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# A NICMOS search for obscured supernovae in starburst galaxies*

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**ABSTRACT**

The detection of obscured supernovae (SNe) in near-infrared monitoring campaigns of starburst galaxies has shown that a significant fraction of SNe is missed by optical surveys. However, the number of SNe detected in ground-based near-IR observations is still significantly lower than the number of SNe extrapolated from the FIR luminosity of the hosts. A possibility is that most SNe occur within the nuclear regions, where the limited angular resolution of ground-based observations prevents their detection. This issue prompted us to exploit the superior angular resolution of NICMOS-HST to search for obscured SNe within the first kpc from the nucleus of strong starbursting galaxies. A total of 17 galaxies were observed in SNAPSHOT mode. Based on their FIR luminosity, we did not expect to detect fewer than ~12 SNe. However, no confirmed SN event was found. From our data we derived an observed nuclear SN rate <0.5 SN/yr per galaxy. The shortage of SN detections can be explained by a combination of several effects. The most important are: i) the existence of a strong extinction, $A_V \gtrsim 11$; ii) most SNe occur within the first 0.5″ (which corresponds in our sample to about 500 pc) where even NICMOS is unable to detect SN events.

**Key words.** stars: supernovae: general – galaxies: starburst – infrared: galaxies

## 1. Introduction

Current measurements of supernova (SN) rate are entirely based on events detected during surveys carried out at the optical wavelengths. This constitutes a problem, since many SNe could be obscured by dust. As a consequence, the derived SN rates may be only lower limits, especially for core-collapse and Ia "prompt" SNe (Mannucci et al. 2005, 2006) in the distant universe. As an example, we point out that several monitoring campaigns of starburst galaxies, carried out at optical wavelengths, do not show evidence of an enhanced SN rate with respect to normal quiescent galaxies (e.g. Richmond et al. 1998; Navasardyan et al. 2001). Near-infrared (near-IR) observations can shed light on this problem, as the extinction at these wavelengths is about ten times lower than in the optical. The importance of near-IR was demonstrated by Maiolino et al. (2002), who showed, on the basis of a small sample of SNe detected in the near-IR, that the rate of supernovae measured in the optical could be significantly reduced by dust extinction up to an order of magnitude.

During the past decade other near-IR searches for extincted SNe were attempted. Van Buren et al. (1994) detected SN1992bu (a possible SN but not spectroscopically confirmed). Grossan et al. (1999) monitored a large number of galaxies over two years, but failed to detect extinguished SNe, probably because of their poor spatial resolution. Bregman et al. (2000) searched for line emission at longer wavelengths (6.63 $\mu$m using ISOCAM), but did not detected any feature connected with SN events. More recently, Mattila et al. (2005a,b) discovered two SNe during their monitoring in Ks band with the William Herschel Telescope. Di Paola et al. (2002) reported the near-IR serendipitous discovery of SN2002cv, a highly extincted ($A_V \sim 8$) type Ia SN. In late 1999 Mannucci et al. (2003) started a $K'$-band monitoring campaign of a sample of 46 Luminous Infrared Galaxies (LIRGs, $L_{FIR} > 10^{11}\ L_\odot$), aimed at detecting obscured SNe in the most powerful starbursting galaxies. During the monitoring 4 SNe were detected, two of which were discovered by our group: SN1999gw (Cresci et al. 2002) and SN2001db, the first SN detected in the near-IR which has received a spectroscopic confirmation (Maiolino et al. 2002).

The number of detected events was about an order of magnitude higher than expected from the $B$ band luminosity of the parent galaxies (Cappellaro et al. 1999), showing that the $B$ band luminosity cannot be used to trace the star formation in starburst galaxies. Although these results highlight the capability of near-IR observations to reveal obscured SNe, otherwise missed in classical optical surveys, Mannucci et al. (2003) also showed that the inferred SN rate was still 3–10 times lower than that expected from the far-infrared (FIR) luminosity of the galaxies of the sample. A possible explanation for the shortage of near-IR SNe is the presence of dust extinction $A_V > 25$ mag, which would make SNe heavily obscured even in the near-IR. Another reason could be the reduced capability of ground-based observations to detect SNe within the first 2″ from the galactic nuclei. The reduced sensitivity in the nuclear region is a direct consequence of the presence of the residuals, which are obtained during the images subtraction (see Mannucci et al. 2003 for details).

