Funded by the U.S. National Science Foundation and the Simons Foundation

From the First to the Last Photons

Unveiling the progenitor demographics of Type Ia supernovae

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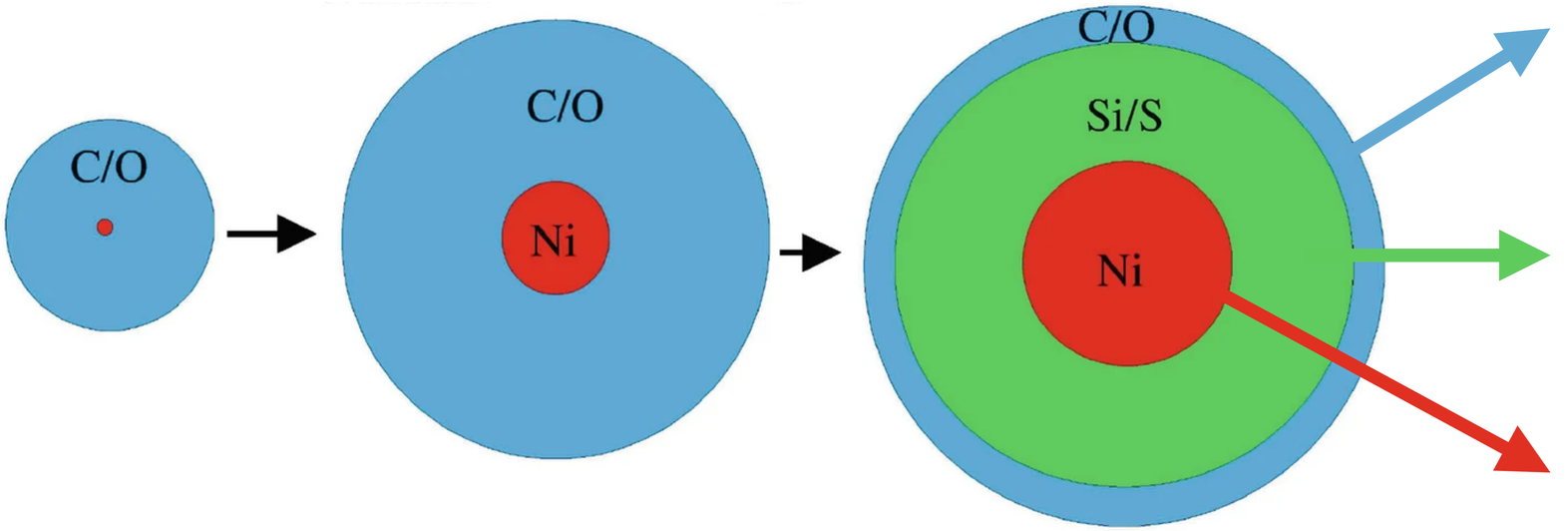
CIERA/Northwestern

2025.8.22 One Hundred Years of Supernova Science

Near-M_{Ch} WD

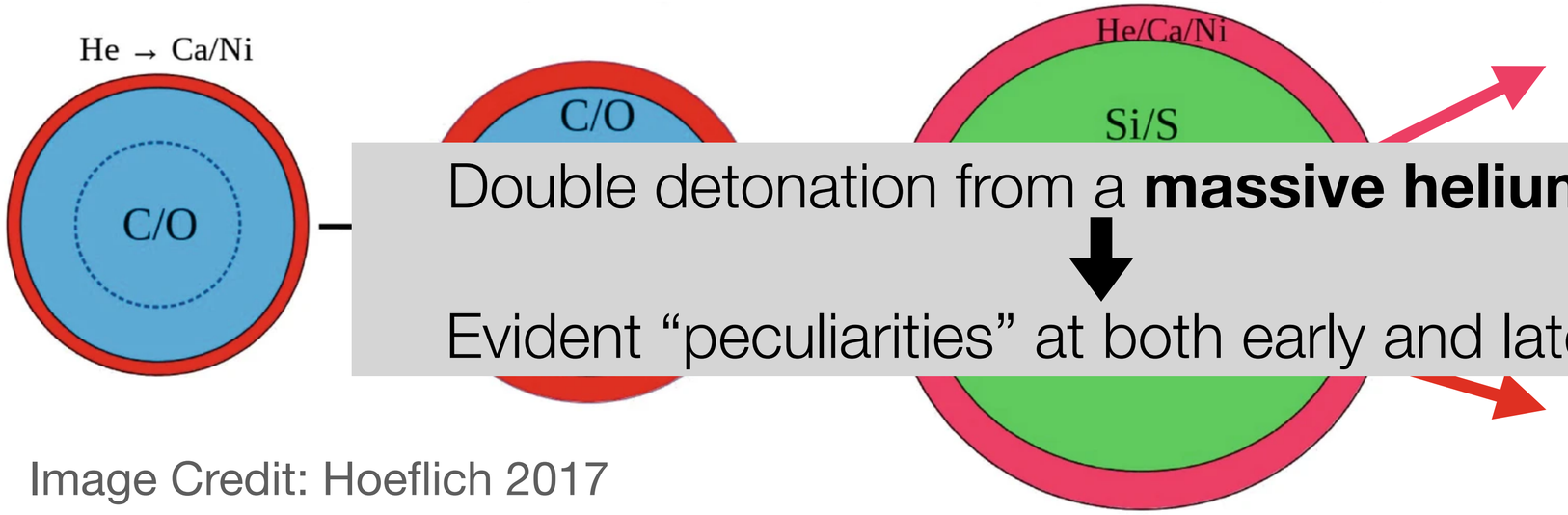


Early-time (hours to days after the explosion)

Near **maximum** luminosity

Late-time (>200 days)

Sub-M_{Ch} WD in a double detonation



Helium shell: early times (depending on the shell mass)

