Near Threshold Resonant Processes in Plasmas

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Support from DOE

Threshold resonances strongly contribute to recombination.
Accurate energy is wildly important.

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STORAGE RING MEASUREMENT OF THE C IV RECOMBINATION RATE COEFFICIENT

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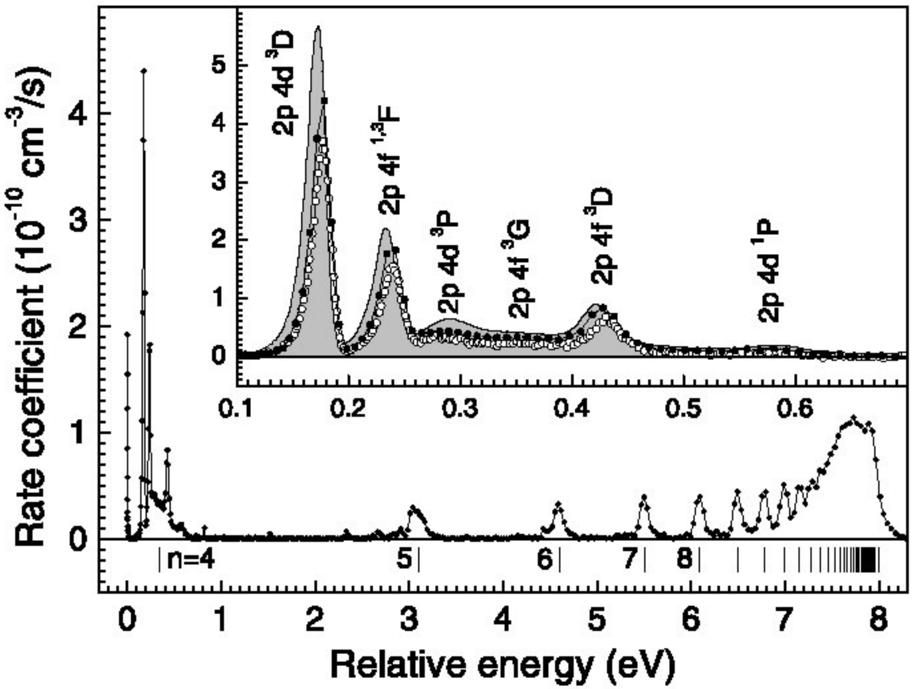


Resonances of C^{2+} with 2p4L character are within ~½ eV of threshold

0.1 eV = 1160 K

Dielectronic recombination in cold plasmas!

