Modeling the Diversity of Transient Light Curves through PCA

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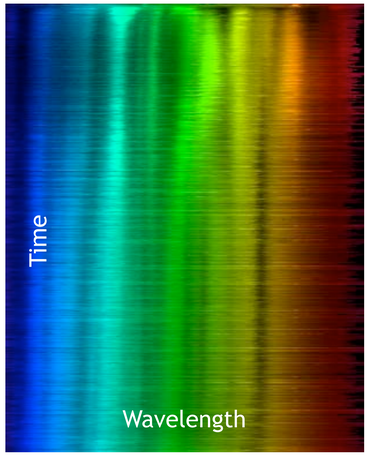
Introduction

Nancy Grace Roman Space Telescope would discover a large number of transients which exhibits a wide variety of diversity in light curves. It is important for us to model photometric light curves with a small number of variables. PCA (Principal Component Analysis) is a technique which enables us to summarize observed diversity with a small number of parameters. We demonstrate that both spectral time series and spectral diversity can be expressed by a small number of parameters. Eventually, we can relate these PCA coefficients to the physical properties and feed into AI for classification and analysis.

Method I : Time Series

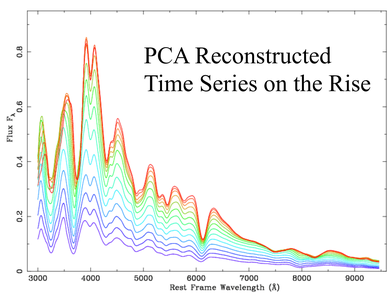
First, as an example, we demonstrate a time series of Type Ia supernova can be expressed by 3 parameters.

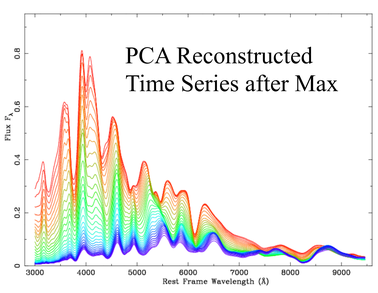


Left figure is a collection of spectral time series of SNIa from the literature and spectral resolution is homogenized. We calculate covariance matrix and diagonalize it to derive eigen spectra which is orthogonal to each other.

$$\vec{S} = \vec{\mu} + \sum_{j=1}^{n} c_j \vec{\xi_j} \qquad \vec{\xi_i} \cdot \vec{\xi_j} = \delta_{ij}$$

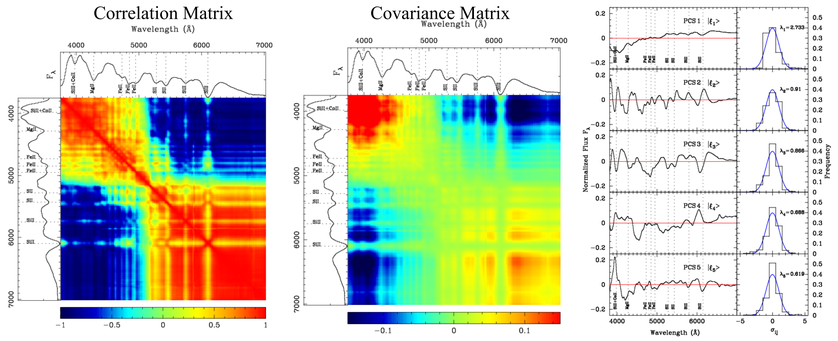
Below is a successful reconstruction of time series using primary 3 eigen spectra.



