Neutron star merger ejecta estimation with kilonova light curve surrogates

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Multimessenger Astronomy II C13.5

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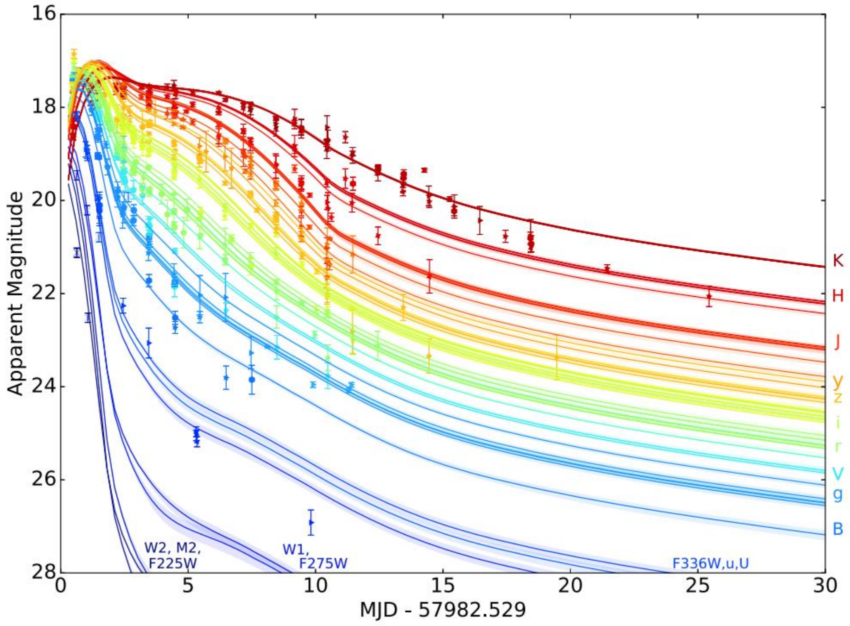
Collaborators: Marko Ristic, Richard O'Shaughnessy, Anjali Yelikar (RIT), Ryan Wollaeger, Chris Fontes, Eve Chase, Chris Fryer, Oleg Korobkin (LANL) Phys. Rev. Res. 5, 013168 (2023) or arXiv:2211.04363

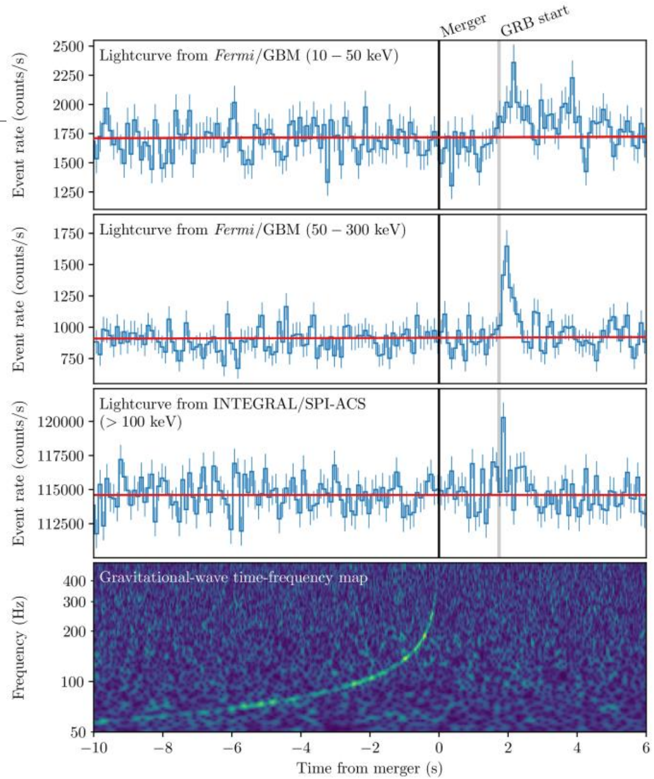
Runtime ~ 10mins

AT2017gfo / GW170817

sGRB ~ 2s



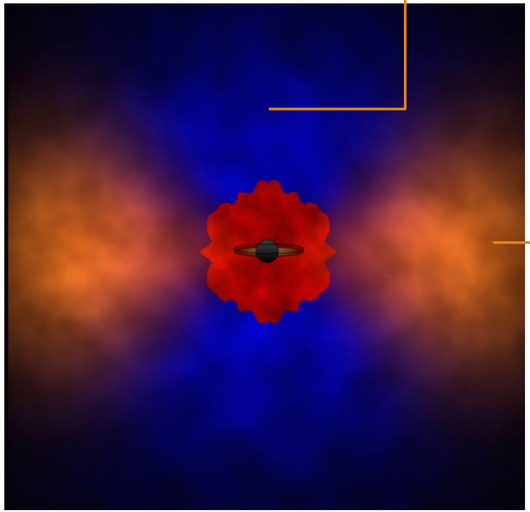
Villar et al [ApJL 2017](#)

