High z luminosity functions through photometric classification of core-collapse supernovae

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Fink@World

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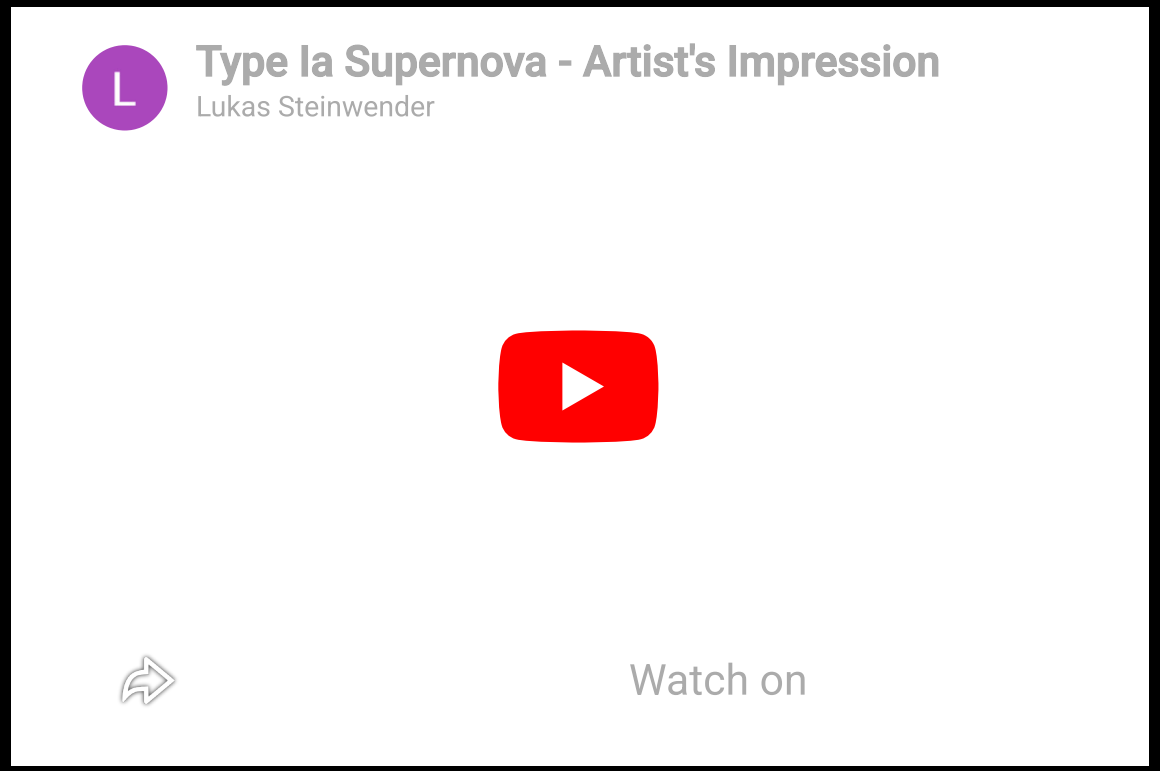
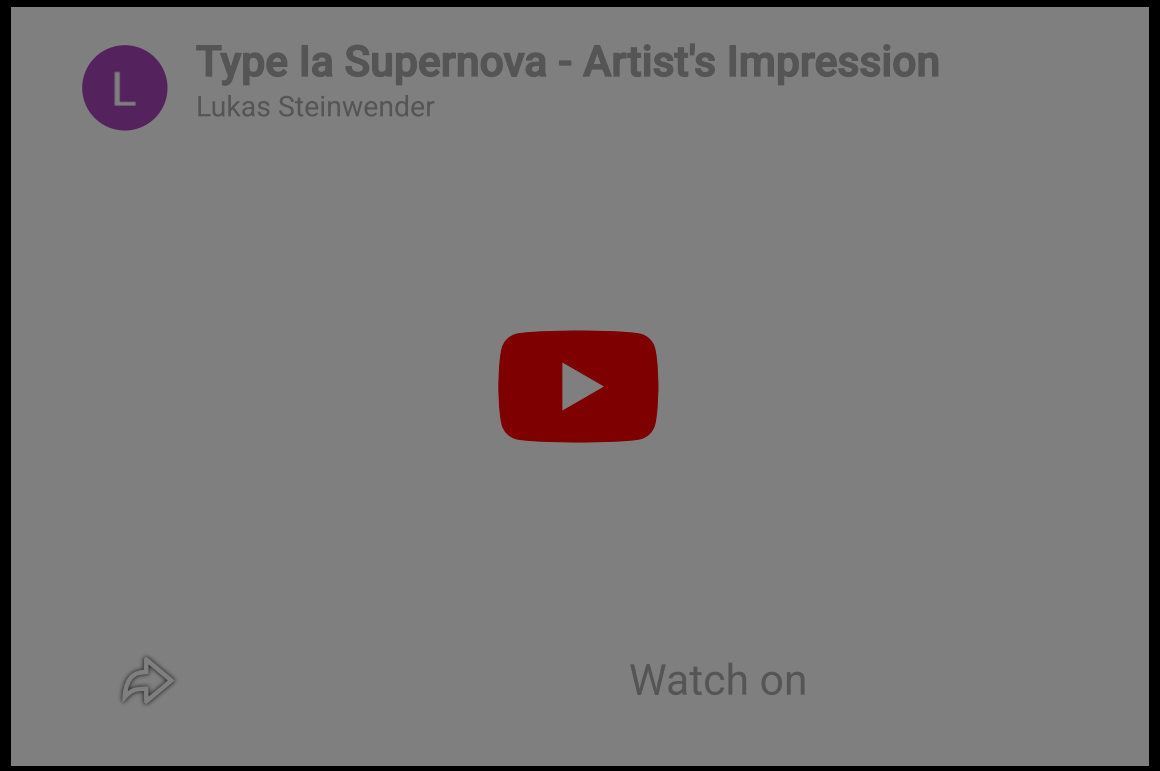
Supernova types



Thermonuclear supernova. (Lukas Steinwender)

Supernova types



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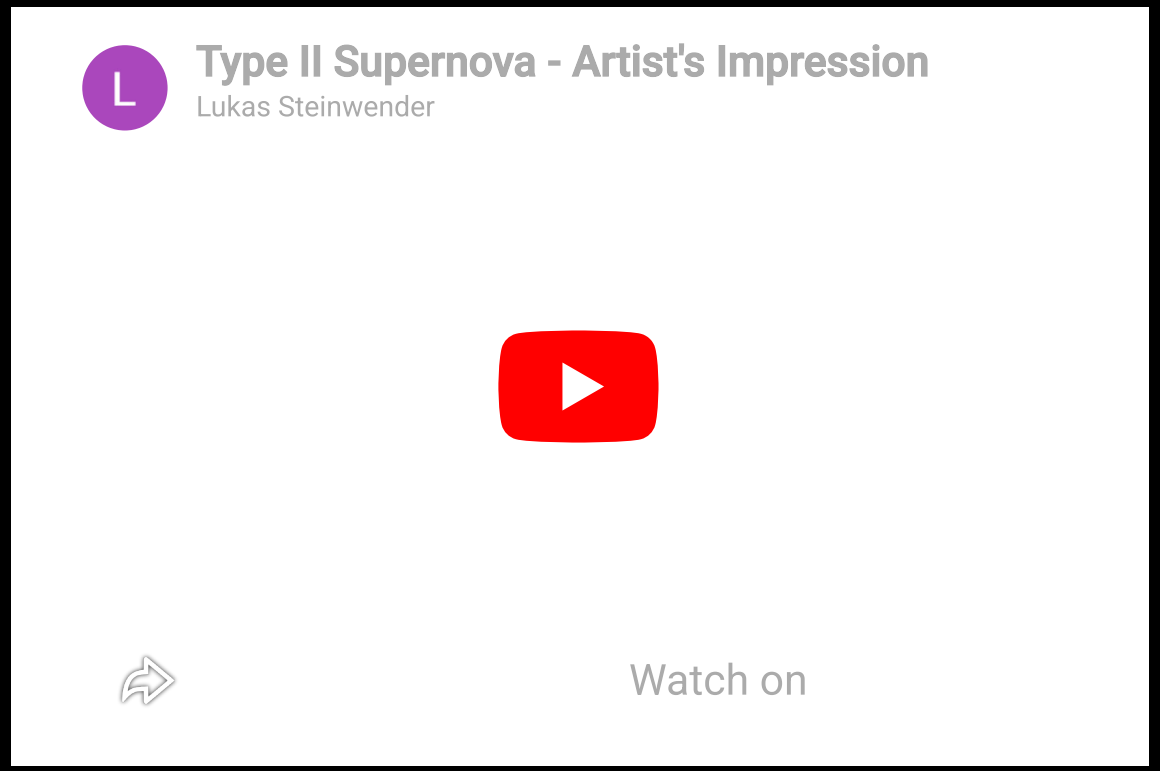
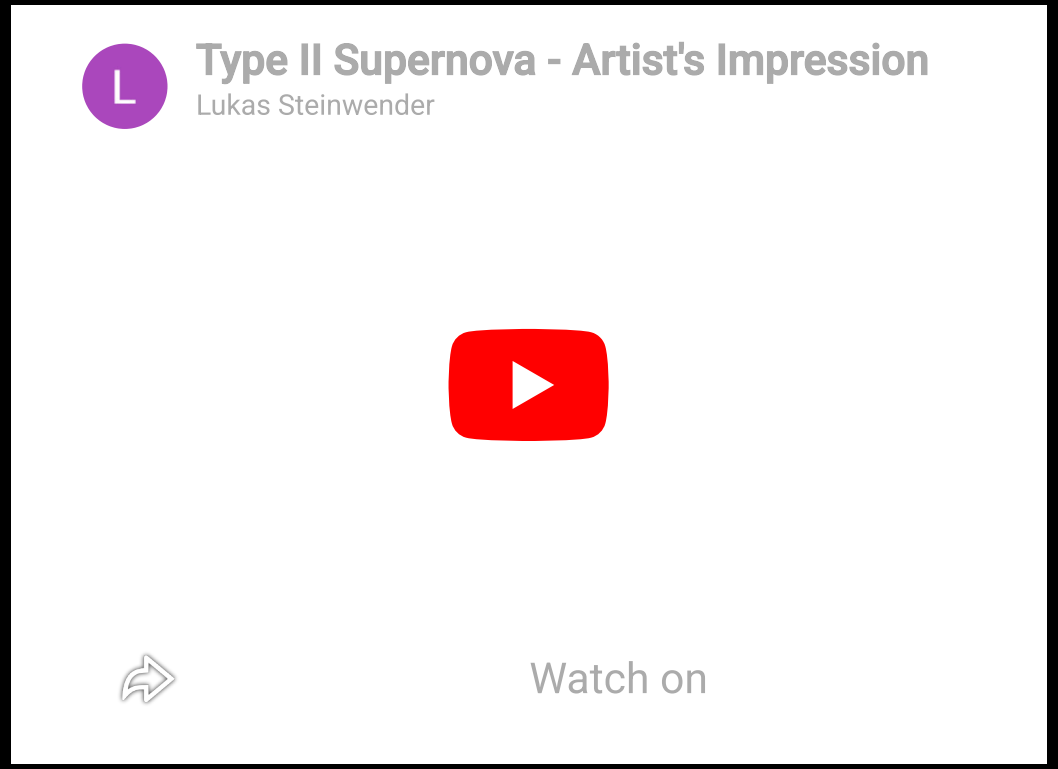


Core-collapse supernova. (Lukas Steinwender)

Core-collapse supernovae

- Death of massive stars ($M_* \geq 8\,\mathrm{M}_\odot$)
- 2 major classes
  - SN II (50% of all SNe)
  - SN Ib/c (25% of all SNe)
- Probes of chemical enrichment
- Probes of extreme physics
- Less than 700 classified
- Most up to $z \approx 0.4$



