NASA, ESA, and A. Riess (STScI/JHU); SH0ES Team

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FIRST IMPRESSIONS

EARLY SN CLASSIFICATION WITH HOST INFORMATION AND SHALLOW LEARNING

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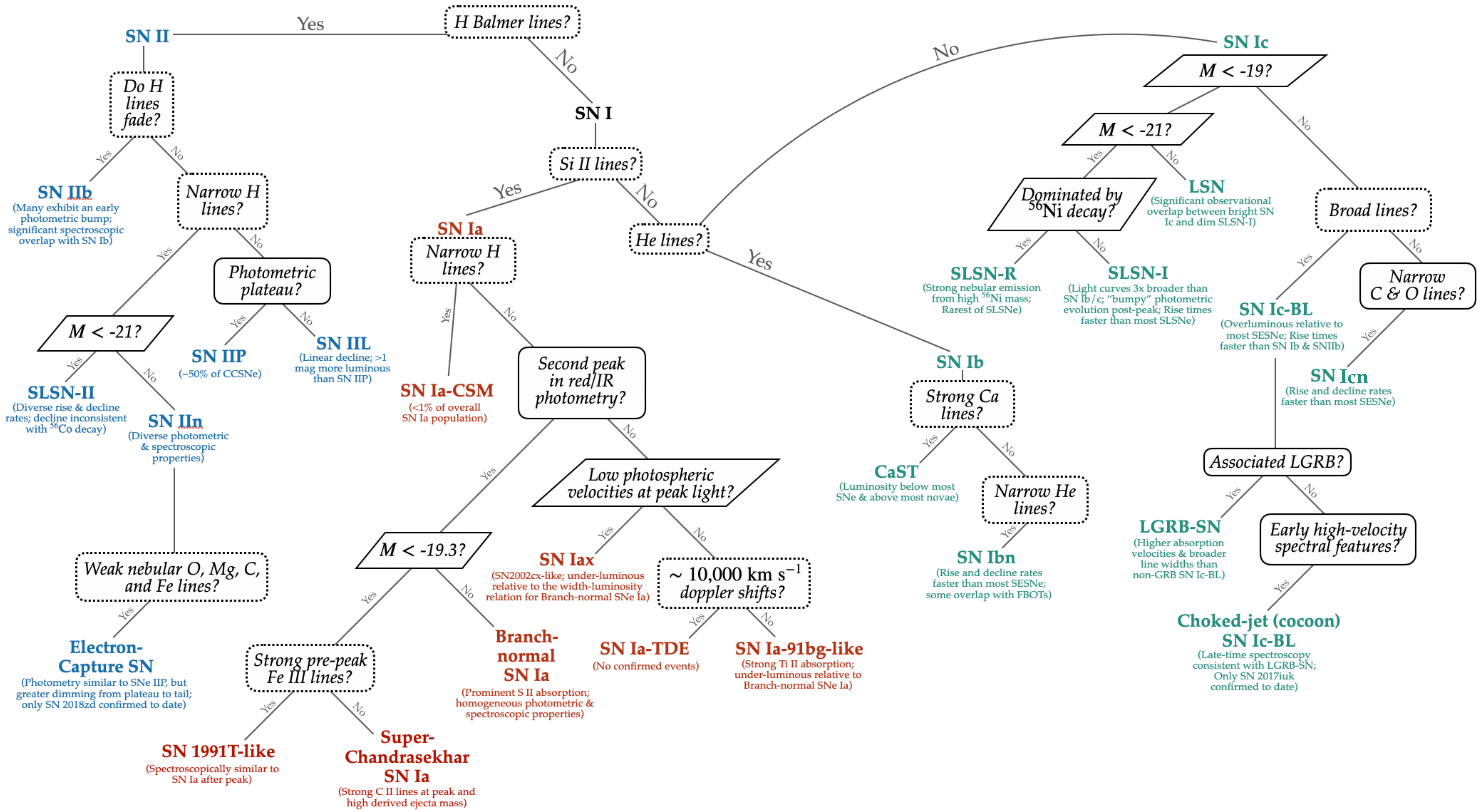
Taxonomy of Terminal Transients



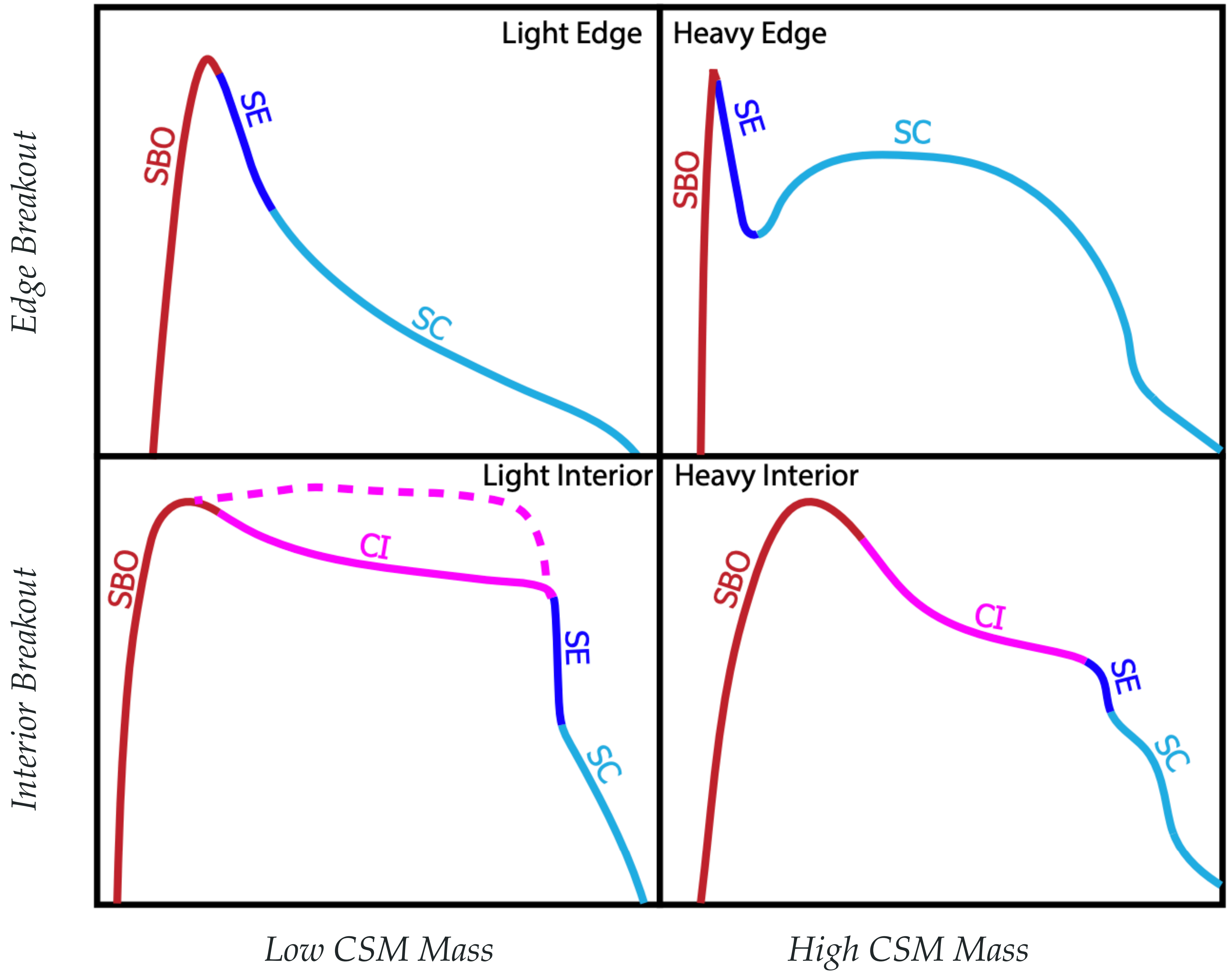
SQUEEZING BLOOD FROM A STONE

The Vera C. Rubin Observatory (2025-2035) will discover 3-4 million SNe among 18,000 deg^2, breaking exponential scaling for the first time.

