H-Balmer spectrum modeling

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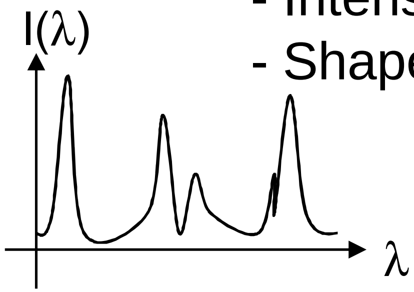
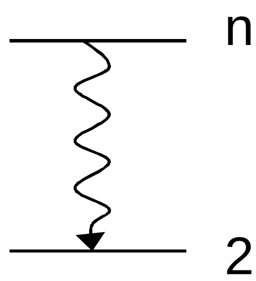
Introduction

Passive spectroscopy is used for the diagnostic of tokamak edge plasmas



- Intensity of the lines
- Shape

N, T…

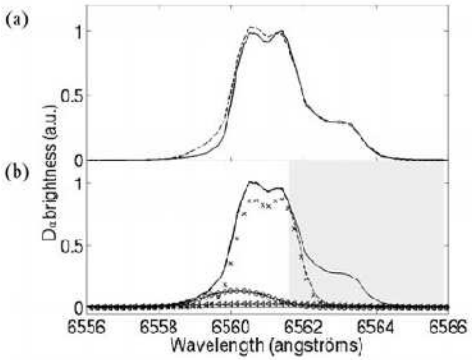


Reliability requires accurate spectroscopy models

<u>Outline</u>

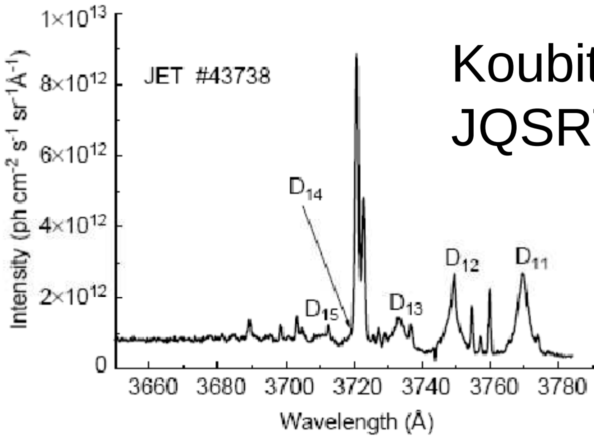
1) Stark and Zeeman effects on Balmer lines
2) Models and recent applications
3) Turbulence

Balmer lines in current tokamaks



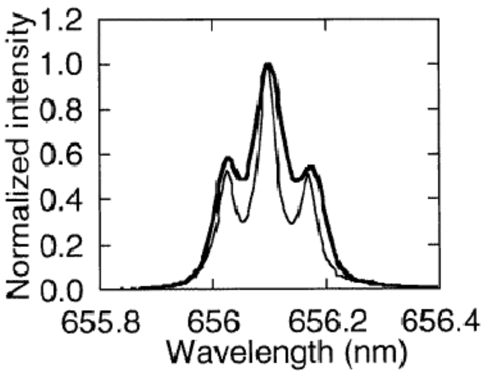
Tore Supra

JET

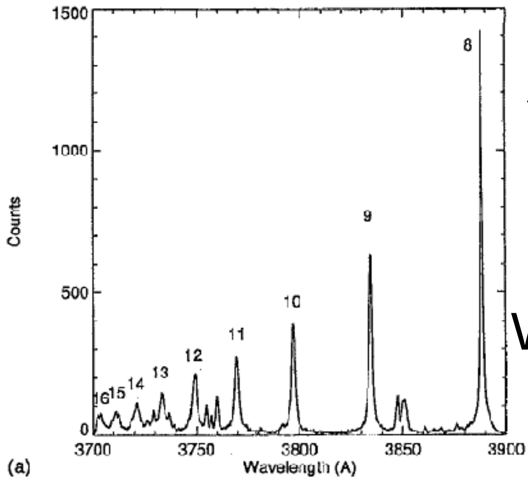


Koubiti et al., JQSRT (2003)

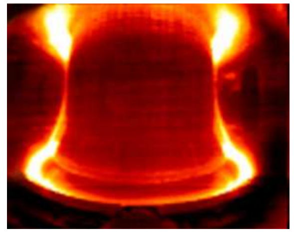
Guirlet et al., PPCF (2001)



JT-60U



Alcator C-Mod



Welch et al., PoP (1995)

