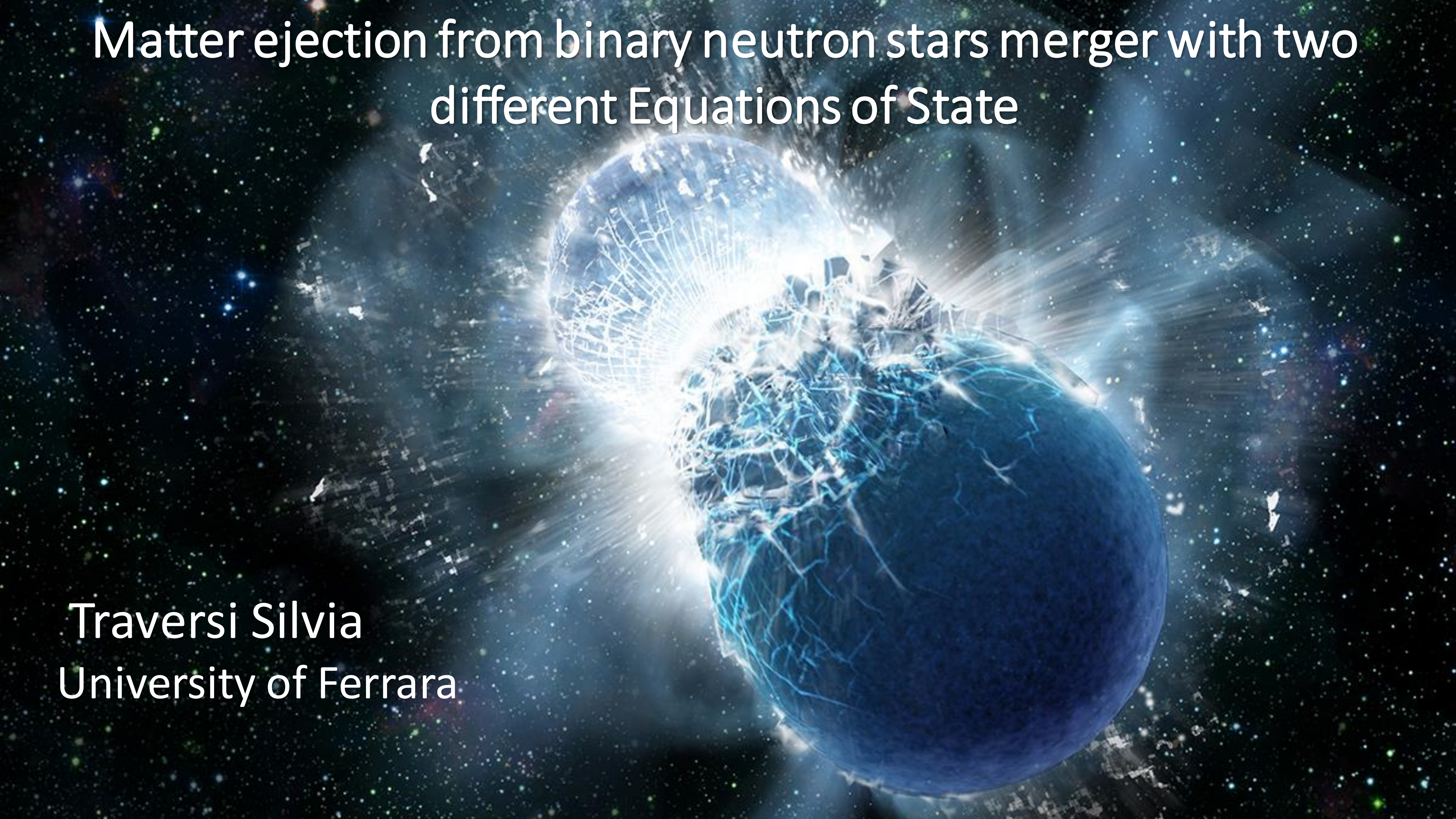
Matter ejection from binary neutron stars merger with two different Equations of State

Traversi Silvia
University of Ferrara



EJECTION MECHANISMS

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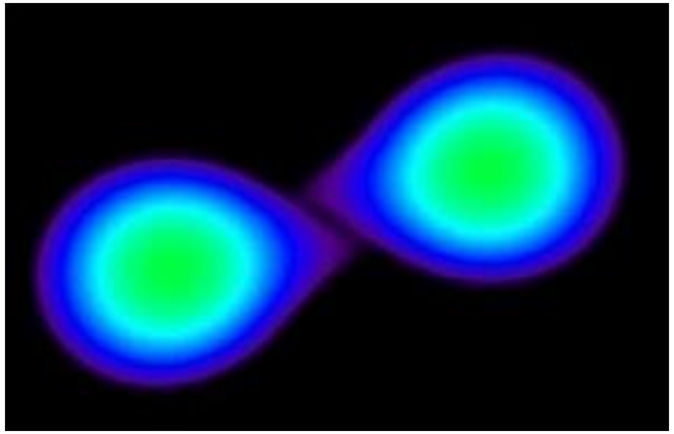
- **Dynamical ejection:**

- Tidal deformation: equatorial plane



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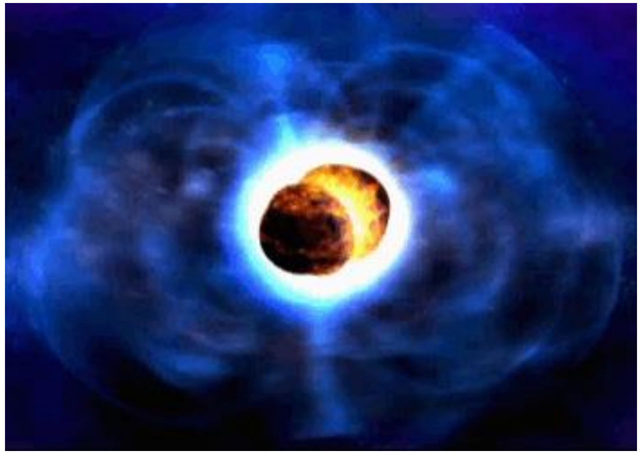

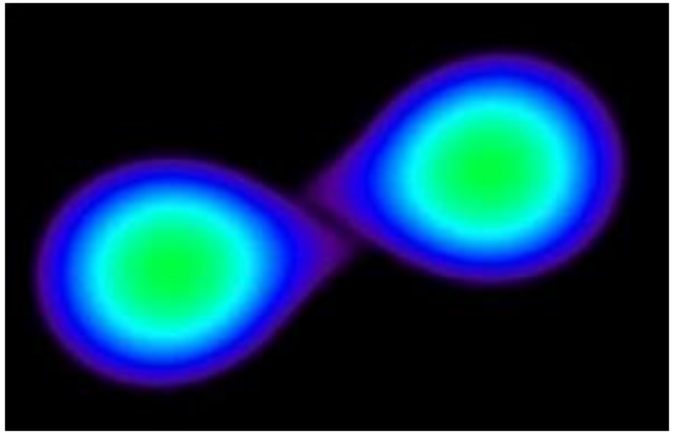

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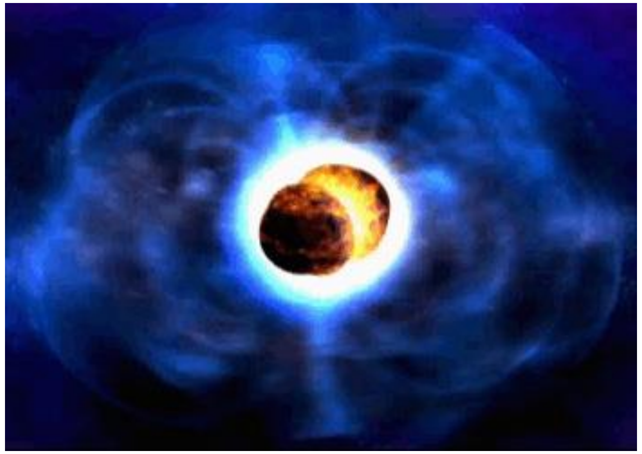
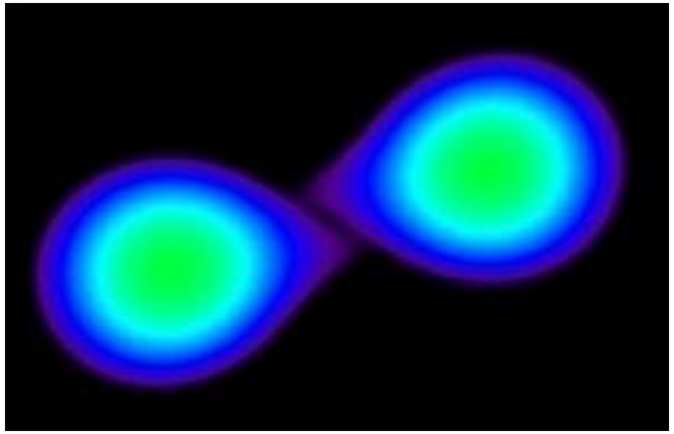
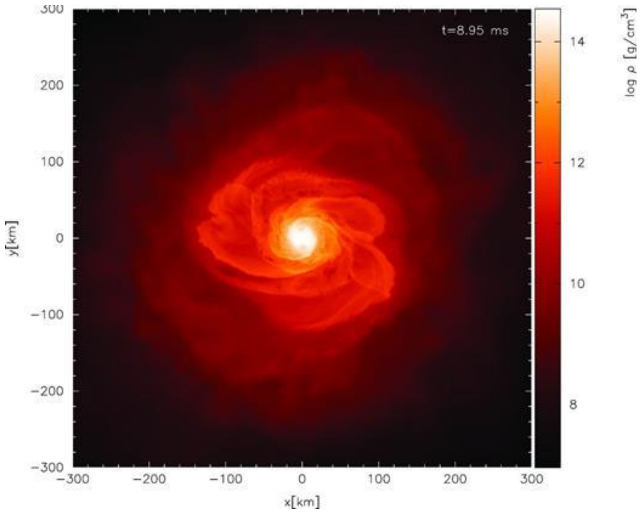


