Stockholm University

Oskar Klein centre

Funded by the European Union

erc European Research Council
Established by the European Commission

ZTF

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

Claudia Skoglund

Department of Astronomy, Stockholm University

claudia.skoglund@astro.su.se

In collaboration with Ragnhild Lunnan, Anamaria Gkini, Yang Hu, Priscila J. Pessi, Steve Schulze, Avinash Singh, Jesper Sollerman , Anjasha Gangopadhyay , et al.

Nordic-Baltic Astronomy Days 2026*, Turku, Finland*

The Finnish Astronomical Society
Suomen tähtitieteilijäseura

Nordic Council of Ministers

SUOMALAIS–TANSKALAINEN KULTTUURIRAHASTO
KULTURFONDEN FÖR FINLAND OCH DANMARK

LETTERSTEDTSKA FÖRENINGEN

JENNY JA ANTTI WIHURIN RAHASTO

FINCA Finnish Centre for Astronomy with ESO

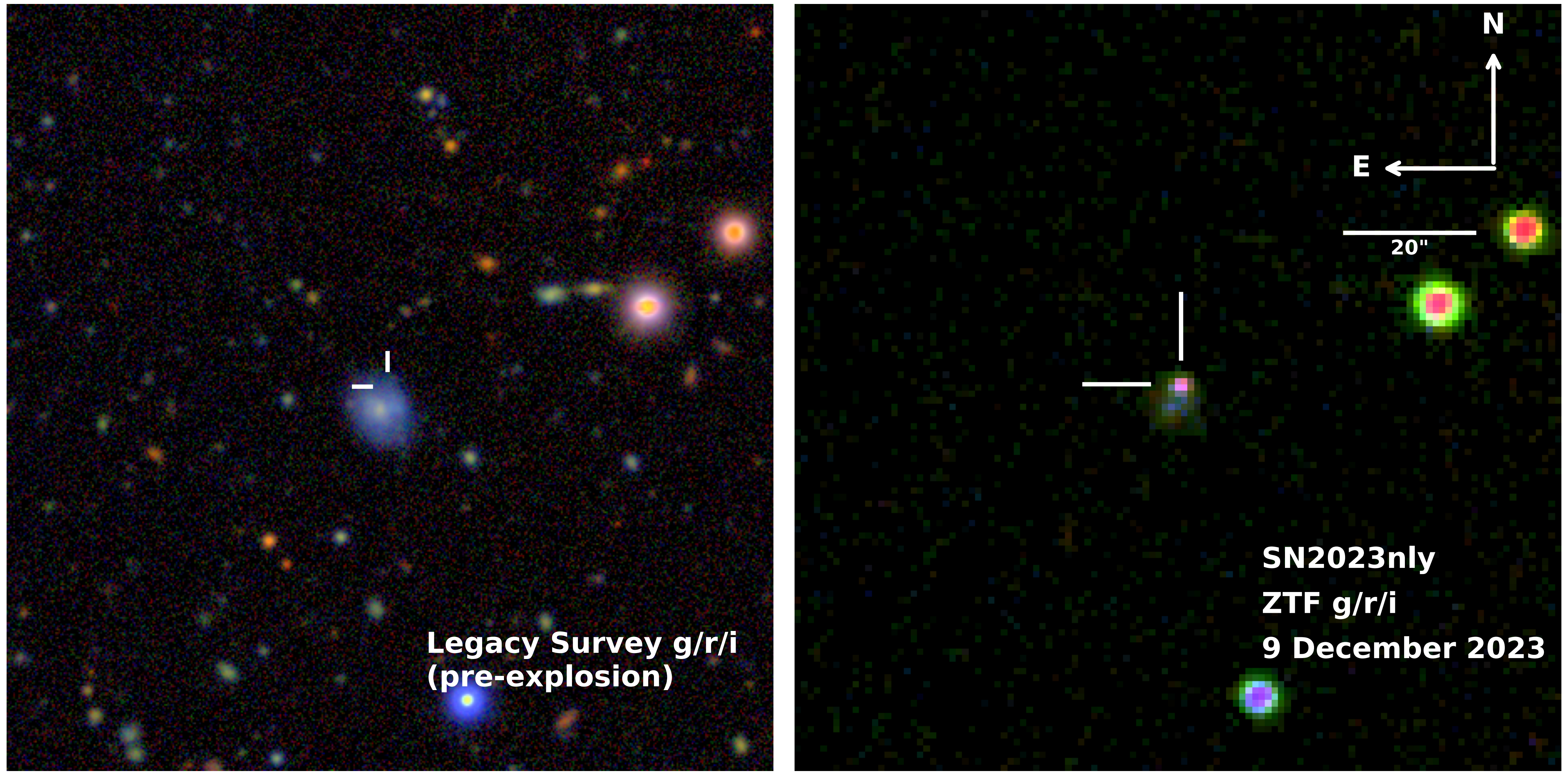
Thursday May 28th, 2026

In this talk

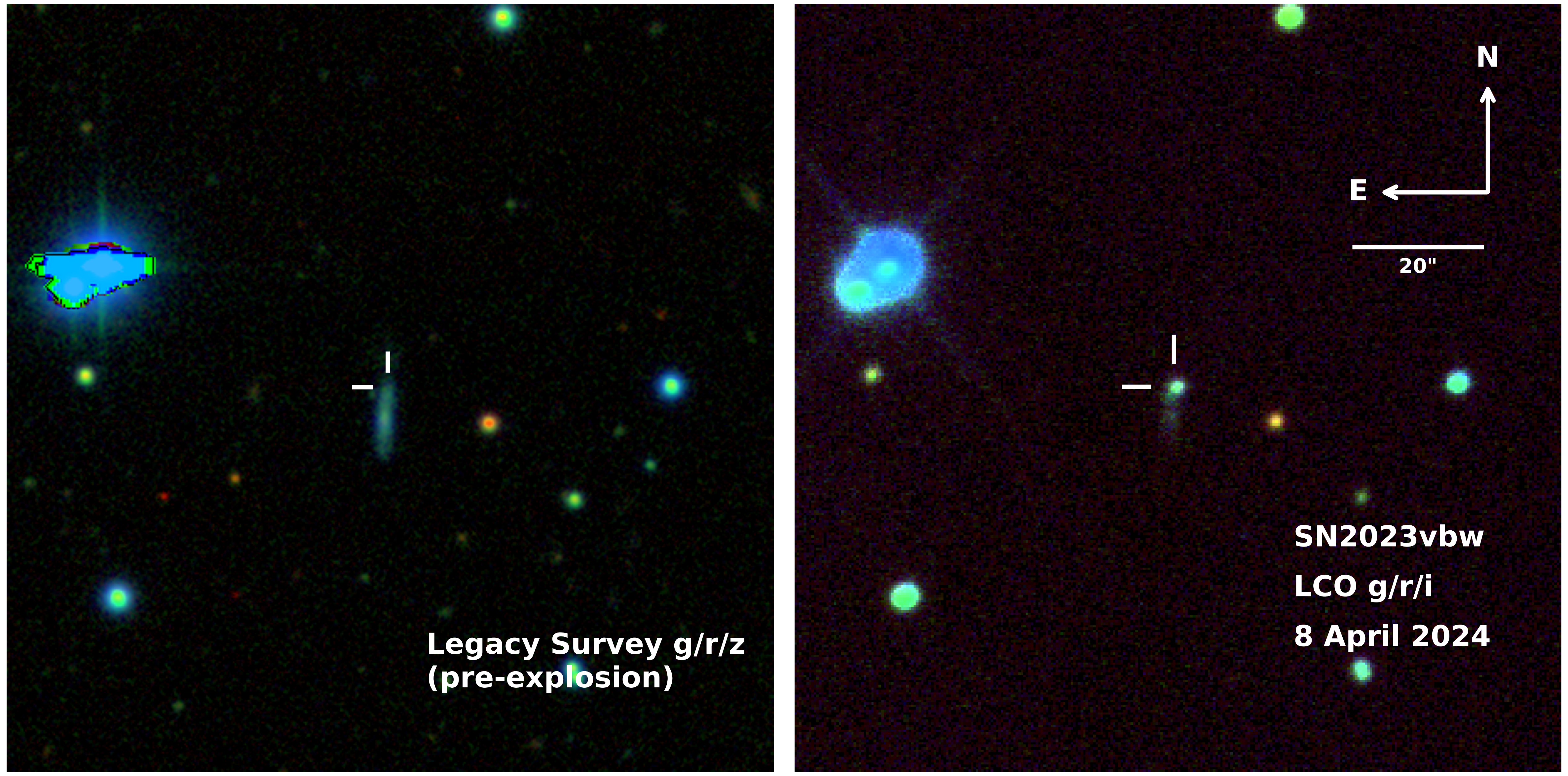
ZTF *We present data from the **Zwicky Transient Facility** (**ZTF**; Bellm et al. 2019) of both SNe.*

Why are these two supernovae (SNe) interesting?

