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A few reminiscences about Renaud Parentani

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Foreword / *Avant-propos*

Simulating gravitational problems with condensed matter analog models : a special issue in memory of Renaud Parentani (1962-2020) / *Simuler des problèmes gravitationnels avec des modèles analogues en matière condensée : un numéro spécial en mémoire de Renaud Parentani (1962-2020)*

A few reminiscences about Renaud Parentani

Quelques souvenirs de Renaud Parentani

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Abstract. In this foreword, we pay a personal tribute to Renaud Parentani, who suddenly passed away in 2020. We express our desire to gather in his memory a series of scientific articles in the field of analogous gravity, which was so dear to his heart. We also bring together a collection of personal memories of Renaud from his closest friends and collaborators: Serge Massar, Florent Michel, Stefano Finazzi, Jeff Steinhauer, and Uwe Fischer.

Résumé. Dans cet avant-propos, nous rendons un hommage personnel à Renaud Parentani disparu brutalement en 2020. Nous exprimons notre désir de réunir en sa mémoire des articles scientifiques dans le domaine de la gravité analogue si cher à son cœur. Nous présentons également un recueil de souvenirs personnels de Renaud par ses amis et collaborateurs les plus proches : Serge Massar, Florent Michel, Stefano Finazzi, Jeff Steinhauer et Uwe Fischer.

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Introduction

Amid the global turmoil of the early 2020s, the news of Renaud Parentani's sudden passing came as a profound shock to his extensive network of friends and colleagues worldwide. None of us was expecting such a sad event and his loss left a great emptiness in our scientific and personal lives, putting a sudden stop to a number of adventures we had been foreseeing with

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Figure 1. Portrait of Renaud by Anna K. Little

him. Independently of the different stages of our careers and our various scientific interests, we had all been strongly influenced by his outstanding scientific personality.

This special issue aims at celebrating his memory by illustrating the strong impact he had and is still having on our research. These articles are related to an international workshop on *Quantum Simulation of gravitational problems in condensed matter analog models* that took place at the *European Center for Theoretical Studies in Nuclear Physics and Related Areas – ECT** in Trento on June 19th–23rd, 2023. This workshop was the 2023 edition of a long-lasting series of events to which Renaud had been a regular participant with crucial contributions to the presentations and to the debates: his presence in the audience ensured stimulating discussions after each talk and throughout the social activities. For this reason, it was a unanimous decision of the organizers to include in the 2023 workshop a Special Day in Memory of Renaud Parentani. The global commu-

nity of Renaud's friends and collaborators participated with enthusiasm to the workshop and to this memorial day. In collaboration with the Società Italiana di Relatività Generale e Fisica della Gravitazione – SIGRAV, a *Renaud Parentani prize* was inaugurated. Starting from 2023, it will be offered to a young scientist for the best presentation at the workshop, with the aim of preserving his memory within the new generations.

Before diving into the research articles of the special issue, we devote this introduction to personal memories of Renaud, starting with a presentation of his early scientific career in the words of Serge Massar in the next section (Section 1), and a memory of his role as a supervisor in the words of Florent Michel in Section 2. These memories will be completed in Sections 3–5 by a few memorial texts by close colleagues and collaborators of his such as Stefano Finazzi, Jeff Steinhauer, and Uwe Fischer. Additional memories on Renaud can be found in the research articles forming the special issue, most of which — we are sure — owe a lot to scientific interactions with Renaud Parentani.

1. Renaud Parentani and the fluxes emitted by accelerated detectors — Memories by Serge Massar

1.1. *Early years*

I met Renaud during the academic year 1990-1991, when I did my master's thesis under the direction of Robert Brout. The next year I started a PhD under the direction of Robert. As I explain below, I really started working with Renaud during spring 1992. In all, we published 17 articles together. My memories of Renaud are intimately linked to our PhD supervisor, Robert, to our joint articles which each have their own story, and to our long discussions together in the different places we worked, Brussels, Tel Aviv, Tours, and Paris.

