II. HIGHLIGHTS ON THE NUCLEI

R.P. KUDRITZKI

M. PERINOTTO

A. PREITE-MARTINEZ

K. BUTLER

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MODEL ATMOSPHERES OF CENTRAL STARS OF PN

R.P. KUDRITZKI and R.H. MÉNDEZ
University Observatory, Munich, Federal Republic of Germany

ABSTRACT. We review the work done in this field since the time of the Mexico Symposium on PN, five years ago. Although substantial progress has been achieved, a lot of work is still needed, and we pay attention to some remaining problems. We briefly describe some recent results about stellar and nebular properties, obtained with NLTE model atmosphere techniques.

1. Introduction

Work on model atmospheres for central stars of planetary nebulae (CSPN) has two main motivations: (a) to obtain direct information about stellar properties by comparison with the observed stellar spectra, and (b) to provide a more reliable input, in particular more reliable stellar fluxes, for improved nebular modeling.

The most outstanding characteristic of CSPN is that they are very hot, with surface temperatures above 25000 K, and the very high energy density in the radiation fields of such hot stars produces two major difficulties: departures from local thermodynamic equilibrium (LTE) in the photosphere, and the presence of strong stellar winds. In Sections 2 and 3 of this review we describe recent progress and current limitations in the plane-parallel, hydrostatic NLTE treatment. Sections 4 and 5 deal in a similar way with NLTE models including winds. In Section 6 we describe some recent results which are relevant to the problem of the Galactic PN luminosity function.

2. "Classic" NLTE models (no metals, no winds)

At the Mexico Symposium we presented (Kudritzki and Méndez 1989; Méndez et al. 1988a,b) a large-scale effort to determine $T_{\rm eff}$, log g and photospheric He abundances of CSPN, by comparison of the observed stellar H and He absorption line profiles with theoretical profiles obtained from plane-parallel, hydrostatic, metal-free (H and He only) NLTE model atmospheres in radiative equilibrium. Subsequently, some more work has been done using the same kind of models (Heber et al. 1988; McCarthy et al. 1990, 1991; Méndez et al. 1990; Herrero et al. 1990; Napiwotzki 1992). This kind of "classic" NLTE analysis is suitable, in principle, for H-rich CSPN showing predominantly absorption-line spectra, if we take into account the corrections we will describe in Section 5. The determination of the basic atmospheric parameters, with typical uncertainties of ±10% in $T_{\rm eff}$

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and ±0.2 in log g, permits to place these CSPN in the log g - log $T_{\rm eff}$ diagram, leading to a better knowledge of their evolutionary properties and to the derivation of luminosities and spectroscopic distances. We will come back to these applications in Sections 5 and 6.

Napiwotzki (1992) has reported the existence of a "Balmer line problem" affecting temperature determinations in the case of very high gravity CSPN, already positioned on the white dwarf cooling tracks. The problem is that, for such high gravities, different Balmer lines indicate different temperatures. The reason for this problem is not clear; it might be attributed to deficiencies in the broadening theory or to metal line blanketing effects. For the moment, we would give more weight to temperatures derived from H_γ or H_δ, because, in the case of NGC 7293, they are in better agreement with the H and He II Zanstra temperatures, while H_β and especially H_α give, according to Napiwotzki, much lower (clearly unrealistic) temperatures for this central star.

The available information about photospheric He abundances has been recently reviewed by Méndez (1991a). What about other elements? Given sufficiently high spectral resolution and signal-to-noise ratio, the visual spectra of CSPN show many useful lines of C, N, O, Mg, Al and Si, particularly at temperatures below 30000 K. If we are dealing with a H-rich CSPN, then a "classic" NLTE analysis, coupled to adequate NLTE line formation calculations, permits to obtain some information about photospheric abundances. One example of this kind of work is given by McCarthy et al. (1991), who made a determination of the O and Si photospheric abundances in the spectrum of CD-41 13967, the central star of He 3-1863. Microturbulent velocities of 10 and 20 km/s for Si III and O II, respectively, were adopted in order to obtain no dependence of abundance as a function of equivalent width. The O II microturbulent velocity may be a bit too high, perhaps indicating that more improvements are needed (see Section 4 below, and Kudritzki 1992).