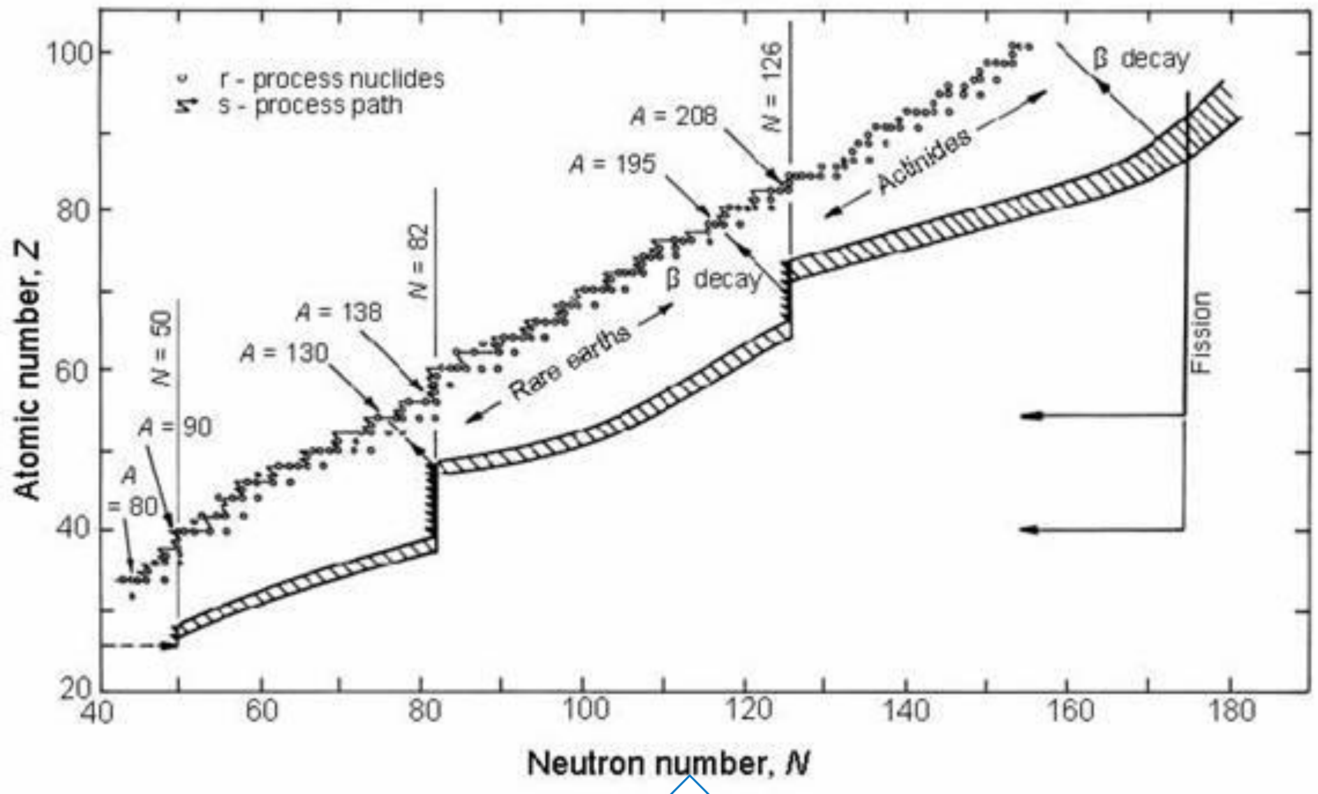


❖ Shock at NSs interface and radial oscillations

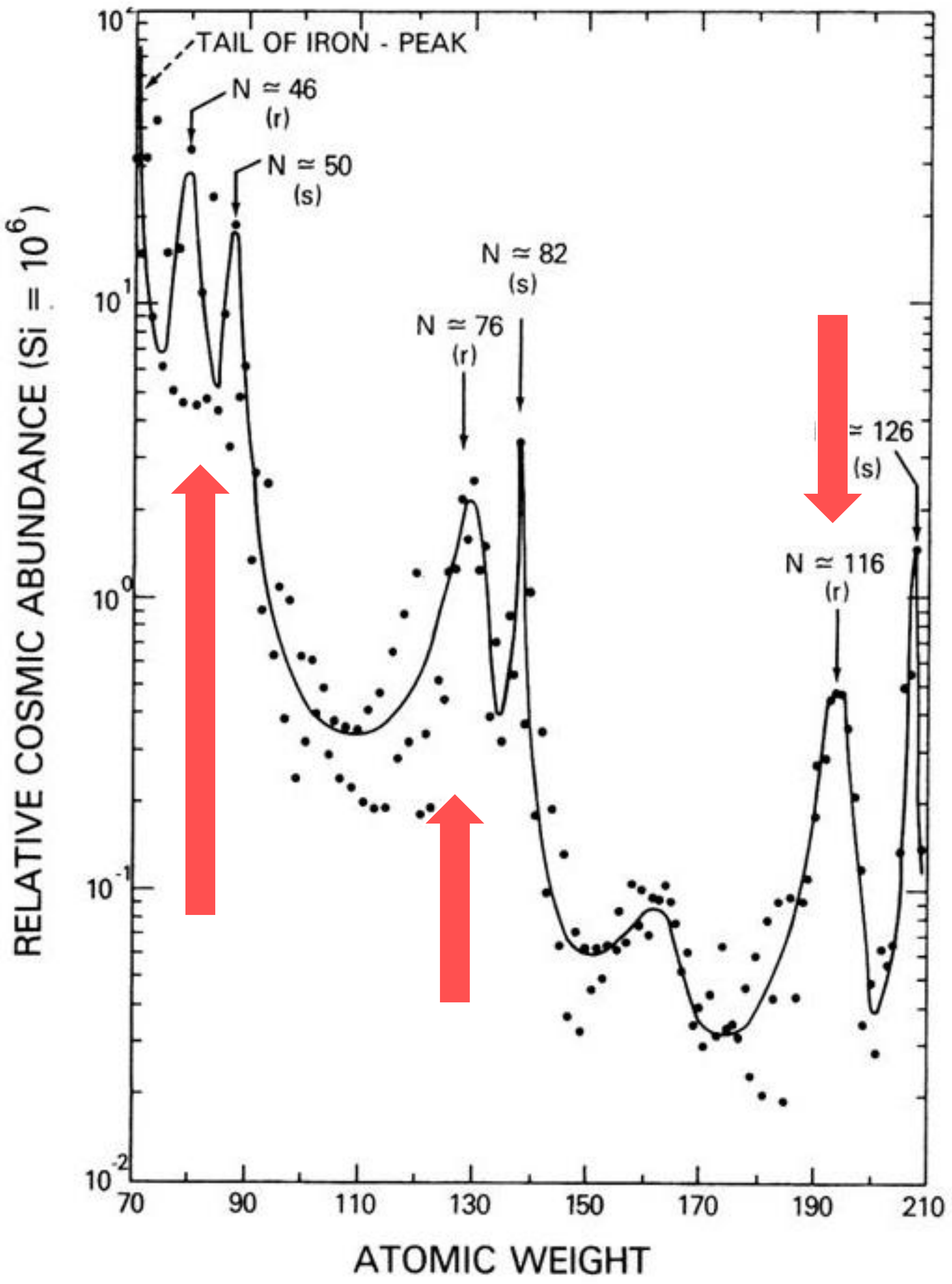
- **Disk:** $10^{-3}\ M_{\odot} < M_{disk} < 0.03 M_{\odot}$