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**Table 1.** The galaxy sample.

| Galaxy | RA (J2000) | Dec | $\mathcal{L}_{FIR}$ | $z$ |
|---|---|---|---|---|
| NGC 34 | 00h11m06.5s | −12d06m26s | 11.43 | 0.020 |
| NGC 1614 | 04h33m59.8s | −08d34m44s | 11.41 | 0.016 |
| VII-ZW031 | 05h16m47.3s | +79d40m12s | 11.94 | 0.053 |
| IRAS 05189-2524 | 05h21m01.4s | −25d21m45s | 11.89 | 0.042 |
| IRAS 08572+3915 | 09h00m25.4s | +39d03m54s | 11.99 | 0.058 |
| UGC 5101 | 09h35m51.4s | +61d21m11s | 11.90 | 0.039 |
| NGC 3256 | 10h25m51.8s | −43d54m09s | 11.44 | 0.009 |
| IRAS 10565+2448 | 10h59m18.1s | +24d32m34s | 11.87 | 0.042 |
| NGC 3690 | 11h28m31.9s | +58d33m45s | 11.72 | 0.011 |
| NGC 4418 | 12h26m54.6s | −00d52m39s | 11.00 | 0.007 |
| Mrk 273 | 13h44m42.1s | +55d53m13s | 12.10 | 0.038 |
| UGC 8782 | 13h52m17.7s | +31d26m44s | 12.27 | 0.045 |
| IRAS 14348-1447 | 14h37m38.2s | −15d00m26s | 12.27 | 0.082 |
| Arp 220 | 15h34m57.3s | +23d30m12s | 12.12 | 0.018 |
| NGC 6090 | 16h11m40.3s | +52d27m26s | 11.35 | 0.029 |
| IRAS 20414-1651 | 20h13m29.4s | −16d40m16s | 11.99 | 0.087 |
| IRAS 23128-5919 | 23h15m46.8s | −59d03m14s | 11.80 | 0.044 |

Note: the RA and Dec position reported correspond to the optical center of the galaxies; $\mathcal{L}_{FIR}$ is $\log(L_{FIR}/L_{\odot})$ (Mannucci et al. 2003, where $L_{FIR}$ is defined accordingly to Helou et al. 1988 as the luminosity between 42.5 to 122.5 $\mu$m); $z$ is the redshift.

Even if 2″ corresponds to a relatively small region for the host, it could contain most of the star-formation activity and produce most of the near-IR flux (Soifer et al. 2000; Soifer et al. 2001). If most SNe are really lost in the nuclear regions, one can explain the shortage of SN detections without calling for a large near-IR extinction.

In this paper we present a near-IR search for nuclear SNe exploiting the superior angular resolution of NICMOS-HST. The ability of NICMOS to search for nuclear obscured SNe, the observations and data reduction will be presented in the following section; in Sect. 3 we derive the expected number of SNe in our data, which is compared to the results obtained in Sect. 4. Our conclusions follow in Sect. 5.

## 2. The use of NICMOS to search for nuclear obscured SNe

The HST near-IR camera NICMOS is an excellent tool for searching for obscured nuclear SNe in starburst galaxies, since it joins high sensitivity in the near-IR, where the dust extinction is greatly reduced, to a high angular resolution (0.2″) and stable PSF, allowing for a much easier detection of SNe close to the nucleus in the difference image.

We selected a sample of 35 Luminous and Ultraluminous Infrared Galaxies (LIRGs and ULIRGs) closer than about 450 Mpc ($z \leq 0.1$) and already observed once with NICMOS in the *F160W* filter with the NIC2 camera, so that a first-epoch image was already available. We then obtained a second epoch in SNAPSHOT mode for 16 of the selected galaxies. For one galaxy, NGC 34, we compared two images at different epochs that are already present in the archive (see Table 2) The list of these 17 galaxies is given in Table 1, along with their far-IR flux and redshift, while the relative observational setups are given in Table 2. Images were reduced by using the *On The Fly Reprocessing* system of the HST archive (Swam et al. 2001).

The comparison of the images was in fact performed with ISIS, a tool developed by Alard & Lupton (1998) and refined by Alard (2000). The images are aligned using field stars, then the image with the best PSF is selected as a reference to be compared with all other frames of the galaxy. In order to correct the effects of the variable PSF, the reference image is convolved with an appropriate kernel determined by a least-square fit. The images are then normalized in flux and subtracted. Typically we were able to subtract 98% of the galaxy flux.

