



“Scary Barbie”: An Extremely Energetic, Long-duration Tidal Disruption Event Candidate without a Detected Host Galaxy at $z = 0.995$

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Rare Gems in Big Data Conference
Tucson, Arizona



College of Science



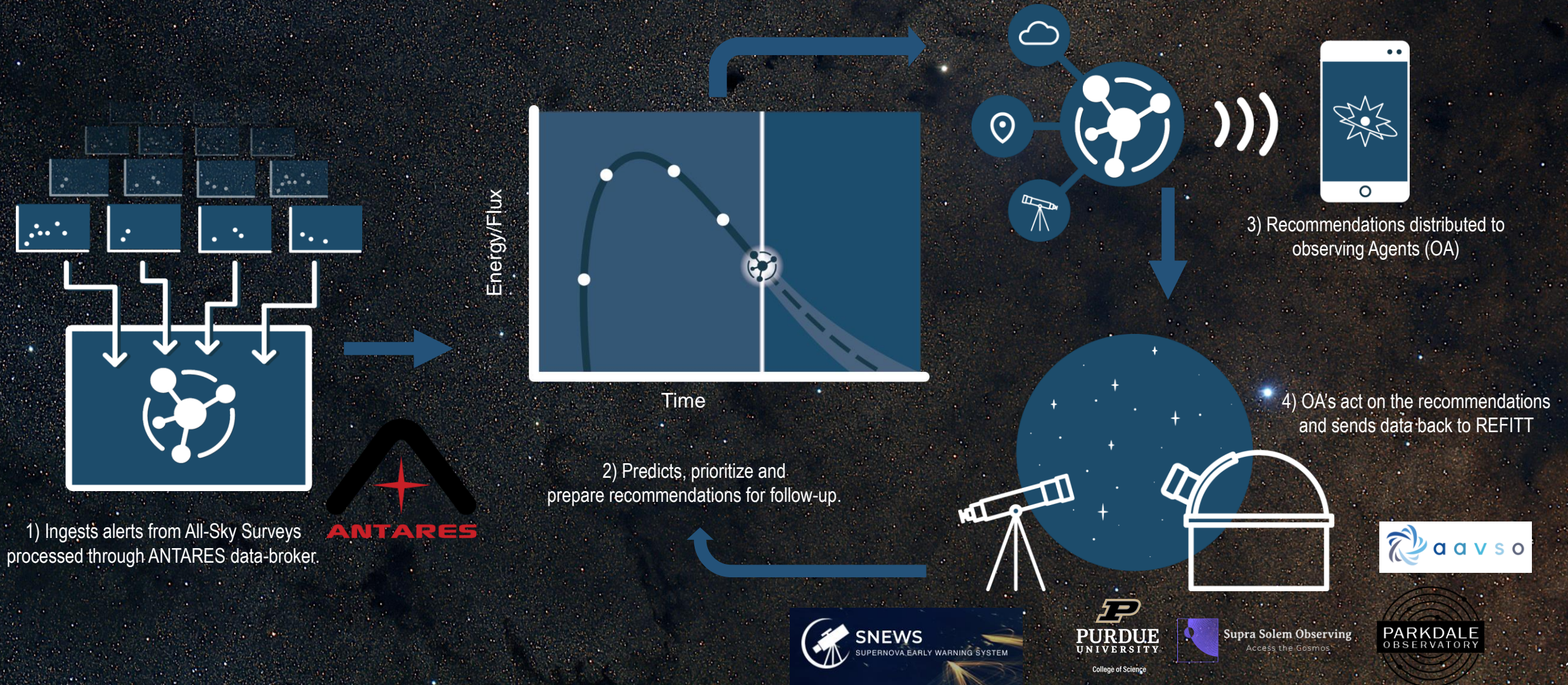
REFITT

Recommender Engine For
Intelligent Transient Tracking

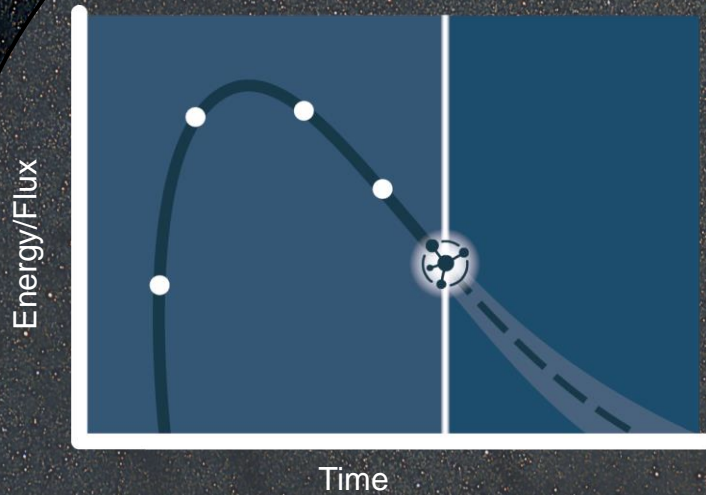
Recommender Engine For Intelligent Transient Tracking (REFITT)

Pravara et al. 2020

College of Science



Real Time Characterization of Evolving Core-collapse Supernovae from Zwicky Transient Facility Light Curves

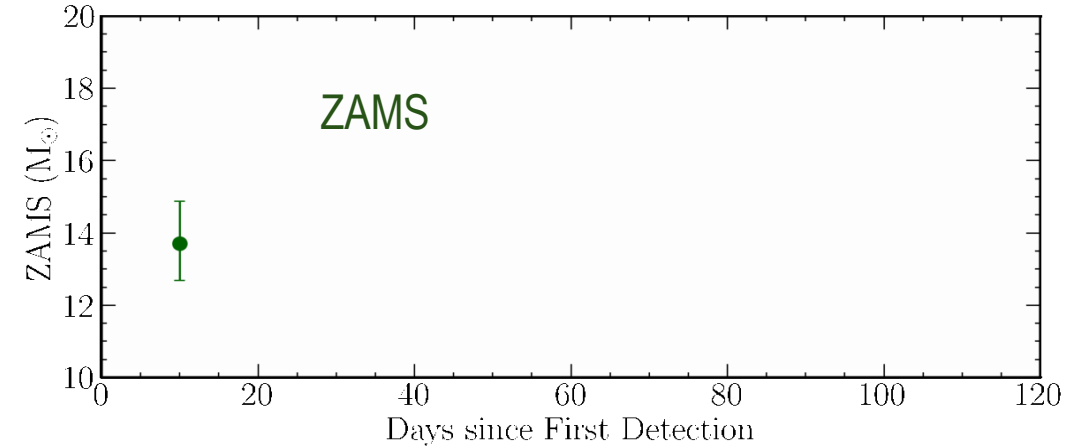
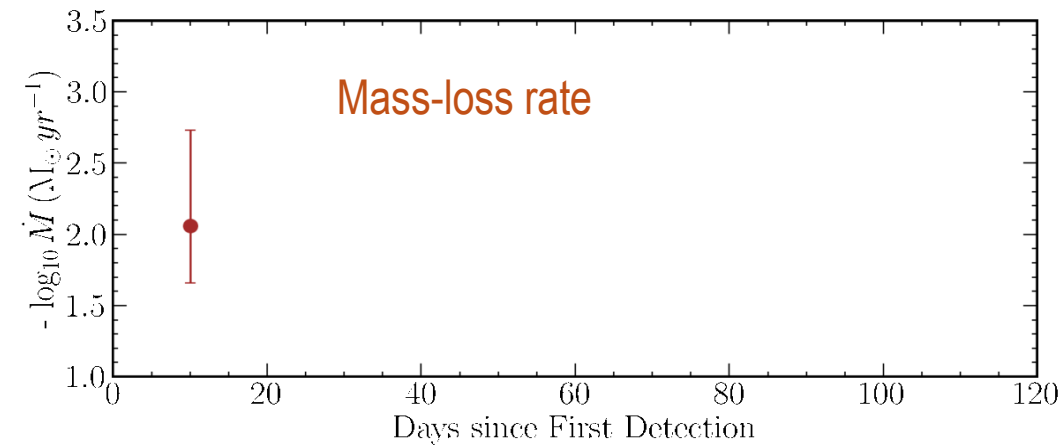
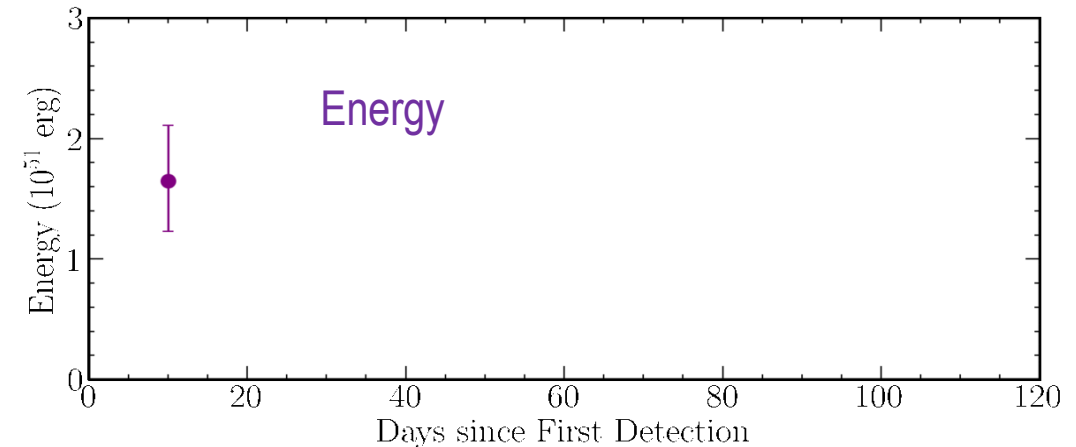
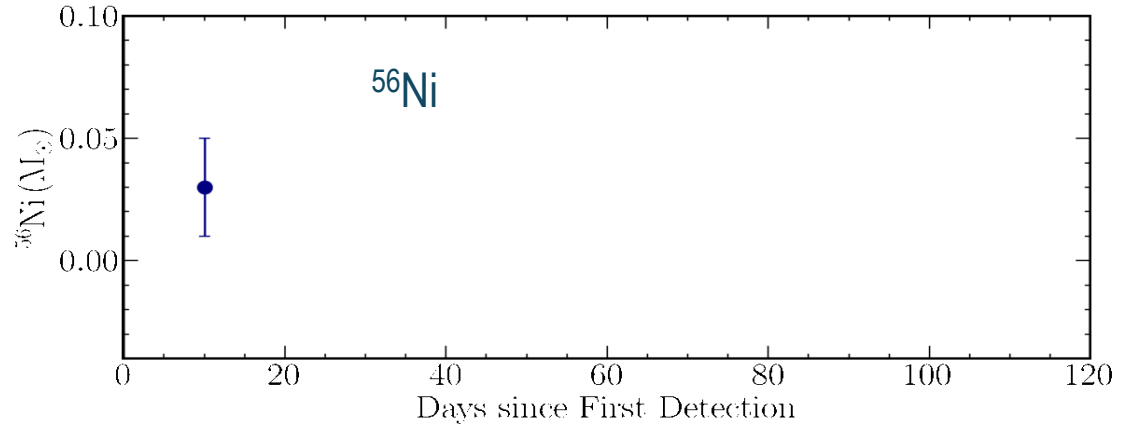
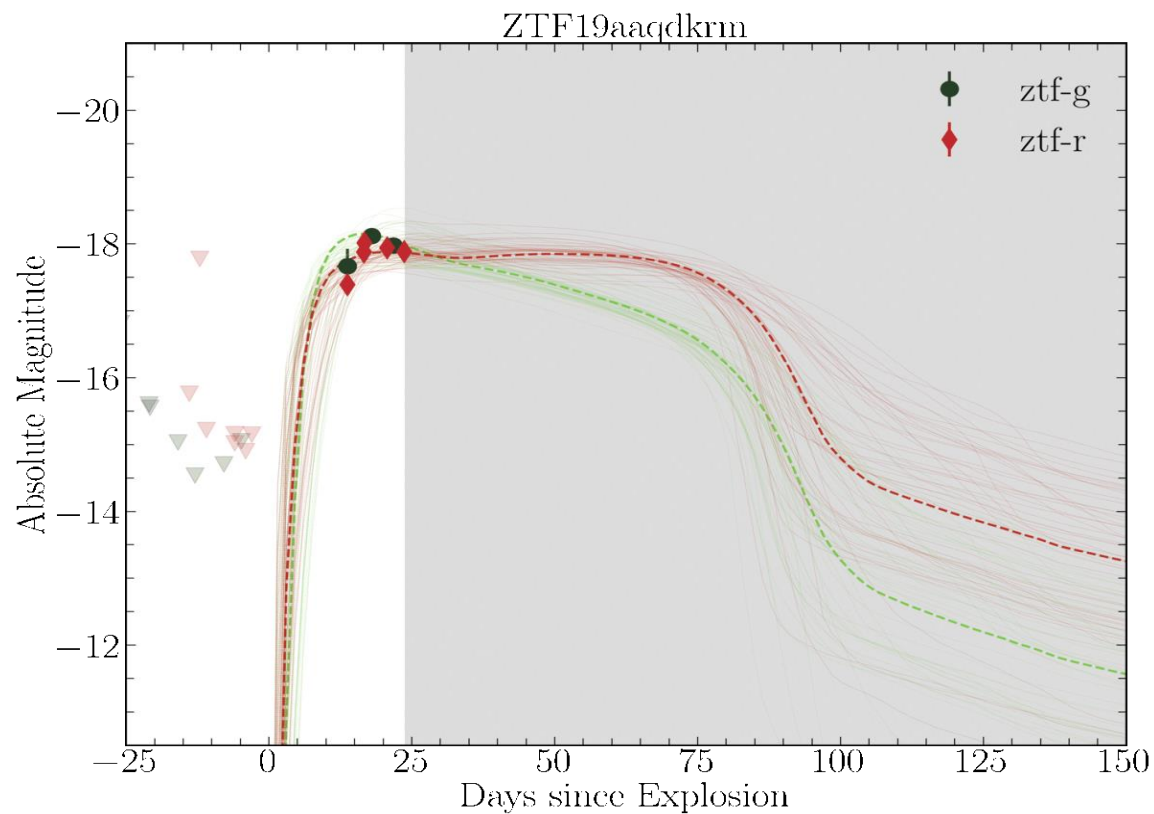


