Ion Populations in Astrophysical Plasmas:

Carbon in the Lower Solar Atmosphere

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Background

Solar atmosphere temperature and density

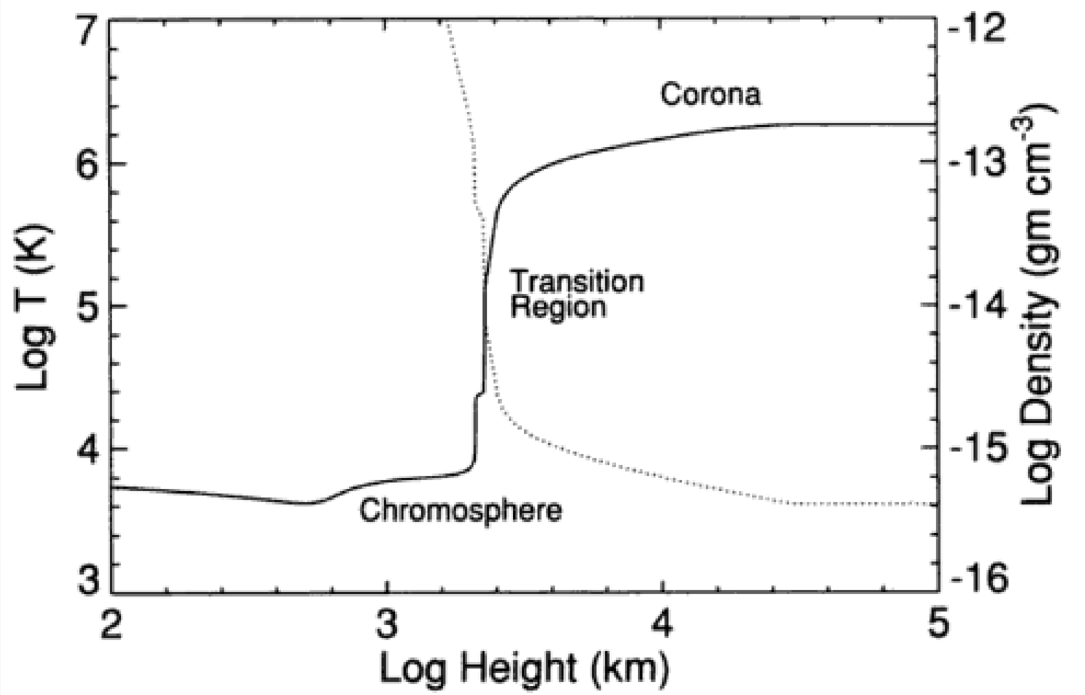
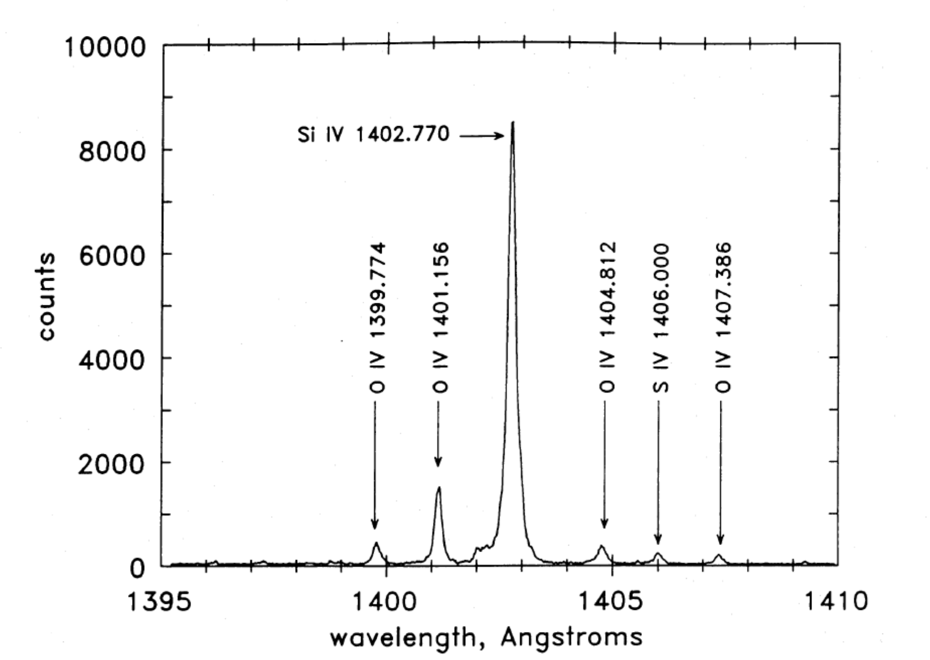