SN 2023nly



SN 2023vbw



claudia.skoglund@astro.su.se

Type II SNe powering mechanism: Core-collapse

Progenitor: **Massive star**! 8-20 $M_\odot$

Star has onion-shell structure due to multiple phases of nuclear burning

Chandrasekhar-mass collapse

Compressed to neutron star

Infalling material bounce, causing outward shock

Shock stalls but is re-ignited via neutrino heating

—> Surrounding material is blasted away, leaving only a degenerate remnant

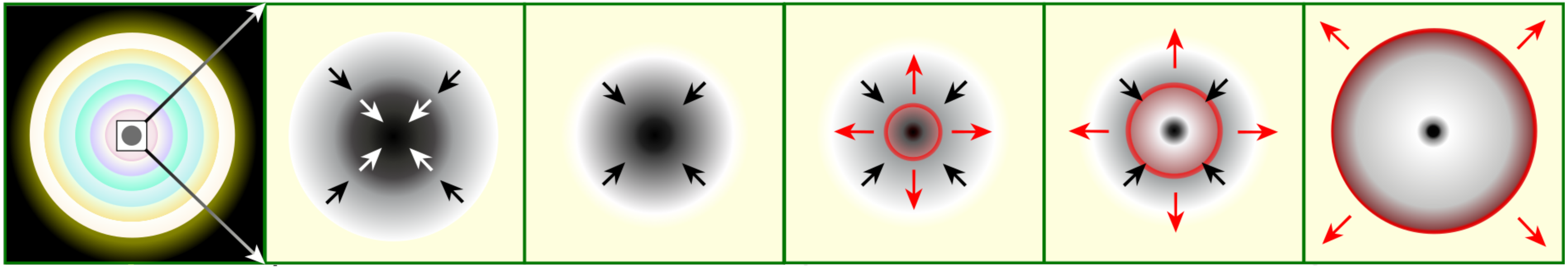


Image credit: Wikimedia commons, https://en.wikipedia.org/wiki/Supernova

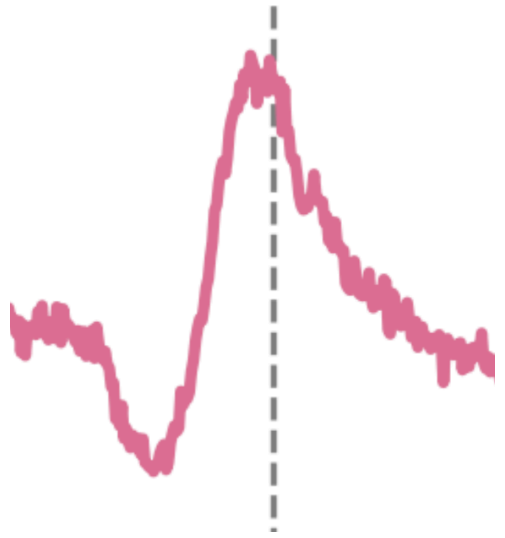
claudia.skoglund@astro.su.se

Spectra

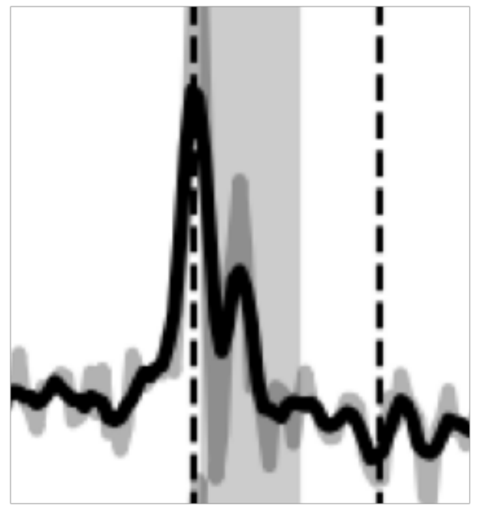
SN 2023nly and SN 2023vbw

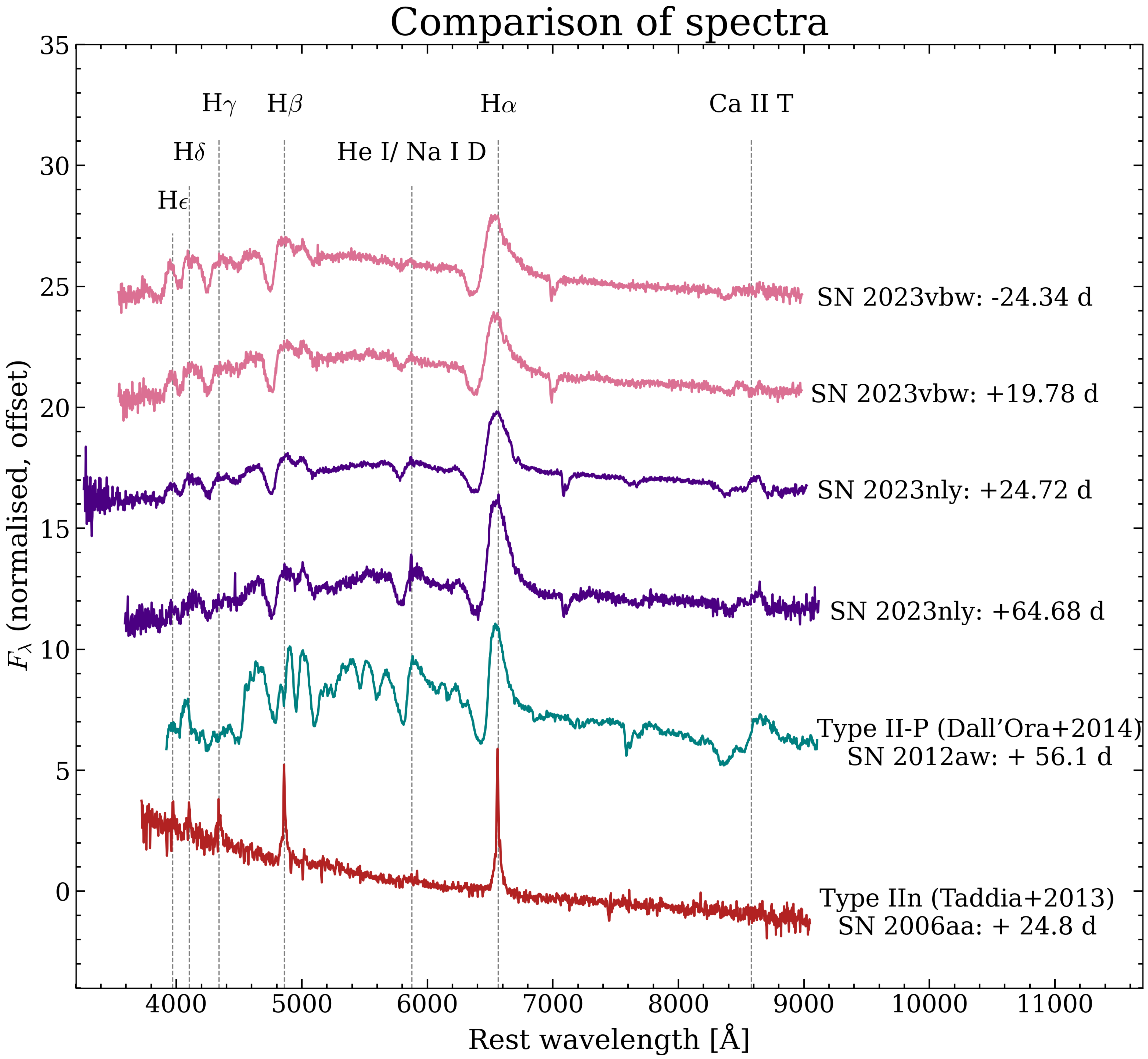
- **Normal P-cygni profiles** across all epochs
- Similar to **normal Type II/II-P** spectra
- **No narrow lines** as seen in interacting (IIn) spectra

