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Determination of 7-30 MeV electron intensities: ULYSSES COSPIN/KET RESULTS

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Abstract

The COsmic and Solar Particle INvestigation Kiel Electron Telescope was designed to measure electrons from a few MeV up to a few GeV using particle energy loss and particle velocity measurement techniques. Unfortunately the KET channel measuring electrons in the energy range from 7-170 MeV is contaminated by a γ-ray background (Ferrando *et al.*, 1996). Besides a possible slight contribution from the RTG radiation, we have shown that this background is mainly generated by high energy protons interacting with the spacecraft matter. Such γ-rays can enter "unseen" the instrument and are partially converted into electrons in the calorimeter consisting of a high Z lead fluoride Cherenkov detector. Such electrons could be counted in the 7-170 MeV electron channels. In this paper we present a method to quantify this background and thus determine lower and upper limits for the intensities of electrons with energies from 7 to 30 MeV. Our analysis shows that above 30 MeV the background in this specific channel is so dominant, that no correction is possible.

1 Introduction

The KET on-board Ulysses measures proton, and α-particles in the energy range from $\sim$4 to $>$2000 MeV/n and electrons in the range from $\sim$2 to $>$300 MeV in different energy channels. Fig. 1 shows a sketch of the KET sensor. The telescope is described in Simpson et al. (1992) and consists in principal of two parts: (1) the entrance telescope with the semiconductor detectors D1 and D2, the Cherenkov detector C1, and the anti-coincidence A, and (2) the calorimeter, a lead fluoride Cherenkov detector C2, in which an electromagnetic shower can develop, and a scintillation detector S2, which counts the number of charged particles leaving C2. Up to 2 GeV/n for protons and up to 300 MeV for electrons protons are separated from electrons by

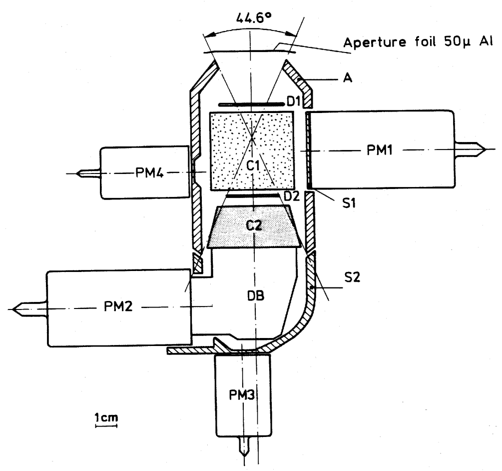

Figure 1: Sketch of the KET sensor

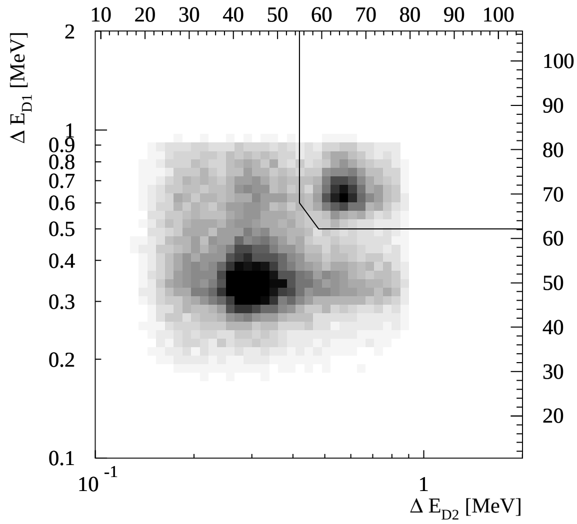

Figure 2: Left: Energy loss matrix of D1 and D2. The upper area marks the expected range for two electrons simultaneously crossing D1 and D2.