Although the NICMOS PSF is much stabler than in ground-based images, the results of the subtraction of NICMOS images are still affected by residuals in the nuclear regions, but on a smaller scale. The residuals are brighter where the emission has a strong radial gradient and non circular structures (such as the diffraction spikes of the spider arms that are not reproduced very well even by the complex ISIS kernel). The presence of residuals is due to the HST PSF variations on a long time scale (e.g. Krist & Hook 1997) and to the different orientation of the diffraction spikes due to the different roll angle of HST at the various epochs of observation. As a consequence, the limiting magnitude for poin-source detection is much brighter than expected from the photon noise, and it is strongly dependent on the location and on the distance from the galactic center, as the subtraction residuals are concentrated in the nuclear regions of the galaxies.

For each galaxy we have evaluated two different limiting magnitudes, $\mathrm{Mag}_L$(in), in the region of the galaxy affected by the residuals of the subtraction (between 0.5″ and 1.35″ from the nucleus, on average) and $\mathrm{Mag}_L$(out) in the outer parts. The SN detection limit was estimated through simulations, by adding artificial stars to the original images before image subtraction. The artificial stars were added at random locations, respectively inside and outside the circular aperture around the nucleus were significant residuals of the subtraction are visible, and with different luminosities. The inferred limiting magnitudes for SN detection, defined as the completeness level of 90%, are listed in Table 2. However, the limiting magnitude is strongly dependent on the particular location inside the circular area around the nucleus, due to the presence of stronger residuals corresponding to the diffraction spikes or to secondary nuclei of the galaxies. As an example, in Fig. 1 we report the results of our SN recovering completeness simulations inside the circular area around the nucleus in ARP 220. Although some SNe are lost in correspondence with the strongest residuals at the most conservative $\mathrm{Mag}_L$(in) = 19.0, much dimmer sources are still detectable at different locations, such as the possible SN observed in this galaxy which was detected with $H = 20.5$ (see Appendix).

In the following, the number of expected SNe is evaluated using both $\mathrm{Mag}_L$(out) and the more conservative limiting magnitude $\mathrm{Mag}_L$(in), relative to the nuclear regions of the galaxies where most of the starburst activity is expected to be hosted.

Furthermore the ISIS kernel, which is used to convolve one of the images in order to correct the effects of the variable PSF, was derived in regions around the brightest objects in the field. Since only a few field stars were present in the field of view, we were forced to include the galactic nucleus so as to properly evaluate the PSF and to obtain a good subtraction over the whole field. Unfortunately, this method prevented us discovering the innermost SNe. We estimated the size of the non-detectability region by simulations: bright point sources ($m_H = 16.5$) were added to the nuclear regions of the original images and then recovered after subtracting with ISIS. The size of the region where SNe cannot be detected is given in Table 2.

Although the detection of very nuclear SNe (within the central ~0.5″, corresponding to about 200–600 pc for our galaxy sample) is still impossible even with NICMOS, there is a significant improvement compared to ground-based observations, where strong residuals prevent the detection of even bright SNe ($m_K < 17$) within the central 2″−3″.

