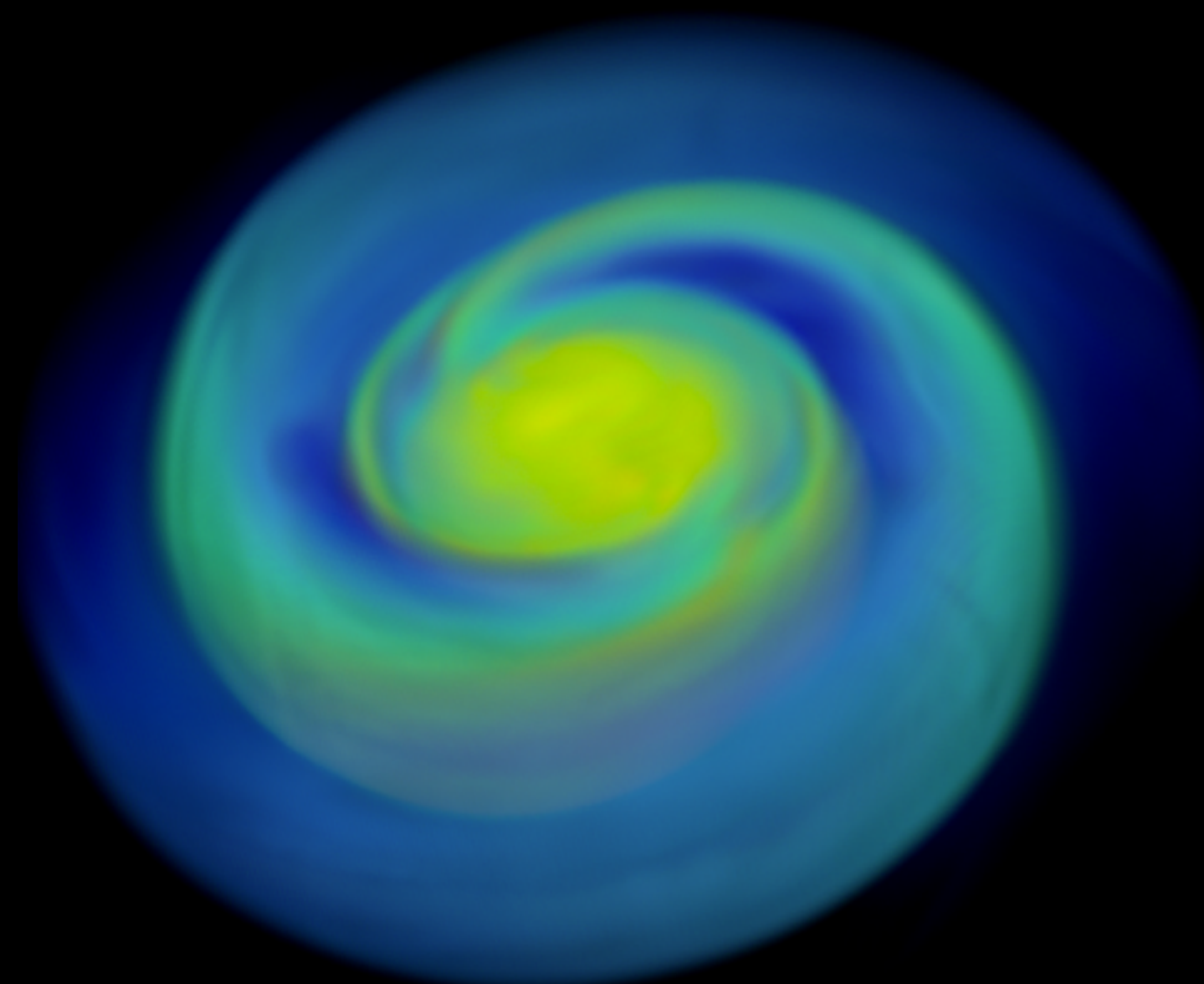
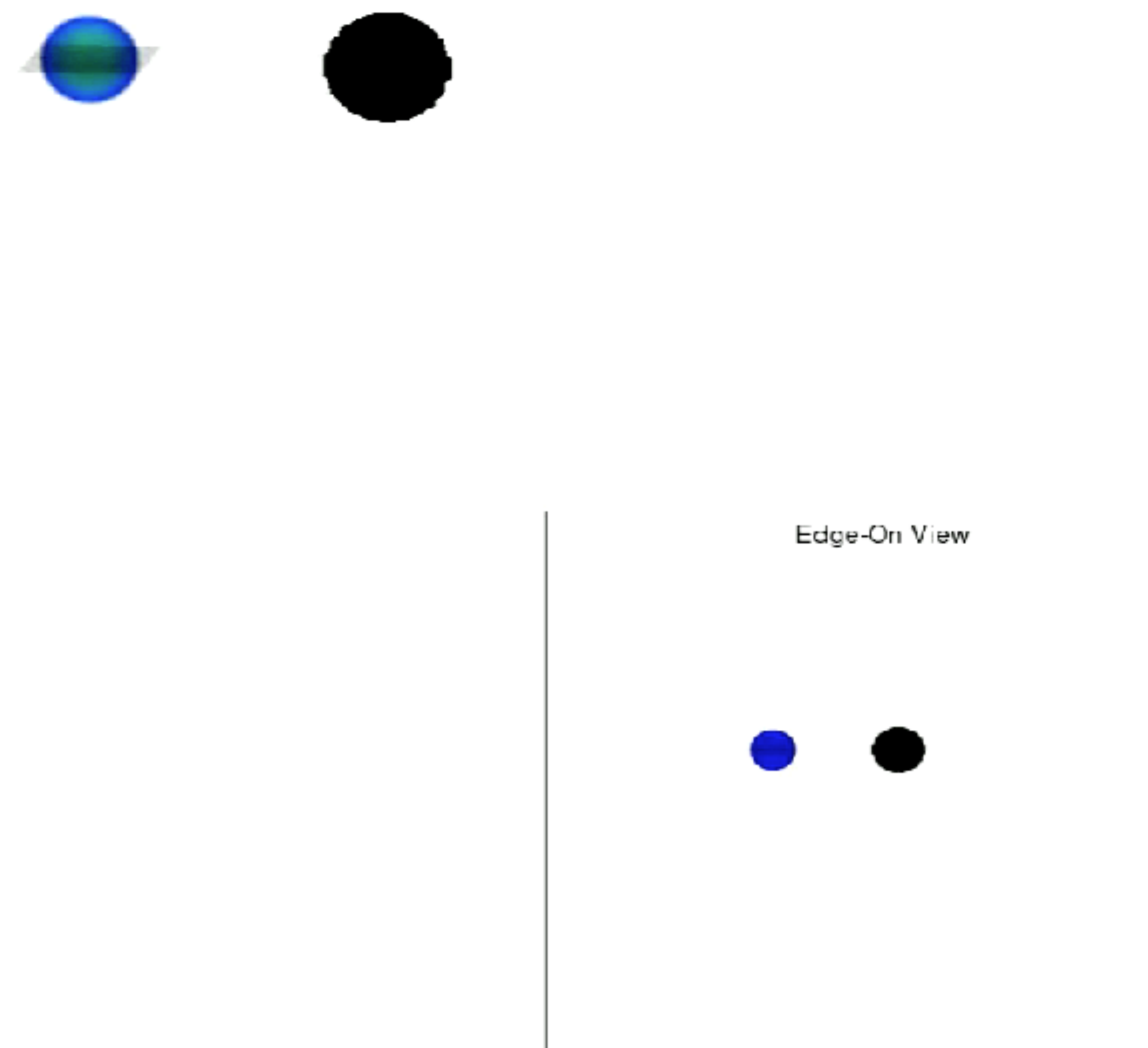
Matter Outflows in Neutron Star Mergers