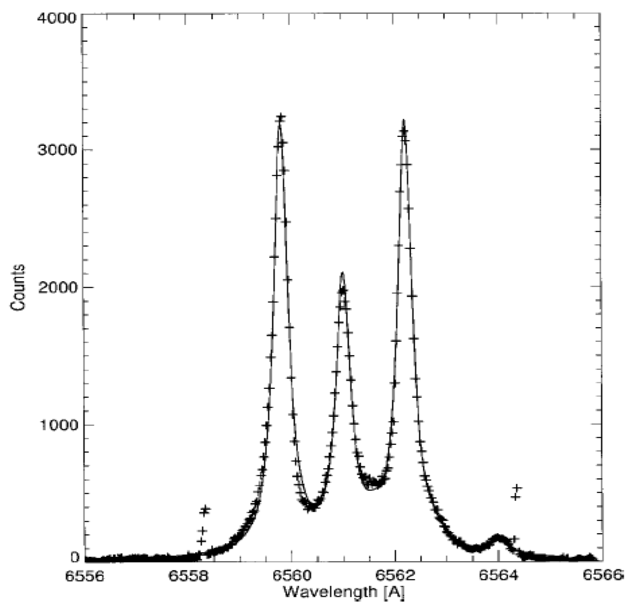
Kubo et al., PPCF (1998)

Low-n lines: Zeeman-Doppler profiles => information on f(v), B

High-n lines: Stark effect => information on N

Low-n lines can also be affected by the Stark effect

Alcator C-Mod divertor: N up to 10^{15} cm^{-3} and higher



Dα Zeeman-Lorentz triplet:
both Doppler & Stark effects
contribute to the broadening

Welch et al., PoP (2001)

Such high-density conditions can be expected in ITER
(B2-EIRENE simulations, V. Kotov et al.)

Accurate Stark models are required

Ion dynamics

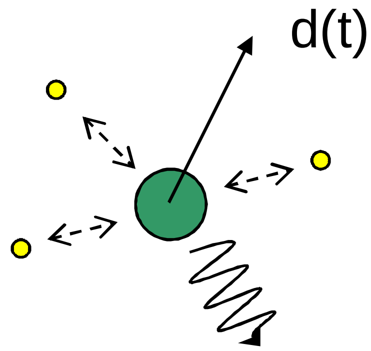
Stark broadening formalism

e.g. Griem, Plasma Spectroscopy (1974)

Fourier transform of the dipole autocorrelation function

$$I(\omega) = \frac{1}{\pi} \mathrm{Re} \int_0^\infty C_{dd}(t) e^{i\omega t} dt$$

$$C_{dd}(t) = \{ \mathrm{Tr}(\rho d(0) d(t)) \}$$

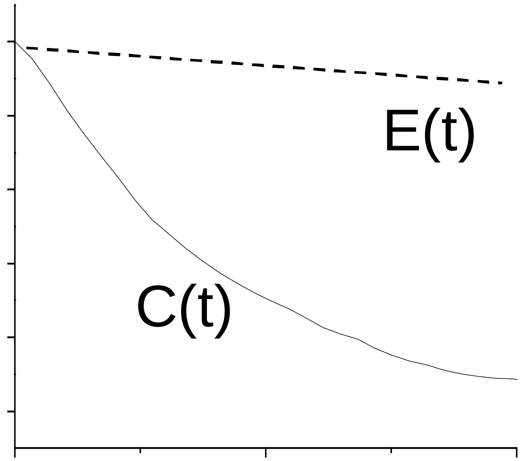


$$\vec{d}(t) = U^+(t) \vec{d}(0) U(t)$$

- ρ: atomic density matrix
- d: dipole matrix elements
- U(t): time dependent Schrödinger equation

$$i\hbar \frac{dU}{dt}(t) = (H_0 - \vec{d}.\vec{E}(t)) U(t)$$

Two limiting cases

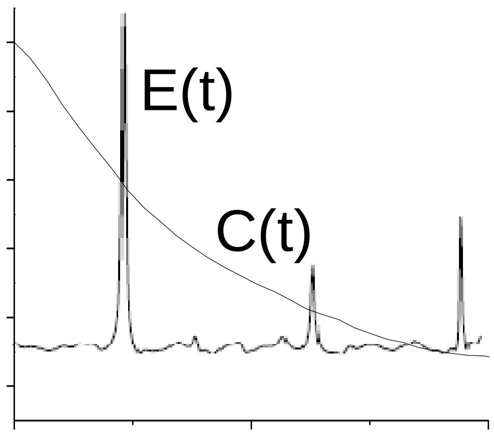


Quasistatic

$$\vec{E}(t) \approx \overrightarrow{\text{cst}}$$

in Schrödinger's Eq.

