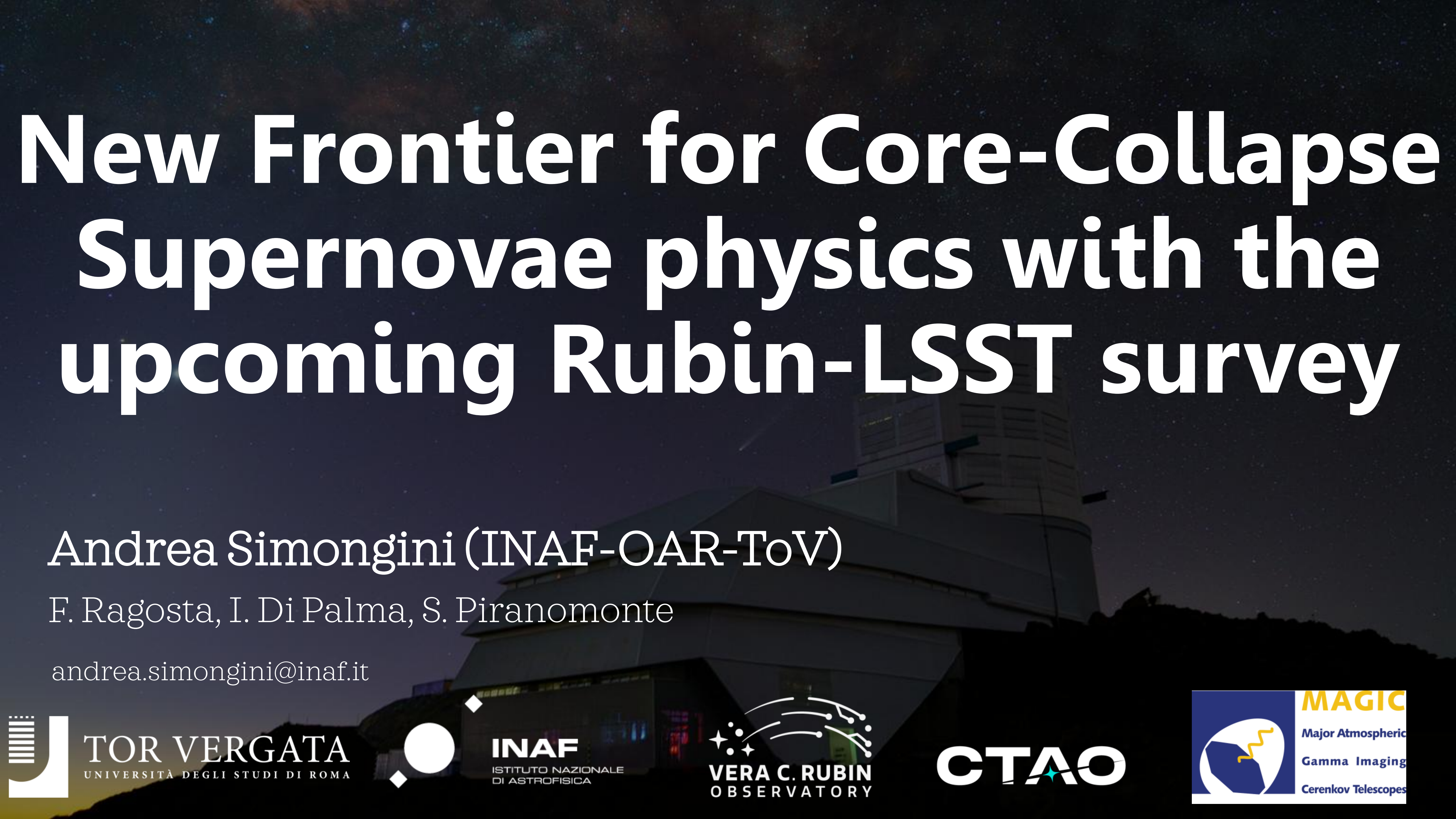

New Frontier for Core-Collapse Supernovae physics with the upcoming Rubin-LSST survey

Andrea Simongini (INAF-OAR-ToV)

F. Ragosta, I. Di Palma, S. Piranomonte

andrea.simongini@inaf.it

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

INAF
ISTITUTO NAZIONALE
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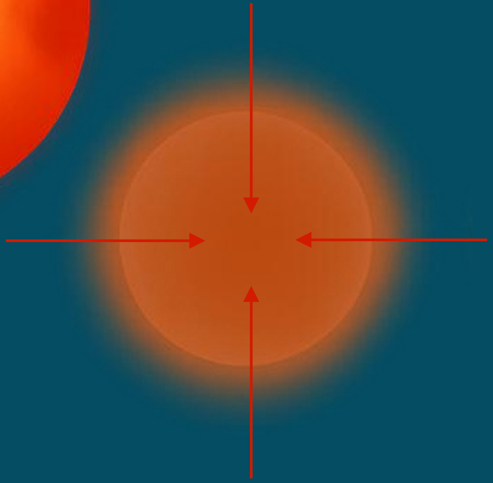
MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

HOW STARS DIE.

Credits: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA

Aftermath of explosive stellar deaths

Massive stars end their life as core-collapse supernovae



Gravitational instability occurs when the nuclear fusion in the nucleus stops.

