Kilonovae and the microphysics of Binary Neutron Star mergers

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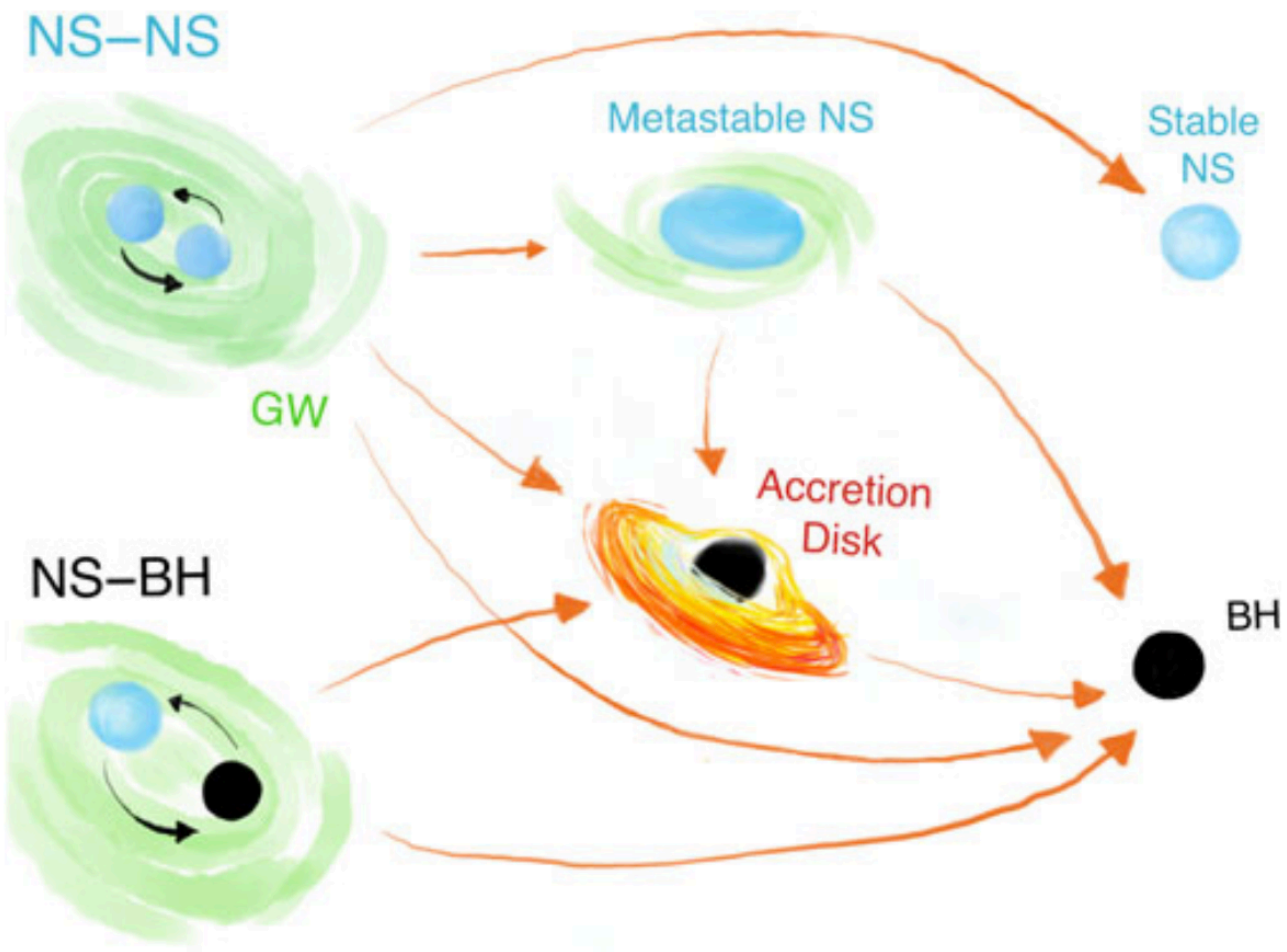
Binary Neutron Star mergers

