Frequency modulation spectroscopy at the large optical depth regime

Chang Chi Kwong[1,2], Eng Aik Chan[1,3], Syed Abdullah Aljunid[3], Rustem Shakhmuratov[4,5], David Wilkowski[1,2,3,6]

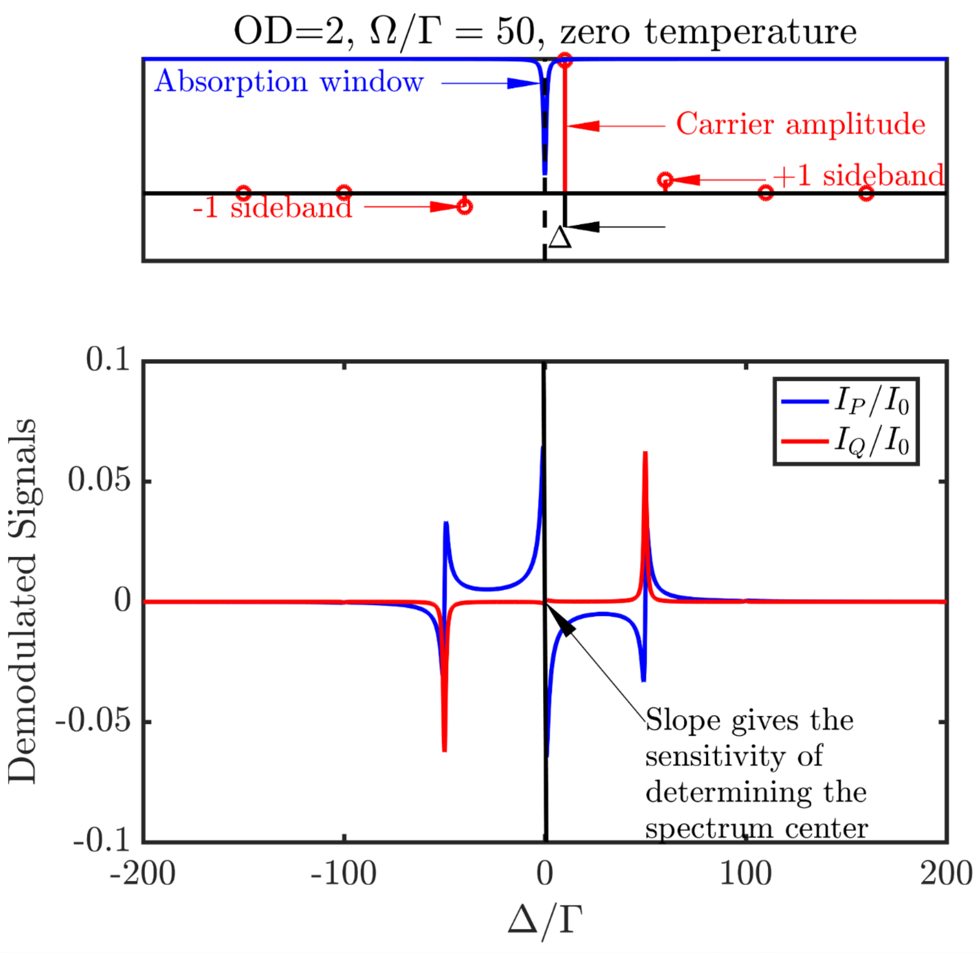
[1]School of Physical and Mathematical Science, Nanyang Technological University, Singapore 637371, Singapore.
[2]MajuLab, CNRS-UNS-NUS-NTU International Joint Research Unit UMI 3654, Singapore.
[3]Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637371, Singapore.
[4]Kazan Physical-Technical Institute, Russian Academy of Sciences, Kazan 420029, Russia.
[5]Kazan Federal University, Kazan 420018, Russia.
[6]Centre for Quantum Technologies, National University of Singapore, Singapore.

Motivation

The conventional band-resolved frequency modulation (FM) spectroscopy applied in the transmission, loses its sensitivity at large optical depth (OD). We propose and test an FM spectroscopic technique, with good sensitivity at large OD, and with applications in a wide array of systems. One such application could be to study cooperative effects of light scattering in dense atomic samples [1-3].