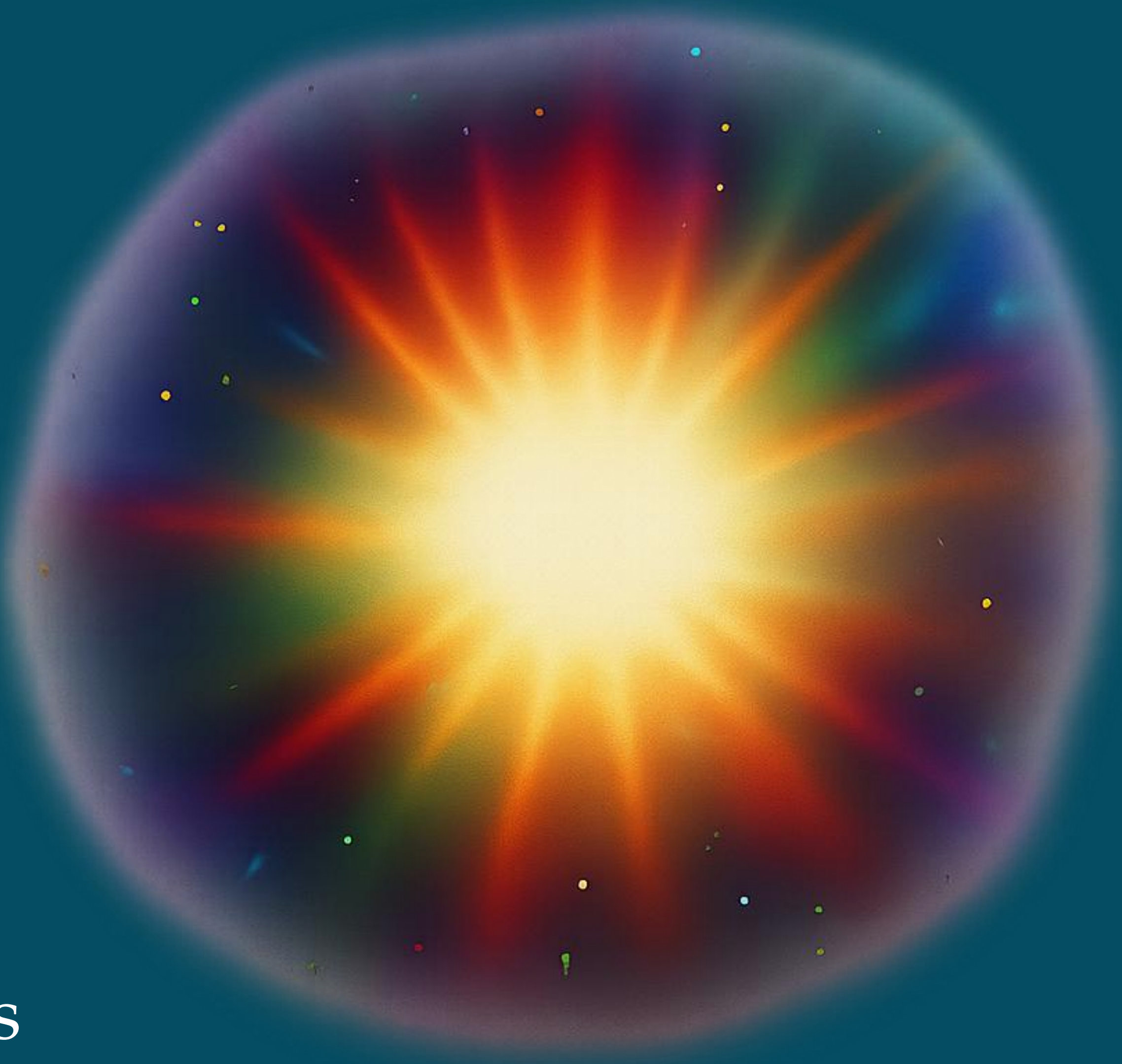
The star starts to collapse…

And collapse…

Until it reaches a critical density (NS)

