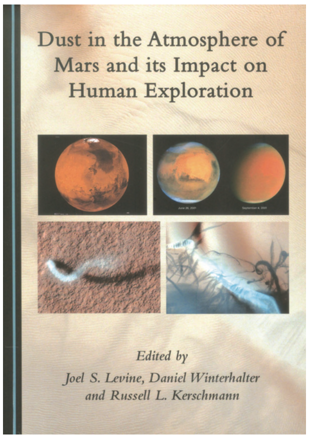

Dust in the Atmosphere of Mars and its Impact on Human Exploration. Joel S. Levine, Daniel Winterhalter and Russell L. Kerschmann (eds). Cambridge Scholars Publishing, Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK. 2018. xii + 293 pages. Price: £61.99.

Human exploration of outer space started with Apollo program of USA and the world recently celebrated the 50th anniversary of human landing on Moon. The quest for human exploration of Mars is also seriously being planned to boost human urge to explore new frontiers and to excite and stimulate the next generation of scientists, engineers, mathematicians, etc. This may also lead to presence of human species on two planets by establishing a human colony on Mars. However, many factors need to be accounted before such an effort could be fructified. Apollo missions taught many lessons for future human exploration and one of them was to know the deleterious impact of lunar dust on the astronauts, their spacesuits and equipment. Lunar dust permeated everything and impacted mechanical systems. The dust on the Moon's surface was disturbed and became airborne by the routine actions of the astronauts as they walked and performed their activities on the lunar surface.

Over the last decade, as NASA's plans for the human exploration of Mars have developed and matured, a major concern has been the possible negative impacts of Mars surface and atmospheric dust on human health and on the surface systems and surface operations on the red planet. Mars being a dusty planet, the impact of Martian dust on human exploration has been a serious issue. The dust on the Mars is more persistent and its surface is covered with unconsolidated soil and dust that is frequently transported into atmosphere by horizontal and vertical winds. Mars is often frequented by localized, regional and planetary scale dust storms. A planetary scale dust storm occurred in 2001 and more recently in 2018 (Figure 1). Even though many remote sensing-based studies have been made to understand Martian dust in atmosphere and on its surface, there is a need to investigate its composition and its impact on human health, space suits and mobility systems. The book under review is an outcome of the proceedings of a three-day workshop held at Lunar and Planetary Institute (LPI) in Houston, Texas, USA during 13–15 June 2017 on this subject organized by the NASA Engineering and Safety Centre (NESC).

In this book, 41 Mars scientists, mission engineers and planners and medical researchers have reviewed our current understanding and identified the knowledge gaps in a wide range of areas, including the chemical, physical and electrical properties of atmospheric dust of Mars; the evolution and occurrence of localized, regional and planetary-scale dust storms; the human health effects of atmospheric dust of Mars, including inhalation of and potential toxicity of dust particles; and the impact of atmospheric dust of Mars on surface systems and on surface operations, among others. The book consists of 17 chapters organized into three sections.

The first eight chapters in section one cover different aspects of Martian dust including its nature, structure, composition, distribution, electric properties, etc. Chapter 1 provides a review of current knowledge about the Martian dust properties in terms of toxicity, biological degradation and potential for equipment corrosion, etc. The discussion about the gaps in the current knowledge for precursor measurements required to reduce the risk of first human mission to Mars is also interesting. Chapter 2 mainly focuses on two-way planetary protection issue and the role of dust in terms of providing a cover to Earth microbes, protecting them against UV irradiation and finally leading to contamination of Mars. The second important aspect about the inhalation of Martian dust which is rich in perchlorates by the crew. This can lead to unknown potential for acute and chronic effects on health. Perchlorates are reactive chemicals first detected in arctic Martian soil by NASA's Phoenix lander that landed on Mars in May 2008. Chapter 3 presents a good review of chemical, mineralogical and physical properties of Martian soil and dust based on remote sensing and *in-situ* measurements carried out by Martian rovers such as Curiosity. Estimates from such missions suggest that particle size of Martian dust is in the range of 1–3 microns and mineralogy is dominated by basaltic minerals but a significant amount of chemical alteration of basaltic material has produced 15–25 wt% of clay-sized material. It is recommended that impacts of dust and soil on human missions must be studied in detail, however authors suggest that they do not foresee this as 'show stoppers' on the basis of available data.

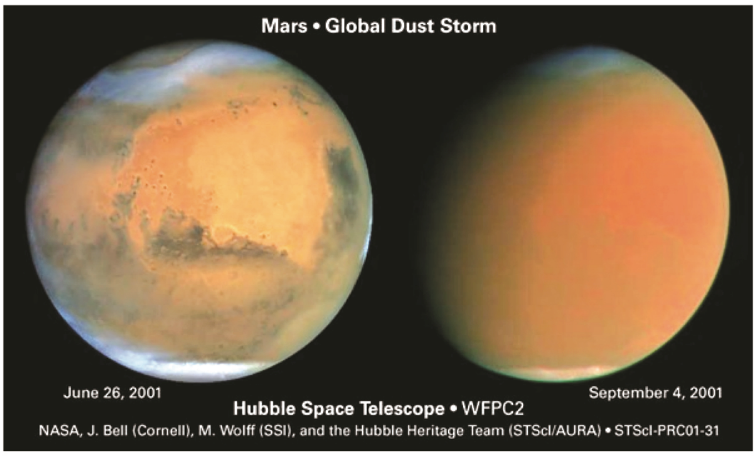

Figure 1. Hubble images of Mars show the effects of global-scale dust storms. (credit: NASA, J. Bell (Cornell), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA)).