Thermal Rates: DR only

derived from experiment

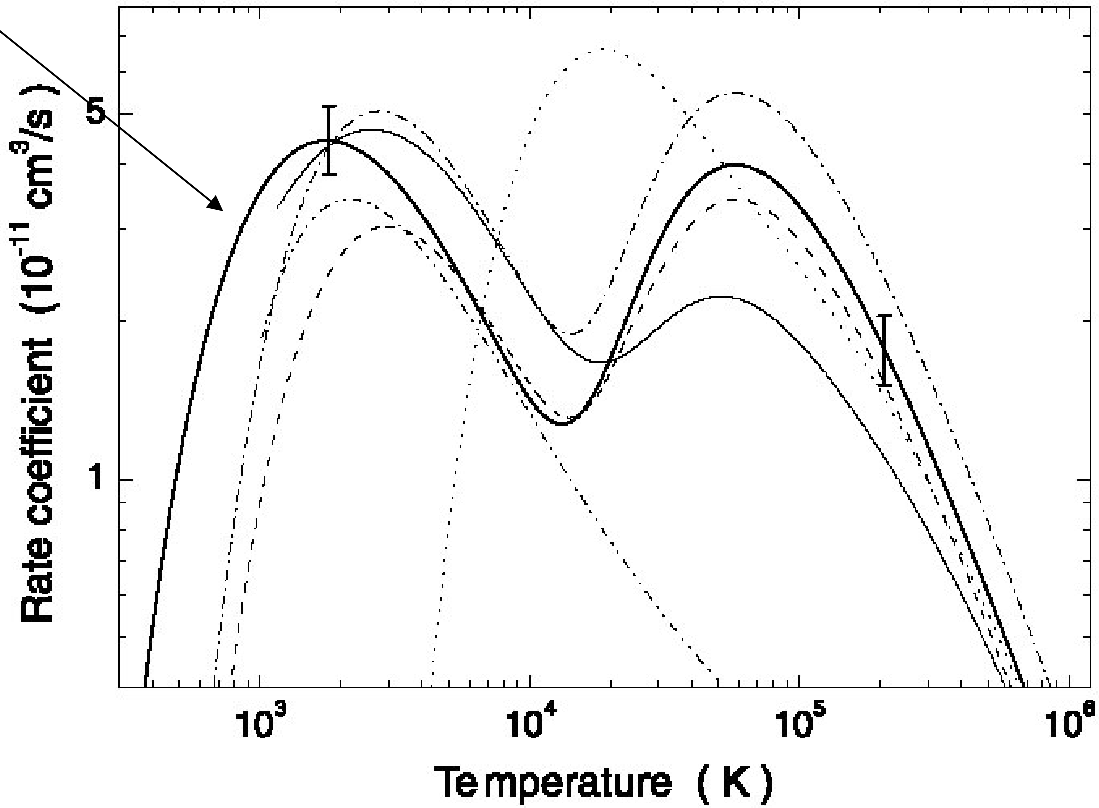


FIG. 6.—C IV $\Delta n = 0$ DR rate coefficients in a plasma: this work (*thick solid line*; systematic uncertainty $\pm 15\%$), McLaughlin & Hahn (1983; *dashed line*), Nussbaumer & Storey (1983; *dash–double-dotted