Ions, high-n



Impact

Series of collisions

$$-\vec{d} \cdot \vec{E}(t) \rightarrow -iK$$

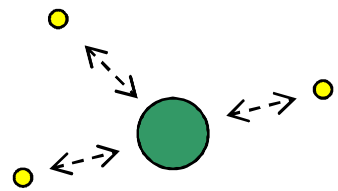
Electrons

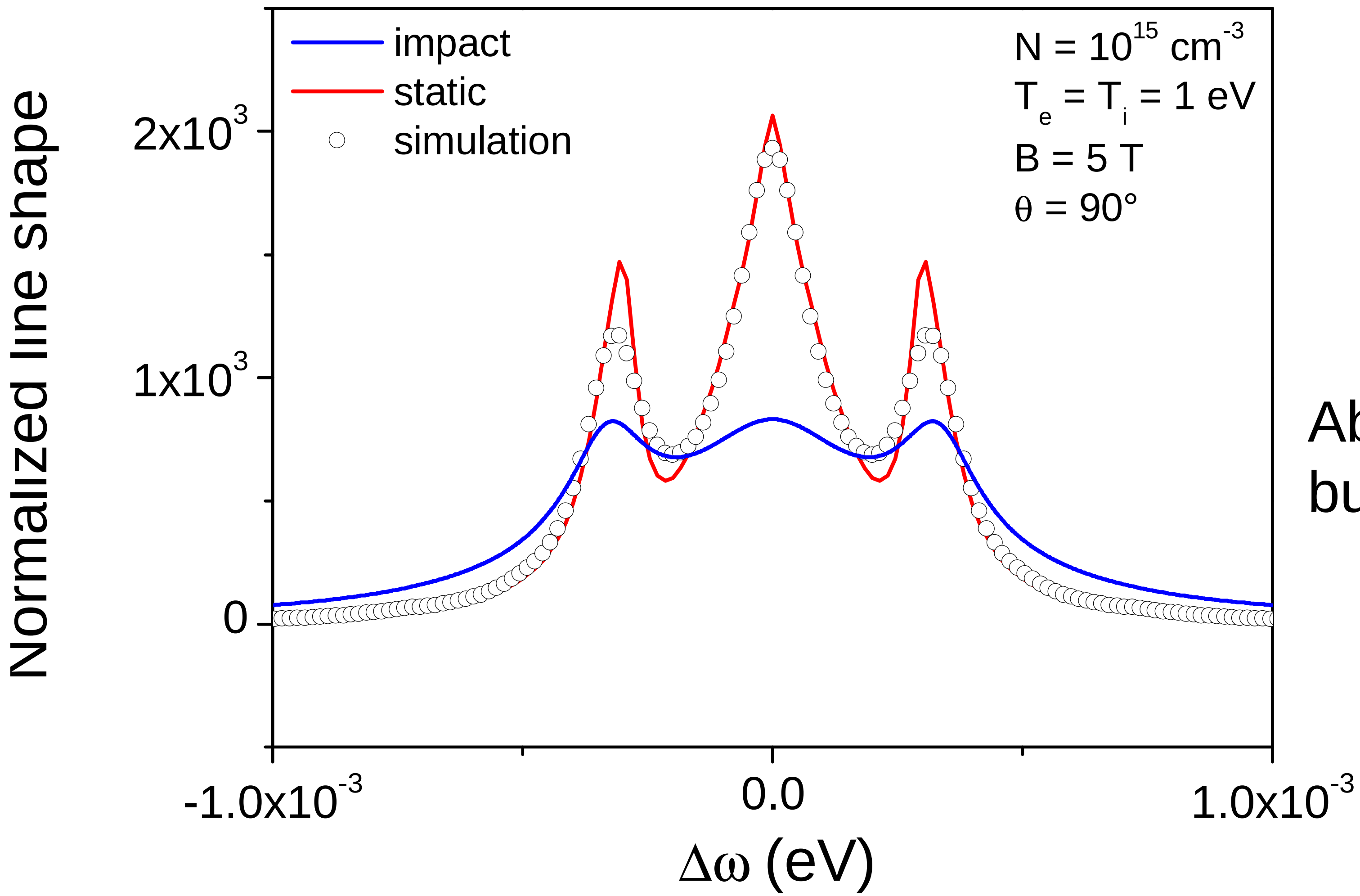
Ions, low-n & N

Low-n & high N: ion dynamics

A numerical simulation method

i) Simulation of the microfield
ii) Numerical integration of the Schrödinger equation

