A method of fiducial-value normalizing to leveling the global average atomic number of lunar surface calculated by orbital Gamma spectroscopy data

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Abstract. As “banded structure” is a vexed question in orbital Gamma spectroscopy data inversion. In this paper, a new method to level the lunar global data of average atomic number by the fiducial-value in the stable composition circle is proposed. In order to verify the accuracy, the existing moon-sampling rock data as the “standard sample” and fast neutron data are also presented. The slope of the positive fit curve is 1.875 and the correlation coefficient is 0.72. And some geological characteristics, such as the structural boundaries and internal features of the Antarctic Aiken Basin, can identify obviously.

1. Introduction
The Chang’e-1 gamma ray system (CE1-GRS) has an on-orbit time of up to 1 year. During the flight detection process, it is affected by various factors such as solar activity period, spatial radiation variation, flight attitude change, and may generate various invalid data unavoidably (Ma Tao, 2010). A total of 2,467,169 spectral lines were collected and subjected to “abnormal screening →data correction →energy spectrum cumulation →smooth noise reduction” (Yang Jia, 2013). The spectral line pre-processing work concludes that dividing the gamma-ray spectrum detection line data of the whole moon into a grid of 5°×5° (150km×150km), and performing spectral-by-region spectral analysis on the gridded data (Yang Jia, 2010). While the result of elements distribution, such as ⁴⁰K, Th, U and others, still shows stripe distribution (Yang Jia, 2017; Li Xiaoli, 2015), so as the average atomic number of lunar surface (Ge Liangquan, 2018).

Data leveling is be widely used in inversion, such as cutting-line level adjustment (Huang HP, 1999), measuring-line level (Green, 2003; Huang, 2008; White, Beamish, 2015), median-filtering level (Mauring et al., 2002; Mauring and Kihle, 2006), singular value decomposition (SVD) (Yang Jia, 2015; Smith et al., 2004), and so on. It is various that the orbital gamma data has not an actual measurement benchmark. In addition, CE1-GRS is a polar-orbiting flight vehicle, and the acquired gamma data has time-characteristics (significant differences in different longitude lines). So some methods mentioned above are not very effective in leveling the global average atomic number of lunar surface.
2. Fiducial-value normalizing level

2.1. The average atomic number of lunar surface

The average atomic number of lunar surface ($Z_A$) calculated by equation (1):

$$Z_A = a \frac{N_{0.511}}{\varepsilon_{0.511} \sum_{i=1}^{n} \mu_{E_i} \ln E_i \cdot (N_0^{E_i} / \varepsilon_{E_i})}$$

Where, $N_{0.511}$ and $N_0^{E_i}$ are the net peak areas with 0.511-MeV and $E_i$, $\varepsilon_{E_i}$ is the peak efficiency of the gamma-ray spectrometer at energy $E_i$, $\mu_{E_i}$ is the linear attenuation coefficient of the lunar rock and soil for gamma rays with energy $E_i$, $a$ is a coefficient. The deriving process of this formula can be found in (Ge Liangquan, 2018).

Calculate the distribution of the average atomic number of the lunar surface, and the spatial resolution of the result is 5°×5° (150km×150km). Table 6-2 shows the results of a measurement line crossing the “Mare Imbrium” basin in the range of 30°N and 55°W~15°E. According to formula (1), the effective atomic number $Z_A$ and the ratio of positron annihilation radiant flux with the ratio of gamma ray flux at which electron pairing can occur have a positive correlation. The positive proportional coefficient is $a=1.1$, and preliminary calculation results of effective atomic number distribution of surface media over the whole moon are shown in Figure 1. Obviously, it is serious that banded structure cannot be removed.