2) Predicts, prioritize and prepare recommendations for follow-up.

Motivating prioritization and follow-up with underlying physics of transients ?

Can we make predictive forecasts on transient evolution by fitting hydrodynamical models to time-series data in real time?

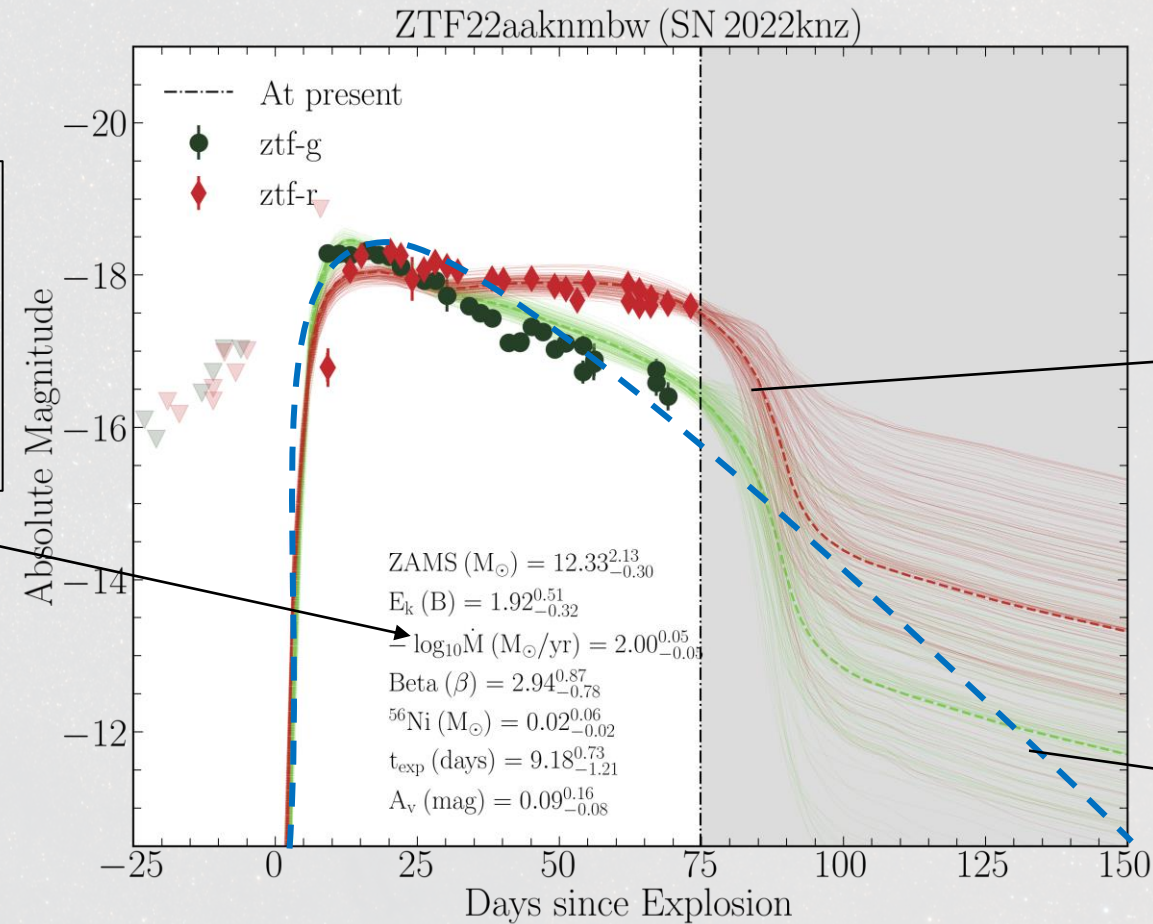
Real-Time Characterization and Parameter Evolution



Prioritization of events with desired parameter spaces (gems) and Follow-up at Information Rich Epochs with Real-Time Transient Characterization

Progenitor properties and Explosion estimates to:

- develop prioritizations of parameter ranges of CCSNe that are least explored.
- **detect anomalies (rare gems)**



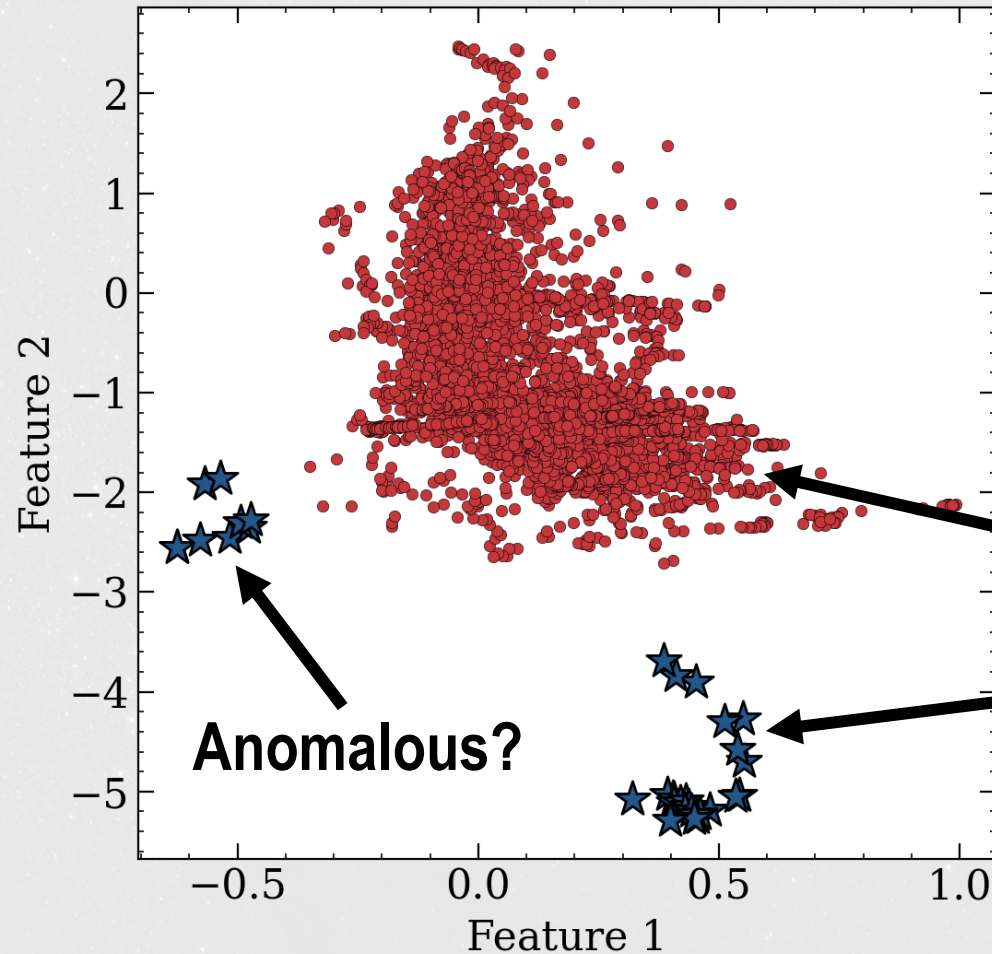
Theoretically motivated information rich epoch to follow up by coordinating world-wide observing facilities.

