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A Quest for Truth?

Heroic Patterns in Early Cosmic Ray Physics

The early twentieth century was the heyday of natural science. Especially physics witnessed numerous new developments: discoveries of new kinds of radiation and new particles, the formulation of quantum mechanics or the relativity theories, to name but a few. One of these new fields of physics was the study of cosmic rays, soon becoming one of the pillars on which nowadays high energy particle physics rests.

Most interestingly though, laboratory physics had been an important part of early cosmic ray studies and, at least from the 1920s onwards, new technical developments in unmanned balloon flight had made these kind of experiments unnecessary, cosmic ray physicists engaged personally in field research that led them to extreme places, like the highest mountain tops or even the arctic ice. These endeavours sometimes even cost the lives of some of the scientists. The decisive question is: why were those experiments still performed well into the 1930s?

This article will have a closer look at the different experiments performed in extreme places and at the way physicists presented these expeditions in scientific papers and other media, assuming that the actors themselves understood their scientific work as a modern-day heroic enterprise. Especially the recurring motif of (self-) sacrifice evokes the impression that cosmic ray physicists devoted to a certain type of experimental fieldwork tried to establish their self-image as 'scientific heroes'. The sacrifice was described either as a form of self-chastening, declining all unnecessary comfort, or as actual sacrifice of the scientist's life, and the fight against the adversary conditions in nature, often portrayed as superhuman entities. In a kind of imitation of the myths surrounding the great discoverers of bygone times these cosmic ray physicists seem to have placed special emphasis on choosing extreme work places and communicating the peculiarities of their environment.

Early cosmic ray studies – A brief introduction

Cosmic Ray Studies,[1] the predecessor of astroparticle physics, developed between the late nineteenth and early twentieth century. Already before 1900 British meteorologist Charles Thomas Rees Wilson discovered an ionisation effect while he conducted work on cloud formation (Wilson, Condensation 240). In the following decade meteorologists and physicists turned to the problem and soon established the fact that the effect was caused by some "penetrating radiation" (Rutherford/Cooke 183). Though the origin of this radiation was yet unknown, some scientists hinted at the possibility that the rays might have similar properties as the ones emitted by radioactive elements (cf. e.g. Elster/Geitel; Rutherford/Cooke). Between 1909 and 1912 measurements showed that the penetrating rays did not derive from radioactive elements in the earth's crust or manufacturing errors of the instruments but were coming "from above" (Hess 1091), indicating that they may be of cosmic origin, though some argued that the rays were produced in the earth's atmosphere (cf. e.g. Gockel, Messungen; Hess; Kolhörster, Neukonstruktion; Kurz; Wulf).

From then on well into the 1920s physicists concentrated on the analysis of the different properties of the radiation, like the absorption rate of the rays or the possible places of their origin: either the atmosphere or outer space. After much controversy in the mid-1920s the idea of high energy particles of cosmic origin penetrating the earth's atmosphere from above (Millikan 445-446) was finally experimentally established and generally accepted. This led to a conceptual change in cosmic ray studies. The search for the actual sources of the radiation was now also used as a means to learn more about outer space and the structures of the universe. Especially the question about the general constitution of the universe, namely whether it is at a steady state or expanding, sparked new interest in the science of cosmic rays, but also the problem of matter formation and the development of the bigger structures (cf. Millikan 447; Jeans 116).

Though in the second half of the twentieth century cosmic ray studies fell behind when it came to detecting new particles, in the immediate post-war years physicists relied on its cheap and easy to access methods. Major technical improvements in the chemistry of photographic emulsions – by then replacing the cloud chamber as a method to trace single particle tracks – led to the detection of a number of new particles, like pions and kaons. But soon particle physics became dominated by accelerators and it took scientists until the late 1980s to rediscover cosmic rays as a vital means to learn about high energy particles and the structure of the universe (De Rújula v-vi).

Frequently used methods

As mentioned above, even the very beginnings of cosmic ray studies had been closely linked to work in the laboratory. Wilson had been working to establish a cloud chamber, a device that would enable him to monitor cloud formation on a small scale and under laboratory conditions. Though he had removed all kinds of dust from the expansion chamber he still witnessed a condensation effect. It turned out that radiation passing through the chamber would work as condensation nuclei and leave a small fog-like trail for every ray or particle (cf. Wilson, Apparatus 277-280).[2] Thus, the cloud chamber became an ideal instrument for physicists to work on radiation. Accordingly many scientists decided to make use of it. It was especially valuable for tracing single particle tracks and to measure to what extent layers of lead and other materials could be used as shielding against different kind of radiation. In the 1920s and early 1930s the work with cloud chambers was quite successful: it led to the discovery of new particles as well as the first photographs of high energy particles. As a consequence, scientists also turned their interest to the construction of other kinds of particle detectors, like e.g. Geiger counters or bubble chambers and eventually developed devices to accelerate particles artificially: the beginning of modern day High Energy Particle Physics (Cirkel-Bartelt 163-164). But this development took its time and besides, these first generation accelerators were far from reaching the energies naturally accelerated particles achieved. For that reason, field research was an important aspect in cosmic ray research for at least the first part of the twentieth century.

In the first years after Wilson and others had witnessed an inexplicable ionisation effect, many scientists considered it to be caused by their experimental setups being contaminated with some radioactive residue, either in the instruments or in the immediate surroundings. Therefore Theodor Wulf (Wulf 811-813) took his instruments to the top of the Eiffel Tower, in order to make measurements undisturbed by this so-called rest-effect which he considered to be caused by radioactive materials in the earth's crust. What he found was quite the contrary. Other than expected, he found more ionisation the higher he got, this being an indicator of some kind of radiation coming from above. In the following years, studies concentrated on the question how and where it was produced. In order to learn about these facts physicists had to find out more about the properties of the radiation. Did the measurements depend on air pressure, time of day or sidereal time? Scientists thought if e.g. the ionisation effect had been strongly correlating with the rising of a certain star it would have been a good indicator that the radiation causing the effect came from that certain region of outer space. As the range of particles that could be measured with the contemporary technical means consisted almost entirely of charged particles that can be deflected by the galactic magnetic field, no sufficient directional information could be gained (Bosetti 13).