Francois Foucart (UNH)

N3AS Seminar


Edge-On View

Nuclear Physics and Neutron Stars

Measuring NS masses/radii constrains unknown nuclear physics

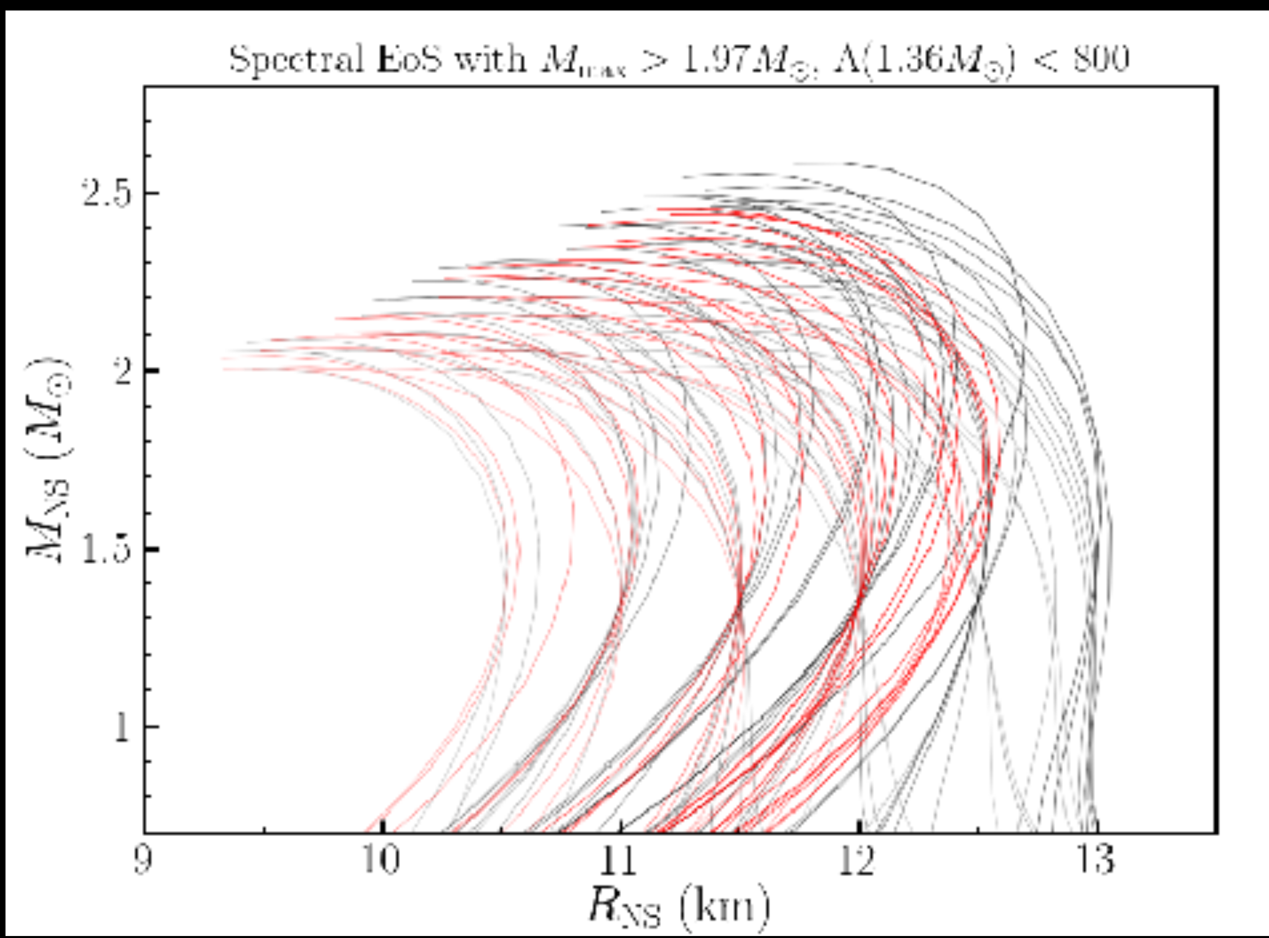


Image: F. Foucart+ 2019

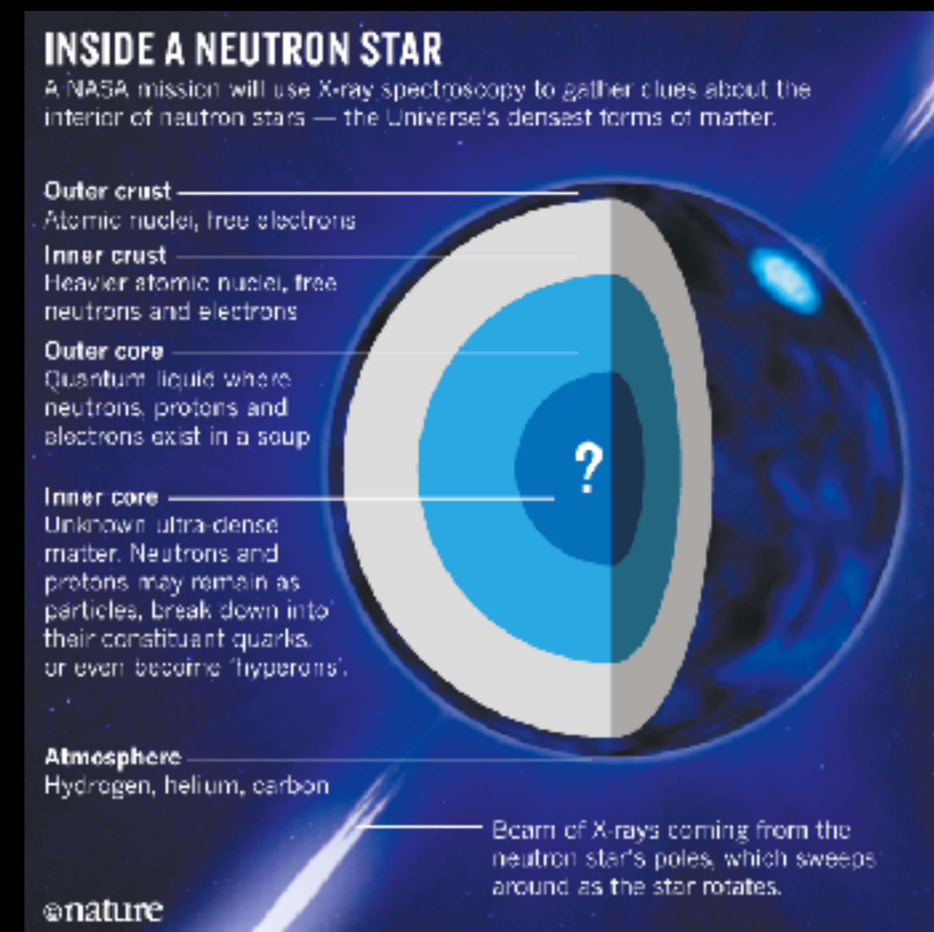
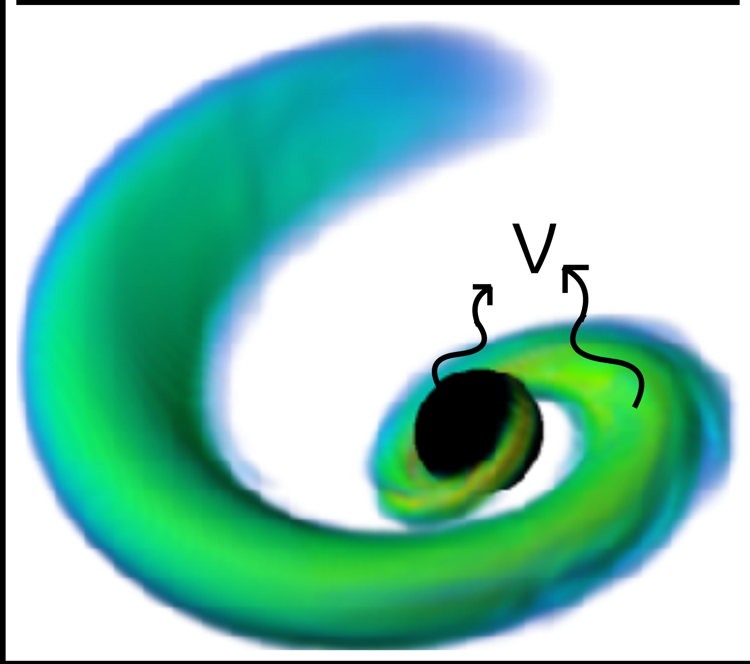


Image: NICER, Nature

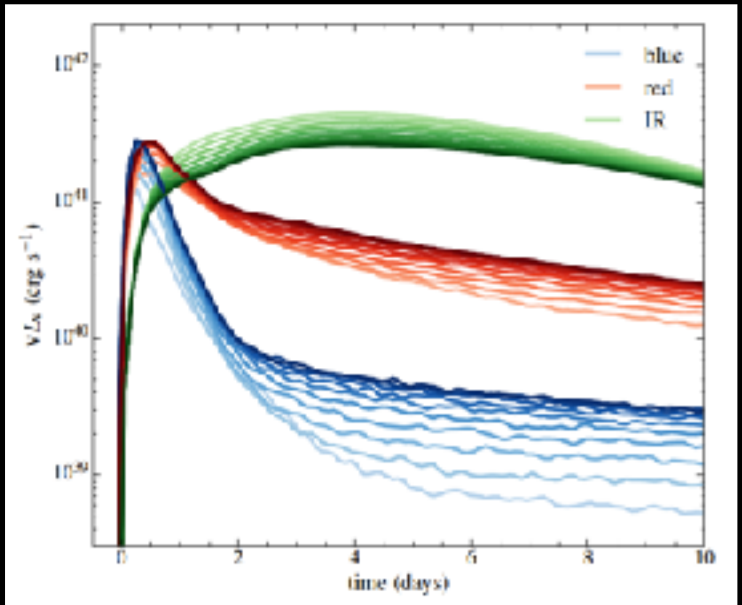
Radioactively powered electromagnetic transients

Merger event produces **unbound outflows**



