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KEIJO KAJANTIE AND HEAVY ION COLLISIONS

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Keijo and I met for the first time in 1980 on the first visit to Europe I had ever made. Helmut Satz had arranged a meeting at Bielefeld on exotic properties of matter, sometimes referred to as the first Quark Matter meeting, but I understand there are other contenders. It was the beginning nevertheless of several very influential meetings organized by Helmut at ZIF in Bielefeld without which I am certain there would be no ultra-relativistic heavy ion community.

At the meeting, I was supposed to talk about computations I had done several years earlier with Barry Freedman on the properties of zero temperature, high density quark matter. I was really more excited at that time about work Ben Svetitsky and I had been doing about finite T Monte-Carlo simulations and work with Peter Koehler and Ramesh Anishetty on ultrarelativistic heavy ion collisions. I was successful in getting the first on the program but not the second. I made a point of trying to advertize the latter work in private.

Somehow I got to know one of the young Finnish theorists, Carl Kallman. We had a common interest: The Ambassador Club. It was one of the few places for night life in Bielefeld, complete with a sliding window through which they carefully checked you out before being able to enter. We always got in, somewhat to our surprise. Carl, Andrei Linde and myself went there several nights. Carl was interested in QCD at high temperature, and so the three of us would talk long into the morning.

It turned out that Keijo was rooming with Carl. Everyone who works with Keijo knows that he is an early riser. He is often up before the sun rises, which was fine until one night we didn't stay up late enough. Carl came home before Keijo was up. I learned from Carl the next day how serious Keijo was about protecting his sleep, and that in spite of his Finnish reserve could get a little excited.

I initially thought of Keijo as quiet and reserved. This seemed logical-the stereotype of Finns is that they are reserved to the point of shyness. Much later during a visit to Helsinki, I discovered that young people at Helsinki had a completely different view of him. In response to my remark that he was typically Finnish, one of them asked me if I had seen him at the train station yesterday. It seemed that he had shocked his students by wearing a colorful short sleaved shirt, maybe not Hawaiian, but along those lines.

As I came to know both Keijo and Finland better, I realized that a quiet exterior can mask bold originality, an ability to cut through to the solution of a problem in a startingly new way. A very close friend of Keijo, who will remain nameless for reasons of confidentiality, worked in public health and shared with me a story which illustrates this. Helsinki, like most large cities, has a problem with pigeons. Pigeons are of course filthy birds that blight urban landscapes with their droppings and carry a number of diseases. Most cities make some effort to control the birds without offending the sentimental types, but none has discovered a solution as clever as that quietly put into effect by the public health authorities in Finland. They offered a secret bounty for dead pigeons, so long as the birds were killed during hours when normal citizens were asleep, I think it was between two and five A. M. Their agents were alcoholics, the only people generally out at such hours. The Finns killed two birds with one stone-the pigeons disappeared, and those informal assistants of the public health department had a useful stipend, helping to keep them mellow in the not-quite dark early hours of the Finnish summer.

Keijo became interested in the work which we had been doing on heavy ion collisions. He and I spent some time talking, and Keijo got very excited about the possibility of testing some of the ideas people had been developing about high energy density matter in heavy ion collisions. Not too long after this meeting, he and Hannu Miettinen wrote their classic paper on production of photons and dileptons[1].

This was one of the first few papers suggesting that photons and dileptons could be useful probes of matter produced in heavy ion collision. It, along with the paper by Shuryak, had a very strong effect on the field[3]. These works make use of the observation that such electormagnetically produced particles will not interact strongly with the matter once they are produced. They are therefore useful probes of the matter when it is hottest and densest as they can easily escape the production region in the earliest stages of the collision.

While working with Hannu, Keijo was at the same time getting young people excited about heavy ion collisions and the properties of high density matter. This is a pattern which I have seen consistently throughout Keijo's career. He himself gets excited about a new idea. He starts collaborating with senior people abroad and at his own institute. But simultaneously and most importantly, he educates and brings in a community of young scientists.

Finland has a surprisingly strong interest in physics. Finnish science is way off scale in impact compared to the size of the country. It is because of Keijo

and a few of his colleagues that this is true. I remember a few months ago reading in the New York Times about Helsinki as the model for the future of high tech cities, with rapid and modern telecommunications capabilities, and just about everything available and used which is hi tech. Could it be the cold winters bringing out the creative imagination?

Not long afterwards, Keijo, Claus Montonen and Esko Pietarinen did their classic analysis of the phase transition in SU(3) lattice gauge theory. This was, I believe, the first SU(3) Monte-Carlo computation and its results were remarkable: The phase transition was of first order. This is different from SU(2) gauge theory where it is second order. Of course if the confinement-deconfinement phase transition is truly of first order, there are order one consequences. First order phase transitions generate large scale density fluctuations and these could have consequences in both heavy ion collisions and in cosmology.

