IOCAT 2026 Conference

The 1st International Online Conference on Atoms

29–30 January 2026 | Online

MDPI

# Multi-sideband RABBITT scheme for attopulses interacting with hydrogen atoms

A Mendizábal[1], Omar Fojón[1,2] , Diego Boll[2]

1 Faculty of Exact Sciences, Engineering and Surveying, National University of Rosario, Argentina

2 Rosario Physics Institute, National Council for Scientific and Technical Research, Argentina

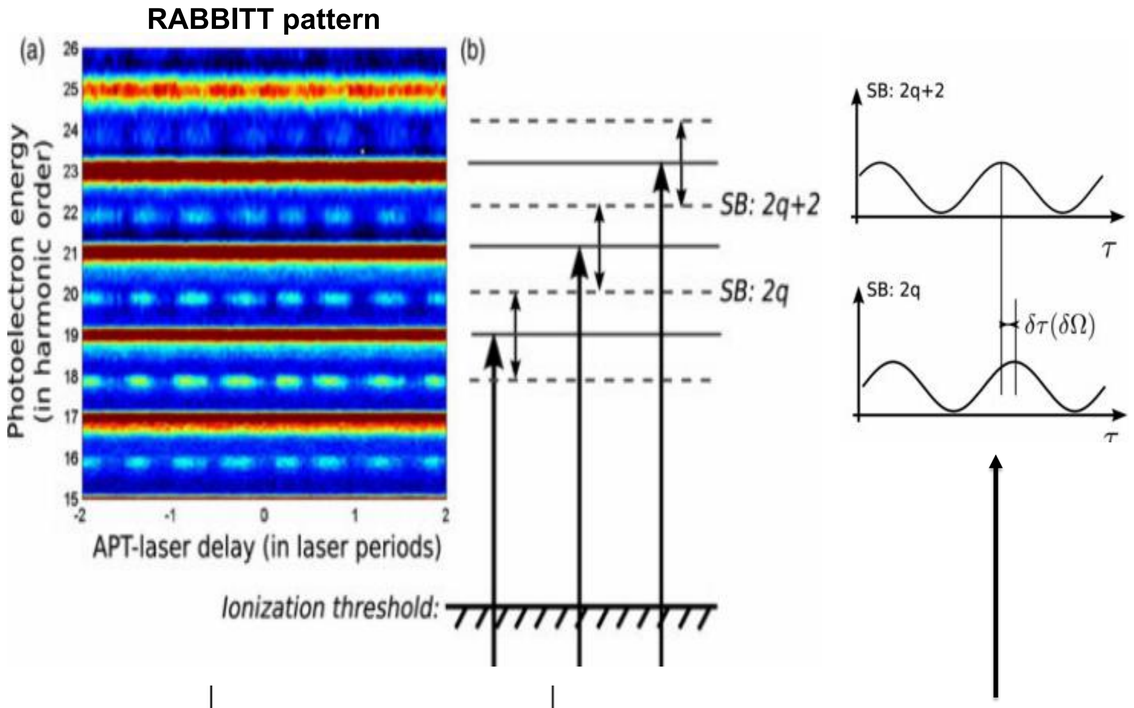
## INTRODUCTION & AIM

Technological advances in ultrashort pulses have enabled the development of pump-and-probe experimental techniques with attosecond ($10^{-18}$ s) time resolution. Among these, Reconstruction of Attosecond Beat By Two-photon Transition (RABBITT) interference has become established as one of the most effective methods to obtain information about the initial state and potential experienced by the ionized electron as it escapes, offering structural and dynamic details of the environment in which the electron moves. In a RABBITT characteristic pattern, Dressed Harmonic (DH) and SideBand (SB) are identified. The DHs lines correspond to photoelectrons detected after being ionized by a single XUV photon from an attosecond pulse train (APT) assisted by a infrared laser field with a definite delay between them, whereas the signal present in the SBs comes from photoelectrons that exchanged two photons with the fields. This implies the absorption of a photon from the ATP followed by the absorption or emission of an infrared. RABBITT schemes are particularly suited for measuring Eisenbud-Wigner-Smith (EWS) time delays in photoionization.

