

Challenges and Progress Toward Modeling Carbon/Oxygen White Dwarf Spectra



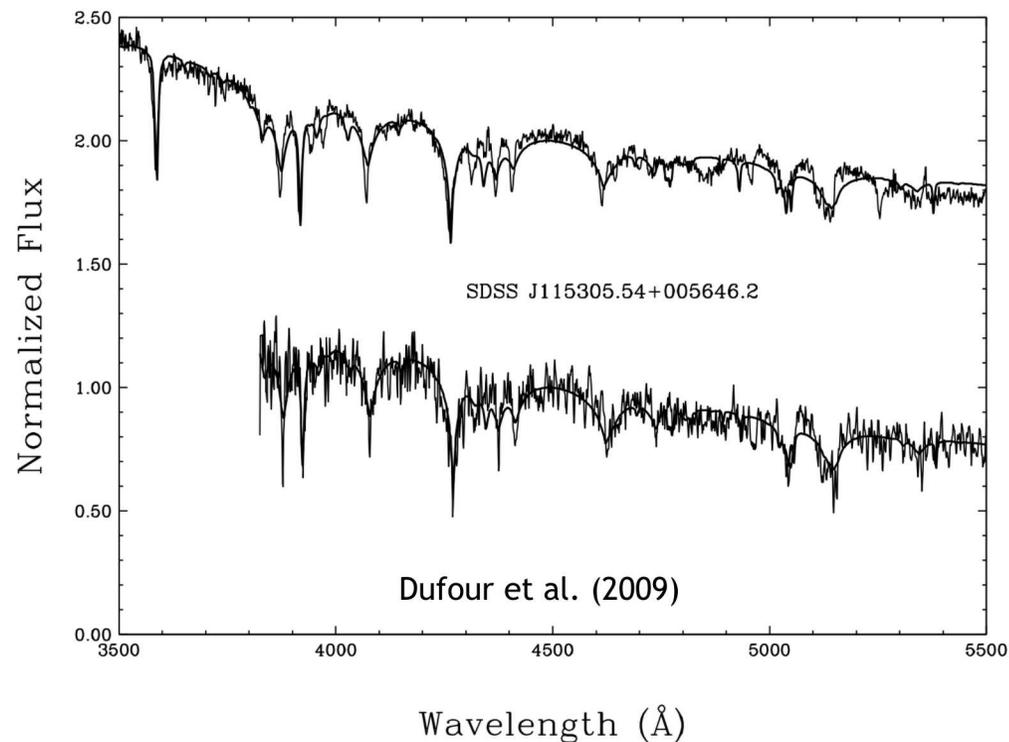
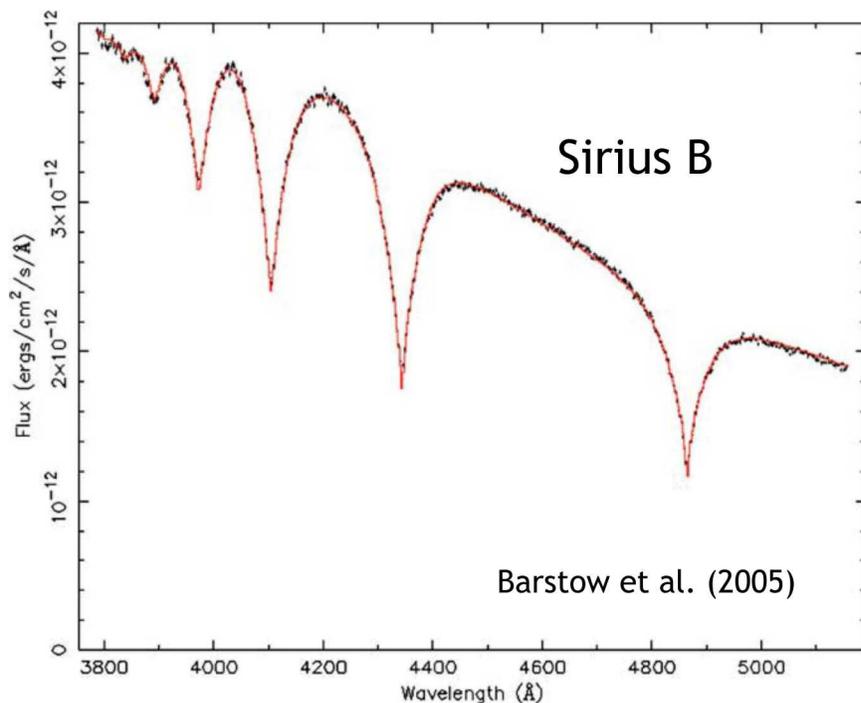
Thomas Gomez, T. Nagayama, C. Fontes, D. Kilcrease, M. Montgomery, D. Winget



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Synthetic Spectra are used to Determine White Dwarf Surface Conditions

Fitting measured spectra with a model can be used to determine surface conditions, such as gravity and temperature...



...Assuming that we know all of the relevant physics

Structure of the atmosphere

- Temperature
- Density

And at every level in the atmosphere we need necessary atomic data

- Atomic energy levels
- Atomic oscillator strengths
- Atomic populations
- The line broadening

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This has never been measured, we have faith that our atmosphere models are correct (or close enough)

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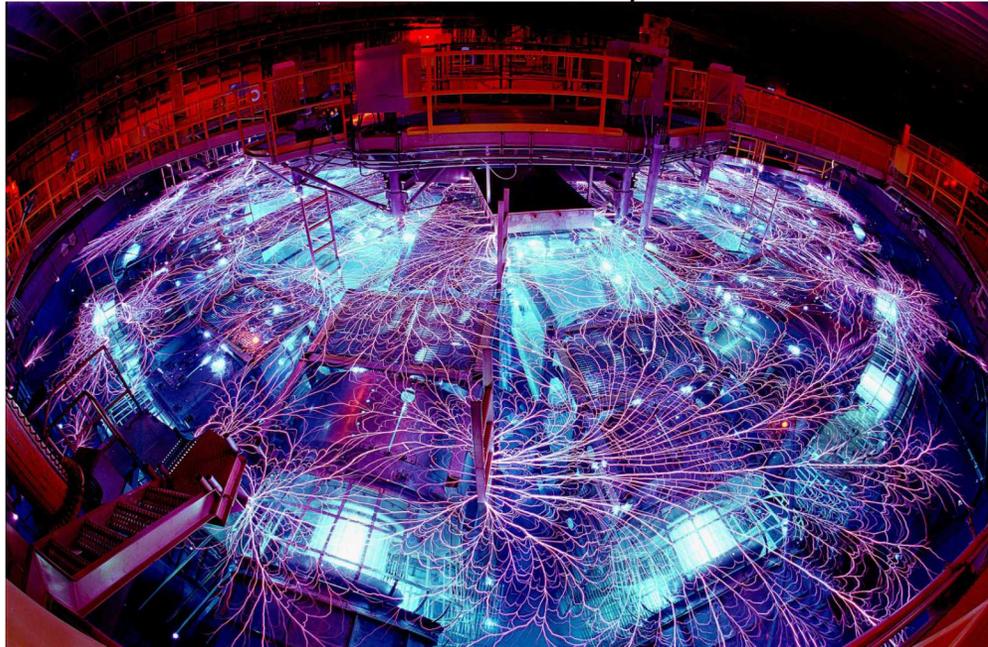
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← These parameters can be measured in the laboratory (e.g. Wiese et al. 1972; Falcon et al. 2015) and can be constrained



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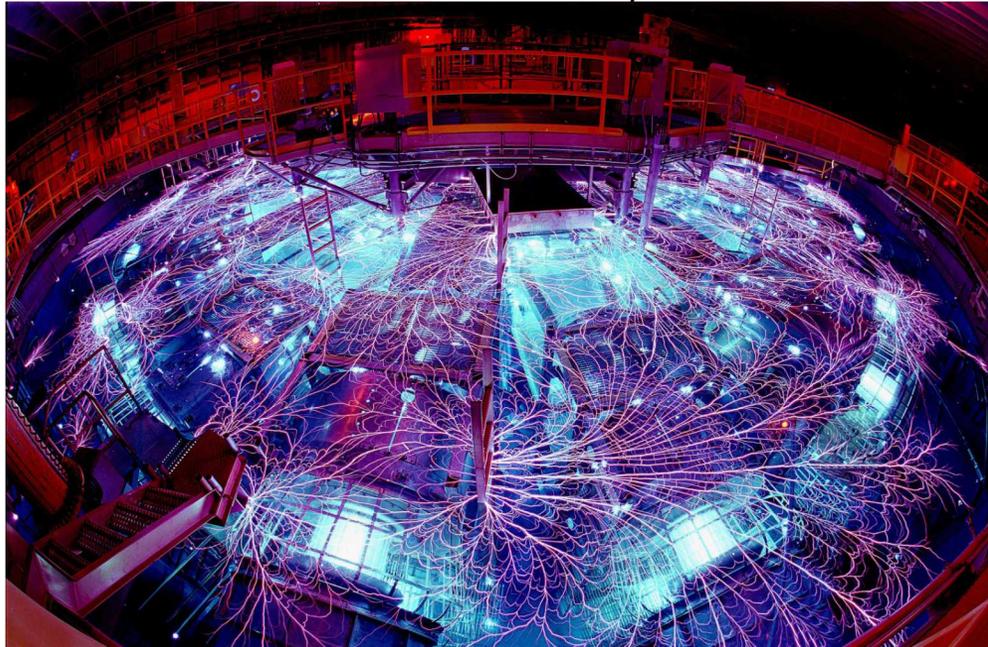
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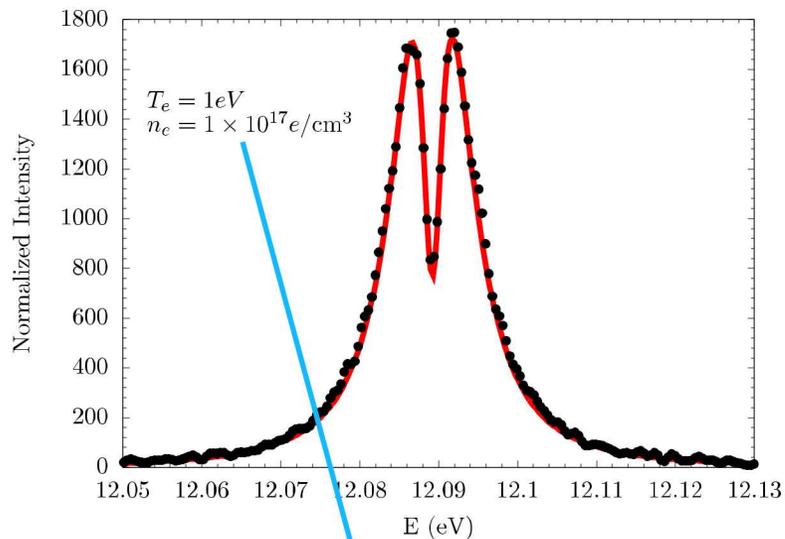
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Line Broadening Models are used to Calculate Synthetic Spectra of White Dwarfs



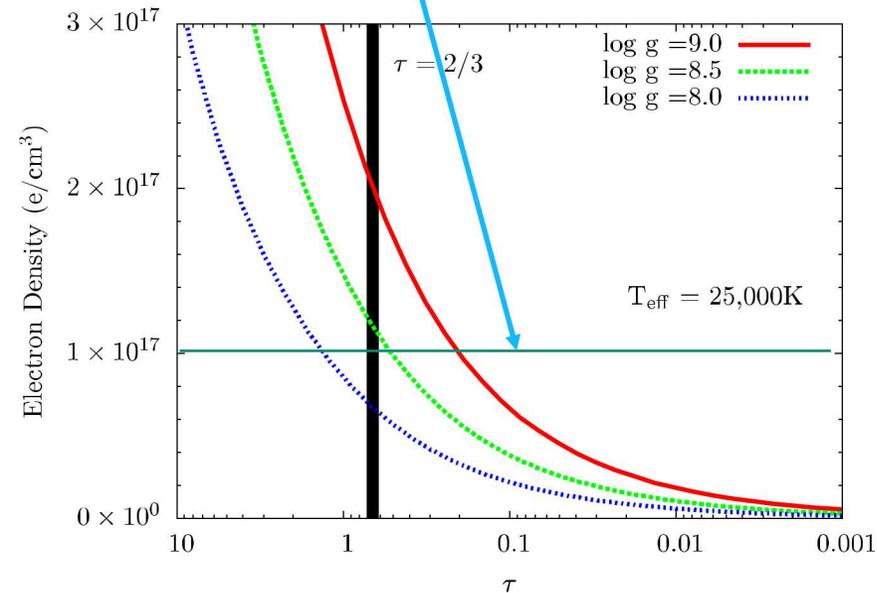
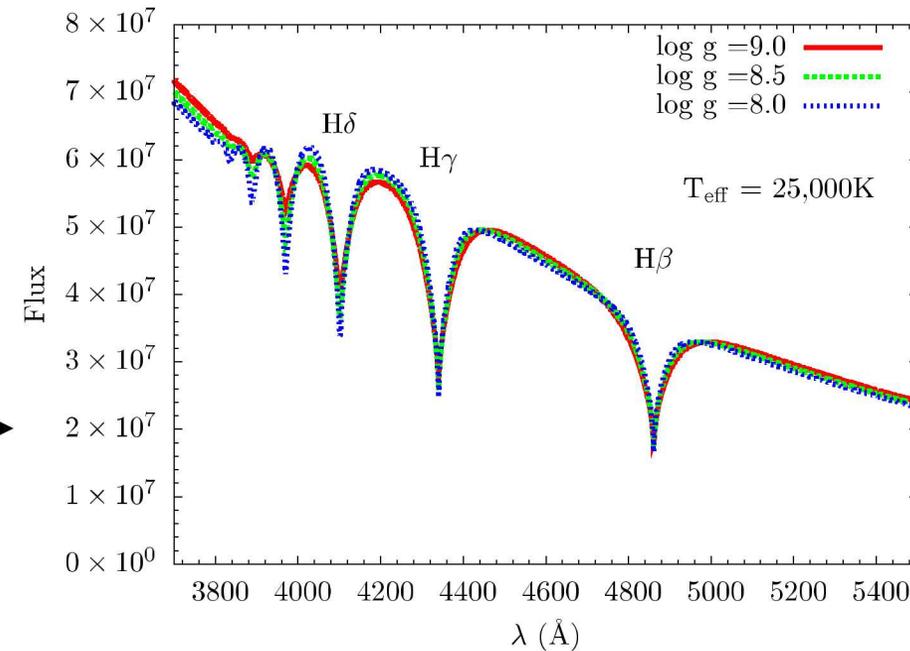
Spectral Line
Shape at Different
Plasma Conditions