r-process nucleosynthesis in neutron rich ejecta produces heavy elements

Radioactive decay of heavy elements heats ejecta



Hot ejecta produces **optical/IR transient**

Merger Outcomes

BH-NS mergers : Potential outcomes

Simulations : F. Foucart

Contraining BHNS parameters

Important dimensionless parameters for merger outcome:

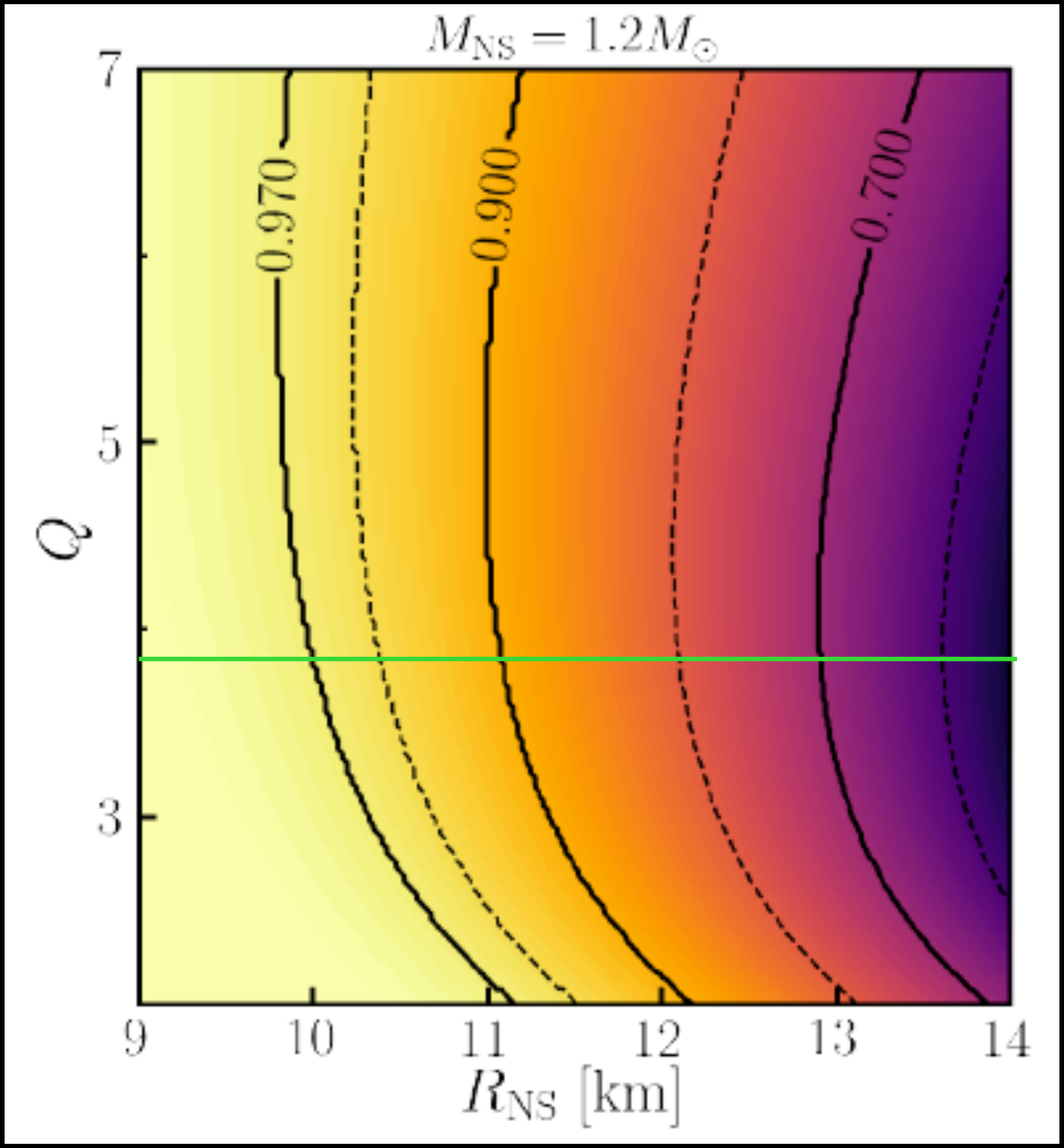
Symmetric mass ratio $\eta = m_{\rm NS} m_{\rm BH}/(m_{\rm NS}+m_{\rm BH})^2$