line*), Romanik (1988; *dash-dotted line*), Safronova et al. (1997; *thin solid line*), and Mazzotta et al. (1998; *dotted line*).

Thermal Rates: DR+RR

derived from experiment

RR and DR have same rate ~800 K

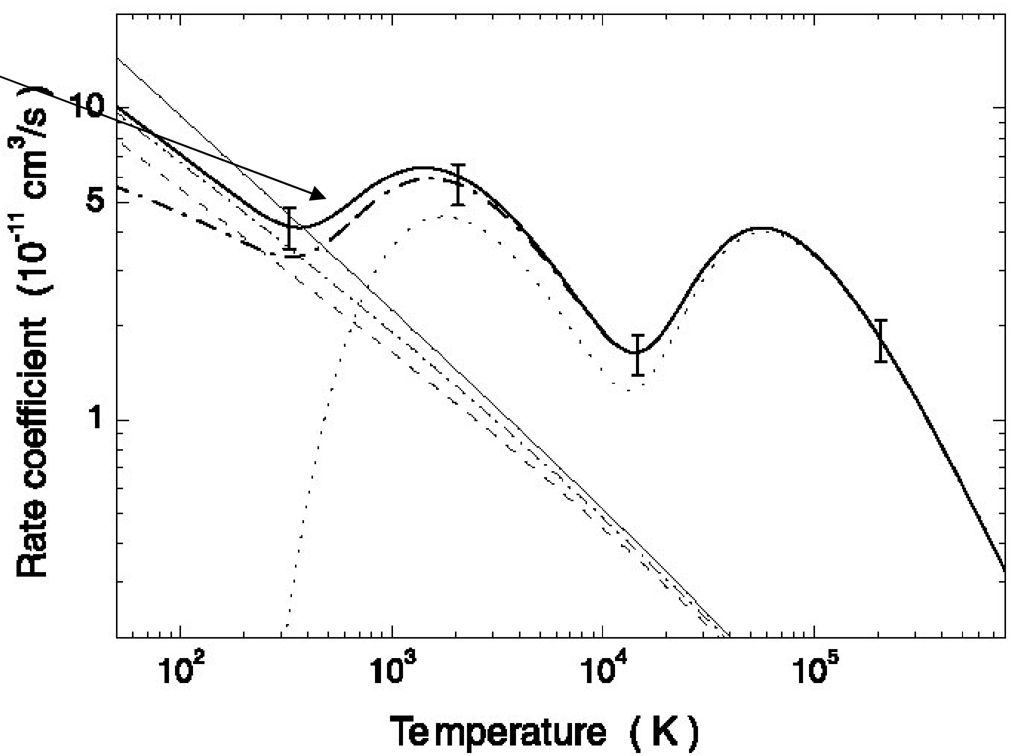
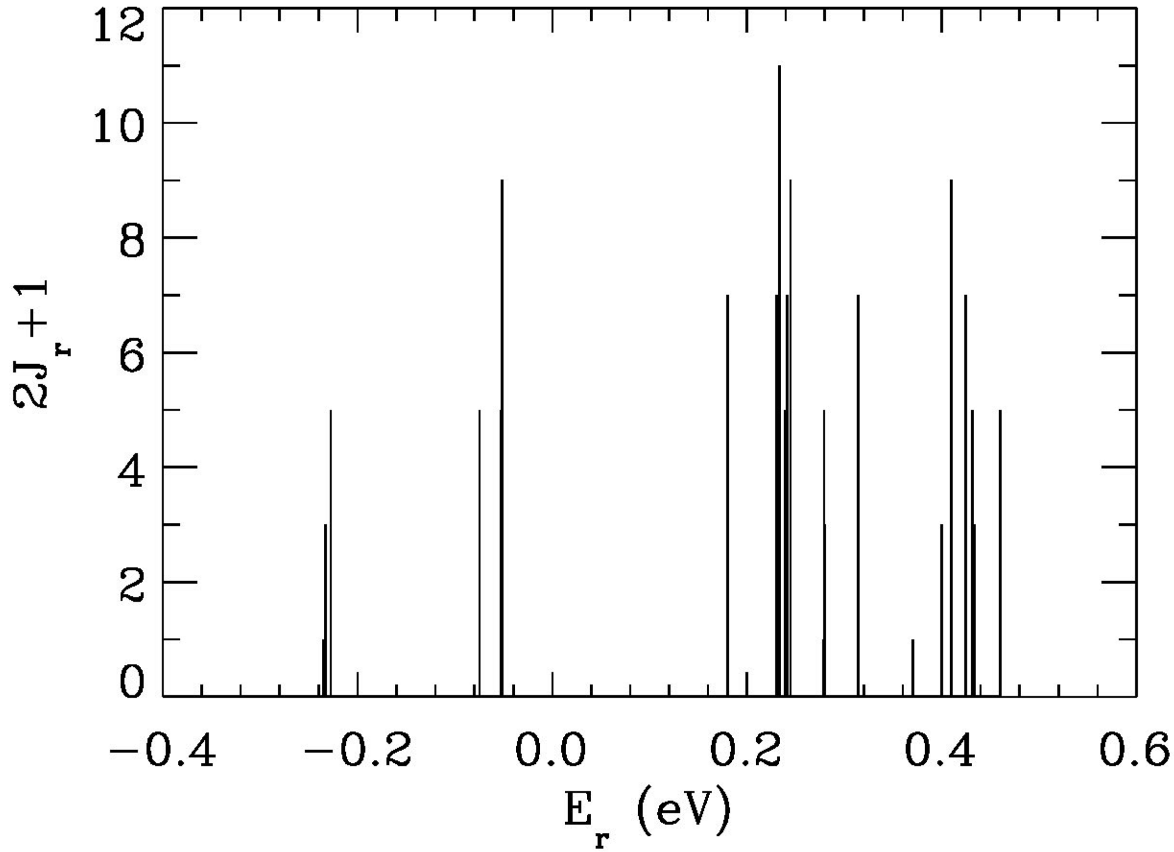


