SATELLITE SPECTRA FOR HYDROGEN PERTURBED BY OSCILLATING FIELDS

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Outline

1. **Introduction**
2. Simulations
3. Summary

Blokhintsev spectra

Dmitry Blokhintsev (1908-1979), among many contributions to quantum mechanics, calculated the Stark spectra of atoms in an oscillating field, and predicted as early as 1933 the possibility of observing a large number of satellites on a line shape.

-Starting point for dressed atom and Floquet models

Spectroscopy issues studied in last decades

-Role of a static and dynamic field created by the plasma particles simultaneously with the oscillating field.

-Resonance effects preventing the appearance of satellites?

D. Blokhintsev, Phys. Z. Sow. Union **4**, 501 (1933)

Atom interacting with a monochromatic field

Schrödinger equation for the emitter submitted to electric fields

$$i\hbar \frac{d|\varphi\rangle}{dt} = (H_0 + H_1(t))\,|\varphi\rangle$$

$H_1(t) = \vec{D}.\vec{E}_W \cos(\omega t + \theta)$, with D the dipole operator.

The wave field $\vec{E}_W$ can be arbitrarily large

The periodic time dependance of the Hamiltonian suggests looking for periodic solutions $T=2\pi/\omega$

We look for solutions $\varphi_\varepsilon(\boldsymbol{r}, t)=\exp(-i\varepsilon t/\hbar)\phi_{\ \varepsilon}(\boldsymbol{r}, t)$,

Where $\phi_{\ \varepsilon}(\boldsymbol{r}, t)$ is time-periodic with period T

Fourier development $\phi_{\ \varepsilon}(\boldsymbol{r}, t) = \sum_{n=-\infty}^{n=\infty} \exp(in\omega t)\, \phi_\varepsilon^{\ (n)}(\boldsymbol{r})$

Quasi-energy and Shirley-Floquet method

If $|a\rangle$ and $|b\rangle$ are two eigen-states of H_0, we can use Floquet states $|a,n\rangle$ and a Floquet Hamiltonian H_F

$\langle b,m|H_F|a,n\rangle = h_{ba}^{n-m} + n\hbar\omega\,\delta_{ab}\delta_{nm}$

where $h_{ba}^{q} = \frac{1}{T}\int_0^T e^{-iq\omega t}\,\langle b|H_0+H_1|a\rangle\,dt$

This method makes the problem time independent

Quanta $n\hbar\omega$ are exchanged with the atom, and can appear as satellites on the line shape.

In our simulation we retain electron broadening with an impact operator, the time dependent field of the ion perturbers, and solve numerically the Schrödinger equation for the emitter submitted to the plasma particles field and to the oscillating field

