Binary Neutron Star mergers using microscopic Equations of State

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ECT* Trento, 17/10/2019

Outline

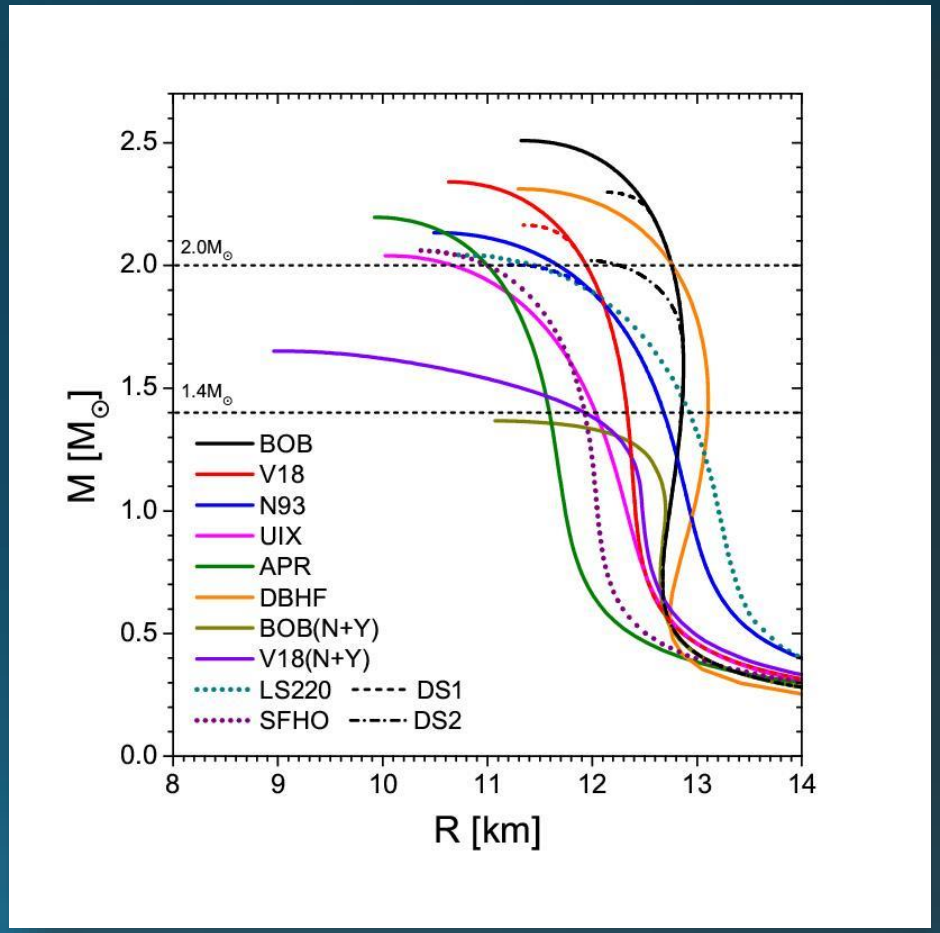
- Introduction - The Equations of State Set
- Binary neutron star mergers using microscopic EoS & temperature treatment
- Conclusions

The Equations of State set

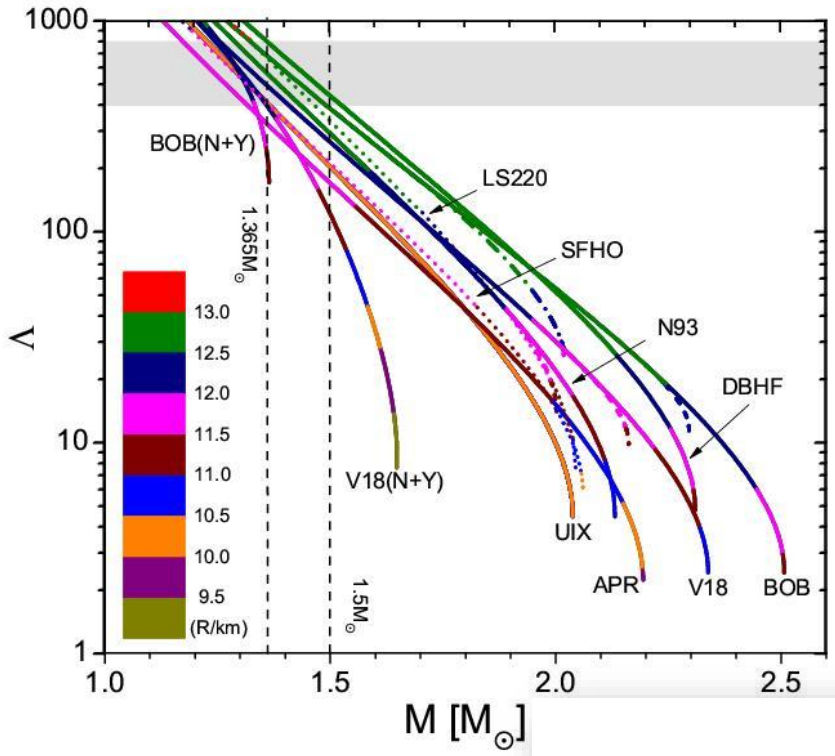
- Microscopic EOS based on many-body calculations developed by the Catania group (PI Fiorella Burgio).
- BHF many-body theory with realistic two-body and three-body nucleonic forces for nuclear (hadronic) matter.
- The BHF theory has also been extended with the inclusion of hyperons, which might appear in the core of a NS: we consider two EOSs containing hyperons, which will be labelled as BOB(NN+NY) and V18(NN+NY+YY).
- Hybrid stars are also considered: a Dyson-Schwinger model with variable interaction parameters (Wei et al. 2017) for deconfined QM combined with the BHF approach is used.