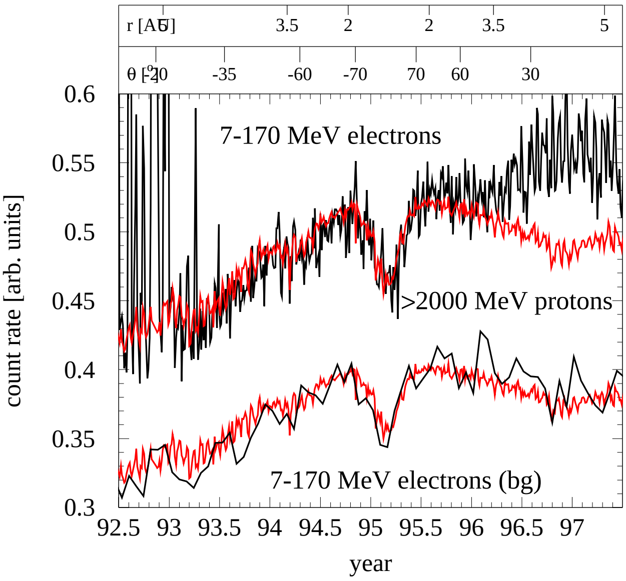

Figure 3: 4 day averaged raw count rate of 7-170 MeV electrons (e) and >2000 MeV protons (upper curves) and 7-170 MeV electrons, identified as background (bg) as well as >2000 MeV protons (lower curves).

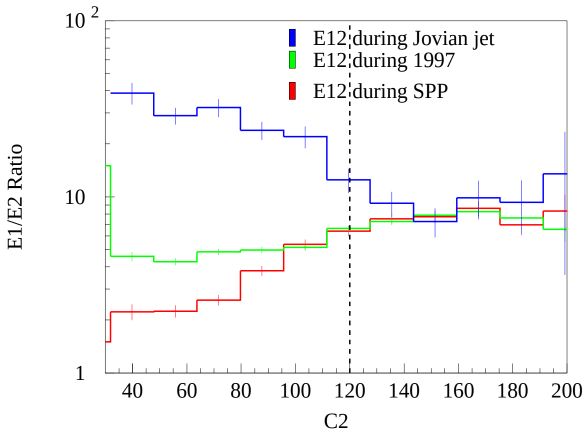

Figure 4: One to two electron distribution as a function of the C2 signal for different time periods (see text).

the fact, that electrons do trigger the Aerogel Cherenkov detector C1 and protons do not. >2 GeV/n protons and >300 MeV electrons are separated from each other by simultaneously analysing the C2 and S2 signals (Rastoin et al., 1995 and Ferrando et al., 1996).

2 Observations

The KET electron channel E12 is defined by the coincidence conditions: D1, C1, D2, C2, $\overline{S2}$, $\overline{S1}$, $\overline{A}$, where D ($\overline{D}$) means that Detector D has (not) given a signal (compare with Fig. 1). As suggested by Ferrando *et al.* (1996) a large contribution to the count-rate in E12 are due to γ-rays, generated locally in the spacecraft by hadronic interaction of galactic cosmic rays with the spacecraft material. These γ-rays may enter the telescope from behind and are converted in C2 into electrons and/or positrons and leaving the instrument in direction of the aperture without a signal in the anti coincidence A. Since no information on the directionality of a particle is available, such particles would give a valid coincidence and be counted in E12.

Fig. 2 displays the in-flight energy loss distribution in D1 vs D2 for the E12-channel. As discussed by Ferrando *et al.* (1996) the entries in the upper right corner can be unambiguously attributed to a simultaneous crossing of two electrons in D1, C1 and D2 ($\sim$1 μs). We interpret these entries as background electrons moving from the back to the front of the instrument. Note that there is a small number of electrons, which are entering the KET-Aperture and backscattered and therefore could also give rise to a two electron passage.

