Helmut Satz and the Theory of Strongly Interacting Matter at Very High Energy Density*

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Abstract

Helmut Satz has had an extraordinary influence on the theoretical and experimental development in studies of the Quark Gluon Plasma. I discuss here these scientific accomplishments, and reminisce about Helmut and my friendship with him.

1 Introduction

I first met Helmut Satz in 1980, at a meeting he organized at the Center for Interdisciplinary Studies (ZiF) in Bielefeld, Germany. This meeting proved to be the landmark in the development of theoretical ideas related to the properties of matter at very high energy density, and I shall describe it in greater detail below. More important for me personally, it marked my first meeting with Helmut, and the beginning of our continuing friendship. I will describe Helmut and his accomplishments below, and try to sketch something of Helmut's character and personality.

*This paper is based in part on a talk given in 2006 at a meeting at Brookhaven National Laboratory to celebrate the 70'th birthday of Helmut Satz

Figure 1: (a) Helmut and his horse. (b) From left to right: Helmut, Johann Rafelski (Professor at University of Arizona), Tatiana Faberge (former Cern theory group Secretary and owner of the rights to Faberge eggs) and Rolf Hagedorn.

In the picture shown in Fig. 1a you see Helmut as he is now, astride his horse. He is an excellent rider, something that would surprise no one who knows him. Whatever Helmut does, he does with style and intensity.

2 Helmut's Early Years

Helmut Satz was born in Germany in April 1936, during Hitler's rise to power and shortly before the beginning of the second world war. His father fought in this war and somehow survived it – but did not survive Stalin. He was "interned" by the Russians after the war, and never heard from again. It is difficult to estimate the amount of human misery that each of the great "idealists", Stalin and Hitler, inflicted upon humanity. The impact of that war on Helmut and his family was felt with varying intensity by families from almost all groups of those involved in the war that was the background of his childhood.

After the war, his mother moved to the United States with her three young children; Helmut was educated there. His American accent is flawless, but his choice of words is often more precise and vivid than most Americans, an advantage often seen in those who know more than one language perfectly. Helmut attended Michigan State University where he received his Bachelor of Science degree in 1956 and a Master of Science in Physics in 1959. He returned to Germany to get a doctorate at Hamburg University in 1963. He habilitated in 1967.

Helmut did postdoctoral work at DESY, UCLA, CERN and Helsinki. During his time in Helsinki, he and Keijo Kajantie, one of the icons of Finnish theoretical physics, became good friends. He accepted a position as a Professor of Theoretical Physics at the University of Bielefeld in 1971, and remained a professor there until his retirement. He also had joint affiliations with Brookhaven National Laboratory from 1985-1992, and with CERN from 1989-1994.

The earliest work of which I am aware by Helmut was "Sum Rules for Multi-Pion Production Processes".[1] At this time people were mystified by the fact that the exponential slope characteristic of particle production was universal. Hagedorn suggested in 1965 that the matter produced in hadron collisions was thermally equilibrated at a universal temperature, the Hagedorn temperature as it is now called.[2] This proposal remains controversial, although the weight of opinion is that such matter is not thermally equilibrated. It most probably behaves this way because particle production saturates phase space, and as such, the matter appears with thermal distributions even though the underlying matter is not equilibrated. Nevertheless, Hagedorn made a remarkable conjecture that because of the lack of a change of temperature as one increased the energy of collisions, and hence the energy density of the matter produced, there must be a limiting temperature. This lack of increasing temperature with increasing energy of collision can be understood as arising from an exponentially growing density of states, that causes the energy density of matter to diverge at a fixed temperature. We understand this now as an approximate statement: If the number of color of quarks and gluons were infinite, then it would take an infinite energy density to make unconfined quarks and gluons. Therefore in this limit there must be some limiting temperature, corresponding to the temperature at which ordinary strongly interacting particle become ionized into their constituents of quark and gluons. [3] The Hagedorn limit-

ing temperature is the de-confinement temperature. Helmut, together with Prof. Hagedorn, is shown in Fig. 1b.