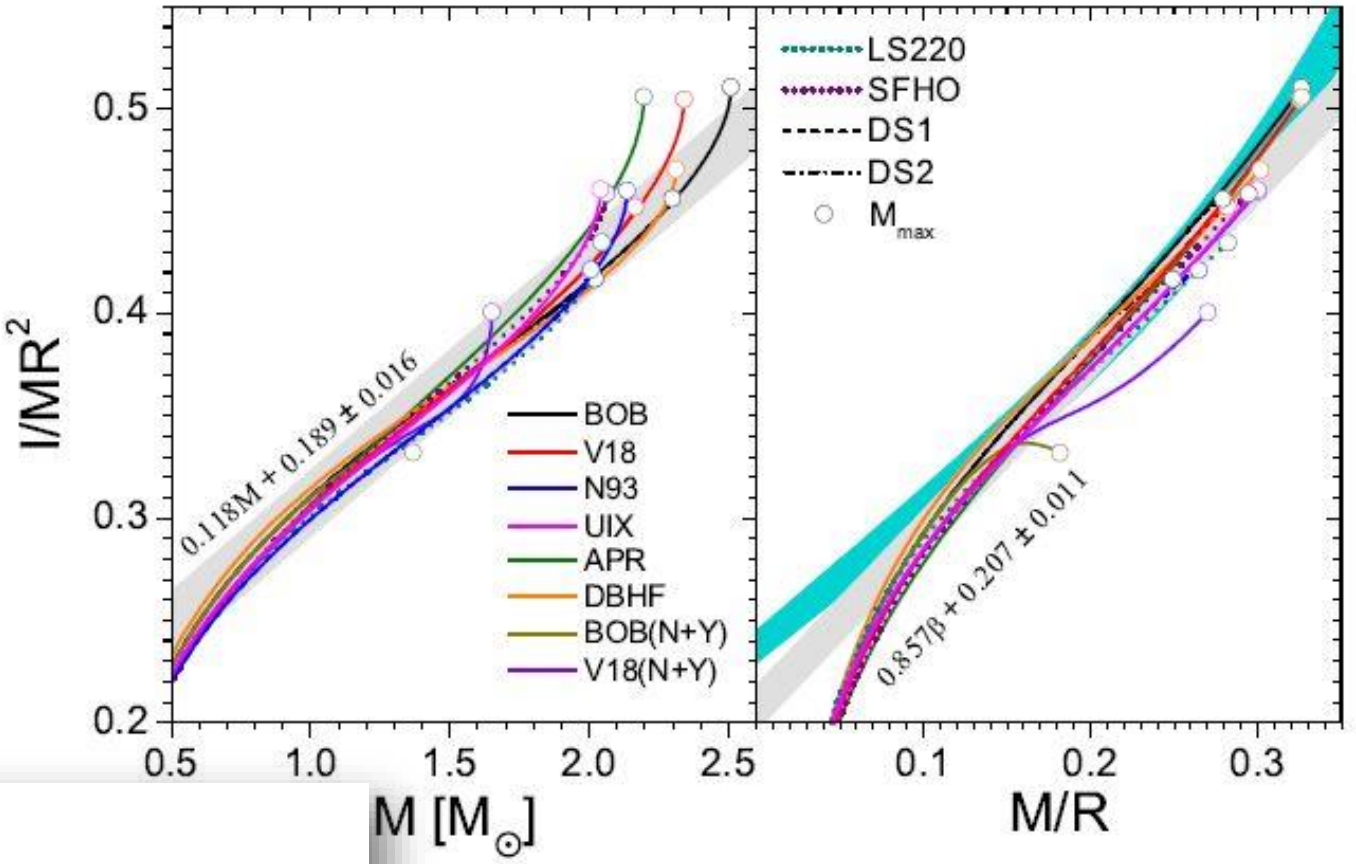
The Equations of State set

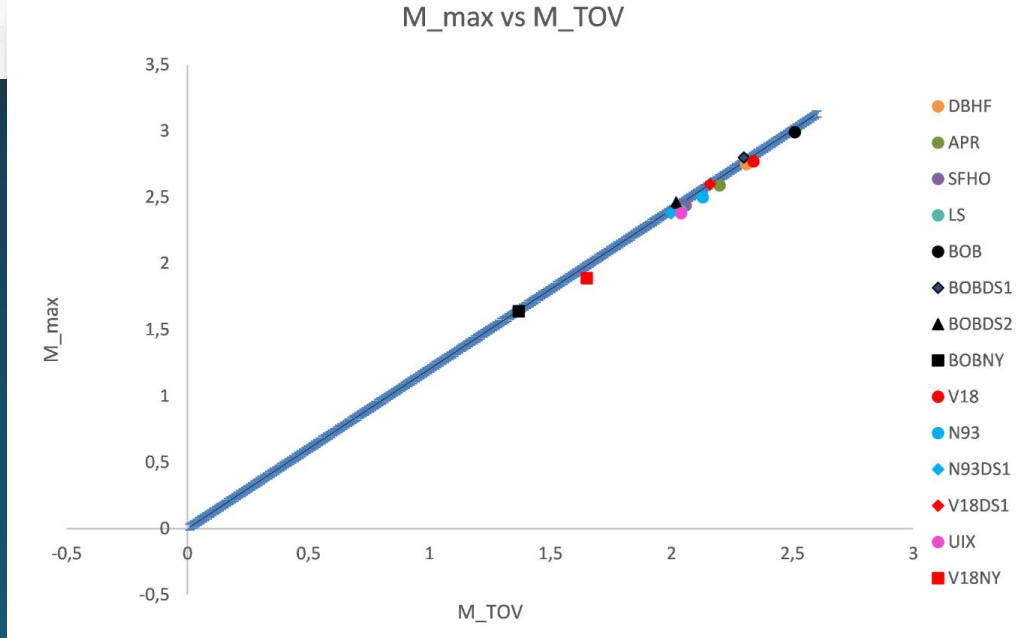
EOS	$M_{\max}\,[M_\odot]$	$R_{M_{\max}}$ [km]	$R_{1.4}$ [km]	$\Lambda_{1.4}$
BOB	2.51	11.32	12.85	584
BOB+DS1	2.30	12.13	12.85	584
BOB+DS2	2.02	11.95	12.85	584
BOB+DS3	1.79	11.72	12.75	539
BOB+DS4	1.60	11.38	12.12	346
V18	2.34	10.63	12.33	419
V18+DS1	2.16	11.34	12.33	419
V18+DS2	1.93	11.15	12.33	419
V18+DS3	1.75	10.95	11.96	320
V18+DS4	1.61	10.74	11.36	215
N93	2.13	10.49	12.68	474
N93+DS1	2.00	11.17	12.68	474
N93+DS2	1.80	10.76	12.64	459
N93+DS3	1.67	10.48	11.76	250
N93+DS4	1.58	10.31	11.05	162
UIX	2.04	10.02	12.03	340
UIX+DS1	1.98	10.59	12.03	340
UIX+DS2	1.82	10.63	12.03	340
UIX+DS3	1.69	10.44	11.81	10
UIX+DS4	1.59	10.30	11.22	6
APR	2.20	9.92	11.59	274
DBHF	2.31	11.29	13.10	681
SFHO	2.06	10.31	11.93	334
LS220	2.04	10.67	12.94	542
BOB(N+Y)	1.37	11.07	—	—
V18(N+Y)	1.65	9.00	11.92	302



