Recent results on Equation of State from NewCompStar

NewCompStar COST Action 1304

WG2/TL2 Meeting

G.G. Barnaföldi,
Wigner RCP of the Hungarian Academy of Sciences
CPOD2016, Wrocław, Poland, 31st May 2016

NewCompStar: exploring fundamental physics with compact stars

(NewCompStar COST ACTION MP1304 2014-2017)

PI: Luciano Rezzolla (Goethe University, Frankfurt)

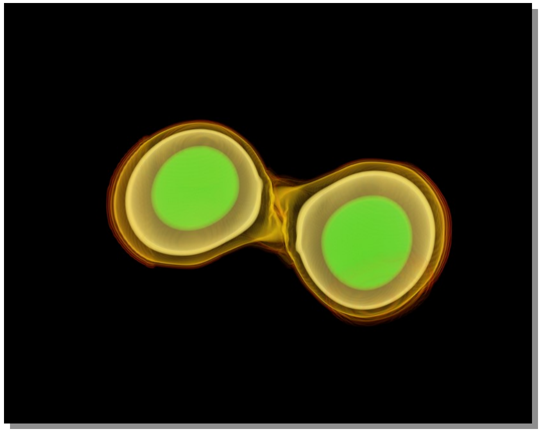
Objective: *provide an innovative connection between the micro- and macrophysics of compact stars; explore the behavior of matter and spacetime under the most extreme physical conditions, not accessible to laboratory experiments*

Working Groups of NewCompStar

WG1: Observations and modelling of compact stars.

WG2: Physics of strong interaction, theory & experiment.

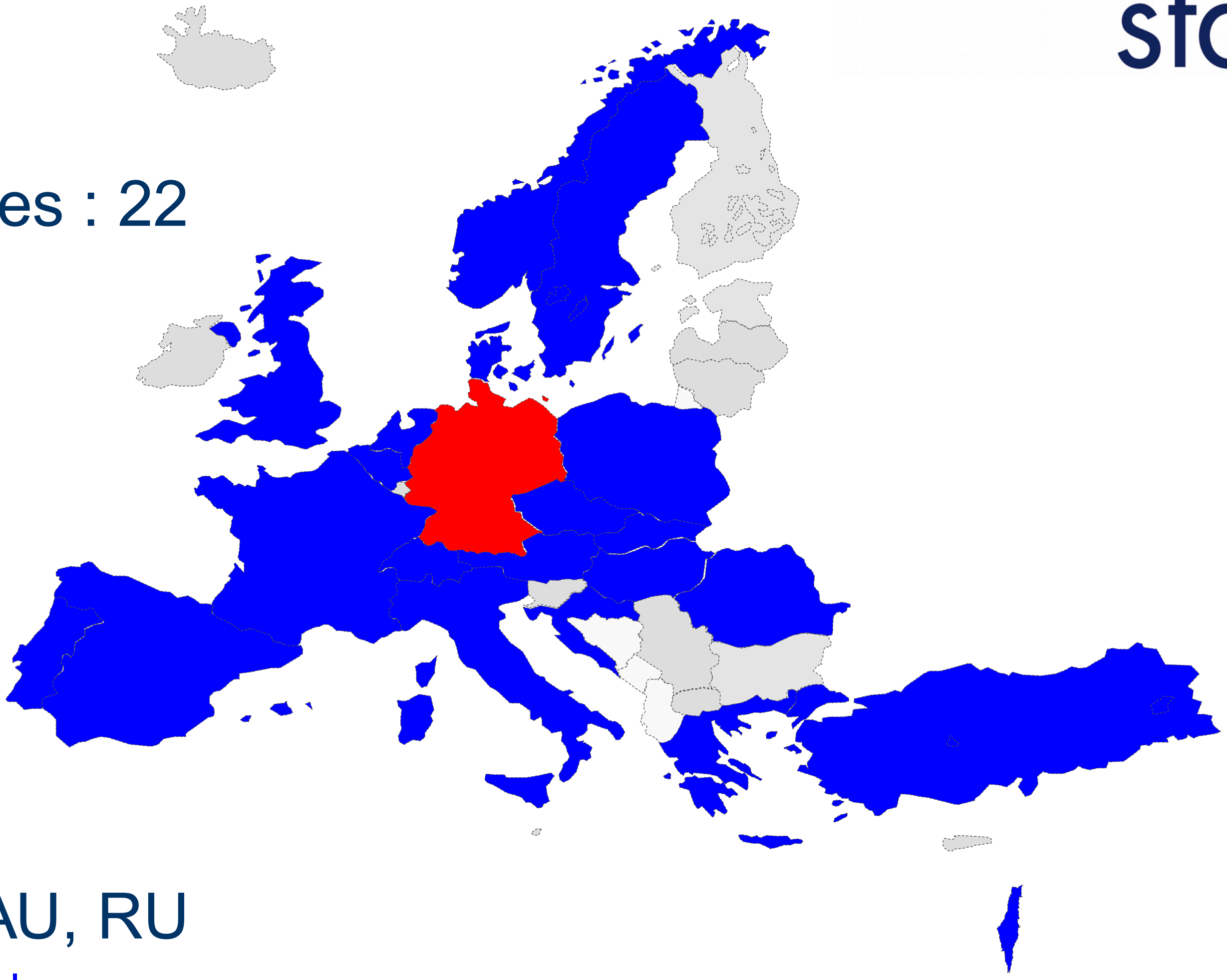
WG3: Gravitational-physics theory and observations.



Web & Info: http://compstar.uni-frankfurt.de

NewCompStar: exploring fundamental physics with compact stars

(NewCompStar COST ACTION MP1304 2014-2017)



Associated Countries : 22

Proposer : DE

AT, BE, CH, CZ, DK, EL, ES, FR, HR, HU, IL, IT, NL, NO, PL, PT, RO,SK, SE, TR, UK

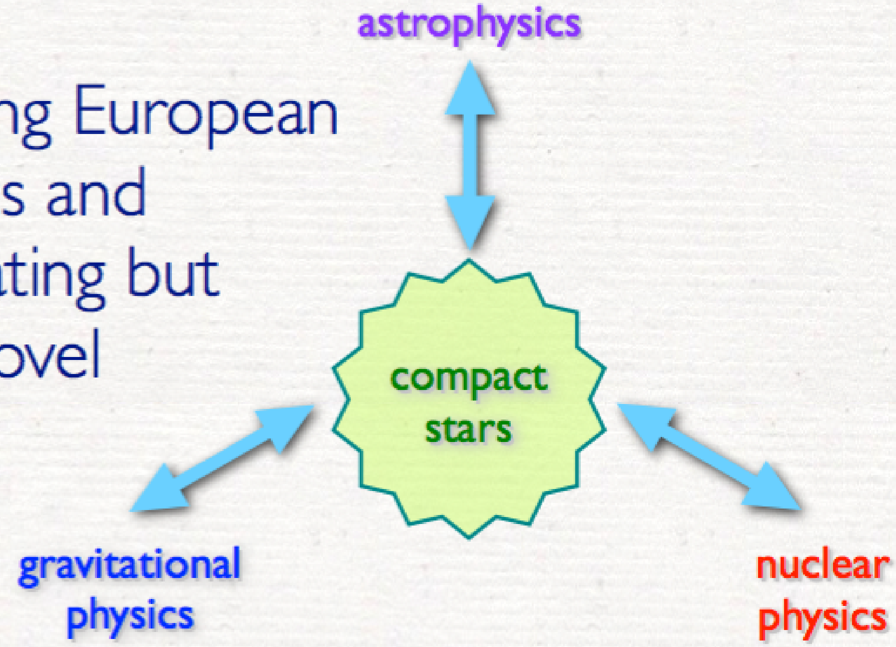
*NON-COST : AR, AU, RU

Proposer : red Participants: blue

*included within the full proposal

Driven by science to exploit synergies

- This Action is driven to research fundamental physics, although technological and industrial fallbacks are expected (more later).
- This Action will address a few fundamental but challenging questions concerning the physics and astrophysics of compact stars.
- This Action will bring together leading European experts in astrophysics, nuclear physics and gravitational physics to tackle a fascinating but challenging research area through a novel interdisciplinary approach.



- This Action will provide important value to the large-scale European efforts in observational astrophysics and experimental nuclear physics.

Working Group 2: physics of the strong interaction, theory and experiment

WG coordinators: Jérôme Margueron (IPN Lyon)

Topic coordinators:

Nuclear equation of state for compact stars and supernovae
Isaac Vidaña (Univ. of Coimbra),

Low energy QCD and super-dense matter
Gergely Gábor Barnaföldi (TL, Wigner RCP, Budapest),

Superconductivity and superfluidity in compact stars
Nicolas Chamel (TL, IAA Bruxelles),

Transport phenomenon and reaction rates for compact stars and supernovae
Laura Tolos (TL, ICE Barcelona).

Synergy agents:

Nuclear-Gravity: Micaela Oertel (LUTh Meudon)
Nuclear-astrophysics: Pawel Haensel (CAMK, Warsaw)

Memorandum of Understanding of the COST Action MP1304

1. Validate available equation of state across different experiments and observations. The WG will define a protocol where the equation of state, and the underlying interactions, are consistently checked and compared with nuclear experiments and observations of compact stars.

2. Investigate the predictions for the phase diagram of hot and dense matter, clarifying the role of phase transitions and exotic degrees of freedom predicted by nuclear physics and low-energy QCD.

3. Investigate superfluidity and superconductivity in dense matter. The WG will employ the numerous observations to understand the occurrence of superfluidity and superconductivity in various regions of compact stars and predict signatures revealing their presence in compact stars.

