Extreme light for molecules at the extremes

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Interrogation and manipulation of molecules is a challenging task, when sensitivities beyond parts per trillion or accuracies for frequency measurements approaching the uncertainty of primary frequency standards are requested. It indeed requires an overall rethinking of radiation sources, spectroscopic techniques and molecular samples preparation. Compared to atoms, difficulties are increased by the weaker absorption line-strengths, as well as by the need to cover the huge 2-1000 micron wavelength interval, where fundamental ro-vibrational bands of molecules are found, by appropriate photonic tools and spectroscopic techniques. To make matters worse, cryogenic cooling is often required to suppress the strong background radiation noise from which this spectral range suffers. However, a tremendous progress in photonics and spectroscopy, as well as in molecular sample preparation, is revolutionizing the scenario [1]. In the last twenty years, the main game changers on the photonics side have been frequency comb synthesizers [2-3], quantum cascade lasers [4-5] and quasi-phase-matching schemes for nonlinear generation of coherent radiation [6]. For spectroscopy, extension to the infrared and THz range of precision frequency measurements, beyond 10^{-11}, and the achievement of sensitivities better than 1 part-per-trillion are providing novel, powerful physical probes and new areas of application for sensing [7]. On the side of molecular samples, a key role is played by the emerging technologies for the production of cold and ultra-cold stable molecules, including buffer-gas cooling and magneto-optical trapping [8-11].

Several examples showing significant, often ground-breaking, results in the areas cited above will be discussed, together with perspectives in these areas.

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