沙尘暴对火星表面探测器的影响：回顾与展望

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Citation: 科学通报 (2022); doi: 10.1360/TB-2022-0445

View online: https://engine.scichina.com/doi/10.1360/TB-2022-0445

Published by the 《中国科学》杂志社

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The success and accuracy of Entry-Descent-Landing (EDL) for a surface mission to Mars depends on local and regional atmospheric conditions, including atmospheric density, winds, their variations with altitude, and the moment to execute the EDL. Dust storms and their enhanced atmospheric dust loading can affect the radiative heating of the atmosphere, atmospheric density structure, winds, and even the power output of the solar arrays onboard rovers/landers. The assessment and prediction of Martian dust storms are urgently required to serve the currently operating China's Mars Rover-Zhurong and would be beneficial to China's Mars mission to return Mars samples in the future. However, it is challenging to accurately predict when and where dust storms will occur on Mars. A detail review of the effects of dust storms on Mars landers and rovers, which landed on the Martian surface between 1997 and 2018, will allow for a preliminary exploration of the patterns of dust storm effects on rovers on the Martian surface. Studies on the critical effects of dust storms showed that dust accumulates at a relatively steady rate on the surface of solar arrays on rovers, and dust storms, particularly global storms, can greatly accelerate the rate of dust deposition. For example, the global dust storm in 2007 rapidly reduced the dust factor of opportunity and spirit solar arrays by approximately half. Against a background of dust accumulation, most detectors (e.g., solar array) onboard the rover would experience relatively more frequent dust removal events, which may be linked to the speed and direction of the background winds and dust storm transport trajectory. Moreover, the removal of dust from the surface of solar arrays occurs in a seasonally repeating pattern that might accompany the appearance of dust storms. Notably, dust removal event is not always proportional to background wind speed, meaning that dust removal event is stronger when the background wind speed is higher. This implies that the mechanisms of dust accumulation and removal are complex and cannot be described using a single meteorological indicator. As the first lander to arrive at Mars during the dust storm season, InSight took several actions during the design phase to avoid the risk of dust storms, and the actions can be summarized in two main areas: assessing the impact of dust storms on the performance of EDL system and assessing the impact of dust storms on solar arrays. Four engineering atmospheric models for EDL performance assessment were developed during a preliminary research, which would be of great reference for subsequent engineering designs. The InSight team used the observations from the Martian orbit and surface, and rigorous monitoring of dust storms in the landing zone was carried out in the weeks prior to InSight's landing. The

response of InSight to dust storms provides valuable lessons for our upcoming Mars sample return mission. Prospective scientific guidance is the key to ensuring the successful implementation of engineering tasks. An analysis of the preliminary scenario design for a Mars sample return mission indicates that if the rover reached Mars around September 2029, it is highly likely to coincide with the outbreak of a Martian dust storm. It is recommended that the rover be launched as early as possible in 2028 to avoid the risk of lander landing or rising in a dust storm environment. Nevertheless, theoretical guidance requires accurate measurements of meteorological indicators in the vicinity of the landing zone and further effective integration of global and mesoscale climate models are needed to weigh the meteorological indicators for more accurate assessment and prediction of dust storms.