In memoriam Jan Zaanen 1957-2024:

The universe in a speck of rusting copper.

This Thursday, January 18th 2024, our esteemed colleague Jan Zaanen passed away. Jan was one of our star scientists, larger than life, with an unabashed boisterous drive for the best of physics at the Institute Lorentz, at the Leiden Institute of Physics and in the full international scientific community. His booming voice always announced his presence from afar, and we shall deeply miss him and the deep and provocative insights that he shared with us for so many years.

Jan was a world-renowned leader in the field of strongly correlated electron systems and high Tc superconductors in particular. High Tc superconductivity was discovered in 1986 in stacked layers of copper oxides --- flakes of copper rust. By sheer fate these copper oxides were --- in their guise as Mott-insulators; atomic crystals where there is precisely one valence electron per atom --- the topic of Jan's PhD thesis under the guidance of George Sawatzky at Groningen University in the same year 1986. Whereas the classical physics picture suggests that Mott-insulators with a free valence electron should be metals, in real materials any additional electron feels a repulsive potential due to the quantum mechanical Pauli principle and needs to be in higher energy level; hence they are insulators. In his thesis Jan showed more precisely that it is the interplay between the tendency to flow (the bandwidth W) and the local repulsive forces (Hubbard potential U) that governs the conducting state of copper- and other transition-metal-oxides, in what is now known as the Zaanen-Sawatzky-Allen classification.

Jan continued as a post-doctoral fellow at the Max Planck Institute at Stuttgart where, in recognition of his scientific excellence, he was quickly promoted to a member of the scientific staff. Here, Jan made one of his most noted and notable discoveries: the prediction of a striped phase in high Tc superconductors. As high Tc superconductors are Mott insulators, one needs to chemically dope them (replace some of the heavy metal nuclei with neighbors in the periodic table that have one less electron) to make them conducting. At dopings below the one where the transition to superconductivity is highest, the magnetic spins of the conducting electrons arrange themselves at low temperature in striped patterns, aligned with the magnetic spins of the copper atoms. This was controversial at the time, but ultimately Jan's insight was experimentally proven correct. Rightfully so, these Zaanen-Gunnarson stripes are specifically mentioned as one the reasons for his 2006 Spinoza Award, the highest scientific distinction in the Netherlands.

During his time in Stuttgart Jan Zaanen also co-invented LDA+U: the combination of the Local Density Approximation + the Hubbard potential U, which adds a far more realistic local potential felt by electrons and is now a well-known tool in quantum chemistry.

Opportunity knocked when a grant from FOM offered Jan the chance to join the famous Bell Labs, the fount of the majority of many of the discoveries that our modern electronic and computing society rests on. With eleven Nobel-Prize winning discoveries, it was also the place

where the frontier of condensed matter physics research was breached time and time again. Jan thrived in this atmosphere of academic excellence and became fully integrated in the leading community, that was trying to understand the mysteries of high Tc superconductivity.

When Bell Labs was dismantled in the heady deregulations and reorganizations of the early 90s, it was our fortune that Jan chose to move to the Institute Lorentz at Leiden University with a prestiguous KNAW fellowship in 1993, where he soon became full Professor. In the spirit of the Institute Lorentz's founding members, Paul Ehrenfest and Hendrik Lorentz, Jan bestrode all of theoretical physics, and more, in his manifest presence at the Institute. He proudly learned string theory at this later stage in his career, to discover what the excitement and hype was about, but was equally proud of winning the 2004 Dutch National Science Quiz. His academic breadth and depth was recognized through his selection to the Editorial Board of the both the journal Science and the journal Nature; he wrote quite a few commentaries and News and Views articles for Nature, that on hindsight have turned out to be visionary and crucial in setting the direction of the field. He also reinvigorated the Colloquium Ehrenfestii series and the visiting Lorentz Professorships, inviting future Nobel Laureates Duncan Haldane, Kip Thorne, Roger Penrose and others to Leiden.

In recent years Jan's notion of "Planckian dissipation" --- a conjecture he put forward himself as a fundamental quantum bound on relaxation times in heat-and-charge transport ---- has been a driving force in the strongly correlated physics community. It has led to deep insights into the realization that strong correlations must go hand in hand with strong entanglement, defining a new state of "quantum supreme matter" in Jan's terminology. Remarkably such theories exist and are under computational control when approached in an alternate dual holographic language of black holes in string theory. A pioneer also in this field, Jan has co-authored the 2015 textbook "Holographic duality for condensed matter physics". In a foresight that even surprised himself, it made fully material the title of his 2008 Spinoza lectures "The universe in a speck of rusting copper".

Jan lived for science. We all knew him as such: a singular scientist whose impact in the field of strongly correlated condensed matter physics and high Tc superconductivity has been immense, a leader with an unbounded passion for physics, who set the bar high for himself and for colleagues. Even as his illness took a turn for the worse, he managed to write a memoir as well as a book "On Time" soon to be published by Oxford University Press. His cheerful enthusiasm could be as infectious as brusque; he could not stand "bureaucratisch geneuzel" and could revel in being undiplomatic, but we knew he always acted in the best interest of pure science. His parting leaves a substantial hole in the Institute Lorentz. We will remember him with respect, appreciation and with immense gratitude for what he has meant for Leiden physics and science as a whole.