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CAUGHT IN THE RELATIVITY WEB: MY 30 YEARS NEAR REMO'S WORLD LINE

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Princeton played an important role not only in the renaissance of general relativity that occurred in the 1960s and 1970s, but also in Remo's career. A brief overview is given of the background story through the lens of my own connections to Princeton and Remo and Rome and of my subsequent work in Bianchi cosmology and the geometry of spacetime splittings.

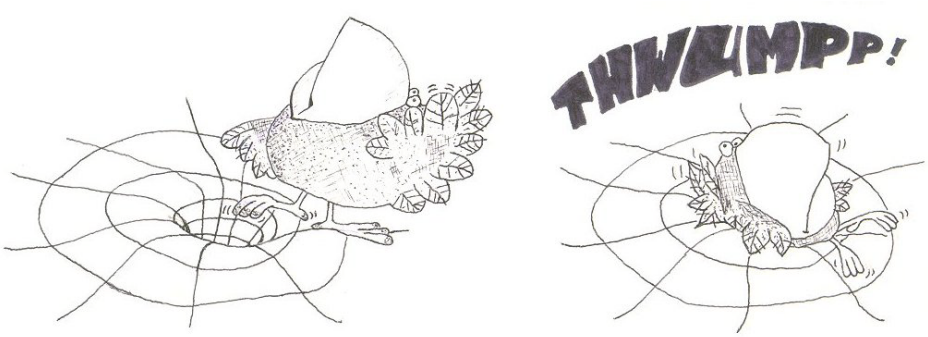

Figure 1. My entry into the field: stumbling into relativity (like falling into a black hole) ... or getting stuck like a fly in the web of extended GR? [*Illustration courtesy of drbobenterprises.com*]

1 Introduction

Thirty years ago in 1972 I was a 2nd year undergraduate physics student at Princeton University and I didn't know a whole lot about relativity when a 3rd year student named Jim Isenberg recruited me to fill the minimum number of students needed to offer a student initiated spring semester evening seminar. The topic was differential geometry for general relativity and the professor was some Italian physicist working with John Wheeler, then my modern physics survey course professor. This is how I met Remo and began my journey in both relativity and Italian life. It was one year after the famous article *Introducing the Black Hole* by Ruffini and Wheeler[1] had come out in *Physics Today*, but I was still in a different universe.

There were three other undergraduates who worked with Remo in those years:

- Bob Leach,[2] who worked on modeling Cygnus X-1 as a black hole system.
- Mark Johnston,[3] who worked on the geodesics around a rotating black hole,

Figure 2. mr bob: the Princeton undergraduate years. This was the early 1970s when long hair and bell-bottomed jeans were in style; bob had his hair in a ponytail.

whose original graphics became the logo of the Marcel Grossmann Meeting and inspired the TEST[4] sculpture by the artist Attilio Pierelli, awarded as a prize for the Marcel Grossmann Awards since 1985 (and which played a role in the story of Remo meeting his wife Anna).

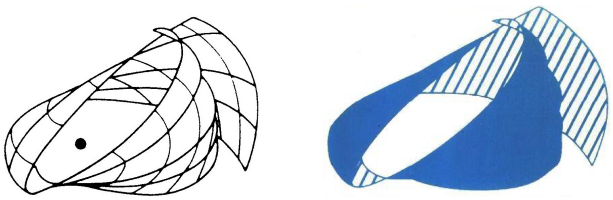

Figure 3. MG/ICRA logo

- Richard Hanni,[5] who began the work on the electrodynamical properties of black holes later carried on by Thibault Damour[6] who came to Princeton to do his Ph.D. thesis with Remo after I left. ("Rick" died tragically in the mid 1990s.)

I still recall the winter of 1973 when (visiting grad student) Nathalie Deruelle, Bob Leach and I drove out to the APS meeting in Chicago in a car rented by Remo, and I gave my first public talk, 10 minutes on Bianchi cosmology. This was during the famous gas crisis which led to long lines of cars at gas stations on the east coast of the US and to make sure we had enough gas to get out of New Jersey, we sent our only woman with a gas can to jump line and get some reserve gas, aided by her charming French accent. Nathalie had come to Princeton from France to study scalar fields near black holes for her doctoral thesis.[7] Later that year I met Demetri Christodoulou[8] who had already gotten his Ph.D. with Remo before I met Remo

myself. We were among the first and second generations of Remo's long history of collaborating with young students, inspiring them to enter relativity or relativistic astrophysics. There were others in those early years, but none that I had met then or that now remain in the field.

