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Sandia National Laboratories

Multi-photon Absorption Based Method to Detect and Quantify Electric Fields

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Introduction and motivation

Identifying and implementing measurement capabilities that can quantify key quantities of interest is a core role of a metrologist.

Laser spectroscopy provides a metrologist the ability to target specific transitions associated with atomic or molecular species of interest and learn something about their local environment. By matching the right technique to the desired application, it is possible to measure quantities of interest such as density, velocity, and even electromagnetic fields.

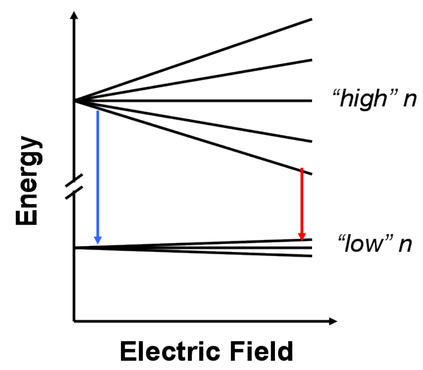
The motivation of this poster is to share past experiences in attempt to seed new ideas to further the Primary Standards Laboratory (PSL) capabilities.

Core Concepts

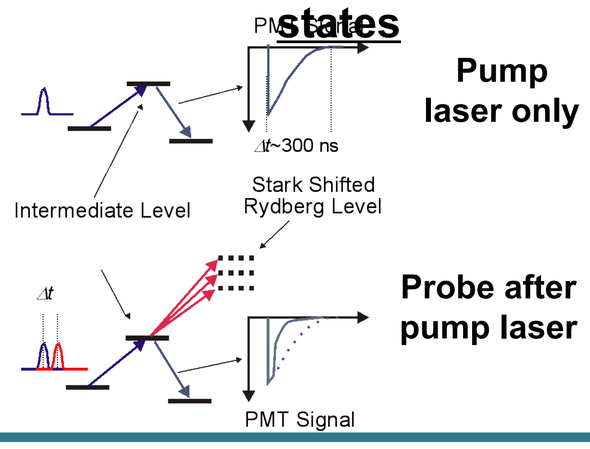
Electric fields can be detected optically by interrogating higher lying (Rydberg) states of atomic (and molecular) states. The physics is based on the Stark effect measuring energy shifts in Rydberg states due to external electric fields.

Mixing of Rydberg states

$$H = H_0 + ea_0 \boldsymbol{E}\langle \ell | r | \ell \pm 1 \rangle$$



LIF-Dip detection of shifted states



Stark Effect on Rydberg States

Methods need to be developed to induce and assess Rydberg state response to local electric fields. Below are the key steps to test measurement technique.

Excitation

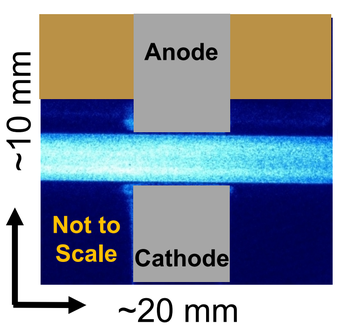
520 – 560 nm, 25 ps, 200 μJ — Probe

202.4 nm, 20 ps, 20 μJ — Pump

50 to 500 ps delay

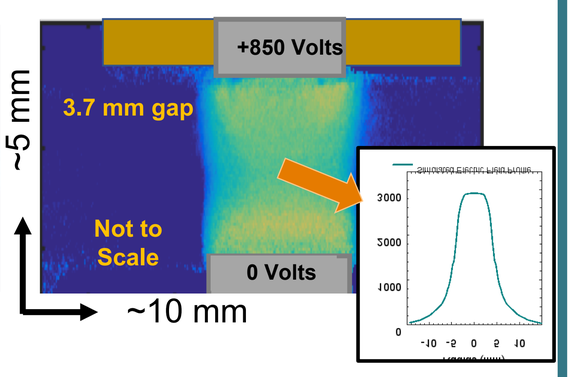
Two photon, Pump-probe method for ground state excitation

Setup



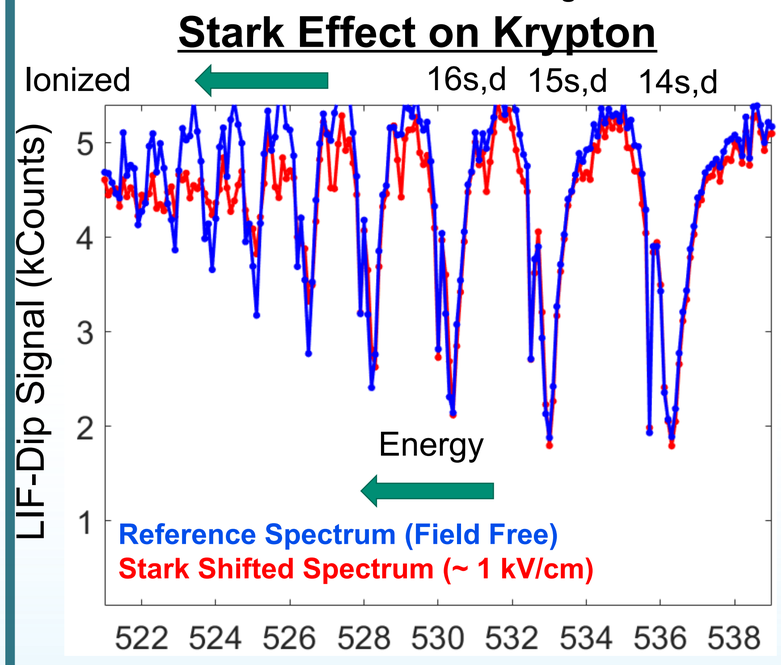
2D image of LIF Dip with out applied voltage

