Type II supernova spectral variability and spectral template

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SNe through the ages, 2016
Type II SNe: one family

Anderson+14
Motivation

- Light curve fitter for SNe II
- SiFTO (Conley+08) for SNe Ia uses spectro-photometric templates convoluted at different filters
- Can we do this for SNe II with SiFTO and Nugent template? → SN 2012A (typical SNIIP)
Motivation

Without a stretch factor
Motivation

SN 2013by

Without a stretch factor  With a stretch factor
Motivation

SN 2013by

Without a stretch factor

With a stretch factor

Spectrophotometric template:
Nugent+02
Can we find a general purpose light-curve fitter that simultaneously fits multiple filters at different redshifts and that properly accounts for SNII variability?
Type II spectral template

- Spectrophotometric template for SNe II with good wavelength and phase coverage
- Useful for many things: to understand SNII variability and physics: IIP-IIL, hydrogen
- Useful for K-corrections in cosmology
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Type II spectral diversity

SPEC SAMPLE
- At low-z: 261 SNe (CSP, literature)
- At high-z: 47 SNe (SDSS, SNLS)

REFERENCE EPOCH
- maximum
- explosion
Type II spectral sample

**SPEC SAMPLE**

- Use of >1300 spectra from >130 SNe from the CSP and the literature, corrected to rest-frame and MW extinction.

CATS, CSP: Gutierrez in prep.
SN II spectra and weights

- Wavelength coverage: 3500-9500Å, Epoch coverage: 0-150d after explosion → each attribute is a $\lambda$ at a given $t$ (bins of different size)

- Use of Savitzy-Golay filter to smooth all spectra and obtain an error
SN II spectra and weights

- Use of narrow bands colors to adjust base template: 1500km/s bin
- To avoid normalization problems take the derivative: $f_1/f_2, f_2/f_3$... or in mag the colors: $m_1-m_2, m_2-m_3$...
- Use logarithmic flux (magnitude) to take better into account the edges

Similar to SNe Ia (Hsiao+07)
Spectra average and weights

WEIGHTS
1. Spectral errors: $\omega^i_{\text{err}} = 1/\text{err}^2$
2. Spectral coverage: $\omega^i_{\text{cov}}$ with trapezoidal function to take into account miscalibration edges
3. Multiplicity or # spectra of same SN in given bin: $\omega^i_{\text{mult}}$
4. Effective date per given bin:

$$t_{\text{effective}} = \frac{\sum w_i t_i}{\sum w_i}$$

$$w_{\text{epoch}} = \exp \left[ \frac{(t_{\text{SN}} - t_{\text{effective}})^2}{2\sigma_t} \right]$$

→ Final weight:

$$\omega_i = \omega^i_{\text{err}} \cdot \omega^i_{\text{cov}} \cdot \omega^i_{\text{mult}} \cdot \omega_{\text{epoch}}$$

(Other weights: telluric lines, peculiarity)

AVERAGE
For each grid element:

$$c = \frac{\sum w_i c_i}{\sum w_i}$$

Similar to SNe Ia (Hsiao+07)
SNII spectral template

Preliminary spectral template series

Caveats:
1. Not photometric yet
2. Spectra with respect to maximum

Normalized to B-band
Preliminary spectro-photometric template series

1. Normalized to SNII light-curves (L. Galbany)
2. Spectra with respect to maximum
Principal Component Analysis (PCA)

Search of “principal component” eigenvectors that describe most of the data with the fewest number of components.

http://stats.stackexchange.com/
Principal Component Analysis (PCA)

Search of “principal component” eigenvectors that describe most of the data with the fewest number of components.

PCA allows you to reconstruct the data with fewer variables and losing little information.

If $X$ is the original data matrix ($n_{obs} \times n_{var}$) and $\bar{X}$ the vector of means, then one can reconstruct the data:

$$F_{rec} \approx \bar{X} + \sum_{j=1}^{M} c_j P_j$$

where $P_j$ is the matrix of eigenvectors and $c_j$ are the projections of the data on $P_j$.

Classic PCA solves the following minimization problem:

$$\chi^2 = \sum_{i,j} [X_{ij} - PC_{ij}]^2$$
Expectation Maximization PCA (EMPCA)

- Expectation maximization (EM) is an iterative method to maximize a likelihood function for models with hidden (latent) variables.
- It allows the inclusion of weights, so that:
  \[ \chi^2 = \sum_{i,j} W_{ij} [X - PC]_{ij}^2 \]
- With weights \( W_{ij} = 0 \), one can have missing data.
- It involves two steps in each iteration:
  1. E-step: find expectation value of hidden variables with current model:
     \[ c_j \leftarrow \bar{x}_j \cdot \phi \]
  2. M-step: modify model parameters to maximize fit likelihood:
     \[ \phi \leftarrow \frac{\sum_j c_j \bar{x}_j}{\sum_j c_j^2} \]

Similar to Bailey+09, Sadelli+15
PCA vs EMPCA: example

- Sum of sine functions multiplied by random numbers:
- Perturbed with a different noise and added zero weights (missing data):
PCA vs EMPCA: example

- Eigenvectors found:
PCA vs EMPCA: example

- Eigenvectors found:
SNII EMPCA reconstruction

Nvec=8
Epoch=+5d
SNII EMPCA eigenvectors

Eigenvector #0

Eigenvector #1

Eigenvector #2

Eigenvector #3

Ha line

continuum

RATIO SPECTRA
SNII EMPCA eigenvectors

RATIO SPECTRA

NORMAL SPECTRA

Eigenvector #0

Eigenvector #1

Eigenvector #2

Eigenvector #3

Ha line

continuum
SNII EMPCA projections

Spectroscopic parameters (C. Gutierrez)

Errors calculated with MC that changes random seed and included reference epoch uncertainties
Spectroscopic parameters (C. Gutierrez)
SNII EMPCA projections

Photometric parameters

Anderson+14
SNII EMPCA projections

Photometric parameters

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Outlook

- Construct template based on eigenvectors
- Test EMPCA template for K,S-corrections
- Include bluer wavelengths (high-z) and IR (low-z)
- Compare to EMPCA from light-curves (L.Galbany) and obtain common parameters
- Develop a fitter for SNe II