NEUMATT (neutron/ new matter)
RN: Giuseppe Pagliara, Unife&INFN-FE
(dopo 6 anni di onorata attivita' di Alessandro Drago)

4 nodi:

FE (con partecipazione di personale di Parma e PoliTo)

LNGS

CT

PI

Tot: ~ 17 FTE

- INFN Unit Ferrara

Staff members

- Michal Bejger (30%, INFN Ferrara)
- Mattia Bulla (20%, Univ. Ferrara) **New!!**
- Roberto De Pietri (50%, Univ. Parma)
- Alessandro Drago (70%, Univ. Ferrara)
- Cristiano Guidorzi (10%, Univ. Ferrara)
- Andrea Lavagno (60%, Politecnico Torino)
- Giuseppe Pagliara (80%, Univ. Ferrara, RL)
- Piero Rosati (10%, Univ. Ferrara)
- Jorge Rueda (10%, ICRANET) **New!!**

Other participants

- Francesco Di Clemente (100%, PhD, Univ. Ferrara)
- Alessandra Feo (50%, Postdoc, Univ. Parma)
- Kevin Franceschetti (50%, PhD, Univ. Parma)
- Mirco Guerrini (70%, PhD, Univ. Ferrara)

- INFN Unit: LNGS

Staff members

- Massimo Mannarelli (80%, LNGS, RL)
- Fabrizio Nesti (30%, Univ. L'Aquila) **New!!**
- Giulia Pagliaroli (55% , GSSI, L'Aquila)
- Francesco Vissani (30%, GSSI, L'Aquila)

Other participants

- Lorenzo Cipriani (50%, PhD, Univ. L'Aquila)
- Saqib Ussain (100%, Postdoc GSSI, L'Aquila)
- Vittoria Vecchiotti (100%, Postdoc GSSI, L'Aquila)
- Silvia Trabucco (100%, PhD GSSI, L'Aquila)

- INFN Unit: Catania

Staff members

- Giorgio Arcadi (100% Univ. Messina)
- Fiorella Burgio (100% INFN Catania)
- Hans-Josef Schulze (100% INFN Catania, RL)
- Isaac Vidana (50% INFN Catania)

Other participants

- Harish Das (100%, Postdoc, INFN Catania)
- David Cabo Almeida (100%, PhD, Univ. Messina)

- INFN Unit: Pisa

Staff members

- Ignazio Bombaci (100%, Univ. Pisa, RL)

Chiofalo M.L 40%

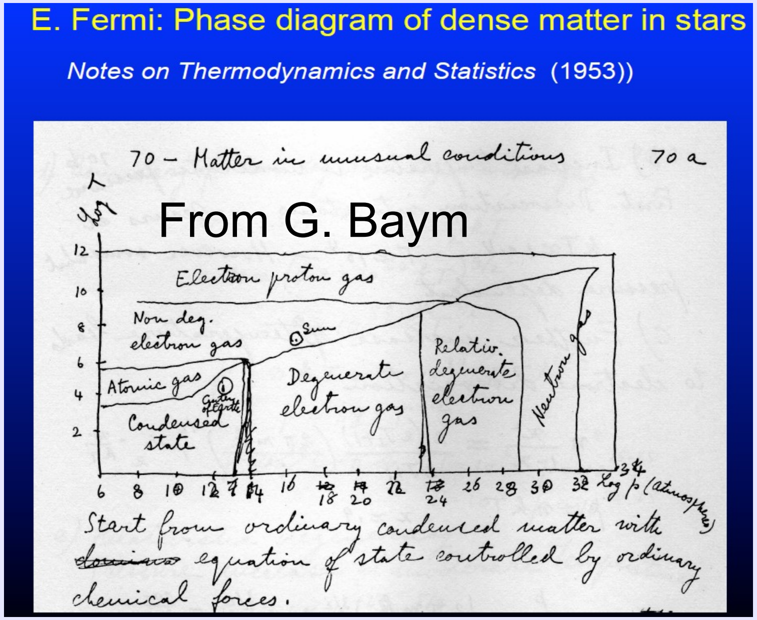
News: INFN fellowship assigned to NEUMATT-Pisa!!

