On the Distribution of Dust in the ``Born-again'' Planetary Nebula A30

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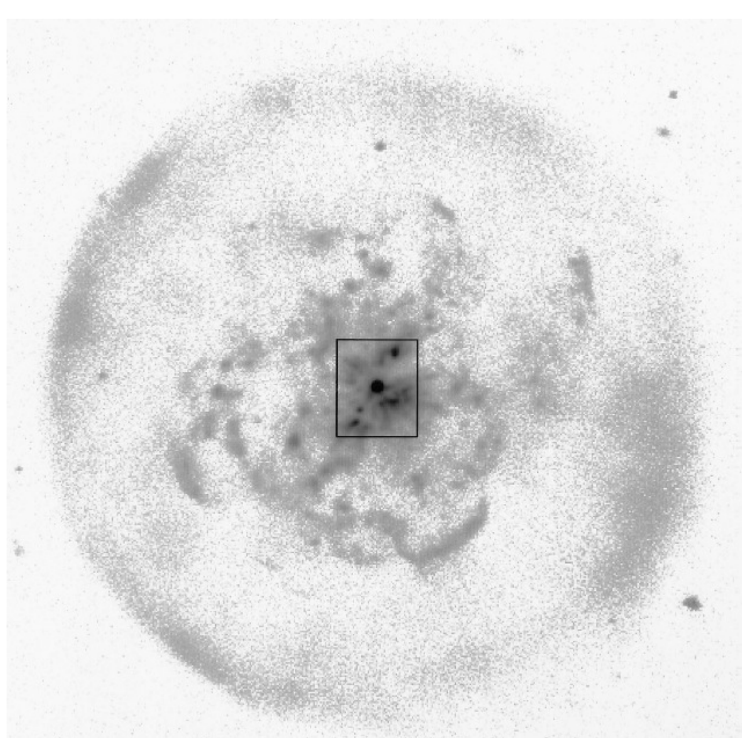
The planetary nebula (PN) A30 consists of two nebular shells, one old, spherical, hydrogen-rich PN and a second, younger, hydrogen-poor, and dust-rich nebula which is the result of a very late thermal pulse (VLTP), a helium shell flash that occurred long after the central (CS) star had left the asymptotic giant branch (AGB). During the VLTP the CS returned to the AGB and became a ``born-again'' giant for a few years. During this extremely fast episode of stellar evolution a final mass-loss phase created the second, dusty PN a few thousand years ago. Such a VLTP should occur in 20% of all post-AGB stars according to theory but only a handful of ``born-again'' PNe are known, a discrepancy that remains unexplained so far. In the case of A30 the ``born-again'' PN is highly filamentary and the individual knots clearly show signs of erosion from the fast wind of the - yet again - hot CS, such as "cometary" tails. While optical imaging ([OIII]-gas emission) obtained with the HST has provided excellent spatial resolution, near infrared imaging (emission from dust) had been very limited in resolution so far. With our new PANIC/Magellan data we quite literally see the other side of the coin and as a consequence, for the first time we are able to shed light on this complex interplay between gas and dust in this PN. We will use the data to better understand the effect of single-photon heating of small dust grains by the hard UV-radiation field of the CS. A 30 forms an evolutionary sequence with V4334 Sgr (10 yrs after the flash) and V605 Aql (100 yrs) and, hence, provides valuable insight into the physics of the still poorly understood ``born-again'' PNe.