Helmut was deeply affected by the arguments of Hagedorn. He was, I believe, much taken with the possibility that one might use high energy collisions to make matter at very high energy density. During his postdoctoral appointments at CERN and Helsinki, and during his early years at Bielefeld, he wrote many papers about multi-particle production. He maintained strong ties with the theoretical physics group at Helsinki, and in 1973 wrote his first paper with the group at the Bogolyubov Institute for Theoretical Physics in the Ukraine.[4] Gennady Zinovyev from Kiev was to become a very good friend of Helmut, and through Helmut, a good friend of mine.

In the late 70's, Helmut became intrigued with the ideas of phase transitions in strongly interacting matter. This led to his later work in lattice gauge theory and the phenomenology of heavy ion collisions.

It is fair to say that many of the ideas developed in these early days were applied without worrying about whether or not matter produced in proton-proton or for that matter electron-positron collisions was really thermalized, Now most would agree that this is not the case, at least for the energies achievable to date. This consensus became more firmly established after the successes of the parton model and the underlying theory of strong interactions, Quantum Chromodynamics (QCD). To put it simply, the ideas Helmut was pursuing seemed to be increasingly remote from possible testing in experiments that might be done in existing accelerators.

Helmut and others thus began to think about collisions of ultrarelativistic nuclei, where the sizes of the nuclei might be large enough so that the matter might become thermalized before falling apart. It was at this point in his thinking that Helmut and I got to know one another, and our interest in such collisions developed. Before proceeding to describe that development, I would first like to tell the reader a little about Bielefeld, the city where Helmut spent most of his academic career.

3 Bielefeld

Bielefeld is the cultural capital of Westphalia, in northwestern Germany. The area entered recorded history largely because of Arminius, known locally as Hermann the German. Hermann was a tribal chief

who defeated the Roman army when the Romans were trying to conquer the area east of the Rhine River. He was an ambitious politician, and unsuccessfully tried to unify the local German tribes. One of his notable diplomatic gestures was to send the severed head of the Roman general he had defeated to the King of Bohemia, who politely declined the gift and forwarded it on to Rome. The statue of Hermann the German sits on a ridge line near Bielefeld as shown in Fig. 2a , and Helmut often takes visitors there.

Westphalia was also unfortunate to be located in the border region between Catholic and Protestant areas during the 30 Years War. A Westphalian village might be first under the rule of one side and then the other. Each time it changed hands, the leading figures in public and spiritual life would be cruelly tortured to death for their heresies, oftentimes by being burnt to death slowly while imprisoned in iron cages. Needless to say, villages in the border area might be conquered and re-conquered many times. It was not a good time to be involved in politics, earthly or spiritual. It still can be risky for good people to enter into politics, although the consequences may be less catastrophic. Helmut often will take a visitor up to Sparrenburg castle, with its wonderful view shown in Fig. 2b, and its interesting historical displays.

Helmut will occasionally take a good friend out to one of the excellent restaurants that serve Westphalian cuisine. Famous local dishes are blood sausage and blood pancakes, both made from pigs' blood. When you are out with Helmut, he will carefully read through the menu, translating German into English if needed, commenting upon how fresh the sausages and pancakes are. Of course, you will order them. I found them to be quite extraordinary.

The University of Bielefeld is located entirely within a single enormous building. It looks somewhat like a giant lego construction from the exterior, but has a spacious feel inside. The main floor has a huge cafeteria, where one can choose from among the main dishes that appear on a belt that seems to emerge from the bowels of the earth. As Bielefeld was the first place I visited in Europe, seeing the cafeteria at Bielefeld led to unrealistic expectations of German efficiency. Photos of the University of Bielefeld are shown in Fig. 3.