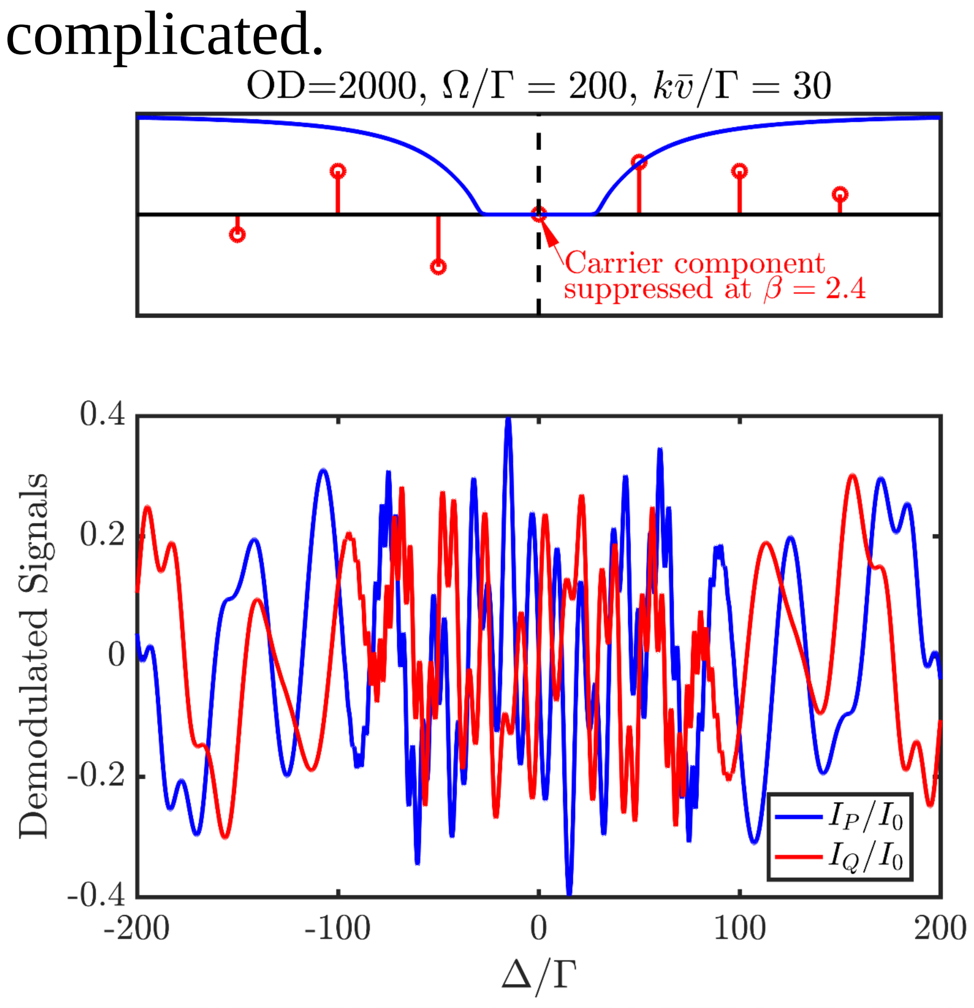
Conventional FM spectroscopy

The conventional low modulation index FM spectroscopy [4] works by having the carrier component of the probe beam interacting with the sample. The spectroscopic signal is then obtained by demodulating, at the modulation frequency Ω, the beat note between the carrier component and the weak first sidebands.