The NLTE line formation calculations we have just mentioned are characterized by the assumption that the ion under consideration can be treated as a trace element, so that, given a good (NLTE) model atmosphere, the atmospheric structure can be kept fixed and we only need to solve a system of radiative transfer and statistical equilibrium equations restricted to the ion we are studying. Previous experience indicates that this method provides reliable abundances only if the model ion is sufficiently complex, including many energy levels and transitions: see e.g. Eber and Butler (1988) on C II; see also Becker and Butler (1988, O II; 1989, N II; 1990, Si II, III and IV).

Becker and Butler (1992) have recently completed a Fe V model ion, and have made NLTE line formation calculations aimed at reproducing the HST ultraviolet spectrum of the sdO star BD+75 325, resulting in a determination of the photospheric iron abundance. They have shown that NLTE effects in line formation must be taken into account. Model ions for Ni IV, V and VI have also been developed (Becker and Butler in preparation). This opens the way to the future determination of Fe and Ni photospheric abundances in CSPN. More comments about this project at the beginning of Section 4.

3. NLTE line blanketing

The CSPN show such a variety of spectral characteristics (see e.g. Méndez 1991a) that no single set of models can be adequate to study them all. Much work in the last 5 years has been devoted to remove the limitations of the "classic" NLTE models (no metals, no winds), in an effort to extend the NLTE analyses to all kinds of CSPN. In this Section we deal with recent progress in line blanketing problems.

Most remarkable has been the development, by the Kiel group, of plane-parallel, hy-

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drostatic NLTE models for the quantitative analysis of some H-deficient, C-rich CSPN and related objects (the PG 1159 stars); see in particular Werner (1992). The analysis requires NLTE model atmospheres including the effect of line blanketing due not only to H and He, but also at least to C and O, because their abundances are so high that they cannot be treated as trace elements. Therefore it is necessary to introduce, in the model atmosphere code, the statistical equations for the populations of more than 100 atomic levels. This became possible in practice through the application of the so-called "Accelerated Lambda Iteration" method (Werner and Husfeld 1985).

Having obtained a reasonable representation of the atmospheric structure, it is still necessary to solve very complicated line formation problems, because most of the diagnostic lines arise from highly excited levels, thus requiring very complex model atoms. Besides, there is a severe blending problem, because all the ions that produce diagnostic lines have one-electron spectra. And finally, accurate broadening theories for the diagnostic C IV, N V, O VI lines are still lacking (although the situation is improving, at least for C IV; see the new Stark broadening calculations by Schöning 1992). Despite all these difficulties, Werner et al. have been able to obtain satisfactory line profile fits for a handful of PG 1159 stars, giving fundamental information about their $T_{\rm eff}$, log g and H, He, C, N and O abundances. Further work along this line will be of great help to understand the evolution of H-deficient CSPN.

One of the dreams of NLTE model makers is to be able to treat metal line blanketing in as much detail as in Kurucz's LTE models. Although that is not possible for the moment, some people are making good progress. Grigsby et al. (1992) have used NLTE metal line blanketed model atmospheres with solar abundances (see Anderson 1985, 1989) for the analysis of late O and early B young stars in clusters and associations; similar models can be used to study cool CSPN. Dreizler and Werner (1992) have constructed exploratory NLTE model atmospheres for hot post-AGB stars, featuring H, He and Fe with solar abundances. The NLTE iron line blanketing is treated in a statistical way, following Anderson (1989). As a first step, their models are blanketed by some tens of thousands of observed Fe III - Fe VII transitions. Further work will include all predicted transitions, which are roughly a factor 100 more numerous, as well as other iron-group elements.

Such NLTE metal line blanketing studies will make it possible to investigate, for example, if metal line blanketing can solve Napiwotzki's problem, or, in general, how relevant is metal line blanketing for the determination of $T_{\rm eff}$, log g, energy distributions and photospheric abundances of CSPN. The first results for massive OB stars (Grigsby et al. 1992) would seem to indicate that the "classic" NLTE determinations of $T_{\rm eff}$ and log g are not wrong by more than their estimated error bars.