Renaud's master's thesis was carried out under the direction of Robert, on black hole evaporation and the Unruh effect. He graduated in physics from Université Libre de Bruxelles in 1984, together with Jean-François Lagae and Jean Orloff. All three started a PhD under the direction of Robert in the Service de Physique Théorique headed by François Englert. Jean-François's topic was on effective quark models for hadron spectroscopy, Jean's topic was QCD confinement. However, before starting his PhD which was to be the continuation of his master's thesis, Renaud took a year off travelling with his backpack through Italy, Greece, Turkey, and Israel.

Doing a PhD in the Service de Physique Théorique was not so easy. Robert and François focused on the most impactful questions they could address. Their extremely broad knowledge of physics, and their focus on the important problems, was exhilarating. Their track record in physics was extraordinary (for a biography of Robert, see [1], for a biography of François, see [2] and the English translation [3]). But working with them was also difficult, as the young student was not given much training solving simple problems but put into deep water straight away, or left to himself to create his own problems and questions. Consequently PhDs with them often took longer than usual.

Jean Orloff got interested in string theory, and Renaud focused his initial work in this direction. His only published article on this topic is with Rob Potting, now at Algarve University, who was a postdoc in the group of François Englert and Robert Brout for two academic years between 1988 and 1990. Rob fondly recollects his collaboration with Renaud:

While continuing to collaborate with researchers I had worked with as a graduate student, I was trying to initiate a collaboration with the people at ULB. The person I connected to scientifically very well was Renaud. He was passionate about physics, and loved to discuss it. In the office, on the blackboard, or during lunchtime, with calculations often carried out on paper napkins. For Renaud

it was not enough to obtain some calculational result. He always wanted to understand everything deeply, intuitively. The discussions were not terminated until he was sure all possible loose ends had been wrapped up. I think we got the idea about our paper on the Hagedorn temperature and the accelerated observer from earlier papers by Troost and van Dam [4,5], maybe as a result of one of the regular seminars that were organized at the time with the group from KU Leuven, that included Walter Troost and Antoine van Proeyen. We then worked on applying it to string theory, came up with a very nice result [Renaud and Rob showed that for a bath of free strings there is a critical acceleration corresponding to a temperature equal to T_H/π , where T_H is the Hagedorn temperature] and managed to publish it in *Phys. Rev. Lett.* [6]. I also remember Renaud as a warm and gentle person. He loved hiking on long vacations: I remember him talking about trips in Provence and in Corsica.

Renaud several times told me that he also obtained another result in string theory [not having worked in the field, I have forgotten what exactly was the result] but that he hesitated to submit it, maybe not confident that it was good enough, and in the end he was scooped by another group, and never published it.

Renaud never went back to string theory. But his experience in this area profoundly affected his understanding of quantum mechanics. It taught him that quantum mechanics takes place in phase space, most naturally in momentum representation, and that insisting to work in position representation could be inefficient and even misleading, sometimes giving the wrong intuitions. I illustrate this with an example below.

After his excursion in string theory, Renaud started working intensely with Robert on pair creation in an electric field, the Unruh effect, and black hole evaporation. His next papers tried to connect these different effects by describing them in as unified a language as possible [7–9].

1.2. Working with Renaud

My master's thesis, in 1990-1991, was on black hole evaporation. In fall 1991 I started my PhD with Robert Brout. The beginning was very frustrating. Robert and Renaud, as I just mentioned, were trying to find a unified description of different particle production processes in background fields. Almost every day there would be long discussions in Robert's office between him and Renaud. I was listening passively, and did not know how to contribute. The breakthrough came in spring 1992, when Robert left for a long Easter vacation in Greece. The pace of discussions slowed down. Renaud and I had time to explore more mundane questions. We got intrigued by a debate concerning the energy fluxes emitted by a uniformly accelerated detector in equilibrium with the Unruh heat bath (see below for a short presentation). Discussing around the coffee table of our lounge, we studied and clarified the model in [10]. I proudly presented these (rather simple) results to Robert when he came back from vacation, and we went on to publish them [11]. This was only the first paper Renaud wrote on this problem, which — as I describe below — turned out to be much more subtle and complex than we initially thought.