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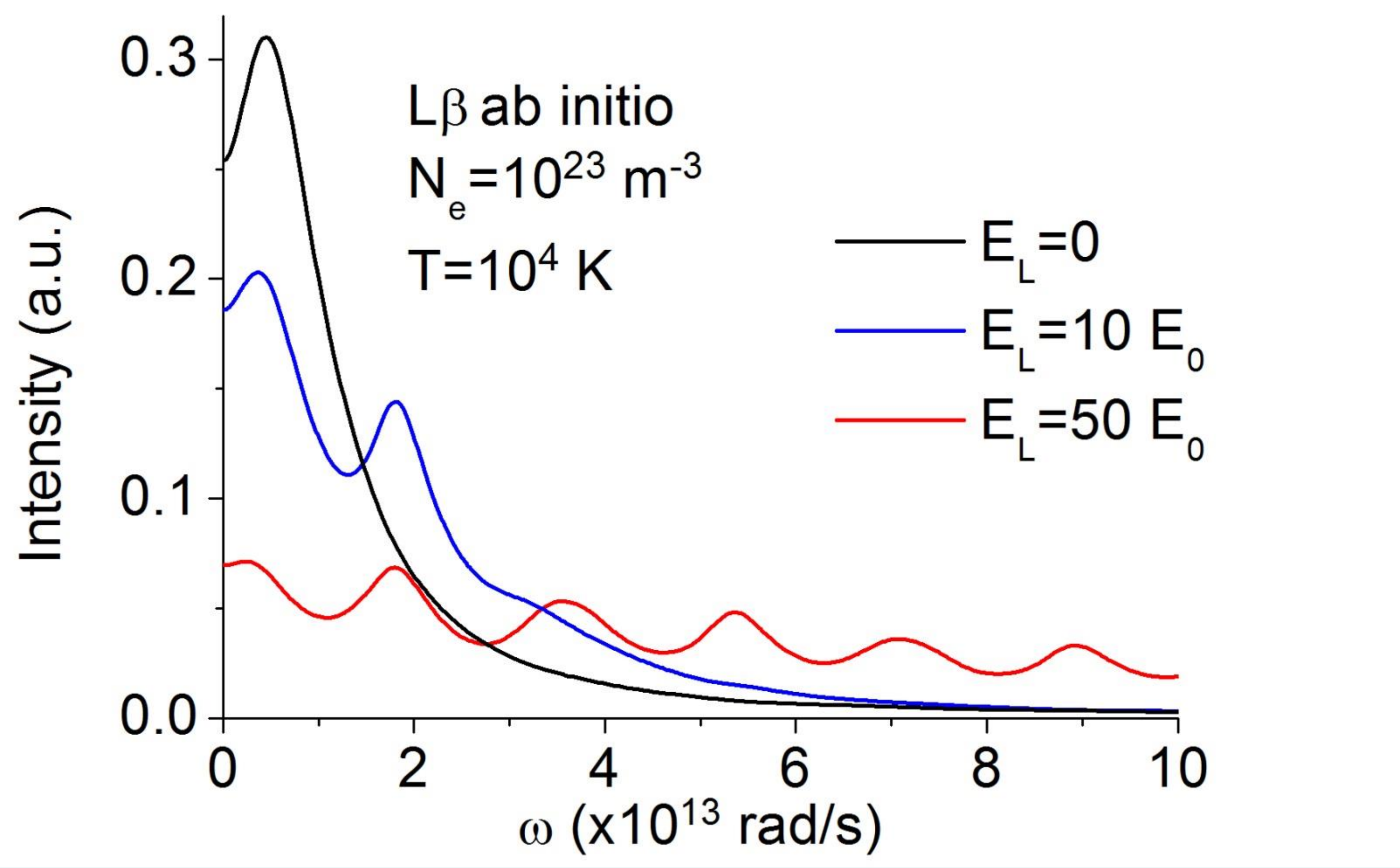
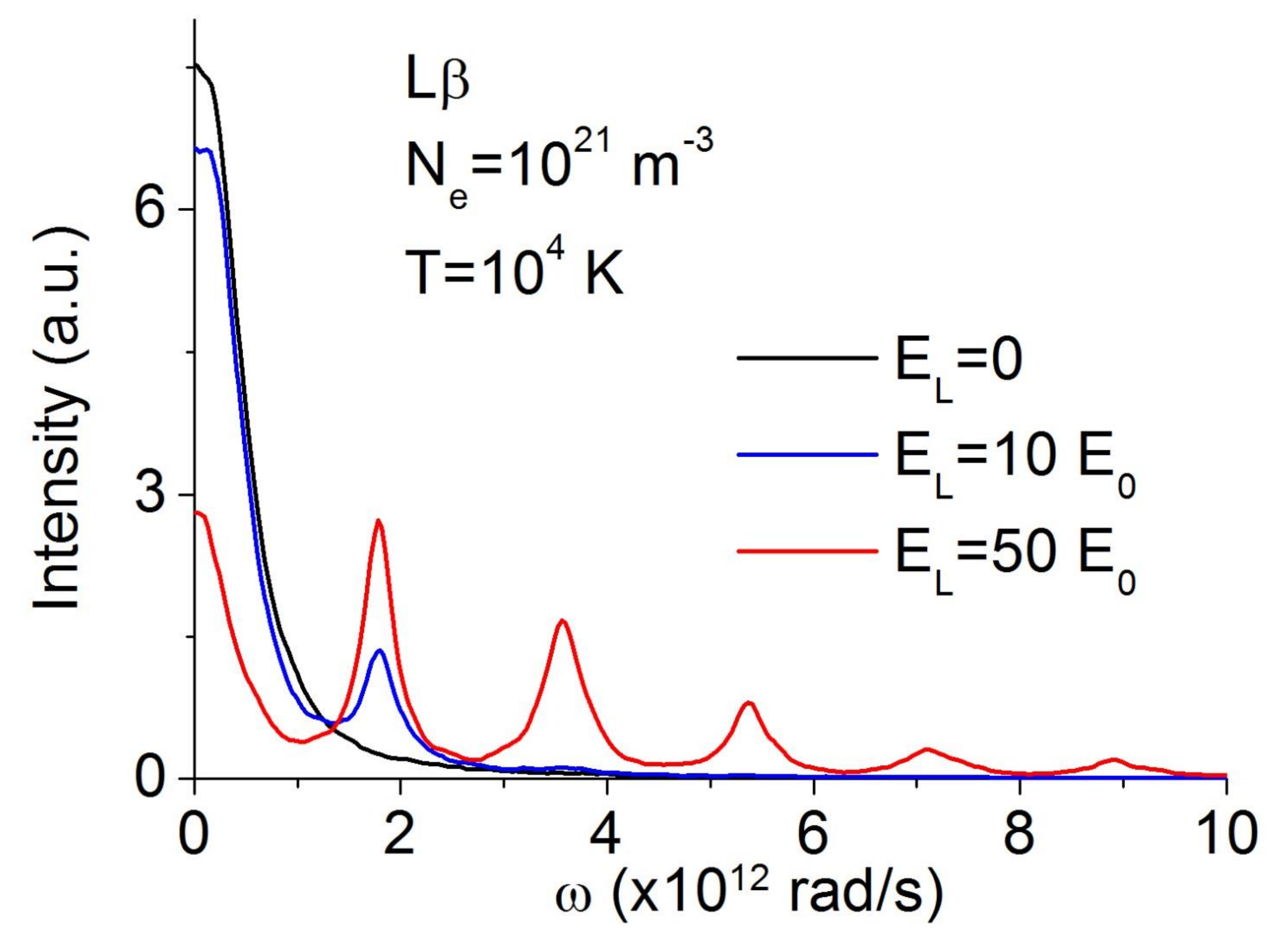