Across the street from the University is the Center for Interdisciplinary Research (Zentrum für Interdisziplinäre Forschung). This is a center that supports both long-term and short-term visits of scholars. It is a bit like the Institute for Advanced Study in Princeton, serving

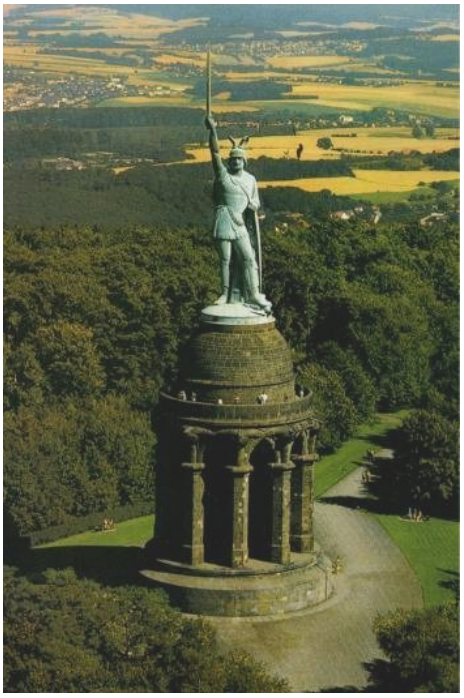

Figure 2: (a)The statue of Hermann the German in Westphalia. (b) Historic Sparrenburg Castle and Its Dungeon of Horrors.

Figure 3: (a) The University of Bielefeld. (b) The mall of the University.

not just different fields of physics but many other academic disciplines. When I first met Helmut, he was running a program at ZiF. Helmut

was acting Director of ZiF (1974-1980) when he organized the 1980 conference.

I was much impressed by ZiF. There was a beer machine right inside the front door. There are also comfortable living quarters, a cafeteria, a swimming pool, and a sauna. The living quarters are quite interesting. The building was decorated I believe in the 70's with the conception at that time of the most modern furniture and furnishings. Staying there is a bit like being part of a living installation at the Pompidou Centre.

Immediately behind ZiF is a forest. If while staying at ZiF you are invited to Helmut's house for dinner, and if you know your way, you can walk through the woods to get there. If you do not know the way, you may be lost for a very long time. Some photos of ZiF are shown in Fig. 4

Figure 4: (a) The exterior of ZiF (b) The interior of ZiF.

4 The Statistical Mechanics of Quarks and Hadrons

The ZiF meeting at which Helmut and I met in 1980 was The Statistical Mechanics of Quarks and Hadrons. That meeting marked the beginning of serious attention to theoretical work on the properties of matter at high energy density. It was both seminal within theory, and influential in the development of experimental programs to study such matter at Brookhaven National Laboratory and at CERN. It brought

together a number of distinguished senior scientists such T. D. Lee from Columbia University, "Papa" Migdal from the Landau Institute, Gordon Baym from the Universiy of Illinois, Keijo Kajantie from the University of Helsinki, and Ebs Hilf – then at Darmstadt, now at Oldenburg. The younger generation included Jorgen Randrup from LBL, Andre Linde from the Lebedev Institute, Rob Pisarski (now at BNL), Ludwik Turko and Krzysztof Redlich (now both at Wroclaw). Frithjof Karsch was at that time a young graduate student at Bielefeld. A photo at the reception of the meeting is shown in Fig. 5a, and a photo of Helmut from about that time is shown in Fig. 5b.

I came to Europe for the first time to attend this meeting. Helmut had obtained funds that paid for the travel and staying expenses of participants. I received the invitation far in advance of the meeting, and Helmut invited me to speak there on work I had done with Barry Freedman on computing the properties of cold matter at very high baryon density[5]. I had done this a few years before the meeting and felt it was a little stale, so I began two new projects for the meeting. One was with Ben Svetitsky, using Monte Carlo methods to show the confinement-deconfinement transition in QCD.[6] This paper, along with the co-temporaneous work of Kuti. et. al, was the first in this area.[7] Also, together with Peter Koehler and Ramesh Anishetty, I computed the energy and baryon densities of matter expected in ultra-relativistic heavy ion collisions.[8] All of these works are described for the non-expert on the physics page of my web site at www.larrymclerran.com.

I wanted to get the new works on the agenda, and needed to talk with Helmut. I am afraid I was pushy, and I should have told Helmut about the talks in advance, but this was the first such meeting I had ever attended and I did not know what the proper behavior was.