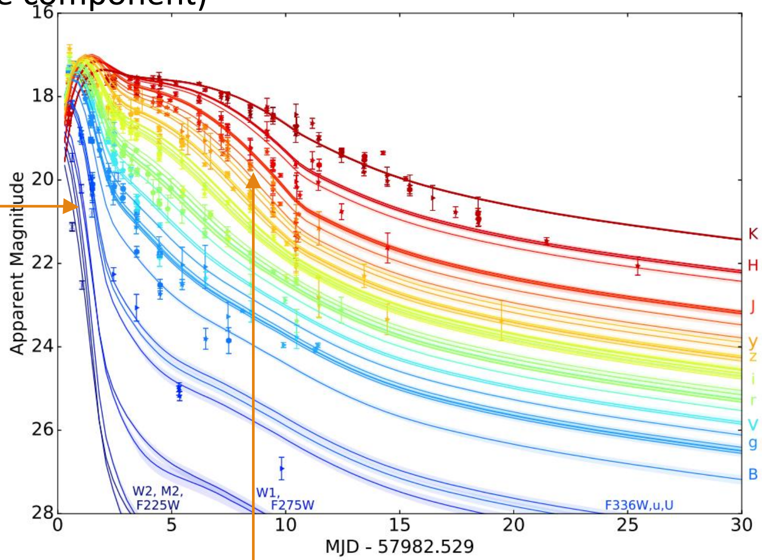


Abbott et al [PRL 2017](#) , LLO

Ejecta components corresponding to the kilonova spectrum

Wind ejecta (blue component)

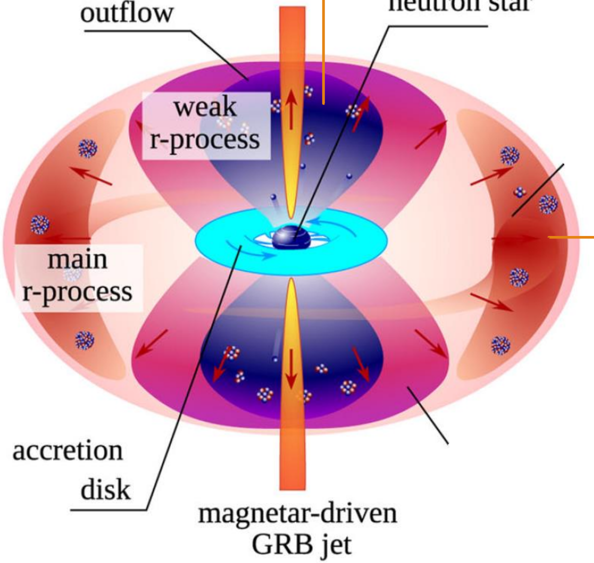




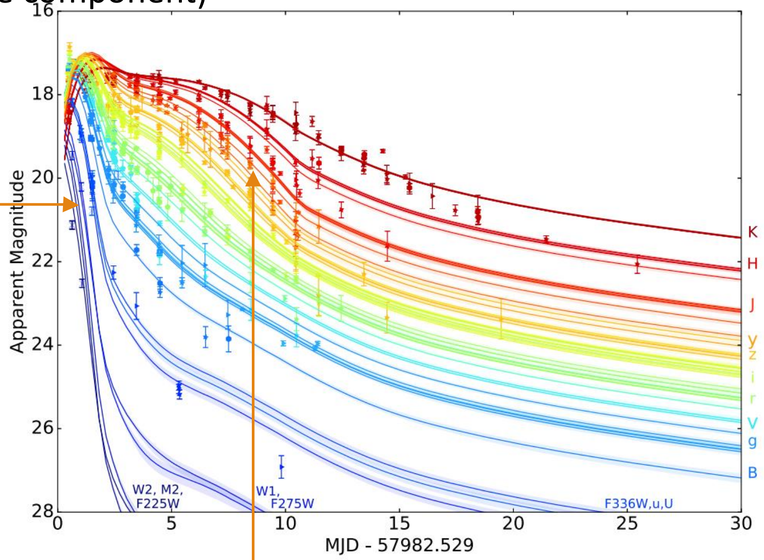
Dynamical ejecta
(red component)

Kasen et al [Nature 2017]

Ejecta components corresponding to the kilonova spectrum



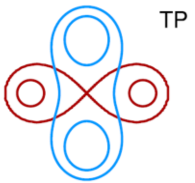
Wind ejecta (blue component)



Dynamical ejecta
(red component)