One successful approach to measuring cosmic rays was to take the instruments to mountain tops. Reaching higher up in the atmosphere the radiation in the mountains was more intense and the natural surroundings did interfere less with the instruments. The lack of iron used for buildings and other constructions guaranteed that there were very little magnetic or static disturbances and besides, snow and ice could be used as a shield against radioactive traces in the rocks. Tunnels, especially of mountain railways, on the other hand, were used as a shield against the background noise: only very high energetic rays could penetrate a few hundred meters of rock. These first mountain campaigns were often conducted under the most primitive circumstances. The physicists involved had to bivouac in tents or igloos they had dug themselves into the permanent snow cover. During a series of measurements on the summits of *Jungfrau* and *Mönch* in the Alps from 1923 to 1928, von Salis and Kolhörster documented their surroundings, the ascent as well as their very plain lodgings, in words and pictures (Flückiger 127; Kolhörster/von Salis, Strahlung 366-370; von Salis 795). Given how arduous work was in the open on a mountain top at a height of more than 4000 metres, cosmic ray physicist were happy to use existing infrastructure were it was available. Soon, existing meteorological stations were used, in other cases high mountain observatories were purpose-built, usually to be used by any scientists from different disciplines (Cirkel-Bartelt 186-188). Permanent stations had the advantage of allowing storage of more equipment and that series of experiments could be performed for extended periods. New types of stationary experiments were invented, like the detection arrays of Pierre Auger and his co-workers, who established the concept of using not only a single detection device at a time, but deployed a number of them on a mountain plateau, gaining extra information through the joined analysis of all data (cf. e.g. Auger et al.). The basic principle of this kind of stationary field research is still in use today.

Measurements of the radiation at sea-level were also common. Aside from laboratories and observatories in scientific institutions, boats or ships were frequently used for those. Depending on what properties scientists wanted to measure, the experiments were performed over or under water. Like the tunnels or the ice in the mountains, the water could be used as a shield against either the radiation in the earth's crust or atmospheric particles.

Another very successful method to measure cosmic radiation in the higher atmosphere was the use of balloons. Together with telescope arrays they became the most common and most successful tools of cosmic ray and astroparticle physics. Meteorologists had already used manned balloons for a long time when radiophysicists like Viktor Hess took to them to measure the rest-effect. His series of balloon flights in 1911 and 1912 or rather the results of his measurements that for the first time established quite unambiguous evidence for the hypothesis of some kind of radiation increasing with height from ground (cf. Hess 1090-1091) is usually referred to as the "discovery" (De Maria et al., The discovery 166) of cosmic rays. But manned balloon flight had its limits. First, the necessities for pilot and physicist on board, like food and especially the oxygen supply, limited the space for scientific instruments and secondly, under normal conditions they could not reach as high as unmanned balloons would. The record established by Auguste Piccard and his co-pilot in 1932 for manned balloon flights was 16 kilometres (Piccard et al. 71-72),[3] a height that was easily reached by sounding balloons (Millikan 446). So it was flights with unmanned sounding balloons that became the prime source of measurement data for cosmic ray physicists. These balloons – usually a tandem of two rubber balloons – could carry a load of very different kinds of equipment from self-recording electrometers to plates with photographic emulsions into the highest atmosphere. Having the disadvantage of sometimes getting lost in difficult terrain, they fostered the development of transponder devices either to be traceable or to send the data directly. Besides, scientists felt encouraged to work together in larger co-operations in order to hunt for their renegade balloons across state borders (Cirkel-Bartelt 293).

Given that the use of aeroplanes in general was something relatively new in the 1920s, they were used quite early on for cosmic ray studies. But as the particles of the exhaust fumes could have negative influence on the measurements, especially as the first aeroplanes used were open double-deckers, they could not be established as a means of conducting experiments on cosmic radiation, though they seem to have delivered comparable results like balloons (cf. e.g. Wigand). Airships seemed at first somewhat more suitable, as they had a closed cabin and could stay in the air without the engines running, but they still had issues with vibration, fumes disturbing the instruments when the engines were working. Additionally they were rather dangerous devices, as will become clear later.

As already mentioned, after the cosmic origin of the new radiation had been established, physicists hoped to learn more about its sources and the general structure of the universe. Consequently, from the late 1930s onwards scientists tried to conduct measurements outside the earth's atmosphere, their experiments signalling the beginnings of unmanned space flight. Before World War II the results of these efforts were pretty mediocre. German physicists were planning to shoot a barrel-shaped container into space with a rocket, but in Nazi Germany rocket building and the study of missile engineering was soon to become limited to military purposes only (Paetzold 167). It took till the late 1940s until the first *rockoon* – a balloon-borne rocket – was built, a device that was finally used to study the solar space and the later so-called Van Allen radiation belt before the advent of space flight proper (Corliss 25-27).

Another important place of debating knowledge about cosmic rays was the social space. Personal letters between the physicists involved played as important a role as meetings and conferences. Controversies on certain new findings were common and often carried out in public (De Maria et al., Cosmic ray romancing 211-250; De Maria et al., The discovery 178-189; Cirkel-Bartelt 219-271), but co-operation and the exchange of methods and instruments were also decisive aspects.

Fighting nature's adversary conditions

Most of the field research done in early cosmic ray studies was not particularly risky. Deploying experimental setups in tunnels, under water or in open terrain for an extended period of time was rather technically challenging. The insulation of the apparatuses could become permeable and water could leak through or the drying agent itself would draw humidity from the surroundings. Sometimes little insects or spiders entered the vessels with the electroscopes and ruined the measurements (Gockel, Beiträge 346; Kähler 27-29).

Manned balloon rides and ascends to high mountain tops were naturally quite dangerous. However, with the growing use of sounding balloons and the technical progress that made it easier to take precision instruments on these flights an alternative had been found. Yet, as already indicated, physicists would not stop performing this kind of research. A good example is the campaign on the *Jungfraujoch* by Kolhörster and von Salis mentioned above. The expeditions themselves, like most of the field research conducted, may not have been extreme. The two physicists made extensive use of the commodities of civilisation, like the close by *Jungfraubahn* that carried some of their equipment to the summit of the *Jungfrau*, so that the scientists did not have to carry the load all the way from the valley to the top. However, neither the photos in the final publication nor other pictures taken during that campaign show the technological infrastructure. Instead, they rather seem to emphasise how the two physicists and their helping hands, as well as occasional guests, had to fight the elements. Those other photographs[4] also show them in the company of an elderly gentleman whose name is not mentioned in the description of the images (Flückiger 127). Comparison with other images of the time suggests that this has to be Walther Nernst. In articles on the final results, Nernst received explicit thanks for his encouragement of and involvement in the experiment, with an emphasis on his interest in Kolhörster's and von Salis' work. (cf. e.g. Kolhörster/von Salis, La période). So why would a renowned and by then almost retired Nobel Prize-winning chemist endure the discomfort of a makeshift shelter, only to engage in a few series of measurements the two physicists could surely have managed without him? Nernst was certainly interested in cosmology and hoped that cosmic ray studies would provide new insights into the physics of the universe (Nernst 59-63). Still, that does not require his personal attendance as a celebrity guest and a photographer to capture the events on the mountain top. One probable explanation lies in the numerous controversies in cosmic ray studies in the late 1920s and early 1930s. International debates about how to interpret the collected data concerning the properties of cosmic radiation correctly as well as about the supremacy of discovery stirred a lot of public interest in this field of physics (De Maria et al., Cosmic ray romancing 211-214, 242-250). Some of the efforts to make experiments ever more spectacular were certainly owed to this competitive attitude. Though the campaign in the Alps may not have been particularly dangerous, it is a good example indicating how the adventurous aspect of field research and maybe even its advertising impact gained importance in the late 1920s. And while most of the field research in early cosmic ray studies would equal Kolhörster's and von Salis' series of measurements, some of their colleagues would engage in far more risky enterprises with a much more questionable outcome and a far less promising scientific output.