Hα at 19.78 d of SN 2023vbw



Hα at 42.1 d from **Hu et. al. 2025**





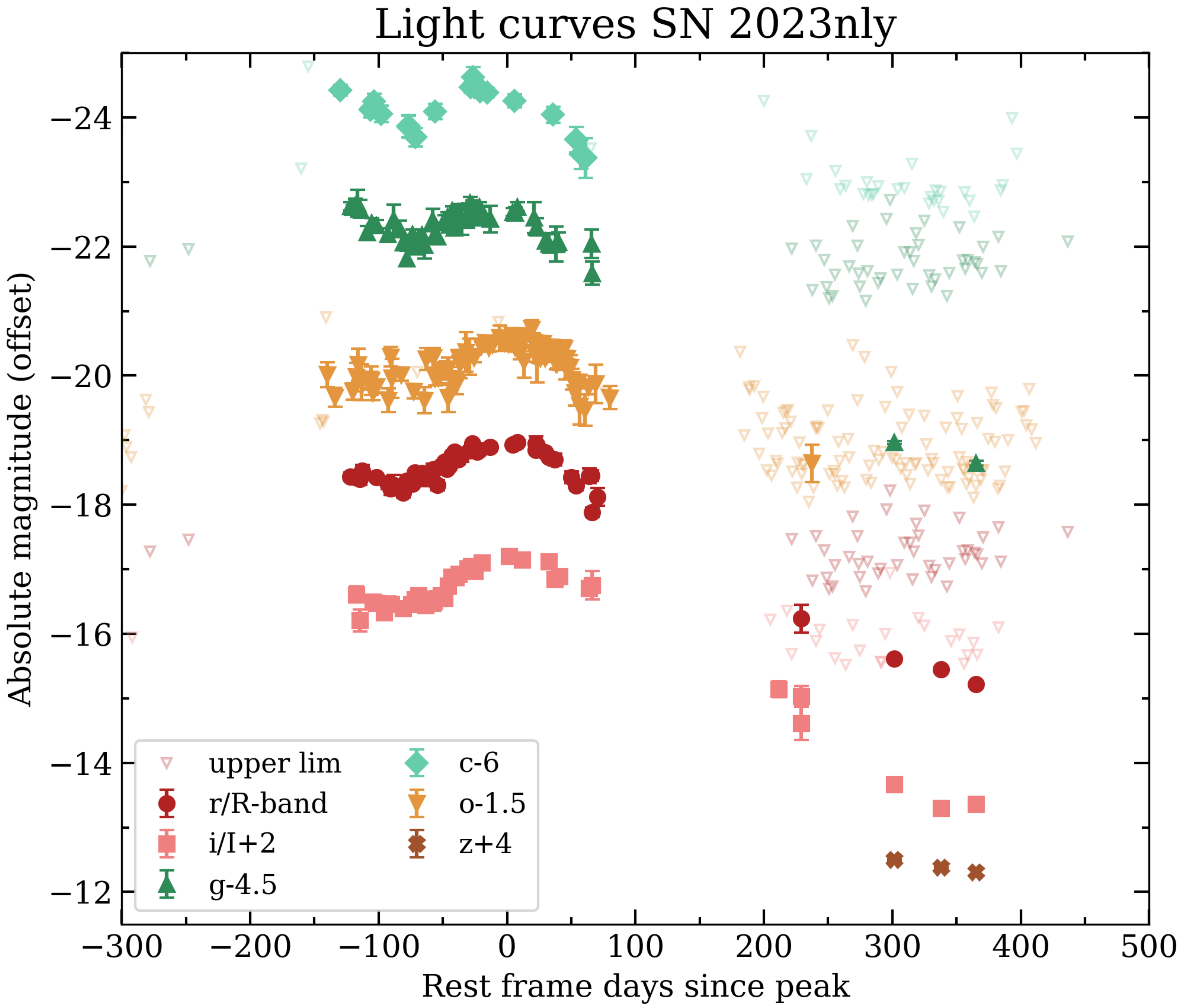
claudia.skoglund@astro.su.se

Light curves

SN 2023nly

Rise time > 120 days

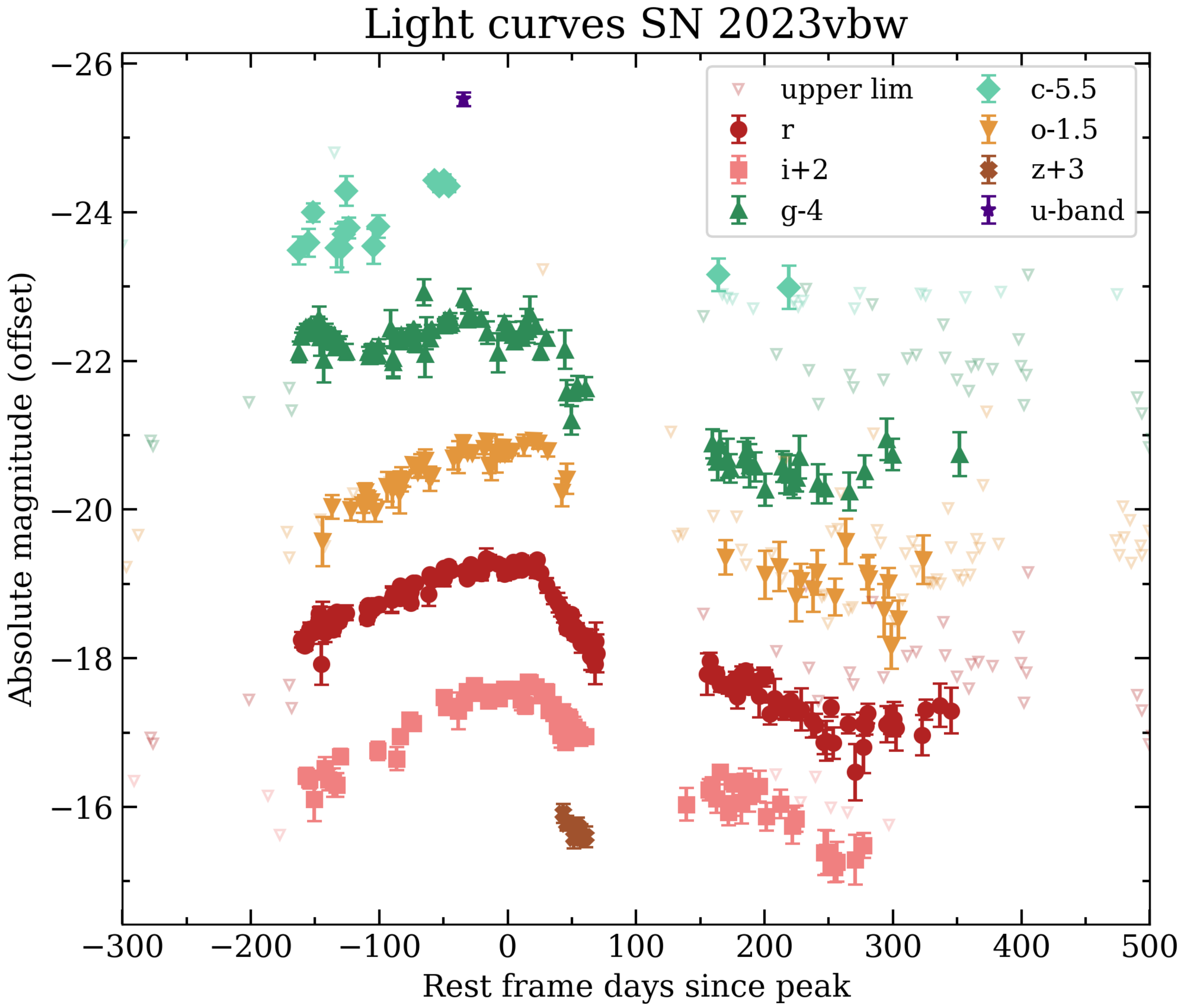
Peak absolute magnitude $M_r = -18.94 \pm 0.02$



