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Constraining the Explosion Mechanisms of Type Ia Supernovae

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ABSTRACT

It is known that type Ia supernovae (SNe Ia) are the result of a thermonuclear explosion of a white dwarfs (WD). However, the mechanism leading to these bright transients is still not fully understood. In this work we perform the largest analysis of the Ni-56 distribution of SNe Ia to date. Our sample consists of 91 SN Ia, provided by The Zwicky Transient Facility (ZTF), and we use the model light curves of Chandrasekhar mass explosions with a range of Ni-56 distributions provided by Magee (2020).We find that ~70% of objects are reasonably well matched by Chandrasekhar mass explosions. Furthermore, the sample is dominated by models with a high degree of Ni-56 mixing towards the surface of the ejecta (low p values). We develop a method of identifying potential early excesses (bumps), and find ~10% of the objects show such an excess, which could be indicative of companion or circumstellar matter interactions, Ni-56 clumps in the outer ejecta or a detonation of a helium shell on the surface of the WD.

INTRODUCTION

- *The origins of SNe Ia are still unclear: Does the progenitor system consist of a double degenerate system (DD) or a single degenerate (SD)?*
- *What is the explosion mechanism? Does the explosion occur at sub-Chandrasekhar mass or Chandrasekhar mass?*
- *Early light curves help us unravel these mysteries -they tell us about the ejecta composition and the matter in the immediate vicinity of the WD [1,2,3,4]*

