The Journal of Open Source Software

proEQUIB: IDL Library for Plasma Diagnostics and Abundance Analysis

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DOI: 10.21105/joss.00899

Software

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Submitted: 30 June 2018
Published: 04 December 2018

Summary

The emission lines emitted from gaseous nebulae carry valuable information about the physical conditions and chemical abundances of ionized gases in these objects, as well as the interstellar reddening. We determine the electron temperature, the electron density, and the ionic abundances from the dereddened fluxes of *collisionally excited lines* (CEL) and *recombination lines* (RL) identified in nebular spectra (see e.g. Danehkar, Parker, & Ercolano (2013); Danehkar, Todt, Ercolano, & Kniazev (2014); Danehkar, Parker, & Steffen (2016); Danehkar (2018a)).

`proEQUIB` is a library including several application programming interface (API) functions developed in the Interactive Data Language (IDL), which can be used to determine temperatures, densities, and chemical abundances from emission lines of ionized nebulae. This IDL library can also be used by the GNU Data Language (GDL) (Arabas, Schellens, Coulais, Gales, & Messmer (2010); Coulais et al. (2010)), which is a free and open-source alternative IDL compiler. This IDL/GDL package employs the IDL library `AtomNeb` *Atomic Data for Ionized Nebulae* (Danehkar (2018b)), which contains collision strengths and transition probabilities for collisional excitation calculations, and recombination coefficients for recombination calculations. This package includes several API functions to determine physical conditions and chemical abundances from CEL and RL, derive interstellar extinctions from Balmer lines, and deredden the observed fluxes:

- The API functions for the *CEL analysis* were developed in the IDL programming language based on the algorithm of the FORTRAN program `EQUIB` (Howarth & Adams (1981); Howarth et al. (2016)), which calculates atomic level populations and line emissivities in statistical equilibrium in multi-level atoms for the given physical conditions. These API functions can be used to determine the electron temperature, the electron density, and the ionic abundances from the dereddened fluxes of *collisionally excited lines* emitted from ionized gaseous nebulae.
- The API functions for the *RL analysis* were developed in IDL according to the algorithm of the recombination scripts by X. W. Liu and Y. Zhang included in the FORTRAN program `MOCASSIN` (Ercolano, Barlow, Storey, & Liu (2003); Ercolano, Barlow, & Storey (2005)). These API functions can be used to determine the ionic abundances from the dereddened fluxes of *recombination lines* emitted from ionized nebulae.
- The API functions for the *reddening analysis* were developed based on the methods of the reddening functions from the Space Telescope Science Data Analysis System

(STSDAS) IRAF Package (Bushouse & Simon (1994); Shaw & Dufour (1994)). These API functions can be employed to obtain *interstellar extinctions* for different reddening laws from the observed fluxes of Balmer lines detected in nebular spectra, and deredden the measured fluxes of emission lines.

proEQUIB has recently been used for plasma diagnostics and abundance analysis of some planetary nebulae (Danehkar et al. (2016); Danehkar (2018a)). This IDL/GDL package heavily relies on the IDL Astronomy User's library (Landsman (1993); Landsman (1995)) and the IDL library AtomNeb (Danehkar (2018b)). The API functions of this IDL library can easily be utilized to generate spatially-resolved maps of extinction, temperature, density, and chemical abundances from integral field spectroscopic observations (see e.g. Danehkar et al. (2013); Danehkar et al. (2014); Danehkar (2014)).

Acknowledgements

A.D. acknowledges the receipt of a Macquarie University Research Excellence Scholarship.

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