Benchmark



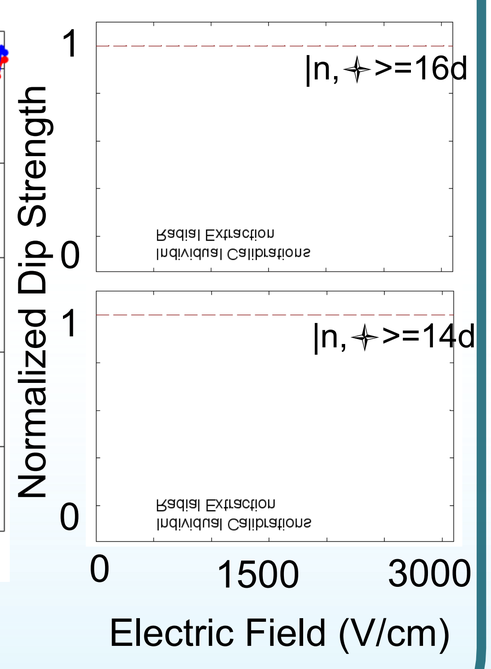
2D image of LIF Dip during applied voltage

Stark Effect on Krypton



Rydberg States of Krypton (blue) and their response to an electric field

Scaling Trends

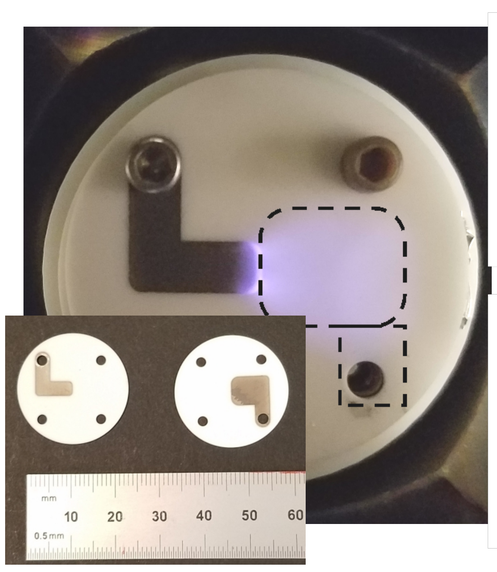


Response of selected Rydberg states

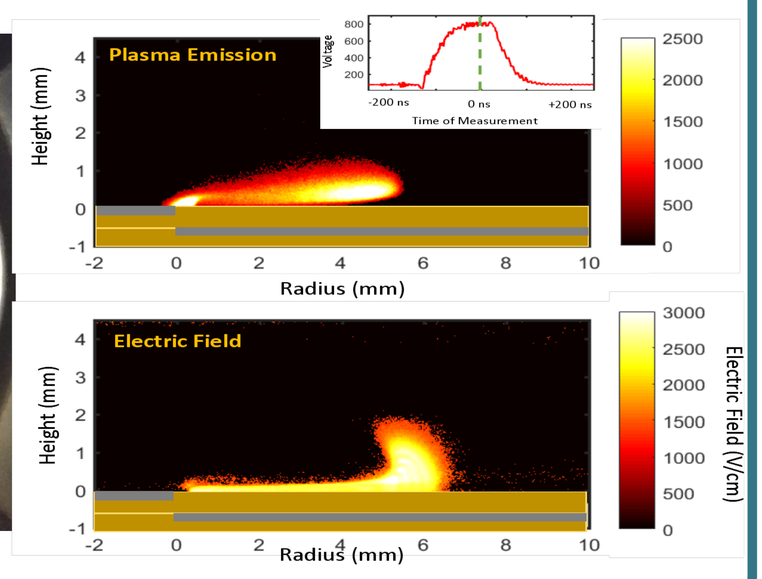
Exemplar Measurement

The key advantage of this technique is its ability to provide temporal (~ 1 ns) and spatial resolution (~ 10 μm) of electric fields.

Ionization Wave Setup



Representative Results

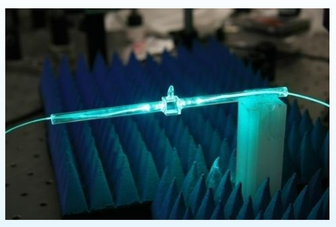


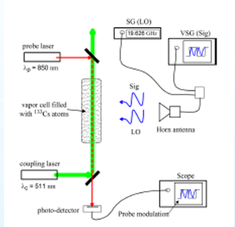
Proof-of-principle implementation of developed diagnostic to illustrate the ability to peer into a challenging environment.

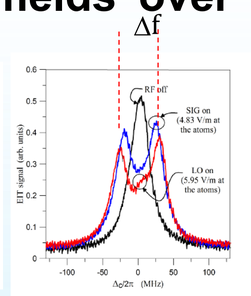
Looking Forward

Part of my goal is to work with the various PSL labs through the R&D team to identify where we need new ways of accessing key quantities of interest.

For example, NIST is using Rydberg states for non-invasive, directly ***SI-traceable***, ***self-calibrated*** measurement of electric fields over a huge frequency range (DC to THz).







$$E = 2\pi\hbar / \wp \Delta f$$

Δf=Splitting of peak (MHz)

$\wp$=Transition dipole moment (constant for a given state)

How can concepts like this serve PSL mission??

https://www.nist.gov/programs-projects/rydberg-atom-based-quantum-rf-field-probes

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