the bar parameters, and the influence the bar has on its surroundings, is not clear, and is the subject of our further exploration, partly aided by INGRID imaging.

5. Summary

In this short paper, we illustrate the power of the INGRID NIR camera on the WHT in obtaining deep, wide-field, imaging of nearby spiral galaxies. We describe results from our study of bar torques, or bar strengths, in a large sample of galaxies which we imaged with INGRID, and show that this bar strengths only very weakly correlates with de Vaucouleurs bar type, or with bar axis ratio.

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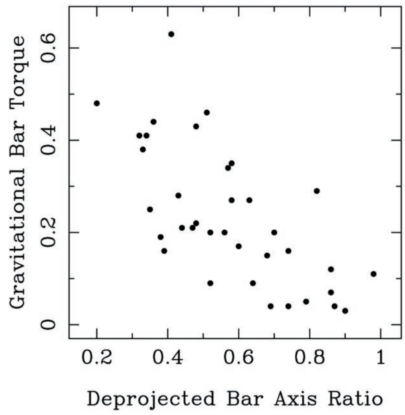

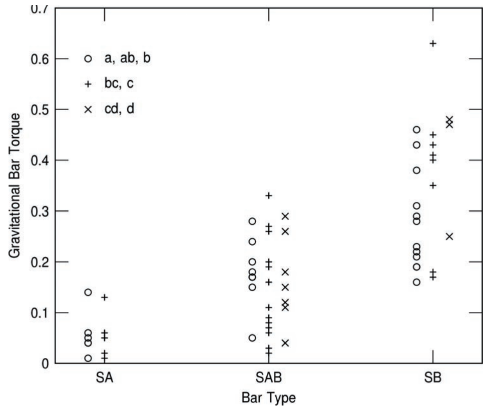

Figure 4 (left). Bar strength plotted as a function of deprojected bar ellipticity, or bar axis ratio. From Block et al. (2001). Figure 5 (right). Bar strength plotted as a function of Hubble type for our sample galaxies. From Block et al. (2001).

Searching for Obscured Supernovae in Nearby Starburst Galaxies

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We are currently carrying out a K_s band survey for core-collapse supernovae (CCSNe) in the nuclear (central kpc) regions of nearby starburst galaxies with the INGRID near-IR camera at the WHT. In this article we concentrate on describing mainly the observations and the real time processing of the SN search data, which makes use of the ING's integrated data flow system.

Very little is currently known about the behaviour of SNe in a starburst environment. The enhanced metallicity in starburst regions is expected to result in large mass-loss rates (Vink et al., 2001) for the SN progenitor stars. In addition, many of these events are expected to occur within molecular clouds (Chevalier & Fransson, 2001), adding further to the density of material surrounding the SN. Therefore, nuclear SNe can be expected to explode within a dense circumstellar medium. In general, a dense (but non-nuclear) circumstellar environment has been observed to produce bright CCSNe with slow near-IR light decline rates (e.g. SN 1998S, Fassia et al., 2000). However, the behaviour of SNe in nuclear starburst regions may be much more extreme (Terlevich et al., 1992). The high-*z* CCSN surveys with the VLT, HST and NGST (e.g., Dahlen & Fransson, 1999; Sullivan et al., 2000) will use SNe to probe the cosmic star formation rate. For this, it is important to determine (i) a better estimate of the *complete* local CCSN rate (cf. Sullivan et al., 2000), (ii) a proper understanding of the behaviour of SNe within the dusty, high-density starburst environment and (iii) the extinction towards these events.

Most of the CCSNe in young starbursts like M 82 (Figure 1; Mattila & Meikle, 2001, 2002) are expected to be heavily obscured by dust, and therefore remain undiscovered by current SN search programmes working at optical wavelengths. However, in the near-IR K_s-band the extinction is greatly reduced and the sensitivity of ground-based observations is still good. That is why we are using INGRID to carry out an imaging survey of the

~40 most luminous nearby ($d<45$ Mpc) starburst galaxies visible in the northern hemisphere. These galaxies have been selected to have far-IR luminosities greater than or comparable to those of the two prototypical starbursts, M 82 and NGC 253, but excluding galaxies whose far-IR luminosity is powered by a population of old stars or an AGN. The expected CCSN rates in these galaxies (Mattila & Meikle, 2001) range from around 0.05 yr^{-1} in NGC 253 ($L_{FIR}\sim10^{10.3}L_{\odot}$ and 0.2 yr^{-1} in NGC 4038/39 ($L_{FIR}\sim10^{10.8}L_{\odot}$) to around 1–2 CCSNe per year in Arp 299 ($L_{FIR}\sim10^{11.8}L_{\odot}$).

