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Anisotropic interactions between cold Rydberg atoms

Luis Marcassa
INSTITUTO DE FISICA DE SAO CARLOS

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Final Report

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Instituto de Física de São Carlos
Av. Trabalhador são-carlense, 400 - Pq. Arnold Schimidt, CEP: 13566-590, São Carlos
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14. ABSTRACT

In this project, we have investigated Förster resonance processes in an atomic sample trapped in a CO2 optical dipole trap. The process was investigated as a function of: i) atomic density; ii) dc electric field; iii) and electric field orientation. In the literature, such process has been associated with a many body effect. However, we have obtained experimental and theoretical results which support that the process is dominated by two body interactions. This has been possible thanks to the collaboration with Prof. Shaffer group from University of Oklahoma. Several papers were published, and one workshop was organized in Brazil.

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Report to AFOSR

Anisotropic Interactions between Cold Rydberg Atoms

Prof. Dr. Luís Gustavo Marcassa

INSTITUTO DE FÍSICA DE SÃO CARLOS / USP
Av. Trabalhador SãoCarlense 400, Cx. Postal 369
13566-560 São Carlos, SP, Brazil

Principal Investigador:

Prof. Dr. Luis Gustavo Marcassa
Instituto de Física de São Carlos - Universidade de São Paulo
Av. Trabalhador Saocarlense, 400
São Carlos – SP – 13560-970 – Brazil
marcassa@ifsc.usp.br
phone: +55 16 3373 9806

Final Report for FA9550-12-1-0434

Objective:

The main goal in this research is to study anisotropy in Förster resonances involving Rydberg atoms trapped in the CO_2 optical dipole trap.

I. Results

In this report, we present the main results obtained in the last year in the experiment of Rydberg atoms. We will present the results involving the density dependence of a Förster resonance as a function of the electric field. We also present the preliminary results involving angular dependence of the same process.

I.1. Förster resonances in an optical dipole trap

We have studied the process of energy transfer involving the state 37D (37D + 37D → 39P + 35L (L = 11 and 12)) due to a DC electric field. At low densities, the 39P yield as a function of electric field exhibits resonances. With increasing density, the linewidths increase until the peaks merge. Even under these extreme conditions, where the Förster resonance processes show little electrical field dependence, the 39P population depends quadratically on the total Rydberg atom population, suggesting that a 2-body interaction is the main mechanism (Fig. 1).

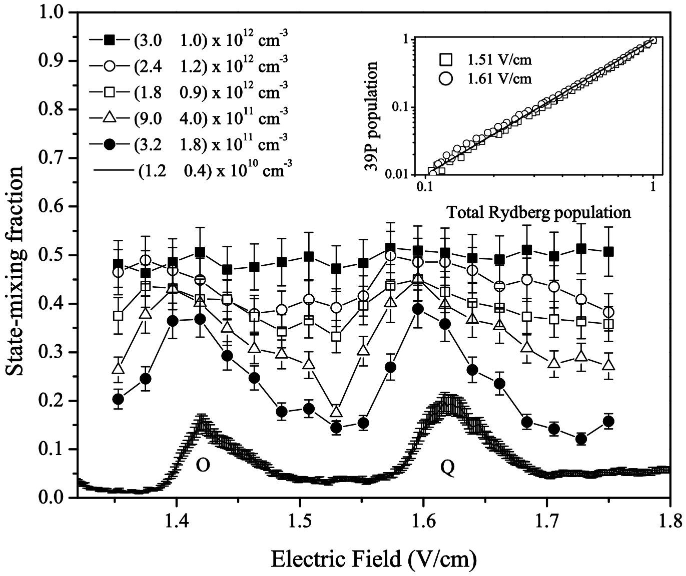

Figure 1 – State transfer fraction from 37D to 39P as a function of the dc electric field and the atomic density. Related resonances the L = O (11) and Q (12) are selected. The lower density was carried out in a magneto-optical trap. In the inset, we show the 39P state population as a function of the Rydberg atom population, which shows a quadratic dependence both on resonance (1.61 V / cm) and out of resonance (1:51 V / cm).

