The CANDELS + CLASH Supernova Program

Steve Rodney and Adam Riess

Report to the Space Telescope Users Committee
2013 October 17
## SN Program Summary

<table>
<thead>
<tr>
<th>Program</th>
<th>HST Cycle</th>
<th>Field</th>
<th>Survey Orbits</th>
<th>SNe Detected</th>
</tr>
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<tbody>
<tr>
<td>CANDELS</td>
<td>18-19</td>
<td>GOODS-S</td>
<td>230</td>
<td>23</td>
</tr>
<tr>
<td>5 fields</td>
<td>18</td>
<td>UDS</td>
<td>88</td>
<td>10</td>
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<tr>
<td>751 orbits</td>
<td>18</td>
<td>EGS-a</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>93 SNe</td>
<td>19</td>
<td>COSMOS</td>
<td>88</td>
<td>12</td>
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<tr>
<td></td>
<td>19-20</td>
<td>GOODS-N</td>
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<td>34</td>
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<tr>
<td></td>
<td>20</td>
<td>EGS-b</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>CLASH</td>
<td>18</td>
<td>Clusters 1-10</td>
<td>181</td>
<td>16</td>
</tr>
<tr>
<td>25 clusters</td>
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<td>Clusters 10-20</td>
<td>198</td>
<td>15</td>
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<tr>
<td>474 orbits</td>
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<td>Clusters 20-25</td>
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<tr>
<td>40 SNe</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td><strong>1225</strong></td>
<td><strong>133</strong></td>
</tr>
</tbody>
</table>

Note: includes “decliners” (SNe found after max brightness)
Redshift distributions of SN detections and follow-up

All SN Types (excludes decliners)

<table>
<thead>
<tr>
<th>Redshift</th>
<th>0.0</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
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<tbody>
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<td>CLASH</td>
<td>2</td>
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<td>6</td>
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<td>CANDELS</td>
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<td>ToO Follow-up</td>
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</tbody>
</table>

Number of SN Detections

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Trends in ToO Usage Over 3 Cycles

- less grism
- more reconnaissance
- more multiplexing
CANDELS/CLASH SN Papers

Published

- Graur, O. et al. submitted : Type Ia SN Rates from CLASH

This Year

- Patel, B. et al. in circulation : Lensed SNe from CLASH
- Rodney, S. et al. in circulation : Type Ia SN Rates from CANDELS

Next Year

- Frederiksen, T. et al. in prep : SN Host galaxies at z>1
- Rodney, S. et al. in prep : SN Colfax at z~2.1 with HST Medium Band IR filters
- Dahlen, T. et al. in concept : Core Collapse SNe at z>1.5
- Hayden, B. et al. in concept : Evolution of SNIa Host Galaxy Properties
- Strolger, L. et al. in concept : The Composite HST SN Sample 2002 - 2012
7 Type Ia SNe at $1 < z < 1.5$

- **GSD11Was**, $z=1.32$:
  - $\chi^2 = 1.4$
  - $P(Ia) = 1.00$
  - $\Delta t = 0.05$

- **GND13Cam**, $z=1.22$:
  - $\chi^2 = 1.1$
  - $P(Ia) = 0.82$
  - $\Delta t = 0.02$

- **EGS13Wai**, $z=1.17$:
  - $\chi^2 = 1.6$
  - $P(Ia) = 0.99$
  - $\Delta t = 0.01$

- **GND13Jay**, $z=1.02$:
  - $\chi^2 = 1.2$
  - $P(Ia) = 1.00$
  - $\Delta t = 0.01$

- **GND13Gar**, $z=1.07$:
  - $\chi^2 = 1.8$
  - $P(Ia) = 1.00$
  - $\Delta t = 0.02$

- **GND13Cam**, $z=1.01$:
  - $\chi^2 = 1.8$
  - $P(Ia) = 1.00$
  - $\Delta t = 0.02$
8 Type Ia SNe at $z > 1.5$
A Grism Alternative: SN Classification and Redshift Estimation using Med-band IR Filters

![Graph showing flux/transmission vs. wavelength for different SN types and redshifts.](image-url)
A Grism Alternative: SN Classification and Redshift Estimation using Med-band IR Filters

![Graph showing wavelength vs flux/transmission for different filters and redshifts](image)
The SNIa Rate to $z \sim 2$
The CANDELS+CLASH SN rates are uniquely suited for constraining the fraction of “prompt” Type Ia SNe that emerge from a very young population.
SNIIa Rates: measuring the fraction of SNIIa that explode promptly after formation

Fraction of SN IIa that are "prompt" ($\tau < 500$ Myr)

$\hat{f}_p = 0.8$

$0.5$

$0.1$
High-z SN Ia : Testing for evolution

Salzano, Rodney, et al. 2013

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Lensed SN Ia : SN Caracalla

B. Patel et al. (in prep)

Type Ia
z = 1.28
behind MACS1720

cluster mass modeling $\implies \Delta m_{\mu} = 0.83 \pm 0.16$ mag
Lensed SN Ia : SN Caracalla

B. Patel et al. (in prep)
Comparison against other high-z SN Ia and $\Lambda$CDM

SN Caracalla

B. Patel et al. (in prep)
Lensed SN Ia : SN Caracalla

B. Patel et al. (in prep)

Comparison against other high-z SN Ia and ΛCDM

Cluster mass modeling $\Rightarrow \Delta m_\mu = 0.83 \pm 0.16 \text{ mag}$

Light curve fit + ΛCDM $\Rightarrow \Delta m_\mu = 0.86 \pm 0.17 \text{ mag}$
How much of our science could have been achieved through a classic Large Program?

CANDELS + CLASH ~ 1500 orbits

“Really Large” program ~ 250 orbits

⇒ SN sample size reduced by a factor of ~6
How much of our science could have been achieved through a classic Large Program?

SN sample size reduced by a factor of ~6

+ it turns out SN Ia are intrinsically rare in the early universe

⇒ Instead of 15 SN Ia at z>1, we would have ~3
How much of our science could have been achieved through a classic Large Program?

SN sample size reduced by a factor of ~6

+ lensed SNe are intrinsically rare

⇒ Instead of 3 lensed SNe from CLASH, we would have probably none.
The added flexibility of a 3-year allocation was very important for the SN program!

- No way to predict the precise number of orbits needed in any given cycle
- Follow-up in Cycle 20 was very different than in Cycle 18
- Our science objectives evolved and our efficiency improved
The extraordinary commitment of STScI staff was key to the success of the SN program

Particularly:

- Tricia Royle (CANDELS PC)
- Beth Perriello (CLASH and SN PC)
- Tracy Ellis (data delivery)
- Calendar builders (27+ ToO disruptions)
- Greg Masci (STScI GOODS cluster support)