Exploring Two Long-Rising Energetic Type II Supernovae Without Interaction Signatures

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Motivation

- **Type II-L SNe**
  Rise-time ~ 13 days
  Peak magnitude ~ -18
- **Type II-P SNe**
  Rise-time ~ 7 days
  Peak magnitude ~ -16
- **1987a-like SNe**
  Rise-time > 40 days
  Peak magnitude ~ -16
- **SN 2023nly & SN 2023vbw**
  Rise-time > 100 days
  Peak magnitude $\lesssim -19$

Scientific importance

The prolonged and bright light curves of SN 2023nly and SN 2023vbw suggest **additional powering compared to typical Type II Supernovae**, making these two events good candidates for exploring powering mechanisms beyond the traditional core-collapse mechanism. At the same time, both SN 2023nly and SN 2023vbw exhibit **normal P-cygni profiles** in their spectra, in contrast to the narrow lines seen in interacting SNe.

*Here, we present data from the **Zwicky Transient Facility** (**ZTF**; Bellm et al. 2019) of both SNe.*

Long-rising and luminous Type II SNe

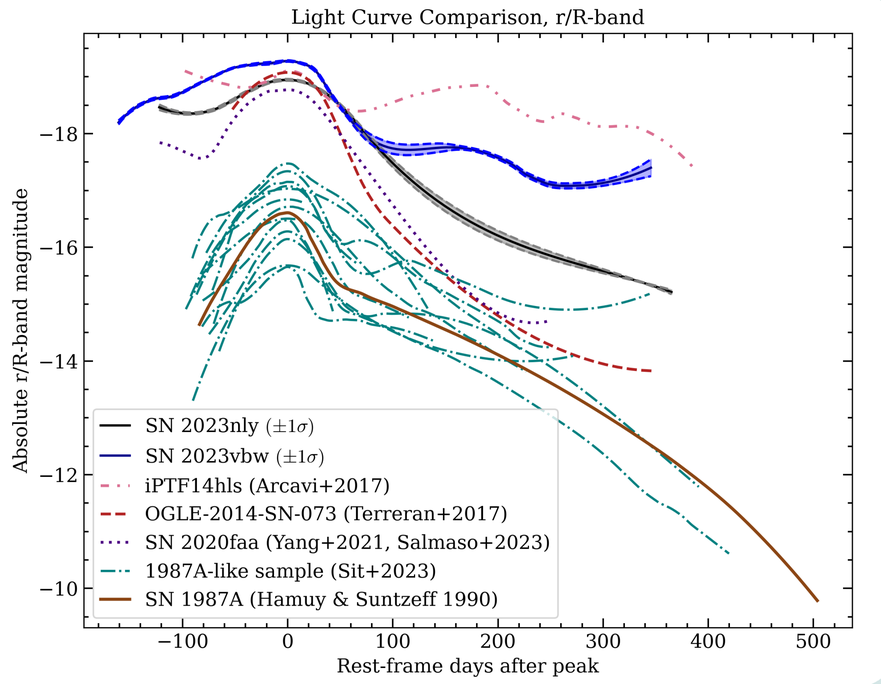
Many long-rising SNe II are 1987A-like and have peak luminosities similar to that of normal Type II.

Only a few of events like OGLE-2014-SN-073, SN 2020faa and iPTF14hls fall in similar magnitude ranges as SN 2023nly and SN 2023vbw.

Suggested powering mechanisms

The prolonged and luminous behaviour can be explained by mechanisms like **(pulsational) pair instability, CSM interaction** or **magnetar spin-down**.

The light curves in the figure to the right have been interpolated using ***Automated Loess Regression*** (***ALR***; Rodríguez et al. 2019).

