Discovery of a Double-Shell Structure in the Planetary Nebula LoTr 4

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Introduction

- PN G 291.4+19.2
- $\alpha_{1950} = 11^h 49^m 58^s$, $\delta_{1950} = -42°00'56''$
- discovered by Holmberg et al. (1978)
- confirmed to be a PN by Longmore & Tritton (1980) → LoTr 4
- central star
- almost pure He II absorption-line spectrum (Rauch & Werner 1995) in contrast to related objects (e.g. PG 1159 stars) which additionally show strong C IV absorptions
- classification scheme of Méndez (1991): O(He) subtype (together with K 1-27 — only two stars of this subtype are known!)
- $T_{\rm eff} = 120$kK, $\log g = 5.5$, $n_{\rm H}/n_{\rm He} = 0.5$, $n_{\rm N}/n_{\rm He} = 0.001$ (Rauch et al. 1995)
- photospheric abundances can be explained by the "born-again post-AGB star scenario" (Iben et al. 1983)

→ possible progenitor of PG 1159 star

Results and Conclusions

- angular diameter: 39"
- two clearly separated nebula shells (radii 7.5" and 13.5" → background image)
- central star appears to be off-centered by about 2" to the south-east
- fragment of third shell with a radius of 22.5" south-east of the central star
- strong decrease of brightness from south-east to north-west
- inner nebula seems to be composed of several filaments

→ nebula could well have been expelled in several ejections in different directions

- crescent slope of the bright segment

→ interaction with the ambient medium (cf. Borkowski et al. 1993)

- high excitation nebula
- distance $6.0^{+3.2}_{-2.5}$ kpc (Rauch et al. 1995)

→ radius ≈ 0.6pc

- helium abundance is definitely solar (±0.05 dex)
- no stratification of the He/H abundance ratio
- trace elements with solar abundances (±0.1dex)

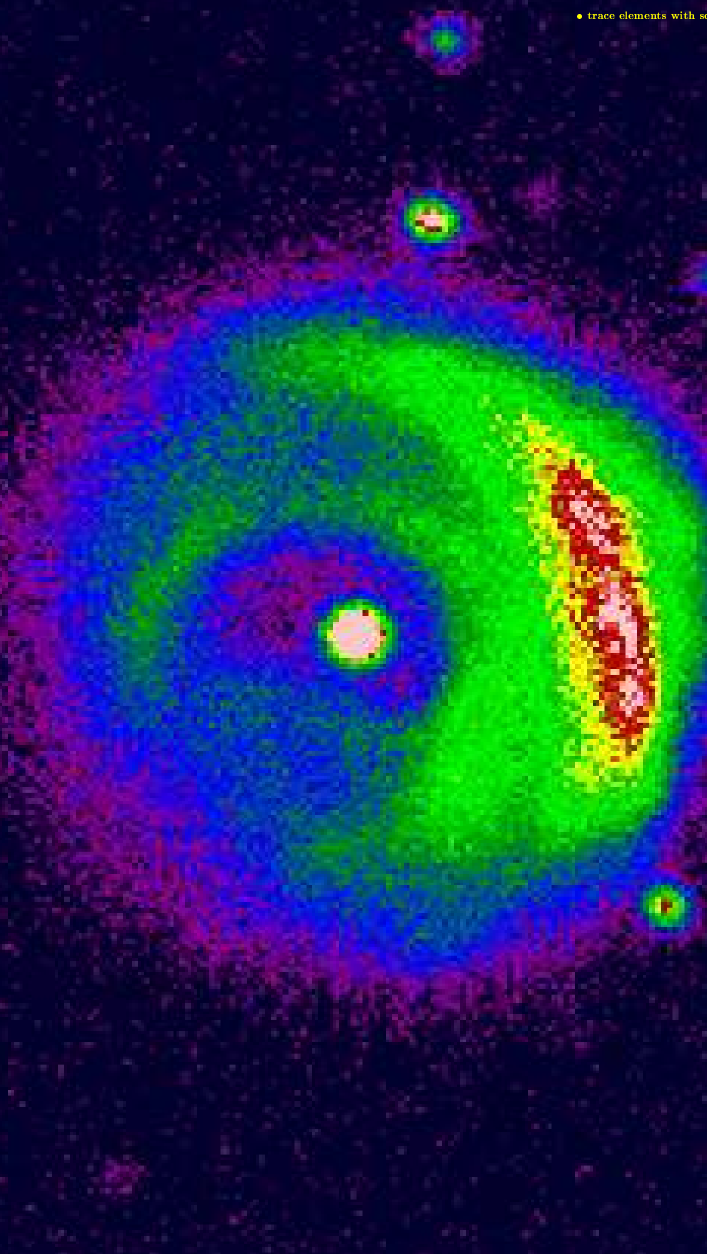

Fig. 1. The PN LoTr 4 in a reproduction from the ESO SRC survey (J 320, orientation: north down, east right). This and all other images are covering a region of $60'' \times 60''$

Direct imagery

- 3.5m NTT with EMMI at ESO, Apr. 1995
- CCD ESO # 36 (TEK TK 2048 EB) 2048×2047 px, 0.268″ / px

– Hα, 40 min (Fig. 2)

→ background image

– [O III] λ 5007 Å, 20 min (Fig. 3)