Double detonation from a **massive helium shell**

↓

Evident “peculiarities” at both early and late times

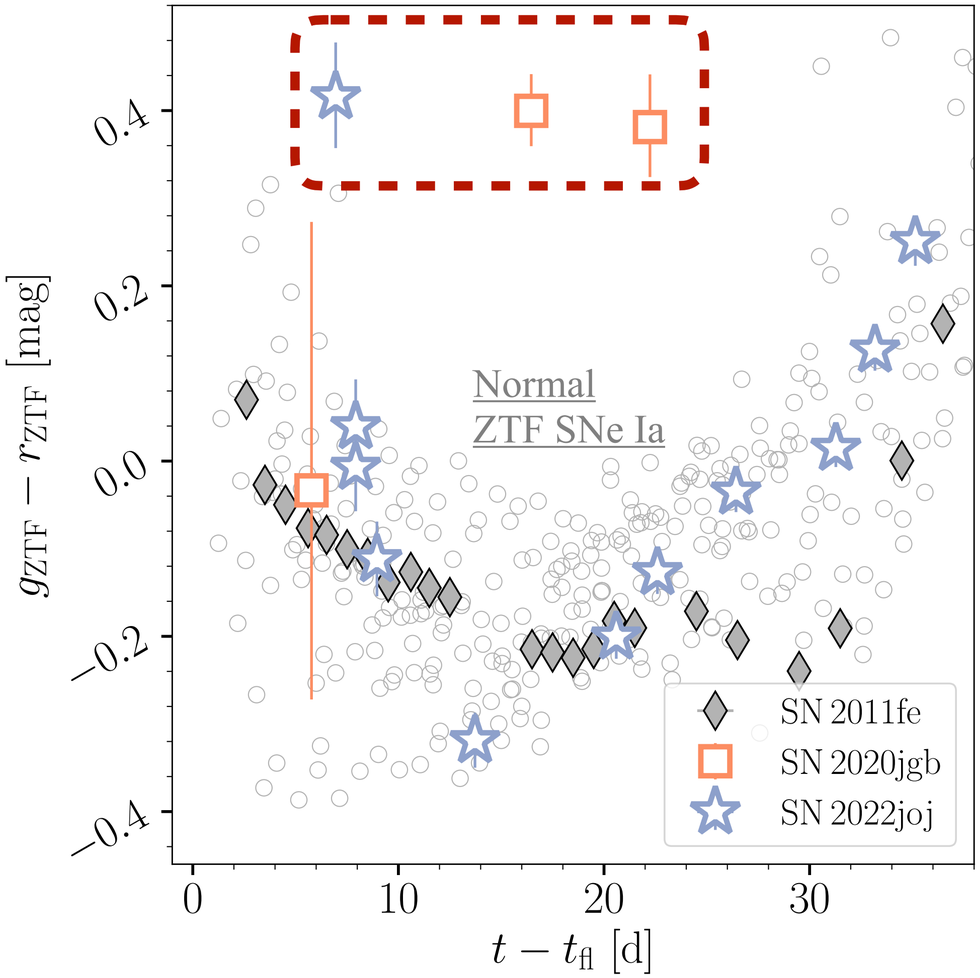
Nucleosynthesis yields: nebular phase

Image Credit: Hoeflich 2017

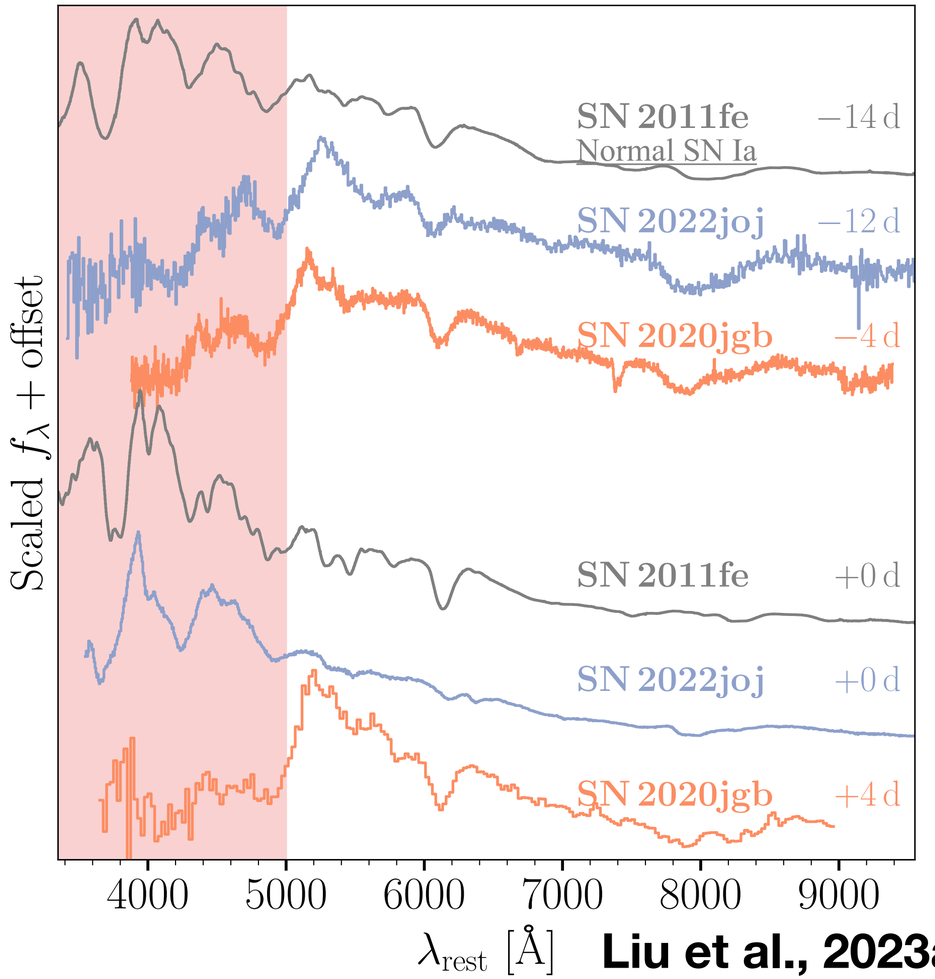
Massive He-shell Double Detonation

From days after explosion to maximum luminosity

Unusual **red** colors



Suppression of flux <5000 Å

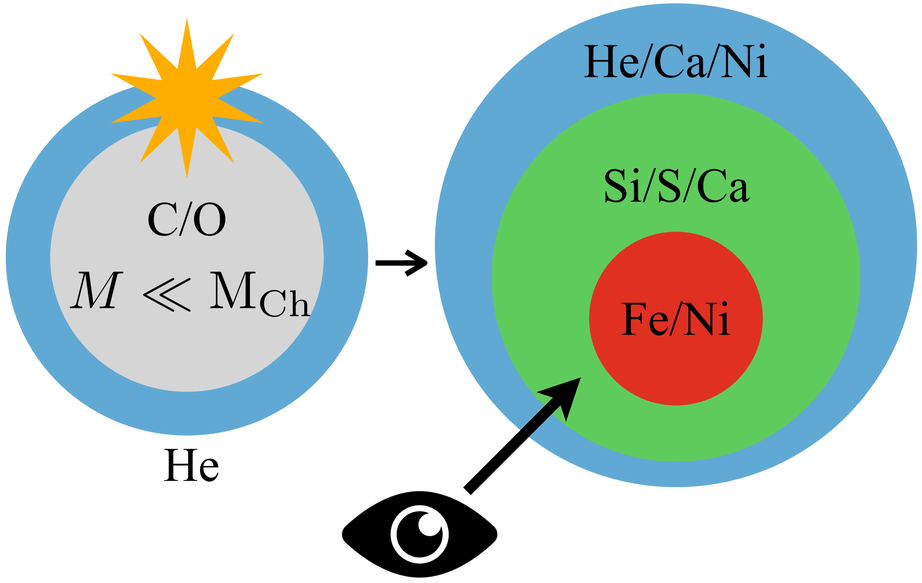


Liu et al., 2023a, b

SN2022joj: Asymmetric Double Detonation?

