The "Continuous" Central Stars of Planetary Nebulae – Are their Spectra Really Continuous?

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The Puzzle of the "Continuous" Central Stars

Twenty-five per cent of all central stars of planetary nebulae which have been studied spectroscopically are classified as "continuous", which means that they do not show any sign of stellar absorption or emission lines, at least in the visible part of the spectrum. The existence of this kind of spectrum poses an interesting problem: The effective temperatures of the "continuous" objects can be estimated from the emission line spectrum of the surrounding nebula my means of the well-known "Zanstra method". As it turns out, the temperatures are mainly between 50,000 K and 100,000 K. On the other hand, non-LTE model atmosphere calculations for very hot stars (as carried out in Kiel) show that even at 100,000 K there should be easily detectable H or He lines for any reasonable surface gravity, unless the atmosphere is essentially free of these elements. But even if we admit the absence of hydrogen and helium, we can estimate that strong lines of carbon (or nitrogen or oxygen) should be observable in this case.

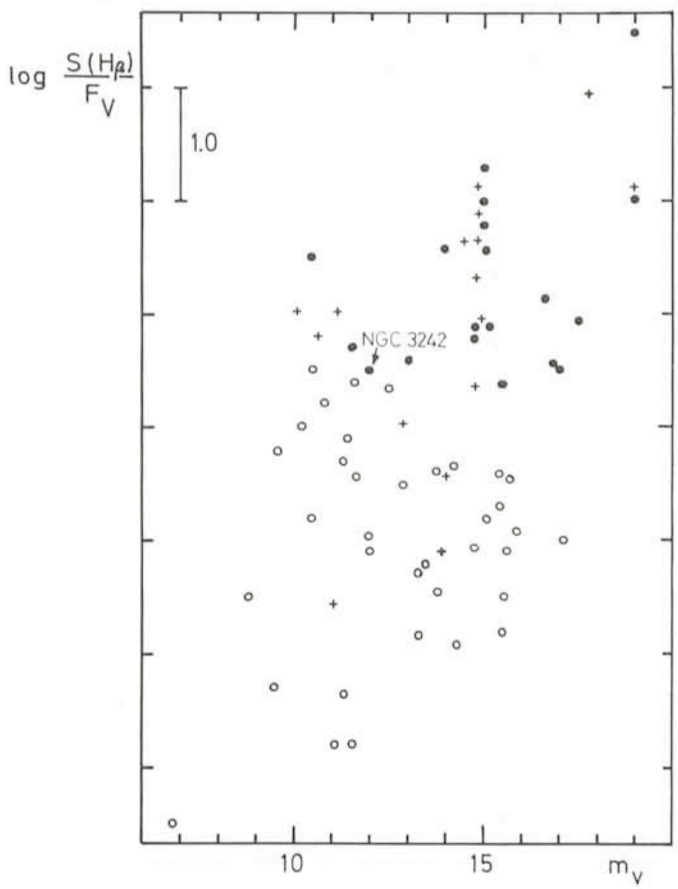

Fig. 1: *The surface brightness of planetary nebulae S (Hβ) (in units of the stellar flux F_V) versus apparent magnitude m_v of the central stars. The central stars are divided into three classes: + objects with broad emission lines (WR, O VI), ○ absorption line objects (sdO, O, Of), ● continuous objects. The position of NGC 3242 is also indicated. For discussion see text.*

A Solution?

A way out of this problem is an idea first published by Aller (1968, 1976), who stated that probably many of the "continuous" CPN have weak, narrow absorption lines which are completely masked by overlying nebular emissions. However, he also mentioned that there are at least a few "bright" stars which, even at coudé dispersions, did not exhibit stellar lines and which therefore have to be regarded as true examples of the "continuous" spectral type: NGC 3242, NGC 7009, NGC 7662.