Physics-blind, purely data driven fit incorrectly predicts the evolution and misses recombination drop-off

Data Driven Anomaly Detection



Braden Garretson



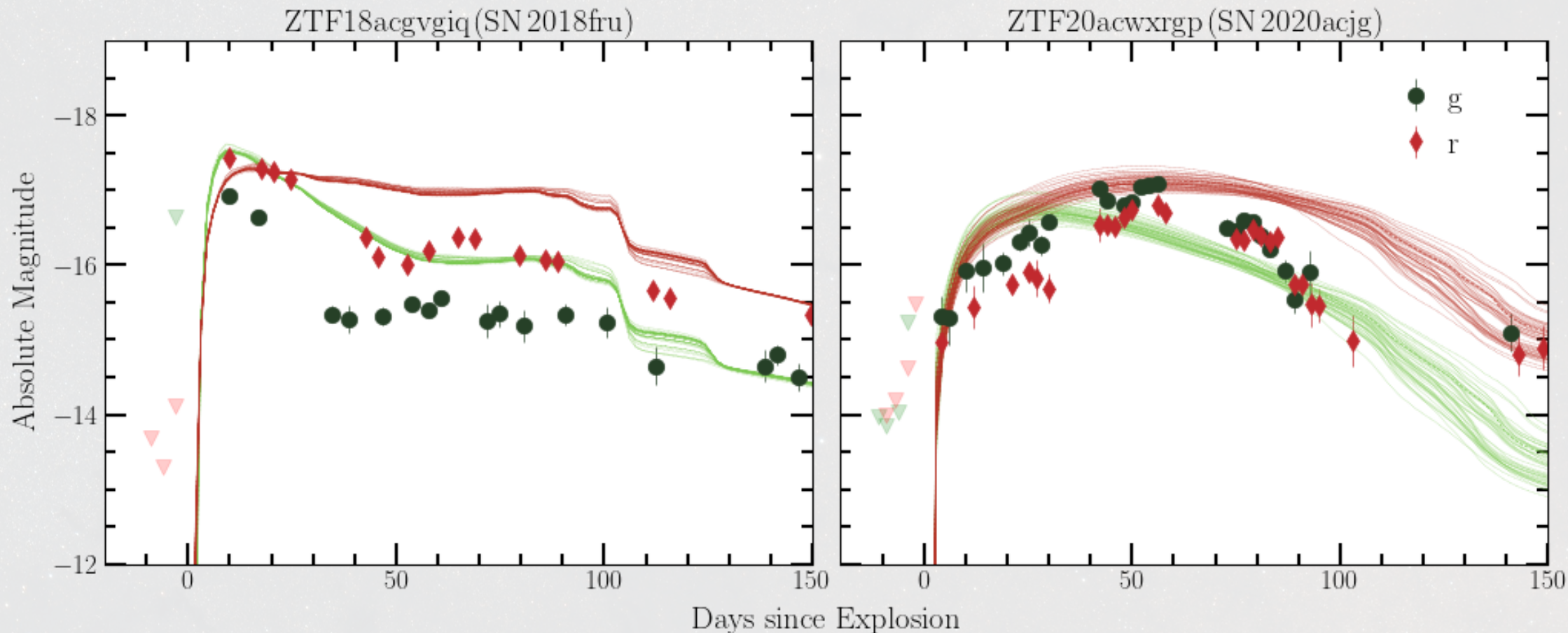
While extremely useful for discovering rare transients, data driven modeling doesn't tell us if we understand the underlying physics

Data driven modeling tells us how similar new events are to previous events

Theoretically Driven Anomaly Detection



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Long duration events, Re-brightening events, Models that do not fit well!
follow-up

→ Flagged for



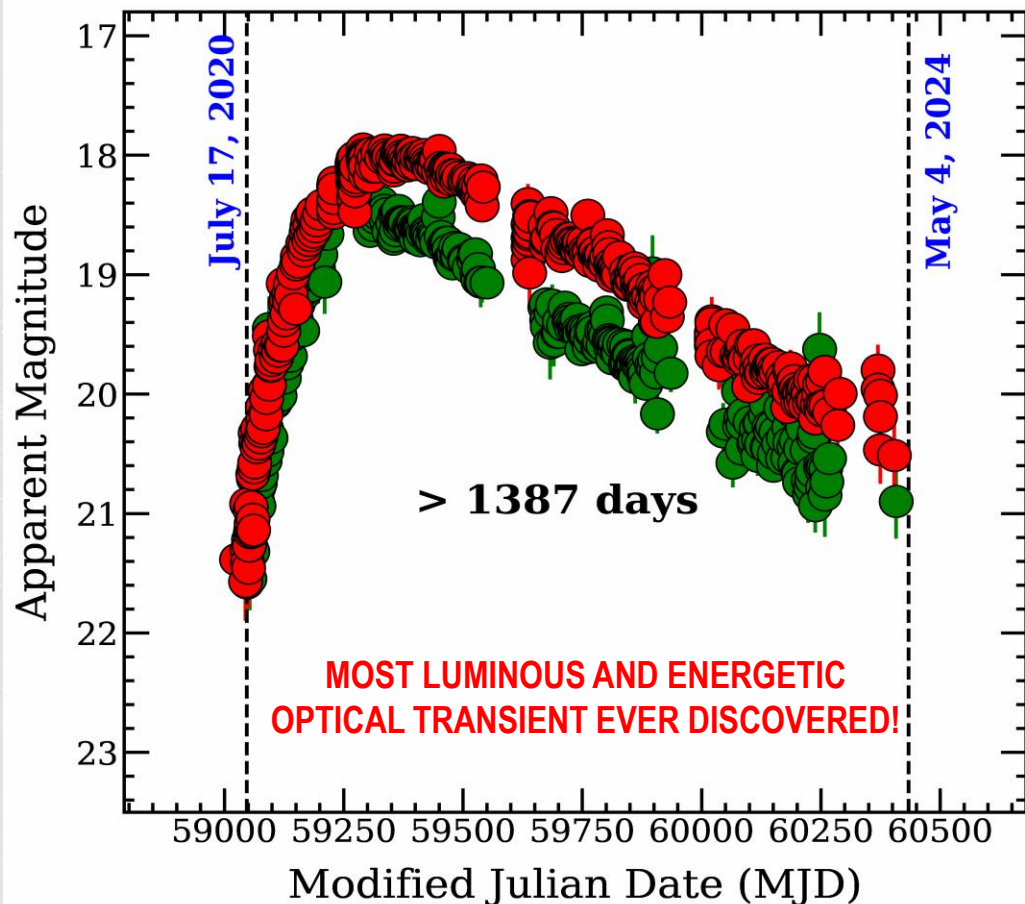
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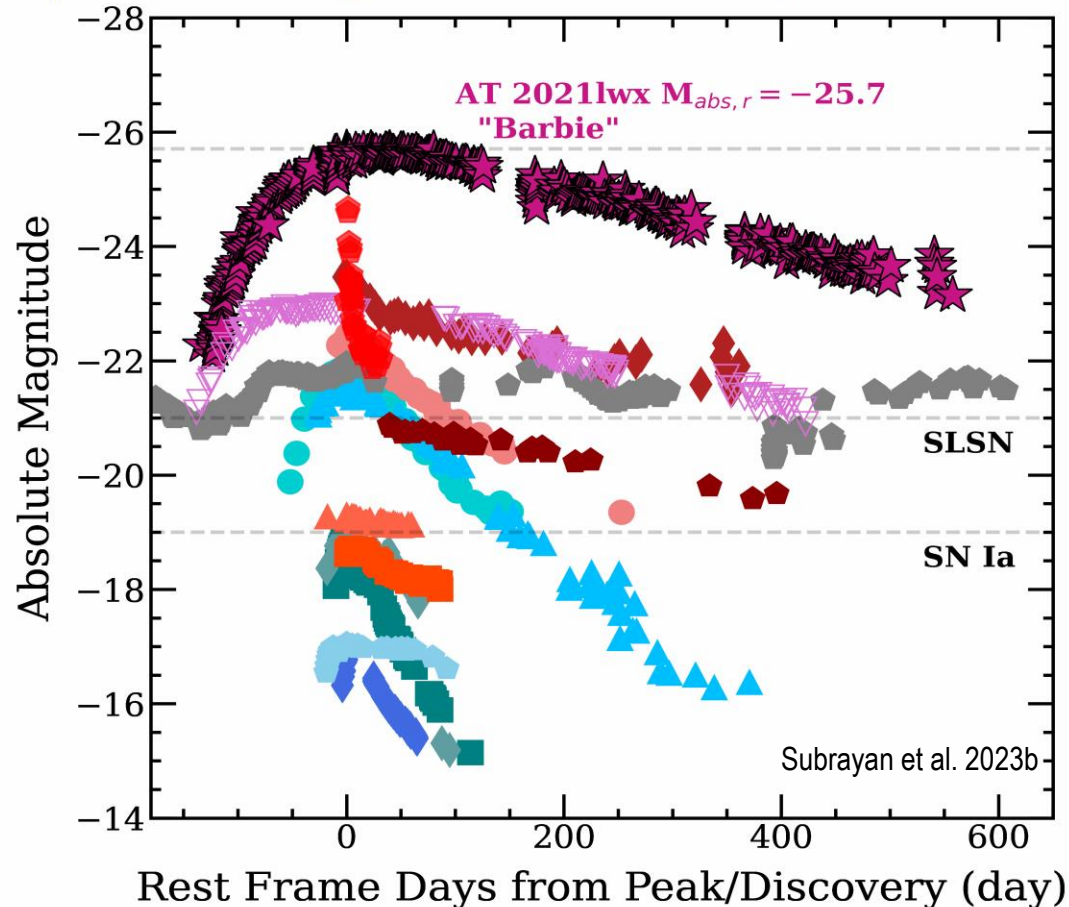
AT 2021lwx aka "Scary Barbie": Ultra luminous, Extremely Energetic, Long-Duration Optical Transient at $z = 0.9945$

AT 2021lwx aka ZTF20abrbeie aka "Barbie"
 $\log L_{\text{peak}} = 45.7 \text{ erg s}^{-1}$ and $E_{\text{radiated}} > 10^{53} \text{ erg}$

