Computationally inexpensive kilonova models and parameter inference of AT2017gfo

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March 14, 2023

Covering: Ristic+ (2022) *PRR* 4, 013046
Ristic+ (2023) *in prep.*

RIT

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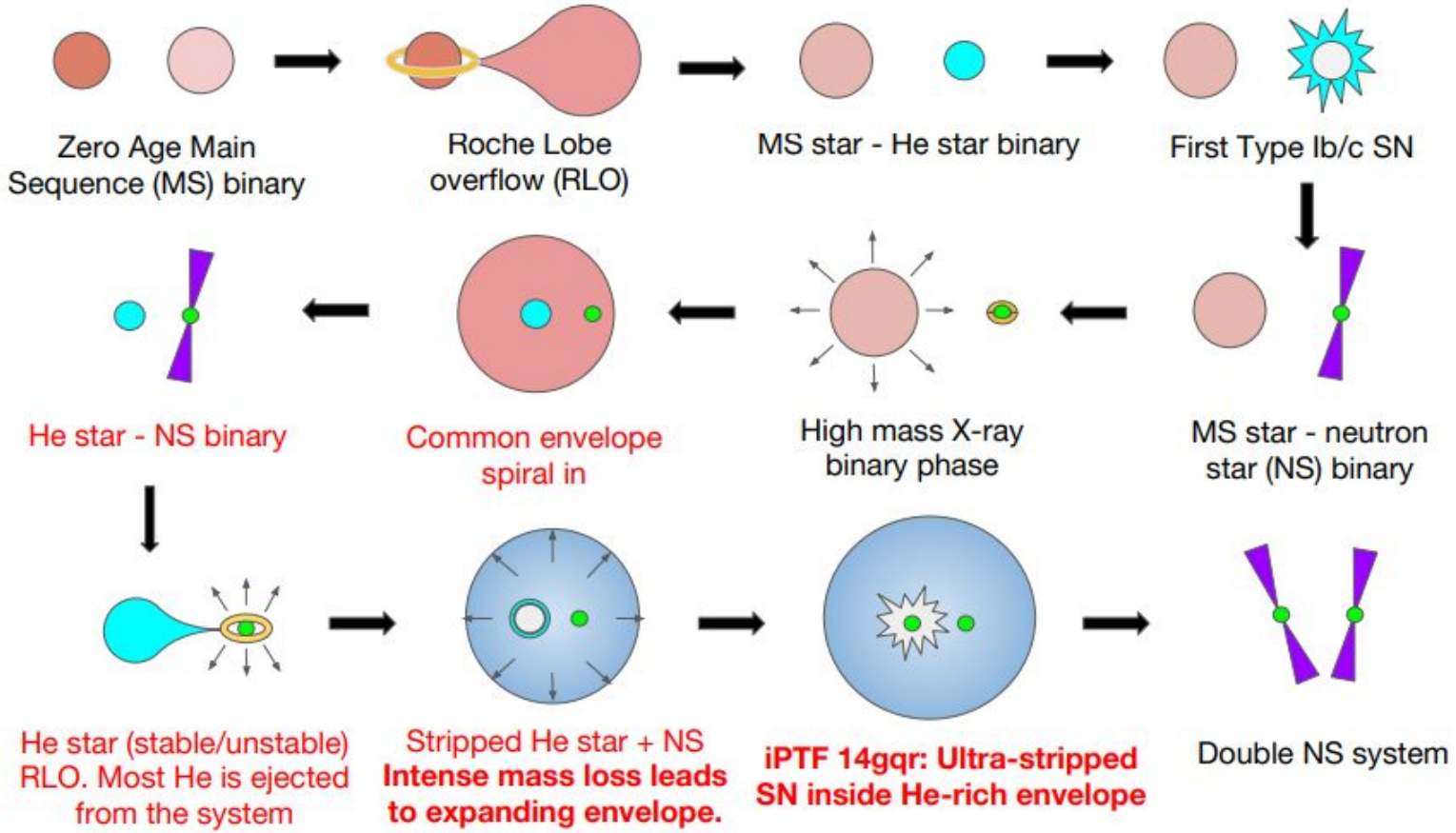
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

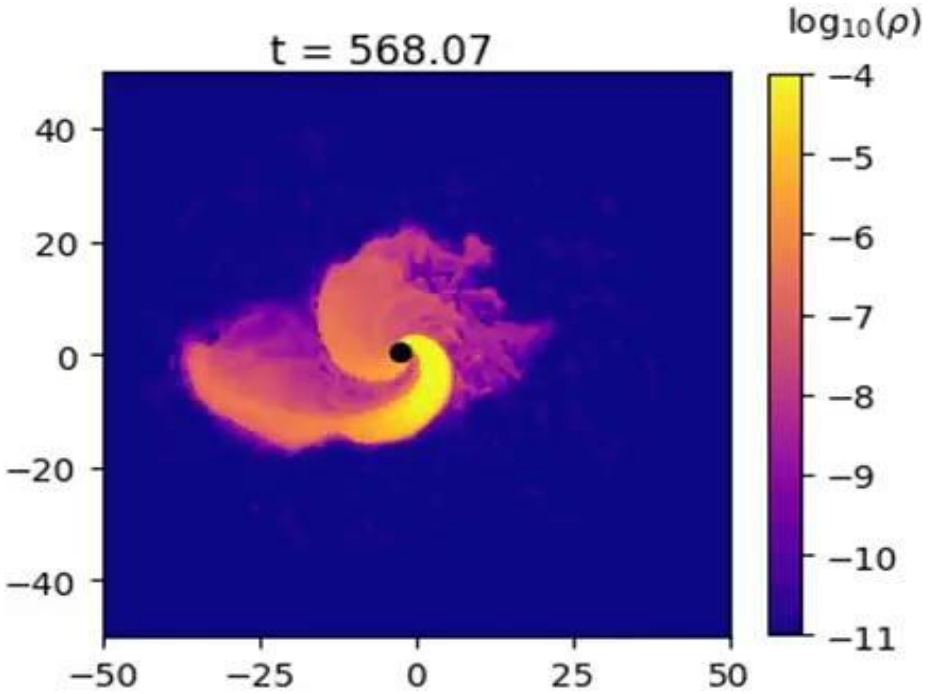
Outline

- Kilonova background
- Light curve interpolation and parameter inference
- Spectra interpolation and parameter inference
- Blue underluminosity problem
- Current attempts at a solution
- Future work



De+ (2018) *Science* 362, 201D

Neutron Star Merger Ejecta



Video Courtesy of T. Gupte (RIT)

Electron Fraction and Beta Decay

$$Y_e = \frac{n_p}{n_p + n_n}$$

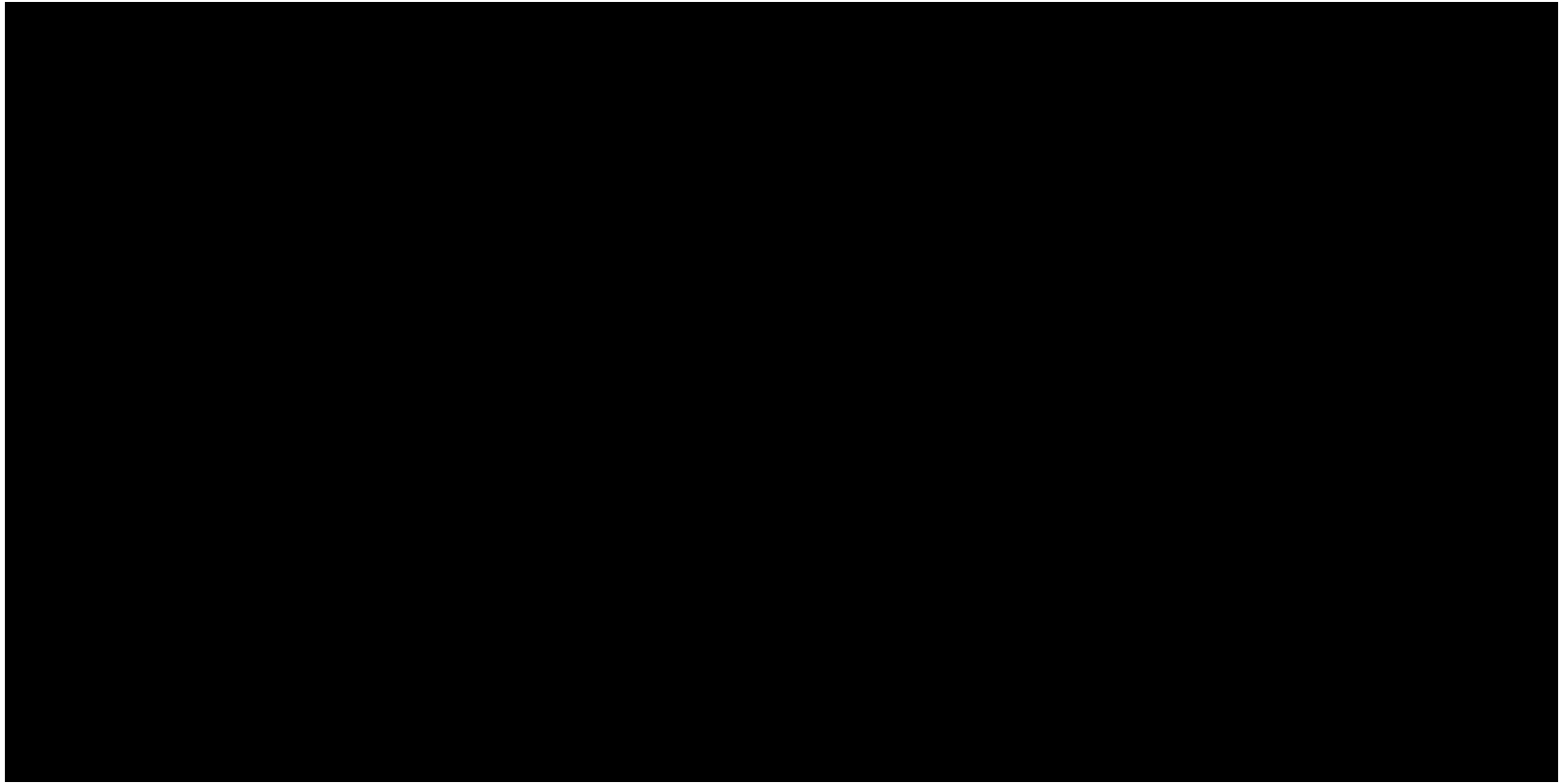
Neutron-rich: Ye → 0

Stable matter: Ye → 0.5

(Neglecting fission, etc...)