Image from J.T. Mariska, *The Solar Transition Region*, CUP, 1992

Background

Observed intensities from HRTS



Predicted intensities from modelling

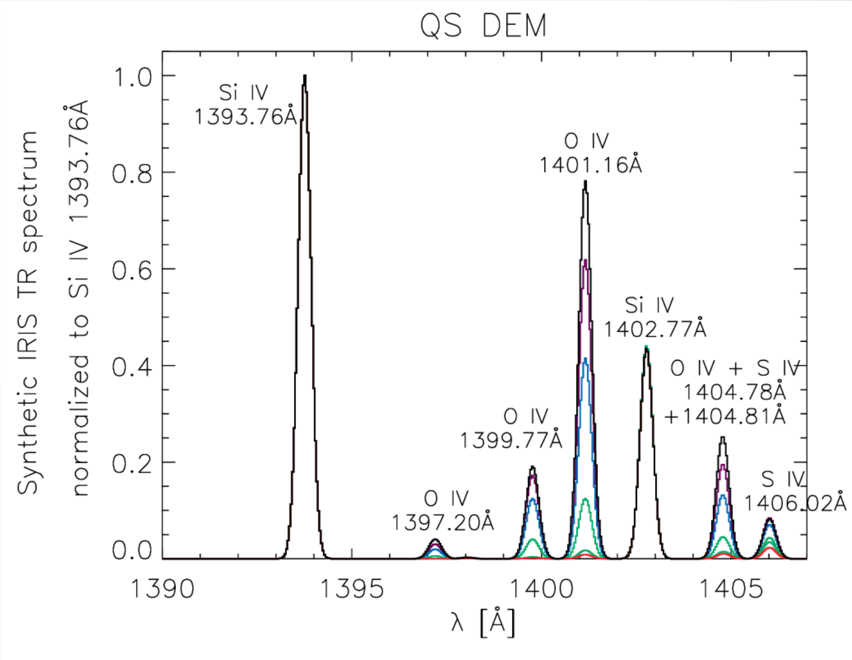
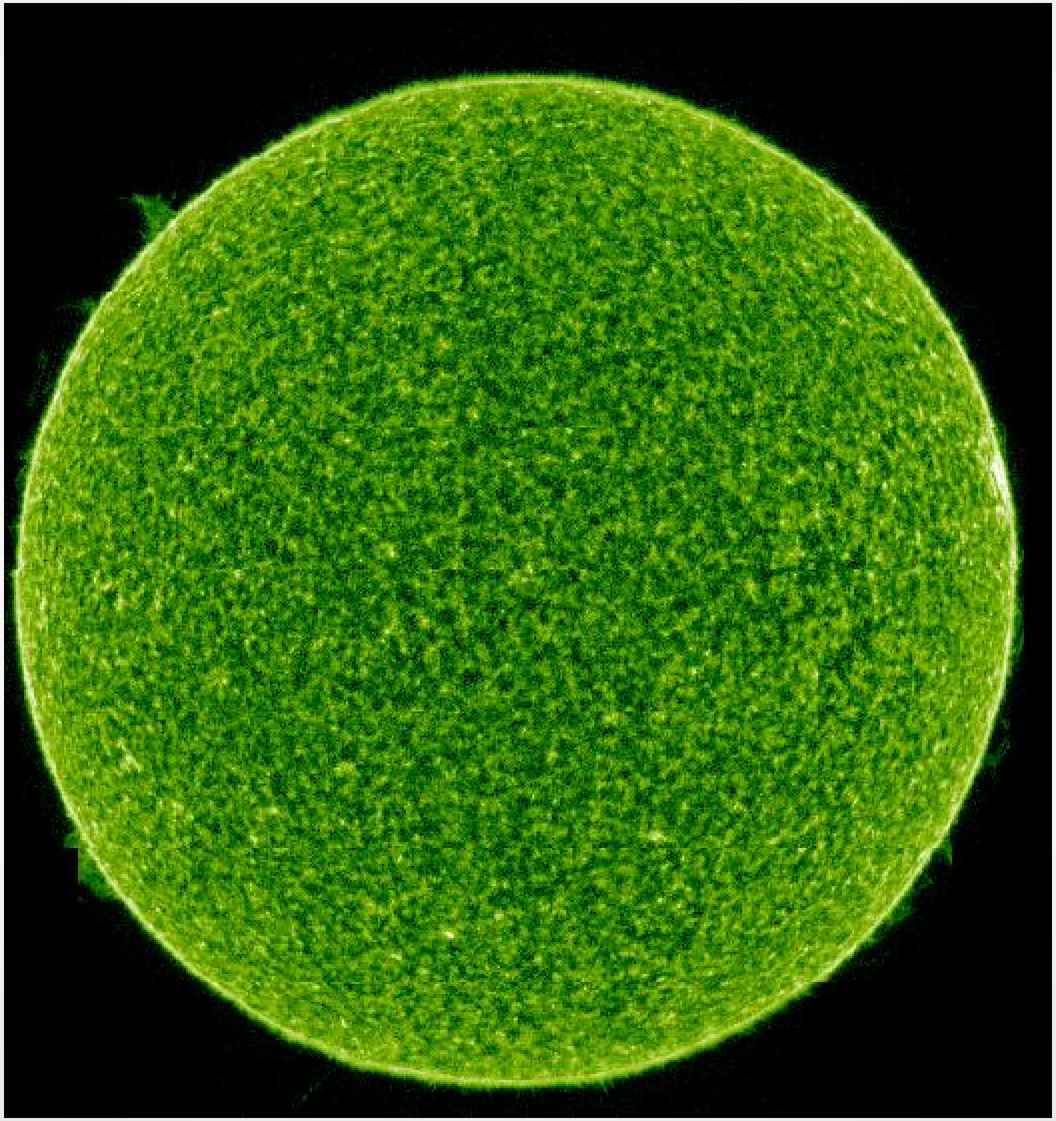


Image from Dudik J., et al., 2014, ApJL, 780, L12

Background

C IV (C^{3+})

1548 Å line emission at $\sim 10^5$K

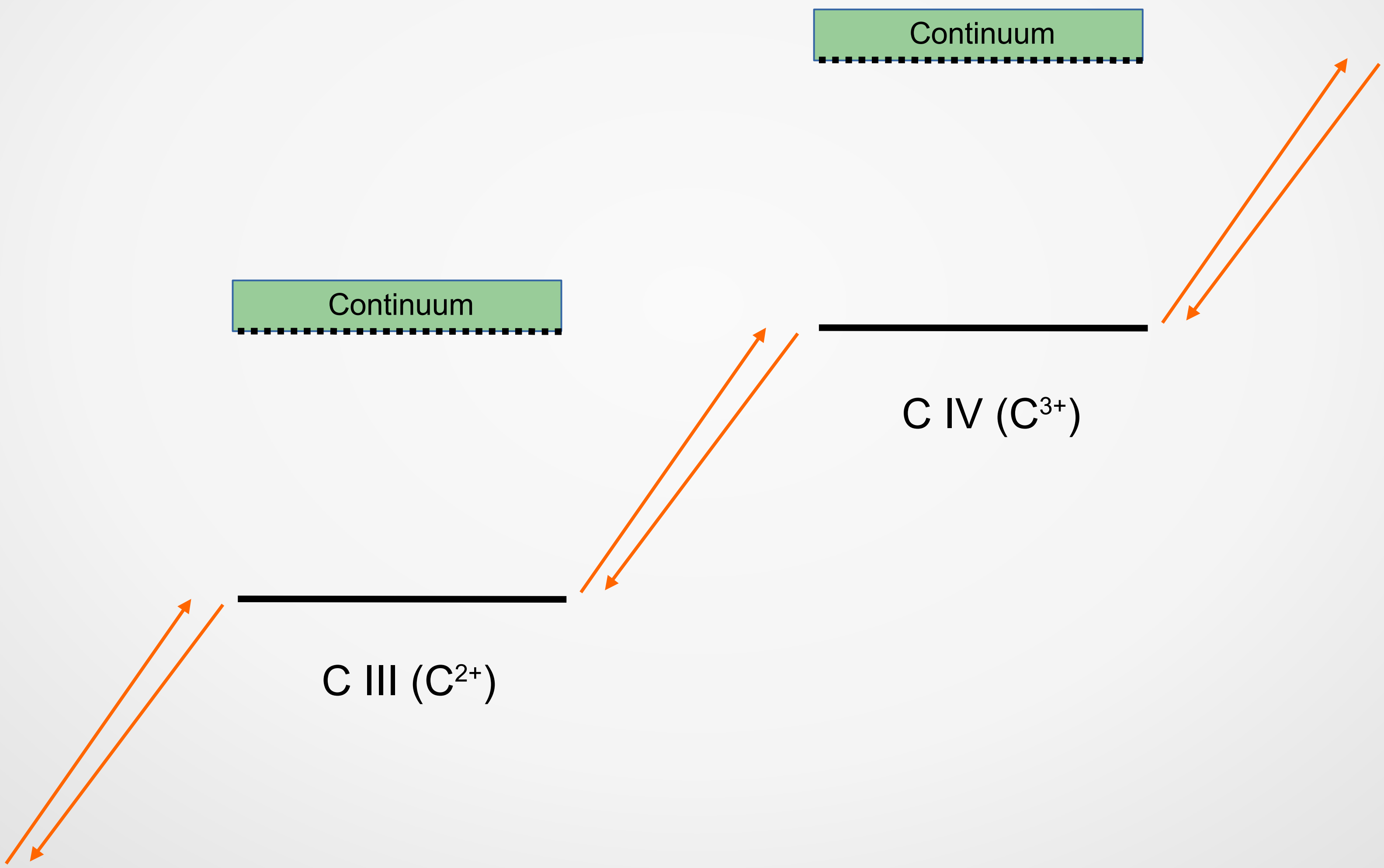


Courtesy of SOHO/ SUMER instrument (ESA & NASA)