I was much struck by Helmut when I met him. Anyone who has even briefly encountered Helmut knows how charismatic he is. He speaks very clearly, and each word is carefully thought out before it is spoken. He has very penetrating blue eyes which contrast with his blond hair.

Somehow I conquered my fears, and succeeded in getting the talk about the lattice Monte Carlo computations on the agenda. The subject of heavy ion collisions was discussed in private, mainly with Keijo Kajantie, who immediately understood the point, and we developed a long term friendship and collaboration.

There were many exciting talks at this meeting: T. D. Lee talked

Figure 5: (a) From left to right: "Papa" Migdal, Gordon Baym (background), Jorgen Randrup (far background), T. D. Lee, the Mayor of Bielefeld, Helmut. (b) Helmut at about the time of the meeting in Beilefeld .

about high density Lee Wick matter, Rob Pisarski about instantons at finite temperature. "Papa" Migdal presented his work on pion condensation. Gordon Baym discussed quark stars. Andre Linde talked about the breakdown of perturbation theory at finite temperature due to infrared divergences, and about his early ideas on inflationary cosmology. We younger scientists got to know one another and became good friends during late night sessions held informally at the infamous "Ambassadors Club". The Ambassador Club was an all night bar, where to get in you first needed to knock on the door. A slit in the door would open, the bouncer would look you over, and if you met his approval he would let you in.

"Papa" Migdal seemed to like to take saunas, and enjoyed the swimming pool. Later we discovered that the sauna was coed, and was occasionally used by undergrads from the university.

There were some fireworks at the meeting as well. A very young Krzysztof Redlich gave a talk about work he was doing on QCD at finite temperature for systems of finite size. At that time Krzysztof could barely speak English, but he gave an understandable and reasonable talk. At the end of his presentation, an older physicist attacked him strongly, speaking very quickly, and Krzysztof with his poor En-

glsih could not understand the questions. I think there was a lot of gamesmanship in the questions, but in any case, at one point Ebs Hilf stood up and angrily began asking the older physicist questions, whereupon the older physicist backed down. I became good friends with Ebs. I found this incident typical of the man Ebs is. He is ready for a good fight, if there is a good side for which to fight.

The work that I presented on lattice computations of the de-confinement-confinement transition at finite temperature,[6] and the talk by Janos Polonyi on the same subject,[7] got much attention. TD Lee understood the point immediately: Properties of QCD at finite temperature could be determined from first principles, numerically.

Helmut and his group had been planning to do such computations but had not got them working before the meeting in Bielefeld. In later work done by Helmut and his group, and that done by his student Frithjof Karsch, they did the comprehensive early studies of QCD at finite temperature and now do the world's strongest work on finite temperature and density QCD. They did seminal studies of $SU(2)$ Yang-Mills theory at finite temperature.[9] They were the first to include quarks in such computations.[10] They established that the deconfinement phase transition in QCD without fermions is a first order phase transition and determined the latent heat of the transition.[11] They determined the critical behaviour of the $SU(2)$ phase transition.[12] They later began studying the effect of the de-confinement phase transitions on heavy quarks and did the seminal work in this area.[13]. All of this work was done within ten years of the meeting at Bielefeld, and represents creative developments that have led to the more detailed and quantitative studies of modern times. Pictures of Frithjof Karsch and Helmut, Fig. 6a, and Rajiv Gavai and Helmut, Fig. 6b from that era of the development of lattice gauge theory are shown below.

The meeting at Bielefeld was remarkable not only for the science it generated, but also for promoting the careers of young scientists, many from at that time developing countries such as Russia, India, Poland, and China. Young scientists were strongly represented in both attendance and talks. This was typical of Helmut, who sought out and supported young talent from around the world throughout his career.


Figure 6: (a) Helmut and Frithjof Karsch in the early 80's (b) Helmut and Rajiv Gavai in the 80's .

