Preface

It was an eye-opening encounter in the evening train commuting home from Zurich back in the early 1980ies. I (HB) was studying some book on fluid dynamics to prepare a lecture. A young native English speaking couple sitting opposite in the same compartment became curious about what I am reading. When they realized that this was a physics book they started enthusiastically telling me that they were just reading George Gamow's book "Mister Tompkins in Wonderland" (Gamow, 1965). They showed me the picture with Tompkins cycling with relativistic speed through a city street canyon showing length contracted houses as they were supposed to look for Mr. Tompkins. I explained them that this is not what Mr. Tompkins sees from the bicycle, but corresponds to a different type of observation. I then explained them aberration and what Tompkins actually would have seen. I was truly surprised when I realized their reaction: they were extremely disappointed and almost angry, not at me, but at the fact that not even such accepted books by eminent scientists were reliable. What could they rely on if not on such information?

The confusion about length contraction and aberration prevailed through a long time after the Einstein (1905a) publication although Einstein made a distinction between the two conceps of "observers". The confusion perhaps started because Einstein used the German word *Beobachter* (observer) for the two different viewpoints, the local observer looking around from his position in space and the *geometry* of spacetime with points, distances, and synchronized clocks. Although Lampa (1924) correctly described the appearance of moving bodies to a local observer (in German language), the erroneous description of length contracted appearance of bodies unfortunately remained a common habit. More than 30 years later, Terrell (1959) reinterpreted the appearance in an approximation for very small bodies as a rotated appearance. This interpretation again stirred some confusion of what exactly is rotated: the entire bicycle or the license plate and wheels separately, as can be argued easily (Gamow, 1961). This pragmatic interpretation, pretending simplicity, also obscures the beauty of the symmetries behind aberration. Penrose (1959) exploited these symmetries by presenting four proofs on a few lines that a spherical object always presents a circular outline to any local observer independent of his motion. The potential in the patterns of aberration to serve as a foundation of special relativity was presented in a short but stimulating article by Komar (1965). This article became the starting point to our work on teaching relativity in a more intuitive but still rigorous way, which we tried to condense in the present work.

We asked several colleges from theoretical physics to review the work and give us their opinion. Sometimes, they immediately asked back why we don't write all in covariant form where all is much *easier* and clearer. This may be correct for physicists, and these books are already written, but it is not useful for the target audience we have in mind. The theory of special relativity is perhaps the simplest non-trivial theory reaching beyond our picture of the world, which is limited by our senses and everyday experi-

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ence. This makes the theory an attractive example to teach physics as more than a set of equations and technical procedures but to demonstrate physical thinking.

Radical relativity is a set of ideas about teaching special relativity in an intuitive but rigorous way. To reach this goal, several patterns of standard introductions are omitted: no history, no synchronization, no paradoxes. The conclusions are the same, however, a terminology radically adjusted to the theory reveals some surprising aspects and insights.

Relativistic spacetime requires a revision of classical dynamics. If Newtons second law is written in quantities that are defined in the frame of reference of the moving body on which the force is acting the introduction of a relativistic mass can be avoided. This is used to establish relativistic *dynamics* in a comprehensive way that backs on the *kinematic* consequences of Special Relativity alone.

The special theory of relativity is a theory of space and time, and as such, at the very foundation of physics. Everyday experience gives us the impression of having a clear picture of what is space and time as two independent phenomena. Everyday experience is limited to a narrow range of distances, time spans, and especially velocities. Within these ranges the classical view of space and time is valid to an extent that can not be challenged by everyday observations. On the other hand, phenomena such as light, radio waves, electricity, and magnetism, although they belong to our everyday life, can only be properly understood as consequences of qualities of space and time that become relevant far outside the range of personal perception.

The first comprehensive description of electrodynamics developed through the 1860ies and presented by Maxwell (1873) was the first genuine relativistic theory. The wave solution was already found by Maxwell, but only verified experimentally some 20 years later by Hertz (1888b,a).

Perhaps one of the crucial points in the theory of Lorentz (1895) was the difference in the velocity addition theorem between electrodynamics and mechanics (Einstein, 1982), which was resolved in the Einstein (1905a) paper on "Die Elektrodynamik bewegter Körper". At almost the same time, Poincaré (1905) published a short paper "Sur la dynamique de l'électron" and a year later a comprehensive work with the same title (Poincaré, 1906). Minkowskis mathematical formulation of spacetime radically changed the classical picture of space and time as independent entities and showed that space and time must be treated mathematically as a "union" (Minkowski, 1909).