JB Wei, AF, F. Burgio & HJ Schulze 2019

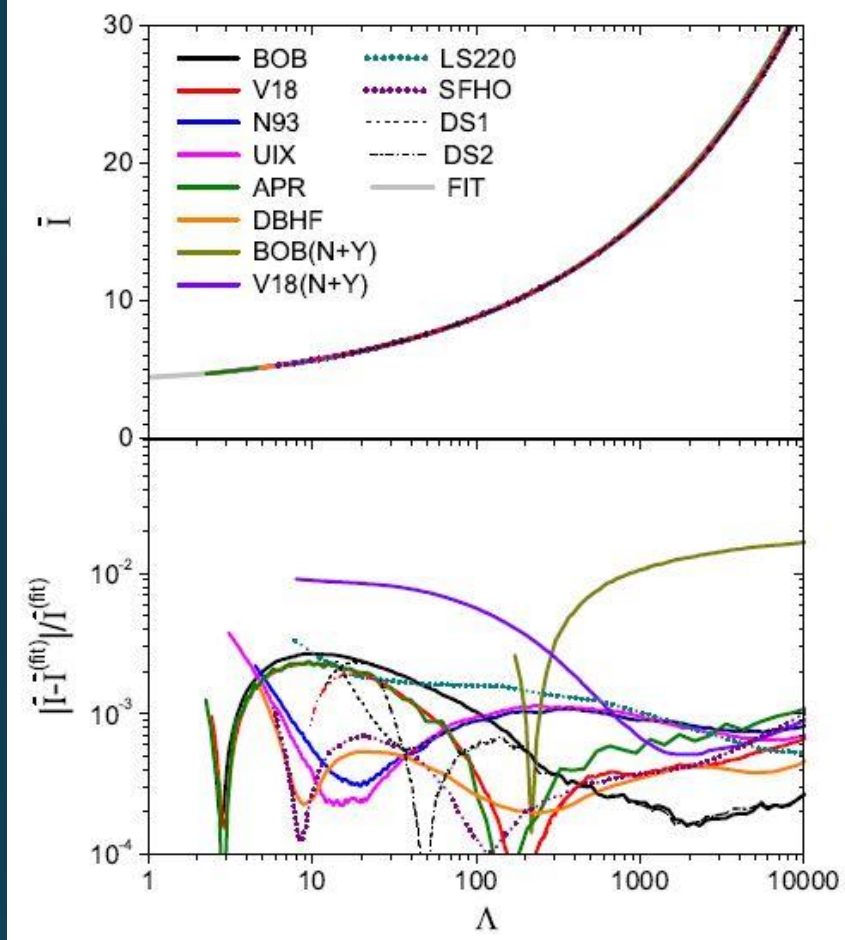


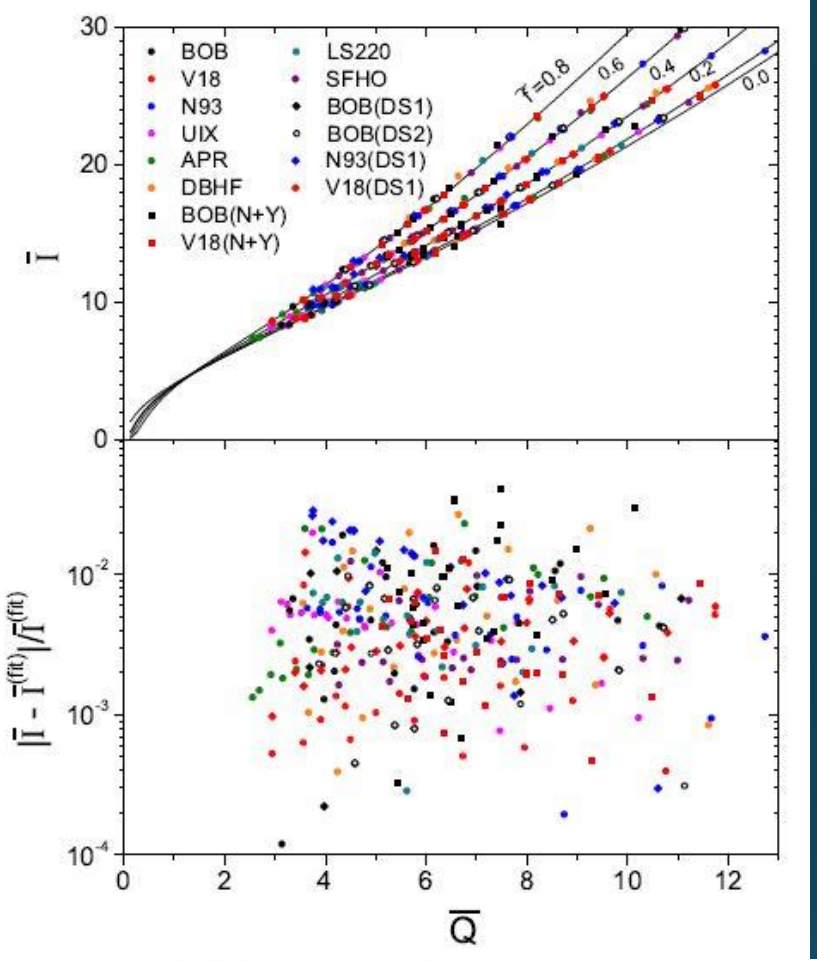




$$M_{max} \sim (1.203 \pm 0.022) M_{TOV}$$

***Breu & Rezzolla* 2016**





$$\ln(I/M^3) = 1.496 + 0.05951\ln\Lambda + 0.02238(\ln\Lambda)^2 - 6.953\times10^{-4}(\ln\Lambda)^3 + 8.345\times10^{-6}(\ln\Lambda)^4$$

Yagi and Yunes (2017)

$$\ln\bar{I} = 1.393 + 0.5471\ln\bar{Q} + 0.03028(\ln\bar{Q})^2 + 0.01926(\ln\bar{Q})^3 + 4.434\times10^{-4}(\ln\bar{Q})^4$$

$i=$	0	1	2	3	4
$\mathcal{A}_{i0}$	1.35	0.3541	-1.871	3.034	-1.860
$\mathcal{A}_{i1}$	0.697	-1.435	8.385	-14.75	10.05
$\mathcal{A}_{i2}$	-0.143	1.721	-9.343	18.14	-12.65
$\mathcal{A}_{i3}$	0.0994	-0.8199	4.429	-8.782	6.100
$\mathcal{A}_{i4}$	-0.0124	0.1348	-0.7355	1.460	-1.008
$\mathcal{B}_{i0}$	1.35	0.1570	-0.3244	0.09399	0.02863
$\mathcal{B}_{i1}$	0.697	-0.6386	1.509	-0.6932	0.05381
$\mathcal{B}_{i2}$	-0.143	0.7711	-1.636	0.8434	-0.1210
$\mathcal{B}_{i3}$	0.0994	-0.3594	0.7482	-0.3079	0.06019
$\mathcal{B}_{i4}$	-0.0124	0.05788	-0.1140	0.05262	-0.03466

$$\ln\bar{I} \approx \sum_{i,j=0,4} \mathcal{A}_{ij} a^i (\ln\bar{Q})^j \approx \sum_{i,j=0,4} \mathcal{B}_{ij} \tilde{f}^i (\ln\bar{Q})^j$$

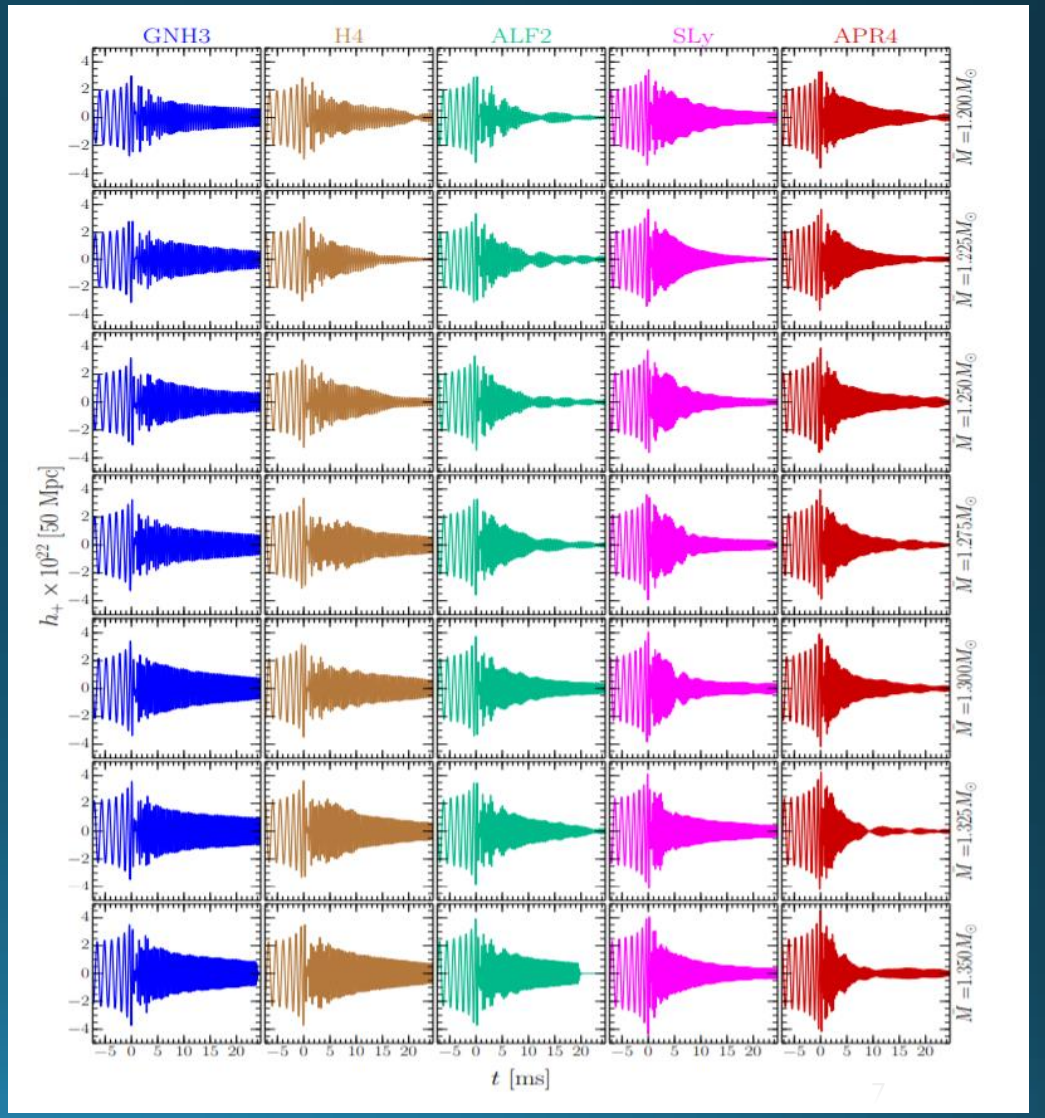
Chakrabarti et al. 2014

BNS mergers with microscopic EOS

- Collaboration with INFN – Sezione di Catania (PI Dr. Fiorella Burgio) and the RelAstro group - ITP Frankfurt (PI Prof. Luciano Rezzolla)

- Systematic study of the gravitational wave properties for different microscopic EoS, as in Rezzolla et al. 2016