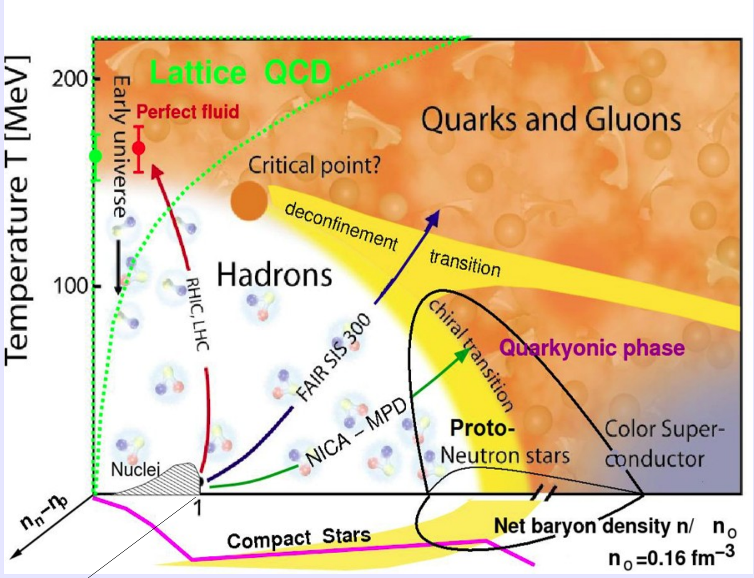
Goal of NEUMATT: understanding/modeling the properties of high density strongly interacting matter through the rich phenomenology of compact stars

<u>A few numbers on neutron stars:</u>

Masses ~ 1.4 M_{sun}
Radii ~ 10km
ρ up $10\rho_{saturation}$
Temperature at birth: ~ few tens of MeV (generated in SN events)… after ~ 100 years strongly degenerate matter
Isospin asymmetries down to Y_p ~ 0.1
Rotational frequency: up to 716 Hz
Magnetic fields: up to 10^{15} Gauss (magnetars)

A lot of interesting nuclear and particle physics: chiral symmetry restoration, deconfinement, color superconductivity, strangelets, formation of heavy baryons (hyperonic matter), superfluidity (in the crust) … r-processes in the matter ejected during explosive events, neutrino interactions in dense matter…

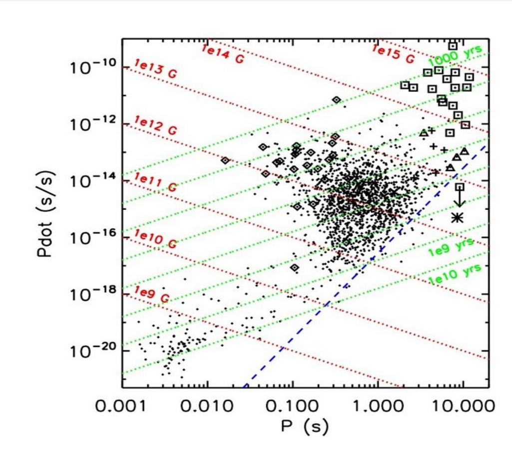


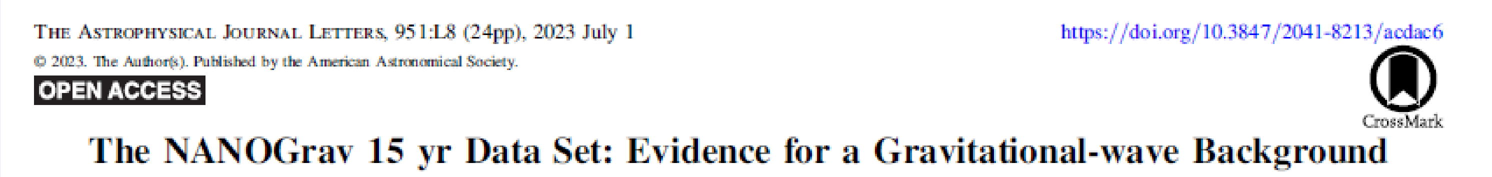


and

a lot of DATA!!!

