# Evaluating the fraction of obscured supernovae in luminous infrared galaxies with adaptive optics surveys

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**Despite the expectation of a high supernova (SN) rate, there is a deficit discovered in luminous infra-red galaxies (LIRGs) in optical surveys, due to high levels of extinction by dust and contrast issues against the bright nuclear background. Searching in the near infra-red (NIR) allows observations to penetrate this dust, and using adaptive-optics (AO) achieves the resolution required to observe supernovae (SNe) close to the nuclei of these galaxies. Over the last decade, multiple observing programs using the best AO instrumentation mounted on large telscopes have accumulated a dataset of many LIRGs, and met with much greater success in discovering nuclear SNe. However, there is still a significant proportion being missed. Using techniques to evaluate our detection efficiency in this data and simulations of the SNe occuring in these galaxies, we can evaluate the nature of these transients.**

## Introduction

Luminous infrared galaxies (LIRGs) exhibit high star formation rates and although they are relatively rare in the local universe, they begin to dominate star formation at a redshift of z~1. Due to their high rates of star formation, LIRGs also have a high supernova (SN) rate, in the order of 1 per year (Mattila & Meikle, 2001). However, there was an observed deficit of supernovae (SNe) discovered in LIRGs by optical surveys (e.g. Horiuchi et al, 2011) which has been attributed to the large amounts of dust present, especially in the nuclei of LIRGs as well as low contrast against the bright nuclear background (Mattila et al, 2012). To compensate for this, searches can be made in the near-infrared (NIR), where the extinction due to dust is much less.

To find SNe close to the nuclei of LIRGs also requires high spatial resolution, ~0.1", which is only achievable from the ground with the use of adaptive optics (AO). This has motivated our use of multiple observing facilities equipped with such instrumentation over the last decade, such as Gemini North/South and the VLT, to search for SNe in these LIRGs. These searches have unveiled a dozen SNe, often at close distances to the nuclei of their hosts. With these we can investigate if the SN rate we observe is consistent with our understanding of the nature of the SNe, and our limitations on detecting them. We can also compare with expected levels of extinction, the star formation rate and distribution of massive star formation in LIRGs.