Rubin median inter-night gap, Wide-Fast-Deep, rolling cadence:

- 24.96 days in *u*
- 22.93 days in *g*
- 6.92 days in *r*
- 7.93 days in *i*
- 8.03 days in *z*
- 13.96 days in *y*

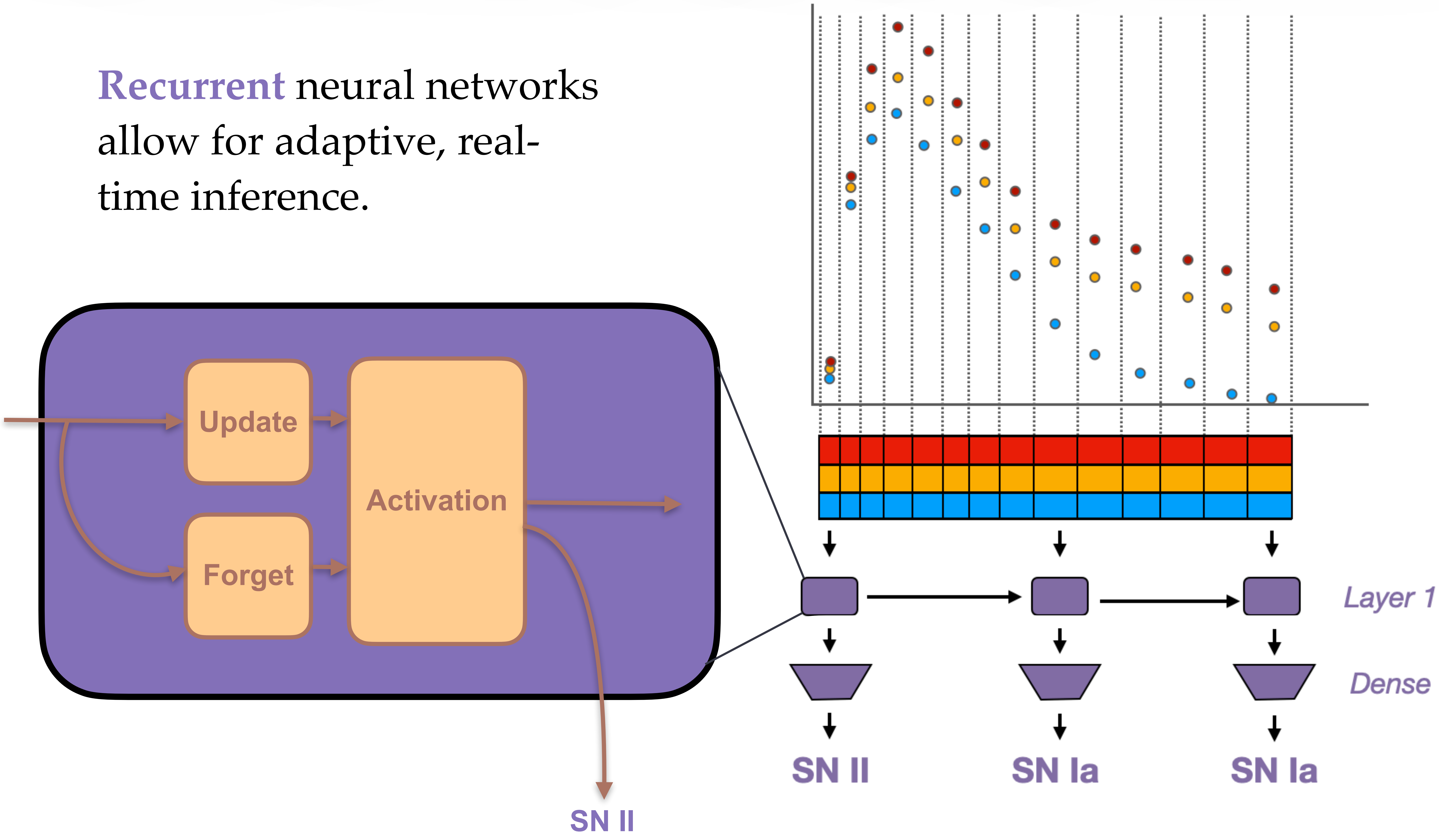
Khatami & Kasen, 2023



SN characterization now pushes *far* beyond classification to timescales of ~hours and wavelengths across the EM spectrum.

Neural Networks for Real-Time Classification

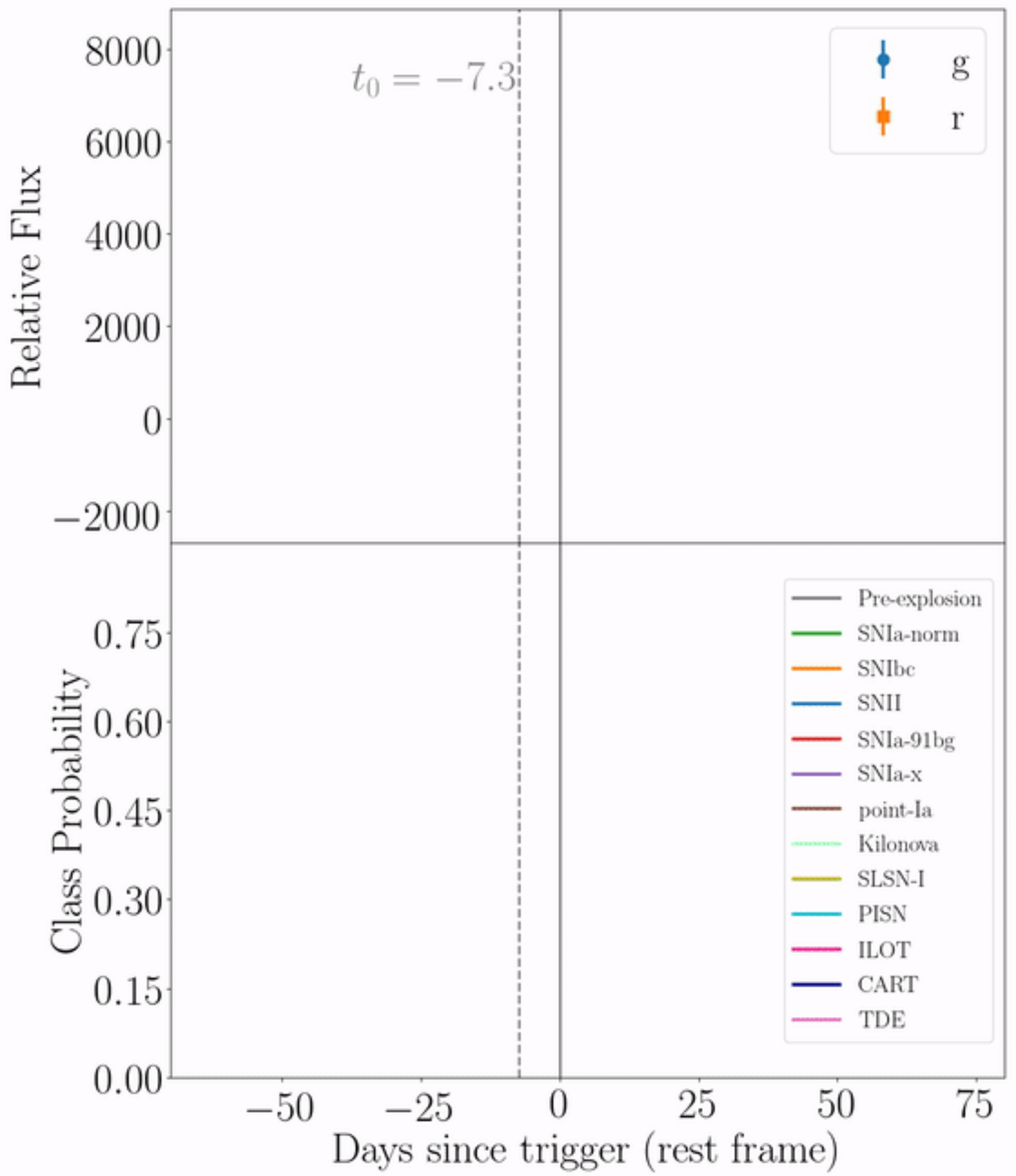
Recurrent neural networks allow for adaptive, real-time inference.