**Table 2.** Summary of the first epoch archive image and second epoch new NICMOS observation.

| Galaxy | First epoch | | Second epoch | | Comparison | | |
|---|---|---|---|---|---|---|---|
| | Date | Exp. Time (s) | Date | Exp. Time (s) | $Mag_L$(in) | $Mag_L$(out) | Non-Det. Radius |
| NGC 34 | 1997 Dec. 2 | 255.98 | 1998 Oct. 11 | 255.98 | 17.8 | 20.2 | 0.45″ |
| NGC 1614 | 1998 Feb. 07 | 383.85 | 2004 Gen 05 | 599.44 | 17.0 | 20.7 | 0.68″ |
| VII-ZW031 | 1997 Nov. 17 | 599.44 | 2003 Dec. 31 | 599.44 | 19.0 | 21.5 | 0.52″ |
| IRAS 05189-2524 | 1997 Dec. 09 | 223.76 | 2003 Sep. 29 | 599.44 | 17.6 | 21.4 | 0.38″ |
| IRAS 08572+3915 | 1997 Nov. 11 | 159.81 | 2004 Mar. 17 | 599.44 | 20.2 | 20.7 | 0.30″ |
| UGC 5101 | 1997 Nov. 07 | 559.48 | 2004 Feb. 07 | 599.44 | 18.6 | 21.3 | 0.52″ |
| NGC 3256 | 1997 Nov. 28 | 191.83 | 2003 Nov. 17 | 599.44 | 18.3 | 20.8 | 0.30″ |
| IRAS 10565+2448 | 1997 Nov. 29 | 479.54 | 2003 Nov. 11 | 599.44 | 19.1 | 21.2 | 0.45″ |
| NGC 3690-N1 | 1997 Nov. 04 | 207.80 | 2003 Sep. 02 | 599.44 | 19.0 | 20.8 | 0.45″ |
| NGC 3690-N2 | 1997 Nov. 29 | 207.80 | 2003 Sep. 02 | 599.44 | 18.5 | 20.7 | 0.52″ |
| NGC 4418 | 1997 Nov. 26 | 351.66 | 2004 Apr. 26 | 599.44 | 19.1 | 21.0 | 0.60″ |
| Mrk 273 | 1997 Dec. 10 | 255.73 | 2004 May. 11 | 599.44 | 18.8 | 21.0 | 0.38″ |
| UGC 8782 | 1998 Aug. 19 | 2175.8 | 2004 Mar. 17 | 599.44 | 19.6 | 21.9 | 0.52″ |
| IRAS 14348-1447 | 1998 Jul. 09 | 479.54 | 2004 Apr. 23 | 599.44 | 19.5 | 21.2 | 0.45″ |
| Arp 220 | 1997 Apr. 04 | 1023.0 | 2004 Jan. 10 | 599.44 | 19.0 | 21.2 | 0.35″ |
| NGC 6090 | 1997 Nov. 10 | 383.63 | 2003 Dec. 01 | 599.44 | 18.8 | 21.3 | 0.45″ |
| IRAS 20414-1651 | 1998 Jul. 01 | 639.85 | 2003 Oct. 24 | 599.44 | 21.3 | 21.5 | 0.45″ |
| IRAS 23128-5919 | 1998 Mar. 08 | 639.85 | 2003 Oct. 13 | 599.44 | 18.9 | 21.8 | 0.52″ |

Note: *Exp. Time* is the exposure time in second used for that image. *$Mag_L$* the limiting magnitude obtained in the subtraction in the region of the galaxy interested by the subtraction residuals (in) and in the outer parts (out); *Non-Det. Radius* the radius of the central region where the detection of SNe is not possible.

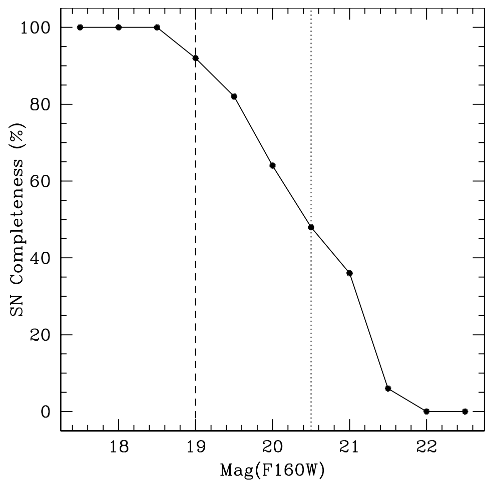


**Fig. 1.** Example of SN recovering simulations for the circular regions 1.35″ around the nucleus in ARP 220. Although some SN are lost in correspondence with the strongest residuals at the most conservative $Mag_L(in) = 19.0$ (dashed line), corresponding to the 90% recovering completeness in this region, much dimmer sources are still detectable at different locations, such as the possible SN discussed in Appendix which was detected with $H = 20.5$ (dotted line).

## 3. Expected number of SNe

According to the relation provided by Mannucci et al. (2003), the expected number of SNe in each galaxy every 100 yr is given by

$$SNe_{FIR} = (2.4 \pm 0.1)\, \frac{L_{FIR}}{10^{10}\, L_{\odot}}\, \frac{SN}{100\ yr}, \qquad (1)$$

as a function of the far-IR luminosity $L_{FIR}$ of the host galaxy.

