EMILI - An Aid to Emission Line Identification in Emission-Line Regions

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Abstract

We present results from EMILI, our software optimized to identify weak emission lines in planetary nebulae and H II regions. We discuss the steps carried out by the code to arrive at identifications, and planned future improvements.

1. Introduction

High resolution and signal-to-noise emission spectra of planetary nebulae and H II regions reveal large numbers of weak emission lines. Identifying these lines is both difficult and time consuming, given the large number of atomic transitions which could be responsible. Model spectra require precise information about atomic parameters, such as collision strengths, recombination coefficients, and spontaneous emission coefficients, information which is not always available for the wide variety of possible transitions that could be associated with such lines. Our code, EMILI for Emission Line Identifier, is specifically tailored to help identify such lines, by using a minimum of such information, and by providing easy to interpret results.

2. Calculation Steps

A user submits a list of unidentified lines and their measured parameters (wavelength, between 3000-11000Å, and associated measurement error, flux with respect to Hβ, and FWHM), and supplies estimates for the temperature and electron density of the object from which the spectra and its lines are drawn, as well as a value for the instrumental resolution. Optionally, a list of pre-identified lines can be used by the code to correct for the systemic velocity and any ionization energy dependent velocity structure within the spectra. Using default solar abundances, or a user supplied abundance table, the code calculates ionic abundances for all elements $Z \leq 30$. These abundances use a set of ionization correction factors that are either reasonable default values, or are calculated from the strengths of certain lines in the user-supplied pre-identified list.

For each unidentified line a transition database (Atomic Line List v2.04, van Hoof 2001, `http://www.pa.uky.edu/~peter/atomic`) is searched for nearby lines. The wavelength of the

unidentified line is then corrected for the systemic velocity and for any ionization energy dependent velocity structure present that is appropriate for the ion producing the transition. Only transitions where the residual wavelength difference between the corrected observed wavelength and the laboratory wavelength are within a few observed wavelength measurement error sigma, are retained.

For surviving transitions, a *template flux* is calculated utilizing a simplified one temperature/density zone model of the object, a two-level atom, the specified nebular attributes, calculated ionic abundances, and assumed generic values of the atomic parameters appropriate for the type of transition (electric dipole, quadrupole, magnetic dipole). Each calculation includes contributions from collisionally excited and recombination populated origin levels, regardless of transition type. The transitions with template fluxes within the top 3 decades, among all transitions for which the flux was calculated, are retained under the assumption that they are the most likely to be seen in the actual spectrum.

For transitions reaching this stage, the code endeavors to find additional *multiplet lines*, if any, that could correspond to other unidentified lines in the submitted list. A match is considered "found" if the relative observed flux of the line currently being tested, to the flux for the one considered as a match for the other multiplet line, is roughly equal to the ratio of the products of the statistical weight and spontaneous transmission coefficient for each of the respective multiplet lines, or within an order of magnitude if the coefficients are not available. Furthermore, the residual wavelength differences between the observed lines and the respective laboratory wavelengths for their associated transitions must be nearly the same, to reflect that all multiplet lines come from the same region of the object and are produced by the same excitation mechanism.

Finally, the code sorts the remaining transitions, using a simple ranking mechanism which employs the relative amounts of residual wavelength differences, the relative strengths of the template fluxes, and the results of the multiplet checks, to provide a ranking and a quality of identification "score" for each unidentified line. The user may interpret these results to select a probable line identification.

3. Sample Results

Figure 1 is a segment of our recently obtained, resolution=30000 (10 km/sec), spectrum of IC 418 (Sharpee *et al.* 2002, in preparation). Figure 2 is an EMILI identification of a weak line at 4641.45 Å marked in Figure 1. EMILI suggests N III λ4640.46 Å is the most likely ID, as indicated by a low number/score in column G of Figure 1 for this transition as compared to the other suggested alternate IDs. EMILI arrives at this conclusion by noting: 1) The residual wavelength difference (in km/sec, column E) between the corrected observed wavelength (column A) and the laboratory wavelength for the transition (column B) is fairly small. 2) The template flux (column D) is the largest among all the potential IDs, and fairly close to the observed value. 3) The multiplet check indicates that another observed line from the same line list matches well with another transition belonging to the same multiplet as N III

λ4640.46 Å, with a similar residual wavelength difference (column H). EMILI indicates that it found one of two multiplet lines with strengths predicted to be strong enough to observe (column F) if this ID is really the correct ID, which are better statistics than for any other alternate ID in the list.