Despite of the negative result for these three stars, Aller's idea still remained attractive for us. The main reason for this was a diagram which is shown in Figure 1. In this diagram the surface brightness of the surrounding nebula (in units of the stellar flux in the V-band) is plotted versus the apparent magnitude of the central star. We divided the central stars into three spectroscopic classes: objects with absorption lines (O, sdO, Of), objects with broad stellar emission lines (OVI, WR) and the "continuous" objects. The diagram is striking: absorption-line objects are placed in nebulae with relatively low surface brightness: The fainter the central star, the weaker the nebular surface brightness. This is obviously a selection effect, caused by the fact that, at the low resolution necessary for faint objects, the surface brightness has to be very low to make stellar absorption features detectable. On the other hand, the "continuous" objects are embedded in nebulae with relatively high surface brightness. This means that, if these stars have stellar absorptions, there is a good chance that they are masked by nebular emissions.

Also the emission-line objects are mainly found within nebulae of high surface brightness. However, in this case the stellar emission lines are very broad (Aller, 1968, 1976), so that the presence of strong nebular lines does not affect the identification of these spectral types.

An IDS Spectrum of NGC 3242

From Figure 1 we concluded that "continuous" central stars are probably rather similar to the absorption-line objects, but that in this case strong nebular emission lines fill in the photospheric absorptions. We, therefore, concentrated on those objects which are close to the border between "absorption line" and "continuous" CPN. One of these objects is NGC 3242: We observed this central star on December 8/9, 1980 with the Image Dissector Scanner and the Boller and Chivens spectrograph at the Cassegrain focus of the ESO 3.6-m telescope. We used a grating of 1,200 grooves mm^{-1}, giving a dispersion of 29 Å/mm in the 2nd order. To reduce the contribution of the nebular light as far as possible without loosing to much stellar light we selected an entrance aperture of 2 × 2 arcseconds in size.

Figure 2 shows the spectrum of the central star of NGC 3242 from 4220 to 4780 Å. It is flat field corrected and wavelength calibrated by means of a He-Ar comparison spectrum taken before and after observation of the star. Besides the typical nebular emissions (Hγ, [O III] λ 4363, He I λ 4471, [N III] λ 4634, λ 4641, C IV λ 4658, He II λ 4686, [Ar IV] λ 4712,

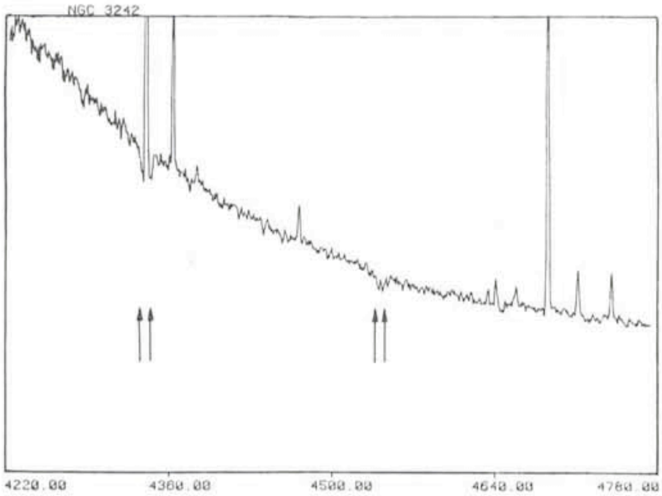

Fig. 2: *IDS spectrum of NGC 3242. The photospheric absorption of Hγ and He II 4542 are indicated by arrows. The abscissa refers to wavelengths in Angström. The intensity scale is in arbitrary units, the bottom corresponds to zero intensity.*