- Investigation of the temperature treatment in BNS simulations

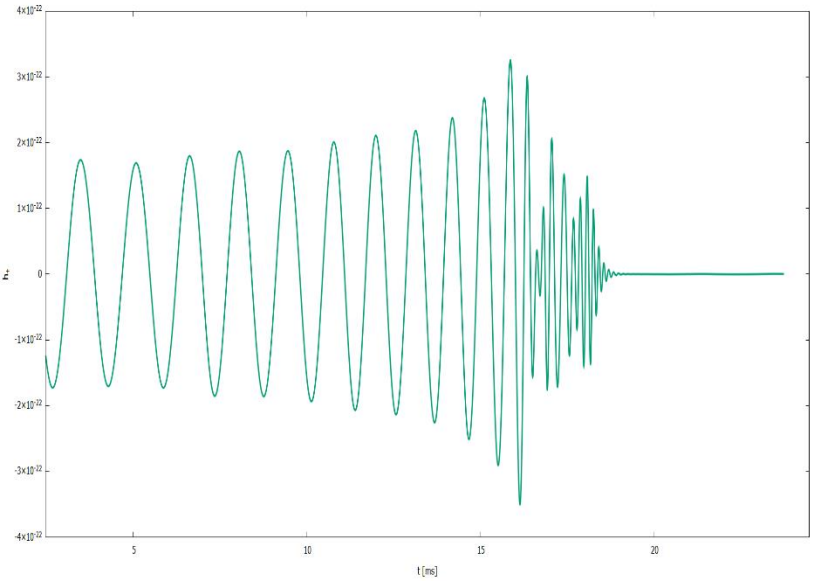


BNS mergers with microscopic EOS

- Initial data produced with LORENE (open source).
- Simulations carried out with ET with WhiskyTHC [D. Radice and L. Rezzolla. A&A 547, A26 (2012)]
- Spacetime evolution with CCZ4 (McLachlan).
- Simulation setup: $1.35\ vs\ 1.35\ M_\odot$ - $d\ =\ 45\ km$ – multigrid setup with $0.16\ M_\odot$ maximum res

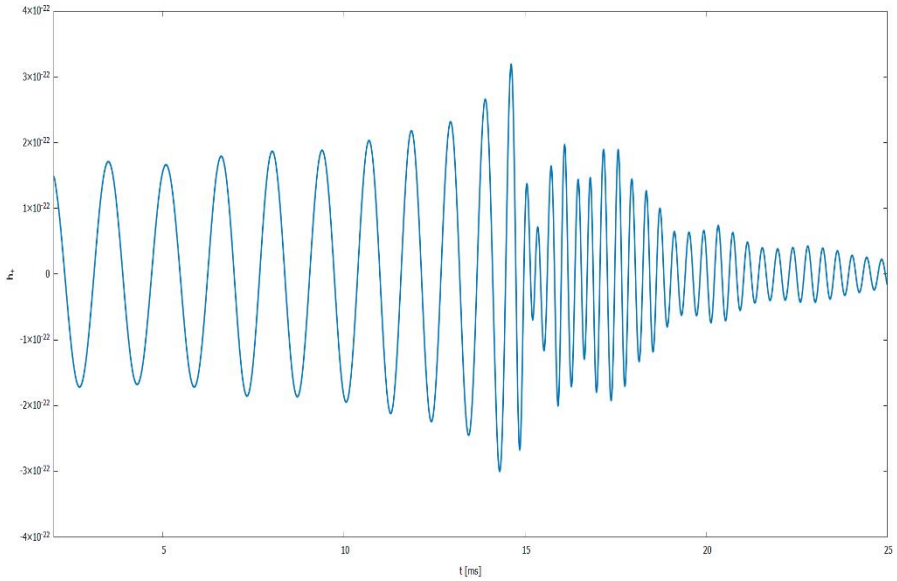
BNS mergers with microscopic EOS

BCPM EoS

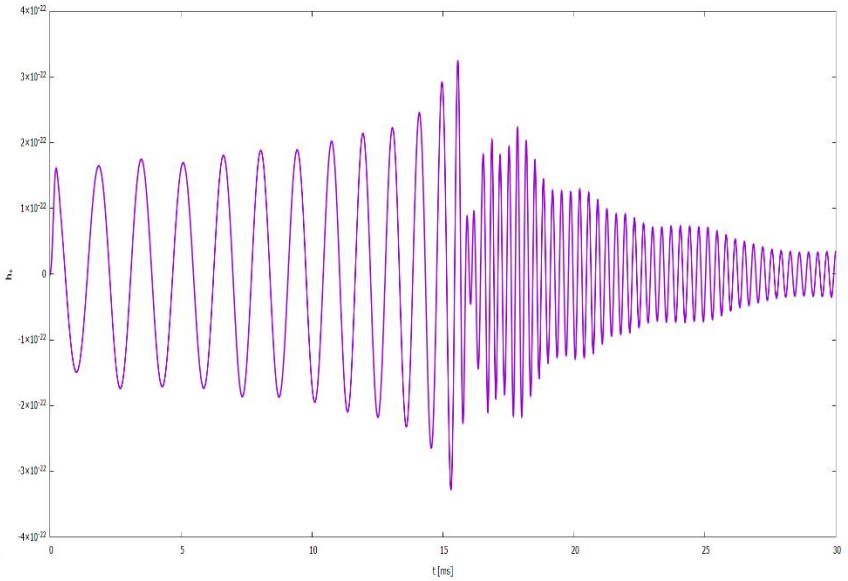


Sharma B K, Centelles M, Viñas X, Baldo M and Burgio G F 2015 A&A 584 A103

BOB EoS



V18 EoS



Li Z H and Schulze H J 2008 Phys. Rev. C 78 028801

Temperature effects in NS simulations

- NS are expected to be cold…
- …but this is not true in BNS mergers!
- 2 approaches can be used

1) Use a **Finite-Temperature EoS,** $P = P(\rho, T)$

✓Most accurate approach

❖Difficult to compute -> scarce availability

2) Use a **Hybrid EoS**

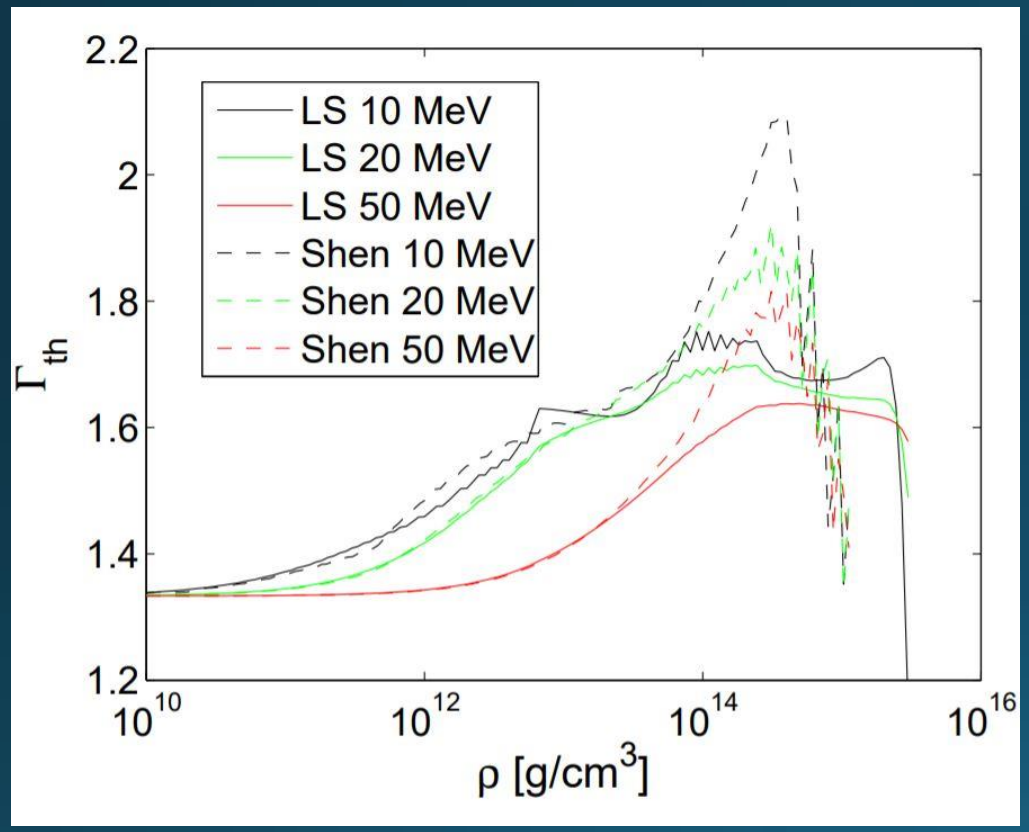
$$P = P_{cold} + \rho\epsilon_{th}(\Gamma - 1)$$