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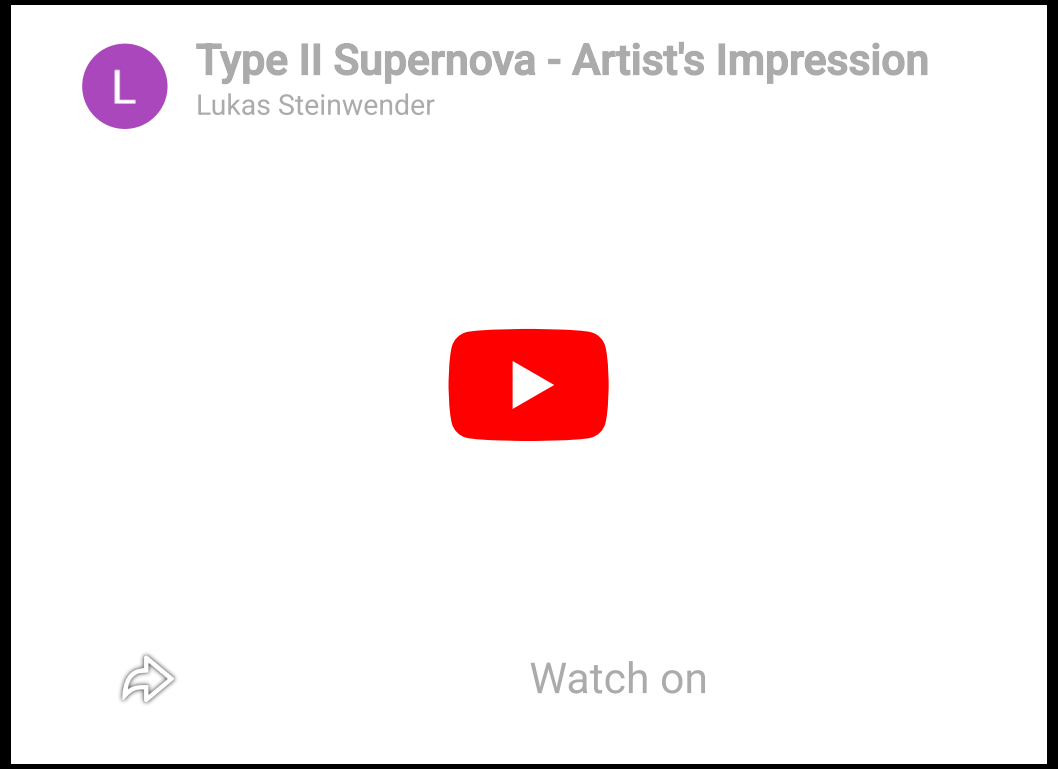
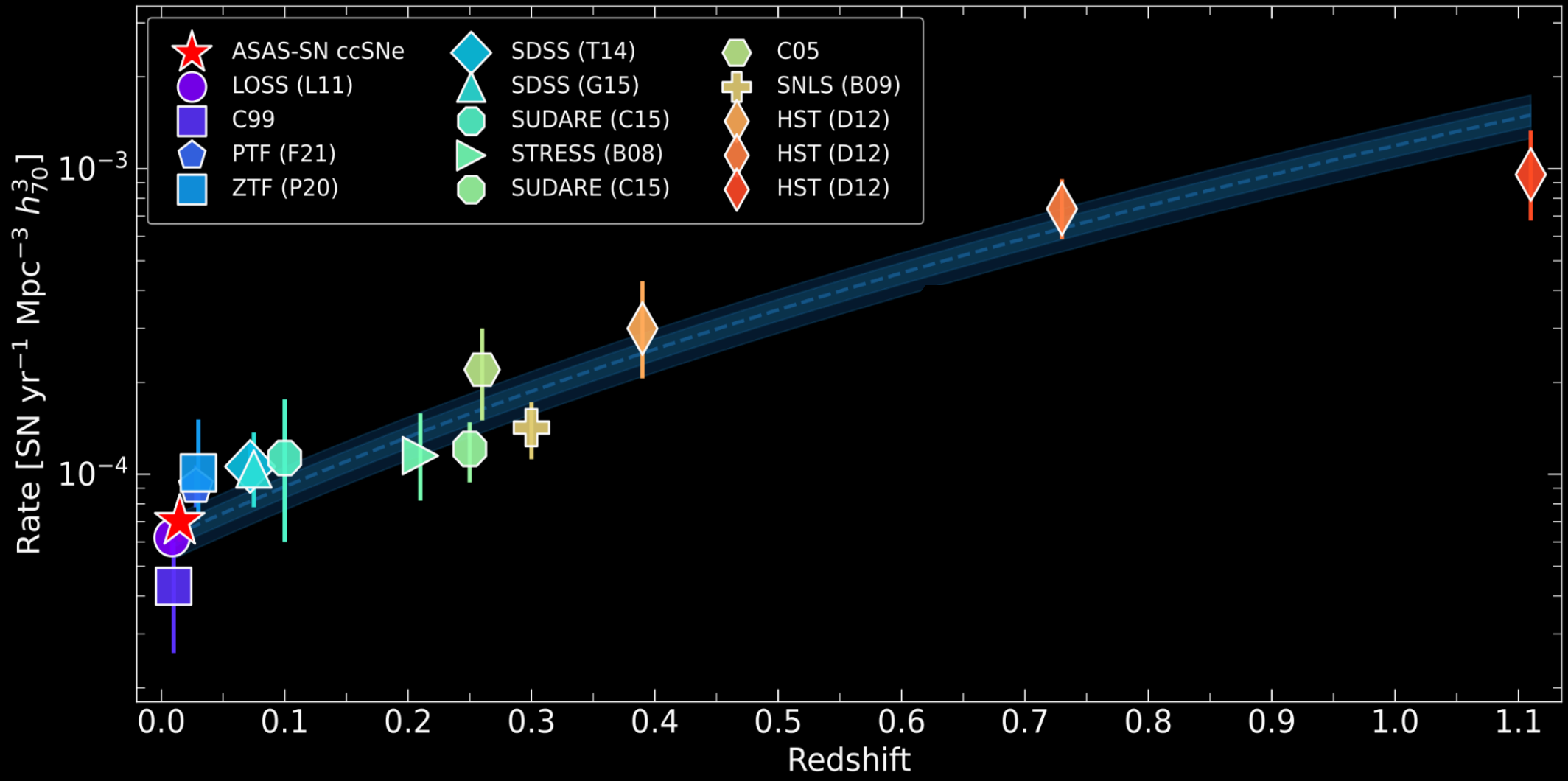
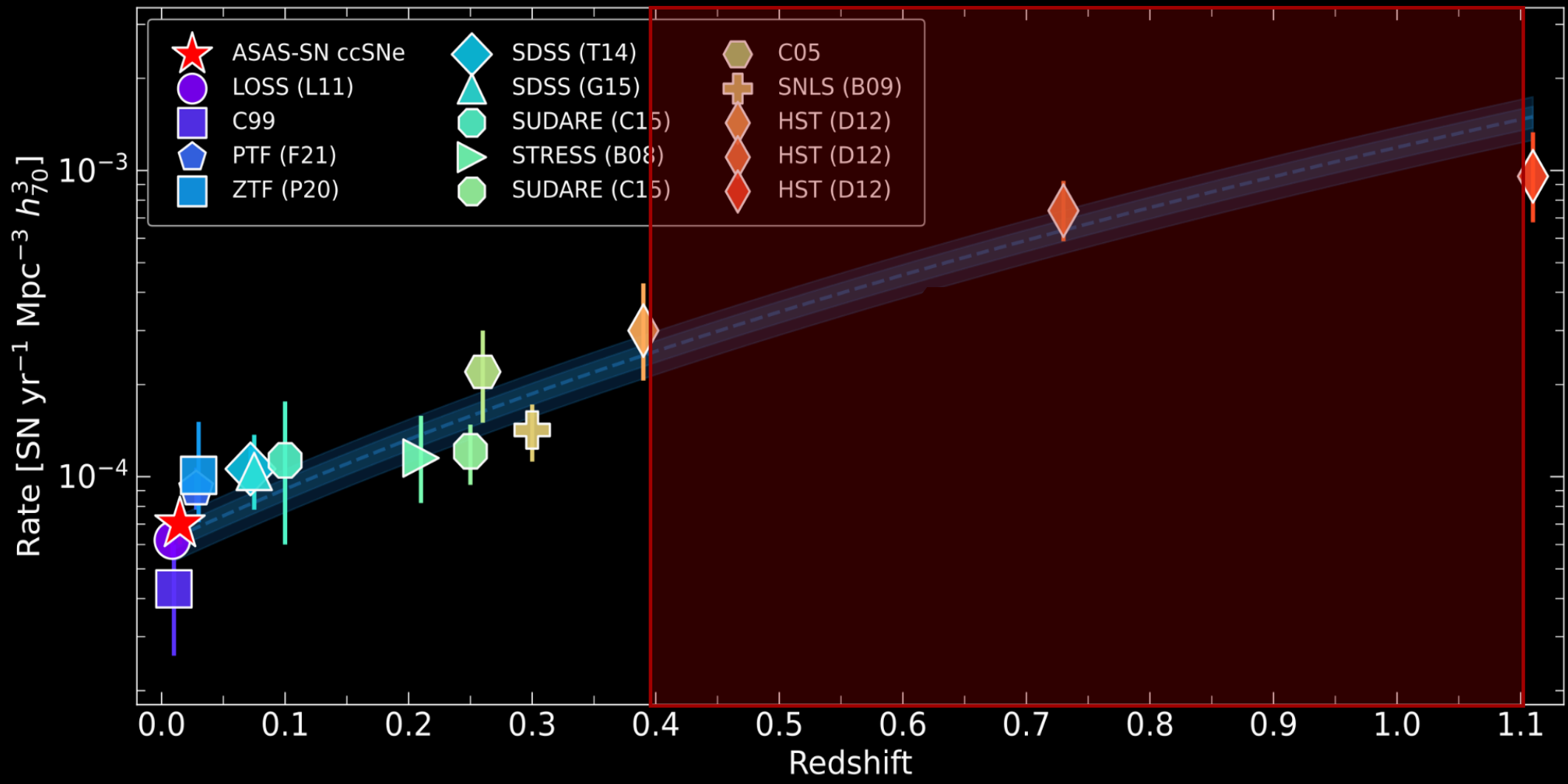


Core-collapse supernova. (Lukas Steinwender)

We need more of them!



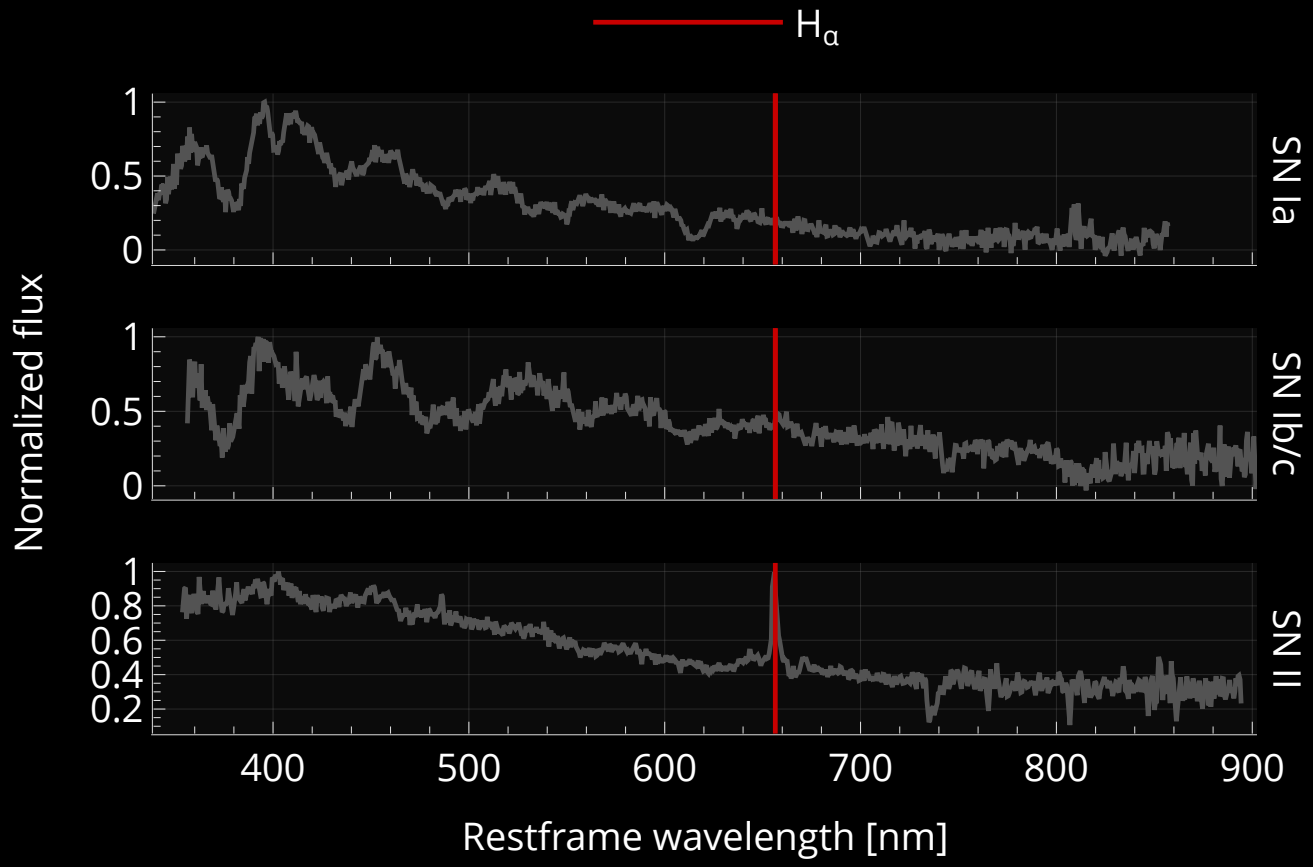
Current SNe CC rate landscape. (Pessi et al., 2025)



Current SNe CC rate landscape. (Pessi et al., 2025)

Supernova classification - spectroscopy

- Traditional approach
- Time-intensive to follow up
- Limited to close-by SNe



Spectra of supernova subtypes.

