近赤外高赤方偏移超新星サーベイ

NIR high-redshift supernova survey

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High-redshift supernova survey with HSC in optical

- HSC SSP transient survey
  - we found a SN at z = 2.4 (the second most distant SN ever found)
  - HSC discovery -> Keck/LRIS spec. follow-up
- optical transient surveys can reach z ~ 4 (Tanaka, Moriya et al. ’12)

Moriya et al. (2019), Curtin et al. (2019)
2020s : Era of NIR transient surveys

Many NIR wide-field imagers are planned enabling us to discover high-redshift supernovae.

WFIRST: wider field, in space
ULTIMATE: accessible up to 2.3µm
Searching for pair-instability supernovae

**Pair-instability supernova (PISN)**
Supernovae that most easily explode theoretically. Predicted in 1960s.
Explosions of massive stars with the He cores between ~ 65 Msun and ~ 135 Msun
Corresponds to the ZAMS mass between ~ 150 Msun and ~ 250 Msun when there is no mass loss

Langer (2012)
Searching for pair-instability supernovae

PISNe: need to have massive He core to explode
when metallicity is high,
mass loss prevents massive He core formation
Searching for pair-instability supernovae

PISNe: need to have massive He core to explode

when metallicity is high,
mass loss prevents massive He core formation

First stars

1. no metals, almost no mass loss
2. many massive stars are predicted to form (top heavy IMF)

first stars between 150 Msun and 250 Msun should explode as PISNe

NIR transient survey

Hirano et al. (2015)

First star IMF

high-redshift SN survey = NIR transient survey
Searching for pair-instability supernovae

PISNe can produce a lot of radioactive $^{56}\text{Ni}$ and become very luminous “hypernovae”: produce 0.5 - 1 Msun of $^{56}\text{Ni}$

PISNe: ~ 50 Msun or more $^{56}\text{Ni}$ can be synthesized at most

Moriya et al. (2019)
Survey strategy

- one epoch / half year is enough to discover PISNe at $z > 6$
- to reach $z > 6$ where Pop III star formation occurs, we need 26.5 mag/epoch
Survey strategy

• if we cover 1 deg2 with ULTIMATE (14’ x 14’) down to K = 26.5 mag every half year..
  • 70 hours/epoch (~ 9 nights/epoch)
• if we conduct 5 year survey, 700 hours (~ 90 nights) are required.
• we can also get very deep K band image for 1 deg2!!
Discovering PISNe from the first stars

- survey simulation by assuming de Souza et al. (2014) Pop III SFR
Discovering PISNe from the first stars

Moriya et al. (2019)

WFIRST 26.5 mag limit (F184)
ULTIMATE-Subaru 26.5 mag limit (K)

t_{\text{int}} = 180 \text{ days}, \, N_d = 2

Flat IMF

\Delta z = 0.1
Discovering PISNe from the first stars

Moriya et al. (2019)
Discovering PISNe from the first stars

<table>
<thead>
<tr>
<th>Band</th>
<th>FoV</th>
<th>Limit</th>
<th>$t_{\text{int}}$</th>
<th>$N_d$</th>
<th>Flat IMF</th>
<th>Salpeter IMF</th>
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<tbody>
<tr>
<td></td>
<td>(deg$^2$)</td>
<td>(mag)</td>
<td>(d)</td>
<td></td>
<td>$z &gt; 5$</td>
<td>$z &gt; 6$</td>
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<td>$K^*$</td>
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<td>26.5</td>
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<td>7.9 ± 0.4</td>
<td>2.4 ± 0.2</td>
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<td>26.5</td>
<td>180</td>
<td>3</td>
<td>6.4 ± 0.5</td>
<td>1.8 ± 0.3</td>
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<tr>
<td></td>
<td>2</td>
<td>26.0</td>
<td>180</td>
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<tr>
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<td>2</td>
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<td>180</td>
<td>3</td>
<td>3.4 ± 0.2</td>
<td>0.3 ± 0.1</td>
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<tr>
<td>$F184^i$</td>
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<td>26.0</td>
<td>90</td>
<td>3</td>
<td>5.0 ± 0.4</td>
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<tr>
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<td>10.6 ± 0.3</td>
<td>4.4 ± 0.2</td>
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<td>2</td>
<td>57 ± 2</td>
<td>6.8 ± 0.7</td>
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<td></td>
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<td>26.0</td>
<td>180</td>
<td>2</td>
<td>13.2 ± 0.6</td>
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</tr>
</tbody>
</table>

Moriya et al. (2019)
Discovering PISNe from the first stars

- expected numbers increase if we conduct the survey towards the clusters of galaxies thanks to the gravitational lensing

\[ \text{Flat IMF, RSG only}\]
\[ K = 26.5 \text{ mag limit}\]
\[ \text{tint} = 180 \text{ days, } N_d = 2, \Delta z = 0.1\]

\[ \text{no lensing random field clusters (average)} \]

<table>
<thead>
<tr>
<th>Source</th>
<th>( z &gt; 5 )</th>
<th>( z &gt; 6 )</th>
<th>( z &gt; 7 )</th>
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</thead>
<tbody>
<tr>
<td>No lensing</td>
<td>7.9 ± 0.4</td>
<td>2.4 ± 0.2</td>
<td>0.06 ± 0.03</td>
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<tr>
<td>Random field</td>
<td>8.1 ± 0.4</td>
<td>2.9 ± 0.2</td>
<td>0.7 ± 0.1</td>
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<tr>
<td>Cluster average</td>
<td>12.2 ± 1.7</td>
<td>6.4 ± 1.5</td>
<td>3.6 ± 1.3</td>
</tr>
</tbody>
</table>

\[ K = 26.0 \text{ mag limit}\]

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<th>( z &gt; 7 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No lensing</td>
<td>2.4 ± 0.2</td>
<td>0.52 ± 0.08</td>
<td>0</td>
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<tr>
<td>Random field</td>
<td>2.9 ± 0.2</td>
<td>0.61 ± 0.09</td>
<td>0.08 ± 0.03</td>
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<tr>
<td>Cluster average</td>
<td>5.5 ± 1.1</td>
<td>2.2 ± 0.8</td>
<td>1.1 ± 0.6</td>
</tr>
</tbody>
</table>

Wong et al. (2019)
Spectroscopic follow-up observations

• TMT, JWST…

• good candidate selection method required
  • simultaneous optical observations with HSC and/or WFIRST
  • host galaxy information
LTAO + X-Shooter-like spectrograph on Subaru?

- D-Shooter (Daughter of X-Shooter) — “ultimate” spectrograph

![Graph showing Moffat FWHM vs Wavelength](image)

- GLAO (0.2’’ @ K)
- LTAO (0.05’’ @ all λ)
LTAO + X-Shooter-like spectrograph on Subaru?

- D-Shooter (Daughter of X-Shooter) — “ultimate” spectrograph

started to talk with X-Shooter project scientist
Your input will be highly appreciated!
LTAO + X-Shooter-like spectrograph on Subaru?

- if we make a copy of X-Shooter by collaborating with ESO
  - cost: ~ 300 M JPY
  - GLAO commissioning at ~ 2026
Summary

- ~ 90 nights with ULTIMATE
- a few PISNe at $z > 6$
- very deep K band image in K band

Moriya et al. (2019)