Probably the most direct application of line broadening by astronomers is to determine $\log g$ and T_{eff}

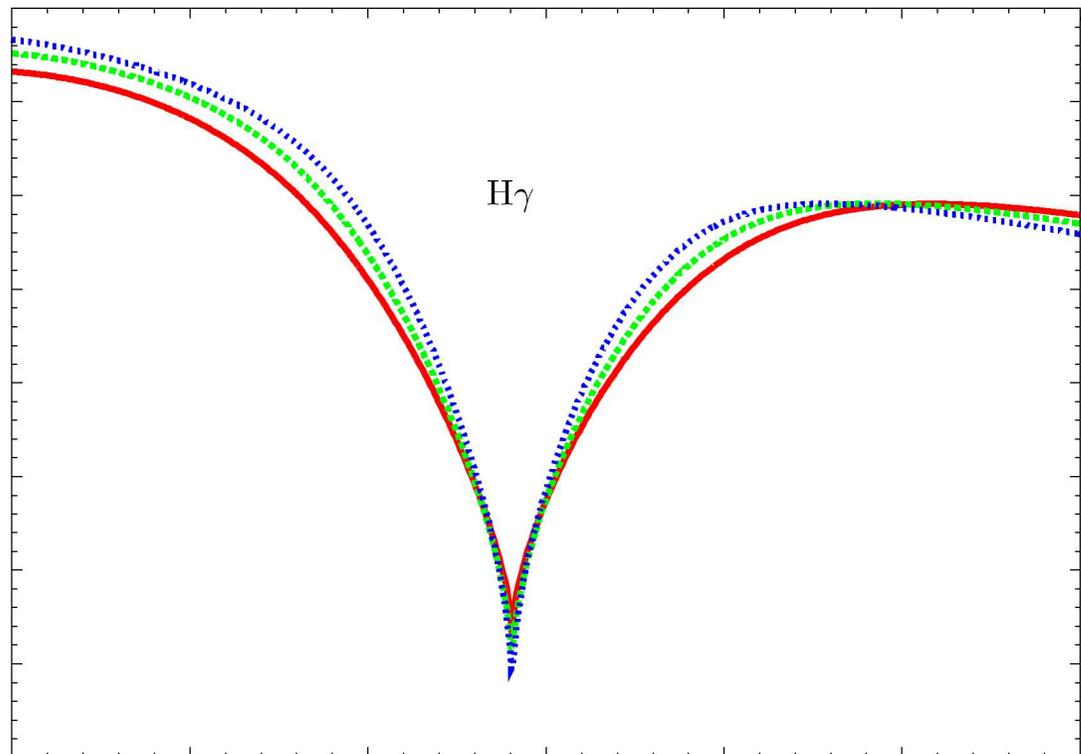
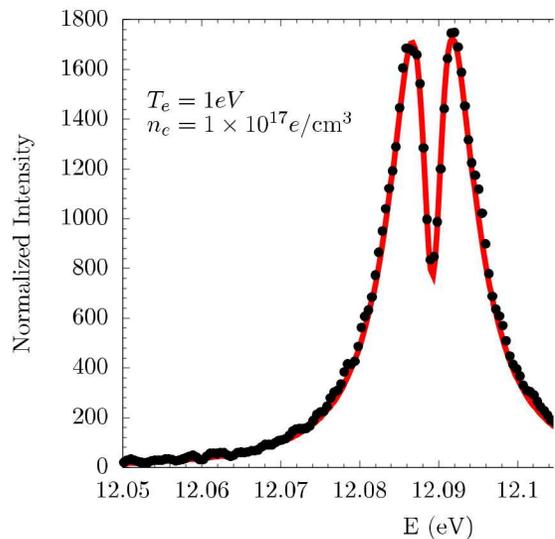
The reason for this is that

- line broadening is sensitive to the density
- Density is sensitive to gravity

Then Integrated
over the different
plasma conditions
in the atmospheres
Give the emergent
Spectra

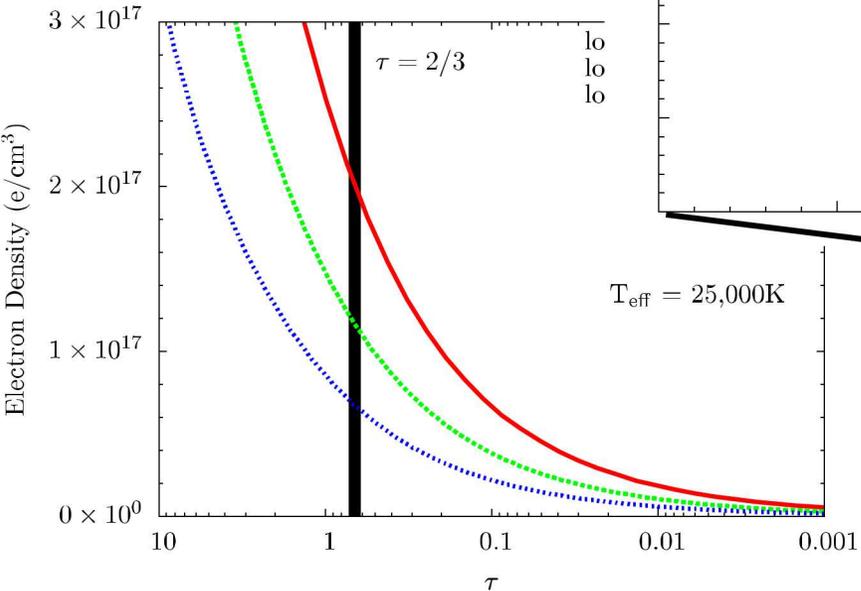
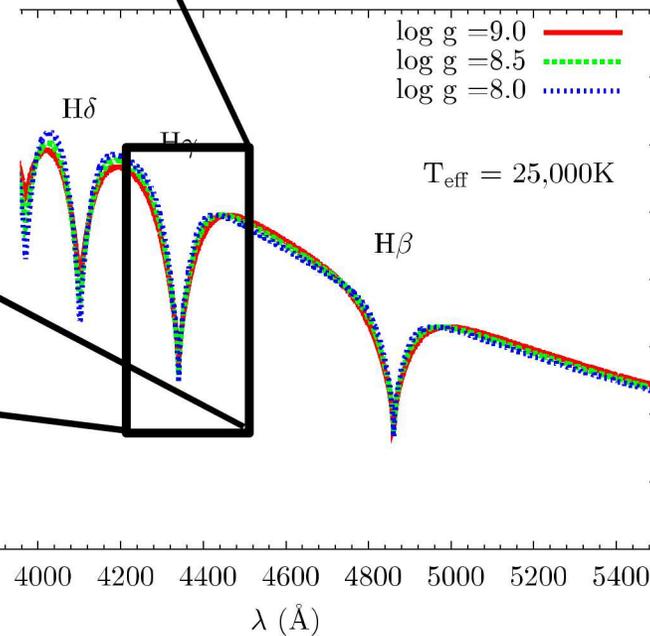


Line Broadening Models are used to Calculate Synthetic Spectra of White Dwarfs

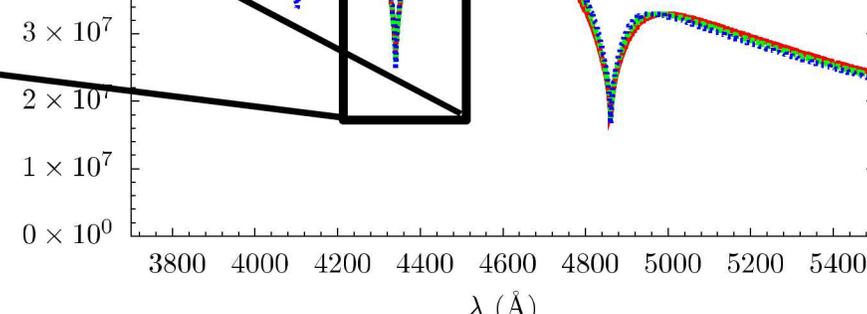


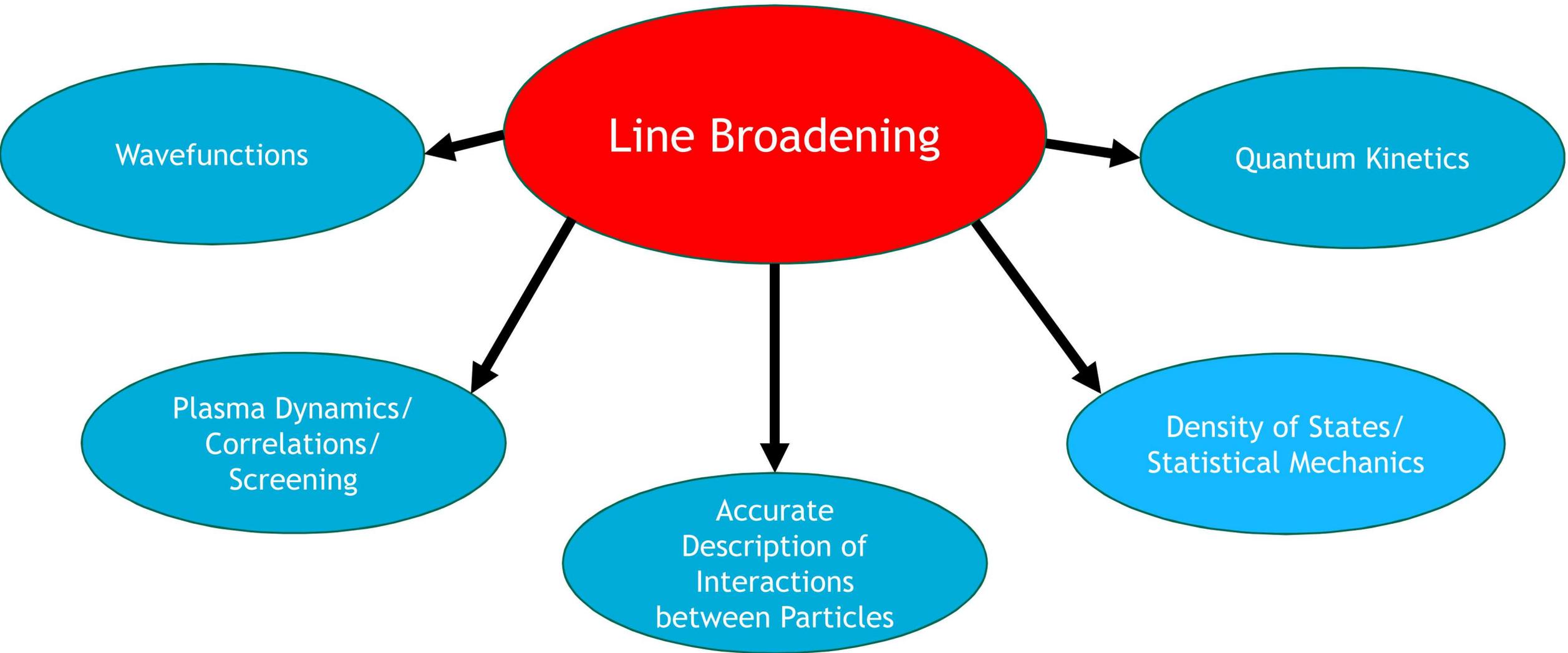
Direct application of line broadening models is to determine log g