SN 2023vbw

Rise time > 160 days

Peak absolute magnitude $M_r = -19.28 \pm 0.01$



claudia.skoglund@astro.su.se

Comparison to other long-rising Type II SNe

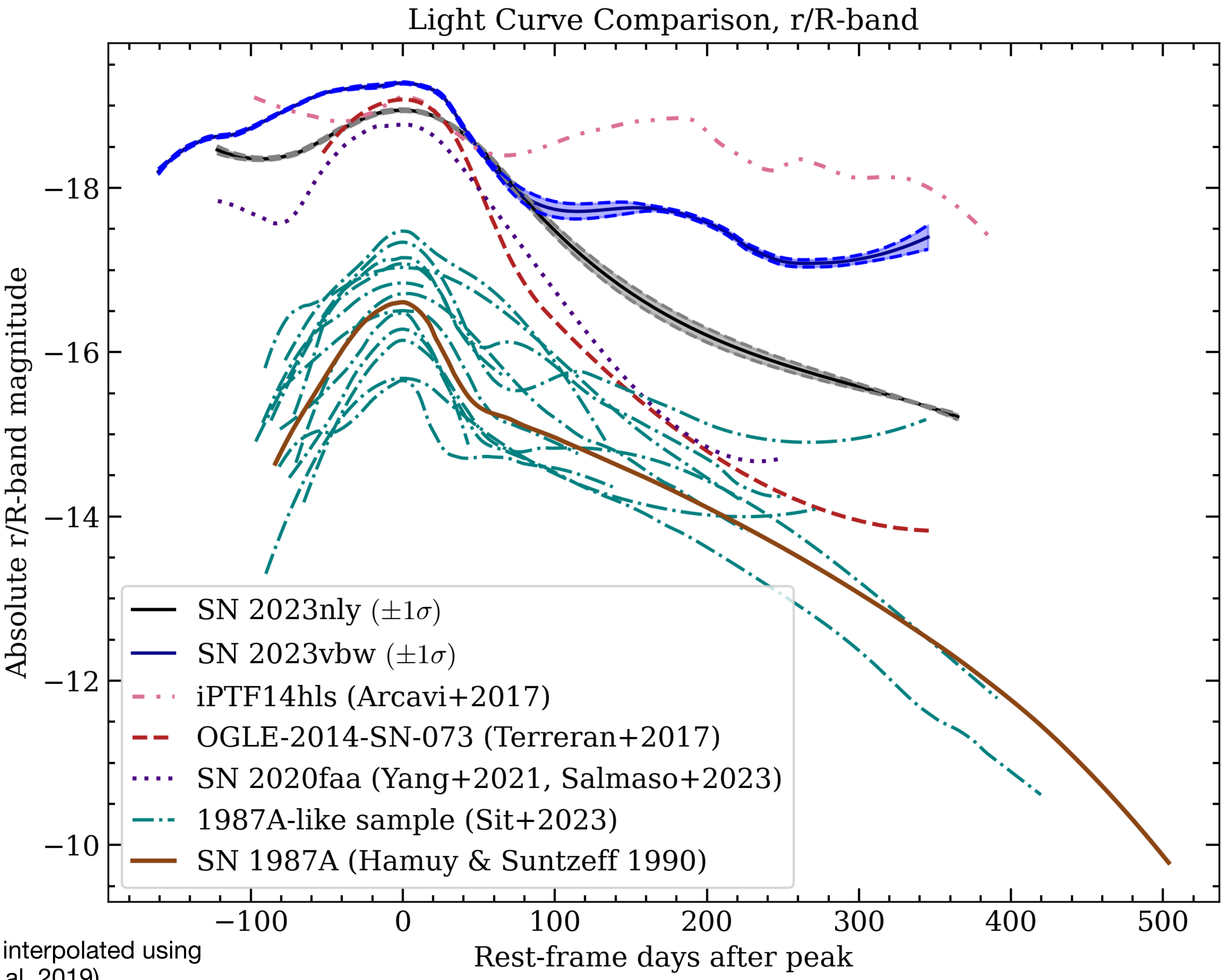
R/r-band light curves

- **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 $\lesssim -19$



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

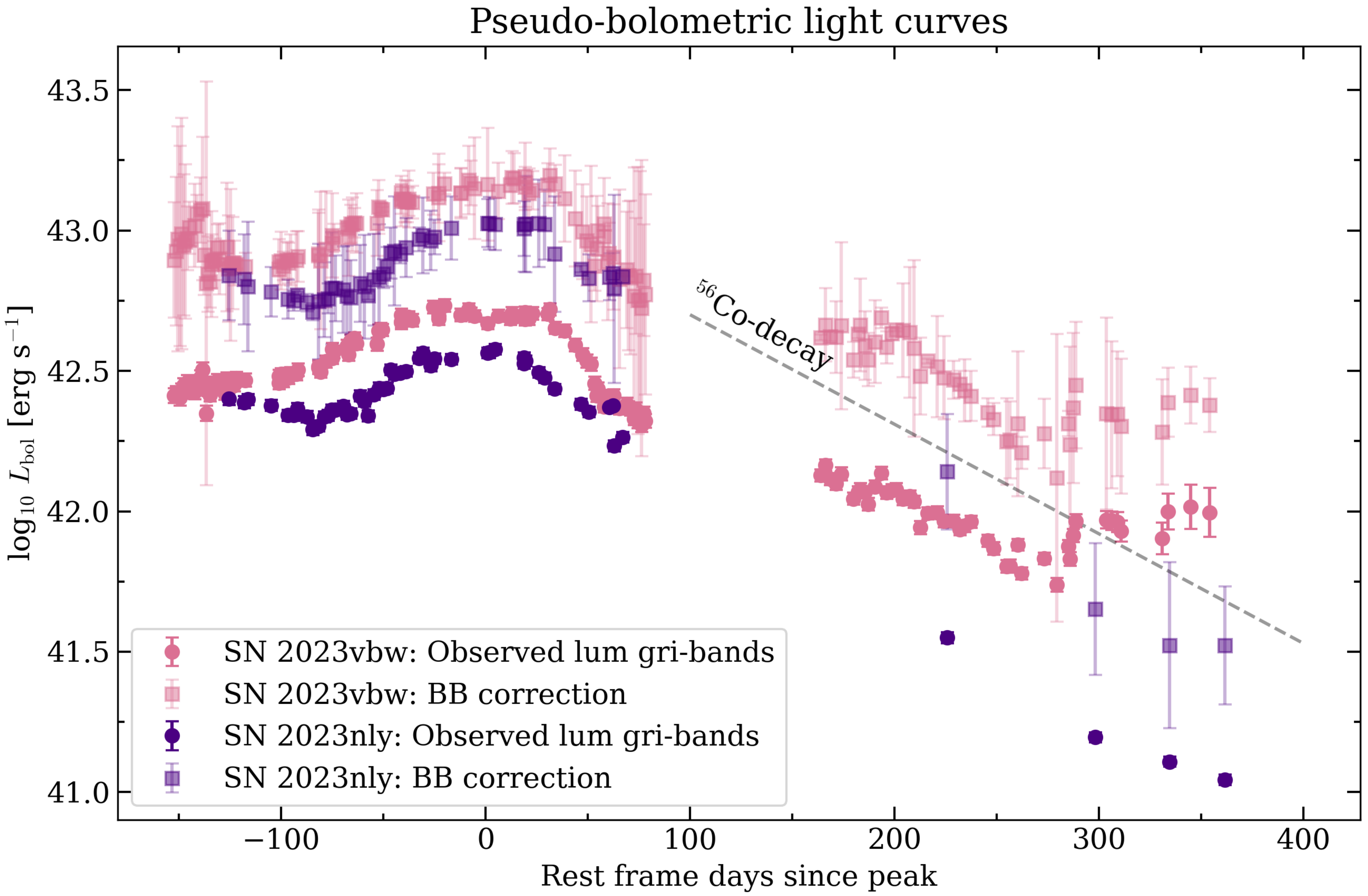
claudia.skoglund@astro.su.se

Bolometric light curves

Total radiated energies $> 10^{50}$ erg

Bolometric light curves constructed using *SuperBol* (Nicholl, 2018).

