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Planetary nebulae with DENIS*

Capabilities for imaging nebulae

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Abstract. The Deep Near Infrared Southern Sky Survey (DENIS) is the first attempt to survey the entire southern sky in the near infrared (NIR) range in three bands (I, J and K_s; Epchtein et al. 1997). A lot of studies have been done on planetary nebulae (PNe) in the NIR throughout the last decades. These investigations often use J, H and K bands. Thus the DENIS survey will lead, due to different bands and to the total sky coverage, to a new view on PNe in this wavelength domain. We demonstrate here the capabilities for the imaging of planetary nebulae with DENIS on basis of nebulae observed during the first phase of the survey. We also compare the results for NGC 2440 with deep high-resolution images obtained at the 100-inch Las Campanas duPont telescope. The DENIS data, being comparable to ISOCAM in spatial resolution (Cesarsky et al. 1996), will also support investigation done at longer wavelengths by means of ISO (Kimeswenger et al. 1997a). We also assess the quality of photometry obtained with DENIS by comparison with literature results. In regions with high background stellar confusion we are able to improve on the photometry significantly in accuracy and reliability.

Key words: planetary nebulae: NGC 2440; NGC 3242; NGC 3918; NGC 5189; Hb 5; KFL 14 – surveys

1. Introduction

So far the only attempt to survey the sky in the near infrared range was the Two Micron Sky Survey (TMSS, Neugebauer & Leighton 1969). This survey contains mainly bright late-type stars. PNe have been investigated by means of aperture photometers (e.g. Pena & Torres-Peimbert 1987, Whitelock 1985, Kwok et al. 1986, Phillips & Cuesta 1994, Preite-Martinez & Persi 1989) in the past. Exploiting the present capability of detection provided by the recently developed panoramic detector arrays sensitive to near-infrared photons, a new imaging instrument was designed in the 90's (Epchtein et al. 1994, Copet et al. 1997, Epchtein et al. 1997) to survey the southern sky with the ESO 1m telescope. This survey will provide a large sample of PNe in this wavelength domain. Combining the data with narrow band images (H_α, HeII or [OIII] e.g. Balick 1987, Schwarz et al. 1992) will allow spatially resolved investigations of the mainly continuum components of the radiation. Spatially resolved observations also provide better information about the contamination from red (or highly reddened) stars. The survey will uncover the nature of several objects suspected to be PNe by means of their IRAS colours, but having no optical/NIR identification yet. We show here the capabilities for the imaging of PNe with DENIS and do a comparison with high-resolution deep NIR images obtained for NGC 2440. We also give aperture photometry values, obtained from the images and compare them with the data from the literature. Some of the photometric measurements are new. Catalogues containing a huge set of PNe ($>$ 600) images from DENIS are being prepared and will be available in electronic form (see Kimeswenger & Kienel 1997 and Kimeswenger et al. 1997b).

What kind of emission do PNe have in the DENIS bands ?

Nebulae emit in this wavelength domain as detailed below (for a summary see also Hora & Latter 1996):

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* Based on observations collected at the European Southern Observatory, La Silla, Chile

K_s-band: ($1.98\,\mu m \leq \lambda \leq 2.32\,\mu m$)
The nebulae's line flux in the K_s band will be dominated by the $Br_{\gamma\,2.17\mu m}$ hydrogen and two $HeI_{2.06+2.11\mu m}$ lines. The *free-bound* and *free-free* flux contributes to the continuum. Both should be correlated to the hydrogen flux in the visible. Additionally very hot dust already appears in that wavelength domain. The outer regions of the nebulae may also show emission from molecular hydrogen (H_2) due to shocks.

J-band: ($1.07\,\mu m \leq \lambda \leq 1.40\,\mu m$)
The hydrogen $Pa_{\beta\,1.28\mu m}$, $Pa_{\gamma\,1.09\mu m}$ and $He_{1.083\mu m}$ lines, dominate this band. Additionally small contributions may result from $HeI_{1.2+1.25+1.3\mu m}$ and $[OI]_{1.13+1.32\mu m}$.