Taking risks – The polar expedition

One of the key issues scientists argued about in the aforementioned controversies was the question whether the radiation they actually measured consisted of charged particles or of γ-rays. If the former was the case, the intensity of the radiation had to depend on the influence of the earth's magnetosphere, i.e. the magnetic poles had to be attracting the charged particles, leading to a higher intensity at the poles. Scientists therefore planned to take their experiments to the arctic ice (Swinne 530).

Cosmic ray physicists were not the only ones interested in the polar regions. After Amundsen's and Scott's spectacular race to the South Pole in 1912 and the long history of failed expeditions to the North Pole, the Arctic region was still some kind of *terra incognita* in the mid-1920s. In 1926 the American biologist, geologist and millionaire Lincoln Ellsworth funded a first polar expedition to be conducted from an airship. Together with Italian general Umberto Nobile, famous

Norwegian polar researcher Roald Amundsen and their team they reached the North Pole on the Italian military airship *Norge* in May 1926 (Běhounek, Eisscholle 19-23). In 1928 the expedition was repeated, this time without Ellsworth and Amundsen, but again with help from the Italian government, the Norwegian *Aeroclub* and a team of soldiers to navigate the airship and scientists from Italy and other European countries. The experiments planned included meteorological, oceanographical and physical measurements, but the explorers also planned to map so far unknown land (ibid. 24). Though everybody involved stressed the "strictly scientific" (ibid. 28) character of the whole enterprise (ibid. 28; Nobile 9-13), the modern day reader cannot help but read some national bias and a certain will to conquest between the lines (Běhounek, Eisscholle 42). Běhounek describes the circumstances of ownership of land in the north polar region as a constant source of quarrel: "Die Frage des Heimatrechts in Spitzbergen ist seit Jahrhunderten strittig" (ibid. 13). During the ride from Italy to the pole first measurements were taken, but from the beginning onwards, bad weather, including thunderstorms and thick fogs, hindered a smooth advance to the North (ibid. 50-54, 63-64). The whole enterprise turned out a disaster. In the end seventeen people were dead or missing, including Roald Amundsen, who, though he had not originally been a member of the expedition itself, had tried to come to a rescue (ibid. 258-259).

To some extent, of course, taking the extreme risk of such an expedition might have been necessary for a cosmic ray physicist. Measurements at the North Pole and the close by magnetic pole could and cannot be substituted by any experimental set-up construed in a laboratory. Yet on the other hand, in only two or three series of measurements conducted during the immediate ride in the airship over the pole, one can hardly collect enough reliable data. Besides, airships obviously had the same problems as airplanes. Běhounek mentions the problem of the motor fumes sticking to the ship that would be electrically charged, thus disturbing the electrometers used for measuring cosmic rays (Běhounek, Forschungen 50). From a scientific point of view, conducting longer experiments, ideally in dust-free air, though maybe not at the pole itself but at least close to the pole, would have generated more, and especially more reliable results. Such less adventurous yet more concise research was not only possible but also successfully conducted by other physicists. For example, Swedish astronomer Axel Corlin carried out several series of measurements north of the polar circle between 1929 and 1930 (cf. Corlin, Ultrastrahlungsmessungen 1065-1071; Corlin, Höhenstrahlungsintensität 6). He made use of a scientific research station in the town of Abisko that had been built as early as 1913, after a first meteorological station nearby had burnt down. With access to this station in northern Sweden he would later participate in Compton's *Cosmic Ray Survey* in 1932 (cf. Corlin, Measurements).

Czech cosmic ray physicist František Běhounek is a good example for the type of adventurous scientist who accompanied missions like Nobile's fateful expedition. A disciple of Marie Curie's, he was well acquainted with questions concerning radioactivity and had turned his interest to cosmic radiation. While working at the University of Praha he got accredited for installing and running the instruments in the airship during the flight from Italy to the polar region (Běhounek, Eisscholle 26-30). Běhounek had already designed the instruments for cosmic ray measurements during Amundsens's and Nobile's first successful expedition, without actively taking part in the overflight of the pole (ibid. 20).[5] Likewise, he was not supposed to run the experiment himself during the next flight across the North Pole. Due to the limited space in the airship and the necessity to use the bulk of it for storing fuel, it was planned that Professor Aldo Pontremoli (ibid. 32) would supervise all the apparatuses of his colleagues, while they would run measurements at the base camp in Kings Bay, Spitzbergen, now known as Ny-Ålesund. But in deviation from that plan and as he had hoped from the start of the adventure, Běhounek joined the final pole flight (ibid. 36, 82-83). On 25 May 1928 around 11 o'clock in the morning the airship crashed, due to adverse weather conditions, problems with the engines, a lack of gas and faulty instruments for navigation (ibid. 96-98). The ship was torn apart and while a small group landed on the ice together with some of the supplies and instruments that would finally save most of their lives, six other crew members were carried away with the wreck immediately (ibid. 100). As the survivors were able to build a primitive apparatus for radio communication, they could call for help, but due to the weather, an unusual amount of polar ice for the season and international dispute about administrative responsibility it took several weeks until the last surviving member of the expedition would be saved (ibid. 170-246). The rescue missions were as much a mess as the original enterprise. Amundsen was not the only one who died or went missing on a rescue flight. Nine of the seventeen casualties to be mourned in the end were members of rescue parties that failed (ibid. 259). The shipwrecked scientists even tried to reach the Spitzbergen archipelago themselves, sending a party of three. But one of the three, Malmgren, died on the trip, while his Italian comrades narrowly escaped. They had left him somewhere on the ice while he was still alive, had taken all his supplies with them, and one of them was considerably more well-nourished than the other when they both were found. These details in particular infuriated contemporaries (ibid. 152-158). The fact that someone would rather save his own life than stay true to a (dying) friend or colleague was dubbed by Běhounek as "polar psychosis" (ibid. 152). To him and certainly to his audience as well it was understood that sacrifices had to be made in order to make scientific progress (ibid. 34, 143). This notion of self-sacrifice seems to have been deeply rooted in the self-conception of many physicists. It is this very aspect of sacrifice to the 'greater good' where the self-conception of the physicists as adventurers gets its heroic overtones. There is no evidence that any of their contemporaries ever challenged this ideal, at least there is no mentioning of it in the sources related to this field of study. This might be owed to the fact that studies on a meta-level about the connection of the subconscious and the heroic were yet to come, like Campbell's epoch-making work about the so-called monomyth in the late 1940s (Campbell). The knowledge about the role of heroes and the heroic has increased dramatically since then, but due to this lack of reflection, it is hard to trace the often scattered evidence. What is clear though is that the cosmic ray physicists involved were not targeting a scientific audience only.