that is sensitive to the density and surface gravity

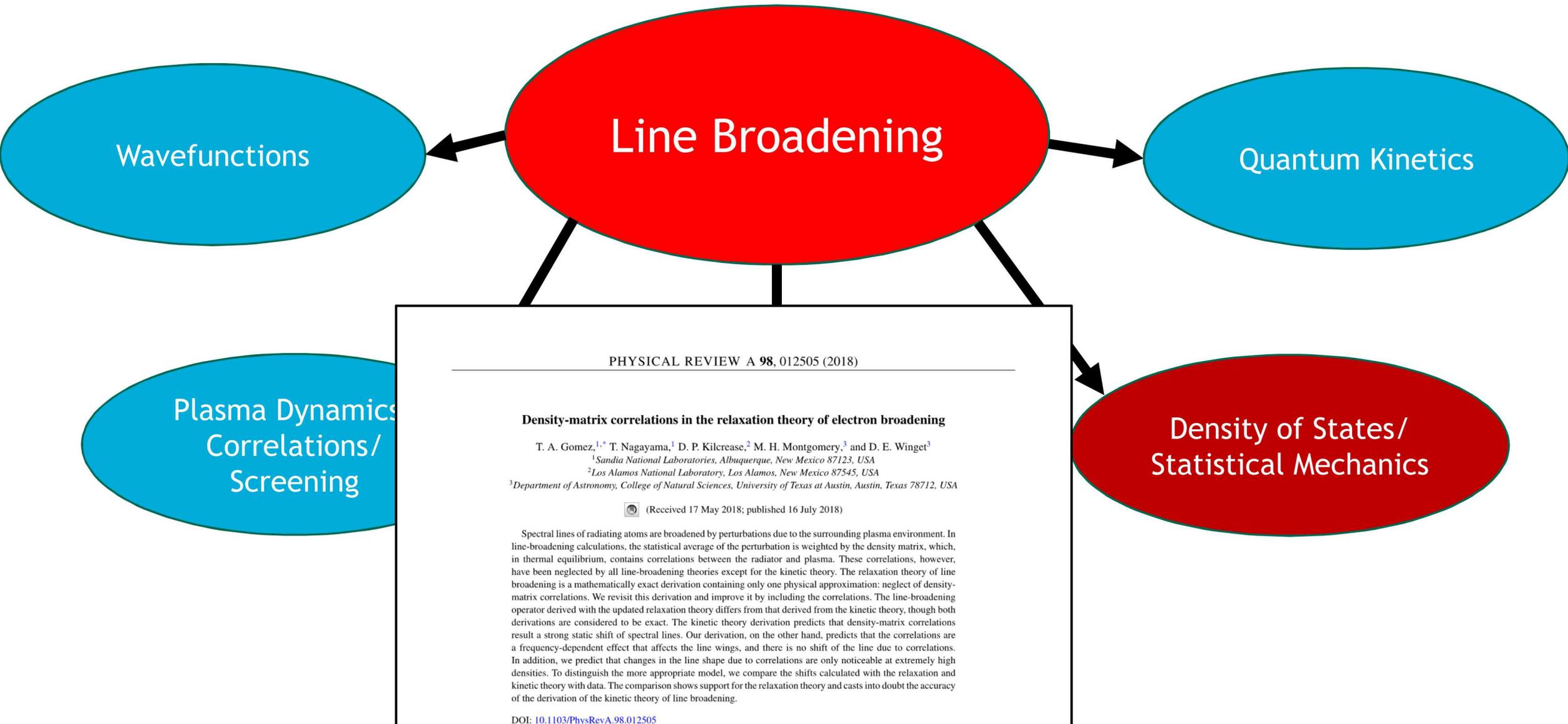


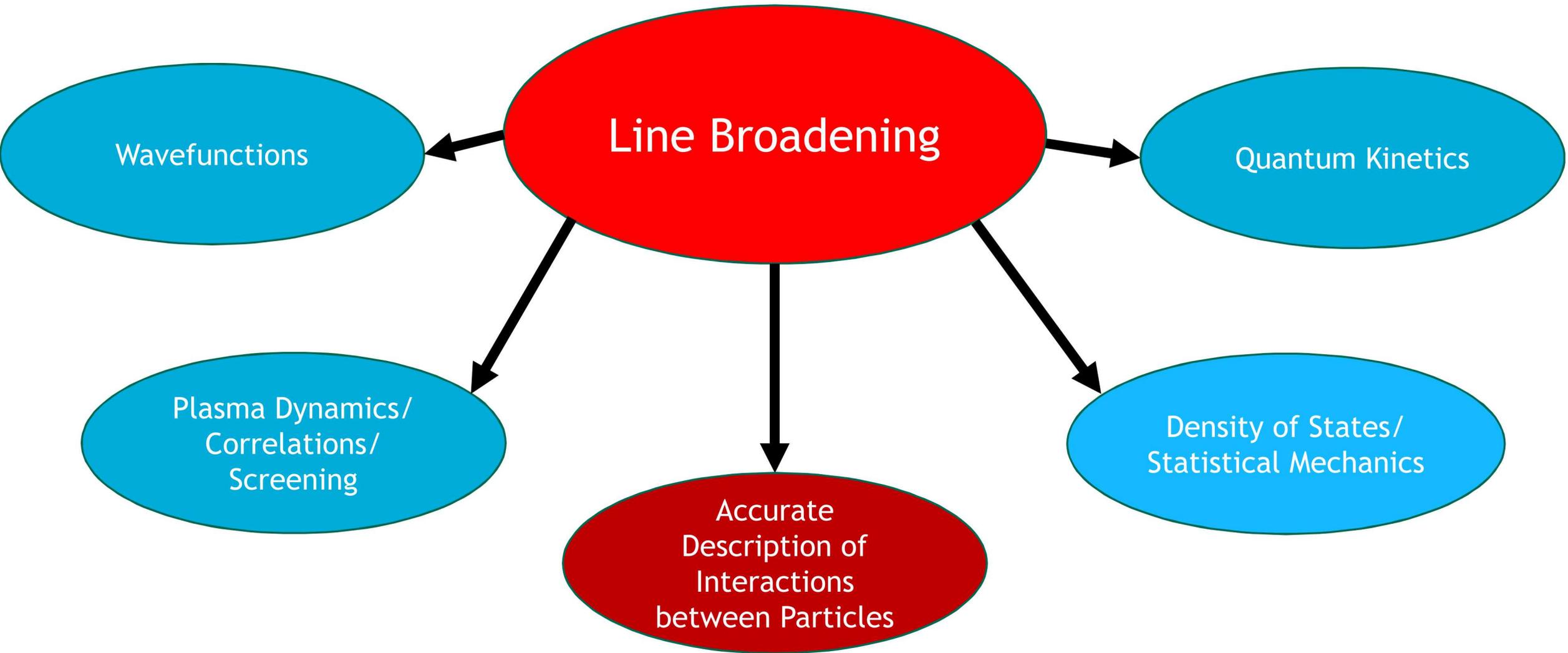
In the atmospheres
Give the emergent Spectra



