DETERMINATION OF MASS-LOSS RATES OF PLANETARY NEBULAE NUCLEI USING THE FIRST ORDER MOMENT OF P CYGNI LINE PROFILES

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Stellar winds have been detected in planetary nebulae nuclei, mostly from the P Cygni line profiles observed with IUE in the low resolution mode. The most powerful method to derive mass-loss rates from these underresolved line profiles is the use of the first order moment of the line profile as suggested by Castor, Lutz and Seaton (1981) (hereafter CLS). This method has namely the advantage to be insensible to the degradation of the spectral resolution and to the possible presence of a superimposed nebular line.
If the line is optically thin, the first order moment

$$W_1 \; \alpha \; \int \left(\frac{E(\lambda)}{E_c} - 1\right)(\lambda-\lambda_0)\,d\lambda$$

reduces to the quantity W_1° which is directly proportional to $\dot{M}\,\bar{n}$(level) for both resonance and subordinate lines. $\dot{M}$ refers to the mass-loss rate while $\bar{n}$(level) refers to the mean fractional abundance of an element in the lower atomic level.

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If the line is not optically thin, the first order moment W_1 becomes a complex function of the parameter W_1^o (which is proportional to the quantity $\dot{M}\ \bar{n}$(level) (see Surdej, 1983 and Hutsemékers, Surdej, 1986).

Recently, Cerruti-Sola and Perinotto (1985) (hereafter CP) have compiled IUE low-resolution spectra of PNN where P Cygni line profiles have been detected. They have measured the first order moment W_1 of these profiles and determined the mass-loss rates on the basis of the approximation that these lines are optically thin, i.e. assuming that $W_1 = W_1^o$. Unfortunately, this approximation leads to a systematic underestimate of the mass-loss rates. This is readily seen on the following figure. In this figure, we have reported the value of Log W_1 given by CP against Log W_1^o values. The subordinate lines of OIV and OV have been considered here because they are of primary importance for the mass-loss rate determinations since the approximation n(OIV)+n(OV)=1 can reasonably be made. The curve (1) has been obtained using the same opacity and velocity laws that those chosen by CLS and CP. Since these distributions are in reality unknown, we prefer to compute the relation between W_1 and W_1^o for realistic opacity and velocity laws found to reasonably fit the stellar wind observations of early-type stars (18 models have been considered). The average curve of these 18 model calculations is represented in the figure (curve (2)) altogether with typical dispersions. Both the curves n°1 and 2 show a systematic departure from the linear relation used by CP and CLS which gives a value of W_1^o (or $\dot{M}$ $\bar{n}$(level) underestimated by a factor varying between 1.5 and 7 (curve (1)) or better between 2 and 20 (curve (2)).

In order to determine the mass-loss rates from these subordinate lines, we also need the value of the stellar flux near 600 Å, i.e. the flux which populates the lower level of the transition via photoexcitations. CP have computed this ratio assuming that the star radiates as or black-body at $T=T_Z$(HeII). But if the model proposed by Adam and Köppen (1985) for the wind of NGC 1535 is applicable to all nuclei for which a wind has been detected, the HeII Zanstra temperature does overestimate their effective temperature. For the nuclei of the 3 PN NGC 6826, NGC 6210 and NGC 6543, we have derived the mass-loss rates using the flux determinations of Natta et al. (1980) and found that the flux approximation of CP again underestimates the mass-loss rates by a factor 3 (Hutsemékers, Surdej, 1986).

It is important to note that the difference between our values of W_1^o and those inferred from the linear relation, increases when the measured value of W_1 increases (see fig.). In fact, the curves (1) and (2) do converge towards an asymptotic value such that above the value $W_1 > 0.49$ mass-loss rates cannot be derived anylonger. It is interesting to see that all the W_1 values measured by CP for the P Cygni profiles of NV are above this asymptotic value as well as about 50 % of those measured for CIV; therefore, these resonance lines cannot provide any meaningful information about the mass-loss rates. Interpreting these saturated lines needs new computations which take into account their doublet structure.

