LIRIS Discovers Supernovae in Starburst Galaxies

S. Mattila (Stockholm Observatory), R. Greimel (ING), P. Meikle (Imperial College, London)

In the nuclear regions of M82 and other nearby starburst galaxies one core-collapse supernova (CCSN) is expected to explode every 5–10 years. Furthermore, in luminous infrared galaxies (LIRGs) such as the interacting system Arp299 (NGC3690 + IC0694) at least one CCSN can be expected every year. However, due to the high dust extinction astronomers have been unable to detect these SNe. By observing in the near-IR *Ks*-band the extinction is strongly reduced, making searches for such dust obscured SNe look feasible (Mattila & Meikle, 2001). In fact, recent near-IR searches have been able to detect a couple of SNe in starburst galaxies (Van Buren et al., 1994; Maiolino et al., 2002). These are however only extinguished by a few of magnitudes in the visual wavelengths (Mattila, Meikle & Greimel, 2004). Now also the newly commissioned near-IR imager LIRIS on WHT has discovered two new SNe within the nuclear regions of Arp299 and NGC2146.

We have been carrying-out a near-IR *Ks*-band search campaign for SNe obscured by dust in the nuclear regions of nearby starburst galaxies with the William Herschel Telescope (WHT) since August 2001. Initially, the search started using the INGRID near-IR imager (for details see Mattila et al., 2002a). In March 2004 observations with LIRIS commenced. By that time the search had only produced the detection of a possible SN (Mattila et al., 2002b) in old images making any follow-up observations and definite confirmation of this SN impossible. We estimated that the lack of SN detections from the INGRID SN search database indicates an average extinction towards the nuclear SNe exceeding $A_V = 10$ (see Mattila, Meikle & Greimel, 2004). Such high extinctions would certainly be expected for most of the SNe within the nuclear regions of starburst galaxies such as M82 (see Mattila & Meikle, 2001).

Already on the first run on 6 March 2004 LIRIS observed a SN, SN 2004am, within the nuclear regions (~500 pc) in one of our primary targets, M82. The discovery of this event, however, had already been reported (Singer, Pugh & Li, 2004) just one day before our LIRIS observation. Our 0.89–1.53-micron LIRIS spectrum showed broad (FWHM ~2800 km/s) hydrogen lines demonstrating that this was a type II event (Mattila et al., 2004). The LIRIS *JHKs* images show a moderately reddened source exactly coincident with a bright starburst knot within the nuclear regions of M82. The optical-near-IR colours also showed that the extinction towards this SN was $A_V \sim 5$. In Figure 1, a *JHKs* image of M82 (+SN2004am) observed by LIRIS as a part of our monitoring campaign on 2004 Nov 25 is shown together with a subtracted *Ks*-band image clearly showing the location of the SN. Note that by this time the SN had already dimmed considerably.

Our most recent LIRIS run on 2005 January 30 has, at last, produced discoveries of subsequently confirmed SN events in the interacting luminous infrared galaxy Arp299 (distance ~45 Mpc) and in the nearby starburst galaxy NGC2146 (distance ~13 Mpc). Both Arp299 and NGC2146 have high expected CCSN rates of ~1–2 and ~0.2 SNe per year, respectively, as indicated by their far-IR luminosities (Mattila & Meikle, 2001). SN 2005U (Mattila et al., 2005a), with m(*Ks*)= 16.2, was discovered at 3.7" west and 4.9" south of (or 1.3 kpc from) the *Ks*-band nucleus A (Gehrz et al., 1983) of Arp299 (see Figure 2). A couple of days later it was classified as a type II within a few weeks past explosion (Modjaz et al., 2005). The near-IR colour of the SN estimated from our LIRIS images, $J-K = +0.4 \pm 0.5$, indicates an extinction of $A_V \sim 4$ towards the SN. Another SN, SN 2005V (Mattila et al., 2005b), was also discovered by LIRIS on the same night. SN 2005V has a magnitude of m(*Ks*)= 13.8, and is located at 1.8" east and 3.4" north of (or 330 pc from) the *Ks*-band nucleus of NGC 2146 (Figure 3). On February 1, it was spectroscopically classified as a type Ib/c SN, about 1–2 weeks past maximum light (Taubenberger & Pastorello, 2005). The near-IR colours from LIRIS, $J-H = +0.13 \pm 0.33$ and $H-K = +0.18 \pm 0.34$, indicate an extinction of $A_V \sim 3-4$ towards SN 2005V.

