

# Pulse-shape Effects on the Autler-Townes Doublet in Strong-field Ionization of Atomic Hydrogen

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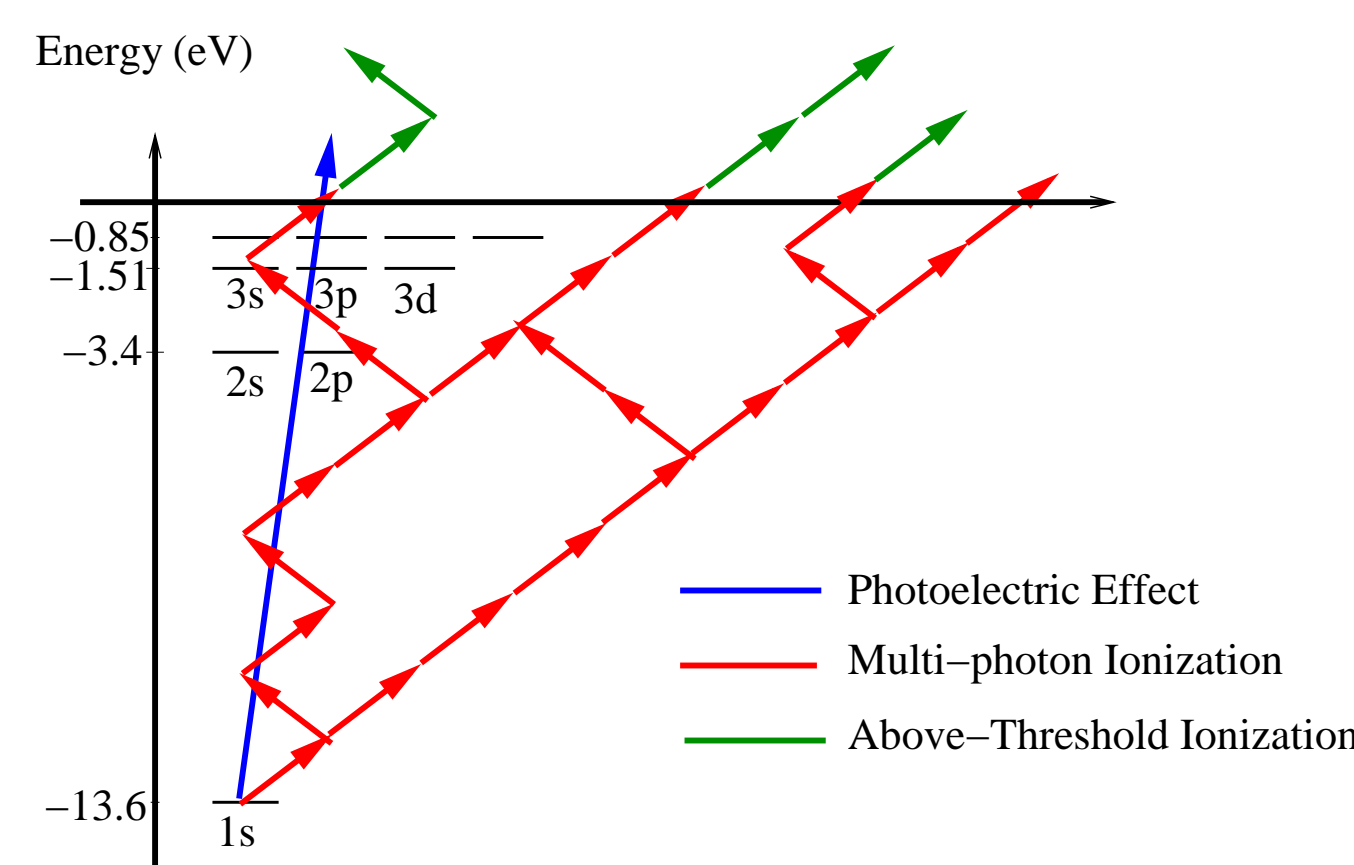
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## Abstract

We have applied a newly developed parallelized computer code to treat the ionization of atomic hydrogen by a strong laser pulse. In particular, we studied the effect of the pulse shape, as well as the peak intensity and the central wavelength, on the theoretical results for the so-called Autler-Townes doublet. While the splitting is well known for the quasi-static case, the *dynamic (time-dependent)* Stark effect studied here is much less understood. The strong dependence on the laser pulse found in this work is not only surprising, but may also be a limiting factor for calibrating absolute laser intensities.