4. Calculate the transport properties and the reaction rates for validated equations of state. The WG will supply the simulations modelling core-collapse supernovae and binary neutron-star mergers with the transport properties and reaction rates of hot and dense nuclear matter.

WG2/TL2

Open Questions from the MoU:

1. What are the transport properties of hot/cold dense matter?
2. What is the role of the equation of state in core-collapse supernovae?
3. What is the role of the equation of state in binary neutron star mergers?
4. Are binary neutron star mergers behind short gamma-ray bursts (GRBs)?
5. How does the equation of state influence pulsar/magnetar dynamics?
6. How can observations of neutron stars (isolated or in binaries) constrain the EoS?
7. How do matter properties change under extremely strong electromagnetic fields?
8. How can neutron stars be used to test general relativity and other theories of gravity?

WG2/TL2

The Big Picture (WG2):

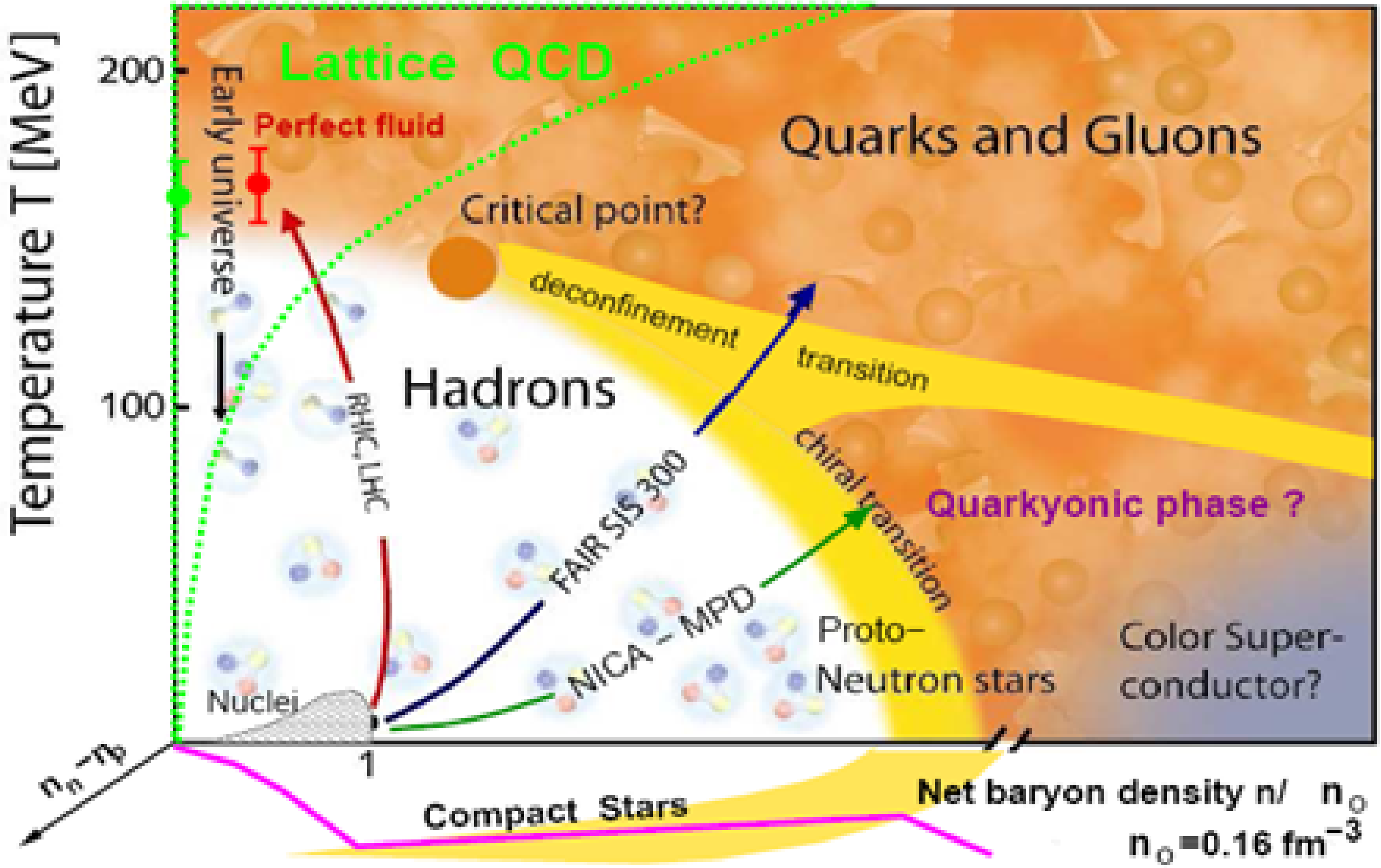
The physics of the strong interaction, theory & experiment

The Small Picture (TL2):

Investigate the predictions for the phase diagram of hot and dense matter, clarifying the role of phase transitions and exotic degrees of freedom predicted by nuclear physics and low-energy QCD.