Introduction

The discovery of Sakurai's object (V4334 Sgr) in 1996 (see Duerbeck et al. 1996, ApJ 468, L111, Kerber et al. 1998, Ap&SS 255, 279 for details) has created strong interest in late phase of stellar evolution and in the physics of the final helium shell flash. On the one hand, a final helium shell flash is a rare observational event due to its brief visibility. V4334 Sgr is the first example since V605 Aql/A58 in 1919. On the other hand, such a flash is not at all extraordinary in terms of stellar evolution. It will take place in about 20% of all low mass stars after they have left the asymptotic giant branch (AGB) according to theory (Iben et al., 1983, ApJ265, 605). As a result of the final helium flash the star will balloon to gigantic proportions while cooling and thereby returns to the AGB. From there it will retrace its own post-AGB evolution for a second time(``born-again''). This will lead also to the formation of a second PN composed of hydrogen-poor gas and dust (Harrington 1996, ASP Conference Ser. 96, Hydrogen-Deficient Stars, C.S., Jeffery and U.Heber (eds.), p.193).

Figure 1: Ground-based image of Abell 30 showing the spherical outer PN and the inner clumpy PN which is the result of the final helium shell flash. The rectangle indicates the region covered by the HST image (Fig. 3); taken from Borkowski et al., 1995, ApJ 449, L143)



New high resolution near-IR imaging

The prototypes of these "born-again" PNe are A30 andA78 (Jacoby & Ford, 1983, ApJ 266, 298; Hazard et al., 1980, Nature 285, 463) which have two spatially separated and chemically distinct nebula (Fig. 1). While in both cases the final flash happened a few thousand years ago, V605 Aql/A58 (Seitter, 1987, ESO Messenger 50, 14) experienced its flash in 1919, producing a nebula that is 1 to 2 arcsec in size today. Up until now high resolution study of the ejecta of A30 had been limited to optical wavelengths using HST. WFPC observations employing narrow band filters centered on prominent emission lines of the nebula mapped out the distribution of the gas. They revealed a highly complex structure of the ejecta (Borkowski et al., 1995, ApJ 449, L143, Fig. 3) as a result of distinctly non-spherical mass loss. Furthermore the central star has again evolved to high temperatures (>100,000K). The resulting fast(>1000 km/s) wind is an abrasive agent whose action can be seen in full detail in the individual clumps of A30 forming prominent cometary tails and mass loaded flows. Due to the high dust content of the ejecta, the optical observations necessarily give a highly incomplete picture of circumstellar environment which is characterised by the interaction of gas and dust which is very important for the physical processes in the nebula and its evolution. In the near infrared imaging had been very limited in spatial resolution so far (Borkowski et al. 1994, ApJ, 435, 722, Dinerstein & Lester, 1984, ApJ, 281, 702). With PANIC on Magellan we have obtained high resolution images in Y, J, H, Ks bands (March 2007) in very good seeing (~0.5 arcsec). The Y-band (dominated by gas emission) image is shown in Fig. 2 while the K-band image (hot dust) of A30 is presented in Fig. 4.

With the new Magellan/PANIC imaging we are for the first time in a position to have directly compare the distribution of the hot dust in the near-IR with the gas as seen in the WFPC images. We will quite literally see the other side of the coin and as a consequence for the first time we will be able to shed light on this complex interplay between gas and dust in these nebulae.
Fig. 4 shows the distribution of the dust in A30 to be very uneven. Using our gas image (Fig. 2) and a cautious comparison with the optical HST image (Fig. 3) it is safe to say that the dust is mostly located in an equatorial disk which has been fragmented into small dense individual clumps by the hot fast wind from the central star. Much fainter trails extend from most of the clumps. Since the dust is destroyed by the hard UV radiation from the CS and the matter in both equatorial and polar knots are at about the same distance from the CS we conclude that the dust was preferably created in an equatorial disk during the final helium shell flash. Using Y, J, H, Ks photometry we will construct spectral energy distributions of the individual knots and derive the physical properties of the dust grains, temperature, size distribution by using modeling their radiation environment.