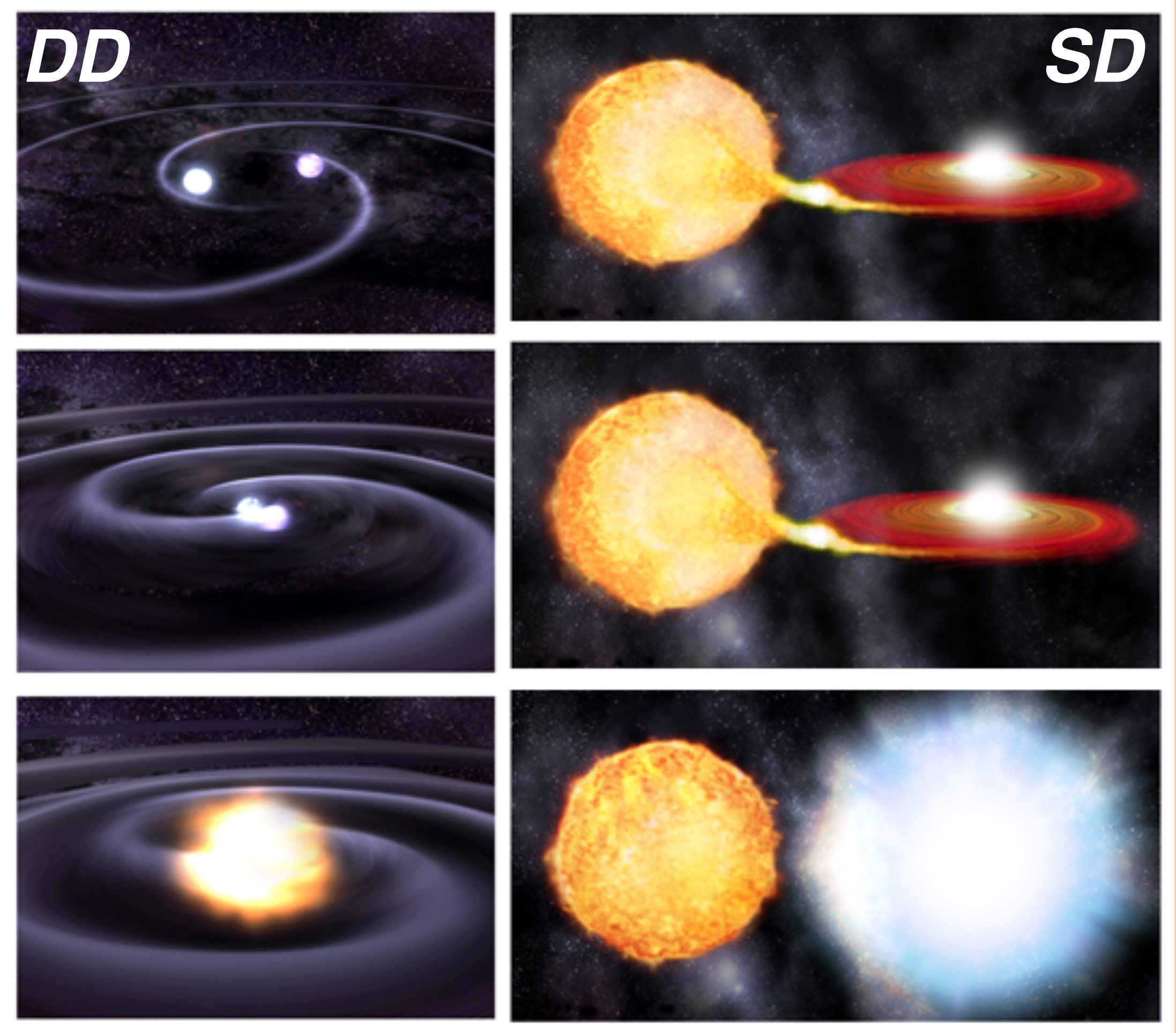


Fig. 1: Cartoons showing the merger of two WDs (DD, left) and a WD accreting from a red supergiant (SD, right)

- *In this work we focus on the Ni-56 distribution which is dependent on the explosion mechanism - e.g. a subsonic deflagration allows for more mixing to take place than a full supersonic detonation [1]*
- *More Ni-56 towards the surface of the WD means light from radioactive decay can escape faster and will cause the light curve to rise sooner [2,3]*