Aftermath of explosive stellar deaths

What follows is the strongest explosion in the Universe

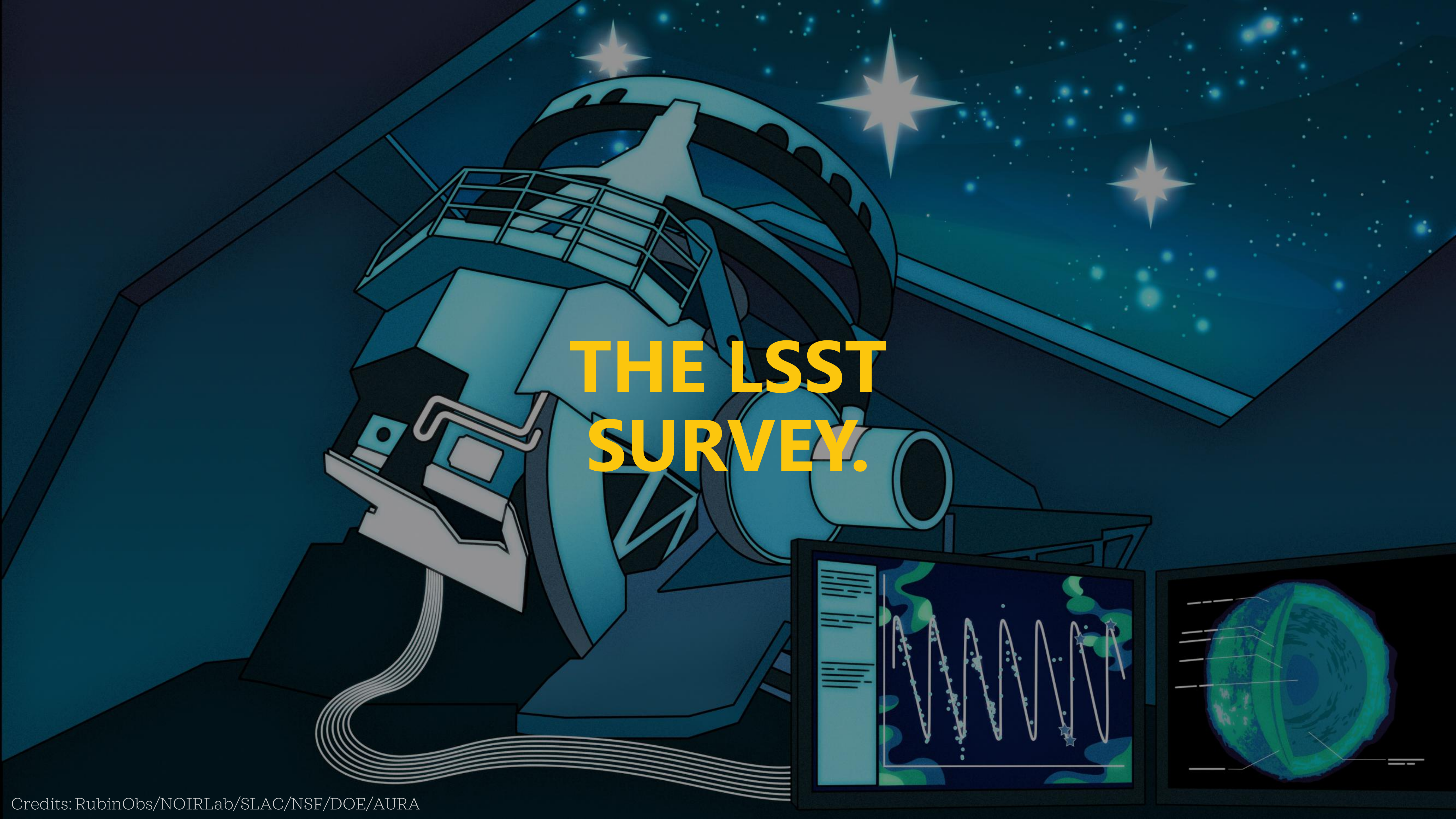


Matter and light are emitted at relativistic speeds

Multimessenger: photons, neutrinos and GW (?)

Multiwavelength: from radio to X, maybe gammas

THE LSST SURVEY.



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The greatest movie of all time

Starting late 2025, the LSST survey of the Vera Rubin Observatory:

- 10 years of data
- 18000 deg2 region
- 32 trillion observations
- 20 billion galaxies
- 6 filters (ugrizy)
- r ~ 27.5 mag

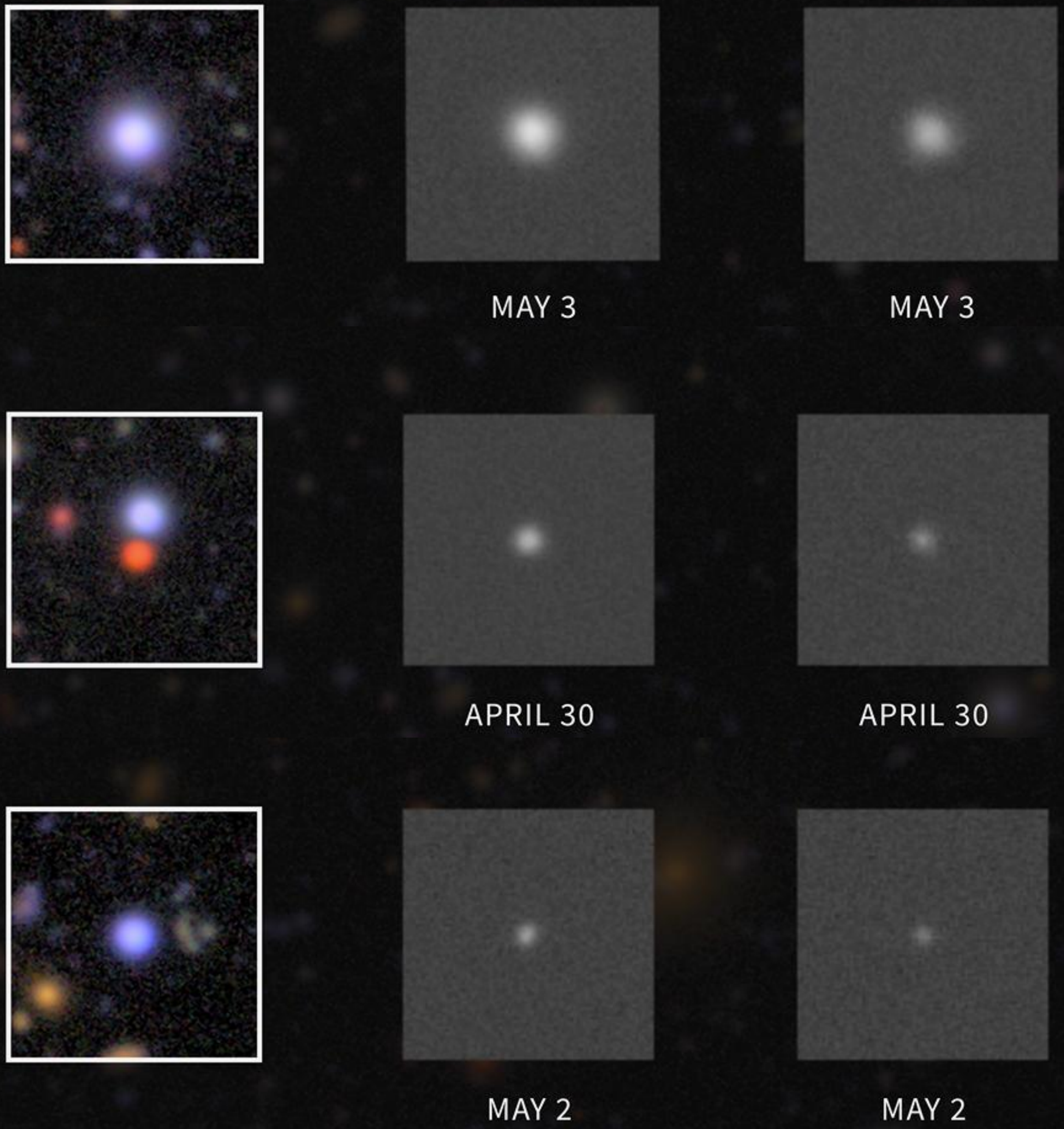
*Credits: Ivezic et al. 2019

LSST + Supernovae*

- 10 million SNe detected during 10 years of operation.
- 14 thousands objects in high detail
- Unprecedented opportunity to characterize progenitors of known and peculiar SNe

*Credits: Ivezic et al. 2019

Variable stars



Our work

- Address the possible limits and systematics of CCSNe parameters estimation using only LSST simulated light curves.

