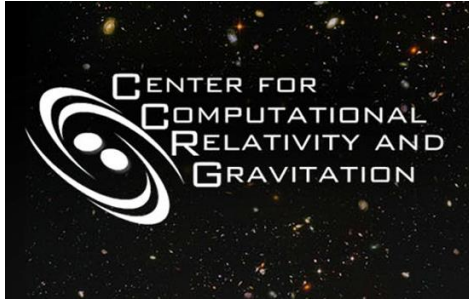


# Multi-messenger Astrophysics: Neutron star merger ejecta estimation with kilonova light curve surrogates



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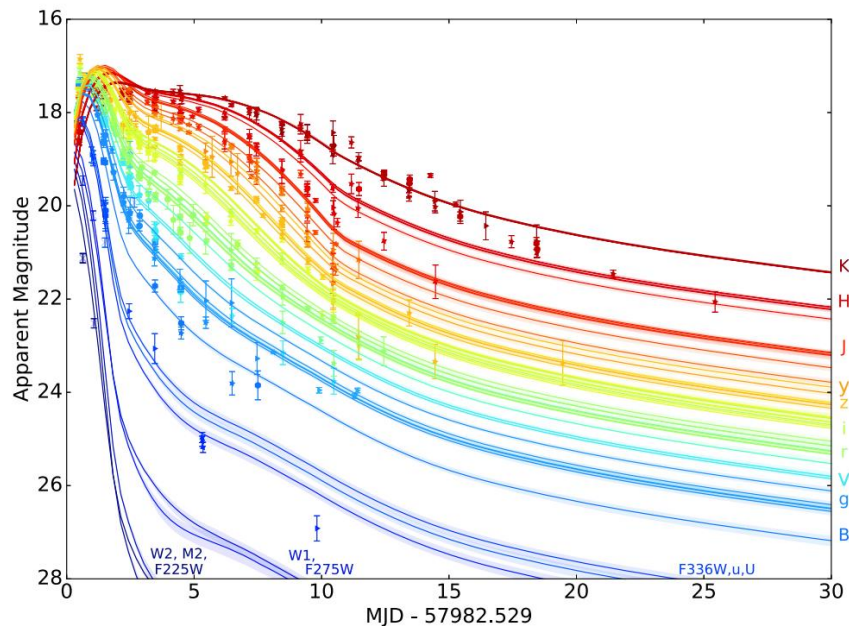
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APS April meeting [Multimessenger Astronomy II C13.6](#) | 4/15/2023

Collaborators: Marko Ristic, Richard O'Shaughnessy, Anjali Yelikar (RIT), Ryan Wollaeger, Chris Fontes, Eve Chase, Chris Fryer, Oleg Korobkin (LANL) [Phys. Rev. Res. 5, 013168 \(2023\)](#) or [arXiv:2211.04363](#)

