Final Report

I did a ten months internship at the University of Granada, department of condensed matter physics, group of statistical and computational physics, from 15/05/2017 to 28/02/2018. My supervisor has been Professor Miguel Angel Muñoz. During this internship I did the central research work of my Master Thesis. I knew Professor Muñoz work appeared in international academic journals like PNAS and Physical Review letters. In addition, he is a near collaborator of Professor Amos Maritan, my bachelor's thesis supervisor at the University of Padova. Finally Professor Frey accepted to be my internal supervisor here at LMU. I contacted Muñoz by email explaining to him that I was interested in his research and if was possible to do an internship of research supervised by him. He has been really happy to accept me in his group of research and to propose me different possible line of investigations. We chose to work on the argument of Collective Phenomena in Biology and in particular in Bet-Hedging strategies. This topic of research really interested me and created great expectations in me. Let me introduce the general theme and our concrete contributions. This general philosophy is an important part of what I learned.

Physics is the part of science that tries to understand the word with the tool of mathematics. This is a most general definition that one could think of, but represent the actual research spirit in physics. Statistical physics is the branch that studies collective phenomena in nature. To give an example let’s think for a moment about water. When in everyday live we experience the contact with it we see it, at least, in three “phases”: gas, solid(ice) and liquid. We normally assign it a temperature, a pressure and a volume. These are the variables that rule the behavior of a gas, thanks to its state equation

\[ PV = nRT \]

where P is pressure, V volume, n the moles of the substance, R the universal gas constant \( R = k_B n_A = 8.3144598 Jmol^{-1}K^{-1} \) product of the Avogadro number and the Boltzmann constant and finally T its temperature. But if we stop a moment it comes to our mind that we know that in reality water, as all matter, is made by atoms. So its complete and fundamental physical description should rely on the properties of atoms, how the form molecules and interact to shape matter. Here we find a conceptual problem: if we take a molecule could we assign it a temperature? Or a pressure, a volume? No. This are called “macroscopic “ properties that “emerge ” from the interaction of an enormous number of “microscopic” agents, the molecules. In particular the temperature is an estimation of how much the atoms of matter vibrate, an phenomenon called Brownian Motion. Statistical physics builds a bridge between the behavior of the microscopic level to the macroscopic one. To do so we use statistics: the Avogadro Number tells us that in a mole of matter there 6.022140857(74) \( \times 10^{23} \) molecules. Is not
possible to follow the behavior of all of them, we need to study this in average. From this perspective physics tries to study the different state of matter (Liquid, solid, gas, superfluids, plasma etc) that are called “phases”. From the ’80 a lot of statistical physicist started to study with this approach collective phenomena outside physics, like in biology, ecology, economy and social sciences. My research work follow this ideal path, and we started to study evolving populations as physical systems exhibiting collective phenomena. A population of bacteria, or any plant or animals, collaborate to survive. A lot of times a population acts like a “collective being”, such amazing are its correlations. Let’s think for example of the geometries that a flock of birds could draw in the sky. Here we have also a “microscopic level”, the single bird, and the “macroscopic” one, the population together. These systems that exhibit collective emerging behavior from a collection of identical agents are called “complex systems”. The project that professor Muñoz proposed me was to study with this approach evolutions in bacteria. In particular we wanted to theoretically and mathematically understand the result of an experiment by the group of Ophelia Venturelli recently published in Plos One : Computational Biology.

Bacteria when are growing on different types of sugars exhibits a behavior that is called “Diauxic Shift”: the generally first completely depleted the preferred sugar and then move to it the less preferred one. In the time between this shift they experience phase of not growing that is called “lag phase”(see fig 1A). Lag phase has been understood to be a moment when the organisms activate the proteins that they need to eat the second sugar.

What is seen in this experiment is that the activation of these proteins is to forced to be done just between the two sugars but can also be done in an anticipatory way. The population splits in two and a part follow the normal schema and another one activate early the proteins, to be ready for the first sugar depletion(see fig 1B). This populations diversification strategies are called “Bet-hedging” because an organism, or a community, bets on the possible fluctuations of the environments being ready for any outcome. How these mixed strategies developed in nature is not clear. They are present at all the scale of organisms. Birds produce eggs in different size is an example: producing many small eggs could maximize the number of offsprings but big eggs have larger possibilities to survive. Producing eggs with difference sizes is the best solution to maximize the fitness. In a tree not all the flowers blossom at the same time:
a large group at the best moment but a small groups blossom a little bit early just in case of a environmental catastrophic event.

We studied this phenomenon with tools of statistical physics. We wrote down a “microscopic” equation for the evolution dynamics of the bacteria in the phenotypic space and studied it with computer simulations. We found that after a good amount of time our simulated population was always evolving to this optimal behavior with this split between “early and late activators”. Furthermore we derived a macroscopic mean field equation that was describing the phenomenon by the collective point of view of the total population. We verified that the two are giving the same result. Now that I introduced our activity I will comment on more general aspects of my internship. The statistical physics used in this situation is called “Non equilibrium physics” and its development is an hot topic in actual research. Organisms are not in thermal equilibrium: they interact constantly with each other and the environment exchange heat and energy. A complete theory of non equilibrium is still not present, and any new model is a new clue.