I went off to Berkeley sent by Remo to work with Abe Taub (who retired in 1978 when I received my Ph.D.), while Remo spent a few years traveling and then returned to Rome via Sicily with a hand from Edoardo Amaldi. The Physics Department group G9 (short for group 9) was born (reborn?) in 1978 with Remo as its director and later it spawned ICRA as its interface with the outside world. Rick Hanni was its first postdoc in 1978 and I followed in 1979 with Misao Sasaki,[9] when I met Luigi Stella,[10] with whom I shared an apartment while at the Harvard-Smithsonian Center for Astrophysics in Cambridge a few years later. It was then that TEX (and Digital VAX computers) first entered my life and soon changed the way we all work in documenting our research. To try to preserve some of the history of people who passed through the G9/ICRA group/center, I set up a web site with a people list and a photo history mostly from my own private photos. Contributions are welcome at my Villanova University website.[11] During the 1980s I was fortunate to be able to visit the group 3 or 4 times a year and felt like a part of a family as the group evolved and still had strong student social ties and some continuity, but as with all things that period passed and I am feeling more and more like an outsider during my continuing annual summer visits.

Our computing power started with a single DEC VT100 terminal on Valeria Ferrari's[12] desk in what is now the ICRA/G9 secretary room; eventually TEX came to Rome from CERN after my futile lobbying efforts at the Sapienza Computing Center failed, and technology exploded first through more VAX terminal access, then personal computers and the group's own microVAX, and finally to networked PC's and MAC's and the internet domain "icra.it" in the mid 1990s. [In the early days of the DECNET networked VAX computers in Italian physics, my plain TEX macro file `bobmacro.tex` spread farther in Italy than I could have imagined.]

I was also fortunate to have met George Coyne[13] and Bill Stoeger[14] of the Vatican Observatory through their connection with Remo. George had only become director in 1978 and in the summer of 1981, I was the first of many summer residence guests hosted by the "Specola Vaticana" in Castel Gandolfo. George has been a longtime friend and colleague and over the years has offered the unique collaboration of the Vatican Observatory in many ICRA scientific meetings, including arranging some memorable Papal audiences with Pope John Paul II.

2 Princeton

In all of this Princeton has really been the catalyst of Remo's career and my own, and the question naturally arises: why Princeton? And you may be wondering what all this has to do with the first part of my title: "Caught in the Relativity Web." [The "world line" phrase in my title comes from George Gamov's book *My World Line*[15] that has been shelved over Remo's office desk for many years; perhaps one day I will find the time to read it.]

The word "web" has entered our everyday vocabulary in the 1990s with a rich

imagery of a complicated configuration of many links through its use to describe the world wide web aspects of the internet. Science itself is built on an intricate web of human relationships, both directly through collaboration, friendships, positive and negative influences ... and indirectly through building on other peoples work—interaction at a distance both in space and in time. Scientific autobiographies or biographies focus on one thread in this web and its links with the whole. Scientific surveys try to illuminate a portion of this web through the lens of some particular topic, but it is too complicated to be captured in any single description, and certainly not very well in a linear discussion. The parable of the elephant being examined by four blind men who interpret it as four completely different objects comes to mind in this sense. What you see is not what you get but depends instead on how you look.

By a series of circumstances time does not permit examining, I arrived at Princeton in 1970 as an undergraduate student from a small rural village a few hours north in New York state. I was interested in mathematics and had already bumped into general relativity in high school at the public library where I had found this book by Lieber and Lieber on Einstein's general theory of relativity,[16] but did not even know calculus at the time. At Princeton I soon jumped from mathematics into physics and then fell into relativity as I have already explained above. But it was only much later that I understood what had prepared the ground for this golden age of relativity at Princeton.