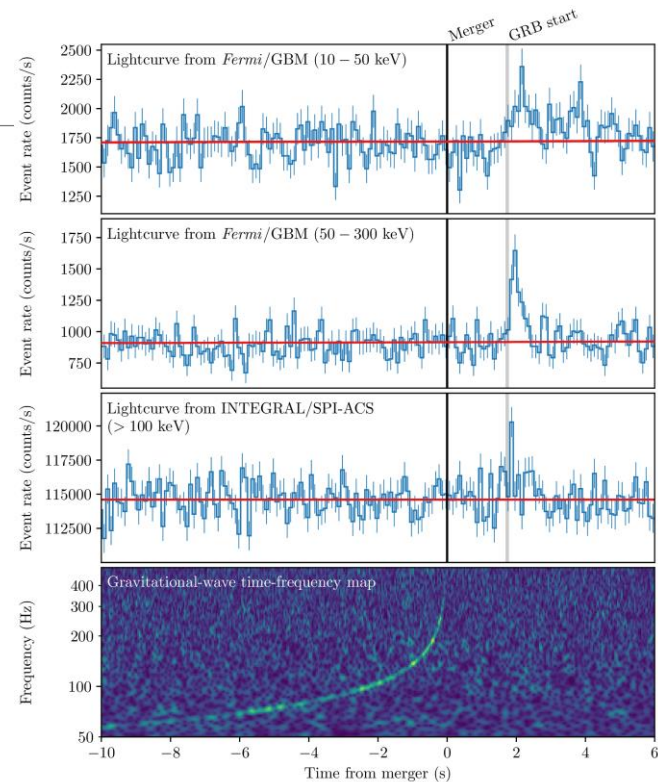
Runtime ~ 10mins

# AT2017gfo / GW170817



Villar et al ApJL 2017

sGRB  $\sim 2$ s



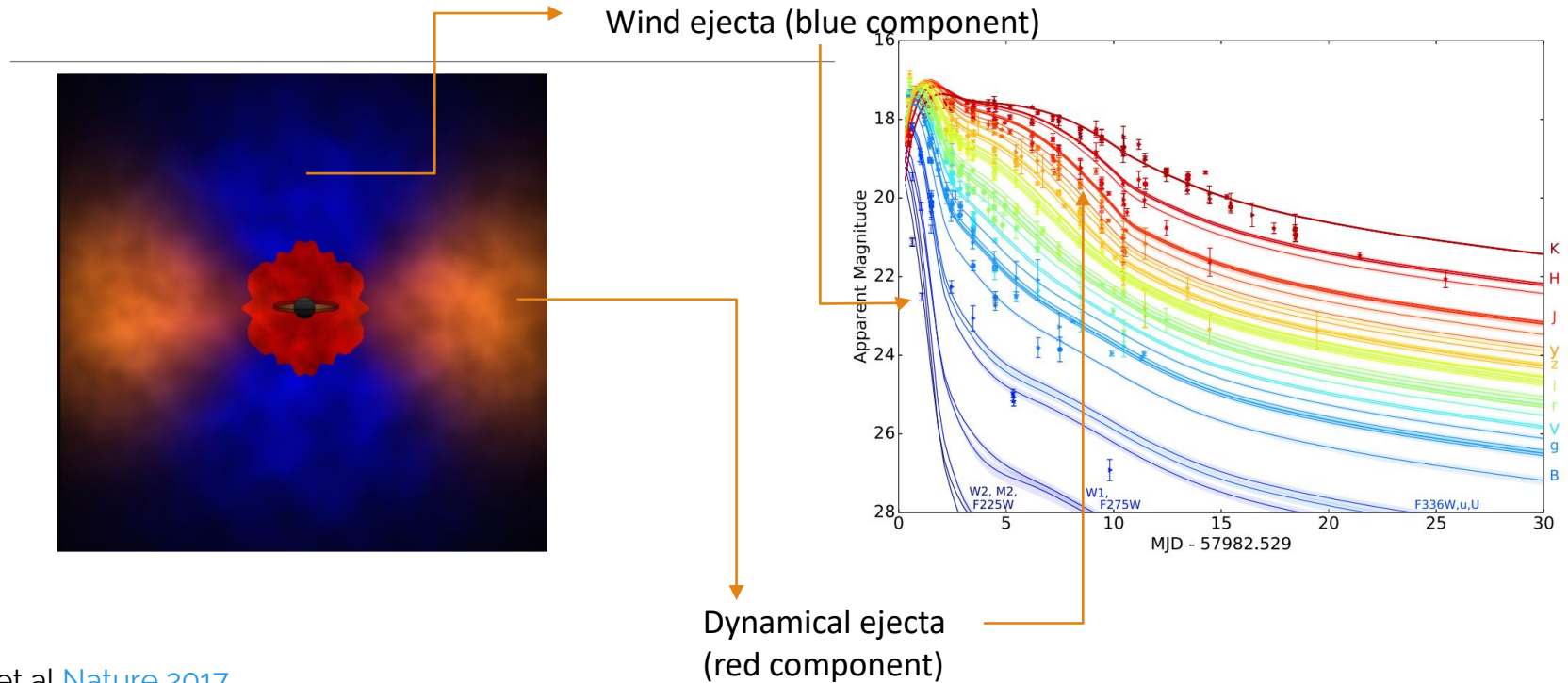
Abbott et al PRL 2017

# Index

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