Pulsar timing analysis (radio): a few thousands pulsars …
so many and so well known that one can use them for detecting gravitational waves backgrounds



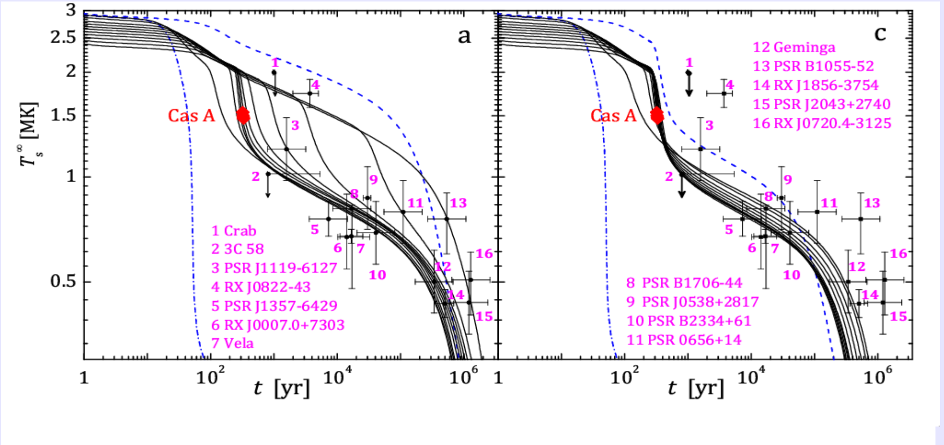


The Astrophysical Journal Letters, 951:L8 (24pp), 2023 July 1
https://doi.org/10.3847/2041-8213/acdac6

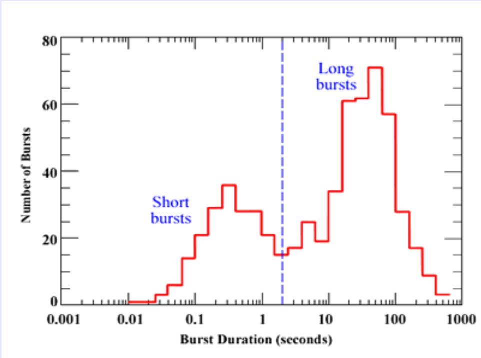
CrossMark
The NANOGrav 15 yr Data Set: Evidence for a Gravitational-wave Background

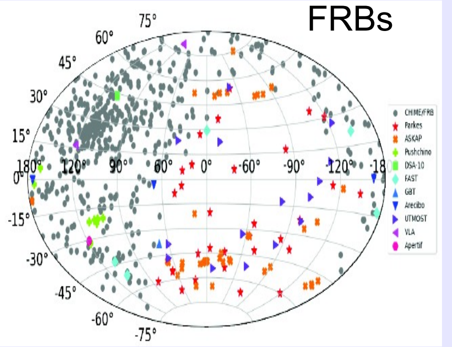
For those that are in binaries one can precisely measure the mass…
also glitches could occur which reveal the crustal activity...

X-ray cooling data: a few objects whose emission is detected and followed in time



X, gamma , radio transients: thousands of observations of gamma-ray bursts (short and long), fast radio bursts, gamma repeaters...all of them are related, in some way, to neutron stars (probably magnetars)

