SN 2024adtg: One of the brightest hydrogen-rich superluminous supernovae

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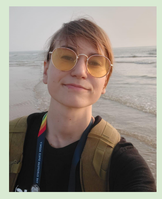

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Introduction

- **Superluminous supernovae (SLSNe)** are a rare and diverse subtype of core-collapse supernovae (SNe) with extreme brightness ($M_{peak} \lesssim -20^m$) [1].
- H-rich SLSNe with broad lines (SLSNe II) are particularly rare (≲10% of all SLSNe) [2]. Only around 20 of such events have been found to date.
- **Power sources of broad-lined SLSNe II are not well constrained,** but the main models include the magnetar spin-down [3], interaction with the circumstellar material (CSM) [e.g. 4], or fallback accretion onto a black hole [5].
- Although not numerous, broad-lined SLSNe II are quite heterogeneous. Most of them can be divided into two groups: spectrally similar to normal SNe II (SN II-like) or to a prototypical SN 2008es (08es-like). 08es-like events have higher luminosity ($M_{peak} \lesssim -21^m$) and slower evolving light curves [2].
- **Here we present a preliminary analysis of SN 2024adtg,** one of the brightest 08es-like broad-lined SLSN II with the first medium-resolution spectra of this class, offering new insight into these enigmatic events.

SN 2024adtg

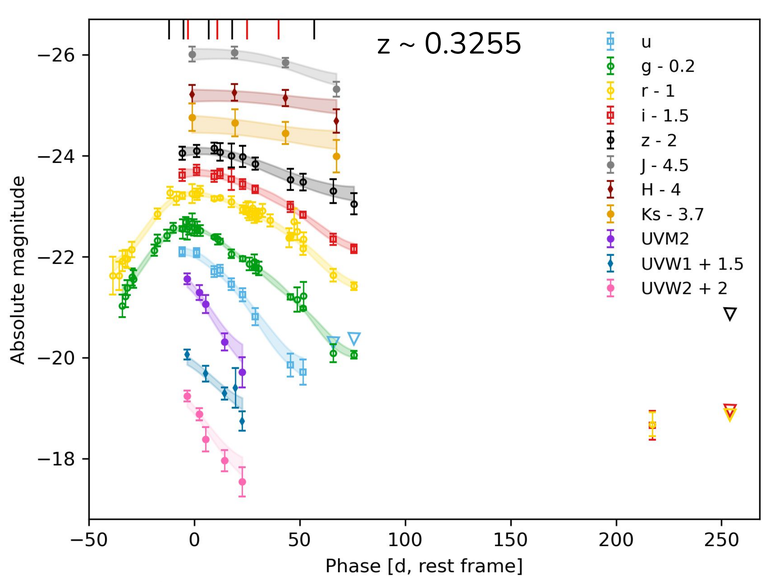

Figure 1: Absolute light curve of SN 2024adtg.

Table 1: Light curve properties of SN 2024adtg.

M_{peak} [mag]	-22.25 ± 0.04
log L_{peak} [erg/s]	≳44.66
E_{rad} [erg]	>2.45x10^{51}
$t_{rise,0.5}$ [d, rest]	~24 d
$t_{dec,0.5}$ [d, rest]	~43 d

* rest-frame g

- **The high radiated energy E_{rad} excludes the neutrino-driven mechanism for SN 2024adtg** [6].
- **The spectral evolution** (Fig. 2) shows that H I lines appear early on, followed by weak He I and Fe I+Mg I blend. Additionally, host absorption and emission lines are detected, including Mg II, Fe II, [O II], and [O III].
- SN 2024adtg is the **first broad-lined SLSN II with medium-resolution spectra obtained with VLT/X-shooter** during the photospheric phase**. They show narrow CSM components** prominent in Hα profile but present also in other H I and He I profiles.