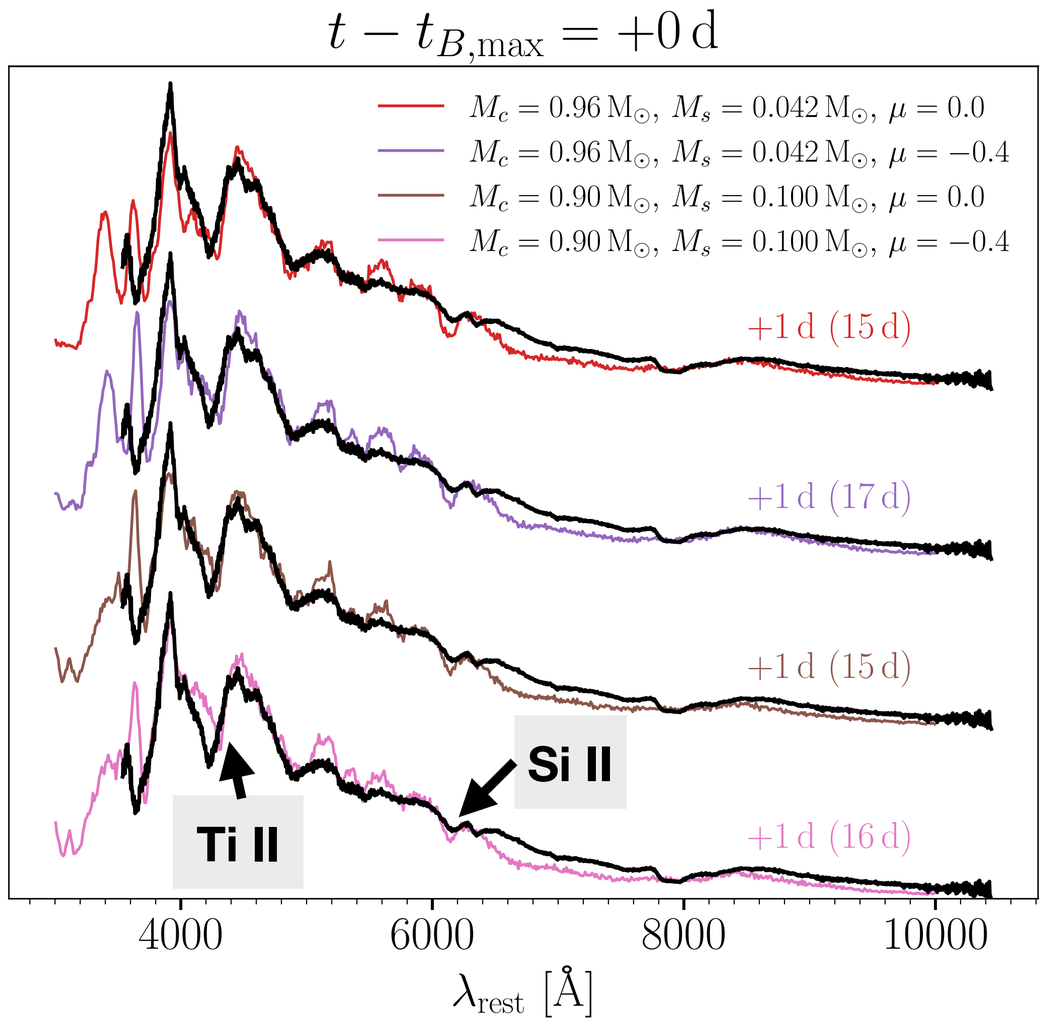
Maximum luminosity

Strong Ti II: Helium shell ashes



Weak, slow Si II: sightline opposite to the He detonation

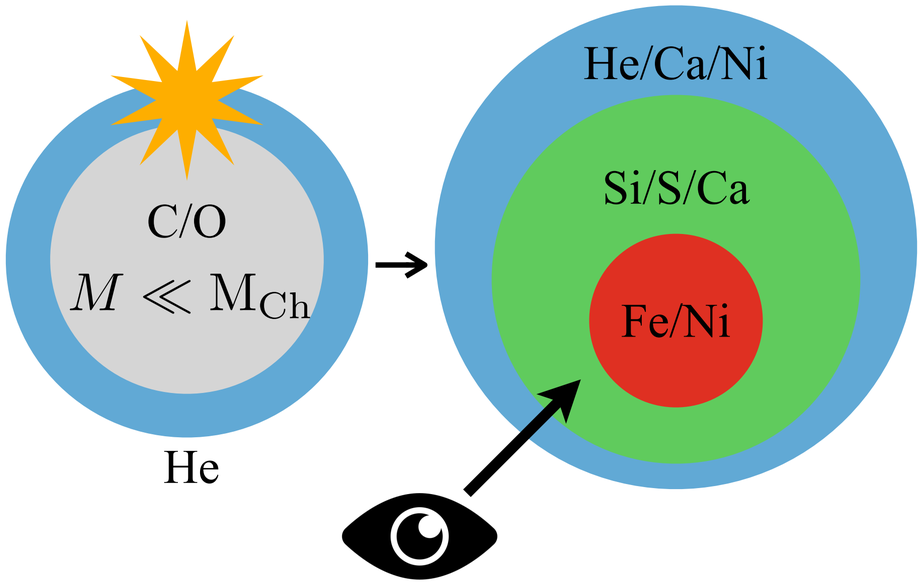
Liu et al., 2023b



SN2022joj: Asymmetric Double Detonation?

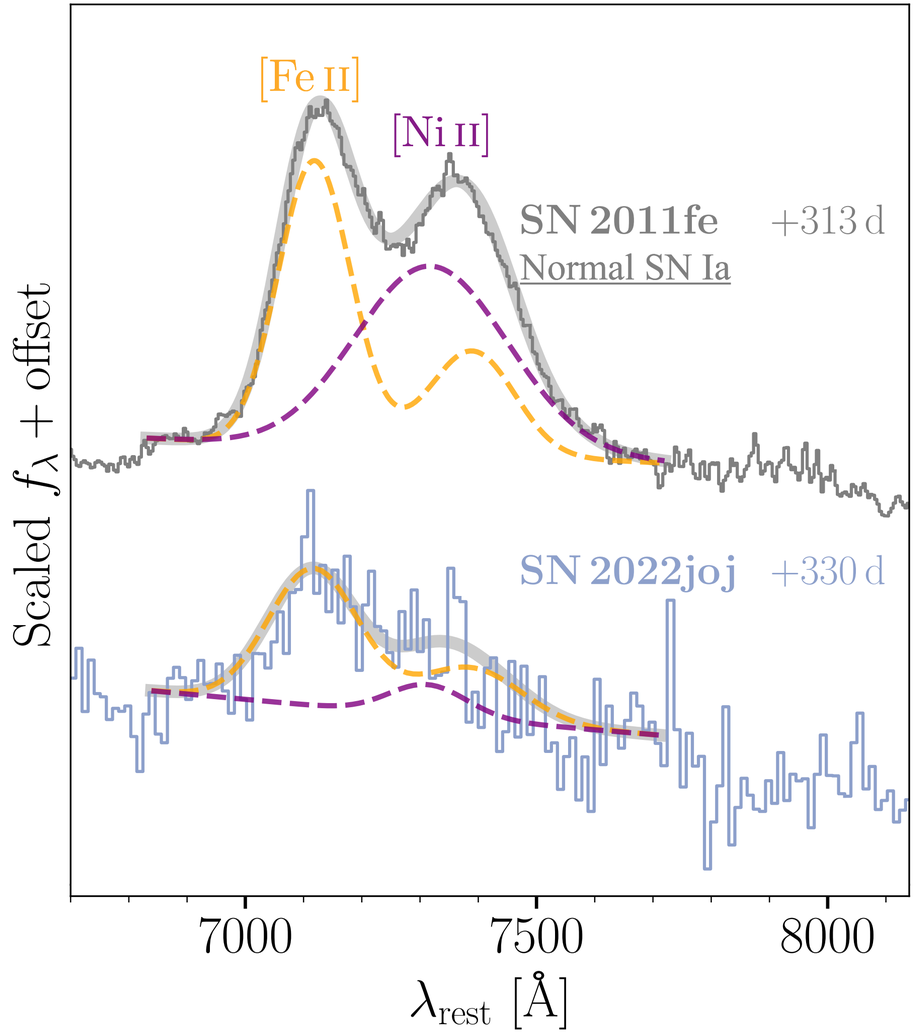
>200 days after explosion

Absence of [Ni II]: low central density in the progenitor



Blueshifted Fe core: sightline opposite to the He detonation

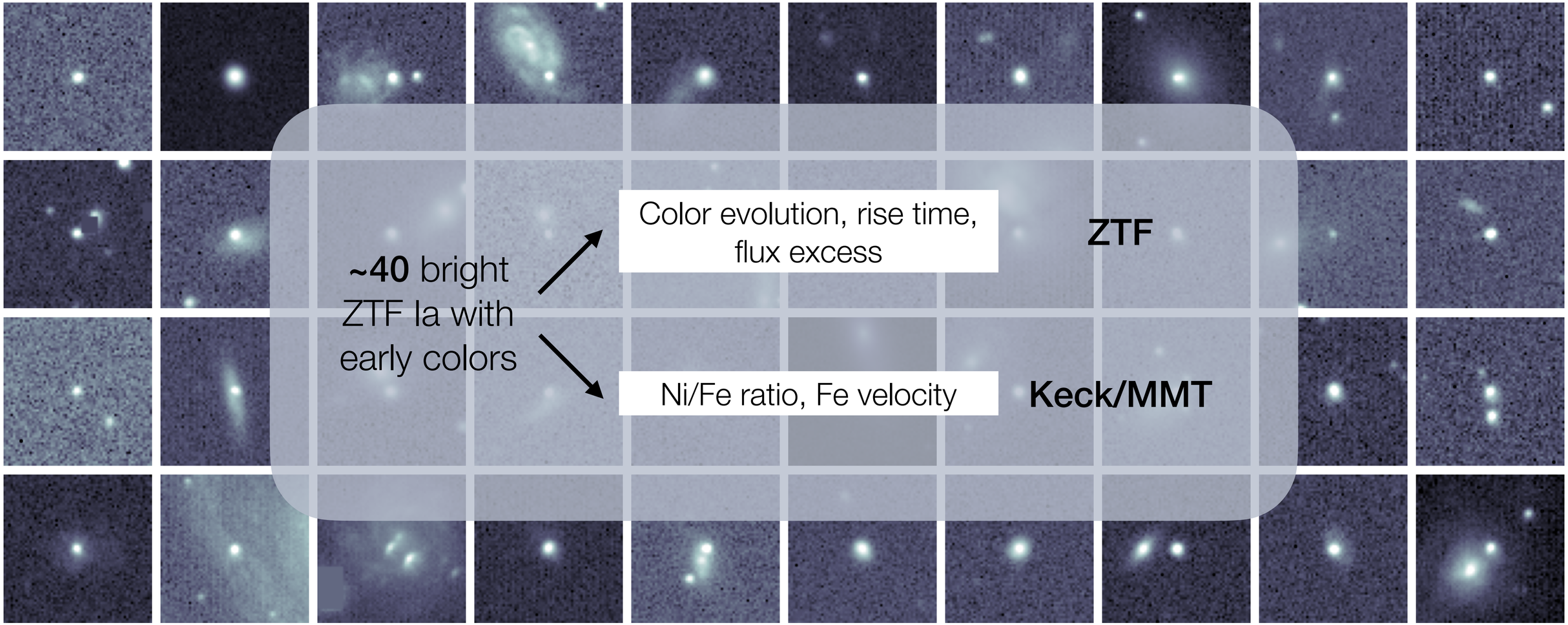
Liu et al., 2023b



But what about the normal la?