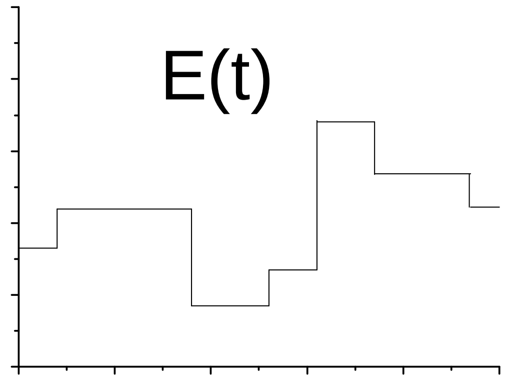




Ab initio,
but CPU intensive…

Alternative approaches

The “model microfield method”



- The electric field is replaced by a stepwise constant function
- The values are generated according to a given PDF
- The jumping times are also generated according to a given PDF

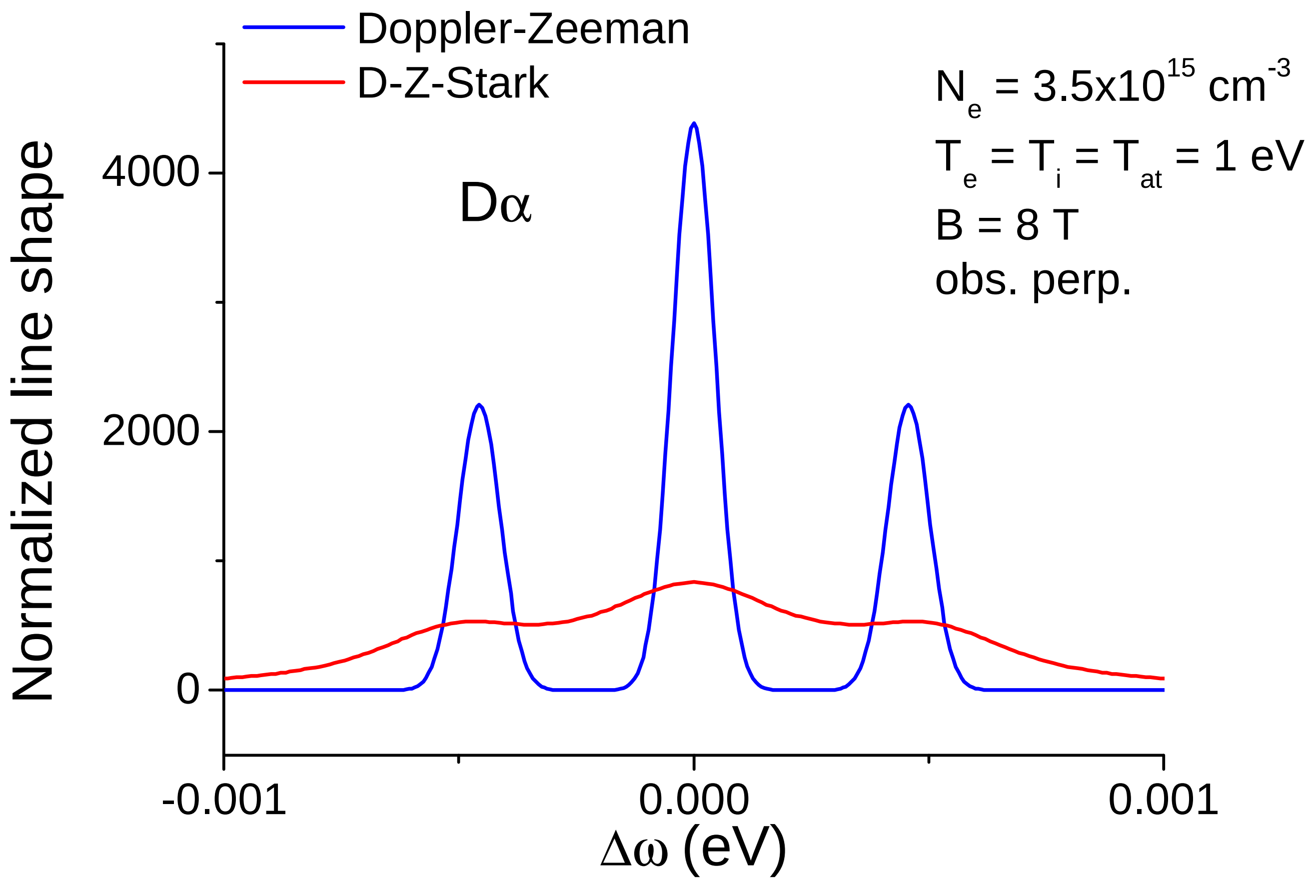
e.g. “kangoroo” process

Similar approach: “frequency fluctuation model”

(Aix-Marseille Univ.)

