Precision Measurement of the monthly cosmic Ray fluxes e^- , e^+ , p, He) with the Alpha Magnetic Spectrometer on the ISS

Maura Graziani

¹KIT, Karlsruhe Institute of Technology

Abstract. The precision measurements of the monthly cosmic ray fluxes with Alpha Magnetic Spectrometer on the International Space Station are presented. Individual electron, positron, proton and helium spectra have been measured for each Bartel's rotation period (27 days) in the time range from May 2011 to May 2017. This period covers the ascending phase of solar cycle #24 together with the reversal of the Sun's magnetic field polarity through the minimum. The fluxes reveal a characteristic time dependence below 20 GeV. The data show a strong charge-sign dependent effects corresponding to the the polarity reversal of the solar magnetic field.

1 Introduction

The study of Cosmic Rays (CR) constitutes a unique instrument for understanding our universe. By means of the CR hadronic component, the knowledge about CR propagation through the galaxy and the Interstellar Medium can be improved. With the CR electromagnetic component (as well as the other rare components of CR like antiprotons) we can investigate the local CR sources, looking for indirect signs of Dark Matter. However, CR spectra, when measured near Earth, are significantly affected by the solar activity. The solar activity has a cycle of ~ 11 years, during which it increases reaching a maximum and then decreases again. The intensity of cosmic ray radiation is anti-correlated with the activity of the sun [1], and this is the so called Solar Modulation (SM) effect. In order to have a correct understanding of CR spectra out of the heliosphere, the SM should be well known and taken into account. A detailed study of the CR fluxes evolution with time is needed in order to develop and test different models of the SM effects based on the interaction of cosmic rays with the Heliosphere. The simultaneous measurements of e^- and e^+ (or p and \bar{p}) over a complete solar activity cycle can represent a sound test of the current charge-sign dependent modulation models. AMS-02 can provide the most accurate measurements of the time dependence of particle and anti-particle fluxes since 2011 thanks to its high acceptance and the excellent performance of the detector. In this letter, the time variation of CR electron (e^{-}) , positron (e^{+}) , proton (p) and Helium (He) fluxes during the first 6 years of data taking will be presented.

2 The AMS-02 detector

The AMS-02 is a large acceptance CR detector which has been installed during the STS-134 NASA Endeavour Space Shuttle mission in May 2011 on the International Space Station, where it will collect

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

CR until the end of the ISS operation, currently set to 2024. Thanks to the long exposure time combined with a large detector acceptance $(0.5 \text{ m}^2 \text{ sr})$, AMS is able to study the primary CR fluxes in the energy range GeV-TeV with unprecedented precision and sensitivity. The core of the instrument is a spectrometer, composed of a permanent magnet (with a magnetic field with an intensity of 0.14 T), and of 9 layers of double-sided micro-strip silicon sensors that constitute the Tracker. Above and below the spectrometer two planes of Time of Flight counters are placed. A Transition Radiation Detector is located at the top of the instrument. The detector is completed with a Ring Imaging Cherenkov detector and an Electromagnetic Calorimeter. The central part of AMS-02 is surrounded by an Anti-Coincidence system. The AMS-02 detector is described in details in [2].

3 Flux measurements

The AMS data from May 2011 to May 2017 have been analysed for the measurement of e^- , e^+ , p and He fluxes in time. The results have been published in [3, 4]. The applied analysis follows the formula used for the measurement of the time-averaged electron and positron fluxes [5], improving low-energy effective acceptance. The fluxes have been measured in 79 different time interval, each one corresponding to a different Bartel's rotation, in the rigidity range from 1 to 60 GV for p, from 1.9 to 60 GV for He, and in the energy range from 1 to 50 GeV for e^- and e^+ .

3.1 Electron and positron fluxes in time



Figure 1: (a) Fluxes of CRs e^+ (red, left axis) and e^- (blue, right axis) as functions of time, for 5 energy bins with the statistical uncertainties. Prominent and distinct time structures are marked by dashed vertical lines. (b) The e^+/e^- ratio, R_e , as a function of time with the statistical uncertainties. The red curves show a best-fit parametrisation obtained with an analytical function described in [3]. The polarity of the heliospheric magnetic field is denoted by A < 0 and A > 0. The period without well-defined polarity is marked by the shaded area.

In Figure 1a, the time dependence of the e^- and e^+ fluxes is reported for 5 characteristic energy bins (for more details see [6]). Both e^- flux and e^+ flux show a significant time dependence with a

long-term time structure and short-term time structures (delimitated by the shaded lines). The time dependency of fluxes increases with the decrease of energy. Above 20 GeV, neither the electron flux nor the positron flux exhibits significant time dependence. For E<10 GeV, we observe that from May 2011 to May 2013, both for e⁻ flux and e⁺ flux decrease with time. In July 2013 the solar magnetic field reversal occurred. From May 2013 to April 2015, the flux of electrons continues to decrease, but with reduced slope, while the positron flux begins to increase. Then, from April 2015 until May 2017, both fluxes rise steeply. The observed different behaviour between e⁻ flux and e⁺ flux are related to the charge-sign dependent solar modulation effects. The main reason for this to occur is that when the solar magnetic field reverses its polarity, the galactic CRs of opposite charge will reach Earth from different heliospheric directions due to the magnetic drift. The charge-sign dependencies of solar modulation, can be clearly observed in Figure 1b in which the e⁺/e⁻ ratio (R_e) is shown as a function of time for all energy bins up to 5 GeV. In R_e , the important, newly discovered short-term variations in the fluxes largely cancel, and a clear overall long-term trend appears. At low energies, R_e is flat at first, then smoothly increases after the time of the solar magnetic field reversal, to reach a plateau at a higher amplitude.