Kunze, Kudritzki and Puls (in preparation) are working on a hydrostatic code that includes NLTE opacity due to H, He, C, N, O, Ne, Mg, Al, Si, S, Ar in order to investigate the effects of metallicity on the emergent ionizing continuum flux between 228 and 911 Å. They have also used these models to investigate wind blanketing effects (Abbott and Hummer 1985), finding that wind blanketing does not significantly change the number of ionizing photons (see Kudritzki et al. 1991).

4. NLTE models including winds

Let us go back for a moment to the NLTE line formation problem for Ni and Fe. In the case of hot stars, the relevant ions of these elements (Ni IV - VI, Fe V - VII) produce many weak lines in the ultraviolet, giving us a chance to determine the photospheric Ni

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and Fe abundances. There is, however, a complication, recently described by Kudritzki (1992): for ions with so high atomic weights, the thermal velocities are almost one order of magnitude smaller than the sound speed. As a consequence, even a small, subsonic outflow velocity in the deep photosphere can shift the metal lines by a few thermal Doppler widths into the neighboring continuum, increasing their equivalent widths. Clearly, a hydrostatic NLTE line formation formulation would require the introduction of a spuriously high microturbulent velocity, in order to reproduce the resulting curve of growth. This is a good example of a case in which wind effects must be taken into account well below the sonic point. Becker and Butler (see their poster abstract in these proceedings) have reformulated the Fe V, Ni IV, Ni V NLTE line formation problem, in order to incorporate Kudritzki's (1992) analytical approximation of the aforementioned wind effect. They have tried to compare the resulting synthesized ultraviolet spectrum with the observed high-resolution IUE spectra of the central stars of IC 3568 and NGC 6826 (whose main atmospheric parameters had been improved by Méndez et al. 1992, see also Section 5 below). The value of this comparison is very limited because of the very low signal-to-noise ratio of both IUE SWP spectra. Hubble Space Telescope UV spectrograms, when available, will allow a reliable determination of photospheric Ni and Fe abundances.

One of the most encouraging results of the "classic" NLTE analysis of CSPN was that stars closer to the Eddington limit, in the log g - log $T_{\rm eff}$ diagram, show stronger winds (Méndez et al. 1988b, Pauldrach et al. 1988), as expected from the theory of radiatively driven winds. The Munich group (Pauldrach, Puls, Butler, the Gablers, Kudritzki) has devoted much effort along several years to improve this theory. Although it is not ready yet, it is increasingly used for spectral diagnostics in all kinds of hot stars with moderate winds. Just to remind the reader, the idea is to solve simultaneously the extended atmospheric structure and radiation driven wind hydrodynamics, treating the problem (including all opacities) fully in NLTE. A list of references is given by Kudritzki et al. (1992). A high degree of physical and numerical detail (e.g. the very complicated Grotrian diagrams always used to astonish the audience) is essential; otherwise the results are not satisfactory. The theory in its final form ought to provide masses, radii and distances for all kinds of hot stars with mass loss, given the following observational quantities determined from the stellar spectrum: wind terminal velocity, mass loss rate and effective temperature.

One aspect of this project is the development of so-called "unified" model atmospheres (Gabler et al. 1989; a preliminary report had been presented in our Mexico review). A brief description of unified models is also given in Gabler et al.'s poster abstract in these proceedings. The unified models permit to study the influence of radiatively driven winds and of atmospheric extension on the stellar energy distribution and on the profiles of diagnostic lines. In the remaining part of this Section we consider energy distributions, and in Section 5 we deal with diagnostic lines.