Reaching a wider audience

The drama of the shipwrecked expedition and the many failed and sometimes even fateful attempts at a rescue was top news of these days. The question of whose fault the whole disaster was spurred the educated reader's interest (Běhounek, Eisscholle 5, 234), while the yellow press spread rumours of cannibalism (ibid. 81). But even in the case of a successful expedition the public would have been informed in all detail as Nobile had, like it had obviously been the case in the previous expedition, accredited a journalist of the *Corriere della serra* as a member of the team right from the start (ibid. 30). A second would join them later at the pole (ibid. 82, 85-86). Nobile also had a number of cameras on board to actually film the expedition (Nobile 21). Besides, everyone else was also keen to reach the biggest audience possible. Běhounek e.g. dropped letters to local newspapers from the ship's cabin when the *Italia* reached the Czech airspace (Běhounek, Eisscholle 49). Unfortunately, most of these newspaper articles are lost today. However, we may deduce from other articles how euphoric audiences were about anything that had to do with contemporary science in general and physics in particular. About a successful experiment by Robert Andrews Millikan with unmanned balloons the New York Times wrote that the cosmic radiation should be named after him: the man with the "penetrating mind that passed through the miles of space to the far frontiers of our atmosphere and there met these strange forces of the universe coming out of space" (Anonymous 461-462). The article has survived because it had been reprinted in the November issue of Science in 1925. The fact alone that such a pompous little article has been reprinted in a scientific journal shows the importance attributed to the public opinion. As a consequence, the literary output of Nobile's expedition was larger than the scientific one. Běhounek published a detailed account of the events in the arctic ice in 1929 (cf. Běhounek, Eisscholle), especially about the seven weeks after they were stranded on a floe in the floating pack ice. The book went into the tenth print within the same year. Cesco Tomaselli, the expedition's journalist, also published his reminiscences in a popular book in 1929 (Tomaselli). The scientific publication was rather mediocre in comparison. Consisting of little more than one hundred pages, including tables with data, maps and photos, the joint publication by eight of the expedition's meteorologists and physicists can be understood as an attempt to justify the efforts made and the human lives lost by showing what intellectual profits could have been gained, if the *Italia* had not been shipwrecked (cf. Nobile). Even the results of the dead researchers were published, as far as they could have been saved or restored (cf. Malmgren, Pontremoli).

Another sacrifice to science

The question if the intensity of cosmic radiation changed depending on latitude was still not answered in the early 1930s (cf. Brüche). The matter was finally settled with a measurement campaign that was to become one of the first big multi-national cooperations, marking the advent of the institutional structures of what is nowadays called *big science*. The *Cosmic Ray Survey* had been initiated by Compton (De Maria et al., Cosmic ray romancing 222-239) as the results of previous campaigns like the first one by Corlin in North Sweden were considered inconclusive (Compton 388). It was the first concerted action of several expeditions and measurement series conducted at the same time in universities, high mountain observatories or even on ships (ibid.). In 1933, when Compton published the results obtained so far and first conclusions were being drawn, sixty international researchers had joined the survey, more than eight expeditions had been realized and the data of 69 stations had been collected with standardized instruments (ibid. 389). Though some of the experiments continued for a while, by the end of 1932 it had become clear that the spectrum of the radiation that could be measured with the instruments available consisted of charged particles that were deflected by the magnetosphere (ibid. 400).

One of the expeditions in 1932 was supposed to measure cosmic rays on Mt. McKinley, nowadays renamed Denali, the highest peak in North America and one of the so-called seven summits. The first successful attempt to ascend to the peak had just been managed in 1913 by an amateur mountaineer, the Alaskan Archdeacon Hudson Stuck and his party.[6] Allen Carpé and Theodor Koven were flown to the Muldrow glacier close to the summit, where they were supposed to wait for the rest of their party and conduct first measurements. But when the mountaineering expedition of Lindley and Liek that had started at about the same time to climb the Mt. McKinley on ski reached Carpé's and Koven's camp, they found nothing but an empty tent. A provisional search found the dead body of Koven. He had obviously fallen into a crevasse, managed to climb out again, but died of his injuries. Carpé was not found, as the search had to be stopped for safety reasons and he seems not to have been with Koven at the moment of his accident. The rest of the missing party was found somewhat down the slope. They had been forced to delay their ascent due to medical conditions (Beckey 127-131). So the question is not only why Carpé and Koven would want to make measurements at a height of about six to seven kilometres while balloons could already reach about three times this height, but also why they would leave aside every safety measure? Why not wait for the rest of their group and why not at least form a rope team? Maybe Carpé overestimated his abilities as a mountaineer. He had participated in mountaineering expeditions before (Hickson 16) and may have thought that he could deal with the difficulties on the glacier.

At least the *Cosmic Ray Survey* could settle the matter and prove the existence of charged cosmic particles. Thus, in the following years the research interest of most physicists in the field would turn away from the different probable sources of the radiation so they could again scrutinize its properties and find out about the actual mechanisms of production (De Maria et al., Cosmic ray romancing 265-266).

On a mission to find truth?