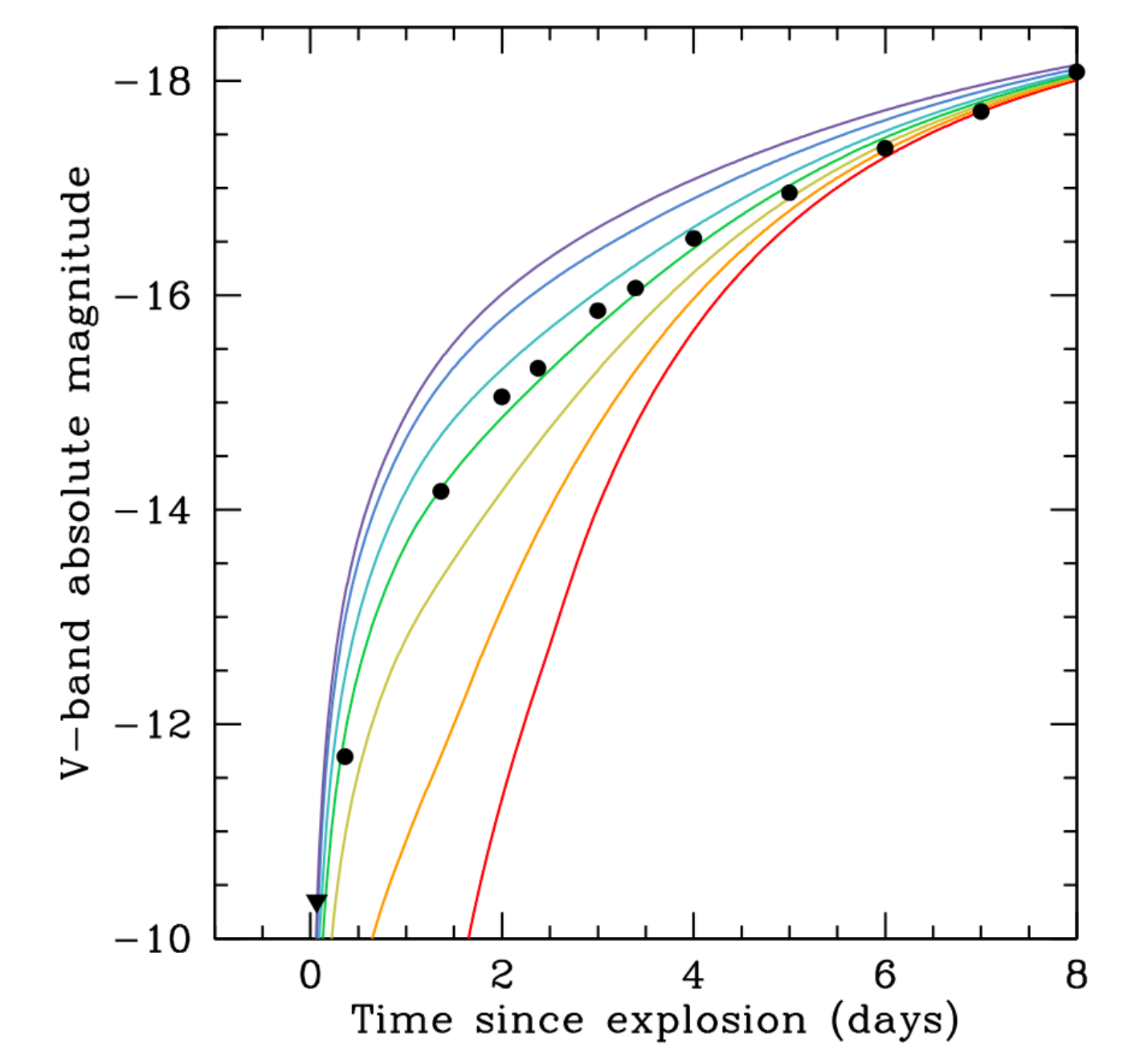


Fig. 2: Light curves with varying amounts of Ni-56 mixed towards the surface of the ejecta (indigo = highly mixed, small p-value red = Ni-56 restricted to inner ejecta, high p-value). Taken from [2]

- *We model SNe Ia light curves from the ZTF 2018 sample with TURTLS models [3] to determine the Ni-56 distributions*

RESULTS

Objects fit by Chandrasekhar Mass explosions

- *We find that ~70% of objects are well fit by Chandrasekhar mass explosions*
- *Majority of objects are matched by models with a large amount of Ni-56 mixed towards the surface*