Neutron star compactness $C_{\rm NS} = G m_{\rm NS}/(R_{\rm NS} c^2)$

Black hole spin $\chi_{\rm BH} = J_{\rm BH}/m_{\rm BH}^2$

Symmetric binaries, large stars, and rapidly spinning black holes are more likely to lead to tidal disruption and mass ejection. (See Foucart, Hinderer, Nissanke 2018 for quantitative predictions)

Example : GW190426



Coughlin+ 2020

If less that 9% of a solar mass is ejected

NS-NS merger : Types of remnants

Outcome of merger <-> [Total mass of binary] / [Maximum mass of NS]

See David Radice's talk last semester

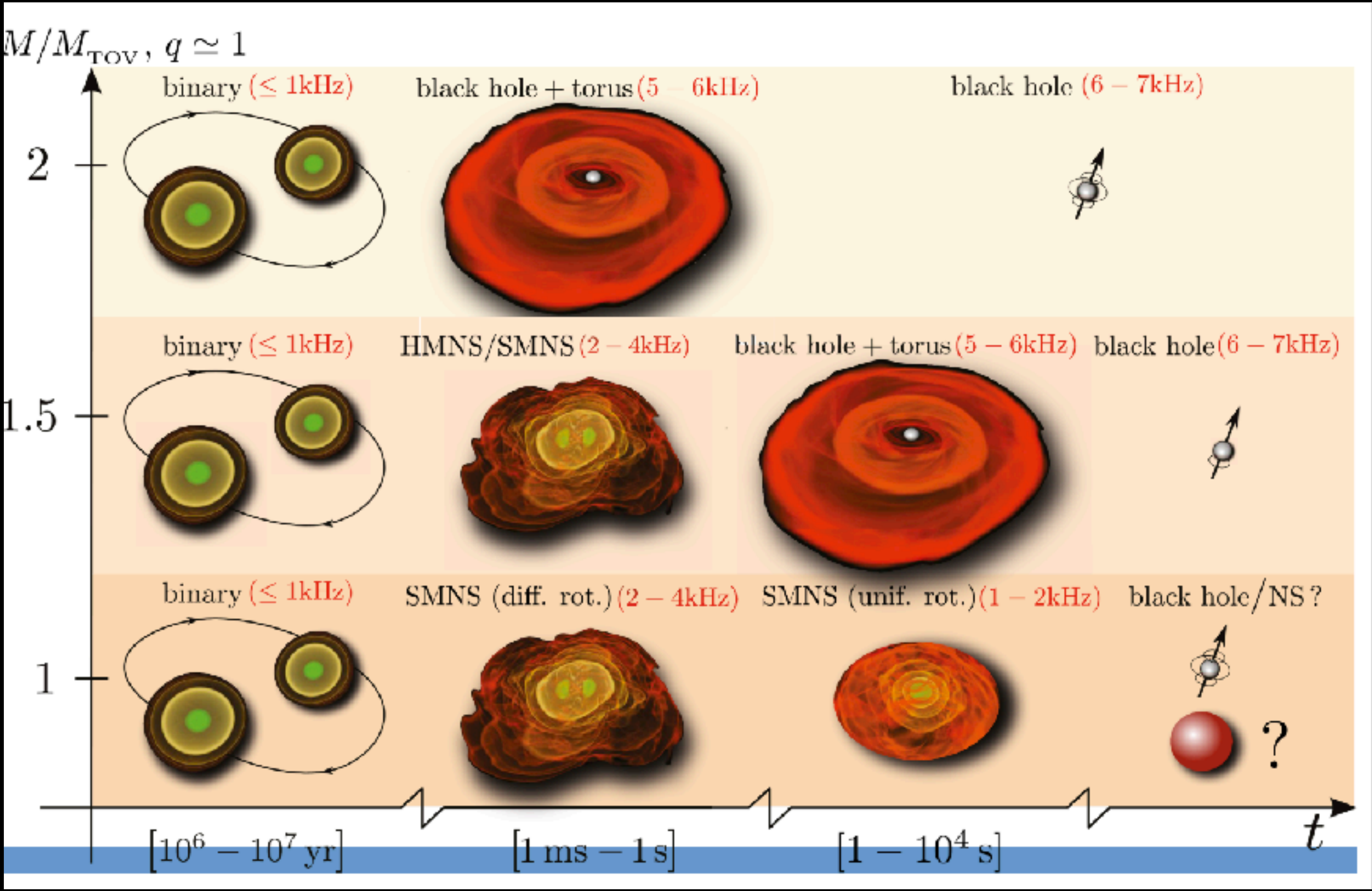


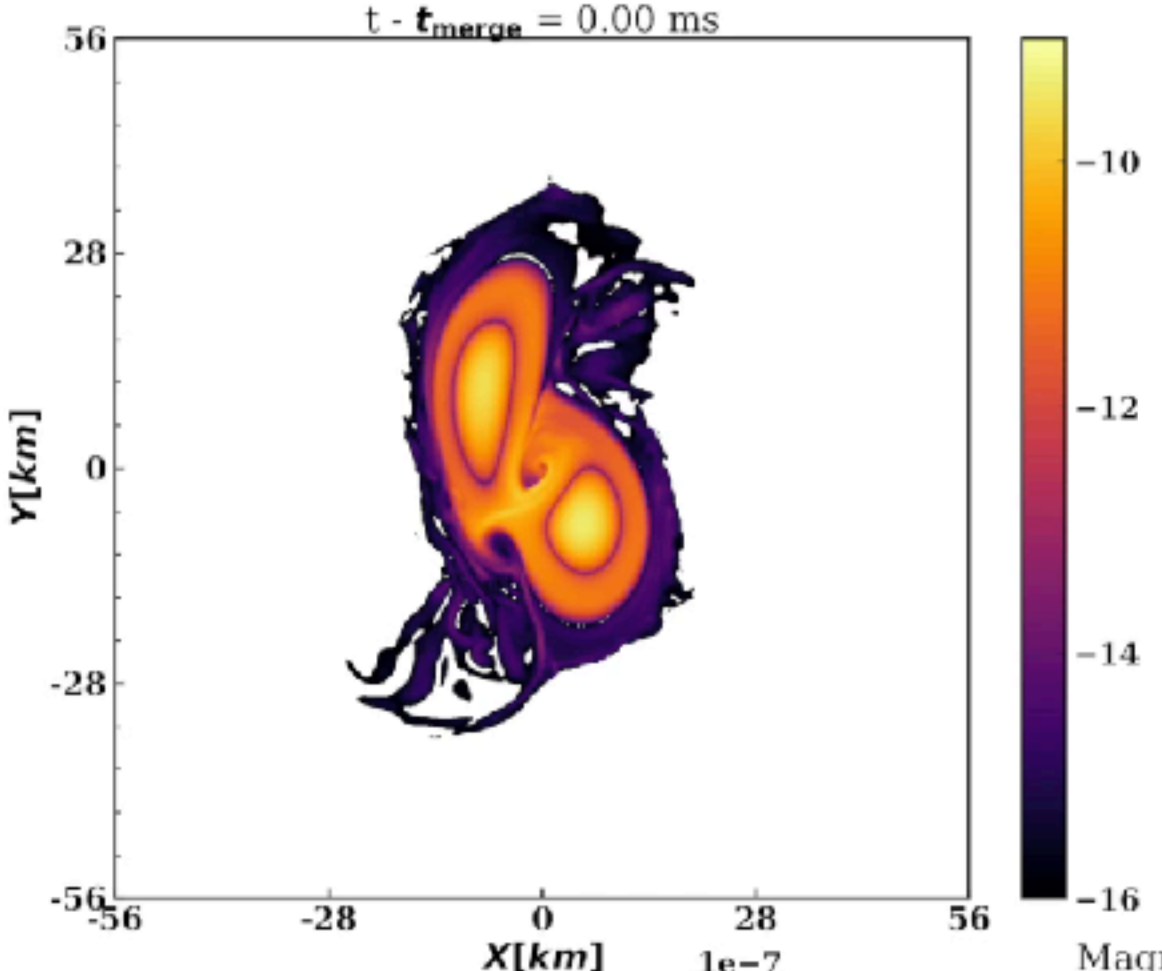
Image: Baiotti+ 2017

Post-Merger outflows

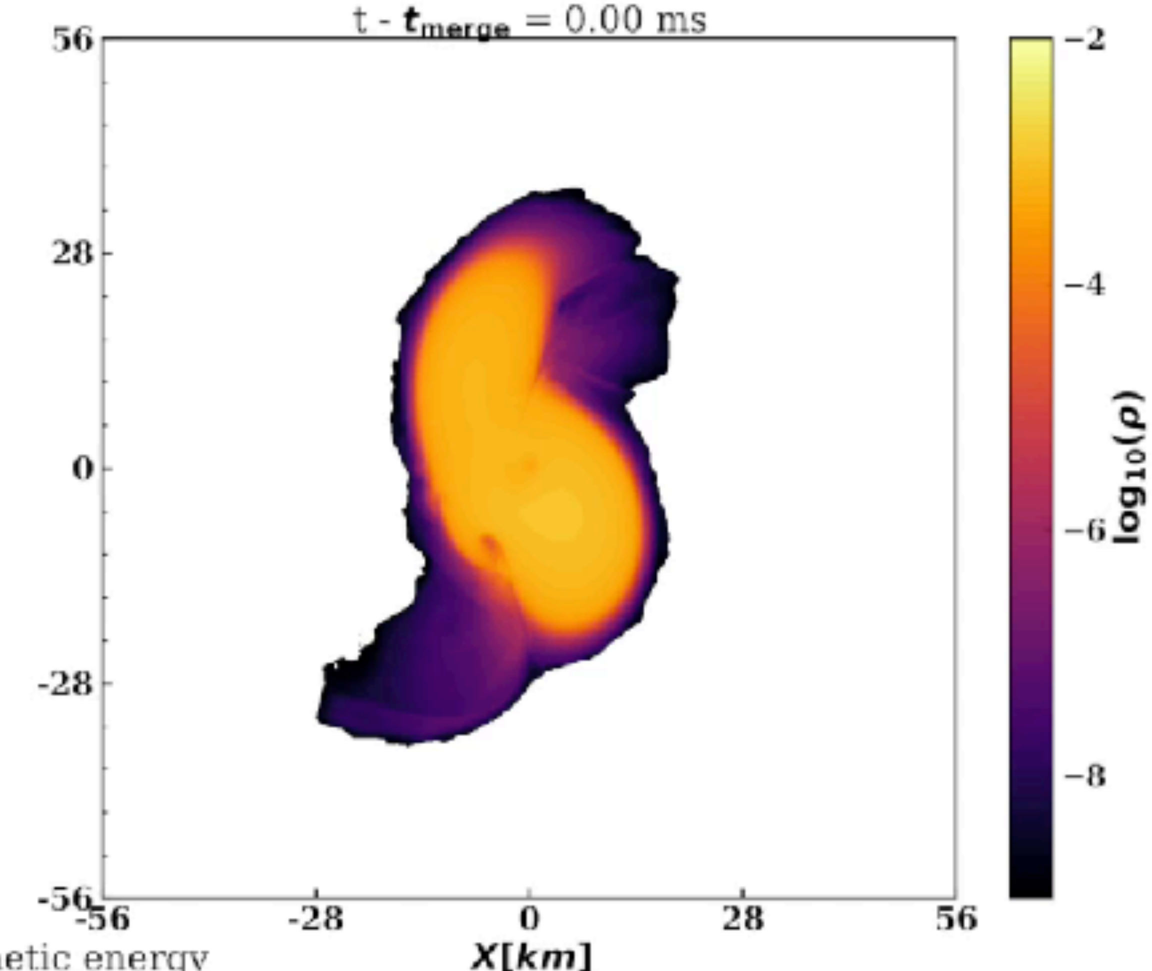
- Post-merger outflows are important to kilonova modeling
- ~15%-50% of disk mass eventually unbound (Siegel+, Fernandez+, Christie+)
- Main source of uncertainties:
  - Large-scale structure of post-merger B-field (Christie+)
  - Missing physics in post-merger simulations (Neutrino transport, 3D, massive neutron star,…)

