

Finding Spectral Twin Type Ia Supernovae Using PCA

Reis Tyson (r.tyson1@lancaster.ac.uk)

Supervisor: Dr Mathew Smith

Lancaster University Physics Department, Lancaster, LA1 4YB, United Kingdom



(1) Spectra as Luminosity Indicators

- Type Ia supernovae (SNIa) are standardisable candles used in cosmology.
- Spectra encode ejecta composition, velocity and temperature – all of which correlate to intrinsic SNIa luminosity. [1]
- Broad absorption features (shown in figure 1) vary between supernovae and encode underlying explosion physics.

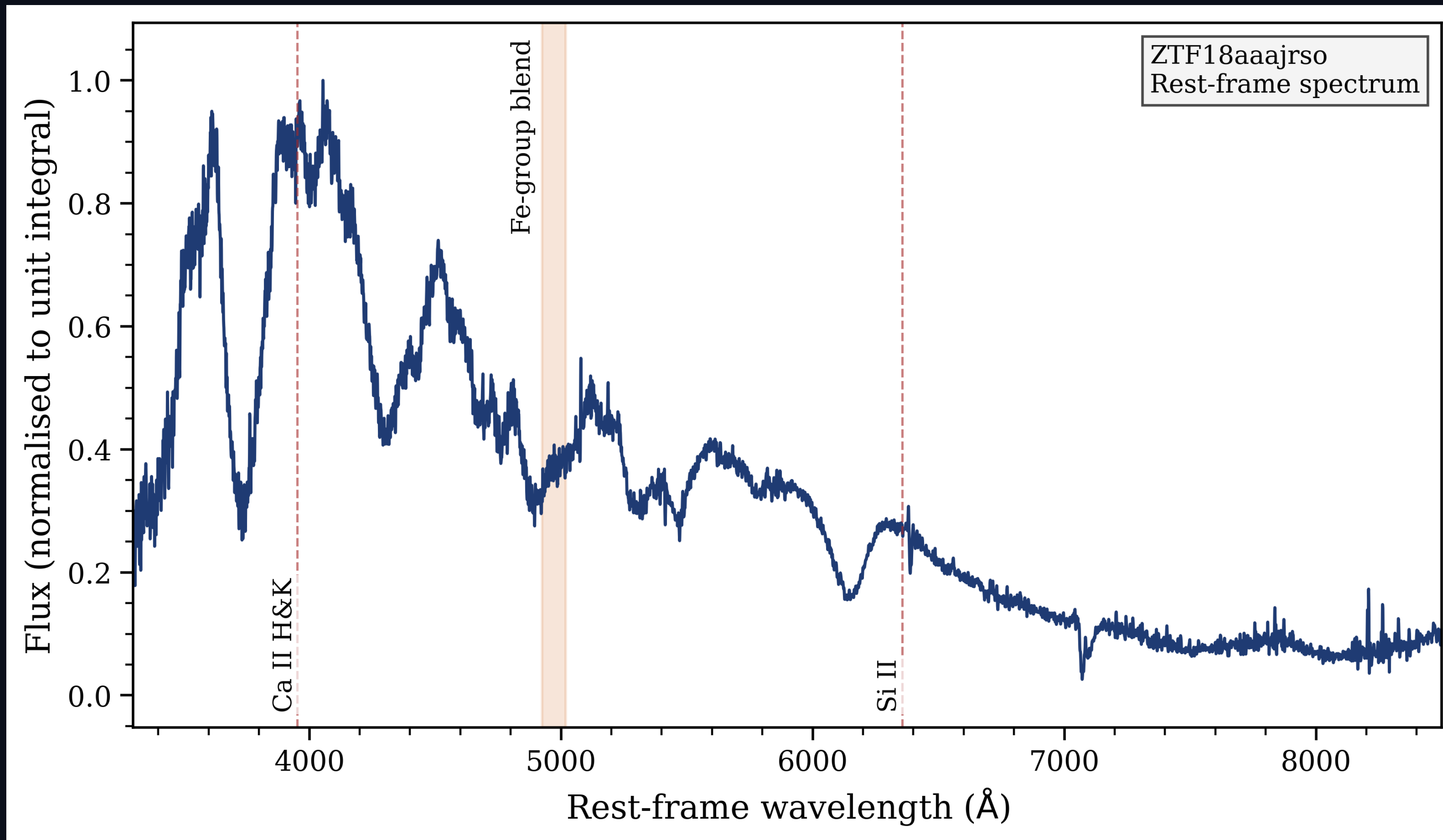


Fig 1. Type Ia supernova spectra encode physical information, motivating the identification of spectrally similar “twin” supernovae.

