Research and Prospects of Radiation Mechanisms in Macroscopic Astrophysics

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Abstract. In the field of astrophysics, the study of radiation from different celestial bodies is of great significance. Celestial bodies such as stars, galaxies, and planets emit various types of radiation. However, traditional research has limitations in understanding the radiation mechanisms of some celestial bodies, and the specific processes and factors affecting radiation are not fully clear, which restricts the further development of astrophysics. In this study, a multi-band observation and comprehensive data analysis method is adopted. Through the calibration and normalization of observation data, spectral analysis, image analysis, and other means, the characteristics and mechanisms of celestial body radiation are explored. The results show that different celestial bodies have unique radiation characteristics and evolution processes. This research can optimize the design and planning of space missions. Galaxies consist of numerous stars and have unique radiation features due to active galactic nuclei and interstellar medium. Planets reflect and emit radiation based on their interaction with stars and internal heat sources. This research holds significant value in understanding the structure and evolution of the universe. It provides insights into the physical processes occurring in celestial bodies and helps people better understand the nature of the cosmos.

Keywords: Galactic cosmic radiation, Radiation intensity, Radiation measurement.

1. Introduction

In the vast expanse of the universe, the study of celestial bodies and their radiation has always been a fascinating and important area of research. Astrophysics plays a crucial role in understanding the nature of the universe, from the birth and evolution of stars to the structure and dynamics of galaxies. The research on celestial body radiation has a wide range of applications. It helps people understand the physical processes occurring in celestial bodies, such as nuclear fusion in stars, black hole activities in galaxies, and the formation and evolution of planetary systems. Many previous studies have made significant contributions to this field. For example, research on the sun's radiation has provided insights into the energy source and variability of the star. Studies of galaxies have revealed the complex radiation mechanisms associated with active galactic nuclei. However, there are still many challenges and limitations. The radiation mechanisms of some celestial bodies remain unclear, and the data processing and analysis methods need to be further improved. The interaction between different types of radiation and the influence of the environment is not fully understood. To address these issues, this study employs a multi-band observation approach and advanced data processing and analysis methods. By integrating observations from different wavelengths and using techniques such as spectral analysis and image analysis, this research aims to gain a more comprehensive understanding of celestial body radiation.

2. Origin of Radiation

2.1. Fixed Star

Stars release a large amount of high-energy radiation during nuclear fusion reactions in their cores, including ultraviolet, visible, and infrared, as well as X-rays and gamma rays. For example, the sun constantly emits various electromagnetic radiations into the surrounding space, which has a crucial impact on life and the environment on Earth.

Stars produce extremely strong radiation during the late stages of evolution, such as supernova explosions. The energy released by supernova explosions is enormous, and the radiation covers the entire frequency range from radio waves to gamma rays.

2.2. Galactic Center

Many galaxies have supermassive black holes at their centers, which produce strong radiation during the process of accreting matter. Including X-ray radiation and high-energy particle jets. This radiation can extend great distances and have an impact on the evolution of the entire galaxy.

3. Development of Radiation

In 1896, French physicist Antoine Henri Becquerel accidentally discovered while studying uranium salts that uranium could spontaneously emit an unknown type of radiation that could penetrate black paper and make photographic film sensitive. This discovery opened up humanity's scientific understanding of radiation phenomena. Afterward, Marie Curie and Pierre Curie conducted further research on radioactive substances, discovering radioactive elements such as radium and polonium, and further confirming that radioactivity is an inherent property of certain elements. At the beginning of the 20th century, Ernest Rutherford and others gained a clearer understanding of the nature of radiation through a series of experimental studies. They found that there are three main types of radiation emitted by radioactive materials: alpha rays (helium nuclei), beta rays (electron flow), and gamma rays (high-energy photons).

Scientists have also conducted in-depth research on the interaction mechanism between radiation and matter. For example, through the study of the photoelectric effect, Einstein proposed the photon hypothesis, explaining the emission phenomenon of electrons when light is irradiated onto a metal surface, and further elucidating the interaction process between photons and electrons. Meanwhile, the discovery of the Compton effect also provides an important basis for studying the scattering process of high-energy photons and electrons.