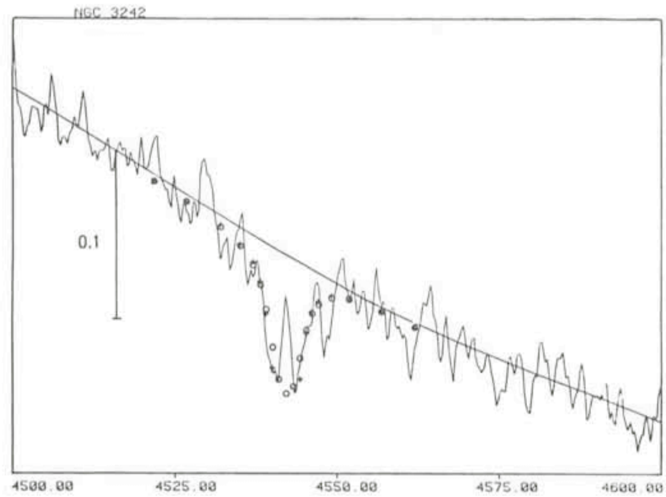

Fig. 4: *Intensity tracing around He II 4542 compared with the non-LTE profiles for T_{eff} = 50,000 K, log g = 4.0, y = 0.09 (crosses) and T_{eff} = 100,000 K, log g = 5.0, y = 0.09 (circles).*

λ 4740) we find quite normal photospheric absorptions at Hγ and He II 4542 (see also Kudritzki *et al.*, 1981). Obviously, our observation reveals that one of the best examples among "continuous" central stars is a normal absorption-line object.

One might ask why the absorption lines in the spectrum of NGC 3242 have not been discovered before: notice that the resolution of our spectrum (FW HM ≈ 1.6 Å) should be lower than that of Aller's coudé spectrograms. On the other hand, our IDS observations have three advantages:

(a) A small entrance aperture, which reduces the contribution from the strong nebular emissions, thus permitting to look deeper into the absorption line cores.

(b) A much better signal-to-noise ratio, which helps detection of low-contrast absorption features.

(c) The linearity of the detector, which allows to get rid of all the well-known photographic effects, which occur at the junction of dark and bright areas.

A Comparison with Non-LTE Model Atmosphere Calculations

The Hγ and He II 4542 absorptions can be used for an estimate of surface temperature, gravity and helium abundance of NGC 3242. This can be done by a comparison of the observed profiles with the results of non-LTE model atmosphere and line formation calculations (see Hunger and Kudritzki, 1981, *Messenger* No. 24, page 7, Kudritzki and Simon, 1978, or Méndez et al. 1981).

Since in the case of NGC 3242 only two absorption lines can be used for a fit, whose cores, additionally, are contaminated by nebular emission, the result is a bit uncertain. We find that the star has a normal helium abundance (i.e. $N_{He}/(N_H + N_{He})$ = 9%) and a temperature between 100,000 K and 50,000 K. The gravity is between log g = 4.0 or 5.0. This is demonstrated by Figures 3 and 4, which show that the observed profiles can be

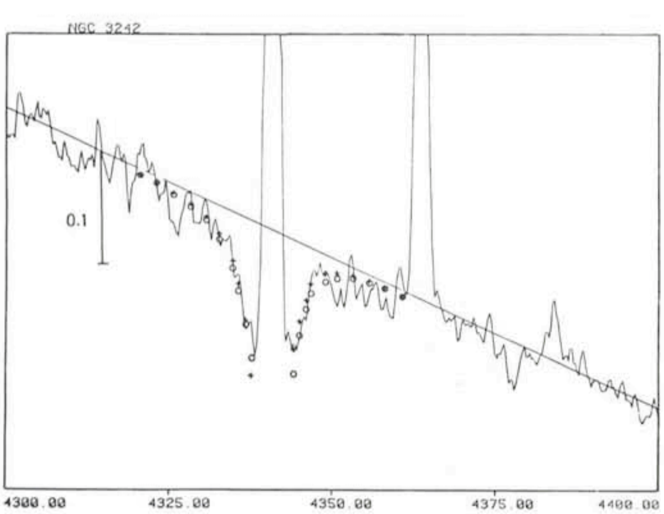

Fig. 3: *Intensity tracing around Hγ compared with non-LTE profiles calculated for T_{eff} = 50,000 K, log g = 4.0 (crosses), T_{eff} = 100,000 K, log g = 5.0 (circles) and y = N (He)/N(He) + N(H)) = 0.09. The calculations are convolved with the instrumental profile. Furthermore, the blending with the corresponding He II line has been taken into account, which causes the slight asymmetry in the theoretical profile. 10% below continuum intensity is indicated by the bar.*