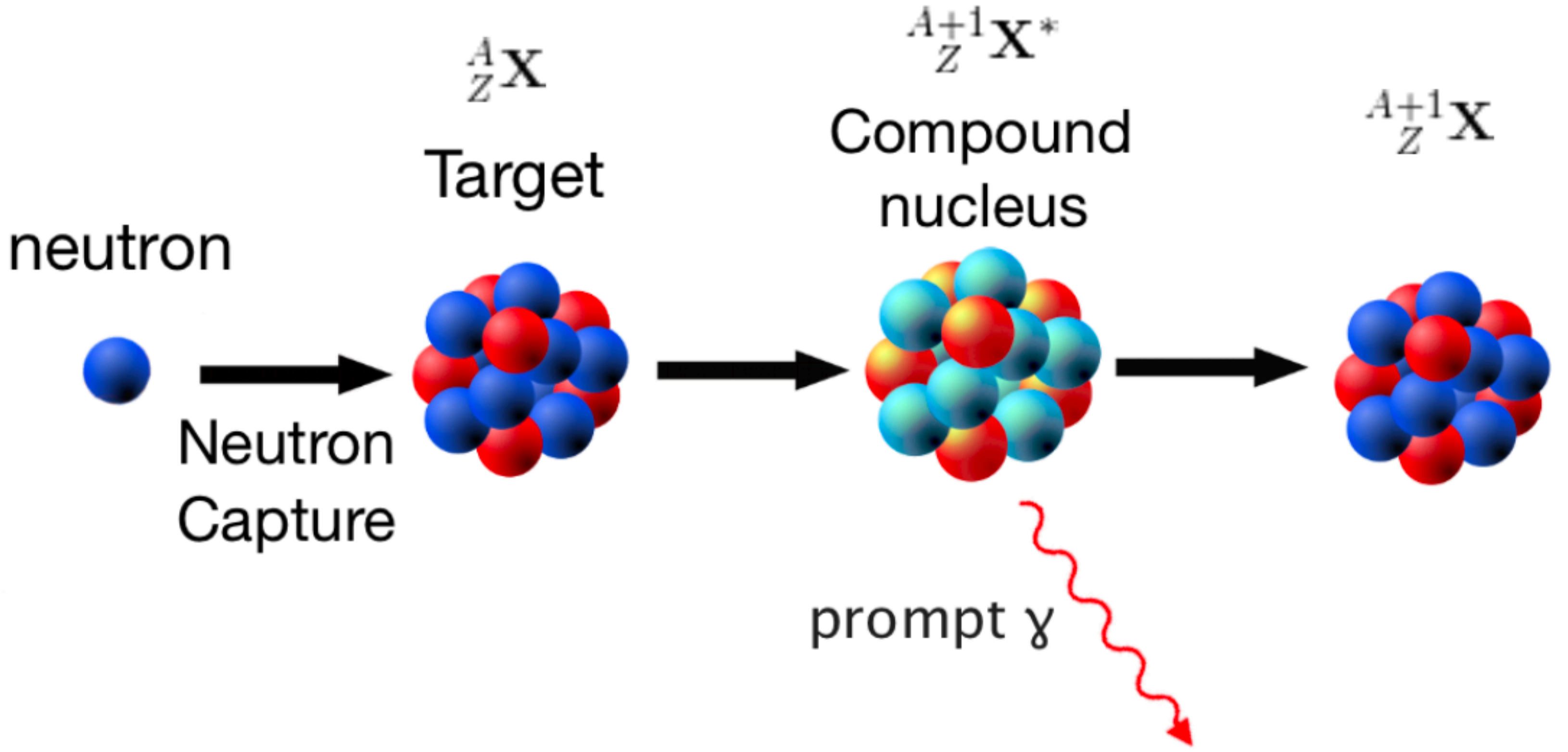
- Emission of gravitational waves & electromagnetic counterparts
- Production of astrophysical transients, such as Gamma Ray Bursts and Kilonovae
- Correlation between properties of transients and merger microphysics