FIG. 8.—Experimental total C IV recombination rate coefficients in a plasma corrected for the influence of the finite experimental resolution (*thick solid line*; systematic error $\pm 15\%$). The comparison with our pure DR rate coefficient (*dotted line*) shows that RR is noticeable up to ~30,000 K. The thick dash-dotted line is our total recombination rate coefficient uncorrected for the influence of the finite experimental resolution. The other lines are C IV RR rate coefficients of Péquignot et al. (1991; *thin solid line*) and corresponding RR rate coefficients (see text) for $n_{max} = 20$ (*thin dashed line*) and $n_{max} = 40$ (*thin dash-dotted line*).

All Near Threshold States

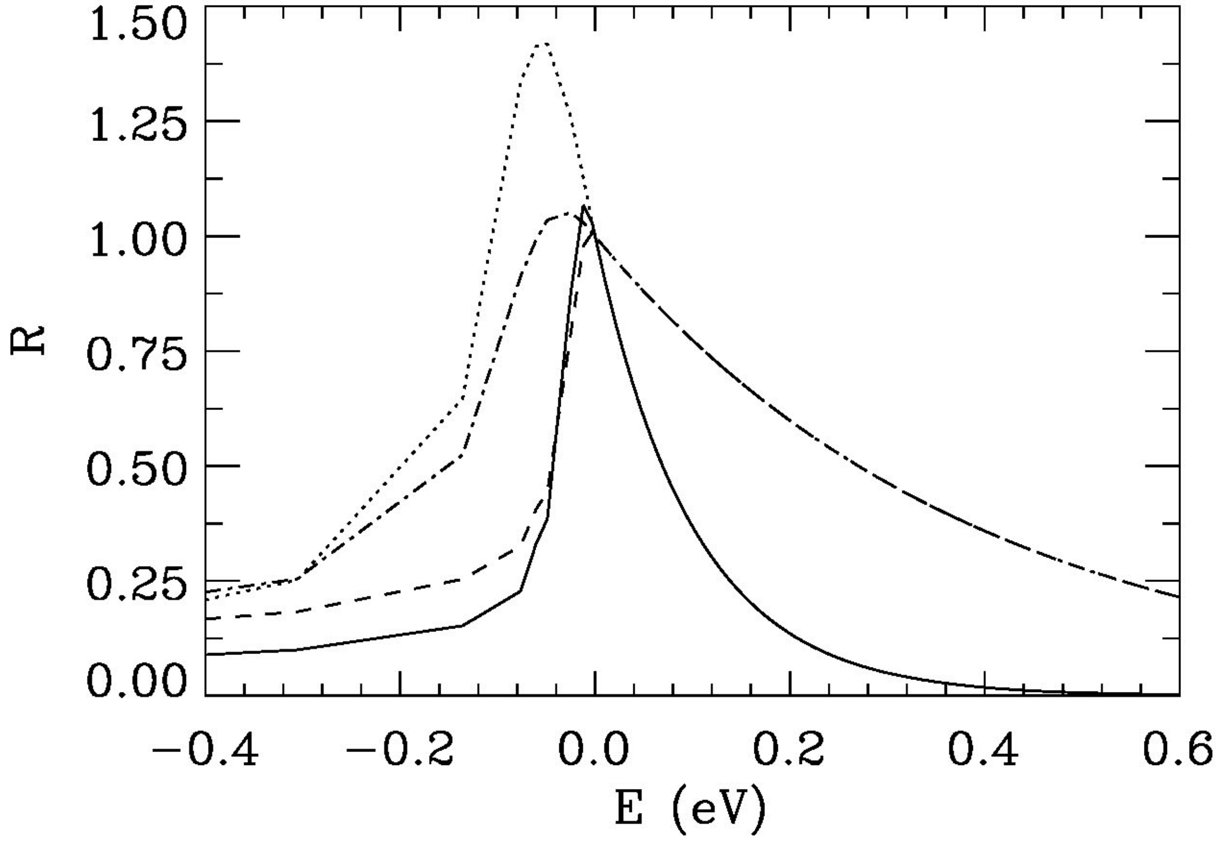


Energies & multiplicities from NIST database

Energies of all 2p4L states within ½ eV of threshold

Why bother with negative energy states?

Plasmas Populate Negative E



solid T = 0.1 eV, 2.2E6 cm^{-3}, dotted T = 0.1 eV, 2.2E8 cm^{-3}
dash T = 0.4 eV, 2.2E6 cm^{-3}, dot-dash T = 0.1 eV, 2.2E8 cm^{-3}

Negative E States "Autoionize"

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Bound even-parity $J = 0$ and 2 spectra of Ca: A multichannel quantum-defect theory analysis*

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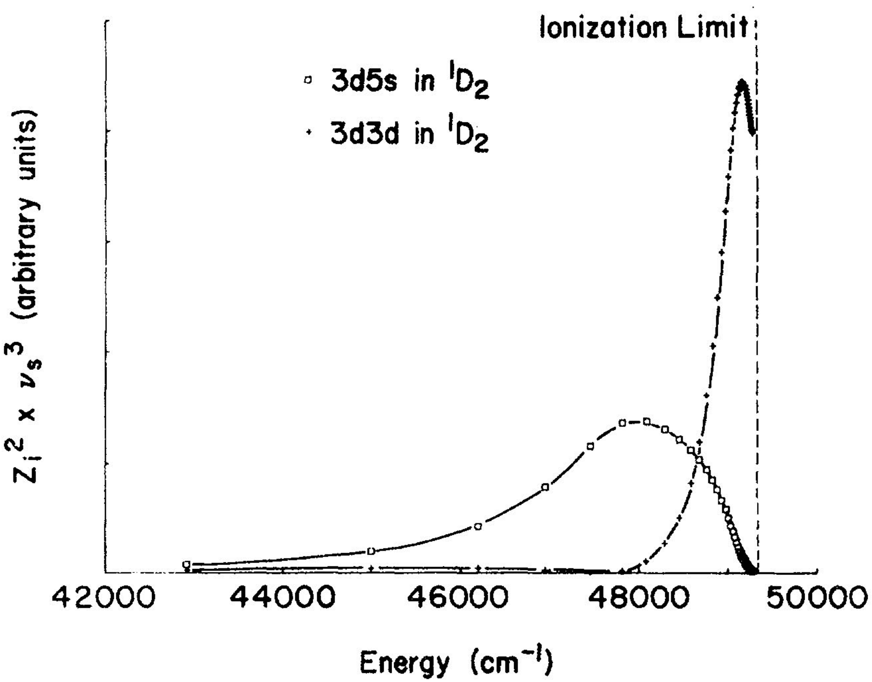
(c)



