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PHR1315–6555: a bipolar Type I planetary nebula in the compact Hyades-age open cluster ESO 96–SC04

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We have identified a bipolar Type-I planetary nebula (PN), PHR1315–6555, in the distant, compact, intermediate-age open cluster, ESO 96–SC04. This is currently the only known example of a PN physically associated with a Galactic open cluster. Cluster membership is extremely important as it allows for very precise estimates of the fundamental properties of the PN as the cluster is at a known distance. The PN was discovered during systematic searches for new Galactic PNe of the AAO/UKST Hα survey and had been missed in earlier broadband surveys, including specific CCD studies of the host cluster. We present original discovery images and CTIO 4-m MOSAIC-II camera follow-up narrow-band images that reveal its bipolar morphology. We also present: (i) low-resolution optical spectra that spectroscopically confirm the PN; (ii) accurate radial velocities of PN and cluster stars from high-resolution spectroscopy which show they are consistent; and (iii) a reliable, independent distance estimate to the PN using a robust PN distance indicator which agrees with the published cluster distance to within the errors. We also provide preliminary estimates of basic PN properties and abundance estimates from deeper spectra that show it to be of Type I chemistry consistent with that of the cluster and its estimated turn-off mass. Taken together these findings present a powerful case for clear physical association between the PN and host cluster. Results for this association will be of considerable interest to specialists across differing astrophysical disciplines, including PNe, white dwarfs, and open clusters.

PHR1315-6555: a bipolar Type I planetary nebula in the compact Hyades-age open cluster ESO 96-SC04

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Abstract: We have identified a bipolar Type-I planetary nebula PHR1315-6555, in the distant, compact, intermediate-age open cluster, ESO 96-SC04. This is currently the only known "confirmed" example of a PN physically associated with a Galactic open cluster. Cluster membership is extremely important as it allows for very precise estimates of the fundamental properties of the PN as the cluster is at a known distance. Results will be of considerable interest to specialists across differing astrophysical disciplines, including PNe, white dwarfs, and open clusters. These are presented in detail in Parker et al. (2010).

Fig.1. Left panel: a 5'× 5' colour composite SuperCOSMOS discovery image with Hα (red) broad-band SR (green) and B-band (blue). The image is centred on the PN which falls well within the cluster 32" half-light radius. Middle: a 1'×1' CTIO 4-m MOSAIC-II colour composite of the PN with its bipolar morphology evident from the Hα+[N II] (red), [O III]-off (green) and [O III] (blue) narrow-band filters. Right panel: quotient image from dividing the Hα+[N II] image by the Hα off-band image which is effective in showing the fainter outer regions of this unique bipolar PN. North-east is to the top left in all panels.

Fig.2. Cleaned 2-D wide-slit 2.3m DBS red spectral image of PHR1315-6555 with wavelength increasing to the right used for line flux measures. The bipolar nature of the PN is confirmed. The vertical direction is about 30" and the slit width was 19". From left to right the lines are [N II]6548Å, H, [N II]6584Å and the [S II] doublet at 6717 & 6731Å at the extreme right.

Discovery. The PN was found during systematic searches for new Galactic PNe for the original MASH survey (Parker et al. 2006) on the AAO/UKST Hα survey (Parker et al. 2005). The PN had been missed in earlier broadband surveys, including CCD studies of the host cluster (e.g. Carraro et al., 2005). Here we present original discovery images and CTIO 4m MOSAIC-II camera follow-up narrow-band images that reveal its bipolar morphology. We also present confirmatory spectroscopy and provide preliminary estimates of basic PN properties and abundance estimates from deeper spectra that show it to be of Type I chemistry consistent with that of the cluster and its estimated turn-off mass.

PN cluster membership. This rests on several key arguments and other pieces of evidence which are presented in the figures and tables to the right.
i) Close (23") angular proximity of PN to the cluster centre well within the 32" half-light radius (see Fig.1).
ii) Excellent 1km/s radial velocity agreement of PN and cluster stars from our high resolution spectra (Table.1). Open cluster velocity dispersions are typically only ~1kms/ (e.g. Mathieu, 2000 and Hole et al. 2009).
iii) Very good agreement between our independently estimated PN distance via our new surface brightness radius relation (Frew 2008) and that of the host cluster provided in the literature, to within the errors (Table.1).
iv) Independently determined cluster redenings and our own PN reddening estimates are in good agreement. (important in distance estimates).
v) The PN and cluster metallicities agree and are consistent with a Hyades age cluster as inferred from previous photometric studies of the cluster.
vi) The physical PN parameters evaluated at the estimated distance, such as physical nebula extent and likely progenitor mass, are all consistent with PN values and the estimated cluster turn-off mass of ~2.5 Msun (assuming a non-binary nucleus).
vii) A Galactic |z| height and statistical likelihood argument shows that a chance alignment of an unrelated distant PN with this remote compact cluster is exceedingly unlikely (there is no Galactic warp signature at the galactic longitude of the cluster).

Conclusion: Taking these diverse strands of evidence together they present an extremely compelling case for membership. Now that membership is proven the astrophysical potential inherent in this rare association can be exploited.