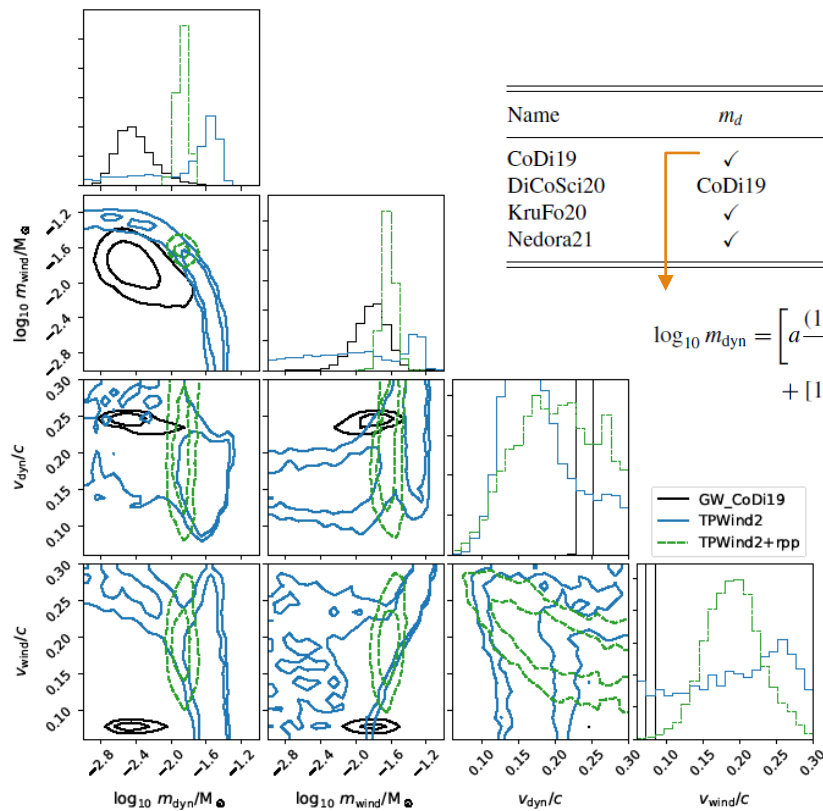
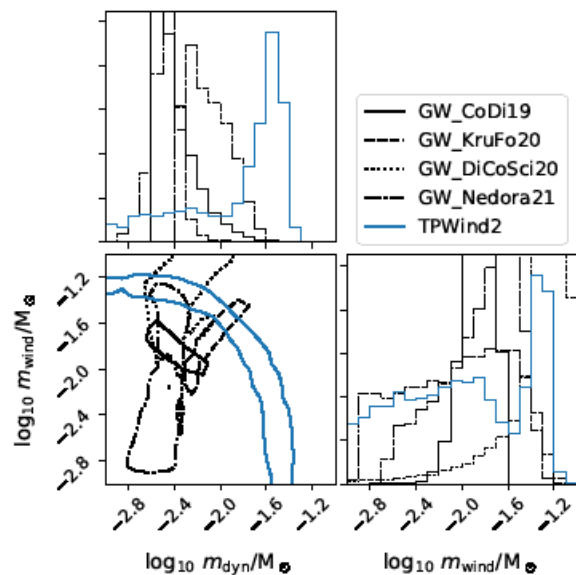
1. Kilonova
2. Ejecta models
3. Surrogates
4. Parameter Estimation

# Ejecta components corresponding to kilonova spectrum



Kasen et al [Nature 2017](#)