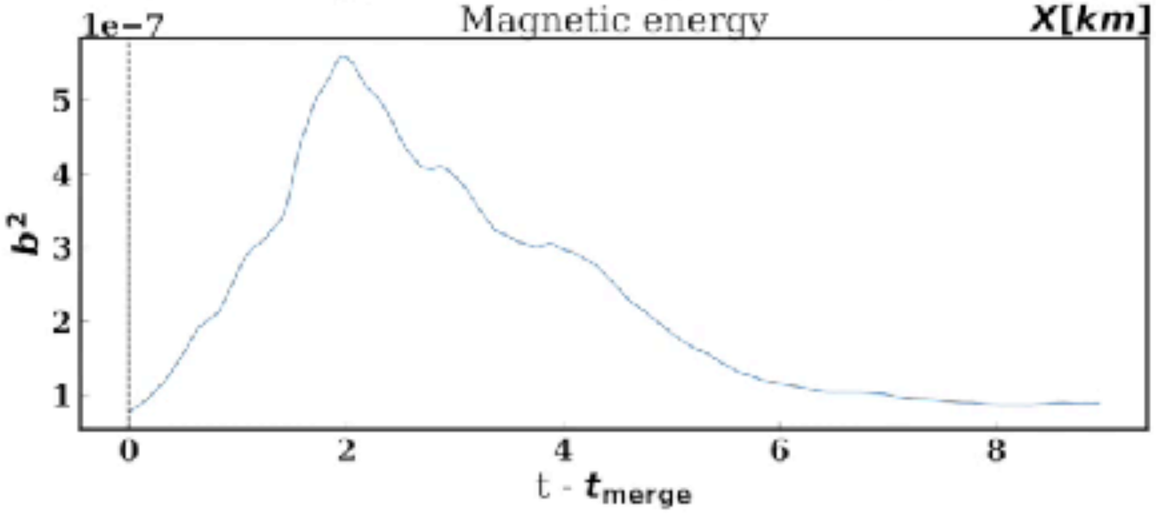
NS-NS mergers : B-fields

Magnetic Energy Density



Fluid Density

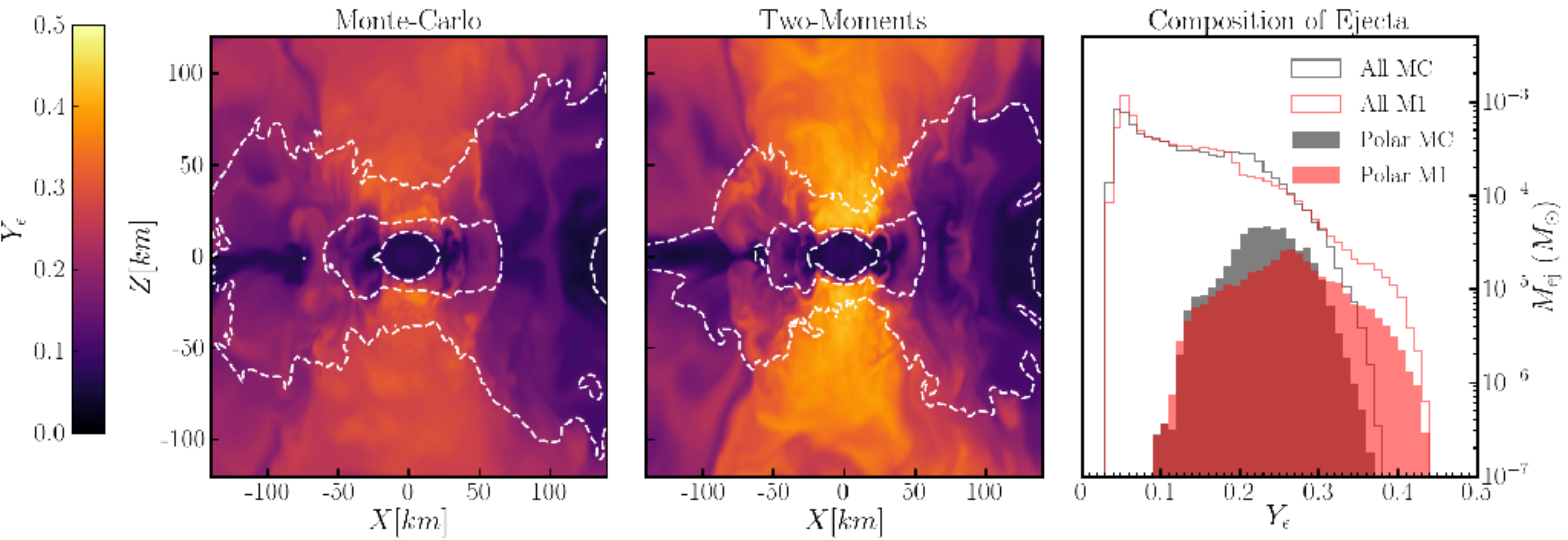




Simulation: A. Chernoglazov (UNH)

NS-NS mergers : Neutrino transport

- Neutrino transport required to capture composition of outflows
- Monte-Carlo transport now possible in simulations
- Difference between MC and simpler transport ~10-20%