Carpé's and Koven's sacrifice turned out to be in vain. As Compton reports, though their notebook with the data could be retrieved, the barometer to gauge the instruments was lost, so that the results were not absolutely reliable (Compton 399-400). Most interestingly, though Compton refers several times to the accident of Carpé and Koven (Compton 399-400, 403), he does not even once indicate the death of a guide who was killed in the course of a South African expedition during the survey (De Maria et al., Cosmic ray romancing 238). Was he not seen as a 'sacrifice' to science because his death did not hinder the gain of knowledge like in the case of the two physicists? Or was it due to the fact that danger was simply considered part of a (probably native) guide's job in contrast to the gentleman scientists who had deliberately left the safety and calm of their university to venture into the world and bring back new knowledge? The sense that it was the right mind-set that made a scientist a heroic scientist was obviously strong in their contemporaries. In MacLean's Magazine in an article published in May 1925, the author Hickson commented on the mountaineers and polar researchers of the mid-1920s that they were driven by "the spirit of adventure, enterprise and daring" (Hickson 17) and that, in his opinion, it was that very spirit that could constitute whole empires.[7] The description evokes the image of scientific discovery as a quest: the hero is bound to gain insight into so far hidden knowledge, tackle all threats and thus finally achieve immortality. So far, there has been little analysis of the question why this particular group of scientists and maybe others as well have not only made such heavy use of such heroic imagery, but actually seem to have modelled the set-up of their scientific experiments and even their lives accordingly. But, though further research might be needed, there are numerous clues to what an explanation might look like.

As Berton (Berton 627) has pointed out, it was not least the promise to have one's name inscribed onto the maps of newly discovered lands that fuelled the aims and hopes of many explorers.[8] Certainly, the physicists involved in dangerous expeditions shared their attitude. The Arctic and high mountains seem to have appeared equally interesting in that regard in the late 1920s. Hickson pointed out that “the spirit which animates attempts at Everest and Logan” (Hickson 17) – the highest peak in Canada – was “the same as that which has prompted Arctic and other expeditions” (ibid.). Taylor confirms the image of mountaineers being strongly interested in the lasting fame of their very enterprise. About the posthumous ‘apotheosis’ of an unhappy climber that was killed by an accident in the US in the early 1930s the author observes:

> [C]limbing’s ultimate price is not death. Such accidents are personal tragedies, but longer perspective suggests that they can also be segues into myth and legend. Even a brief review of the many biographies on doomed climbers and dangerous mountains illustrates how the dead, and even the foolish, gained a measure of immortality through their follies. (Taylor 191)

Moreover, Taylor points out that mountaineering was a specifically male way to fame (ibid.). This is an interesting clue, for, though female scientists were quite common in cosmic ray studies, i.e. compared to other fields of the natural sciences at that time, they seem not to have engaged in the more dangerous kind of field research.[9] They would rather ask others to take their instruments on a balloon ride before taking part in the ascent themselves (cf. Blau). This was certainly partly owed to the fact that most female cosmic ray physicists had to work under financially more difficult conditions than their male counterparts (Fengler 199). They could probably simply not afford to start overly expensive measuring campaigns. On the other hand, there exists no proof that they ever wished to. Marietta Blau, e.g., complained to her fatherly friend Stefan Meyer, head of the *Radiuminstitut* in Vienna, about being dependent on the good will of others, when she and her co-worker planned to have stacks of photo plates with their newly developed photographic emulsion lifted into the atmosphere by balloons.[10] But there is no mention that one of them wished to participate actively in the balloon ascent (cf. Blau). So one might argue that the experimental research under extreme conditions was a specifically male way of conducting these kind of experiments. For the group of engineers Paulitz has pointed out that the role of the male engineer changed dramatically between the late nineteenth and the mid-twentieth century, with regard to both public opinion and self-perception. According to Paulitz this led to the image of the engineer being torn between the feeble but clever academic genius on the one side and the problem-oriented, energetic practitioner on the other (Paulitz 341-348). Maybe something comparable happened to experimental physicists, letting them wish to participate in ever more extreme research campaigns in order to define their role anew. Probably the growing importance of theoretical physics in the fields of nuclear and particle physics, those fields most cosmic ray researchers traditionally came from, caused an identity crisis comparable to the case of the engineers. But this question must be left as a desideratum, as such an analysis is still pending.

The sources used for this article give no immediate evidence that such a self-assurance of gender stereotypes was what the actors had had in mind while running their experiments. If it was the case it rather influenced them on a subconscious level. Though alternative approaches to the problems those physicists dealt with had been available they apparently felt some kind of necessity to take their research to such extremes: not only on high mountain tops, but the highest mountain tops, not only north of the polar circle, but exactly over the North Pole. What scientists did try to find in the company of mountaineers and polar researchers was not simply personal fame, their mission was to find nothing but ‘truth’. The anonymous writer of the aforementioned newspaper article on Millikan stated it this way:

> He [i.e. Millikan] has brought back to earth a bit more of truth to add to what we knew about the universe. There is no human satisfaction that can be greater than adding even a fragment to the body of ascertained truth. (Anonymous 462)

The semantics of the public narrative thus reinforced the heroic status of the physicist. And the quest for truth adds further to the image of the scientific hero as it gives him a mission and an antagonist: truth has to be wrenched from nature, like the treasure from a dragon’s lair, the more adversary the conditions the mightier the hero. The polar research flights aimed at the “heart of the unknown land” (Nobile 11) and the failed expeditions were “ill-fated” (Compton 399) and this is only the wording of the scientific papers, let alone the more personal accounts of the events. Běhounek e.g. takes the image of the hero even further, adding a religious overtone to it. About the farewell of his friend Malmgren who refused to dictate last words before his final departure, in case their little rescue party of three would not be saved, Běhounek observes:

> You were right, my poor friend, why should I speak of you – after all, I could say nothing more than what is repeated by the whole world today: that an honest and noble man perished, one of many, like Scott, de Long and all the other martyrs of science[11] who found their grave in the wastelands of the north or south and whose death was as honourable as their work! (Běhounek, Eisscholle 143)[12]

The ideal of the search for truth was not only a very expressive way to portray science as useful and important in a broader context. It also touches on a deeper problem. In the case of cosmic rays the entities in question are not easily accessible. Charged cosmic particles may influence the leaves of an electrometer, but one has to deduce from the fact that there are no other electrifying agents that the radiation actually exists. Devices that render a more direct proof of the existence of certain rays, like cloud chambers, are already quite intricate instruments. So, venturing out into nature to 'collect' data, especially under very inconvenient or right out dangerous conditions can be read as a very strong statement that to these physicists the entities in the world did actually exist and that knowledge about them could be gained by making use of scientific instruments. This may at first sound somewhat trivial, but it is far from that. From the turn of the century many new discoveries like x-rays, radioactivity and new ideas like the relativity theories and quantum mechanics had challenged classical physics (Peacock 3-14). Especially the so-called Copenhagen interpretation of quantum mechanics that described the orbital electron in the atom as a statistical probability function had raised the question to what extent an entity like an elementary particle could be measured and if not the measurement itself would influence the result (ibid. 79-84).