In cosmology, the discovery and study of cosmic microwave background radiation was one of the most important scientific achievements of the second half of the 20th century. The cosmic microwave background radiation is a remnant of the Big Bang, and its spectral characteristics and uniformity provide key evidence for the origin and early evolution of the universe. Meanwhile, studying the radiation emitted by various celestial bodies in the universe, such as stars, galaxies, quasars, etc., also helps people understand the structure and evolutionary history of the universe. In addition, the study of cosmic rays has always been a hot topic, as scientists attempt to uncover the origin and propagation mechanisms of cosmic rays, as well as their role in the evolution of the universe.

4. Applications of Space Telescopes

The space telescope is located outside the atmosphere, avoiding various interferences from the Earth's atmosphere on observations. For example, the atmosphere absorbs and scatters some light, causing ground-based optical telescopes to be unable to observe certain wavelengths of light, while space telescopes can observe the entire spectrum.

The water vapor and clouds in the atmosphere can affect the observations of ground-based radio and infrared telescopes, while space telescopes are not affected by these factors and can obtain clearer and more accurate observation data.

Multi-band observations help people explore the large-scale structure and origins of the universe. Cosmic microwave background radiation is a remnant of the Big Bang, discovered in the microwave band. Through precise observation and study of the cosmic microwave background radiation, This research can understand the early structure of the universe and some basic physical parameters, such as the age and density of the universe. Meanwhile, observations in other frequency bands can also provide supplementary information about the structure of the universe. Help people depict the distribution of matter in the universe.

To achieve multi-band collaborative observation, multiple observation stations or equipment need to work simultaneously, and precise time synchronization and spatial positioning are required. For example, to study the multi-band characteristics of a celestial body at a certain moment, optical telescopes, radio telescopes, infrared telescopes, X-ray telescopes, and gamma-ray telescopes need to be observed simultaneously, and these observation devices need to be precisely aligned with the same celestial body and record the observation data at the same time.

As shown in Fig. 1, the effective range of cosmic radiation received by the round-trip flights of 8 international routes was calculated. Between 14.3 and 117.5 μ Sv, the measured data is between 0 and 110 μ Sv. Row. Except for one actual test data of the 0 μ Sv route, calculations were made for the other seven international routes. The ratio of accuracy between machine simulation and measured data is 1.06 ± 0.32. Using the CARI-6 series. The effective dose range of cosmic radiation received by the three domestic flight routes calculated by statistics is between 3.2 and 8.8 μ Sv, the measured data is between 0 and 10 μ Sv. Exclude actual testing. In addition to the 0 μ Sv route, there are two other domestic routes that have been simulated and tested by computer. The accuracy ratio of the measurement data is 0.82 ± 0.08. The maximum dose rate of cosmic radiation received.It is 2.26 μ Sv/h [1].

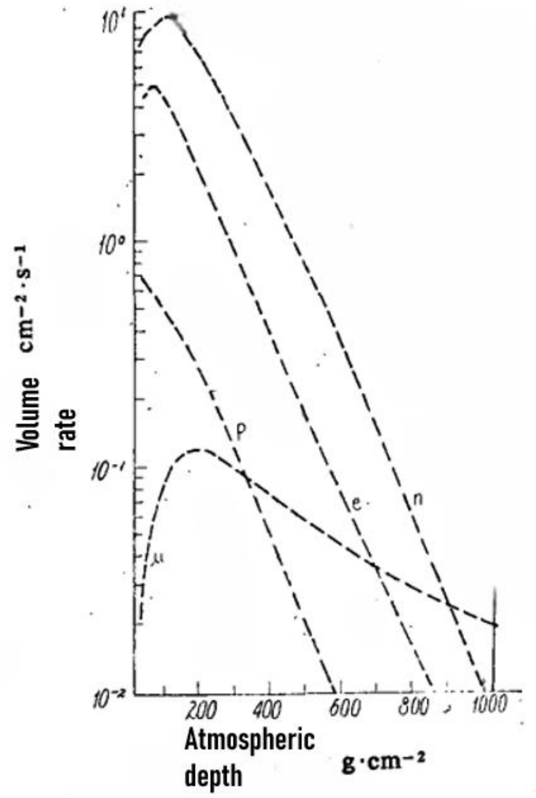

Fig. 1 The variation of cosmic radiation particle flux rate with atmospheric depth [2]

