X-ray, EUV and Infrared Coronal-Line Radiation from Planetary Nebulae

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The interacting stellar winds (ISW) theory (Kwok, S., Purton, C. R., Fitzgerald, P. M., 1978, ApJL, 219, L125) is nowadays widely accepted in the physics of Planetary Nebulae (PNe). It received much support from the observed fast winds in the central stars of PNe (CSPN), recognized to be a quite common phenomenon (e.g., Perinotto, M., 1993, in IAU Symp. No.155, Planetary Nebulae, eds. R. Weinberger and A. Acker, Kluwer, Dordrecht, 57). Thus, the existance of a hot bubble in the PNe structure is a cornerstone of the ISW model. The high velocities (600–3500 km s^{-1}) of the CSPN winds , are, according to the ISW model, directly responsible for an high gas temperature in the hot bubble, which is then expected to be the source of an extended X-ray and extreme ultraviolet (EUV) radiation. The PNe should also emit infrared coronal lines (IRCL) of highly ionized species since the high temperature plasma of the hot bubble is in contact with the much colder outer shell (optical PN) and the thermal conduction will produce a region of intermediate temperatures (5×10^5– 10^6 K). A model considering the structure of the hot bubble in PNe with taking into account the thermal conductivity effects was present by Zhekov and Perinotto (1996, A&A, 309, 648).

This model has been applied to NGC 6543 in order to derive its hot-bubble X-ray, EUV and IRCL ($\lambda > 1\mu$) characteristics. The best known parameters for the CSPN in NGC 6543 are probably: $T_{eff} = 60000 \pm 10000\,K$; $\lg(L/L_\odot) = 3.75$; $R_*/R_\odot = 0.7$; $R_*/d = 1.1\times10^{-11}$; $d = 1.44$ kpc; $\dot{M}_w = 4\times10^{-8}$ $M_\odot$ yr^{-1}; $V_w = 1900$ km s^{-1}. The evolutionary track of a CSPN having stellar mass $M = 0.61$ $M_\odot$ would indicate an evolutionary stellar age, $t_{age,evol}$, of about 3500 – 4200 years. Given the NGC 6543 parameters: $V_{exp} =$ 20 km s^{-1}, $R_2 = 0.039$ pc at $d = 1$ kpc (Weinberger, R., 1989, A&AS, 78, 301), the PN age, as given by the model, is $t_{age,ISW} = 3600$ years. On the other hand, if we assume $d =$ 1.44 kpc (see above) the radius of NGC 6543 will be $R_2 = 0.0562$ pc which would mean $t_{age,ISW} = 5100$ years. Thus, we see that the two independent estimates of the PN age are in an acceptable accordance. In the frame of the ISW model, the slow wind parameter $\dot{M}_6/V_{10}$ (where the mass-loss rate is in units ot 10^{-6} $M_\odot$ yr^{-1}, and the wind velocity is in units of 10 km s^{-1}) can be estimated if the PN expansion velocity and radius are known which in the case considered here turned out to be in the range $\dot{M}_6/V_{10} = 1 \div 6$. The corresponding theoretical X-rays luminosity is $L_X(0.05-2.5\,keV) = (2\div7)\,10^{32}\,erg\,s^{-1}$, the EUV luminosity is $L_{EUV}(70 - 700\,\AA) = (1-3)\,10^{33}\,erg\,s^{-1}$, and the luminosities of various IRCL are in the range $10^{28} - 10^{29}\,erg\,s^{-1}$. Moreover, the observed X-ray spectrum fairly agrees with the one predicted from the ISM theory.

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