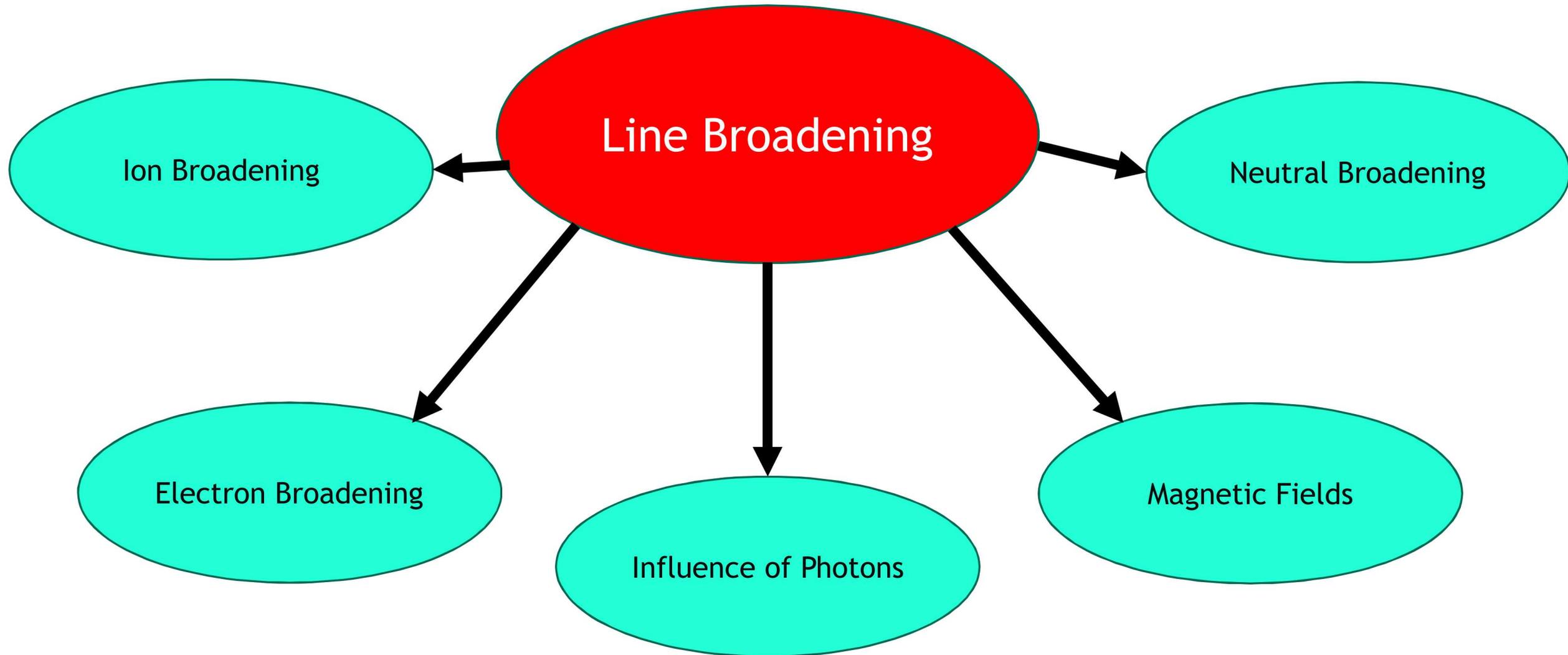


Line-Broadening Requires Multi-Disciplinary knowledge

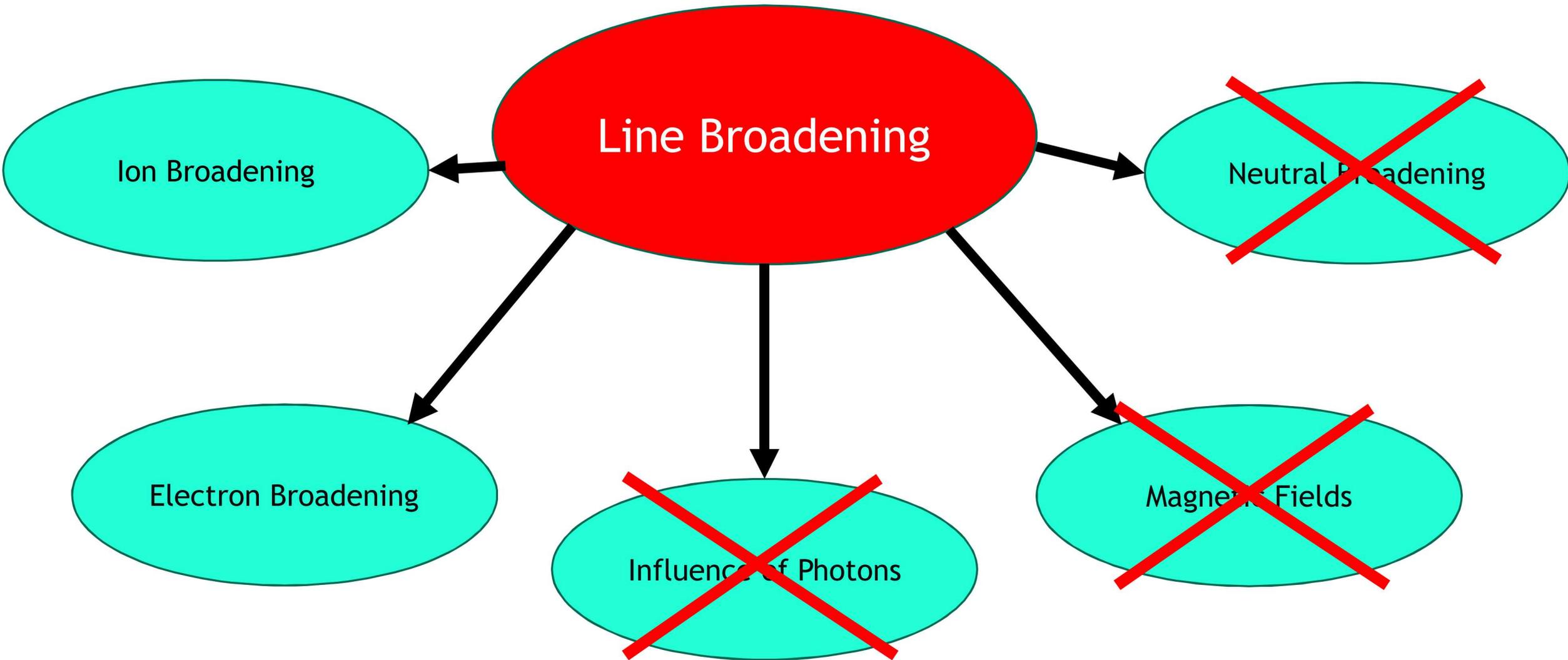




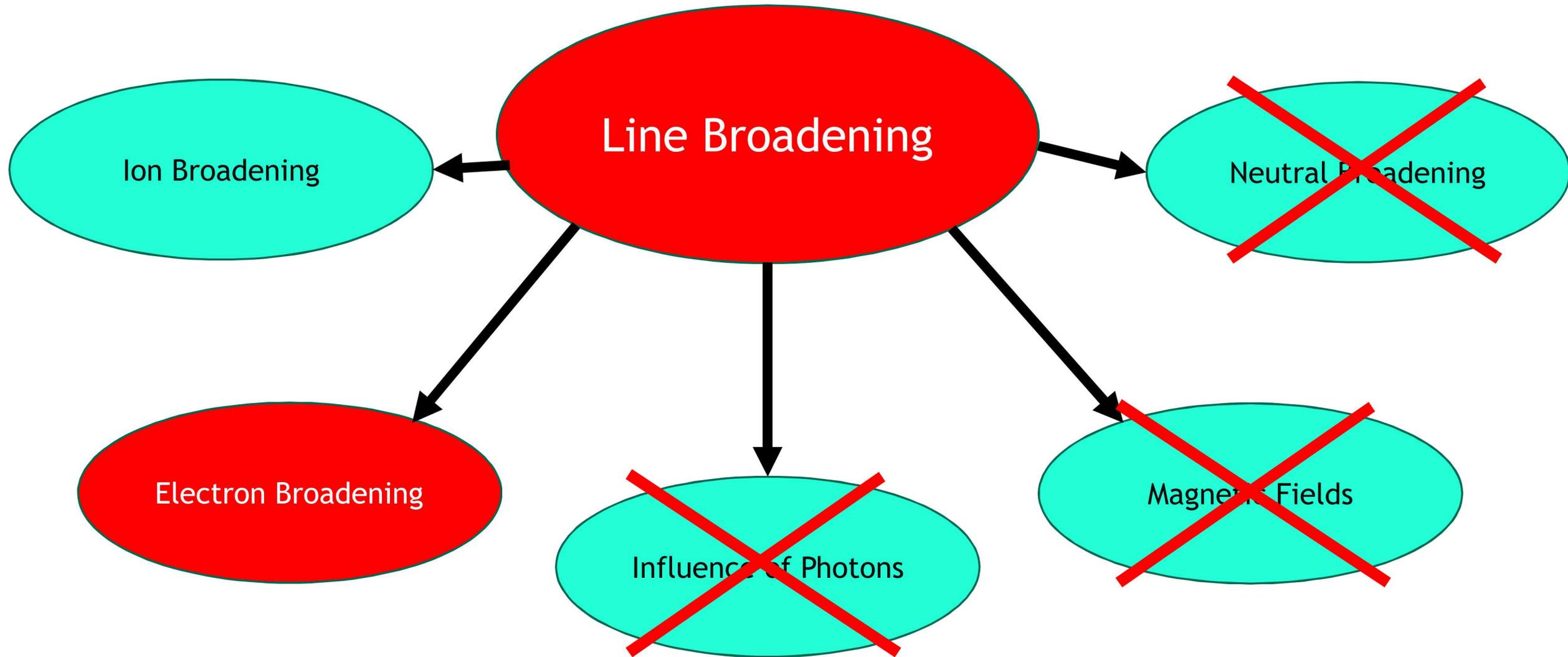
There are many Different Mechanisms that can Broaden Spectral Lines



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There are many Different Mechanisms that can Broaden Spectral Lines



Broadening of Multi-Electron atoms is incomplete

Any atom that has more than one bound electron is considered a multi-electron atom

The simplest are those with one valence electron: Li-like, Na-like, K-like, etc.

The next simplest are those with closed l shells and one electron in an open shell: B-like, Al-like

The most complex are with more than one electron in open shells

Multi-Electron Atoms

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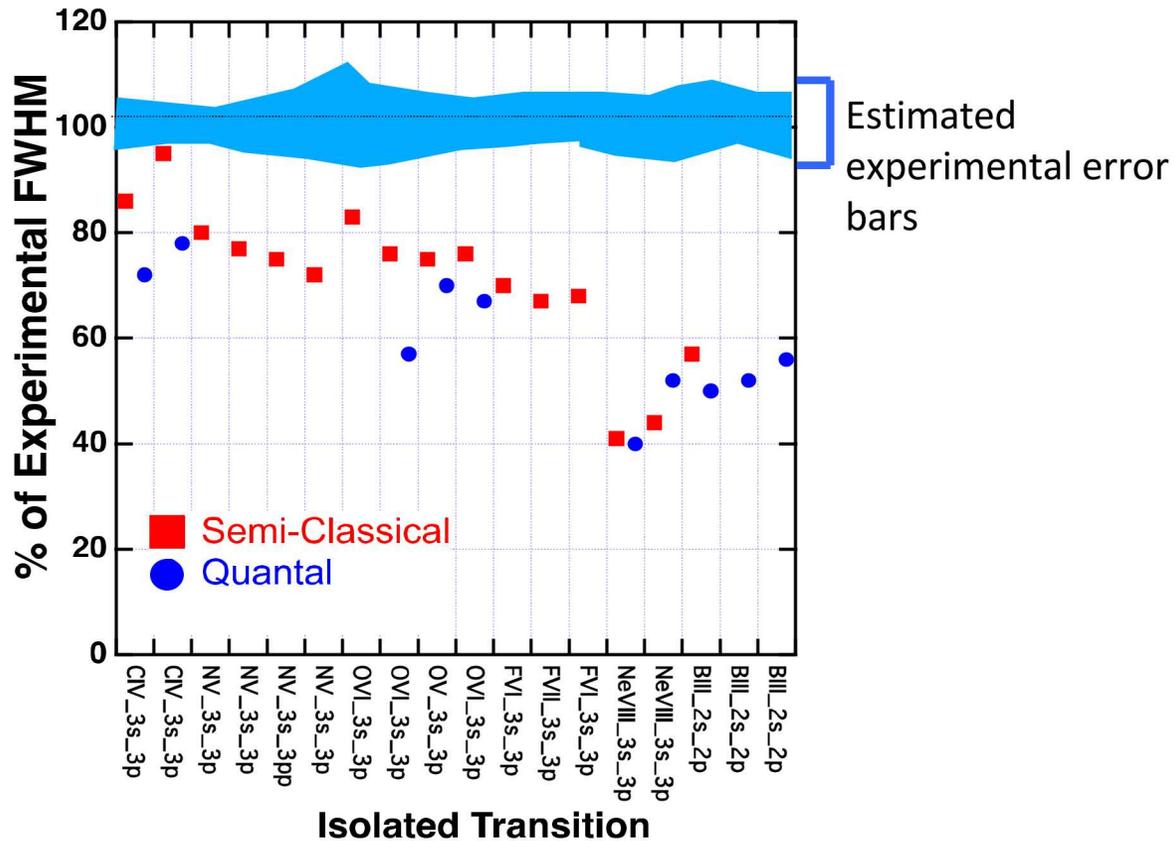
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We DO NOT Understand the Broadening of the Simplest Multi-Electron Atoms

Calculations Cannot Match Line-Width Measurements for 3-Electron Atoms



There are measurements of 3-electron atoms with independent plasma diagnostics

Current *ab-initio* calculations of line broadening of simple 3-electron atoms currently cannot match measured widths

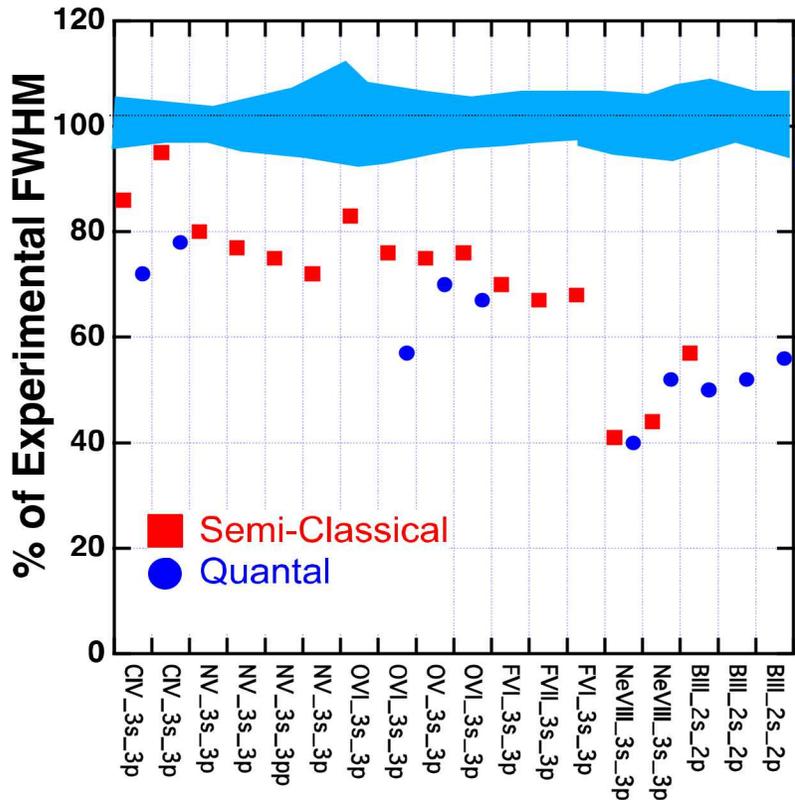
- Factor of two in some cases

Current *semi-empirical* calculations fare better

- uncertain within 20-30% for these lines.

Discrepancy is worse with large energy separation between states

Calculations Cannot Match Line-Width Measurements for 3-Electron Atoms



Estimated experimental error bars

There are measurements of 3-electron atoms with independent plasma diagnostics

Current *ab-initio* calculations of line broadening of simple 3-electron atoms currently cannot match measured widths

This is known as the isolated-line problem and has led to a decades-long investigation

Isolated Transition

Lee, Private Communication

Eur. Phys. J. D 54, 51-64 (2009)
DOI: 10.1140/epjdr/a2009-00167-8

Regular Article

Quantum Stark broadening of 3s-3p spectral lines in Li-like Z-scaling and comparison with semi-classical perturbation

H. Elabidi^{1,*}, S. Sahal-Brechot², and N. Ben Nessib³

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² LERMA, Observatoire de Paris, CNRS, Université Pierre et Marie Curie, Place Jules Janssen, 92190 Meudon
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THE EUROPEAN PHYSICAL JOURNAL

Journal of Quantitative Spectroscopy & Radiative Transfer 99 (2006) 10-20

Semiclassical calculations of line broadening in plasmas: Comparison with quantal results

S. Alexiou, R.W. Lee*

Lawrence Livermore National Laboratory, University of California, L-399, P.O. Box 808, 7060 East Avenue, Livermore, CA 94550, USA

Atoms 2014, 2, 157-177; doi:10.3390/atoms2020157

Article

The Second Workshop on Lineshape Code Comparison: Isolated Lines

Spiros Alexiou^{1,*}, Milan S. Dimitrijević², Sylvie Sahal-Brechot³, Evgeny Stumbulchik⁴, Bin Duan⁵, Diego González-Herrero⁶ and Marco A. Gigasos⁶

¹ TETY, University of Crete, 71409 Heraklion, TK2208, Greece
² Astronomical Observatory, Volgina 7, Belgrade 11060, Serbia; E-Mail: mdimitrijevic@aobrs
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⁴ Institute of Physics, National Academy of Sciences, 11134 Sofia, Bulgaria
⁵ Institute of Physics, National Academy of Sciences, 11134 Sofia, Bulgaria
⁶ Institute of Physics, National Academy of Sciences, 11134 Sofia, Bulgaria

PHYSICAL REVIEW A VOLUME 45, NUMBER 12 15 JULY 1992

Stark broadening of spectral lines along the isoelectronic sequence of Li

S. Glenzer, N. I. Uzelac,* and H.-J. Kunze
Institut für Experimentalphysik V, Ruhr-Universität, 4630 Bochum, Federal Republic of Germany
(Received 13 January 1992)

Experimental Stark widths of the 3s²S - 3p²P^o transitions in the Li-like ions CIV, NV, OVI, and NeVIII are reported. The measurements were performed for a set of plasma parameters so that the density and temperature behavior of the Stark widths could be observed and compared with calculations. The experimental results did not show a scaling with Z⁻², where Z is the spectroscopic charge number, which is expected from theoretical calculations in the electron-impact approximation. Furthermore, deviations from linear scaling appear for Z = 8.