5 Getting to Know Helmut: 1980-1986

From 1980-1986, I came to know Helmut from several different perspectives. He had a second meeting at Bielefeld in 1982, where the ISR was discussed as a possible place to do heavy ion experiments. This was a last-ditch effort as the ISR was being closed down at CERN and the effort failed, but it ultimately helped in developing similar programs at CERN and BNL.

After that meeting, I held a workshop in Seattle that Helmut attended. We hiked to the top of Granite Mountain, which is a steep hike near Snoqualmie pass. It is a long trail and a good workout. When you get to the top, you are tired and sweaty. At the summit there is a magnificent view. This was the first of many hikes we have done in the Alps, on Mount Rainier and the Cascades.

We also had a dinner party at my house. My wife Alice has always enjoyed Helmut at the table. He always has good stories, and the ladies are charmed. That night I learned that Helmut was a gifted dancer. When Alice and another guest – who like Alice loved the classic rapid Viennese waltzes – learned that Helmut enjoyed waltzing, after dinner they rearranged the furniture to create a dance floor and put on suitable music. Helmut took turns dancing with each of them until both women were almost out of breath. All that mountain hiking kept him in remarkable condition!

We also would regularly go to the Hirschegg meeting, a small meeting on the ski slopes held at the Waldemar-Peterson house in the

Kleinwalsertal of Austria. The meeting is run by the Technical University in Darmstadt; the Waldemar-Peterson house is owned by the University. I would sometimes go back-country skiing with Keijo Kajantie and Helmut. Helmut is a great cross country skier; I think his time in Finland allowed him to develop this skill. Once skiing with Helmut and Vesa Ruuskanen (from the University of Jyvaskyla), I remember coming to a steep hill. Vesa went down it without hesitation. Helmut looked for a second or two and then went down. I stood there for a few minutes, asking myself how I get into such messes, but eventually made it down, still standing up at the end. In the evening at Waldemar-Peterson House, we would sit around drinking wine or beer and talking about physics.

In 1985, Helmut became a staff member at Brookhaven National Laboratory in addition to his position at the University of Bielefeld. This took place shortly after the Long Range Plan for Nuclear Physics in the US had recommended that the Relativistic Heavy Ion Accelerator be built at BNL. I would often meet him at BNL, where he provided leadership both for the experimentalists and theorists. Helmut played an absolutely essential role in motivating the experiments at RHIC, and at the CERN SPS and LHC. Helmut later became a staff member at CERN for six years. Without him, it is quite likely there would be no heavy ion program at RHIC or CERN.

I grew to understand Helmut's style of doing physics, which is quite different from my own. Helmut likes to take a problem and resolve it in terms of its simplest features. He then makes an intuitively plausible framework in which to embed these simple features. He presents the idea with clarity and flair, and with little mathematics. A presentation drawn from such simple elements is quite exciting.

6 Helmut and J/Ψ Suppression

Helmut's best known contribution to theoretical nuclear physics is his argument that the J/Ψ resonance would melt in hot matter, and therefore if hot matter was made in heavy ion collisions, one would see a suppressed number relative to expectations arising from proton-proton collisions. The classic paper was done with Tetsuo Matsui,[14], and there were many subsequent developments in collaboration with Dima Kharzeev.[15]. Helmut, Tetsuo and Dima are shown in Fig. 7 The situation is a little like building a snowman on a cold day, as