Before going into that story, which is the larger web in which my own little neighborhood was spun, let me explain my insertion point and Remo's effect on my own career in mathematical relativity, not a particularly illustrious one, but sufficiently interesting to keep me entertained for three decades. Remo had come to Princeton to work with John Wheeler in 1967, first at the Institute for Advanced Study, then as an instructor and assistant professor at the university exactly during my four undergraduate years (1970–1974), and then a few more years traveling before returning to Italy in 1976. Wheeler had the idea of getting students to do some independent project within his courses to encourage them to go out and seek knowledge for themselves, so when Remo offered his seminar on differential geometry for relativity, he followed Wheeler's example. Not being a cosmology specialist, the Landau-Lifshitz[17] brief introduction to Bianchi cosmology peeked his interest, especially with the Italian connection, and he suggested a possible project of translating the original Bianchi paper[18] underlying the mathematics of the field, with him translating and dictating. I took the bait, but only had three semesters of college Spanish language study under my belt, and there was never time to actually follow through together that spring semester. I would eventually learn that time management was not one of Remo's strong points.

That summer, after a little Italian grammar study, I was able to get most of the translation done myself, with Remo then helping me over the rough spots (while I was working with my carpenter dad during the summer vacation). However, the result, typed up by a Jadwin Hall secretary, was never published or distributed. It did serve the purpose of hooking me on the study of Lie groups and their application to the dynamics of spatially homogeneous cosmological models, which I pursued for quite some time alone, and then later with my Swedish collaborator Kjell Rosquist

later joined by his student Claes Uggla, a match initially arranged by Malcolm MacCallum, who had been a postdoc of Taub at Berkeley while I was still at Princeton.

Twenty seven years later, Andrzej Krasinski as Golden Oldie editor of the journal *General Relativity and Gravitation* contacted me about translating that very same long article for their reprint series, so I scanned the equation-laden typewritten document, laboriously converting it to LaTeX and cleaned up the translation with my actual speaking knowledge of Italian acquired in the intervening years, aided greatly by Andrzej's careful proofreading collaboration comparing the original and collected works versions with my original and new versions for accuracy. [At this time Remo gave me a photocopy of Bianchi's book[19] on continuous groups which had undoubtedly greatly influenced Eisenhart.] In the meantime, I spent my first two decades of the past three working on Bianchi cosmology before being edged into another topic that Remo never engaged himself but was still curious about: spacetime splitting techniques, symbolized by the book of Cattaneo[20] that he had had in his possession for many years but did not particularly know what to do with. My own initiation into spacetime splitting came with the Misner, Thorne and Wheeler book *Gravitation*,[21] some proofs of which Wheeler had proudly presented in photocopy form in my modern physics class in 1973, and through my work in Bianchi cosmology where the lapse and shift play important roles in the dynamics.[22]

During that time as an undergraduate at Princeton, I began learning about Lie groups and came across Luther Eisenhart's books,[23] one of which was a Dover paperback on continuous groups that Remo gave to me (and when Abe Taub died in 1999, I got his original hardback edition) and which was perhaps the singlemost important book in my learning process for that topic. Although I vaguely knew Eisenhart had been associated with Princeton, I knew almost nothing about him. Remo also arranged for me to meet Gödel at the Institute for Advanced Study to discuss rotating cosmological models, and I found him still aware of the current literature and indeed was pointed by that conversation to the work of Misner's student Mike Ryan.[24] (As an undergraduate, I had not yet had much experience with the literature, and we did not have the great computer tools now available that make this so easy.) Little did I know that Eisenhart, as a differential geometer very much interested in relativity and in part responsible for building up the university math department in its early days, played a role in the story of the founding of the Institute in Princeton and its attraction for Einstein and Gödel and that he had invited Abe Taub, already interested in relativity and hoping to work with H.P. Robertson,[25] to come out to Princeton from Chicago to graduate school in mathematics during the Depression. (Abe had to hide his marriage to Cece at the time since graduate students were not allowed to be married.)

I did not know much about any of this history until the 1990s when I was able to visit Abe Taub quite a few years in succession because of the presence of my former collaborator Paolo Carini as a grad student at Stanford University in the GP–B group directed by Francis Everitt and the Stanford MG7 meeting and other ICRA activities, but I did not pay much attention to the details of Cece's stories and Abe was not a man of many words. When I finally did get interested in this history,

Abe was no longer in a condition to remember and died not long afterwards. While I was in the Fine Math/Physics library at Princeton in 1999 hunting down some hints of the connections between Eisenhart and Gödel's first use of Bianchi's work in rotating cosmology[26] followed immediately by Abe's work[27] (that eventually led to Remo sending me on to work with Abe from Princeton—again I had no idea I was remaining in the shadow of Eisenhart and Princeton even out there in Berkeley), by accident I stumbled across an oral history project *The Princeton Mathematics Community in the 1930s*[29] that Abe had participated in back in 1985 which finally opened my eyes up to the story of mathematics and Princeton, and explained how the scene had been set for me to fall into the trap once I got there myself.