Initially, we have speculated that the explanation for such results was related to the inner part of the potential curves, which presents several "spaghetti" potential curves with many interactions, including dipole-quadrupole and quadrupole-quadrupole. Unfortunately, this interpretation was wrong, because we had not considered the Rydberg excitation blockade, which happens in samples of Rydberg atoms. Therefore, to reproduce the experimental data, it was necessary to consider a model that includes the excitation blockade. In Fig. 2, we show the 37 D and 39P populations as a function of the excitation frequency, the solid lines are the theoretical model. We should emphasize that the theoretical model was able to reproduce the correct ratio of the 37D and 39P populations.

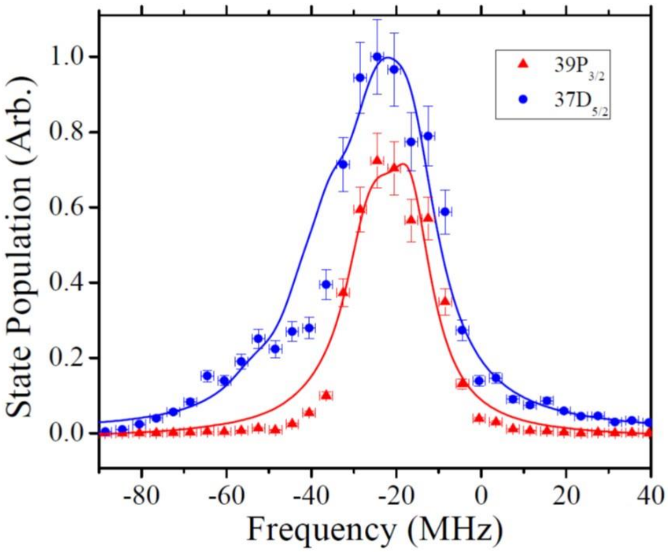

Figure 2 – 37D and 39P populations as a function of the excitation frequency of the Rydberg state. The solid lines were obtained from our theoretical model with no free parameters. The electric field in this situation was of 1.61 V / cm.

In Fig. 3, we show the mixture fraction as a function of electric field and the atomic density. The red lines are for the theoretical curves considering the errors in the density determination. The agreement is very good. As the atomic density increases, the fraction of mixture saturates at 0.4. At low density, the model predicts the correct linewidth of the resonance, which is due linewidths of the lasers, the multi-level nature and potential of pair distribution function.

The natural question is "which mechanism is responsible for the transfer of population saturation behavior at high densities". It is clear that the outer part of the potential curves is responsible for the explanation of such behavior, which seems contradictory. As the atomic density increases, the excitation blockade occurs; in another word, just one Rydberg atom is excited in a 5 um radius sphere. For a distance greater than 5 um, the potential is irrelevant, but the mix of states is very strong because the states are almost degenerate. The atomic pair distribution function is also irrelevant, since at the working densities such parameter is basically equal to one. Combinations of all these parameters lead to a transfer rate that saturates and is independent of dc electric field. We should emphasize that this is the first model that explains Förster resonance in Rydberg atoms considering two body interaction. This model is based on two bodies and has no free parameters; therefore, we have submitted the manuscript to the journal Physical Review Letters.

