The Type Ia Supernova Rate and Progenitor from Transient Survey

Jun Ernesto Okumura @SN+SNR 16/10/2012

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   - SN Ia progenitor, SN Ia rate and Delay Time Distribution

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   - Rate Result
   - Future Survey
Type Ia Supernova

- Thermonuclear Explosion of White Dwarf (WD) which exceeds Chandrasekhar limit
- **Progenitor system** forms binary
- ~ $10^{51}$ erg, $M_{B_{\text{max}}}= -19.1 \text{mag}$
- $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$

- Spectrum is basically “**Black Body+lines**”
- Homogeneous LC → Cosmology
Type Ia Supernova

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</thead>
<tbody>
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<td>Ni, Si, S, Ca</td>
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</tbody>
</table>

Kim97’
SN Ia Progenitor models

1. Mass Transfer

- Companion: Main Sequence, Sub-Giant
- mass accretion from Roche-love overflow
- Recurrent Nova > stable nuclear burning

Single Degenerate (SD)

- Companion: WD
- gravitational wave radiation
- merge of two WDs > SN Ia

2. Exceed Chandrasekhar Mass (~1.4 Msun)

Double Degenerate (DD)

2. Shrinkage

1. Gravitational Wave
1. Dense circumstellar matter (CSM)
   No Radio & X-ray detection
   (Panagia+06, Chomiuk+12', Hancock+11')
   see also Dilday+12', Taddia+12' → CSM

2. Hydrogen from the companion
   SN2005am, SN2005cf (Leonard 07')
   SN2011fe (Shappee+12')
Observational Constraints on the progenitor

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4. Supersoft X-ray Sources (SSS)
   Di Stefano 10’, Gilfanov&Bogdan 10’
   but see also Hachisu+10’, Meng&Yang 11’
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Di Stefano 10’, Gilfanov & Bogdan 10’,

\[ N_{\text{acc}} = 1500 \left( \frac{\Delta M}{0.4 M_\odot} \right) \left( \frac{8 \times 10^{-7} M_\odot \text{ yr}^{-1}}{\beta M_{\text{in}}} \right) \left( \frac{L_B}{10^{10} L_\odot} \right)^{\text{ang 11’}} \]

<table>
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<th>Galaxy</th>
<th>SSSs</th>
<th>QSSs</th>
<th>Other Sources</th>
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</table>
Delay Time Distribution (DTD)

- SFH and Delay Time Distribution (DTD)
- Delay Time: time duration between the birth of the binary and the explosion as a Supernova
Delay Time Distribution (DTD)

SN Ia rate is coupled with SFH and DTD

\[ R_{Ia} = \int_0^t \psi(t') \text{DTD}(t - t') \, dt' \]
Delay Time Distribution (DTD)

- Population Synthesis Calculation
- SD: Lifetime of the secondary  DD: WDs separation
- Theoretical absolute number lies a factor below the observation
Delay Time Distribution (DTD)

- Population Synthesis Calculation
- SD: Lifetime of the secondary
- DD: WDs separation
- Theoretical absolute number lies a factor below the observation

\[ t_{Ia} \sim t_{GW} \propto a^4 \quad a : \text{separation} \]
\[ f_{\text{sep}}(a) \propto a^\beta \]
\[ f_D \propto f_{\text{sep}}(a) \frac{da}{dt_{Ia}} \propto t_{Ia}^{-3\beta/4} \]
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1. SN Ia rate can constrain SFHxDTD
2. theoretical DTDs consists with DD model (t^{-1} DTD)
3. Still remains contradiction in the absolute number
Delay Time Distribution (DTD)

1. SN Ia rate can constrain SFHxDTD
2. theoretical DTDs consists with DD model (t⁻¹ DTD)
3. Still remains contradiction in the absolute number
Why SN Ia rate?

- SN Ia is crucial tool for astronomy
  1. Ia cosmology: homogeneous LCs
  2. Chemical Evolution: ~0.6M\text{sun} Fe per event
  3. Cosmic/Galactic Star Formation History (SFH)
- ...but we don’t have clear comprehension about explosion mechanism, progenitor, environment

- SN Ia rates at high-z are not clear yet!
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  - Ia cosmology: homogeneous LCs
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Numerical Simulation
Statistical Constraint

$R_{Ia} = \int_0^t \psi(t') \text{DTD}(t - t') \, dt'$

- Li+'11
- Dahlen+08
- Neill+06
- Dilday+11
- Graur+11
- Barbary+12
- Perrett+12

- DTD index -0.5
- DTD index -1.0
- DTD index -1.5
- DTD index -2.0
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Transient Studies

Transient Survey

classification
Spectrum
Light Curves
Colors
Bayesian analysis

transient sample
production rate
host galaxy progenitor
(galaxy evolution)
Subaru/XMM-Newton Deep Survey (SXDS)