Modelling Carbon Ion Populations

Contents

Modelling: Coronal Approximation



Modelling: Coronal Approximation

Recombination:

$$R_{ij} = N_e \alpha_{ij}^{rr} + N_e \alpha_{ij}^{dr}$$

Radiative + dielectronic

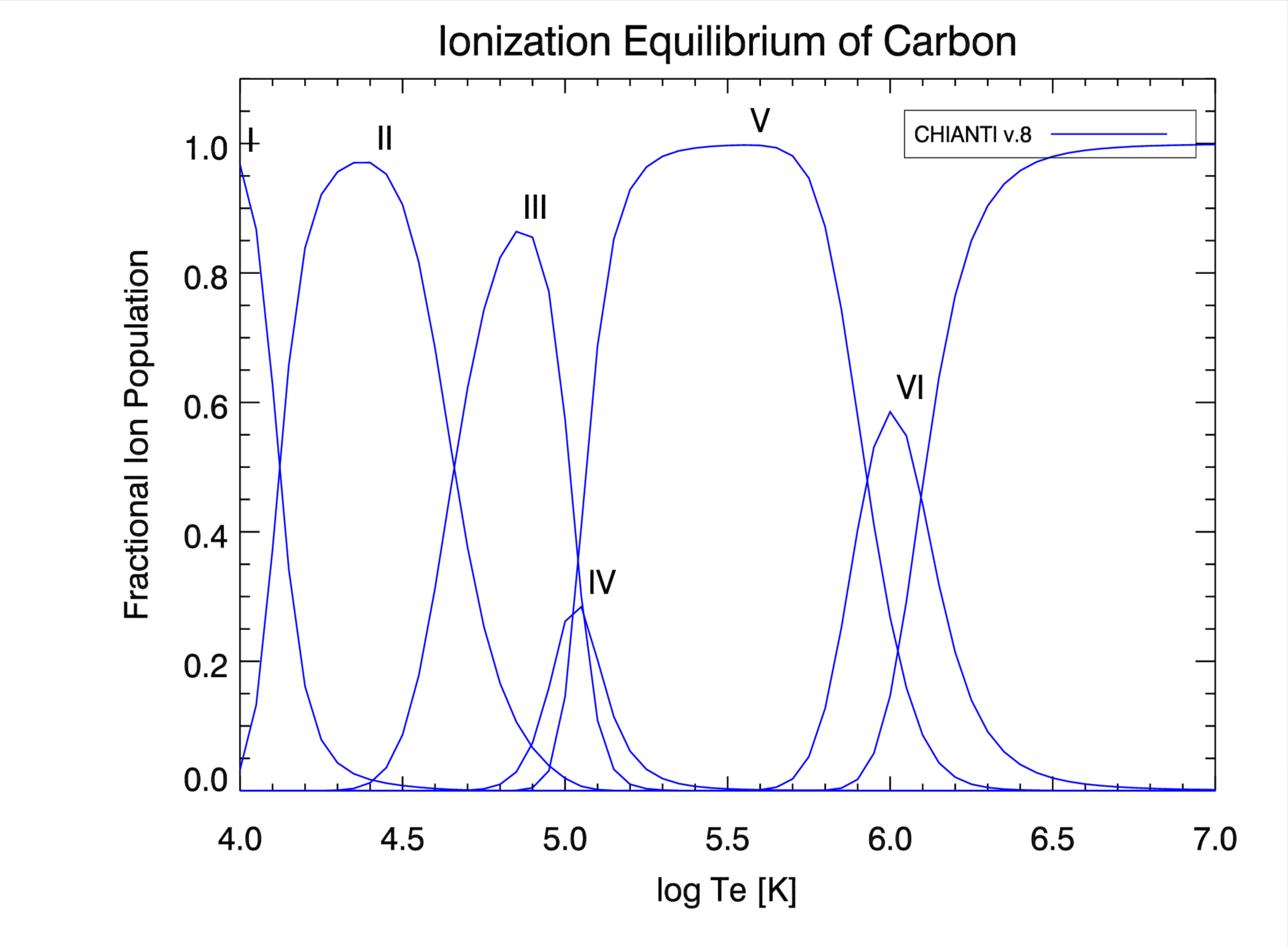
Ionization:

$$S_{ij} = N_e Q_{ij}^{di}$$

Collisional

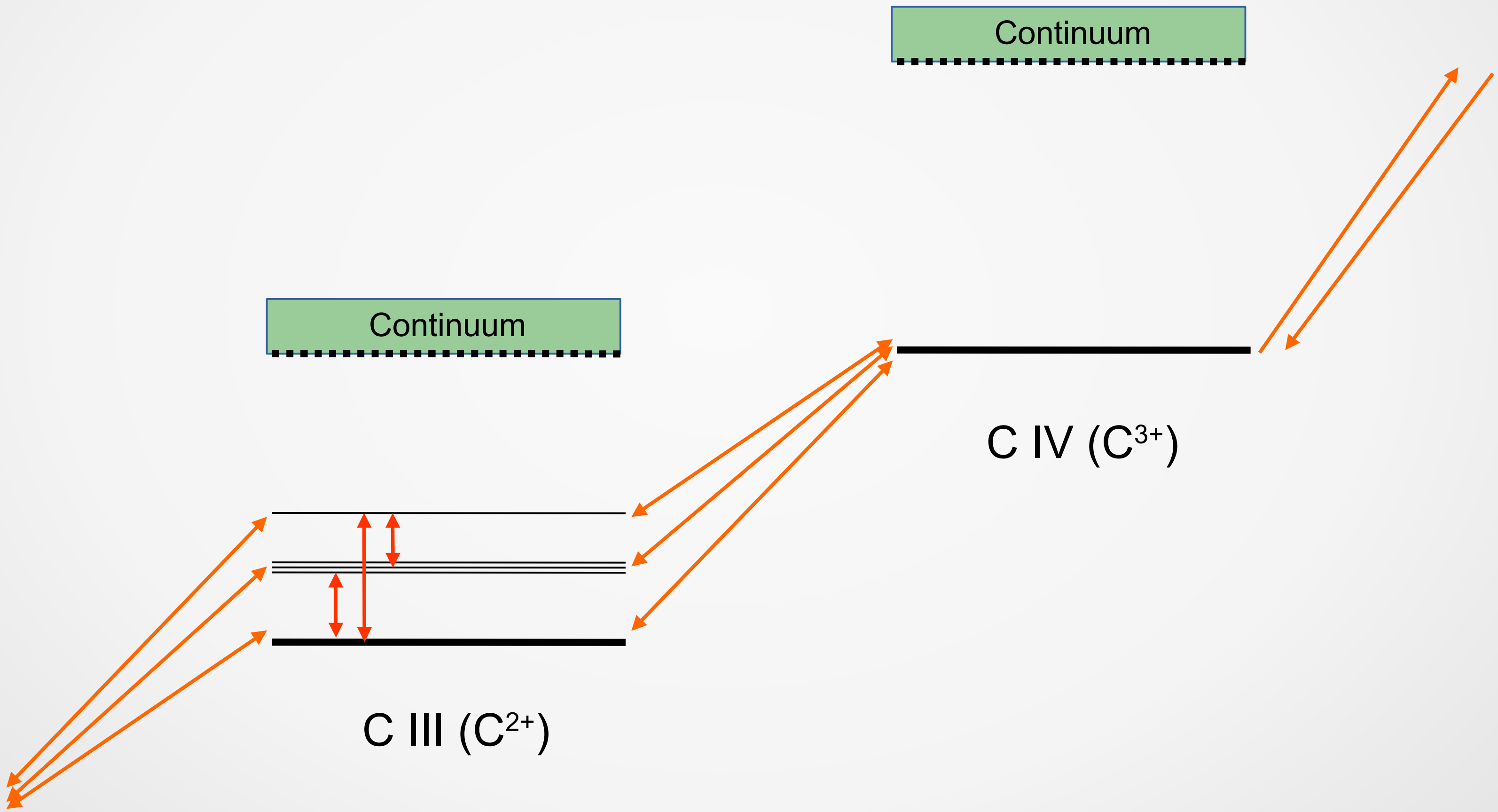
$$\frac{dN^z}{dt} = R^{z+1} N^{z+1} - S^z N^z = 0$$