Gunn-i-band: ($0.72\,\mu m \leq \lambda \leq 0.88\,\mu m$)
Here again the hydrogen dominates through the higher lines of the Pa series and the *free-bound* continuum of that series. Additionally some contribution from the $OI_{0.845\mu m}$ may be expected. The strong $[SIII]_{0.907\mu m}$ line is excluded from this special (narrower) kind of I-band.

The filter curves (plots) are given in Epchtein et al. (1994) and in Copet et al. (1997). Thus the hydrogen of the nebulae dominates these bands. There are almost no forbidden lines of heavy elements contributing significantly to the total flux. Therefore the behaviour in transitions from thin to dense regions in the nebulae is totally different from that of optical wide band images, which are dominated by forbidden lines.

2. The data

2.1. The DENIS data

The DENIS data is taken in Gunn-i, J and K_s bands. The sampling is 1 arcsec/pixel, while the physical pixels themselves are 3×3 arcsec (overlapping by 2/3) in J and K_s. This is produced by the use of 9 short exposures shifted by 1/3 of a pixel each. The spatial resolution is comparable to that of ISOCAM (Cesarsky et al. 1996) in the mid infrared range. The exposure time is about 10 seconds per frame. For details on the DENIS data and on the data reduction one may refer to Deul et al. (1995) and Borsenberger (1997). The objects presented here were selected from the pool of already observed PNe with diameters greater than 15 arcseconds having NIR information in the literature (except for NGC 5189). Some of the targets (NGC 2440, 3242 and 3918) have been observed several times with DENIS. The timescales between the observations vary from days to one year. Thus these observations allowed to perform checks on the instrumental stability and on the calibration consistency. The differences between the measurements are less than $0\overset{m}{.}03$. This accuracy is better than that obtained on point sources due to the large number of pixels involved per nebula.

2.2. The high-resolution images

The deep images of NGC 2440, shown here for comparison (Fig. 1), were taken with the NICMOS3 camera attached to the Las Campanas du Pont 100-inch telescope during an observing run in March 1996. We used the J and the K_s filter taking 20 and 30 individual frames, 60 and 35 seconds each, giving a total integration time of 1200 and 1050 seconds, respectively. The spatial resolution was 0.35 arcsec/pixel.

Table 1. Photometric results for NGC 2440 obtained with DENIS and the literature data

band	aperture [″]	DENIS [mag]	literature [mag]	ref.
K_s/K	total	9.38		
	27	9.52	9.39	[1]
	24	9.63	9.68	[3]
	14	10.22	10.07	[2]
J	total	9.99		
	24	10.21	10.33	[3]
	14	10.71	10.67	[2]
I	total	11.21		

[1] Persson & Frogel 1973; [2] Pena & Torres-Peimbert 1987; [3] Whitelock 1985

3. Individual objects

3.1. NGC 2440 (= PN G234.8+02.4)

This object is listed with $m_J = 10\overset{m}{.}33$ and $m_K = 9\overset{m}{.}68$ (Whitelock 1985) and is one of the classical bipolar PNe (sometimes even classified as quadrupolar). The nebula is listed as 16″ in diameter in Acker et al. (1992). Already the DENIS images of NGC 2440 (Fig. 1) show that the main nebula is significantly larger (22″×28″), while the deep images obtained at Las Campanas even show the outer wings known from deep optical imaging (Balick 1987). The deep K_s band image shows an additional extended structure in the symmetry plane. NIR narrow band images by Kastner et al. (1996) show an identical structure due to molecular H_2 emission. To avoid confusion due to different aperture sizes, we obtained not only the total flux, but also determined the flux using the aperture sizes used in the studies found in the literature. The aperture was first centred on the object, and then the, often used in the IR photometry, peak-up position was obtained. There was no significant difference between these two positions. The photometric flux obtained with DENIS in the K_s band is slightly lower than the one given in the literature for K (except that one for Whitelock 1985 who was using a narrow K). This may be due to the slightly narrower and bluer K_s filter used for the DENIS survey. The J band results correspond very well in the small aperture and differ in case of the bigger one. The total I band flux was corrected slightly for stellar contamination ($0\overset{m}{.}08$).