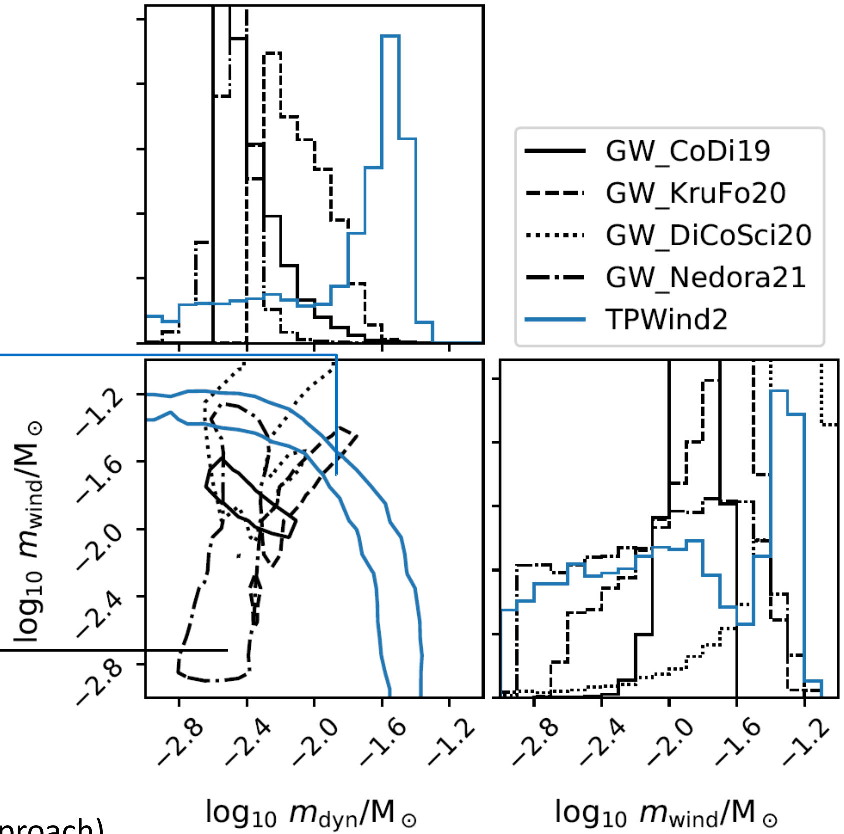
Rosswog, Korobkin, [Ann. der Phys. 2022]()

EM v GW ejecta parameter tension

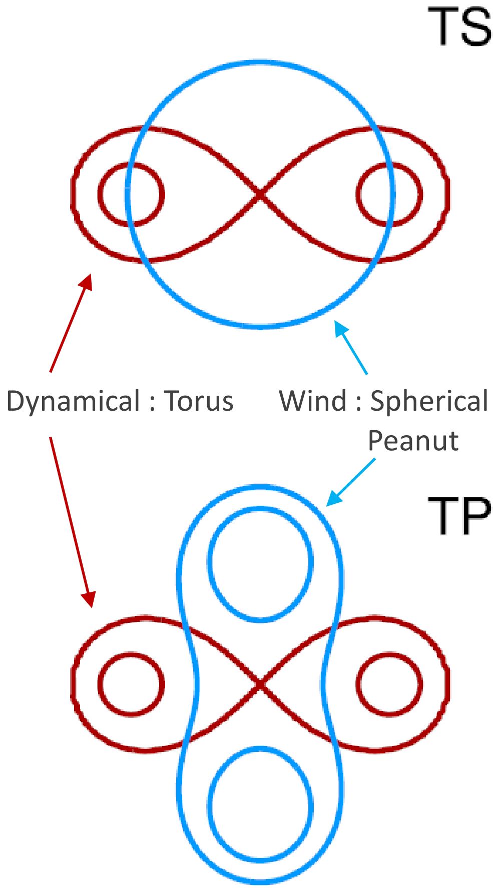


Kilonova approach
← Assuming(Torus, Peanut morphology)

GW approach
(using NR based fits)



Ejecta masses (Kilonova approach) > Ejecta masses (GW approach)



Korobkin et al 2021 ; Wollaeger et al 2021

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].

	Wind		
Name	Morphology	Y_e	Dynamical
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}