Mixture into the 4snd Rydberg series

Number of Participating States

Compute thermal average of 2 J_r + 1

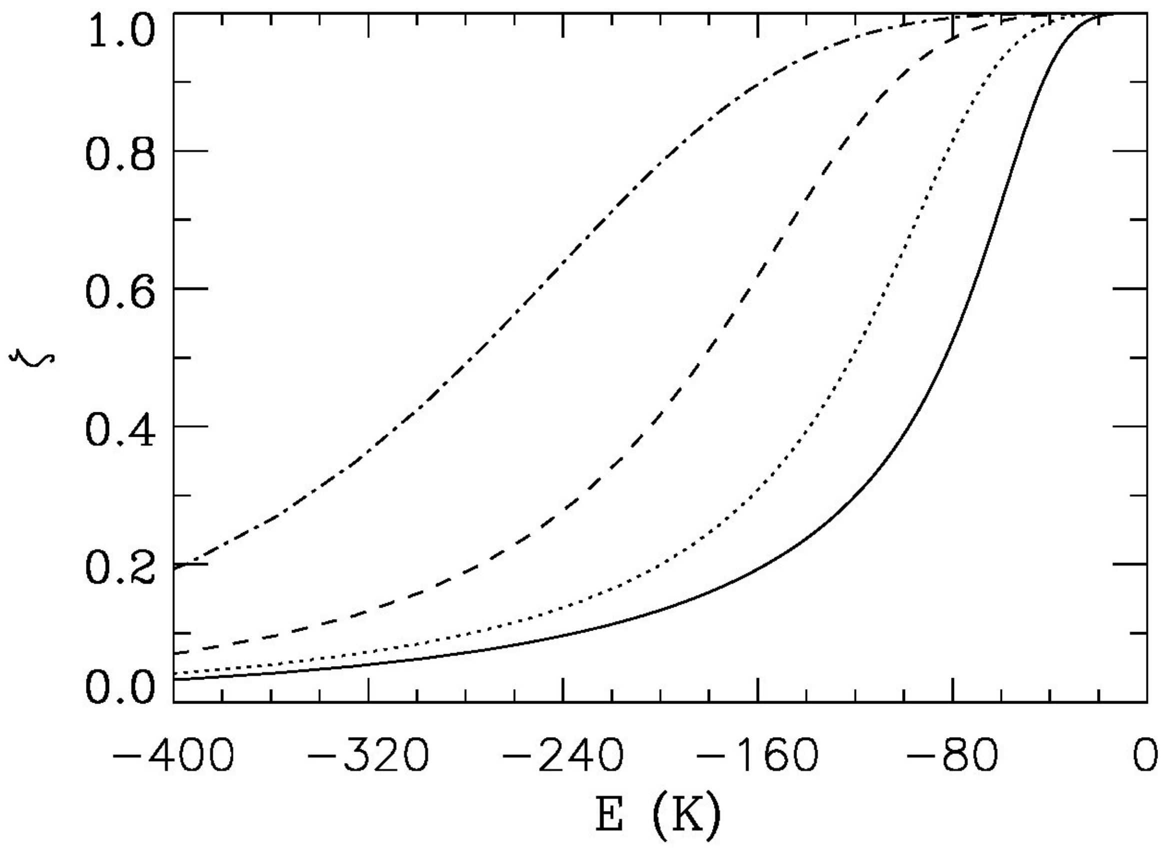
0.1 eV, 2.2E6 cm^{-3}:
Positive E: 7.2 Negative E: 11.6

0.1 eV, 2.2E8 cm^{-3}:
Positive E: 7.2 Negative E: 44

0.4 eV, 2.2E6 cm^{-3}:
Positive E: 47 Negative E: 13.5

0.4 eV, 2.2E8 cm^{-3}:
Positive E: 47 Negative E: 32

Ratio to Thermal @ 250 K



solid 1.0E4 cm^{-3}, dotted 1.0E5 cm^{-3}
dash 1.0E6 cm^{-3}, dot-dash 1.0E7 cm^{-3}

Contribution of Near Threshold States to Recombination in Plasmas

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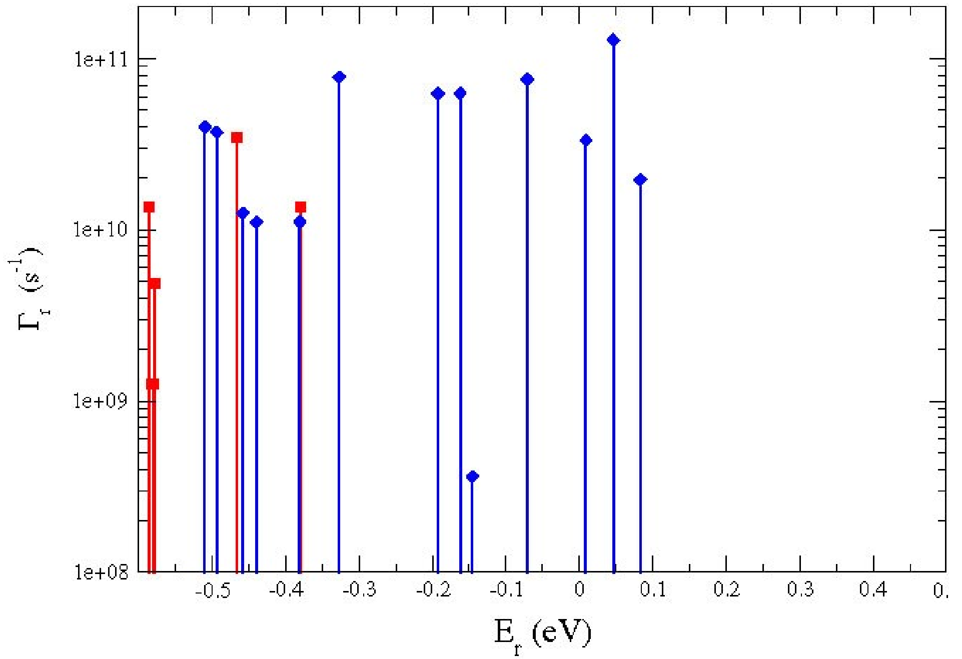
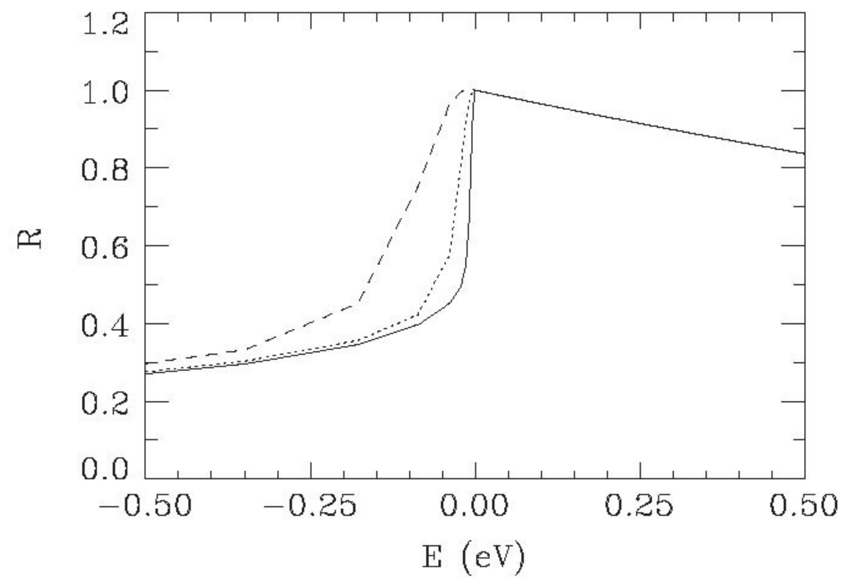