ZTF Early-Late Ia Sample (2023-2024)

Combining early light curves and nebular spectroscopy

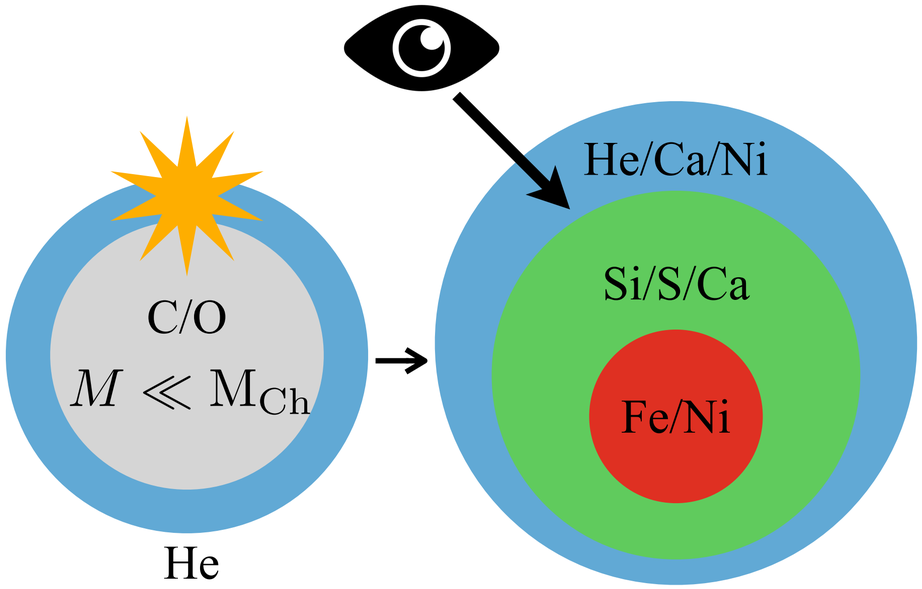


(Not quite) Early + Late

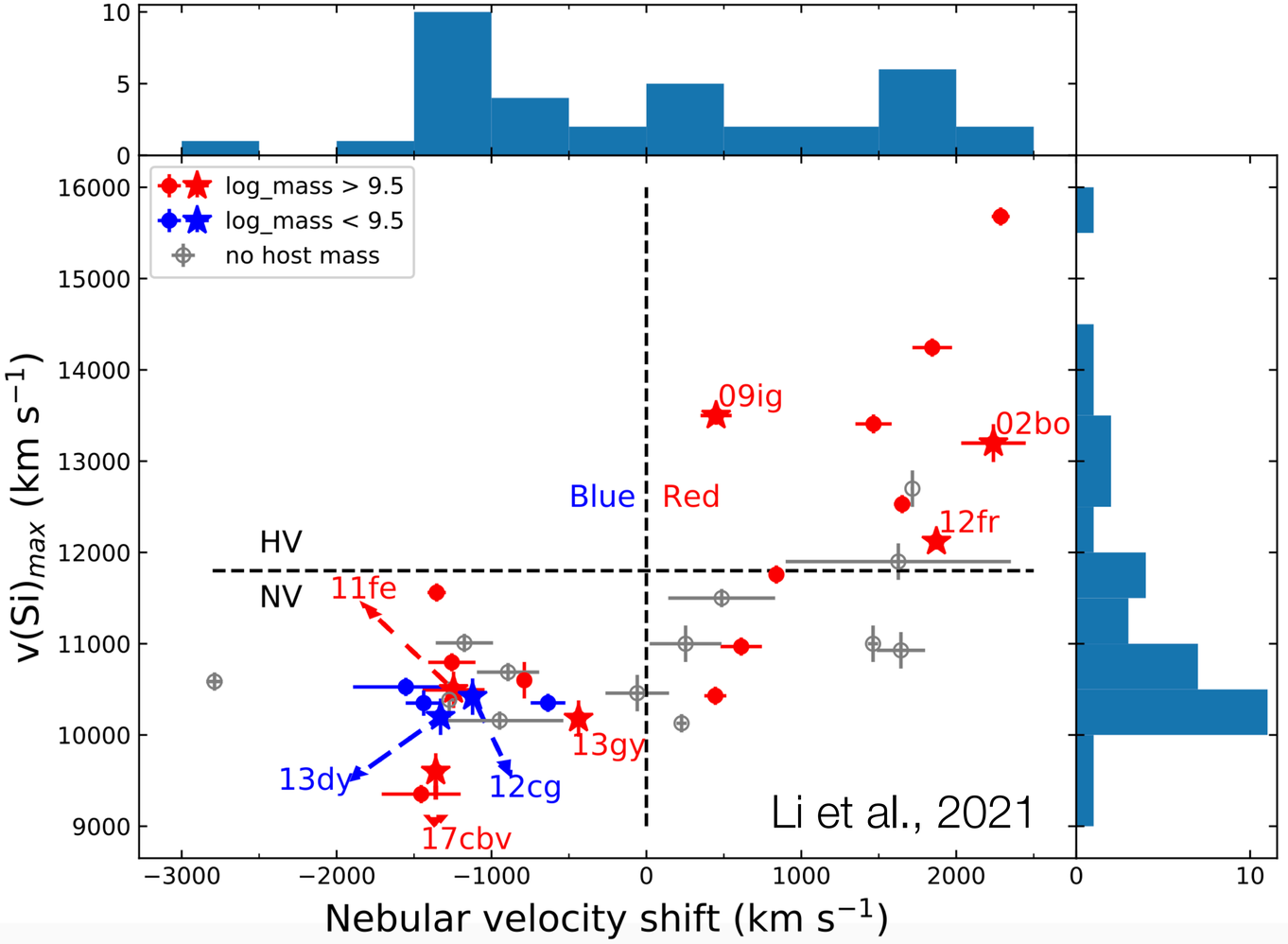
Independent probes of the population

Consistent with **double detonations** at certain **viewing angles** (Boos et al., 2021)

High Si velocity at peak:
sightline near the He detonation



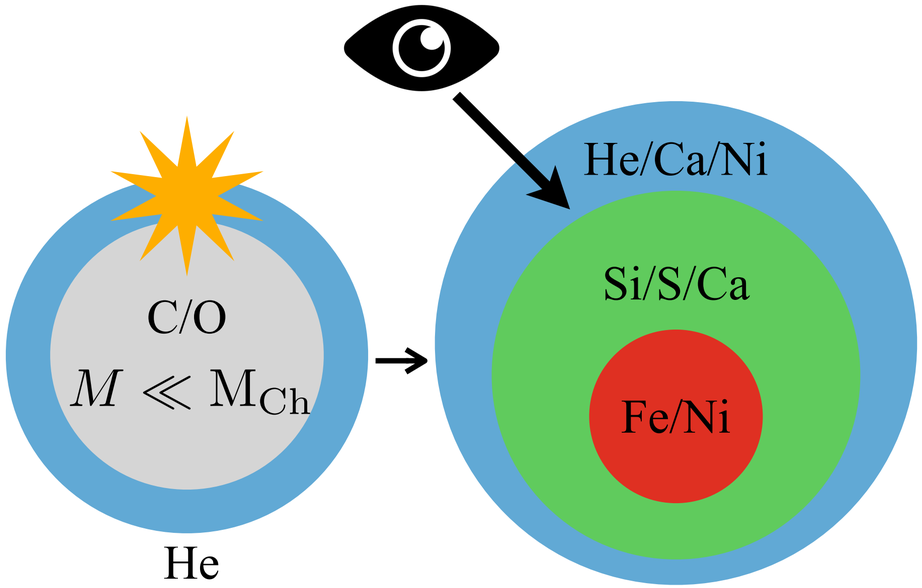
Redshift Fe core at late time:
sightline near the He detonation



Early + Late

Independent probes of the population

Light curves at early time



Redshift Fe core at late time:
sightline near the He detonation

He shell ashes?

Ni-56 asymmetry?

IME asymmetry?