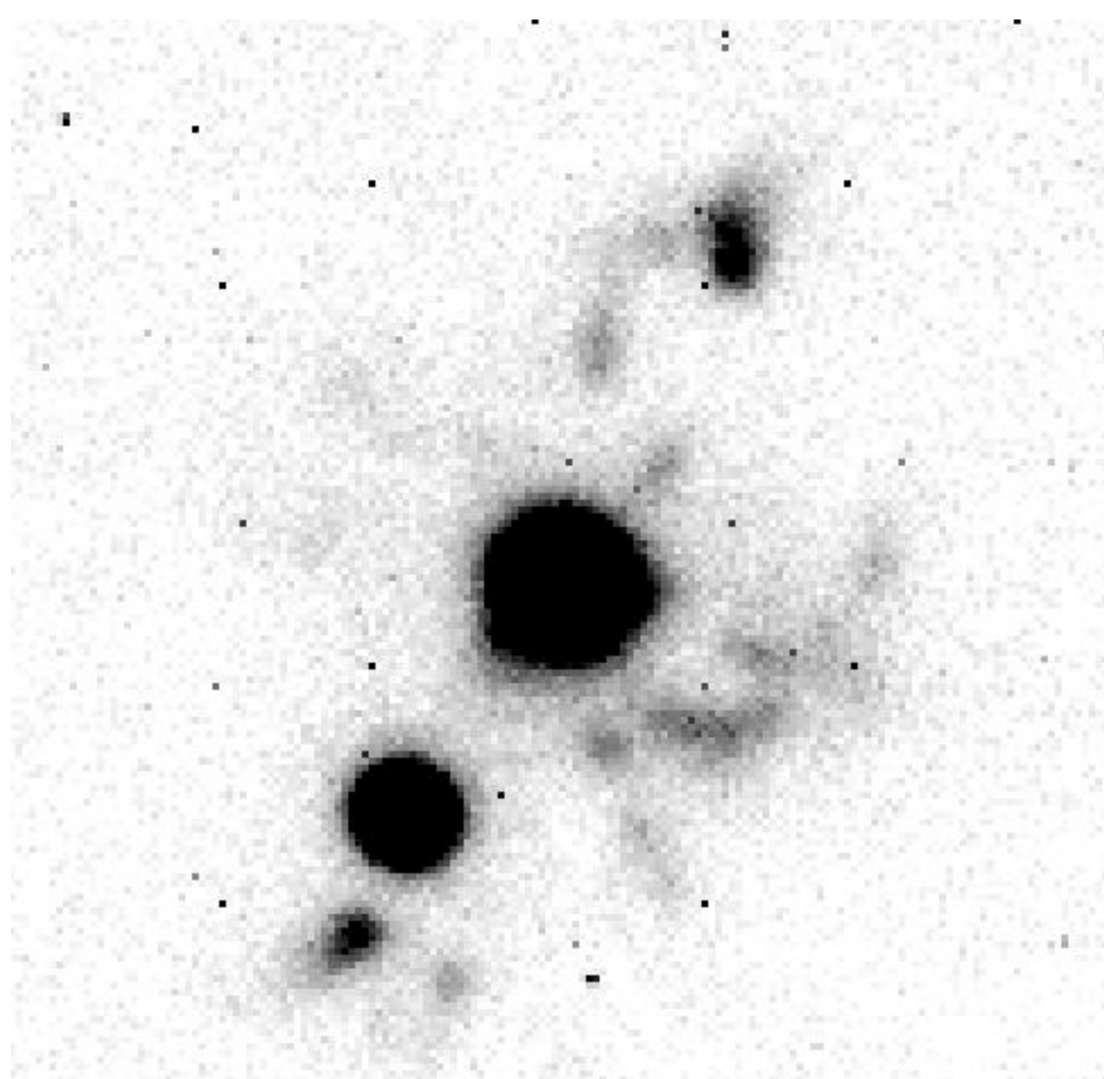


Figure 1: Y-band (λcen ~1000 nm, scale ~17 by 18 arcsec) image of Abell 30 showing the distribution of gas (mostly He I 1083 nm) in the nebula. This image was taken in very good seeing with PANIC on Magellan in March 2007; for comparison see the HST Image (Fig. 2) taken in [OIII].