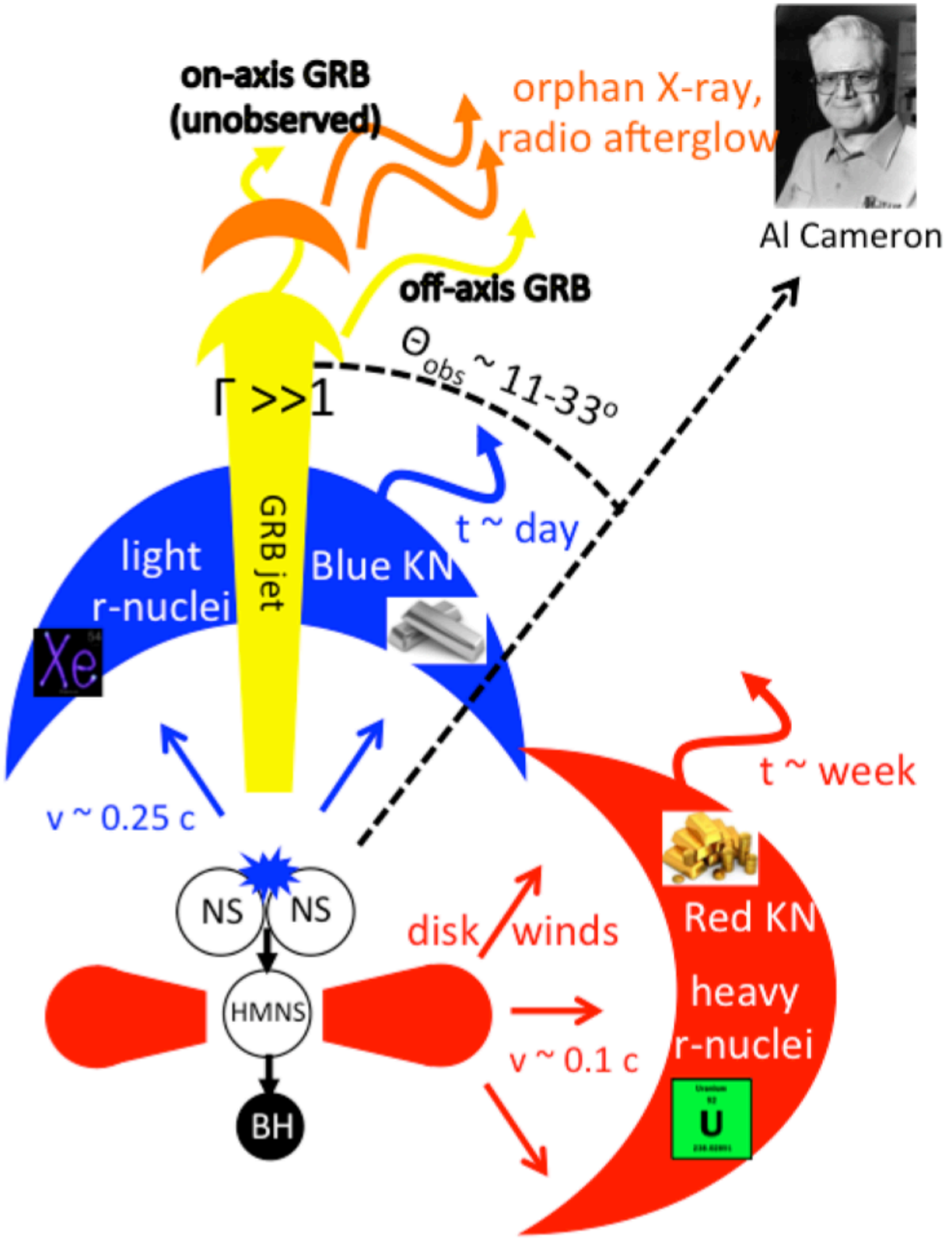


Credits: Ascenzi et al. 2021

The Kilonova

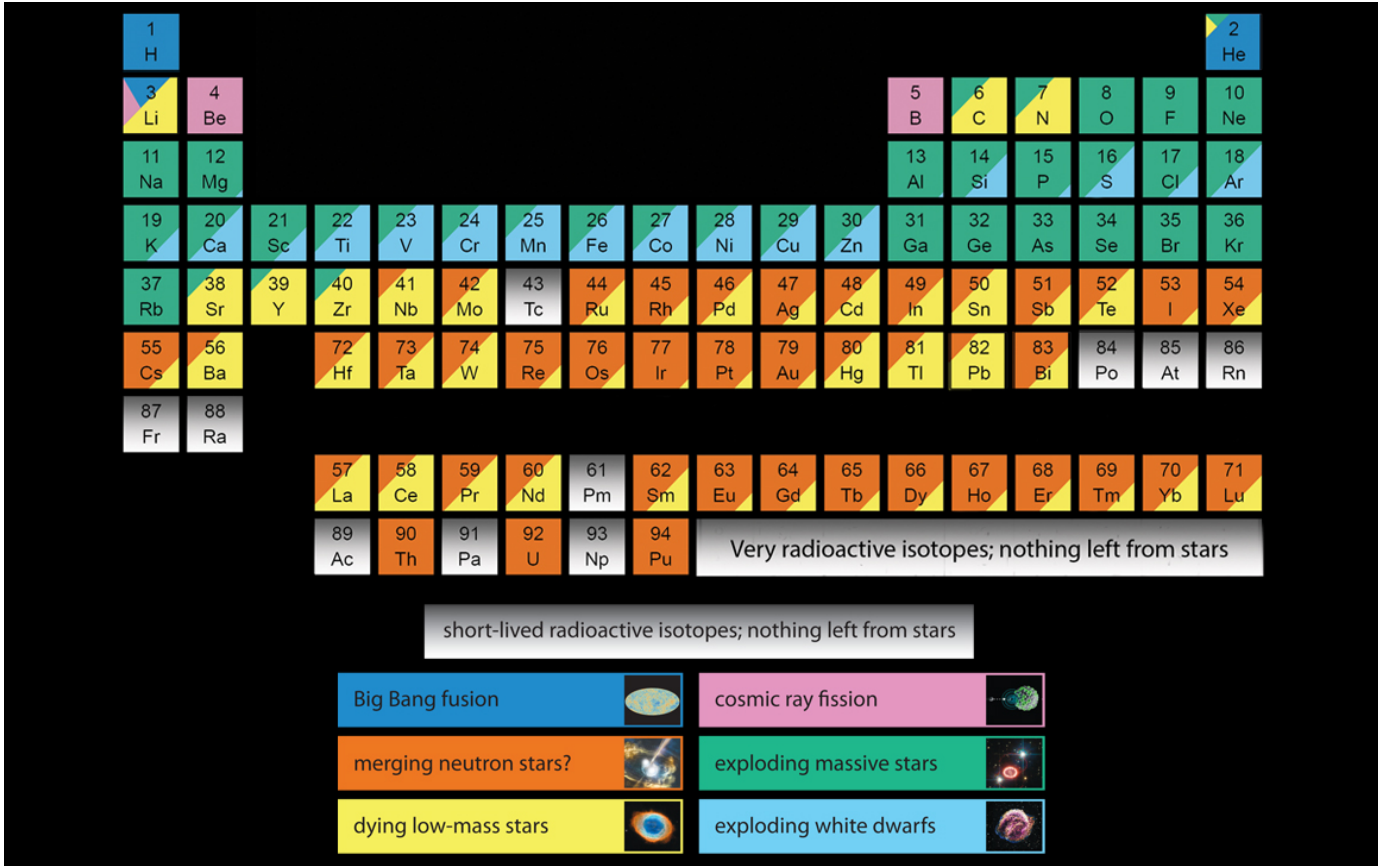
- Ejection of matter before and after the merger
- Neutron rich ejecta → heavy elements nucleosynthesis via neutron capture.
- Quasi-thermal EM emission powered by the nuclear decay of heavy elements.