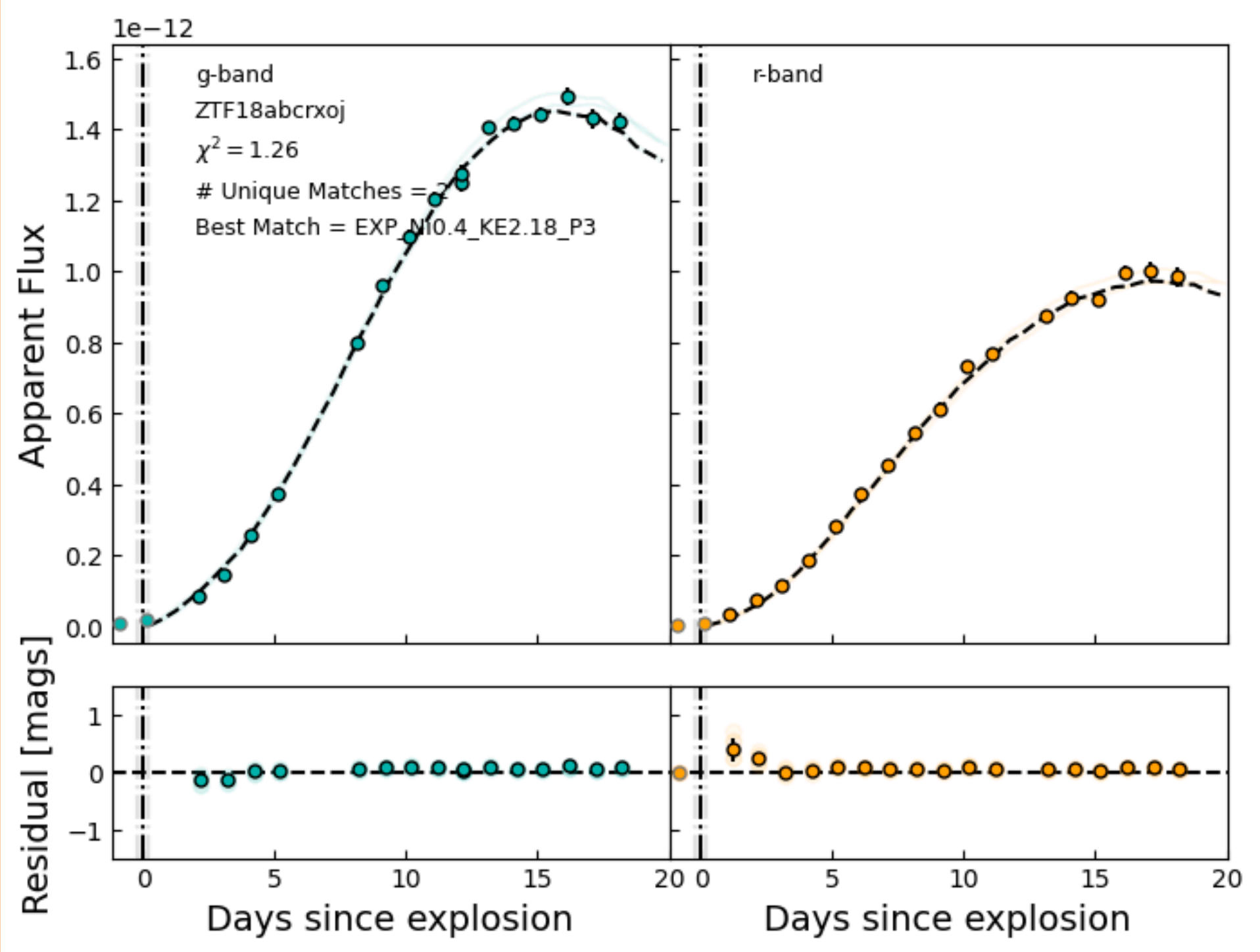


Fig. 3: Example of a light curve (in flux) that was well fit by the models, residuals are shown in magnitude. Left = g-band, right = r-band)