Chapter 4 focuses on electrified dust storms on Mars and associated lightning discharges in the atmosphere of Mars. The nature of the discharge is directly associated with environmental hazards that any explorer may encounter on the dusty surface. Frequently occurring dust on Mars acts as electrical generators and a theoretical treatment of the problem is nicely explained. The chapter concludes with recommendations to obtain more *in-situ* measurements of the Martian DC electric field, RF activity and atmospheric conductivity. Chapter 5 is devoted to the dust deposition observations on natural and spaceflight hardware collected in Gale crater, which is the home of Mars Curiosity rover. This rover is equipped with an instrument called Mars Hand Lens Imager (MAHLI), which is a robotic arm-mounted colour camera that can focus on subjects at working distance of 21 mm to infinity with highest resolution of ~16 micron/pixel. The findings suggest that the dust coating on natural surfaces along the Curiosity traverse was thin (<1 mm). MAHLI images also show sand size dust aggregates, which are contributed by sedimentary rocks erosion through prevailing winds on Mars.

Chapter 6 is focused on the spatial and temporal distribution of dust in the atmosphere of Mars, and provide a summary of the large number of studies carried out using satellite-based remote sensing instruments, e.g. Mars Global Surveyor (MSG), Mars Orbiter Wide angle Camera (MOC-WA), Mars Reconnaissance Orbiter (MRO), Mars Color Imager (MARCI), etc. The results from these observations are used for developing understanding about dust storm pathways and evolution of these events. The focus on dust uncertainties, future measurement requirements and role of coupling them with atmospheric models is also discussed. It would be nice to have more recent results from Indian Mars Orbiter Mission (MOM) on dust storms and associated measurements on atmospheric optical thickness dynamics. Chapter 7 provides a nice summary of the results obtained by Mars Climate Sounder (MCS), an instrument on MRO satellite, measuring vertical distribution of dust through decade long observation record. Observations show that on Mars, dust can be uplifted to as high as 50–60 km from the surface. Chapter 8 focuses on current capabilities of forecasting dust storm on Mars using atmospheric models resolving thermal and dynamical structures. The sections on dust storm classification, current capabilities of dust forecasting and future needs of developing data assimilation schemes into atmospheric models are interesting to read.

Section 2 contains 3 chapters covering the impact of Mars surface and atmospheric dust on human health. Chapter 9 focuses on the lessons learned from the lunar dust experiences through Apollo missions and raises pertinent questions about our understanding for Mars. The chapter ends with a list of 16 important questions related to health hazards for crew members. Chapter 10 brings out important aspects related to reduced gravity environment of Mars and associated processes controlling aerosol deposition in the human lungs. It is brought out that a significant gap exists in the knowledge regarding the spatial distribution of fine particulates in the human lung in reduced gravity. Such studies may help in developing mitigation procedures against dust inhalation by astronauts. The last chapter of this section deals with an interesting aspect of human physiology when it comes to interaction with Martian dust. This chapter lists specific toxic effects of Martian dust form various chemicals such as perchlorates, chromium VI, arsenic, cadmium, beryllium, etc. Impact of Martian dust to human eyes and skin is discussed. Emergency medicine response and disaster preparedness is also discussed extensively.

The last section consisting of 6 chapters covers the impact of Mars surface and atmospheric dust on surface systems, e.g. space suits, habitats mobility systems and associated surface operations. Chapter 12 provides an overview about human mission equipment and typical operations required to be done on the Mars surface. In chapter 13, specific points are brought out about the impacts of dust storm on mission equipment and operations. Discussions are focused on surface power systems, surface habitat, rovers, EVA spacesuits and tools and Mars ascent vehicle. Chapters 14 and 15 are dedicated to *in-situ* resources utilization (ISRU) and history of *in-situ* studies of the hazards of dust in human exploration of Mars, developing appropriate filters for astronaut and associated number of applications. The book ends with chapters 16 and 17 which are focused on geophysical and environmental monitoring of astronaut exploration zones and dust dynamics issues related to site selection for human exploration. This is important for defining where and how human crews sent to Mars will land, live and work on the Martian surface. Many factors are considered for selecting the probable landing sites, but a significant factor is dust that either resides at or is brought to this site by local environmental conditions.

Overall this book provides deep insight about the dust in the atmosphere of Mars and its impact on future exploration of Mars by humans. The book provides a nice summary of the current knowledge about Martian dust and possible impact on human health, surface hardware and operations. It also brings out the gaps in our current knowledge such as to better know the chemical composition of atmospheric dust, including the identification of possible toxic compound, the electrical nature of Mars atmospheric dust particles and how potential electrical charges on dust particles may be dissipated, how to better predict the occurrence, location, severity, and duration of dust storms on Mars, to understand its impact in human respiration in a reduced gravity environment over the extended periods and to better understand the role of the omnipresent atmospheric dust in the potential transport of Earth microorganisms around Mars (forward contamination) and the role of atmospheric dust in transporting possible Mars microorganisms back to Earth with the astronauts. I hope this book will be useful for planetary scientists and engineers involved in exploration of Mars.

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