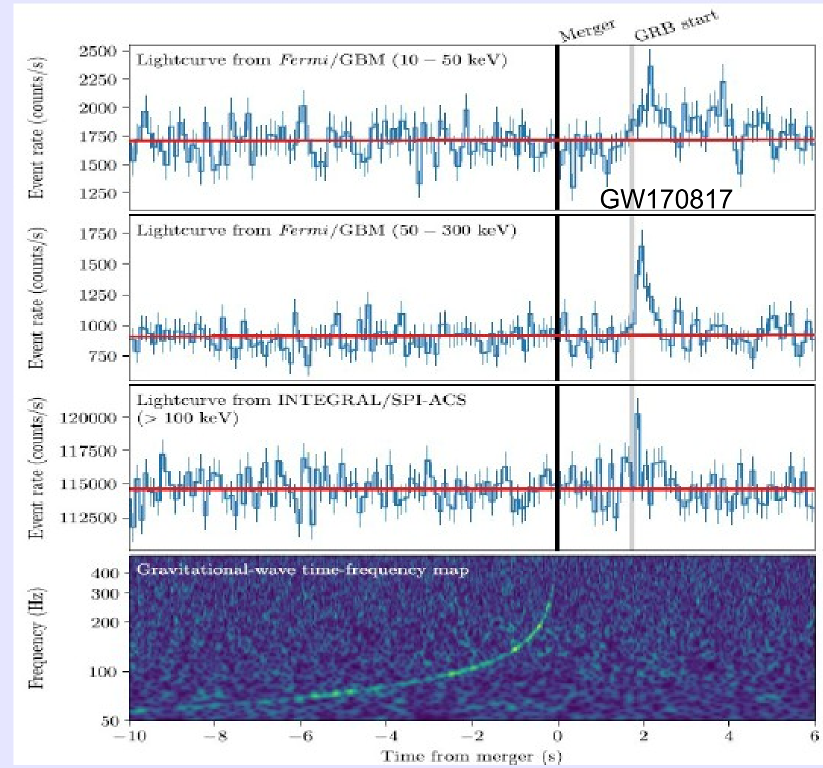




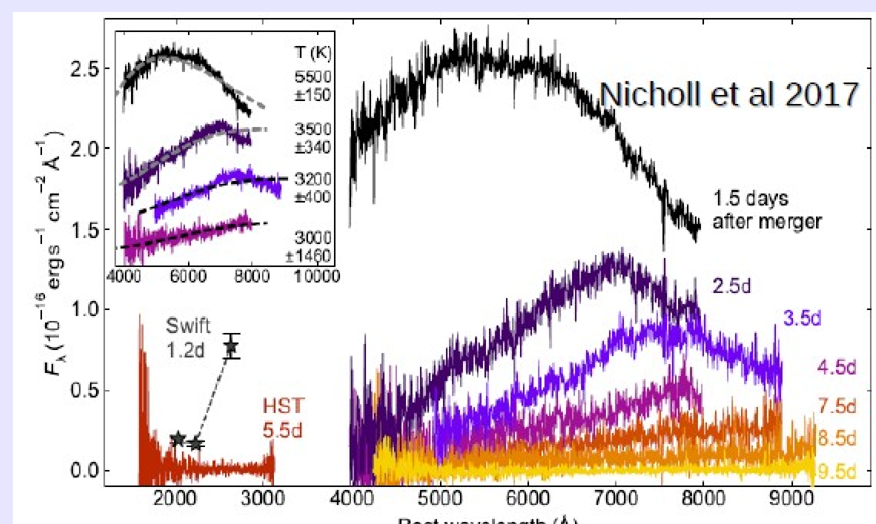
Gravitational waves and related EM signals: two signals associated with NS-NS systems + three associated with NS-BH systems.

Annual number of detections[iii iv] **Petrov et al ApJ 2022**

	NS-NS	NS-BH	BH-BH
O3	5^{+14}_{-5}	13^{+15}_{-9}	24^{+18}_{-12}
O4	34^{+78}_{-25}	72^{+75}_{-38}	106^{+65}_{-42}
O5	190^{+410}_{-130}	360^{+360}_{-180}	480^{+280}_{-180}



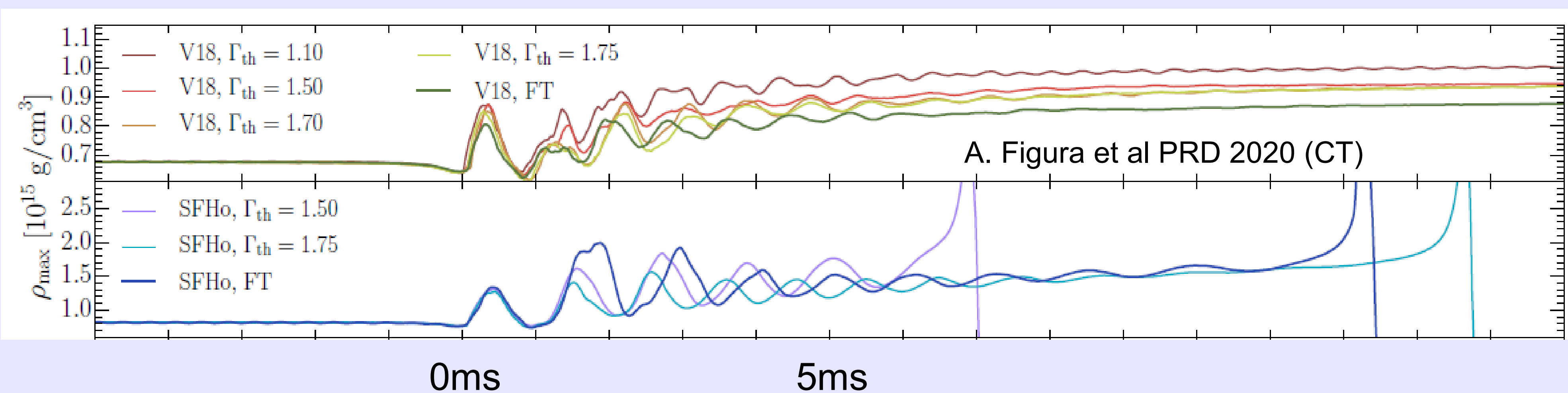
For the case of GW170817 also sGRB + Kilonova the last one being generated by the large amount of mass ($0.01M_{sun}$) of neutron rich matter ejected during /after the merger of the neutron stars.