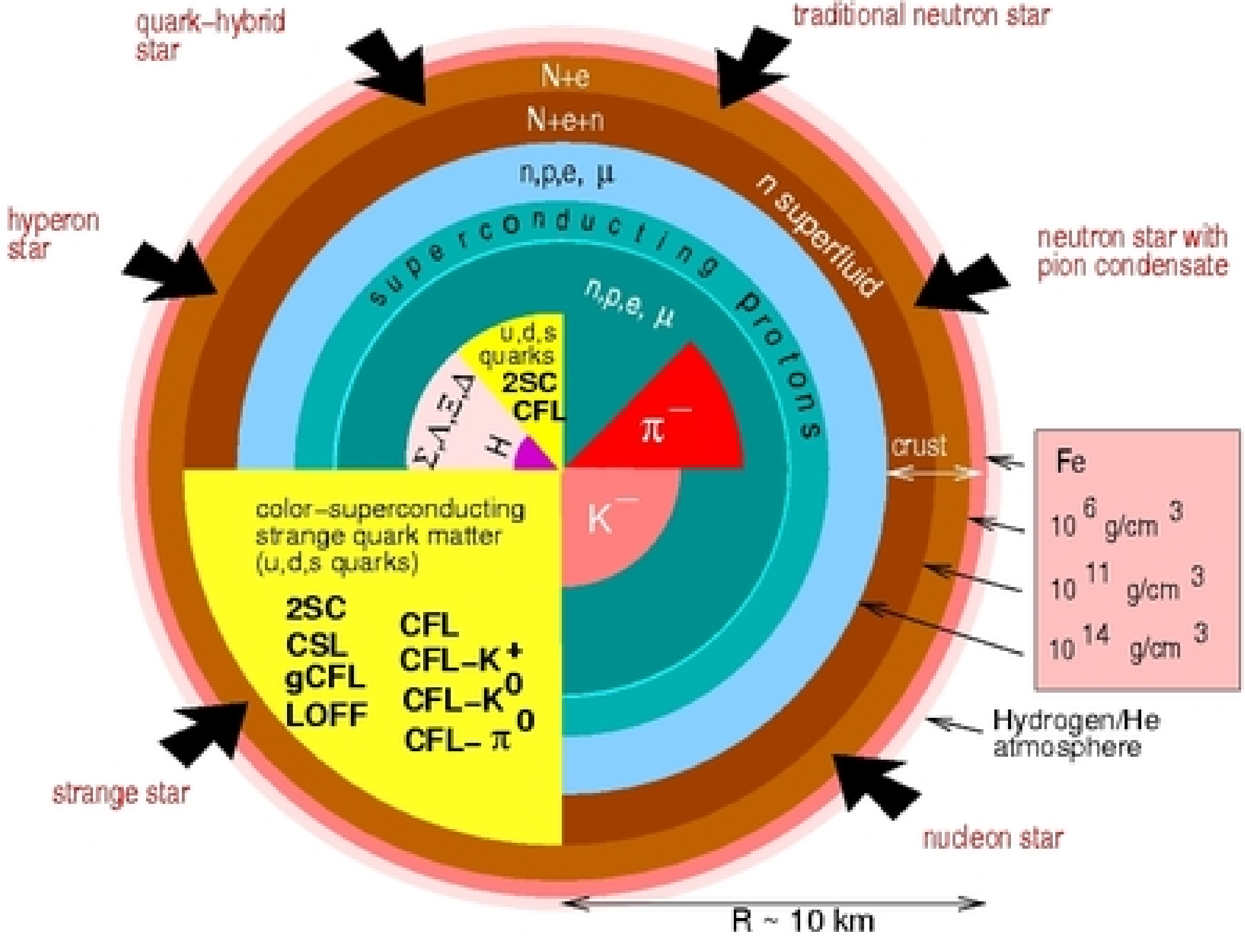
WG2/TL2

Which is generally all about this Big Picture…



WG2/TL2

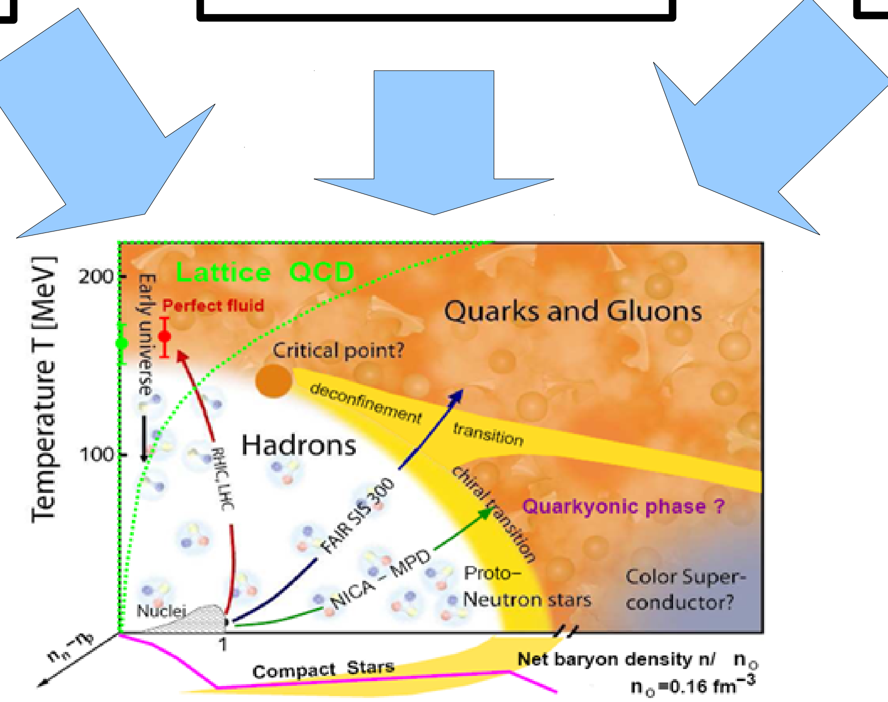
Or how can we make the circle from the square...



Lattice QCD at high T

High/low-energy measurements

Low QCD methods



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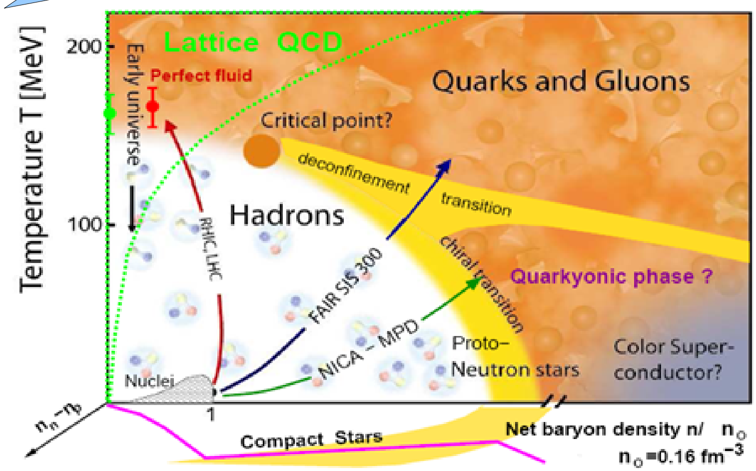
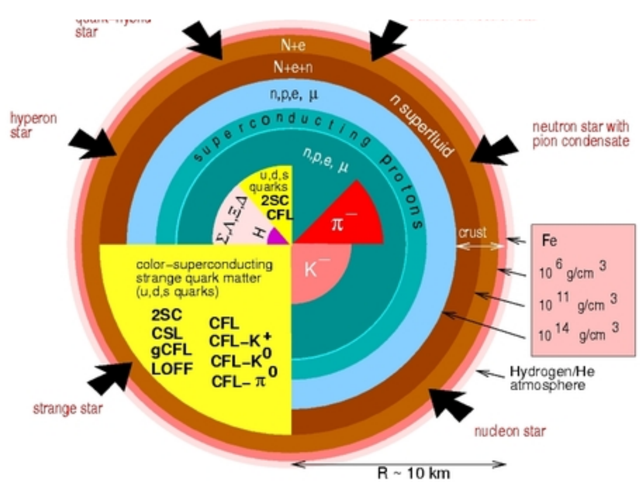


Constraints by Mass-Radius relation



Constraints by Gravity measurements

CompOSE

- CompOSE: Compstar Online Supernovae EoS
  - Aim is to collect and make a CompStar EoS database
  - Web: http://compose.obspm.fr
  - Any parametrized EoS are welcome

CompOSE CompStar Online Supernovæ Equations of State

comp star

- Home
- Manual
- EoS
  - EoS Overview
  - EoS Details
    - 1 parameter EoS
    - 2 parameter EOS
    - 3 Parameter EOS
  - Software (Interpolation, etc)
    - Software for treating NS EoS
- About CompOSE
- Newsletter
- Contact

Monday 21 July 2014
by webmaster

The online service CompOSE provides data tables for different state of the art equations of state (EoS) ready for further usage in astrophysical applications, nuclear physics and beyond.

If you decide to publish work using one or more of the here provided EoS we ask you to cite the given references and would be happy if you acknowledge CompOSE.

Inputs to the EoS

- Astrophysical Observations
  - Electromagnetic measurements
  - Gravitational measurements
  - Future satellites and telescope (NICER, SKA)

- Experimental observation: QCD phase diagram
  - Observation so far (SPS, RHIC, LHC)
  - Facilities of the near/far future
  - Resources for future numerical calculations

- General trends in QCD theory
  - Investigations of the QCD phase diagram
  - Search for the critical Endpoint (CEP)
  - Lattice QCD results
  - Future's theoretical developments

Astrophysical observation of the Compact Star parameters and/or Equation of State

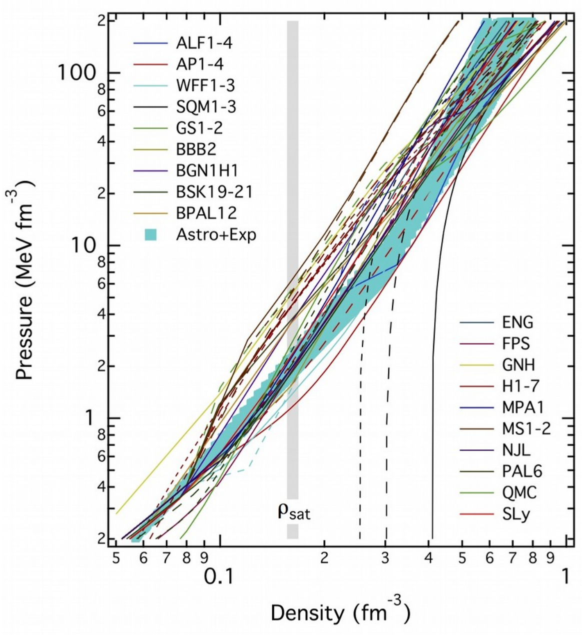
Inputs to the EoS

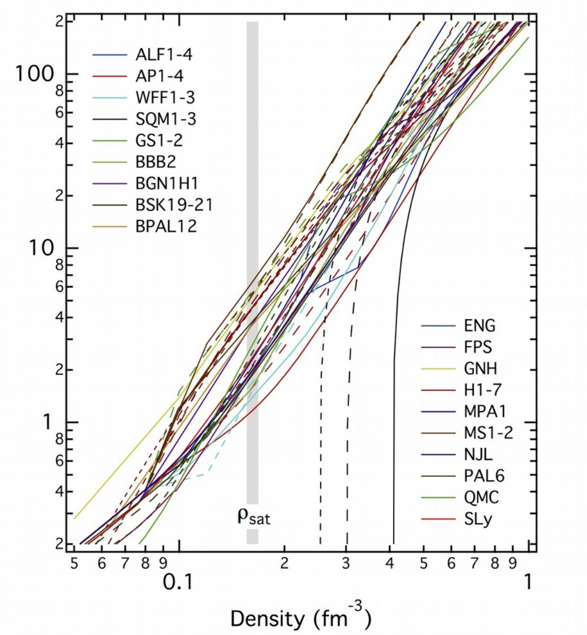
- Usual solution: Tolmann – Oppenheimer – Volkoff equation

$$\frac{dm}{dr} = 4\pi r^2 \varepsilon \ ;$$

$$\frac{dP}{dr} = -\frac{Gm\varepsilon}{r^2}\left(1+\frac{P}{c^2\varepsilon}\right)\left(1+\frac{4\pi r^3 P}{c^2 m}\right)\left(1-\frac{2Gm}{c^2 r}\right)^{-1} ,$$

- Equation of state Özel et al.





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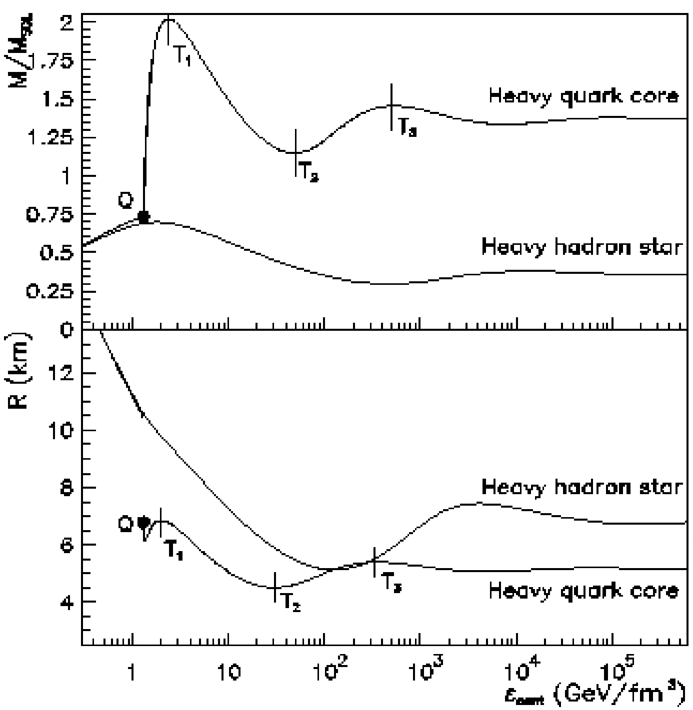