I have always been deeply grateful to Renaud for helping me overcome a kind of “researcher's block” — my inability to do original work for over a year — during Easter 1992, when Robert was away. This first collaboration was followed by many discussions and brainstormings together, later often by email. We complemented each other well, and developed a long and fruitful collaboration.

Renaud defended his thesis in 1992. He stayed on for approximately a year before going to the Hebrew University of Jerusalem for his postdoc.

Several further works with Renaud stand out from when I was doing my thesis.

Sandu Popescu joined the group as a postdoc. Sandu had carried out his thesis at Tel Aviv University under the direction of Yakir Aharonov, and had a deep knowledge of the foundations of quantum mechanics. He introduced us to the notion of weak values [12,13] which allow a description of quantities at an intermediate time during a quantum process. We applied this to the process of charged particle-antiparticle pair creation in an electric field, obtaining a description of the charge density and current density as the pair is created [14]. The beautiful pictures that emerged showed currents and charge density oscillating in the region where the particle pair was produced before settling down to real positive values in the region where the particles are on shell. This was maybe the first time this approach was used to describe a quantum process as it occurs, and certainly the first application to field theory.

Another work from this period was Renaud's first contribution to analog gravity. I remember well that we were discussing, together with Philippe Spindel and Robert Brout, a preprint of Unruh's in which he had carried out a numerical investigation of sonic black holes [15] based on his earlier work [16]. Robert was enthusiastic, and pushed us to study this in more depth and try to make an analytical model. We had all the tools at the tips of our fingers, and the result was quickly obtained [17]. This was the first of Renaud's contributions to analog gravity, a topic on which he would later make many important contributions.

In 1993, Robert decided that we should write up a review article covering the team's insights on particle creation in external fields. It took us the better part of a year to write, and was finally published in 1995 [18]. Philippe jokingly called this our "Grand Oeuvre". Writing it helped close many loose ends in our understanding and raise new questions.

1.3. *Fluxes emitted by an accelerated detector*

I now go back to a problem which Renaud devoted much effort to clarify, namely the energy fluxes emitted by an accelerated detector. This is not Renaud's most important or impactful work. But it illustrates well his approach to physics.

As shown by Unruh in 1976, a uniformly accelerated detector perceives the vacuum to be a thermal bath at a temperature $T_U = \frac{a}{2\pi}$ (in natural units) [19]. The detector will absorb and emit quanta at a steady rate. What is the energy emitted by the detector during these processes?

Unruh and Wald were the first to study the energy emitted by the accelerated detector when it makes transitions. They showed that from the point of view of an inertial observer, each time the detector makes a transition it modifies the state of the field, and these modifications necessarily increase the energy of the field, since initially it was in the vacuum state, i.e. the minimum energy state [20]. On the other hand, as pointed out by Grove [21], the accelerated detector will thermalise, and reach a stationary state, whereupon, from the point of view of the detector nothing is changing (on average), and no energy is emitted or absorbed. This was confirmed in an exactly solvable model (consisting of an accelerated harmonic oscillator coupled to a massless field in $1+1$ dimensions) in [10] which we reanalysed in [11] confirming Grove's conclusion. In this work, Renaud formulated in a precise and elegant way, by exploiting the boost invariance of the trajectory, why in the steady state there could not be any energy emitted by the uniformly accelerated detector, a result we called "Grove's theorem".