In this work, a theoretical study of the delay times acquired during the photoionization process was performed using a RABBITT experiment model for linearly polarized fields. Preliminary results for higher-order processes corresponding to the exchange of three photons corresponding to multi-sideband RABBITT schemes are also presented. Interference patterns are similar to the ones of the standard RABBITT but more complex due to the appearance of additional lines, for instance, the so called Center Band (CB).

## METHOD

**RABBITT pattern**




$$I_{2q}(\hat{k}) \propto \left| \sum_{L,M} M_{L,M} Y_L^M(\hat{k}) \right|^2 \propto A + Bsin(2\omega_{IR}[\tau - \tau_{atm}])$$

$$M_{L,M} = {M_{L,M}}^{+} + {M_{L,M}}^{-}$$

$$M_{L,M}^{\pm n} = e^{\pm n\omega_0 \tau} \sum_{\lambda_i,\mu_i} A_{L,\lambda_i,l_0} T_{L,\lambda_i,l_0}^{\pm n}$$

**Two-photon exchange**

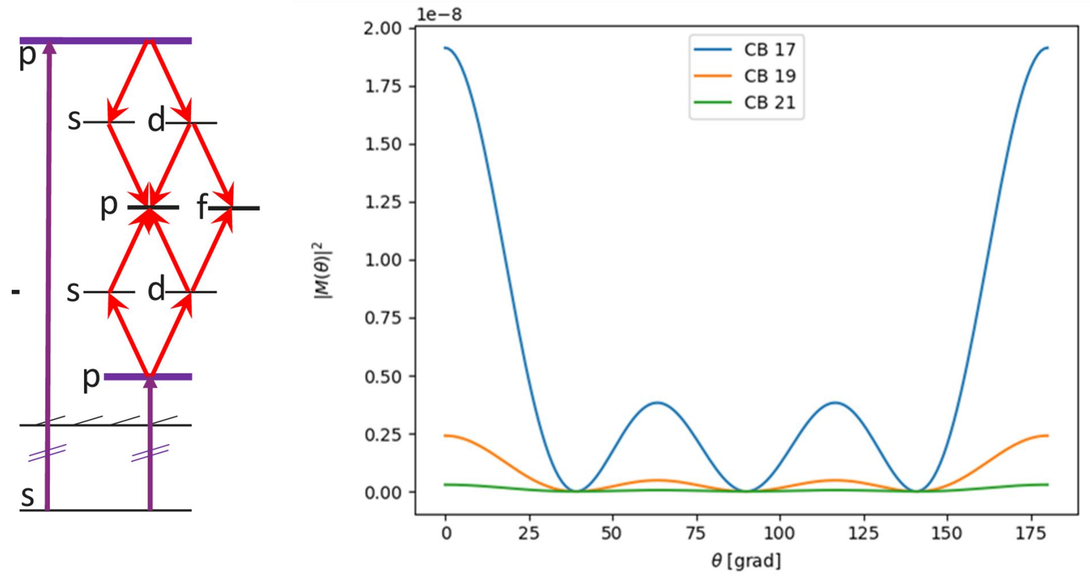
$$T_{L,\lambda}^{\pm,l_i} = (-i)^L e^{i\eta_L(k)} \sum \frac{\langle R_{k,L}|r\,|R_{\kappa,\lambda}\rangle \langle R_{\kappa,\lambda}|r\,|R_{n,l_i}\rangle}{\varepsilon_i + \Omega_{\mp} - \varepsilon_\kappa}$$

