FROM HIGGS TO PANDEMICS:
DID CURIOSITY KILL THE CAT?

Francesco Sannino
Professor, University of Southern Denmark

THE PROLOGUE

By December 2019 the world was about to face, largely unprepared, one of the deadliest pandemic in human history. The pandemic exploded in the Wuhan region of China in December 2019 and many of us wrongly assumed that it would have been somehow contained. I was, in fact, planning a number of research trips including one for a lecture at MIT at Boston and a longer research visit at Yale University. About two decades ago, I had spent there three wonderful years as research fellow. Not only had I learnt so much from the colleagues and senior researchers at Yale but also learned about how to function as a fully independent researcher.

My journey started after returning to Denmark from a research visit in Napoli, Italy in mid-February 2020. Europe was about to become the primary target of the pandemic with its epicenter in northern Italy. As the situation was unfolding, we received a message from the University telling us that we had to postpone our research trips. However, nobody could tell us when we could travel again.

THE STORY

It was then that I felt the urge to understand what was going on, and hopefully answer the question: When can we travel again?

Despite the well known idiom on how ”curiosity killed the cat”, I decided to give in to my own curiosity and use my theoretical physics bag of skills to make a dent in understanding the dynamics of the pandemic and its evolution.

Research is often more fun when it is shared with colleagues. I was very fortunate to start this endeavor with Michele della Morte, also a theoretical physicist. Michele is part of the center of excellence in theoretical physics of elementary particles and cosmology that I brought to life in 2009 in Denmark and which was financed, for a decade, by the

The author *Francesco Sannino earned two PhDs in theoretical physics, one from Syracuse University and the other from Federico II university, in 1997. Subsequently, he held a research fellow position at Yale university from 1997 to 2000. In 2000, he arrived in Copenhagen to assume the position as fellow in Nordita. After that, in 2004 he was awarded the Excellence Team Grant of the EU commission and established an independent research group at the Niels Bohr Institute as associate professor. In 2006 he became scientific associate at CERN, in Geneva and in 2007 became full professor at the University of Southern Denmark (SDU). At SDU he obtained a prestigious 10 years grant awarded by the Danish National Research Foundation to establish the Centre for Excellence in Cosmology and Particle Physics (CP3-Origins). He has also been the creator of the Danish Institute of Advanced Studies (DIAS). Currently, Francesco Sannino holds dual professorships at Federico II University in Napoli (Italy) and at SDU in Denmark. In Napoli, he is now building a research group consisting of young and eager researchers from theoretical physics to computer science for genetics and epidemiology. Francesco Sannino is also a chair in theoretical physics at the Scuola Superiore Meridionale in Napoli and at the Danish Institute for Advanced Study.*

The CP3-Origins has been a platform for many Finnish students, postdocs and junior faculty members. In 2015 Sannino was invited as a foreign member to the Finnish Academy of Science and Letters. In 2018, he was elected foreign member of the Royal Danish Academy. Starting in 2022 he will also be an appointed distinguished visiting fellow of the prestigious T.D. Lee Institute (TDLI) in Shanghai.

Danish National Research Foundation. Later on, I was immensely happy that one more colleague, Domenico Orlando from INFN, Torino in Italy, joined the team.

Given that our background was in high energy physics, and more specifically in Higgs physics, numerical simulations of the strong force and string theory, we had to start from scratch in epidemiology. It seemed reasonable to begin our investigation with the data available on the World Health Organisation (WHO) website. We concentrated on the temporal evolution of the number of SARS-COV-2 infected people in China, Korea, Italy and other reported countries.

From the outset, we focused on the temporal evolution of the outbreaks in various regions of the world. This was different from the bulk of other studies. Further, this allowed us to reduce as much as possible the inevitable biases that occur when focusing on restricted regions of the world. At the same time our global approach is better suited to reveal general patterns in the transmission and diffusion of the virus.

The typical S-shape behavior of the logistic function used to fit the data immediately reminded me of the dynamics of certain physical systems. This dynamic is controlled by symmetry principles such as approximate invariance of the short and large time cumulative number of infected individuals upon a time rescaling. These type of symmetry principles are the pillars on which the modern physics of fundamental interactions relies on, from the physics of the Higgs (discovered in 2012 at CERN) to string theory. String theory was introduced to unify the theory of quantum gravity with the other forces discovered so far. We dubbed the approach Epidemic Renormalization Group (eRG)[1] in honor of the physicist Kenneth Wilson that revolutionized physics with the introduction of the RG approach. The latter is an extremely powerful tool. It is devised to encode the relevant degrees of freedom needed to describe a given physics problem at hand. It is further apt to capture rescaling symmetries via the appearance of fixed points in the theory.

An important step was to further link our work to established mathematical models [2]. We therefore constructed an explicit map between our framework and classical epidemiological approaches. These use various versions of the Susceptible-Infected-Removed (SIR) type of models, which were introduced almost a century ago, and more precisely in 1927, by Kermack, McKendrick and Walker [3]. The crucial difference between SIR and the eRG is that the latter is devised to be more reliable on longer time scales than SIR.

To our surprise, not only did the approach prove efficient in describing and predicting the evolution and spread of the virus within a region of the world. Once generalized [4], it proved efficient in describing the diffusion across different regions of the world. This was work done in collaboration first with Giacomo Cacciapaglia, researcher at the CNRS in Lyon France, and later on also with Corentin Cot, PhD student at the University of Lyon. Since the beginning of August 2020, we predicted, by averaging through hundreds of simulations, that the second wave in Europe would take place between the end of August and the first months of 2021 [5]. Our simulations and forecasts were designed to prepare governments, industries and citizens of the various European states to take the relevant measures to avoid, delay and/or reduce the impact of the second pandemic wave. Because of the relevance of our results the work was selected by Nature for an international press release.

THE EPILOGUE

Let us come back to the initial question: When can we travel again? Already from the first paper it became clear that rather than postponing I had to cancel the trips. More generally, our work has shown that the eRG framework efficiently captures the temporal evolution of the pandemic diffusion across the globe with just two relevant parameters per each region of the world.

My current interests regarding this novel line of research is in the following topics: understanding human behavior by, for example, combining Apple and Google data to investigate human mobility during a pandemic [7]; and learning about the genesis and evolution of virus variants [8], including the impact of vaccination strategies [9]. The latter results were achieved by marrying machine learning techniques to genome data with the epidemic Renormalisation Group framework. One of our recent discoveries is that each wave of the COVID-19 pandemic has been driven by a new and more aggressive variant [8,10]. Last but not least we wrote a review of our work and of general approaches to epidemiology that might be a useful introduction to this exciting research field [11]. In these more recent endeavors I have been immensely fortunate to learn from several new colleagues with deep expertise in different fields. These include Maria Óskarsdòttir and Anna Sigridur (Department of Computer Science, Reykjavík University in Iceland) in computer science, Francesco Conventi (University Federico II of Napoli in Italy) in experimental particle physics and Stefan Hohenegger (University of Lyon in France) in string theory. Our research benefitted especially from the work of our super engaged junior collaborators Adele de Hoffer, master student at the Politecnino di Torino, and Shahram Vatani, doctoral student at the University of Lyon.

Overall our story is a clear example of highly interdisciplinary work that is key to human progress. Perhaps the idiom should be changed into *curiosity didn't kill the cat, it saved it.*

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