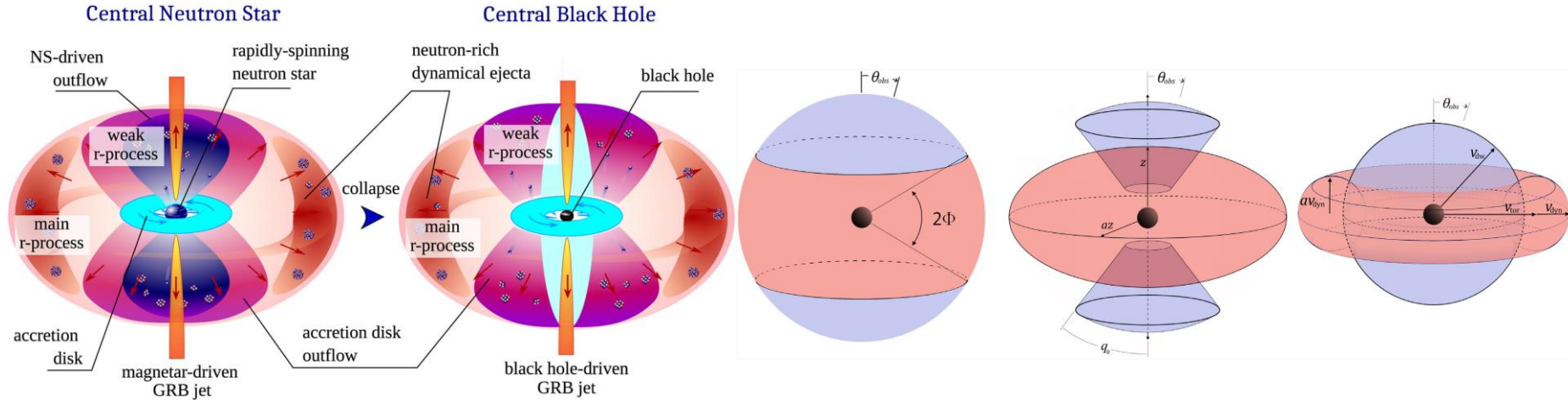
# EM v GW ejecta parameter tension



Name	$m_d$	$m_w$
CoDi19	✓	✓
DiCoSci20	CoDi19	✓
KruFo20	✓	✓
Nedora21	✓	CoDi19

$$\log_{10} m_{\text{dyn}} = \left[ a \frac{(1 - 2C_1)m_1}{C_1} + b m_2 \left( \frac{m_1}{m_2} \right)^n + \frac{d}{2} \right] + [1 \leftrightarrow 2],$$

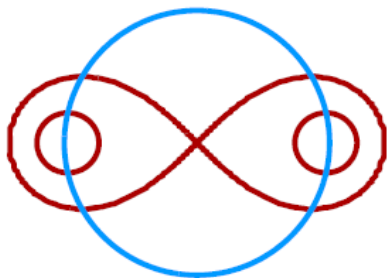
# Kilonova ejecta morphologies



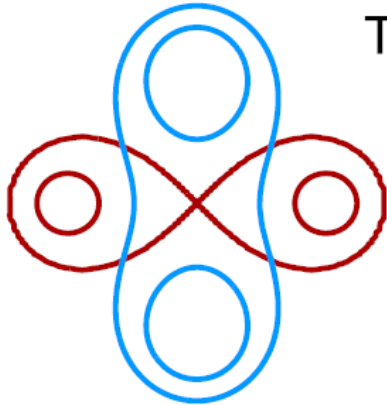
Rosswog, Korobkin, [Ann. der Phys. 2022](#)

Heinzel et al, [MNRAS 2021](#)

TS



TP



# Ejecta profiles

TABLE I. Ejecta morphologies and compositions studied in this paper. The composition of the dynamical component is fixed at  $Y_e = 0.04$ . In terms of this notation, the previous investigation studied a TPwind2 outflow [32].

Name	Wind		Dynamical
	Morphology	$Y_e$	
TPwind1	Peanut	0.37	Torus
TSwind1	Spherical	0.37	Torus
TSwind2	Spherical	0.27	Torus

