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AtomNeb: Atomic Data for Ionized Nebulae

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Software

- Review
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Summary

Ionized nebulae are used as an astrophysical tool to trace of the chemical composition of the interstellar medium in the Milky Way and other galaxies, and understand stellar mixing processes. Temperatures, densities, and ionic abundances are determined from *collisionally excited lines* by solving statistical equilibrium equations using collision strengths and transition probabilities of ions. Similarly, physical conditions and ionic abundances are calculated from *recombination lines* using recombination coefficients of ions. Hence, the atomic data for both the collisional excitation and recombination process are important to determine physical conditions and elemental abundances of ionized nebulae from collisionally excited lines and recombination lines (see e.g. Danehkar, Parker, and Ercolano 2013; Danehkar et al. 2014; Danehkar 2014, 2018; Danehkar, Parker, and Steffen 2016). Moreover, atomic data are essential for calculations of level populations and line emissivities in photoionization codes (e.g. Ferland et al. 1998; Kallman and Bautista 2001; Ercolano et al. 2003; Ercolano, Barlow, and Storey 2005).

`AtomNeb` is a database containing atomic data stored in the Flexible Image Transport System (FITS) file format produced for nebular spectral analysis, plasma diagnostics, and chemical abundance analysis. FITS tables provide easy access to atomic data for spectral analysis tools. Specifically, `AtomNeb` includes the atomic data for both the *collisional excitation* and *recombination* process of ions typically observed in nebular astrophysics. It is equipped with application programming interface (API) functions in the Interactive Data Language (IDL) to read the atomic data stored in FITS files.

- The API functions written in IDL were designed to easily read *collision strengths* and *transition probabilities* of given ions, which can be used to derive electron temperatures, electron densities, and ionic abundances from measured fluxes of collisionally excited lines in spectral analysis tools, and to simulate line emissivities in photoionization codes. The collisional excitation data include energy levels, collision strengths, and transition probabilities from the CHIANTI database version 5.2 (Landi et al. 2006), version 6.0 (Dere et al. 2009), and version 7.0 (Landi et al. 2012), as well as those atomic data used in pyNeb (Luridiana, Morisset, and Shaw 2015).
- The API functions written in IDL were designed to provide easy access to *recombination coefficients* and branching ratios of recombination lines of given ions. The recombination data include effective recombination coefficients for C II (Davey, Storey, and Kisielius 2000), N II (Escalante and Victor 1990), O II (Storey 1994; Liu et al. 1995), Ne II (Kisielius et al. 1998), hydrogenic ions for Z=1 to 8 (Storey and Hummer 1995), effective recombination coefficients for H, He, C, N, O, and Ne ions (Pequignot, Petitjean, and Boisson 1991), effective recombination coefficients for He I (Porter et al. 2012, 2013), effective recombination coefficients for N II

(Fang, Storey, and Liu 2011, 2013), and effective recombination coefficients for O II (Storey, Sochi, and Bastin 2017).

`AtomNeb` uses the FITS file related IDL procedures from the IDL Astronomy User's library (Landsman 1993, 1995) to read atomic data stored in FITS files.

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References

Danehkar, A. 2014. "Evolution of Planetary Nebulae with WR-type Central Stars." PhD thesis, Macquarie University, Australia. https://doi.org/10.5281/zenodo.47794.

———. 2018. "Bi-Abundance Ionisation Structure of the Wolf-Rayet Planetary Nebula PB 8" 35 (January):e005. https://doi.org/10.1017/pasa.2018.1.

Danehkar, A., Q. A. Parker, and B. Ercolano. 2013. "Observations and three-dimensional ionization structure of the planetary nebula SuWt 2" 434 (September):1513–30. https://doi.org/10.1093/mnras/stt1116.

Danehkar, A., Q. A. Parker, and W. Steffen. 2016. "Fast, Low-ionization Emission Regions of the Planetary Nebula M2-42" 151 (February):38. https://doi.org/10.3847/0004-6256/151/2/38.

Danehkar, A., H. Todt, B. Ercolano, and A. Y. Kniazev. 2014. "Observations and three-dimensional photoionization modelling of the Wolf-Rayet planetary nebula Abell 48" 439 (April):3605–15. https://doi.org/10.1093/mnras/stu203.

Davey, A. R., P. J. Storey, and R. Kisielius. 2000. "Recombination coefficients for C II lines" 142 (February):85–94. https://doi.org/10.1051/aas:2000139.

Dere, K. P., E. Landi, P. R. Young, G. Del Zanna, M. Landini, and H. E. Mason. 2009. "CHIANTI - an atomic database for emission lines. IX. Ionization rates, recombination rates, ionization equilibria for the elements hydrogen through zinc and updated atomic data" 498 (May):915–29. https://doi.org/10.1051/0004-6361/200911712.