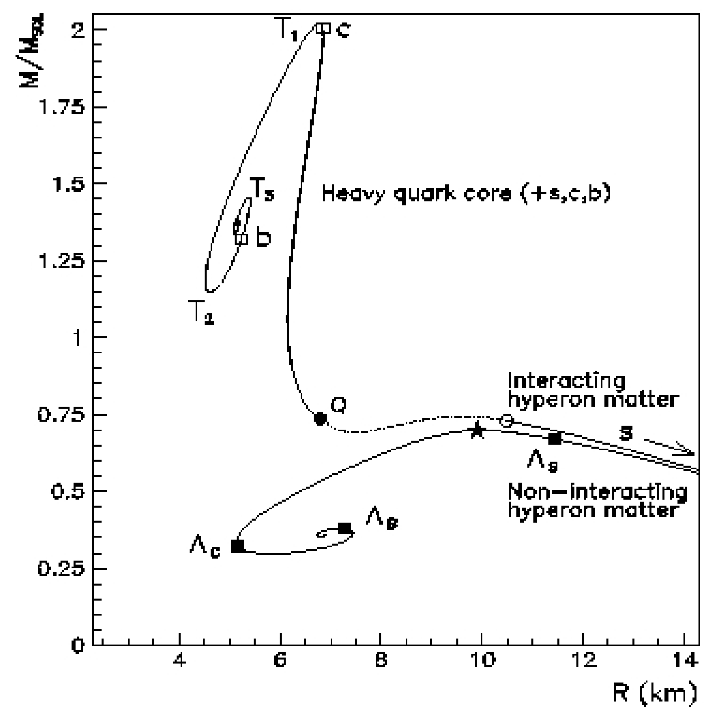

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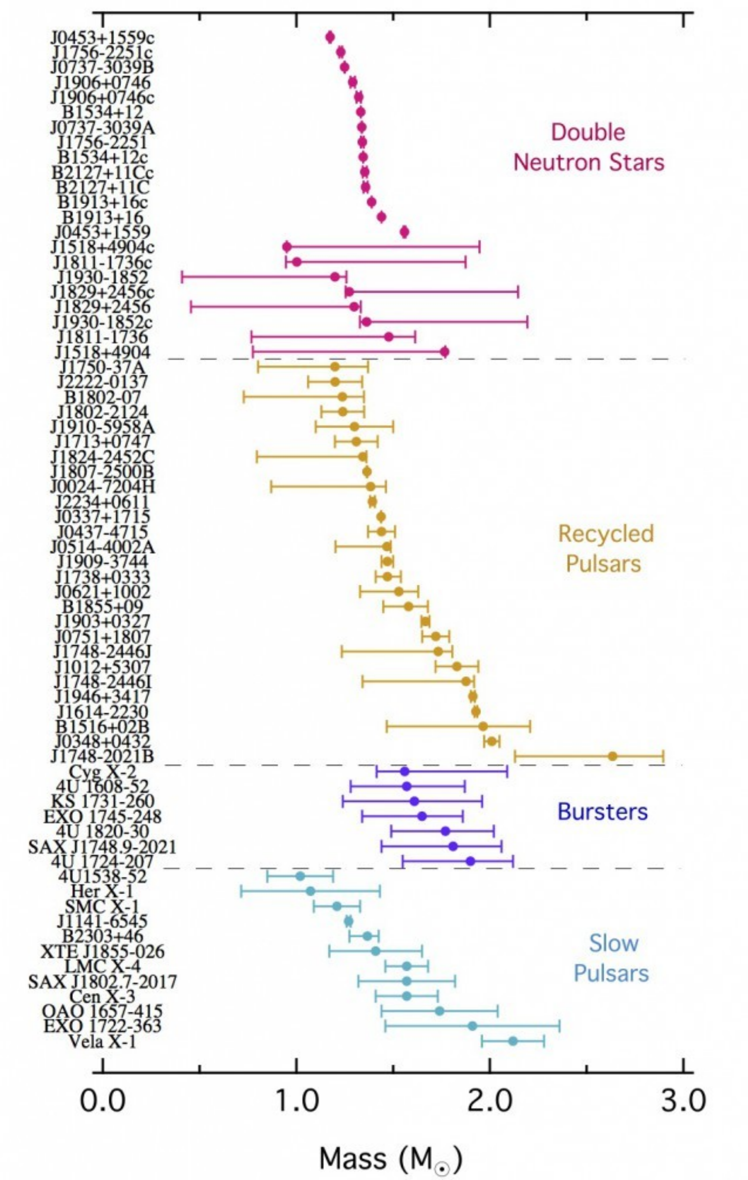


- Calculations:
  - Initial condition: $\varepsilon(R_{min}) = \varepsilon_c$
  - Edge of the star: $p(r=R) = 0$

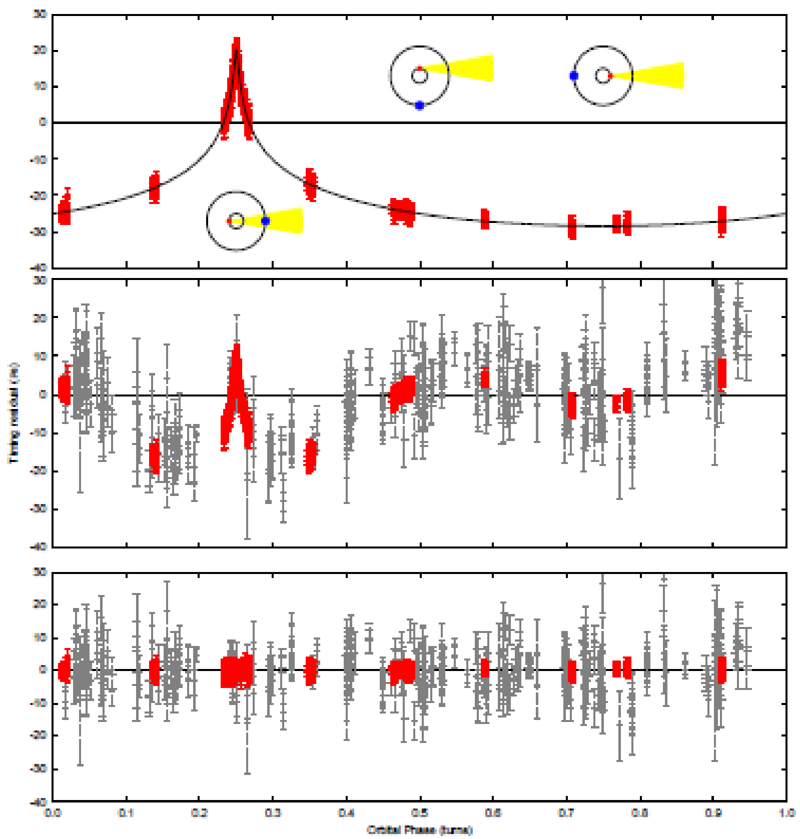
→ Result a M-R of the star, which is comparable to data fromobservation

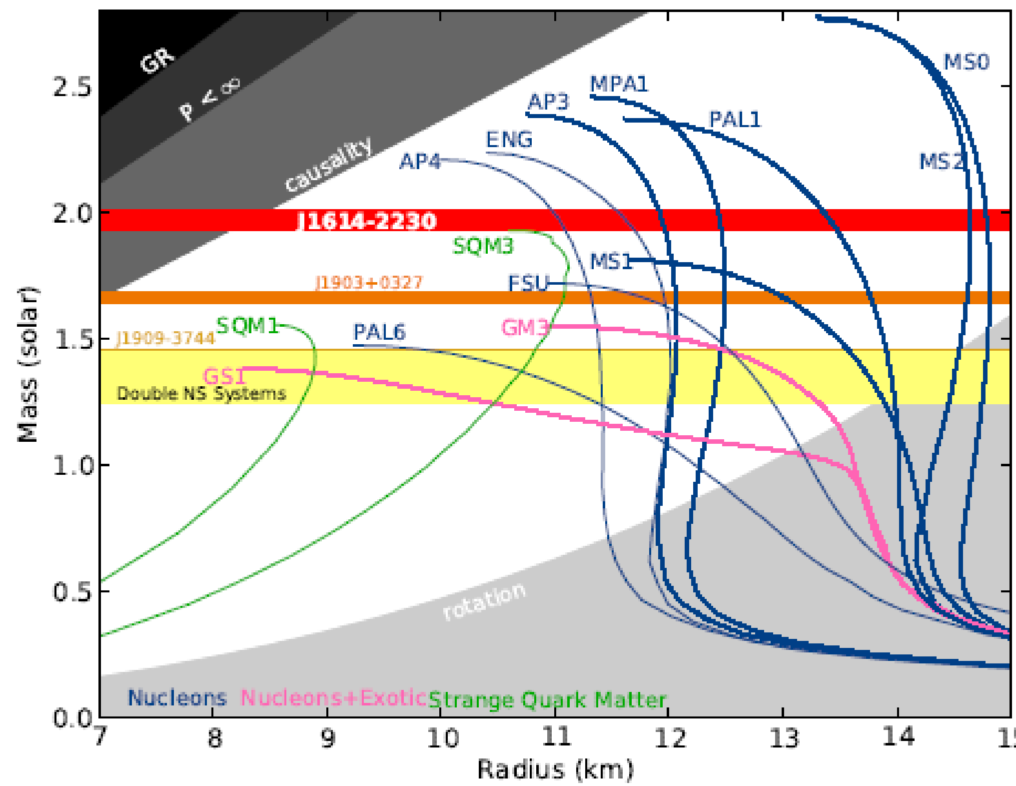
→ Freedom is the inner stucture, which is not testable