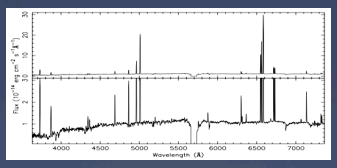

Fig3. left, flux calibrated, medium resolution 2.3m DBS spectrum of PHR1315-6555. The red and blue arm data have been independently flux calibrated (note gap at 5800Å). The upper panel shows the spectrum with the full range of line intensities plotted while the lower panel is re-scaled to reveal the important, fainter diagnostic lines more clearly. The [OII] doublet at 3727Å is well seen. It is clearly a PN. According to its spectral signature.

Observation	Date	log F Hα	Log F [OIII]
SAAO narrow-slit	May 2001	-12.49 ± 0.10	-12.28 ± 0.10
DBS wide-slit	May 2008	-12.44 ± 0.05	-12.32 ± 0.05
CTIO MOSAIC-II	June 2008	-12.45 ± 0.02	-12.35 ± 0.02

Table.2 Comparison of independent redenned PN line flux estimates showing excellent agreement.

Property	PHR1315-6555	ESO 96-SC04
Position RA (J2000)	$13^h15^m18.9^s$	$13^h15^m16.0^s$
Position Dec (J2000)	$-65°55'01''$	$-65°55'16''$
Position l,b	305.368, -3.158	305.362, -3.162
Distance (kpc)	9.1 ± 2.9	10.4 ± 1.8
Reddening $E(B-V)$	0.79 ± 0.08	0.72 ± 0.02
Radial velocity	59 ± 2.5 kms^{-1}	57 ± 5 kms^{-1}

Table.1. Main PN and cluster data comparisons

Reference	Telescope	D (kpc)	$E(B-V)$	Age (Myr)
PJM94, JP94	0.9m CTIO	7.57	0.72	...
CVO95	3.5m NTT	11.8	0.75	700
CM04	1.0m SAAO	12 ± 1	0.7 ± 0.2	800
CJE05	1.0m CTIO	10.1*	0.7*	800
Adopted values		10.4 ± 1.8	0.72	800

Table.3. Fundamental parameters for ESO 96SC04. Refs: CVO95, Carraro et al. (1995); PJM94, Phelps et al. (1994); JP94, Janes & Phelps (1994); CM04, Carraro & Munari (2004); CJE05, Carraro et al. (2005).

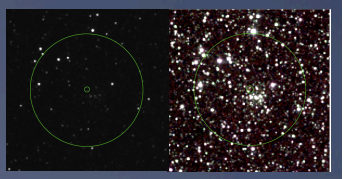

Fig.4. left: 2MASS K-band image centred on the PN with a 2' radius outer circle. Note the difficulty of seeing the cluster in this standard scaled image. Right: combined 2MASS JHK cluster image at high contrast. ESO 096-SC04 is too distant for 2MASS to derive an cluster reddening from the JHK data The cluster MSTO is V = 17. Even at V-K~ 2, the top of the MS is at K = 15. The 2MASS limit is K = 14.3 and at low latitudes could be 1.5 magnitudes brighter.

Characteristic	Estimated value
Major & Minor axes	18 × 14 arcseconds
Morphology	Bipolar
Chemistry	Type-I
DM excitation class	7.8
Electron density ([S II])	240 electrons cm^{-3}
Electron temperature, [O III] & [N II]	17700 & 10700 K
Physical radius	0.4 pc
Estimated age	16,000 years
Galactic z height below the plane	~575 pc
Estimated ionised mass	0.5 $M_\odot$
M_{8007}	−0.7
Estimated CSPN V mag	23.5 ± 1
CSPN temperature (cross-over)	218,000 K

Table.4. Measured & derived properties for PHR1315-6555. Cluster distance is used in calculation of PN parameters.

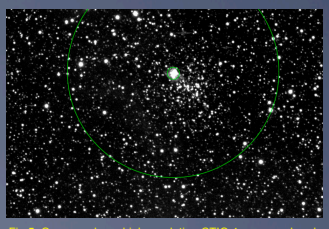

Fig.5. Our new, deep, high resolution CTIO 4m narrow-band [OIII] data of the PN and cluster which shows the context of PN and cluster to better effect. The outer green circle is of 4' diameter and the small inner circle is centred on the PN.

Element	PHR1315-6555	Type I	non-Type I	Solar
He	11.17	11.11	11.05	10.93
N	8.17	8.72	8.14	7.78
O	8.26	8.65	8.69	8.66
Ne	7.73	8.09	8.10	7.84
S	7.08	6.91	6.91	7.14
Ar	6.28	6.42	6.38	6.18
log(N/O)	−0.09	+0.07	−0.55	−0.88
log(Ne/O)	−0.53	−0.56	−0.59	−0.82
log(S/O)	−1.18	−1.74	−1.78	−1.52
log(Ar/O)	−1.98	−2.23	−2.31	−2.48

Table.5. PHR1315-6555 abundances from Hoppla with usual notation of 12+log(X/H). The abundances for Type I and non-Type I PN are taken from Kingsburgh & Barlow (1994) and for solar from Asplund et al. (2005).

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