Obstacles to Rubin-Era Processing

1. **Ensuring classification performance on *observed* partial-phase supernovae.**

Performance has been validated on simulated samples from the Photometric LSST Astronomical Time-Series Classification Challenge (e.g., *Muthukrishna+2019; Möller+2019; Qu+2021*).



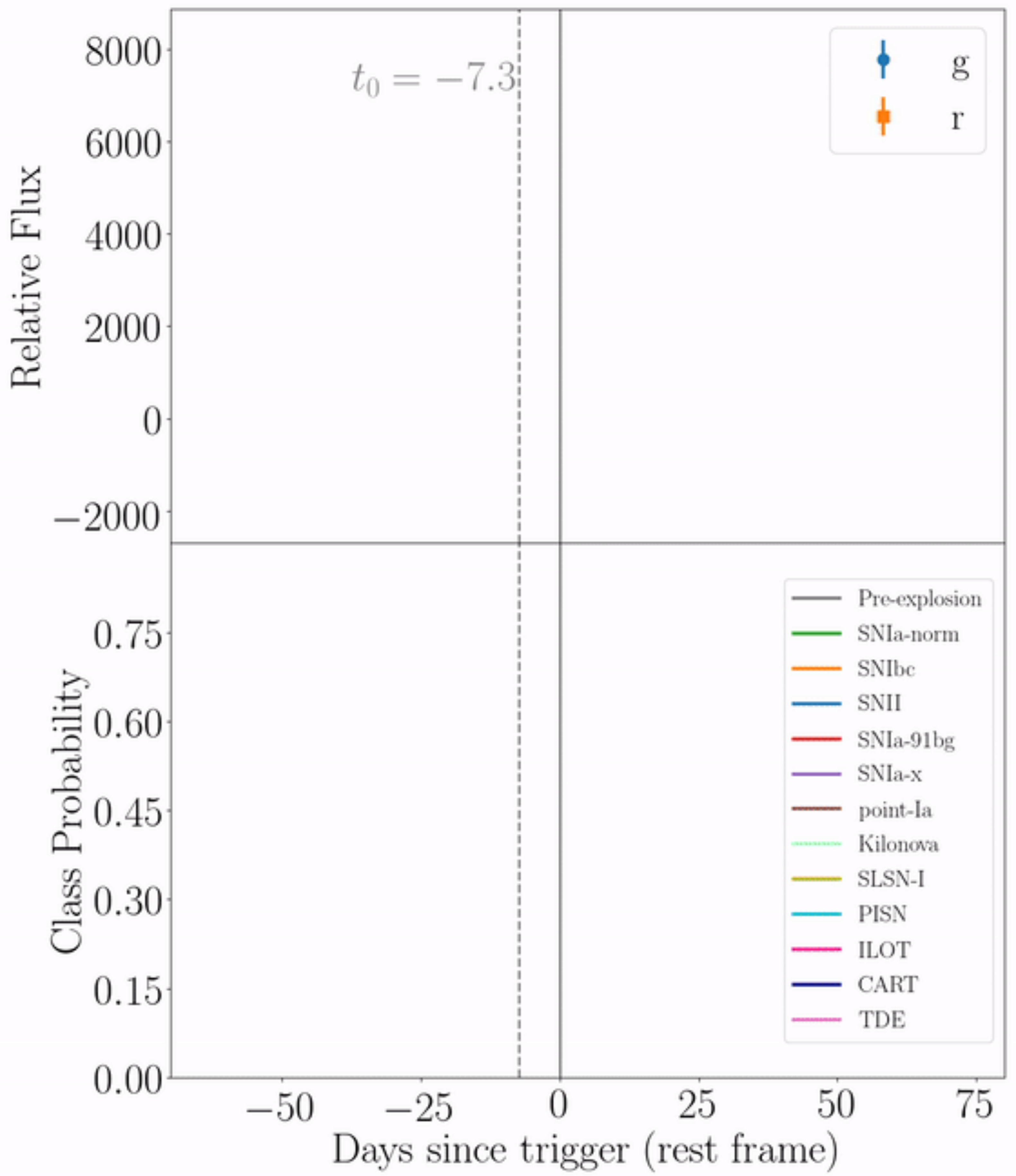
Muthukrishna+2019

OBSTACLES TO RUBIN-ERA PROCESSING

1. **Ensuring classification performance on *observed* partial-phase supernovae.**

2. **Scaling to 10 million alerts per night.**

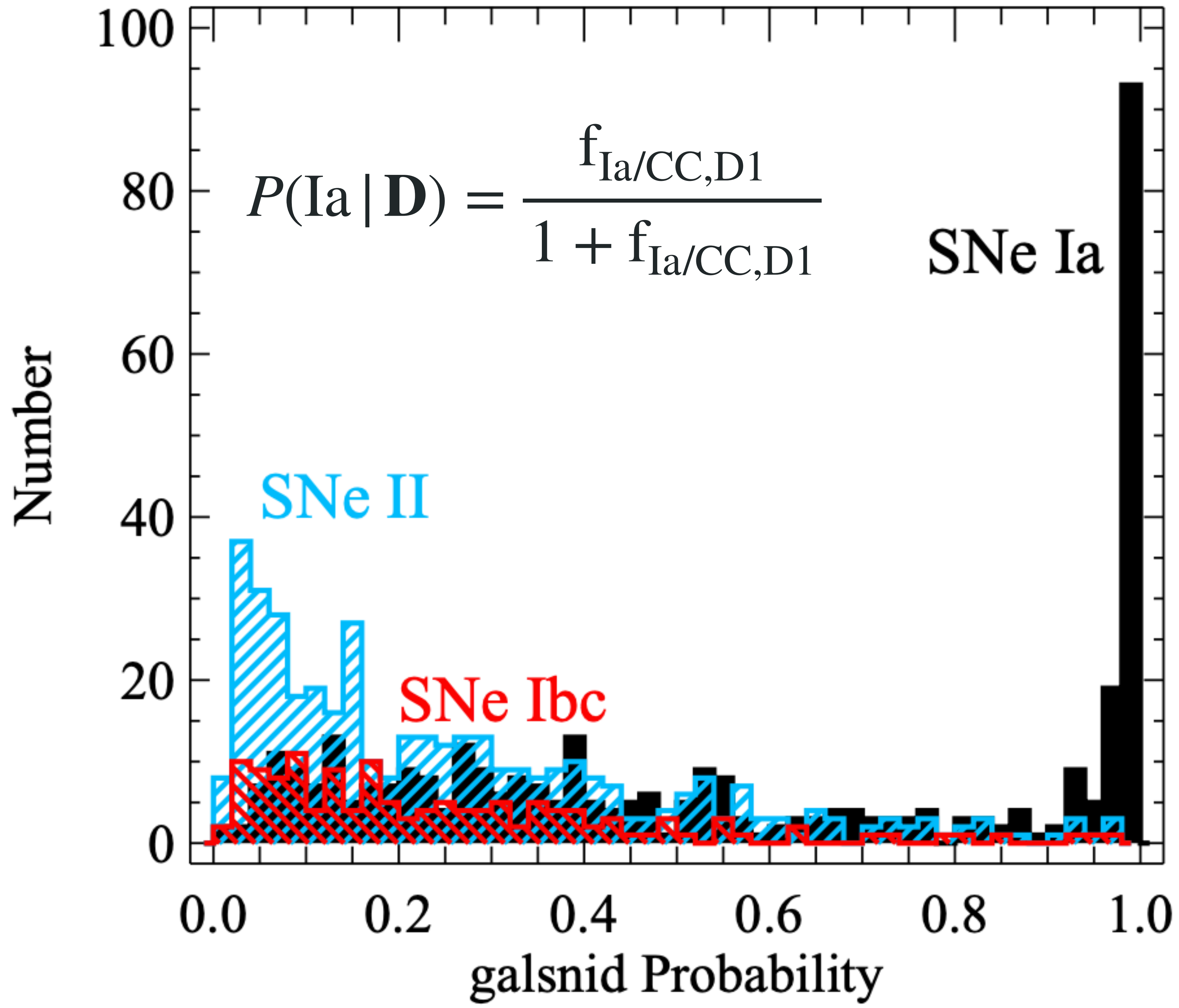
A significant computational bottleneck is simply loading the model into memory (*Allam Jr., 2023*).