3.2. NGC 3242 (= PN G261.0+32.0)

For the diameter of the main nebula a value of 25″ is given in the literature (Acker el al. 1992). The elliptical shape containing two knots is clearly visible (Fig. 2a). The halo extends out to 42″ and has a very uniform surface brightness. Its contribution to the total flux is significant even in the K_s band where it is faintest. The aperture photometries are given in Table 2.

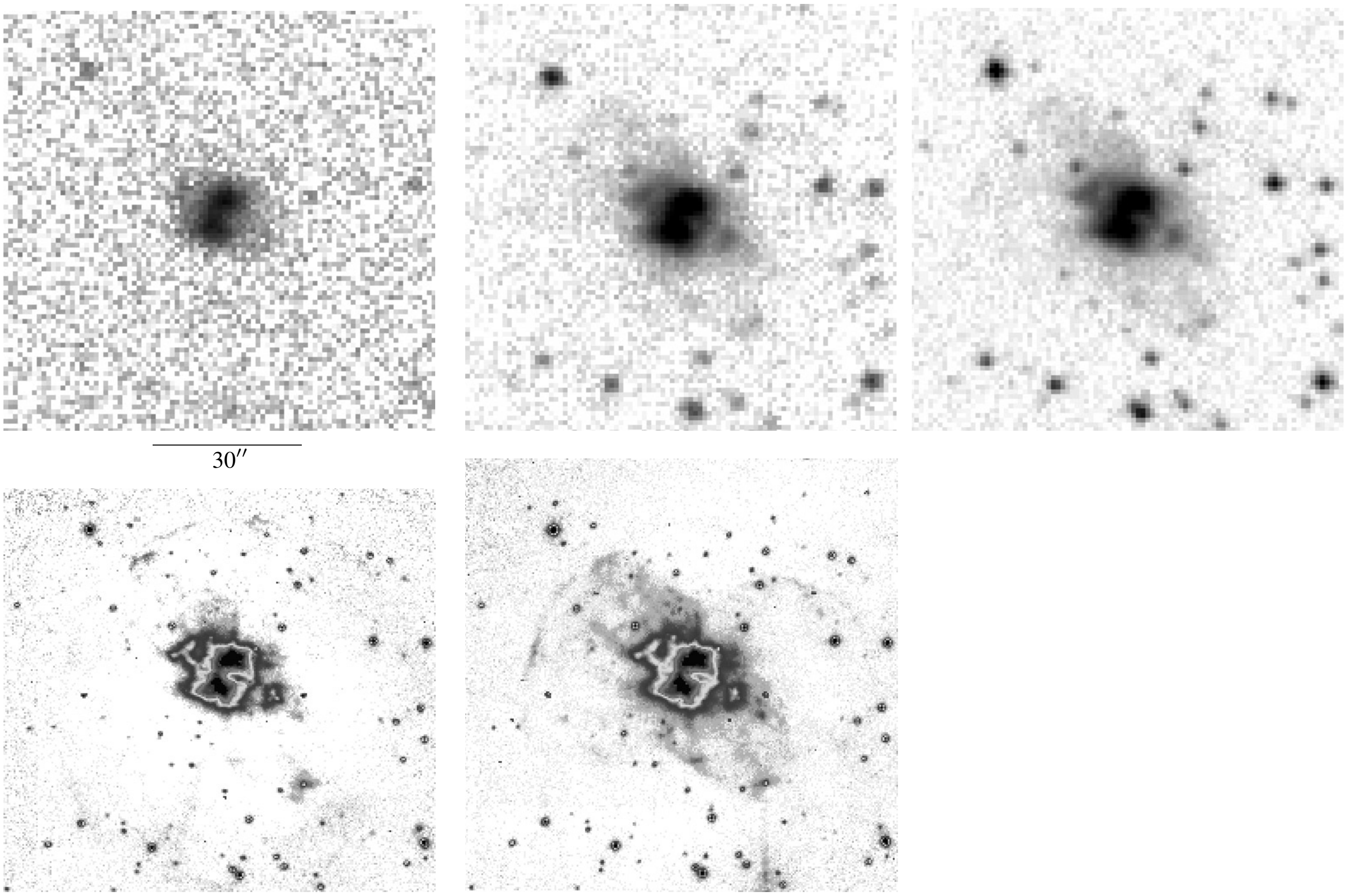

Fig. 1. Images of NGC 2440 by the DENIS survey at the ESO 1m (top, from left to right: K_s, J, I) with a resolution of 1"/pixel and an exposure time of 10 seconds and the deep images taken at the Las Campanas 100 inch (bottom, K_s, J) with a resolution of 0.35"/pixel and an exposure time of 1050 and 1200 seconds respectively.