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}X' + e^{-} + \overline{\nu}_e$$

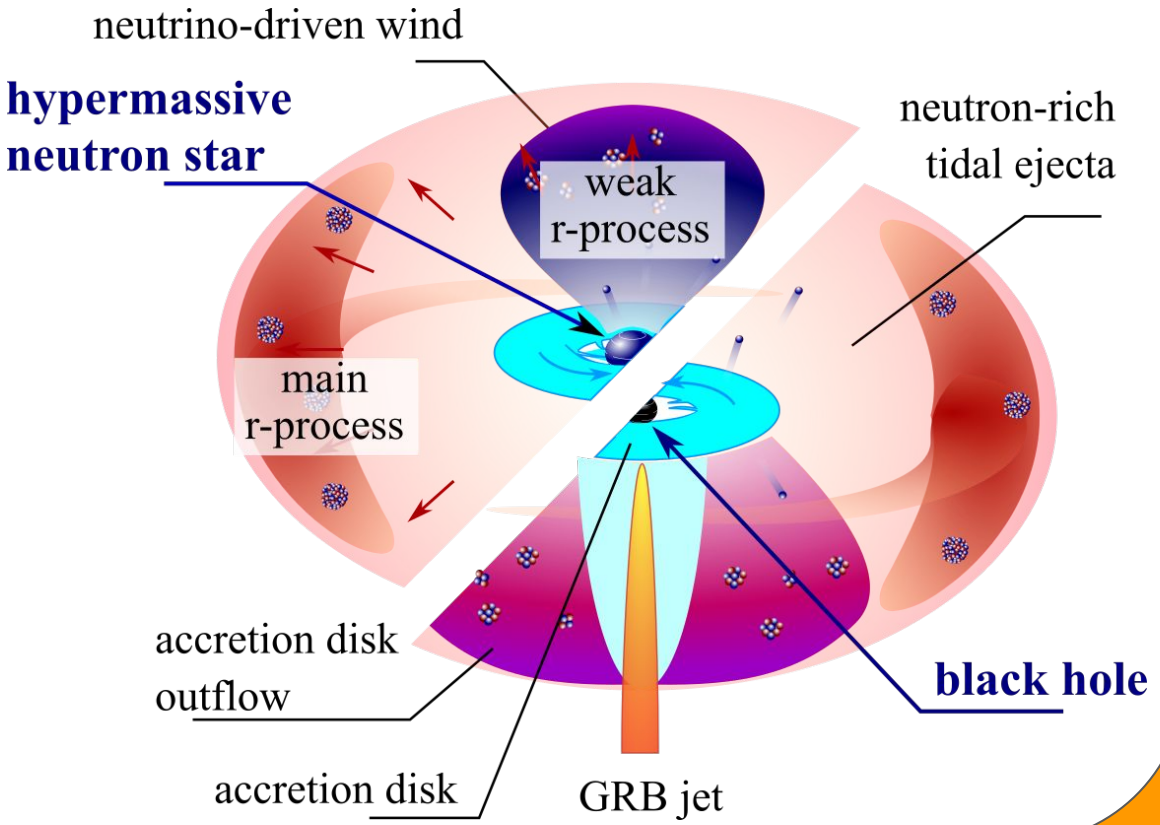
Rapid Neutron Capture Process (*r*-Process) Nucleosynthesis



Modeling Approach

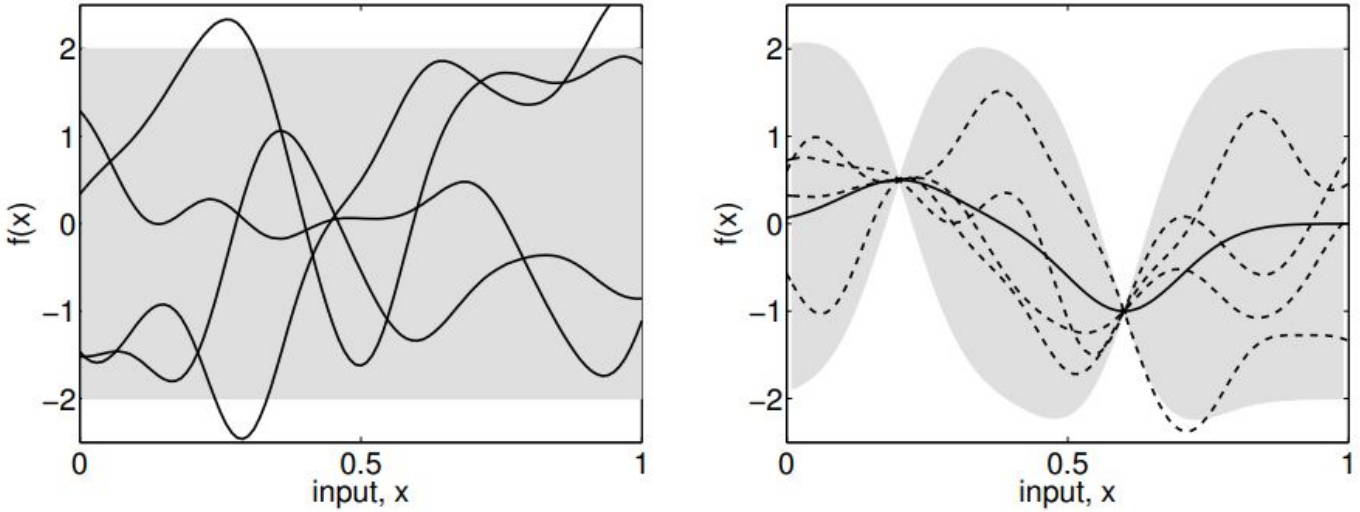
Model Parameters
(per component):

- Mass
- Velocity
- Morphology
- Composition



Korobkin+ (2021) *ApJ* 910, 116

Gaussian Processes for Machine Learning

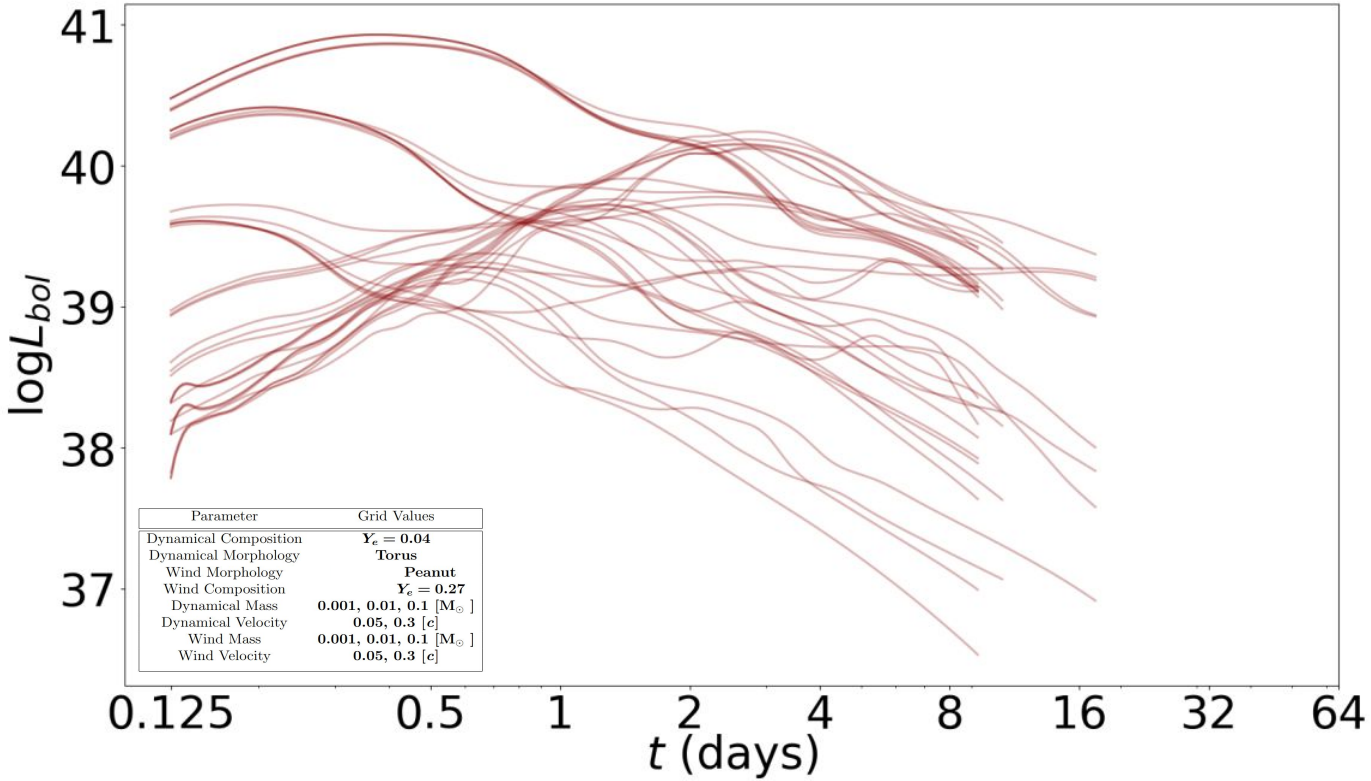


(a), prior (b), posterior

Figure 1.1: Panel (a) shows four samples drawn from the prior distribution. Panel (b) shows the situation after two datapoints have been observed. The mean prediction is shown as the solid line and four samples from the posterior are shown as dashed lines. In both plots the shaded region denotes twice the standard deviation at each input value x.

C. Rasmussen, C. Williams (2006)

Initial Simulation Grid



Parameter	Grid Values
Dynamical Composition	$Y_e = 0.04$
Dynamical Morphology	**Torus**
Wind Morphology	**Peanut**
Wind Composition	$Y_e = 0.27$
Dynamical Mass	**0.001, 0.01, 0.1** [$M_\odot$]
Dynamical Velocity	**0.05, 0.3** [c]
Wind Mass	**0.001, 0.01, 0.1** [$M_\odot$]
Wind Velocity	**0.05, 0.3** [c]

