Supernovae detection rate with the ILMT and their followup strategy with ARIES facilities

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Abstract

The 4m International Liquid Mirror Telescope (ILMT) is presently under commissioning phase at Devasthal Observatory (Nainital, India). This facility continuously scans the same strip (22' wide) of the sky (in g', r', and i' bands) with a fixed pointing towards the zenith direction. Consequently, it provides a unique opportunity for supernovae (SNe) detection and study. We estimated the SNe detection rate with the ILMT by considering the progenitor mass range for Type Ia SNe and core-collapse supernovae (CCSNe) as 3-8 M⊙ and 8-50 M⊙, respectively. Here, the CCSNe mass range is for different types of events (Ibc, IIL, IIP, and IIn). Our calculation indicates that it is possible to detect hundreds of supernovae each year by implementing an optimal image subtraction technique. The photometric classification of SNe is also possible with the ILMT data. The observatory hosts two additional optical facilities (1.3m DFOT and 3.6m DOT) along with the ILMT and therefore, immediate monitoring of ILMT-detected transients/SNe is planned under the target of opportunity mode. The spectroscopy with the DOT facility will be useful for the classification of SNe.

Supernovae overview

Supernovae (SNe) are catastrophic explosions at the life-cycle termination stage of stars. An enormous amount of energy (order of 10^{50} ergs) is released during such explosions. SNe are primarily responsible for the chemical enrichment of galaxies through their heavy elements and dust. Depending on the observational features (spectra and light curve), they are broadly categorized into two groups i.e. thermonuclear and core-collapse supernovae (CCSNe) which are further classified into several subcategories, viz. thermonuclear (Type Ia) and CCSNe (Type Ib, Ic, Ic-BL, Ibn, IIP, IIL, IIb, and IIn). Thermonuclear SNe are consequences of the thermonuclear disruptions of a carbon-oxygen white dwarf, reaching the critical Chandrasekhar mass limit (1.4 M⊙). The progenitors of Ia SNe are supposed to be intermediate-mass stars (3-8 M⊙) and are hosted by galaxies of different morphological types. The CCSNe arise from the gravitational collapse of the iron core of young massive progenitors (mass ≥ 8 M⊙). Various physical mechanisms play a crucial role during the evolutionary phases of progenitors, resulting in heterogeneity in the post-explosion observational features (e.g. light curve shapes, luminosities, spectral evolution, etc).

The new generation large area survey programmes have greatly contributed to discovering new SNe. For a detailed study, the newly discovered peculiar objects are further followed up with other observing facilities. In combination with several advantages (inexpensive, easy data handling, deeper imaging, etc.) the 4m International Liquid Mirror Telescope (ILMT) will provide a unique opportunity to discover and study different types of SNe each year.

