Document on the post-processed data of Tianwen-1 Mars Energetic Particles Analyzer (MEPA)

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This document details the post-processed data of the Mars Energetic Particles Analyzer（MEPA）level 2B datasets obtained from Tianwen-1. These datasets were downloaded from the Lunar and Planetary Data Release System at National Astronomical Observatories of China, accessible at https://moon.bao.ac.cn/web/zhmanager/mars1.

The level 2B data involves quantity of parameters including UTC-time, Heavy-Ion_Events_Count, Heavy-Ion_Fake_Events_Count, Heavy-Ion_Science_Data, e/p/he_Events_Count, e/p/he_Fake_Events_Count, e/p/he_Science_Data, Divide_Ratio, VA_Temperature, CSI2_Temperature, SI2_Temperature, PSDH_Temperature, Total_Trigger_Count, e/p/he_Trigger_Count, Heavy-ion_Trigger_Count, Penetration_Count, Longitude， Latitude, Altitude, Instrument_Observation_Direction_X/Y/Z, Solar_Incident_Angle, Solar_Azimuth_Angle and X/Y/Z-axis_Position_J2000.

The differential flux is computed using e/p/he_Events_Count, e/p/he_Trigger_Count and e/p/he_Science_Data as detailed in Section I. However, the downloaded level 2B data contains numerous incidents that fall outside the instrument's field of view, resulting in unaccounted diffusion events. We processed the data by applying a theoretical model of particle distribution to discern the actual vs. diffusion event proportions, and employing statistical methods for random sampling and elimination based on the diffusion event ratio. The methodology and results are shown in Section II.

The data we have processed is consistent with the instrument simulation results of Tang et al., 2020, but in the practical application of proton flux, high-precision differential flux and integral flux may cause significant errors due to statistical methods (such as extremely large or small proton flux at a certain time). When the data is taken with lower time accuracy, the size of integral flux will reduce due to the average of the data, but this will be more in line with the actual distribution of proton flux. The differential flux of alpha particles in the processed results resembles noise, possibly due to high-energy alpha particles within this energy spectrum, a scenario that remains under-explored, so the data of alpha particles should be used with caution. The electronic data was not processed due to difficulties in discerning diffusion events.

I. Principle of flux calculation

A detector located in an isotropic particle radiation field, whose detected particle count rate N is proportional to the particle flux J.

The proportional coefficient G called the geometric factor and can be expressed by the following formula:

$$G = \frac{N}{J}$$

We calculate the sampling ratio by dividing e/p/he_Events_Count by e/p/he_Trigger_Count , and differentiate the particle types using the particle energy data in e/p/he_Science_Data to obtain the index of different particles. After completing the elimination of diffusion events, we obtain the Proton/He_Index. Then we count the particle counts (obtaining the value of N) using the on-orbit particle identification criteria (as shown in Table 1) and calculate the differential flux (the value of J) of the particles using geometric factors (the value of G, as shown in Table 2) and the center values of each energy channel (the value of E_c). Calculated as follows:

$$\text{flux}=\frac{\text{counts}}{\text{ratio}*G*E_c}$$

Table 1: On-orbit particle identification criteria

Particle Type	PID criteria (ΔE, E andΔE1 all in unit of MeV)
Electron	$\Delta E \cdot E \le 20$ && $\Delta E < 1$ && $\Delta E > 0.05$
Proton	$(20 < \Delta E \cdot E \le 150$ || $(\Delta E \cdot E \le 20$ && $\Delta E > 1))$ && $\Delta E_1 < 1$
Helium	$150 < \Delta E \cdot E \le 1200$ || $(\Delta E \cdot E \le 150$ && $\Delta E_1 \ge 1)$
Heavy ion	$\Delta E \cdot E > 1200$

Table 2: Geometric factors of energy channels for electrons, protons, and alpha particles