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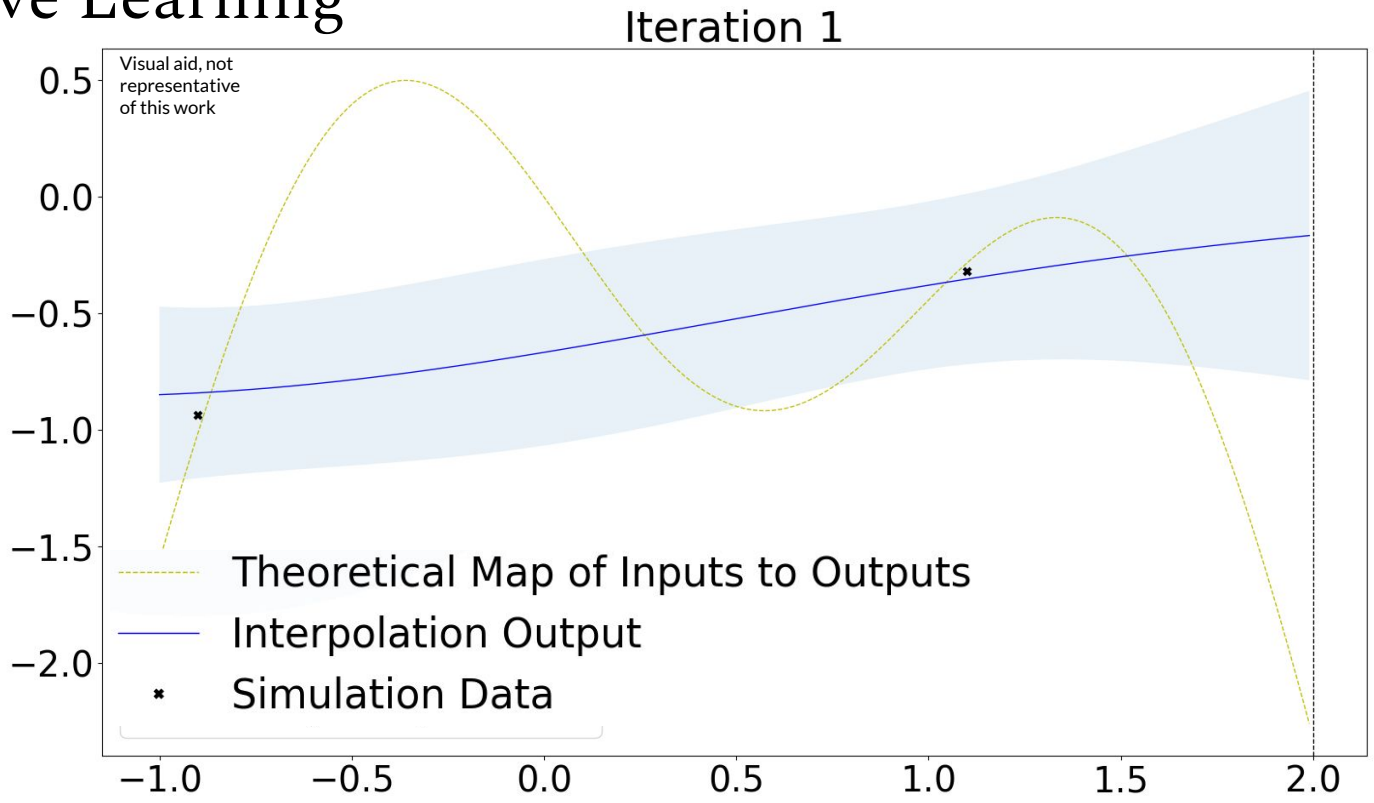
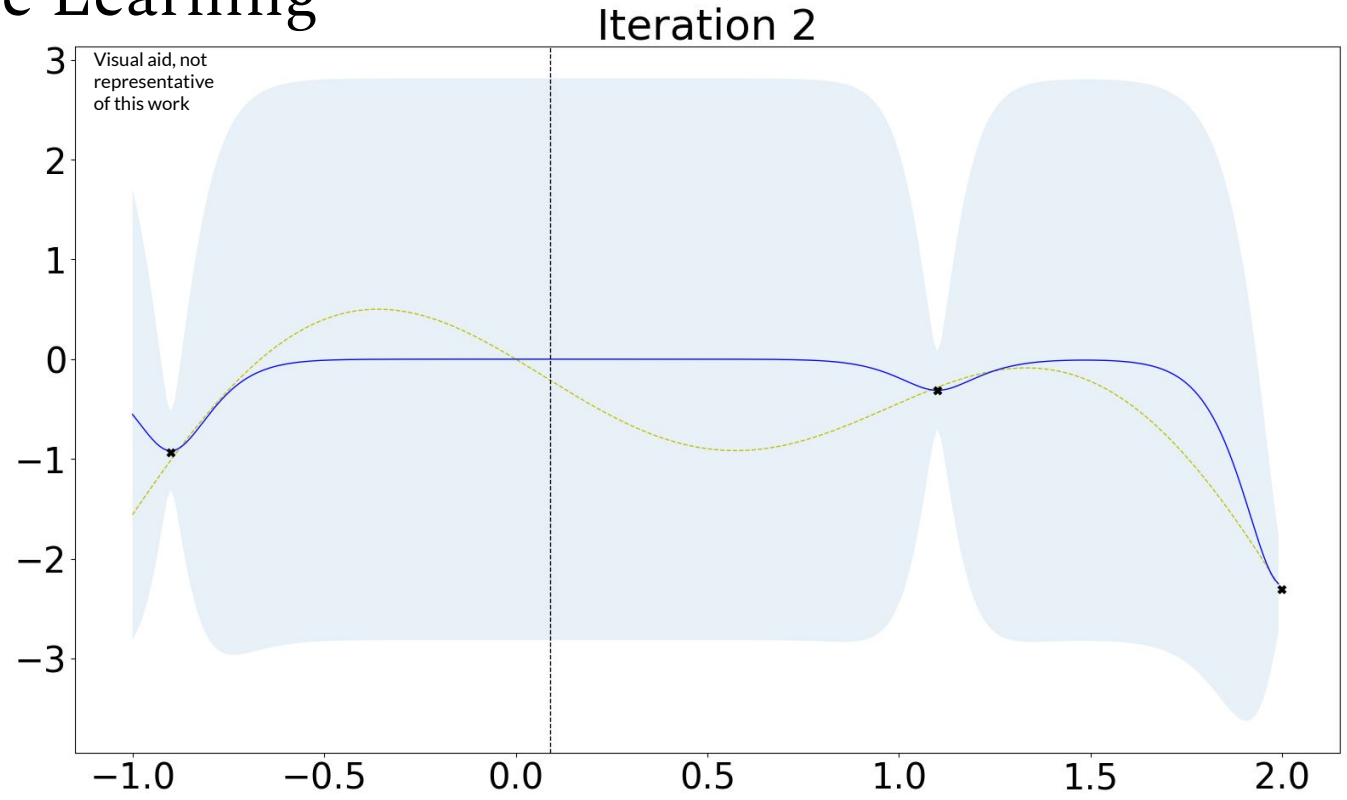
Active Learning