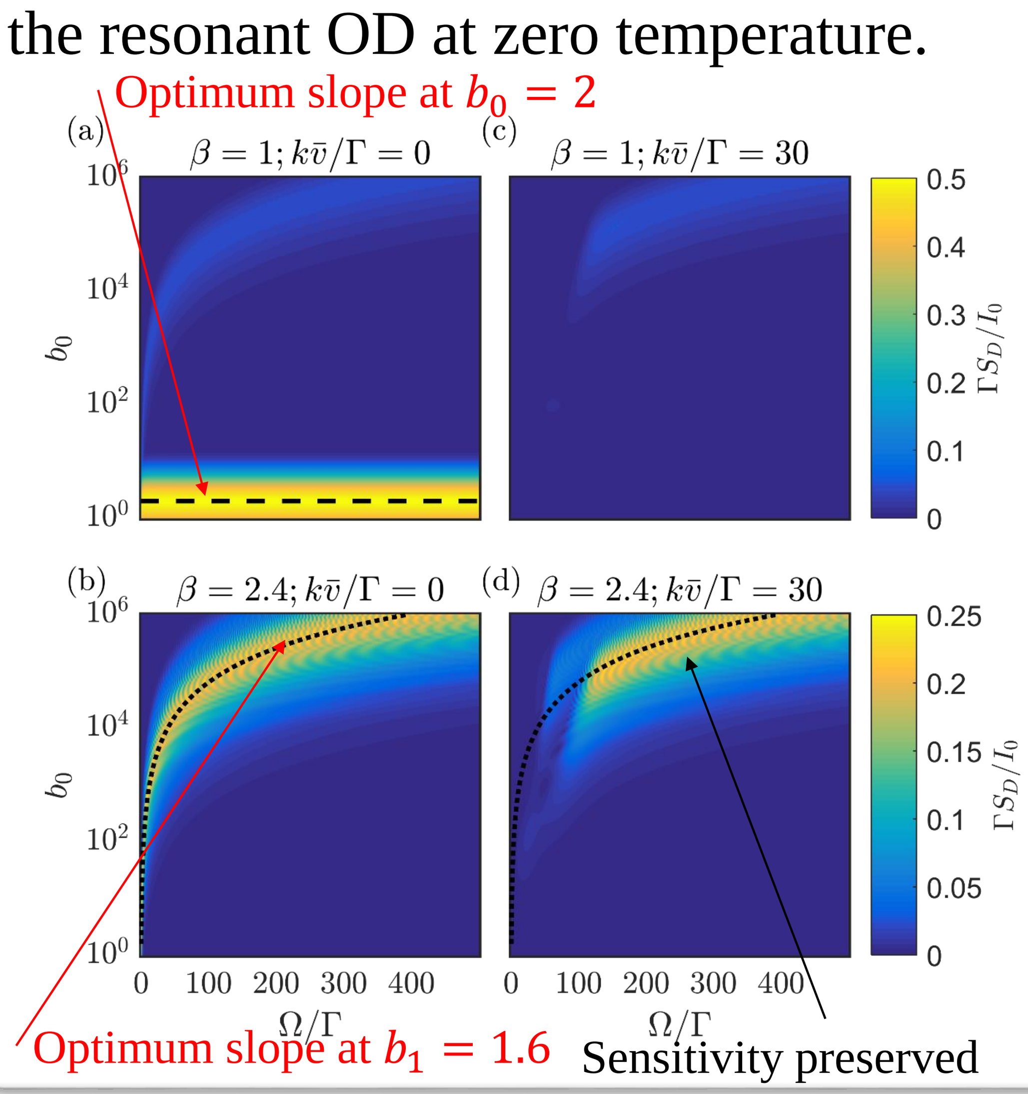
Large OD FM Spectroscopy

For conventional FM spectroscopy, the carrier component is exponentially absorbed at large OD. Setting the modulation index β close to 2.4, the sensitivity is recovered [5]. The spectroscopic signal now originates from the beat note between the transmitted sidebands. The signal becomes more complicated.