**Three-photon exchange**

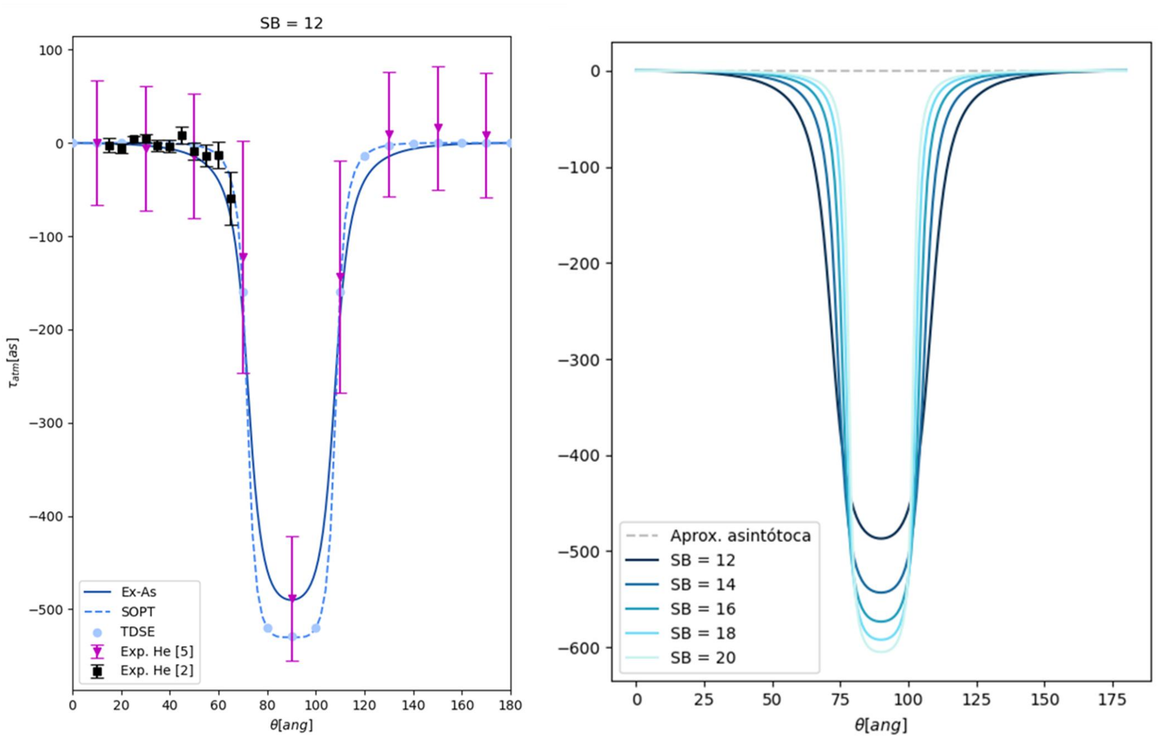
$$T_{L,\lambda_1,2}^{\pm,li} = (-i)^L e^{in_L(k)} \sum \frac{\langle R_{L,k}|r|R_{\lambda_2,\kappa_2}\rangle \langle R_{\lambda_2,\kappa_2}|r|R_{\lambda_1,\kappa_1}\rangle \langle R_{\lambda_1,\kappa_1}|r|R_{i,n}\rangle}{(\omega_i + \Omega_{xuv} + \omega_{ir} - \omega_k)(\omega_i + \Omega_{xuv} - \omega_j)}$$

## RESULTS & DISCUSSION

**Angular distribution of photoelectrons**




**EWS Delay times**




The results previously reported in [4] and [6] for the two-photon exchange process were successfully reproduced. This was achieved using a semi-asymptotic model, in which the states of the hydrogen atom continuum were treated as an asymptotic approximation, except for the final state, which was evaluated exactly.

Based on these results, the study of higher-order (third-order) processes was advanced using a completely asymptotic approximation

## CONCLUSION

According to our preliminary results, we conclude that the asymptotic approximation is a reliable tool to describe the EWS delay times even for high order photon exchange.

## FUTURE WORK / REFERENCES

As the asymptotic approximation eliminates the angular dependence of the system, so the next step will be to extend the semi-asymptotic model to third order in order to recover this angular dependence.

References

[1] Dahlström, et al. (2012). J. Phys B: At. Mol. Opt. Phys. 45. 10.1088/0953-4075/45/18/183001.
[2] S. Heuser, et al. (2016). Phys. Rev. A 94, 063409.
[3] Bharti, et al. (2021). Phys. Rev. A 103, 022834.
[4] Boll, et al. (2022). Phys. Rev. A 106, 023116.
[5] W. Jiang, et al. (2022). Nat. Commun. 13, 5072.
[6] Boll, et al. (2023). Phys. Rev. A 107, 043113.