Results: Coronal Approximation



CHIANTI v.8 Atomic database - Del Zanna et al., 2015, A&A, 582, A56

Modelling: Level-Resolved



Modelling: Level-Resolved

Recombination: $R_{ij} = N_e \alpha_{ij}^{rr} + N_e \alpha_{ij}^{dr} + \ldots$

Radiative + dielectronic + three-body + …

Ionization: $S_{ij} = N_e Q_{ij}^{di} + N_e Q_{ij}^{ea} + P_{ij}^{pi} + \ldots$

Collisional + excitation-autoionization + photo-ionization + …

Excitation: $C_{ij} = N_e Q_{ij}^{ce} + P_{ij}^{pe} + A_{ij} + \ldots$

Collisional + photo-excitation + radiative decay + …

$$\frac{dN_i^z}{dt} = \sum_j R_{ij} N_j^{z+1} - \sum_j S_{ji} N_i^z + \sum_j C_{ij} N_j^z - \sum_j C_{ji} N_i^z$$

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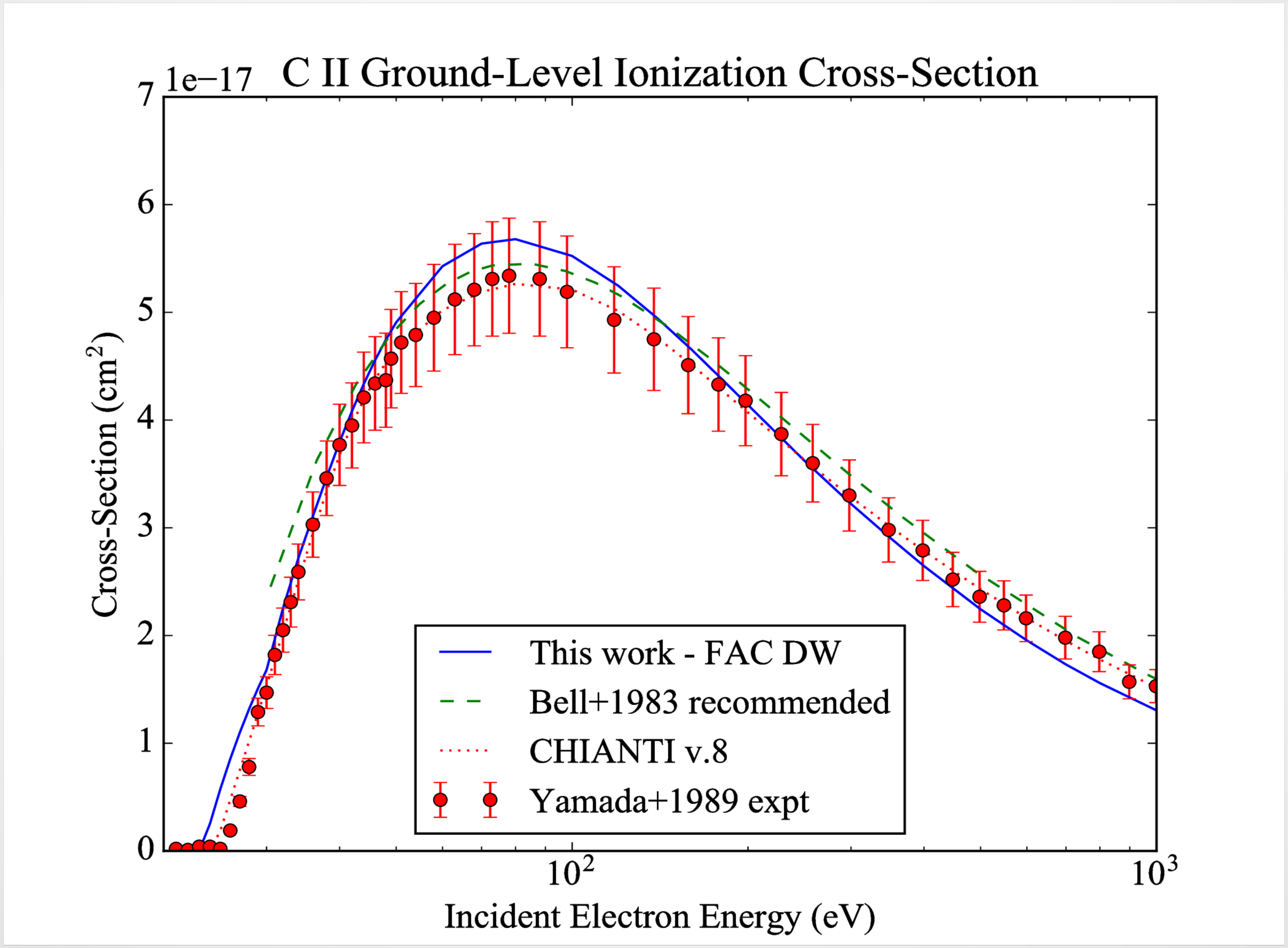
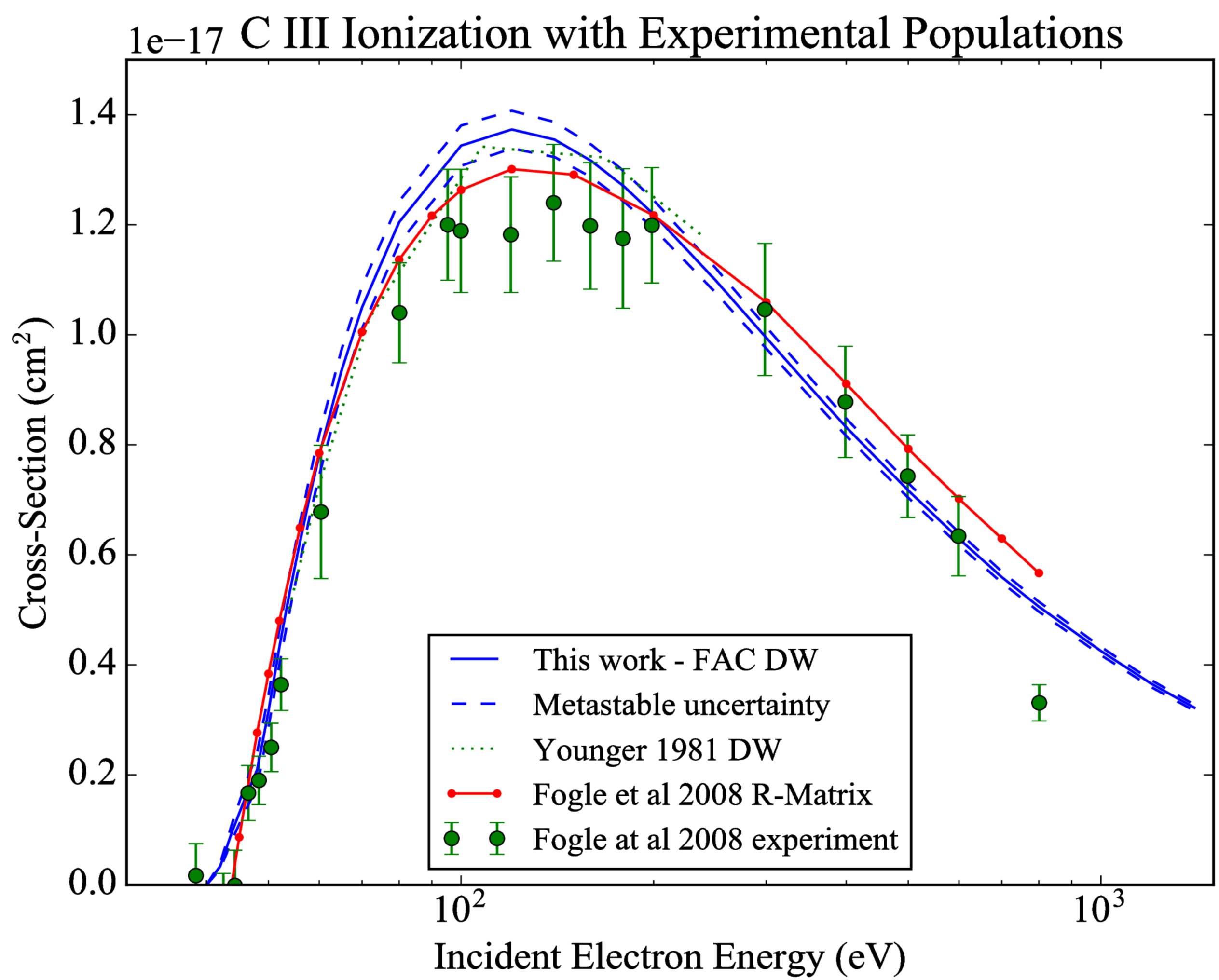
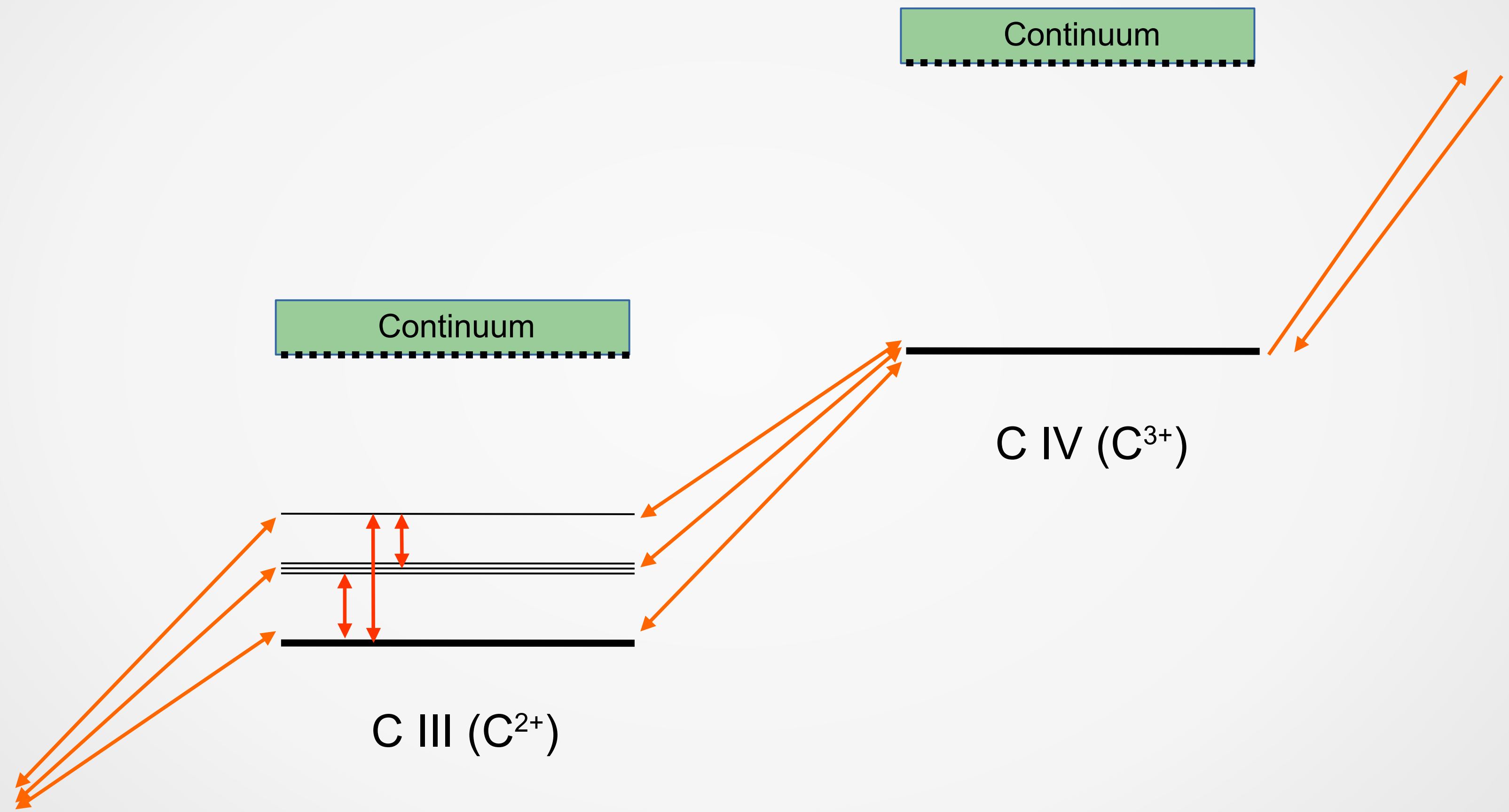
Results: Atomic Data