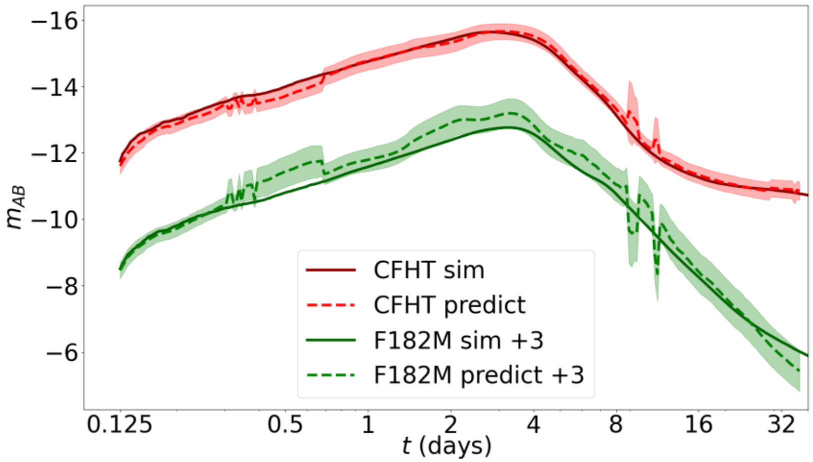
Simulation setup

- 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. 2012)
  - Thermalization model of (Barnes et al. (2016))
  - Atomic opacities (Fontes et at. 2020)
- Reprocessing of light from one component to another.
- Active learning (by reducing χ^2 error) to expand the spanned parameter space.

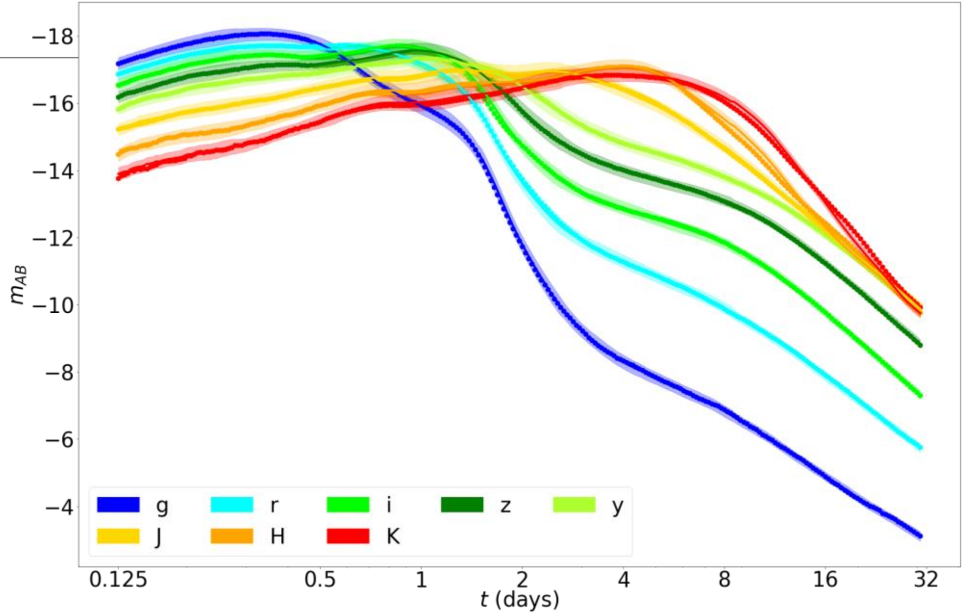
(Wollaeger et al 2013, 2014, 2018, 2021; Ristic et al, PhysRevResearch (2022))