$$\epsilon = \epsilon_{cold} + \epsilon_{th}$$

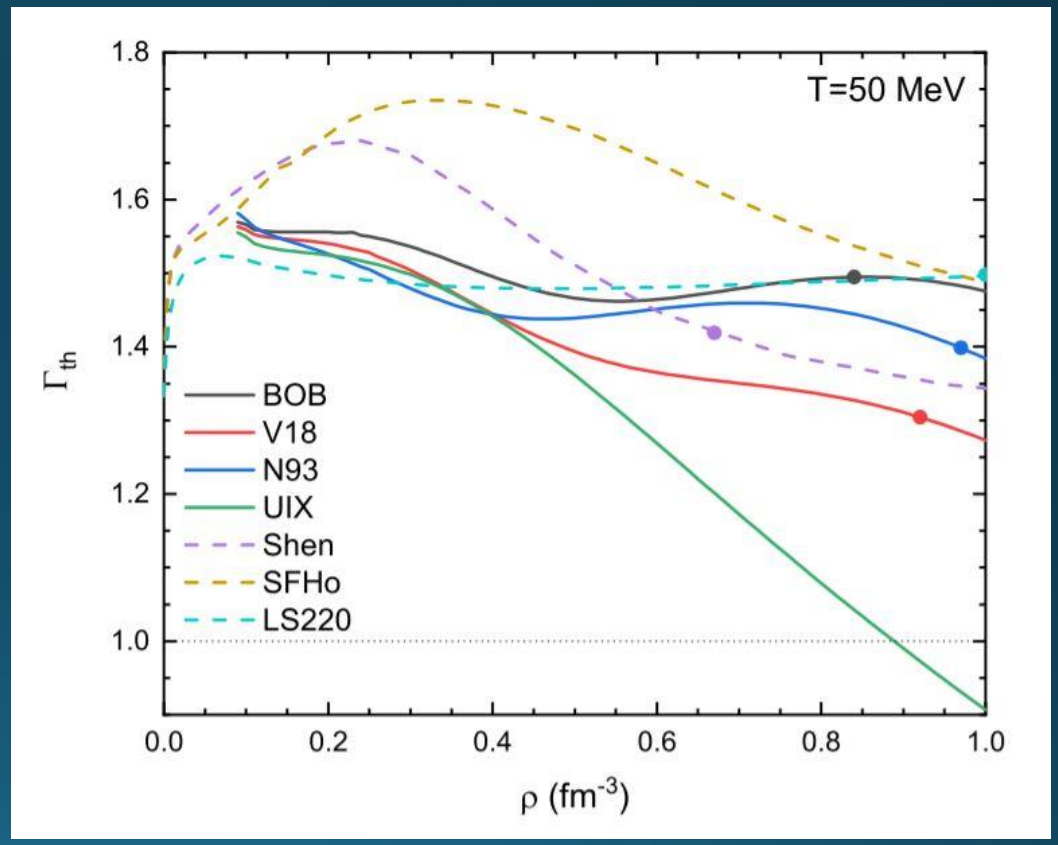
✓Every $0T$ EoS can be used

❖Inaccurate – Γ is constant…

Temperature in NS simulations



A. Bauswein, H.-T. Janka, and R. Oechslin Phys. Rev. D ***82****, 084043*



J.-J. Lu, Z.-H. Li, G. F. Burgio, and H. J. Schulze, (2019), arXiv:1907.03120 [nucl-th].