The issue of whether or not there is a first order phase transition when the effect of dynamical quarks are included is still controversial. At high baryon number density, there are convincing arguments that the transition is first order. At high temperature and low baryon number density, the answer depends on details such as the value of the strange quark mass, and various computations which include effects such as these have not entirely reached consensus. The results of the Helsinki group are nevertheless well established for the pure gauge theory and have led to a deeper understanding of the nature of confinement.

As a side note: Finland is well known for its low temperatures, and for its work on low temperature physics. At one point I believe Finland held the record for the lowest temperature ever recorded in a laboratory. Keijo's work tied down a claim on the other end of the spectrum, the highest temperatures ever studied. How did this strange fascination of Keijo's arise? I can imagine him as a little boy running from the sauna to the frozen lake....

Keijo also got involved with my former colleague Joe Kapusta from the University of Minnesota in an attempt to understand the gluon propagator[4]. One of the problems was to understand the behavior of the propagator at soft momentum. Did one somehow generate magnetic as well as electric screening? This was seminal work of great impact, and ultimately led to the Braaten-Pisarski hard thermal loop action[9]. At the time, there were issues related to understanding how long distance scattering singularities were cured in a hot quark gluon plasma, and whether or not anyone could make sense of perturbation theory beyond a certain order. The work by Keijo and Joe was one of the first systematic studies. It was also an outgrowth of Keijo's much earlier work with Claus Montonen on the plasmon effect in gauge theory[5].

It was brave work, since they chose to work in axial gauge $A^0 = 0$. This gauge has well known problems at zero frequency $k^0 = 0$ problems which one must find some way to regulate. Unfortunately, at finite temperature, there is exact zero Matsubara frequency. I have always wanted to get Keijo drunk some night and figure out how he regulated away this singularity. Joe would never tell me. Keijo later followed this work up with another well known sem-

inal paper in this field with Ulrich Heinz and T. Toimela,[6] which led to the later work with Elze and various combinations of previous collaborators[7]-[8]. These works developed analytic tools for understanding real time response and Debye screening and used a variety of methods including lattice Monte-Carlo simulation.

Keijo and I were at the second of the Bielefeld meetings in May of 1982. I had recently arrived in Helsinki and was visiting Keijo there for several months. At this time, Bjorken had written his classic paper on ultra-relativistic heavy ion collisions[10]. I remember giving a talk at the Bielefeld and getting thoroughly roasted by Leon van Hove for not referring to Shuryak's work on the subject, work with which at that time I was unfamiliar[11]. Keijo was talking about parameters and signals for quark-gluon plasma formation in heavy ion collisions. There was lots of discussion initiated by Bill Willis about trying to keep the ISR open so that one could do heavy ion experiments. Things were already rolling in this business, although even now we have yet to have a heavy ion collide in RHIC, and it was many years before the first results from CERN.

When I got to Helsinki, Keijo was immediately trying to understand what it was that Bjorken had done. We wanted to generalize his results to the fragmentation region of heavy ion collisions. This understanding would be very important at experiments if they were done at the CERN SPS. We wrote a couple of papers together on this subject and I think we more or less understood how to set up initial conditions for hydrodynamic equations[12].

In the meantime, Keijo was leading the charge of people who were trying to sort out signals for the production of a quark gluon plasma. With Miettinen, he considered di-muon production[13]. He also began a long and extremely fruitful collaboration with Vesa Ruuskanen on hydrodynamics of heavy ion collisions[15]. This has been a recurring theme in his career[14].

Keijo is probably the strongest collaborator with which I have ever worked. He is the kind of person who can turn a half thought out idea into a precise statement. We would work for hours together, Keijo forcing us to think through problems in more depth and with more precision.

I also discovered that Keijo liked fine cigars. In those days, we could sit in Keijo's office, turn on the red light, and have a really good smoke. Let me explain about the red light. In Helsinki University they have a system which I wish could be implemented everywhere. On the door of a professors office, there are three lights, red green and yellow. The professor controls which are on. Green means to feel free to come in. Yellow means come in but it better be important. Red means the professor is very busy and should under no circumstances be bothered.

Speaking of Reds: Finland at the turn of the century had a very brutal civil war that was the mirror image of what happened in Russia. In Finland the whites won. A central figure in this battle was Mannerheim, who organized the white guards and put down the reds. It was through the efforts of Mannerheim that Finland was able to successfully declare her independence from Russia.

Mannerheim later became president of Finland, and led the Finnish army in its defense against the Russians prior to and during World War II. He is a hero to most Finns, and Keijo has a bust of Mannerheim on his desk at home. (I have been told that Keijo inherited the bust from his father and simply kept it where it used to be.)

When I was visiting Finland many years ago, every year there was a May Day rally of the communist in the church square in downtown Helsinki. Old Communists and their fellow travelers from all over Finland arrived in the square, and sang the Internationale. When I was there it was largely a rally of old survivors of the civil war, and was touching to watch. Keijo told me where I could get Cuban cigars so I could go to the rally. (Keijo did not go.) At one point my cigar went out, and I walked into an alley by the church, turned my back to the wind and snuggled into a corner to light the cigar. A distinguished senior lady who was walking by saw my back, while I was hunched over lighting the cigar, and said, "The Communists, they have no respect for religion."