To prepare myself for the internship I read all the material that Professor Muñoz sent me and I reviewed the main aspect of statistical physics needed. My level of spanish was already high, because I studied it for five years during high school, and I did not need to review it. I was expecting high quality research in physics and this i what I found. Furthermore I found a really cheerful, relaxed and interesting work environment. I had a work desk with computer in the office of the PhD students of the group. My working day was starting at nine and ending around 17.00 or 18.00, depending on the amount of work. I was working independently on the project and every two or three days I was reporting the state of the things to Professor Muñoz. His office was always open for questions and doubts. I had the possibility to use Proteus, the super computer cluster of the group. During the first months (May and June) professor Muñoz explained the general theme of research and made me read and report him various scientific papers. Then in June we started to define mathematically our model. In September the model was completely defined and we started the computational analysis. In November we had the first good results and, we implemented a second round of different simulations. In Gennuary we started working on the mean field equation and starting to write down the master thesis. I was completely free in organize my working day as I wanted, so I was not stressed or too busy.

Finally in June I had also the possibility to participate to the “Granada Seminar on statistical physics”, a periodic international conference organized by the group of Statistical Physics. This year theme was “Quantum Many-Body system in and out equilibrium”. Despite this was not my research theme I really enjoyed the conference because enlarged my background and gave me the possibility to interact with international known invited scientists.

I really enjoyed the internship. First of all the theme and the modalities of work. I learned so much during this internship. Basically I used all the knowledge that I had acquired in my master like: coding in C++, computational techniques, analytical tools from Stochastic process and Statistical Physics and
basics of Biology. I have improved so much in the computational skills and discovered new analytical techniques. Further I have really started to understand how real research work. It so different from just studying during the master. When you do research there is no done solution to your problem. You have to work hard and for a long time. Study the problem from all the possible point of views and have a global perspective.

Second Professor Muñoz has been an outstanding supervisor. The first day he introduce me all the other professors and student and made me feel at home. He has always been available for questions about the project and much more. His good humor and cheerfulness have helped me in the most difficult moment. When I was stucked he has always capable to see which was the path to follow to solve the problem. He gave a lot of good advice for my career.

Third the other professors and the Phd students of the group were always open for questions, curiosities or a coffee. Any time that I had a problem with a code or just a doubt not worth to disturb Professor Muñoz there was always somebody ready to help me. In particular I created a really good relationship with a couple of Phd students. I did not have any problem in the work environment.

Outside the work environment I was able to make a lot of friends and connections. Granada is an amazing city to be a student. Every night there are concerts, theater performance of other activities. Who is interested in this should download Yuzin, the monthly cultural agenda of the city. For sure one of the best thing to do in Granada is to walk around the ancient arabic city, the Albaicín. Street musicians are playing at any corner. There is a square, commonly named Huerto Carlos, where all the musicians meet up to jam. I play the saxophone so for me has been easy to meet a lot of musicians and become friends with them. The typical night life in Granada starts with cerveza and tapas: in bar you order a beer and automatically you receive a small plate of the day...for just two euros. Also I recommend to just be curious and walk around the city, get lost in callejones, speak with people in the street. My favorite place in the city was the Mirador de San Miguel Alto: a beautiful balcony in the top hill where one can see an outstanding sunset.
Flamenco, the music born in Andalusia by the union of gypsy and Spanish tradition, is the blood of Granada music life. Any native person can at least "palmear", shake hands following the rhythm of the palos like bouleria. In any an improvised flamenco jam can start. To future students I advice to visit "Casa de Porras", the cultural university center. There one can follow a lot of interesting courses: yoga, flamenco, theater, painting, language and much more for really cheap prices.

During the weekends and the holidays I was traveling in all Andalusia and Portugal. In particular I really appreciated the cities of Cordoba, Lisboa and the beautiful natural park of Cabo de Gata in Almeria.

My level of Spanish has improved during the internship, as my C2 level in the test can certify. In particular at the end of my permanence I was able to speak and understand the slang of the city and a bit of Andalusi, the dialect of the region.

Granada is a city that for is history has been the meeting point of at least three different cultures: the Islamic, Christian and Jewish. Everybody feel at home in its streets. I had really a good impression of the city and its habits.

I was living in a beautiful house in Paseo de los Tristes, the down part of Albaicin. I found the apartment thanks to a friend that had lived there some years ago. I rate it quite good. The house was really old but with good standard and cheap rent. Just when ones lives in the Albaicin needs to get used to the really high temperatures during summer (til 40 degrees) and the cold of winter. The last is not so problematic except that no old house has the heating! One has to organize himself with electrical heaters and good winter blankets.

Thanks to this internship I really understood that doing research in statistical physics is what I like. Now I am more motivated to continue my career and apply for a Phd student position. I would really like to continue to work in the group of Professor Muñoz and I will apply for a Phd there. Furthermore it gave me the possibility to really review all my knowledge in physics. The bachelor and the master program are really a short period where you are focused in get the knowledge you now to pass the exams. During the master thesis and the research internship I had a good chance to think about my investigation subject with all the calm that I needed. I really understood in deep my subject and the method of research.

The group of Professor Muñoz is internationally known and every year some international students, like me, comes for an internship. So the situation is prepared for any possible internship or Erasmus project. I strongly advise any physics student interested in statistical physics and complex system to consider Granada and professor Muñoz’s group for an internship. He/she will feel really welcome both in the research group, in the university and in the city.