

Type Ia supernova in the near-infrared: from explosion to cosmology

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ESO - Bruno 65 conference

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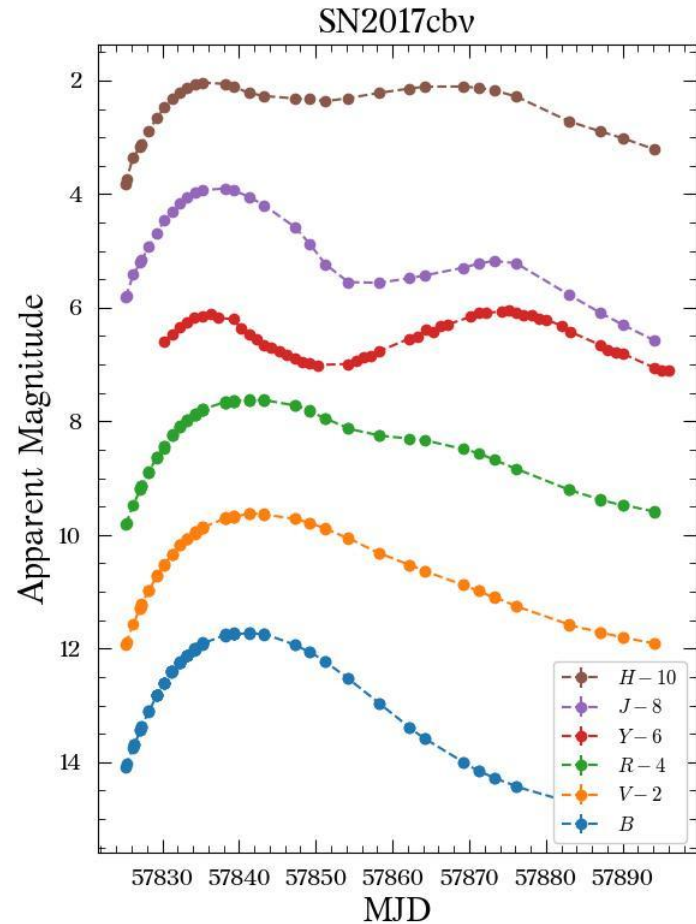


SNe Ia in the NIR

SNe Ia are more homogeneous
→ good for cosmology

Very prominent secondary peak in
the NIR → good for physics

NIR wavelengths are less affected by
dust → good for cosmology +
physics



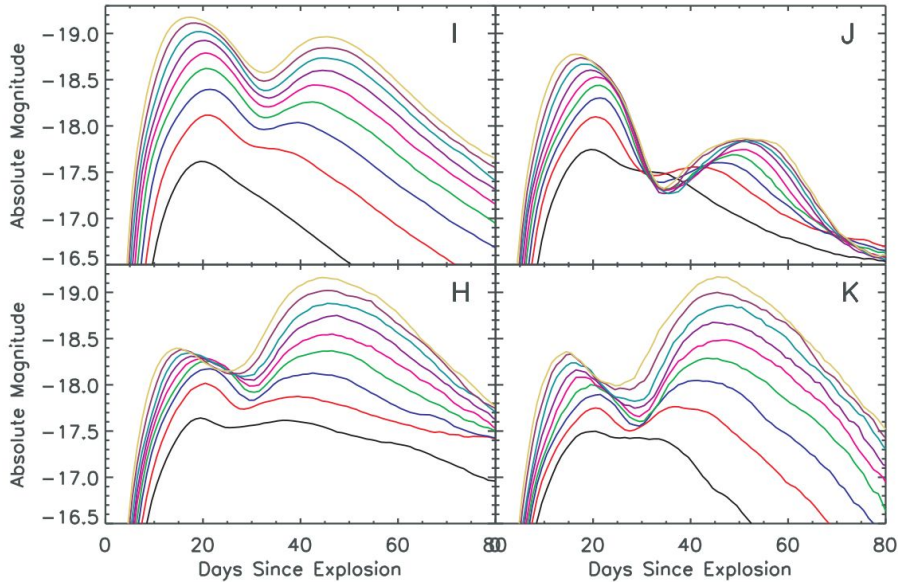
The physics behind the secondary NIR peak

There is limited theoretical work on SNe Ia at NIR wavelengths:

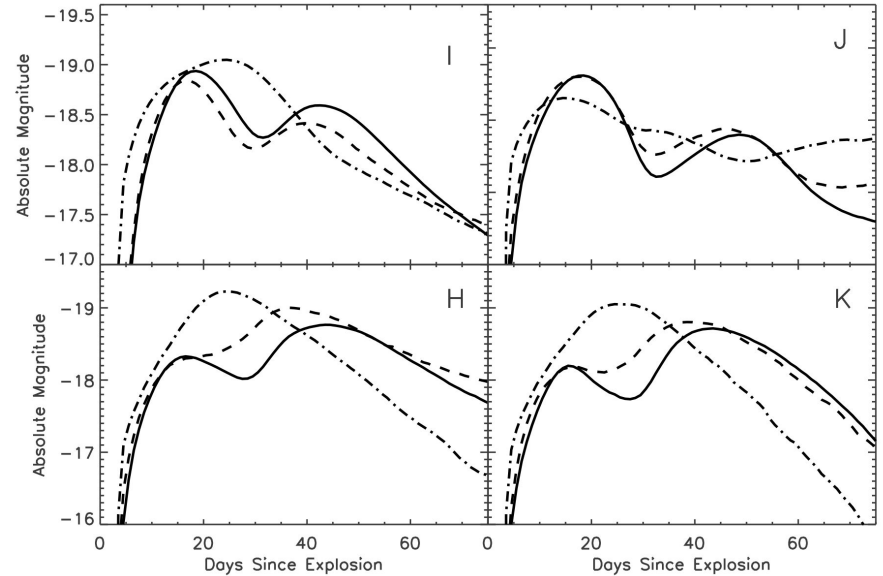
- Höflich et al. (1995)
- Pinto & Eastman (2000)
- Kasen (2006)

The secondary NIR peak is driven by a change in ionisation of iron-group elements (e.g. FeIII \rightarrow FeII)

The physics behind the secondary NIR peak

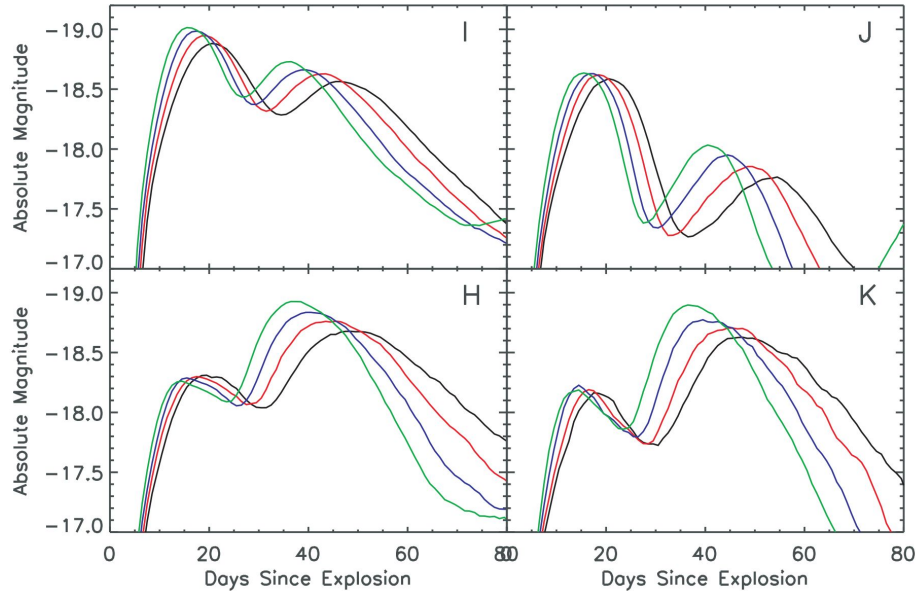


Effect of $M_{\text{Ni}^{56}}$, from 0.1 (black) to 0.9 M_{\odot} (yellow), on NIR light curves (Kasen 2006)

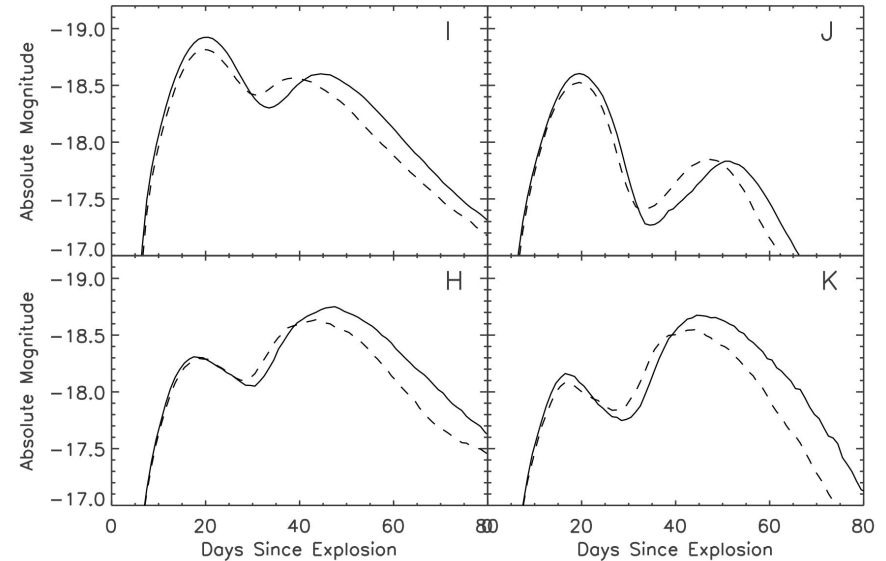


Mixing of Ni^{56} : low (solid line) to high (dot-dashed line)