● ZTF g ● ZTF r



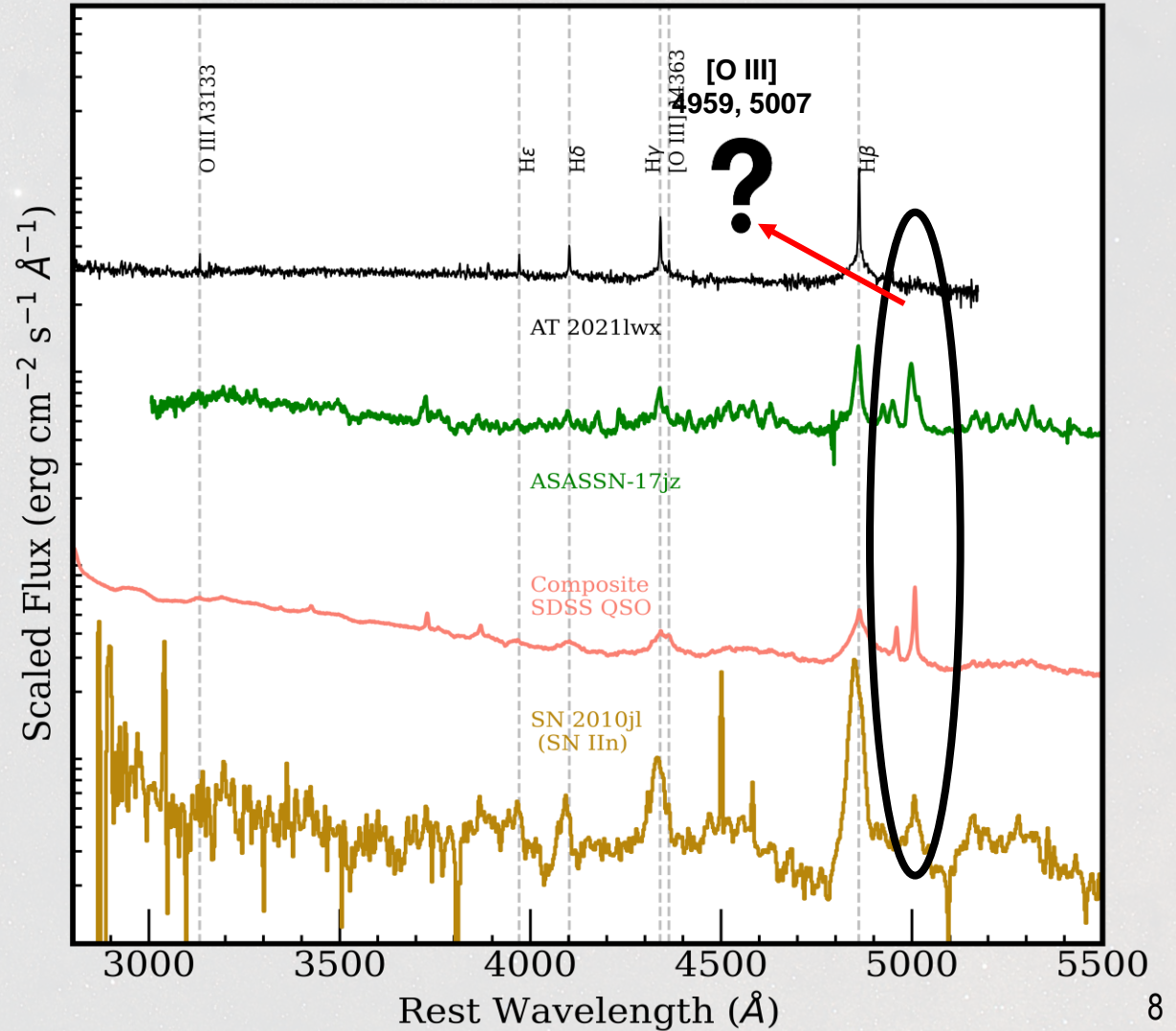
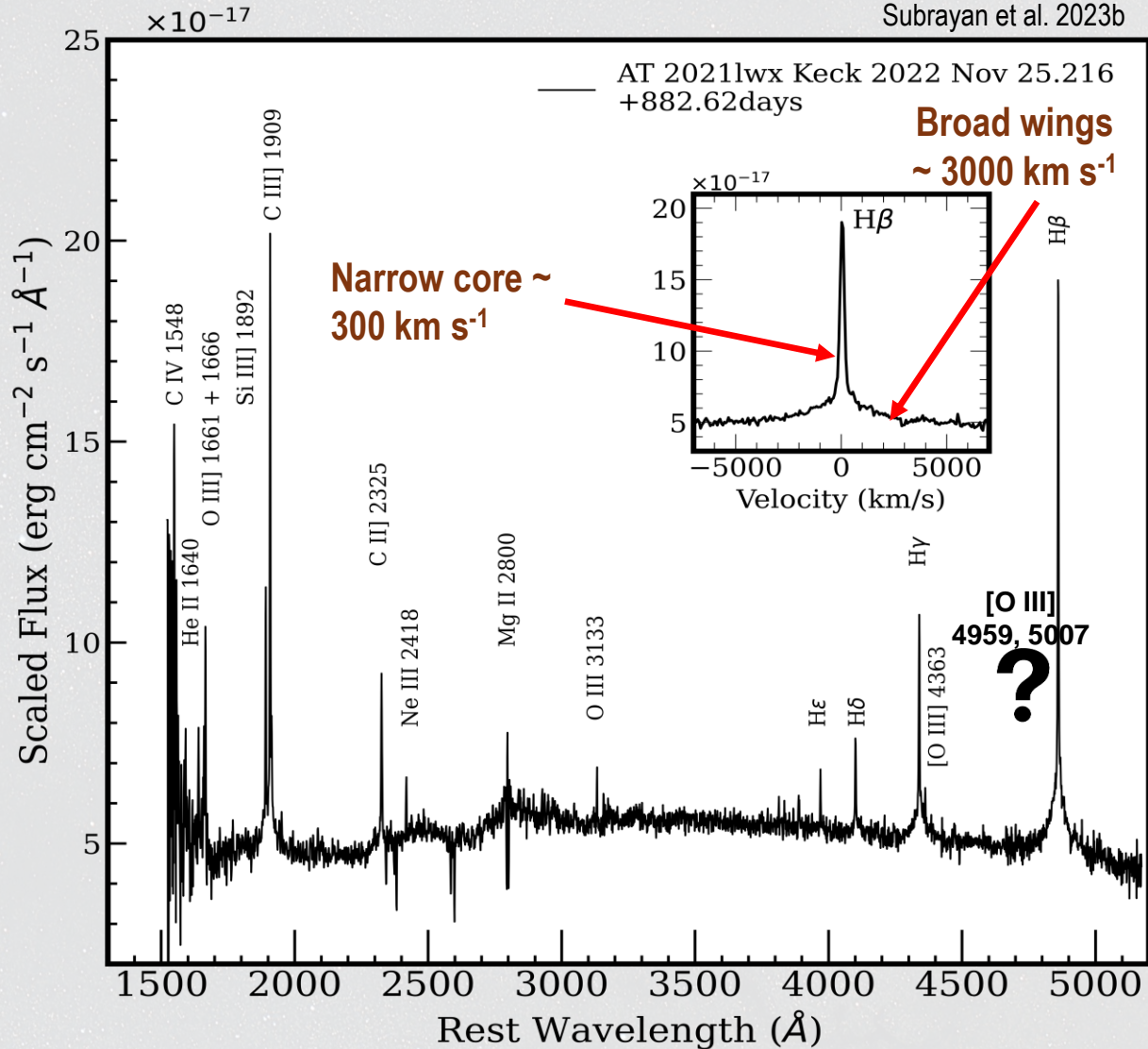
- ★ AT 2021lwx
- SN Ia
- SLSN-II
- ▲ SLSN-I
- ◆ SN I Ib
- ◆ SN IIP
- ◆ SN IIn
- ◆ ASASSN-15lh (TDE)
- ▲ ASASSN-14li (TDE)
- ASASSN-17jz (ANT)
- ◆ ASASSN-18jd (ANT)
- ASASSN-14ae (TDE)
- ◆ AT 2022cmc (TDE)
- ◆ AGN
- ▽ AT2019brs (AGN Flare)



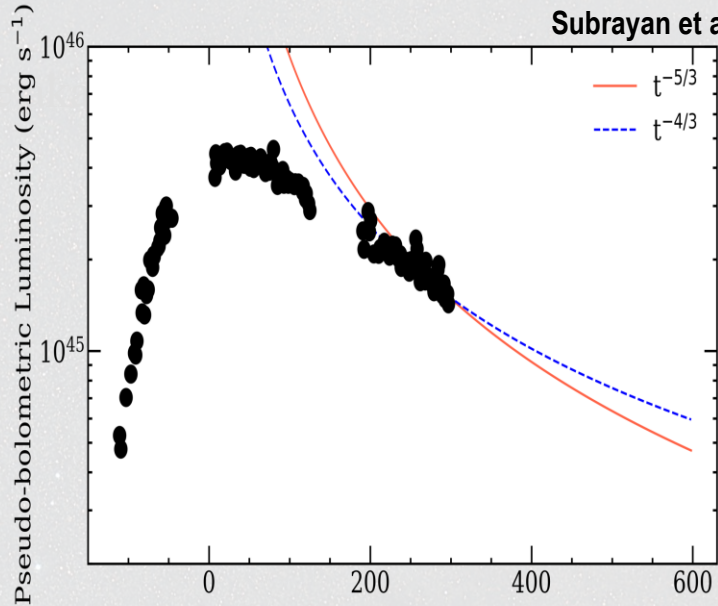
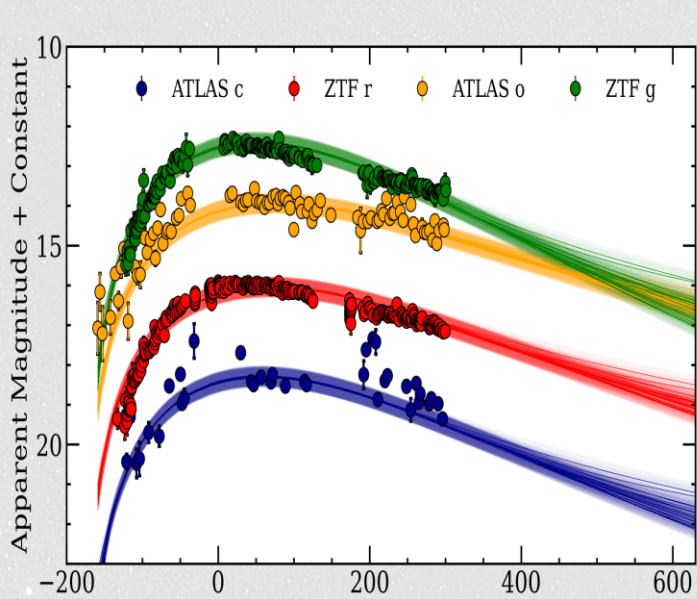
Optical Spectroscopy

Narrow hydrogen cores with broad wings, prominent semi-forbidden lines

Missing [O III] 4959, 5007



A possible extreme tidal disruption candidate?