Inputs to the EoS: Large Mass NS

- P. Demorest et al,arXiv: 1010.5788 [astro-ph] 2 M_{sol}

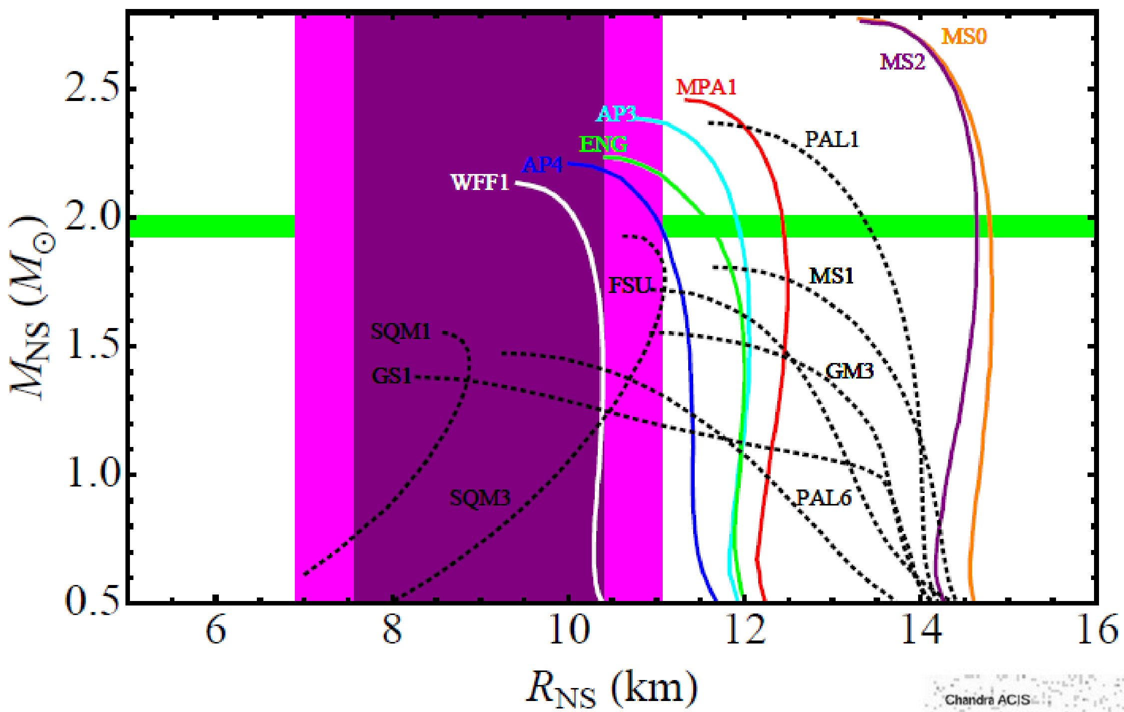
  M.H. van Kerkwijk & R.P. Breton AJ 13 (2010) 1.9 M_{sol}

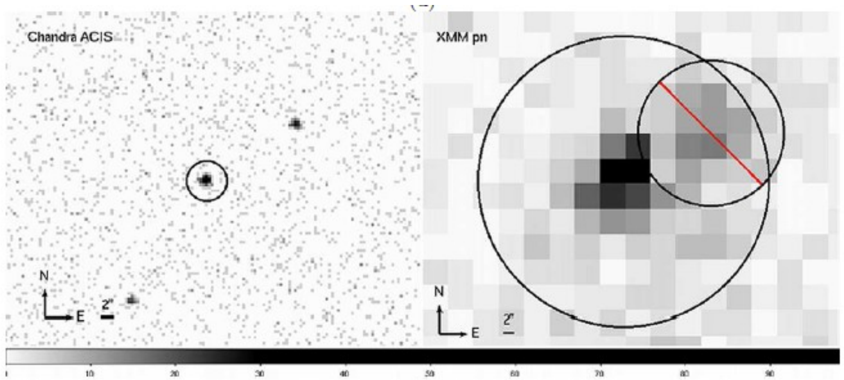




Inputs to the EoS: Radius of NS

- S. Guillot et al: AJ 772 (2013) 7 Low Mass X-ray Binaries





Inputs to the EoS: Mass - Radius

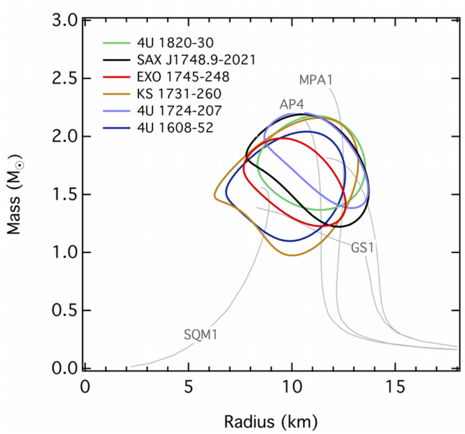
- F. Özel et al, arXiv:1505.05155 [astro-ph]

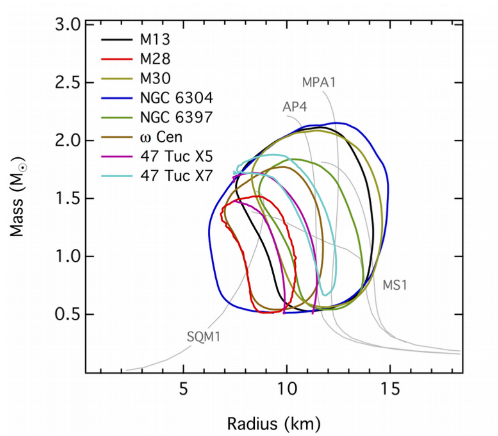
  Measurements of NS binaries

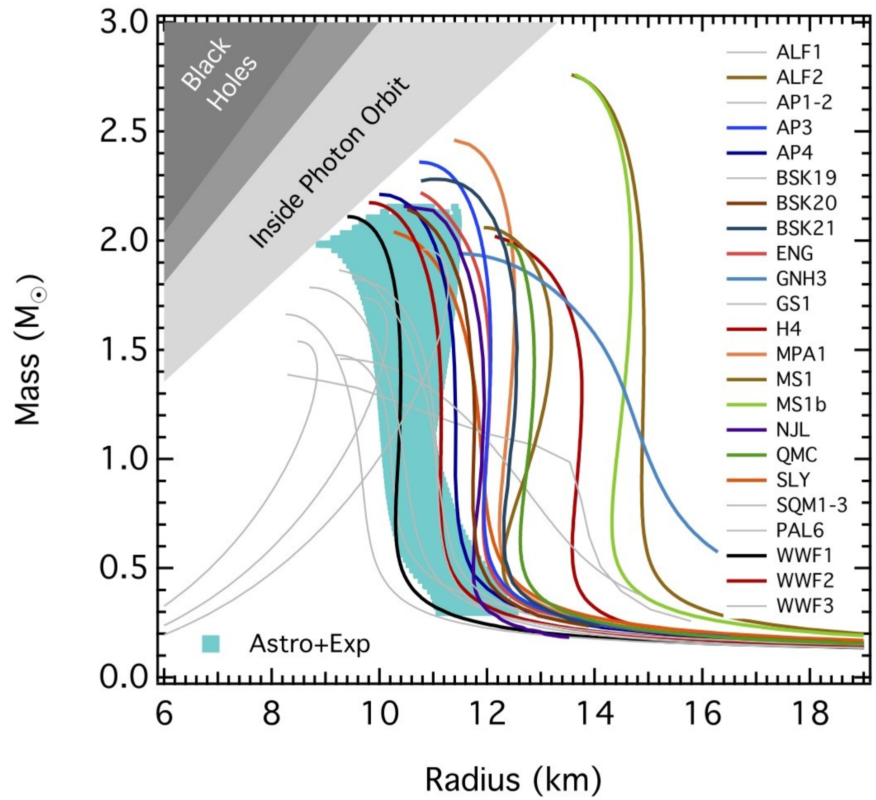
  with Low MassX-ray comapnion

  in Globular clusters

  So far 14 of these → Radii detectable







Inputs to the EoS: Mass-Radius

- S. Bogdanov, arXiv:1603.0163 [astro-ph]