Right from the beginning of the twentieth century philosophical debates were heavily influenced by these changing concepts in physics. Many philosophers turned to the conceptual problems the downfall of classical, mechanistic physics had left, like the members of the Vienna Circle, who were trying to establish a "scientific philosophy" with strong "anti-metaphysical notions" and an "empiricist enlightened reasoning" (Stadler 1-14). The Viennese were, of course, not the only philosophers interested in modern science and it would by far exceed the scope of this article to go into the complex details of an intellectual development that would influence twentieth century positivism, as well as logical empiricism, to name but a few. What all the different approaches to a scientific philosophy seem to have had in common are the questions they asked about the relation of science and truth. How can we have knowledge of the world? And how may we relay this knowledge in a proper scientific way (ibid. 11-13, 29-31, 37)? The Vienna Circle is especially interesting when trying to evaluate how much the common scientist knew about these 'specialist debates'. For one, it was closely linked to the local physicist community that contained a large number of world-renowned researchers from the field of 'new physics': radioactivity, nuclear or cosmic ray physics. So it is probably safe to say that the physicists were well aware of the ongoing debates in philosophy. Besides, though the Vienna Circle had started as an informal group of intellectuals discussing current trends in philosophy and science, its members started to establish the *Verein Ernst Mach*, a branch that was to foster public interest in science (ibid. xxvi, 157).

The work of the *Verein* certainly fell on fertile ground as German speaking audiences in the 1920s and 1930s were not only interested in science proper but seem to have been drawn to anything even faintly related to science. Though the term *science fiction* had not been coined yet, novels like Kurd Laßwitz's *technical fairy tales* or the more mediocre, but far more successful *future novels* of Hans Dominik already answered the demands of a mass market (Fischer 57, 179). In his book on Musil's *Mann ohne Eigenschaften*, one of the more famous novels to encompass modern science, Arslan observes on the "*literarische Moderne*", that the definition of modernity by the actors was understood as "that what is in contrast to the past" (Arslan 17-18), but not as that which it actually is. This makes it a definition *ex negativo*, and modernity a movement characterised by what it is not – mirroring the hard to grasp definitions of physics. For future investigations into the link between science and heroism it will certainly be an interesting question whether the experimental physicist who goes on expeditions to collect data in the field in order to enhance physical knowledge becomes a specific modern hero insofar as he not only conquers nature, but also the uncertainty and the uprooting that come with modernity in general and modern physics in particular.

In connection with the Vienna Circle, Uebel has tried to describe modern science as a social act that divides rationality into three main categories: "cognitive-instrumental", "moral-pragmatic" and "aesthetic-expressive" (Uebel 17). This describes perfectly how 'heroic' scientists themselves and their audience reflected on the role of this certain type of scientist. In the article about *Canadas Everest* mentioned above, Hickson justifies the efforts being made for climbing Mt. Logan:

> Are this expedition and exertions which it involves worth while? Does not this attempt on Mt. Logan represent a sheer waste of energy and money and an unnecessary risking of human life? What is gained by taking the chances involved? […] The appeal made by mountaineering is partly physical, partly intellectual and moral and partly aesthetic. […] A peak like Logan is like Everest, a challenge to the powers of man, to his capacity to endure, and to his intelligence to plan and circumvent. (Hickson 17)

Conclusion

In the first half of the twentieth century scientists developed the tendency to take more risks in connection with their work than necessary from a pragmatic point of view. Experimental cosmic ray physicists may not have been the only scientists who chose to take field research to a whole new level, but their case is intriguing as the alternative approaches to their research questions were so obviously ready at hand. Yet, for the actors it seems to have been mandatory to choose this path. Being fully aware of the adventurous character of their work, they even delighted in risking their lives and sometimes even used this air of peril as a means to advertise their work to eagerly listening audiences. This public appraisal and possibly the attempt to define gender roles anew spurred the interest of young men of science to participate in expeditions that would take them to their extremes, offering the opportunity to become a hero of and for science, but also the chance to fail epically in a quite literal sense. Female scientists were apparently more reluctant to risk their health and lives.

Besides this all male competition for the admiration of their peers and applause from the audience, they were looking for truth and certainty in an otherwise constantly changing world. Physicists went out to collect data with their instruments, 'finding' new particles and different kinds of radiation like their forefathers had collected specimen of rock or rare orchids. Their somewhat naive approach to finding truth was backed by a strong realist stance that can be understood as a reaction to the philosophical debates of their time. It took another few decades before philosophers and sociologists of science and others would start to question the theory-ladenness of experiments and thus challenge the claim of experimental physics in general and field research in particular to be the primary path to (scientific) truth. Though more historical analysis might be needed in order to establish that the case of the cosmic ray physicists was not an exception from all the other natural sciences, one might say that the role of the scientific hero at this specific point in time was to establish order where the revolutionary findings of modern physics – questioning the traditional concepts of matter as much as those of time and space – had left chaos. Not only in public perception, but also from an inner-scientific perspective this reassuring role gained importance, as the emergence of more and more sub-disciplines of physics seemed to rather divide than unify the knowledge about the world we live in. Cosmic ray physics, connected to such diverse fields as cosmology or particle physics, held the promise of a future reunification, making its physicists standard bearers of a higher ideal of science.

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1 This introduction only gives a brief overview over the most important events and quotes the related sources. For a more systematic historic perspective cf. e.g. Cirkel-Bartelt.

2 For purists it might be somewhat sloppy to talk of 'rays *or* particles' but even after the advent of quantum mechanics and the wave-particle-dualism, cosmic ray physicists did not bother to be precise about these facts. They usually used the term '*rays*' when talking or writing about (high energy) γ-radiation and the term 'particle' for α- and β-radiation or elementary particles in general (cf. Cirkel-Bartelt 203).

3 Piccard's well-known record ascent is another good example of how in early cosmic ray studies aspects of adventure and competitive extreme sports often prevailed over scientific interests in a strict sense. The connection to extreme sports is insofar intriguing as in the recent years the paradigm in sports psychology has shifted, understanding 'high-risk-seekers' no longer as simple adrenaline junkies but analysing their affirmative and positive self-image established by conquering adversary conditions in nature and even facing lethal dangers (cf. Brymer/Oates). Further scrutiny in how far the self-proclaimed hero-scientists of the past might have been driven by similar motives might prove fruitful.

4 It would be desirable to know more about the use of photographs as a specific strategy to advertise scientists as heroes, but as photographs are generally rare in scientific publications of the time and the actual pictures taken are scattered over many different media and their respective archives, one can so far only argue on a case-to-case basis.