The physics behind the secondary NIR peak



M_{Fe} from **electron capture elements**:
from 0.0 M_{\odot} (black) to 0.3 M_{\odot} (green)



Metallicity on M_{Fe} : zero (solid black line) and 3 times solar (dashed line)

About this work

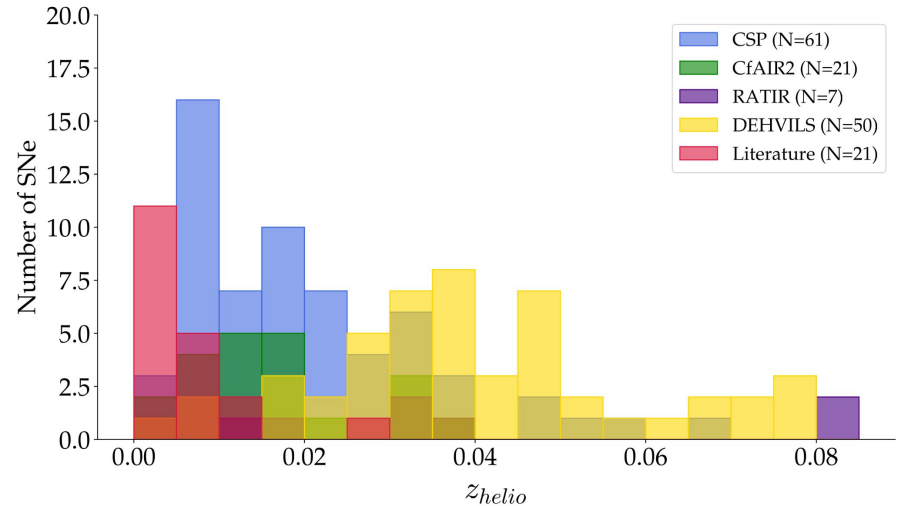
SNe Ia NIR samples: Initial selection

“Normal” SNe Ia

Five NIR epochs on any bands

Coverage from first to second
NIR peak

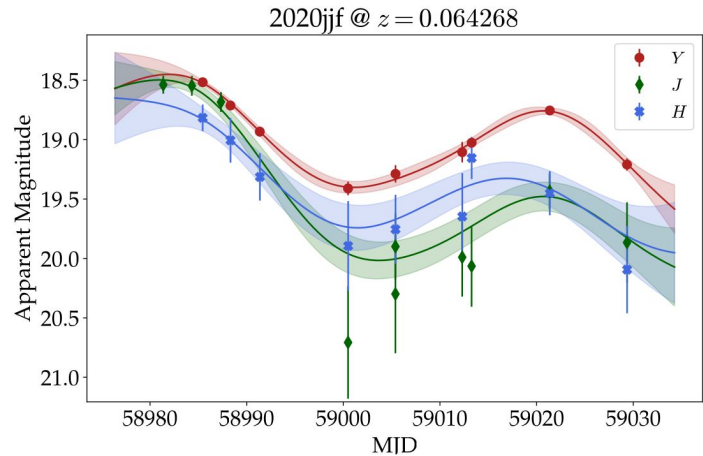
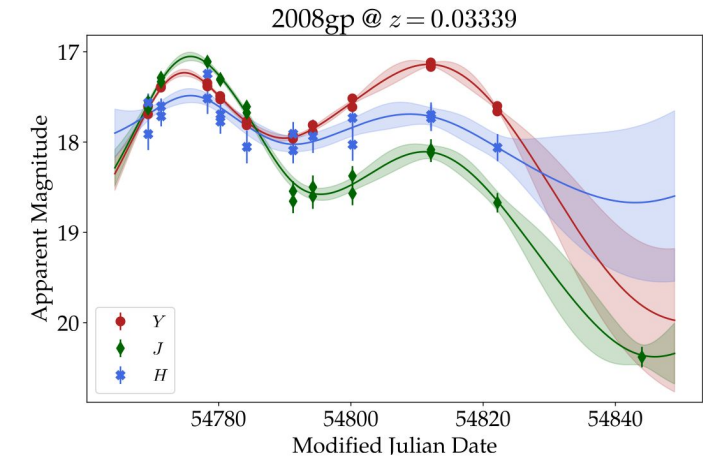
→ Initial sample of 160 SNe Ia



Rest-frame light curves

SNooPy (*max_model*; Burns+2011) is used for K -correction and MW extinction correction

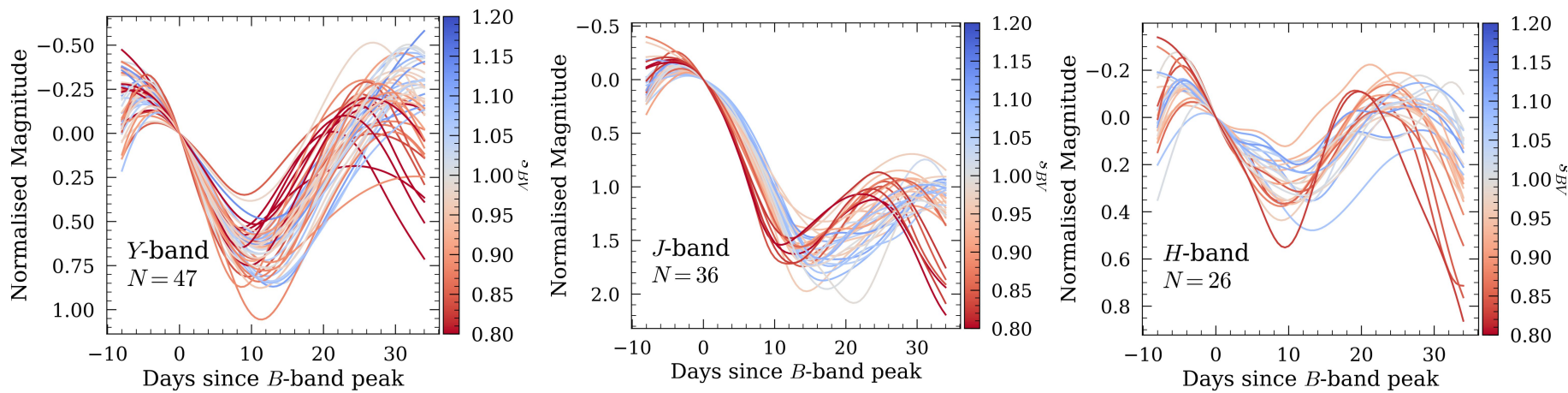
PISCOLA (Müller-Bravo+2022a) is used for interpolating (in 2D) the corrected light curves