- Example of SN characterization on a sample of II-P

- Analysis of 6730 simulations with the software CASTOR.

OUR WORK.

Data

- Simulations of LSST light curves of SNe*.
- 3D distribution (redshift, reddening, cadence)
- Filters: magnitude limit of the instrument and saturation.
- Interpolation of data (leaving gaps).

*Credits: Moriya et al. 2023

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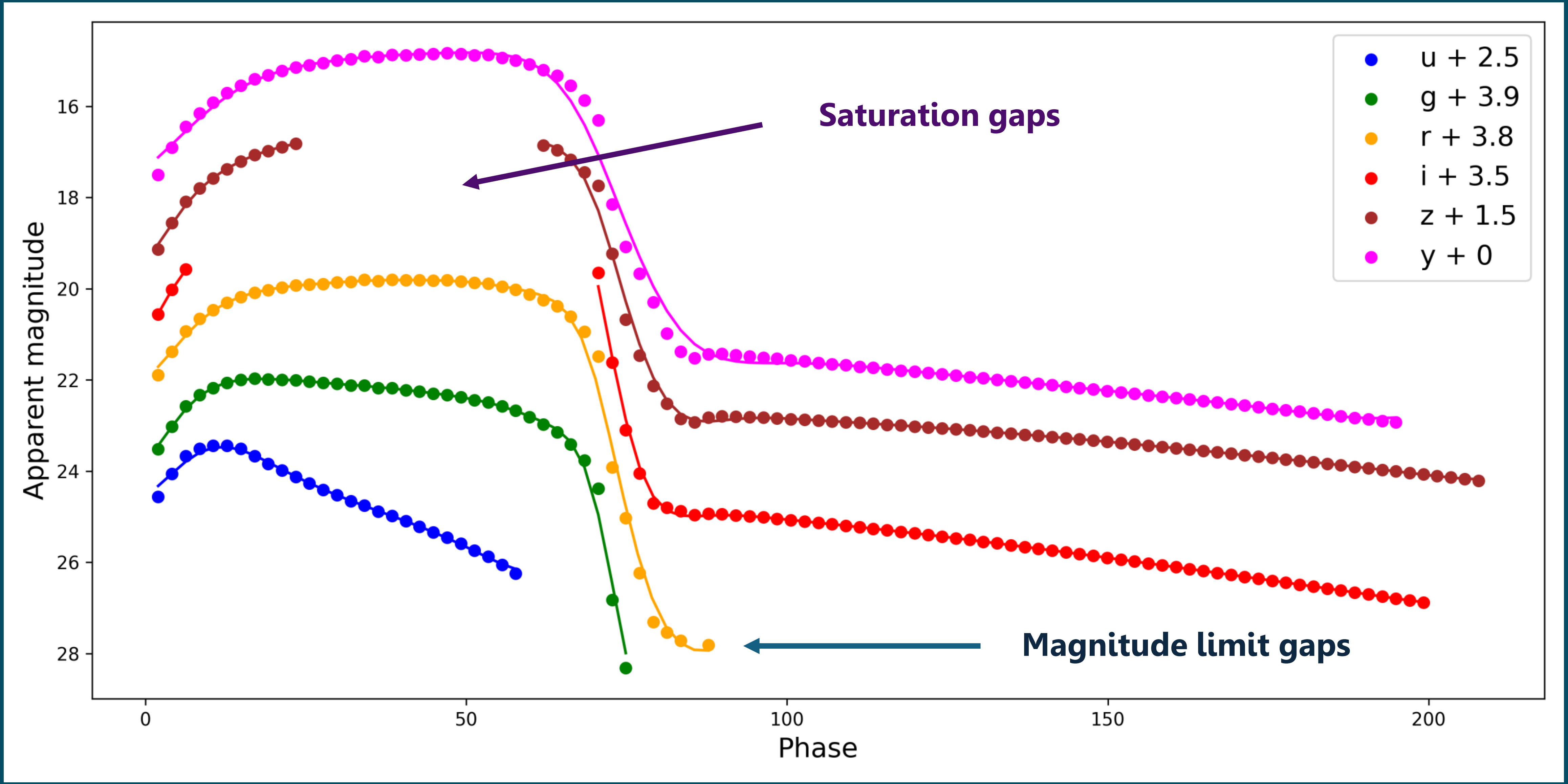
Analysis

- We use CASTOR* to estimate parameters of every event from only the interpolated light curves.
- Three steps:
  1. Comparison
  2. Building synthetic spectra
  3. Parameter estimation

*Credits: Simongini et al. 2024, 2025

How our light curves look like



Saturation gaps

Magnitude limit gaps

FIGURES OF MERIT.

KL divergence

The Kullback–Leibler (KL) divergence is a statistical tool that quantifies the difference between two distributions.