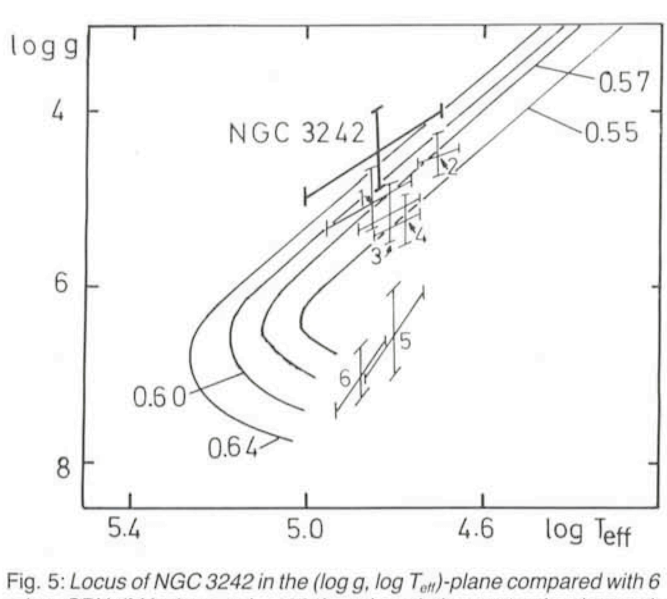

Fig. 5: *Locus of NGC 3242 in the (log g, log T_{eff})-plane compared with 6 other CPN (Méndez et al., 1981) and evolutionary tracks descending from the AGB as calculated by Schönberner (1979, 1981). The numbers designating the tracks refer to masses in solar units. The six other CPN's are: 1: NGC 4361; 2: NGC 1535; 3: A 36; 4: NGC 1360; 5: NGC 7293; 6: A 7.*

fittet at T_{eff} = 100,000 K, log g = 5.0 and T_{eff} = 50,000 K, log g = 4.0, if a normal helium abundance is assumed.

In spite of these uncertainties, the locus of NGC 3242 in the (log g, log T_{eff})-plane, obtained from the comparison with non-LTE calculations, contains some additional information about the nature of the star. In Figure 5 the position of the star is shown, together with six absorption line central stars which have been analysed already before (Méndez *et al.*, 1981) and with theoretical evolutionary tracks computed by Schönberner (1979, 1981) (see also Hunger and Kudritzki, 1981, *Messenger,* No. 24, page 7). If we assume that these tracks represent the evolution of all the PN central stars shown here, we can conclude that NGC 3242 is slightly more massive than the other objects, which have masses from 0.6 $M_\odot$ to 0.55 $M_\odot$.

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Variability of the Continuum and the Emission Lines in the Seyfert Galaxy Arakelian 120

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Introduction

The brightness variability of Seyfert galaxies and quasars is one of the most direct pieces of evidence for the intrinsic smallness of the optical continuum source in these objects. If the power of a source varies with a time scale τ by a significant amount it must originate from a region which cannot have a size much larger than $c \cdot \tau$ across where c is the velocity of light; τ is observed to be typically of the order of months for such sources but may be much less. Not only the continuum strength but also the emission lines may vary in strength and shapes. This phenomenon is interesting with regard to the structure and kinematics of the line-emitting region as well as to the radiation mechanism within the continuum source.