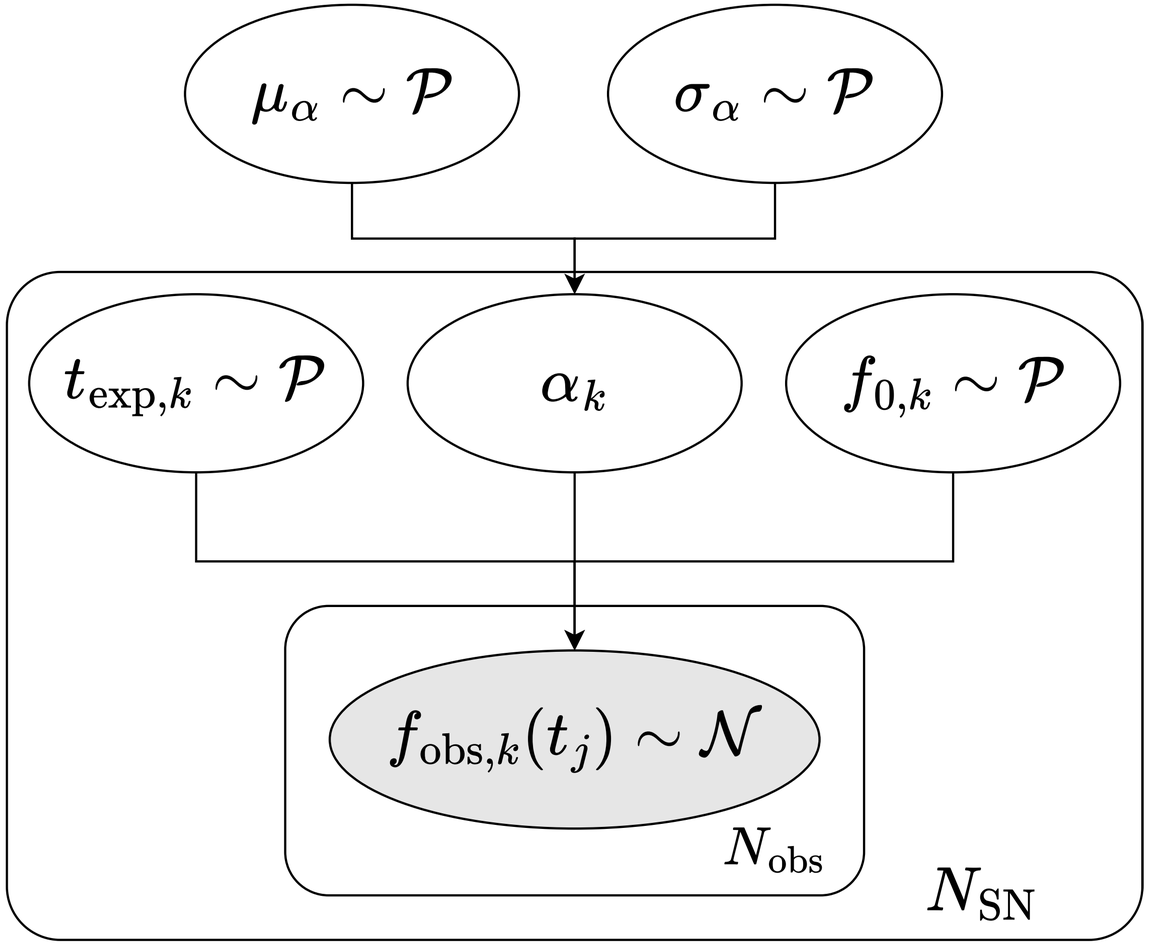
A Systematic Study on the Rise

~10^3 SNe Ia from ZTF DR2 (Rigault et al. 2025)

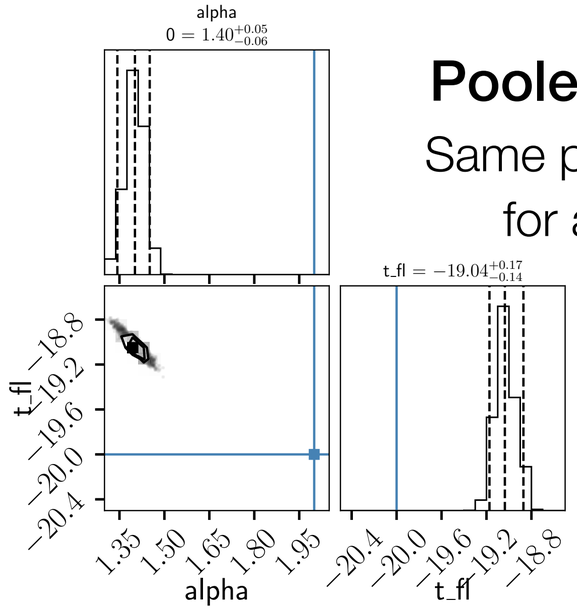
$$f_{\mathrm{obs},k}(t_j) = f_{0,k}(t - t_{\mathrm{exp}})^{\alpha_k}$$

- **Previous model:** fit each SN independently to infer α_k
- **Hierarchical model:** draw α_k from the same distribution controlled by hyper-parameters

Fit **ALL** SNe simultaneously!