Concerning energy distributions: Gabler et al. (1989) have been able to reproduce the observed continuum IR excess of the famous O4f star ζ Puppis, implying that the unified models would be useful for modeling the IR spectral energy distribution of CSPN, with possible incidence upon studies of dust properties. Of more relevance to our knowledge of CSPN is the far-UV energy distribution, because it is directly related to the old problem of the "Zanstra discrepancy" between Tz(H) and Tz(HeII). As usual, we refer to Zanstra temperatures as calculated using blackbodies. Gabler et al. (1991) have used a grid of unified models to show that wind effects can substantially decrease the strong absorption edge shown by most plane-parallel, hydrostatic NLTE models at the He II Lyman limit,

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leading, in the most favorable cases, to an increment of more than two orders of magnitude in the extreme UV continuum flux of CSPN below 228 Å. This is an important step towards a model atmosphere able to explain simultaneously the stellar *and* the nebular spectrum. But it is not enough, because in several cases Tz(HeII) is higher than $T_{\rm eff}$ as derived from a photospheric NLTE analysis, implying either that $T_{\rm eff}$ must be increased or that the EUV flux produced by the unified models is still insufficient, sometimes by as much as one order of magnitude.

Therefore, some more work is needed to fully understand the difference between Tz(HeII) and $T_{\rm eff}$. At the same time, photospheric NLTE studies have provided strong support (Méndez et al. 1992) to the idea that most of the difference between Tz(HeII) and Tz(H) can be attributed simply to optically thin PN giving too low values of Tz(H).

5. Improved diagnostics

Two of the fundamental motivations for the development of "unified" models are, first, to be able to extend the NLTE analysis technique to stars showing strong winds; second, to find out what systematic errors are made when the NLTE analysis is based on plane-parallel, hydrostatic models.

The first aspect is related to the problem of modeling those stellar lines which are more affected by wind and atmospheric extension. Gabler et al. (1989) were immediately able to reproduce, qualitatively at least, the strong observed stellar emission in lines like H_α, P_α, B_α, He II $\lambda\lambda$ 1640, 4686, 10124. In particular, the most easily observable He II 4686 and probably also H_α are very promising mass loss rate indicators. What is needed at the present time is to implement a fully self-consistent code; current limitations are described by Gabler et al. (poster abstract in these proceedings).

A systematic comparison between "unified" versus plane-parallel, hydrostatic NLTE models is still in preparation. However, preliminary results have already shown that the unified models are indeed able to produce a much better fit to both absorption and emission lines for CSPN with Of spectra. Figures 1 to 3 show some examples. Although not very good, because some tuning is still required, these preliminary fits permit to estimate the size of the corrections needed for the values of $T_{\rm eff}$ and log g that had been determined using hydrostatic, plane-parallel NLTE models. The corrections are small, and in agreement with previous estimates (Méndez et al. 1992): the "hydrostatic" log g must be increased by an amount which can be conveniently expressed as a function of the "hydrostatic mass" of the CSPN. The maximum correction (+0.2 in log g) must be applied for hydrostatic masses above 0.8 solar masses. For hydrostatic masses below 0.7 solar masses the correction to log g is already smaller than +0.1. The temperature corrections, mostly caused by the increased gravity, are of the order of +1000 or +2000 K at temperatures between 30000 and 40000 K.

Méndez et al. (1992) have made preliminary corrections, where needed, to the gravities, masses and spectroscopic distances determined in previous studies. The corrected distances are between 5% and 20% smaller than derived previously (and several distances did not need any correction). The spectroscopic distances are still roughly comparable to (perhaps slightly smaller than) the distances of Cudworth (1974). See Fig. 5 in Méndez (1991b). More comments about distances in next Section.

A non-negligible fraction of all CSPN show very strong winds (Of-WR and WC objects, see e.g. Méndez 1991a). Most of them are H-deficient and show high He and C abundances. For such objects a photospheric NLTE analysis is not possible, because all the spectral

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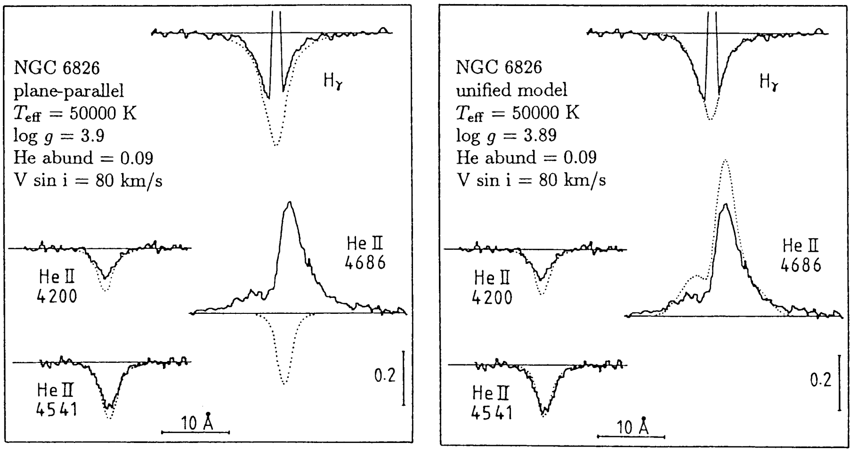

