KN signals in NS-BH mergers

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Main points

- Numerical simulations indicate a rather direct relation between the amount of mass ejected during and after the NS-BH merger and the tidal deformability of the NS

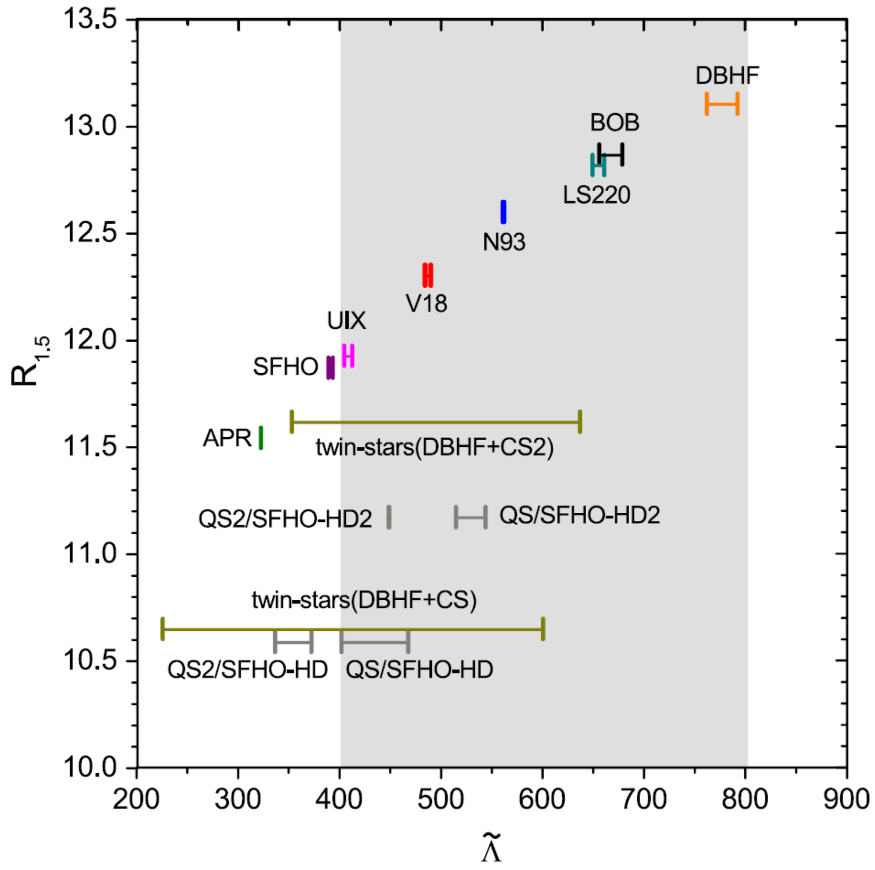
- Tidal deformability is related to the radius of the star

- By using the most recent results of NICER we can put limits on the radius and therefore on the amount of mass ejected and on the KN signal

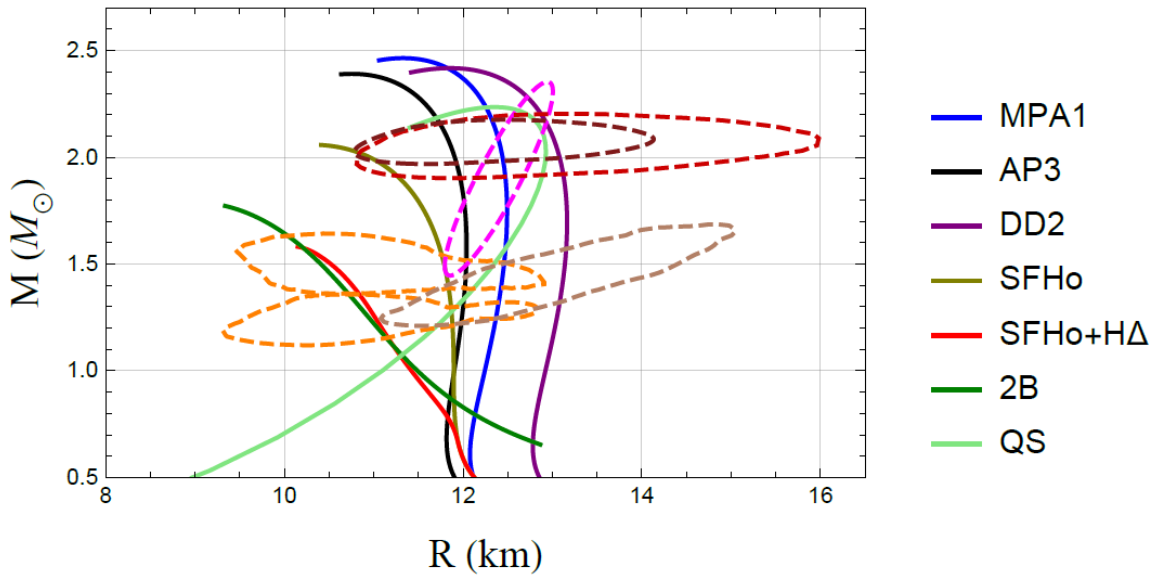
- In the “normal” scenario in which only one type of compact stars exists the KN signal is rather strong for BH masses below about 10 M_s and if the BH spin is not too small (in the case of GW200105 and GW200115 the signal is weak/inexistent)

- In the two-families scenario in which neutron stars and strange quark stars co-exist the KN signal is very weak, because
  - **QS-BH does not produce any KN** (Kluzniak, W., & Lee, W. H. 2002, Mon. Not. Roy. Astron. Soc.,335, L29) and
  - **NSs have small radii in that scenario**