What does NEUMATT compute?

- Computation of the equation of state (EoS) of dense hadronic matter in a wide range of densities, temperatures and isospin asymmetry. Also the formation of hyperons, deltas,… are taken into account. Two main approaches: microscopic calculations (*see talk of D. Logoteta)* that are implemented within the units of Pisa and Catania. Phenomenological calculations (all NEUMATT units). Those calculations are key for modeling the structure of compact stars but also for the simulations of the merger of compact stars and of supernovae.
In particular, the units of PI and CT are to date among the few in our community that have been able to perform merger simulations by using **microscopic finite temperature tables,** at variance with many phenomenological EoSs (e.g. Lattimer-Swesty) or hybrid approaches using an effective thermal adiabatic index. This is one of the main achievement of NEUMATT.

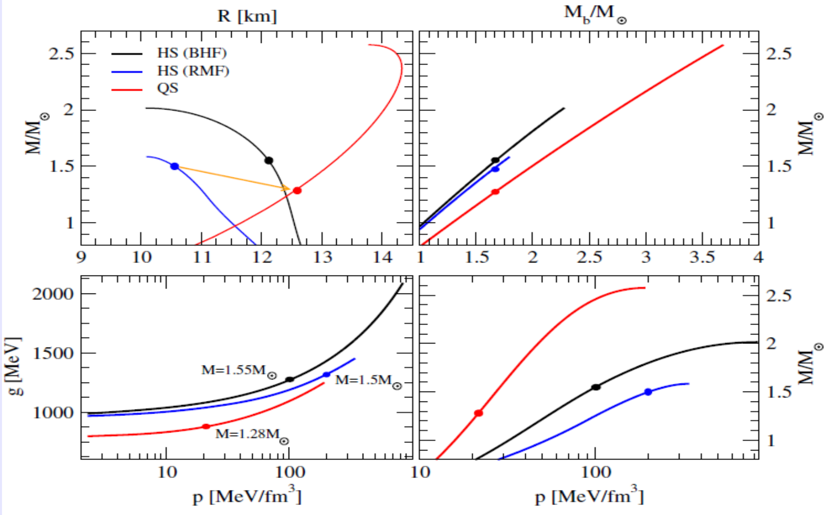
Mon.Not.Roy.Astron.Soc. 497 (2020) 2, 1488 (PI), Phys.Rev.D 102 (2020) 4, 043006 (CT)



- Computation of the equation of state of quark matter and/or mixed hadronic matter quark matter phases (all the NEUMATT units, *see talk of M. Guerrini*). Several models are adopted: MIT bag model, the Dyson-Schwinger method, the Field Correlator and the color dielectric models. Color superconductivity seems to be a crucial "ingredient" for explaining the phenomenology of compact stars (large maximum masses + possible crystalline phases for glitches, *see talk of S. Trabucco*).

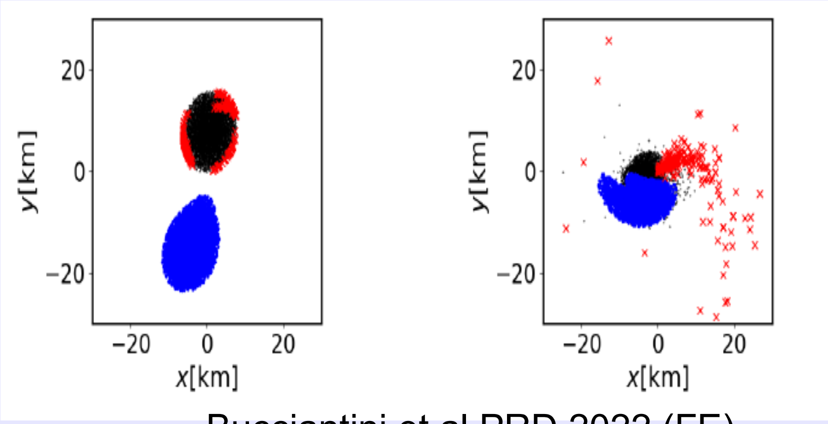
NEUMATT has proposed and is developing the so called **two-families scenario** namely the idea that strange quark matter could be absolutely stable and that quark stars can coexist with hadronic stars (FE+PI).