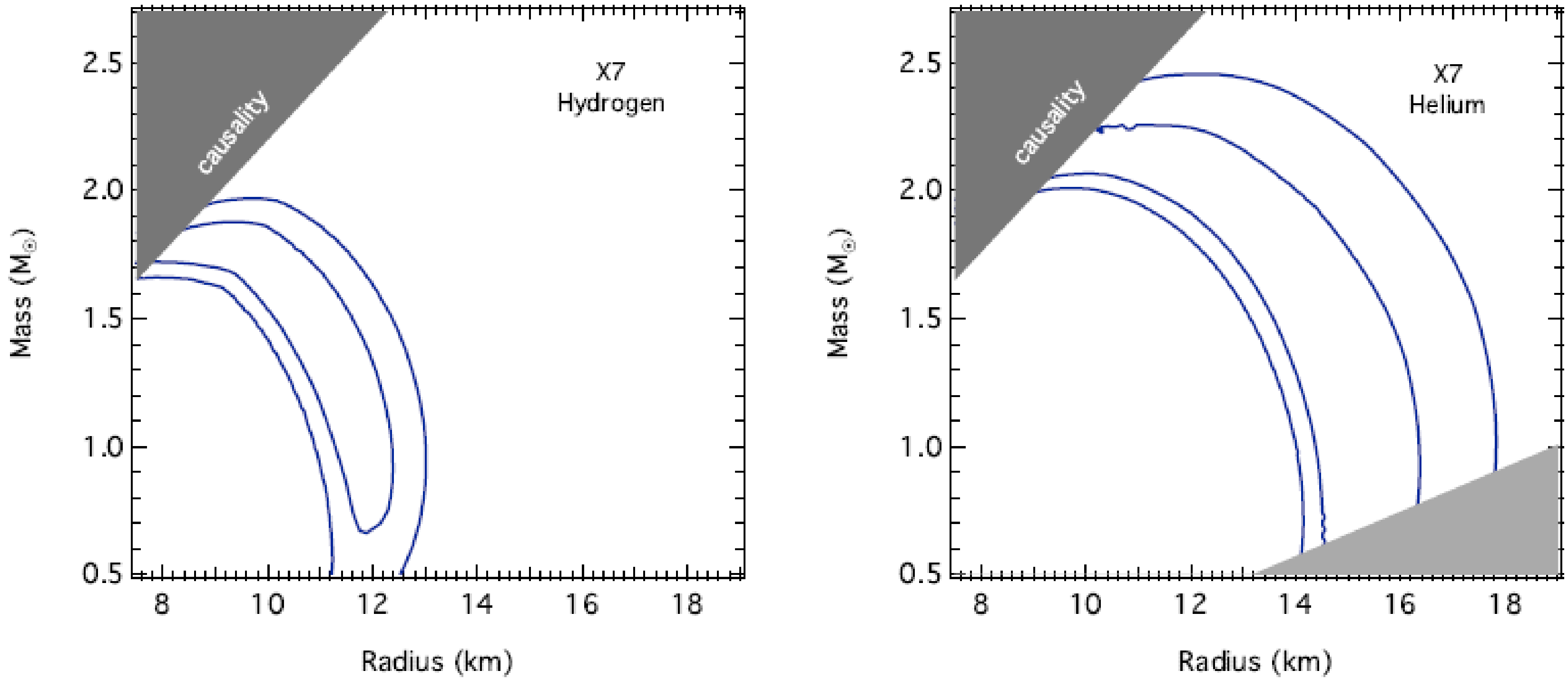


FIG. 9.— The mass-radius constraints obtained for X7 from the *Chandra* ACIS-S subarray data assuming the `nsatmos` H atmosphere (left) and `nsx` He atmosphere (right) models. 68% and 95% confidence contours are shown obtained from the posterior likelihood over M and R (see text). A 3% systematic uncertainty in the calibration and a model for 1% pile-up are included in the analyses. See Table 2 for the best fit parameters.

Inputs to the EoS: Mass-Radius

- S. Bogdanov, arXiv:1603.0163 [astro-ph]

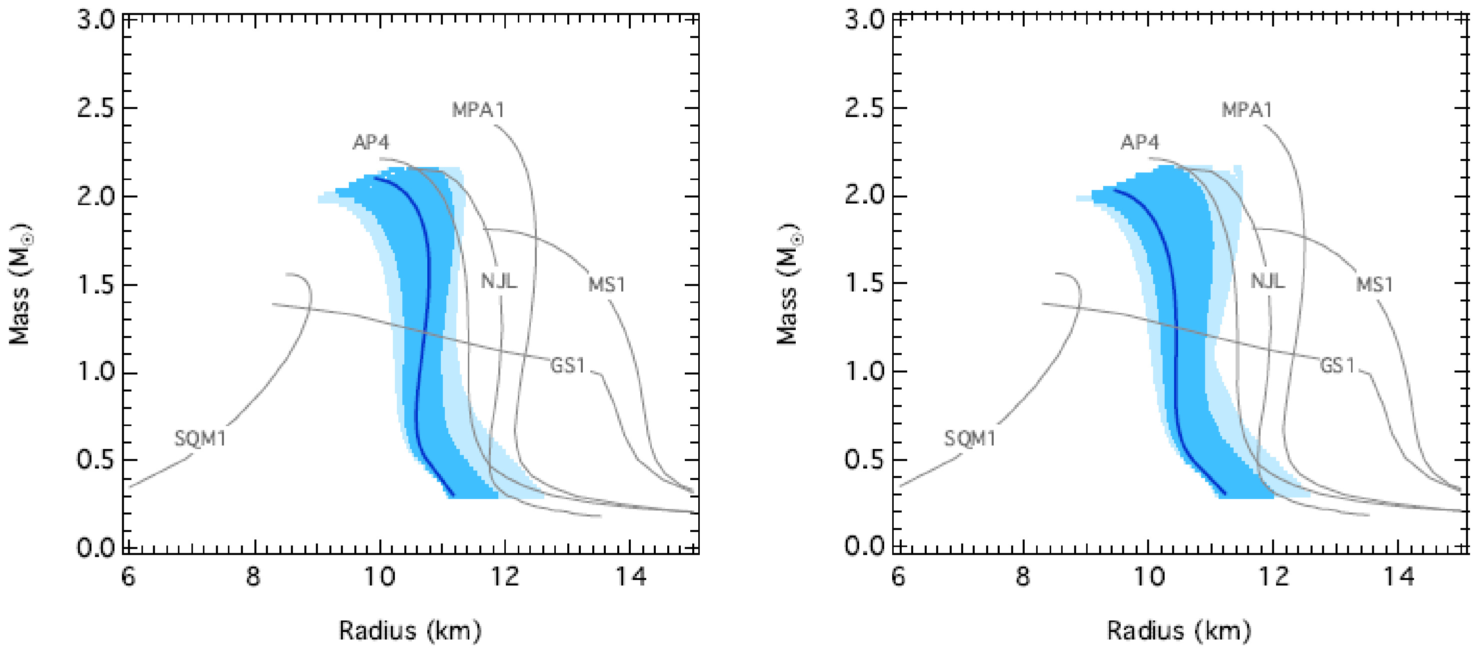
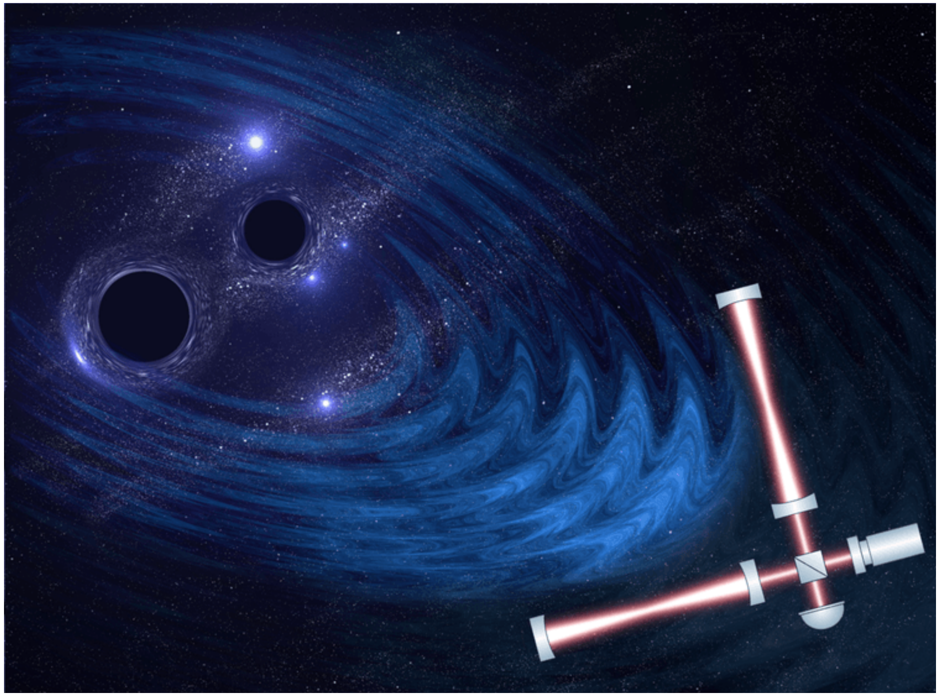