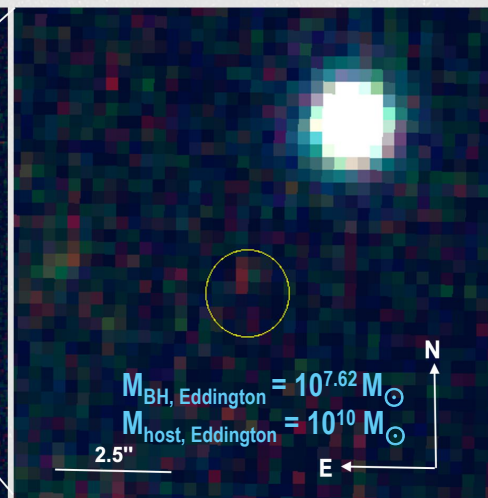
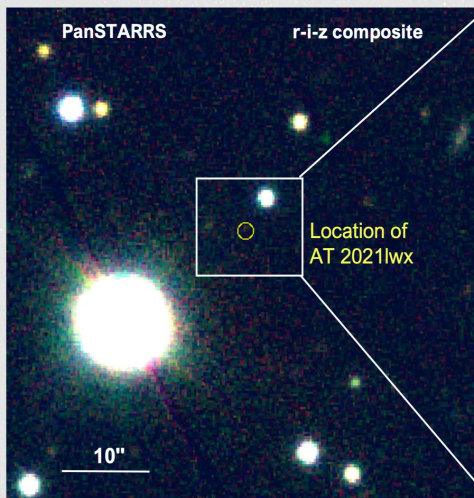
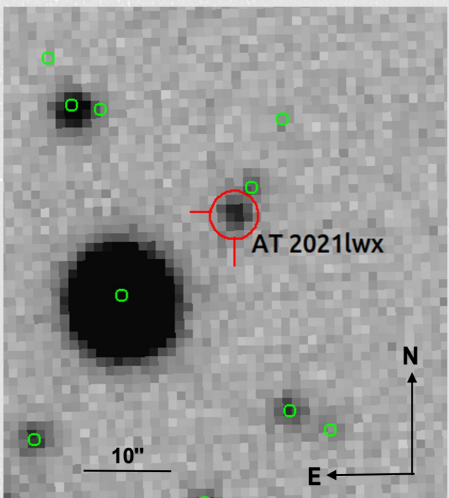


- Extreme parameters for mass of the star and black hole from TDE modelling:

$$M_{\text{star}} = 14.28^{+0.67}_{-1.65} M_{\odot}$$

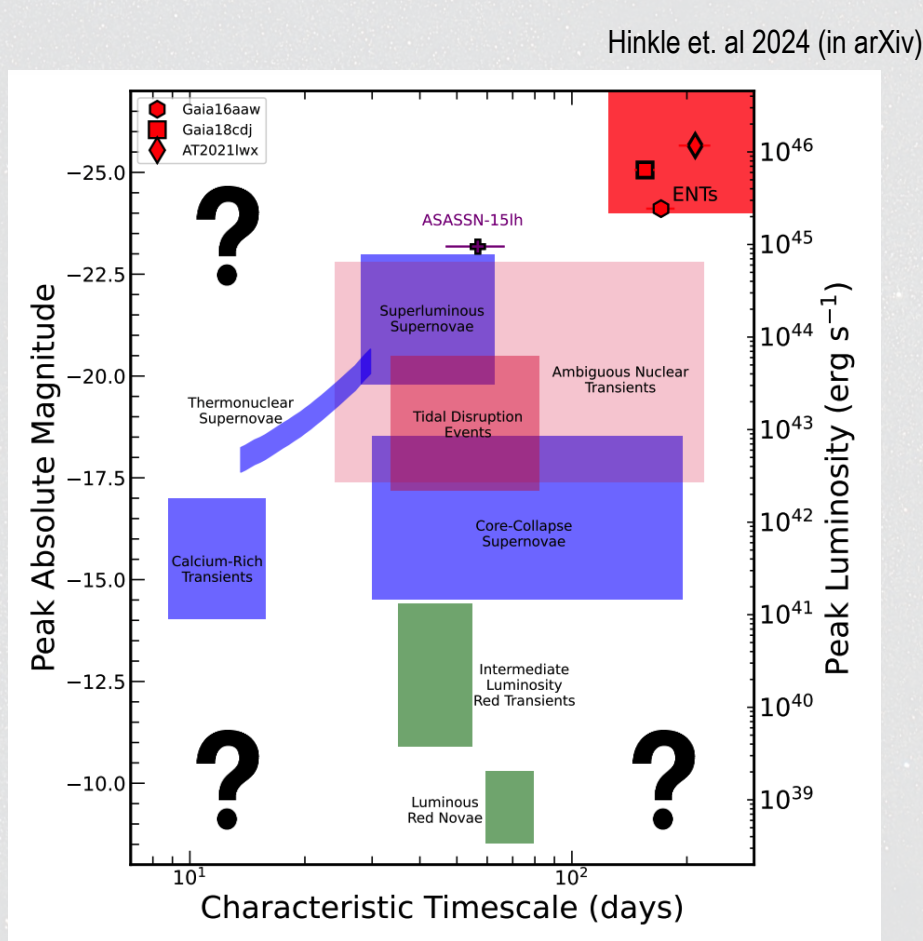
$$M_{\text{BH}} = 1.7 \pm 0.1 \times 10^8 M_{\odot}$$

- Swift-XRT observations of AT 2021lwx in 2023, yielded X-ray emission with 3σ significance, indicating a luminosity of $10^{45} \text{ erg s}^{-1}$ in the 0.3–10 keV.
- No detection in radio. VLASS non-detection $F_{\nu} < 0.35 \text{ mJy}$ at $\approx 3 \text{ GHz}$. No jets detected yet!

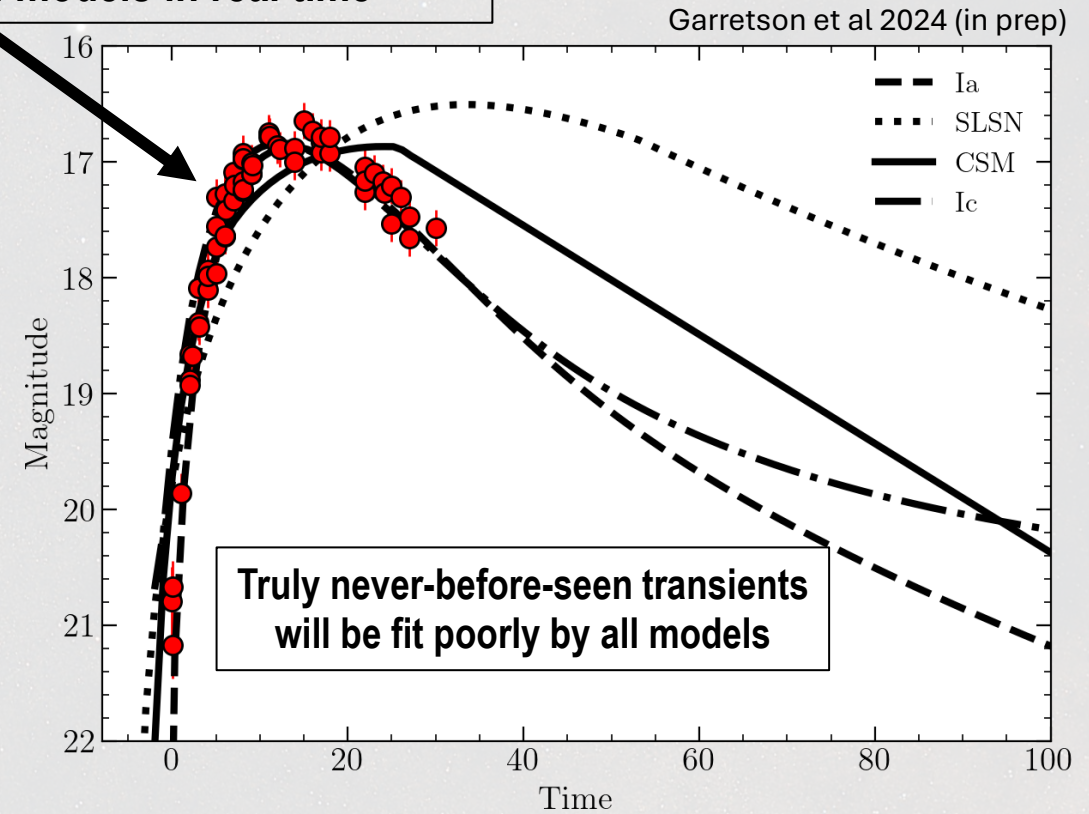


But NO host galaxy detected yet?

Finding Rare Gems in Big Data



Modern machine learning tools can allow observations to be compared against **all theoretical models in real time**



Approaches involving filters with host less transients + Real-Time Characterization using theoretical models + Anomaly Detection

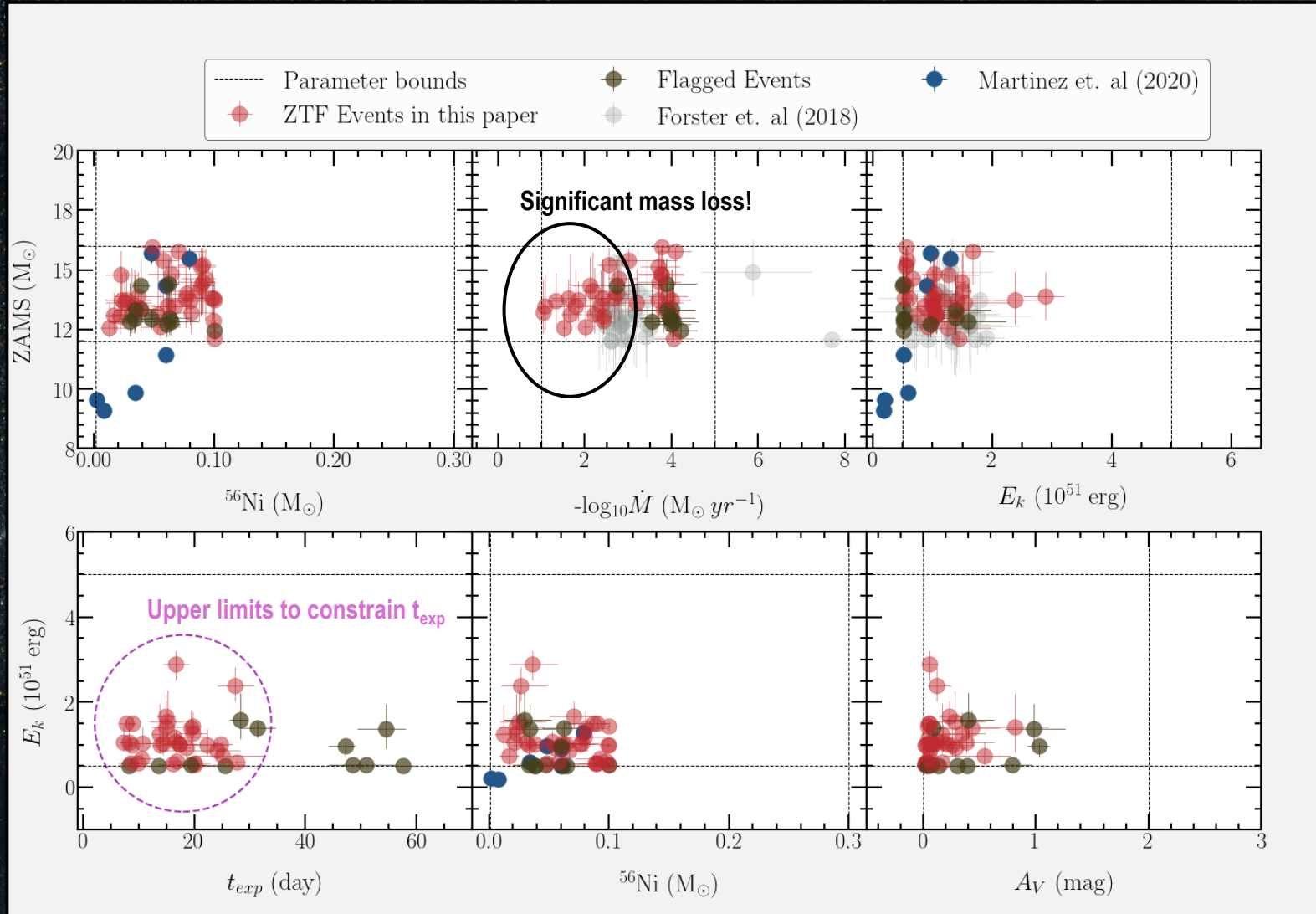
Summary

- AT 2021lwx aka “**Scary Barbie**” is an ultra luminous $L_{\text{peak}} = 10^{45.7} \text{ erg s}^{-1}$, extremely energetic ($> 10^{53}$ ergs), long duration evolving optical transient (> 1000 observer-frame days) at $z \sim 1$.
- TDE modelling of these extreme luminosities indicate extreme parameters for the disruption:
 $M_{\text{star}} = 14.28_{-1.65}^{+0.67} M_{\odot}$
 $M_{\text{BH}} = 1.7 \pm 0.1 \times 10^8 M_{\odot}$
- Ground-based optical images of the field do not detect an underlying galaxy hosting the theorized supermassive blackhole.
- Finding the host galaxy with future observations will be fundamental to test the physical interpretations.
- Real Time Characterization of Transients using underlying physics will be an invaluable tool in finding **RARE GEMS IN BIG DATA from LSST**.