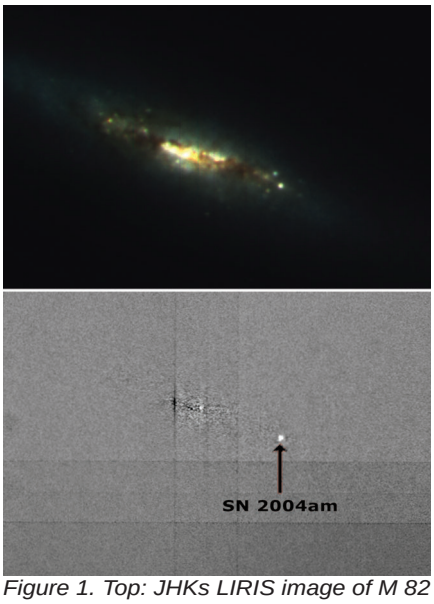

Figure 1. Top: JHKs LIRIS image of M 82 (+ SN 2004am) observed on 2004 Nov 25. Bottom: The result of alignment, image matching and subtraction (Alard, 2000) between LIRIS Ks band images from March 2004 and November 2004.

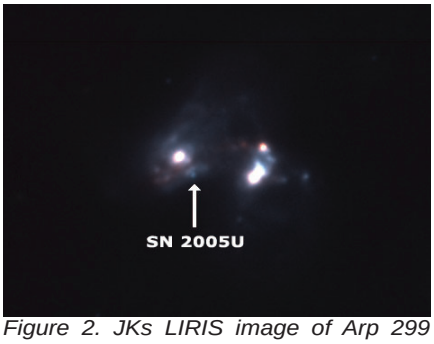

Figure 2. JKs LIRIS image of Arp 299 (+SN 2005U) observed on 2005 Jan 30.

In Figure 4, a LIRIS *Ks*-band image of the Antennae (NGC 4038/9) is shown. This image obtained on 2005 January 30 shows also SN 2004gt located within the circumnuclear regions of the galaxy. The SN is clearly

visible in the subtracted image. However, SN 2004gt had already been discovered optically on 2004 December 12 (Monard, 2004), and therefore is likely to have a modest extinction. It has been spectroscopically classified as a type Ib/c (Kinugasa et al., 2004; Ganeshalingam et al., 2004).

Our combined INGRID and LIRIS SN search database now includes repeat images for 40 nearby starburst galaxies, on average ~4.3 epochs per target. However, the nuclear SN detection efficiency falls rapidly as the seeing quality declines. Therefore, the depth of the search varies strongly between the images with different seeings. During the search there have been four confirmed CCSN events

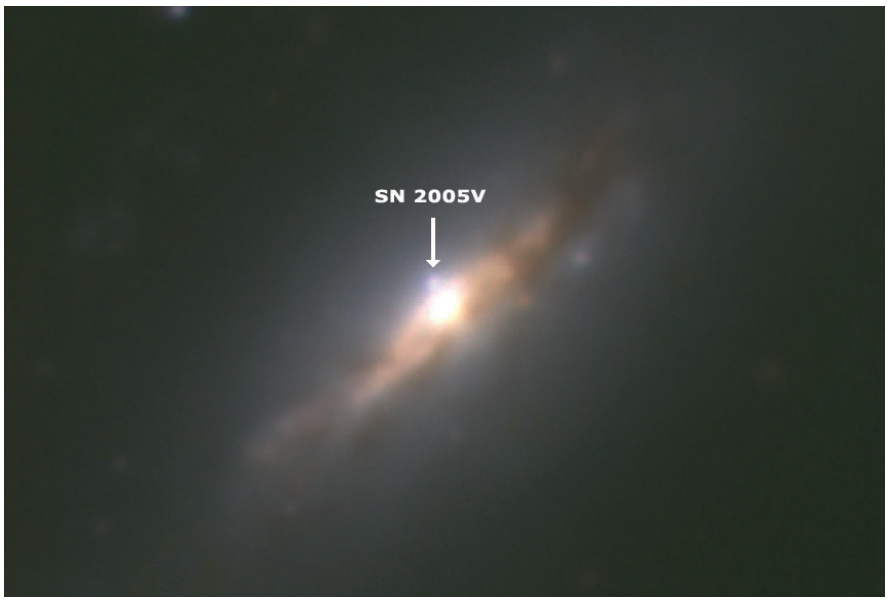

Figure 3. JHKs LIRIS image of NGC 2146 (+SN 2005V) observed on 2005 Jan 30.