First-principles expressions (kinetic theory)

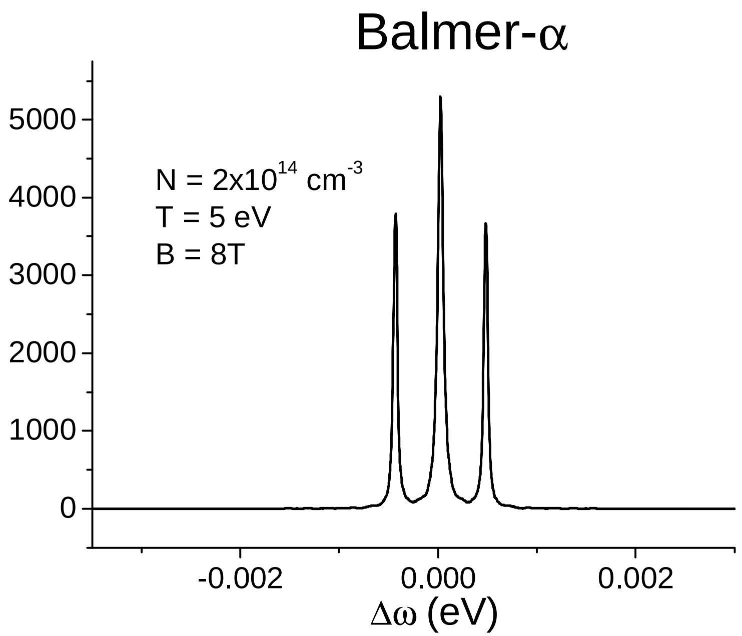
Dα in ITER: Stark vs Doppler

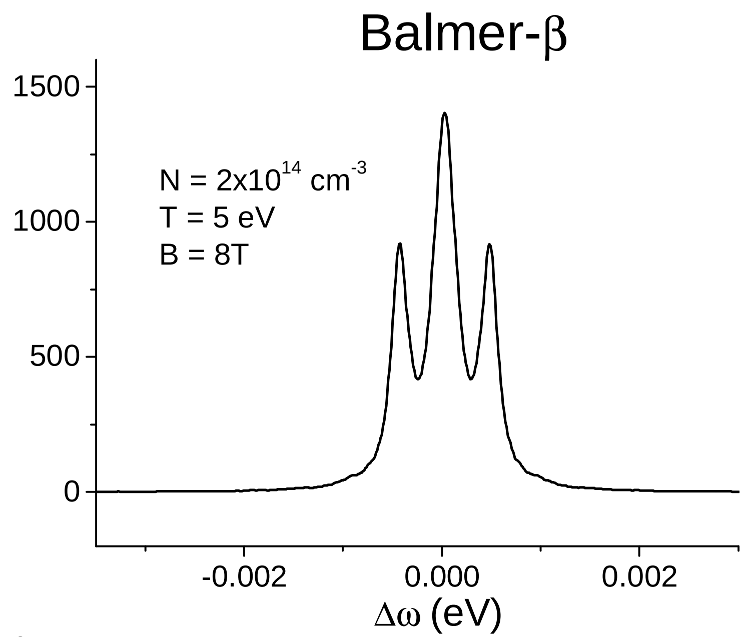


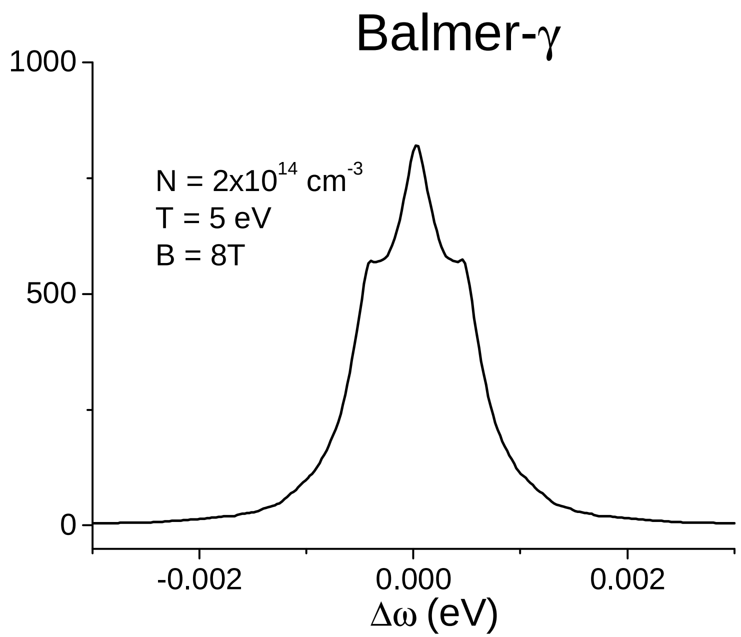
Stark and Doppler broadenings are of the same order