Finally, we conclude that the mass-loss rates of PNN derived by CP have been systematically underestimated by one or nearly two orders of magnitude.

References

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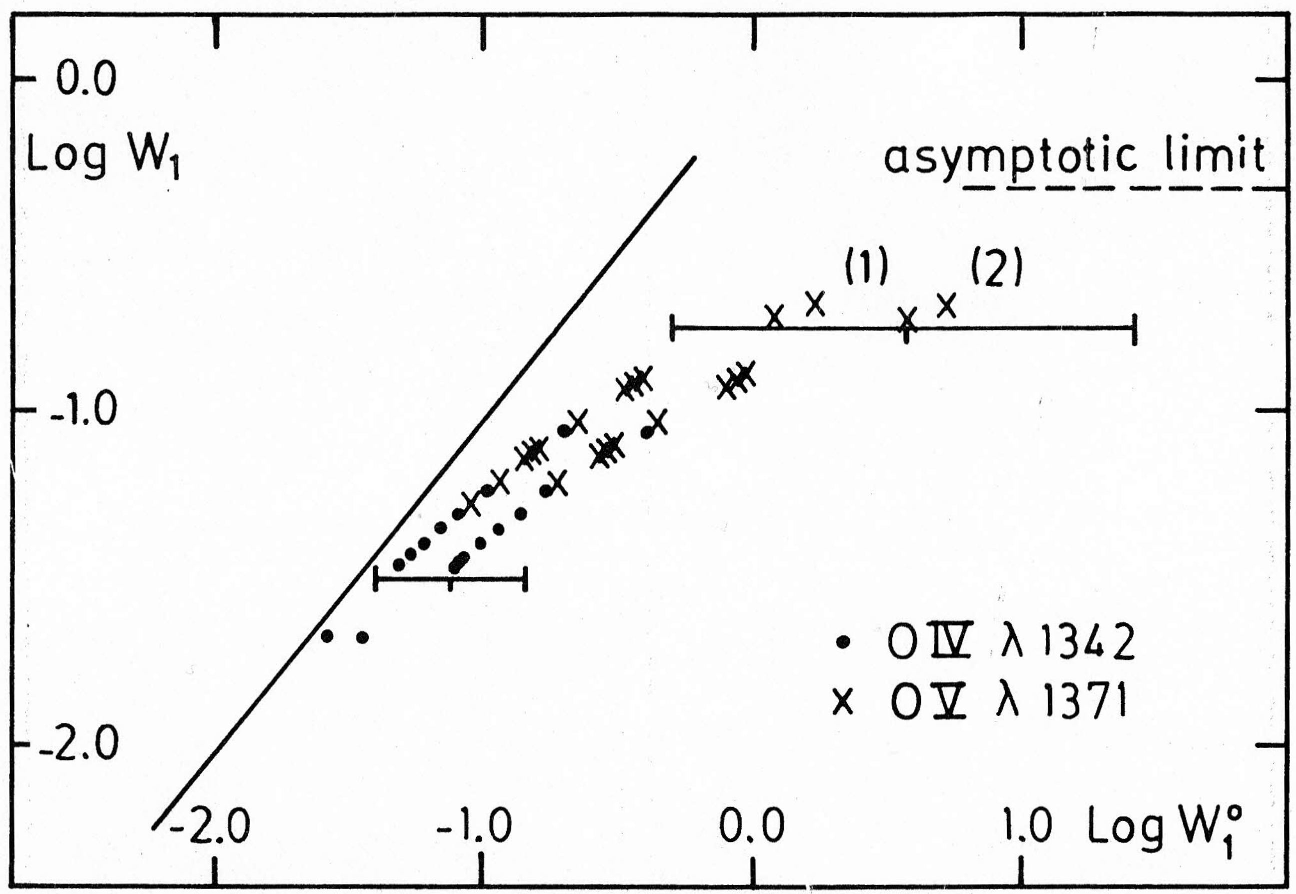

Adopting the velocity and opacity laws used by CLS and CP (curve 1) and the average results (curve 2) of 18 realistic model calculations, we have represented in this figure the values of W_1 published by CP for various PNN.