## Introduction and Motivation

- Very short and intense laser pulses can be used to study the details of (valence) electron interactions in atoms and molecules.
- Typical laser intensities in this field range from  $10^{12}$  to  $10^{15}$  W/cm<sup>2</sup>.
- **$10^{14}$  W/cm<sup>2</sup> is a million billion times stronger than the radiation that the Earth receives from the Sun directly above us on a clear day.**
- Such intensities can rip electrons away from atoms in several ways:
  - **Multi-photon ionization**
  - **Above-threshold ionization**
  - **Field (tunnel) ionization**



## The Stark Effect

$$|nlm\rangle = \begin{cases} |200\rangle \\ |210\rangle \\ |211\rangle \\ |21-1\rangle \end{cases} \begin{cases} m=0 & \frac{1}{\sqrt{2}}[|200\rangle - |210\rangle] \\ m=\pm 1 & |211\rangle, |21-1\rangle \text{ 2 degenerate states} \\ m=0 & \frac{1}{\sqrt{2}}[|200\rangle + |210\rangle] \end{cases}$$

- The Stark effect splits up the energetically degenerate (for fixed  $n$ ) energy levels in atomic hydrogen by the interaction with a strong external electric field.
- The energy splitting is proportional to the electric field strength.
- For linearly polarized light, we can “see” only the two  $m = 0$  levels.
- These levels form the “Autler-Townes” doublet in the energy spectrum of the ejected electron.
- We investigate this doublet in two-photon ionization, where the central frequency of the laser is tuned in such a way that it either hits ( $0.375$  a.u. =  $10.2$  eV) or just misses ( $0.350$  a.u.) the  $1s \rightarrow 2s, 2p$  resonance transition as stepping stone.
- Also, **we vary the splitting by ramping on/off the pulse.**

## Results

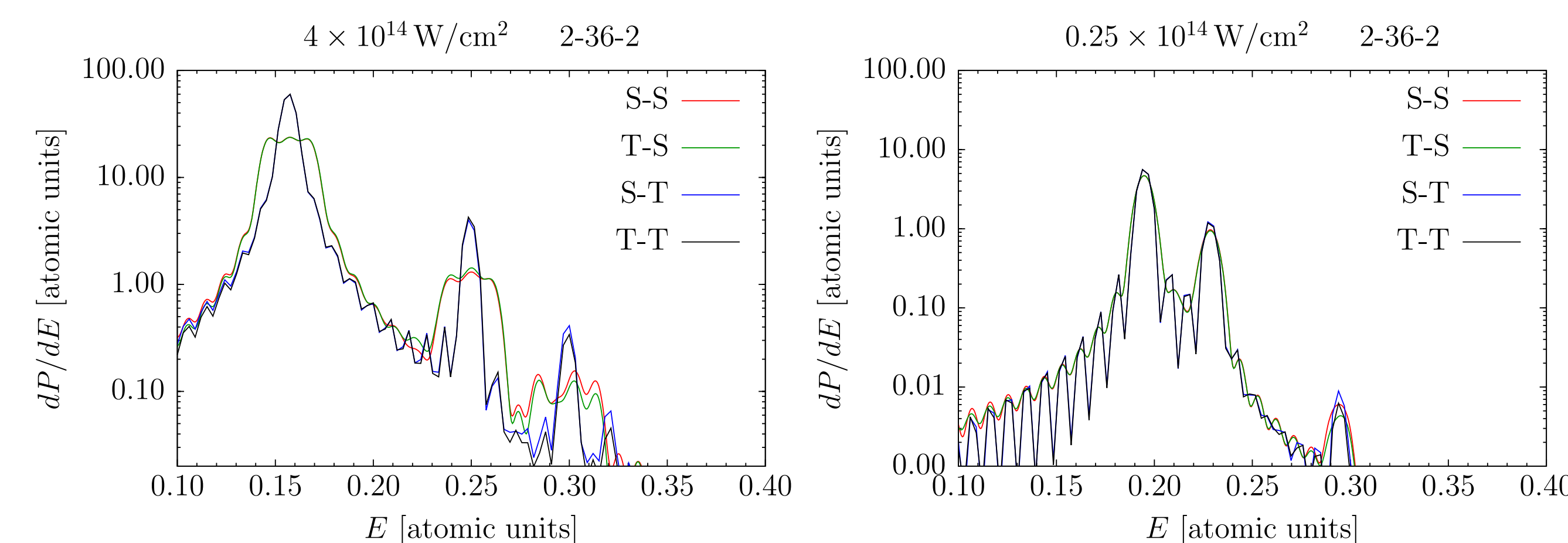


FIG. 1: LEFT: **0.350 AU** frequency plot with highest intensity RIGHT: **0.350 AU** frequency plot with lowest intensity