Muthukrishna+2019

Ensuring Classifications without Supernova Photometry

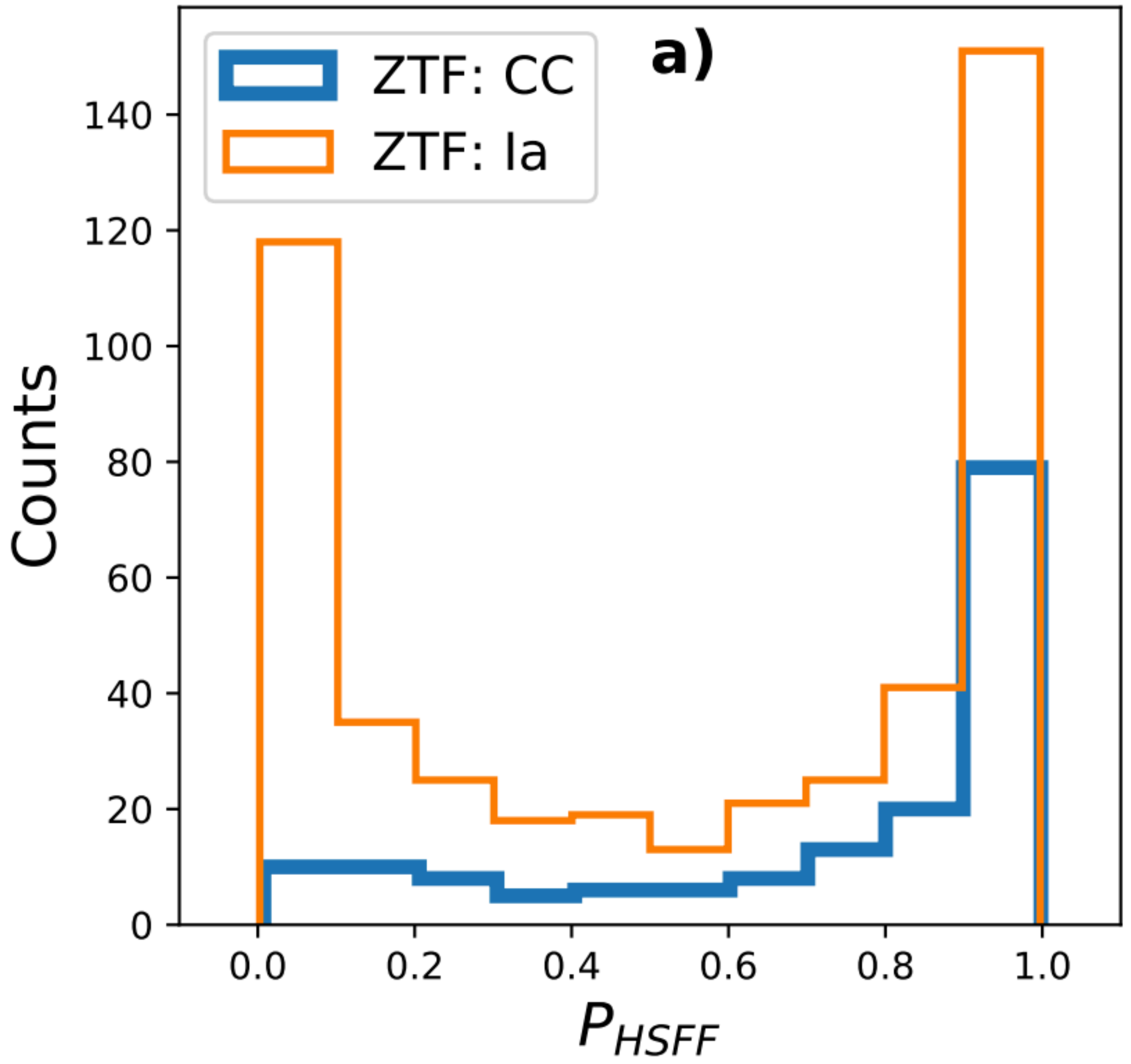
SN Ia probability as odds ratio over host galaxy morphology, color, luminosity, and offset.



Cutting on $p > 0.97$ increases the FoM, which balances efficiency and weighted purity, by a factor of ~2.

(Mandel & Foley, 2013)

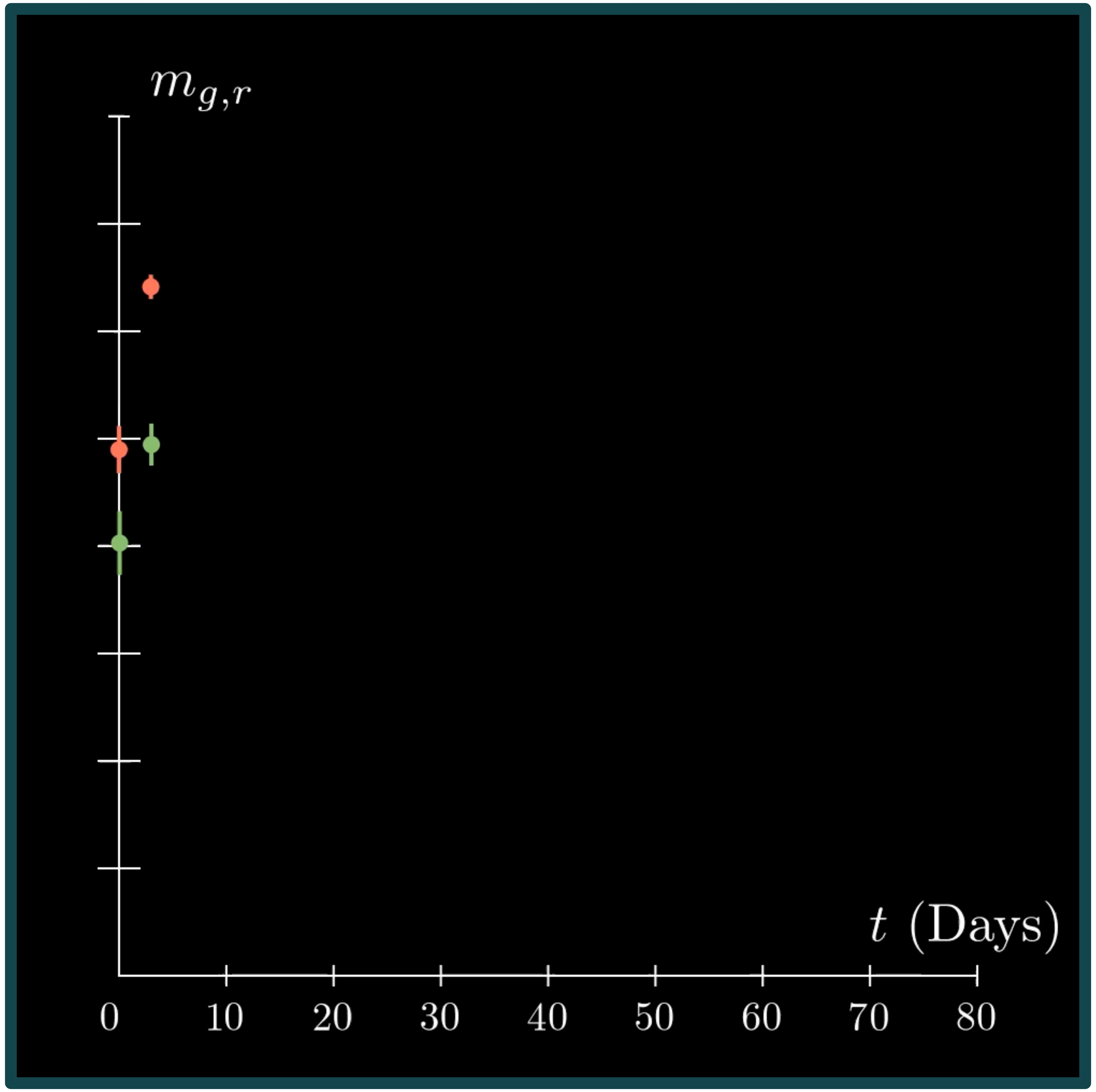
Random-forest model trained to classify hosts as highly star-forming (within 0.3 Gyr) or not.