Energy channel serial number	Electron		Proton		Alpha particle	
	Energy channel division (MeV)	Electron _Geom (cm^2 sr)	Energy channel division (MeV)	Proton _Geom (cm^2 sr)	Energy channel division (MeV)	He _Geom (cm^2 sr)
1	[0.1,0.13)	0.08	[2, 2.6)	0.20	[25, 29.2)	0.21
2	[0.13,0.18)	0.11	[2.6, 3.3)	0.21	[29.2, 34.1)	0.22
3	[0.18, 0.25)	0.16	[3.3, 4.2)	0.20	[34.1, 39.8)	0.21
4	[0.25, 0.33)	0.19	[4.2, 5.3)	0.21	[39.8, 46.5)	0.21
5	[0.33, 0.45)	0.21	[5.3, 6.8)	0.20	[46.5, 54.3)	0.22
6	[0.45, 0.60)	0.23	[6.8, 8.7)	0.21	[54.3, 63.5)	0.24
7	[0.60, 0.81)	0.23	[8.7, 11.1)	0.22	[63.5, 74.1)	0.24
8	[0.81, 1.10)	0.25	[11.1, 14.1)	0.22	[74.1, 86.6)	0.26
9	[1.10, 1.48)	0.27	[14.1, 18.1)	0.24	[86.6, 101.2)	0.29
10	[1.48, 1.99)	0.30	[18.1, 23.1)	0.26	[101.2, 118.1)	0.32
11	[1.99, 2.69)	0.36	[23.1, 29.4)	0.33	[118.1, 138)	0.39
12	[2.69, 3.63)	0.52	[29.4, 37.6)	0.42	[138., 161.2)	0.51
13	[3.63, 4.89)	0.77	[37.6, 48.0)	0.79	[161.2, 188.3)	0.86
14	[4.89, 6.60)	0.96	[48.0, 61.3)	1.23	[188.3, 219.9)	1.16
15	[6.60, 8.90)	1.07	[61.3, 78.3)	1.44	[219.9, 256.8)	1.39
16	[8.90, 12)	1.20	[78.3, 100)	1.58	[256.8, 300)	1.50

II. Introduction to processed data

We processed the data based on some methods and suggestions provided by the payload development team as shown in Figure 1. As we mentioned earlier, there are diffusion events outside the field of view in particle data, and the distribution of these diffusion particles is scattered in the ΔE-E two-dimensional spectrum of the ΔE-E telescope. We firstly removed most of the diffusion particles that were not mixed in the feature bands using the envelope method. Then, based on the Gaussian distribution of the effective data particles in the 'counts-log(E*ΔE)' graph, the actual particle distribution was fitted with 'Gaussian distribution+diffusion event distribution'. Then, based on the proportion of diffusion events, the particles at each recording time are statistically randomly removed, and the final result is consistent with the theoretical and simulation results of the instrument.

