

The Simulations and Observations of the Cosmic Dust

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Abstract. As a matter of fact, researches in cosmic dust are useful to astronomy observations and the analysis of the history of the galaxies due to its optical properties and grains' structure. Thanks to the theoretical development as well as the upgrade of the state-of-art detectors, various novel results have been obtained. With this in mind, this study will systematically analyze the known special properties of cosmic dust as well as the observations based on the advanced facilities and simulations methods based on the state-of-art models of it. To be specific, the simulation principle and recent observations will be demonstrated. According to the analysis, this study will present the evaluations for limitations as well as clear up the researches process and propose future outlooks about the use of the results of the observations and simulations of the cosmic dust. Overall, these results shed light on guiding further exploration of analysis of cosmic dust.

Keywords: Cosmic dust, Observation, Simulation, interstellar dust, stardust.

1. Introduction

Cosmic dust can be classified as interstellar dust, interplanetary dust, circumplanetary dust. Cosmic dust is significant to the researches of the formation of the stars and the planets as well as the astronomy observation. Normally, one uses models to study the properties of the dust inside the labs, for example, cosmic dust grains' model of optical properties relying a distribution of hollow sphere [1]. Besides, one uses telescopes on spaces and ground to observe the dust, from the observations, one can get lots of properties of the dust. From analyzing the formation of the dust grain, one can indicate the information of the galaxy. However, to get the samples that can be analyzed in labs, especially the interstellar dust, is a quite hard job. Whereas, some of the dust would drop into the earth, so researchers don't have to spend so much time.

Early in 19th century, scientists had discovered the importance of doing research in cosmic dust. Nowadays, dust around or entering the earth is comprehensively researched, which has great effect on knowing the historical environment or formation of the earth. For instance, Plane did a detailed research about cosmic dust in earth atmosphere, it reviews the magnitude of the dust that come into the atmosphere of earth, and the consequences from about 100 kilometres to the surface of earth [2]. With regard to interstellar dust, early at around 1970s, scientists had known that interstellar dust is important to the researches of the interstellar medium.

After knowing the significance of interstellar dust, one needs to know how scholars discovered its existence and how to observe it. Moreover, one can deduce the dust from the polarization of the light. Nowadays, some scientists even use the super computers to simulate the behaviour of the dust according to its optical properties. A project called THESAN is doing this well. While the collection of the interstellar dust is still an expensive and difficult mission, hence this study will mainly introduce the observation and the simulation of the interstellar dust.

2. Basic Descriptions

As a matter of fact, cosmic dust can be generally classified as interstellar dust and interplanetary dust. Slightly larger particles tend to completely melt, but may survive their high-speed entry into the atmosphere and fall to Earth as micrometeorites [3]. Cosmic dust grains are fundamental to planets, stars and galaxies' evolution and formation across the whole history of the Universe. Dust grains play a key role in essentially all astrophysical contexts. It is found on all scales throughout the Universe and is formed in varying and often extreme environments, from the earliest Universe until today.

These different stellar and galactic environments directly affect the properties of the dust grains. The seeds of astrophysical dust are produced around stars that inject the dust into the interstellar medium through winds (ISM) or in explosive events. The discovery of several dust-rich galaxies less than a billion years after the Big Bang demonstrates the rapid production of both elements heavier than He, formation of dust seed particles, and the rapid growth of the dust grains. However, a growing number of dust-poor galaxies are being discovered, showing a very wide range of conditions in the early universe. As dust is an essential ingredient for the formation of stars, even in early galaxies, it is imperative to understand their properties, and how these potentially differ from local galaxies. The time scale for grain growth has been shorter than in local galaxies, but also the abundance of elements, the potential stronger UV-radiation field, as well as the higher temperature of the CMB, likely all play an significant role in the destruction and formation of the dust [4].