J. Rosato, V. Kotov, and D. Reiter, J. Phys. B (2010)

Stark broadening increases with n







Recent developments

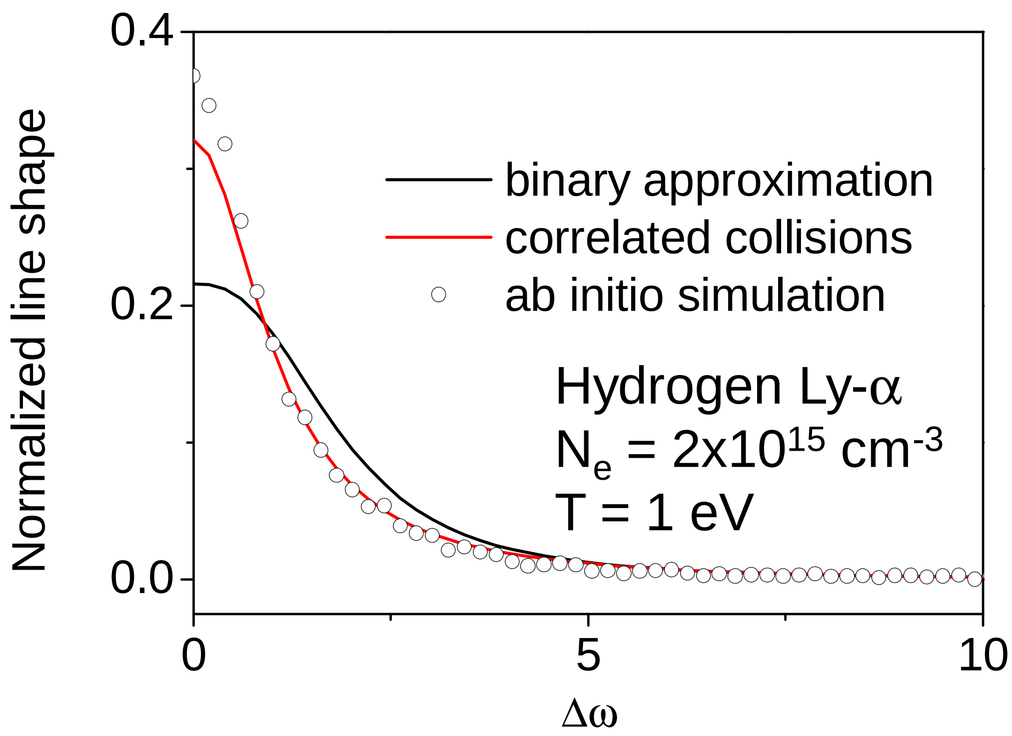
"Unified Theory": D. Voslamber, Z. Naturforsch. (1969)
E. W. Smith, C. R. Vidal & J. Cooper, Phys. Rev. (1969)

