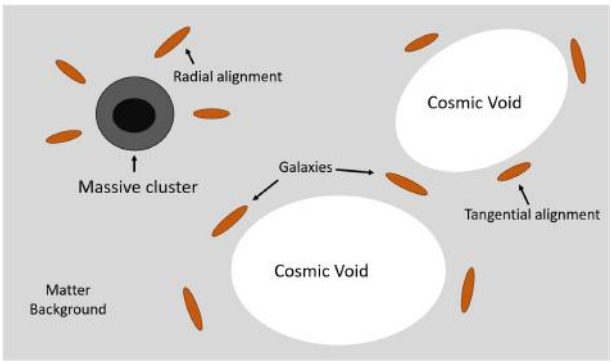

Figure 2 – *Intrinsic alignment behaviours. Galaxies align radially near massive clusters, and tangentially near voids. The effect is exaggerated, because in reality it is not visible to the eye.*

[Physicists' life]

M1 intership : gravitational effect of cosmic voids

I did my M1 internship in cosmology, at Utrecht university, Netherlands, and then in France in 'télétravail' under the supervision of Elisa Chisari. First, I have been impressed by the department of theoretical physics of Utrecht University, which is known worldwide for its excellence. So I would recommend you to go there for the work, but not for social activities, inhabitants are not very friendly with foreigners, but maybe I didn't stay long enough.

The subject of my internship was the study of the intrinsic alignment of galaxies around cosmic voids. Let us clarify the various terms. Cosmic voids are very large regions in the universe ($\sim 150\ .10^6$ light years), with a very low density of matter (see Figure 1). The intrinsic alignment of galaxies is the analogue of the tidal effect of the moon on earth : due to variations of the gravitational field, galaxies are subjected to tidal forces, which modify their shapes. We know for example that near a massive cluster, galaxies are stretched in the direction of the cluster. The subject of the internship is therefore to evaluate the effect of cosmic voids on the deformation of galaxies.

Why is it interesting ? I will give you few reasons, but there are many others. Galaxy intrinsic alignment is an active field of research in cosmology, because it is a tracer of dark matter density region. Maybe you are familiar with weak lensing survey which investigate the distribution of dark matter : intrinsic alignment is a source of errors for these studies, so it has to be removed during the analysis. Last but not least, the study of intrinsic alignment around cosmic void is a tool to check some properties of cosmic voids as their matter distribution, and their emptiness.

It may seem strange to study the gravitational effect of empty regions. We can make an analogy to better understand what is happening, with a well known electromagnetism problem : the problem of the field generated by a positively charged ball, which has a hole inside. The trick to solve this problem is to apply Gauss's theorem twice, once to the positively charged ball (without the hole), and once to the hole, as a negatively charged little ball, which by superposition gives a neutral hole inside a charged ball. The effect of the hole is the one of a negatively charged ball. Here it is the same process, the gravitational effect of a cosmic void is the same as a region that would contain a negative mass of matter. We therefore expect the galaxies to not align tangentially to the direction to the void (the galaxy is compressed, see Figure 2).

My internship consisted of two parts. During the first one, I developed more or less complicated models to quantify the effect we intuitively deduced in the previous paragraph. A very important and often used object for these kind of study, is the correlation function :

$$\xi(\vec{r}) = \langle \delta_v(\vec{x}) \gamma_+(\vec{x}+\vec{r}) \rangle_x,$$

where we average over the whole space $\langle \rangle_x$, the void distribution $\delta_v(\vec{x})$ which is 1 if x is the position of a cosmic void, 0 otherwise, and the field which quantifies the shapes of galaxies $\gamma_+(\vec{x}+\vec{r})$ (there is a value $\gamma_+^i(\vec{x}_i)$ for every galaxy i, so one has a discrete function, and then one considers the continuous limit, which is a field). In practice with data, it is a class of objects that can be directly calculated, because we have access to void positions, galaxy positions and shapes. Of course I do not mention many details and difficulties.