Supernova classification - spectroscopy

- Traditional approach
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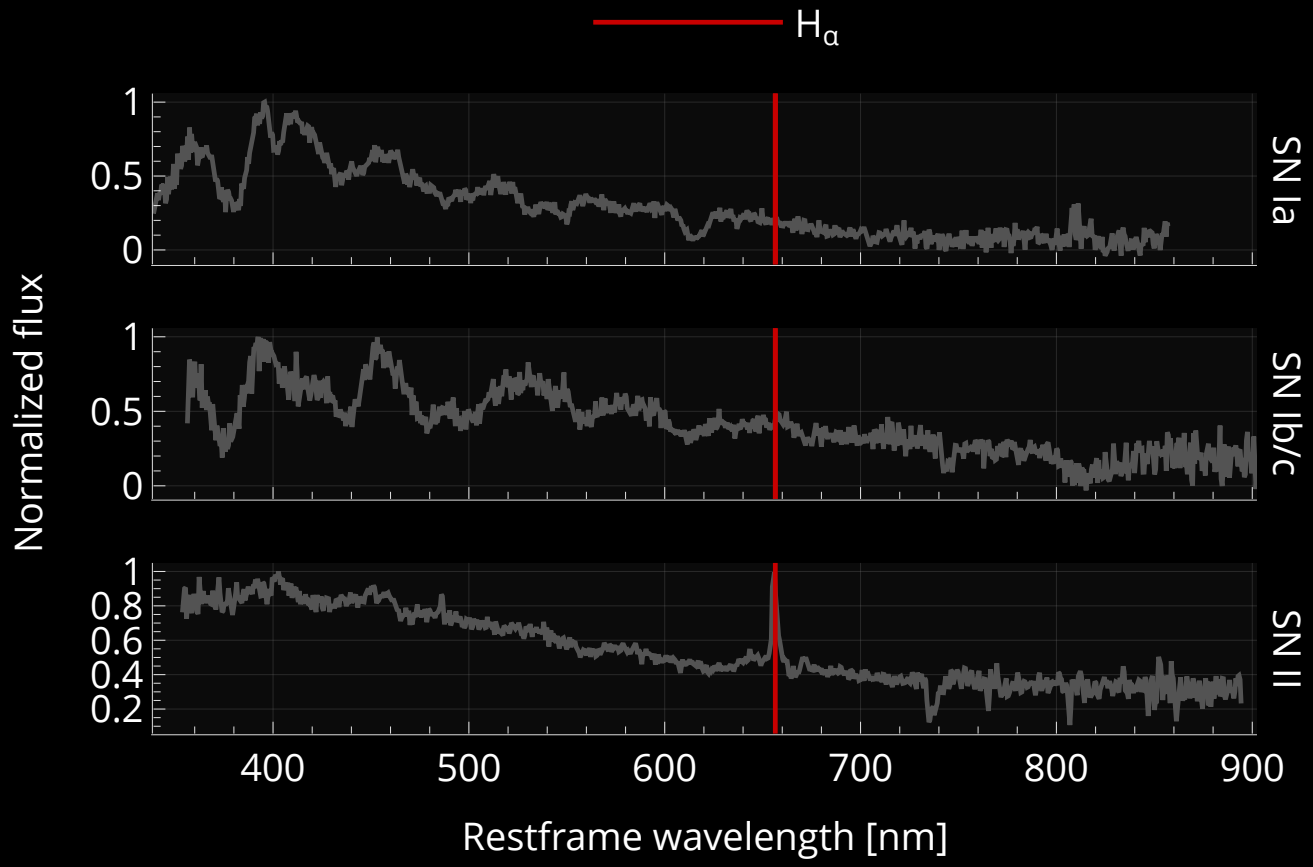
We need an alternative!



Spectra of supernova subtypes.

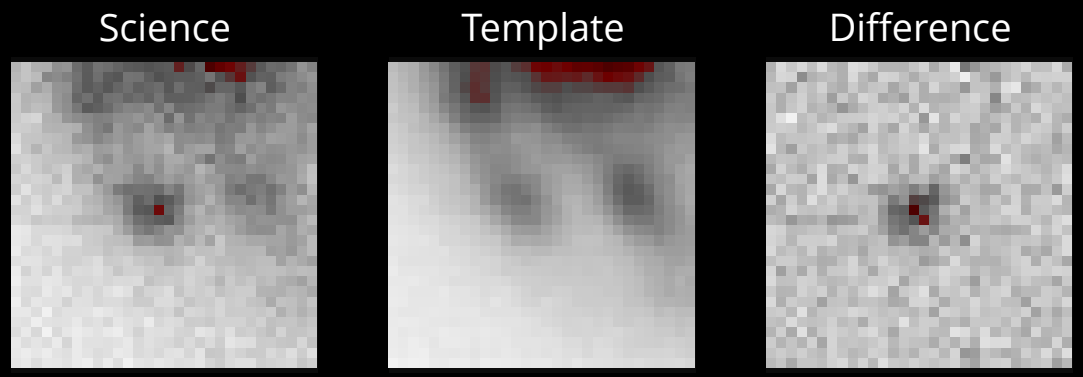
The Vera C. Rubin Observatoy

huge opportunity with new challenges

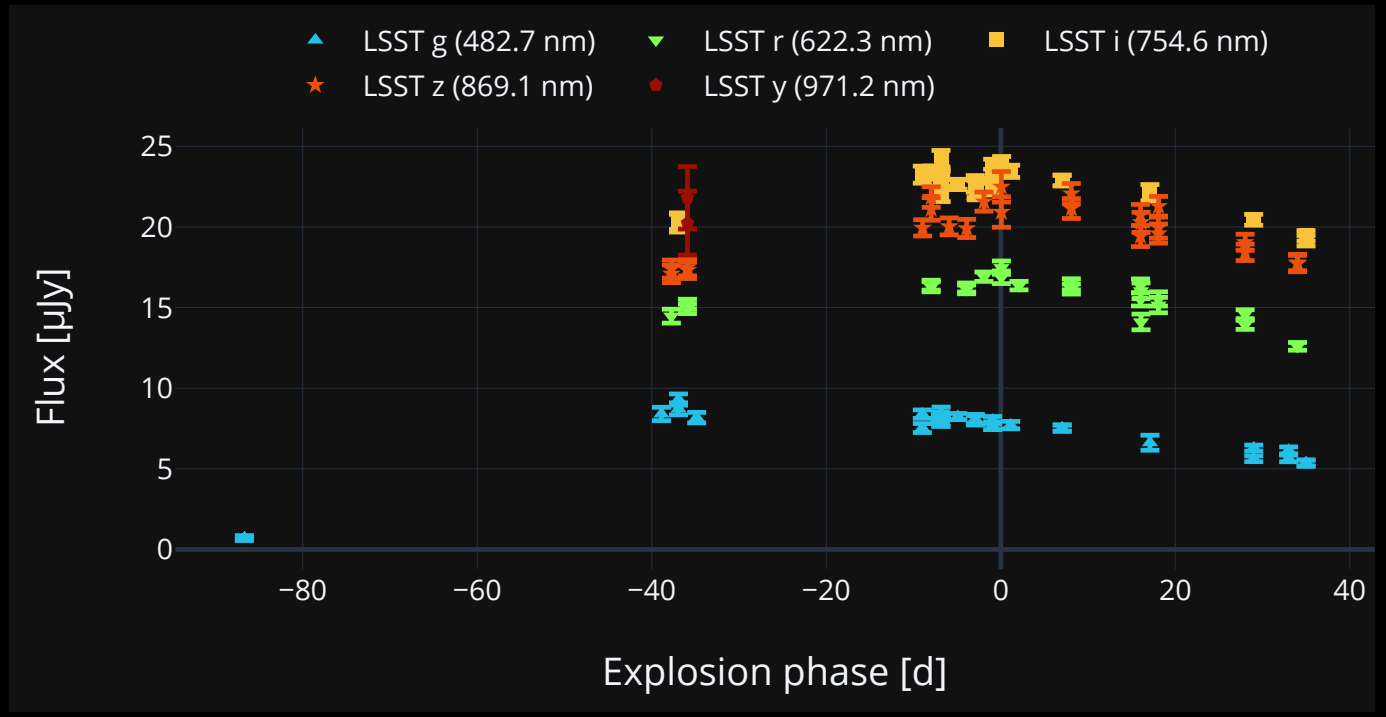
- Legacy Survey of Space and Time (LSST, Ivezić et al., 2019)
  - Southern night-sky
  - For 10 years
  - Once every 3 days
  - 6 colors
- 10 million alerts per night
- Largest digital camera ever built

(NSF-DOE Vera C. Rubin Observatory/NOIRLab/SLAC/AURA)

Discovery by visual inspection



Difference imaging.



Lightcurve of a SN II.

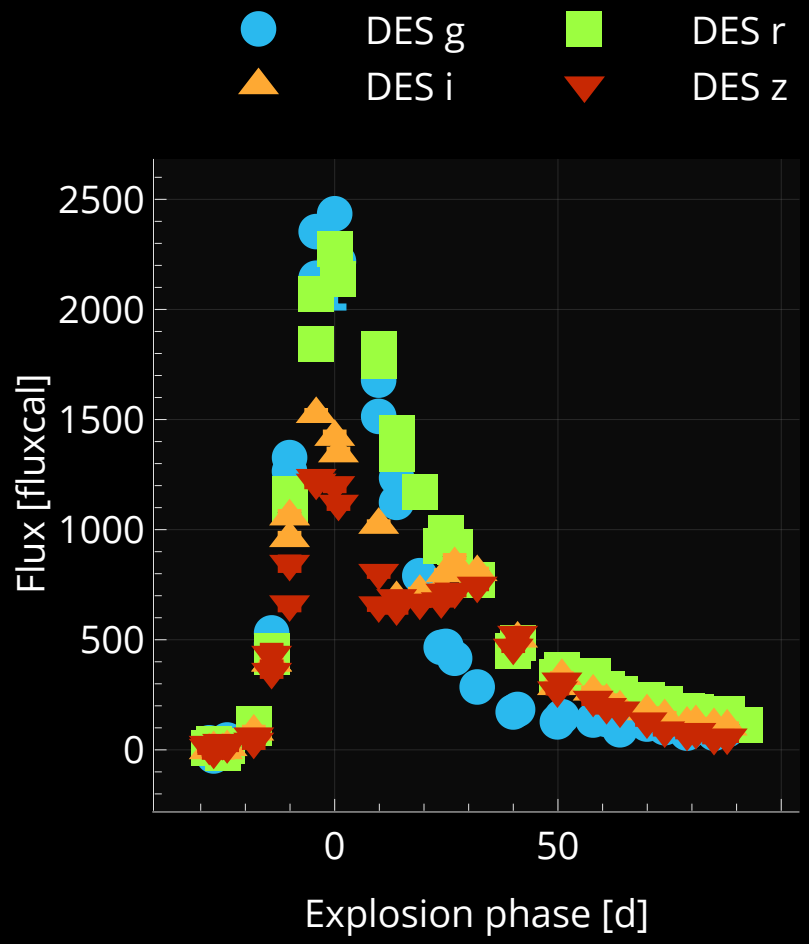
ThumP! visual inspection for transient discovery.

- Find things that are changing through difference images
- A lot of domain knowledge needed

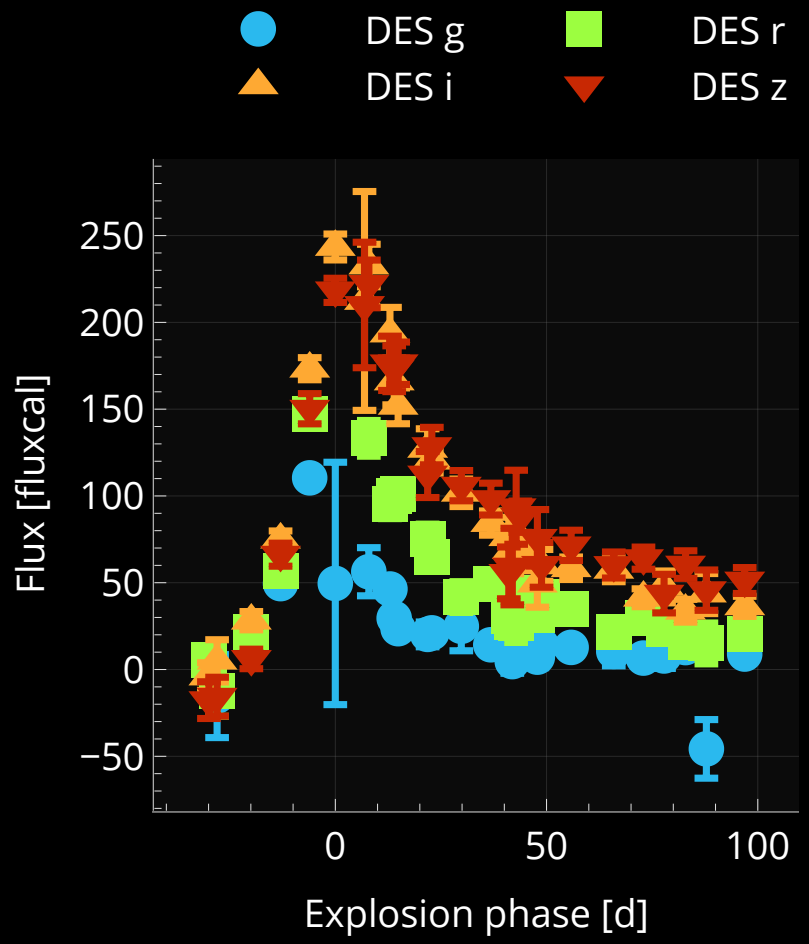
> *There is no certainty on the type of SN!*

ThumP! in action for Rubin's first alerts!

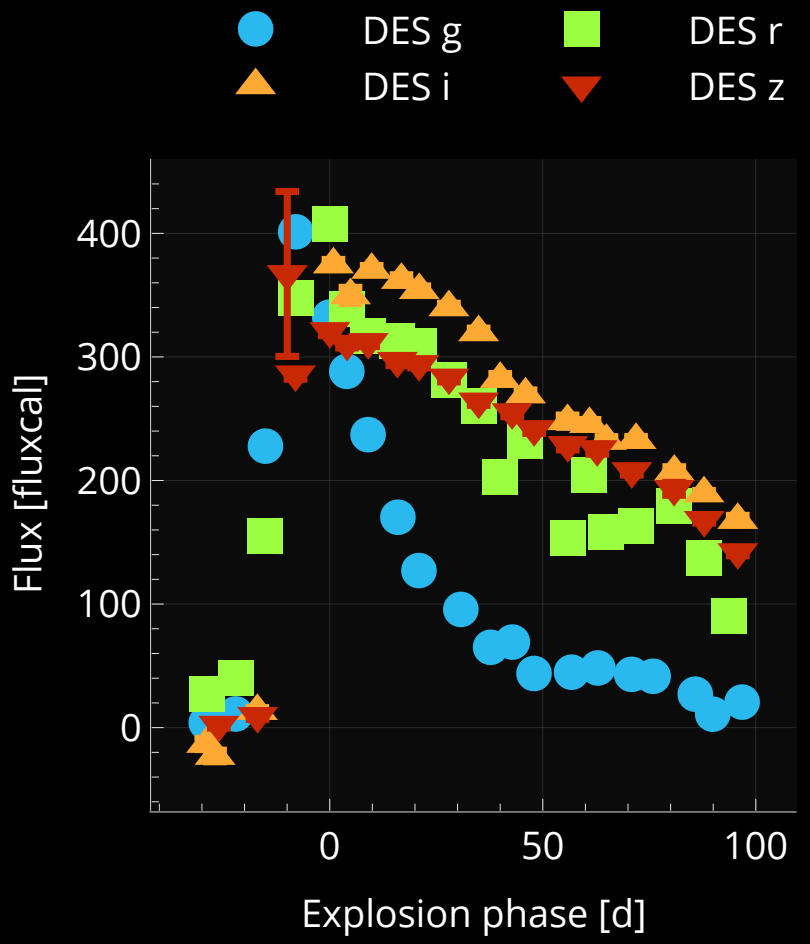
Photometric classification



SN Ia lightcurve.