❖ Viscous or neutrino heating





R-process path

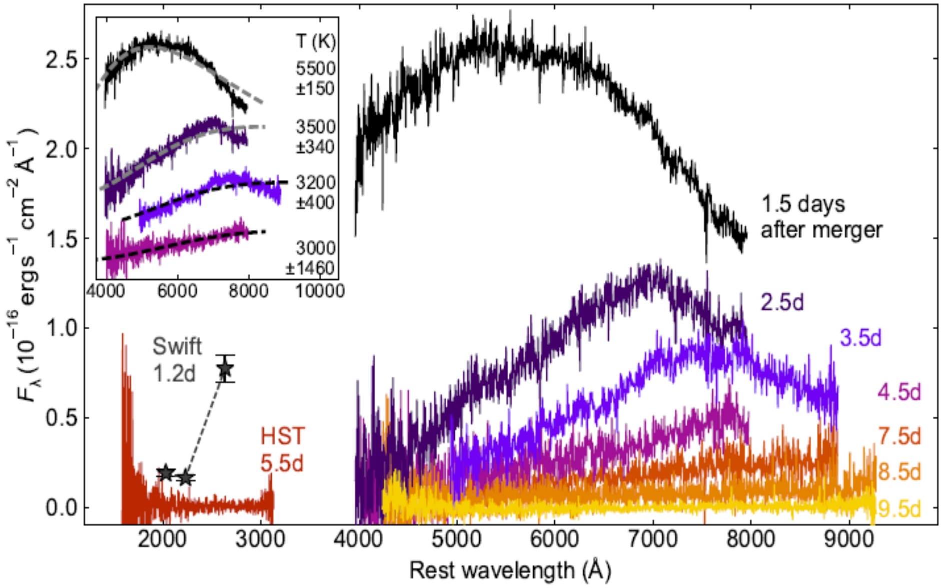


Haevy elements peacks

The kilonova signal

$$t_{peak} \propto \left(\frac{kM_{ej}}{v}\right)^{1/2} \qquad L_{peak} \propto \left(\frac{vM_{ej}}{k}\right)^{1/2}$$

$$T_{peak} \propto \left(vM_{ej}\right)^{-1/8} k^{-3/8}$$



Nicholl et al. [arXiv:astro-ph.HE/1710.05456]

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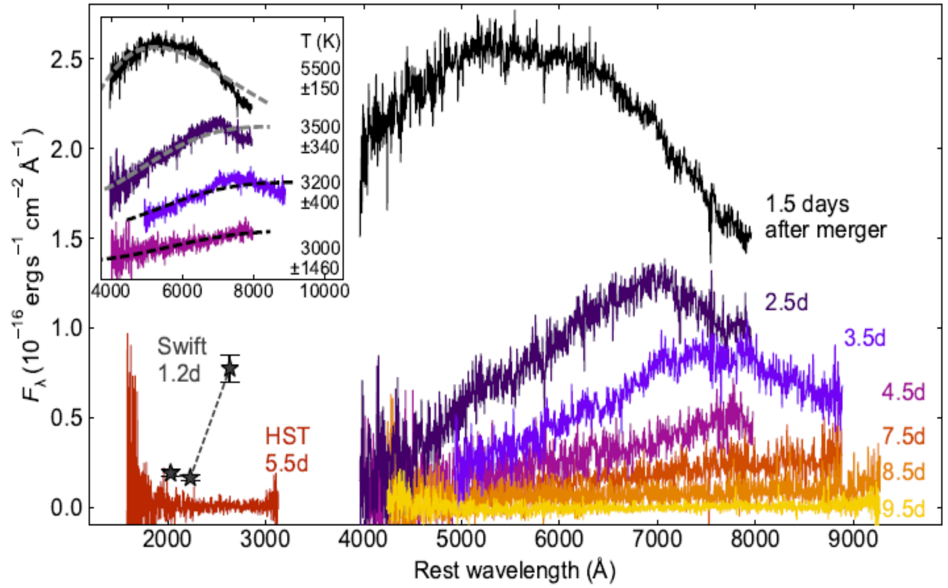

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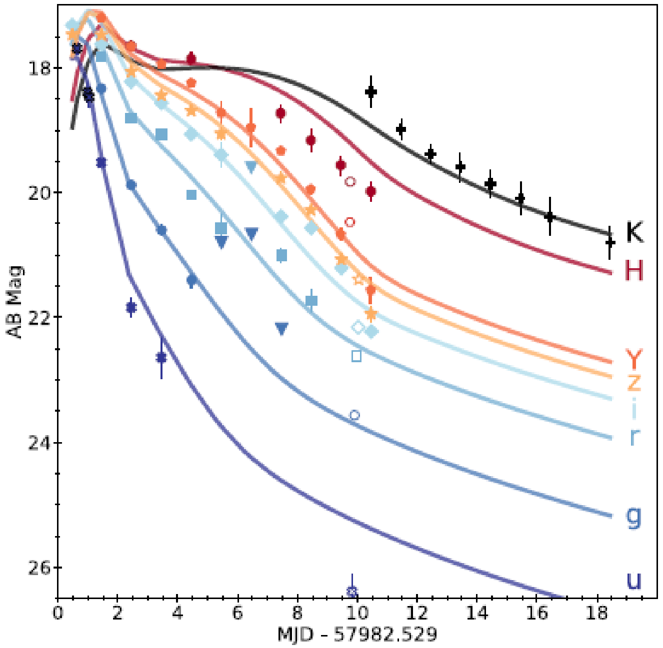


Cowperthwaite, P.S.; others. [arXiv:astro-ph.HE/1710.05840].

Blue Kilonova

$M_{ej}^B \sim 0.01\, M_\odot\, , v_{ej}^B = 0.27c\, ,$
$k^B = 0.5 cm^2 s^{-1}$

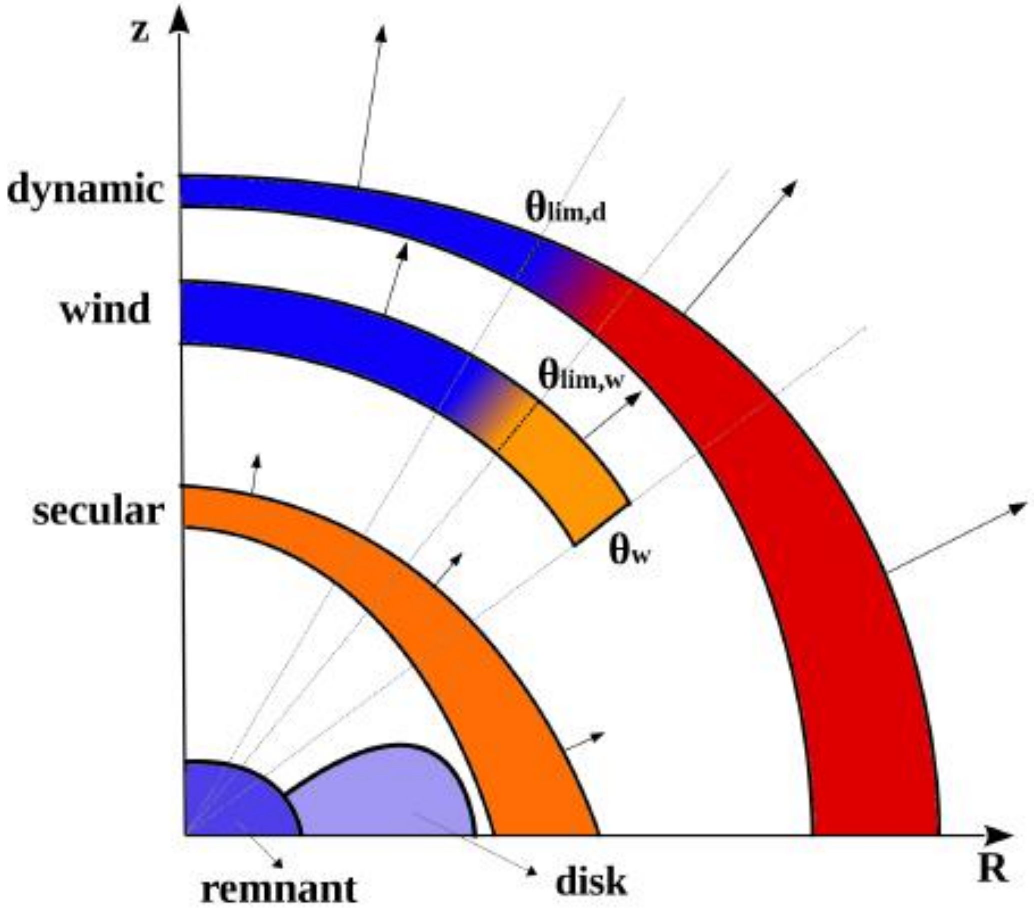
Purple Kilonova

$M_{ej}^P \sim 0.03\, M_\odot\, , v_{ej}^P = 0.11c\, ,$
$k^P = 3 cm^2 s^{-1}$

Red Kilonova

$M_{ej}^R \sim 0.01\, M_\odot\, , v_{ej}^R = 0.16c\, ,$
$k^R = 10 cm^2 s^{-1}$

The electron fraction



Perego, A.; Radice, D.; Bernuzzi: [arXiv:astro-ph.HE/1711.03982].