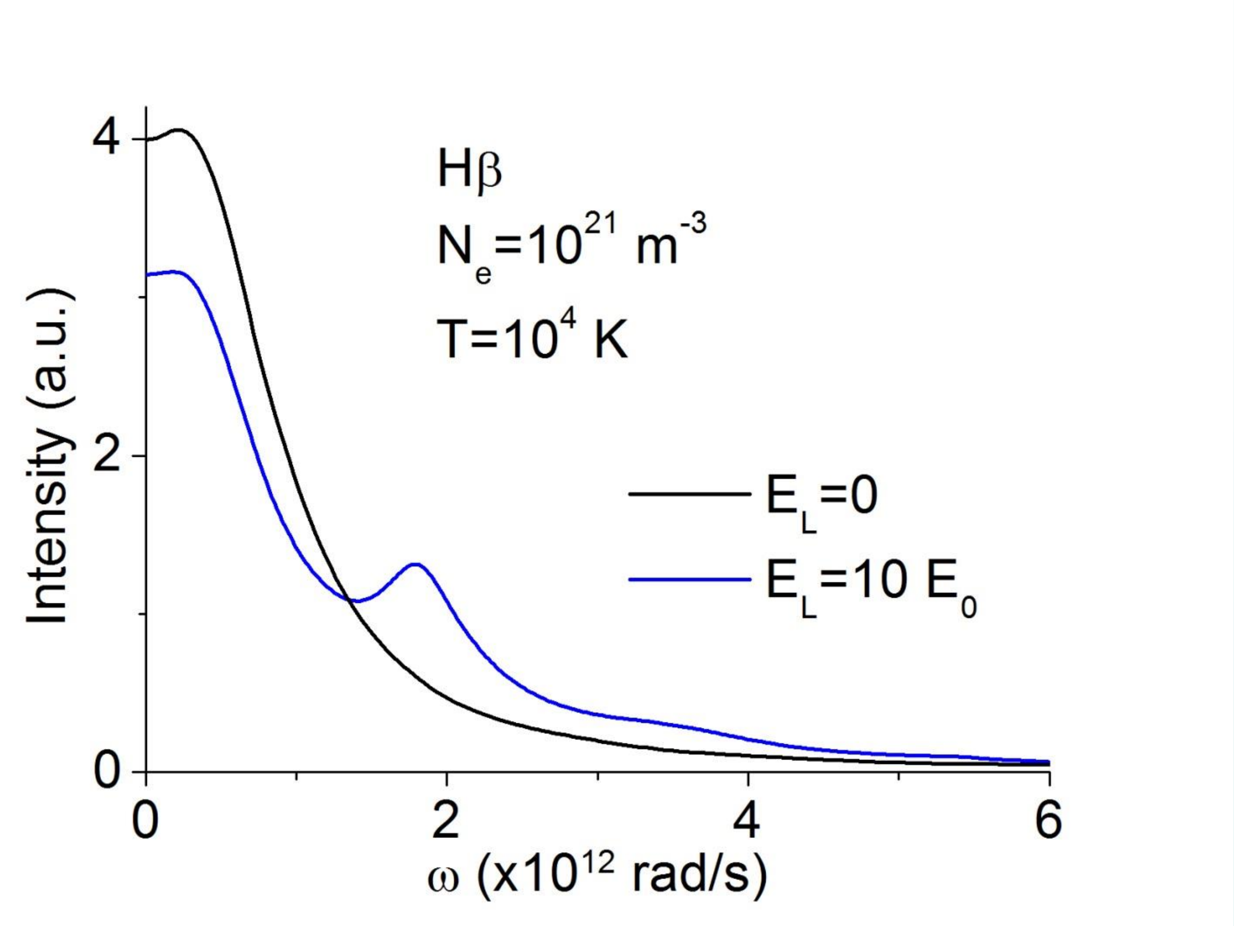
Ab initio Lyman β, $N_e=10^{23}$ m^{-3}