However, since these observation devices are often distributed in different geographical locations, it is very difficult to achieve accurate time synchronization and spatial positioning. As shown in Fig. 2, different observation devices may be affected by different environmental factors, such as weather, atmospheric interference, etc., which also increases the difficulty of collaborative observation.

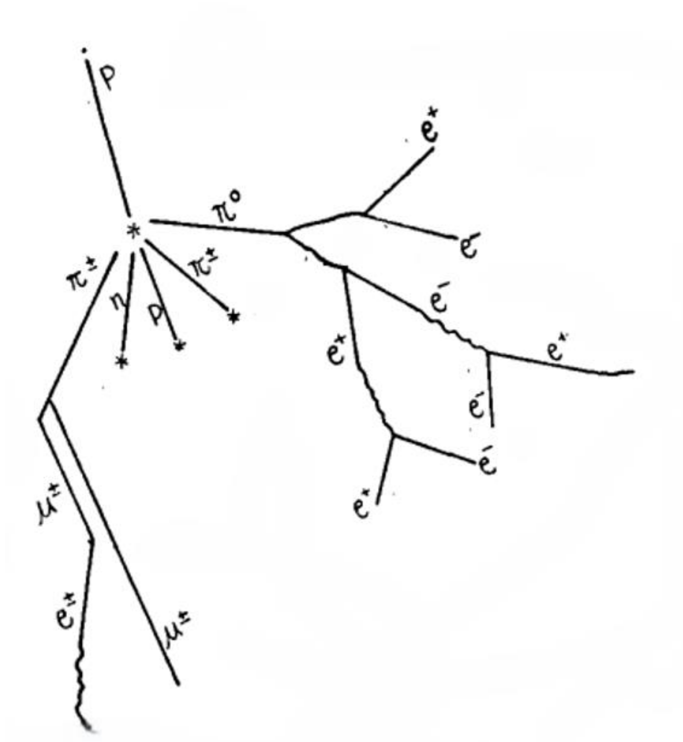

Fig. 2 Schematic diagram of the intermediate coupling process of cosmic rays in the atmosphere [2]

It is a feasible method to study the dosimetry of cosmic radiation inside spacecraft cabins using the experimental conditions of a return-type satellite. The results of five satellite experiments conducted in China show that the higher the orbit, the higher the dose level inside the cabin. At an altitude of about 500km, the thickness of the cabin material has a significant impact on the dose level inside the cabin, and this effect disappears. Orbital spacecraft exhibits significant non-uniformity in the radiation field inside the cabin, and a reasonable layout of instruments and equipment inside the cabin can effectively reduce dose levels. The main radiation component that forms the dose inside the spacecraft cabin in near Earth orbit is protons, while the dose contributions of neutrons and X-rays can be ignored. These results have important reference value for space radiation protection and the development of radiation dose monitoring instruments [3].

5. The Radiation on Mars

5.1. Types of Radiation

When a large solar flare occurs on the surface of the sun, it is often accompanied by the emission of a massive number of high-energy charged particles. This phenomenon is known as a solar proton event. The energy of solar particle radiation is extremely high, presenting a significant danger to astronauts. It is undoubtedly one of the crucial hazard factors for manned Mars exploration. In addition to solar flares, the shock wave preceding a coronal mass ejection from the sun can also generate a high-energy particle flow that is sometimes even more intense than a solar flare.

5.2. Radiation Conditions on the Surface of Mars

As indicated by data from radiation assessment detectors, this is already close to the annual absorbed natural background radiation dose on Earth, Mars lacks a strong intrinsic magnetic field, unlike Earth which has a magnetosphere that provides significant protection against cosmic radiation. Due to the absence of a strong magnetic field on Mars, the Martian atmosphere has been gradually eroded by the solar wind over time. As a result, the Martian atmosphere is extremely thin, with a density only about 1% of that of the Earth's atmosphere. Consequently, the Martian atmosphere is unable to offer sufficient radiation shielding for humans.