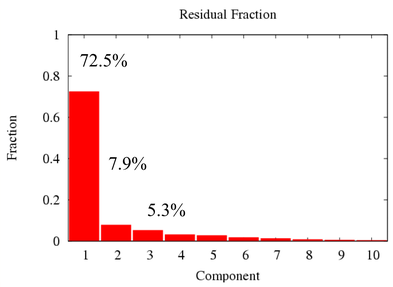


Method II : Diversity

Second, we demonstrate PCA application to the diversity of supernovae

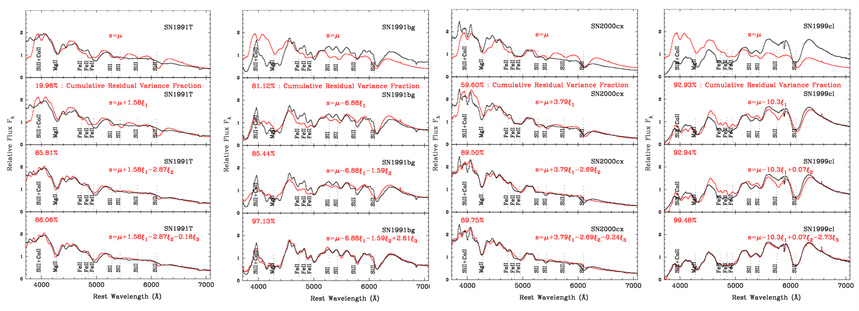


For a demonstration purpose, we fix the phase for now at the time of maximum, and we compose correlation matrix (left) and covariance matrix (middle). Correlation matrix shows high degree of correlation between spectral lines which implies the data can be represented by a small number of parameters. We diagonalize the covariance matrix and derive the eigenspectra (right).



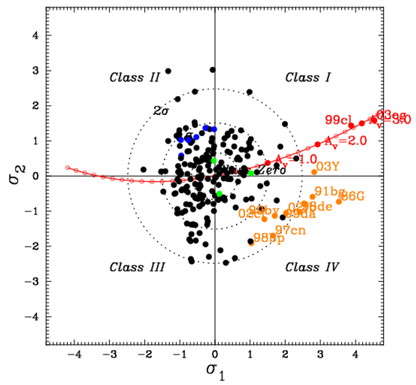
How many eigenspectra?

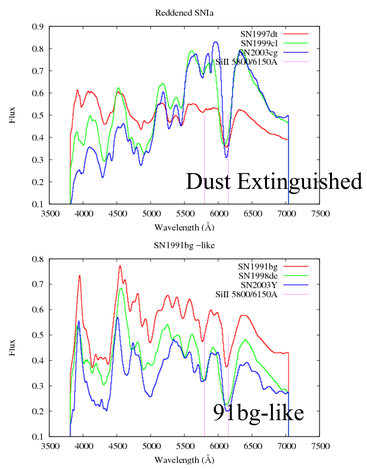
Histogram shows how important the primary eigenspectra are. 86% of variance can be absorbed by the 3 eigenspectra. Figures below shows the reconstruction process using 3 eigenspectra + mean spectrum. With 3 coefficients, we can describe normal, 91T, 91bg, 00cx-like and dust-extinguished SNe



Diversity described by PCA coefficients

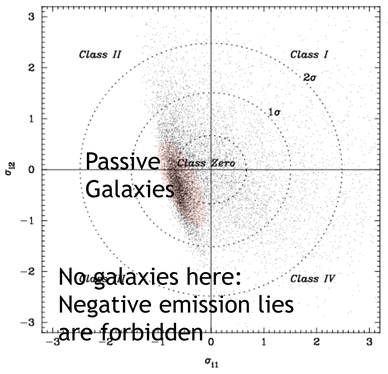
Figure (left below) shows the distribution of PCA coefficients of the first 2 eigenspectra and the red locus represents dust extinguished SNe while orange color dots represents 91bg-like SNe.



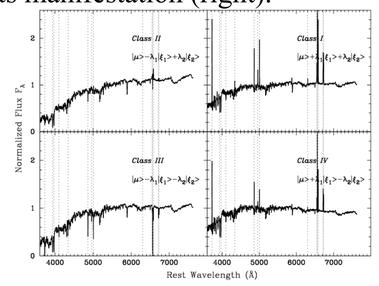


Future Applications

This technique can be applied any transients. SN-Ibc, SNII and kilonova templates are being developed. PCA is already widely used by SDSS for galaxies, sttellar spectra and quasars.



Another example of galaxies. PCA coefficient distribution (left) and its manifestation (right).



References

1. Suzuki et al. (2005). ApJ, 618, 592
2. Suzuki (2006): ApJS, 161, 110
3. Cormier & Davis (2011): MNRAS, 410, 2137

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