An extension of the impact approximation that accounts for incomplete collisions

$$I(\Delta\omega) \propto \left[\Delta\omega + iK(\Delta\omega)\right]^{-1}$$

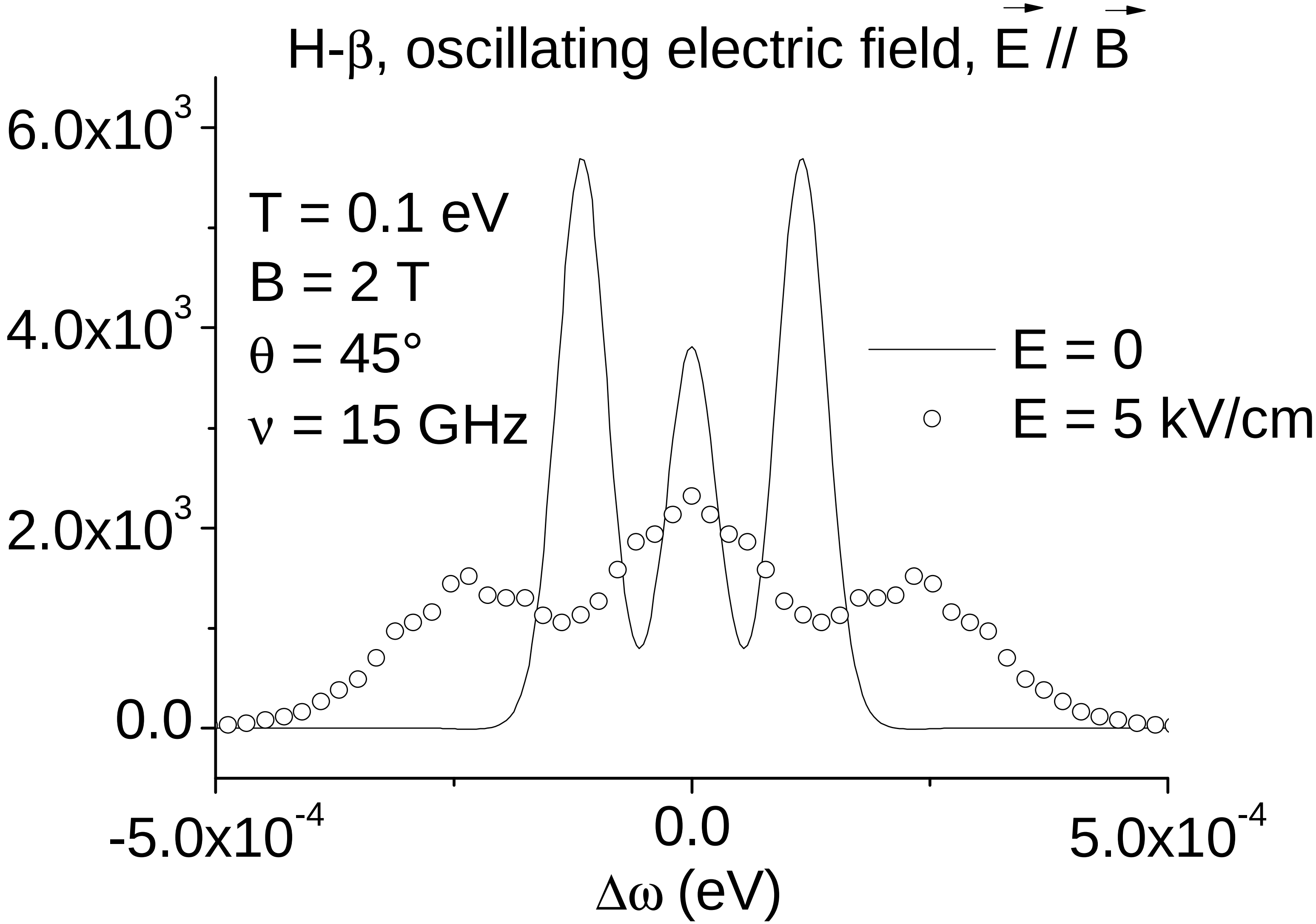
New: **correlated collisions**

J. Rosato et al.,
Transport Theor. Stat. Phys. (in press);
ICSLS conference (2012)



Line shapes and oscillating fields

Antennas in Tore Supra (C. Klepper et al.):
diagnostic of the electromagnetic field based on Balmer lines

