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Deviations from inverse-square law in standoff Raman spectroscopy and telescropy

Standoff Raman spectroscopy has evolved from a research technique to a commercial technology over the past decades. Modern systems can acquire high signal-to-noise ratio (SNR) spectra at distances of 1–10 m, while specialized setups with large-aperture collection optics can extend this range to 10–100 m. Despite the wide range of applications, the theoretical understanding of how Raman intensity decays with distance remains unclear. Some studies have even reported deviations from the inverse-square law for experiments without focusing sample probes. This motivated us to perform systematic experiments and simulations of Raman intensity as a function of distance for different sample types using standoff Raman spectroscopy setup with collimated laser beam (Figure 1a). Ray-tracing analysis provides insight into this behavior (Figure 1b). When the sample is close to the spectrograph (0.2 m), the Raman signal spreads across the full slit height due to beam propagation after lens L1. At larger distances (e.g., 5 m), the signal becomes concentrated near the center of the spectroscopic slit. This effect is confirmed experimentally by CMOS images of benzene Raman signals recorded at various distances (Figure 1c). The deviation is caused by the presence of lens L1, which modifies beam propagation and is typically unavoidable in Raman systems. Without L1, the intensity follows the inverse-square law. These findings enable more accurate prediction of Raman signal intensity at different distances for standoff geometries with and without laser focusing probes. Moreover, when standoff Raman spectrometer is combined with motorized turret, telescope and imaging sensor, it can perform standoff Raman telescropy mapping as shown on Fig. 1f.

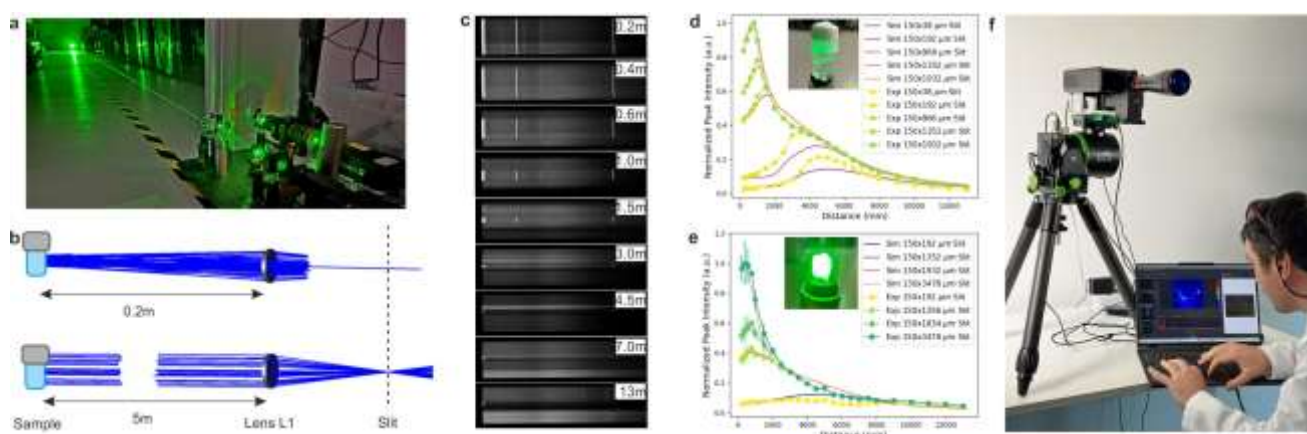


Figure 1: (a) Standoff Raman setup with collimated laser beam, (b) illustration from Zemax Optics Studio of Raman ray tracing to the spectroscopic slit at different distance to the sample (0.2 and 5m), (c) CMOS images of benzene Raman signals recorded at various distances, (d) intensity profiles of Raman signals of benzene versus distance extracted from CMOS images, (e) Raman intensity of sulphur crystal versus distance. Solid lines on Figure 1d,e represent experimental data, dotted lines represent simulation, (f) standoff Raman telescropy mapping of the painting.