A related paradox concerns the Fulling-Rindler vacuum, the state of the field in which an accelerated detector sees no quanta. The energy density in this state is negative everywhere. How is this possible, since the lowest energy state, the usual vacuum state, has zero energy? Renaud showed that the Fulling-Rindler vacuum is in fact singular on the horizons, where an infinite positive energy flux is present. As a consequence the total energy, as measured by an inertial observer, is infinite and positive [22]. This infinity arises when one regularises the Rindler modes near the horizon, expressing that uniform acceleration is only physical if it lasts a finite time.

Much later, with Nathaniel Obadia, Renaud would carry out a similar analysis of the fluxes emitted by an accelerated mirror, showing that in this case also transients are responsible for ensuring overall positivity of the energy radiated by the mirror [23,24].

The results obtained by Renaud in [22] provided a basis for resolving the above paradox concerning the fluxes emitted by a uniformly accelerated detector. The key point is that a trajectory uniformly accelerated for all times is not physical as it tends towards the speed of light at early and late times. To tame this singular behaviour, we introduced in [25] a switch-on and -off function that specifies how long the detector interacts with the field. It was then shown, through a perturbative analysis, that both interpretations of the emitted fluxes are correct. In the accelerated frame the fluxes can be positive, negative, or null, depending on whether the detector emits photons from the thermal bath, absorbs photons from the thermal bath, or is in equilibrium with the thermal bath. These fluxes are accompanied by small transients induced by the switch-on and -off function. In the inertial frame, because of the exponential blue shift, these transients dominate, and give rise to positive fluxes in all cases. This conclusion was accompanied by an analysis of the number of quanta emitted — as measured in the inertial frame — of the oscillator model of [10,11]: the number of quanta emitted grows linearly in proper time. This argument, and the critical role of transients, is similar to the earlier resolution of the paradox concerning the radiation emitted by a uniformly accelerated charge by Boulware [26].

In [25] we also analysed the fluctuation in energy that would give rise to a transition of the detector in the future, using the weak value approach introduced previously in [14]. This analysis was then transposed to the black hole case in [27,28] where it highlights the unphysical transplanckian frequencies that are redshifted to become the Hawking radiation emitted by the black hole.

A second resolution, more physical and fundamental, of the above paradox concerning the fluxes emitted by a uniformly accelerated detector was provided by Renaud in [29]. In this work, Renaud proposed to take into account that the uniformly accelerated detector necessarily has a finite mass. Consequently the detector recoils when it emits a quantum, so as to ensure momentum and energy conservation. These recoils modify the trajectory of the accelerated detector, and consequently the Lorentz invariance that ensured the validity of Grove's theorem no longer holds. Renaud showed that upon taking into account these recoils, the emitted fluxes necessarily become positive after a finite time. This is because the emitted quanta are entangled with the momentum of the detector, and therefore successively emitted quanta can no longer interfere to create negative fluxes. This analysis was carried out in momentum space, without giving the detector a definite trajectory, but rather by using the wavefunction — well known to Renaud from his work on pair creation in an electric field — of uniformly accelerated particles. More specifically, this model considers two kinds of charged particles, with the same charge but slightly different masses, accelerated in an electric field, coupled by an external massless field. This work illustrates Renaud's deep mastery of quantum mechanics.

Renaud would apply the same analysis to an accelerated mirror, showing that the recoils of the mirror gave rise to loss of coherence of the emitted quanta, and hence to positive emitted fluxes [30].

Renaud then carried out a combined analysis of both the Schwinger pair production and Unruh using the model he introduced in [29] (I am coauthor of this paper, but the main contributions were all Renaud's). The ratio of creation of the light and heavy particles is exactly such as to ensure that they are created in thermal equilibrium at the Unruh temperature [31]. This consistency in fact also extends to the production of pairs of charged black holes in an electric field, which are created with temperature equal to the Unruh temperature. With Philippe Spindel and Claude Gabriel, this analysis was extended to the case where the exchanged particle is massive

and also charged, whereupon the simple transition rates and the connection between Schwinger and Unruh effects no longer holds [32].