Gaussian Process regression Surrogate models

Example interpolation for un-simulated parameters



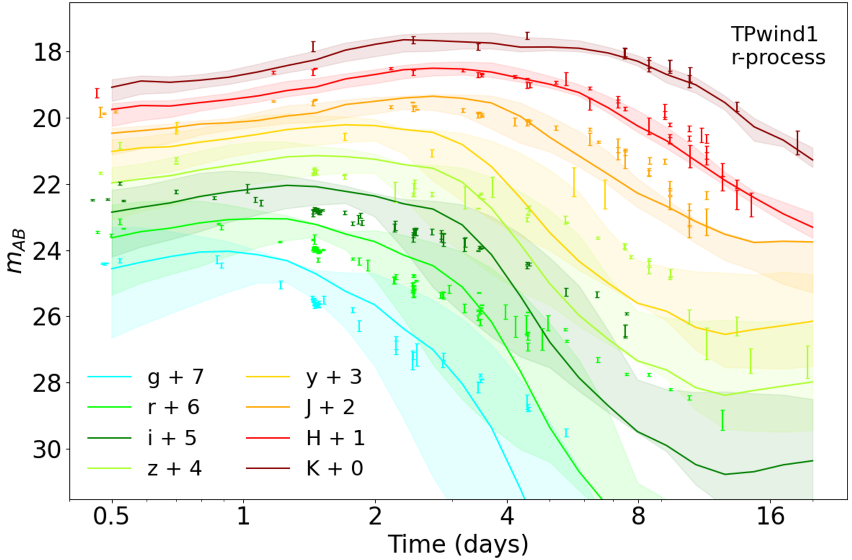
TPwind1 wavelength interpolation



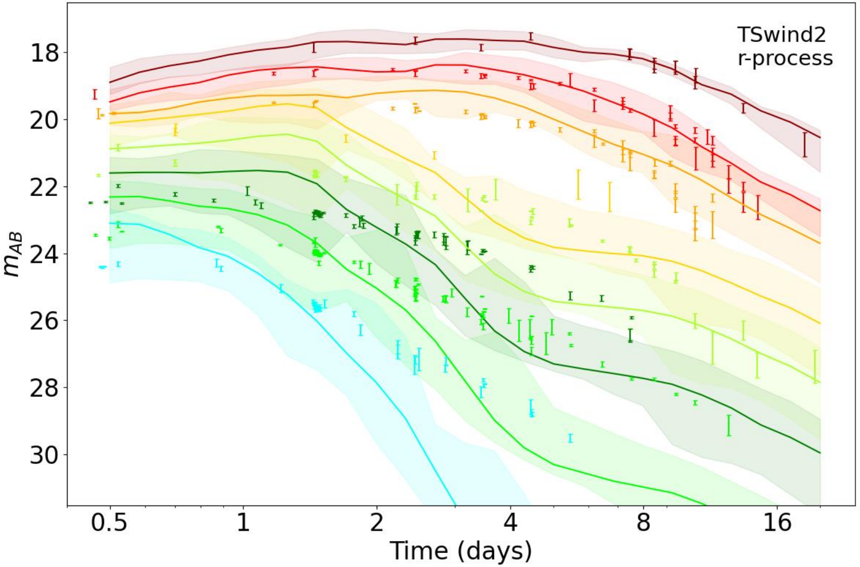
TSwind2 light curve interpolation
(*mdyn*, *vdyn*, *mwind*, *vwind*, *Θ*) = (0.097, 0.198, 0.084, 0.298, pole)

Simulation data : https://zenodo.org/record/7335961#.ZAE4iXbMKsM
GP Surrogate models : https://github.com/markoris/surrogate_kne

Fit Light curves (to AT2017gfo)



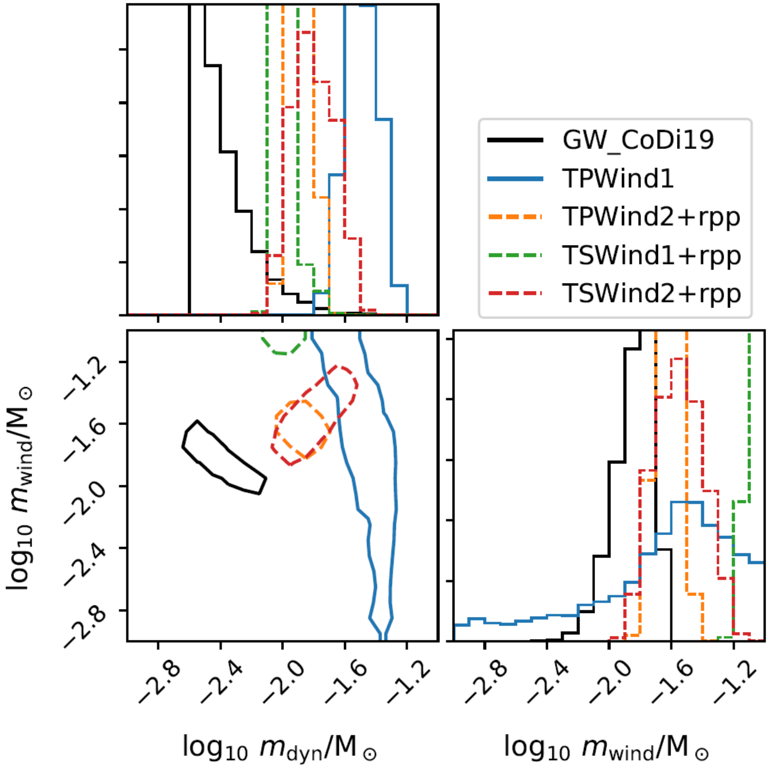
TorusPeanut (high Ye)



TorusSpherical (low Ye)

AK et al
[Phys. Rev. Research 5, 013168](https://doi.org/10.1103/PhysRevResearch.5.013168) (2023)

EM v GW ejecta parameter estimation



AK et al, Phys. Rev. Research 5, 013168 (2023)

Ejecta parameters with the broader ejecta model:

- Different morphologies predict different ranges in the parameter space
- TSwind2 and TPwind2 are significantly closer to GW estimate!
- Some differences still remains!