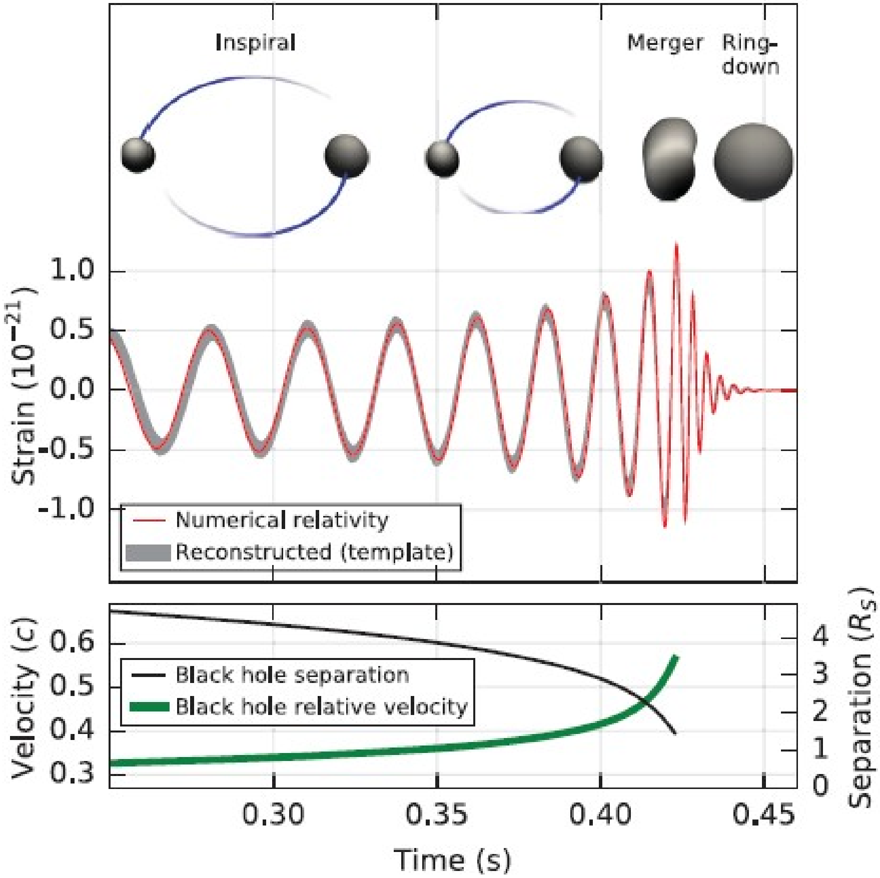
FIG. 10.— The mass-radius relation (solid blue curve) corresponding to the most likely triplet of pressures that agrees with the current neutron star data. These include the X5 and X7 radius measurements shown in this work, as well the neutron star radii measurements for the twelve neutron stars included in Özel et al. (2015), the low energy nucleon-nucleon scattering data, and the requirement that the EoS allow for a $M > 1.97 M_\odot$ neutron star. The ranges of mass-radius relations corresponding to the regions of the (P_1, P_2, P_3) parameter space in which the likelihood is within $e^{-1/2}$ and e^{-1} of its highest value are shown in dark and light blue bands, respectively. The results for both flat priors in P_1, P_2, and P_3 (left panel) and for flat priors the logarithms of these pressures (right panel) are shown.

Inputs to the EoS: EoS effect on GW

- LIGO Collaboration, Phys. Rev. Lett 116 061102 (2016)

  Merging black hole binary 36 M_{sol} & 29 M_{soll}





Inputs to the EoS: EoS effect on GW

- L. Rezzolla, K Takami, arXiv:1604.0024 [gr-gc]

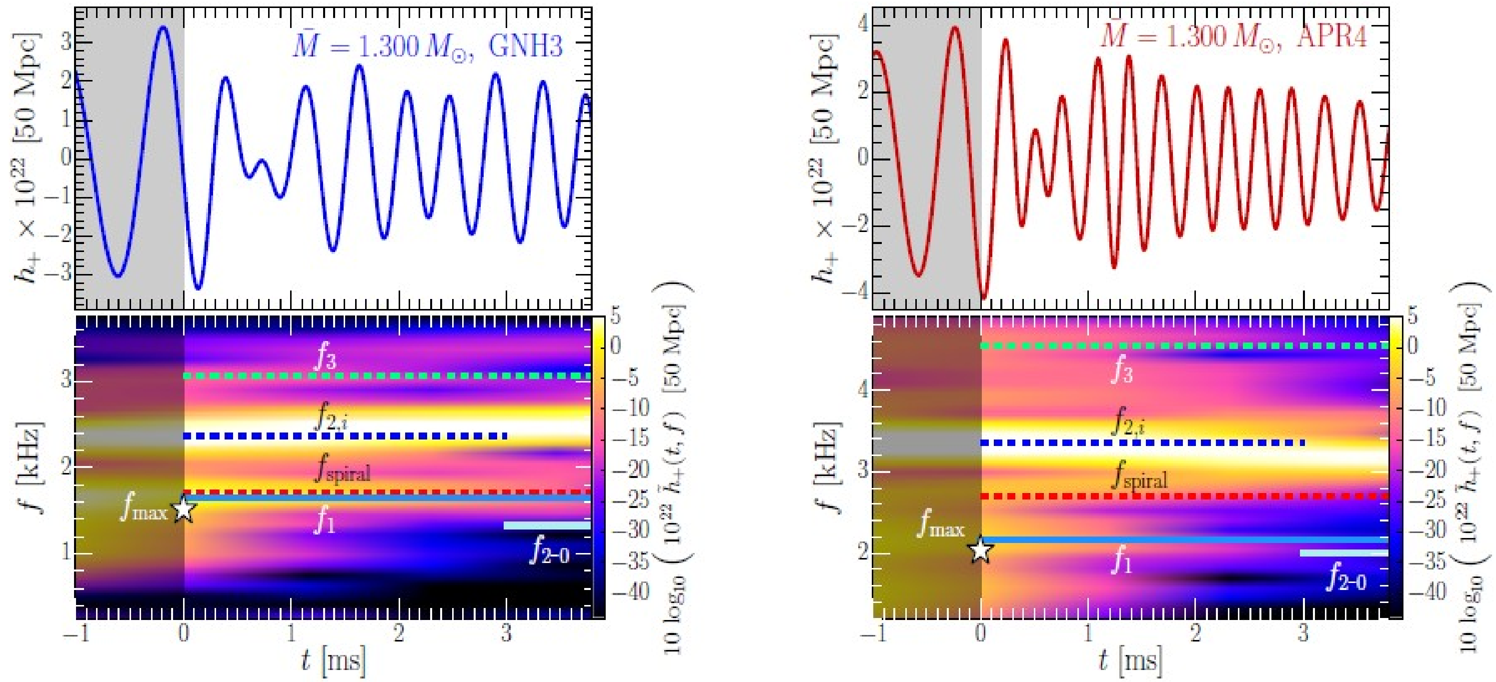


FIG. 2. Two examples of the GW emission around the merger, i.e., 1 ms before the (gray-shaded area) and 4 ms after the merger. Both panels refer to a fiducial mass of $\bar{M} = 1.300\, M_\odot$, with the left panel showing a representative stiff EOS (i.e., GNH3), while the right panel a representative soft EOS (i.e., APR4). The top part of each panel reports the gravitational strain h_+ for a source at 50 Mpc, while the bottom part the corresponding spectrogram. Also marked with horizontal lines of different type and colour are the various frequencies discussed so far in the literature (see main text).

