The Infrared Supernova Rate

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Summary. Optical searches can detect supernovae (SNe) only if they suffer of a limited amount of dust extinction. This is a severe limitation as most of the core-collapse SNe could explode inside dusty regions. We describe a few ongoing projects aimed at detecting dusty SNe at near-IR wavelengths both in ground-based and HST images and to study their properties.

1 The Problem

Supernovae (SNe) exploding inside dusty regions could dominate, even by a large amount, the number of core-collapse events in the universe, as most of the star-forming activity is hidden by dust. Nevertheless, centuries of optical searches have discovered only very few SNe in dusty regions and no very obscured event.

This is clearly a selection effect, and infrared or radio observations are needed to reveal highly obscured SNe. Events detected at these long wavelengths can be used to study the properties of the SNe in dusty galaxies, and to obtain a complete estimate of the total SN rate in the local universe, important to calibrate the SN rate at high redshift now under study. In principle the number of events could also be used to derive information on the main energy source (starburst vs. AGN) of the galaxies when they are dominated by a hidden central source, as for the Luminous Infrared Galaxies (LIRGS).

2 Optical vs. Near-Infrared

The observed rates of the core-collapse SNe, when derived from optical observations and normalized to the B luminosity of the galaxy, don't show any significant dependence on the galaxy type. Normal galaxies between Sa and Sm [1], starburst galaxies [8], galaxies with an active nuclei [1], and interacting galaxies [7], all show the same SN rate of about 1 in SN units SNu (number of SNe per century per 10^{10} solar luminosities in the B band).

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This is a puzzling result. When a new episode of star formation starts in an old galaxy, both the B luminosity and the SN rate increase (if the obscuration by the dust is neglected) but the SN rate expressed in SNu is not expected to remain constant. The SN rate, barely contaminated by the underlying old population, is expected to show a sharper increase and evolve on different time scales. As a result the constancy of the SN rate cannot be explained by dust-free models of galaxy evolution.

Large amount of dust are always present in starburst galaxies, effecting both the B luminosity and the SN rate. Extinctions of $A_V \sim 10$ are often found, preventing the detection of SNe by optical observations. It is therefore crucial to use radio or infrared observation to derived a more complete view of the SN events. Already in the near-infrared, at 2 μm of wavelength, dust extinction is much reduced, being about 1/10 of that in V.

When dealing with dusty active galaxies, the normalization based on the B luminosity has no clear meaning as this band is produced by both the old and new populations and is absorbed by the dust. In this case we prefer to use the "far infrared SN unit" SNuIR, define as the number of SNe per century per 10^{10} solar luminosities in the Far Infrared (FIR). This normalization is more meaningful as the FIR luminosity is proportional to the current Star-Formation Rate (SFR). It is actually possible to predict the number of expect SN from the FIR luminosity [5, 6]. This prediction depends on several factors, as the radio properties of the SN (used to estimate the intrinsic SN rate in nearby galaxies), the relation between SFR and FIR luminosity, the Initial Mass function (IMF), the presence of an AGN. The number of detected SN can also be used to constrain these parameters.

3 The Ground-based Observations

Several groups have completed or started near-IR SN searches (see [2, 6, 9] and the *SWIRT* project web site[1]), but these works produced only two detections and no spectroscopic follow-up. The reason of these negative results are probably due to a combination of low spatial resolution, limited field-of-view, low sensitivity and small number of expected events.

Our campaign started in 1999. Observations up to 2001 are described in [5], while in this contribution we present the updated results up to summer 2003. The galaxies were selected to have large FIR luminosities, between $2 \times 10^{11} L_\odot$ and $2 \times 10^{12} L_\odot$, corresponding to about 0.3–3 expected SNe per year per galaxy. Such high expected rates were chosen to assure significant statistical results even in a short period of time. The distances are below 200 Mpc, assuring enough sensitivity and resolution to detect point sources over the bright galaxy background. We monitored 47 starburst galaxies in the K band (2.2μm) mainly by using 4m class telescope in sites of good seeing,

[1] *http://www.te.astro.it/attivitascientifica/telescopi/azt24/swirt_eng.html*

the TNG in La Palma and the NTT at La Silla. Some observations were also obtained by the University of Arizona 61 inch telescope. In 2002 and 2003 we obtained 50 new images, mainly with the NTT. The total number of observations is now 304, with an average number of 6.5 observations per galaxy. A sample of less distant, less luminous galaxies were also monitored with the TIRGO 1.5m telescope. The results will be discussed in a different paper (Cresci et al., in preparation).

The various images of the same galaxy were carefully aligned, scaled to the same flux, reduced to the same PSF and subtracted. Typical limiting magnitudes were K$\sim$17 on the nucleus and K$\sim$19 at distances larger that about 1 arcsec.

These observations produced the detection of 4 events, the first significant sample of events detected in the near-infrared. For one event, SN2001db [3], we also obtain a spectroscopic follow-up: this event is a type II SN discovered after maximum light. The extinction, measured by the Hβ/Hα and Brα/Hα line ratios [4] is $A_V \sim 5.6$. As expected, this one was the SN with the highest extinction known at that time.