Light curves preprocessing

Most SNe have S_{BV} in the $[0.8, 1.2]$ range

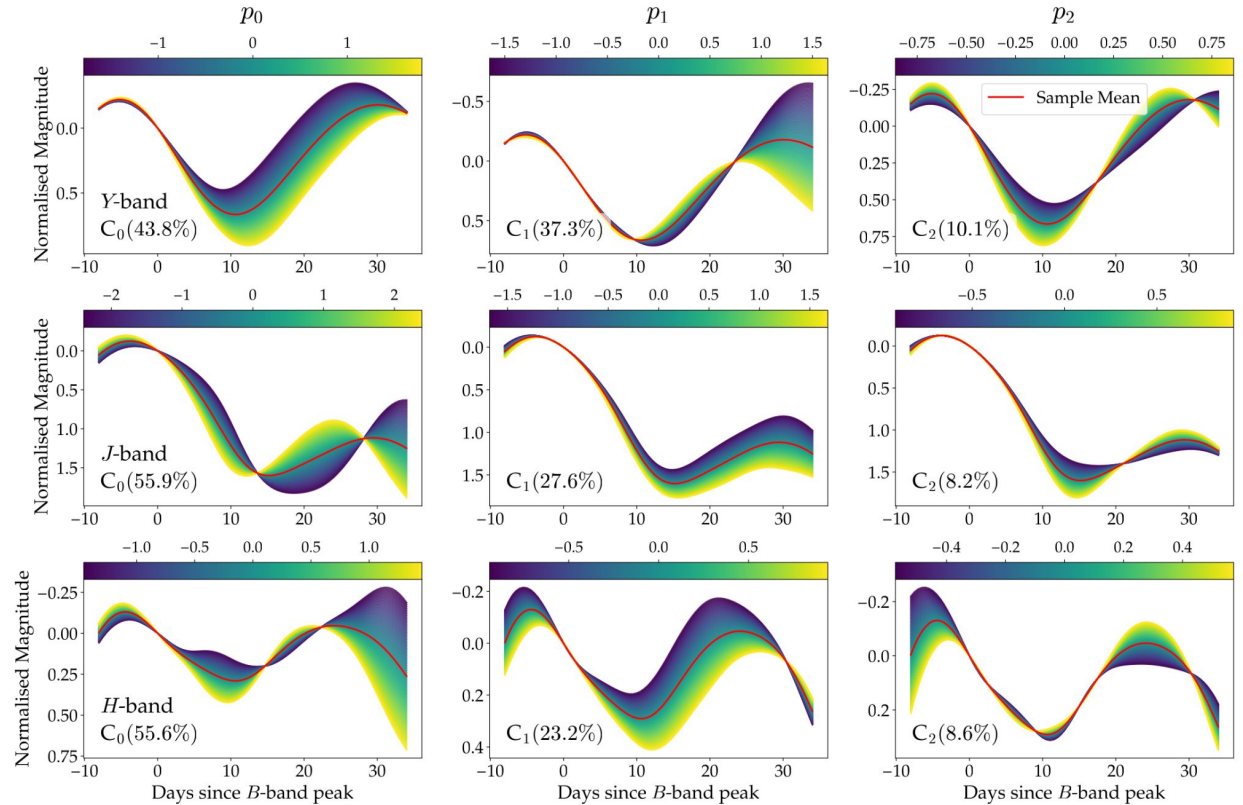
The light curves are shifted to match, in time and mag, at B-band peak



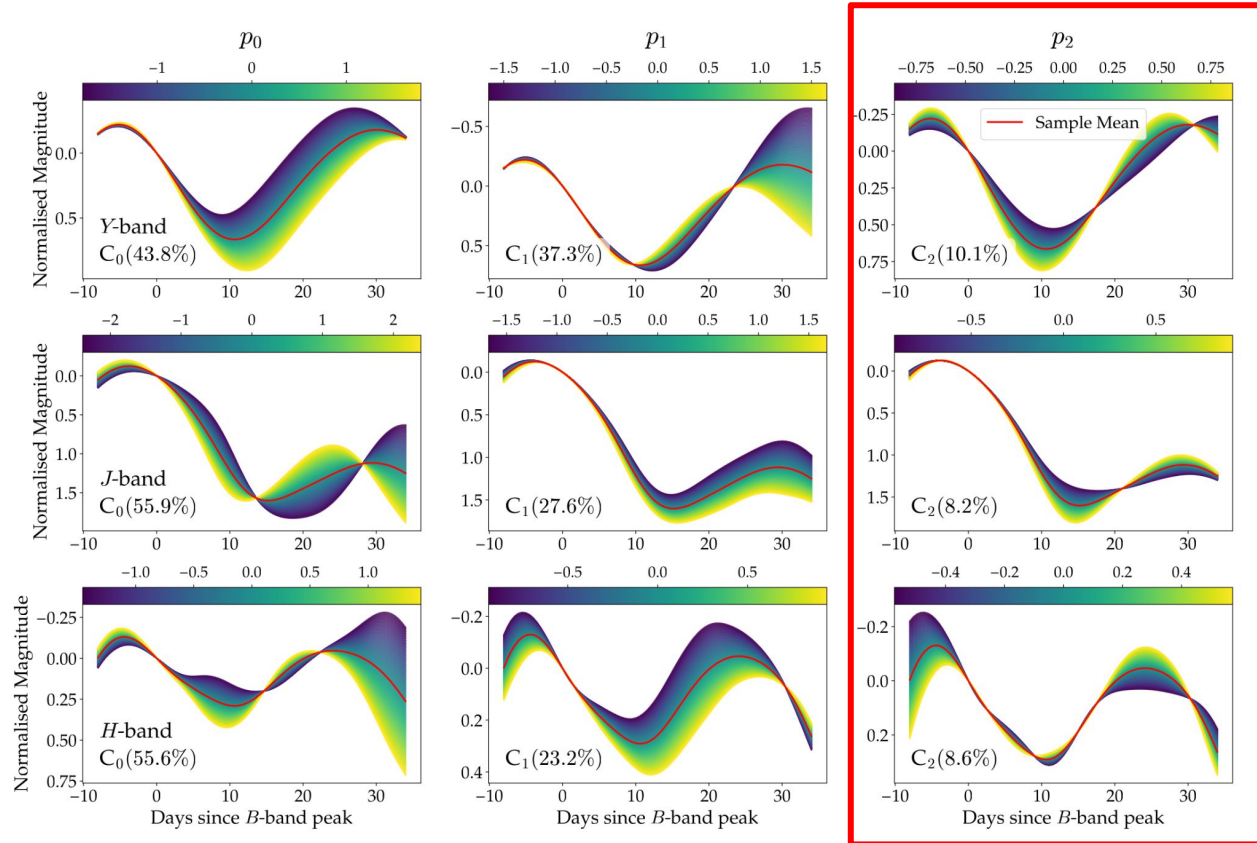
Principal Component Analysis (PCA)