Results: Atomic Data

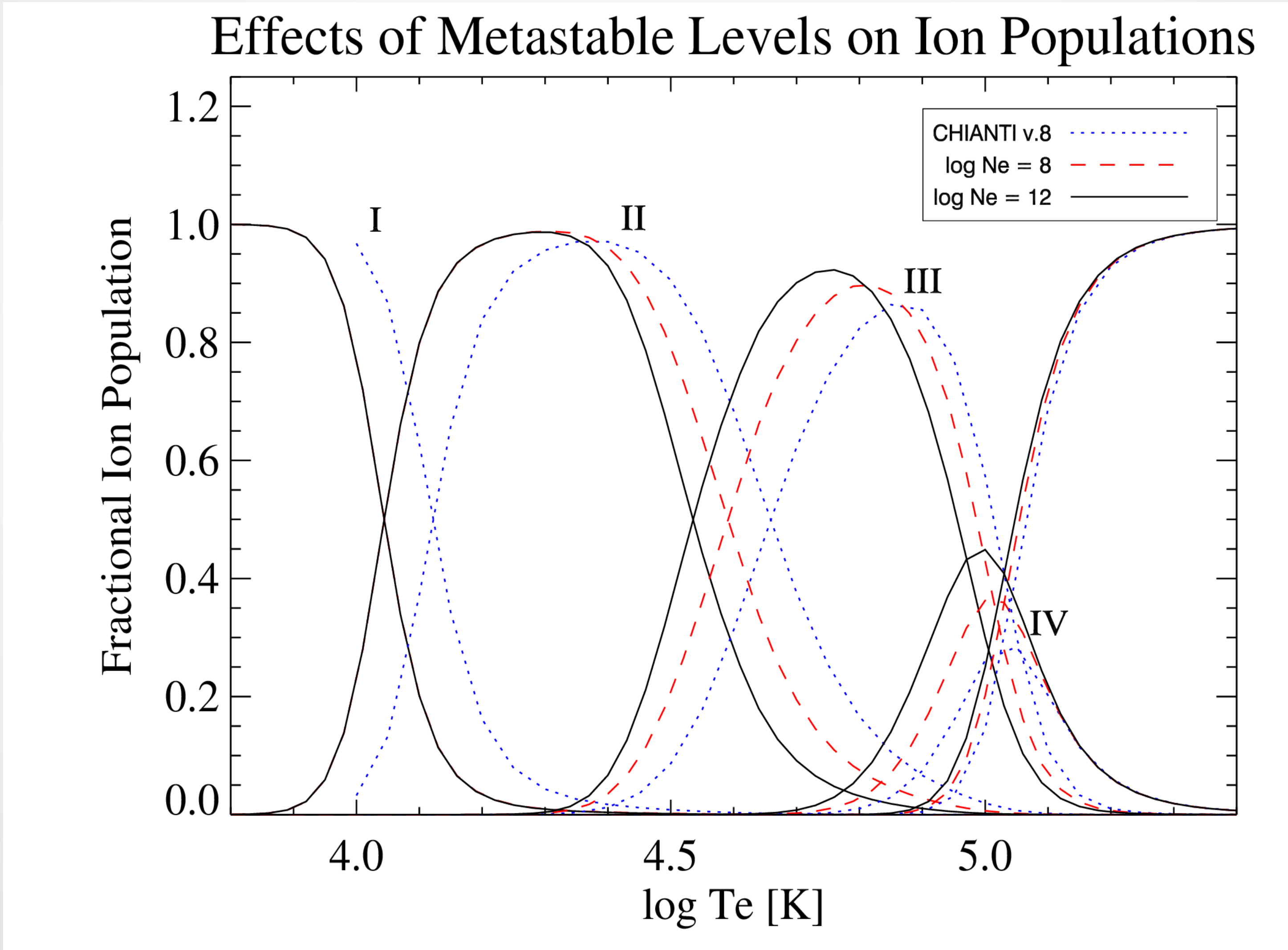


Modelling: Level-Resolved



$$\frac{dN_i^z}{dt} = \sum_j R_{ij} N_j^{z+1} - \sum_j S_{ji} N_i^z + \sum_j C_{ij} N_j^z - \sum_j C_{ji} N_i^z$$

Results: Level-Resolved Collisional Ionization



Dielectronic Recombination

Effect of density on DR rates demonstrated by Burgess & Summers (1969), ApJ, 157, 1007.

- DR suppression calculated by scaling rate at given density to rate at lowest density.

- Uses tables given in Summers H.P. (1974), MNRAS, 169, 663.

