Supplementary Materials for

First measurements of low-energy cosmic rays on the surface of the lunar farside from Chang’E-4 mission

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Published 14 January 2022, Sci. Adv. 8, eabk1760 (2022)
DOI: 10.1126/sciadv.abk1760

The PDF file includes:

- Determination of geometric factor of CE-4/LND
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Other Supplementary Material for this manuscript includes the following:

- Data files S1 to S5
Determination of the geometric factor of CE-4/LND

Geometric factor (GF) is an important property of particle detectors and can be calculated by

$$GF = \frac{N_d}{j},$$

(6)

where $N_d$ is the count rate, $j$ is the spatial differential flux in units of $(cm^{-2} \cdot s^{-1} \cdot sr^{-1})$. The GF of the CE-4/LND used in this work is simulated by the GEANT4 (Geometry And Tracking) toolkit (76-78). In the simulation, a sphere particle source with radius $R$ is used, which can encircle the detector completely. The primary particles inject randomly from the sphere surface and then transport inwardly with cosine distribution (angle between particle incident direction and the local surface normal) to produce an isotropic incident flux in the inner space. The number of particles $N$ traversing the sphere source volume can be written as (79)
\[ N_r = \iint j \, ds \, d\Omega = 4\pi R^2 \left( \int_0^\theta \int_0^{\theta/2} d\phi \cos \theta \sin \theta \right) \cdot j = 4\pi^2 R^2 \cdot j. \quad (7) \]

Equation 7 is the one-to-one correspondence relationship between the spatial differential flux and the number of incident particles. On the basis of Eqs. 6 and 7, \( GF \) can be easily deduced to be

\[ GF = 4\pi^2 R^2 \cdot \frac{N_d}{N_r}. \quad (8) \]

Here, the error of \( GF \), \( \delta GF \), can be obtained by

\[ \delta GF = 4\pi^2 R^2 \cdot \frac{\delta N_d}{N_r}, \quad (9) \]

where \( \delta N_d \) is the error of \( N_d \).

To ensure the detection of charged-particle radiations and the identification of their composition, the CE-4/LND is designed as a telescope configuration, a stack of ten 500-\( \mu \)m-thick dual-segment Si solid-state detectors labeled A through J as shown in figure 4 of (36). To determine the GF for a specific charged particle in an energy channel, coincidence measurements in different detector segments are applied. The information of primary energy ranges and the corresponding detectors stopping in for the proton, \(^3\)He, \(^4\)He, CNO, and heavy ions (HIs) are listed in table 6 of (36), and the criterion for a charged particle stopped in a specific detector segment is listed in table 3 of (36) as well.
In our simulations, $R$ and $N_r$ are set to be 10 cm and $1.0 \times 10^8$, respectively, unless otherwise specified. $N_d$ is determined in the simulation by the coincident measurement in detector segments as mentioned above. By now, with this strategy we can obtain the GF of each energy channel for all related ions.

The weighted GFs for the $^3\text{He}+^4\text{He}$, CNO, and HI groups can further be calculated by

$$GF_{\text{wgt}} = \sum_{i=1}^{N} W_i \cdot GF_i,$$  \hspace{1cm} (10)

where $N$ is the total number of component elements for these particle groups, such as $N = 2$ for $^3\text{He}+^4\text{He}$, $N = 3$ for the CNO group, and $N = 10$ for the HI group. $GF_i$ is the measured GF for the $i$th component element. $W_i$ is the weight of the $i$th component element, which can be obtained on the basis of the observations from the ACE/SIS for the CNO and HI groups, while a ratio of 3:100 is taken for $^3\text{He}+^4\text{He}$ approximately according to the results of differential flux ratio of $^3\text{He}$ to $^4\text{He}$ obtained in this work, and defined as

$$W_i = \frac{\overline{F}_i}{\sum_{i=1}^{N} \overline{F}_i},$$  \hspace{1cm} (11)

where $\overline{F}_i$ is the average differential flux of the $i$th component element. The error of $W_i$, $\delta W_i$, can be given as

$$\delta W_i = W_i \cdot \left( \frac{\delta \overline{F}_i}{\overline{F}_i} \right)^2 + \left( \frac{1}{\sum_{i=1}^{N} \overline{F}_i} \right)^2 \left( \sum_{i=1}^{N} \left( \frac{\delta \overline{F}_i}{\overline{F}_i} \right)^2 \right).$$  \hspace{1cm} (12)

Using Eq. 10, the error of $GF_{\text{wgt}}$ can be deduced to be

$$\delta GF_{\text{wgt}} = \sqrt{\sum_{i=1}^{N} \left( W_i \cdot GF_i \right)^2 \left( \frac{\delta W_i}{W_i} \right)^2 + \left( \frac{\delta GF_i}{GF_i} \right)^2 \left( \frac{\delta GF_i}{GF_i} \right)^2}. $$  \hspace{1cm} (13)
Finally, the GFs for these particle groups can be calculated on the basis of the Eqs. 6 to 13. The obtained GFs are shown in Table S1. Note that the errors of GFs listed in the table include only contributions from the statistical and misidentification count rate errors of $N_d$ as well as the error of weight $W_i$.