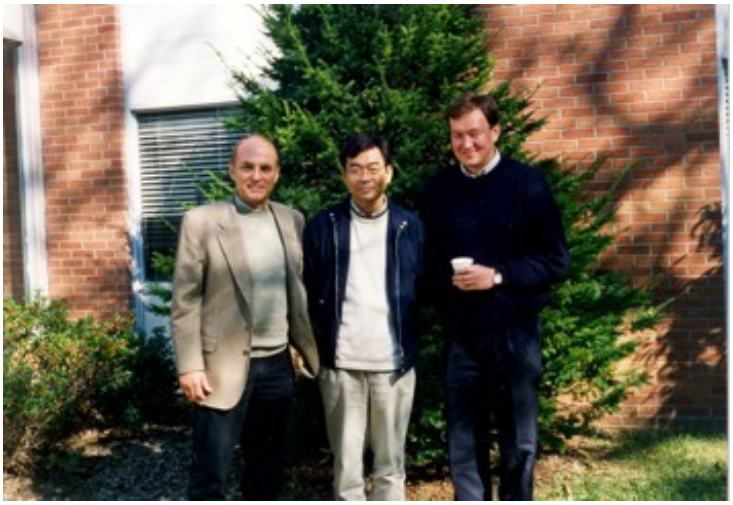

Figure 7: Helmut Satz, Tetsuo Matsui and Dima Kharzeev

shown in Fig. 8a. The vacuum is matter at zero temperature and the snowman can exist at low temperature. If it gets hot, as is the case in heavy ion collisions, oops, there goes the snow man as shown in Fig. 8b.

Figure 8: (a) Mr. J/Ψ in the cold. (b) Mr. J/Ψ when is hot. .

I remember visiting Bielefeld when Helmut was developing this idea. We talked about it a little, but I did not follow up on the conversations. After Helmut and Tetsuo published the paper, I remember the excitement which was generated when NA50 first presented its data on J/Ψ production.[16]. Helmut immediately seized on the fact that they were seeing about 30% of the J/Ψ expected from *pp* interactions. There was a lot of media attention. To quote from Wikipedia: http://en.wikipedia.org.wiki/Quantum-chromodynamics:
In a hot medium, when the temperature is raised well beyond the deconfinement temperature, the J/Ψ and its excitations are expected to melt. This is one of the signals predicted for the formation of a quark gluon plasma. Several experiments at CERN's Super Proton Synchrotron may have seen this phenomenon.

From the

Online APS News:

July 1998 Edition

Evidence suggest first observation of quark-gluon plasma in J/Ψ particle production.

There was much euphoria over this finding. It was expected that at RHIC, since higher temperatures than those possible at CERN are made, that there might be even more J/Ψ suppression. Such an effect was looked for, and it was found that there is about the same suppression in the central region of RHIC collisions as there is at the lower energy CERN collision.[17] There are a variety of explanations associated with what is seen in Phenix, many of which involve some variant of J/Ψ melting. Presumably this will get sorted out in the coming years.

The first reaction to the Phenix results might be that Helmut is in hot soup, as shown in Fig. 9a. On the other hand, being in hot soup is not so bad, Fig. 9b, since in physics this means that your ideas are controversial and of interest. This remains the case with J/Ψ melting. (The Fig 9b, reminds me of a camel trip which Dima and Helmut took through northwestern India some years ago, but you will have to ask Dima or Helmut about that.)

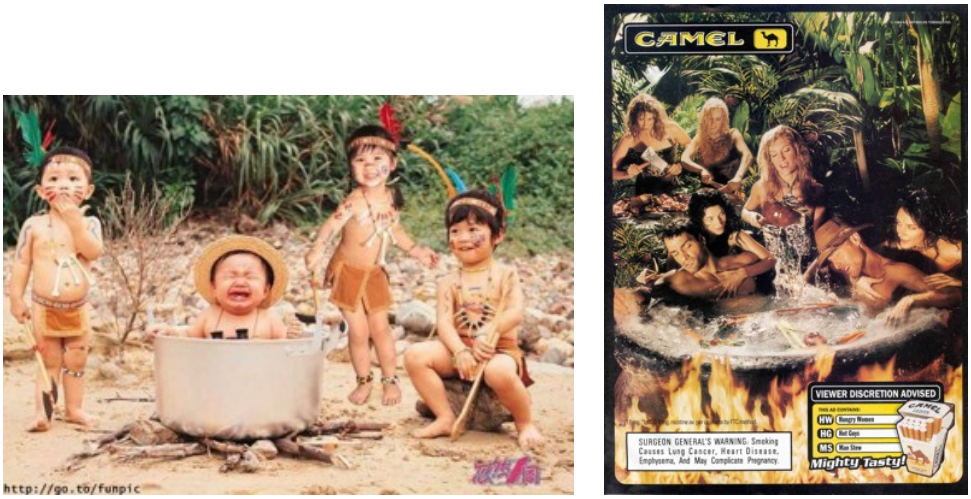

Figure 9: (a) Helmut in the soup. (b) Helmut enjoying the soup.

