THUNDER - THermal UNpolarized radiation Design for Energy Recycling

Executive Summary – Environment Challenge

The world's consumption and production of energy are ever-growing and predicted to continue doing so. It has become of vital importance to find efficient and carbon-free solutions that will allow us to harvest and store energy produced from industrial processes, in order to reduce our emissions and impact on the planet. Among heat-harvesting energy technologies, thermophotovoltaics promises excellent performance. Indeed, theory predicts that thermophotovoltaics could approach the thermodynamic limit for the conversion of heat into electricity. Similarly, daytime radiative cooling promises to be a clean way to lower the internal temperature of buildings without any external energy input, other than, of course, sunlight. Recent breakthroughs in both of these topics have been made possible by developments in the field of nanophotonics, where designing subwavelength structures has resulted in unprecedented capabilities to control light over very broad wavelength ranges.

In this framework, the possibility of engineering the spectrum of thermal radiation to tailor it for specific applications is exciting, as it can dramatically boost the performance of these devices. If thermal emission possessed properties such as, directionality, a high degree of polarization and chirality, applications would benefit from it massively. Directionality, for example, is important for radiative cooling, as the light emitted by the device must not be radiated towards the object it is cooling, but needs to travel away from it. Directional emission would also benefit heat transfer and, consequently, thermophotovoltaics, providing a directed flow of energy from the emitter to the cell. In addition to this, a control on polarization and chirality could have several interesting consequences. Designing the polarization profile of the emitter can allow for more channels to be excited in the absorber, increasing the capacity of the device and the heat flux. Furthermore, chirality could be exploited to design devices with nonreciprocal responses. These properties and degrees of freedom of light have been extensively studied for coherent, monochromatic light. However, interest towards the study of these quantities in the framework of thermal radiation has not been transversal yet. This is because the magnitude of the performance achievable with radiative heat-harvesting devices has only recently been fully understood. However, recent promising results have shown that the manipulation of thermal radiation can drive devices with unprecedented efficiencies and a clean footprint.

Via project **THUNDER** (**TH**ermal **UN**polarized radiation **D**esign for **E**nergy **R**ecycling), I plan to design thermal emitters to harvest the power of thermal radiation leveraging on phenomena which are robust and due to the intrinsic nature of light. For example, I plan on designing directional emitters that rely on spin-momentum locking or on a large reactive power, a task I have previously successfully achieved with coherent nanophotonic designs. Other degrees of freedom such as Poynting vector, chirality and angular momentum will also be examined. I will develop a theoretical framework that allows for the description of thermal fields and a formalism to calculate their degrees of freedom. Via this, I will be able to evaluate their magnitudes and the possibility of engineering them to attain specific values. The devices realized with this method will serve as a model to estimate the effect that the manipulation of each degree of freedom can have on thermally emitted spectra. Once the phenomena that can enhance radiative heat transfer have been identified, they can be combined to explore their joint effects.

This is a very exciting moment to work on these topics, as devices based on thermal emission are becoming the state-of-the-art for energy conversion right in front of our eyes. Recent scientific advances are showing us the possibility for the waste heat generated in industrial processes to be exploited as an abundant energy resource. It is time to give thermal radiation the same attention that has been given to coherent, directional and monochromatic light, as the potential for discoveries in this field is vast. Discoveries in this field could be the solutions that will empower us to face climate change and pull the break on the disastrous damages we have done to the planet.