SAND2020-7961C

Improvements in Mg Line shape Models

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Electron-Broadened Line Shapes are Given by the Average Collision Amplitude

- The line shape as derived is approximately the thermally-averaged collision amplitude (which is defined by the T-matrix) multiplied by the electron density

$$\langle \alpha \left| \mathcal{H}(\Delta\omega) \right| \alpha' \rangle = n_e \lambda_T^3 \int_0^\infty d^3\vec{\mathbf{k}}\; e^{-\beta \frac{1}{2} k^2} \langle \alpha \mathbf{k} \left| T(E) \right| \alpha' \mathbf{k} \rangle$$

$$E = \Delta\omega - E_{\alpha'} + E_{\mathbf{k}}$$

- The important quantity that we need to calculate is the T-matrix
  - The T-matrix is often calculated by many collision codes, so we can benchmark
  - These collision codes only calculate T-matrix for $\Delta\omega = 0$

The T-matrix Depends on Interaction Between Atom and Plasma Electron

- The T-matrix is defined as a function of the energy, and the interaction, V, between atom and plasma electron

$$T(E) = \frac{1}{1 - V(E - H_0)^{-1}} V$$

- The V interaction is a Coulomb interaction between charged particles
    - This interaction also includes Pauli repulsion

Line Broadening Calculations Often Approximate T-matrix and Interaction

- The most convenient method of evaluation is to perform a Taylor expansion of the inverse operation

$$T(E) \approx V + V(E - H_0)^{-1}V$$

- Likewise, the V interaction is also approximated with a Taylo/Multipole expansion where only dipole term is retained

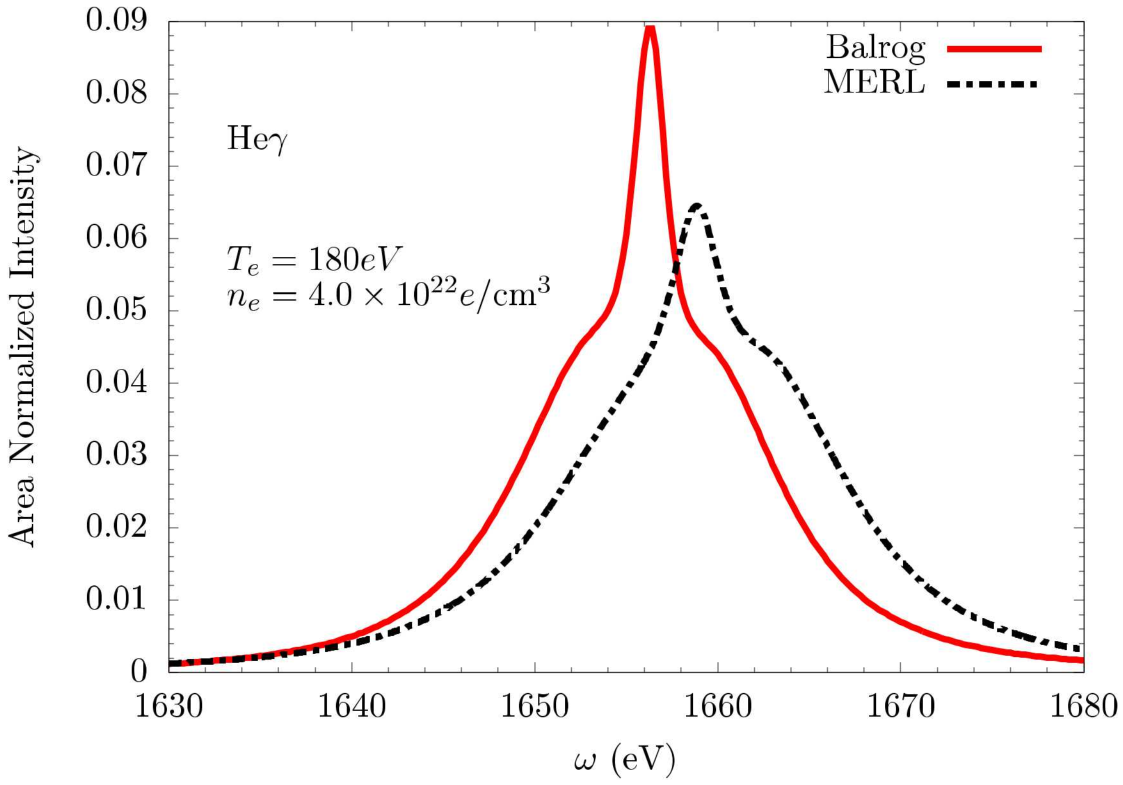
$$V \approx \vec{D} \cdot \vec{F}$$

- Therefore, line-broadening codes (such as MERL) make two Taylor expansions
- Sometimes this is OK, sometimes not.

We’ve spent much effort to do everything as exact as possible

- Many of these approximations are made (by people like Griem) with little more than hand waving explanations
  - Then Griem also includes things like strong collision corrections to make up for the problems with these approximations
  - Further Griem assumes plasma is classical
- We can never know the accuracy of these approximations until we do the problem exactly
- We therefore have developed a code–dubbed “balrog”—that does everything exactly
  - Complete Coulomb interaction with Pauli Repulsion
  - Solve T-matrix exactly
  - Quantum Electrons (including electron recombination/capture)

The Results: Exact Treatment Gives Additional Shift and Less Broadening than MERL



- Monopole Coulomb interactions Give Rise to Shifts
- Second-order T-matrix is OK approx here
- Full Coulomb treatment leads to weaker interaction->smaller line widths
- Electron Recombination not important here

How do we know it's right? We compare against other established collision codes

- Here is my code compared with CCC
- We are at the point where we can replicate their results and can turn on and off certain features
- Big thanks to Igor Bray and Mark Zammit for providing calculations and helping me figure out exchange issues