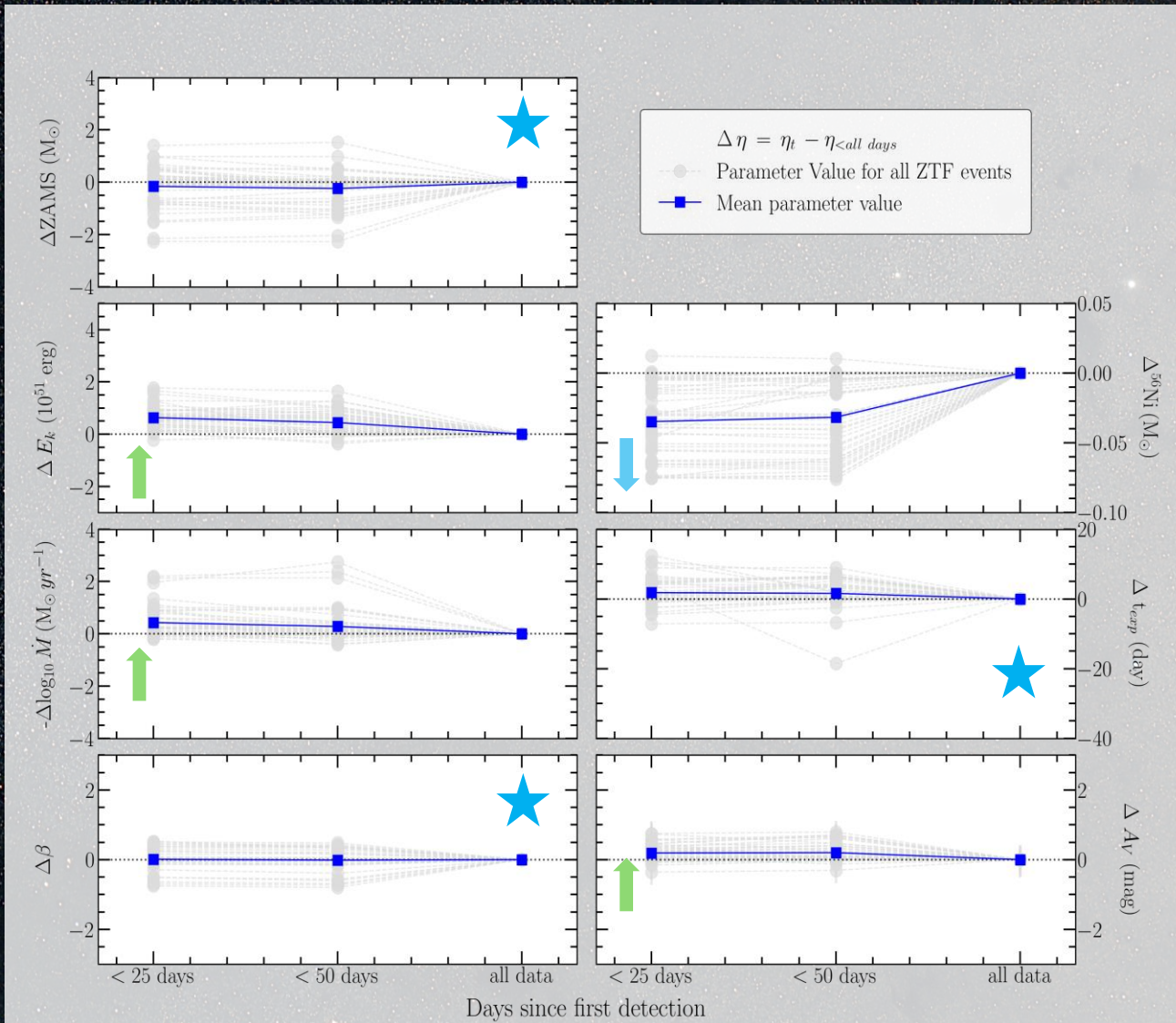
Extra / Back-up Slides

Parameter Spaces : Progenitor Properties and Explosion Physics



- 34 events with confident fits, remaining 11 events are flagged.
- Flagging due to:
 - a) poorly constraining rise time data along with no upper limits
 - b) parameter inferences approaching model boundaries
- Non-negligible fraction (8 out of 45) showing high mass-loss rates $\dot{M} \leq 10^{-2} M_{\odot} \text{ yr}^{-1}$

How do different parameters change as data come in?



Relative change in parameter values with respect to complete data:

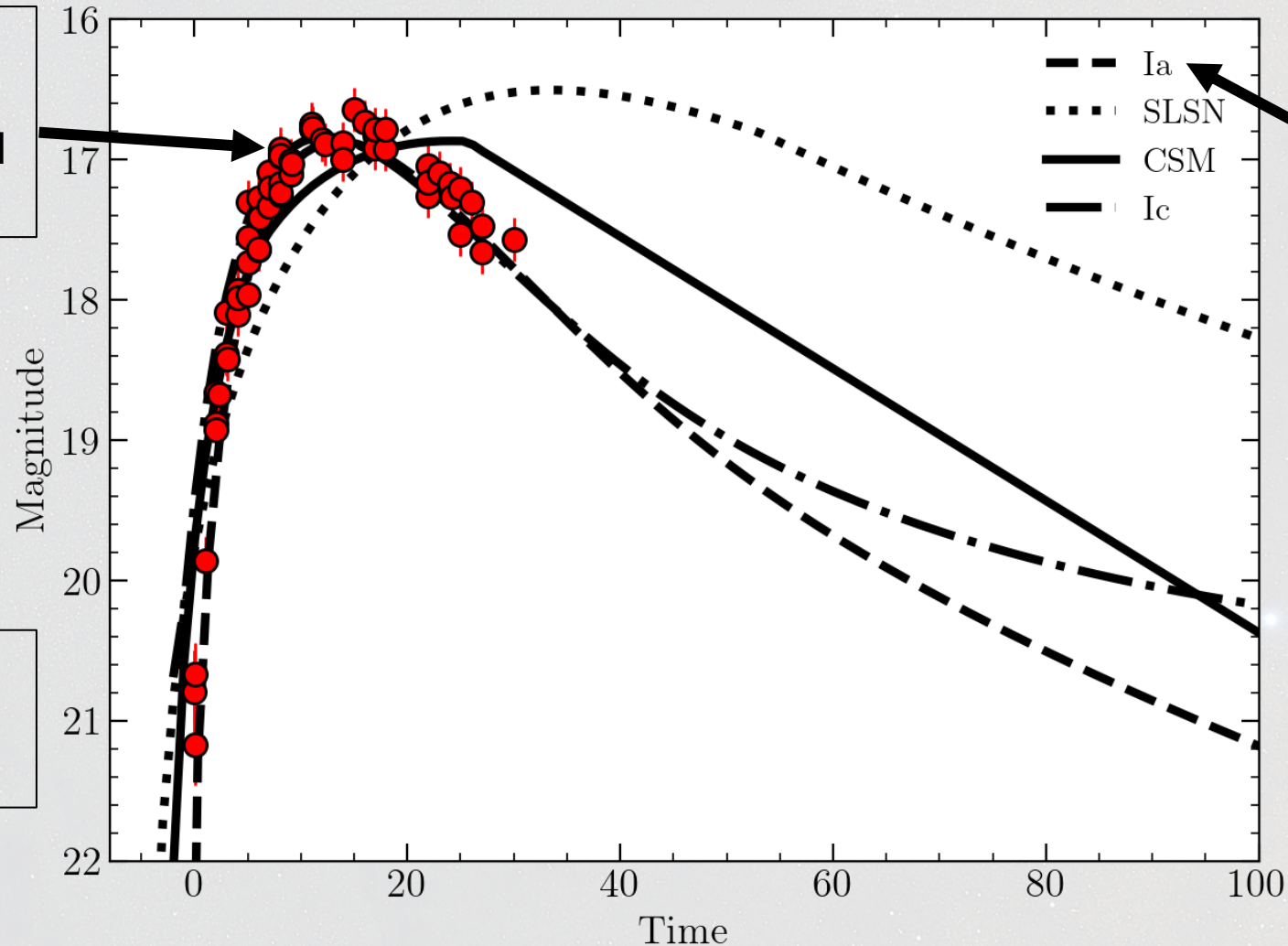
$$\Delta \eta = \eta_t - \eta_{\text{complete data}}$$

- The explosion energy, host extinction and mass-loss rate are slightly **overestimated** during initial phases of evolution, while the ^{56}Ni mass is heavily **underestimated**.
- The ZAMS mass, explosion date and β estimates **do not change significantly** at different phases.

The Future of Theoretically Driven Inference

Modern machine learning tools can allow observations to be compared against **all theoretical models in real time**

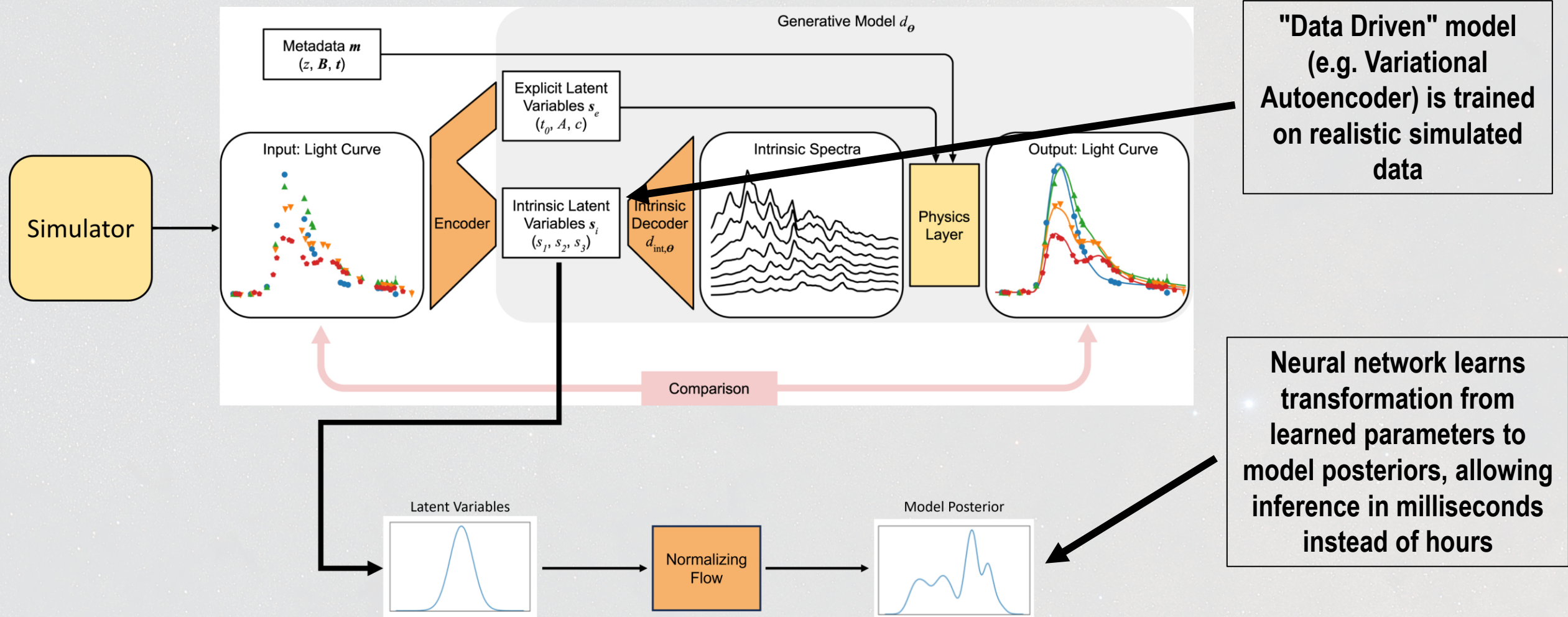
Truly never-before-seen transients will be fit poorly by all models