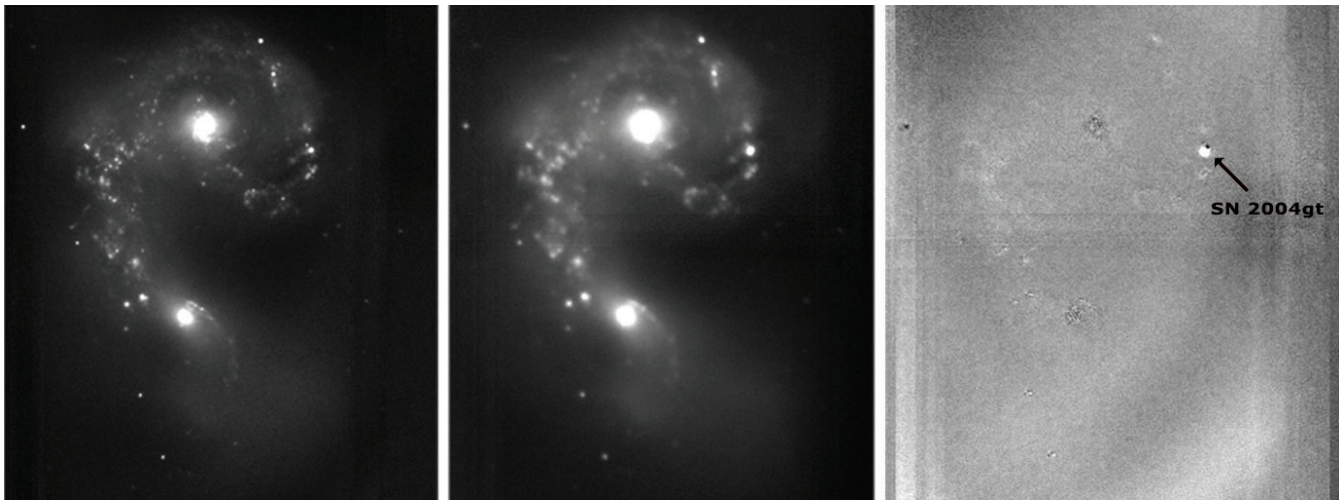

Figure 4. Left: Ks band INGRID image of the Antennae (NGC 4038/9) observed on 2002 January 3 with ~0.8" seeing. Middle: Ks band LIRIS image of Antennae (+SN 2004gt) observed on 2005 January 30 with ~1.6" seeing. Right: The result of alignment, image matching and subtraction between INGRID and LIRIS images using the Optimal Image Subtraction method (Alard, 2000).

discovered in our starburst galaxy sample, two of which were discovered by us. In addition, we have a number of unconfirmed possible SNe present in our *Ks*-band data. All these were detected in old images, and therefore no optical/near-IR follow-up was possible. Although, several CCSNe have now been discovered in starburst galaxies at near-IR wavelengths, they are all extinguished by only a few magnitudes in A_V. The expected population of highly extinguished supernovae within the nuclear regions of starburst galaxies therefore still remains unrevealed. The final conclusion from our study will require extensive statistical analysis of the near-IR SN search database. This is now underway (Mattila et al., in prep.).

The WHT 'Nuclear SN search' (`http://astro.imperial.ac.uk/nSN.html`) team also includes Stuart Ryder, Nic Walton, and Bob Joseph. We thank Chris Gerardy, Per Gröningsson, and Rubina Kotak for taking part in some of the observing runs. ¤

References:

Alard, C., 2000, *A&AS*, **144**, 363.

Ganeshalingam, M., Swift, B. J., Filippenko, A. V., 2004, *IAU Circ*, 8456.

Gehrz, R. D., Sramek, R. A., Weedman, D. W., 1983, *ApJ*, **267**, 551.

Kinugasa, K., Kawakita, H., Yamaoka, H., 2004, *IAU Circ*, 8456.

Maiolino, R., Vanzi, L., Mannucci, F., et al., 2002, *A&A*, **389**, 84.

Mattila, S., Meikle, W. P. S., 2001, *MNRAS*, **324**, 325.

Mattila, S., Greimel, R., Meikle, W. P. S., et al., 2002a, *ING Newsl*, **6**, 6.

Mattila, S., et al., 2002b, *IAU Circ*, 7865.

Mattila, S., et al., 2004, *IAU Circ*, 8299.

Mattila, S., Meikle, W. P. S., Greimel R., 2004, *New Astron Rev*, **48**, 595.

Mattila, S., Greimel, R., Gerardy, C., Meikle, W. P. S., 2005a, *IAU Circ*, 8473.

Mattila, S., Greimel, R., Gerardy, C., Meikle, W. P. S., 2005b, *IAU Circ*, 8474.

Modjaz, M., Kirshner, R., Challis, P., 2005, *IAU Circ*, 8475.

Monard, L. A. G., 2004, *IAU Circ*, 8454.

Singer, D., Pugh, H., Li, W., 2004, *IAU Circ*, 8297.

Taubenberger, S., Pastorello, A., 2005, *IAU Circ*, 8474.

Van Buren, D., Jarrett, T., Terebey S., et al., 1994, *IAU Circ*, 5960.

Seppo Mattila (seppo@astro.su.se)