3. Simulations

There are many simulations of different types of researches to plenty of the cosmic dust. Understanding the scale of the massive influx of interstellar dust particles that enter solar system objects is critical to getting to know their impact on the surface & atmosphere. Therefore, those models of stardust are needed to describe the evolution, production, and transportation of dust from their the to the planetary atmosphere [5-7]. Those models can predict the dust's distribution of mass and velocity, also the amount of radiation and scattered background from the meteor shower. Depending on three parameters which is velocity, mass, and amount of radiation - dust particles can be completely dissolved upon entry into the atmosphere, either as unmelted micrometeorites (if dust particles don't reach melting temperatures), or as astronomical spheres (deformed at temperatures above melting point). The chemical ablative model (CABMOD) and zodiacal cloud model (ZoDy) estimate the three contribution sources of the dust - Jovian comets (jfc), the asteroid Belt (AST), Halley's Comets (HTCs) - to metals and organics in the earth, mars and venus 'atmosphere. Dust particles that survive entry into the atmosphere may be an important source of organic material on the planet's surface. CABMOD 3 includes multiphase processing to interpret the FeNi, silicate metallic phases in IDP. on the basis of chemical analysis proposed by Jarosewich , the Fe distribution between silicate blocks and Fe-Ni metal particles and FeS sulfide clumbs in CABMOD 3 was estimated [8]. To study the evolution of dust in the volume of the universe, the scientists conducted simulations of hydrodynamic in which the metal abundance and dust is consistent with stellar feedback and formation of stars. Dust production is closely related to metal abundance, and the relationship between stardust abundance and metal abundance provides a powerful test for models of dust evolution. Some cosmological models with dust implementations also use this relationship for key tests. Thus, for low mass galaxies, the dust-gas ratio is $\dot{m}_{\text{dust}} \propto \dot{m}_{\text{gas}} Z$ (seen from Fig. 1) [5].

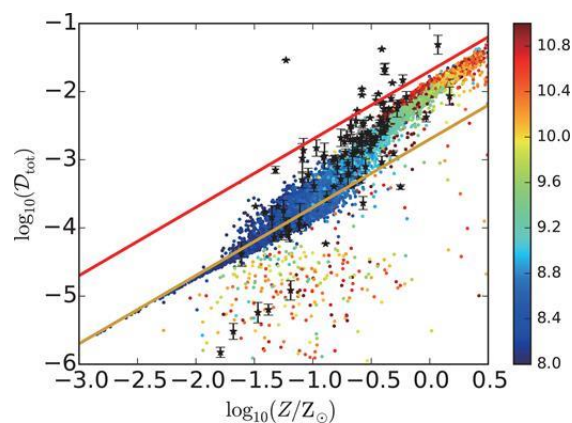


Figure 1. The dust-gas mass ratio in relation to the metallicity Z of a single galaxy. The color represents a logarithmic stellar mass ($M_{\odot}$)

There are still simulations of cosmic dust on behalf of the reaserches of the observations of the infant universe, like Thesan. A new component of THESAN's simulation is the inclusion of cosmic dust, which makes this project even more unique in the landscape of astrophysical simulations. Cosmic dust refers to the collection of tiny solid particles of matter that form between galaxies and stars. One side effect is that the dust locks small portions of the atomic and molecular gas made up of heavy elements into amorphous and crystalline structures, which have important implications for cosmic chemistry and cooling. The dust also converts ultraviolet and visible light into lower-energy photons, altering the effect of radiation on the galaxy formation process and, in some cases, causing galaxies to glow brightly at infrared wavelengths. As a result, light from dust reprocessing has recently become a powerful way to probe the properties of the first galaxies, and has quickly provided a wealth of information about the state of the infant universe. For this reason, while the dust model in the simulation is a relatively new field, self-consistent modeling of this component is critical to testing what one knows about the first galaxies as scholars approach observations with increasingly powerful telescopes [6]. Recently, a group of scientists firstly introduced a visually realistic model of dust that combines a rough mixture of RFA, which is fractal aggregates and aggregated solid to replicate the phase of curve of polarization that was observed in the condition of the 2I/Borisov interstellar comet . They describe techniques used to generate particles(solid) & RFA that replicate the results of light scattering from the Granada Amsterdam Light scattering database and simulate the properties of polarization of the t 2I/Borisov(a interstellar comet). After validating the RFA model structure, they further developed a model that considers porous cosmic dust RFA and low-porosity solid particles. In the model, the RFA structure is thought to represent porous aggregates of cosmic dust, while the aggregated debris particles are thought to represent solid particles with low porosity. It is therefore clear that the third category of comets needs particular treatment with easier methods. Therefore, one thinks tiny particles with a size of "2.5 μ m", with a more primitive morphology [7].