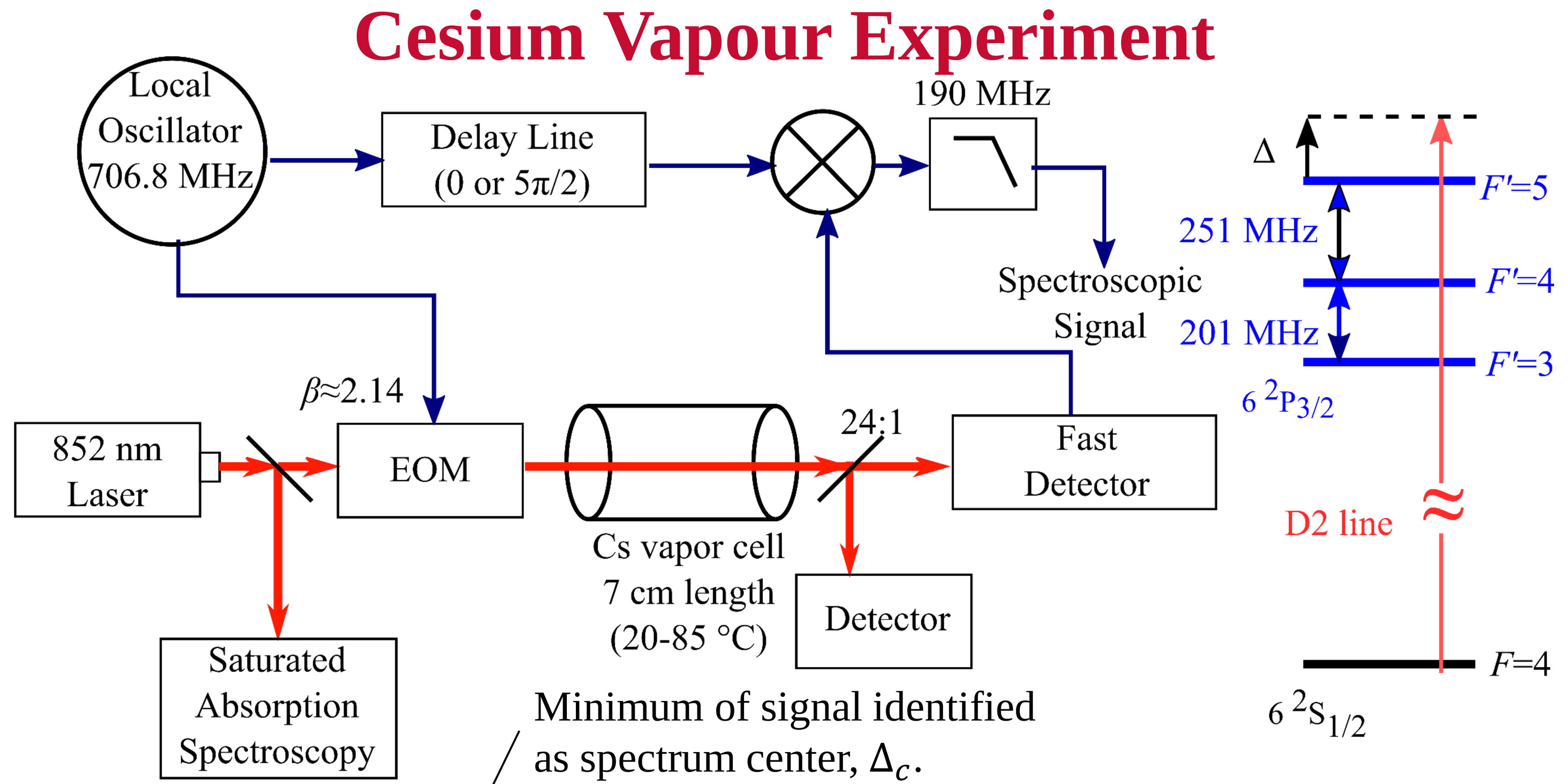


Sensitivity

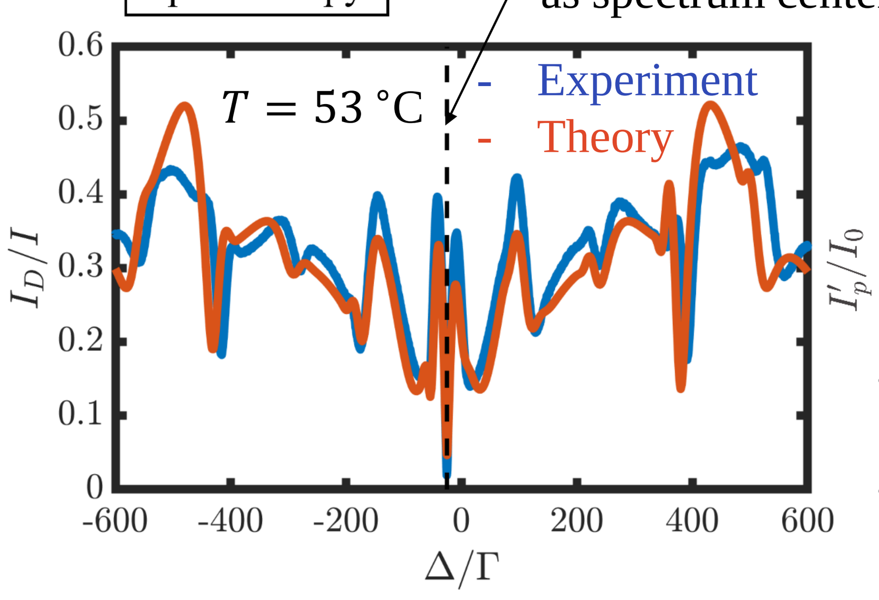
The sidebands probe the tails of the resonance, which are dominated by the homogeneous Lorentzian profile. For large Ω, the sensitivity (the slope at the center S_D) of