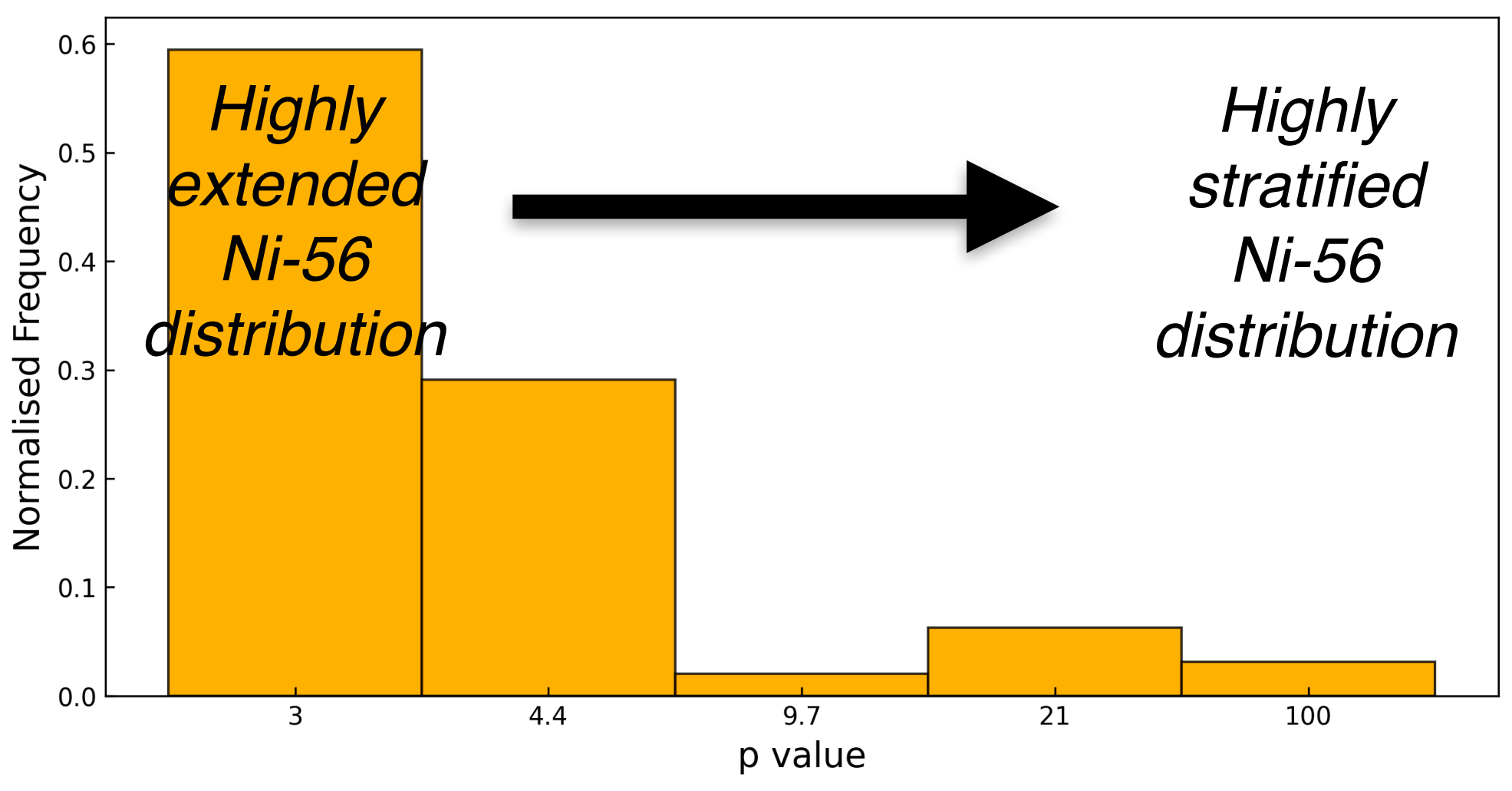


Fig. 4: Histogram showing the distribution of p-values in the ZTF sample, indicating that our sample is dominated by objects where Ni-56 has been allowed to mix towards the surface of the ejecta

Flux Excess

- *We find 10 objects out of 91 (11%) that display a flux excess either in g or r band*
- *This could be indicative of circumstellar matter/companion interaction [2, 5], clumps of Ni-56 at high velocities [6] or a helium shell detonation [7]*