PCA decomposition

$$LC^{\text{SN}} = \overline{LC} + \sum_{i=1}^{N=3} C_i \times p_i^{\text{SN}}$$



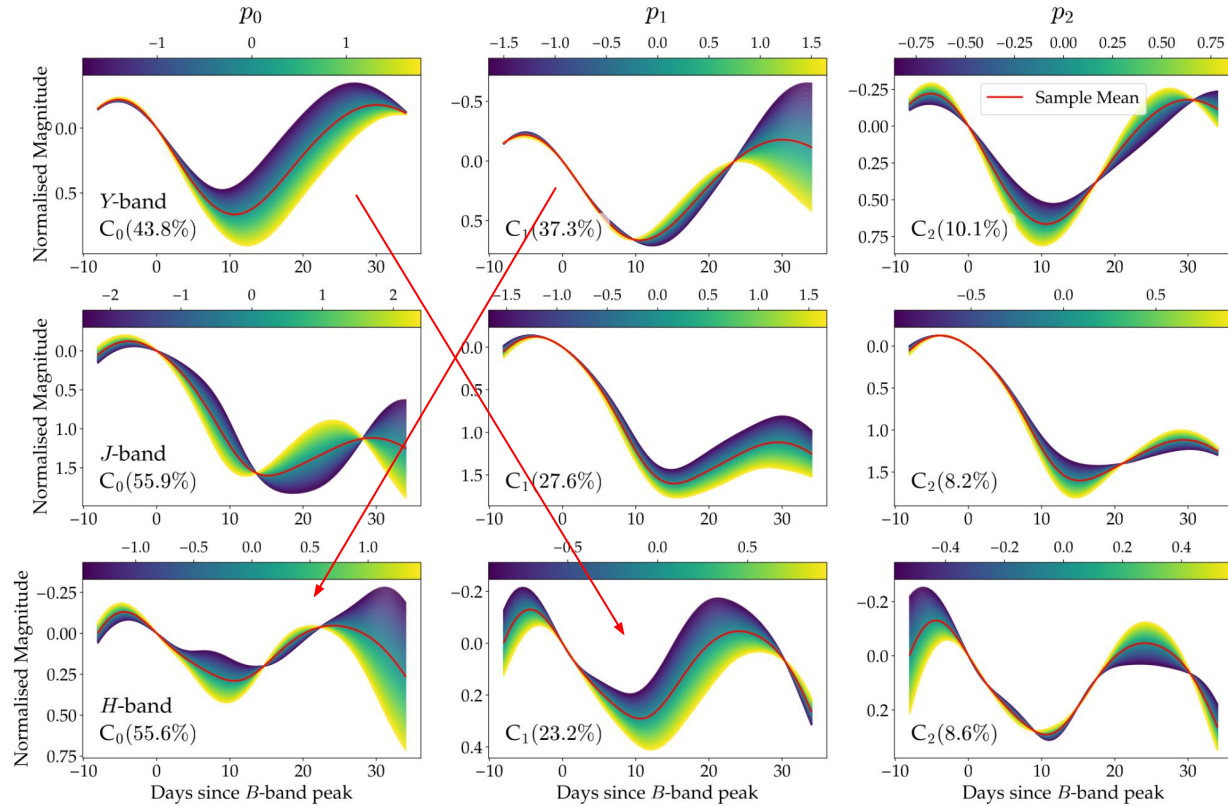
PCA decomposition



Components ignored due to low variance

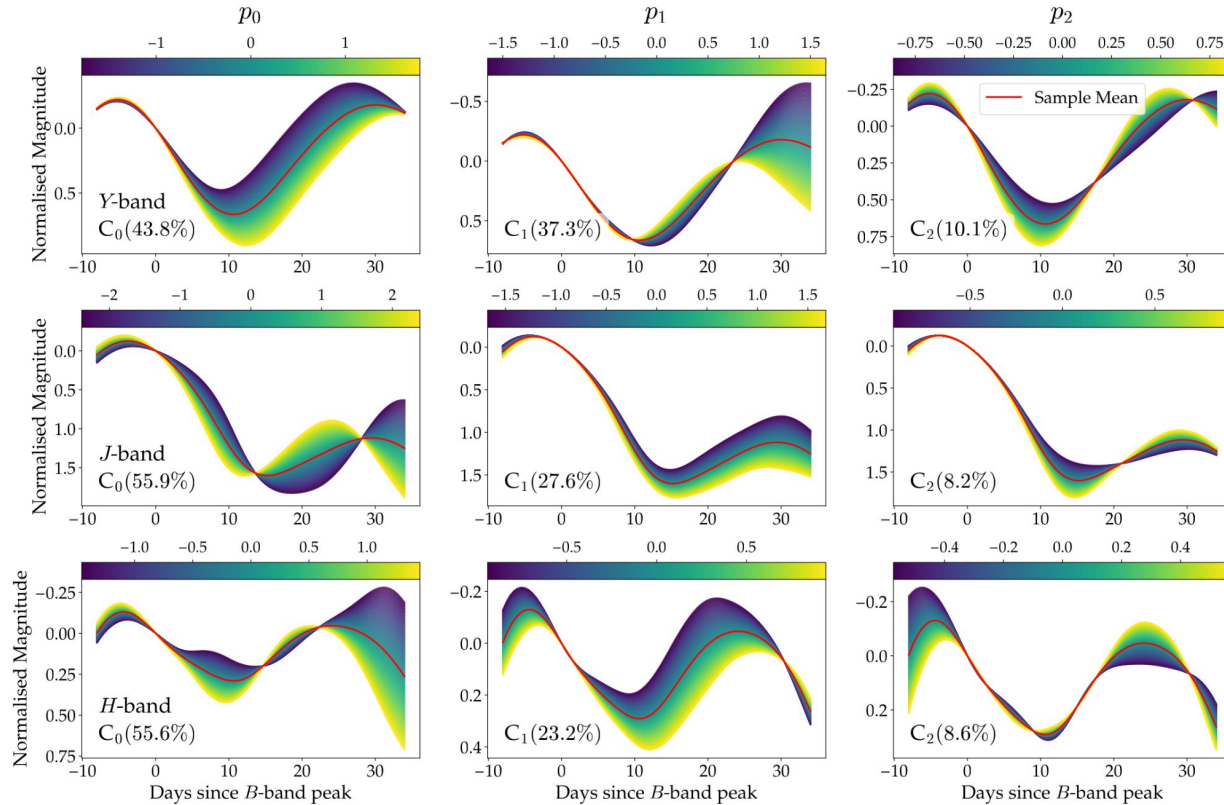
PCA decomposition

Similarity

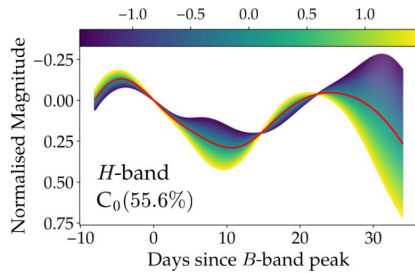
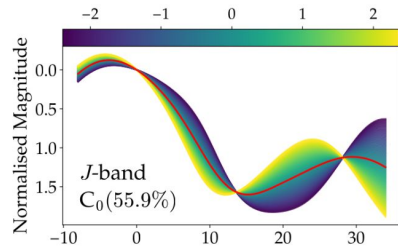
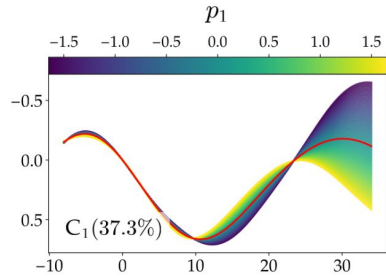


Towards a physical interpretation

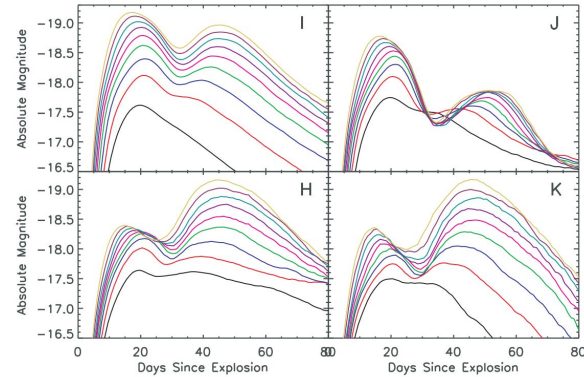
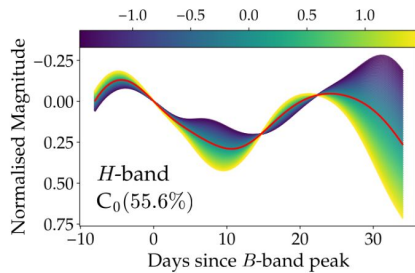
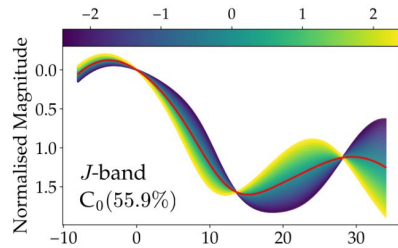
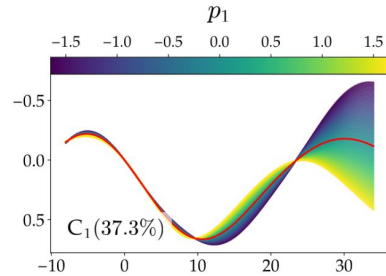
PCA decomposition



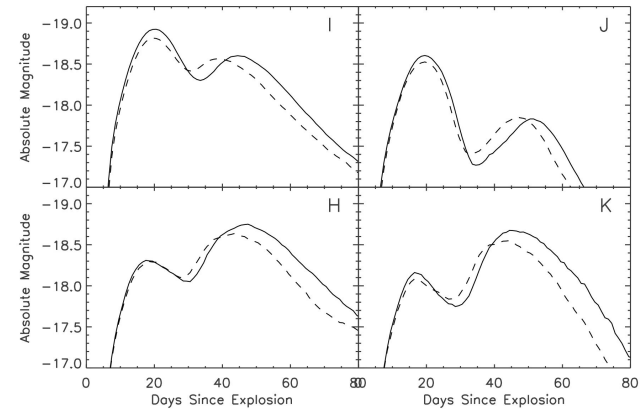
JH-C₀ & Y-C₁



JH-C₀ & Y-C₁

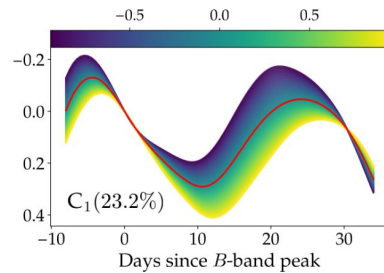
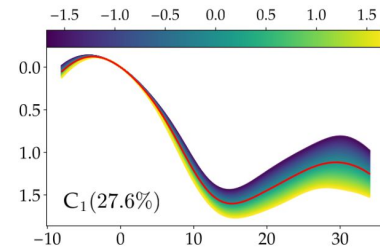
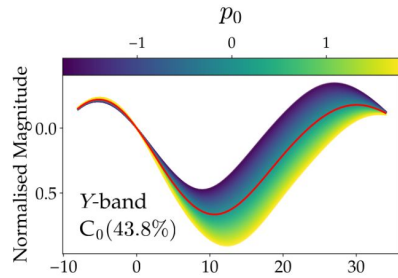


Nickel mass

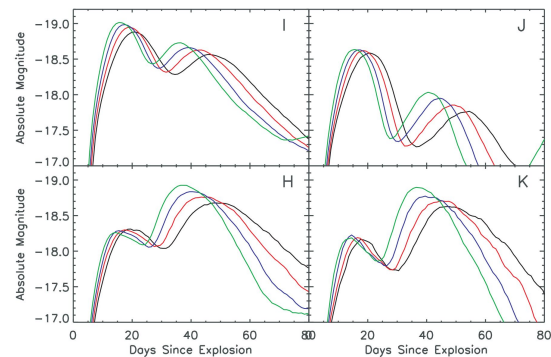
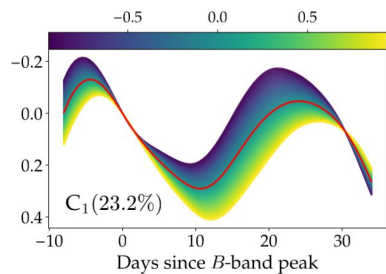
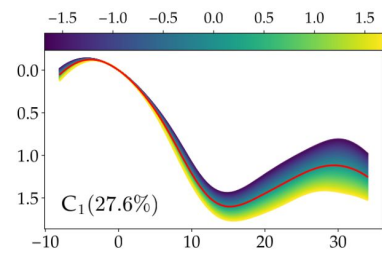
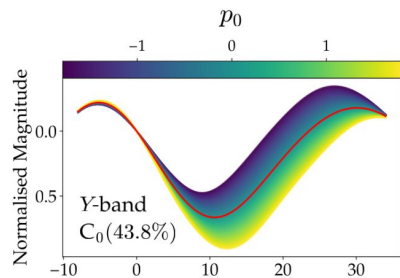