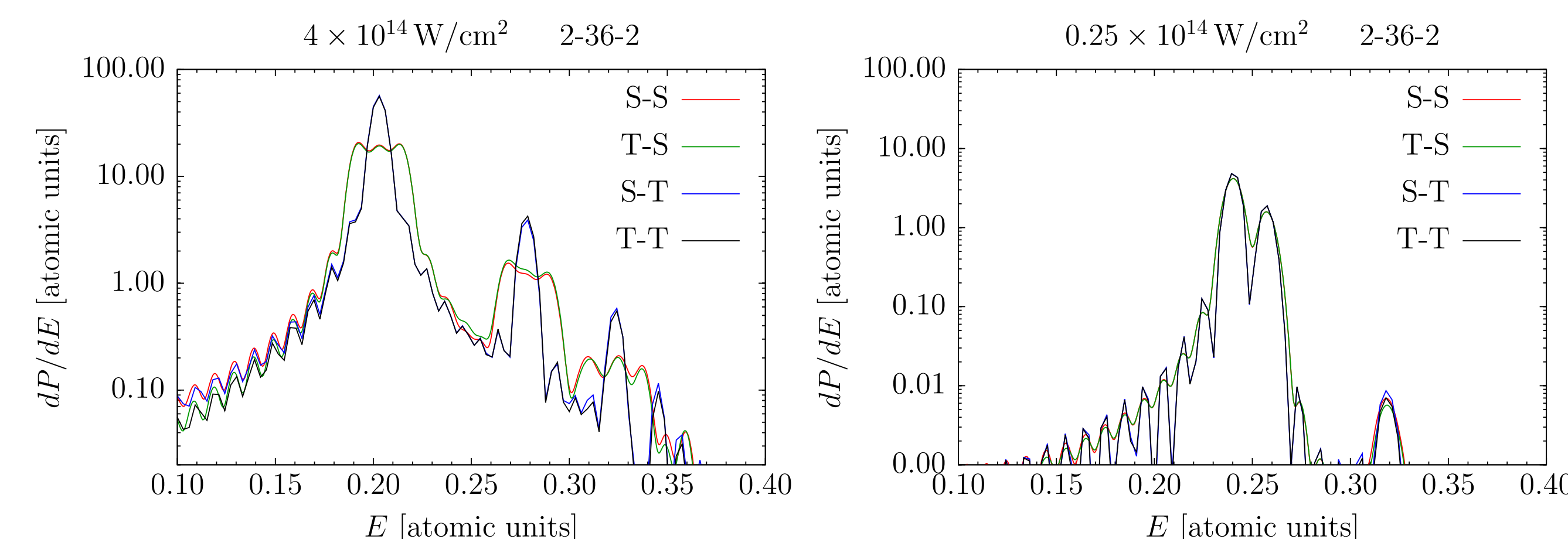


FIG. 2: LEFT: **0.375 AU** frequency plot with highest intensity RIGHT: **0.375 AU** frequency plot with lowest intensity