When enough hyperons are produced at the center of a hadronic star, nucleation of strange quark matter could start (its Gibbs potential smaller than the one of the hadronic phase). When a droplet of critical radius is produced (quantum or thermal nucleation) the conversion process will start. It is exothermic, mass defect ~ $0.1M_{sun}$.



Bombaci et al PRL 2021 (FE+PI+CT)

A consequence of this scenario:
strangelets production during the merger of binaries containing a quark star and a hadronic star (first ever simulation of such a mixed system, thanks to A. Bauswein).

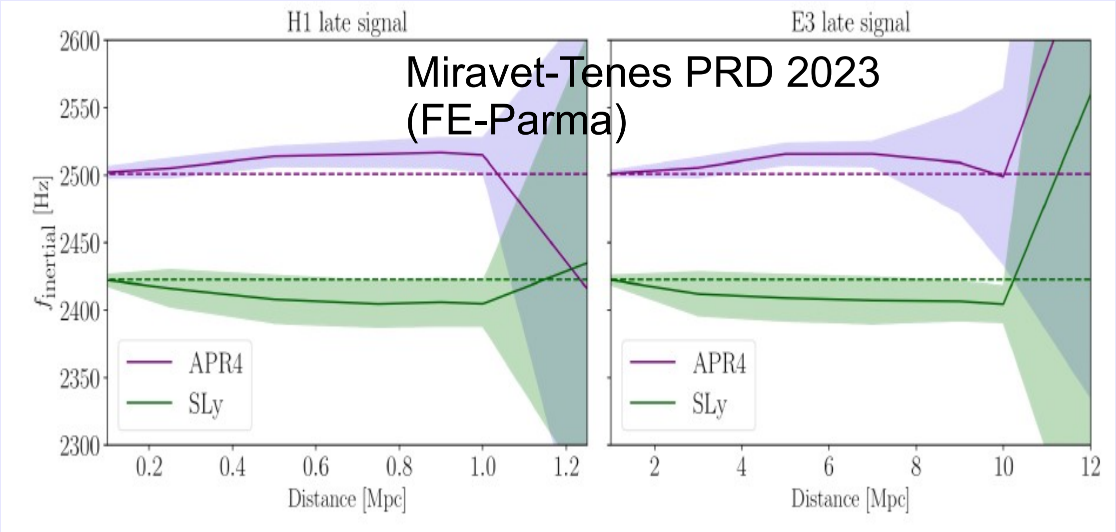


Bucciantini et al PRD 2022 (FE)

Merger simulations + Kilonovae simulations + GWs data analyses *(see talk of M. Bejger)*