- Spectral diversity suggests intrinsic physical differences between SNIa.
- Similar spectra may therefore indicate intrinsically similar luminosities.
- Identifying **“SPECTRAL TWINS”** may improve supernova standardisation. [2]

(2) PCA Decomposition

- Principal Component Analysis (PCA)** compresses high-dimensional spectra into a low-dimensional representation.
- Each spectrum is represented by a small set of PCA coefficients.
- Increasing the number of PCs improves representation accuracy.

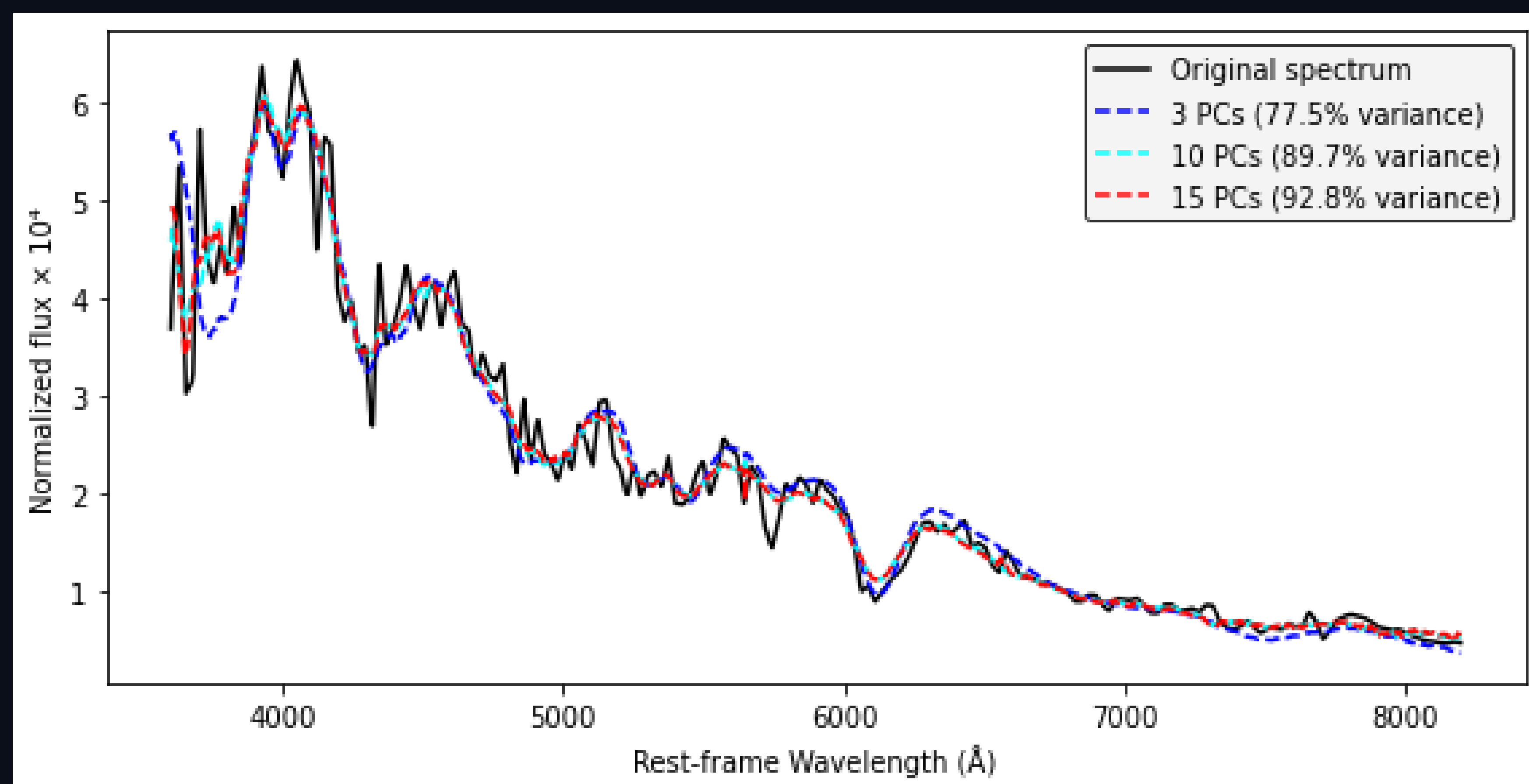


Fig 2. PCA reconstruction preserves major spectral features using a small number of principal components.

(3) PCA Distance

- PCA distance (d_{ij}^{PCA}) was defined as the Euclidean separation between supernovae in PCA space.

$$d_{ij}^{PCA} = \sqrt{\sum_k^N (X_{i,k} - X_{j,k})^2}$$

- Supernovae close in PCA space are spectrally similar.