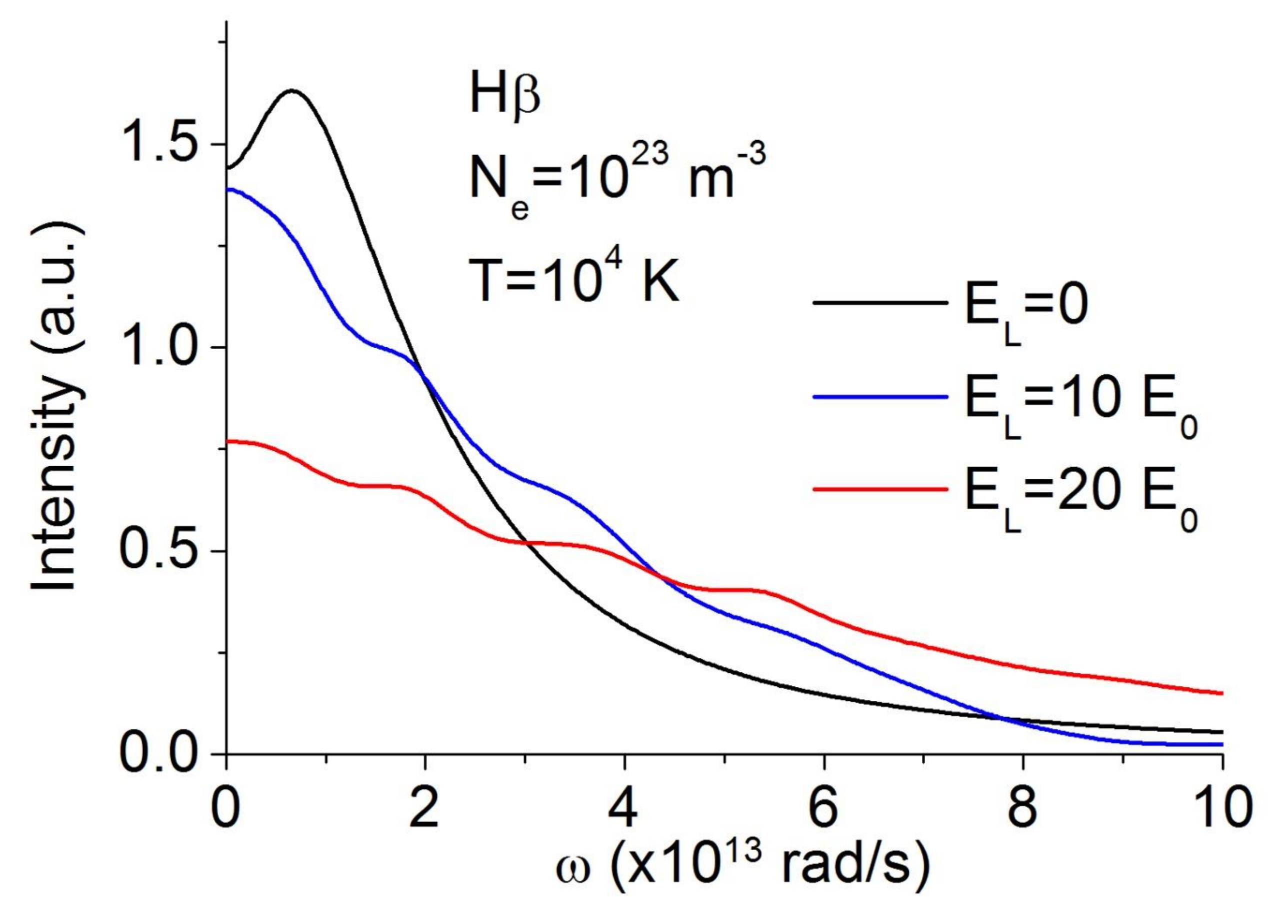
Lyman β, $N_e=10^{21}$ m^{-3}



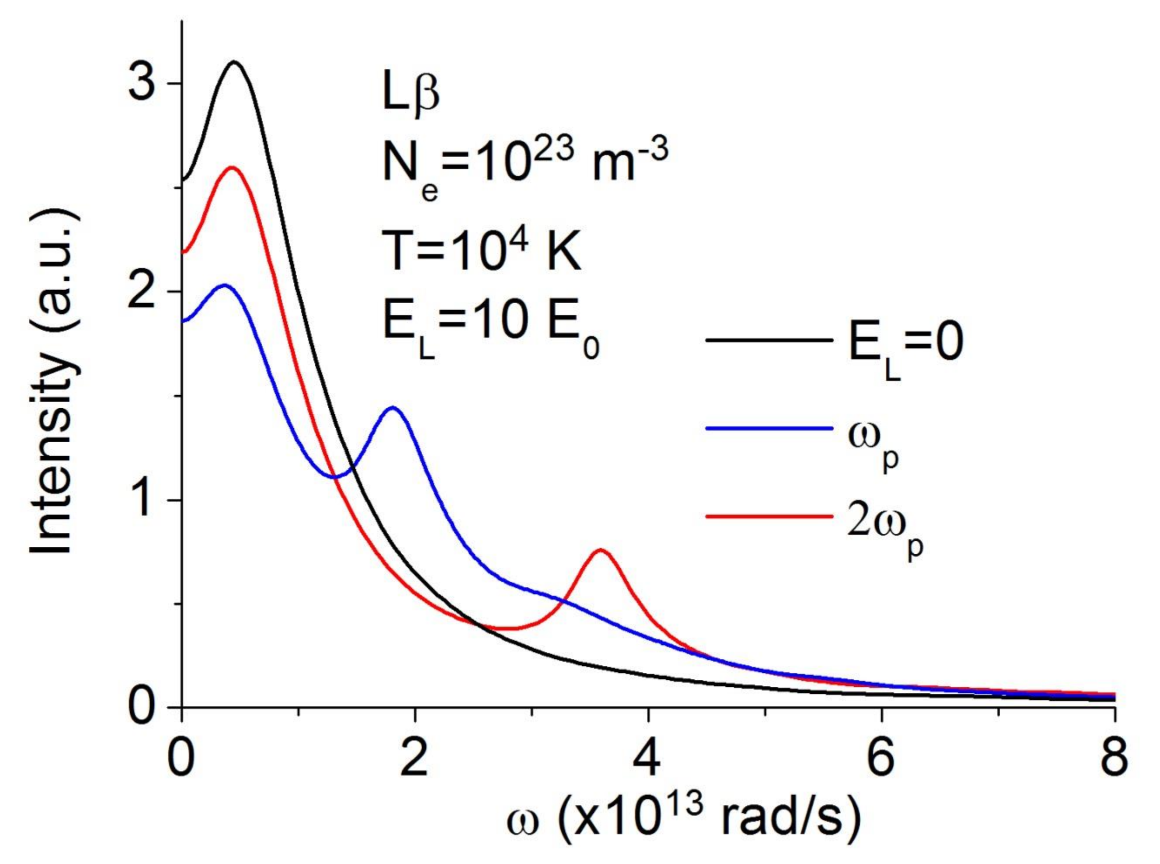
Balmer β, $N_e=10^{21}$ m^{-3}



Balmer β, $N_e=10^{23}$ m^{-3}

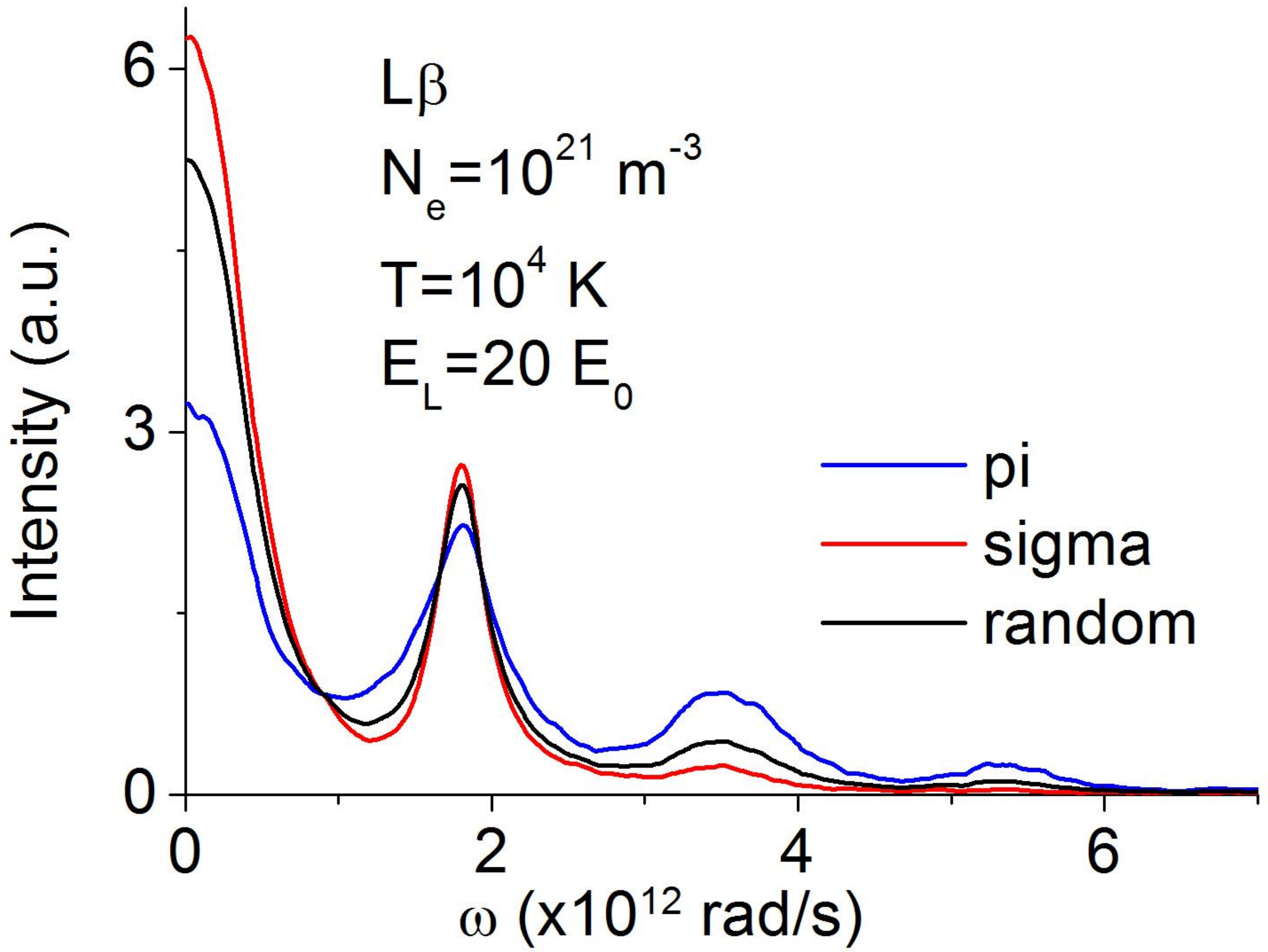


Lyman β, $N_e=10^{23}$ m^{-3}, frequencies ω_p and 2 ω_p



Center of the line less modified for a $2\omega_p$ oscillation

Lyman β, $N_e=10^{21}$ m^{-3}, polarization

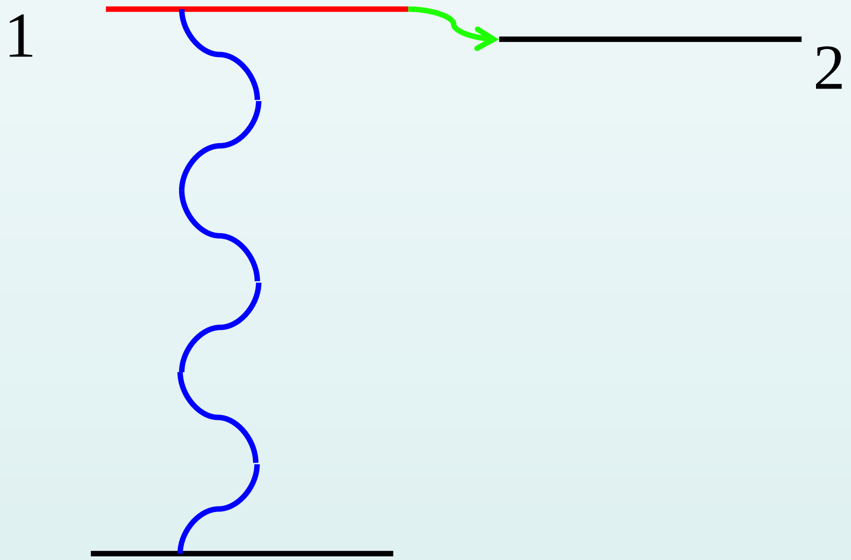


Adiabatic/non-adiabatic interactions

Two categories of interactions

-Adiabatic : shift of the energy levels → phase shift (frequency shift)

-Non adiabatic : induces a radiationless transition out of the initial state



Usually terminates the probability that an ω_0 photon is emitted, but..

Overlapping lines

If $E_1 - E_2 \sim V$=-$\overrightarrow{d}$. $\vec{E}$, transitions back and forth between level 1 and 2

The probability of emission at ω_0 is not completely destroyed :

Problem of overlapping lines (phase-memory effect) , takes place if $|E_1 - E_2| < |\, V|$

-Non-adiabatic effects are important for oscillating perturbations

References : M. Baranger, Phys. Rev. 111, 494 (1958)

A. Kolb, H. Griem, Phys. Rev. 111, 514 (1958)

Non linear effects: Wave collapse

As W =$\varepsilon_0|E|^2/(4N_e k_B T)$ becomes of the order of 1, fluid equations predict that a nonlinear coupling of waves may be observed.