$$D_{KL} = \sum_{i} P_i log_2 \left(\frac{P_i}{Q_i} \right)$$

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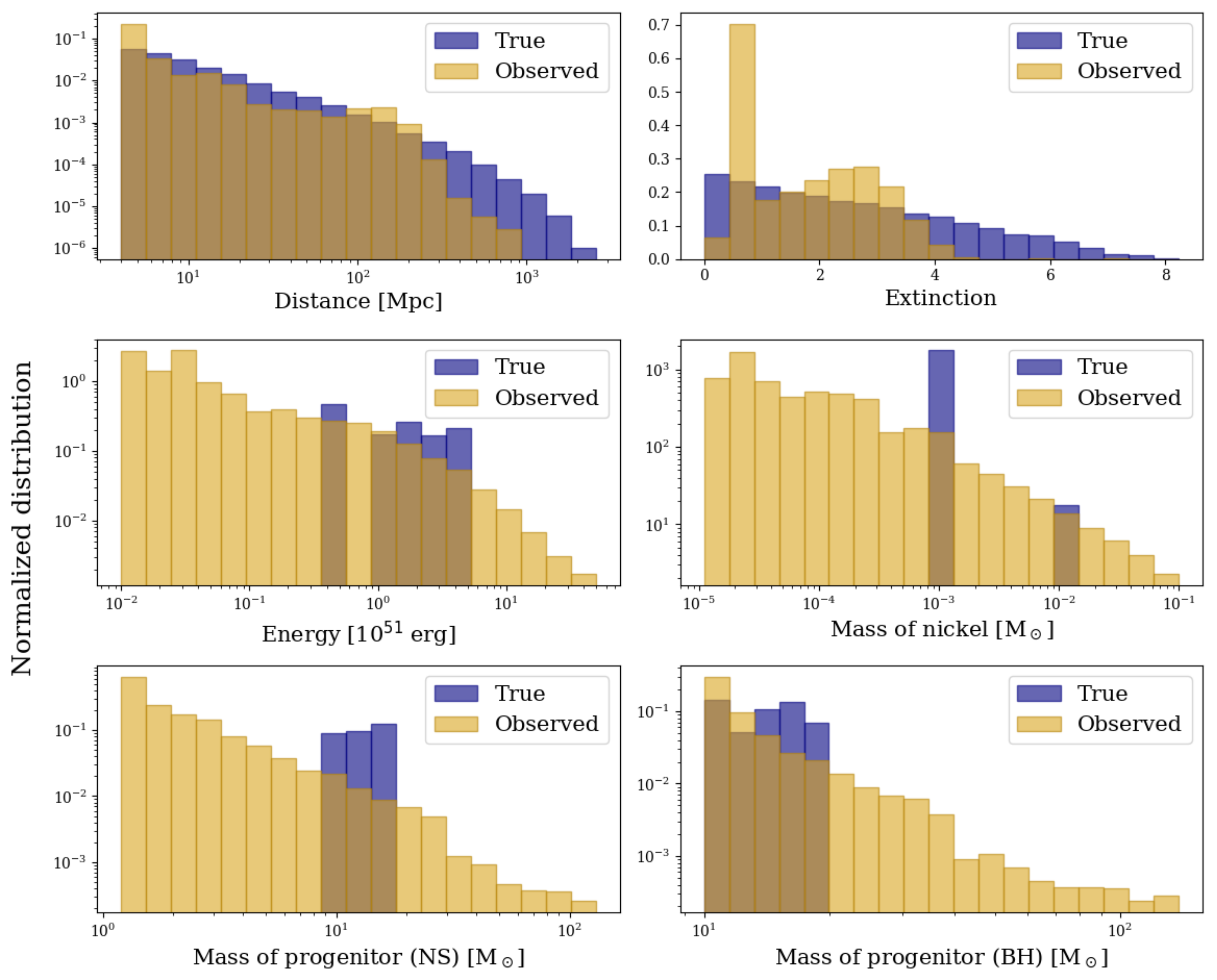
$$D_{KL} = \sum_i P_i log_2\left(\frac{P_i}{Q_i}\right)$$

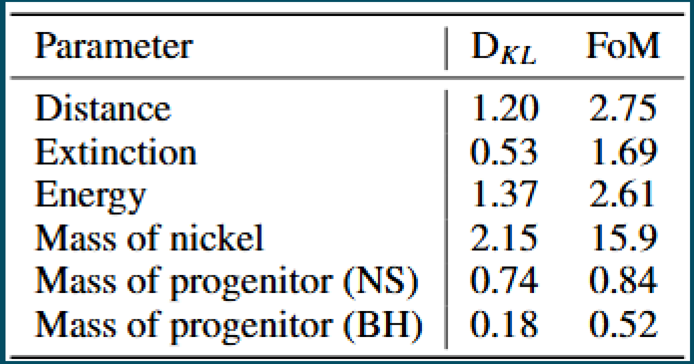
FoM

We define the FoM as the relative deviation of two distributions on a single-event base. It quantifies the relative error of estimation.

$$\mathrm{FoM} = \frac{1}{n}\sum_i \frac{|S_i - T_i|}{T_i}$$

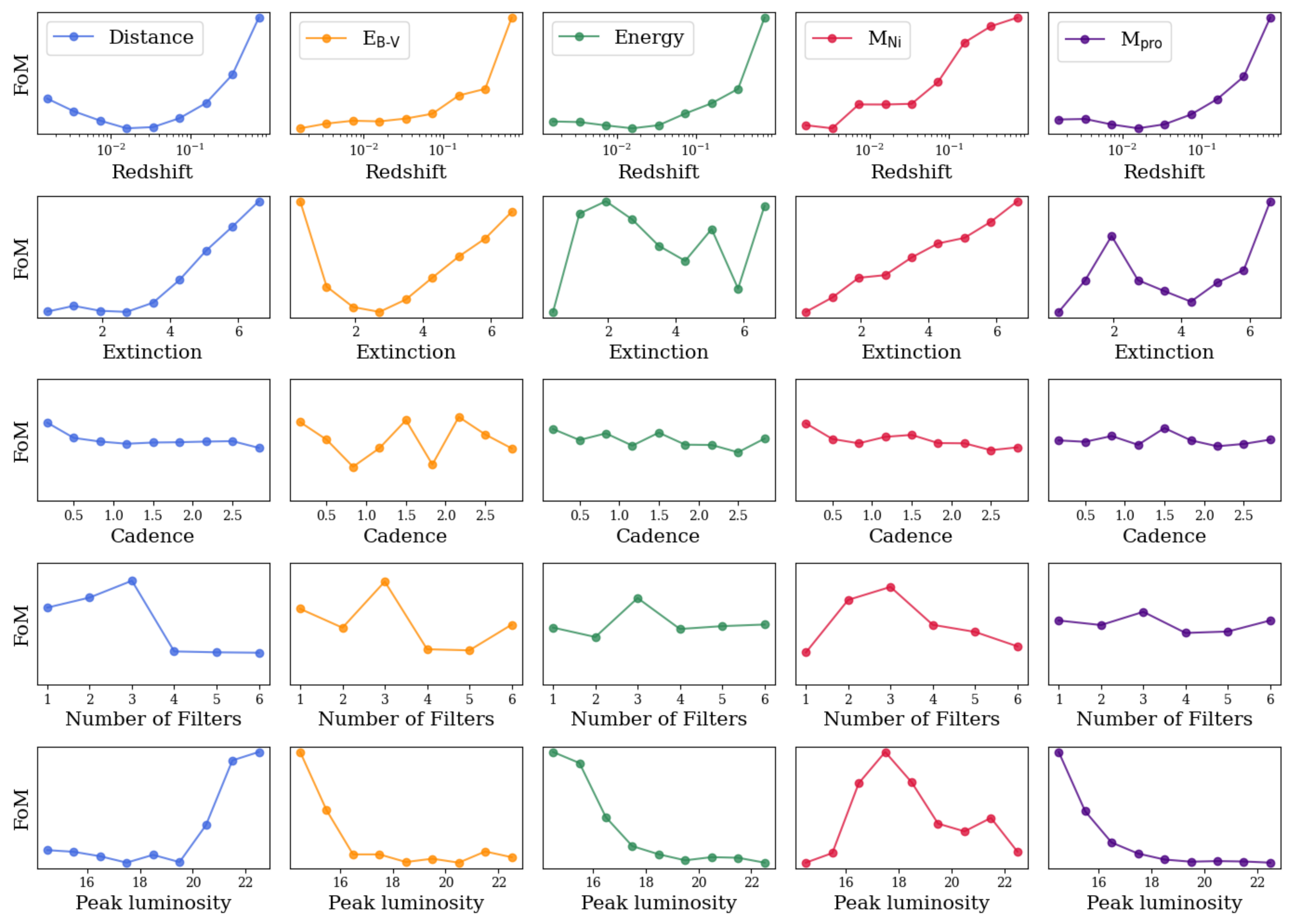
RESULTS.