SN Ib/c lightcurve.



SN II lightcurve.

SuperNNova (Möller et al., 2020)

- Recurrent Neural Network for SN classification
- Trained on LCs
- Designed for SNe Ia
- Discovered 2500 SNe Ia
- Biggest high redshift SNe Ia cosmology sample
- Used by 4 surveys

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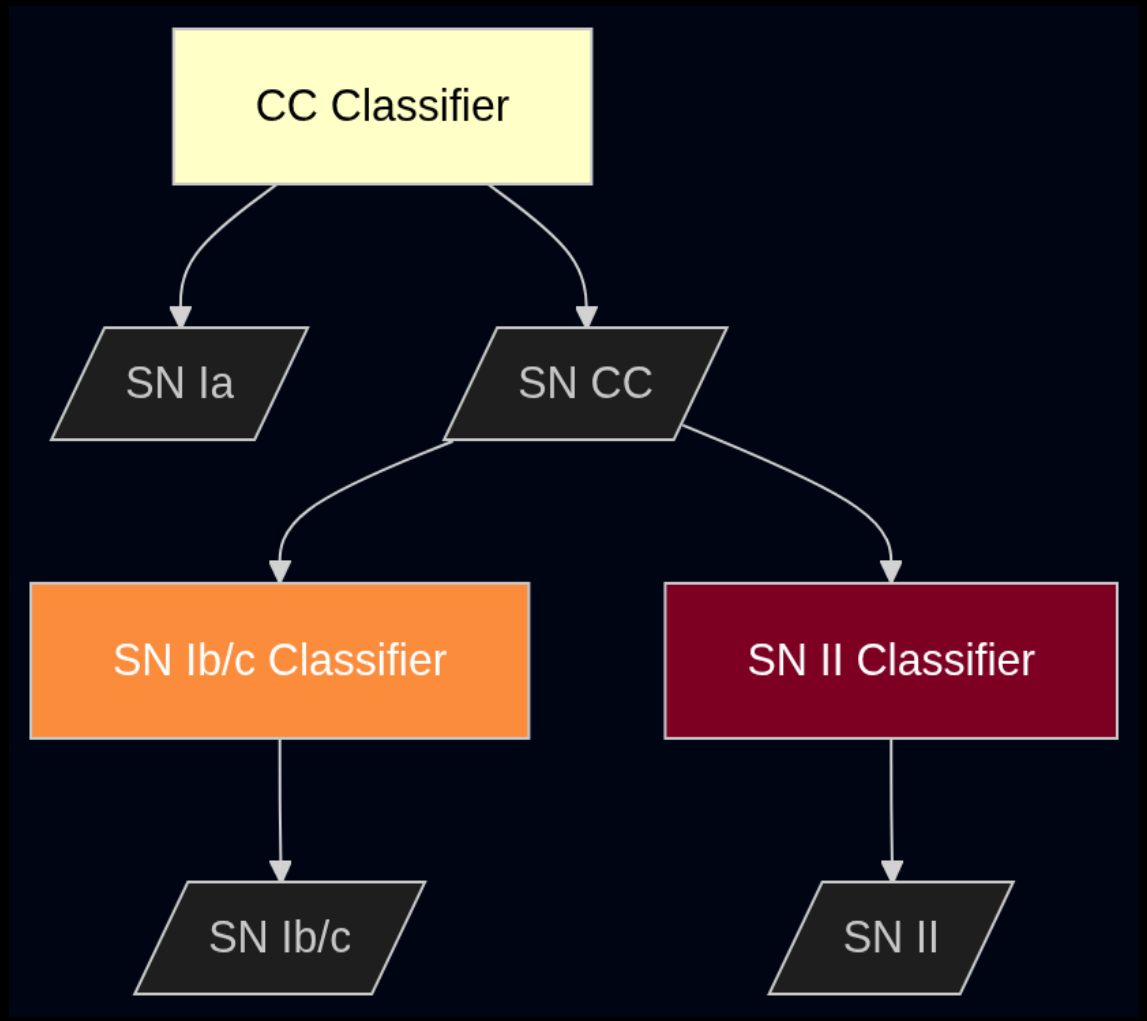
Designed to deal with sparse, irregular data

- *No extrapolation*
- *No filling*
- *Use Δt as feature*

Pipeline



2-step approach.

Dark Energy Survey

- Bernstein et al. (2012)
- Similar depth to Rubin
- 4 passbands similar to Rubin
- Cadence similar to most of Rubin
- Well understood
- SN CC detectable up to $z = 0.7$

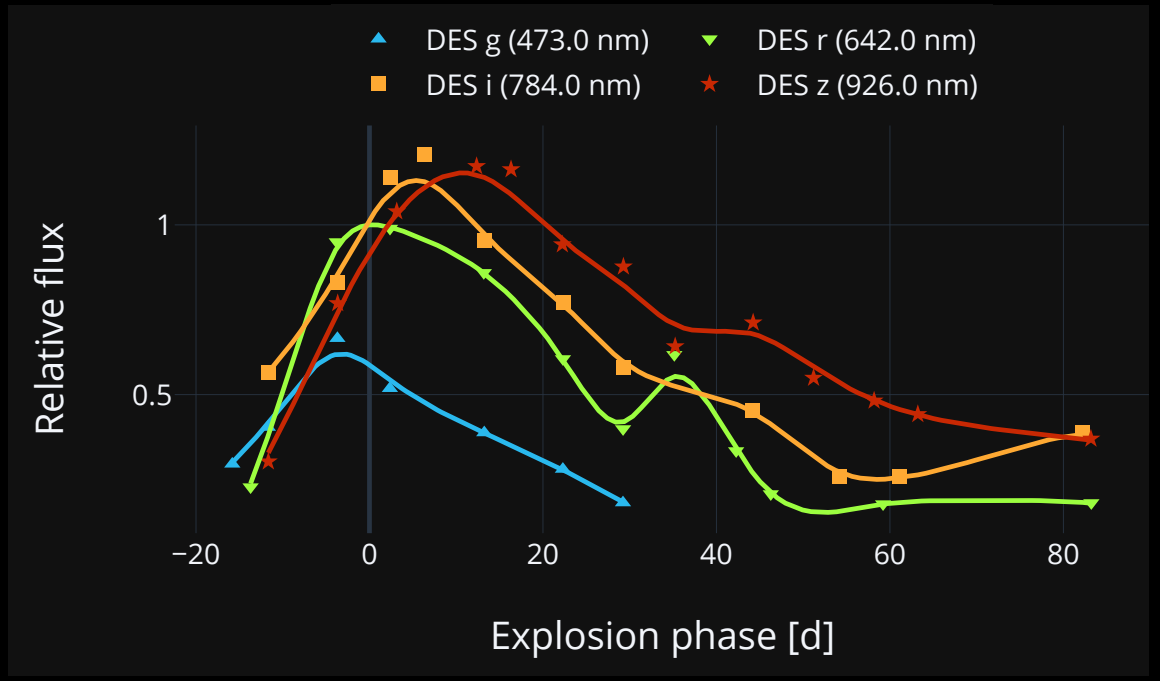
Blanco 4-meter Telescope.
(CTIO/NOIRLab/NSF/AURA/D. Munizaga)

Training data: DES simulations

- Möller et al. (2020)
- Truth known
- As close to reality as possible
- Well-behaved LCs

SN Ia	SN Ib/c	SN II
900 000	300 000	700 000

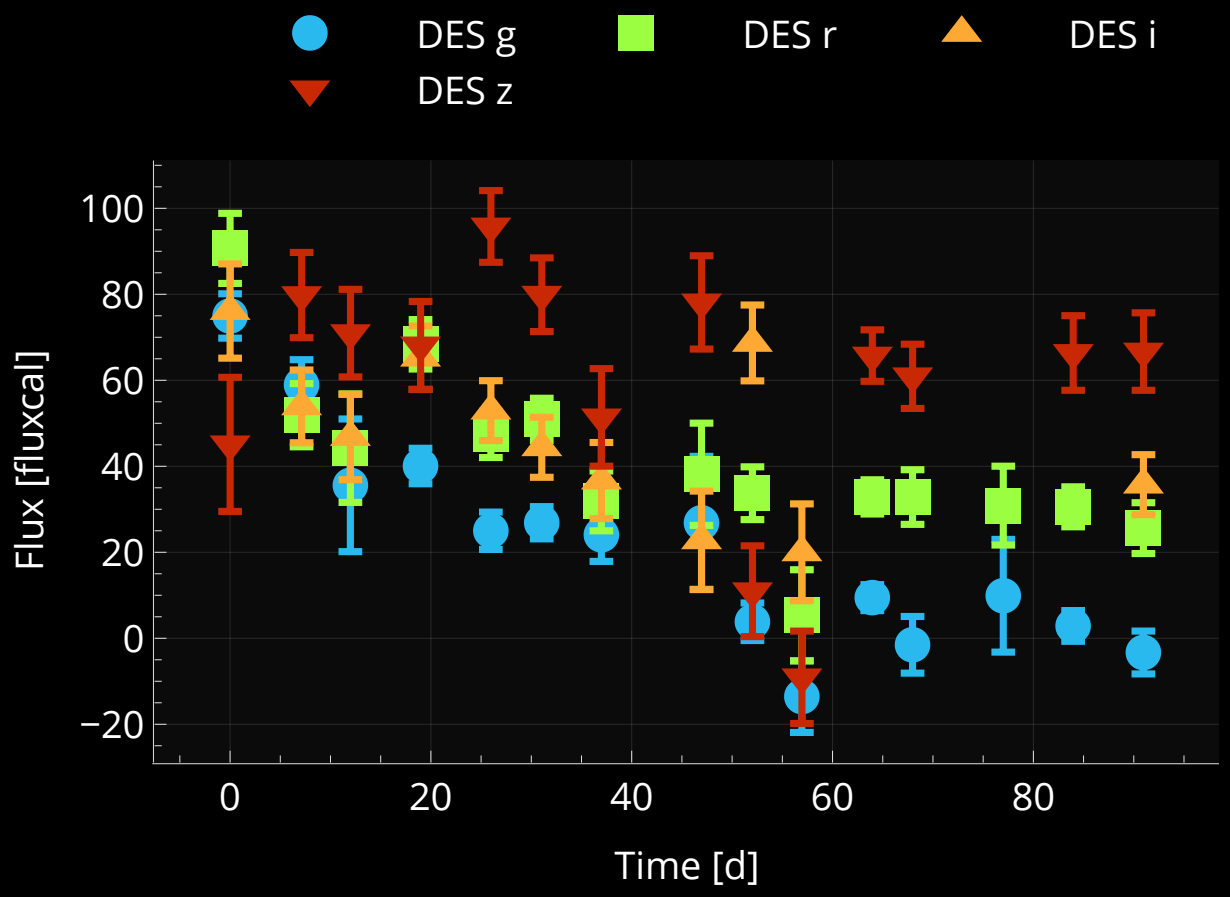
Over 94% accuracy! Below 5% contamination!



Simulated DES SN Ib/c LC.

Real data

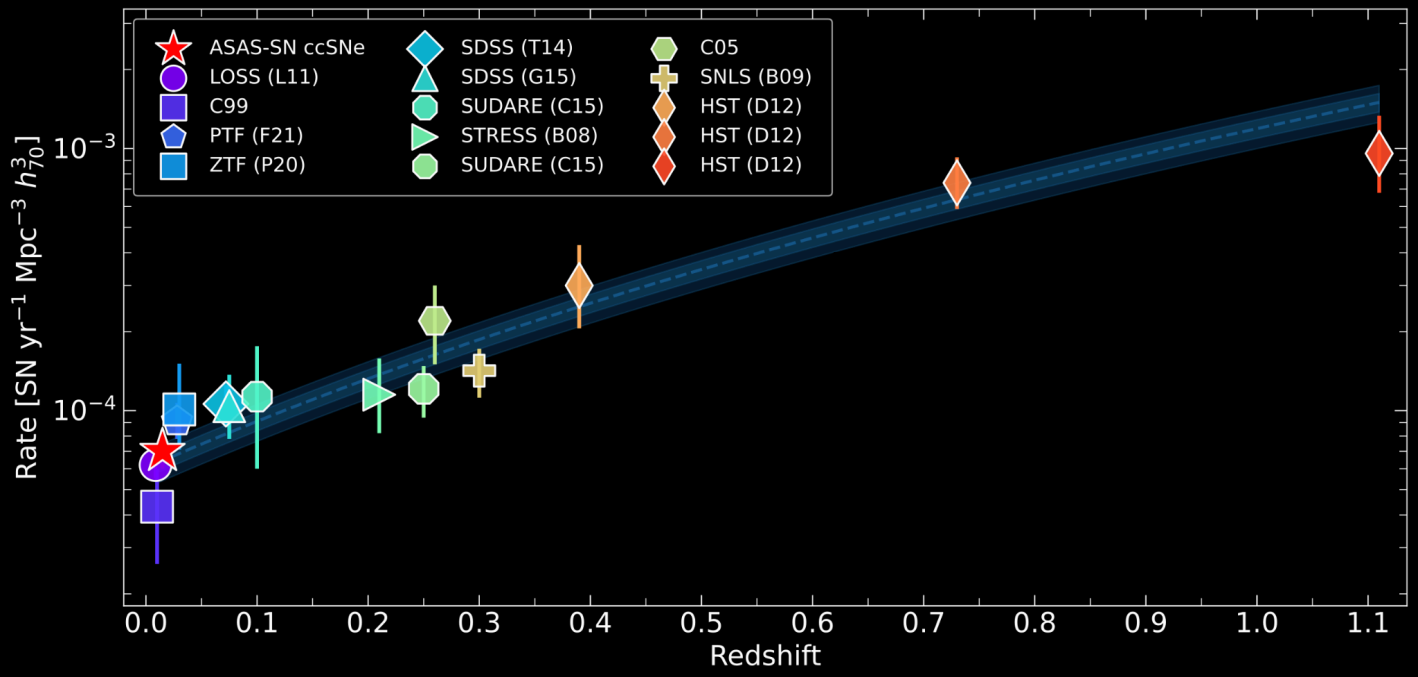
- 13 000 SN-candidates from Möller et al. (2024)
    - DES 5 year survey
- What we actually care about
- Can contain new things we don't know about
- Limited dataset size
- Real data is messy...