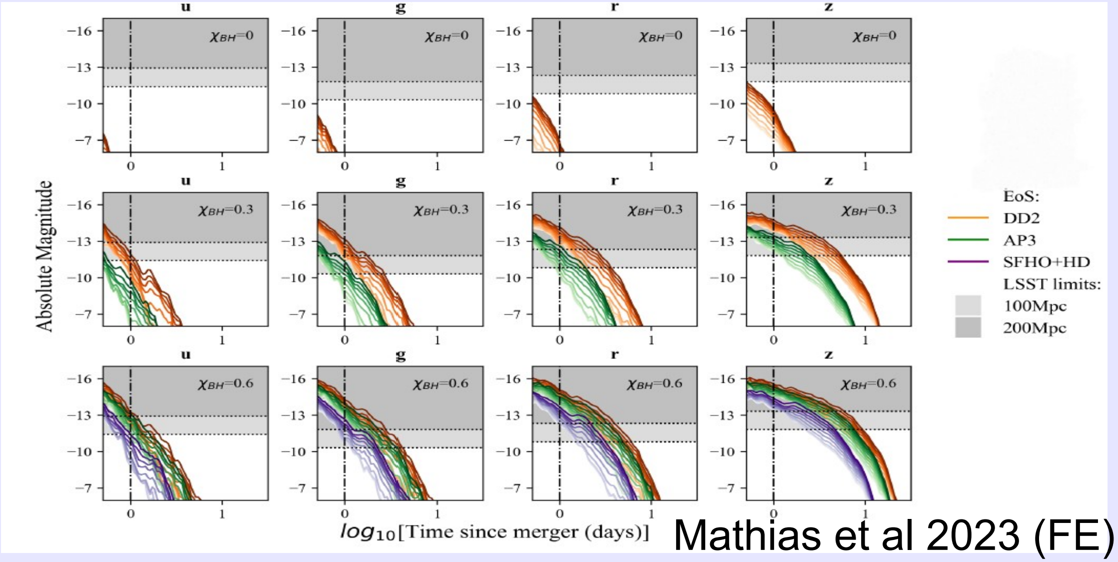
NEUMATT collaborates with the leading groups of numerical relativity which perform the simulations of compact stars mergers: A. Bauswein (GSI-Darmstadt), L. Rezzolla (Uni Franfurt am Main), S. Bernuzzi (Uni Jena), D. Radice (Penn State Uni) and hosts also experts of numerical relativity: the group of R. De Pietri (Parma).

Long term simulations of the postmerger phase: possibility of detecting different oscillation modes through GWs.



Miravet-Tenes PRD 2023 (FE-Parma)

Simulation of KN light curves and EoS. New!! thanks to M. Bulla who recently joined NEUMATT. Two-families vs one family: much fainter KNs in the first case due to the softness of the hadronic EoS.

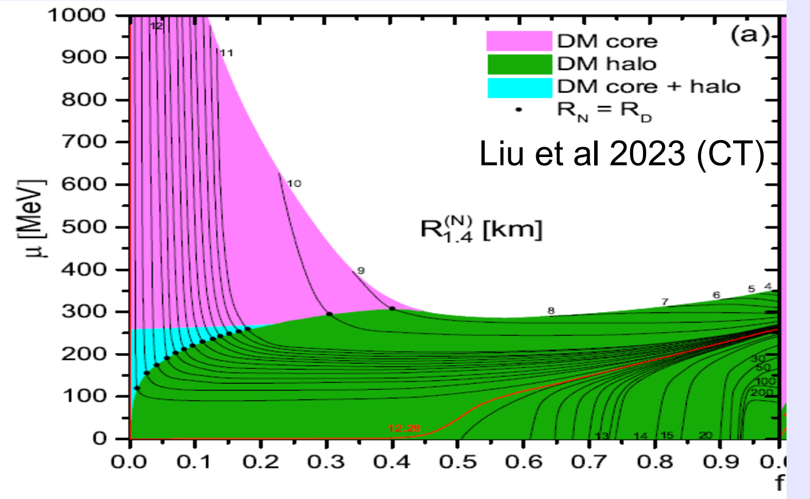


Mathias et al 2023 (FE)

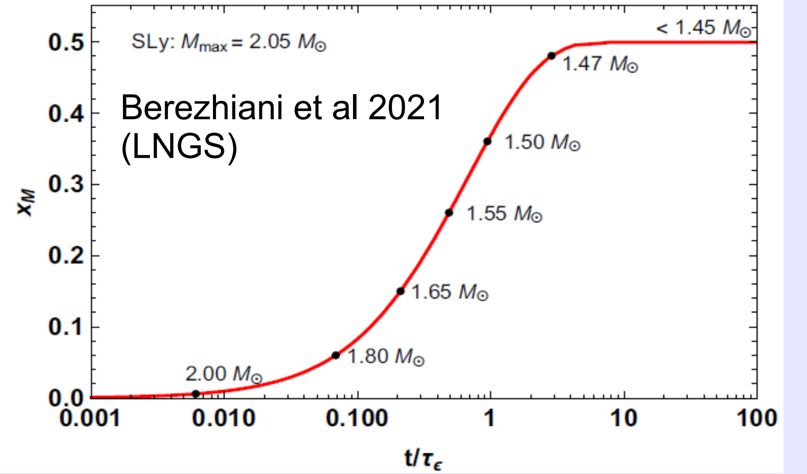
Dark matter particles in compact stars?