4. Observation

The observation of the cosmic dust has been done from both ground and space, both traditional and advanced telescopes. Some times the observation results are even used to test or be tested by the cosmic simulations. In early times, Scientists have come to realize that this light exists in all directions of the celestial body, taking on the solar spectrum and being partially polarized. Therefore, they believe that this is caused by sunlight being scattered by little particles (solids) (e.g., Wright). Additionally, those small particles are the forming dust of zodiacal clouds. The brightness of clouds comes mainly from the scattering of visible light and the thermal emission of infrared, so it can be researched in both ranges of wavelength. The most whole review of its nature was published nearly 20 years ago in the IAU Committee 21 report: Light in the Night Sky 60 "A 1997 Reference for Diffused Night Sky Brightness" (Leinert et al.) and in the book "Interplanetary Dust" [8, 9]. Zodiacal light is usually observed in terms of brightness and polarization in different wavelength ranges. The intensity of zodiacal light depends on the location of the observer in the orbit of Earth, the wavelength, the direction of observation relative to the sun. The distribution of dust which is arranged around Sun basically follows a symmetry of mirror-like, relative to the surface near the ecliptic. Due to the mobility of dust, one evaluated their characteristics in different regions of the solar system. The Earth-orbiting D2A satellite measured zodiacal light in a plane perpendicular to the sun-Earth direction

Its results confirm the validity of 130 ground-based measurements and provide some evidence for the inhomogeneity of interplanetary dust [8]. Besides, some observations of the magnetic fields of the dust are made. The magnetic directions of molecular clouds and interstellar filaments are tracked by polarization of starlight, as well as polarization hot dust emission. Observations reveal the magnetic properties of a variety of objects, providing the necessary input and basis for theoretical work and simulation to understand the evolution and origin of magnetic fields. In astrophysical processes, such as the formation of planets and stars in molecular clouds and the formation of galaxies

and cosmic structures, magnetic fields are often passive dynamics, but play a key role at certain stages [9].

The final results show that the typical particle velocity is assumed to be $\sim 18\text{km/s}$, and the dust particle size is between 1 and 12 microns. The observation results of dust into the atmosphere of Martian improve the knowledge of the sources, sinks and transportation of IDPs inside the solar system and the related effects on the Martian atmosphere. Thanks to its function of detecting electric fields of high-frequency, MAVEN's Langmuir Probe and Waves (LPW) instrument can detect dust. When the particles hit the spacecraft at orbital velocity, a pulse of electricity formed by the plasma cloud can be observed. LPW takes photos of time series named data bursts, and the characteristics of dust impacts in the time series can change. The dust observed at LPW is small (particle radius of nanometers to microns). And these impacts don't endanger spacecraft. Many previous interplanetary and planetary missions have demonstrated the use of electric field instruments for dust detection. The instrument's response to dust impacts depends on a number of factors, including the orientation of the spacecraft, the electrical connections between the spacecraft surfaces, and the design of the electric field instrument. After making the necessary assumptions about the impact velocity and the material of the spacecraft receiving the impact, the amplitude of the impact signal can be used to estimate the size of the observed dust particles [10]. The results are given in Fig. 2 and Fig. 3.

