The Born-again Planetary Nebulae Abell 30 and Abell 78

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Abstract. The planetary nebulae Abell 30 and Abell 78 are born-again nebulae, which are believed to have undergone a very late thermal pulse, resulting in the ejection of hydrogen-poor material.

Born-again PNe are a rare phenomenon, only a few are known. It is really intriguing that in all cases the expansion of the hydrogen-poor ejecta is highly asymmetrical. Here we present new HST observations of the expansion of the ejecta in Abell 30 and Abell 78, and compare them to ≈20 yrs older HST images.

1. Introduction

Planetary nebulae (PNe) consist of stellar material ejected by low- and intermediate-mass stars. In the canonical model of PN formation, the so-called interacting stellar winds (ISW) model, the envelope of a star is stripped off through a slow and dense wind, as the star evolves off the asymptotic giant branch (AGB). It is subsequently swept up by a fast stellar wind of the central star (CS) which further evolves to a white dwarf (WD). The PNe Abell 30 and Abell 78 are believed to have undergone a very late thermal pulse (VLTP) when the CS was already on the WD track. As the WD envelope is shallow, the increase of pressure from this last helium shell flash leads to the ejection of newly processed hydrogen-poor material inside the old PN. The PNe of Abell 30 and Abell 78 are both extended, i.e. about 2′ in diameter, and appear almost spherical and limb-brightend in Hα with H-deficient knots in the inner regions (see Fig. 1). Their CSs are H-deficient and of spectral type [WC]-PG 1159.

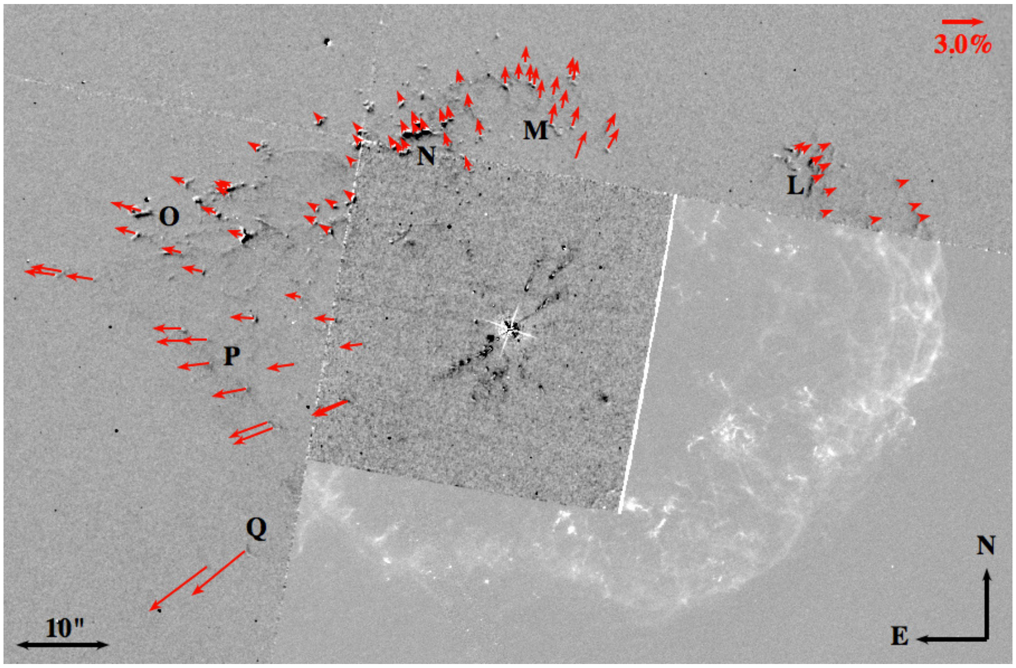

Figure 1. Residual image of Abell 78. White indicates the new *HST* image, while black represents the old data. Red arrows show directions of expansion with lengths proportional to values of fractional expansion δ_{exp}. The red scale bar (upper right) illustrates $\delta_{\mathrm{exp}} = 3\,\%$. Groups of features with similarities in δ_{exp} are labeled (see also Fig. 2)

2. The expansion of the H-poor knots

In addition to the existing *Hubble Space Telescope (HST)* F502N images of the *Wide Field and Planetary Camera 2 (WFPC2)* from 1994-03-06 (Abell 30) and 1995-07-11 (Abell 78), new observations, also centered on the nebular [O III] emission line, on 2013-03-21 (Abell 30) and on 2012-11-22 (Abell 78) were obtained with the *Wide Field Camera 3 (WFC3)*. These images are mostly dominated by features, such as compact knots with cometary tails and petal-like filaments (see Fig. 1).

To quantify the expansion of these structures the radial angular distance of the knots and filaments in the WFPC2 (R_{WFPC2}) and WFC3 (R_{WFC3}) images were measured and a fractional expansion

$$\delta_{\mathrm{exp}} = \frac{R_{WFC3} - R_{WFPC2}}{R_{WFPC2}} = \frac{\Delta R}{R_{WFPC2}} \tag{1}$$

was calculated (see Fig. 1 and Fig. 2). As shown in Fig. 2 the expansion of the features is non-homologous. Therefore, with the time Δt between the observations, we can only infer apparent expansion ages $\Delta t/\delta_{\mathrm{exp}}$ of 610 – 950 yr for Abell 30 and 605 – 1140 yr for Abell 78 respectively (Fang et al. 2014).