Since the average distance to our targets is ~30 Mpc, most of them fit well within one quadrant of the INGRID detector (2 arcmin×2 arcmin). This enables us to observe most of the target galaxies using the *quadrant jitter* method in which the galaxy nucleus is placed in the middle of each quadrant of the array in turn. As the three other quadrants contain "empty" sky, the actual target frames can be used to create a sky frame for each of the galaxies and a sky flat field frame for the whole night. Thus, there is generally no need for offset sky images. This improves the observing efficiency allowing 2–3 galaxies to be observed per hour (with 10–20 minutes on-source exposure time each). The catch of a clear night is therefore 20–30 galaxy images in which nuclear CCSNe might be hiding. In Figure 2 we show four individual frames and the final combined frame of Arp 299, a luminous infrared galaxy at a distance of 45 Mpc, as an example of a *quadrant jitter* observation. In Figure 3 the K_s image of another sample galaxy is shown, NGC 4038/39 (the Antennae, distance 20 Mpc). In general, to increase the number of frames and thus the total on-source exposure time per galaxy we perform a 4-point dither on each of the quadrants in turn. Therefore, a full quadrant jittering cycle produces typically 16 frames per galaxy, all with different offsets. When creating a sky frame the quadrants in which the galaxy is known to be are masked out. Thus the number of pixels which are median-combined to form a sky frame is 12. The observing procedure is simplified by the use of scripts which control the telescope/data acquisition sequence. The target quadrant identification is encoded into the object string in the image header, for subsequent use by the data pipeline.

The full sampling of the seeing disk (FWHM ~ 0.7") by INGRID (0.24"/pixel) allows us to compare the reduced galaxy images to reference frames obtained earlier, using image subtraction. For this we use the Optimal Image Subtraction method (Alard & Lupton, 1998; Alard, 2000) which derives a convolution kernel to match the better seeing image to the image with the poorer seeing. It also matches the background differences. In Figure 4 we show an example of image subtraction using a pair of images of NGC 253 (distance ~3 Mpc) observed under different seeing and photometric conditions in August 2001 (FWHM = 0.9") and January 2002 (FWHM = 1.1"). Here, 21 different 5.7"×5.7" regions automatically selected by the image subtraction program were used for deriving the convolution kernel. The spatial variations of the INGRID PSF were modelled with a 2nd order polynomial and the differential background variations with a 1st order polynomial. The subtraction residuals are very small except for the two bright stars visible in the north-east and south-west from the nucleus. When the image subtraction is carried out with a constant kernel solution using just one

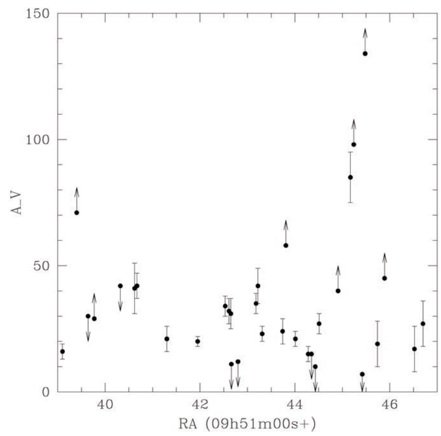

Figure 1. Extinctions (A_V) towards 33 SNRs in M 82 (from Mattila & Meikle, 2001, 2002).

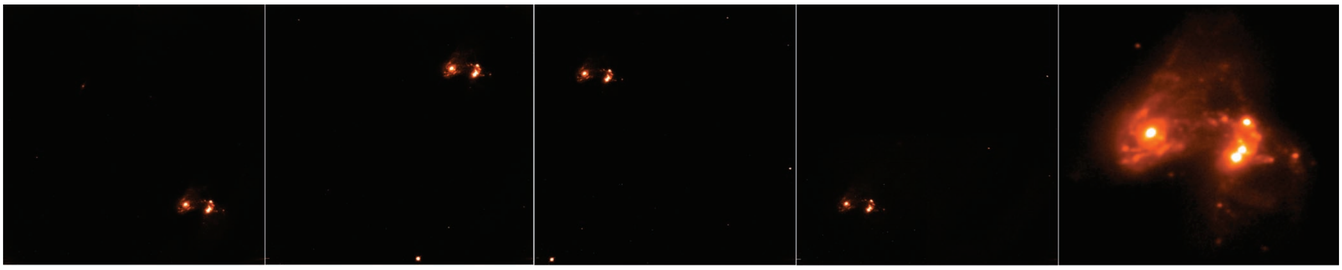

Figure 2. K_s band images of Apr 299 (North is up and East to the left) obtained with INGRID at the WHT on January 2nd, 2002. Four quadrant jitter frames with 10×6 sec. exposure time are shown on the left, and the combined frame formed from 32 individual frames (32 minutes total exposure time) on the right. The intensity in the combined frame has a square root scaling.

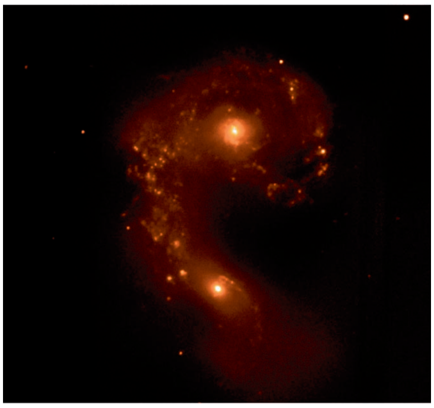

Figure 3. K_s band image of the Antennae, NGC 4038/39 (North is up and East to the left) obtained with INGRID at the WHT on January 2nd, 2002 (640 second exposure time).