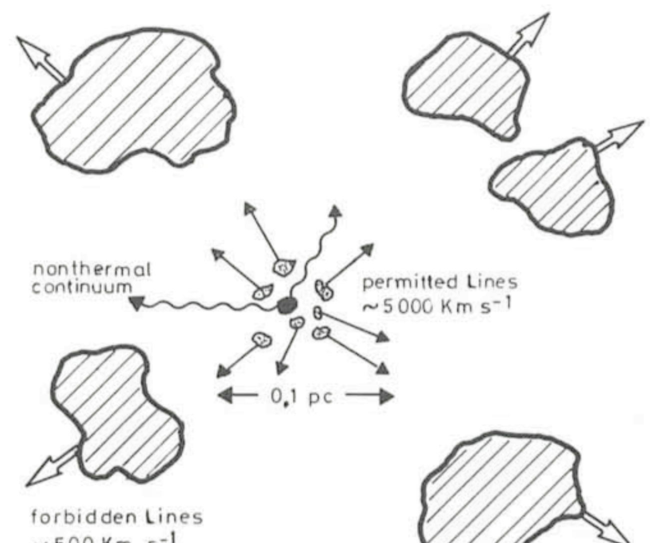

Fig. 1: *Schematic model for a Seyfert 1 nucleus with its three components: (i) a point-like central source of nonthermal continuum radiation, (ii) a broad emission line region $\lesssim$ 1 light-year across with numerous fast moving dense ($n_e > 10^6$ cm^{-3}) clouds emitting the permitted lines, and (iii) a narrow emission line region ~ 500 pc across containing less dense ($n_e \lesssim 10^5$ cm^{-3}) clouds with smaller velocities.*

A schematic sketch of an active galactic nucleus is shown in Figure 1. A nucleus of a Seyfert 1 galaxy or of a quasar consists of three components: (i) the optically unresolved (i.e. smaller than ~ 1 arcsec) continuum source which emits predominantly radiation exhibiting a nonthermal spectrum; (ii) a small inner region (~ 0.1–1.0 pc) from which the broad hydrogen and "permitted" lines originate with equivalent velocity dispersions typically 3,000 km/s up to 10,000 km/s and beyond. The electron density in the emitting clouds must in this region be larger than 10^6 cm^{-3} and may range up to 10^{11} cm^{-3}. In the latter case electron scattering may account for the full width of the permitted emission lines. Synthetic integrated line profiles for such a cloud aggregate show that the total number of these clouds must be enormous (E. Capriotti et al., 1981, *Astrophysical Journal* **245**, 396); it has been estimated to be as large als 10^{11} from observations (1981, H. Netzer, Proc. of the 5th Göttingen-Jerusalem Symposium, Göttingen 1980). A very clumpy structure has also been postulated on theoretical grounds (G. R. Blumenthal and W. G. Mathews, 1979, *Astrophys. J.,* **233**, 479). The total mass of the clouds is relatively small ($\lesssim$ 1,000 $M_\odot$). This region is probably entirely absent in the so-called Seyfert 2 galaxies; (iii) an outer region from which the narrow "forbidden" lines like the nebulium line of O^{++} originate and which is ~ 500 pc across.

There is evidence that the radiation from at least the inner regions (i) and (ii) may vary. We report in this article on continuum and spectrum variations in the Seyfert 1 galaxy Arakelian 120 which we observed in the optical with the ESO 3.6-m and 1.5-m telescopes and in the UV using the IUE telescope operated from Villafranca near Madrid.

Long-term optical variabilitiy of Akn 120 since 1929 has been established by Miller from the University of Georgia, Atlanta, who inspected archival plates of the Harvard College Observatory. In addition, he reported rapid variability during the epoch 1977–78 with amplitudes ~ 0.3 mag on a time scale of ~ 1 month which confirms earlier work by Lyutyi from the Soviet Union. Variability of this source on somewhat longer time scales ($\lesssim$ 1 year) are also known from radio and X-ray measurements.

Continuum Variations

We first observed Akn 120 in October/November 1979 in the optical and UV (for observational details see an article by H.