Mass [Mo]	Velocity [c]
0.001, 0.003, 0.01, 0.03, 0.1	0.05, 0.15, 0.3

225 + 225 (active learning sims) = 450 / {Name}

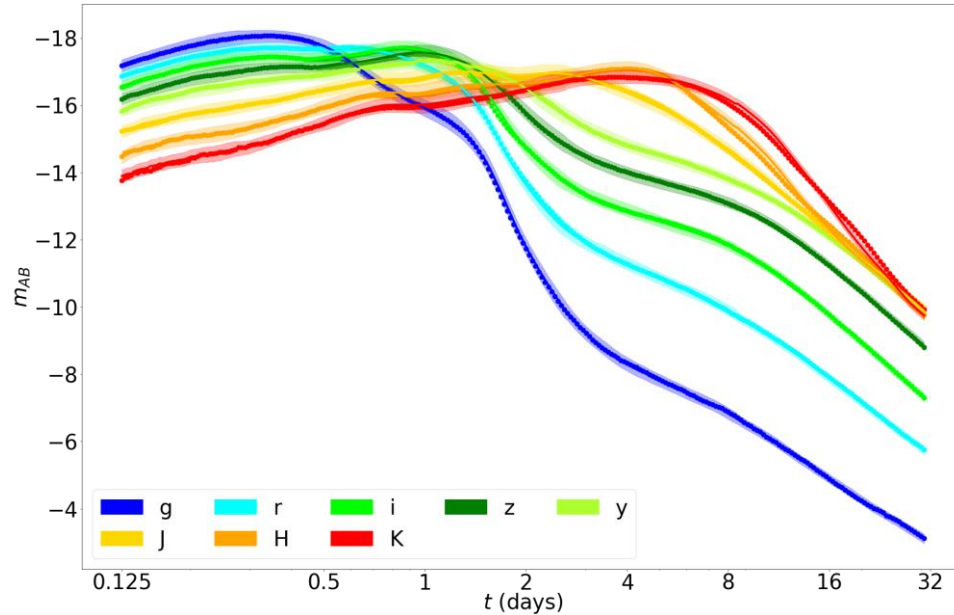
# Simulation setup

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- Radiative transfer software using tabulated binned opacities on **SuperNu**. (Wollaeger et al 2013, 2014)
  - Composition and radioactive heating from r-process elements, nucleosynthetic results from **WinNet**. (Winteler et al. 2012)
  - Nuclear model
    - Heating rates (Korobkin et al. )
    - Thermalization model of (Barnes et al. (2016))
    - Atomic opacities (Fontes et al. 2020)
  - Reprocessing of light from one component to another.
  - Active learning to choose next set of models to reduce  $\chi^2$  error.
- (Wollaeger et al 2013, 2014, 2018, 2021; Ristic et al, [PhysRevResearch \(2022\)](#) )



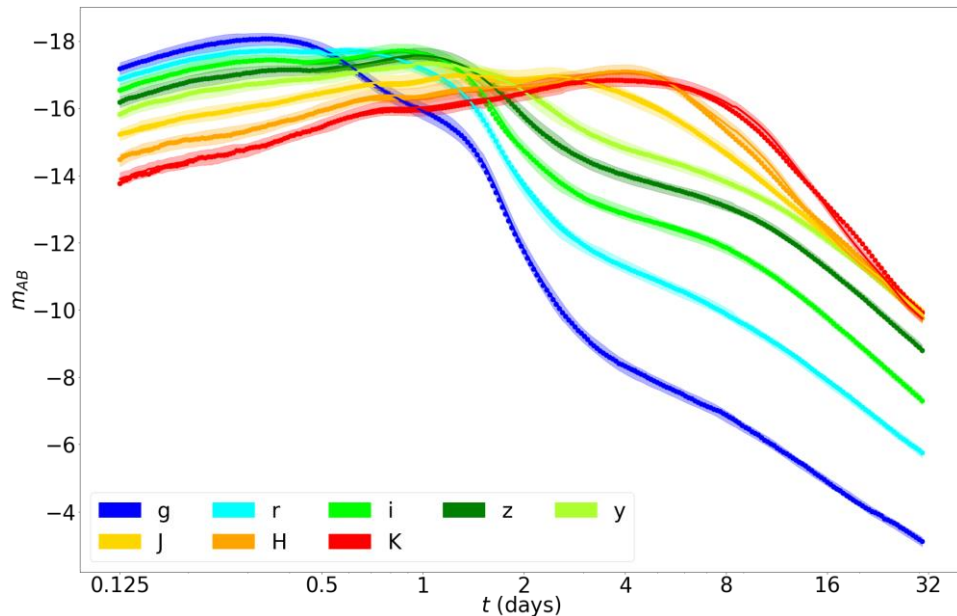
# Gaussian Process regression Surrogate models



$(m_{dyn}, v_{dyn}, m_{wind}, v_{wind}) = (0.097, 0.198, 0.084, 0.298)$

TSwind2

# Gaussian Process regression Surrogate models

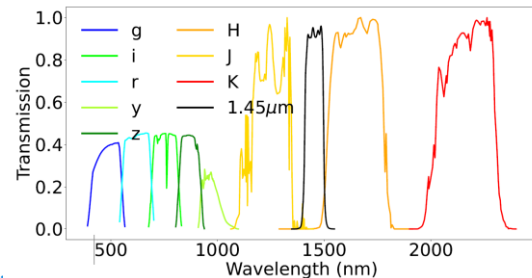
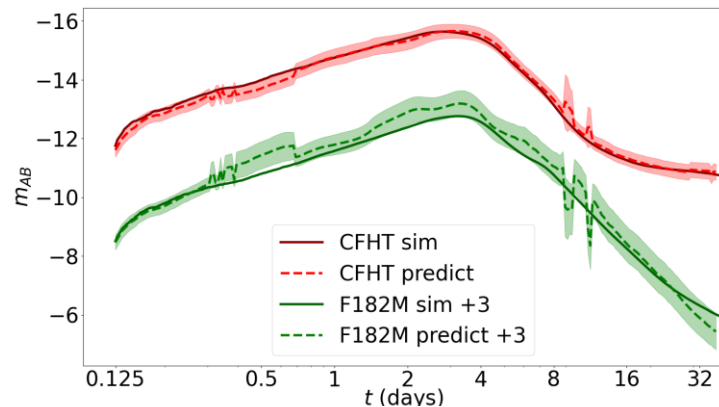