the large OD FM spectroscopy is unaffected by Doppler broadening. b_0 in the following figure is the resonant OD at zero temperature.



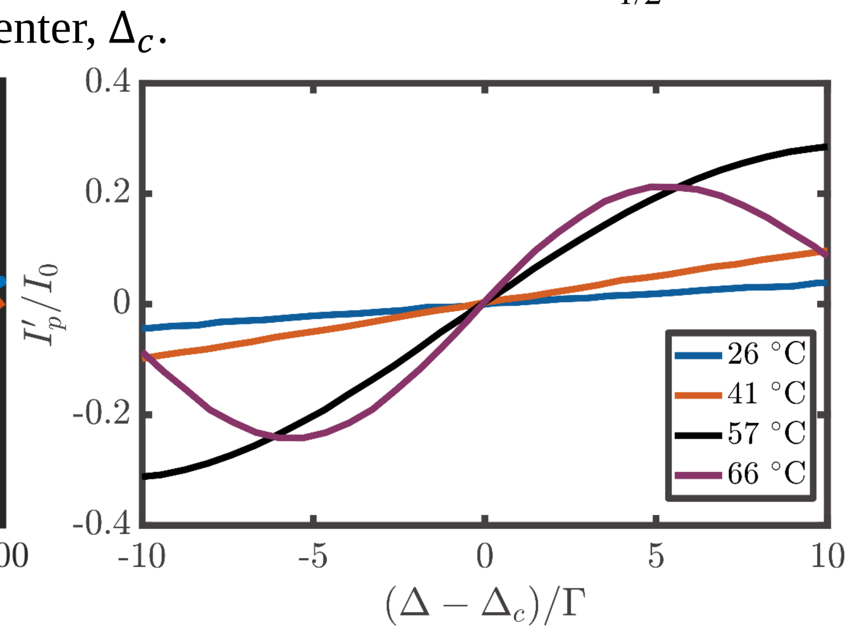
Cesium Vapour Experiment



Minimum of signal identified as spectrum center, Δ_c.