Cutting on predicted star-formation fraction ($P_{HSFF} < 0.1$) decreases SN II contamination by ~20%.

(Baldeschi+2020)

Combining Early SN+Host Photometry: The "First Impressions" Classifier



Improvements over prior methods:

1. *Gaussian process regression of partial-phase photometry*
2. *Lightweight model architecture for rapid re-training & evaluation - 10% of RAPID (Muthukrishna+2019), 75% of SCONE (Qu+2021)*
3. *Use of contextual information (host-galaxy photometry)*

How do we generate large samples of realistic contextual information for training?

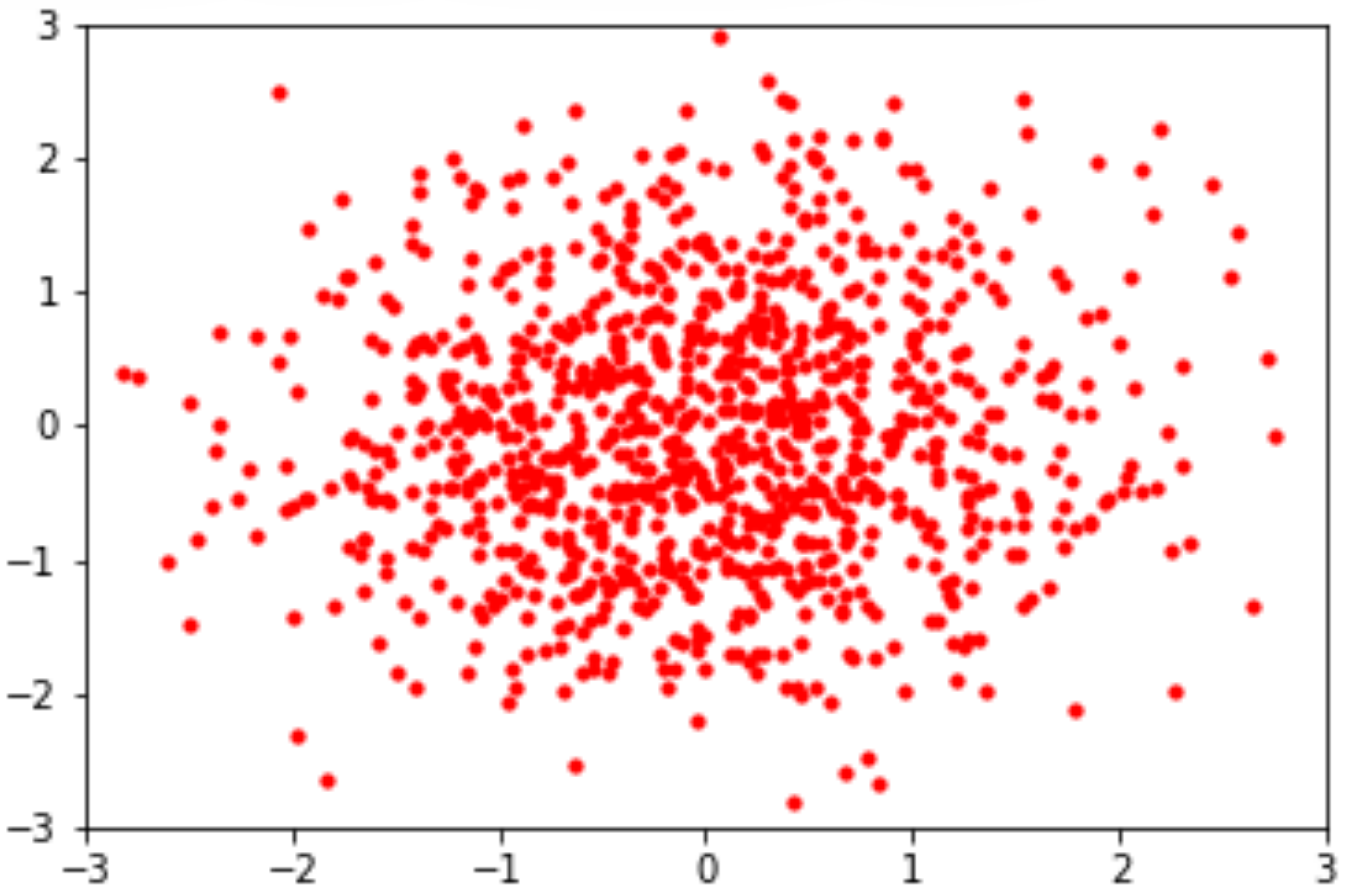
Host-Galaxy Photometry From Normalizing Flows

We want to sample from a multivariate distribution p(x), but don't know how.

Instead, we can approximate *p(x)* as an ***invertible*** function *g* applied to a simple latent distribution (e.g., a Gaussian).

$$u \sim N(0, I) \qquad x = g(u)$$

Then, we can sample from *p(x)* by drawing samples *u* and applying *g*.



