The Classification of Supernovae: Prospects & Challenges for the LSST Era

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CIERA/Northwestern University & Adler Planetarium

CIERA LSST SN Workshop
2 June 2017

Filippenko 97
SNe with LSST

LSST will discover ~2000 new SNe per night

Vast majority will be faint (m > 23 mag)

~1000 hr/night on 8-m class telescopes needed for spec

~100 hr/night available on all 8-m class telescope

LSST will primarily be a photometric-only transient survey
(brief) History of SN Classification

1941  Minkowski separates Types I & II
      9 objects: homogeneous & lack H (type I)
      5 objects: have H, but heterogeneous (type II)
(brief) History of SN Classification

1941 Minkowski separates Types I & II

1964 Bertola separates Type Ib from Ia
   1962L — lacks strong Si II absorption

spec
(brief) History of SN Classification

1941  Minkowski separates Types I & II

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1965  Zwicky introduces Types III, IV & V

1961I  — broad light curve maximum, type III
1961F  — weak H emission, type IV
1961V  — unusual light curve & spectrum, type V

spec & phot
(brief) History of SN Classification

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  — 1961I — broad light curve maximum, type III
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  — 1961V — unusual light curve & spectrum, type V

All are type II (peculiar)
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<th>Event</th>
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<td></td>
<td>15 type II SNe show “plateau”</td>
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<td>8 type II SNe show linear decline</td>
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<td>1983V — does not show He I absorption</td>
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History of SN Classification

1941 Minkowski separates Types I & II
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1965 Zwicky introduces Types III, IV & V
1979 Barbon et al. separate Type IIP from IIL
1986 Wheeler & Harkness separate Type Ic from Ib
1988 Filippenko suggests continuum of events II \rightarrow Ib

1987 K - spectrum transitions from II \rightarrow Ib “IIb”
such events were predicted by Woosley, who coined term IIb
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8 type II SNe with narrow emission on top of broad base
(brief) History of SN Classification

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(brief) History of SN Classification

SN spectrum

\[ \text{H?} \]

\[ \text{yes} \rightarrow \text{II} \]
\[ \text{no} \rightarrow \text{He?} \]

\[ \text{yes, then no} \]

\[ \text{narrow?} \]

\[ \text{yes} \rightarrow \text{IIln} \]
\[ \text{no} \rightarrow \text{II} \]
\[ \text{no} \rightarrow \text{Ib} \]

\[ \text{He?} \]

\[ \text{yes} \rightarrow \text{Ic} \]
\[ \text{no} \rightarrow \text{Ia} \]

\[ \text{Si & S?} \]

\[ \text{no} \rightarrow \text{Ia} \]
(brief) History of SN Classification

Two big issues:

Physical understanding (often) post taxonomical classification

Spectroscopy drives our classification scheme
Should New Scheme Be Adopted?

A possibility put forth in the Handbook of Supernovae (A. Gal Yam chapter)

\[\text{SN} \quad \text{AA} \quad X.Y \quad iX.Y \quad mX.Y \quad vX.Y \quad rX.Y \quad dX.Y\]

**AA** : string
   “Ia” for thermonuclear, “CC” for core-collapse

**X.Y** : float
   0.0 = strong H, 1.0 = strong He, no H, 2.0 = no He, no H

**iX.Y** : float, optional
   interaction flag. i0.0 = H interaction, i1.0 = He interaction

**mX.Y** : float, optional
   peak magnitude offset from mean class member

**vX.Y** : float, optional
   fractional shift in velocity with respect to mean class member @ peak

**rX.Y** : float, optional
   rise time to peak in rest-frame days

**dX.Y** : float, optional
   decline rate. \(\Delta m_{15}(R)\)
(Brief) Intro to Machine Learning

- Labeled Data
- Training Data
- Test Data
- Machine Learning Model
- Unlabeled Data
- Mapping between features and labels
- Model evaluation on independent data
- Predictions on unlabeled data
SNPhotCC

Supernova Photometric Classification Challenge (SNPhotCC)

Developed by R. Kessler and S. Jha in 2010 to simulate DES-like light curves

~100k simulated light curves (5 yr baseline), ~18k light curves in challenge

1256 SNe training set, based on hypothetical follow-up

2 challenges for users: classify full light curves, classify on the 6th detection
Problems with the DES classification challenge:

TABLE 2

<table>
<thead>
<tr>
<th>Non-Ia subtype</th>
<th>Fraction</th>
<th>No. of measured templates</th>
<th>No. of composite templates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ibc</td>
<td>0.29</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>II-P</td>
<td>0.59</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>II-L</td>
<td>0.08</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>II-n</td>
<td>0.04</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Kessler+10

To be addressed by PLAsTiCC?
SNPhotCC

4 general strategies employed:
- Fit Ia template to determine type
- Bayesian inference using Ia and non-Ia templates
- Define Hubble diagram >> Ia are those that are close
- Perform parametric light curve fits, then ML/statistics