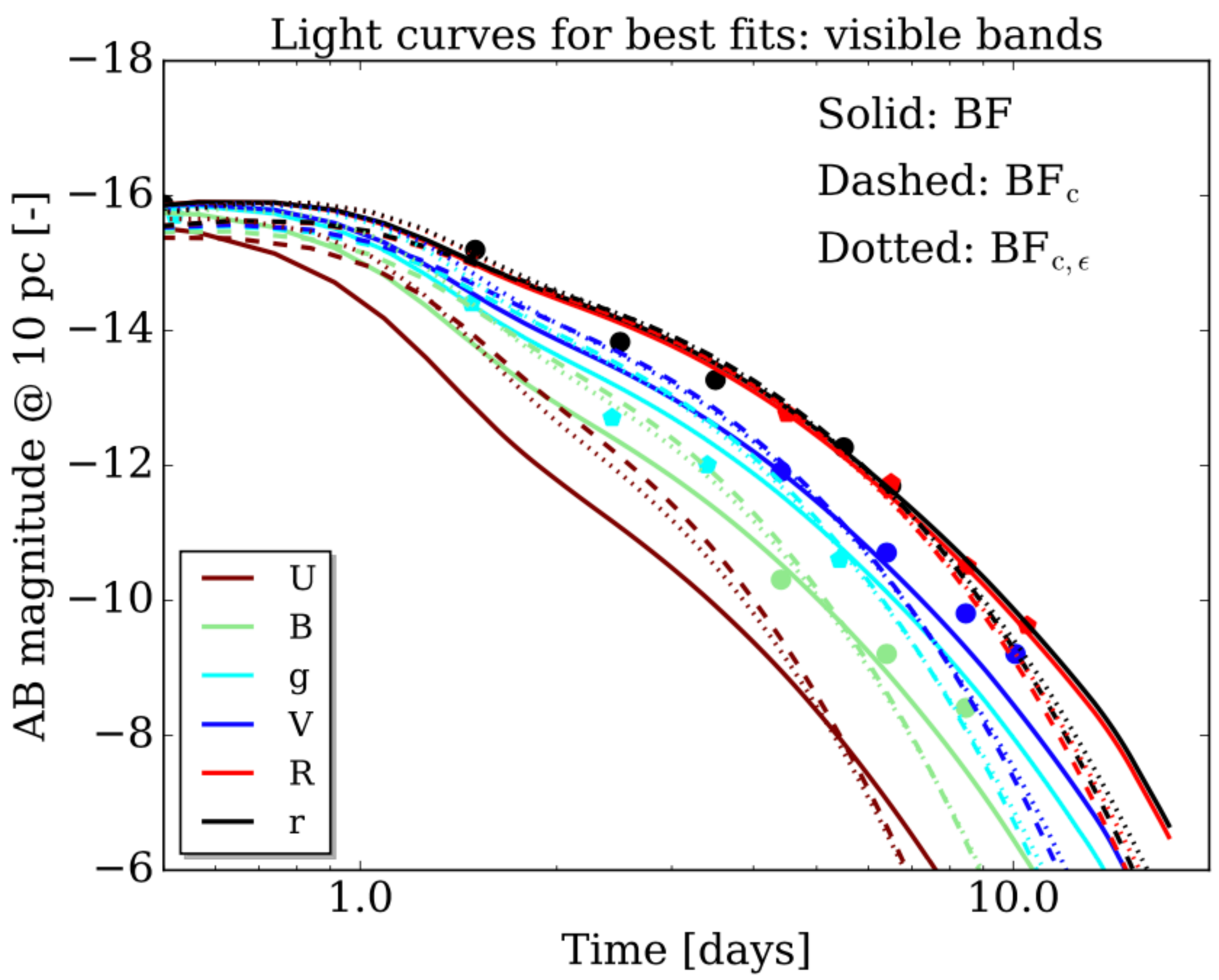
Credits: P. K. Das 2017, Metzger 2018

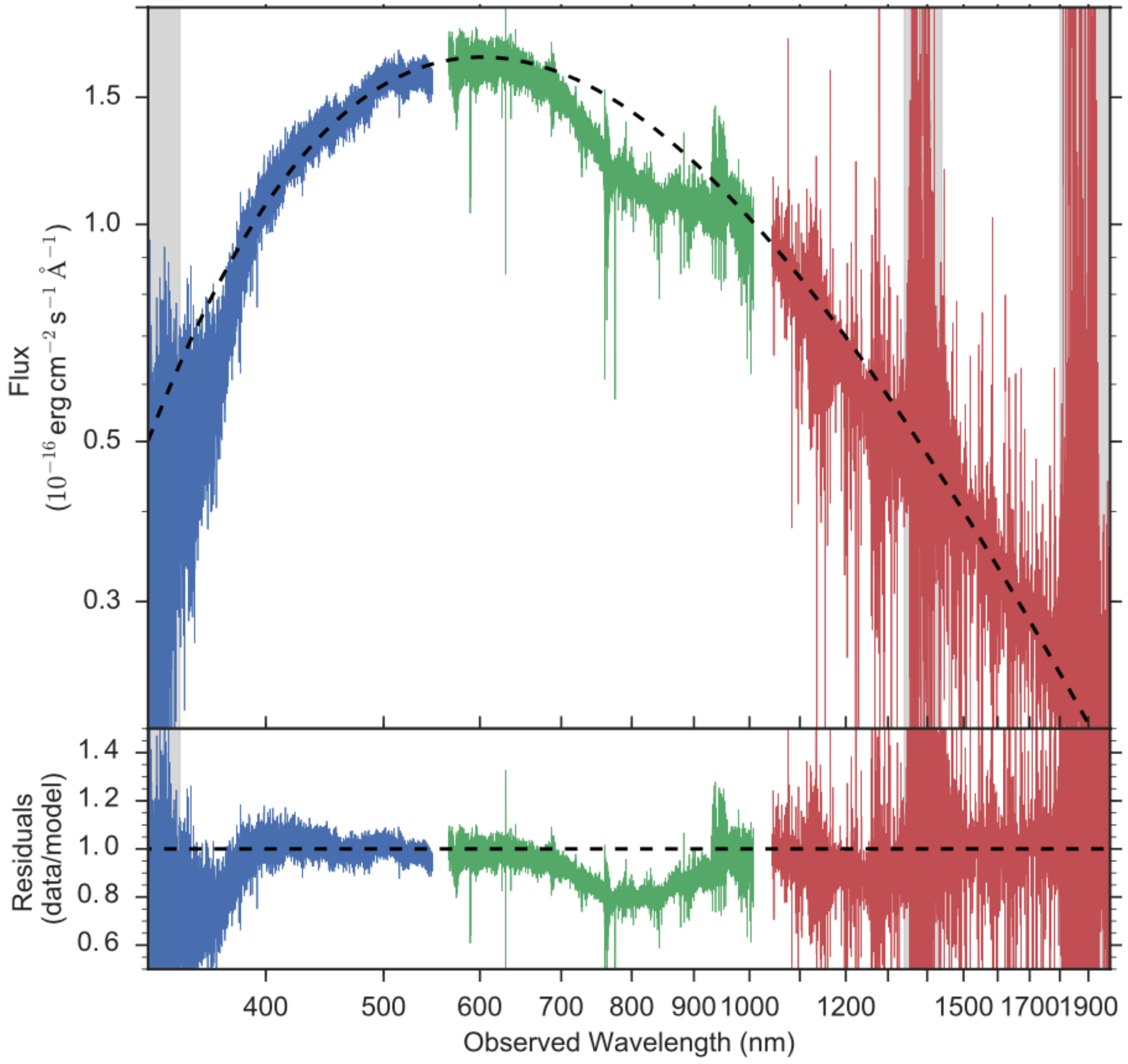
Kilonovae and the origin of heavy elements