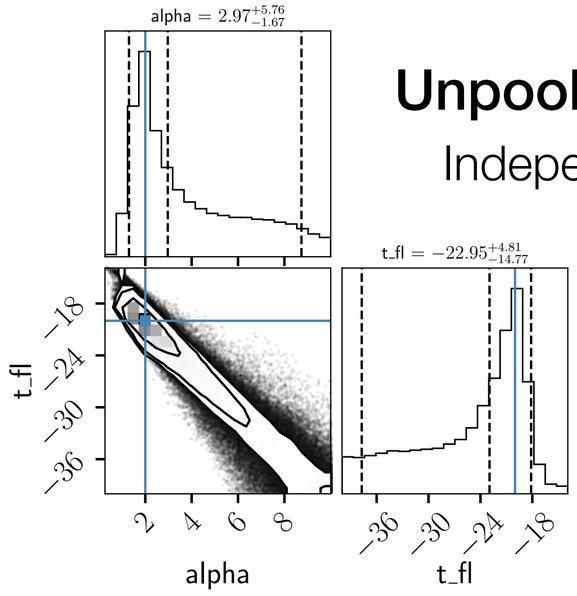


100 Synthetic Light Curves with: $\alpha_i \sim N(2, 0.1)$ $t_{\rm fl} \sim N(-20, 1)$



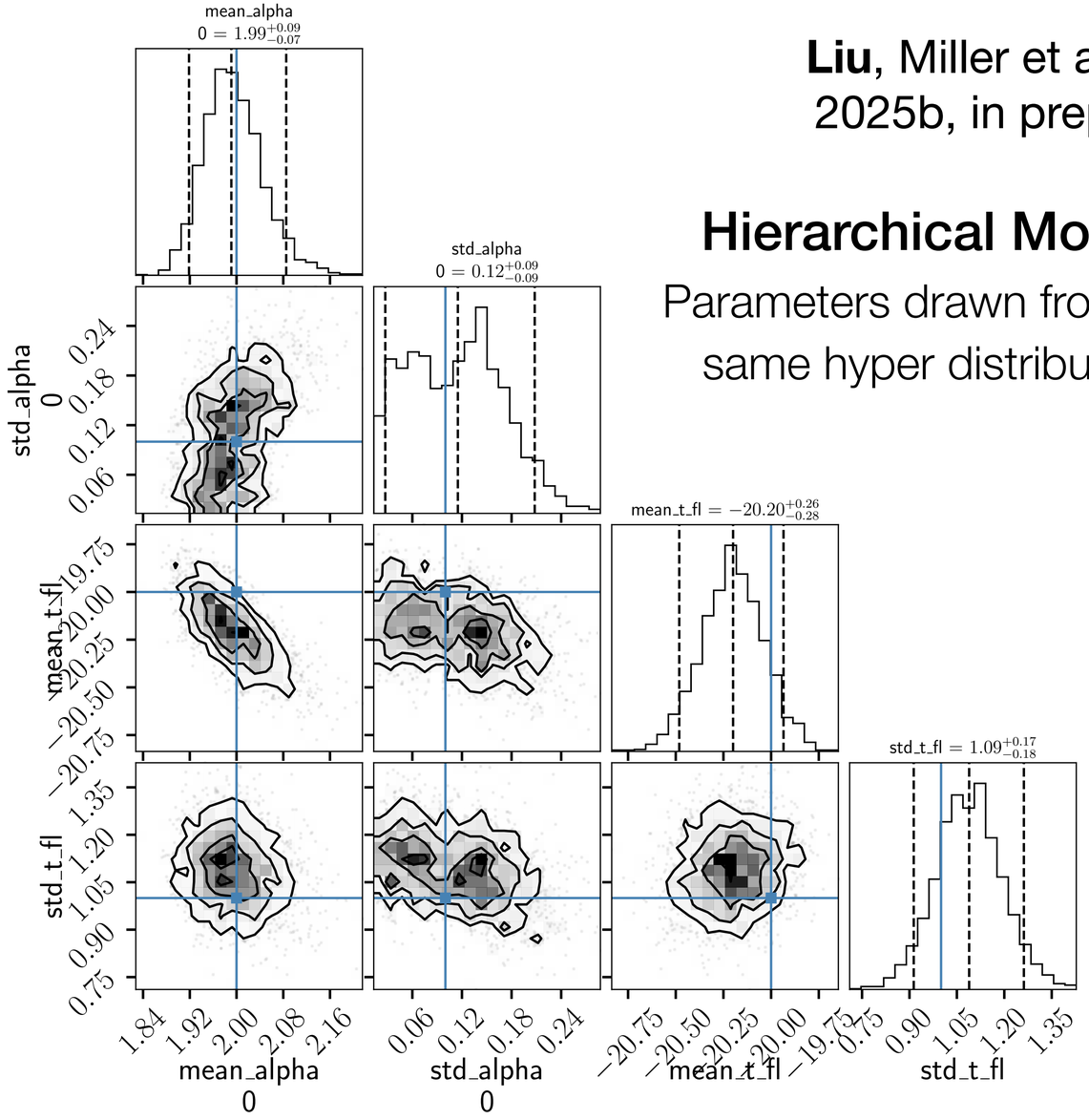
Pooled model

Same parameters for all SNe



Unpooled model

Independent fits



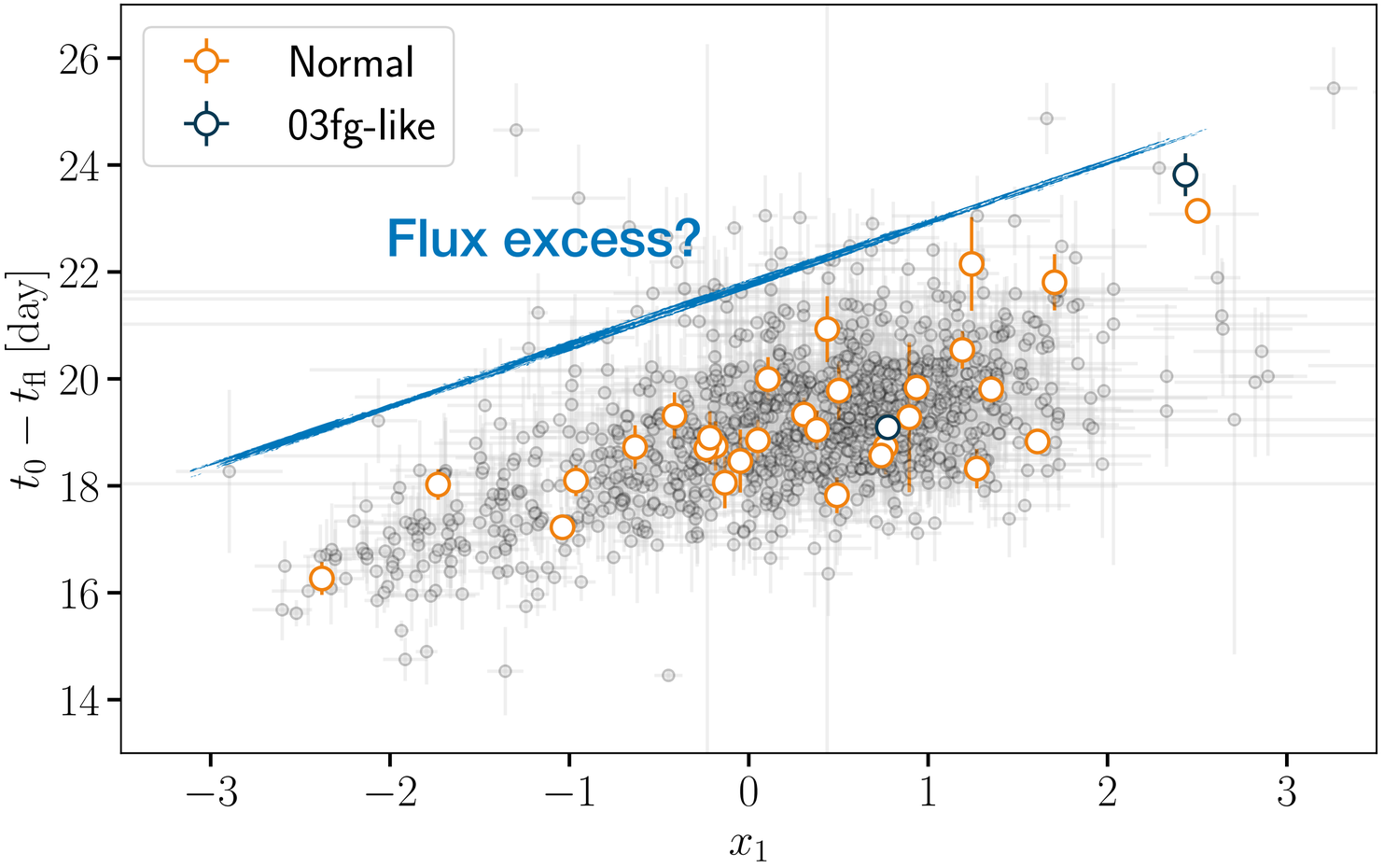
Liu, Miller et al., 2025b, in prep.

Hierarchical Model

Parameters drawn from the same hyper distribution

A Systematic Study on the Rise

~10³ SNe Ia from ZTF DR2 (Rigault et al. 2025)



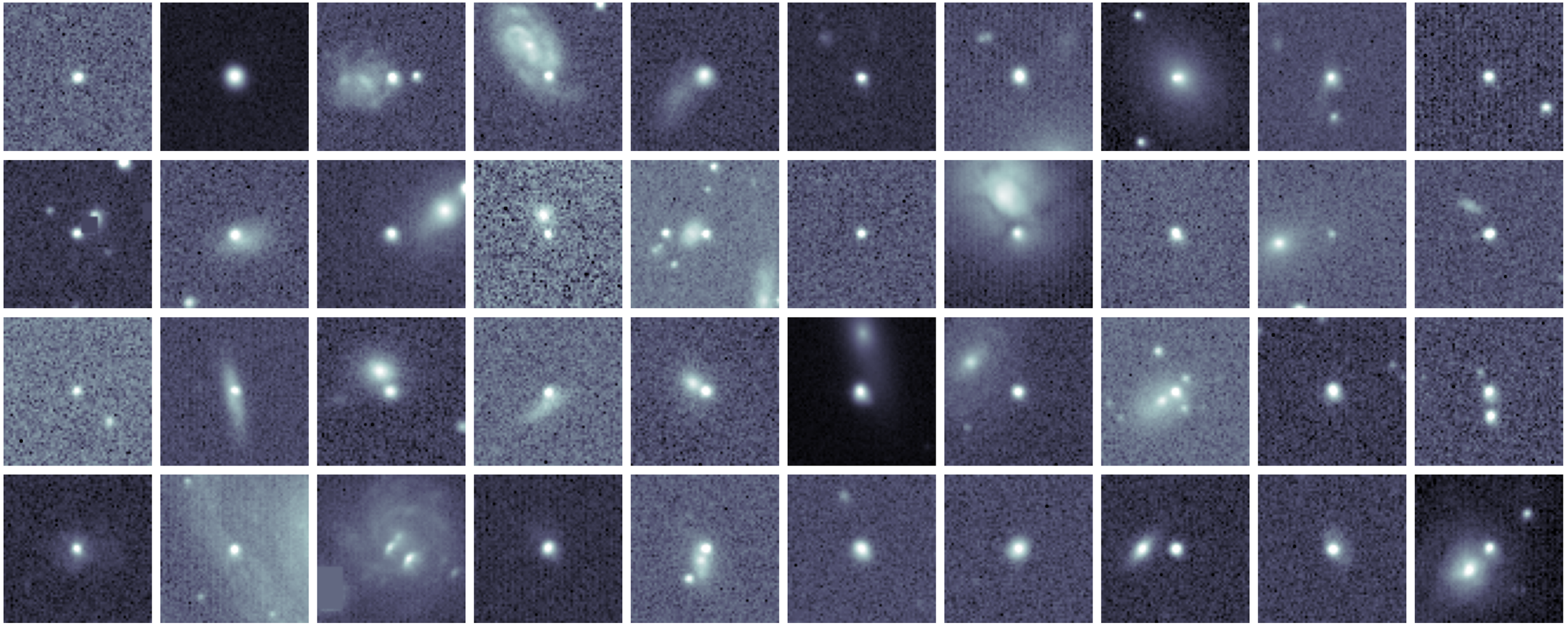
$$t_0 - t_{\rm fl}\ [\rm day] \sim \mathcal{N}(19.1 \pm 1.6)$$

$$\alpha_g \sim \mathcal{N}(2.28 \pm 0.36)$$

$$\alpha_r \sim \mathcal{N}(2.08 \pm 0.28)$$

ZTF Early-Late Ia Sample (2023-2024)

Significant host contamination in >50% of the targets



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HostSub_GP

Liu & Miller 2025 - on arXiv today!

Modeling the 2d spectrum of host galaxies with Gaussian process (GP) for better background subtraction in supernova spectroscopy.