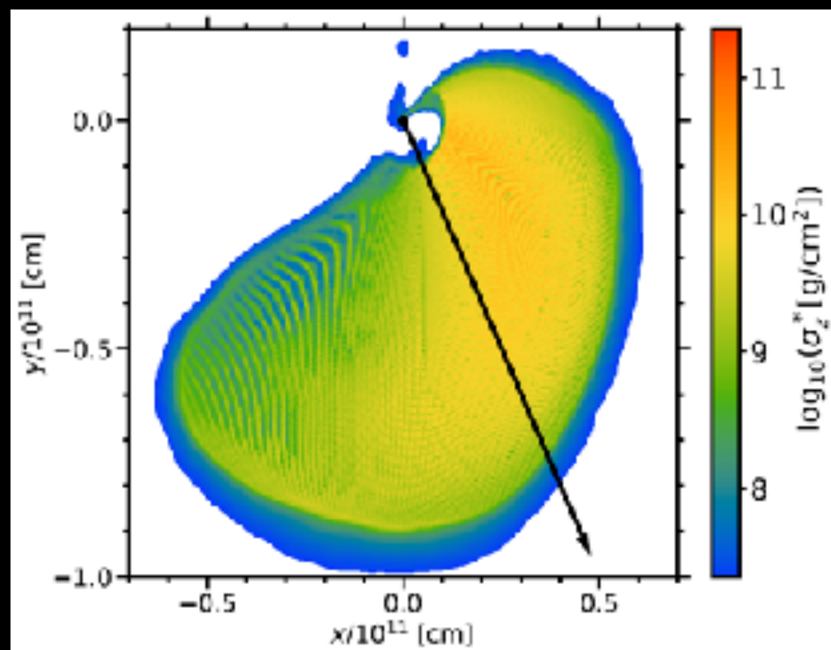
Foucart+ 2020

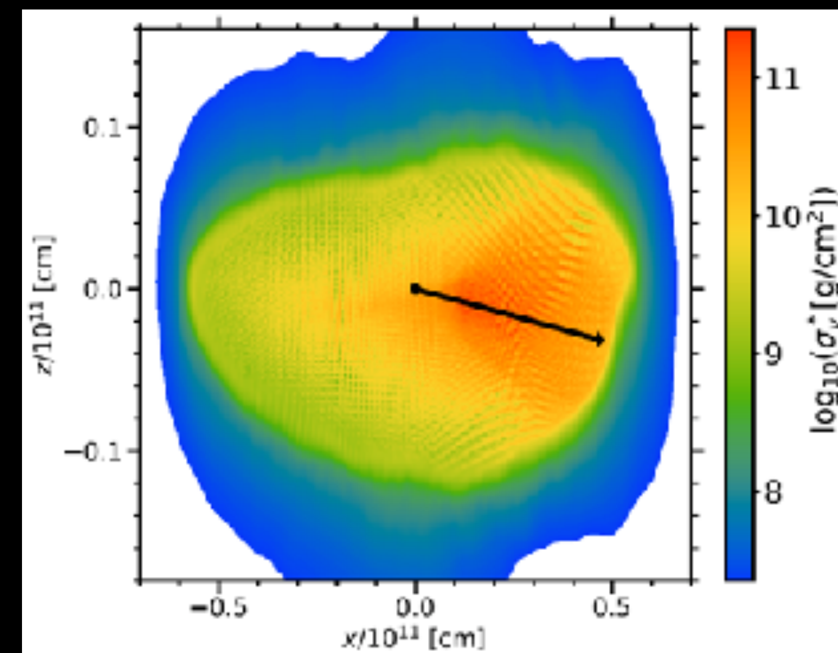
Long-term evolution of merger outflows

r-process heating in BHNS outflows

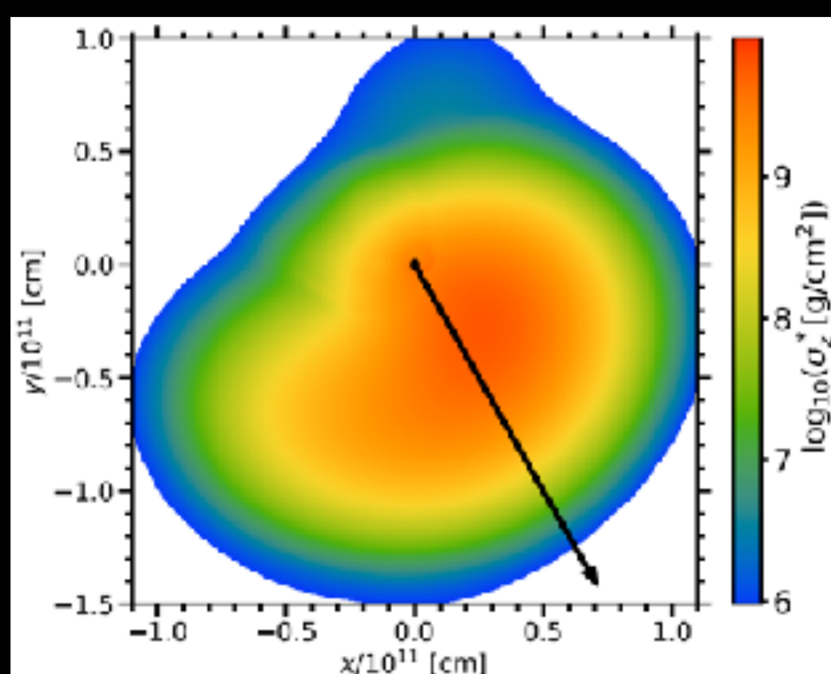
Equatorial plane | **Vertical snapshot**

No Heating





Heating



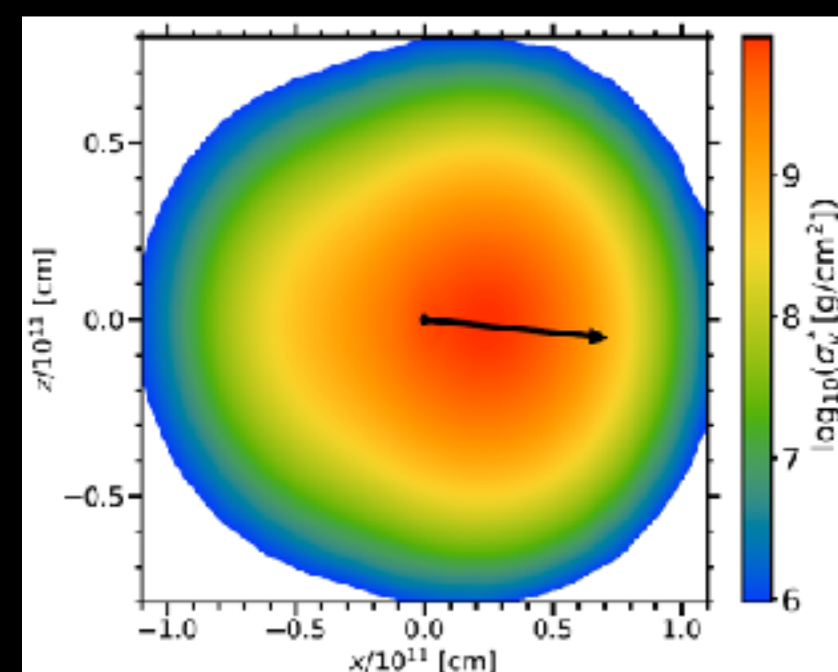
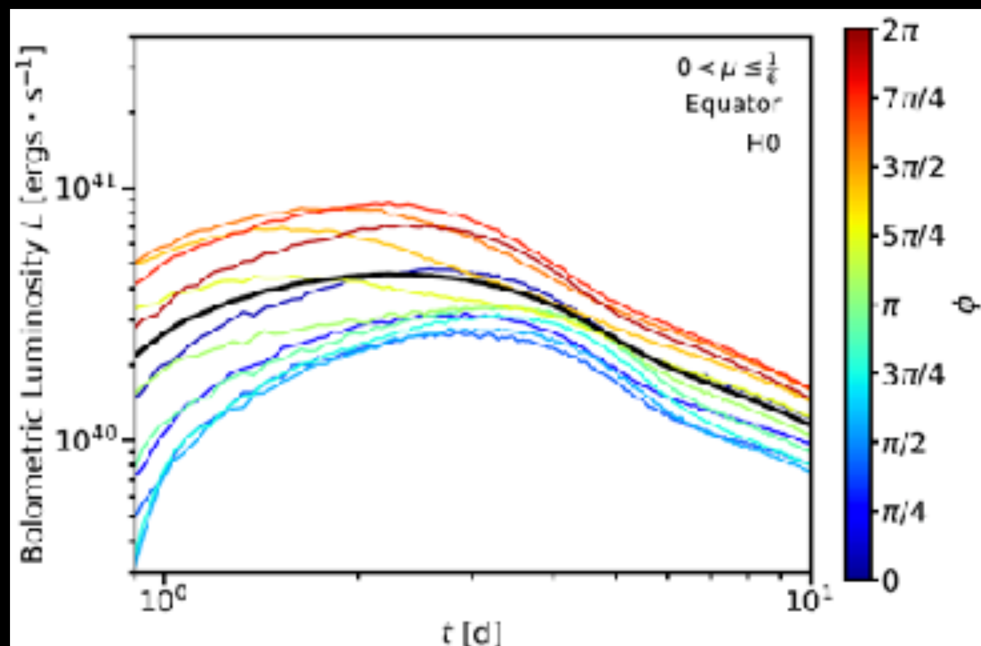