Once the models were developed, and some predictions were obtained (3 months), I used data catalogs to measure this correlation function (2 months), and study the compatibility with my prediction (1 month of analysis). The calculation of the correlation function with real data remains complex, because to observe this kind of weak effect, one needs huge amounts of data, typically 500 000 galaxies, and with naive algorithms, the code can run for several months (it is even

worst because you have to check your code with some data generated randomly, and usually one uses 10 000 000 'random' galaxies). K-mean algorithm has been helpful to optimize the code and the correlation : you sort data into convex clusters, and compute the correlation between voids of a given cluster and galaxies of this clusters and its neighbors ! There are also some procedures specific to cosmology, as the Jackknife method to quantify error bars, that need to be implemented.
In the end we found a weak and noisy effect, but still promising, and we hope to publish my results soon, but a first article is always difficult to write ! (**William d'Assignies Doumerg** - M2 student)

Sir, I have a question

Vous êtes khôlleur ou tout simplement curieux ? Peut-être trouverez-vous dans les questions suivantes un problème ouvert intéressant. Vous observez un phénomène étrange ? Arrêtez de regarder *The Lupin* et envoyez-nous une question (adresses mail en fin de review) !

I : How much time is needed for a plastic bottle to degrade ? And for a banana peel ? ;

II : What is the size of a shoal of fish in function of the relevant parameters ? ;

III : Can you fit the map of all French rivers with a fractal graph given the upspring and the outsprings ? What could be its dimension ? ;

IV : How much power could you retrieve from all rivers in France at an instant t ? Could you replace some nuclear reactors with this power ? ;

V : To what distance can we see a big object trough the atmosphere ? ;

VI : With dimensional arguments, find Stefan's Law ($P=\alpha T^4$). ;

VII : If we wrapped our phone into aluminium foil, would it still be connected ? ;

VIII : Set an homogeneous ball of matter only driven by gravitational interaction. Show that it will stay homogeneous when it collapses. ;

IX : How does work a metronome ? ;

X : Could you estimate the energy of the electronic bound in H_2 ? What is the energy density of hydrogene fuel ? Compare it with gas ? ;

Thanks to **G.Rochefort, L.Brivady, E. Foucher, R. Orageux & B. Dhote**

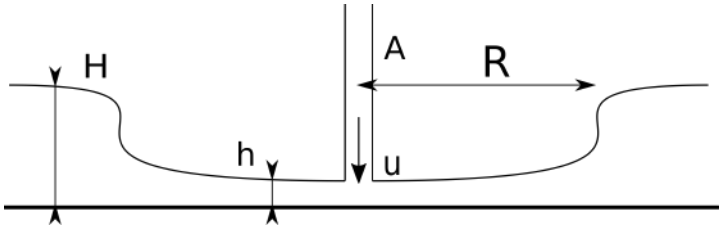

Figure 3 – *Situation sketch*

About the previous questions...

Question II of N_7

When you're doing the dishes or in your bathroom, you might observe something that became usual for us : open a tap, see the pattern at the bottom. There is a disk with a radius depending of the flow, where the water level is dramatically smaller than at the boundary. It seems to be no water in it. The main aim of physicists is in my opinion to ask relevant questions on this lambda phenomenon and emulsify a lot of stuff around it. Such that this banal picture reveals a (no-surprisingly) complexity.

i. Description

In this question, we want to describe the evolution of the radius R of the disk depending of $q = A\,u$ the volumic flux (taken before the bottom- A is the beam area and u the mean speed of the turbulent flow). The level of water goes from h to H at the radius R. The fluid viscosity is ν (m/s^2) - see Fig 3.

Let's have a short qualitative description of this phenomenon. This is an example of a common phenomenon observed in open surface flow, the hydraulic jump. When the velocity of the flow decreases and the water level increases. The kinetic energy is converted into potential energy and there is loss due to turbulence. We can define the hydraulic charge for the flow (mean speed v and height h) :

$$E = 1/2v^2 + gh \tag{1}$$

To compare the "relative contribution" of the two kind of energy, one can define the *Froude number* :

$$Fr = \sqrt{\frac{v^2}{gh}} \tag{2}$$

$Fr > 1$ is called a super-critical flow, $Fr = 1$ a critical one and $Fr < 1$ a sub-critical. For a critical *Froude number*, the flow is maximal. In our situation, we might go from a sub-critical flow to a super-critical one.