Ongoing work

- Upgrades to nuclear and atomic physics
  - Upgrades to the binned Opacity, MNRAS (Fontes et al (2022))
  - Heating rates new formulation (Rosswog and Korobkin 2022); Update example at Bulla, MNRAS (2023)
- Disk Wind simulations with νbhlight (Jonah Miller et al. ApJ2019, PRD2019, ApJS2021)
  - Variable Ye in ejecta profiles
- Third component
  - Why : to power the late-time underluminous Blue peak
  - How: cocoon shock cooling, or magnetar-like central engine activity. (motivated by the recent GRB211211A)

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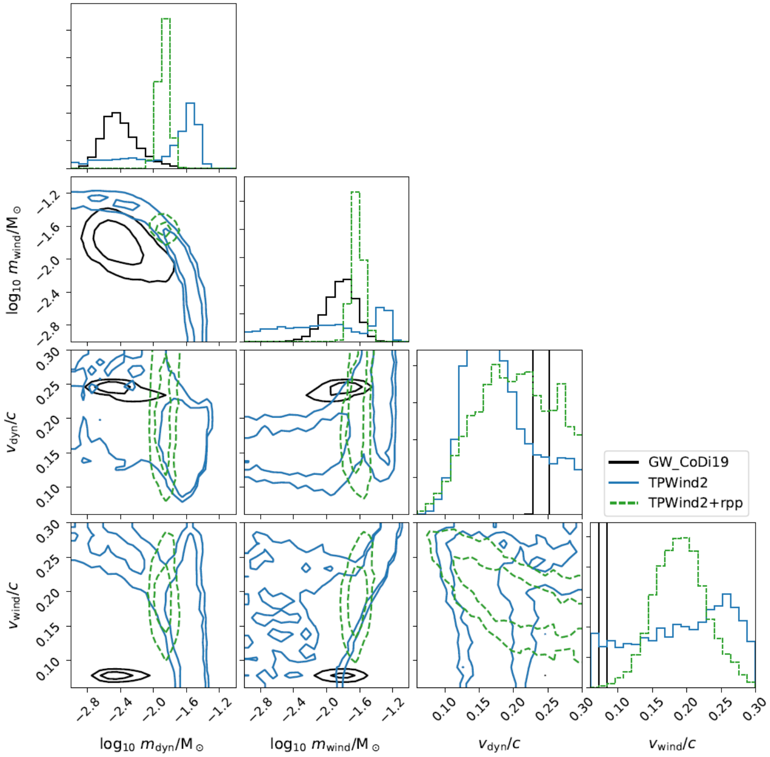
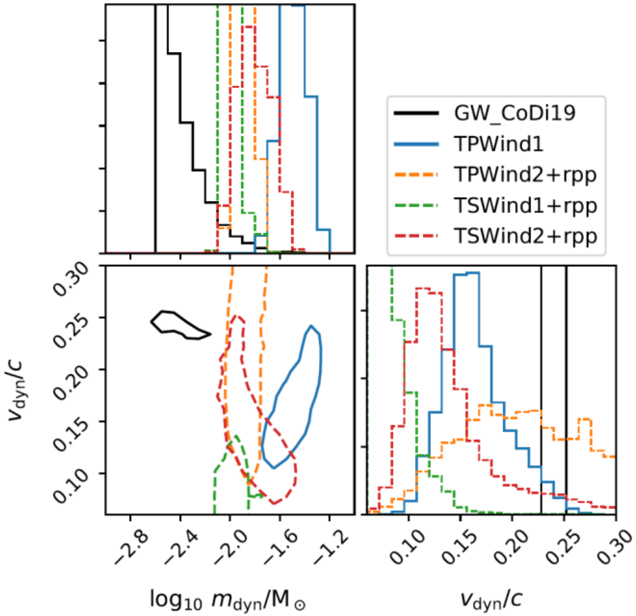
Extra slides