In summary, this problem illustrates how Renaud always strove to find the physical principle underlying a phenomenon and to illustrate it with the simplest example possible. Here he initially used Lorentz invariance to prove the absence of the mean fluxes (through “Grove’s theorem”). Later he understood the more fundamental role of energy and momentum conservation: taking the detector’s recoils into account gives rise to decoherence and emission of positive fluxes.

1.4. *Conclusions*

Renaud was a deep and thorough thinker. He tackled complex problems, and would not leave a stone unturned until he was sure that all aspects of the problem were clarified. Working with him was a great education on how to do research.

For those interested in Renaud’s own words on quantum gravity and cosmology, see [33] (English translation available in [34]). One perceives well from the text Renaud’s reluctance to be interviewed, and then his gradual enthusiasm for talking about the science he loves.

Acknowledgments

I thank Rob Potting and Jean Orloff for their very useful input without which I would not have been able to reconstruct Renaud’s first years in the Service de Physique Théorique.

2. Staring at the Horizons — Memories from Renaud Parentani and the “if-then physics” by Florent Michel

2.1. *Renaud as a supervisor*

I will forever remember the first advice that Renaud gave me as we wrote our first paper together: “First, you must choose the figures. This is the most important part. The rest is easy: just write the words you need to describe them.” This “easy” part often involved weeks, if not months, of back and forth drafting, re-drafting, erasures, additions, re-organisations, new calculations, proofreading, and re-re-drafting, until every sentence fit in its place, like a piece in a jigsaw puzzle. Yet he was right all along: the version we finally settled on was the one where every word was there to introduce, describe, or explain results shown in a graph or diagram.

The second advice he gave me was: “Always ask yourself: What will the reader learn?” For writing an article with Renaud was always about learning something and sharing it; everything else was secondary. This is something I find in all of his works, from the first articles he wrote with Robert Brout and Serge Massar to his very last ones, and his unfortunately unfinished works: the drive to teach, to enlighten, to make sure that every reader, whether new to the field or world expert, can find something interesting to learn.

“What will the reader learn?”... Pondering this question as I was writing this text in memory of Renaud, wondering what I could provide that was not already explained in papers I or others wrote with him, I came to the conclusion that there are only two things I could offer to potential readers that most of them would not already know: a brief (and, necessarily, hand-wave-y) description of one of the open questions I had the pleasure to discuss with him and, maybe more importantly, Renaud’s point of view on it. Why did he find specific problems particularly interesting? Which topics kept coming up in our discussions and how did he think about them in relation to his previous works? I have, or course, only very incomplete answers to these questions;

and I am sure that testimonies from other researchers who worked with him will draw a more complete picture of the ingenious, inventive, honest, and always insightful ways Renaud thought about each problem he strove to solve. But I hope that providing my humble perspective can contribute to highlight how his unique approach to Science shaped the fields he worked on way beyond the simple sum of his published papers; and how it left, on me and certainly on all those who worked with him, an unforgettable impression.

One thing which always springs to my mind when thinking about my time at LPT Orsay, working on my PhD under Renaud's supervision, is a simple phrase he told me as we were discussing the merits of some mathematical model (I think it was about Universal Horizons in Lorentz-violating theories of gravity): "I like if-then physics". He went on to explain that making assumptions is fine, whether or not they turn out to be true, as long as they are explicitly spelled out and can tell us something about a physical phenomenon: if they are correct, we'll learn something about physics; if not, understanding why they are wrong can teach us even more.