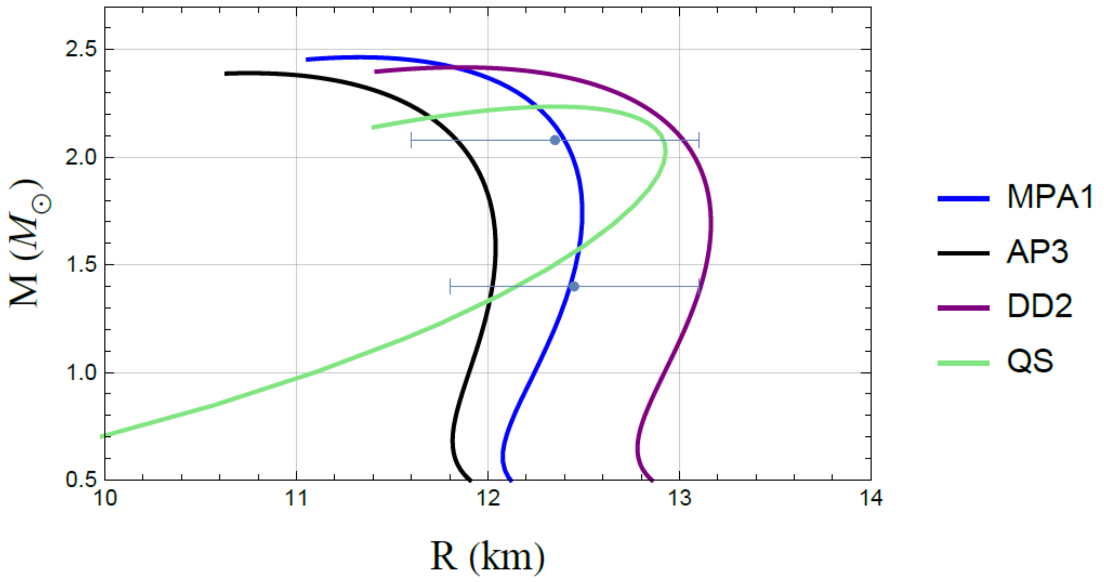
Linear relation between radius and tidal deformability
Burgio et al. ApJ 860 (2018) 139



NICER results and representative EoSs

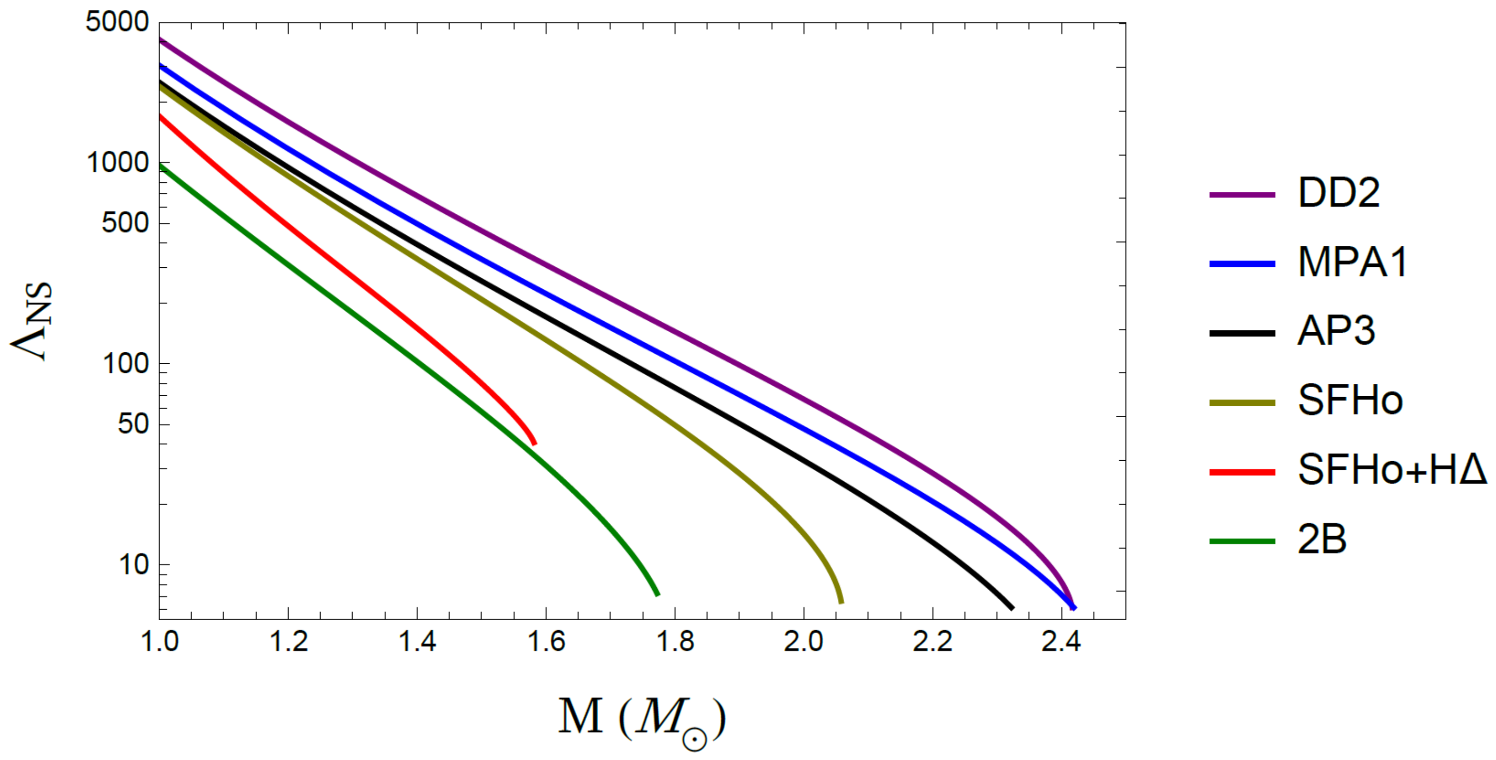


NICER results for PSR J0740+6620: brown from Riley et al. (2021) and dark red from Miller et al. (2021). NICER results for PSR J0030+0451, sepia, from Riley et al. (2019). Violet, limits on 4U 1702-429 from Nattila et al. (2017). Orange, limits from GW170817 from Abbott et al. (2018).