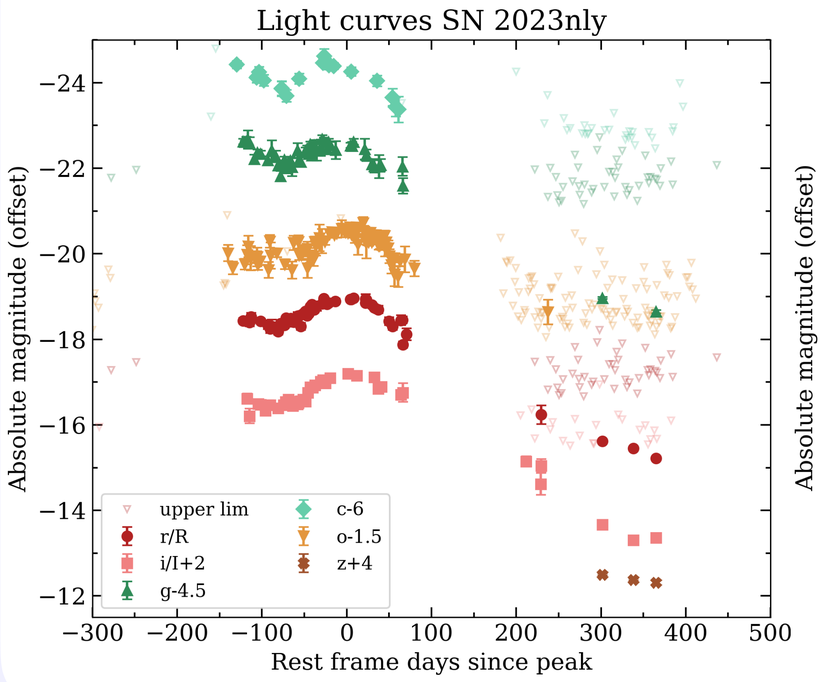


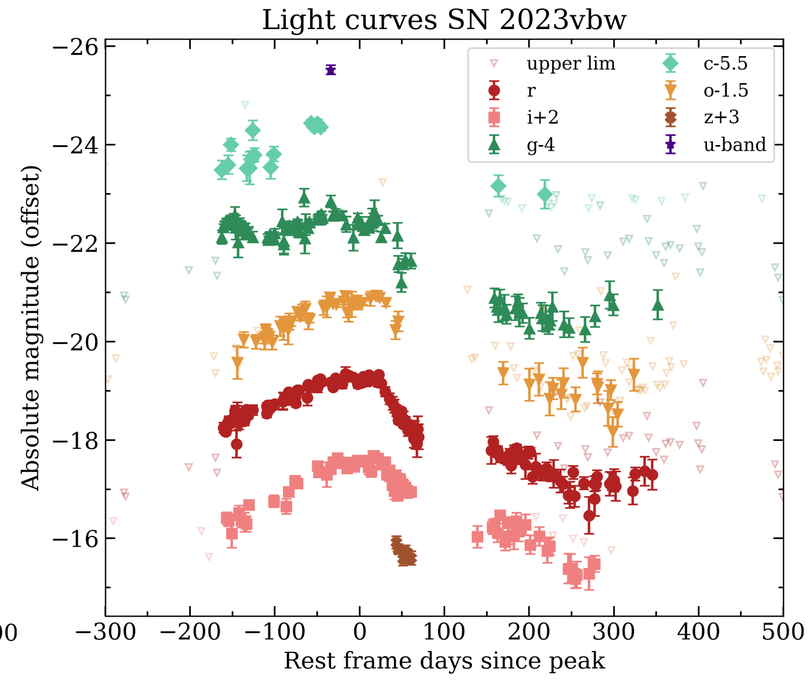
Data and observed properties

Discovery and classification

SN 2023nly (**redshift $z = 0.0732$**) was discovered by the *Asteroid Terrestrial-impact Last Alert System* (*ATLAS*; Tonry et al. 2018) on June 7th, 2023 (Tonry et al. 2023) and later classified by *ZTF* as **Type II SN** on November 2nd, 2023 (Sollerman et al. 2023).