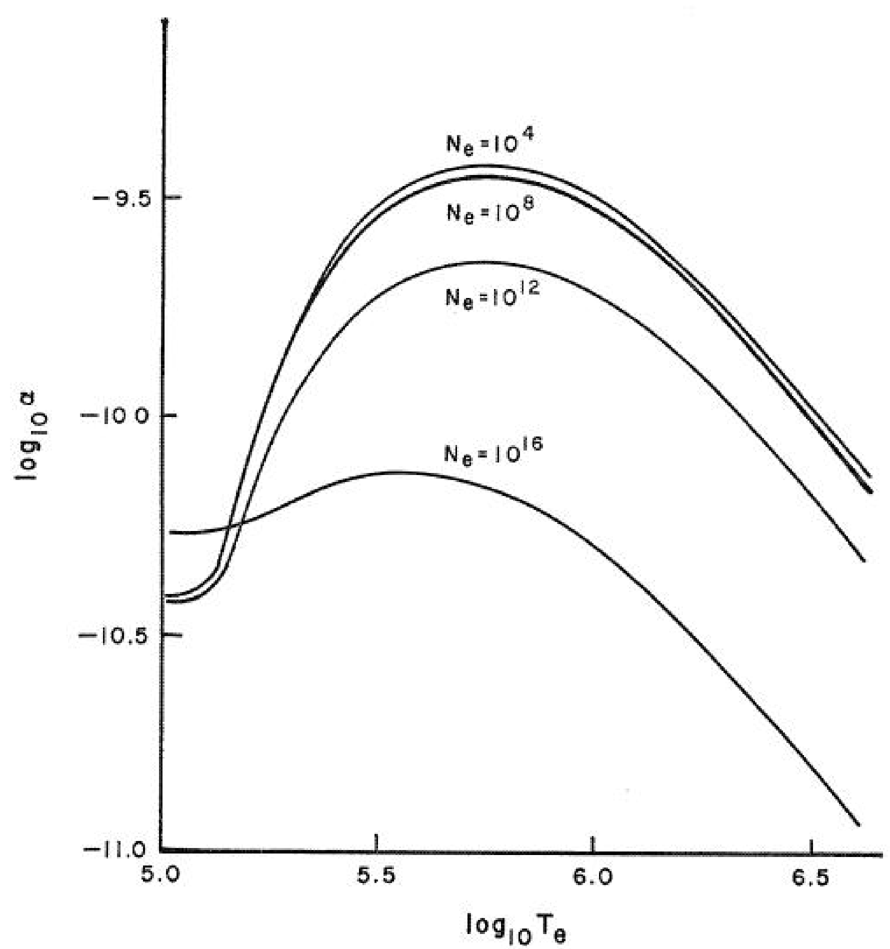
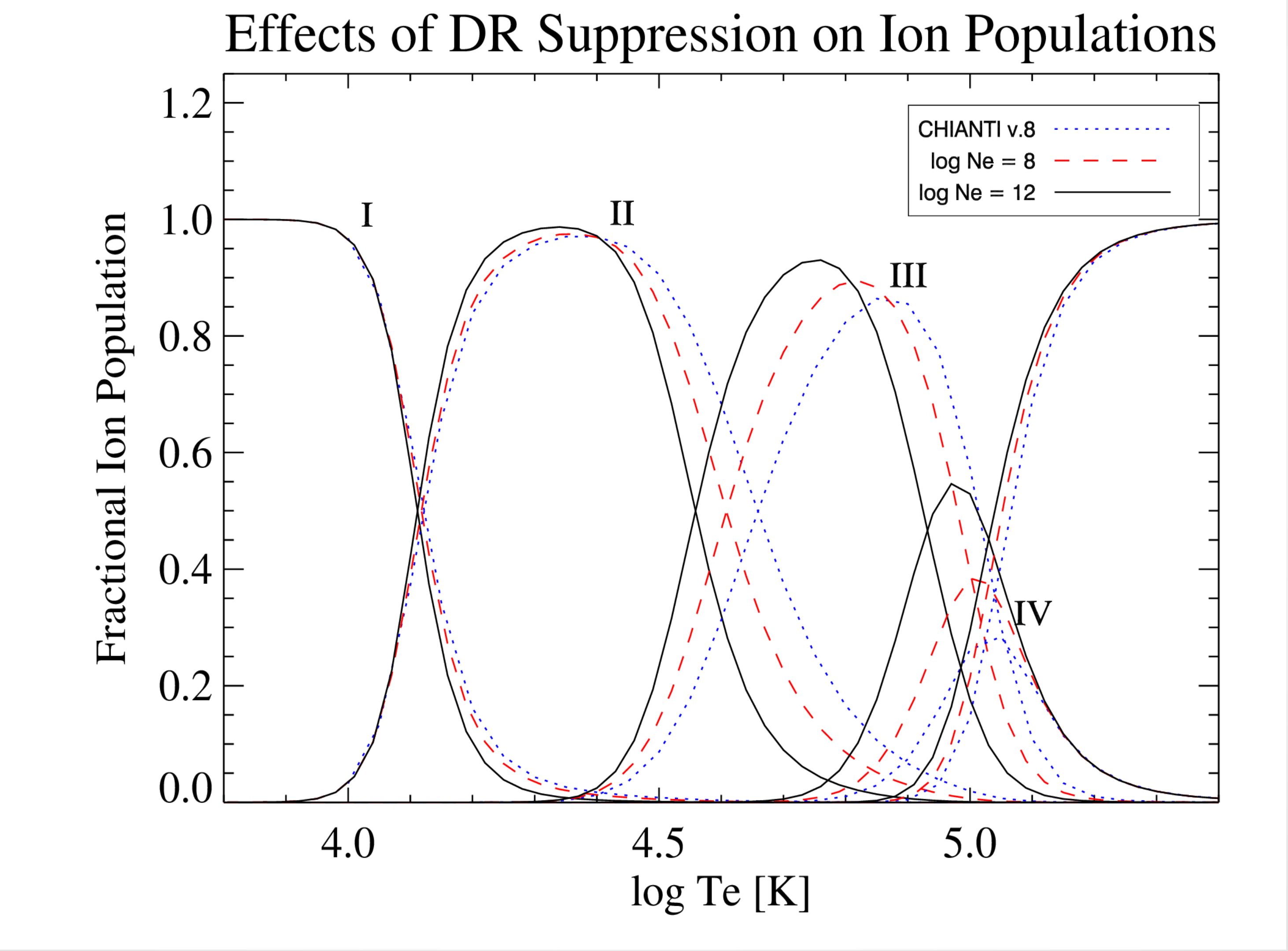
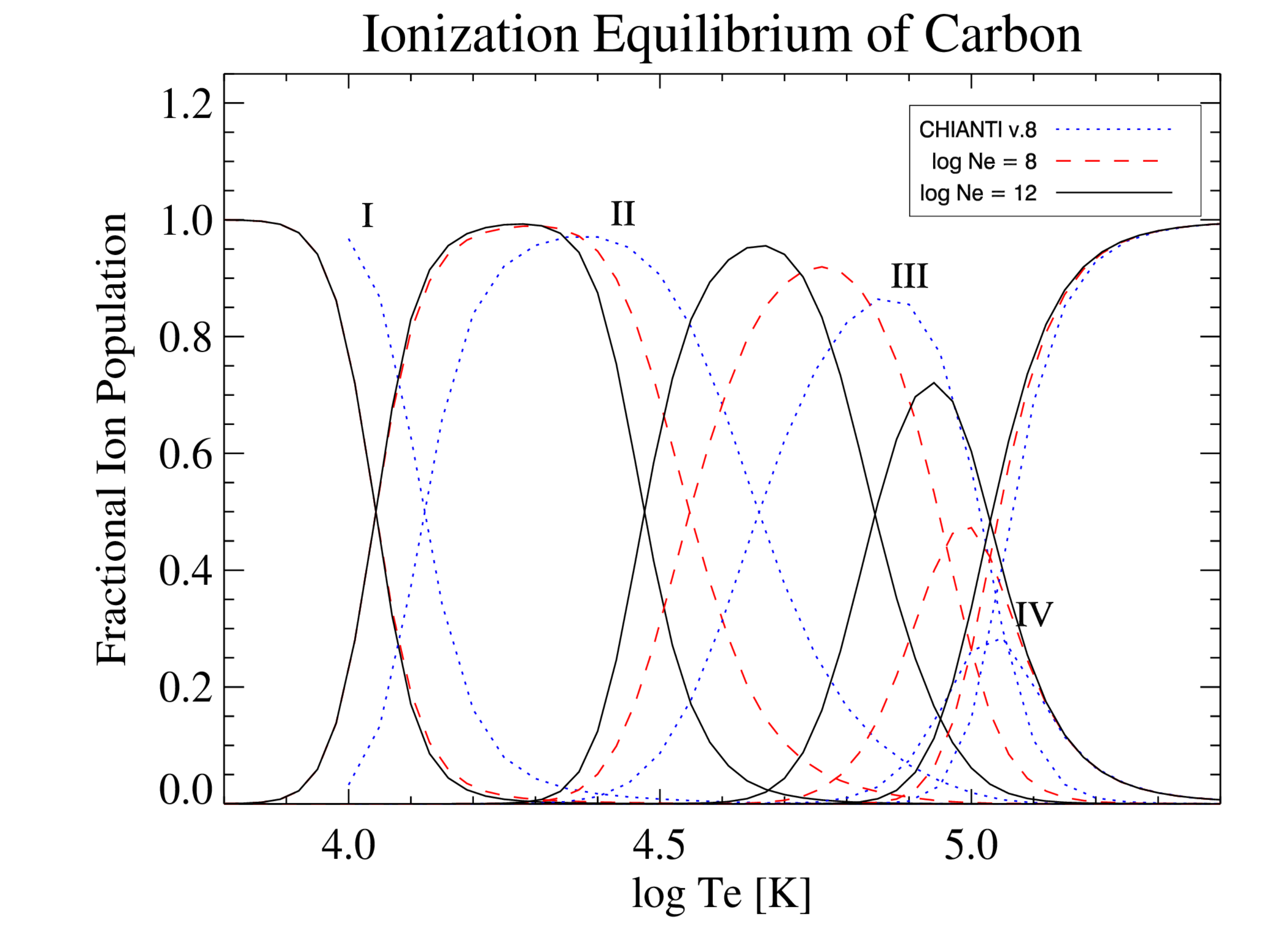