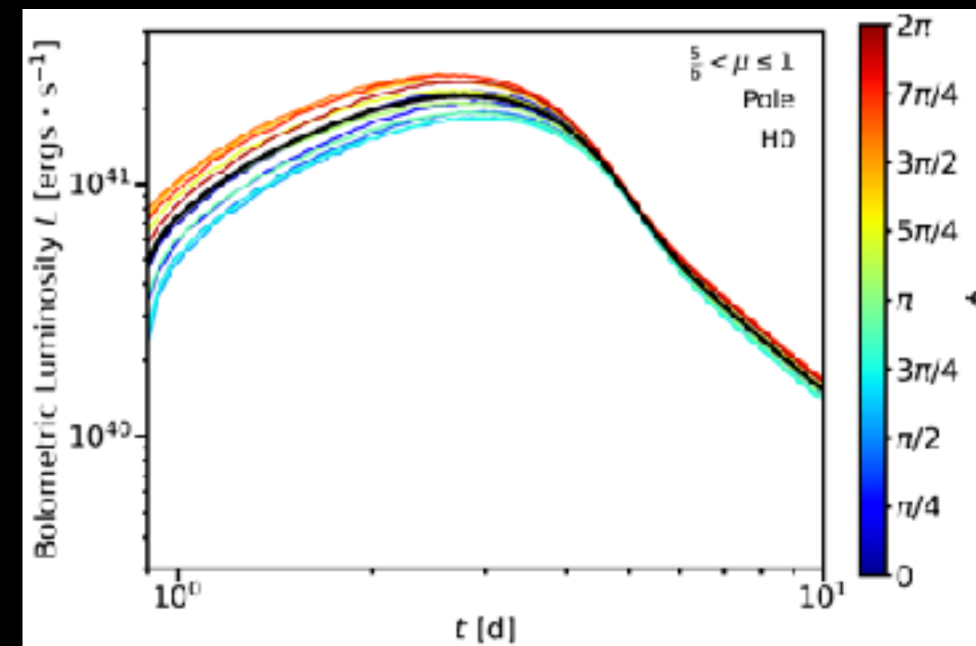
Image: S. Darbha+ (2021)

Bolometric luminosity

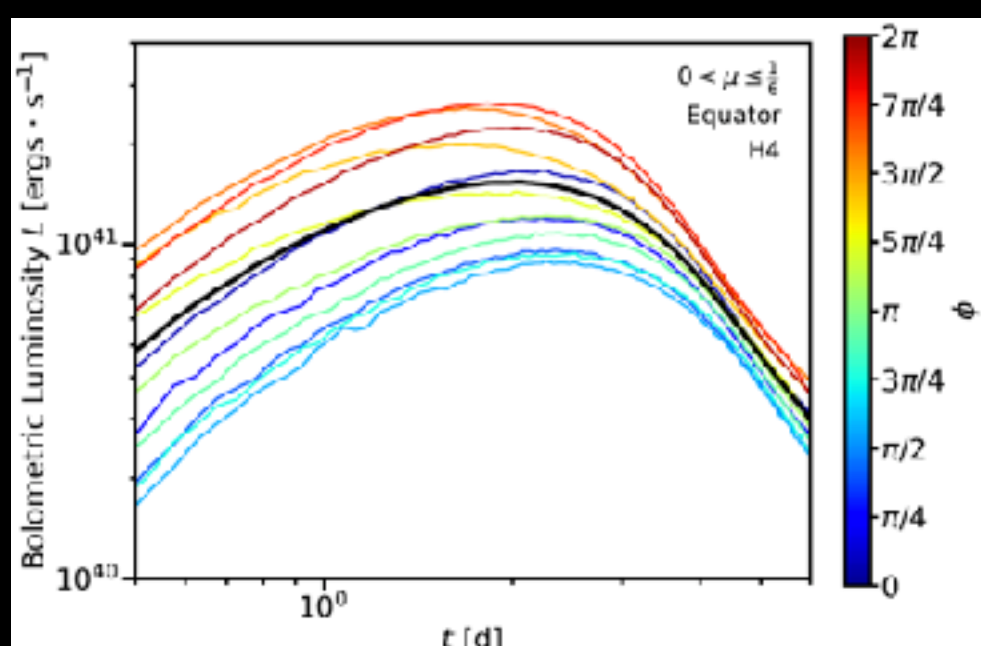
Edge-on | **Face-on**

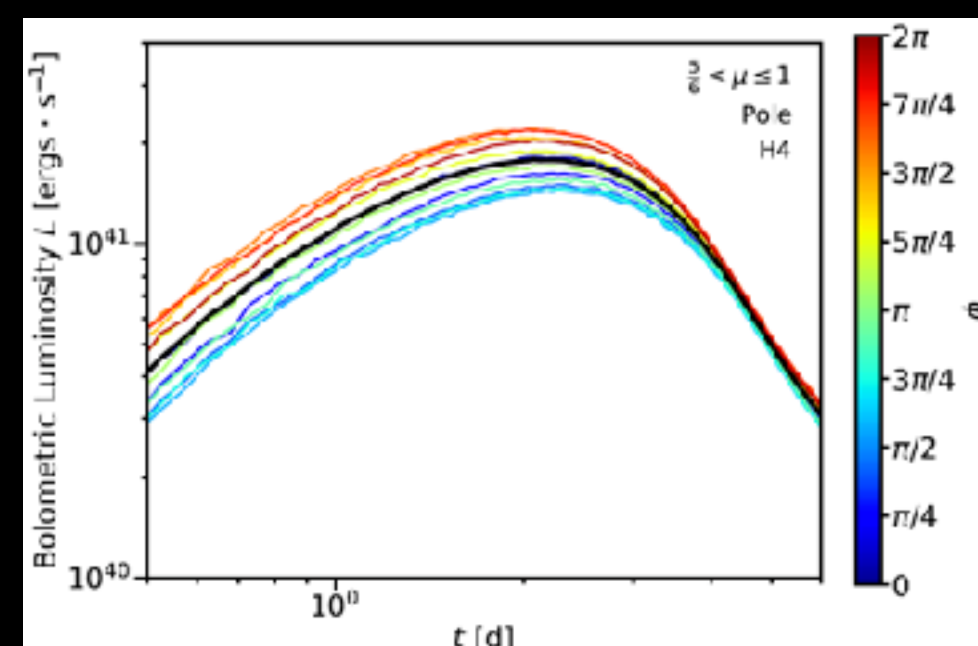
No Heating





Heating





Summary

- Inspiral / Merger phase well understood
  - Provide some simple cutoffs in parameter space when observing kilonovae
- Post-merger evolution still limited by incomplete physics
  - B-fields underresolved (hardest problem!)
  - Neutrino-matter interactions approximately modeled
  - Error bars on kilonova models poorly understood, and often underestimated
- ***Detailed parameter estimation from kilonova observations remains a delicate exercise today!***