Metallicity

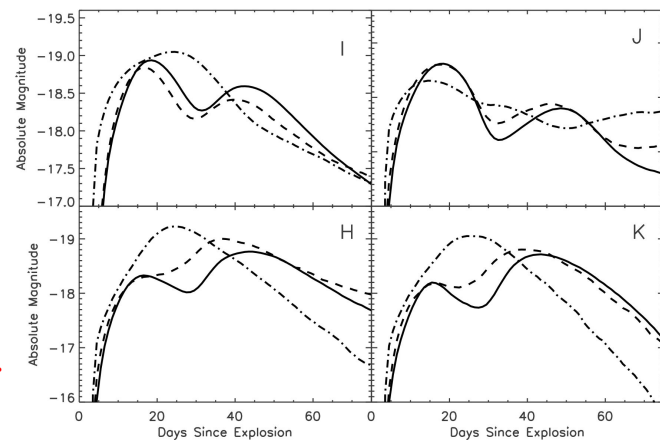
Y-C₀ & JH-C₁



Y-C₀ & JH-C₁

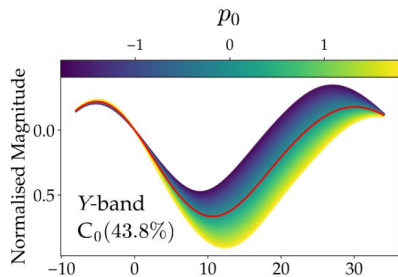


M_{Fe} from
electron
capture
elements

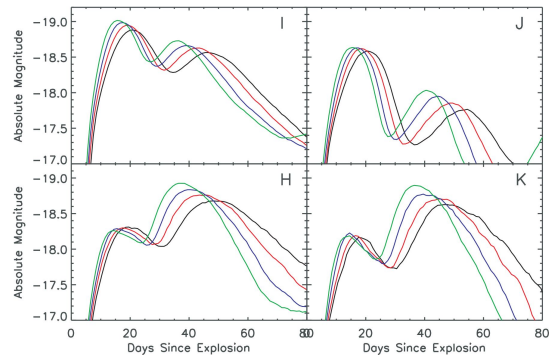
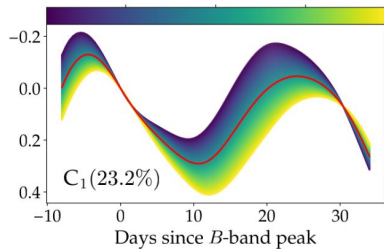
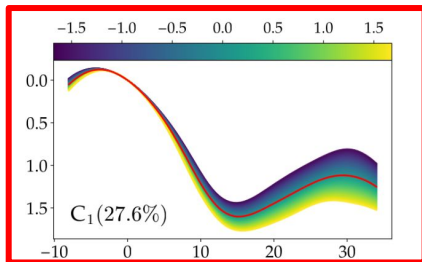


Nickel
mixing

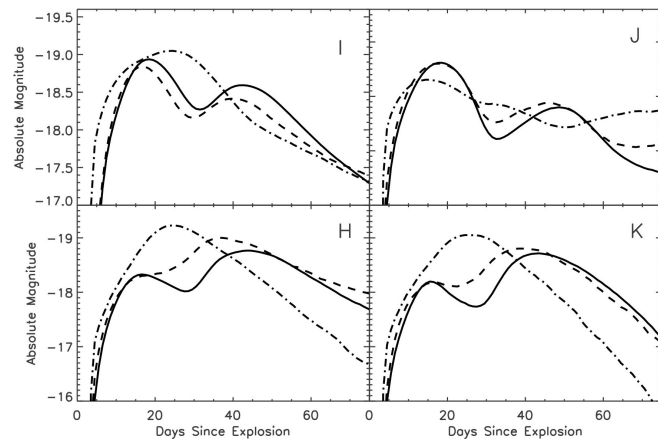
Y-C₀ & JH-C₁



Nickel mass is also required to explain J-C₁



M_{Fe} from electron capture elements



Nickel mixing

Comparison against light-curve parameters

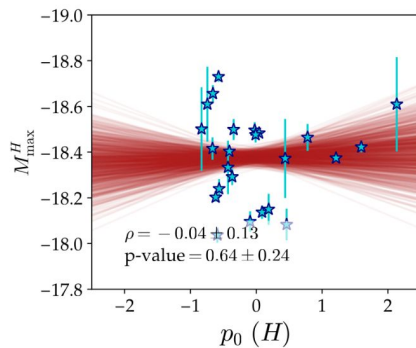
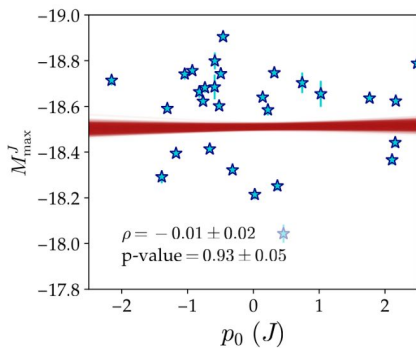
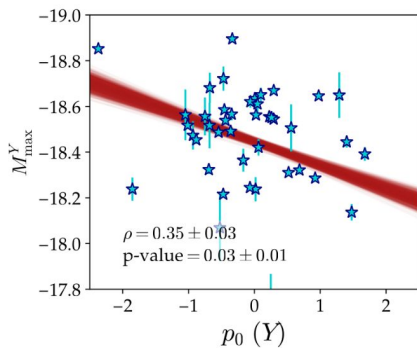
NIR M_{max} Y

J

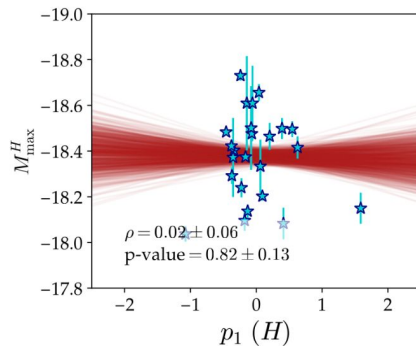
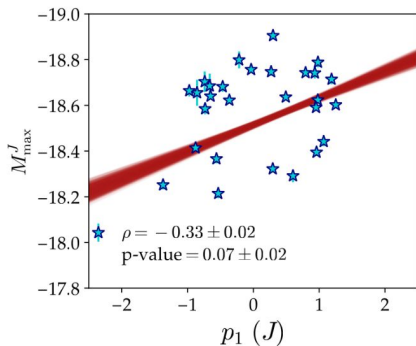
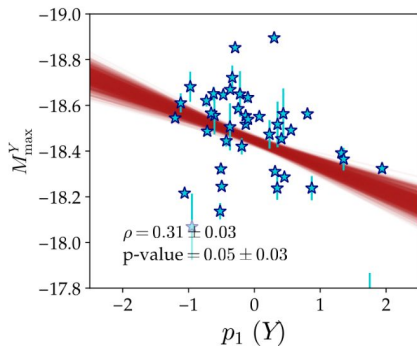
H