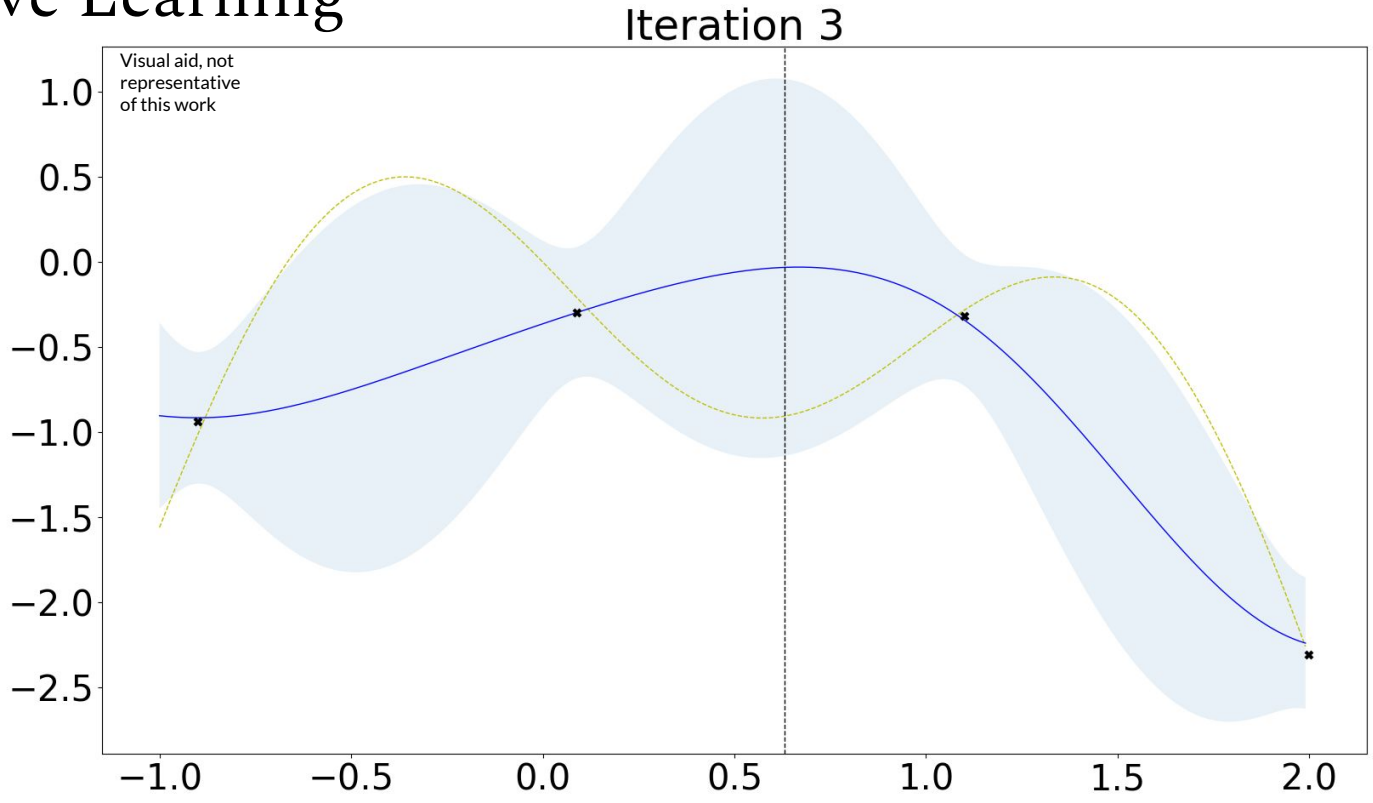
Credit: Martin Krasser

Active Learning



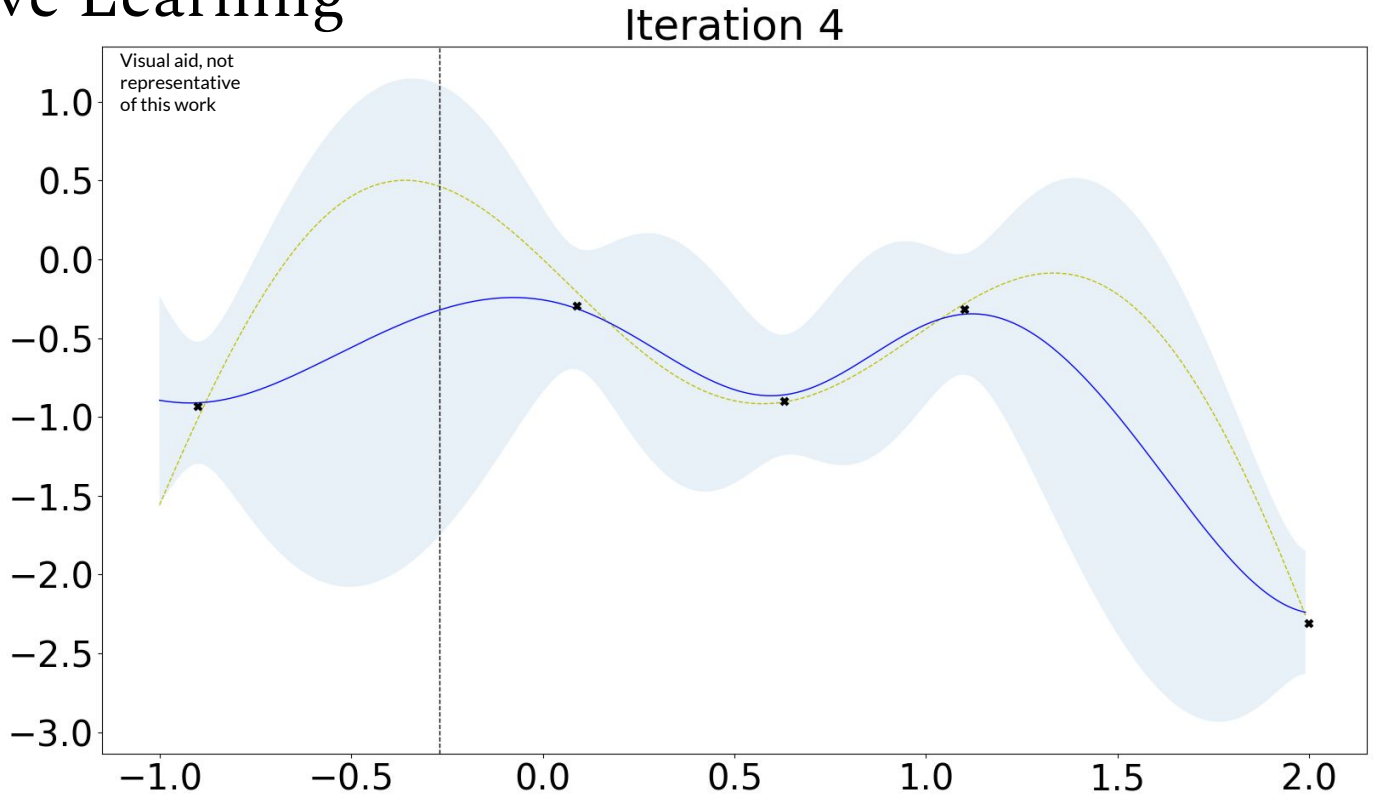
Credit: Martin Krasser

Active Learning



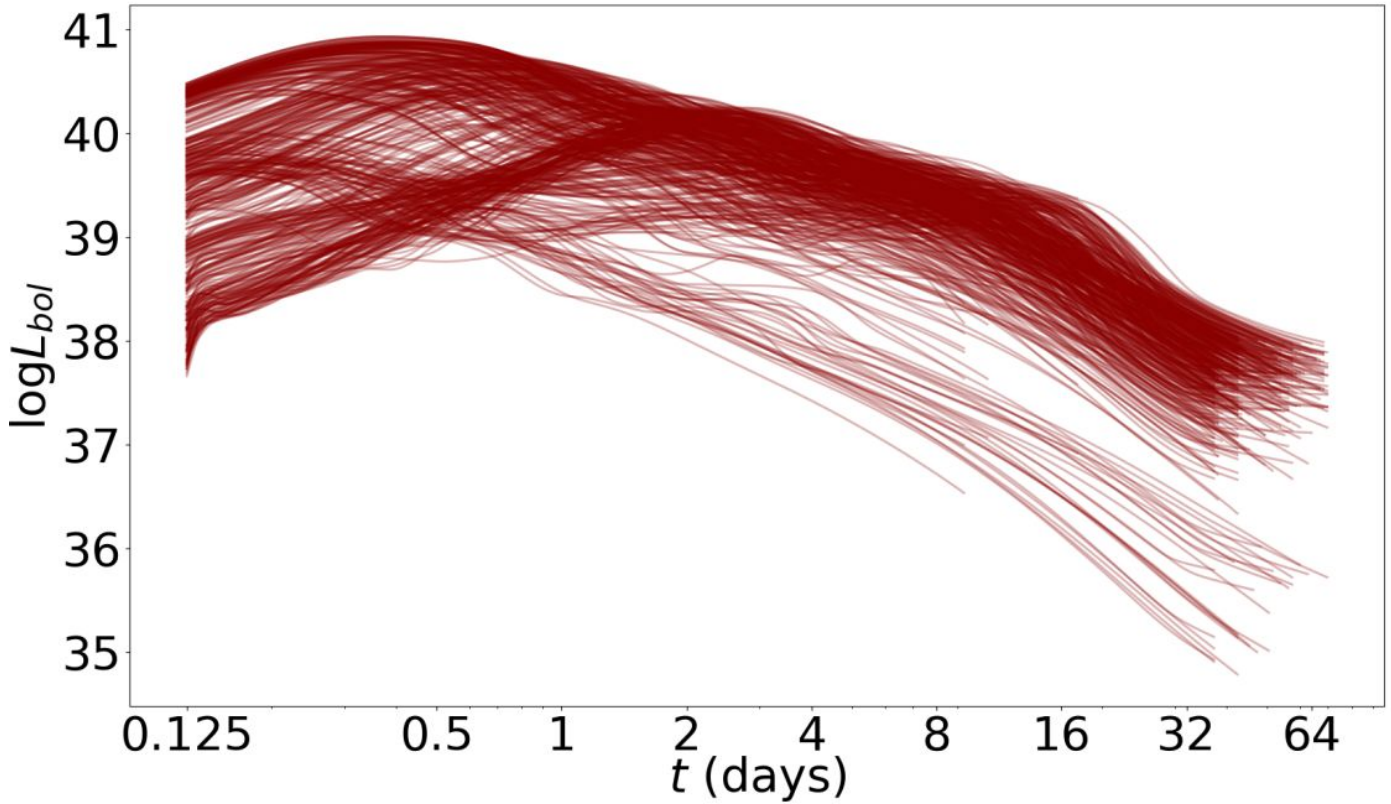
Credit: Martin Krasser

Active Learning



Credit: Martin Krasser

Final Simulation Grid



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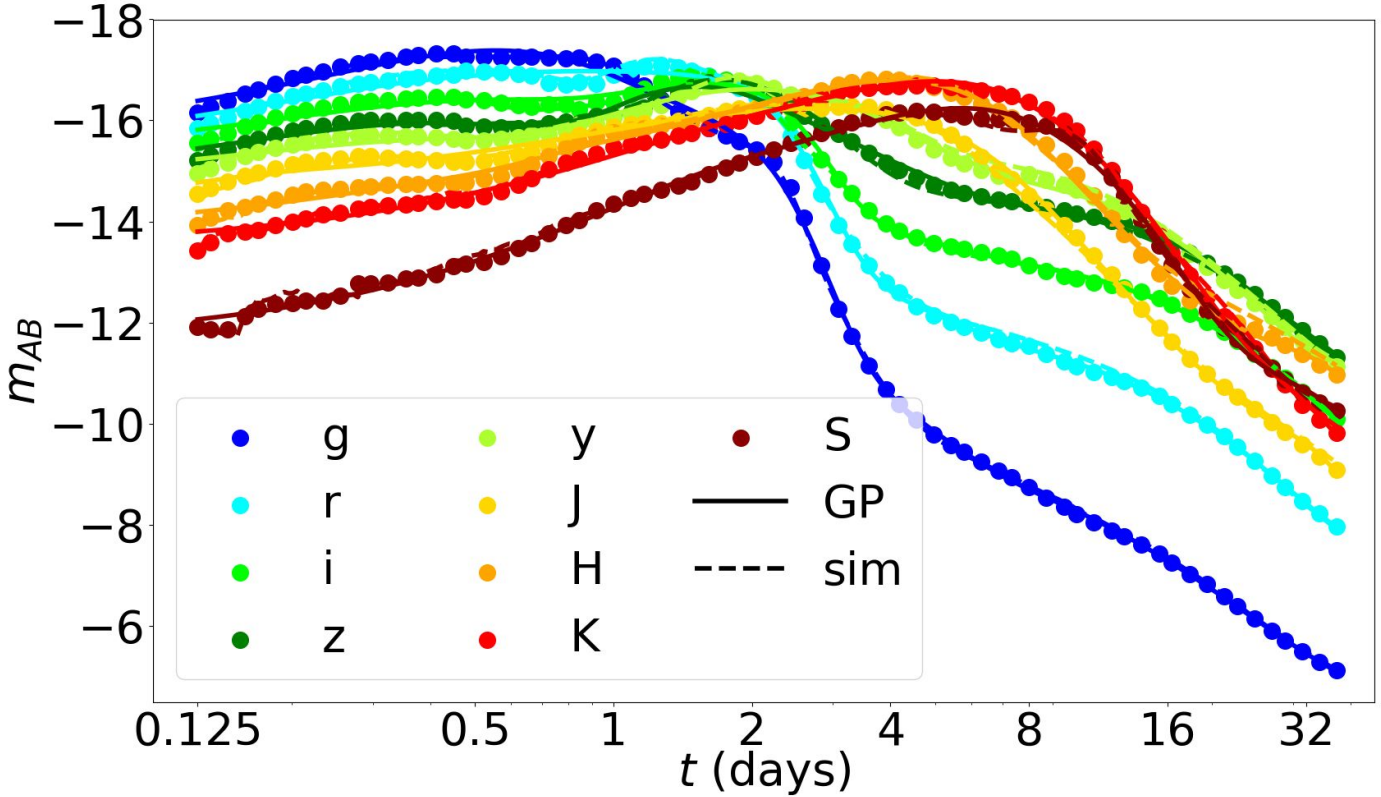
Interpolated Light Curves