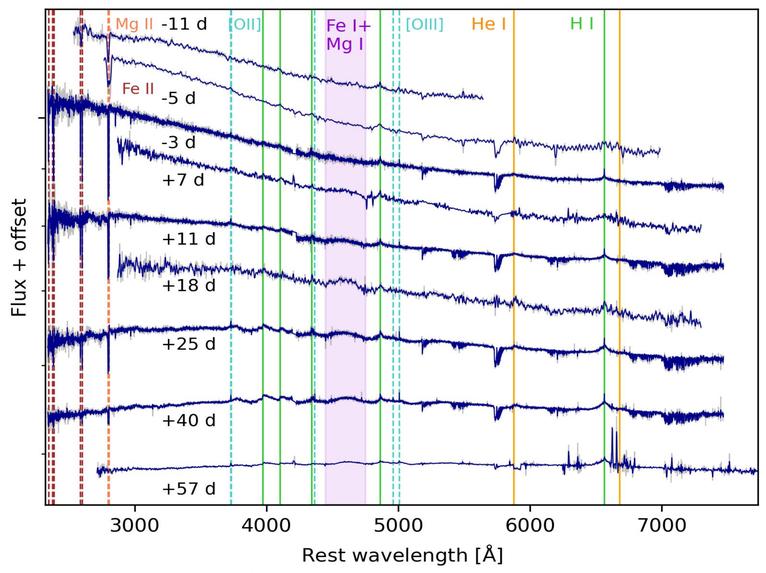

Figure 2: Spectral sequence of SN 2024adtg.

Hα profile properties (Fig. 3)**:**

- The broad emission component is getting stronger with time (FWHM~3300-4000 km/s).
- Narrow CSM absorption is blueshifted by ~300 km/s.
- Assuming this velocity, CSM had to be ejected ~4.5 yr before the explosion
- Narrow emission is mainly a host line.

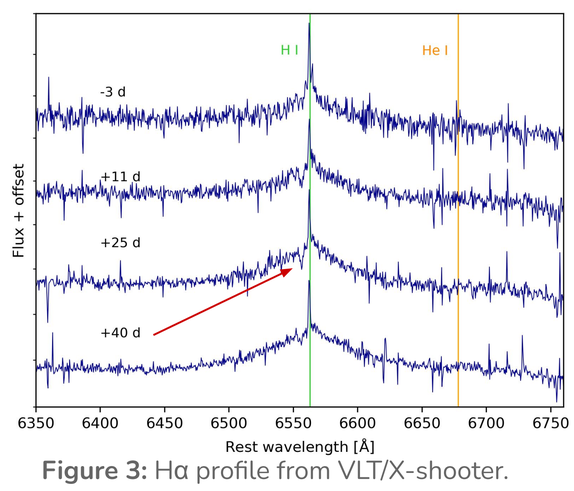

Figure 3: Hα profile from VLT/X-shooter.

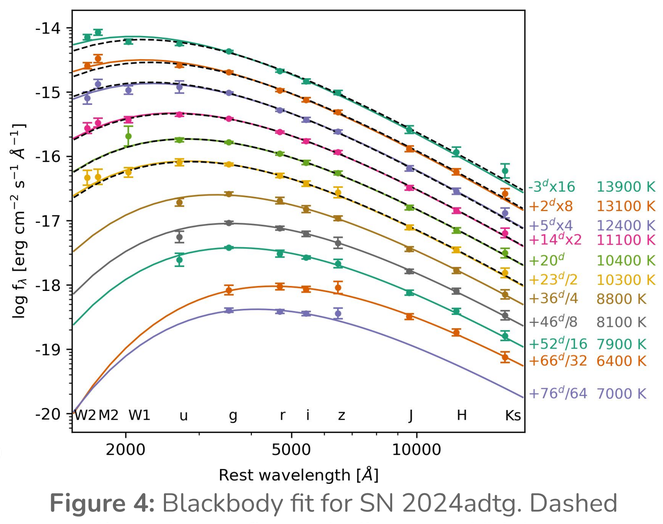

Figure 4: Blackbody fit for SN 2024adtg. Dashed lines denote fits excluding near-UV data.