Normalizing Flows, Eric Jang

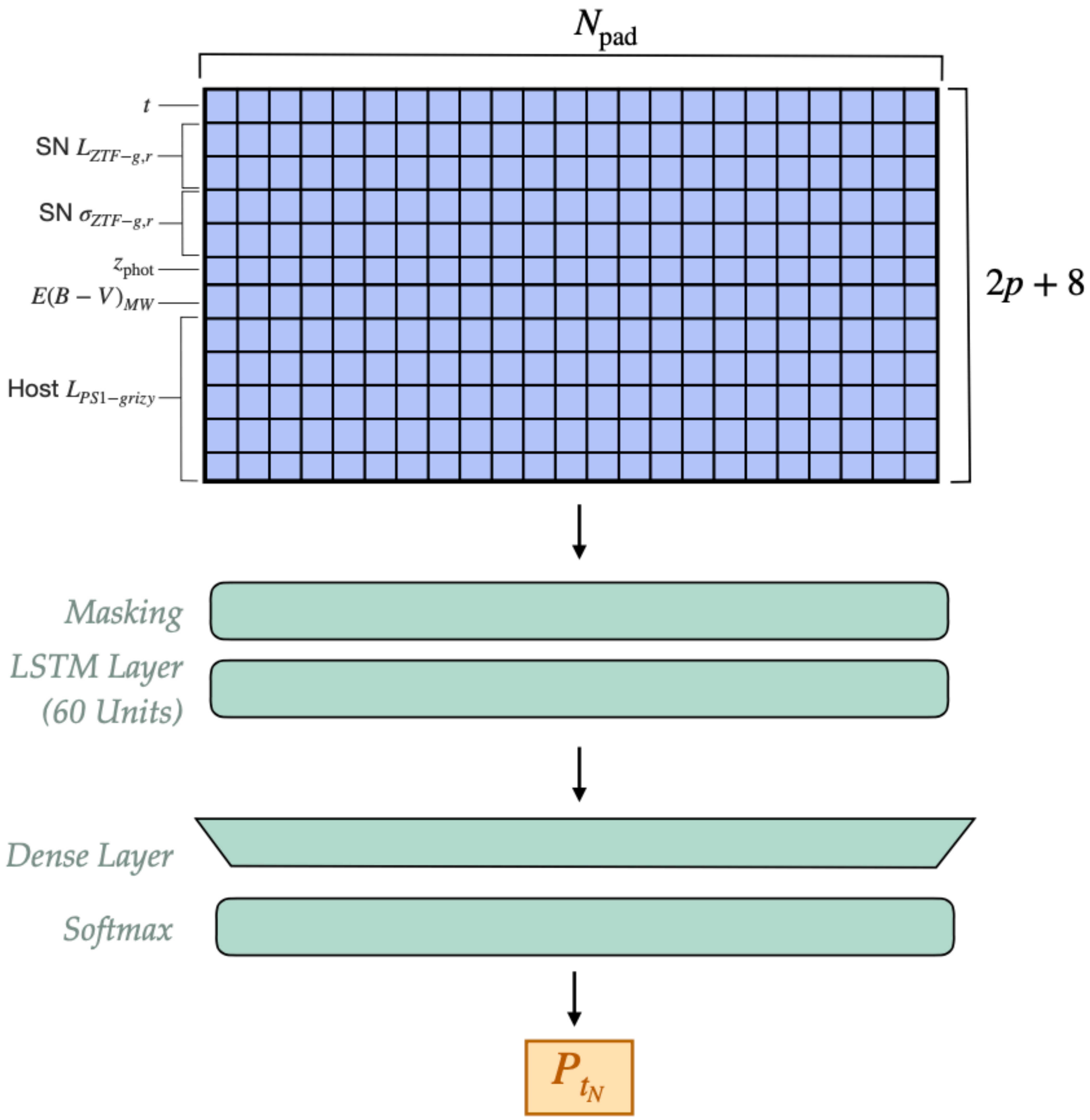
Generating Host-Galaxy Photometry with Conditional Flows

If g is invertible, we can also estimate probability densities for our observations x:

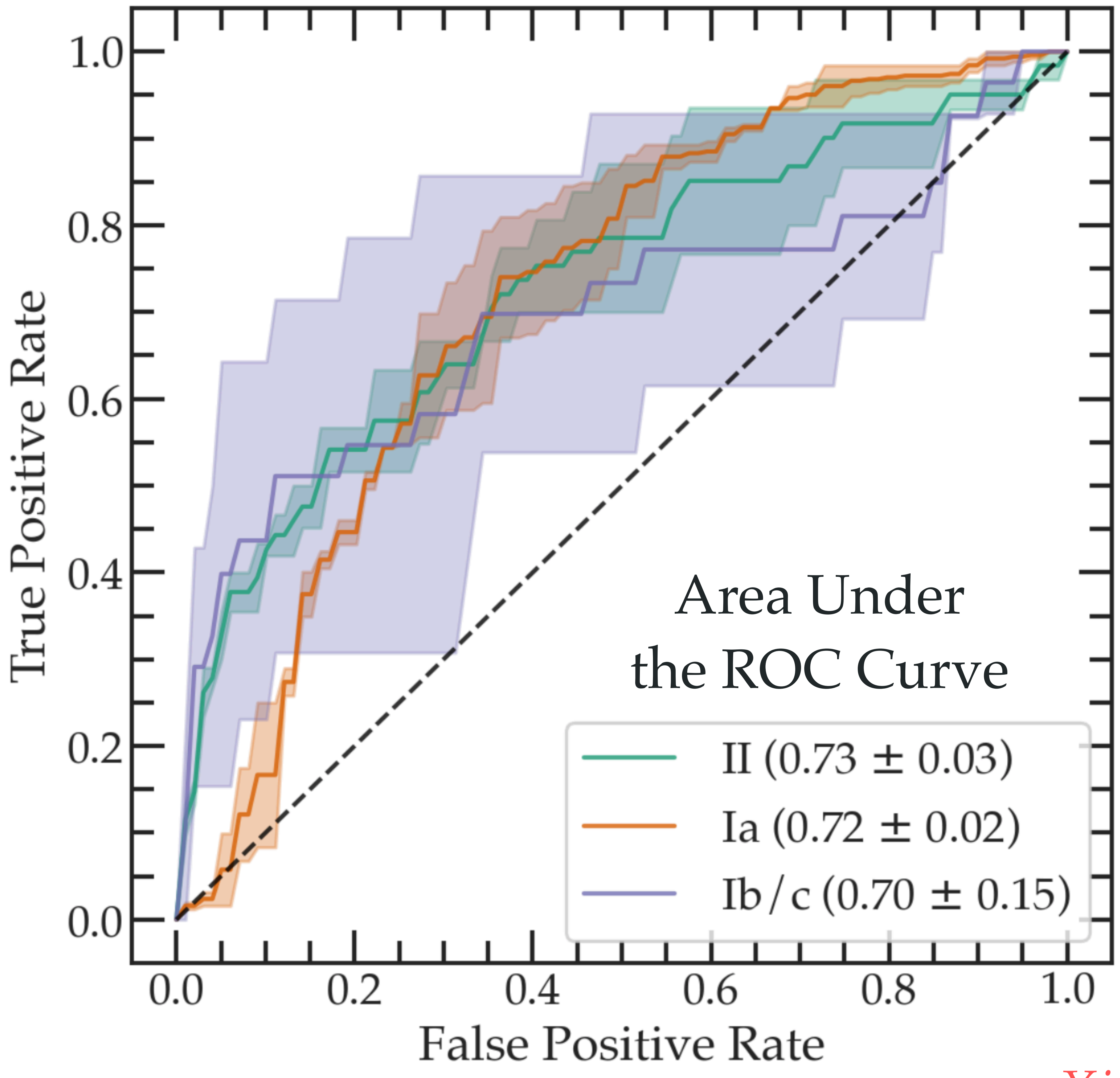
$$p(x) = N(g^{-1}(x), I)\ |\det(dg^{-1}/dx)|$$