At first, I did not really understand the value of what he said. If physics was about the real world, about explaining actual observations and predicting future ones, surely a hypothesis can only be acceptable if it is true, or at least a good approximation of reality? What I was missing, but soon became clear as we kept discussing, is the invaluable insight that exploring the consequences of a hypothesis can give, both on a particular model and the relevance of the hypothesis itself. In retrospect, I realise that most, if not all, of the work I did with Renaud fits in the following picture: build a simple model, explore its consequences, then take a step back and consider how close or far it is from experimental results — and, most importantly, learn from both the similarities and differences. We never tried to accurately model a specific system. Instead, Renaud always advised me to look for the simplest possible description of how we thought it could behave, down to the very mathematical essence of the phenomenon that can then be applied to many different systems.

Of course, this approach is not uncommon in theoretical physics, which could nearly be defined as the intersection area of conceptual thinking and experimental sciences. But Renaud pushed it much further than most would dare to, able to see value in virtually any mathematical model (if only, for the most far-fetched ones, for the contrast they provide with more realistic descriptions) and drawing surprisingly deep physical insight from even the most bare-bone and apparently simplistic formulations. This is, I think, part of the reason why he was drawn to analogue gravity: seeing the same phenomena at play in the early universe, black holes, surface water waves, cold atoms, and more was both a strong vindication of his approach to physics and an infinite source of fascinating physical effects with even more fascinating and surprising links with each others.

His genius for seeing the conceptual simplicity hidden in the most complex systems, for capturing in a few words and pictures the main lessons of tens of pages of calculations, and for creating new concepts embodying seemingly disparate physical phenomena have been an invaluable source of inspiration for me, and certainly for all those who have had the chance to work or chat with him, at LPT Orsay or at Café de Flore, a cup of tea in hand, talking with the same passion about the Information Paradox in black holes, the beauty of Bach's partitas, dispersion relations for water waves, or the letters of Honoré de Balzac...

2.2. *Quasi-quasinormal modes*

To this day, quasi-quasinormal modes are among the first thoughts which occur to me when I think about the time I worked with Renaud, a vivid example of how he approached challenging problems by putting intuition first, designing new concepts to gain insight into the physics before formalising them rigorously (often after the problem was essentially solved).

In this section we consider systems without dissipation. The modes defined (or tentatively defined) here generally (although not always) still exist with a small dissipative term, but the late-time dynamics is more complex. We will also focus on one-dimensional systems, although the main ideas presented here can be extended to higher-dimensional ones.

Intuitively, and throwing a lot of mathematical details and system-dependent considerations under the carpet, Quasi-Normal Modes (QNMs) are “decaying” solutions of linearised field equations escaping to infinity, which describe the late-time evolution of a system following a localised (in time and space) perturbation. To be slightly more formal, they may be defined as solutions satisfying “outgoing” asymptotic conditions, e.g., with the group velocity oriented toward infinity. This generally implies some form of exponential growth in at least one direction, hence they are not on the same level as better-behaved linear perturbations — for instance, they are generally not associated with pairs of creation/annihilation operators in canonical quantization. Yet, they play a major role in understanding how a system recovers from a localised perturbation. For instance, the typical decay time is (under some conditions which are out of scope of this hand-wave-y introduction) inversely proportional to the smallest imaginary part of QNM frequencies.

QNMs also play an important role in understanding how some analog systems, such as pairs of black- and white-hole horizons in a “black-hole laser” configuration, become unstable when changing some parameters (like the separation between the horizons). Indeed, as shown in several of Renaud’s works [35–37], the unstable modes giving rise to the instability can be traced down to QNMs of the stable version, which turn into physical modes at the onset of instability. Renaud liked to say that QNMs are “ancestors” of instabilities.

QNMs are straightforward to define in infinite systems with asymptotically uniform backgrounds. But their definition does not extend easily to finite systems with, for instance, periodic or reflexive boundary conditions. Indeed, a finite system generally does not have modes which correspond to QNMs in the limit where its size goes to infinity: since they are exponentially growing at infinity, they do not satisfy “sensible” boundary conditions for large systems.