**Table S1.** List of the GFs for the proton, $^3$He, $^4$He, $^3$He+$^4$He, and the CNO and HI groups detected by the CE-4/LND on the basis of the GEANT4 simulations.

|       | Energy Channels ($MeV/nuc$) | 9.0-10.6 | 10.7-12.7 | 12.8-15.7 | 15.9-18.4 | 18.6-21.0 | 21.2-29.2 | 29.6-31.3 | 31.5-33.0 | 33.4-34.5 |
|-------|-----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $^3$He | $GF_{wff}$ ($cm^2 \cdot sr^{-1}$) | 0.2940 ±0.0051 | 0.2757 ±0.0049 | 0.2795 ±0.0085 | 0.2642 ±0.0060 | 0.2403 ±0.0095 | 0.2416 ±0.0021 | - | - | - |
|       | $GF_{wff}$ ($cm^2 \cdot sr^{-1}$) | - | 0.2945 ±0.0062 | 0.2830 ±0.0062 | 0.2784 ±0.0068 | 0.2639 ±0.0072 | - | - | - | - |
| $^4$He | Energy Channels ($MeV/nuc$) | 8.9-9.5 | 9.6-10.9 | 10.9-12.6 | 12.8-15.7 | 15.9-18.5 | - | - | - | - |
|       | $GF_{wff}$ ($cm^2 \cdot sr^{-1}$) | - | 0.2847 ±0.0049 | 0.2897 ±0.0050 | 0.2824 ±0.0071 | 0.2479 ±0.0066 | - | - | - | - |
| $^3$He+ $^4$He | Energy Channels ($MeV/nuc$) | 18.5-21.0 | 21.0-29.3 | 29.3-31.4 | 31.4-32.8 | 32.8-34.4 | - | - | - | - |
|       | $GF_{wff}$ ($cm^2 \cdot sr^{-1}$) | 0.2304 ±0.0132 | 0.2452 ±0.0409 | - | - | - | - | - | - | - |
| CNO   | Energy Channels ($MeV/nuc$) | 16.6-20.5 | 20.5-25.5 | 25.5-31.0 | 31.0-37.3 | 37.3-42.3 | 42.3-54.5 | 54.5-57.8 | 57.8-61.2 | 61.2-72.8 |
|       | $GF_{wff}$ ($cm^2 \cdot sr^{-1}$) | 0.1378 ±0.0352 | 0.2822 ±0.0351 | 0.1911 ±0.0300 | 0.1430 ±0.0430 | 0.1184 ±0.0202 | 0.2001 ±0.0746 | 0.0443 ±0.0204 | 0.0371 ±0.0163 | 0.0328 ±0.0146 |
| HI    | Energy Channels ($MeV/nuc$) | 24.6-37.7 | 31.0-38.2 | 38.2-47.5 | 47.5-52.1 | 52.1-67.1 | 67.1-91.6 | 91.6-79.8 | 79.8-101.6 | 101.6-132.5 |
### Data file S1.
Data on the CE-4/LND and spacecraft observations and the CRÈME modeling CR energy spectra for the proton, helium, and the CNO and HI groups in Fig. 1.

### Data file S2.
Data on the CR flux ratios of the CE-4/LND measurements to the near-earth spacecraft observations at 1 AU and the CRÈME modeling results for the proton, helium, and the CNO and HI groups in Fig. 2.

### Data file S3.
Data on the weighted average flux ratios of the CE-4/LND measurements to the spacecraft observations and those predictions from the CRÈME models for the proton, helium, and the CNO and HI groups in Fig. 3.

### Data file S4.
Data on the CR energy spectra of $^3\text{He}$ and $^4\text{He}$ along with the ratios of $^3\text{He}$ to $^4\text{He}$ from observations and the GALPROP model’s predictions in Fig. 4.

### Data file S5.
Data on the ratios of the observed CR fluxes in the lunar local morning to those in the lunar local afternoon for the proton, helium, and the CNO and HI groups in Fig. 5.

| $GF_{\text{eff}}$ | 0.1903 ±0.0183 | 0.0763 ±0.0115 | 0.0605 ±0.0341 | 0.0380 ±0.0246 | 0.0372 ±0.0239 | 0.1033 ±0.0665 | 0.0067 ±0.0086 | 0.0144 ±0.0059 | 0.0023 ±0.0076 |
|------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|

| \( (\text{cm}^2\cdot\text{sr}^{-1}) \) | \( 0.1903 \) | \( 0.0763 \) | \( 0.0605 \) | \( 0.0380 \) | \( 0.0372 \) | \( 0.1033 \) | \( 0.0067 \) | \( 0.0144 \) | \( 0.0023 \) |
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