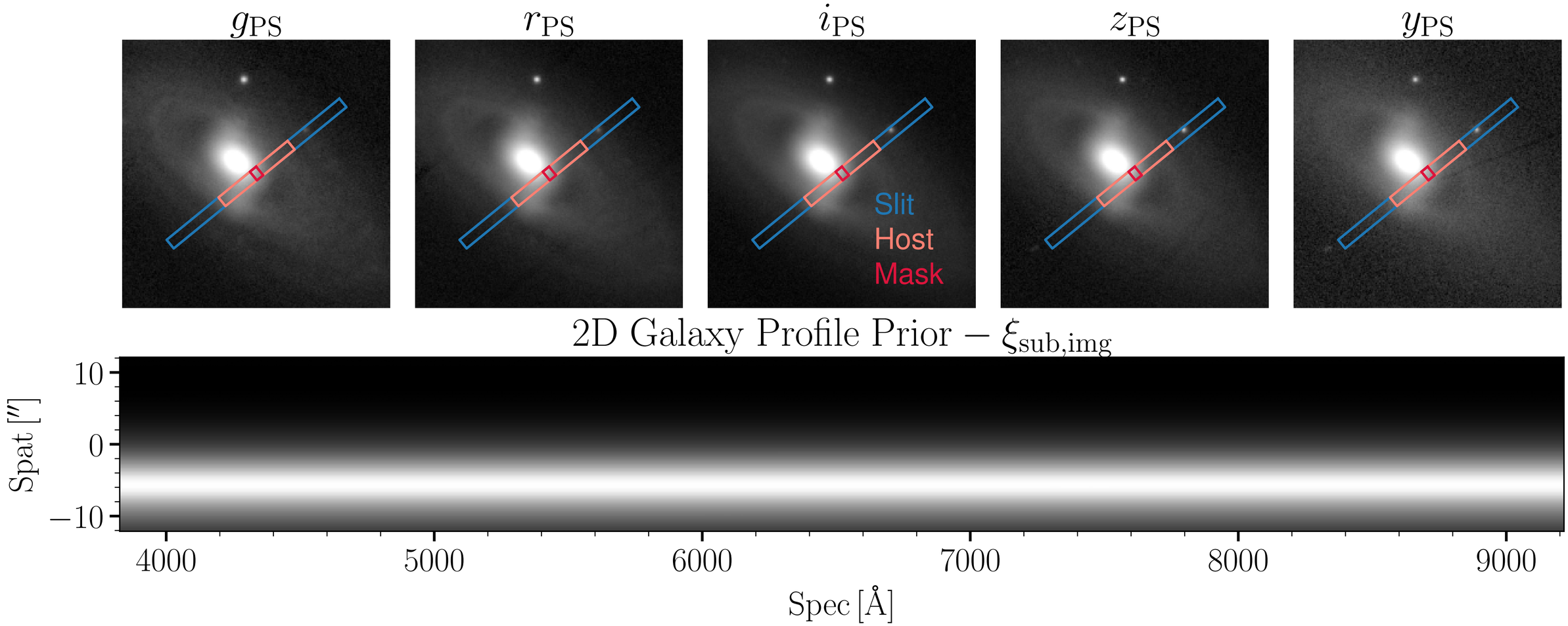
- Fully **Python** + available at GitHub
- Leveraging **archival imaging** as priors
- Accelerated by JAX: **Just-in-time** compilation + **automatic differentiation**

Robust galaxy background removal in a few minutes on your laptop!

HostSub_GP Pipeline

Building the prior - normalized 2D profiles

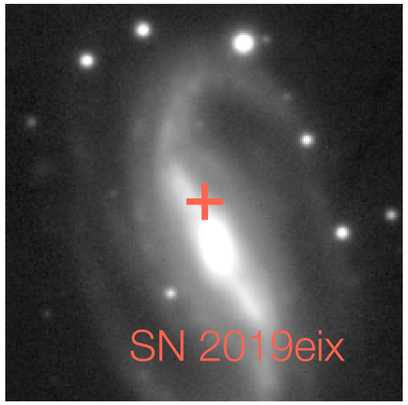
Liu & Miller 2025



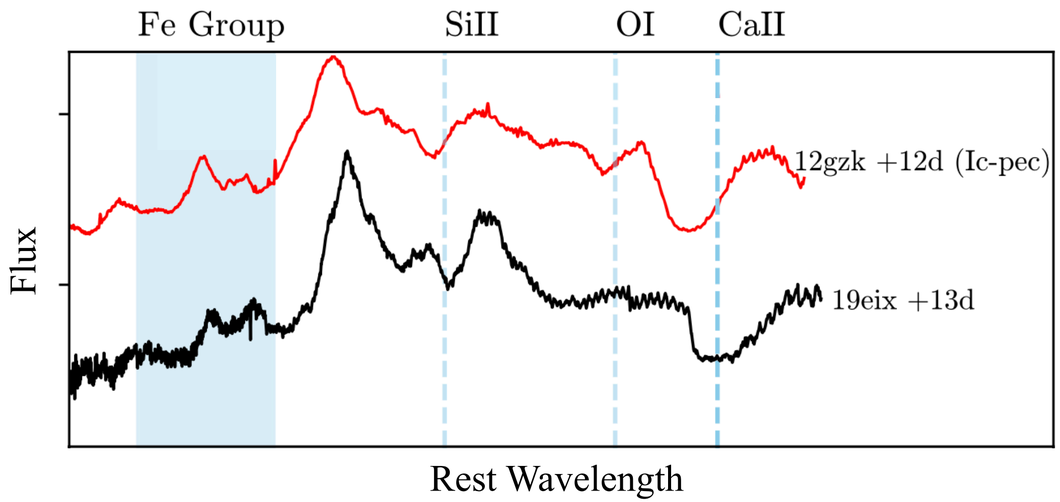
HostSub_GP Pipeline

Revisiting SN 2019eix — peculiar Ia or Ic?

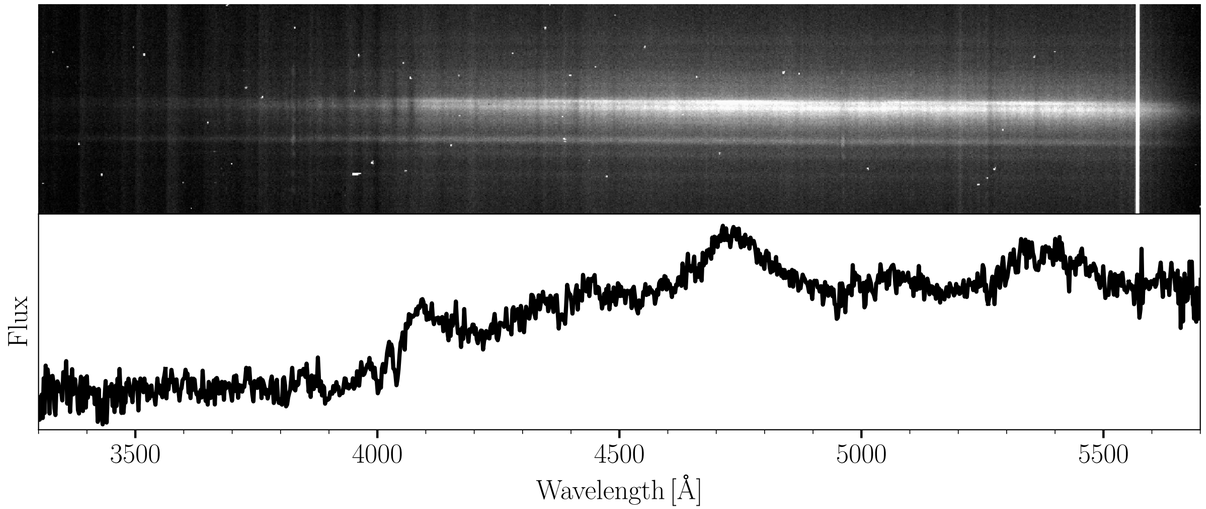
Photospheric phase
Resembling both double-detonation Ia and some Ic/Ic-BL