Then this question : why the fluid is going from a state to the other ? An explanation might lies in energy dissipation.

[1] measured that the hydraulic jump (in our case) occurs when the viscous boundary layer is roughly equal to the height. As in the case of *tip-top* (you know, this small spinning top which surprisingly tip), the system tends to adopt a configuration which minimizes dissipation. We will use the following hypothesis in our computation : when the viscous layer (scaling as $\delta(x) = \sqrt{\frac{\nu x}{v}}$) is equal to the water level h, the hydraulic jump occurs.

We will resume the approach of [2]. Here, the viscous dissipation is assumed to be negligible (since there is a viscous layer) in the disk. Then, using the mass conservation, at a radius r, the rate of flow $2\pi rh$ is equal to the initial one Au. Then, one finally gets :

$$h = \frac{A}{2\pi R} \tag{3}$$

Then using the hypothesis from [1], one gets : $h = \sqrt{\frac{\nu R}{v}}$. Leading to :

$$R = \frac{q}{2\pi(\nu R v)^{1/2}} \Rightarrow R \propto v^{1/3}\nu^{-1/3} \tag{4}$$

The radius is likely to scale as $v^{1/3}$, following experimental results of [2]. **L.Brivady**

ii. Post-scriptum

Hydraulic jumps are widely studied experimentally because they provide strong analogy with general relativity. When you study the dispersion of waves, you could see that in the disk, no wave propagates. Thus, an analogy between white holes and circular hydraulic jumps is studied -see [3].

iii. References

[1] Robert P. Godwin *The hydraulic jump ("shocks" and viscous flow in the kitchen sink)*, American Journal of Physics 61, 829 (1993) ;

[2] Bréchet, Yves & Néda, Zoltán. (1999). On the circular hydraulic jump. American Journal of Physics. 67. 723-731 ;

[3] Gil Jannes and Germain Rousseaux *The circular jump as a hydrodynamic white hole*, Chapter V from *Analogue Gravity*. SIGRAV Graduate School on Contemporary Relativity and Gravitational Physics, IX Edition, Como (2011) (Springer, 2013).

Mystery photo

Mystery photo of N_9

The mystery photo of our current edition is shown on Fig. **??**. Could you guess what is it ? We warmly thanks for this picture !