The invertibility of p allows us to train conditional flows: $p(x\,|\,y)$

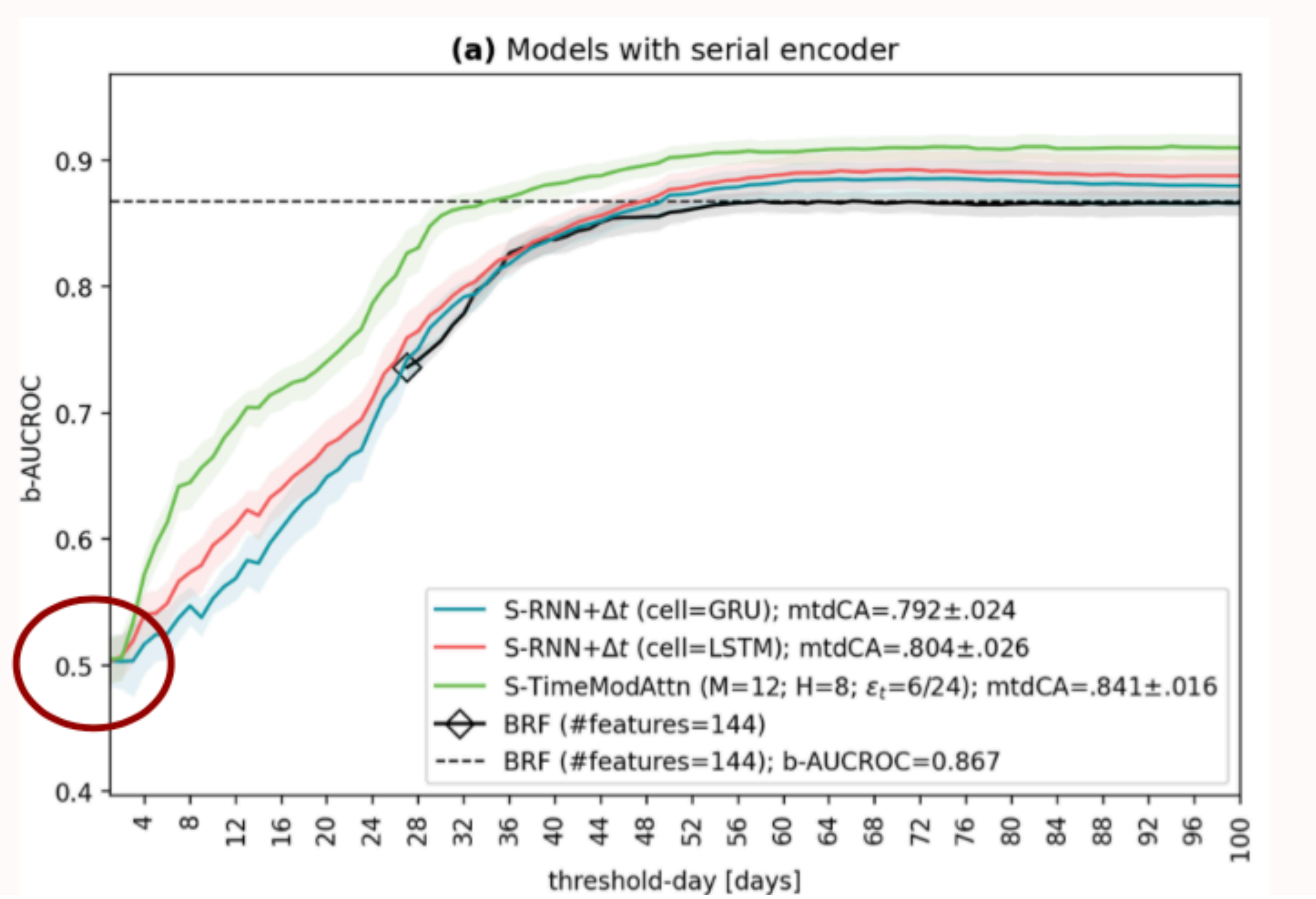
Here, we train and sample from $p(grizy_{\mathrm{Host}}, z_{\mathrm{phot}}\,|\,z_{\mathrm{spec}})$.



Day 3 Performance: ZTF BTS
(Fremling+2020, Perley+2020)



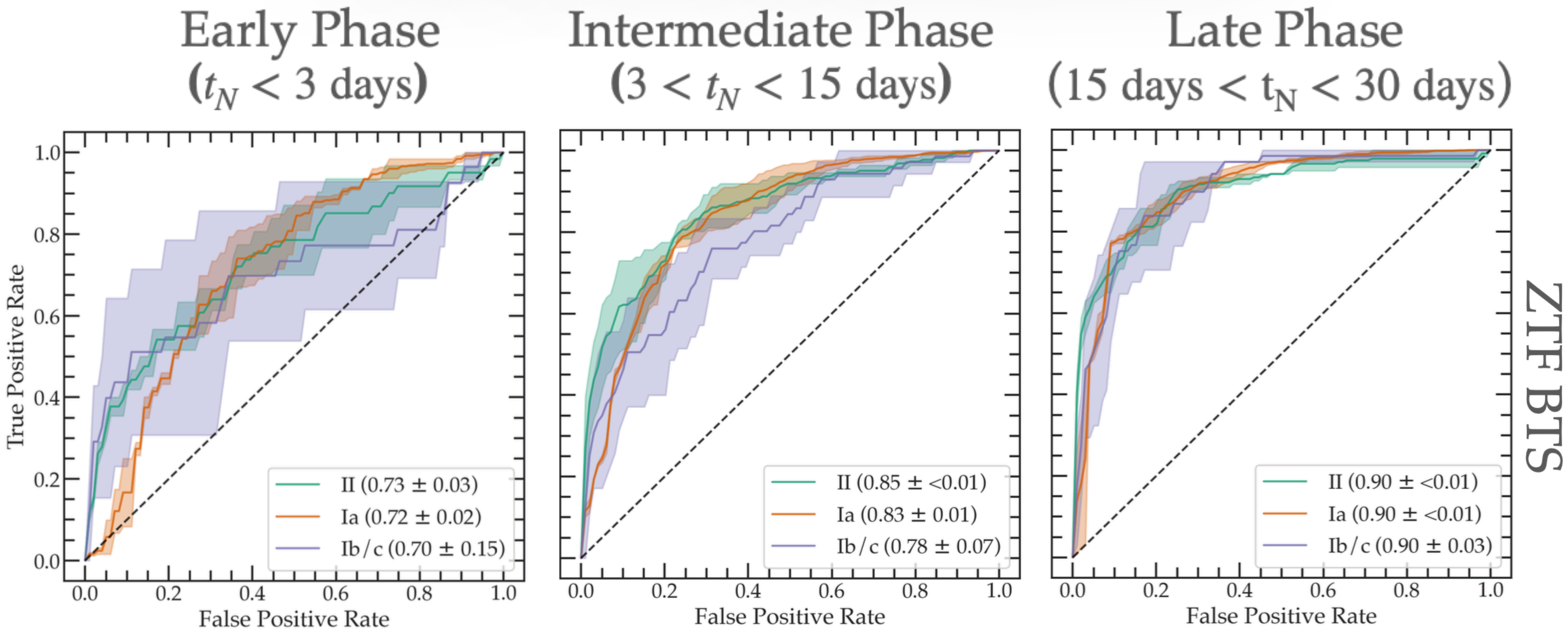
We achieve 82% accuracy and 72% AUROC *within 3 days of discovery*, from ZTF photometry with a ~2 day cadence.



(*Pimentel+2022*)

arXiv:2305.08894

Late-Phase Performance



arXiv:2305.08894

Performance suggests a later focus on light-curve information - attention networks could confirm!

Framework easily extended to classes with stronger host-galaxy correlations (e.g., TDEs, SLSNe-I).

Validation of Model Architecture and Training

Model	b-AUROC	b-AUPRC	b-Precision	b-Recall	b-F_1 Score	Accuracy
Baseline	0.74 ± 0.04	0.52 ± 0.07	0.58 ± 0.13	0.46 ± 0.09	0.48 ± 0.11	0.82 ± 0.02
No Host	0.72 ± 0.08	0.48 ± 0.09	0.48 ± 0.12	0.41 ± 0.09	0.40 ± 0.08	0.78 ± 0.02
No Primary Training	0.71 ± 0.04	0.45 ± 0.02	0.40 ± 0.18	0.34 ± < 0.01	0.30 ± 0.01	0.81 ± < 0.01
No Adaptive Training	0.65 ± 0.03	0.43 ± 0.02	0.41 ± 0.02	0.39 ± 0.05	0.39 ± 0.03	0.66 ± 0.02