This book intends to present Special Relativity to students and physics teachers, however, not in the sense of a textbook covering all the theoretical and technical aspects of the theory in full depth. The challenge is to teach relativity in a way that a deeper understanding is possible without coverage of all aspects in every detail. In this effort we follow a recommendation, that proved to be extremely helpful, of late Markus Fierz, a professor of theoretical physics at ETH Zurich, Switzerland:

> If you want to learn a new field (in physics), then try to understand the simplest non-trivial example.

Usually such examples contain all aspects of a field that are relevant for the understanding. Generality and completeness are certainly relevant aspects for professional research and applications of a scientific field, however, not necessarily for teaching and the students understanding. The principal aims of the text are illustrated by the following seven points:

1. The different types of observers, a *local individual observer* looking at the world around him from one point in space (and time) and the *Einsteinian observer* who represents the description of events in spacetime. The first is called *observer*, the latter *frame of reference* in the present text. The confusion of these two types of observers caused some pitfalls in relativistic texts in the past (Section 1.3.1).
2. Different measures of the speed of a motion are strictly distinguished depending on the frame of reference, in which the distance is measured, and the frame of reference, in which the time is measured. The different possibilities, called *coordinate velocity* (or velocity), *proper velocity* (or celerity) and *rapidity* are useful for derivation of the various kinematic and dynamic relations and laws (Section 3.1).
3. Rapidity is measured entirely within the frame of the accelerated object and thus links spacetime and kinematics to inertia and forces (Section 3.1.2)
4. Electrodynamics is genuinely relativistic and has no classical counterpart. This makes special relativity ubiquitous (omnipresent) in daily life, although in an abstract and not necessarily intuitive way (Section 3.3).
5. A hierarchical construction of physics is suggested, starting with space and geometry and next with time and kinematics i.e. moving objects. The objects can be “charged” with additional properties such as *inertial mass* leading to dynamics with forces and acceleration, with *electric charge*, leading to electrodynamics, and with *gravitational mass* leading to gravity (Section 1.4.1).
6. Physics has aspects resembling the axiomatic approach in mathematics and can be based on a comparably small number of *hypotheses*. Space, time, inertia, and electric charge are introduced through few hypotheses, and we illustrate how mathematics finally restricts the possibilities for the formulation of physics, making the axiomatic approach to physics particularly powerful (Section 1.4).
7. The importance and presence of relativistic phenomena in daily life, science and science fiction is used to demonstrate the specific relativistic phenomena in comparison with their classical counterparts in daily life and technology (Chapter 6) and science fiction by discussing the possibilities and limits of an accelerated intergalactic spaceflight (Chapter 7).

The project “Radical Relativity” emerged from many discussions that we lead during lunch on the many Thursday’s when we found time for *discorsos*. It does not cover everything we talked about, but it is a topic we visited frequently in our conversations.

Our first *acknowledgments* goes to a class in the Gymnasium (College) in Zofingen, Switzerland, where one of us (HB) was teaching mathematics and physics back in the 1970ies. The students asked me to teach them special relativity, a request that I gladly fol-

lowed. I chose a few textbooks on relativity on the appropriate level and followed their contents relatively closely. However, I had bad feelings in some parts when explaining verbally what we just learnt in some mathematical form. Driven by this I spent days in the library of ETH Zurich searching the literature on relativity, and, my bad feelings were confirmed. I encountered the Penrose (1959) paper on *The apparent shape of a relativistically moving sphere* which identified the confusion between length contraction and aberration common in most textbooks of that time. Thus, the unusual request of the Gymnasium class finally triggered my interest and the subsequent studies about didactics of relativity. I also acknowledge the unknown couple on the train that opened my eyes to the responsibility when teaching physics. Of course, it is always the contemporarily accepted wisdom that is presented in textbooks and most likely, it will eventually be corrected in details in the future. It is now a long time since the request of the students triggered the start of this work. Perhaps, such a book is never truly finished, but eventually one must decide to expose it.

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