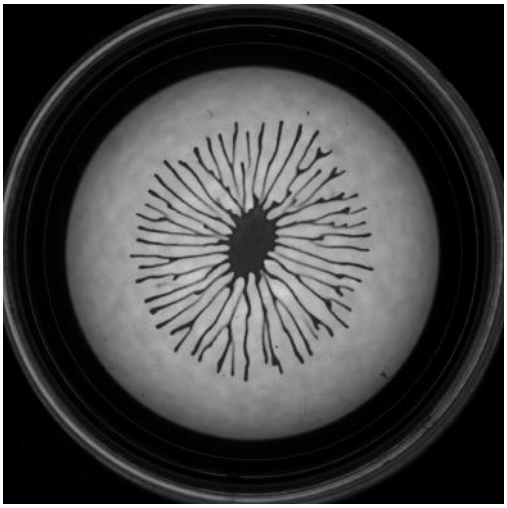

Figure 5 – *The previous Mystery photo*

Answer to the previous photo

This mystery photo shows a recently discovered collective phenomenon involving several millions of micro-algae called *Chlamydomonas reinhardtii* that react to a specific light field. *Chlamydomonas reinhardtii* (see Fig 6, extracted from [1]) is a single-celled organism that swims using a pair of flagella that beat in a breaststroke fashion to propel the cell forward along helicoidal trajectories at $V \approx 100^{-}\text{m.s}^{-1}$. Being a micro-algae it performs photosynthesis to grow and prosper. As most photosynthetic organisms that are also motile (i.e. that swim) it can reorient in light fields to migrate towards region of adequate irradiance, not too intense to prevent intracellular damages from the electromagnetic radiations and not too dimm in order to optimize photosynthesis. Such ability is called phototaxis, which is dubbed positive if towards the light source and negative in the opposite case. The cells manage to do so thanks to a basic light detector called an eyespot and schematized as a red ellipse on the figure. This eyespot is made of two main components. Embedded in the cell membrane are photo-activable proteins named "*Channel-Rhodopsins*" (light-gated ion channels) whose functioning is similar to action potentials in neurons and that convey signals to the flagella in order to rectify the cell motion. Just beneath the membrane a few layers of *Carotenoid* granules act as a dielectric mirror that either block or reflect the light towards the proteins depending on the cell orientation. The global mechanism of reorientation, from the integration of the light signal by the eyespot to the modulation of flagellar beating, is still not well understood. Coming back at the mystery photo, the darker region, with branches connected to a central blob, is a dense phase of micro-algae with volume fraction estimated to be in the range $\sim 30 - 60\%$. This phase spontaneously emerges when cells migrate towards the center of the *Petri* dish (diameter $\sim$ 3.5cm) following strong enough illumina-

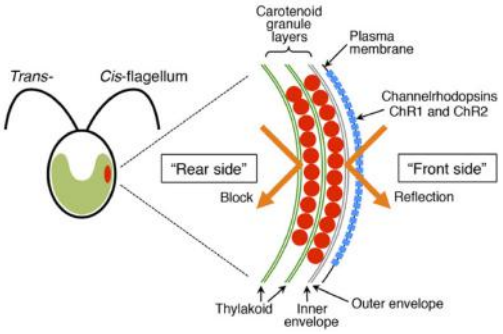

Figure 6 – *Taken from [1]*

tion with light sources placed on a concentric ring. The initial uniform suspension has a volume fraction $\sim 0.2\%$. Once formed, this phase "flows" and the fingers slowly retract ($\sim$ one order of magnitude slower than a single swimming cell) until obtaining (after $\sim 5-10$ minutes) a steady circular "drop" in the center of the system, now respecting the symmetry of the light field. We believe the initial destabilization that leads to a coarsening dense phase originates from the coupling between light propagation and density field, mediated by light absorption (and perhaps diffusion) by the cells and negative phototaxis, which allows amplifying local density fluctuations. We currently work on understanding finely this mechanism, notably by using mutants that present defects on the eyespot and are less accurate at detecting the light direction. I have also recently learned that this system presents strong analogies with magneto-optical traps of atoms where such shading effects have been predicted and theorized by Jean Dalibard at ENS in 1988 [2]. More to come in the next months ! (**R.Jeanneret**)

References

[1] *Eyespot cancels lens effect in Chlamydomonas*, Noriko Ueki & Al.. Proceedings of the National Academy of Sciences May 2016, 113 (19) 5299-5304 ; `https://www.pnas.org/content/113/19/5299`

[2] J. Dalibard, *Laser cooling of an optically thick gas : The simplest radiation pressure trap ?*, Optics Communications ; Link

Free Particle

Chers $\phi 20$, en fin de L3 vous devrez trouver un stage expérimental et à votre rentrée de M1, vous présenterez un beau rapport sur cette expérience d'un mois. Pour vous aider dans cette tâche, voici un lien hypertexte vers un cloud avec plusieurs de nos rapports de stage. `https://cloud.eleves.ens.fr/index.php/s/YwtF4C69fmNSQZn?`

I. Postcard : *INMED*

In order to animate our section "Post card" [1], I would like to propose you a short review of the beginning of my intership.

I am working at the INMED (*Institut de Neurobiologie de la Méditéranée*), located on the Luminy campus in Marseille. Something nice is that we are in in the thick of the Calanques National Park (see Fig 7). My topic is Neurosciences and more precisely the study of the neocortical activity in the area receiving input for the whiskers in the rodent, the barrel cortex. For this application, I am supervised by Hervé Rouault and Jean-Claude Platel. The singularity of the project is to work between two aspects of neurosciences : experiences, in my case imaging the activity in the barrel cortex and develop the set-up for stimulation of the whiskers. And networks modelisation, namely use tools from physics (statistical physics, dynamical systems, and so on...) to describe the dynamics observed and finally simulate the networks (the main part of my work for this side).