7 Helmut in Recent Years

I was at Helmut's retirement party in Bielefeld several years ago. In the German system, professors face mandatory retirement. It is a system which has positive and negative sides: It makes room for younger scientists. When a senior person is not so active, of course it is better for them to play a diminished role. In some cases, such as Helmut's, it is not so good, since Helmut is very active, generating ideas and working with young people. Nevertheless, perhaps in Germany more than most places, the rules are the rules.

Helmut is actively involved in organizing scientific meetings, and in the intellectual and scientific life of our field. He also consults. I value his opinions and judgement very much. He is a scientist who believes in the power of ideas, as do I. He will not do long and detailed computations with little hope of drawing conclusions from results. He believes one should use one's brain to think.

I am grateful for his close and reliable friendship. He introduced me to many aspects of physics, people and places that I might otherwise never have experienced. We have been up mountains together, and we have shared good times and hard times. Without Helmut, in my opinion, there would not be a program at RHIC nor at CERN doing a systematic study of QCD at high energy density. I conclude by

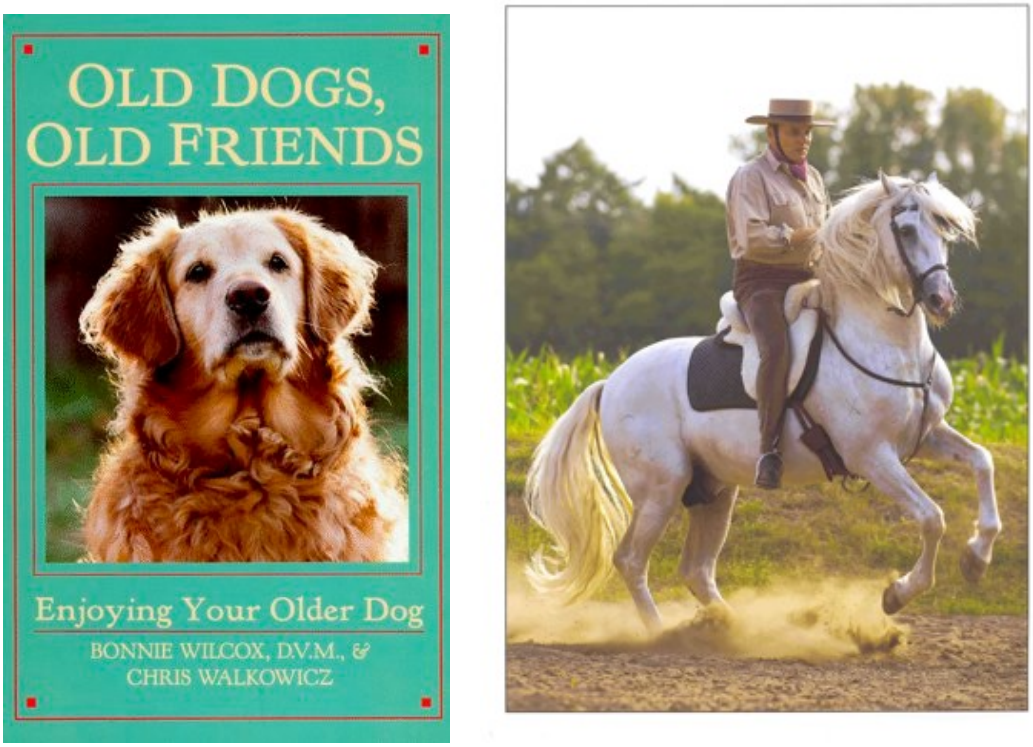

Figure 10: (a) The jacket of the book "Old Dogs, Old Friends". (b)Helmut riding his horse.

showing the cover page of the book by Wilcox and Walkowicz, Fig. 10a, and by a photo of Helmut riding his horse, Fig. 10b

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