PACS number(s): 32.70.Kz, 32.70.Jz

I. INTRODUCTION
Investigations of Stark widths of highly charged non-hydrogenic ions along isoelectronic sequences are of great interest since cross sections for impact broadening scale

II. THEORETICAL STARK WIDTH
For the calculation of the Stark widths we use a semiclassical impact theory of Ref. [5] and a semiempirical approach as given in Ref. [6]

Journal of Quantitative Spectroscopy & Radiative Transfer 81 (2003) 371-384

Electron-impact broadening of the 3s-3p lines in low-Z Li-like ions

Yu.V. Ralchenko^{a,*}, H.R. Griem^b, I. Bray^c

^a Faculty of Physics, Weizmann Institute of Science, Rehovot 76100, Israel
^b Department of Physics, University of California, San Diego, La Jolla, CA 92037, USA
^c Lawrence Livermore National Laboratory, University of California, L-399, P.O. Box 808, 7060 East Avenue, Livermore, CA 94550, USA

PHYSICAL REVIEW A VOLUME 49, NUMBER 1 JANUARY 1994

Collision operator for isolated ion lines in the standard Stark-broadening theory with applications to the Z scaling in the Li isoelectronic series 3P-3S transition

Spiros Alexiou
Department of Nuclear Physics, Weizmann Institute of Science, Rehovot 76100, Israel
(Received 8 March 1993)

In this work we review some aspects of the semiclassical dipole impact approximation for isolated ion lines with a view to the questions on Z scaling raised by two recent experimental studies. Some theoretical and practical aspects of line-shape calculations are discussed. Detailed calculations are performed in the semiclassical (dipole) impact approximation for the Li isoelectronic series 3P-3S line. Particular emphasis is given to inelasticity effects. In contrast to previous calculations, very good agreement is obtained for the lighter elements of the isoelectronic series. Ion dynamical corrections are also considered and are found to be negligible in the dipole approximation.

PACS number(s): 32.70.Jz, 32.30.Jc, 32.60.+i

Things to Consider for Electron Broadening

Size of Atomic Basis set

Accuracy of Atomic Wavefunctions

Density of States/Populations

Description of Plasma Electrons

- Classical
- Quantum
 - Exchange

Interaction between Atom and Plasma

- Dipole Approximation
- Coulomb Interaction

Collision Treatment

- Coulomb-Born
- Distorted-Wave
- CCC

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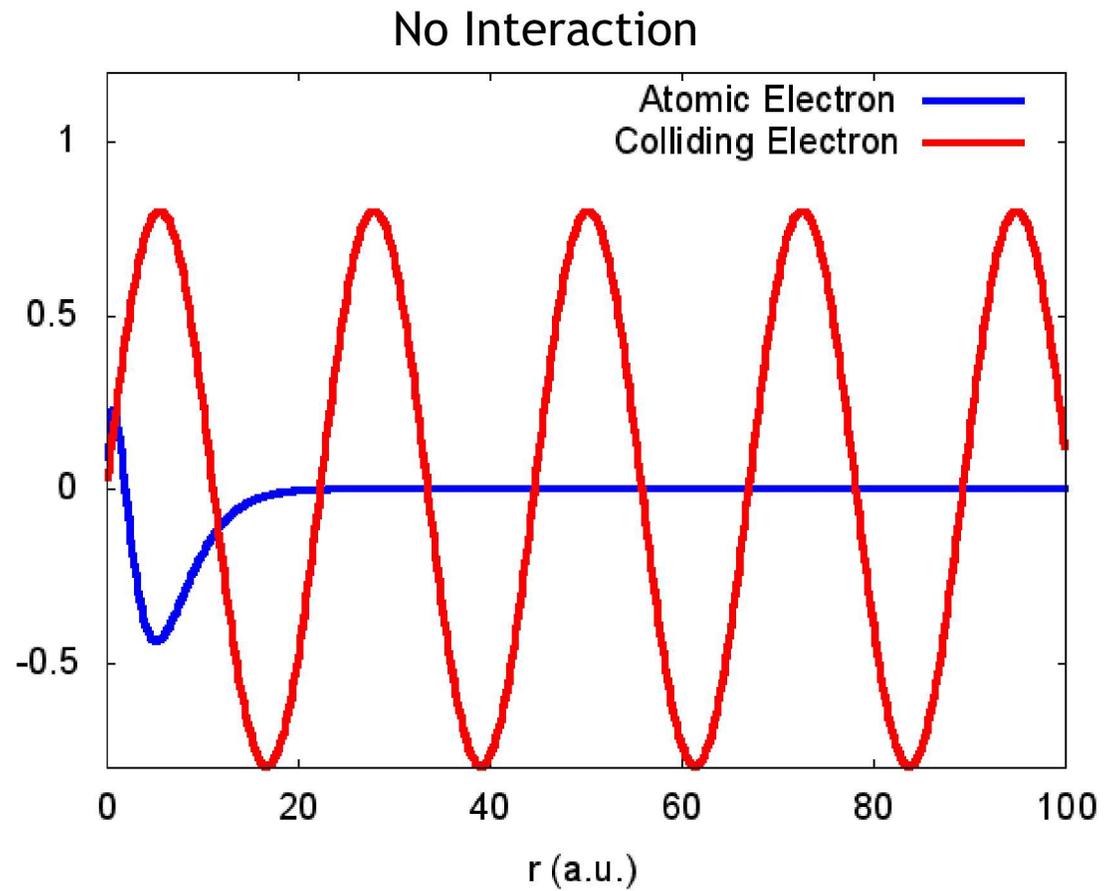
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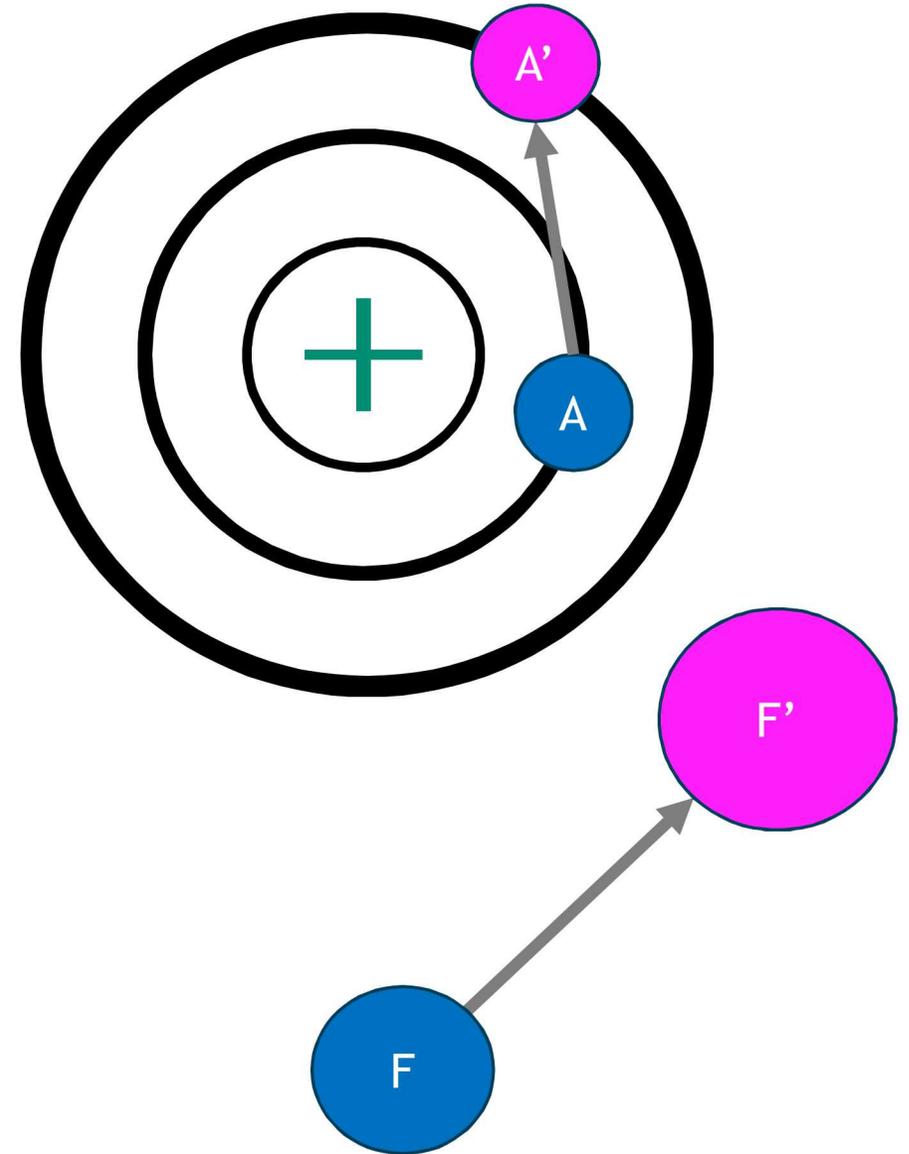


Direct Interactions are Straightforward

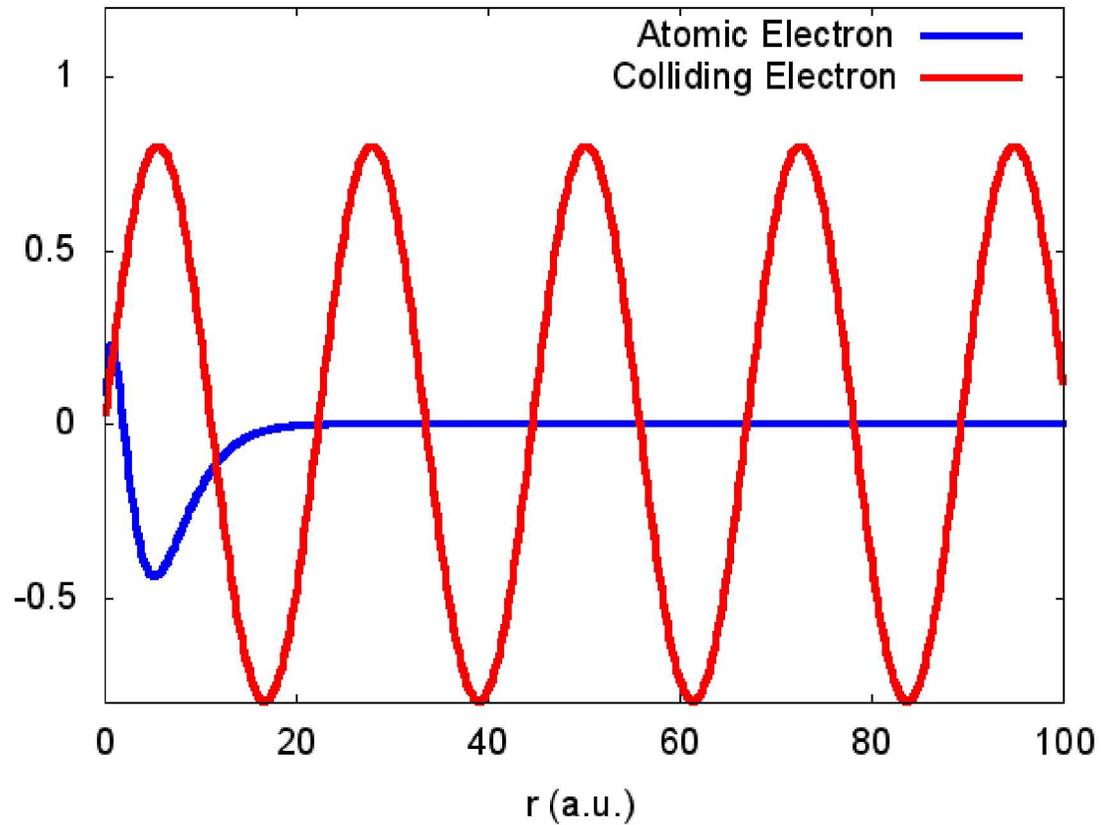
This type of interaction is where the atom and electrons change states

But the atomic electron remains the atomic electron and the free electron remains the free electron