ρ : Pearson coefficient

$C_0 \rightarrow$

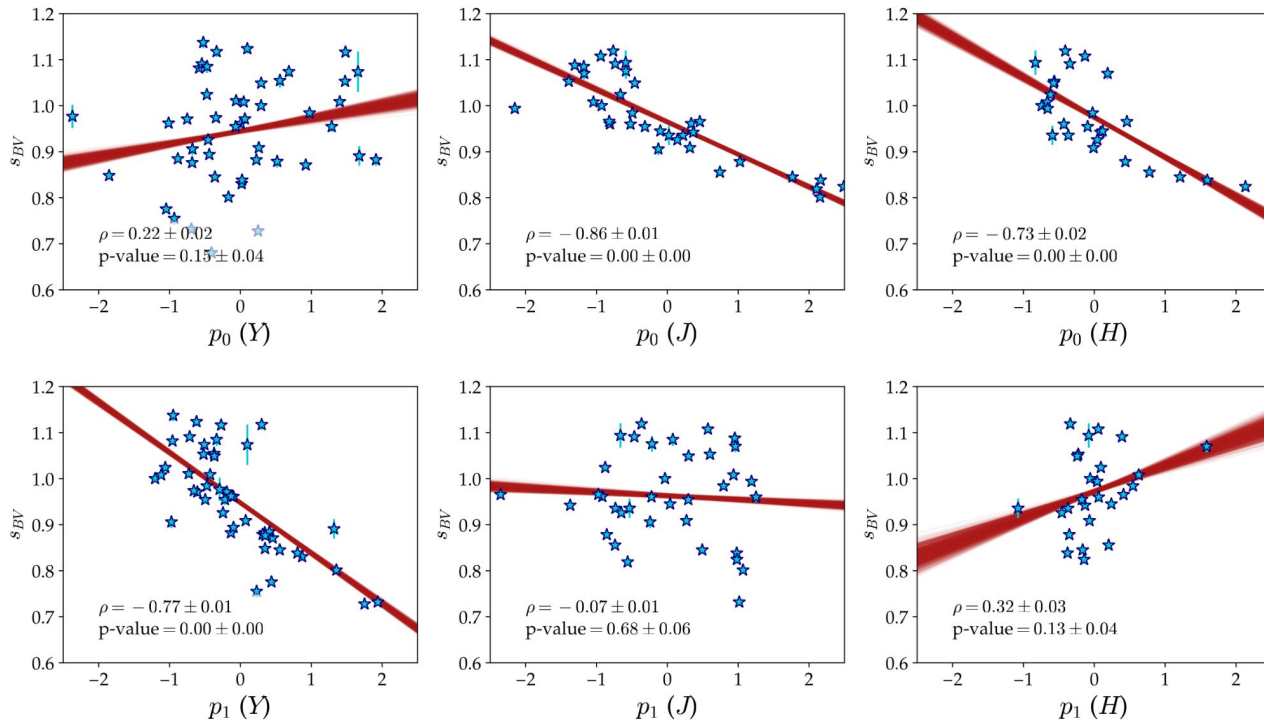


$C_1 \rightarrow$



Lack of correlation, except for the Y-band \rightarrow Why?

Colour-stretch, s_{BV}



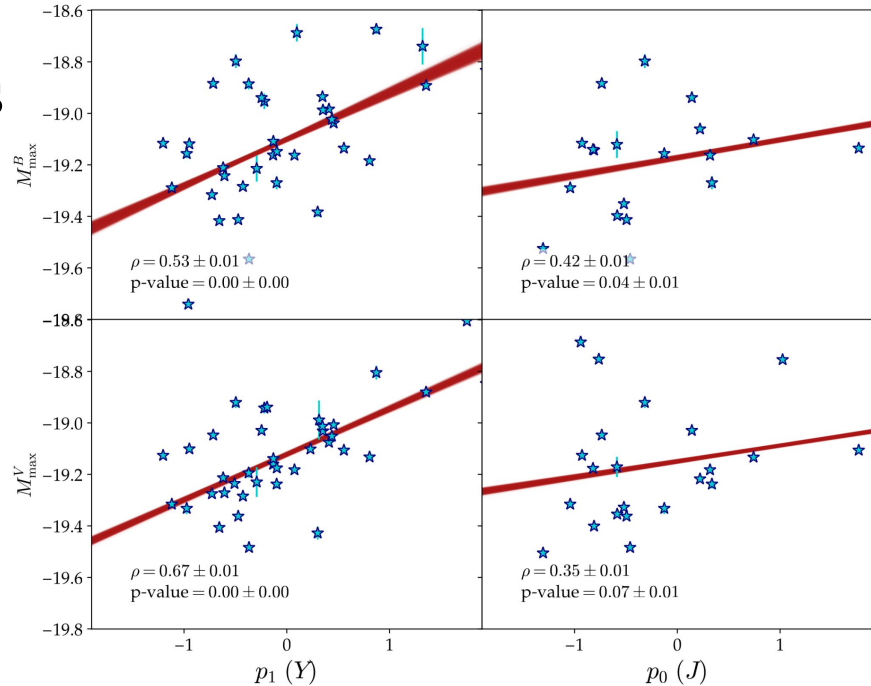
Expected correlations are found

Optical M_{max} vs C_0

Optical peak luminosity correlates with Nickel mass (Arnett's rule)

These component correlates with Nickel mass (except for H band)

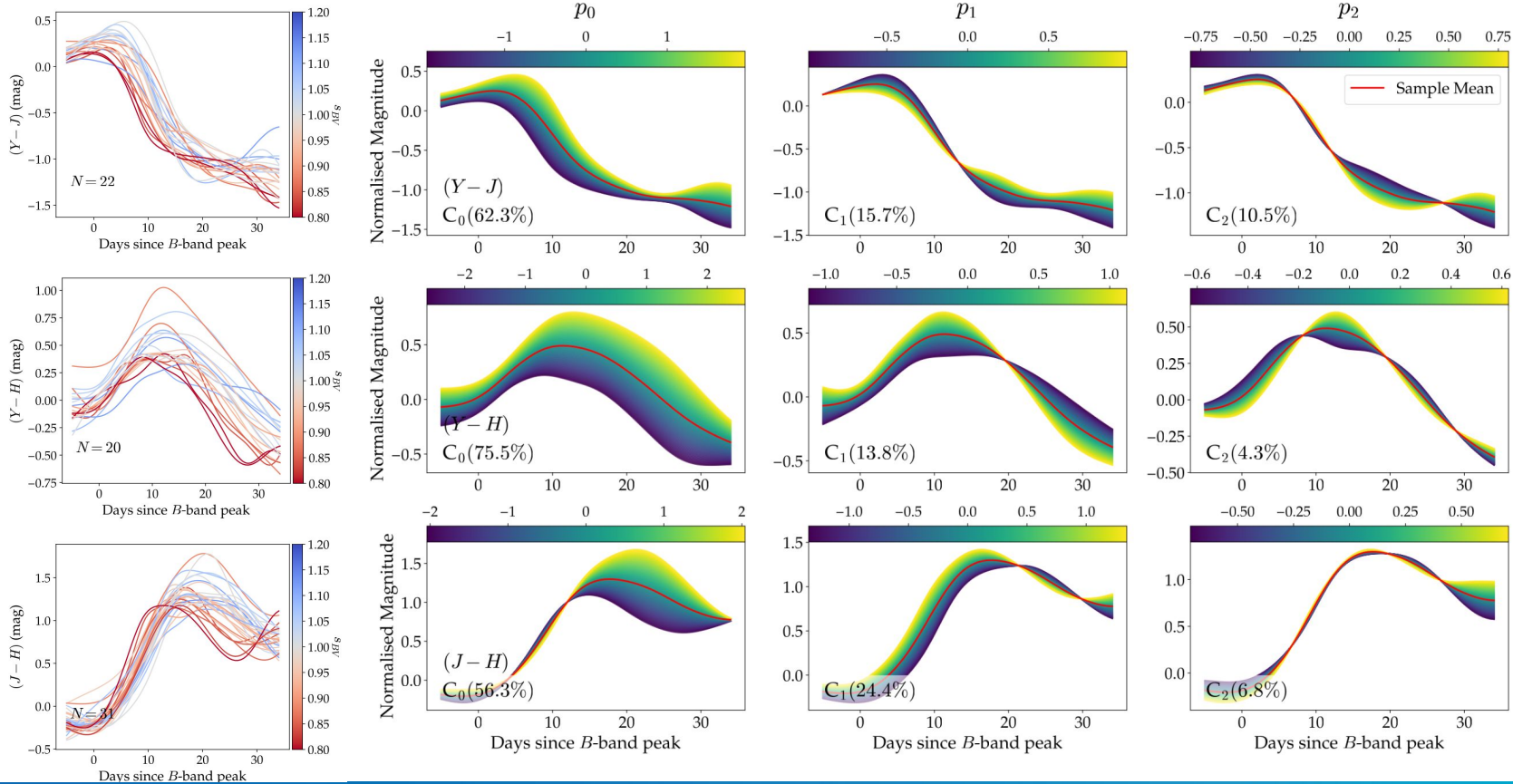
Expected behavior (Phillips 2012)