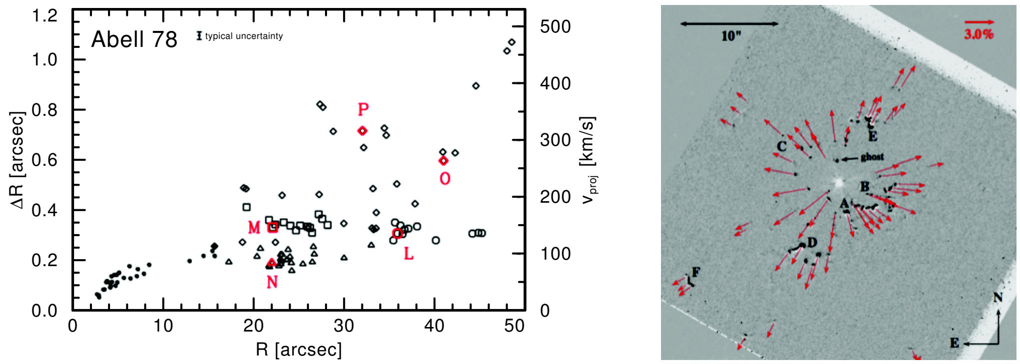

Figure 2. *Left panel:* Radial variations of the angular expansion ΔR and the sky-projected velocity $\upsilon_{\rm proj}$. *Right panel:* As in Fig. 1, but for inner region knots of Abell 30

3. Spectral analysis

Abell 30 and Abell 78 are sources of soft X-rays. To investigate the origin of these X-rays observations with *XMM Newton* were performed on 2009 Oct 21 (Abell 30) and on 2013 Jun 3 (Abell 78, see Fig. 3). Abell 30 was also observed with *Chandra* on 2011 Jan 1. A closer inspection of the radial profiles of the X-ray emission of both objects revealed that there is a point-like source associated with the CS and a diffuse component that seems to be related to the structures in the PNe.

We performed spectral analyses of the CSs with help of the *Potsdam Wolf-Rayet (PoWR)* model atmosphere code for expanding atmospheres. UV spectra from the *International Ultraviolet Explorer (IUE)* and the *Far Ultraviolet Spectroscopic Explorer (FUSE)* were obtained from the *NASA Mikulski Archive for Space Telescopes (MAST)*.

Complementary high-dispersion optical spectra of Abell 30 were obtained using the *Ultraviolet and Visual Echelle Spectrograph* on the 8 m UT2 of the *Very Large Telescope* at Paranal Observatory on 2003 February 19 in the framework of the large

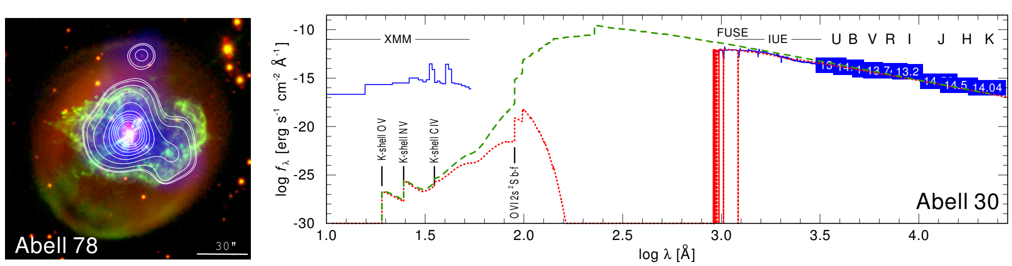

Figure 3. Abell 78. *Left panel:* composite picture of He II 4686 Å (red), O [III] (bright green), and soft X-ray (blue and also white contours) in the 190-600 eV band of *XMM Newton*, cf. Toalá et al. (2014). *Right panel:* Spectral energy distribution of Abell 30: Observed spectra (blue solid lines) and photometry (blue boxes) vs. *PoWR* model with interstellar extinction (red dotted), and without (green dashed). Model parameters as in Tab. 1

project 167.D-0407 (PI: Napiwotzki). An optical spectrum of Abell 78 was obtained at the 3.5m-telescope at Calar Alto on 1994 September 15 (see Werner & Koesterke 1992).

For both objects our spectral analysis resulted in similar stellar parameters, which are summarized in Tab. 1. The H-deficient, N-rich compositions as well as the over-abundance of neon and fluorine in the case of Abell 78 (see also Werner et al. 2005) provide further evidences that these objects are formed by a VLTP. Moreover, we found that the observed X-rays cannot be of photospheric origin, as the predicted flux at these wavelengths is by orders of magnitude lower than measured (see Fig. 3).

Table 1. Results of CS spectral analysis from Guerrero et al. (2012) and Toalá et al. (2014)

parameter	Abell 30	Abell 78	comment
$T_{\rm eff}$ [kK]	115	117	
$\log L/L_{\odot}$	3.78	3.78	adopted
R_{*} $[R_{\odot}]$	0.20	0.19	$R \propto L^{1/2}$
v_{∞} [km/s]	4000	3100	
D	10	10	density contrast
$\dot{M}$ $[M_{\odot}/{\rm yr}]$	2.0×10^{-8}	1.6×10^{-8}	$\dot{M} \propto D^{-1/2} L^{3/4}$
d [kpc]	1.76	1.40	$d \propto L^{1/2}$
E_{B-V} [mag]	0.18	0.12	
He	0.63	0.55	mass fraction
C	0.20	0.30	
N	0.015	0.015	
O	0.15	0.15	
Ne	–	0.04	
F	–	1.3×10^{-5}	$25\times$ solar

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