Table 2. Photometry for NGC 3242.

band	aperture ["]	DENIS [mag]	from literature [mag]	ref.
K_s/K	total	8.59		
	33	8.80	8.84	[1]
	27	8.97	8.98	[2]
J	total	9.02		
I	total	10.02		

[2] Persson & Frogel 1973; [1] Willner et al. 1972

3.3. NGC 3918 (= PN G294.6+04.7)

This nebula is a "classical" round PN without structure at a scale of a few arcseconds. The ring is hardly visible. It is more likely a uniform brightness object (Fig. 2b). Persi et al. (1987) give $m_K=8\overset{m}{.}85$ and $m_J=9\overset{m}{.}13$ for this object. The aperture used in their work is not clearly identified, but taking into account that the size of the main nebula is only 19″, we assume that the whole object was within the aperture. We find $K_s = 8\overset{m}{.}71$, J = $9\overset{m}{.}18$ and I = $10\overset{m}{.}58$.

3.4. NGC 5189 (= PN G307.2-03.4)

This extended and highly structured nebula is an example of a nebula for which aperture photometry is not possible, due to stellar contamination (Fig. 2c). A total photometric flux does not give any meaningful information. The stars my be substracted by using PSF fitting. Some more investigations about the undersampled stellar PSF are currently ongoing. The K_s band image is at the lowest detection limit. This will be significantly improved, once in spring 1997 the DENIS focal instrument gets an additional cooling for the optical elements of the beam splitter. Note also the remarkably blue appearance of the central star (marker) compared to the very red one directly west of it.

3.5. Hb 5 (= PN G359.3-00.9)

Hb 5 nicely illustrates another complication that may arise with conventional photometry but that easily can be avoided with DENIS data. The technique of IR-photometry usually requires a beam-throw/offset position for comparison in order to obtain a value for the background flux. But even a very careful selection of this position may lead to serious problems. The area marked