Velocity tension

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

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

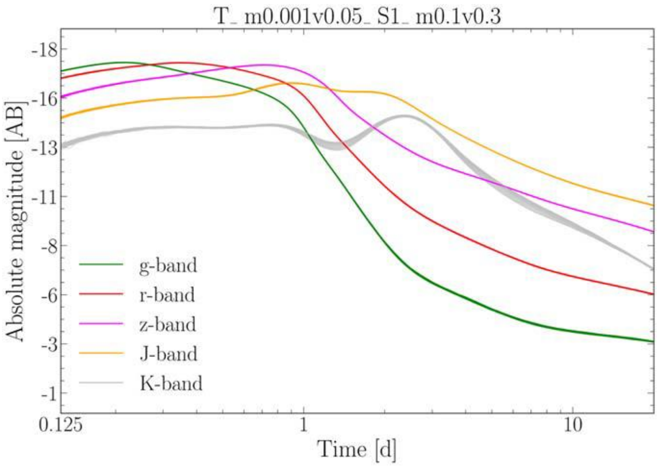


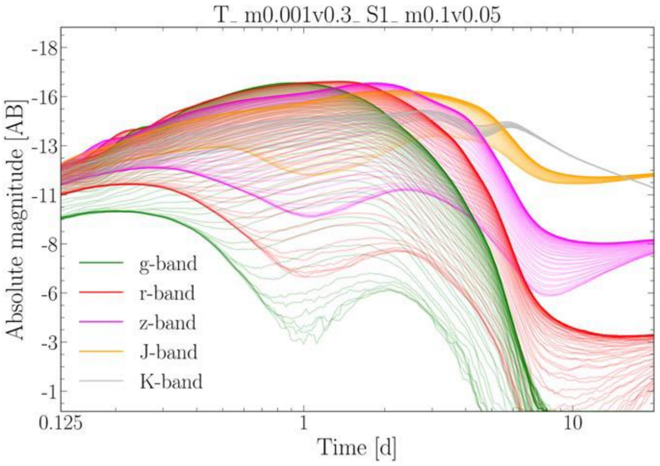


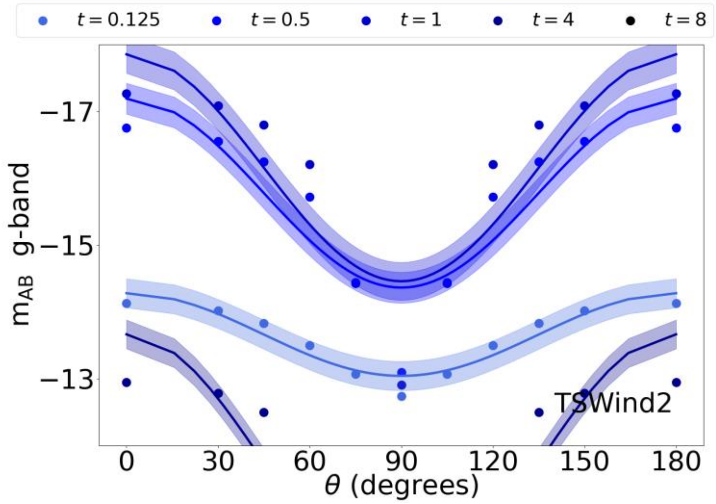
Lanthanide curtaining

Wollaeger et al [ApJ 2021]

Korobkin et al [ApJ 2021]







(*mdyn, vdyn, mwind, vwind, Θ*) = (?,?,?,?)

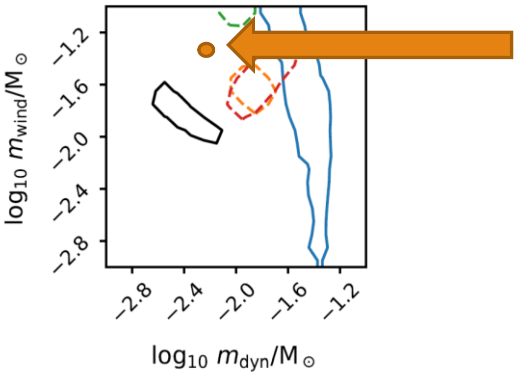
Potential relief

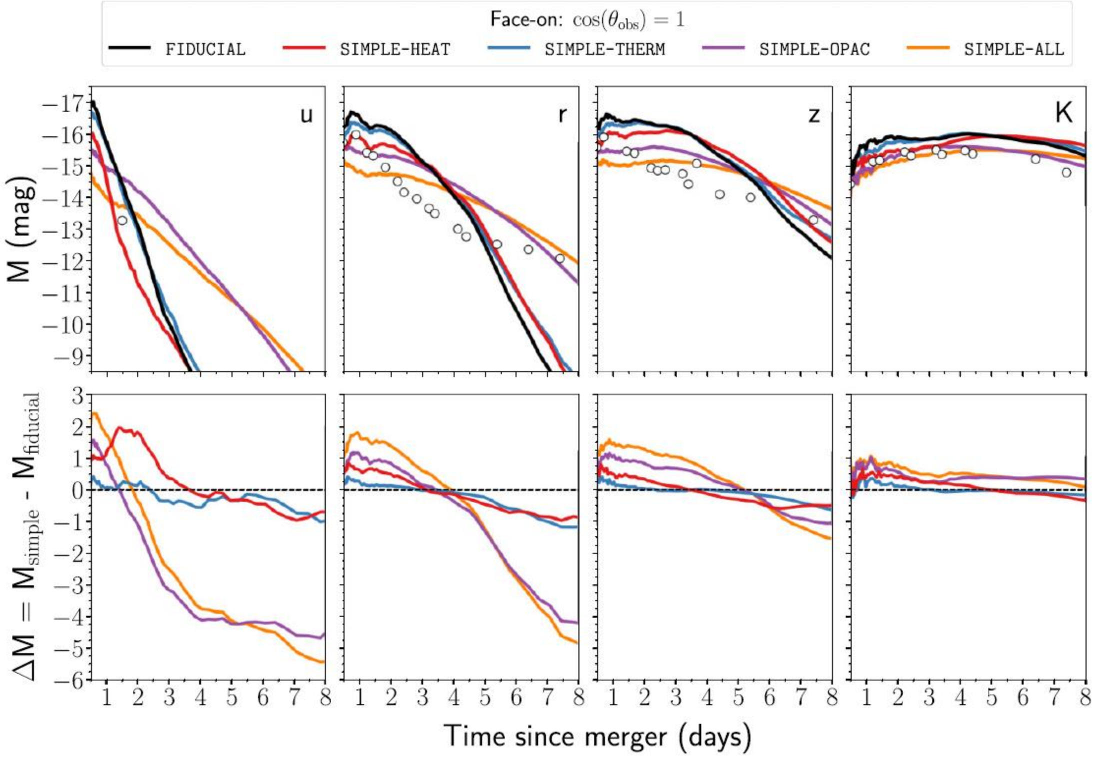
(Updated Heating rates)

