THE CANDELS+CLASH SUPERNOVA PROGRAM

Steve Rodney (JHU)
Adam Riess (STScI/JHU)

Azalee Bostroem
Stefano Casertano
Brad Cenko
Pete Challis
Tomas Dahlen
Mark Dickinson
Harry Ferguson
Alex Filippenko
Peter Garnavich
Or Graur
Brian Hayden
Jens Hjorth
Tom Holoiien
Saurabh Jha
David Jones

Bob Kirshner
Anton Koekemoer
Bruno Leibundgut
Dani Maoz
Tom Matheson
Curtis McCully
Elinor Medezinski
Bahram Mobasher
Alberto Molino
Mario Nonino
Brandon Patel
Marc Postman
Jeff Silverman
Lou Strolger
Ben Weiner

Redshift

\[ \text{SNR} \propto A M_\ast + B M_\ast \]
\[ \text{DTD} \propto t^{-1} \]
\[ \text{gaussian, } \tau = 1.5 \text{ Gyr} \]

0.1
0.5
1.0
1.5
2.0
2.5
Redshift

0.1
0.5
1.0
1.5
2.0
2.5
Redshift

0.0
0.5
1.0
1.5
2.0
2.5
Redshift

0.0
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2.5
Redshift

0.0
0.5
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1.5
2.0
2.5
Redshift

0.0
0.5
1.0
1.5
2.0
2.5
Redshift
SN-MCT Science Goals

1. Detection, classification and characterization of high redshift supernovae

2. Examination of SNIa environments at high redshift

3. Measurement of SN rates and constraints on progenitor models from the delay time distribution

4. Cosmology and systematic uncertainty tests using SNIa from the early universe
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## Orbits Used & SN Yield

<table>
<thead>
<tr>
<th>Program</th>
<th>HST Cycle</th>
<th>Field</th>
<th>Orbits Processed</th>
<th>Orbits Remaining</th>
<th>SNe Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>CANDELS</td>
<td>18-19</td>
<td>GOODS-S</td>
<td>230</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>5 fields</td>
<td>18</td>
<td>UDS</td>
<td>88</td>
<td>0</td>
<td>10</td>
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<tr>
<td>751 orbits</td>
<td>18</td>
<td>EGS-a</td>
<td>50</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>COSMOS</td>
<td>88</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>19-20</td>
<td>GOODS-N</td>
<td>104</td>
<td>151</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>EGS-b</td>
<td>0</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>CLASH</td>
<td>18</td>
<td>Clusters 1-10</td>
<td>181</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>25 clusters</td>
<td>19</td>
<td>Clusters 10-20</td>
<td>198</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>474 orbits</td>
<td>20</td>
<td>Clusters 20-25</td>
<td>0</td>
<td>95</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td></td>
<td><strong>939</strong></td>
<td><strong>286</strong></td>
<td><strong>95</strong></td>
</tr>
</tbody>
</table>
CANDELS finds more at high-z due to larger WFC3-IR search area and wider cadence.
Classification and Characterization of High-z SNe

SN Primo : Type Ia SN at $z = 1.55$ from CANDELS
(at publication, the most distant spectroscopically confirmed SNIa)

Jones et al. (in prep)
SN Wilson : Type Ia SN at $z=1.91$ from CANDELS
(the most distant SNIa yet recorded)

Future papers (2013)
Type Ia SNe at $z=1.8, 2.1$ from CANDELS
Two SNe from CLASH with lensing magnification
1. Detection, Classification, Characterization

* SN Primo: Type Ia SN at $z = 1.55$ from CANDELS
* At publication, the most distant spectroscopically confirmed SNIa

Steve Rodney (JHU)  CANDELS+CLASH  SN Program
Jones et al. (in prep)
* SN Wilson: Type Ia SN at $z=1.91$ from CANDELS
* The most distant SNIa yet recorded

Steve Rodney (JHU)
CANDELS+CLASH SN Program
New modes for classification:
* HST Grism spectroscopy has been costly and difficult to accommodate
* At certain redshifts WFC3-IR medium-band filters can provide leverage for color classification
1. Detection, Classification, Characterization

Hubble Diagram Residuals

Steve Rodney (JHU)  CANDELS+CLASH SN Program
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2. High-z SNIa Environments

* Measured properties of the Primo host galaxy at z=1.55
* SED fitting + UVOIR spectrum from VLT+Xshooter
* Like other high-z SNIa hosts: high SFR, less mass than low-z SNIa hosts

Now in prep: the SN Wilson host galaxy at z=1.91 (will be Frederiksen et al. 2013)
2. High-z SNIa Environments

Hayden et al. (in prep)
* Extending the Frederiksen case studies to the full CANDELS SNIa sample
* Do correlations between host properties and SN brightness at low redshift persist at high z?
SN-MCT Science Goals