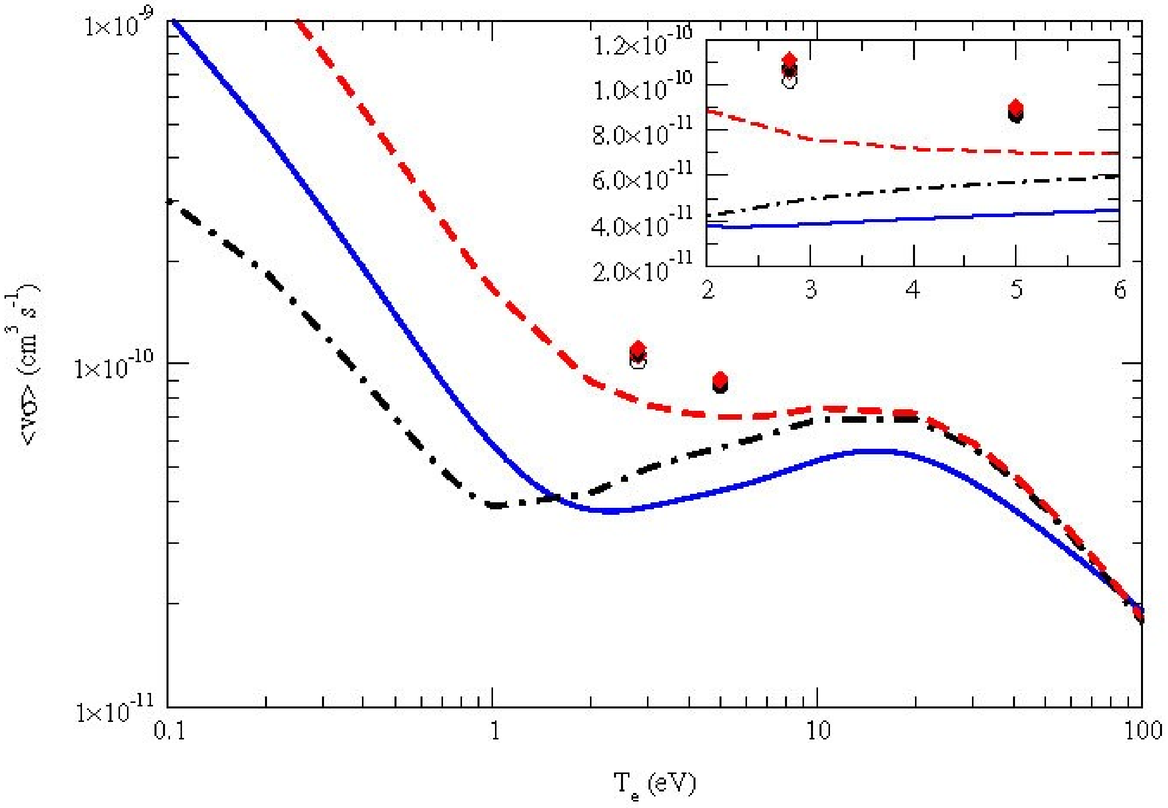


Mg^{7+} states

T = 2.8 eV

10^4, 10^6, 10^8 cm^{-3}

Contribution to Recombination Rate



Blue line = experiment, red line = correct Autostructure, black line = Autostructure (states below 70 meV shifted below threshold)

Symbols include negative E states (unshifted & shifted Auto)

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Dielectronic recombination in C^{3+} above and below the ionization threshold