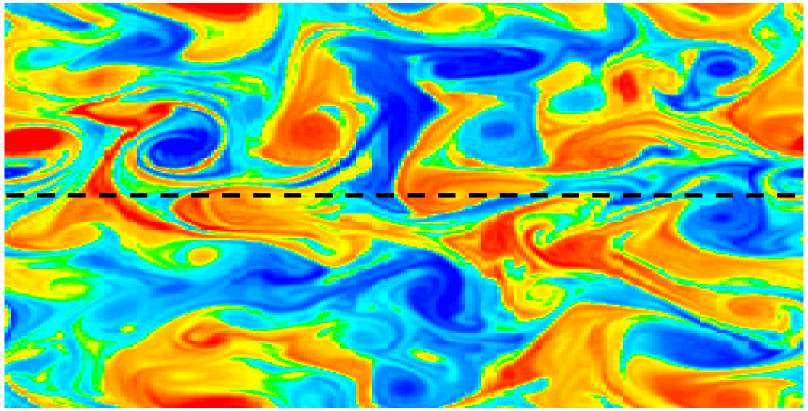


Line radiation and turbulence

$$I = \langle N_a(N_e, T_e)\hbar\omega_{ab}A_{ab}\rangle$$

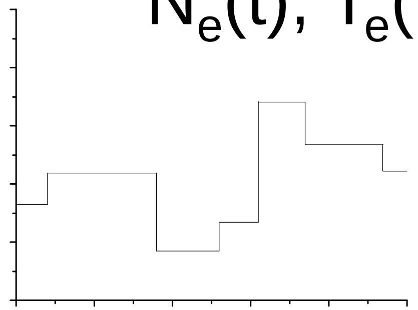
Spectrometer

Line of sight

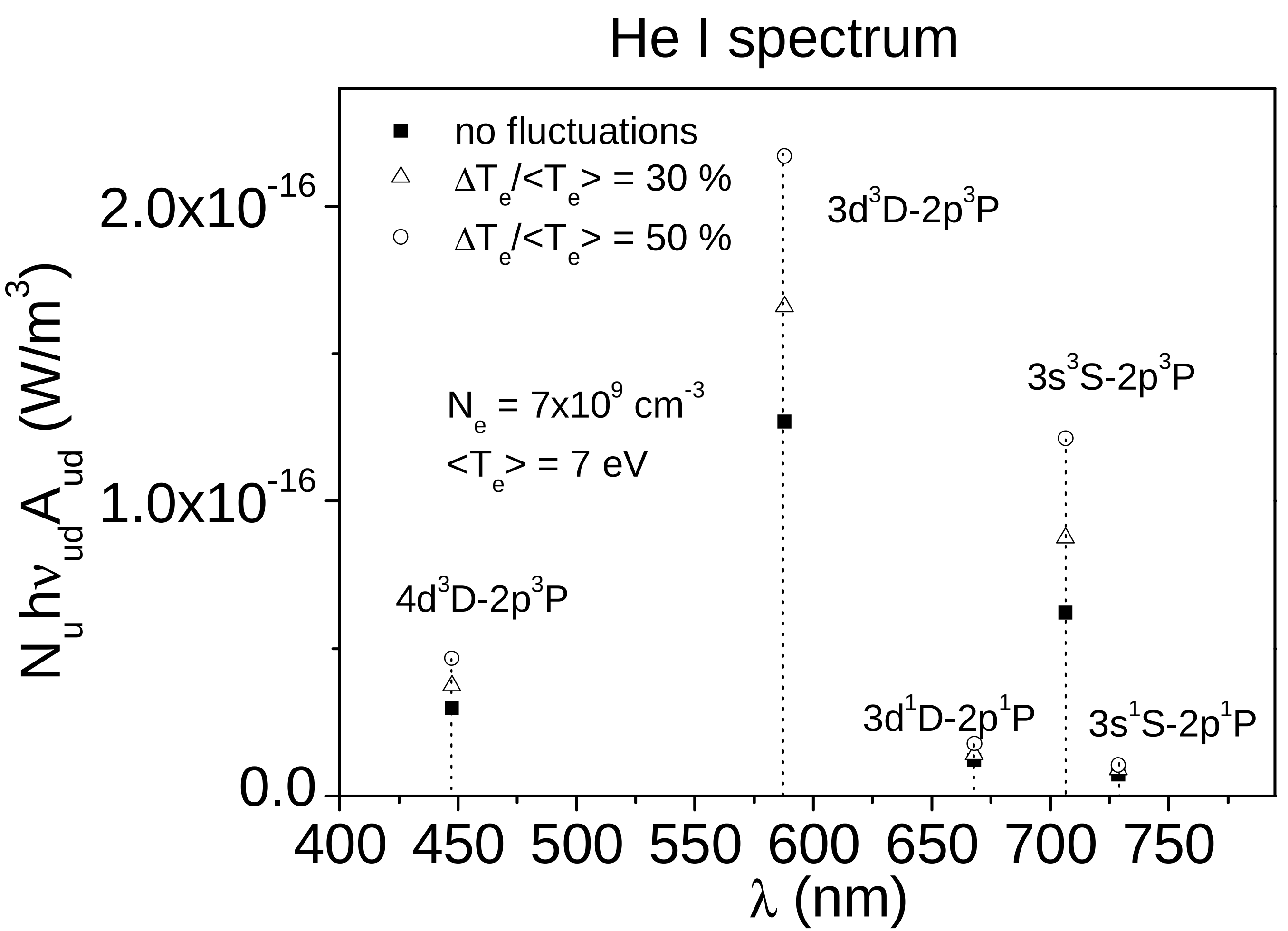


Collisional-radiative model with stochastic rates

$$\frac{dN}{dt}(t) = M(t)N(t) + S(t)$$



Application to line ratios



J. Rosato et al., ICPD 2010

Application to hydrogen:

F. Catoire et al., PRA (2011)
R. Hammami et al., 20th PSI (2012)
R. Hammami, PhD, in preparation

Summary

Passive spectroscopy of Balmer lines provides information on the parameters of tokamak plasmas:
present machines, ITER… commercial fusion reactor?

At high density regime (divertors), all lines of the Balmer series are affected by Stark broadening

Stark models involve various and complementary approaches:
first-principles, ad hoc, or fully numerical treatments

The line radiation is sensitive to plasma fluctuations
=> potential diagnostic for turbulence?

<u>Work in progress:</u>
sensitivity of spectral lines to the statistical properties of turbulence