Supernova Classification Using Swift UVOT Photometry

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Abstract

With the great influx of supernova discoveries over the past few years, the observation time needed to acquire the spectroscopic data needed to classify supernova by type has become unobtainable. Instead, using the photometry of supernova could greatly reduce the amount of time between discovery and classification. For this project we looked at the relationship between colors and supernova types through machine learning techniques in Python. Using data from the Swift Ultraviolet/Optical Telescope (UVOT), each photometric point was assigned values corresponding to colors, absolute magnitudes, and the relative times from the peak brightness in several filters. These values were fed into three classifying methods, the nearest neighbors, decision tree, and random forest methods. We will discuss the success of these classification systems, the optimal filters for photometric classification, and ways to improve the classification.

Introduction

Type Ia supernovae (SNe Ia) are an important tool in observational cosmology and are characterized by a strong Si II absorption line and an absence of a hydrogen absorption line in the spectroscopic data. In order to see these characteristics in the data, a telescope equipped with a spectrometer must be available. With the increased number of photometric observations of SNe, these spectroscopic follow-up observations become more difficult to keep up with. Instead, there has been an effort to classify SNe using their light curves.

Machine learning algorithms have been implemented to classify SNe from light curves like those in Figure 1 (Kessler 2010, Lechner 2016). For this project we use the Python package Scikit-learn (Pedregosa 2011) to assess the success rate of three different classification methods in classifying SNe Ia. All three of the classifiers rely on characteristics defined by the user. From the Swift UVOT data, 22 characteristics (including 10 colors, 6 absolute magnitude values, and 6 relative times from the peak brightness in each of the filters) were assigned to each photometric point as well as one of the possible SN types (Ia, Ib, Ic, II). These data structures were separated randomly into training and testing sets.

Classifiers

- K Nearest Neighbors Classification (KNN) – Of the three classifiers, the KNN algorithm does not generate a model from which it draws conclusions. Instead it looks at the points in the training set and assigns a class to the new object based on its closest neighbors in the feature space. The space in which this classifier works is hard to visualize when there are more than three features. The k value indicates how many of the nearest neighbors the algorithm looks at. For this project, k = 15.
- Decision Tree Classification (DT) – This classifier builds a decision tree based on different cutoff values for all of the features fed into the program. These trees are more easily visualized when the feature list includes more than three characteristics.
- Random Forest Classification (RF) – Using the same main ideas as the DT classifier, this classifier creates many trees based on subsets of the dataset. The trees are then compared to each other to find the optimal decision tree.

Data

- The data, in six filters: uvw2, uvm2, uvw1, u, b, and v, comes from the Swift Optical/Ultraviolet Supernova Archive (SOUSA).
- Calculated absolute magnitudes using distance moduli from Cepheids, star brightness fluctuations, planetary nebula luminosity functions, and host galaxy velocities.
- Of the 172 SN with sufficient observation data and calculated absolute magnitudes, 660 photometric points were available to use for the classifiers.
- The photometric points were randomly assigned to training (396 points) and testing (264 points) sets.
- Each feature, or characteristic, was assigned a number:

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>uvm2-uvw1</td>
<td>uvm2-u</td>
<td>uvw1-b</td>
<td>uvw2-u</td>
<td>u-v</td>
<td>b-v</td>
</tr>
</tbody>
</table>

Results

- KNN
- DT
- RF

<table>
<thead>
<tr>
<th>Classifiers</th>
<th>Ia precision</th>
<th>Ia recall</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNN</td>
<td>0.71</td>
<td>0.98</td>
<td>0.73</td>
</tr>
<tr>
<td>DT</td>
<td>0.82</td>
<td>0.98</td>
<td>0.81</td>
</tr>
<tr>
<td>RF</td>
<td>0.76</td>
<td>0.99</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Future Work

Parameterizing the entire light curves instead of relying on individual photometric points could lead to a higher total score. To see if some of the misclassifications come from missing data, we could use simulated light curves with no epochs of missing observations. We could see if this process works on other transient objects.

References

Kessler, R. et al. Results from the Supernova Classification Challenge (2010)

Acknowledgments

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