SN Ia rate evolution from Subaru/XMM-Newton Deep Survey

Jun E. Okumura[1], Yutaka Ihara[2,3], Mamoru Doi[2], Tomoki Morokuma[2], Reynald Pain[4], Tomonori Totani[1], Kyle Barbary[5,6], Naohiro Takanashi[7], Naoki Yasuda[8], Greg Aldering[6], Kyle Dawson[6,9], Gerson Goldhaber[6], Isobel Hook[10,11], Chris Lidman[12], Saul Perlmutter[5,6], Anthony Spadafora[6], Nao Suzuki[6], Lifan Wang[13] *affiliations are described blow

Abstract

We present measurements of the rates of high-redshift Type Ia supernovae derived from the Subaru/XMM-Newton Deep Survey (SXDS). We carried out repeat deep imaging observations with Suprime-Cam on the Subaru Telescope, and detected 1040 variable objects over 0.918 deg^2 in the Subaru/XMM-Newton Deep Field. From the imaging observations, light curves in the observed *i'*-band are constructed, and we fit the observed light curves of the variable objects to the template light curves. Out of the variable objects detected by the SXDS, 43 objects are classified as Type Ia supernova using a light curve fitting method at the redshift range of 0.2<z<1.3. We find that the Type Ia supernova are increasing up to z~1.3. The rate can be fitted by a simple power law function, $r_V(z)=r_0(1+z)^{\alpha}$ with the values of $r_0=0.19^{+0.03}_{-0.03}$ (stat.) $^{+0.03}_{-0.04}$ (sys.), $\alpha=2.15^{+0.36}_{-0.36}$ (stat.) $^{+0.22}_{-0.32}$ (sys.). In the future SN surveys, SN Ia rate at high redshift regime will be one of the most interest. The Hyper Suprime-Cam (HSC) survey is one of the promising survey in this context. The survey aims to detect ~100 SNe Ia in the redshift range of 1.0<z<1.5. Our method utilized to Suprime-Cam will be also useful to the HSC survey.

§1 Observation (SXDS)

The Subaru/XMM-Newton Deep Survey (SXDS) is a multi-wavelength survey from X-ray to radio (Sekiguchi et al. 2004), which covers ~1 deg^2 area. The detail survey parameters are summarized in Table. 1.

Transient: During the survey, the Suprime-Cam observations were split into exposures of 1800-7200 seconds separated by periods of days to weeks, in order to detect and follow the light curves of optically faint variable objects. In total, 1040 optical transients have been detected. The transient's light curves have basically observed in i'-band and some of them have color information (R_c, z'). Follow-up spectroscopic observations have carried out to identify transient using several ground-based 8-10m telescopes and ACS grism on HST. In total, 8 objects were classified as SN Ia in the follow-up observations.

Host Galaxies: The properties of transient's hosts were derived from Lephare code with PEGASE2 templates, using 10 bands photometry (B, V, R_c, i', z', J, H, K, 3.6μm, 4.5μm).

telescopes/ Instruments	wavelength & depth
Subaru Suprime-Cam	B (28.4), V (27.8), Rc (27.7), i' (27.7), z' (26.6) *3σ, 2.0" aperture
UKIDSS	J (24.9), H (24.2), K (24.6)
Spitzer/IRAC	3.6μm (23.1), 4.5μm (22.4)
XMM-Newton	0.5-2.0keV (1×10^{-15} erg^{-1} cm^{-2} s^{-1}) 2.0-10.0keV (3×10^{-15} erg^{-1} cm^{-2} s^{-1})

Table1: photometry information used in this works

§2 rate calculation

The expected number of SN Ia in the redshift bin [z_1, z_2] can be expressed as below. Here r_V is SN Ia rate, V is comoving volume, and CT is the control time ("effective visibility time" of SN Ia in observed frame) of SXDS.