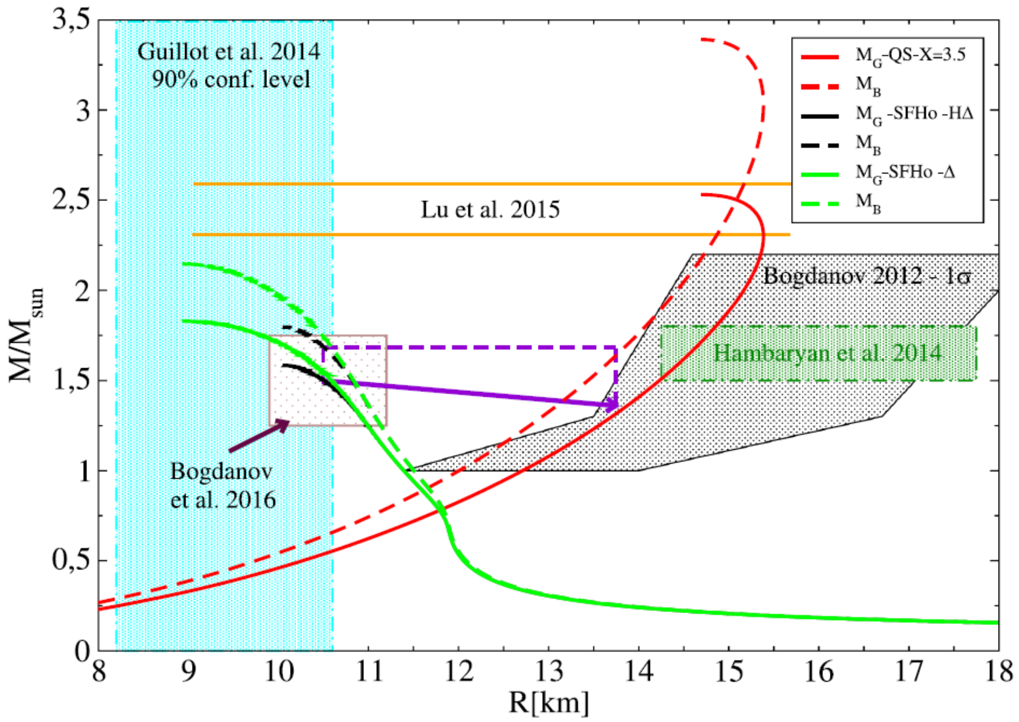
Limits on the radius at 68% of credibility interval for stars with masses 1.4 Ms and 2.08 Ms based on the analysis of NICER results and on GW170817 (Miller et al. 2021), with three nucleonic EoSs and a QS. The nucleonic EoSs are MPA1 (Muther et al. 1987), DD2 (Typel et al. 2010), AP3 (Akmal et al. 1998), SFHo (Steiner et al. 2013). SFHo+HD (Drago et al. 2014b) incorporates Δ-resonances and hyperons and 2B is a soft piece-wise polytropic used as a reference (Markakis et al. 2009).

Tidal deformabilities



Two-families of compact stars
Stars made of hadrons co-exist with stars made of strange quark matter

A. Drago, A. Lavagno, G. Pagliara, Phys. Rev. D89 (2014) 043014
G. Wiktorowicz, A.Drago, G. Pagliara, S. Popov; Astrophys. J. 846 (2017) 163



The existence of strange quark stars is based on the validity of the validity of the Witten’s hypothesis, telling that the absolute ground state of matter is made of a mix of deconfined up, down and strange quarks.

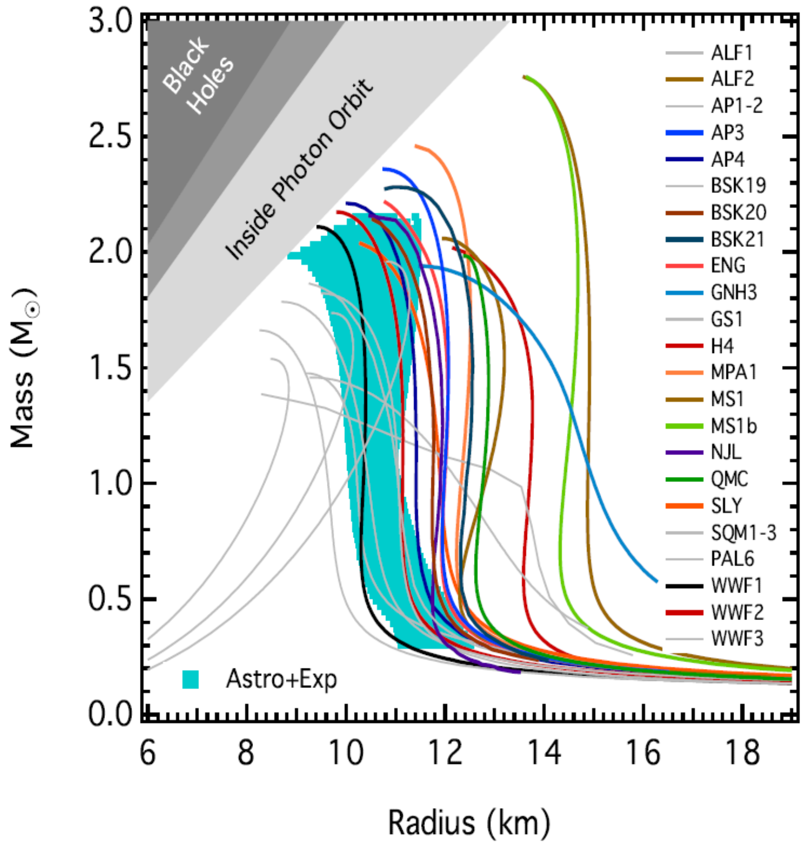
The velocity of sound in quark matter need not to be close to 1 in this scheme.

