Electromagnetic Structures and Exploitation of the Dark Universe for Cooling on Earth

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From the point of view of the Second Law of Thermodynamics, high-temperature heat sources, and low-temperature heat sinks, are both very valuable thermodynamic resources that are required to efficiently extract work from heat through the use of a thermal engine. It is widely recognized that Nature provides us with a near ideal heat source in the form of the sun, which sits at a temperature close to 6,000K. A significant portion of global renewable energy research has therefore focused on harvesting light and heat from the sun.

Less widely recognized however is the fact that Nature has also provided us with a near-ideal heat sink: outer space, which sits at an ultra-low temperature of 3K. Moreover, the Earth's atmosphere has a transparency window in the wavelength range from 8 to 13 micron. Thus, an object on Earth with a typical temperature near 300K (27°C), can radiate heat through the atmosphere to outer space in the form of thermal electromagnetic waves, and cool down. This approach is known as radiative cooling. All objects on earth therefore in fact have radiative access to the coldness and darkness of the universe.

From the viewpoint of the Second Law, given the near symmetrically equal importance of a high-temperature heat source and a low-temperature heat sink in the efficiency of a Carnot engine, it is quite surprising, at least to us, that compared with solar energy harvesting, far fewer modern works have been devoted to harvesting the coldness of the dark universe.

Here we show that nanophotonic structures provide the key towards harvesting the coldness of the universe. Nanophotonic structures provide tremendous flexibilities for tailoring the absorption and thermal emission properties, and therefore provide significant opportunities for a wide variety of energy application. As an illustration, we show that one can use nanophotonic structures to achieve passive radiative cooling during the daytime. The key here is to design structures that strongly reflect sunlight, while simultaneously emitting thermal radiation in the transparency wavelength window[1,2,3]. We show that under direct sunlight and with sky access, such a structure can reach equilibrium temperature that is significantly below ambient temperature, opening up the possibility of air-conditioning without electricity input, and providing a general strategy for improving the efficiency of heat engines on earth by reducing the temperature of the heat sink.

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[3] L. Zhu, A. Raman, K. Wang, M. Anoma, and S. Fan, "Radiative cooling of solar cells", Optica (submitted).