29th International Cosmic Ray Conference Pune (2005) **6**, 333–336

Electric field influence on the radio emission of air showers

S. Buitink[g], W.D. Apel[a], F. Badea[a], L. Bähren[b], K. Bekk[a], A. Bercuci[c], M. Bertaina[d], P.L. Biermann[e], J. Blümer[a,f], H. Bozdog[a], I.M. Brancus[c], M. Brüggemann[h], P. Buchholz[h], H. Butcher[b], A. Chiavassa[d], K. Daumiller[a], A.G. de Bruyn[b], C.M. de Vos[b], F. Di Pierro[d], P. Doll[a], R. Engel[a], H. Falcke[b,e,g], H. Gemmeke[i], P.L. Ghia[j], R. Glasstetter[k], C. Grupen[h], A. Haungs[a], D. Heck[a], J.R. Hörandel[f], A. Horneffer[e,g], T. Huege[a,e], K.-H. Kampert[k], G.W. Kant[b], U. Klein[l], Y. Kolotaev[h], Y. Koopman[b], O. Krömer[i], J. Kuijpers[g], S. Lafebre[g], G. Maier[a], H.J. Mathes[a], H.J. Mayer[a], J. Milke[a], B. Mitrica[c], C. Morello[j], G. Navarra[d], S. Nehls[a], A. Nigl[g], R. Obenland[a], J. Oehlschläger[a], S. Ostapchenko[a], S. Over[h], H.J. Pepping[b], M. Petcu[c], J. Petrovic[g], T. Pierog[a], S. Plewnia[a], H. Rebel[a], A. Risse[m], M. Roth[f], H. Schieler[a], G. Schoonderbeek[b] O. Sima[c], M. Stümpert[f], G. Toma[c], G.C. Trinchero[j], H. Ulrich[a], S. Valchierotti[d], J. van Buren[a], W. van Capellen[b], W. Walkowiak[h], A. Weindl[a], S. Wijnholds[b], J. Wochele[a], J. Zabierowski[m], J.A. Zensus[e] and D. Zimmermann[h]

(a) Institut für Kernphysik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany
(b) ASTRON, 7990 AA Dwingeloo, The Netherlands
(c) National Institute of Physics and Nuclear Engineering, 7690 Bucharest, Romania
(d) Dipartimento di Fisica Generale dell'Università, 10125 Torino, Italy
(e) Max-Planck-Institut für Radioastronomie, 53010 Bonn, Germany
(f) Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76021 Karlsruhe, Germany
(g) Department of Astrophysics, Radboud University Nijmegen, 6525 ED Nijmegen, The Netherlands
(h) Fachbereich Physik, Universität Siegen, 57068 Siegen, Germany
(i) Inst. Prozessdatenverarbeitung und Elektronik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany
(j) Istituto di Fisica dello Spazio Interplanetario, CNR, 10133 Torino, Italy
(k) Fachbereich Physik, Universität Wuppertal, 42097 Wuppertal, Germany
(l) Radioastronomisches Institut der Universität Bonn, 53121 Bonn, Germany
(m) Soltan Institute for Nuclear Studies, 90950 Lodz, Poland
Presenter: S. Buitink (s.buitink@astro.ru.nl), net-buitink-SJ-abs1-he13-oral

The radio emission of extensive air showers can be understood as coherent geosychrotron emission of electrons and positrons travelling through the earth's magnetic field. Here we investigate if atmospheric electric fields can play a significant role in the emission process. For fair weather conditions ($E \approx 100\,\mathrm{Vm}^{-1}$) this effect can only slightly change the emission intensity. We show that these changes depend on the direction to the observer. In thunderclouds, however, electric fields reach much higher magnitudes that enhance the emission strongly. We investigate LOPES data that was recorded during thunderstorms and compare it with fair weather data. We find that air showers that take place during thunderstorms emit more radio emission than fair weather air showers with similar characteristics.