- Normal Type II SNe have radiated energies $\sim 10^{49}$ erg
- 2023nly and 2023vbw are approaching energies of **interacting** and **superluminous** supernovae



claudia.skoglund@astro.su.se

^{56}Ni mass

A probe of the explosion mechanism

- The supernova explosion produces significant amounts of **radioactive material** that later powers the light curve
- **Typical Type II**: $M_{^{56}\mathrm{Ni}} \sim 0.01 - 0.1 M_{\odot}$
- **2023nly & 2023vbw:** $M_{^{56}\mathrm{Ni}} \sim 1 - 1.5 M_{\odot}$

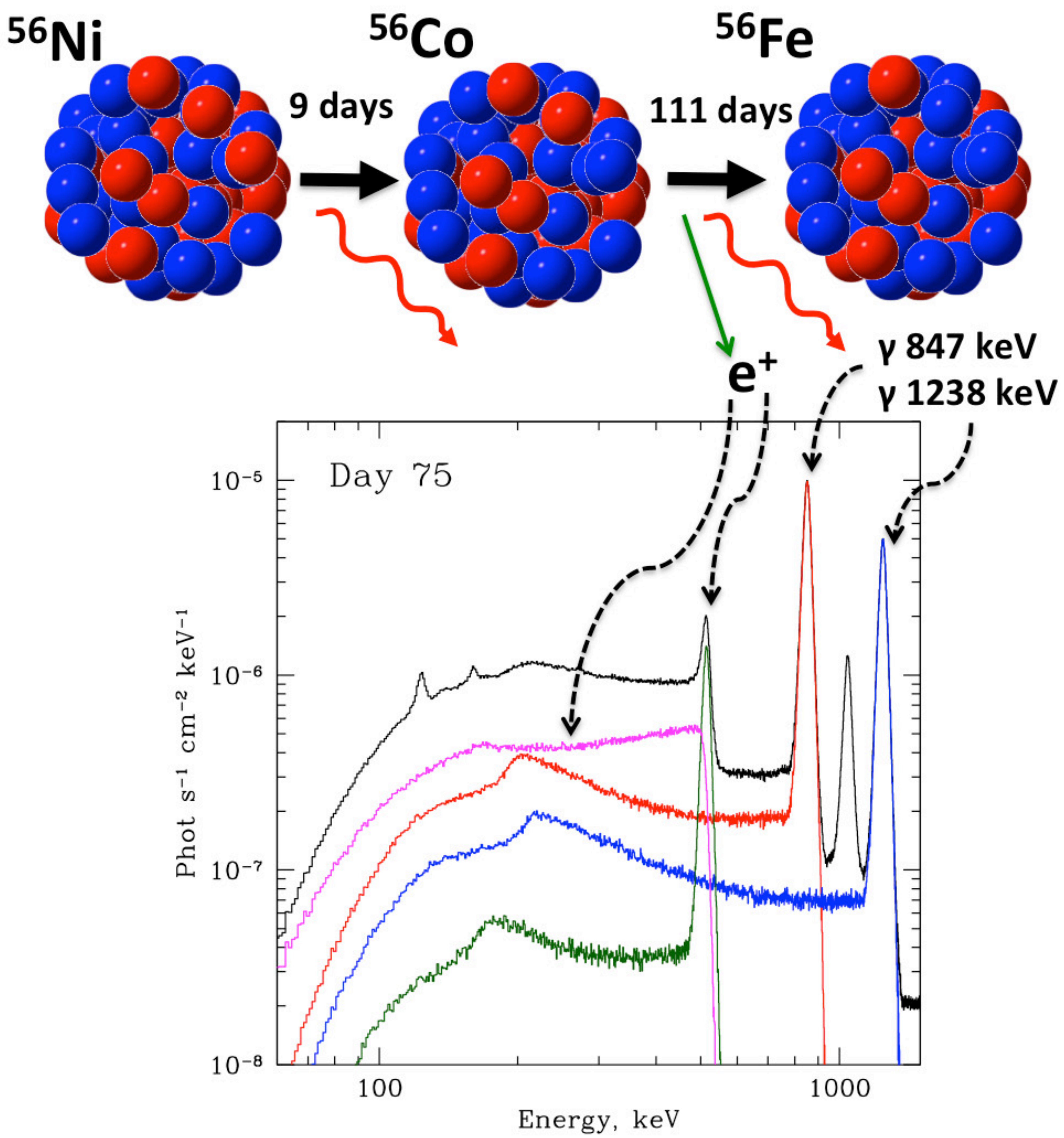


Image credits: Churazov et al. (2014), via https://wwwmpa.mpa-garching.mpg.de/mpa/institute/news_archives/news1408_ddd/news1408_ddd-en.html

claudia.skoglund@astro.su.se

The traditional core-collapse mechanism is **not enough to explain** the behaviour of SN 2023nly and SN 2023vbw….

…What other powering mechanisms could be in action?

claudia.skoglund@astro.su.se

Alternative powering mechanisms

Beyond the traditional core-collapse mechanism

Magnetar spin-down

A rapidly rotating and highly magnetised neutron star **injects rotational energy** into the expanding ejecta as it spins down

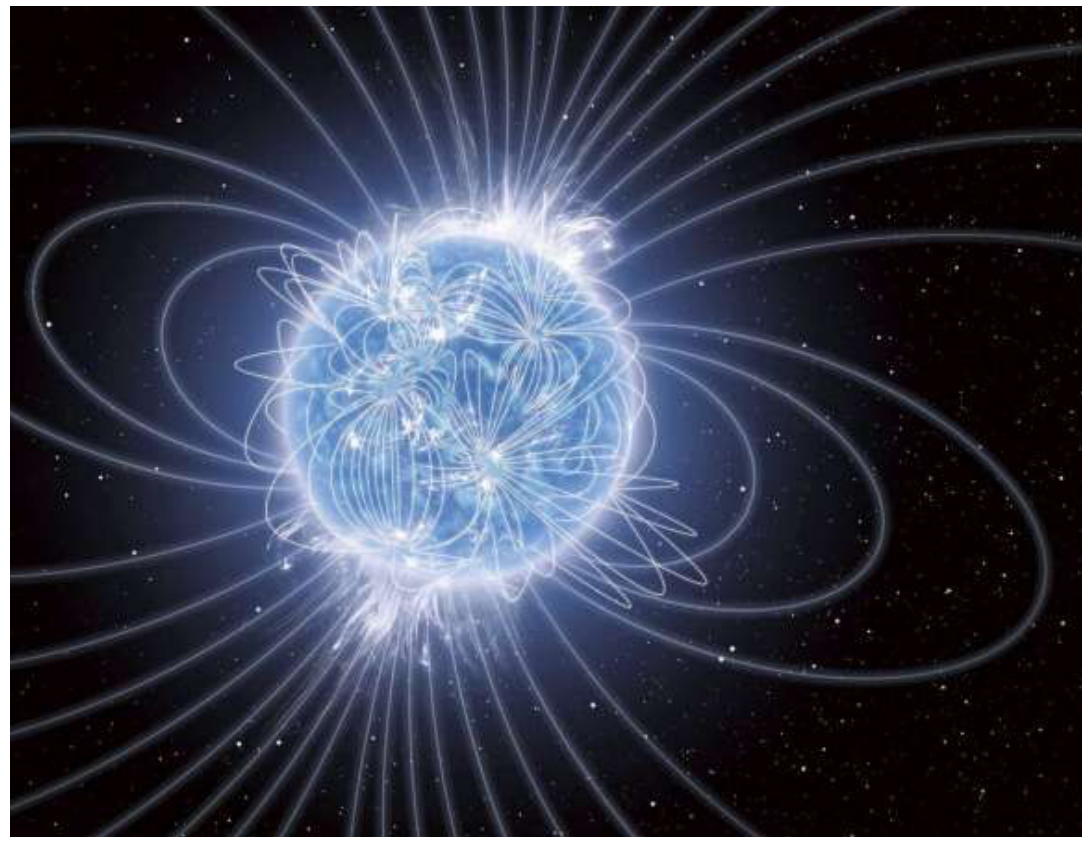
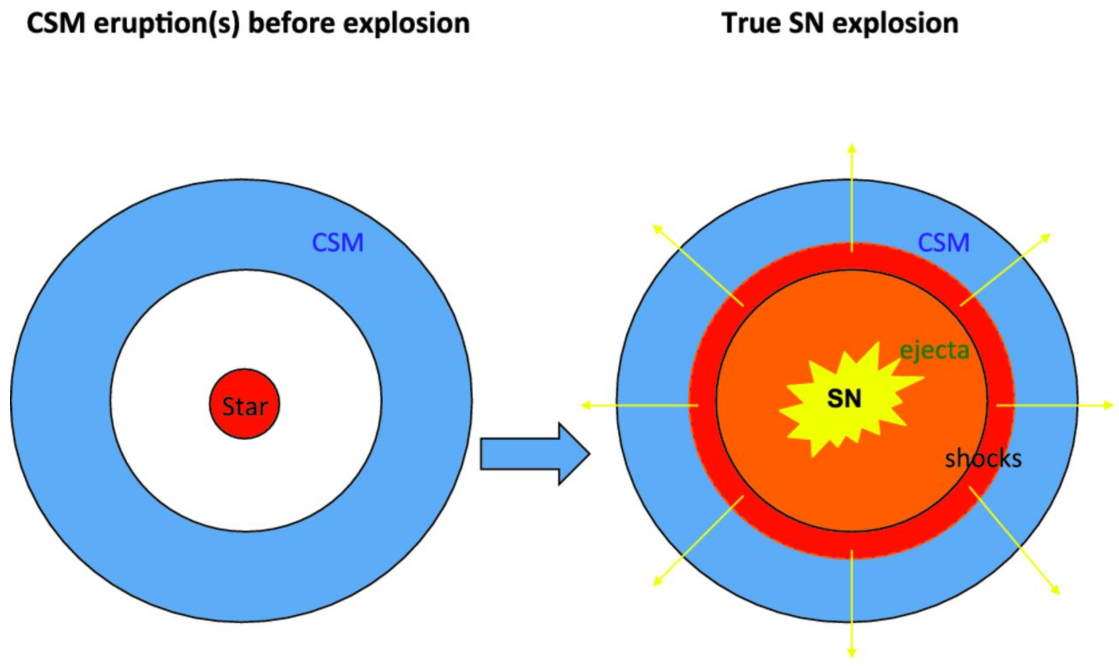