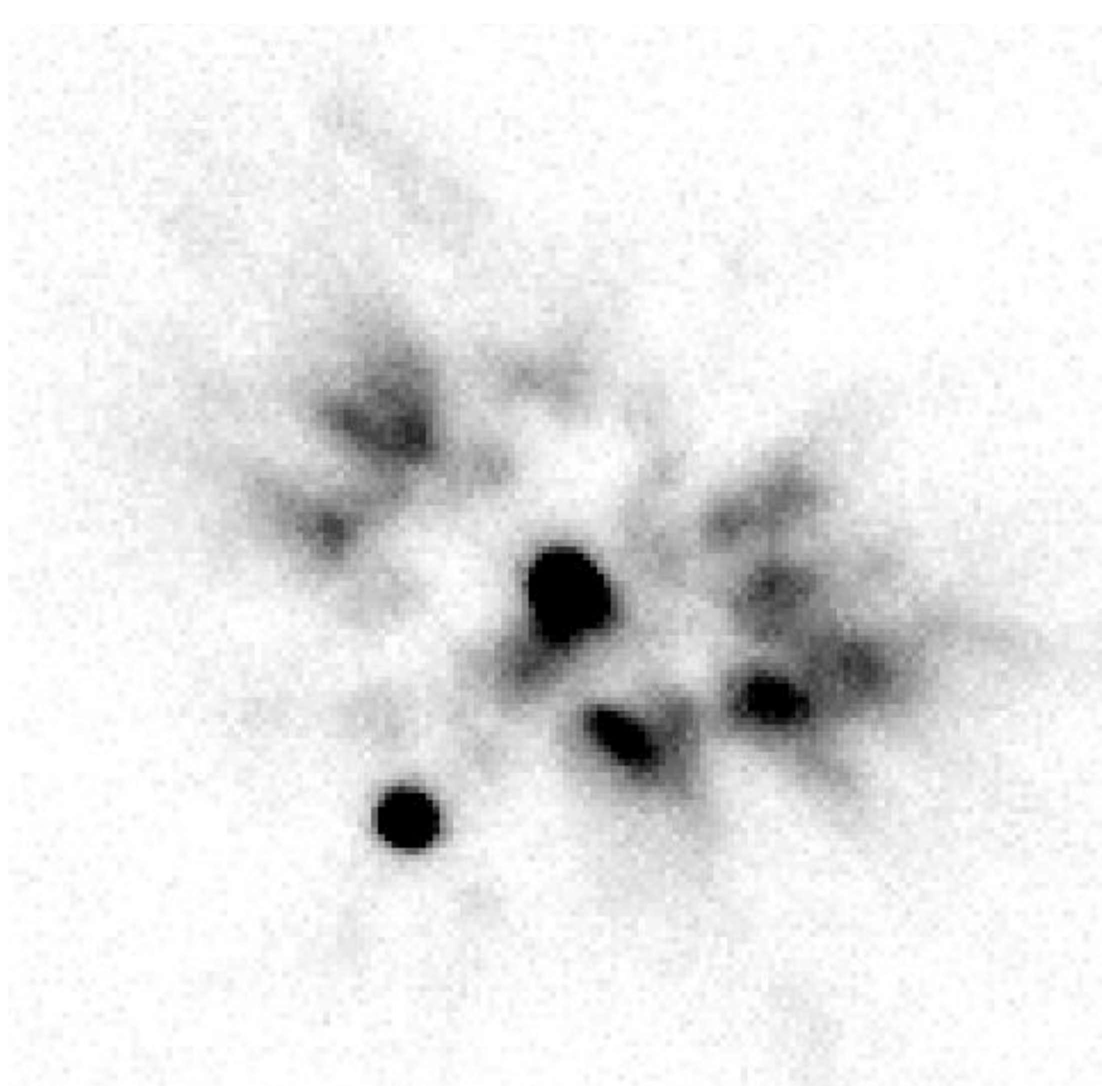


Figure 3: K-band image (~17 by 18 arcsec) of A30 showing the distribution of hot dust in the nebula. This image was taken in very good seeing with PANIC on Magellan in March 2007. There is a striking difference between the distribution of gas and dust, e.g. the polar knots that are very prominent in the gas are absent in the dust component.