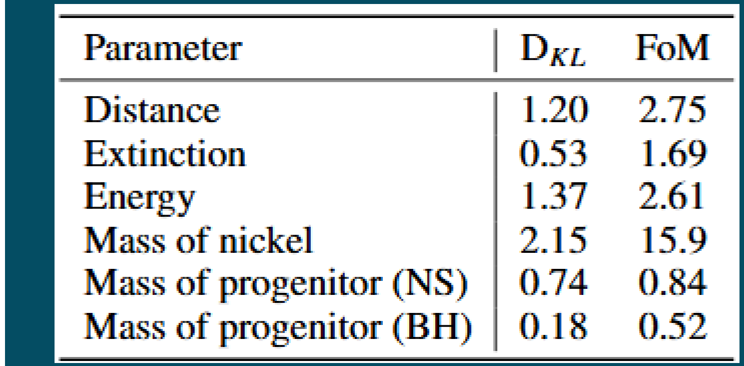




Parameter	D_{KL}	FoM
Distance	1.20	2.75
Extinction	0.53	1.69
Energy	1.37	2.61
Mass of nickel	2.15	15.9
Mass of progenitor (NS)	0.74	0.84
Mass of progenitor (BH)	0.18	0.52

Simongini et al. A&A, 699, A98 (2025)





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CONCLUSIONS.

Main results:

- Saturation leads to high errors.
- High redshift requires other techniques.
- Number of filters: if limited, leads to underestimation.
- Technological limit: LSST alone will not suffice for a perfect characterization of every event.
- All these problems can be solved by complementing LSST observations with other telescopes: global Network

Best reconstructed supernova:

- A SN in the range z = 0.01-0.1 with average extinction and peak luminosity, with at least 4 filters and >10 points in the linear decay phase.

Take home message

Andrea Simongini
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- LSST will boost our knowledge of CCSNe in an unprecedented way.
- From characterization of the progenitor to information on the explosion, chemical yields and more.
- Need for community: LSST alone will not suffice alone for a complete and accurate characterization of every event.
- Have a look at our work! A. Simongini et al. 2025, A&A, 699, A98

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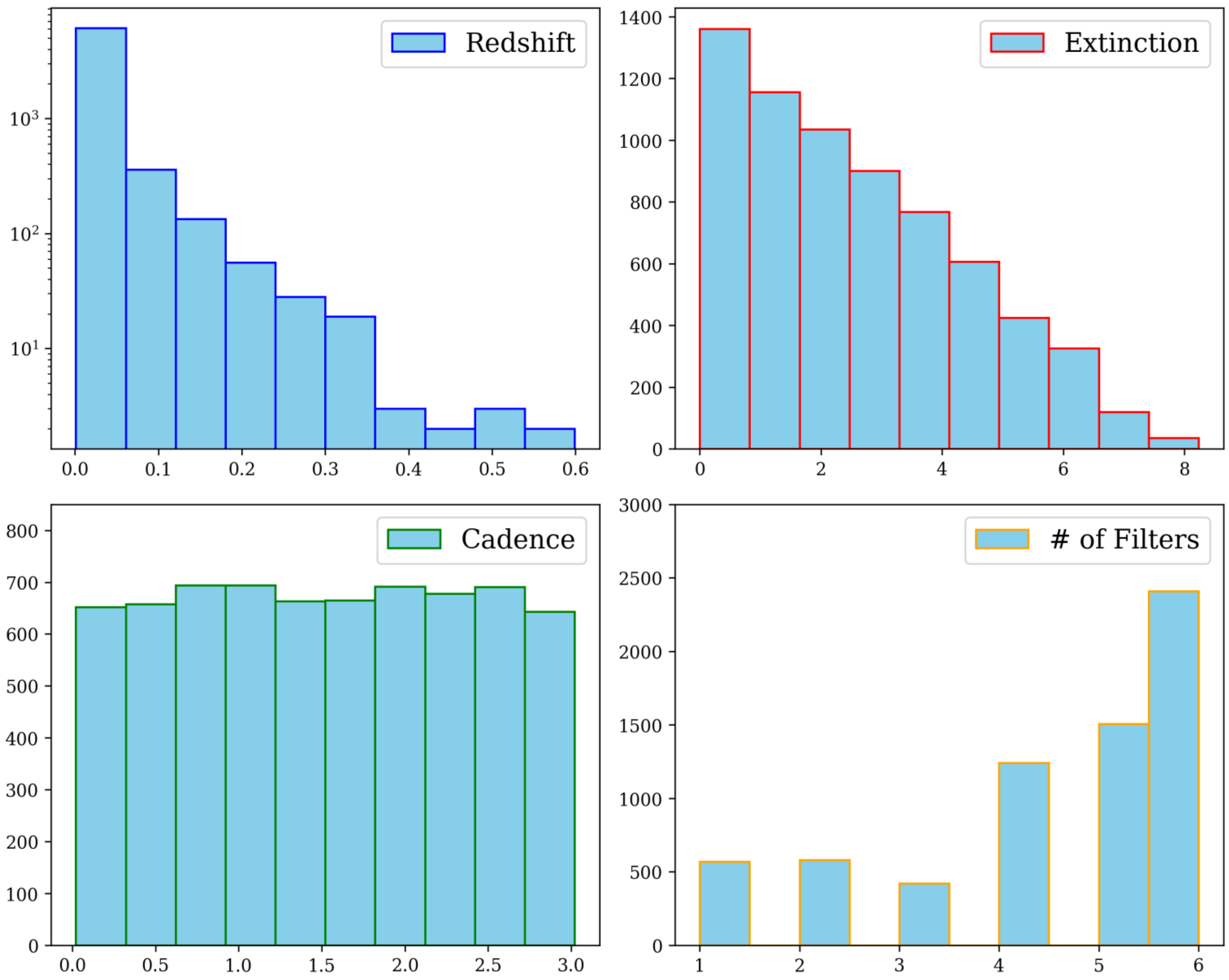
CREDITS.