For each galaxy we computed the control time (the amount of time in which a SN is expected to be brighter than the detection limit in each of our images) by using the limiting magnitudes in Table 2 and the mean $H$-band light curve for core-collapse SNe derived by Mattila & Meikle (2001). The control time in each image is defined as the amount of time the $H$-band light curve of a SN, at the distance of the galaxy, is brighter than our detection limit. Using the FIR flux of each galaxy and the derived control time, Eq. (1) yields (after assuming no extinction)

$$SN_{expt}(out) = 26.8 \pm 4.9,$$

by using the limiting magnitude outside the subtraction residuals, and

$$SN_{expt}(in) = 12.6 \pm 4.7,$$

after assuming the more conservative limiting magnitude in the nuclear regions. The uncertainty on the expected number of SNe is dominated by the large intrinsic dispersion of the SN light curves in the near-IR, while uncertainties due to the the limiting magnitude estimates and the use of Eq. (1) are negligible. Therefore the error bars correspond to an upper and a lower limit for the number of events, as expected when using as reference the light curves corresponding, respectively, to the brighter and fainter envelopes of the $H$-band SN light curves. The control time and the number of expected events for the two images of each galaxy are listed in Table 3.

## 4. Results and implications

Despite the high number of SNe expected in the NICMOS imaging of our sample, only a possible candidate was discovered in Arp 220, as discussed in Appendix. This corresponds to an observed rate over the full sample that is lower than

$$SN_{obs} < \frac{N_{obs}^{max}(90\%)}{CT(in)} = \frac{3.89\ SN}{7.8\ yr} = 0.5\ SN/yr, \qquad (2)$$

where $N_{obs}^{max}(90\%)$ is the maximum number of SNe compatible with one detection at 90% confidence level, assuming Poisson statistics, and CT(in) is the total control time for the more conservative $Mag_L$(in) limiting magnitude.

**Table 3.** Expected SNe according to Eq. (1), using the mean *H*-band light curve for core-collapse SNe derived by Mattila & Meikle (2001) as a reference and when assuming no extinction. We report the expected number of events when using both $Mag_L$(out) and $Mag_L$(in) limiting magnitudes (see text). C-*Time* is the control time of our observations assuming the more conservative $Mag_L$(in).

| Galaxy | C-Time (days) | Exp. SNe $Mag_L$(out) | Exp. SNe $Mag_L$(in) |
|---|---|---|---|
| NGC 34 | 155.6 | 0.49 | 0.22 |
| NGC 1614 | 132.6 | 0.70 | 0.22 |
| VII-ZW031 | 79.4 | 1.56 | 0.45 |
| IRAS 05189-2524 | 10.8 | 1.56 | 0.05 |
| IRAS 08572+3915 | 156.4 | 1.25 | 1.00 |
| UGC 5101 | 98.6 | 1.60 | 0.51 |
| NGC 3256 | 331.8 | 0.95 | 0.60 |
| IRAS 10565+2448 | 121.8 | 1.38 | 0.59 |
| NGC 3690 | 311.8 | 1.61 | 1.08 |
| NGC 4418 | 428.6 | 0.38 | 0.28 |
| Mrk 273 | 120.2 | 2.40 | 0.99 |
| UGC 8782 | 153.2 | 4.04 | 1.88 |
| IRAS 14348-1447 | 43.2 | 2.13 | 0.53 |
| Arp 220 | 254.8 | 3.68 | 2.21 |
| NGC 6090 | 158.6 | 0.52 | 0.23 |
| IRAS 20414-1651 | 171.0 | 1.20 | 1.10 |
| IRAS 23128-5919 | 103.2 | 1.35 | 0.43 |
| All galaxies: | 7.8 yr | 26.8 | 12.4 |

The observed lack of SNe can be explained in several ways:

1. The FIR flux is dominated by obscured Active Galactic Nuclei (AGN). In this case most of the FIR luminosity would not be related to the star formation, but it would be AGN heated. Indeed some of the sources in our sample do host an AGN, as inferred from X-rays and optical spectra (e.g. UGC 5101, Mrk 231, NGC 3690). However, even in these cases most of the FIR luminosity appears to be dominated by the starburst component (Corbett et al. 2002; Thean et al. 2001; Genzel et al. 1997; Lutz et al. 1998; Clements et al. 2002).
2. Another possibility is based on underluminous SNe (e.g. Pastorello et al. 2004) may forming a significant fraction of all core-collapse events. If this is the case, these SNe would stay above our detection limit for a shorter time, thus decreasing the total control time in Table 3. However, even assuming that all SNe in our galaxies are underluminous, we still expect ~22 SNe using $Mag_L$(out) and ~8 using $Mag_L$(in) limiting magnitudes.
3. If most starburst activity is concentrated within the inner 200–300 parsec of the galaxy a large fraction of SN events would not have been detected in our images (last column of Table 2). It was indeed shown (e.g. Petrosian & Turatto 1990; Bressan et al. 2002) that active and star forming galaxies show a higher concentration of SNe toward the center than it is observed in normal galaxies. As discussed in detail in Mannucci et al. (2003), current data do not put tight constraints on the size of the starburst region in those galaxies. Smith et al. (1998), Rovilos et al. (2005) and Lonsdale et al. (2006) have monitored the central arcsec of the nucleus of Arp 220 with VLBI at 18 cm, with a resolution of a few milliarcsec, and they could in principle detect the SNe inside our "non-detection" zone. They revealed a few variable compact radio sources attributable to SN, and detected a total of 9 new sources in 9 years of observations, thus providing a radio SN rate of ~1 SN/yr. However, this value is still uncertain, as core-collapse SNe show a broad range of radio luminosities (e.g. Weiler et al. 2005). Similar results were obtained in NGC 3690 (Neff et al. 2004) and Mrk 273 (Bondi et al.2005), finding a nuclear rate between 0.5-1 SN/yr. After comparing these results with the "observed" rate of <0.5 SN/yr discussed in this paper, or even with an observed rate of <0.25 SN/yr as derived using $Mag_L$(out) instead of $Mag_L$(in) limiting magnitude, one can infer that at least some SNe have been lost in the IR because they occurred too close to the nucleus. However, the nuclear SN rate observed at radio wavelengths in these galaxies is only the 25% of the total rate expected from their FIR luminosity (see Table 3).
4. The most likely possibility is that many events are embedded in dust so deeply that they are highly extincted even in the near-IR. In order to compute the (average) $A_V$, we dimmed the template light curve with different amounts of extinction up to match one (or less) SN detection, at a formal confidence level of 90%. We obtained $A_V > 25$ and $A_V > 11$, after using $Mag_L$(out) and $Mag_L$(in), respectively, and assuming the standard Galactic extinction law (Rieke & Lebofsky 1985). If we include the candidate SN in Arp 220, the needed extinction decreases to $A_V > 22$ and $A_V > 9$. We noticed that such high extinctions are not unlikely to occur in these powerful starbursting systems (e.g. Genzel et al. 1997; Sturm et al. 1996).

## 5. Conclusions

We have presented the analysis of near-IR NICMOS-HST images for 17 galaxies, which were observed at two different epochs, with the goal of detecting nuclear-obscured SNe. This study was prompted by the shortage of SNe detected in near-IR monitoring campaigns of starburst galaxies and by the possibility that most of the missing SNe occur in the nuclear region, where the limited angular resolution of ground-based observations prevents their detection.

Taking advantage of the high angular resolution of NICMOS and its stable PSF, we were able to explore the central regions of starbursting galaxies to search for obscured SNe, up to about $0.5''$ from the nucleus and down to a limiting magnitude ranging from $H \sim 18.0$ in the very nuclear regions of the galaxies (closer than $\sim1''$ to the nucleus) to $H \sim 21$ farther away from the strongest subtraction residuals. This is a clear improvement with respect to ground-based searches that are limited to $\sim2-3''$ from the nucleus. Within a radius of $\sim0.45''$ from the center, even NICMOS is unable to reliably detect SNe. Our analysis found a possible SN in Arp 220, but due to its faintness and proximity to the nucleus we were not able to provide the spectroscopic confirmation of this event. From our data we have derived a nuclear SN rate ≤0.5 SN/yr per galaxy. The comparison with rates measured via radio-surveys suggests that some SNe occurring in the inner ~500 pc are lost. However, this is not enough to explain the discrepancy between the expected and observed number of SNe. We have discussed various possible explanations, the most likely of which is that in these starburst galaxies dust extinction is so high ($A_V \gtrsim 11-25$) to be effective in obscuring SNe even in the near-IR.