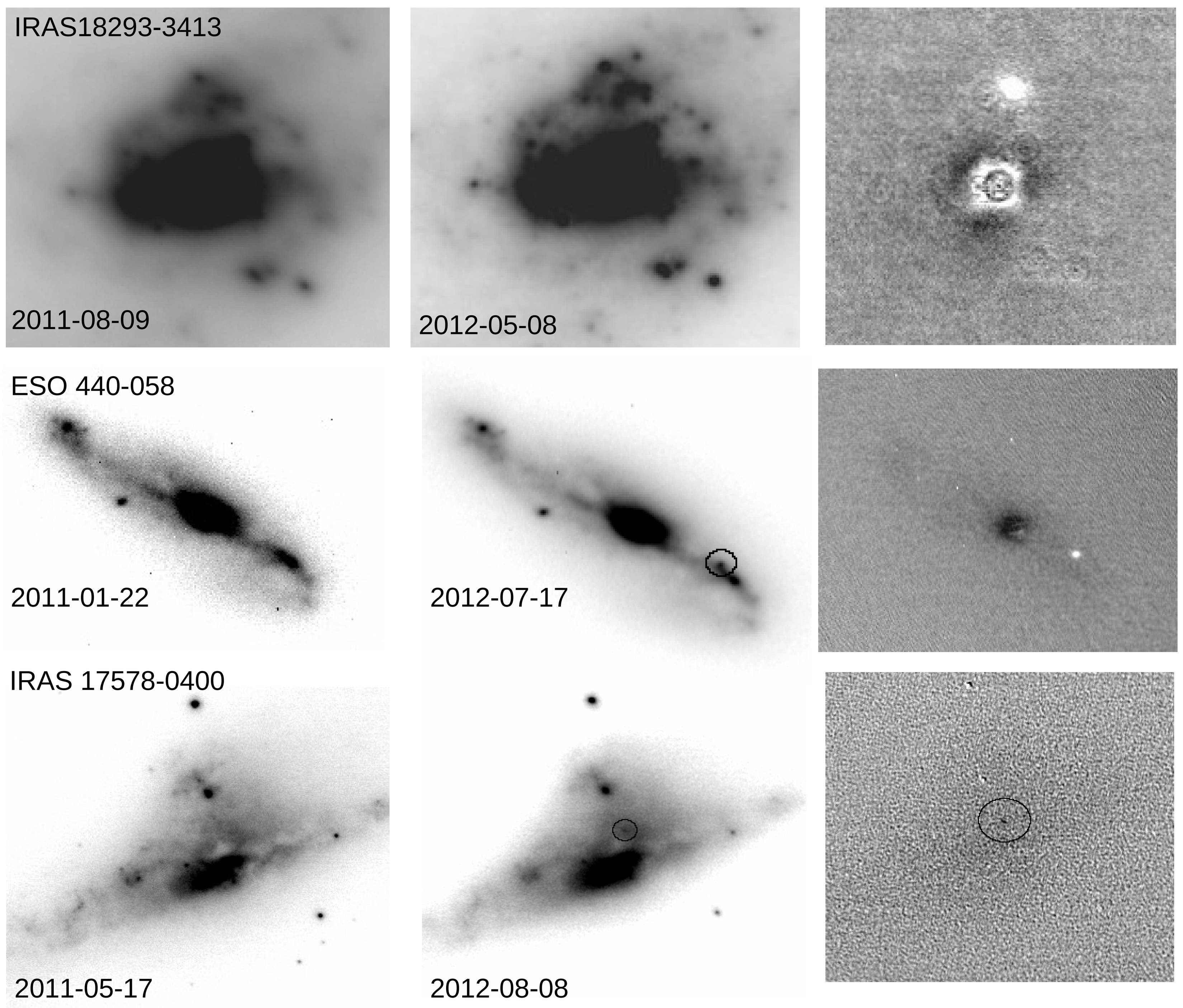


*Fig.1. Examples of SNe detections in VLT/NACO images of LIRGs*

### Datasets

Multiple datasets are included in this study, collected by the SUNBIRD (Supernovae UNmasked By InfraRed Detection) survey (see Kool et al, 2017) and precursor programs. The LIRGs observed have intrinsic SNe rates of ~0.5-2 per year and are within 120Mpc. Selection was restricted by the requirement of suitable nearby stars that could be used as a guide star for the AO systems. Images were obtained in K band at intervals of ~3 months, with H and J band followup data for SNe discoveries (see Kankare et al, 2008, 2012, 2014)

· 9 LIRGs were observed with Gemini North ALTAIR/NIRI with laser guide star AO.
· 26 LIRGs were observed with VLT/NACO between 2010-2013. A total of 95 K band images were taken with natural guide star AO.
· 13 LIRGs were observed with Gemini South GeMS/GSAOI between 2013-2016. A total of 38 K band images were taken with laser guide star multiple conjugate AO.
· 21 LIRGs have been observed with KECK NIRC2. Observations began in 2016 and are ongoing, with 43 K band images taken so far with laser guide star AO.

LIRGs with particularly high SN rates have been observed preferentially, with the maximum number of epochs being 20. The dataset contain 14 SNe, which provide a statistical baseline for the analysis of the overall SN population in these galaxies. Multiple objects were discovered at a projected distance of less than 0.5kpc from the nucleus of their host. The SNe are summarised in the table to the right.

We can estimate the expected SN rate of our sample of galaxies using a relationship with the far-IR luminosity obtained in Mattila & Meikle et al. 2001. Adopting a typical K band absolute magnitude and light curve evolution from the same source for core-collapse SNe and assuming we detect all SNe brighter than 19.3 mag (see the detection efficiency below), we expect a typical SN to be detectable for about 130 days in a LIRG at the distance of ~98Mpc, the mean for the sample. With these values we can estimate an expected number of detectable SN of 44.3 across our survey. This estimate, however, does not include the effects of extinction, which can be substantial even in K band, or the proportion of the SNe occuring in the central 100pc which have a much lower likelihood of detection. Thus the true expected detection rate will be significantly lower than this.

To find this expected detection rate more precisely, we simulate SN explosions and recovery during our survey time period taking into account our observing cadence. This requires an accurate assessment of the intrinsic parameters of the SN events, as well as the evaluation of our ability to detect them in the data.

| | Host Galaxy | SN rate ($yr^{-1}$) | Facility | Type | Reference | Extinction (mag) | Projected distance (Kpc) |
|---|---|---|---|---|---|---|---|
| SN2004ip | IRAS 18293-3413 | 1.74 | VLT/NACO | II | Mattila et al. (2007) | 5-40 | 0.5 |
| SN2004iq | IRAS 17138-1017 | 0.71 | NICMOS/HST | II | Kankare et al (2008) | 0-4 | 0.66 |
| SN2008cs | IRAS 17138-1017 | 0.71 | Gemini-N/ALTAIR | II | Kankare et al (2008) | 17-19 | 1.5 |
| SN2010cu | IC 883 | 1.26 | Gemini-N/ALTAIR | II | Kankare et al (2012) | 0-1 | 0.18 |
| SN2011hi | IC 883 | 1.26 | Gemini-N/ALTAIR | II | Kankare et al (2012) | 5-7 | 0.38 |
| SN2013if | IRAS 18293-3413 | 1.74 | Gemini-S/GSAOI | IIP | Kool et al. (2017) | 0-3 | 0.2 |
| SN2015ca | NGC 3110 | 0.55 | Gemini-S/GSAOI | IIP | Kool et al. (2017) | 3 | 3.5 |
| SN2015cb | IRAS 17138-1017 | 0.71 | Gemini-S/GSAOI | II | Kool et al. (2017) | 4.5 | 0.6 |
| AT2015cf | NGC 3110 | 0.55 | Gemini-S/GSAOI | II? | Kool et al. (2017) | 2-5 | 3.5 |
| SN2010O | Arp 299 | 2.05 | Gemini-N/ALTAIR | Ib | Kankare et al (2014) | 2 | 1.6 |
| SN2010P | Arp 299 | 2.05 | Gemini-N/ALTAIR | IIb | Kankare et al (2014) | 7 | 1.2 |
| AT2012xx | IRAS 18293-3413 | 1.74 | VLT/NACO | II? | Reynolds et al (in prep) | ? | 0.6 |
| AT2012xx | IRAS 17578-0400 | 0.60 | VLT/NACO | II? | Reynolds et al (in prep) | ? | 0.32 |
| AT2012xx | ESO 440-058 | 0.62 | VLT/NACO | II? | Reynolds et al (in prep | ? | 1.2 |

