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The mysterious age invariance of the planetary nebula luminosity function bright cut-off

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Supplementary Discussion

Extinction corrections to the PNLF cut-off

The extinction towards extragalactic planetary nebulae is a combination of foreground extinction (within our Galaxy), local extinction (within the host galaxy) and circumstellar extinction (within the stellar ejecta). The foreground is normally constant across the host galaxy and is known. The local extinction is a stochastic parameter, which mostly affects PNe located within the disk of spiral galaxies. Circumstellar extinction stems from dust located in the non-ionized regions surrounding the PN. Observed planetary nebula luminosity functions are generally corrected for foreground extinction, but not for the poorly known local and circumstellar extinction.

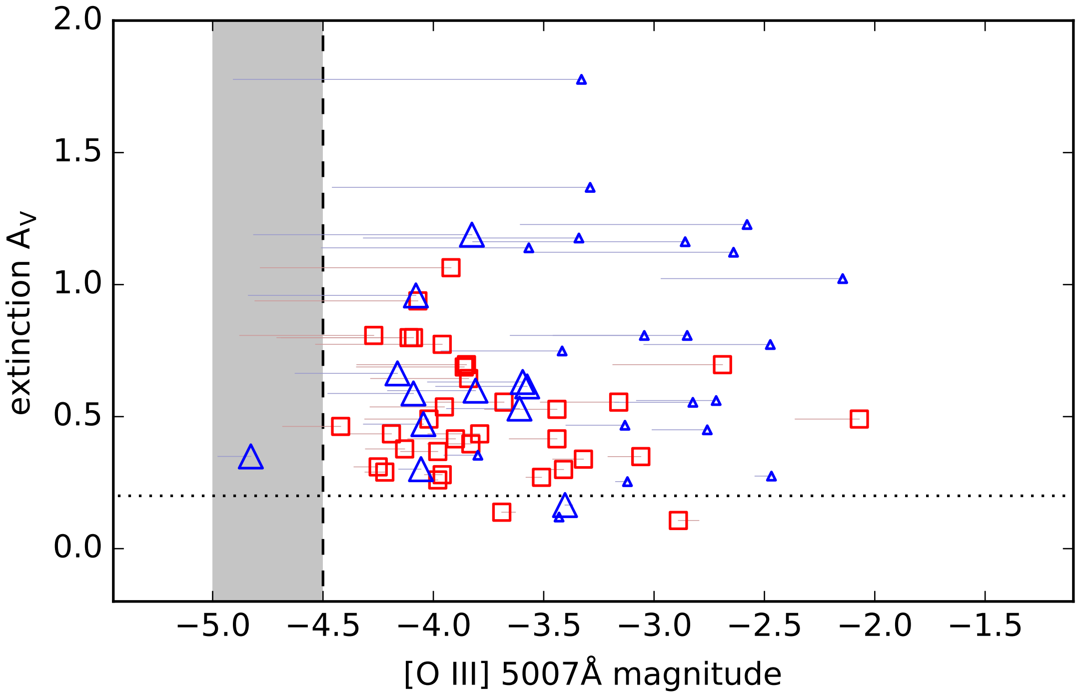
We calculate the circumstellar extinction using the equation[1]

$$A_{\rm V} \approx 0.5 \left[\frac{\dot{M}}{10^{-5}\,M_\odot\,{\rm yr}^{-1}}\right] \left[\frac{v_{\rm exp}}{15\,{\rm km\,s}^{-1}}\right]^{-1} \left[\frac{r}{10^{16}\,{\rm cm}}\right]^{-1}.$$

This assumes a standard ratio of $N_{\rm H_2} = 2 \times 10^{21} A_{\rm V}\,{\rm cm}^{-2}\,{\rm mag}^{-1}$, appropriate for interstellar silicate dust[2]. For our minimum radius of 0.01 pc and assuming $\dot{M} = 5 \times 10^{-5}\,M_\odot\,{\rm yr}^{-1}$ and $v_{\rm exp} = 15\,{\rm km\,s}^{-1}$, this predicts $A_{\rm V} \approx 0.8$ mag. The smallest radii of Galactic PNe are around 0.03 pc[3], giving an expected $A_{\rm V} \approx 0.25$ mag.

As a test, the well studied PNe population of the outer disk of the Andromeda galaxy M 31 is shown in Supplementary Figure 1. The foreground extinction to M 31 amounts to $A_{\rm V} = 0.175$. The corresponding value of A_{5007} is presented as the horizontal dotted line. The coloured symbols show M_{5007} corrected for foreground extinction only, and the thin lines indicate the shift when corrected for the total extinction, which here is derived from the spectra. The majority of objects have additional extinctions of a few tenths of a magnitude or less. A few have higher extinction. After correcting for the full extinction, the value of the cut-off of the PNLF shows a small shift from $M^*_{5007} = -4.2$ to -4.5. In our models, the former value would indicate an age of the stellar population of around 7 Gyr, while the corrected value corresponds to stellar ages of less than 6 Gyr. This illustrates the diagnostic power of the PNLF to constrain star-formation histories, provided accurate extinctions are available. In this age range, few other diagnostics are available. It should however be noted that extinction corrections can be uncertain, especially if there is significant circumstellar extinction and scattering, potentially involving non-standard dust grains[4].

The grey band in the plots shows the dimming effect a circumstellar extinction of up to 0.5 mag would have on the observed PNLF, when compared to the theoretical, extinction-free curves. Such an extinction is possible for the most compact PNe, from the above calculations.



Supplementary Figure 1: **Observed values of M_{5007} for planetary nebulae of the outer disk of the Andromeda galaxy, M 31.** The data is taken from different sources, shown as red squares[5,6,7,8] and blue triangles[9]. Extinctions were calculated from the published Hα/Hβ ratio, assuming a ratio of 2.85. M_{5007} was taken from a single source[10], with one exception[9] where M_{5007} is measured from the spectra itself. The small triangles indicate objects where the extinction is less accurate because of low S/N on the Hβ line. The foreground extinction is $A_{\rm V} = 0.175$, extinction at [O III] is taken as $1.2\,A_{\rm V}$, and the distance modulus to M 31 is taken as 24.47. The coloured symbols show M_{5007} corrected for foreground extinction; the thin lines indicate the M_{5007} magnitudes after correction for the total extinction. The canonical value of $M^*_{5007} = -4.5$ is shown as the vertical dashed line. The grey vertical band represents the corresponding range of values assuming extinction correction up to 0.5 mag. The horizontal dotted line represents the foreground component to A_{5007}.

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