Partly as a way of saving Abe's part in this story for posterity, I was moved to do another scanning and conversion project, this time to put the 700 some pages of that project on-line with supporting documents that detail the story leading up to the decade of the 1930s when the Princeton Mathematics department really rose to prominence at the national level and the Institute for Advanced Study was founded but shared the old Fine Hall with the Math Department for some 6 years. A chance meeting with historian of science and professor emeritus Charles Gillispie[31] suggested by a Fine Hall librarian facilitated this project. Only then did I learn the facinating details of Eisenhart, Veblen, Weyl, Einstein, Gödel, and that famous decade for Princeton mathematics, then closely associated with physics, with Robertson and Wigner and von Neumann holding joint appointments between the two departments, and Abe having taken both the math and physics comprehensive Ph.D. exams. Robertson had been brought to Princeton by Eisenhart, and had been important in the early theoretical foundations of relativistic cosmology. And of course it was Wheeler's[28] later friendship with Einstein in the 1950s that peeked his interest in relativity, ultimately leading to the first generation of theoretical relativists coming out of Princeton (Bryce de Witt, Charles Misner, among others) during that decade, and producing the leading theoretical group in general relativity in the US in the 1960s and early 1970s when I arrived.

3 Rome

The relativity tradition in Rome is also a long one, started by Tullio Levi-Civita shortly after the birth of general relativity, which captured his attention as a contemporary of Eisenhart in Princeton. Levi-Civita, as a mathematician (professor in rational mechanics) with a keen interest in physical problems, was instrumental in developing the tools of tensor calculus with his mentor and collaborator Gregorio Ricci Curbastro in the decades leading up to Einstein's introduction of his gravitational theory in 1916. Levi-Civita's parallel transport followed in 1917 and he moved from Padua to the Mathematics Department of the University of Rome in 1918 where he taught until 1938 when he was forced into retirement by fascism. His first year of university studies had been at the University of Rome as well.

While Levi-Civita was applying his methods to Einstein's theory in a long series of articles which appeared during the years 1917–1919,[34] Enrico Fermi was an extremely bright young student in a classics high school in Rome teaching himself mathematics and physics with his close friend and classmate Enrico Persico.

Fermi went off to university in Pisa where he wrote his first three scientific papers on general relativity, the third one leading to his named Fermi transport that remains with us today.[32,33] He then returned to Rome in 1922 for a few years, just in time for the second set of Levi-Civita lectures that later became Levi-Civita's book,[35] edited by Persico who had remained in Rome. This was another book I got from Remo, which I photocopied with his "Xeroxing" account in Jadwin in those first years in Princeton (when photocopying had finally come into its own), later acquiring the Dover reprint many years later.

Together Fermi and Persico became the first two professors of theoretical physics in Italy in 1927, when Fermi founded the famous "ragazzi di Via Panispera" school of modern physics, revitalizing the physics department of the University of Rome, later fleeing to the United States from fascism in 1938. Edoardo Amaldi,[36] one of the original "razazzi" (literally "boys", since they were all young scientists in this talented group), continued the tradition of Fermi rebuilding Italian physics after the war, eventually founding the Rome gravity wave group and helping Remo return to Rome as a professor of theoretical physics. Meanwhile, the mathematics relativity tradition was carried on by Levi-Civita's student Carlo Cattaneo[20] in the Rome Mathematics Department, who was succeeded by Giorgio Ferrarese.

In Rome over the past several decades Remo has introduced the exciting problems of relativistic astrophysics to many generations of university students through his physics department course in theoretical physics and he has gotten the best of them involved in current research in the field through the university laurea degree theses that he directed. I have been fortunate in being able to work with some of these students over the years. In 1988 one of them, Paolo Carini, was pondering the Landau-Lifshitz[17] definition of electric and magnetic field quantities in one of their textbook exercises and how they related to the quantities used by Hanni and Ruffini and later others in studying the electromagnetic properties of black holes. This opened up a whole can of worms about splitting spacetime, and Remo gave me Cattaneo's book on the topic to see what I could make of it.