❖ **Shock: $Y_e > 0.25 - 0.3$**
Lanthanide poor

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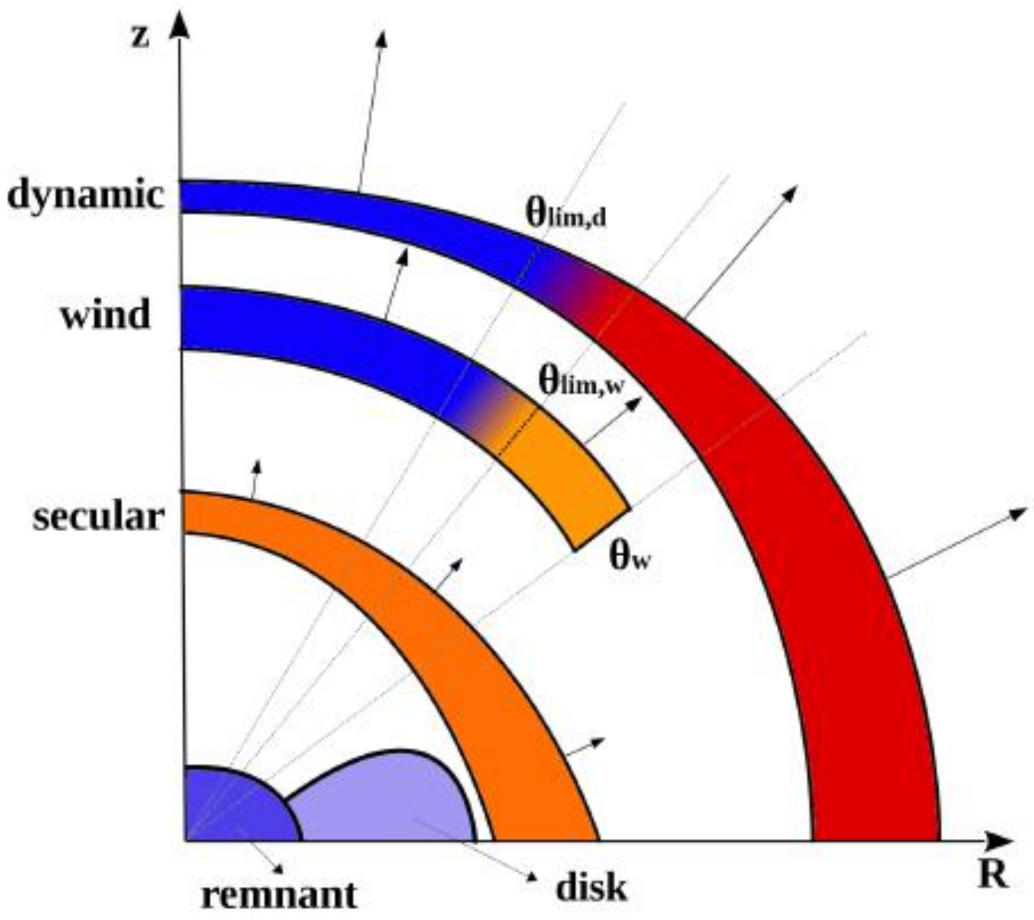

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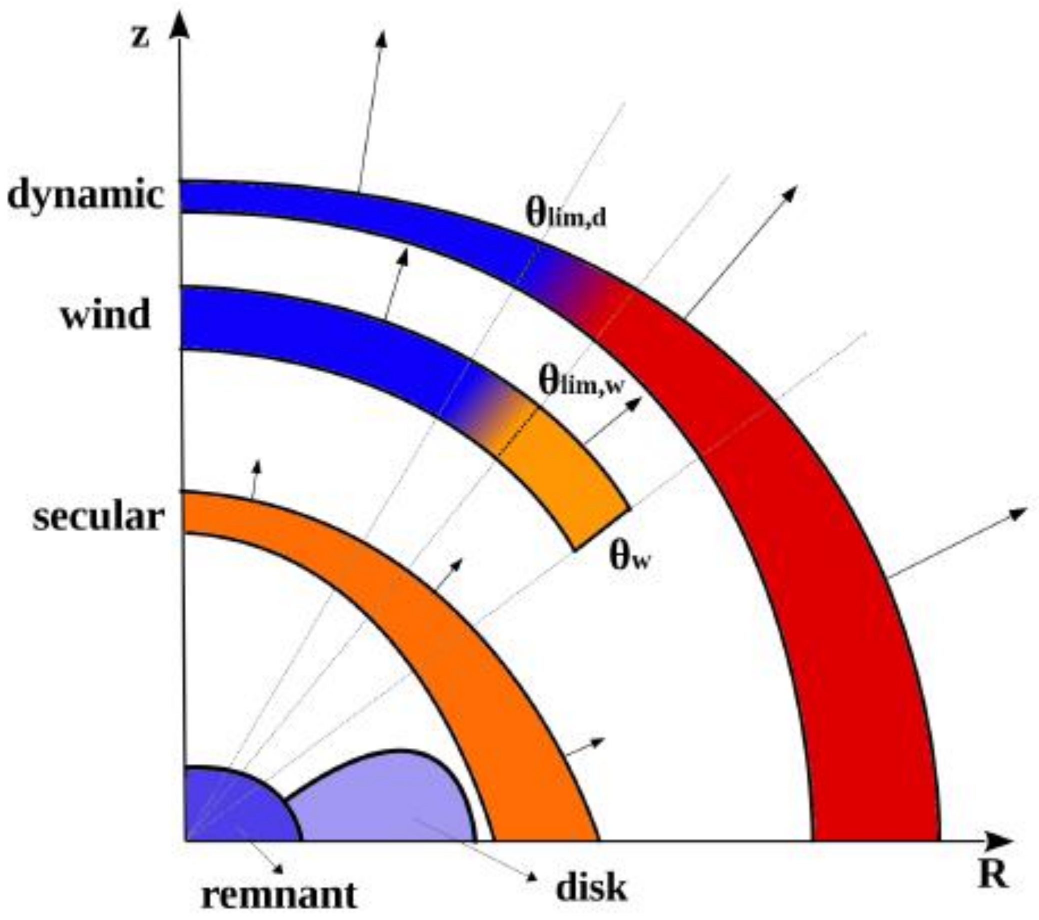

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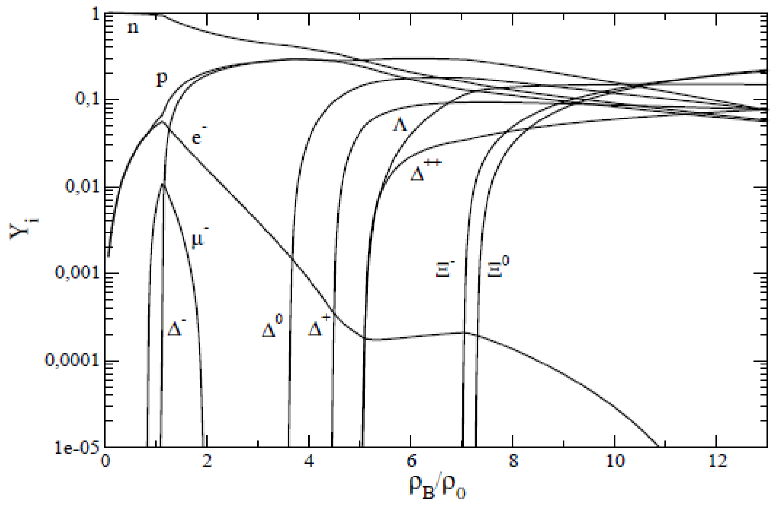
- Shock: $Y_e > 0.25 - 0.3$
  Lanthanide poor
- Tidal ejection: $Y_e < 0.1$
  Lanthanide rich
- Wind in polar direction: $Y_e = 0.3 - 0.4$
  Lanthanide poor
- Wind and secular: $Y_e \sim 0.2$
  Depends on the lifetime of the HMNS

The two families scenario

1. **Hadronic stars:** $M_{max} \sim 1.6 M_{\odot}$, $R \sim 10km$
2. **Quark stars:** $M_{max} \sim 2 M_{\odot}$, $R > 11km$

The two families scenario



Appearance of hyperons and Δ-resonances

Softening of the EOS

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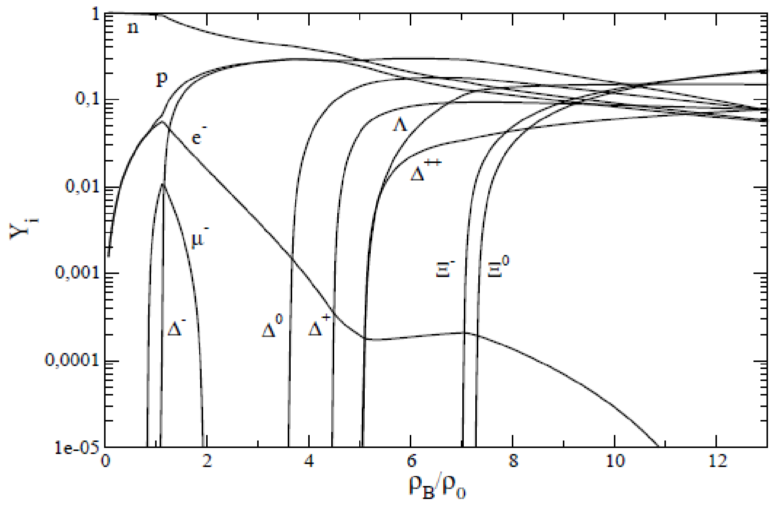