The Kilonova

- UV/optical/IR signal, rapidly evolving & faint
- Spectra contain information on the elements produced

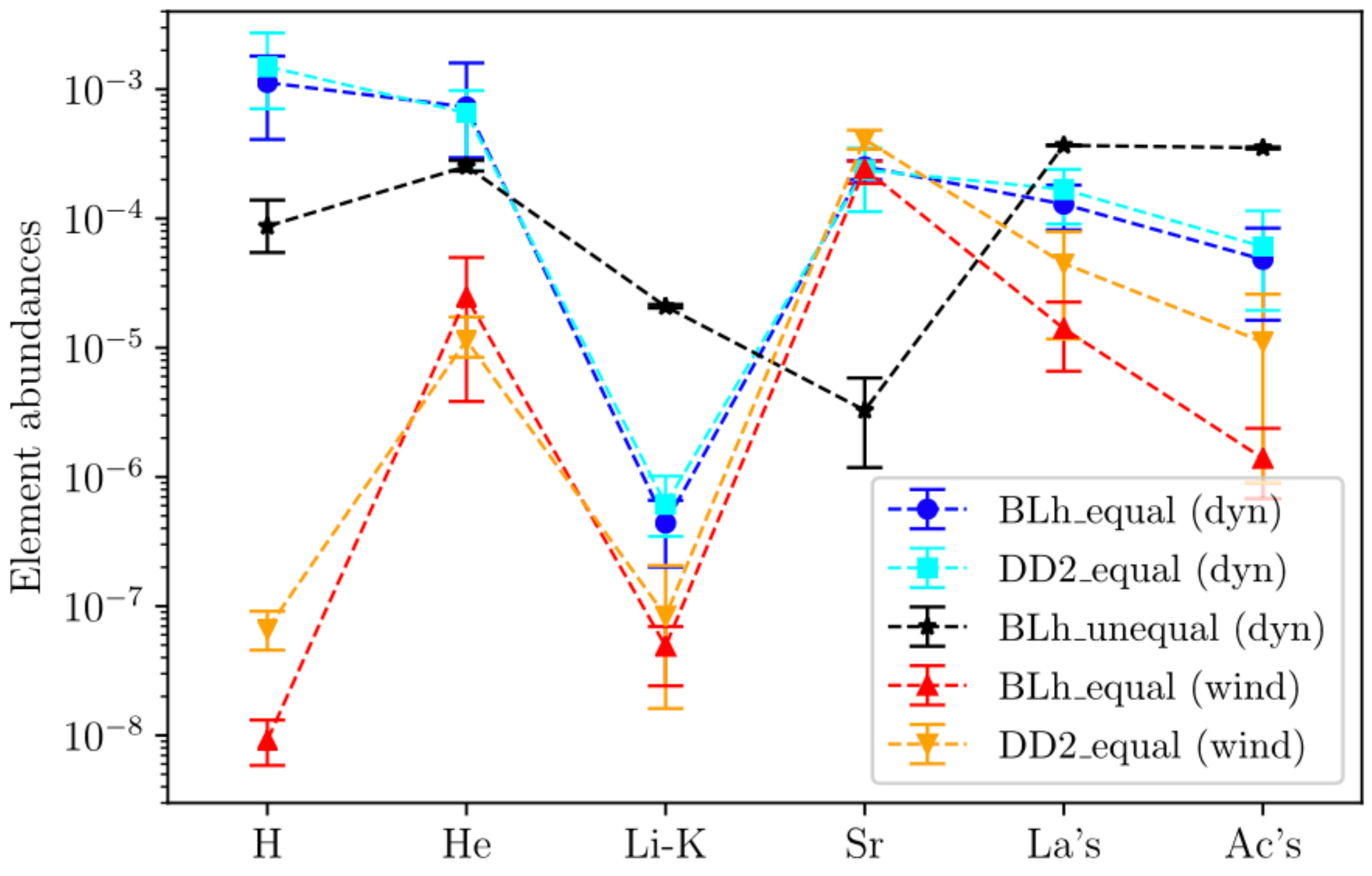


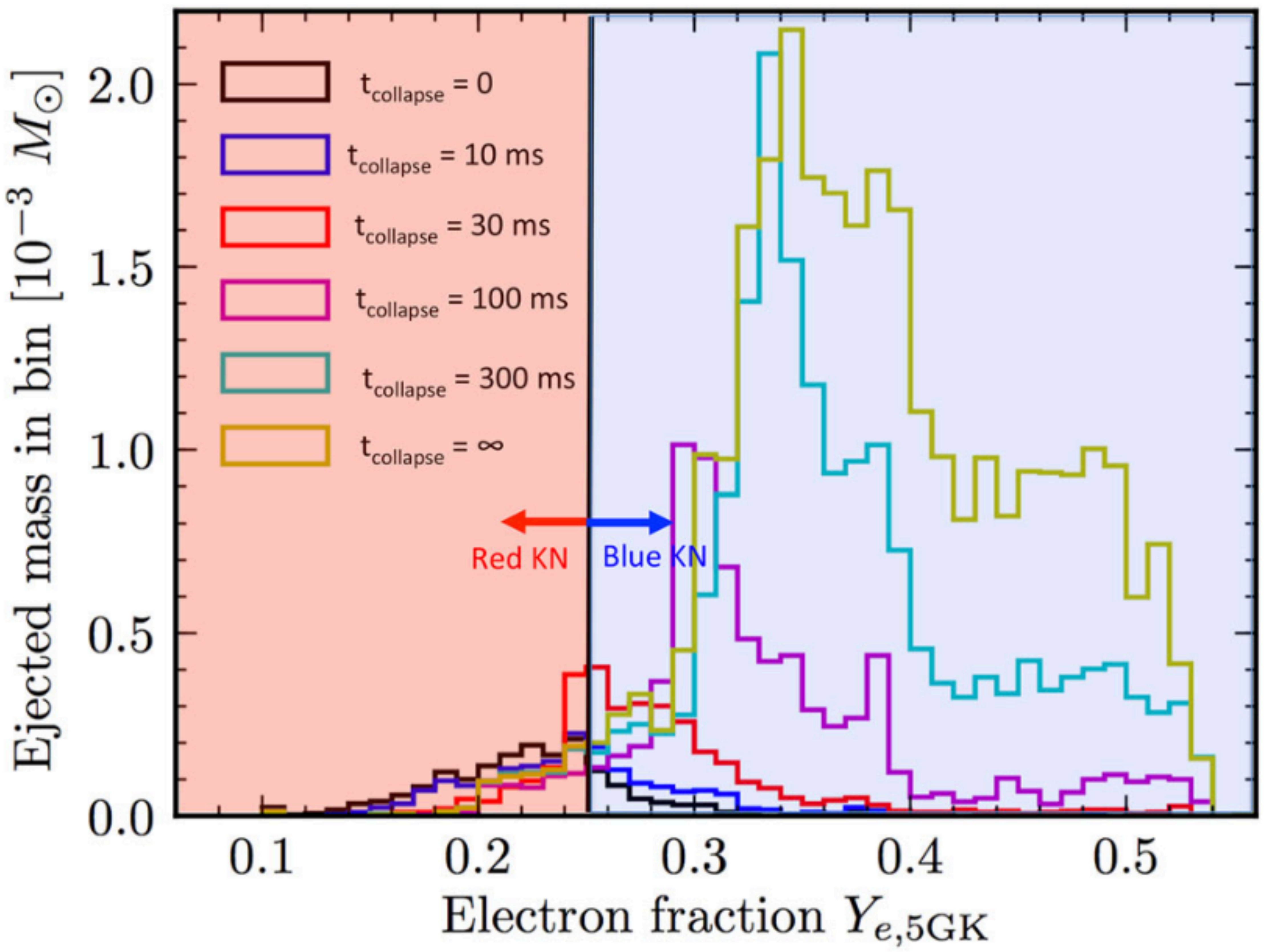


Credits: Perego et al. 2017, Watson et al. 2019

The Kilonova and the merger microphysics

- Merger microphysics (Equation of State of nuclear matter) → ejecta and remnant properties → KN signal