Spectroscopic observations allow for the correct model to be chosen with certainty

Rapid Inference with Machine Learning

Parsnip (Boone 2021)



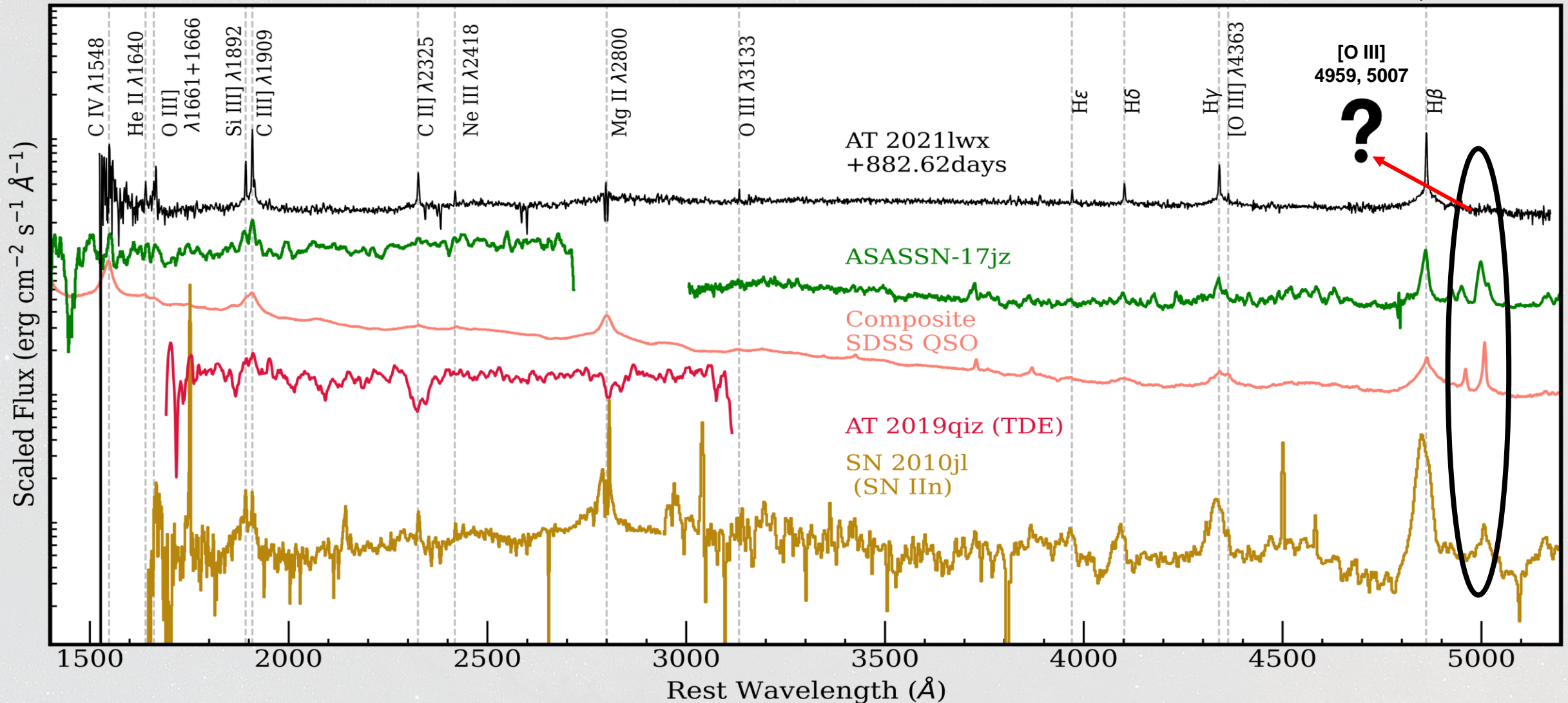
"Data Driven" model (e.g. Variational Autoencoder) is trained on realistic simulated data

Neural network learns transformation from learned parameters to model posteriors, allowing inference in milliseconds instead of hours

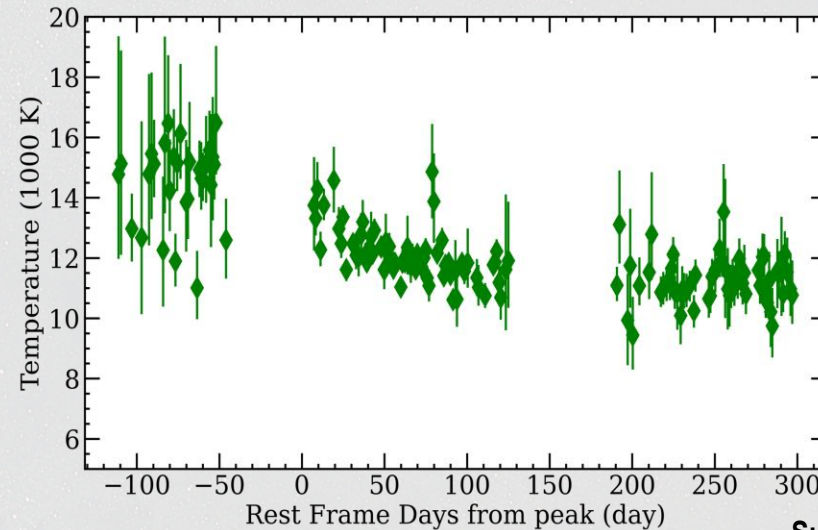
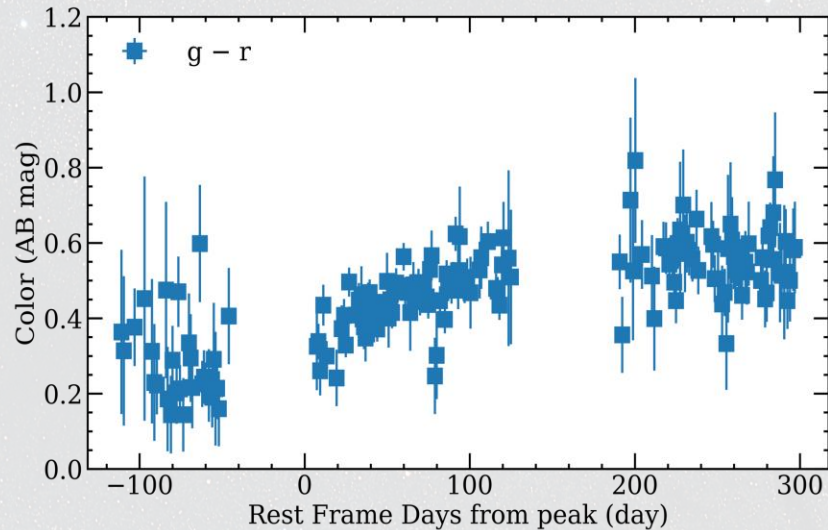
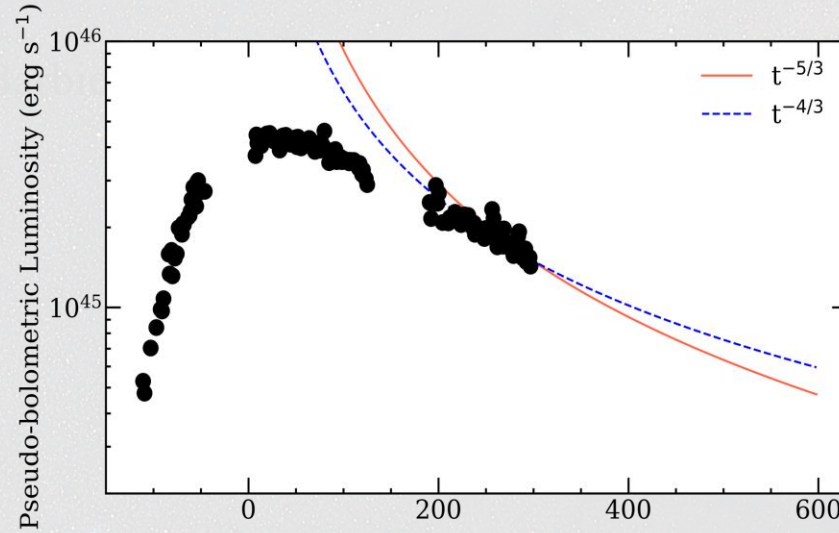
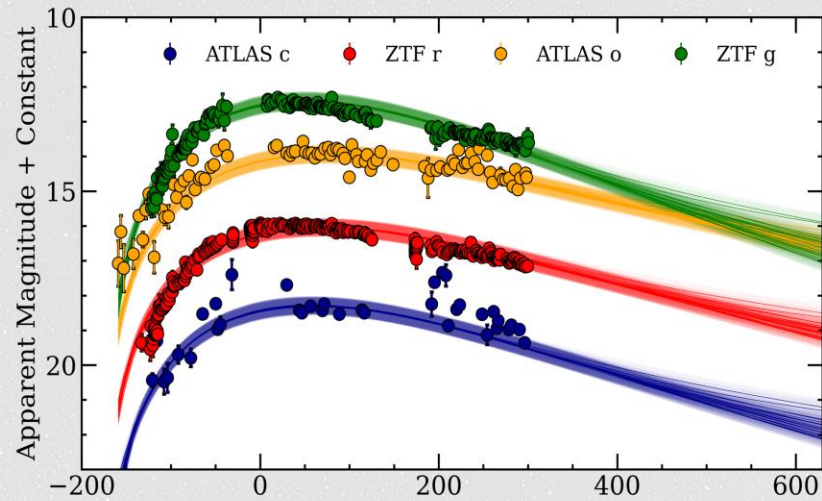
Comparison with other optical transients

Missing [O III] 4959, 5007

Subrayan et al. 2023b



A possible extreme tidal disruption candidate?