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## Appendix A: A possible supernova in Arp 220

A possible SN was discovered in ARP 220, the most active galaxy in our sample, observed on January 10th, 2004 (see

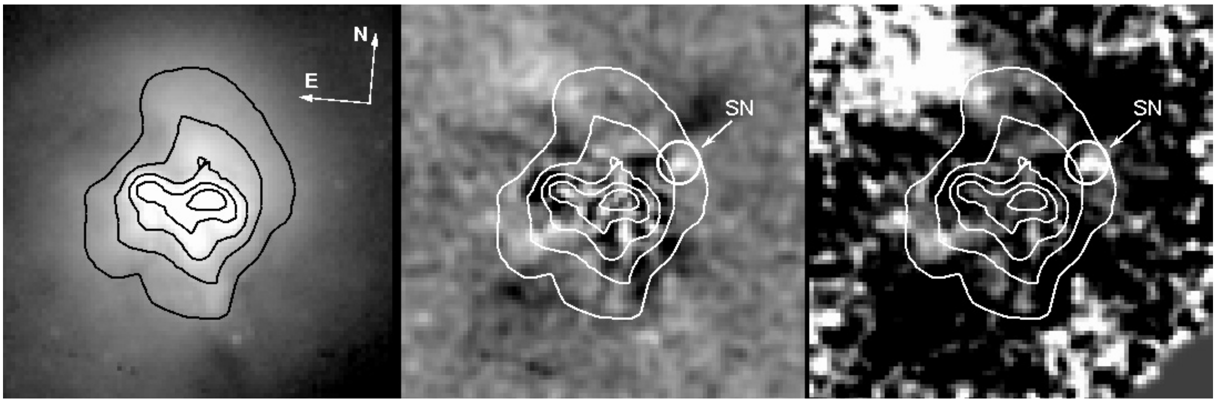


**Fig. A.1.** *Left panel*: the discovery image of a candidate SN in ARP 220, obtained with NICMOS on 10th January 2004. The box is about 6″ × 6″, *Middle panel*: the electronic subtraction with the archive image obtained in 1997. The subtraction was optimized by using a PSF-matching algorithm. The distance between the SN and the nucleus is only ∼1.1″ (SN location: RA 15:34:57.13; Dec. +23:30:12.0; J2000). *Right panel*: the subtraction divided by the original image, to show the fraction of residual flux. The color scale spans between −1% (black) to 3% (white) of the galaxy flux. The candidate SN contains about 4% of the galaxy flux at that location.

Fig. 1). It was found at 1.1″ from the brightest nucleus of the galaxy (SN location: RA 15:34:57.13; Dec. +23:30:12.0; J2000), and it might be the most nuclear SN ever discovered. It was detected as a positive residual after careful alignment, normalization, reduction to the same PSF, and subtraction of two images of the galaxy taken at different epochs. The SN was detected with a significance of 3.5$\sigma$ with respect to the background noise, and it results in a magnitude of $H \sim 20.5$. It is unlikely that the "bright spot" shown in Fig. A.1 is the result of an incorrect subtraction of the PSF. In fact, the luminosity of the SN candidate is about twice larger than the contribution of the PSF of the bright galactic nucleus computed at the position of the SN candidate. In addition, the candidate SN is located away from the bright PSF spikes (that cannot be perfectly subtracted due to their highly asymmetric shape), where the limiting magnitude is much higher than the most conservative $\mathrm{Mag}_L$(in) reported in Table 2. In fact, our simulation shows that an SN with $H = 20.5$ would be recoverable close to the candidate SN location with comparable S/N.

The absolute magnitude of the detected object is about $M_H = -13.8$, i.e. about 4 mag fainter than an average type II SN at maximum light. This may indicate that this SN was discovered at about 300 days from its maximum light, according to the template $H$-band light curve by Mattila & Meikle (2001). Alternatively, this SN could have been discovered near its maximum light, but it is a very extincted object, about 4 mag in the $H$ band, corresponding to $A_V = 23$.

We obtained spectroscopic follow-up of this object in the $J$ band using ISAAC at the VLT, with the low-resolution grism ($R = 500$) and a 1″ slit, in order to detect the broad lines typical of the nebular phase of an SN such as Pa$\beta$ and [CaII]$\lambda$7300, 8500 (see e.g. Maiolino et al. 2002). The spectrum was obtained on April 11, 2004, 3 months after detection. Although the spectrum exposure time of 1h42′ was chosen in order to have a clear detection of the SN features, assuming a source up to $H \sim 21.5$, the signal-to-noise of the spectrum was not sufficient to detect SN features over the bright galaxy spectrum. The non-detection may still be due to the long delay time between the HST discovery image and spectroscopic observations. In fact, an SN is expected to become ∼2 mag fainter in the three months occurred between the two observations in the near-IR, corresponding to $H \sim 22.5$. As a result the SN detection in ARP 220 remains tentative.

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