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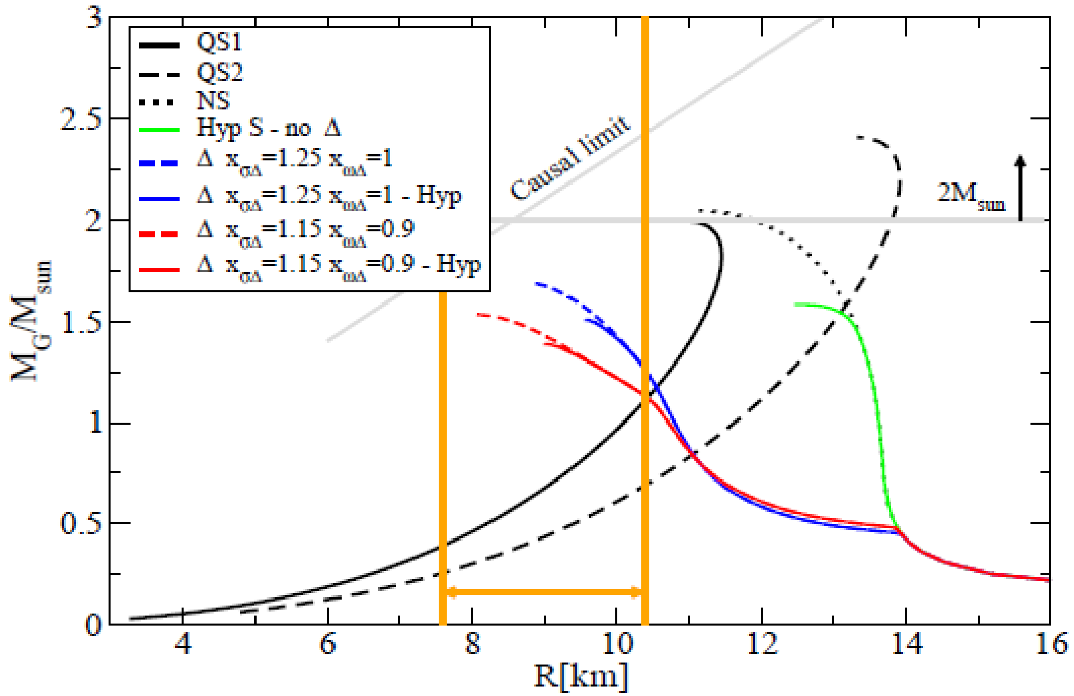

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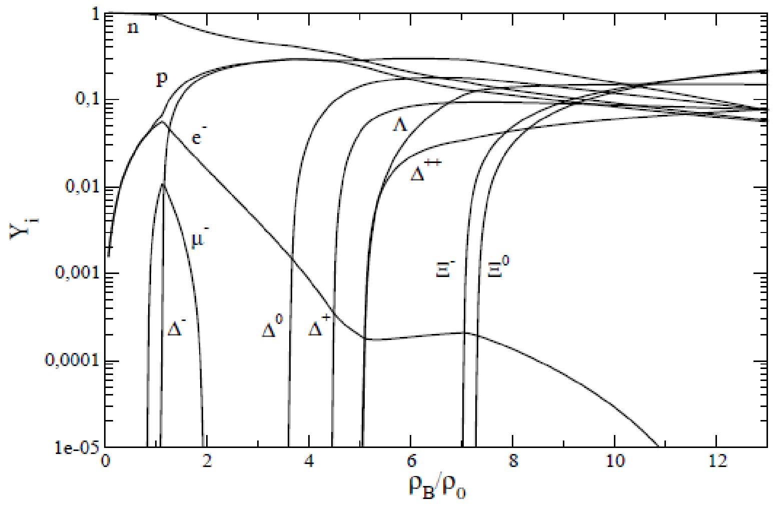

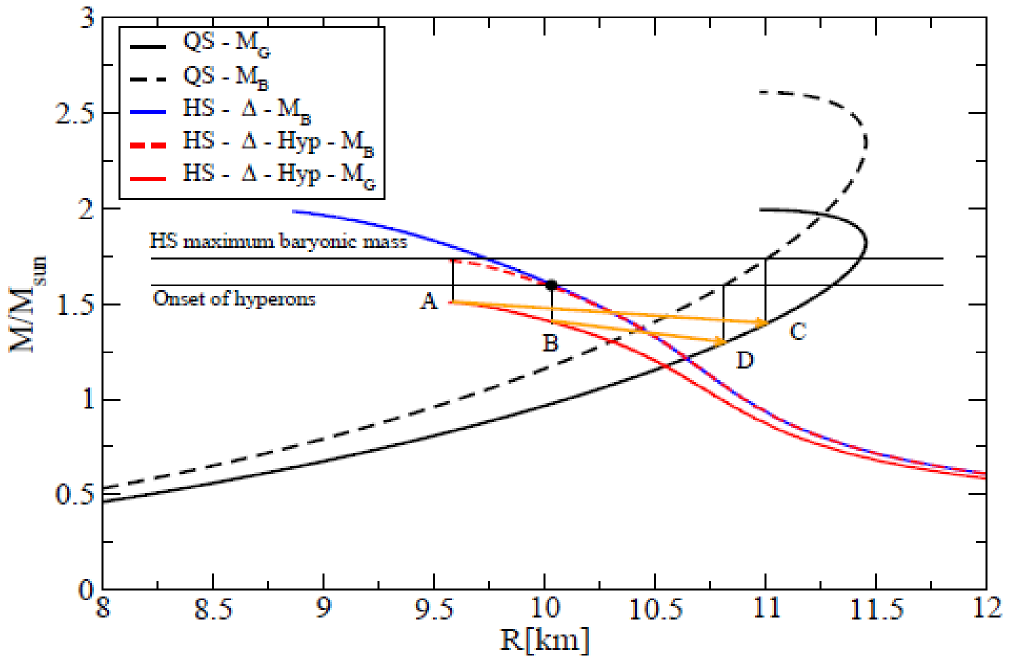

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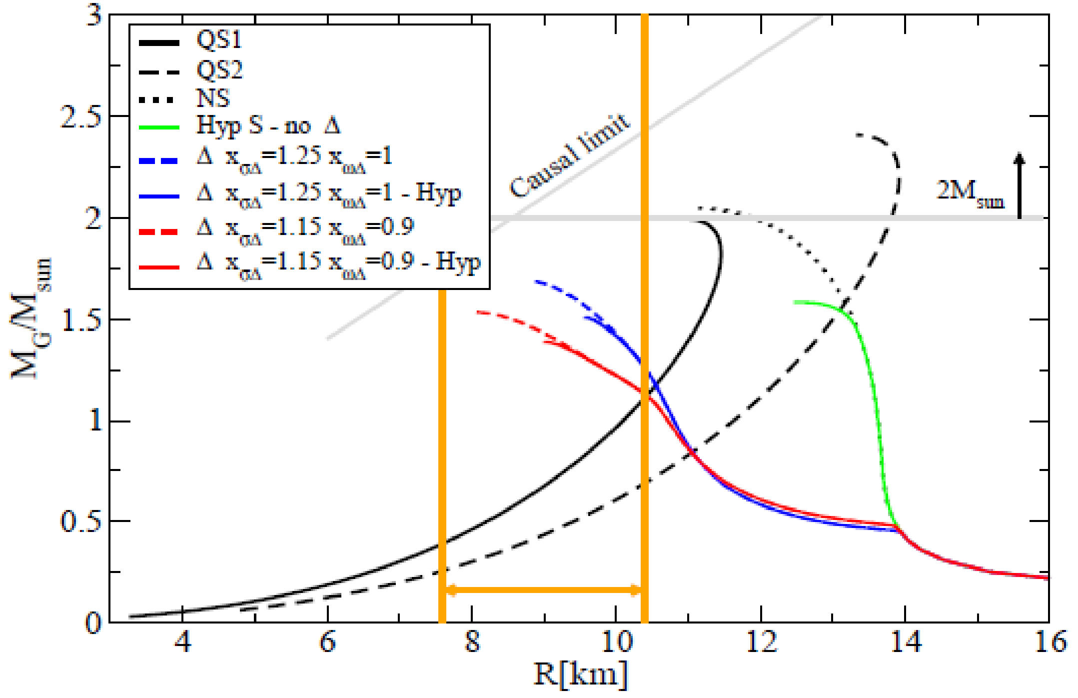

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The framework of the simulations

Two Equations of state

SFHo

N, $e^{\pm}$, γ, nuclei

$\boldsymbol{\beta}$- equilibrium condition

Hadronic 2 families EOS

= SFHo for low densities

Hyperons and Δ in the nucleus

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- Masses of the symmetric binaries from $1.15 - 1.15\ M_{\odot}$ to $1.3 - 1.3\ M_{\odot}$
- Einstein Toolkit code: full General Relativistic framework

The framework of the simulations

Two Equations of state

SFHo	Hadronic 2 families EOS
N, $e^{\pm}$, γ, nuclei	= SFHo for low densities
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The threshold mass