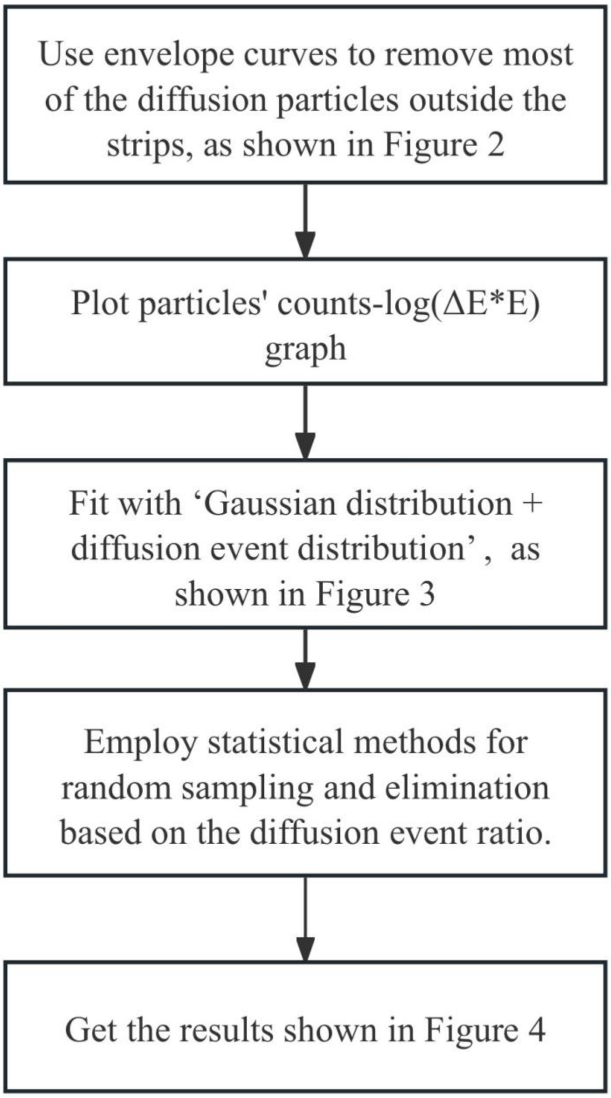

Figure 1: Data processing flow

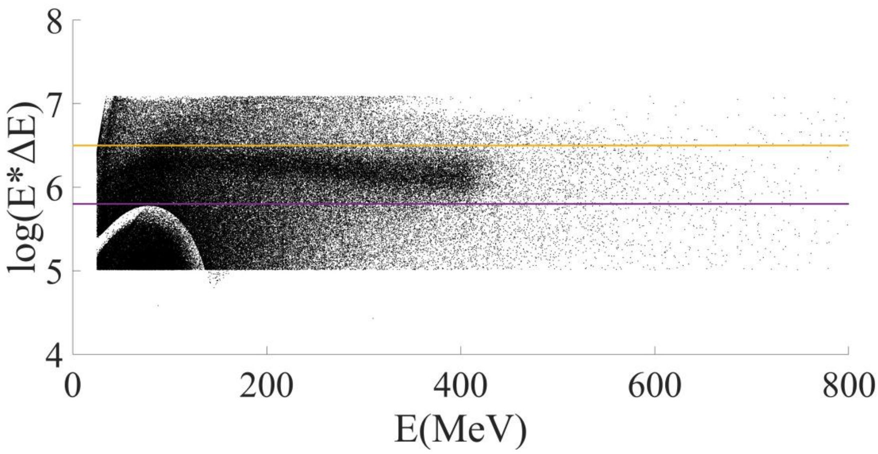

Figure 2: Envelope processed particle log(E*ΔE)-E two-dimensional spectrum

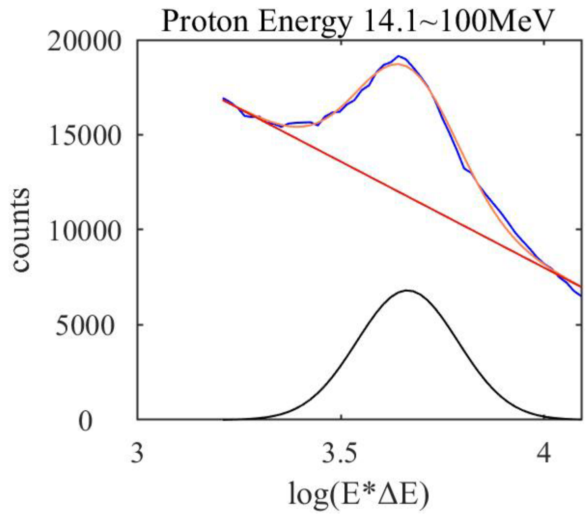

Figure 3: Proton fitting results with energy channels from 14.1 to 100MeV. The vertical axis of the image is the number of particles, the horizontal axis is log(E*ΔE), the purple broken line is the actual distribution of particles, the orange curve is the fitted distribution of particles, the black curve is the effective particle distribution, and the red curve is the diffusion particle distribution

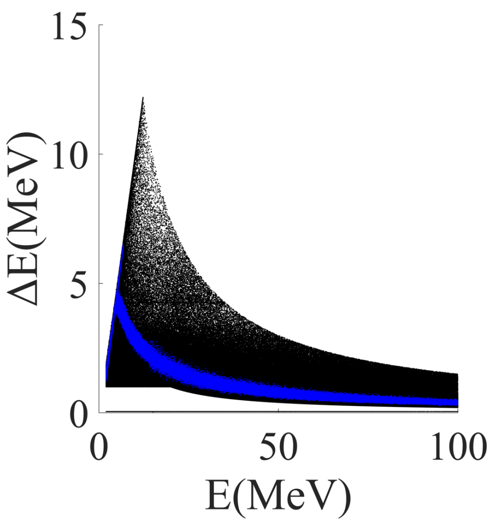

Figure 4: The ΔE-E two-dimensional spectrum of the particle fitting results, in which the black part is the diffusion event and the blue part is the actual effective particles obtained by processing

The new post-processed data are all saved in files named HP_xxx_x_xxxxxxxxxxxxxx_xxxxxxxxxx_xxxxx.txt (the file name retains the downloaded 2B level data file name, except for the instrument name). Here is an example of a file name (as shown in Figure 5). The meaning of the file name is as follows:

HP_SCI_N_20200724142137_20200724235957_00002.txt

Figure 5: A stored file name

digit 1-2: HP, the processed 2B level data is a dataset containing heavy ion data

digit 4-6: SCI, science data

digit 8: N, including real-time data (data collected directly downstream) and playback data (data stored by the detector and delayed for playback).

digit 10-13: year of the first data

digit 14-15: month of the first data

digit 16-17: day of the first data

digit 18-19: hour of the first data

digit 20-21: minute of the first data

digit 22-23: second of the first data

digit 25-28: year of the end data

digit 29-30: month of the end data

digit 31-32: day of the end data

digit 33-34: hour of the end data

digit 35-36: minute of the end data

digit 37-38: second of the end data

digit 40-44: detection cycle number

Table 3: Post-processed data file structure

Field Name	Field number	Bytes of Each Data	Description
Time	1	14	Coordinated universal time with four-second cadence.
Epoch_Time	2	14	The epoch time format for the IRF package with four-second cadence.

Longitude	3	12	Spacecraft longitude (maybe a nan value).
Latitude	4	12	Spacecraft latitude (maybe a nan value).
Altitude	5	12	Spacecraft altitude (maybe a nan value).
X_J2000	6	17	J2000 Coordinate System.
Y_J2000	7	17	J2000 Coordinate System.
Z_J2000	8	17	J2000 Coordinate System.
X_MSO	9	16	MSO Coordinate System.
Y_MSO	10	16	MSO Coordinate System.
Z_MSO	11	16	MSO Coordinate System.
Instrument_Observation_Direction_X	12	12	Incidence vector of the symmetry axis of the sensor FOV in J2000 Coordinate System.
Instrument_Observation_Direction_Y	13	12	Incidence vector of the symmetry axis of the sensor FOV in J2000 Coordinate System.
Instrument_Observation_Direction_Z	14	12	Incidence vector of the symmetry axis of the sensor FOV in J2000 Coordinate System.
Solar_Incident_Angle	15	6	Solar incident angle.
Solar_Azimuth_Angle	16	6	Solar azimuth angle.
Energy_CSI_1～Energy_CSI_22	17~38	7	The particle energy value detected by the CsI detector (third detector) that is separately distinguished from the original data. Due to the fact that each data packet records 22 events when the detector records particle events, the data is divided into 22 variables for recording, with an energy value format of m * 22 and "m" representing the number of time counts (the same applies to other data recorded as 22 variables thereafter).
Energy_SD1_1～Energy_SD1_22	39～60	7	The particle energy value detected by the SD1 detector (first detector) that is separately distinguished from the original data.
Energy_SD2_1～Energy_SD2_22	61～82	7	The particle energy value detected by the SD2 detector (second detector) that is separately distinguished from the original data.
Energy_Total_1～Energy_Total_22	83～104	7	The sum of event energies detected by three detectors.
He_Index_1～He_Index_22	105～126	1	The alpha particle index is obtained by distinguishing particle types based on the energy relationship detected by each detector. A value of 1 corresponds to the energy value of the alpha particle, and a value of 0 represents other particles **(the diffuse event data has been removed).**

Electron_Index_1～Electron_Index_22	127～148	1	The electron index obtained by distinguishing particle types based on the energy relationship detected by each detector, where a value of 1 corresponds to the energy value of the electron, and a value of 0 represents other particles (the diffuse event data was not excluded).
Proton_Index_1～Proton_Index_22	149～170	1	The proton index obtained by distinguishing particle types based on the energy relationship detected by each detector, with a value of 1 corresponding to the energy value of the proton, and a value of 0 indicating other particles **(the diffuse event data has been removed).**
He_Sample_Counts_1~He_Sample_Counts_22	171～192	2	The value of alpha particle event count (the diffuse event data was not excluded).
Electron_Sample_Counts_1～Electron_Sample_Counts_22	193～214	2	The value of electron event count (the diffuse event data was not excluded).
Proton_Sample_Counts_1～Proton_Sample_Counts_22	215～236	2	The value of proton event count (the diffuse event data was not excluded).
He_Flux_1～He_Flux_22	237～258	16	Calculated alpha particle flux **(the diffuse event data has been removed).** But the reliability of the results needs to be verified.
Electron_Flux_1～Electron_Flux_22	259～280	16	Calculated electron flux (the diffuse event data was not excluded).
Proton_Flux_1～Proton_Flux_22	281～302	16	Calculated proton flux **(the diffuse event data has been removed).** Take the average of these 22 data points at each time during use.