Stark Broadening Models in Prism Codes

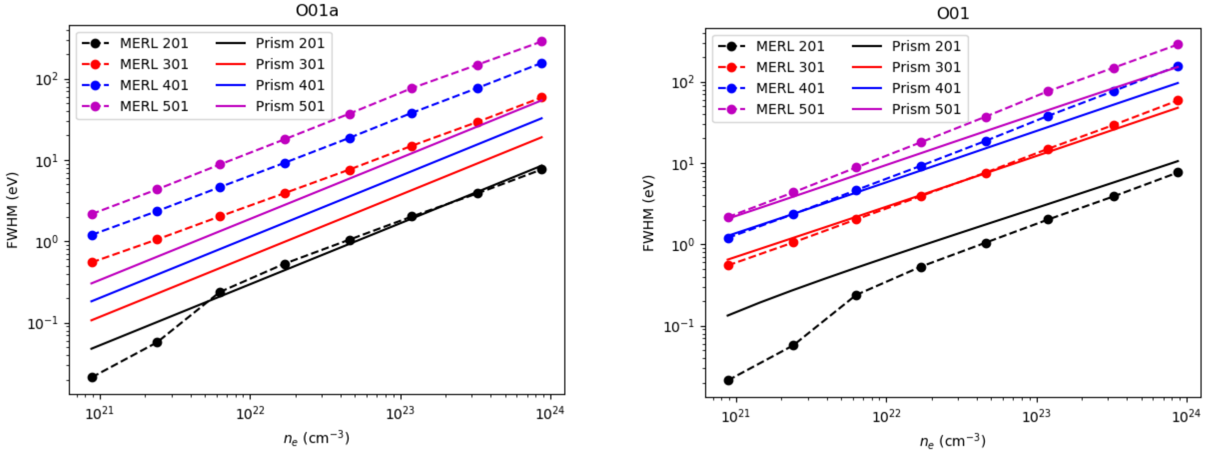
Until 2022, Prism codes utilized a semi-empirical method proposed by H. R. Griem (JQSRT, 17, p729 (1977)) for most transitions. Several improvements over the semi-empirical model for K-shell transitions. For low Z elements ($Z < 10$), we utilize modified Griem's formalism (Phys. Fluids B, **4**, p. 2346 (1992)) for Lyman and Balmer lines in H-like ions. For mid-Z elements ($10 \leq Z \leq 20$), we use line width fitted to detailed calculations by D. Haynes (private communications (2001)) across a wide range of electron number density. The fits include alpha (n=2) though epsilon (n=6) lines in H and He-like ions. Widths for higher n are scaled with n^3 based on the epsilon width. The error of the fit in most cases is less than 15%.

The newly implemented Stark broadening in PrismSPECT/Spect3D is based on the semi-empirical model detailed in Gu and Beirsdorfer (Phys. Rev. A, 101, 032501). In this approach, the line width calculation starts with the electron broadening in the impact approximation, calculated with the Baranger's formula using detailed electron impact excitation rate coefficients already required in the collisional radiative models. For LTE calculations, where detailed cross sections are not typically loaded, we estimate the impact width using oscillator strengths of electric dipole transitions. The impact widths are then combined with the quasi-static and quasi-contiguous approximation of Stambulchik and Maron (J. Phys. B, 41, 095703) to include the ion contributions. However, these approximations are generally only valid for weakly coupled plasmas, where the ion micro field is assumed to follow the classical Holtsmark distribution. For plasmas with strong coupling, the ion micro field deviates from the Holtsmark distribution significantly, we therefore introduce a correction factor, which is the ratio of the quasi-static width calculated using the realistic ion micro field to that calculated using the Holtsmark distribution. The micro field distribution for strongly coupled plasmas are calculated using a fitting formula developed by Gu and Beiersdorfer (Phys. Rev. A, 101, 032501), which is designed to closely match the numerical results from the Adjustable Parameter Exponential Approximation (APEX) of Iglesias, Lebowitz, and MacGowan (Phys. Rev. A., 28, 1667).