At first sight, this makes sense: the late-time dynamics of a finite system is (in the absence of dissipation) fundamentally different from that of an infinite one: while in the latter case the late-time dynamics is dominated by the decay of the slowest perturbations to “escape at infinity”, in the former all perturbations remain — by definition — localised. There is thus no a priori reasons for analogues of QNMs to exist.

Yet, for large enough systems and localised enough initial perturbations, there should be a window in time where the dynamics resembles the late-time evolution in infinite systems, when the decaying behaviour already dominates yet most of the energy (and/or other conserved quantities) carried by the perturbations has not yet reached the boundaries. This intuition from Renaud sparked the following question: can we describe this intermediate-time dynamics in a way that is intrinsic to the problem defined in a finite system? In other words, can we define “modes” of the finite system, either exact or approximate solutions to the linearized field equations, whose profile and complex frequencies would determine the evolution of perturbations in this time window? Renaud conjectured that these “modes” should exist, and converge to the QNMs in the limit where the system size goes to infinity. He called them Quasi-Quasinormal Modes, or QQNMs.

Renaud and I, unfortunately, never had the chance to work on this problem much, nor even to review the literature for potential solutions. I would not be surprised if QQNMs were already known, maybe not as “modes” in the usual sense, and probably under another name. Yet they remain, for me, intrinsically linked to the way Renaud saw physics, with mathematics seen as a tool — a very important one, and maybe the most important one — which should not limit our intuition and imagination to solve problems. And as an example of how formalism was, to him, always a way to express and communicate intuition, never an absolute truth in itself: if the QNMs

(or other types of solutions) can't effectively describe and convey what he wanted to express, he would rather bend the definition of "modes", extend it until it fits the picture he had in mind like a cellist inventing new ways to use their instrument when the traditional ones fail at what they want to express.

One possible way to define QQNMs more formally, I guess, could be to divide the finite region into a "near" region, large enough to include most of the initial perturbation, and a "far" region where finite-size effects become relevant. QQNMs could then be seen as the QNMs for the "near" region. I have no doubt, though, that Renaud would have come up with a much better, clearer, and more inventive and useful definition.

3. Memories by Stefano Finazzi

I do not want to remember Renaud primarily as a scientist. There are many people far more qualified than I am to speak about his scientific achievements. Instead, I would like to remember him as a friend, a teacher, and a mentor.

I still remember the first day I met him. It was the summer of 2008, on a ferry to Lošinj. I was attending my first summer conference on black holes in general relativity and string theory. Renaud gave a fascinating talk on nonlinear dispersion relations near black hole horizons. At the time, I could never have imagined that several months later I would have the privilege of working with him during my PhD.

I met him a few more times at conferences, and during the second year of my PhD my supervisor, Stefano Liberati, offered me the opportunity to collaborate with Renaud. One of Renaud's students, Jean Macher, had developed a remarkable code to study particle creation near black hole horizons in the presence of nonlinear dispersion relations. When Jean decided to leave physics, I was given the chance to take over and further develop his work. That was the beginning of my collaboration with Renaud.

We did not meet very often, perhaps only a few days each year, at conferences, when I visited him in Orsay, or when he came to Trieste. Yet that was more than enough to build a fruitful collaboration. His extraordinary physical intuition, combined with exceptional mathematical rigor, guided me through some of the most challenging and profound problems I worked on during my PhD. I would spend weeks running simulations, only to discover that he had already anticipated the results. Nothing ever seemed to surprise him. The calculations were simply confirming something that had long been clear in his mind.

Some of my strongest memories of Renaud come from the time I spent with him in Paris. During my first visit, we sat on the grass in Place des Vosges and talked for hours. He was proud of the city and especially of the Marais, where he introduced me to his favorite places and took me to a wonderful *pâtisserie* nearby. I can still remember the taste of the cake, but even more vividly I remember the light in his eyes as he described it. The same enthusiasm appeared whenever he talked about food, wine, or physics.