$(m_{dyn}, v_{dyn}, m_{wind}, v_{wind}) = (0.097, 0.198, 0.084, 0.298)$

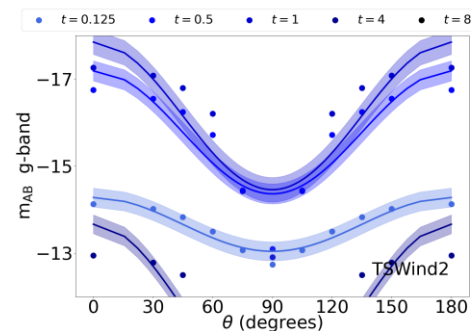
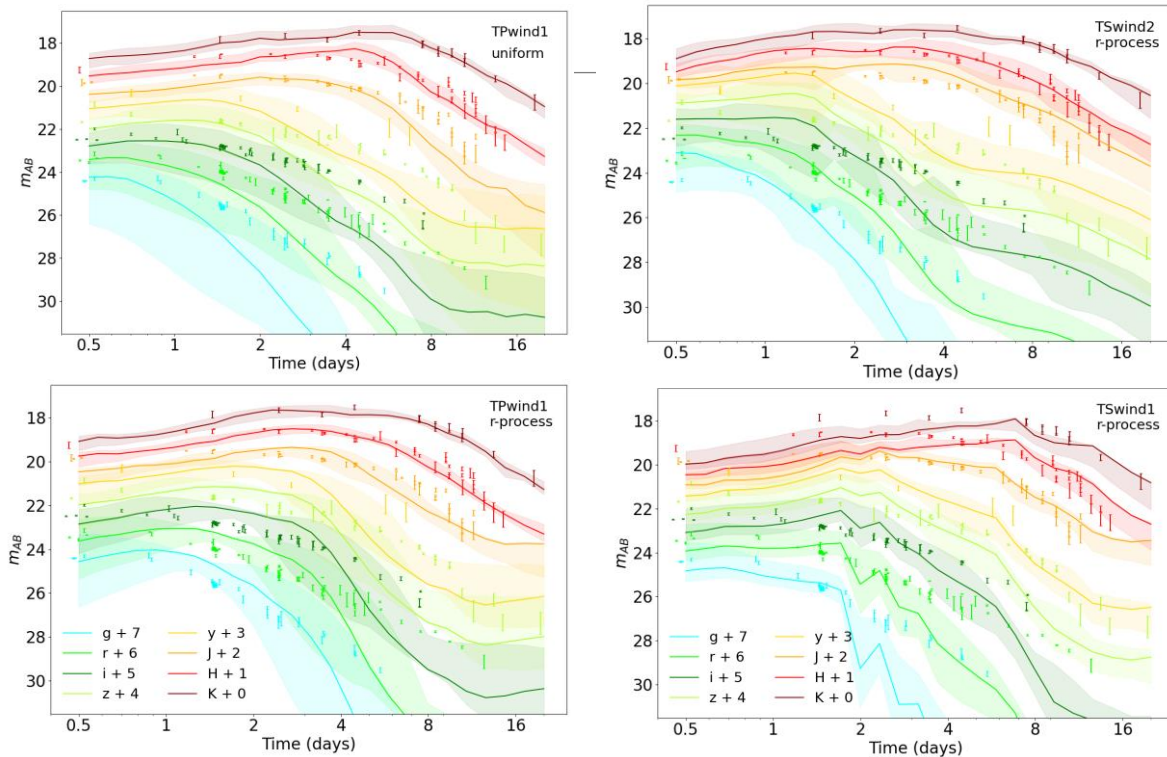
TSwind2

Simulation data : <https://zenodo.org/record/7335961#.ZAE4iXbMKslvi>

GP Surrogate models : [https://github.com/markoris/surrogate\\_kne](https://github.com/markoris/surrogate_kne)