Fig. 3 displays the 4 day averaged countrate of 7-170 MeV electrons and >2000 MeV protons (upper curves). Both curves are normalised to each other during Ulysses's rapid pole-to-pole passage. As discussed in Ferrando *et al.* (1993) and Simpson *et al.* (1993) the sharp increases in 1992/1993 of the electron intensity are due to special propagation conditions of electrons from Jupiter to Ulysses. The increase in the electron flux starting in 1996 will be discussed by Ferrando *et al.* (SH.3.2.14). From mid 1993 to beginning of 1996 both curves track each other well. Since the intensity of >2000 MeV protons exceeds the one of 7-170 MeV electrons, we conclude that this channel is dominated by GCR-proton induced background. This effect is even more obvious, when we concentrate on the time profile of particles counted in E12 and giving rise to an entry in the D1-D2-Matrix area, which can be interpreted as a simultaneous crossing of two electrons. In what follows we will refer to these time profiles as the 2-electron time profiles. Correspondingly the electron E12-time profile, which is determined by neglecting entries within the marked area in Fig. 2 are denoted as the 1-electron time profile. When we compare the 26-day averaged 2-electron time profiles of 7-170 MeV electrons (E12) with the one of $>$2000 MeV protons as shown in Fig. 3 by the lower curves, we find that both curves track each other very well for the whole time period. As discussed by Ferrando *et al.* (1996) we can reduce the background count rate in E12 by using only the 1-electron time profiles. However, we can not exclude, that the γ-ray generated background is also contributing to the 1-electron count rates. One would expect, that the number of 1-electron background entries should be dependent on the energy-loss in C2. In what follows we will analyse the E12 time history by using the information in the D1-D2-Matrix as well as the signal in C2 to calculate upper and lower electron intensities.

3 Data Analysis and Discussion

As shown in Fig. 2 the observed 1- to 2-electron ratio depends on the energy of the particle, as measured by the Pulse-Height-Signal in the calorimeter C2. This ratio is not only energy but also time dependent in the C2$<$120 range, as indicated by the three curves evaluated at three different time periods. These periods were selected to illustrate the maximal observed variation in this ratio. The first period in 1992 when Ulysses was close to Jupiter is dominated by Jovian jets (see for example Ferrando *et al.*, 1993, and Simpson *et al.*, 1993). During the second period, when Ulysses is at high southern heliographic latitudes, this ratios drops to its minimal value, and increased to intermediate values again in 1997. Since for C2$>$120 the count rate ratio is independent of time we conclude, that our measurements are dominated by the background contribution. From the KET-calibration measurements, we determined a mean C2-value of $\sim$110 and $\sim$125 for 30 MeV and 50 MeV electrons, leading to the conclusion, that we are not able to determine electron spectra above $\sim$ 30 MeV. However, because of modulation of galactic cosmic ray electrons and protons, this might change during minimum period in the next A$<$0-solar cycle.

In what follows we assume that our measurements with separation in 1- (ce_1) and 2- (ce_2) electron channels is a mixture of two components for each C2-bin. The first component are the real electrons (e_1 and e_2) we are interested in and the second component ($\overline{e_1}$, and $\overline{e_2}$ is the γ-ray background. From Fig. 3 it is reasonable to assume that the background is proportional to the $>$2 GeV proton count rate (c_p):

$$ce_1 = e_1 + \overline{e_1}\,,\, ce_2 = e_2 + \overline{e_2} \quad \text{and} \quad \overline{e_1} = f_1 \cdot c_p\,,\, \overline{e_2} = f_2 \cdot c_p \qquad (1)$$

We assume further that $\Delta = e_1/e_2$-ratio is constant. This ratio could be in principle determined by using KET calibration measurements. Unfortunately the statistic for e_2 is very low and therefore only lower and upper limits of $\sim$10 to $\sim$100 were found. We also assume that $\overline{\Delta} = (f_1 \cdot c_p)/(f_2 \cdot c_p)$ is constant with time. Since no calibration using a γ-ray source were made no estimate on this ratio can be given. In Fig. 5 the 52-day running mean averaged count rates of the E12 1-electron (a) and the 2-electron (b) subchannel with C2$<$80 are displayed. The count of the $>$2 GeV proton channel (c) is normalised to the ”2-electron”-subchannel during the rapid pole-to-pole passage. In contrast to Fig. 3 ce_2 with C2$<$80 is tracking the $>$2 GeV proton channel not for the whole time period. Due to our selection of C2$<$80 only $\sim$10% of all entries are taken into account, and the 2-electron E12-channel, as displayed in Fig. 3, is dominated by the C2$>$120 contribution, which is not changing with time. Therefore we conclude, that the amount of ”2-electrons” produced by real electrons is not negligible in the C2$<$80 ”2-electron”-subchannel. To derive a corrected E12-1-electron (C2$<$80) time history as displayed by the curves (d) and (e) in Fig. 6 we make the following assumptions: (1) By comparing curve (b) and (c) it is reasonable to assume, that at polar regions in 1994 the ”2-electron”-subchannel is dominated by the γ-ray background, leading to $f_2 = 0.0045 \pm 0.0003$.