EMILI provides a similar group of possible identifications for every observed line submitted by the user. For the 500+ lines in the full spectrum to which Figure 1 belongs, a standard desktop computer requires approximately 5-6 minutes to process them all.

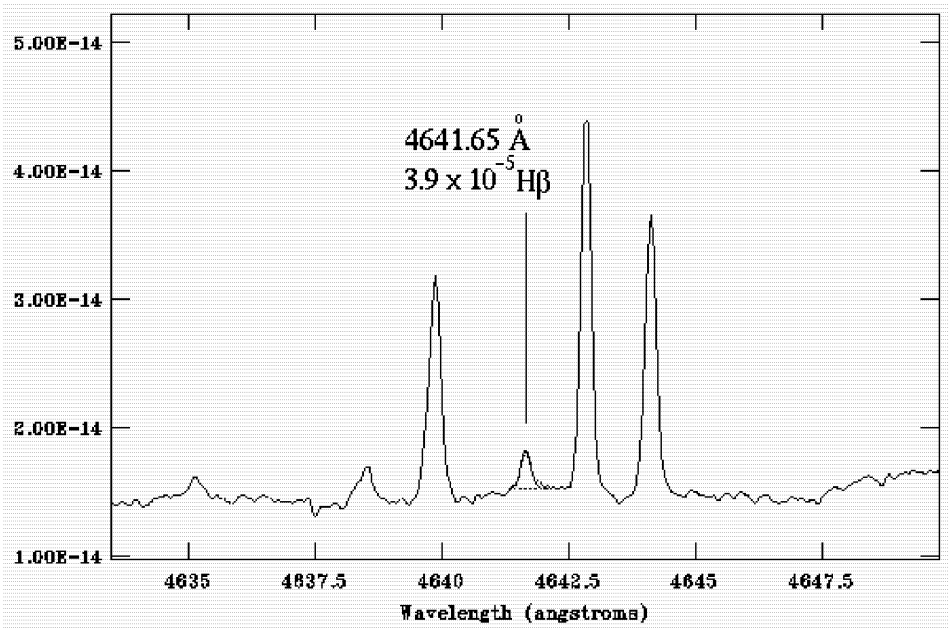

Fig. 1.— A section of our recently obtained, high resolution and signal-to-noise spectra of IC 418. Indicated is a weak line at 4641.65 Å. The EMILI derived identification list for this line is shown in Figure 2.

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Observed Line:   4641.65   3.9E-05  S/N:     23.35 FWHM:  15.9
    4640.57 |    4640.47   Fe II]   8.0E-07    5.9 4/0 8
+   4640.61 |    4640.54   Ni II    4.4E-06    4.6 4/0 6D
+   4640.60 |    4640.59   Fe III   6.4E-05    0.6 5/0 4B
+   4640.60 |    4640.64   N  III   2.0E-04   -2.5 2/1 2A 4634.12  -2.6
    4640.57 |    4640.66   Cr I     2.5E-07   -6.3 7/0 8
    4640.61 |    4640.73$  Ni II    3.9E-06   -7.4 0/0 5C
    4640.60 |    4640.75   S  IV    4.3E-05   -9.6 3/0 7

      A          B        C        D      E F G     H
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Fig. 2.— The EMILI identification list for the line at 4641.65 Å indicated in Figure 1. An explanation of these results is given in the text.

4. Future Directions

To improve the existing code we plan on making two major modifications. The first involves cross correlations between IDs in separate lines, beyond the multiplet check, which have the same source ion and excitation mechanism. This is to see if they have roughly the expected relative strengths and residual wavelength differences, and to look for patterns that could provide further corroborating evidence for a group of possible IDs for different lines. Secondly, we plan on making the code iterative, using the best IDs from an initial run to re-calculate and improve the accuracy the ionic abundances and velocity structure corrections, for use in successive runs.A preliminary version of the code is now available at:
`http://www.pa.msu.edu/people/sharpee/emili.html`