Ercolano, B., M. J. Barlow, and P. J. Storey. 2005. "The dusty MOCASSIN: fully self-consistent 3D photoionization and dust radiative transfer models" 362 (September):1038–46. https://doi.org/10.1111/j.1365-2966.2005.09381.x.

Ercolano, B., M. J. Barlow, P. J. Storey, and X.-W. Liu. 2003. "MOCASSIN: a fully three-dimensional Monte Carlo photoionization code" 340 (April):1136–52. https://doi.org/10.1046/j.1365-8711.2003.06371.x.

Escalante, V., and G. A. Victor. 1990. "Effective recombination coefficients of neutral carbon and singly ionized nitrogen" 73 (July):513–53. https://doi.org/10.1086/191479.

Fang, X., P. J. Storey, and X.-W. Liu. 2011. "New effective recombination coefficients for nebular N ii lines" 530 (June):A18. https://doi.org/10.1051/0004-6361/201116511.

———. 2013. "New effective recombination coefficients for nebular N II lines (Corrigendum)" 550 (February):C2. https://doi.org/10.1051/0004-6361/201116511e.

Ferland, G. J., K. T. Korista, D. A. Verner, J. W. Ferguson, J. B. Kingdon, and E. M. Verner. 1998. "CLOUDY 90: Numerical Simulation of Plasmas and Their Spectra" 110 (July):761–78. https://doi.org/10.1086/316190.

Kallman, T., and M. Bautista. 2001. "Photoionization and High-Density Gas" 133 (March):221–53. https://doi.org/10.1086/319184.

Kisielius, R., P. J. Storey, A. R. Davey, and L. T. Neale. 1998. "Recombination coefficients for Ne Ii lines at nebular temperatures and densities" 133 (December):257–69. https://doi.org/10.1051/aas:1998319.

Landi, E., G. Del Zanna, P. R. Young, K. P. Dere, and H. E. Mason. 2012. "CHIANTIAn Atomic Database for Emission Lines. XII. Version 7 of the Database" 744 (January):99. https://doi.org/10.1088/0004-637X/744/2/99.

Landi, E., G. Del Zanna, P. R. Young, K. P. Dere, H. E. Mason, and M. Landini. 2006. "CHIANTI-An Atomic Database for Emission Lines. VII. New Data for X-Rays and Other Improvements" 162 (January):261–80. https://doi.org/10.1086/498148.

Landsman, W. B. 1993. "The IDL Astronomy User's Library." In *Astronomical Data Analysis Software and Systems Ii*, edited by R. J. Hanisch, R. J. V. Brissenden, and J. Barnes, 52:246. Astronomical Society of the Pacific Conference Series.

———. 1995. "The IDL Astronomy User's Library." In *Astronomical Data Analysis Software and Systems Iv*, edited by R. A. Shaw, H. E. Payne, and J. J. E. Hayes, 77:437. Astronomical Society of the Pacific Conference Series.

Liu, X.-W., P. J. Storey, M. J. Barlow, and R. E. S. Clegg. 1995. "The rich O II recombination spectrum of the planetary nebula NGC 7009: new observations and atomic data" 272 (January):369–88. https://doi.org/10.1093/mnras/272.2.369.

Luridiana, V., C. Morisset, and R. A. Shaw. 2015. "PyNeb: a new tool for analyzing emission lines. I. Code description and validation of results" 573 (January):A42. https://doi.org/10.1051/0004-6361/201323152.

Pequignot, D., P. Petitjean, and C. Boisson. 1991. "Total and effective radiative recombination coefficients" 251 (November):680–88.

Porter, R. L., G. J. Ferland, P. J. Storey, and M. J. Detisch. 2012. "Improved He I emissivities in the case B approximation" 425 (September):L28–L31. https://doi.org/10.1111/j.1745-3933.2012.01300.x.

———. 2013. "Erratum: 'Improved He I Emissivities in the Case B Approximation"' 433 (June):L89–L90. https://doi.org/10.1093/mnrasl/slt049.

Storey, P. J. 1994. "Recombination coefficients for O II lines at nebular temperatures and densities" 282 (February):999–1013.

Storey, P. J., and D. G. Hummer. 1995. "Recombination line intensities for hydrogenic ions-IV. Total recombination coefficients and machine-readable tables for Z=1 to 8" 272 (January):41–48. https://doi.org/10.1093/mnras/272.1.41.

Storey, P. J., T. Sochi, and R. Bastin. 2017. "Recombination coefficients for O II lines in nebular conditions" 470 (September):379–89. https://doi.org/10.1093/mnras/stx1189.