5 According to Běhounek's own account, he did not even receive funding for his participation in the first expedition and thus had to cover all his expenses on his own (Běhounek, Eisscholle 27-28).

6 Stuck's account of the event shows an approach to mountaineering that differs considerably from the professional mountaineers and polar-researchers of the other expeditions and the scientists in their company: he was driven by a deep love for the country and its nature (Stuck 13), castigating the chauvinist western attitude of his contemporaries as "supercilious" (ibid. 11). But though he was an amateur, Stuck collected his share of data on the Denali; he measured the height of the summit that had so far only been estimated (ibid. 107-112).

7 The community of mountaineers, polar researchers and scientists seems to have been closely entangled in general. The captain of the *Italia*, next in line of command after Nobile, had been the adjutant of the famous adventurer Prince Luigi Amedeo, Duke of the Abruzzi, who was, amongst others, the first to climb Mt. St. Elias, close to Mt. McKinley (Běhounek, Eisscholle 34; Hickson 16).

8 Berton has also pointed out that the 'helping hands' of such expeditions could not expect their fair share of fame afterwards as the interest would fully concentrate on the man in the lead (Berton 627-628).

9 The fact that other women outside science would participate in dangerous and adventurous endeavours like e.g. the race for records in the early history of flying by Amelia Earhart and others, even proves this point. Apparently, women in the late 1920s and the 1930s had the choice to partake in the 'heroic', but female cosmic ray physicist chose deliberately not to.

10 The experiment, when finally conducted, made Blau and her co-worker Hertha Wambacher the first to take pictures of spallation events, a natural type of nuclear fission (Fengler 166-167).

11 The way Běhounek compares meteorologist Malmgren to Scott and other polar researchers proves that for Běhounek and his audience the distinction between the different disciplines seems not to have been as important as it would be today.

12 Original: „Du hattest recht, armer Freund, wozu sollte ich etwas von dir erzählen, – ich konnte doch nichts anderes sagen, als was heute die ganze Welt wiederholt, daß ein ehrlicher und edler Mann zugrunde gegangen ist, einer von den vielen, wie Scott, de Long und alle übrigen Märtyrer der Wissenschaft, die ihr Grab in den Einöden des Nordens oder Südens fanden und deren Ende so ehrenvoll war wie ihr Werk!" (Běhounek, Eisscholle 143)

Works Cited

Anonymous. "Millikan Rays." *New York Times*; reprinted in: *Science* 62. 1612 (1925): 461-462.

Arslan, Cüneyt. *Der Mann ohne Eigenschaften und die Wissenschaftliche Weltauffassung. Robert Musil, die Moderne und der Wiener Kreis*. Wien: Springer, 2014.

Auger, Pierre Raymond Maze and Thérèse Grivet-Mayer. "Extensive cosmic showers in the atmosphere containing ultra-penetrating particles." *Comptes Rendus Academie de Science* (Ser.II) 206 (1938): 1721-1722.

Berton, Pierre. *The Arctic Grail*. New York: Viking, 1988.

Běhounek, František. "Forschungen über atmosphärische Elektrizität." *Die Vorbereitungen und die wissenschaftlichen Ergebnisse der Polarexpedition der Italia. Ergänzungsheft Nr. 205 zu Petermanns Mitteilungen*. Ed. Umberto Nobile. Gotha: Justus Perthes Verlag, 1929: 46-62.

Běhounek, František. *Sieben Wochen auf der Eisscholle. Der Untergang der Nobile Expedition*. Leipzig: Brockhaus, [10]1929.

Bosetti, Peter. *Trends in Astroparticle-Physics*. Stuttgart: Teubner, 1994.

Brüche, Erich. "Wo erreichen kosmische Elektronenstrahlen die Erdkugel?" *Physikalische Zeitschrift* 32. 24 (1931): 31-32.

Brymer, Eric and Lindsey Oates. "Extreme Sports: A Positive Transformation in Courage and Humility." *Journal of Humanistic Psychology* 49 (2009): 114-126.

Blau, Marietta. *Letter to Stefan Meyer from 22nd July, 1937*. Archiv der Österreichischen Akademie der Wissenschaften Wien, FE-Akten, Radiumforschung, X. Nachlass Stefan Meyer, K 11, fiche 175-176.

Campbell, Joseph. *The Hero with A Thousand Faces*. Princeton: Princeton UP, 1949.

Cirkel-Bartelt, Vanessa. *Kosmische Kontroversen*. Bochum: Bochumer Universitätsverlag, 2013.

Compton, Arthur Holly. "A Geographic Study of Cosmic Rays." *Physical Review* 43. 6 (1933): 387-403.

Corlin, Axel. "Ergebnisse der Ultrastrahlungsmessungen in Nord-Schweden." *Physikalische Zeitschrift* 31. 23 (1930): 1065-1071.

Corlin, Axel. "Messungen der Höhenstrahlungsintensität zwischen 55° und 70° nördlicher geographischer Breite. Vorläufige Mitteilung." *Arkiv för matematik, astronomi och fysik Meddelande från Lunds Observatorium* 22.2, Heft 1 (1930): 6.

---. "Measurements of the Cosmic Ultra-Radiation in Northern Sweden." *Lund Observatory Circulations* 6 (1932): 124-132.

Corliss, William R. "NASA Sounding Rockets, 1958-1968: A Historical Summary." T*he NASA Historical Report Series* SP-4401 (1971): 1-158.

De Maria, Michelangelo and Arturo Russo. "Cosmic ray romancing: The discovery of the latitude effect and the Compton-Millikan controversy." *Historical Studies in the Physical and Biological Sciences* 19. 2 (1989): 211-266.

De Maria, Michelangelo, Maria Grazia Ianniello and Arturo Russo. "The discovery of cosmic rays: Rivalries and controversies between Europe and the United States." *Historical Studies in the Physical and Biological Sciences* 22. 1 (1990): 165-192.

De Rújula, Álvaro (ed.). *A Unified View of The Macro- and The Micro-cosmos. 1. International School on Astroparticle Physics, Erice (Sicily, Italy)*. Singapore: World Scientific Publications, 1987.

Elster, Julius and Hans Geitel. "Über den Einfluß eines magnetischen Feldes auf die durch die Becquerelstrahlen bewirkte Leitfähigkeit der Luft." *Verhandlungen der Deutschen Physikalischen Gesellschaft* 1 (1899): 136-138.

Fengler, Silke. *Kerne, Kooperation und Konkurrenz: Kernforschung in Österreich im internationalen Kontext (1900-1950)*. Wien: Böhlau, 2014.

Fischer, William. *The Empire Strikes Out: Kurd Lasswitz, Hans Dominik, and the Development of German Science Fiction*. Bowling Green: Bowling Green UP, 1984.