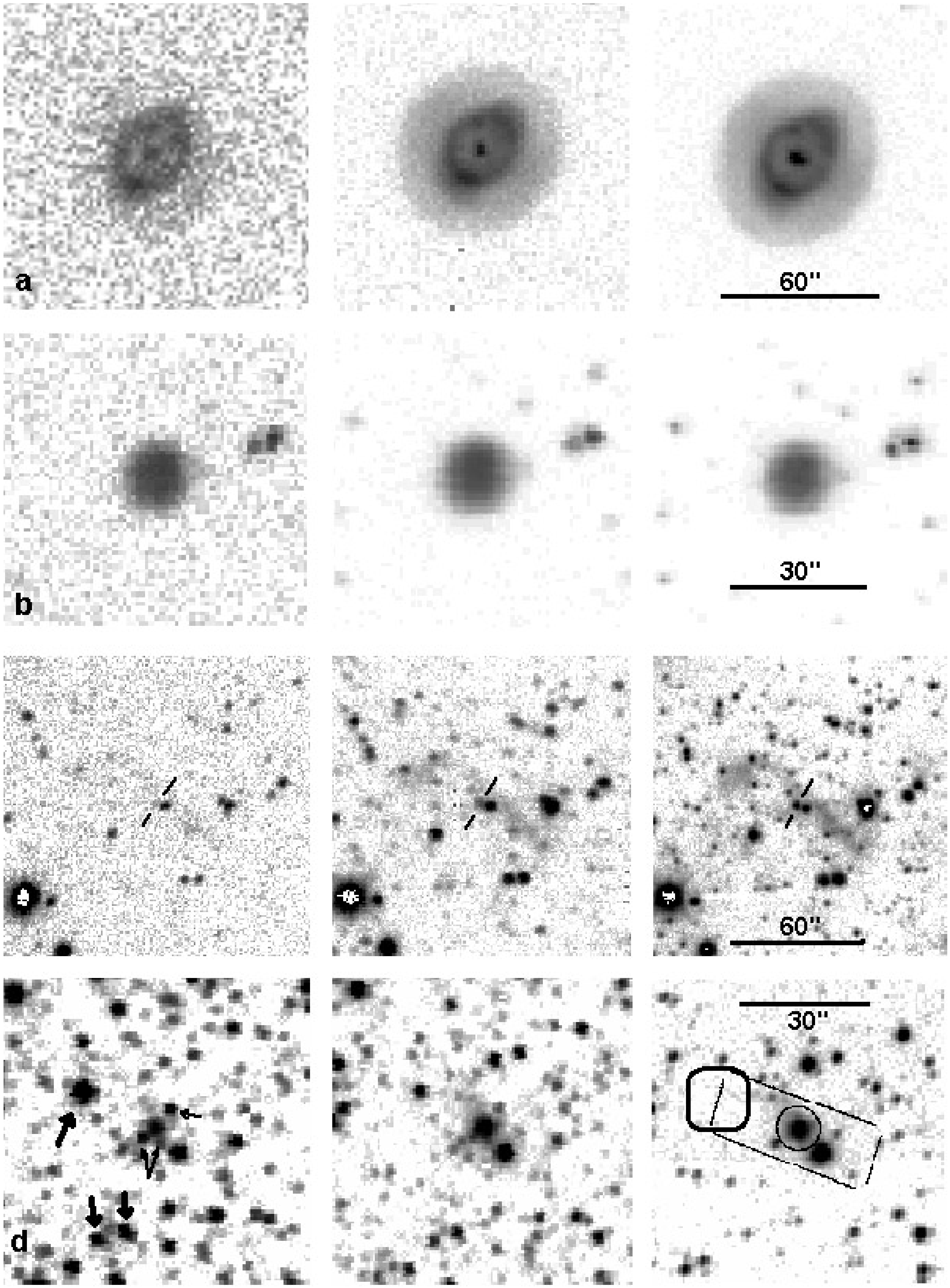

Fig. 2. The NIR image gallery obtained with the DENIS survey: NGC 3242 (top, from left to right: K_s, J, I), NGC 3918 (upper middle) and NGC 5189 (lower middle) and Hb 5 (bottom). See the text for explanations of the indicated features.

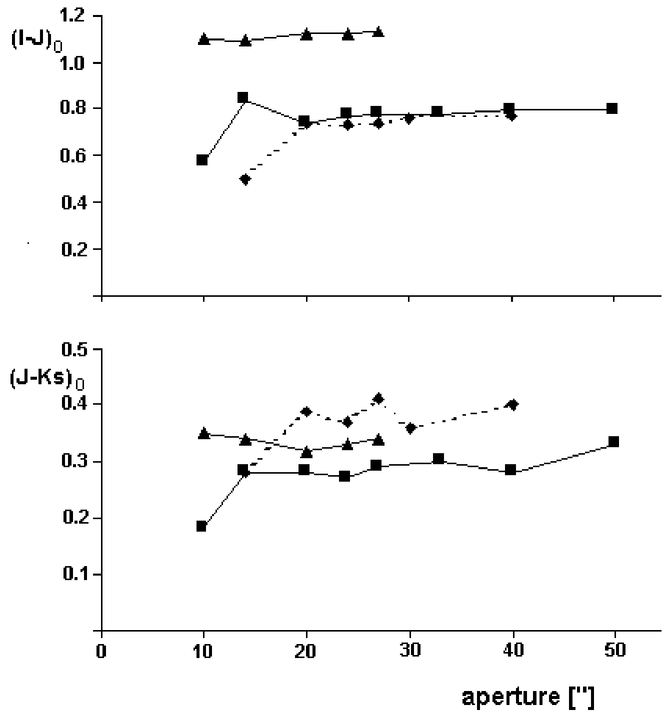

Fig. 3. The DENIS colour indices as function of the aperture diameter for NGC 2440 (diamonds), NGC 3242 (squares) and NGC 3918 (triangles).