Massive stars have larger radii, at variance with models based on one family and with the twin stars scenario.

The process of quark deconfinement is triggered by the formation of a large hyperon content (or maybe by kaon condensation) at the center of the hadronic star.

Small radii from x-ray spectra

Oezel and Freire,
Ann.Rev.Astron.Astrophys. 54 (2016) 401

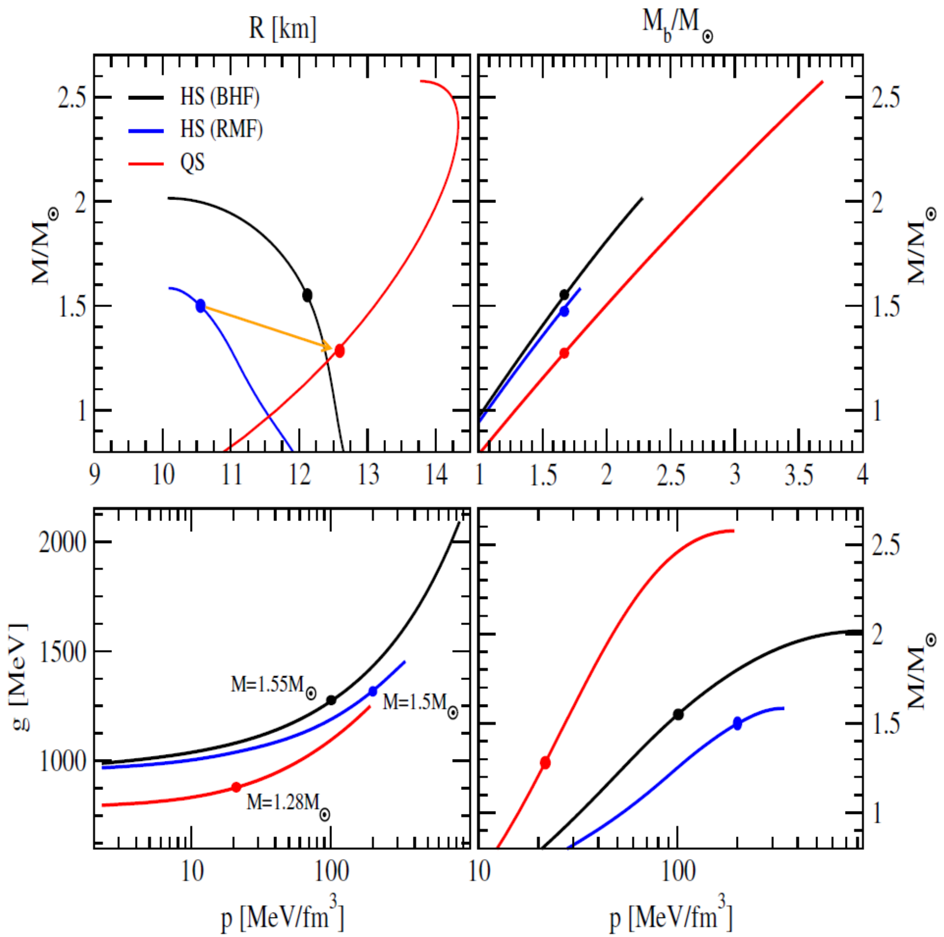


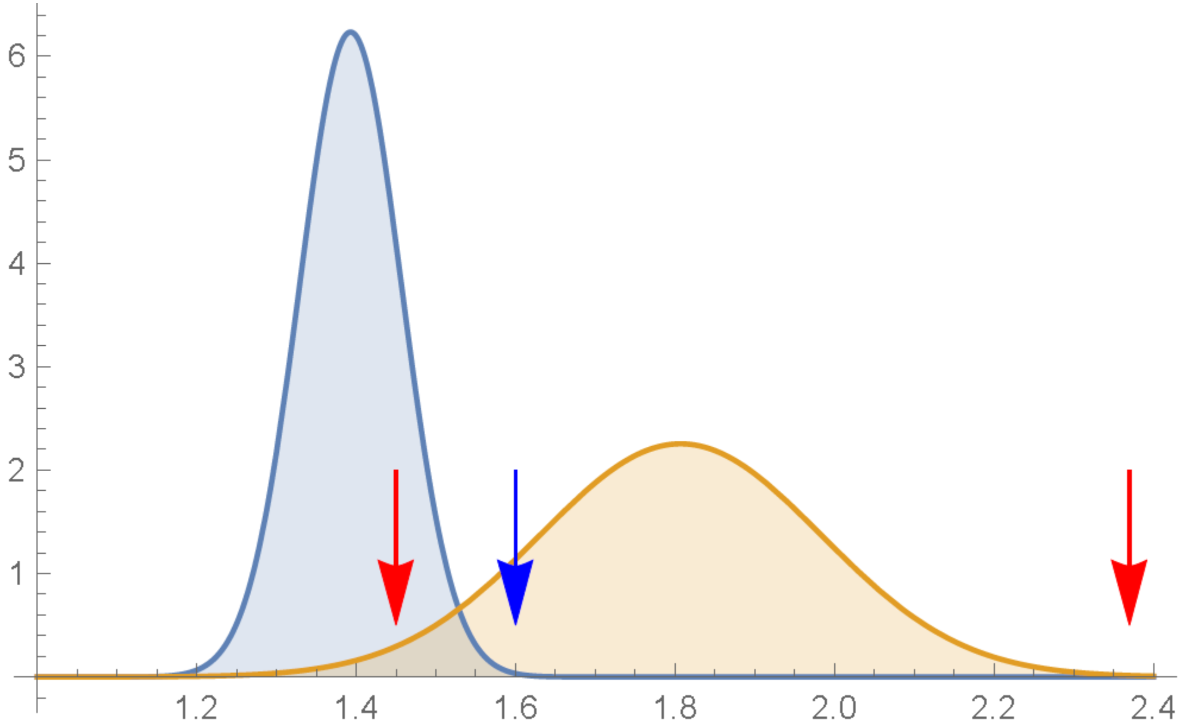
Steiner et al. MNRAS 476 (2018) 412
«Our model with the largest evidence suggests that $R_{1.4}$ is less than 12 km to 95 percent of confidence»