Figure 1. Comparison of profile fits obtained with plane-parallel, hydrostatic NLTE models versus fits obtained with "unified" models, for the central star of NGC 6826. The vertical segment indicates 0.2 times the intensity of the continuum. Wavelength increases to the right. Notice that a better "hydrostatic fit" to H_γ would require a lower gravity.

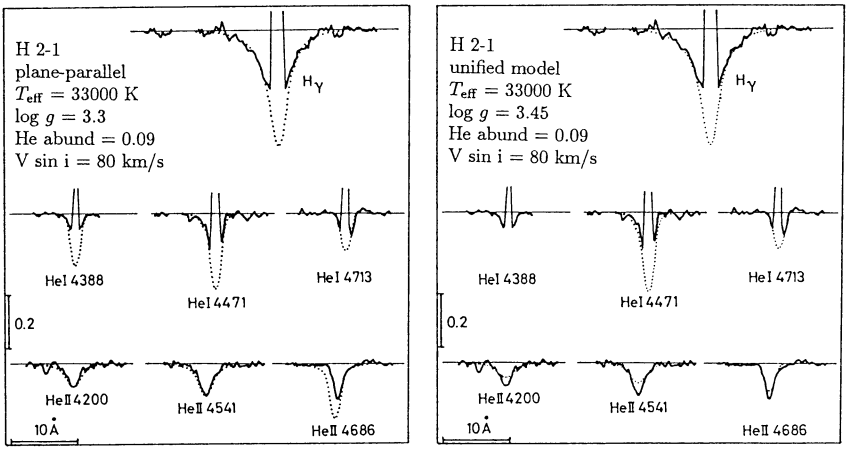

Figure 2. Same as Figure 1, for the central star of H 2-1. The best fit with unified models would require log $g = 3.35$ and $T_{\rm eff} = 34000$ or 35000 K. At these temperatures and gravities the ratio between He I and He II absorptions is a very sensitive function of $T_{\rm eff}$.

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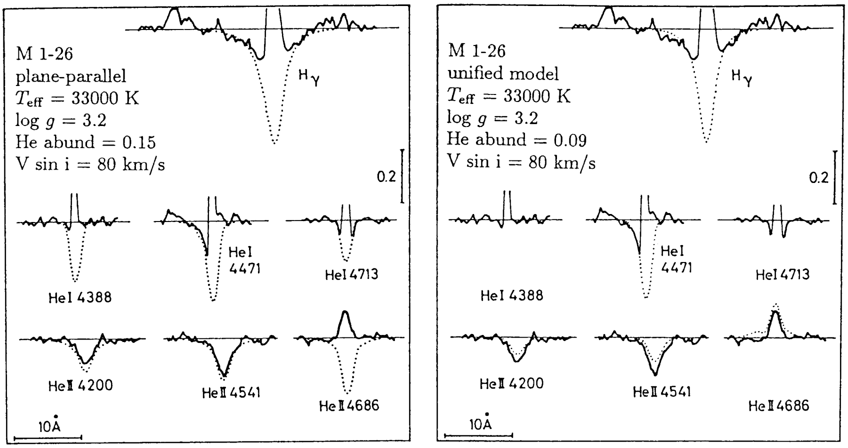

Figure 3. Same as Figures 1 and 2, for the central star of M 1-26. H_γ is better fitted at log $g = 3.3$, and, again, a slightly higher $T_{\rm eff}$ of about 34000 K would be needed to reproduce the observed ratio between He I and He II absorptions.

features are formed in the dense wind. A fully consistent hydrodynamical treatment of these expanding atmospheres is not available yet. However, there are good reasons to be optimistic. The semi-empirical NLTE modeling of Wolf-Rayet stars (for a recent review see Hamann 1992) is now well established as a useful tool. In particular, modeling of WC stars has been developed to such an extent (Hillier 1989, Hamann 1992) that the main spectral features are now reasonably well reproduced. We can expect that the empirical information collected through this kind of analyses will help to understand the physics of mass loss in these CSPN, opening the way to the direct determination of their basic properties.