$$N_{exp}(z_1 < z < z_2) = \int_{z_1}^{z_2} \frac{r_V(z)}{1+z} CT(z) V(z) dz$$

then SN Ia rate can derived as

$$\widehat{r}_v(z_1 < z < z_2) = \frac{N_{obs}(z_1 < z < z_2)}{\int_{z_1}^{z_2} \frac{CT(z)}{1+z} V(z) dz}$$

but observed number (N_{obs}) can be changed by misclassification of SN types. Then the number are corrected by considering completeness of classifying SN Ia (P_{Ia}), and possible misclassification (F_{Ia}).

$$\widehat{N}_{obs}(z) = \frac{N_{est}(z)}{P_{Ia}(z)(1 + F_{Ia}(z))}$$

CT(z), P_{Ia}(z), F_{Ia}(z) are calculated by generating many simulated light-curves using spectral templates (we used Hsiao+'07 template for SN Ia and Nugent +'02 templates for CC SN) and assuming same survey parameter in SXDS.

Affiliations: 1. Kyoto University 2. Dept. of Astronomy, University of Tokyo 3. Institute of Astronomy, University of Tokyo 4. Laboratoire de Physique Nucleaire et de Haute Energies de Paris 5. University of California, Berkeley 6. Lawrence Berkeley National Laboratory 7. Executive Management Program, University of Tokyo 9. Institute for the Physics ans Mathematics of the Universe (IPMU) 10. University of Tokyo, University of Utah 11. University of Oxford 12. Osservatorio Astronomico di Roma 13. Australisan Astronomical Observatory 14. Texas A&M University

§3 SN selection and systematics

Transient selection have been done in the following procedure.

Initial selection of candidates

Among 1040 transients found in SXDS, we removed transients which show variability for more than one year (possible AGN), and faint objects (at least two epoch should be brighter than 5σbf). This selection makes 140 SN candidates.

Discriminating SNe II

Since majority (73 of 140) of the candidates' light curve were only observed in i'-band, we distinguish between SNe I and SNe II based on light-curve-shape as a first step. The likelihood of being certain types of SNe were calculated, and based on this value (P_{type}), 43 objects have been classified as SNe I. Here, PDF(z) is a probability distribution function of host galaxy's redshift.

$$\chi^2_{\rm LC} = \sum_{k=1}^{n} \left(\frac{f_{obs} - f_{temp}}{\Delta f_{obs}}\right)^2 \qquad P_{type}(z) \propto PDF(z) \times \exp\left(-\frac{\chi^2_{\rm LC}}{2}\right)$$