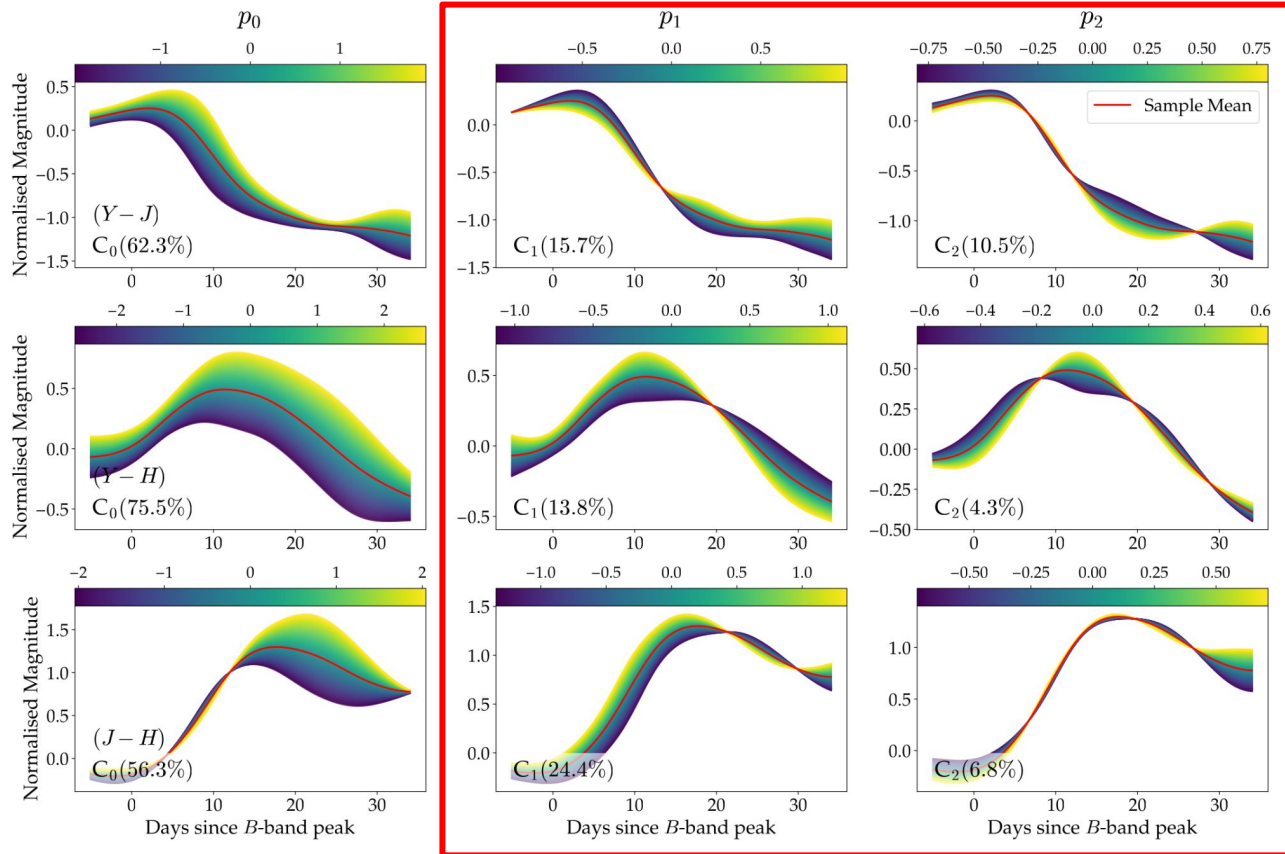
**No correlations with host properties
(stellar mass and reddening)**

NIR colours decomposition

PCA decomposition on colour curves



PCA decomposition on colour curves



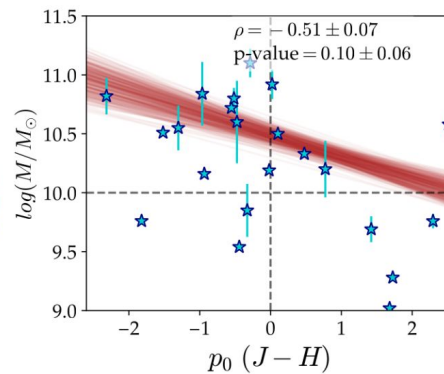
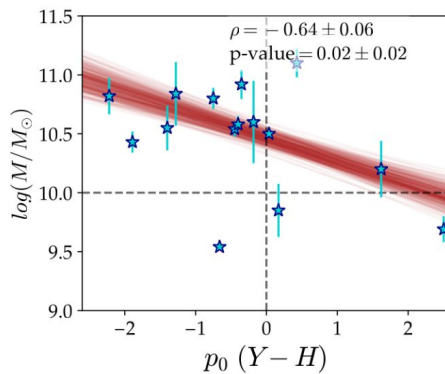
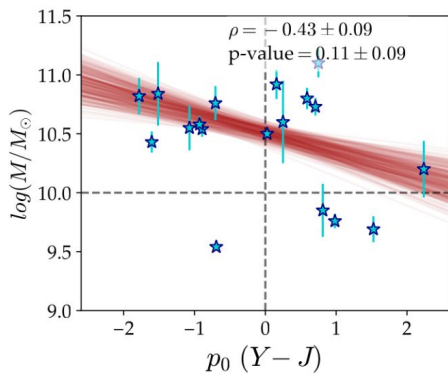
Components ignored due to low variance

Hard to obtain a direct physical interpretation

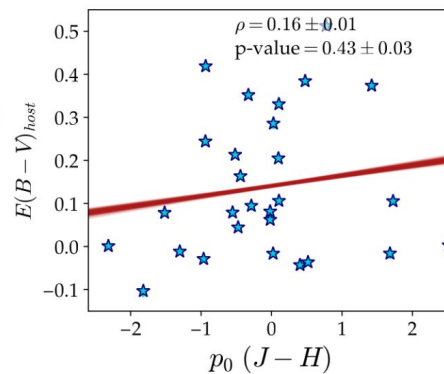
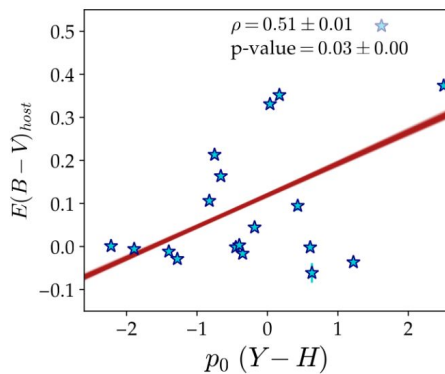
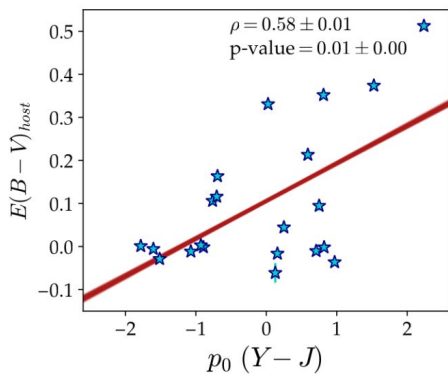
**Nothing of interest in the comparison with
light-curve parameters**

But some interesting correlations with host properties!

PCA coefficients vs host properties



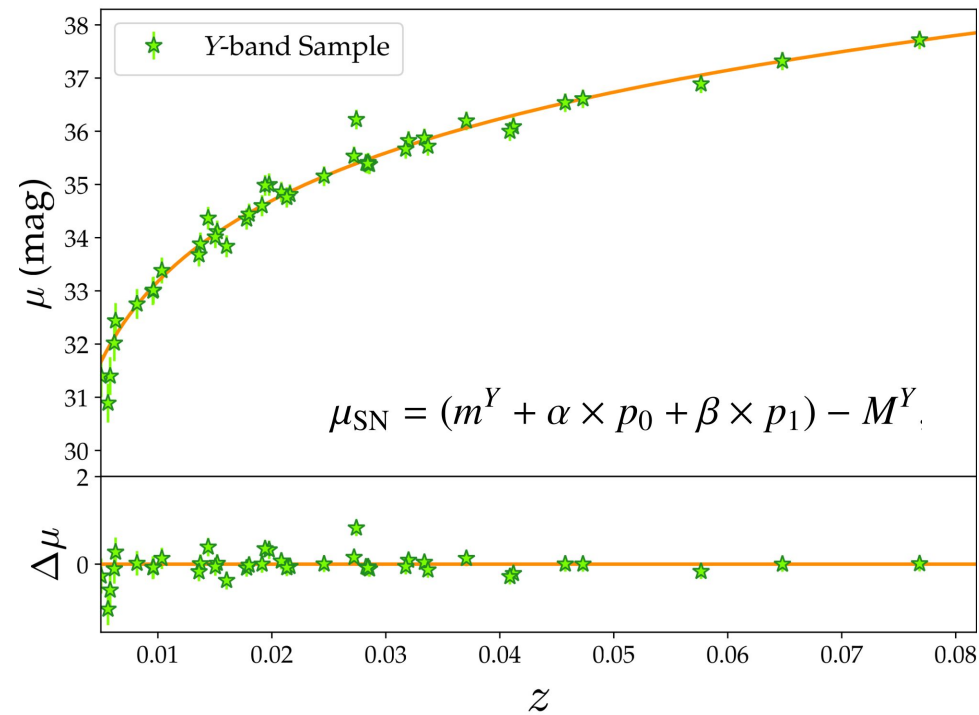
Redder NIR
SNe Ia in
lower mass
hosts? More
metal poor?