Nebular phase
Host galaxy subtraction is extremely challenging



Padilla Gonzalez et al., 2023

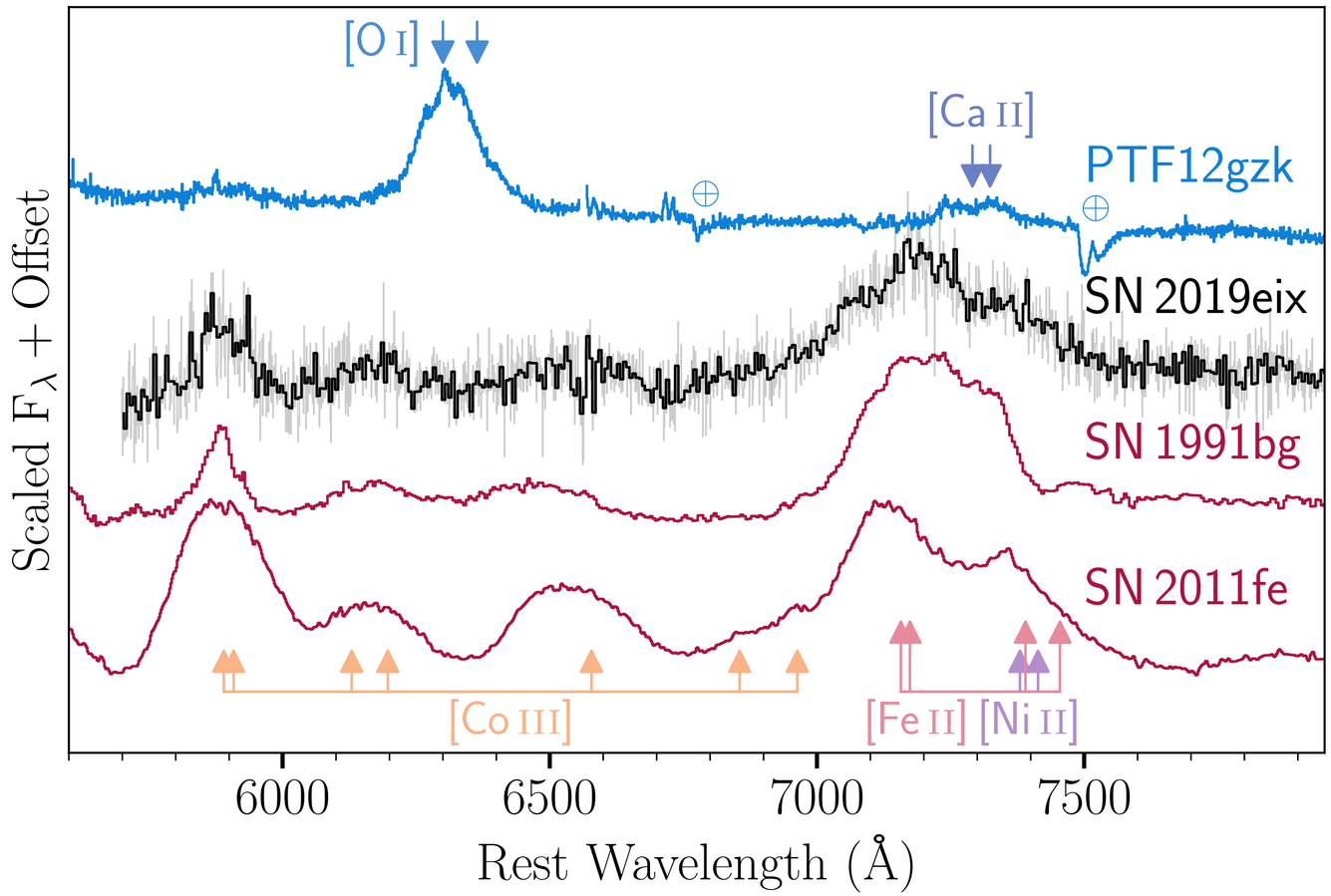


PI: Fremling

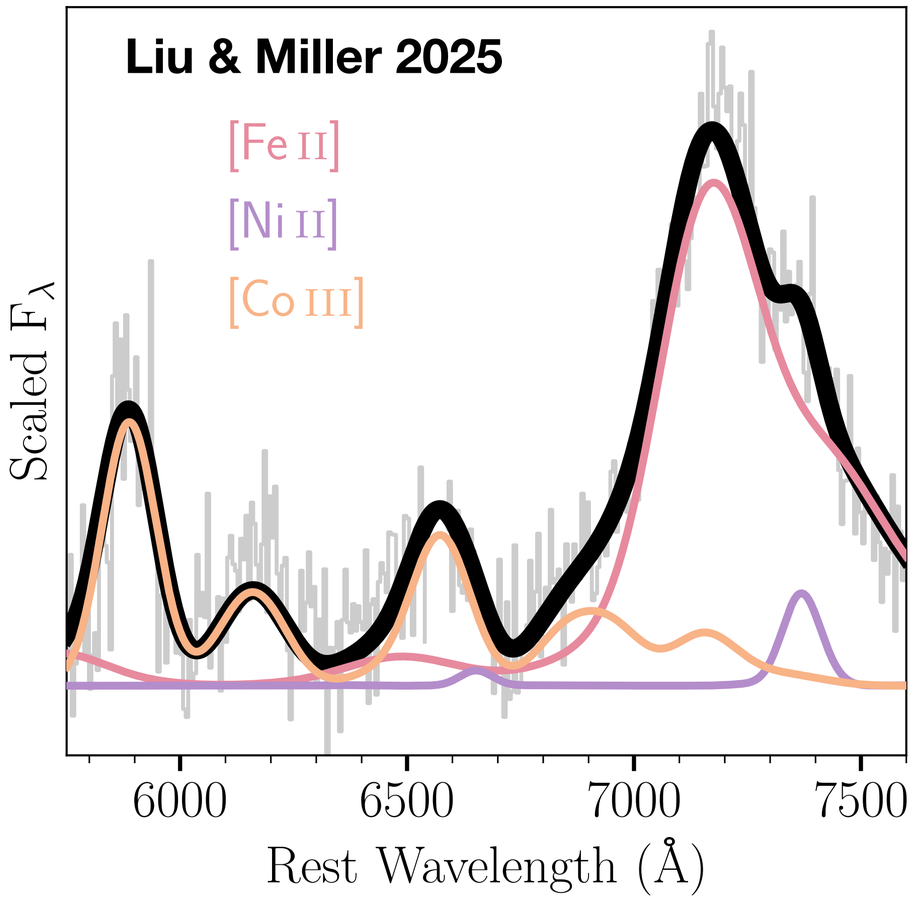
HostSub_GP Pipeline

Revisiting SN 2019eix — double-detonation Ia!

Strong Fe, Ni, Co, no [O I]

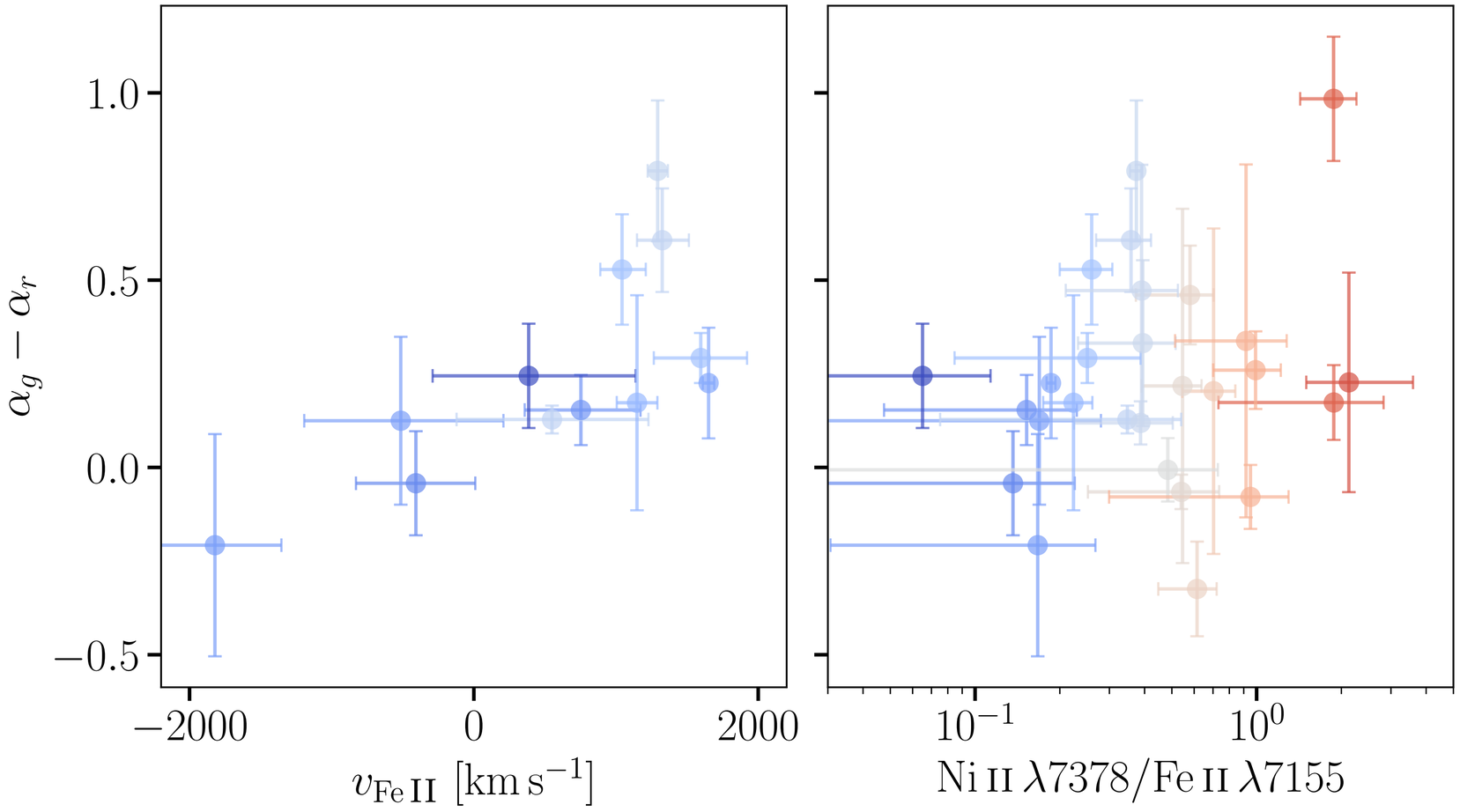


$n_{\mathrm{Ni\,II}}/n_{\mathrm{Fe\,II}} \simeq 0.5\%$



Early v.s. Late

Color evolution v.s. Fe core velocity



Key Takeaways

Still Far from Fully Understanding Ia Progenitors, but…

- **DO NOT** ignore rare weirdos!
- **DO NOT** fit early rises individually!
- **DO NOT** exclude host contaminated SNe from your sample!
- **Do** analyze early and late-time observables jointly!