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Prolegomena

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Abstract

In these preliminary remarks we discuss our motivations for holding the San Vito di Cadore conference as well as some personal reflections on the history and current status of the origin of cosmic rays. We argue that it is time to think beyond the ‘standard model’ and contemplate the possibility of sources other than SNRs contributing to the observed cosmic ray flux even if the bulk originate in SNRs. In fact everyone tacitly assumes that at the very highest energies we do in fact see a new extra-Galactic component, but what it is and where exactly the transition occurs remain subjects of investigation. Similarly the positron excess seen by PAMELA and confirmed by AMS clearly points to an additional source of high-energy leptons in our Galactic neighbourhood. The recent observation by Agile and Fermi of the remarkable Crab gamma-ray flares point to some non-standard and very rapid form of particle acceleration which, if it occurs in other environments, may contribute to the acceleration of cosmic rays. In summary, it is clear that the origin of cosmic rays is a richer field of study than just diffusive shock acceleration in SNRs.

Keywords: Cosmic Ray Origin: Beyond the Standard Models, CRBTSM

1. Historical introduction

The discovery of cosmic rays is generally attributed, following the precedent set by the Nobel Prize committee of the Swedish Academy of Science in 1936, to the Austrian scientist Viktor Hess [1], who was the first to clearly and unambiguously state that the anomalous ionisation observed in the atmosphere was best explained by an “extremely penetrating radiation coming from above the atmosphere” on the basis of measurements made in his balloon flights of 1912-1913. Others had observed strange anomalies in ionisation, and in particular the German Jesuit physicist Theodor Wulf [2, 3] and the Italian scientist Domenico Pacini [4] anticipated Hess on the basis of measurements on the Eiffel Tower and at various depths under water respectively. A key technical advance was the development by Wulf around 1909 of reliable and portable “electrometers” which allowed easy measurements of the ionisation rate of air (or other gases) in closed vessels. These measurements clearly showed that there was a source of ionisation that was not associated with the radioactivity of minerals in the Earth’s crust, but left open the question of whether it was an intrinsic property of the atmosphere or had some other cause. The early history, and in particular the importance of Pacini’s work (which was known to Hess), is well discussed in a recent article by De Angelis [6]. A letter from Hess to Pacini, quoted in [6] is interesting in this regard: *Coming back to your publication in ‘Nuovo Cimento’, (6) 3 Vol. 93, February 1912, I am ready to acknowledge that certainly you had the priority in expressing the statement, that a non terrestrial radiation of* 2 ions $\mathrm{cm}^{-3}\mathrm{s}^{-1}$ *at sea level is present. However, the demonstration of the existence of a new source of penetrating radiation from above came from my balloon ascent to a height of 5000 meters on August 7 1912, in*

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which I have discovered a huge increase in radiation above 3000 meters. Undoubtedly Pacini, and to a lesser extent Wulf, deserve greater recognition than they have received, but it was Hess who convinced the world that the cosmic rays were an astrophysical phenomenon (he carried out observations during a partial solar eclipse to look for possible variations, which could be regarded as the first astroparticle physics experiment, and clearly shows that he thought the radiation came from space and not the upper atmosphere).

Interestingly the suggestion was made as far back as 1900 by C.T.R. Wilson [7] that the anomalous ionisation might be of extra-terrestrial origin, and the same idea was discussed by Wulf (who actually used the phrase *kosmische strahlung* in a paper with Gockel in 1908 [5]), but this was not taken seriously until the work of Hess and its confirmation by Kolhörster [8] in 1914. As Janossy [9] rather nicely puts it in the historical introduction to his 1948 monograph: *After the publication of the first results of Hess and Kohlhörster a violent controversy as to the existence of an extra-terrestrial radiation or cosmic radiation resulted in which Millikan and his co-workers ... took part. The original results were however maintained by Hess (1926) to be correct; they were fully confirmed somewhat later and the existence of cosmic radiation has been fully accepted since about 1926.*

The unfortunate English term "Cosmic Rays" originated with the American scientist R. Millikan who, having initially disputed the findings of Hess and Kolhoerster, then confirmed them and allowed the impression to be given that the cosmic rays were his own discovery (articles in the popular American press referred to 'Millikan rays')! He initially thought that they were very high-energy gamma-rays associated with the creation of the elements in interstellar space - the 'birth-cries of the elements' as he liked to put it. However the demonstration of clear geomagnetic effects by Clay and others, as well as theoretical advances in quantum electrodynamics (Klein-Nishina cross-section) which showed that very high energy gamma-rays could not be so penetrating, soon established that the cosmic rays were dominated by positively charged particles and as we now know consist mainly of stripped atomic nuclei moving at relativistic speeds.

It is remarkable that the origin of this "penetrating radiation", or "höhenstrahlung" as it was termed in the early German-language literature, is still a topic of active research over a hundred years on while almost all other questions in astrophysics and physics from that period have long been settled. This is surely a warning that we should approach the subject with an open and humble mind, which is the spirit in which we conceived the San Vito di Cadore meeting. There is, as we serendipitously discovered, also an excellent historical reason to hold such a meeting in San Vito di Cadore. The town and its surroundings is an area of great natural beauty and was a favoured holiday destination of the great Italian physicist, Enrico Fermi, who spent several summers in San Vito di Cadore hiking in the Dolomites. Fermi, whose seminal contribution to the field lives on in the various forms of 'Fermi acceleration' theory, would have been fascinated to think that a topic to which he had contributed was still being debated in the 21st century in his old holiday resort!

2. Current status

In general people use the term 'Cosmic Rays' to indicate all the energetic charged particles, both ions and electrons, that reach Earth. At low (non-relativistic) energies we have a lot of particles of Solar and Heliospheric origin (rather confusingly in the older literature sometimes called 'Solar Cosmic Rays') which obscure the particles of interstellar origin and of course the Solar wind itself sweeps low energy particles out of the inner Solar system. Thus although there must be a flux of low energy particles in interstellar space this is rather poorly constrained by direct observations. However above particle rigidities (momentum divided by charge) of about 1GV interstellar particles can penetrate into the inner Solar system and at the same time locally produced particles cease to be a problem. At these rigidities the fluxes are sufficiently high (typically a few $cm^{-2}s^{-1}$) that they can easily be measured by quite modest instruments on space probes and it is also technically quite easy to do charge separation. However the fluxes fall rapidly with energy (or rigidity) and thus extending precise measurements to higher energies soon becomes very challenging, especially if one also requires good particle identification. Fortunately as one goes to higher energies (roughly above 1 PeV) it becomes possible to make observations from the ground of the cascades that high-energy particles initiate in the atmosphere and, in effect, to use the Earth's atmosphere as a calorimetric detector. The difficulty of course is that one is no longer directly observing the incident particle and its properties have to be deduced from the shower parameters. Thus our knowledge of composition at high energies is poor, but considerable progress is being made as the high-energy interaction models improve. However the all-particle energy spectrum is now well determined all the way from 1 GeV up to the amazing energy of 10^{20} eV