Yes, that's a SN II...

Grayling et al. (2023)

- 115 DES SNe CC
- Inlcudes subtype classification
- Mostly spectroscopically classified



Current SN CC rate landscape. (Pessi et al., 2025)

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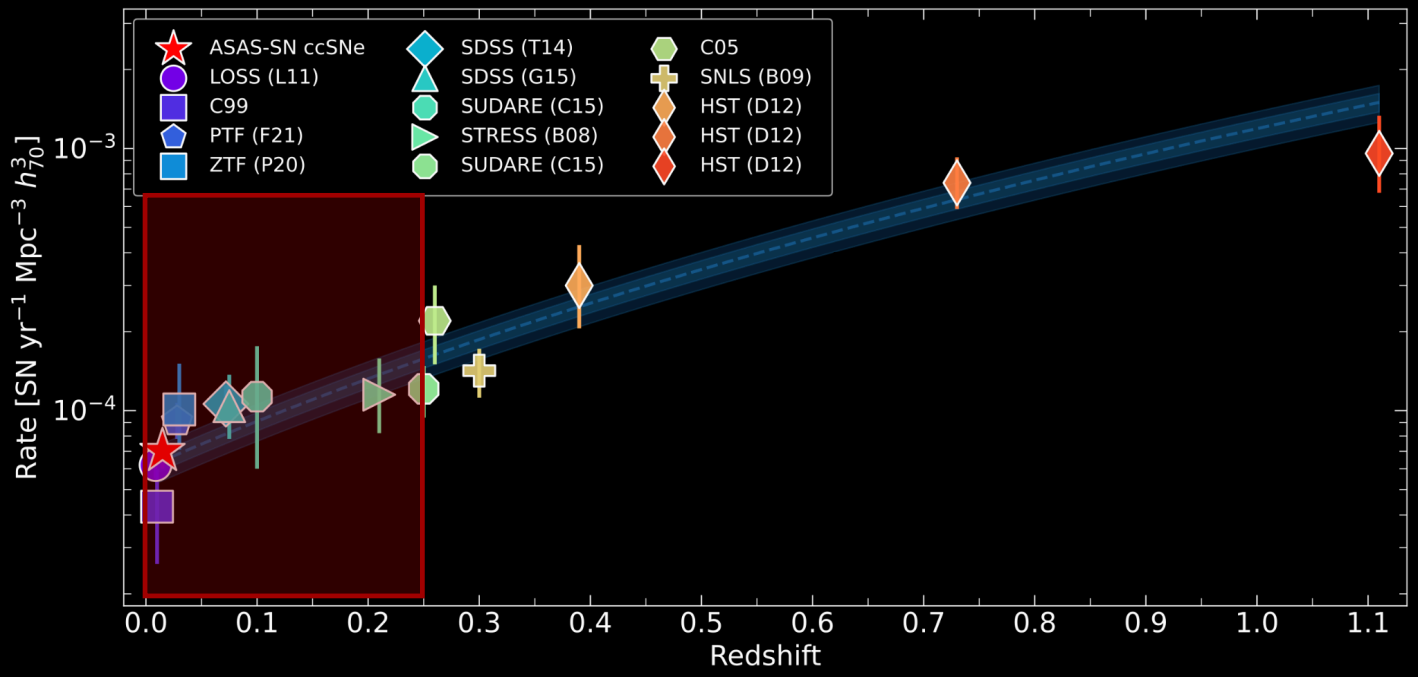
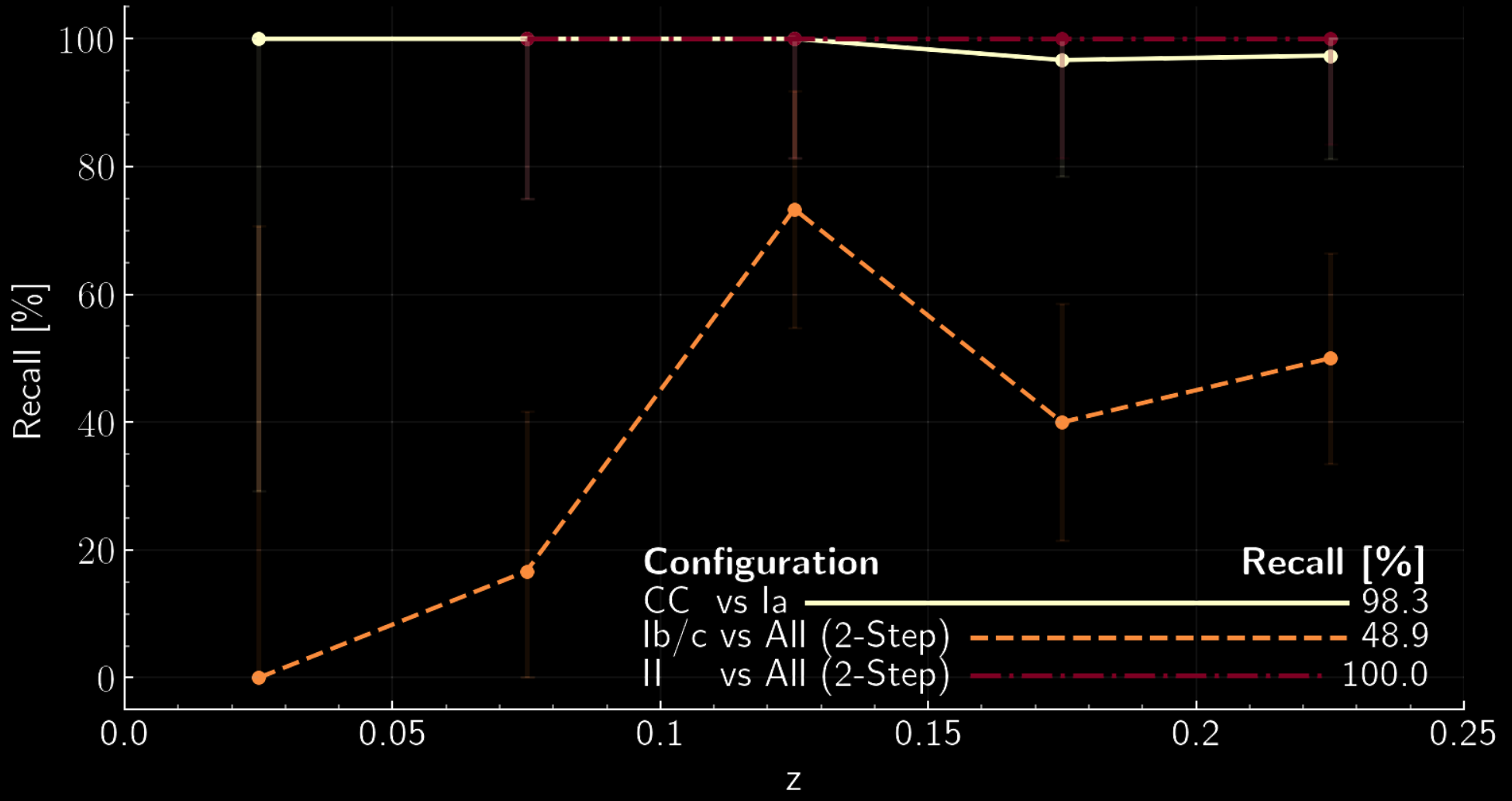
Only up to $z \approx 0.25$



Current SN CC rate landscape. (Pessi et al., 2025)

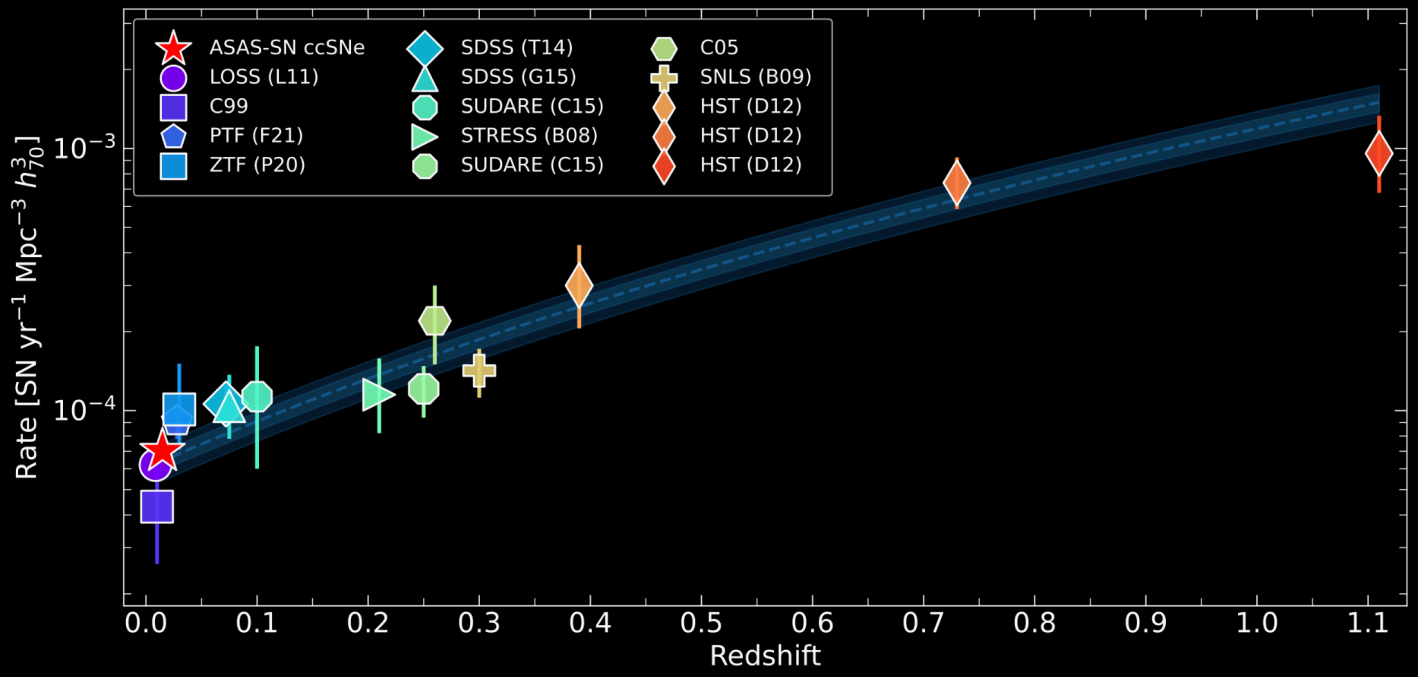
Model performance



Recall on 115 SN CC of Grayling et al. (2023) dataset. (Steinwender et al., in prep.)

Möller et al. (2024)

- 3547 SNe Ia
- Photometrically classified
  - Using SuperNNova



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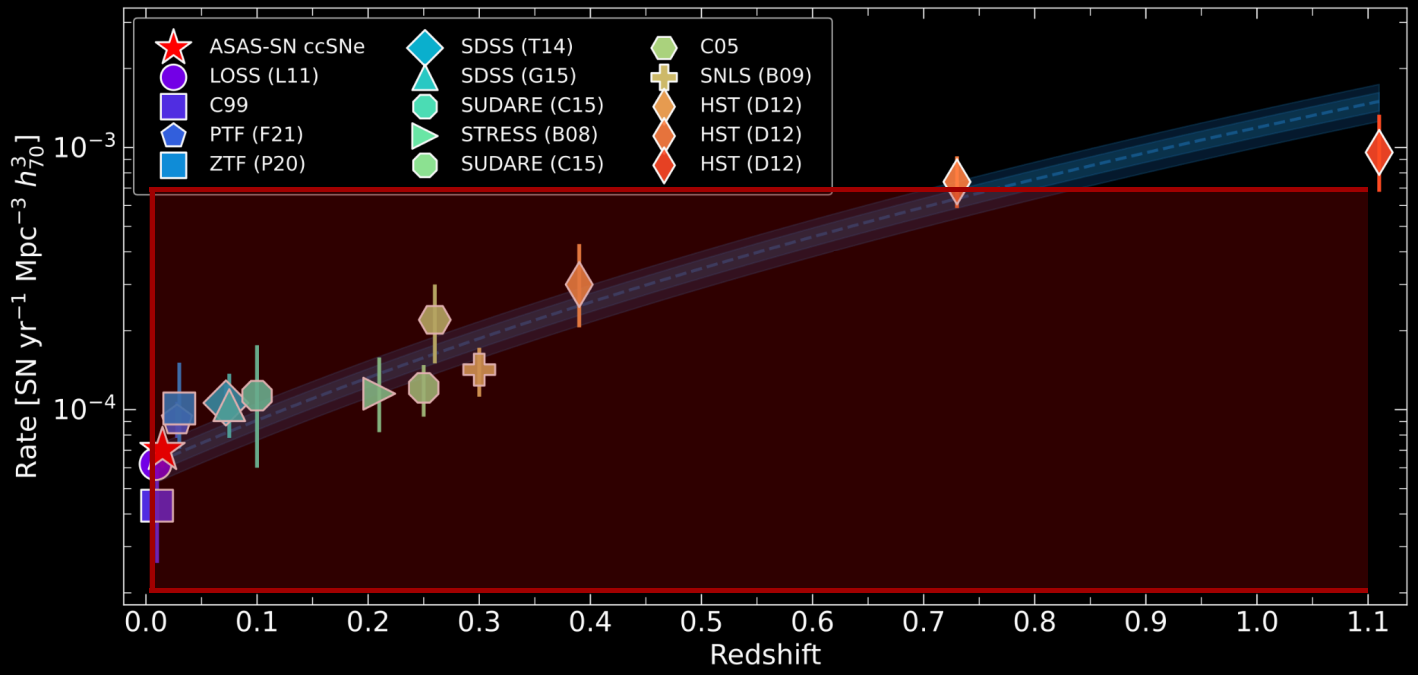
Möller et al. (2024)

- 3547 SNe Ia
- Photometrically classified
  - Using SuperNNova

Beyond $z = 1$!