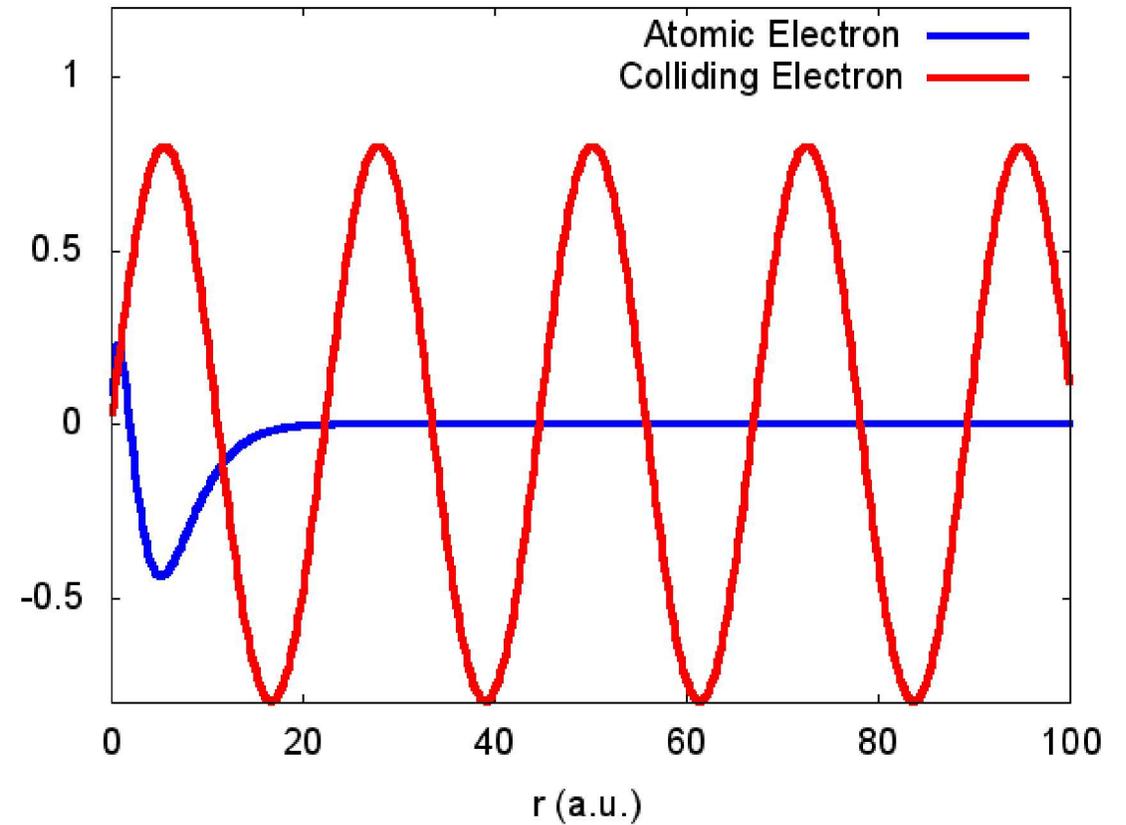
This interaction is usually well modeled because of the simple interactions involved



No Interaction



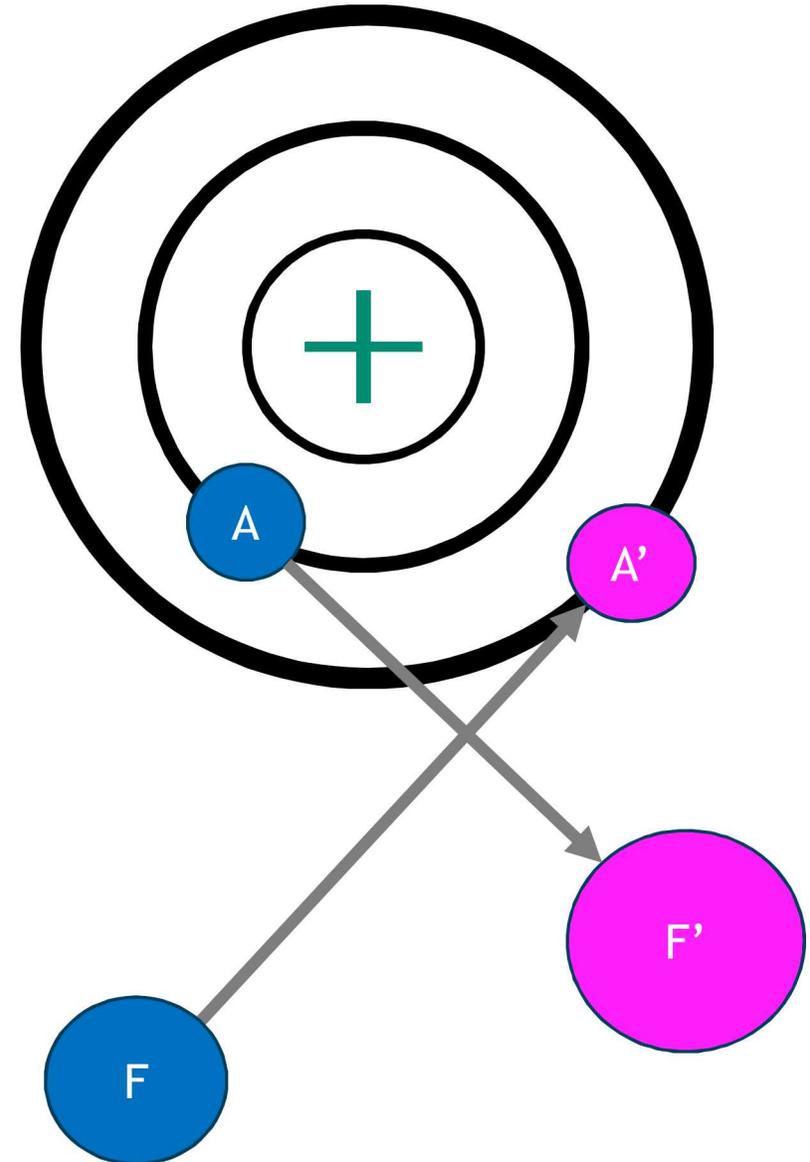
Direct Interaction only



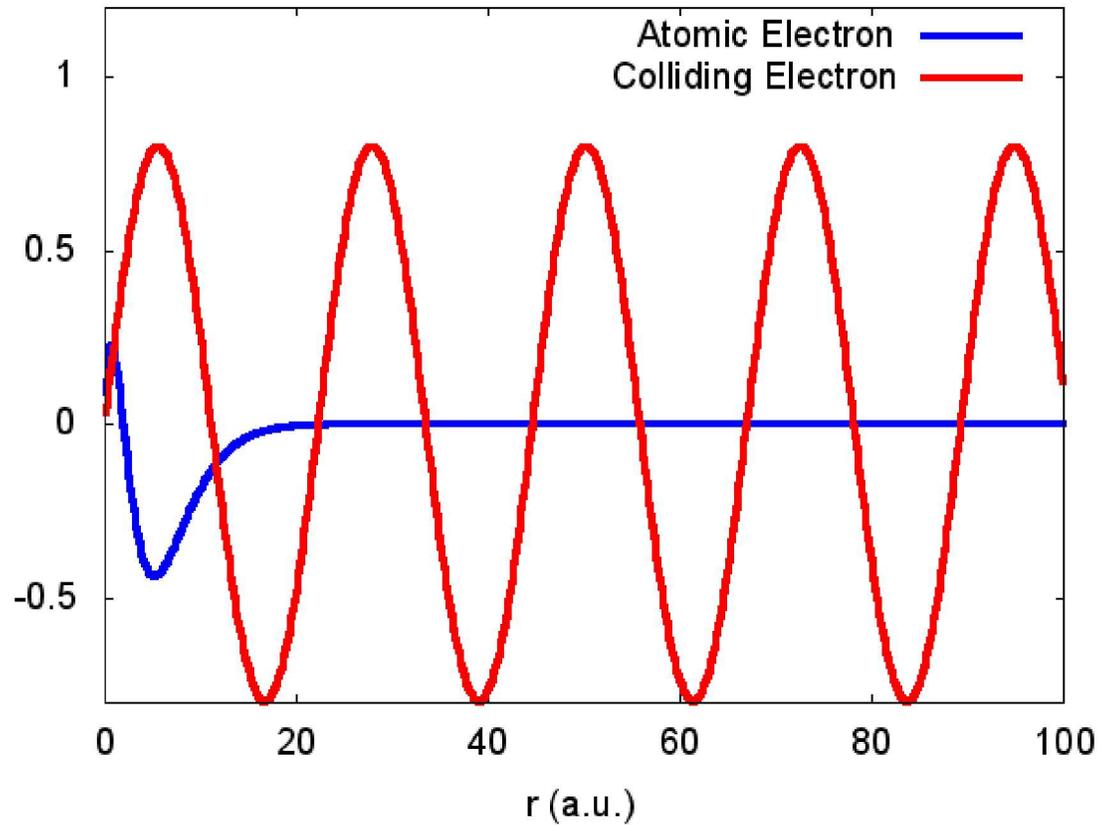
Exchange Interactions

The atomic electron can exchange places with the free electron and change states in this way

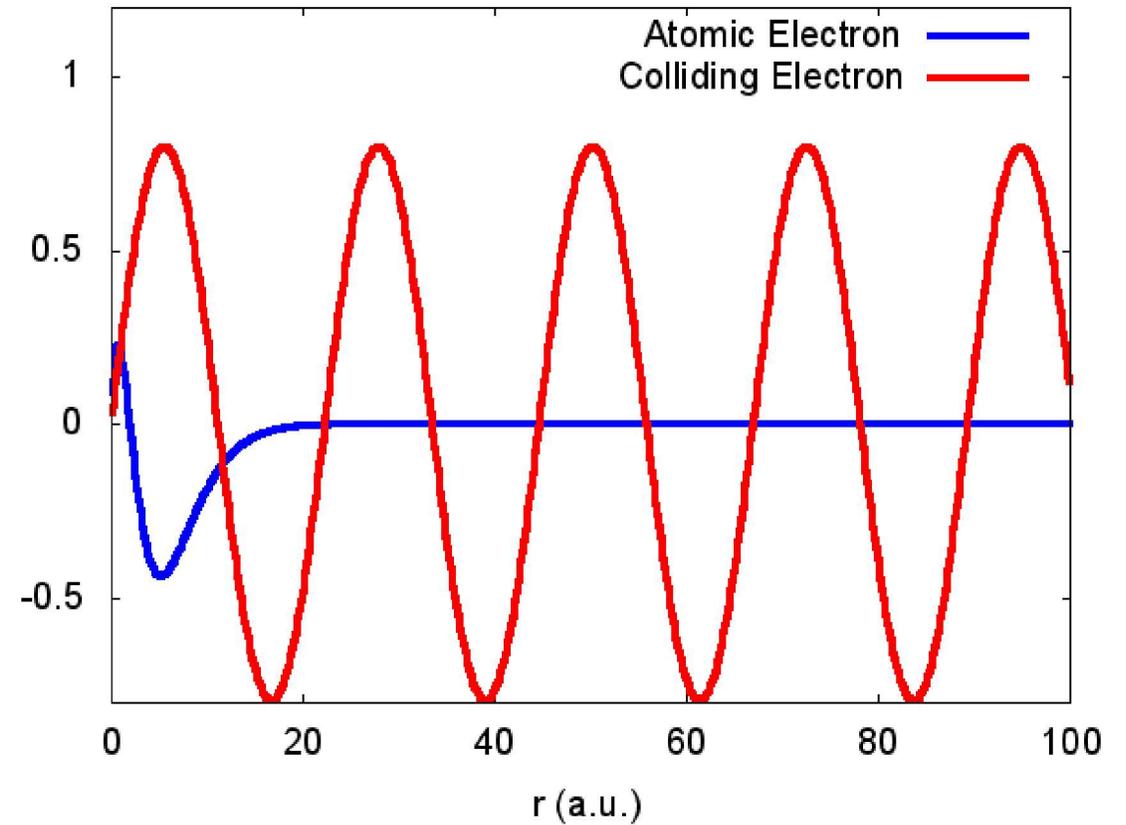
This adds some complexity to the calculation, but is manageable



