Abstract for the general public

Solar cells play a pivotal role in powering space applications, providing a reliable and sustainable source of electrical energy in the harsh environment of outer space. For space applications, solar cell must be light-weighted, highly efficient, and economically viable. Most importantly, it should perform well for longer durations and sustain high doses of cosmic irradiations in a vacuum with extreme temperature variations necessitating specialized solar cell technologies. To date, the power conversion efficiency (PCE) of single-junction photovoltaic systems (PV) has crossed 25% due to their outstanding optoelectronic properties. However, there is a theoretical performance limitation of single-junction solar cell under solar irradiation known as Shokley-Queisser limit equal to 33,7%. To overcome this limitation, multijunction solar cells for instance, InGaP/InGaAs/Ge, $GaInP_2$/GaAs/Ge, etc. have been developed. Though they are much more efficient, under space conditions the efficiency has been reduced drastically over the period. Therefore, new lightweight and highly efficient solar cells, which can withstand high-energy irradiation, need to be developed.

To address this situation, perovskite solar cells (PSCs) are the most promising solution, having already surpassed a PCE of 26%. However, despite the excellent efficiency of PSCs, their stability under atmospheric and space conditions remains a significant hurdle that must be addressed for commercialization. Tremendous efforts have been devoted to making PSCs more efficient and stable, including the design and synthesis of new perovskite materials and device engineering. With these efforts, PSCs have become quite stable under various atmospheric conditions, including air, humidity, and heat. Compared to three-dimensional (3D) perovskite materials, two-dimensional (2D) perovskites and quasi-2D perovskites with an increased number of inorganic sheets have attracted increasing attention due to their excellent stability. Such perovskites can be utilized in solar cells to achieve high performance and stability under extreme environmental and space conditions. However, they are still not sufficiently studied, and a comprehensive understanding of their materials science, device physics, and radiation resistance (crucial for space applications) is necessary for widespread applications in the future.

Among different irradiation conditions, such as proton, electron, neutron, and gamma (ϒ)-ray, high-energy particles can permanently damage electronic devices due to the accumulation of charges in space. However, there are very few studies on 2D perovskites under high-energy particle irradiation. Therefore, it is essential to study the stability of 2D perovskite devices under such conditions, as fundamental processes like charge generation, transport, and recombination may be affected. Detailed analysis can provide insights into PSC dynamics, helping to resolve fundamental issues. In this project, we propose to fabricate 2D PSCs that are fully solution-processable (easy to fabricate and economical) and capable of withstanding harsh space conditions.

Moreover, we propose a fundamental investigation and optimization of 2D PSCs to achieve high performance and stability under atmospheric and space conditions. The complete device will be irradiated by high-energy particles, with an accumulated dose up to 10^{14} particles/cm^2 to investigate its effects on fundamental properties and performance. During the formation of the complete 2D PSC configuration, we will examine the structural, morphological, and optoelectronic properties of all functional layers. Light-matter interactions, studied through transient absorption spectroscopy at the heterostructure, will provide crucial information, including charge extractions and recombination rate constants, diffusion length, exciton binding energy, lifetime, and more. These analyses can estimate the kinetics and, ultimately, the performance and stability of 2D perovskite PSCs under space conditions. The proposed work will help us overcome many challenges encountered during the design and fabrication of efficient and radiation-resistant 2D PSCs for future space applications.