Saturated Absorption in Gaussian beam beyond the perturbative approach

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By essence, spectroscopist used to acquire spectroscopy data for probing Physic models, and eventually the Standard model of Physic and beyond. High-resolution spectroscopy is actually a key tool which is currently associated with continuous-wave laser sources. Unfortunately, if sources exhibiting long coherence time are available, the lifetime, or the observation time of the system under study may be notably shorter than this coherence time. This is typically the case of atomic or of molecular systems probed under saturated absorption (SA). Thus, a simple question but crucial is: what is the ultimate limit of the Lamb-dip width?[1]

Based on this approach, if it is relatively easy to select systems with long lifetime, their environment (i.e., collisions) matters, as well as the volume of the probing electromagnetic field (EMF) since for $T > 0$, the atom/molecule systems are animated by a velocity, making the concept of transit-time fully relevant. It is the object of this study.

Saturated absorption is basically a nonlinear process which is usually approached by perturbative developments, i.e., one of the EMF is assumed to be a pump (eventually strong) saturating beam, while the probe beam has to be weak (i.e., non saturating). We will present a novel non-perturbative approach based on the density matrix (DM) formalism in the time domain to overcome all the weaknesses of the previous approaches. It is particular well adapted to SA in cavity.

The overall approach is to solve the density matrix for 3-level systems, in the time domain by setting a Gaussian temporal shape to the external EMFs, and then to Fourier transform the coherence matrix elements ; and finally to calculate the spectral shape. Hence, the numerical simulations can be fruitfully compared with simulations obtained under stationary EMFs (the limit of long transit-time). Nevertheless, for the current presentation, we will restrict the approach to 2-level systems. If we can summarize numerous current behaviors by using a usual saturation parameter, we can also identify clearly "unstable" behaviors even under moderated saturation. For example, if the "regular" resonance shape follows a standard Voigt profile (for the imaginary part of the coherence) whose components can be clearly identified, the "unstable" spectra do not usually follow analytical shapes. These shapes are very sensitive to the set of the experimental parameters (Rabi frequency, relaxation rates, transit-rate, see Fig. 1). We think that these barely controlled behaviors are specific to the dynamic of the system.

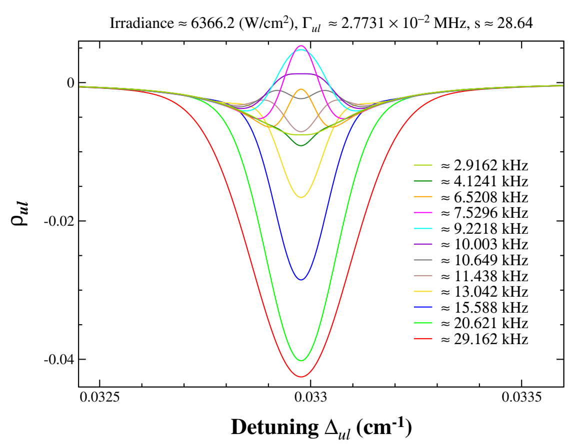

Figure 1. Unstable coherence for a specific irradiance. The values of the transit-rate $\gamma_{\rm tt}$ are provided in the plot caption.

References

1. F.M.J. Cozijn, P. Dupré, E.J. Salumbides, K.S.E. Eikema and W. Ubachs, Sub-Doppler frequency metrology in HD for test of fundamental physics, *Phys. Rev. Letters*, **120**, 153002–5 (2018).