FIG. 7.—Fe $^{+8}$ + e recombination coefficient

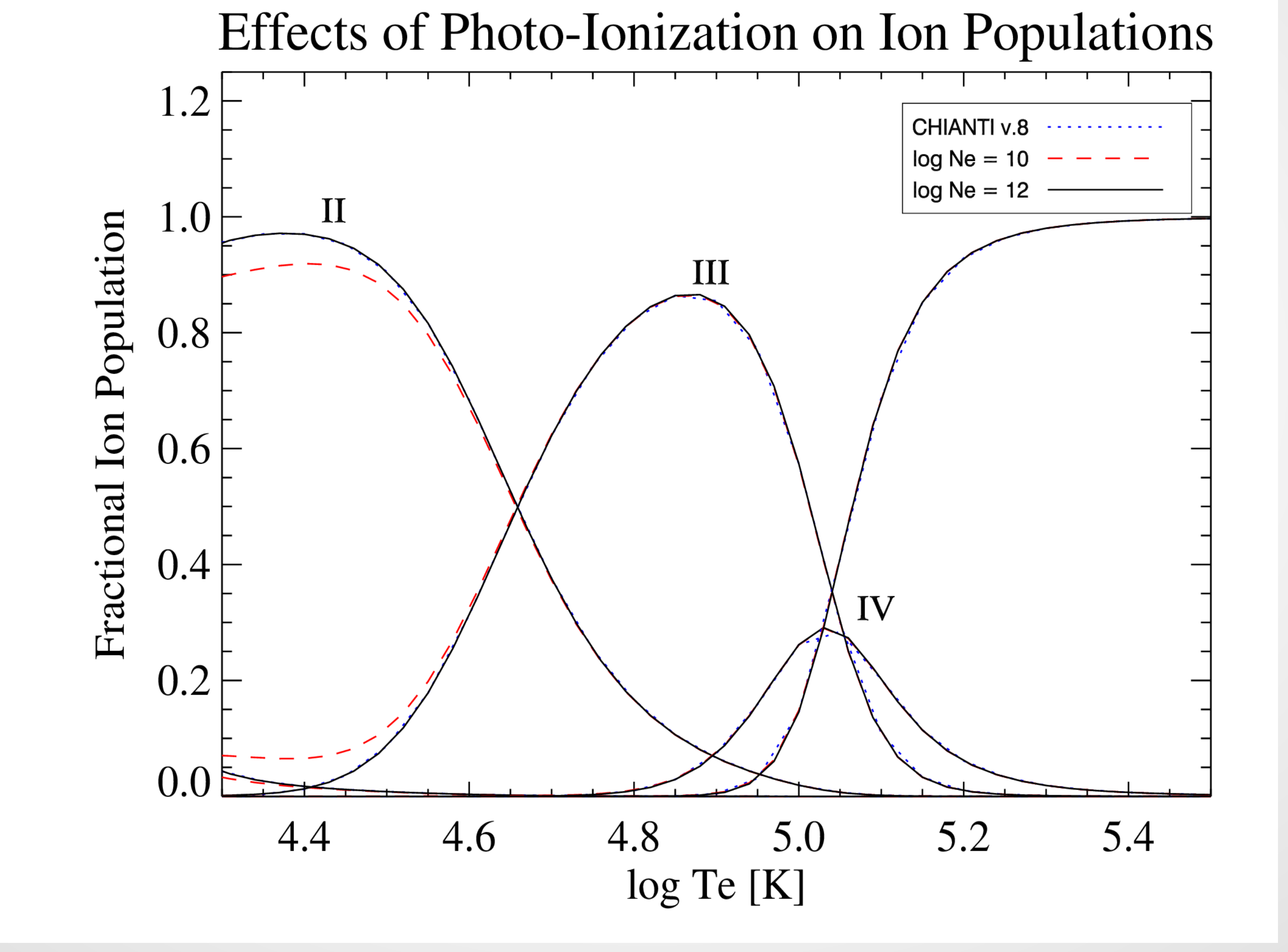
Results: Dielectronic Recombination



Results: Combined Ionization and DR Effects



Results: Photo-Ionization



Modelling Carbon Ion Populations

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Comparison with Observations

Intensity emitted along line of sight:

$$I_{ij} = \frac{E_{ij}}{4\pi} \int A_{ij} N_j^z \; dh$$

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Ratio of theoretical to observed intensities

At constant pressure

$3\text{x}10^{14}$ $\text{cm}^{-3}\ \text{K}^{-1}$

Ion	Wavelength (Å)	CHIANTI	This work
C II	1335	0.89	
C III	977	0.60	
C IV	1548	0.33	

Using quiet Sun observations of Vernazza and Reeves, 1978, ApJS, 37, 485, and Wilhelm et al., 1998, A&A, 334, 685.

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Modelling Carbon Ion Populations

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Modelling Ion Populations

Summary

1) Calculated level-resolved direct and indirect ionization rates

2) Metastable-resolved collisional ionization in modelling

3) Simulated dielectronic recombination suppression in modelling

3) Photo-ionization effects

4) Improved predicted line intensities compared to observations

Further Work

1) Level-resolved modelling up to n=700, for oxygen, silicon, etc.

2) Time-dependent ionization

3) Non-Maxwellian electron distributions

Results: Comparisons with Other Models