There are two ways in which compact stars could be interesting for the study of dark matter:

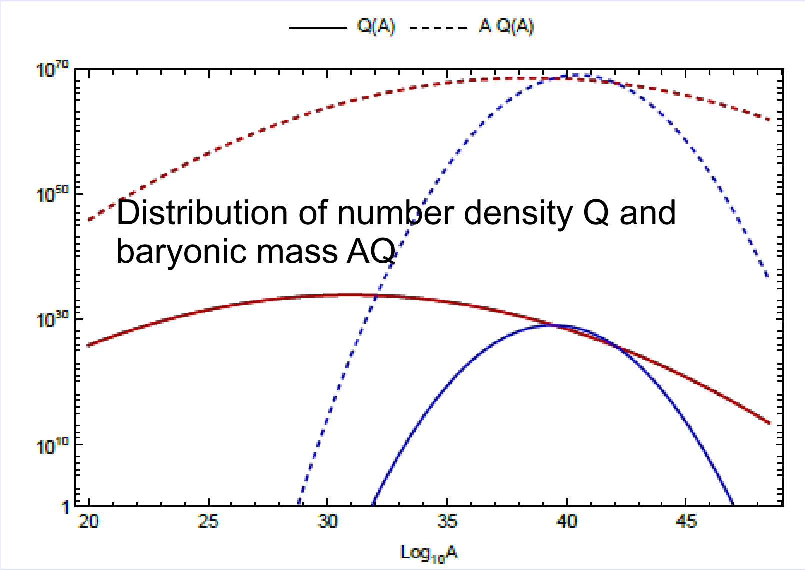
1) They potentially capture dark matter particles: optical radius for different dark matter (bosonic and self-interacting) mass μ and different dark matter mass fractions f. Very small and also very large radii are possible for large values of f, although it is not clear if accretion can be so efficient (it depends on the position of the star in the galaxy).

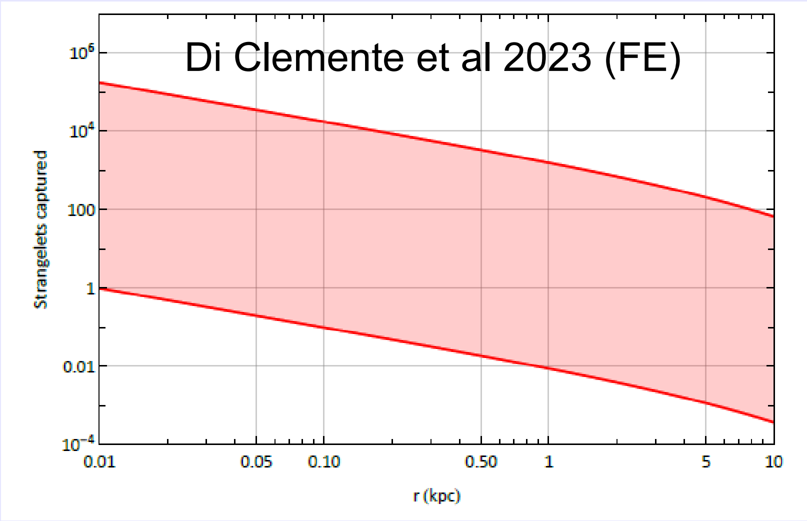


Prediction: the maximum mass depend on the story of the star and it decreases in time.



2) If strange quark stars do exist, strangelets could be a kind of baryonic dark matter and could be captured by MS stars (if the local dark matter density is high enough). A possible path for the formation of low mass ($<1 M_{sun}$) compact stars.





For these new topics, a few experts of LNGS and FE recently joined and/or collaborate with NEUMATT (F. Nesti LNGS)

Conclusions

NEUMATT is a well established network involving most of the people in Italy interested in the theoretical study of compact stars.

Its main achievements and expertise: a wide variety of EoSs computed in different approaches (and different possible compositions) that are currently used in merger and supernovae simulations. Calculations and modeling of cooling of compact stars, glitches of pulsars, explosive phenomena, r-modes instabilities...

NEUMATT in the next years: several new collaborations, new people involved, new topics (dark matter, GWs analyses (interaction with ET@CSN2 and TEONGRAV@CSN4), Kilonovae simulations)

Hope to have some new GWs data before the next Cortona meeting !!