1. Introduction

The secondary electrons and positrons of an extensive air shower produce coherent radio emission in the atmosphere. It was shown by Falcke et al.[1] that the intensity of the radio emission is strongly correlated with the angle of the shower direction with the geomagnetic field, proving that the emission is of geosynchrotron nature. We investigate if the electric field in the atmosphere can play a significant role in the emission mechanism. We consider two types of electric fields: the fair weather field, which is always around $100\,\mathrm{Vm}^{-1}$ at ground level, rapidly decreasing with altitude, and the fields in and around thunderclouds. The largest electric field magnitude typically measured at the base of a thundercloud is $10-50\,\mathrm{kVm}^{-1}$ and $70-200\,\mathrm{kVm}^{-1}$ inside the thundercloud. At ground level the field strength is typically $1-10\,\mathrm{kVm}^{-1}$ during thunderstorm conditions (all values taken from [2]). Under fair weather conditions the electric field can affect the radio emission due to the electric force acceleration. This is described in section 2. Under influence of the large fields inside thunderclouds this effect increases, but also other effects can play a role. Electrons that are created by ionization can runaway and start breakdown avalanches [3], also contributing to the radio emission. In section 3 we investigate the data recorded by the LOPES experiment during thunderstorms and compare it to fair weather data.

2. Electric field effect on radio emission

As the electrons and positrons are curved in the geomagnetic field they emit synchrotron radiation. The intensity of the emission is determined by the acceleration of the particles. A force applied perpendicular to the direction of motion produces a total radiated power which is a factor γ^2 larger than the same force parallel to the direction of motion. The Lorentz force is always perpendicular to the particles' direction, but the electric force can have any angle with respect to the trajectory. Figure 1 shows the trajectories of an electron-positron pair that is created in a vertical shower. The electric field is directed downwards and the magnetic field out of the paper. As the particles curve in the magnetic field, the radius of curvature of the positrons increases, while that of the electrons decreases. In the first part of the trajectories the electric force is parallel to the direction of motion and will not significantly change the emitted power unless the field strength is very high. The emission from this part reaches observers on the north-south axis. Here the electric field effect will be minimal. The further the electrons curve to the west, the higher the fraction of the electric force that acts perpendicular to the direction of motion becomes. The electric force is in the same direction as the Lorentz force, so the acceleration will increase. Observers in the west will therefore see an increase in radio emission. To the east the electric force acts opposite to the Lorentz force and a decrease in radio emission is to be expected. The magnitude of the increase or decrease in radio emission can be estimated by comparing the electric force to the Lorentz force. For a vertical shower under fair weather conditions at the site of the LOPES experiment the electric force is below 3% of the Lorentz force. For highly inclined showers the electric force will have a larger component perpendicular to the direction of motion and its effect will be larger. In thunderstorm electric fields the electric force can even become larger than the Lorentz force.

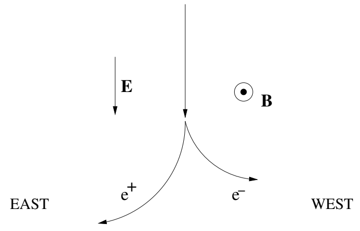

Figure 1. The electrons and positrons make curved trajectories in the magnetic field. Under influence of a downward directed electric field, the positron (electron) radius of curvature will increase (decrease). The asymmetry in the trajectories will be reflected in the radio emission.

3. Evaluation of thunderstorm data

From the LOPES event database we selected a set of 2214 events that took place during thunderstorm conditions. These conditions were identified by looking at lightning maps from a weather station and LOPES detections of lightning strikes, which can be recognized because they produce a saturated signal over the whole frequency range (43-73 MHz). In this way we found 25 hours of useful data divided over 7 separate thunderstorms.

A combined signal of all LOPES antennas was reconstructed by temporal shifting of the pulses in accordance with the arrival direction in the KASCADE air-shower data [4]. The coherence is further optimized by varying the radius of curvature of the shower front. In the dataset we found 6 bright radio pulses. For all these events (A-F) we made a selection of twin events, i.e. events that are associated with a shower with similar electron and muon number (within 10%) but occurred under fair weather conditions. The bright events in these twin groups were compared to the thunderstorm events. The plots of Figure 2 show the normalized radio peak height for all bright events in the 6 twin groups. The thunderstorm event is indicated with a red circle. To normalize, the radio intensity is divided by the muon number and corrected for the geomagnetic angle. For the latter an empirical result from [1] was used: the radio emission peak height is proportional to $(1 - \cos\alpha)$, where α is the angle of the shower direction with the geomagnetic field. In all groups, the thunderstorm event has the highest normalized radio intensity. For some (B,C,D) the intensity of the thunderstorm event is more than three times as large as the fair weather events. To check if our procedure was not biased by selection effects we repeated the whole procedure with a new data set of 2150 events that were recorded during 25 hours of fair weather. In this set, 3 bright events were found. These events and their twin group (G-I) are plotted in Figure 3. In none of the cases the preselected event is the largest of its group.