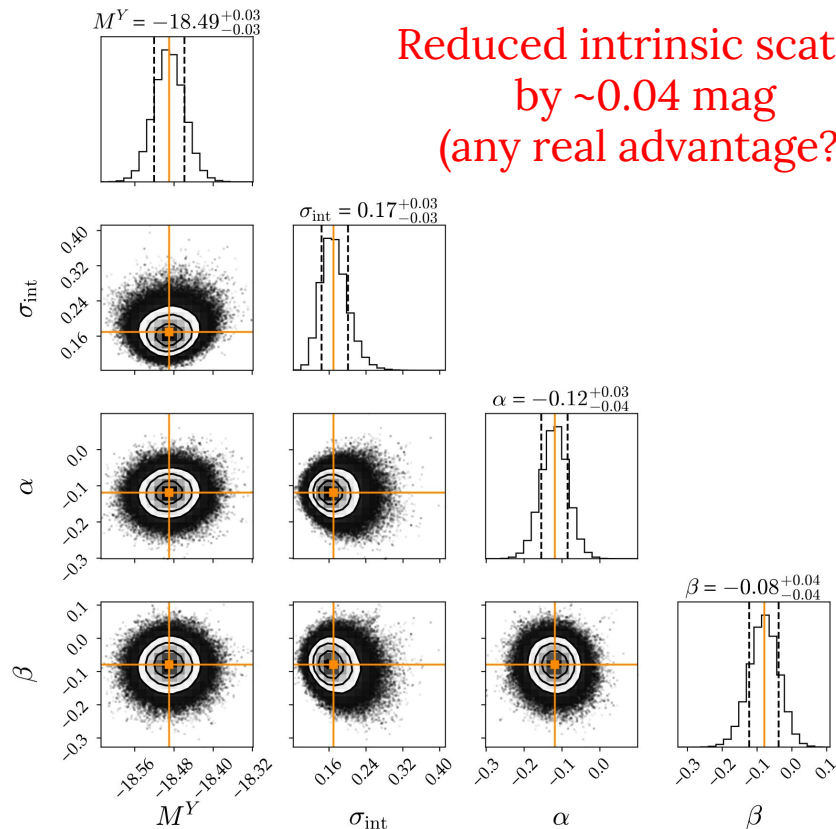
Redder NIR
SNe Ia in
dustier
hosts? Bias
in reddening
estimation?

Y-band standardization

Y-band Hubble Diagram



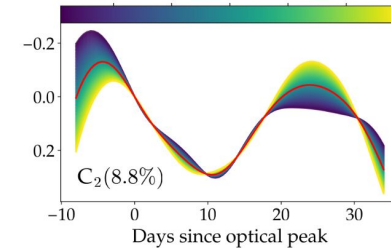
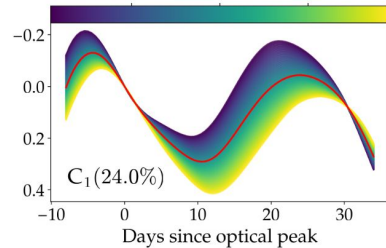
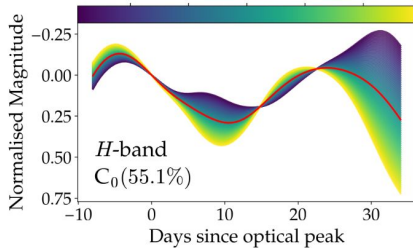
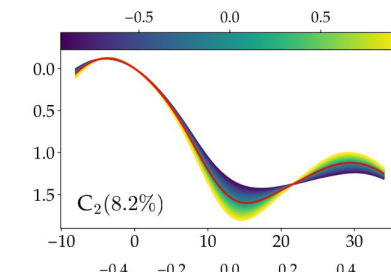
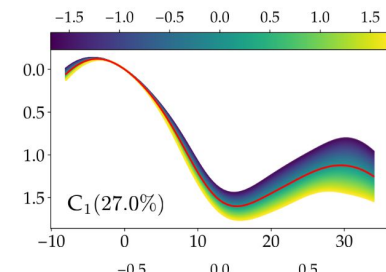
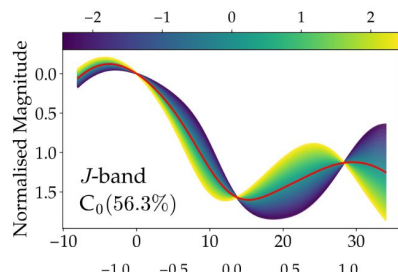
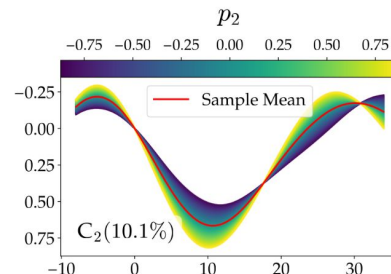
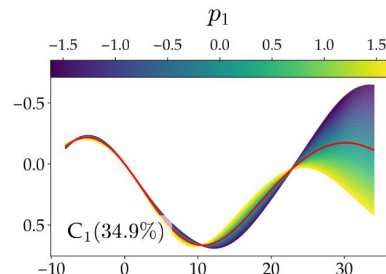
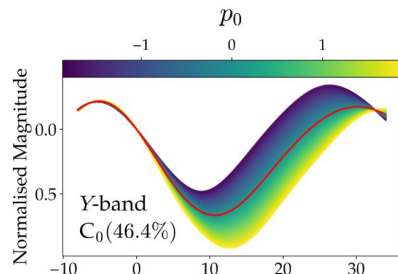
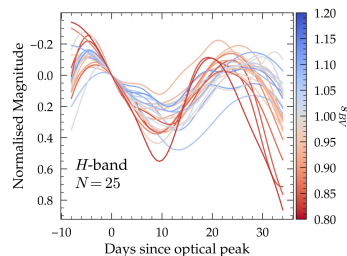
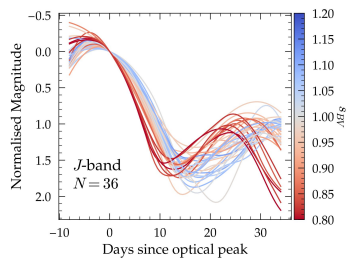
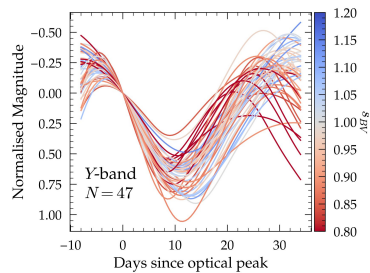
Single NIR epoch (Müller-Bravo+2022b)
or standardisation?



Conclusions

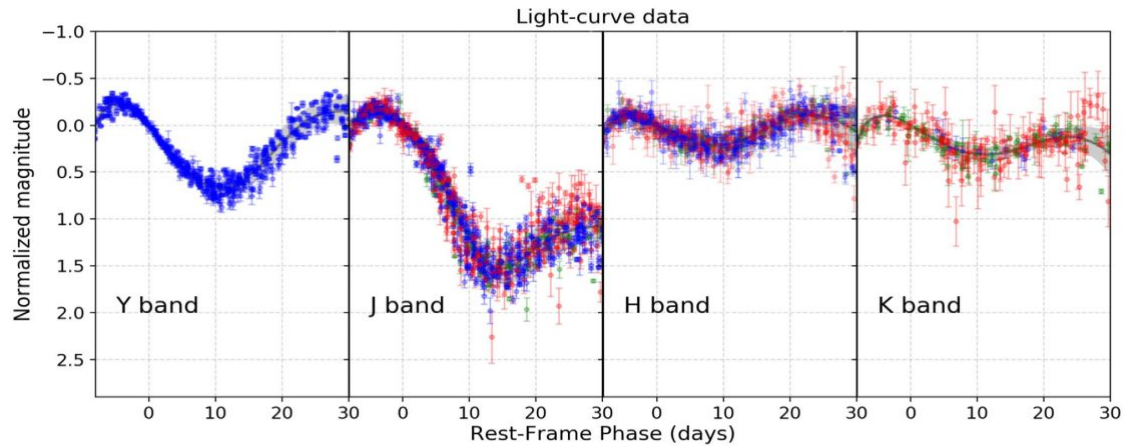
- SNe Ia develop a distinct secondary peak in the NIR, ideal for probing the physics
- The sample of SNe Ia with well-sampled light curves in the NIR has increased in recent years, but it is still limited - CSP is a great addition
- Different PCA components may trace different physics (e.g. nickel mass, metallicity). Some similarity between Y and H bands (due to spectral features?)
- Possible standardization in the Y band (any real advantages?)
- There is currently a lack of SNe Ia models at NIR wavelengths
- **Paper to be submitted to A&A and ArXiv this week!**

PCA decomposition

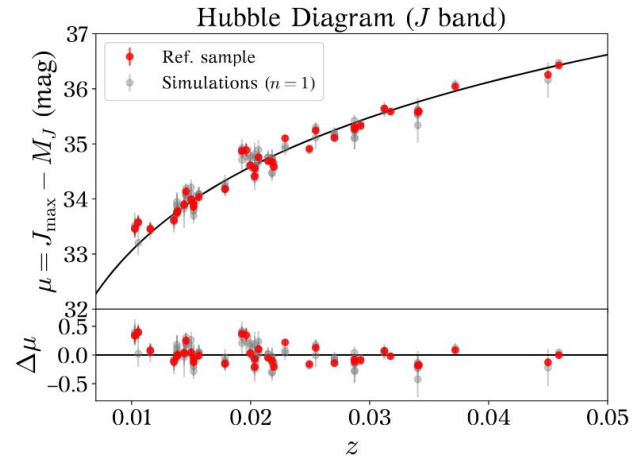


NIR Homogeneity

SNe Ia are pseudo-standard candles in the NIR, partially because they are less affected by dust extinction



Avelino et al. (2019)



Müller-Bravo et al. (2022b)

Carnegie Supernova Project

(CSI)