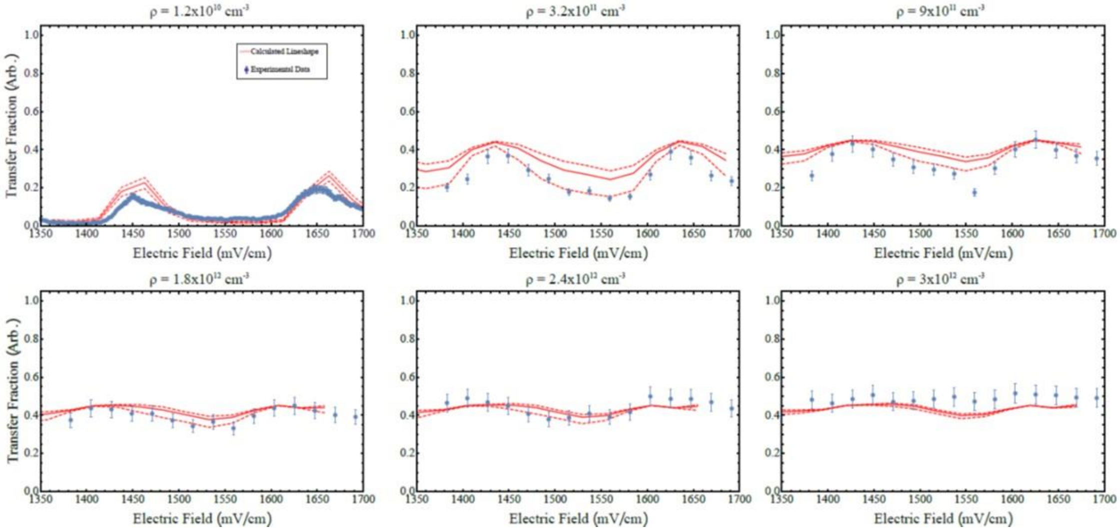

Figure 3 – Population transfer as a function of electric field and the atomic density. Solid lines were obtained from our theoretical model with no free parameters, considering the experimental uncertainties in atomic density.

I.2. Angular dependence of a Förster resonance

In this last year, we have obtained our first results involving the 39P population transfer as a function of the angle between the dc electric field and the axis of the dipole trap. Initially, we have faced some technical dificulties because our dc eletric field control system presented some inhomogeneities. In Figure 4, we show the 39 P population as a function of the electric field for various angle scans in a two-dimensional graph. In the upper part of the figure, we show the 39P population as a function of the dc field for a given angle. In figure 4, the values of each scan was normalized to its highest value, so that all scans are limited to values between 0 and 1. It is clear from the experimental data that the amplitude of the electric field changes depending on the angle; this produces a shift of the Förster resonance peaks.