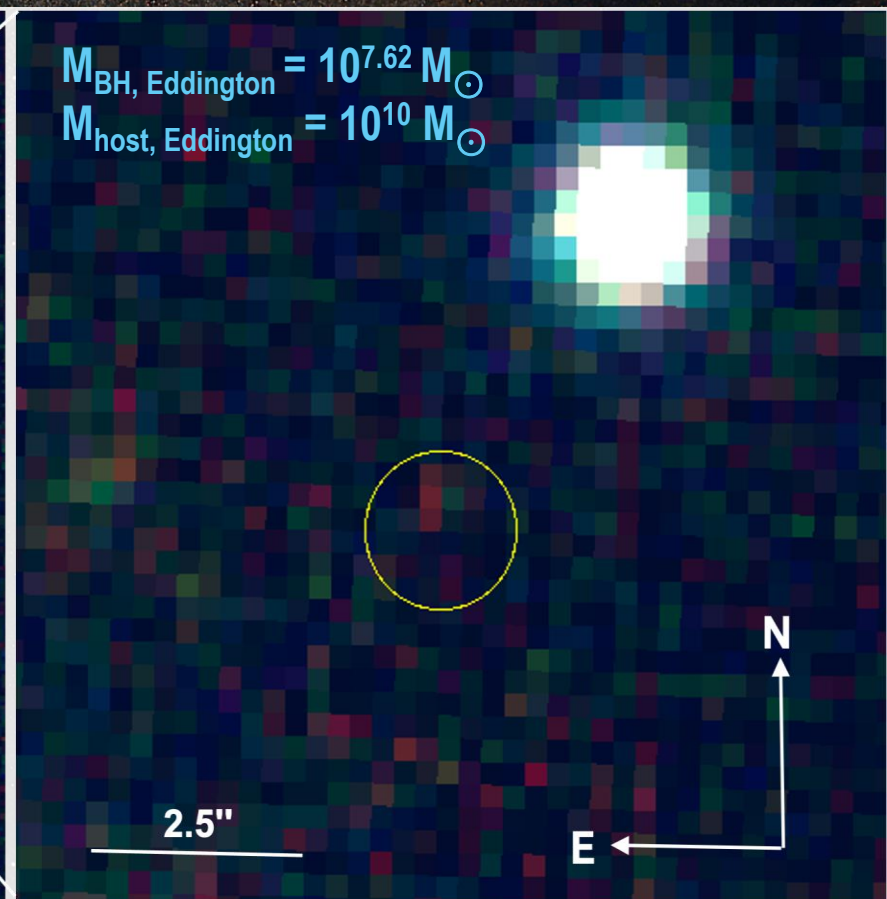
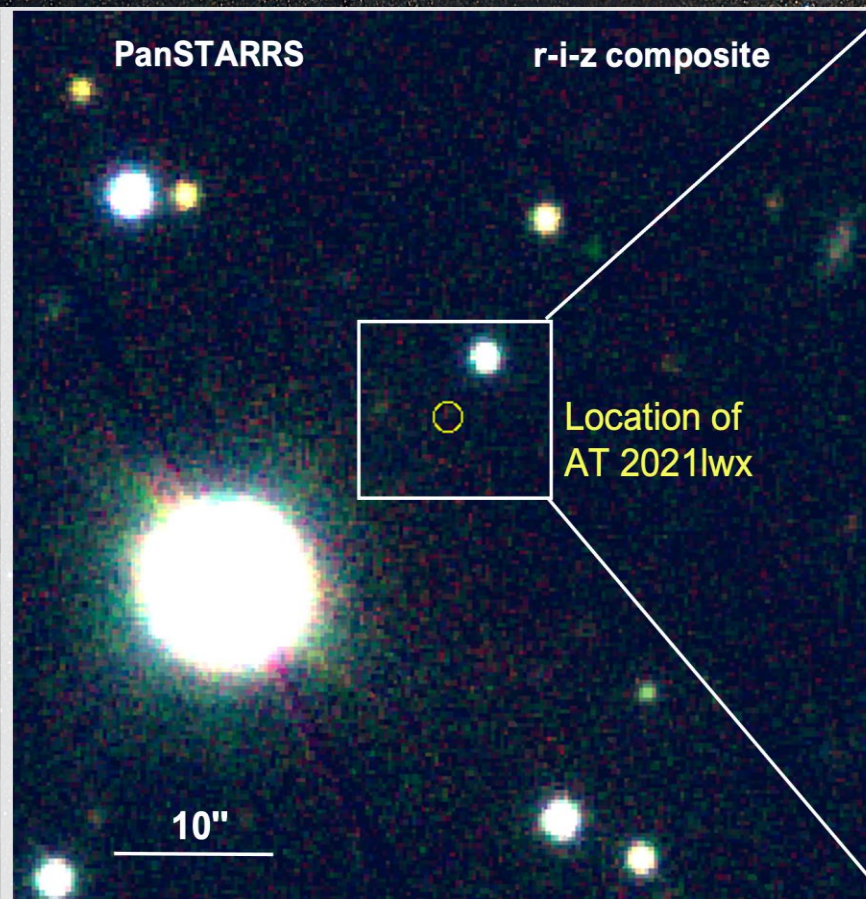
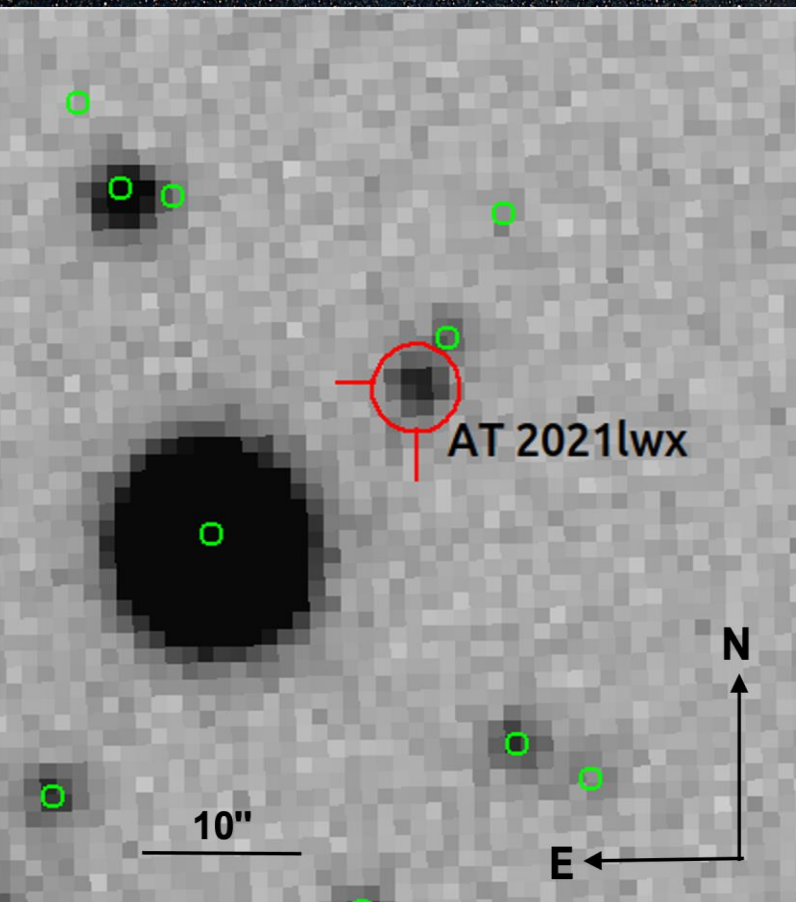
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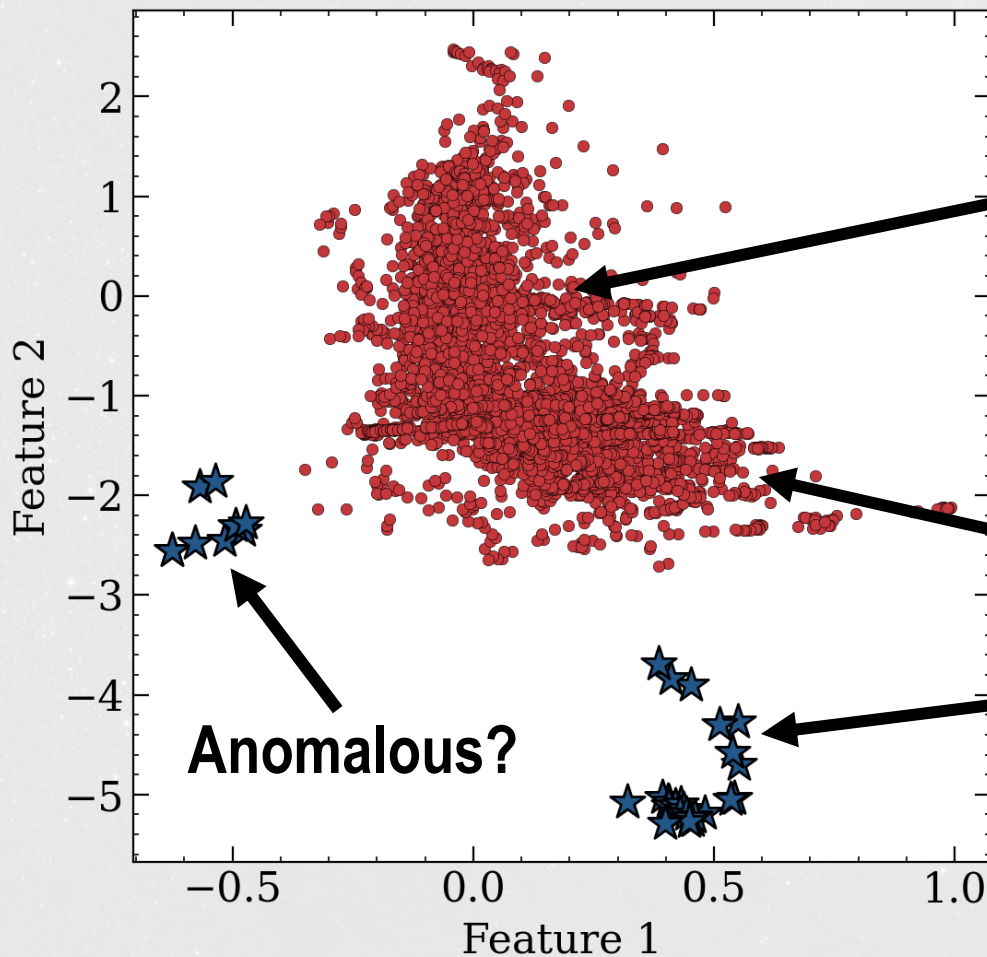


Subrayan et al. 2023b

The story is incomplete yet! Confirming a host for AT 2021lwx is a fundamental test to the current physical interpretations.
More observations will yield exciting science! Stay tuned!



Data Driven Anomaly Detection



While extremely useful for discovering rare transients, data driven modeling doesn't tell us if we understand the underlying physics

A "common" transient may still be poorly fit by theoretical models

Data driven modeling tells us how similar new events are to previous events