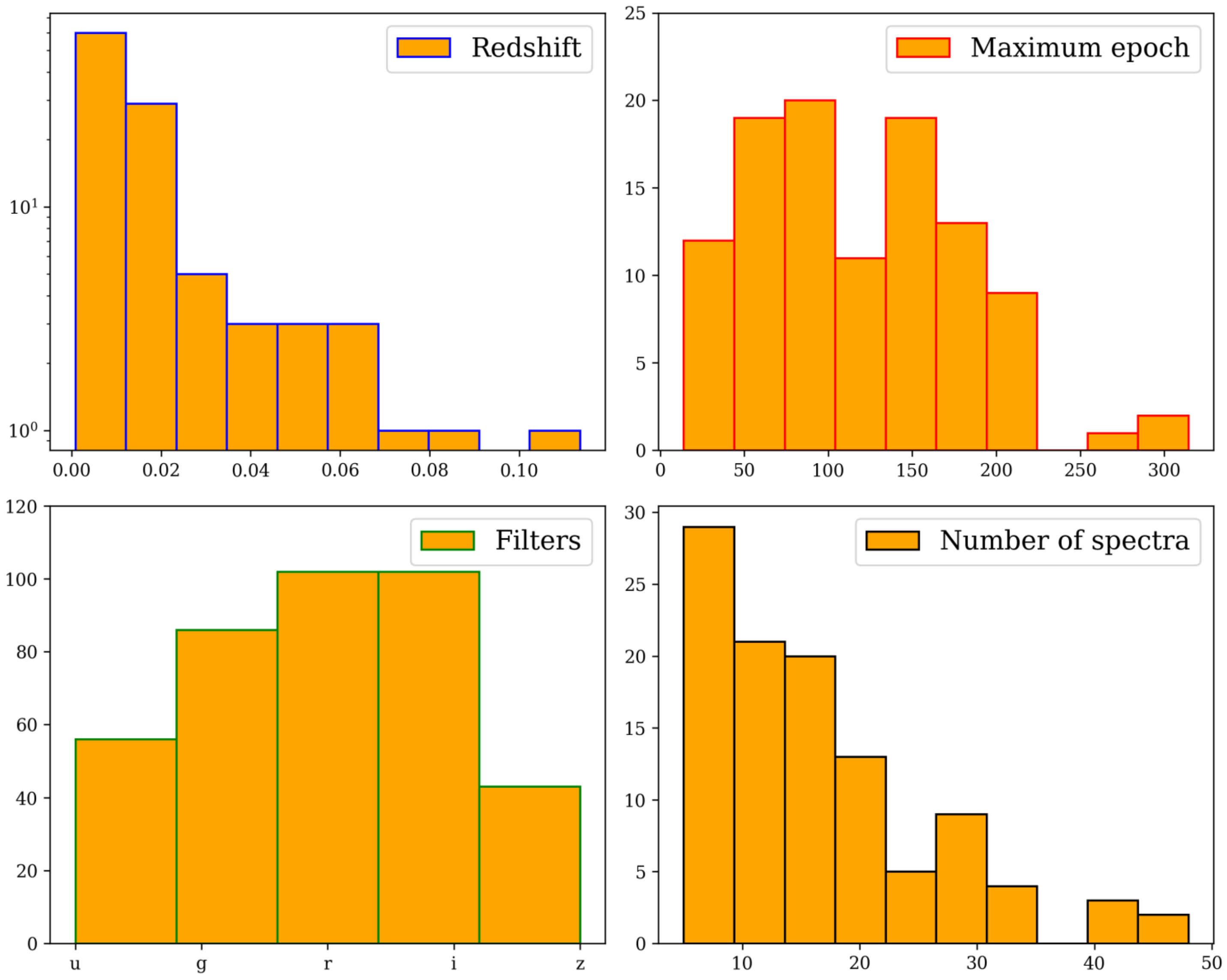
- **Images credits:** RubinObs/NOIRLab/SLAC/NSF/DOE/AURA
- Vera Rubin media gallery: https://rubinobservatory.org/gallery/
- Ž. Ivezić et al 2019 ApJ, 873, 111
- A. Simongini et al. 2024, MNRAS, 533, 3
- A. Simongini et al. 2025, A&A, 699, A98
- T. Moriya et al. 2023, PASJ, 75, 3

APPENDIX.