# Fit Light curves (to AT2017gfo)

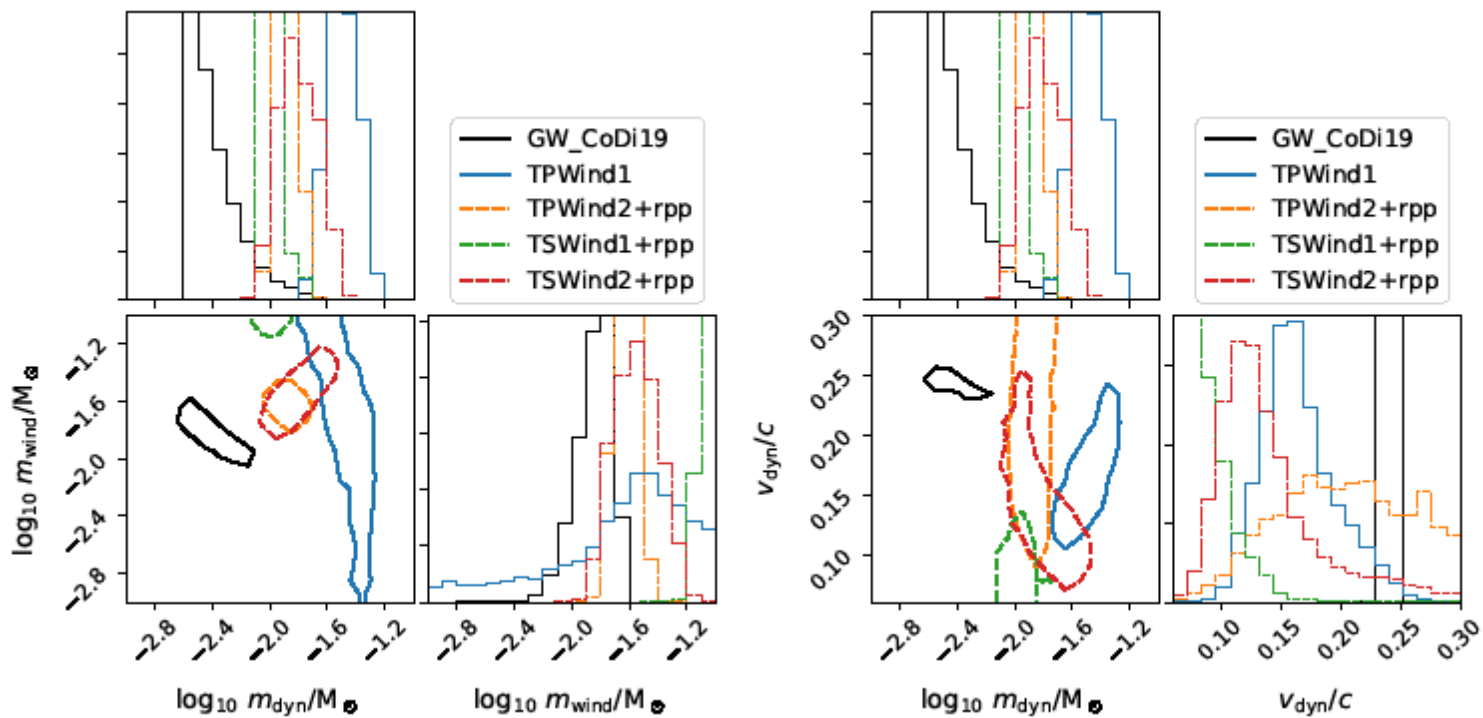


Lanthanide curtaining

AK et al

Phys. Rev. Research 5, 013168 (2023)