SN2023vbw (**redshift $z = 0.0880$**) was discovered by *ZTF* on October 12th, 2023 (Forster et al. 2023) and classified as a **Type II-P SN** by the *Supernova and Gravitational Lenses Follow up* (*SGLF*) project on February 29th, 2024 (Pérez-Fournon et al. 2024).





Light curve properties

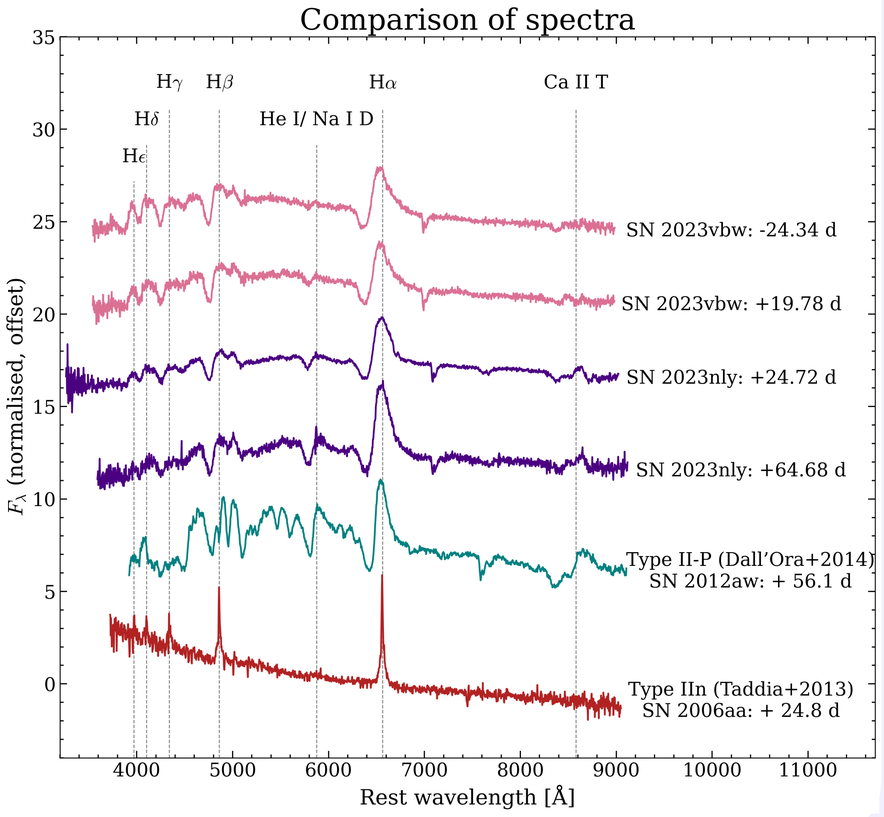
Estimated from the *r*-band interpolated light curves using *ALR:*

- SN 2023nly has a **rise-time > 160 days** and a **peak absolute magnitude** of $M_r = -18.94 \pm 0.02$.
- SN 2023vbw has a **rise-time > 120 days** and a **peak absolute magnitude** of $M_r = -19.28 \pm 0.01$.

Spectra

The spectra of SN 2023nly and SN 2023vbw show **prominent P-cygni profiles at all epochs**. This is in contrast to interacting SNe (IIn), that, instead, exhibit narrow lines (electron scattering profiles).

Below is two spectra for each of our SNe, as well as a typical Type II-P and IIn spectra for comparison.