- Wide ($\sim1\text{deg}^2$), Deep ($m_{\text{lim}}\sim27\text{mag}$)
  - Optical (Subaru / Sprime-Cam) $B$, $V$, $R_c$, $i'$, $z'$
  - NIR (UKIDSS Survey) $J$, $H$, $K$
  - IR (Spitzer / IRAC) $3.6\mu\text{m}$, $4.5\mu\text{m}$
  - X-ray (XMM-Newton) 0.5-2.0, 2.0-10.0keV

- 5 fields (SXDS-C, N, S, E, W)
- 1~10 day cadence (5-7 epochs)
- 1040 Transients (Morokuma+08')

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<th>$\Delta t$</th>
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Control Time

- **Control Time** = “effective visibility time” for observer

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60 days
Control Time

- Control Time = “effective visibility time” for observer
- Montecarlo Simulation

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$\langle CT \rangle = 57.54$ days
Control Time & Rate Calculation

- Ia: spectral template (Hsiao+07’) + Nearby SDSS Ia sample
- CC: 12 individual template

Rate Calculation

Expected SN Ia number in redshift bin \([z_1, z_2]\)

\[
N_{\text{exp}}(z_1 < z < z_2) = \int_{z_1}^{z_2} \frac{rV(z)}{1+z} CT(z)V(z)dz,
\]

if \(r(z)\)=const. during \([z_1, z_2]\)

\[
\hat{r}_v(z_1 < z < z_2) = \frac{N_{\text{Ia}}(z_1 < z < z_2)}{\int_{z_1}^{z_2} \frac{CT(z)}{1+z} V(z)dz}.
\]
SN candidate Selection

1. AGN-like,
2. SN occurred after Transient Search
3. 370 remained

Remove

1. AGN-like,
2. SN occurred after Transient Search
3. 370 remained

Remove

faint objects
140 remained

SXDS Transient
1040

No variability after 2003

1. at last two points brighter than 26 mag
2. at least two points brighter than $5\sigma_{bf}$
lightcurve fitting

- Ia: spectral template (Hsiao+07’)
  - redshift, stretch [0.7–1.2], $M_B$ [-17.5–-20.0], day at Max
- CC: 12 individual LC template
  - redshift, $M_B$ [-17.5–-20.0], day at Max
lightcurve fitting

- **Ia**: spectral template (Hsiao+07')
  \[ P_{\text{type}}(z) \propto PDF(z) \times \exp \left( -\frac{\chi^2_{\text{LC}}(z)}{2} \right) \]

- **CC**: 12 individual LC template
  redshift, \( M_B [-17.5 \sim -20.0] \), day at Max

- **P** type \((z)/PDF(z)\) \(\times \exp \left( -\frac{\chi^2_{\text{LC}}(z)}{2} \right)\)

- **1-090**
  \[ M_B \sim [1.0-1.95] \]
  \[ \text{Flux (counts/s)} \]
  \[ \text{PDF(z)} \times e^{-\chi^2/2} \]

- **1-090 specz: 9.999 photoz: 0.850**
  \[ M_B \sim [1.0-1.95] \]
  \[ \text{Flux (counts/s)} \]
  \[ \text{AB Mag Zero Point = 34.018} \]
SN template fitting

~42 SN Ia detected!
Possible Contamination?

**Rate Calculation**

the rate derivation in redshift bin \([z_1, z_2]\)

\[
\hat{r}_v(z_1 < z < z_2) = \frac{N_{Ia}(z_1 < z < z_2)}{\int_{z_1}^{z_2} \frac{CT(z)}{1+z} V(z) dz}.
\]

\[
N_{est}(z) = N_{Ia}(z) P_{Ia}(z) + N_{II}(z)(1 - P_{II}(z))
\]

1. \(P_{Ia}(z)\): completeness of the fitting
2. \(1 - P_{II}(z)\): misclassification as CC SN

\[
N_{II}(z) = 0.55 \times (1 + z)^{3.6} CT_{II}(z)V(z)
\]

nearby SN II rate (Botticella+08’)

cosmic star formation rate (Hopkins&Beacom 06’)

\(P_{Ia}(z)\): completeness

1-\(P_{II}(z)\): misclassification ratio
SN Ia rate

- SN Ia rate rising up to z~1.4
- Most of high-z results were derived from one epoch obs., which SXDS result have LC confirmation.
Hyper Suprime-Cam

- FoV: 1.77deg$^2$ (7 times larger than SC, 5 times smaller than LSST)
- 0.17”/pix (typical seeing @MK ~0.7”)
- 6 broad-band filters(ugrizy)+several narrow-band filter
Hyper Suprime-Cam

- FoV: $1.77\text{deg}^2$ (7 times larger than SC, 5 times smaller than LSST)
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ACS

LSST

![Graph showing Ia Rate vs. redshift with various DTD indices: -0.5, -1.0, -1.5, -2.0.](image)
Summary

- The importance of statistical (rate) studies of SNe are growing
- Subaru is one of the promising candidate for these studies
- Ia rate from SXDS has been derived
- Ia rate is consistent with other works and showing expectation to reduce the error in the near future (HSC-Survey!)
Supplemental Slides