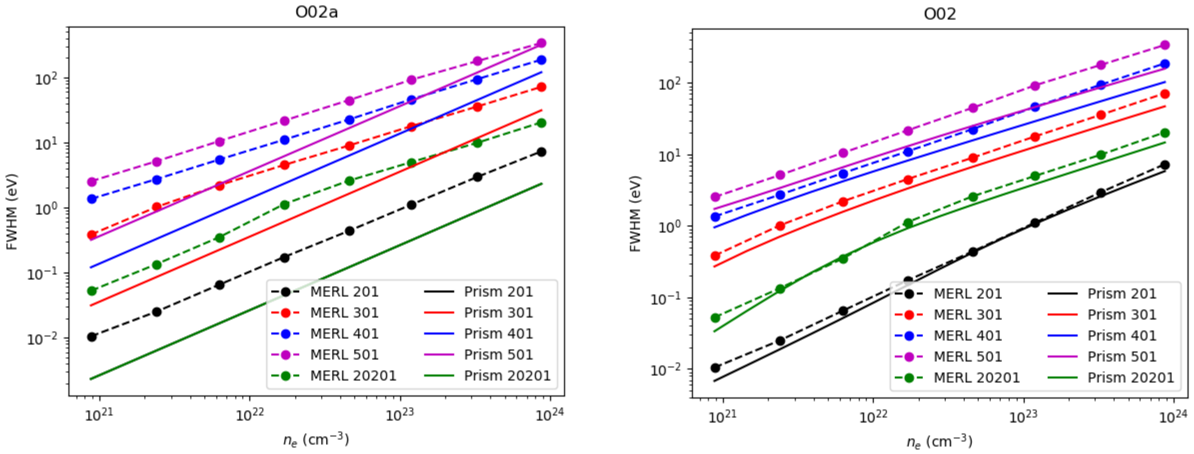
Both old and new models are applied to radiative transitions in ionized species. For transitions in neutral atoms, pressure line broadening includes modified Stark broadening algorithms (Astrophys. J. 224 p. 1079 (1978), Astron. Astrophys. 163 p. 297 (1986)), dipole-dipole resonance and van der Waals broadening (Physics Reports 316, p.339 (1999), Phys. Rev. A 19, 2421 (1979)).

Users of Prism software can control whether to use the old or the new Stark broadening model in preferences for each application. The default option is to use the new model.

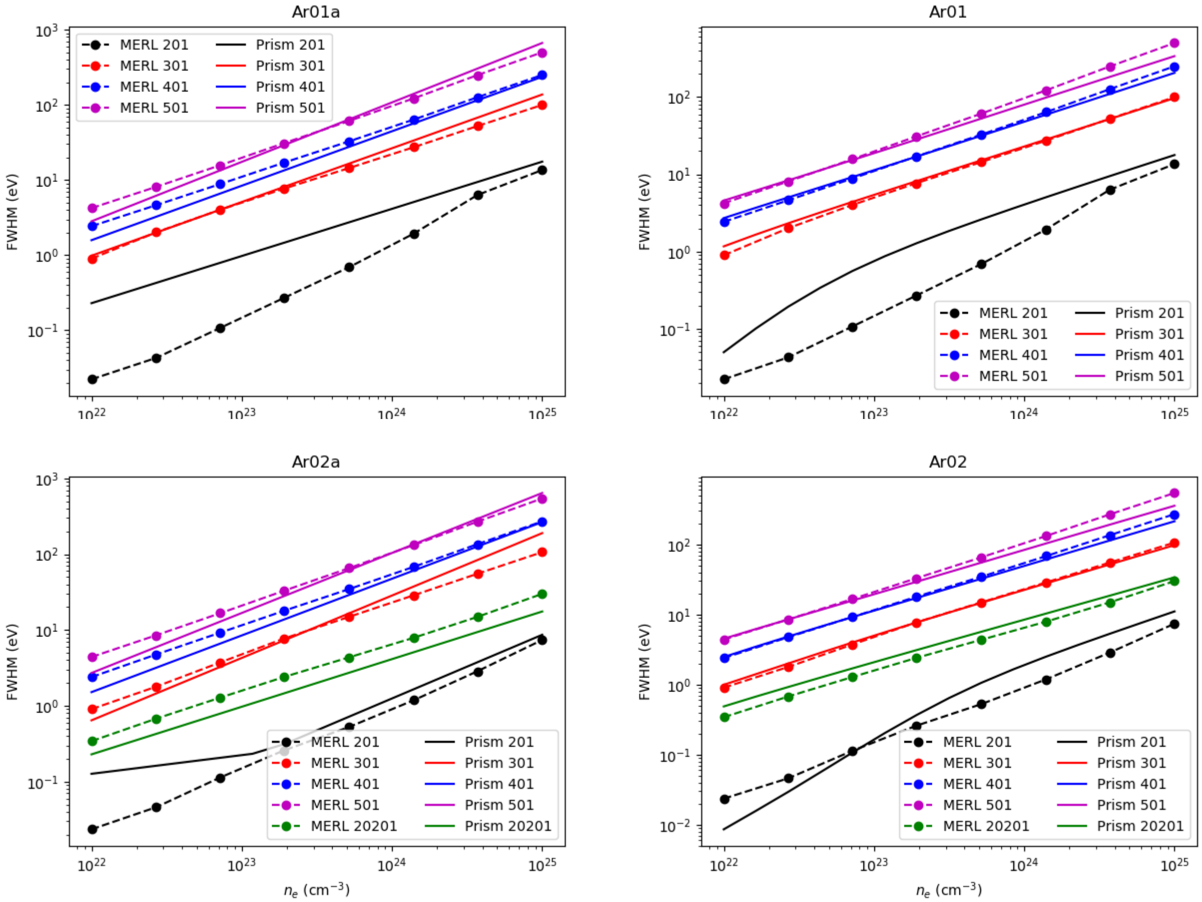
We have computed detailed line profiles of select H-like and He-like ions with MERL (Phys. Rev. A, v. 38, 9, p. 4766 (1988); Comp. Phys. Comm 63, p. 314 (1991)) to calibrate the new model.