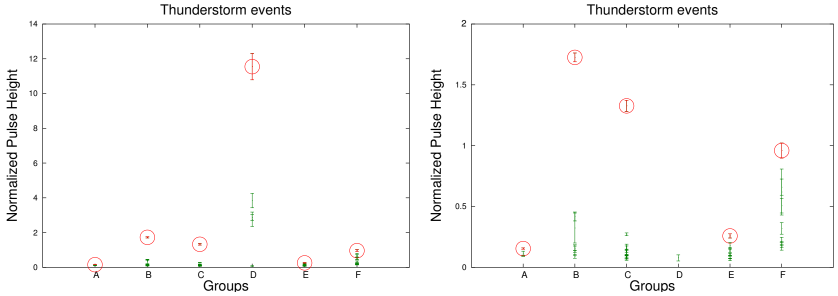

Figure 2. Normalized radio pulse height for 6 groups of twin events. The thunderstorm events are indicated with red circles. Their fair weather twin events are plotted in green. The right plot zooms in on the lower part of the left plot.

4. Conclusions and discussion

Figure 2 shows that for all the 6 bright thunderstorm events that we found, the radio emission is stronger than that of showers with similar electron and muon number. In three cases (B,C,D) this difference is of a factor > 3. In Figure 3 this behaviour is not seen, which proves that it is not a selection effect. The mean distance between the shower core and the antennas is not the same for each event and has a small effect on the measured intensity, which is not corrected for in out analysis.

The enhancement of the radio emission strongly depends on the direction of the electric field. Since electric fields inside thunderclouds can have either positive or negative polarity and are sometimes even horizontally

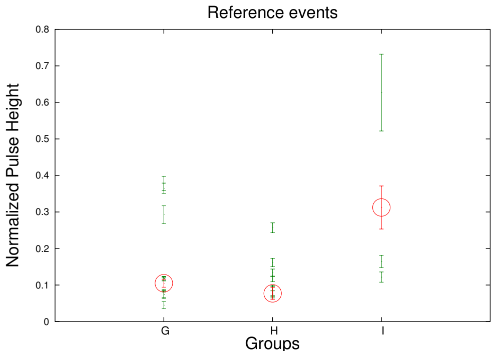

Figure 3. Same as Figure 2 for 3 groups of twin events. The events indicated with red circles are the original events. None of the events are thunderstorm events.

directed, the effect on the air shower electrons/positrons can be different from storm to storm. It is therefore not surprising that some cases show larger radio enhancement than other cases. Our result clearly shows that thunderstorm data should be handled separately from other events. Better statistics can be achieved by evaluating more thunderstorms and improving the detection method for thunderstorm activity. This could be done with a trigger from the radio data or an electric field mill that measures the electric field at ground level.

5. Outlook

We will improve the Monte Carlo code presented in [5] with routines to calculate radio emission of air showers in an electric field. With the code, we will investigate the effect of the fair weather electric field on the radio emission and look for east-west asymmetries in the results. A good understanding of the geometry and size of this effect will improve the accuracy of an air shower energy estimate based on radio emission. Also, we will simulate the effect of strong local magnetic fields as they occur inside thunderclouds. At the same time more thunderstorms will be investigated to gain better statistics and find geometrical asymmetries.

The interaction of air showers and thunderstorms can lead to interesting phenomena. Runaway ionization electrons created by an air shower can cause local field amplification which might produce narrow radio pulses or trigger lightning strikes [3]. The unique possibility of the LOPES experiment to distinguish air shower radio pulses from radio pulses of a different nature, allows us to investigate such theories.

References

[1] H. Falcke et al., Nature 435, 313-316 (2005).
[2] D. MacGorman and W. Rust, The electrical nature of storms (Oxford University Press, New York, 1998)
[3] A. V. Gurevich et al., Physics Letters A 301, 320-326 (2002)
[4] A. Horneffer et al., Proc. SPIE 550-21 (2004)
[5] T. Huege and H. Falcke, A&A 430, 779-798 (2005)