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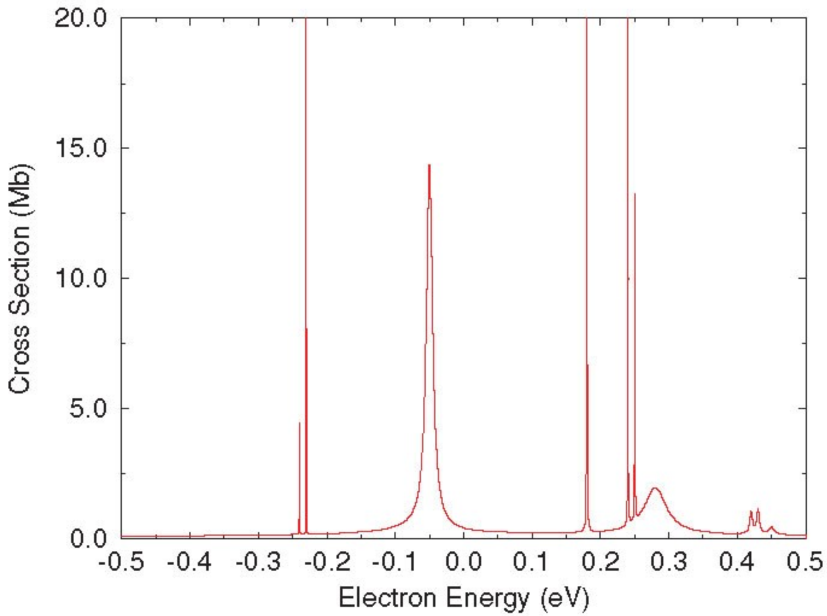
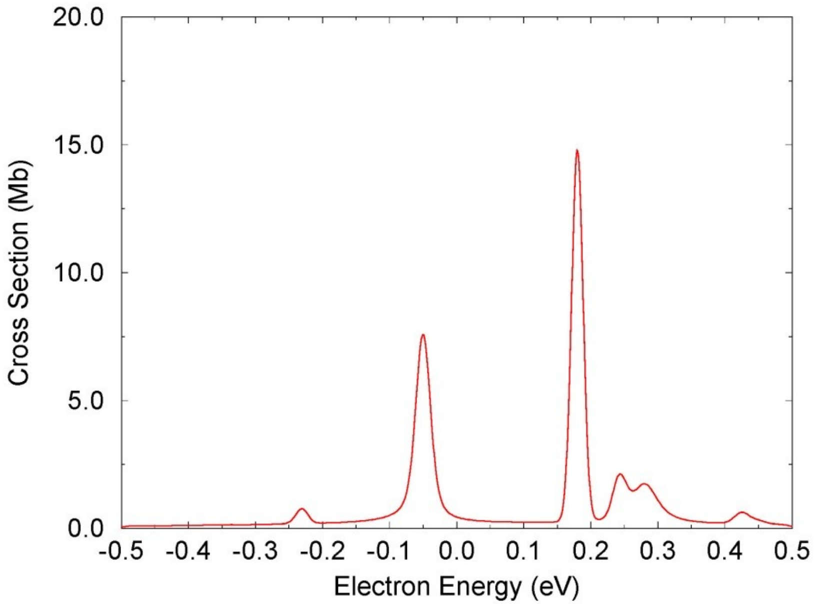
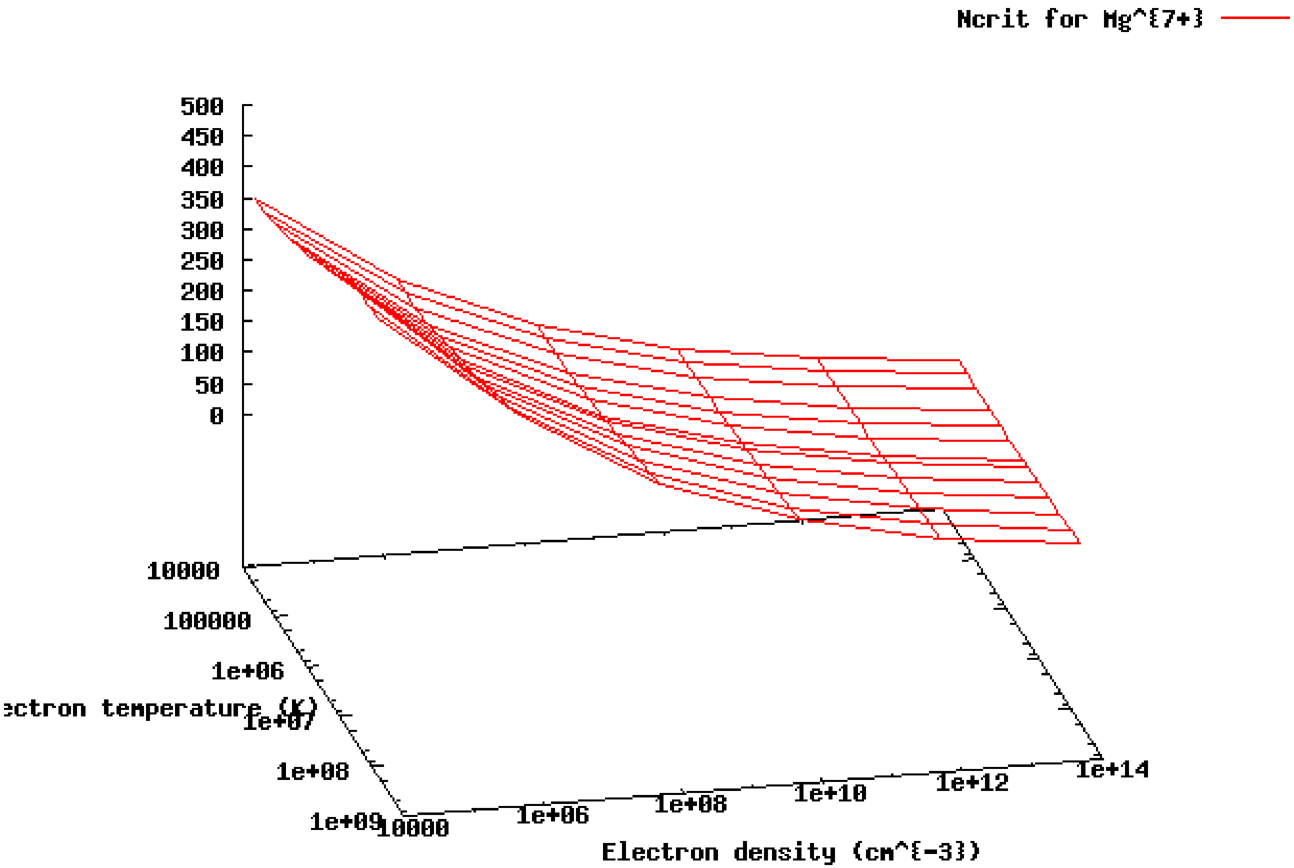