Image credit: Ryuunosuke Takeshige (https://www.space.com/magnetars-rotation-powered-pulsars-missing-link.html)

CSM Interaction

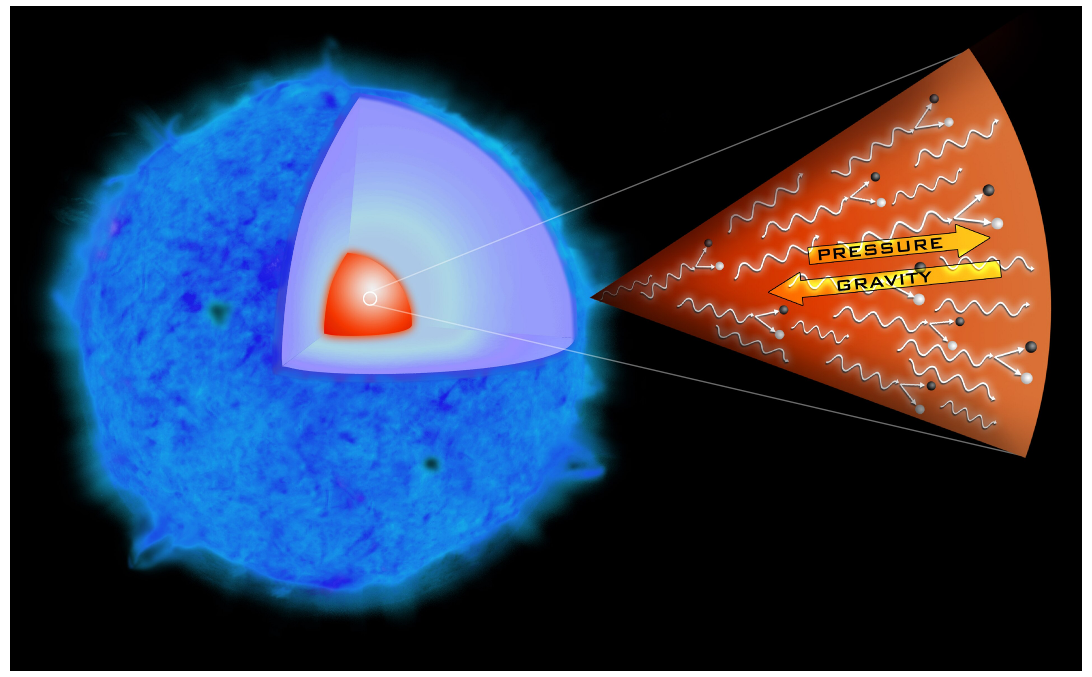
SN luminosity **powered by shocks formed when ejecta collides with a dense CSM** surrounding the progenitor



Murase et al. (2014)

Pair instability

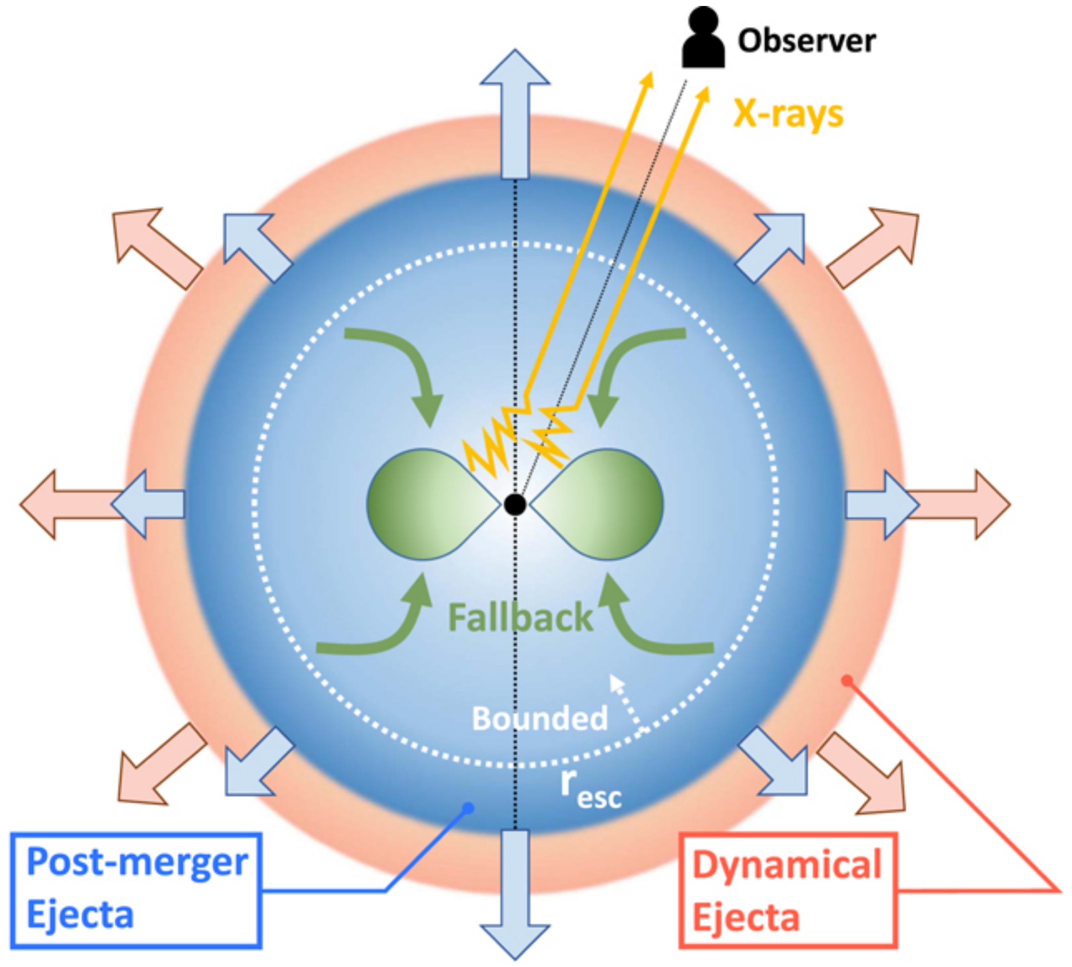
Extremely massive stars that release large amounts of energy as they become unstable due to electron-positron pair production, triggering explosive O-burning that can completely disrupt the star.



By NASA/CXC/M. Weiss http://chandra.harvard.edu/photo/2007/sn2006gy/more.html, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2082949

Fallback accretion

Material that fails to escape the explosion falls back onto the compact remnant. This **accretion releases energy that powers the emission.**



Ishizaki et al. (2021)

claudia.skoglund@astro.su.se

See also an article by another group on SN 2023vbw

Hiramatsu et al. (2026)

arXiv > astro-ph > arXiv:2605.16487

Search...