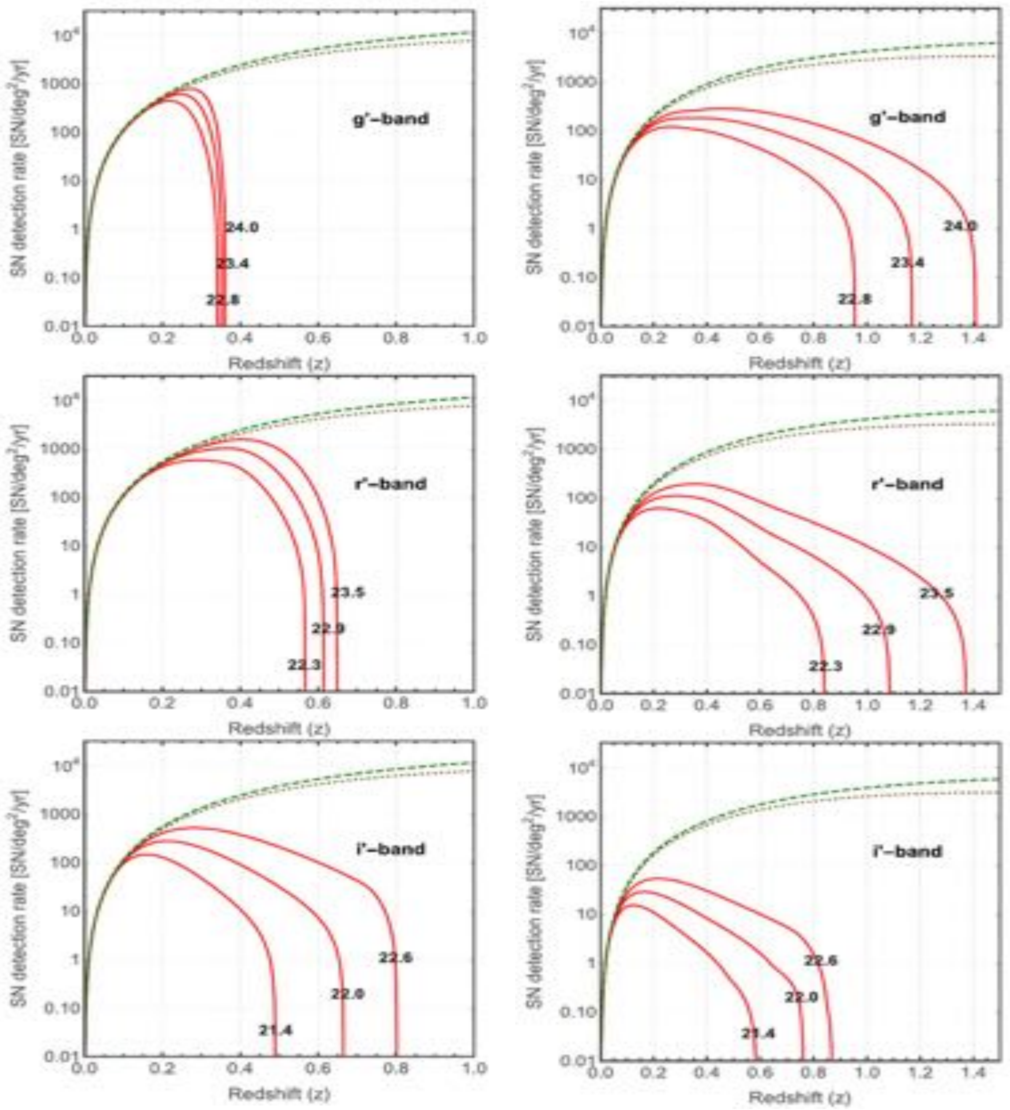


Figure-1: The detection rate of Type Ia (left panel) and CCSNe (right panel) as a function of redshift. The dashed (green color) and dotted (brown color) curves, respectively, indicate the cosmic SN rate without and with dust extinction consideration. The possible number of SNe to be detected with the ILMT in different bands (g', r', and i') and for different magnitude limits (cf. stacking of consecutive night images) is also shown.

Table 2. SN detection rates with the ILMT. 1_N, 3_N, and 6_N indicate the number of SNe for the limiting magnitudes of single, and co-added images of three and six nights, respectively. Total number of SNe (Columns 6, 7, and 8) are the redshift-integrated events in a year (only 160 photometric nights of the site and an average 8 h of observing time each night have been accounted for).

SN type	Filter	SNe (deg^{-2} yr^{-1}) 1_N	3_N	6_N	Total SNe in a year 1_N	3_N	6_N
Ia	g'	63	89	115	1299	1835	2371
	r'	155	274	426	3196	5649	8783
	i'	28	71	174	577	1464	3588
CC	g'	50	97	177	1031	2000	3649
	r'	20	43	87	412	887	1794
	i'	3	8	19	62	165	392

4m ILMT facility

The ILMT is a 4-m zenith-pointing telescope located at Devasthal Observatory (Nainital, India). The first light of the facility was achieved last year (2022 April 29) and presently, it is under commissioning phase. The ILMT images are obtained in Time-Delay Integration (TDI) mode. Given the fixed pointing of the telescope, the stars move in the focal plane along slightly curved trajectories. Therefore, a dedicated five-element optical corrector is being used altogether with the CCD reading the electronic charges in the TDI mode. A 4k x 4k CCD camera (Spectral Instruments) is mounted at the prime focus of the telescope, which can secure nightly images in SDSS g', r', and i' spectral bands. The effective focal length of the optical system is 9.44 m. The reflecting surface of the liquid (~3 mm) is formed by pouring approximately 50 liters of mercury into a recipient whose rotation period (8.02 sec) is precisely controlled. The single scan integration time for the ILMT is 102 sec. A list of important parameters of the ILMT is provided in Table-1.

Table 1. Specifications of the ILMT detector.

Parameter	Value
Array size	4096 × 4096 pixels
Pixel size	$0.33''$ pixel^{-1}
Readout noise	5.0 e^{-1}
Gain	4.0 e^{-1}/ADU
Integration time (TDI)	102 sec

Supernovae detection rate

The limiting magnitude of ILMT was estimated by considering different parameters of the telescope, detector, and site (e.g. transmission coefficients from the mirror, filters, CCD glass, sky, extinction, CCD quantum efficiency, and median seeing of the site, etc., see also Table-1). For an exposure time of 102 sec, the limiting magnitudes were estimated as ~22.8, ~22.3, and ~21.4 mag for the g', r', and i' filters, respectively. Here, we note that by co-adding the consecutive night images, the limiting magnitude can be further improved. The ILMT field of view (FOV) is 22 x 22 arcmin^2 and each night it is possible to monitor ~47 deg^2 sky area. The SN detection rate per unit redshift per unit solid angle in a filter band *x* can be expressed as follows:

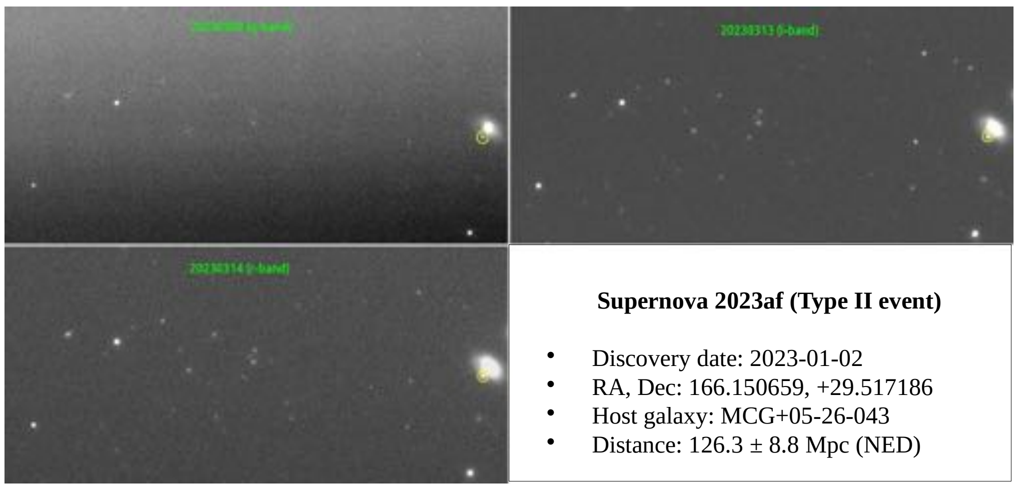
$$\frac{dN_{\mathrm{SN,obs},x}}{dt_{\mathrm{obs}}\,dz\,d\Omega} = R_{\mathrm{SN}}(z)\; f_{\mathrm{detect}}(z; m^{\mathrm{SN}}_{\mathrm{lim},x})\; \frac{r(z)^2}{1+z}\frac{\mathrm{d}r}{\mathrm{d}z}$$

Here, *r(z)* is the comoving distance and $R_{SN}(z)$ is the cosmic SN rate. The quantity $f_{\mathrm{detect}}(z)$ is the fraction of SNe which can be detected by the instrument. In these calculations, the absolute magnitude distribution of the SNe is taken from Richardson et al. (2014). Further, the progenitor mass range for the Type Ia SNe is taken to be 3-8 M⊙ and for CCSNe it is taken to be 8-50 M⊙ (mass range for CCSNe types: Ibc, IIL, IIP, and IIn). For different limiting magnitudes (3 night, 6 night co-added images), the SNe detection rate as a function of redshift is plotted in Figure 1 and also listed in Table-2.

Importance of ARIES facilities

Almost the same (a 4 min shift in RA) sky strip each night will be deeply scanned with the ILMT. Such kind of imaging can be utilized to detect transient sources by implementing robust image subtraction technique. However, once a particular object crossed the ILMT FOV, it can't be monitored during the same night (cf. ILMT zenith pointing) and therefore, conventional telescopes can be triggered for further monitoring. Thankfully two modern optical telescopes just beside the ILMT are already functional (3.6m Devasthal Optical Telescope and 1.3m Devasthal Fast Optical Telescope). We plan to follow-up the newly discovered ILMT transients with these facilities under secured target of opportunity mode. The transient discovery information will also be immediately circulated to the time domain community via web.

Presently, an automated transient detection and classification pipeline is in the developmental stage (see poster by Pranshu et. al.). However, to understand the followup strategy, we searched previously discovered SNe that were discovered in 2023 and located in the ILMT field (commissioning cycle 3). Interestingly, SN 2023af is lying in the ILMT FOV. This SN was discovered on 2023-01-02 and later classified as Type II. It has been possible to monitor the SN with ILMT in g', r' and i' bands (see Fig. 2) during the third phase of the commissioning which started on 06 March 2023. We are also following up this SN with DOT and DFOT. It is expected to detect many SNe with the ILMT in the ongoing cycle.



Supernova 2023af (Type II event)

- Discovery date: 2023-01-02
- RA, Dec: 166.150659, +29.517186
- Host galaxy: MCG+05-26-043
- Distance: 126.3 ± 8.8 Mpc (NED)

Figure-2: ILMT CCD imaging of SN 2023af on three different nights. The SN location is encircled (yellow).

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