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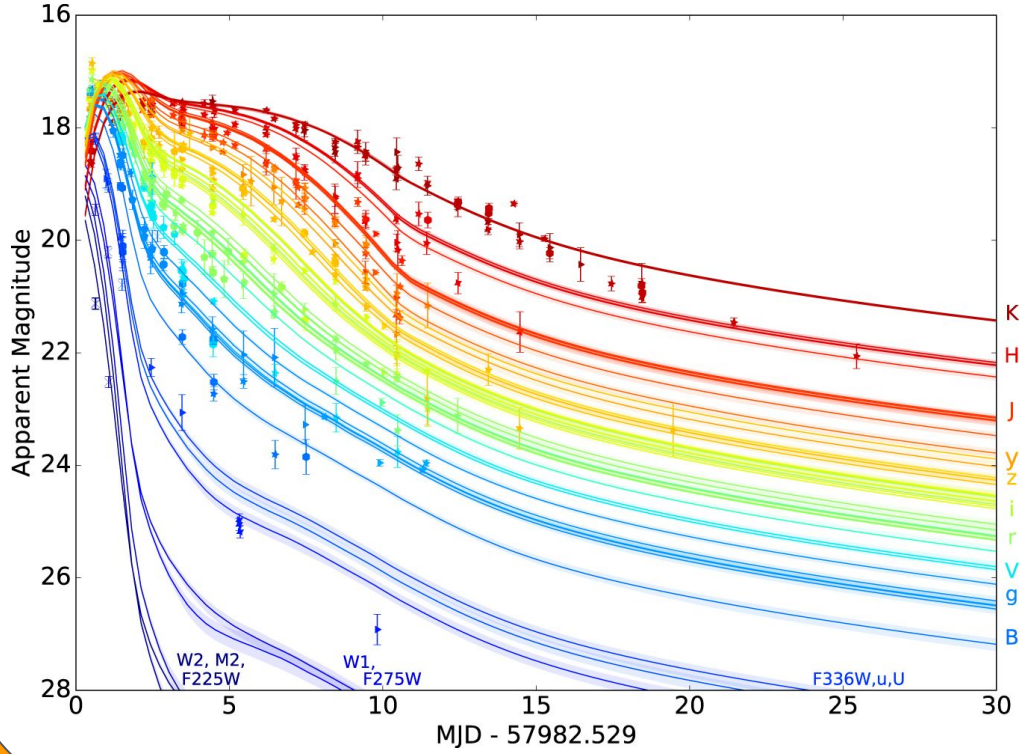
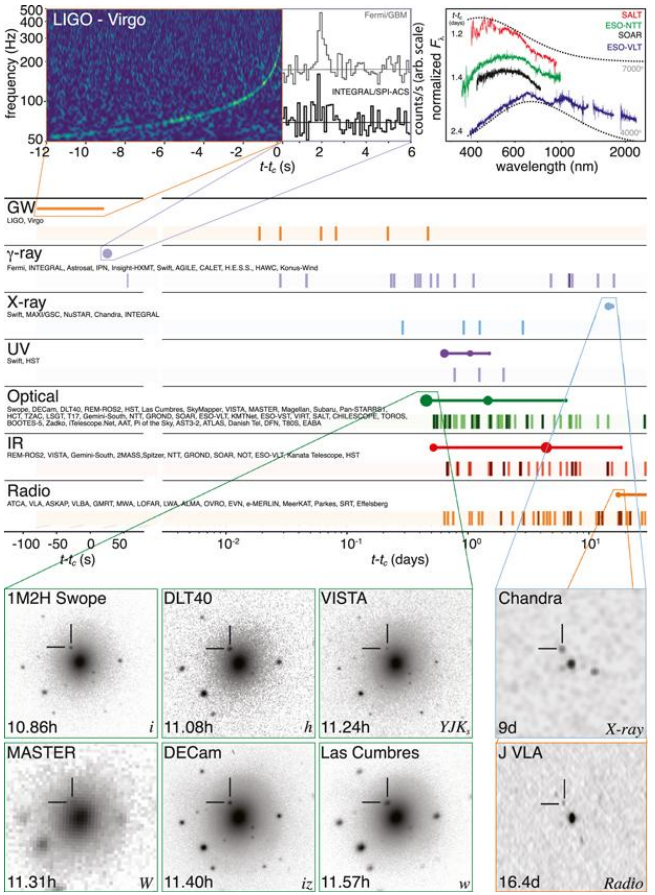
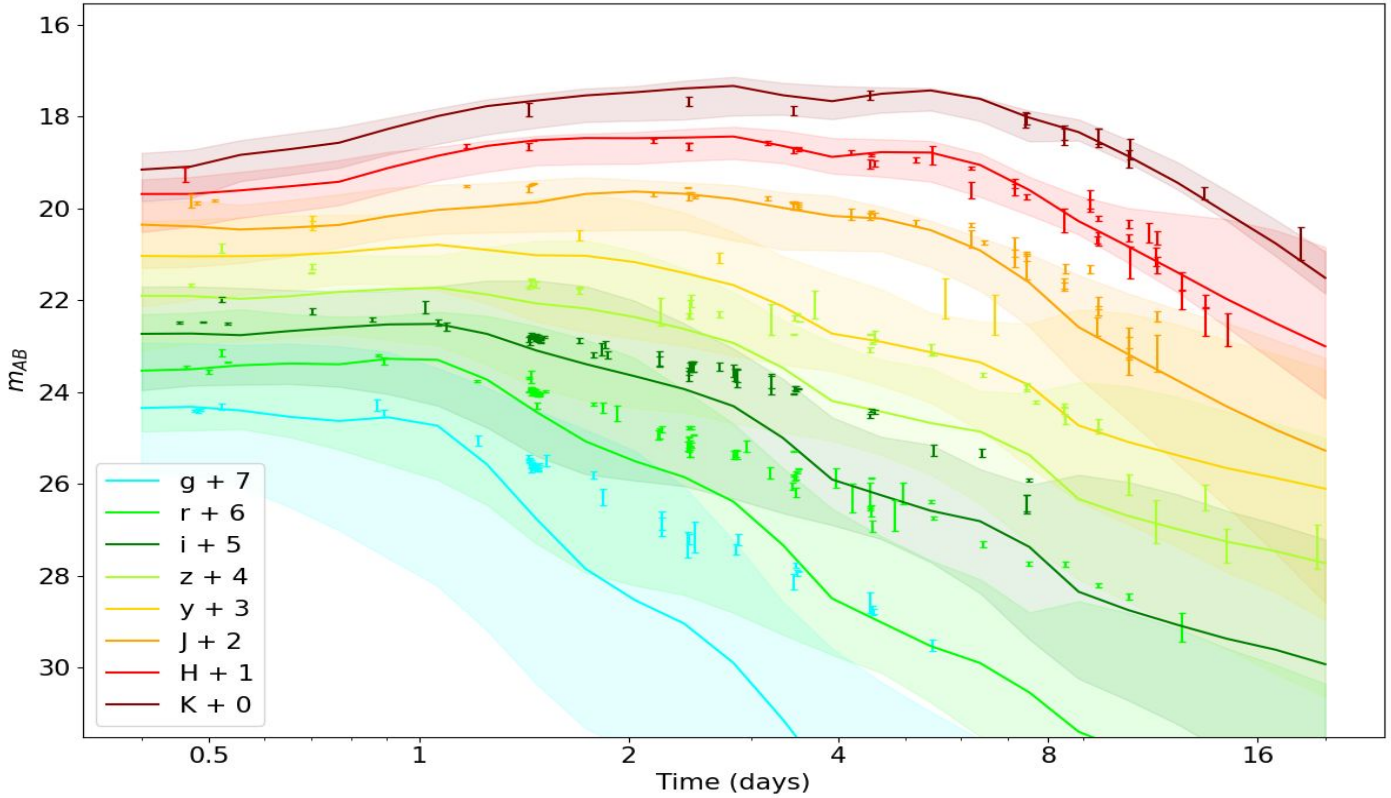
The AT2017gfo Detection





A. Villar et al. 2017 *ApJL* 851, L21; B. P. Abbott et al. 2017 *ApJL* 848, L12

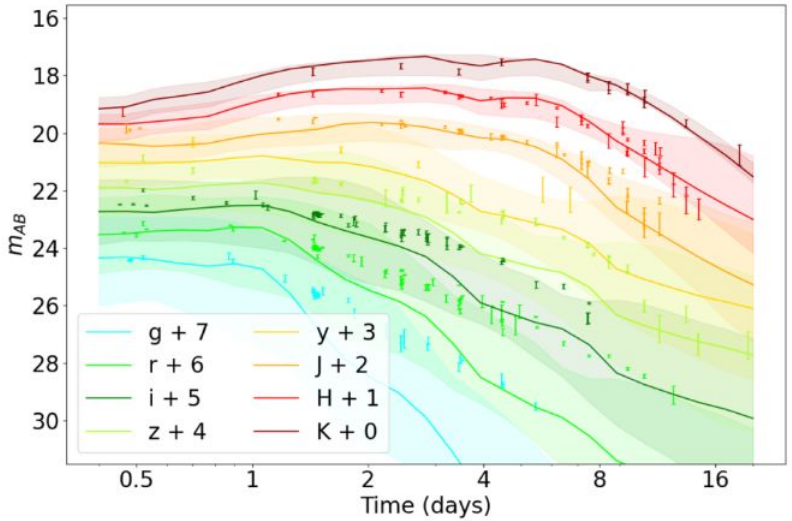
Comparison to AT2017gfo Light Curves



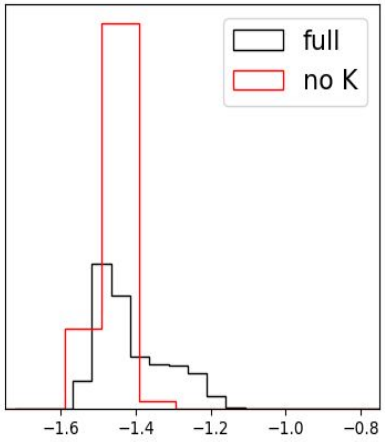
Ristic+ (2022) *PRR* 4 013046

Inference with Our Kilonova Models

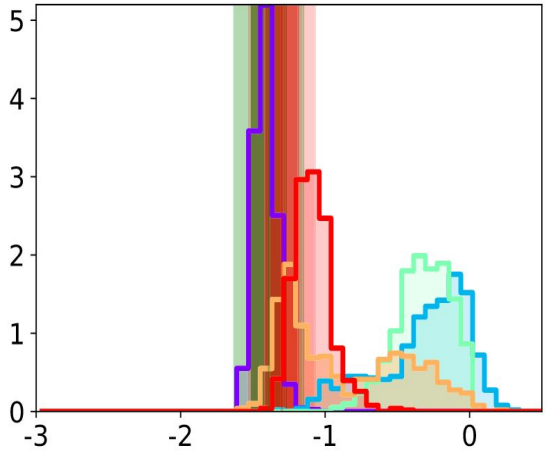
AT2017gfo observed vs. predicted light curves



Ristic+ (2022)



Heinzel+ (2021)



$\log_{10}$ total ejected mass ($M_{\odot}$)

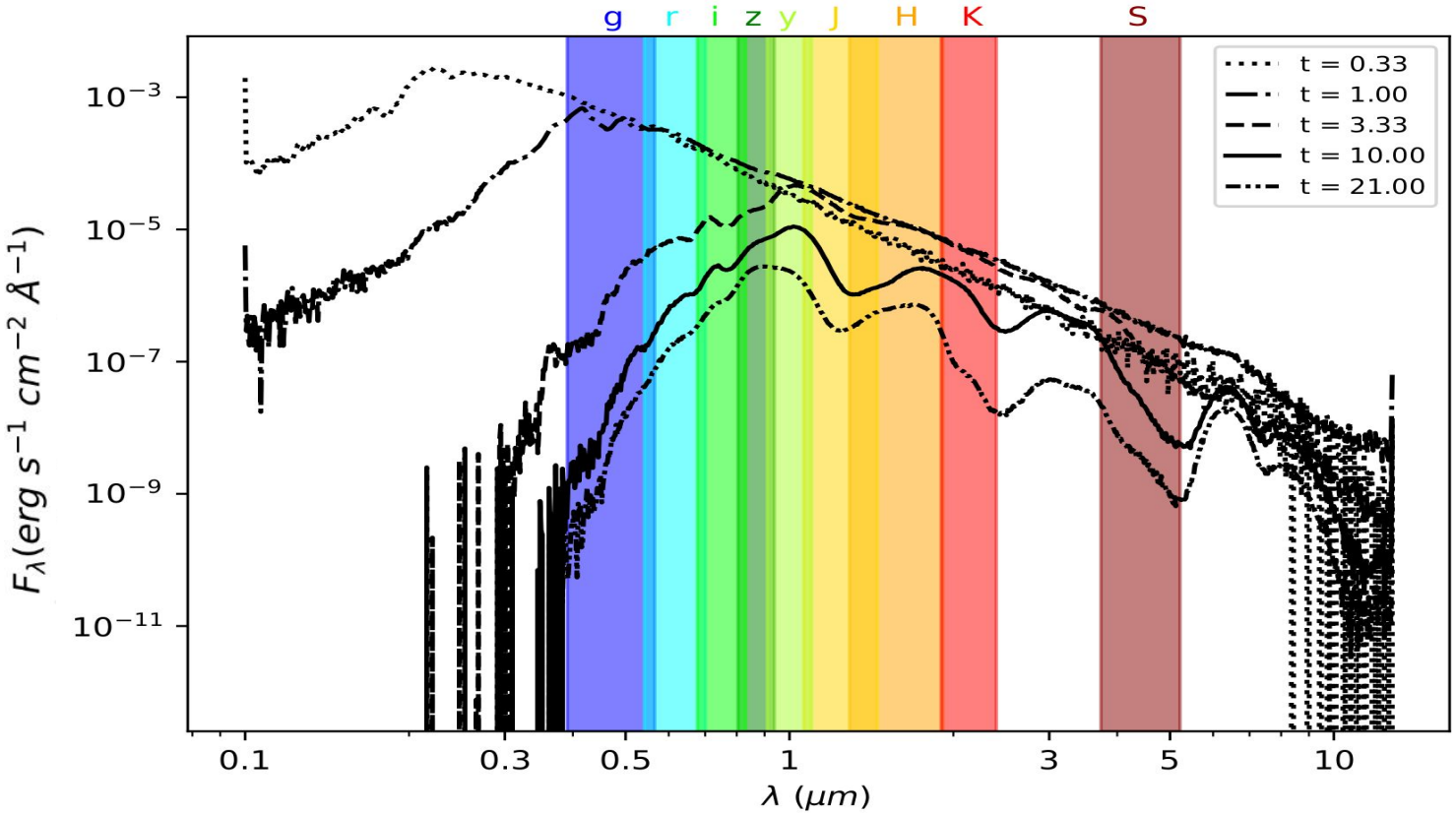
PE code repo: https://github.com/markoris/EM_PE