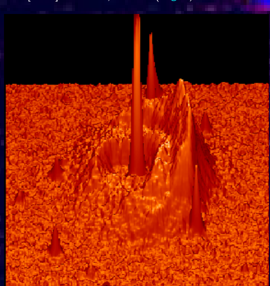

Fig. 2. Distribution of the surface brightness in Hα (normalized to the local background) of the PN LoTr 4, smoothed using a boxcar average of 1". The intensity scale is linear

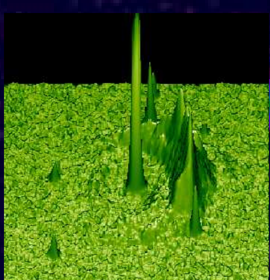

Fig. 3. [O III] λ 5007 Å image of the PN LoTr 4

Properties of the Shells

The [O III] λ 5007 Å emission reaches out to larger radii in south-east direction. Since the visible nebula is optically thin to the He II Lyman continuum, any matter outside would show up strongly in [O III] from the He⁺ zone, the extension of the emission does not reflect an enhancement of the ionization, but a genuine extension of the nebula.

Fig. 4 shows that the eastern limb is brighter in all the lines but it is most prominent in [O III] λ 5007 Å (see also Fig. 3). Hβ and He II λ 4686 Å have nearly identical profiles (bottom panel), while [O III] λ 5007 Å is relatively weaker in the inner part of the nebula disk. If one interprets this cut across the nebula by emission from spherical and homogeneous shells, this concentration of [O III] would be the normal consequence of the ionization stratification.

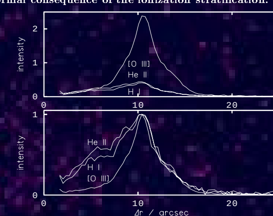

Fig. 4. Intensities of [O III] λ 5007 Å, He II λ 4686 Å, and Hβ (in arbitrary units) in an E-W cut through the nebula (from a spectrum taken at the NTT with EMMI). The lower picture shows the same intensities of the eastern side normalized to their maximum intensity at $\Delta r \approx -11.8''$

We tried a quantitative analysis of the surface brightness distribution of Hβ with the assumption of spherical shells: It turned out to be impossible to reproduce the profile: Since the emissivity of a recombination line depends only weakly on electron temperature and density, its surface brightness distribution is determined almost exclusively by the distribution of the protons along the lines of sight, i.e. it reflects the spatial distribution of the nebula matter. In Fig. 5 we compare the observed brightness distribution with two models: in the first one, the gas density as a function is the sum of three gaussians with parameters adjusted to match the outer part of the eastern limb. Of course, it gives too high an intensity on the western side. But the intensity in the center of the nebula disk is also too high. In a second one, the parameters were chosen as to match the inner part of the eastern side. Again, one notes that in the region close to the central star the model brightness is too high. To reproduce the large ratio between the maximum and the center with a spherical shell, one would need a relatively thin shell, which implies a narrow profile near the maximum. We took this as a strong indication that the nebula not only lacks an E-W symmetry, but also a symmetry along the line-of-sight. Thus the emission of the eastern side might well arise from a quite narrow segment of a spherical shell.

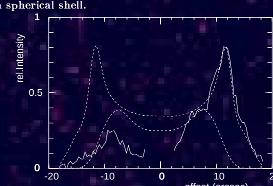

Fig. 5. The variation of the Hβ surface brightness, observed along the E-W direction (solid), and from two models (dashed) with spherical symmetric, homogeneous shells whose radial density distribution is chosen to match the outer or the inner part of the eastern side

Fig. 6 shows that the region of the inner nebula is quite remarkable: the intensity ratio is much lower than in the outer segment, but the ratio is quite constant throughout the region

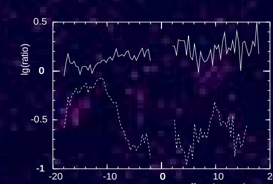

Fig. 6. The variation across the face of the nebula of the intensity ratios of He II λ 4686 Å / Hα (solid) and [O III] λ 5007 Å / Hα (dashed), in arbitrary intensity units

Preliminary Interpretation of the Nebula Data

- finding chart in the catalogue of Acker et al. (1992) shows a faint nebulosity
- ESO-J plate (Fig. 1) reveals that the nebula consists of a bright arc on the eastern limb (see also Fig. 2) and some fainter emission around the central star
- spectrum taken by B. Stenholm with the IDS on the ESO 1.2m telescope on Jan. 23, 1986 shows the typical features of a high-excitation, strongly density bounded object:

→ He II λ 4686 Å / Hβ ≈ 1.1

→ [O III] λ 5007 Å weak and complete absence of low ionic species

→ nebula must be optically thin in the H I Lyman continuum

- resembles rather closely the nebula K 1-27 (Rauch et al. 1994)
- ionization structure differs from that of a 'normal' nebula in that the transition zones between two ionic species are no longer negligibly thin

→ overlap between the He III and the O III zones

- [O III] λ 5007 Å line emission comes preferentially from the outer rim (Fig. 3)

Remarks

A paper "Spectral analysis of the multiple-shell planetary nebula LoTr 4 and its very hot hydrogen-deficient central star" has recently been submitted to A&A. For preprints please contact: rauch@astrophysik.uni-kiel.de .

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