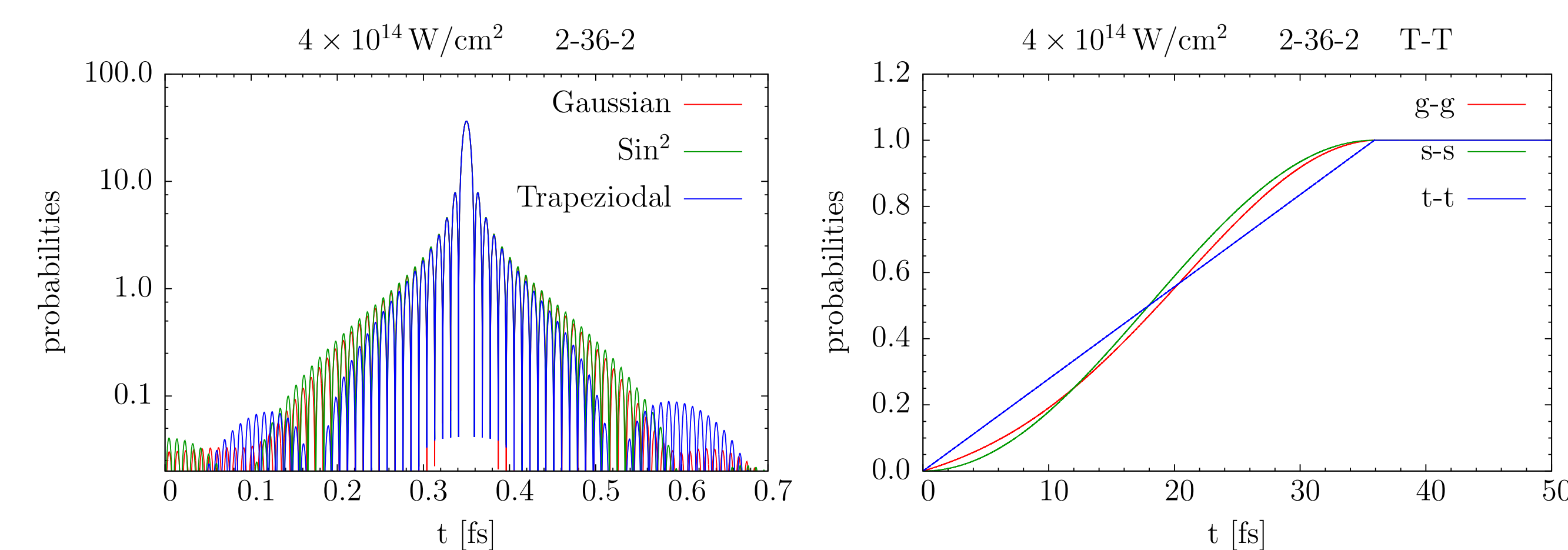


FIG. 3:

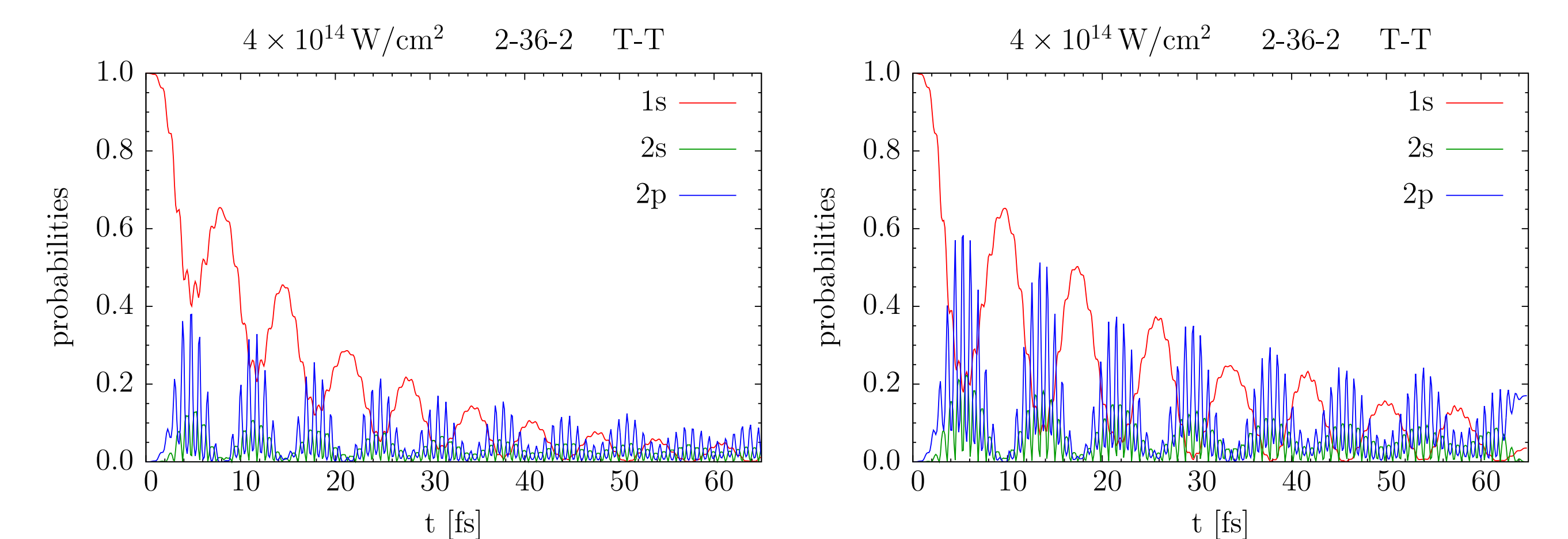
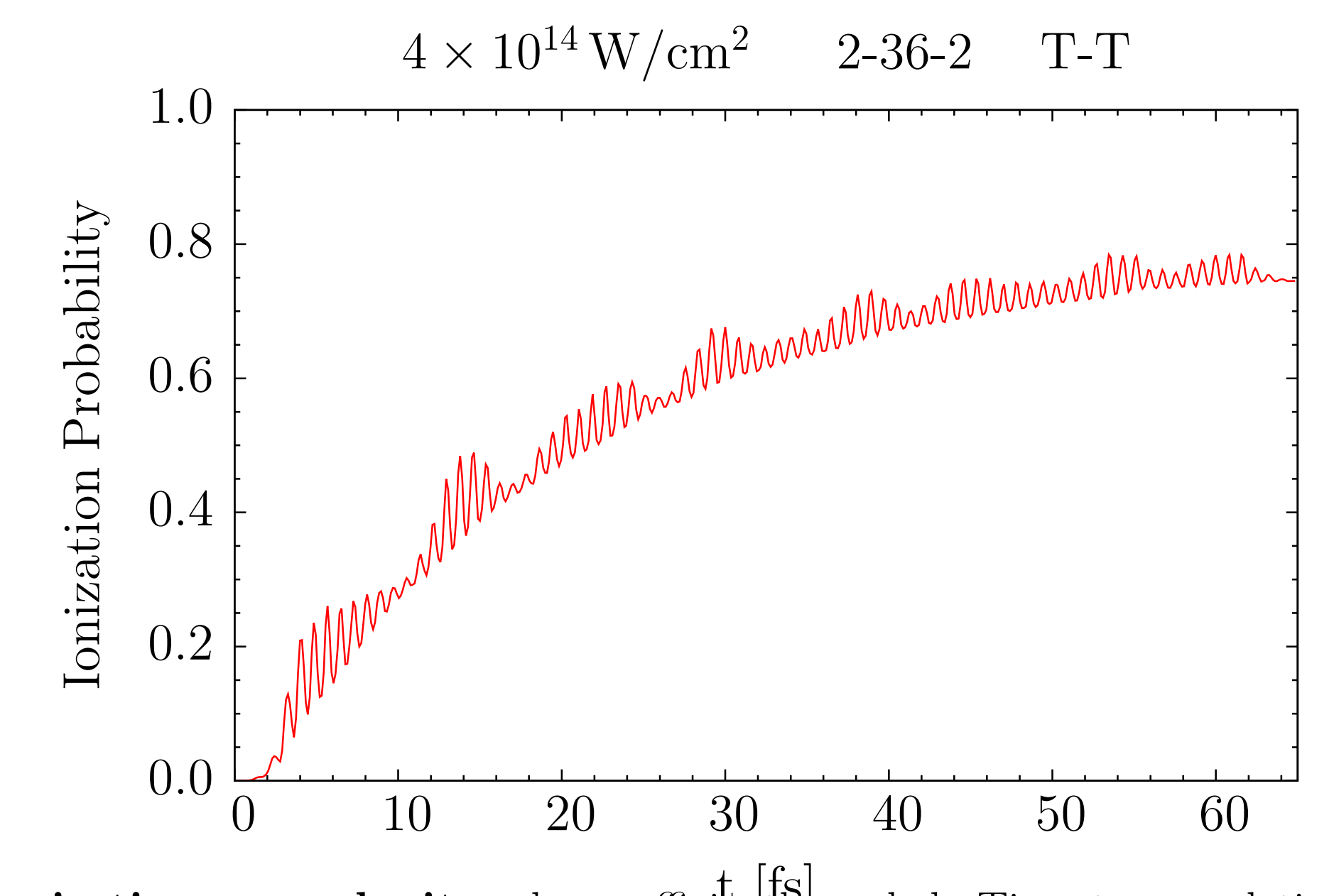


FIG. 4: LEFT: **0.350 AU** frequency plot with highest intensity RIGHT: **0.375 AU** frequency plot with lowest intensity



- **Logarithmic time complexity** when sufficiently scaled. Time to completion depends on the maximum depth of the file system (i.e. most nested directory or file).

- Degenerates to linear time complexity in the worst case (same as Tree-walk).

## Conclusions