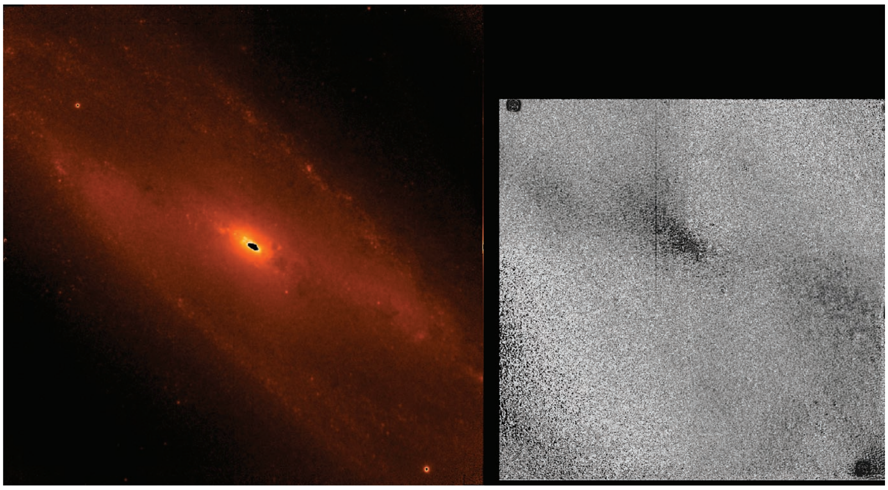

Figure 4. K_s band image of NGC 253 (North is up and East to the left) obtained with INGRID at the WHT on August 31st, 2001 (300 second exposure time) is shown with a square root intensity scaling on the left. The result of image matching and subtraction is shown on the right.

region centred on the galaxy nucleus for deriving the kernel, a slight PSF variation between the frames over the INGRID field of view (4 arcmin× 4 arcmin) is visible. Such relative PSF variations can be caused by e.g. differential rotation between the two frames (Alard, 2000) as a result of imperfect image registration. More image subtraction examples and starburst galaxy images can be found at `http://astro.ic.ac.uk/nSN.html`.

The quick, effective reduction and analysis of the SN search data is essential for this programme to succeed. Therefore, the INGRID data taken in this project are pipeline-processed in near-real time at the telescope (see Figure 5). The IRAF-based pipeline runs on one of the Beowulf clusters at the telescope (Greimel et al., 2001). At the beginning of the observing run, calibration data is taken to generate a bad pixel mask and a dome flat field for the image processing. When a new image is taken by the Data Acquisition System it is automatically copied to the cluster and the post-pre image subtraction is done. An image grouping task then waits until all the exposures for a given galaxy have been taken before feeding the list of exposures to the next step. Once all the images for one object are on the cluster they are combined to give an initial sky frame. The images and the initial sky frame are then fed into a modified de-dithering routine (`idedither_qd`) from the INGRID quicklook package (`ingrid_ql`) in which the images are registered on a user defined star (this will be automated in future); a final sky image is created based on quadrant masking; then every image is sky subtracted, bad pixel masked and flat fielded; and the processed images are finally combined. The last processing step is to apply a World Coordinate System (WCS) solution based on the USNO catalogue to the combined image. At this point a data analysis task takes over. The new image of the object is compared with an archived image from previous runs. The rotation, shift and scaling are calculated for the image, based on user-selected stars. In the future this will be automatically done based on the WCS solution. The final step in the data analysis is the image subtraction using the Optimal Image subtraction software (ISIS) as described above. The subtracted images are then inspected by eye. In addition, the fully reduced search images are compared to the existing reference images by blinking. Apart from automating the various pipeline steps, we are also working on the implementation of a web-based interface for the pipeline which will allow easy steering of the pipeline as well as immediate access to the data by off-site collaborators. Having acquired a complete set of INGRID reference images we estimate a probable discovery rate of between 0.4 and 0.8 SNe in each clear night's observations (see Mattila & Meikle, 2001, 2002). The newly developed data processing pipeline for the on-going nuclear CCSN search on the WHT enables an easy real-time analysis of the search data. This is essential for the rapid follow-up observations of discovered SNe, in order to determine the nature of these events. Near-IR (*JHK*) photometry and spectra will probe both the conditions in the immediate circumstellar/interstellar environment of the SN and the line-of-sight extinction towards the SN. A large amount of near-IR imaging data still needs to be collected if we are to detect a sufficient number of obscured SNe to derive a statistically significant SN rate in nearby starburst galaxies. Therefore, we invite any observers who will be acquiring or have recently acquired *K*-band data of luminous nearby starburst galaxies to take part in the Nuclear SN search. Full details of this, and contact information, are given on the 'Nuclear SN Search' pages at `http://astro.ic.ac.uk/nSN.html`

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