Table 1. Calculation data of average atomic number in the 30°N region on lunar surface

| Longitude | 55°W | 50°W | 45°W | 40°W | 35°W | 30°W | 25°W | 20°W |
|-----------|------|------|------|------|------|------|------|------|
| $Z_A$     | 11.55| 11.78| 12.20| 12.36| 12.86| 12.39| 12.43| 12.66|

| Longitude | 15°W | 10°W | 5°W | 0 | 5°E | 10°E | 15°E |
|-----------|------|------|-----|---|-----|------|------|
| $Z_A$     | 12.24| 12.27| 12.26| 12.28| 12.32| 11.94| 11.03|

Figure 1. Average atomic number distribution of the lunar surface without data leveling

2.2. Fiducial-value normalizing data leveling

The main performance is as follows: the band profile of the elemental distribution shows obvious distribution along the meridian (Yang Jia, 2013). In addition, due to the obvious regional distribution characteristics of the lunar surface geological body, as shown in Figure 2 ("Chang'e-1 Full Moon Terrain Atlas" Committee, 2013), this makes the lunar gamma ray spectrum show regional differences at different latitudes. (Li Xiaoli, 2016).
Influenced by the above two objective factors, the deviation of gridding gamma spectroscopy data, and even some pseudo-abnormalities of data appears randomly. Therefore, the following methods for data screening and leveling are proposed:

1. Setting a threshold to eliminate obvious pseudo abnormal data;
2. Selecting the lunar surface stable element distribution area (latitude circle) as the baseline, and correcting the grid data to eliminate the strip effect of the data strip, which is “substance stability circle reference correction”; 
3. For some of the remaining sporadic outlier data, it can be corrected according to the background characteristics of the geological body and the adjacent grid data.

The “strip” correction is performed according to the “material stability circle” reference value: extract the latitude data of 75°N~80°N in the average mass distribution map of the lunar surface medium (Figure 1). The uncorrected effective atomic number \( Z_{AiZ(75-80)} \) data distribution is shown in Figure 3. The data fluctuation ranges from 10.6 to 12.2. The standard deviation of this set of data is 0.34, the arithmetic mean is 11.50, and the relative standard deviation is 3%. In particular, the measurement data of the Mare Imbrium concentration area (-45°~0), on the front of the moon, generally shows a large positive deviation, while on the two meridian measurement belts centered on -120° and 65°. The measurement data is generally lower than the average of the whole moon, and this feature is consistent with the banded distribution of the data presented in Figure 1. Therefore, “i” and “j” is set as the longitude and latitude respectively. And extract the root mean square (rms) of the average atomic number value in the "material stability circle", as in formula (2):

\[
Z_{rms,i}^{(75-80)} = \sqrt{\frac{\sum Z_{AiZ,(75-80)}^2}{72}} , i \in (-180,-175,..170,175)
\]  

According to the above formula, the rms value of the "material stability circle" is 11.49. The calculation result of the "material stability circle" can be used as the reference value of the data of different longitude lines (different flight tracks) globally.
The method for correcting the data consistency between different lines using the result as a reference value is as follows: Firstly, calculate the system calibration parameter $\xi_{i, 75~80}$ of different line data under the condition of the reference value. The specific calculation method is as follows:

$$\xi_{i, 75~80} = \frac{Z_{i,75~80}^{cal}}{Z_{i,75~80}^{total}}, i \in (-180, -175, ..., 170, 175)$$  \hspace{1cm} (3)

The calculation results are shown in Table 3:

**Table 2.** System correction parameters for different line data $\xi_{i, 75~80}$

| longitude | parameter | longitude | parameter | longitude | parameter |
|-----------|-----------|-----------|-----------|-----------|-----------|
| -180      | 1.02      | -120      | 0.93      | -60       | 1.00      |
| -175      | 1.01      | -115      | 0.95      | -55       | 1.00      |
| -170      | 1.03      | -110      | 0.96      | -50       | 0.99      |
| -165      | 0.99      | -105      | 1.02      | -45       | 1.03      |
| -160      | 0.99      | -100      | 1.01      | -40       | 1.04      |
| -155      | 0.98      | -95       | 1.00      | -35       | 1.05      |
| -150      | 0.99      | -90       | 1.00      | -30       | 1.05      |
| -145      | 0.97      | -85       | 0.99      | -25       | 1.05      |
| -140      | 0.97      | -80       | 1.00      | -20       | 1.04      |
| -135      | 1.02      | -75       | 1.00      | -15       | 1.03      |
| -130      | 0.94      | -70       | 1.00      | -10       | 1.03      |
| -125      | 0.93      | -65       | 1.01      | -5        | 1.03      |
| 0         | 1.03      | 60        | 0.93      | 120       | 1.03      |
| 5         | 1.02      | 65        | 0.94      | 125       | 1.00      |
| 10        | 0.99      | 70        | 0.93      | 130       | 1.01      |
| 15        | 1.01      | 75        | 1.02      | 135       | 1.00      |
| 20        | 0.97      | 80        | 1.00      | 140       | 1.00      |
| 25        | 0.98      | 85        | 1.03      | 145       | 1.00      |
| 30        | 0.98      | 90        | 1.01      | 150       | 1.00      |
| 35        | 0.97      | 95        | 0.99      | 155       | 0.99      |
| 40        | 0.97      | 100       | 1.00      | 160       | 0.99      |
| 45        | 0.98      | 105       | 0.99      | 165       | 1.03      |
| 50        | 1.03      | 110       | 0.99      | 170       | 1.02      |
| 55        | 1.03      | 115       | 1.03      | 175       | 1.02      |

Secondly, based on the acquisition of different orbital correction parameters, the system calibration parameters of the latitude circle of 90°S~90°N can be obtained, $\xi_{i,j} = \xi_{i,75~80}$. This parameter can be used to eliminate the system deviation between different tracks, and adjust the data of different tracks to the same level, then the corrected calculation $Z_{A_{i,j}}^{cal}$ is based on the following formula:

$$Z_{A_{i,j}}^{cal} = \xi_{i,j} \cdot Z_{A_{i,j}}, \quad \begin{cases} i \in (-180, -175, ..., 170, 175) \\ j \in (-90, -85, ..., 85, 90) \end{cases}$$  \hspace{1cm} (4)

2.3. Result verification

According to the data leveling method in above section (1) to (3), the average atomic number distribution of the lunar surface is obtained, as shown in Figure 4. The red contour line in the figure is the main area geological structure boundary which is drawn according to the whole moon topographic map (Figure 4).
In order to verify the accuracy of the average atomic number distribution, the average atomic mass of the sampled rocks (Apollo 11, Apollo 12, Apollo 15–17, Lunar 16, Lunar 20, and Lunar 24 landing points (Gasnault, 2001)) are selected. The linearly fit the two sets of data of the average atomic number of the rock and the average atomic mass by the least squares method. The result is shown in Figure 5:

Compare inversion of atomic mass distribution by fast neutron flux characteristics with inversion of effective atomic number distribution by positron annihilation gamma radiant flux characteristics, as shown in Figure 6. The high and low characteristic range of the effective atomic number distribution is consistent with the basic geological structure distribution of the lunar surface, especially the medium with high average atomic number concentrated in the mare Imbrium area. In addition, the distribution feature can also identify the structural boundaries and internal features of the Antarctic Aiken Basin.
3. Conclusions
After leveling, some new discoveries can be recognized, such as a certain number of high average atomic number points are scattered in typical impact crater areas on the surface around the moon, Schwarzschild crater (70.1N 121.2E). The impact crater is an impact structure formed after the impact of meteorites on the moon. In this structure, the overburden mantle material accumulated, gushed out or invaded the upper part of the lunar crust at the bottom of the impact crater. Resulting in a sharp rise in the content of basalt, which presents a high effective atomic number. This phenomenon is highly consistent with the mass tumor phenomenon involved in gravity. The fiducial-value data leveling is benefit for removing the stripings on average atomic number image mostly. It is meaningful to expand the application of lunar orbital gamma ray data.

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