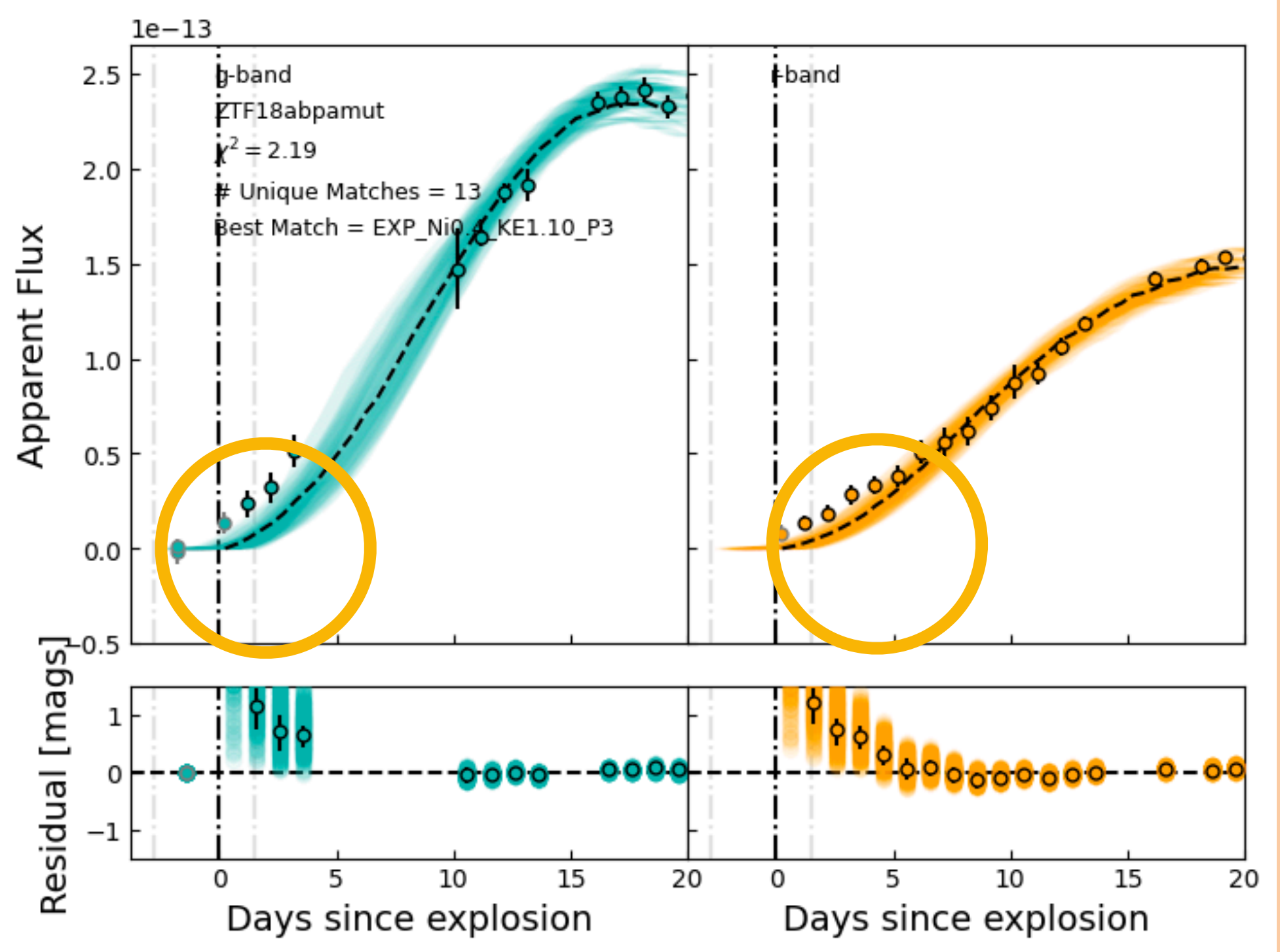
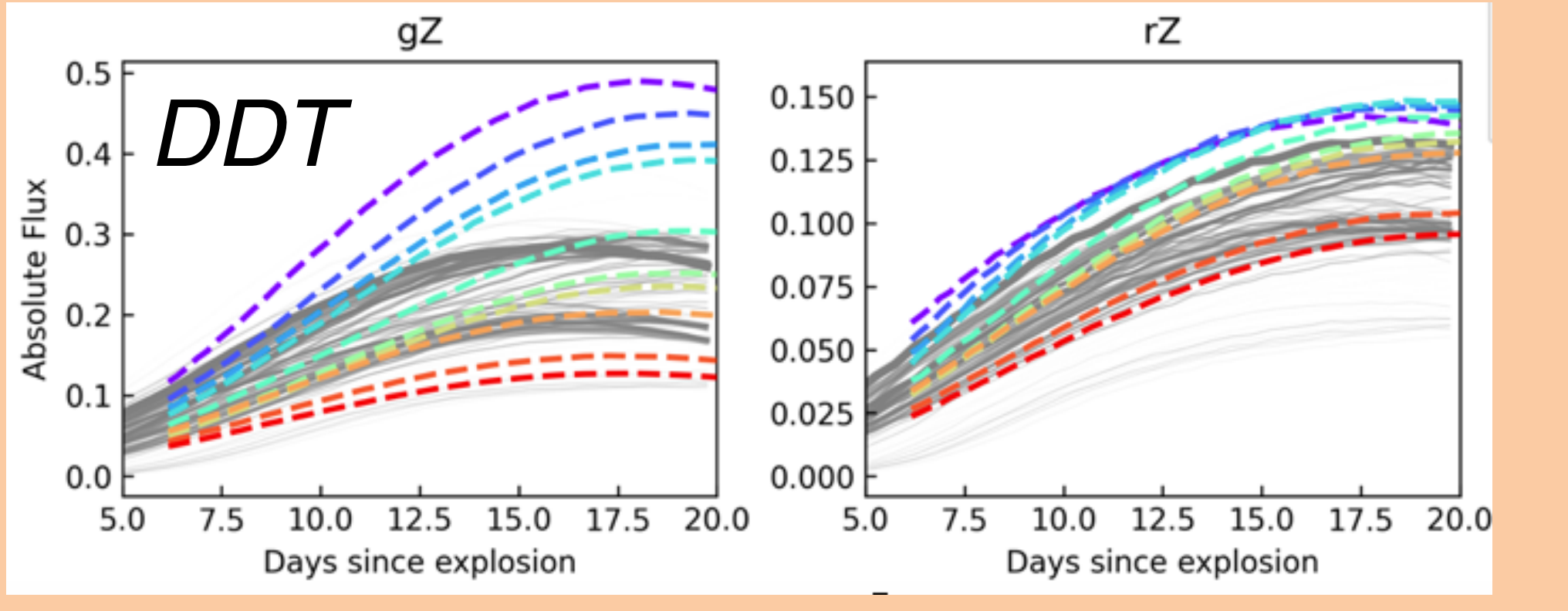


Fig. 5: Example of an object where we detected a flux excess in the early light curve ("bump" highlighted by orange circle)

Implications for explosion mechanism?