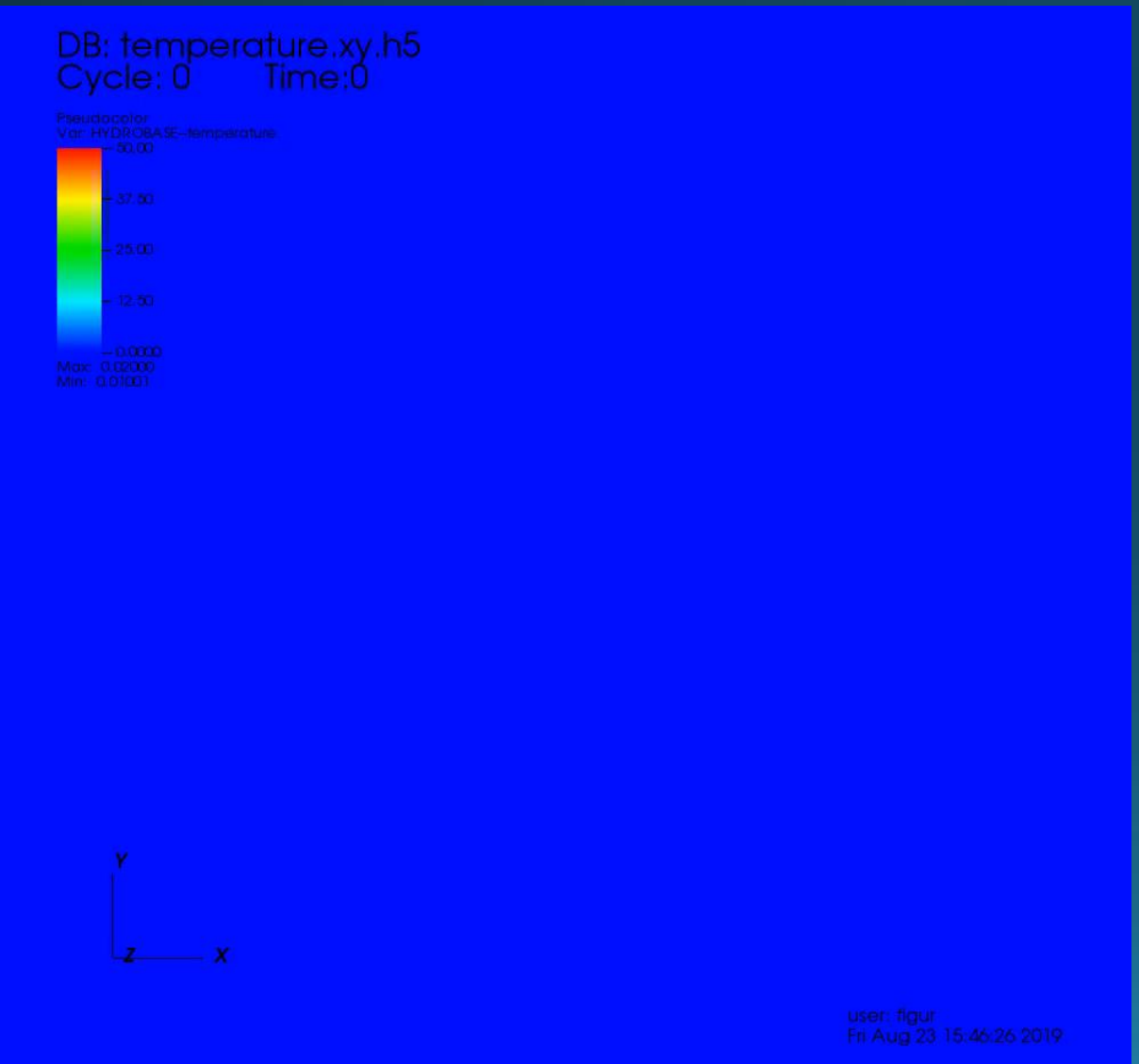
Temperature in NS simulations

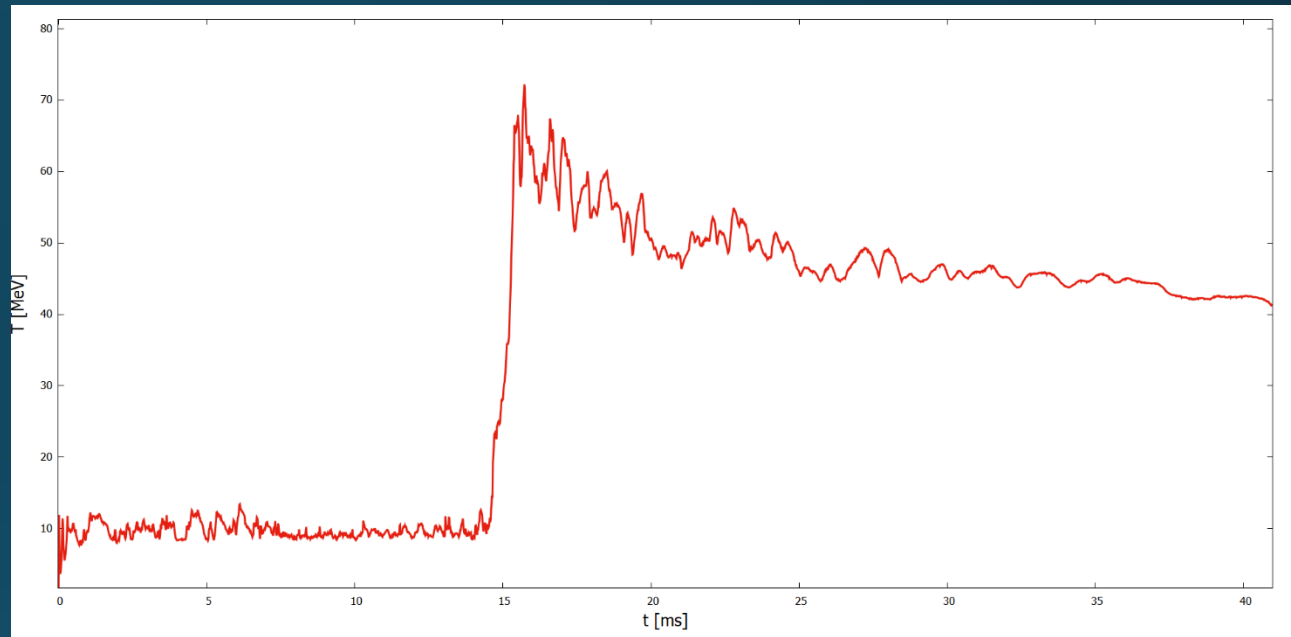
- We aim to study the impact of temperature treatment in BNS mergers
- We employ the newly developed FT EoS (*J.-J. Lu, Z.-H. Li, G. F. Burgio, and H. J. Schulze, (2019)*, converted in the *stellarcollapse* h5 format
- EoS used: $V18 - FT$ & $hybrid$ (with $\Gamma = 1.1, 1.5, 1.75$)

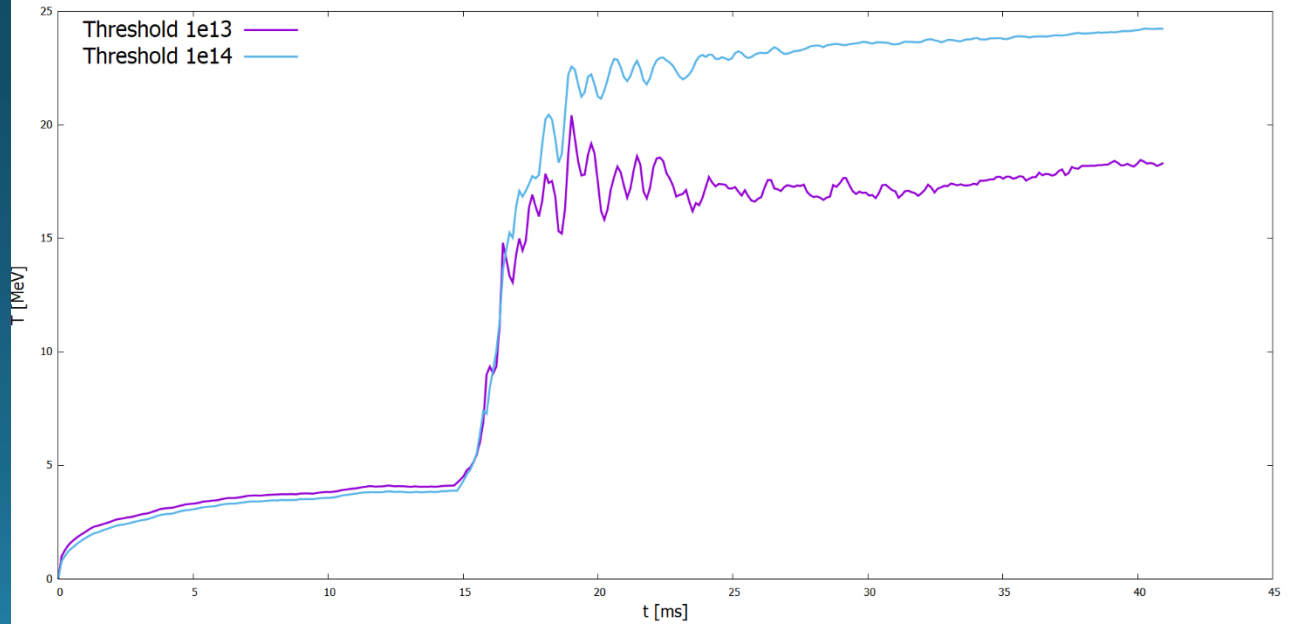
  with H.Shen crust
- ID are created using a $0T$ $\beta - eq.$ cut of the full table

