Non-resonant two-photon excitation to high Rydberg states

T.E. Wall[1], D.B. Cassidy[1], and S.D. Hogan[1]

[1] *Dept. of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK*

Presenting Author: t.wall@ucl.ac.uk

The imbalance of matter and antimatter in the universe is one of the great mysteries of modern physics. One test that might shed light on this puzzle is a measurement of how antimatter acts in a gravitational field. We are building an experiment to test antimatter gravity by measuring the free-fall of positronium [1]. Limited by annihilation, the ground state of triplet Ps has a lifetime of 142 ns, allowing free-fall of only around 100 fm (if $\bar{g} = g$). However, Rydberg states have negligible annihilation rates, with lifetimes limited only by radiative decay. In experimentally feasible conditions these could be on the order of 10 ms, long enough to permit observable free-fall. Atoms in these highly excited states can also possess extremely large electric dipole moments, allowing manipulation with inhomogeneous electric fields [2].

Typical methods of Ps generation produce very hot atoms ($v/c \sim 10^{-3}$), resulting in significant Doppler broadening (e.g., ~ 0.5 THz for 1s–2p). Efficient production of Rydberg Ps has been achieved with broad bandwidth (85 GHz) lasers that give reasonable overlap with these large Doppler profiles [3]. However, this technique limits the resolution and prevents accurate state selection at higher n.

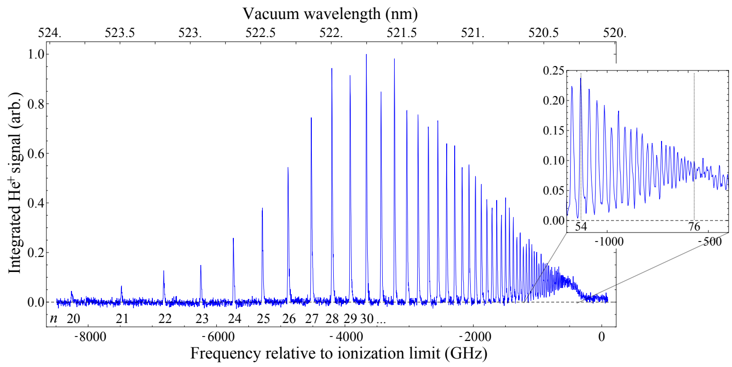

Figure 1: *Helium Rydberg spectrum of $m = 2$ states from $n = 20$ up to the ionization limit, produced by non-resonant two-photon excitation.* Inset: *The spectrum shown in detail for states with $54 \leq n \leq 76$.*

To overcome this we plan to implement non-resonant Doppler-free two-photon excitation with much narrower bandwidth (3 GHz) pulsed dye lasers. This scheme allows state-selectivity at high-n, opening up possibilities for transfer to higher angular momentum states. As a demonstration of this scheme we have performed non-resonant two-photon Rydberg excitation in a pulsed supersonic beam of helium. Using circularly polarized light we have driven transitions from the 1s2s $2\,^3S_1$ state to the 1snd Rydberg states in the range from $n = 20$ up to $n \simeq 100$, resolving states up to $n = 76$ (Fig. 1). We shall describe the effects of a range of experimental parameters, including polarization, dc electric fields and laser pulse energy. We discuss the application of this scheme to Ps and present calculations of the two-photon transition rates to Ps Rydberg states. In addition to the preparation of Rydberg Ps, non-resonant two-photon excitation schemes of this kind also have applications in precision spectroscopy of molecules and tests of QED [4].

References

[1] A. P. Mills Jr., M. Leventhal, Nucl. Instr. Meth. B **192**, 102–106 (2002)
[2] E. Vliegen *et al.*, Phys. Rev. Lett. **92**, 033005 (2004)
[3] D. B. Cassidy *et al.*, Phys. Rev. Lett. **108**, 043401 (2012)
[4] D. Sprecher *et al.*, Faraday Discuss. **150**, 51–70 (2011)