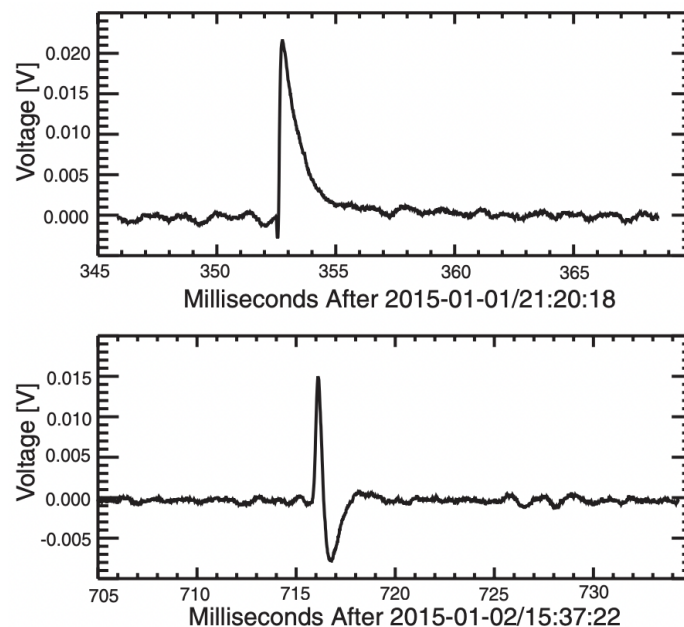


Figure 2. 2 examples of impacts of the dust which is recorded by the LPW. Location of the impacts, the potential energy between the spacecraft and the sensor, the size of the dust, the dust velocity, affect the time series shapes. (1) Example of current recovery of LPW sensor. (2) Bipolar current signals collected by both the LPW sensor and the spacecraft body.

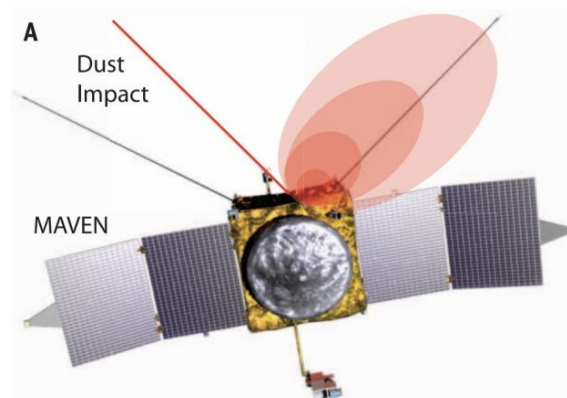


Figure 3. Dust impacts

5. Limitations and Prospects

The observations and the simulations of cosmic dust have been started for a period of time. Until now, there are many classic models that simulated the cosmic dust. There are simulations describes the process of dust going through the atmosphere and not only the earth atmosphere. Moreover, variety of simulations are designed to study the distribution of the cosmic dust in different galaxies. Besides, some detailed models are made to simulate the optical properties of the dust to study its formation as well as many Chemistry models that study the formation of the dust. Nowadays, more and more projects of simulations are provided to study the relations between cosmic dust and galaxies history. Whereas, the models are not perfectly combined with the observations' results. Sometimes the observations are not clear enough, so one can use the simulation models to get more detailed results. In addition, the observation results can test the accuracy of the simulations. The simulation models should be more relied on super computers, just like the Thesan and illustris-TNG, to get higher accuracy. Works in aspects of programming can be much better, more advanced codes of physics, e.g., the illustris-TNG has employed the most advanced code of the magnetic hydrodynamics simulation. More codes like this should be work out in the future. The observations of the details inside the cosmic dust are apparently not enough, especially for the dust clouds that are too far and too expensive to collect the samples, then it is more substantial to design relatively small detectors to observe closely to the dust. Just like the MAVEN's Langmuir Probe and Waves (LPW), so that one could get the comprehensive data of the dust. Its magnetic and electrical fields, its density or mass flux, its basic elements formation, etc. All in all, it is important to combine the exisiting useful individual models together, and also combine those of them to the super computers at the same times.

6. Conclusion

To sum up, this study summarizes the academic meaning of the researches of the cosmic dust and the general progress of researches of the cosmic dust in the respects of its observation and simulation. Until now, the researches about the IDPs around earth or has fallen to earth is quite specific and clear, it benefits the study of the origin of organic chemicals and the history of the solar system. For those dust clouds far away from earth, most of the way is to observe directly by telescopes or with simulations using several methods and models above. It is better to combine each models and super computers ,as well as the observations together. Moroeover the cosmic detectors can be designed with more functions aim at the cosmic dust.

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