Evolution of a final helium flash object

Sakurai's object is the best studied case and the only one observed at wavelengths other than optical. Its evolution suggests the following sequence of events: on the AGB (T_{eff}~5000 K) V4334 Sgr showed fast and massive changes in its spectrum as carbon bearing molecules formed more than a year after the actual helium flash in 1995 (Asplund et al., 1997, A&A 321, L17) very much comparable to V605 Aql (Clayton & de Marco, 1997, AJ 114, 2679). Shortly thereafter its started to form dust in an extended, optically thin shell around the star (Kerber et al., 1999, A&A 350, L27). As a consequence V4334 Sgr showed massive fadings in visual brightness as our line of sight became optically thick; a behavior well known from a special kind of irregular variables, the R CrB stars (Clayton, 1996, PASP, 108, 225). As the mass loss continued V4334 Sgr became very faint in the visual (> 20 mag) in 1999 and has remained so because it is ``buried'' in its own dust. Evolutionary calculations (Herwig 2001, ApJ 554, L71) clearly suggest that the star will not stay in the born-again phase for very long. It will leave the AGB, heat up and retrace its own evolution towards the PN phase for a second time.

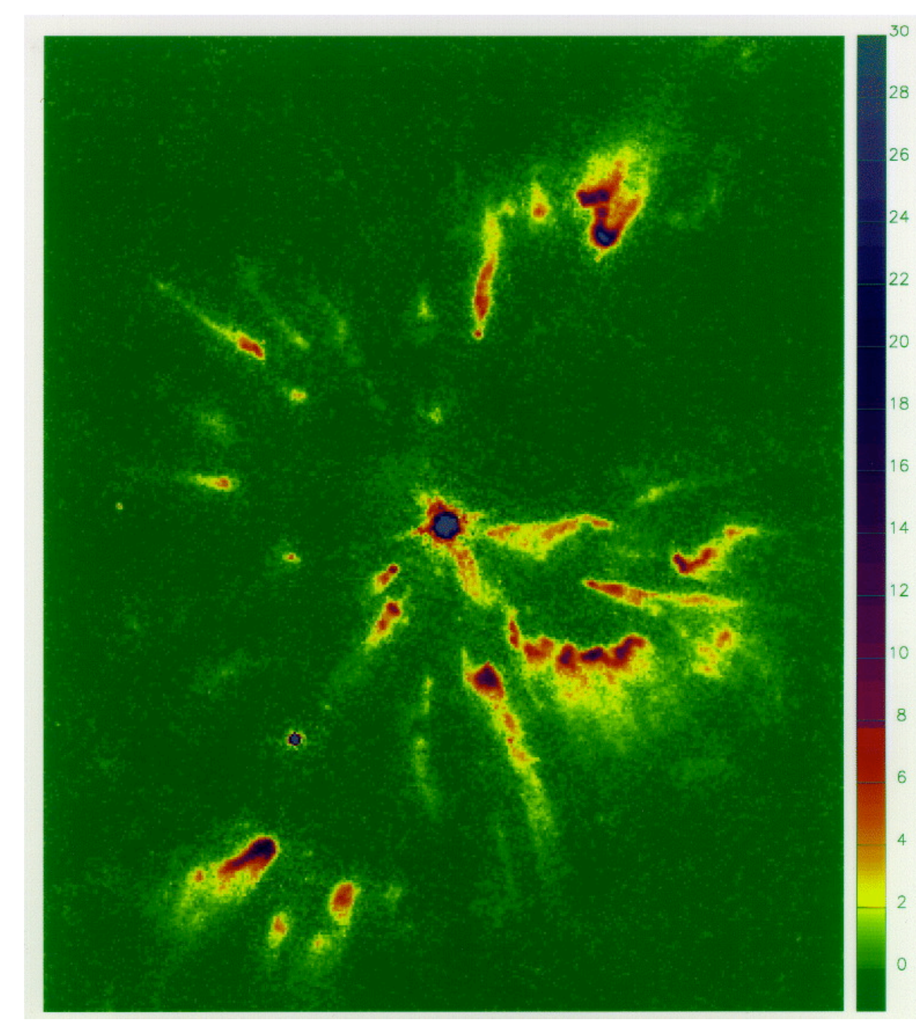


Figure 2: Central region of A30 imaged with the Hubble Space Telescope WFPC2 showing the distribution of ionized gas in the nebula ([O III] narrow-band filter, λcen ~500.7 nm). The field of view is 15.3" × 18.5". The scale is in counts pixel^{-1}. For this image, each count pixel^{-1} corresponds to 6.6×10^{-15} ergs cm^{-2} s^{-1} arcsec^{-2} (taken from Borkowski et al., 1995, ApJ 449, L143).

When the central star turns hot again …

In Sakurai's object the first indications of an evolution off the AGB were found in 2001 when optical emission from ionised matter in a fast 350 km/s) circumstellar outflow was detected (Kerber et al. 2002, ApJ, 581, L39) . Soon thereafter an ionised source was also discovered at radio wavelength (Hajduk et al. 2005). While these observations were probably related to shock excited matter direct proof has now been found for an increase in the temperature of the central star (van Hooft et al. , 2007, astro-ph/0706.3857). Having reached 12,000 K in 2006 V4334 Sgr it is predicted to heat up at a rate of about 1000 K/yr. The resulting hardening of the radiation field will have a fundamental effect on the circumstellar material and will lead to the destruction of the dusty cocoon.