Flückiger, Erwin O. and Rolf Bütikofer. "Untersuchungen der kosmischen Strahlung auf dem Jungfraujoch - 50 Jahre Neutronenmonitore." *Mitteilung der Naturforschenden Gesellschaft in Bern* 65 (2008): 123-141.

Gockel, Albert. "Messungen der durchdringenden Strahlung bei Ballonfahrten." *Physikalische Zeitschrift* 12. 14 (1911): 595-600.

Gockel, Albert. "Beiträge zur Kenntnis der in der Atmosphäre vorhandenen durchdringenden Strahlung." *Physikalische Zeitschrift* 16. 19 (1915): 345-352.

Hess, Viktor Franz. "Über Beobachtungen der durchdringenden Strahlung bei sieben Freiballonfahrten." *Physikalische Zeitschrift* 13 (1912): 1084-1091.

Hickson, Joseph William. "Will Canada's Everest Be Scaled?" *Maclean's Magazine* 38. 9 (1925): 16-17.

Jeans, James Hopwood. "Highly-Penetrating Radiation and Cosmical Physics." *Nature* 116 (1925): 861.

Kähler, Karl. "Registrierung des Emanationsgehalts der Bodenluft in Potsdam mit dem Benndorf-Elektrometer." *Physikalische Zeitschrift* 15 (1914): 27-31.

Kolhörster, Werner. "Über eine Neukonstruktion des Apparates zur Messung der durchdringenden Strahlung nach Wulf und die damit bisher gewonnenen Ergebnisse." *Physikalische Zeitschrift* 14 (1913): 1066-1069.

Kolhörster, Werner and Gubert von Salis. "Intensitäts- und Richtungsmessungen der durchdringenden Strahlung. III. Teil." *Berliner Berichte* (1923): 366-377.

---. "La période diurne du rayonnement d'altitude." *Archives des sciences physiques et naturelles* 8 (1928): 278-280.

Kurz, Karl. "Die radioaktiven Stoffe in Erde und Luft als Ursache der durchdringenden Strahlung in der Atmosphäre." *Physikalische Zeitschrift* 10 (1909): 834.

Malmgren, Finn. "Bericht über den Flug nach Nordland. (Nikolaus-II-Land)." *Die Vorbereitungen und die wissenschaftlichen Ergebnisse der Polarexpedition der Italia. Ergänzungsheft Nr. 205 zu Petermanns Mitteilungen*. Ed. Umberto Nobile. Gotha: Justus Perthes Verlag, 1929: 63-65.

Millikan, Robert Andrews. "High Frequency Rays of Cosmic Origin." *Science* 62 (1925): 445-448.

Nernst, Walther. *Das Weltgebäude im Lichte der neueren Forschung*. Berlin: Springer, 1921.

Nobile, Umberto. "Das geographische Problem der Arktis, das Programm und die Durchführung der Flüge der 'Italia'." *Die Vorbereitungen und die wissenschaftlichen Ergebnisse der Polarexpedition der Italia. Ergänzungsheft Nr. 205 zu Petermanns Mitteilungen*. Gotha: Justus Perthes Verlag, 1929.

Paetzold, Hans-Karl, Georg Pfotzer and Erwin Schopper. "Erich Regener als Wegbereiter der extraterrestrischen Physik." *Zur Geschichte der Geophysik. Festschrift zur 50jährigen Wiederkehr der Gründung der Deutschen Geophysikalischen Gesellschaft*. Eds. Herbert Birett, Klaus Helbig, Walter Kertz and Ulrich Schmucker. Berlin: Springer, 1974: 167-188.

Paulitz, Tanja. *Mann und Maschine. Eine genealogische Wissenssoziologie des Ingenieurs und der modernen Technikwissenschaften, 1850-1930*. Bielefeld: transcript Verlag, 2012.

Peacock, Kent. *The Quantum Revolution. A Historical Perspective*. Westport, CT: Greenwood Press, 2008.

Piccard, Auguste, Émile Stahel and Paul Kipfer. "Intensité du rayonnement cosmique à16000m d'altitude." *Compte Rendus* Academie de Science 195 (1932): 71-72.

Pontremoli, Aldo. "Beobachtungen." *Die Vorbereitungen und die wissenschaftlichen Ergebnisse der Polarexpedition der Italia. Ergänzungsheft Nr. 205 zu Petermanns Mitteilungen*. Ed. Umberto Nobile. Gotha: Justus Perthes Verlag, 1929: 87-89.

Stadler, Friedrich. *Der Wiener Kreis: Ursprung, Entwicklung und Wirkung des Logischen Empirismus im Kontext (Veröffentlichungen des Instituts Wiener Kreis)*. Wien: Springer, 2015.

Stuck, Hudson: *The Ascent of Denali. A Narrative of the First Complete Ascent of the Highest Peak in North America. (Reproduction)*. New York: Charles Scribner's Sons, 1918.

Swinne, Richard. "Zum Ursprung der durchdringenden Höhenstrahlung." *Naturwissenschaften* 7 (1919): 529-530.

Taylor, Jacob. "Mapping adventure: A historical geography of Yosemite Valley climbing landscapes." *Journal of Historical Geography* 32 (2006): 190-219.

Tomaselli, Cesco. *L'inferno bianco. Racconto della spedizione Nobile*. Milan: Unitas, 1929.

Uebel, Thomas. *Vernunftkritik und Wissenschaft: Otto Neurath und der erste Wiener Kreis*. Wien: Springer, 2000.

Rutherford, Ernest and Hereward Lester Cooke. "A Penetrating Radiation from the Earth's Surface." *Physical Review* 16 (1903): 183.

Von Salis, Gubert. "Beitrag zum Intensitätsverlauf der Höhenstrahlung." *Zeitschrift für Physik* 50 (1928): 793-807.

Wigand, Albert. "Messungen der Ionisation und Ionenbeweglichkeit bei Luftfahrten." *Physikalische Zeitschrift* 22. 2 (1921): 36-46.

Wilson, Charles Thomson Rees. "Condensation of Water Vapour in the presence of Dust-free Air and other Gases." *Proceedings of the Royal Society of London* 61 (1897): 240.

---. "On an Expansion Apparatus for Making Visible the Tracks of Ionising Particles in Gases and Some Results Obtained by its Use." *Proceedings of the Royal Society of London* 87 (1912): 277-292.

Wulf, Theodor. "Beobachtung über die Strahlung hoher Durchdringungsfähigkeit auf dem Eifelturm." *Physikalische Zeitschrift* 11 (1910): 811-813.