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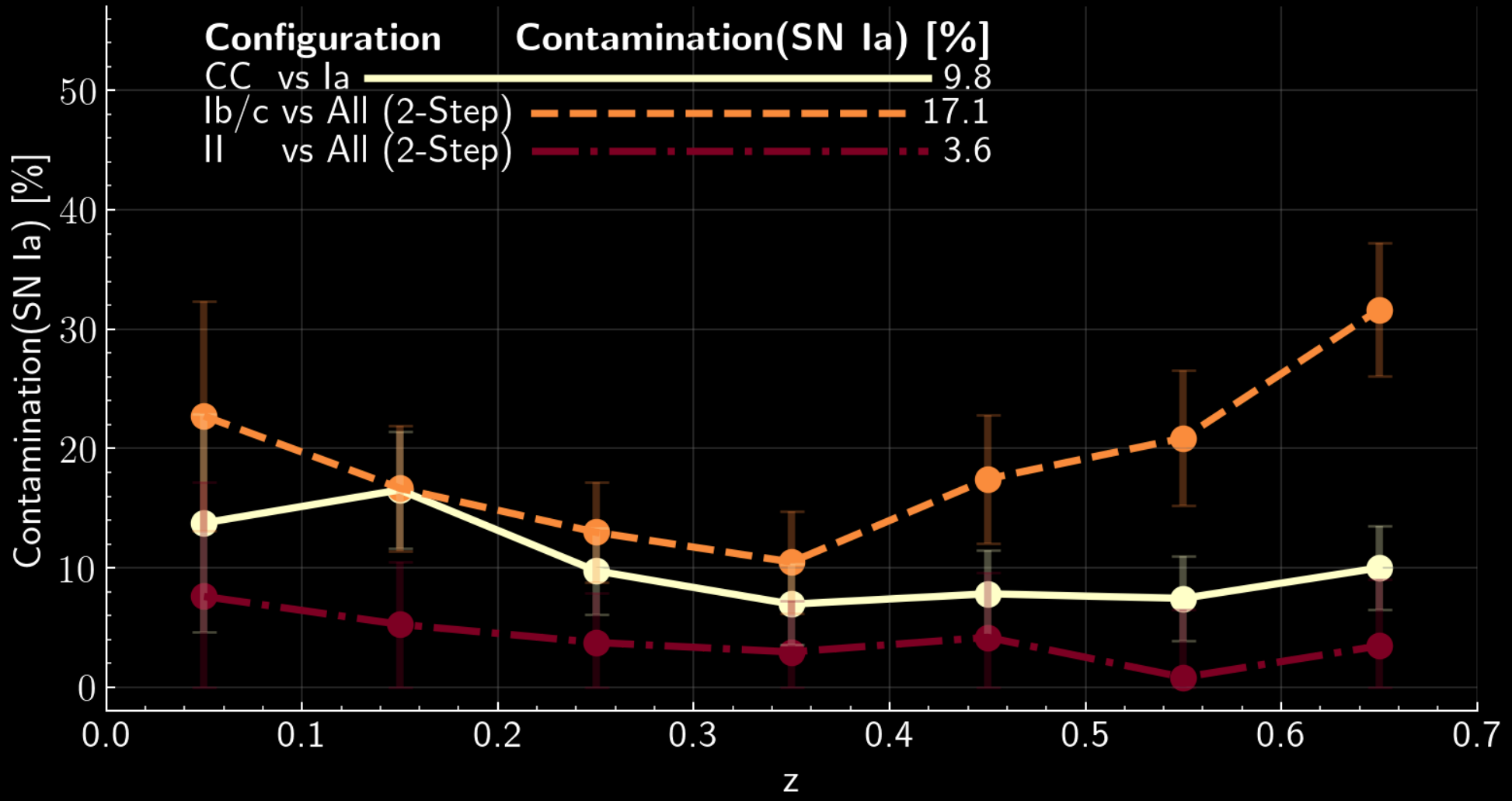
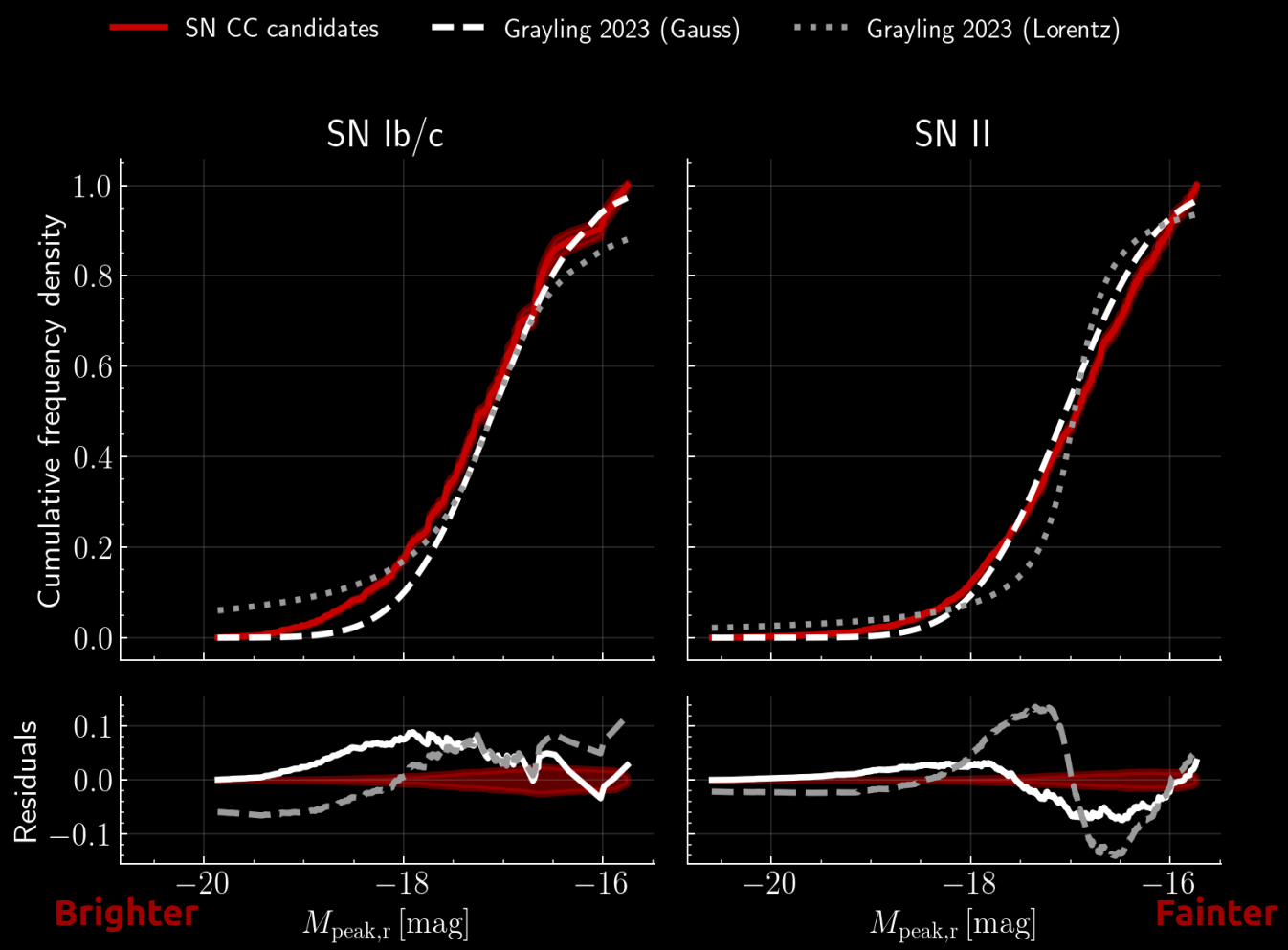


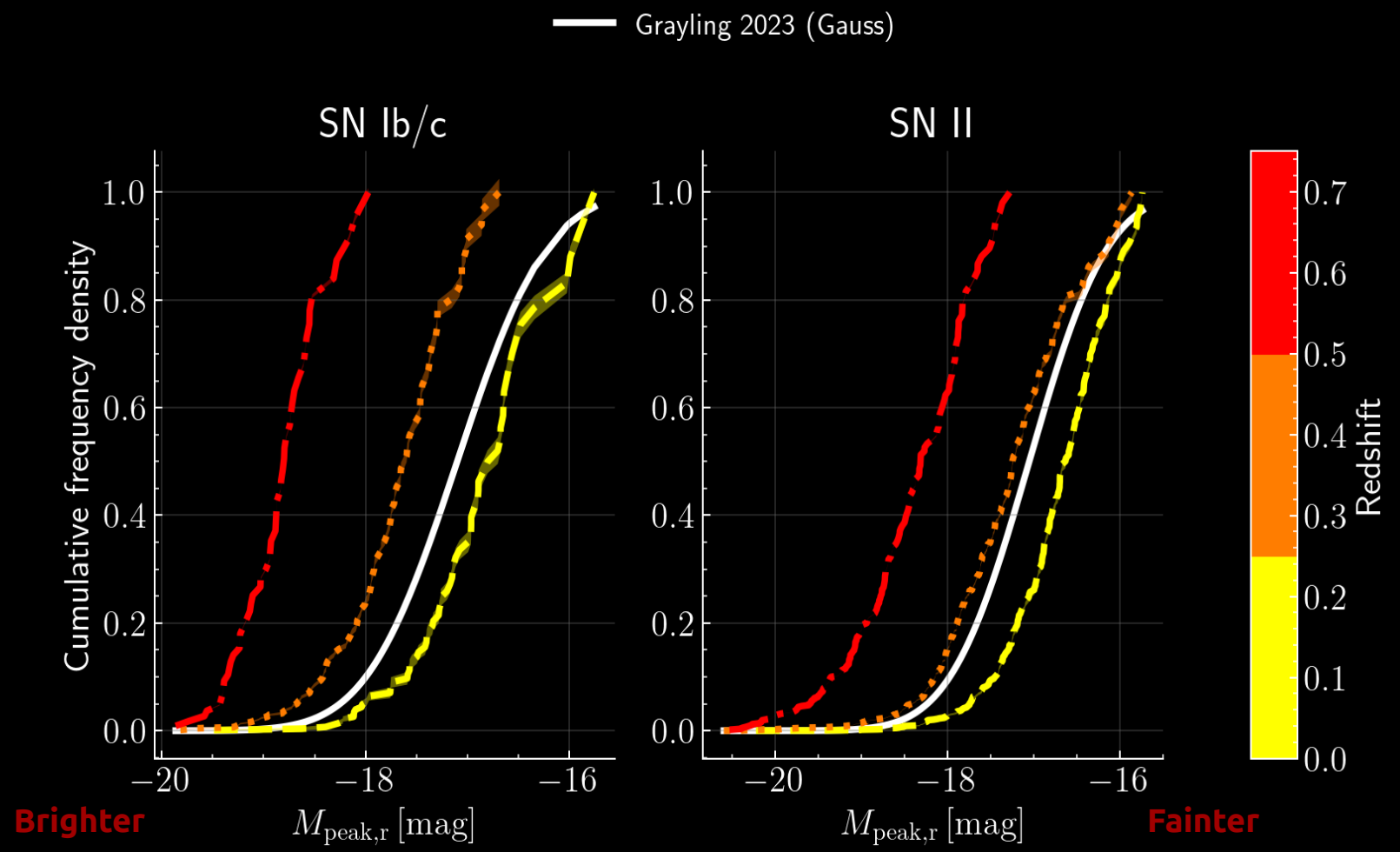
Contamination on Möller et al. (2024) dataset. (Steinwender et al., in prep.)