# GW v EM ejecta parameter estimate tension



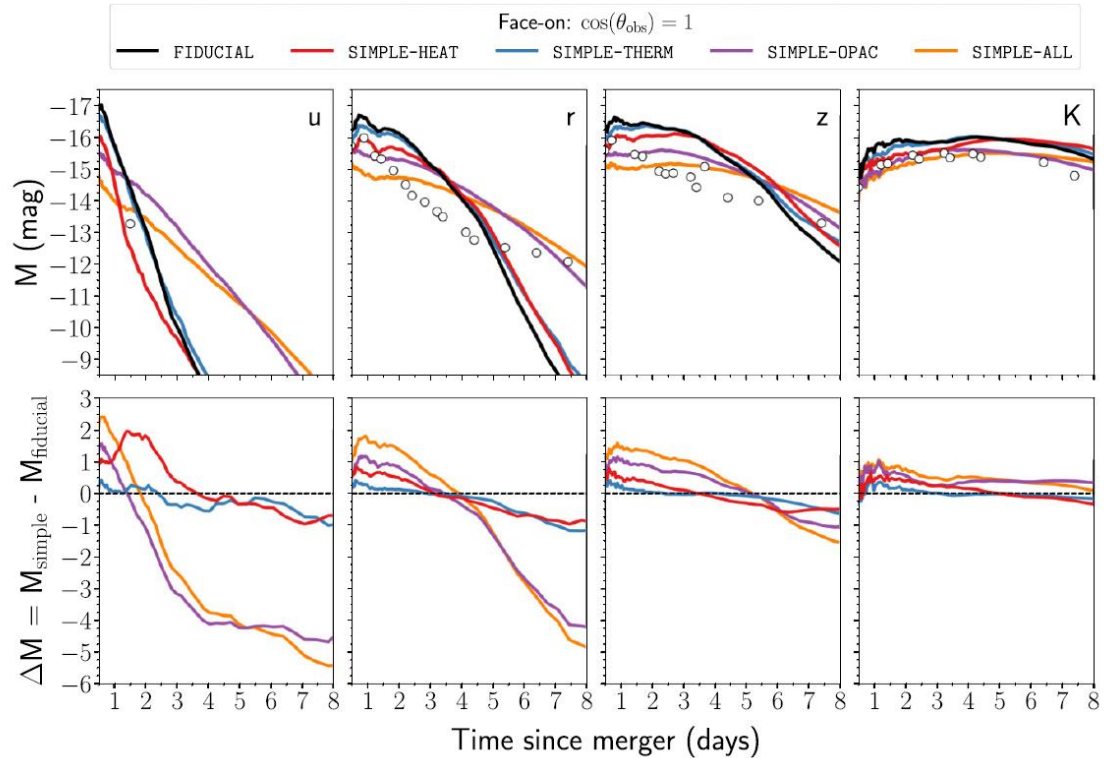
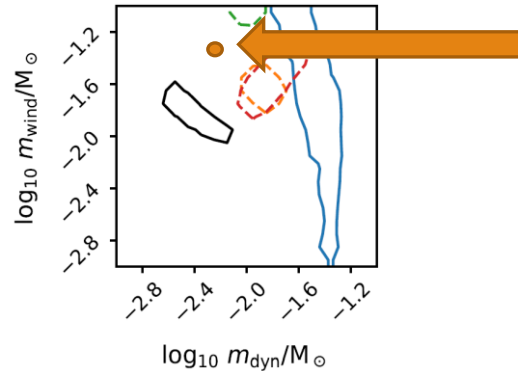
# Potential relief : More observations!

(also Updated Heating rates)

Fiducial (Black curve) : All updated

Simple-Heat (Red curve): heating rate formula non-local

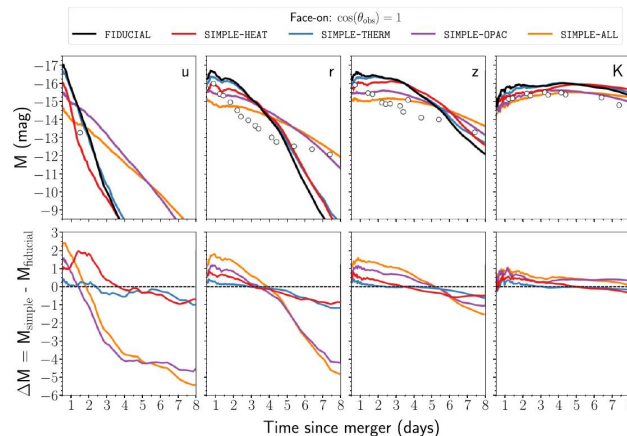
$(m_{\text{dyn}}, v_{\text{dyn}}, m_{\text{wind}}, v_{\text{wind}}) = (0.005, 0.2, 0.05, 0.05)$



Bulla, MNRAS (2023) – POSSIS update

# Ongoing work

- Upgrades to the binned Opacity (Fontes et al 2022)
- Heating rates new formulation (Rosswog and Korobkin 2022)
- Variable  $Y_e$  along ejecta profiles.
- Third component to power the missing Blue peak cocoon shock cooling, or magnetar-like central engine activity. (motivated by the recent GRB211211A)
- Disk Wind simulations with vbhlight (Miller et al.)



Simulation data : <https://zenodo.org/record/7335961#.ZAE4iXbMKsM>

GP Surrogate models : [https://github.com/markoris/surrogate\\_kne](https://github.com/markoris/surrogate_kne)

Talk by Marko Ristic: F13.00006 Sunday 9:30 AM



# Extra slides

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