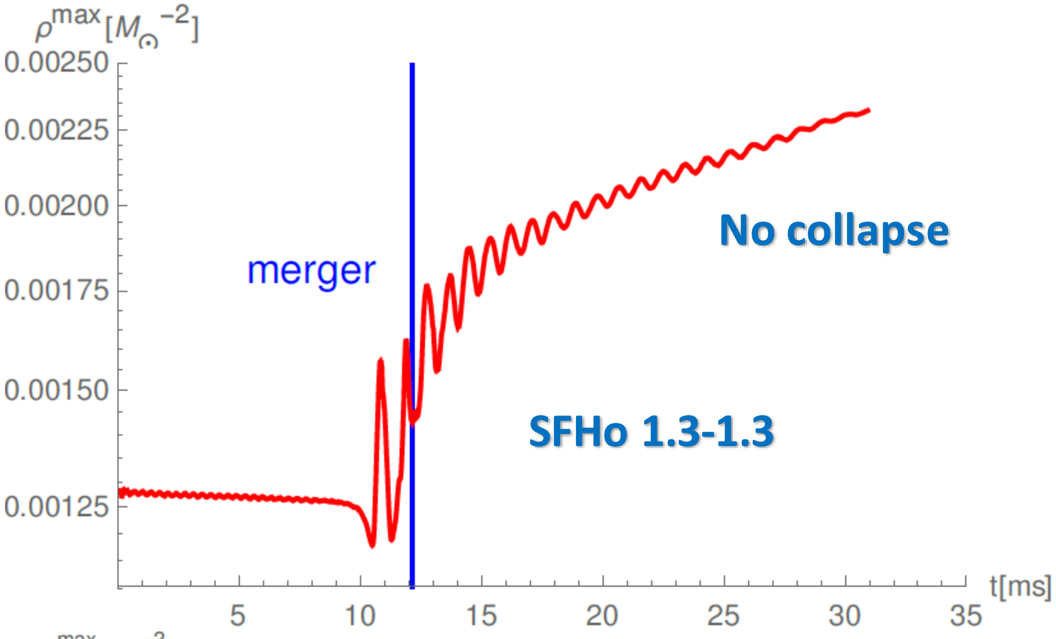
$$M_{thresh} = (1.54 \pm 0.05) M_{TOV}$$

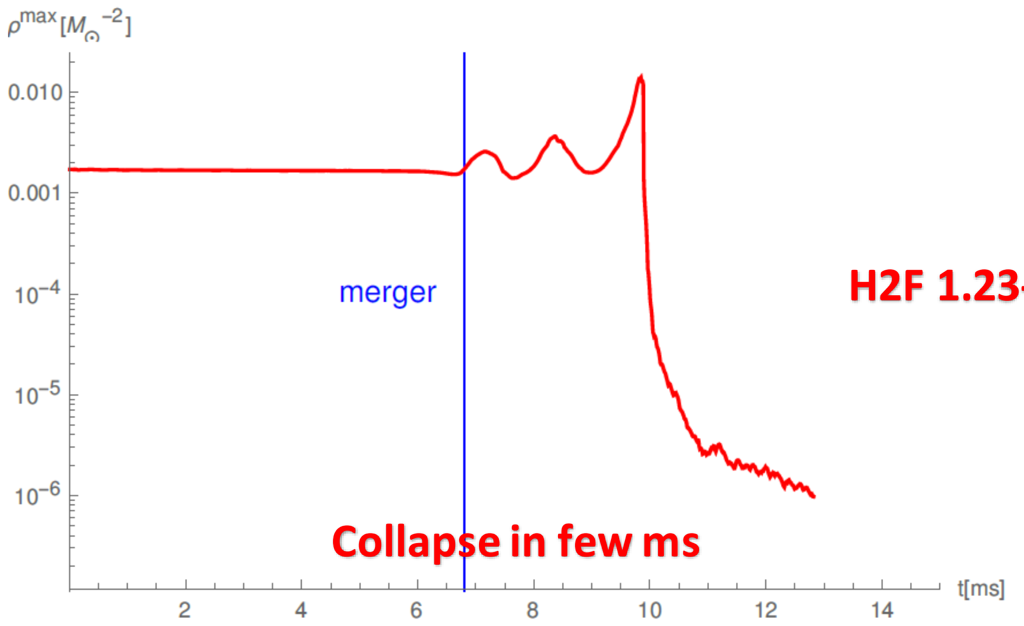
$$M_{thresh} = (2.43 - 3.38 C_{max}) M_{TOV}$$

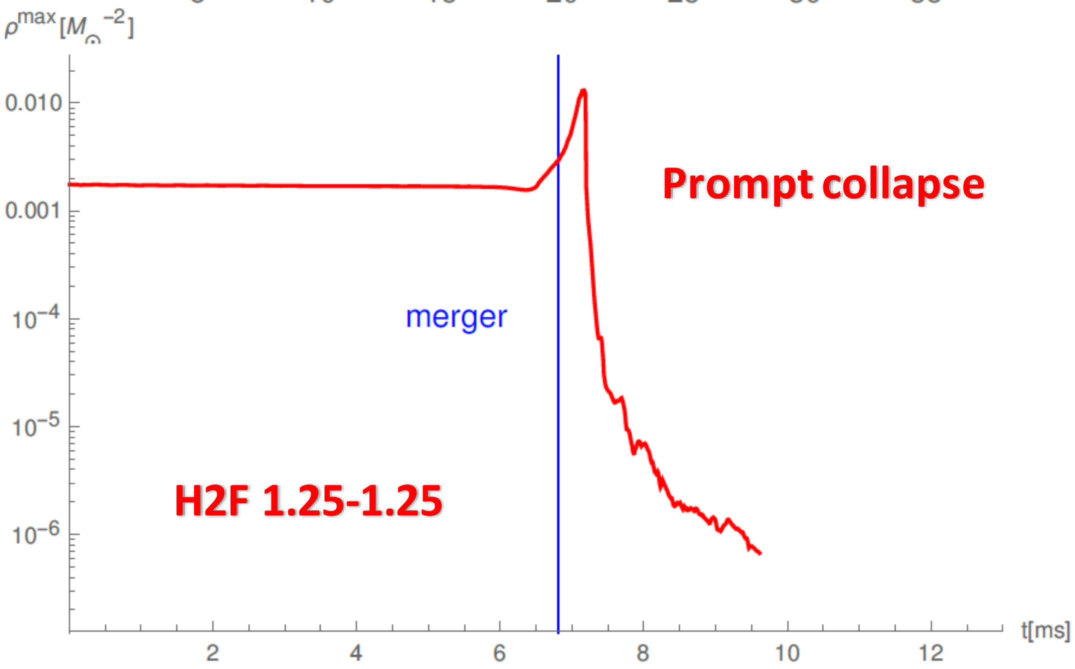
$$\boldsymbol{M_{thresh}^{SFHo} > 2.8 M_{\odot}}$$

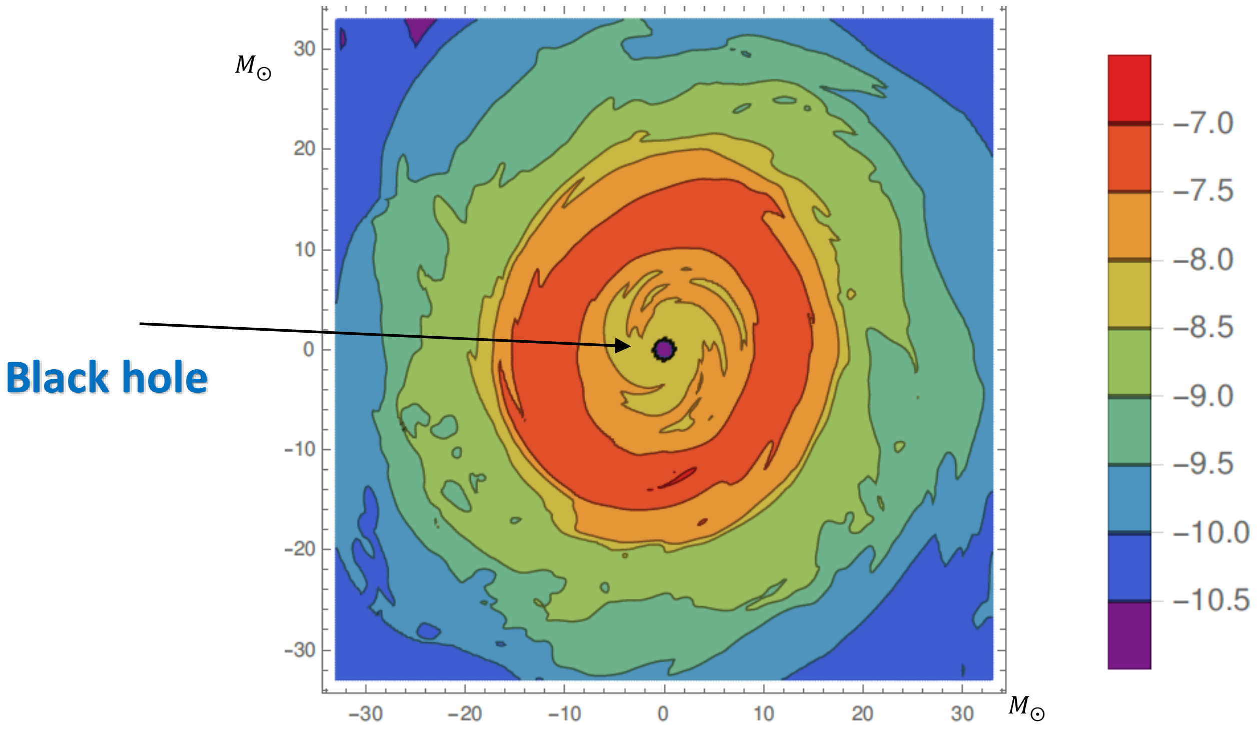
$$\boldsymbol{M_{thresh}^{H2F} \sim 2.5 - 2.6 M_{\odot}}$$