d'Etivaux et al. ApJ 887 (2019) 48
"In our analysis, we have shown that without nuclear physics inputs, the constant-RNS approximation prefers radii around ~11.1 +/- 0.4 km "

Evidence of bimodality in the mass distribution of MSPs with a WD companion (from Antoniadis et al. 2016 and Tauris et al. 2017) compared with the two-families scenario

Bombaci, I., Drago, A., Logoteta, D., Pagliara, G., & Vidana, I. 2021, Phys. Rev. Lett., 126, 162702,





Example of an EoS satisfying Miller et al. limits and including Δ resonances, hyperons and kaons

Thapa, Sinha, Li, Sedrakian, arXiv:2102.08787

Configuration	$NY\bar{K}$			$NY\Delta\bar{K}$					
				$V_\Delta = V_N$			$V_\Delta = 5/3\ V_N$		
$U_{\bar{K}}$ (MeV)	$M_{max}(M_\odot)$	R(km)	$n_c(n_0)$	$M_{max}(M_\odot)$	R(km)	$n_c(n_0)$	$M_{max}(M_\odot)$	R(km)	$n_c(n_0)$
0	2.008	11.651	6.107	2.021	11.565	6.160	2.049	11.226	6.349
−140	2.005	11.652	6.096	2.019	11.566	6.151	2.032	11.343	6.214
−150	1.994	11.664	6.13	2.006	11.61	6.143	1.973	11.448	6.028

Hyperons are produced at densities of 2-3 ρ_0. Kaon condensation can also take place if the (anti-)kaon attractive potential exceeds about 140 MeV.