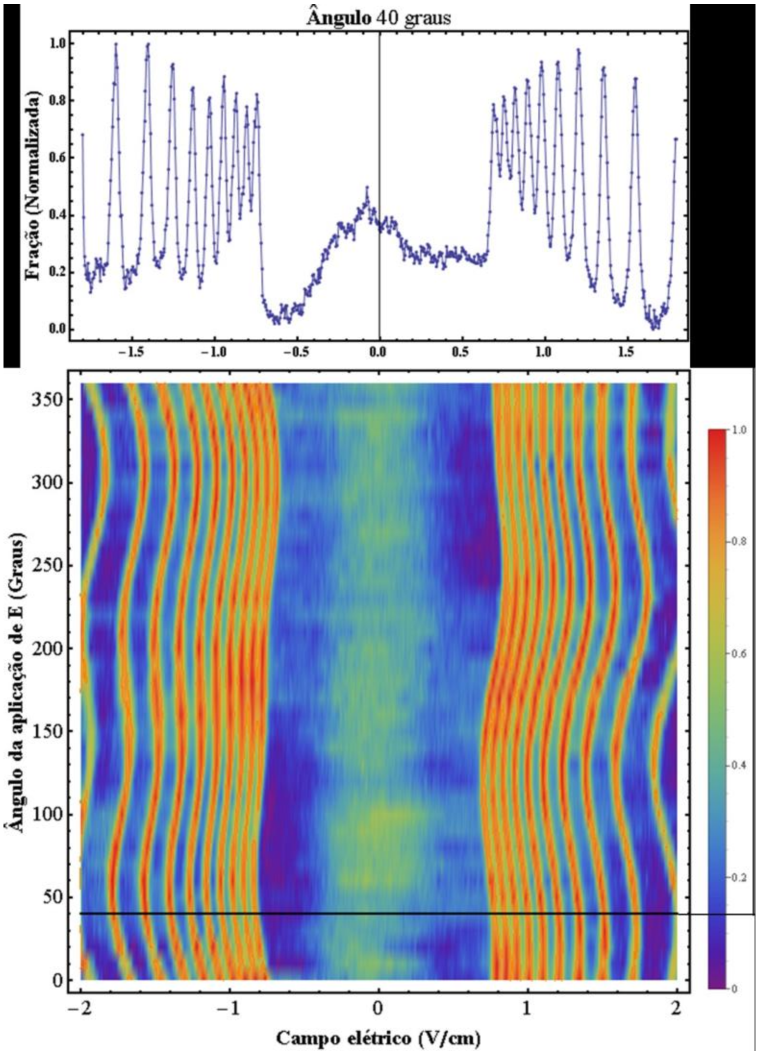

Figure 4 - Angular map of the 39 P population transfer as a function of the electric field. Scans are performed at fixed angles. The upper plot shows the 39P population for a 40 degree angle.

Apparently, the problem was related to the electrode calibration procedure. After redoing the calibration procedure, we have performed an angular scan of the dipole trap in a static electric field, corresponding to a peak of a Förster resonance. Figure 5a shows the 39P population as a function of the angle between the electric field and the axis of the trap in the x direction. We can clearly observe an angular dependence in the maximum density region. In fig. 5b, we show the population due to the dc electric field. We are currently collaborating with the OU group to explain this anisotropy.

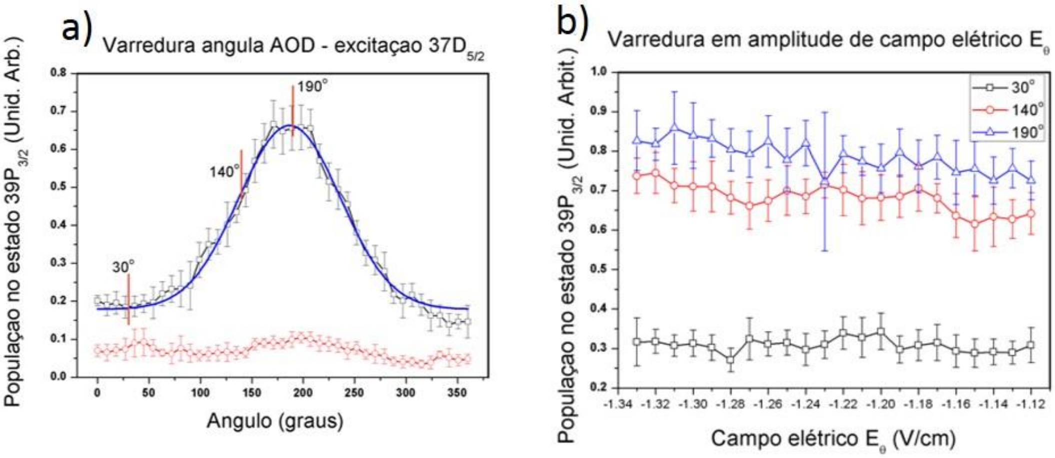

Figura 9 – a) Population 39P state as a function of angle for high and low density. b) Population according to the static field for three angles.

Personnel Supported

List of personnel associated with the research:

Prof. Dr. Luis Gustavo Marcassa

Jader S. Cabral

Jorge J. Kondo

Luis F. Gonçalvez

São Carlos, 22/September/2015

Prof. Dr. Luis Gustavo Marcassa

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Primary Contact E-mail
Contact email if there is a problem with the report.

marcassa@ifsc.usp.br

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Abstract

In this project, we have investigated Förster resonance processes in an atomic sample trapped in a CO2 optical dipole trap. The process was investigated as a function of: i) atomic density; ii) dc electric field; iii) and electric field orientation. In the literature, such process has been associated with a many body effect. However, we have obtained experimental and theoretical results which support that the process is dominated by two body interactions. This has been possible thanks to the collaboration with Prof. Shaffer group from University of Oklahoma. Several papers were published, and one workshop was organized in Brazil.

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