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# A METASTABLE HYDROGEN PROBE BEAM TO MEASURE STATIC AND OSCILLATING ELECTRIC FIELDS

{ L. CHÉRIGIER-KOVACIC, C. POGGI, T. GUILLAUME, F. DOVEIL }

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## SUMMARY

A new diagnostic to measure directly an electric field in vacuum or in a plasma has been developed. It is based on the emission of the Lyman- $\alpha$  line by a hydrogen probe-beam in the 2s state when the beam passes through a region where an electric field is present (Electric Field Induced Lyman- $\alpha$  Emission). The electric field couples the Lamb-shift spaced 2s and 2p atomic hydrogen levels, the 2s lifetime is shortened and this level decays via 2p to the ground state. By measuring the intensity of the subsequent Lyman- $\alpha$  radiation, it is possible to determine the magnitude of the field in a defined region.

The aim of this work is to study the performances of this diagnostic when measuring an oscillating electric field at frequencies around Lamb-shift frequency (1 GHz), where Lyman- $\alpha$  emission is enhanced by a factor of almost 400. We show a good agreement between measurements in vacuum and results of a simulation of both experimental device and diagnostic. A calibration of the diagnostic using absolute static field measurements is proposed.

## EXPERIMENTAL PRINCIPLE

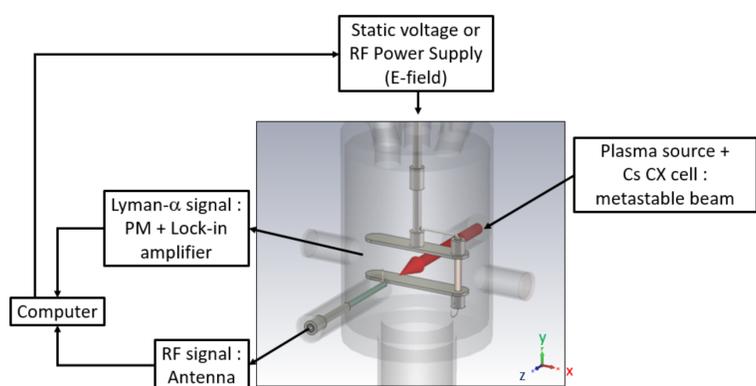


Figure 1: Experimental scheme

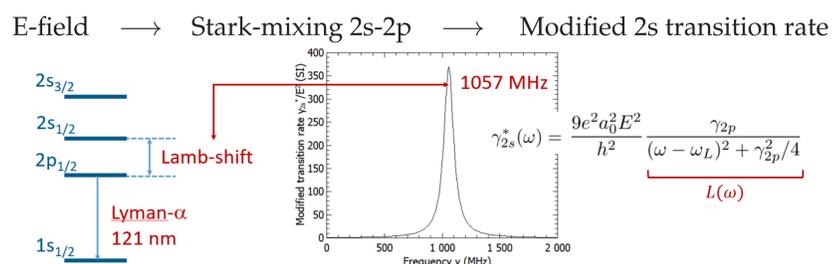


Figure 2: Physical principle

L. Chérigier-Kovacic, Review of Scientific Instruments 86, 063504 (2015)

## STATIC E-FIELD CASE

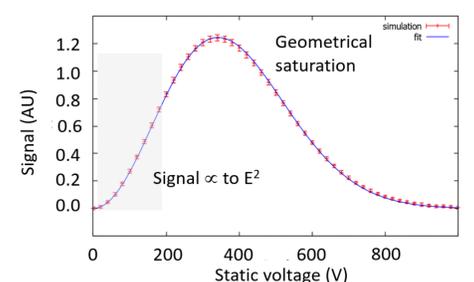
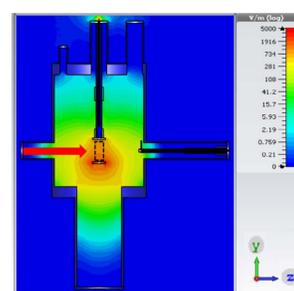


Figure 3: Computed static E-field map (CST) and Lyman- $\alpha$  signal

CST Computer Science Technology website <https://www.cst.com>

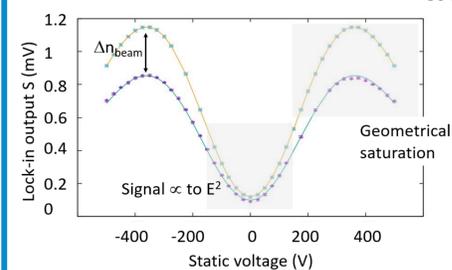


Figure 4: Experimental data and fit with model

$$\text{Fit model : } S(V) \propto \Delta N_{2s} \approx AV^2 e^{-BV^2}$$

Electric field  $E(z)$  increases along the beam path, from 0 outside the vessel to  $E = V/d$  between the plates