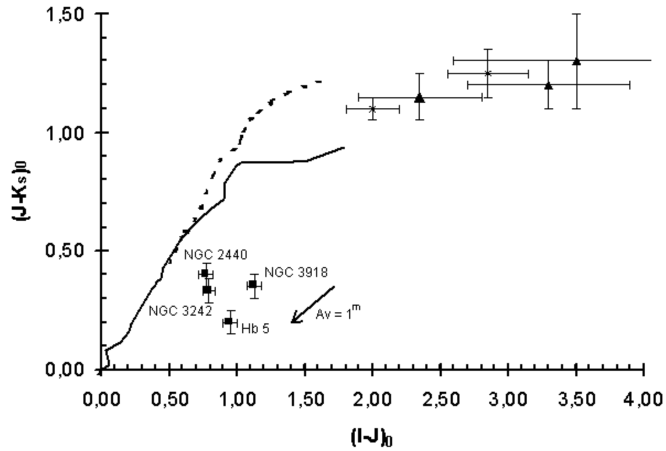

Fig. 4. The locus of NGC 2440, NGC 3242, NGC 3918 and Hb 5 in the DENIS colour-colour diagram. The position of the stellar main sequence (solid line) and the giant sequence (dashed line) is given for comparison reasons. The location of the SRVs (crosses) and that of the Miras (triangles) are indicated including the possible range of colours during a typical period (after Hron & Kerschbaum 1994).

by a square outlined box (Fig. 2d) is completely devoid of stars even in the I-band, let alone the optical bands of the available sky surveys. In J a star appears which is the strongest source in the field in K_s. So selection of the marked area as offset position, which would have been a good choice based on the existing data would have led to a useless result. Also the very red stars (big arrows in Fig. 2d) may confuse beam throw techniques. The stars near the nebula centre (small arrows) are confusing the photometry. For orientation we have indicated the round aperture of Phillips & Cuesta (1994) and the optical nebula extensions found by Schwarz et al. (1992) in the I-band image (thin box). Photometry is confused due to its position in front of the galactic bulge. The star density rapidly grows in the K_s band. This is an indication for a high interstellar extinction towards this object. Phillips & Cuesta give $m_K=9\overset{m}{.}07$ and $m_J=10\overset{m}{.}34$ for this nebula using a 15″ beam. They list the visual extinction towards the nebula as $A_V=3\overset{m}{.}6$. The individual distance is given by Sabbadin (1986) as ≈2 kpc. Such a high extinction occurring on the first 2 kpc "hides" the stars of the bulge in visual light. Using the aperture of Phillips & Cuesta, we can reproduce their results with DENIS (K_s = $8\overset{m}{.}90$, J = $10\overset{m}{.}27$ and I = $12\overset{m}{.}35$). But this does not give the intrinsic colours of the nebula. The (dereddened) colours, using the 15″ aperture, are identical to an early M star. As Tables 1 and 2 and Fig. 3 show, the colours of the other nebulae do not vary very strongly within the nebulae with the aperture size. Therefore we used a 5″ aperture to derive the uncontaminated colours of Hb5. This gives the (dereddened) colours of $(J-K)_0=0\overset{m}{.}20$ and $(I-J)_0=0\overset{m}{.}95$. Therefore this object too belongs to the region in the colour colour diagram, where the normal PNe are expected (Kimeswenger 1997).

3.6. The colours of the PNe

To investigate the colours of the nebulae as function of the aperture, photometry of NGC 2440, NGC 3242 and NGC 3918 was done with different diaphragm diameters. The colour index does not depend on the aperture diameter (Fig. 3). Only the innermost measurements show some effect due to the blue central star. Thus the colour-colour diagrams of the photometry obtained in the past (e.g. Pena & Torres-Peimbert 1987, Whitelock 1985, Kwok et al. 1986, Phillips & Cuesta 1994, Preite-Martinez & Persi 1989) are usable for comparison, even if they missed some flux at the outskirts of the nebulae. The loci of NGC 2440, NGC 3242, NGC 3918 and Hb 5 in the DENIS colour-colour diagram (Fig. 4) are well separated from those of normal stars, semiregular variables (SRVs) and Miras.

