Constraining the origin of dark energy through measurements of exploding stars

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Objectives

The aim of this project is to obtain an algorithm to determine outliers and correlations in our supernova sample. This could be used for Supernova classification in future surveys. It could also help us understand the supernova explosions themselves, allowing us to distinguish between the leading theoretical models of dark energy

Type Ia Supernovae

Type Ia Supernovae (SNe) are thermonuclear explosions of white dwarfs in close binary systems.

Great importance in astrophysics:

- ☆Main source of iron in the Universe
- ☆ Consistent peak luminosity allows us to measure distances: can be used to obtain the accelerating rate of expansion of the Universe and some properties of dark energy.

Collecting data

Our 123 SNe were recorded by the Zwicky Transient Facility (ZTF), one of the biggest SN surveys to date.

Requirements:

- ☆[-7,7] days from explosion date.
- ☆Host galaxies found in SLOAN Digital Sky Survey (SDSS) SQL query database.

This reduces the sample to 50 SNe.

Determining the host galaxy

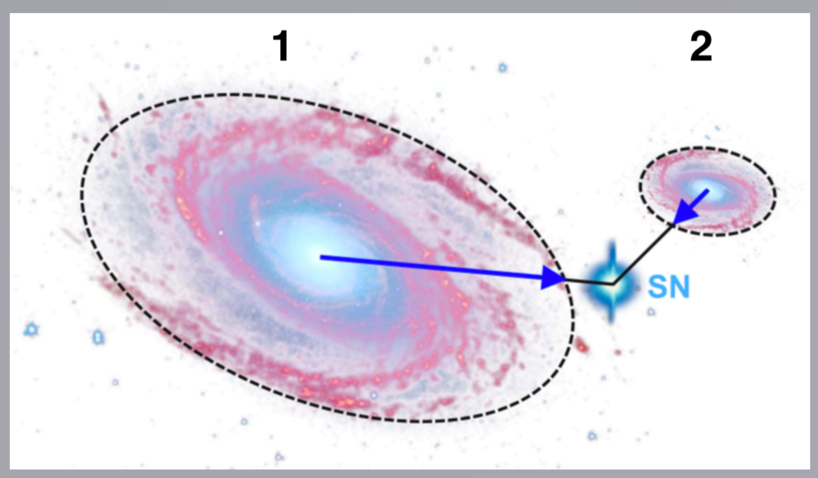


Figure 1: Directional Light Radius method [1]. Galaxy 1 is more likely to be the host galaxy due to its larger size and overall distance to the DLR, even if its centre is further from the SN.

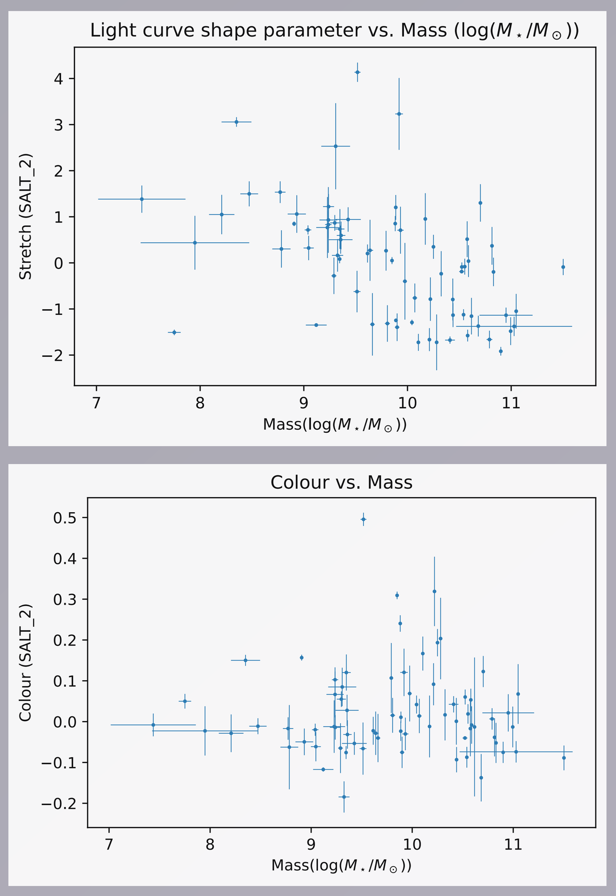
Host galaxy mass is computed as described in Rigault et al. (2018)

$$log\left(\frac{M_\star}{M_\odot}\right) = 1.15 + 0.7(g-i) - 0.4M_i \quad (1)$$

- $M_\star / M_\odot$=stellar mass of the galaxy in solar mass.
- G- and I are relative magnitudes in g and I bands
- M_i the absolute magnitude in the i-band.