5.3. Protective Measures and Research Directions

Going deeper into the surface of Mars can provide some degree of protection against harmful radiation. The regolith on Mars acts as a barrier to cosmic radiation to a certain extent.

Scientists are actively engaged in researching and developing more advanced materials and technologies for enhanced protection against cosmic radiation. For instance, the development of polyethylene nanocomposite materials and water walls as potential protective measures. Additionally, natural geological structures such as cave skylights or lava tubes are being considered as potential radiation shelters on Mars. These research efforts aim to find innovative solutions to safeguard astronauts from the harmful effects of cosmic radiation during long-duration missions to Mars.

5.4. Radiation Monitoring Equipment Carried by Space Probes

5.4.1. Radiation Dosimeters

Many Mars probes are equipped with radiation dosimeters for directly measuring the radiation dose in the Mars environment. These dosimeters usually work based on the principles of semiconductor materials or ionization chambers. Semiconductor dosimeters can accurately measure the charge accumulation caused by radiation and thus determine the radiation dose. Ionization chambers calculate the radiation dose by measuring the ionization current generated by radiation in a gas. For example, the Curiosity rover is equipped with the Radiation Assessment Detector (RAD), which includes multiple radiation dosimeters and can measure different types of radiation such as galactic cosmic radiation and solar particle radiation.

5.4.2. Particle Detectors

To determine the particle types and energy distributions in Mars radiation, particle detectors are also carried on probes. These detectors can distinguish different types of particles such as protons, alpha particles, and heavy ions.

A common particle detector is the scintillation detector, which uses the flashes generated by the interaction of radiation with scintillator materials to detect particles. Another is the solid-state detector such as a silicon detector, which can accurately measure the energy and trajectory of particles. For example, the Solar Wind Ion Analyzer (SWIA) on the Mars Atmosphere and Volatile Evolution (MAVEN) probe can measure the ion types and energies in the solar wind, thereby indirectly understanding the impact of solar particle radiation on Mars.

6. Remote Measurements by Ground Observatories

6.1. Radio Observations

Radio telescopes on Earth can infer the radiation environment of Mars by receiving radio signals emitted by Mars. When high-energy particles on Mars interact with the Martian atmosphere, radio radiation is generated. Radio observations can provide information about the radiation belts of Mars and the influence of solar activities on the Martian radiation environment. For example, by monitoring the frequency and intensity of Mars radio bursts, the degree of influence of solar particle events on Mars can be understood. However, radio observations are affected by Earth's atmosphere interference and signal attenuation and require complex data processing and calibration.

6.2. Optical Observations

Optical telescopes can observe the aurora phenomenon on Mars, which is the result of the interaction between Mars radiation and the atmosphere. The intensity and distribution of auroras can provide information about Mars' magnetic field and radiation environment. In addition, by analyzing the spectral characteristics of the Martian atmosphere, the influence of radiation on atmospheric components can be inferred. For example, ultraviolet radiation can cause photochemical reactions in molecules in the Martian atmosphere, thereby changing the composition of the atmosphere. The limitation of optical observations is that they can only provide indirect radiation information and are limited by weather conditions and observation times.

7. Simulation Experiments and Theoretical Models

7.1. Ground Simulation Experiments

To better understand the Mars radiation environment, scientists have conducted many ground simulation experiments. These experiments usually use accelerators to generate high-energy particle beams to simulate the particle types and energies in Mars radiation. In experiments, the effects of radiation on different materials can be studied, the effectiveness of radiation protection technologies can be tested, and the interaction mechanisms between radiation and Martian surface substances can be explored. For example, by simulating the impact of Mars radiation on plant growth, the feasibility of agricultural production in future Mars colonization can be evaluated.