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3. SNIa Rates and Delay Times

Rodney et al. (in prep)
* Measured SNIa rates from the first half of CANDELS, to z~2
* Preliminary results still show a decline in the SNIa rate at z>1.5 (consistent with past HST rates measures)
3. SNIa Rates and Delay Times

Rodney et al. (in prep)
* To be consistent with the fashionable $t^{-1}$ delay time distribution, requires a steeply declining SFR(z)

Behroozi+ 2012
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TBD (2013-2014)
# Data Products

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Title</th>
<th>Description</th>
<th>First Release</th>
<th>Final Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Gold Type Ia SN Sample</td>
<td>Definite Type Ia SNe with good light curves and redshifts (N~8).</td>
<td>2013</td>
<td>2014</td>
</tr>
<tr>
<td>B</td>
<td>Full SN Sample</td>
<td>Both CCSN and SNIa. Some with sparse light curves or found on the decline. (N~100)</td>
<td>2013</td>
<td>2014</td>
</tr>
<tr>
<td>C</td>
<td>All Transients Catalog</td>
<td>Includes likely AGN, moving objects, variable stars, image artifacts, etc.</td>
<td>...</td>
<td>2014</td>
</tr>
<tr>
<td>D</td>
<td>Host Galaxy SED Fitting</td>
<td>SEDs and template fits for all host galaxies of SNe in samples A and B, with stellar mass, age, metallicity, etc.</td>
<td>2013</td>
<td>2014</td>
</tr>
<tr>
<td>E</td>
<td>Data Processing Pipeline</td>
<td>Python code with data processing pipeline and analysis tools.</td>
<td>...</td>
<td>2014</td>
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<tr>
<td>Science Goal</td>
<td>Paper Titles</td>
<td>Author (Institution)</td>
<td>Pub Date</td>
<td></td>
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<tr>
<td>--------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
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<tr>
<td>Detection, classification, characterization</td>
<td>“A Type Ia Supernova at Redshift 1.55 in HST Infrared Observations from CANDELS”</td>
<td>S. Rodney (JHU)</td>
<td>2012</td>
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<tr>
<td></td>
<td>“Discovery of the Most Distant Type Ia Supernova at Redshift 1.91”</td>
<td>D. Jones (JHU)</td>
<td>2013</td>
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<td></td>
<td>“Two Core Collapse Supernova at z&gt;2 from CANDELS”</td>
<td>T. Dahlen (STScI)</td>
<td>2013</td>
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<td></td>
<td>“Constraining Cluster Dark Matter Profiles with Strongly Lensed SNe from CLASH”</td>
<td>C. McCully (Rutgers)</td>
<td>2013</td>
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<tr>
<td></td>
<td>“Discovery, Classification and IR Light Curves for N SNE in CANDELS+CLASH”</td>
<td>D. Jones (JHU)</td>
<td>2013</td>
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<td>“The Complete CANDELS+CLASH Transient Catalog”</td>
<td>O. Graur (Tel Aviv+AMNH)</td>
<td>2014</td>
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<tr>
<td></td>
<td>“Classification and Redshift from Medium-band IR Observations of Two SNe at z&gt;1.5”</td>
<td>S. Rodney (JHU)</td>
<td>2013</td>
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<tr>
<td>High-z SN Environments</td>
<td>“The Dwarf Starburst Host Galaxy of a Type Ia SN at Redshift 1.55”</td>
<td>T. Frederiksen (U.Copen.)</td>
<td>2012</td>
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<td></td>
<td>“Two Supernova Host Galaxies at Redshifts z&gt;1.5”</td>
<td>T. Frederiksen (U.Copen.)</td>
<td>2012</td>
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<td>“Environmental Effects on the Properties of High Redshift Type Ia Supernovae”</td>
<td>B. Hayden (Notre Dame)</td>
<td>2013</td>
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<td></td>
<td>“Properties of High Redshift SNIa Host Galaxies from HST and VLT+Xshooter”</td>
<td>T. Frederiksen (U.Copen.)</td>
<td>2013</td>
<td></td>
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<td>“Probing SN Environments with Sub-galactic SED Fitting of Their Host Galaxies”</td>
<td>B. Mobasher (UC Riverside)</td>
<td>2014</td>
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<tr>
<td>SN rates and the Delay Time Distribution</td>
<td>“The Volumetric Type Ia Supernova Rate From the First Half of CANDELS”</td>
<td>S. Rodney (JHU)</td>
<td>2013</td>
<td></td>
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<td></td>
<td>“The Volumetric Type Ia Supernova Rate From the First Half of CLASH”</td>
<td>O. Graur (Tel Aviv+AMNH)</td>
<td>2013</td>
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<td>“New Constraints on the SNIa Delay Time Distribution from CANDELS + CLASH”</td>
<td>L. Strolger (WKU)</td>
<td>2013</td>
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<td>“The Core Collapse SN Rate to z~1 from CANDELS + CLASH”</td>
<td>T. Dahlen (STScI)</td>
<td>2013</td>