Light curve parameters

Type Ia SNe's consistent peak magnitudes allow us to compare between plots of brightness over time, called **lightcurves**. Define two main parameters: The **stretch** is given by the time it takes to reach peak magnitude. The **colour** corresponds to the difference in magnitude between the r and i-bands.



Figures 2ab: Plots of stretch (a) and colour (b) vs. galactic mass show a small correlation between mass and stretch

Spectral features

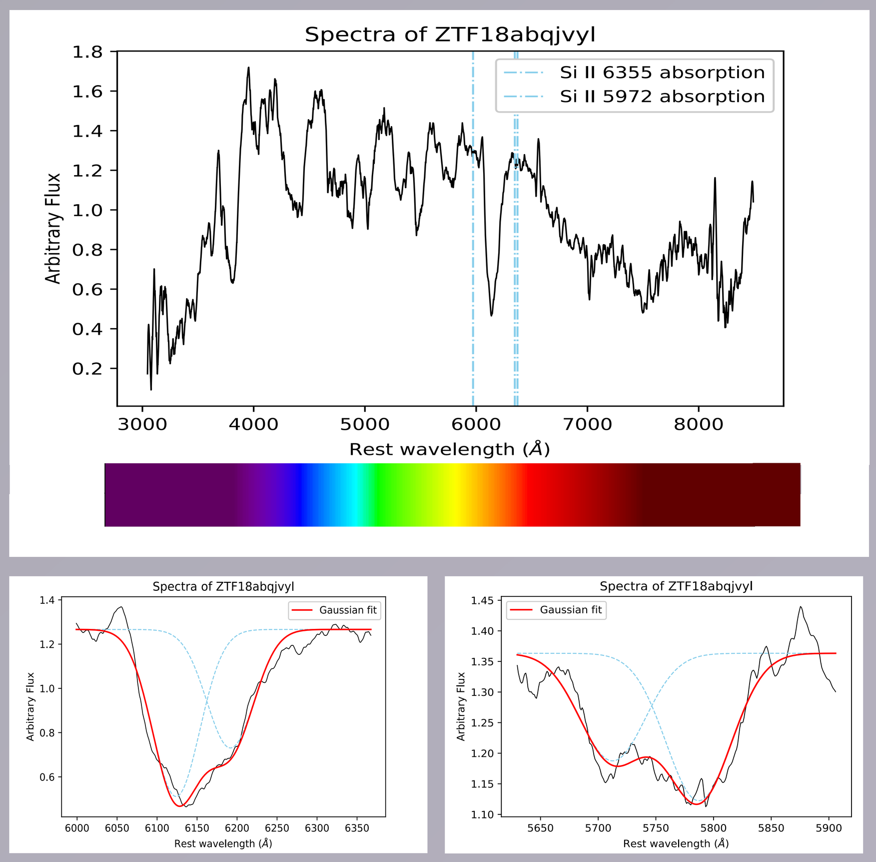


Figure 3: Type Ia SNe are characterised by their Si II absorption features ("dips" in their spectra) at $\lambda_{rest} = 6371\ \text{Å}\ and\ 5972\ \text{Å}$. This is the spectrum for one of the SNe in the sample: ZTF18abqjvyl and the double Gaussian fit for features of interest

Two more parameters can be computed:

Si velocity:

$$v = c\left(\frac{\lambda - \lambda_{rest}}{\lambda_{rest}}\right) \quad (2)$$

c=speed of light (3·10^8 m/s)
λ=the x value of peak
λ_{rest}=wavelength in the ejecta rest frame

Equivalent Width:

$$EW = \sigma_1 h_1\sqrt{\pi/ln(16)} + \sigma_2 h_2\sqrt{\pi/ln(16)} \quad (3)$$

σ = Gaussian width (set $\sigma_1 = \sigma_2$)
h = the strength of the curve.