Preliminary results

On the temperature treatment

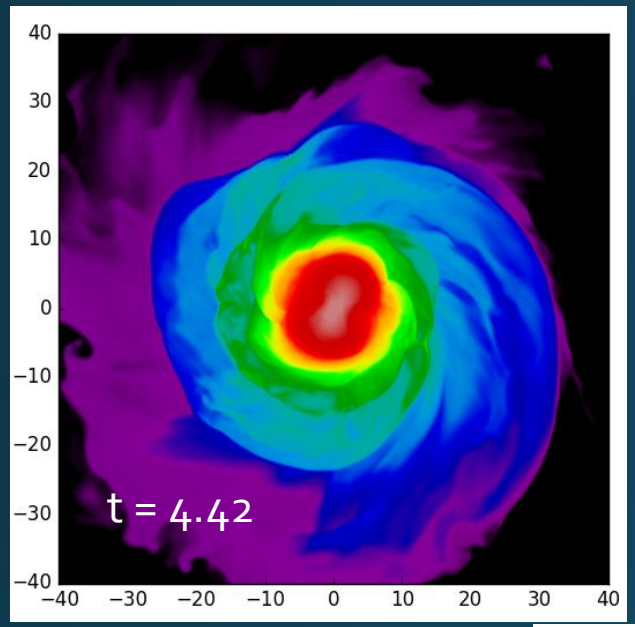


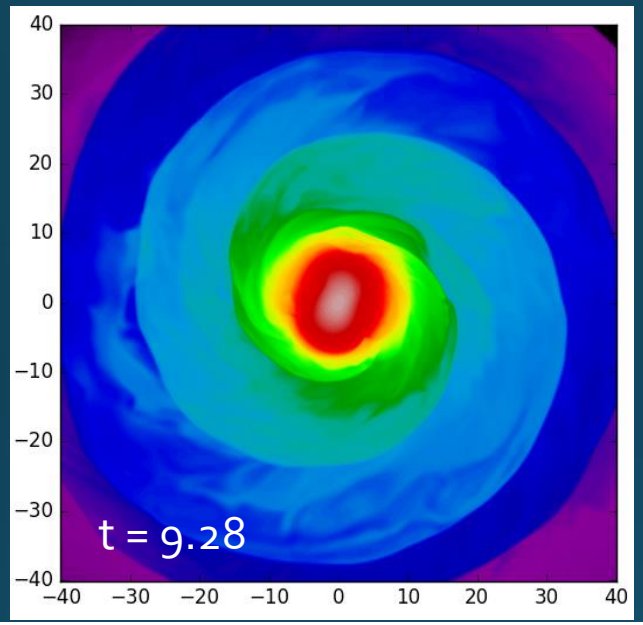


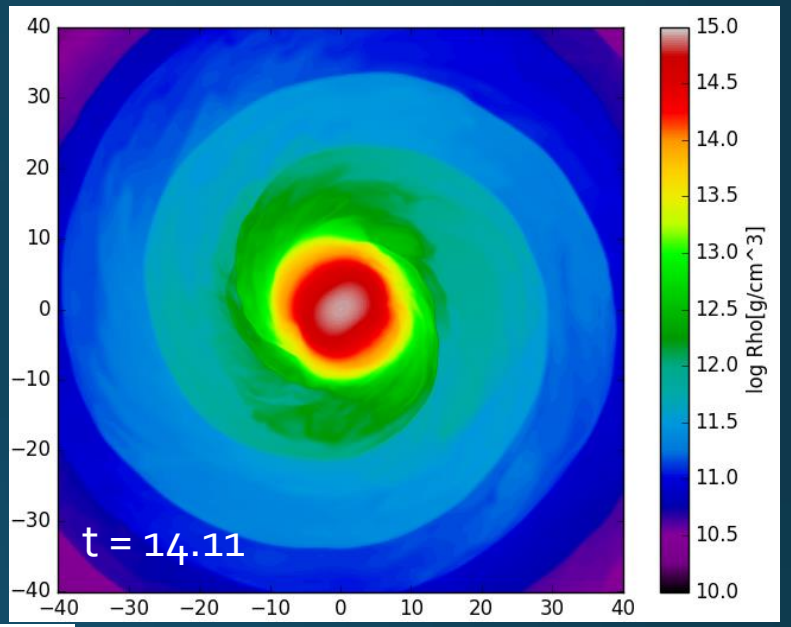


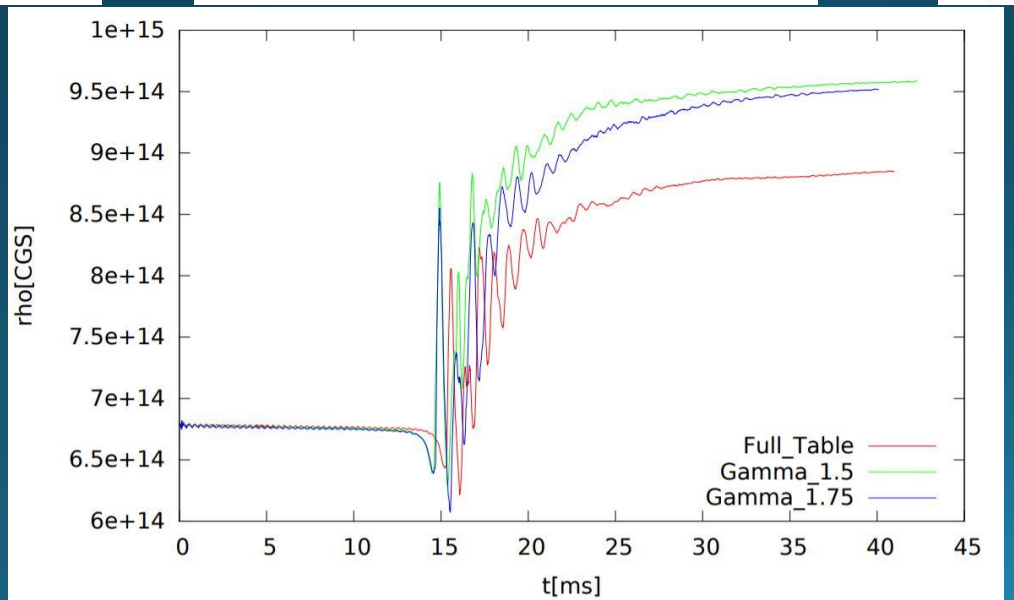
Preliminary results

Density profiles







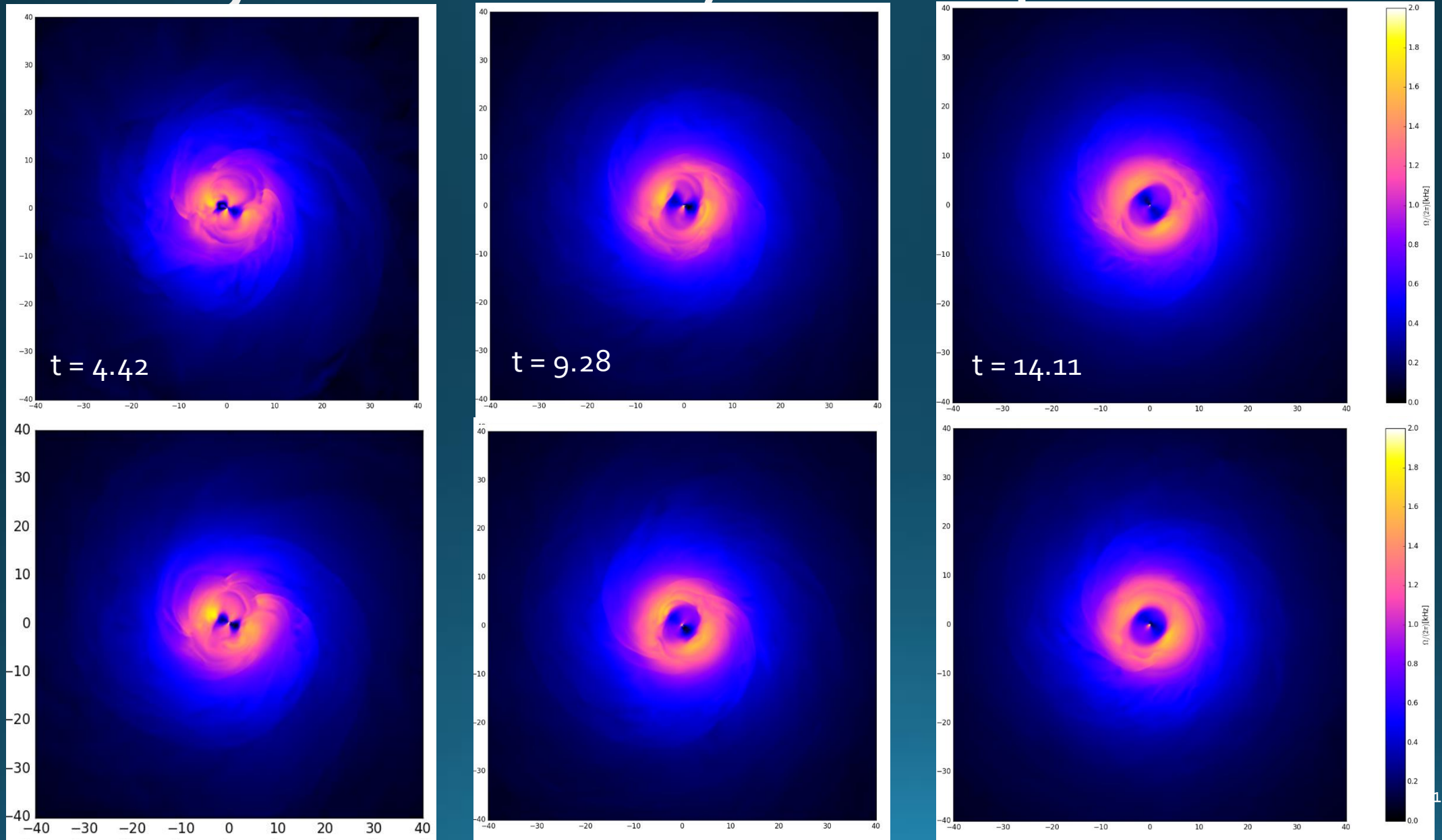


Preliminary results

Angular Velocity & Temperature

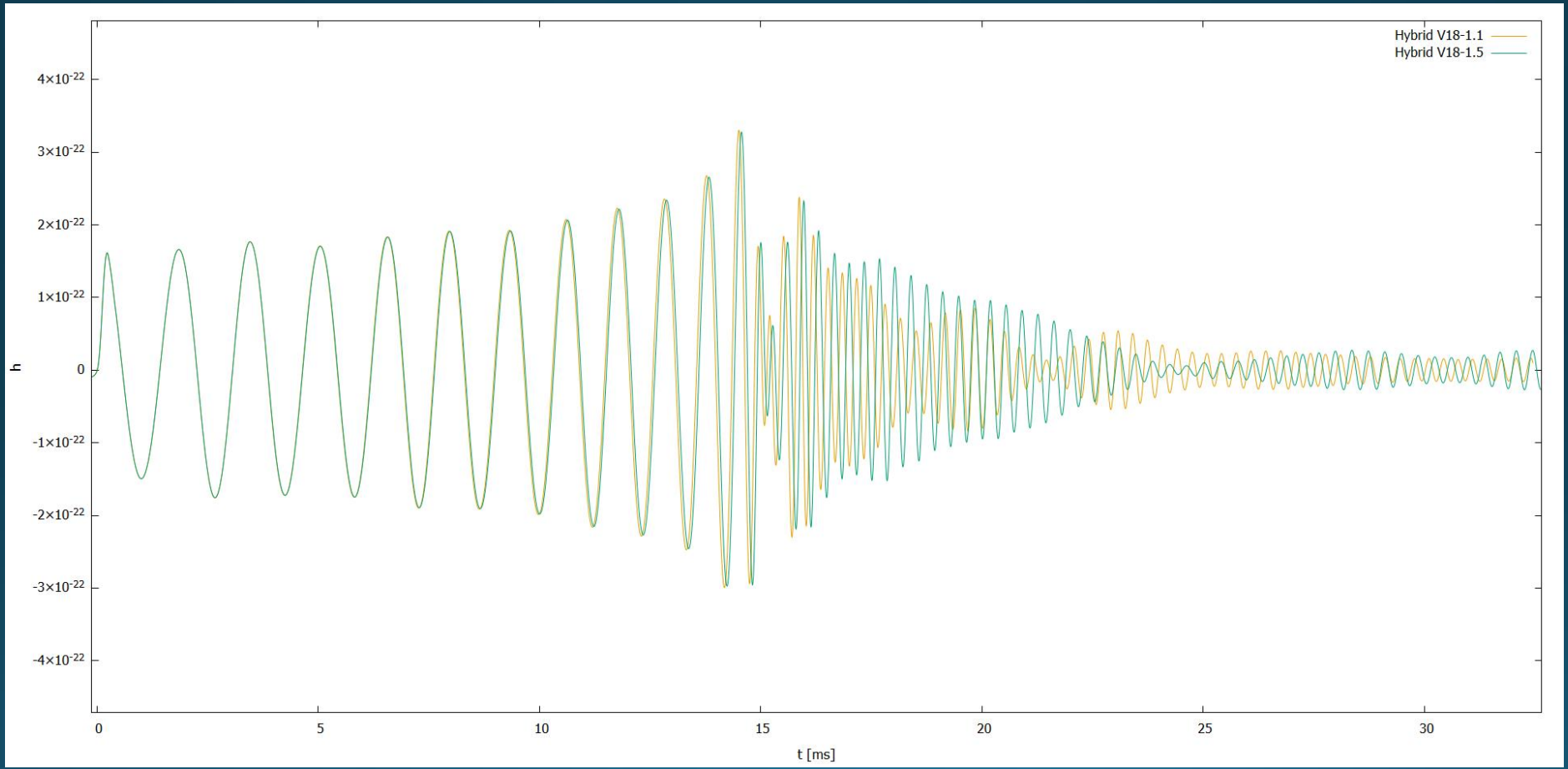
$\frac{\Omega}{2\pi}$ FT

$\frac{\Omega}{2\pi}$ $\Gamma = 1.5$



Preliminary results

Strain - Comparison



AF et al. – in preparation