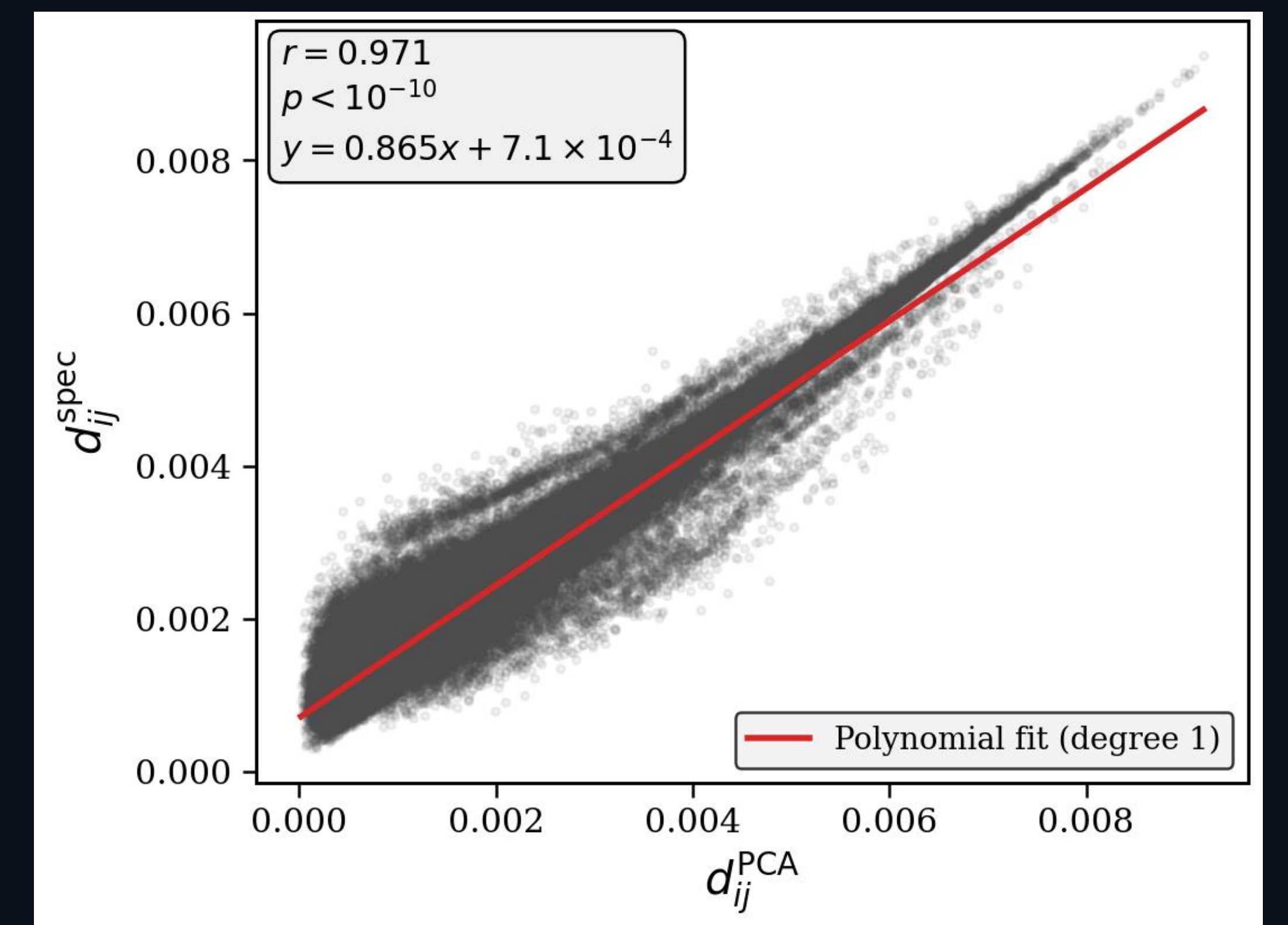


Fig 3. PCA distance strongly correlates with full spectral distance ($r = 0.97$).

(4) Spectral Twins

- Supernovae nearby in PCA space exhibit highly similar spectral structure.