### Detection Efficiency

SNe were detected in the images using the image subtraction package ISIS 2.2 (Alard & Lupton 1998; Alard 2000). To evaluate our ability to detect SNe, we modelled the PSF in an image, placed artificial SNe based on this PSF at random locations in the images and attempted to recover them in subtractions. Recovery was based on the signal in the detection aperture being 3x the standard deviation calculated for a grid of surrounding apertures. The results for a typical LIRG are shown below.

From these curves, we found that the 50% detection threshold is at magnitude 16.73 in the central 100pc, and 19.28 in the 100-300pc region of the LIRG.

### Simulation

To find the expected number of detections in our sample, we simulate SNe across the time of the observations. Important simulation parameters are

• The peak magnitude and light curve of typical SNe
• The extinction experienced by the SNe, which can often be extremely high
• The spatial distribution of the SNe, which can be expected to follow the star formation
• The expected SN rates in our LIRG sample. This can be found most accurately by fitting the spectral energy distribution of the individual LIRGs.

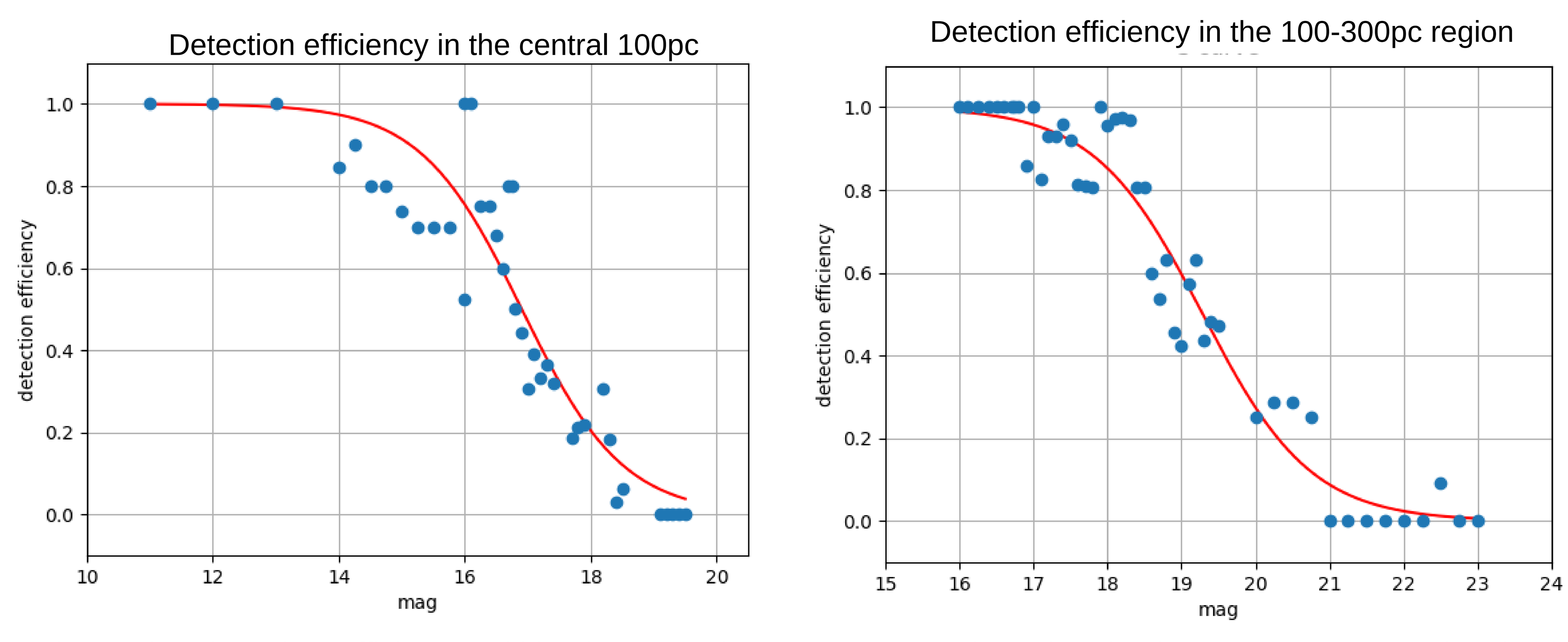


*Fig.2. The detection efficiency within the central 100pc compared to that in the 100pc-300pc region in the LIRG IRAS18293-3413. Note that it is much more difficult to detect SNe in the central region.*

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