V605 Aql/A58 which experienced its final helium flash in 1919 is exactly in this phase in which the radiation of its 95,000 K central star (Clayton et al. 2006, ApJ, 646, L69) is working its way through the dust. Its circumstellar nebula is about 1 1 arcsec in size (Bond et al., 1993, in IAU Symp.155, eds. p. 499; Clayton & De Marco, 1997, AJ 114, 2679; Guerrero & Manchado (1996, ApJ 472, 711) and remains difficult to resolve from the ground.
A30 on the other hand is much more advanced in its post-helium flash evolution (a few thousand years) and its nebula can be studied in detail. To this end we will describe the radiation field of the hot >100,000 K) central star by means of state of the art NLTE atmospheric models.
This radiative input will be used to calculate the effect of single photon heating on the dust grains. This NILFISC code (Koller & Kimeswenger 2001, ApJ, 559, 419) has been instrumental in understanding the peculiar near infrared emission of the dust in the central knot of A 58. In this way we hope to obtain the physical properties of the dust grains, temperature, size distribution in a realistic radiation environment.

V4334 Sgr, V605 Aql/A58, A30 an evolutionary sequence

A30 is the older sibling of V4334 Sgr and A58 and studying its circumstellar environment will provide valuable insight in the physics governing the process during and after the final helium shell flash.
Our new high resolution near-IR images allow us, for the first time, to make a detailed comparison between the distribution of the gas and dust in A30.

The evolution of the H-poor dusty ``born-again'' PNe can only be understood in terms of the interplay of the gas and dust. A case in point is the phenomenon of mass loaded flows also can explain the existence of non-radial structure in the wind-swept nebulae; see Figs. 3 &4 (Borkowski et al., 1993, ApJ L47, Harrington et al., 1995, ApJ 439, 264).
While we try hard to follow the fast paced evolution of Sakurai's object, A58 signals an important milestone in the post-flash evolution whereas A30 provides a good blue print for its final outcome.