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New Collisional Ionization Equilibrium Calculations for Optically Thin Plasmas

D. W. Savin, P. Bryans[1], & W. Mitthumsiri[2]

Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA

savin@astro.columbia.edu

N. R. Badnell

Department of Physics, University of Strathclyde, Glasgow, G4 0NG, UK

T. W. Gorczyca

Department of Physics, Western Michigan University, Kalamazoo, MI 49008, USA

J. M. Laming

E. O. Hulburt Center for Space Research, U.S. Naval Research Laboratory, Code 7674L, Washington, DC 20375, USA

ABSTRACT

Reliably interpreting spectra from electron-ionized laboratory and cosmic plasmas requires accurate ionization balance calculations for the plasma in question. However, much of the atomic data needed for these calculations have not been generated using modern theoretical methods and their reliability are often highly suspect. We have carried out state-of-the-art calculations of dielectronic recombination (DR) rate coefficients for the hydrogenic through Mg-like ions of all elements from He to Zn as well as for Al-like to Ar-like ions of Fe. We have also carried out state-of-the-art radiative recombination (RR) rate coefficient calculations for the bare through Na-like ions of all elements from H to Zn. Using

[1]Current address: NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, Maryland 20771, USA.

[2]Current address: Department of Physics, Stanford University, Stanford, CA 94305, USA.

our data and the most recently recommended electron impact ionization data, we present improved collisional ionization equilibrium (CIE) calculations. Here, as an example, we present our calculated fractional ionic abundances for iron using these data and compare them with those from the previously recommended CIE calculations.

1. Introduction

Electron ionized plasmas (also called collisionally ionized plasmas) are formed in a diverse variety of objects in the universe. These range from stellar coronae and supernova remnants to the interstellar medium and gas in galaxies or in clusters of galaxies. The physical properties of these sources can be determined using spectral observations coupled with theoretical models. This allows one to infer electron and ion temperatures, densities, emission measure distributions, and ion and elemental abundances. But reliably determining these properties requires accurate fractional abundance calculations for the different ionization stages of the various elements in the plasma (i.e., the ionization balance of the gas).

Since many of the observed sources are not in local thermodynamic equilibrium, in order to determine the ionization balance of the plasma one needs to know the rate coefficients for all the relevant ionization and recombination processes. Often the observed systems are optically-thin, low-density, dust-free, and in steady-state or quasi-steady-state. Under these conditions the effects of any radiation field can be ignored, three-body collisions are unimportant, and the ionization balance of the gas is time-independent. This is commonly called collisional ionization equilibrium (CIE) or sometimes coronal equilibrium.

2. Recent Improvements in Atomic Data

Recently, improved theoretical dielectronic recombination (DR) and radiative recombination (RR) rate coefficients have been published by Badnell et al. (2003), Gu (2003a,b, 2004) and Badnell (2006a,b,c). Data are available for fully-stripped through Mg-like ions of all elements from hydrogen through zinc as well as Al-like through Ar-like for Fe. For electron impact ionization (EII), Dere (2007) has reassessed the ionization database and, using a combination of laboratory measurements and theoretical calculations, has generated recommended EII data for all charge states of all elements from hydrogen through zinc.

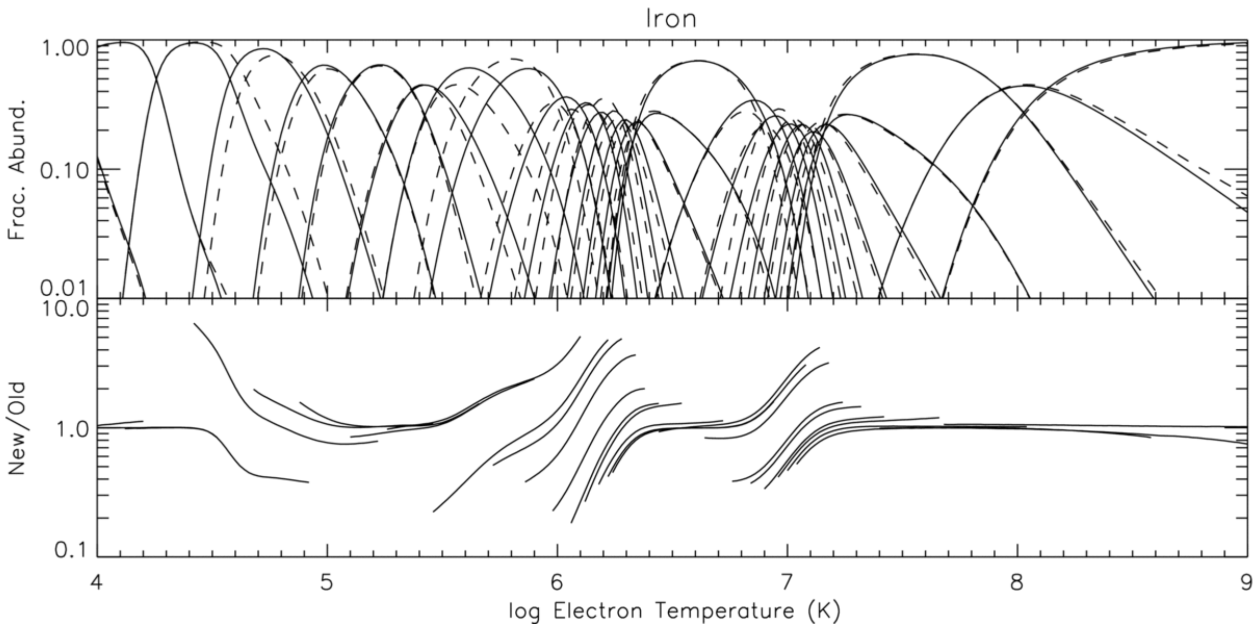

Fig. 1.— Top: CIE fractional abundances for iron from Bryan et al. (2009; solid curves) versus Mazzotta et al. (1998; dashed curves). Bottom: Ratio of the Bryans et al. fractional abundances relative to those of Mazzotta et al.

3. Representative CIE results

These recent improvements to the relevant atomic data have led to a reevaluation of the fractional ionic abundances all elements from hydrogen through zinc (Bryans et al. 2006, 2009). An example of these new CIE results (solid curves) is shown in Figure 1. The previous CIE results are from Mazzotta et al. (1998, dashed curves). Differences of up to factors of ~ 10 are seen.

4. Conclusion

On a regular basis, a number of different groups have evaluated the available atomic data and produced updated CIE calculations (reviewed in Bryans et al. 2006). New DR, RR, and EII data are continually becoming available. Our efforts here are just another step in what promises to be a long line of studies aimed at providing the astrophysics community with the most reliable CIE calculations currently possible.

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