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<td>“The SNIa Delay Time Distribution in CANDELS+CLASH from Host Galaxy Ages”</td>
<td>S. Rodney (JHU)</td>
<td>2013</td>
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<td>“The Volumetric SNIa Rate from the Full CANDELS+CLASH Survey”</td>
<td>O. Graur (Tel Aviv+AMNH)</td>
<td>2013</td>
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<td></td>
<td>“The SNIa Delay Time Distribution from the Full CANDELS+CLASH Survey”</td>
<td>L. Strolger (WKU)</td>
<td>2014</td>
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<tr>
<td>SN Cosmology &amp; Systematics</td>
<td>“Improving Dark Energy Constraints with High-z SNIa from CANDELS+CLASH”</td>
<td>V. Salzano (UPV/EHU)</td>
<td>2013</td>
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<td>“Examining SNIa Evolution Without Dark Energy Interference at z&gt;1.5”</td>
<td>A. Riess (JHU + STScI)</td>
<td>2013</td>
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<td>“The Dark Energy Equation of State with SNIa from CANDELS+CLASH”</td>
<td>D. Scolnic (JHU)</td>
<td>2014</td>
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<td>“Testing Exotic Cosmologies with SNIa from CANDELS+CLASH”</td>
<td>D. Scolnic (JHU)</td>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Survey Operations</td>
<td>Completion Targets</td>
<td>Data Product Release</td>
<td>Primary Publications</td>
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<tr>
<td>------------</td>
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<td>-------------------------------------------------------------</td>
<td>------------------------------------------</td>
<td>--------------------------------------------</td>
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</tbody>
</table>
| 2012.11 - 12 | GOODS-N epoch 07  
Start CLASH cluster 21  
GOODS-N epoch 08  
Start CLASH cluster 22 | Visual search of reprocessed data                           | B1: 2-yr Full SN Catalogs                | Jones “SN Ia at z=1.91”  
Frederiksen “SN Ia Host at z=1.91” |
| 2013.01 - 02 | GOODS-N epoch 09  
Start CLASH cluster 23  
GOODS-N epoch 10 |                                 |                                           | Rodney “CANDELS Rates 1”  
Graur “CLASH Rates 1” |
| 2013.03 - 04 | Start CLASH cluster 24  
GOODS-N epoch 11  
EGS-b epoch 01  
GOODS-N epoch 12 | Automated search of reprocessed data                        | A1: Gold SN Ia light curves  
D1: SN Ia Host Gal. SED Fits | Jones “SN Light Curves and Classification”  
Hayden “Host Galaxy and SN Properties”  
Frederiksen “SN Hosts with HST+VLT” |
| 2013.05 - 06 | EGS-b epoch 02  
Start CLASH cluster 25  
GOODS-N epoch 13 |                                 |                                           |                                           |
| 2013.07 - 08 | GOODS-N epoch 14 |                                 |                                           |                                           |
| 2013.09 - 10 | All survey data in Cycle 20 Ends |                                 |                                           |                                           |
| 2013.11 - 12 | HST Follow-up Completed |                                 |                                           |                                           |
| 2014.01 - 02 | Final SN Classifications |                                 |                                           |                                           |
| 2014.03 - 04 | Final Light Curve Fitting |                                 |                                           |                                           |
| 2014.05 - 06 | Final Host Galaxy Redshifts Collected |                                 | C2: SN Host Galaxy SED Fits  
B2: Full SN Sample | Graur “SN Ia Rates 2”  
Strolger “DTD 2”  
Dahlen “CCSN Rates” |
| 2014.07 - 08 | D2: All Transients Catalog  
E2: Data Processing Pipeline |                                 |                                           | Graur “All Transients Catalog”  
Rodney “Data Processing pipeline” |
| 2014.09 - 10 | A2: Gold SN Ia Sample |                                 |                                           | Scolnic “High-z SN Cosmology”  
Riess “High-z SN Evolution” |
Notable STScI Support

- Guard Dark Program: dark frames before each epoch, ongoing in Cycle 20 (PID 13081), very helpful for avoiding false positive SN detections
  
  Brian Hilbert, Knox Long

- Fast-ftp delivery and MAST data hosting: rapid responses to problems, careful attention to scheduling of planned downtime
  
  Tracy Ellis, Karen Levay

- Scheduling: Complex constraints on survey orbits and rapid, flexible handling of ToO Follow-up visits

  Beth Perriello, Tricia Royle, calendar builders, etc.
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Redshift

SNR ∝ A M, + B M,  

DTD ∝ t⁻¹

gaussian, τ=1.5 Gyr