No Interaction



Direct + Exchange Interaction

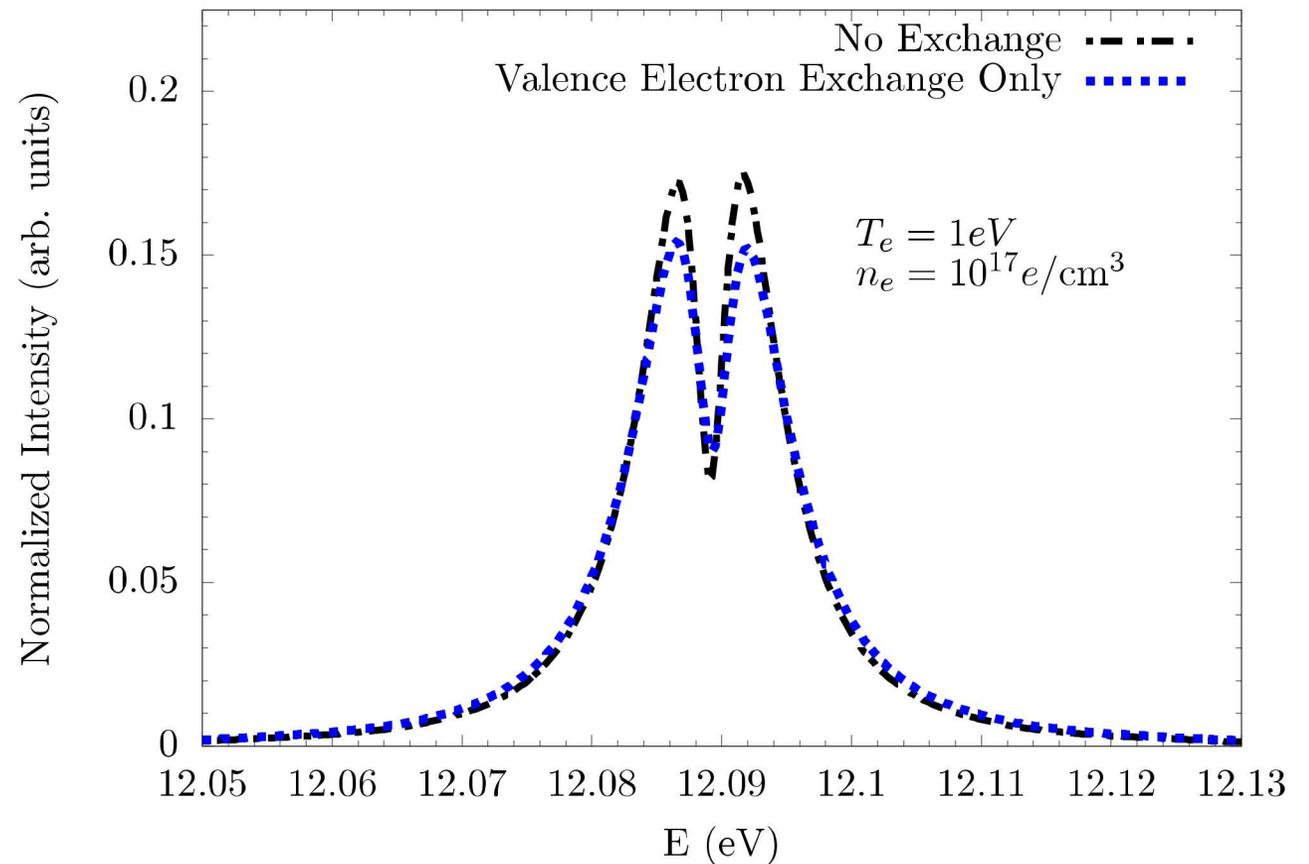


Exchange is Important Even for Hydrogen

One might be led to the conclusion that because hydrogen spectra is accurately modeled by semi-classical methods that exchange is unimportant

But this is not true in the slightest

Exchange can add substantial broadening for hydrogen



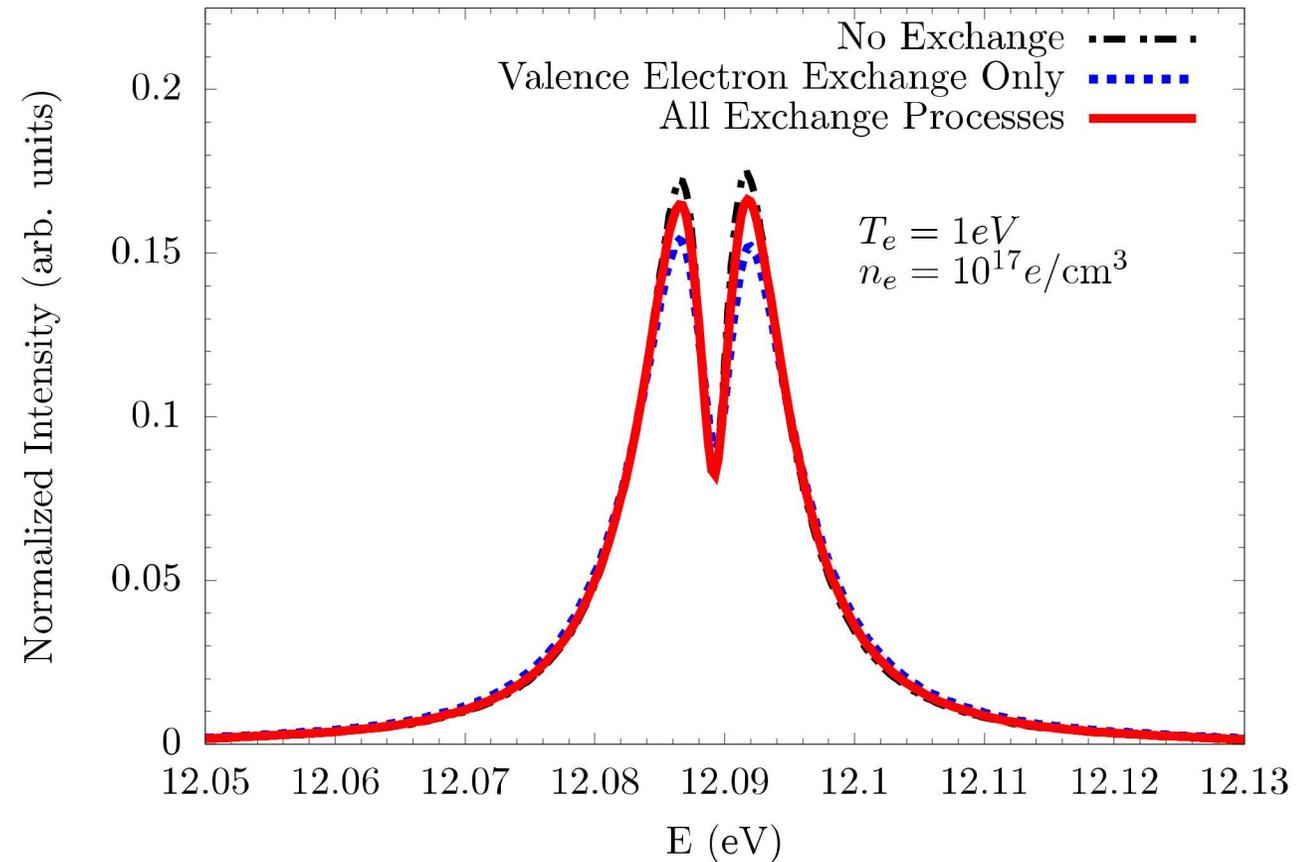
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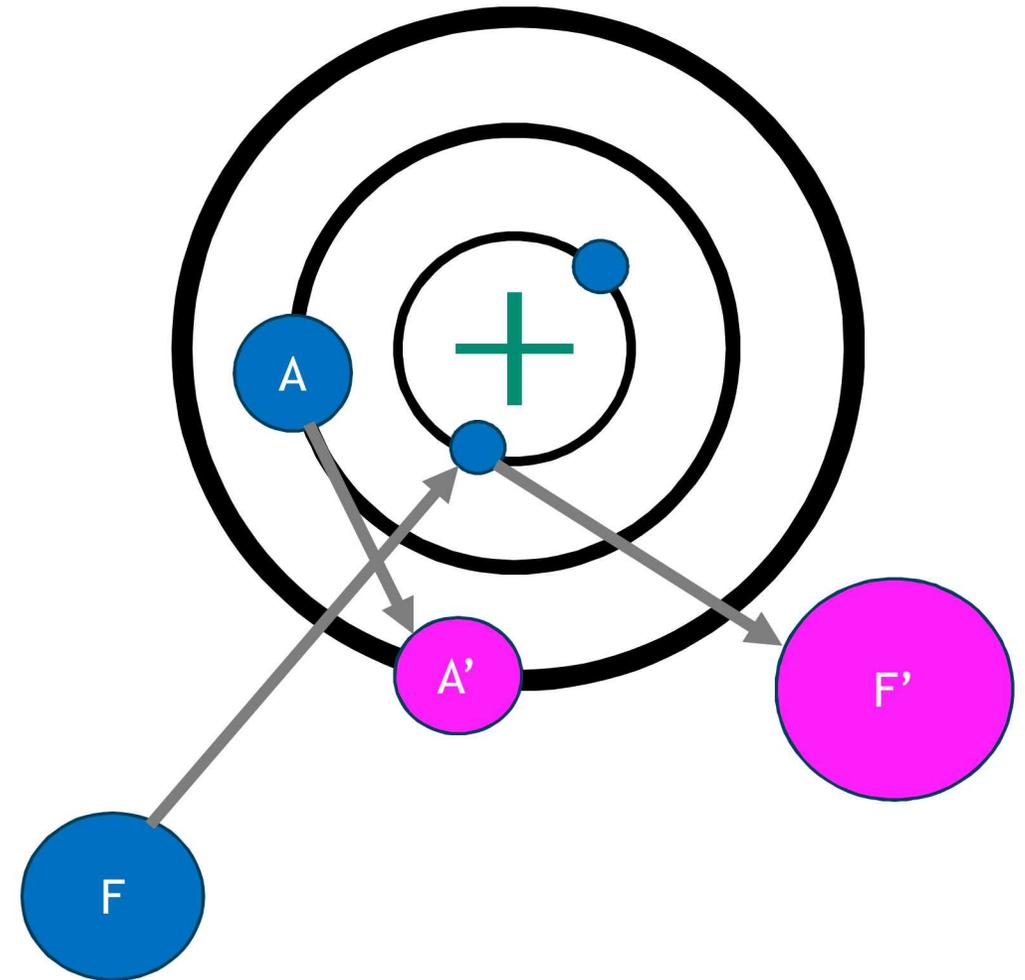
But because exchange can also occur with nuclear interactions, the effect of exchange is largely cancelled for hydrogen



Exchange Interactions for Multi-Electron Atoms

Seaton (1953) laid out the relevant exchange processes in collisions

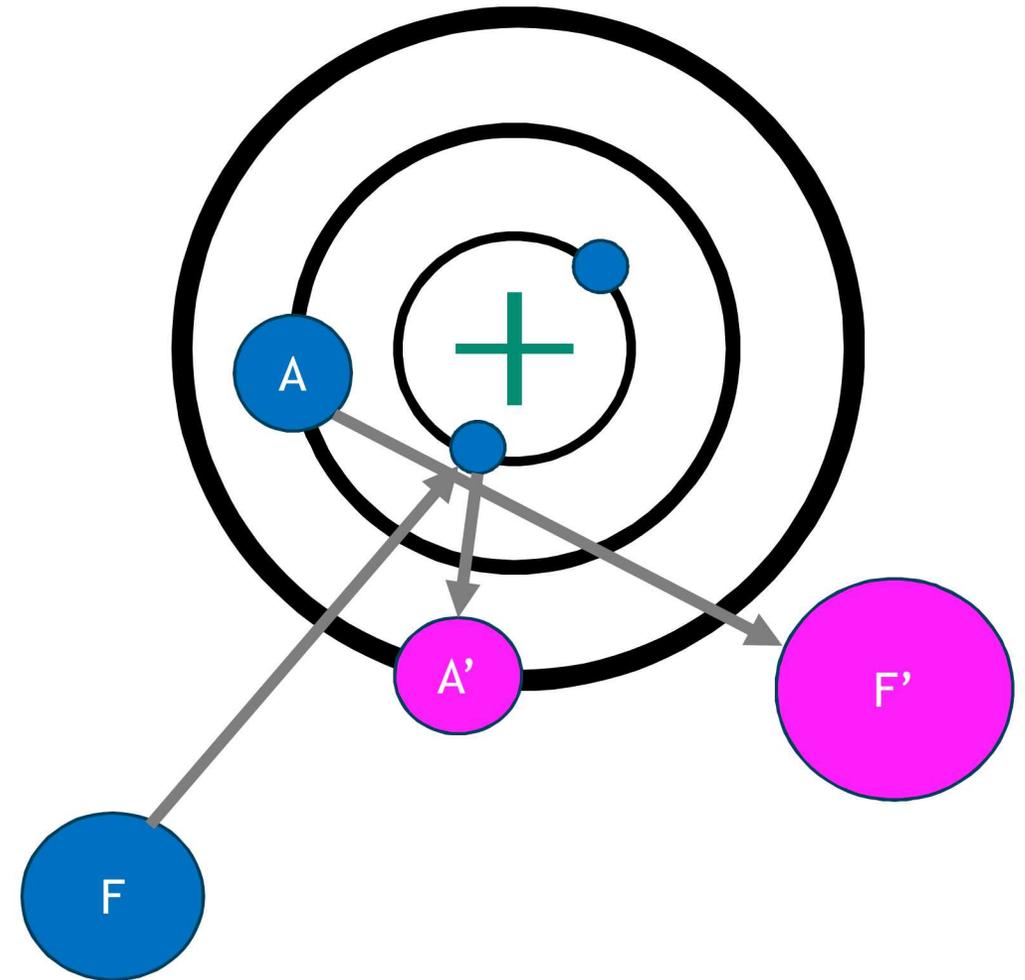
These include not only two-body exchange, but three-body exchange as well (assuming atomic wavefunctions are roughly orthogonal)