Maximum density

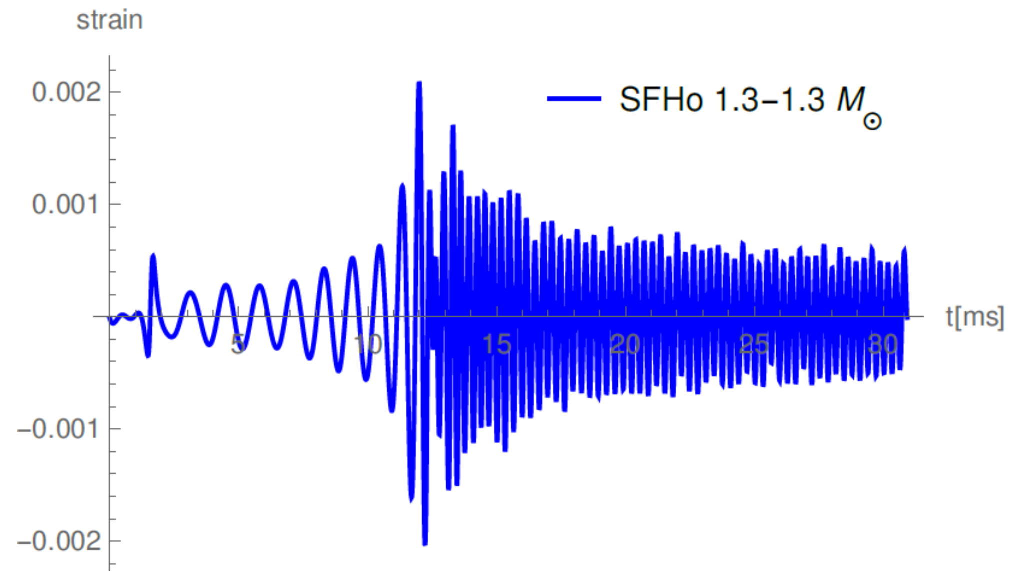


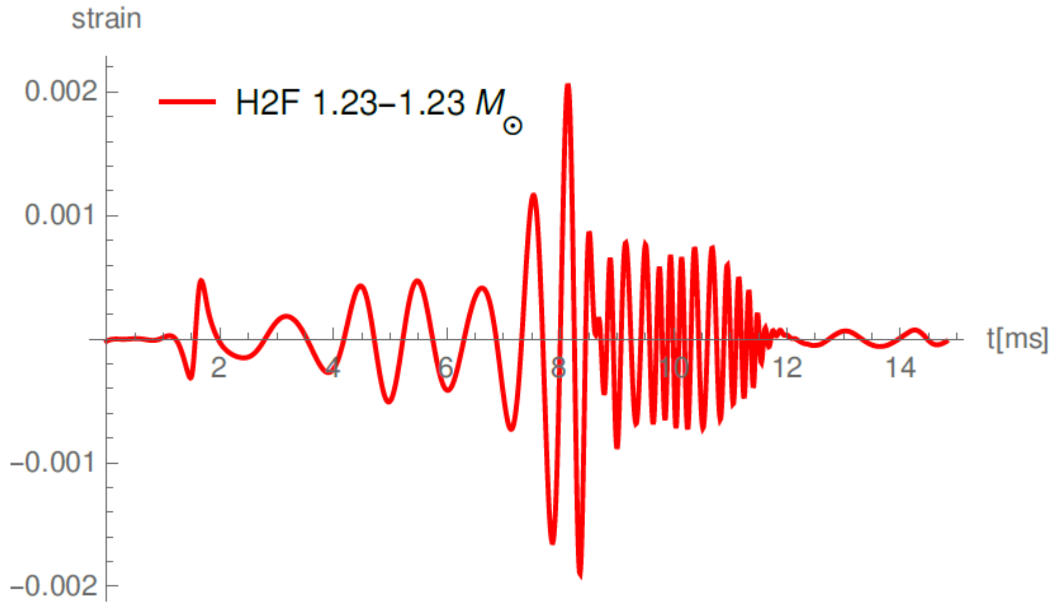


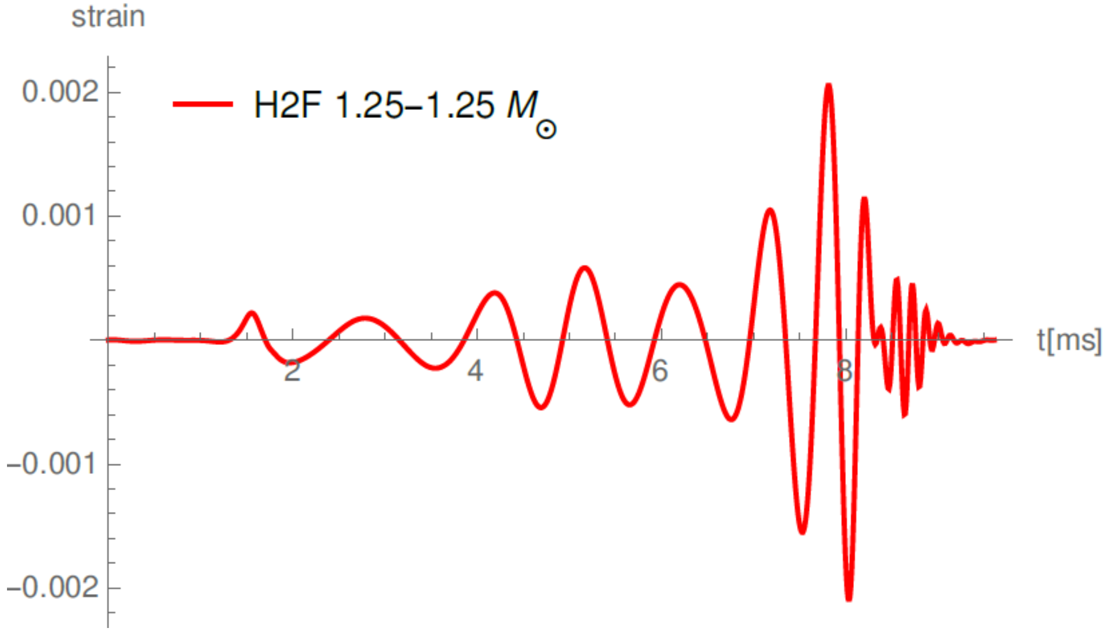




Gravitational waves







$$M_{thresh}^{SFHo} > 2.6M_\odot$$

$$M_{thresh}^{H2F} \sim 2.48M_\odot$$

Dynamical ejecta

- Calculate the **Lorentz factor** W the **time component of the 4-velocity** u_t for fixed time and all cells
- Identify the cells containing unbound fluid → Geodesic criterion $-u_t > 1$
- Obtain **the mass** integrating on the cells
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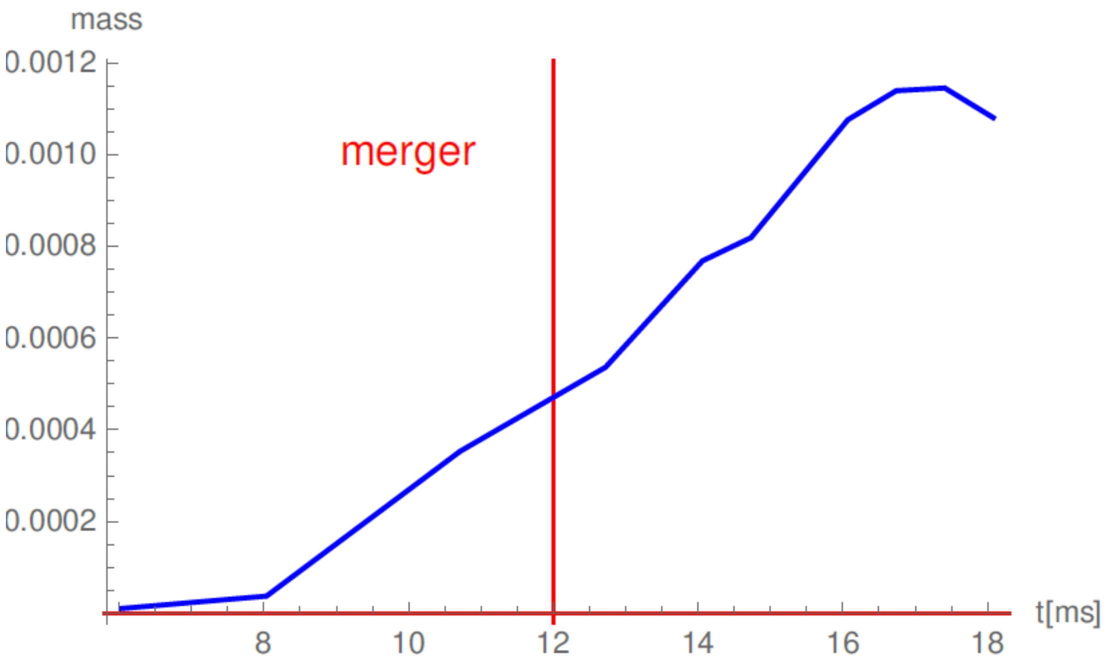
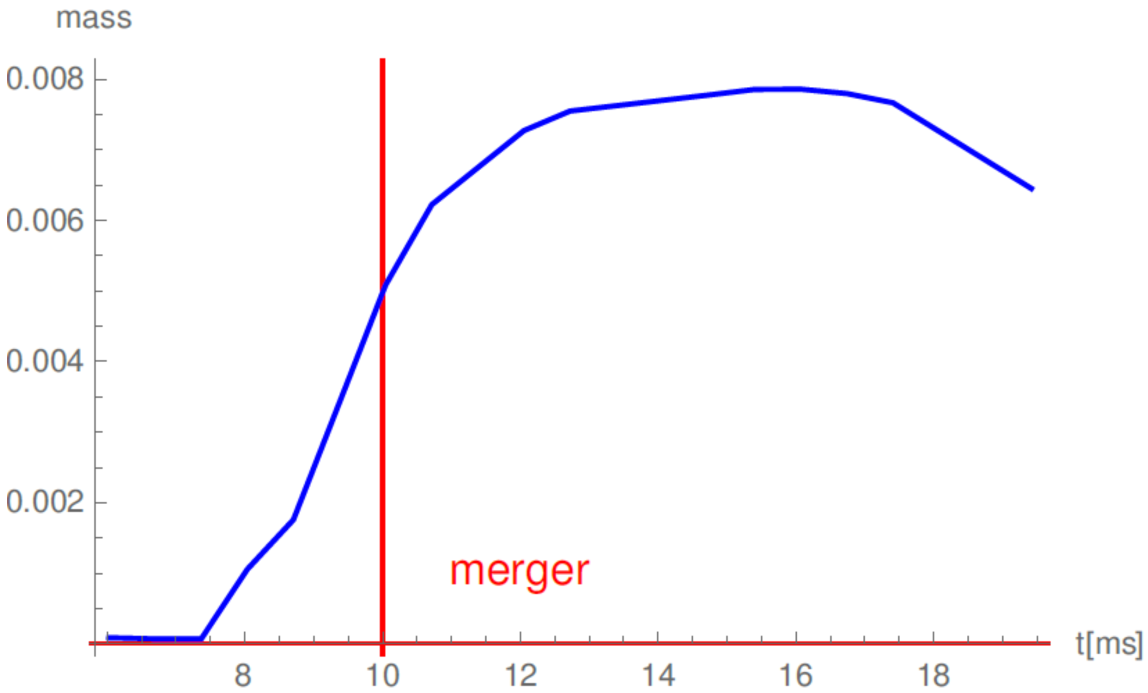
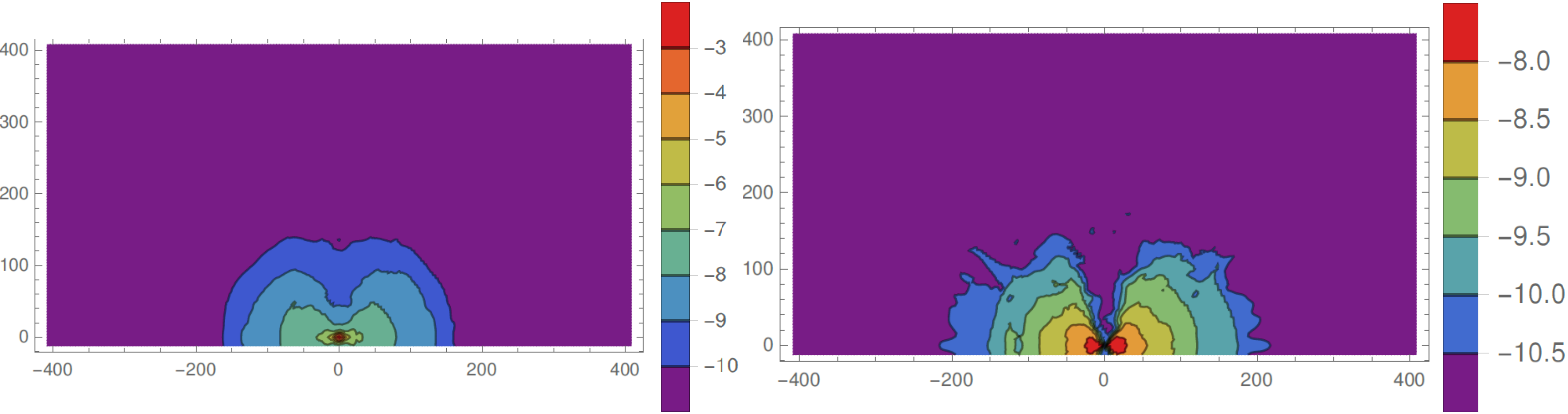




Mass of the disk

- Consider the last time available (20 ms after merger): quasi stationary state
- High density cut at $10^{13} gcm^{-3} \sim 10^{-5} M_{\odot}^{-2}$
- Low density cut at $5 * 10^{6} gcm^{-3} \sim 10^{-11} M_{\odot}^{-2}$ or $5 * 10^{7} gcm^{-3} \sim 10^{-10} M_{\odot}^{-2}$