A1. Distributions of the simulations



A2. Distributions of the training set



A3.
Injected parameters

- Mass of the progenitor
  10, 12, 14, 16, 18 M$\odot$

- Explosion Energy:
  0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 $\times 10^{51}$erg

- Mass of nickel:
  0.001, 0.01 M$\odot$

A4.
Kernel for GPs

We use a mixture of three Matérn kernel functions setting the lengthstcale parameter as the min, max and mean value of the sampling step.

$$k(x) = A\left(1 + \frac{\sqrt{3x}}{\sigma}\right)\exp\left(-\frac{\sqrt{3x}}{\sigma}\right)$$

A5. Distance

Distance is estimated using the Hubble's law:

$$d = \frac{cz}{H_0}$$

Where the redshift is taken from the relative shift of emission lines in the synthetic spectra using the Doppler's law.

A6.
Extinction

Extinction is estimated using the Cardelli's law with the prescriptions from McCall 2004.

The $\boldsymbol{E_{B-V}}$ parameter is taken as the difference between the peak magnitude of a blue and a visible filter.

When the number of filters is < 3 (or there are not the right filters) we simply use the model from Cardelli et al. 1989 averaging over the available filters.

A7.
Energy

We estimate energy using the model from Simongini et al. 2024.

Defining ξ as the neutrino contribution (from SN1987A model) we define the explosion energy as:

$$E = \xi L_{bol} t_{rise}$$

A8.

Mass of progenitor

We estimate the mass of progenitor combining the models from Arnett 1982 and Simongini et al. 2024 assuming perfect mass conservation.

The mass of progenitor is defined as:

$$M_{pro} = M_{rem} + M_{ej} = M_{rem} + \frac{10}{3}\frac{E}{v_{ej}^2}$$

A9.
Mass of nickel

We estimate the mass of nickel using the model from Lusk & Baron 2017.

The mass of nickel is defined as:

$$M_{Ni} = \frac{L_{Ni}}{s}$$

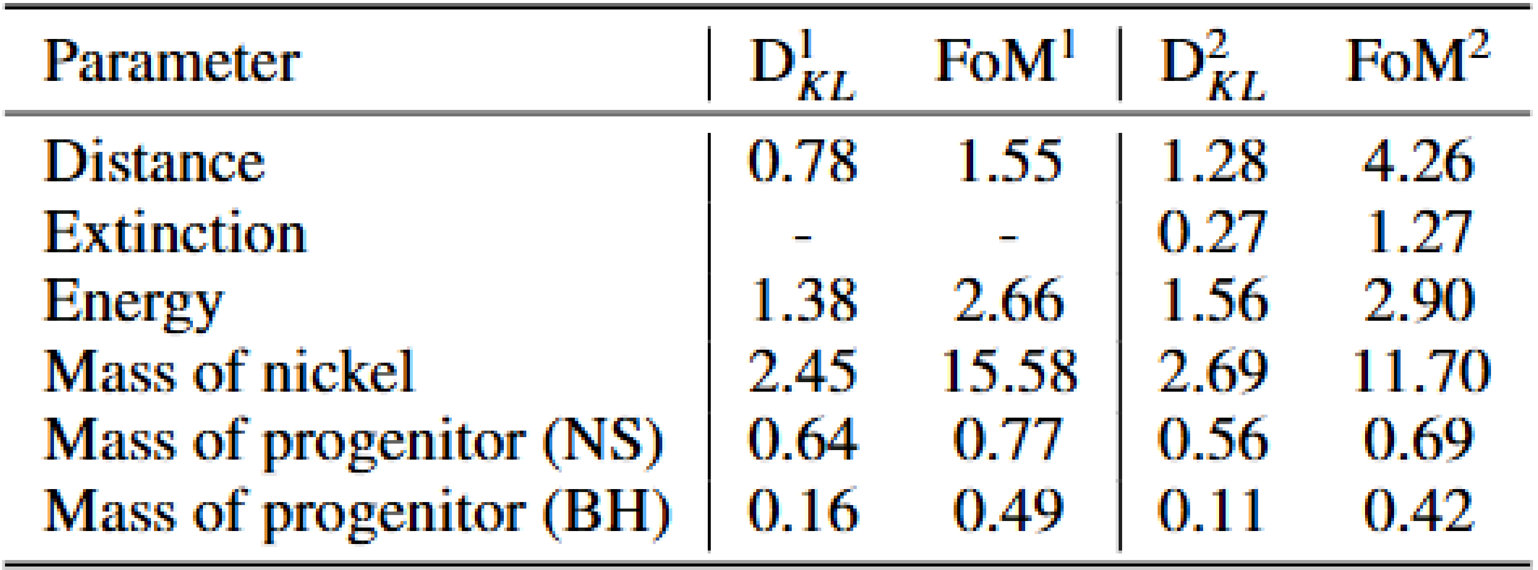
with:

$$s = 3.90 \times 10^{10} e^{-\gamma_1 t} + 6.78 \times 10^{9} (e^{-\gamma_2 t} - e^{-\gamma_1 t})$$

A10.

Additional tests

As additional tests we made two extra runs with (1) fixed extinction and (2) light curves with no saturation.



Parameter	D^1_{KL}	FoM^1	D^2_{KL}	FoM^2
Distance	0.78	1.55	1.28	4.26
Extinction	-	-	0.27	1.27
Energy	1.38	2.66	1.56	2.90
Mass of nickel	2.45	15.58	2.69	11.70
Mass of progenitor (NS)	0.64	0.77	0.56	0.69
Mass of progenitor (BH)	0.16	0.49	0.11	0.42

A11.
Mass of nickel

We bin the FoM of the Mass of nickel in terms of the number of points that are observed in the linear decay phase. We notice a huge improvement.