Blackbody fits (Fig. 4) show the following properties:

- **UV-excess is not present in SN 2024adtg**, unlike in most 08es-like events with available near-UV data. However, it cannot be excluded that it appears after the last epoch with near-UV points at +23 d.
- A linear fit to the radius evolution yields a photospheric velocity of ~4300 km/s, which is relatively low and not yet well understood.

Comparison within the 08es-like SLSNe II sample

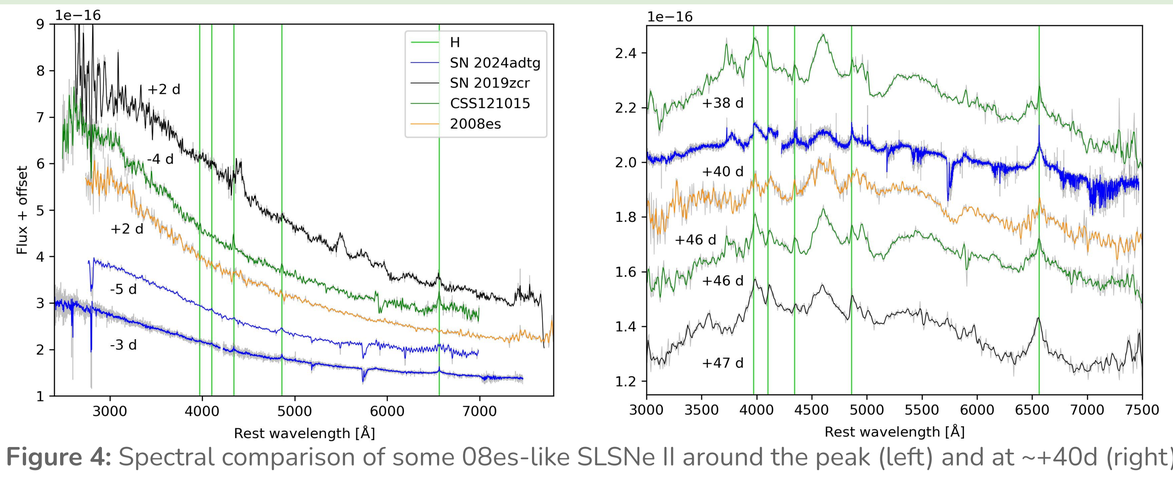

Figure 4: Spectral comparison of some 08es-like SLSNe II around the peak (left) and at ~+40d (right).

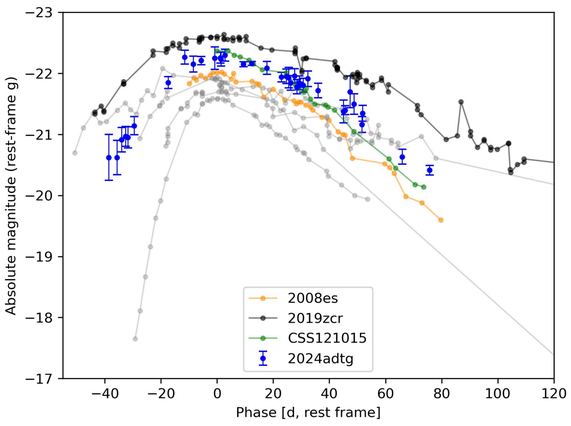

Figure 5: Absolute light curve comparison of SN 2024adtg and other 08es-like SLSNe II.

While the 08es-like SLSNe II sample currently contains <10 events, their shared properties suggest a common class that includes SN 2024adtg. Their light curves and spectra (especially after +40 d) are broadly similar (Fig. 4,5). However, **several notable differences** are present:

- In most 08es-like events with available near-UV data, the **UV-excess** indicating interaction with CSM is present, often visible already near the peak. In SN 2024adtg, it either is absent or appears unusually late.