Preliminary results

PSD - Comparison

- f2 peak positions (in Hz):

➢ FT : 2783.21

+68.6

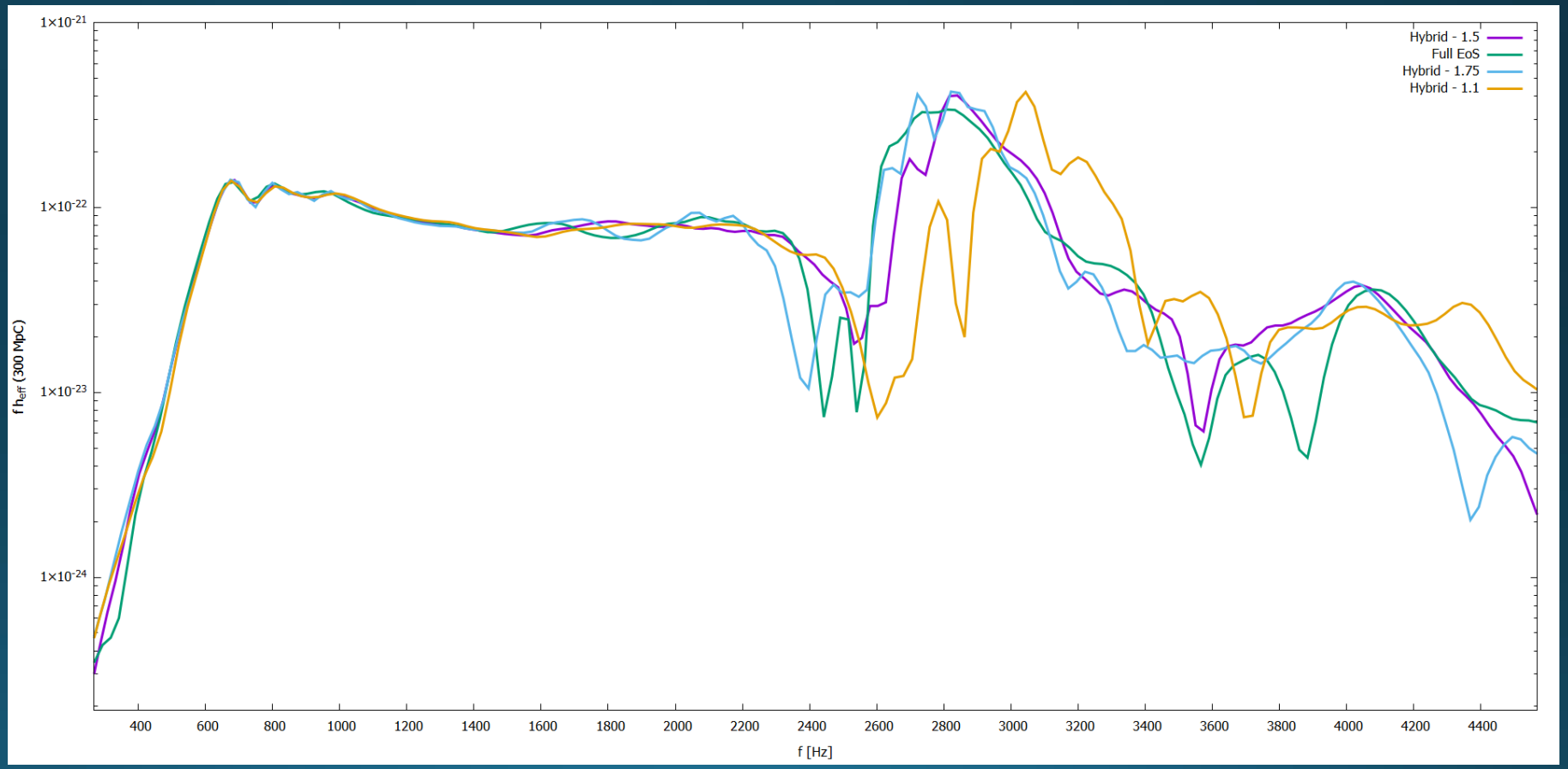
➢ Γ 1.5: 2851.81

-60.2

➢ Γ 1.75: 2723.01

+260.85

➢ Γ 1.1: 3044.06



Conclusions

- I have investigated and compared results related to BNS merger simulations using different treatments for temperature effects
- The widely used $\Gamma = 1.75$ may not be representative of all FT EoS.
- The EoS we are considering are public (Jiajing's talk) and available in H. Shen or h5 format.

Thank you for your attention