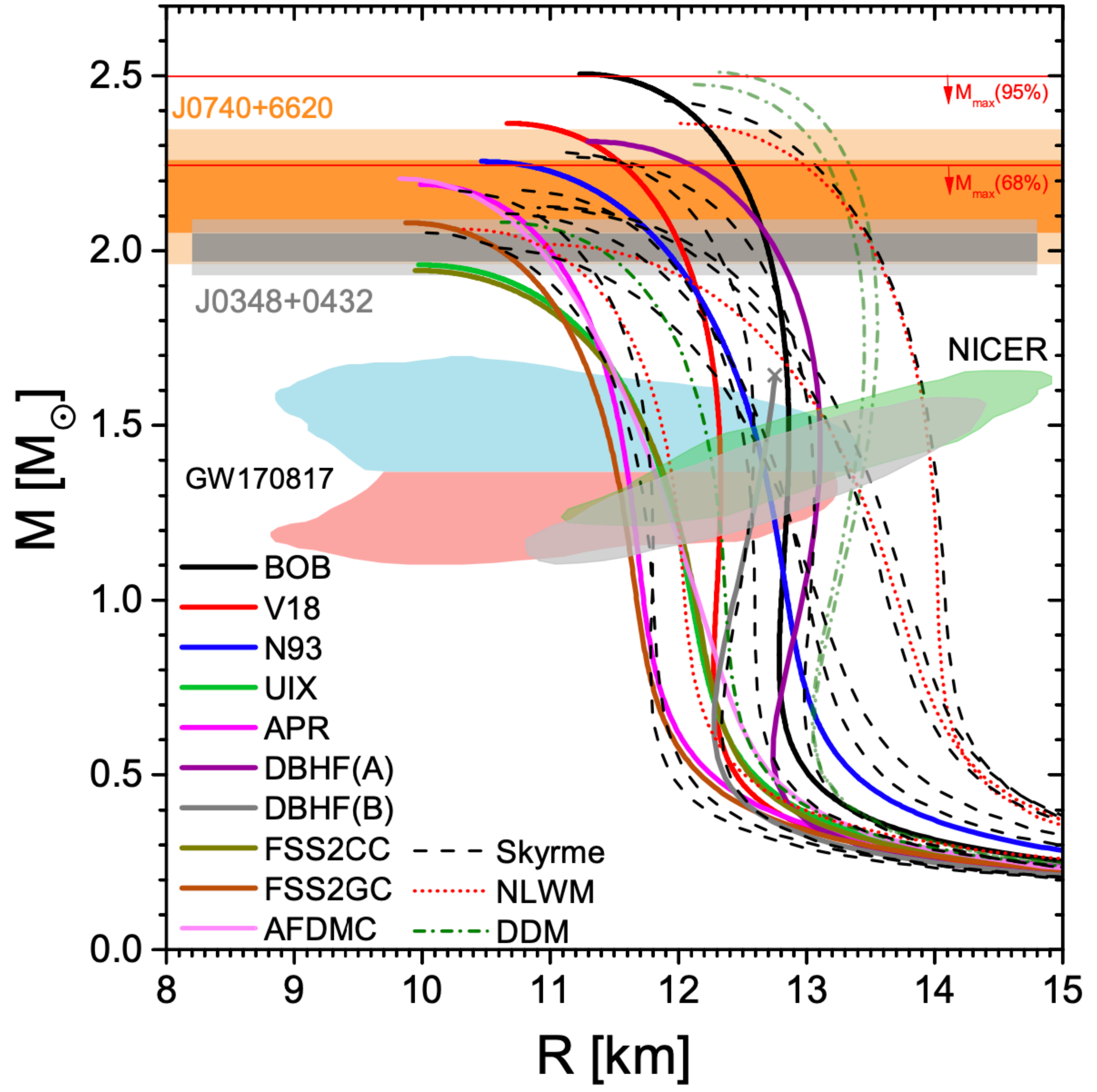




Credits: Perego et al. 2022, Metzger 2018

The Equation of State of nuclear matter

- EOS: relation between matter density, temperature and thermodynamic variables
- The EOS of Neutron Stars is uncertain
- Many models developed for the EOS
- Modelling of nuclear interaction and relevant degrees of freedom: neutrons, protons, pions, quarks, muons, …
- The relevant degrees of freedom depend on the temperature other than the density



Credits: Burgio et al. 2021

Modeling the microphysics of the merger: why?

Accurate description of the microphysics (i.e. EOS)

Precise numerical simulations of BNS mergers

Reliable predictions of GW and EM signals

Necessary for detecting and interpreting signals

Detection of GW and EM signals from the merger

Compare with predictions from numerical simulations (based on modelling)

Get a constrain on the microphysics of the merger

Insight into nuclear forces

Kilonovae joint detection: a bright future!

- Improved sensitivity of LIGO, Virgo, KAGRA $\rightarrow$ larger number of detectable BNS mergers
- ET and CE will detect $\sim 10^5$ BNS mergers per year up to redshift $\sim 5-10$
- ET and CE $\rightarrow$ improved parameters estimation, in particular sky-localisation
- Next generation telescopes as VRO and ELT will increase detection probabilities!

The Scientific Goals: a melting pot

Constrain the merger microphysics and the EOS

Identification of light elements in KN spectra

Assessing prospects for joint detection of KNe and GWs

Provide theory tools to interpret photometric and spectroscopic observations

Improving theoretical modelling of merger microphysics

Assessing the role of BNS mergers in the production of heavy elements in the Universe

More importantly...

What do you practically do in this kind of research?

1. Developing a theoretical model

—> *study, read papers, think, discuss, bother everyone in your group and outside*

2. Implementing your model

—> *programming, debugging and optimisation*

3. Understanding the results

—> *look for the physical reasons motivating your results (simulations are not oracles...), so again think, discuss, bother everyone...*

4. Predicting the impact on observables and defining the observational strategy

—> *here comes the fun!*

Thank you and enjoy your PhD!