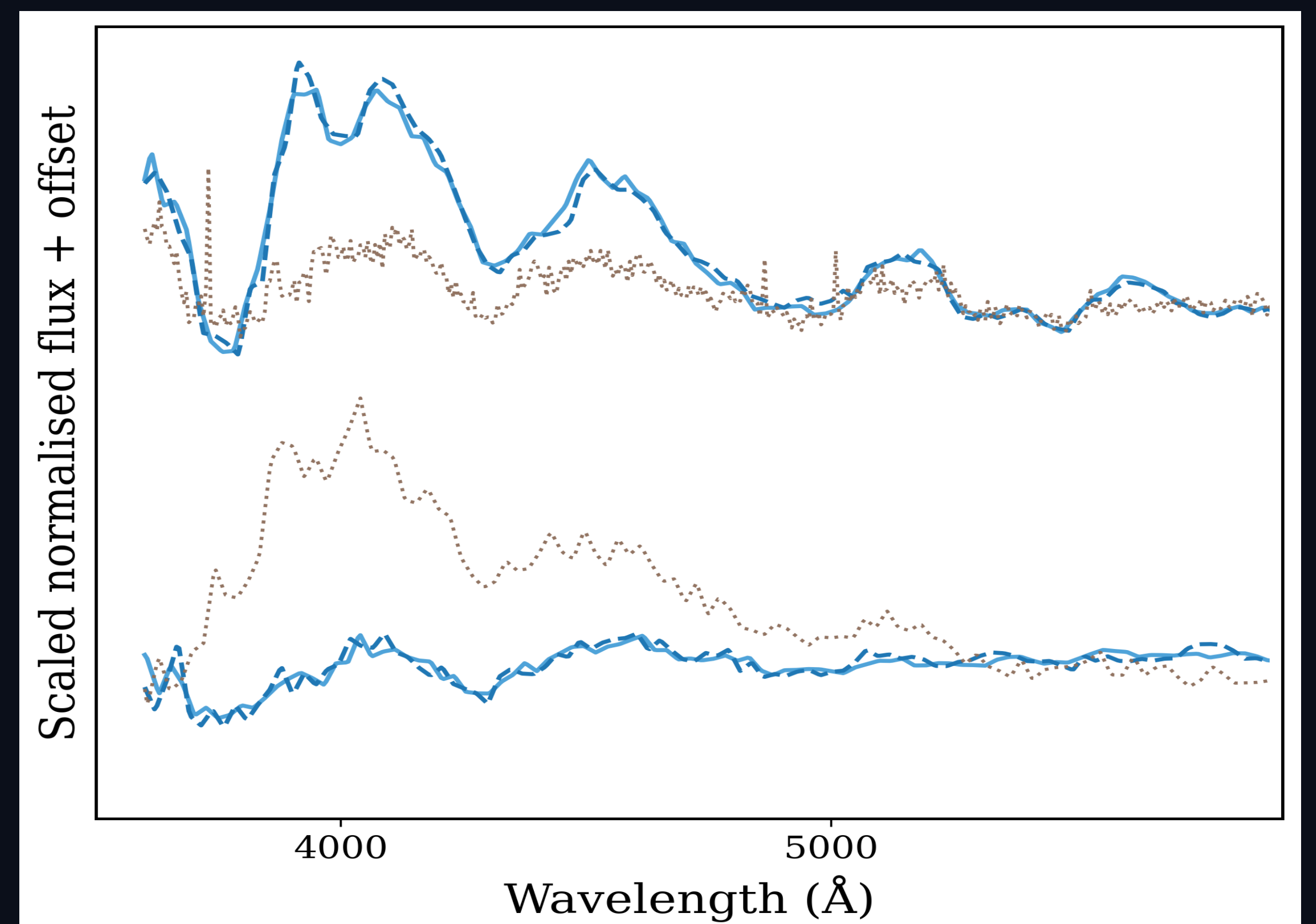


Fig 4. PCA-selected spectral twins (blue) show significantly stronger agreement than randomly selected supernova pairs (brown).

- The lowest d_{ij}^{PCA} pairs show strong agreement across all major features.
- Random supernova pairs show significant spectral variation.
- PCA distance can therefore be used to identify spectrally similar supernovae.

[1] Bailey S, Aldering G, Antilogus P, Aragon C, Baltay C, Bongard S, et al. Using spectral flux ratios to standardize SN Ia luminosities. . 2009 Jun;500(2):L17-20.

[2] Fakhouri HK, Boone K, Aldering G, Antilogus P, Aragon C, Bailey S, et al. Improving Cosmological Distance Measurements Using Twin Type Ia Supernovae. . 2015Dec;815(1):58.

- 15 PCs preserve **93%** of spectral variance.
- PCA distance strongly reproduces spectral similarity ($r=0.97$).
- Closest PCA distance pairs exhibit substantially stronger spectral agreement (**RMS $\mathcal{O}(10) \times$ lower**).
- PCA provides an **efficient framework** for identifying **twin supernovae**.