Help | Ad

Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 15 May 2026]

The pair-instability origin of supernova 2023vbw

Daichi Hiramatsu, Edo Berger, Daichi Tsuna, Sebastian Gomez, Harsh Kumar, Peter K. Blanchard, Walter W. Golay, Anya E. Nugent, Takashi J. Moriya, D. Andrew Howell, Alexei V. Filippenko, Thomas G. Brink, WeiKang Zheng, Yi Yang, Moira Andrews, K. Azalee Bostroem, Joseph Farah, Curtis McCully, Megan Newsome, Estefania Padilla Gonzalez, Giacomo Terreran

Stars in the initial and carbon-oxygen core mass ranges of $\sim 140-260$ and $50-130$ $M_{\odot}$, respectively, with low metallicity are predicted to experience copious electron-positron pair production in their cores, leading to a runaway thermonuclear explosion that obliterates the entire star in a luminous and long-duration pair-instability supernova explosion. Some previous supernovae have been interpreted in this context but lack the full range of predicted properties. Here, we report detailed observations and modeling of the hydrogen-rich supernova 2023vbw, which exploded in a low-metallicity (~ 0.1 $Z_{\odot}$) environment in a dwarf star-forming galaxy at a redshift of 0.088. Its light curve exhibits a luminous (1.6×10^{43} erg s^{-1}) and long-duration (190 days) main peak, resulting in a total radiated energy of 3×10^{50} erg, more than an order of magnitude greater than canonical core-collapse supernovae. Semi-analytical light-curve modeling yields a blue supergiant-like progenitor with an ejecta mass of $170-350$ $M_{\odot}$, radioactive nickel mass of $1.2-1.6$ $M_{\odot}$, and explosion energy of $(6-13) \times 10^{52}$ erg, well matched by pair-instability models. The early and late-phase light curve and spectra also show evidence for interaction of the supernova ejecta with an aspherical circumstellar medium. Discoveries of numerous such events with the upcoming Rubin Observatory and Roman Space Telescope will shed light on the deaths of the most massive stars in the Universe.

Outlook

Future directions of the project

- Light curve modelling 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
- Modelling of **nebular spectra** to further constrain powering mechanisms

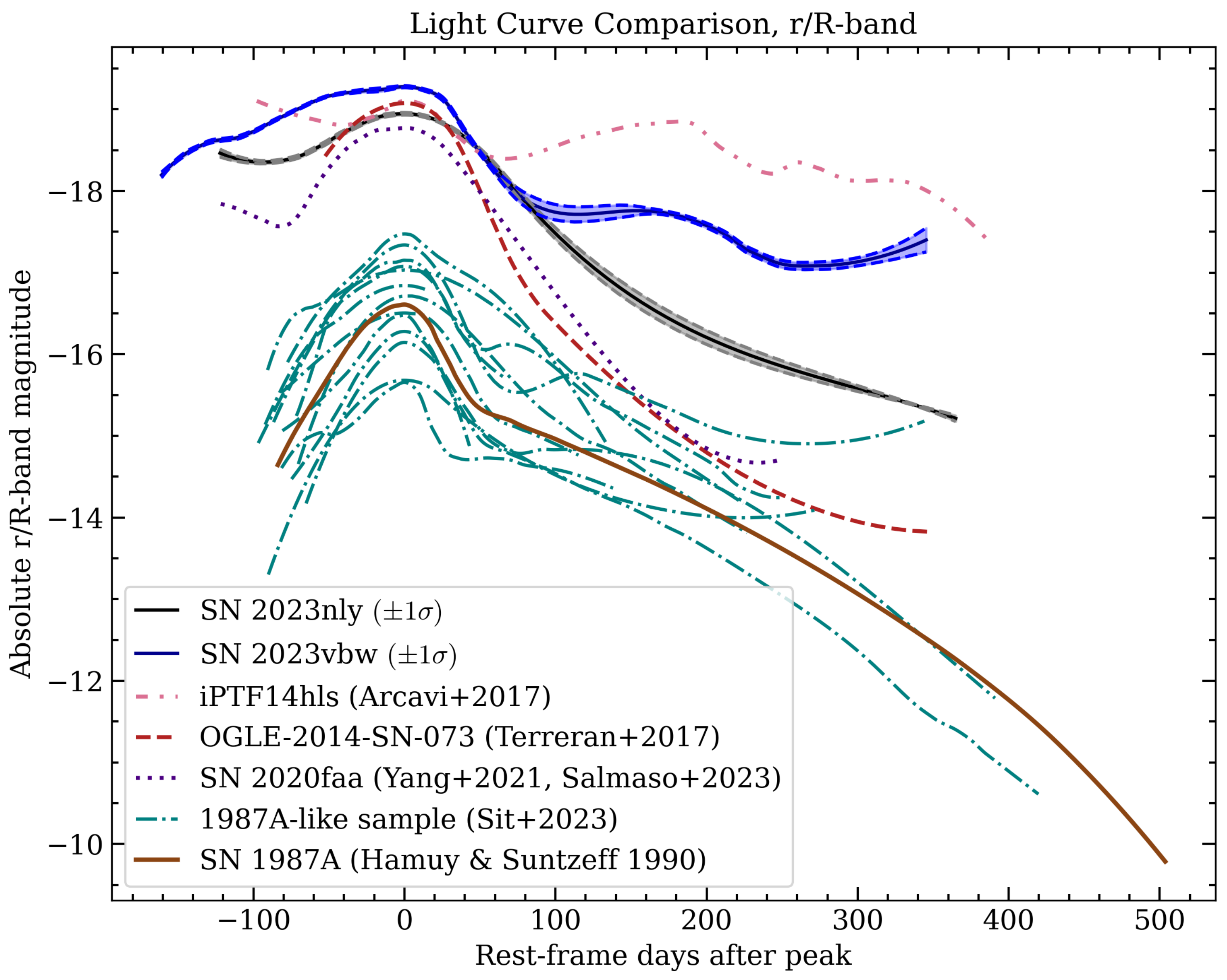
claudia.skoglund@astro.su.se

Conclusions: SN 2023nly & SN 2023vbw

Brighter than many long-rising SNe II

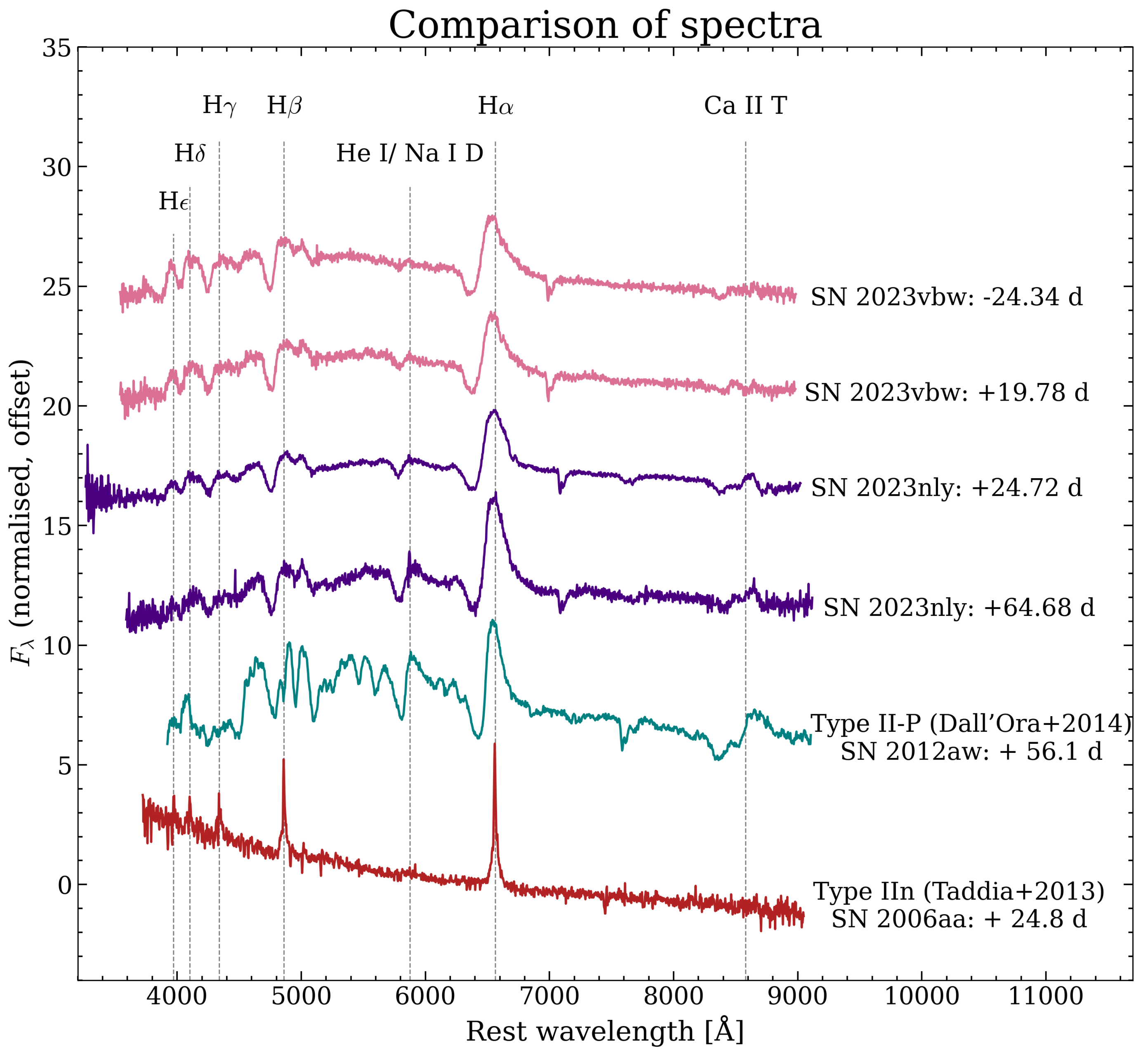
Rise-times > 100 days

Peak magnitudes $\lesssim -19$



Normal P-Cygni profiles in spectra

No narrow lines (typical for interacting SNe).