Figure 7 – *View of the calanques - By RocketMan974 — Travail personnel, CC BY-SA 4.0, https ://commons.wikimedia.org/w/index.php ?curid=78979749*

What I am doing

Currently mainly experiments. And for this I am tutored by Jean-Claude who performs all the stuff necessary for imaging : injections of markers in the mice (yes, I forgot to tell you, we are doing *in vivo* experiences with mice), management of lineage and ... surgeries. Because we record the brain activity with a two photon microscopy imaging, we need to get a small window for the laser to access the area of interest in the brain. The performed surgeries consist of removing a small disk (typ less than 0.5 µm of radius) of the skull. Then we put a glass plate to cover the hole and stick a metallic bar on

1. Don't be shy and don't hesitate to write us some words about your intership !

Figure 8 – *Head-restricted mouse*

the skull. The metallic bar allow us to maintain the mouse during recording (Fig 8.

Me, I am struggling to develop a step-up for our recording. First, we want to track the whiskers (with 3D coordinates) during sessions. Consequently I have to set two cameras for this and an IR-light. Then work with tracking software. Second, we want to stimulate the whiskers with touch-like stimulation. For this, I am going to use a stepper motor (from a DVD driver) controlled by a microcontrollor that I am programming.
The challenge here is to put all the stuff we need (camera, light, mouse, mouse holder, etc) in a reduced space (due to the microscope)!

As I have said, I am also performing network modelling with Hervé. Recently I finally manage to code with Python a simple neural network (two populations, inhibitory and excitatory neurons, and both of them receive input from a thalamic neurons). The simulated network aims to explain experimental results from [1]. Here they studied the response of neurons in the barrel cortex to touch. They saw that a complex active filtering occurs to make emerge touch sensation. [2] performed the simulation of the network previously studied and numerical exploration allows them to state that the active filtering is performed thanks to a delayed inhibition of the excitatory population regarding the input from thalamic neurons. I took their model, code it and manage to get the same results. It is interesting because we now get a working code which are going to be improved to take into account other effect, like synaptic facilitation.

I have to thanks here Hervé and Jean-Claude for the huge amount of energy they are giving to our project and to tutor me during the internship, it is a great experience! These are pieces from the work of the past weeks. Now, we are building an ambitious and exciting project around the touch activity in developmental barrel cortex!

Figure 9 – *View of Marseille from Col de L'Espigoullier, in the Sainte-Baume mountains*

A few words about Marseille

The life in Marseille is very nice in my opinion and heavily contrasts with life in Paris. There is obviously the weather and the living environment. Since I love cycling, I enjoy the beautiful landscapes of the Provence, Calanques, Sainte-Baume (Fig 9 or the roads following the Mediterranean Sea. I also found that the Provencal lifestyle is calmer and more hearty than how I feel the Parisian lifestyle, a continuous sprint. And I enjoy this new atmosphere! (**L.Brivady**)

i. Referenes

[1] Yu, J., Gutnisky, D., Hires, S. et al. Layer 4 fast-spiking interneurons filter thalamocortical signals during active somatosensation. Nat Neurosci 19, 1647–1657 (2016). https ://doi.org/10.1038/nn.4412

[2] Gutnisky DA, Yu J, Hires SA, To M-S, Bale MR, Svoboda K, et al. (2017) Mechanisms underlying a thalamocortical transformation during active tactile sensation. PLoS Comput Biol 13(6) : e1005576. https ://doi.org/10.1371/journal.pcbi.1005576

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We thank our contributors for their fantastic articles and questions. We also thank everyone who send us their feedback and encouragements. And thank you dear reader!

We need you !

If you would like to contribute or support us, don't hesitate to contact us :

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