6. Spectroscopic distances and the Galactic PN luminosity function

As we have seen, it is not possible yet to study all kinds of CSPN with NLTE model atmosphere techniques. However, many CSPN can be and have been analyzed in that way, giving important information for evolutionary discussions, and providing spectroscopic distances with estimated uncertainties of about 25% (the most recent data can be found in Méndez et al. 1992). During this Symposium we have detected some resistence to believe in the model atmosphere technique and the resulting stellar luminosities and distances. While we wait for more powerful methods of distance determination (the VLA expansion distances appear to be most promising) we think it is useful to emphasize that there is some independent evidence supporting the spectroscopic distances. First of all, a NLTE analysis of the hot post-AGB star ROB 162 in the globular cluster NGC 6397 (Heber and Kudritzki 1986) has given a distance of 2560 pc (Méndez et al. 1988b), in very good agreement with the cluster distance (2400 pc according to Alcaino and Liller 1980). Wind effects cannot change this result (no wind is detected in the spectrum of ROB 162), and the subsequent improvements made in the Stark broadening theory for He II 4686 (Schöning and Butler 1989), already incorporated in the CSPN work, would only slightly *decrease* the spectroscopic distance of ROB 162, bringing it in even better agreement with the cluster distance.

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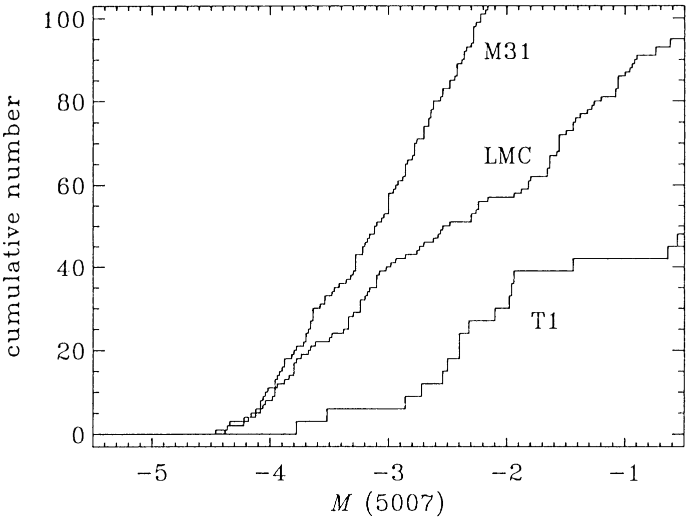

Figure 4. Cumulative PNLFs for M 31, LMC and the local sample (labeled T1), which consists of 24 PN for which spectroscopic distances are available (their central stars have been analyzed with NLTE models). Given the small amount of objects in the local sample, the corresponding cumulative numbers have been multiplied by a factor 3.

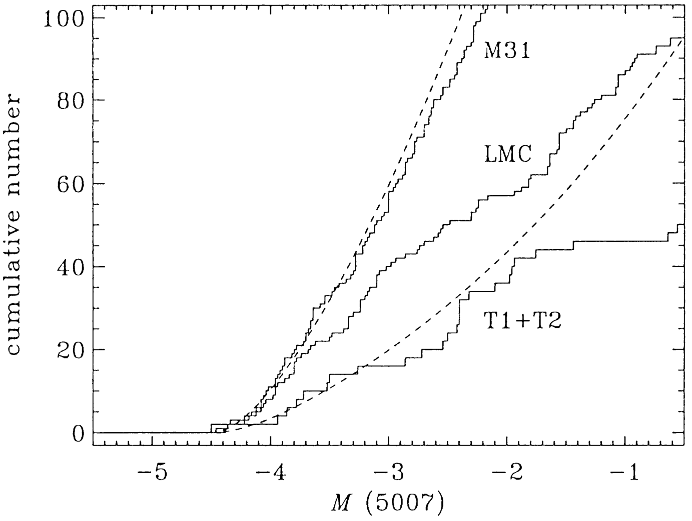

Figure 5. The same comparison, now using an extended local sample, labeled T1+T2 (see text), whose cumulative numbers have been multiplied by a factor 2. The dashed lines are analytical representations of the PNLF, derived from Formula (2) of Ciardullo et al. (1989). The three observed PNLFs have similar shapes and cutoffs.