→ Part of metastable atoms have already decayed before entering diagnosed volume between the plates

→ Geometrical saturation at high voltage

C. Poggi et al., Plasma Sci. Technol. 20, 074001 (2018)

## OSCILLATING E-FIELD MEASUREMENT AND SIMULATION / CALIBRATION

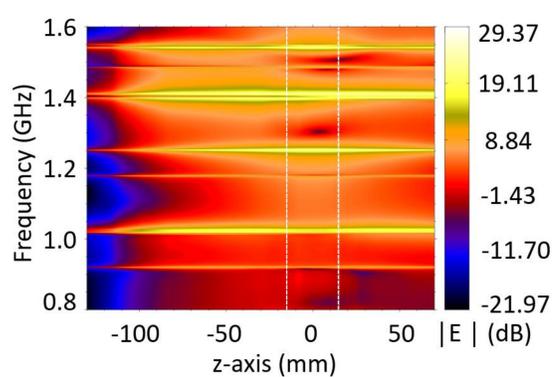


Figure 5: Relative amplitude of E-field along the beam path, determined from computed E-field map at different frequencies, displayed here in color scale. Resonant frequencies are clearly exhibited.

Lyman- $\alpha$  and antenna spectra show peaks at same resonant frequencies as in simulation. Peaks at 1.026 GHz, 1.252 GHz and 1.404 GHz are robust in both simulation and experimental results under small modifications of vessel geometry (position of metallic elements in the vessel).

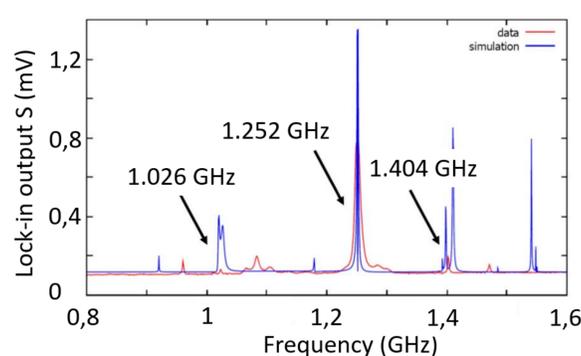


Figure 6: Lyman- $\alpha$  signal in function of frequency : simulation (blue) and experimental data (red).

Lyman- $\alpha$  signal depends on metastable density  $N_{2s}$  between the plates, yet  $N_{2s}$  depends on the field all along the beam path. Amplitudes of the peaks in E-field spectra are thus not comparable.

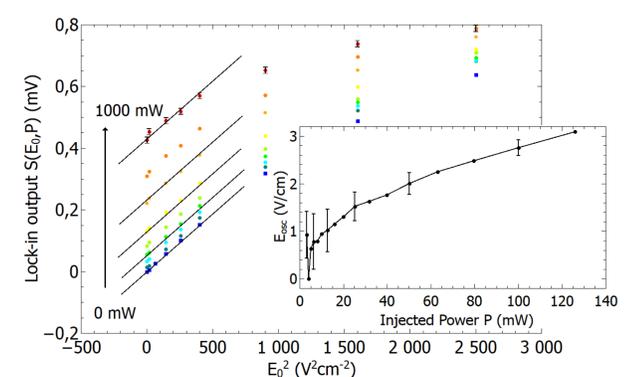


Figure 7: Lyman- $\alpha$  signal in function of static field  $E_0$  for different injected power @1.252 GHz and absolute value of oscillating E-field in function of injected power.

Calibration : if signal not saturated  
→  $E_0^2 < 500 \text{ V}^2 \cdot \text{cm}^{-2}$

$$S(E_0, P) \propto \gamma_{2s}^* = \beta L(0)E_0^2 + \beta L(\omega)E_{\text{rf}}^2(P)$$

## CONCLUSION

- Measurement of the local electric field, spatial resolution  $\approx 1 \text{ cm}$ , can be improved by a diaphragm on the metastable beam ;
- Measurement of resonant frequencies of the vessel ;

- Calibration based on superposition of static and oscillating fields ;
- Detection limit of oscillating E-field 1V/cm ;
- If signal saturated, E-field amplitude underestimated.

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