K-means algorithm

The clustering algorithm is the k-means algorithm, which aims at minimising the variance within each cluster

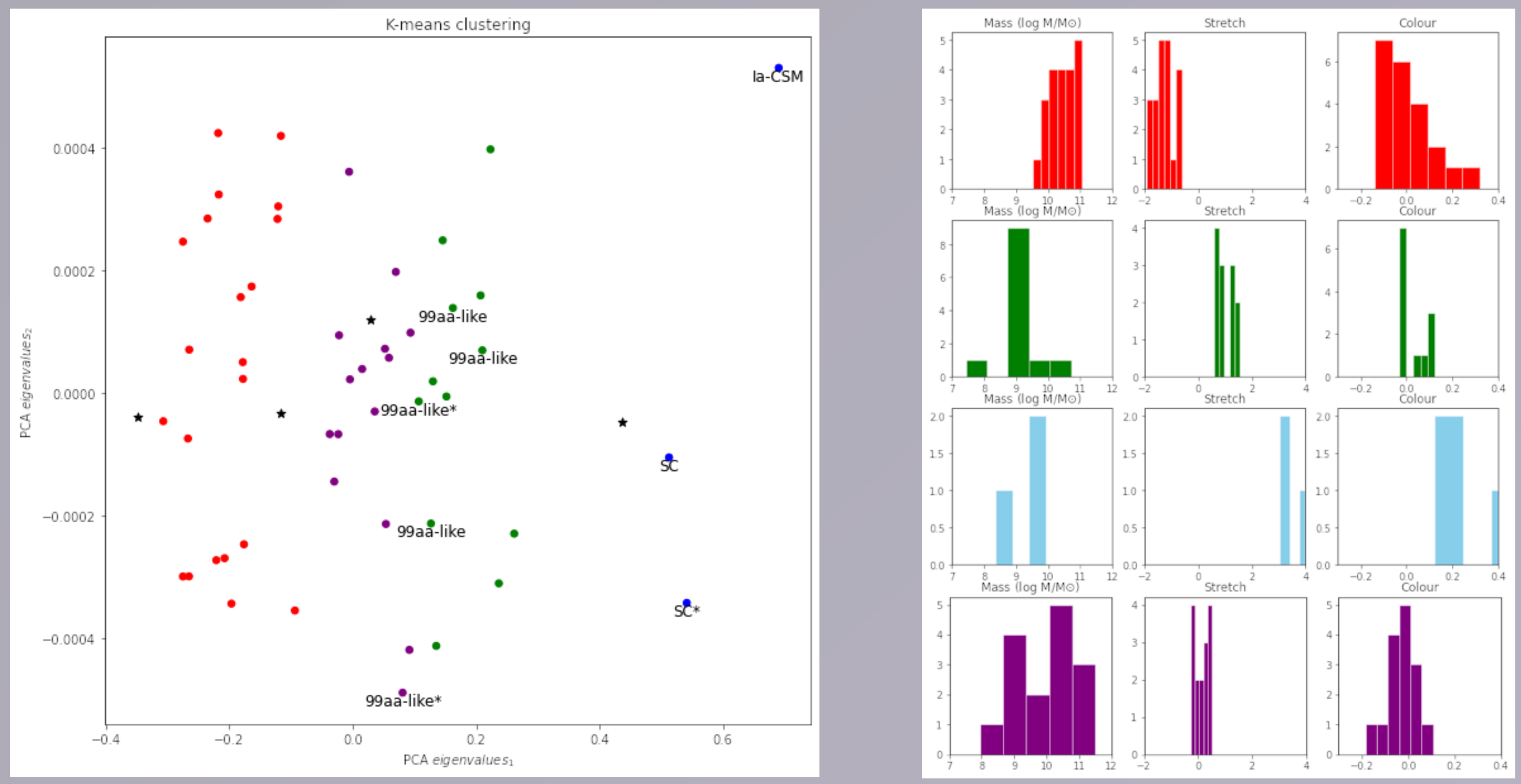


Figure 4:2D projection of the best k-means clustering algorithm, with cluster centroids marked with a star symbol. SNe that are not classified as "normal" have been labelled. The most useful parameter for SNe classification appears to be the stretch. However, this is not convenient because it cannot be obtained in the early days after the explosion. Further work and improvements in the algorithm could lead to finding alternatives that will allow for SNe classification at earlier stages.

Conclusions and further work:

- ☆The use of the stretch gives the best results in our k-means clustering algorithm, with other parameters (galactic mass and Silicon velocities) accounting for 0.1% of the weight.
- ☆This clustering algorithm can be used for the classification of SNe in future surveys.
- ☆Further work inspecting other defining parameters of SNe that can be obtained at earlier times could lead to faster classification of the samples.

Acknowledgements:

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References:

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