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Second, let us consider the extragalactic evidence. Careful surveys and measurements of PN in nearby galaxies like M 31 and the LMC (Ciardullo et al. 1989, Jacoby et al. 1990) have provided a good knowledge of the bright end of the PN luminosity function (PNLF). There is growing empirical evidence (Ciardullo et al. 1991, see also Jacoby's review in these proceedings) that this bright end of the PNLF is sufficiently invariant to be useful as a secondary standard candle for extragalactic distance determinations. Therefore we expect our Galaxy to show a similar PNLF. Are the spectroscopic distances consistent with this expectation? We have selected 24 PN whose central stars have been analyzed using NLTE models. Given the dereddened nebular fluxes at [O III] 5007 (which we call I), expressed in erg cm^{-2} s^{-1}, we calculate the corresponding apparent magnitudes m, following Jacoby's (1989) definition: $m = -2.5 \log I - 13.74$. Knowing the spectroscopic distances, we can also obtain the corresponding absolute magnitudes M. Now we define the cumulative PNLF at any absolute magnitude M as the number of PN with absolute magnitudes brighter than or equal to M. The resulting cumulative PNLF is shown in Figure 4, where it is compared with cumulative PNLFs calculated in the same way for the Large Magellanic Cloud (data taken from Jacoby et al. 1990; adopted distance 50 kpc) and for M 31 (data taken from Ciardullo et al. 1989; adopted distance 710 kpc).

In Figure 4 we find no obvious disagreement with the extragalactic cumulative PNLFs. The local cumulative PNLF does not reach as bright absolute magnitudes as the extragalactic ones, but this can be easily explained as a consequence of the small sample size; see e.g. the discussion in Sect. VII of Ciardullo et al. (1989). The important fact in our Figure 4 is that the situation would only become worse if we decreased the spectroscopic distances.

For further discussion we need to enlarge our local sample. For that purpose we have added 12 other local PN with what we consider to be sufficiently reliable distances, determined with the following methods: (a) VLA expansion distances (Masson 1989a, 1989b); (b) several distances derived from observations of H I absorption at 21 cm (Gathier et al. 1986a); (c) a few extinction distances (Gathier et al. 1986b). Full details will be given by Méndez, Kudritzki, Ciardullo and Jacoby (in preparation).

The improved local cumulative PNLF is shown in Figure 5. Although this cumulative PNLF must be still seriously affected by incompleteness, anyway it appears to be in reasonable agreement with the extragalactic ones. In the enlarged local sample we have now one very bright object: NGC 7027, with $M = -4.49$, right at the cutoff proposed by Ciardullo et al. (1989).

In summary, we find no reason to doubt that NLTE model atmosphere techniques, applied to CSPN with weak and even moderate winds (Of type), give reliable information about stellar temperatures, gravities, luminosities and distances. Given further theoretical and observational work, it may well be possible to promote the PNLF technique from a secondary to a primary extragalactic distance indicator.

References

Abbott D.C., Hummer D.G. 1985, ApJ 294, 286
Alcaino G., Liller W. 1980, AJ 85, 680
Anderson L.S. 1985, ApJ 298, 848
Anderson L.S. 1989, ApJ 339, 558
Becker S.R., Butler K. 1988, A&A 201, 232
Becker S.R., Butler K. 1989, A&A 209, 244

https://doi.org/10.1017/S007418090017007X Published online by Cambridge University Press