Data release: https://github.com/markoris/surrogate_kne

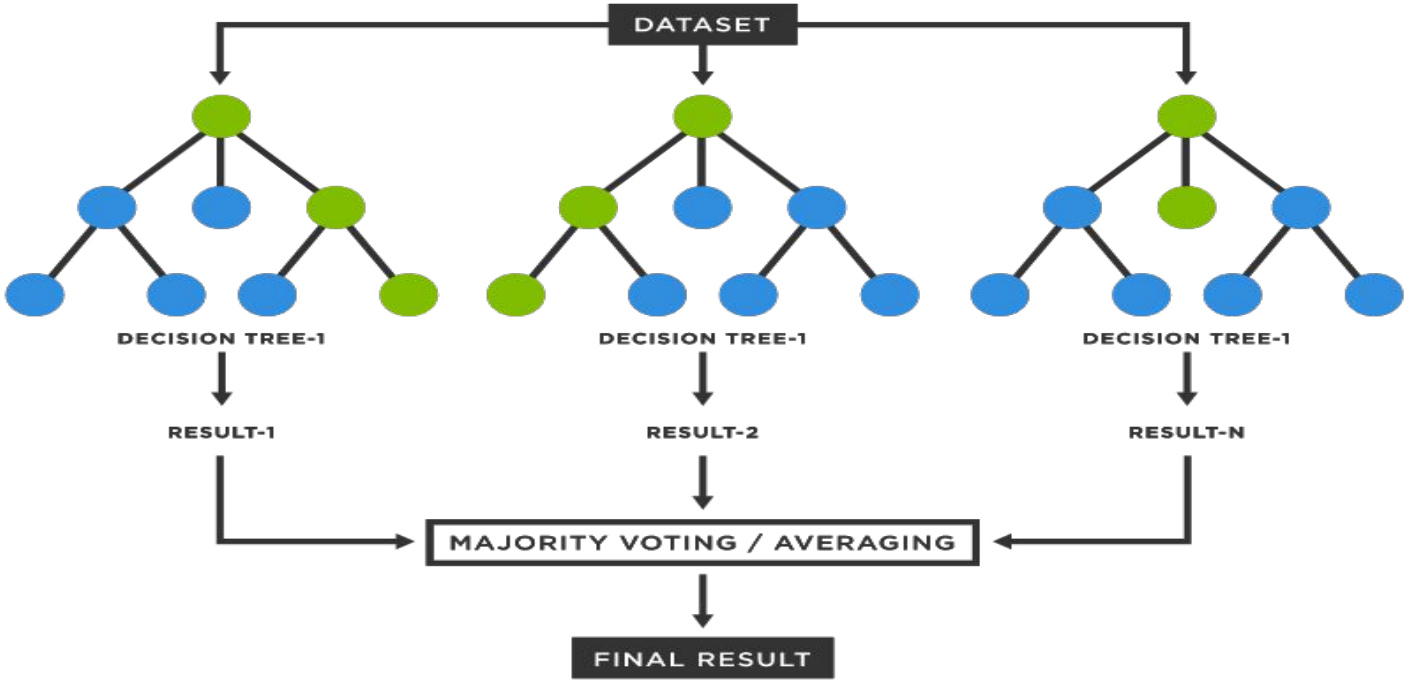
Simulation data repository: https://zenodo.org/record/5745556

Ristic+ (2022) *PRR* 4 013046, Heinzel+ (2021) *MNRAS* 502 3057H

What About the Spectra?

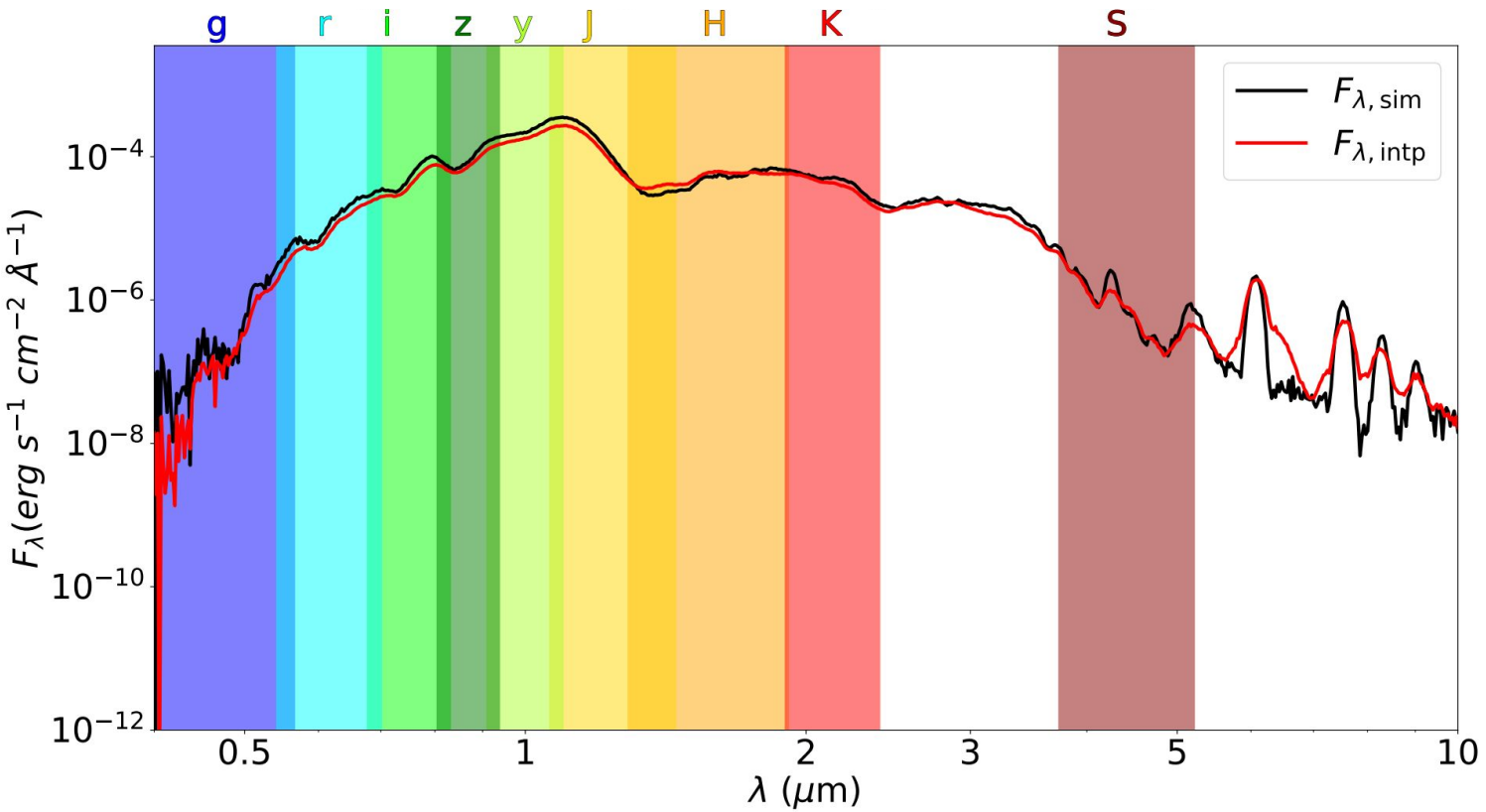


Random Forest Regression



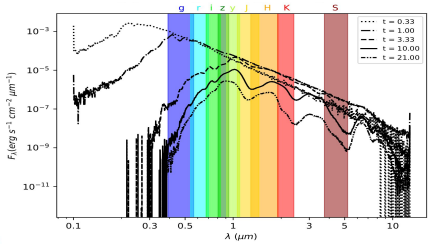
Credit: Tibco

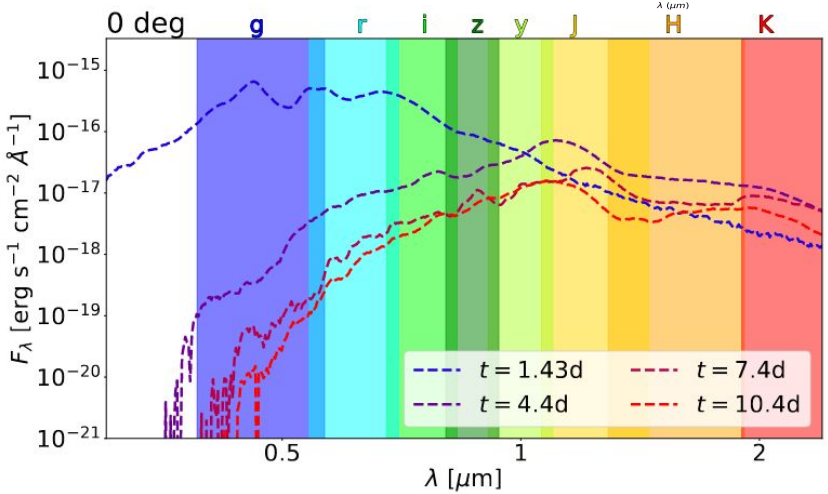
Spectra Interpolation with Random Forests