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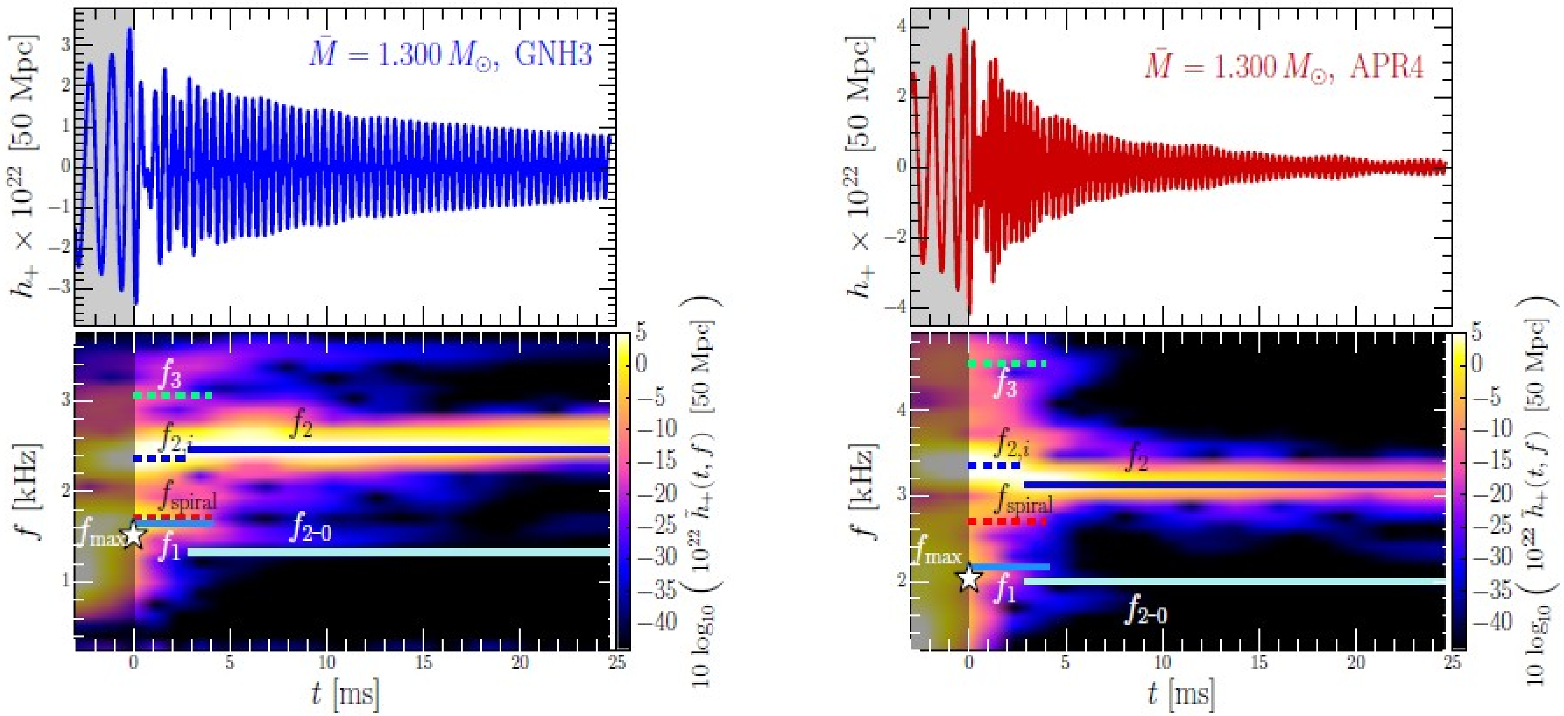
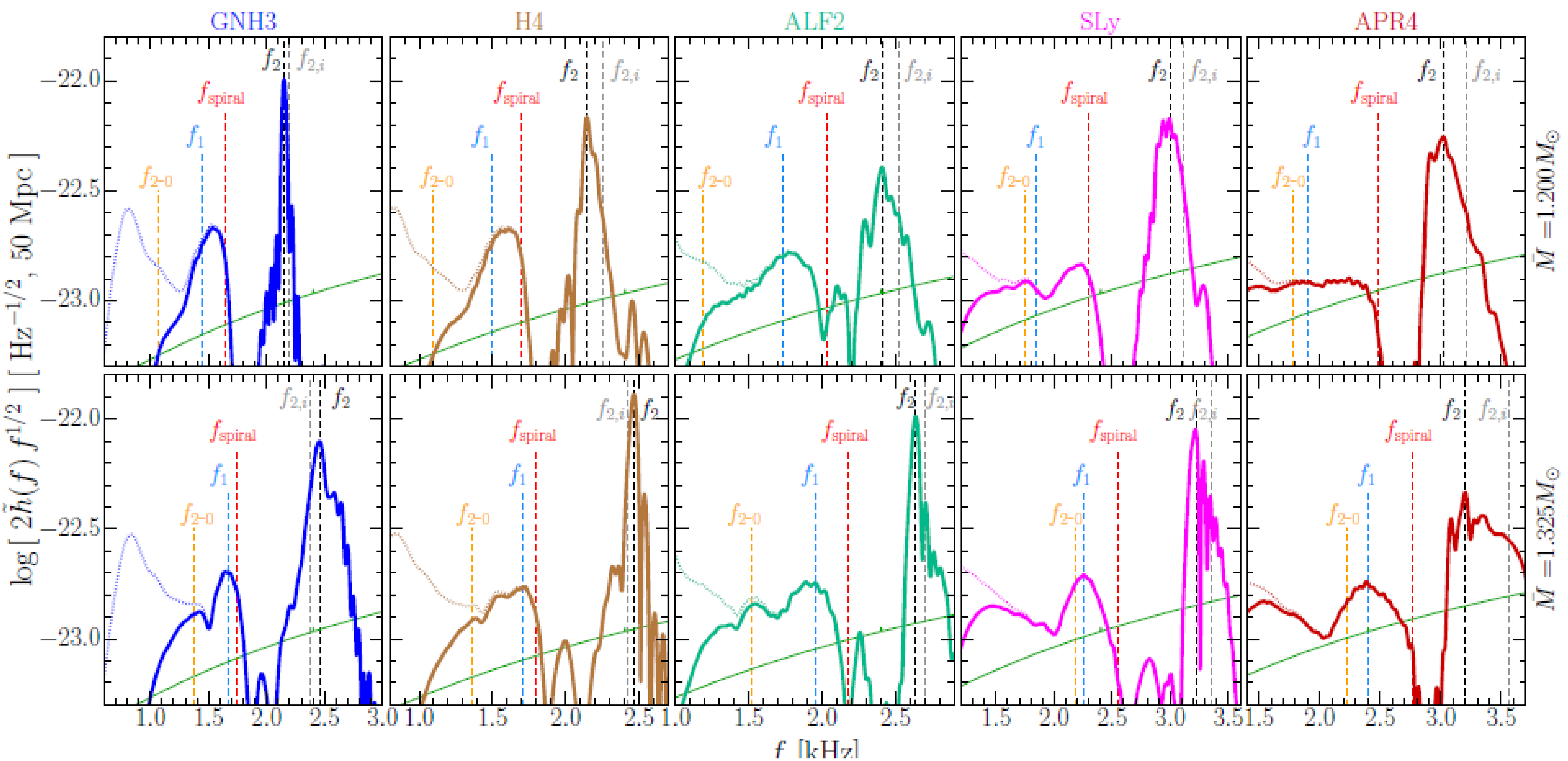


FIG. 3. The same as in Fig. 2, but shown on a much longer timescale, i.e., 25 ms after the merger. Note that all of the peaks present in the short transient stage (i.e., $t \lesssim 3$ ms) essentially disappear in the quasi-stationary evolution. The only exception is the f_2 peak, which slightly evolves from the $f_{2,i}$ frequency. In the case of a stiff EOS (e.g., for the H4 EOS, but not shown here) a trace of the $f_{2\text{-}0}$ mode is still present, although at very low amplitudes.

Inputs to the EoS: EoS effect on GW

- L. Rezzolla, K Takami, arXiv:1604.0024 [gr-gc]



Inputs to the EoS: EoS effect on GW

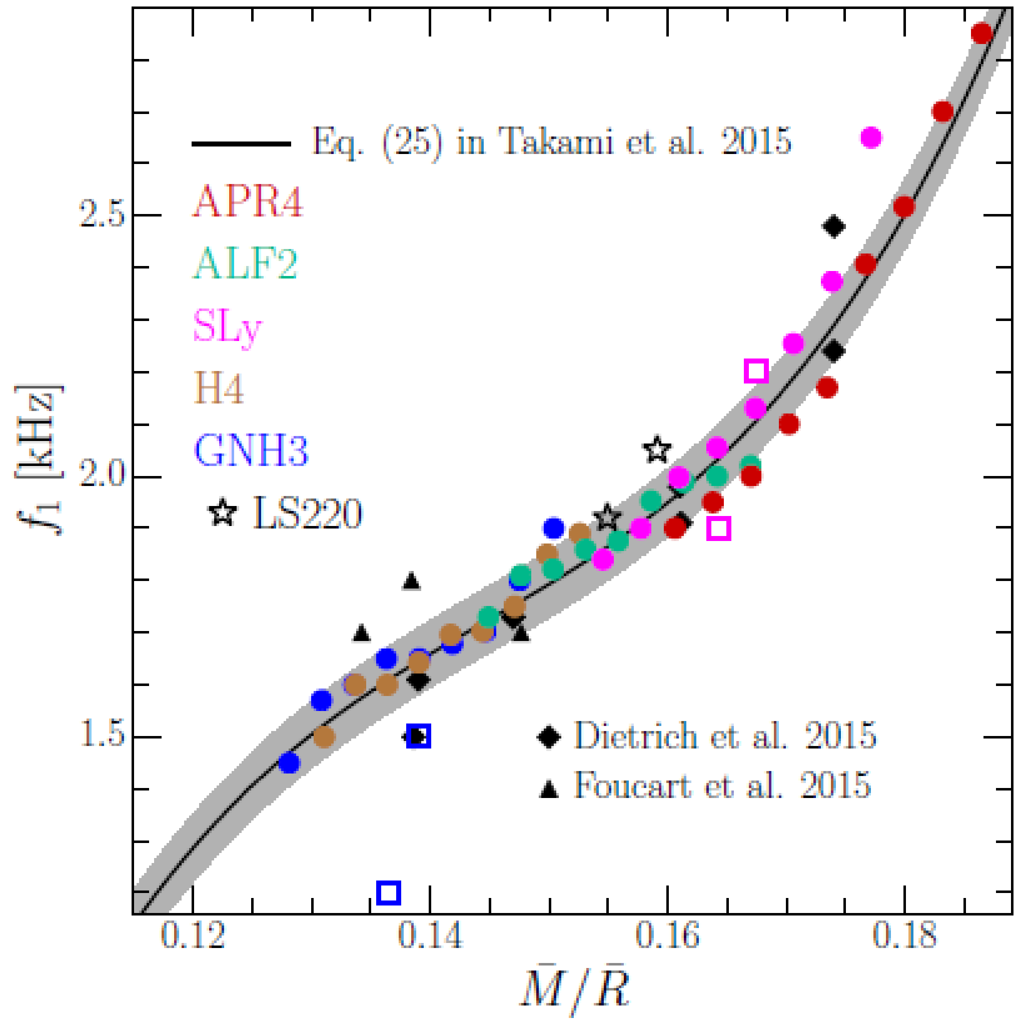
- L. Rezzolla, K Takami, arXiv:1604.0024 [gr-gc]

Full and detailed overview

Frequency vs. compactness

Calculations for specific stars

Hardly detectable now...



QUESTIONS for dense matter EoS

- Experimental observation of QCD phase diagram
  - Beam energy scans
  - Variable size collisions
  - How can we make constraints from the high T and μ?
- General QUESTIONS in QCD theory
  - Lattice at finite chemical potential: can we calculate?
  - Hyperon puzzle: how to reconcile pulsar masses of 2M with the hyperon softening of the equation of state (EoS)?
  - Masquerade problem: modern EoS for cold, high density hadronic and quark matter are almost identical?
  - Reconfinement puzzle: what to do when after a deconfinement transition the hadronic EoS becomes favorable again?

Overview of the WG2 meeting

- Gordon Baym: Quark matter in neutron stars
- Toru Kojo: QCD in stars
- Michael Buballa: Inhomogeneous chiral condensates in the QCD phase diagram
- Thomas Klaehn: Consequences of simultaneous chiral symmetry restoration and deconfinement for the QCD phase diagram
- Alexander Ayriyan: Bayesian analysis of new class of realistic hybrid EoS models based on M-R data
- Hovik Grigorian: Cooling of neutron stars with stiff stellar matter
- See more on the Poster’s at the background

Let's see the theoretical part...