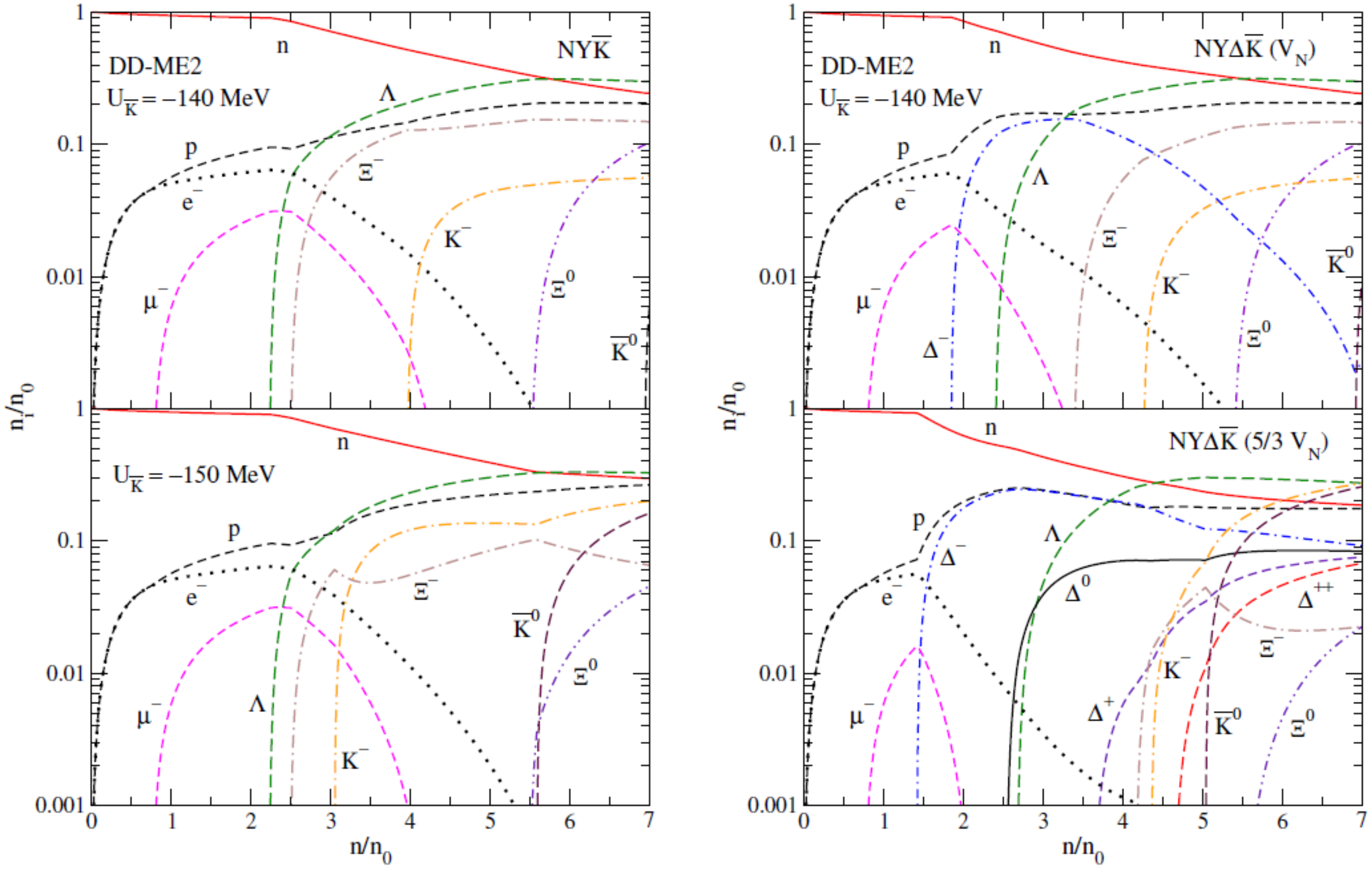


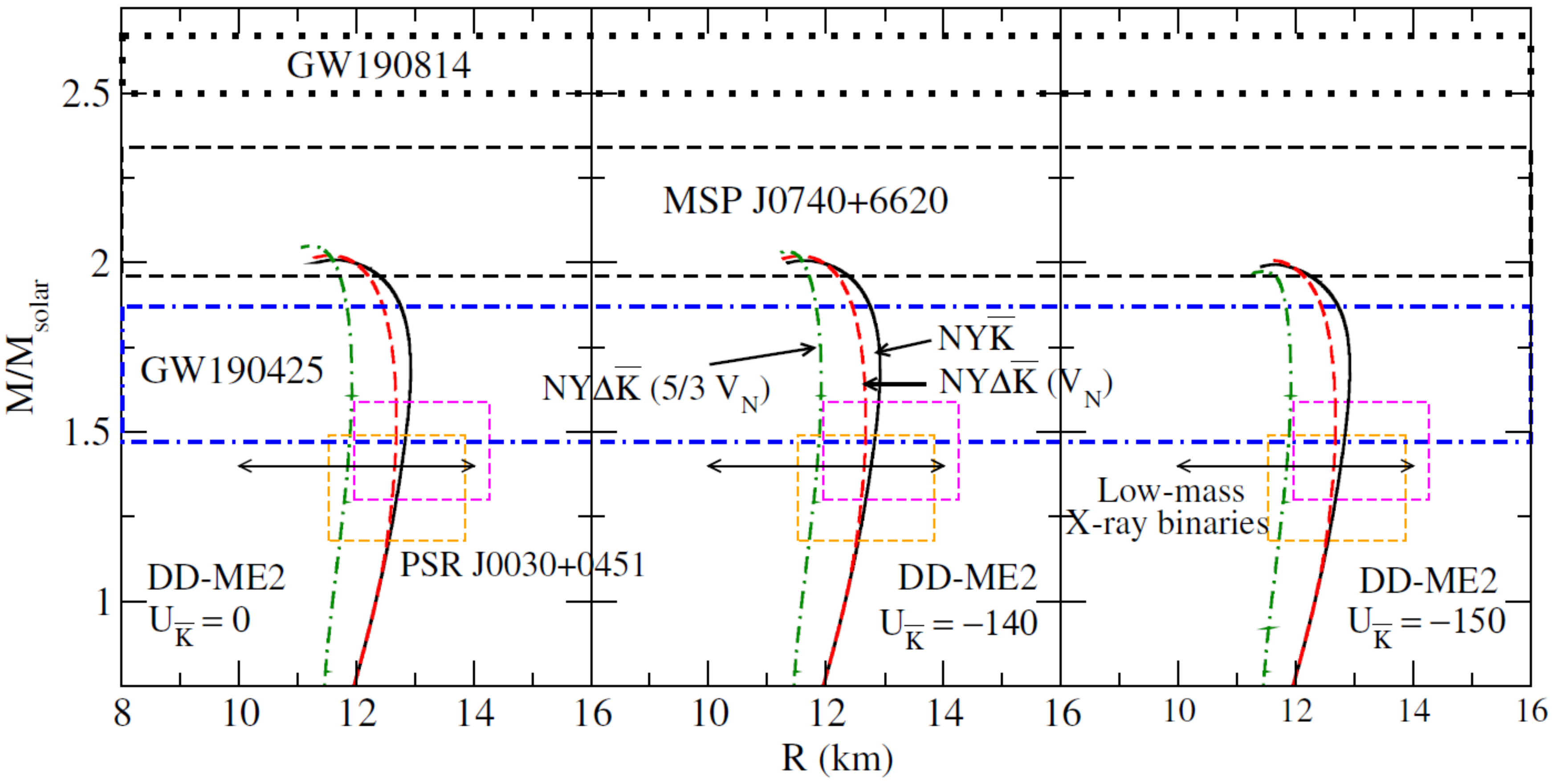
TABLE V. Threshold densities, n_u for (anti)kaon condensation in NY and NYΔ matter for different values of Δ-potentials and K^- optical potential depths $U_K(n_0)$.

Config.	$NY\bar{K}$		$NY\Delta\bar{K}$			
			$V_\Delta = V_N$		$V_\Delta = 5/3\ V_N$	
$U_{\bar{K}}$ (MeV)	$n_u(K^-)$ (n_0)	$n_u(\bar{K}^0)$ (n_0)	$n_u(K^-)$ (n_0)	$n_u(\bar{K}^0)$ (n_0)	$n_u(K^-)$ (n_0)	$n_u(\bar{K}^0)$ (n_0)
−120	–	–	–	–	–	–
−130	–	–	–	–	5.86	6.79
−140	3.97	6.95	4.26	6.92	4.37	5.05
−150	3.06	5.59	3.33	5.39	3.90	4.37

Example of an EoS satisfying Miller et al. limits and including Δ resonances, hyperons and kaons

Miller et al. limits are well satisfied.