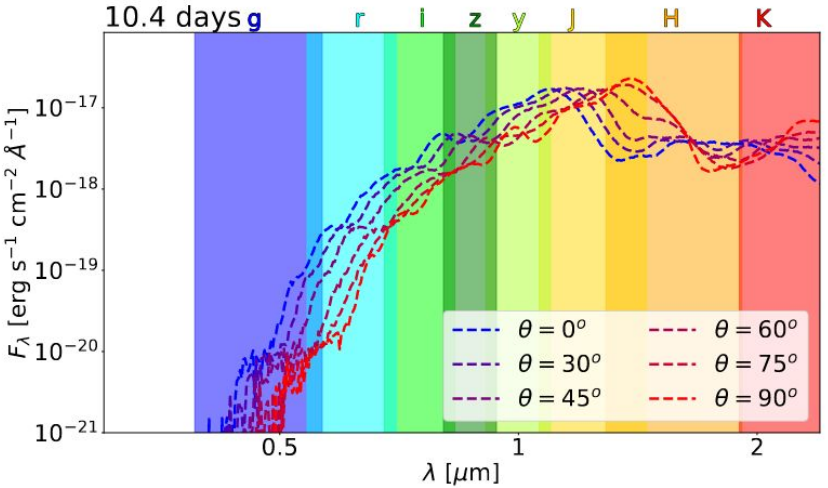


Ristic+ (2023) *in prep.*

Spectra Interpolation in Time/Angle

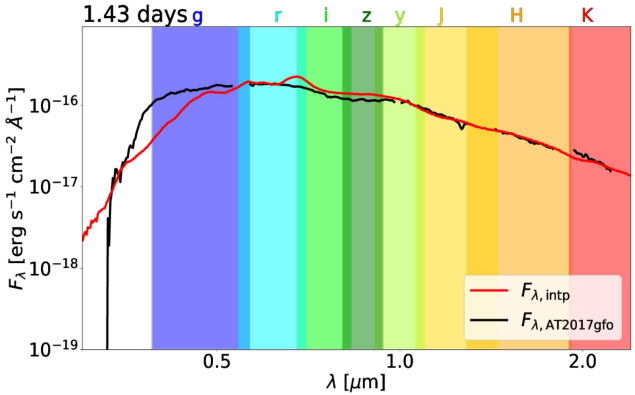


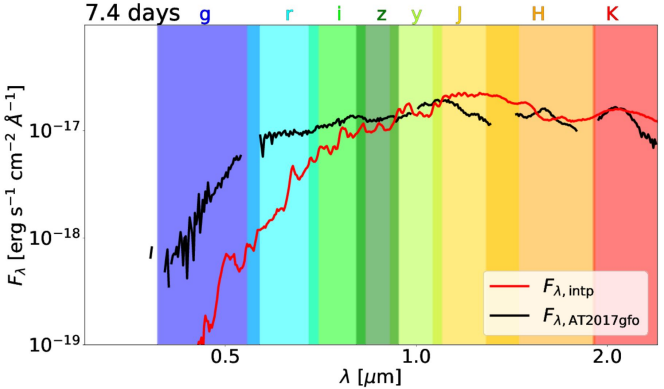


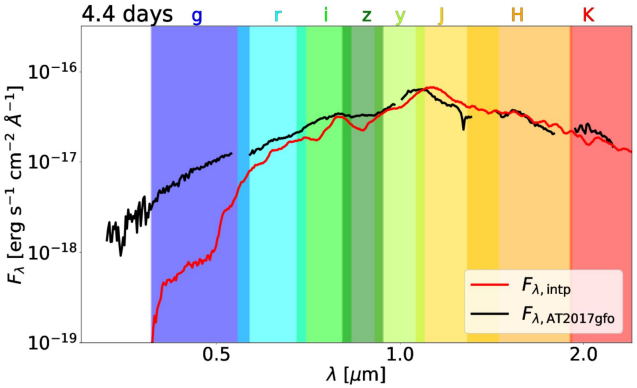


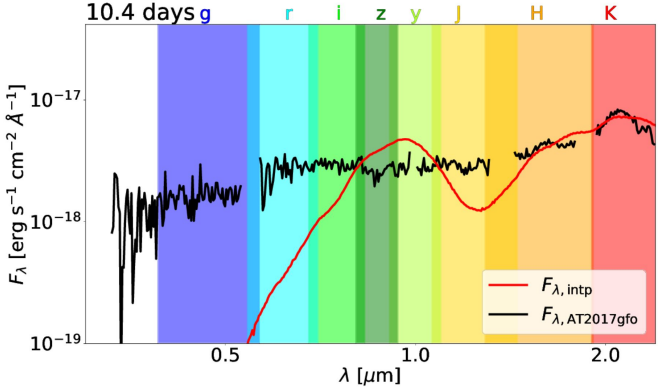
Ristic+ (2023) *in prep.*

Initial Two-Component Fit







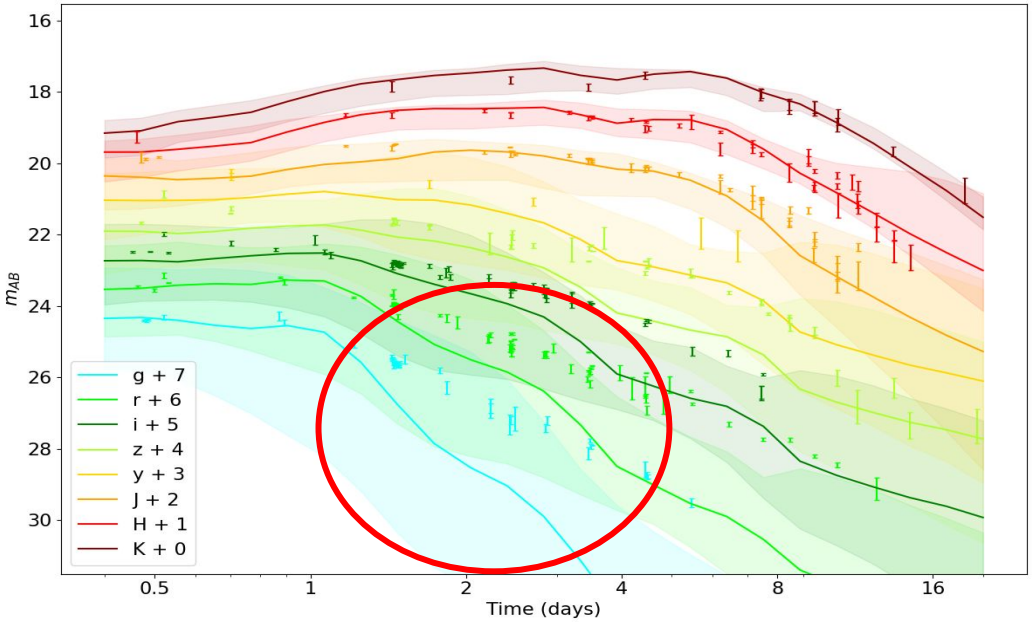


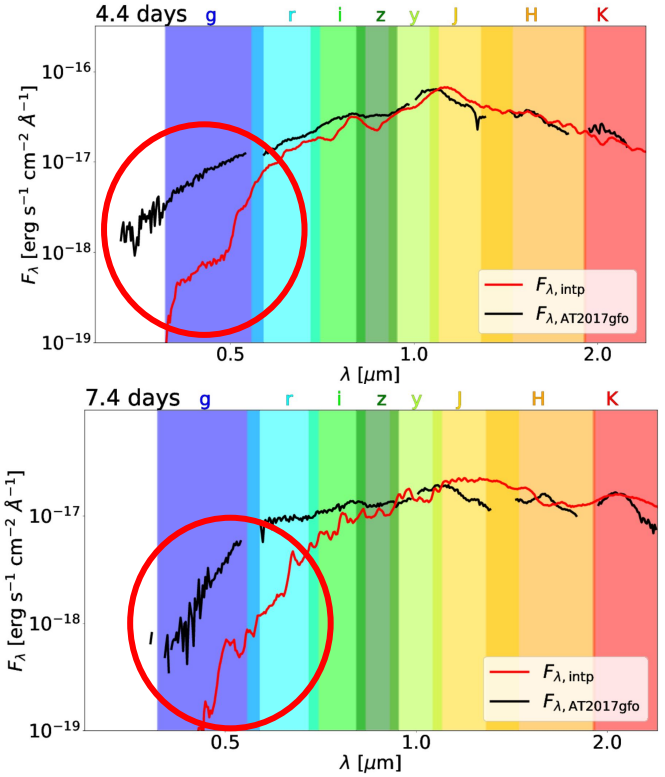
Two-Component Fit

AT2017gfo Observed Spectrum

Ristic+ (2023) *in prep.*

Consistent blue underluminosity





Ristic+ (2022) *PRR* 4 013046, Ristic+ (2023), *in prep.*

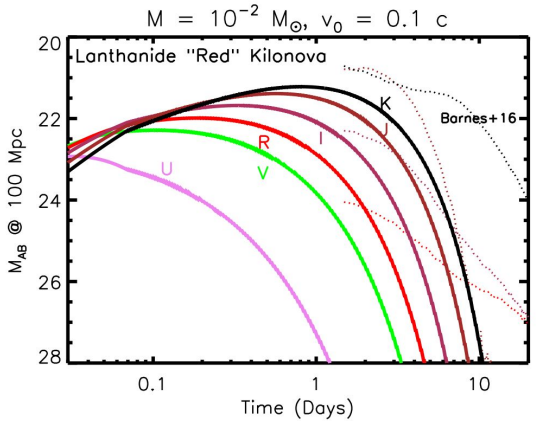
Metzger Model Description

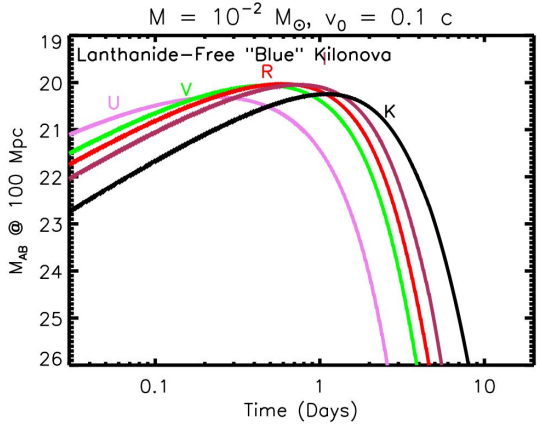
1. $$\frac{d(\delta E_v)}{dt} = -\frac{\delta E_v}{R_v}\frac{dR_v}{dt} - L_v + \dot{Q}$$

2. $$L_{\rm tot} = \int_{v_0} L_v \frac{dM_v}{dv} dv$$

3. $$T_{\rm eff} = \left(\frac{L_{\rm tot}}{4\pi\sigma R_{\rm ph}^2}\right)^{1/4}$$