In absence of magnetic field, Langmuir waves couple with ion sound and electromagnetic waves.

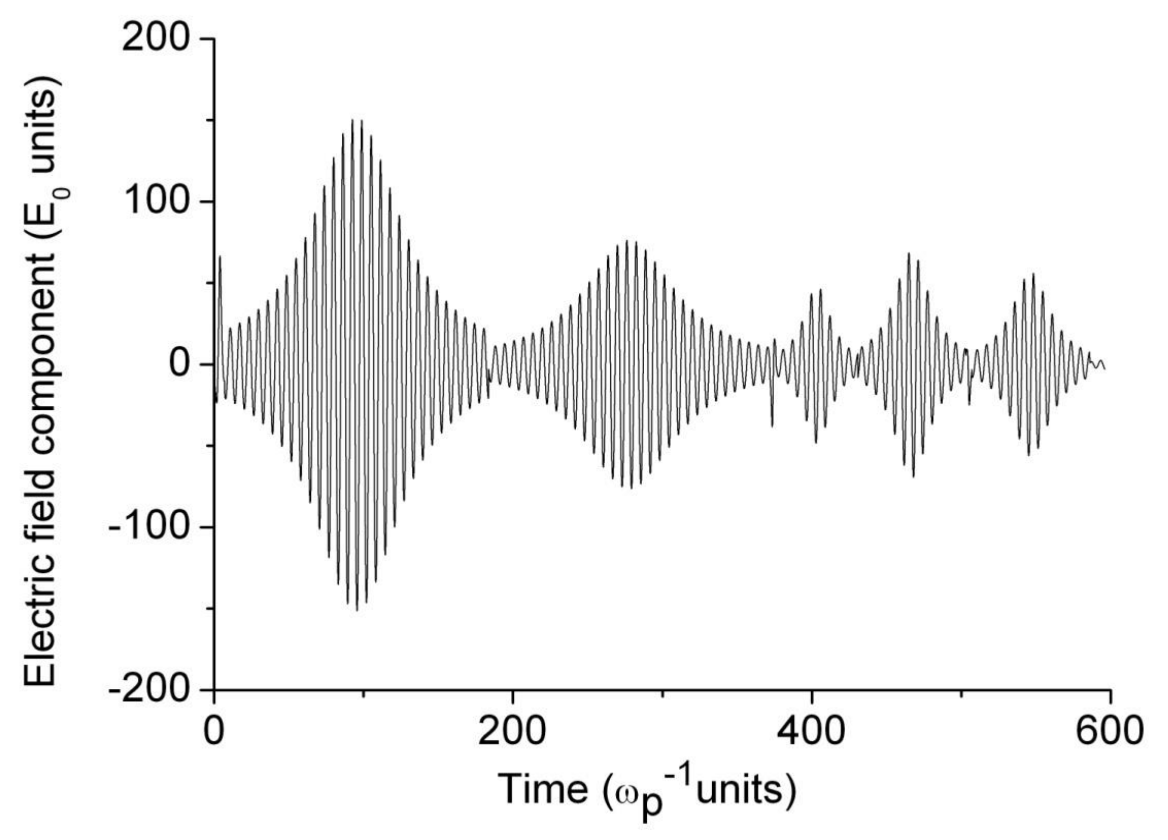
Creation of wave packets (envelope solitons) is possible and act on the emitter as a sequence of solitons

I. Hannachi et al., EPL 114, 23002 (2016)

Electric field history

Average peak field 100 E_0, jumping frequency $\nu=\omega_p/50$

plasma T= 10^4 K, $N_e=10^{19}$ m^{-3}



Results in a broadening, but reduces the number and intensity of satellites

Summary

Simulations of dynamic ion field and simultaneous oscillating electric field have been performed on hydrogen lines

Satellites are ubiquitous on a line shape, but need a large oscillating field magnitude to be observable

Satellites modify more significantly the line shapes for lines having no central Stark component (beta lines)

In progress: study of resonance effects for alpha and beta lines