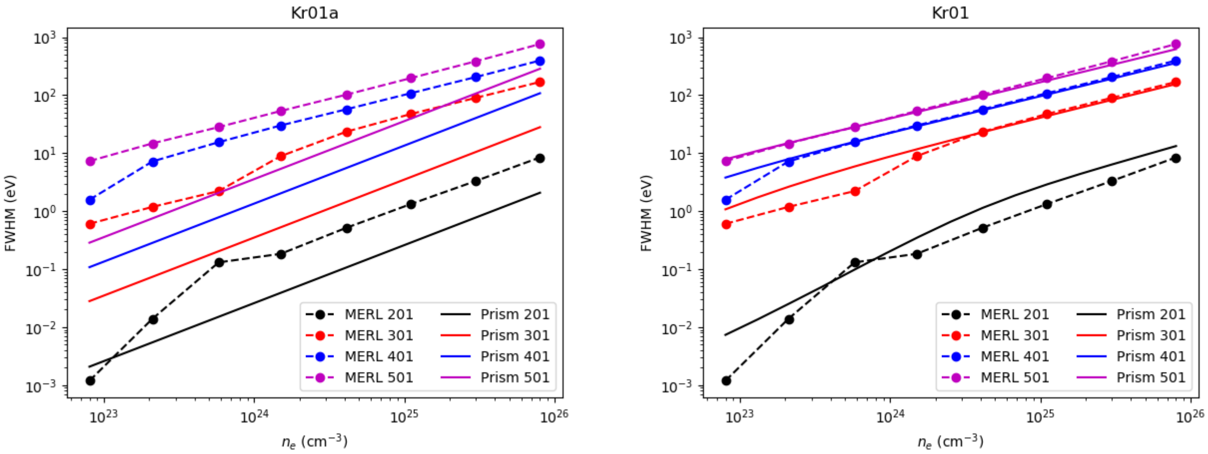
The above figure shows the FWHM of the Lyman series of H-like Oxygen calculated with MERL and the old (left panel) and new (right panel) Stark width model of PrismSPECT. The figure below shows the same for He-like Oxygen series, including the KLL satellite transitions to the Lyman α line.