We were soon joined by Donato Bini (laurea with Ferrari), who had a post-laurea fellowship with Ferrarese and got his physics Ph.D. degree under Remo (with my supervision), thus synthesizing the two Roman schools of relativity. Together we rediscovered the work in the 1950s of Møller, Cattaneo, Lichnerowicz and others that preceded the familiar "ADM approach"[38] to splitting the spacetime metric and the Einstein equations, and tried to introduce a common language that would encompass all the various approaches developed to use space-plus-time quantities in studying the properties of spacetimes and of the Einstein field equations.[39,40] We were also finally able to pin down what the Abramowicz school was doing with relativistic inertial forces and optical geometry[41] and understand how the various parts of the gravitational field contribute to the differential properties of the world lines of test particles following circular orbits.[42]

While none of these investigations have been fundamental, they have been helpful in shedding some light on how one interprets the properties of black hole spacetimes, and in my earlier work in Bianchi cosmology, in understanding the beautiful way in which the Bianchi spacetime symmetry influences the associated dynamics, keeping me in the Eisenhart tradition of pursuing the mathematics of general rel-

ativity and some of its interesting problems from the sidelines. The opportunity Remo has given me to have a second life in as a part-time American ex-patriate in Italy, together with the interesting topics he is responsible for directing me towards during the past thirty years, is something I will always be grateful for. Of course none of this would have been possible without the farsighted investment of my parents, Maureen and Ted Jantzen, in my education prior to arriving at Princeton in 1970. They prepared me and Remo came along to guide me along a path that has enabled me to experience many wonderful relationships with people in and out of Italy that have enriched my life considerably.

4 Marcel Grossmann

Of course this tale would not be complete without mentioning my involvement with Remo's Marcel Grossmann Meetings on General Relativity. Somehow I wound up as a somewhat trusted facilitator for these meetings after my direct experience in the local organizing committee of MG4 in Rome when my TEX ing skills came in handy for the Grossmann Awards. Even before that TEX proved useful leading up to MG3 in Shanghai (1982) when Remo needed to create a travel document for Tsvi Piran to use in place of his Israeli passport since Mainland China had no diplomatic ties with Israel and admitting Israeli participants proved to be a big stumbling block. This was before the world of Windows, laser printers and easy-to-use word processing software had opened up, and TEX output was produced on expensive Imagen electrostatic printers. I was just embarking into the TEX world at the time at the Harvard-Smithsonian Center for Astrophysics, as well as using a computer terminal for the first time, having last dealt with punch cards back in high school. Based on the wording of my US passport, we designed an academic travel document later signed by Abdus Salam of the Institute for Theoretical Physics at Trieste which was finally accepted as a way of avoiding direct confrontation with the Israeli passport issue.

By the time MG5 in Perth Australia came around in 1988, the internet and worldwide email was developing, although Australia, being so far from the rest of the world, had not yet arrived. I insisted that they at least request participants to list their email addresses on their registration forms and Remo agreed. Not knowing quite what to do with this data after it was compiled, we were fortunate that Malcolm MacCallum[43] stepped up to the plate with his idea to start a general relativity email mailing list, and this effort provided him with a sizable number of names for it. World Scientific took over publishing the proceedings from North Holland starting with MG5, but it did not have a professional proceedings TEX or LATEX macro style file until MG8 (in spite of many complaints I had made in the meantime). I wrote an amateur macro file that we used for MG7 based on the unsatisfactory World Scientific example files, and we lost an inch of vertical space on every page because of their failure to take the matter seriously. My front and back matter proceedings macros written then have proved more long-lived.

For MG7 Remo appointed me chairperson of the newly created International Coordinating Committee for the MG Meetings (an offer I could not refuse), which via email coordinates a network of volunteers all over the world whose cooperation

helps make these meetings possible. My role in this position as a facilitor for Remo might be compared to the way in which Grossmann the mathematician helped Einstein the physicist with the tools he needed to formulate general relativity. (Okay, let's not carry the analogy too far! It's the mathematician/physicist collaboration that I'm aiming at here, which is reflected in the MG theme of bringing together a diverse community of scientists for exchanging ideas.)

By MG9 we were ready to take advantage of the world wide web, with online submission of registrations, abstracts, and conference proceedings all handled automatically. Clearly over the past 30 or 40 years Remo and I have seen an incredible evolution in the way we use technology as scientists, and he has always recognized its importance as ICRA has grown since its inception in the 1980s. He has also made these tools available to young students who have gotten a good initiation into scientific research through the opportunities he has created, even if some may have later drifted into other fields. I hope he is able to continue doing this for many years to come.

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