Obtaining an infrared SN rate from the data is not straightforward and is subject to large uncertainties: this is due to the small number of detected events, to the variability of the properties of core-collapse SNe in the near-IR and to the dependence of the detection limit on the distance from the galaxy nucleus. Using the same hypothesis of [5] we derive an expected number of 55 SNe if they are all out of the nucleus and 16 if they are in the central arcsec. Reducing these numbers to the observed 4 events imply extinctions of $A_V = 33$ and $A_V = 10$, respectively. The measured SN rate SN_r^{NIR}, assuming that 80% of the SNe explode in the nucleus (see [5]), is 0.40 SNuIR.

These limits are already quite high and are based on 4 years of (sparse) observations. To do better it is necessary to use instruments with higher sensitivity to point sources, as the HST.

4 Archive HST Observations

The NICMOS camera on the HST is an ideal instrument to look for SNe in the near-infrared. Its resolution is a few times higher than from the ground under average seeing, and the PSF is much more stable allowing for a better subtraction even near the bright galactic nucleus.

Most nearby starburst galaxies were already observed with this camera. Unfortunately, the HST target selection policy does not usually allow for duplicate observations of the same object with the same instrument setting. As a consequence, only very few archive data can be used to look for variability.

In a pilot study, we have searched the NICMOS archive for repeated observations of starburst galaxies with a long time span. We found 4 objects: NGC34, NGC5256, Arp200 and NGC6240. For NGC34 and Arp220 a narrow-band filter image was acquired a few months after the corresponding

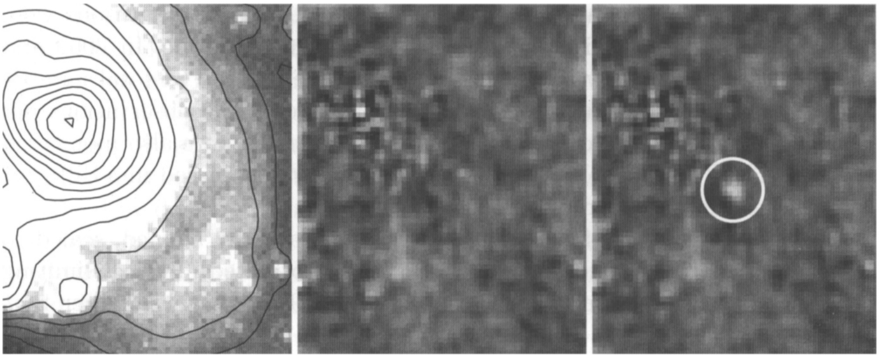

Fig. 1. *Left panel:* NICMOS image of the nucleus of NGC3690 in the F160W filter taken in Aug 2003; *center panel:* residuals with an image taken in 1997 with the same instrument setting; a fraction of less then 0.3% of the flux in the central arcsec (H$\sim$ 13.6) remains in the residual image. *Right panel:* a simulated SN with magnitude H = 19.5 is added to show the residual noise level and the NICMOS detection power. The circle is 1 arcsec of diameter.

broad-band one. In this case each pixel of the broad-band image can be "scaled" to the other bandpass by interpolation over the observed broad-band colors. NGC5356 was observed twice with the same F160W filter but with a different camera. NGC6240 was observed twice in the same broad-band filter and camera, probably because of problems with the PSF of the first observation. All the images have short exposure times, up to 4 minutes: nevertheless the resulting limit magnitudes are between H = 18.8 and 21.0. The nuclear region where the residuals of the subtraction are large is confined in the central 0.3 arcsec, but we expect to reduce it when the same instrument setting is used.

Despite the limited sample of only 4 objects, the small number of observations and the far than ideal instrument settings, the galaxies should produce about 5 observable SNe given their FIR luminosities, the time span of the observations and limit magnitudes. Despite of these expectations, no SN was detected. Also in this case we attribute this lack of detection to the presence of high extinctions, but the limits are less stringent.

5 Incoming HST and VLA Observations

In order to obtain more useful data, recently an HST proposal by our group was approved for cycle 12. The aim of the proposal is to obtain second epoch images of a sample of 37 nearby starburst galaxies already observed by NICMOS in the F160W filter. This "snapshot" program is already active and at the moment of writing the first galaxy was already observed (see Fig. 1). If

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all the galaxies will be observed, we expect to detect up to 50 SNe, value corresponding to no extinction. Even if all SNe suffer an extinction of $A_V = 30$ we would still expect to detect 8 SNe. Therefore we are looking forward to these observations.

All the detected objects will be observed spectroscopically. Any event detected in galaxies within 100 Mpc will be observed by VLA: in these starburst galaxies we expect to find SNe with peculiar radio properties, as the emission of the core-collapse SN at these wavelength is dominated by the interaction of the ejecta with the circumstellar medium. The radio properties of these SNe can be used to derive the density and the structure of the circumstellar medium and the details of the late stages of the presupernova stellar evolution. Comparison with the existing radio SN models will also test their validity in a wider range of physical conditions than previously available.

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