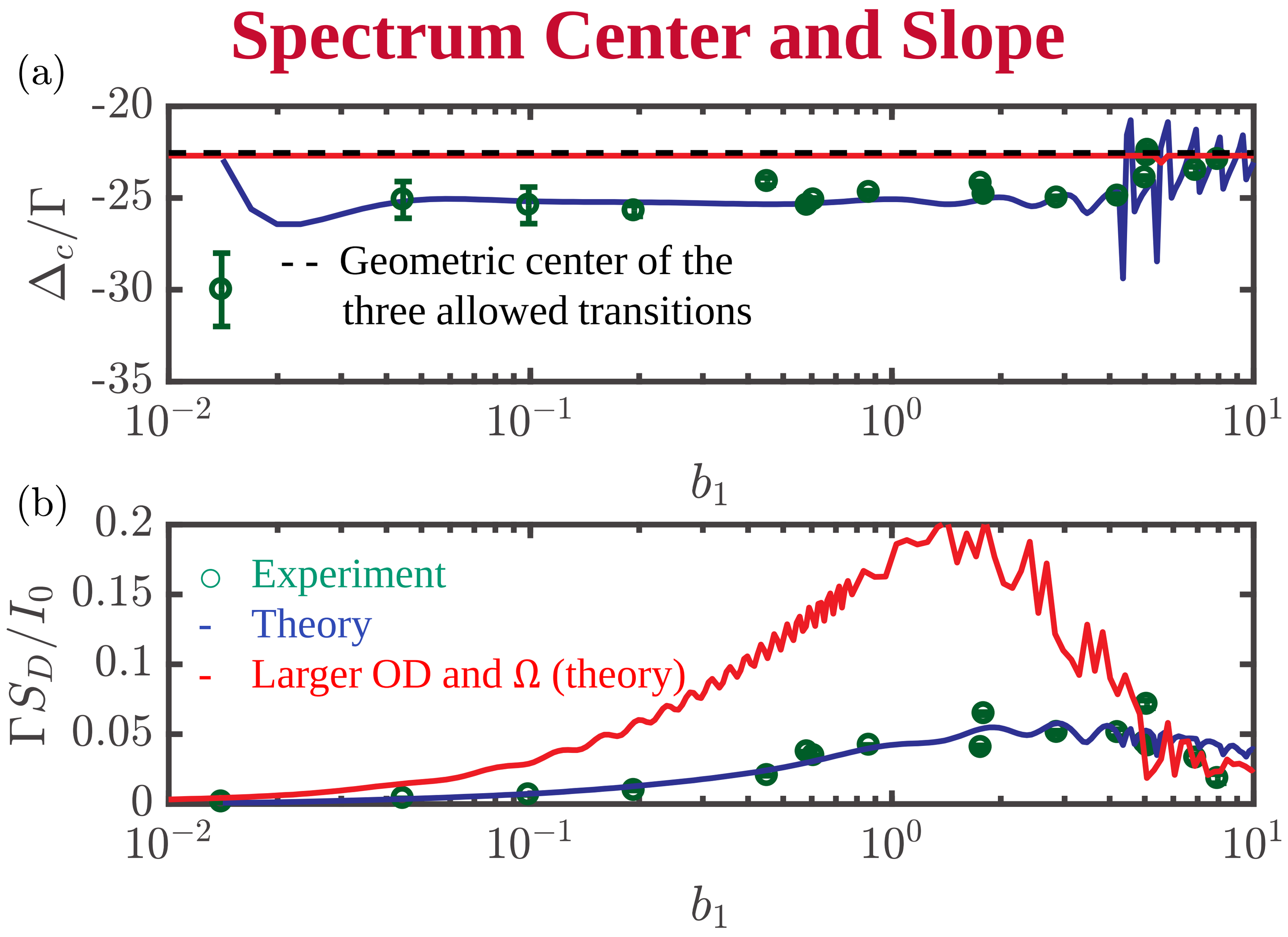
Magnitude of spectroscopic signal



Zoom of a component around Δ_c

[1] J. Keaveney *et al.*, Phys. Rev. Lett. **108**, 173601 (2012).
[2] J. Pellegrino *et al.*, Phys. Rev. Lett. **113**, 133602 (2014).
[3] S. L. Brombley *et al.*, Nat. Comm. **7**, 11039 (2016).
[4] G. C. Bjorklund, Opt. Lett. 5, **15-17** (1980).
[5] C. C. Kwong et al., arXiv:1902.06926 [physics.atom-ph].

Spectrum Center and Slope



Spectrum center and slope plotted against the OD at first sideband, b_1.

Extracting the Linewidth

The complicated spectroscopic signal could also be used to accurately determine some parameters of the system. We show this by extracting the homogeneous linewidth from a fitting procedure. The sensitivity of determining the linewidth increases, when the spectroscopic signal is included. This could be a new method to determine collisional broadening in a dense sample.