Becker S.R., Butler K. 1990, A&A 235, 326
Becker S.R., Butler K. 1992, A&A in press
Ciardullo R., Jacoby G.H., Ford H.C., Neill J.D. 1989, ApJ 339, 53
Ciardullo R., Jacoby G.H., Harris W.E. 1991, ApJ 383, 487
Cudworth K.M. 1974, AJ 79, 1384
Dreizler S., Werner K. 1992, in: Heber U., Jeffery C.S. (eds.) The Atmospheres of Early-Type Stars. Kluwer, Lecture Notes in Physics, 401, p.436
Eber F., Butler K. 1988, A&A 202, 153
Gabler R., Gabler A., Kudritzki R.P., Puls J., Pauldrach A. 1989, A&A 226, 162
Gabler R., Kudritzki R.P., Méndez R.H. 1991, A&A 245, 587
Gathier R., Pottasch S.R., Goss W.M. 1986a, A&A 157, 191
Gathier R., Pottasch S.R., Pel J.W. 1986b, A&A 157, 171
Grigsby J.A., Morrison N.D., Anderson L.S. 1992, ApJS 78, 205
Hamann W.R. 1992, in: Heber U., Jeffery C.S. (eds.) The Atmospheres of Early-Type Stars. Kluwer, Lecture Notes in Physics, 401, p.87
Heber U., Kudritzki R.P. 1986, A&A 169, 244
Heber U., Werner K., Drilling J.S. 1988, A&A 194, 223
Herrero A., Méndez R.H., Manchado A. 1990, Ap&SS 169, 183
Hillier D.J. 1989, ApJ 347, 392
Jacoby G.H. 1989, ApJ 339, 39
Jacoby G.H., Walker A.R., Ciardullo R. 1990, ApJ 365, 471
Kudritzki R.P. 1992, A&A in press
Kudritzki R.P., Gabler R., Kunze D., Pauldrach A.W.A., Puls J. 1991, in: Leitherer et al. (eds.) Massive Stars in Starbursts. Cambridge Univ. Press, STScI Symp. Series, 5, p.59
Kudritzki R.P., Hummer D.G., Pauldrach A.W.A., et al. 1992, A&A 257, 655
Kudritzki R.P., Méndez R.H. 1989, in: Torres-Peimbert S. (ed.) Proc. IAU Symp. 131, Planetary Nebulae. Kluwer, p.273
Masson C.R. 1989a, ApJ 336, 294
Masson C.R. 1989b, ApJ 346, 243
McCarthy J.K., Mould J.R., Méndez R.H., et al. 1990, ApJ 351, 230
McCarthy J.K., Rich R.M., Becker S.R., et al. 1991, ApJ 371, 380
Méndez R.H. 1991a, in: Michaud G., Tutukov A. (eds.) Proc. IAU Symp. 145, Evolution of Stars: the Photospheric Abundance Connection. Kluwer, p.375
Méndez R.H. 1991b, in: Crivellari L. et al. (eds.) Stellar Atmospheres: Beyond Classical Models. Kluwer, NATO ASI Series C (Math. and Phys. Sciences), Vol. 341, p.331
Méndez R.H., Groth H.G., Husfeld D., Kudritzki R.P., Herrero A. 1988a, A&A 197, L25
Méndez R.H., Herrero A., Manchado A. 1990, A&A 229, 152
Méndez R.H., Kudritzki R.P., Herrero A. 1992, A&A 260, 329
Méndez R.H., Kudritzki R.P., Herrero A., Husfeld D., Groth H.G. 1988b, A&A 190, 113
Napiwotzki R. 1992, in: Heber U., Jeffery C.S. (eds.) The Atmospheres of Early-Type Stars. Kluwer, Lecture Notes in Physics, 401, p.310
Pauldrach A., Puls J., Kudritzki R.P., Méndez R.H., Heap S.R. 1988, A&A 207, 123
Schöning T. 1992, A&A in press
Schöning T., Butler K. 1989, A&A 219, 326; A&AS 78, 51
Werner K. 1992, in: Heber U., Jeffery C.S. (eds.) The Atmospheres of Early-Type Stars. Kluwer, Lecture Notes in Physics, 401, p.273
Werner K., Husfeld D. 1985, A&A 148, 417

https://doi.org/10.1017/S007418090017007X Published online by Cambridge University Press