Preliminary results

Simulation	collapse	dynamical ejecta		disk
	tc - tmdens	Mej	Vav a tmax	Mdisk (cut 10^(-11))
SFHo 1,2	no	0.00127	0.18	0.1006
H2F 1,2	4,39	0.0056	0.13	0.025
SFHo 1,23	no	0.001144	0.18	0.092
H2F 1,23	3,6	0.00786	0.15	0,0214
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❖ Disk: SFHo $\sim 10^{-1} M_{\odot}$, H2F $\sim 10^{-2} M_{\odot}$

- For stiff EOS the tidal deformability is bigger

Interpretation of GW170817

Total mass of about $2.72 M_{\odot}$: in the two families scenario, the event cannot be a NS-NS merger because it would lead to prompt collapse

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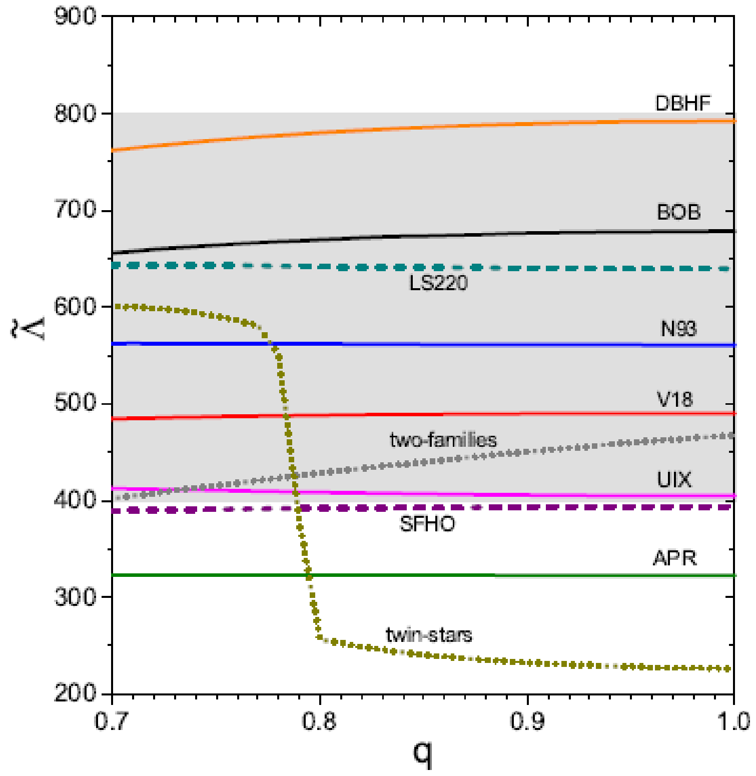
For the future: we would like to perform simulations with the quarks EOS



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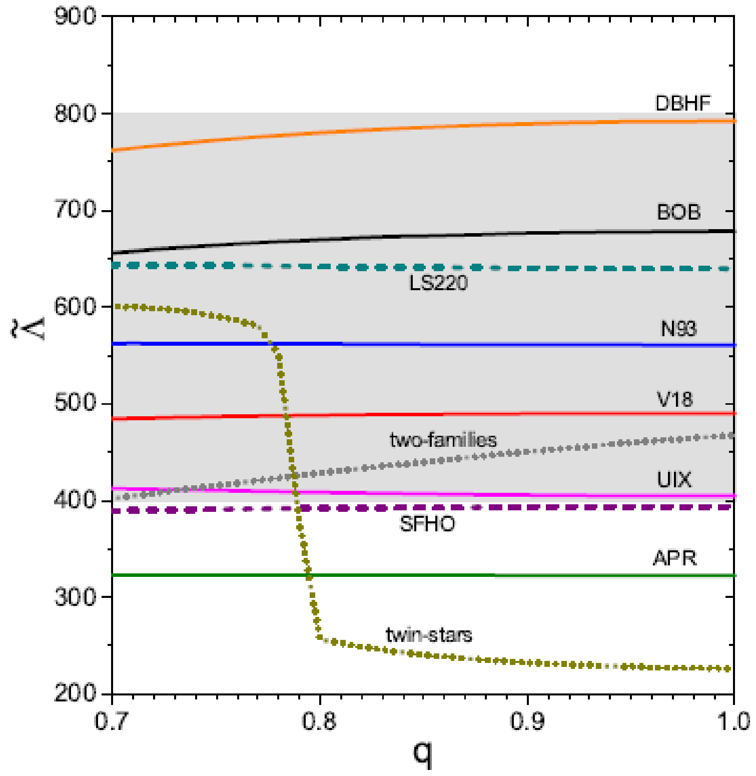

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Thanks for the attention