Analysis and future directions

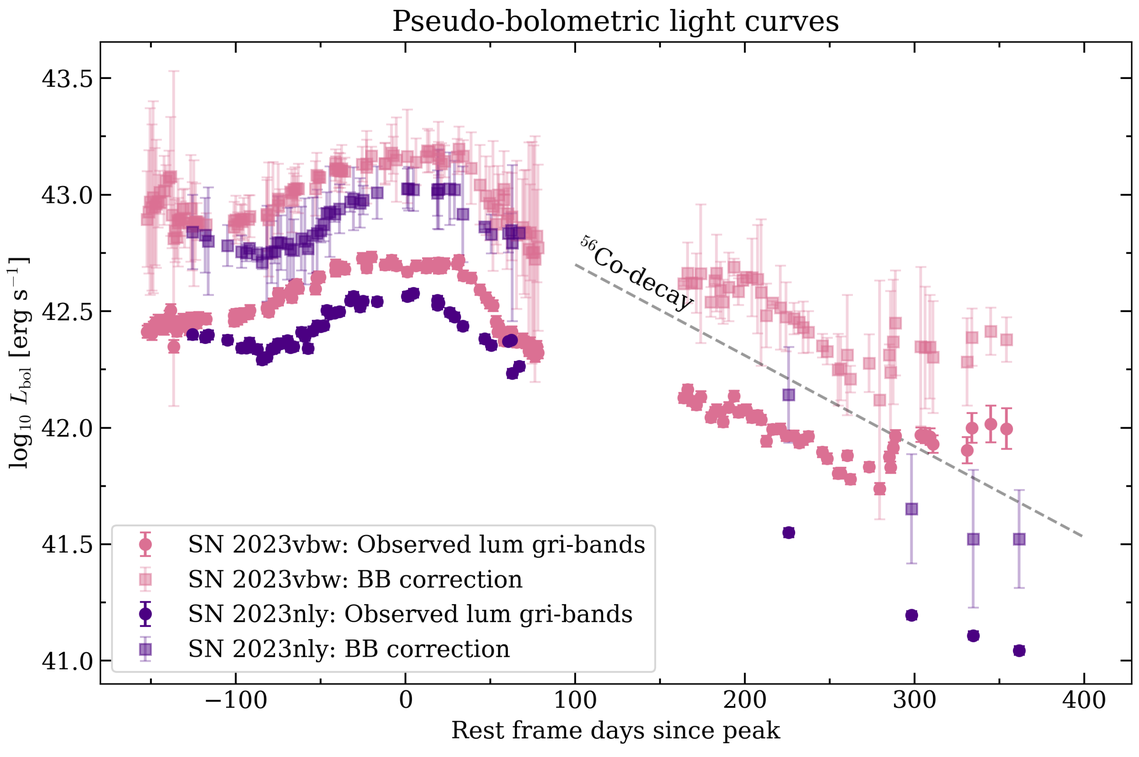
Bolometric light curves

We constructed pseudo-bolometric light curves in the *gri*-bands using *SuperBol* (Nicholl, 2018). The *g* and *i* bands were interpolated to match the time of the observations in the *r*-band. Using *SuperBol*, we also applied ultraviolet and near-infrared corrections by fitting a modified blackbody (BB) to the SEDs.

SN 2023nly: From the bolometric light curve, we estimate a **total radiated energy** of $6.39 \pm 0.29 \times 10^{49}$ erg in the *gri*-bands and $1.96 \pm 0.54 \times 10^{50}$ erg with the BB correction.

SN 2023vbw: From the bolometric light curve, we estimate a **total radiated energy** of $1.04 \pm 0.059 \times 10^{50}$ erg in the *gri*-bands and $2.95 \pm 1.16 \times 10^{50}$ erg with the BB correction.

Our estimated total radiated energies lie above the expected $\sim 10^{49}$ erg for normal Type II SNe, thereby approaching typical values for interacting or superluminous SNe.



Future directions

- Light curve modeling with existing powering mechanisms, such as **pair instability** and **magnetar spin-down.**
- Spectral analysis of **pseudo-equivalent widths** and **line velocities.**
- **Spectral comparison** to other long-rising Type II SNe.
- Modeling of **nebular spectra** to further constrain the powering mechanisms.

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