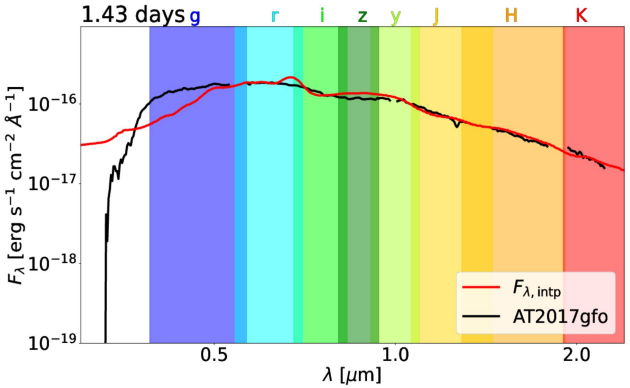
4. $$F_\nu(t) = \frac{2\pi h\nu^3}{c^2}\frac{1}{\exp\left[h\nu/kT_{\rm eff}(t)\right]-1}\frac{R_{\rm ph}^2(t)}{D^2}$$

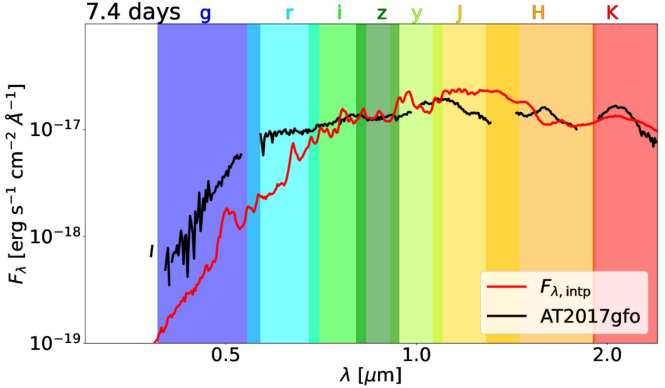


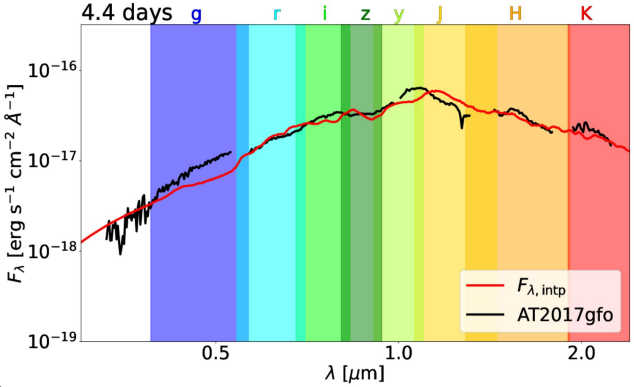


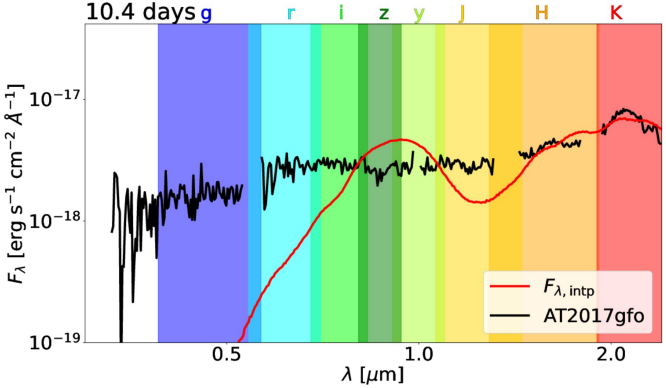
Metzger (2019) *LRR* 23, 1M

Toy Model Three-Component Fit







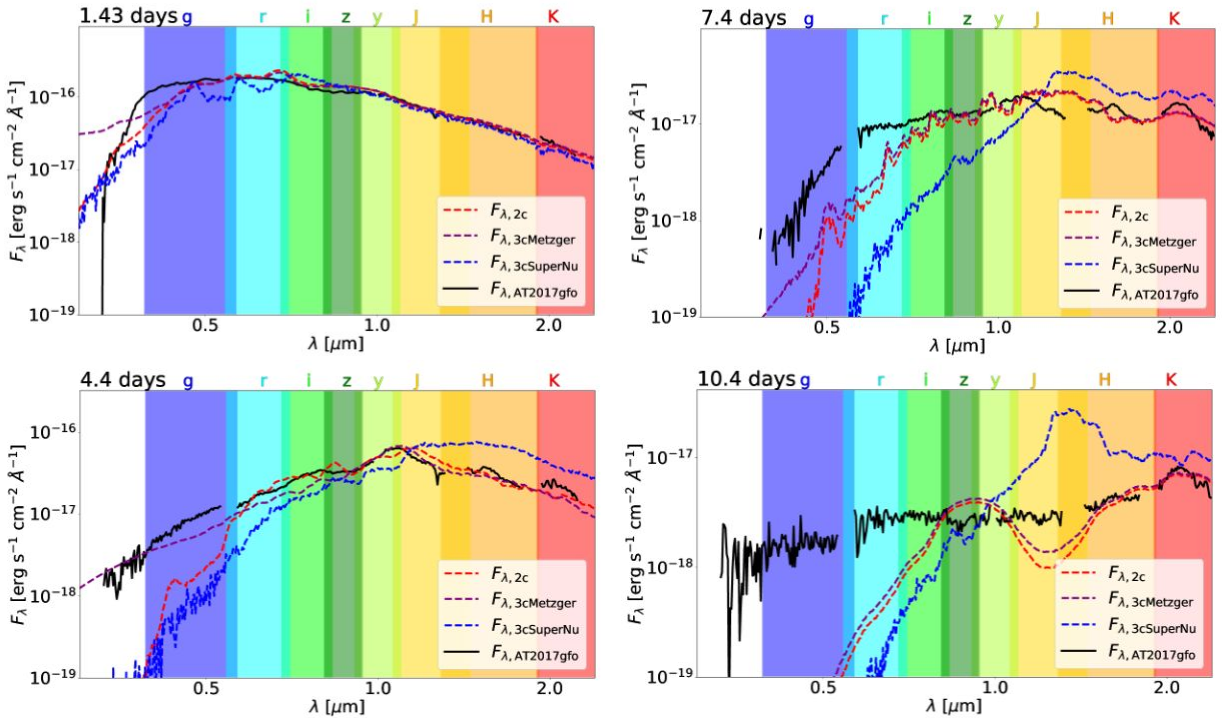


Two-Component Fit

AT2017gfo Observed Spectrum

Ristic+ (2023) *in prep.*

Realistic Third-Component Implementation



Two-Component Fit

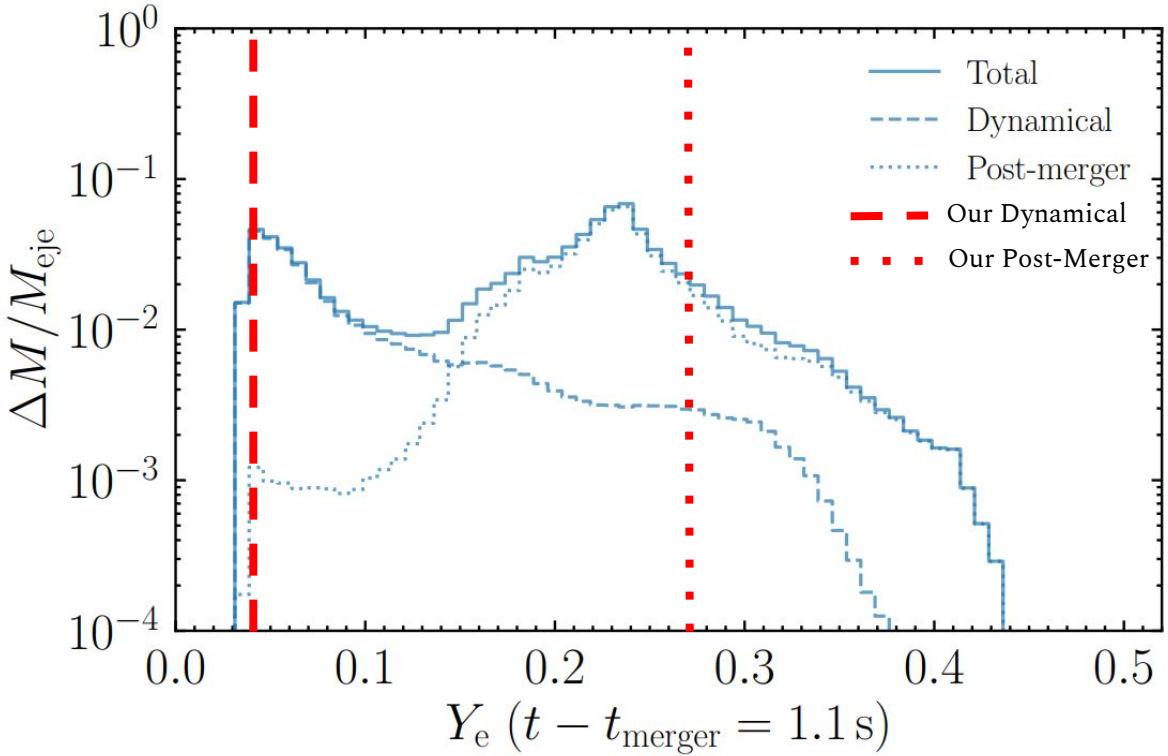
Three-Component Fit (Toy Model)

Three-Component Fit (Realistic Model)

AT2017gfo Observed Spectrum

Ristic+ (2023) *in prep.*

Things Don't Work; Future Studies

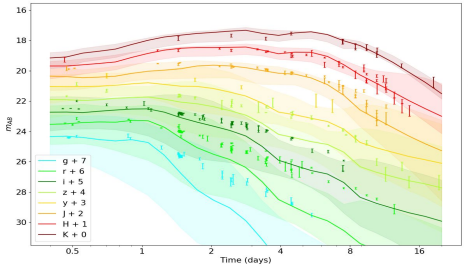


Kiuchi+ (2022) *arXiv* 2211.07637

Conclusions

1. Light-curve and spectra interpolation exhibit blue underluminosity
2. Two-component fit insufficient to match AT2017gfo observations
3. Three-component fit + toy model decent, but unrealistic
4. Realistic three-component fit also insufficient as-is
5. More realistic ejecta modeling in future studies

1.



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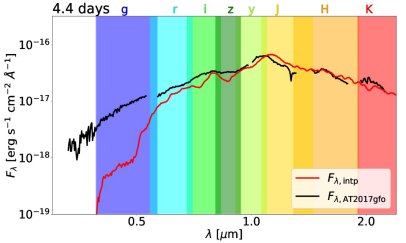

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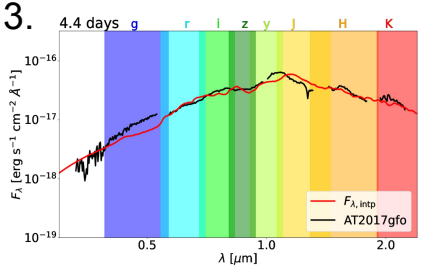

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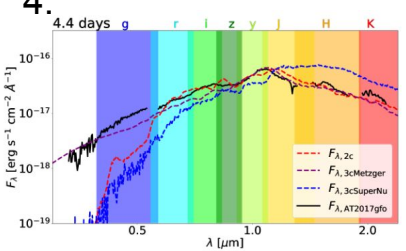

5.