Luminosity functions



DES luminosity functions. (Steinwender et al., in prep)

Luminosity functions in cosmic time



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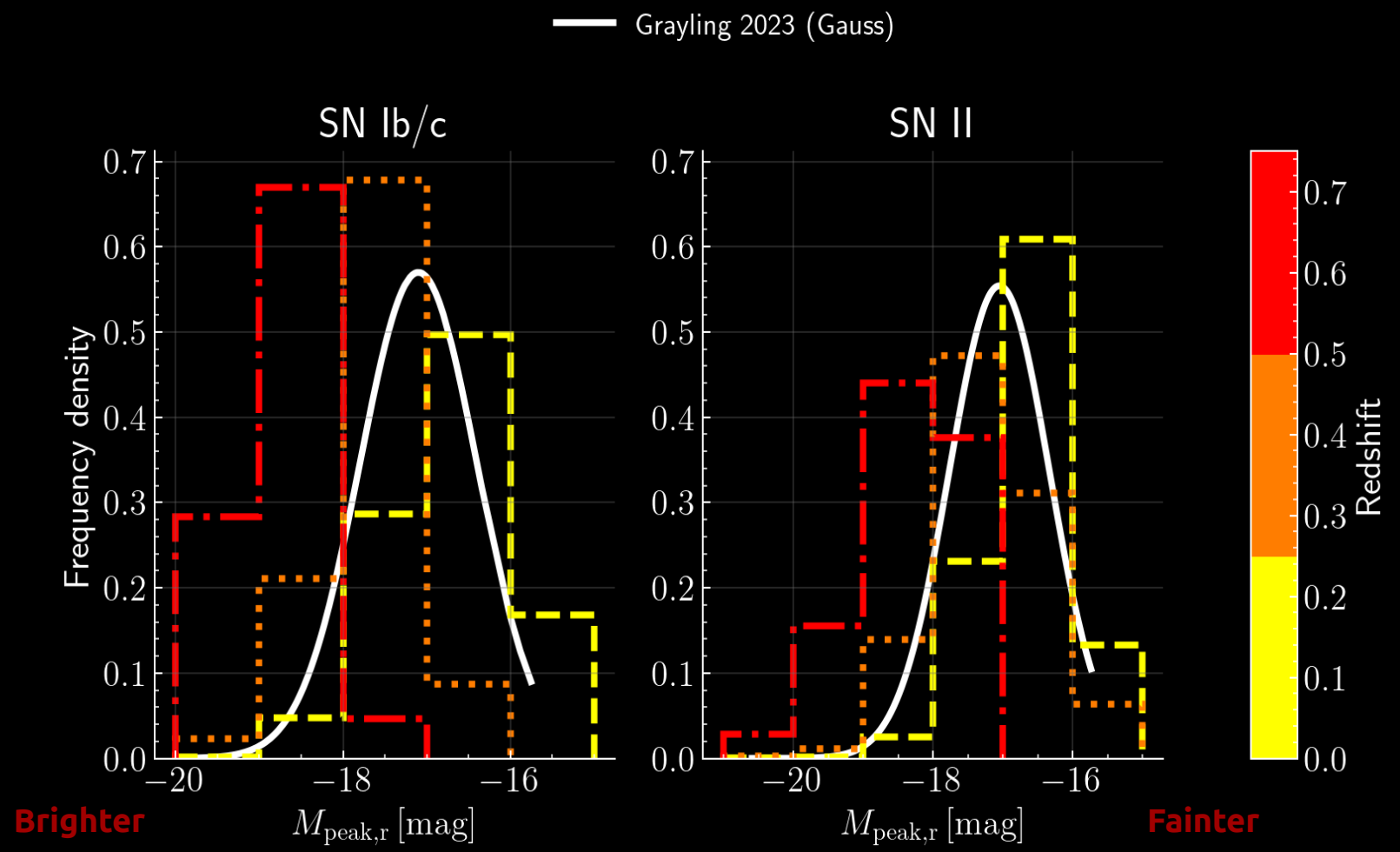


DES luminosity functions. (Steinwender et al., in prep)

Future work

→ ? → Classification

Future work

Transformers
(Vaswani et al., 2017)

Classification

Future work

Transformers
(Vaswani et al., 2017)

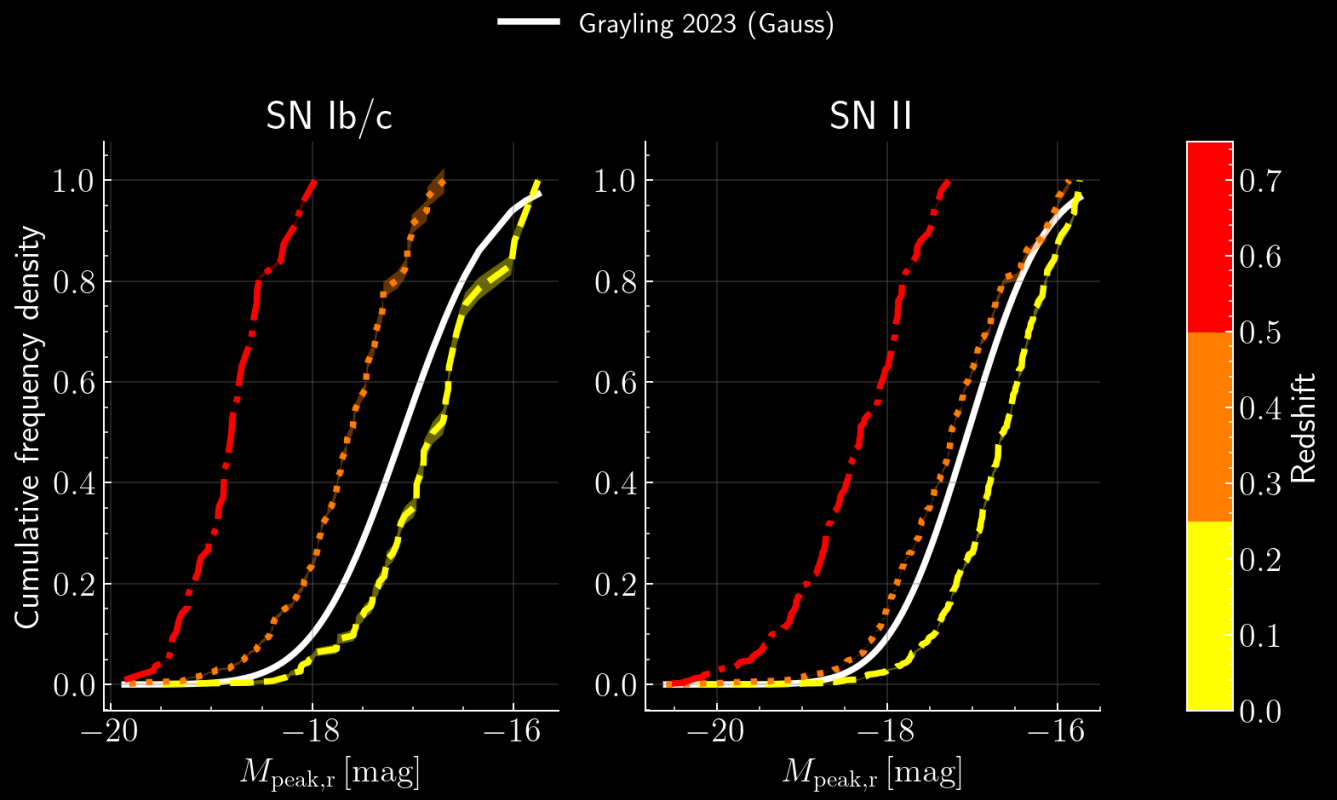
Classification

What can we learn about SNe CC at $z \geq 0.4$ by data-mining modern, large surveys?

Summary

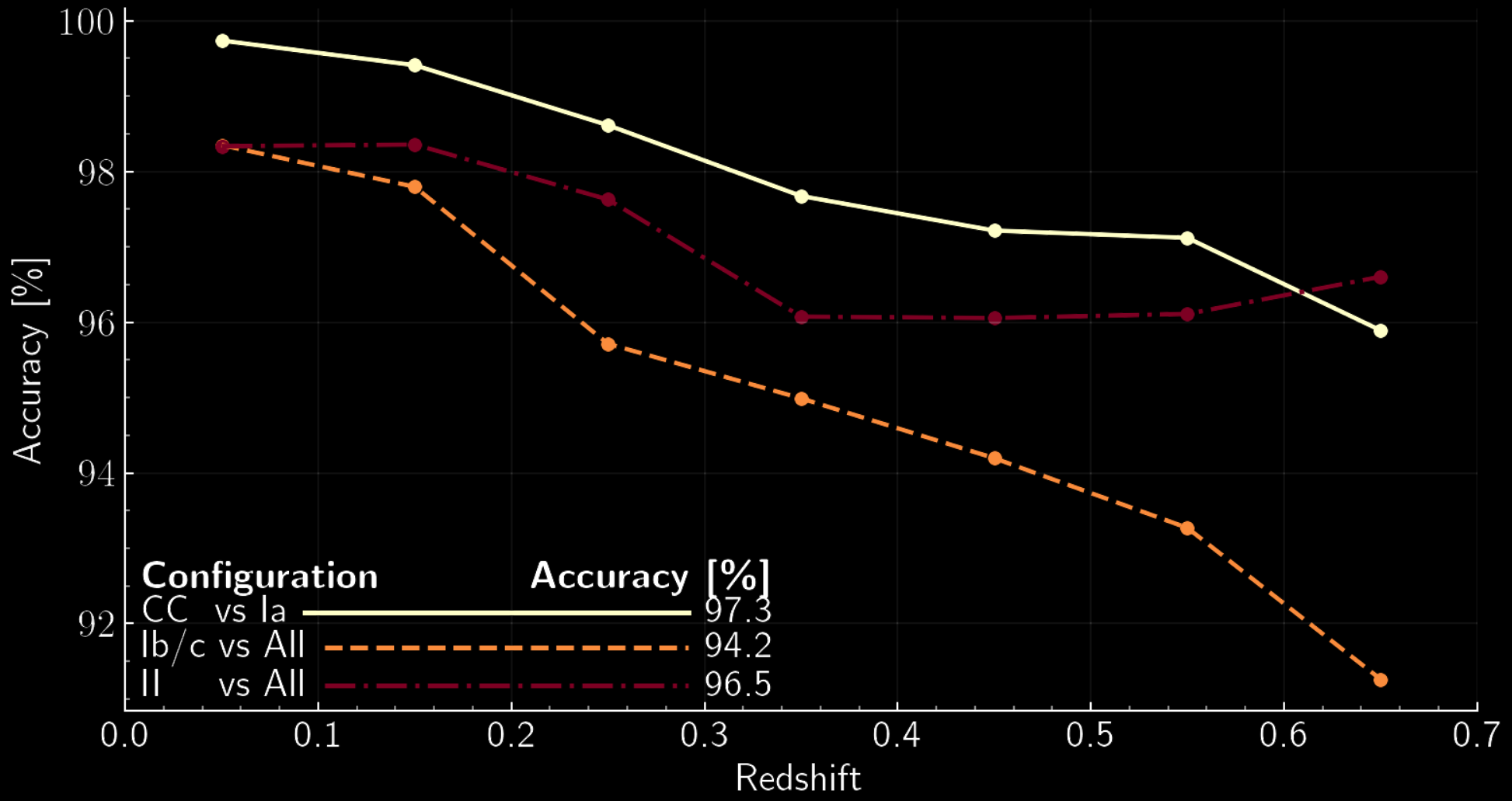
exciting times for supernova astronomy through big-data

modern surveys allow probing SNe CC across cosmic time



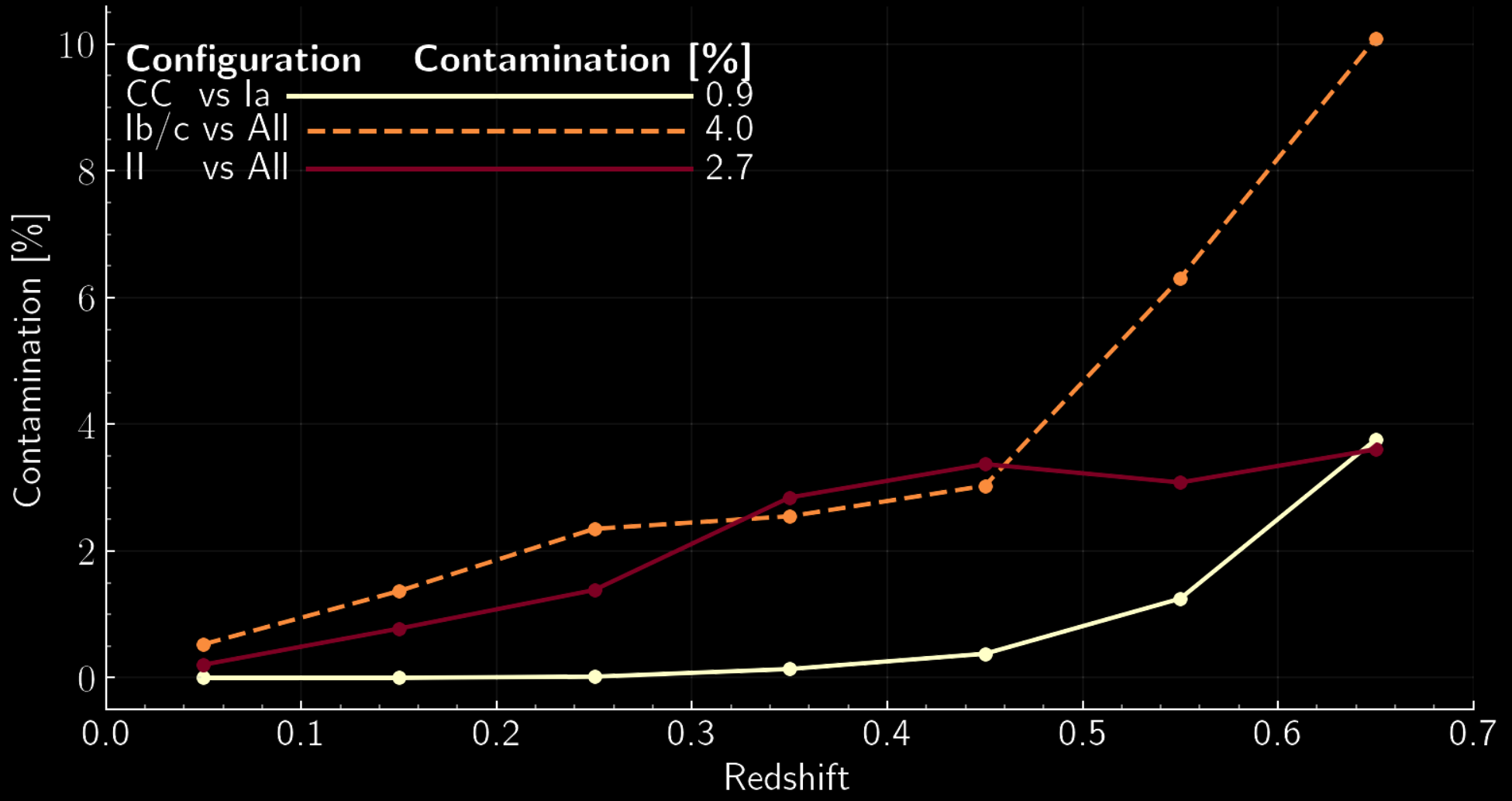
Bonus slides

Model performance



Accuracy on simulations. (Steinwender et al., in prep.)

