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A Deep UV-Blue Planetary Nebula Template Spectrum from NGC 7027

J. R. Walsh
ST-ECF, ESO, Karl-Schwarzschild Strasse 2 , D-85748 Garching, Germany

D. Péquignot
Observatoire de Paris - Meudon, F-92195 Meudon Cedex, France

C. Morisset
Institut d'Astrophysique de Marseille, Traverse du Siphon, BP 8, F-13376 Marseille Cedex 12, France

P. J. Storey
Department of Physics & Astronomy, University College London, Gower Street, London WC1E 6BT, UK

B. Sharpee & J. Baldwin
Department of Physics & Astronomy, Michigan State University, East Lansing, MI 48824-1116, USA

P. A. M. van Hoof
Canadian Institute for Theoretical Astrophysics & Department of Astronomy, University of Toronto, 60 St. George Street, Toronto, ON M5S 3H8, Canada

R. E. Williams
Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

NGC 7027 is justifiably THE template spectrum for PNe. Its vast range of emission species – from molecular and neutral to ions with ionization potential > 120eV – its high surface brightness and accessibiliy for northern observatories make it the PN laboratory of choice. However the quality of the spectra from the UV to the IR is mixed, many line fluxes and identifications still remaining unchecked from photographic or image tube spectra. Very deep spectra of NGC 7027 (emission line strengths $<10^{-4}$ of Hβ) in the 0.65 to 1.05μm region (Baluteau et al. 1995) showed the presence of many faint emission lines. Péquignot & Baluteau (1994) showed that heavy elements from the 4th, 5th and 6th rows of the Periodic Table have much higher abundances than Solar,

confirming the synthesis of neutron capture elements in low mass stars and providing new constraints on stellar evolution theory.

Using the William Herschel Telescope and ISIS spectrograph, ultra-deep spectra from 4400Å down to the atmospheric cut-off (the shortest line detected was at 3020Å) have been obtained. The combined spectrum contains 272 lines ($\geq 3\sigma$) to (observed) strength of 3×10^{-5} of Hβ. Many lines not listed previously have been reliably detected. Some 35% of the lines initially remained unidentified. The task of identifying the emission lines is outlined.

One approach extends the search of line catalogues by automatic line ID software (EMILI) which interrogates a master linelist for transitions and computes an expected template flux for each transition, based upon generic cross sections, an assumed abundance and ionization distribution. An on-line database is the Atomic Line List v2.04 (http://www.pa.uky.edu/~peter/atomic/) of van Hoof. For each putative ID, the linelist is searched for other lines belonging to the same multiplet that should be observable if that line is the correct ID. The EMILI software then assigns a numerical 'ID Index' to each putative ID based upon its expected flux, wavelength agreement with the observed line, and the presence of other lines of that multiplet. Applied to the NGC 7027 UV-blue spectrum, EMILI produced about 30 new strong identifications. However, line lists based on laboratory spectroscopy are far from complete for nebula spectroscopy and specific data bases are required.

A second approach compares to that of spectral synthesis for stellar spectra (Péquignot, 1996). The basic entity is a *line set*, that is a list of line wavelengths and intensities relative to a "reference line". Each set corresponds to a pair formed by one ion and one "elementary" process. A given line may belong to several sets, its intensity being the sum of partial intensities. Relative intensities within a set should be little dependent on physical conditions. For example, radiative recombination lines for a given ion are nearly proportional and even an approximate knowledge of average physical conditions in the nebula will uniquely determine the set. In this approach an observed spectrum will appear as a sum of line sets, each one being scaled by the intensity attributed to its reference line. Complementary information defining the spectrum includes intrinsic line profiles, instrumental profile, exact positioning of the continuum, interstellar reddening correction and physical conditions.

A code for spectral synthesis (named X-SSN), incorporating libraries of atomic data, is under development. The X-SSN code, which already includes over 3000 lines, benefits from recent advances in atomic physics through the calculation of the intensities of the many recombination lines that dominate the spectra at very low intensities (e.g., Davey et al., 2000). The code will be applied to the deep NGC 7027 template spectrum, extending the comprehensive line identification to the whole of the optical range.

References

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