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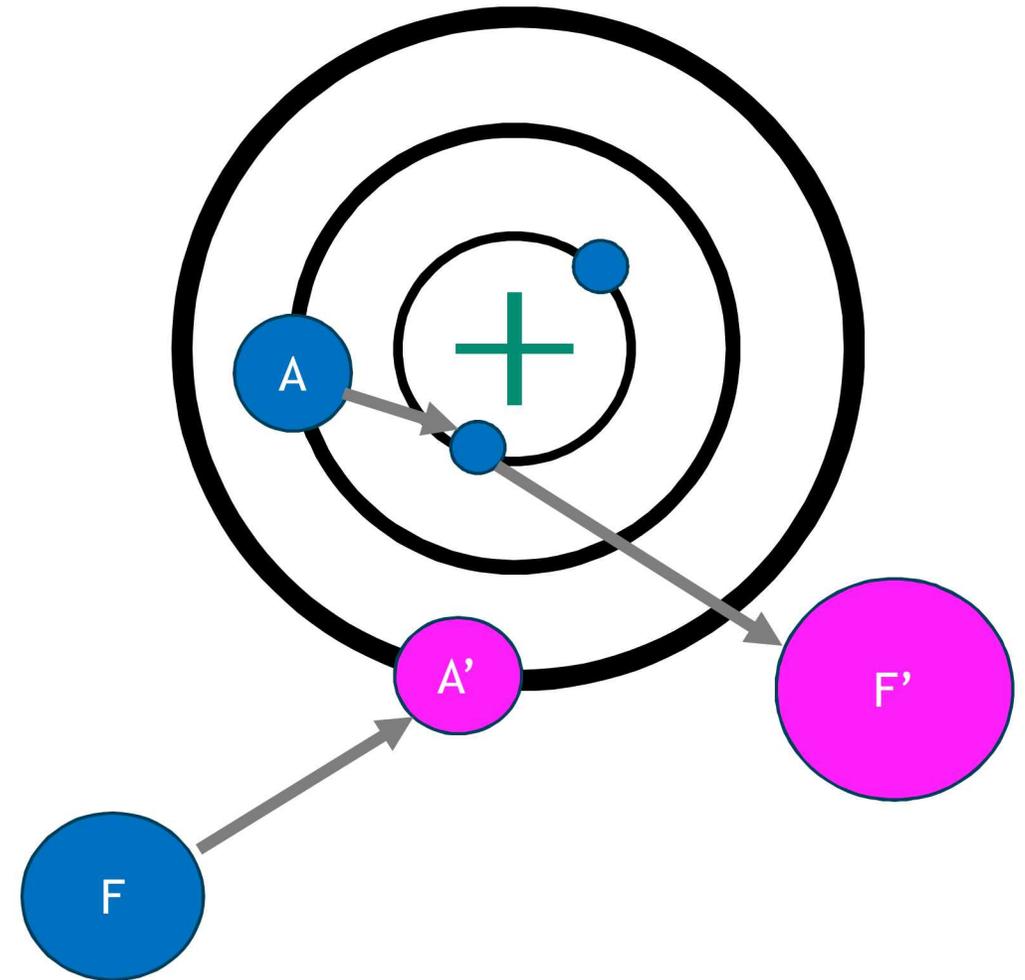
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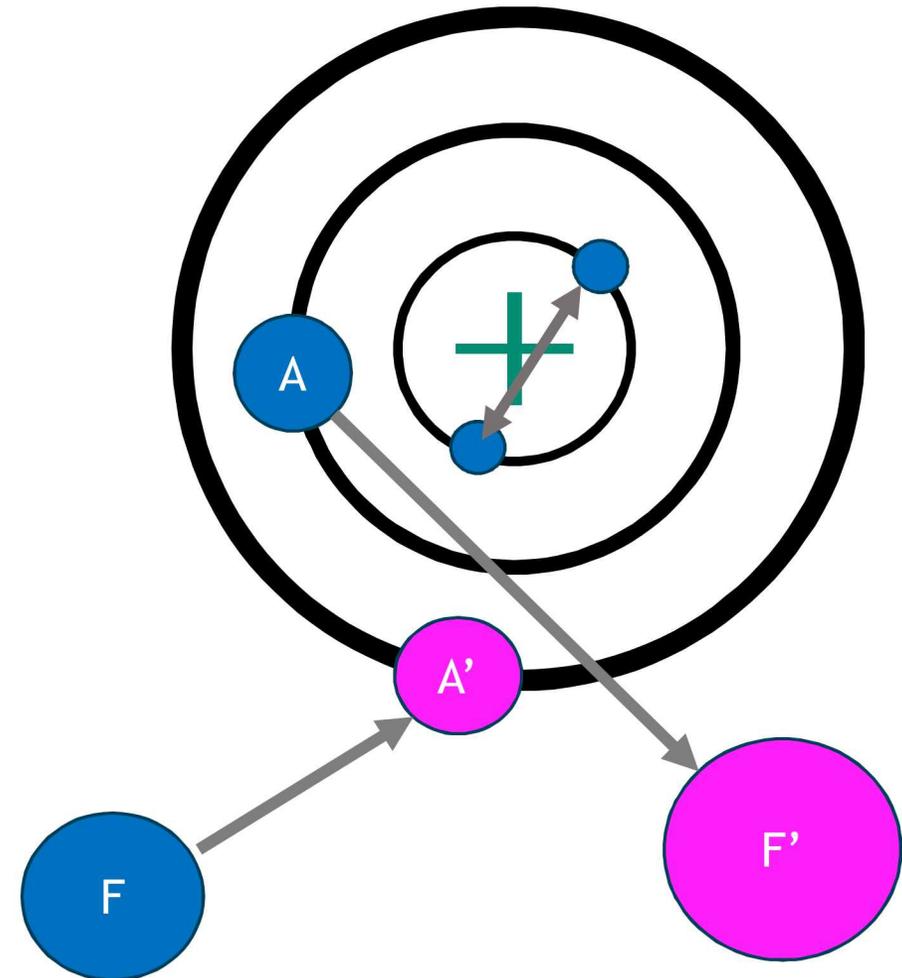
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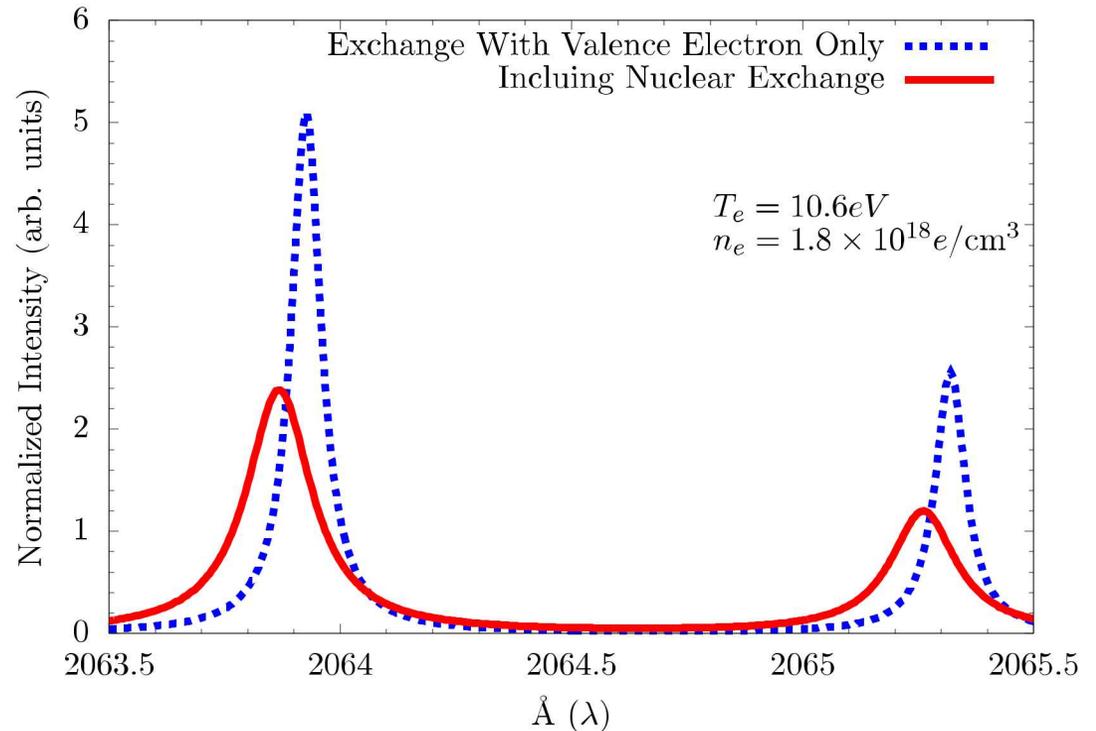


These Exchange Terms are Large

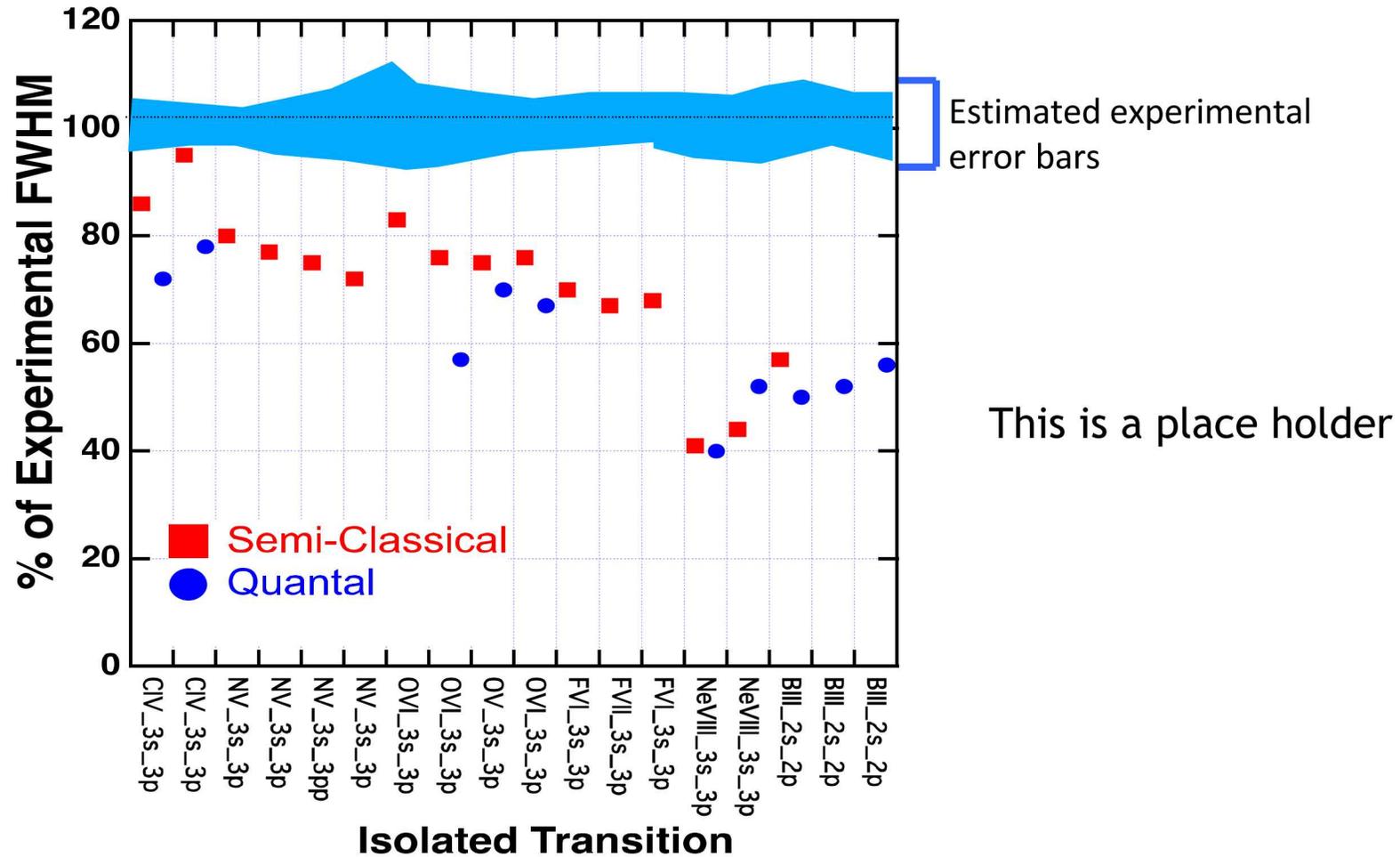
One exchange process—such as the nuclear contribution—can contribute a factor of two in the line shape

This shows that exchange processes are important

Exchange has no classical analog and semi-classical calculations cannot model these systems from an *ab-initio* calculation



Current Progress on Matching Experimental Data



This is a work in progress to accurately model—from an *ab-initio* method—multi-electron systems

This work will be valuable for determining masses of white dwarfs with carbon-rich atmospheres

- thought to be some of the most massive white dwarfs

This will also be important for calculating line broadening and line shifts of helium lines that will aid in determining their masses as well (See Marc Scheauble's talk)