- *The models matched by objects are more comparable to delayed detonation models (DDT, deflagration transitions into detonation, [8]) than deflagration models (DEF, subsonic deflagration of a WD, [9])*

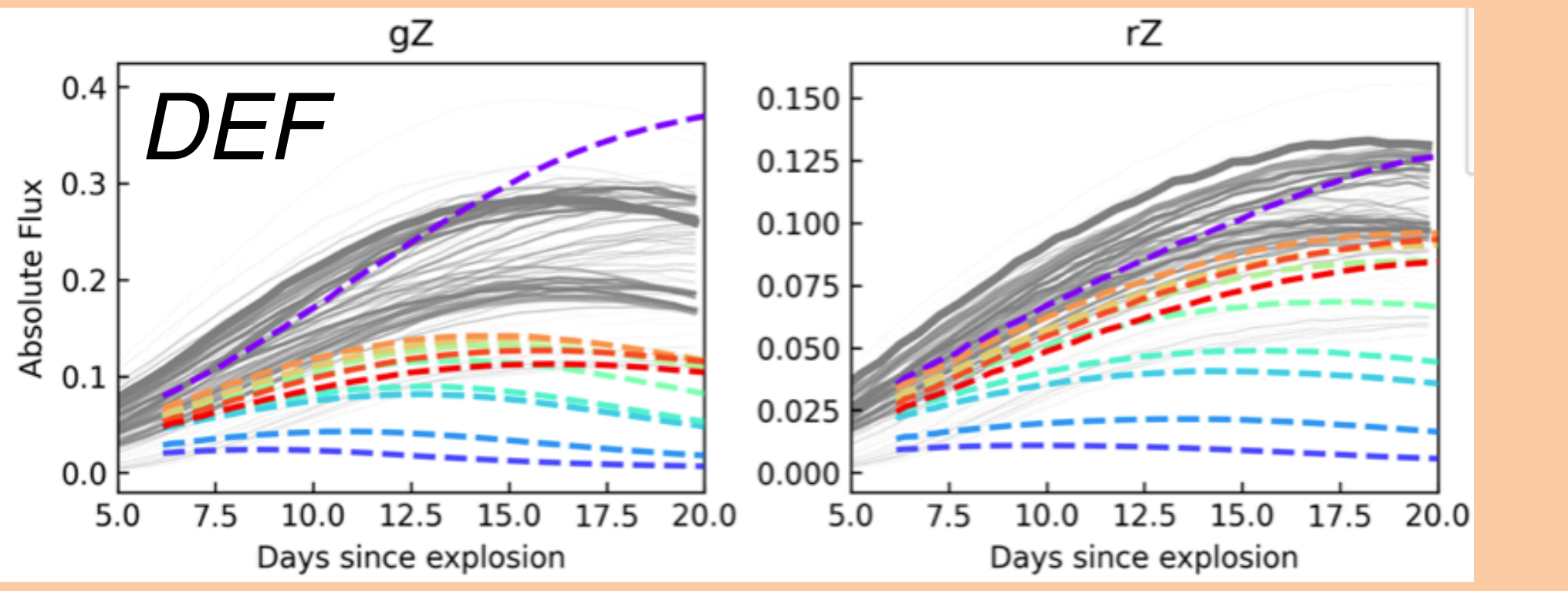


Fig. 6&7: Comparisons of light curves between DDT (top, coloured), DEF (bottom, coloured) and TURTLS models (grey lines) matched to our objects. Models taken from [8,9]

CONCLUSIONS

- *We find that majority of objects in the ZTF sample are well fit by Chandrasekhar mass explosions*
- *The sample is dominated by objects with highly extended Ni-56 distributions*
- *Approximately 10% of objects show a flux excess (in the form of a shoulder or bump)*
- *This highlights the importance of surveys such as ZTF as they allow us to catch SNe within a few days of explosion and this might allow us to unravel the mystery around the origins of SNe Ia*

Future work

- *Apply machine learning methods to detect light curves with a flux excess during the initial rise with the aim of rapid spectroscopic follow up to distinguish between different explosion scenarios*

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