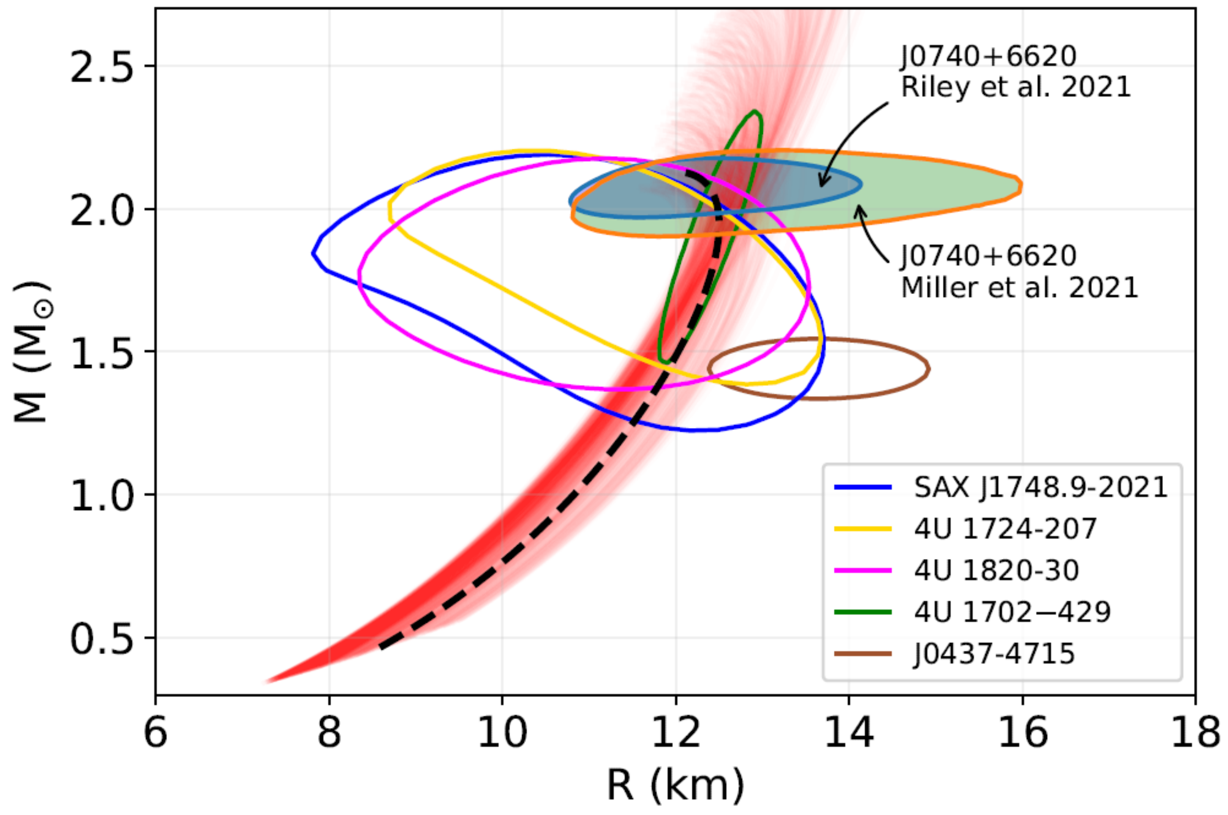
Notice that **the maximum mass cannot significantly exceed about 2 M_s**



Properties of dense matter, such as viscosity, thermal and electrical conductivity strongly depend on the composition.

NICER analysis of J0740+6620 suggests a rather stiff EOS: a QS satisfies perfectly that request. Analysis NOT based onto J0740+6620, whose radius is predicted

Traversi, Char, Pagliara, Drago



Parametrization of M_{DISK} and of M_{DYN}

We have used the analyses of:

Kawaguchi, K., Kyutoku, K., Shibata, M., & Tanaka, M. 2016, The Astrophysical Journal, 825, 52

Foucart, F., Hinderer, T., & Nissanke, S. 2018, Phys. Rev. D, 98, 081501

Barbieri, C., Salafia, O. S., Perego, A., Colpi, M., & Ghirlanda, G. 2020, The European Physical Journal A, 56, 8

M_{DISK} and of M_{DYN} can be estimated in terms of the tidal deformability and of the compactness of the star, once the masses and the spins of the NS and of the BH are given.

Mass of the disk and dynamically ejected mass MPA1 vs SFHoHD for a NS having M=1.4 M_s