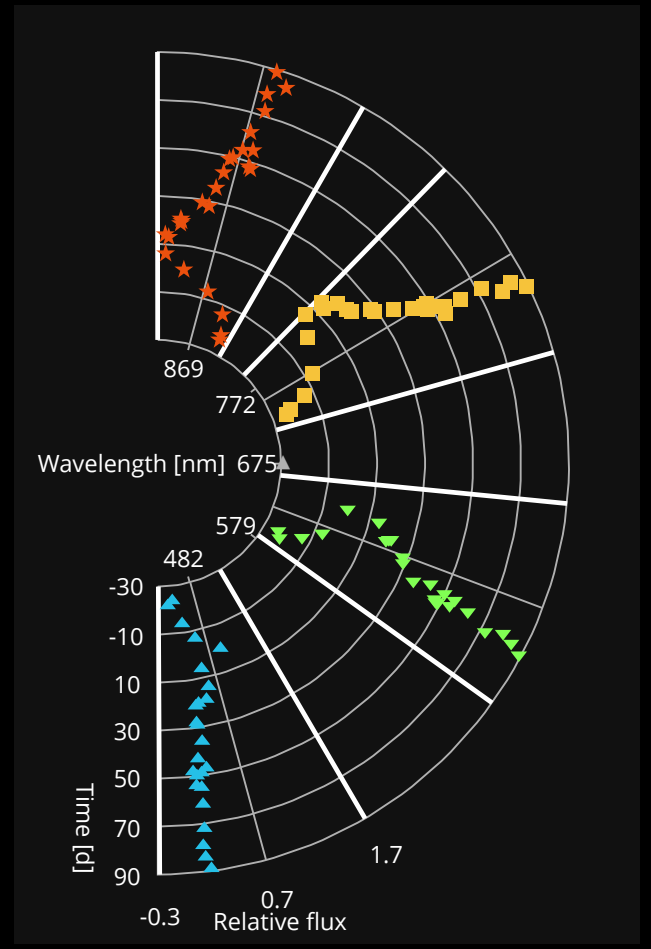
Model performance



Contamination on simulations. (Steinwender et al., in prep.)

Sample cleaning

Cut	Total	Percent	Grayling 2023	Grayling 2023 [%]
Möller 2024 SN Candidates	13117	100.0	115	100.0
Physics cuts	2435	18.6	79	68.7
Prediction cut (SN Ia)	1301	9.9	77	67.0
Prediction cut (SN II)	981	7.5	59	51.3
Prediction cut (SN Ib/c)	331	2.5	16	13.9



LStein applied to DES SN Ib/c.

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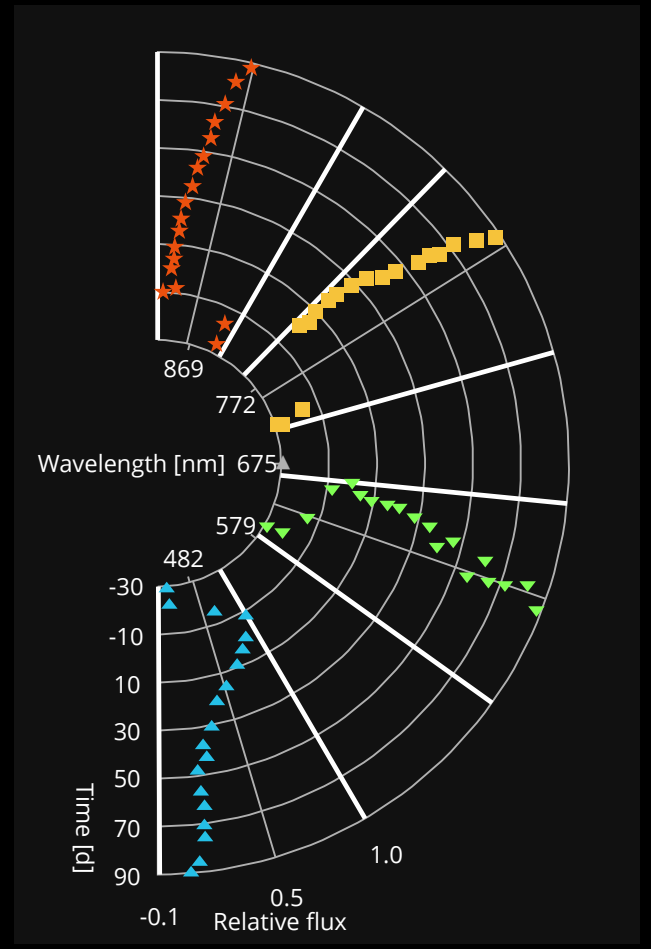
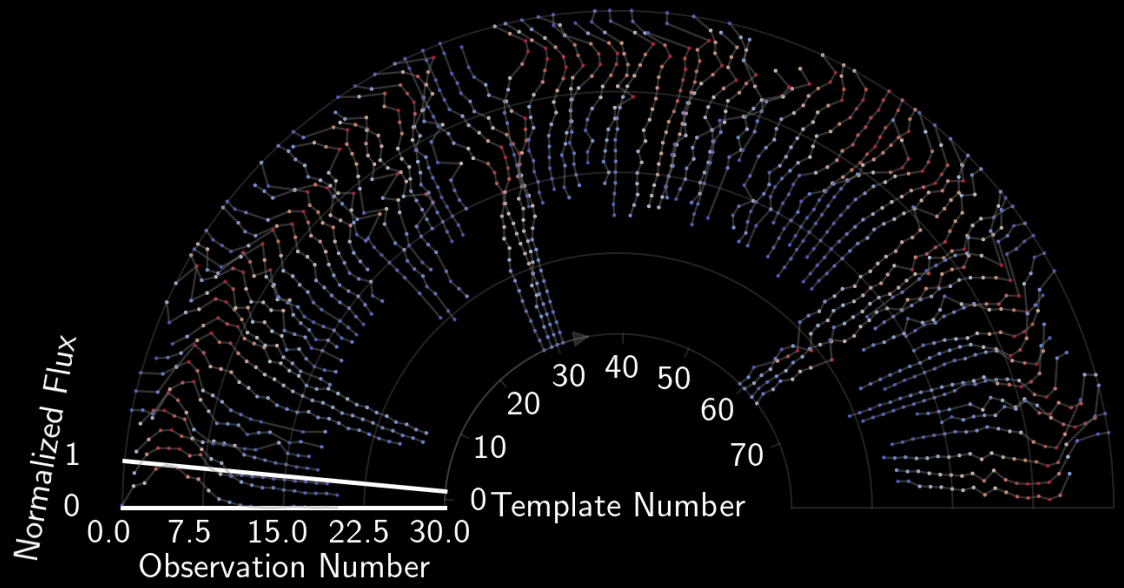


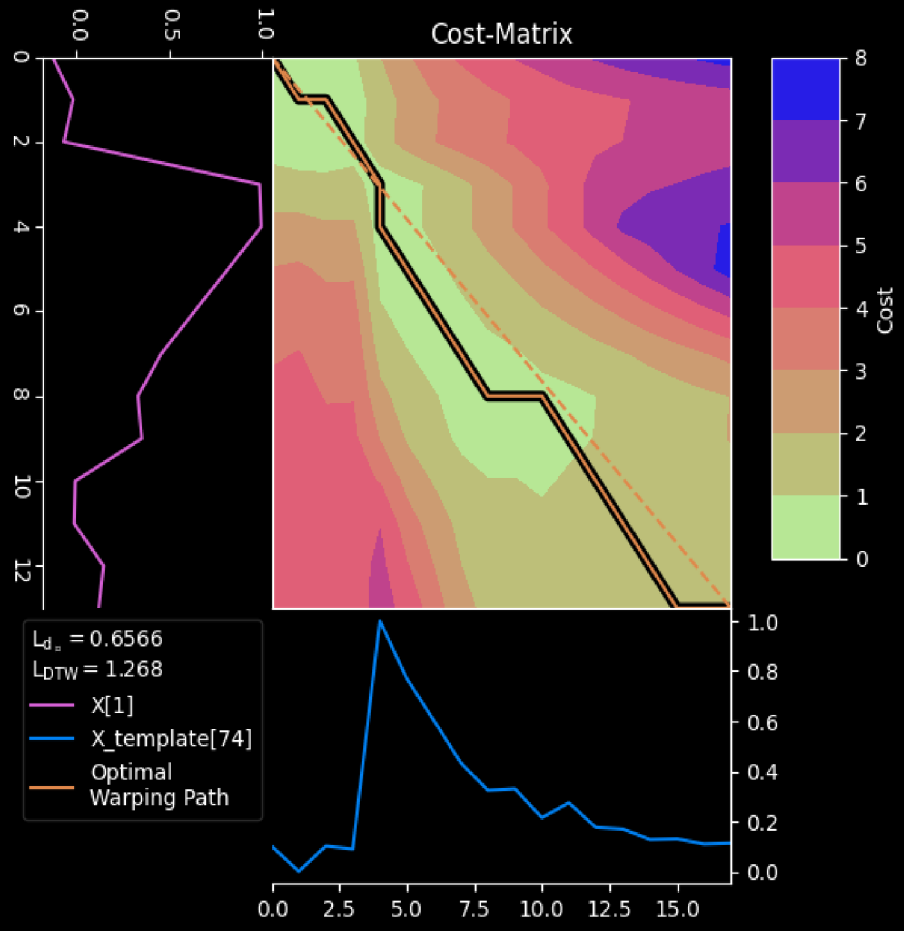
LStein applied to DES SN II.

Dynamic time warping

- Allows template matching between timeseries
- Compare pariwise distances
- Compute optimal warping path



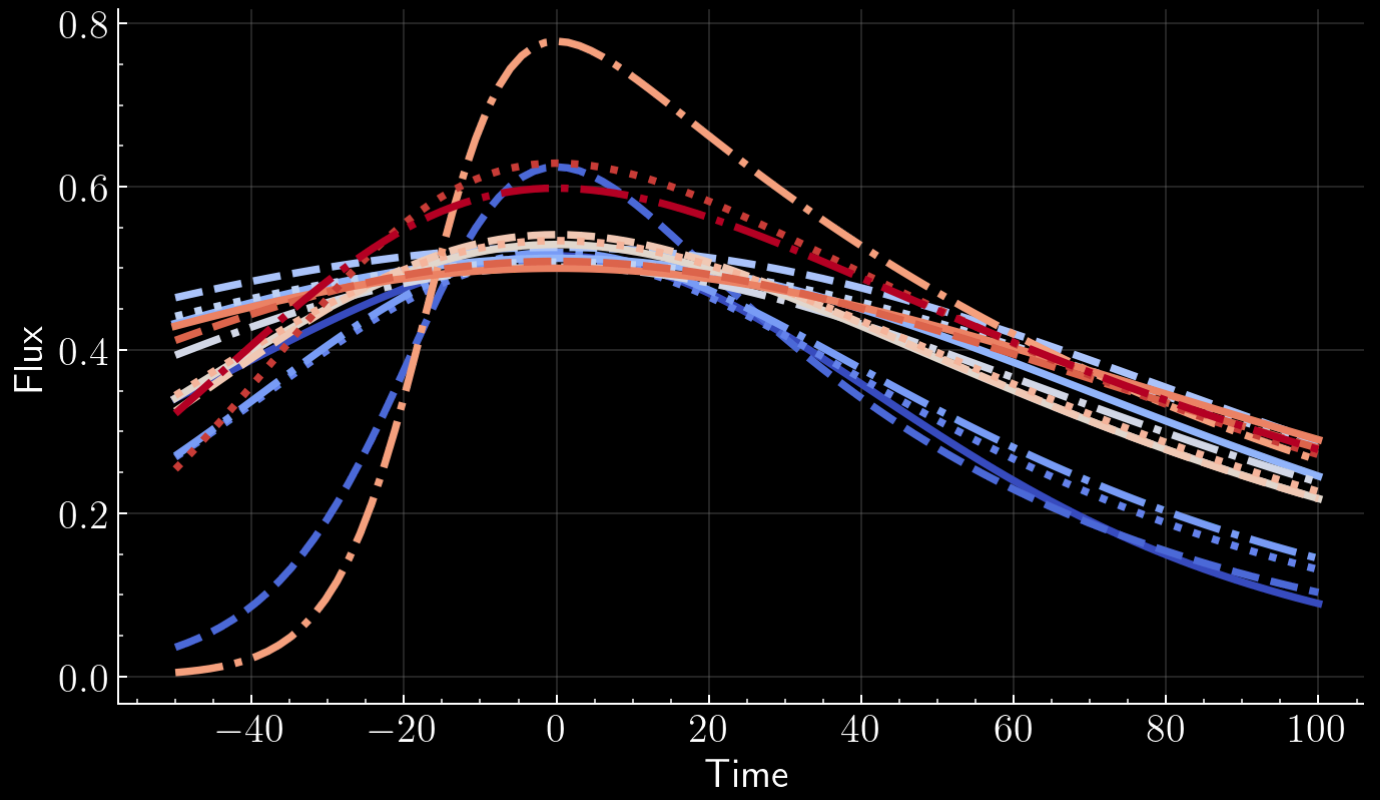
Used SN CC templates.



Dynamic time warping on a SN Ib/c.

Bazin modelling

- Based on Bazin et al. (2011)
- Phenomenological
- Exponental decay and rise
- Contains amplitude and time of maximum light



Bazin model parameter space.