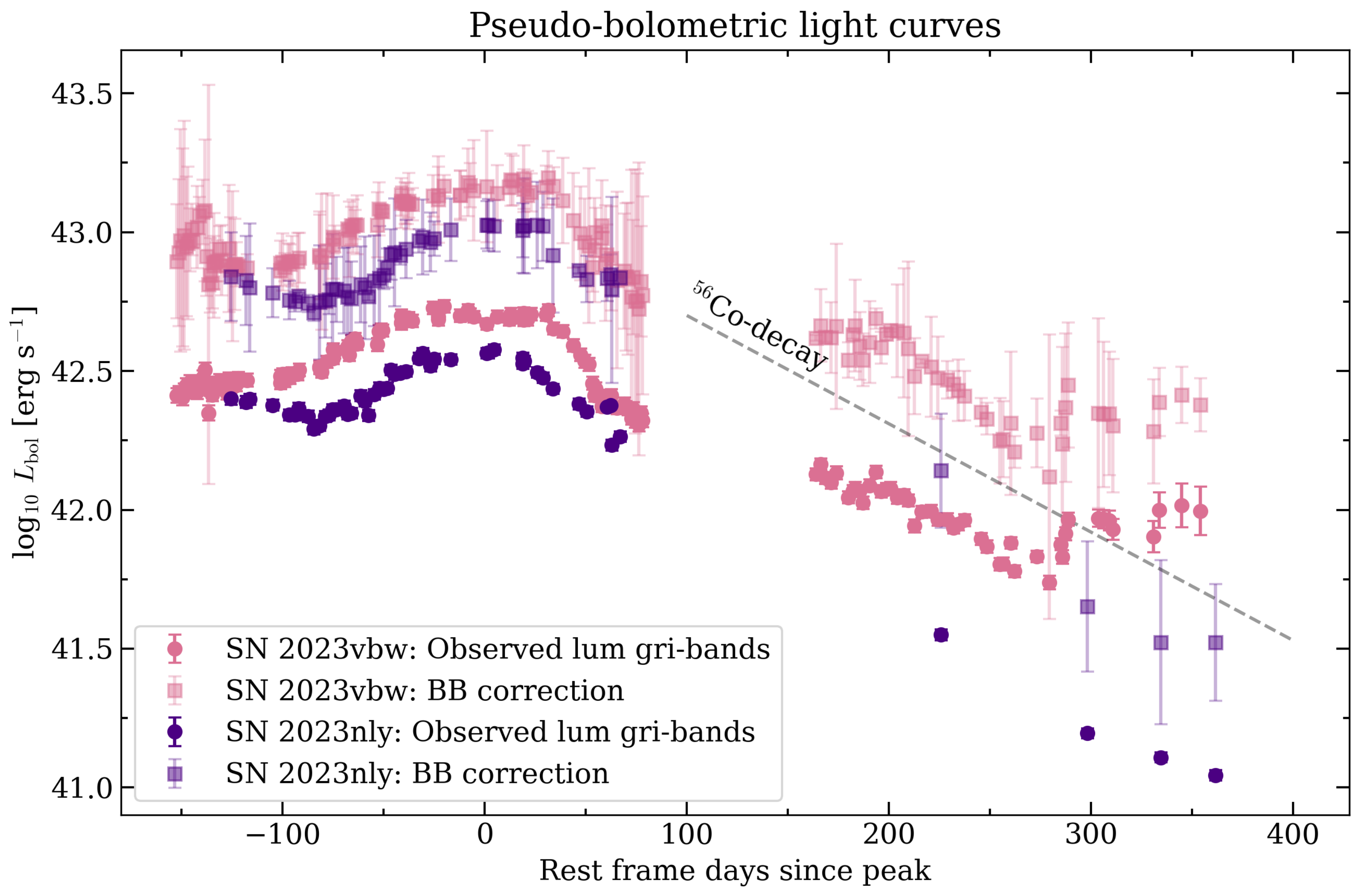


Total radiated energies $\gtrsim 10^{50}$ erg

Approaching that of interacting and superluminous SNe

Nickel-56 masses: $\sim 1 - 1.5 M_{\odot}$

Typical Type II: $\sim 0.01 - 0.1 M_{\odot}$



→ SN 2023vbw and SN 2023nly require **powering beyond the typical core-collapse mechanism.**

→ Magnetar-spin down? Pair instability? CSM interaction?

claudia.skoglund@astro.su.se

References

Acknowledgements
R. Lunnan is supported by the European Research Council (ERC) under the European Union's Horizon Europe research and innovation programme (grant agreement No. 10104229 - TransPIre)

Funded by the European Union

European Research Council
Established by the European Commission

References

Arcavi, I., Howell, D. A., Kasen, D., et al. 2017, *Nature Astronomy*, 551, 210

Bellm, E. C., Kulkarni, S. R., Graham, M. J., Dekany, R., Smith, R. M., Riddle, R., ... & Zolkower, J. (2019). The Zwicky Transient Facility: system overview, performance, and first results. *PASP*, *131*(995), 018002.

Churazov, E., Sunyaev, R., Isern, J., Knödlseder, J., Jean, P., Lebrun, F., ... & Renaud, M. (2014). Cobalt-56 γ-ray emission lines from the type Ia supernova 2014J. *Nature*, *512*(7515), 406-408.

Dall'Ora, M., Botticella, M. T., Pumo, M. L., Zampieri, L., Tomasella, L., Pignata, G., ... & Wright, D. (2014). The type IIP supernova 2012aw in M95: hydrodynamical modeling of the photospheric phase from accurate spectrophotometric monitoring. *ApJ*, *787*(2), 139.

Hamuy, M., Suntzeff, N. B., Bravo, J., & Phillips, M. M. 1990, *PASP*, 102, 888

Hiramatsu, D., Berger, E., Tsuna, D., Gomez, S., Kumar, H., Blanchard, P. K., ... & Terreran, G. (2026). The pair-instability origin of supernova 2023vbw. *arXiv preprint arXiv:2605.16487*.

Ishizaki, W., Ioka, K., & Kiuchi, K. (2021). Fallback accretion model for the years-to-decades x-ray counterpart to GW170817. *The Astrophysical Journal Letters*, *916*(2), L13.

Murase, K., Thompson, T. A., & Ofek, E. O. (2014). Probing cosmic ray ion acceleration with radio-submm and gamma-ray emission from interaction-powered supernovae. *Monthly Notices of the Royal Astronomical Society*, *440*(3), 2528-2543.

Nicholl, M. (2018). SuperBol: A user-friendly Python routine for bolometric light curves. *Research Notes of the AAS*, *2*(4), 230.

Salmaso, I., Cappellaro, E., Tartaglia, L., et al. 2023, *A&A*, 673, A127

Rodríguez, Ó., Pignata, G., Hamuy, M., et al. 2019, *MNRAS*, 483, 5459

Sit, T., Kasliwal, M. M., Tzanidakis, A., et al. 2023, *ApJ*, 959, 142

Taddia, F., Stritzinger, M. D., Sollerman, J., Phillips, M. M., Anderson, J. P., Boldt, L., ... & Suntzeff, N. B. (2013). Carnegie Supernova Project: observations of type IIn supernovae. *A&A*, *555*, A10.

Terreran, G., Pumo, M. L., Chen, T.-W., et al. 2017, *Nature Astronomy*, 1, 713

Yang, S., Sollerman, J., Chen, T.-W., et al. 2021, *A&A*, 646, A22

Hu, Y., Lunnan, R., Pessi, P. J., Saldana-Lopez, A., Jerkstrand, A., Sollerman, J., ... & Young, D. R. (2026). SN 2021aaev: a hydrogen-rich superluminous supernova with early flash and long-lived circumstellar interaction in an unusual host environment. *The Astrophysical Journal*, *999*(2), 176.

claudia.skoglund@astro.su.se