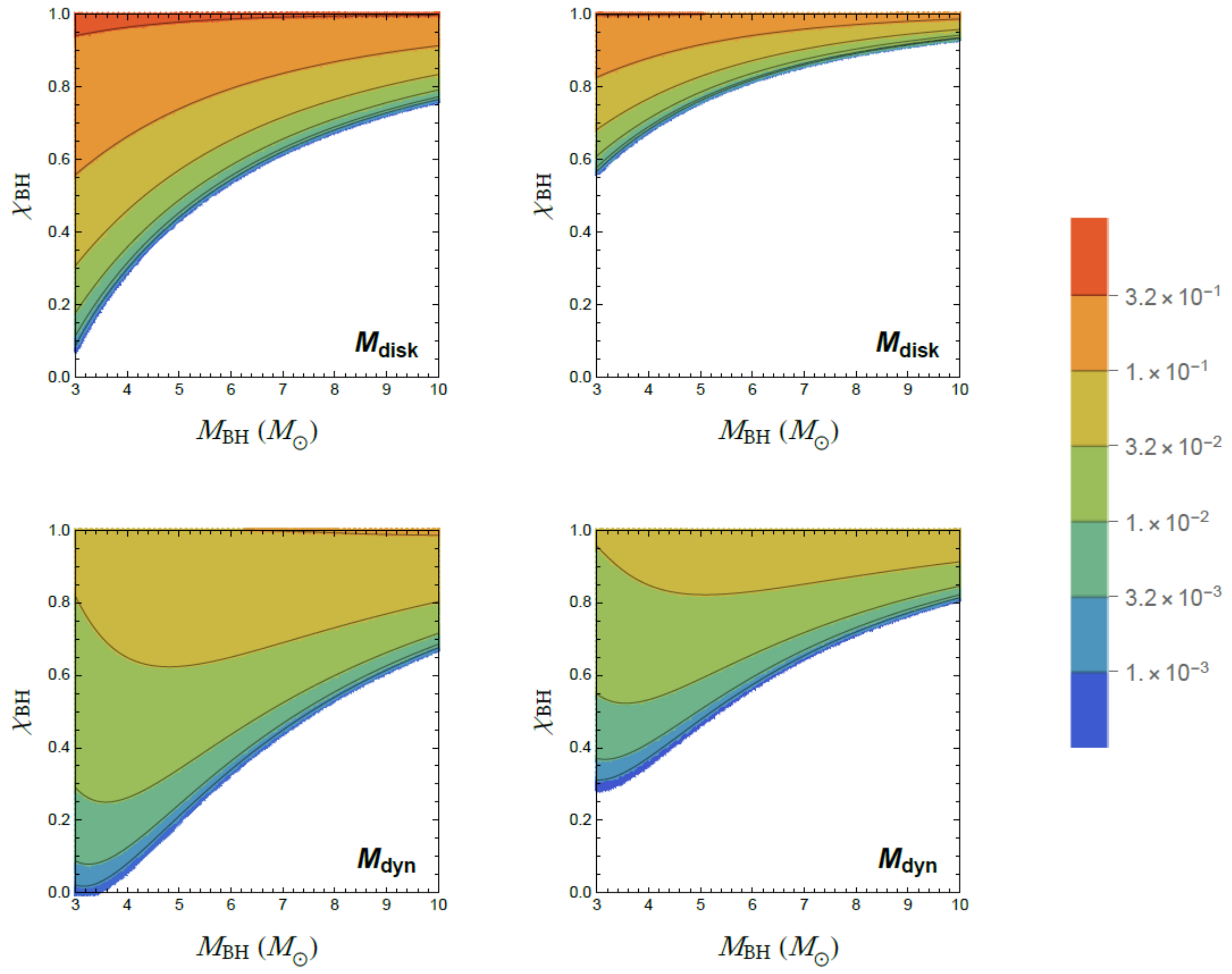
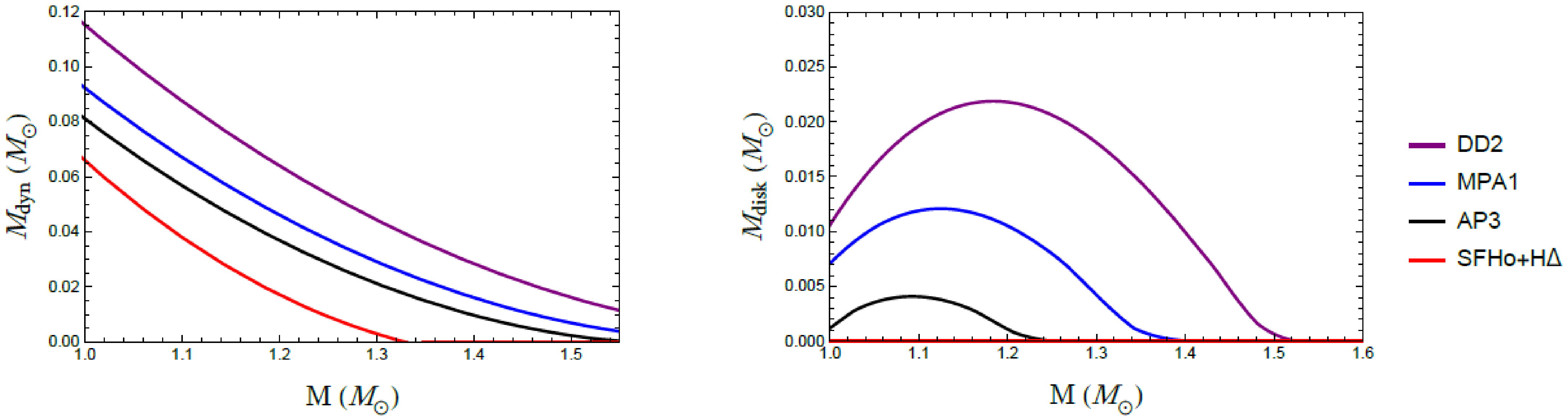


Figure 3. Plots for the mass of the disk on top and for dynamical ejecta on bottom. Left figures are relative to MPA1, right figures to SFHo+HD. The considered mass of the star is $\sim 1.4\,M_\odot$. Values for tidal deformability for MPA1 and SFHo+HD are respectively $\Lambda_{NS} \simeq 462$ and $\Lambda_{NS} \simeq 151$. Plots are function of the BH mass (M_{BH}) and of the adimensional spin parameter χ_{BH}.

One-family vs two-families
M_{BH} = 5 M_s and χ = 0.4



Conclusions

The first two NS-BH mergers have been detected by LIGO-Virgo, GW200105 and GW200115.

No EM counterpart has been detected, also in agreement with the result of our analysis due in particular to the very small BH spin.

The new runs of LIGO-Virgo and the new telescopes (James Webb and Vera Rubin) will allow to search for KN signals at very large distances, allowing to test the predictions of the models and to discriminate among the possible scenarios.

The two-families scenario is very predictive and it can be tested in a variety of ways. In particular it predicts the possibility of having NS-NS mergers with a total mass smaller than that of GW170817 (2.73 M_s) and collapsing directly to a BH. This is because in the two-families scenario GW170817 was associated with a NS-QS merger, but NS-NS mergers with total mass exceeding about 2.5 M_s would instead collapse directly to a BH.

Drago, A., & Pagliara, G. 2018, ApJ, 852, L32,

De Pietri, R., Drago, A., Feo, A., et al. 2019, ApJ, 881, 122