DR cross section



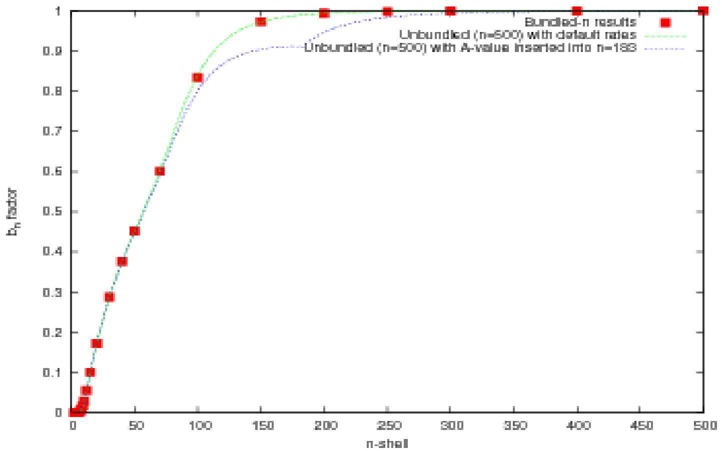
convolved 0.02 eV

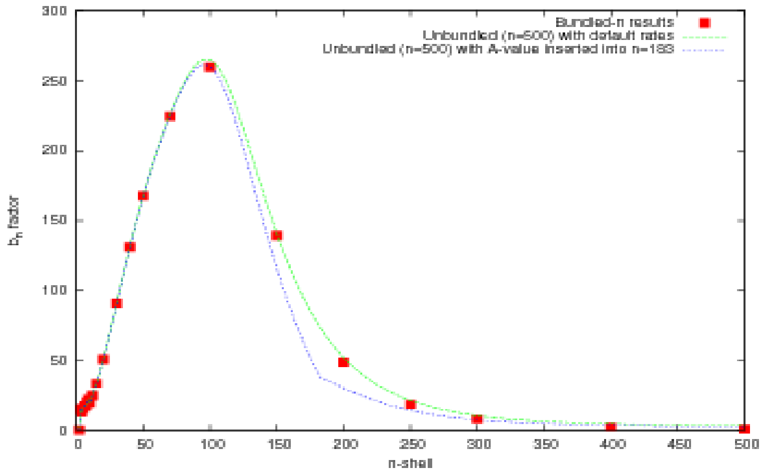


The plot shows the critical n-shell at which the Mg7+ Rydberg levels blend with their nearest neighbor.

Population modeling of the Rydberg states

- We used ADAS204 to model the population of the 'negative energy' electrons.
  - Semi-empirical data for everything, except for DR (AUTOSTRUCTURE).
- We also investigated the role of allowing a doubly excited state embedded in the Rydberg 'continuum' to allow the Rydberg states to radiate.
- Results are shown for Mg7+ for Te = 5.8 x 10^4 K (top plot) and 4.47x10^7 K (bottom plot)





Concluding Remarks

Perturber states just below threshold might contribute as much or more to low T processes

Compact states embedded in Rydberg series often left out

Simple theory if energy width is greater than Rydberg spacing (or big collisional width of Rydberg state)

Possible important processes: photo-recombination, electron impact excitation (weak transitions), dissociative recombination in molecular ions

Super accurate energy not necessarily important; energy error less than T