Supernovae Wavelet Spectral Index Method: A Step Toward Precision Cosmology

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Supernovae Wavelet Spectral Index Method: A Step Toward Precision Cosmology

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Summary
The wavelet spectral index method is a useful tool in studying Type Ia supernovae (SNe Ia), their evolution, and the correlations between peak magnitude and spectral features. The Wavelet Spectral Index Method (WSIM) eliminates much of the uncertainty inherent in the equivalent width methods used previously. Strong correlations have been found between several spectral features near maximum and the rate of decline after maximum. These correlations can be used in two ways: 1) to better calibrate the maximum magnitude of an individual SNe Ia, and 2) to develop synthetic spectra that correlate to different light curve shapes. Lastly, the WSIM can be expanded to other areas of research since it is not dependent on what type of spectra is being studied.

Introduction
In order to measure distances in the universe, astronomers use objects that have well-known brightness. These objects are referred to as “standard candles.” One such standard candle is the Type Ia supernova (SN Ia). These supernovae are believed to originate from a White Dwarf with a giant companion. The white dwarf’s gravity pulls material off of its companion, when the white dwarf has reached a mass of ~1.4 times the mass of the sun it becomes unstable and explodes. It has been shown that SNe Ia have essentially been removed. Also, with proper normalization, a natural reference (the zero flux line) arises so that the ambiguity of the continuum line is removed.

The Wavelet Spectral Index Method (WSIM)
The Wavelet Spectral Index Method (WSIM) uses the á trous wavelet (Holtschneider et al. 1989, Shensa 1992; Starck et al. 1995, 1997) to decompose each supernova spectrum into different components representing variations on each scale (see Figure 3). The lower scales contain mainly noise in the data while the higher scales contain information from the overall shape of the spectrum (i.e. the continuum). If only the components of the scales related to spectral feature widths are selected than the confounding variations have essentially been removed. Also, with proper normalization, a natural reference (the zero flux line) arises so that the ambiguity of the continuum line is removed.

Five spectral features were chosen and the spectral index was defined as the area enclosed between the zero flux line and the normalized flux, downward features were given negative indexes (see Figure 4). Spectra were gathered from depositaries freely available as well as a few unpublished spectra (ex. Harvard CfA SN Archive). These spectra were all run through the WSIM. The spectral catalog used contained spectra from as early as ~10 days before maximum to over two weeks after maximum. The results will be explained in the next section.

Results
The first thing that can be noticed about the WSIM is that it reproduces previous results. It had been previously shown that the Si II spectral feature with wavelength 5750 Å correlates strongly with the decline rate of the SN magnitude (Hachinger et al. 2006), WSIM successfully reproduces this (see Figure 5). Also, Branch et al. (2009) established subgroups of SNe Ia by plotting the two spectral features against each other, these groups are retained by the WSIM (see Figure 6).

The plots mentioned above use spectra near maximum brightness, however the WSIM is not restricted to maximum brightness. The spectral indexes can be traced over the course of the explosion. Spectral features can be seen weakening and even disappearing or (as in Figure 7) they can be seen strengthening. This evolution of the spectral features is due to changes in opacity in the explosion causing different compositional layers to be revealed.

The evolution of correlations between the spectral features with each other and with the decline rate can be explored (see Figure 8). It is clear that several strong correlations are present near maximum but there is also a second epoch of strong correlation 2-3 weeks after maximum. It is during these epochs that the most information can be extracted from the spectra. Lastly, Principal Components Analysis (PCA) was performed on the spectral index data and decline rates at each epoch. The PC1 coefficients are plotted in Figure 9 showing that epochs within 1 week of maximum all contribute nearly equally to the variation in the data.

Future Work
There is much to do with the WSIM. The WSIM was developed with the goal of developing a system to generate synthetic SNe Ia spectra. The purpose of this was to test photometric techniques to gather information about SNe Ia that would normally be gathered via the spectra. Another natural application was to develop a correction to the Hubble diagram using the PCA results. The WSIM method can also be extended into other regions of the spectra such as the near infrared which has shown some promise in correlating spectral features to the decline rate. Ultimately, the WSIM could be extended outside SNe research and even outside astronomy itself since there are very few assumptions about the data being analyzed.

References

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