Gjergo+13
Sako+11
Newling+11
Richards+12
SNPhotCC

4 general strategies employed:
- Fit Ia template to determine type
- Bayesian inference using Ia and non-Ia templates
- Define Hubble diagram >> Ia are those that are close
- Perform parametric light curve fits, then ML/statistics

No single method clearly outperforms others

For SNe Ia — Efficiencies typically high, purity somewhat lower
ML for SN Classification

To optimize ML classification — follow-up should be random

<table>
<thead>
<tr>
<th>Set</th>
<th>S</th>
<th>( S_B )</th>
<th>( S_{m,23.5} )</th>
<th>( S_{m,24} )</th>
<th>( S_{m,24.5} )</th>
<th>( S_{m,25} )</th>
<th>( S_{z,0.4} )</th>
<th>( S_{z,0.6} )</th>
<th>( D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1103</td>
<td>686</td>
<td>294</td>
<td>73</td>
<td>26</td>
<td>11</td>
<td>44</td>
<td>15</td>
<td>1103</td>
</tr>
<tr>
<td>( \mathcal{P} )</td>
<td>0</td>
<td>1765</td>
<td>979</td>
<td>508</td>
<td>272</td>
<td>155</td>
<td>240</td>
<td>117</td>
<td>19 792</td>
</tr>
<tr>
<td>Total</td>
<td>1103</td>
<td>2451</td>
<td>1273</td>
<td>587</td>
<td>302</td>
<td>165</td>
<td>284</td>
<td>135</td>
<td>20 895</td>
</tr>
</tbody>
</table>

Reduce \( N_{\text{spec}} \) by \( \sim 7x \)

<table>
<thead>
<tr>
<th>Training set</th>
<th>( \epsilon^* )</th>
<th>( i_{\text{la}}^* )</th>
<th>( f_{\text{la}}^* )</th>
<th>( \hat{f}_{\text{la,pred}} )</th>
<th>( \hat{p}_{\text{la,pred}} )</th>
<th>( \hat{e}_{\text{la,pred}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1.4</td>
<td>0.58</td>
<td>0.757</td>
<td>0.126</td>
<td>0.503</td>
<td>0.497</td>
</tr>
<tr>
<td>( S_B )</td>
<td>1.4</td>
<td>0.65</td>
<td>0.840</td>
<td>0.011</td>
<td>0.240</td>
<td>0.125</td>
</tr>
<tr>
<td>( S_{m,23.5} )</td>
<td>1.4</td>
<td>0.54</td>
<td>0.796</td>
<td>0.058</td>
<td>0.404</td>
<td>0.316</td>
</tr>
<tr>
<td>( S_{m,24} )</td>
<td>1.0</td>
<td>0.46</td>
<td>0.728</td>
<td>0.155</td>
<td>0.605</td>
<td>0.459</td>
</tr>
<tr>
<td>( S_{m,24.5} )</td>
<td>1.0</td>
<td>0.45</td>
<td>0.610</td>
<td>0.250</td>
<td>0.730</td>
<td>0.501</td>
</tr>
<tr>
<td>( S_{m,25} )</td>
<td>1.0</td>
<td>0.37</td>
<td>0.494</td>
<td>0.305</td>
<td>0.724</td>
<td>0.654</td>
</tr>
<tr>
<td>( S_{z,0.4} )</td>
<td>1.4</td>
<td>0.41</td>
<td>0.664</td>
<td>0.061</td>
<td>0.896</td>
<td>0.085</td>
</tr>
<tr>
<td>( S_{z,0.6} )</td>
<td>1.2</td>
<td>0.29</td>
<td>0.600</td>
<td>0.112</td>
<td>0.772</td>
<td>0.249</td>
</tr>
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</table>

Increase FoM by \( \sim 2.5x \)
ML for SN Classification

Feature extraction > algorithm choice

Lochner+16

Lochner+16

Newling+11

Lochner+16

Newling+11
ML for SN Classification

Deep Learning (DL) adopted by Charnock & Moss 2017

DL does not require any feature engineering

Overall classifications are similar to other ML methods

Most promising solution for ~real-time classification

(72% purity & 63% completeness)
ML for SN Classification

Initial results on real data (Open SNe Catalog) are promising
Conclusions

LSST will be a photometric only survey
~2k SNe/night; real-time spectra won’t happen

SN Classification is a mess
Classes defined from small samples (ignoring continuous distributions)
Spec scheme may not be useful for LSST

Machine learning is great — might solve LSST SNe classification
Beware data-driven methods, they need data
Cadence will play a big role here

Optimal follow-up (for ML) requires representative training set
Biases toward bright end degrade ML performance

Ia/non-Ia classification is not good enough (be more ambitious)
Ia (for cosmo) and IIp are easy (see D. Scolnic & R. Chornock talks)
Lots of ML development right now - we should be asking hardest questions