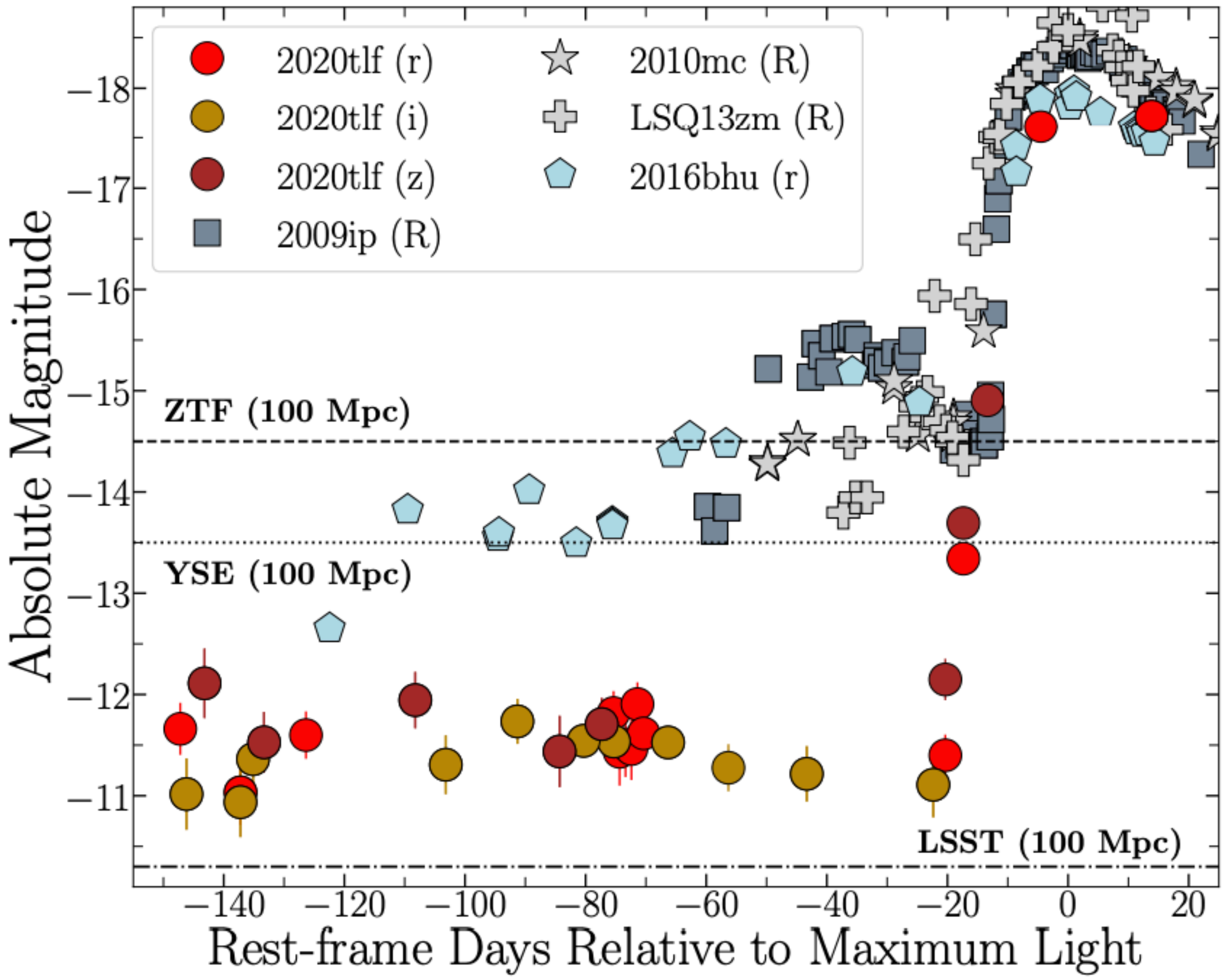
Host-galaxy photometry, balanced training, *and* re-training on real data improves every classification metric.

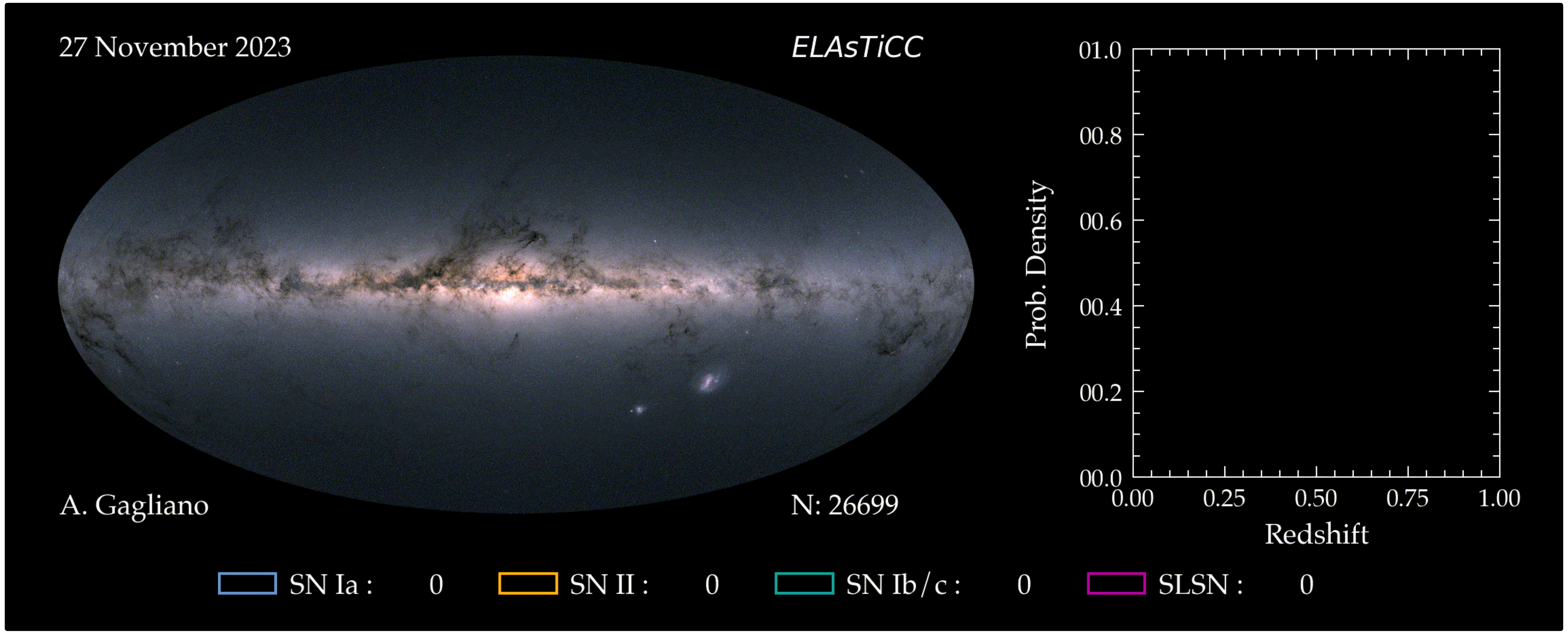
(Mandel & Foley, 2013)

	Exclusively Using Observable		
Observable	Peak FoM	Improvement Factor	Difference in Medians
Baseline[a]	0.121	N/A	N/A
Using All Galaxy Data[b]	0.269	2.23	0.34
Morphology	0.262	2.18	0.15
Color	0.128	1.06	0.10
Luminosity	0.135	1.12	0.07
Effective Offset	0.122	1.02	0.03
Pixel Rank	0.123	1.02	0.00

Incorporating (even small) postage stamps will further improve performance.

Proactive Supernova classification with Rubin





(Jacobson-Galán+2022)

Deep, precise photometry with LSST will enable **broad pre-explosion variability studies**, further revolutionizing our transient taxonomy.

Drivers for Supernova Science with Rubin

(TVS Roadmap, Hambleton+2022; Data to Software to Science, Breivik+2022; DESC Science Overview, 2023)

1. **In-Depth Studies of Fast Phenomena**
2. **Refined Progenitor Theories**
3. **Expanding the Supernova Classification Schema**
4. **Understanding Transient-Host Galaxy Correlations**

These demand:

- *Automation of the Discovery and Analysis Chain*
- *Accurate Identification of Host Galaxies*
- *Realistic Precursor Datasets*

Simple, context-aware models bring us closer to realizing these goals.

CONCLUSIONS

- **Contextual information can aid early Ia/Ibc/II classification** (~20% higher AUROC in the first three days than similar approaches), but models should be adaptive to new data *(Gagliano+2023, arXiv:2305.08894)*.

- Transfer learning allows networks to accommodate increased complexity of real data and observed SN demographics.

- Simple, scalable inference models will be essential for both population-level and single-object studies of Rubin supernovae. **We should validate them now.**