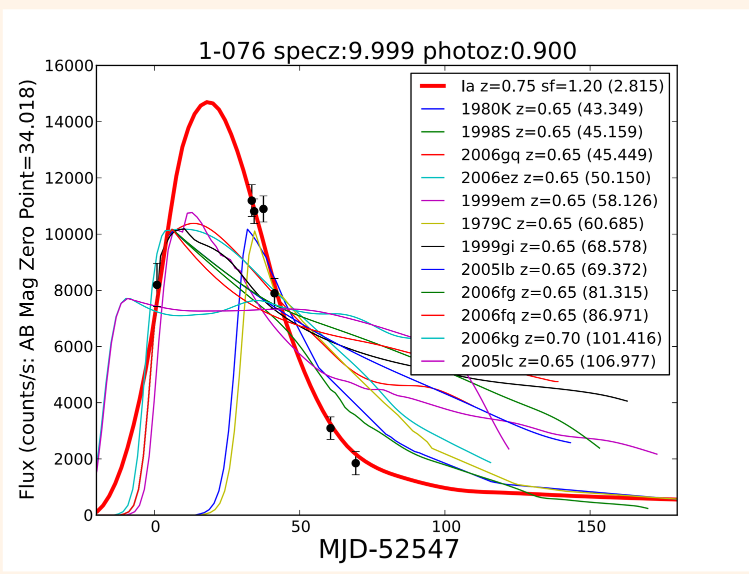

Fig.1: an example of LC fitting

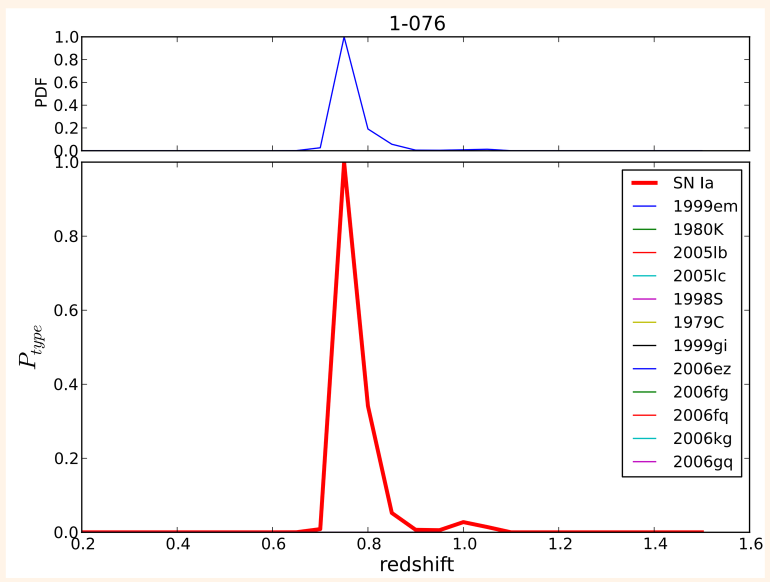

Fig.2: calculated P_{type} as a function of redshift

SNe Ib/c contamination

The SN Ib/c contamination have been considered by two methods. First, we used 15 out of 43 SNe I which have color information, and 2 objects (~13%) located around possible SN Ib/c region in (R_c-i') vs (i'-z') plots. Secondly, we calculated the contamination assuming 10% of CC SNe are SNe Ib/c. These estimations were consistent, then the contamination is estimated to be ~13%

AGN contamination

Though most of AGNs have been removed in the first procedure, there might be possible AGN contamination. To estimate this uncertainty, we checked X-ray detection, and only one object (~2.4%) was detected in X-ray.

§4 results

The estimated rates are plotted in Fig.3. Our results are consistent with other published studies for wide redshift range (0.2<z<1.4). In the high-redshift regime (z>1), the uncertainty is still large and we need more statistics. For this purpose, Hyper Suprime-Cam (HSC) survey will be one of the promised survey. HSC will carry out wider (x7 than SXDS) and deeper transient survey which aims to detect ~100 SNe Ia in 1.0<z<1.5 region.

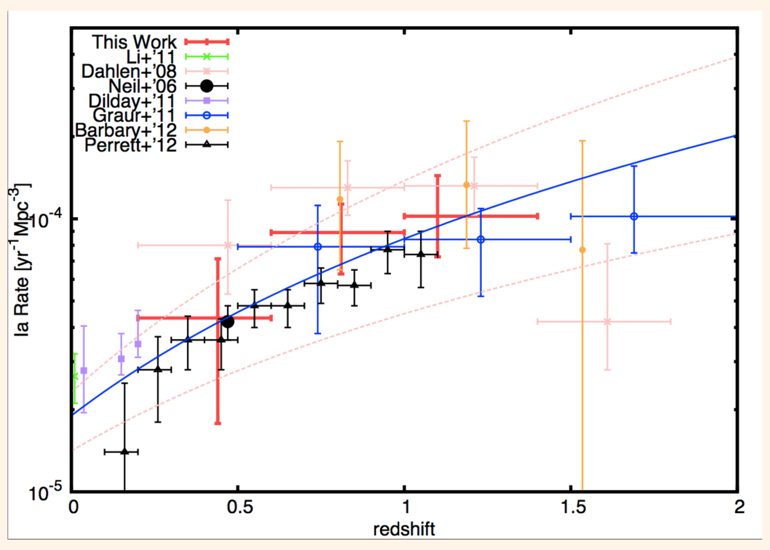

Fig.3: SN Ia rate results compared with other recent studies