Keijo was a patriotic Finn. I learned that I could buy cheap Russian translations of physics books at the Kaansan Kulturi. I did not know what and I could not find the store in the phone book. I asked some of the young people in Helsinki University how to find it and later discovered that Keijo had been somewhat embarrassed. Kaansan Kulturi means People's Culture, and yes, you can guess who ran the bookstore.

Together with Keijo, Miklos Gyulassy and Hannu Kurki-Suonio, a brilliant young student of Keijo's, we asked the question as to what the consequences of first order phase transition might be[16]. We worked out how nucleation bubbles would expand and understood the difference between detonation and deflagration bubbles. This was one of the most enjoyable projects I have ever worked on. Keijo was the one who had the physical understanding of the deflagration bubbles and how shocks formed, and as well carefully developed the theory of the rarefraction front which follows a detonation. I've always been proud of what our collaboration produced. The paper has survived the test of time. It has been useful in astrophysics and in the theory of heavy ion collisions. I must say that I was disappointed when no one seemed to want to put a racy title on the paper, but that is another story.

During this visit I met Riitta, Keijo's wife. Riitta is a good humored woman of strong character. A few years later she was at a meeting I had organized in Seattle. One night at a party we threw, she met a young physicist with very long hair who was suntanned to a bronzish brown. When going home with Keijo that night, she asked who was the American Indian at the party. Turns out it was Carl Kallman, the young physicist who had introduced Keijo and me at Bielefeld years before. Riitta was always fond of this story.

During the next several years, Keijo continued his work on heavy ions. He wrote one of the first papers on how matter was formed in heavy ion collisions[17]. This work went largely unnoticed, but is important since it shows how clearly Keijo understood the dynamics of matter formation. This area is

having a rebirth now within the context of small x physics. Keijo with Rudy Hwa tried to understand the relations between initial temperature and thermalization time. This understanding is crucial as it eliminates a great deal of uncertainty in initial conditions[18].

Keijo and Vesa Ruuskanen and other members of the Finnish Mob gained a virtual monopoly on hydrodynamical simulation of heavy ion collisions[19]-[22]. Keijo and collaborators were the first to look at flow effects on dilepton emission and strangeness production.

The friendship of Keijo and Vesa went back a long time, and occasionally I had a glimpse of the years in which they were lads together. Sometime back in the late 80's, I was traveling by train with Keijo to Jyvaskyla. His old friend was waiting for us at the station. When we got off at the depot, we could not help noticing a couple of young men attempting to stand upright near the fence. To my surprise, the eyes of both my companions softened. Keijo remarked, "That really brings back good memories." Vesa looked back and nodded "Indeed it does."

Keijo's international collaborations became wider and wider. One of his most famous works was with R. Hwa, where they used their initial time computations to get an estimate of the photon and dilepton rates[23]. This interest was stimulated in part by a paper by Tuomo Toimela and myself on photon and dilepton emission[24]. We had done a lot of formal work in relating dipepton emission to computations of the thermal electromagnetic correlation function, and had ended the paper concluding there was a tremendous uncertainty in rates. Given Keijo's past interest in the problem, he got very excited and discovered that there really was not so much uncertainty.

In the late 80's Keijo began his work on minijets in a paper together with Peter Landshoff[25]. The idea and hope was that in heavy ion collisions, the dominant form of energy deposition is the productions of a multitude of semihard to hard particles, the so called mini-jets. I was initially very sceptical of this claim, but now believe it to be true. This idea was largely pushed by Keijo and the Helsinki Mob[26] (strongly reinforced by the active participation of the Jyvaskyla Affiliate presently managed by Vesa and Kari Eskola). This picture leads to a relation between the physics of deep inelastic scattering, and unitarization of high energy scattering. I think this seminal work will be very important in an ultimate first principles understanding of the high energy limit of hadronic processes within QCD. It is very important work.

I am now embarrassed by my failure to immediately recognize the importance of this particular work of Keijo's, but after all such lack of initial appreciation is not uncommon in our field. It is perhaps the rule that the first reaction to anything truly ground breaking is that it is wrong. The second stage is to admit that it is right, but believe that one had thought of it oneself earlier. The last stage is to accept it as trivial and obvious. Only after much time does a breakthrough come to be recognized as important.

Not long afterwards, Keijo and I both became less interested in heavy ion

physics, and became interested in different areas of astrophysics. I understand that Misha Shaposhnikov will describe that part of Keijo's career. Keijo and I had some similar interests during that period, we even worked together on a paper-but largely were going in different directions. Now we both have a renewed interest in heavy ion physics, an areas deeply influenced by Keijo's seminal work. I expect that over the next decade, strong parallel interests will draw us into active collaboration again.

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