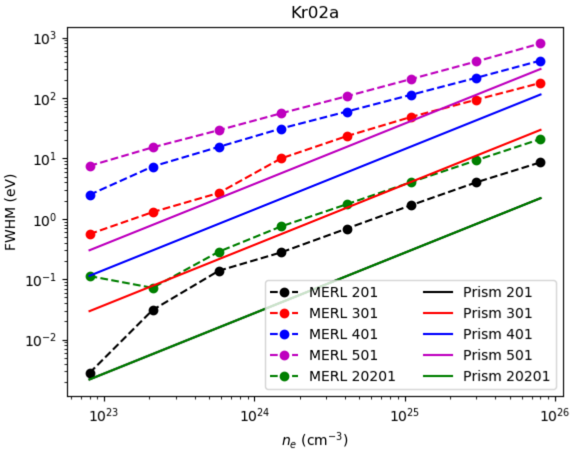


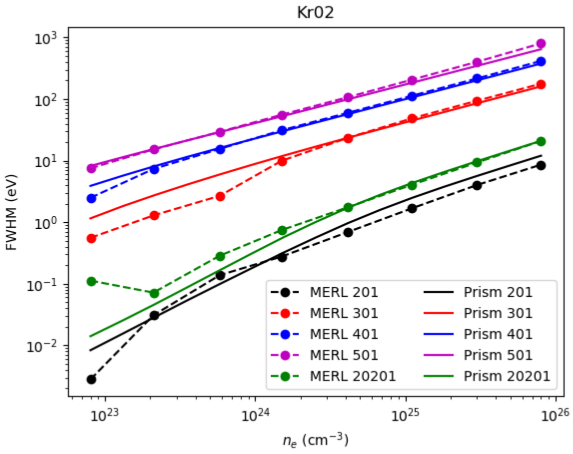
It is seen that the new model provides much better estimates of Stark width for these transitions of Oxygen ions. The same comparisons for H-like and He-like Argon ions are show below. Here we find the old model in PrismSPECT gives reasonable estimates of Stark width, because for a select range of ions (including Argon), a numerical fit to the MERL calculated line profiles was used.



However, for higher Z ions such as Krypton, we once again find the existing model in PrismSPECT to be inadequate, and the newly implemented model shows much better agreement with MERL profiles.

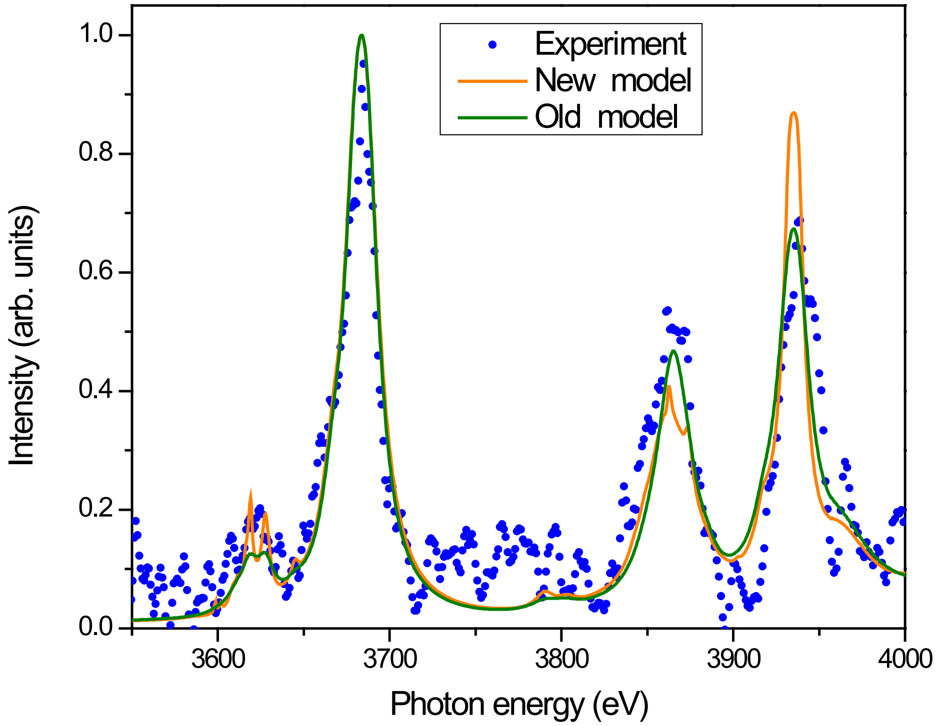






Several calculations were performed to illustrate the effects of the new Stark broadening models on the formation of spectral features in different plasmas.

For Ar-dopped ICF implosions, two models produce similar results. This can be expected because the line width in K-shell Ar was originally based on fitted MERL data. The figure below illustrates comparison of both new and old Stark models with experimental measurements (Sandia shot Z860).



For plasmas that involve elements with Z < 10 and Z > 20, more significant differences between the models can be expected. Shown in figure below are the result of oxygen opacity calculations performed with the old and the new Stark broadening model as well as the experimental data presented at APS DPP 2021 by J. Bailey.