THz Spectroscopy in the Lab and at Telescopes

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Abstract

Terahertz (THz) radiation extends roughly from 0.1-10×10^{12} Hz, or 3-333 cm^{-1}. Spectroscopy at THz frequencies holds the key to our ability to remotely sense environments as diverse as primeval galaxies, star and planet-forming circumstellar disks, comets, laboratory plasmas, semiconductor materials, and hydrogen bonded liquids/polymers. For astrophysical applications, the upcoming deployments of the Herschel Space Telescope, the Stratospheric Observatory For Infrared Astronomy (SOFIA), and the Atacama Large Millimeter Array (ALMA) observatories promise to revolutionize our understanding of the THz sky.

To fully realize this promise, however, and to capitalize more broadly on the science possible at THz frequencies, it is essential that we achieve a quantitative experimental understanding of the complex materials (dust, ice, and gas) which are found in nature; yet THz laboratory studies largely lag behind the astronomical capabilities that Herschel, SOFIA, and ALMA will deploy, thanks primarily to technological limitations. In this talk I will first review the molecular and icy/solid state tracers that can serve as probes of both remote environments and man-made materials, and then turn to emerging laboratory tools that make their detailed characterization possible.

For the astrophysical (and potentially planetary) applications, I will concentrate on new THz routes to the study of prebiotic chemical evolution, namely the detection of the lowest frequency skeletal vibrations of 'molecular grains' such as Polycyclic Aromatic Hydrocarbons (PAHs) and the torsions of complex organics such as amino acids and/or sugars that are in principle observable in both the solid state and gas phase. While of interest in their own right, such species can also serve as model systems to guide the experimental and theoretical investigation of the molecular properties of biological polymers and other 'soft materials.'

In assessing the state of laboratory studies, I will outline how an integrated approach using both frequency- and time-domain approaches should lead to a dramatically improved ability to characterize the optical properties of complex materials across the full THz window. Such results will be central to the interpretation of new observations made possible by the next generation of microwave → THz telescopes and in the development of coherent control strategies for the large amplitude motion that operate in even the simplest building blocks of biological macromolecules. Indeed, particularly distinct tools involving *non-linear* THz spectroscopic and dynamical probes should soon become available using mW-average power devices such as THz quantum cascade lasers and high pulse energy femtosecond THz time-domain systems. Possible non-linear THz studies of the nano-structured materials that are present in nature or that form the heart of solar energy conversion and photoremediation strategies will be briefly highlighted.

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