Fiducial (Black curve) : All updated

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

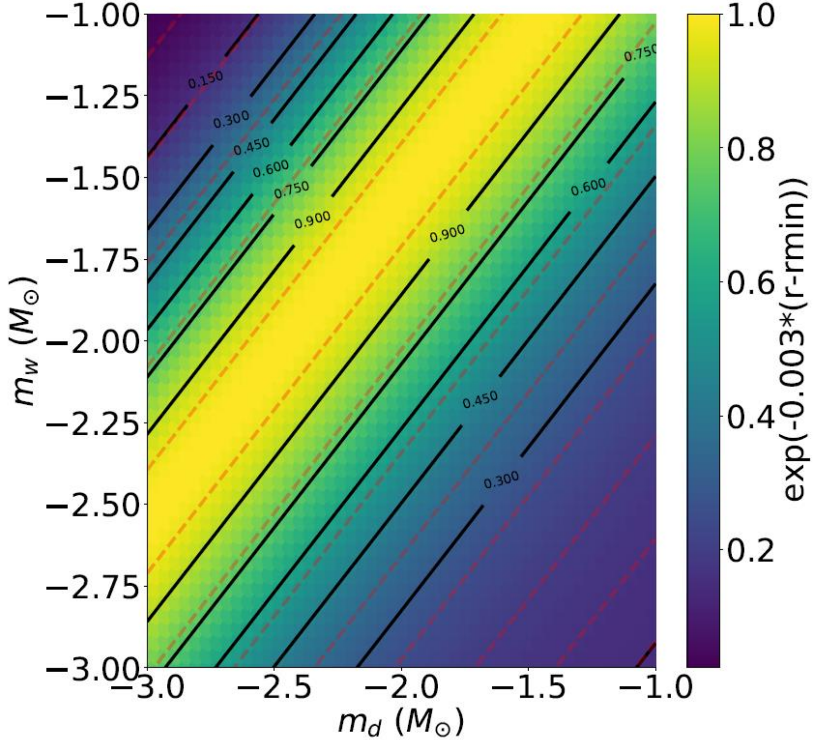
(*mdyn*, *vdyn*, *mwind*, *vwind*) = (0.005, 0.2, 0.05, 0.05)

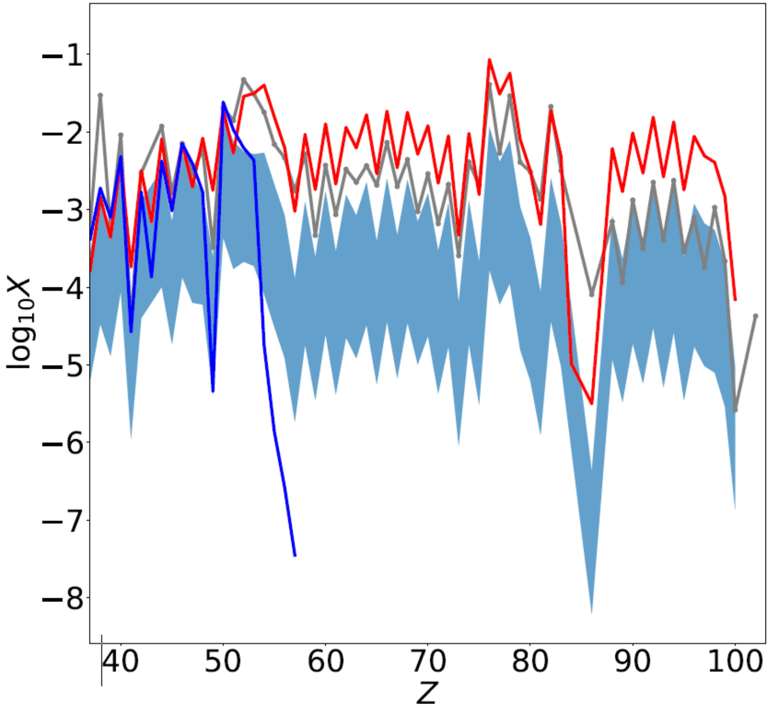




Bulla, MNRAS (2023) – POSSIS update paper

R-process prior





Ristic et al, arXiv (2022)