4. Studies using the surroundings of the nebulae

Another important capability of imaging is to study the surroundings of the nebulae. The stellar field can be used to separate foreground PNe from bulge PNe (see Acker et al. 1992). This is of importance, since the bulge sample often is used to calibrate statistical properties of PNe (e.g. Van de Steene & Zijlstra 1994). We picked the nebula KFL 14 (PN G002.5-05.4) as an example. It is classified as a possible member of the bulge sample (Acker et al. 1992). The extinction of the nebula was measured by means of the Balmer decrement (Acker et al. 1991). They list an extinction of c=1.53 ($E_{B-V}=1\overset{m}{.}0$). Comparing of the stellar counts on the NIR images with those on the optical sky surveys clearly shows, that the stellar bulge population is obscured by interstellar extinction significantly larger than

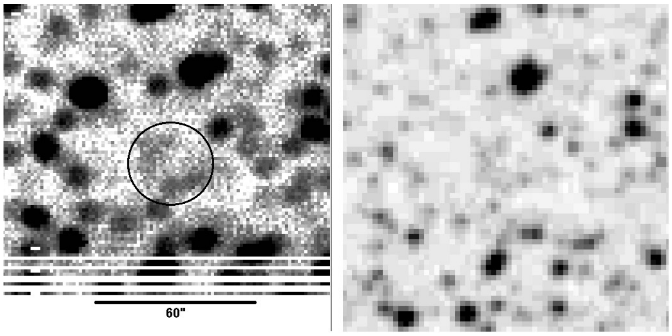

Fig. 5. The DENIS J image (left) and the digitised blue sky survey plate (right) around KFL 14. The reddening of the stellar population gives an estimate of the high interstellar extinction towards the bulge. The stripes at the bottom of the DENIS image are the effect of the microscanning on the image edge.

$E_{B-V}=1\stackrel{m}{.}0$. Thus KFL 14 has to be in front of the bulge. This conclusion is supported also by its angular size (nearly $20''$ on the DENIS images). Therefore KFL 14 has to be removed from the bulge sample. This kind of image also can be used to derive individual distances towards PNe by means of extinction distance diagrams.

5. Summary and conclusions

We have shown that the imaging capabilities of the DENIS near infrared survey can be used effectively to study PNe. The five objects discussed in Sect. 3 are seen extended on the DENIS images. The image data allows to separate features in the brighter regions of the nebula. The photometry was checked internally by use of revisited nebulae (NGC 2440 was measured five times, NGC 3242 four times and NGC 3918 three times). Using apertures similar to those in published photometry the results here are in fine agreement. The (J-K_s) values of the extended nebulae are slightly lower than those obtained with aperture photometry. This might be due to the fact that aperture photometry partly excludes the outermost parts and thus enhance the effect of the helium lines in the J band near the PN center. The survey data also can be used to calibrate high-resolution images. The contamination of very red (or strongly reddened) background stars confusing photometry can be removed efficiently. Problems with finding an offset position do not occur here. As the NIR bands are dominated by hydrogen emission, these images can be used to study the excitation. The K_s band images are of importance for spatial studies of recombination lines. We also showed, that the stellar field can be used to separate foreground objects from the bulge sample objects. This is of importance, since the bulge sample often is used to calibrate statistical properties of PNe.

We have examined the data obtained with DENIS on several well studied Planetary Nebulae. These data are consistent with the results published in the literature. Reliable photometry can be obtained easily from DENIS on extended objects ($\sim$ 20 arcsec.) down to at least $K_s \sim 10$. The DENIS data will be especially useful for identifying PN candidates selected from IRAS

Table 3. Summary of the DENIS PNe photometry

Name	E_{B-V}	I	I-J	J-K_s	Rem.
NGC 2440	0.26	11.21	1.22	0.61	
NGC 3242	0.44	10.02	1.00	0.43	
NGC 3918	0.20	10.58	1.40	0.48	
Hb 5	1.13		2.10	0.74	(1)

(1) intrinsic colours - see text

and radio surveys. The huge sample of nebulae coming from DENIS will give also the input for new statistical investigations to improve the general properties of PNe. Thus we are looking forward with high expectations to the complete data set expected to be available by the end of this century.

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