7.2. Theoretical Models

Based on physical principles and observation data, scientists have established various theoretical models to predict Mars radiation environment. These models can consider factors such as solar activities, the Martian magnetic field, and atmospheric composition on radiation. Theoretical models can help plan Mars missions, select appropriate radiation protection measures, and predict the risks of radiation to astronaut health. However, the accuracy of models is affected by many uncertainties and needs to be continuously compared and verified with actual observation data. In conclusion, there are various measurement methods for Mars radiation. It is necessary to comprehensively use means such as space probes, ground observatories, simulation experiments, and theoretical models to fully understand the characteristics and variation laws of the Mars radiation environment.

8. Protect Bodies from Radiation

Magnetic field protection deflects charged particles through the Lorentz force. If the magnetic field is strong enough, very fast particles can be deflected with a very small radius to avoid hitting spacecraft. Therefore, most secondary radiation can be avoided. The efficiency of this protection method depends on the strength of the magnetic field, but the magnetic field strength is limited by the mechanical strength of the conductive coil because the coil is subjected to additional induced forces. With the current development of superconducting technology, this form of protection is easier to implement and more worthy of study [4]. Among the hazards of the Martian environment, the most serious one is radiation hazard. Astronauts may encounter two types of radiation during their journey to Mars: one is galactic cosmic radiation; the other is solar particle radiation. In addition, if the Mars spacecraft uses a nuclear-powered rocket, this becomes a third radiation source. Galactic cosmic radiation comes from the Milky Way and is a high-energy charged particle flow. The energy of particles can be as high as 1020 eV, and the average particle flux is 2.5 particles per square centimeter per second. Due to their high energy, the particles of galactic cosmic radiation have strong penetrating power and are therefore relatively difficult to protect. The main components of these particles are protons (about 85%), alpha particles (about 13%), and the nuclei of elements with atomic numbers greater than 2 (about 2%). Among the nuclei with atomic numbers greater than 2, there is a type called high-energy heavy particles. Not only do they have a large atomic number, but also extremely high energy, and they are the most harmful in galactic cosmic rays. They can not only penetrate the cabin wall of a manned spacecraft but also cause serious damage to tissues and organs after hitting the human body.

When a large solar flare appears on the surface of the sun, it is often accompanied by the emission of a large number of high-energy charged particles. This phenomenon is called a solar proton event. Due to the very high radiation energy of solar proton events and their great danger to astronauts, it is one of the important hazard factors for manned Mars exploration [5].

9. Conclusion

This study adopted a multi-faceted approach to conduct research on the radiation of celestial bodies. By using multi-band observation techniques and comprehensive data analysis methods, including calibration and normalization, spectral analysis, image analysis, and more. The results demonstrated that different celestial bodies exhibit distinct radiation characteristics. Stars emit radiation through nuclear fusion processes and have different radiation spectra depending on their temperature and evolution stage. Galaxies consist of numerous stars and have unique radiation features due to active galactic nuclei and interstellar medium. Planets reflect and emit radiation based on their interaction with stars and internal heat sources. This research holds significant value in understanding the structure and evolution of the universe. It provides insights into the physical processes occurring in celestial bodies and helps people better understand the nature of the cosmos.

References

[1] Qi Yanmin, Bai Guoyin, Qiu Bing, etc. Comparative study on the estimation of cosmic radiation by pilots and experimental measurements. Air Force Medical Journal, 2016, 32 (06): 422-423.

[2] Technical safety room environmental radiation group Measurement of Low Altitude Cosmic Radiation Dose and Empirical Patterns of Its Variation with Altitude. Radiation Protection, 1984, (01): 7-17.

[3] Qi Zhangnian, Chen Mei, Li Xianggao. Measurement and Analysis of Cosmic Radiation Dose in Satellite Cabin. Journal of Astronautics, 1993, (04): 56-60.

[4] Chen Shishi, Zhang Ningbo, Xiong Fenfen. Analysis and Research on Active Space Radiation Protection Methods. Proceedings of the 9th Academic Annual Meeting of the Deep Space Exploration Technology, 2012:7.

[5] Wu Guoxing. The harsh and terrifying Martian environment Space Exploration, 2005, (05): 18-20.