That light was unmistakable. Sometimes there would be a touch of frustration when he was trying to explain an idea that seemed completely obvious and simple to him but not to the rest of us. He would search for different words, different examples, determined to make it clear. And then, the moment understanding finally arrived, his face would light up and he would exclaim: "Exactly!"

Another memory remains as vivid today as it was then. One evening in Trieste, we sat together on a small wall along the Napoleonic Road, watching the sun set over the Gulf of Trieste. We talked about physics, of course, but also about life, careers, and the future. In those conversations he helped me find my own path. He offered advice with the wisdom of a mentor, the generosity of a friend, and the care of someone who felt almost like family.

There are very few people whom I met only a handful of times, yet whose presence left such a deep and lasting impression on me. Even now, I can recall almost every moment we spent together.

Six years after his passing, I remain grateful for those moments, for his guidance, for his friendship, and for everything I learned from him.

Thank you, Renaud.

4. Memories by Jeff Steinhauer

During the several years that I had the honor of knowing Renaud Parentani, he served as my consultant in the fields of real and analogue gravity. It was as if he had memorized an index into the thousands of equations and hundreds of figures in his vast library of publications. In response to almost any question I might ask, he immediately referred me to an equation or a figure in his works. An exception was when I asked Renaud for the phase of the product of the Bogoliubov coefficients α and β in Hawking radiation in a sonic black hole. This product is important, because its Fourier transform gives the correlations between the Hawking and partner particles, a measurable quantity. The phase appeared nowhere in his works, so Renaud and his student Florent Michel computed it in their next paper. They added the useful insight that due to the phase, the correlations appear to originate slightly away from the horizon.

In another case, one of Renaud's papers gave a criterion for determining whether analogue Hawking radiation is entangled. This criterion served as the basis for my measurements, but the measurements featured commuting observables only. This was puzzling since the well-known methods of measuring entanglement involve non-commuting observables. I asked Renaud about it, and he responded by writing a 16-page paper with his students Scott Robertson and Florent Michel, on the subject of assessing entanglement via commuting observables.

For me, and many others I believe, Renaud cannot be replaced.

5. Dedicated to the Memory of Renaud Parentani — by Uwe Fischer

I have met Renaud only a few times. However, all of these encounters left a deep impression about him with me.

The first time was in Tours, in 2002, when I came back from a Postdoc stay with Tony Leggett in Urbana-Champaign, Illinois, and Renaud organized a EU workshop there on the topic of cosmology in the laboratory. The way in which he spoke to me about Robert Brout was deeply admiring. Renaud both respected and knew how to recognize scientific achievement. With Renaud there was no “bullshitting”, he was questioning everything to the scientific core.

He told me that it is rare these days that people are correct in acknowledging scientific achievement. I quote from an e-mail exchange between us in November 2017 (we met in that year in July 2017 at SISSA/Trieste). Me: “Are there no more papers of yours which you feel we should cite? We included three now which we deemed the most important ones also for historical reasons, but you have made many of the most important contributions in the field in question, so I want to make sure”. Renaud: “Thanks for asking this question — quite unusual in our days”. It radiated a certain level of disillusion already. I would also like to stress that I never asked anyone before or after this instance a similar question.

When I met Renaud at the Trento analogue gravity meeting in 2019, we began a collaboration. He had, however, stopped communicating after September 2019 already. When I heard of Renaud the next time it was when Scott Robertson in May 2020 sent me an e-mail, telling me that Renaud had ended his own life. I was left deeply shocked.

I had myself a similar experience, in 2022, of deep depression, due to the massive disillusion about the working environment for foreign faculty in my physics department at Seoul National University, South Korea. It resulted in a two-month stay in psychiatry, the first month in closed psychiatry, after a suicide attempt. I would like to use this opportunity to leave a message to others. That when you are in a deep depression, one should accept help, and in fact should cry out for it. Else there is only one possible end when being trapped in a downward spiral. Renaud did not accept help and did not cry out.

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