Minimum: To estimate the lower values for the electron intensity we assume that the ”1-electron” subchannel is also fully contaminated, when Ulysses was at southern polar regions in 1994. In this case $f_1 = ce_1/c_p =$

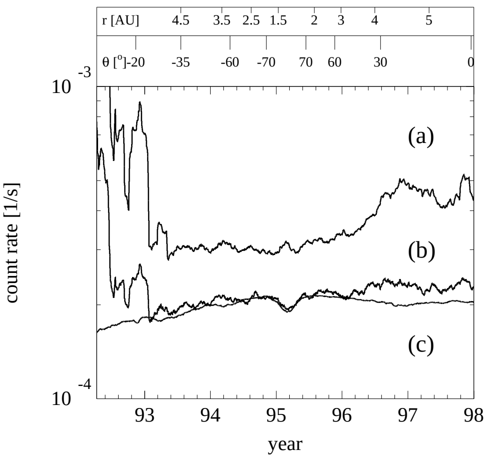

Figure 5: 52-day running mean averaged count rates for the E12 1-electron (a) and 2-electron (b) subchannel (C2<80), and for normalised >2 GeV protons.

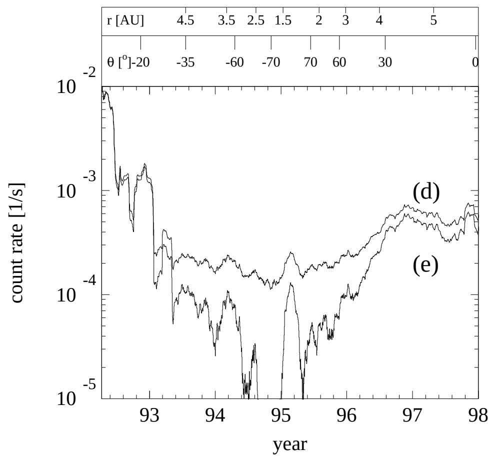

Figure 6: 52-day running mean averaged E12 (C2<80) 1-electron time history correct for different amount of γ-ray background as explained in the text.

0.0085 ± 0.0008 could be determined during this selected time period. e_1 is then given for all other time periods by $e_1 = ce_1 - f_1 \cdot c_p$ and is displayed by curve (e) in Fig. 6.

Upper values (d): In contrast to our first approach we don't assume that ce_1 is dominated by the background at any time, but we assume that ce_1 is dominated by real electrons during Jovian event time periods and that at these time periods the ce_2 has a contribution of real electrons plus a known background (f_2 is known from the 1994 time period). The ratio $\Delta = e_1/e_2 \sim 10$ was calculated by making use of Jovian jets. Then f_1 can be determined by using the correlation.

$$\overline{e_1} = ce_1 - \underbrace{\Delta \cdot \overbrace{(ce_2 - f_2 \cdot c_p)}^{e_2}}_{e_1} = f_1 \cdot c_p \tag{2}$$

A least square root fit to the data (not shown here) leads to $f_1 = 0.008 \pm 0.001$. The lower limit is in good agreement with the result of the previous section. The upper limit is given when using $f_1 = 0.007$ and is displayed as curve (d) in Fig. 6. Note that the correction presented here are a selection of $<\sim$1% of all entries measured in the E12-channel and therefore we only get a small accuracy for the time period from 1993 to mid of 1996.

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