3.2 Helium and proton fluxes in time



Figure 2: (a) The AMS p (blue, left axis) and He (red, right axis) fluxes as function of time for 5 rigidity bins. The error bars are the quadratic sum of the statistical and time dependent systematic errors. Detailed structures (green shading and dashed lines to guide the eye) are clearly present below 40 GV. The red vertical dashed lines denote structures that have also been observed by AMS in the e^- flux and the e^+ flux. (b)The AMS p/He flux ratio as function of time for 9 characteristic rigidity bins. The errors are the quadratic sum of the statistical and time dependent systematic errors.

In Figure 2a, the time dependence of the p and He fluxes is reported for 5 characteristic rigidity bins (for more details see [7]). Both the p and He fluxes exhibit large variations with time at low rigidities which decrease with increasing rigidity. The structures in the p flux and He flux are nearly identical in both time and relative amplitude (indicated by the green shading) that decrease progressively with rigidity. The five red vertical dashed lines in the figure indicate the structure that have been also observed in the electron flux and the positron flux. After one year from the solar maximum (April 2014 for solar cycle 24), the amplitudes of the structures are considerably reduced and the proton and helium fluxes steadily increase at rigidities less than 40 GV. Figure 2b shows the AMS p/He flux ratio as a function of time for 9 rigidity bins. We can observe that, depending on the rigidity range, the p/He flux ratio shows two different behaviours in time. Above ~3 GV the ratio is time independent. Below ~3 GV the ratio has a long-term time dependence. An analytic fit on p/He ratio was performed and has shown that above 3.29 GV the p/He flux ratio is consistent with a constant value at the 95% confidence level. This shows the universality of the solar modulation of cosmic ray nuclei at relativistic rigidities. Below 3.29 GV, the observed p/He flux ratio is steadily decreasing with time.

4 Conclusion

The fluxes for p, He, e^+ and e^- as a function of time have been measured by AMS during the ascending phase of solar cycle 24 through its maximum and toward its minimum.

The unique performance of AMS-02 provides measurment of both e^+ and e^- fluxes as a function of time with an unprecedented high time granularity. Based on 23.5×10^6 events, we report the observation of short-term structures on the timescale of months coincident in both the e^- flux and the e^+ flux. These structures are not visible in the e^+/e^- flux ratio. The precision measurements across the solar polarity reversal show that the ratio exhibits a smooth transition over 830 ± 30 days from one value to another. The midpoint of the transition shows an energy dependent delay relative to the reversal and changes by 260 ± 30 days from 1 to 6 GeV.

The precision p flux and the He flux observed by AMS have fine time structures nearly identical in both time and relative amplitude. The amplitudes of the flux structures decrease with increasing rigidity and vanish above 40 GV. The amplitudes of the structures are reduced during the time period, which started one year after solar maximum, when the proton and helium fluxes steadily increase. In addition, above ~3 GV the p/He flux ratio is time independent. Below ~3 GV the ratio has a long-term decrease coinciding with the period during which the fluxes start to rise. Before AMS data, several effects had been proposed that lead to a time dependence of the p/He flux ratio at low rigidities, such as velocity dependence of the diffusion tensor, differences in the interstellar spectra of p and He, and the ${}^{3}He$ and ${}^{4}He$ isotopic composition [8–10].

AMS is measuring solar effects for all nuclei, particle and anti-particle fluxes in the present and next solar cycle providing information for the development of refined solar modulation models.

References

- [1] M.S. Potgieter, Living Reviews in Solar Physics 10, 3 (2013)
- [2] Phys. Rev. Lett. 110, 141102 (2013)
- [3] Phys. Rev. Lett. 121, 051102 (2018)
- [4] Phys. Rev. Lett. 121, 051101 (2018)
- [5] Phys. Rev. Lett. 113, 121102 (2014)
- [6] See Supplemental Material at http://link.aps.org/supplemental/10.1103/PhysRevLett.121. 051102
- [7] See Supplemental Material at https://journals.aps.org/prl/supplemental/10.1103/PhysRevLett. 121.051101/SM-p-He-vs-BR-REV.pdf
- [8] The Astrophysical Journal Letters 849 (2017)
- [9] G. Gloeckler, J.R. Jokipii, Phys. Rev. Lett. 17, 203 (1966)
- [10] I. Cholis, D. Hooper, T. Linden, Phys. Rev. D 93, 043016 (2016)