- **Narrow CSM absorption** is detected only in SN 2024adtg, as it is the only event with a medium-resolution spectrum. However, similar features could be present in other events.
- In early epochs, SN 2024adtg has a lower temperature and less prominent spectral lines.

Possible power sources

- Power sources of 08es-like SLSNe II are still debated. Their radiated energies are >10^{51} erg, which makes the **neutrino-driven mechanism problematic or impossible** and **likely requires a central engine**. Additionally, their host galaxies resemble those of H-poor SLSNe, consistent with a central engine scenario.
- At the same time, in many 08es-like events, there are **clear signs of CSM interaction (CSI)**.
- This suggests a possible combination of power mechanisms across the class.

We tried a CSI model [4] and a magnetar central engine model [3] from *Redback* [7] (Fig. 7). **Despite the reasonable fit, parameters of these models are problematic**:

- **The CSI model** yields $E_k \sim 10^{53}$ erg – too high even for a central engine mechanism. This suggests that CSI may not fully power the observed emission.
- T**he magnetar model** gives $E_k < E_{rad}$, implying an additional energy source may be required. Moreover, the inferred ejecta + magnetar mass (~5 $M_\odot$) appears too low for a H-rich SN progenitor.

Based on this, **it seems that both central engine and CSI may be required.**

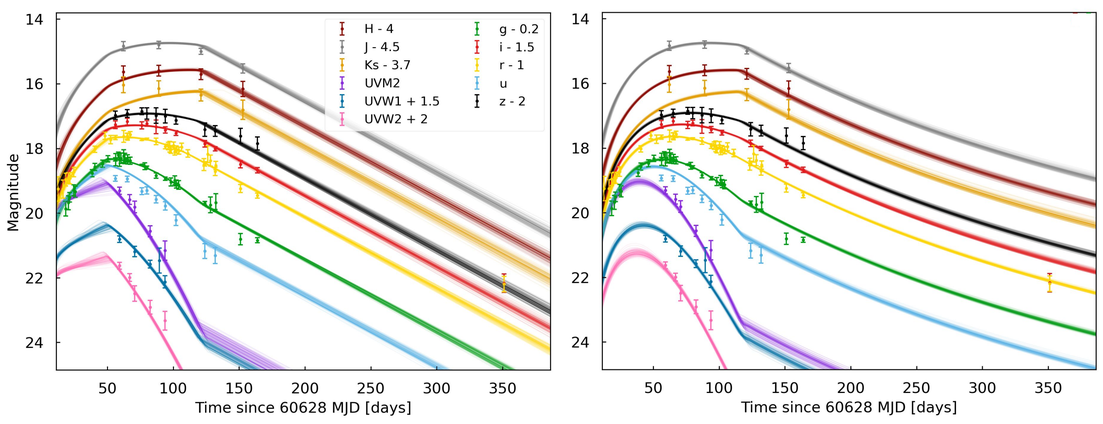

Figure 7: Redback light curve fits for SN 2024adtg. Left: CSM model [4], right: magnetar model [3].

Corner plots and priors

Preliminary Summary

- SN 2024adtg is one of the most luminous H-rich SNe.
- Signs of CSM interaction (narrow absorption) detected for the first time using VLT/X-shooter spectrum.
- Due to high energy central engine is likely needed.
- No UV-excess unlike other events of the class.
- The most likely power source at the moment is central engine + CSI.

References

[1] Gal-Yam, A. 2019, ARA&A, 57, 305
[2] Kangas, T. et al. 2022, MNRAS, 516, 1193
[3] Kasen, D. & Bildsten, L. 2010, ApJ, 717, 245
[4] Chatzopoulos, E. et al. 2013, ApJ, 773, 76
[5] Dexter J., Kasen D., 2013, ApJ, 772, 30
[6] Ertl, T. et al. 2020, ApJ, 890, 51
[7] Sarin, N. et al. 2024, MNRAS, 531, 1203-1227